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1990 BEAUFORT SEA ICE SCOUR REPETITIVE MAPPING PROGRAM

VOLUME 1

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FRONTISPIECE

GROUNDED MULTI-YEAR PRESSURE RIDGE FRAGMENT, PHOTOGRAPHED IN 1972 NEAR THE AMAULIGAK SITE IN 30 METRES WATER DEPTH
(After Shearer and Blasco, 1975).

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Susan Queen of CSR conducted many of the measurements on new scour events identified during the ESRF 1990 data. Patrick Campbell, Nick Deagle and Ken Miller of CSR are acknowledged for their contributions in updating the digital data bases and conducting GIS analysis. Finally, the authors would like to thank Elizabeth Hare of CSR, whose design and CAD capabilities greatly enhanced the final report.

STATEMENT OF ACCESS

Copies of the digital data, processing software, and impact rate maps may be obtained from Canadian Seabed Research Ltd., in Halifax. For further information, interested parties should contact Mr. Glen Gilbert at (902) 827-4200.

EXECUTIVE SUMMARY

Canadian Seabed Research Ltd. (CSR) was awarded a contract by the Environmental Studies Research Funds (ESRF) in 1990, to conduct an extensive repetitive mapping and scour tracking program in the Beaufort Sea, and to update the Beaufort Sea New Scour Database (NEWBASE) with all new scour events identified between 1986 (last published update of NEWBASE) and the ESRF 1990 survey. The ultimate goal of the repetitive mapping program is to provide sufficient information on present day ice scour dynamics to effectively constrain the design of sub-sea installations in the Beaufort Sea.

Approximately 1390 line kilometres of sidescan sonar, microprofiler, echo sounder and 3.5/7.0 kHz sub-bottom profiler data were collected along repetitive mapping corridors during the ESRF 1990 survey. A total of 2291 new scour events, formed during the previous one to eight years (i.e. range of re-survey time intervals), were identified on geophysical data collected along these corridors. Most of the new scours recorded are less than 1.0 metres deep. Approximately 3% (n=72) of the new events identified on the ESRF 1990 records have scour depths of 2.0 metres or greater.

The Beaufort Sea New Scour Database (NEWBASE) has been updated to 1990, and now includes all new scours identified through repetitive mapping surveys conducted since 1978. Scour depth, width, length, orientation, water depth, and scour location are among some of the key scour parameters included with each new scour record in NEWBASE. New scour events added to the database since the 1986 update were recorded during the following surveys; the ESRF 1990 survey (2291 new events), the Nahidik 1989 survey (783 new events), and the Tully 1988 survey (1373 new events). An associated database of survey positioning information (NNAVBASE) has also been updated, and includes all repetitive surveys conducted between 1978 and 1990. Appendix 1 provides a complete listing and description of the data fields in NEWBASE and NNAVBASE.

NEWBASE now contains detailed measurements for 5329 geographically-referenced new scour events. This represents a substantial new scour population which can be utilized for statistical and spatial analyses using a GIS-platform, such as, CSR's ARC/INFO based Scour Information Processing System (SIPS).

A preliminary exploration of the updated version of NEWBASE (n=5329) was conducted to provide an overview of new scour characteristics. Some of the highlights are as follows:

- New scour events recorded in NEWBASE occur in water depths ranging from 2 to 38 metres. Most of the new scours were observed in water depths of 6 to 30 metres. Only 2% of new scour events were recorded in water depths of 30 metres or greater.
- Average and maximum recorded scour depths are 0.57 metres and 4.0 metres, respectively. In water depths of less than 18 metres, more than 90% of the

scour population have scour depths of less than 1.0 metres. In water depths ranging from 18 to 32 metres, 20% to 40% of the scours (within any given 1.0 metre bathymetric interval) have scour depths of 1.0 metres or greater. The increase in the number of deeper scours in water depths greater than 18 metres may reflect the influence of multi-year ice scouring beyond the landfast ice edge.

- A total of 122 extreme new scours, defined as scours with depths of 2.0 metres or greater, have been identified to date. Extreme scours account for approximately 2.3% of the entire new scour population. No extreme scour events were recorded in water depths of less than 13 metres. Five extreme scours occur in water depths ranging between 13 to 17 metres. Approximately 96% of extreme scours occur in water depths greater than 17 metres.

- Scour width measurements range from 1 to 1281 metres, with an average width of 30.9 metres. Average and median scour width values increase slightly with increasing water depth. This increase in scour width is primarily due to a significant increase in number of multi-keeled scours in deeper water depths.

- The distribution of scour orientation measurements contains a strong preferential east-southeast component which is consistent with predominant ice movement direction.

- New scour events with the same or similar orientations often occur in clusters. This suggests that numerous scours may be formed during a single scouring event. Although most scour clusters are dominated by scours less than 0.5 metres deep, pairs and small groups of extreme scour events (depths of 2.0 metres or greater) are also apparent.

A series of maps, demonstrating the analytical capabilities of the SIPS GIS-platform, illustrate regional and local variations in scour distribution and new scour impact rates. New scour impact rate maps, calculated for survey line segments crossing 1.0 metre bathymetric intervals, are included for the Tully 1988, Nahidik 1989, and ESRF 1990 surveys. Local variations in impact rates, reflecting the episodic nature of the scouring process, are commonly observed along survey lines in which only one or two years have elapsed since the previous survey. Such variations are less apparent along corridors where four or more years have elapsed since the previous survey was conducted. Regionally, the rate of new scour impacts is related to water depth. For the ESRF 1990 survey, the highest impact rates generally occur on the Kringalik Plateau and Akpak Plateau, in water depths of 6 to 25 metres. New scour impact rates in this area are generally greater than 1.0 scours/km/yr and commonly exceed 2.0 scours/km/yr. The maximum new scour impact rate, calculated for a line segment greater than 0.5 km long, is 6.42 scours/km/yr. This is for a line segment crossing the steeply-sloping eastern edge of Kugmallit Channel in 28 to 29 metres water depth.

Scours with extreme depths pose the greatest hazard to buried sub-sea installations. Impact rates calculated for extreme scours recorded during the ESRF 1990 survey (scour depth 2.0 metres or greater) are generally less than 0.01 scours/km/yr. These low rates reflect the paucity of extreme scour events, especially in water depths less than 17 metres. Even in the deeper water areas with the greatest concentration of extreme scours, impact rates seldom exceed 1.0 scours/km/yr. The maximum observed impact rate for extreme new scours recorded during the ESRF 1990 survey is 2.02 scours/km/yr for a line segment crossing the 20 to 21 metre water depth interval on the Kringalik Plateau. Similar impact rate analysis, conducted with sub-sets of the new scour database at pre-determined minimum scour depth cut-offs, could be used to model scour impact potential for sub-sea installations at various burial depths.

Scour rise-up panels and scour parameter tables, documenting changes in key scour parameters along the length of each scour, are presented for seven extreme scours surveyed in detail during the ESRF 1990 and Nahidik 1989 surveys. The age of the tracked scours, at the time of the 1990 survey, ranged from one year (Scour N90-5) to an estimated 215 years (Scour N90-2). Key scour parameters recorded at each cross-over of the scours, include; scour depth, scour rise-up (elevation), scour width, incision width, berm dimensions, and sediment infill. Scour rise-up observations fall within the three-stage scouring model originally developed during the 1984 ESRF scour tracking study. In Stage 1, the base of the scour remains at a constant elevation, and scour depth increases gradually as the ice keel scours into shallower water depths. During Stage 2 (a typically short-lived transitional period of rise-up), the scour base elevation begins to rise-up, but at a rate less than the decrease in water depths. As a result, scour depth increases gradually as the ice keel continues to scour upslope. During Stage 3 scouring, the scour base elevation and seabed elevation rise-up at approximately the same rate, and the scour depth remains relatively constant. Local variations in rise-up elevations observed during Stage 3, including periods of slight drop-down of the scour base elevation, are related to local changes in the near-seabed sediment type. A maximum total scour rise-up, of 8.2 metres, was observed along the length of Scour N90-2, a 50.5 km long scour. The maximum scour depth within each stage of scouring is a function of the physical properties of the seabed sediments, the size of the ice ridge, the geometry of the ice keel, and the driving force. Scour depths within Stage 1 exceed 5.0 metres for three of the seven tracked scours, with a maximum depth of 6.8 metres observed along Scour N90-2. Maximum scour depths 7.1 metres and 8.5 metres were observed along Stage 2 and Stage 3 portions of Scour N90-2, respectively.

RÉSUMÉ

En 1990, le Fonds pour l'étude de l'environnement (FEE) a accordé à la Canadian Seabed Research Ltd. (CSR) un contrat visant l'exécution d'un programme complet de cartographie répétée et d'examen de l'affouillement par les glaces en mer de Beaufort ainsi que de mise à jour de la Base de données sur les nouveaux affouillements en mer de Beaufort (NEWBASE) d'après tous les nouveaux affouillements identifiés entre 1986 (dernière mise à jour publiée de la NEWBASE) et le relevé exécuté pour le FEE en 1990. L'objectif ultime du programme de cartographie répétée est de fournir suffisamment d'information sur la dynamique de l'affouillement contemporain par les glaces pour préciser efficacement les paramètres de conception d'installations sous-marines en mer de Beaufort.

Dans le cadre du relevé exécuté pour le FEE en 1990, on a recueilli des données au sonar à balayage latéral, au microprofileur, à l'échosondeur et au sondeur de sédiments à 3,5 et 7,0 kHz sur une distance approximative de 1390 kilomètres le long de corridors de cartographie répétée. On a identifié au total 2291 nouveaux affouillements qui sont survenus au cours des une à huit dernières années (selon l'intervalle entre deux relevés) d'après les données géophysiques recueillies le long de ces corridors. La plupart des nouveaux affouillements relevés sont d'une profondeur inférieure à 1,0 mètre. Approximativement 3 % (72) des nouveaux affouillements identifiés lors du relevé de 1990 présentent une profondeur de 2,0 mètres ou plus.

La Base de données sur les nouveaux affouillements en mer de Beaufort (NEWBASE) a été mise à jour d'après les données de 1990 et comprend maintenant tous les nouveaux affouillements identifiés lors de relevés de cartographie répétée exécutés depuis 1978. La profondeur d'affouillement, la largeur, la longueur et l'orientation des traces ainsi que leur position et la profondeur l'eau comptent parmi les paramètres fondamentaux de chacun des nouveaux enregistrements de la NEWBASE. Les nouveaux affouillements ajoutés à la base de données depuis la mise à jour de 1986 ont été enregistrés lors des relevés suivants : relevé de 1990 pour le FEE (2291 nouveaux événements), relevé Nahidik de 1989 FEE (783 nouveaux événements) et relevé Tully de 1988 (1373 nouveaux événements). Une base de données associée sur l'information de positionnement des relevés (NNAVBASE) a également été mise à jour et comprend tous les relevés répétés exécutés entre 1978 et 1990. Une liste complète et une description des champs de données de la NEWBASE et de la NAVVBASE figurent à l'appendice 1.

La NEWBASE renferme maintenant des mesures détaillées de 5329 nouveaux affouillements géoréférencés. Cela représente une substantielle population d'affouillements qui peut faire l'objet d'analyses statistiques et spatiales sur des plates-formes de SIG comme le Système de traitement de l'information sur les affouillements (*Scour Information Processing System* (SIPS)) sur ARC/INFO de la CSR.

Une exploration préliminaire de la version mise à jour de la NEWBASE (n = 5329) a été effectuée afin d'obtenir un aperçu des caractéristiques des nouveaux affouillements; certaines de ces caractéristiques importantes sont décrites ci-après.

- Les nouveaux affouillements enregistrés dans la NEWBASE se sont produits par des profondeurs de l'eau de 2 à 38 mètres. La plupart des nouveaux affouillements sont observés par des profondeurs de 6 à 30 mètres. Seulement 2 % des nouveaux affouillements ont été enregistrés par des profondeurs de 30 mètres ou plus.

- Les profondeurs moyenne et maximale des affouillements qui ont été enregistrées sont respectivement de 0,57 et 4,0 mètres. Par des profondeurs de l'eau inférieures à 18 mètres, plus de 90 % des affouillements présentent des profondeurs de moins de 1,0 mètre. Par des profondeurs de l'eau comprises entre 18 et 32 mètres, de 20 à 40 % des affouillements (compris à l'intérieur d'un intervalle bathymétrique de 1 mètre quelconque) présentent des profondeurs de 1,0 mètre ou plus. Le plus grand nombre d'affouillements plus profonds par des profondeurs de l'eau supérieures à 18 mètres pourrait refléter l'influence de l'affouillement par la glace de plusieurs années au delà de la limite de la banquise côtière.

- Au total, on a jusqu'à maintenant identifié 122 nouveaux cas d'affouillement extrême dont la profondeur est de 2,0 mètres ou plus. Les affouillements extrêmes représentent approximativement 2,3 % de la population totale de nouveaux affouillements. Aucun affouillement extrême n'a été relevé par une profondeur de l'eau inférieure à 13 mètres. Cinq cas d'affouillement extrême ont été enregistrés par des profondeurs de l'eau variant de 13 à 17 mètres. Approximativement 96 % des affouillements extrêmes se produisent par des profondeurs de l'eau supérieures à 17 mètres.

- La largeur des affouillements mesurés varie de 1 à 1281 mètres et leur largeur moyenne s'établit à 30,9 mètres. Les largeurs moyenne et médiane des affouillements augmentent légèrement en fonction d'une augmentation de la profondeur de l'eau. Cet accroissement de la largeur d'affouillement est principalement attribuable à une augmentation importante du nombre d'affouillements par de multiples quilles en eau plus profonde.

- La distribution des mesures de l'orientation des affouillements présente une tendance préférentielle suivant l'axe est-ouest qui est conforme à la direction prédominante du déplacement des glaces.

- Les nouveaux affouillements présentant des orientations identiques ou similaires se présentent souvent en groupes. Cela suggère que de nombreux affouillements peuvent survenir pendant un unique épisode d'affouillement. Bien que la plupart des groupes d'affouillements soient dominés par des traces d'une profondeur inférieure à 0,5 mètres, il existe également des paires ou des petits groupes d'affouillements extrêmes (profondeur de 2,0 mètres ou plus).

Une série de cartes, démontrant les possibilités d'analyse de la plate-forme de SIG SIPS, illustre les variations régionales et locales de la distribution des nouveaux affouillements et de la fréquence des collisions. Des cartes des fréquences des collisions produisant de nouveaux affouillements calculées pour des segments de lignes de relevés traversant des intervalles bathymétriques de 1,0 mètre sont présentées pour les relevés Tully de 1988, Nahidik de 1989 et du FEE de 1990. Des variations locales des fréquences des collisions, reflétant la nature épisodique du processus d'affouillement, sont couramment observées le long des lignes de relevé pour lesquelles il ne s'est écoulé qu'une ou deux années depuis le relevé précédent. De telles variations sont moins apparentes le long des corridors pour lesquels il s'est écoulé quatre ans ou plus depuis l'exécution du relevé précédent. À l'échelle régionale, la fréquence des collisions produisant de nouveaux affouillements est reliée à la profondeur de l'eau. Dans le cas du relevé du FEE de 1990, les fréquences de collision les plus élevées sont généralement observées sur les plateaux Kringalik et Akpak par des profondeurs de l'eau de 6 à 25 mètres. Les fréquences des collisions produisant de nouveaux affouillements dans cette région sont généralement supérieures à 1,0 affouillement/km/année et dépassent couramment 2,0 affouillements/km/année. La fréquence maximale calculée pour un segment de ligne d'une longueur supérieure à 0,5 km s'établit à 6,42 affouillements/km/année. Il s'agit d'un segment de ligne traversant la bordure très inclinée du chenal Kugmallit par une profondeur de l'eau de 28 à 29 mètres.

Les affouillements de profondeur extrême sont les plus dangereux pour les installations sous-marines enfouies. Les fréquences de collision calculées pour les affouillements extrêmes lors du relevé du FEE de 1990 (profondeur d'affouillement de 2,0 mètres ou plus) s'établissent généralement à moins de 0,01 affouillement/km/année. Ces faibles fréquences reflètent la rareté des affouillements extrêmes, surtout par des profondeurs de l'eau inférieures à 17 mètres. Même dans les régions aux eaux plus profondes présentant la plus grande concentration d'affouillements extrêmes, les fréquences de collision dépassent rarement 1,0 affouillement/km/année. La fréquence de collision maximale observée pour les nouveaux affouillements extrêmes dans le cadre du relevé du FEE de 1990 est de 2,02 affouillements/km/année le long d'un segment de ligne de relevé traversant l'intervalle de profondeur de 20 à 21 mètres sur le plateau Kringalik. Des analyses similaires de la fréquence de collision exécutées pour des sous-ensembles de la base de données sur les nouveaux affouillements à des valeurs de coupure prédéterminées de la profondeur minimale d'affouillement pourraient être utilisées pour modéliser les possibilités de collision de masses de glaces sur le fond marin pour des installations sous-marines enfouies à diverses profondeurs.

Des affichages de l'élévation du fond des traces des affouillements et des tableaux des paramètres d'affouillement documentant les changements de paramètres clés le long de chaque trace d'affouillement sont présentés pour sept affouillements extrêmes levés de manière détaillée dans le cadre du relevé du FEE de 1990 et du relevé Nahidik de 1989. Au moment du relevé de 1990, l'âge des affouillements levés variait de un an (affouillement N90-5) à un âge estimé à 250 ans (affouillement N90-2). Les paramètres clés des affouillement enregistrés en chaque recoupement des affouillements sont : la profondeur d'affouillement, l'élévation du fond de l'affouillement, la largeur de l'affouillement, la largeur d'incision, les dimension des bermes et le comblement par des sédiments. Les observations de l'élévation du fond des affouillements concordent avec le modèle de formation en trois phases à l'origine mis au point dans le cadre de l'étude de suivi d'affouillements du FEE de 1984. Pendant la première phase, le fond de la trace d'affouillement reste à une hauteur constante et la profondeur d'affouillement augmente progressivement à mesure que la quille de glace continue à affouiller le fond marin par des profondeurs moindres vers le haut de la pente. Pendant la deuxième phase (de manière caractéristique une période de transition de courte durée pendant laquelle il y a élévation du fond de la trace d'affouillement), le fond de la trace d'affouillement commence à s'élever, mais moins rapidement que diminue la profondeur de l'eau. La profondeur d'affouillement augmente par conséquent progressivement à mesure que la quille de glace continue à se déplacer vers le haut de la pente. Pendant la troisième phase, le fond de la trace d'affouillement et le fond marin s'élèvent approximativement au même rythme, ce qui fait que la profondeur d'affouillement reste relativement constante. Des variations locales de l'élévation du fond de la trace d'affouillement pendant la troisième phase, incluant des périodes de faible diminution de l'élévation du fond de la trace, sont reliées à des changements localisés du type de sédiments près du fond marin. Une élévation maximale totale de 8,2 mètres a été observée le long du fond de la trace d'affouillement N90-2 qui est d'une longueur de 50,5 km. La profondeur maximale d'affouillement pendant chacune des phases dépend des propriétés physiques des sédiments du fond marin, de la taille de la crête de glace, de la géométrie de la quille de glace et de la force d'entraînement. Les profondeurs d'affouillement pendant la première phase sont supérieures à 5,0 mètres dans le cas de trois des sept traces suivies et une profondeur d'affouillement maximale de 6,8 mètres a été relevée le long de l'affouillement N90-2. Des profondeurs d'affouillement maximales de 7,1 et 8,5 mètres ont respectivement été observées le long des phases 2 et 3 de l'affouillement N90-2.

1.0 INTRODUCTION AND OVERVIEW

1.1 INTRODUCTION

Ice scouring is the process, whereby, sea-ice ridges or icebergs contact the seabed forming long, linear gouges in the seafloor sediments. This scouring process has long been recognized as a potential threat to sub-sea engineering activities such as; pipeline or cable installations and the safe capping of wellheads on the seafloor.

Sidescan sonar records, such as that presented in Figure 1.1.1, are the testimony that ice scours can attain considerable dimensions. In addition, they are known to extend for 10's of kilometres and are thought to disturb the sub-scour sediments to depths greater than the visible depth of excavation. Figure 1.1.2 illustrates one example of disrupted acoustic stratigraphy forming a "halo" around the original scour perimeter (Comfort et al., 1990).

In Canada, ice scouring is well documented on the continental shelves of the Arctic Ocean and the Eastern seaboard, as far south as the Grand Banks of Newfoundland. Scouring is also recognized in many of the large inland lakes, embayments and in some of the larger river systems. Examples of Canadian offshore engineering projects that have studied the implications of ice scour on engineering design include; a proposed petroleum pipeline route in the Beaufort Sea, the Hibernia petroleum development in Newfoundland, high-voltage transmission cables in the Great Lakes, and the Strait Crossing project linking Prince Edward Island to the mainland across the Northumberland Strait.

The current project relates to the process of ice scour in the Canadian Beaufort Sea (Figure 1.1.3). Although the ice scour problem has been studied in that region since the early 1970's, many engineering questions still remain unanswered today. This prompted the Canadian Association of Petroleum Producers to rank ice scour as a significant constraint to pipeline engineering and petroleum development in the Canadian Beaufort Sea.

One major program that has been jointly funded by the Environmental Studies Research Funds (ESRF), the petroleum operators in the Beaufort Sea (especially; Gulf, Amoco and Esso), the Panel on Energy Research and Development (PERD), and the Geological Survey of Canada (GSC) is the repetitive ice scour mapping project. This program involves re-mapping a selected network of survey lines, as frequently as is possible, over a number of years. Through such repetitive surveys new scours can be identified, their dimensions catalogued, and their return frequencies quantified in regions of potential petroleum operations. Such knowledge is required in order to optimize cost-effective pipeline burial strategies in terms of safe and regulated, environmental engineering practices.

