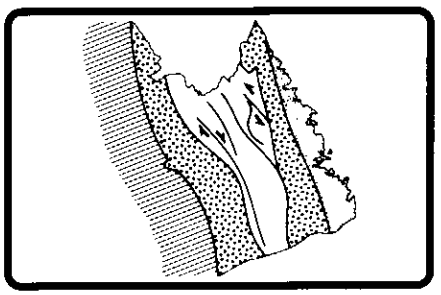

Gravity profile and crustal structure across the northern New Québec Orogen

Jean-Claude Mareschal, Gino Dalla Coletta, Isabelle Clevenot, and Normand Goulet
Département des Sciences de la Terre and GEOTOP
Université du Québec à Montréal
C.P. 8888, Succ. A.
Montréal, Québec H3C 3P8

Summary
Detailed gravity data, collected along an east-west transect across the northern New Québec Orogen near Leaf Bay, provide constraints on the deep structure of this segment of the orogen. The Bouguer anomaly profile contains long and short wavelength components. A steep gravity gradient and a strong positive anomaly near the centre of the orogen are related to the presence of dense mafic volcanic rocks in the shallow crust. Two alternative models are presented that are compatible with the long wavelength gravity data. The authors prefer to interpret the long wavelength components in terms of crustal thickening beneath the orogen and increased crustal density in the Rae Province, to the east. A scenario based on this crustal density structure is suggested for the evolution of the orogen. It calls for (1) the formation of a small ocean separating the Superior and Rae provinces; (2) subduction of this ocean beneath the Rae Province; and (3) complete closure of the basin with overthrusting of the Superior margin and, possibly, obduction of the Rae Province onto the Superior Province craton.

Résumé
Un profil gravimétrique est-ouest à travers la partie nord de l'orogène du Nouveau-Québec a fourni des données sur la structure profonde de ce segment de l'orogène. L'anomalie de Bouguer contient des courtes et grandes longueurs d'onde. Un fort gradient et une anomalie positive près du centre de l'orogène sont causés par des roches volcaniques mafiques dans la croûte supérieure. Deux modèles sont compatibles avec les anomalies de grande longueur d'onde. Les auteurs préfèrent évoquer un épaississement de la croûte sous l'orogène et une augmentation de sa densité moyenne vers l'est, dans la Province de Rae. Un scénario, basé sur cette structure de densité de la croûte, est suggéré pour expliquer l'évolution de l'orogène. Les étapes principales en sont : (1) la formation d'un mini-océan entre les blocs du Supérieur et de Rae; (2) la subduction de l'océan sous la Province de Rae; et (3) la fermeture du bassin avec chevauchement de la marge du Supérieur et, peut-être, l'obduction du bloc de Rae sur le craton du Supérieur.

Introduction
The New Québec Orogen (NQO) (Hoffman, 1988) in northern Québec is one of several Proterozoic orogenic belts surrounding the Ungava Peninsula of the Archean Superior Province (Figure 1). Collectively, these belts have been referred to as the circum-Ungava foldbelt (*e.g.*, Condie, 1982). On the eastern edge of the Superior Province, the NQO is probably the best exposed and preserved of these belts. It separates the Superior Province to the west from the Rae Province to the east; it extends, with a NNW strike, over more than 1,000 km from Kangirsuk in the north to the Grenville Province. Other segments of the circum-Ungava foldbelt are the Cape Smith fold belt and the Belcher Islands belt, which fall within the Trans-Hudson Orogen (Figure 1); additional segments of this orogen are exposed further west in the Fox River belt and in the Thompson Nickel belt, in Manitoba.

The most common interpretation for these belts follows that of Gibb and Walcott (1971), who analyzed their gravity signature and proposed that they represent ancient active plate margins. The nature and evolution of these margins have remained controversial: some researchers favour continental collision (Kearey, 1976), while others advocate an Andean type of tectonism (Thomas and Gibb, 1977). Alternative hypotheses have also been formulated: Dimroth (1981) interprets the NQO as a Proterozoic rift, while Condie (1982) compares the circum-Ungava system with the Keweenawan rift system.

