Polarforschung 74 (1-3), 21 – 39, 2004 (erschienen 2006)

Seismic Reflection Profiles from Kane to Hall Basin, Nares Strait: Evidence for Faulting

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Abstract: Three major tectonic boundaries are predicted to be present beneath the waters of this segment of Nares Strait: (1) the orogenic front of the Paleozoic Ellesmerian Foldbelt between thrust sheets on Ellesmere Island and flat-lying foreland rocks on Greenland, (2) the supposed sinistral strike-slip plate boundary of Paleocene age between the Ellemere Island section of the North America plate and the Greenland plate, and (3) the orogenic front of the Eocene to Oligocene Eurekan Foldbelt that must lie between thrust tectonics on Ellesmere Island and undeformed rocks of Greenland. To understand this complicated situation and to look for direct evidence of the plate boundary, new seismic reflection profiles were collected and, together with industry data in the south, interpreted. The profiles are clustered in three areas controlled by the distribution of the sea ice. Bathymetry is used to extrapolate seismic features with a topographic expression between the regions. Based on high-resolution boomer and deeper penetration airgun profiles five seismic units are mapped. These units are interpreted in the context of the adjacent onshore geology. Along Dobbin Bay there is a direct correlation between the seismic profile and three major onshore thrusts. Onshore changes observed in the amount of crustal shortening are related to the trend of the Eurekan structures as they adjust orientation from E–W to NE–SW. Offshore of Ellesmere Island from just north of the Bache Peninsula to Hans Island, there is a linear sedimentary basin that follows the coast. In cross-section the basin is asymmetric shallowing towards Greenland. Several seismic sections illustrate the character of the steep fault that delimits the eastern margin of the basin. This basin bounding fault is interpreted to have originated as a linked strike-slip fault system that was reactivated during a compressional phase. Its near surface expression is hypothesized to be the leading edge of the plate boundary between the North American and Greenland plates.

Zusammenfassung: Bedeckt vom Wasser der Nares Strait werden in diesem Abschnitt drei bedeutende tektonische Grenzen postuliert: (1) Die orogene Front des paläozoischen Ellesmerian Faltengürtels zwischen dem Deckenstapel von Ellesmere Island und dem Vorland auf Grönland. (2) Die Grenze zwischen der nordamerikanischen (Ellesmere Island) und der eurasischen (Grönland) Platte als vermutlich paläozäne sinistrale Blattverschiebung. (3) Die orogene Front des eozänen bis oligozänen Eureka-Faltengürtels, gleichfalls zwischen Überschiebungsschuppen auf Ellesmere Island und undeformierten Gesteinen auf Grönland. Um diese komplizierte Situation aufzulösen und gleichzeitig nach direkten Belegen der Plattengrenze zu suchen, wurden neue refexionsseismische Profile gewonnen und zusammen mit einem Industrie-Datensatz im Süden interpretiert. Die neuen Profile sind eisbedingt auf drei Abschnitte beschränkt. Die mehr flächendeckenden bathymetrischen Daten werden benutzt, um seismische Strukturen mit topographischer Ausprägung zwischen den Abschnitten zu interpolieren. In Kombination von hoch auflösenden oberflächennahen Boomer und tiefer reichenden Airgun-Profilen werden fünf seismische Einheiten ausgehalten. Diese Einheiten werden mit Hilfe der geologischen Verhältnisse in den benachbarten Küstengebieten interpretiert. Im Fjord der Dobbin Bay ist eine direkte Korrelation der seismischen Profile mit drei ausgeprägten Überschie bungen an Land möglich. An Land beobachtete Variationen der Krustenverkürzung quer zum Streichen werden durch den Wechsel im Trend der Eurekan-
Strukturen von E–W zu NE–SW verursacht. Offshore in der Nares Strait liegt parallel zur Küste ein lang gestrecktes Sedimentbecken zwischen Hans Island und der Nordküste der Bache Peninsula. Das Becken hat einen asymmetrischen Querschnitt mit der größten Tiefe vor Ellesmere Island und Verflachung Richtung Grönland. Mehrere seismische Profile zeigen steile Störungen am östlichen Rand des Beckens. Dies Störungssystem am Beckenrand wird von uns als verknüpftes, sinistrales Blattverschiebungssystem interpretiert, das durch eine folgende kompressive Phase reaktiviert wurde. Als Arbeitshypothese fassen wir die oberflächennahen Teile dieses Systems als Stirn der Plattengrenze zwischen Nordamerika und Grönland auf.

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Manucript received 06 December 2004, accepted 29 May 2006
GSC contribution # 2005 526.

INTRODUCTION

The Late Cretaceous and Tertiary deformation on Ellesmere Island (Fig. 1) called the Eurekan Orogeny has been attributed to the counter clockwise rotation of Greenland (e.g., OKULITCH & TRETTIN 1991). However reconciling the geology on opposite sides of the Strait (Fig. 2) with the predicted plate motions has been fraught with difficulties. Many authors (e.g., DAWES & KERR 1982) suggest that the onshore geology can be correlated across the Strait indicating it is not the position of a plate boundary. Marine seismic profiles are essential to determine if deformation has occurred in the Strait as predicted by published plate reconstructions (e.g., SRIVASTAVA 1985, ROEST & SRI VASTAVA 1989). Ice cover has restricted seismic vessels operating in the region; thus the quantity and quality of data were limited. In fact, no seismic profiles previously existed in Kennedy Channel or further north.

With the goal of determining if the seismic reflection character changes across the Strait, we collected marine profiles with two distinct resolutions and penetrations. To optimize the comparison of the mapped onshore geology with the offshore, seismic lines were run along the fiords and continued into the Strait. The new seismic reflection profiles are interpreted with the support of multichannel profiles previously collected by industry (Fig. 1) and onshore geology, bathymetry and refraction. Based on the new and recompiled data assembled here, this paper aims to identify if features consistent with deformation occur in Nares Strait from northeast Kane to Hall basins.

GEOLOGICAL BACKGROUND

The rocks exposed (Fig. 2) along Nares Strait (TRETTIN 1991) can be divided into five types: 1) Archean to Lower Proterozoic metamorphic-plutonic basement, 2) Upper middle and Upper Proterozoic sedimentary and volcanic rocks of the Thule Basin (e.g., DAWES & KERR 1982), 3) Vendian to Devonian shelf deposits, 4) deep water deposits of the basin (STUART SMITH & WENNEKERS 1979, TRETTIN 1987, 1991) Franklinian and 5) a Tertiary foreland basin (PIEPJOHN et al. 2000). Onshore of our seismic data, from Kane Basin north to Robeson Channel, lower Paleozoic shelf sequence and deep-water succession of the Franklinian Basin predominate. Limited exposures of Tertiary sedimentary deposits also exist along the coast of Kennedy Channel and Princess Marie Bay (MAYR & DE VRIES 1982, PIEPJOHN et al. 1998).

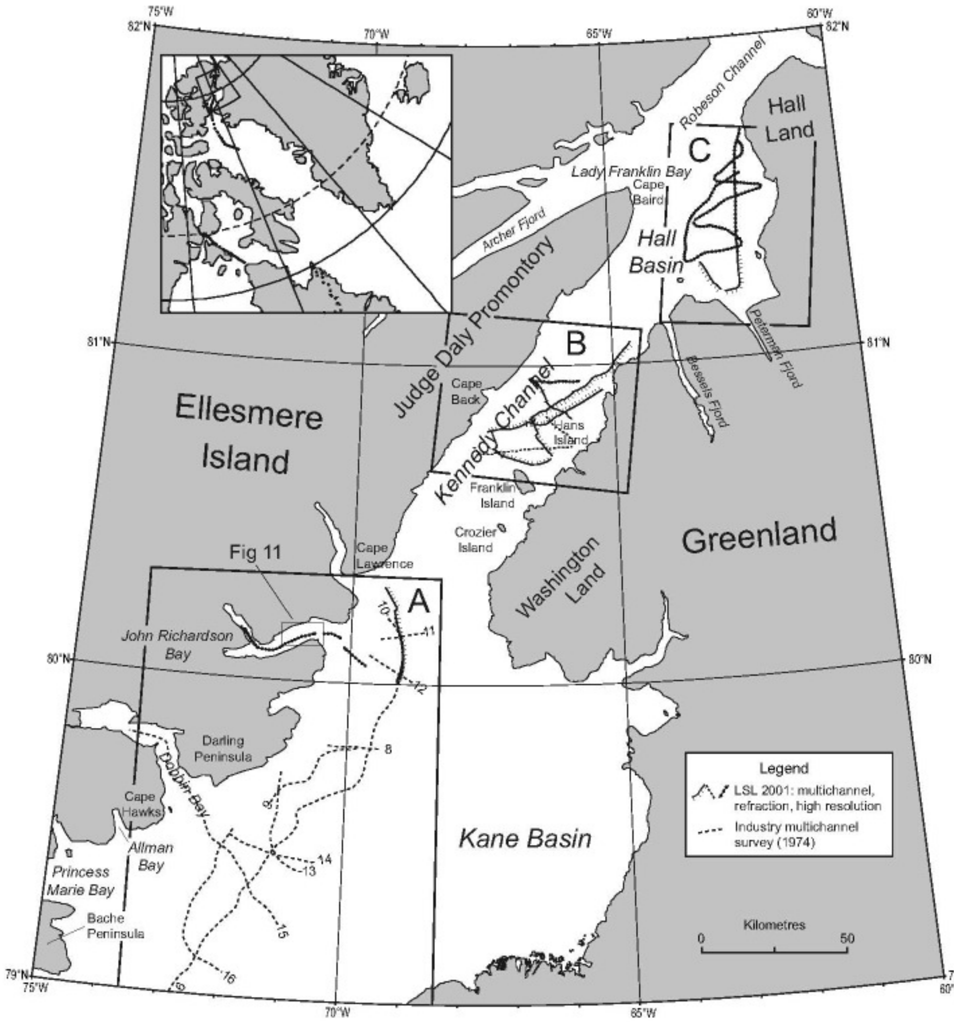


Fig. 1: Location map showing the position of the industry, high resolution (Huntec), the BGR seismic reflection and refraction profiles. The three boxes labeled A, B and C indicate regions described in more detail.

The tectonic development of the area was influenced by two major deformations. The Franklinian Basin development was followed by the Ellesmerian deformation (e.g., THORSTEINSSON & TOZER 1970, TRETTIN & BALKWILL 1979, HIGGINS et al. 1981, TRETTIN 1991) in Late Devonian / Early Carboniferous that was dominated by km-scale folding of the Franklinian Basin succession (KLAPER 1990, PIEPJOHN et al. in press). In the Dobbin Bay area, the southern termination of the Ellesmerian Fold-and-Thrust Belt is situated in the vicinity of the Dobbin Bay Syncline (Fig. 1 and 2): the areas south of that syncline belong to the Ellesmerian foreland (PIEPJOHN et al. in press).

After the Ellesmerian deformation, the development of the Sverdrup Basin farther west started with sedimentation of upper Early Carboniferous to Lower Tertiary clastic and carbonate deposits (e.g., THORSTEINSSON & TOZER 1960, TRETTIN 1991). In most areas of northeast Ellesmere Island, Carboniferous to Lower Cretaceous deposits are lacking. However, there are several isolated basins along Nares Strait which contain Tertiary rocks (MAYR & DE VRIES 1982): in the Allman Bay area, Upper Cretaceous mudstones and sandstones and thick Tertiary conglomerates disconformably overly limestones of the Silurian Allen Bay Formation (DE FREITAS et al. 1997, DE FREITAS & SWEET 1998, PIEPJOHN et al. 1998). At Cape Lawrence, at Cape Back and on northeast Judge Daly Promontory, Tertiary sandstones and conglomerates unconformably overly intensely folded Silurian to Ordovician strata (Figs. 1, 2).

The sedimentation of the Sverdrup Basin was followed by compression of the Eocene Eurekan deformation (THORSTEINSSON & TOZER 1970). As the edge of the Ellesmerian foreland is interpreted in the vicinity of the Dobbin Bay syncline, the seismic section in the bay (Fig. 1) lies entirely in the Eurekan Fold-and-Thrust Belt.

On the Greenland or eastern side of the Kennedy Channel, unmetamophosed and unfolded Paleozoic rocks of the Arctic platform crop out (DAWES & KERR 1982). On Washington Land, these rocks developed as a Lower Silurian (DAWES 1999) carbonate-dominated passive margin sequence (HIGGINS et al. 1991). The islands in the middle of the Strait (Hans, Franklin and Crozier islands Fig. 1) are part of the Silurian reef belt. They do not exhibit deformation.

