Review of seismicity and other geophysical data near Nares Strait

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Nares Strait is aseismic even to small magnitude levels, in contrast to nearby active areas in Baffin Bay, the Lincoln Sea and the Sverdrup Basin. Activity immediately to the south of the Strait is infrequent and minor. The nature of Lg propagation suggests a discontinuity in the continental crust at the southern terminus of Nares Strait while seismicity in the Lincoln Sea seems most logically related to an extension of the activity in the Sverdrup Basin.

Intense seismic activity in Baffin Bay appears to be confined south of latitude 75°N. Focal mechanisms for recent earthquakes in Baffin Bay and north of Greenland do not support the hypothesis of large left-lateral displacements along Nares Strait.

Free air gravity anomalies indicate that some of the seismicity of northern Baffin Bay and Baffin Island may be related to glacial rebound or uncompensated sedimentary loads acting on zones of weakness. The aseismic nature of Nares Strait under the action of stresses due to local glacial unloading or regional north–south compression argues against the presence of a relatively young shear zone of major crustal or lithospheric dimension.

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Two basic premises of plate reconstructions of Greenland and North America are that a major structural zone exists along Nares Strait and that this zone has resulted from or enabled relative movement between Greenland and Baffin Island. The timing of this motion is considered to be mainly post-Late Cretaceous. A corollary to these assumptions is that since the motion involves intermediate size continental plates, the resulting structures must be significant discontinuities in the crust and lithosphere.

Small magnitude seismicity in the Nares Strait region has been monitored since the mid-1960s by the Canadian Seismograph Network. The relationships between seismicity, geology, gravity and glacial rebound information are considered here to see if they support the hypothesis of such a significant structural zone.

Seismicity data

The seismicity data for the Nares Strait region shown in Fig. 1 are taken from the Earth Physics Branch's Earthquake Data files which contain information on all known earthquakes in or near the Canadian Arctic. The events plotted occurred in the interval from 1933 to December 1979. The map is divided into two time periods at 1960, because significant improvements in the earthquake coverage took place in the 1960s with the expansion of the Canadian Seismograph Network in northern Canada. Prior to the 1960s little information is available on earthquakes with magnitude less than 5.0 and epicentres must be considered generally uncertain by 100–300 km (Leblanc & Wetmiller 1974). However, by the late 1960s earthquakes with magnitudes as low as 3.7 are almost completely detected and the epicentre uncertainties are reduced to less than 50 km in general (Basham et al. 1977). This amount of uncertainty still precludes a correlation of earthquakes with specific geological features but it does allow a correlation of seismic activity with geological provinces and thereby sheds some light on current tectonic processes. It should be noted, however, that almost no information is available on the focal depth of the earthquake activity which is generally thought to be occurring at shallow depths in the crust (Hashizume 1973, Qamar 1974, Basham et al. 1977) but it may extend to depths of 65 km (Stein et al. 1979).

The earthquake history of the region prior to 1960 is characterized by a few large poorly located events. None are in Nares Strait. The largest and first is a M 7 1/4 event in November, 1933. This is the largest earthquake in northern Canada, one of the largest anywhere in the Arctic and obvious evidence of significant tec-

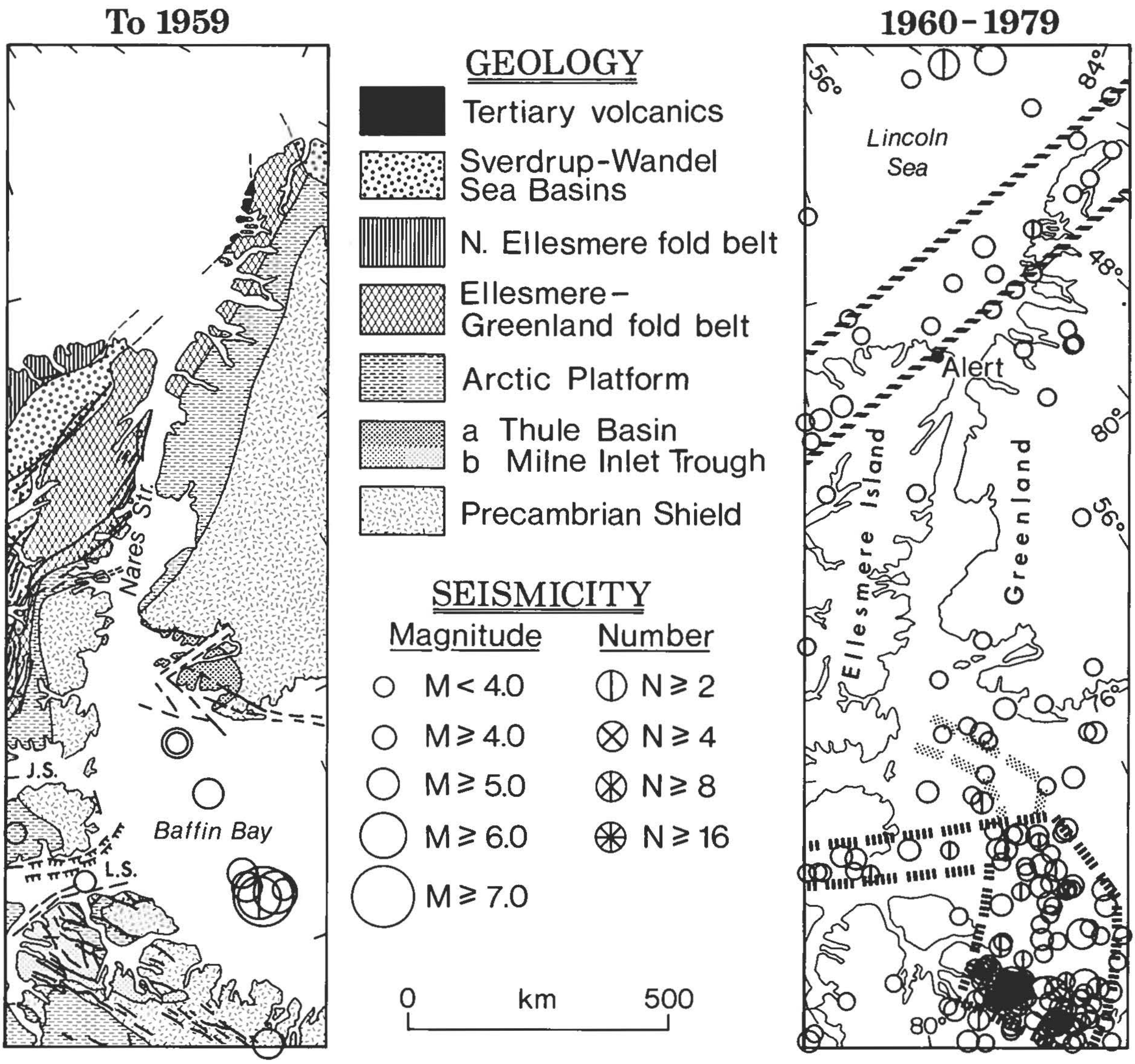


Fig. 1. Seismicity of the Nares Strait region prior to 1960 and since 1960. Geology after Kerr (1967) and Dawes & Soper (1973). Hashed lines on right figure indicate anomalous zones distinguished by epicentre trends or interrupted Lg propagation. L. S. – Lancaster Sound; J. S. – Jones Sound.

tonic activity in northern Baffin Bay within a few hundred kilometres of Nares Strait. Stein et al. (1979) consider this event to be the result of glacial rebound in a coastal area acting on pre-existing faults at a depth of 65 km. The pre-existing faults are thought to be those of the rift system which allowed the separation of Baffin Island and Greenland via the opening of Baffin Bay. The linear trend of epicentres down central Baffin Bay for the period prior to 1960 (only the northern half of that trend of epicentres is visible in Fig. 1) has been taken as evidence by some researchers (Qamar 1974, Barrett et al. 1971) of the central ridge of the rift zone. However, the large uncertainties in location that must be assigned to the events in this period do not allow the central linear trend to be defined with any real confidence. A strong central trend is not apparent in the more recent and better located data.

