Problems with plate tectonic models for Baffin Bay – Nares Strait: evidence from the Labrador Sea

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Grant, A. C. 1982. Problems with plate tectonic models for Baffin Bay – Nares Strait: evidence from the Labrador Sea. – In: Dawes, P. R. & Kerr, J. W. (eds), Nares Strait and the drift of Greenland: a conflict in plate tectonics. – Meddr Grønland, Geosci. 8: 313–326.

Plate tectonic models for the geologic development of Baffin Bay require major strike-slip displacement through Nares Strait. However, these models are based mainly upon observations made in other areas, such as the Labrador Sea, the North Atlantic, or the Arctic Ocean. This paper reviews a synthesis of available geological and geophysical data from the Labrador Sea that indicate severe problems with plate tectonic models for that area, which must also affect any such model for Baffin Bay. The Labrador Sea data can be interpreted alternatively in terms of vertical crustal movements. Applied to Baffin Bay, such a mechanism involving vertical rather than lateral crustal displacements accommodates the evidence from field studies in the Nares Strait area that there is geological continuity from Ellesmere Island to Greenland.

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The thesis of this paper is that there are clearly demonstrable problems with plate tectonic models for the Labrador Sea, and that these problems must affect any such model for the geological development of Baffin Bay. Regarding the question of whether Greenland has drifted along Nares Strait, it is only in terms of rigid-plate models that lateral movements are required in Nares Strait. This paper therefore disputes the occurrence of such movements.

This paper is mainly a summary of a recent interpretation of geological and geophysical data from the Labrador Sea that defines specific problems with conventional plate tectonic models for that area (Grant 1980). The conclusions of that study agreed with the then available evidence for geologic continuity across Nares Strait (e.g. Kerr 1967, Dawes 1976, Christie et al. 1978). It is relevant to review that study in the light of the extensive additional evidence for geologic continuity from Ellesmere Island to Greenland that has been presented in this symposium. In addition, exploratory wells off West Greenland, and regional magnetic and gravity maps of the Canadian Arctic Islands and northern Greenland, provide further evidence that is pertinent to the question of displacement along Nares Strait.

Problems with plate tectonic models – regional considerations

The most direct method of demonstrating the reality of problems with plate tectonic-type models for the Baffin Bay – Labrador Sea region (Fig. 1) is to compare some of the models that have been proposed. Grant (1980) assembled a number of pre-drift fits of Greenland relative to Canada (Fig. 2), and divided them into several categories: (1) 'historical' (a, b); (2) fits based on studies of the North Atlantic (c–f); (3) fits based on Arctic Ocean studies (g–i); (4) fits based on studies of Baffin Bay and Greenland (j–m); (5) fits based on studies of the Labrador Sea (n–p). The principal point illustrated by this collection is the great variety in the reconstructions, not only between the categories defined but within them as well. It is clear that the resultant fit depends upon the particular data used, or ignored. For example, each study in categories 4 and 5 has juxtaposed the Tertiary volcanics at Cape Dyer, Baffin Island, with those in the Disko region of West Greenland (Fig. 1). Greenland can be pivoted about this point to close either Baffin Bay, or Labrador Sea, as preferred. Studies centred on the North Atlantic or the Arctic Ocean (categories 2 & 3) arrive at quite different reconstructions (Fig. 2).

In the category labelled 'historical' (Fig. 2a, b), fit b is the well known reconstruction by Bullard et al. (1965). Fit a is by Choubert (1935); it appears to be about as satisfactory as any of the fits in this collection (Fig. 2).

The compilation of reconstructions in Fig. 2 is arbitrary in many respects, and it should not be considered as a criticism of any individual piece of work. The discrepancies among these reconstructions, however, should be recognized as a demonstration of the fact that there are indeed problems with plate tectonic-type models for the Labrador Sea – Baffin Bay region, and that no consensus derives from these studies regarding the geologic history of Nares Strait.

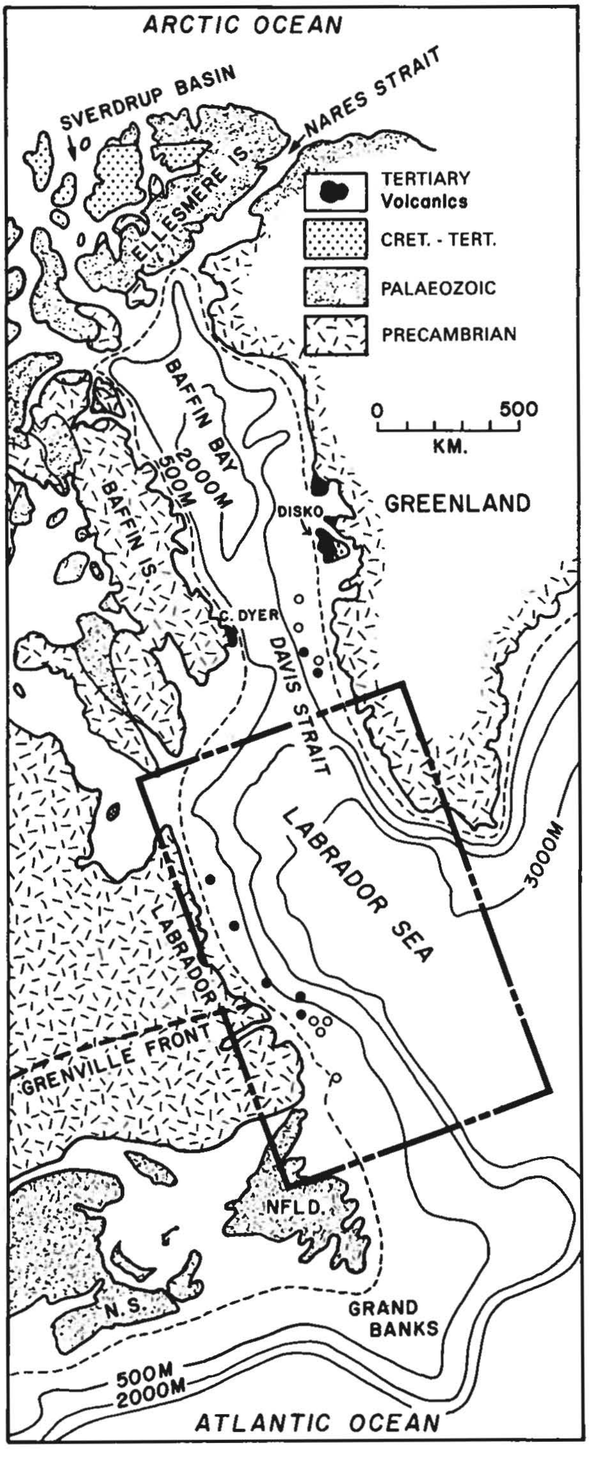

Fig. 1. General geology and bathymetry of the Labrador Sea – Baffin Bay region. The dashed line offshore traces the approximate landward edge of Cretaceous–Tertiary deposits. Circles on shelf mark locations of exploratory wells; filled circles are wells that bottomed in Precambrian rocks. Dashed rectangle shows area of Fig. 3. After Grant (1980).

