26. GEOLOGICAL/GEOPHYSICAL STUDIES IN BAFFIN BAY AND SCOTT INLET-BUCHAN GULF AND CAPE DYER-CUMBERLAND SOUND AREAS OF THE BAFFIN ISLAND SHELF

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Abstract

Marine geological and geophysical studies on the Baffin Island shelf in 1978 by the Atlantic Geoscience Centre were concentrated in the Scott Inlet oil seep area and in the Buchan Gulf area on the northeastern part of the shelf, and between Cape Dyer and Cumberland Sound on the southeastern part of the shelf.

Upper Cretaceous (Senonian) marine calcareous siltstones underlie central and inner Buchan Gulf Trough. These, and possibly older strata, probably underlie Tertiary rocks offshore from Scott Inlet and may locally outcrop. Pre-Tertiary strata flanking a structural high at the outer part of the south wall of Scott Trough are a probable source of hydrocarbon seepage. Gravity and magnetic data at Scott Inlet indicate a thick sedimentary section, whereas the Buchan Gulf section probably is thinner.

Earthquake activity in northern Baffin Island and Baffin Bay was monitored with three ocean bottom seismometers in the Bay and three temporary seismographs onshore. At least forty events were detected in ten days.

Studies of the shelf south of Cape Dyer further delineated the extent of various rock units and outlined a diapiric ridge structure that extends over a distance in excess of 80 km.

Introduction

Geological and geophysical programs to extend on-going studies of the geology of the Baffin Island continental shelf and to measure seismicity in Baffin Bay were carried out from Bedford Institute of Oceanography's **C.S.S. Hudson** during September 18 – October 23, 1978 (cruise 78-029). The shelf studies were concentrated in two main areas: 1) in the vicinity of the oil seep offshore from Scott Inlet and in the adjoining Buchan Gulf area on the northeastern part of the shelf, and 2) between Cape Dyer and Cumberland Sound on the southeastern part of the shelf. Geophysical studies and a few sample stations were carried out enroute between the two main study areas on the shelf. Cruise track and stations occupied are indicated in Figures 26.1, 26.2. The seismicity studies were carried out with ocean bottom seismometers placed off the shelf east of Pond Inlet in conjunction with Earth Physics Branch shore stations.

The continental shelf studies were directed toward 1) delineating the areal extent and structural relationships of the main bedrock units, 2) obtaining information as to the age, lithology and physical properties of these rocks, and 3) attempting to identify the geological origin of the oil seep in Scott Inlet area more closely. These studies were carried out by means of conventional shallow seismic and Huntec high resolution reflection profiling, bathymetric, magnetic, gravity and sidescan sonar profiling, and seismic refraction measurements, all in conjunction with geologic sampling using the BIO underwater electric drill and by dredging. The techniques employed have been outlined previously by MacLean et al. (1977, 1978). Bedrock sampling in the Cape Dyer – Cumberland Sound area was considerably hampered by bad weather.

Vibracoring, piston coring, grab sampling and bottom photography were carried out along with the acoustic profiling to obtain additional reconnaissance data on the unconsolidated sediments.

Scott Inlet – Buchan Gulf Area

A submarine trough which is cut some 700 m into the predominantly sedimentary rocks of the shelf extends seaward from the mouth of Scott Inlet fiord. A similar trough extends across the shelf from the mouths of Royal Society, Cambridge, and adjacent fiords collectively referred to as the Buchan Gulf area, 90 km north of Scott Inlet. In 1976 an oil seep was discovered at Scott Inlet (Loncarevic and Falconer, 1977). During further studies in 1977 oil slicks were observed north of Scott Inlet (Levy, 1978). This, plus the structural similarity of Buchan Trough to Scott Trough suggested that oil might also be seeping at Buchan Trough.

Regional interpretations of the geology and the free air gravity in the Scott Inlet – Buchan Gulf area are shown in Figures 26.3, 26.4. The coastal landmass is composed of Precambrian metamorphic complexes, locally mantled by Quaternary glacial and marine foreland deposits (Jackson et al., 1979). Offshore the general bedrock pattern, which is the subject of this paper, is one of sedimentary rocks underlying most of the shelf and the occurrence of basement highs near the shelf edge. The stratigraphic succession offshore is known to include Upper Cretaceous (Senonian) rocks in the floor of Buchan Trough and Tertiary (late Eocene) strata in the walls of Scott Trough. These age assignments are from palynological studies of drill cores and dredge samples by G.L. Williams (pers. comm., 1978, 1979).

Studies in the Scott Inlet area in 1978 confirmed the presence of a structural high outcropping at the south wall of the submarine trough and supported its association with hydrocarbon seepage as reported by MacLean (1978) from reconnaissance of the area in 1977. In detail, the high consists of two basement ridges separated at the surface by strata that occupy a small half-graben (Fig. 26.5). Two short drill cores of metamorphic rocks were recovered from the westernmost of the ridges (Fig. 26.3, 26.5, Table 26.1). Positive magnetic and gravity anomalies are associated with

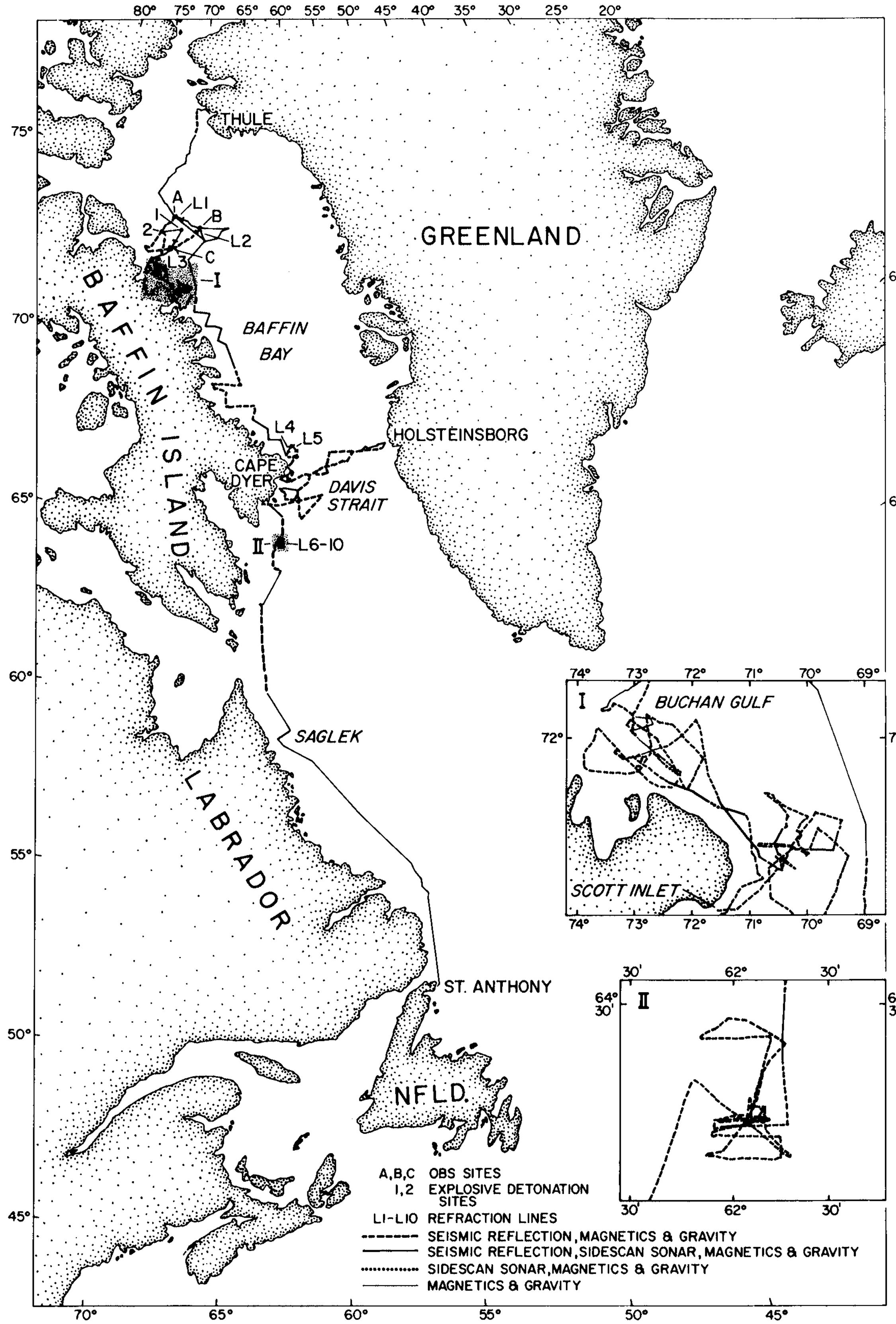

Figure 26.1. *Tracks showing types of underway data collected and ocean bottom seismometer sites. Cruise 78-029.*