The aseismic nature of the area since 1960 indicates an apparent absence of significant dynamic processes along Nares Strait. However, the possibility exists that we could be witnessing a quiescent period in a non-stationary record of seismicity. While the record is too short to distinguish this possibility, it should be noted that such quiescence indicates the area is void of events with magnitudes greater than about 3.7. Seismic activity is concentrated however in northern Baffin Bay, near the epicentre of the M 7 1/4 event, and on adjacent Baffin Island. Fig. 1 shows that the earthquake trend in

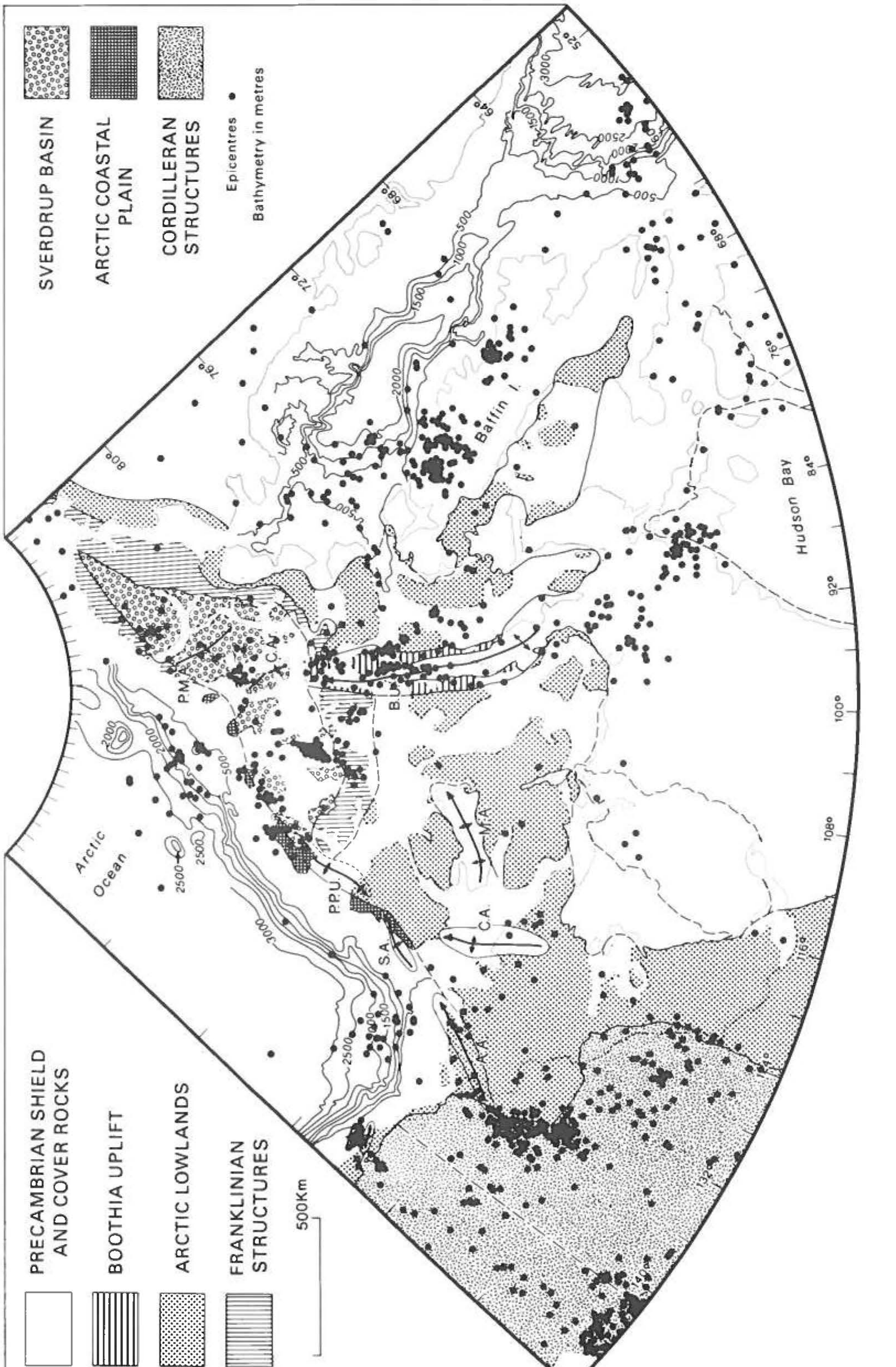


Fig. 2. Recent seismicity and geological structures of the Canadian Arctic and adjacent northern Greenland (after Basham et al. 1977). B.U. – Boothia Uplift; P.M.A. – Princess Margaret Arch; C. Ar. – Cornwall Arch; P. P. U. – Prince Patrick Uplift; S. A. – Storkerson Arch; A. A. – Aklavik Arch; C. A. – Coppermine Arch; M. A. – Minto Arch.

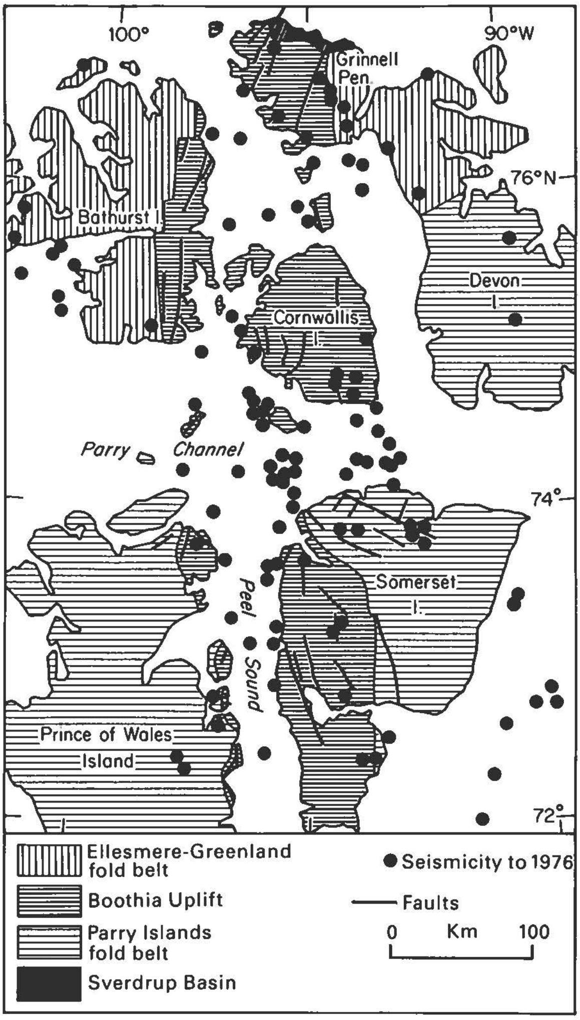


Fig. 3. Seismicity and structural trends of the Cornwallis Fold Belt – Boothia Uplift. Geology after Kerr (1977).

northern Baffin Bay may be cut off by another trend along Lancaster Sound. This trend is only poorly defined by the recent data showing a weak alignment of epicentres parallel to the Sound and a subtle change in the character of the seismic activity in Baffin Bay in line with the Sound. North of Lancaster Sound recent seismic activity is generally less frequent and of smaller magnitude.