The geological and tectonic settings of the NQO are relatively well documented (see for instance Dimroth, 1981; Hoffman, 1988, and references therein). The geology of the study area is shown in Figure 2. The Archean Superior Province, to the west of the NQO, contains granitoid intrusions and gneisses *ca.* 2.7 Ga old. The lower Proterozoic NQO contains different lithostratigraphic assemblages with contrasting deformation styles. A thin autochthonous sedimentary sequence rests unconformably on Superior-type basement; it contains shallow water shelf sequences grading eastward to deeper water sediments. It is followed to the east by an allochthonous zone consisting of an imbricated thrust and fold belt with westward structural vergence and folded nappes (Goulet, 1986). A narrow rift-related volcano-sedimentary sequence marks the boundary between the allochthonous and autochthonous units. The metamorphic grade increases eastward to such intense levels that it has obscured the boundary between the NQO and the Rae Province. Structural relationships indicate that the orogen was thrust over the Superior Province. Geochronometric studies (Machado *et al.*, 1989) have yielded Archean ages for the basement in the Rae Province; Hudsonian metamorphism did not affect this Archean basement but, in the Rae Province, the latest phase of metamorphism was dated at *ca.* 1.78 Ga. The DePas batholith, lying within the Rae Province, parallels the NQO along most of its extent. U-Pb ages of 1.81 and 1.84 Ga were obtained from zircons by T. Krogh and by S. Bowring for the De Pas batholith (reported by Hoffman, 1988).

Geophysical data provide information on the subsurface structure, and thus constrain evolutionary models for the NQO. Contemporary mountain ranges are characterized by a distinctive gravity signature (Karner and Watts, 1983) with a well-marked positive-negative couple which is interpreted as evidence for crustal thickening and lithospheric flexure. This gravity signature has remained fossilized in deeply eroded, ancient orogens such as the Grenville Front, the Thelon Front, and the NQO (see, for instance, Gibb and Thomas, 1976). Several authors, following Gibb and Walcott (1971), have used gravity data to delineate ancient plate boundaries in the Canadian Shield and to support specific models for evolution of the circum-Ungava system (*e.g.*, Gibb, 1975, 1983; Gibb *et al.*, 1983; Kearey, 1976; Thomas and Gibb, 1977; Thomas and Kearey, 1980).

The purpose of this paper is to report on the interpretation of a gravity profile measured across the northern part of the NQO, in the vicinity of Tasiujaq, Québec.

Data and Interpretation
Near Leaf Bay, where the gravity measurements were conducted, the NQO is less than 60 km wide. The survey included 112 gravity stations along a profile extending over more than 110 km. The locations of all gravity measurement sites are displayed on Figure 3a. The sites are located along the shoreline (because of restricted inland access), thus providing elevation control. Unfortunately, the measurement sites are very unevenly distributed.

Because the geological structures strike north-south, the Bouguer anomaly was projected on an east-west line. The interpretation assumes that the geological units have infinite strike length: the Bouguer anomaly was calculated for two-dimensional density models and compared with the projected data. The gravity profile, projected on the east-west direction, is shown on Figure 3b. The major geological boundaries are also