Specific problems, Labrador Sea

Multichannel seismic data and stratigraphic control from exploratory wells drilled on the Labrador Shelf (Fig. 3) provide evidence of specific problems with plate tectonic models for the Labrador Sea (Grant 1980). The definition of these problems is based upon interpretation of seismic reflectors in two zones of the Labrador margin, as illustrated in Fig. 4. Firstly, a buried erosional surface on the shelf in the depth interval 1 to 2 seconds (2-way time) has been tentatively dated as Late(?) Miocene in age (arrow 1, Fig. 4D), using available seismic and well data. An example of the character of the reflectors expressing this surface is shown in Fig. 5. Mapping this surface shows that it deepens from a minimum depth of about 0.5 km off southern Labrador to more than 2 km off northern Labrador (Fig. 6). This post-Late(?) Miocene differential in subsidence of the shelf from south to north is also evident from drilling results, and in addition, Gradstein & Srivastava (1980) have shown that the rate of subsidence of the Labrador Shelf has been increasing in late Cenozoic time (Fig. 7). This increase in the rate of subsidence, and the differential in subsidence from south to north shown by the Late(?) Miocene erosional surface (Fig. 6), are contrary to the predictions of conventional plate tectonic models for this region. Such models contend that sea-floor spreading ended in the Labrador Sea in Early Oligocene time (e.g. pre-anomaly 13, Srivastava 1978), and therefore the rate of subsidence of the adjacent continental margin should have decreased since then, at a rate proportional to the square root of time (e.g. Sclater et al. 1971). Thus the data compiled in Fig. 7 indicate that the Labrador Shelf has experienced tectonism in late Cenozoic time that is not anticipated or explained by conventional plate tectonic models.

The second point of interpretation concerns the strong, smooth reflector buried deeply beneath the continental slope and rise off northern Labrador (arrow 2, Fig. 4D). An example of the character of this reflector is presented in Fig. 8. Grant (1980) proposed that this reflector represents an erosional unconformity, correlative with the strongly reflective erosional surface that is developed regionally beneath the shelf off southern Labrador (Fig. 4A) and Newfoundland, on rocks ranging in age from early Palaeozoic to Early Cretaceous. This surface on the Grand Banks has been referred to as the Avalon Unconformity (Jansa & Wade 1975), of Early Cretaceous age (Amoco Canada Petroleum Company Ltd & Imperial Oil Ltd 1973). This unconformity is provisionally designated as 'Early Cretaceous' in age off Labrador; a corresponding hiatus occurs in all wells on the Labrador Shelf (Umpleby 1979). This unconformity is downwarped to the north across the zone where the Grenville Front projects seaward beneath the shelf (Fig. 9). South of this zone the unconformity slopes gently seaward (Fig. 4A), but off northern Lab-

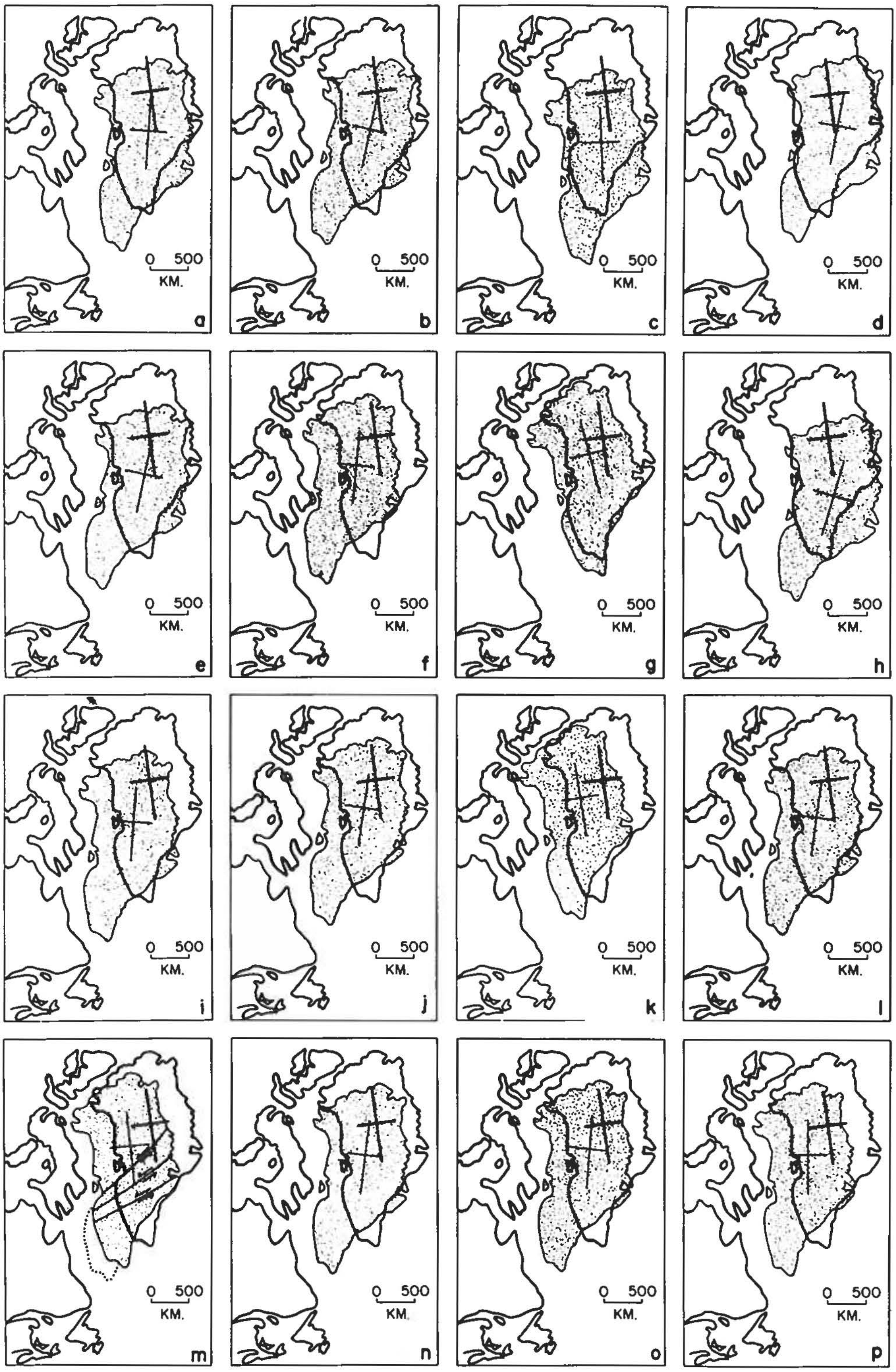

Fig. 2. Pre-drift fits for the Labrador Sea – Baffin Bay region by various authors. a, Choubert (1935) as reviewed by van Houten (1975); b, Bullard et al. (1965); c, Pitman & Talwani (1972); d, Laughton (1972); e, Le Pichon et al. (1977); f, Kristoffersen (1978); g, h, Churkin (1973); i, Harland (1973); j, Keen et al. (1972); k, Martin (1973); l, Bridgwater et al. (1973); m, Beh (1975); n, Le Pichon et al. (1971); o, Hyndman (1973); p, Srivastava (1978). The shaded areas indicate inferred past positions of Greenland; crosses show relative translation and rotation. After Grant (1980).