In 1990, the ESRF awarded a contract to Canadian Seabed Research Ltd. of Halifax to undertake a large repetitive mapping program in the Beaufort Sea. This program included; designing the survey network, carrying out the survey field work, identifying new scours on the geophysical records, and updating the data base of new scour events (NEWBASE; Gilbert et al., 1989). Upon completion of a very successful field program, it was evident that considerably more data had been collected than was previously expected. As this data would lead to more than double the predicted number of new scours being found, the GSC

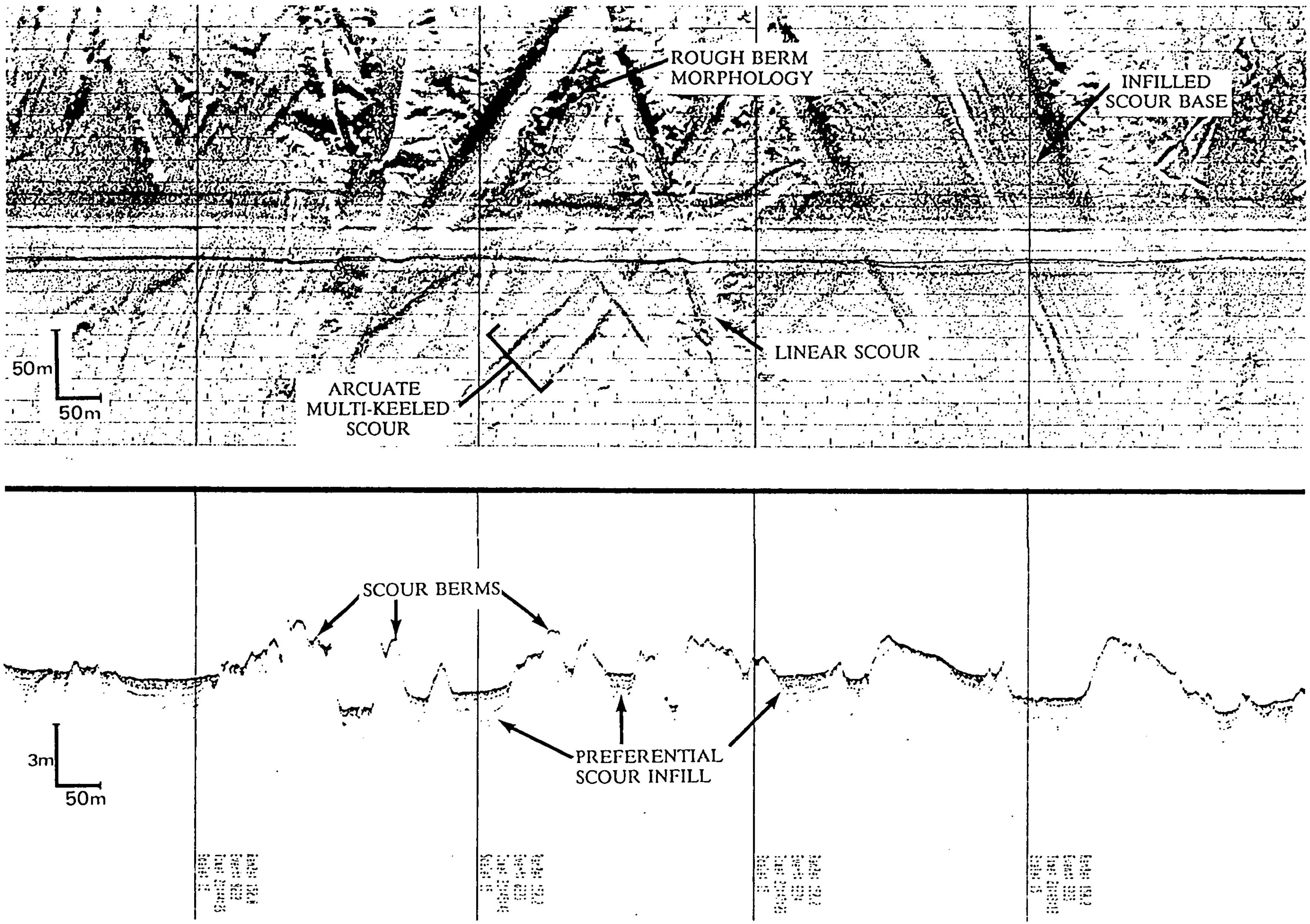


Figure 1.1.1 Combined sidescan and microprofiler record showing example of ice scouring.

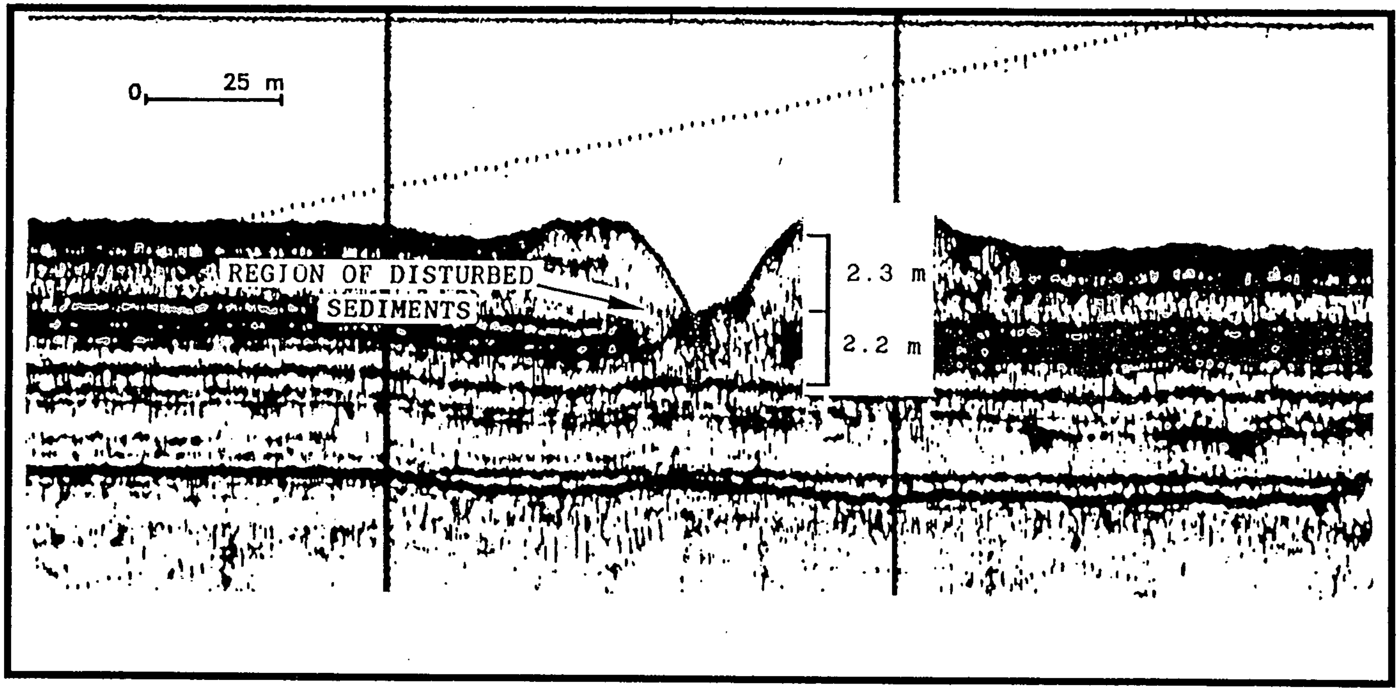


Figure 1.1.2 Sub-bottom profiler record showing an example of sub-scour acoustic disturbance.

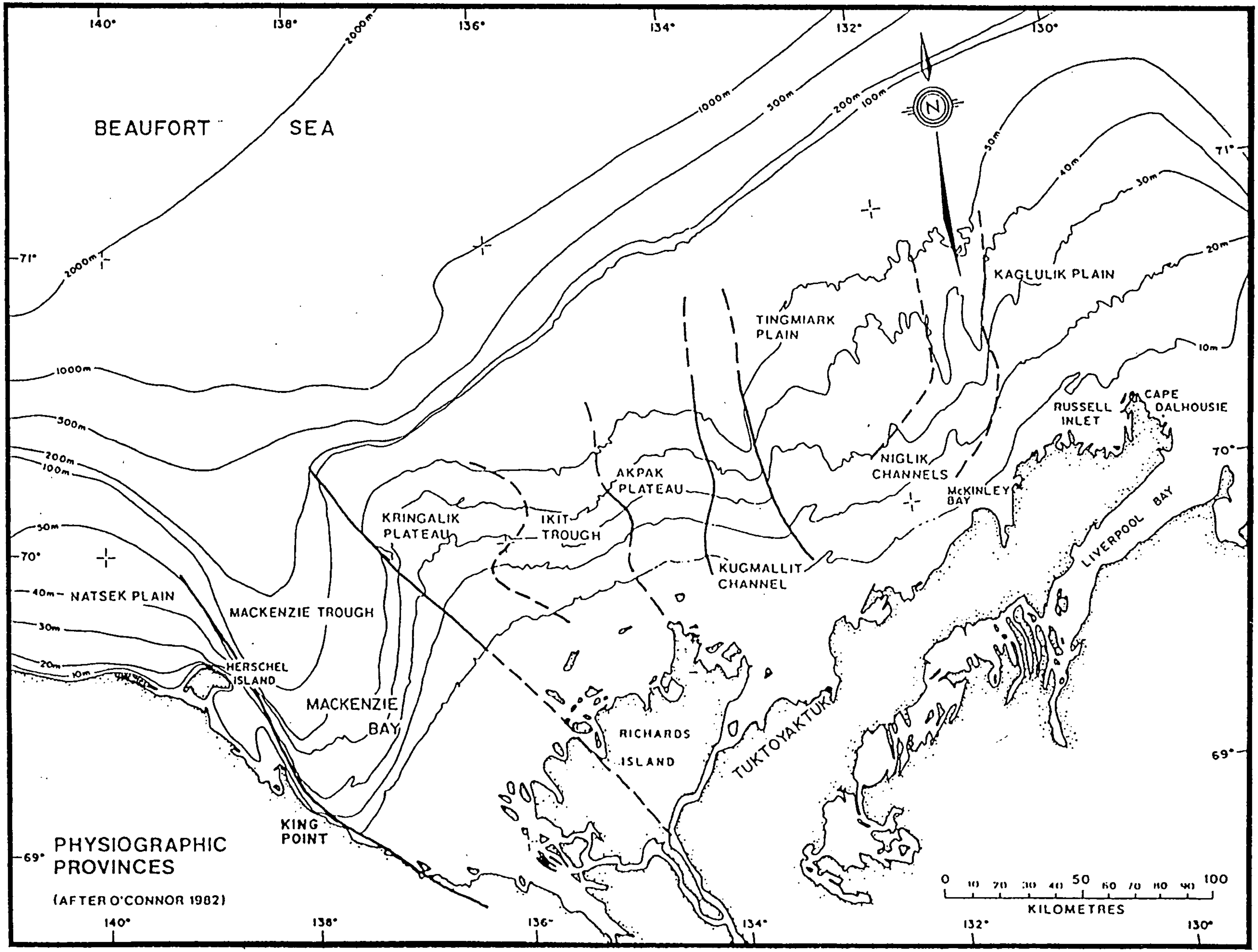


Figure 1.1.3 Location map showing physiographic regions of the Beaufort Sea.

helped fund the additional reduction and mapping of the project results.

This report presents the results of the 1990 ESRF Repetitive Ice Scour Mapping Program. The specific objectives of the program are noted as follows;

1.2 STUDY OBJECTIVES

- To design a new survey network that builds on the repetitive scour mapping corridors established in the Beaufort Sea, from 1984 to 1989. To organize and conduct the repetitive mapping field program, in the fall of 1990.

- To profile the Gulf Pipeline Route, extended to 50m water depths and to re-run two outer lines of the route to identify new scour events. Also to select extreme scours along the pipeline corridor for inclusion in the scour tracking portion of the project.

- To test and evaluate new digital survey technology, designed by CSR, for ice scour research. This technology includes; a Klein digital sidescan sonar configured with a narrow-beam, downward-looking, microprofiler for accurate scour depth measurement.

- To conduct special scour tracking operations to yield process-related information for unique scour features, such as, the deepest and longest scours in the Historical and the New Scour data base. To fully interpret these data in terms of dimensional analyses and scour rise-up processes.

- To review all the repetitive sonar data to identify, measure and data base all New Scours found on the 1990 data. To further, build a GIS system and illustrate it's functionality with a series of spatial operations including; point-value scour occurrence, frequency-normalized scour occurrence and impact rates, as a function of water depth.

1.3 ICE SCOUR PARAMETERS RELEVANT TO ENGINEERING DESIGN

The following section outlines some of the key parameters that are commonly examined in the determination of risk estimates for sub-sea pipeline or fibre optic cable installations.

GENERAL SCOUR STATISTICS BY BATHYMETRY

The study of individual scour parameters, by bathymetry, is necessary in determining the impact of ice scouring at various positions along a sub-sea, engineering installation. In turn, bathymetry, controls the expression and magnitude of many geological processes in the Arctic, especially ice scour.

IMPACT RATES OR TEMPORAL SCOUR FREQUENCY

Temporal scour frequency can be determined through repetitive mapping surveys of the seafloor. These surveys provide information on the return period of ice scours of different magnitudes with respect to bathymetric zonation. This information is critical in defining a safe water depth where a pipeline may rest directly on the seafloor without risk of failure due to ice.

It is noted that impact rates may vary significantly from year to year, based on the severity of the winter ice conditions. Therefore, in order to calculate acceptable risk estimates for sub-sea pipeline installations, a repetitive mapping program must be undertaken for a number of years.

SCOUR DEPTH

The Scour Depth parameter is perhaps the most important in estimating the minimum trenching depths required for a sub-sea pipeline installation. Scour depth is a variant parameter, depending on a number of factors including: size of the scouring ice keel, scour age, amount of infill, bathymetry, physiographic location and the geotechnical soil conditions. The scour depth parameter represents a measurement that is derived from the acoustic data at some time after the passage of the ice keel. As a result, these values are considered minimum values. For example, upon scouring some immediate sediment backfill may take place, especially in sandy or silty soils. Subsequent to this, the scour may become infilled by hydrodynamic reworking, normal sedimentation, bioturbation or by additional scouring by other ice keels. Due to the nature of acoustical profiling, the absolute scour depth value is also minimized by geometric and beam angle considerations (Gilbert, 1989).

SUB-SCOUR DISTURBANCE

Previous studies have indicated that a zone of acoustic disturbance often surrounds scour incisions in areas of finely laminated sediments such as Mackenzie Trough (Figure 1.1.2). Comfort et al. (1990) conclude that while acoustic artifacts are commonly associated with seismic profiles of ice scours, at least some of the sub-scour acoustic disturbance observed beneath ice scours is caused by disruption of sediment bedding planes during scouring. Comfort et al. (1990) report that the zone of acoustic disturbance may extend beneath the base of a scour to a depth equal to the scour incision. As such, sub-scour disturbance may be an important factor in sub-sea design, in that, it may extend the depth to which an ice keel influences the seabed sediments, and any buried installations. Evidence of such disturbance was generally not observed on the ESRF 1990 acoustic profiles. This is possibly due to a lack of fine-scale sediment stratification over most of the 1990 survey area.

SCOUR INFILL

A scour, once formed, may be susceptible to immediate backfill by scour wall slumping or by subsequent infill through hydrodynamic processes or normal marine sedimentation. Either process tends to diminish and "mask" the true scour depth value that should be used for burial depth risk estimates. Scour wall slumping depends on two critical parameters; the slope of the scour wall created by passage of the ice keel and the physical properties of the scoured sediments.

Another major scour infill process is that of post-scour sedimentation. Regional sedimentation rates, while dependent on the geologic setting, are generally on the order of millimetres per year. Local hydrodynamic activity, however, may erode the scour berms and lead to preferential scour infill with rates that may greatly exceed the average sedimentation rates in the localized area.

Younger scours which cross-cut existing scours also result in localized infilling of the older scours. The degree of infilling through this process is difficult to quantify. It is largely based on the frequency of scouring, in relation to the sedimentation rates in a given area. Scour frequency in turn is based on the water depth and the severity of the ice conditions over time. The process is clearly operative in the Beaufort Sea and has been recorded by Gilbert and Pedersen, (1986) who undertook a series of cross-cutting scour analyses for relative age determination.

Another possible scour infilling process that has not been conclusively confirmed results from liquefaction and slumping of the scour wall sediments. This process may occur during storms where repeated wave loading creates excess pore pressures that ultimately causes liquefaction and sediment flow (Steve Blasco, pers. comm).

Scour infill processes may, therefore, make scour depth and extremal statistics difficult to verify.

SCOUR ORIENTATION

The scour orientation parameter defines the angle at which an ice keel will intersect the sub-sea pipeline structure. If the preferred orientation (mode) of the scour population in the region is at right angles to the sub-sea pipeline orientation, a higher risk for damage is warranted due to the increased number of possible intersections with a pipeline. The lateral extent of damage resulting from scour impacts at right angles would likely be limited to the width of the scouring ice keel. Conversely, when the orientation mode is parallel to the pipeline direction, the intersection risk is minimized, but a greater degree of damage to the pipeline may occur. This is because the zone of disruption may extend along the length of the pipeline for greater distances.

SCOUR WIDTH

The scour width parameter is important in engineering design, as it, in conjunction with the scour orientation parameter, defines the actual width of possible damage that might occur to a pipeline upon impact.

SCOUR FORM

Scour Form relates to the ice keel type, as defined by the number of individual scour keels recognized along the base of the scour feature. The Form parameter also yields evidence regarding the nature of the scouring process. For example, some scours may change Form from a single keel to a multi-keel event, or visa-versa, indicating that changes in the scouring dynamics of the ice mass have occurred. Scour Form is also known to change with bathymetry.

SCOUR LENGTH

The Scour Length parameter should be considered in sub-sea installation design models for it may influence the potential extent of damage to a pipeline, given a parallel scouring direction of the ice keel. Some discussion in the past has questioned whether a partially buried or fully-exposed trenched pipeline or sub-sea cable might actually serve as a conduit, routing the passage of similarly oriented ice keels along its extent. The length parameter is also important in the event that a sub-sea pipeline is twinned.

1.4 BACKGROUND

Yearly repetitive mapping is the best method of documenting and measuring scour features resulting from modern-day ice scour processes. Work to date has illustrated that scour frequency can be highly variable, from one year, to the next. This episodic nature of scour can be accurately documented by continued, yearly surveys of the repetitive mapping scour network.

The first major scour survey in the Beaufort Sea was undertaken in 1984, by the ESRF. This survey established a baseline repetitive mapping network from which new scour events could be identified and statistically documented (Shearer et al, 1986). Information regarding the spatial distribution and impact rates for known new scour events resulted from this study. Since this information was known to be critical to engineering design, it was stored as part of the Beaufort Sea Ice Scour Base SCOURBASE system (Gilbert and Pedersen, 1986). The SCOURBASE project (funded by the ESRF) represented a 1 1/2 year project to reduce over 5000 kms of acoustic survey data into a computerized format with over 45,000 scour records (SCOURBASE and ECHOBASE).

Shearer and Pedersen (1990) updated SCOURBASE and ECHOBASE with an additional 7,433 scour records from the Yukon Shelf region. At this point, the data base was used by Det Norske Veritas to perform statistical modelling and extremal analyses studies (Nessim et al. 1986). The successful DNV project served as a quality control check and helped to establish the utility of the ESRF, SCOURBASE system.

SCOURBASE AND ECHOBASE were also updated by CSR in 1988-1989, under ESRF funding, to include an additional 1600km of survey line data from the ESRF84, Tully85 and Tully86 cruises (Gilbert et al. 1989). The upgraded version of SCOURBASE was used to conduct a comprehensive analysis of the parameters; scour orientation, depth and width, as a function of water depth and physiographic region on the Beaufort Shelf (Gilbert and d'Apollonia, 1989). New scours identified as a result of repetitive coverage were compiled into a separate data base (NEWBASE) comprised only of new scour events (Table 1.4.1).

Table 1.4.1 Components of the Beaufort Sea Scourbase System

Name	**Origin**	**# Records**	**Function**
SCOURBASE	Sidescan	66,549	Stores baseline scour parameters, archived and no longer updated.
ECHOBASE	Echo Sounder	24,801	Stores scour depth and bathymetry, archived and no longer updated.
NAVBASE	Navigation	22,669	Stores exact navigation data.
NEWBASE	Sidescan Echo Sounder	5329	Stores New Scour records, updated for ESRF 1990 survey.
NNAVBASE	Navigation	13802	Stores New Scour navigation data, updated for ESRF 1990 survey.

In 1988, the survey network was partially re-surveyed, by CSR, under a joint GULF Canada Resources Ltd. and GSC program. That survey yielded many important new scour results (Gilbert, 1988). Additional repetitive mapping was conducted by CSR in 1989, under funding from the Geological Survey of Canada (Gilbert, 1989). Both the 1988 and 1989 survey data sets were reduced by CSR, and all new scours identified were added to the new scour data base (NEWBASE).

The updated data base was again statistically analyzed by DNV (Det Norske Veritas, 1988) to illustrate trends in specific New scour parameters (NEWBASE) and compare those trends with the scours found in the Historical data base (SCOURBASE and ECHOBASE).

The current ESRF 1990 program represents a continuation of efforts to survey the repetitive mapping network, especially in regions not covered by the 1988 and 1989 surveys.

A total of 2291 new scours were identified on the ESRF 1990 survey data, resulting in a total of 5329 new scours compiled in the NEWBASE data base to date. This population was used by C-FER to model the characteristics of New Scours and to further statistically compare the New and Historical ice scour populations (Nessim and Hong, 1992).

CSR, under contract to Shearer Consulting used CSR's SIPS Geographic Information System to produce a series of scour frequency and impact rate maps for each major repetitive mapping interval from the Beaufort Sea program. Shearer (1996a) used these maps and data base listings to document the frequency and impact rates of New Scours, primarily in terms of water depth and physiographic location.

Successful utilization of the ice scour data bases by third parties has helped establish the utility and validity of the Beaufort Sea Repetitive Mapping program. The resulting data will enhance our knowledge of the recurrence rate of extreme ice scour events across the shelf and, thereby, aid in defining safe risk protection strategies for petroleum-related seafloor installations.

1.5 REPORT OVERVIEW

Chapter 1 provides background information regarding previous data basing of Beaufort Sea ice scours, as well as, the historical development of repetitive mapping and the new scour data base (NEWBASE). Several key scour parameters relevant to sub-sea engineering design are also addressed in Chapter 1. Chapter 2.0 summarizes the ESRF 1990 repetitive mapping field program and addresses the implications of new survey technology used during the survey. A complete report of field operations is presented in Appendix 4.

Chapter 3.0 describes new scour identification, scour parameter measurement, and data processing techniques. The concept of Geographic Information Systems is introduced, and CSR's Scour Information Processing System (SIPS) is described with respect to ice scour research applications. Chapter 3.0 includes the results of a comparative scour depth re-measurement project.

The results of the NEWBASE update and the scour tracking study are presented in Chapter 4. An exploration of the new scour data base, in Section 5.1, compares the pre-existing and updated versions of NEWBASE, documents the values of some key scour parameters, and provides a preliminary analysis of scour distribution and scour depth distribution with respect to water depth. Section 5.2 addresses the spatial distribution of the new scour population through a series of maps constructed using CSR's SIPS-GIS system. Detailed descriptions of the tracked scours and a three stage model of the scour rise-up processes are presented in Section 4.3.

Chapter 5.0 provides a summary of the ESRF 1990 update and analysis of the new scour data base (NEWBASE), as well as, the results of the scour tracking study. Several recommendations based on the results of this project are presented as well.

Table 1.5.1 defines the acronyms used in this report.

Table 1.5.1 Acronym Definition

Acronym	Definition
ESRF	Environmental Studies Research Funds
PERD	Panel on Energy Research and Development
GSC	Geological Survey of Canada
AGC	Atlantic Geoscience Centre
C-FER	Centre for Frontier Engineering Research
CSR	Canadian Seabed Research
GIS	Geographic Information System
SIPS	Scour Information Processing System
NEWBASE	Data Base of New Scour Events
NNAVBASE	Navigation Data Base for Repetitive Mapping Surveys
ECHOBASE	Historical Scour Data Base (scour depth and bathymetry)
SCOURBASE	Historical Scour Data Base (scour/survey parameters)
CCSP	Cross-cut Sediment Pile

2.0 FIELD SURVEY PROGRAM SUMMARY

2.1 INTRODUCTION

The repetitive ice scour mapping survey was carried out aboard the Canadian Coast Guard Vessel Nahidik during the period of August 30/90 to September 17/90 in the Canadian Beaufort Sea. As prime contractor for the survey, Canadian Seabed Research Ltd. (CSR) was responsible for planning the regional network, providing geophysical equipment and personnel and organizing a suitable navigation package. A SYLEDIS/ARGO navigation system was provided under subcontract by Challenger Surveys and Service Ltd. of Edmonton. The navigation chain and signals were provided by Halliburton Geophysics Ltd.