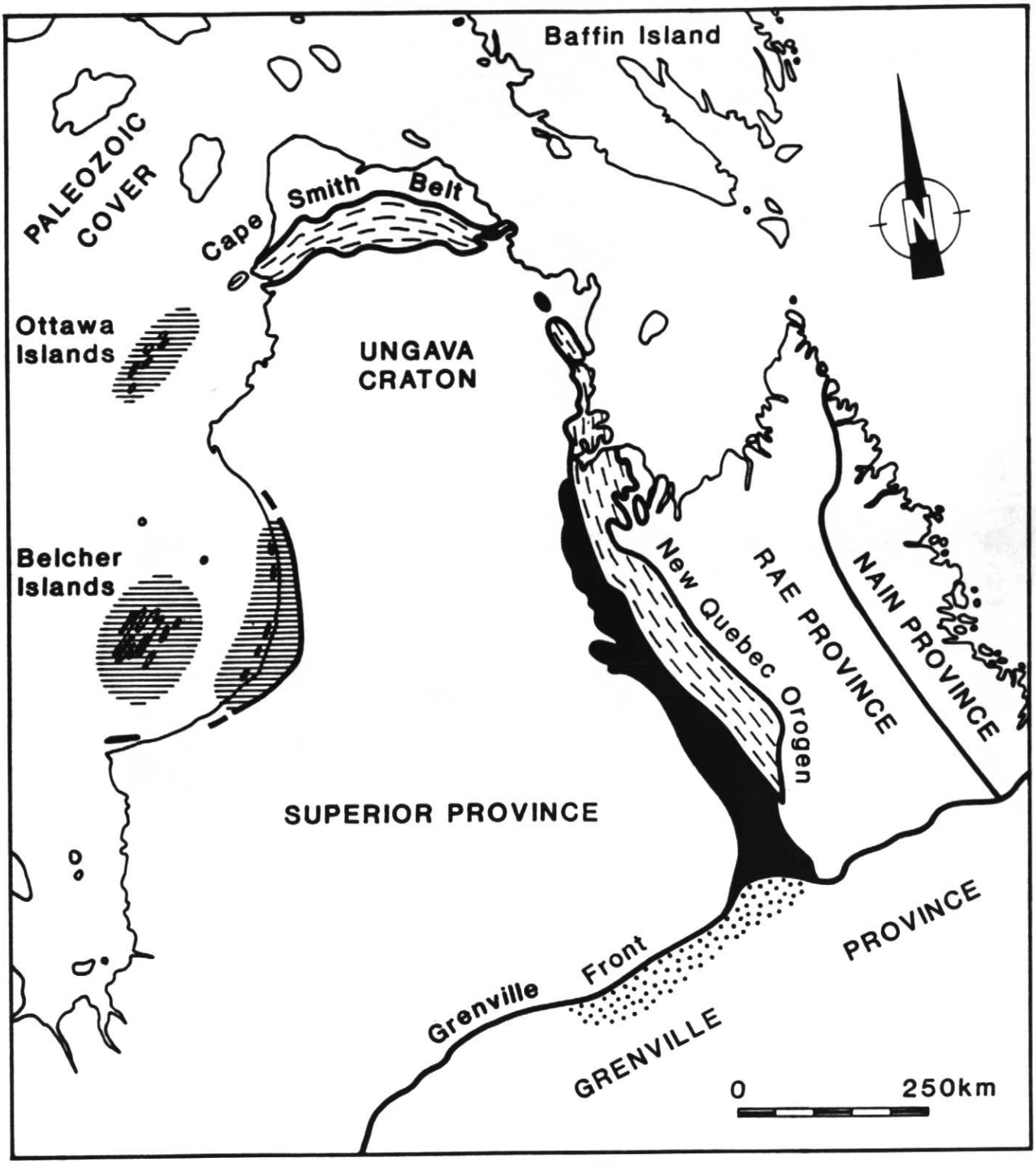

Figure 1 *The circum-Ungava fold belt system. (After Condie, 1982).*

indicated. The scatter caused by the projection is small; this indicates that the gravity anomaly does not vary much along the north-south direction and that the two-dimensional assumption is valid.

The gravity profile is dominated by a long wavelength low on which is superimposed a short wavelength high located near the centre of the orogen where mafic volcanic rocks are exposed. The Bouguer anomaly increases both eastward and westward, away from the NQO; the gradient is slightly steeper on the eastern edge of the orogen, toward the Rae Province, than on the western end, toward the Superior Province. Note that, because the

