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CRUSTAL STRUCTURE AND GRAVITY FIELD ANOMALIES IN EASTERN CANADA

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MACHAHO! TELLEM CHAHO!

«C'est la formule magique qui donne accès au monde à la fois étrange et familier, où toutes les merveilles sont à portée de désir et tous les voeux miraculeusement exaucés - comme dans les rêves -, ou cruellement déçus - comme dans la réalité». Mouloud Mammeri.

À la mémoire de mon frère Samir.

RÉSUMÉ

Cette thèse présente les résultats d'études gravimétriques menées dans le Bouclier canadien. Les mesures du champ de gravité récoltées le long et à proximité de divers transects Lithoprobe y sont interprétées. Chacun des chapitres de cette thèse est un article publié ou soumis.

Le premier article présente l'interprétation gravimétrique le long de la ligne sismique 52 de Lithoprobe, dans la province de Grenville. À l'échelle régionale, la modélisation de l'anomalie de Bouguer invoque un amincissement crustal au sud du front de Grenville sous le terrane allochtone du réservoir Cabonga. Cet amincissement, localisé au niveau de la croûte inférieure, peut être associé à une extension post-orogénique. Ceci est compatible avec l'interprétation des données sismiques. Le modèle gravimétrique a aussi permis de mettre en évidence des caractéristiques majeures non révélées par les données sismiques, telle que la zone de contact subverticale entre les terranes du réservoir de Cabonga et du réservoir Dozois. La géométrie de la rampe de Baskatong mise en évidence par le modèle gravimétrique est aussi en accord avec l'interprétation sismique. Cette rampe représenterait une discontinuité majeure le long de laquelle, les terranes protérozoiques furent accrétés. Par ailleurs, un modèle de l'anomalie résiduelle, dans la partie nord du profil, met en évidence trois corps gabbroïques peu profonds, complétant ainsi l'interprétation sismique qui ne fournit pas d'image de la base de ces intrusions.

Le second article présente des modèles crustaux du nord de la province du Supérieur à la lumière de nouvelles données de gravité récoltées le long d'un transect traversant les sous-provinces de Nemiscau et La Grande. Ce transect prolonge, vers le nord, le profil de gravité obtenu le long de la ligne sismique 48 de Lithoprobe, traversant le nord de l'Abitibi et l'Opatica. L'interprétation de l'anomalie de Bouguer pour le nord de l'Abitibi et l'Opatica, invoque un épaississement crustal compatible avec l'interprétation sismique et complète les données de sismique réflexion, qui ne fournissent pas une image satisfaisante des séquences supracrustales. Pour les sous-provinces de Nemiscau et La Grande, l'interprétation gravimétrique invoque une densité de la croûte supérieure plus élevée qu'en Abitibi et en Opatica. Un léger épaississement crustal est observé dans la sous-province de La Grande. Des séquences supracrustales mafiques sont aussi mises en évidence à l'extrémité nord du profil dans la sous-province de La Grande. La signature gravimétrique associée à la variation latérale de densité et les évidences de terrain indiquent un pendage vers le nord des principales frontières tectoniques.

Le troisième chapitre fait l'objet d'une étude du champ de pesanteur au dessus de la région de la baie d'Ungava à partir de données satellite et de nouvelles données récoltées le long de la côte sud de la baie. Un levé gravimétrique partant de la baie aux Feuilles, dans la province du Supérieur, traversant l'Orogène du Nouveau Québec (ONQ), et finissant près de la rivière George dans le craton de Rae, a été réalisé. L'interprétation des données acquises a permis de fournir des modèles de densité. Ces modèles mettent en évidence un épaississement crustal sous l'ONQ et un amincissement sous le terrane de Kuujjuaq, à l'est de l'orogène. Alors que plus à l'est, dans le craton de Rae, une anomalie négative de quelques dix milligals est corrélée avec les extensions vers le nord de la zone de cisaillement de la rivière George (ZCRG) et du batholite de De Pas. Ces structures ont été modélisées comme deux corps peu profonds (entre 1.5 et 4 km). L'orientation des structures sur les modèles de gravité est compatible avec les réflexions plongeant vers l'est, observées le long de la ligne sismique nord de Lithoprobe; suggérant un chevauchement du craton de Rae au dessus de l'ONQ. Par ailleurs, des données satellitaires d'altimétrie ont été utilisées pour pallier à l'absence de mesures de gravité dans la baie d'Ungava. Les données satellite ont été combinées avec les mesures terrestres pour établir des cartes composites du champ de gravité au dessus de la région de la baie d'Ungava. Les nouvelles données au sol ont permis de s'assurer que les données satellite sont correctement corrélées avec les signatures des structures géologiques continentales.

Des profils extraits à travers la baie, le long de la côte et sur le continent ont permis de vérifier la continuité en mer de structures majeures telle que la ZCRG. Les données de gravité associées aux données de sismique marine et à d'autres données géologiques, donnent un aperçu de l'architecture de la partie nord-est du craton de Rae et des processus tectoniques mis en oeuvre lors du développement du NE de Laurentia.

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J'aimerais terminer en pensant à ma famille, mes parents, ainsi qu'à ma femme Ratiba et mes enfants Ariles et Ines. J'ai trouvé auprès d'eux l'affection, la compréhension et le soutien moral, qui m'ont permis de surmonter les difficultés qui se sont dressées le long de ce bout de chemin.

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INTRODUCTION

Le mécanisme des interactions entre le manteau terrestre et la croûte continentale est une des questions les plus actuelles en géodynamique. L'étude des anomalies de grandes longueurs d'onde des champs de potentiel permet de mettre en évidence ces interactions. Ces anomalies sont causées par les variations de l'épaisseur de la croûte terrestre ainsi que par les variations à grande échelle de sa composition. Ainsi, les cartes gravimétriques et magnétiques sont souvent utilisées pour identifier les grandes structures géologiques et délimiter les frontières des grands éléments tectoniques.

Le Bouclier canadien qui englobe la moitié du pays, occupe une part importante de l'est canadien. Il est subdivisé en provinces principales et en sous-provinces sur la base de l'histoire tectonique. Les structures définissant les frontières entre les provinces, telles que le front de Grenville ou l'orogène du Nouveau Québec (Fosse du Labrador), apparaissent distinctement sur les cartes de grandes longueurs d'onde des champs de potentiel. Elles sont souvent caractérisées par une anomalie de Bouguer fortement négative (Fig. 1). Cette signature gravimétrique associée à ces frontières tectoniques, est souvent interprétée en termes d'épaississement crustal suite à des processus de convergence, collision et suture (Gibb et al., 1976).

Le projet Lithoprobe est un programme de recherche national comprenant différents transects à travers le Canada. Ce projet qui regroupe diverses disciplines des sciences de la terre, a voulu répondre à certaines questions concernant la nature, la structure et l'évolution

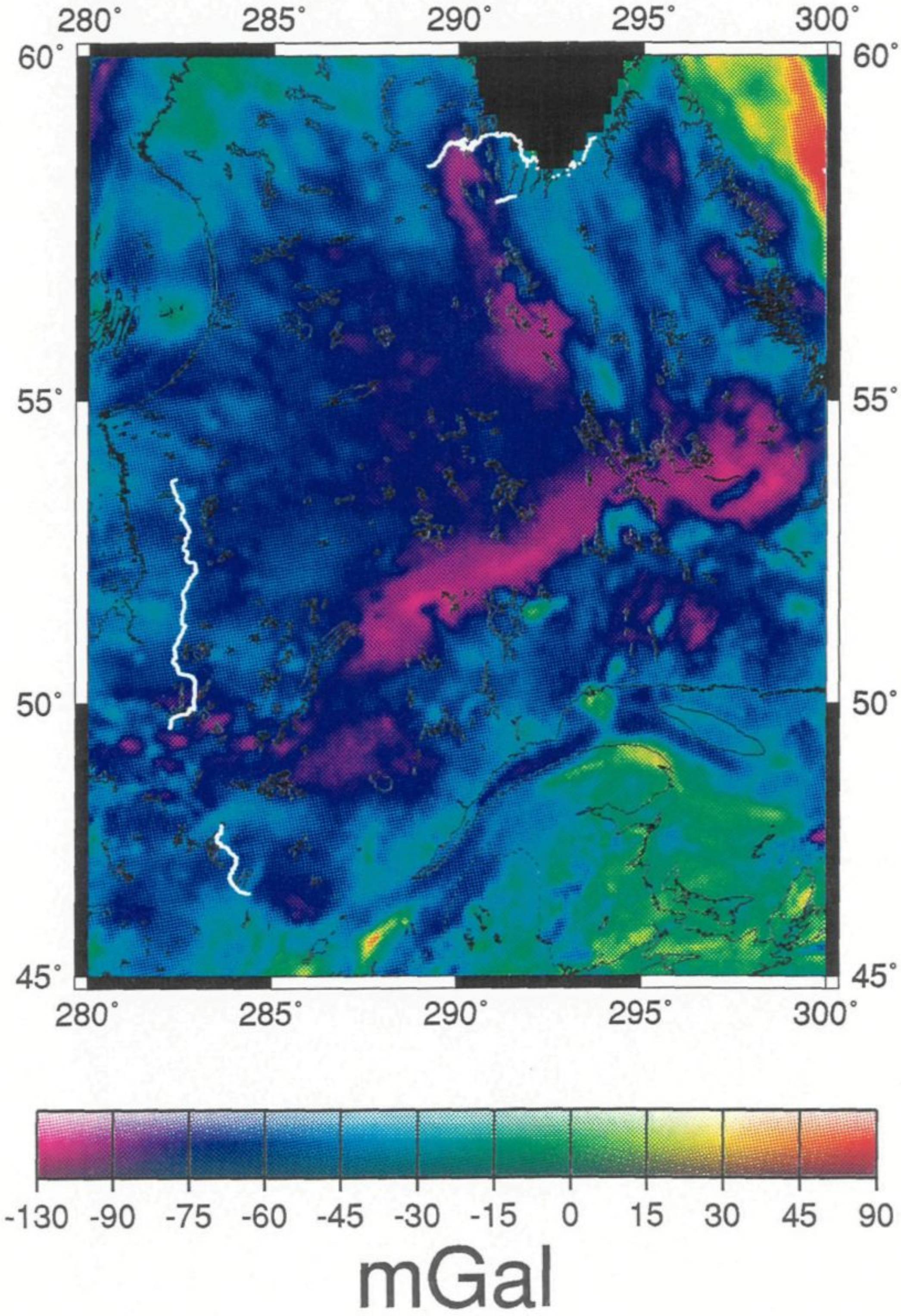

Fig. 1. Carte de l'anomalie de Bouguer de l'Est du Canada. Les données récoltées apparaissent en points blancs

de la lithosphère continentale. Dans l'Est du Canada, deux transects (Abitibi-Grenville et ECSOOT) situés dans le Bouclier canadien sont concernés par cette étude (Fig. 2). Le transect Abitbi-Grenville est concentré sur la ceinture archéenne de roches vertes de l'Abitibi, dans la partie sud de la province du Supérieur, et sur l'orogène mésoprotérozoique de Grenville, dont une partie est exposée dans le sud-est du Bouclier canadien. Le transect ECSOOT, le long de la côte est du Canada, recouvre les cratons archéens du Nain, du Supérieur et de Rae, un bloc de croûte archéenne de la province de Churchill, piégé entre les deux premiers cratons. Les orogènes protérozoiques du Nouveau Québec et de Torngat suturent les trois cratons sus-cités à l'ouest et à l'est, respectivement.

Des données de gravité de grande précision ont été récoltées le long de certaines lignes sismiques du projet Lithoprobe (Fig. 1). Les données gravimétriques permettent d'étudier les structures géologiques à différentes échelles, et d'élaborer des modèles de croûte terrestre le long des transects. De plus, les contraintes fournies par les données de gravité et des propriétés physiques des roches sont souvent très utiles pour relier les structures définies en profondeur par les données sismiques à la géologie de surface.

Il existe différentes méthodes d'interprétation des données gravimétriques. La méthode indirecte ou la modélisation est une des approches les plus utilisées. Elle consiste à calculer l'anomalie de gravité pour un modèle initial et à la comparer avec l'anomalie observée sur le terrain. La distribution de densité et (ou) la géométrie des corps constituant le modèle, sont ajustées par essais et erreurs. Le modèle peut être amélioré par des méthodes d'inversion jusqu'à l'obtention d'un ajustement acceptable. Le principal problème

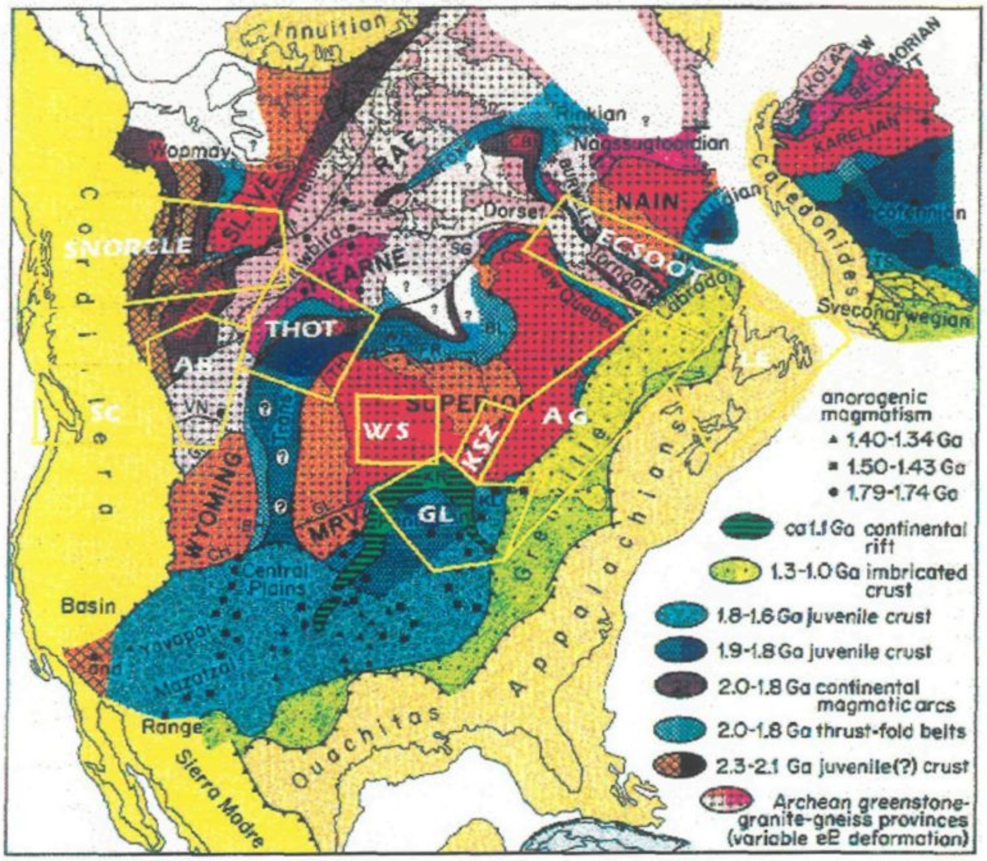

Figure 2. Carte des transects LITHOPROBE.

Les transects concernés par cette thèse sont:

AG: Abitibi-Grenville;

ECSOOT: Eastern Canadian Shield Onshore-Offshore Transect.

de l'interprétation réside dans la non-unicité du modèle résultant, en l'absence d'autres informations sur les sources. En effet, de nombreux modèles peuvent s'ajuster avec l'anomalie observée. Cependant, ce problème peut être réduit en contraignant le modèle avec d'autres informations, telles que les données magnétiques, sismiques ou des données de forage. Le modèle initial est établi à partir des mesures de densité sur des échantillons de roches récoltés in situ et certaines contraintes de la géologie. Toutefois, il est souvent nécessaire de considérer des modèles alternatifs.

La province de Grenville qui constitue la partie sud-est du Bouclier, est séparée des provinces du Supérieur, de Rae et de Nain par le front de Grenville (Wynne-Edwards, 1972). Elle a été subdivisée en trois ceintures principales reflétant le caractère tectonique de l'orogène (Rivers et al., 1989). La ceinture parautochtone la ceinture polycyclique allochtone et la ceinture monocyclique allochtone. Les transects sismiques menés à travers la province de Grenville, dans l'Ouest du Québec ont permis de fournir une image de la limite croûte-manteau et de définir la géométrie en profondeur des terranes grenvilliens (Martignole et Calvert, 1996). Le premier chapitre de cette thèse, présente une interprétation gravimétrique le long de la ligne sismique 52 de Lithoprobe qui part du terrane du réservoir Dozois dans la ceinture parauthochtone, à 60 km au sud-est du front de Grenville, traverse le terrane du réservoir Dozois et se termine dans le terrane allochtone de Mont Laurier.

Le modèle de gravité ajoute une dimension à l'interprétation sismique en ce sens que, à travers la densité, il est sensible à la composition de la croûte. Par ailleurs, la concordance entre l'interprétation gravimétrique (géométrie des corps) et les réflecteurs sismiques conforte le modèle sismique. Les paramètres d'acquisition des données sismiques ne permettent pas d'imager la croûte superficielle ni les réflecteurs très inclinés. Ce modèle gravimétrique a permis de mettre en évidence des caractéristiques majeures non révélées par les données sismiques, telle que la zone de contact subverticale entre les terranes du réservoir de Cabonga et du réservoir Dozois. Un modèle local établi pour le terrane du réservoir Cabonga, incluant l'intrusion de Bouchette, dans la partie nord du profil, complète les données sismiques qui ne fournissent pas une image de la base des séquences supracrustales.

La ligne sismique 48, traverse le nord de la ceinture de l'Abitibi et toute la ceinture de l'Opatica dans la province du Supérieur. Des réflecteurs sismiques, à la base de la croûte, pénètrent dans le manteau supérieur sous l'Opatica (Calvert et al., 1995). Cette réflexion mantellique a été interprétée comme étant la relique de la zone de subduction de l'Abitibi sous l'Opatica.

Les résultats de sismique réfraction (Winardhi et Mereu, 1997) et de sismique réflexion (Clowes et al., 1992) ont montré que les roches de la sous-province de Pontiac s'étendent sous la ceinture de l'Abitibi au sud et sont associées à un épaississement crustal. L'accrétion tectonique Abitibi-Opatica datée à 2700 Ma (Davis et al., 1994) est plus ancienne que l'accrétion tectonique Abitibi-Pontiac, dont l'âge est estimé à 2685 Ma (Corfu et al., 1989). Ceci va dans le sens d'un modèle d'accrétion progressive du nord vers le sud dans la province du Supérieur.

Un transect de gravité établi le long de la ligne sismique 48, a été prolongé vers le nord à travers les sous-provinces de Nemiscau et La Grande. L'interprétation de ces données fait l'objet du second chapitre de cette thèse.

Des modèles gravimétriques présentés à travers les quatre sous-provinces que traverse le transect, sont compatibles avec les réflexions imagées sous l'Abitibi et l'Opatica, et complètent l'information sismique en contraignant la géométrie des séquences supracrustales. Dans les sous-provinces de Nemiscau et La Grande, des contraintes sont fournies par des données magnétiques ainsi que par des mesures de densité effectuées sur des échantillons récoltés in situ. L'interprétation gravimétrique permet d'estimer l'épaisseur crustale et de déterminer la géométrie des terrains superficiels.

Les données de gravité sont particulièrement importantes pour le transect ECSOOT. Elles permettent de corréler les structures géologiques identifiées sur le continent avec les images de la croûte fournies le long du profil de sismique marine à travers la baie d'Ungava (Hall et al., 1995). Il n'y a pas eu de mesures de gravité dans la baie d'Ungava. L'anomalie d'air libre peut cependant être calculée à partir de données satellitaires d'altimétrie (Smith et Sandwell, 1995). De nouvelles données au sol, ont été récoltées pour établir une couverture continue de la gravité le long de la côte sud de la baie d'Ungava. Une carte du champ de gravité combinant les données au sol et satellite a été établie au dessus de la région de l'Ungava. Ces données ont été interprétées et des modèles de densité à travers le craton de Rae et l'orogène du Nouveau Québec ont été proposés. Ces modèles sont comparés aux modèles d'évolution proposés dans la région. Cette étude fait l'objet du troisième chapitre de ce mémoire.

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CHAPITRE I

Gravity modeling along a LITHOPROBE seismic traverse, northern Grenville Province, western Québec

Abstract

High precision gravity data were collected along Lithoprobe seismic reflection lines, in the northern part of the Grenville Province, in western Québec. An interpretation is presented for Line 52 which starts some 60 km southeast of the Grenville Front, traverses the parauchthonous Réservoir Dozois Terrane including the allochthonous slice of the Réservoir Cabonga Terrane, and ends near the town of Mont-Laurier, in the allochthonous Mont-Laurier Terrane. At the regional scale, the Bouguer gravity anomaly is consistent with the interpretation of the seismic reflection data. It supports crustal thinning southward of the Grenville Front, under the Cabonga allochthon. This thinning may be related to post-orogenic extension. The gravity modeling shows dramatic thinning of the lower crust and suggests that extension was accommodated by extrusion of the lower crust. The gravity modeling also requires a steep boundary between the Réservoir Cabonga and the Réservoir Dozois terranes extending to ~ 15 km. The geometry of the Baskatong ramp derived from gravity data is also consistent with the seismic interpretation. This supports the suggestion that the Baskatong ramp is a major discontinuity along which Proterozoic terranes were accreted. In the Réservoir Cabonga Terrane in the northern part of the profile, the residual gravity anomalies (short wavelength variations) are related to outcropping mafic intrusions. Modeling of these anomalies complements the seismic reflection data which did not image the base of the intrusions. The interpretation calls for three small distinct gabbroic bodies that extend no deeper than 3 km. The total volume of the intrusions is ~ 3,000km^3.

1. Introduction

During the past five years, a variety of geological, geochemical, and geophysical data was collected along the transect conducted by Lithoprobe in the Grenville Province. These data have shed new light on the evolution and final assembly of the Grenville Province. This note presents an interpretation of gravity data collected along the seismic profile surveyed by Lithoprobe in western Québec.

The Lithoprobe seismic reflection line 52 (Fig. 1) starts in the parauchthonous Réservoir Dozois Terrane (RDT), some 60 km south of the Grenville Front. It extends into the Réservoir Cabonga Terrane (RCT), reenters the RDT, and terminates south of the Baskatong shear zone near the town of Mont-Laurier, well within the allochthonous Mont-Laurier Terrane (MLT). Archean model ages in the RDT (Dickin et al. 1989) have been interpreted to suggest that it is an Archean promontory penetrating into the Grenville Province as far as the Baskatong reservoir (Martignole and Calvert 1996) where the Allochthon Boundary Thrust (Rivers et al. 1989) have been postulated. Preliminary results from Lithoprobe seismic reflection line 52 show reflectivity of the upper crust in the RCT extending to depths of ~ 20 km well within the mid-crust (Calvert et al. 1994). The reflectivity changes from south apparent dip, north of the RCT, to north apparent dip, south of the RCT. South of the Baskatong shear zone, these north dipping reflectors are truncated by south dipping reflectors that can be extrapolated to the shear zone (Martignole and Calvert 1996). These latter reflectors outline a ramp (Baskatong ramp) over which the Proterozoic terranes were accreted. The reflectivity is also apparently dipping to the south or undulating in the MLT. No strong shallow reflections appear over the entire section, because of the acquisition procedure and the environmental noise affecting the data. However, recent reprocessing has enhanced the shallow reflectivity and shown a reflector at 1.5-2 s (~ 4-5 km) under the RCT. This reflector probably corresponds to the base of the Cabonga Terrane (Martignole and Calvert 1996).

The Réservoir Cabonga Terrane is a 3,000 km^2 slab consisting of Proterozoic metasedimentary (marbles, metapelites and quartzites) and meta-igneous (gabbro-anorthosites) rocks resting upon a migmatitic sole. It is bounded and dissected by mainly southeast-dipping shear zones. However, its southeast contact dips towards the northwest (Martignole and Pouget 1994). Located at northwestern edge of the RCT, the Bouchette intrusion is a lobate, highly deformed gabbro-anorthosite complex. Several shear zones with evidence of northwest-directed tectonic transport have been identified in the Bouchette intrusion (Indares and Martignole 1990).

The Bouchette intrusion presents a strong positive magnetic anomaly in the south, a narrow positive anomaly at its northern edge and a broad negative anomaly in the center, coinciding with the anorthositic part of the intrusion. Results from electromagnetic and magnetic modeling (Kellett 1995) suggest that the Bouchette intrusion is dominantly gabbroic, with the anorthosite restricted to a thin lens in the center. According to this interpretation, the Bouchette intrusion is entirely bounded by thrust faults, and can be divided into two distinct blocks each less than 3 km thick. The southern block dips to the south at a shallow angle under the metasedimentary terrane. It has a higher magnetic susceptibility (7 X 10^{-2} SI) than the northern block (9 X 10^{-3} SI). Given the previous lack of detailed gravity data, the shape and the depth of the Bouchette intrusion has not yet been determined in detail.

This note presents an interpretation of gravity data acquired along Lithoprobe seismic line 52 which crosses the Bouchette intrusion. Models (regional and local) that fit the gravity data are useful to: 1) confirm the variations of crustal thickness infered from the seismic data in this part of the Grenville Province, 2) complement the seismic information on the subsurface geometry of the different terranes, and 3) determine the thickness of the Bouchette intrusion that could not be estimated using the seismic data.

2. Gravity modeling

High-precision gravity data were collected at 1 km intervals along all the Lithoprobe seismic reflection lines in the Grenville Province. Because of the very precise leveling done for Lithoprobe, the elevation was determined with an accuracy better than 10 cm. This accuracy eliminated the main source of errors in the reduction of the gravity data. Consequently, the Bouguer anomaly can be calculated with an accuracy better than 0.1 mGal. In addition, the average station spacing of 1 km provided more detailed data than previously available in this part of the Grenville Province, where average station spacing is on the order of 10 km. Line 52 starts about 60 km southeast of the Grenville Front; it extends over ~ 180 km and ends near the town of Mont-Laurier (Fig. 1). The data were reduced to Bouguer anomalies using a standard correction density of 2.67 $Mg.m^{-3}$. In order to do 2.5D interpretation, the data collected along line 52 were projected on a NNW-SSE profile, perpendicular to the strike of the major structures. The length of the profile after projection is ~ 150km. The Bouguer anomaly profile shows relatively long wavelength (~75 km) variations of about 25 mGal, superposed with short wavelength variations in the NNW part of the transect (Fig. 2). The long wavelength variations show a relative low over the Réservoir Dozois Terrane and a high, in the SSE end of the profile, over the Mont-Laurier Terrane. These long wavelengths can be interpreted in terms of variations in crustal thickness and (or) average composition. In the NNW part of the profile, the short wavelength positive anomalies, which require a shallow source, are associated with mafic rocks, essentially gabbro, as exposed in the Réservoir Cabonga Terrane.

The data were interpreted with 2.5D gravity modeling where a body is approximated by an horizontal polygonal prism with finite length in the strike direction. The model consists of an ensemble of 2.5 D prisms that map in cross-sectional form the interpreted variations in subsurface density. The third dimension of the model, perpendicular to the cross section, extends far enough to avoid edge effects. The total length (double the distance from the profile to the end of the prism) is 40 km for all the bodies, except for the shallower bodies located at the northern end of the profile, which are 20 km long. Tests showed little change in the calculated gravity anomaly when the length is increased to 60 km. The modeling was done with SAKI, an interactive gravity profile modeling program that uses generalized linear inversion to iteratively improve selected model parameters

(Webring 1985). The model parameters that can be iteratively improved are the location of prism vertices and the density of each prism.

Gravity interpretation is well known to be non-unique; the ambiguity of the interpretation can be reduced by the knowledge of the geology, density measurements and the use of other geophysical information, such as seismic data. Rock samples, mainly gneiss, anorthosite, gabbro and metasediments, were collected in the region of the Bouchette intrusion. The density was measured in the laboratory on these samples. Although relatively few samples were available, the resulting densities are close to published values for the average density of these rocks (Daly et al. 1966). The density measurements are summarized in Table 1. In the modeling, a value of 2.82 $Mg.m^{-3}$ was assumed as the average density of the upper crust in the Grenville Province. This value corresponds to the mean density of the Grenville Supergroup supracrustal rocks evaluated by Kearey (1978). Standard values of 2.92 $Mg.m^{-3}$ and 3.12 $Mg.m^{-3}$ are assumed for the average densities of the lower crust and the upper mantle, respectively (Stacey 1977).

