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032 Canadian Beaufort Sea 1984 Repetitive Mapping of Ice Scour

Canada

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During the summer of 1984, an extensive survey of ice scour, sponsored by the Environmental Studies Revolving Funds (ESRF), was carried out over much of the Canadian Beaufort continental shelf. The survey used side-scan sonar and precision echo-sounding equipment to establish a base-line network that would serve as the basis for future repetitive mapping studies of ice scour. Accurate re-surveying of any portion of the network could then be used to establish the frequency of new scouring events.

Much of the 1984 network covered corridors and control areas that had already been surveyed. Where overlap occurred, data on impact rate were calculated. In the western Beaufort Sea, near the southern end of the Tarsiut-Nektoralik corridor, re-scouring rates as high as 4 impacts/km/yr have been observed in water depths of 20-25 m. The impact rates decrease towards the East Mackenzie corridor, which is located in shallower water in Mackenzie Bay. In this area, the impact rate is about 1 impact/km/yr in water depths of 20-25 m. In the eastern Beaufort Sea, the impact rates are even lower in the Tingmiark-Nerlerk and Kaglulik corridors, where rates in the order of 0.2-0.4 impact/km/yr have been observed in water depths of 20-30 m.

No new scours were observed in areas where water depths are greater than 40 m. A maximum new scour depth of 3.5 m was recorded during the repetitive survey of the Tarsiut-Nektoralik corridor.

During the winter of 1983-84, a multi-year ice incursion took place in the southern Beaufort Sea, which resulted in the grounding of a number of large ice masses. Accurate locations of the grounded ice were obtained during a Gulf Canada Resources reconnaisance survey, and, during the following summer, the sea floor was surveyed with side-scan sonar and a precision echo sounder. From the data collected during the survey sea-floor mosaics were constructed which upon detailed examination revealed that scour depths associated with individual ice masses can vary considerably along their track.

A scour track seems to be formed in three stages. In the first stage, the base of the scour remains at a constant elevation. In the second stage, the base of the scour rises up but at a rate less than the decrease in water depth. In the third stage, the rise-up in the base of the scour and the decrease in water depth are the same.

At the E-2 location in the Kugmallit Channel, a scour with a constant depth of 3 metres experienced a net rise up of 3 metres.

A maximum scour depth of about 4 1/2 metres was identified at one of the new scour locations (W-2 site). This "new" scour is deeper than the deepest "new" one (3 1/2 metres) observed on the repetitive survey network.

Résumé

Au cours de l'été 1984, une étude exhaustive sur le phénomène d'affouillement des fonds marins par les glaces, parrainée par les Fonds Renouvelables pour l'Etude de l'Environnement (FREE), a été réalisée sur une grande partie du plateau continental canadian de la mer de Beaufort. Au moyen d'un sonar à balayage latéral et d'un écho-sondeur, l'étude visait principalement à établir un réseau de lignes de sondage qui servira dans le futur lors d'éventuelles études sur le phénomène d'affouillement à un site spécifique et pour une période de temps donnée.

La majeure partie du réseau établi en 1984 comprend et des corridors et des aires de contrôle qui ont déjà été examinés dans la passé, permettant ainsi le calcul de la fréquence de collision des masses de glace sur le fond marin. Dans le secteur ouest de la mer de Beaufort, près de la partie la plus au sud du corridor Tarsiut-Nektoralik, une fréquence de collision atteignant 4 collisions/km/an a été observée entre les isobathes de 20 et 25 mètres. Les fréquences de collision diminuent vers le corridor "East MacKenzie", situé dans la zone peu profonde de la Baie de MacKenzie. Dans ce secteur où la profondeur d'eau est de 20 à 25 m, la fréquence de collision est d'environ 1 collision/km/an. Dans la partie est de la mer de Beaufort, où se situent les corridors Tingmiark-Nerlerk et Kaglulik, des fréquences de collision encore moins élevées, de l'ordre de 0.2 à 0.4 collision/km/an, ont été mesurées sentre les isobathes de 20 à 30 mètres.

Aucune nouvelle trace d'affouillement par les glaces n'a été identifiée dans les zones où la profondeur d'eau est supérieure à 40 m. De plus, l'étude des corridors a montré qu'une profondeur maximale de 3.5 m a été observée dans le corridor Tarsiut-Nektorlik.

Durant l'hiver 1983-84, l'entrée de quantités importantes de glace dans la partie méridionale de la mer de Beaufort provoqua de nombreuses collisions de masses de glace sur le fond marin. Le positionnement de certaines masses de glace aux endroits présumés d'impact a été établi lors d'une campagne de reconnaissance menée par la compagnie Gulf Canada Resources Inc. Au cours de l'été suivant, l'impact causé par ces masses de glace sur les fonds marins a été étudié à l'aide d'un sonar à balayage latéral et d'un écho-sondeur. Les sonogrammes ainsi recueillis ont servi à la construction de mosaïques du fond de la mer. L'examen détaillé des mosaïques a démontré la grande variabilité des profondeurs des traces d'affouillement le long de leur parcours.

Le processus de formation d'une trace d'affouillement semble se dérouler en 3 phases. La première phase débute lorsequ'une quille de glace entre en collision avec le sol marin et se termine lorsque le fond de la trace d'affouillement commence à s'élever par rapport au niveau de la mer. Durant la second phase, le fond de la trace d'affouillement continue à s'élever mais dans une measure moindre que la diminution de la profondeur d'eau. Au cours de la troisième phase, l'élévation du fond de la trace d'affouillement et la diminution de la profondeur d'eau sont identiques.

Le fond d'une trace d'affouillement, d'une profondeur constante de 3 m, s'est élevé de 3 m relativement au niveau de la mer au site E-2, localisé dans le chenal Kugmallit. La nouvelle trace d'affouillement la plus profonde observée lors de l'étude de 1984 a été de 4 1/2 m (Site W-2)

1.0 INTRODUCTION

1.1 RELEVANT STUDIES

Ice scour tracks are sea-bed features caused by the contact with the sea-bed by moving ice masses. The degree of sea-bed scouring is related to the forces involved in the ice movement and the properties of the sea-bed soils. Wind energy, ocean currents, bathymetry, bottom slope, and bottom sediment type are important components in the study of ice-scouring processes (Pelletier and Shearer, 1972).

The process of sea-bed ice scouring has been recognized for many years from observations of grounded ice keels and the presence of sediment incorporated into pressure ridges (Kindle 1924; Tarr 1897). The ice scours observed on the sea-bed of the Canadian Beaufort Sea are caused mainly by bottom contact from ice keels of first-and multi-year pressure ridges (Lewis 1977).

From the shore-lines to the continental slope, the winter sea ice can be divided into three distinctive zones each closely related to the water depth. The three are referred to as the fast-ice zone, the shear zone, and the pack-ice zone (Kovacs and Mellor 1974).

With the advent of sonar echo-sounding in the 1950s it became impossible to examine the actual effect of moving sea ice masses on the sea-bed (Carsola 1954). Since the early 1970s (Kovacs 1972; Pelletier and Shearer 1972; Reimnitz et al. 1972) the use of the side-scan sonar proved to be a valuable method for mapping the sea-bed scours. The side-scan sonar method used short pulses of sound transmitted outwards and the return echoes received by a transducer oriented sideways from the ship (Tucker 1966).

Initially a morphological classification was conceived in an attempt to date the scours on the basis of relative ages (Shearer and Blasco 1975). It was suggested that a scour with fresh,detailed features of the scour base and excavated soil mound was a result of a more recent event than a scour with subdued, indistinct features. This relative age concept proved to be very subjective and was dependent on several factors including sedimentation rate, which varies throughout the Beaufort Sea (Harper and Penland 1982). Relative age dating was superseded by the desire for real or absolute ages. Various dating techniques were attempted with some degree of success, but the lack of reliable dateable material and the inaccuracy of the determined ages left the detailed understanding of recent events still unresolved[1].

1.2 SCOPE AND AUTHORIZATION OF THE PRESENT STUDY

The repetitive survey over identical sectors of the sea-floor, with side-scan sonar equipment, was believed to be a valuable and accurate technique with which to identify new scours (Shearer 1979). A comparison of the sonograms collected from different survey periods would permit the identification of new scours and, hence, the calculation of impact rates. Prior to 1984, only localized repetitive mapping surveys were performed and the calculated impact rates were too isolated when attempting to document regional variations. As a result, the ESRF Sea Bottom Ice Scour Committee realized that a regional base-line network of survey lines which covered most of the Beaufort Sea continental shelf was needed. Because the 1984 survey lines would cover some previously surveyed areas, the impact rate could be calculated for the interim period. Further resurveying could be undertaken at a later date.

A request for proposals was issued in the ESRF Update of May, 1984, and authorization to proceed with the study was granted to Geoterrex Limited under ESRF Study Proposal No. 232-14-05 (S) "1984 Beaufort Sea Repetitive Ice Scour Mapping."

1.3 OBJECTIVES OF THE STUDY

Two main lines of study are developed in this report: The first is the study of frequency of new scouring events, or the impact rate using repetitive mapping; and the second is the examination of the changes in physical characteristics of a number of selected scours by detailed tracking throughout their complete scour path.

1.3.1 Regional, Repetitive Baseline Network

To identify new ice scours and to determine impact rates, a base-line network of good-quality, side-scan sonar information was developed for different areas of the

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[1] R. Pilkington, Gulf Canada Res. Inc. Calgary, Pers. Comm. 1983.

Beaufort Sea shelf. This regional repetitive base-line ice scour mapping network now incorporates control areas and corridors that had already been established by the petroleum industry. This study entailed collecting and reviewing all available, relevant information from industry, government, and public sources.

With the regional, repetitive baseline network established, any repeated surveys over the same area or corridor would enable the documentation of any new scour events that might have occurred in the interim, which would then permit impact rates to be calculated for specific areas of interest.

In addition, the baseline network will serve as the basis for future repetitive mapping projects in the Beaufort Sea.

1.3.2 Detailed Tracking of New Ice Scours

The second objective of the study was to examine the physical dimensions and nature of a number of recent ice scours over their entire length. The changes in these parameters should provide information on the relative influence of various environmental factors.

Little information exists on the physical parameters of a scour throughout its length. One of the most important measurements for which data is lacking is the scour depth. Echo-sounding traverses across a given ice scour event, at several locations, has provided data from which transversal and longitudinal profiles of scour depth were constructed. Furthermore, the interrelationship of scour depth and water depth was examined. Length, width, and orientation of specific ice scour were also examined during this study.

The winter of 1984 was somewhat exceptional in that a number of second-year ice features were observed to be grounded in the sea-bed. These incursions provided a unique opportunity to examine in detail some rather significant recent scour events throughout the entire length of the scour track.

1.4 TERMINOLOGY

For the purposes of clarity, a listing of the terms used in describing the observed scours is given below. the first list shown is that describing the age of scour.

"New" - This is applied to a scour with a known age, either from the repetitive survey observations or being the scour formed during a given winter by ice ridge features observed and mapped on the surface.

"Recent" - This applies specifically to the scours formed by observed surface ice ridge features.

The following classification of ice scours, is based upon the strength of the echoes from the walls, berms, and bottom of the scour.

"Very fresh" - Both scour walls and berms display high return signal strength; non-reflective scour bottom.

"Fresh" - Both scour walls and berms display high return signal strength; normally reflective scour bottom.

"Semi-fresh" - Reduced signal strength on scour walls; berms still visible; normally reflective scour bottom.

"Semi-smooth" - Normal background signal strength from scour walls and bottom; berms not visible.

"Smooth" - Whole ice scour barely visible.

2.0 SURVEY DESIGN

The 1984 ESRF survey consisted of two separate activities; the establishment of a regional repetitive base-line network and the sites for detailed tracking of new scours.

2.1 REGIONAL REPETITIVE BASELINE NETWORK

The primary requirement for determining impact rates for ice keels is to be able to compare data collected from one survey to that collected over the same area, during another year.

The areas selected for repetitive surveying are based to some extent on the hydrocarbon potential and the expected oil and gas activity in the region. Geological potential is believed to exist in a region between Herschel Island and Baillie Island (Plate 1), with most of the exploration activity occurring between Mackenzie Bay and the Kugmallit Channel. The survey was designed to cover this region of highest activity, with reduced line coverage for the regions outside this area.

Given the prime area of interest, a number of other factors must be taken into consideration when designing a realistic set of base-line survey lines. Any repetitive information collected to date has shown an almost exponential increase in ice scouring activity with decrease in water depth; therefore, equally spaced survey lines for all water depths would be an inappropriate model. To document ice scouring processes accurately in shallow waters, a more closely spaced grid was established in these areas. The increase in scour activity with a decrease in depth is related to the shear zone where contact occurs between the multi-year floes of the pack ice and the fast ice.

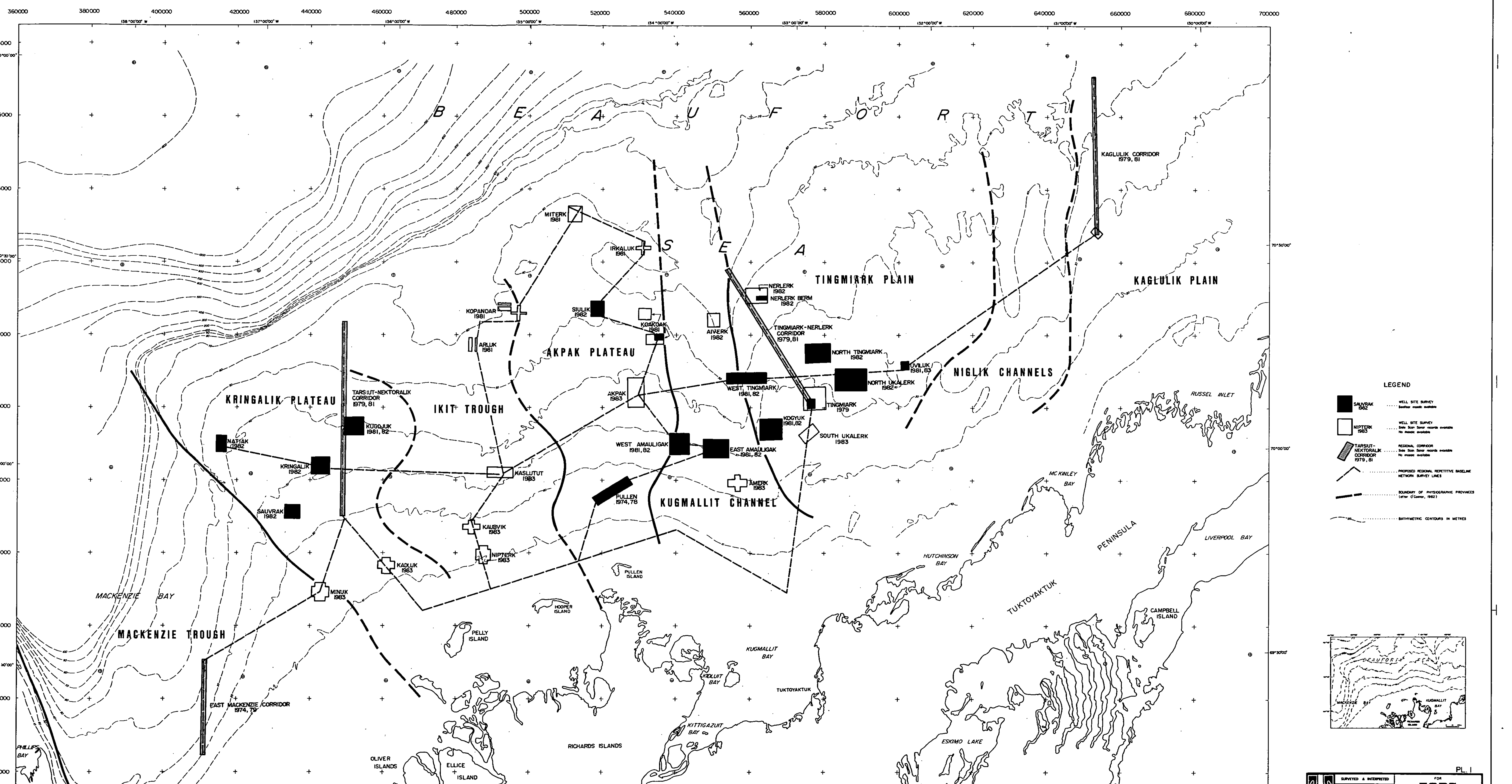
In addition, the surficial geology varies considerably across the Beaufort Sea shelf (Meagher 1978; Vilks et al. 1979; O'Connor 1980 and 1982) necessitating line coverage over all of the different physiographic provinces (see Plate 1). The surficial geology of the Beaufort Sea shelf is defined principally by different accumulation rates of fine silty clay sediments. Since the last marine transgression, which is believed to have occurred about 15,000 years ago (Forbes 1980), the Mackenzie River and its tributaries have been a source of fine sediment influx into the Beaufort Sea. Three main coastal areas serve, or have served, as sediment sinks;

Mackenzie Trough, Ikit Trough, and Kugmallit Channel. Within all three of these areas of deposition, average thickeness of fine silty clay exceeds 10 m, (O'Connor 1982.)

Prior to the regional repetitive surveys in 1984, a number of other surveys had been undertaken that provided good-quality, side-scan information for localized areas. The earlier data were obtained from two main sources. The first source was from a number of survey corridors that were established during the late 1970s in an attempt to provide regional information on new scours. The corridors, shown on Plate 1, are identified as Kaglulik, Tingmiark-Nerlerk, Tarsiut-Nektoralik, and East Mackenzie. These corridors run in a north-south direction scattered throughout the central Beaufort Sea and most have water depths of 20-50 m.

The second source of repetitive scour information consists of specific well-site surveys which were conducted by various industry groups. These specific site surveys (see Plate 1) consist primarily of sea-floor mosaics constructed from sonograms gathered over prospective drill-site areas in water depths from 10-35 m (Table 1.) The Pullen survey area is the only one with water depths shallower than 20 m. (See Table 1 for listing).

Some discussion exists as to the width of the base-line swath needed to ensure that a repetitive survey over an identical portion of the sea-floor can be achieved. During the 1984 survey, the side-scan sonar was operated at a range of 150 m per channel which yielded a scale of 12 m sea-floor coverage per centimetre of sonogram record. At this scale features of less than 1 m in width could be resolved. With the advent of very accurate navigational systems, which were unavailable 10 years ago when the original surveys were begun, it was felt that one survey line would be sufficient to establish a proper base-line. Scours within the 300-m-wide path covered by the side-scan sonar would provide the basis for the data for future repetitive studies of ice scour and for calculations of impact rate.



PL. I

SURVEYED & INTERPRETED
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OTTAWA, ONTARIO

FOR
ESRF
CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS

PROPOSED REGIONAL REPETITIVE BASELINE NETWORK

SURVEY DESIGN

ARGO
NAVIGATION SYSTEM

TABLE 1.

Control Corridors And Areas Previously Surveyed And Resurvyed During The 1984 Ice Scour Repetitive Mapping Study

Name	Years of Survey
KAGLULIK corridor (Dome)	1979,81
TINGMIARK-NERLERK corridor (Dome)	1979,81
TARSIUT-NEKTORALIK corridor (Dome)	1979,81,83
EAST MACKENZIE corridor (Dome)	1974,79
PULLEN area	1974,78
AMERK area (Esso)	1983
NIPTERK area (Esso)	1983
KAUBVIK area (Esso)	1983
KADLUK area (Esso)	1983
MINUK area (Esso)	1983
NORTH UKALERK area (Gulf)	1982
SOUTH UKALERK area (Gulf)	1983
KOGYUK area (Gulf)	1982
EAST AMAULIGAK area (Gulf)	1982
SAUVRAK area (Gulf)	1982
TINGMIARK area (Gulf)	1974,79
KASLUTUT area (Gulf)	1983
UVILUK IS. area (Dome)	1983
UVILUK IS.-KAGLULIK (Dome)	1981

2.2 DETAILED TRACKING OF NEW SCOURS

During the fall of 1983 a significant incursion of second-year ice took place in the shallow waters of the Beaufort Sea and a number of major ice ridges grounded (Plate 2). Because of the unusual occurrence of second-year ice in shallow water, Gulf Canada Resources, Inc. undertook a winter survey program to locate accurately and measure sail heights and the corresponding keel depths of some of these grounded ice ridges[2]. Locations of significant sails for the eight sites were obtained through satellite positioning, so that a follow-up study could be undertaken the following summer. Of these three were in the eastern zone (E-1, E-2, and E-3 sails), three in the middle zone (M-1, M-2, and M-3 Sails) and two is the western zone (W-1 and W-2 Sails) of the Beaufort Sea study area (see Plate 2). Ice sails of up to 11 m in height were observed and through-ice measurements of bottom depth were made in an attempt to locate the bottom scours created by the grounded pressure ridges. The through-ice measurement techniques however met with only limited success.

Prior to the commencement of the 1984 ESRF program, few scours had been tracked and examined in detail from beginning to end, with the exception of a few scours tracked during specific well-site surveys. Although beginning and end points of scours are rarely observed, the properties of the mid-length of the scour track have proven helpful in understanding some of their behaviour over bathymetric ridges and depressions. Therefore, the incursion of second-year ice features during the 1983-84 winter provided a rare opportunity to examine in detail ice scour events along their entire length.

The different characteristics of ice scours are determined most clearly and accurately using acoustic equipment. Side-scan sonar records provide information on the morphology, orientation, and density of the scours whereas echo-sounding records provide scour depth data. The nature of the surficial sediments is determined using sub-bottom profilers. The characteristics of this suite of acoustic equipment is described in more detail in the following section.

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[2]"Sail" height is commonly the height attained by the ice blocks which comprise the pressure ridge feature in question.


BEAUFORT SEA
KAGLULIK CORRIDOR 1979, 81
TINGMIARK - NERLERK CORRIDOR 1979, 81
NORTH UKALERK 1982
UVILUK IS. 1983
TINGMIARK 1979
SOUTH UKALERK 1983
EAST AMAULIGAK 1982
KOGYUK 1982
AMERK 1983
E-1 Site (PL.6a&b)
E-3 Sail
E-2 Sail
E-1 Sail
TARSIUT - NEKTORALIK CORRIDOR 1979-1981-1983
M-2 Sail
M-2 North Site (PL.1a&b)
M-2 Site (PL.7a&b)
M-3 Sail
M-1 Sail
KASLUTUT 1983
PULLEN 1974, 78
PULLEN 2 Site (PL.3)
SAUVRAK 1982
W-2 North Site (PL.12a&b)
Plate 5
KAUBVIK 1983
NIPTERK 1983
KADLUK 1983
MINUK 1983
W-2 Sail
W-2 Site (PL.8a&b)
EAST MACKENZIE CORRIDOR 1974, 79
MACKENZIE BAY
PHILLIPS BAY
PULLEN ISLAND
HOOPER ISLAND
PELLY ISLAND
OLIVER ISLANDS
ELLICE ISLAND
RICHARDS ISLANDS
KIDLUIT BAY
KITTIGAZUIT BAY
KUGMALLIT BAY
TUKTOYAKTUK
HUTCHINSON BAY
TUKTOYAKTUK PENINSULA
ESKIMO LAKE
McKINLEY BAY
RUSSEL INLET
LIVERPOOL BAY
CAMPBELL ISLAND
138°00'00" W
137°00'00" W
136°00'00" W
135°00'00" W
134°00'00" W
133°00'00" W
132°00'00" W
131°00'00" W
130°00'00" W
70°30'00"
70°00'00"
69°30'00"
NAUTICAL MILES
MILES
KILOMETRES
LEGEND
ESRF 118 SURVEY LINE IDENTIFIER
4247 FIX LOCATION and FIX NUMBER
20 BATHYMETRIC CONTOURS IN METRES
SITE and CORRIDOR AREAS
APPROXIMATE POSITION OF OUTER EDGE OF SHORE-FAST ICE and GROUNDED MULTI-YEAR FLOES
E-2 Sail
E-1 Sail
LOCATION OF ICE SAIL (WINTER 1983-84)
INDICATES DETAILED EXAMINATION OF GROUNDED ICE
NEW SCOUR TRACKING SITE (SUMMER 1984)
OBSERVED NEW ICE SCOURS
30 DEPTH (m) TO THE BASE OF ICE SCOUR FROM SEA LEVEL
3 MAXIMUM DEPTH (m) OF NEW ICE SCOUR
2 CALCULATED IMPACT RATE OF NEW SCOURS (IMPACTS/km/yr)
RICHARDS ISLAND
PL. 2
SURVEYED & INTERPRETED
geoterrex ltd
OTTAWA, ONTARIO - SIDNEY, B.C.
FOR
ESRF
CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR
MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS
BASELINE NETWORK
AND
NEW ICE SCOUR OCCURRENCE
LOCATION MAP
INTERPRETED BY: B.L. J.S.
DRAWN BY: M. FRENDAS
ARGO
NAVIGATION SYSTEM
MAY, 1985
GEOTERREX PROJECT No. 095

3.0 FIELD INVESTIGATION

3.1 SURVEY EQUIPMENT

The geophysical instruments used throughout the survey operations to measure the various characteristics of the sea-bed ice scours included the following: a Klein side-scan sonar system composed of a 3.5-kHz Klein subbottom profiler coupled with the 100-kHz side-scan sonar tow fish; a 200-kHz Raytheon precision echo sounder; and a Raytheon sub-bottom profiler as back-up unit (see Appendix A).

The side-scan sonar fish was towed off the stern of the survey vessel (Figure 1). The sea-floor echoes, received by the side-scan transducer, were transmitted to the wet paper recorder through a strengthened electrical cable and a winch equipped with a slip-ring connector. A scanning range of 150 m per channel was used throughout the survey to provide sea-floor coverage with maximum resolution of small scour features. A K-maps processor was interfaced to the side-scan sonar unit to remove from the sonograms the water column between the tow-fish and the sea-bed. In addition, the K-maps system corrected for distortions incurred by the slant angle of the acoustic signal and variations in the ship's speed. These corrections permitted the true size and orientation of the scours to be determined.

The echo sounder was secured to the midship starboard side of the survey vessel (see Figure 1). The immersion depth of the echo sounder transducer was corrected on the echograms by means of a draft setting (1.3 m) which allowed actual water depths to be recorded. In addition, to ensure that the recorded depths are accurate, the echo sounder was calibrated for speed of sound in water by lowering an acousticaly reflective plate to obtain echoes at different pre-measured depths below the transducer.

The echo sounder was sensitive particularly to the sea state because of its rigid connection to the survey vessel. A heave compensator system was introduced in an attempt to filter out, on the echograms, the sea-bed oscillations induced by the ship roll in response to the wave motion. The heave compensator was effective when the wave periods were greater than 4 s; however, wave periods were often less as a result of short-duration, moderate-to-strong wind activity.

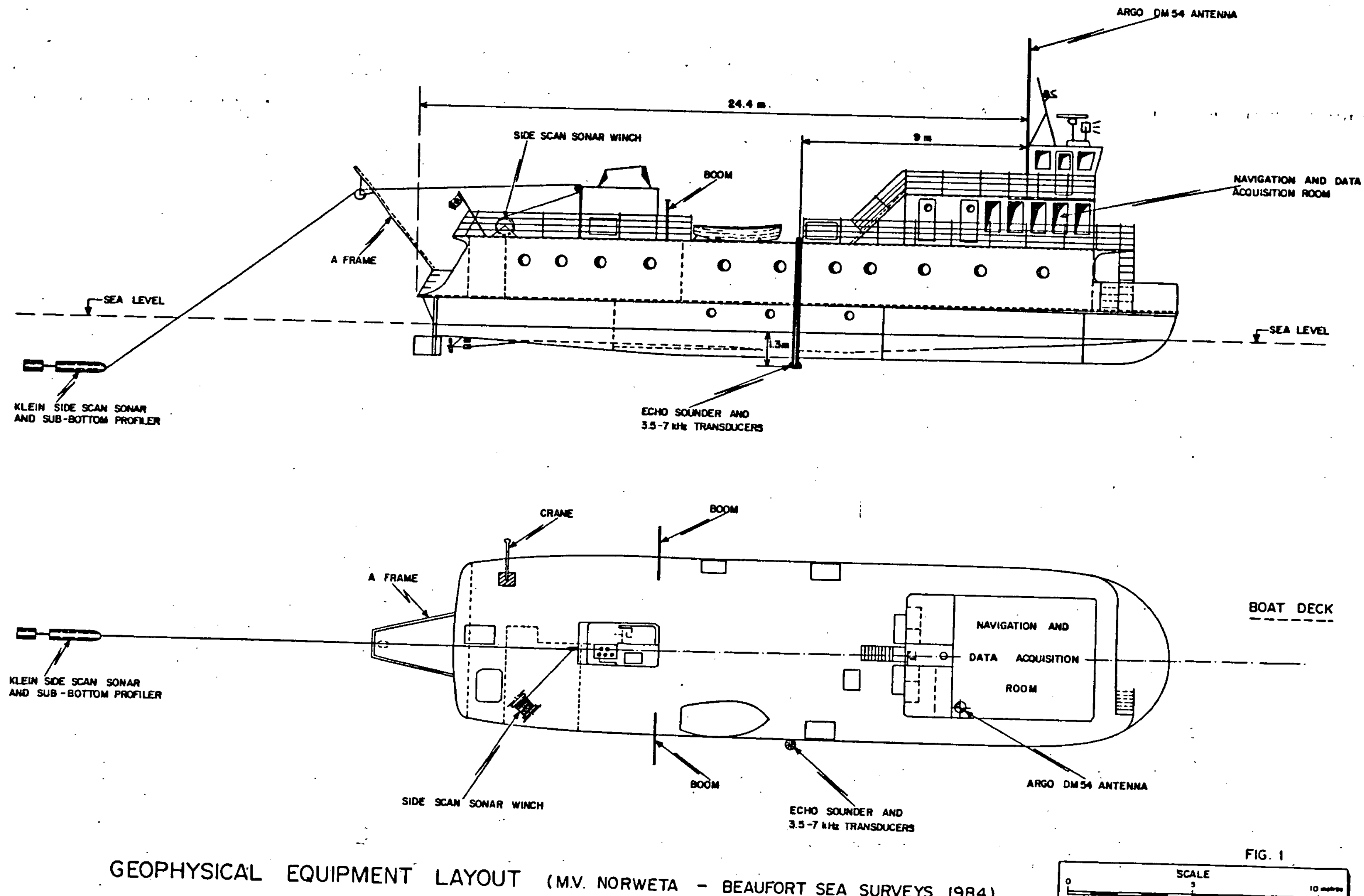


Figure 1. Layout of geophysical equipment on-board MV Norweta during Beaufort Sea Survey 1984.

Two separate subbottom profiling systems were used during the field investigation: a Klein, Model 532S, and a Raytheon, Model RTT 1000A. As mentioned previously, the Klein profiler was mounted in the side side-scan sonar tow-fish, whereas the RTT 1000A unit was combined with the echo sounder assembly. In general, these two systems were operated simultaneously to provide a comparative check when anomalous conditions were encountered.

3.2 LOGISTICS

The survey vessel used to carry out the survey operations was the MV Norweta which was mobilized from Hay River, Northwest Territories. All the geophysical and navigational equipment were tested and installed in Hay River before departure for the Beaufort Sea. A mobile telephone and telecopier were installed on-board the vessel in Tuktoyaktuk to provide close communication through the Beaudril base at Tuktoyaktuk. In addition, telex messages as well as ice flow information collected via synthetic aperature radar (SAR) imagery could be relayed to the ship during the field operation. Information on ice conditions throughout the Beaufort Sea proved useful in planning the location of survey profiles. In fact, severe ice conditions that persisted during the field program hampered the survey operations. Sustained logistical support, which included air freight shipments to and from Tuktoyaktuk, and offshore support via helicopter to various drilling platforms and offshore bases, was provided courtesty of Beaudril and Gulf Canada Resources, Inc. The success of the 1984 field operations during a year made difficult by ice cover can be attibuted largely to an effective logistical support. Figure 2 illustrates the time spent on the different activities during the ESRF survey. About two-thirds of the available time for survey operations (15 of a possible 24 days) was used to collect data.

3.3 SURVEY OPERATIONS

The ESRF project study involved two major fields of investigation which used both side-scan sonar and echo-sounding equipment. Although related in scope, each required a differrent approach. The locations of all survey lines are shown on Plate 2. The same equipment configuration was used during the entire survey operations.

The base-line network survey lines were often very long and were run through a broad range of water depths.