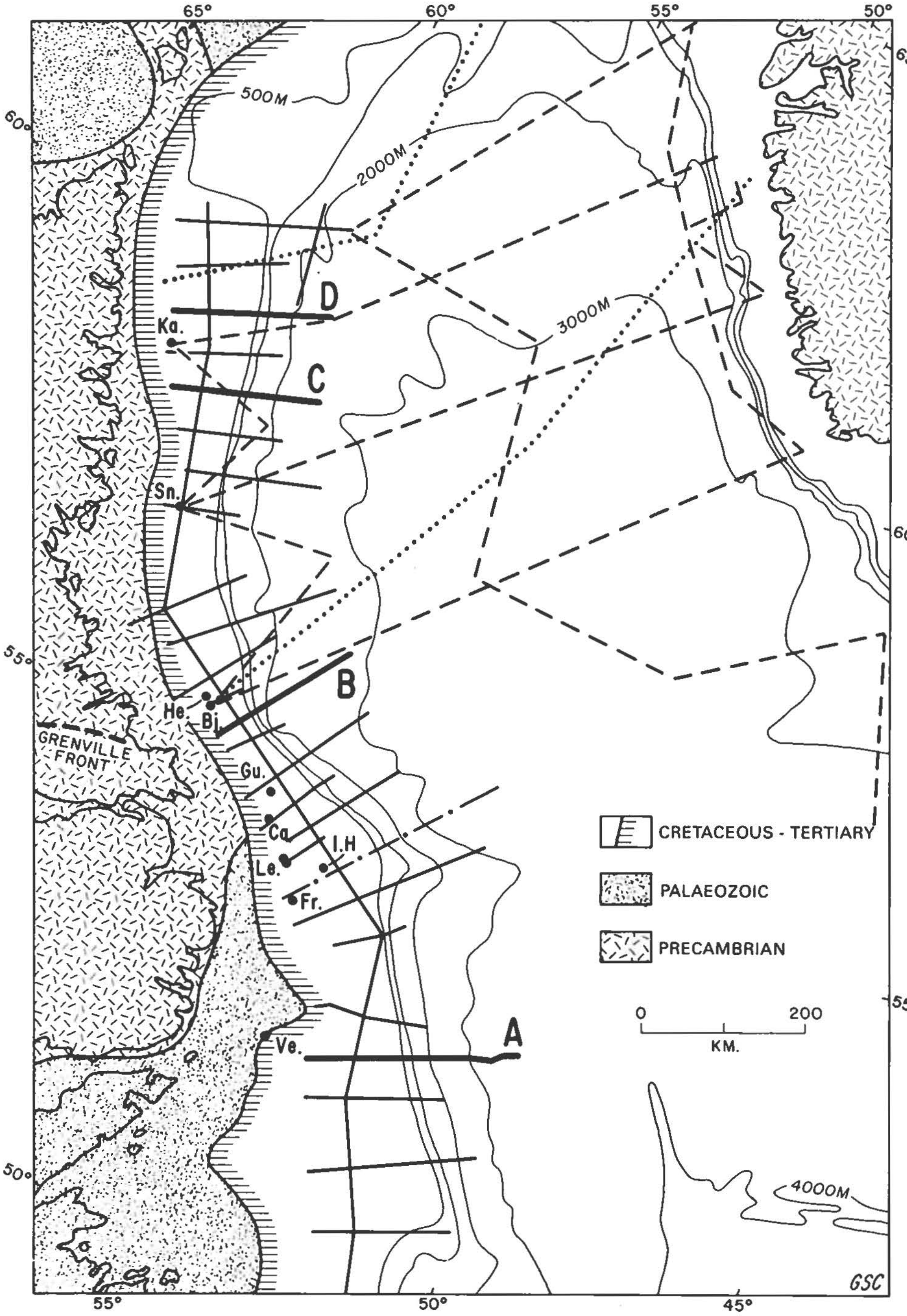

Fig. 3. Geology and bathymetry of the Labrador Sea region, with locations of multichannel seismic lines (solid, Seiscan-Delta; dash-dot, Catalina; dashed, B.G.R.; dotted, C.G.G.) and exploratory wells (Ka, Karlsefni H–13; Sn, Snorri J–90; He, Herjolf M–92; Bj, Bjarni H–81; Gu, Gudrid H–55; Ca, Cartier D–70; Le, Leif M–48 and E–38; I. H., Indian Harbour M–52; Fr, Freydis B–87; Ve, Verrazano L–77). Letters A to D on heavy lines indicate locations of diagrams of seismic profiles in Fig. 4. After Grant (1980).

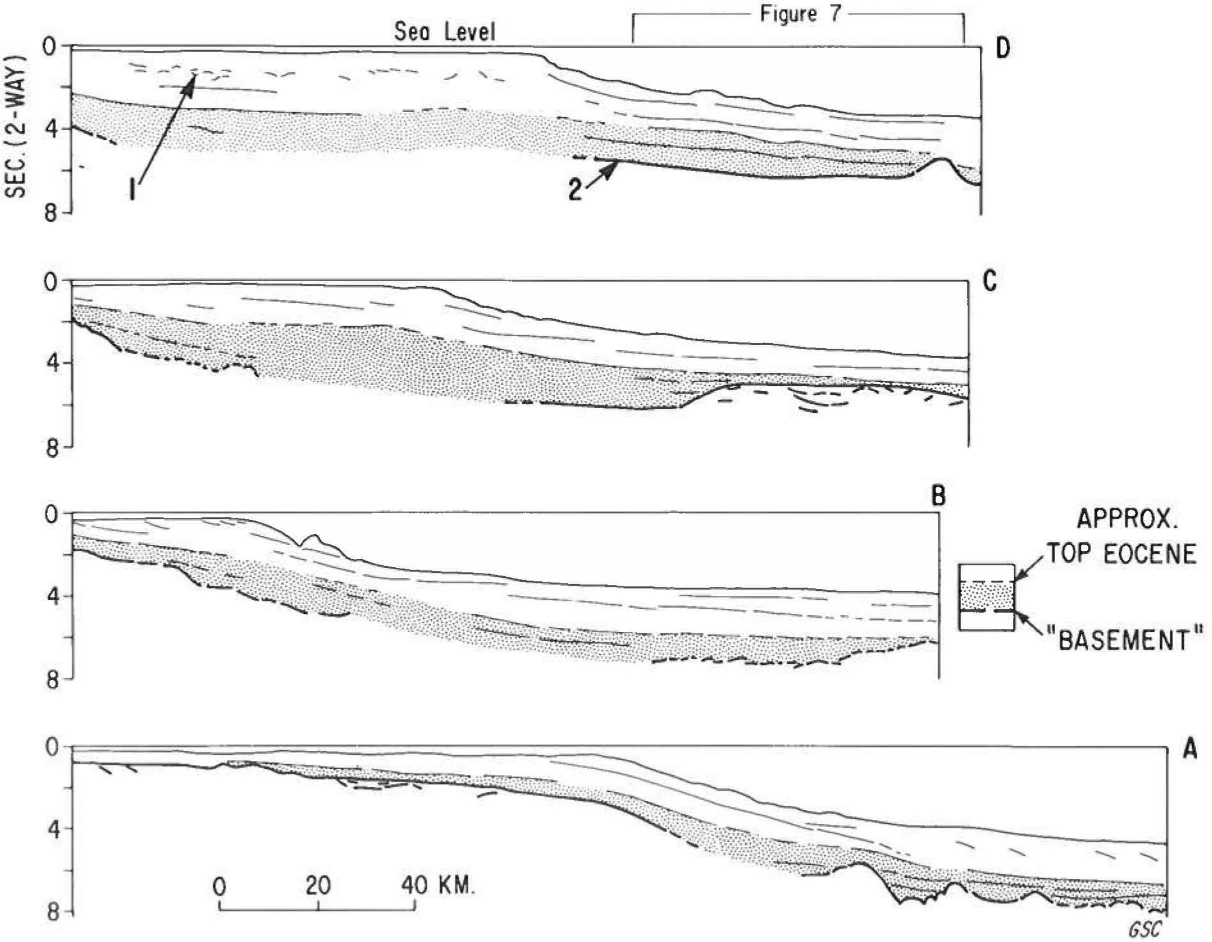

Fig. 4. Diagrams of multichannel seismic profiles of the Labrador margin (locations shown in Fig. 3). The 'basement' reflector is emphasized by a heavy line. Arrows 1 and 2 (profile D) denote points of interpretation discussed in text. After Grant (1980).