3. Regional Bouguer anomaly model

Gravity interpretation is non-unique and many density distribution models could be compatible with the long wavelength gravity data of line 52. An initial regional model was established on the basis of constraints from the geology and the seismic reflection study (Martignole and Calvert 1996). Figure 3 shows the final model after improvement by inversion of density and shape of selected bodies. Continous lines indicate the boundary between bodies of different density; they mark density contrasts required to fit the gravity data. Discontinuous lines in the upper crust indicate the terrane boundaries inferred from observed reflections or significant changes in crustal reflectivity in the seismic data that are not accompanied by a marked change of density and thus not constrained by the gravity data. The crust-mantle boundary (Moho) is constrained by the seismic reflection data. The Moho occurs at a depth of ~ 40 km on both ends of the profile. The crust thins to ~ 36 km beneath the Réservoir Cabonga Terrane. The boundary between the upper and the lower crust is located ~ 20 km depth, in the NW end of the profile. It deepens to 32-33 km beneath the Réservoir Cabonga Terrane, then ascends gently to reach a depth of 27-28 km at the RCT-RDT boundary and ~ 22 km in the SE end of the profile beneath the MLT. The gravity data alone could not have resolved the crustal thinning under the RCT, because its effect is not obvious on the profile, given the superposed effect of other crustal structures such as the attenuation of the lower crustal layer. However, the interpretation shows that the observed gravity data are compatible with the thinning of the crust observed in the seismic reflection, provided that the lower crustal layer also be thinned.

In the center of the profile, the gravity low over the RDT south of the Cabonga slice is caused by an asymmetrically shaped large body in the upper crust with a density of 2.77 $Mg.m^{-3}$. It may correspond to the gneiss and migmatitic material of the RDT that are exposed over 60 km at the surface. This body appears to thin and to dip steeply north under the RCT, where it is modelled at 17-18 km depth over some 40 km. The geometry of the body is needed to fit the strong gradient observed in the middle of the profile at the RCT-

RDT boundary. However, it must be noted that the seismic line turns in this region and is at a wide angle to the direction of the profile. The projection of the gravity data on the profile may thus have resulted in steepening the gradient. At the SE end of the profile, beneath the MLT, a 10 km thick body, gently dipping to the SE, is interpreted in the upper crust. Its density (2.805 $Mg.m^{-3}$) was obtained after several iterations. Although it is not strongly constrained because it extends further than the detailed gravity profile, this body is consistent with the seismic reflection image in which it was identified as the Baskatong ramp (Martignole and Calvert 1996).

In the RCT, at the NW end of the profile, short wavelengths positive anomalies are modelled as caused by three shallow gabbroic bodies with a density of 3.03 $Mg.m^{-3}$. The regional anomaly modeling will provide a more detailed picture of these bodies. The gravity data do not constrain the base of the Cabonga slab; it is inferred in Figure 3 from seismic reflection data (Martignole and Calvert 1996).

4. Residual gravity model

Short wavelength anomalies in the northeastern part of the profile coincide with exposures of gabbro of the Bouchette intrusion region. The residual gravity anomaly was obtained by removing the regional anomaly (the long-wavelength trend) from the Bouguer anomaly by wavelength filtering. The data were interpolated with a constant step and reflected to suppress the linear trend and avoid edge effects in the Fourier transform. The filter eliminated all wavelengths longer than 40 km. (There would be no significant difference if the cutoff had been 30 km or 50 km). The residual gravity obtained by inverse Fourier transform contains two large positive anomalies of about 20 mGal amplitude over the Bouchette intrusion and the northwestern part of the RCT area. The model fitting the gravity data across the northwestern part of the RCT and the Bouchette intrusion was obtained by iterative improvement from the initial regional model previously discussed. It was also constrained by the surface geology and the density measurements performed on rock samples. The density contrast of the gabbroic bodies is large (0.21 $Mg.m^{-3}$). The result of this modeling (Fig. 4) involves three gabbroic bodies that are not rooted. In the central part, the short wavelength negative anomaly requires a small narrow body with approximately the same depth as the gabbro. This small body with a large negative density contrast of -0.23 $Mg.m^{-3}$, could be due to a fault zone into the RCT. However, it is possible that some very thin lenses of anorthosite (~ 100 m) are present at the surface and that small volumes of anorthosite could be found between the gabbroic bodies. Nonetheless, the volume of anorthosite is much less than that of gabbro. The smallest gabbroic body located in the NW does not extend deeper than 1.5 km, while the other two extend to depths of ~ 2.8 km and ~ 2.6 km. It was not possible to fit the gravity data with a thicker body and a lower density contrast that could account for the presence of anorthositic material. The gravity interpretation is very similar to the results of magnetotelluric and magnetic modeling that delineated an intrusion formed of three distinct bodies extending to ~ 2 km (Kellett 1995). It is also noteworthy that the vertical body with negative density contrast is also detected by the magneto-tellurics. It appears as a zone of very low resistivity ($<10\Omega.m$

vs >10,000Ω.m for the gabbro). The low electrical resistivity of this zone suggests that it is not associated with anorthosites but with a fault zone.

5. Discussion

5.1 Crustal thickness

The Moho occurs at 40 km depth on the NW edge of the profile where a tendency towards a crustal thickening is apparent. Near the center of the profile at the boundary between the RCT and the RDT, the crust is thinned to ~ 36 km. This is consistent with the recent interpretation of seismic images from the Grenville crust (Martignole and Calvert 1996) and seismic refraction results (Mereu et al. 1986). These data provide no evidence for any other change in crustal thickness. Otherwise, the thickening of the lower part of the crust may contribute to the long wavelength increase in gravity on each side of the profile.

The upper-lower crust boundary shallows in the SE part of the profile and is parallel with NW dipping reflectors shown by seismic reflection (Martignole and Calvert 1996). However, it is difficult to correlate this boundary with a particular seismic reflector. The crust is extremely heterogeneous in this area (Mereu et al. 1986) and because of the low density contrast (0.1 $Mg.m^{-3}$) between the upper and the lower crust, this transition has little influence in the global interpretation.

The gravity data alone would not have resolved the crustal thinning under the RCT. The crustal thickness was a constraint imposed by the seismic reflection data. With this constraint, the geometry of the upper-lower crustal boundary was determined only from the gravity interpretation. The non-trivial result is that the geometry of this boundary is consistent with the changes in dip of the reflectors observed in the seismic data. Furthermore, the dramatic thinning of the lower crust modelled by the gravity is also consistent with the hypothesis that crustal thinning is related to post-orogenic extension (Martignole and Calvert 1996). It suggests that the extension could have been, to a large extent, accommodated by lateral extrusion of the ductile lower crust.

5.2 Other regional features

In general, the geometries of the main features resolved by the gravity correlate well with the seismic interpretation (Fig. 3). In particular, the changes in dip of the interfaces seem to follow the changes in the attitude of the seismic reflectors. The boundary between upper and lower crust in the NW part of the profile (Fig. 3) can be extrapolated to the Grenville Front that marks the boundary between the lower autochthonous Archean crust and the upper parautochthonous Archean crust. The interpretation of the COCRUST seismic refraction data did not show a mid-crustal seismic discontinuity (Mereu et al. 1986). Nevertheless, the gravity interpretation is in agreement with the Lithoprobe seismic reflection results where this discontinuity is fairly well defined and can be extrapolated to the Grenville Front (Martignole and Calvert 1996). The ~ 12 km thick (GFZ) layer located between this discontinuity and the SE-dipping discontinuous line at around 12 km depth in the NW end of the profile, may be extrapolated to the Grenville Front Zone.

In the central part of the profile, a light body in the RDT, steeply dipping to the NW, can be correlated with the NW-dipping reflectors dominating the Archean crust in this area (Martignole and Calvert 1996).

In the mid crust, the discontinuous line represents a NW-dipping reflector interpreted to lie within the Archean crust.

At the SE end of the profile, the gravity model supports the seismic interpretation that a 10 km thick SE-dipping zone truncates the RDT. This zone may be correlated with the Baskatong Ramp, identified in the seismic reflection as a major tectonic element over which the Proterozoic terranes were accreted.

5.3 Bouchette intrusion

In the northeastern part of the transect, three dense gabbroic bodies have been modelled. The regional interpretation provides an initial model that was iteratively improved to fit the residual anomaly (Fig. 4). The two bodies at the NW end of the profile fall within the Bouchette intrusion; the southernmost body intrudes into the RCT (Fig. 1). The Bouchette intrusion is separated from this other intrusion by a narrow low density body. It is interpreted as a fault, possibly the thrust contact zone. There is no radiometric age for the Bouchette intrusion. It has been assumed that it is within the age range of most anorthosites in the Grenville Province (1650 to 1130 Ma), while surrounding rocks have a metamorphic age of ~ 1000 Ma (Childe et al. 1993; Friedman and Martignole 1995). Because of the evidence for thrust faults within the intrusion and for significant displacement of the blocks (Otton 1978; Indares and Martignole 1990; Martignole and Pouget 1993, 1994), it has been widely assumed that the Bouchette intrusion was transported. The seismic data do not show any strong shallow reflections (Calvert et al. 1994) except perhaps a reflector at ~ 5 km depth which probably corresponds to the base of the Réservoir Cabonga Terrane. The gravity data suggest that the gabbro does not even extend that deep and that the total volume is ~3,000 km^3. It has been suggested that the gabbro-anorthosite intrusions in the Grenville Province formed as large layered igneous complexes (Ashwal 1993). The relatively small volume of the intrusions suggests that the gabbroic bodies were part of an originally larger complex. The gravity interpretation is consistent with recent magnetotelluric and magnetic studies of Kellett (1995), Lithoprobe seismic results (Calvert et al. 1994; Martignole and Calvert 1996) and is consistent with tectonic transport probably effected by northwest directed thrusting.

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Table 1. Rock densities for Bouchette region.

Rock type	No. Of Samples	Average density	Std. Dev.	Density range
Gneiss	4	2.77	0.04	2.74-2.83
Anorthosite	12	2.83	0.15	2.67-2.95
Gabbro	12	3.03	0.21	2.77-3.45
Metasediments	6	2.94	0.09	2.88-3.10

Note: Density in $Mg.m^{-3}$.

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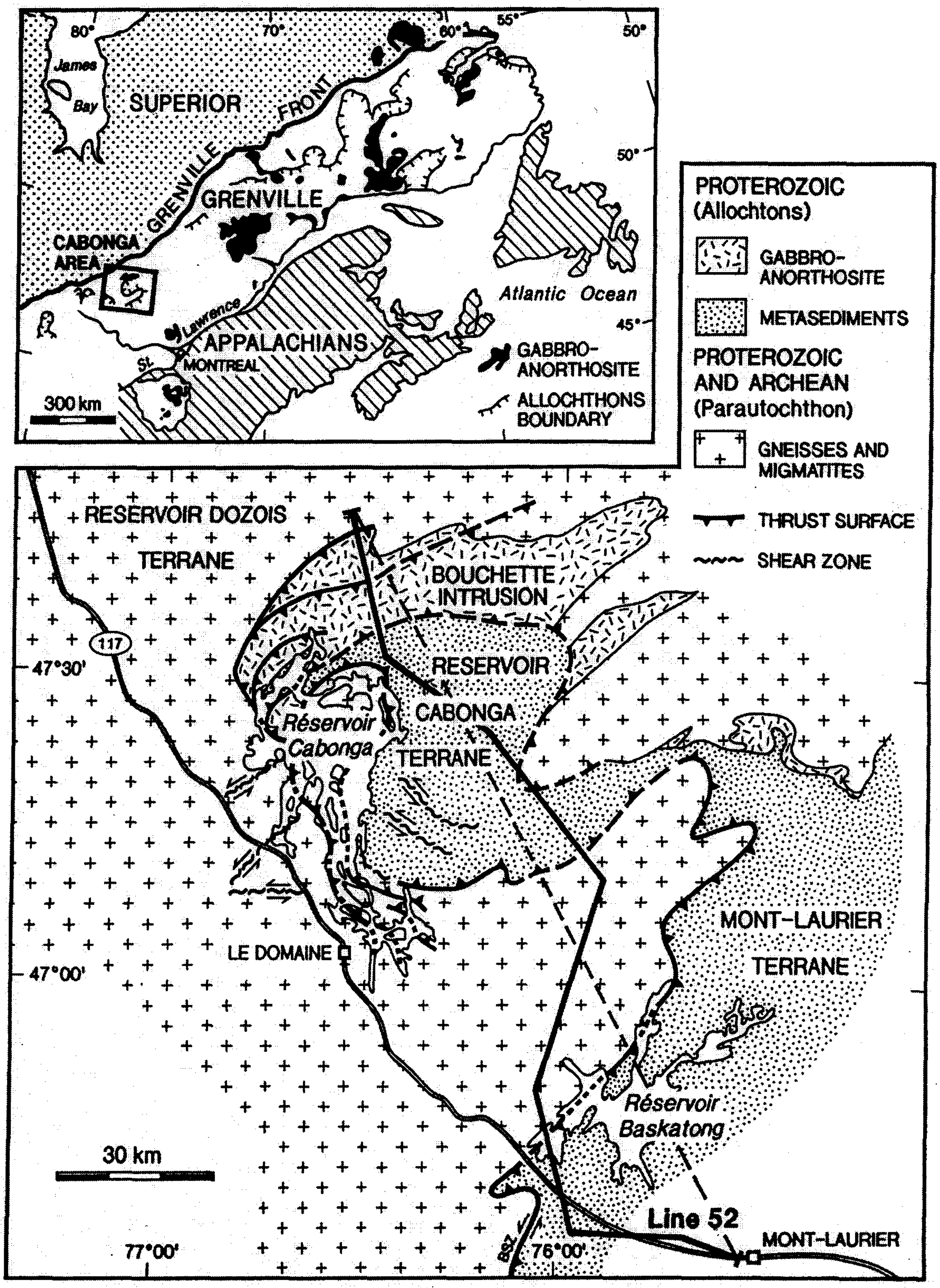
Figure captions

Figure 1. Tectonic setting of Bouchette intrusion area adapted from Martignole and Pouget (1993; 1994) and location of Lithoprobe seismic line 52. The gravity data were projected on the profile represented by the discontinuous line. BSZ is the Baskatong shear zone.

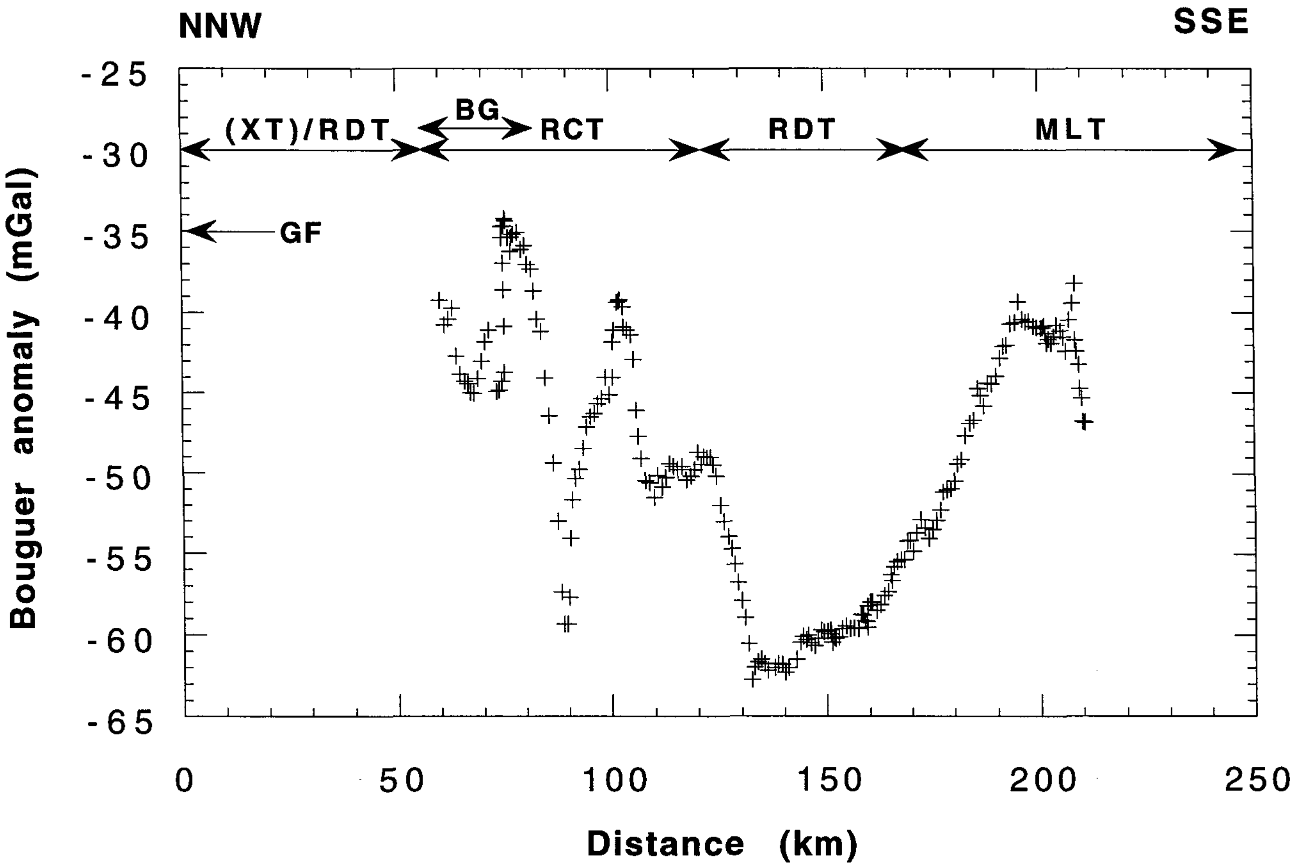
Figure 2. Bouguer gravity data projected along a N340 directed profile. The distance in km is measured southward from the Grenville Front. GF: Grenville Front; RCT: Réservoir Cabonga Terrane; RDT: Réservoir Dozois Terrane; MLT: Mont Laurier Terrane; BG: Bouchette Gabbro; XT: X Terrane.

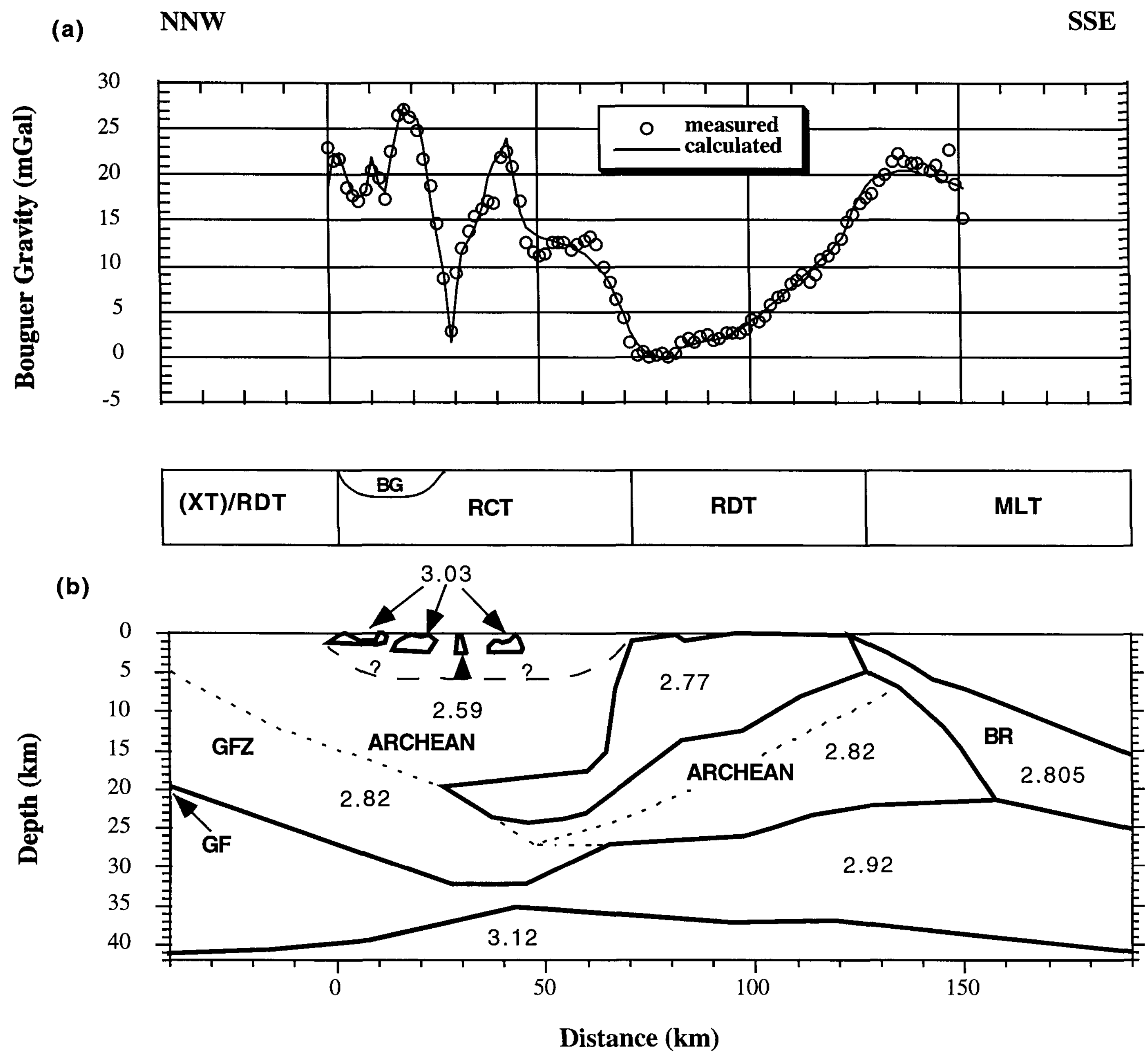
Figure 3. a) Comparison between observed and calculated gravity. b) Crustal model. GF: discontinuity that can be extrapolated to the Grenville Front; RCT: Réservoir Cabonga Terrane; RDT: Réservoir Dozois Terrane; MLT: Mont-Laurier Terrane; BG: Bouchette Gabbro; GFZ: Grenville Front Zone; BR: Baskatong Ramp. Continuous lines indicate changes in density required to fit the gravity data. Discontinuous lines indicate discontinuities inferred from the seismic data that are not accompanied by a change in density. With the exception of the thin Cabonga slice, the upper crust north of the Baskatong ramp is interpreted to be Archean.

Figure 4. a) Observed and calculated residual gravity on the Bouchette intrusion. b) Density model that fits the gravity data (density difference from the average 2.82 $Mg.m^{-3}$ crustal density).

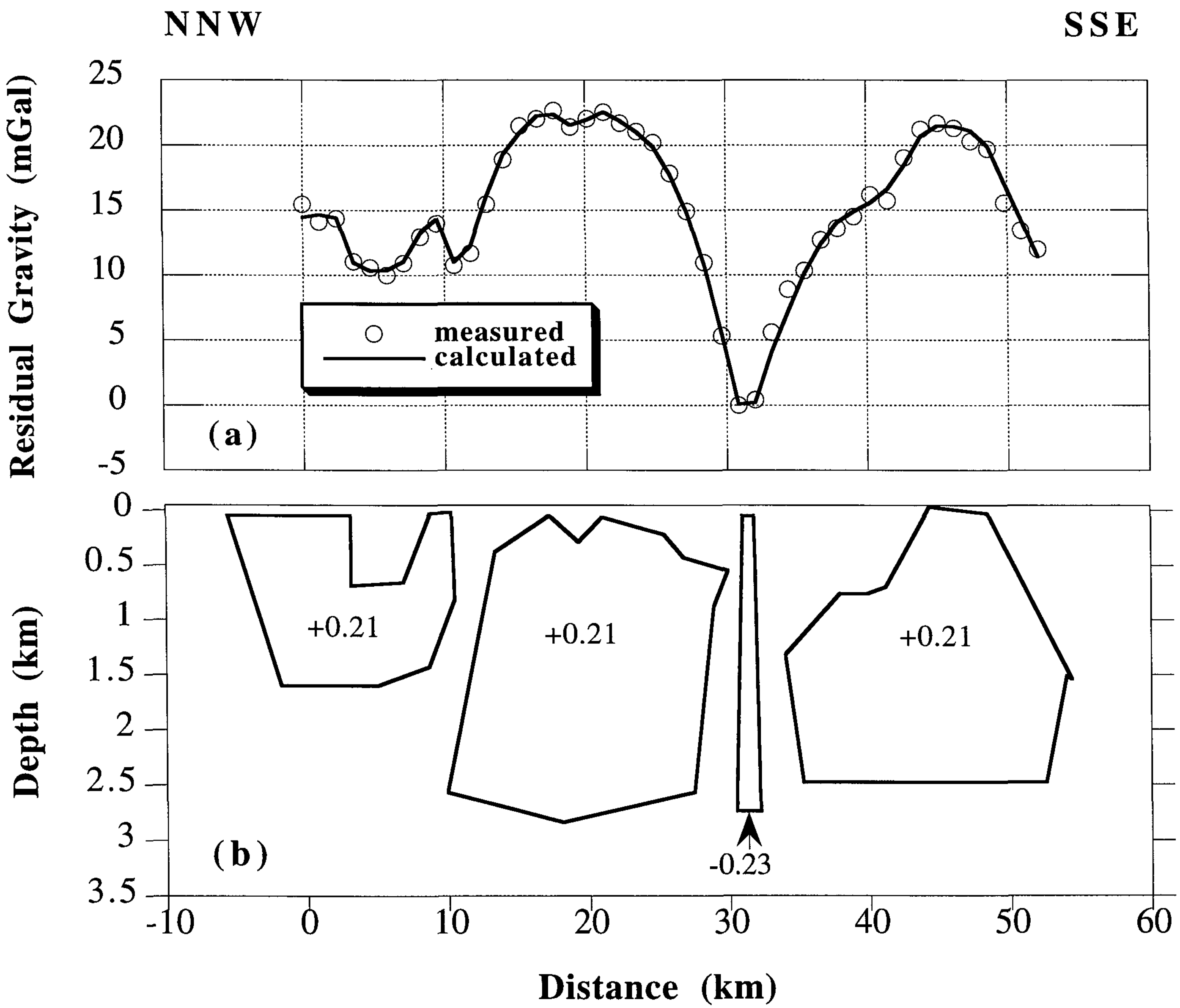


80°
70°
60°
55°
50°
James Bay
SUPERIOR
GRENVILLE FRONT
GRENVILLE
CABONGA AREA
St. Lawrence
MONTREAL
APPALACHIANS
Atlantic Ocean
45°
GABBRO-ANORTHOSITE
ALLOCHTHONS BOUNDARY
300 km
PROTEROZOIC (Allochtons)
GABBRO-ANORTHOSITE
METASEDIMENTS
PROTEROZOIC AND ARCHEAN (Parautochthon)
GNEISSES AND MIGMATITES
THRUST SURFACE
SHEAR ZONE
RESERVOIR DOZOIS TERRANE
BOUCHETTE INTRUSION
RESERVOIR CABONGA TERRANE
117
47°30'
Réservoir Cabonga
LE DOMAINE
47°00'
MONT-LAURIER TERRANE
Réservoir Baskatong
30 km
Line 52
MONT-LAURIER
77°00'
76°00'
BSZ


NNW
SSE
-25
-30
-35
-40
-45
-50
-55
-60
-65
(XT)/RDT
BG
RCT
RDT
MLT
GF
Bouguer anomaly (mGal)
0
50
100
150
200
250
Distance (km)



(a)
NNW
SSE
Bouguer Gravity (mGal)
30
25
20
15
10
5
0
-5
measured
calculated
(XT)/RDT
BG
RCT
RDT
MLT
(b)
3.03
Depth (km)
0
5
10
15
20
25
30
35
40
2.77
2.59
ARCHEAN
GFZ
2.82
ARCHEAN
2.82
BR
2.805
GF
2.92
3.12
0
50
100
150
Distance (km)



NNW
SSE
Residual Gravity (mGal)
25
20
15
10
5
0
-5
measured
calculated
(a)
0
0.5
1
1.5
2
2.5
3
3.5
Depth (km)
+0.21
+0.21
+0.21
-0.23
(b)
-10
0
10
20
30
40
50
60
Distance (km)

CHAPITRE II

Crustal models of the eastern Superior Province, Quebec, derived from new gravity data

Abstract

New gravity data were collected in the Nemiscau and La Grande subprovinces of the Superior Province. This ~350 km gravity profile follows the Matagami-Radisson road and extends northward the gravity transect along the ~260 km long Lithoprobe seismic line 48, across the northern Abitibi and Opatica subprovinces. For the northern Abitibi and Opatica belts, the interpretation calls for an increase of crustal thickness which is consistent with the interpretation of Lithoprobe's seismic line 48. The gravity model complements the seismic reflection data that did not image well the uppermost supracrustal sequences coinciding with the transparent upper 2 seconds of the data. Most of the intrusives in the Opatica belt appear as thin (< 5 km) bodies. Across the Nemiscau and La Grande subprovinces, the Bouguer anomalies are of short wavelengths and their sources lie in the upper crust. The crustal thickness is constant from the northern Opatica belt throughout the southern part of the Nemiscau subprovince. The interpretation calls for upper crustal density relatively higher in the Nemiscau and La Grande subprovinces than in the Abitibi and Opatica belts. There is some crustal thickening beneath the La Grande subprovince and a gravity high at the northern end of the subprovince is related to the occurrence of mafic supracrustal sequences. The gravity anomaly signature associated with the lateral density variation and field evidence indicate that the main tectonic boundaries between the different subprovinces must dip to the north.