The primary objective of the survey was to re-survey specific corridors across the Beaufort Shelf using high resolution geophysical instrumentation to identify and document new scour events. This objective was fully realized through the collection of over 1600km of regional and scour-specific survey lines data. Secondary objectives included undertaking detailed scour tracking studies and profiling the Gulf Pipeline Route to identify New and extreme ice scour events. The success of the 1990 survey can be attributed to the excellent weather and clear ice conditions that were experienced, as well as, the provision of new and 100% backed-up geophysical equipment.

2.2 SURVEY COVERAGE

A total of 79 lines were surveyed during the ESRF 1990 field program, resulting in a total of 1651.6 km of survey line data. This data was collected in 14 available survey days, thus yielding an excellent daily production rate of 118 km/day. A general breakdown of the survey lines is shown in Table 2.2.1. The bulk of the survey data were regional repetitive scour mapping lines, accounting for over 1300 km of data. These lines were shot in many diverse environments encompassing most of the major physiographic and bathymetric regions of the Beaufort continental shelf. The location of these regional lines are displayed in the operations report (Appendix 4).

A series of 7 lines were also shot to profile the Tingmiark glory hole site. This glory hole may represent a hazard to shipping as it is reported to have the remains of a drilling pipe protruding from the site's dredged depression. Search lines were initially run in a nearby, but incorrect location. The site was subsequently located at a position of 7,786,671N and 576,358E and the protruding pipe successfully identified and profiled by sidescan sonar.

A total of 28 lines were also run to profile and track six unique scours on the Beaufort Shelf. These scour tracking operations are utilized to reveal along-track, process-related information over the entire length of the scouring event.

For additional survey information, please refer to the complete operations report in Appendix 4. Requirements for planning and completion of a successful repetitive mapping program, compiled from CSR's experience in undertaking the ESRF Beaufort Sea surveys, are outlined in Appendix 3.

TABLE 2.2.1 ESRF 1990 Survey Line Distances

LINE TYPE	TOTAL LINES	DISTANCE (KM)
Regional	44	1389.6
Tingmiark Survey	7	7.8
Scour Tracking Studies		
SCTARN2	13	81.2
SCNEWDP	3	48.2
SCPIP16	5	17.4
SCPIP26	2	33.7
SCPIPEA	2	32.8
SC7	3	40.9
TOTALS	**79**	**1651.6**

2.3 NEW SURVEY TECHNOLOGY AND IMPLICATIONS

2.3.1 KLEIN 595 DIGITAL SIDESCAN SONAR SYSTEM

In order to achieve the highest possible data quality in the field, CSR purchased a new, KLEIN 595 digital, sidescan sonar system for the ESRF 1990 program. This system offers complete real-time, scale correction, as well as, water column removal and aspect ratio correction. CSR configured this system with manual, rather than digital tuning in order that the operator can control contrast and gain settings for optimal resolution. One example of the high resolution imagery of this system is presented in Figure 1.1.1.

In addition to being a state-of-the-art system, the Klein sonar was especially configured, by CSR, to display a 3rd channel profile for accurate scour depth measurement. The Klein microprofiler is a 100 kHz, downward-looking profiler which is used to produce very high resolution detail of the seafloor micro-topography. This system differs from conventional sounders in that it uses a narrower 8.0° beam, shorter pulse length and it is towed closer to the seafloor for optimal energy return. Consequently, the microprofiler is able to detect very subtle seafloor features and is therefore an ideal tool for scour depth determination.

The data produced by the microprofiler system proved to be so accurate, that the scour depths derived from all previous surveys had to be re-evaluated. That study forms part of this report and can be found in Section 3.5. In addition to recording the scour profile in high resolution, the microprofiler also resolved sediment infill in many of the scours, as shown in Figure 1.1.1. Accurate measurement of the true scour base and therefore, depth of the scour is obviously a critical input to pipeline design. Although such information has been difficult to measure in the past, the integrated microprofiler and Klein digital 595 sidescan system recorded this data very accurately, during the 1990 survey.

2.3.2 SCOURBASE SYSTEM

SCOURBASE is a microcomputer-based software system that stores and manipulates the Beaufort Sea Ice Scour Data Base System. The SCOURBASE system was used onboard the ESRF 1990 survey as a tool for accessing and retrieving relevant survey track and scour data required during the cruise. This system is the property of CSR and is composed of a DOS-based 386 laptop computer, configured with data base and digital mapping software.

The SCOURBASE system proved very useful in rapidly selecting the specific x,y line coordinates required for repetitive survey, while in an active survey mode. This data could be posted to a digital file and a hard copy printout. The print out was utilized by the navigators for input to the navigation computer and by the bridge for plotting purposes. The system also contains routines for conversion of UTM to Geographic coordinates so that the ship's navigators could plot the proposed lines on hydrographic charts.

SCOURBASE was also used to perform on-line queries for extreme scour events in the data base. Events such as the longest, deepest scours etc. could be readily located and important attributes such as UTM coordinates posted to the printer. Many of these scours were then tracked to confirm the data values residing in the data base and to reveal information regarding rise-up.

Other products such as scour distributions, regressions, rose diagrams, contour and 3 dimensional data plots are all possible for certain regions, sediment types or water depths of the Beaufort Shelf using this system.

3.0 METHODOLOGY

3.1 NEW SCOUR PROCESSING TECHNOLOGY AND IMPLICATIONS

3.1.1 INTRODUCTION

Building the ice scour and associated navigation data bases is a time consuming and labour intensive undertaking. In 1988 and 1989, CSR developed a series of computerized routines to help automate this process (Gilbert et al. 1989). These routines were based upon the Foxplus data base programming language and an in-house mapping program (GEOCAD). While these programs greatly aided in the automated processing of ice scour data, CSR has recently improved on this capability through Geographic Information System (GIS) technology.

A new Scour Information Processing System (SIPS) has been developed which is based on the ARC/INFO Geographic Information System (GIS) platform. Implementation of the SIPS, GIS system has increased the efficiency, and thus, reduced the cost of building and manipulating the ice scour data bases. In addition, the end product has greater functionality for spatial analyses and modelling of ice scour and environmental data than was previously possible.

This section will identify the advantages of using GIS technology. The major components of the SIPS scour processing system used to construct, update, and analyze the new scour data base are also addressed.

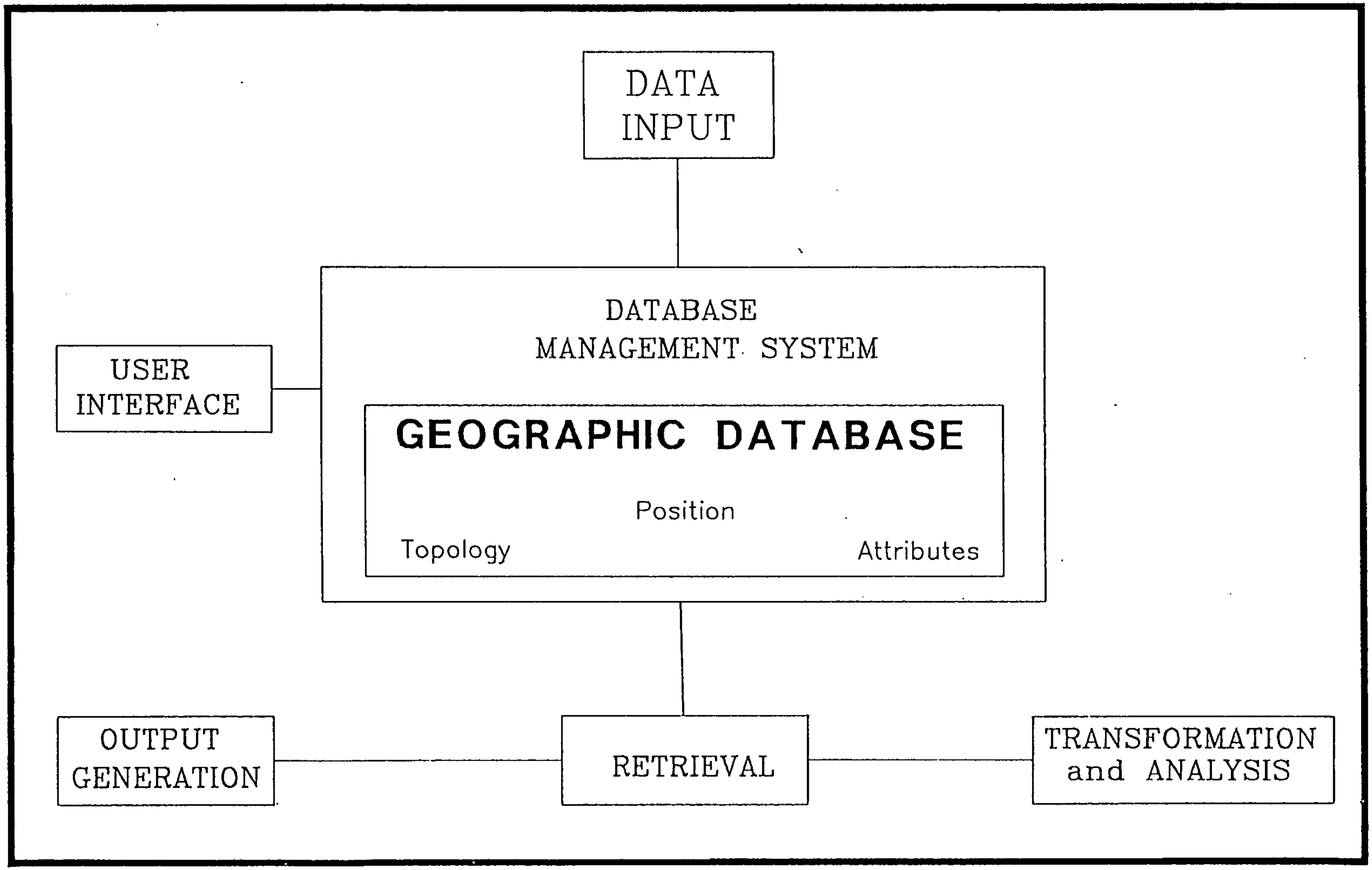
3.1.2 GIS - PURPOSE AND FUNCTIONALITY

Originating within the Canadian government during the 1960's, GIS technology has been adopted and fostered by a wide range of disciplines and application fields. These include forestry, mining, municipal government, and surveying. Implementation of the technology has been particularly rapid since the mid-1980's, due to the significant maturation of computer hardware technology.

Although many definitions exist, a Geographic Information System (GIS) may be defined as follows:

> The GIS consists of ... "a powerful set of tools for collecting, storing, retrieving at will, transforming, analyzing, and displaying spatial data from the real world for a particular set of purposes." (Burrough, 1986).

A schematic diagram of a GIS system is shown Figure 3.1.1. The common thread among all the areas of application is the requirement to deal with spatially-referenced data. All entities represented within a GIS must therefore be referenced to a real-world coordinate system. In the case of the ice scour data bases, the scour UTM position is the spatial co-ordinate and parameters such as scour length, width, depth, and line identifiers are considered attributes. There also exists topological relationships between the scours



(After Borrough, 1986)

Figure 3.1.1 Functional diagram of a typical GIS system.

(points), survey tracks (lines) and bathymetric or physiographic zonations (polygons).

GIS Versus CAD and Desktop Mapping Systems

There are some similarities between true GIS systems, desktop mapping systems and CAD-based drafting systems. For example, all relate objects to a known coordinate system, they all handle non-graphic attributes (such as text) and they all must utilize points, lines and polygons as the basic graphic elements (with some notable exceptions).

However, there are critical differences that primarily relate to the GIS's more advanced functions of spatial analysis and data base linkages. The primary differences are outlined in Table 3.1.1.

TABLE 3.1.1 Comparison of GIS, Desktop Mapping, and CAD Systems

TASK	GIS ARC/INFO	DESKTOP SYSTEMS	CAD SYSTEM
Data Query	Yes	Yes	No
Report Generation	Yes	Limited	No
Mapping	Yes	Limited	Yes
Graphic Products	Yes	Limited	Limited
Spatial Analysis	Yes	No	No
Data Integration	Yes	No	No
Topology	Yes	No	No
High Data Volume	Yes	Limited	Limited

Geographic Information Systems have adopted much of the basic functionality of CAD technology. However, the GIS has greatly enhanced and expanded upon these tools. Therefore, the GIS can offer a superior graphical environment, while also providing a range of data management and modelling functionality.

It was for these reasons, CSR selected the ARC/INFO GIS system as the base platform for the development of a suite of processing and display routines for the ESRF 1990 ice scour data. These routines have become known as,"SIPS," after the Scour Information Processing System.

3.1.3 SCOUR INFORMATION PROCESSING SYSTEM (SIPS)

The Scour Information Processing System (SIPS) is a series of software routines developed within the pc ARC/INFO GIS environment. This system was purposely designed, by CSR, to help build, process and analyze ice scour and related geological data sets. A functional diagram of the system is shown in Figure 3.1.2.

The Key elements of SIPS include the following modules;

DATA CONVERT Module

This module represents a linkage to the SCOURBASE data bases developed previously. These data bases (SCOURBASE, ECHOBASE, NAVBASE etc.) can be transferred in an automated fashion to the SIPS system and converted into ARC/INFO coverages. NAVBASE files were converted from point data into line entities during this process.

IMPORT Module

This module allows SIPS to access data from other data bases, Autocad files, ASCII files or other GIS software. Other data bases such as Geotechnical, Environmental or Oceanographic can be easily read and imported into the SIPS system.

NAVBUILD Module

This module allows systematic compilation of repetitive mapping positioning data, regardless of the type of navigation system used during the survey. It is comprised of a series of routines to read and format digital navigation files, and import the data into the new navigation data base (NNAVBASE). Overlap information (OPART) and bathymetry values are assigned to the navigation records during the NAVBUILD operations.

SCOUR BUILD Module

These routines are used in building the ice scour data bases. First, they assign UTM values to each scour record in the NEWBASE file, based on an interpolation from the NAVBASE file. They then overlay both files with a 1.0m bathymetric polygon coverage and the physiographic region polygons. Through this overlay process, each data base record is "tagged" with the appropriate values. Previous methodologies (Gilbert et al. 1989) for this process were very cumbersome and time consuming.

QUALITY CONTROL Module

Once all the scour parameters for a particular survey line are keypunched into SIPS, a

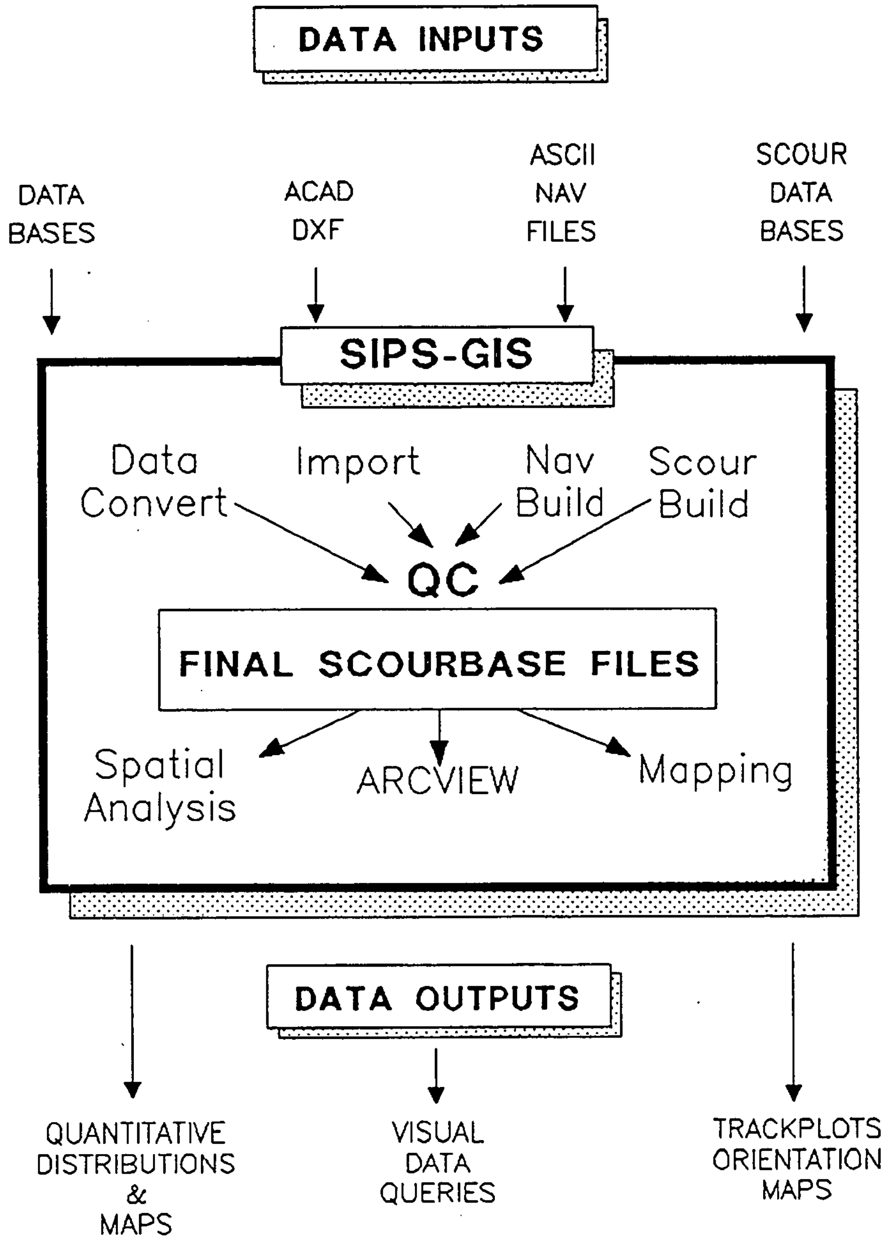


Figure 3.1.2 Functional diagram of CSR's SIPS system.

series of quality control operations are undertaken. Two examples of quality control routines are presented below.

The first routine, called QC, checks the various parameters of each scour against allowable character strings or numeric limits. For example, the parameter orientation can only be 0 - 179 degrees, or the quality codes can only be "G","F",or "P". These parameters can be easily checked for incorrect record entries by the QC routine.

Another routine, NAVCHECK is designed to check that each fix is greater than the preceding one, and that all fixes are within start and end bounding limits pre-determined for that line. Irregular positional data that falls outside the specified limits is also flagged. In this way errors in positions can be identified and corrected early in the processing.

ARCVIEW Module

This module allows the user to easily display any of the coverages existing in SIPS. Enhanced query and display options along with zoom and pan capabilities help the user perform quality checks and visual analysis of datasets.

SPATIAL ANALYSIS Module

This module allows the user to perform spatial analyses, such as the determination of scour frequency (# of scours/km) or impact rates (# scours/km/year) within a user-defined polygon. New polygons may be created by overlay "union" from a series of environmental surfaces, such as; bathymetry, physiographic region or surficial geology.

MAPPING Module

High quality and full scale maps are an important element of the SIPS output capabilities. Routines exist to generate a wide variety of maps, including; scour plots colour-coded by depth, scour orientation bar plots, survey track maps, and scour frequency or impact rate maps in 1.0m bathymetric intervals. With the interactive set of software tools at the user's disposal, virtually any combination of scour attributes or processed data can be mapped. Since ARC/INFO is a vector-based system, the resultant maps are very high quality and publication ready.

EXPORT Module

This module is used to convert data from the ARC/INFO format to other GIS systems, Autocad, or smaller desk top mapping packages. Data may be supplied in ASCII, DXF, dbf or the Standard Interchange Format (SIF).

MODELLING

The GIS can be used to test the association of a dependent parameter, such as scour frequency, with a series of independent variables, such as; bathymetry, sediment type, physiographic region, etc.. Such environmental variables would typically be overlain in the GIS to produce a union set of polygons in order that scour frequency could be quantified within each polygon subset. High scour frequencies can, thereby, be statistically correlated and ranked with environmental parameters. These associations thus form a predictive model which can be used to predict scour frequencies in regions of poor data coverage.

WHY IS SIPS IMPORTANT?

In summary, the SIPS system has been used by CSR to build, map, analyze and model the Beaufort Sea ice scour data. To date, however, bathymetry, coastline, and physiographic regions are the primary overlay themes that exist within the system.

Full analytical capabilities of SIPS will be realized when the system is updated for additional information themes, such as; sediment type, geotechnical borehole data, sedimentation rates, seabed slope, ice zonation data and oceanographic information such as winds and current velocities and directions (Figure 3.1.3). With such a full data set, ice scour occurrence (frequency and impact rates) can be modelled in terms of the major controlling environmental influences. The GIS model can therefore be used to more fully understand the scouring process and ultimately to predict the return rates of scours with extreme dimensions in different spatial locations on the Beaufort Shelf.

3.2 NEW SCOUR MEASUREMENT AND DATA PROCESSING

3.2.1 INTRODUCTION

Imaging the seafloor by sidescan sonar yields an oblique plan view of seabed morphology, as a function of acoustic reflectivity. Through detailed examination of sidescan data collected in the Beaufort Sea, new scours can be identified and their attributes documented in a data base environment. Such parameters include; orientation, form, morphology, smoothness, length, width, depth, sediment fill, sediment type, and associated bathymetry and relevant survey parameters.

The identification, measurement and cataloguing of the New Scour data requires direct involvement of skilled geologists and data processors. These aspects of ice scour data reduction are the least automated and require stringent quality control checks.