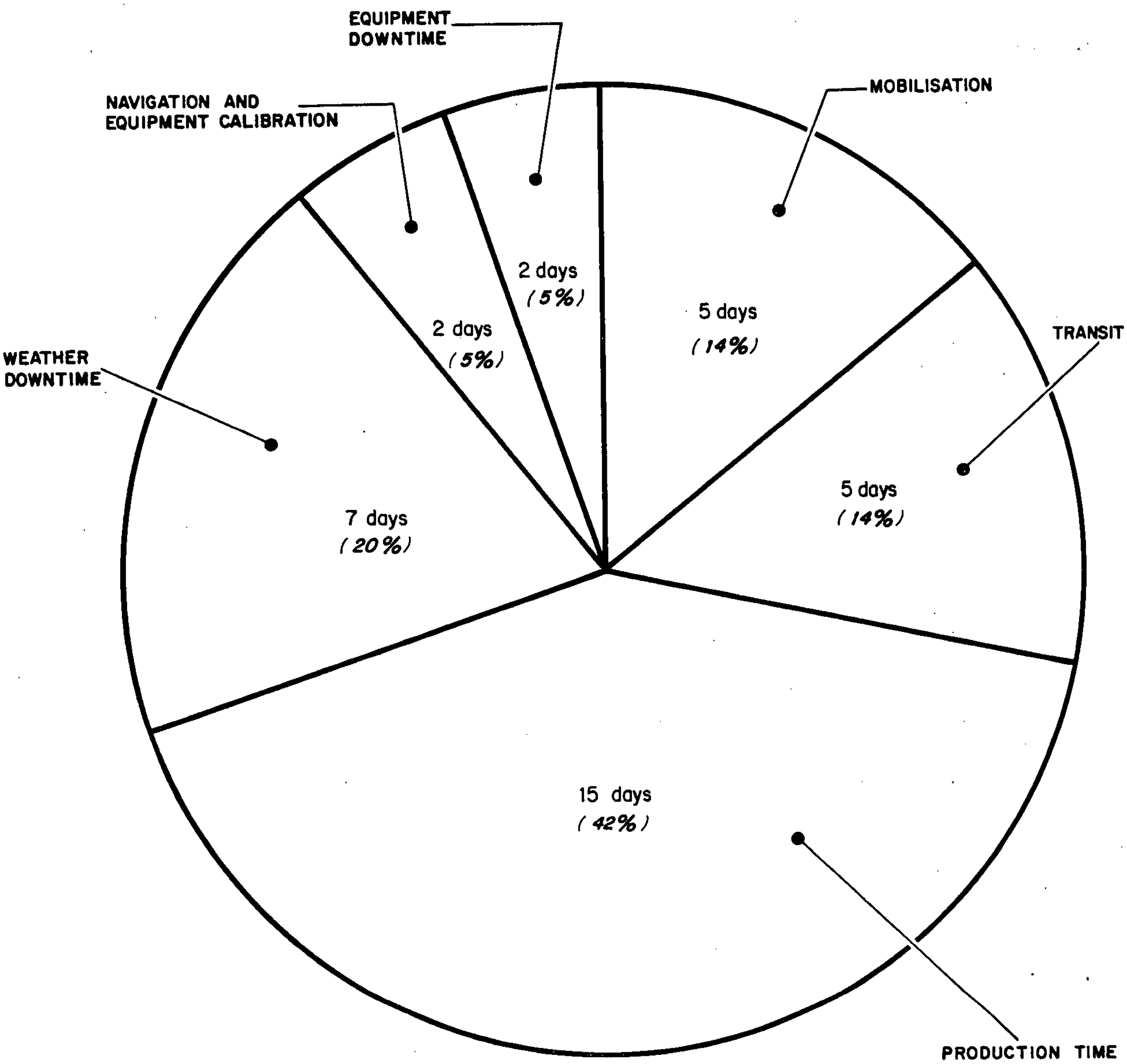


Figure 2. Time distribution for 1984 ESRF survey. (16 July - 20 August, 1984)

Consequently, areas with various surficial sediment composition were traversed. The detailed Tracking , on the contrary, was generally localized and necessitated rapid course changes to follow meandering scour tracks. The tow-fish was kept close to the ship so that any directional changes did not cause it to lose forward velocity and to come in contact with the sea floor.

In previous surveys, the weather conditions and the sea state were crucial factors affecting the quality of the data. Because the collection of high-quality data was essential to the entire project, it was decided to survey only in weather conditions that permitted the acquisition of good-quality, side-scan sonar information. For this reason, the survey was temporarily halted when ambient sea noise interference significantly reduced the effective range and quality of the side-scan sonar.

A comparison of Plates 1 and 2 reveal that the 1984 base-line survey did not extend into the deeper water areas as proposed in the original design outline (see Plate 1). Marginal sea-ice conditions allowed only partial resurveying of the northernmost three control corridors (Tarsiut-Nektoralik, Tingmiark-Nerlerk, and Kaglulik corridors).

4.0 RESULTS

A number of new ice scour features were examined in detail. The scope of interest ranged from the return period of ice scours for different water depths and various regions of the Beaufort Sea shelf to the morphological expression of the new scour marks on the sea bottom.

To establish the "Regional Repetitive Base-line Network", during the 1984 ESRF survey, a total of 1,460 km of sea-floor were surveyed as follows: 1,140 km of single swath; 300 km of double swath (total 600 km); and 20 km of triple swath (total 60 km) survey lines. About 1,000 km are original data, whereas the rest, about 460 km, were lines repeated over pre-existing control areas.

The second phase of the program, "Detailed Tracking of New Scours," comprises about 350 km of survey lines.

4.1 REGIONAL REPETITIVE BASE-LINE NETWORK

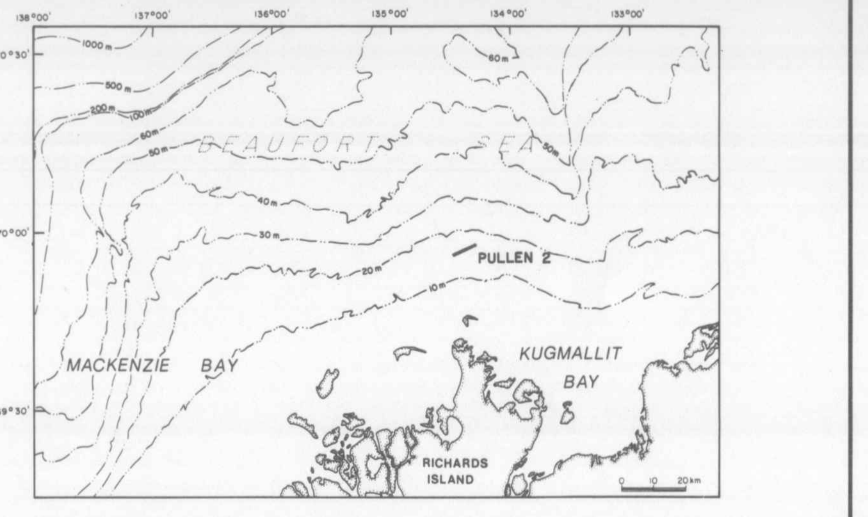
Unfortunately, the presence of second-year ice floes over the Beaufort Sea shelf, during much of the survey, prevented the establishment of new base-line corridors in the deeper water areas (see Plate 1). Plate 2 shows the areas where the 1984 ESRF base-line data were collected, which includes the areas that were surveyed during previous years (from 1979 to 1983). The ice scour data collected in these previously established corridors and well-site survey areas provided the base-line information to be used for the identification of new scours.

Plates 3 and 4 provide examples of comparative studies of identical segments of the sea-floor conducted on two different survey lines that were traversed during different years. The identification of common scour signatures on the repetitive lines (e.g., locations 3 and 4, Plate 3), permits the recognition of the new ice scours which were formed in the interim period.

4.1.1 New Scour Impact Rate for Re-surveyed Areas

In this study, the impact rate of new scours is defined by the number of new scours per kilometre per year. The calculation of impact rates was achieved by dividing the number of new scours, which were identified in a specific area (between the 1984 ESRF and previous study, see Table 1) by the total length of the survey lines in kilometres and by the number of years between the surveys. For instance, the centre line for the Pullen site (see

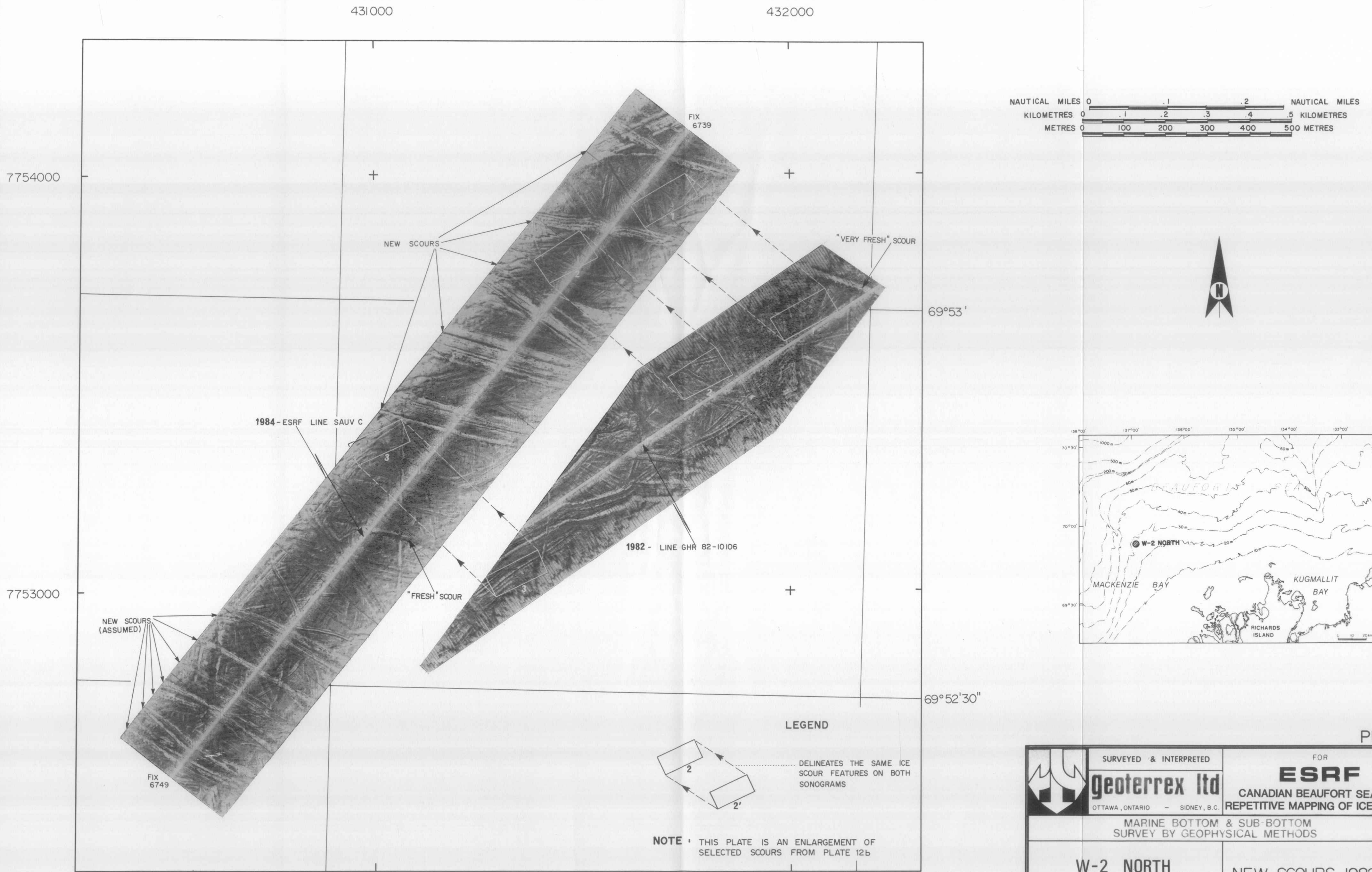
NAUTICAL MILES 0 1 2 3 4 5 NAUTICAL MILES
KILOMETRES 0 2 4 6 8 10 KILOMETRES
METRES 0 200 400 600 800 1000 METRES



NOTE: 12 .... REFERS TO A PREVIOUS STUDY

PL. 3

SURVEYED & INTERPRETED geoterrex ltd OTTAWA, ONTARIO – SIDNEY, B.C.	FOR **ESRF** CANADIAN BEAUFORT SEA 1984 REPETITIVE MAPPING OF ICE SCOUR
MARINE BOTTOM & SUB-BOTTOM SURVEY BY GEOPHYSICAL METHODS	
PULLEN 2 (1978 and 1984)	SIDE SCAN SONAR MOSAIC
INTERPRETED BY: B.L. J.S. DRAWN BY: M. FRENDAS — ARGO NAVIGATION SYSTEM	MAY, 1985 — GEOTERREX PROJECT No. 095



NOTE : THIS PLATE IS AN ENLARGEMENT OF SELECTED SCOURS FROM PLATE 12b

PL. 4

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FOR
ESRF
CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB-BOTTOM SURVEY BY GEOPHYSICAL METHODS

W-2 NORTH

NEW SCOURS 1982-84

INTERPRETED BY: B.L. J.S.
DRAWN BY: M. FRENDAS

ARGO
NAVIGATION SYSTEM

MAY, 1985

GEOTERREX PROJECT No. 095

Plate 3) has an impact rate of about 2.4 impacts/km/yr (160 new scour divided by 11 km and by 6 yr). The impact rates shown on Plate 2 have been calculated and averaged for all the control site areas. In the Tarsiut-Nektoralik corridor the quality of the data obtained in 1983 was so poor, that the survey run in 1981 was used for comparison.

New scours were observed in different areas over a wide range of water depths. Some of the deepest new scour events discussed in this study were identified in those sites where detailed tracking was conducted; in particulat, at sites W-2 and W-2 North where a maximum water depth of 36 m was observed. In spite of the fact the deepest new scour observed in the Kaglulik area occurred in water 30-35 m deep (similar to the western control sites), the frequency of occurrence is considerably less in this area as compared to the western sites. For example, the impact rate in the Tarsiut-Nektoralik corridor is 1.6 impacts/km/yr, in water 25-30 m deep, which is eight times greater than the calculated impact rate (0.2 impact/km/yr) for the same depth range in the Kaglulik corridor.

Information on impact rates for various parts of the shelf have been grouped into 1-m water depth intervals to analyse the variation of impact rates as a function of the water depth. Figure 3 shows the observed, averaged, impact rate for each 1-m range of water depth. These impact rates are the result of averaging all the known rates from a given 1-m. water depth interval over the Beaufort Shelf. This figure is a composite of impact rates calculated from the 1984 ESRF survey and from re-surveys done earlier in a number of areas, including Kaglulik, Tingmiark, and Pullen. The maximum impact rates of about 4 impacts/km/yr occur in 22-24 m of water. From this maximum rate, an abrupt decrease in impact rates occurs with increasing water depths, whereas a more gradual decrease is observed in shallower water.

4.1.2 Percentage of Re-scouring

The percentage of re-scouring for a particular area is the portion of the sea-bed which has been re-scoured along a given survey line. A re-scoured portion of the sea-bed can be divided into areas that were incised only and those which include the berms. The incised area is defined as a zone where the sea-bed has been gouged by the scouring ice whereas the disturbed area exhibits spoil piles along one or both sides of the scour.

Figure 4 illustrates the percentage of the area re-scoured (including both incised and disturbed areas) as

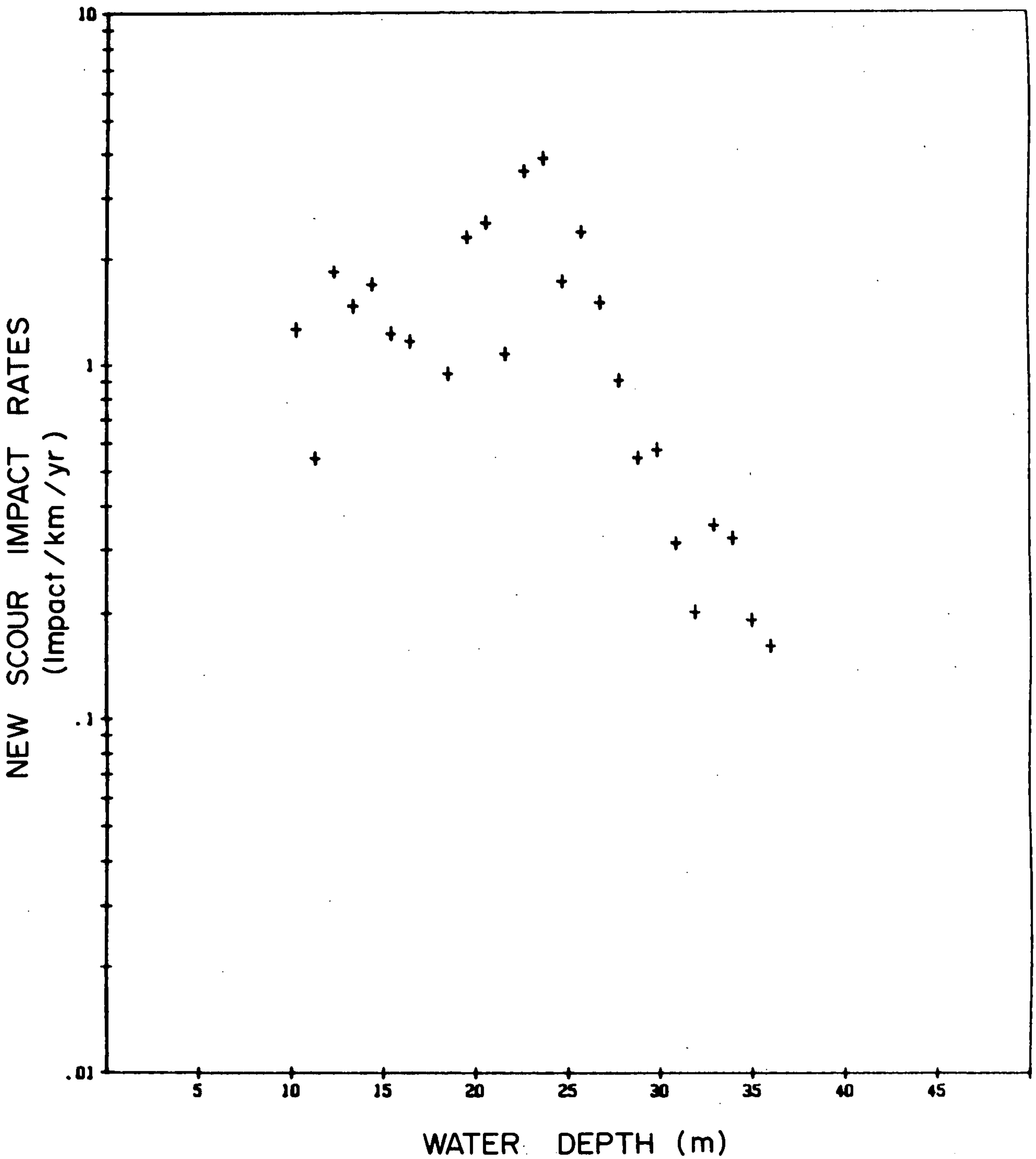


Figure 3. New scour impact rates for 1-m depth intervals.

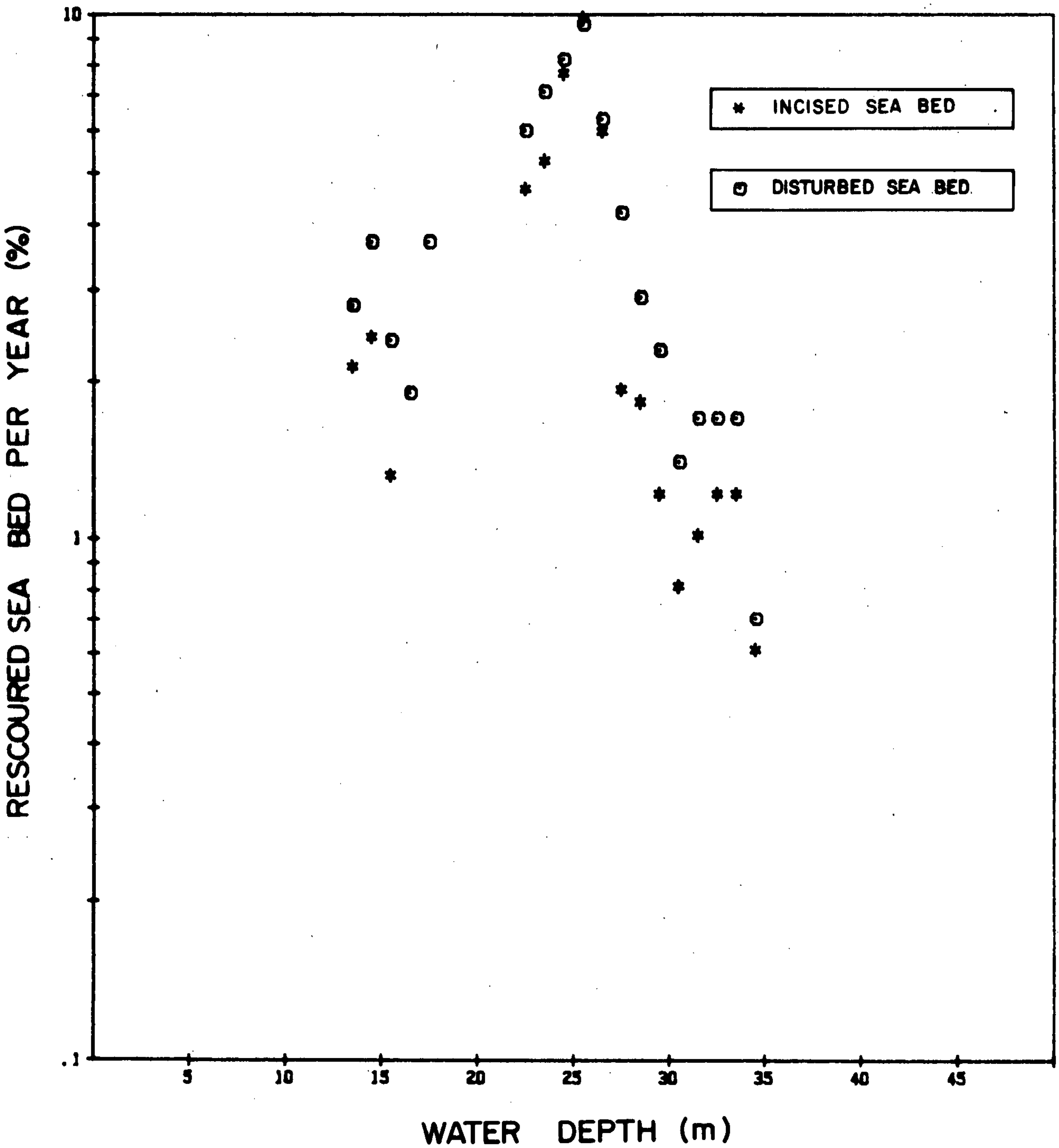


Figure 4. Average area of the sea bed re-scoured per year.

a function of water depth (1-m water depth intervals) using the Pullen data (1978-84) and the Tarsiut-Nektoralik data (1979-81 and 1981-84). The percentage of sea-bed re-scoured per year is greatest when the water depth reaches about 26 m. The percentage of re-scouring decreases more slowly towards shallower water than towards deeper water regions where the decrease is relatively rapid.

4.1.3 New Scour Depth Distribution

In 1984 a number of new scours were observed to have formed during the time since the last survey (see Table 1). The scour depth distributions for these specific sites are presented in Appendix B. Several sites have such a small data set that analysis at this time is problematic, but the Pullen and Tarsiut-Nektoralik sites each have sufficient data with which to construct a graph of frequency versus scour depth.

The new scour data for the Pullen site comes from those scours observed to have occurred during the time of the last survey in 1978 and the 1984 ESRF survey. The new scour data for the Tarsiut-Nektoralik corridor comes from those scours observed to have occurred between the last good survey (1981) and the ESRF 1984 survey.

Because the water depths are similar over the whole Pullen site, the new scour occurrences are somewhat uniform. Contrary to this, the Tarsiut-Nektoralik corridor covers a water depth from 20 to 50 m with associated new scour occurrences ranging from frequent to absent. In this regard, uniform new scouring was observed between the depths of 22-26 m (see Appendix B). This zone was then taken as representative of the new scour occurrences for this depth range for this area.

The number of new scours observed in each scour depth interval were divided by the number of kilometres surveyed and by the time interval between surveys. Figure 5 is a histogram of the new scour depth distribution for the Pullen site and the 22-26 m water depth interval on the Tarsiut-Nektoralik corridor. The scour depth distributions for the Pullen Site and the Tarsiut-Nektoralik corridor indicate a high incidence of shallow scour depths with an exponentially decreasing number of deeper scour depths. Even though both areas have a similar number of very shallow scours (0-0.5 m interval) the number of deeper ones (0.5-1.0 m; 1.0-1.5 m; 1.5-2.0 m intervals for instance) differ considerably (i.e., actually bimodal for Tarsiut-Nektoralik). In the shallow-water Pullen site, the

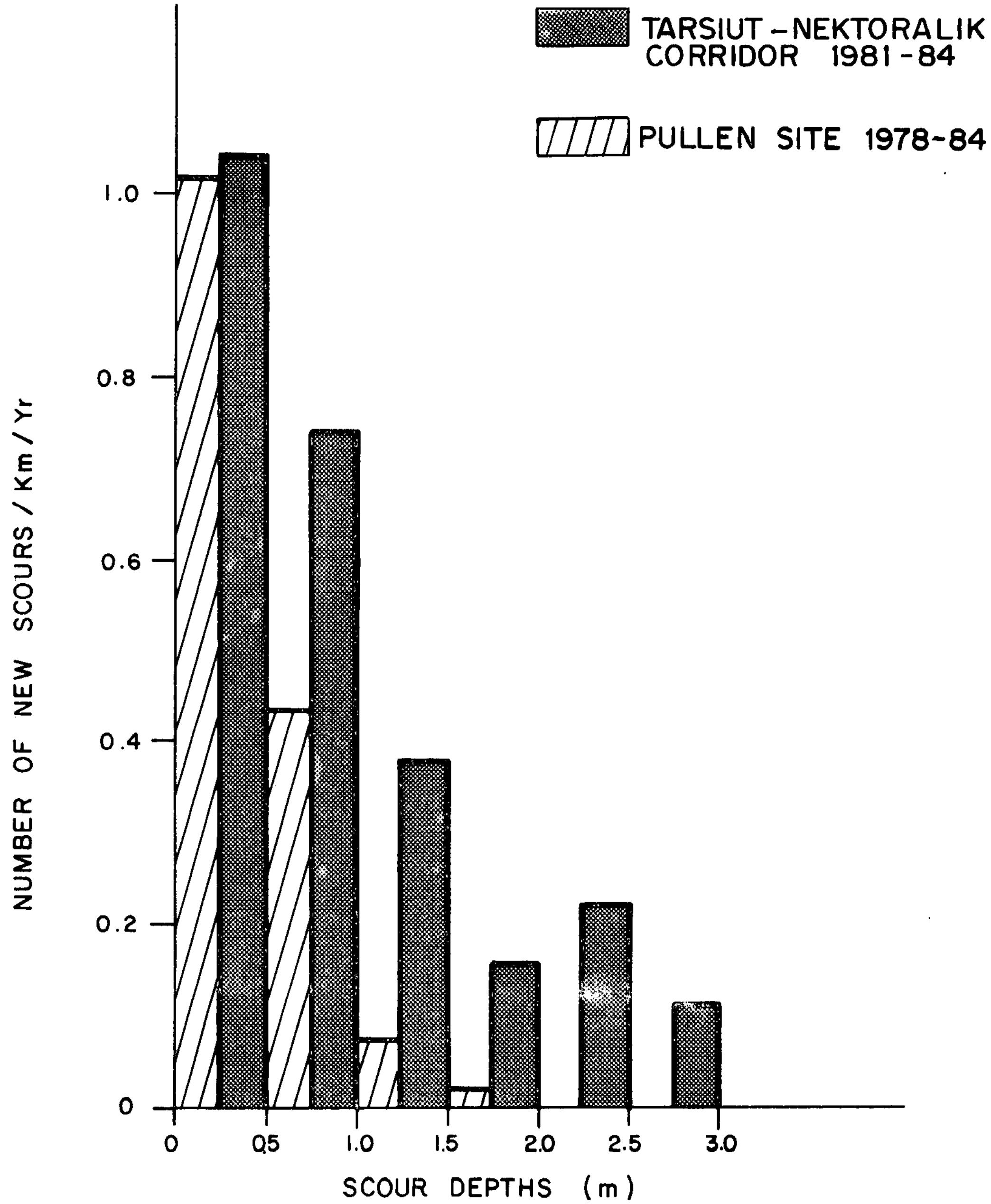


Figure 5. New scour depth distribution.

number of deeper scours is significantly less than for the Tarsiut-Nektoralik corridor.

Another study for Energy Mines and Resources (Shearer in press) examined the re-scouring rate for these areas for other time intervals (Pullen 1974-78, Tarsiut-Nektoralik 1979-81). The same study compared the information from these two different time intervals (same area) and found the new scour frequencies to be quite comparable.

Examination of Figure 5 shows the total number of new scours observed to be about 1.6/km/yr for the Pullen site and 2.7/km/yr in water depths of 22-26 m on the Tarsiut-Nektoralik corridor.

4.2 DETAILED TRACKING OF NEW SCOURS

During the winter of 1983-84, Gulf Canada Resources Inc. obtained accurate positioning (with the use of satellite navigation) of eight sails of major, grounded ice riges. Plate 2 shows the location of these eight sails in relation to the seaward edge of the grounded, second-year floes. E-1, E-2, and E-3 are situated east of the Amerk site in the eastern (E) sector of the study area; M-1, M-2, and M-3 are located in the middle (M) sector of the study area, between the Kaslutut and Pullen sites; whereas W-1 and W-2 sails were positioned in the western (W) sector, between the East Mackenzie corridor and the Minuk site. Each location was examined by means of side-scan sonar imagery and only sites E-1, M-2, and W-2 displayed distinct scour termination points that justified further detailed examination of the ice scour tracks. The identification of scour end points provided a unique opportunity to trace a recent scour track along its entire length. Although scour end points were not observed conclusively at the other five locations, recent ice scouring activity was obvious. Finally, two more sites, labelled M-2 North and W-2 North on Plate 2, were examined in detail because of the large number of "very fresh"-looking scours observed in these areas.

For the purposes of this study, a morphological classification for scours has been developed from examination of side-scan sonar imagery.

The strength of the reflected, acoustic, side-scan sonar echoes depends upon the nature and compaction of the sea-bed material; and on the steepness of the slope of the reflecting surface. All the sites examined in detail are situated west of the Kugmallit Channel where bed material consists of recent marine silts and clays. With these silty clays more than 5 m thick at all the sites, the incisions created by the scouring pressure ridges do not penetrate into any underlying layers of different soil types. From the sub-bottom information obtained at these locations, no bedding laminations were observed in the soft silty clays presumably because frequent bottom scouring had obliterated, or prevented the development of, any layering. One exception to this general presence of soft silty clays, occurs in the Pullen site where the Isserk sand body can be observed near the eastern edge (see fixes 2852- 2856, Plate 3). Nevertheless, because of these silty clays, the reflective characteristics of the different scours at each site are thought to be related not to abrupt changes in sub-bottom soil types but rather to gradual, time-related sediment infilling. The scours that are known to have formed during the winter of 1983-84 exhibit a characteristic set of reflective properties. Plates 4 and 5 (particularly at fix 6618) show clearly the highly reflective nature (strong signal return) of the scour walls of these new scours. These strong echoes are believed to result from steep slopes present along the sides of the scour. In contrast, the scour base is almost void of echoes and appears light grey on the sonograms. The nature of the ice-scouring process itself may be responsible for this poor acoustic response. Ice scouring may possibly cause forward rotation and compaction (resulting in expulsion of interstitial water) of the soft clays, resulting in a more parallel orientation of the flat clay particles.

A comparison of the bottom of the most recent scours (Plate 5, fix 6618) with slightly older ones (Plate 5, fix 6610) shows a return to background reflectivity. A few years of suspended sediment deposition with random orientation of the clay particles might account for these observed changes. On the other hand, these several years of sediment accumulation do not appear to affect significantly the strong acoustic response from the scour walls.

4.2.1 Detailed Examination of Grounded Ice Locations

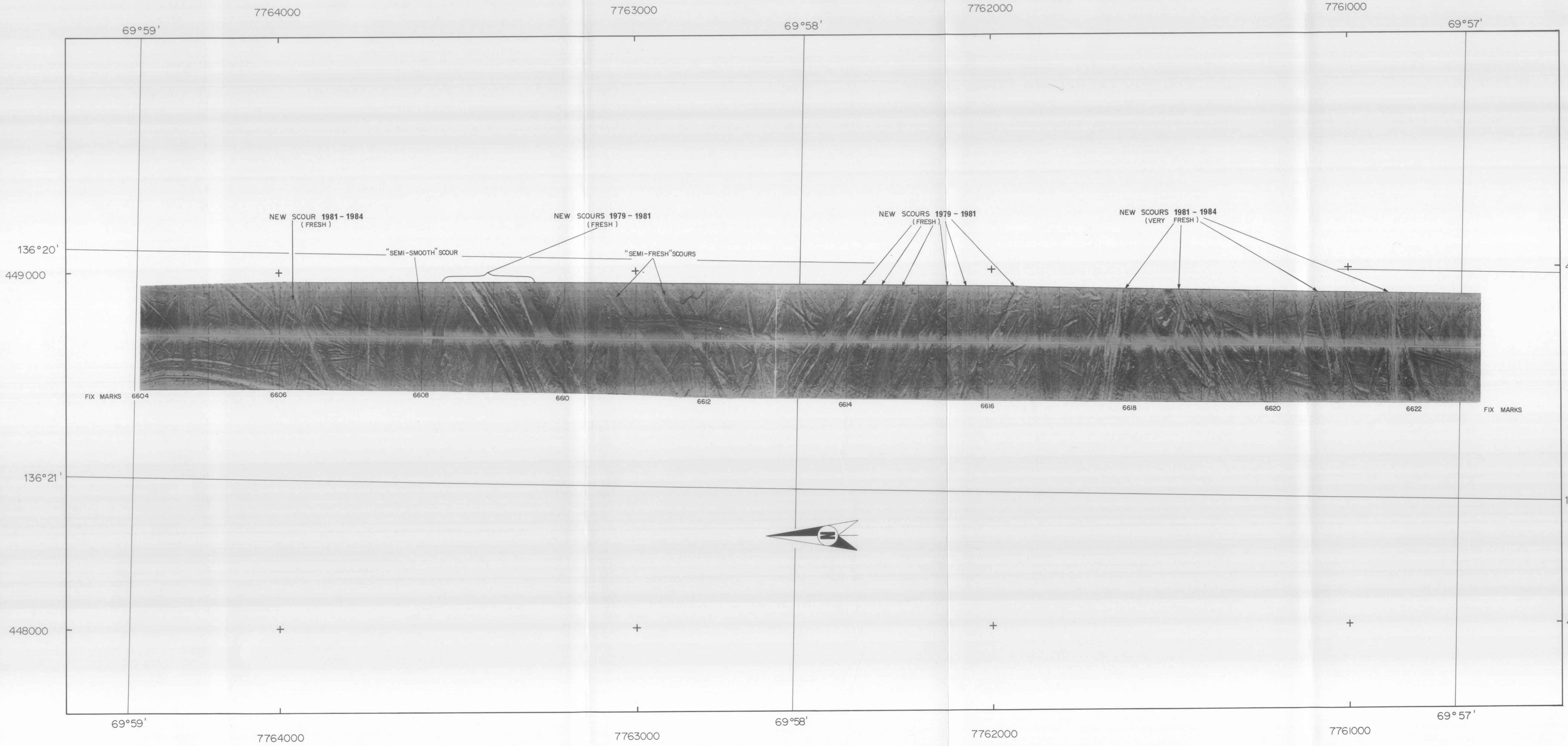
4.2.1.1 E-1 Area - During the 1983-84 winter survey, three pressure ridges (E-1, E-2, and E-3) grounded east of the Amerk Site (See Plate 2). Each area was surveyed the following summer and evidence of a distinct scour termination was observed at location E-1.