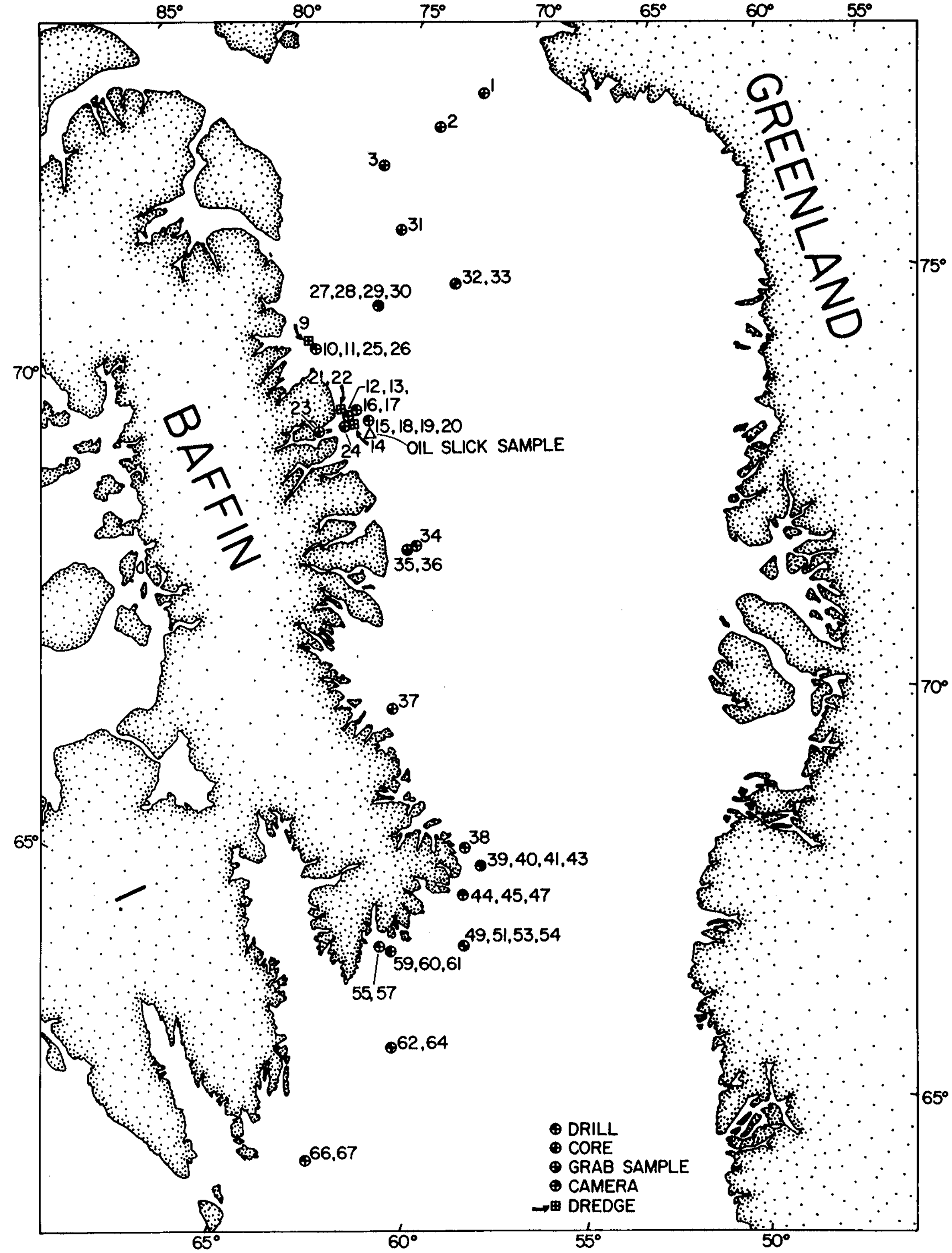

Figure 26.2. *Geological stations occupied during cruise 78-029.*

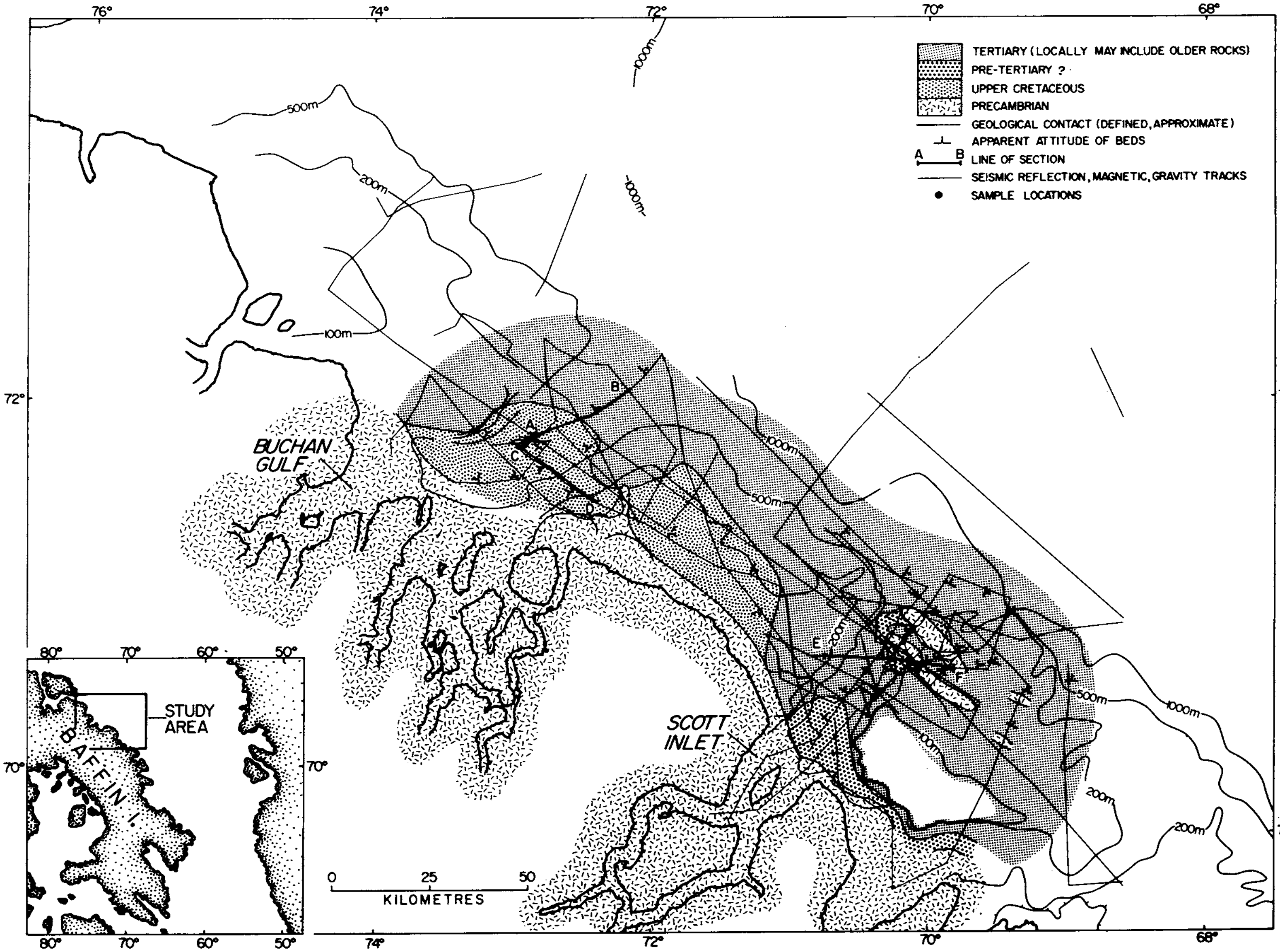

Figure 26.3. *Geological map of Scott Inlet – Buchan Gulf offshore area. Control tracks (seismic reflection, together with gravity and magnetic profiles) and sample stations are indicated. The unstippled area within the 100 m bathymetric contour east of the entrance to Scott Inlet fiord contains shallow water (Hecla and Griper Banks) and so far has not been geophysically surveyed.*

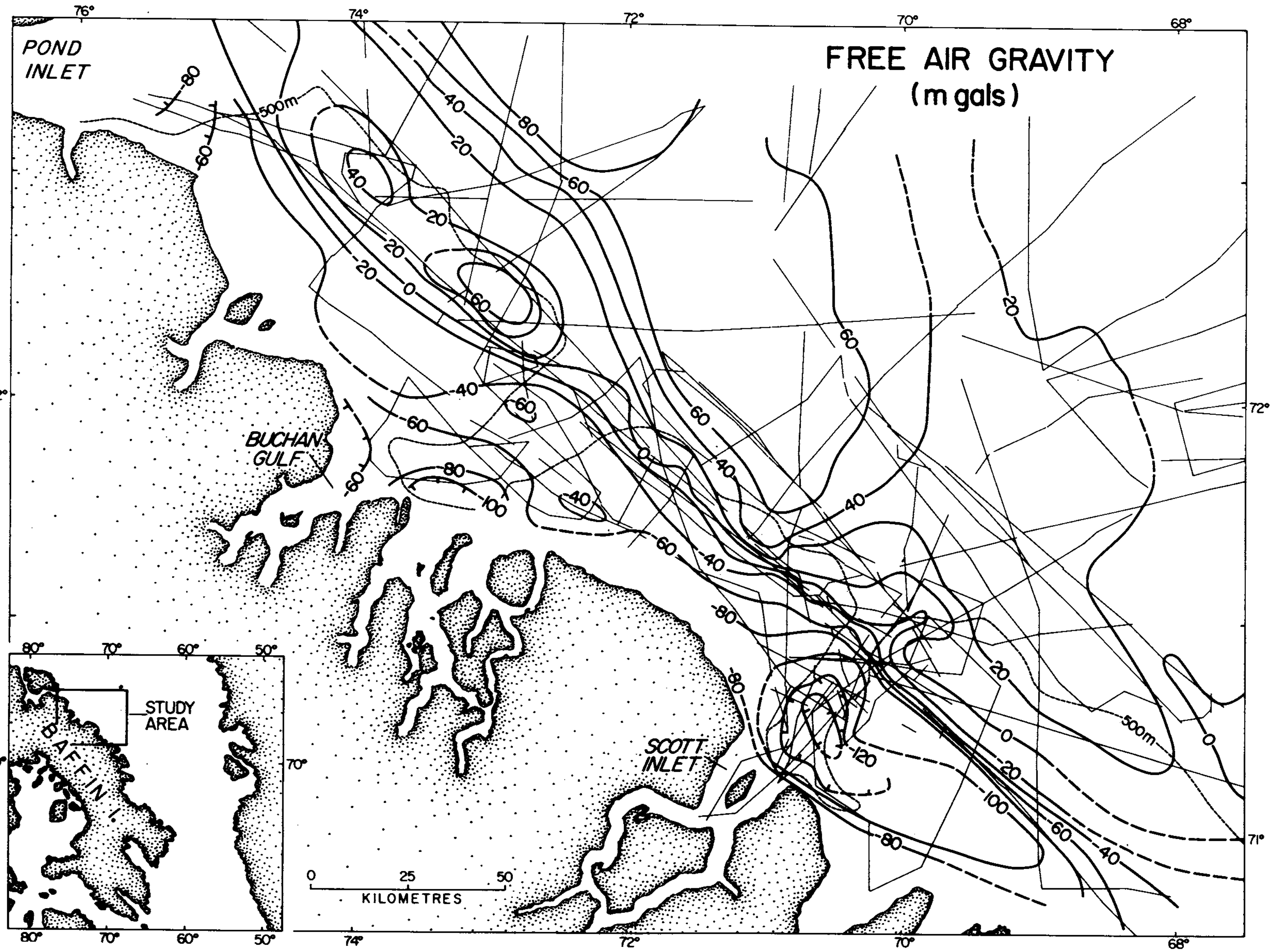

Figure 26.4. *Free air gravity map of Scott Inlet – Buchan Gulf offshore area. Solid lines indicate gravity tracks. The dashed line marks the 500 m bathymetric contour.*

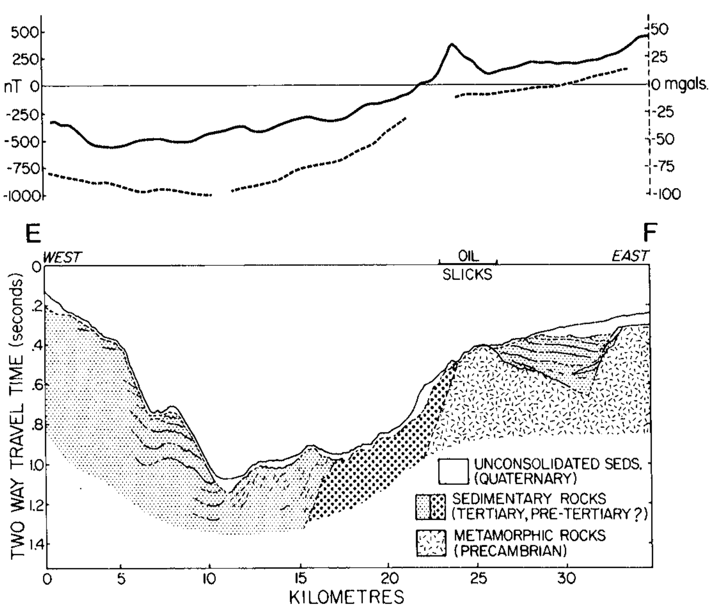

Figure 26.5. *Cross-section E-F (see Fig. 26.3 for location) across the outer part of Scott Inlet trough showing Precambrian rocks of the structural high and adjoining sedimentary sequences. The extent of an oil slick along track over the westernmost basement ridge on September 24, 1978 is also indicated. Magnetic (solid) and gravity (dashed) profiles accompany the section.*

the ridges. The basement high extends south as a subsurface feature to at least 69°W. Magnetic anomalies suggest that the high extends right across the mouth of the trough. However, it must plunge northward as it is not seen on seismic reflection profiles beyond the mid-line of the trough. Elsewhere the walls of the Scott trough consist mainly of flat-lying Tertiary strata as seen at the western side of the trough in Figure 26.5. However, towards the basement high these rocks assume a westerly dip. Strata flanking the western side of the high (Fig. 26.3, 26.5) are acoustically harder than the overlying Tertiary sediments. Rocks of similar seismic and magnetic character underlie the inner part of the Scott Trough. These rocks (designated pre-Tertiary on Fig. 26.3, 26.5) apparently are acoustically harder than the Upper Cretaceous rocks in Buchan Trough and may be older. Strata in the floor midway along Scott Trough have been disturbed by folding and faulting, but seem to be part of the Tertiary sequence sampled by MacLean (1978) that forms the walls, so have been mapped with that unit. They may, however, locally include some Upper Cretaceous strata, which are presumed to be present beneath the Tertiary sequence here as at Buchan.