METHODS

Nares Strait is usually an ice-choked waterway. In order to attempt seismic surveying from Kane Basin to the north, it is necessary not only to have a ship capable of working in the drifting sea ice and icebergs but also to have sufficient open water to tow the sound sources and receivers. During the 2001

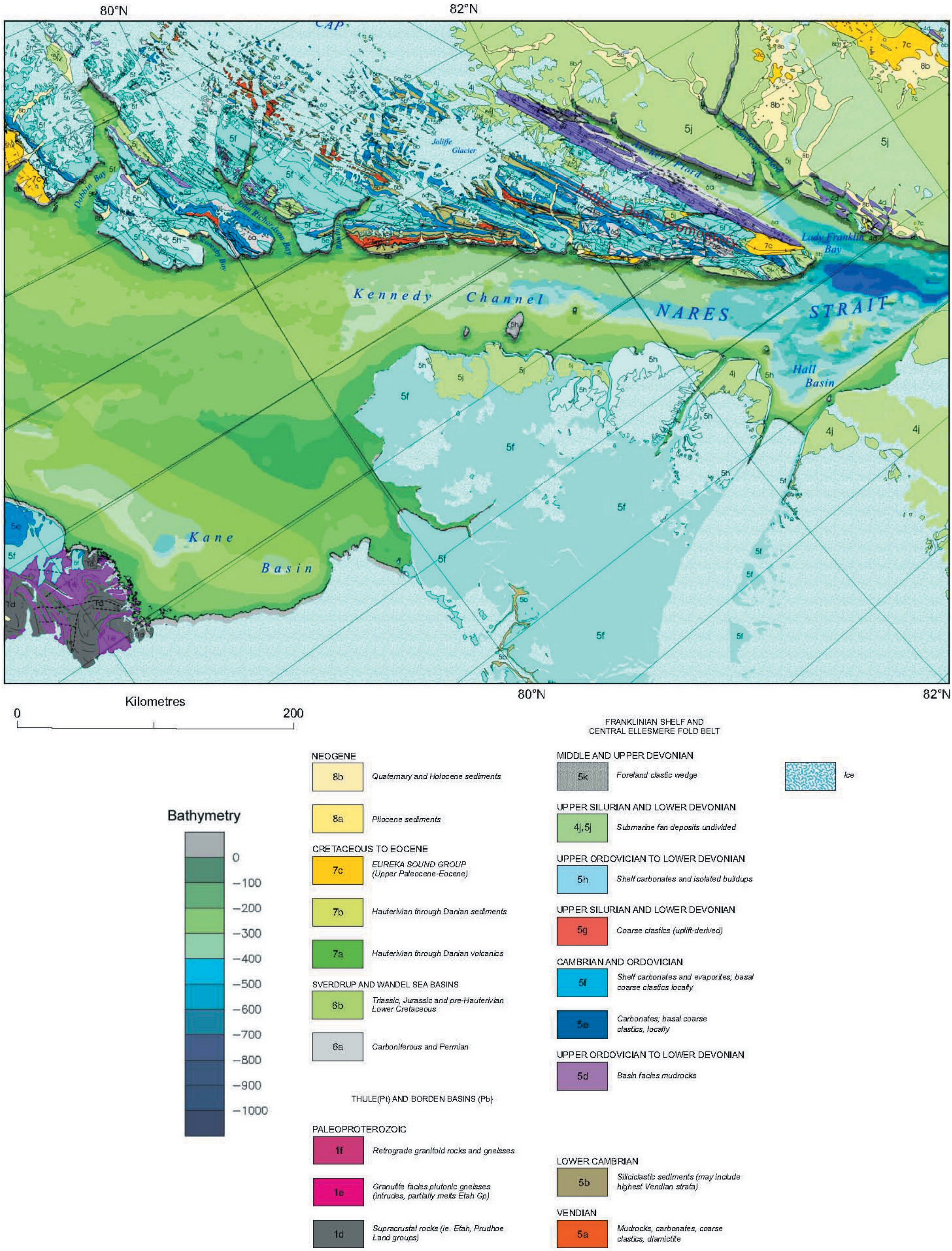


Fig. 2: Geology map based on the published map sheets in the region recompiled by Harrison et al. 2006. It shows the contrasting patterns in the exposed geology across Nares Strait. The speckled blue areas are ice covered. The bathymetry shown is based on the available soundings that have been gridded.

survey the ice conditions were not ideal. The drifting sea ice never left the western side of the Strait so it was not possible to run lines as planned, crossing the Strait from side to side. Partially compensating for the erratic direction and line spacing (Fig. 1) is the ability to do onshore/offshore correlations of the geology along the narrow fjords with the seismic profiles. In addition, bathymetry measurements are employed to extend features mapped on the seismic profiles that have distinct topographic expressions.

Seismic method

This paper draws on several data sets, most of them were collected in August–September 2001 during the CCGS "Louis S. St Laurent" expedition to Nares Strait. Global Positioning System (GPS) used on the cruise provided a position accuracy of 25-40 m. The Huntec Deep Tow Seismic system is a high-resolution sub-bottom profiler, capable of 10 cm resolution to about 0.5 s below the sea floor. The acoustic source (ED 10 F/C boomer) and two hydrophones are stored within an underwater towed body (fish). A 3-5 m, 10-element streamer, is towed behind the fish. Ice conditions demanded that operators be able to recover the instrument quickly. For this reason the fish was towed at depths between 20-30 m for about half of the time. When ice conditions were better, the fish was towed at 50 m depth.

The 2001 cruise was the first time Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) used an array of six Sodera GI (Generator-Injector) airguns as the acoustic source for multichannel seismic reflection profiles. GI guns differ in their construction and function from conventional airguns in a number of ways in order to reduce the bubble pulse. A GI gun consists of two independent airguns within a single chamber – the generator, which produces the primary pulse, and the injector, which controls the oscillation of the bubble produced by the primary pulse from the generator. A 48-channel array with 24 hydrophones per group was available. Unfortunately, due to less than ideal ice conditions (>3/10), the length was shortened to 100 m in all profiles discussed in this paper.

This paper also re-examines seismic profiles collected in Dobbin Bay and the western portion of Kane Basin (Rendell & Craig 1976). This survey utilized a 600-900 cubic inch airgun array, with a 1200 m seismic streamer. They stated that a 2400 m streamer would have been ideal; however, ice conditions at the time of the survey prevented this, a persistent problem in Nares Strait. A commercial software package Lynx Information Systems Data Archivist was used to convert the 1974 analogue records to digital SEG-Y format, and a Kirchoff post stack time migration was applied to line 15 (Fig. 1).

For the refraction experiment in the Kane Basin the six GI guns were recorded on three land based seismometers. The observed signal to noise ratio was excellent. The ice conditions changed rapidly during the experiment and the firing of the airguns in a straight line across Kennedy Channel was not accomplished as planned. Fortunately, the results from the wide-angle reflection/ refraction experiment (Funck, Dehler et al. 2006) provide velocities that are used to assist in the interpretation of the seismic reflection profiles.

Bathymetric method and interpretation

The bathymetric data provide information on the shape of the seabed that is useful for constraining interpretations based on the seismic profiles. The soundings collected on the 2001 expedition were added to the available bathymetry (Oakey et al. 2001) and were gridded (Figs. 3 and 4). In the Strait the spot soundings are 2 km apart, closer where they are augmented by ship's tracks. From the gridded data set a number of synthetic profiles were made in order to visualize the shape of the sea floor.

North of 79 °N in Kane Basin, there are two bathymetric deeps. Near the coast of Ellesmere Island there is a channel up to 300 m deep, steepest on the western side (Figs. 2 and 4). This depression is located immediately south of Kennedy Channel linear deep (Fig. 2). In eastern Kane Basin along the Greenland coast there is a deeper valley that can be traced to the mouth of the Humboldt Glacier (Figs. 2 and 4). The proximity of the trough to the glacier suggests a glacial origin.

In Kennedy Channel the maximum water depth is about 500 m increasing in depth from south to north. The deep forms a linear trough near the centre of the Strait. Here the bathymetric profile is slightly asymmetric, steeper near Ellesmere Island and deepest to the west (Fig. 4). In Hall Basin the maximum water is found just to the north of the fault controlled tip of the Judge Daly Promontory (Fig. 2). This bathymetric low extends northward into Robeson Channel. The orientation of the trough in the Kennedy Channel and the Hall Basin to Robeson Channel trough are similar but offset.

SEISMIC REFLECTION INTERPRETATION

Area A: Kane Basin to Cape Lawrence

The seismic profiles are described starting in the south and integrating them with the onshore geology (Fig. 1). Reflection profile 15 in Dobbin Bay interpretation is consistent with the onshore geology. The RMS velocity of 5.00 km s^{-1} (Rendell & Craig 1976) used to migrate the section in the Bay is in harmony with the characteristic of rocks that are principally Lower Paleozoic in age (Fig. 5). Three major ENE–WSW trending sets of thrust faults are mapped adjacent the shore of Dobbin Bay (Fig. 5). The Dobbin Bay Thrust mapped on the Darling Peninsula can clearly be seen on the seismic record between points 1 and 2 (Fig. 6).

Closer to the mouth of the Bay (between points 5 and 6) the seismic reflections are offset and interpreted as cut by faults. On both sides of the narrow fjord the Parrish Glacier Thrust (Kerr 1973a, b) is well delineated by the onshore geology (Fig. 5). At the mouth of Dobbin Bay the Cape Hawks Thrust crosses Washington Irving Island. Based on the character of the seismic profile near point 8, we extrapolate the thrust offshore. Offshore of the thrust on the seismic section, a sequence of dipping reflectors is seen to 1.8 s. On Washington Irving Island and onshore between Cape Hawks and Allman Bay (Fig. 5) as well as on the headlands such as Cape Lawrence, Tertiary conglomerates with a thickness of up to 1 km (Mayr & de Vries 1982) are reported. There are many carbonate clasts in the conglomerates and the matrix is well

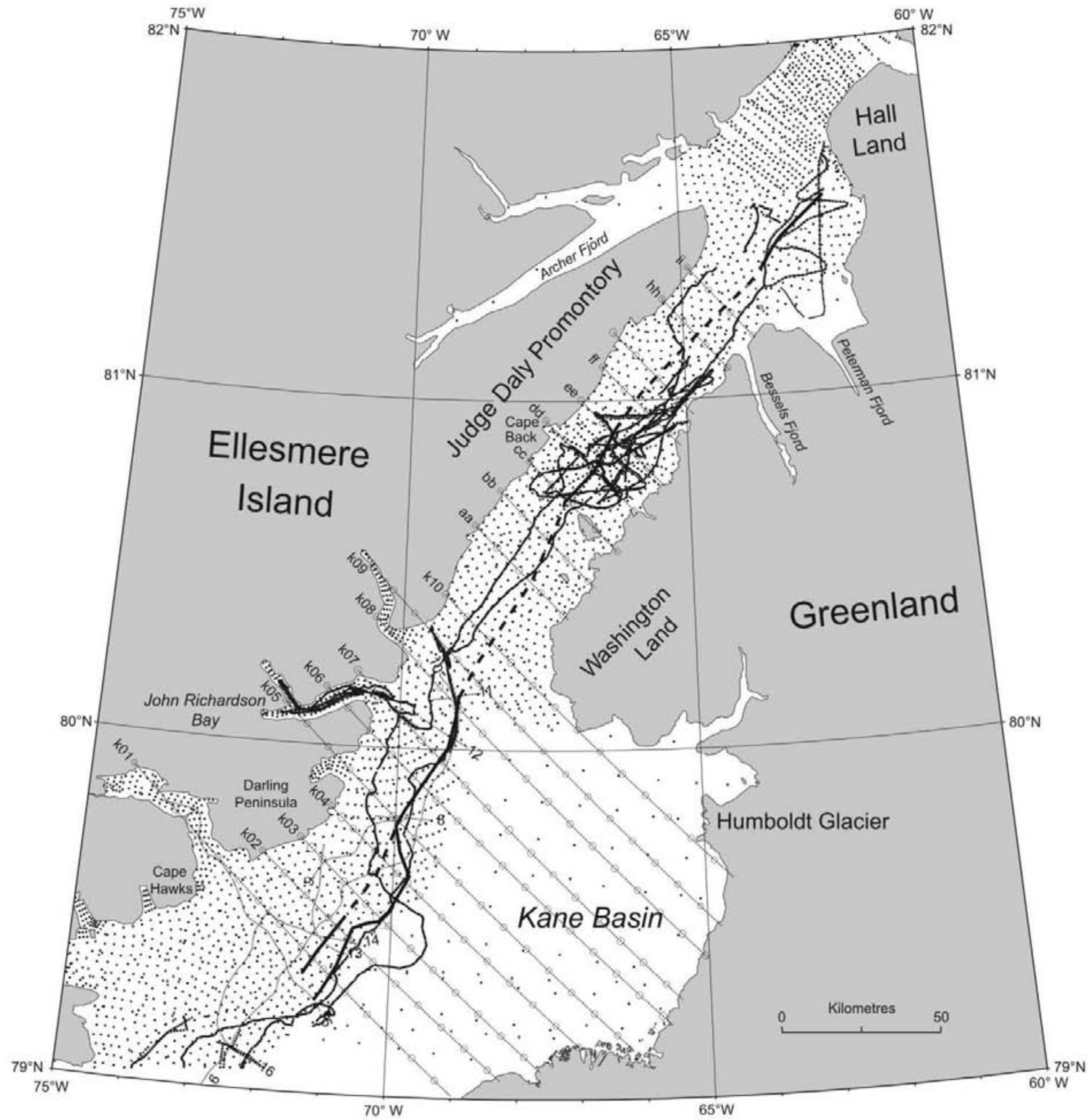


Fig. 3: Location of the soundings (solid dots) used to produce the gridded bathymetry map and the position of the synthetic profiles derived from them. The solid (or dashed) line suggests the easternmost portion of a fault.

silicified, hence it forms resistant cliffs. The Cape Hawks Thrust has Tertiary strata in the footwall. The RMS seismic velocity (Rendell & Craig 1976) of the section seaward of the faults is 3.0 km s^{-1} indicating a minimum sedimentary section of 3 km below sea level.