3.2.2 TRACK PLOT

The first step of the operation was to generate an accurate track plot of all lines shot during the field survey. The digitally-recorded, ESRF 1990 navigation data was plotted using the

SIPS-GIS

Scour Information Processing System
Geographic Information System

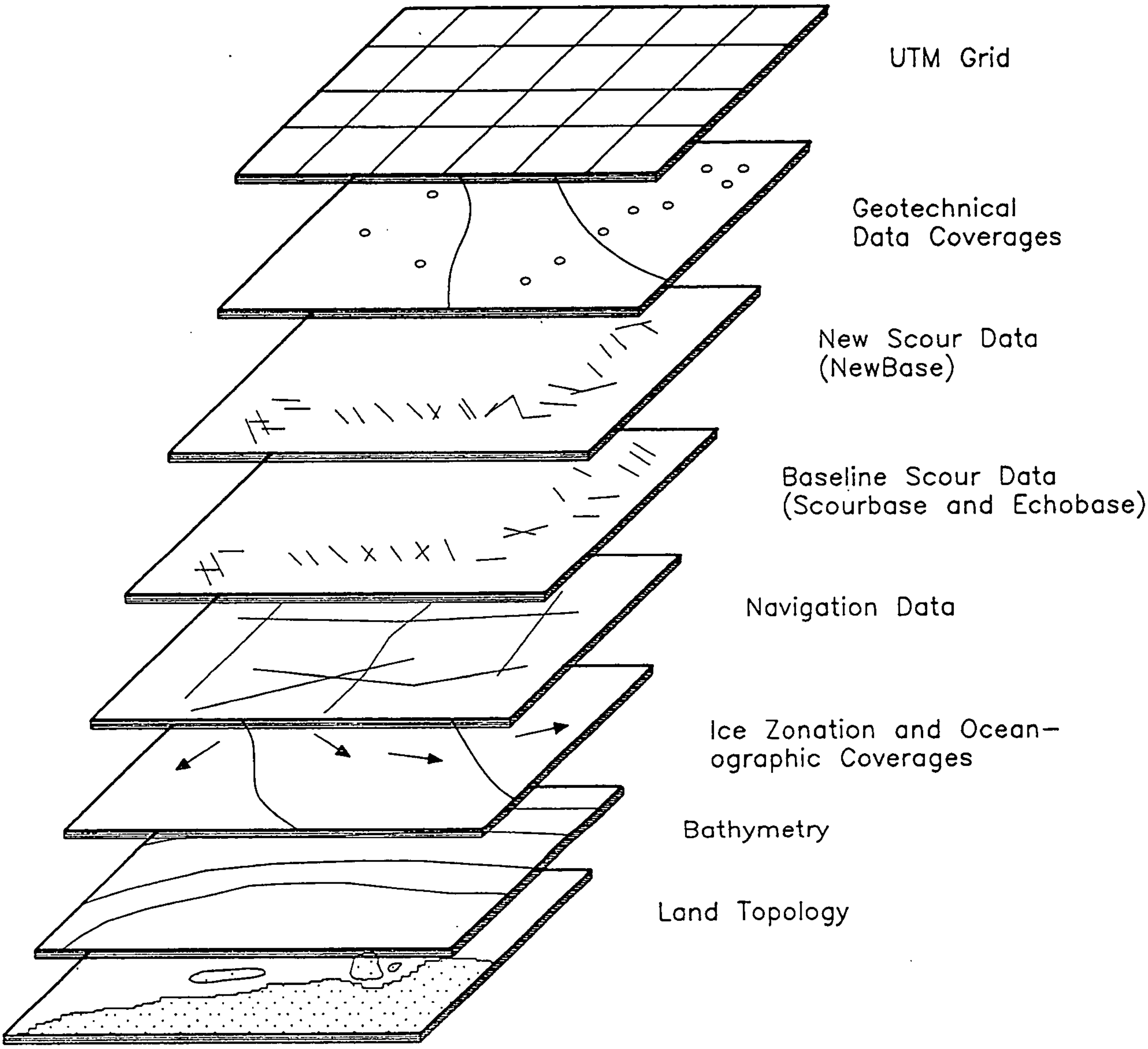


Figure 3.1.3 Schematic representation of typical SIPS coverages.

SIPS system as part of the operations report found in Appendix 4. A fully annotated version of the track plot was used to identify any obvious navigation problems that were corrected before further processing was undertaken. The ESRF 1990 track plot was then compared to track plots from previous years to determine the lines or line sections where overlap occurs from the base year to the repetitive year.

The exact sections of lines that overlap were carefully documented, in order to correctly locate potential areas of new scour occurrence. For example, there may be breaks in both the base year and repetitive year data sets due to poor weather, equipment problems, navigation malfunctions or paper changes. As the overlapping line distances are also used to calculate impact rates (# New scours/km/year) the overlap sections must be correctly recorded for input into NNAVBASE.

3.2.3 NEW SCOUR IDENTIFICATION

The ESRF 1990 sidescan data was compared with previously collected data to identify the New Scours. This involves a fix-by-fix comparison of the new and previous sidescan records to recognize identical seabed features and, ultimately, to identify and flag new scour events. This procedure required an experienced interpreter with full knowledge of the limitations and data quality of the acoustic data. Jim Shearer of Shearer Consulting was subcontracted by CSR to identify the new scour events from the ESRF 1990 data.

For example, experience has shown that it may be difficult to confidently identify a new scour event if the underlying base year data is of lower quality. In addition, where the new scour frequency is high, or when the time interval between survey intervals is considerable, the bottom may be almost completely re-scoured. In such cases, identification of new scour events was a very difficult and time consuming process.

Once the New scours were flagged, a general visual check of the sidescan data was undertaken, and quality control sheets completed for each survey line. Information recorded on these sheets include; data quality breaks, unusual features, ship heading, and sediment type. The final selection of overlap data was made using these description sheets.

3.2.4 PARAMETER MEASUREMENTS

Scour parameters were measured manually from the sidescan sonar and microprofiler data sets for each new scour event. All measurements were obtained from the sidescan records with the exception of the scour depth and infill which were measured from the microprofiler display. Data coding sheets were used to record all new scour parameters, as well as, related information such as maximum age, source, previous company and previous year.

The following section presents a brief overview of the Key scour parameters that were measured from the sidescan and microprofiler records. The reader is referred to Appendix 1 for a complete listing and description of the new scour data base parameters.

FIX

The Fix is a unique reference mark that is recorded on both the navigation logging system and on all geophysical records. Each New scour is referenced to the decimal fix value at the location where it crosses the ship's track. For scours which did not cross the ship's track, the decimal Fix was measured at the location where the scour was closest to the ship track.

ORIENTATION

Orientation is the bearing of the scour referenced to true north and expressed, by convention, between 0-179 degrees inclusive. The orientation of a sinuous or arcuate scour was measured as a chord connecting the scour end points.

FORM

Form classifies the new scour event as either; single or multi keeled. This is usually obvious from the sidescan data alone, however, the microprofiler data was often used as a useful cross check.

MORPHOLOGY

Morphology refers to the shape of the scour in plan view. Scours were classified as either; linear, arcuate or sinuous (changes orientation more than once). See Figure 3.2.1 for examples of both morphology and form.

SMOOTHNESS

Smoothness is a highly subjective description of scour morphology. It is based on the sharpness of the acoustic returns which vary depending on; scour morphology, angle of scour sonification, data quality, water depth and sediment type. Descriptive values for this field range from very rough (characterised by sharp back-wall reflectors, opaque reflectance from the scour floor and well-defined scour berms) to very smooth (characterised by weak back-wall reflectors, uniform scour base reflectance, and poorly-defined scour berms. This attribute may relate to relative age amongst new events. Smoothness examples are presented in Gilbert et al. (1989).

LENGTH

Length is measured manually along the longest axis or the scour. Unfortunately this measurement is often limited by the range of the sidescan scale setting and seldom reflects the true length of the scour.

WIDTH

Scour width is measured in metres from berm crest to berm crest, as defined by the acoustic shadows cast by the berms on the sidescan records. In cases where the width of the scour changed along it's length, an average width value was recorded. Width measurements were obtained assuming a 1:1 aspect ratio on the sidescan records.

INCISION WIDTH

Incision width is measured as the distance between the interior walls of the scour at the approximate height of the pre-scoured or undisturbed seabed. This measurement is usually made from the sidescan data, although problems associated with acoustic shadowing must be taken into consideration. The measurement is often difficult to confidently make, resulting in the associated INCISION WIDTH QUALITY qualifier which indicates the interpreter's confidence in the measurement. Incision width may also be measured from the microprofiler with appropriate geometric corrections for scour orientation. See Figure 3.2.2 for examples of scour width and incision width.

SCOUR DEPTH

Scour depth is one of the most important scour parameters measured. It is referenced to a smoothed seafloor datum which must be visually estimated by the interpreter (Figure 3.2.3). Scour depth is measured from the referenced seabed datum to the deepest point of the scour. In the case of infilled scours, depth measurements were made from the referenced datum to the top of the infill. The thickness of the sediment infill, as measured from the microprofiler record, was recorded in the SFILL field. In order to obtain the original scour depth, the scour depth and infill fields must be summed.

SUB-BOTTOM PROFILER (SBP)

This field identifies which type of acoustical profile was used to obtain scour depth measurements. This field is important as each system has different resolution and penetration capabilities which will influence the scour depth and infill measurements. This field is also used to indicate whether a scour has crossed the ship's path and, thus, has the potential for a depth measurement is available.

MULTI-KEELED NUMBER

Multi-keeled number is only occasionally used. This field links together individual scour events that the interpreter feels may have resulted from the same ice scouring event. Each event group is given a unique numeric value. Some events occurring over a 5.0 km span are linked with this field. Future surveys may provide conclusive evidence that these individual events indeed formed from the same large ice incursion.

MULTI-KEELED WIDTH

Multi-keeled width is used in conjunction with multi-keeled number to record the maximum width of the recorded scour event.

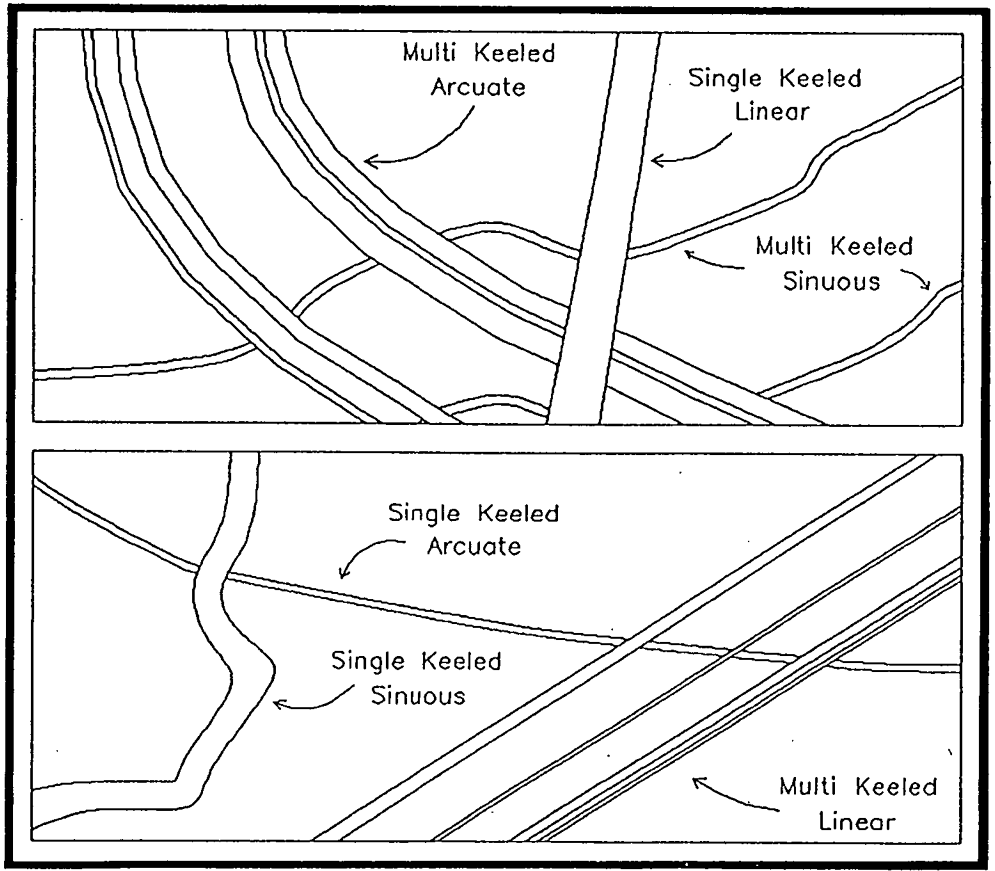


Figure 3.2.1 Illustration of scour morphology and scour form.

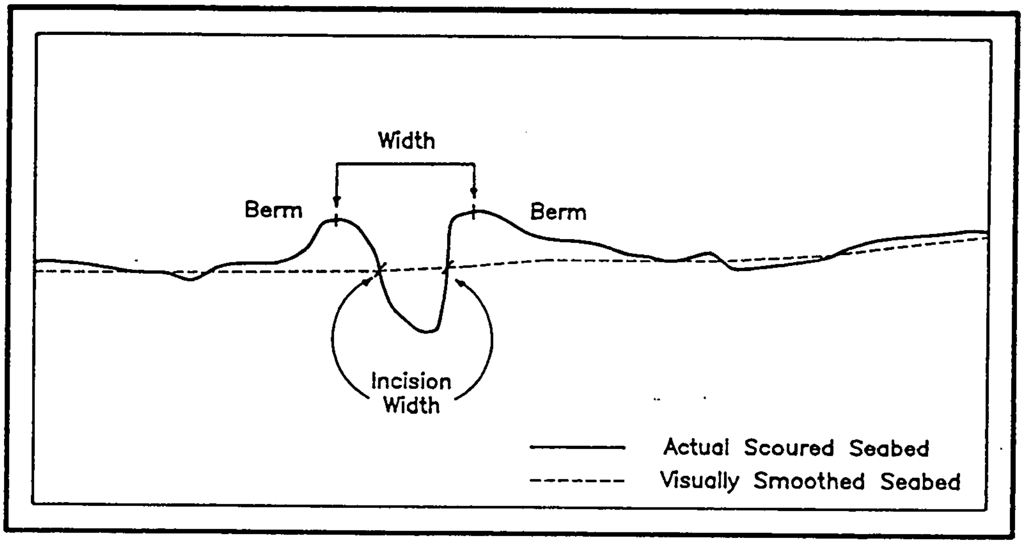


Figure 3.2.2 Illustration of scour width and incision width measurements.

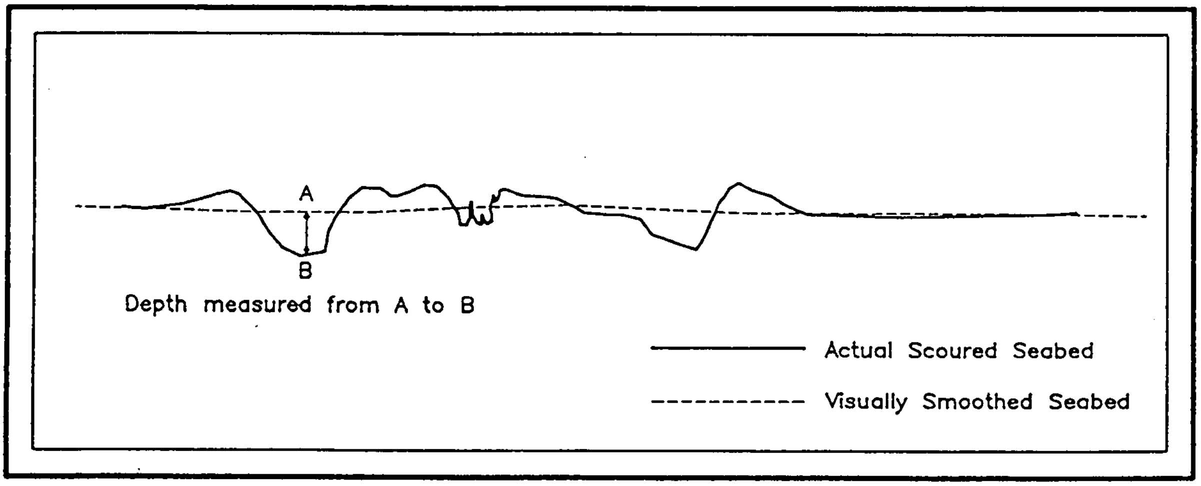


Figure 3.2.3 Illustration of seabed smoothing and scour depth measurement.

SEDIMENT INFILL

Sediment infill is not usually present in New scours and is therefore rarely utilized. Infill may occur on shallow water lines where the sediments have a high sand content or if considerable time has elapsed between repetitive surveys. Infill thickness is measured in metres from the microprofiler data using the same scale established for depth measurements.

DATA QUALITY

Data quality is a fix by fix breakdown of the sidescan and microprofiler's imagery. Overall quality may be good or fair but an equipment malfunction at a particular fix causing the data to be of poor quality is noted in this field. A poor data quality rating often is accompanied by an explanatory comment.

COMMENTS

Remarks entered in this field usually apply to the scour itself (eg. termination visible or cross-cut sediment piles in the scour base). This field also indicates the reason for poor scour definition or poor data quality, such as; severe noise or tow-fish motion.

3.2.5 KEYPUNCHING

Scour parameters recorded on data coding sheets are keypunched into a pre-formatted data base file using the SIPS system. The keypunching is structured with 3 priority levels for data entry. The first level allows for entry of those parameters that are unique to each record (eg. ORIENTATION, FIX, LENGTH, WIDTH etc.). Secondly, those parameters that generally remain constant throughout the line (eg. SED. TYPE, QUALITY etc.) are input. The last stage is to globally replace all records with those fields that are constant for the whole line (eg. COMP, YEAR, LINE, etc.). This process is advantageous as it minimizes keypunching of repetitive information, thus improving data quality.

3.2.6 QUALITY CONTROL

A series of computerized quality control routines were applied, once all the scour parameters for individual survey lines had been keypunched into NEWBASE format. The first routine sorts the data by fix to insure that all fix values fall within the allowable limits for each survey line. Subsequent routines ensure that parameter values fall within allowable limits or match pre-set codes. Survey line heading values are checked to ensure that they are less than 360os. Orientation values are checked to ensure that they fall within the allowable range of 0 to 179 degrees. Form, morphology and smoothness are each checked to ensure that the keypunched values match allowable codes. Dimensional parameters are checked for null value entries, as well as, threshold values. For example, scour depth values greater than 5.0 metres were compared with the original data entry forms for possible key-punching errors. The width and incision width routine ensures that the incision width does not exceed the scour width, and that both width and incision width entries are greater than 1. Sediment types and quality code routines check for proper input positioning, as well as, allowable code values. In all, more than thirty global checks were made in addition to visual checks.

3.2.7 NAVIGATION MERGE

The remaining processing sequence uses survey positioning data (NNAVBASE) and the program INTERP2 to generate UTM values for each new scour event. Since each new scour was assigned a fix value in the new scour data base (NEWBASE), the exact x,y UTM position of that fix can be interpolated from NNAVBASE. The resultant Northing and Easting value is automatically input into the appropriate NEWBASE data fields. The final step is tagging the scour record with a bathymetric and physiographic location value. This is accomplished through an overlay process within the SIPS GIS system. At this point the new scour data compiled in NEWBASE is available for interpretation.

3.3 NEW SCOUR NAVIGATION DATA BASE (NNAVBASE)

3.3.1 INTRODUCTION

NNAVBASE is a data base, created by CSR, to store repetitive survey line navigation, bathymetry, physiographic area and overlap information in a readily useable format. Developed as a separate data base, it can be used as a stand alone system to derive navigation related information, or interfaced with the new scour data base to normalize various scour parameters. This data base resulted from of a number of important requirements that are explained as follows;

> In order to correctly represent ice scour statistics between regions, they must be normalized by the available survey line kilometre distances. Scour frequency and impact rate calculations both require accurate survey line distances stored in a digital processing system. Previous measurements of line length utilized the first and last scour position data from SCOURBASE, however, this method is acceptable only in densely scoured areas where scours occur close to start and end of line positions.
>
> NNAVBASE offers a digital storage system that organizes all the lines collected for the Beaufort Sea Repetitive Mapping Program. This is important for future repetitive mapping surveys. This data base therefore provides accurate line UTM positions from former surveys without extensive searches through navigation tapes or inaccurate manual measurements from paper track plots.
>
> A natural byproduct of creating NNAVBASE allows for the interpolation of UTM geographic position data for scours records in NEWBASE, as previously described. This is accomplished through processing routines where scour fix positions are passed to the NNAVBASE system and exact UTM positions are interpolated and returned to the scour data base. This facility has greatly improved the speed and accuracy of

NEWBASE data processing operations.

Once the survey line navigation information is stored in digital format it also allows for digital mapping applications through CSR's, SIPS-GIS system.

3.3.2 NNAVBASE PARAMETERS

The most important NNAVBASE parameters are; fix mark, geographic position, bathymetry, physiographic area, data source and the start and end of line overlap information. Each record corresponds to a specific location along a survey line. For any survey line, there are; start and end of line records, start and end of line parts, and regular position fixes at intervals along the survey line. The reader is referred to Appendix 1 for a complete listing of NNAVBASE parameters and the format of the NNAVBASE structure.

In the design of the NNAVBASE structure, the format was standardized to accommodate previous survey data sets and yet retain full compatibility with the pre-existing SCOURBASE, ECHOBASE, and NEWBASE data bases.

Accordingly, the following conventions were adopted:

- All fields which were identical in NEWBASE were of the same length and type in NNAVBASE, to ensure compatibility amongst the data bases.
- All positions were converted to Universal Transverse Mercator grid positions referenced to Zone 8 (Central Meridian 135° W longitude).
- All bathymetric information was derived from the Natural Resources 1:250,000 map sheet.
- All fixes that were shot in time (for example, most Government surveys fix at 5 minute GMT intervals) were transformed and stored as cumulative minutes. This allows the time of day to be retained, but as well, provides a sequential numbering system that does not revert to zero at 2400 hours.

3.3.3 SIPS - NAV BUILD MODULE Data Processing System

The types of navigation data used in creating NNAVBASE were varied, and a systematic method of reading data, formatting it to the NNAVBASE structure, and inserting additional data was required. The SIPS navigation processing software system was designed and coded at CSR to accomplish these tasks. A series of programs were written in the ARC/INFO programming language to perform data base preparation or information extraction operations in a convenient and flexible fashion.

The SIPS system is composed of a series of discrete steps. Regardless of the format of the entered data, the sequence of steps involved in the SIPS operation are as follows.

CONVERSION OF NAVIGATION DATA TO SIPS

The original navigation text file data was checked visually for any obvious errors and to ensure that the fixes were all converted to UTM zone 8 co-ordinates. The data was then transferred into SIPS through the Nav-build module. This module created; a line (arc) coverage, it's attribute dbf file, a point coverage for the individual fixes, and it's corresponding point attribute data base file. The arc and point coverages are linked to their corresponding attribute files using a unique identifier in each file.

ERROR CHECKING FOR BAD FIXES

The point attribute dbf file was then checked for any bad fixes as identified by the survey company and those found by running a program UTM-CHK.prg. The bad fixes were either deleted or corrected.

Additional error checking was performed by first viewing the navigation lines on the display and secondly by obtaining a check plot of the navigation with every line name and 50th fix plotted.

ADD BATHYMETRY AND PHYSIOGRAPHIC REGION

The bathymetry and physiographic region were inserted into the navigation file using the overlay function of the SIPS system. In this operation, every record is updated with a corresponding bathymetry and physiographic area value based on it's x,y position with respect to the overlay polygons.

After the overlays were complete, the data base was visually checked for gaps or deviations and any errors, corrected.

ADD OVERLAP INFORMATION (OPART)

Overlap refers to those sections of the recent repetitive line that totally overlap with the base year survey line. This overlap information is added to the NNAVBASE by manual insertion from coding sheets which list the start and end fixes where the overlap occurs. Again visual checks were made at the end of this process.

FINAL COMPILATION OF NNAVBASE

Once all the information has been inserted and checked, the process of building GIS coverages must be repeated in SIPS to ensure that the ARC/INFO coverages and corresponding attribute files are linked correctly. At this point, a final navigation data base and base maps are ready for future spatial analyses.

3.4 SCOUR TRACKING METHODOLOGY

3.4.1 INTRODUCTION

Scour Selection and Survey Design

Several scours were identified and located using CSR's SCOURBASE system prior to the commencement of survey operations. Scours were primarily selected on the basis of extreme scour depth and/or known age. Additional extreme scours were identified from records collected along the proposed Amauligak pipeline corridor during the ESRF 1990 survey.

The survey vessel crossed back and forth over the scour during tracking operations. This sinuous track line provided low-angle cross-overs of the scour at 0.5 to 1.0 kilometre intervals along the scour. Along some of the scours, a second survey line was run in order to increase the number of cross-overs. The number of scour cross-overs recorded varied from 10 to 86, depending on the length of the scour and cross-over spacing. Sidescan sonar, echo sounder, microprofiler, and 3.5/7.0 kHz sub-bottom profiler data were collected along each of the scours.

Data Interpretation

Preliminary measurements of most scours were carried out by Shearer Consulting and various personnel at AGC. These were critically reviewed and, where necessary, updated by CSR personal.