The E-1 site is situated some 60 km north-northwest of Tuktoyaktuk in the Kugmallit Channel. This site was selected for detailed examination because of its potential to provide information along a complete scour track. The area investigated extends northwest from the E-1 location, passing through the Amerk well site (see Plate 2).

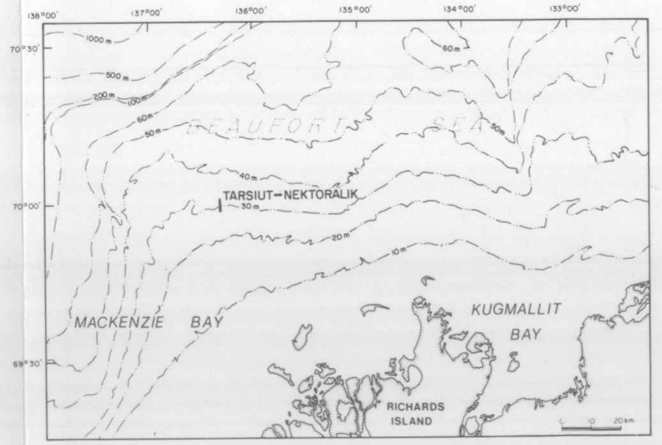
Plate 6a encloses a side-scan sonar mosaic constructed from sonograms obtained during the tracking of the scour whose termination point (Te, Plate 6b) is situated near the E-1 sail location. Plate 6b displays the interpretated results presented on an overlay which can be superimposed over the sea-floor mosaic (see Plate 6a) for direct comparison.

The proximity of the major ice scour (outlined on Plate 6a as a "very fresh" event) which terminates near the E-1 sail location (150 m to the east) indicates that it was probably created by the grounded pressure ridges observed at this location during the winter of 1983-84. This termination was observed on the side-scan sonar records but was never actually traversed with an echo sounder. Although no direct measurement of the termination point and berms could be made, nevertheless their depth and height can be estimated from of the side-scan records. The shadows created on the sonar records by these features indicate that the termination point is probably no deeper than the scour itself. Likewise, the berm height seems no more than a few metres and although the slopes cannot be measured, they appear to be no steeper than those observed in the scour walls (maximum between 30^{0} and 40^{0}). The scour begins near fix 196 (see Plate 6b) and likely was created by ice movement in a southeasterly direction. At the beginning of scouring, the scour is quite narrow (less than 10 m) and widens to 50-80 m between fixes 96 and 116). Along the track of the main scour, the various scours of this multi-keeled feature exhibit different positions relative to one another. The area of maximum width is observed in the vicinity of fixes 88-92 and seems to be related to an abrupt change in scour direction from the southeast towards the east. After about 11 km of scouring along an almost straight course, from the beginning of the scour until fix 96, an ice floe rotation and direction change seems to have occurred near fix 88. Finally, after another 1.7 km of scouring, the scour reaches its termination point (see Te Plate 6b).

During the scour tracking, the survey vessel crossed the deepest part of the scour several times. The depth, from sea level, to the deepest part of the scour base, as well as the depth to the sea-floor for each of these locations, are marked on Plate 6b. These depths permitted



NAUTICAL MILES 0 .1 .2 NAUTICAL MILES
KILOMETRES 0 .1 .2 .3 .4 .5 KILOMETRES
METRES 0 100 200 300 400 500 METRES



PL. 5

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FOR

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CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB BOTTOM
SURVEY BY GEOPHYSICAL METHODS

TARSIUT — NEKTORALIK

CORRIDOR

NEW SCOURS 1979-81 1981-84

INTERPRETED BY: B.L. J.S.
DRAWN BY: M. FRENDAS

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MAY, 1985

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PL.6a

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CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS

E-I AREA

SIDE SCAN SONAR
MOSAIC

INTERPRETED BY: B.L. J.S.
DRAWN BY: M. FRENDAS

ARGO
NAVIGATION SYSTEM

MAY, 1985

GEOTERREX PROJECT No. 095


LONGITUDINAL DEPTH PROFILE
DEPTH FROM SEA LEVEL
20m
25m
30m
SEA BOTTOM
BASE OF SCOUR
LOCATION OF E-1 SAIL
(FROM SATELLITE POSITIONING)
WINTER PROGRAM 1984
BEGINNING OF SCOUR
"FRESH" ICE SCOUR
"FRESH" ICE SCOUR
(4 m deep)
NAUTICAL MILES
KILOMETRES
METRES
LEGEND
SURVEY LINE IDENTIFIER
FIX LOCATION and FIX NUMBER
REFER TO ACCOMPANYING REPORT
REFER TO THE LONGITUDINAL DEPTH PROFILE
MAJOR "VERY FRESH" ICE SCOUR TRACKED TO E-1 LOCATION
OBSERVED OUTLINES
ASSUMED OUTLINES
OTHER MAJOR "VERY FRESH" OR "FRESH" ICE SCOURS
INDICATES ICE SCOUR TERMINATION POINT
DEPTH (m) TO BASE OF SCOUR FROM SEA LEVEL
DEPTH (m) TO SEA BOTTOM FROM SEA LEVEL
PROPOSED DIRECTION OF ICE MOVEMENT
MACKENZIE BAY
KUGMALLIT BAY
PL. 6 b
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FOR
ESRF
CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR
MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS
E-1 AREA
DETAILED EXAMINATION OF
GROUNDED ICE LOCATION
(WINTER, 1984)
INTERPRETED BY: B.L. J.S.
DRAWN BY: M. FRENDAS
ARGO
NAVIGATION SYSTEM
MAY, 1985
GEOTERREX PROJECT No. 095

the construction of a longitudinal depth profile along the scour track (see Plate 6b). This profile allows direct correlation between depth of ice scouring and water depth. Initially, the scour track appears to cut deeply into the soft silty clays as water depth decreases, for the base of the scour maintains a constant elevation of 26.75 m below sea level. Between locations 2 and 3, the base of the scour rises about 0.25 m, whereas the water depth at this point has decreased by 0.75 m. At location 4, a maximum scour depth of about 3 m is reached. From this point the scour maintains a relatively constant depth, whereas both the base of the scour and sea floor a rise about 3 m.

One should note that the depths to the base of the scour are more reliable than the water depth soundings. Water depth measurements necessitate the smoothing of the echo-sounder profile to filter out high-frequency variations in water depth as a result of ice scouring. The accuracy of smoothed water depths is estimated to be +/- 0.33 m relative to the actual sea-bed, whereas soundings to the base of the scour are believed to be accurate to +/- 0.17 m. The scour depth is the difference between the smoothed sea bed and the depth to the scour base. Therefore, the error in the water depth (i.e. +/- 0.33 m) is also present in the estimates of scour depth. Nevertheless, the inaccuracy in water depth measurements does not affect the significance of the observed rise up of the bottom of the tracked ice scour.

Examination of the mosaic (see Plate 6a) indicates the presence of many other "fresh" and "very fresh" scours. Several scours (R-R', S-S', and T-T') appear younger than the "very fresh" scour that terminates at E-1. Two other scours, delineated at fixes 80 and 200, belong to the "fresh" category and display depths in the 3.5 to 4 metre range. Scours in the "semi-smooth" and "smooth" categories are also present in this study area (see Plate 6a), but were not outlined on Plate 6b.

4.2.1.2 <u>M-2</u> <u>Area</u>. Three potential sites, M-1, M-2, and M-3, were surveyed between the Kaslutut and Pullen sites. Although sites M-1 and M-3 were incised by several "very fresh" and "fresh" scours, no major directional changes or termination points were observed. Site M-2 was examined because a major, "very fresh" scour with a significant direction change was observed. The M-2 site is located about 35 km north of Hooper Island (see Plate 2).

Plate 7a is the side-scan mosaic constructed from the sonograms obtained in the area where the tracked scour displays a major directional change at Tm. Plate 7b is the interpretation overlay of the sea-floor mosaic.

The proximity of the major change in direction of scouring to the M-2 sail position indicates that the ice scour, tracked through this location, probably originated from the same complex of grounded ice ridges that was observed in this area (see Plate 2) during the winter of 1983-84. The termination observed at M-2 is traversed by one of the survey lines. Echo-sounding profiles indicate a berm height of 1-2 m with rather gentle slopes.

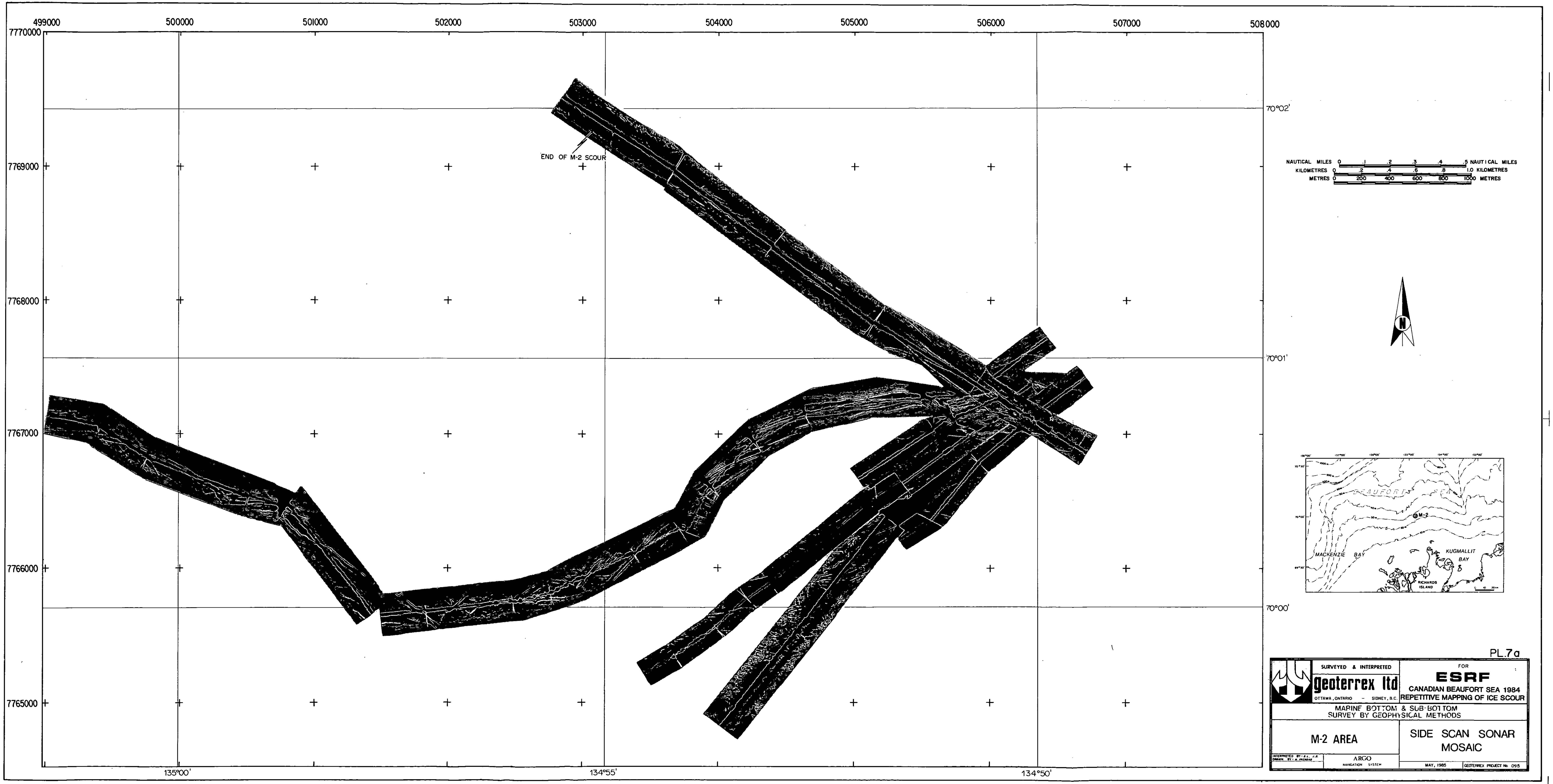
A complete coverage of this major ice-scouring event was not obtained, but apparently the initial direction of ice movement was from the west. The scour can be observed first at point A, with a direction change at point B, with the eventual loss of side-scan coverage at point C (see Plate 7b). A number of parallel scours are also visible and are thought to belong to the same ridge complex.

The tracked scour features stop at the location of a major directional change (TM on Plate 7b), but reappear again to the northwest with different characteristics. The width of the scour feature decreased towards the northwest as the pressure ridge feautre reached deeper water. Locations R and S pinpoint a secondary scour, which cuts all others confirming that the scouring activity towards the northwest was more recent. Note that the limited coverage of the survey does not permit the establishment of the relative position of all the secondary scour events.

Likewise the first portion of the tracked scour (see A, B, and C on Plate 7b), although interpreted as part of the major ice scour feature, cannot be directly connected, by means of side-scan sonar imagery, to the scour event observed in the proximity of the M-2 sail location. Consequently, the construction of a longitudinal profile of a scour depth versus water depth was believed impractical.

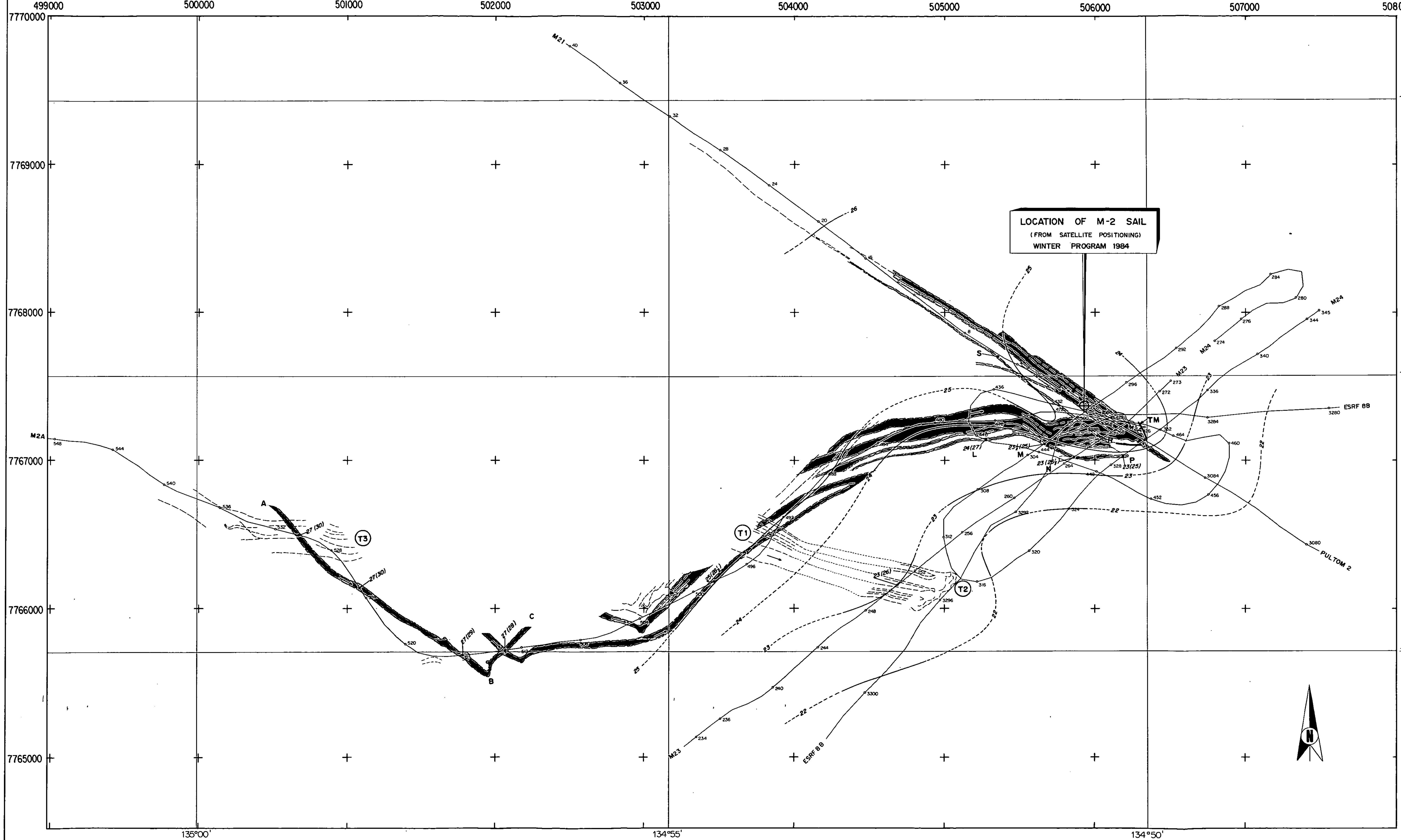
Only a short section of one scour (L-P) was intersected sufficiently to provide some idea of the base of scour elevation fluctuations. Although the water depth decreases regularly from L,M,N, to P (24 m, 23.5 m, 23 m, and 23 m respectively), the depth to the scour base varies irregularly (27 m, 25 m, 26.5 m, and 25 m). The maximum scour depth was observed at location N where a depth of 3.5 m was recorded.

Another "fresh" or "very fresh" ice scour is delineated between locations T1 and T2 on Plate 7b. This feature is younger than the major "very fresh" scour examined in detail and displays a well defined termination



PL.7a

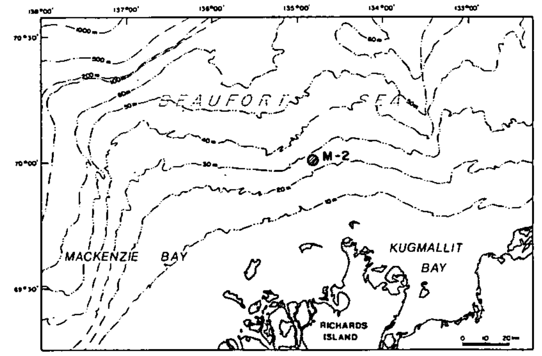
SURVEYED & INTERPRETED geoterrex ltd OTTAWA, ONTARIO – SIDNEY, B.C.	FOR ESRF CANADIAN BEAUFORT SEA 1984 REPETITIVE MAPPING OF ICE SCOUR
MARINE BOTTOM & SUB-BOTTOM SURVEY BY GEOPHYSICAL METHODS	
M-2 AREA	SIDE SCAN SONAR MOSAIC
ARGO NAVIGATION SYSTEM	MAY, 1985 — GEOTERREX PROJECT No. 095



NAUTICAL MILES 0 1 2 3 4 5 NAUTICAL MILES
KILOMETRES 0 2 4 6 8 1.0 KILOMETRES
METRES 0 200 400 600 800 1000 METRES

LEGEND

M24	SURVEY LINE IDENTIFIER
344	FIX LOCATION and FIX NUMBER
24, 23	APPROXIMATE BATHYMETRIC CONTOURS IN METRES (DEFINED; ASSUMED)
A, B, C...	REFER TO ACCOMPANYING REPORT
T1, T2, T3	INDICATES THE SAME ICE SCOUR EVENT
TM	INDICATES MAJOR DIRECTION CHANGE OF ICE SCOUR
	MAJOR VERY "FRESH" ICE SCOUR TRACKED TROUGH M-2 LOCATION
	OTHER "FRESH" or VERY "FRESH" ICE SCOURS (OUTLINES: DEFINED; ASSUMED)
	PROPOSED DIRECTION OF ICE MOVEMENT
27 (29)	DEPTH (m) TO BASE OF SCOUR FROM SEA LEVEL; DEPTH (m) TO SEA BOTTOM FROM SEA LEVEL



PL. 7b

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CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

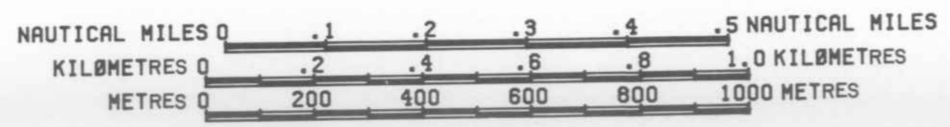
MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS

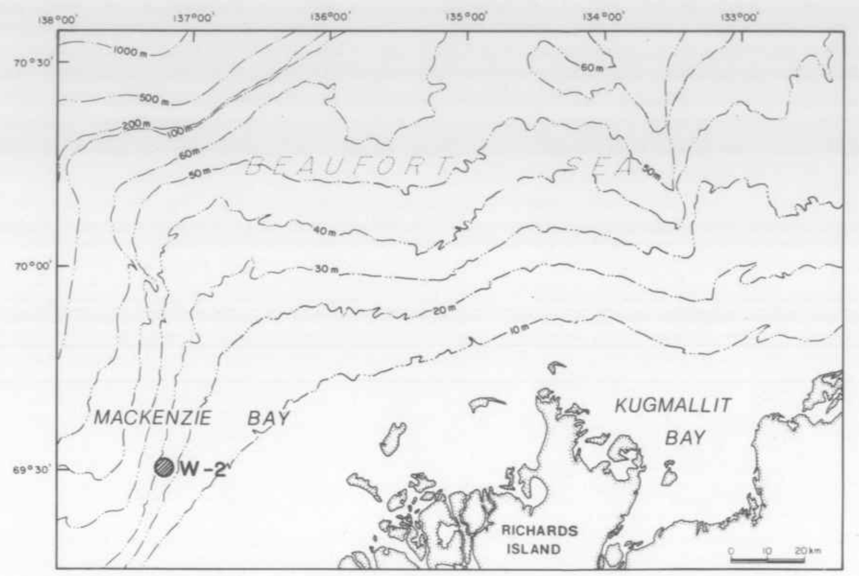
M-2 AREA

DETAILED EXAMINATION OF GROUNDED ICE LOCATION
(WINTER, 1984)

ARGO
NAVIGATION SYSTEM

MAY, 1985
GEOTERREX PROJECT No. 095





PL.8a

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FOR

ESRF

CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS

W-2 AREA

SIDE SCAN SONAR MOSAIC

INTERPRETED BY: B.L. J.S.
DRAWN BY: M. FRENDAS

ARGO
NAVIGATION SYSTEM

MAY, 1985

GEOTERREX PROJECT No. 095

near location T2. The scour assemblage at location T3 may also be part of the T1-T2 scour event.

4.2.1.3 W-2 Area. Site W-2 is located in Mackenzie Bay about 10 km east of the East Mackenzie corridor (see Plate 2). No significant ice scour features were observed at the sail location (W-1) and, therefore, the detailed examination of grounded ice was directed towards W-2 site.

A side-scan sonar mosaic (Plate 8a) was constructed from the sonograms recorded during both an operation to track ice scours and a more systematic survey which was conducted subsequently along survey lines orientated north-northeast. Plate 8b displays the interpretation results of the detailed examination of this grounded ice location.

The proximity of the W-2 sail location (see Plate 8a) to the T3 scour termination (100 m north) indicates that the scour track examined is probably related to the complex of ridges observed grounded at the W-2 location (see Plate 2). The only ice scouring confirmed to have occurred during the winter of 1983-84 is the one ending at termination point T3. Nevertheless, a number of other scours with similar "very fresh" characteristics were delineated on Plate 8b and termination points were observed at T1, T2, T4, T5, and T6. The echo-sounding profile over T1 indicates no extraordinary berm heights or slopes.

Significant bathymetric departures from background depths outline clearly the new, "very fresh" scours in this area, as well as two, prominent, "fresh," multi-keeled scours (A-A' and B-B'). Some of the "very fresh" scours, delineated in the southern half of the area, appear to have originated from eastward-moving ice but no consistent scouring direction was noted in the northern part of the area.

Two "very fresh" events, scours S-1 and S-2 outlined on Plate 8b, are described in more detail because each exhibits a distinct termination point and each was intersected at a number of locations by perpendicular survey lines. These two ice scours are almost parallel and initially display a curvilinear path which eventually becomes linear and oriented east-southeast. The parallel tracks suggest that they were scoured by the same ice complex.

Plates 9 and 10 consist of sea-floor mosaic enlargements and echo-sounding profiles from which the longitudinal depth profiles along scours S-1 and S-2 were constructed (see bottom of Plates 9 and 10, respectively). The scouring process begins to the west, where scour widths of about 20-30 m were noted, and ends at termination points T4 and T5, where the maximum scour widths reach about 50 m.

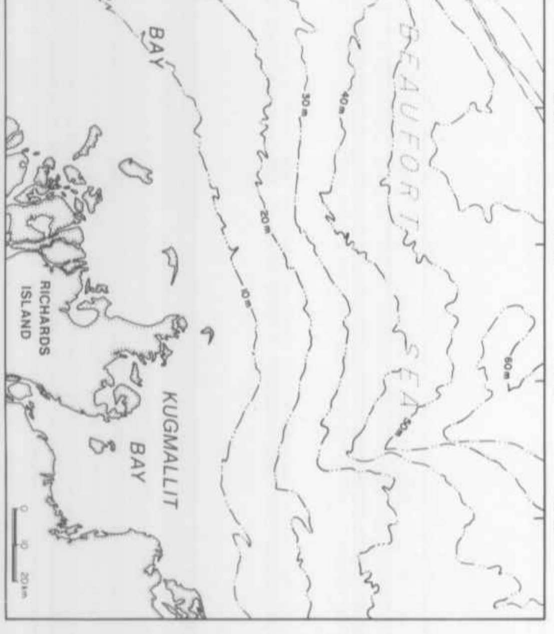
Although scours S-1 and S-2 display generally curvilinear-to-linear paths, close examination suggests that the scouring process was somewhat more episodic. The beginnings of the scours at locations J and K (see Plates 9 and 10, respectively) show marked changes in direction from westerly to northerly. Plate 10 demonstrates other abrupt direction changes at locations L and M. Along the scour tracks, evidence of a minor termination can be observed at reference number 2 and 8 on Plates 9 and 10, respectively. Both ice scours end at a major termination point, however scour S-1 (see Plates 8b and 9) shows evidence of further movement at P after stopping at T4. Scour S-2 displays a major termination point at T5 with a probable minor standstill at T5' (see Plates 8b and 10). Although the side-scan sonar and echo sounding survey lines do not traverse the terminations themselves, the line running close to T4 and between T5 and T5' indicates a significant change in the scour depths.

Plates 9 and 10 illustrate only the echo-sounding profiles that intersect ice scours S-1 and S-2 in an almost perpendicular direction. The echo-sounding profiles shown are the segment of echo sounding line which run over the scour. The maximum slopes of about 35' observed for the scour walls contrast significantly with the more gentle slopes of the berm material of the scours and of the termination points. (maximum 20'). The presentation of the echograms collected across the curvilinear portions of the scours was deleted because little information could be gained in comparison to the considerable space needed to display them on a drawing. The longitudinal depth profile along scour S-1 (see Plate 9) indicates a gradual decrease in the water depth from 30.5 m at reference number 1 to 26.5 m (see Plate 8b for location) at termination point T4. Although the water depth decreases in a somewhat regular fashion, the depth to the base of the scour suggests some fluctuations relative to the sea floor. At reference numbers 3 and 4 the scour depths are only 1.5 m compared to 3 m deep for most other sections of the scour.