Recent seismic activity is scattered elsewhere in the map area without any definite trends except for the possible linear zone of epicentres along the Arctic coast of Greenland and Ellesmere Island in Fig. 1.

The lack of seismic activity along Nares Strait is more remarkable when the extent of seismic activity and relationships to geological structures elsewhere in northern Canada are considered. Fig. 2 shows the recent seismicity in northern Canada superimposed on the geological provinces. Many features such as the Boothia Uplift (Fig. 3) and the structures of the central Sverdrup Basin (Fig. 4), that have geologically demonstrated tectonic activity from the Palaeozoic to the Cretaceous, have contemporary seismic activity associated with them (Forsyth et al. 1979). Thus the lack of seismic activity along Nares Strait, a feature that plate reconstruction theories require to have been active contemporary with and more recently than these other Arctic features, indicates that it is certainly not the present site of any significant dynamic tectonism and casts considerable doubt on the presence of a large crustal or lithospheric rift zone.

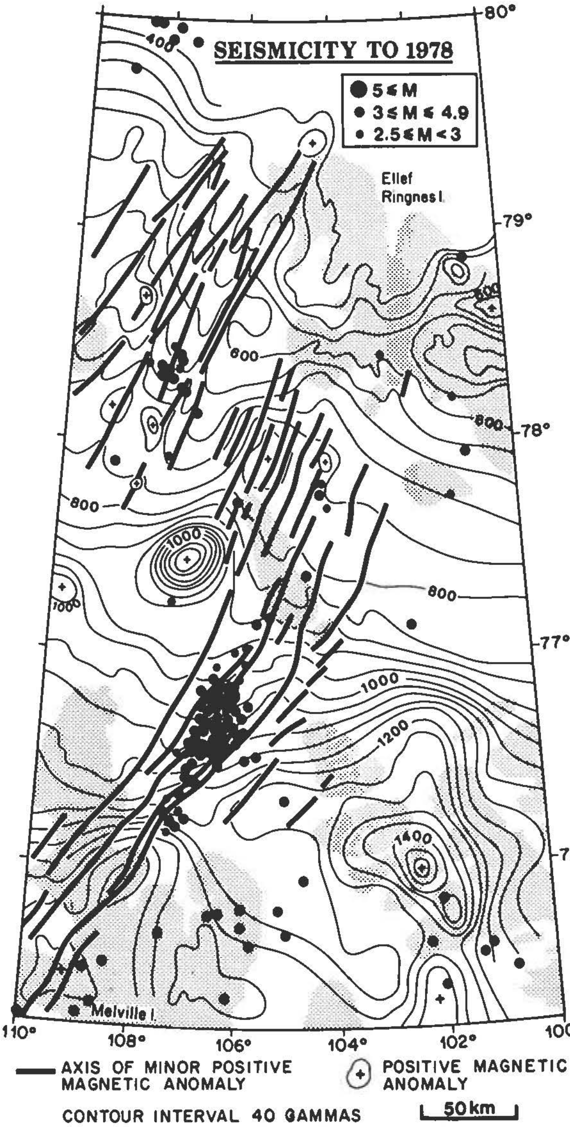


Fig. 4. Seismicity and structural trends of the central Sverdrup Basin.

Lg propagation data

Although Nares Strait has been shown to be aseismic in recent years, at least down to the magnitude 4.0 level, earthquakes in the surrounding areas shed some light on the nature of the crust in the Strait and the possible existence there of any major shear zones. The local earthquake phase, Lg, is sensitive to the gross properties of the Earth's crust (Knopoff et al. 1974) and will not propagate through oceanic crust. This fact has been used to identify areas of oceanic crust in the Arctic (Oliver et al. 1955, Wetmiller 1974) on a regional scale. If there has been large-scale relative motion of crustal plates along Nares Strait, then there should be a discontinuity in the crustal structure along the Strait that could cause a change in any Lg phase that crosses it.

The better data are from recent earthquakes in northern Baffin Bay (Table 1) for which the Lg phase propagates north along the length of Nares Strait to the Canadian seismograph station at Alert on the northern coast of Ellesmere Island (Fig. 1). Fig. 5 shows the distribution of the available data. The Alert seismogram for the May 28, 1972 earthquake is a typical example of the propagation of Lg along Nares Strait. The Lg phase is well developed and indicates that the propagation path from northern Baffin Bay to Alert across Nares Strait is composed of normal continental crust with no major discontinuities. The wavelength of the Lg phase in this case is not more than a few km so that any major break in the gross crustal parameters of more than a few wavelengths (i.e. 10 km) anywhere along the propagation path should result in changes in the Lg phase on the Alert seismogram.

A major break of the crust is apparent in northern Baffin Bay. Fig. 5 shows the evidence for this feature. The Lg phase of any earthquake that crosses the break zone in Fig. 5 is strongly attenuated. The seismograms shown in Fig. 5 are uncorrected for individual station gain, earthquake magnitude or epicentral distance. The best indication of the relative attenuation of the Lg phase in this case is the ratio of the maximum amplitudes on each record of the Lg phase to that of the Sn phase. For propagation in continental areas, the amplitudes of the Lg phase are typically much greater than those of the Sn phase since the energy in the Sn phase travels beneath the crust and is relatively independent of changes in the crustal character. The Resolute record of the May 28, 1972 event is a typical example of the propagation of the Lg phase across the break zone in northern Baffin Bay. In contrast to the Alert record of this event discussed previously, the Resolute record shows that the Lg phase is clearly attenuated; the maximum amplitude of Lg is much smaller than that of Sn. Evidence for this break in the continental crust in northern Baffin Bay was first presented by Wetmiller (1974).

Table 1. Earthquakes used for Lg propagation study of Nares Strait.