1. Introduction

A gravity profile was obtained along the Matagami-Radisson road, in northwestern Quebec, across several subprovinces of the Superior craton (Fig. 1). It consists of two different surveys: i) a segment collected at 1km interval along the ~260 km Lithoprobe seismic line 48 across the northern Abitibi belt and the Opatica subprovince (Antonuk and Mareschal, 1994), it is the section between P1 and P2 on Fig. 2; and ii) a ~350 km long traverse collected during the summer of 1996 at ~2 km interval of across the Nemiscau and La Grande subprovinces, it corresponds to the P2-P3 section on Fig. 2.

The objectives of this study were to obtain a continuous gravity transect across the northern Superior Province and to unravel, from these data, the crustal organisation of the northern Abitibi, Opatica, Nemiscau and La Grande subprovinces.

This paper presents crustal density models for the transect. These models, which fit the measured gravity data: i) are consistent with the north dipping reflections shown in the seismic section under the Opatica and those inferred under the Nemiscau; ii) complement the seismic information on the subsurface geometry of the shallow bodies along the Lithoprobe seismic line; iii) determine the thickness and the geometry of the surface terranes mapped in the Nemiscau and the La Grande subprovinces, constrained by density measurements on outcrop samples; and iv) suggest some variations of crustal thickness in the Nemiscau and La Grande subprovinces.

2. Geological setting

The transect crosses the north central Superior Province. It follows the Matagami-Radisson road, from the Casa Berardi tectonic zone, in the northern Abitibi, to the La Grande subprovince, west of the LG2 (Robert Bourassa) Reservoir (Fig. 1).

The late Archean Superior craton consists of a sequence of E-W trending granite-greenstone belts and metasedimentary subprovinces that formed between ca. 3.1 and 2.65 Ga with a southward trend of broadly decreasing age (Card, 1990). This sequence was interpreted as due to the amalgamation of progressively younger terranes along north-facing subduction zones (Percival et al., 1994). Models for the late Archean evolution of the southern Superior generally call for major episodes of north-south compression during convergence and collision of magmatic arc-terranes (Benn et al., 1992).

2.1. The northern Abitibi belt

The northern part of the Abitibi belt consists of a volcanic zone comprising 2730-2725 Ma subaqueous basaltic sequences with felsic centers and 2723-2711 Ma felsic volcanic and plutonic rocks (Chown et al., 1992). The northern volcanic zone (NVZ) was deformed and metamorphosed to greenschist facies during a north-south shortening event between ~2.71 and 2.69 Ga (Mortensen, 1993; Davis et al., 1995).

2.2. The Opatica subprovince

The Opatica subprovince consists predominantly of metaplutonic rocks different in structural style and metamorphic grade from those in the Abitibi subprovince (Sawyer and

Benn, 1993). The Frotet-Evans greenstone belt, a thin allochthonous E-W band of metavolcanic rocks, lies in the central part of the Opatica subprovince. The allochthonous Lac Rodayer complex, at the northern limit of the Opatica belt, is the oldest unit (ca. 2.82 Ga; Davis et al., 1995) within the Opatica subprovince. However, ages of ~2.81 Ga were found on zircons in the grey gneisses, which form the most voluminous suite in the central portion of the belt; thus indicating that parts of the Opatica belt involve pre-2.80 Ga crust that may have been more extensive prior to being recycled during formation of the Opatica gneisses (Davis et al., 1994; 1995). The Opatica gneisses are interpreted as the hinterland of an Archean mountain belt in which the adjacent Abitibi metavolcanic assemblages represent the foreland part (Sawyer and Benn, 1993). The age of intrusion of late- tectonic pink granites implies that the collision of the Opatica with the northern Abitibi occurred between 2.70 and 2.68 Ga (Davis et al., 1995).

2.3. The Nemiscau subprovince

The Nemiscau subprovince is essentially a metasedimentary assemblage (Card and Ciesielski, 1986) located between the Opatica subprovince to the south and the La Grande and Opinaca subprovinces to the north. The northern boundary of the Nemiscau subprovince follows the Lower Eastmain River volcanic band (Fig.1; Franconi, 1978). The nature of this boundary remains imprecise, but it could be an E-W ductile fault zone (Hocq, 1994). From north to south, the Nemiscau subprovince is now divided into the Lac

Champion plutonic terrane (LCT) and a metasedimentary assemblage with meta-volcanic components.

The LCT, which had been included in the La Grande subprovince by Card and Ciesielski (1986), consists of biotite-hornblende monzonitic to granodioritic plutons with strips of paragneiss and amphibolite. Narrow amphibolitic bands separate the LCT from the southern metasedimentary terrane. The latter is subdivided into three domains delineated by an important positive magnetic anomaly along the Nemiscau river. Domain N2, which corresponds to this anomaly, consists of E-W striking amphibolites and paragneisses separating the dominantly sedimentary N1 and N3 domains. Syn-kinematic tonalitic to granodioritic massifs and large areas of pegmatites occur in the three domains. Ductile fault zones, parallel to the amphibolitic bands and the main rivers, were also recognized (Hocq, 1994). They correspond to mylonite zones located close to the boundaries of Domain N2.

2.4. The La Grande subprovince

The La Grande subprovince, defined as volcano-plutonic assemblage (Card and Ciesielski, 1986), is characterized by narrow, sinuous and partly interconnected greenstone belts surrounded and intruded by voluminous granitoids rocks (Card, 1990). Structural trends are predominantly east-west to southeast-northwest. The greenstone belts have lower basalt-rhyolite cycles and komatiites overlain by differentiated calc-alkalic and tholeiitic volcanics. Sequences of quartz pebble conglomerate, quartz arenite, ironstone, mafic-ultramafic material and tuffs are also present towards Lake Sakami (Roscoe and Donaldson, 1988). Proterozoic fault zones were reported and brittle normal faults surround the sedimentary rocks of the Sakami formation (Hocq, 1994).

The tonalitic basement in the La Grande subprovince has been dated as between 2.88 and 2.79 Ga (Mortensen and Ciesielski, 1987; David and Parent, 1997; Parent, 1998). In addition, inherited zircons with ages of up to 3.3 Ga may indicate the involvement of older basement rocks.

The intrusions within the La Grande subprovince include ultramafic complex, tonalites, granites, syenites, and monzonites. Although the ultramafic intrusions are younger than the volcanic rocks, they were equally affected by the regional deformational events. Syn- to post-tectonic felsic plutons were intruded between 2.71 and 2.62 Ga; proterozoic diabase dykes are also present (David, 1996; David and Parent, 1997; Parent, 1998).

3. Gravimetric survey

The gravity survey consists of a transect of about 600 km along the Matagami-Radisson road, in northwestern Quebec. All measurements were done with a Lacoste-Romberg, model G gravity meter lent by the Geological Survey of Canada (GSC). The transect comprises two different gravity surveys. The first one contains data collected at 1 km interval along Lithoprobe seismic line 48, labeled as P1-P2 on Fig.2. This ~260 km long traverse extends across the northern Abitibi belt, the entire Opatica and a small part of the southern Nemiscau subprovinces. Because of the very precise leveling done during the Lithoprobe survey, the Bouguer anomaly data were obtained with precision higher than 0.1 mGal. The second set consists of gravity data collected during the summer of 1996 along a ~350 km long traverse that extends northward of Lithoprobe line 48, across the Nemiscau and La Grande subprovinces shown as P2-P3 on Fig. 2. The station spacing is about 2 km. The elevation was measured with digital barometric altimeters and controlled on benchmarks located in the area. The elevation, which is the main source of errors, was determined with an accuracy estimated at ~2 m. For this part of the transect, the Bouguer anomaly is obtained with an accuracy better than 0.5 mGal.

These two data sets were projected onto a N-S profile, perpendicular to the strike of major structures; the total length of the profile after projection is about 470 km. The projected profile is compared on Fig. 3 to a profile interpolated from the GSC data base projected onto the same direction. The long wavelength trends are very similar, but our data show several short wavelength anomalies that are absent from the regional data base.

The Bouguer anomaly (Fig. 3) decreases from about -40 mGal at the southern end of the profile, over the greenstone rocks of the northern Abitibi subprovince, to about -75 mGal over the Opatica tonalite-gneiss belt. It increases and fluctuates around -50 mGal in the metasedimentary Nemiscau subprovince. It decreases steeply to about -70 mGal in the La Grande subprovince with two short wavelengths peaks (-45 mGal at ~300 km and -50 mGal at ~340 km). At the northern end of the transect, the Bouguer anomaly increases to about -35 mGal over the volcanic belts of the La Grande subprovince.

Samples of the representative lithologies were collected on outcrops along the traverse. The density measurements on these samples and those obtained from borehole samples in the Matagami area (Antonuk and Mareschal, 1994) are summarized in Table 1.

4. Magnetic field data

A total magnetic field map (Fig. 4a, 4b) was obtained from the 200 m spacing data base available from the Ministère des Ressources naturelles du Québec. The aeromagnetic data base consists of a compilation of surveys conducted at a line spacing of 800 m and a flight elevation of 300 m in the early 1950's, and of aeromagnetic surveys at a line spacing of 200 m and a flight elevation of 150 m thereafter (Lefebvre, 1994).

The northern Abitibi and the La Grande subprovinces are characterized by strongly magnetic, elongated zones (Fig. 4a) which correspond to mafic-ultramafic intrusions and volcanic bands. The high magnetic band in the northern Abitibi belt is associated with the greenstone rocks that form part of the northern volcanic zone and Bell River Complex gabbroic intrusion. The Frotet-Evans allochthon, in the Opatica belt, is also associated with a magnetic high (Fig. 4a). An elongated positive magnetic anomaly is conspicuous in the southern part of the Nemiscau subprovince; it corresponds to the exposure of mafic amphibolite bands exposed along the boundaries of domain N2. A positive magnetic anomaly is also present at a latitude of 52° N within the N1 domain (Fig. 4b), where field observations only showed the presence of granitoid rocks. A few kilometers further north, a narrow band of high magnetic field is conspicuous (Fig. 4b) and corresponds to the iron formations of the Eastmain River. The high magnetic bands in the La Grande subprovince (Fig. 4b) correlate with occurrences of volcanic rocks.

A N-S magnetic profile compiling the information gathered along the P1-P2 and P2-P3 transects of Fig. 4 is shown on Fig. 5. In the Abitibi subprovince, a high magnetic peak (~400 nT) at ~20 km correlates with the Bell River Complex which also defines a positive gravity anomaly. In the Opatica, two peaks of about 500 nT and 900 nT correlate with the Frotet-Evans greenstone belt zone. The positive magnetic field anomaly (~800 nT) occurring at ~190 km is associated with the amphibolitic material present in domain N2 of the southern Nemiscau subprovince. Another positive anomaly of about 500 nT, at ~290 km, is also associated with amphibolitic rocks present in this area. The very strongly positive anomaly of more than 1000 nT, at ~300 km, correlates with the iron formation of the Eastmain River. Several short wavelength peaks between km 400 and 460 correspond to basaltic lava flows of the La Grande subprovince.

Modeling simultaneously the gravity and the magnetic anomalies is not practical in the present study because the gravity data are sampled at longer wavelengths and affected by deeper crustal levels than the magnetic data. However, constraints imposed by the magnetics were introduced in the gravity modeling.

5. Gravity interpretation

5.1. Gravity modeling

The interpretation of the gravity data was done with a 2.5 D gravity modeling where a body is approximated by a horizontal polygonal prism with a finite length in the strike direction. Selected model parameters, which consist of the geometry and the density of each prism, can be iteratively improved by linear inversion (Webring, 1985).

The model consists of a set of 2.5-D prisms that map in cross-sectional form the interpreted variations in subsurface density. In the third dimension, perpendicular to the cross section, the model extends far enough to avoid edge effects. Tests showed that there is no change in the calculated gravity as long as the deeper units are extended a distance equivalent to five times their depth. Thus, the strike length for the deeper units was taken as 200 km. The near surface units were matched to their mapped extent.

The gravity model is constrained by the structure revealed by the seismic reflection profile in the southern part of the transect, the densities determined from outcrop samples and the surface geology. However, the geological relationships remain uncertain in the northern half of the transect (Nemiscau and La Grande subprovinces) that was not mapped in detail. Here, the magnetic data were used to provide additional constraints.

5.2. Density considerations

Densities of the near surface lithologies were estimated from measurements on samples collected along or near the profile. Average values were determined for the main geological units in each province and used as a basis for the gravity modeling. A mean density value of 2720 Mg m^{-3} was assumed for the upper crust under the northern Abitibi and Opatica belts; this value is identical to that used by Antonuk and Mareschal (1994).

A density value of 2740 Mg m^{-3} is used for the upper crust in the Nemiscau subprovince. This value corresponds to the average density of gneiss and paragneiss rocks (Table 1) that form the majority of the surface exposure. A north-south projection of the density values measured on outcrop samples along the Nemiscau and the La Grande suprovinces transect (P2-P3) is shown on Fig. 6. The northern half of the projection, which corresponds to the La Grande subprovince, presents high density values due to the occurrence of mafic-ultramafic material, superposed with lower density grantoid rocks. However, the mean weighted density of the upper crust in the La Grande subprovince remains the same as in the Nemiscau (2740 Mg m^{-3}) due to the presence of low density felsic rocks intermingled with the mafic material. The mean upper crustal density of the Nemiscau and La Grande subprovinces is higher than in the Abitibi and Opatica belts. A density value of 2950 Mg m^{-3} was assumed for the lower crust, which is considered to be gabbroic, and a standard density value of 3300 Mg m^{-3} was assumed for the mantle.

5.3. The gravity models

5.3.1. *Abitibi-Opatica transect*

The gravity anomaly projected on a north-south profile, perpendicular to the strike of the geological structures shows minor, but significant scatter caused by the projection (Fig. 3). This is especially evident over the northern end of Abitibi subprovince near the Canet pluton (Fig. 1), where the transect runs oblique to the direction of the profile. This is also the case for the section south of the Frotet-Evans belt, where the profile is sub-parallel to the strike of the structures. The 2.5-D assumption may not be valid for these sections. Consequently, two parallel profiles separated by a distance of ~30 km, were used for the modeling (see Fig. 2): i) an eastern profile, where the sections labeled AB and CD were replaced by data interpolated from the GSC data base and ii) a western profile, where the section labeled B'C' is replaced also by GSC data. Because of the differences in sampling distances, all data were interpolated with a constant step. The two profiles and the resulting models are shown on Fig. 7 (eastern) and Fig. 8 (western).

5.3.1.1. Eastern model

Seismic reflection data (Calvert et al., 1995) were used to constrain the geological structures below ~25 km. At the south of the profile, a negative anomaly is caused by increased crustal thickness below the Abitibi-Opatica boundary, where the Moho is found at a depth of 44 km. In the northern Opatica and southern Nemiscau subprovinces, the crustal thickness was fixed at 37.5 km after the seismic reflection interpretation (Calvert et al., 1995).

The boundary between the upper and the lower crust is defined as the lower-crustal decollement inferred from the seismic reflection image in the northern Abitibi (Calvert et al., 1995). The depth to this boundary varies from ~27 km at the southern end of the transect in the Abtitibi subprovince, to ~30 km under the Abitibi-Opatica boundary, and reaches ~32 km at the Opatica-Nemiscau boundary.

The high positive anomaly at ~20 km from the southern end of the profile coincides with the mafic-ultramafic Bell River Complex (BRC) intruded in the northern volcanic zone. Its density of 2910 $Mg.m^{-3}$ was determined from borehole logging study (Table 1). This ~3 km thick body is bounded to the south by a granitoid intrusion which is surrounded by an assemblage of felsic volcanic rocks. These rocks thicken southward to a maximum thickness of 10 km. Their density of 2670 $Mg.m^{-3}$, slightly less than that determined for felsic rocks (2700 $Mg.m^{-3}$; Table 1), was obtained after many iterations. The narrow positive anomaly at 35-40 km is related to the Canet pluton which appears as a 2.5 km thick body with a mean density of 2870 $Mg.m^{-3}$ (Table 1). A narrow body pile of felsic volcanics, extending to a depth of 2.5 km with density of 2700 $Mg.m^{-3}$ is present between the BRC and Canet pluton. At ~70 km, the Lac Ouescapis pluton was modeled as a ~3 km thick body with a density of 2640 $Mg.m^{-3}$ (the average density of granitic intrusions in the Opatica belt; Table 1). The positive anomaly at ~110 km coincides with the Frotet-Evans greenstone belt. It was modeled as a thin sheet (< 2 km) with a density of 2800 $Mg.m^{-3}$, the mean density determined for metasediments collected in this area (Table 1). The Lac Rodayer pluton, at the northern end of the Opatica belt, is characterized by a positive anomaly at ~160 km on the profile. It was modeled as a ~4 km thick body, with a density of 2800 $Mg.m^{-3}$ corresponding to the mean density measured of outcrop samples collected *in situ* (Antonuk and Mareschal, 1994). The northern limit of the Lac Rodayer pluton dips steeply to the north. This zone could be correlated with the Lac Coulomb shear zone which marks the boundary between the Opatica and Nemiscau subprovinces.

5.3.1.2. Western model

On the western profile, constructed mainly from GSC data (section B'C' of Fig. 2), short wavelength anomalies are not as well resolved as on the eastern profile. The geometry of the deeper units is the same as that on the eastern profile. The Bouguer anomaly is ~10 mGal higher than on the eastern profile because, along this section, the BRC is more voluminous at depth, (~5 km thick with the same density of 2910 $Mg.m^{-3}$). Furthermore, this gabbroic body has a density very close to that of mafic volcanic rocks abundant in the Northern Abitibi (2870 $Mg.m^{-3}$; Table 1). A ~5 km thick body with a density of 2640 $Mg.m^{-3}$ is needed to fit the data north of the BRC. It could be the western extension of the Lac Ouescapis granitoid intrusion.

The positive anomaly at ~100 km was modeled as a body thinner than 3 km with a density of 2800 $Mg.m^{-3}$. The Frotet-Evans greenstone belt occurring at ~120 km was modeled as a narrow triangular shaped body with a northward dip consistent with the seismic reflection interpretation (Calvert et al., 1995). It is dense (3000 $Mg.m^{-3}$; Table 1) and shallow-rooted (less than 2 km).

5.3.2. Nemiscau-La Grande transect

For our interpretation (Fig. 9), the boundary between the upper and the lower crust constrained by the northern end of the seismic reflection profile (Calvert et al., 1995), is maintained constant at ~32 km under the Nemiscau and La Grande subprovinces. The crustal thickness increases from 38 km under the southern part of the Nemiscau, to reach 42 km in the northern end of the Nemiscau. It is constant under the La Grande subprovince. The mean density of the upper crust must be higher in the Nemiscau and La Grande subprovinces than in the Opatica belt to obtain a reasonable fit between the observed and the calculated gravity. The mean density of the upper crust in the Nemiscau and La Grande subprovinces was fixed at 2740 Mg m^{-3}. The thickness of the surface bodies was first inferred from the wavelength of the gravity anomaly and iteratively improved by inversion.

There is no long wavelength variation of the Bouguer anomaly in the Nemiscau metasedimentary subprovince. Nevertheless, a few short wavelength anomalies are present and due to shallow-rooted supracrustal sequences. Several narrow amphibolitic bands were reported and mapped in the Nemiscau subprovince. These bands were modeled as thin lenses, 02-0.8 km in thickness, with a mean density of 3000 Mg m^{-3} as determined on samples collected during the survey. Granitic material (pegmatite, leucogranite) also occurs in the Nemiscau. The short wavelength negative anomalies at ~180 km and ~195 km are correlated with lenses of granitic material (0.4-0.8 km thick) with density of 2630 Mg m^{-3} estimated from outcrop samples (Table 1). In the center of the Nemiscau profile, between ~230 km and ~250 km, a negative anomaly with a positive peak at ~240 km is correlated with two granitoid intrusions, separated by an amphibolite lens. These post-tectonic intrusions are interpreted as shallow-rooted bodies, less than 1.5 km thick, with a density of 2630 Mg m^{-3} (Table 1). A thin dense body (probably an amphibolitic material) between 270 km and 280 km, with density of 3000 Mg m^{-3} is needed to improve the fit. Two negative anomalies at ~290 km and ~320 km were interpreted to result from the presence of two granitoid bodies (~2 to 3 km thick) with a density of 2630 Mg m^{-3} (Table 1). Between these bodies, the iron formation of the Eastmain River is modeled as a very thin (~0.4 km) and extremely dense (~3700 Mg m^{-3}) lens. The short wavelength positive anomaly at ~335 km is correlated with a thin (0.4 km thick) basaltic body (density ~3000 Mg m^{-3}).

The boundary between the Nemiscau and La Grande subprovinces is not marked by any prominent feature on the gravity profile. However, conspicuous field evidence indicates the presence of a major thrust zone (Gauthier, M. and Larocque, M., pers. comm., 1997). The negative anomaly in the southern La Grande subprovince is due to a granitoid intrusion, interpreted as reaching a depth of ~3.5 km. The density of 2650 Mg.m^{-3} was measured on outcrop samples. The positive anomaly observed in the northern end of the La Grande subprovince is interpreted as due to dense supracrustal sequences, essentially basaltic lavas with peridotites and gabbros. These sequences, which have a mean density of 3040 Mg m^{-3}, are thicker in the south (~2.2 km) than in the north (~1 km).

6. Discussion

6.1. Abitibi-Opatica

The geometry of the crustal root beneath the northern Abitibi subprovince and the Opatica belt was well imaged along line 48 of Lithoprobe. The seismic reflection image (Calvert et al., 1995) revealed a structure interpreted as a relict 2.69 Ga old suture zone, based on a prominent reflection zone that extends to at least 30 km in the upper mantle, with a shallow northward dip. This structure may be a relict feature of an Archean subduction zone, possibly related to the convergence of the Abitibi and Opatica plates.

The interpretation of Sawyer and Benn (1993), that the low-grade Abitibi greenstones and the high-grade Opatica gneisses represent a deeply eroded Archean mountain belt, is consistent with the southern half of the gravity model, where the gravity profile defines a negative-positive couplet. Such a gravity signature appears in young mountain belts and has been recognized across several structural province boundaries within the Canadian Shield (Gibb and Thomas, 1976). The interpretation of the Bouguer anomaly suggests an increase of crustal thickness below the contact zone between the subprovinces, consistent with the structural interpretation of Lithoprobe line 48.

In the Abitibi and Opatica subprovinces, the gravity models complement the seismic reflection data that did not clearly image the uppermost crustal sequences, which coincide with the transparent upper 2 seconds of the seismic profile. In the Abitibi subprovince, the BRC is interpreted as relatively thin (~4 km) and the greenstone rock sequences of the Abitibi northern volcanic zone do not extend deeper than 10 km. This agrees with results from other gravity studies in the Abitibi greenstone belt (Keating, 1992 ; Dion et al., 1992). In the Opatica belt, the gravity signature of the Canet pluton is only marked in the eastern profile, whereas that of the Lac Ouescapis and Lac Rodayer plutons are apparent on both profiles. All these intrusives are thinner than 6 km. The gravity signature of the Frotet-Evans metavolcanics is well defined on the western profile; modeling shows that the sequence does not extend deeper than 2 km.

6.2. Nemiscau-La Grande

The structure of the deep crust and upper mantle beneath the Nemiscau and La Grande subprovinces is not constrained by seismic data.

In the Canadian Shield, the boundary between the upper and lower crust is frequently taken at an intermediate (~20 km) depth between the surface and the Moho (Telmat et al., 1997; 1998). However, the seismic image revealed a thicker upper crust in the northern Opatica and the southern Nemiscau subprovinces, with the upper-lower crust boundary possibly as deep as ~32 km (Calvert et al., 1995). Because there is no clear change of the long wavelength Bouguer anomaly in the Nemiscau subprovince, this depth was assumed constant. Nevertheless, a lateral density increase is needed to fit the gravity data. The mean density measured on gneiss samples collected along the transect was used as the mean density for the upper crust in the Nemiscau subprovince. The density of the upper crust in the La Grande subprovince is assumed equal to that estimated in the Nemiscau subprovince.

A relative crustal thickening beneath the La Grande subprovince is suggested by long wavelength gradient of the Bouguer anomaly between ~280 km and ~370 km. The trend of the gravity anomalies over the inferred boundary between the Nemiscau and La Grande subprovinces is a negative-positive couplet from south to north. This also appears to be the case for many fossil plate boundaries in the Canadian Shield (Gibb and Thomas, 1976). This type anomaly decreases gradually from a background level over the older province to a minimum near the inter-province boundary zone, and then increases sharply to a broad maximum over the younger province. It was modeled as due to the younger crustal block being thicker and slightly denser than the older (Gibb and Thomas, 1976).

The horizontal gradient of the Bouguer anomaly is minimum over the Nemiscau and maximum over the La Grande. It is about 0.2 $mGal.km^{-1}$ and 0.8 $mGal.km^{-1}$, respectively. These values are identical to the average gradient values over the older and younger province margins as determined by Gibb and Thomas (1976).

In our model, the crust is only slightly thicker under the La Grande subprovince, but it could be much thicker if it were denser than under the Nemiscau. This would not be surprising, in view of the large quantity of mafic and ultra-mafic rocks in the La Grande subprovince, that increase the mean upper crustal density. The tectonic boundary between the Nemiscau and La Grande subprovinces, described as a major thrust zone (Gauthier and Larocque, pers. comm., 1997), could be interpreted as a suture zone. The presence of mylonite zones imbricated with the syn to post-tectonic tonalitic-granitic intrusions in the Lac Yasinski area, is consistent with the gravity interpretation.

Combined petrological and geochemical studies still need to be conducted to characterize the crust, particularly in the Nemiscau subprovince, and confirm the presence of sutures between the subprovinces. The polarity of the gravity anomaly and field observations indicate that such suture zones dip towards the north.