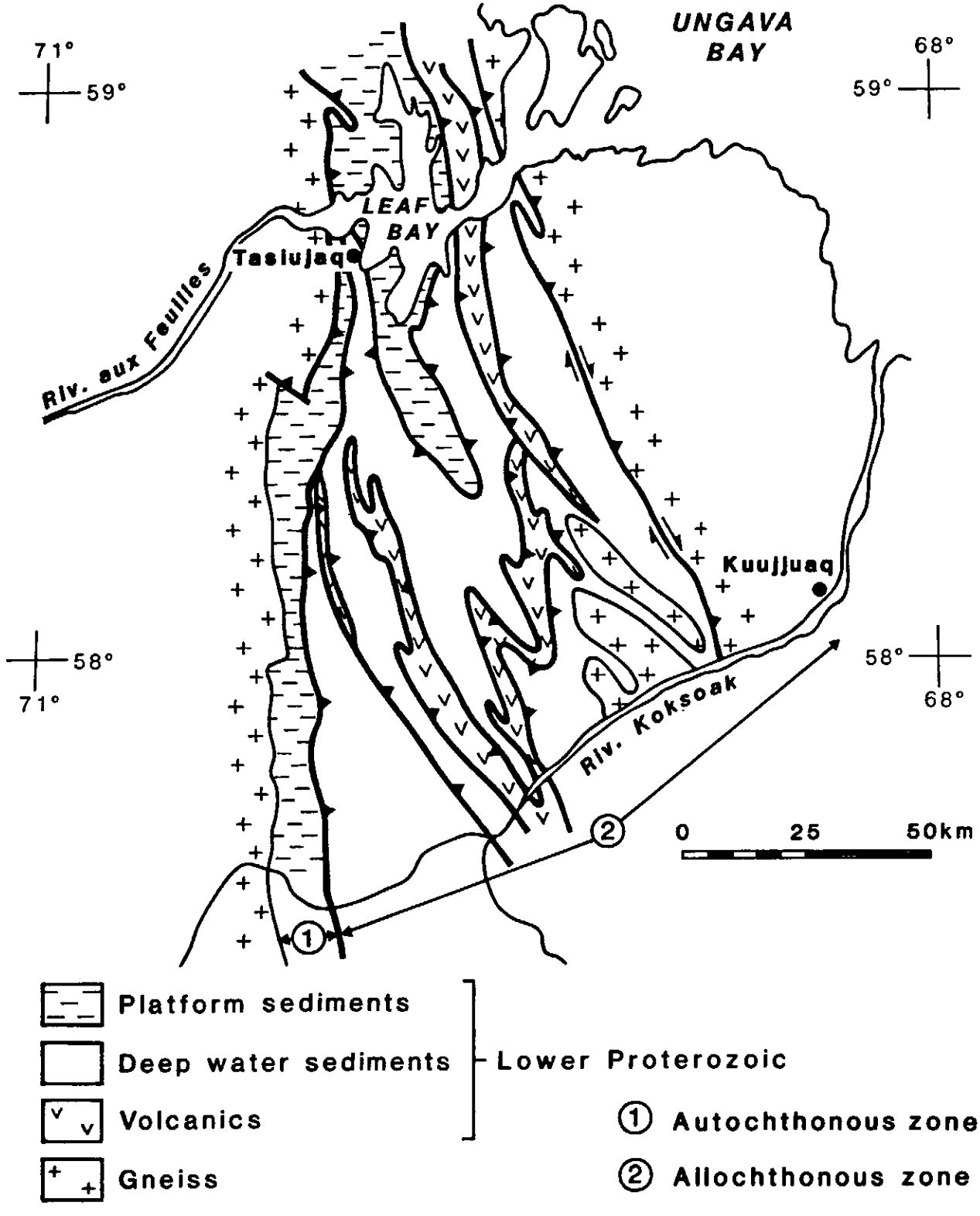

Figure 2 *Major geological divisions in the northern New Québec Orogen, between the Koksoak River and the Rivière aux feuilles.*

westernmost part of the transect is oriented southwest, the gradient when projected on the east-west direction appears steeper than measured along the actual traverse.

The short wavelength high between 70 and 80 km requires shallow sources and a high density contrast. Mafic igneous rocks exposed near Point Reef have high density and the data constrain the thickness of this mafic sequence relatively well. The average density measured on fresh outcrop samples is 3.05 $Mg \cdot m^{-3}$ (*i.e.*, it is 0.3 $Mg \cdot m^{-3}$ higher than basement gneisses). The thickness of the volcanic rocks is thus estimated to be between 2.5 and 4 km. The detailed gravity models suggest that the sequence extends 5 to 10 km eastward beneath the Archean rocks and Proterozoic supracrustal rocks of the Rae Province. Such a geometry is consistent with structural data demonstrating westward overthrusting.