Date	Time GMT	Magnitude	Epicentre °N	°W
07 Feb. 1966	00:^{h}14^m:01^s	4.2	75.42	77.00
10 Aug. 1966	23:17:50	4.3	75.00	73.67
07 Sep. 1966	18:02:44	4.7	75.50	65.00
02 June 1971	20:47:49	4.6	74.92	67.56
14 May 1972	14:19:48	4.1	75.07	74.15
28 May 1972	23:08:03	4.2	76.16	72.30
20 Dec. 1978	16:23:58	4.0	76.44	70.16

The existence of the break zone suggests the presence of a significant anomaly in the crustal structure of northern Baffin Bay at the southern end of Nares Strait. The northwest trend of the zone does not support a feature simply continuous with Nares Strait. The break zone is not a seismically active feature; Fig. 5 shows that the earthquake activity in northern Baffin Bay does not seem to be localized on the zone. To the south (in line with Lancaster Sound) the zone merges with the area of high seismicity identified previously. Wetmiller (1974) suggests that the break zone does not continue into the active seismic zone south of Lancaster Sound and does not join the area of oceanic crust in the deep central part of Baffin Bay.

Here again, Lancaster Sound appears to play a fundamental role in the distribution of current seismotectonic features in northern Baffin Bay; it is the southern limit of the break zone and the northern limit of the active seismic zone. The relationship of the break zone and the active seismic zone is intriguing. Perhaps at one time there was an active continuous tectonic zone over both features, possibly a zone of underthrusting running from Baffin Island to Ellesmere Island. Subsequent tectonic processes have then cut the zone at Lancaster Sound, leaving a crustal break and a lower level of seismic activity to the north and a higher level of seismic activity to the south. None of our data suggest that Nares Strait was involved in any of the tectonic activity of northern Baffin Bay.

P nodal solutions

Seven independent P nodal solutions have been published for four earthquakes located in the northern Baffin Bay region south of Nares Strait. A summary of these solutions is given in Table 2. No P nodal solutions are available for Nares Strait itself as the Strait is aseismic but some significant earthquakes have occurred in the Lincoln Sea to the north and east of the Strait. A P nodal solution has been calculated for an event on January 4, 1978 in this area. This earthquake is the closest to the northern end of Nares Strait for which a P nodal solution is possible. It is too far away to be directly related to the present character of the Strait, but by comparison with the P nodal solutions to the

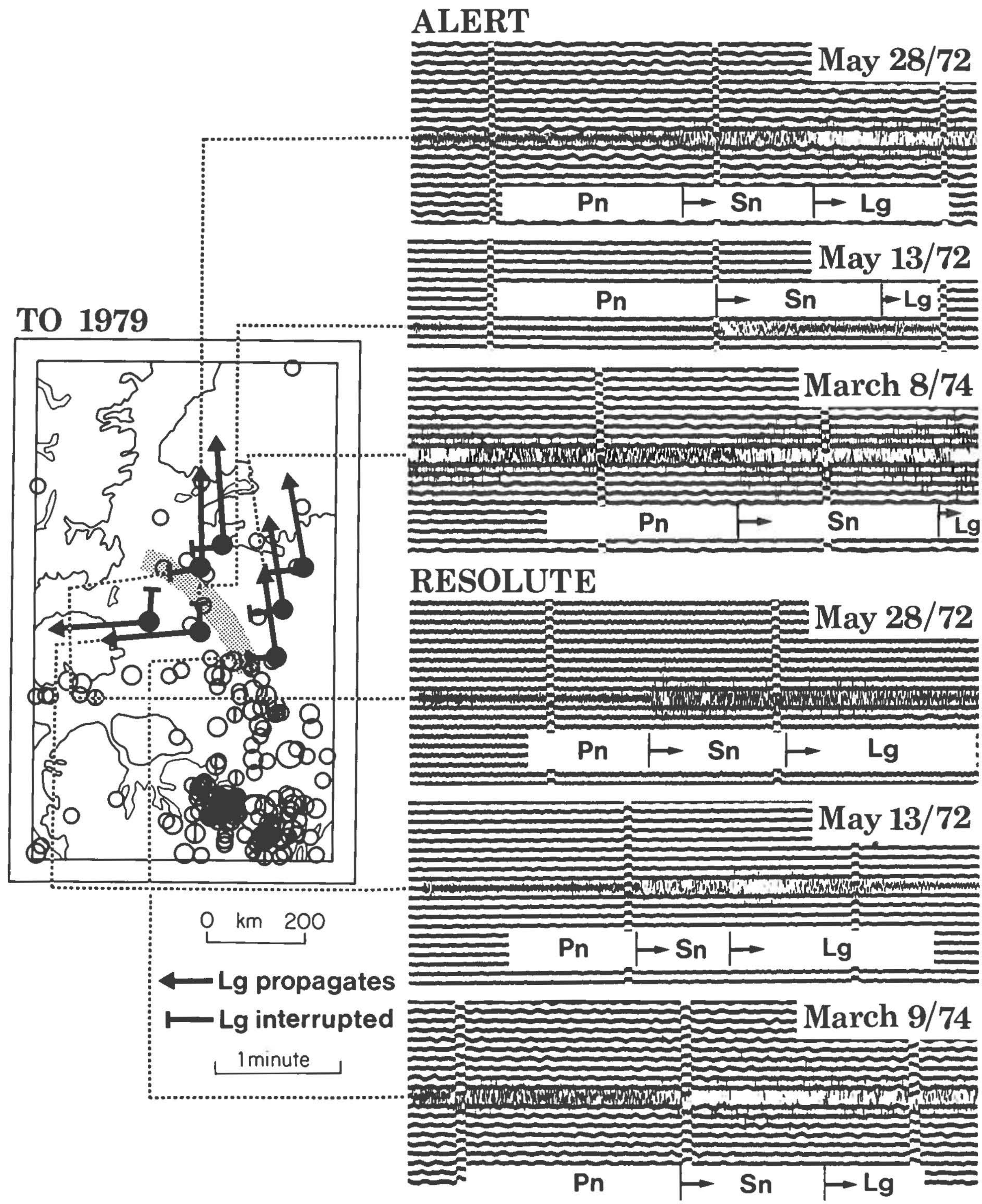


Fig. 5. The nature of Lg propagation from northern Baffin Bay. The minute scale refers to seismogram time scale.

Table 2. Summary of P nodal solutions published for earthquakes near Nares Strait.

Date	Location	Magnitude	Reference
Nov. 1933	Baffin Bay	7.3	Stein et al. (1979)
Sep. 1963	Baffin Island	6.3	Stein et al. (1979) Qamar (1974) Sykes (1970)
Jan. 1972	Baffin Island	4.5	Hashizume (1973)
Nov. 1976	Baffin Bay	5.4	Stein et al. (1979) Wetmiller & Horner (1978)
Jan. 1978	Lincoln Sea	5.0	This study

south, it provides some information on the nature of the stress field to the north and south of the Strait.

The equal area projection of the P nodal solution for the Lincoln Sea event is shown in Fig. 6 and the parameters are summarized in Table 3. First motions at seismograph stations in Canada were read from original records; for stations outside of Canada, data were taken from the Earthquake Data Report (EDR) 78–1 of the National Earthquake Information Service (NEIS). The solution is based entirely on short period data which are sometimes unreliable for such work but the earthquake was too small and the long period seismograph records were too noisy at the time of the event to derive any more reliable data. Readings within 16° of the epicentre are plotted at an angle of emergence of 49°, otherwise angles of emergence are calculated from the Herrin 1968 Tables assuming a focal depth of 15 km. (The EDR lists the event as having a focal depth of 33 km but this is only a default depth used by NEIS when the focal depth is shallow and no data exist to constrain it). The solution indicates almost pure strike-slip motion on either of two steeply dipping planes. There is no independent evidence in this study with which to distinguish either of the nodal planes as the actual fault plane. The principal axis of compression (P in Fig. 6) is nearly horizontal and oriented in the north–south direction. On the whole, the solution is well confined by the data distribution, the relatively large number of reversals (17) are typical of short period data.