Scott Inlet is marked by a very conspicuous gravity negative of -145 mgals (Fig. 26.4). This anomaly is a local feature superimposed on a regional coast parallel negative trend which is coincident with a continuous U-shaped magnetic anomaly landward of the offshore basement high. The regional gravity and magnetic negatives extend north of where, on the basis of magnetics, the basement high ends just north of Scott Inlet. A refraction line of Jackson et al. (1977) between Scott and Buchan inlets along the zero milligal contour revealed 4 km of sediment. The regional magnetic and gravity negatives suggest that even more sediment may be present in the structural depression extending from south of Scott Inlet northward across the trough. The sedimentary

Table 26.1

1978 bedrock sample station* data

Station	Location		Water Depth (m)	Seafloor Penetration (cm)	Results
	Lat.	Long.			
10	71°53.6'N	72°55.3'W	567	243	19 cm core dark grey siltstone
19	71°23.7'N	70°03.3'W	269	392	61 cm core metamorphic rock
20	71°23.1'N	70°03.9'W	274	177	73 cm core metamorphic rock
22	71°19.0'N	70°23.9'W	dredged interval 640 – 550 m		sandstone sample recovered
25	71°54.3'N	72°53.8'W	545	341	18 cm core dark grey siltstone
26	71°54.2'N	72°53.6'W	539	222	71 cm core dark grey siltstone
34	70°12.7'N	66°42.5'W	118	520	95 cm core metamorphic rock
44	66°23.7'N	61°06.9'W	164	125	76 cm core metamorphic rock
47	66°23.7'N	61°06.7'W	166	292	72 cm core metamorphic rock
57	65°26.9'N	63°07.5'W	196	535	232 cm core metamorphic rock
60	65°25.8'N	62°43.5'W	124	157	144 cm core metamorphic rock

*Drill stations, except No. 22 which was a dredge station.

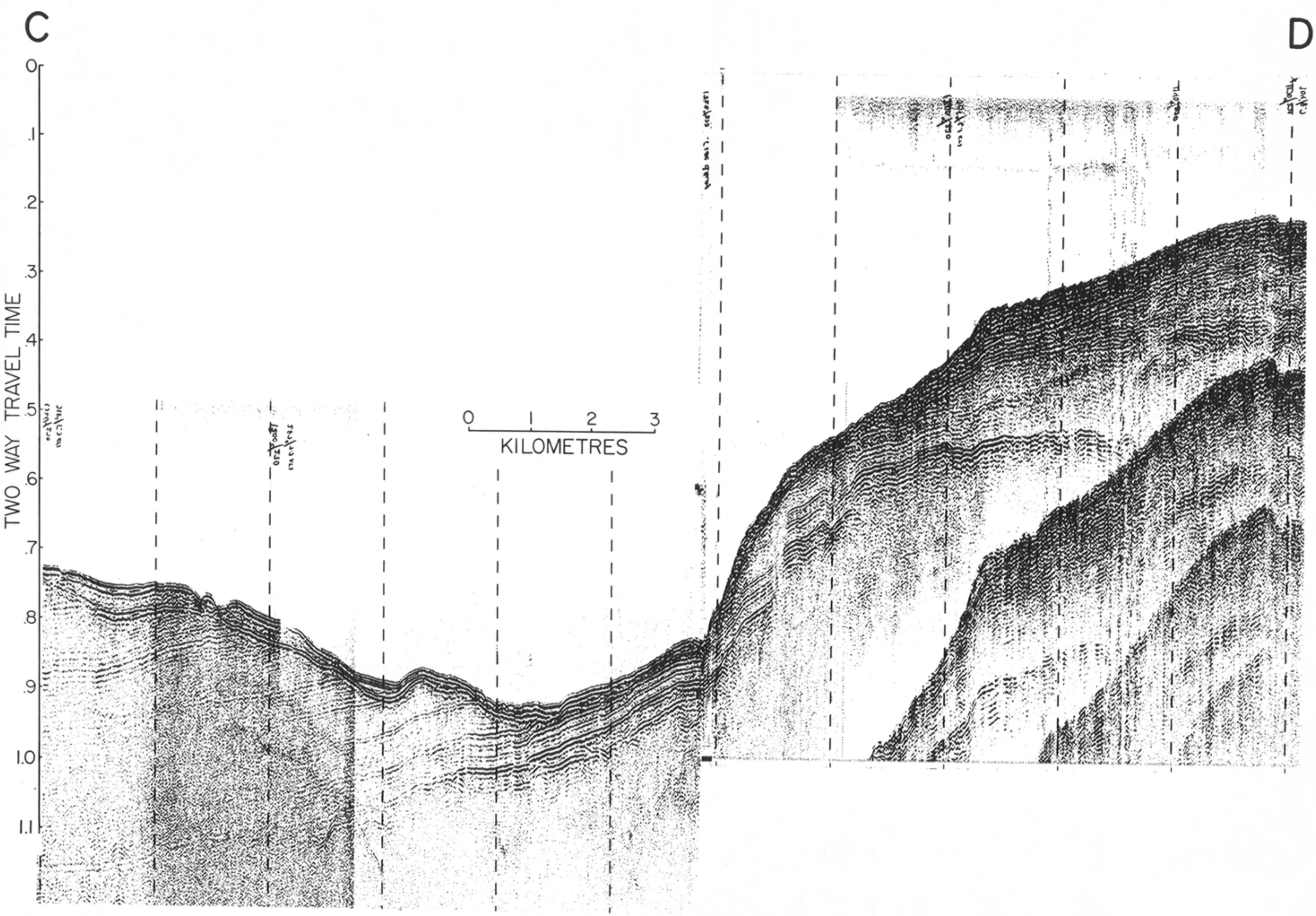

Figure 26.6. *Profile C-D (see Fig. 26.3 for location). Seismic reflection record across inner central section of Buchan Trough showing Cretaceous strata thickening to the northwest beneath the floor of the trough. Drill core samples from these strata were obtained just to the northeast of C.*