Gravity interpretation is non-unique and many density distribution models may be compatible with the data. This uncertainty is of particular concern for the long wavelength anomalies, which can be explained by density variations at depth or by shallower and more gradual changes. The gravity low beneath the western part of the NQO could be caused by the lower density of the metasedimentary rocks within the NQO. This hypothesis, however, is not supported by density measurements on outcrop samples that yield an average density for the metasedimentary rocks of 2.72 $Mg \cdot m^{-3}$ (*i.e.*, about the same or even slightly higher than that of the gneisses of the Superior Province). The gravity low at the centre of the profile is thus interpreted in terms of increased crustal thickness beneath the NQO.

A thinner crust beneath the Rae Province, *i.e.*, a shallower Moho, could explain the eastward increase in the gravity field away from the low. Most investigators have assumed that the crust is thicker beneath the Rae Province than below the Superior Province because seismic data, in other parts of the Canadian Shield, show that the crust is usually thinner beneath the Superior Province than in the surrounding younger provinces (Berry and Fuchs, 1973; Mereu and Hunter, 1969). This is not always observed though: for instance, seismic refraction data between Mont-Laurier and Val d'Or (Mereu *et al.*, 1986) show crustal thinning 80 km south of the Grenville Front, beneath the Reservoir Dozois terrane. This situation is not found on other COCRUST profiles near Sudbury (Ontario) or Chibougamau (Québec), but it suggests that a thicker crust beneath the Superior Province cannot be ruled out altogether. Figure 4 thus shows a model that fits the long wavelength anomaly with a thin crust beneath the Rae Province. An intermediate boundary between the upper and lower crust is included, but is not required by the data. Small density contrasts (0.025 $Mg \cdot m^{-3}$) were introduced locally within the metasedimentary rocks in order to improve the fit between the calculated and observed anomaly. However, their effect is small (*i.e.*, not larger than the scatter in the projected data). With the exception of the short wavelength high, the gravity anomaly could thus be fitted with changes in crustal thickness alone.

Although the density model shown on Figure 4 fits the gravity data, the authors prefer a model with a thicker crust east of the NQO. Indeed, the steep gradient east of the orogen suggests that the density contrasts are shallow. The data could be fitted either by a progressive increase of the upper crustal density (*i.e.*, corresponding to higher metamorphic grade), or by variations in the depth of the "boundary" between upper and lower crust. Figure 5 shows a model in which the density of the upper crustal material east of the orogen is close to that of the lower crust. The boundary between this relatively dense material and normal upper crust has an eastward dip because it is compatible with known westward overthrusting, but models with the reverse dip would fit the data equally well. Alternatively, an eastward increase in the average crustal density could also be invoked to explain the eastern half of the gravity profile. This higher density could be due to increased metamorphic grade following crustal thickening and deep erosion, which is compatible with geological observations showing an eastward increase in metamorphic grade (Perreault *et al.*, 1987). Crustal thickening in the Rae Province is thus compatible with Hudsonian reactivation (petrological and geochronological data in the western NQO indicate that the Superior Province was not reactivated during the Hudsonian Orogeny; Machado *et al.*, 1989). Similar models with an eastward increase in the average crustal density were proposed by Kearey (1976) for the central part of the NQO.