Fig. 7 shows the distribution of all eight P nodal solutions that are available near Nares Strait. A common feature of all the solutions is that the principal axis of compression (P) is oriented in the north–south direction. This suggests that the regional tectonic stress is also oriented in the same direction, i.e. sub-parallel to

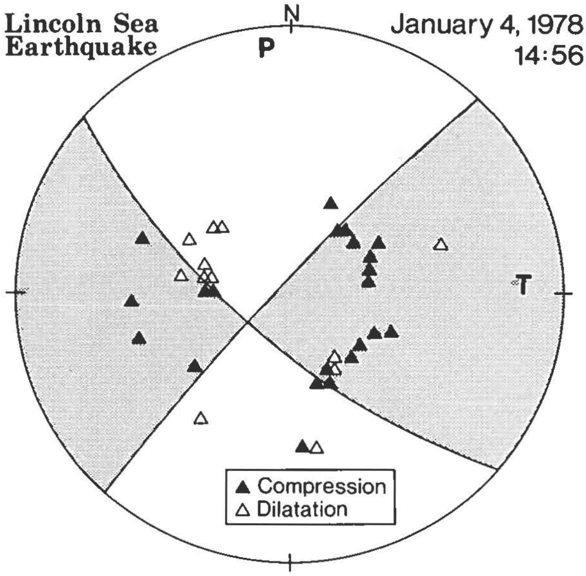


Fig. 6. P nodal solution (lower hemisphere) for event of January 4, 1978. One symbol may represent more than one reading.

the trend of Nares Strait itself. However, the lack of seismicity along Nares Strait shows that any proposed geological structures along the Strait are not responding to this stress while other features in the region are active.

Seven of the P nodal solutions are for earthquakes in the active seismic zone identified previously in northern Baffin Bay and on Baffin Island. An understanding of the present tectonic processes in this zone may indirectly shed some light on the origin of Nares Strait. Three independent P nodal solutions have been published for a 1963 M 6 1/4 earthquake on Baffin Island. The solution by Qamar (1974) in the middle of the 1963 solutions (Fig. 7) is clearly in error and should be disregarded. It is strongly weighted to the first motion at FBC (Frobisher Bay Canada) that, unknown to that author, had a reversed polarity at the time of the earthquake. Without the incorrect reading at FBC, Qamar's (1974) solution for this earthquake would be quite similar to the independent solutions published by Sykes (1970) and Stein et al. (1979). The P nodal solutions for the two earthquakes on Baffin Island are consistent with normal faulting on east–west to northwest-trending planes. The solutions are also consistent in depicting

Table 3. Parameters of the P nodal solution of the January 4, 1978 earthquake in the Lincoln Sea.

Readings	Reversals	A Plane		C Plane		P-Axis		T-Axis	
		az.[1]	dip	az.[1]	dip	az.[1]	dip	az.[1]	dip
80	17	42°	86°NW	130°	76°SW	355°	7°	87°	13°

1) azimuth measured clockwise from north.