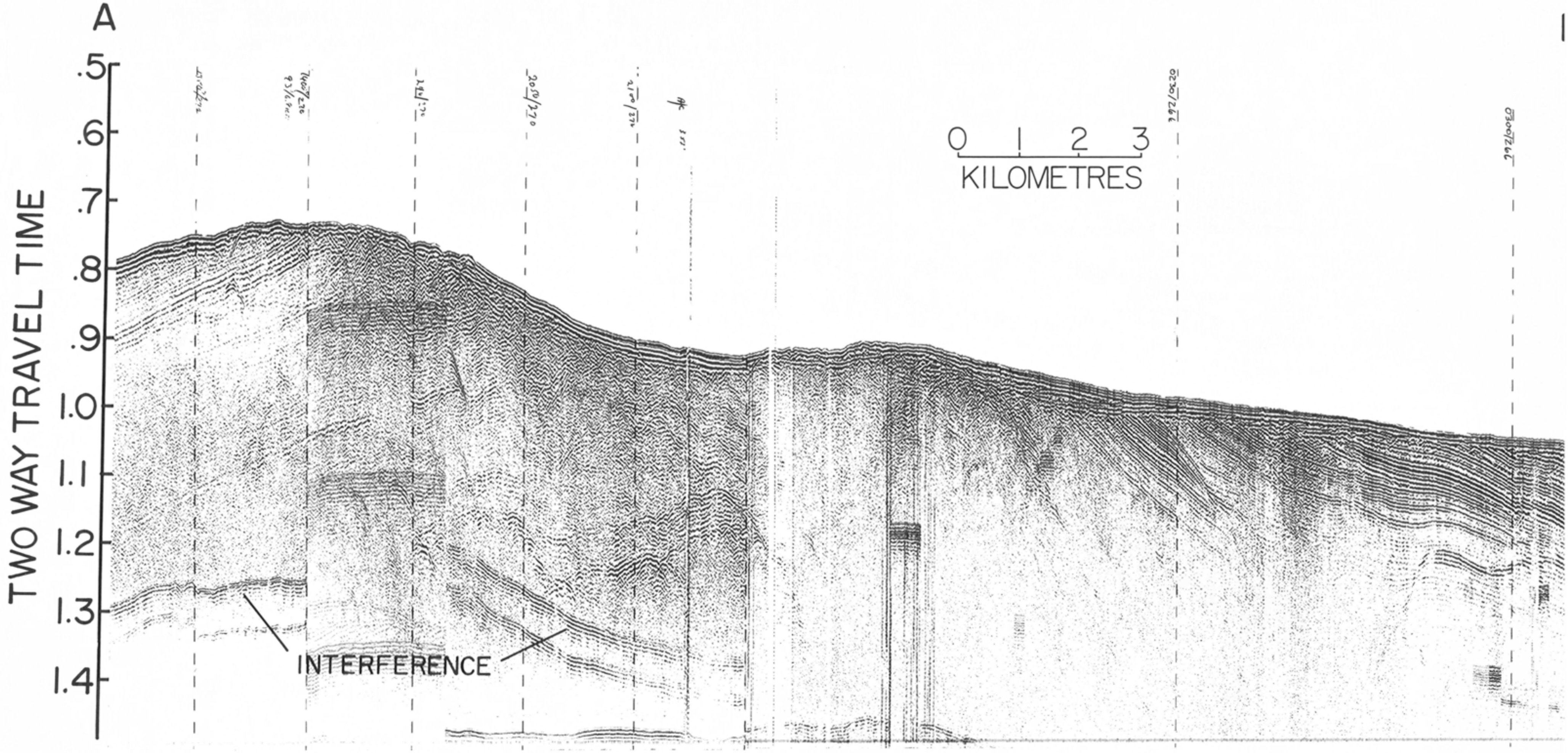

Figure 26.7. *Profile A–B (see Fig. 26.3 for location). Seismic reflection record along the axis of Buchan Trough showing Cretaceous strata dipping northwesterly at A, thinning over a basement ridge a little west of the profile mid-point, and overlain toward B by seaward dipping strata presumed to be of Tertiary age.*

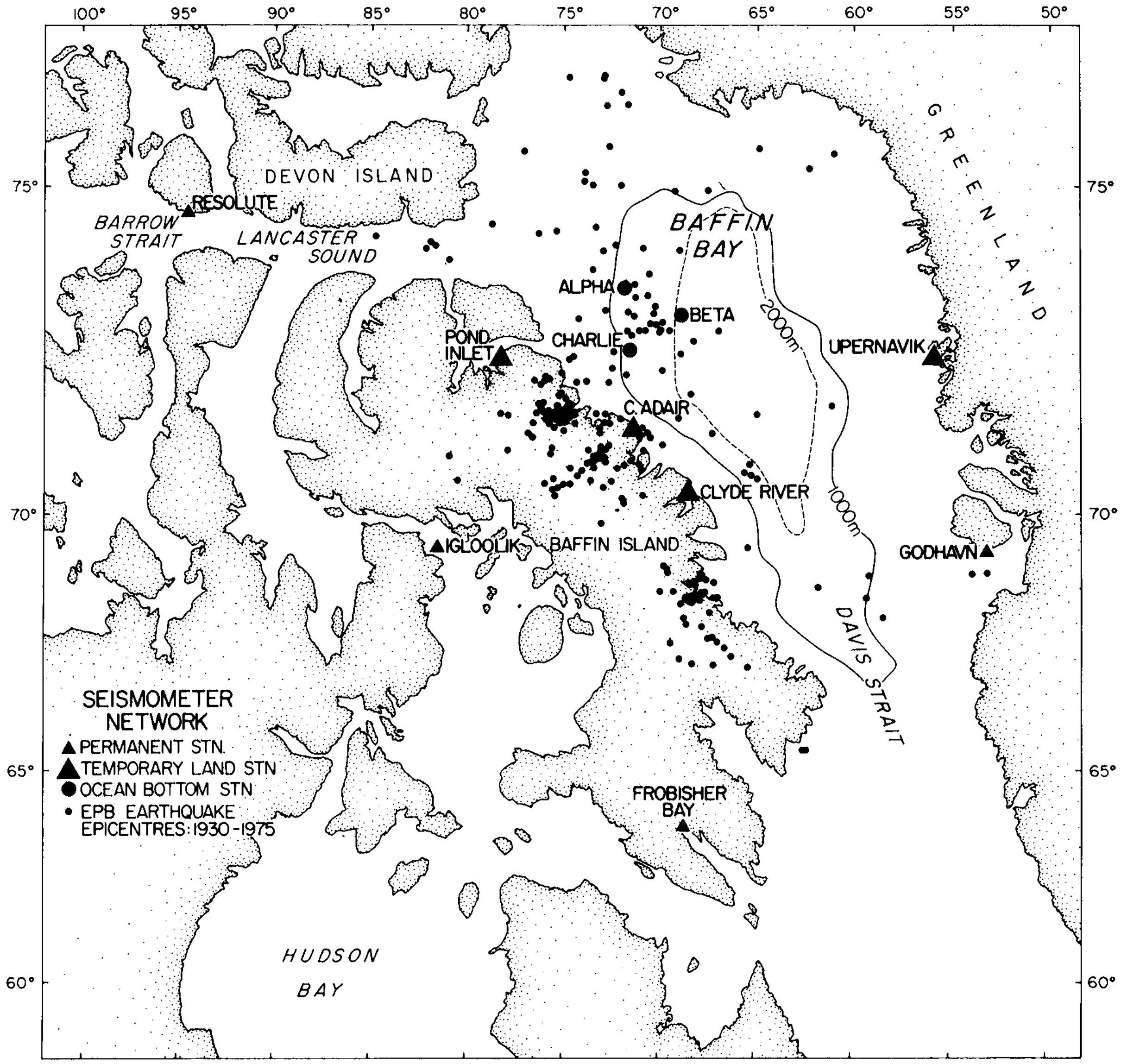

Figure 26.8. *Earthquake activity in the Baffin Bay region and locations of seismometers. Only epicentres north of 65°N and east of 90°W are plotted.*

section probably thins south of Buchan Trough as gravity anomalies become less negative and magnetic anomalies in the Buchan area are positive and indicative of shallow basement.

Cores of Upper Cretaceous (Senonian) (G.L. Williams, pers. comm., 1979) dark grey calcareous siltstone of probable neritic origin were recovered on three drilling attempts at two localities in the floor of Buchan Trough (Table 26.1, Fig. 26.3). The nearest previously established occurrence of Cretaceous rocks is in the Pond Inlet – Bylot Island area 200 km to the northwest where they have been described by Jackson and Davidson (1975) and Jackson et al. (1975). Assemblages in the samples from Buchan Trough resemble Senonian dinoflagellate assemblages from Bylot Island (G.L. Williams and N.S. Ioannides, pers. comm., 1979). Layered sediments observed from the air in stream channels cut into the Quaternary forelands adjacent to the entrance to Scott Inlet may include rocks of Cretaceous-Paleogene age (Jackson et al., 1979; G.D. Jackson, pers. comm., 1979). The Cretaceous strata sampled at Buchan Gulf thicken northward and westward over basement rocks in the central and inner part of the trough (Fig. 26.6, 26.7), underlie inferred Tertiary strata farther seaward (Fig. 26.7), and are thought to form the bedrock across part of the area between Buchan Gulf and Scott Inlet (Fig. 26.3).