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Table 1: Rock density measurements used as a basis for gravity modeling

Subprovince	Rock type	No. of samples	Average density	Std. Dev.	Density range
Abitibi	mafic volcanics*	609	2.87	0.06	
	felsic volcanics*	1368	2.70	0.05	
	sedimentary rocks**	6	2.75	0.02	2.73-2.77
	gabbro, Bell River Complex*	3996	2.91	0.11	
Opatica***	grey tonalitic gneiss	34	2.67	0.02	2.63-2.74
	mafic intrusions in gneiss	21	2.91	0.09	2.81-3.14
	granitic intrusions in gneiss	29	2.64	0.02	2.60-2.66
	Canet pluton (gabbro to granodiorite)	13	2.87	0.10	2.74-3.07
	Lac Rodayer pluton	34	2.80	0.12	2.64-3.14
	Frotet-Evans belt (metavolcanics)	14	3.00	0.09	2.82-3.14
	Frotet-Evans belt (metasediments)	3	2.80	0.04	2.76-2.84
Nemiscau	granitoids	15	2.63	0.03	2.55-2.69
	gneiss-paragneiss	16	2.74	0.02	2.69-2.80
	mafic (amphibolite)	1	3.00		
La Grande	mafic volcanics	15	3.04	0.06	2.92-3.18
	felsic volcanics	5	2.76	0.02	2.72-2.79
	granitoids	15	2.65	0.05	2.59-2.78
	gneiss-paragneiss	14	2.74	0.03	2.68-2.80
	others (amphibolite)	1	3.00		

- * from borehole logging (Milkereit, B. and Adam, E. work, in Antonuk and Mareschal, 1994)
- ** from Antonuk and Mareschal (1993)
- *** from Antonuk and Mareschal (1994)

Figure Captions

Figure 1: Simplified geological map showing the major geological subdivisions of the Superior province and the location of the gravity profile along the Matagami-Radisson road. Modified from Hocq (1994) and Sawyer and Benn (1993). BRC: Bell River Complex; CP: Canet pluton; FEGB: Frotet-Evans Greenstone Belt; LOP: Lac Ouescapis pluton; NRSZ: Nottaway River Shear Zone; LRT: Lac Rodayer Thrust; LRP: Lac Rodayer pluton; LCT: Lac Champion terrane; SOA: axis of the eroded southern Opatica antiform.

Figure 2: Bouguer anomaly map of the NW Quebec, calculated from the GSC data base and interpolated on a 2.5 mn grid. The section between P1 and P2 corresponds to the data set collected along Lithoprobe seismic line 48; the section between P2 and P3 corresponds to the data set collected during the summer of 1996. The sections between A and B and between C and D are used for the eastern model, the section between B'and C' for the western model.

Figure 3: Comparison of the gravity measurements along the Matagami-Radisson road with a profile interpolated from the GSC data base.

Figures 4a and 4b: Total magnetic field map of the James Bay region, NW Quebec, obtained from the Ministère des Ressources naturelles du Québec data base. The sites of gravity measurements are shown in black points. P1, P2 and P3 as in Fig. 2. The solid lines represent the profile shown on Fig. 5.

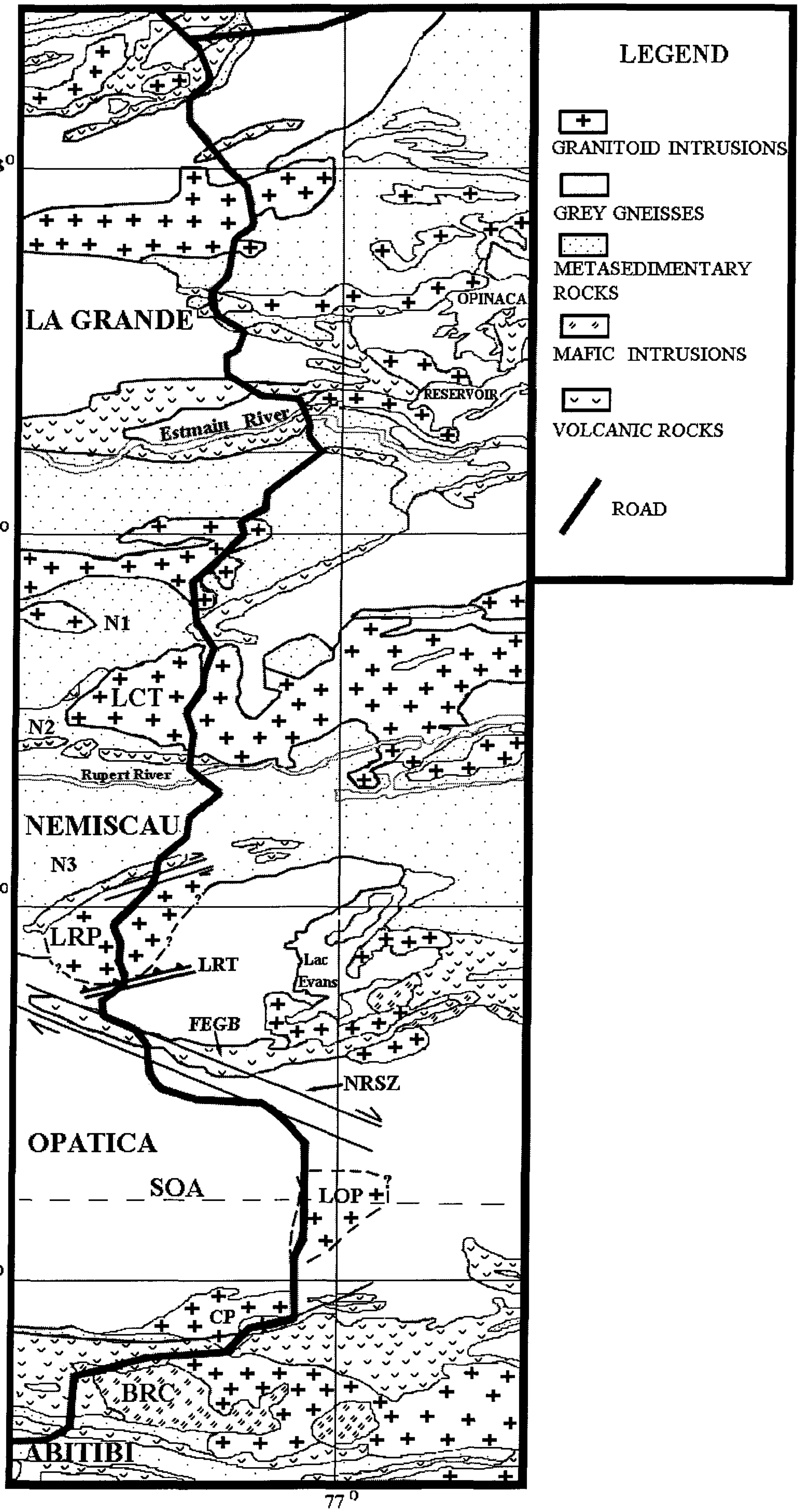
Figure 5: S-N profile extracted from the total magnetic field data map presented in Fig. 4. Ab: Abitibi; Op: Opatica; Nem: Nemiscau; LG: La Grande.

Figure 6: Density measurements of samples on the P2-P3 transect across the Nemiscau and La Grande subprovinces. The high densities in the northern half of the transect are mostly related to iron formations, amphibolites and basaltic rocks.

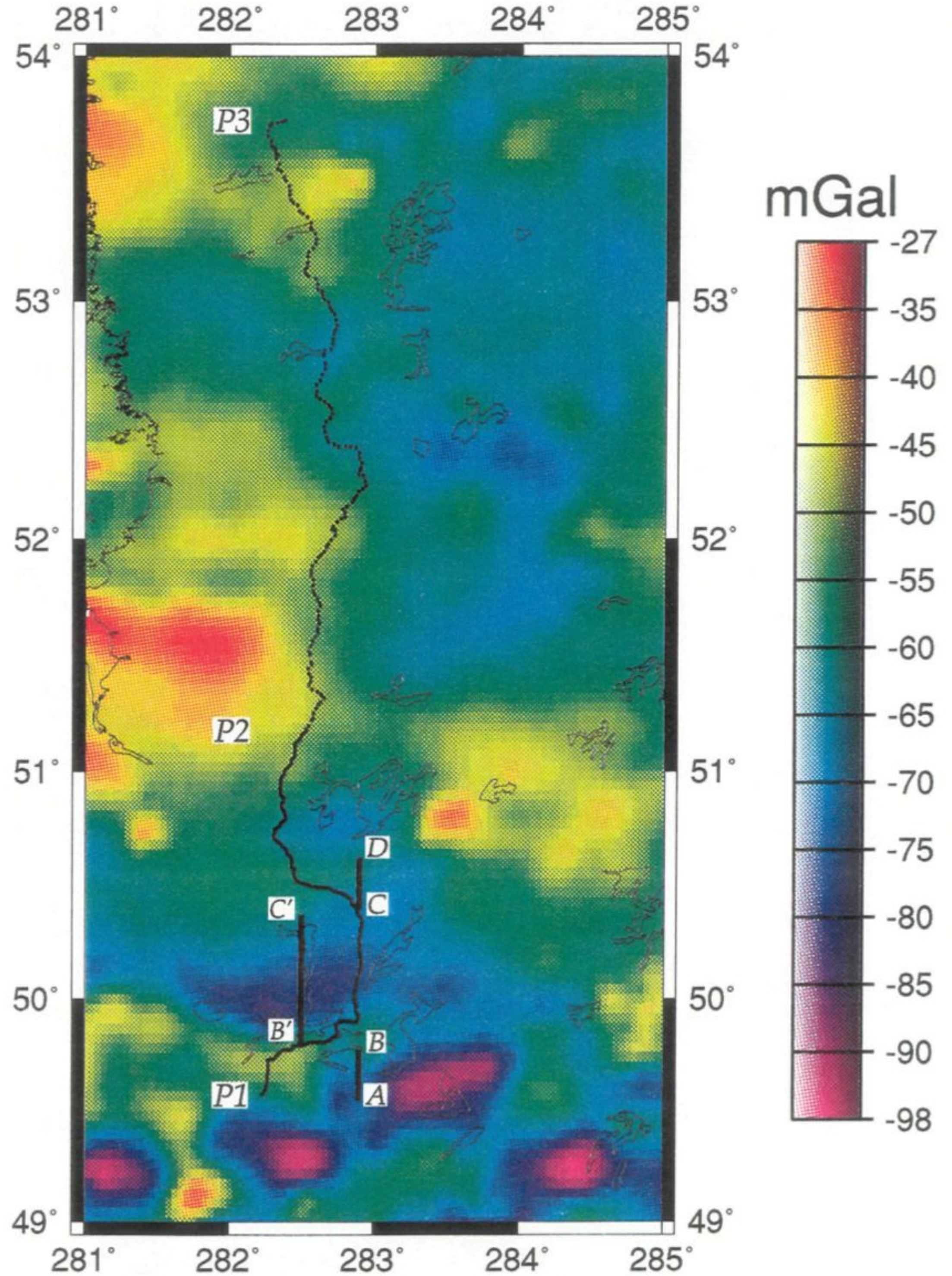
Figure 7: a) Comparison between observed and calculated gravity along the eastern Abitibi-Opatica transect. The gravity profile contains data extracted from the GSC data base (AB and CD sections, see Fig. 2). b) Eastern Abitibi-Opatica crustal density model. BRC, CP, LOP and LRP as in Fig. 1.

Figure 8: a) Comparison between observed and calculated gravity along the western Abitibi-Opatica transect. The observed gravity profile contains data extracted from the GSC data base (B'C' section, see Fig. 2). b) Western Abitibi-Opatica crustal density model. BRC and LRP as in Fig. 1. LOP? inferred western extension of the Lac Ouescapis pluton.

Figure 9: a) Comparison between observed and calculated gravity along the Nemiscau-La Grande transect. b) Nemiscau-La Grande crustal density model. **?** Inferred boundary between the Nemiscau and La Grande subprovinces.



LEGEND
GRANITOID INTRUSIONS
GREY GNEISSES
METASEDIMENTARY ROCKS
MAFIC INTRUSIONS
VOLCANIC ROCKS
ROAD
53°
52°
51°
50°
77°
LA GRANDE
OPINACA
RESERVOIR
Estmain River
N1
LCT
N2
Rupert River
NEMISCAU
N3
LRP
LRT
Lac Evans
FEGB
NRSZ
OPATICA
SOA
LOP
CP
BRC
ABITIBI



281°
282°
283°
284°
285°
54°
53°
52°
51°
50°
49°
P3
P2
P1
A
B
B′
C
C′
D
mGal
-27
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-45
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-55
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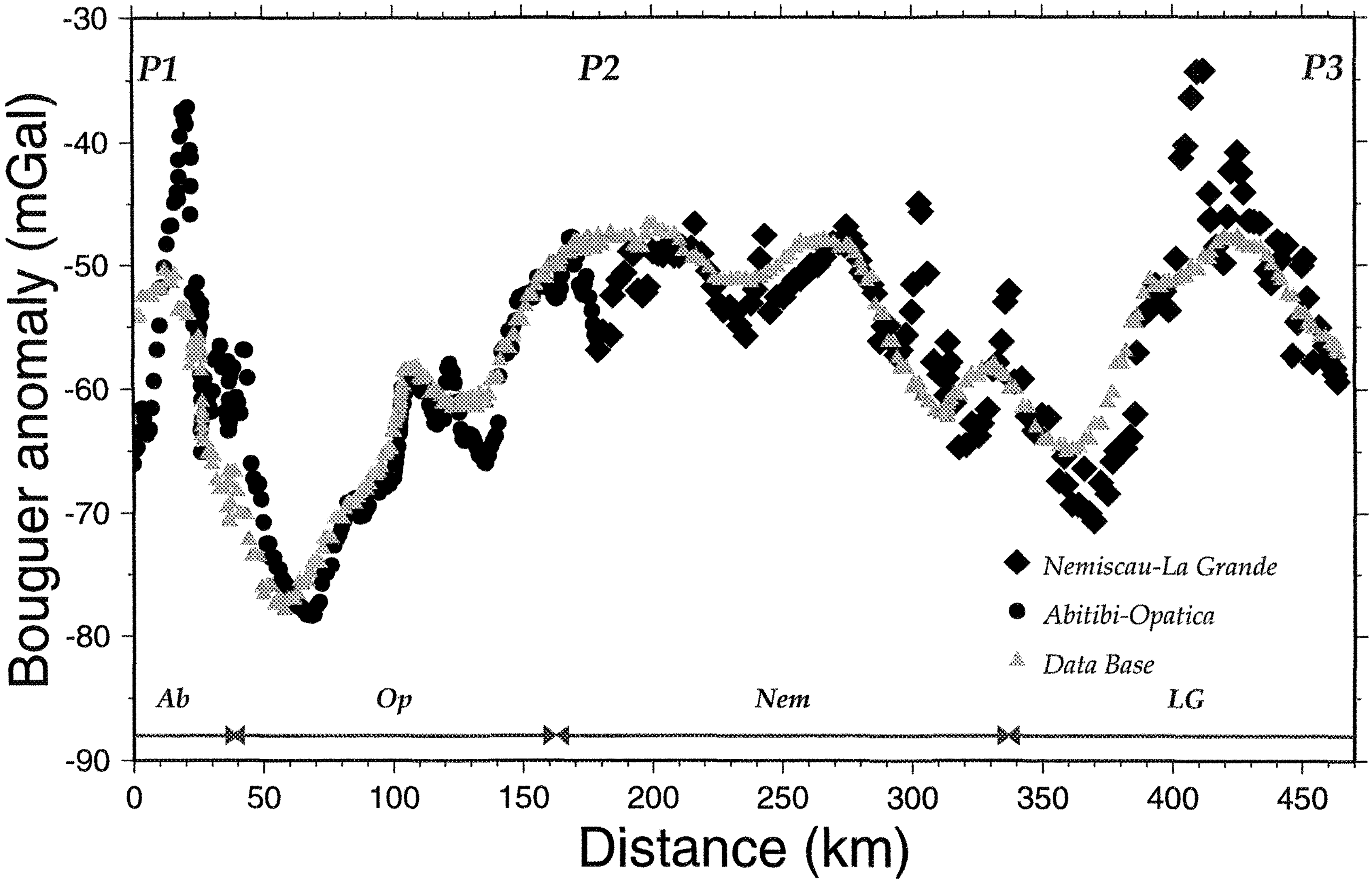
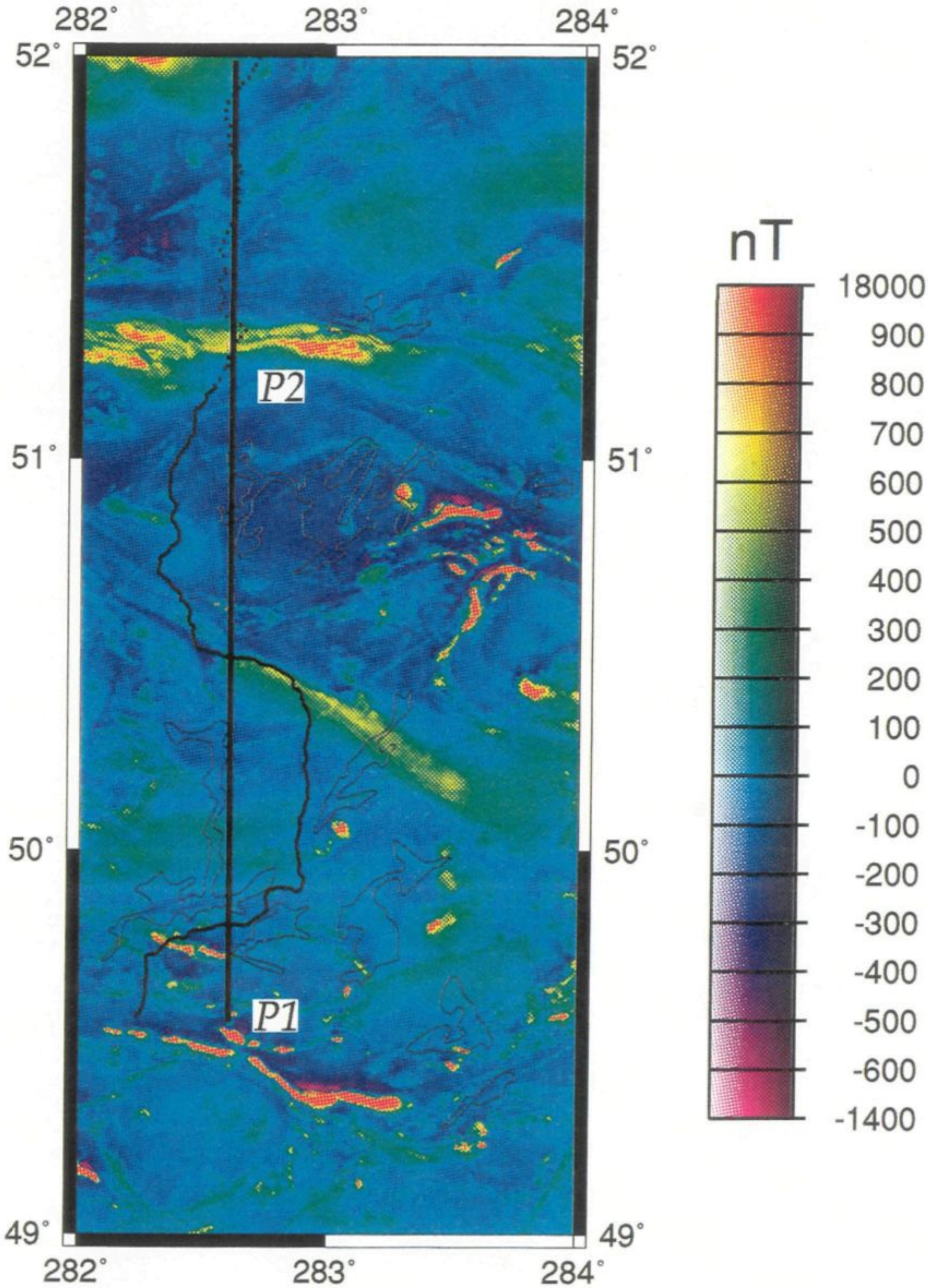
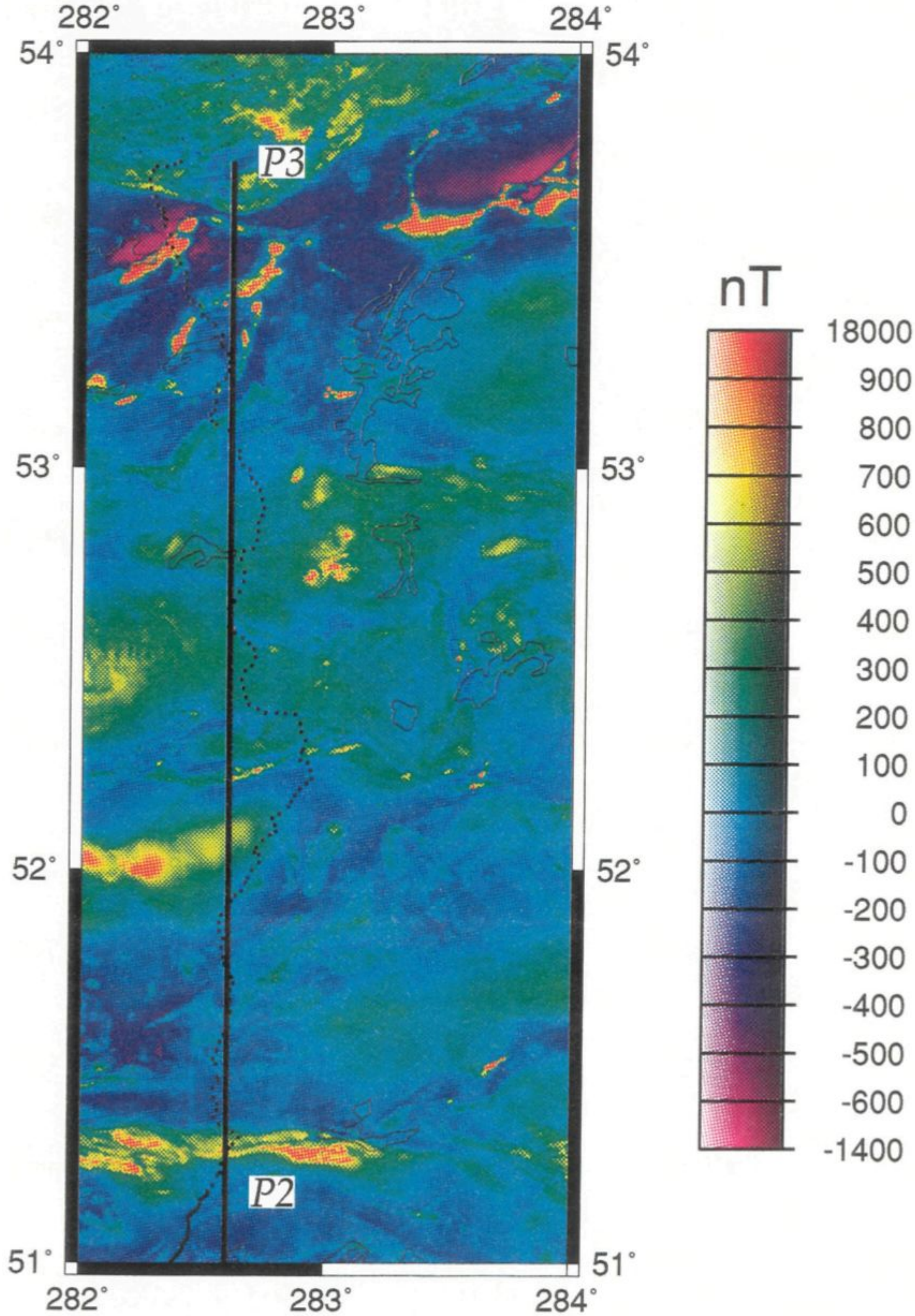
-80
-85
-90
-98



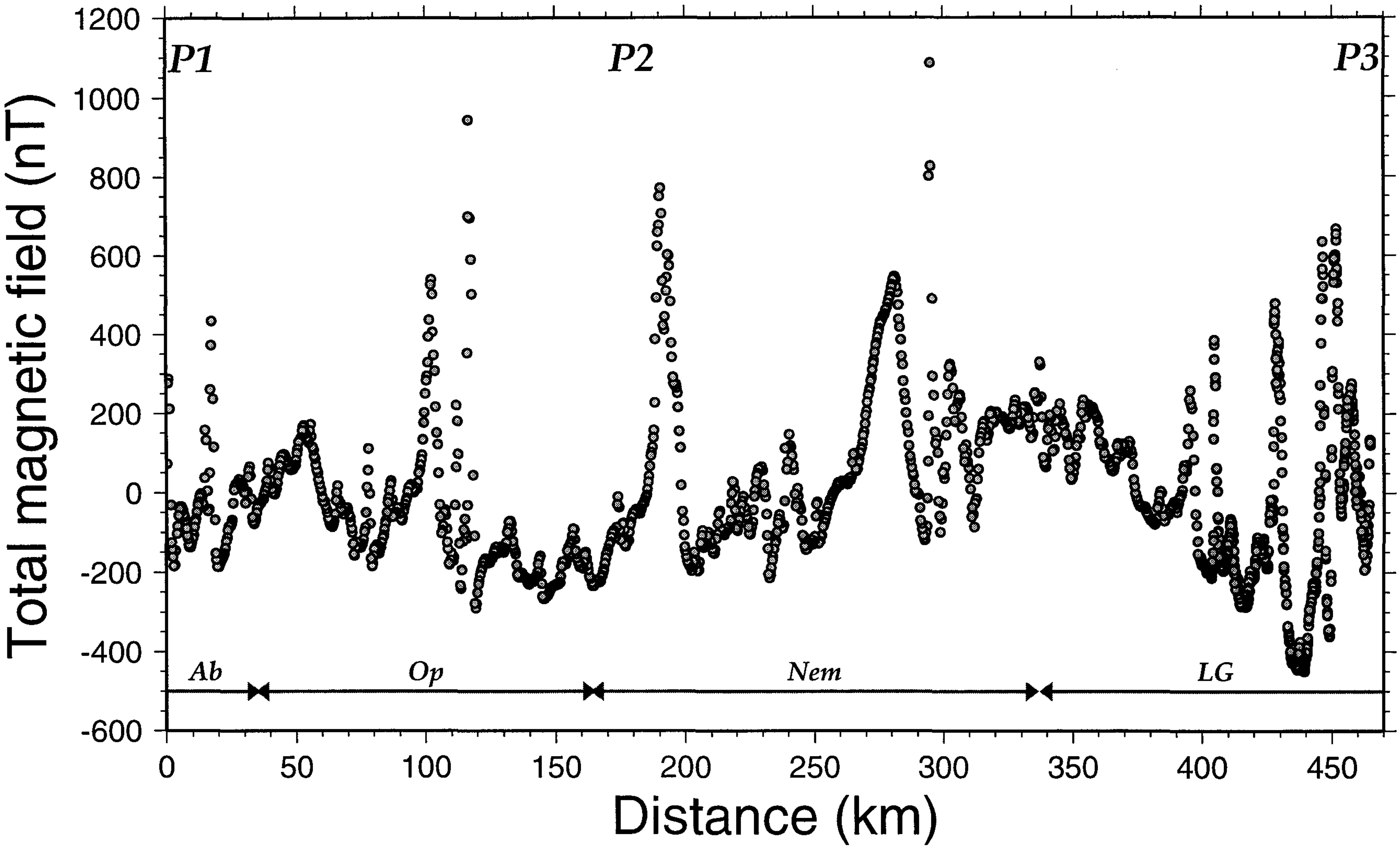
P1
P2
P3
Bouguer anomaly (mGal)
-30
-40
-50
-60
-70
-80
-90
Distance (km)
0
50
100
150
200
250
300
350
400
450
Ab
Op
Nem
LG
Nemiscau-La Grande
Abitibi-Opatica
Data Base