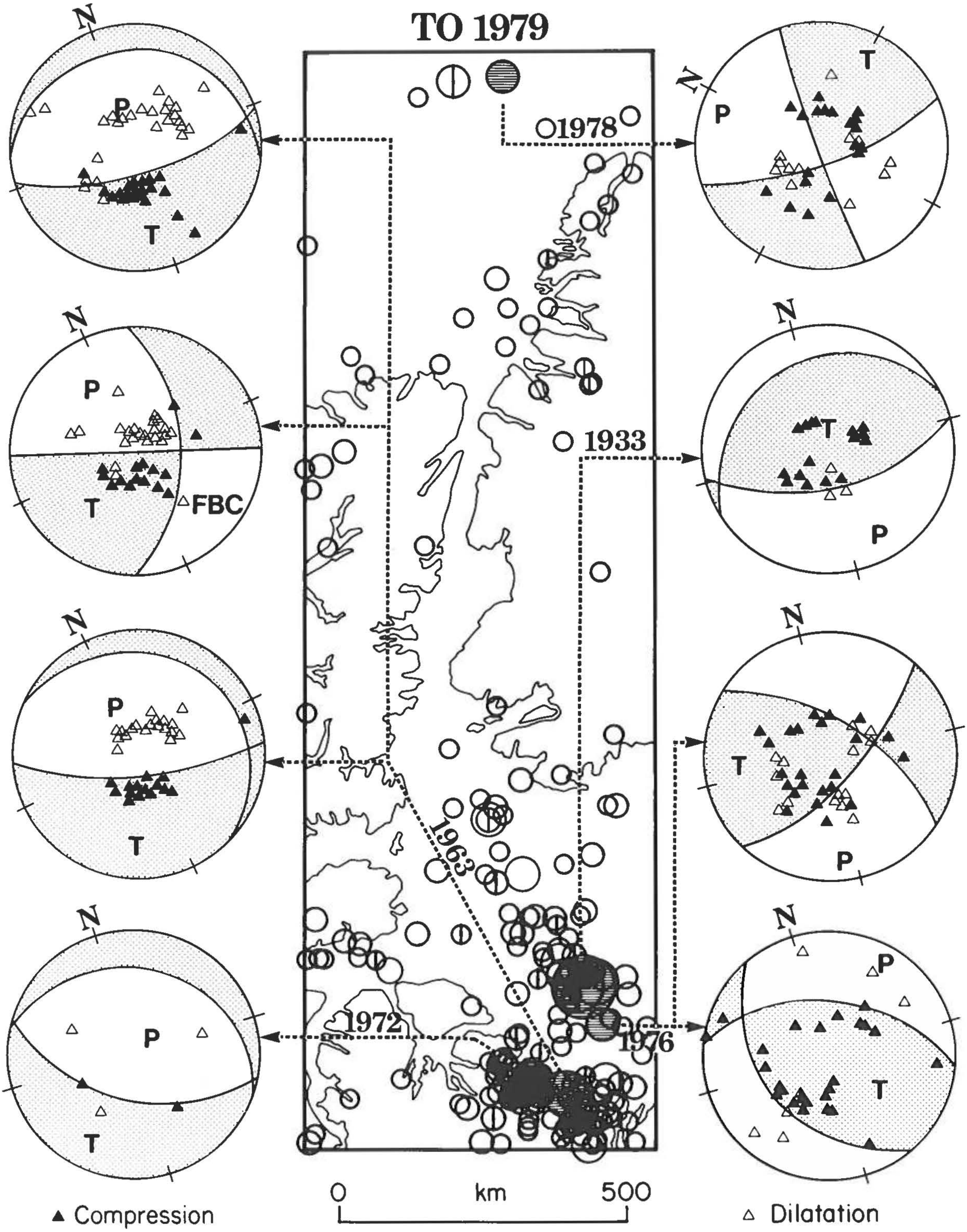
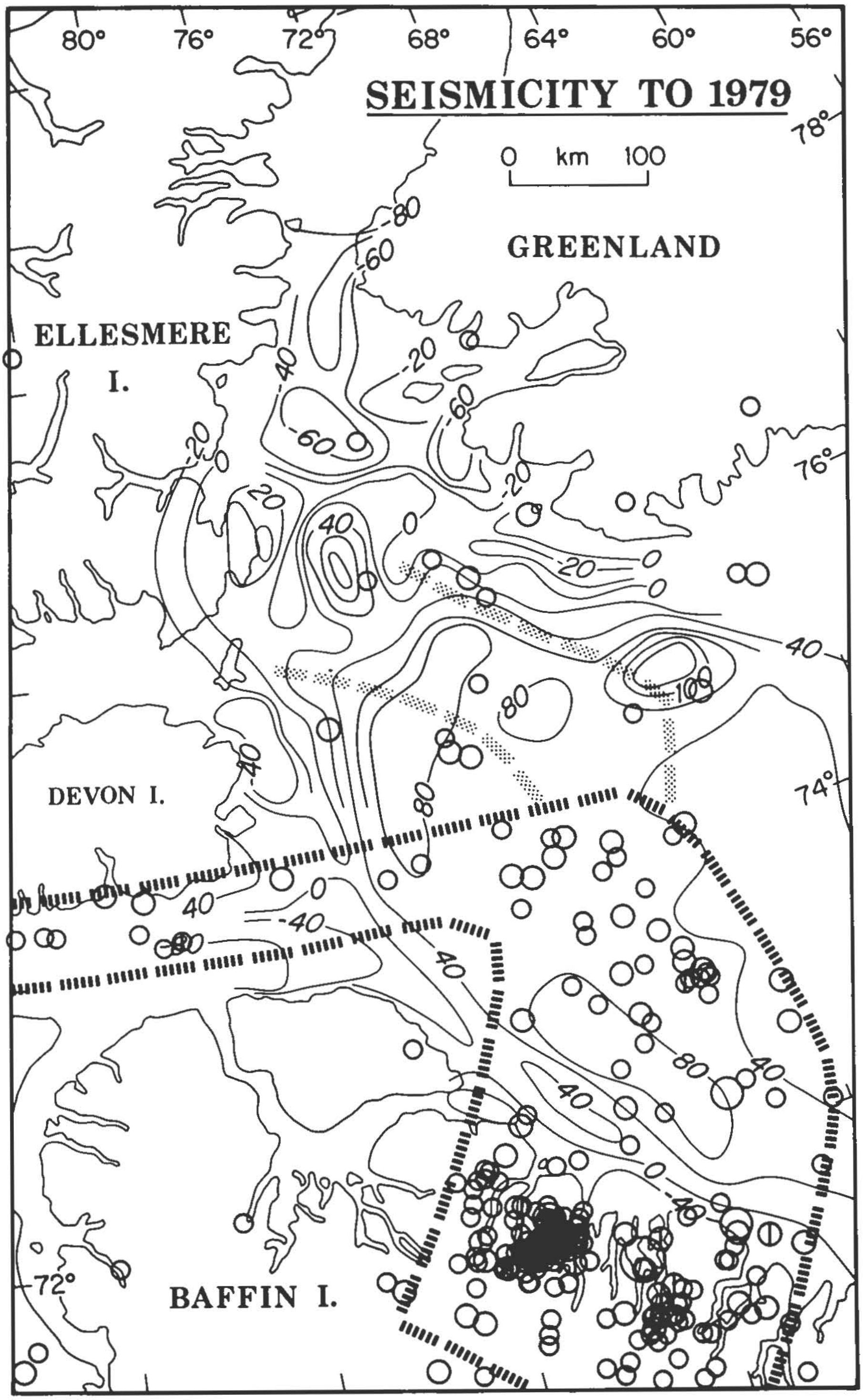


Fig. 7. P nodal solutions in the area of Nares Strait.

Fig. 8. Free air gravity and seismicity in the northern Baffin Bay – southern Nares Strait region.



one plane dipping very steeply to the south. These planes are similar in orientation and in line with the major fault structures outlining the northeast edge of the Milne Inlet Trough (Jackson et al. 1975). Miall et al. (1980) indicate the Trough is a basin formed by a Cretaceous to mid-Eocene Eurekan period of rifting of a northwest–southeast structural grain that has been periodically rejuvenated since the Proterozoic.