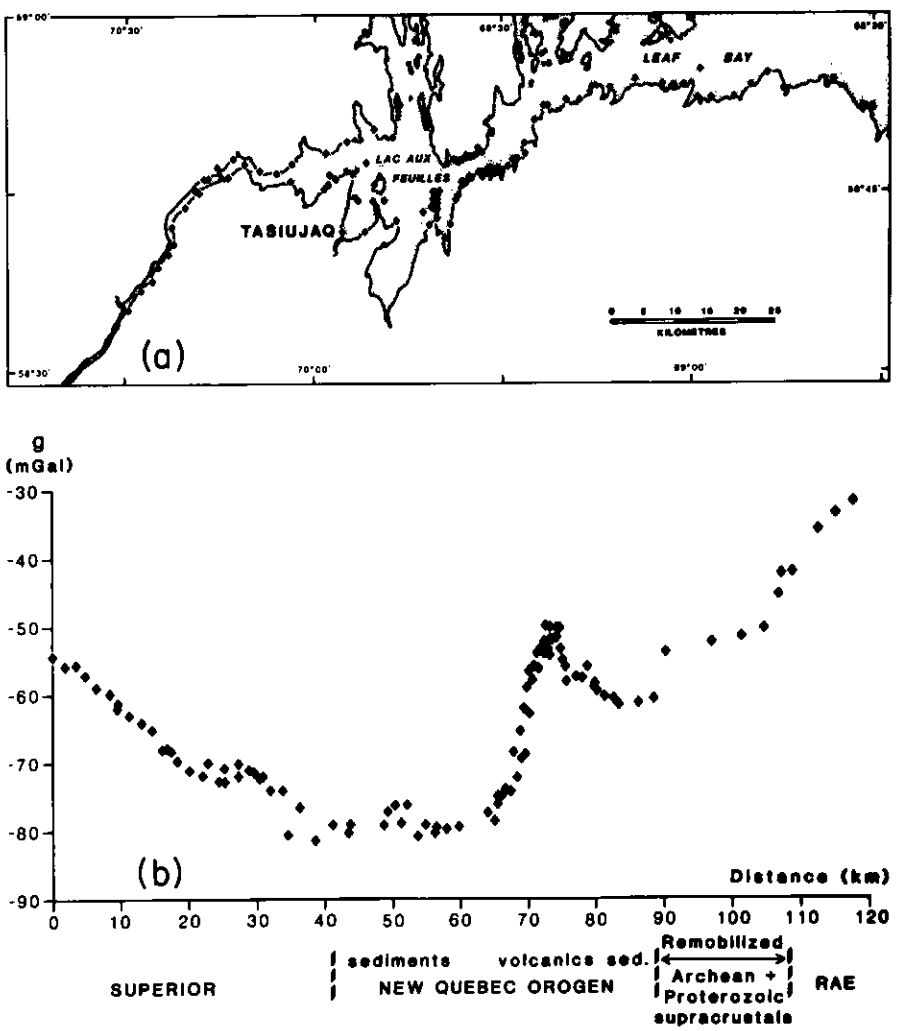

Figure 3 (a) *Location of all gravity measurements along the traverse. The measurements were made along the shore of the river and bay at the high tide level.*
(b) *The gravity profile projected onto an east-west line. The figure indicates that variations along the north-south direction exist, but are small relative to east-west variations. Distance is in km from the western termination of the profile.*

Discussion

Several crustal density distribution models fit the gravity data in the northern New Québec Orogen. Although the gravity data do not provide strong constraints, they do suggest some remarks concerning the crustal structure and evolution of the NQO.

The gravity signature of the circum-Ungava system is distinctly different from that of intracontinental rifts, such as the Keweenawan where the gravity anomaly is strongly positive. Also, the gravity data indicate crustal thickening beneath the NQO and confirm that the volcanic rocks are confined to a relatively narrow band. In the authors' opinion, the gravity data, as well as the presence of sedimentary rocks typical of a continental margin, exclude the intracontinental rift model.

The Bouguer anomaly does not uniquely constrain the density distribution, and other geophysical data that could resolve the ambiguity of interpretation for the northern NQO are not available. Two alternative density models are thus proposed: both show crustal thickening beneath the orogen, but differ in the crustal thickness assigned to the Rae Province. In one model, the crust is thinner beneath the Rae Province, while in the other, the crust is thicker and denser than in the Superior Province.