rador it is broken by faults and deepens rapidly beneath the inner shelf (Fig. 4B–D). Cretaceous and Early Tertiary sediments on the Labrador Shelf occupy a linear, coast-parallel graben (Cutt & Laving 1977, Umpleby 1979, Miall et al. 1980), dubbed the Erik Graben by N. J. McMillan (pers. comm.). As mapped and described by Cutt & Laving (1977), to the south of the Grenville Front zone this graben is developed in continental basement rocks within the area of the well-preserved Early Cretaceous unconformity (Fig. 9). It can be seen in Fig. 9 that the area mapped as continental crust beneath the slope and rise off northern Labrador is reasonably explained as the downwarped, northward continuation of the continental basement rocks that lie on the seaward side of this graben.

If the reflector mapped beneath the slope and rise off northern Labrador (Fig. 9) indeed represents the 'Early Cretaceous unconformity', then it must be underlain by rocks that are at least 100 m.y. old, and presumably continental in origin. Conflicts of this interpretation with plate tectonic models are indicated in Fig. 9, where magnetic lineations are plotted that have been interpreted (Srivastava 1978) to represent sea-floor spreading-type magnetic anomalies. Anomaly 28, which should represent oceanic crust about 65 m.y. old, lies within the area interpreted to be underlain by continental crust more than 100 m.y. old. This conflict poses questions not only as to whether the magnetic anomalies have been correctly dated, but also whether the magnetic anomalies can be 'true' sea-floor spreading-type anomalies. If the interpretation based on seismic evidence is correct, both these questions must be answered negatively, which prompts examination of linear magnetic anomalies in the Labrador Sea on a more regional scale. This larger question has been touched on by Hinz et al. (1979), who mapped six different types of oceanic basement in the Labrador Sea on the basis of seismic reflection character. The boundaries of these basement zones appear to be independent of the trends and occurrence of linear magnetic anomalies. This indicates that the source of the magnetic anomalies lies deeper than the surface mapped as oceanic base-

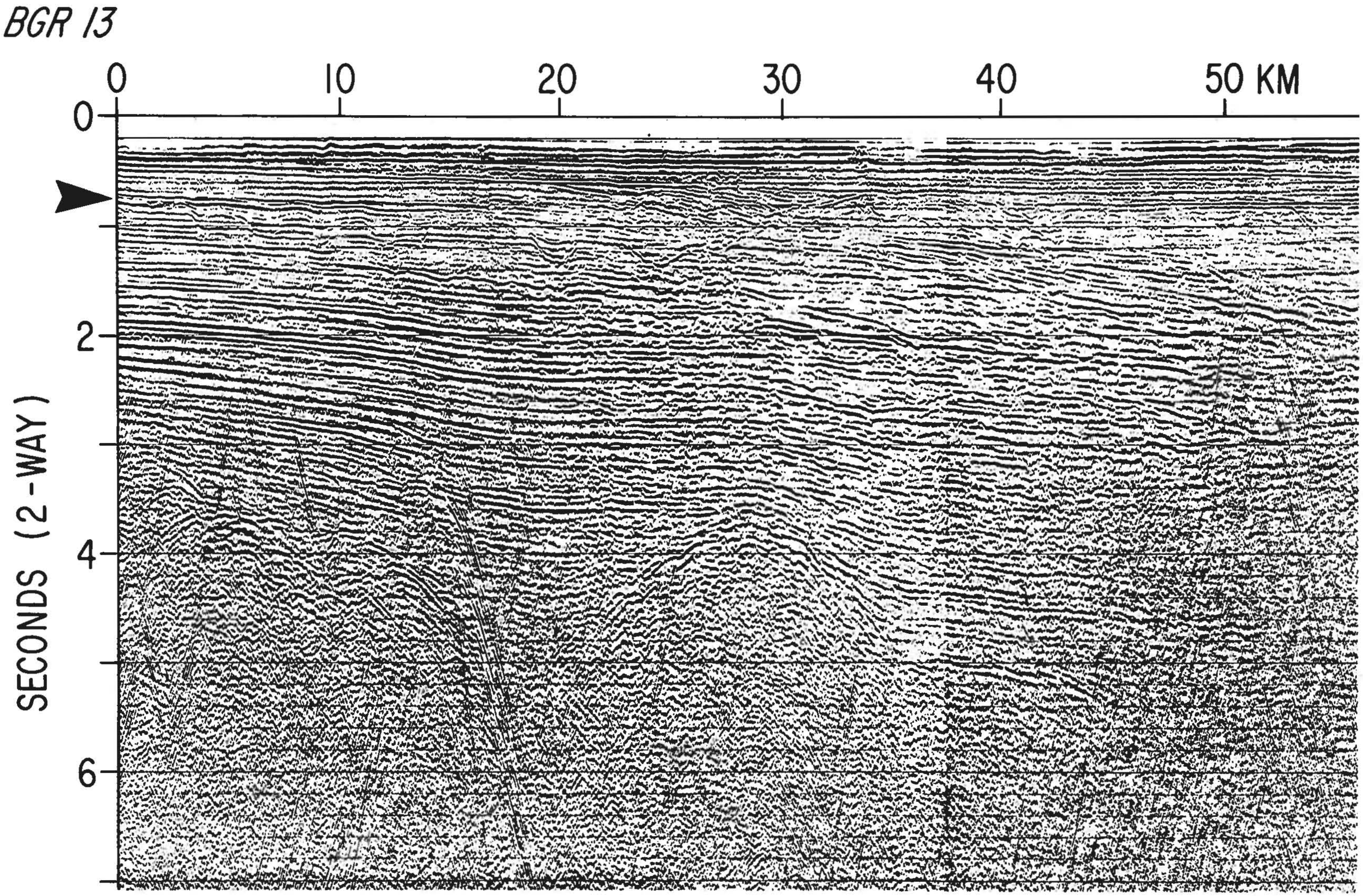

Fig. 5. Photograph of a representative seismic section from the continental shelf off northern Labrador (location shown in Fig. 6), reproduced with permission of the Federal Institute for Geosciences and Natural Resources, Hannover. Arrow indicates level of reflectors interpreted as representing a Late(?) Miocene erosional surface. After Grant (1980).