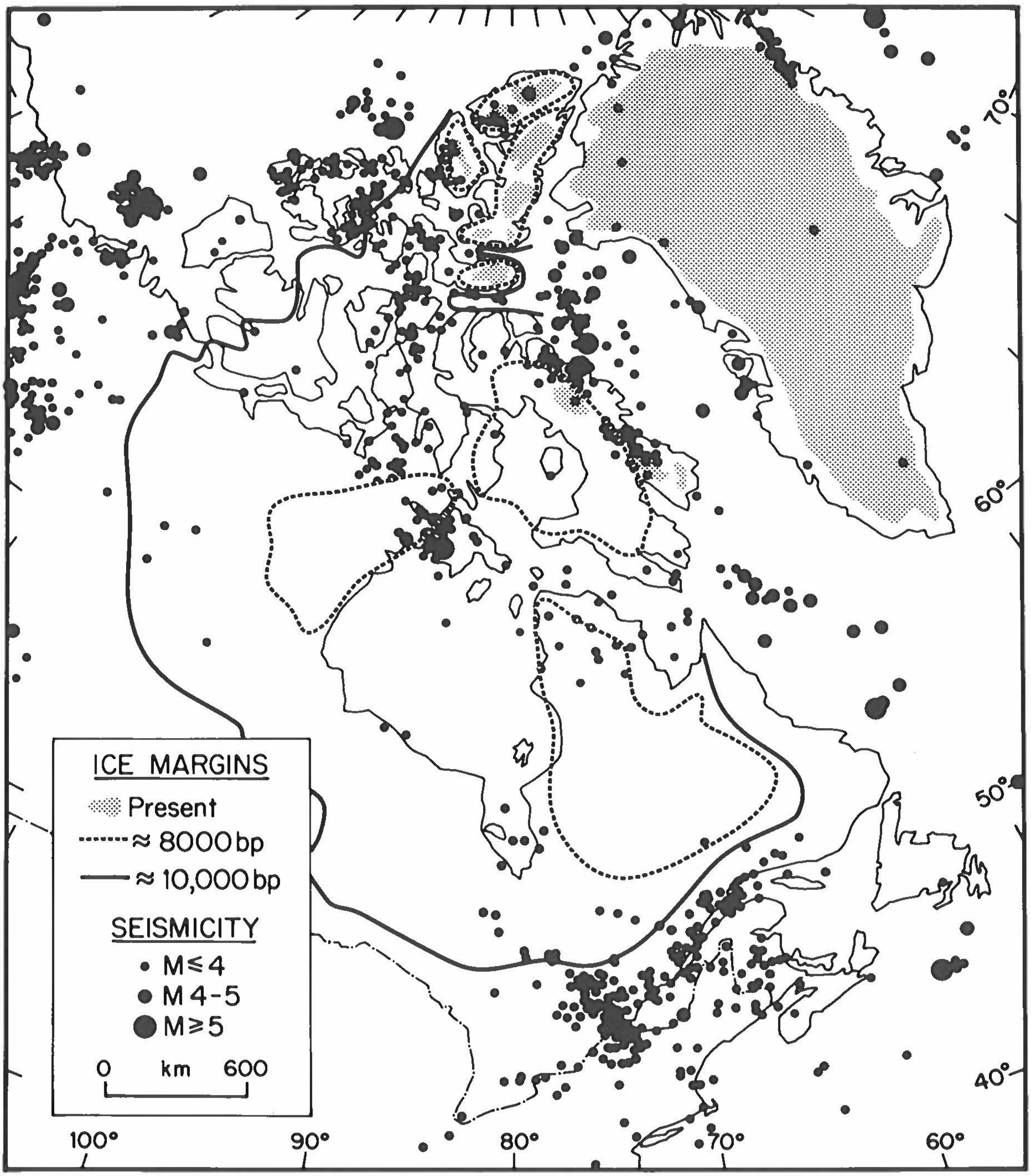


Fig. 9. Distribution of epicentres in northern Canada and Greenland compared to the centres of ice loading during the later stages of the last glaciation.

Two independent and different P nodal solutions have been calculated for the 1976 earthquake in Baffin Bay in the active seismic zone. The difference between the two solutions is mainly due to different focal depths assumed for this earthquake. The lower 1976 solution in Fig. 7 is by Stein et al. (1979) and assumes a focal depth of 33 km. This value is the NEIS default depth and is not an independent calculation. The upper 1976 solution is by Wetmiller & Horner (1978) and assumes a focal depth of 18 km. Again, this is a default depth as there exist no data with which to calculate reliably the focal depth. The difference in the two solutions indicates the sensitivity of the P nodal solutions to focal depth and the care which must be taken in cases where focal depth is poorly known. The two 1976 solutions considered here have in common thrust faulting (Greenland over Baffin Island) on a plane trending roughly northwest–southeast and dipping to the north.

Finally, Stein et al. (1979) have published a P nodal solution for the major 1933 M 7 1/4 earthquake in northern Baffin Bay. Their solution requires thrust faulting on east–west striking planes. They also calculate the focal depth to be 65 km, a surprisingly large value, that is based on a recording of the earthquake at one seismograph station in California.

In all, the four earthquakes in the active seismic zone for which there are P nodal solutions show a simple pattern. Those events located offshore have a solution consistent with thrust faulting, those located onshore have a solution consistent with normal faulting. One interpretation of these observations would be that the thrust activity offshore represents a region of interaction between Greenland and Baffin Island as they respond to a mainly north–south compressive stress. The lack of seismicity along Nares Strait would imply the adjustment is being taken up further west in the Canadian Archipelago and argues against the presence of a relatively young shear zone along Nares Strait.

Sediment loads

Another mechanism which may explain some of the seismic activity in northern Baffin Bay is the effect of recent sediment loading. Fig. 8 shows that there is a large region of positive free air gravity in the northwest-

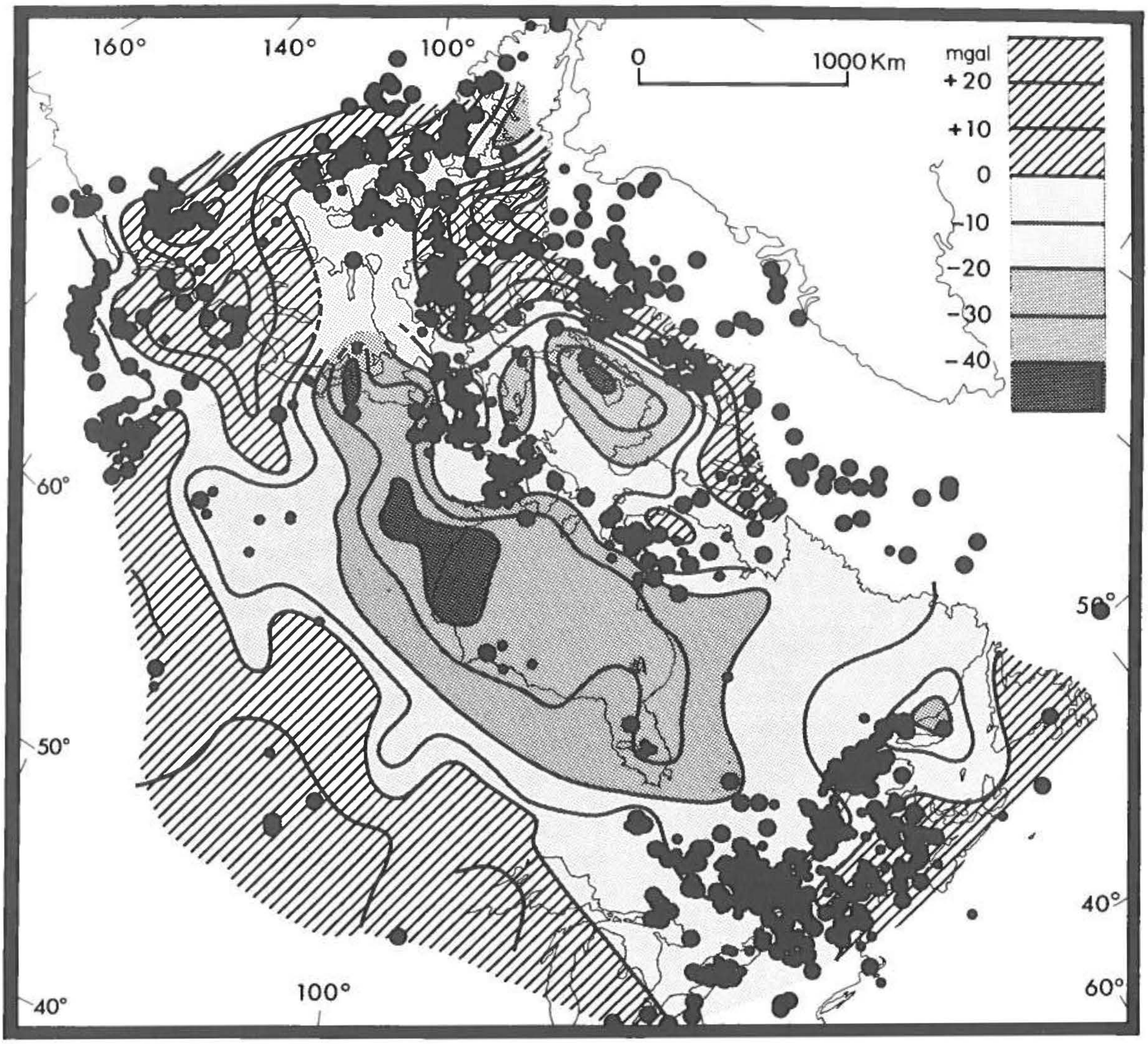


Fig. 10. Distribution of epicentres in northern Canada compared to the smoothed free air anomaly map by Walcott (1972).