Line 15 forms part of a two-dimensional seismic survey (Rendell & Craig 1976) that was run at the edge of Kane Basin (Fig. 1), called the Franklin Pierce Basin. Based on this survey an isopach map was produced, to a horizon, labeled A. The mapping of horizon A indicates a wedge shaped basin deeper near Ellesmere Island and shallowing eastward. On line 15 (Fig. 6) the shape of the basin is clearly seen from beyond shot 8 to the southeast. Line 15 and 13 are the only sections that cross the inner edge of the basin adjacent Ellesmere Island. The steep edge is consistent with it being fault controlled. Within the basin's dipping reflector sequence Rendell & Craig (1976) mapped several faulted anticlinal structures as north trending folds. These features are asymmetrical and can be explained as hanging wall anticlines above easterly transported thrusts (Harrison et al. 2006). The dipping horizons as they approach the edge of the basin are offset and diffractions are observed. We draw faults at the eastern edge of the basin (Fig. 6).

All of the seismic lines in the Kane Basin survey terminated in the east in a similar way to that presented on lines 10 and 11 (Fig. 7) and 14 and 15 (Fig. 8). Line 10 (Fig. 7) and BGR 21 (Figs. 1, 9, 10) are nearly coincident. Both profiles show the abrupt termination of the basin indicating that the changes in seismic character are real and not caused by acquisition or processing artefacts. We interpret a nearly vertical fault where the difference in seismic characteristic occurs. The changes in seismic horizons along the profiles are best illustrated on lines 10 and 11 that are perpendicular (Fig. 7). The flat-lying reflector sequence east of the fault on line 10 and northwest on

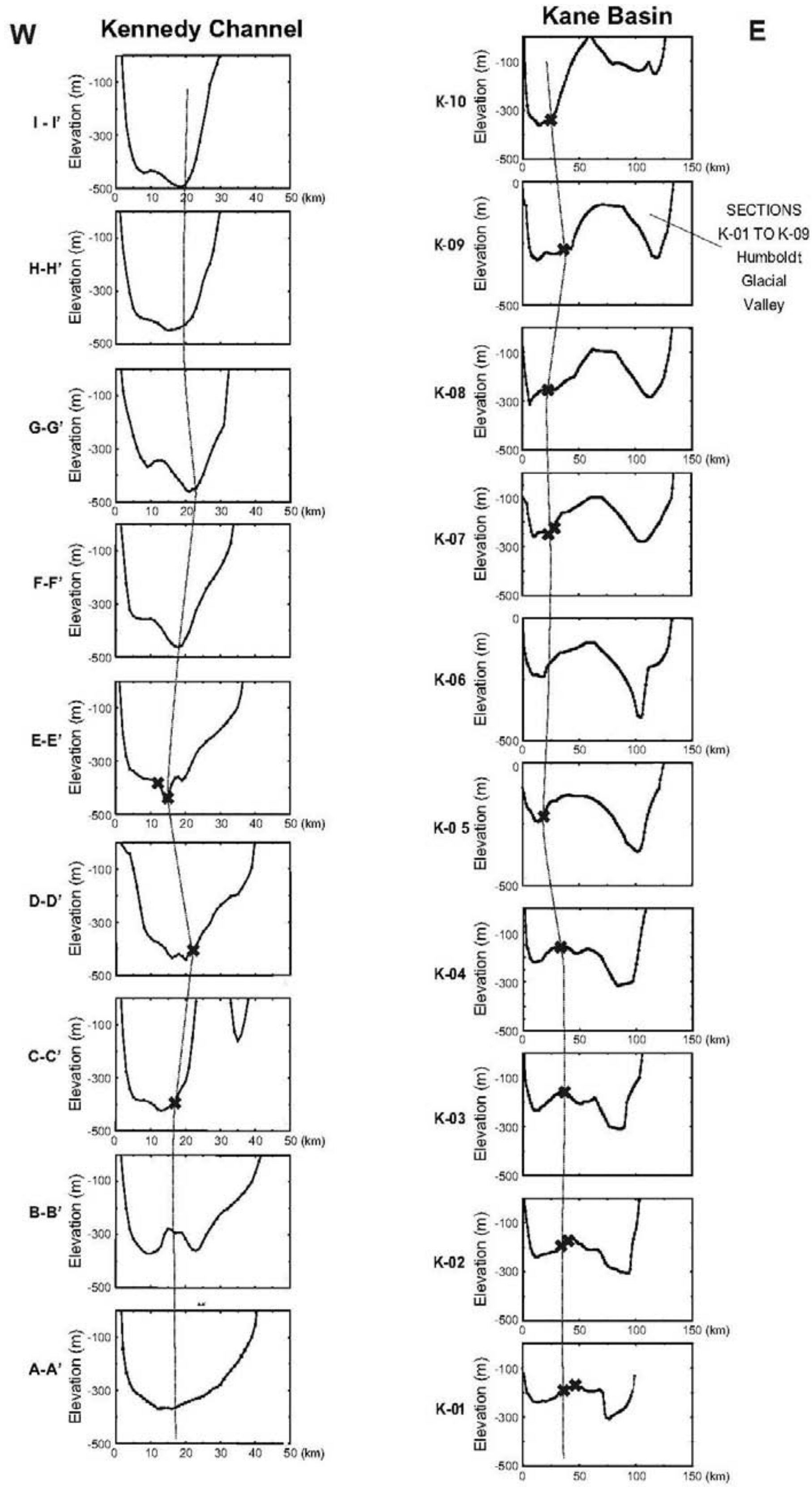


Fig. 4: Synthetic bathymetric profiles. The crosses indicate the eastern edge of the sedimentary basin where there is seismic control.

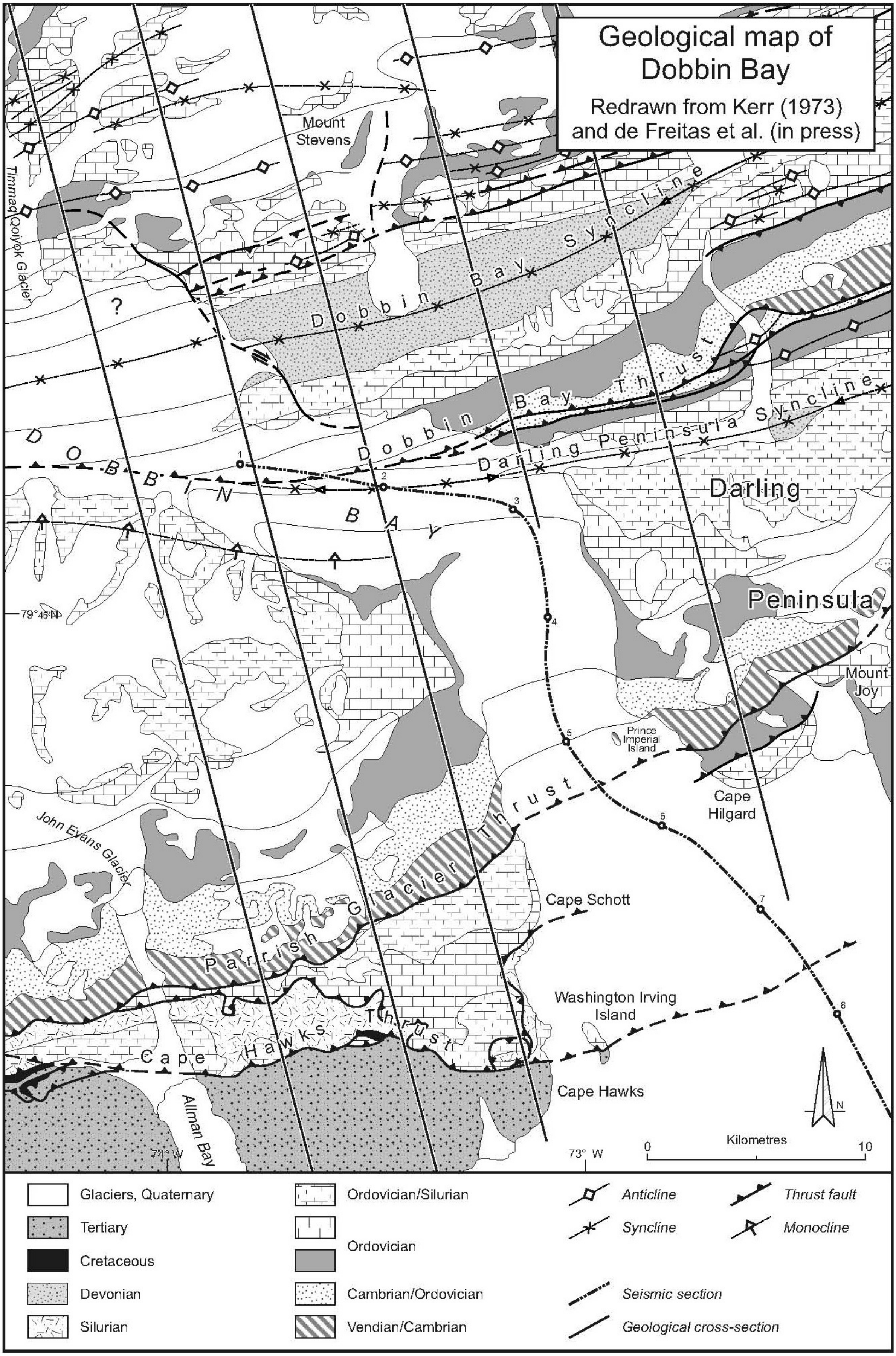


Fig. 5: Onshore geology with the location of seismic section 15 (dotted line with shot points) in Dobbin Bay. The solid diagonal lines are the geological cross sections shown in Figure 14.