The authors prefer the latter model, shown in Figure 5, which suggests that the higher crustal density can be explained by exposure of a section of the lower crust. Such a model appears compatible with the model of continental convergence and subsequent obduction proposed by Fountain and Salisbury (1981). Alternatively, this model is also compatible with eastward increase in density and metamorphic grade, which would suggest a crustal reactivation, continental collision episode (Dewey and Burke, 1973). The authors' preferred tentative scenario for the NQO evolution is as follows:

(a) The Rae Province is separated from the Ungava part of the Superior Province by a small ocean. A passive continental margin developed on the eastern edge of the Superior Province.

(b) This episode was followed by eastward subduction of the ocean floor beneath the Rae Province and development of an Andean-type tectonic regime within the Rae Province characterized by crustal thickening, reactivation, and formation of the De Pas batholith.

(c) Final closure of the ocean was accompanied by obduction of the Rae Province and overthrusting of the Superior continental margin deposits onto the Superior craton.

Combined geophysical, petrological, and geochronometric studies should be conducted to test the proposed scenario. It seems important to obtain a profile of metamorphic grade, including paleotemperatures and pressures east of the NQO. This could be combined with geochronometric studies.

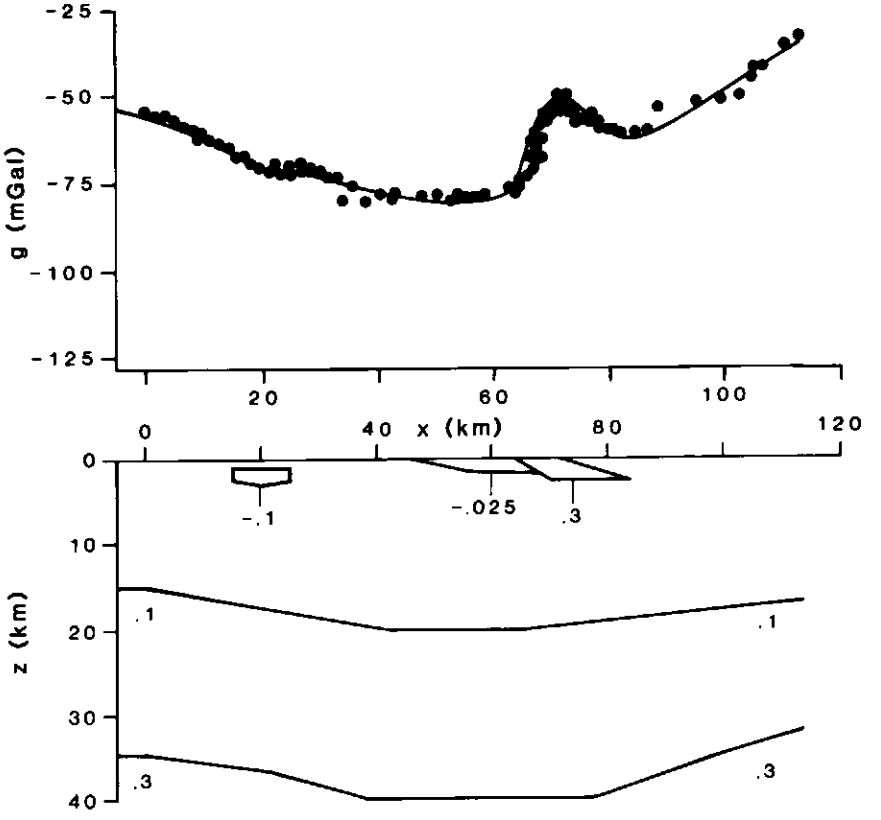

Figure 4 *Tentative density model for the New Québec Orogen. All the long wavelength variations are attributed to changes in crustal thickness. The short wavelength gravity variations are related to the volcanic rocks exposed in the central part of the orogen.*