The first step in analyzing the scour tracking data was to map the scour in plan view on 1:10000 to 1:40000 scale navigation track charts. The distance along the scour to each cross-over was measured manually from the track chart, and each cross-over was assigned a Kilometre Point (KP) value, representing the distance from the onset of scour tracking. The KP values were used to plot the position of the measured scour parameter values along the rise-up and scour depth profiles.

Scouring Direction

It is important to know the direction of scouring in order to properly interpret the scour rise-up profiles. Scour direction can be determined from various observations of the scour trace on sidescan sonar records. A scour endpoint associated with surrounding berm material generally marks the end of a scour event and is known as a scour termination point. Similarly, partial and/or incomplete termination points are sometimes recognized. However, scour termination points are not always well-defined and may be difficult to distinguish from the scour starting point, particularly if only one endpoint is observed.

In many cases where a scour cross-cut a large, older scour, an asymmetrical cross-cutting soil/debris pile is created. In these cases, the resultant cross-cutting debris within the older scour is concentrated adjacent to the berm first encountered by the newer scour. Similarly, if a scour loops back on itself it will cut across its earlier created berm and the relative age of the cross-cutting scour segments, and hence scouring direction, can be determined.

If scour termination events or cross-cutting relationships can not be recognized scouring direction is more difficult to ascertain. If there is a fairly large change in bathymetry along the length of the scour, the direction of scouring may be inferred to be from deep water to shallower water. However, such an assumption may not always be correct, as several scours were tracked into shallower water depths, at which point they changed direction and continued back into deeper water.

3.4.2 SCOUR PARAMETER MEASUREMENTS

Scour measurements were obtained at each cross-over of the scour. Scour width, incision width, and berm width measurements were obtained from the sidescan sonar records. Bathymetry and scour base elevations, and scour depth were measured from echo sounder records. Infill thickness was measured from microprofiler records. Scour measurements for each scour were compiled in the Scour Parameter Tables contained in Appendix 2. The scour measurements are described below:

FIX

Reference navigation fix number at the cross-over location. Can be used to relocate cross-over on the geophysical profiles.

KP KILOMETRE POINT

Cumulative along-scour distance in kilometres from the beginning of tracking. Measured manually from track chart.

DEPTH TO TOP OF INFILL (A)

Elevation to the top of sediment infill at the base of the scour, measured in metres below sea-level from echo sounder data. Measurement obtained from the deepest part of the scour cross-over. Absolute accuracy is dependent on the sounding system employed as well as weather conditions at the time of survey. The Raytheon DE 719 is rated at +/- 0.5 % of depth (+/- 0.2 metres at 40 metres water depth). Heavy swell conditions may increase the uncertainty significantly.

BATHY BATHYMETRY (B)

Depth from the sea surface datum to the manually smoothed seafloor datum. Due to the irregular surface of scoured seafloor a pre-scour seafloor elevation estimate or smoothed seafloor datum is required to measure scour depth (Gilbert et al., 1989). This datum is visually interpreted to an estimated accuracy of +/- 0.25 metres under optimum conditions. In areas of intense scouring and/or poor data quality due to vessel heave, accuracy may decrease to +/- 0.5 metres.

The echo sounder data was not corrected for tidal variations or the effects of sea-level changes related to storm activity. Thus while measurements of elevation relative to sea-level are expected to be internally consistent during tracking of individual scours, absolute elevation values may vary by +/- 1.0 metre or more. In fact, comparison of echo sounder data collected over the same location during past surveys show variations of up to 2.0 metres to 3.0 metres.

INFILL SCOUR INFILL THICKNESS (C)

Thickness of sediment infill (in metres), obtained from the microprofiler records. The microprofiler is capable of resolution of approximately 0.1 metres. Measurement accuracy is dependent on proper pick of the sub-bottom reflector marking the base of the scour.

DEPTH TO BASE OF INFILL (A+C)

Elevation of the base of scour in metres. Obtained by adding the DEPTH TO TOP OF INFILL and INFILL values. Accuracy is that of component values but, in the case of infilled scours, is also dependent on the match-up of echo sounder and microprofiler cross-over profiles. These two systems were deployed on opposite sides of the survey vessel during the ESRF 1990 survey with a resultant across-track offset of approximately 20 metres. The cross-sections observed on the echo sounder and microprofiler records are rarely identical. In general, in light of the close proximity of the cross-over locations, this is not a problem if the scour infill is due to regional sedimentation processes. However, it is possible to have localized scour infill that is associated with cross-cutting by more recent scours. The depth to the base of infill was not measured, or is qualified, in cases where major differences were observed between the echo sounder and microprofiler profiles.

SCOUR DEPTH TO TOP OF INFILL (A-B)

Maximum scour depth to the top of sediment infill, in metres below the smoothed seafloor as obtained from echo sounder data. Variations in fish height along the sinuous ship's track precluded measurement of scour depth directly from the microprofiler, except in cases where echo sounder data was not available. Measurements obtained from the deepest portion of the scour cross-over. Measurement accuracy is primarily dependent on the selection of the seafloor datum and is estimated to be approximately +/- 0.25 metres under optimum conditions.

SCOUR DEPTH TO BASE OF INFILL (A-B+C)

The maximum scour depth from the smoothed seafloor datum to the base of the scour. Obtained by adding the SCOUR DEPTH TO TOP and INFILL values. Accuracy is that of component values but is also dependent on the match-up of echo sounder and microprofiler scour profiles (see DEPTH TO BASE OF INFILL).

WIDTH SCOUR WIDTH

Berm crest to berm crest width value as defined by the acoustic shadow on sidescan sonar records. Measurement obtained from portion of sidescan record adjacent to cross-over. Estimated measurement accuracy of approximately +/-5 metres.

INWIDTH INCISION WIDTH

The incised width of the main scour keel obtained from sidescan sonar records. This parameter is more difficult to measure from the sidescan records. Measurement obtained from portion of sidescan record adjacent to cross-over. Estimated measurement accuracy, where obtainable, of approximately +/- 5.0 metres.

MKWID MULTI-KEEL WIDTH

Measurement of the overall width of the outer scour dimensions when adjacent outrider keels are present (Scour N90-7 only). Measurement obtained from portion of sidescan record adjacent to cross-over. Estimated measurement accuracy of approximately +/- 5.0 metres.

BERM HEIGHT

Height of each berm from the smoothed seafloor datum to the highest point on the berm crests. Measurements obtained from echo sounder data. Berms were not measured if significant rubble from adjacent scour activity is included in the berm morphology. Measurement accuracy is dependent on the selection of the smoothed seafloor datum, and is estimated to be approximately +/- 0.25 metres

BERM WIDTH

Width of each berm measured from sidescan sonar record adjacent to cross-over. Measurement accuracy of approximately +/- 5.0 metres.

ORIEN		SCOUR ORIENTATION

Scour orientation, calculated from orientation of ship track and angle of scour cross-over on sidescan sonar records. This parameter retained from preliminary scour measurement at AGC (Scour N90-2 only).

3.4.3 SCOUR TRACKING PANEL CONSTRUCTION

Plan View

Survey track lines were imported from the NNAVBASE positioning files. The scour trace was determined from sidescan records and plotted manually. Due to the offset between the sidescan fish and the echo sounder transducer, and the low angle of the scour cross-overs, the fix position of the scour on echo sounder records does not generally coincide directly with the position of the scour as determined form sidescan records. The differences are generally +/- 0.5 Fixes or less. KP distances indicated on the Plan View were measured manually along the tracked length of the scour.

Profiles and Width Chart

The along scour profiles were constructed digitally. Scour parameter measurements were entered into a digital data base and x,y plots produced of KP distance (x co-ordinate) versus appropriate scour parameter measurements (y co-ordinates). For the rise-up profiles, smoothed seabed elevation, elevation to the top of infill and, elevation to the base of the scour were plotted versus KP distance for each cross-over where such measurements were obtained. Individual points were connected using a splined P-line, rather than with straight line segments, in an attempt to best represent the continuous nature of most of the scours.

Points were not plotted for cross-overs where a particular parameter could not be measured. In cases where cross-cut sediment piles (CCSP) obscured the scour base, the elevation to the top of the CCSP was plotted on the rise-up profile. These CCSP points were not considered when drawing the top of infill elevation profile.

Scour Cross-sections

Scour cross-sections were traced from echo sounder records. Scour infill was measured from the corresponding microprofiler cross-over and manually plotted on the tracing made from the echo sounder records. The profiles were scale corrected for speed variations and the angle at which profiles crossed over the scour. These corrections assume a constant vessel speed and direction between adjacent fixes. All cross-sections were constructed such that the viewer of the scour tracking panel is looking in the direction of scouring.

3.5 SCOUR DEPTH RE-MEASUREMENT PROJECT

3.5.1 INTRODUCTION

During the 1990 field survey, a new, high-resolution profiling device was used to measure scour depths. This microprofiler was integrated into CSR's Klein sidescan system thus providing directly linked plan-view and profile imagery. The data generated by the microprofiler was of such high resolution, there was some speculation that the scour depths measured during previous surveys may not be accurate. Figure 3.5.1 is an example of two cross-overs of the same scour; one collected in 1990 using the microprofiler and one collected during the 1989 baseline survey. Since the scour depth parameter is perhaps the most important in determining safe burial depths, it was decided that a scour depth re-measurement study be undertaken for the whole New scour population.

The intent of the study was to use the 1990 survey data to update the depths of previously measured new scours that occur along the same corridors re-surveyed by the 1990 study. The project involved quite a time consuming scour re-location and re-measurement exercise. The results of this study are presented in this section.

3.5.2 SCOUR IDENTIFICATION

The first step in the project was to locate all the previously measured New scours (ie. pre-1990) on the ESRF 1990 sonar data.

The SIPS Arc/Info system was used to assign the closest 1990 Fix and geographic position for each of the pre-1990 scour events. The actual scour parameter values (eg. orientation width etc.) and the 1990 fix positions were used to accurately identify the pre-1990 scours on the 1990 sidescan records. Although relocating the scours was time consuming, the procedure was, in general, very successful. Of the 790 scours available for depth re-measurement, 631 (80%) were successfully located.

3.5.3 DEPTH MEASUREMENT

Scour depth is defined as the distance between a manually smoothed seabed datum and the deepest part of the scour trough. New scour depth values were measured in decimeters from the 1990 microprofiler records.

It should be noted that the measurement of scour depth is somewhat subjective. Potential errors are dependent on proper selection of the seabed datum, variation in tow-fish height caused by ship heave and other environmental factors and the rounding off of depth measurements. Maximum error for old scour depth values present in ECHOBASE is estimated at +/- .21 metres (Gilbert et al 1989). For the purposes of this study, this value will be utilized as the maximum error in measuring any one scour depth value.

Since two depth measurements are being made, a maximum depth difference of 0.42 metres

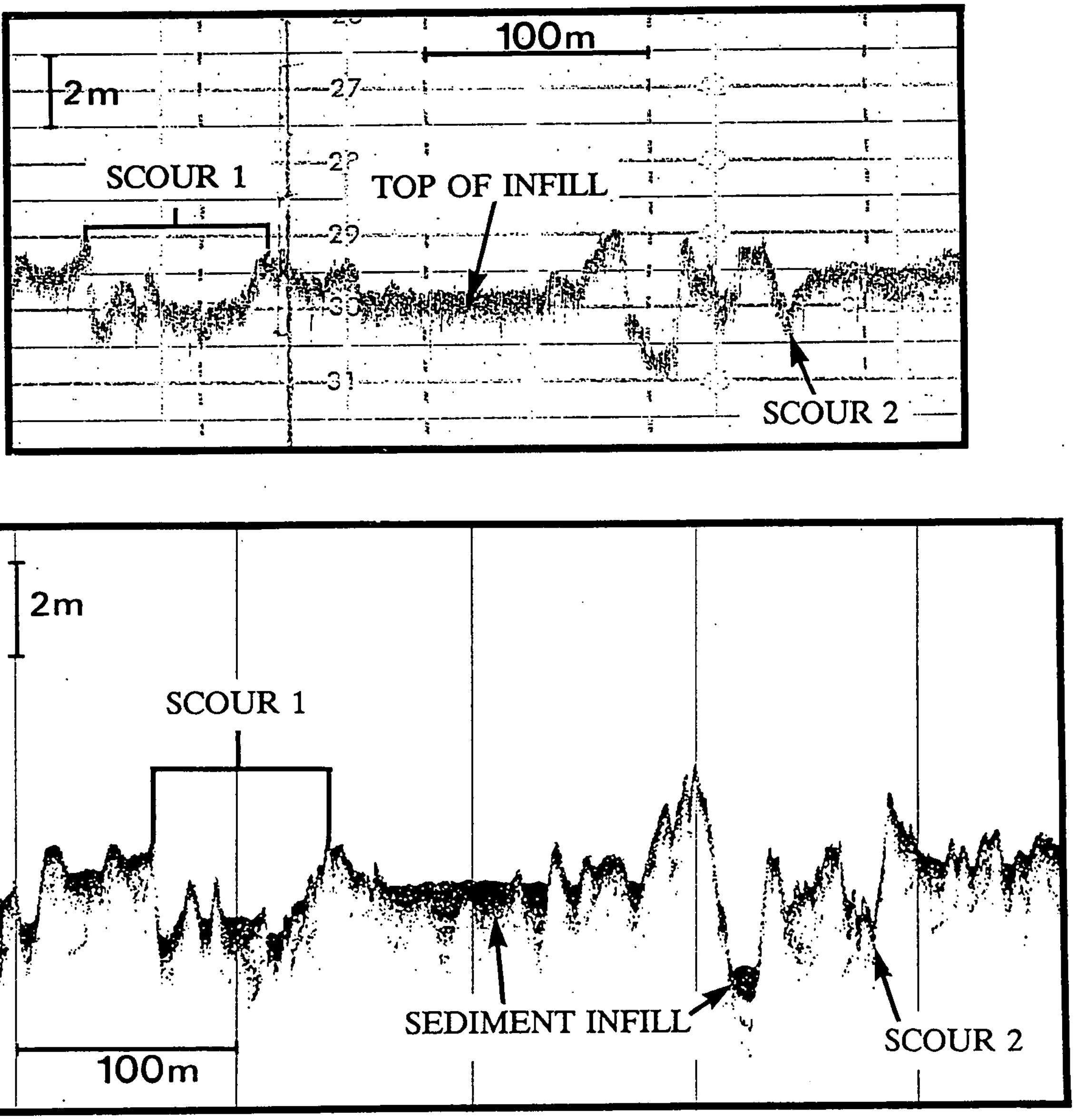


Figure 3.5.1 Comparison of scour profiles on microprofiler and echo sounder records. The microprofiler provides better resolution of the micro-relief associated with scoured seabed sediments. Note that narrow grooves, at the base of Scours 1 and 2, are apparent on the microprofiler record but not on the echo sounder record. The microprofiler also penetrates through sediment infill deposits, and profiles the original base of infilled scours.

(+/-.21m * 2) between new depth and old-depth values may occur for any given scour.

3.5.4 RESULTS

Concern over the relatively high potential error to scour depth ratio led to a two stage assessment of depth re-measurement.

I. In the initial stage of the project, a small population of scours bearing old depths less than 1.0m were measured. These 229 scours had depths > = 0.1m and < 1.0m (Note that scour infill was added to the scour depth where appropriate). Comparison of the mean old-depth with mean new-depth yielded 0.53m and 0.58m, respectively for scours with an old-depth range of > = 0.1 & < 1.0m. The difference between the two mean values amounted to .05m.

II. In light of the potentially high error to depth value ratio for shallow scours and the statistically insignificant difference in mean depth values determined from Phase I of the study, it was decided to measure only those scours with a old-depth of 1.0m or greater in Stage II.

Out of a total of 2297 scours available for possible re-measurement, only 790 were selected for analysis based on the results of Phase I of the study. Of these, new depth measurements were obtained for 631 scours. A number of scours could not be measured as they were; off-line, crosscut by other scours, in regions of poor data, or the scour could not be located. For each measured scour, a quality indicator was given for the re-measurement. A quality of 1 signifies that the measurement confidence is high. Quality of 2 indicates the confidence may be moderate or low. A line-by-line breakdown of the re-measured scours is shown in Table 3.5.1.

In order to statistically compare the mean differences between the scour depths, the population of 631 scours was reduced to eliminate zero scour depth values for both the old and the new depth populations. This resulted in a sample size of 483 scours which included both quality 1 and 2 scour depth values.

The number and percent of scours bearing greater depths resulting from the microprofiler measurement is illustrated in Table 3.5.2. The differences are further illustrated in histogram format in Figure 3.5.2. In this figure, positive values are indicative of microprofiler depth values greater than old depth measurements. The results indicate a fairly equal dispersion about the zero value, with a small bias towards greater values in the positive differences.

Mean scour depth, as a function of individual scour depth classes, is presented in Figure 3.5.3. This figure illustrates that mean microprofiler depth measurements are similar to mean old-depth values across a range of scour depth classes. That is, there is no apparent difference between the two measurements for deep or shallow scours. The most striking observation is an actual decrease in scour depth measurement for scours larger than 2.5m.

Table 3.5.1 Quality of Scour Depth Re-measurements

Line	Attempted Measurement # Scours	Qual=1	Qual=2	Unmeasurable
84-2E	1	1	0	0
84-8B	1	0	0	1
84-8BN	1	1	0	0
84-PULL4	2	0	1	1
84-SAUVC	3	3	0	0
84-TARN1	11	3	3	5
84-TARN2	2	1	0	1
84-TINGN	1	1	0	0
78-PULNK	12	2	8	2
89-7	325	243	22	60
89-8	2	2	0	0
89-10	16	11	4	1
89-11A	68	58	4	6
89-11B	17	12	1	4
89-15B2	19	19	0	0
86-1	66	49	0	17
88-4	1	1	0	0
88-6	103	30	37	36
88-11	8	7	0	1
88-14	3	3	0	0
88-1A	73	57	0	16
88-1B	52	47	0	5
84-8BS	1	0	0	1
89-13	1	0	0	1
88-7	1	0	0	1
Total	790	551	80	159

Notes:

1. Un-measurable scours are scours that could not be measured because they were either off-line, other scours were crossing over, poor data, or the scour could not be re-located on the ESRF 1990 records.

2. Measurements were attempted for all baseline scours for Line 89-7

3. Only scours with old-depths > = .5 metres were measured for lines 86-1, 88-1A, and 88-1B. Only scours with old-depths > = 1.0 metres were examined for all remaining lines.

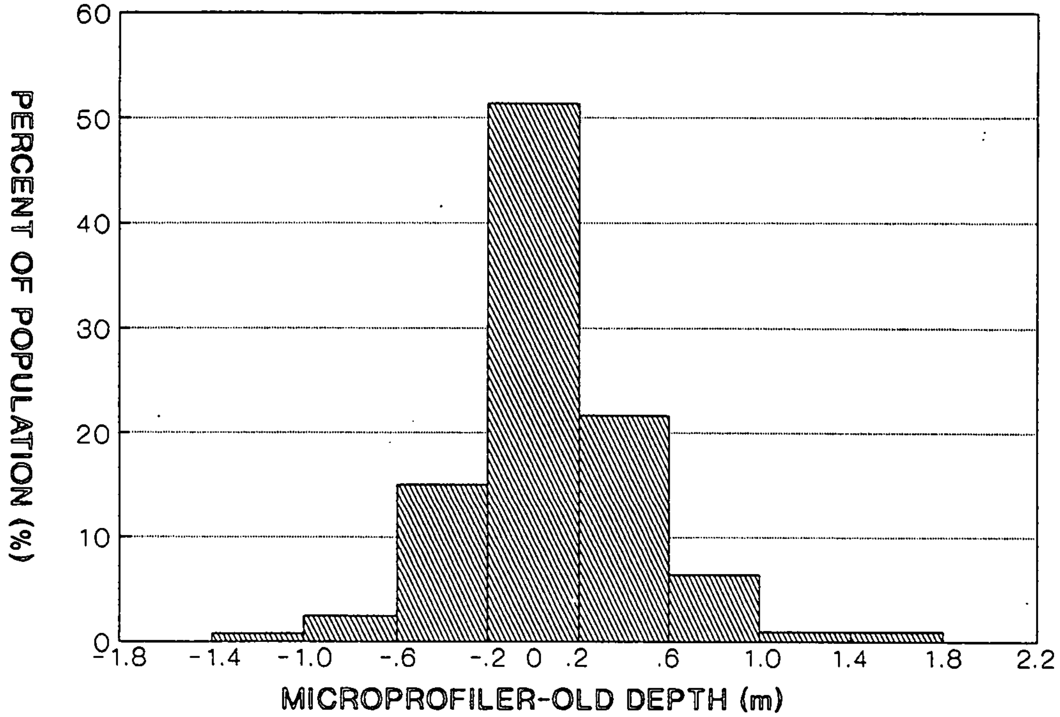


Figure 3.5.2 Histogram showing the difference in old depth measurements and ESRF 1990 scour depth measurements for all scours in which both depth values were greater than zero (n=483).

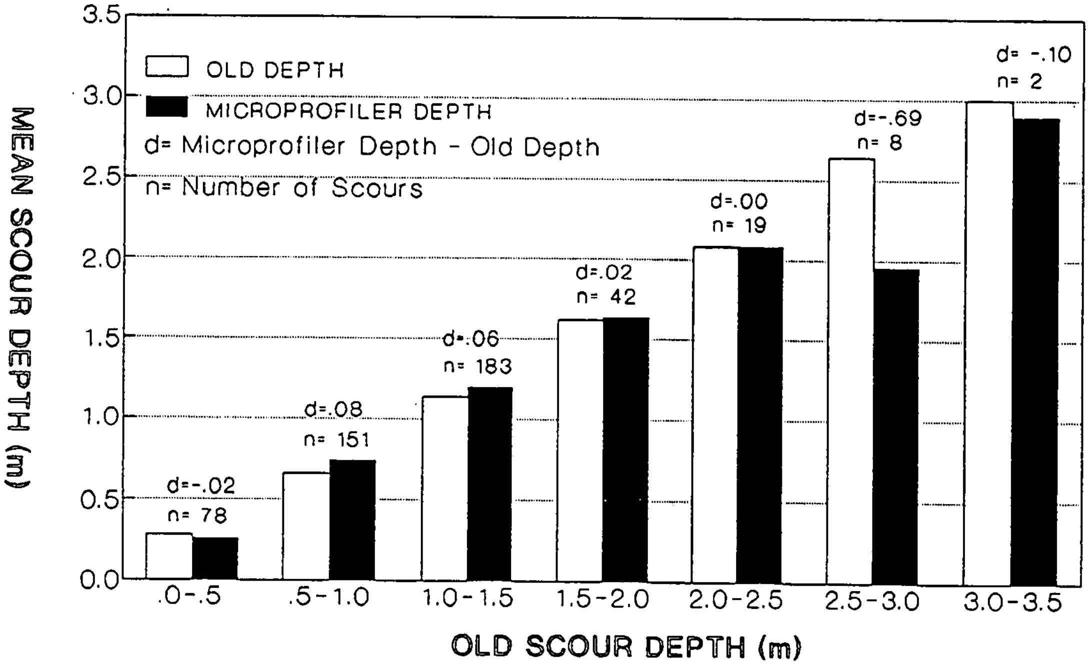


Figure 3.5.3 Histogram showing average old depth and ESRF 1990 microprofiler depth, calculated for 0.5 metre bin intervals.

This may be a result of the small population (n=10) and data quality factors. When higher data quality is isolated, the differences are still negative, but are closer to zero.