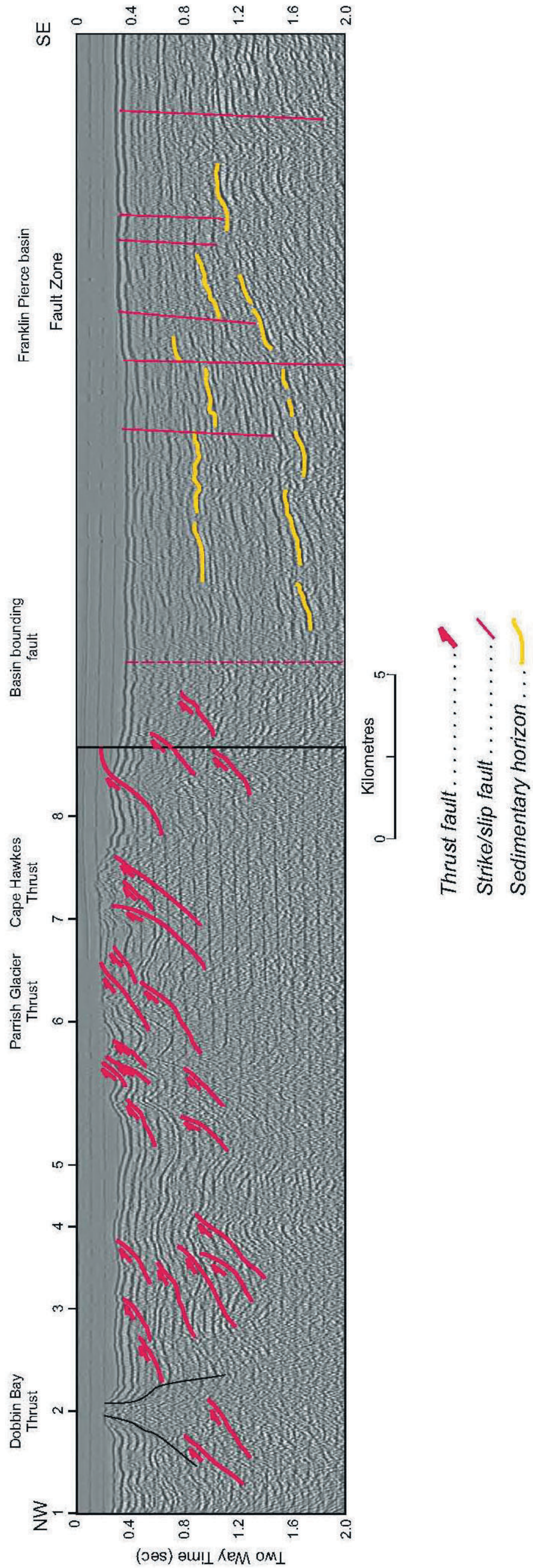


Fig. 6: Migrated version of profile 15. The red lines indicate the faults and the yellow highlights dipping reflections.

line 11 is not due to an apparent dip change due to line orientation because it is at the same attitude on both profiles. In contrast, near Ellesmere Island the dipping reflectors are observed on both lines 10 and 11. The width of the fault zone varies along the basin edge. Near Cape Lawrence it is about 1 km wide compared with the more southerly portion of the basin as shown on lines 14 and 15 where it extends over a 10 km wide zone. A fault zone that is steep, narrow and can be traced over 200 km exhibits properties commonly associated with strike-slip regimes (Davison 1994).

The seismic survey maps the eastern termination of the Franklin Pierce Basin in the Kane Basin at a limited number of points. We compare the position of the edge of the basin with the bathymetry data (Fig. 4) and find it is located to the east of the deepest water. This is consistent with the younger sedimentary rocks eroding more easily than the older rocks that are exposed onshore. The coincidence of the sedimentary basin with deep-water is used to extrapolate its position between regions A and B.

In John Richardson Bay we obtained a Huntec profile (Fig. 11) that we compare with the onshore geology. To the north of John Richardson Bay, there are two faults that dip towards each other and reach the shore. Directly offshore of these faults the high-resolution seismic section shows two topographic highs with an intervening low. From the western asymmetrical basement high, the acoustic basement can be seen to gradually increase in depth and be buried by glaciomarine sediments. As the water depth increases to the east, stratified unconsolidated sediments are observed at the base of the steep eastern scarp. The reflections on this steep surface are clear and sharp. No penetration is observed except near the foot of the slope where a slump is inferred. We interpret the steep face as the faulted bedrock consistent with the onshore geology. This section illustrates the characteristics of a fault on the high-resolution seismic profile.

Area B: Kennedy Channel

The newly collected multichannel seismic profiles from Kennedy Channel (Fig. 9) and Kane Basin are used to distinguish (e.g., Fig. 10) five seismic units: The lower Paleozoic carbonates unit I and the reefal unit II, the Paleozoic clastic unit III, the dipping sedimentary strata of the Franklin Pierce Basin unit IV of possible Cretaceous to Tertiary age and a glacial unit V from the Quaternary.

In Kennedy Channel, seven seismic profiles are available for interpretation (Figs. 9, 10). Unit II has an undulating seabed surface, a strong bottom simulating reflector (BSR) or base of the bubble pulse and no deeper reflections are observed. This unit is mapped near Crozier, Franklin and Hans islands that are exposed carbonate reefs. Based on the wide-angle reflection/refraction lines run during this expedition in this area (Funck, Dehler et al. 2006) there are high velocities of 5.8-5.9 km s-1 at the seabed. These velocities are similar to the in situ velocities 5.9-6.1 km s-1 measured on a carbonate sample from the region (Funck, Dehler et al. 2006). The high seabed velocities are consistent with the limited reflective energy beneath it. Unit I has a smoother expression at the seabed than unit II and grades into it (e.g., Fig. 10, profile

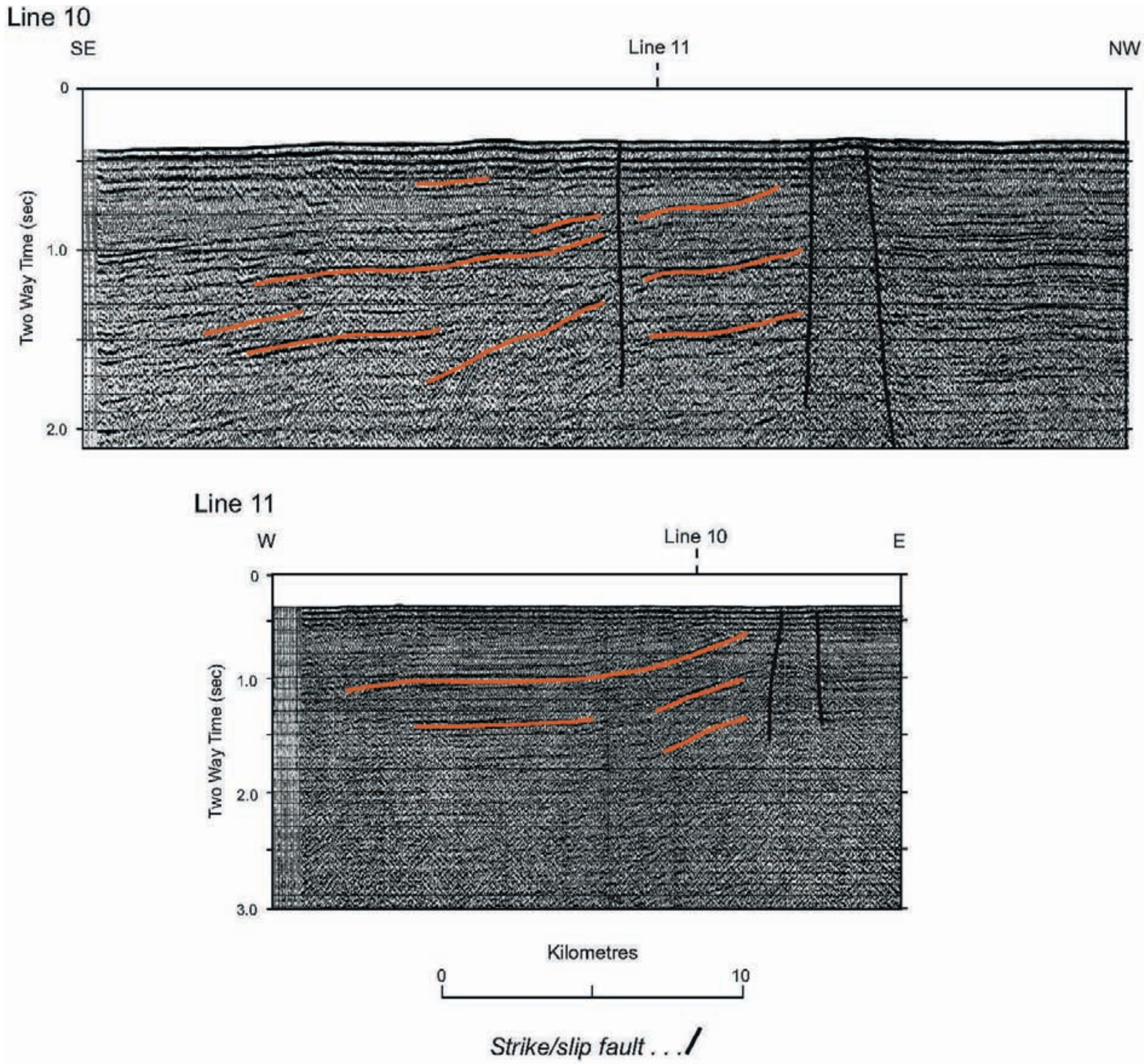


Fig. 7: Seismic lines 10 and 11 that intersect (Fig.1). The dashed line above the profile indicates their intersection. The dipping reflectors on both sections terminate abruptly in a zone with incoherent energy. To the northwest on line 10 and to the east on line 11 there are parallel reflectors. We suggest a fault zone separates the dipping and parallel reflectors.

BRG 11). Its lateral distribution is near the coast of Greenland where carbonates are exposed. Therefore it has been interpreted as being caused by carbonate rocks but not the reefal facies.

Seismic sections BGR 8, 9 and 21, 21A display another seismic unit IV (Fig. 10) at the deepest water depths and corresponding lowest relief seabed. Near Ellesmere Island, on the southwestern end of BGR 8, there is a reflector at a depth of 1 s that rises to the seafloor at the point where the water depths begin to decrease more rapidly. The reflector in unit IV has a constant slope across much of the section, at its eastern limit it turns up relatively sharply before terminating or being truncated at the seafloor. The westernmost end of the BGR 9 shows a similar dipping reflection. The dip direction of reflectors on both these profiles shallows towards Greenland and its depth are similar to horizon A in the Franklin Pierce Basin and to the character of BGR 21 (Fig. 10) off Cape Lawrence. It is interpreted to be a Cretaceous to Tertiary unit. The Tertiary sedimentary rocks cropping out along Kennedy Channel (Fig. 2) would produce a good velocity contrast with the Paleozoic rocks that cropout regionally. One interpretation is that the shape of the reflectors is consistent with a low angle thrust or compression after strike-slip (Fig. 10).

On Huntec 3 profile (Figs. 9, 10), a narrow stratified sedimentary basin occurs adjacent to a steep rise in the seafloor with no penetration on the slope. The character of the Huntec profile is similar to that observed in John Richardson Bay offshore of the mapped faults Fig. 11). Based on the edge of the upturned reflectors on BGR 8 and 9 that we interpret as related to faulting, we continue the interpretation of the basin bounding fault northward to Huntec 3.

On the western end of BGR 8 and on the northern end of BGR 12 there are several curved arrivals that originate at the seafloor or just below it (Fig. 10, A and B). These are interpreted as diffractions that are caused by glacial eratics on the seabed or out of plane if they originate below it. The Huntec profiles in Kennedy Channel show numerous point-source