North of Buchan Trough a belt of positive gravity anomalies extends parallel to the shelf edge for 80 km. Large positive magnetic anomalies, up to 1500 nT, coincide with the belt, but two separate features are indicated. Keen et al. (1972), from a magnetic, gravity, and seismic profile across part of the feature, and model studies, conclude that basic intrusives are the probable source of the feature.

Probable Sources of Seepage

Thin oil slicks were observed at several localities in the Scott Inlet area where they had been observed in 1977 (Levy, 1978). A more noticeable oil slick and bubbles were present in the vicinity of the westernmost basement high at the outer part of the Scott Trough (Fig. 26.5) where they previously had

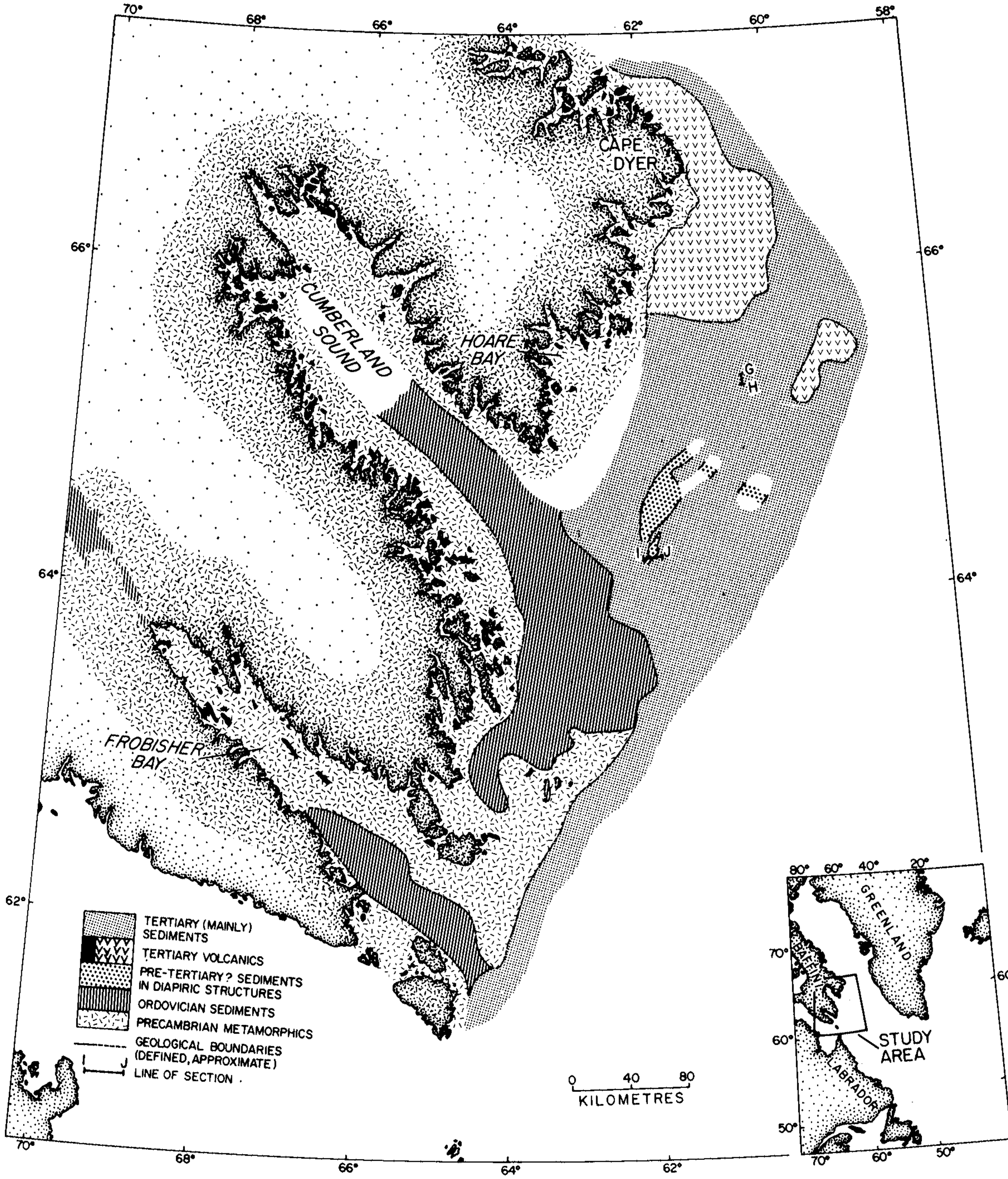

Figure 26.9. *Generalized geological map of the Baffin Island shelf from Cape Searle to Resolution Island. (Land geology from Blackadar, 1967; Clarke and Upton, 1971; Jackson and Taylor, 1972.)*

been observed in 1976 and 1977 (Loncarevic and Falconer, 1977; Levy, 1978). An oil slick at this locality was also observed during aerial surveys of the area in 1978 by Canada Centre for Remote Sensing. Persistence in time and space of the slick and bubbling point to this as an area of seepage and the underlying geological structure is compatible with such a conclusion. Seepage is thought to occur through migration of hydrocarbons updip in the strata flanking the basement high or along the contact with the basement rocks. A slick also was observed east of F (Fig. 26.3, 26.5) where strata flank the east side of the basement high. Seepage may occur elsewhere along the Scott Trough and farther northward along the shelf, e.g. Buchan Trough. No slicks were observed at Buchan Trough, but methane anomalies were encountered (E.M. Levy, pers. comm., 1979). Acoustic masking possibly caused by gas has been observed on some of the seismic profiles between Buchan Gulf and Scott Inlet.

The samples of Upper Cretaceous rock obtained indicate that marine conditions existed in this region at that time. Plate tectonic predictions (e.g. Srivastava, 1978) imply that Baffin Bay began opening about that time, but significant spreading did not occur until 20 million years later. The sediment filled depression on the shelf bounded by offshore basement highs could be a tensional marginal trough related to the opening. It probably predates significant spreading.