Similar to scour S-1, the longitudinal depth profile for scour S-2 (see Plate 10) indicates a gradual decrease in sea-bed depth from 29.5 m at reference number 7 to 26.5 m at 12. Considering that the depth to the base of scour S-2 is 33 m below sea level at locations L and M (not shown on the longitudinal profile), the shallower depth of 32 m to the scour base at reference number 7 is believed

LEGEND

- 8296 ...... SURVEY LINE IDENTIFIER (ESRFW) ...... FIX LOCATION and FIX NUMBER
- 28 29 ...... APPROXIMATE BATHYMETRIC CONTOURS IN METRES (DEFINED ; - - - ASSUMED)
- K, L, M ...... REFER TO ACCOMPANYING REPORT
- 1 to 6 ...... REFERENCE NUMBERS (see PL. 9)
- 7 to 12 ...... REFERENCE NUMBERS (see PL. 10)
- (A) (A') ...... INDICATES MULTI-KEELED ICE SCOUR EVENT
- T5 ...... INDICATES ICE SCOUR TERMINATION POINT
- ...... DELINEATION OF "VERY FRESH" SCOURS
- → → ...... PROPOSED DIRECTION OF ICE MOVEMENT



PL. 8b

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FOR

ESRF

CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS

W-2 AREA

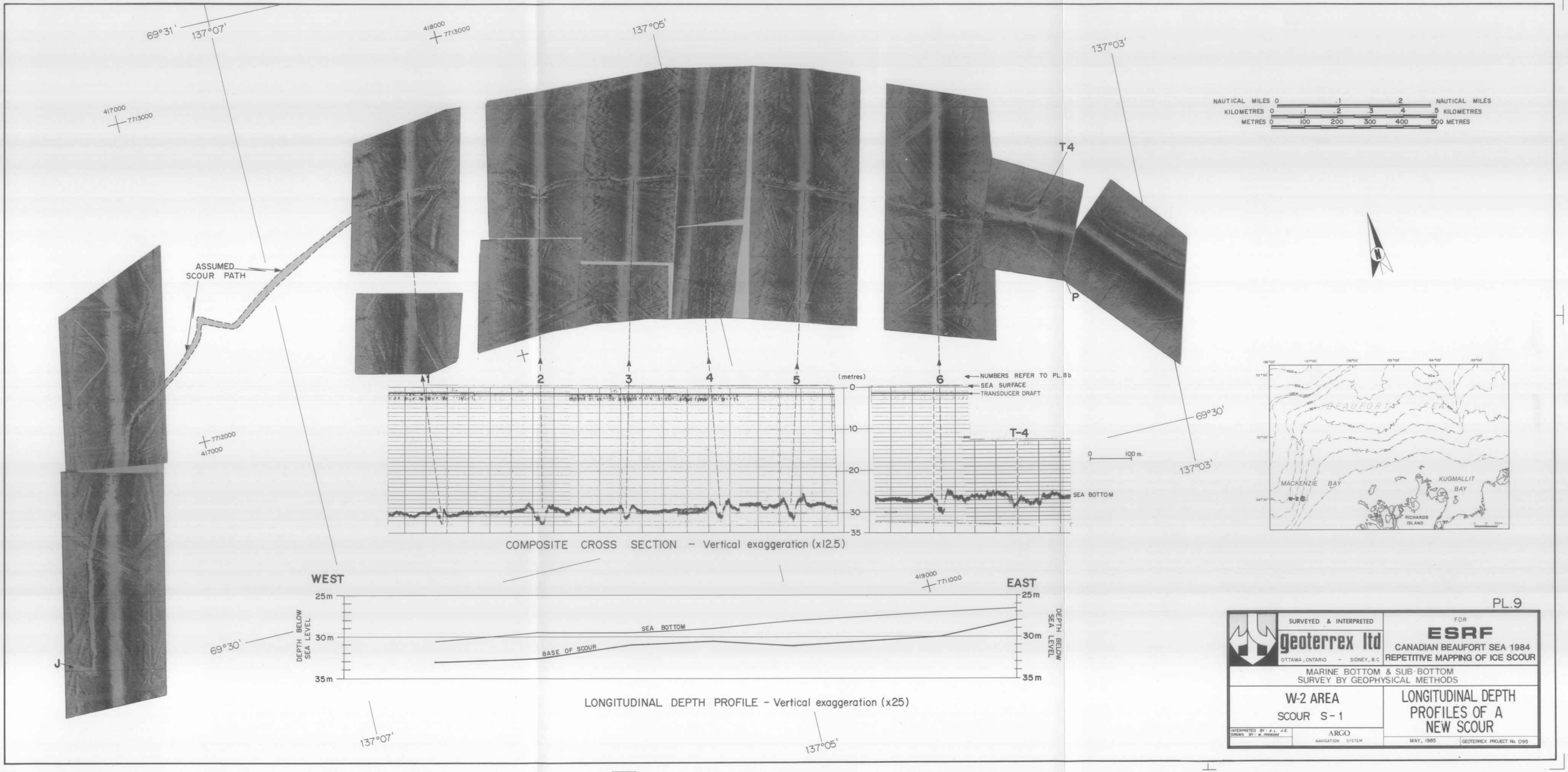
DETAILED EXAMINATION OF
GROUNDED ICE LOCATION
(WINTER , 1984)

INTERPRETED BY : B.L. J.S.
DRAWN BY : M. FRENCHS

ARGO
NAVIGATION SYSTEM

MAY, 1985

GEOTERREX PROJECT No. 095


ASSUMED SCOUR PATH
T4
P
J
1
2
3
4
5
6
(metres)
NUMBERS REFER TO PL.8b
SEA SURFACE
TRANSDUCER DRAFT
T-4
SEA BOTTOM
COMPOSITE CROSS SECTION - Vertical exaggeration (x12.5)
WEST
EAST
DEPTH BELOW SEA LEVEL
SEA BOTTOM
BASE OF SCOUR
LONGITUDINAL DEPTH PROFILE - Vertical exaggeration (x25)
NAUTICAL MILES
KILOMETRES
METRES
MACKENZIE BAY
KUGMALLIT BAY
RICHARDS ISLAND
BEAUFORT SEA
PL.9
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FOR
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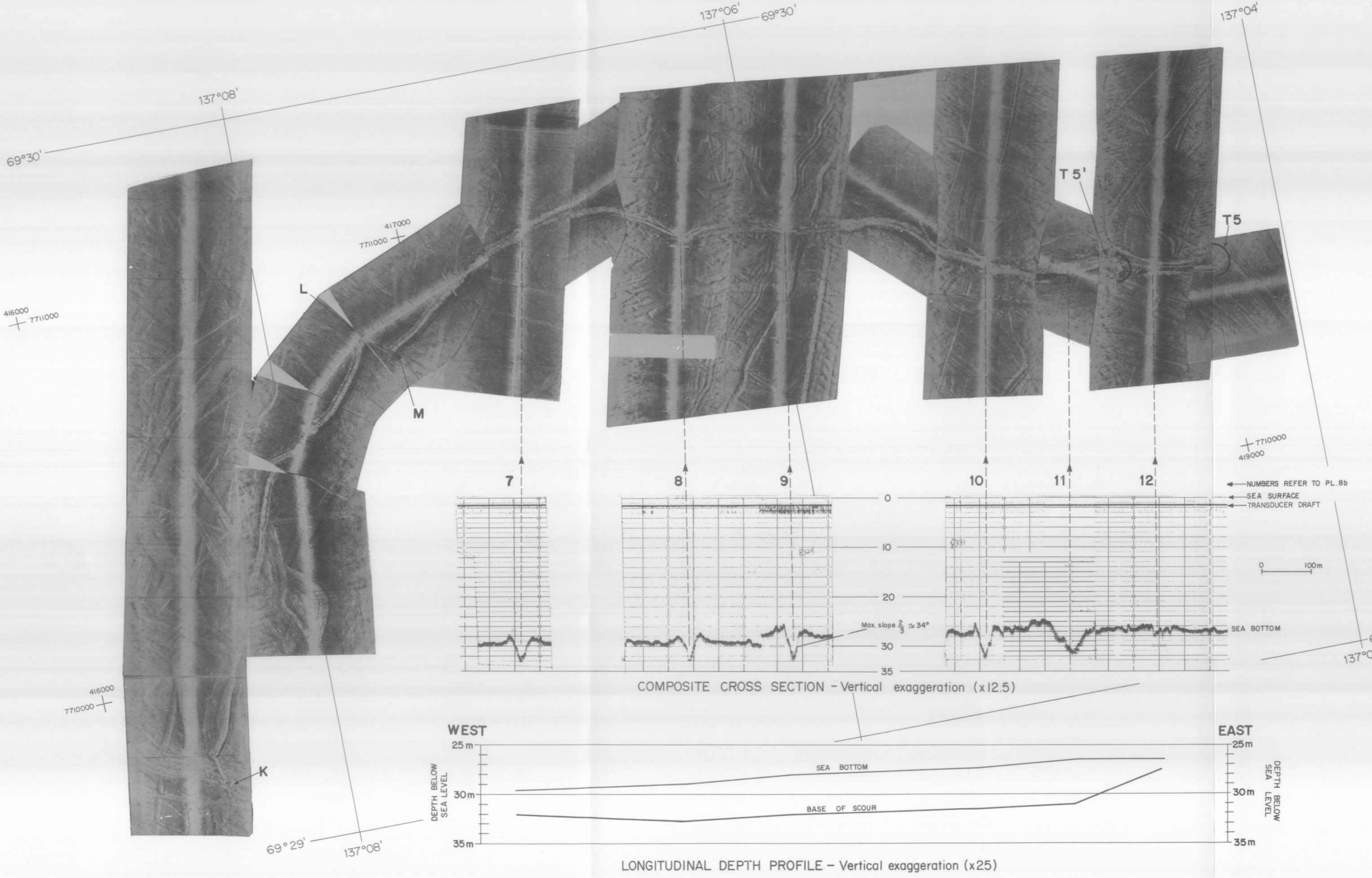
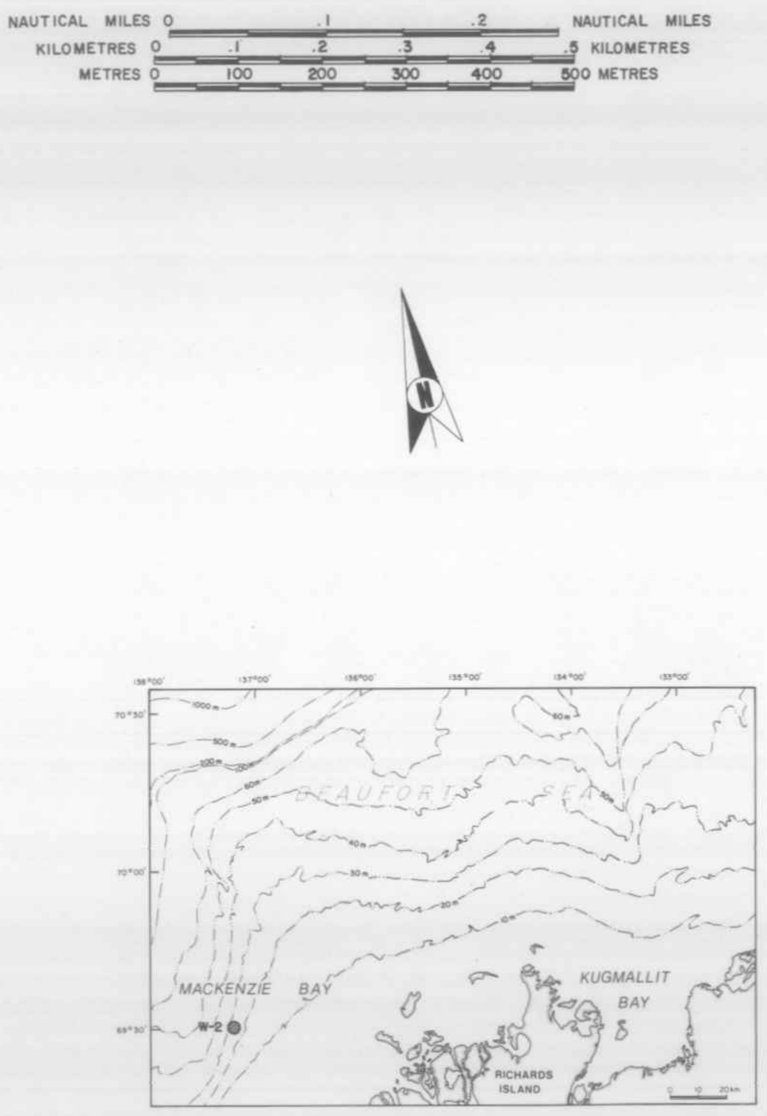
CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR
MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS
W-2 AREA
SCOUR S-1
LONGITUDINAL DEPTH
PROFILES OF A
NEW SCOUR
ARGO
NAVIGATION SYSTEM
MAY, 1985
GEOTERREX PROJECT No. 095





PL. 10

SURVEYED & INTERPRETED geoterrex ltd OTTAWA, ONTARIO - SIDNEY, B.C.	FOR **ESRF** CANADIAN BEAUFORT SEA 1984 REPETITIVE MAPPING OF ICE SCOUR
MARINE BOTTOM & SUB-BOTTOM SURVEY BY GEOPHYSICAL METHODS	
W-2 AREA SCOUR S-2	LONGITUDINAL DEPTH PROFILES OF A NEW SCOUR
INTERPRETED BY: H.L. J.S. DRAWN BY: M. FRENDAS — ARGO NAVIGATION SYSTEM	MAY, 1985 — GEOTERREX PROJECT No. 095

anomalous. Further upslope, the base of the scour returns to about 33 m at reference number 8 suggesting a scour depth of 4-4.5 m. From this point, the base of the scour rises slowly until termination point T5' where the scour bottom rises dramatically, almost up to the sea floor near termination point T5 (31 m to 27.5 m).

The lack of sub-scour information resulted principally from the deformation of laminated sediments at the base of the scour feature during active scouring.

4.2.2 Detailed Examination of "Very Fresh" Scours

While surveying areas near the edge of the fast-ice zone (see Plate 2), a number of "very fresh" scours were observed on the sonograms. Although no pressure ridges were present in the immediate vicinity, these "very fresh" scours appeared to result from recent ice-scouring activity. Subsequently, two sites, M-2 North and W-2 North, were investigated in detail.

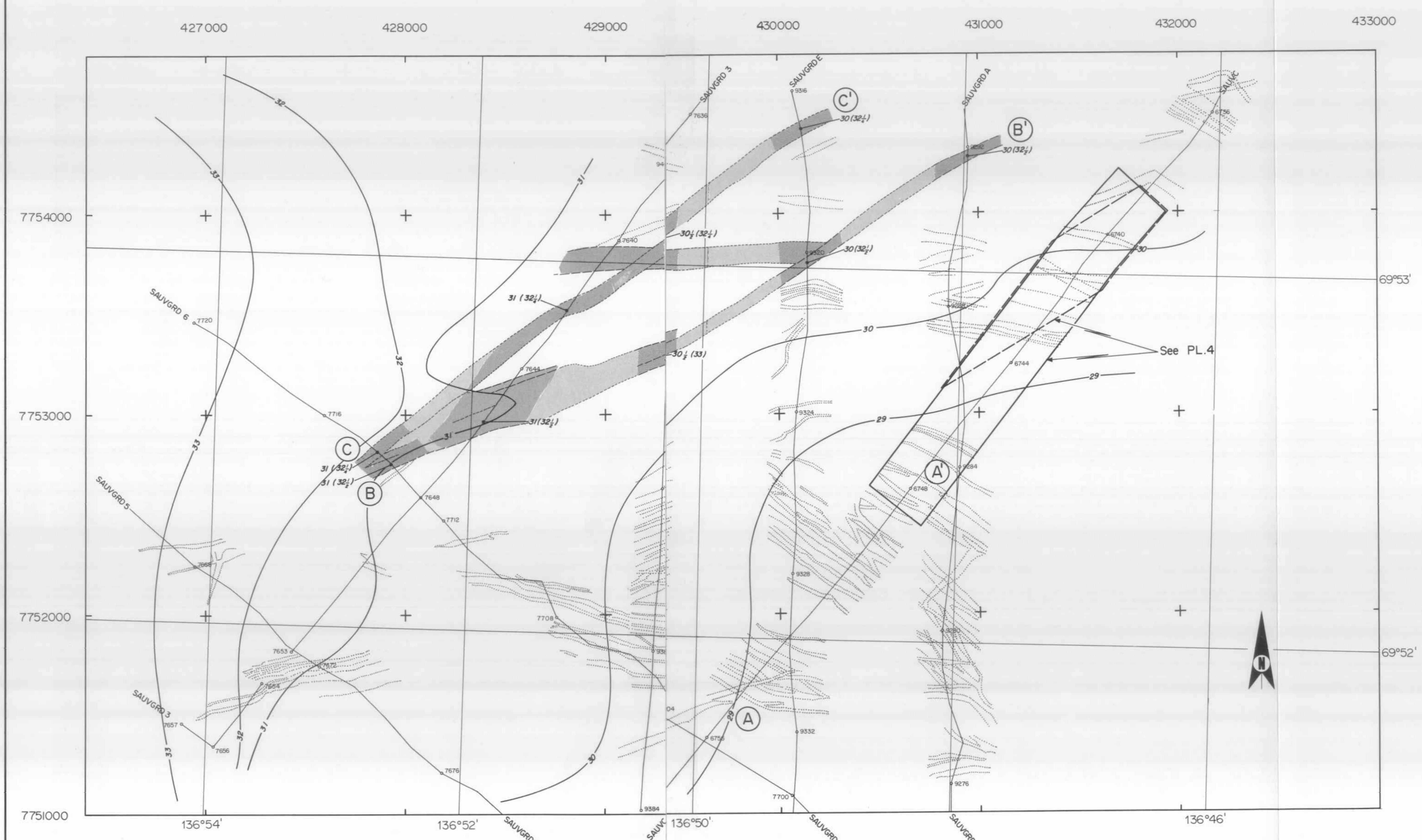
4.2.2.1 M-2 North site. The M-2 North site is situated just northeast of Kaslutut site and overlaps the northwestern corner of the M-2 site (see Plate 2). The side-scan sonar mosaic (Plate 11a) suggests that most of the observed ice scours were probably created by irregular movement of the same pressure ridge. Supporting this contention, the scour signature at locations K, K', L, and L' (Plate 11b) are virtually identical.

The northern part of the M-2 North area was surveyed previously (line GHR 83-03) in 1983 during offshore geophysical site investigations carried out by Geoterrex Ltd. on behalf of Gulf Canada Resources Inc. An examination of the re-surveyed sea floor (see Plates 11a and 11b) indicates that the "fresh" scour (M-M') is visible on both sonograms (lines GHR 83-03 and M22), whereas the "very fresh" scour at location A was detected only on the 1984 ESRF records. The high density of "very fresh" scours are thought to result from ice scouring that occurred during the winter of 1983-84. It is speculated that the ice scouring occurred when a single pressure ridge feature was frozen into the pack ice and drifted back and forth through the area (water depths 32-34 m).

4.2.2.2 W-2 North area. The W-2 North area is located on the eastern side of the Mackenzie Bay, just southwest of the Sauvrak site about 40 km north of the W-2 site (see Plate 2).

A detailed analysis of the side-scan sonar mosaic (Plate 12a) suggests that "very fresh" ice scouring has occurred over about 50 % of the mosaic area. Several "very fresh" ice scours are parallel, such as those outlined between locations A and A' on Plate 12b, and likely were formed by a wide, multi-keeled pressure ridge. Scour depths are generally shallow (less than 1.5 m), however, a number of scours with greater depths can be identified at B-B' and C-C' (see Plate 12b). At these locations, the sea-floor gradually decreases eastward from a depth of 31 m to 30 m. The base of scour C-C' remains at a constant depth of 32.25 m below sea level. Except for the central portion of scour B-B', where the bottom of the scour reaches a maximum depth of 33 m, the depth to the base of the scour is constant at 32.5 m.

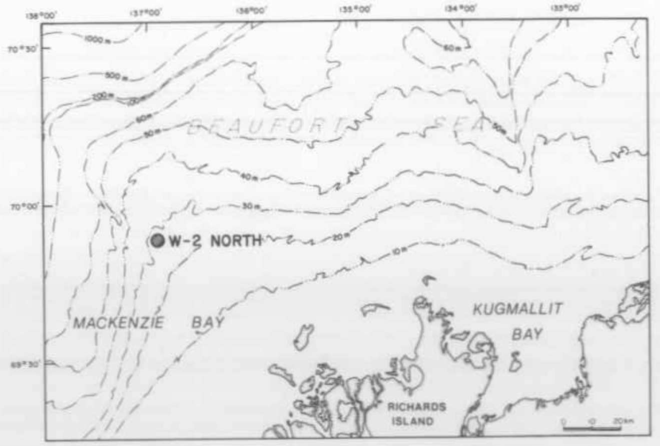
In the eastern margin of Plate 12b, a small surface of the sea-floor covered by side-scan sonar imagery was enlarged from 1:10,000 to 1:5,000 on Plate 4 to identify clearly new scour features. Some reference areas notably 1-1', 2-2', and 3-3', exhibit the same scour events on both 1982 and 1984 sonograms. A number of new scours are identified on the 1984 ESRF Line SAUV C (see Plate 4). Apparently most of the "very fresh" to "fresh" scours observed were formed after the 1982 survey and may be the result of anomalous ice movement observed over the entire Beaufort Sea during the winter of 1983-84.



NAUTICAL MILES 0 .1 .2 .3 .4 .5 NAUTICAL MILES
KILOMETRES 0 .2 .4 .6 .8 1.0 KILOMETRES
METRES 0 200 400 600 800 1000 METRES

LEGEND

- 6737 SAUVC — SURVEY LINE IDENTIFIER; FIX LOCATION and FIX NUMBER
- 32 / 31 — APPROXIMATE BATHYMETRIC CONTOURS IN METRES
- (B) (B') — 'REFER TO ACCOMPANYING REPORT'
- "VERY FRESH" ICE SCOUR — OBSERVED OUTLINES; ASSUMED OUTLINES
- MULTI-KEELED "VERY FRESH" ICE SCOUR
- 30 (32½) — DEPTH (m) TO BASE OF SCOUR FROM SEA LEVEL; DEPTH (m) TO SEA BOTTOM FROM SEA LEVEL



PL.12b

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REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB BOTTOM
SURVEY BY GEOPHYSICAL METHODS

W-2 NORTH AREA

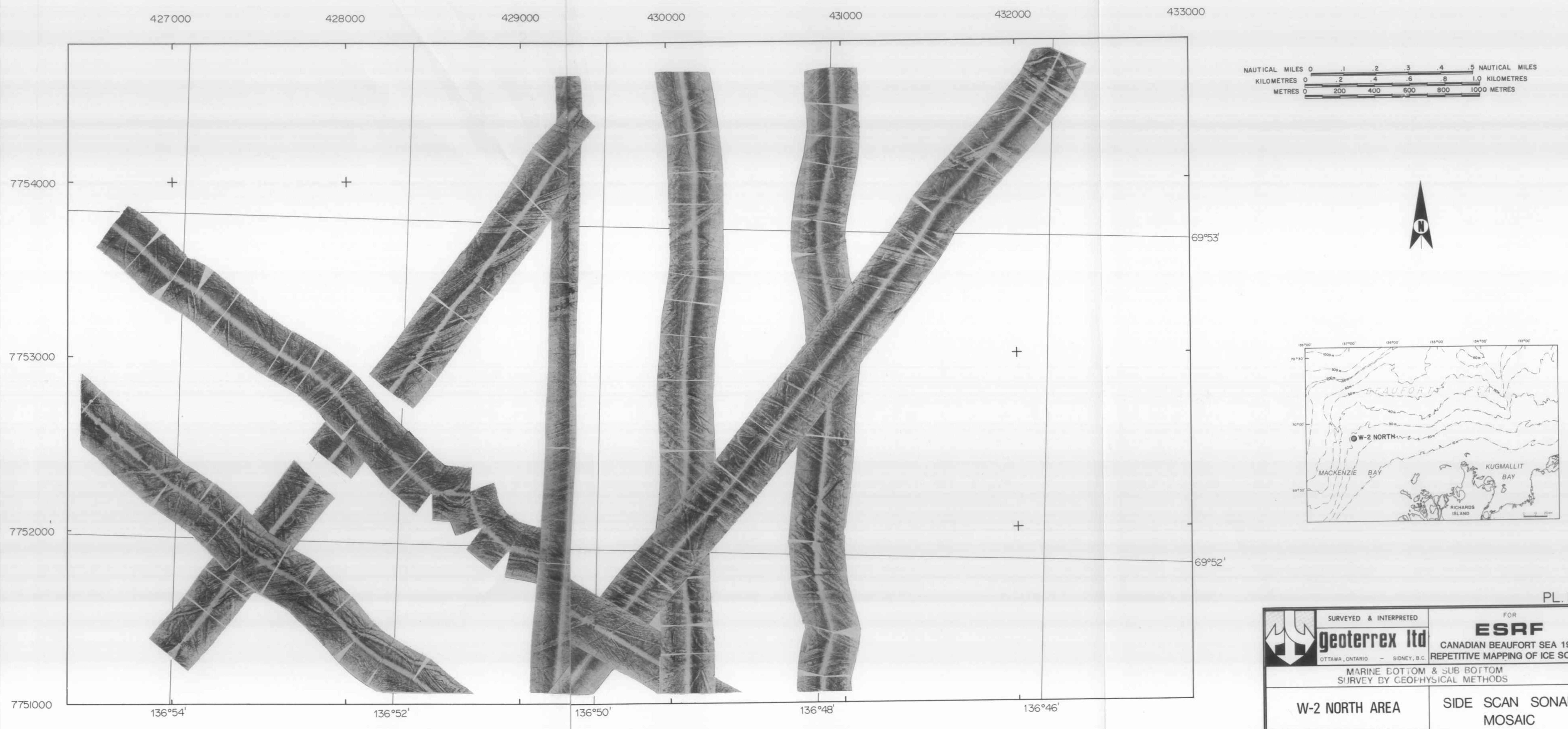
DETAILED EXAMINATION OF "VERY FRESH" ICE SCOURS

INTERPRETED BY: B.L. J.E.
DRAWN BY: M. FRENDAS

ARGO
NAVIGATION SYSTEM

MAY, 1985

GEOTERREX PROJECT No. 095



PL. 12a

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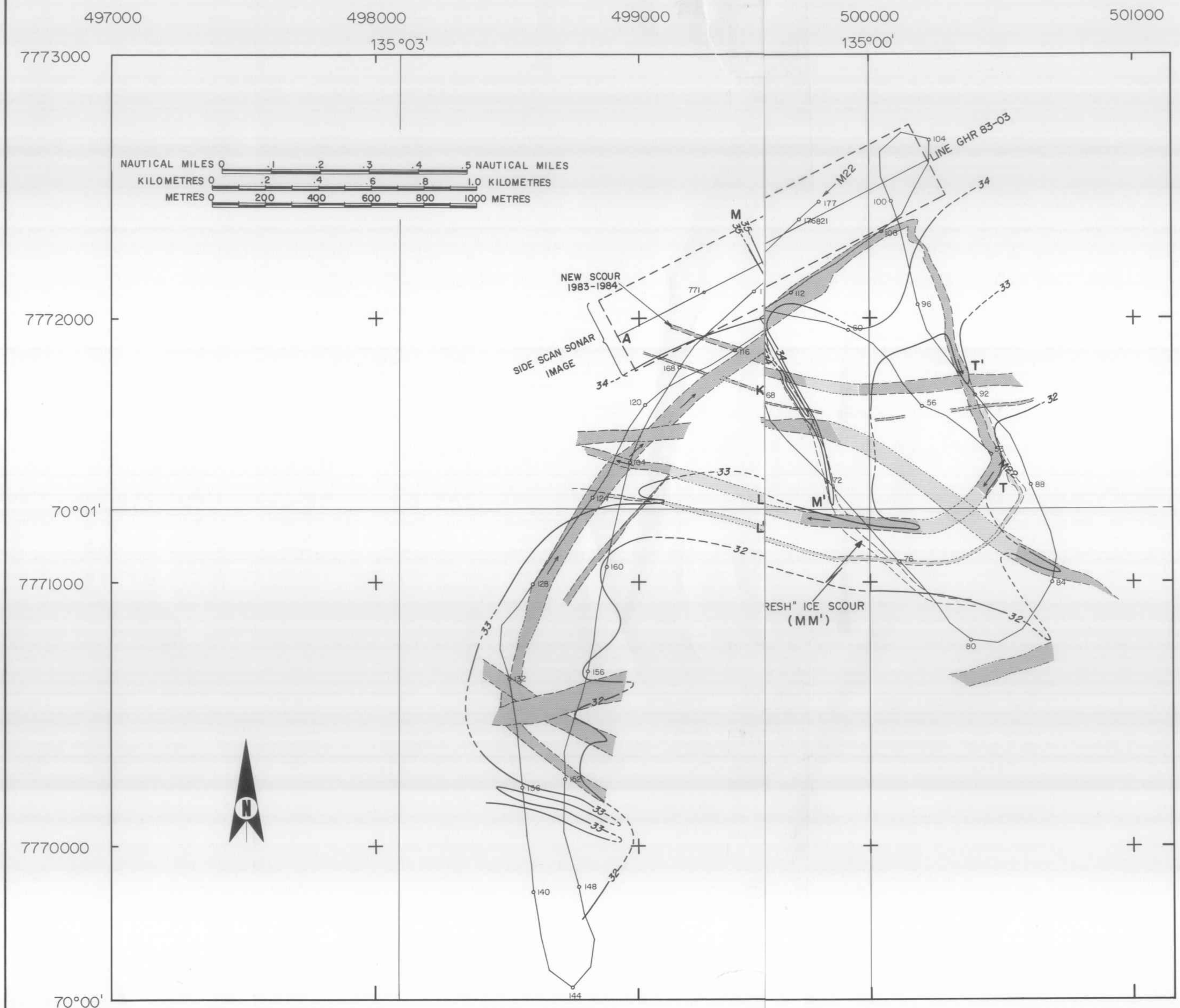
CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

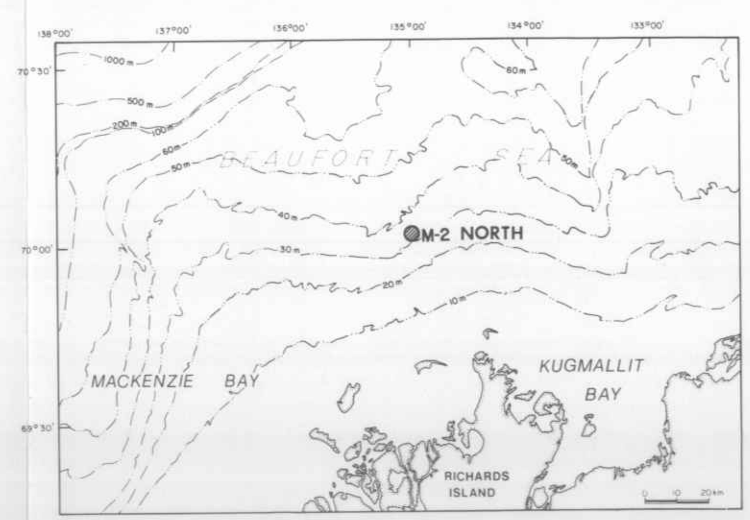
MARINE BOTTOM & SUB BOTTOM
SURVEY BY GEOPHYSICAL METHODS

W-2 NORTH AREA	SIDE SCAN SONAR MOSAIC
INTERPRETED BY: ... DRAWN BY: ... / ARGO NAVIGATION SYSTEM	MAY, 1985 / GEOTERREX PROJECT No. 095



LEGEND

M22 .... SURVEY LINE IDENTIFIER
176 .... FIX LOCATION and FIX NUMBER
33 -- 32 -- .... APPROXIMATE BATHYMETRIC CONTOURS IN METRES (DEFINED ; ASSUMED)
A, K, T' .... REFER TO ACCOMPANYING REPORT
"VERY FRESH" ICE SCOUR
OBSERVED OUTLINES
ASSUMED OUTLINES
→ ⇢ .... PROPOSED DIRECTION OF ICE MOVEMENT
LINE GHR 83-03 .... GCRI 1983 REGIONAL LINE



PL. 11b

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FOR
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CANADIAN BEAUFORT SEA 1984
REPETITIVE MAPPING OF ICE SCOUR

MARINE BOTTOM & SUB-BOTTOM
SURVEY BY GEOPHYSICAL METHODS

M-2 NORTH AREA

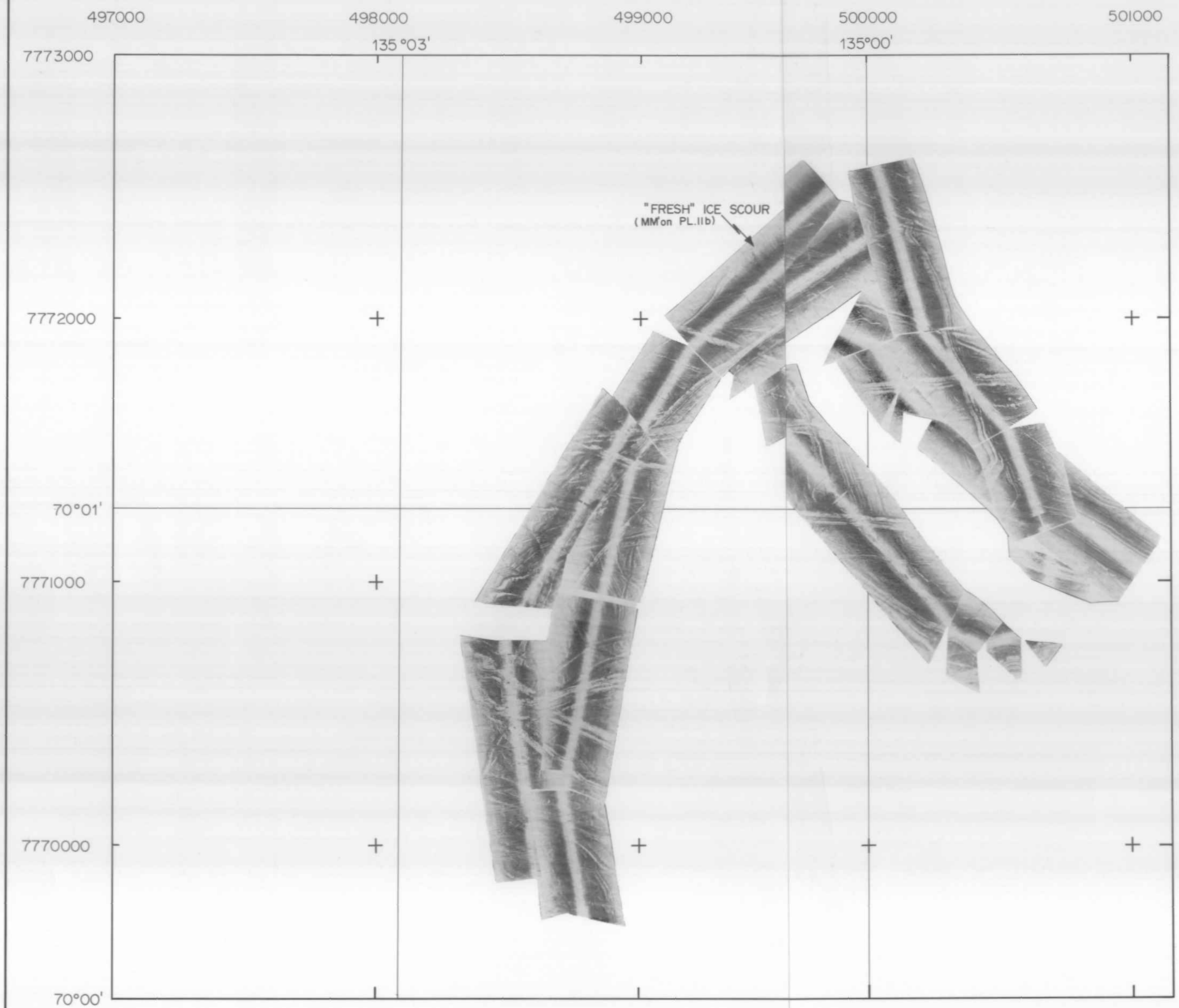
DETAILED EXAMINATION OF "VERY FRESH" ICE SCOURS

INTERPRETED BY: B.L. J.S.
DRAWN BY: W. FRENDAS

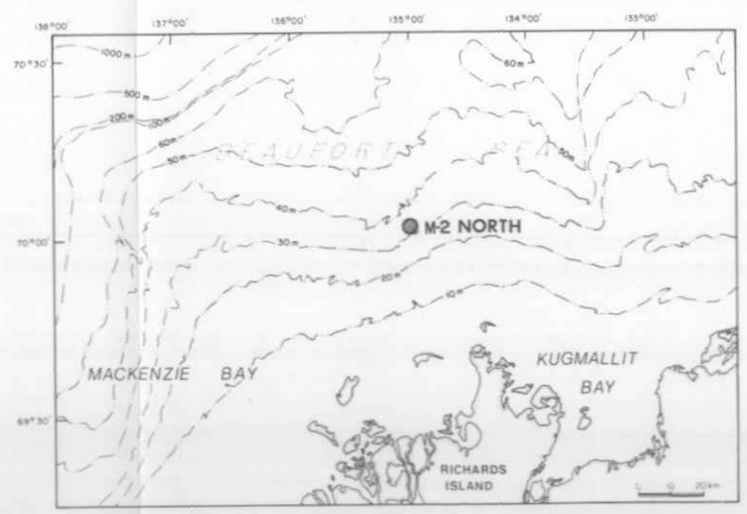
ARGO
NAVIGATION SYSTEM

MAY, 1985

GEOTERREX PROJECT No. 095



NAUTICAL MILES 0 .1 .2 .3 .4 .5 NAUTICAL MILES
KILOMETRES 0 .2 .4 .6 .8 1.0 KILOMETRES
METRES 0 200 400 600 800 1000 METRES



PL. IIa

SURVEYED & INTERPRETED geoterrex ltd OTTAWA, ONTARIO – SIDNEY, B.C.	FOR **ESRF** CANADIAN BEAUFORT SEA 1984 REPETITIVE MAPPING OF ICE SCOUR
MARINE BOTTOM & SUB-BOTTOM SURVEY BY GEOPHYSICAL METHODS	
M-2 NORTH AREA	SIDE SCAN SONAR MOSAIC
INTERPRETED BY: B.L. J.S. DRAWN BY: M. FRENDAS ARGO NAVIGATION SYSTEM	MAY, 1985 GEOTERREX PROJECT No. 095

5.0 DISCUSSION

The temporal (repetitive network) and physical or spatial (scour tracking) properties of ice scours are discussed separately in this section.