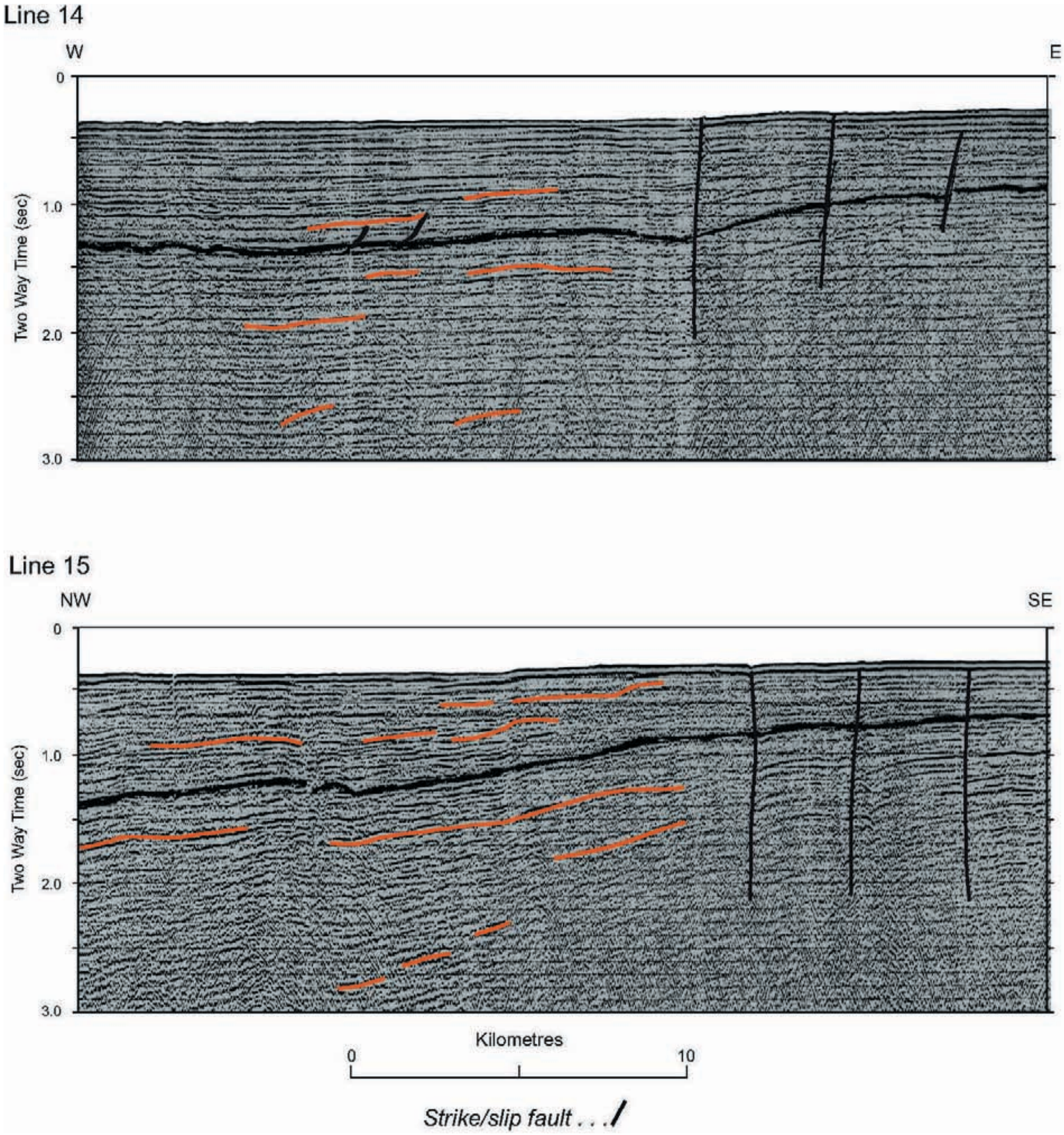


Fig. 8: Distal end of profiles 14 and 15 near the southern end of the Franklin Pierce Basin. The heavy black line is Horizon A from Rendell & Craig (1976). The vertical lines indicate faults at the edge of the basin that can be correlated between the lines.

diffractions generally associated with tills consistent with this explanation. Furthermore, on BGR 12 near the coast of Washington Land where the onshore rocks are un-deformed, these events are unlikely to have been produced by folds in Paleozoic formations.

Area C: Hall Basin

In Hall Basin where Nares Strait widens and the Peterman Glacier enters from the Greenland ice cap, there are eight new BGR profiles (Figs. 12, 13). All but one, BGR 13, have accompanying higher resolution Huntec records. There are significant glacial marine, iceberg turbate and channel deposits on the Huntec sections not seen in Kennedy Channel. For example, a deep basin can be seen on line BGR 14 on the southern section that crosses in front of the Peterman Glacier.

As well as the units identified in Kennedy Channel, a glacial horizon unit V is mapped with the assistance of the Huntec records.

An undulating high-standing seabed is interpreted to be due to the carbonate reefs (unit II) on many of the lines. Unit II has a BSR associated with it as in area B that is well developed on BGR 20 located near the centre of the Hall Basin. The deeper regions have a veneer of glacial deposits and suggest a lateral change to a less resistant rock such as the carbonate unit I. The seismic character of much of BGR 14, between the locations of BGR 18 to 15, is different than the other profiles in the area. Where the profile runs north–south near the coast of Hall Basin, reflections are observed that are not parallel to the seabed and the BSR is not seen. This reflector unit III (Fig. 13) is inferred to be Paleozoic submarine fan deposits (Fig. 2) similar to that observed along the adjacent coast of Greenland.

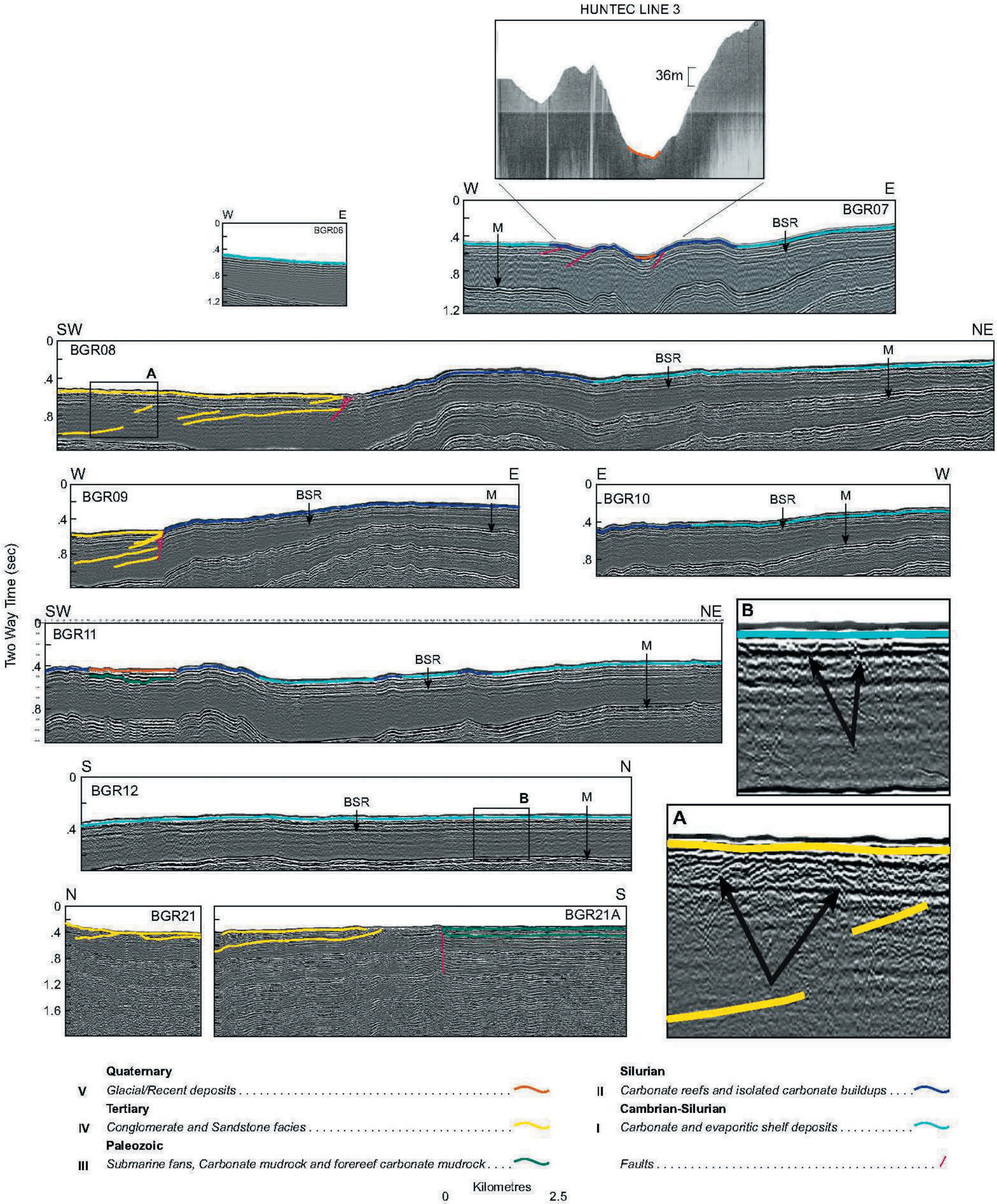


Fig. 10: BGR profiles collected in area B plus a short portion of a Huntec profile. The areas labeled A and B are enlarged to show diffraction patterns that are not indicative of folding. BSR is the abbreviation for bottom simulating reflector and M for water bottom multiple.

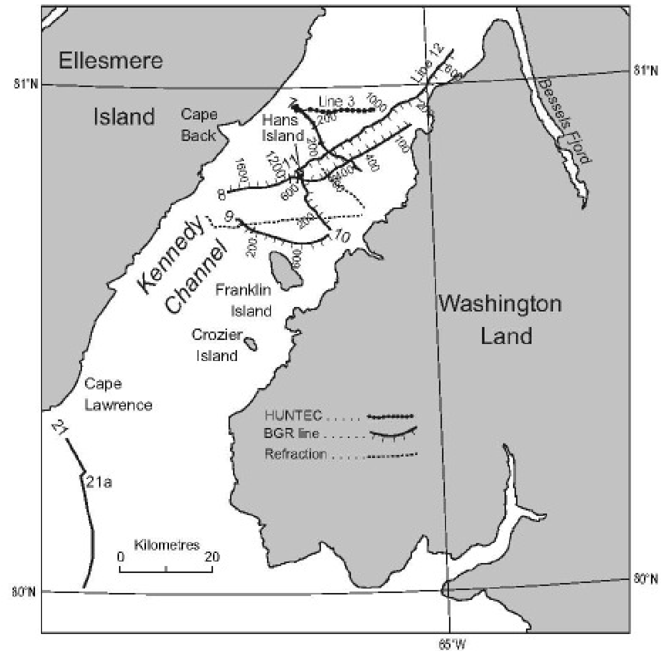


Fig. 9: Relative locations of seismic sections in area B.

BGR 14 is intersected six times by other profiles in the Hall Basin multi-channel seismic survey (Fig. 12), where it crosses BGR 16, a steep-sided valley is observed with a stratified sedimentary fill. This valley is observed at right angles on BGR 16 and on the accompanying Huntec records. The Huntec profile (Fig. 13) displays a steep slope consistent with exposed bedrock. Based on analogy with the Huntec record in John Richardson Bay, and the shape of the bottom and the reflector sequence on the BGR profiles, we suggest a fault either strike-slip or normal here.

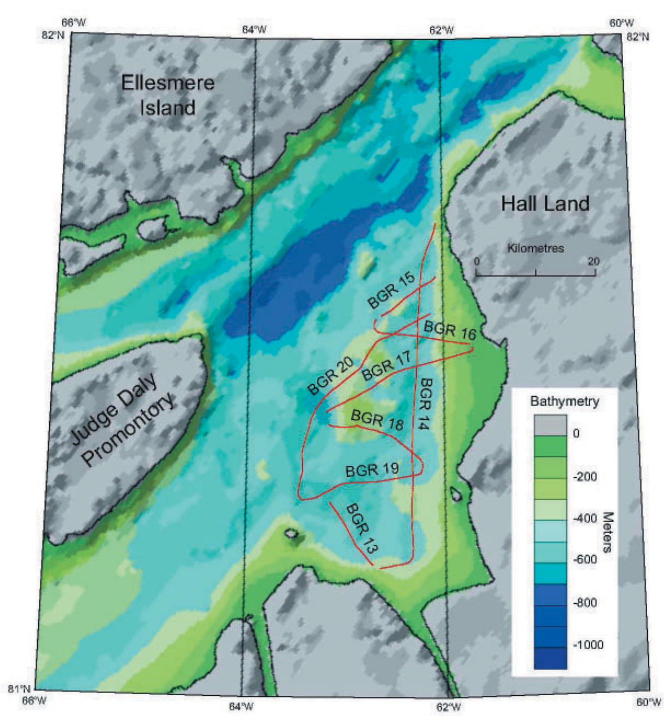


Fig. 12: BGR profiles in area C (for location see Fig. 1) with respect to the gridded bathymetry.

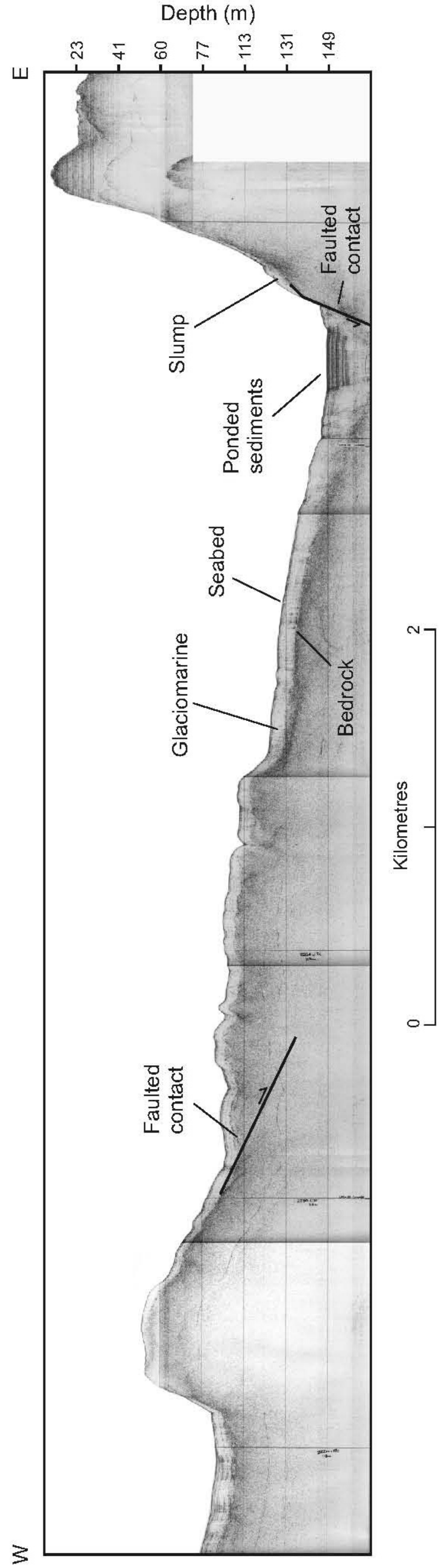


Fig. 11: The Huntec profile in John Richardson Bay (the location is shown in Fig. 1) offshore of two faults that dip towards each other.