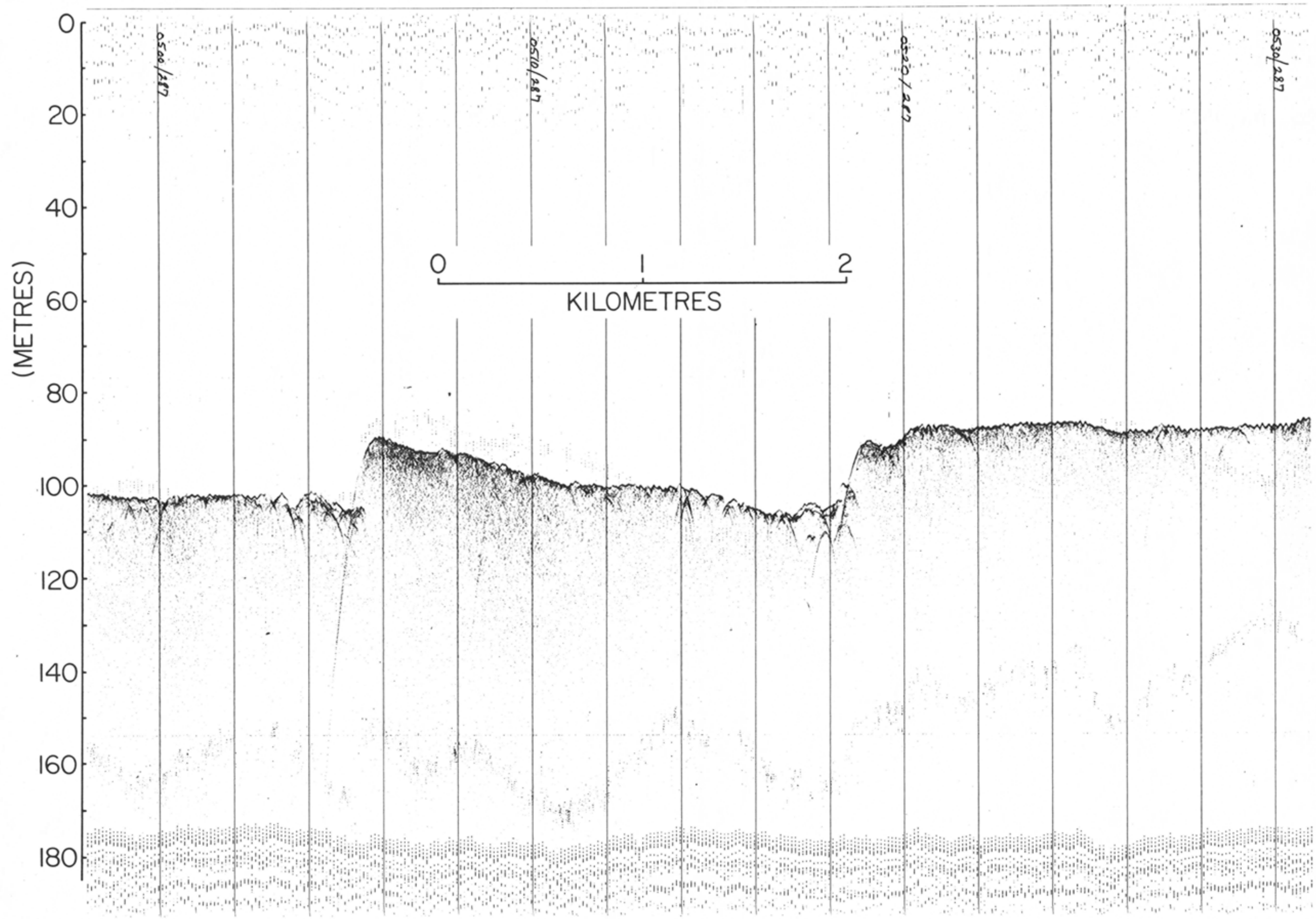

Figure 26.10. *Profile G-H (see Fig. 26.9 for location). Huntec high resolution record showing scarps apparently of relatively recent fault origin on the central part of the shelf east of Hoare Bay. Vertical scale is equivalent to the velocity of sound in water.*

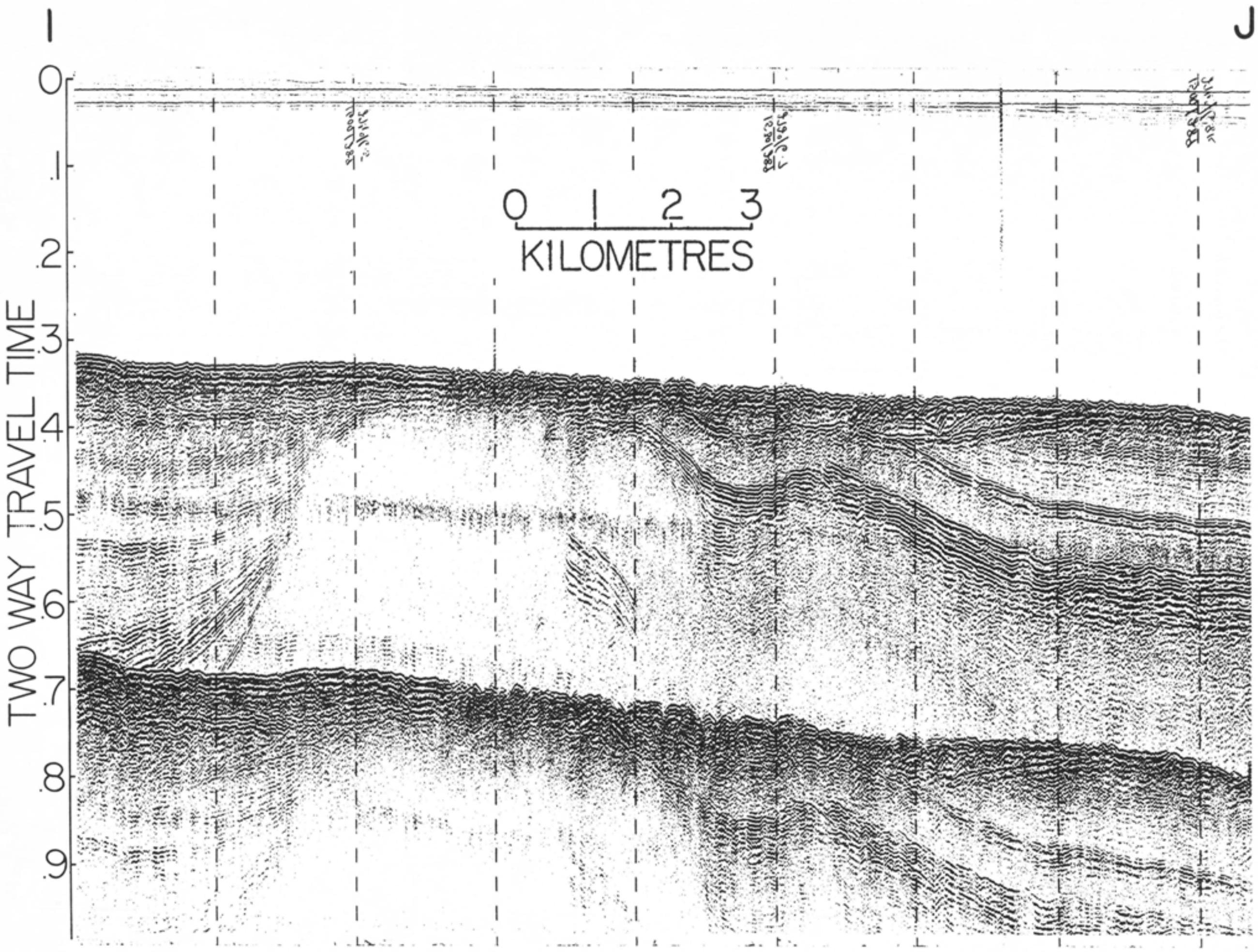

Figure 26.11. *Profile I-J (see Fig. 26.9 for location). Seismic reflection record across a diapiric ridge structure east of Cumberland Sound.*

The presence of marine Upper Cretaceous strata at Buchan Trough must be regarded as encouraging to the search for petroleum resources in the Baffin Bay region. The percentage of organic carbon in the samples (1%, M.A. Rashid, pers. comm., 1979) is at a level generally considered adequate for a source rock, if other factors such as maturity and carbon origin are favourable (Welte, 1965). Further analyses to determine the source potential of these rocks are in progress. While not indicative of the presence of hydrocarbons in exploitable quantities the occurrence of the seeps does indicate that conditions favourable for the generation of hydrocarbons have existed in the region.