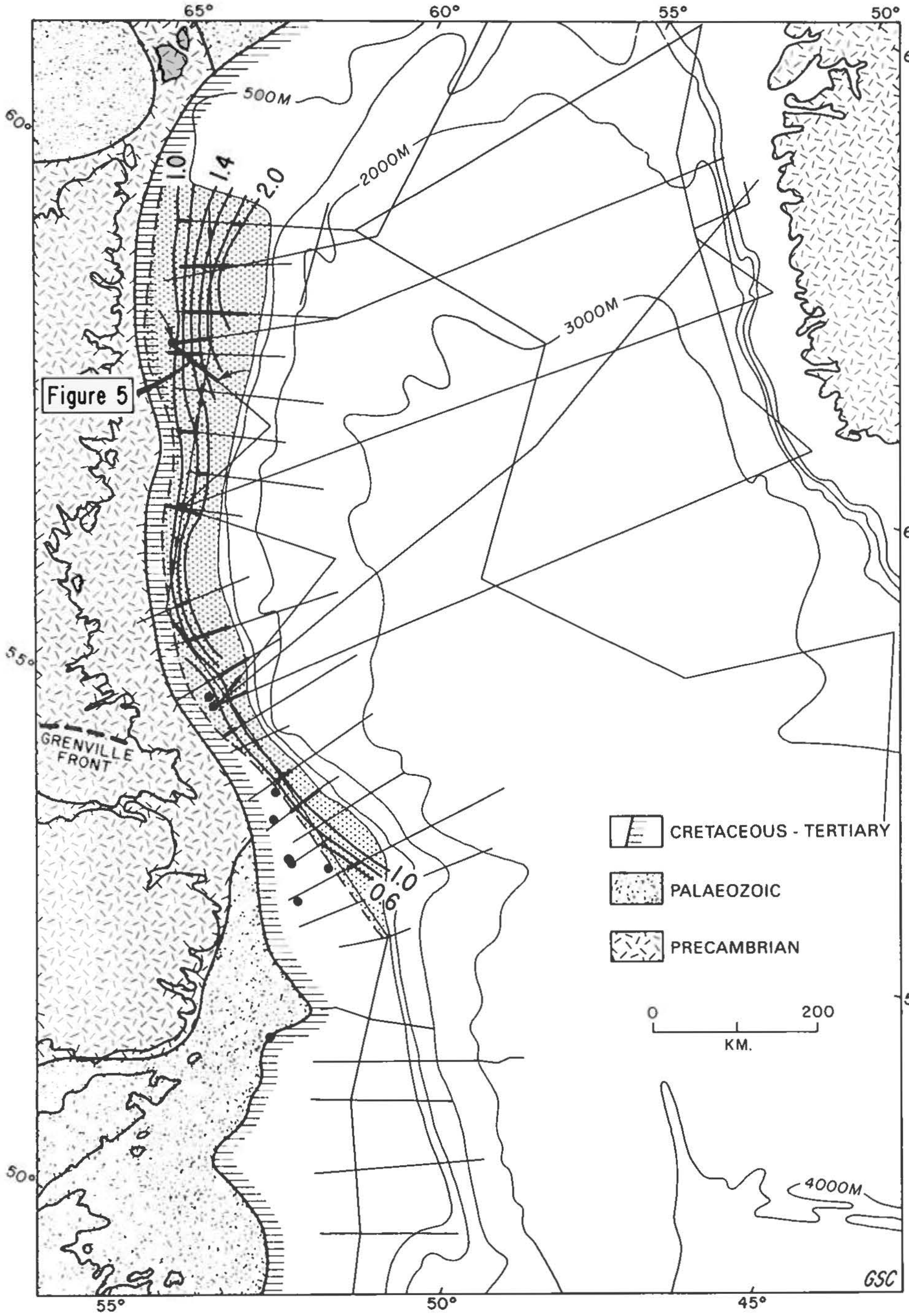

Fig. 6. Generalized bathymetry and geology of the Labrador margin, and lines of multichannel seismic coverage. Stippled area represents the mapped extent of the inferred Late(?) Miocene erosional surface. Heavy parts of the seismic lines show where this surface is represented by an irregular seismic reflector. The contours on this surface (heavy lines) are in seconds of reflection time. Curved arrows mark extent of record section in Fig. 5. After Grant (1980).

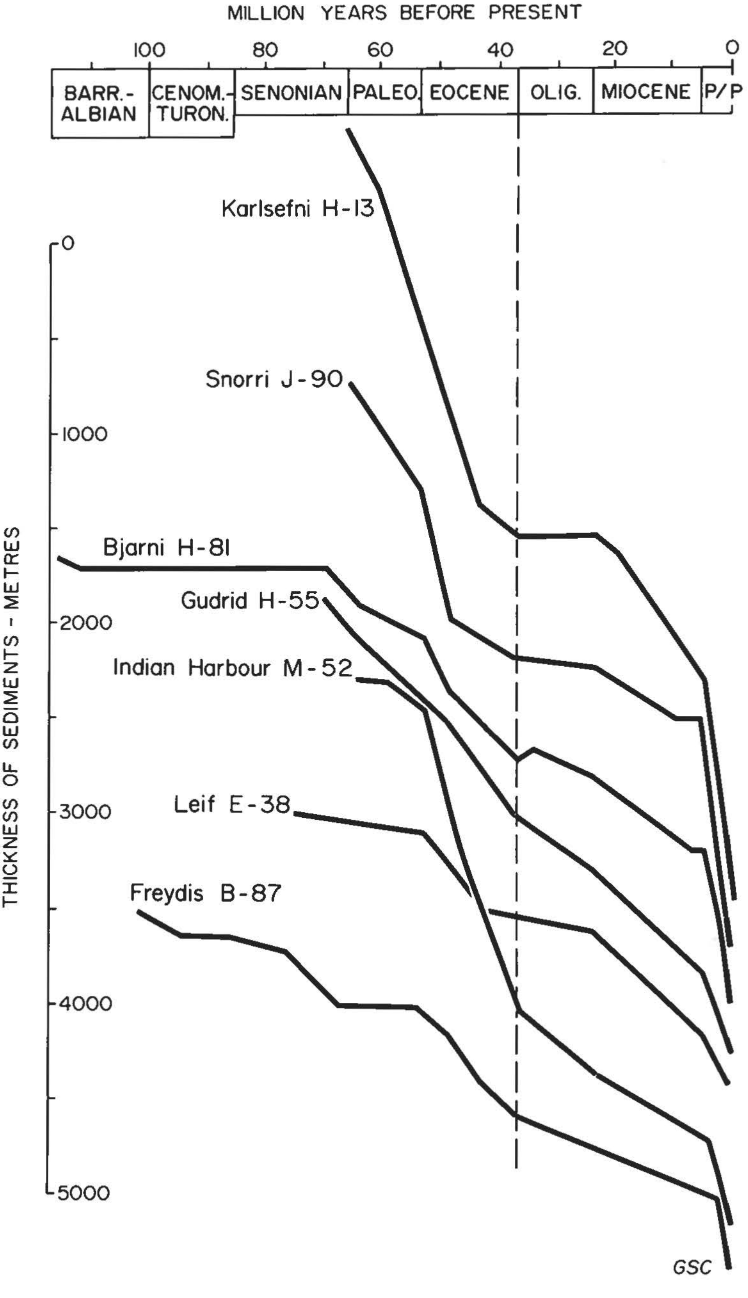

Fig. 7. Curves showing sediment accumulation for wells on the Labrador Shelf (locations in Fig. 3), from data published by Gradstein & Srivastava (1980). After Grant (1980).

ment, and that the formation of oceanic basement and the generation of linear magnetic anomalies are separate processes. It is difficult to reconcile this relationship with a Vine & Matthews (1963) 'tape recorder' mechanism for the formation of oceanic crust. Further, the remarkable parallelism of linear magnetic anomalies and linear gravity anomalies in the Labrador Sea (see Srivastava 1978: fig. 7) suggests that the magnetic anomalies reflect a much more substantial origin than might be expected simply from changes in the polarity of magnetization of the basement rocks. A buried system of linear fractures, which underwent differential vertical displacements and also served as conduits for volcanic extrusion, would be among the simplest sets of conditions sufficient to explain these magnetic and gravity anomalies. Linear fractures, with differential vertical displacements, are well developed in the continental crust beneath the Labrador Shelf; possibly the basalts that have been drilled on the Labrador Shelf (McMillan 1980) were extruded through such fractures.