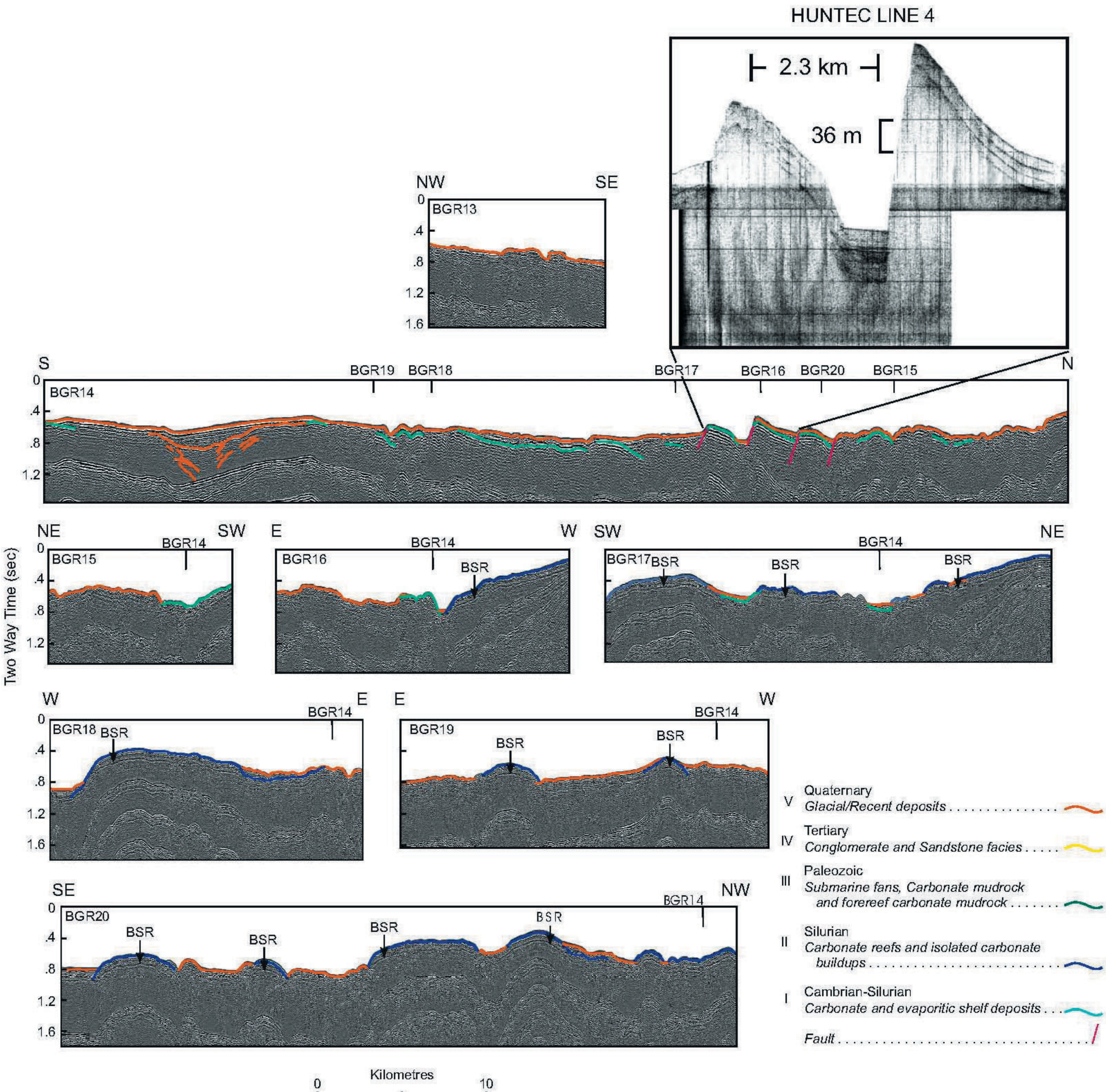


Fig. 13: BGR profiles in area C (for location see Fig. 1) and their interpretation. In addition, a short section of a Huntec profile at the location of proposed fault is presented.

The seismic track plot is overlain on the bathymetry of Hall Basin (Fig. 12). BGR 14 is located along the coast of Hall Land in slightly deeper water than at the centre of our survey. At the intersection of BGR 14 and 16 a short linear low is observed on the bathymetric map where we interpret faulting on the seismic sections. This low is parallel to the major deep offshore of Judge Daly Promontory that is fault controlled and would be consistent with this fault being due to strike-slip. South of the intersection of BGR 14 and 17 there is a broader bathymetric low. Inspection of the BGR profile suggests that this is caused by a carbonate high, terminating eastward. This interpretation is based on the disappearance of the BSR and on the observation of weak parallel reflectors. More easily eroded Paleozoic siliceous rocks are suggested as the cause for the deep on BGR 18 near BGR 14. The central area of the survey C is an irregular bathymetric high. Carbonate reefs cut by glacial valleys are proposed for the origin of this seabed relief. This is consistent with the character of the Huntec profiles and the position of the Peterman Glacier and its probable path offshore.

DISCUSSION

Thrusting in the Dobbin Bay area

In the Dobbin Bay area (Fig. 5), a more detailed description of the complex geology is required in order to place reflection profile 15 in its regional context (Fig. 14). The structural architecture is characterised by both large thrust-faults and km-scale fold structures (Piepjohn et al. in press). The Franklinian deposits are affected by a number of large distinct thrust zones (Dobbin Bay, Parrish Glacier, and Cape Hawks thrusts) that trend approximately ENE–WSW and have SSE-wards transport directions of the hanging walls. In addition, two major synclines are developed in the hanging wall of the Dobbin Bay Thrust (Dobbin Bay Syncline) and in the hanging wall of the Parrish Glacier Thrust (Darling Peninsula Syncline). Both synclines are deep-seated and contain the entire succession of the Franklinian Basin, including the Early Devonian Eids Formation in their cores. The basal décollement or floor thrust of the Eurekan deformation must be situated at 5-6 km depth in this area (Piepjohn et al. in press).

The style of the thrust faults is different (Fig. 14). The Dobbin Bay Thrust is a steeply NNW-dipping fault that cuts through the connecting anticline between the Dobbin Bay and Darling Peninsula synclines. Continuous shortening following the formation of the large Darling Peninsula Syncline (and anticline) probably caused it. Along strike, the Dobbin Bay Thrust seems to cut obliquely through the Franklinian pile of sedimentary formations: in the east, it affected mainly Vendian to Lower Ordovician deposits, but towards the west, it seems to climb up stratigraphically into Ordovician to Silurian deposits (Figs. 5, 14).

The Parrish Glacier Thrust (Figs. 5, 6), in contrast, is characterised by an approximately 25° dip towards the NNW. It represents a major thrust-fault of the Eurekan Fold-and-Thrust Belt. This thrust carried the entire, 6 km thick pile of Franklinian Basin deposits ESE-wards over the Tertiary outcrops in the Allman Bay area (de Freitas et al. 1997, de Freitas & Sweet 1998, Piepjohn et al. 1998, Piepjohn et al. in press). The Parrish Glacier Thrust is oriented parallel to the bedding of the sediments in the hanging wall. This thrust represents the major Eurekan décollement or floor thrust, respectively, although other thrusts and detachments faults (Cape Hawks Thrust, Allman Bay Reverse Fault, Cape Fields Thrust) indicate further continuous shortening (foreland propagating) in the foot-wall of the Parrish Glacier Thrust. Significantly, the involvement of Upper Cretaceous to Lower Tertiary strata in the thrusting along the Parrish Glacier Thrust indicates that it clearly represents a Eurekan structure (de Freitas et al. 1997, de Freitas & Sweet 1998, Piepjohn et al. 1998).

The geology north of the Parrish Glacier Thrust is much more complex, a major problem is the structural difference in the areas west and east of Dobbin Bay (Fig. 5). The geology exhibits a simple geometry with sub-horizontal strata in the hanging wall of the Parrish Glacier Thrust that become steeper towards the surface termination of the Parrish Glacier Thrust in the SSE (Fig. 14). Whereas, the geology of Darling Peninsula is dominated by the deep-seated Darling Peninsula Syncline and a number of en-échelon thrust-faults that represent the transition of the approximately E–W trending Eurekan structures to their NE–SW trend parallel to Nares Strait northeast of Darling Peninsula. Thus, the core of the huge Dobbin Bay Syncline east of Dobbin Bay faces sub-horizontal strata west of Dobbin Bay along strike (Fig. 5).

Unfortunately, the critical area for solving this contradiction is covered by the waters and ice of Dobbin Bay. Further west of Dobbin Bay, however, the Dobbin Bay Syncline is the only large fold-structure in the hanging wall of the Parrish Glacier Thrust instead of two km-scale synclines on Darling Peninsula.

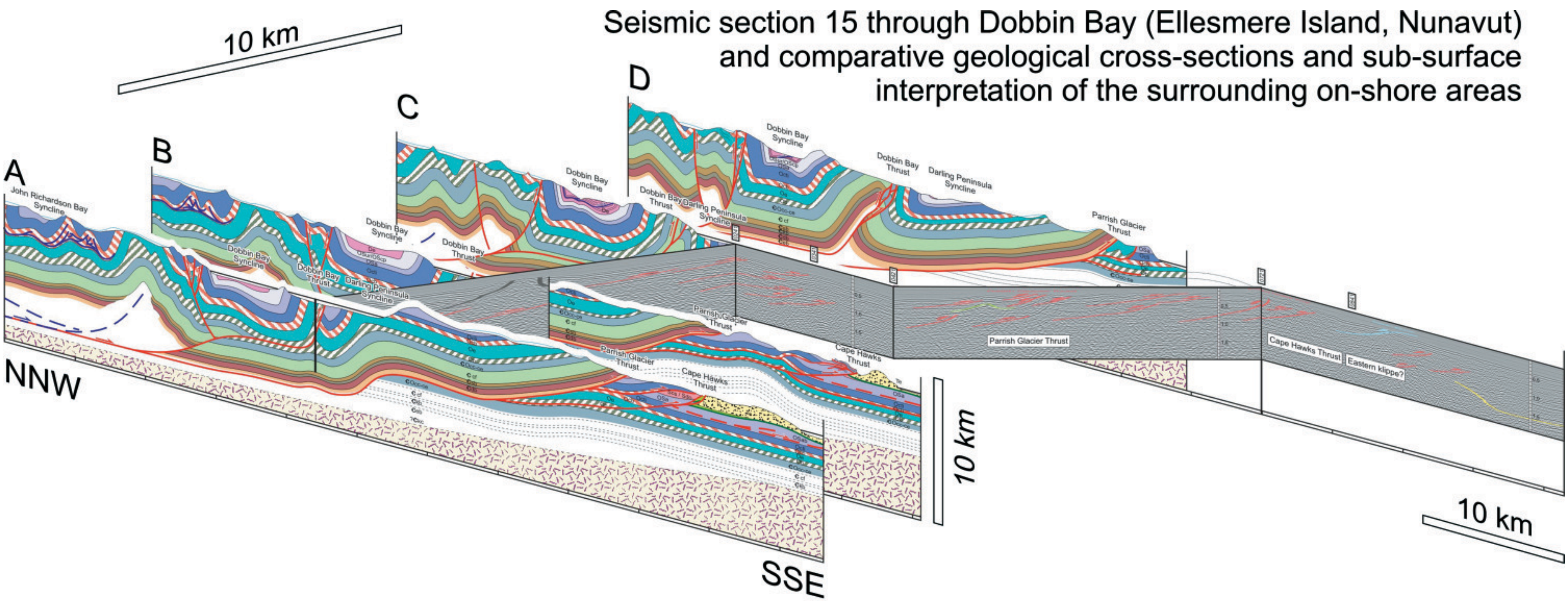
A solution of this three-dimensional structural puzzle with missing pieces below the waters of Dobbin Bay may be a possible westward continuation of the Dobbin Bay Thrust (Fig. 5). The geological map east of Dobbin Bay suggests that the axis of the Darling Peninsula Syncline is not horizontal but steepens both towards the ENE and WSW with a maximum depression 10 km east of Dobbin Bay. It is most likely, that the Darling Peninsula Syncline wedges out dramatically towards the west, and it is possible that the Dobbin Bay Thrust continues westwards into the inner part of Dobbin Bay. As the Dobbin Bay Thrust possibly climbs-up section towards the west, it may be that it passes from the northern limb of the Darling Peninsula Syncline westwards into the southern limb of Dobbin Bay Syncline (Fig. 14).