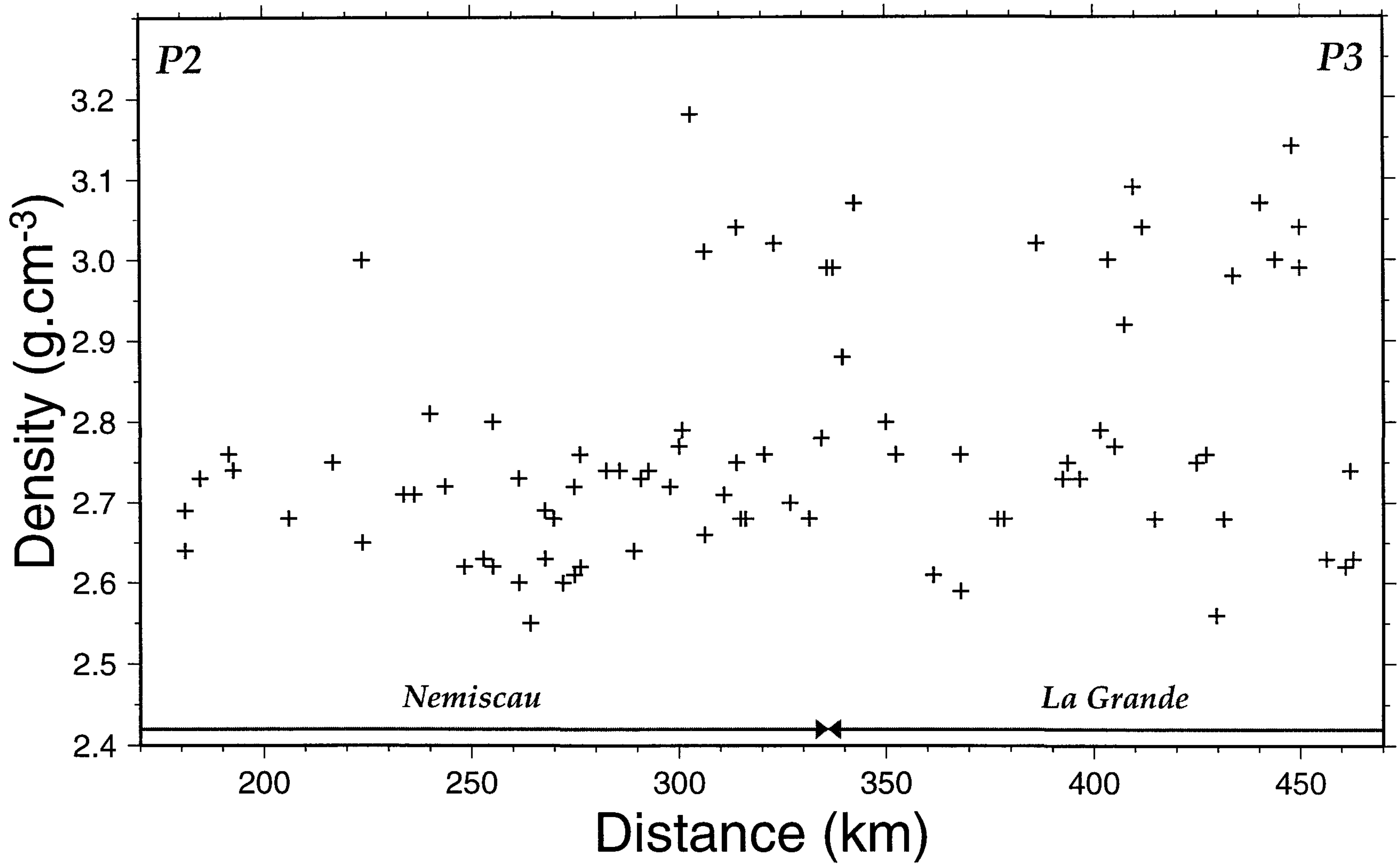
282°
283°
284°
52°
51°
50°
49°
P2
P1
nT
18000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-1400

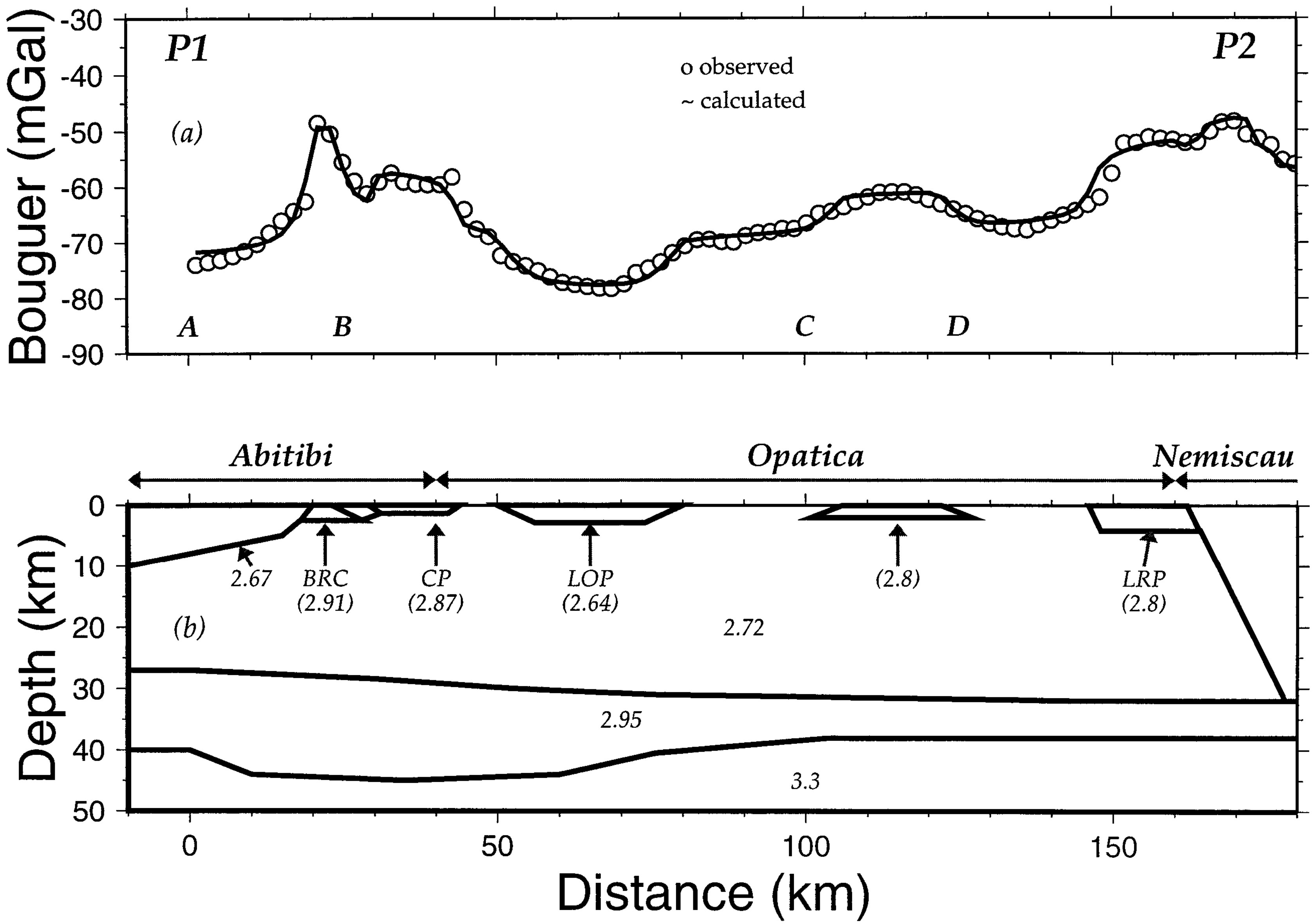


282°
283°
284°
54°
53°
52°
51°
P3
P2
nT
18000
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-1400

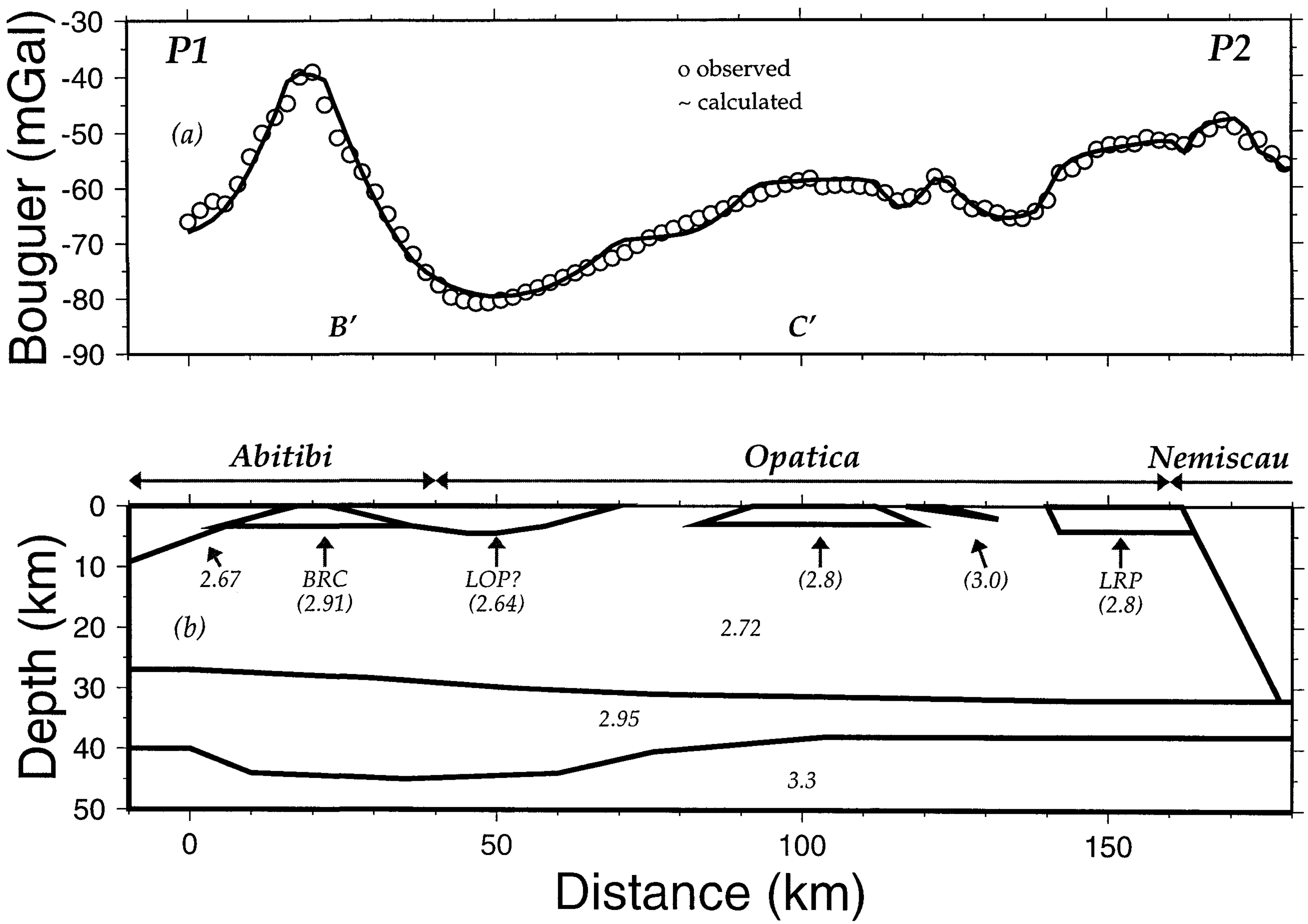


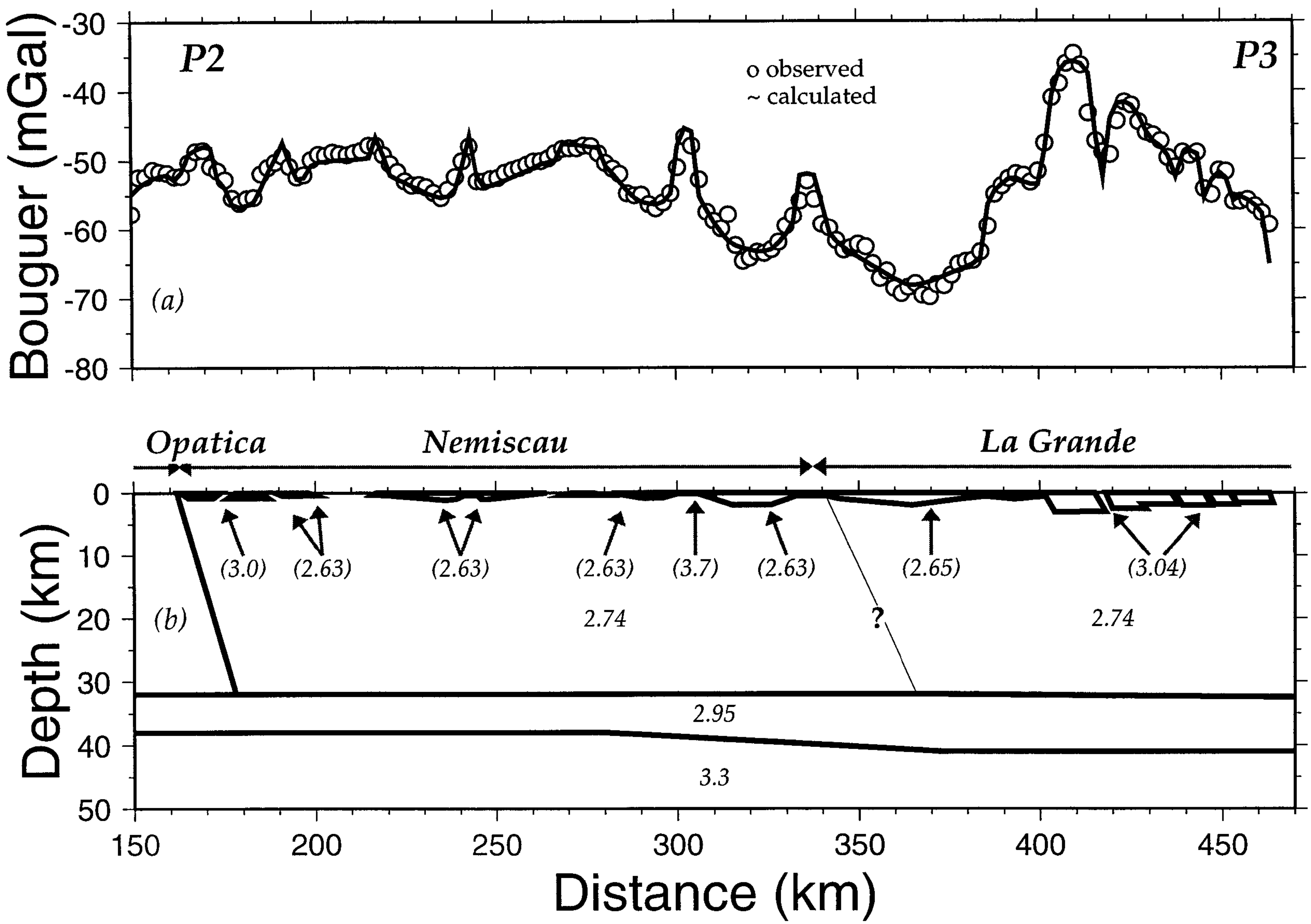
P1
P2
P3
Ab
Op
Nem
LG
Total magnetic field (nT)
Distance (km)
1200
1000
800
600
400
200
0
-200
-400
-600
0
50
100
150
200
250
300
350
400
450


P2
P3
Density (g.cm-3)
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
Nemiscau
La Grande
200
250
300
350
400
450
Distance (km)



Bouguer (mGal)
-30
-40
-50
-60
-70
-80
-90
P1
P2
o observed
~ calculated
(a)
A
B
C
D
Abitibi
Opatica
Nemiscau
Depth (km)
0
10
20
30
40
50
2.67
BRC
(2.91)
CP
(2.87)
LOP
(2.64)
(2.8)
LRP
(2.8)
(b)
2.72
2.95
3.3
0
50
100
150
Distance (km)


Bouguer (mGal)
-30
-40
-50
-60
-70
-80
-90
P1
P2
o observed
~ calculated
(a)
B′
C′
Abitibi
Opatica
Nemiscau
Depth (km)
0
10
20
30
40
50
2.67
BRC
(2.91)
LOP?
(2.64)
(2.8)
(3.0)
LRP
(2.8)
(b)
2.72
2.95
3.3
0
50
100
150
Distance (km)



Bouguer (mGal)
-30
-40
-50
-60
-70
-80
P2
P3
o observed
~ calculated
(a)
Opatica
Nemiscau
La Grande
Depth (km)
0
10
20
30
40
50
(3.0)
(2.63)
(2.63)
(2.63)
(3.7)
(2.63)
(2.65)
(3.04)
(b)
2.74
?
2.74
2.95
3.3
150
200
250
300
350
400
450
Distance (km)

CHAPITRE III

The gravity field over the Ungava Bay region from satellite altimetery and new land-based data

Abstract

Gravity data were obtained along two transects on the southern coast of Ungava Bay, which provide continuous gravity coverage between Leaf Bay and George River. The transects, and the derived gravity profiles extend from the Superior province to the Rae craton across the New Quebec Orogen (NQO). Interpretation of the transect along the southwestern coast of Ungava Bay suggests crustal thickening beneath the NQO and crustal thinning beneath the Kuujjuaq Terrane, east of the NQO. Two alternative interpretations are proposed for the transect along the southeastern coast of the bay. The first model shows crustal thickening beneath the George River Shear Zone (GRSZ) and two shallow bodies correlated with the the northern extensions of the GRSZ and the De Pas batholith. The second model shows constant crustal thickness and bodies more deeply rooted than in the first model. The gravity models are consistent with the easterly dipping reflections imaged along a Lithoprobe seismic line crossing Ungava Bay and suggest westward thrusting of the Rae craton over the NQO.

Because there no gravity data have been collected in Ungava Bay, satellite altimetry data have been used as a means to fill the gap at sea. The satellite-derived gravity data and standard Bouguer gravity data were combined in a composite map for the Ungava Bay region. The new land-based gravity measurements were used to verify and calibrate the satellite data and to ensure that offshore gravity anomalies merge with those determined by the land surveys in a reasonable fashion. Three parallel east-west gravity profiles were extracted across Ungava Bay (59.9°N) , on the southern shore of the Bay (58.5°N) and

onshore ~ 200 km south of Ungava Bay (57.1°N). The gravity signature of some major structures, such as the GRSZ, can be identified on each profile.

1. Introduction

During the Eastern Canadian Shield Onshore-Offshore Transect (ECSOOT) of Lithoprobe, marine seismic reflection profiles were acquired across Ungava Bay and eastern Labrador (Fig. 1). The seismic transects image structures related to the formation of Archean crust and the successive accretion of Proterozoic terranes (Hall et al., 1995). Gravity data were collected along the southern coast of Ungava Bay during the summers of 1995 and 1996 (Fig. 2). These data extend a detailed transect initiated in previous surveys by Mareschal et al. (1990), Séguin and Goulet (1990), and fill some of the gaps in the on-shore data compiled by the Geological Survey of Canada (GSC). The gravity data will be used to correlate onshore geological features with images of the crust obtained along the ECSOOT profile (Hall et al., 1995).

Because no gravity data are available in Ungava Bay, satellite altimetry data have been used to fill this gap. Free air gravity data were derived from the combination of the ERS-1 satellite altimeter and the GEOSAT geodetic data (Smith and Sandwell, 1995). The land-based gravity data obtained during this study are useful for calibrating the satellite data to ensure the onshore-offshore continuity of gravity features. All available Bouguer (on land) and free air (offshore) anomaly data were combined to produce a regional map over the Ungava Bay area. The gravity map was filtered to better delineate some geological structures of the region (Telmat and Mareschal, 1996; Telmat et al., 1997).

2. Geological setting of the Ungava Bay region

The Superior and Nain provinces in northern Quebec and Labrador are separated by two paleoproterozoic belts: the New Quebec Orogen (NQO), a collision zone between the Superior and Rae provinces, and the Torngat Orogen, a collision zone between the Rae and Nain provinces (Hoffman, 1989). The NQO consists predominantly of low-grade sedimentary and mafic volcanic rocks disposed in a west-verging fold and thrust belt (Wardle et al., 1990). The Bouguer anomaly across the NQO shows a negative-positive pair, characteristic of boundaries between several structural provinces in the Canadian Shield (Gibb and Thomas, 1976; Thomas and Kearey, 1980); gravity profiles across the NQO have been interpreted in terms of collision of the Superior and Rae protocontinents during the Hudsonian Orogeny (Kearey, 1976). Further interpretation of the gravity data suggests a model involving west-directed transport of rocks over the Superior craton (Mareschal et al., 1990).

The northern segment of the NQO is subdivided, from west to east, into the Chioak and Baby zones, which constitute the foreland, and the Rachel and Kuujjuaq zones, which are the hinterland (Wares and Goutier, 1990). The eastern boundary of the NQO remains poorly defined. Girard (1990) proposed that it lays at the Lac Tudor Shear Zone (LTSZ; Fig. 1). However, detailed field mapping during the summer of 1996 did not reveal the presence of a major structural boundary in the surveyed area of the LTSZ (Bardoux, M. pers. comm., 1996). This suggests that the boundary between the hinterland of the NQO and the Rae craton lies to the west of the area where the gravity survey was conducted (P96 profile; Fig. 2).

The Rae craton consists predominantly of reworked Archean crust interfolded with Paleoproterozoic cover rocks (e.g. Machado et al., 1989; Nunn et al., 1990; Wardle et al., 1990, James et al., 1994). Along the southwestern shoreline of Ungava Bay, the crust comprises upper amphibolite gneisses, locally highly migmatized. The Paleoproterozoic supracrustal sequences consist of thin remnants (usually less than 100 m) of metasediments that were infolded and metamorphosed with their basement rocks. Numerous granitoid magmas intruded the Rae craton during and after its deformation. Structural trends are generally oriented N-NW. When extrapolated offshore across Ungava Bay to the ECSOOT seismic line, they intersect the line at an oblique angle.

The George River Shear Zone (GRSZ) is the most important tectonic feature of the Rae craton within the gravity transect. Conspicuous shear sense indicators within the GRSZ indicate that it was affected by dextral movement (Bardoux et al., 1996). Rocks on both sides of this high-strain zone are lithologically similar, but metasedimentary units and migmatitic features are more abundant on the SW side of the shear zone. Migmatites and granitoid intrusives are well developed west of the GRSZ, where they may represent the northern extension of the De Pas batholith (Fig. 1). The migmatites and granitoid rocks are barely deformed suggesting that they formed in a post-collisional setting, as also suggested for the De Pas batholith (Dunphy and Skulski, 1996).

The Torngat orogen is a Paleoproterozoic orogenic belt resulting from a transpressional collision between the Archean Nain province and the Rae craton. It comprises high grade, strongly deformed domains such as the Tasiuyak domain, a zone exposing sedimentary gneisses, the Lac Lomier complex and Burwell Terrane, consisting of belts of granitoid plutons (eg. Ermanovics and Van Kranendonk, 1990; Van Kranendonk and Ermanovics, 1990; Wardle et al., 1990; Mengel et al., 1991; Bertrand et al., 1993). The most prominent deformational feature of the Torngat Orogen is the Abloviak Shear Zone (ASZ), which was mainly developed within the Tasiuyak gneisses, albeit it also affected adjacent units of the Nain and Rae provinces (Wardle et al., 1990).

The easterly dipping reflections at the western end of the Lithoprobe seismic profile are consistent with the dip of the predominant foliation(s) observed onshore south of Ungava Bay (Hall et al., 1995). The seismic reflection profile does not show evidence for the presence of mantle-penetrating features at the western end of the line, where it would coincide with the on-strike projection of west-verging structures within the NQO. However, strong sub-horizontal reflections at the base of the crust between 0-100 km were interpreted to reflect lower crustal shearing (Hall et al., 1995). This process would have transferred strain from shallow to deep crustal levels and may have involved the mantle, to the east. On the eastern part of the profile, easterly dipping reflectors are still identifiable on the seismic sections near the Torngat Orogen despite the poor signal to noise ratio.

3. Gravimetric survey

Eighty gravity stations were measured with a model G Lacoste-Romberg gravity meter loaned by the GSC. The data were collected during the summers of 1995 and 1996 along two transects which extend over about 200 km (P95 and P96 on Fig. 2). The measurements were made along the shoreline at the level of the high tide watermark, in order to facilitate the determination of station elevations. The data collected along both profiles were linked to the reference national gravity station located at the Kuujjuaq airport. Because of the field conditions and limited availability of a helicopter, the measurements are not evenly spaced. The station spacing along transect P96 (~ 2 km) is more regular than along transect P95 (~ 3 km). Samples of representative lithologies were systematically collected at each site for rock density measurements. Profile P96, which is oriented NW-SE (Fig. 2), extends the Leaf River and Leaf Bay transect of Mareschal et al. (1990). In order to link P96 and P95 with previously collected data, the profiles were projected on an E-W line (Fig. 3). Because the data obtained by Mareschal et al. (1990) had not been linked to the national base station at the Kuujjuaq airport, and were based on arbitrary gravity datum, they had to be increased by +10 mGal, to yield the same value at the overlapping stations near the mouth of Leaf Bay (~ -40 mGal).

The Bouguer anomaly and rock density data projected on NW-SE and SW-NE profiles are shown on Fig. 4. The Bouguer anomaly along P96 (Fig. 4a) increases regularly southeastward from about -40 mGal east of Leaf Bay to about -30 mGal. Density values for rocks collected along P96, ranging between ~ 2.6 $Mg.m^{-3}$ and ~ 2.8 $Mg.m^{-3}$ (Fig. 4b), follow the same trend as that of the Bouguer anomaly (Fig. 4a). The high density of ~ 3.2

$Mg.m^{-3}$, measured on mafic rock units outcropping around km 45 seems correlated to the short wavelength Bouguer anomaly high between km 40 and 50.

The P95 Bouguer anomaly profile (Fig.4c) shows a prominent ~ 10 mGal amplitude negative anomaly at about km 60 which coincides with the GRSZ. Rock samples collected within the GRSZ yielded the lowest density values along P95 (Fig. 4d). This low density has been interpreted (Telmat and Mareschal, 1996) as an effect of rock recrystallisation/partial melting with concomitant density reduction by injection of granitic magma (Hess, 1989). The short wavelength positive anomalies between km 85 and 95, appears related to the presence of several swarms of gabbroic dikes at the NE end of the transect P95.

4. Gravity modeling

Two gravity profiles were separately interpreted with 2.5-D gravity modeling. This modeling was done with SAKI, an interactive program that uses generalized linear inversion to iteratively improve selected model parameters, such as the density of the prisms and the location of their vertices (Webring, 1985).

The model consists of an ensemble of prisms that map in cross sectional form the interpreted variations in subsurface density. In the direction perpendicular to the cross section, the model prisms extend far enough to avoid edge effects for the long wavelength bodies. Consequently, the total strike length (twice the distance from the profile to either end of the prism) is 200 km for the deep bodies and 40 km for the shallow units. The extent of shallow units was determined from geological mapping whenever available. For the deeper units, tests done with variable strike lengths showed almost no change as long as they extended a lateral distance that is five times their depth.

In the modeling, a standard value of 2.67 $Mg.m^{-3}$ was assumed as the average density of the upper crust; it corresponds to the average density measured on the outcrop samples that we collected (Fig. 4b and 4d). Standard density contrasts of 0.2 $Mg.m^{-3}$ and 0.4 $Mg.m^{-3}$ are assumed for the lower crust and the upper mantle, respectively.

4.1. Southwestern profile

The P96 and the data collected across the northern NQO (Mareschal et al., 1990) were combined in a single east-west profile perpendicular to the strike of the geological structures (Fig. 5a). The small scatter caused by the projection indicates that the gravity anomaly does not vary much in the north-south direction and that the assumption that the geometry of geological units can be approximated by prisms of finite strike length (2.5-D) is valid. The interpretation, constrained by the geology and density measurements, calls for crustal thickening beneath the NQO (Fig. 5b). The crustal thickness increases from 38 km in the Superior Province to at least 43 km beneath the NQO. The Moho depth decreases to ~ 37 km beneath the Kuujjuaq Terrane and it is 38 km at the eastern end of the profile. The boundary between the upper and the lower crust follows the same trend as the Moho, from ~ 20 km depth to the west, in the Superior province, to ~ 26 km beneath the NQO, and ~18 km beneath the Rae craton. An alternative interpretation with a crust thicker and denser in the Rae craton than in the present model, had been proposed by Mareschal et al. (1990). However, the density measurements on samples from the Rae craton along P96 transect seem to rule out this model. We have interpreted the gradual increase in density at the eastern end of P96 transect (Fig. 4b), as due to an increase in the abundance of amphibolitic rocks corresponding to small superficial bodies.