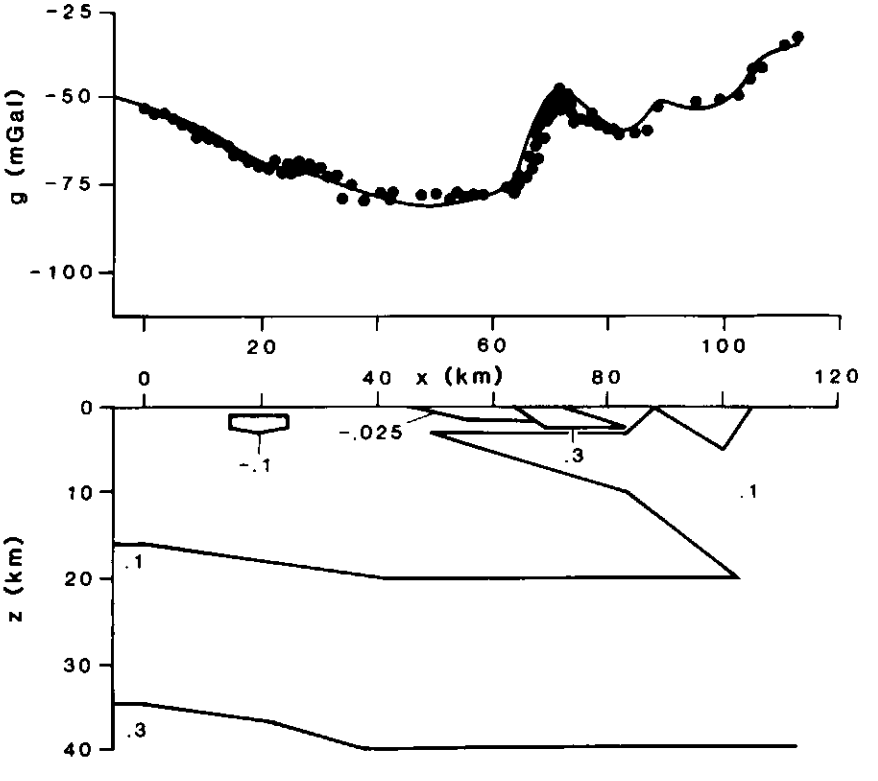

Figure 5 *Preferred density model for the New Québec Orogen. The average crustal density increases eastward; the geometry is compatible with westward overthrusting and obduction of the Rae Province over the Superior Province.*

Also, density measurements on samples collected east of the orogen will reduce the ambiguity remaining in gravity interpretation. Geophysical and geochronometric studies should also be oriented toward the northern part of the De Pas batholith to verify its continuity with the southern segment and a possible relationship with the evolution of NQO.

Acknowledgements

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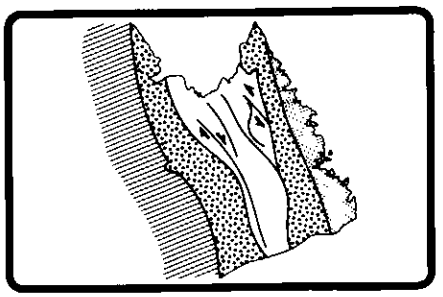

Does the Labrador–Québec border area of the Rae (Churchill) Province preserve vestiges of an Archean history?

Bruce Ryan
Geological Survey Branch
Newfoundland Department of Mines and Energy
P.O. Box 8700
St. John's, Newfoundland A1B 4J6

Summary

This paper presents new data from an area of the Rae (eastern Churchill) Province where migmatite and gabbro-anorthosite complexes are intruded by metamorphosed diabase dykes. The pre-dyke rocks are lithologically comparable to Archean components in the Nain Province and may be correlative with them; the dykes may be equivalents of the Early Proterozoic dyke swarms of the Nain Province. It is proposed that this area comprises Archean crust that has escaped pervasive Early Proterozoic structural overprint, but was affected by the prevailing metamorphism. Preservation of these types of relationships may be more widespread in the Rae Province than presently recognized. Some tectonic implications of the data are discussed.

Introduction

Strain partitioning within deeper levels of orogenic belts is such that "islands" of pre-orogenic rocks escape the imprint of younger tectonism and retain a record of their earlier crustal history (*cf.* Kalsbeek *et al.*, 1988). This paper presents some lithostratigraphic data which suggest that some of the gneisses in the Early Proterozoic-deformed Rae Province of Labrador retain their Archean mesoscopic attributes in spite of the younger tectonism. These suggestions are supported by limited preliminary U-Pb zircon dating in progress (U. Schärer, written communication, 1990).