5.1 REGIONAL REPETITIVE BASE-LINE NETWORK

When ice scouring of the sea-bed was first observed and studied, characteristics of interest were measured on the scour population as a whole. Initially, depth distribution statistics contained scour depths from all bathymetric ranges between 10 and 60 m and from various physiographic provinces, from Kaglulik Plain in the east to Herschel Island in the west. With the increasing size of the scour population, bathymetric subdivisions were established that enabled the study of the ice scouring activity for various depth intervals.

The knowledge of ice scour characteristics across the Canadian Beaufort Sea originates from the petroleum industry requirements to determine minimum burial depths for pipelines and bottom-mounted, offshore structures. Therefore, the re-scouring rate and the depth of ice scouring into the sea-bed for any specific bathymetric intervals were of particular interest.

For a number of years, scours with different morphological characteristics have been observed, ranging from "fresh" looking (steep sides and detailed scour mound) to "very smooth" (gently sloping sides and little or no relief of the scour mound). Initially, it was believed that all "fresh" scours might result from recent ice scouring. Undoubtedly, "fresh" scours indicate a more recent regime than the population as a whole. However, other factors exist that complicate the distinction of younger scours from older scours.

One of the main factors creating uncertainty when compiling the depth distribution of "fresh" scours only, is the different rates of sediment accumulation throughout the Beaufort Sea shelf. For example, "fresh" scours in the eastern region of the Beaufort Sea shelf (east of longitude 133^{o}W), might be considerably older than a similar-looking "fresh" scour in Mackenzie Bay, where the sedimentation rate is much higher.

To deal with these complex interrelationships (e.g., ice scour shape versus age; and scour depth versus sedimentation rate) and better understand the present scour regime, a definitive approach would be to ascribe an absolute age to every scour. However, determination of the age of ice scours from calculations of sedimentation rates, paleomagnetic measurements, and Carbon 14 and other isotope dating techniques were generally unsuccessful. Inaccuracies in locating the sample and the lack of adequate material for age determination were the major difficulties encountered when attempting to date ice scours.

About 10 years ago, repetitive survey techniques were considered a valuable alternative to previously attempted dating methods. A repetitive survey implies the re-surveying of an already established line or mosaic of the sea floor to permit comparison of images of the same area. In this manner, new scours could be identified and impact rates and scour depths related to these recent events could be documented. This information is believed to represent accurately the scour regime for the interim time period between the two surveys. The longer the time period between repetitive surveys, the more knowledge can be obtained on the current regime. Of course, if the time between two surveys is too long (i.e. longer than the anticipated resident time) then the new scour information will be only partially representative. Short term variation in the scouring rate will be missed if the interim time period between two surveys is too great. Ideally, re-surveying every year for many years (10-20 yr) would provide the most useful data.

As shown on Plate 2, new scours did occur throughout the Beaufort Sea from east (Kaglulik corridor) to west (East Mackenzie corridor). Generally, new scours were not observed in water depths greater than 30 m and impact rates, in shallower water, varied considerably across the Beaufort Sea. Interestingly, impact rates vary by a factor of 8 to 1 for similar water depths (i.e. 25-30 m); in fact, an impact rate of 1.6 impacts/km/yr was calculated in the Tarsiut-Nektoralik corridor whereas a rate of 0.2 impact/km/yr was obtained in the Kaglulik corridor.

The relatively low impact rates for new scours which were observed in the East Mackenzie corridor may be attributed to the fact that this region is often covered by fast-ice. Similarly, very low impact rates seem to prevail further east; these low rates may be a result of a reduction in frequency of significant incursions of the pack ice in this area. The predominant direction of the flow of the pack ice into the Beaufort Sea is apparently from the northwest, which may explain why the scouring activity is more frequent in the Tarsiut-Nektoralik area.

In shallow water, the impact rates (see Figure 3) are relatively low probably because of the general presence of the fast-ice zone. The impact rate reaches a maximum of 4 impacts/km/yr at a water depth of 24 m and then decreases with increasing depth because of a smaller probability of contact between the ice keels and the sea-bed. The maximum impact rates appear to occur at the outer edge of the fast-ice boundary zone.

An impact rate of 4 impacts/km/yr in 20-25 m water in the Tarsiut-Nektoralik corridor implies, on average, a probability of one impact every 0.25 km/per yr. Therefore, the probability for an ice keel colliding with a 50-km long pipeline, laid directly on the sea floor in 20-25 m of water, is in the order of 200 impacts/yr, or 6,000 impacts over a lifetime of 30 yrs. Impact rates calculated from work done previously are similar to those observed from this year's survey, for instance Pullen Is. (Shearer 1979).

A rough estimate of the resident time for any given scour may be calculated from the knowledge of the new scour impact rate and the actual general scour frequency per km observed. In the 25-30 m water range in the Tarsiut-Nektoralik corridor, for instance, a new scour impact rate of aroung 1.6 impacts/km/yr exists. The actual number of scours/km is around 20 to 30. This indicates that some 15 yr or so would be needed to completely re-scour the sea-floor. As discussed below this is not quite accurate because of the super-imposition of newer scours on new scours.

Another approach to evaluate the frequency of new scour occurrence for a given area is the percentage of the area re-scoured per year in different water depths (see Figure 4). In 30 m of water for instance, the percentage of the sea bed that appears actually to be freshly scoured is about 1%/yr. Theoretically this figure implies that the sea-floor will approach complete re-scouring in about 100 yrs. Nevertheless, this estimate is not strictly true, as with time, more and more new scouring will superimpose on slightly older new scours. In fact, after 100 yr of 1% re-scouring per year some 37% of the original bottom will remain untouched by the scouring of the last 100 yr.

In somewhat shallower water, (i.e., 25 m in depth) the re-scouring rates reach a maximum of 10%/yr which implies that up to 37% of the bottom may remain untouched after 10 yr (9% after 25 yr). The percentages of sea floor re-scoured per year in Figure 4 are determined at the sea floor and would decrease with depth into the sea-bed. The area of highest re-scouring coincides with the outer edge of the transition zone at the fast-ice boundary.

Of interest, along with the impact rates and the percentage of sea bed re-scoured per year, are the depths of these new scours. The new scour depths have been examined in detail in the Pullen area and Tarsiut-Nektoralik corridor (see Plate 2 and Figure 5). Although the Pullen area and the Tarsiut-Nektoralik corridor are found in different water depths, 14-18 m and 22-26 m, respectively, both areas exhibit about the same number of new scours for the shallowest depth interval (i.e., 0-0.5 m). No new scours deeper than 2 m appear to have occurred in the Pullen area, whereas in the Tarsiut-Nektoralik corridor 8% of the new scours are deeper than 2 m. The reason for the absence of deeper scours in shallow water may be related to the smaller size of the ridges in this area.

Ice Keels that collide with the sea bed in 14 - 18 m of water will not ground in the deeper waters around Tarsiut-Nektoralik, where the ice features have to be considerably larger to scour the sea-bed. Most of the ice scouring and the associated depth of scouring are not indicative of an equilibrium situation between the ridged ice and the competence of the soil. It is not understood why for all water depths, the most common scour depth interval is the 0-0.5 m with an exponential decrease in frequency for the deeper scour depths. Nevertheless, the deeper new scours for both control areas are thought to represent conditions approaching some balance between pressure ridge size and soil strength. A larger mass of ice will have a greater amount of potential energy for any given vertical displacement. Conversely, more resistance from the soil (i.e., greater scour depths) must occur before any vertical displacement will take place. Given sufficient lateral forces from the moving pack ice, this limit condition (where the soil resistance is sufficient to cause vertical uplifting), might occur some of the time. The presence of smaller ice masses (less potential energy) which ground in shallower water might explain why the maximum observed depths of new scours are less than for deeper water. These relationships are also pertinent to the following discussion "Detailed Tracking of New Scours."

The deepest new scour recorded during the regional repetitive survey over control corridors and areas is 3.5 m deep (see fix 6618, Plate 5). Deeper new scours were recognized during the detailed tracking of new scours, but, because these scours were not randomly observed, their contribution to the new scour population would bias the ice scour depth statistics. However, these extreme scour depth values of 4.5 m (see scour S-2, Plate 10) and 3 m (see scours E-1 and M-2, Plates 6b and 7b) could be included in a depth distribution of the total scour population (i.e., number of new ice scours for the depth interval in question as opposed to the number of new ice scours per kilometre per year for the same depth interval).

The main objective of the 1984 ESRF study was to improve the actual knowledge of the current ice scour regime so that realistic assessment and planning could be undertaken. Events such as the second-year ice incursion during the winter of 1983-84, however, can give both anomalously high impact rates and percentages of sea bed re-scoured. This accounts to some degree why the scour depths observed during the detailed studies of the grounded-ice locations are significantly higher than those measured during the repetitive surveys.

A section of the sonogram collected in 1984 along the Tarsiut-Nektoralik corridor (see Plate 5) is believed to be a good example of the new scours formed during the 1981-84 interim period. In addition, some other scours, which have occurred during the 1979-81 interim period (interpreted from a set of 1979 and 1981 sonograms), are also identified on Plate 5. The scour crossing fix 6610 was formed between 1979 and 1981 and exhibits a depth of about 4 m; this depth is comparable to the extreme values recorded during the 1984 survey.

A review of winter ice conditions for the last 20 yr has indicated the occurrence of other similar severe incursions of the pack ice particularly during the winters of 1973-74 and 1979-80. The anomalous ice condition encountered during the winter of 1983-84 is thought to have a return period in the order of 1 event in 10 yr, which is considered significant for a production planning horizon of 30 yr.

5.2 DETAILED TRACKING OF NEW SCOURS

The detailed examination of new ice scour features on the sea floor was initiated during the winter of 1983-84 when observed, large, grounded ice masses were positioned by means of a satellite navigation system. The known location of these grounded masses enabled, during the following summer, the tracking of the specific scour event from the termination point, along its entire length to the beginning. The scour characteristics, which were measured subsequently from the side-scan sonar records, were the scour orientation, length, width, depth, and scour bottom rise-up. These characteristics are influenced by several environmental factors such as: the drift direction of the pack ice, size of the ice ridge, nature of the soil, the sea-floor slope, and the water depth.

The detailed examination of a complete scour track can be divided into two areas of interest; namely the scour track itself, and the termination point of the scour.

Initial examinations of all sites have shown that a new ice scour may be orientated in one of a number of directions. For instance, a major ice scour event at M-2 North location (see Plate 11b) crosses over its own track a number of times. Most of the tracked new scours begin in deeper water and move shoreward into shallower areas. At sites E-1 and M-2 (see Plates 6b and 7b, respectively), the ice keels scoured at an oblique angle relative to the bathymetric contours, whereas at site W-2 (see Plate 8b) the scouring was generally perpendicular to the sea-floor slope.

As illustrated on Plates 6b (E-1 area) and 7b (M-2 area), the width of the scours varies along their track in response to the rotation of the ice feature. As well it is likely that, as scour depths increase in response to decreasing water depth, a larger cross-sectional area and, hence, width will result, which can be seen with scour S-1 and S-2 in the W-2 site.

The direction of the moving pack ice appears to be the main mechanism responsible for the scour orientation, whereas surface rotation of ice features and decreasing water depth seem to be a major factor controlling scour width variations.

Until recently, the scour depth was believed to be the most significant factor when describing the magnitude of the ice scour activity. A deeper ice scour was considered a more significant event than a shallower scour. Another characteristic which is considered to be interrelated to scour depth, is the rise-up experienced by the scouring ice ridge. The rise-up is determined by measuring the change in elevation of the scour bottom at different locations along the same scour track. This phenomenon has been examined in some detail by Wahlgren (1979) who has observed the net rise-up of the base of a scour track from two or more echo-sounding cross-sections. The presence of a considerably greater number of scour crossings has enabled a refinement of this initial concept.

Ice scouring usually begins when an ice island or a ice ridge driven by the pack ice grounds on the sea floor as a result of decreasing water depths. Observation indicates that, after the initial contact, the depth from sea level to the scour base remains constant for some distance, as illustrated by locations E-1 (see Plate 6b), W-2 North (see Plate 12b), as well as by scours S-1 and S-2 (see Plates 9 and 10). Here longitudinal depth profiles show the base of the scour at a constant elevation from sea level even though the scour depth is increasing.

The base of the scour at E-1 location (see Plate 6b) for instance, remains at the initial depth of scouring of 26.75 m over a distance of about 3 km. During this first stage of the scouring process, the scour depth increases in response to decreasing water depths. At this point, the resistance of the soil to the moving and scouring ice mass is apparently insufficient to prevent increasing penetration of the ice keel into the sea bed. The first stage of ice scouring can be summarized as follows: as the water depth decreases, the scour depth increases but no rise-up is evident.

As the scour in the E-1 area continued to move up slope, the base of the scour begins to rise-up even though the scour depth is still increasing. The rise-up of the scour bottom is however less than the decrease in water depth. The scours in W-2 North area (see Plate 12b), apparently, never reach the stage where rise-up occurs. The scours S-1 and S-2 (see Plates 9 and 10) cannot be examined during this stage because some anomalous properties in the sediment are though to occur along the first portion of the scours.

In the E-1 area, the tracked scour rises up about 0.25 m (between locations 2 and 3, Plate 6b) whereas the scour depth increases from 1.75 m to 2.25 m. As the ice feature continued to move further up slope (between locations 3 and 5), the depth to the scour base seems again to remain constant (flat), whereas the scour depth continues to increase. It is proposed that, as the resistance to sea-bed penetration increases with increasing scour depth, a small uplift of the ice mass will occur creating a lithostatic load on the sea bed. This mechanism in turn increases the vertical forces exerted on the soil which may result in the deepening of the scouring action of the ice keel, until the vertical ice forces and horizontal soil resistance are again balanced. This second stage of scour development is characterized by decreasing water depths and increasing scour depths, similar to stage one, but differs in that a positive rise-up is observed. This rise-up is less than the decrease in water depth (i.e., increase in scour depth).

As the ice keel (or keels) continues to move upslope, the depth of scouring eventually reaches a constant value. The ice scours at E-1 (see Plate 6b), as well as scours S-1 and S-2 (see Plates 9 and 10) in the W-2 area, eventually reach a constant depth of scouring, such that the profiles of the base of scour and the sea-bed, are identical. The scour at E-1, for instance, reaches a depth of about 3 m at location 4 (see Plate 6b) and remains within 0.25 m of this depth during the next 6 km, whereas the water depth decreases from about 23 to 20 m. A rise-up of this magnitude is apparently not uncommon, because an uplift of 2 m was observed on a ridge that was grounded in the M-2 area during the winter of 1983-84[3].

Apparently, as the ridge moves upslope, some mechanism occurs (i.e., limit to the strength of the water-saturated marine clays) that prevents deeper scouring. At that point, the depth of scouring does not increase and a rise-up, equal to the decrease in water depth, occurs. The rise-up creates a lithostatic load on the sea-bed; the magnitude of loading, of course, increasing with the amount of the rise-up. This third stage of the ice-scouring process is summarized by a constant scour depth and a positive rise-up equal to the decrease in water depth.

However, the possibility exists of a constant depth of scouring, which would results from a fortuitous rise of sea level, or from ice-ridge rotation or from both. In this situation, continual physical adjustments would have had to occur to maintain the lithostatic load at a constant value. These possibilities seem unlikely because of the small tidal amplitude (1 m) and because of the absence of any visible tilting of the uplifted ice ridge[4].

The relative importance of each of the three stages in the ice-scouring process is dependent upon the orientation of the scour in relation to the isobaths, as well as upon the strength of the soil.

Following the major directional change at location E-1 (see Plate 6b), the scour depth remains constant and the rise-up is nil because the scour track parallels the isobath.

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[3]D. McGonigal, Gulf Canada Res. Inc. Calgary, Pers. comm, 1984.
[4]IBID.

At the end of stage two, where the scour depth has reached a maximum value and further upslope movement necessitates equal rise-up, the strength of the soil is critical. If the soil strength had been less, the scour depth would have been greater. For a given ridge size and water depth, the scour depth observed at the end of the second stage is directly related to soil strength. Other scour depths presumably exist in these soils because of the presence of scours at an earlier stage of development (i.e., the first stage or the beginning of the second stage).

For given water depths, ridge size, and soil conditions, the scour depths at the end of the second stage will theoretically be the same, and any change in these variables will produce a different scouring depth at the end of the second stage. The end of the second stage seems to represent the last point along the scour at which the action of ice scouring has resulted in a response in the soil (i.e., an increase in scour depth). The lithostatic load existing at this point appears to be related to strength or to competence of the soil. Anywhere along this scour before this point, a non-equilibrium situation between soil strength and rise-up or lithostatic load exists. The end of the second stage of ice scouring is apparently the limit for the soil, for a given water depth and ridge size. If the strength of the soil varies once a scour is in the third stage, the scouring ice keel will either rise up at a faster rate than the change in water depth or drop down relative to the water depth. As explained later this local increase in soil strength may hasten the grounding of an ice ridge. On the contrary when a local decrease in soil strength occurs the scour situation reverts back to the second stage.

Considering the same water depth, there are an infinite variety of different ice-keel shapes which could conceivably contact and scour the sea bed. At a particular scour depth (i.e., 1 m), these features might have quite different cross-sections. With progression upslope towards a common scour depth of 1.5 m (for example, somewhere middle of the second stage), the lithostatic loads present must be similar if the scour depths are still increasing. The only way to obtain similar loads for a given scour depth, assuming major differences in the shape of the scouring ice features, is to have them reaching these identical scour depths at different water depths. These two features then will have a different rate of rise-up during the initial stages of scouring before the limit condition is achieved. A flat, vertical-walled fragment will need more rise-up, to create the needed lithostatic load to scour the sea bed to a certain depth, than an angular-shaped keel.

Once the third stage of ice scouring has been reached, the increasing lithostatic loads created by the rise-up from continued upslope movement of the scouring ice, seem to have no effect on the soils (scour depth). Nevertheless, the more the rise-up, creating a corresponding increase in the lithostatic load, the greater the force of the ice feature on the sea-bed. This increasing vertical force on the sea-bed is met by increasing horizontal resistance in the soil. Eventually, the vertical load from continued rise-up creates sufficient horizontal resistance in the soil, that dislocation and fractures occur between the pack ice floe and the ice ridge. At this point, the ridge effectively becomes grounded.

Pieces of ice, which are observed to be grounded after a similar amount of rise-up, do not imply that similar lithostatic loads were present. A 3 m rise-up of a smaller ice ridge in shallower water would create a significantly smaller lithostatic load than a similar rise-up of a larger ridge in deeper water.

Apparently during the final stages of grounding for the S-1 and S-2 scours in the W-2 site the scour depths decrease radically. This decrease in scour depth must be a result of an increase in soil strength. Grounding occurred here, because the rise-up from encountering this more-resistant soil created sufficient lithostatic loading which, in turn, increased the horizontal forces of the ice keel on the sea-bed to the point at which fracturing occurred in the surface ice mass. In a sense, this local increase in soil strength hastens the rise-up and the eventual critical lithostatic loading required to create the resistance in the soil needed to cause fracturing in the ice mass. It is sometimes difficult to determine the point at which scour depths stop increasing and remain constant (marking the beginning of the third stage). Localized differences in soil strength assumed to occur in the base of scour as observed at S-1 and S-2 profiles (see Plates 9 and 10) in the W-2 site cause difficulty in delineating the three various stages of the scour evolution.

The longitudinal depth profile along scour S-1 (see Plate 9) shows a steady-state condition during the early stage of the ice-scouring process (reference points 1 and 2). Further upslope to the east (reference point 5), the scour depth actually increases to the point at which the base of the scour drops relative to mean sea level.

Perhaps this occurred because the ice keel scoured into higher-strength sediments, which may be present in the area between reference points 3 and 4 (see Plate 9). It is thought that in an area of thick, silty marine clays, considerable local variations in the strength of sediments may exist because of the complexity of an active ice-scouring regime. With excess lithostatic loads present in the area (stage 3), local variations in soil strength could result in different scour depths. In fact, an increase in soil strength may be the critical factor in creating sufficient resistance to the moving ice mass to cause grounding (S-1 and S-2).

Several of the scours observed during this study show no further indications of ice-keel scouring after the ice mass has stopped at the scour termination point (W-2 and E-1). Where no subsequent ice scouring is visible, it is thought that changes in the direction of the ice floe or changes in the competence of the soil as a result of ice floe pressures from another direction, or both, were insufficient to move the grounded ridge from its original position. Presumably, these features remain grounded until the following spring or summer when, after some melting at the ice surface, a volume adjustment occurs and a new buoyancy regime is established. As the thawing continues, the grounded ice masses begin to float and move away from their original grounded position. Exceptions to sequence are scours M-2 (see Plate 7b) and S-1 (see Plate 9) in the W-2 mosaic area where scouring seems to have occurred after the major termination point was reached. For instance, a major change in scour direction from roughly 080' to 300' seems to have occurred at location M-2 (see Plates 7a and b). As is possible at all termination points, changes in the direction of the ice floe and/or the shear strength of the soil or both, might permit grounded features to become mobile again.

It is believed that all scours do not necessarily evolve into the second or third stages; rather many scours stop during the first and the second stages because of a change in the direction of movement of the ice floe and are not representative of their limit condition (end of second stage).

6.0 CONCLUSIONS

This 1984 study involved the investigation of new scours, using two lines of study.

The first category consisted of the repetitive mapping aspect of the study, which has provided impact rates for new ice scours for the various control corridors and areas. Impact rates in the order of 0.4 impact/km/yr were calculated on the eastern part of the Beaufort Sea shelf. Impact rates were found to be considerably higher (2-4 impacts / km / yr) in the western part of the Beaufort Sea. A maximum of 4 impacts / km / yr was observed in the 24-m water depth range.

New information on ice scour depth indicates a significantly greater number of deeper scours in the deeper waters of the Tarsiut-Nektoralik corridor as compared to the shallower waters of the Pullen area. Re-surveying of this year's base-line network would increase significantly the regional coverage and, thus, would enable a closer examination of the regional variations. In the areas of high impact rates, an important component of the regional variations are the year-to-year variations for any given locality. In areas of shallower water (i.e., less than 30 m), where impact rates are known to be high, repetitive surveys every one to two years would be necessary to better understand the significance of yearly fluctuations of new scour impact rates. A paucity of baseline information exists in the deeper water areas of the Beaufort Sea shelf because of the severe ice conditions encountered during the summer of 1984.

The second category of new scour results concerned the physical characteristics of a few new scour tracks, of which a longitudinal depth profile was considered the primary parameter for examination. Three principal stages are now though to occur during the process of sea bottom scour formation.

In the first stage of ice scouring, scour depth increases as the water depth decreases. The elevation of the base of the scour relative to the mean sea level remains constant. Further scouring may cause the second stage to develop, during which rise-up of the base of the scour occurs, but at a lesser rate than the change in water depth. This permits scour depths to continue to increase. The third stage occurs when the rise-up of the base of the scour and the decrease in water depth are equal giving a constant scour depth. It appears that not all the scours reach the second and/or third stage. Local variations in the competence of the soil may be responsible for depth fluctuations observed in the otherwise quite smooth base of scour elevation profile.

During the summer field investigations, the line spacing for the detailed examination of these new ice scour events was at best about 200 m. A much closer line spacing, in the order of 20-30 m, would enable a considerably more detailed examination of the base of scour elevations and scour termination.

Geotechnical testing of the actual strength of the soils at the bottom of new scour features would permit correlations between any local fluctuations in the depth of the scour base and the soil strength. The measurements could be undertaken on any or all of the S-1, S-2 , M-2, or E-1 scours which were examined in detail during this study.

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APPENDIX "A"

SURVEY SYSTEMS

1. Survey Vessel
2. Geophysical Equipment
3. Navigation
4. Survey Personnel

1. SURVEY VESSEL

a) General Specifications

• Name:	MV Norweta
• Year built:	1971
• Class:	C.S.T. Arctic Class E
• Yard tonnage:	Northern Arctic Shipyards Hay River, N.W.T.
• Dimensions:	Length overall 39.6 m Breadth moulded 7.6 m Draft summer 1.4 m
• Registered tonnage:	Gross 286 tons, net 144.62 tons
• Main engines:	3 Independent 8V-71 Detroit Diesel
• Generators:	1 371 6m 100 Kw 1 Perkins 72 Kw 1 Lister Harbout 15 Kw
• Capacities:	Fuel oil - 14.5 tonne Fresh water - 9.07 tonne
• Speed maximum:	11 knots
• Deck machinery	Unic Hydraulic Crane, 2994 Kg.

b) Electrical Equipment

• Radars:	Decca Marine

- Gyro compass: Sperry Marine, SR-120
- SSB radios: Canadian Marconi Ltd., CH25
- VHF radio telephone: Triton 40
- Depth sounder: Heathkit M101.

2. GEOPHYSICAL EQUIPMENT

2.1 Precision Echo Sounder

a) Equipment

Raytheon Model DE-719B

• Operating frequency:	200 kHz
• Accuracy:	0.5% + 1" depth
• Transducer beamwidth:	8' at the half power point
• Sounding rate:	265 soundings per minute

Meyer Systems Model H1103 Bottom Tracker

- Parallel BCD digital output
- Verification trace (tracer) on the echo sounder's echogram
- Draft compensation

b) Survey Parameters

• Speed of sound in water	1450 m/s
• Transducer draft:	1.3 m
• Mode:	subbottom-bathymetry
• Range:	commonly 13 to 46 m

- Chart speed: 3 in/min
- Scale: 5 m/in
- Other ranges available: key edge 0-33 30-63 60-93 90-123
  Key centre 13-46 43-76

c) Heave Compensator ORE Model 315

- Used to determine the ship's vertical motion with a high degree of accuracy to correct the echo sounder readings.
- Consists of an accelerometer with its sensitive axis vertically stabilized by a liquid-erected vertical gyro.
- Frequency \ 0.25 Hz to 0.08 Hz
- Wave period: 4-12 s

d) See Figure A-1 for wiring diagram.

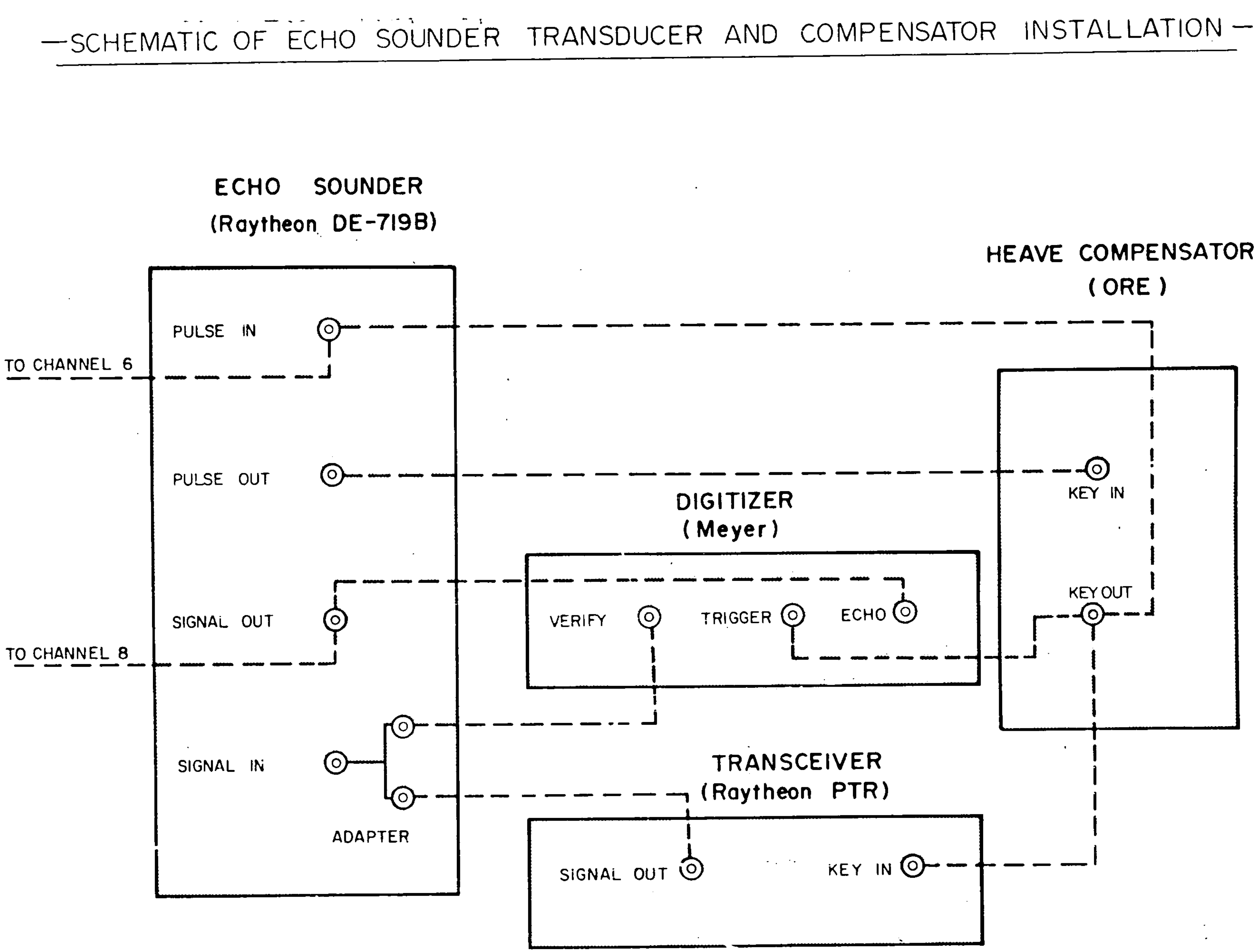


Figure A-1. Wiring diagram for the precision echo sounder and heave compensator.

2.2 Side-Scan Sonar

a) Equipment

- Klein tow fish, 100 kHz, Model 422S-001F
- Klein recorder, Model 531T
- Klein slant range correction box, Model 606
- Klein digital processor, Model 611
- Hewlett-Packard tape recorder, Model HP3968.

b) Survey Parameters

- Horizontal beamwidth - 3/4 degree
- Vertical beamwidth - 40 tilted down (10 to 50 from horizontal)
- Pulse length - 0.1 millisecond
- Weight in water - 20.8 kg
- Length - 142.7 cm
- Range - commonly 150 m
- Scale - 12m/cm.

The side-scan sonar was supplied for the survey program by McQuest Marine Sciences Ltd. Another system, provided with courtesy of the Atlantic Geoscience Centre, was loaded as an alternate in case of malfunction of the first system.

The installation of the side-scan sonar system aboard the MV Norweta was conducted by McQuest Marine Sciences Limited.

c) Figure A-2 shows the wiring diagram for the side-scan sonar and accompanying K maps processing equipment.

SIDE SCAN SONAR WIRING DIAGRAM

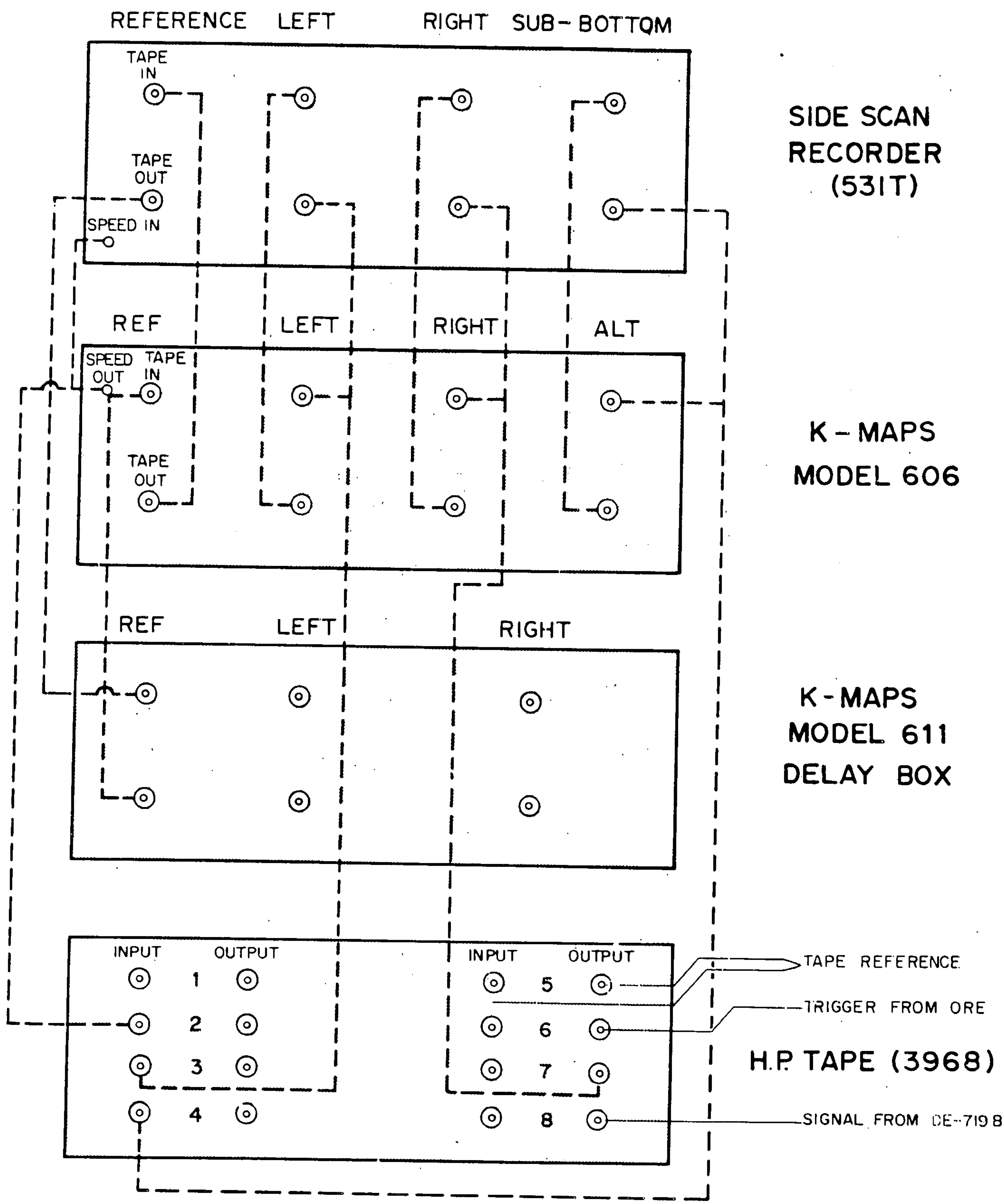


Figure A-2. Wiring diagram for the side-scan sonar and accompanying K Maps processing equipment.