Several short wavelength anomalies appear along this profile. Beneath the NQO, at ~ 20 and 40 km, small wedge-shaped bodies with negative density contrasts of - 0.1 $Mg.m^{-3}$ are required to fit the data. These bodies may correspond to sediment deposits which are found further south in the NQO (e.g. Kearey, 1976). The positive anomaly over the eastern part of the NQO (between 70 and 80 km) is explained by the presence of mafic igneous rocks that must be deeply rooted (~ 5 km). Their average density of ~ 3.05 $Mg.m^{-3}$ was measured on fresh outcrop samples (Mareschal et al., 1990). Modeling shows that they dip eastward. The thickness of these volcanic rocks is estimated to be between 1.5 km and 5 km. In the Rae craton, several short wavelength anomalies are related to shallow sources. The positive gravity peak at ~ 140 km is due to a thin and shallow body with a high density contrast (0.4 $Mg.m^{-3}$). This body must be very thin (~ 200 m) and corresponds probably to transported mafic-ultramafic material. It was not possible to fit the gravity data with a thicker body and a lower density contrast. Two residual positive anomalies are related to relatively high density (~ 2.80 $Mg.m^{-3}$) measured on samples collected in the western part of the Rae craton. The results of many iterations show that these sources do not extend deeper than 1.5 km.

4.2. P95 transect

The Bouguer anomaly data collected along the southeastern transect were projected along line P95 (Fig. 6a, 7a), which is perpendicular to the strike of the major structures. Two alternative interpretations, with either constant or variable crustal thickness, are proposed for this transect (Fig. 6b and 7b).

For both models, the Moho and upper to lower crust boundary are fixed at ~ 38.5 km and ~ 18 km depths respectively, at the southwestern end of the profile. For the first model (Fig. 6b), the ~10 mGal amplitude gravity low that extends across the central part of the profile is interpreted in terms of increased crustal thickness beneath the GRSZ. Here, the Moho is at a depth of ~ 41.5 km and the lower crust occurs at a depth of ~ 20 km. At the northeastern end of the profile, the respective depths are at ~ 40.5 km and ~ 18 km. The two short wavelength lows at ~ 40 km and ~ 60 km are interpreted as due to shallow bodies (~1.5 km depth) with negative density contrasts of -0.06 $Mg.m^{-3}$ and -0.05 $Mg.m^{-3}$. They are correlated with the northern extension of the De Pas batholith and a zone of total rock recrystallization recognized as the GRSZ (Bardoux et al., 1996). At the southwestern end of the profile, where the average density of samples is 2.80 $Mg.m^{-3}$, a dense ($\delta\rho$=0.13 $Mg.m^{-3}$) and thin (~ 1km) body has been modeled. It could be related to one of the metasedimentary sequences lying southwest of the GRSZ (Bardoux et al., 1996). The short wavelength highs, at the northeastern end of the profile, are interpreted as very thin (less than 0.5 km) gabbroic lenses with high density contrasts ($\delta\rho$=0.26-0.33 $Mg.m^{-3}$).

Because the strong gradient indicates shallow sources in the center of the transect, we prefer an alternative interpretation (Fig. 7b) which does not call for crustal thickening. The Moho and the boundary between the lower and the upper crust are at constant depths of ~ 38.5 km and ~ 18 km, respectively. The northern extension of the De Pas batholith and the GRSZ are more deeply rooted than shown in Figure 6, extending to ~ 4 km depth with density contrasts of -0.06 $Mg.m^{-3}$ and -0.05 $Mg.m^{-3}$, respectively. The interpretation is unchanged for the shallow sources at both ends of the profile.

5. Gravity maps of the Ungava Bay region

Because there are no gravity data based on sea-surface or underwater surveys in Ungava Bay, we have used satellite data as a means to fill the gap at sea. The new land-based gravity data provide a link between available onshore data and marine gravity data derived from satellite altimetry. Marine gravity anomalies were extracted from the new global grid at 2 minutes spacing obtained from the combination of ERS-1 satellite altimeter data and GEOSAT geodetic mission data (Smith and Sandwell, 1995). These marine gravity anomalies were computed from the mean sea surface topography, assuming that its surface conforms to the geoid. The elevation of the ocean surface is measured with an accuracy of 3 cm, which yields an accuracy of the order of 5 mGal for the gravity data. The geoid height is mapped at a horizontal resolution of 10-15 km. This measurement sensitivity is sufficient to detect features of the marine gravity field with wavelengths as small as 20 km. Noise in the data comes from non-geoidal components of the sea surface topography such as currents and tides, and errors due to the presence of sea ice. These problems are extremely critical in Ungava Bay where tides are very strong and where sea ice cover is present during 9 months /year in some areas. The resolution of the gravity data is also limited by gaps between adjacent tracks that are larger than the potential resolution of the data and by smoothing as a result of the gridding procedure. Tests were made to compare the satellite derived gravity with onshore data and to verify their continuity. All the onshore Bouguer data available in the Ungava Bay region, including the new data (Fig. 2) were combined with satellite-derived free air gravity data. A subroutine which reads randomly-spaced gravity data and eliminates redundant data, is used to supress undesired effects as spatial aliasing. The data were processed to avoid aliasing of short wavelengths and interpolated on a 2 minutes grid.

The composite Bouguer-free air gravity anomaly map is shown on Fig. 8. This map shows the limited resolution of satellite data. Discontinuities are apparent along the southern shore of the Bay despite the inclusion of the new land-based data set. Nevertheless, this map shows that some trends in the land data can be followed in the satellite-derived gravity anomalies. The dominant feature of the composite map is the large negative anomaly that coincides with the greater part of the NQO. The other trends, parallel to the NQO, appear more clearly on the band-pass filtered map (Fig. 9). This map was obtained by eliminating wavelengths larger than 120 km and shorter than 10 km and retaining those between 20 km and 110 km. Figure 10 presents the vertical gravity gradient obtained from the band-pass filtered map. The GRSZ and the De Pas batholith appear clearly as two parallel structures trending NW direction that can be followed offshore. The eastern boundary of the NQO is also well imaged on land and appears to vanish offshore, north of Leaf Bay.

6. Gravity interpretation and discussion

Three east-west profiles P1, P2 and P3 were extracted from the combined gravity map (positions shown in Fig. 8 and profiles in Fig. 11). These profiles run from longitude 290°E to 295°E at 57.1°N, 58.5°N and 59.9°N, respectively (see Fig. 8).

The western part of the southern profile P1 follows approximately the transect of Kearey (1976) across the NQO, from the Superior Province into the Rae craton. The average station spacing, smaller than anywhere in the study area, provides good resolution. The new data collected along the south shore of Ungava Bay, those collected along Leaf River by (Mareschal et al., 1990) and a few points from the GSC data base are used to obtain profile P2. This profile also starts in the Superior Province, crosses the New Quebec Orogen, the Rae craton, and ends west of the Torngat Orogen. Note that both profiles P1 and P2 contain only Bouguer data. Profile P3 follows approximately the western part of the ECSOOT seismic line (Hall et al., 1995). It contains free air gravity data derived from satellite, and it includes some standard Bouguer data on both sides.

Because the satellite data of Profile 3 do not contain short wavelengths, all three profiles were filtered to make them comparable. Wavelengths shorter than 20 km were eliminated. The linear trend was removed and the data were interpolated with a constant step and reflected to avoid edge effects before fast Fourier transform processing. Profiles were also directly extracted from 2D band-pass filtered data and compared with profiles filtered after extraction from the composite map to verify that they are similar.

Profiles P1 and P2 (Fig. 11a,b) are characterized by a marked gravity minimum over the NQO. The boundaries of the NQO are indicated by arrows on Fig. 11a. The contact between the sediments of the New Quebec Orogen and the gneisses of the Rae craton is well defined on profile P2 (left hand side arrow on Fig. 11b). On both profiles, the Bouguer anomaly increases rapidly over the Rae craton where it is some 40 mGal higher than over the NQO. The George River Shear Zone appears distinctly as a ~ -10 mGal amplitude negative anomaly on both profiles at ~ 260 km (Fig. 11a) and ~190 km (Fig. 11b). It is difficult to distinguish the De Pas batholith from the GRSZ on profile P1 (Fig. 11a).

For profile P3, we have interpreted the marked negative anomaly (~10 mGal) at km 120, as due to the GRSZ. Another negative anomaly appears west the GRSZ at km 90. This might be the extension of the De Pas batholith under the Ungava Bay. The free air anomaly increases gradually east of the GRSZ and a positive anomaly of more than 10 mGal amplitude is present between km 180 and 200. This positive anomaly could be correlated to the similar trend on the onshore profile P2 (Fig. 11b). We suggest that it is related to the offshore extension of the Lake Harbour Group and (or) of the Lac Lomier Complex. The free air anomaly decreases towards the extension of the Torngat Orogen defining a negative anomaly of about 20 mGal between km 200 and 240. We suggest that it could be correlated with the northern extension of the Abloviak Shear Zone (Fig. 1). The strong gradient suggests that this anomaly, tentatively interpreted as the Abloviak Shear Zone (ASZ), is a major tectonic feature well expressed offshore. The seismic image did not show evidence of mantle-penetrating suturing in this area (Hall et al., 1995), but the seismic image is of poor quality near the Torngat Orogen because of lower signal to noise ratio and because of the change in orientation of the turn of the seismic line in this area. We interpret the positive anomaly at the eastern end of the profile P3 as the expression of the Tasiuyak domain which represents the remains of an accretionnary prism, possibly developed on the margin of the Rae craton, and thrusted over Archean gneisses during early Nain-Rae convergence (Rivers et al., 1993). The gravity signature of the Tasiuyak domain might be superposed with that of the Burwell Terrane on the east. Further south, a similar positive anomaly was interpreted as a triangular prismatic body with a maximum thickness of 13 km near to the Nain Province and thinning westward to a feather edge (Feininger and Ermanovics, 1994).

In summary, filtered and gravity gradient maps obtained from combined free air satellite and standard Bouguer data show the continuity of some gravimetric features of major structures, notably the GRSZ and the De Pas batholith. The contact between the NQO and the Rae craton is also well marked, by a positive eastward gradient (Fig. 8). It crosses Leaf Bay west of the P96 transect at a longitude of ~290 E and disappears south of latitude 60N. The expression of the Torngat Orogen is less obvious in the combined map (Fig. 8). We relate it to the large arc-shaped positive anomaly at the eastern edge of the Bay on the band-pass filtered map (Fig. 9). This anomaly is probably underlain also by the Lake Harbour Group, the Tasiuyak domain and the Burwell Terrane.

A global interpretation for all the data collected along the shoreline of Ungava Bay, including those collected in the Leaf Bay region, is presented on Fig. 12. It shows that the depth to Moho is in the range of 37-39 km beneath the Rae craton. This is consistent with the crustal thickness estimated across Ungava Bay along the northern Lithoprobe seismic reflection by Hall et al. (1995), assuming an average basement velocity of 6.5 km^{-1} (Chian and Louden, 1992). The gravity model involving crustal thickening beneath the NQO, is also consistent with the western part of the northern seismic reflection line, which shows a series of reflectors that probably defines the base of the crust and dips gently from east to west (Hall et al., 1995). At the eastern limit of the NQO, the sequence of volcanic rocks dips steeply to the east beneath the Archean and Proterozoic rocks of the Rae craton. This could mark the boundary between the NQO and the Rae craton ~20 km west of the P96 transect. Further east, the GRSZ and the De Pas batholith appear as two important quasi-parallel elongated bodies approximately 4 km thick. This thickness is significant when compared to that of other sequences in the Rae craton, which are superficial. The apparent eastward dip of the gravity structures is consistent with the geological data indicating northwestward transport and thrusting of the Rae craton over the Superior province.

Acknowledgments

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Figure captions

Figure 1. Tectonic map of Ungava Bay region and parts of northeastern Quebec showing the location of ECSOOT northern marine seismic line. Modified from Hoffman (1989), Wardle et al. (1990) and Hall et al. (1995). ASZ: Abloviak Shear Zone; FSZ: Falkoz Shear Zone; GRSZ: George River Shear Zone; HF: Handy Fault; LHG: Lake Harbour Group; LLC?: inferred extent of Lac Lomier Complex; LTSZ: Lac Tudor Shear Zone; MBSZ: Moonbase Shear Zone; NFT: Nachvak Fiord Thrust; RG: Ramah Group; TD: Tasiuyak Domain.

Figure 2. Location map of on-shore gravity measurement sites in the Ungava Bay region.

Figure3. W-E projection of two sets of data: the data collected during the summers of 1995 and 1996 (grey circles) are in good continuation with those (open circles) collected by Mareschal et al. (1990).

Figure 4. a) NW-SE projection of the Bouguer anomaly data collected during the summer of 1996. b) NW-SE projection of rock density values determined on rock samples. The high density at ~45 km is related to the occurrence of mafic dykes. c) SW-NE

projection of the Bouguer anomaly data collected during the summer of 1995. d) SW-NE projection of rock density values determined on rock samples.

Figure 5. a) W-E projection of the Bouguer anomaly data collected along the soutwestern coast of Ungava Bay and those collected along Leaf Bay across the northern New Quebec Orogen. b) composite crustal density model, SP: Superior Province; NQO: New Quebec Orogen; RAP: Remobilized Archean and Proterozoic supracrustals; RP: Rae Province.

Figure 6. a) SW-NE projection of the Bouguer anomaly data collected along transect P95 within the Rae Province and comparison between measured and calculated gravity. b) Crustal density model 1, GRSZ: George River Shear Zone; DPb: De Pas batholith.

Figure 7. a) SW-NE projection of the Bouguer anomaly data collected along transect P95 within the Rae Province and comparison between measured and calculated gravity. b) Crustal density model 2, GRSZ: George River Shear Zone; DPb: De Pas batholith

Figure 8. Combined Bouguer-free air gravity map compiled from GEOSAT data at sea and available on-shore gravity data including the new data, interpolated on a 2 minutes grid. The continuous lines represent the location of profiles P1, P2 and P3 at latitudes 57.1°N, 58.5°N and 59.9°N respectively.

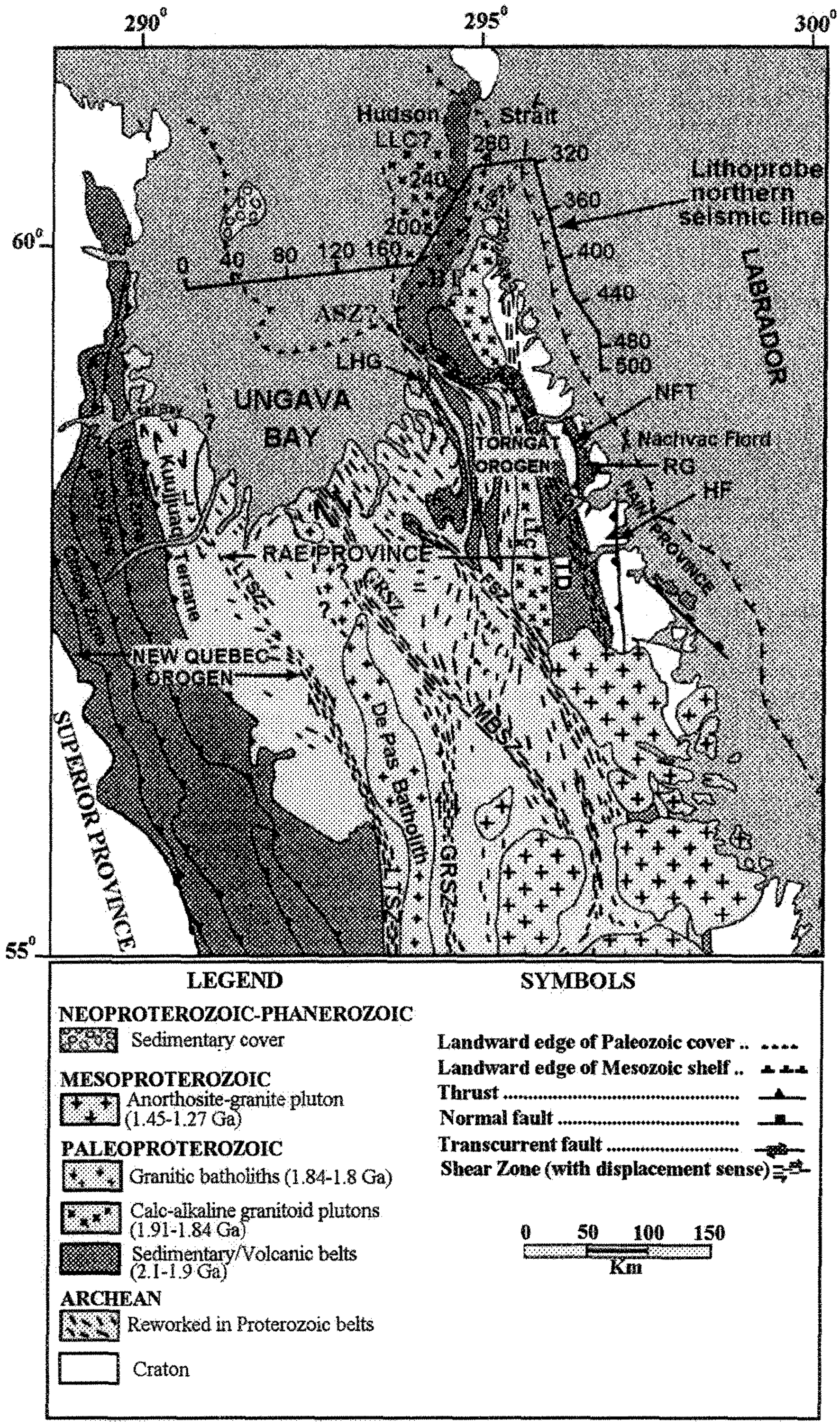
Figure 9. Gravity map using band-pass filter passing wavelengths between 20 and 110 km and eliminating wavelengths greater than 120 km and less than 10 km.

Figure 10. Vertical gradient map obtained from the band-pass filtered map. Structures such as the George River Shear Zone and the New Quebec Orogen are well delineated.

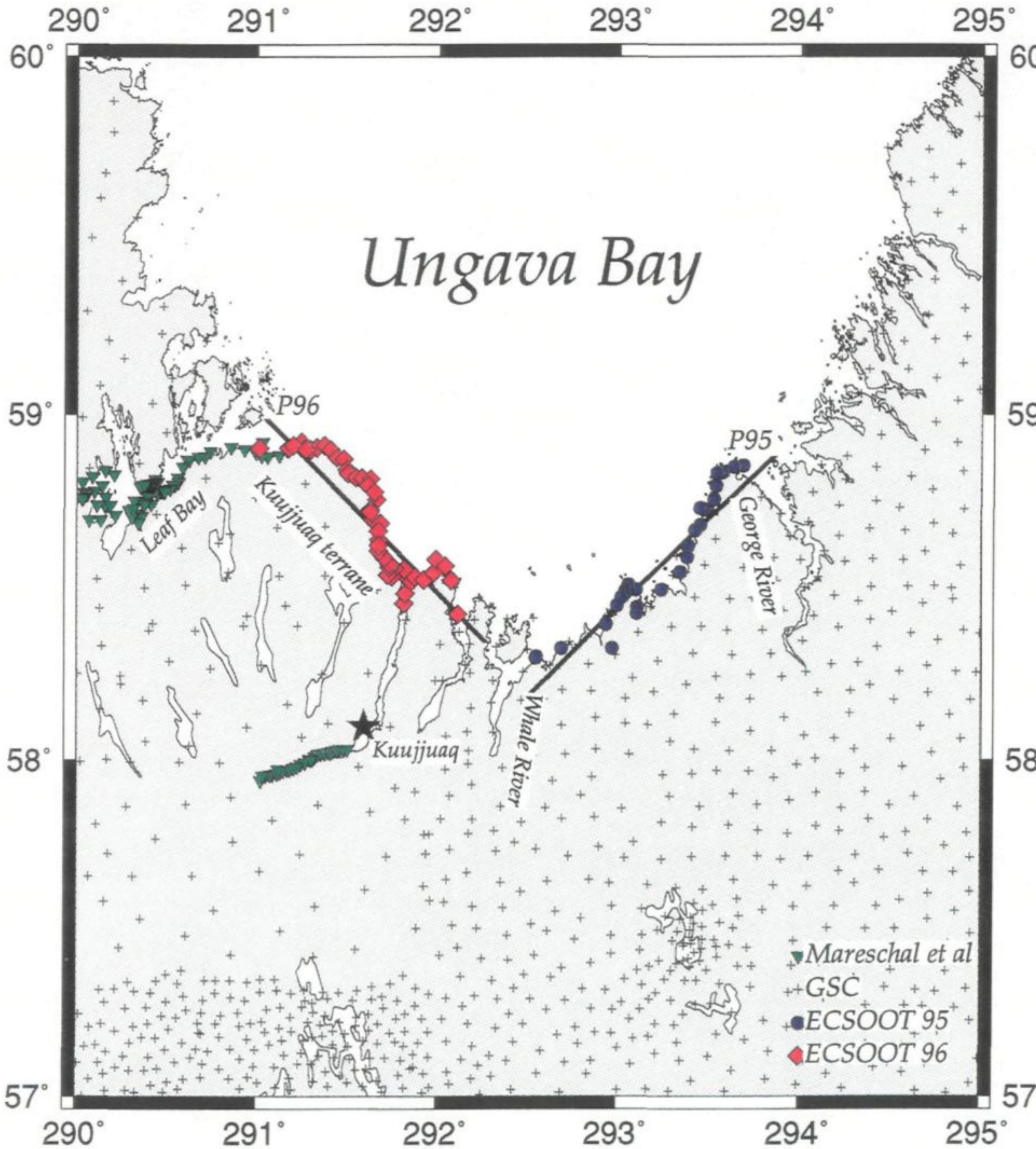
Figure 11. Comparison between Fourier-filtered profiles P1, P2 and P3. a) Profile P1 running from 290°E to 295°E at 57.1°N. This profile follows approximately the profile modeled onshore 200 km south of Ungava Bay by Kearey (1976). b) Profile P2 running from 290°E to 295°E at 58.5°N. This profile contains the new data collected along transects P95 and P96, those collected along Leaf River by Mareschal et al. (1990), and a few standard data extracted from the GSC data base between the P95 and P96 transects. c) Profile P3 running from 290°E to 295°E at 59.9°N. This profile crosses Ungava Bay and follows approximately the northern Lithoprobe marine seismic line (Hall et al., 1995). This profile contains free air gravity data derived from satellite in the bay, and includes some standard Bouguer data on both sides. Wavelengths less than 20 km were suppressed after extraction. Arrows indicate the boundaries of the following elements: ASZ: Abloviak Shear Zone; DPb: De Pas batholith; GRSZ: George River Shear Zone; LHG: Lac Harbour

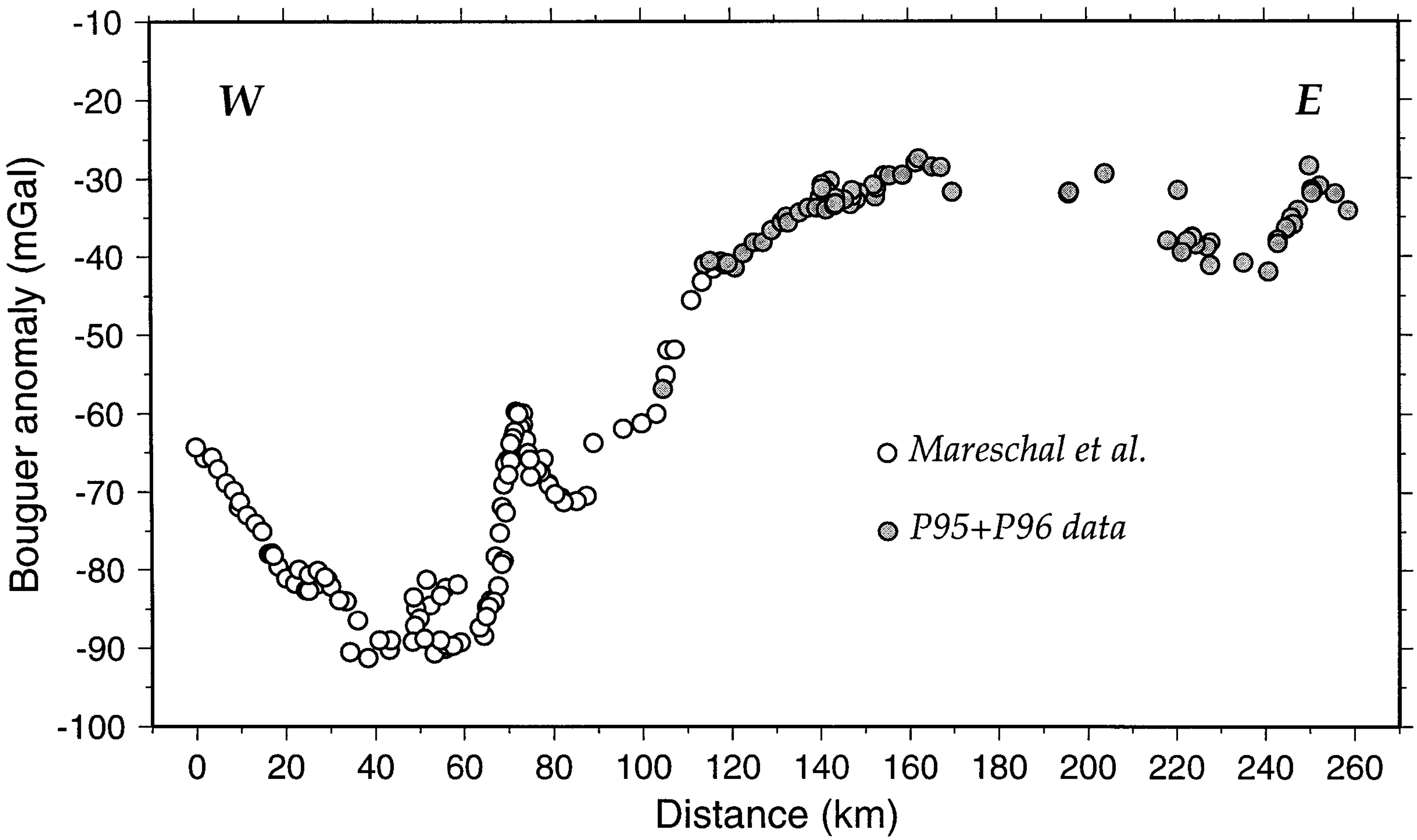
Group; LLC: Lac Lomier Complex; NQO: New Quebec Orogen; RAP: Remobilized Archean and Proterozoic supracrustals; TD: Tasiuyak Domain; BT: Burwell Terrane.