The work of Hinz et al. (1979) also indicates problems with plate tectonic-type interpretations of other geophysical data from the Labrador Sea. They concluded that the magnetic and gravity criteria of Talwani & Eldholm (1973) cannot be used to define the continent–ocean crustal boundary in the Labrador Sea (see dotted line in Fig. 9). Moreover, they reinterpreted the refraction seismic data of van der Linden (1975), and deduced a different location for the continent–ocean crustal boundary. This fundamental difference between interpretations of refraction measurements is an indication of the equivocal nature of refraction seismic depths and velocities for defining continental versus oceanic crust.

Implications of these problems

The points of interpretation outlined above indicate that plate tectonic models fail to predict or explain the post-Late(?) Miocene subsidence of the Labrador Shelf, or satisfactorily define the location of the continent–ocean crustal boundary in the Labrador Sea. Specific observations in the Labrador Sea indicate that the dating of sea-floor spreading-type magnetic anomalies is in error by 30–40 million years, or that the anomalies were not produced by sea-floor spreading processes as currently visualized. Examination of magnetic and gravity anomalies on a regional scale raises further questions regarding sea-floor spreading processes, to the extent that alternative mechanisms must be considered in examining the origin of the Labrador Sea. An obvious alternative is that the Labrador Sea formed largely as a result of differential vertical crustal displacements; there is ample evidence of such displacements amounting to several kilometres, recorded by the accumulation of Cretaceous and Tertiary sediments on the Labrador Shelf.

The basic problem with plate tectonic models for the Labrador Sea thus concerns the inferred mechanisms of such models, which derive from assumed relationships of observed physical properties of the crust to crustal origin. In the Labrador Sea there is a proven inability of currently 'standard' geophysical measurements to distinguish continental from oceanic crust; as outlined above, specified velocities and depths to mantle, and the occurrence of linear magnetic anomalies apparently are not sufficient criteria to make this distinction.

If the geologic history of Baffin Bay is linked to that of Labrador Sea, as implied by rigid-plate models, the efficacy of sea-floor spreading-type processes in Baffin Bay must also be questioned. Formation of Baffin Bay by vertical rather than lateral crustal displacements agrees with the evidence for stratigraphic and structural continuity across Nares Strait.

Evidence from the Baffin Bay – Nares Strait region

The northernmost exploratory wells in the Labrador Sea – Baffin Bay seaway are located on the continental shelf off West Greenland, in Davis Strait (Fig. 1). Two of these exploratory wells bottomed in Precambrian basement (Geological Survey of Greenland 1979), which proved that continental crust in these places extends to the shelf edge, and clearly precludes some of the close fits in Davis Strait indicated in Fig. 2. This geologic evidence must be recognized as an additional constraint in attempting plate tectonic-type reconstructions for this region, and in the context of this symposium it can be viewed as supporting the case for geologic continuity across Nares Strait.

Much of this symposium is concerned with new geological observations from the vicinity of Nares Strait; relatively little has been added to the broad geophysical picture of the Baffin Bay region that has existed for some years. Marine geophysical data generally have been interpreted as evidence that Baffin Bay is a small ocean basin formed by sea-floor spreading processes (e.g. Keen et al. 1974). The time of opening of Baffin Bay usually is inferred by extrapolation from the Labrador Sea, as it is difficult to define and identify magnetic lineations in Baffin Bay. Jackson et al. (1979) mapped linear magnetic anomalies in an area of detailed surveying in central Baffin Bay, and concluded that these anomalies were formed by sea-floor spreading processes. They also report a prominent, linear gravity low extending through the survey area parallel to the magnetic lineations. This is the same relationship between gravity and magnetic anomalies that has been noted in the Labrador Sea. Thus the available data suggest that the same problems outlined for the Labrador Sea regarding the validity of traditional geophysical criteria in defining continental versus oceanic crust may also pertain to Baffin Bay, although much additional geophysical and stratigraphic control is required in Baffin Bay to test for these problems more closely.

Magnetic and gravity data from the Canadian Arctic Islands and northern Greenland may relate more directly to the Nares Strait 'question' than available geophysical observations in Baffin Bay. The regional magnetic and gravity data presented in Figs 10 and 11 are generalized after Coles et al. (1976) and Sobczak (1978) respectively. Despite the drastic generalization, these two maps show trends, and lack of trends, that may bear upon the question of whether strike-slip displacement has occurred along Nares Strait.

The major trends in the magnetic field (Fig. 10) are traced by the boundaries of Magnetic Regions drawn by Coles et al. (1976). The southern boundary of their Magnetic Region IV cuts obliquely across the Nares Strait lineament. South of this boundary several linear positive anomalies trend across Nares Strait. Thus the

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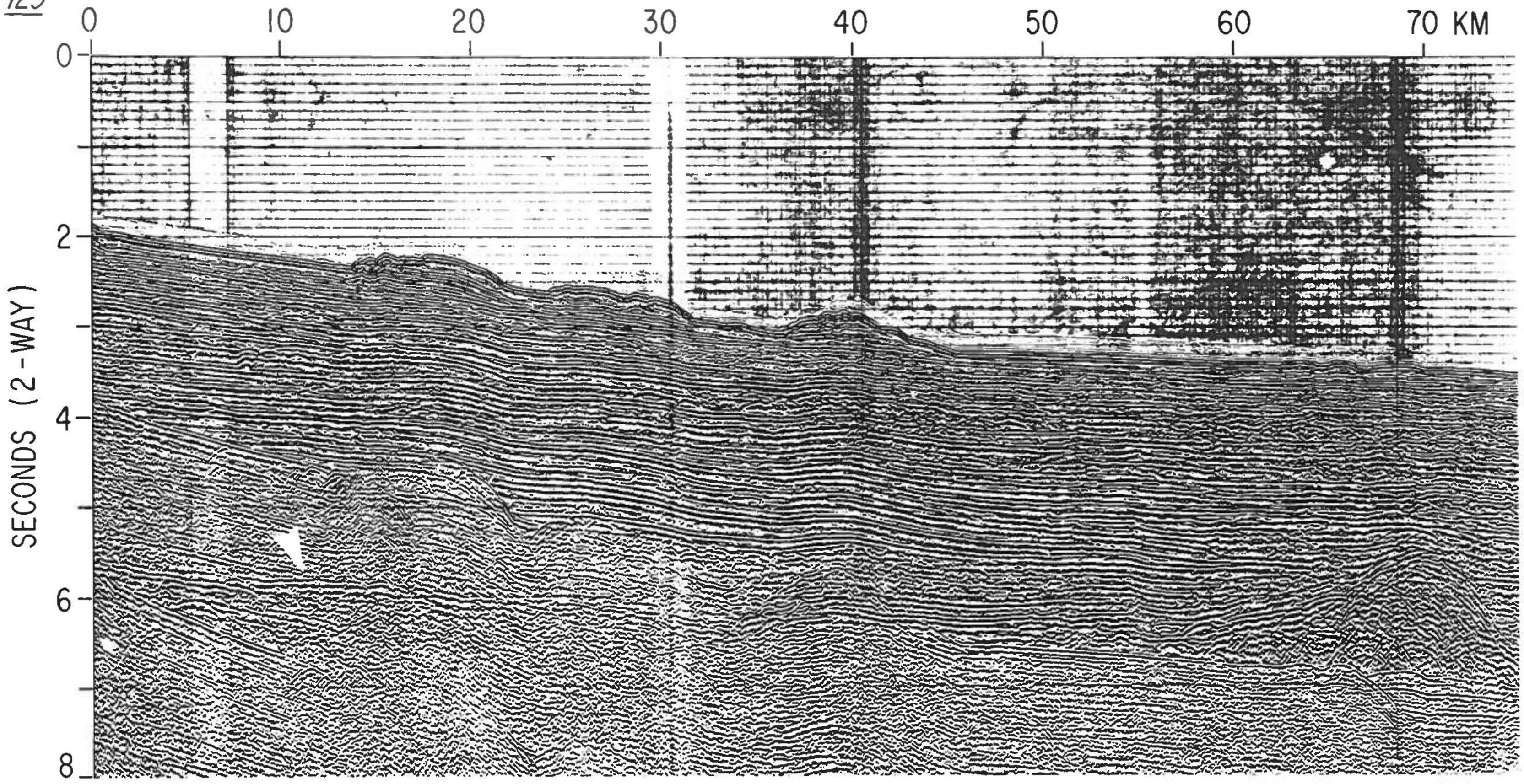

