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ICEBERG-SEABED INTERACTION (NORTHERN LABRADOR SEA)

by

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ABSTRACT

Large-scale furrows occurring in unconsolidated Quaternary sediments on the Labrador Shelf are considered to be gouge marks of bottom-dragging icebergs. Side-scan sonograph mosaics from the northern Labrador Shelf were constructed for two bathymetric interbank areas. They reveal that both relict ice bottom gouging and modern iceberg scouring have taken place at water depths greater than 180 m. The recent scours are linear to curvilinear to crater-like in form, with average widths of 30 m at a mean scour depth of 5 m and lengths in excess of 3 km. The dominant scour trend is north-south, reflecting the Labrador Current.

Impedance of icebergs by bottom interaction is primarily a function of the gross iceberg size and shape, sediment encountered by the keel, and prevailing current. For modern scouring, frequencies of detectable impact decrease exponentially with increasing scour depth, and scour depth is inversely proportional to the sediment shear and compressive strengths.

INTRODUCTION

The large-scale furrows occurring in unconsolidated bottom sediments of the entire Labrador Shelf and Grand Banks are considered to be gouge marks: the result of iceberg/sea bed interaction. With the annual flux of between 500 and 2 500 icebergs drifting southward in 'Iceberg Alley' (Murray 1969), a considerable threat is posed to the offshore development of hydrocarbons in this region. The understanding of the scour frequency and the mechanism of the grounding event is critical to any manipulation of, or protection from, icebergs.

For the northern Labrador, Saglek Bank, region, Lewis and others (in press) report abundant scouring from 150 to 160 m water depth with scour penetration depths up to 10 m. However, many of these furrows may not represent present-day iceberg conditions but may be relict such as those found in the Laurentian Channel, the western Grand Banks (King 1976), and the Norwegian Trough (Belderson and Wilson 1973). Differentiation of modern iceberg scouring from relict ice and iceberg scouring is critical for the assessment of the interaction of present-day icebergs with the sea bottom. This can be determined from records of repetitive sea-floor mapping, sea-level changes, Pleistocene sedimentological history, and scour form and distribution.

DATA ACQUISITION AND PROCESSING

Side-scan data were collected using the system developed by Bedford Institute of Oceanography (BIO) (Jollymore 1974). The system has a slant range of 750 m which effectively averaged 735 m in a projected horizontal plan for the survey. Scour depths and a geologic cross-section were achieved using the Huntec Deep Tow continuous seismic profiling system. Water depth was monitored by a Raytheon sounder system.

In 1976 Total Eastcan Exploration ran a Huntec seismic line through the centre of the study area (Fig. 1). Three continuous seismic profile lines were run in August 1977, each approximately 150 km long (Gustajtis 1979) and 1.25 km apart using the Huntec Deep Tow. These

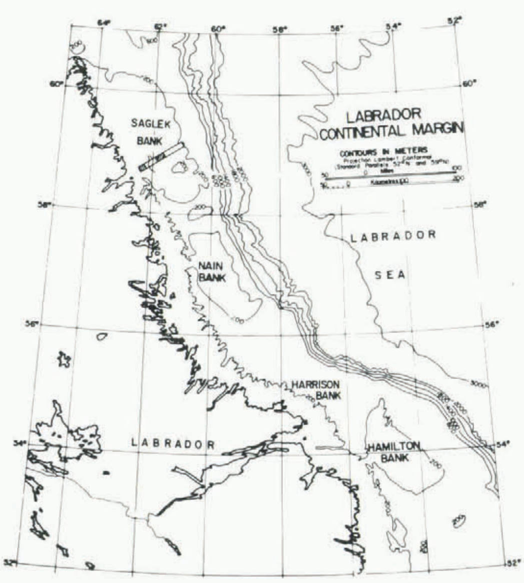

Fig.1. Area of research.