2.3 Subbottom Profiler

The equipment consisted of:

- Klein tow-fish, Model 532S-001
- Raytheon 3.5 and/or 7 kHz transducer
- Raytheon transceiver
- Raytheon 719B recorder.

The instrument parameters for the Klein system are as follows:

- Output frequency - 3.5 kHz
- Acoustic output - 105 db (peak), reference on microbar at 1 m
- Pulse length - 0.4 milliseconds
- Resolution - approximately 60 cm in water
- Beam angle - 50°
- Survey data was recorded on an 8-track H.P. recorder for later playback.

The Klein system was provided by McQuest Marine Sciences Limited, and Raytheon system by Geoterrex Limited.

3. NAVIGATION SYSTEM

a) Positioning Equipment

* ARGO DM-54

ARGO is a acronym for Automatic Ranging Grid Overlay. It is a multi-range, circular geometry, navigation and position system that uses active mobile interrogator (DM-54) and four active responder stations at known fixed locations. For the ESRF 1984 ice scour mapping project, the four responder stations used were SEX, HOOPER, SING, and BAILLIE. Lane width for the ARGO network was about 91 m.

* MX - 1107 R/S Satellite Receiver

A SatNav system was used to assist in monitoring ARGO lane count.

* LEHMKUHL Gyro Repeater

The ship's gyro was used to assist in filtering the navigation information. The individual components for the ARGO positioning system are:

ARGO Shore Station Installation:

- one antenna loading unit plus cable
- one range processing unit plus cable
- Texas towers to heights up to 30 m
- one thermoelectric generator type 5120 c/w fuel harness for cascade fuel system
- tow 12-volt batteries
- one set of ground radials plus stakes.

ARGO Vessel Installation

- one antenna loading unit c/w associated cables
- one range processing unit c/w associated cables
- one power supply
- two 12-volt batteries
- one satellite antenna system.

b) Computer Equipment - Navigation

The navigation software system used was operated on standard Hewlett Packard computer equipment which includes these following equipments:

* HP9826A computer

* HP9826A memory baords and Associated Interfaces - were used as the central processing unit. This provided fast time and enabled integration with satellite and gyro while running lines.

* HP26716 Printer - provided hardcopy of collected information.

* HP7475 Plotter - used to produce navigation track plots.

* Digatek 1331 colour monitor - terminal provided a graphic display of information and transferred it to remote displays on the bridge and in the seismic lab.

* HP5936 relay actuation - link between the navigation system and data gathering systems on board the vessel.

* HP9888 - I/O extender.

* HP2225 - Inkjet Printer (CDU emulator)

c) Computer Equipment - Data Processing

The computer equipment to process and plot the field data is as follows:

- HP9854B - Computer Series 275
- HP7585 - Plotter with HPIB
- HP82910M - 51/4" Dual Disk Drive
- Real Time Clock

Figure A-3 is a diagram of the navigation equipment layout.

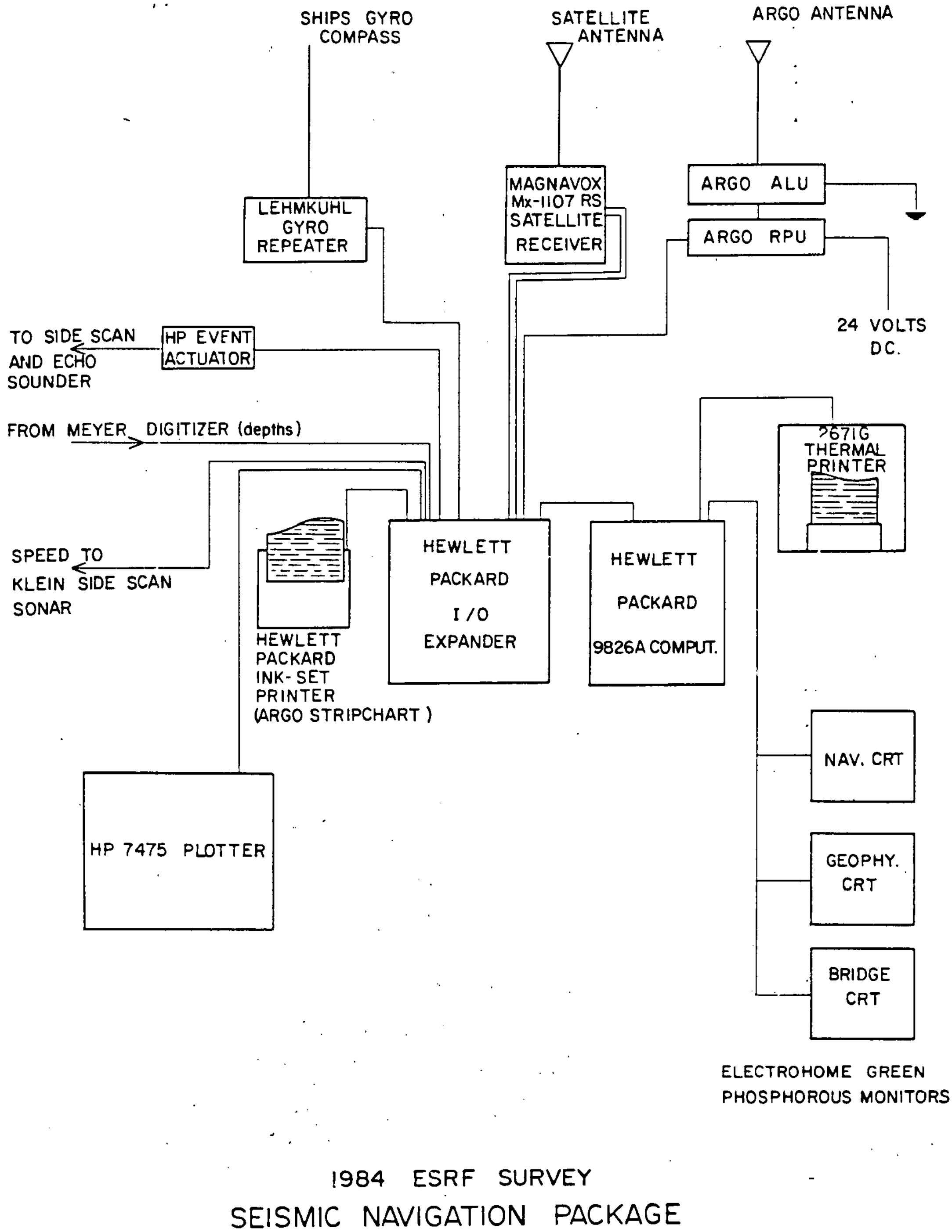


Figure A.3. Diagram of the navigation equipment layout.

4. SURVEY PERSONNEL

Party Chief:	-	Jim Shearer, Geological Consultant
Project Supervisor:	-	Rick Quinn, Geoterrex Limited
Technician: Side-Scan Sonar Subbottom Profiler	-	Ken McMillan, McQuest Marine Limited
Operations Side-Scan Sonar Subbottom Profiler	-	Bernard Laroche, Geoterrex Limited
Navigators	-	John Schleppe, McElhanney Limited
	-	Steward Cannon, Dome Petroleum
	-	Scott McCarron, McElhanney Limited
ESRF Study Adviser	-	A.F. Stirbys, Gulf Canada Resources Ltd.

APPENDIX "B"

NEW SCOURS STATISTICS

PREPARED BY

GEOTERREX, OTTAWA

AND

CANADIAN MARINE ENGINEERING LTD. CALGARY

NOTES

Scour Depth in meters

Water Depth in meters

UND - undetermined

MK - multi-keel

SK - single-keel

LG - large

New Scours - 1, 2 etc represent scours which are fully contained within one fix block or a major portion is contained within block but may extend to one or more other blocks.

(1)↑, (2)↙ means part of a scour is in this fix block but major portion is block indicated by scour.

ie. total new scours per fix block
1 + (1)↑ + (1)↙ = 3

total new scours per large area equal sum of non-bracketed numbers

1 (1)↑
2 (1)↘
1
2 (1)↖

= 6

AREA: KAUBVIK (1983-84)
SCALE: 1:100
LINE 3CA

RESCOURED ANALYSIS

DATE:

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
3417 -3418	10	25	.5	1(1)		PARALLEL TO LINE OF TRAVEL
3418 -3419	10	25	1	1		
3419 -3420	15	28	.5UND.5	3(1)		
3420 -3421	5	9	.5	2(1)		
3421 -3422		20	UND, .5	2	19-19.5	
3422 -3423	1	1.1	UND	2(1)		2 KM
3423 -3424	1.5	3	.5	1		
3424 -3425	0	0	0	0		
3425 -3426	.4	.5	UND	1(1)		
3426 -3427	1	3	1	1		
3427 -3428	0	0	0	0		
3428 -3429	0	0	0	0		
3429 -3430	0	0	0	0		NO NEW SCOURS (NNS)
3430 -3431	0	0	0	0		
3431 -3432	0	0	0	0	18.5-19	
3432 -3433	0	0	0	0		IS
3433 -3434	0	0	0	0		DO NOT USE
3434 -3435	0	0	0	0		
3435 -3436	0	0	0	0		
3436 -3437	3	5	1	1		
3437 -3438	1.5	2	UND	1	18-18.5	
3438 -3439	5	7	.25, .5	2		1.2
3439 -3440	0	0	0	0		
3440 -3441	3	4	1	1		
			18 SCOURS TOTAL			
1533 -1534	30	40	.25, .5	2	20.5-21	
1534 -1535	15	25	.5, 1.5	2		
1535 -1536	0	0	0	0		
1536 -1537	UND	25	UND	(1)	20-20.5	
1537 -1538	40	60	2	1(1)		SCOUR HAS 2 DEPTHS 1M & 2M
1538 -1539	35	45	2	2(3)(2)		
1539 -1540	30	40	1.5	2(1)(2)	19.5-20	2 SCOURS RUN PARALLEL TO LINE
1540 -1541	UND	50	UND	2(2)		
1541 -1542	UND	55	UND	(2)(1)		
1542 -1543	UND	30	UND	1(1)(1)	19-19.5	
1543 -1544	3	5	.5	1		
1544 -1545	0	0	0	0		4 KM
1545 -1546	0	0	0	0	18.5-19	
1546 -1547	3	4	UND	1(1)		
1547 -1548	2	3	UND	1	18-18.5	
1548 -1549	6	8	.5	(2)		
1549 -1550	20	30	.5	2(1)		
1550 -1551	30	35	.25,.25	1(1)		SCOUR RUNS THROUGH SEVERAL INTERVALS
1551 -1552	UND	22	UND	(1)	17.5-18	
			17 SCOURS TOTAL			

AREA: KAUBVIK (1983-84)
SCALE: 1:100
LINE 3D

RESCOURED ANALYSIS

DATE:

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
1345 -1346	4	7	.25	1(1)		SCOUR CLOSE TO
1346 -1347	3	5	.25(5)	1(1)	18-18.5	PARALLEL
1347 -1348	0	0	0	0		
1348 -1349	0	0	0	0		
1349 -1350	0	0	0	0	18.5-19	DO NOT USE
1350 -1351	0	0	0	0		
1351 -1352	0	0	0	0		
1352 -1353	1.5	2	.75(5)	1(1)	19-19.5	↑
1353 -1354	13	20	UND	1		
1354 -1355	13	17	<.25	(1)1(1)		STRIATED RIBS
1355 -1356	20	26	.5,.5	4(1)	19.5-20	
1356 -1357	12	18	.5,2(1.5)	(2)		
1357 -1358	~16	22	1	2(1)	20-20.5	1.8 KM
1358 -1359	28	36	.75,2	2(1)		
1359 -1360	4	8	.5	1(1)		
1360 -1361	8	20	2	1	20.5-21	↓

15 SCOURS
COMPARE 1300 & 1500 LINES

AREA: KAUBVIK (1983-84)
SCALE: 1:150
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
7906 -7907	8	10	UND,1.5	2		↑
7907 -7908	1	1.25	UND	(1)	20.5-21	
7908 -7909	5	7	.25	1(1)		
7909 -7910	1.8	2	1,1	2(1)		
7910 -7911	40	50	1.5,.5	2(1)	20-20.5	
7911 -7912	10	37	1.5	1		ONE DEEP SCOUR AND LIGHT SURFICIAL
7912 -7913	10	35	<.25	(1)3		
7913 -7914	15	52	.5	(1)3	19.5-20	
7914 -7915	8	16	.25	1(1)(1)		
7915 -7916	15	25	1,1,.25	(1)2		4.4 KM
7916 -7917	8	12	.5	1(1)		
7917 -7918	12	16	.5,1	2	19-19.5	
7918 -7919	14	18	(1-2?)	(1)		-CHECK RADIO SEND RECORD FOR SCOUR DEPTHS
7919 -7920	28	36	1.5,1	2(1)		
7920 -7921	0	0	0	0		
7921 -7922	0	0	0	0	18.5-19	
7922 -7923	0	0	0	0		
7923 -7924	0	0	0	0		
7924 -7925	1.3	2	.25	1	18-18.5	↓

23 SCOURS

AREA: NIPTERK (1983-84)
SCALE: 1:100
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
1299 -1300	3	7	UND	(1)	10.5-11	ONE LONG SCOUR PARALLEL TO LINE OF TRAVEL
1300 -1301	2	5.5	UND	1		
1301 -1302	2.5	6	UND	(1)		
1302 -1303	2	3.5	.25	1(1)		1.2 KM
1303 -1304	.5	1	UND	(1)	11-11.5	
1304 -1305	0	0	0	0		
1305 -1306	0	0	0	0		
1306 -1307	0	0	0	0		NOT EXAMINED
1307 -1308	0	0	0	0		
1308 -1309	0	0	0	0	11.5-12	
1309 -1310	0	0	0	0		
1310 -1311	0	0	0	0		
1311 -1312	1	2	UND	(1)		SCOUR CONTINUES
1312 -1313	1	2	<.5	1	12-12.5	FOR THE NEXT 5
1313 -1314	1.5	3	.25	1(1)		INTERVALS
1314 -1315	1	2	UND	(1)		
1315 -1316	6	9	1	1(1)		
1316 -1317	5	9.5	<.5	1	12.5-13	CHECK RADIOSOND FOR SCOUR DEPTH
1317 -1318	.5	1	UND	(1)		
1318 -1319	0	0	0	0		
1319 -1320	0	0	0	0		2.5
1320 -1321	0	0	0	0	13-13.5	
1321 -1322	0	0	0	0		
1322 -1323	2	3.5	UND	(1)		
1323 -1324	UND	8	UND	1		CHECK RADIOSOND

7 SCOURS TOTAL

SCALE 1:100

FIX INTERVAL	% INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
1572 -1573	0	0	0	0		PARALLEL TO INTERVAL LINE 1299 TO 1324
1573 -1574	0	0	0	0		
1574 -1575	0	0	0	0		
1575 -1576	0	0	0	0		
1576 -1577	0	0	0	0		
1577 -1578	0	0	0	0		
1578 -1579	0	0	0	0		
1579 -1580	0	0	0	0		
1580 -1581	0	0	0	0		
1581 -1582	0	0	0	0		
1582 -1583	0	0	0	0		
1583 -1584	0	0	0	0		
1584 -1585	0	0	0	0		
1585 -1586	0	0	0	0	11.5-12	
1586 -1587	0	0	0	0		
1587 -1588	0	0	0	0		
1588 -1589	.8	1.2	<.25	1		2 KM
1589 -1590		<1	UND	(1)		
1590 -1591	~2	3.5	<.25	2	11-11.5	
1591 -1592	~1	1.5	UND	(1)		

3 TOTAL SCOURS

AREA: MINUK (1983-84)
SCALE: 1:150
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
9140 -9141	~7	9.5	.5,UND	1(1)	14	↑
9141 -9142	~1.5	3.5	UND	1	14.5	SCOUR RUNS
9142 -9143	~1	2	UND	(1)		THROUGH 10
9143 -9144	~1	2	<.25	(1)		INTERVALS
9144 -9145	~2	3.5	UND	(1)		
9145 -9146	~1	2	UND	(1)	14.5-15	
9146 -9147	~1	2	UND	(2)		
9147 -9148	~2	5	UND,<.25	1(1)(1)		
9148 -9149	~8	14	.5,<.25	2(2)(1)(1)		
9149 -9150	~4	6	.75	2(1)(1)		
9150 -9151	~3	5	<.25	1(2)(1)	15-15.5	
9151 -9152	~1	2.5	UND	1		4 KM
9152 -9153	~1	1	UND	(1)		
9153 -9154	0	0	0	0		
9154 -9155	0	0	0	0		
9155 -9156	0	0	0	0		
9156 -9157	~4	9	UND	(1)	15.5-16	
9157 -9158	~4	9	1.25	1		
9158 -9159	~7	10.5	.5	1(1)		
9159 -9160	~1	1	UND	(1)	16-16.5	
9161 -9162	0	0	0	0	16.5-17	↓

11 NEW SCOURS

AREA: MINUK (1983-84)
SCALE: 1:100
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
1950 -1951	0	0	0	0		
1951 -1952	0	0	0	0		
1952 -1953	0	0	0	0		
1953 -1954	0	0	0	0		
1954 -1955	0	0	0	0		
1955 -1956	0	0	0	0		
1956 -1957	0	0	0	0		
1957 -1958	0	0	0	0		
1958 -1959	~5	8.5	.2	1		
1959 -1960	0	0	0	0		
1960 -1961	0	0	0	0		
1961 -1962	0	0	0	0		

1 NEW SCOUR

FIX INTERVAL	% INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
3635 -3636	0	0	0	0	↑	↑
3636 -3637	~4	11	<.5	1		CHECK RADIOSOND
3637 -3638	0	0	0	0		
3638 -3639	0	0	0	0		
3639 -3640	~8	20	<.5	1	15.5	
3640 -3641	~5	15	<.5	(1)	TO	
3641 -3642	~9	13	<.5	1(1)		
3642 -3643	<1	2	<.5,<.5	2	16	
3643 -3644	~6	11	.25	1(1)		
3644 -3645	~8	11	1.25,1.5	2(1)		2 SCOURS CAUSED
3645 -3646	2	3	UND	1		BY 1 PIECE ICE
3646 -3647	<5	1	UND	(2)(1)		
3647 -3648	3	4	.25,.25	3		5 KM
3648 -3649	1.5	2.5	UND	(1)(1)	↓	
3649 -3650	6	7.5	.5,.5	3	15.5-16	2 SCOURS CAUSED
3650 -3651	0	0	0	0		BY 1 PIECE ICE
3651 -3652	0	0	0	0	↓	TO 3660
3652 -3653	0	0	0	0		
3653 -3654	0	0	0	0		
3654 -3655	0	0	0	0		
3655 -3656	0	0	0	0		
3656 -3657	0	0	0	0		
3657 -3658	0	0	0	0		
3658 -3659	0	0	0	0		
3659 -3660	0	0	0	0		
3660 -3661	0	0	0	0		
3661 -3662	0	0	0	0		
3662 -3663	0	0	0	0		
3663 -3664	0	0	0	0		
3664 -3665	0	0	0	0		↓

TOTAL # NEW
SCOURS = 15

AREA: MINUK (1983-84)
SCALE: 1:100
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
1937 -1938	0	0	0	0	14.5-15	↑
1938 -1939	2	3.5	.5	1(1)		
1939 -1940	7	10.5	<.25	2(1)		
1940 -1941	4	7	<.25	1(1)		
1941 -1942	0	0	0	0		2.5 KM
1942 -1943	0	0	0	0	15-15.5	
1943 -1944	0	0	0	0		
1944 -1945	2	4	<.25	1		↓
			5 SCOURS TOTAL			
1948 -1949	0	0	0	0	16-16.5	
1949 -1950	0	0	0	0		
1950 -1951	0	0	0	0	16.5-17	
1951 -1952	0	0	0	0		DO NOT USE
1952 -1953	0	0	0	0		
1953 -1954	0	0	0	0		
1954 -1955	0	0	0	0		
1955 -1956	0	0	0	0	16-16.5	1.5 KM
1956 -1957	0	0	0	0		
1957 -1958	0	0	0	0		
1958 -1959	7	9.5	1.5	1		CHECK RADIOSOND
1959 -1960	0	0	0	0		
			1 TOTAL			

AREA: MINUK (1983-84)
SCALE: 1:150
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
8120 -8121	0	0	0	0	↑	
8121 -8122	0	0	0	0		
8122 -8123	0	0	0	0		
8123 -8124	0	0	0	0		2 KM
8124 -8125	0	0	0	0		
8125 -8126	6	14	UND	2		CHECK RADIOSOND FOR SCOUR DEPTH
8126 -8127	8	13	.75	1(1)		
8127 -8128	-	-	-	-		IMAGE UNREADABLE
8128 -8129	.6	1	UND	(1)	15.5	
8129 -8130	10	15	<.5	2		
8130 -8131	.6	1	UND	(1)		
8131 -8132	0	0	0	0	16	
8132 -8133	0	0	0	0		
8133 -8134	0	0	0	0		
8134 -8135	0	0	0	0		DO NOT USE
8135 -8136	0	0	0	0		
8136 -8137	0	0	0	0		
8137 -8138	0	0	0	0		1 KM
8138 -8139	.8	1.5	.25	1		NO SCOURS BEYOND THIS POINT
8139 -8140	0	0	0	0	↓	
				6 TOTAL		

AREA: KADLUK (1983-84)
SCALE: 1:150
LINE

RESCOURED ANALYSIS
==================

FIX INTERVAL		% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
83	-84	~3	5	<.25	1(1)		SCOUR CONTINUES FOR 4 INTERVALS
84	-85	~4	8	<.25	(2)(1)		
85	-86	~3	6.5	<.25	1(1)1	14-14.5	DOUBLE SCOUR
86	-87	~3	6	.25	1(2)		
87	-88	~12	15	<.25	1(1)1		
88	-89	~15	20	<.25	(2)(1)		
89	-90	~22	28	.75	1(2)		
90	-91	~16	28	<.25	(2)		
91	-92	6	10	UND	(2)	14-13.5	
92	-93	4	7.5	UND	1		4 KM
93	-94	3	6	UND	(1)		
94	-95		36				CHECK WITH JIM
95	-96						
96	-97						
97	-98	0	0	0	0		
98	-99	0	0	0	0		
99	-100	0	0	0	0	13-13.5	
100	-101	0	0	0	0		
101	-102	0	0	0	0		
102	-103	0	0	0	0		
103	-104	0	0	0	0		

TOTAL # SCOURS 12

FIX INTERVAL		% INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
2141	-2142	~2	3.5	UND	(1)	14.5-15	
2142	-2143	~2	3.5	.25	1		
2143	-2144	~2.5	4	UND	(1)		
2144	-2145	~2.5	4	UND	(1)	14-14.5	
2145	-2146	1.5	3	UND	(1)(1)		
2146	-2147	2	4	<.25	1		4 KM
2147	-2148	<.5	<1	UND	(1)		
2148	-2149	0	0	0	0	13.5-14	
2149	-2150	0	0	0	0		
2150	-2151	0	0	0	0		
2151	-2152	0	0	0	0		
2152	-2153	0	0	0	0		
2153	-2154	0	0	0	0		
2154	-2155	0	0	0	0		
2155	-2156	0	0	0	0		
2156	-2157	0	0	0	0		
2157	-2158	~1	2	UND	(1)		
2158	-2159	~4	7	UND	1(1)		
2159	-2160	~4	7.5	UND	1(1)	13-13.5	
2160	-2161	0	0	0	0		
2161	-2162	0	0	0	0		
2162	-2163	0	0	0	0		

4 TOTAL NEW SCOURS

AREA: KADLUK (1983-84)
SCALE: 1:100
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
3545 -3546	0	0	0	0	↑	↑
3546 -3547	0	0	0	0		
3547 -3548	-	<.5	UND	(1)		
3548 -3549	~1	1.5	.5	1		
3549 -3550	~1	2	UND	(1)(1)		
3550 -3551	3	5.5	.5	1	14-14.5	2.5 KM
3551 -3552	2	3	UND	(1)		
3552 -3553	0	0	0	0		
3553 -3554	0	0	0	0		
3554 -3555	0	0	0	0		
3555 -3556	<.5	<1	UND	(1)		
3556 -3557	~1	2	<.5	1		
3557 -3558	3	4	<.5	3		CHECK RADIOSOND FOR SCOUR DEPTH
3558 -3559	0	0	0	0		
3559 -3560	0	0	0	0		
3560 -3561	0	0	0	0		
3561 -3562	0	0	0	0	↓	↓

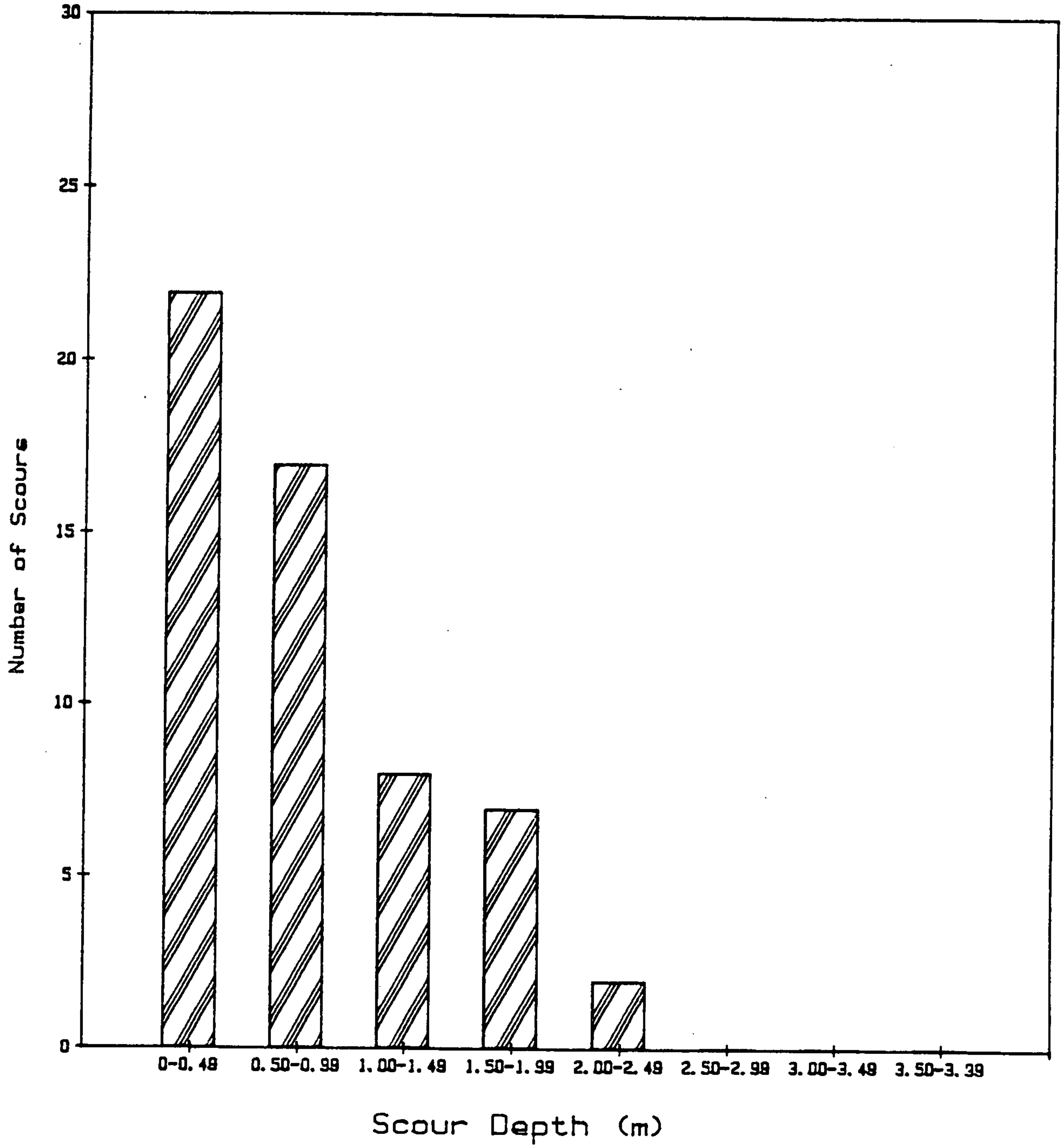
6 NEW SCOURS

AREA: KADLUK (1983-84)
SCALE: 1:150
LINE

RESCOURED ANALYSIS
==================

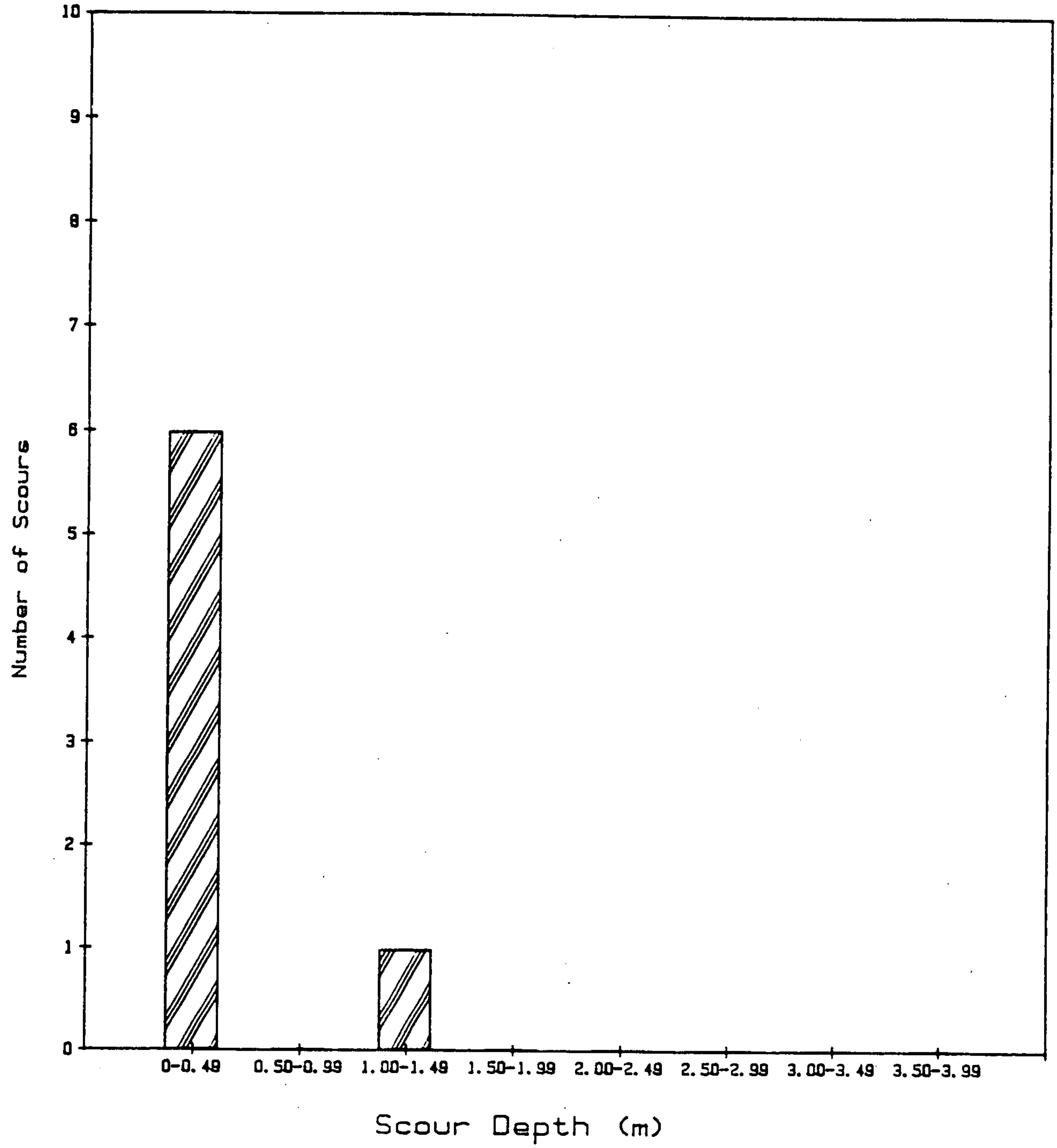
FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
8031 -8032	0	0	0	0	↑	
8032 -8033	0	0	0	0		
8033 -8034	0	0	0	0		
8034 -8035	0	0	0	0		
8035 -8036	0	0	0	0		
8036 -8037	0	0	0	0		
8037 -8038	0	0	0	0		
8038 -8039	0	0	0	0		
8039 -8040	~3	5	.25,<.5	2(1)		SCOUR CONTINUES FOR 5 INTERVALS
8040 -8041	~.75	2	<.5	1		
8041 -8042	~.75	2	UND	(1)		
8042 -8043	~.75	2	UND	(1)		2.5 KM
8043 -8044	~.75	2	UND	(1)	14-14.5	
8044 -8045	0	0	0	0		
8045 -8046	0	0	0	0		
8046 -8047	0	0	0	0	↓	