Seismicity

The existence of seismic activity in northern Baffin Bay and on Baffin Island (Fig. 26.8) has been clearly established by the Canadian and worldwide seismograph networks. The networks generally detect only events of magnitude 3.5 and above with epicentre uncertainties of 50 km. The activity appears to occur in an offshore group and in a separate onshore group concentrated near the coast between Pond Inlet and Clyde Inlet. In order to better understand the reason for the seismic activity, to detect lower magnitude events, and to accurately locate them, a local seismicity study was done jointly by three groups. The Atlantic Geoscience Centre laid three ocean bottom seismometers (OBS's) in Baffin Bay from **CSS Hudson.** The Seismology Division of Earth Physics Branch, Ottawa, established temporary shore seismographs at Pond Inlet, Clyde River, and Cape Adair and the Danish Geodetic Survey established a temporary station at Upernavik.

The three OBS's were laid in a 100 km sided triangle (Fig. 26.8). They were down for 10 days during which time at least 40 events were recorded. About half were detected on only one instrument and appear to be close to the respective instrument. The Baffin Island temporary network detected at least 20 events during the same time, apparently all in Baffin Island or nearshore. The largest was a magnitude 3 event in the Buchan Gulf area. That event and several others of the "land group" were clearly recorded by the OBS's. Two 450 kg shots fired offshore close to the OBS triangle were well recorded by the OBS's and Baffin Island stations and should provide good "artificial earthquakes" for network calibration.

Southeastern Baffin Island Shelf

Figure 26.9 shows the surface bedrock geology of the southeastern Baffin Island shelf. Studies in this area in 1978 were principally between Cape Dyer and Cumberland Sound. They were designed to further establish the shoreward extent and stratigraphic relationships of the volcanic and sedimentary units previously reported by Grant (1975) and further defined by MacLean et al. (1977, 1978), and to obtain additional data on diapiric structures off Cumberland Sound.

Cape Dyer – Cumberland Sound

The two offshore areas of Tertiary (Paleocene) volcanic rocks shown in Figure 26.9 are as presented by MacLean et al. (1978). A third area of volcanics previously was inferred south of the main offshore volcanic area on the basis of magnetic data. Seismic reflection data obtained in 1978 indicate that this is a subsurface feature covered by Cenozoic sediments. Four scarps, with south side down, were observed on a north to south seismic reflection profile across this feature. Two of these are illustrated in Figure 26.10. Apparently they are of relatively recent fault origin. Weather and time did not permit additional profiles to establish strike of the scarps, but the data obtained suggests a series of small en echelon blocks tilted slightly downward to the north.

Drill samples of metamorphic rocks recovered off Exeter Bay just south of Cape Dyer (Fig. 26.2, stn. 44 and 47, Table 26.1) established that the area is underlain by Precambrian rocks and a change noted in the magnetic anomaly pattern (MacLean et al., 1978) therefore reflects the volcanic-Precambrian boundary rather than the presence of less magnetic subaqueous volcanics.

At the southern boundary of the main area of volcanics offshore, the volcanic rocks appear to be onlapped by younger strata, which consequently have been included in the Tertiary map unit, although the seismic data suggest the possibility of some minor faulting. The precise shoreward extent of these sediments off Hoare Bay is uncertain. Precambrian basement rocks which in the Hoare Bay area have an unusually smooth magnetic anomaly signature were sampled at two localities (Fig. 26.2, stn. 57, 60, Table 26.1) and were found to extend seaward to the edge of the area stippled in Figure 26.9. Strata older than Tertiary may be present at the bedrock surface seaward of this boundary. If so, they may correlate with Ordovician rocks delineated and sampled at several localities south of Cumberland Sound (MacLean et al., 1977; MacLean, 1978). Ordovician rocks also underlie the southern side of Frobisher Bay and probably much of Cumberland Sound.

Diapiric Structure

Seismic reflection, magnetic and gravity profiles and seismic refraction measurements were obtained over diapiric structures that underlie the shelf 75 km east of the entrance to Cumberland Sound (Fig. 26.9). The seismic character and shape of these structures is illustrated in Figure 26.11. Typically the west side is steep and the east side apparently more gentle. Similar shaped structures were encountered by Grant (1975) at two localities farther east (Fig. 26.9), but their relationship to the delineated structure is as yet uncertain. The magnetic signature across the features is mainly quite flat except for a few small associated anomalies in the northern part. The northward extent of these structures has not been established, but the fact that they are approximately on trend with the structurally high area of volcanic rocks to the northeast suggests the possibility of some common underlying structural control. S.P. Srivastava in 1974 obtained a short drill core of Albian-Cenomanian sandstone (MacLean et al., 1977) in the vicinity of the small separate structure illustrated in Figure 26.11. In view of the age of this sample and the uplift of strata flanking the structure, Mesozoic and/or older rocks probably are represented here. Although depth to the base of the structure is not known, its size (80 km delineated length), possibilities for entrapping structures against its flanks, and important petroleum reservoirs associated with diapirs elsewhere, suggest structures of this type may be of potential resource significance in this area.

Discussion

Baffin Island is topographically high in the east and slopes downward to the southwest. The Precambrian terrain that forms almost the entire east coast of Baffin Island stands structurally high relative to the rocks of the shelf. Lower Paleozoic strata (Ordovician, Silurian, and some Cambrian rocks in the northwest) occur along western Baffin Island. Ordovician strata also occur at outliers at the head of Frobisher Bay, and underlie much of the inner and central parts of the shelf between Frobisher Bay and Cumberland Sound, and appear to underlie the Frobisher Bay and Cumberland Sound grabens. The Ordovician strata on the shelf were deposited in marine nearshore to outer shelf-upper bathyal environments. Subsequently they were subjected to folding and faulting, and have been extensively bevelled by erosion (MacLean et al., 1977). Where they occur close to shore near Brevoort Island, between Cumberland Sound and Frobisher Bay, the strata dip shoreward and the contact with the basement rocks though not visible on the seismic data must be a fault. The wide occurrence of remnants of Ordovician rocks through the region suggests that the original distribution of these rocks was more widespread. The formation of the Frobisher Bay half graben and the Cumberland Sound graben and uplift of the landmass relative to the shelf must have occurred before the Ordovician strata were completely stripped from the adjacent landmass. It is not possible, however, to say when this movement took place. At Cape Dyer Paleocene rocks lie directly on Precambrian basement (Clarke and Upton, 1971). If Ordovician strata had been present at Cape Dyer, their complete removal by Paleocene time would imply pre-Paleocene formation of the Cumberland Sound and Frobisher Bay grabens (which we previously argued must have taken place before complete removal of Ordovician rocks from adjacent areas). Subaqueous Paleocene volcanics onshore at Cape Dyer now stand 600 m higher than their counterparts on the shelf. As the land must have been near to slightly below sea level during the Paleocene, uplift must have taken place since then. It is possible that the tectonic history of the Cape Dyer area may have been quite different from the Frobisher Bay – Cumberland Sound area, and there may have been more than one period of uplift.

In northern Baffin Island Lower Cretaceous to possibly mid-Tertiary (Eocene) marine and paralic rocks preserved in structural depressions at Pond Inlet and Bylot Island now stand up to 600 m above sea level (Jackson et al., 1975). In the Buchan Gulf – Scott Inlet area, marine rocks of Upper Cretaceous to Eocene ages are present on the continental shelf. This indicates a 600 m vertical movement of the land relative to the shelf since Eocene time, much the same as at Cape Dyer. Thus, the tectonic movements seem to have been relatively similar from Cape Dyer to Lancaster Sound, at least since the Eocene. The fact that older rocks form most of the shelf south of Cumberland Sound indicates that this area has stood structurally higher than the region to the north where younger sediments predominate.

A Cretaceous, or older, age for the Frobisher and Cumberland grabens and the coast parallel sedimentary trough off Scott Inlet would agree with plate tectonic models (e.g. Srivastava, 1978) which predict initiation of rifting by at the latest, Late Cretaceous. The post-Eocene land uplift from Cape Dyer to Lancaster Sound occurs after spreading is assumed to have stopped.

Acknowledgments

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