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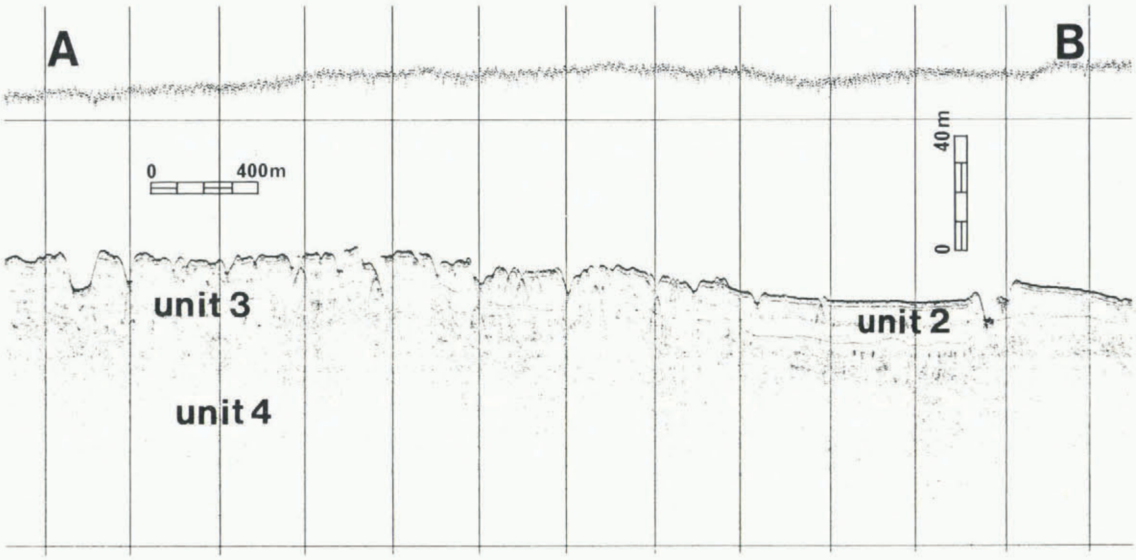

Fig.2. Huntec seismic record from the east region, Saglek Bank.

same three lines were repeated in October 1978 except for 45 km on the eastern end using both the Huntec Deep Tow and the BIO side-scan sonar. Both the 1977 and 1978 surveys used Loran-C Rho-Rho navigation on board CSS *Hudson*, and calibration was achieved from three transponders moored in 1977 (Gustajtis 1979).

A sonograph mosaic was prepared for two areas (Figs. 3 and 4) at a 1:1 aspect ratio using a Honeywell fibre optic recorder modified to match the system developed by Bedford Institute of Oceanography (Josenhans and others 1978). The mosaic construction was based on the 2-min navigation reproduced on a track plot using a 1:10 000 scale. Corrections were applied to account, as close as possible, for fluctuations in ship's speed, variations in slant range due to bathymetric changes, and the actual distance of the side-scan fish to the vessel. Final correction and checking for 1:1 aspect ratio were achieved by comparison of similar geographic features, mainly dominant scour furrows.

Over 430 scours were measured to obtain the parameters of scour orientation, scour width, and scour penetration depth between 150-200 m water depth. Many scours extended beyond the area of the mosaic, so mean scour length was not considered. As these measurements were obtained from the original records, a correction factor was needed because the scale parallel to the length of the sonographs is not equal to that parallel to the width. For orientation of each scour the tangent of the angle between a scour measured from the sonograph and a line parallel to the length on the sonograph was multiplied by the factor 2.2 (the ratio of the lateral range to the ship's track scale) in order to determine the true angle of the tangent (Harris and Jollymore 1974). Then the true angle was either added to or subtracted from the azimuth of the ship's course to give the true scour orientation. The widths of selected scours were measured, knowing the true angle a and the measured angle a' of the scour. Then

$$W = W' \frac{\sin a}{\sin a'} ,$$

where W is the true width and W' is the measured width using the scale parallel to the length of the sonograph (Harris and Jollymore 1974). Direct measurements of scour orientation and width from the 1:10 000 scale mosaics were very close to the corrected measurements calculated from the original records. Scour depths were taken directly off the Huntec seismic record and water depth taken from echograms.

GEOLOGICAL ENVIRONMENT

The Labrador Shelf, covering some 200 000 km^2, is a typical example of a glaciated shelf (Holtedahl 1956). The irregular inshore region is separated by a discontinuous marginal channel from the seaward shelf, characterized by six relatively shallow flat-topped banks.