Fig. 8. Photograph of a representative seismic record section from the continental slope off northern Labrador (location shown in Fig. 9), reproduced with permission of Seiscan Delta Ltd., Calgary. Arrow indicates the reflector interpreted to represent the 'Early Cretaceous unconformity'. After Grant (1980).

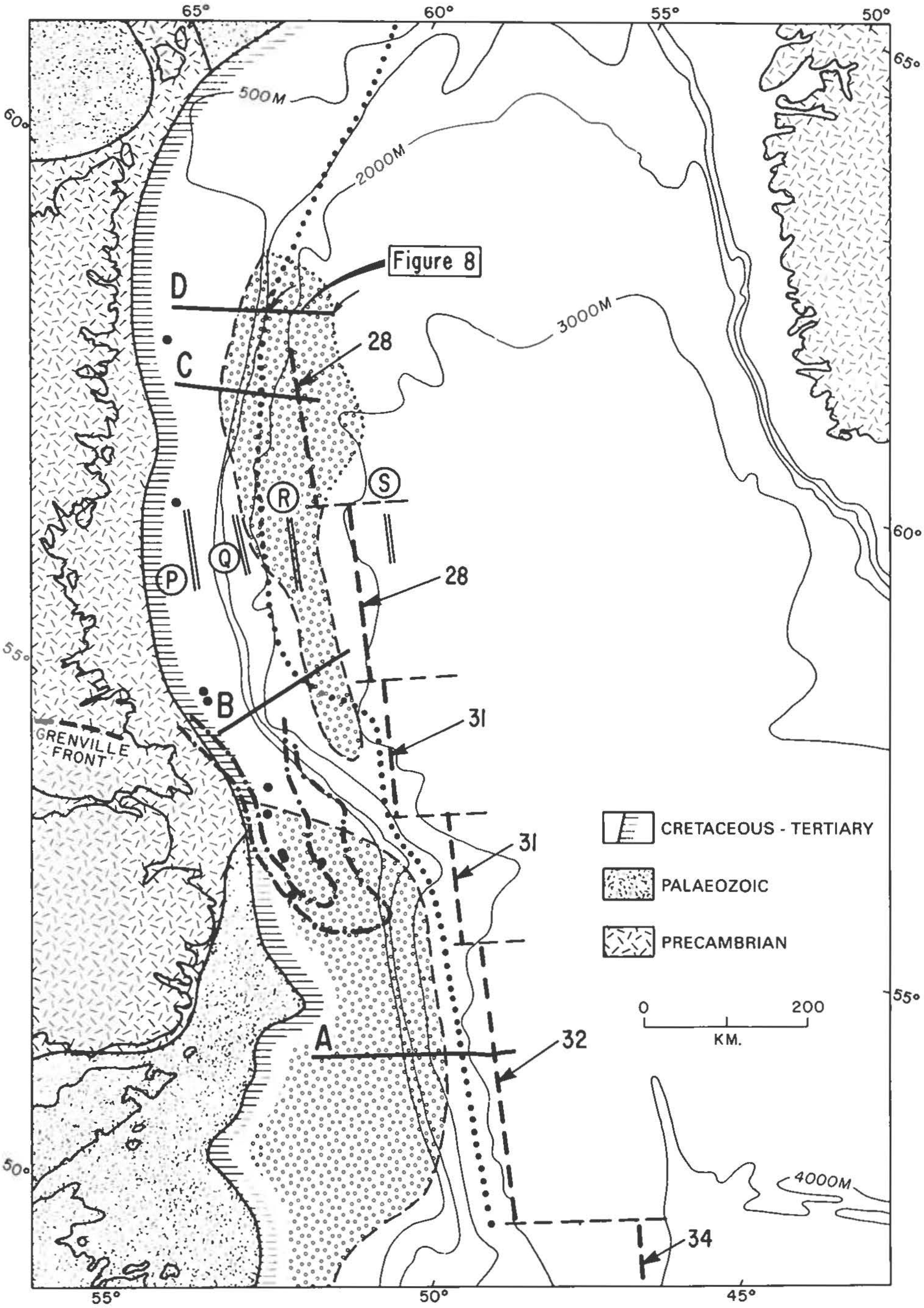

Fig. 9. Generalized bathymetry and geology of the Labrador margin. Shading (circle pattern) indicates inferred minimum extent of smooth basement reflector interpreted to represent an Early Cretaceous unconformity. Double lines labelled P to S (circled) locate refraction seismic profiles (van der Linden 1975). Letters A to D denote locations of seismic profiles in Fig. 4. Dash-dot lines on the shelf represent the extent of Early Cretaceous (inner line) and Paleocene (outer line) sediments (after Cutt & Laving 1977). Numbered dashed lines (28 to 34) represent magnetic anomalies, and the dotted line is the continent–ocean boundary, according to Srivastava (1978). Curved arrows mark extent of record section in Fig. 8. After Grant (1980).