Table 3.5.2 Scour Depth Comparison

DIFFERENCE BETWEEN DEPTHS	NUMBER	PERCENT
Microprofiler Depth < Old Depth	196	40.6%
Microprofiler Depth = Old Depth	77	15.9%
Microprofiler Depth > Old Depth	210	43.5%
TOTAL:	483	100.0%

3.5.5 CONCLUSIONS

Conclusions from the scour depth re-measurement project are as follows:

- New depth values could not be obtained for all scours examined in the study. Mean new depth values are, on average, only slightly greater than mean old-depths.
- New depth values for individual scours may be greater than or less than old-depth values for any given scour.
- Often the 1990 track lines and old track lines do not directly overlie one another. As a result, some of the differences in new versus old-depth values may occur due to "sampling" the depth of the scour at two different locations.
- Variations in tow-fish height due to slight changes in ship speed and/or course were often observed on the microprofiler records. Such variations often made the selection of the smoothed seabed datum more difficult, possibly introducing the potential for increased depth measurement error.
- Some lines appear to have consistently lower new depth values (i.e. 78-PULNK), while others appear to have predominantly larger new depth values (i.e. 88-1B). This raises the possibility that factors other than the higher resolution of the microprofiler may be responsible for some of the variation in new versus old-depth measurements (i.e. older scours could be degrading on PULNK, variations in weather conditions/sea states for different years could result in better or worse depth measurements, etc.). Analysis on a line by line basis were beyond the scope of this study.
- The new depth values were used to replace the old-depth values in the data base, but the old-depth values were also retained for future use should the need arise. The replacement was undertaken primarily to standardize the scour depth results

on the "microprofiler standard". The microprofiler has a higher resolution which appears to better resolve "spiky" scour troughs, thus providing a better scour depth estimate especially for deeper scours. Figure 3.5.1 provides one such example. The microprofiler also penetrates recent clay infill of scour troughs, and there is no layback when the microprofiler and sidescan are employed in the same tow-fish.

This study also serves as a useful cross-check on previously measured scour depths. For a population of 631 re-measured scours, the variations in measurements were not considered statistically significant. The variations that did occur are thought to be more related to irresolvable study limitations, rather than measurement error. The capacity to correct the microprofiler record for variations in tow-fish height would improve the display and allow for greater depth measurement accuracy.

4.0 RESULTS

The ESRF 1990 survey collected approximately 1389 line kilometres of repetitive mapping data. A total of 2291 new scour events, formed over the previous one to eight years prior to the 1990 field season, were identified and measured from the 1990 survey data. The updated version of NEWBASE now contains 5329 new scour events that have been identified from repetitive mapping data sets collected between 1978 and 1990. This represents a substantial population size for statistical analyses, spatial and temporal distribution studies using a GIS-platform, and modelling of scour occurrence. Independent studies undertaken with the updated version of NEWBASE have helped to confirm the validity and utility of the data base (Nessim and Hong, 1992; Shearer, 1996a). Although the updated version of NEWBASE contains a relatively large number of scour records, extreme scour events, defined as those with a scour depth of 2.0 metres or greater (Nessim and Hong, 1992), account for only 2.3% of the total new scour population observed to date.

A preliminary exploration of the updated new scour data base (NEWBASE) is contained in Section 4.1. The spatial distribution of new scour events is addressed in Section 4.2. Section 4.2 also includes a discussion of scour impact rates, calculated for the scours recorded during the ESRF 1990 survey. The results of the scour tracking surveys conducted in 1989 and 1990, including scour rise-up analysis of seven scours, are presented in Section 4.3.

4.1 NEWBASE DATA EXPLORATION

A total of 2291 new scours were identified from 1389 line kilometres of sidescan sonar records collected during the ESRF 1990 repetitive mapping survey. Extreme scour events, defined as those with a scour depth of 2.0 metres or greater (Nessim and Hong, 1992), account for 3.1% of the new scours identified on the 1990 data.

The new scour data base (NEWBASE) now contains 5329 geographically-referenced scour records, each of which contains key scour parameters such as scour depth, scour width, water depth, and maximum age. Table 4.1.1 is a printout from NEWBASE, displaying a sample of scour parameter and survey data recorded for each new scour event. A complete description of each NEWBASE data field can be found in Appendix 1. A comprehensive statistical analysis of NEWBASE was beyond the scope of this study. See Shearer (1996a and 1996b) for a more detailed examination of scour parameters.

This section outlines some key changes to NEWBASE resulting from the ESRF 1990 update, and provides an overview of the updated version of the new scour data base. Table 4.1.2 provides a comparison of average and maximum values of scour depth and scour width, as well as, the number of extreme scours (i.e. scour depth of 2.0 metres or greater) for the pre-1990 update new scours (n=3038), the new scours recorded in during the ESRF 1990 (n=2291), and the updated version of NEWBASE (n=5329).

An additional 72 extreme scour events (scour depth of 2.0 metres or greater) were recorded in the 1990 update. This brings the total number of extreme scours to 122, representing

Table 4.1.1 Sample of NEWBASE Printout

COMPANY	YEAR	LINE	OPART	FIX	HEAD	EASTING	NORTHING	ORIENT	FORM	MORPH	SMOOTH	MAGE	LEN	WID	AREA	INWID	INWIDQL	MKNUM	MKWID	DEPTH	SBP	SFILL	SSDEF	STHK	STYPE	BATHY	QUAL	PCOMP	PYEAR	SOURCE	COMMENT
ESRF	90	3	2	335.5	255	517393	7775181	126	2	5	7	1	1008	46	46368	40	P			1.3	15	.	.	99.0	C	27	P	NAHE	89	C	
ESRF	90	3	2	364.9	254	511713	7773507	158	1	4	7	1	359	8	2872	6	F			1.4	15	.	.	99.0	C	27	P	NAHE	89	C	
ESRF	90	3	2	370.0	254	510866	7773240	22	2	4	9	1	124	19	2356	17	P			1.3	15	.	.	99.0	C	27	P	NAHE	89	C	PSD
ESRF	90	3	2	370.1	254	510851	7773231	37	2	5	8	1	237	16	3792	13	P			1.8	15	.	.	99.0	C	27	P	NAHE	89	C	PSD
ESRF	90	3	3	376.0	254	509737	7772921	69	2	4	8	1	238	50	11900	43	F			1.2	15	.	.	99.0	C	28	P	NAHE	89	C	
ESRF	90	3	3	396.8	254	505759	7771771	7	1	4	8	1	297	9	2673	5	F			1.3	15	.	.	99.0	C	29	F	NAHE	89	C	
ESRF	90	3	3	443.1	254	496890	7769172	135	1	4	9	1	737	13	9581	10	P			1.4	15	.	.	99.0	C	32	F	NAHE	89	C	PSD
ESRF	90	3	3	587.9	254	469067	7761240	163	1	4	9	1	156	11	1716	6	P			1.1	15	.	.	99.0	C	25	P	NAHE	89	C	PSD
ESRF	90	3	3	609.1	254	464996	7760103	105	2	5	8	1	662	40	26480	38	P			0.3	15	.	.	99.0	C	23	P	NAHE	89	C	PSD
ESRF	90	3	3	610.9	254	464653	7760000	178	2	5	8	1	264	111	29304	108	P	1	170	1.3	15	.	.	99.0	C	23	P	NAHE	89	C	
ESRF	90	3	3	611.4	254	464558	7759969	3	2	4	9	1	156	12	1872	10	P	1	170	0.5	15	.	.	99.0	C	23	P	NAHE	89	C	PSD
ESRF	90	3	3	611.6	254	464519	7759956	2	1	4	9	1	166	4	664	2	P	1	170	0.2	15	.	.	99.0	C	23	P	NAHE	89	C	PSD
ESRF	90	3	3	612.1	254	464424	7759926	33	2	5	8	1	212	18	3816	15	P			0.3	15	.	.	99.0	C	23	P	NAHE	89	C	
ESRF	90	3	3	614.3	254	464000	7759798	1	1	5	8	1	234	9	2106	6	P			0.2	15	.	.	99.0	C	23	P	NAHE	89	C	PSDD
ESRF	90	3	3	626.4	254	461664	7759142	167	2	5	8	1	99	46	4554	43	P			0.0	5	.	.	99.0	C	22	P	NAHE	89	C	
ESRF	90	3	3	655.4	254	456107	7757556	170	2	4	8	1	311	198	61578	196	P			0.8	15	.	.	99.0	C	21	P	NAHE	89	C	
ESRF	90	3	3	665.3	254	454205	7757000	84	2	4	8	1	224	18	4032	15	P			0.6	15	.	.	99.0	C	21	P	NAHE	89	C	PSD
ESRF	90	3	3	667.5	254	453784	7756877	37	2	6	7	1	145	18	2610	10	P			2.0	15	.	.	99.0	C	21	P	NAHE	89	C	PSD
ESRF	90	4	1	676.8	195	448244	7753844	121	1	5	8	1	334	4	1336	3	P			1.4	15	.	.	99.0	C	20	P	NAHE	89	C	
ESRF	90	4	1	678.3	195	448159	7753498	160	1	5	8	1	148	8	1184	5	P			0.9	15	.	.	99.0	C	20	P	NAHE	89	C	
ESRF	90	4	1	679.2	195	448117	7753318	121	2	5	8	1	161	52	8372	45	P			1.1	15	.	.	99.0	C	20	P	NAHE	89	C	IN/OUT
ESRF	90	4	1	680.4	195	448059	7753085	93	2	5	8	1	351	25	8775	19	P			1.2	15	.	.	99.0	C	20	F	NAHE	89	C	
ESRF	90	4	1	680.7	195	448044	7753028	82	1	4	9	1	249	19	4731	14	P			1.7	15	.	.	99.0	C	19	F	NAHE	89	C	
ESRF	90	4	1	680.8	195	448039	7753009	18	2	5	8	1	451	33	14883	31	P			1.2	15	.	.	99.0	C	19	F	NAHE	89	C	
ESRF	90	4	1	683.9	195	447871	7752412	150	2	5	8	1	300	152	45600	148	P			2.3	15	.	.	99.0	C	19	F	NAHE	89	C	
ESRF	90	4	1	691.2	195	447473	7751002	76	2	4	7	1	370	43	15910	37	P			2.0	15	.	.	99.0	C	18	F	NAHE	89	C	
ESRF	90	4	1	692.5	195	447413	7750759	98	1	4	9	1	190	8	1520	5	P			0.8	15	.	.	99.0	C	18	P	NAHE	89	C	PSD
ESRF	90	4	1	693.0	195	447388	7750673	60	2	4	8	1	461	158	72838	155	P			0.8	15	.	.	99.0	C	18	P	NAHE	89	C	PSD
ESRF	90	4	1	693.4	195	447372	7750607	62	2	5	8	1	360	63	22680	58	P			2.3	15	.	.	99.0	C	18	P	NAHE	89	C	PSD
ESRF	90	4	1	702.5	195	446894	7748850	76	2	4	7	1	380	315	119700	311	P			2.9	15	.	.	99.0	C	18	F	NAHE	89	C	
ESRF	90	4	1	711.1	195	446433	7747177	130	1	4	8	1	150	2	300	1	P			0.2	15	.	.	99.0	C	17	P	NAHE	89	C	PSDD
ESRF	90	4	1	711.9	195	446387	7746981	66	2	4	8	1	409	17	6953	14	F			1.0	15	.	.	99.0	C	17	F	NAHE	89	C	
ESRF	90	4	1	741.4	195	444902	7741107	130	1	4	8	1	168	9	1512	6	P			1.7	15	.	.	99.0	C	15	F	NAHE	89	C	
ESRF	90	4	1	750.7	195	444534	7739280	63	2	5	8	1	396	32	12672	28	P			0.9	15	.	.	99.0	C	15	F	NAHE	89	C	PSD
ESRF	90	4	1	755.3	195	444160	7738464	112	2	4	8	1	211	35	7385	29	F			2.7	15	.	.	99.0	C	15	F	NAHE	89	C	
ESRF	90	5	1	787.4	147	446323	7728857	57	2	4	7	1	322	49	15778	46	F			0.6	15	.	.	99.0	C	12	P	NAHE	89	C	
ESRF	90	5	1	787.8	147	446370	7728789	26	2	5	7	1	361	40	14440	37	P			0.3	15	.	.	99.0	SI	12	P	NAHE	89	C	
ESRF	90	5	1	798.4	147	447511	7727013	58	1	4	8	1	220	9	1980	6	P			0.2	15	.	.	99.0	SI	11	F	NAHE	89	C	
ESRF	90	5	1	798.5	147	447521	7726996	48	1	4	8	1	238	9	2142	7	P			0.2	15	.	.	99.0	SI	11	F	NAHE	89	C	
ESRF	90	5	1	798.6	147	447530	7726978	54	1	4	8	1	93	7	651	4	P			0.2	15	.	.	99.0	SI	11	F	NAHE	89	C	PSD
ESRF	90	5	1	799.8	147	447656	7726784	42	1	4	8	1	254	4	1016	3	P			0.4	15	.	.	99.0	SI	11	F	NAHE	89	C	
ESRF	90	5	1	799.9	147	447666	7726768	47	1	4	8	1	259	6	1554	3	P			0.2	15	.	.	99.0	SI	11	F	NAHE	89	C	
ESRF	90	5	1	811.4	147	448890	7724831	18	1	5	8	1	252	3	756	2	P			0.3	15	.	.	99.0	SI	10	F	NAHE	89	C	
ESRF	90	5	1	811.7	147	448931	7724783	32	1	4	7	1	350	11	3850	8	F			0.5	15	.	.	99.0	SI	10	F	NAHE	89	C	
ESRF	90	5	1	812.8	147	449061	7724595	24	1	4	8	1	310	3	930	2	P			0.2	15	.	.	99.0	SI	10	F	NAHE	89	C	
ESRF	90	5	1	813.2	147	449102	7724525	47	2	4	7	1	325	31	10075	29	P			0.3	15	.	.	99.0	SI	10	F	NAHE	89	C	
ESRF	90	5	1	813.7	147	449151	7724438	32	2	5	8	1	382	64	24448	62	P			0.4	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	814.1	147	449192	7724369	54	1	4	8	1	291	5	1455	3	P			0.1	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	815.2	147	449322	7724193	47	2	4	8	1	290	92	26680	88	P			0.6	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	815.5	147	449353	7724141	31	2	4	8	1	311	160	49760	157	P			0.3	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	816.5	147	449457	7723969	3	2	4	8	1	459	90	41310	85	P			0.6	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	818.2	147	449645	7723682	27	2	4	8	1	339	18	6102	15	F			0.3	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	818.8	147	449701	7723580	51	1	4	8	1	270	5	1350	3	F	1	450	0.5	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	820.1	147	449850	7723364	45	2	5	8	1	330	33	10890	30	F	1	450	0.3	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	821.2	147	449975	7723185	51	2	4	8	1	257	35	8995	30	P	1	450	0.4	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	822.6	147	450122	7722952	39	2	5	8	1	340	26	8840	23	P			0.3	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	823.3	147	450202	7722835	22	1	4	7	1	345	10	3450	7	P			0.6	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	824.1	147	450270	7722695	41	2	5	7	1	248	13	3224	10	F			0.5	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	824.6	147	450309	7722607	31	2	5	7	1	354	26	9204	22	F			0.5	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	825.3	147	450386	7722490	73	1	5	7	1	343	25	8575	21	F			0.5	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	826.6	147	450555	7722277	53	2	5	8	1	282	21	5922	19	P			0.3	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	827.0	147	450598	7722208	41	2	4	8	1	205	23	4715	20	F			0.3	15	.	.	99.0	SI	9	F	NAHE	89	C	
ESRF	90	5	1	831.6	147	451091	7721437	14	1	5	8	1	387	6	2322	4	P	2	30	0.3	15	.	.	99.0	SI	8	F	NAHE	89	C	
ESRF	90	5	1	831.8	147	451112	7721403	14	1	5	8	1	380	5	1900	4	P	2	30	0.2	15	.	.	99.0	SI	8	F	NAHE	89	C	
ESRF	90	5	1	838.9	147	451860	7720211	25	1	6	8	1	335	12	4020	10	P	0	0	0.2	15	.	.	99.0	SI	8	F	NAHE	89	C	PSD
ESRF	90	5	1	841.4	147	452145	7719801	42	2	5	7	1	174	21	3654	19	P			0.2	15	.	.	99.0	SI	8	P	NAHE	89	C	
ESRF	90	5	1	841.9	147	452200	7719717	33	2	5	8	1	289	11	3179	10	P			0.1	15	.	.	99.0	SI	8	F	NAHE	89	C	
ESRF	90	6	1	862.1	236	451295	7716673	2	2	4	8	1	199	30	5970	27	F			0.1	15	.		99.0	SI	7	F	NAHE	89	C	
ESRF	90	6	1	886.2	236	447293	7713991	14	1	4	8	1	253	14	3542	10	P			0.2	15	.		99.0	SI	7	F	NAHE	89	C	
ESRF	90	6	1	898.5	236	445245	7712617	22	2	5	8	1	289	32	9248	30	P			0.2	15	.		99.0	SI	7	F	NAHE	89	C	
ESRF	90	6	1	932.3	236	439630	7708853	151	2	4	9	1	178	21	3738	18	P			0.3	15	.		99.0	SI	8	F	NAHE	89	C	
ESRF	90	6	1	932.5	236	439597	7708830	114	2	5	8	1	257	41	10537	38	P			0.6	15	.		99.0	SI	8	F	NAHE	89	C	
ESRF	90	6	1	944.2	236	437638	7707548	141	1	4	7	1	316	18	5688	17	P			0.3	15	.		99.0	SI	8	F	NAHE	89	C	
ESRF	90	6	2	960.2	236	434977	7705763	125	2	4	8	1	260	50	13000	42	P			0.3	15	.		99.0	SI	9	F	NAHE	89	C	PSDW

approximately 2.3% of the total number of scours recorded in the updated version of NEWBASE. The maximum observed scour depth increased from 3.6 metres (pre-1990 survey) to 4.0 metres (1990 survey).

The maximum water depth for a new scour occurrence increased from 36-37 metres (pre-update) to 37-38 metres (ESRF 1990 update). An additional 33 scours in water depths greater than 30 metres were recorded in the ESRF 1990 update. Average and maximum scour width increased respectively from 25 metres and 575 metres, prior to the update, to 31 metres and 1281 metres for the updated version of NEWBASE.

Of the 5329 scour events recorded in NEWBASE, a total of 1086 have a recorded scour depth of 0.0 metres. These include 579 new scours (431 pre-1990 scours; 148 ESRF 1990 scours) which were observed on only sidescan records and whose depths could not be measured since the scours did not cross the survey line. These records are identified in the SBP field and should not be used in scour depth analysis. An additional 507 pre-ESRF 1990 scours which did cross the survey line have a recorded depth of 0.0 metres. The 0.0 metre depth values for these scours largely reflects a lack of positive scour correlation between sidescan and echo sounder records. This problem is generally only encountered for very shallow scours with scour depths less than 0.5 metres. The recorded scour depth values of 0.0 metres is probably quite close to the true scour depth for these 507 scours, and could possibly be incorporated into statistical analysis of scour depth. The inclusion of the third channel microprofiler display, in the ESRF 1990 survey, enabled positive identification of shallow scours which in previous years could not be measured from the echo sounder records.

Statistical analysis results for scour depth distribution will vary depending on whether or not scours which crossed the survey line, and have a recorded depth of 0.0 metres, are included. For example, if only those scours with a recorded depth greater than 0.0 metres are considered, average scour depth is 0.59 metres for the pre-1990 update (n=2100), 0.55 metres for the ESRF 1990 records (n=2143), and 0.57 for the entire updated NEWBASE (n=4243). In contrast, when all scours which crossed the survey line are considered, including those with a recorded value of 0.0, the average depth values are as follows; 0.48 metres for the pre-ESRF 1990 scours (n=2607), 0.55 metres for the ESRF 1990 scours (n=2143), and 0.51 metres for the updated version NEWBASE (n=4750). In the following sections all scours which cross the survey line (n=4750) are included in the scour depth distribution plots.

4.1.1 SCOUR PARAMETER EXPLORATION

Figure 4.1.1 illustrates the distribution of all new scour events according to water depth. Very few scours were recorded in water depths less than 6 metres. This is primarily due to an absence of repetitive mapping data in shallow water areas. Most new scour events occur in water depths ranging from 6 metres to 30 metres. The distribution of new scour occurrences is not uniform within these water depths. For example, some 140 new scours are recorded in the 19-20 metre bathymetric interval, while 375 scours are recorded in the 21-22 metre interval. These differences may represent a process-related distribution (i.e.

such as variations in the location of the landfast ice edge) or may reflect the survey coverage (i.e. variations in the total survey line kilometres within different bathymetric intervals). The number of new scour events decreases significantly in water depths greater than 30 metres. Nevertheless, including the ESRF 1990 survey, 86 scours were recorded in water depths of 30 metres or more. The deepest water new scour occurrence recorded to date is a multi-keeled scour, 9.0 metres wide and 0.4 metres deep, located in water depths of 37 to 38 metres.

Figure 4.1.2 shows the distribution of scour depth, binned at 0.5 metre intervals, for all new scour events which crossed the survey line. The scour depth distribution is highly skewed. The number of events within each scour depth bin appears to decrease exponentially with increasing scour depth. Approximately 59% of new scours which crossed the survey line have scour depths less than 0.5 metres, and 83% have depths of less than 1.0 metres. Approximately 2.5% of the scours have depths equal to or greater than 2.0 metres. Nessim and Hong (1992) conclude that scour depth decreases exponentially for scour depths less than 1.5 metres, while scour depths in excess of 1.5 metres are best described by a Gamma or Weibull distribution. Maximum recorded scour depth appears to be dependent on water depth; within 10 metre bathymetric intervals, maximum depth values are 1.6 metres (0m<10 m interval), 2.9 metres (10m<20m interval), 4.0 metres (20m<30m interval), and 3.6 metres (30m<40m interval).

The distribution of several scour parameters such as scour depth, scour width, and scour form vary with water depth. Table 4.1.3 shows the distribution of scour form, scour morphology and scour smoothness according to 10 metre water depth intervals. In water depths of less than 10 metres, the number of single-keel scours is roughly the same as the number of multi-keel scours. In water depths greater than 20 metres, multi-keel scours are roughly three times more abundant than single keel scours. Scours with a linear morphology are more abundant than arcuate or sinuous scours for all water depth classifications. The sinuous scour classification is the least common scour morphology recorded within each 10 metre bathymetric interval. The relative abundance of linear morphology may be partly due to the limited length of any particular scour recorded on the sidescan swath (versus the gentle arcuate nature of most tracked scours in Section 4.3).

The lateral extent of possible damage to a sub-sea installation caused by an ice keel is partly a function of the impacting keel's width. Average scour width for the new scour data base increases from 28.5 metres, in the 0 to 10 metres water depth interval, to 34.0 metres in water depths greater than 20 metres (Table 4.1.4). The median width value also increases progressively with increasing water depth interval. The difference between the median and average width values, within each of the 10 metre water depth intervals, indicates that the average scour width is influenced by a relatively small number of very wide scours. A total of 298 new scours have recorded widths of 100 metres or more. There appears to be little variation in the relative abundance of these wide scour events with respect to bathymetry. The increase in both the average and median scour width values for scours recorded in deeper water partly reflects an increase in the relative abundance of multi-keel scours, as well as, a slight increase in average single-keel scour width.