Saglek Bank is the largest and the most northerly of the banks (Fig. 1). It is covered with an extremely thick layer (100 to 200 m) of compacted glacial drift and periglacial material. On the southern portion of the bank in the area of study, four sedimentological units have been identified (Fillon 1980). The dominant reflecting unit showing the rough undulating boundary is unit 3 (Fig. 2). This dates from 26 000 years B.P. (Fillon 1980). Unit 2 (21 000 to 26 000 years B.P.) which onlaps onto unit 3 is the characteristic depositional unit in the basin (Karlsefni Basin) between the east and west interbank regions and pinches out at about 170 m water depth. In small areas unit 2 is overlain by the more recent unit 1. The underlying unit, unit 4, is exposed on the eastern edge of the bank. It consists of overcompacted fine material which could not be cored for geotechnical definition due to its very high strength characteristics. The entire area has a surficial covering of Holocene green silt and sand largely of ice-rafted origin.

Gustajtis (1979) implies that sea-level under both effects of isostatic recovery following the melting of the ice sheets and post-glacial eustatic rise has been slightly declining since the Holocene transgression. Evidence from deep shelf and slope terraces off Saglek Bank (Fillon and others 1978) suggest that late-

Wisconsin sea-level was relatively close to the present levels in northern Labrador and no sub-aerial exposure occurred. Consequently, since the last glacial advance iceberg grounding has not decreased due to sea-level rise but instead this area could possibly be more vulnerable to iceberg incursion.

ICEBERG SCOURING

The sea bottom as observed from a side-scan acoustic map is shown for two intensely scoured areas of Saglek Bank (Figs. 3 and 4). Figure 3 (east region) covers an area of 28.7 km² with depths ranging from 155 to 180 m while Figure 4 (west region) covering 28.1 km² ranges in depth from 150 to 175 m. Between these two regions is the Karlsefni Basin (Fig. 5) reaching a maximum depth of 205 m. Icebergs do, occasionally, scour in this bathymetrically-protected basin.

The iceberg scour marks are linear to curvilinear to crater-like (circular features that resemble craters on the sonograms) in form. The mean orientation of all the scour-like features reflects the interaction of the prevailing southerly flowing Labrador Current and the bathymetric configuration (Fig. 5). Icebergs entering the east region would, assuming a constant draft, have to enter in the south-east to west quadrants (Fig. 5). The strong east-west component of Figure 6a demonstrates this basic control though the predominant net current is southerly. Gustajtis (1979) suggests that the local bathymetry creates a possible current vortex in this area resulting in northward drift of icebergs, to explain the north-south component (Fig. 6a). By plotting iceberg furrows against bathymetry, evidence has been established for the ability of an iceberg to scour up and down slope, dynamically adjusting its draft. This finding could explain the scouring from north to south following the current and is the only explanation for scours found in the deepest part of Karlsefni Basin, as an iceberg cannot enter this basin and scour without first going over a bathymetric rise of at least 15 m (Fig. 5). The west region is situated such that southerly drifting icebergs have access to the region without restriction, mainly from the north-north-east and north-north-west directions. The orientation of scour furrow marks is dominant then in the north-south segment (Fig. 6b).

The average penetration depth of an iceberg keel over the entire area was 5 m with a maximum scour depth of 17 m. Scour widths reach a maximum of 200 m (Harris 1974) but maximum width bears no relation to maximum depth. The maximum width recorded in the Saglek Bank region was only 85 m, with an average of 30 m.