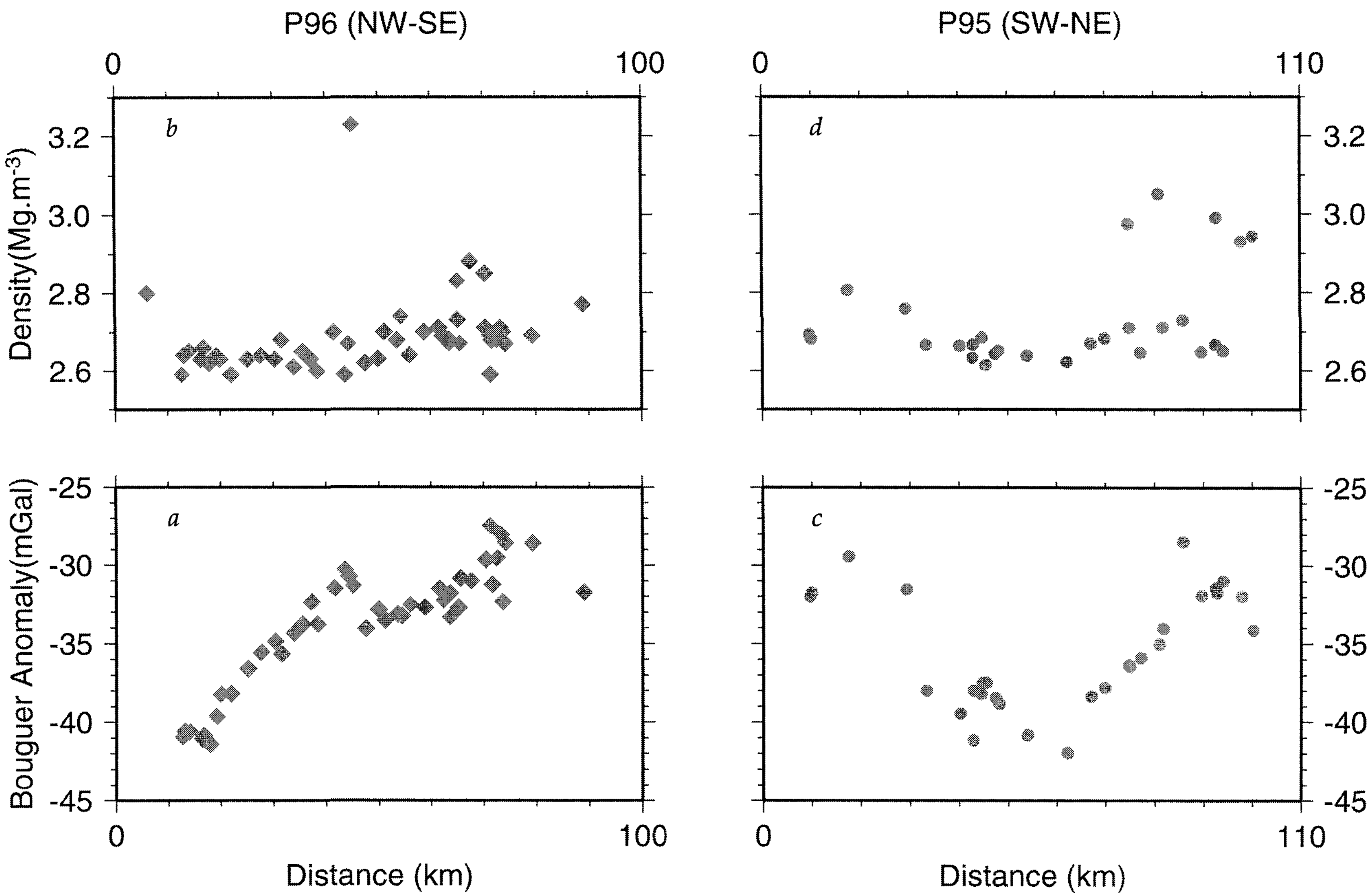
Figure 12. a) Combined gravity data across the northern New Quebec Orogen and the Rae Province (southern shore of Ungava Bay). b) Combined crustal model, GRSZ: George River Shear Zone; DPb: De Pas batholith; SP: Superior Province; NQO: New Quebec Orogen; RAP: Remobilized Archean and Proterozoic supracrustals; RP: Rae Province.

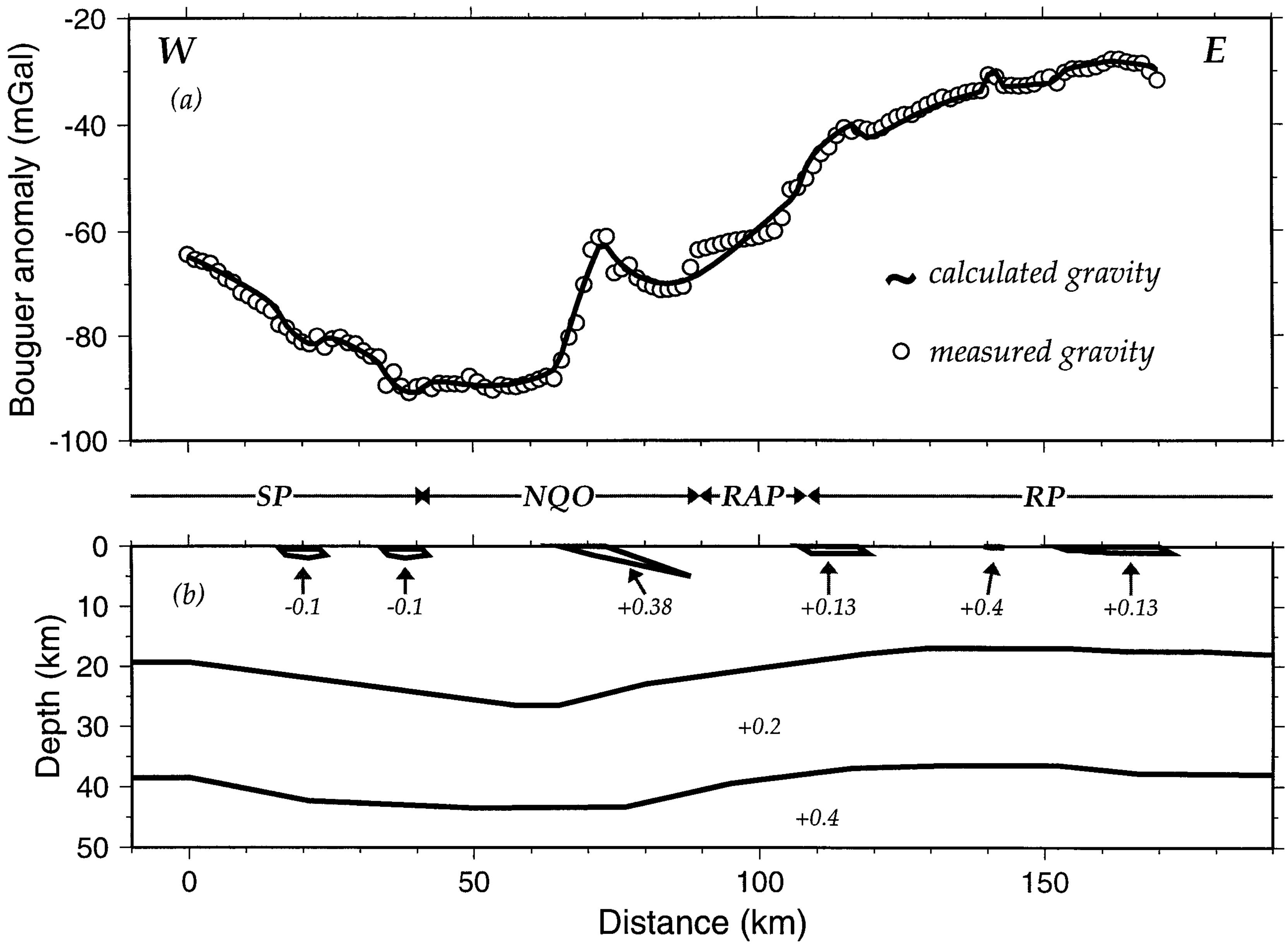


290°
295°
300°
60°
55°
Hudson Strait
LLC?
Lithoprobe northern seismic line
0 40 80 120 160
200
240
280
320
360
400
440
480
500
LABRADOR
ASZ?
LHG
UNGAVA BAY
NFT
Nachvak Fiord
TORNGAT OROGEN
RG
HF
Kuujjuaq Terrane
RAE PROVINCE
LTSZ
GRSZ
FSZ
TD
NEW QUEBEC OROGEN
De Pas Batholith
MBSZ
SUPERIOR PROVINCE
LEGEND
NEOPROTEROZOIC-PHANEROZOIC
Sedimentary cover
MESOPROTEROZOIC
Anorthosite-granite pluton (1.45-1.27 Ga)
PALEOPROTEROZOIC
Granitic batholiths (1.84-1.8 Ga)
Calc-alkaline granitoid plutons (1.91-1.84 Ga)
Sedimentary/Volcanic belts (2.1-1.9 Ga)
ARCHEAN
Reworked in Proterozoic belts
Craton
SYMBOLS
Landward edge of Paleozoic cover
Landward edge of Mesozoic shelf
Thrust
Normal fault
Transcurrent fault
Shear Zone (with displacement sense)
0 50 100 150
Km

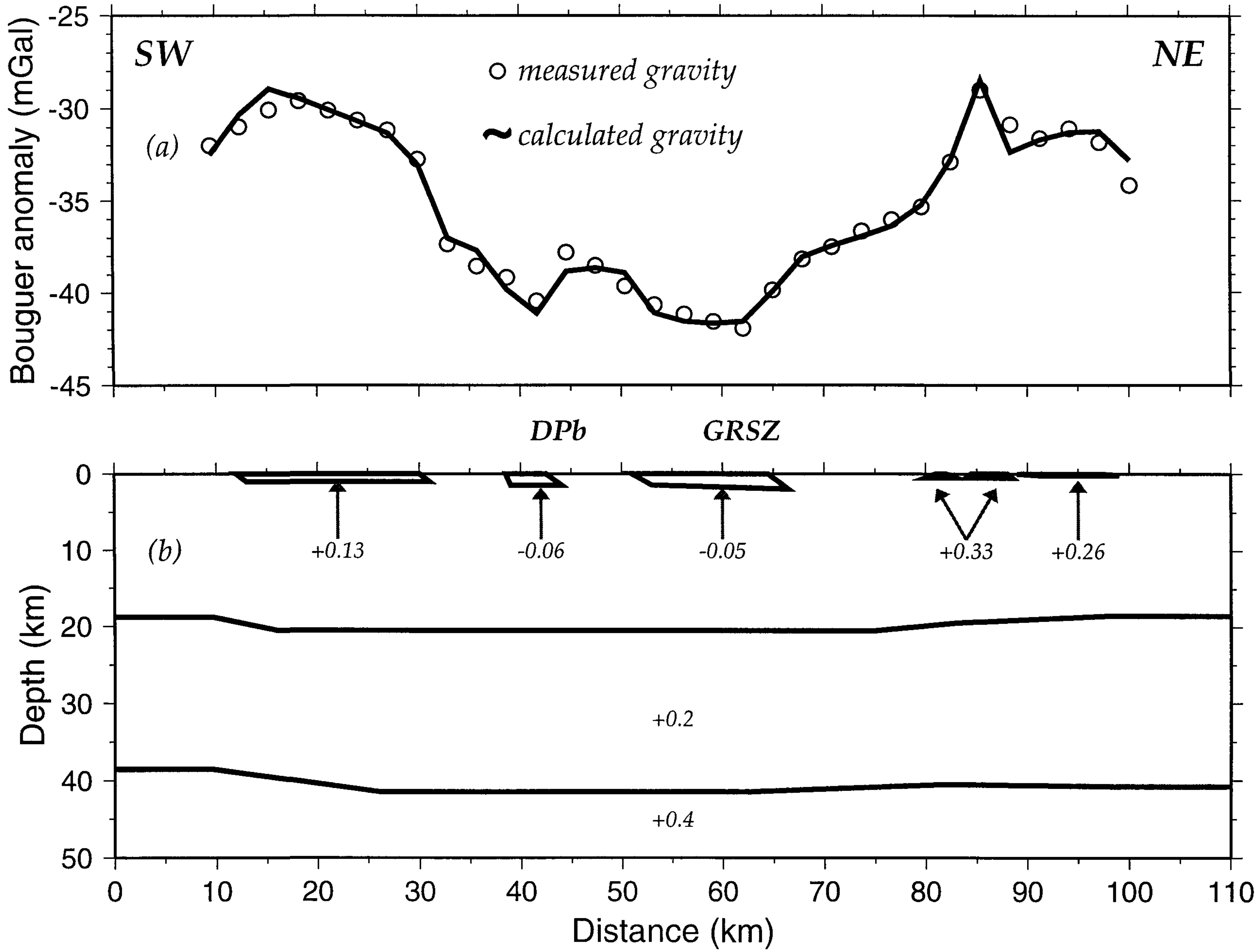

290°
291°
292°
293°
294°
295°
60°
59°
58°
57°
Ungava Bay
P96
P95
Leaf Bay
Kuujjuaq terrane
George River
Whale River
Kuujjuaq
Mareschal et al
GSC
ECSOOT 95
ECSOOT 96


W
E
Mareschal et al.
P95+P96 data
Bouguer anomaly (mGal)
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
0
20
40
60
80
100
120
140
160
180
200
220
240
260
Distance (km)

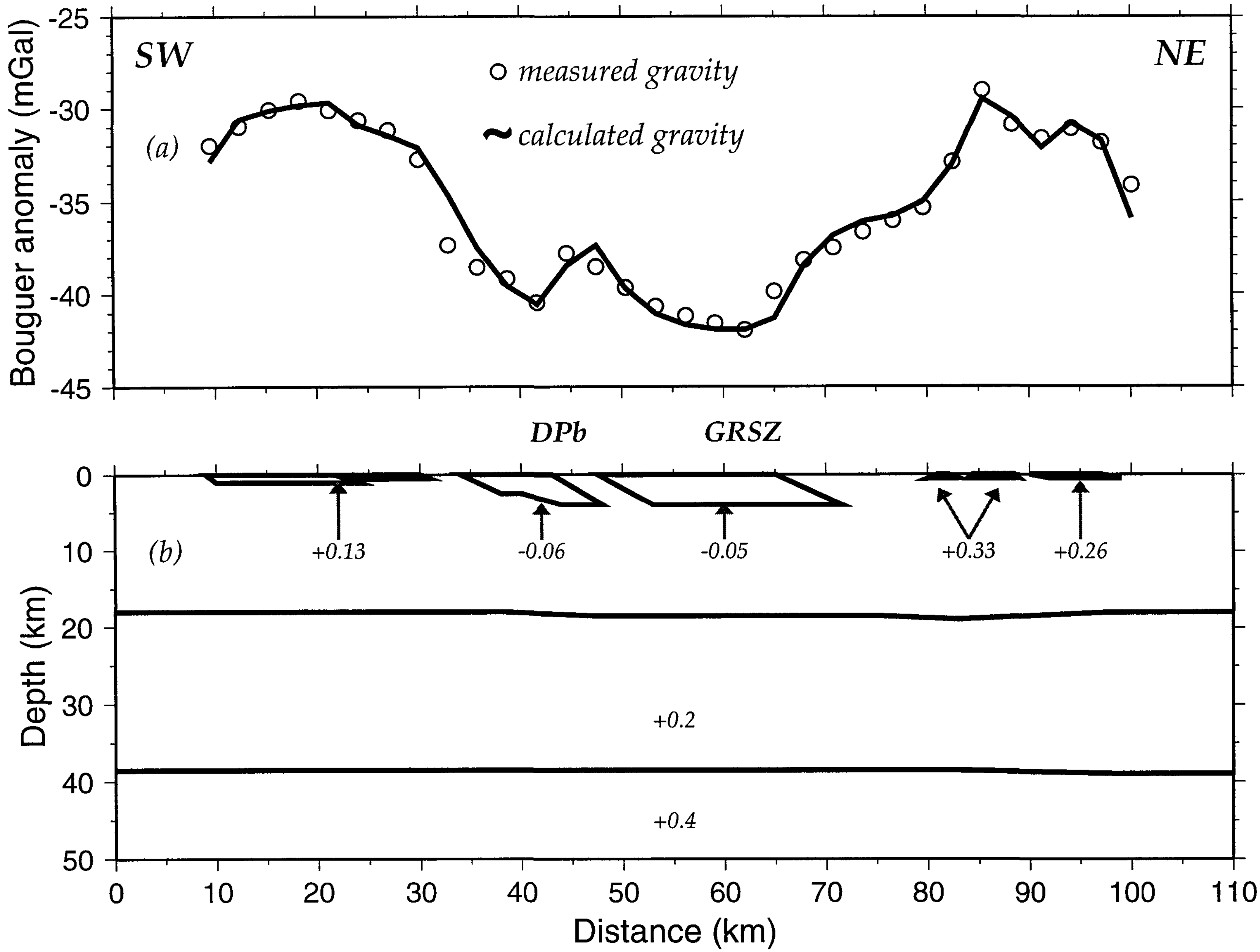

P96 (NW-SE)
P95 (SW-NE)
0
100
0
110
b
d
a
c
Density(Mg.m-3)
3.2
3.0
2.8
2.6
Bouguer Anomaly(mGal)
-25
-30
-35
-40
-45
Distance (km)
Distance (km)



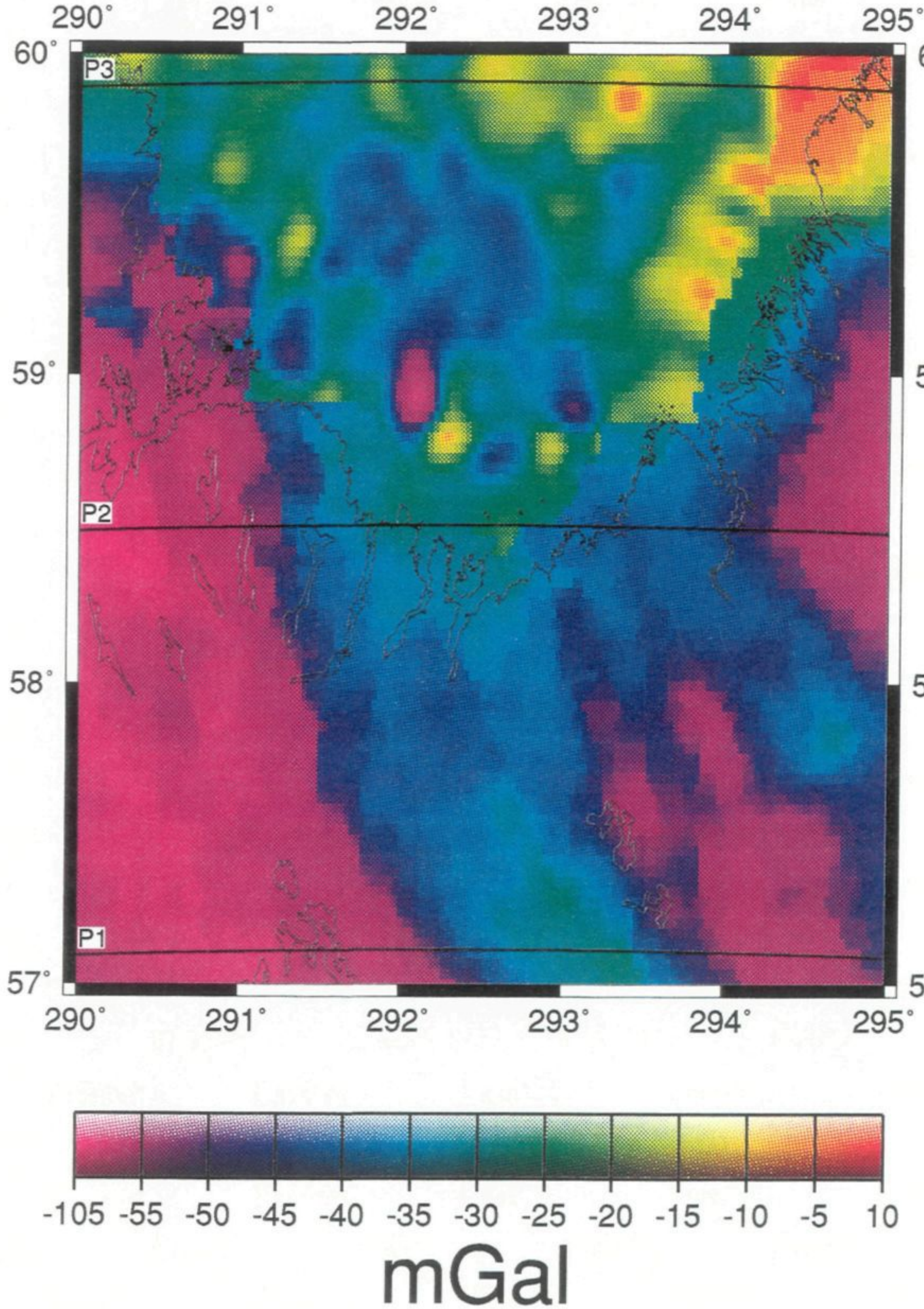
W
E
(a)
Bouguer anomaly (mGal)
-20
-40
-60
-80
-100
calculated gravity
measured gravity
SP
NQO
RAP
RP
(b)
-0.1
-0.1
+0.38
+0.13
+0.4
+0.13
+0.2
+0.4
Depth (km)
0
10
20
30
40
50
0
50
100
150
Distance (km)

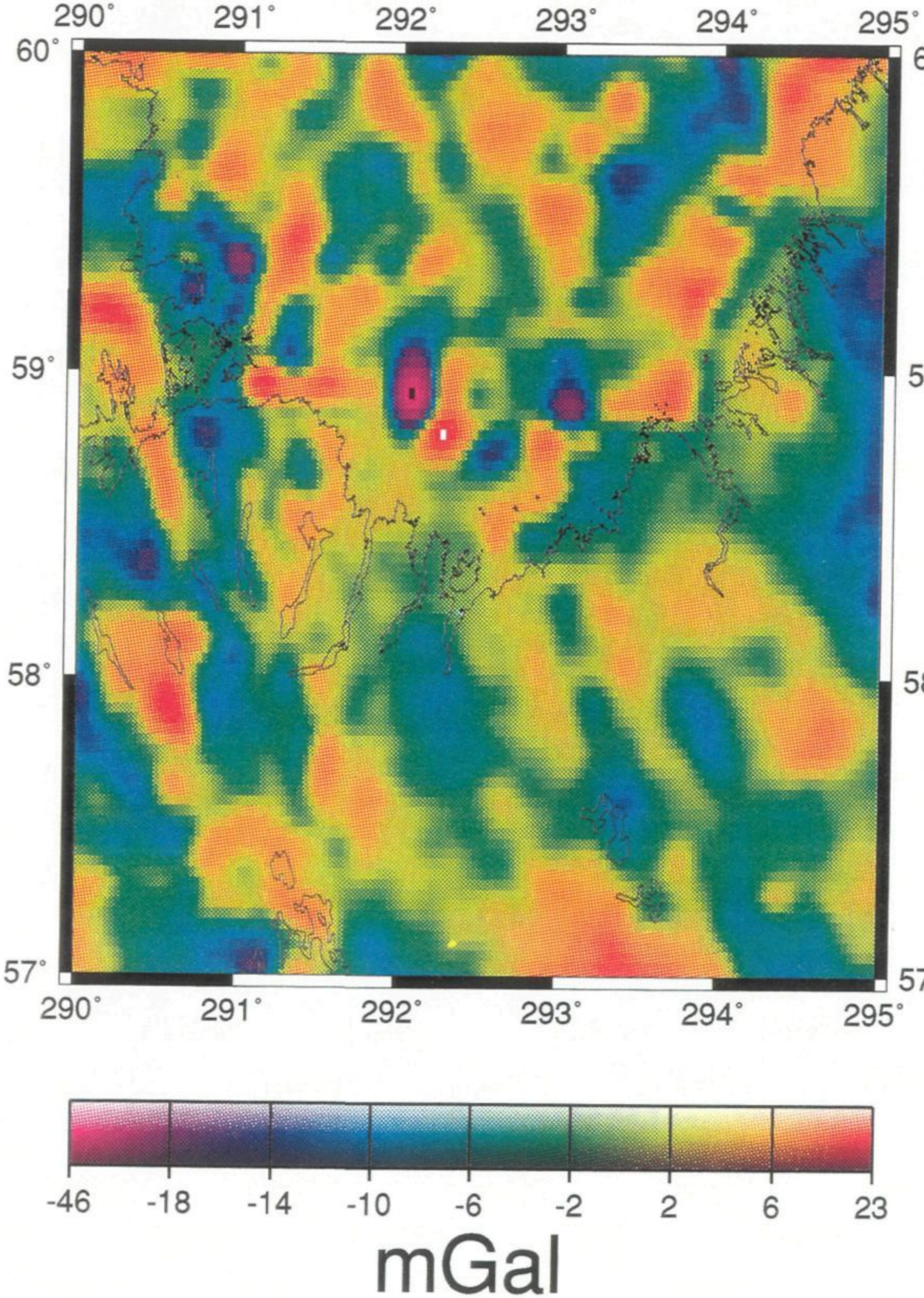


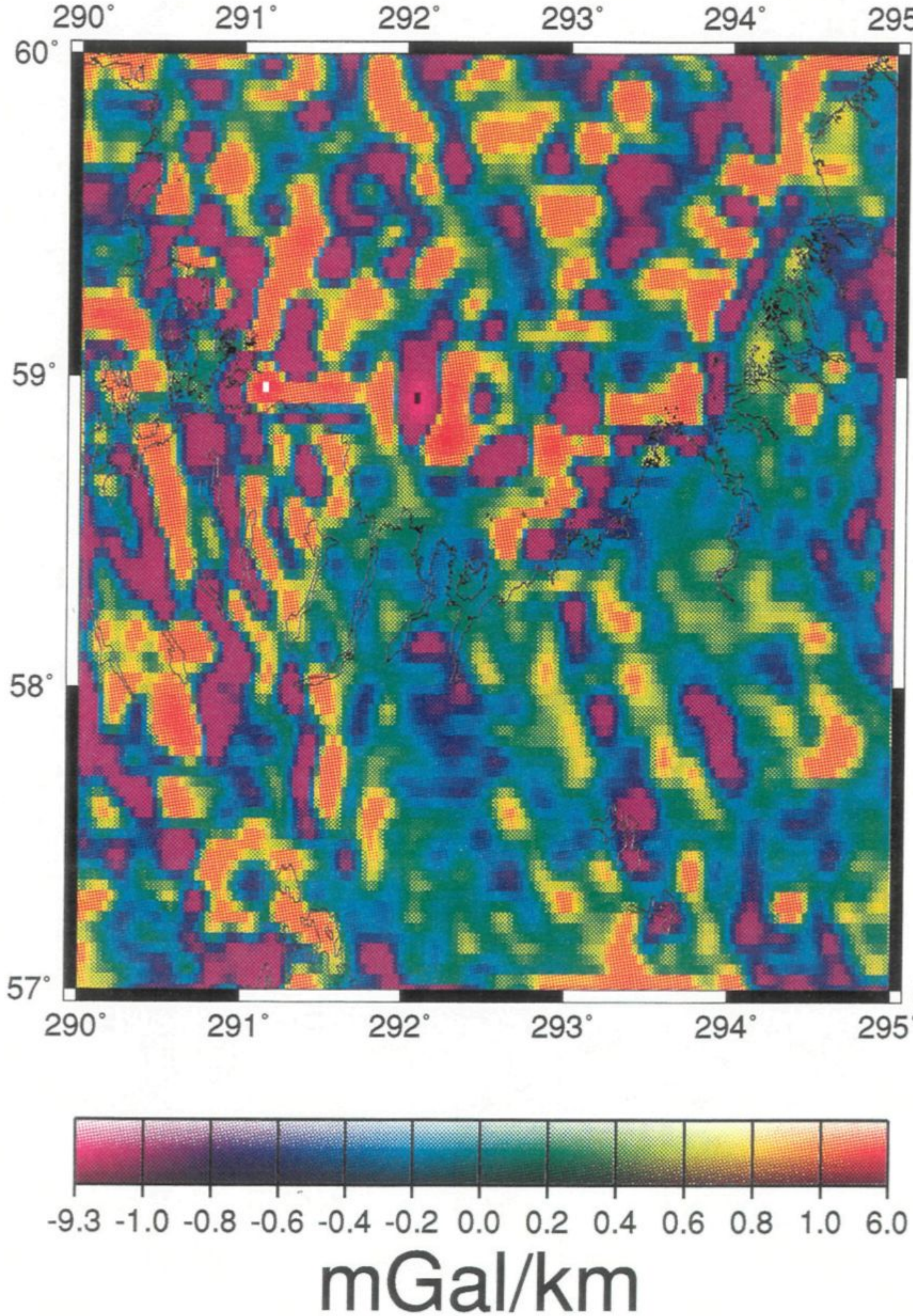
Bouguer anomaly (mGal)
-25
-30
-35
-40
-45
SW
NE
(a)
measured gravity
calculated gravity
DPb
GRSZ
0
10
20
30
40
50
(b)
+0.13
-0.06
-0.05
+0.33
+0.26
+0.2
+0.4
Depth (km)
0 10 20 30 40 50 60 70 80 90 100 110
Distance (km)