Table 4.1.2 Comparison of New Scour Statistics

	PRE-1990 DATABASE	NAHIDIK 1990 SCOURS	UPDATED NEWBASE
Total Number of Scours	3038	2291	5329
Maximum Scour Depth (m)	3.60	4.00	4.00
Average Scour Depth for All Scours (m)	0.41	0.51	0.45
Number of Scours with Depth >0.0m	2100	2143	4243
Average Scour Depth (Depths >0.0m)	0.59	0.55	0.57
Maximum Scour Width (m)	575	1281	1281
Average Scour Width (m)	24.83	38.68	30.78
Number of Extreme Scours (> =2.0 m depth)	50	72	122
Number of Deep Water Scours (> =30 m W.D.)	53	33	86
Deepest Water Scour (m)	36-37	37-38	37-38
Number of Scours with Infill >0.0m	26	141	167
Maximum Infill Thickness (m)	1.0	1.5	1.5
Average Infill; Scours with Measured Infill (m)	0.33	0.20	0.21

Table 4.1.3 NEWBASE Exploration; Scour Form, Morphology, and Smoothness

	SCOUR FORM			SCOUR MORPHOLOGY			SMOOTHNESS			
WATER DEPTH	Single Keel	Multi Keel	Zone of Multi Keels	Linear	Arcuate	Sinuous	Very Rough	Rough	Semi Smooth	Smooth
0-10 m	627	666	0	681	417	195	191	472	548	82
10-20 m	827	1372	3	1267	624	311	212	1110	858	22
20-30 m	424	1322	2	1069	507	172	284	960	501	3
30-40 m	20	66	0	60	19	7	14	50	22	0
TOTALS	1898	3426	5	3007	1567	685	701	2592	1929	107

Table 4.1.4 NEWBASE Exploration; Scour Width Parameter

WATER DEPTH	WIDTH RANGE	AVERAGE WIDTH	MEDIAN WIDTH	N	# SCOURS > =100m
0-10	1-1281	28.5	10	1293	64
10-20	1-974	29.4	14	2202	116
20-30	1-501	34.4	20	1748	114
30-40	2-263	34.0	23	86	4
TOTAL	1-1281	30.9	15	5329	298

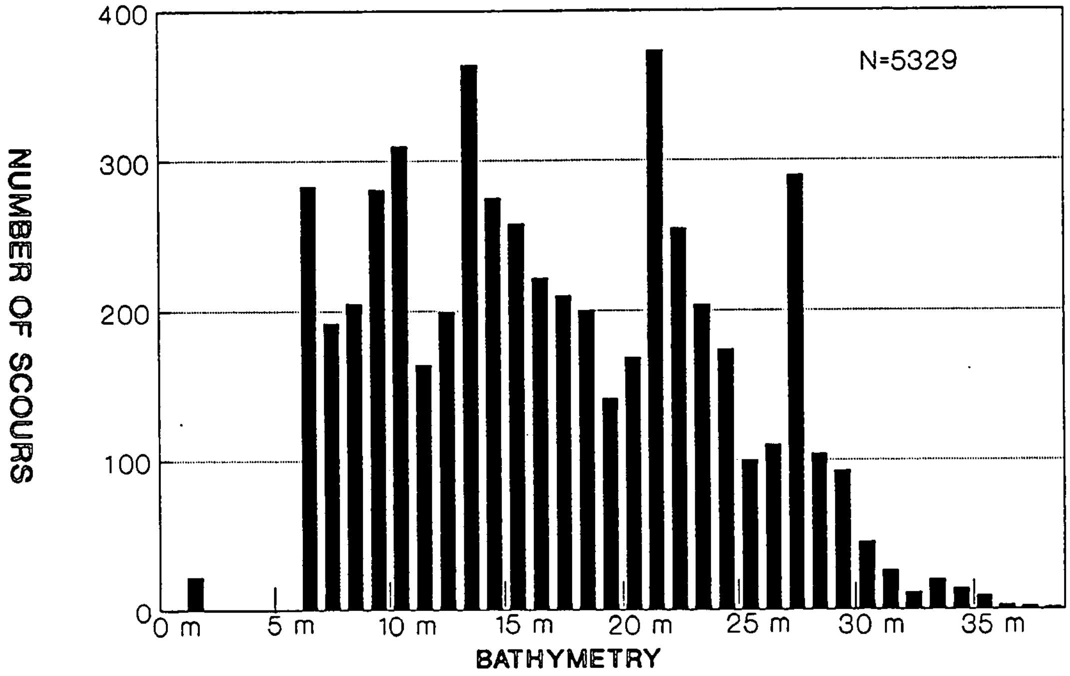


Figure 4.1.1 Histogram showing the distribution of all new scour events according to bathymetry.

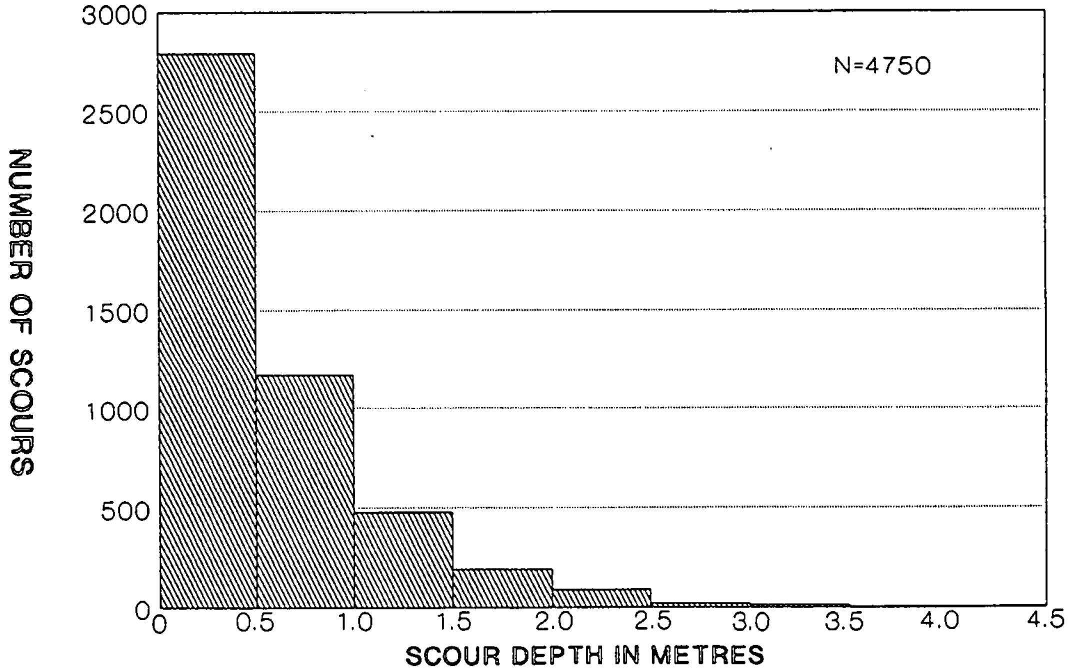


Figure 4.1.2 Histogram showing scour depth, binned in 0.5 metre intervals, for all scours which cross the survey line (n=4750).

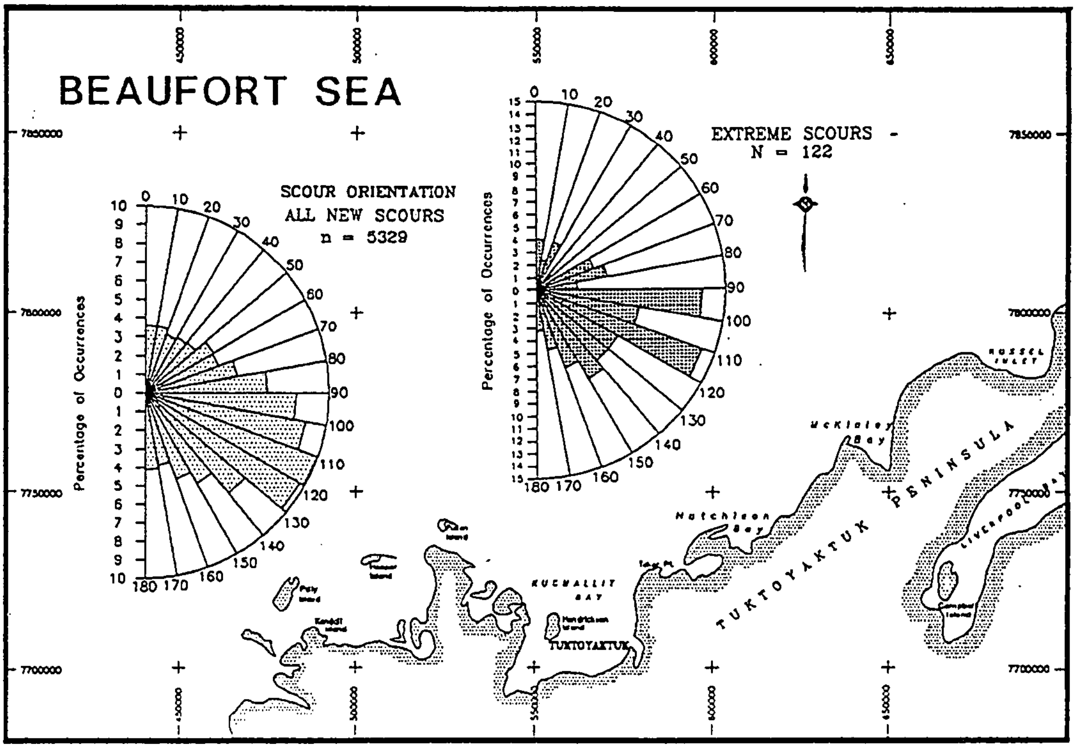


Figure 4.1.3. Rose diagram illustrating scour orientation for all NEWBASE records and for the sub-set of extreme scours (scour depth 2.0 metres or greater).

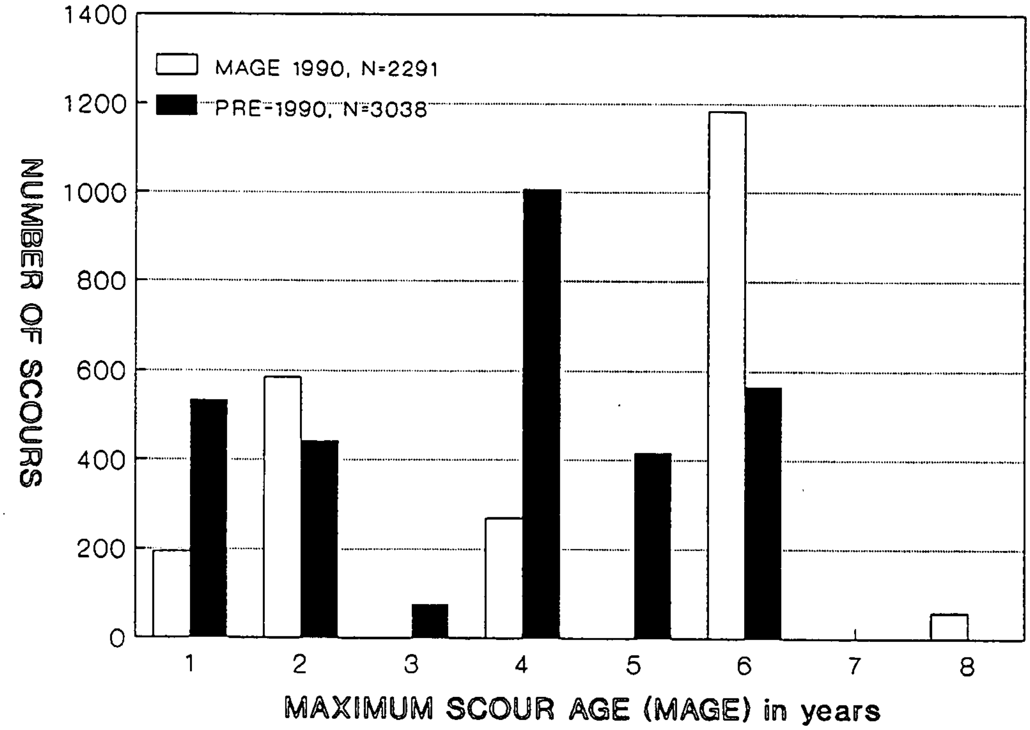


Figure 4.1.4 Histogram illustrating maximum scour age (MAGE) for all NEWBASE records.

Figure 4.1.3 shows the distribution of scour orientation for all new scour events recorded in NEWBASE. Orientation values are recorded, by convention, from 0° to 179°, and do not infer actual scouring direction. Although a significant number of scours fall within each of the 10° orientation intervals, a strong preferred orientation component occurs between 80° to 140°. The distribution of ice scour orientations is very similar to predominant yearly ice movements reported by Dickens et al. (1991). The most common scour orientation values fall within the 110° to 130° interval. Similar trends are apparent for the sub-set of extreme scour events.

The degree of local variation in observed new scour impact rates is, in part, a function of the elapsed time between successive surveys (See Section 4.2). In general, the greatest variation in impact rates, and the highest calculated rates, occur along lines for which only one or two years have elapsed since the previous survey. The maximum age of a scour (MAGE) represents the number of years that have elapsed since that portion of survey line on which the scour occurs was last surveyed. Figure 4.1.4 shows the MAGE of all new scours recorded to date. Approximately 34% of the new scours recorded during the ESRF 1990 update survey have a maximum age of 1-2 years while 52% have a maximum age of 6 years. The updated version of NEWBASE contains 1753 records with a maximum scour age of 1-2 years (approx. 33% of data base) and 3442 records with a maximum scour age of 4-6 years (approx. 65% of data base). The remaining 134 scour records, representing less than 3% of all NEWBASE records, have a maximum scour age of either 3 years or 8 years. NEWBASE contains a significant scour population recorded during surveys one or two years apart (n=1753), allowing for future comparison of maximum yearly impact rates.

4.1.2 SCOUR DEPTH DISTRIBUTION

Figure 4.1.5 shows the distribution of scour depth for all scours which cross the survey line (n=4750), binned at 0.5 metre intervals, in successive 10 metre bathymetric intervals. In water depths of less than 10 metres, 93% of the scours have depths less than 0.5 metres, while less than 1% of scours have depths exceeding 1.0 metres. In water depths of 10 to 20 metres, the abundance of scours with depths less than 0.5 metres drops to 59%, and approximately 13% of scours have depths of 1.0 metres or greater. In the 20-30 metre interval, 33% of scours have depths of 1.0 metres or greater, while 6% have depths of 2.0 metres or greater. These percentages increase to 35% (>=1.0 metre) and 8% (>= 2.0 metre) respectively for the 30-40 metre water depth interval. It is clear from the histograms presented in Figure 4.1.5, that scour depth distribution varies according to water depth. In shallow water depths, scours are predominantly less than 0.5 metres deep. As water depth increases, the relative abundance of scours in the shallow depth range decreases, and the upper-range tail of the depth distribution is much more pronounced.

The variation in scour depth distribution with changing water depth is illustrated in greater detail by plotting the relative percentage of scour depths, binned in one metre intervals, for each one metre bathymetric interval (Figure 4.1.6). Extreme scours (depth>=2.0 metres) are restricted to water depths ranging from 13 metres to 36 metres, and scours with depths of 3.0 metres or greater occur in water depths ranging from 23 to 31 metres. A significant increase in the relative percentage of scours with depths of 1.0 metre or greater, and scours

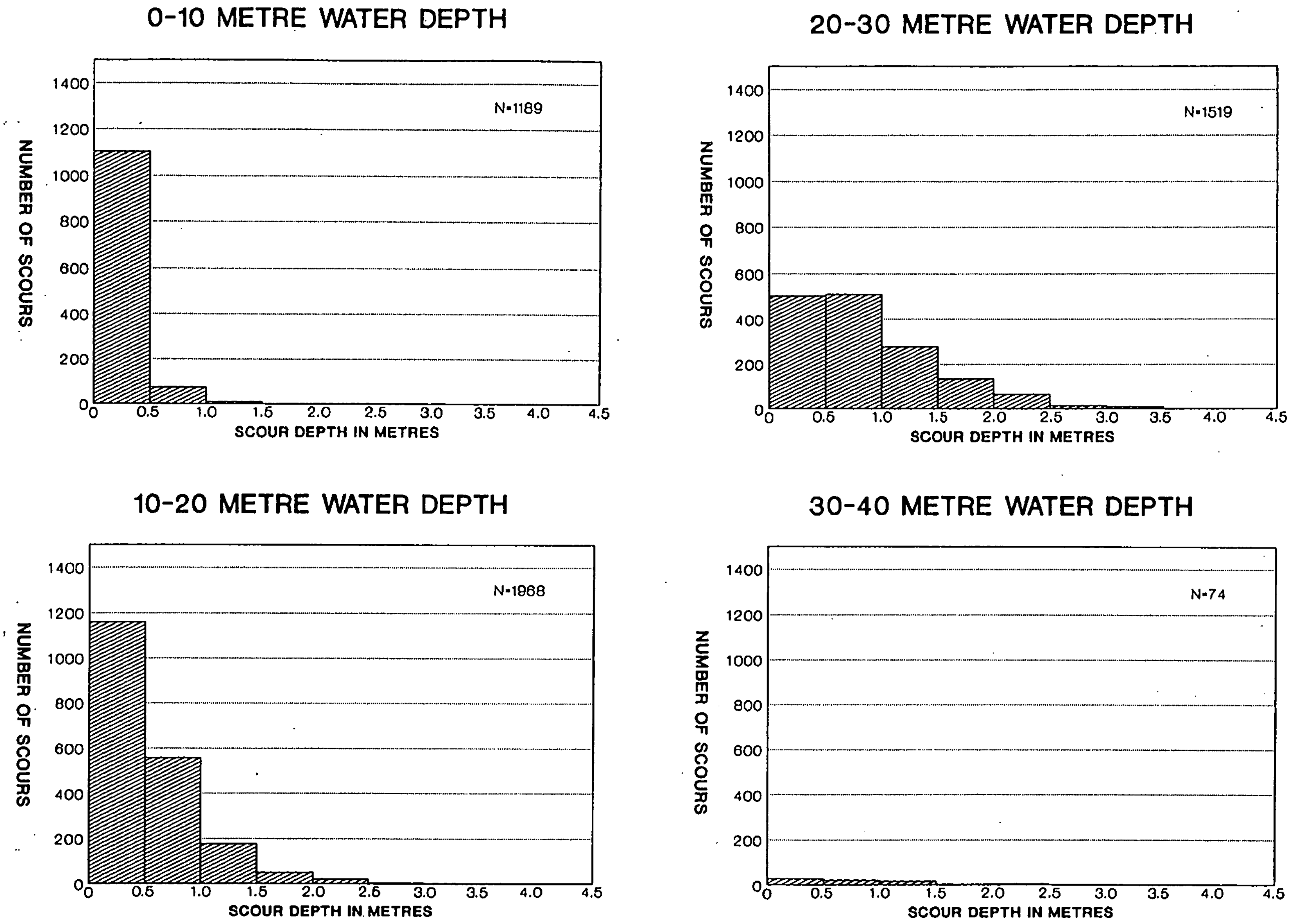


Figure 4.1.5 Histograms showing scour depth, binned in 0.5 metre intervals, for 10.0 metre bathymetric intervals.

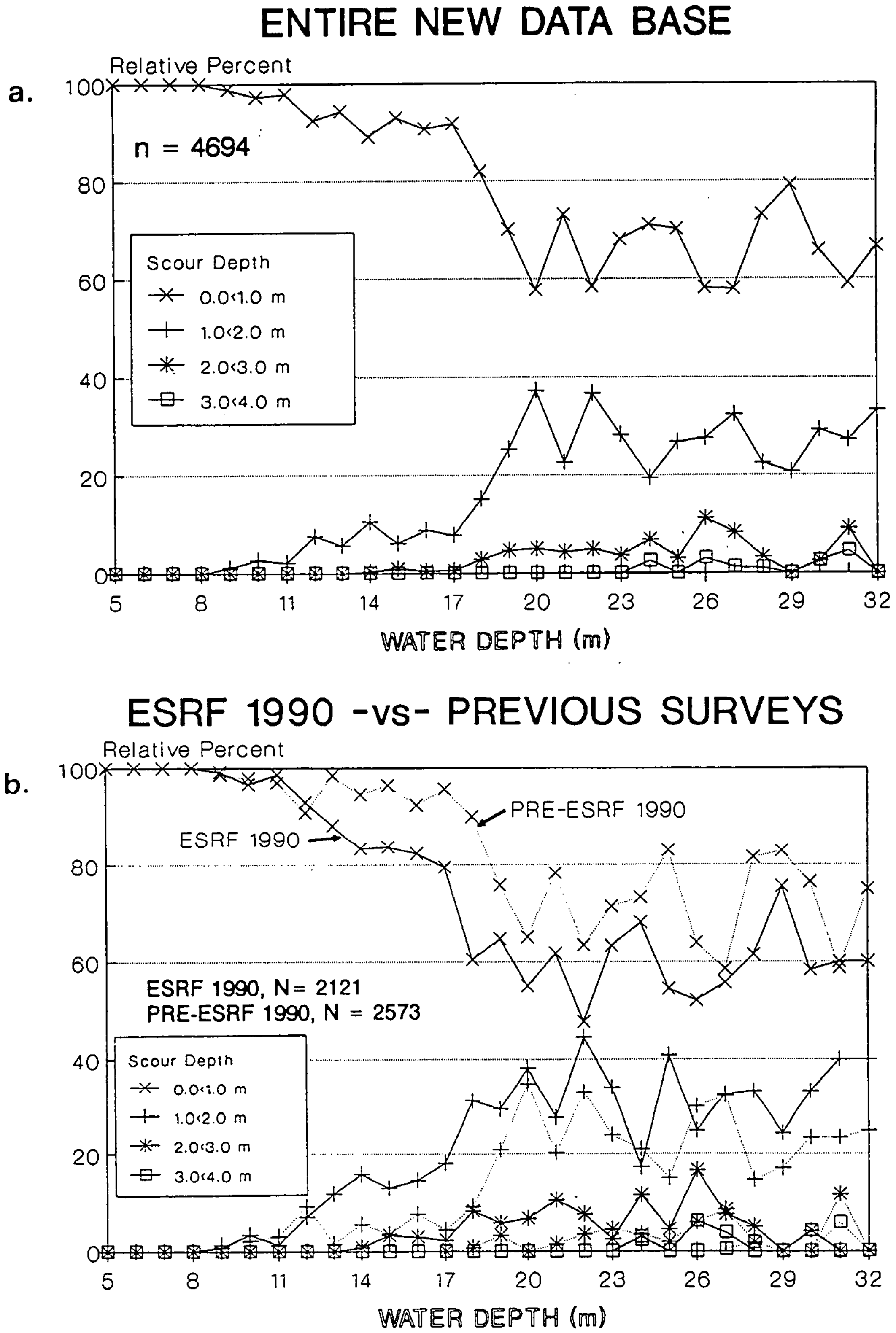


Figure 4.1.6. Relative percentage of scour depth records, binned in 1.0 metre intervals, versus water depth: a) scours which cross the survey line and b) the same population divided into pre-ESRF 1990 scours and scours recorded during ESRF 1990 survey. Note: 56 new scours which cross the survey line in water depths less than 5 metres, or between 32-38 metres are not included on these plots.

with depths of 2.0 metres or greater, occurs across the 17 to 18 metre water depth interval. The influx of deeper scours in deeper water likely represents the influence of scouring by multi-year ice beyond the landfast ice edge.