3 NEW SCOURS



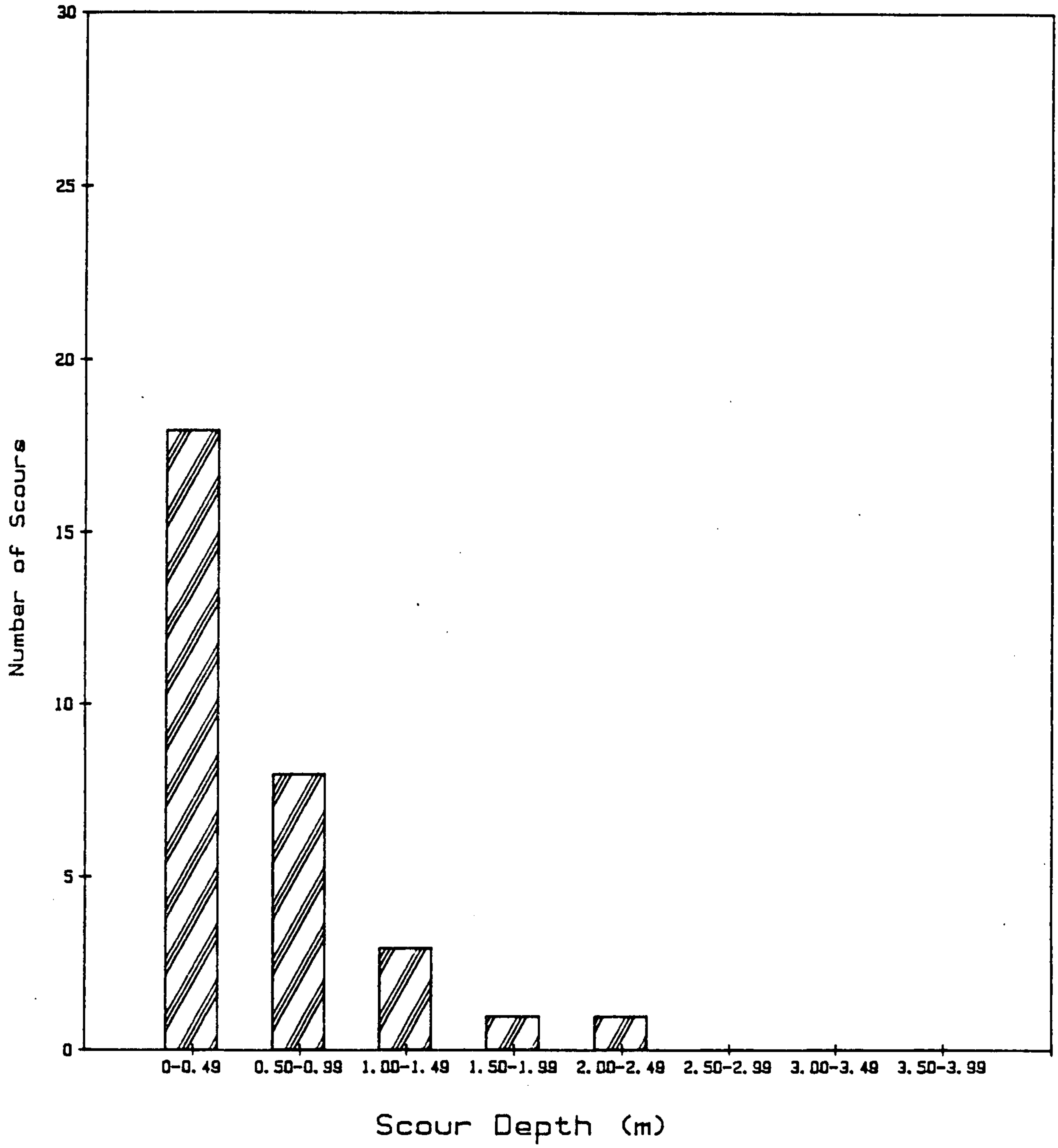
Survey Internal: 1983-84
Total Line Coverage: 13 km
Water Depth: 18 m

SCOUR DEPTH DISTRIBUTION - KAUBVIK



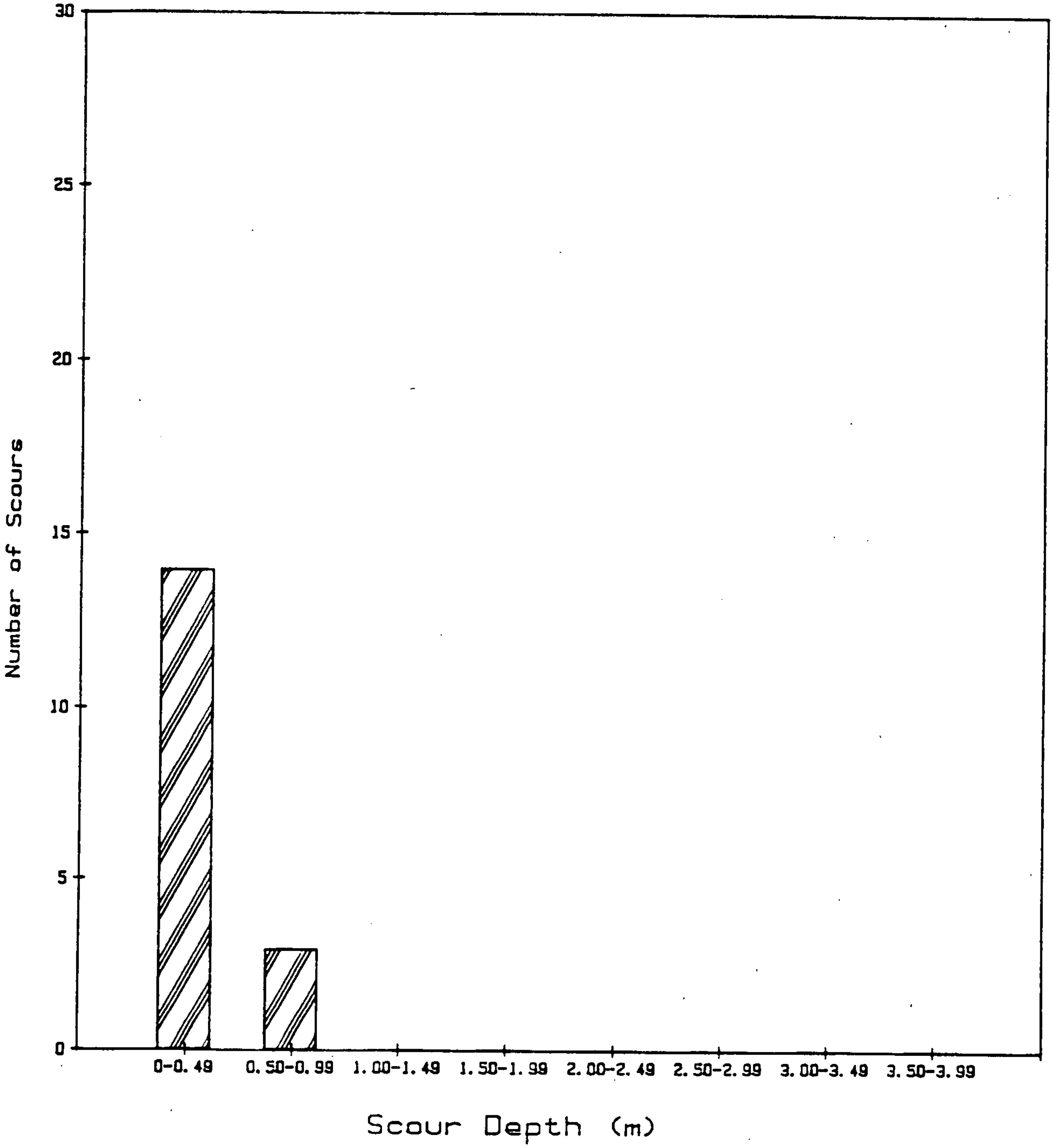
Survey Interval : 1983-84
Total Line Coverage : 11 km
Water Depth : 11 m

SCOUR DEPTH DISTRIBUTION - NIPTERK



Survey Interval	:	1983-84
Total Line Coverage	:	18 km
Water Depth	:	14-15 m

SCOUR DEPTH DISTRIBUTION - MINUK



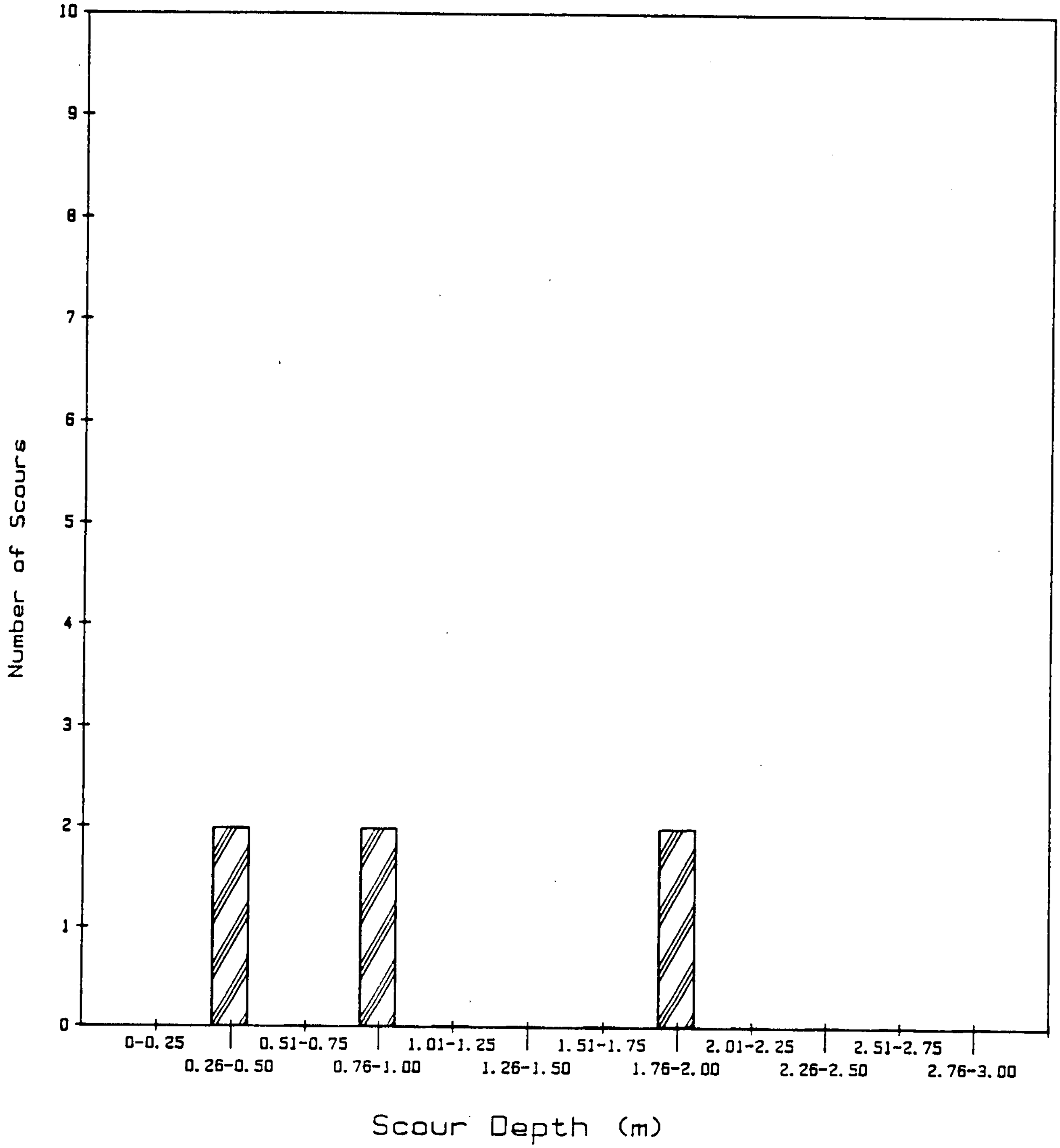
Survey Interval : 1983-84
Total Line Coverage : 14 km
Water Depth : 12 m

SCOUR DEPTH DISTRIBUTION - KADLUK

AREA: W SAUVRAK 6RD8 (1982-84)
SCALE: 150 M
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
6706 -6707	13	16.5	UND,1	(1)(1)	23.5	
6707 -6708	55	65	1.UND	1(1)	23.5	
6708 -6709	9	14	.5	1	24	
6709 -6710	8	13.5	UND	(1)	24	
6710 -6711	3.5	5	UND	(1)	24	
6711 -6712	0	0	0	0	24	
6712 -6713	0	0	0	0	24	
6713 -6714	0	0	0	0	24.5	
6714 -6715	0	0	0	0	24.5	
6715 -6716	7	9	UND	(1)	25	
6716 -6717	23	30	.5,2	2	25	THIS IS OVERLAP
6717 -6718	9	14	UND	(1)	25	WITH SAVURAK
6718 -6719	0	0	0	0	25	MOSAIC 4.6 KM
6719 -6720	0	0	0	0	25.5	
6720 -6721	18	24	2	1	25.5	
6721 -6722	4	6	2	(1)	25.5	
6722 -6723	0	0	0	0	25.5	
6723 -6724	0	0	0	0	26	
6724 -6725	0	0	0	0	26	
6725 -6726	10	13.5	1	(1)	26	
6726 -6727	12	17.5	1	1	26.5	
6727 -6728	0	0	0	0	26.5	
6728 -6729	0	0	0	0	26.5	
6729 -6730	0	0	0	0	27	
			6 NEW SCOURS			
100 M SCALE						
5350 -5351	15	19.5	UND,<.5	2	30	
5351 -5352	13	16	UND,<.5	1(1)	30	
150 M SCALE						
5902 -5903	9	14	.5,UND,UND	1(2)	27	ONLY 600 M
5903 -5904	9	13	.5,.5	2	27	OVERLAP
5904 -5905	4.5	9	.5	1	27	



Survey Interval : 1982-84
Total Line Coverage: 5 km

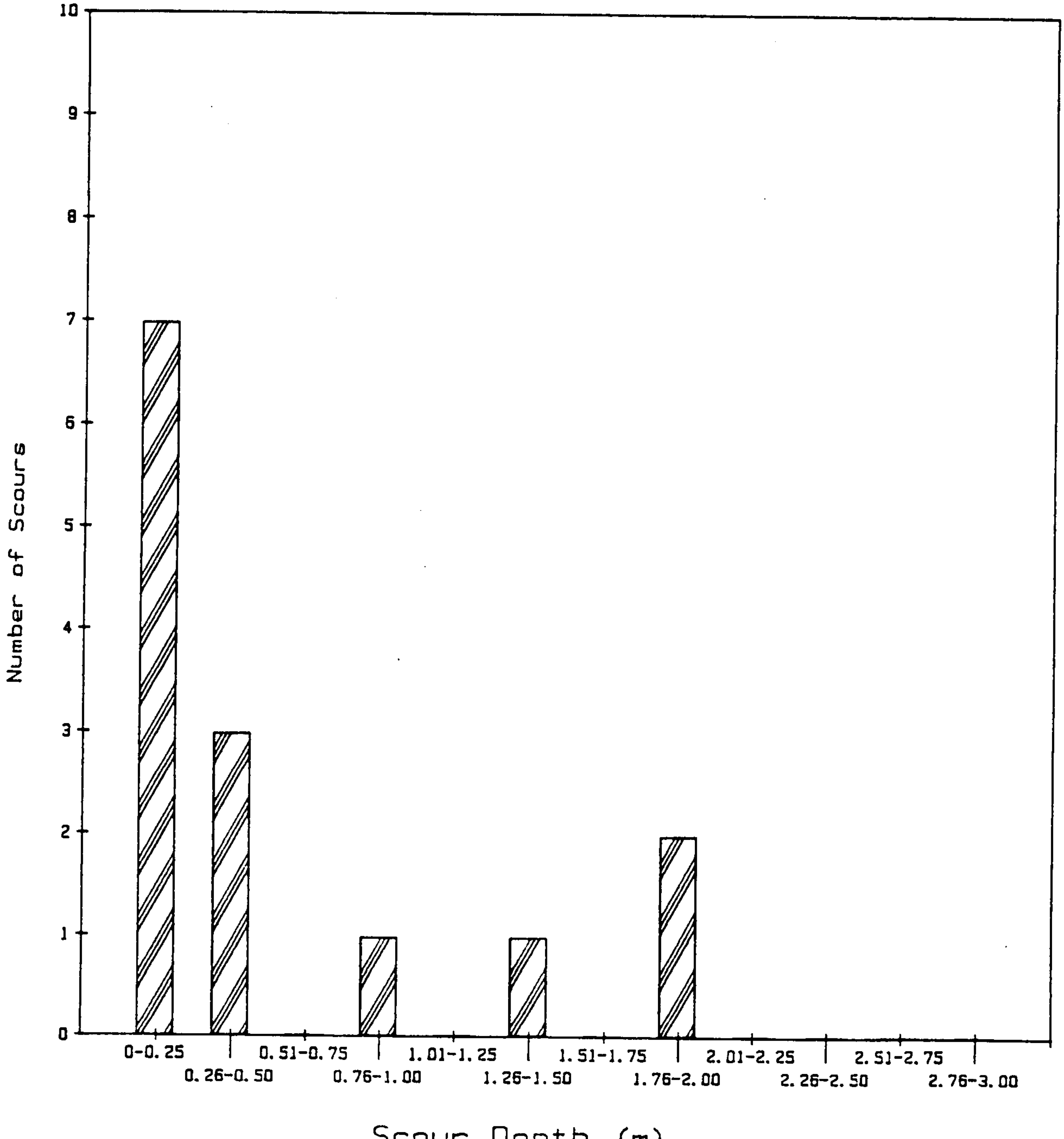
SCOUR DEPTH DISTRIBUTION - SAUVRAK

AREA: East MacKenzie (1979-84)
SCALE: 150 M
LINE EAST MACKENZIE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
						23 KM NO NEW SCOURS
7094 -7095	1.5	3	UND	(1)	20	
7095 -7096	6	12	1	1	20.5	
7096 -7097	8	12.5	UND,UND,UND	2(1)	20.5	
7097 -7098	7	10	UND,UND, <.5,<.5	1(2)(1)	21	
7098 -7099	20	24	<.5,2	1(1)	21.5	
7099 -7100	40	48.5	UND,2	2	22	SAME AS 7086-7088
7100 -7101	12	17	UND,UND,.5	2(1)	22.5	
7101 -7102	16	22	<.5,1.5, UND,UND,UND	3(1)(2)	23	SAME AS 7084-7086
7102 -7103	9	15	UND,UND, UND,<.5	3(1)	23.5	
7103 -7104	3	5	UND,UND,UND	(3)	24	
7104 -7105	1	1	UND	(1)	24	
7105 -7106	1	1	UND	(1)	24.5	
7106 -7107	4.5	9	UND,UND	(1)(1)	24.5	
7107 -7108	5	10	.5	1	25	SAME AS 7082-7084
7108 -7109	2.5	3.5	UND	(1)	25.5	
7109 -7110	1	1	UND	(1)	26	
7110 -7111	2	2.5	2,<.5	2	26	
7111 -7112	2	2.5	UND,UND,UND	(2)(1)	26.5	
7112 -7113	2	3	.5	1	26.5	
7113 -7114	1.5	2	UND	(1)	27	
7114 -7115	0	0	0	0	27	
7115 -7116	3	5	UND	(1)	27.5	
7116 -7117	5	9	<.5	1	28	SAME AS 7071-7074
7117 -7118	3	5.5	UND	(1)	28.5	
7118 -7119	0	0	0	0	28.5	
7119 -7120	0	0	0	0	29	
7120 -7121	0	0	0	0	29	
7121 -7122	.5	1	<.5	1	29.5	SAME AS 7066-7068
7122 -7123	0	0	0	0	29.5	
7123 -7124	0	0	0	0	30	
7124 -7125	0	0	0	0	30.	
7125 -7126	0	0	0	0	30.5	
7126 -7127	0	0	0	0	30.5	
7127 -7128	0	0	0	0	31	
7128 -7129	0	0	0	0	3.5	
7129 -7130	0	0	0	0	32	
7130 -7131	0	0	0	0	325	
7131 -7132	0	0	0	0	33	
7132 -7133	0	0	0	0	33	

END OF LINE 21 NEW SCOURS



Survey Interval : 1979-84
Total Line Coverage : 7 km

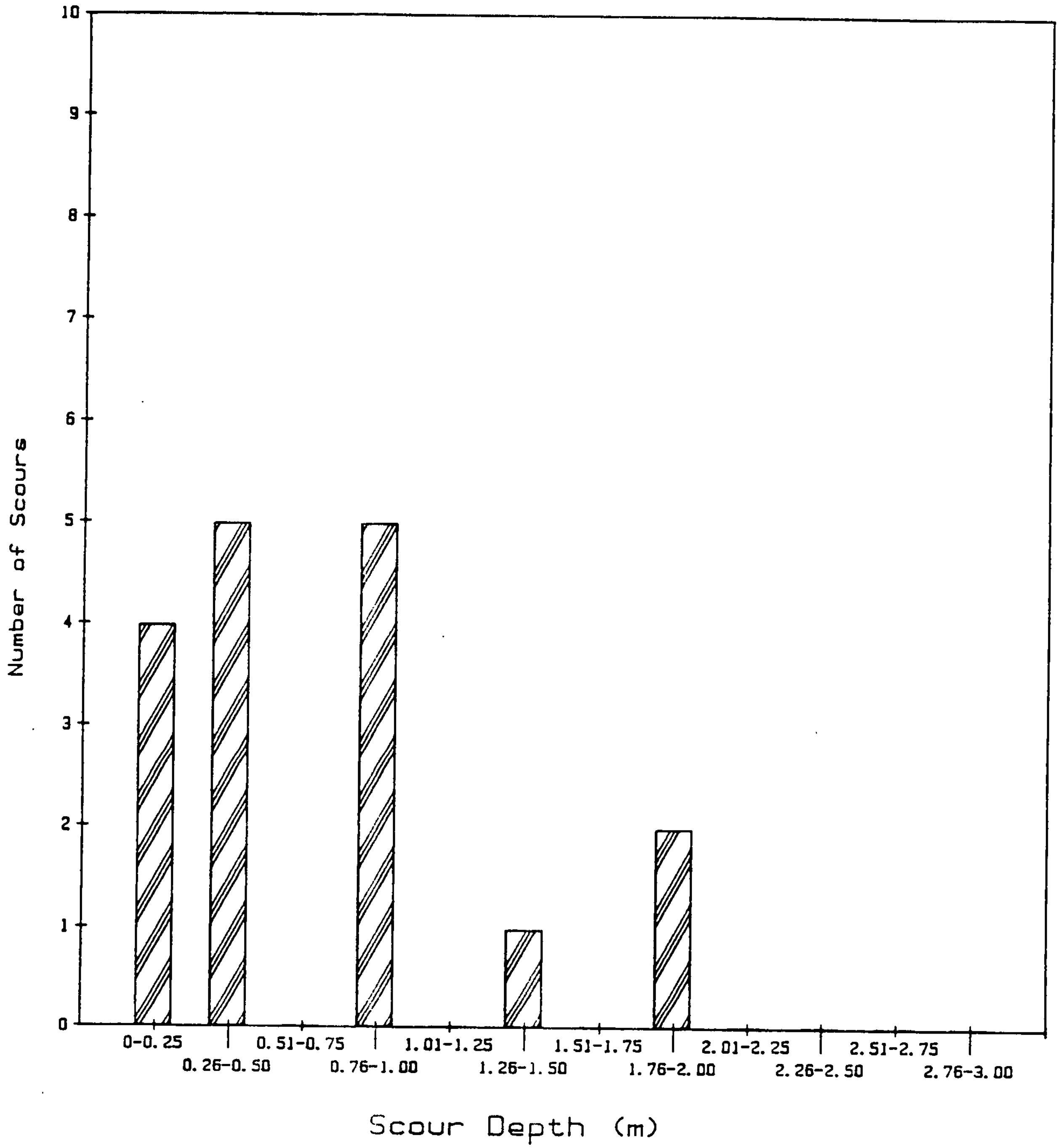
SCOUR DEPTH DISTRIBUTION - EAST MACKENZIE

AREA: AUG. 14/84 East MacKenzie (1979-84)
SCALE
LINE EAST MACKENZIE C

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
						23 KM NO NEW TO H2O DEPTH 44 M
7065 -7066	0	0	0	0	29.5	
7066 -7067	.5	1	.5	(1)	29	
7067 -7068	1	1.5	.5	1	29	SAME AS 7121-7122
7068 -7069	0	0	0	0	28.5	
7069 -7070	0	0	0	0	28	
7070 -7071	0	0	0	0	28	
7071 -7072	3	4	UND	(1)	27.5	
7072 -7073	7.5	10	<.5	1	27.5	SAME AS 7115-7118
7073 -7074	3	4	UND	(1)	27	
7074 -7075	0	0	0	0	27	
7075 -7076	0	0	0	0	26.5	
7076 -7077	2	3	<.5	(1)	26.5	
7077 -7078	7.5	18.5	1,<.5,<.5	2(1)	26	7076-7078 SAME AS 7111-7114
7078 -7079	2.5	3.5	<.5	1	26	
7079 -7080	.5	.5	UND	(1)	25.5	
7080 -7081	3.5	5	<.5	1	25.5	
7081 -7082	2	3	UND,UND	(1)(1)	25	
7082 -7083	4	6	1	1	25	SAME AS 7106-7109
7083 -7084	6.5	9	1	(1)	24.5	
7084 -7085	8	12	.5	1(1)	24.5	SAME AS 7101-7102
7085 -7086	3	4	UND	(1)(1)	24	
7086 -7087	25	33	1,UND	2	23.5	SAME SCAN AS 7098-7101
7087 -7088	13	18	UND,1	2(2)	23.5	
7088 -7089	25	32	1,.5,.5, .5,UND	4(1)	23	
7089 -7090	12	17	UND,UND, UND,UND	1(2)(1)	23	
7090 -7091	3	5	UND	1	22.5	
7091 -7092	5.5	7.5	UND,UND, UND,.5	2(1)(1)	22	NOTE: FIXES END AT 7093 SO CONT. BY EST. FIX POSITIONS
7092 -7093	12	20	UND,2	1(1)	21.5	
7093 -7094	7	13	UND,UND,(1)(2)		21	
7094 -7095	25	42	2	1	20.5	
7095 -7096	8	12	UND	(1)	20	

22 NEW SCOURS

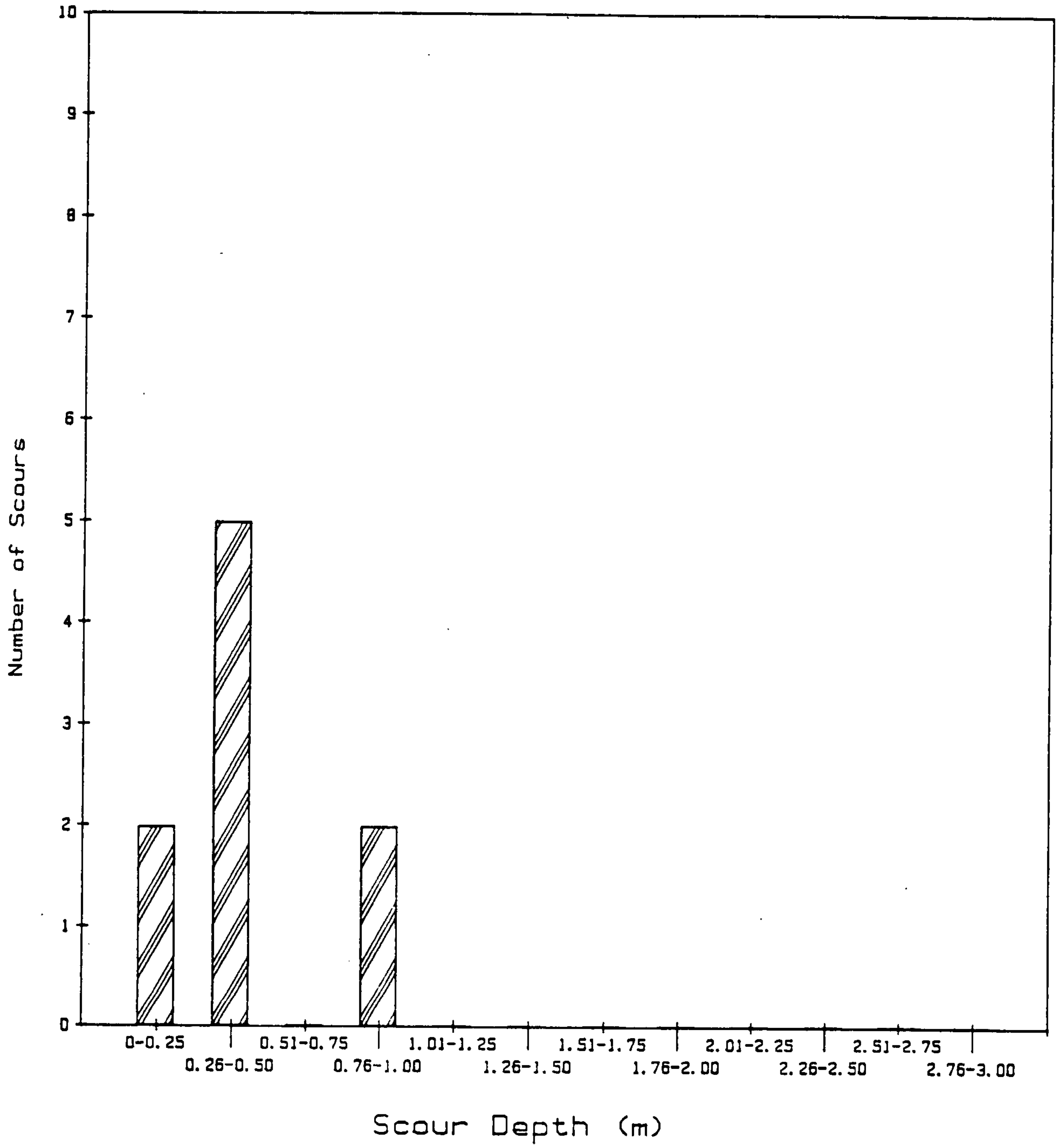


Survey Interval : 1979-84
Total Line Coverage : 6 km

SCOUR DEPTH DISTRIBUTION - EAST MACKENZIE C

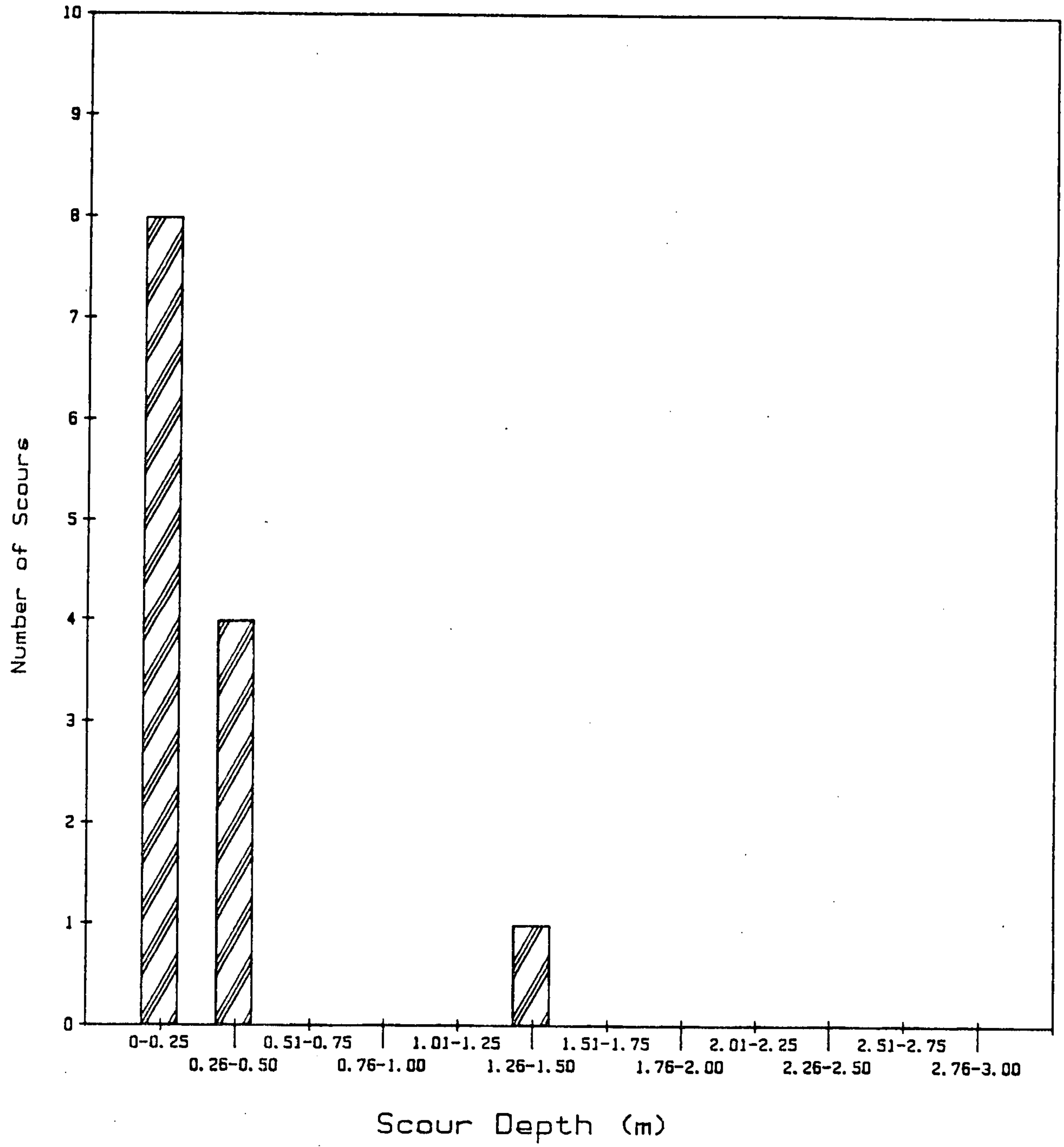
AREA: S. END TINGMIARK-NERLERK CORRIDOR (1979-84)
SCALE: 150 M RESCOURED ANALYSIS
LINE