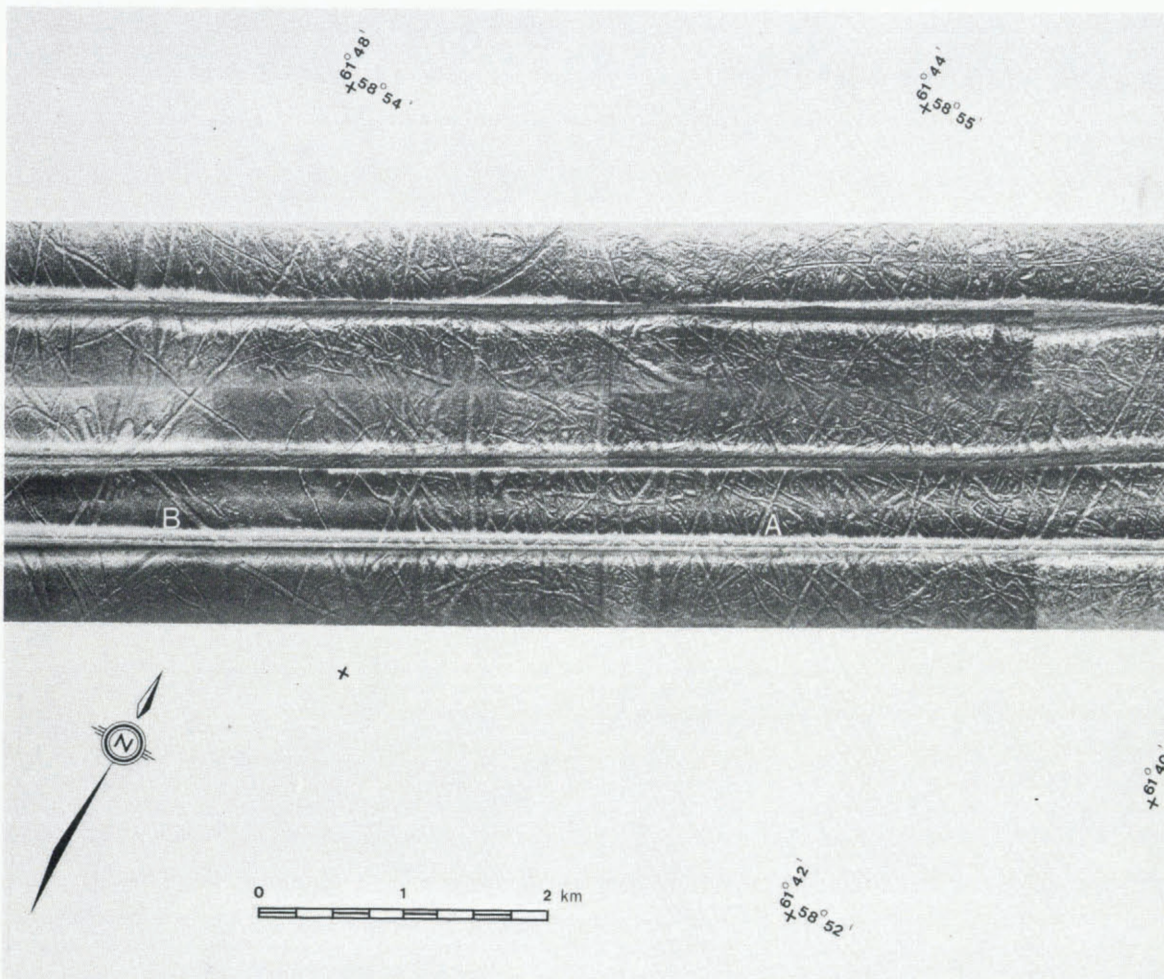

Fig.3. Side-scan mosaic, east region of Saglek Bank. Seismic line (Fig.2) represented by line A-B.