Further west (outside map on Fig. 5), the Dobbin Bay Thrust seems to die out, because there is no indication of a thrust fault within the Dobbin Bay Syncline in the areas west of Dobbin Bay. The rapid changes in the amount of crustal shortening along-strike, as well as the formation of en-échelon oriented synclines and thrusts, is restricted to this area, where the trend of the Eurekan structures turns from E–W north of Princess Marie Bay to a NE–SW trend (parallel to Nares Strait).

Extent and significance of the Franklin Pierce Basin

Based on the available seismic profiles, interpolating between them with bathymetric soundings and by extrapolating the onshore geology, an interpretation of the offshore was developed (Fig. 15). Seismic section 15 (Fig. 6) shows the thrusted section on Ellesmere Island is spatially followed offshore by a wedge-shaped sedimentary basin. In Kane Basin faulting controls the distal end of the Tertiary depot centre. The Tertiary Franklin Pierce Basin is continued north into Kennedy Channel based on the similarity of the dipping reflections, seabed characteristics and onshore Tertiary outcrops. As the basin is traced into Kennedy Channel its eastward termination as seen on BGR 8 and 9 is in increasingly deeper water. To the north we believe the facies changes to a less resistant rock. Onshore at Cape Back the conglomerates are replaced by friable sandstones. In Kennedy Channel the basin follows the bathymetric deep that extends directly north of the sedimentary deposits mapped in Kane Basin.

More difficult to justify is the continuation of the basin to the north of Hans Island on BGR 6. The strong BSR and poor penetration make it difficult to observe the basin on the reflection profiles. The wide-angle reflection/refraction profiles do not have ray paths that cross the entire Strait. However, there is a receiver on Ellesmere Island that indicates the average velo-



Te			Tertiary
			Cretaceous
De	Eids Formation		Devonian
OSur/OScp	Cape Philipps Formation		Ordovician / Silurian
OSa	Allen Bay Formation		
Octi	Thumb Mountain / Irene Bay formations		Ordovician
Ocb	Bay Fiord Formation		
Oe	Eleanor River Formation		
Ob	Baumann Fiord Formation		
€Occ-ce	Cape Clay /Christian Elv formations		Cambrian / Ordovician
€ cf	Cass Fiord Formation		Cambrian
€sb	Scoresby Bay Formation		
€kb	Kane Basin Formation		
€db	Dallas Bugt Formation		
Veb	Ella Bay Formation		Vendian
Vkc	Kennedy Channel Formation		
	Crystalline basement		Proterozoic

Fig. 14: Three-dimensional structural fence-diagram and sub-surface interpretation of the Dobbin Bay area (for locations of cross sections and seismic profile 15 see Fig. 5). Note the congruence of the interpreted thrusts in the seismic profile and the exposed thrusts in the geological cross-sections. Note also the climbing up-section of the Dobbin Bay Thrust towards the west and the consistent drop of the interpreted basement-surface below the Eurekan floor-thrust (Parrish Glacier Thrust).

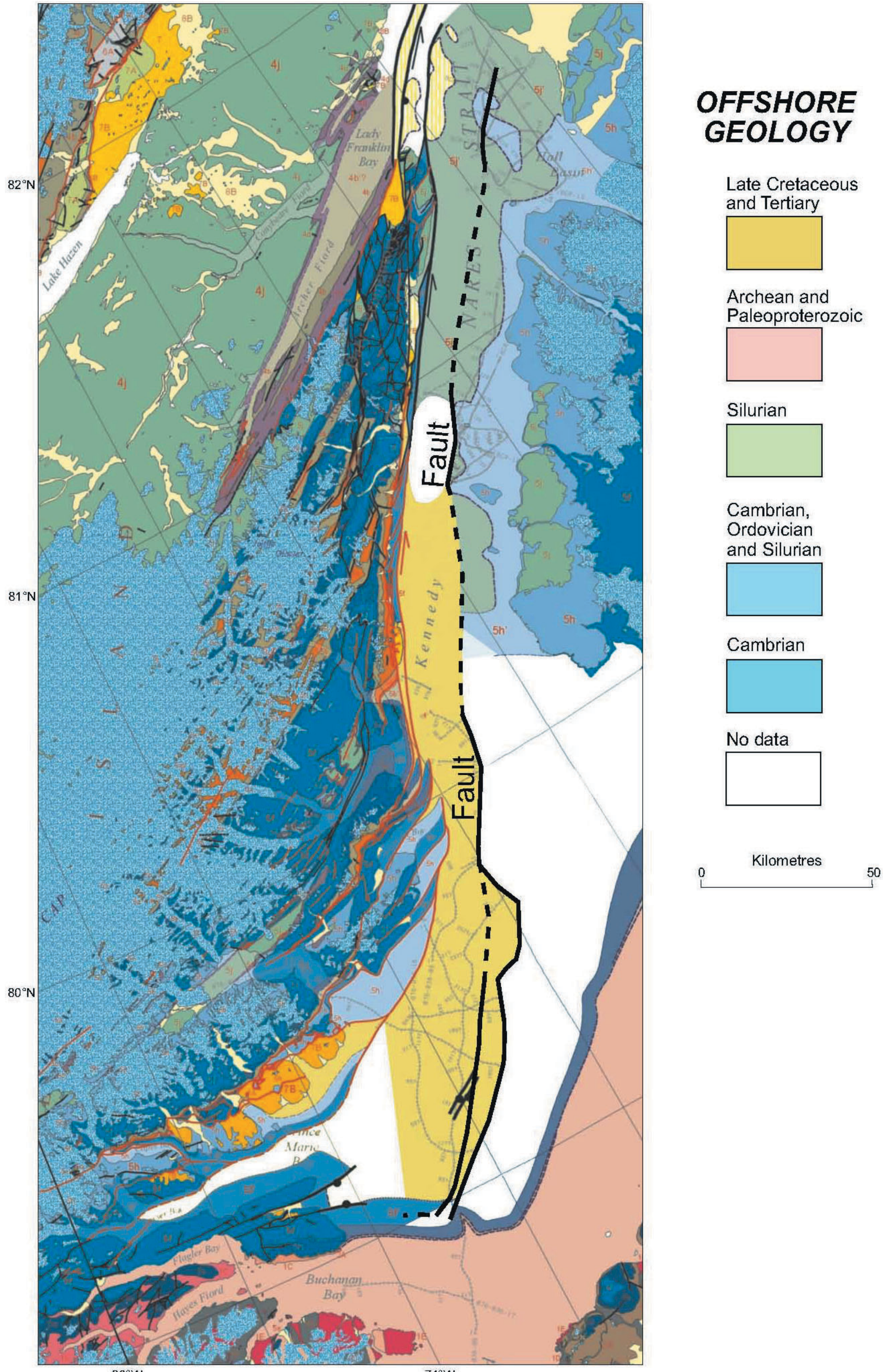


Fig. 15: Leading edge of a linked strike-slip fault system. For more detailed legend for the onshore geology see Figure 2.

city of 5.9 km s^{-1} at the seafloor (FUNCK et al. 2006). It is possible that a weak Tertiary rock existed here and was subsequently eroded consistent with the increasing water depths (Fig. 2).

Onshore faults are traced over tenths of km, not the hundred we indicate in the offshore (Fig. 15). Our seismic data are still too limited and sporadic to determine if there is a continuous fault. More likely a linked fault system exists. Anastomosing broadly contemporaneous faults that line up over a much larger scale than the individual faults (DAVISON 1994) could explain the linear feature that we observe. In map view, strike-slip linkage faults tend to be narrower and more continuous than those in contractional or extensional regimes (ENGLAND & JACKSON 1989). In cross-section strike-slip faults are steeply dipping similar to those observed on the seismic profiles in Kane Basin (Fig. 16). Based on the available information, the offshore sedimentary basin in cross-section is asymmetrical and fault bounded from Kane Basin to at least the southern portion of Kennedy Channel. In plan view a linear basin is mapped parallel to the coast from north of Buchanan Bay to Hans Island (Fig. 15). The available seismic profiles indicate that the Franklin Pierce Basin terminates near Buchanan Bay (Fig. 15). Due to a data gap we cannot relate the seismic profiles described in this paper to the seismic sections described by NEBEN et al. (2006) to the south, so we cannot speculate if or how the basin systems are linked.

A question that arises is how it is possible for a narrow fault zone to separate areas with significant differences in folding and faulting. In order to examine this problem we looked to studies in other orogens such as the Cordillera of western Canada. Temperature is the primary control of the lithospheric strength and its ability to deform. For example a cold craton can be an order of magnitude stronger than a warm thin crust (HYNDMAN et al. 2005). Greenland adjacent Nares Strait shows no evidence of deformation since the Ellesmerian Orogeny in the lower Paleozoic. In contrast, on Ellesmere Island the developing Sverdrup Basin thinned the crust from the Carboniferous to the Cretaceous. In addition, the emplacement of a large Cretaceous magmatic province that includes significant sections of Ellesmere Island and Arctic Ocean (FORSYTH et al. 1986, TARDUNO et al. 1998) could have heated the crust.

Important constraints on the deformation are provided by the tectonic regime (e.g., HYNDMAN et al. 2005). In the Nares Strait area this information is based on plate reconstructions controlled by magnetic anomalies that surround Greenland. There are mapped magnetic lineations in the Arctic Ocean, the Norwegian and Greenland seas, the North Atlantic and the Labrador Sea. In the introduction of this volume (REID et al. 2006) several tectonic models were compared that are all consistent with about 200 km of strike-slip motion being followed by the magnitude of compression. The stability field of the triple junction to the north of Greenland is consistent with Ellesmere Island overriding the Greenland plate (JACKSON & KOPPEN 1985). The interpreted faults on the BGR 8 and 9 support this scenario.

The origin of the Franklin Pierce Basin based on the plate reconstructions is in harmony with features observed on the seismic profiles. Strike-slip motion followed by thrusting is predicted. If trans-current motion was followed by compression, the faults seen on the BGR 8, 9 and 21in the strait could be produced. The offshore Franklin Pierce Basin is a narrow linear feature parallel to the mountain range along the coast of Ellesmere Island. The cartoon in Figure 16 shows the configuration of the basin and its relationship to the deformation on Ellesmere Island. If a linked strike-slip fault system existed in the region (DAVISON 1994) the stem and petal faults of the flower structure (Fig. 16) could control the coast and the distal edge of the offshore basin respectively. The position of the stem fault along the coast is near the position of the Parrish Glacier Thrust, the major thrust fault of the Eurekan deformation. The plate reconstructions suggest that strike-slip motion would be followed by convergence. If this thrust reactivated the older zones of weakness, it would conceal evidence onshore for transcurrent offsets.