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
5466 -5467	5	8	1	(1)	25.5	
5467 -5468	12	19	1	1	25.5	
5468 -5469	9	14	<.5	2	26	
5469 -5470	4	5.5	<.5,<.5,<.5	1(1)	26	
5470 -5471	0	0	0	0	26	
5471 -5472	0	0	0	0	26	
5472 -5473	6	10	.5	1	26.5	
5473 -5474	4	6	<.5,<.5, UND,UND	2(1)(1)	26.5	
5474 -5475	9	13	.5,.5,.5, .5,UND	4(1)	26.5	
5475 -5476	3	5	<.5	1(1)	26.5	
5476 -5477	1.5	2	<.5	(1)	26.5	
5477 -5478	6	10	1.5	(1)	26.5	
5478 -5479	7.5	13.5	1.5	1	26.5	
5479 -5480	0	0	0	0	27	
5480 -5481	0	0	0	0	27	
5481 -5482	0	0	0	0	27	
5482 -5483	0	0	0	0	27	
5483 -5484	0	0	0	0	27.5	
5484 -5485	0	0	0	0	27.5	
5485 -5486	0	0	0	0	27.5	
5486 -5487	6	9.5	<.5,<.5	2	27.5	
5487 -5488	1.5	2.5	<.5,<.5	(2)	27.5	
5488 -5489	2	3.5	.5,UND	1(1)	27.5	
5489 -5490	4	7.5	UND	1	27.5	
5490 -5491	0	0	0	0	27.5	
5491 -5492	7	10	.5	1	28	
5492 -5493	.5	1	UND	(1)	28	
5493 -5494	0	0	0	0	28	33 KM TO H20 DEPTH, 55 M NO NEW SCOURS
				18 NEW SCOURS		



Survey Interval : 1979-84
Total Line Coverage: 3 km

SCOUR DEPTH DISTRIBUTION - TINGMIARK SOUTH



Survey Interval : 1981-84
Total Line Coverage: 6 km

SCOUR DEPTH DISTRIBUTION - TINGMIARK-NERLERK

AREA:KAGLULIK, AUG. 6/84 (1981-84)
SCALE: 150 M
LINE #11A

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
4515 -4516	1.5	2	UND	1	28	
4516 -4517	0	0	0	0	28	
4517 -4518	.5	1	.5	(1)	28	SAME AS 11AW 4889-4990
4518 -4519	1.5	2.5	.5	1	28	SAME AS 11AW 4989-4990
4519 -4520	0	0	0	0	28	
4520 -4521	8	12	1	1	28	
4521 -4522	0	0	0	0	28	
4522 -4523	0	0	0	0	28	
4523 -4524	0	0	0	0	28	
4524 -4525	8	14	UND,<.5	2	28	SAME AS 11AW 4983-4984
4525 -4526	1.5	2	UND,UND	1(1)	28	SAME AS 11AW 4981-4983
4526 -4527	0	0	0	0	28	
4527 -4528	0	0	0	0	28	
4528 -4529	0	0	0	0	28	
4529 -4530	0	0	0	0	28	
4530 -4531	0	0	0	0	28	
4531 -4532	0	0	0	0	28	
4532 -4533	0	0	0	0	28	
4533 -4534	0	0	0	0	29	
4534 -4535	0	0	0	0	29.5	
4535 -4536	0	0	0	0	30	
4536 -4537	0	0	0	0	30	
4537 -4538	1.5	2.5	1	1	30	SAME AS 11AW 4970-4971
4538 -4539	0	0	0	0	30	
4539 -4540	0	0	0	0	30	
4540 -4541	0	0	0	0	30	
4541 -4542	0	0	0	0	30.5	
4542 -4543	0	0	0	0	30.5	
4543 -4544	0	0	0	0	30.5	
4544 -4545	0	0	0	0	31	
4545 -4546	0	0	0	0	31	
4546 -4547	0	0	0	0	31	
4547 -4548	3	5	1	1	31.5	SAME AS 11AW 4959-4960
4548 -4549	2	3	1	(1)	31.5	
4549 -4550	0	0	0	0	31.5	
4550 -4551	0	0	0	0	31.5	27.5 KM OF NO NEW SCOUR TO DEPTH 44 M

8 NEW SCOURS

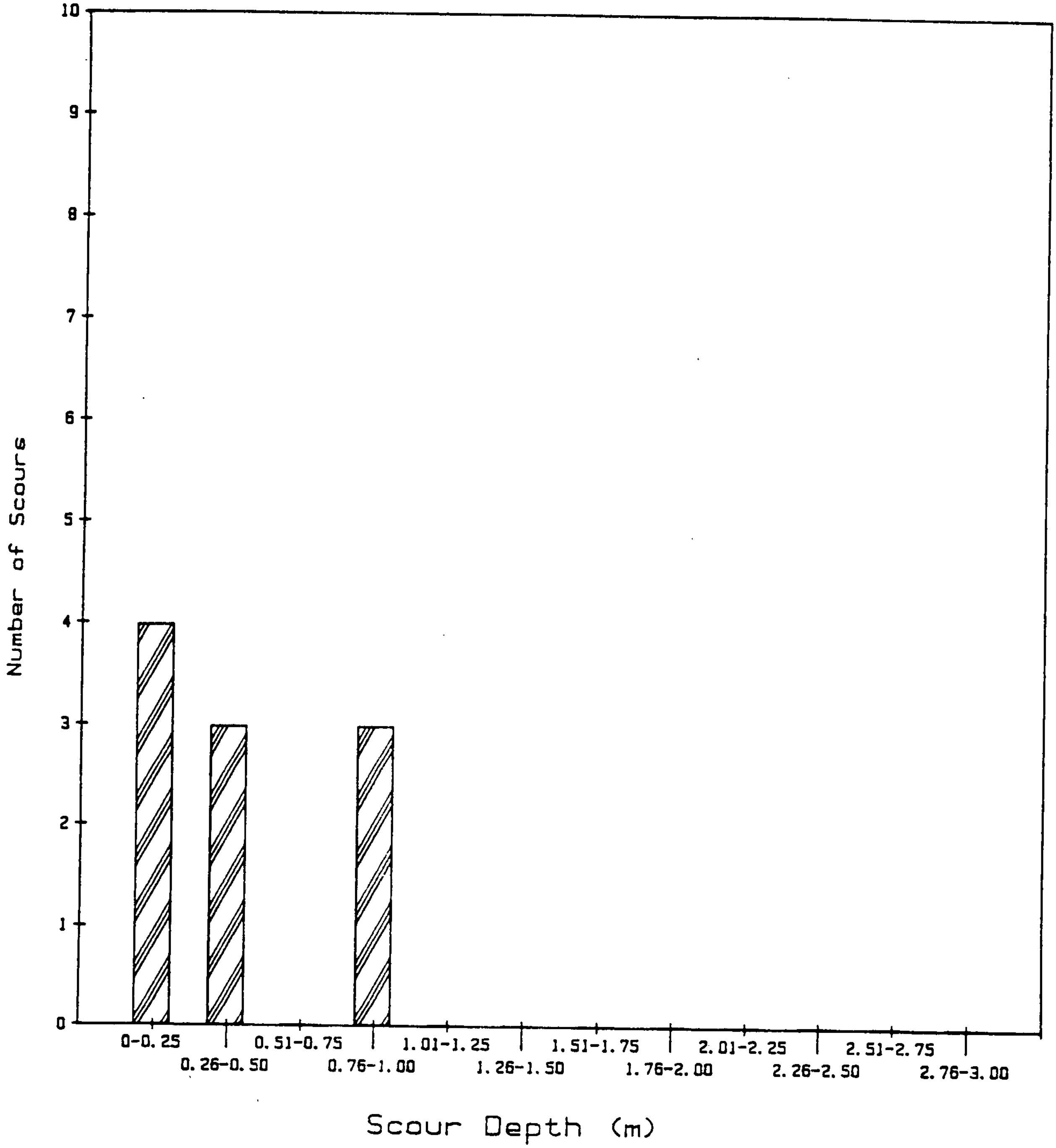
AREA: KAGLULIK, AUG. 7/84 (1981-84)
SCALE: 150 M
LINE #11AW

RESCOURED ANALYSIS

THIS LINE 11 TO 11A 250 M

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
						27.5 KM NO NEW
4958 -4959	0	0	0	0	31	SCOURS
4959 -4960	1.5	2	UND	1	31	SAME AS 11A
4960 -4961	0	0	0	0	31	4548-4550
4961 -4962	0	0	0	0	31	
4962 -4963	0	0	0	0	31	
4963 -4964	0	0	0	0	31	
4964 -4965	0	0	0	0	30.5	
4965 -4966	0	0	0	0	30.5	
4966 -4967	0	0	0	0	30.5	
4967 -4968	0	0	0	0	30.5	
4968 -4969	0	0	0	0	30.5	
4969 -4970	0	0	0	0	30	
4970 -4971	2.5	4.5	<.5	1	30	SAME AS 11A
4971 -4972	0	0	0	0	30	4537-4538
4972 -4973	NO RECORD					
4975 -4976	0	0	0	0	28	
4976 -4977	0	0	0	0	28	
4977 -4978	0	0	0	0	28	
4978 -4979	0	0	0	0	28	
4979 -4980	0	0	0	0	28	
4980 -4981	0	0	0	0	28	
4981 -4982	.5	1.5	UND	1	28	SAME AS 11A
						4524-4526
4982 -4983	.5	.5	UND	(1)	28	4524-4526
4983 -4984	6	13	.5	1	28	4524-4525
4984 -4985	0	0	0	0	28	
4985 -4986	0	0	0	0	28	
4986 -4987	1.5	3	UND	(1)	28	
4987 -4988	2	4	UND	1	28	SAME AS 11A
						4520-4521
4988 -4989	0	0	0	0	28	
4989 -4990	3	5	<.5	1	28	SAME AS 11A
						4518-4519
4990 -4991	0	0	0	0	28	
4991 -4992	0	0	0	0	28	
4992 -4993	2	3	<.5	1	28	SAME AS 11A
						4515-4516
4993 -4994	2.5	3.5	<.5	(1)	28	
4994 -4995	0	0	0	0	27.5	
4995 -4996	0	0	0	0	27.5	
4996 -4997	0	0	0	0	27.5	
4997 -4998	0	0	0	0	27.5	
4998 -4999	0	0	0	0	27	
4999 -5000	0	0	0	0	27	
5000 -5001	0	0	0	0	27	

7 NEW SCOURS



Survey Interval : 1981-84
Total Line Coverage : 15 km

SCOUR DEPTH DISTRIBUTION - KAGLULIK

AREA: TARSIUT-NEKTORALIK
SCALE: 150 M

RESCOURED ANALYSIS

LINE TARSIUT-NEKTORALIK

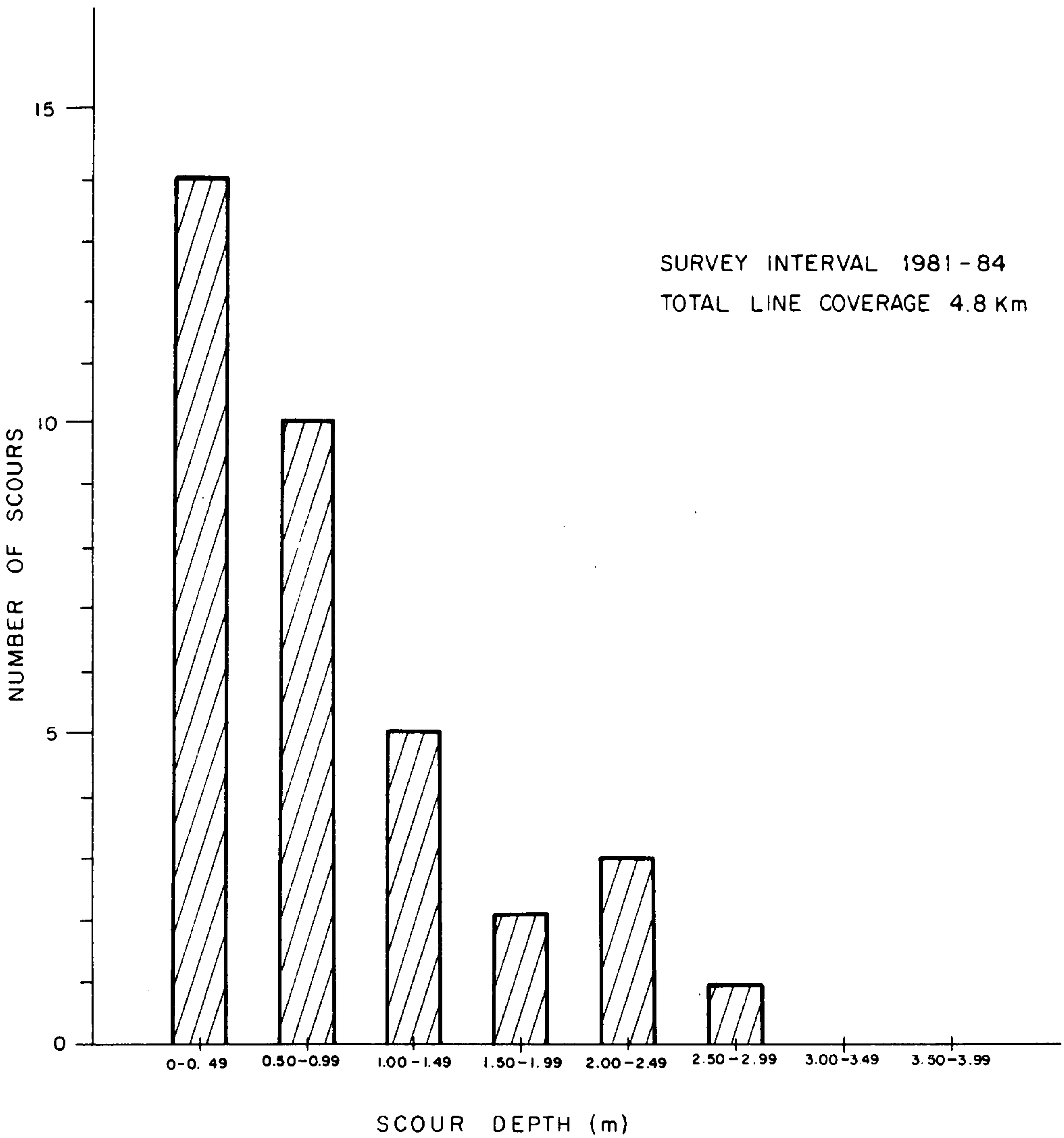
FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
6586 -6606	0	0	0	0		ABOUT 30 KM FURTHER NORTH OF NO NEW SCOUR 28-30.5 4 KM
6606 -6607	4	8	.5	1	28	
6607 -6608	0	0	0	0	28	
6608 -6609	0	0	0	0	27.5	
6609 -6610	0	0	0	0	27.5	
6610 -6611	0	0	0	0	27	
6611 -6612	0	0	0	0	27	
6612 -6613	0	0	0	0	26.5	
6613 -6614	0	0	0	0	26.5	
6614 -6615	0	0	0	0	26.5	
6615 -6616	0	0	0	0	26	
6616 -6617	0	0	0	0	26	
6617 -6618	22	28	3	1	26	
6618 -6619	13	20	2,1	1(1)	25.5	
6619 -6620	10	13.5	1,UND	1(1)	25.5	
6620 -6621	17	24	<.5,<.5, .5,1	4	25	
6621 -6622	12	19	UND,1,2	2(1)	25	
6622 -6623	1	1.5	UND	(1)	24.5	
6623 -6624	12	20	<.5,<.5,1.5	3	24.5	
6624 -6625	12	19.5	1.5,<.5,<.5	2(1)	24.5	
6625 -6626	9	14.5	<.5,.5,1	3(1)	24	
6626 -6627	30	40	1,1.5, 1.5,<.5	2(1)(1)	24	
6627 -6628	31	42	.5,.5,1.5,.5	4	24	
6628 -6629	12	19	.5,UND,1, UND	2(1)(1)	24	
6629 -6630	5	9	UND,UND	(2)	23.5	
6630 -6631	9	18	2,UND,UND	2(1)	23.5	
6631 -6632	10	20	2,UND	1(1)	23.5	
6632 -6633	6	11.5	UND,UND, .5,1	3(1)(1)	23	
6633 -6634	9	18	<.5,1, UND,UND	2(1)(1)	23	
6634 -6635	4	8	UND,UND, UND,UND	1(1)(1)(1)	22.5	
6635 -6636	18	26	.5,1,1	3	22.5	
6636 -6637	16	22.5	1,UND,UND	1(2)	22.5	
6637 -6638	7	10	1.5,.5	2	22	END OF LINE
6638 -6639	7	11	UND	(1)	22	
6639 -6650	0	0	0	0	20.5-22	NOT EXAMINED

40 NEW SCOURS

AREA: TARSIUT-NEKTORALIK (1981 - 84)
SCALE
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED	SCOUR DEPTH	# SCOURS	WATER DEPTH	REMARKS
9441 -9442	0	0	0	0	SAME AS FIX 6589-6588
9442 -9443	0	0	0	0	
9443 -9444	15	1-1.5	1	31	NEW SCOUR 83-84
9444 -9445	5				SAME SCOUR
9445 -9446	90	1.5-2	1	31	NEW 81-83 MK
9446 -9447	40				SAME SCOUR
9447 -9448	0	0	0	0	NO NEW SCOURS
9454 -9455	0	0	0	0	NO NEW SCOURS
9455 -9456	10	1.5-2	1	31.5	NEW 81-83
9456 -9457	0	0	0	0	NO NEW SCOURS
9460 -9461					
9461 -9462	5	<.5	1	32	NEW 81-83



NEW SCOUR DEPTH DISTRIBUTION
– TARSIUT-NEKTORALIK (22-26 m)

AREA: PULLEN ISLAND (1978-84)
SCALE
LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
2748 -2749	4	6.5	<.25,<.25	4		TWO SCOURS ARE PARALLEL
2749 -2750	2	3.1	<.25	(3)(1)		
2750 -2751	6	11	3X.25,1<.25	5(1)		THREE PARALLEL SCOURS
2751 -2752	5	9	UND	1(2)1		TWO PARALLEL SCOURS
2752 -2753	12	20	4X<.25	7(3)(2)		
2753 -2754	17	30	1<.25,4XUND	4(2)		
2754 -2755	3	5	2<.25	1(2)		
2755 -2756	7	12	UND	1(2)1		
2756 -2757	8	17	4X<.25	2(1)1		
2757 -2758	5	8	UND	2(1)(1)		
2758 -2759	3	5	UND	2(2)(1)		
2759 -2760	7	12	3X<.25	7		
2760 -2761	7	12	1UND,1<.25	2(3)		
2761 -2762	5	8	2X<.25,1UND	3(2)		
2762 -2763	18	30	1X.5,3<.25	4(1)(1)		
2763 -2764	7	13	2X<.25	1(1)1		
2764 -2765	2	4	UND	2(1)		
2765 -2766	<.5	1	UND	(1)		
2766 -2767	4	7	1UND,3X<.25	4		
2767 -2768	18	30	3X<.25,3X.5	6(2)		
2768 -2769	14	23	1X.3	2(2)(3)		
2769 -2770	15	24	4X<.25	2(3)(1)		
2770 -2771	14	23	1X.3,1<.25	2(2)		
2771 -2772	6	10	1<.25,1X.5	1,1(1)		
2772 -2773	13	22	1UND,1X.5	1(1)		
2773 -2774	5	9	3X2.3	3(1)(1)		
2774 -2775						INCOMPLETE RECORDING
2775 -2776		IMAGE UNRECORDED				
2776 -2777		"				
2777 -2778	9	15	3X<.25	1(2)(3)		1 SET OF 2 & 1 SET OF 3 PARALLEL SCOURS
2778 -2779	10	17	2X.5,2UND	4(3)(2)		SET OF 3 PARALLEL SCOURS CUT INTO THIS INTERVAL
2779 -2780	5	8	3X.3,3UND	6(1)		
2780 -2781	6	9	1X1.5,5UND	6(1)(1)		
2781 -2782	14	24	2X.25,2UND	4(1)		
2782 -2783	12	28	1			
2783 -2784	14	24	<.25			
2784 -2785	12.8	21	.5,.5	23(2)(2)(2)		
2785 -2786		29	.25,.5			
2786 -2787	21	24.5	.25,<.25			

2787 -2788		6.9	<.25		
2788 -2789		41.3	<.25		
2789 -2790		85	.5	12(2)	V WIDE SCOUR
2790 -2791		93	.5		FROM 2789-2791
2791 -2792		4.3			
2792 -2793	11.4	19.6	.5,.5		
2793 -2794	16	24	<.25,<.25	12(2)	
2794 -2795		18			
2795 -2796		1.9			
2796 -2797					
2797 -2802	?				

AREA: PULLEN ISLAND (1978-84)
SCALE
LINE

RESCOURED ANALYSIS
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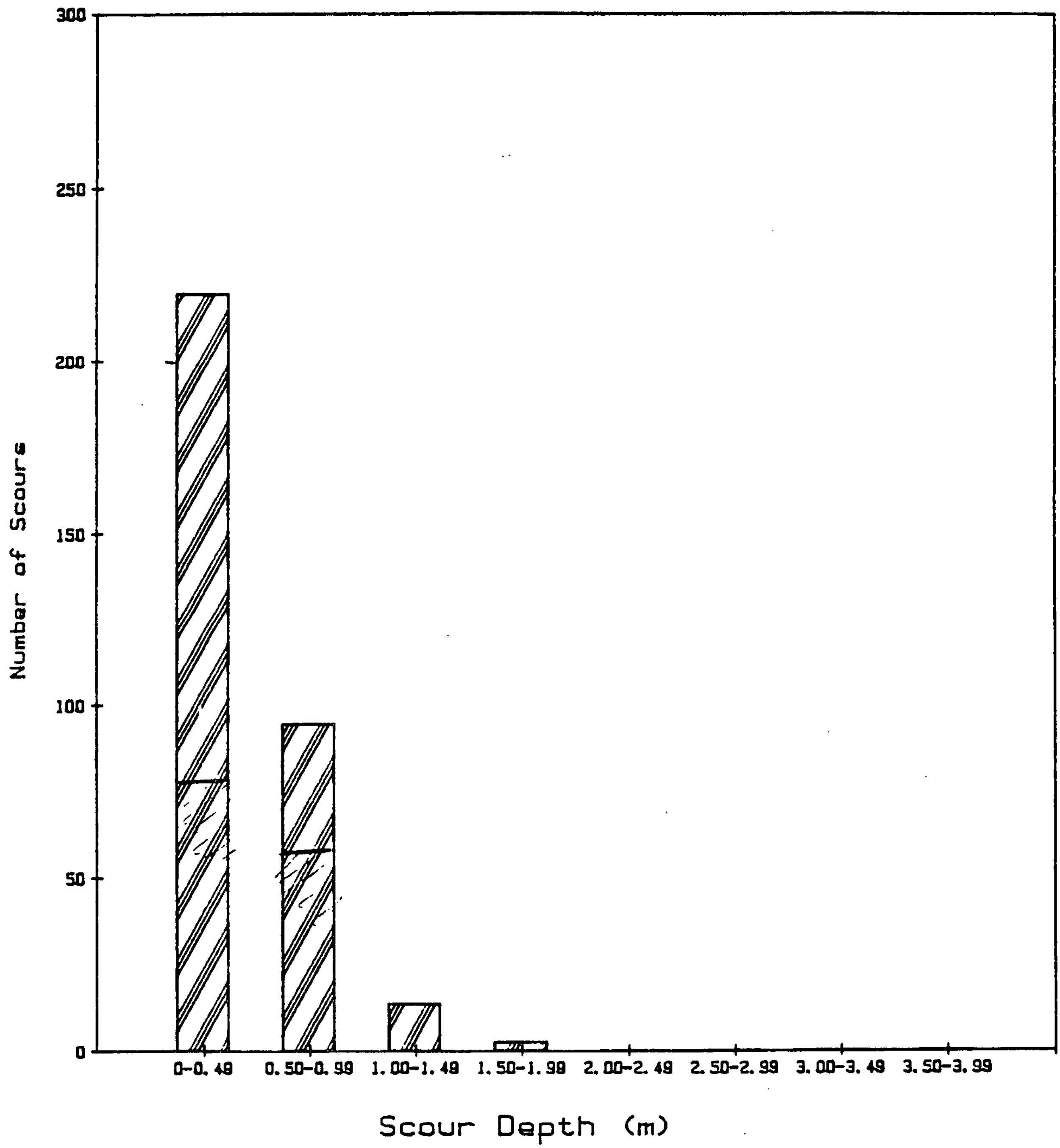
FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
2914 -2915		9.2	<1,1,.5			
2915 -2916		16.1	>.75,1.2 5,1,1.5	18(2)		
2916 -2917		22.4	1.5,.5			
2917 -2918		4.3	.5			
2918 -2919		20.7	<.5,<1,.5,1	______		
2919 -2920		23	<1,1,.5			
2920 -2921		28	<.5,.5,>.5			
2921 -2922		33.7	.5,1,.5, 1,.5,.5	27(12)(2)		
2922 -2923		21.4	<.5,.5,.5,.5			
2923 -2924		5.8	<.25,<1,.5,.75	______		
2924 -2925		7	.5			
2925 -2926		7	.5,.5			
2926 -2927		9.3	.5,.25,.75			
2927 -2928		31	.25,.5,.25,<.5			
2928 -2929		22.4	.5,.5,.5, <.5,.25	21(2)(2) ______		
2929 -2930		7.9	.25,.5,.25			
2930 -2931		33.4	>.5,<.5			
2931 -2932		20.5	.5,.25,.5,.25			
2932 -2933		4.6	.25,.25	17(2)(2)		
2933 -2934		23	.25(2)	______		
2934 -2935		19.2	>.5			
2935 -2936		4.6	.5	17(2)(2)		
2936 -2937		10	<.25,.25,.5,>.5			
2937 -2938		17.7	(.5,.5),.5			
2938 -2939		15.2	.5,.25,.25,(<1,1,.75)(.5,.5).25			
2939 -2940		14.7		______		
2940 -2941		5.5	.5	16(3)(2)(2)(2)		
2941 -2942		9.8	.25			
2942 -2943						
2943 -2944		10.4	<.5	______		
2944 -2945		10	.5			
2945 -2946		9.3	<.5			
2946 -2947		3.7	<.5,<.5	8(2)		
2947 -2948						
2948 -2949				______		
2949 -2950		1.2				
2950 -2951		11.6	.5,<.5			
2951 -2952		10	.5,.5	13(2)		
2952 -2953		10	.5			
2953 -2954		29.5	.5,.5,<.	______		
2954 -2955		2.1	<.25			
2955 -2956		19.2	.5,.5,<.5	6(2)		
2956 -2957		9.1				
2957 -2958						
2958 -2959		19	.75,>.5	______		

2959 -2960	16.5	.5,.75,.75,.5
2960 -2961	27.2	<.25,<.5
2961 -2962	22.5	1,>.5 25[(2)X4]
2962 -2963	26	<.5,<.5,>.5
2963 -2964	18.7	<.5,.5,.5
2964 -2965	22	<.5,<.5
2965 -2966	16.1	<.5,<.5,.5 22(2)(2)(3)(2)
2966 -2967	13.1	.5,<.5,<.5
2967 -2968	28.8	.5,.5,>.5
2968 -2969	20.3	<.25,>1,1

SCALE LINE

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
2802 -2803	8.4	12.1	<.25,<.25			
2803 -2804	20	25	<1,.75,.5,<.25			
2804 -2805		12	.25,<.5	20		
2805 -2806	11	15.9	.25,<.5,.25,<.25			
2806 -2807		8.8	.25			
2807 -2808		19.5	.5,.5,<. 5			
2808 -2809		14.5	<.25,.25 .25	32(2)(2)(2)(2)(3) (2)		
2809 -2810		11.5	<.25,<.25,<1			
2810 -2811		17	<.25			
2811 -2812		10		-		
2812 -2813		21.9	<.25,<.25,.5			
2813 -2814		17.7	.25,<.5	44(2)(2)		
2814 -2815	16.7	19.6	<.5			
2815 -2816		41	<.25			
2816 -2817		14.6	<.5,.25,<.25	-		
2817 -2818	7.3	8.8				
2818 -2819	10	15	.25,<.5,<.25			
2819 -2820	22.4	25.5	<.25	31(2)(2)(2)		
2820 -2821	11	14	<.25,<.5,>.5			
2821 -2822	12.6	17	>.5,>.5,.25	-		
2822 -2823		17	<.25,<.25			
2823 -2824	12.8	14	<.25,.5,.5			
2824 -2825	13	15	<.5,<.25	29(3or4)		
2825 -2826		7	<.25,<.25			
2826 -2827	23	28	.5,<.25,<.5	-		
2827 -2828	23	26				
2828 -2829		21	<.5,<.25	30(2)(4)(2)		
2829 -2830	28	32.4	<.25,<.25			
2830 -2831	9.2	14.6	<.5,.75			
2831 -2832	39.8	46	<.25,<.25,<.25,<.5			
2832 -2833	27.3	39.3	.5,.5,.5 .25,<.5	-		
2833 -2834	6.6	10.6	.25,.75	17(2)(2)(2)(3)		
2834 -2835	6.9	8.6	<.25,.25			
2835 -2836	22.4	31.2	(<.5,<.5,<.5)			*LEFT 1 SCOUR
2836 -2837	5.5	11.8	<1	-		THAT WAS MARKED
2837 -2838	12.2	22	.5,.5,<.5,<.25			C BLACK MARKER
2838 -2839		7.2	.25,.25	17(4)(3)		
2839 -2840	13.5	18.8	.5,.5			
2840 -2841		1.2				
2841 -2842				-		
2842 -2843		2.3				
2843 -2844	19.7	27	<.5,.25,.25			
2844 -2845	18.3	25.5	<.25,<.25	21(2)(2)(2)		
2845 -2846	20.8	24.6	>.5,.25,.25,.5			
2846 -2847	11.2	13.6	<.5,<.25,.5	-		
2847 -2848		5.2				
2848 -2849	12.6	18.8	<.25,.5	9(2)		
2849 -2850		4.5	<.5,<.5			
2850 -2851						
2851 -2852				-		
2852 -2853						
2853 -2854				9(2)(2)		
2854 -2855		11.5				
2855 -2856	36	44	.5,.25			
2856 -2857	8.2	16.4	<.25,<.25,<.5			



Survey Interval : 1978-84
Total Line coverage: 36 km

FIGURE NEW SCOUR DEPTH DISTRIBUTION - PULLEN

AREA:
SCALE: 100 M
LINE 5CA

RESCOURED ANALYSIS

FIX INTERVAL	% RESCOURED % INCISED	% DISTURBED	SCOUR DEPTH	# NEW SCOURS	WATER DEPTH	REMARKS
2531 -2532	0	0	0	0	25	
2532 -2533	0	0	0	0	25	
2533 -2534	0	0	0	0	25	
2534 -2535	0	0	0	0	25.5	
2535 -2536	0	0	0	0	25.5	
2536 -2537	7.5	10	UND	1	25.5	
2537 -2538	0	0	0	0	25.5	
2538 -2539	0	0	0	0	25.5	
2539 -2540	5	8	.5	1	25.5	
2540 -2541	10	18	1	1	25.5	
2541 -2542	4	7.5	<.5,<.5	2	25.5	THIS IS ONLY
2542 -2543	45	53	.5,UND	1(1) 2	25.5	COVERAGE OBTAIN
2543 -2544	19	25	.5,UND	1(1) 2	26	NO EXTRA KM
2544 -2545	40	60	.5	1 2	26	WITH NO SCOURS
2545 -2546	4	7	UND	(1) 7	26	
2546 -2547	0	0	0	0	26	
2547 -2548	0	0	0	0	26	
2548 -2549	10	14	1,.5	2	26	
2549 -2550	0	0	0	0	26	
2550 -2551	0	0	0	0	26	
2551 -2552	3	4.5	<.5	1	26	
2552 -2553	0	0	0	0	26	
2553 -2554	0	0	0	0	26	
2554 -2555	0	0	0	0	26	

11 NEW SCOURS