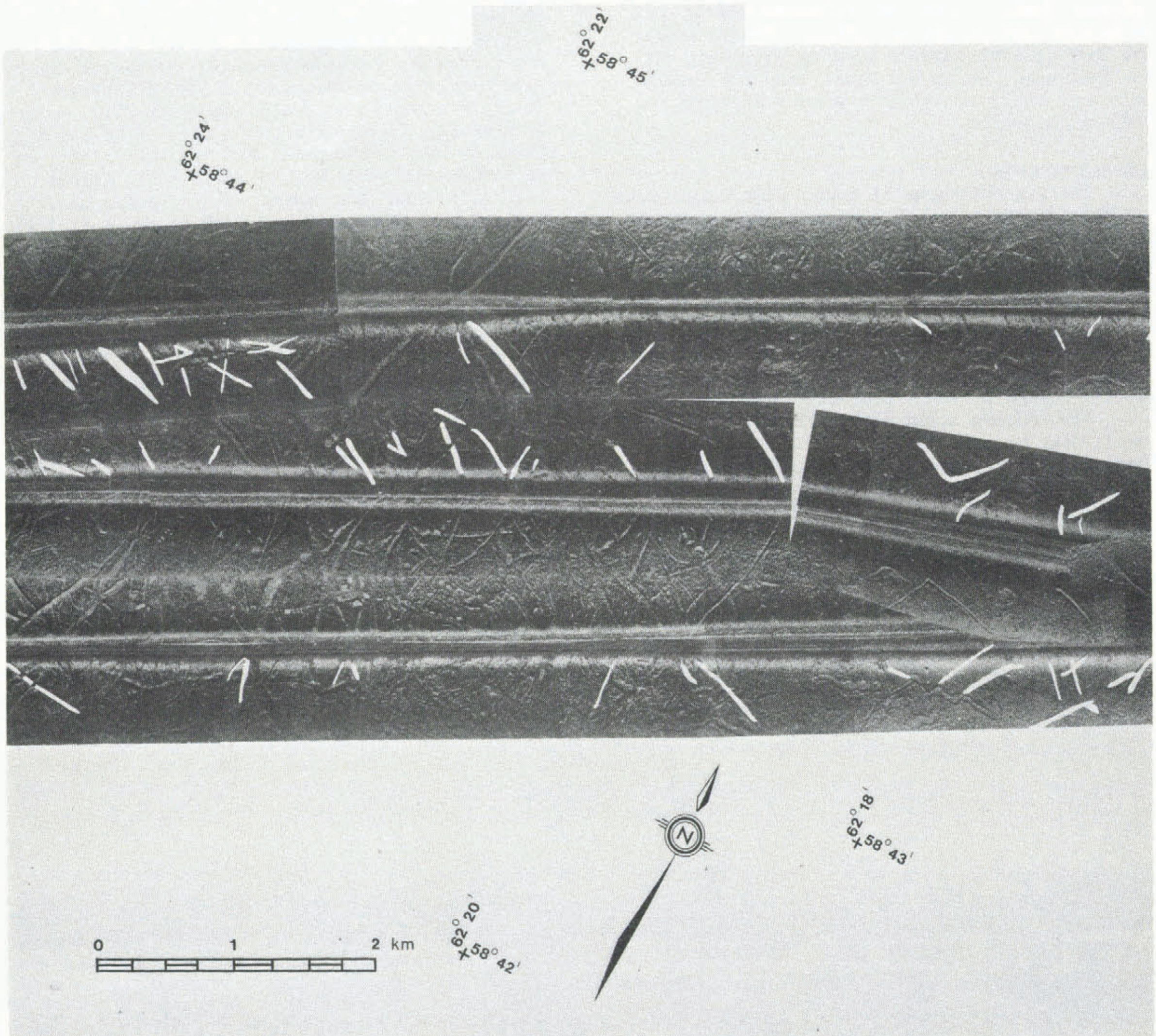

Fig.4. Side-scan mosaic, west region of Saglek Bank. Whiteout portions are areas of analogue tape "cross-talk" between record channels.

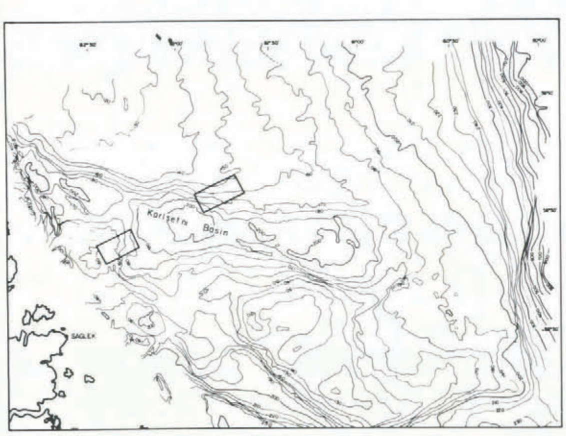

Fig.5. Bathymetry of research area.

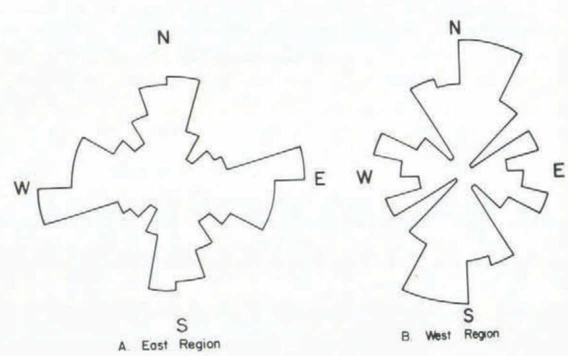

Fig.6. Orientations of 431 furrow marks for the east region (A) and west region (B) of Saglek Bank.

DISCUSSION

The evident scour furrows seen on the whole of the northern Labrador Bank are recorded largely in sediments of middle- to late-Wisconsin time. Sedimentation since that time has been minimal and, therefore, scour deterioration by infilling is minimal. The record preserved on the shelf is a result of any ice/sea bed interactions over at least 20 000 years.