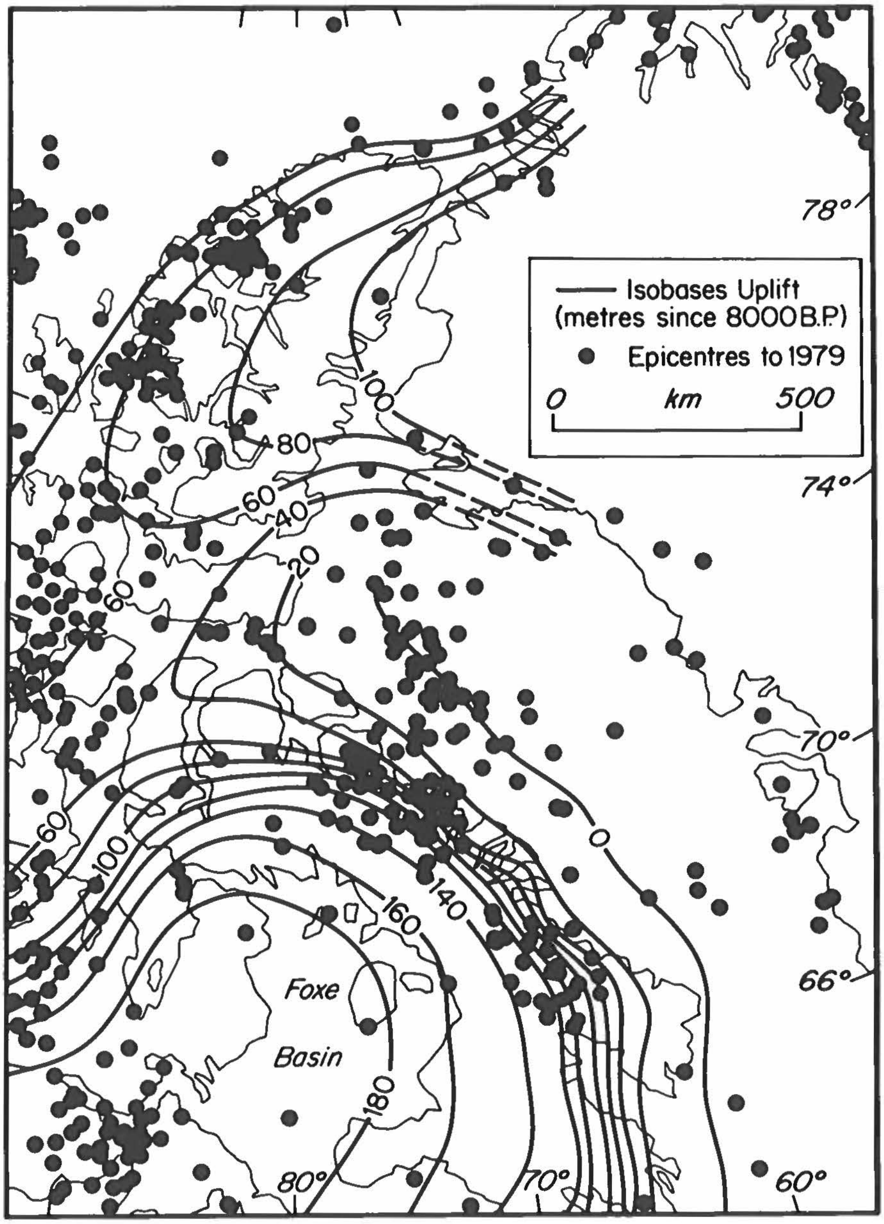


Fig. 11. Glacial isobases and seismicity for the Nares Strait region.

ern part of the Bay. Sobczak (1975) suggests that similar positive free air anomalies along passive continental margins may indicate areas of uncompensated loads of recent sediments. On the Canadian Arctic continental slope there are three such anomalies that correlate with pockets of recent seismic activity (Basham et al. 1977). Whereas the anomalies on the north slope are distinct, the free air anomaly in northern Baffin Bay consists of elliptically-shaped maxima on a broad positive zone circumscribing the northwest area of the Bay.

Fig. 8 shows that most of the recent earthquakes have occurred within the area of the broad positive anomaly. The break zone extending north of Lancaster Sound is aligned with a series of positive anomalies which separate the negative fields over Lancaster Sound and southern Nares Strait.

Considering the thrust nature of the P nodal solutions in the offshore active area, the mass excess indicated by the broad free air gravity high may be evidence of regional crustal thickening caused by the interaction of the Greenland plate with the plate containing Baffin Island. The three smaller elliptical maxima in Fig. 8 may reflect more local sediment loads. Nares Strait appears to be free of any effects due to sediment loading.

Glacial unloading

Stein et al. (1979) consider the pattern of P nodal solutions to be a consequence of glacial rebound at the continental margin reactivating the basement faults remaining from the rifting of Baffin Bay. Basham et al. (1977) have also noted the correlation of seismic activity on Baffin Island and elsewhere in northern Canada with areas of high differential rates of glacial rebound. Fig. 9 shows the epicentral distribution relative to the suggested ice centres of the later stages of the last glaciation (Prest 1970). Note the central areas of the major ice sheets are nearly aseismic with most of the activity centred around the edges. Fig. 10 shows the effect as reflected in the smoothed free air gravity map by Walcott (1972). The broad free air lows over Hudson Bay and the Foxe Basin represent areas that have yet to attain isostatic equilibrium and are aseismic while the fringe or interval areas representing areas of higher rebound gradients are characterized by seismic activity.

Gravity data in Nares Strait are sparse, but uplift isobases from the work of Miller & Dyke (1974) and England (1976) may be compared with the regional seismicity. Fig. 11 shows that for the Foxe Basin – Baffin Island area the relationship between the isobase gradient and seismicity is very similar to that between the free air gravity gradient and seismicity. Note that the uplift over Nares Strait in area Fig. 11 appears to reflect the response of the Greenland sheet and extends uninterruptedly across Nares Strait. A major crustal structural discontinuity along Nares Strait might be expected to influence the glacial response of this area.

Conclusions

Nares Strait is presently aseismic. Focal mechanism solutions from areas immediately south and to the north of the Strait indicate the region is under the influence of a north–south compressive stress, sub-parallel to the Strait itself. Glacial isobases suggest that Nares Strait does not play a significant role in the isostatic rebound of the area. Other major structural features of the Canadian Arctic that have demonstrated tectonic activity contemporary with the activity proposed for Nares Strait, play a significant role in the rebound of the Canadian Arctic and are represented in the present seismicity. The aseismic nature of Nares Strait indicates that it is not presently a zone of active tectonism and contests the hypothesis of a relatively young rift zone of major crustal or lithospheric dimension along the Strait.

Our geophysical evidence indicates that there are currently active tectonic features in northern Baffin Bay. These are probably faults generated by the opening of Baffin Bay that are presently being reactivated by postglacial rebound. However, we can see no evidence to extend these features north into Nares Strait. Instead, our data suggest that the tectonic features in northern Baffin Bay continue west into Lancaster Sound or possibly northwest into Jones Sound. On the basis of this we suggest that movements proposed for Nares Strait in plate reconstructions of Greenland and North America involve deformations west of Ellesmere Island in the Canadian Archipelago.

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