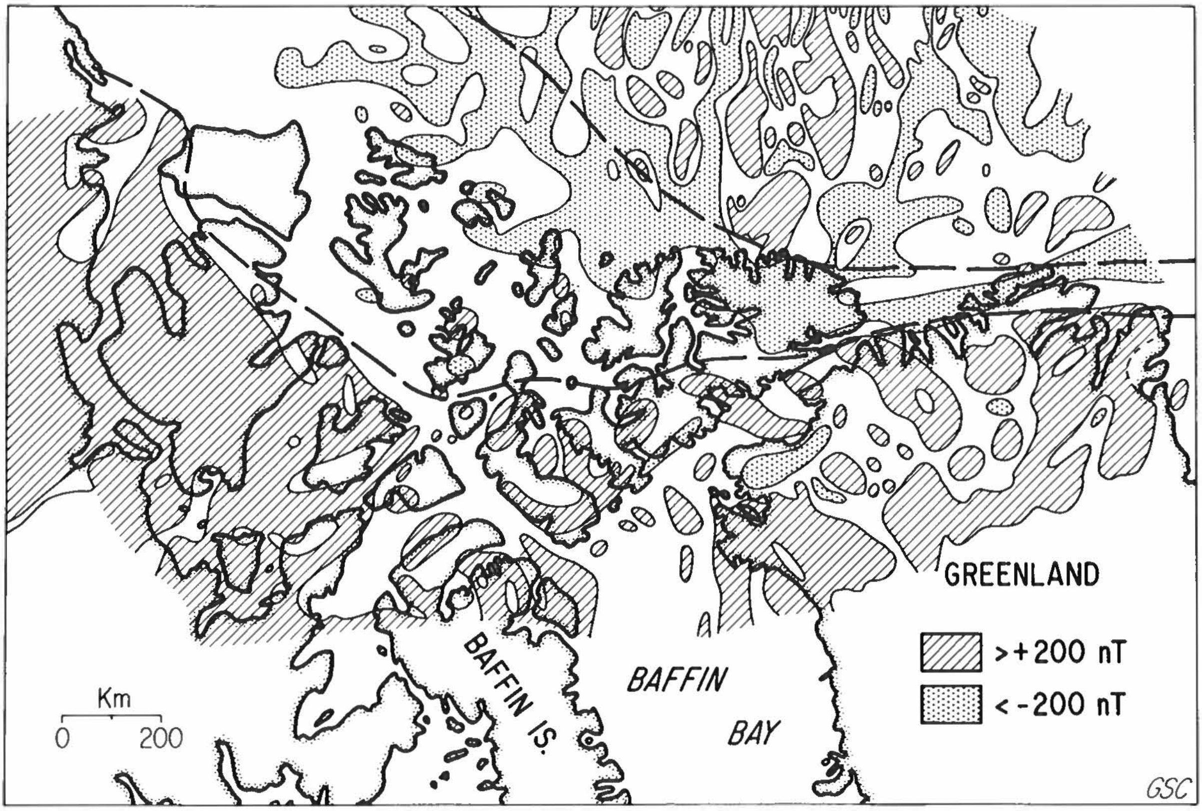

Fig. 10. Vertical component magnetic field residuals, relative to the IGRF. After Coles et al. (1976). Heavy dashed lines are boundaries of magnetic regions defined by these authors.

trends indicated by the magnetic data in Fig. 10 are strong geophysical evidence against displacement in Nares Strait.

The gravity map (Fig. 11) does not show any pronounced trends in the Nares Strait area. This lack of gravity expression can be viewed as an indication that no major crustal disturbance has occurred in the Nares Strait zone, in particular of the subduction type that is required by some of the reconstructions presented in Fig. 2 (e.g. fits a–e, h, i, n).

Conclusions

Discrepancies among plate tectonic-type models for the Labrador Sea – Baffin Bay region indicate that such models do not yield a unique solution to the Nares Strait 'problem'. In the Labrador Sea specific difficulties can be defined with both the predictions and the mechanisms of plate tectonic models, that raise substantial questions concerning the extent to which the Labrador Sea is primarily the product of sea-floor spreading processes. In any 'rigid-plate' scheme these same problems must extend to Baffin Bay, where they may be viewed as a corollary to the geologic arguments for continuity across Nares Strait.

The basic problem with plate tectonic models for this region lies in the ambiguous nature of geophysical data for defining continental versus oceanic crust; available data in the Labrador Sea document the possibility that 'geophysical' oceanic crust may have formed there by processes other than sea-floor spreading. While this may be a condition unique to the Labrador Sea, probably it is worth testing whether geophysical measurements are necessarily more definitive elsewhere. The outstanding requirement at this time is therefore to devise new or refined geophysical measurements of crustal properties that may be more definitive of crustal origin.

Acknowledgements

I thank A. E. Jackson for assistance in compiling data, G. M. Grant and G. L. Cook for preparing illustrations, C. F. M. Lewis, B. D. Loncarevic and R. F. Macnab for reviewing the manuscript. N. J. McMillan has provided much valued comment, but he is not to be blamed for the conclusions of this paper. The Bulletin of Canadian Petroleum Geology granted permission to use Figs 1–9.

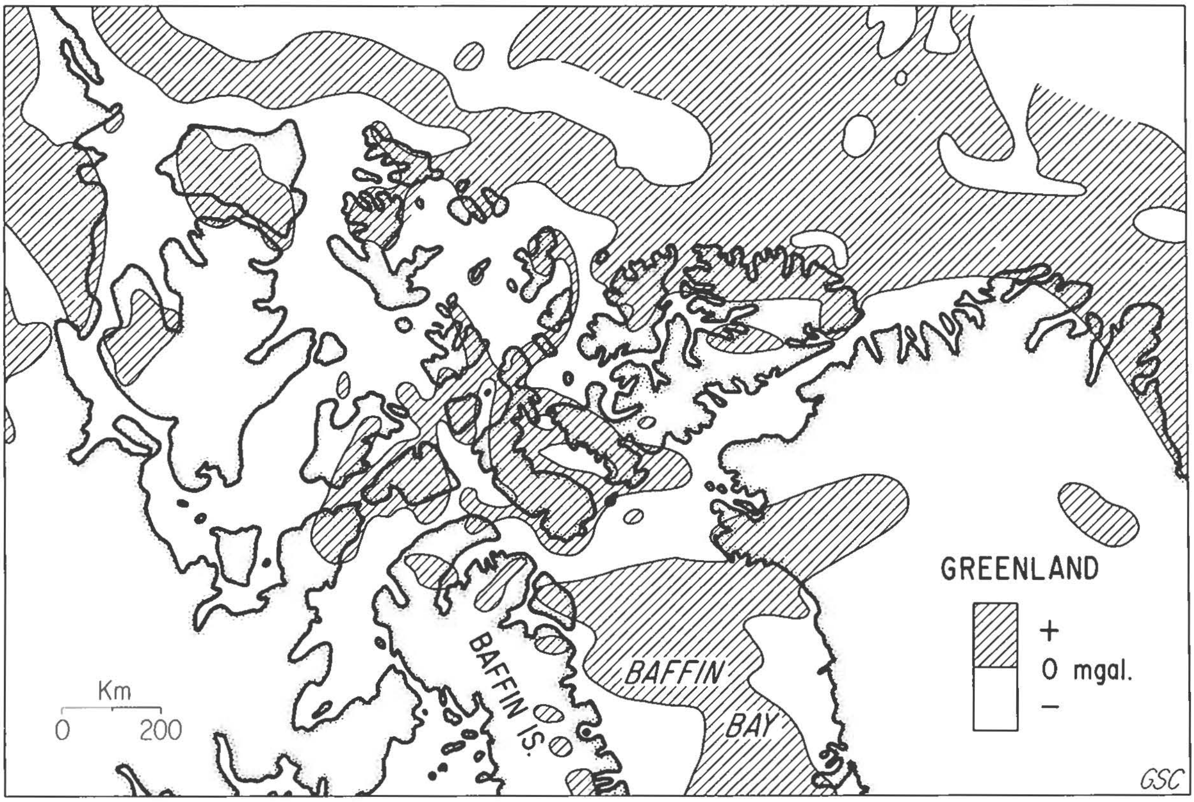

Fig. 11. Free air gravity (Observed/Predicted Field), after Sobczak (1978).

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