The frequency distribution of scour penetration into the sea bed is exponential in form (Fig. 7) as is the characteristic distribution of drift-ice scouring in the Beaufort Sea (Lewis 1978). The shallowest detectable scours are most frequently found, and with increasing scour depth the frequencies decrease rapidly so that scours of extreme depth occur only rarely. This is to be expected as a larger berg entering shallow water and exerting extreme force into the bottom would be a rare occurrence. This is relative to the specific geotechnical characteristics of the sea bed. When the sea bed becomes more compact and the shear and compressive strengths are much greater, the potential extreme scour penetration is reduced. Scours found in geological unit 4 show the exponential pattern but the whole scale of ice-keel penetration depth is reduced due to the overcompacted nature of the substrate.

The mean scour depth was found to decrease with the increase in water depth to 180 m from where scour depth increases with water depth until scours are almost absent and there is no change in scour depth (Fig. 8). The increased scour depths in this area are the result of larger bergs which will generally have deeper keels. If currents are the major force on icebergs (Dempster and Bruneau 1975) and assuming there is decreasing number of large bergs with deep keels then an increase of scour depth with water depth would be anticipated. Relict scours would be expected to have diminished scour depth due to sedimentary infilling, wave and current action at the bottom boundary layer, and the action of benthic fauna. A greater quantity of older scours (relict) relative to new above 180 m water depth could explain the decrease in scour penetration with an increase in water depth. Density of scour occurrence with depth shows (Fig. 8) a distinct division between two frequency modes at approximately the 180 m depth as does furrow orientation with depth. Also, there is no sedimentological change at this significant depth. The geological record then shows scouring taking place for at least 20 000 years above 180 m water depth with a slow deterioration rate while below this depth scouring probably began at a relatively more recent time. Sea-level fluctuations over the period of bottom gouging, especially a net decrease in sea-level would explain this finding. The rate of recent scour additions throughout the area is not known at present.

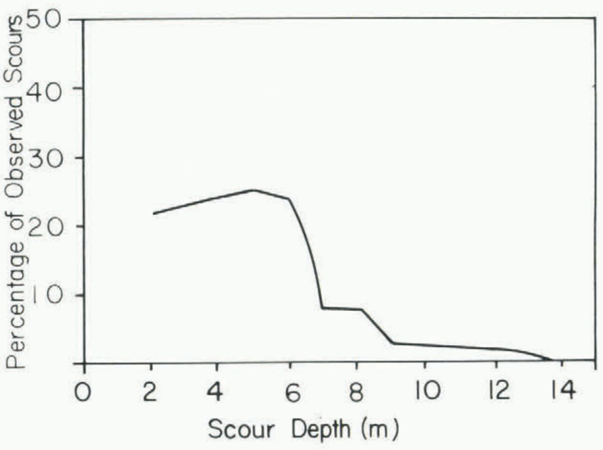

Fig.7. Exponential distribution of scour penetration depths between 160-200 m water depth for Saglek Bank.

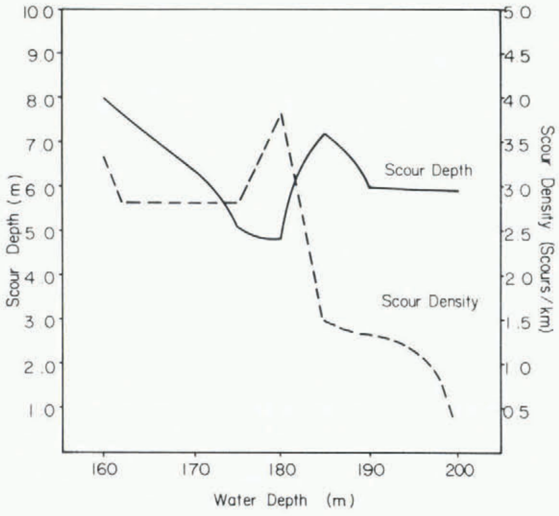

Fig.8. Mean scour penetration depth and scour density (scours/km) between 150-200 m water depth for Saglek Bank.

Side-scan and sea-bed sample data collection carried out in August 1979 over the same study area will give a repetitive map for the determination of absolute scour frequency over a given time span plus quantify geotechnical properties for both calibrating models of iceberg forces and interpreting the significance of variability in scours with respect to the dynamics of icebergs.

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