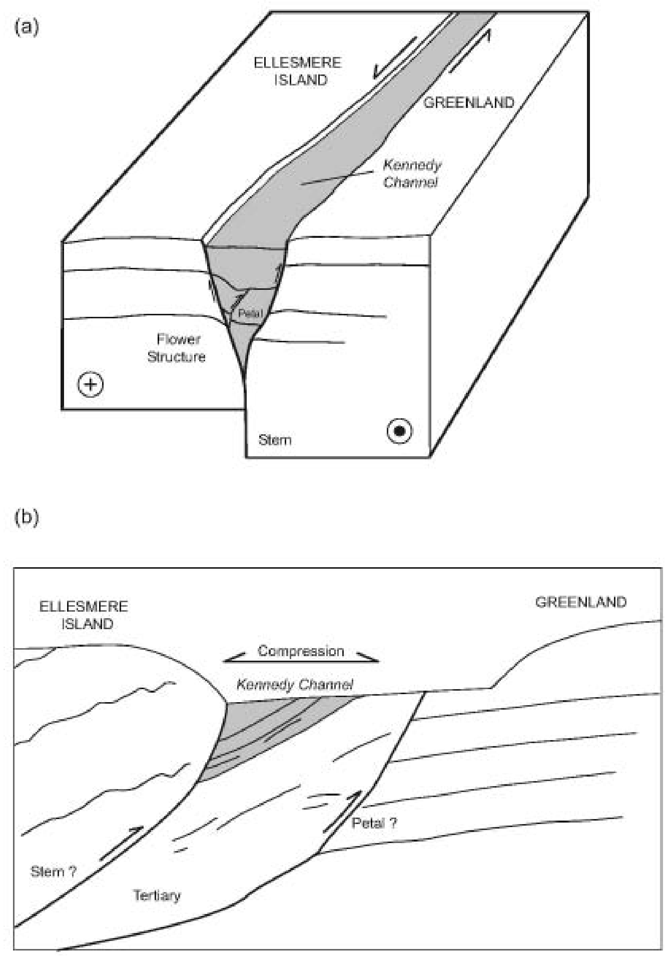


Fig. 16: Carton showing the processes hypothesized to create the offshore sedimentary basin in northern Nares Strait. Section (a) shows the initial strike-slip regime. Section (b) is the second stage that indicates the affect of compression of a feature created by strike-slip.

Evidence that the offshore basin is associated with a major tectonic feature is the Free Air gravity low of up to -120 mGal (JACKSON & KOPPEN 1985). The -100 mGal contour extends from just north of the Bache Peninsula to beyond the northern end of Nares Strait. JACKSON & KOPPEN (1985) and STEPHENSEN (2003) note that the low cannot be due to the water and sedimentary basin alone, but must be related to a deeper crustal feature. The cartoon (Fig. 16) illustrates the relationship of the surface faulting to a postulated crustal structure that is consistent with this section of Nares Strait forming a plate boundary. This would be in harmony with the plate reconstruction models that move Greenland as an independent plate, with the northern portion of Nares Strait as the plate boundary with North America.

CONCLUSIONS

Seismic reflection profiles and bathymetric measurements in the fjords of northeast Ellesmere Island and Nares Strait were examined for evidence of lateral offset and Eurekan folds and thrust. Five seismic units were distinguished in the Strait that represent: the lower Paleozoic carbonates (unit I); a reefal complex (unit II); the Paleozoic flysch (unit III); the dipping sedimentary strata of the Franklin Pierce Basin (unit IV) of possible Late Cretaceous to Tertiary age; and glacial deposits (unit V). By comparing the onshore geology and with a seismic profile in Dobbin Bay, we identified the point where the Eurekan structures change direction from approximately perpendicular to parallel with Nares Strait.

In this portion of the Strait, a basin that is wedge-shaped in profile and elongated in plan view is observed on the seismic profiles. Its probable age is Late Cretaceous to Tertiary based on onshore exposures. The distal eastern edge of the basin is shown to be fault controlled. Unit IV interpreted to be Late Cretaceous to Tertiary sedimentary rocks is faulted against the un-deformed lower Paleozoic carbonates of the Greenland unit II. As well the abrupt edge of the basin adjacent Ellesmere Island, north of Bache Peninsula, is fault controlled based on data from two seismic sections. We hypothesize that the displacement could have occurred on a stem fault of a strike-slip fault system that has been overprinted by shortening in the compressional stage of the Eurekan Orogeny. In summary, we present evidence for faults (Fig. 15) that underlie the northern portion of Nares Strait as predicted by TAYLOR (1910).

ACKNOWLEDGMENTS

The program was initiated under the auspices of the German/Canadian Bilateral Agreement for co-operation in Science and Technology. This project was enhanced by the support of the Canadian Coast Guard. We thank Martin Bergmann scientific liaison for the Canadian Coast Guard for his helpful and consistent backing of the proposal. The Master Stewart Klebert, the officers and crew are grateful acknowledged for enthusiastic and competent assistance. Borden Chapman and Larry Johnston (technical support from the Geological Survey of Canada) efforts to keep the scientific equipment in operation in ice-infested waters were appreciated.

References

Davison, I. (1994): Linked fault systems: Extensional, strike-slip and contractional, Chapter 6.- In: P.L. Hancock (ed), Continental deformation, Pergamon Press, 121-142.

Dawes, P.R. (1999): A review of geoscientific exploration and geology of the Kane Basin region of Greenland, central Nares Strait.- Danmark Grønlands Geol. Unders. Rap. 32: 1-35.

Dawes, P.R. & Kerr, J.W. (1982): Nares Strait and the drift of Greenland: a conflict in Plate Tectonics.- Meddel. om Grønland, Geosci. 8: 1-382.

De Freitas, T., Mayr, U., Harrison, J.C., Piepjohn, K. & Tessensohn, F. (in press): Geology, Dobbin Bay, Ellesmere Island, Nunavut, Geol. Survey Canada Map (scale 1:125,000).

De Freitas, T. & Sweet, A.R. (1998): New observations on the geology of eastern Ellesmere Island, Canadian Arctic, part I: Structure and stratigraphy in the vicinity of Franklin Pierce and Allman Bays.- Geol. Survey Canada, Current Res. 1998-X.

De Freitas, T., Sweet, A.R. & Thorsteinsson, R. (1997): A problematic Early Cretaceous age for the conglomerates that have been assigned to the Eureka Sound Group, east-central Ellesmere Island, Arctic Archipelago.- Geol. Survey Canada, Current Res. 1997-E: 21-32.

England, P. & Jackson, J.A. (1989): Active deformation of the continents: A Review.- Earth Planet. Sci. Letters 17: 197-225.

Forsyth, D.A., Moriel, A., L'Huissier, P., Asudeh, I & Green, A.G. (1986): Alpha Ridge and Iceland-products of the same plume.- J. Geodynamics 6: 197-214.

Funck, T., Dehler, S., Jackson, H.R., Salisbury, M.H. & Reid, I.D. (2006a): A refraction seismic image of the sediments in Kennedy Channel, northern Nares Strait.- Polarforschung 74: 41-50.

Funck, T., Jackson, H.R., Dehler, S.A. & Reid, I.D. (2006b): A refraction seismic transect from Greenland to Ellesmere Island, Canada: The crustal structure of southern Nares Strait,.- Polarforschung 74: 97-112.

Funck, T., Jackson, H.R., Dehler, S.A. & Reid, I.D. (2003): The crustal structure of Nares Strait derived from seismic refraction.- Internat. Conf. Arctic Margins, abstracts, Sept. 30 – Oct. 3, 2003 Dartmouth, N.S., p. 65.

Harrison, J.C. (2006): In search of the Wegener Fault: Re-evaluation of strike-slip displacements along and bordering Nares Strait.- Polarforschung 74: 129-160.

Harrison, J.C., Brent, T.A. & Oakey, G.N. (2006): Bedrock geology of the Nares Strait region of Arctic Canada with explanatory text and GIS content.- Geeol. Surv. CCanada, Open File 5278: 1-61.

Higgins, A.K., Ineson, J.R., Peel, J.S., Surlyk, F. & Sonderholm, M. (1991): Cambrian to Silurian basin development and sedimentation, North Greenland, Chapter 7.- In: H.P. Trettin (ed), Geology of the Innuitian Orogen and Arctic platform of Canada and Greenland, Geol. Survey Canada, Geology of Canada, no. 3 (also Geol. Soc. America, The Geology of North America E): 111-161.

Higgins, A.K., Friderichsen, J.D. & Soper, N.J. (1981): The North Greenland fold belt between Johannes V. Jensen Land and eastern Nansen Land.- Grønlands Geol. Unders. Rep. 106: 35-45.

Hyndman, R.D., Fluck, P., Mazzotti, S., Lewis, T., Ristau, J. & Leonard, L. (2005): Constraints on current tectonics of the northern Canadian Cordillera.- Canadian J. Earth Sci. 42: 1117-1136.

Jackson, H.R. & Koppen, L. (1985): The Nares Strait gravity anomaly and its implications for crustal structure.- Canadian J. Earth Sci. 22: 1322-1328.

Klaper, E.M. (1990): The mid-Paleozoic deformation in the Hazen fold belt, Ellesmere Island, Arctic Canada.- Canadian J. Earth Sci. 27: 1359-1370.

Kerr, J.W. (1973a): Geological map of Dobbin Bay, District of Franklin.- Geol. Survey Canada Map 1358A (scale 1:250,000).

Kerr, J.W. (1973b): Geological map of Kennedy Channel and Lady Franklin Bay, District of Franklin.- Geol. Surv. Canada Map 1359A (scale 1:250,000).

Mayr, U. & de Vries, C.D.S. (1982): Reconnaissance of the Tertiary structures along Nares Strait Ellesmere Island, Canadian Arctic Archipelago.- In: P.R. Dawes & J.W. Kerr (eds), Nares Strait and the Drift of Greenland: a conflict in plate tectonics.- Meddel. om Grønland Geosci. 8: 167-175.

Oakey, G., Ekholm, S. & Jackson, H.R. (2001): Physiography of the Innuitian region, Canadian and Greenland Arctic.- Geol. Survey Canada Open file 3393d (scale 1:1,500,000).

Okulitch, A.V. & Trettin, H.P. (1991): Late Cretaceous – Early Cretaceous deformation, Arctic Islands; Chapter 17.- In: H.P. Trettin (ed), Geology of the Innuitian Orogen and the Arctic Platform of Canada and Greenland, Geol. Survey Canada, Geology of Canada, no. 3 (also Geol. Soc. America. The Geology of North America, E): 469-490.

Piepjohn, K, Tessensohn, F., Harrison, C. & Mayr, U. (1998): Involvement of a Tertiary foreland basin in the Eurekan foldbelt deformation, NW coast of Kane Basin, Ellesmere Island, Canada.- Polarforschung 68: 101-110.

Piepjohn, K., Gosen, W. von, & Tessensohn, F. (in press): The Ellesmerian Fold-and-Thrust Belt (Ellesmere Island, Nunavut) and its Eurekan overprint.- Geol. Survey Canada Bull.

Rendell, G. & Craig, R.W. (1976): Seismic survey Report for Kane Basin, offshore of Ellesmere Island.- Dept. Indian and Northern Affairs Rep. 076-09-10-34: 1-19.

Roest, W.R. & Srivastava, S.P. (1989): Seafloor spreading in the Labrador Sea: A new reconstruction.- Geology 17: 1000-1003.

Stephensen, R.A. (2003): Gravity modelling in the Innuitian on north-eastern Ellesmere Island.- Internat. Conf. Arctic Margins, Sept. 30-Oct. 3, 2003, abstract, Dartmouth N.S., p. 67.

Srivastava, S.P. (1985): Evolution of the Eurasian Basin and its implications to the motion of Greenland along Nares Strait.- Tectonophysics 114: 29-53.

Stuart Smith, J.H. & Wennekers, J.H.N. (1979): Geology and hydrocarbon discoveries of Canadian Arctic Islands.- Amer. Assoc. Petrol. Geol. Bull.

61: 1-27.
Tarduno, J.A., Brinkman, D.B., Renne, P.R., Cottrell, R.D., Scher, H. & Castillo, P. (1998): Evidence for extreme climatic warmth from Late Cretaceous Arctic vertebrates.- Science 282: 2240-2244.
Taylor, F.B. (1910): Bearing on Tertiary Mountain belts and on the origin of the earth's plan.- Bull. Geol. Soc. Amer. 21: 179-226.
Thorsteinsson, R. & Tozer, E.T. (1960): Summary account of structural history of the Canadian Arctic Archipelago.- Geol. Survey Canada Pap. 60-7, 1-23.
Thorsteinsson, R. & Tozer, E.T. (1970): Geology of the Arctic Archipelago.- In: R.J.W. Douglas (ed), Geology and Economic Minerals of Canada, Geol. Survey Canada, Economic Geology Rep. 1: 547-590.
Trettin, H.P. (1987): Pearya: a composite terrane with Caledonian affinities in northern Ellesmere Island.- Canadian J. Earth Sci. 24: 224-245.
Trettin, H.P. (1991): Tectonic Framework; Chapter 4.- In: H.P. Trettin (ed), Geology of the Innuitian Orogen and Arctic platform of Canada and Greenland, Geol. Surv. Canada, Geology of Canada, no. 3 (also Geol. Soc. Amer., The Geology of North America E): 59-66.
Trettin, H.P. & Balkwill, H.R. (1979): Contributions to the tectonic history of the Innuitian Province, Arctic Canada.- Canadian J. Earth Sci. 16: 748-769.