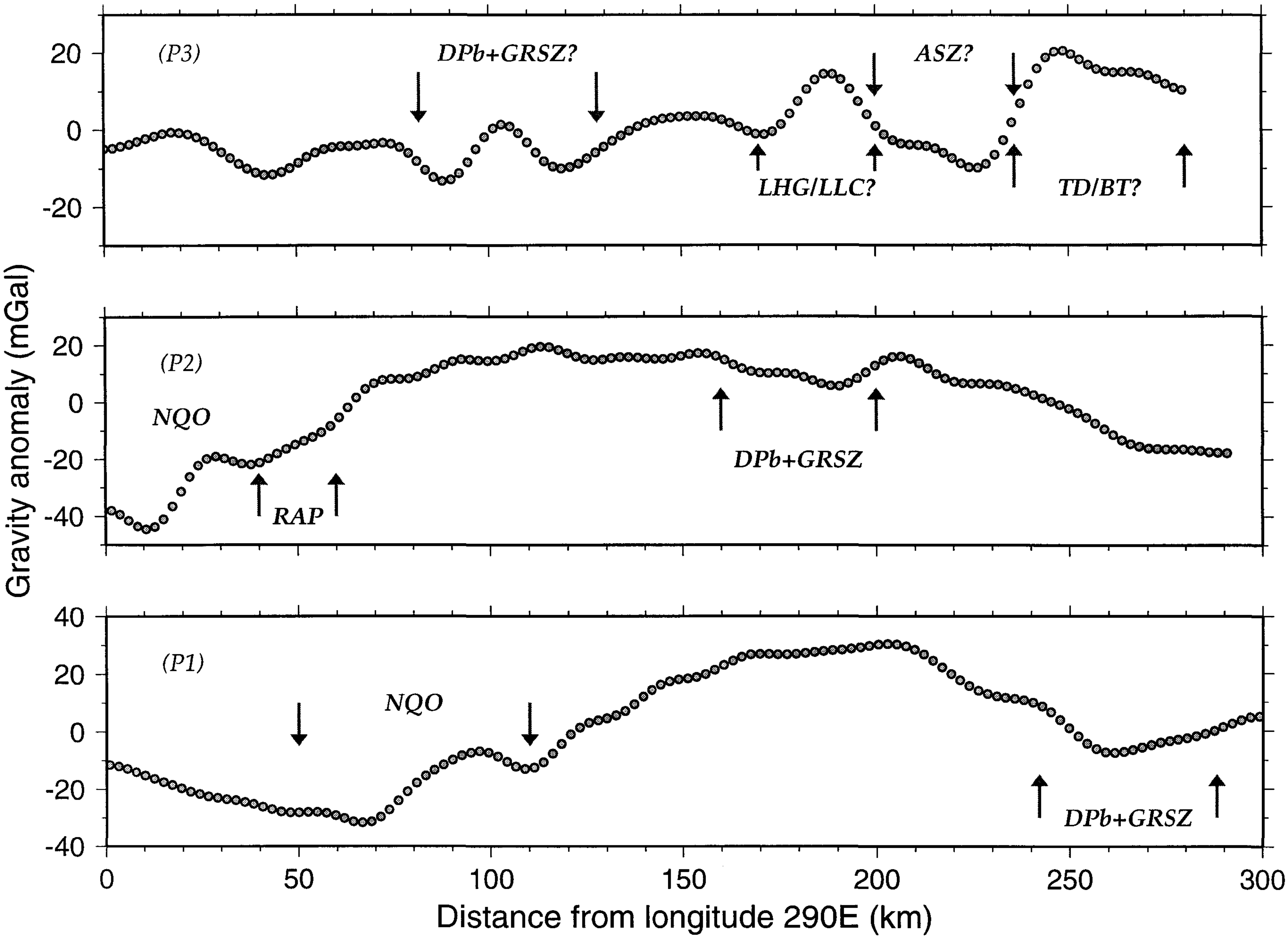
SW
NE
measured gravity
calculated gravity
(a)
Bouguer anomaly (mGal)
-25
-30
-35
-40
-45
DPb
GRSZ
(b)
+0.13
-0.06
-0.05
+0.33
+0.26
+0.2
+0.4
Depth (km)
0
10
20
30
40
50
0
10
20
30
40
50
60
70
80
90
100
110
Distance (km)

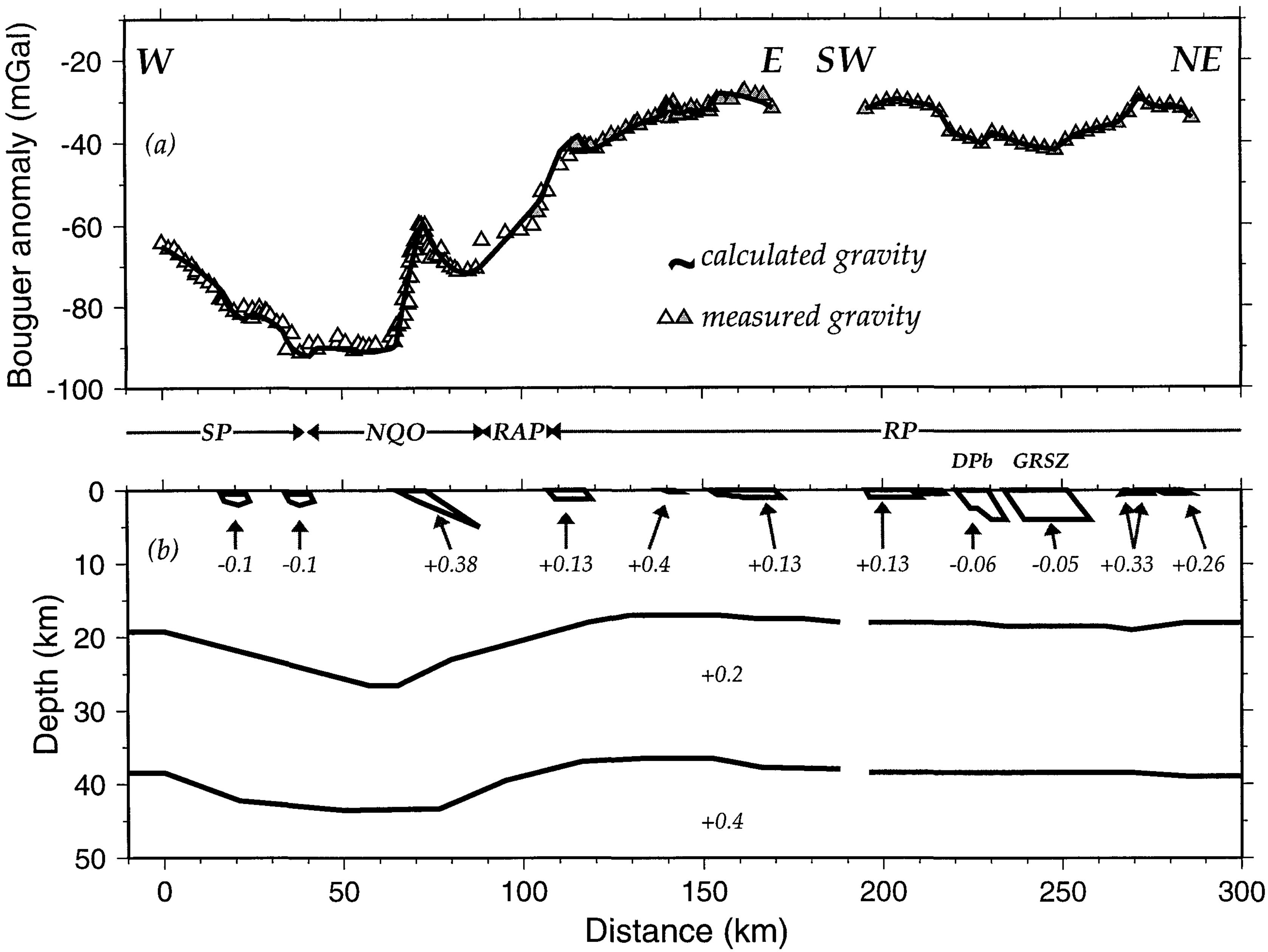

290°
291°
292°
293°
294°
295°
60°
59°
58°
57°
P3
P2
P1
-105
-55
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
10
mGal


290°
291°
292°
293°
294°
295°
60°
59°
58°
57°
-46
-18
-14
-10
-6
-2
2
6
23
mGal



290°
291°
292°
293°
294°
295°
60°
59°
58°
57°
-9.3 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 6.0
mGal/km


(P3)
DPb+GRSZ?
ASZ?
LHG/LLC?
TD/BT?
(P2)
NQO
RAP
DPb+GRSZ
(P1)
NQO
DPb+GRSZ
Gravity anomaly (mGal)
Distance from longitude 290E (km)



W
E
SW
NE
(a)
calculated gravity
measured gravity
Bouguer anomaly (mGal)
-20
-40
-60
-80
-100
SP
NQO
RAP
RP
DPb
GRSZ
(b)
-0.1
-0.1
+0.38
+0.13
+0.4
+0.13
+0.13
-0.06
-0.05
+0.33
+0.26
+0.2
+0.4
Depth (km)
0
10
20
30
40
50
0
50
100
150
200
250
300
Distance (km)

CONCLUSION

Les données du champ de gravité apportent de l'information complémentaire à celle fournie par d'autres méthodes géophysiques. Combinées à des mesures de propriétés physiques des roches, telle que la densité, ces données sont particulièrement utiles. Elles permettent de corréler verticalement les structures définies en profondeur par les données sismiques avec les structures géologiques en surface. Les modèles gravimétriques ont permis de mettre en évidence des caractéristiques majeures non révélées par les données sismiques, notamment dans la partie supérieure de la croûte. Par ailleurs, ces modèles gravimétriques élaborés à travers le Bouclier canadien apportent une contrainte supplémentaire pour la composition crustale, via les contrastes de densité. Ainsi, les études de gravité menées dans le cadre du transect Abitibi-Grenville de Lithoprobe, comprenant l'interprétation des données récoltées le long de la ligne sismique 52 dans la province de Grenville, et de la ligne sismique 48, traversant le nord de l'Abitibi et la ceinture de l'Opatica, ont permis de conforter et de compléter l'interprétation sismique (Martignole et Calvert, 1996; Calvert et al., 1995).

Le long de la ligne 52, les frontières gravimétriques coincident avec les réflecteurs sismiques. Le modèle gravimétrique a permis, en outre, de révéler des caractéristiques majeures non imagées sur la section sismique, tel que le contact presque vertical entre le terrane du réservoir de Cabonga et le terrane du réservoir Dozois.

Le long de la ligne 48, l'épaississement crustal mis en évidence par l'anomalie de Bouguer va dans le sens de l'interprétation sismique. De plus, les données de gravité complètent les données sismiques qui ne fournissent pas d'image des séquences supracrustales correspondant aux deux premières secondes de la section sismique. Les données récoltées au nord de ligne 48 ont permis de donner un aperçu de la structure crustale dans les sous-provinces de Nemiscau et de La Grande. Le modèle de gravité contraint par les mesures de densité et des données aéromagnétiques, invoque une densité de la croûte supérieure plus élevée qu'en Abitibi et en Opatica, ainsi qu'un épaississement crustal dans la sous-province de La Grande. L'orientation de la majorité des structures et le pendage vers le nord des principales frontières tectoniques indiqués par le modèle, sont compatibles avec les observations sur le terrain. Cette interprétation est compatible avec un modèle d'accrétion progressive du nord vers le sud dans la province du Supérieur (Percival et al., 1994). Toutefois, des études géochimiques et pétrologiques, entres autres, sont nécessaires pour caractériser la croûte, notamment dans la sous-province de Nemiscau.

Pour le transect ECSOOT, les données de gravité récoltées le long de la baie d'Ungava étaient nécessaires pour pouvoir corréler horizontalement le profil de sismique marine à travers la baie avec les structures géologiques cartographiées sur terre. En effet, l'ensemble des données au sol fournit une couverture gravimétrique détaillée le long de la côte sud de la baie d'Ungava. Ces données ont servi de contrôle lors de l'établissement de cartes composites du champ de gravité au dessus de la région de la baie d'Ungava. Les données satellitaires d'altimétrie ont été utilisées pour pallier à l'absence de données standard dans la baie. Bien que la résolution des données satellite soit limitée, à cause des fortes marées et du couvert de glace essentiellement, des cartes filtrées du champ de gravité ont montré que certaines structures majeures, telles que la zone de cisaillement de la rivière George, se prolongeaient en mer. La modélisation d'un transect E-W le long de la côte sud de la baie, a permis par ailleurs, de mettre en évidence un épaississement de la croûte sous l'Orogène du Nouveau Québec et un amincissement sous le terrane de Kuujjuaq, à l'est de l'orogène. Alors que plus à l'est dans le craton de Rae, la modélisation a montré que la zone de cisaillement de la rivière George et le batholite de De Pas sont des structures peu épaisses, (moins de 4 km d'épaisseur). L'orientation des structures sur les modèles présentés est compatible avec les réflexions plongeant vers l'est, observées le long de la ligne sismique à travers la baie, suggérant ainsi un chevauchement du craton de Rae au dessus de l'Orogène du Nouveau Québec. Il serait intéressant, à mon sens, de conduire un autre transect de gravité qui couvrirait la partie située au nord-ouest de la rivière George, traversant l'Orogène de Torngat jusqu'au terrane de Burwell. Ce transect permettrait de proposer un modèle de gravité plus complet. Un tel modèle pourrait être comparé aux modèles d'évolution de la partie nord-est du craton de Rae, et fournirait un aperçu de l'architecture du craton dans le contexte des processus mis en oeuvre lors du développement du NE de Laurentia.

Références

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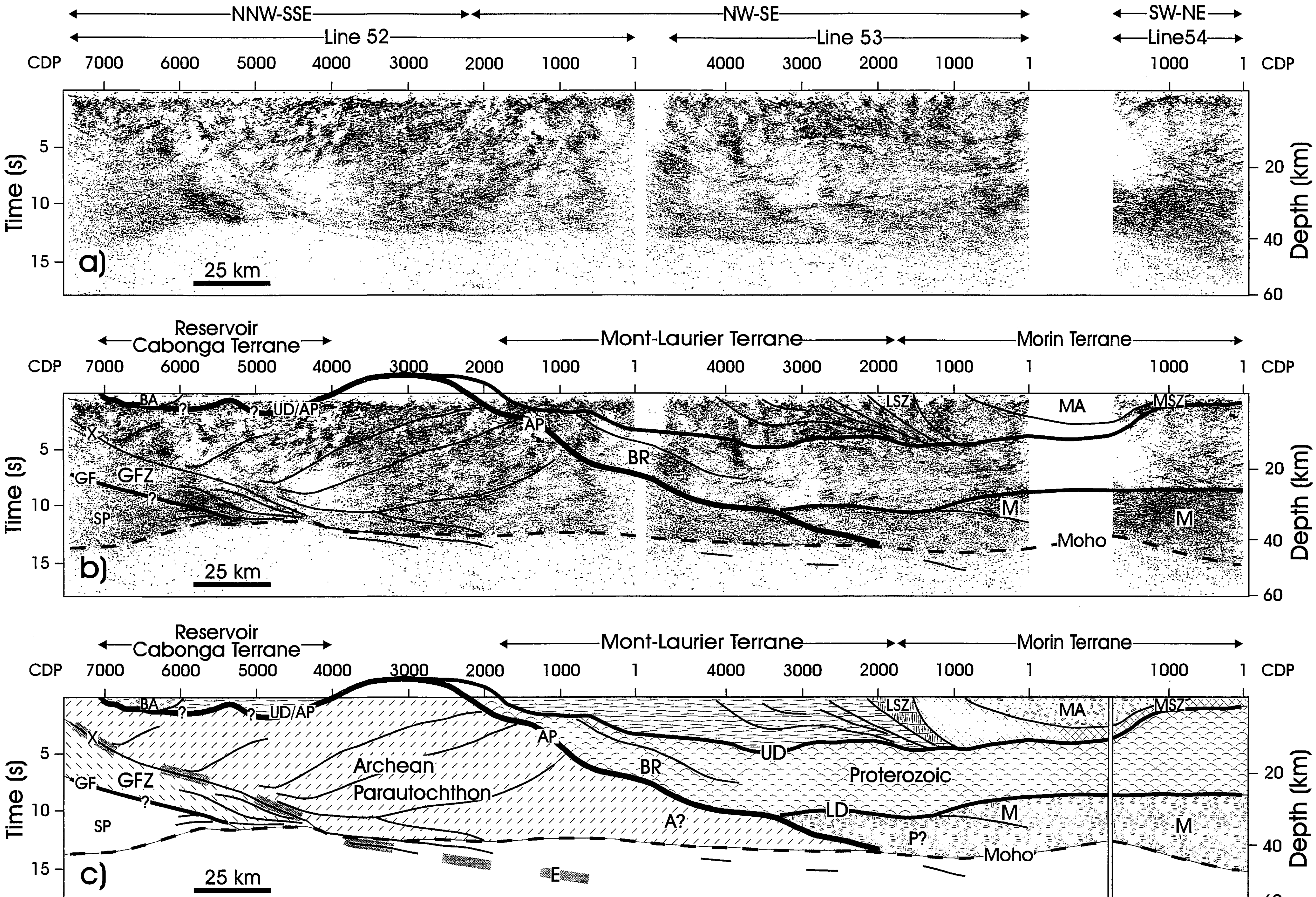
Percival, J.A., Stern, R.A., Skulski, T, Card, K.D., Mortensen, J.K., and Begin, N.J. 1994. Minto block, Superior province: Missing link in deciphering assembly of the craton at 2.7 Ga. *Geology*, **22**: 839-842.

APPENDICE

Sections sismiques de Lithoprobe concernées par cette étude

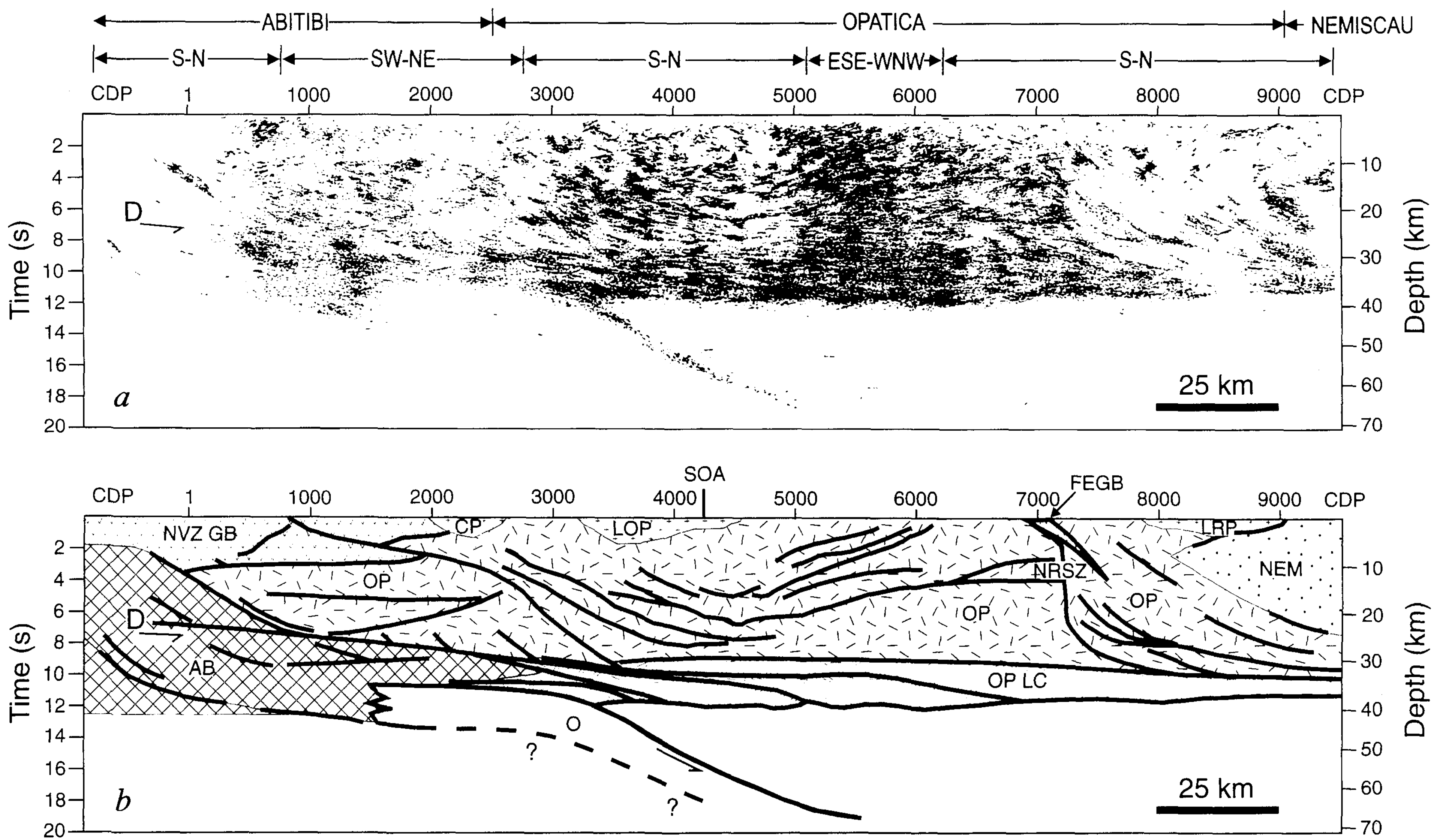
Interpretation of lines 52, 53, and 54 (Martignole and Calvert, 1996).

a) Migrated sections of lines 52, 53, and 54. b) Interpretations of the main features of the reflection profiles. The Moho is marked by a dashed line. The continuous lines indicate reflections or significant changes in crustal reflectivity that mark terrane boundaries. A number of reflections within crustal units are highlighted to show the general orientation of reflectivity. c) Identification of the major crustal units. The thick shaded lines (E) represents the possible reactivation in extension of the major crustal thrusts at the Grenville Front. Abbreviations are SP, Superior Province; GF, downward projection of the Grenville Front; X, downward projection of SE edge of X terrane, GFZ, Grenville Front Zone; BA, Bouchette anorthosite; AP, Archean-Proterozoic boundary; BR, Baskatong ramp; LSZ, Labelle shear zone; MA, Morin anorthosite; MSZ, Morin shear zone; M, reflective lower crust; UD, upper decollement, LD, lower decollement, A/P?, affinity of lower crust, Archean or Proterozoic.


NNW-SSE
NW-SE
SW-NE
Line 52
Line 53
Line54
CDP
Time (s)
Depth (km)
a)
25 km
Reservoir
Cabonga Terrane
Mont-Laurier Terrane
Morin Terrane
BA
UD/AP
AP
BR
LSZ
MA
MSZ
X
GF
GFZ
SP
M
Moho
b)
Archean
Parautochthon
UD
Proterozoic
LD
A?
P?
E
c)

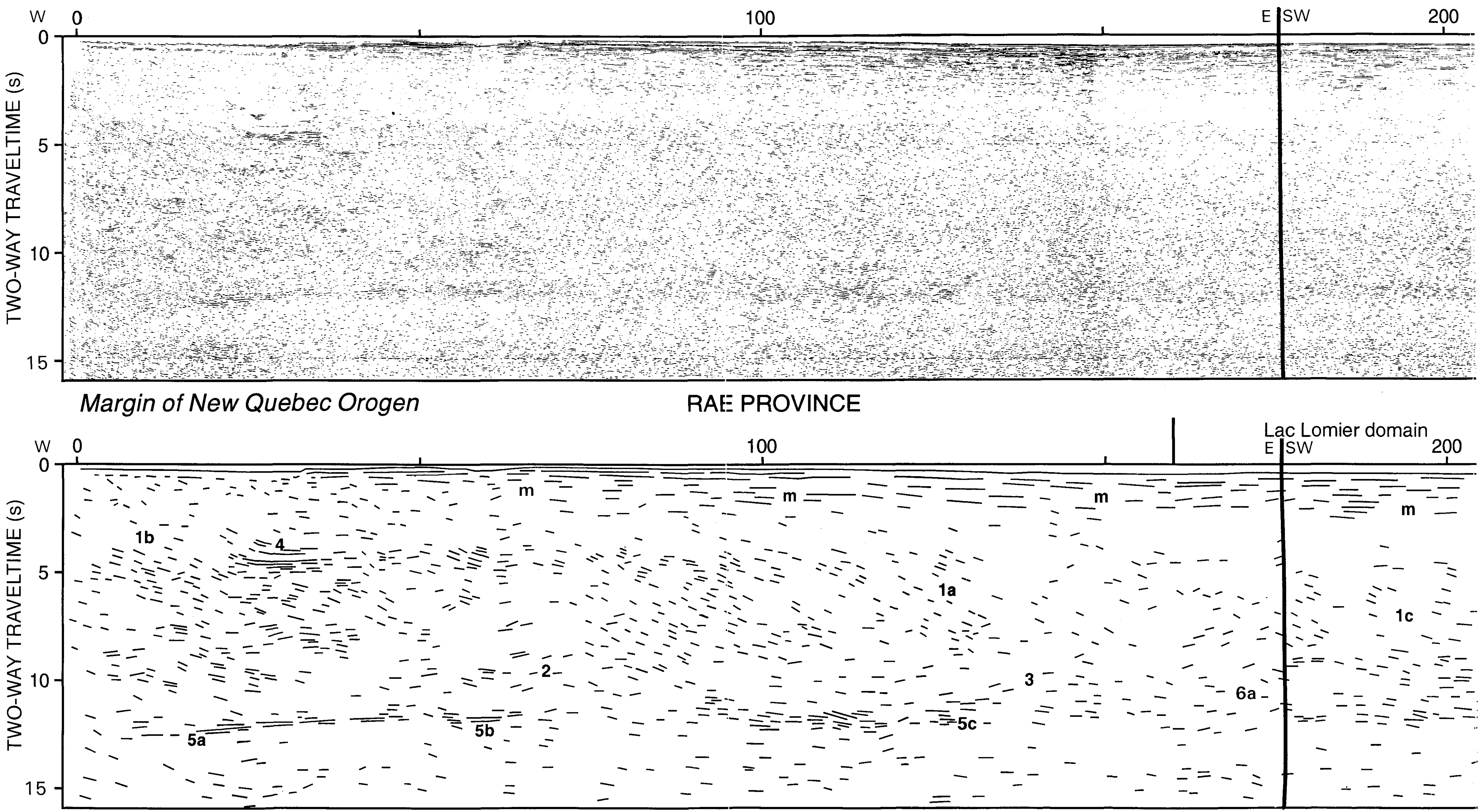
Interpretation of line 48 (Calvert et al., 1995).

a) Line migration of line 48 displayed at true scale (1:1) derived by migrating the stack at 6500 m s^{-1} using apparent local dips estimation over a21-trace window. b) Interpretation of the seismic section in a displayed at true scale (1:1) along the seismic line. The major crustal units are indicated: OP, Opatica crust; OP LC, Opatica lower crust consisting of strong subhorizontal reflectors; AB, Abitibi (sub-greenstone) crust interpreted partly by correlation with earlier seismic data; NVZ GB, greenstone rocks that form part of the Abitibi northern volcanic zone; NEM, Nemiscau (metasedimentary) crust; O, subcrustal units, tentatively identified as a relict Archean oceanic slab. CP, LOP, LRP, SOA, NRSZ, FEGB, as in Fig. 2. D as in a. Unmigrated stack, F-K migration and line migration sections (a) were all empoyed in making the interpretation.


ABITIBI
OPATICA
NEMISCAU
S-N
SW-NE
S-N
ESE-WNW
S-N
CDP
1
1000
2000
3000
4000
5000
6000
7000
8000
9000
CDP
Time (s)
Depth (km)
D
a
25 km
SOA
FEGB
NVZ GB
CP
LOP
LRP
NEM
OP
NRSZ
OP
OP
AB
OP LC
O
?
?
D
b
25 km

Interpretation of the northern ECSOOT line across Ungava Bay (Hall et al., 1995).

Migrated seismic reflection profile and interpreted line drawing from the Lithoprobe ECSOOT 1992 survey, northern line, across Ungava Bay. Profile is plotted as distance along the line against reflection time and is at true scale for a seismic velocity of 6 km/s. Numbers on line drawing refer to descriptions of data in text (Hall et al., 1995). m, residual multiple energy.


W
0
100
E
SW
200
0
5
10
15
TWO-WAY TRAVELTIME (s)
Margin of New Quebec Orogen
RAE PROVINCE
Lac Lomier domain
W
0
100
E
SW
200
0
5
10
15
TWO-WAY TRAVELTIME (s)
m
m
m
m
1b
4
1a
1c
2
3
6a
5a
5b
5c