Plots of the ESRF 1990 and pre-ESRF 1990 depth distributions are shown in Figure 4.1.6. The ESRF 1990 sub-set contains a slightly higher relative abundance of deeper scours for most one metre bathymetric intervals in water depths greater than 12 metres. Interestingly, while both display the same general trends, there are slight differences between the two sub-sets. For example, the ESRF 1990 sub-set shows an increased abundance of 1-2 metre deep scours in water depths of 13 to 18 metres, and a slightly higher proportion of extreme scours (depths > =2.0 metres) in water depths of 17 to 27 metres. Again, these differences in scour depth distributions do not appear random, and may be related to temporal variations in the location of the landfast ice edge.

4.2 SPATIAL AND TEMPORAL ANALYSIS (ESRF 1990 SURVEY)

The frequency and magnitude of new scour events are particularly important factors in the proper design of sub-sea installations. The new scour data base (NEWBASE) contains geographically-referenced records of all new scour occurrences recorded in the Beaufort Sea from 1978 to 1990. By geographically referencing the new scour data within a GIS system, the spatial distribution of any scour parameter or combination of scour parameters can be analyzed. A comprehensive GIS analysis of the new scour data base was beyond the scope of this project, but is recommended for future study of scouring in the Beaufort Sea. Section 4.2.1 presents the results of a spatial analysis of scour distribution for the entire new scour data base (n=5329), as well as, scour depth and extreme scour distributions. Section 4.2.2 addresses scour frequency and impact rates, calculated for new scours recorded during the ESRF 1990 survey.

Figure 4.2.1 shows the location and line number of the ESRF 1990 survey lines, and the number of years since each line was last surveyed. With the exception of Line 37 (last surveyed by Gulf in 1982), the ESRF 1990 survey provided repetitive coverage along baseline corridors established, or most recently surveyed, in 1984 (Shearer et al., 1986), 1986 (Gilbert et al., 1989), 1988 (Gilbert, 1988), or 1989 (Gilbert, 1989). Table 4.2.1 lists the baseline surveys utilized for each of the repetitive mapping surveys conducted since the last published update of the new scour database.

Figure 4.2.2 through Figure 4.2.7 are a series of maps created with CSR's SIPS system. Figures 4.2.2 to 4.2.4 illustrate spatial scour distribution, scour depth distribution, and scour orientation trends by plotting individual scour symbols, centred at the scour UTM co-ordinates. Figures 4.2.5 and 4.2.6 provide a more quantitative assessment of scour frequency and new scour impact rates, calculated in 1.0 metre bathymetric intervals, for the ESRF 1990 sub-set (n=2291) of NEWBASE.

Map 1 through Map 6 (in back pocket) document the scour distribution and the scour impact rates for repetitive ice scour surveys conducted in 1988, 1989, and 1990. All of the new scours incorporated into the NEWBASE database, since the last published update of the Beaufort Sea Ice Scour Database by Gilbert et al. (1989), were observed on sidescan records collected during these three surveys. The enclosed maps were originally constructed by CSR as part of a regional impact rate study sponsored by the Geological Survey of Canada. They are included to provide detailed scour distribution and impact rate information across one metre bathymetric intervals. Impact rates for the ESRF 1990 survey are addressed in Section 4.2.3. Shearer (1996a) presents a detailed discussion of regional impact rates, based on the 1988, 1989, and 1990 surveys.

Table 4.2.1 Listing of Post-1986 Repetitive Surveys

Repetitive Survey	Previous Survey	Number of New Scours
Tully, 1988	Nahidik, 1987	36
Tully, 1988	ESRF, 1984	928
Tully, 1988	Gulf, 1982	409
Nahidik, 1989	Tully, 1988	388
Nahidik, 1989	Nahidik, 1987	7
Nahidik, 1989	ESRF, 1984	388
ESRF, 1990	Nahidik, 1989	194
ESRF, 1990	Tully, 1988	585
ESRF, 1990	Tully, 1986	270
ESRF, 1990	ESRF, 1984	1183
ESRF, 1990	Gulf, 1982	59

The maps and analyses presented in this section illustrate the advantages of using a GIS platform, such as CSR's Scour Information Processing System (SIPS), for Beaufort Sea ice scour research. A more comprehensive understanding of the spatial distribution of the new scour population, and predictive modelling capabilities for extreme scour events, may be realized as additional environmental information are input into the SIPS system.

4.2.1 SCOUR DISTRIBUTION

Figure 4.2.2 shows the spatial distribution of all 5329 new scour events contained in the updated version of NEWBASE. A sub-set of new scours recorded during the ESRF 1990 survey (n=2291), is displayed in Figure 4.2.3. Each new scour event is represented by a colour-coded line symbol centred at the scour UTM position. The colour codes indicate scour depth classifications; scour depths less than 0.5 metres (green), scour depths from 0.5 metres to less than 2.0 metres (yellow), and scour depths of 2.0 metres or greater (red). The orientation of each new scour event is portrayed by the orientation of the corresponding colour-coded line symbol. Figure 4.3.4 displays the distribution for the sub-set of all extreme scours (depths > =2.0 metres; n=122) contained in NEWBASE.

These point-source plots of individual new scour events are primarily visual aids designed

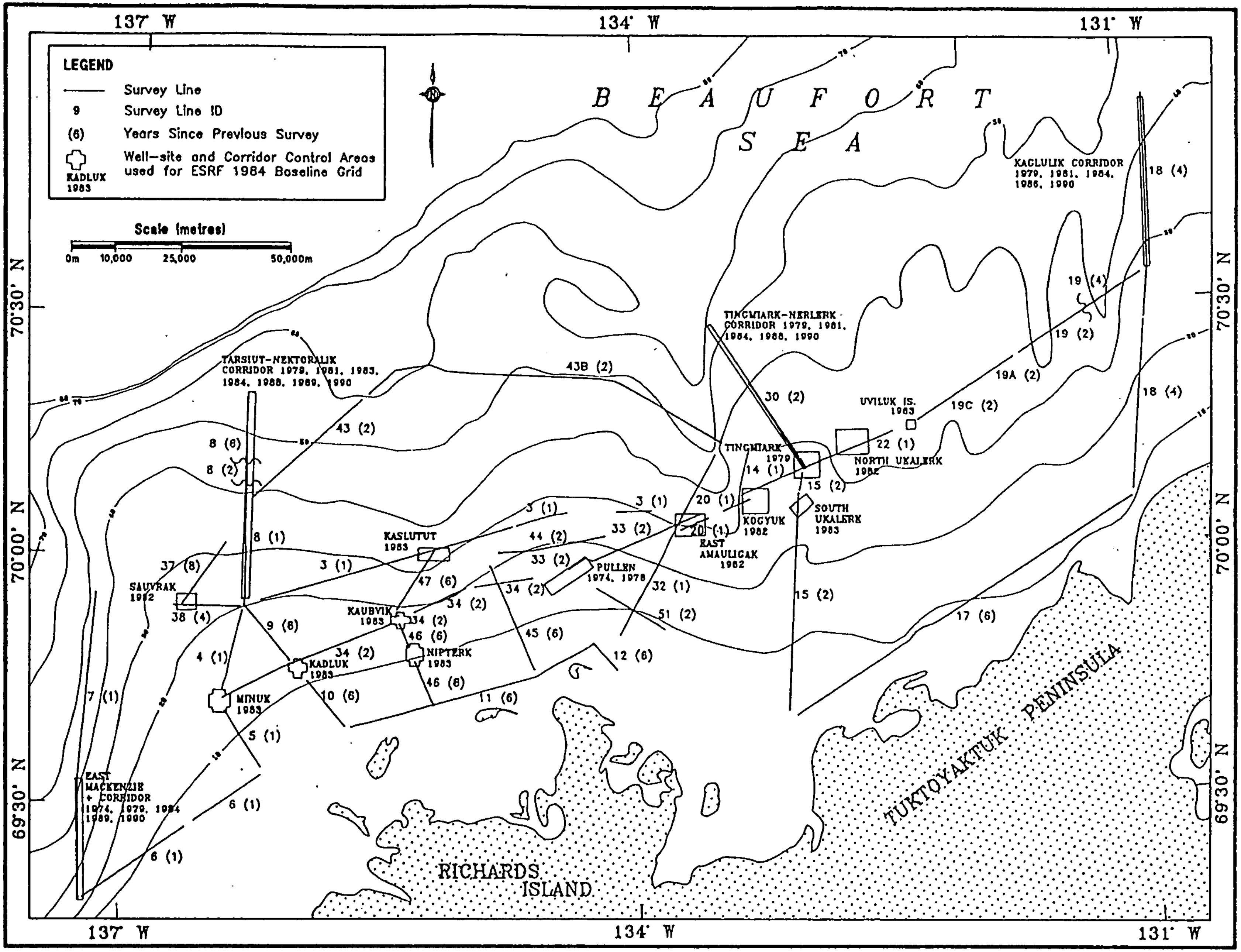


Figure 4.2.1 ESRF 1990 Survey line locations.

to display useful information on scour distribution trends. Assessing the risk of ice scouring to sub-sea installations requires a more quantitative analysis of new scour events, such as that provided by scour frequency (Section 4.2.2) and new scour impact rates (Section 4.2.3). The types of information that can be obtained by displaying individual scour events include:

- Regional distribution trends for all new scour events contained in NEWBASE (Figure 4.2.2), or sub-sets within the database such as the population of extreme scours (Figure 4.2.4). The data base can be related to regional physiographic provinces and to water depth variations along a particular corridor.

- Regional distribution trends for one or more scour parameters. Scour orientation and scour depth are displayed on the maps presented in this section. Similar displays could be constructed for any scour or survey parameter contained in NEWBASE. Such plots would assist in detecting any spatial variations, which might not be readily recognized in a pure statistical analysis, that may occur within a given bathymetric interval or between adjacent intervals.

Several major trends in scour distribution, previously addressed in the data exploration discussion (Section 4.1) are apparent on Figures 4.2.2 and Figure 4.2.3. For example, new scours are most abundant in water depths of 5 to 35 metres, and relatively few new scours occur in water depths greater than 35 metres. Most new scours recorded in water depths less than 10 metres are less than 0.5 metres deep. In contrast, most new scours with depths of 2.0 metres or greater are located in water depths of 15 to 30 metres. As discussed previously, the distribution of deeper scours is probably related to the effects of scouring by multi-year ice, in deeper water regions beyond the limits of the landfast ice edge.

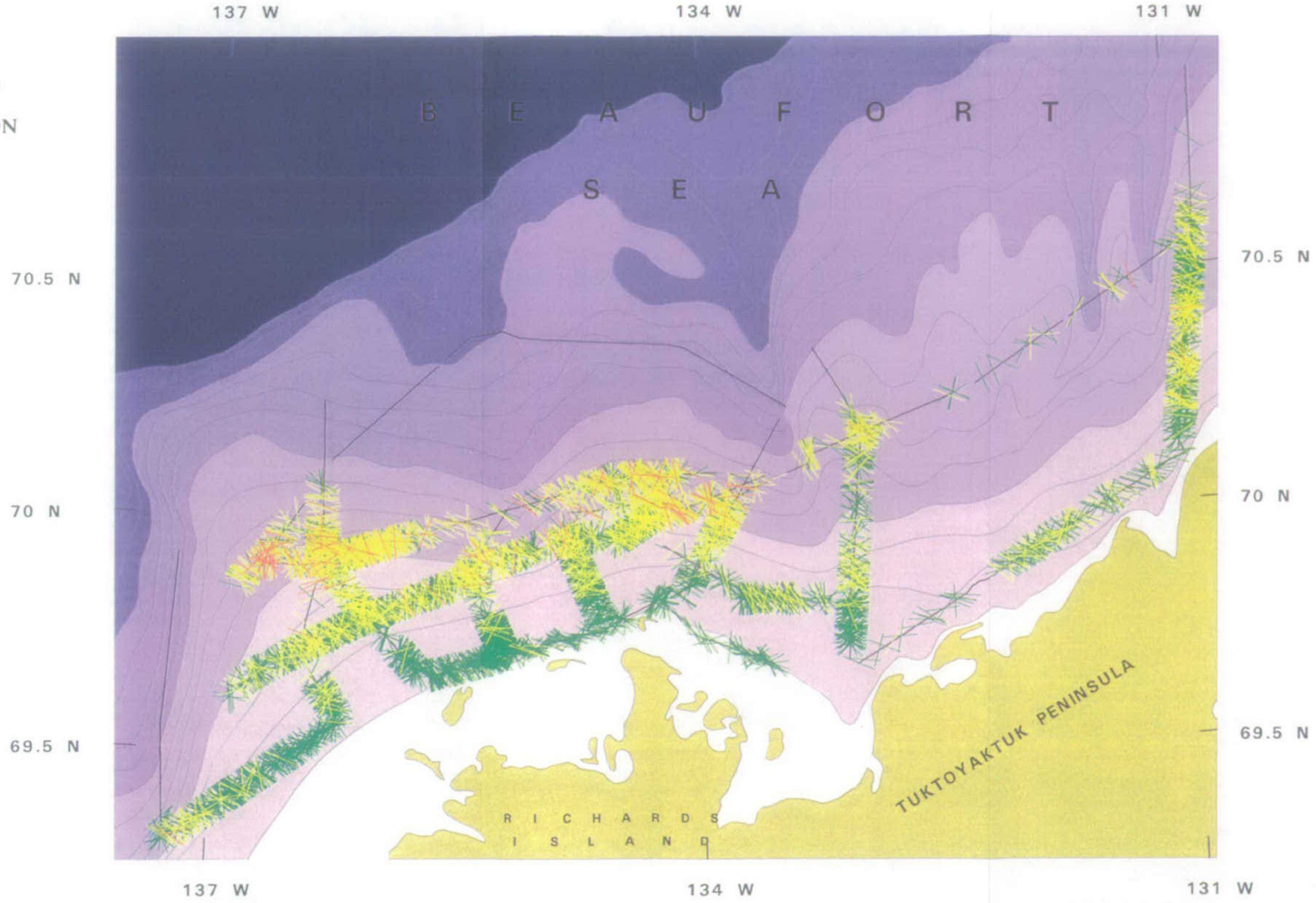
More interesting, are the regional and local variations in scour density, and scour depth distribution, that are illustrated by the SIPS-GIS outputs. Regionally, for example, the majority of extreme new scour events recorded occur west of 133.5° W. Only five of the 122 extreme new scours were recorded east of 133.5° W (Figures 4.2.2 and 4.2.4). Most extreme new scour events recorded during the ESRF 1990 survey occur within two localized areas (Figure 4.2.3). At the western edge of the survey grid, near 136.5°, a cluster of extreme scours occurs in water depths of 16 to 25 metres. A second concentration of scours with extreme scour depths occurs near 134° W, in 17 to 25 metres water depth. In this second area, most of the extreme scours have similar orientations, ranging from 110° to 130°, perhaps indicating that they were formed by the same ice event. As these examples show, GIS-based analyses illustrates useful information, such as the possible pairing or grouping of two or more extreme scour events, which otherwise might not be readily recognized in a pure statistical analysis.

Similar variations in scour density and scour depth distribution are also evident on the GIS displays for all scour depths. A comparison of the entire new scour population versus the

FIGURE 4.2.2

ALL NEW SCOURS (n=5329)

SCOUR DEPTH DISTRIBUTION

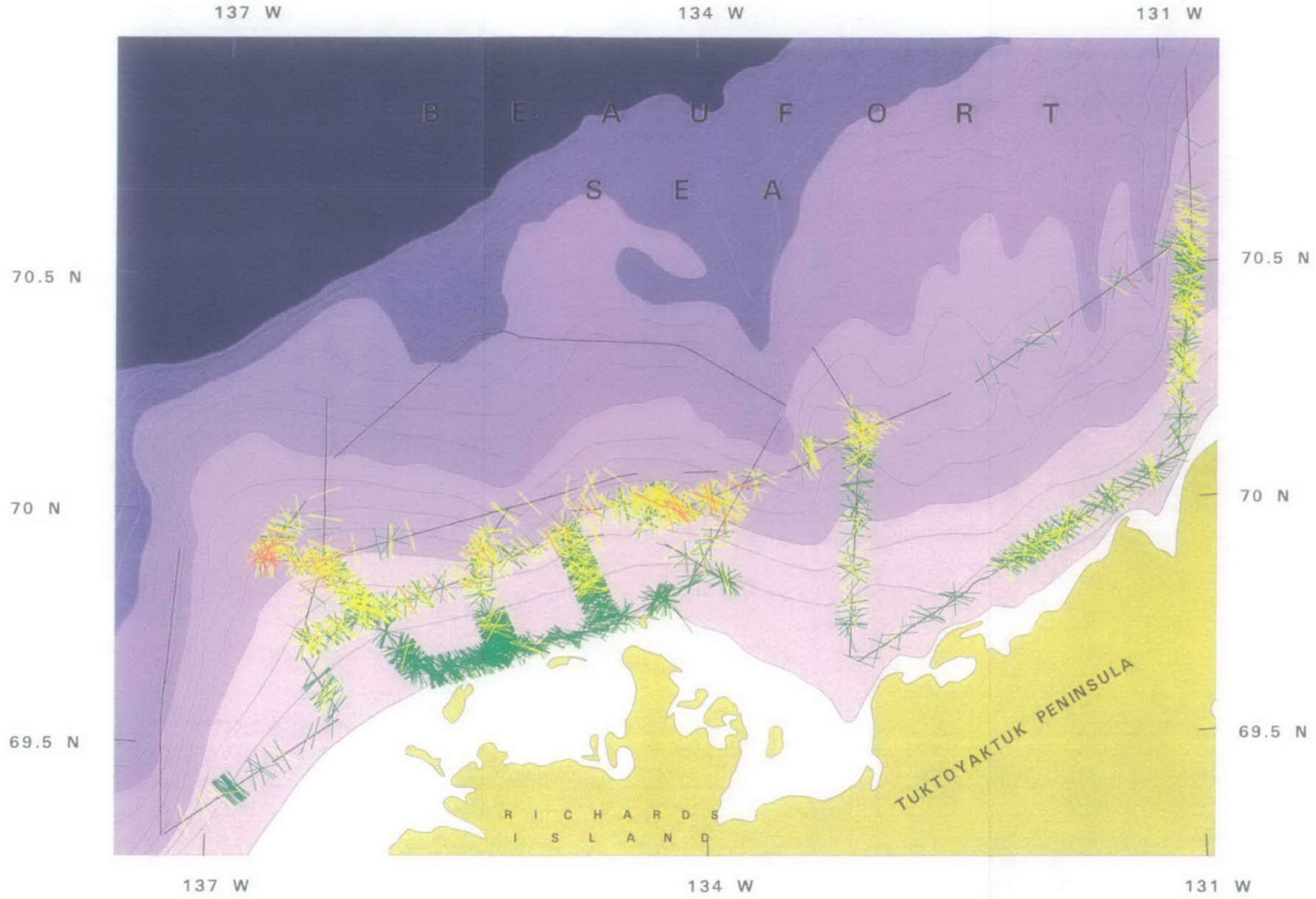


Created with ARC/INFO-GIS by Canadian Seabed Research Ltd., Halifax, N.S.

FIGURE 4.2.3

NEW SCOURS OBSERVED
IN 1990 (n=2291)

SCOUR DEPTH DISTRIBUTION



Geographic Control

Scour Depth (m)
2.00 - 4.00
0.50 - 2.00
0.00 - 0.50

Survey Line - 1990

Bathymetry (m)
Above Sea Level
0 - 5
5 - 20
20 - 40
40 - 60
60 - 80
80 +

metres
0 20000 40000

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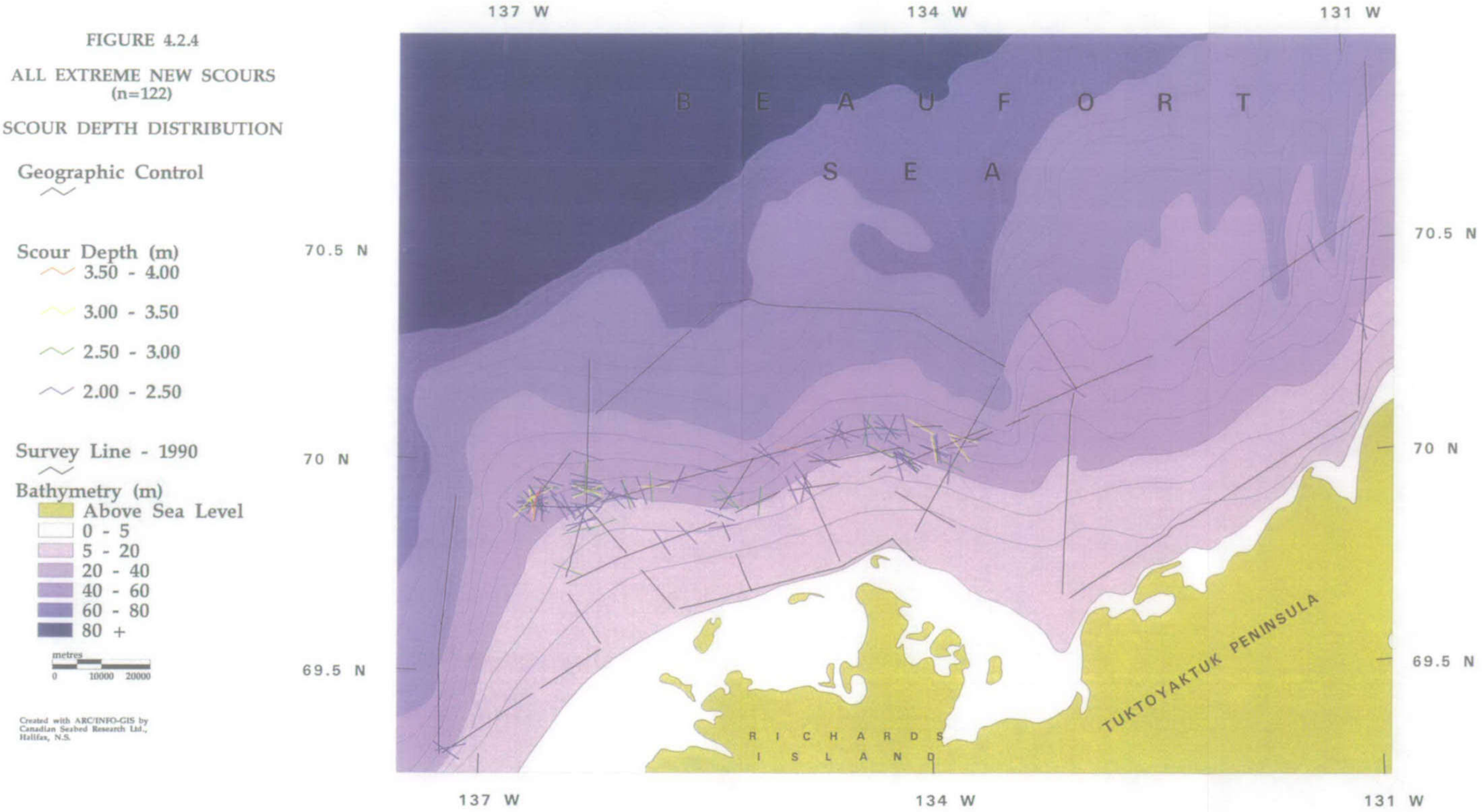
FIGURE 4.2.4

ALL EXTREME NEW SCOURS
(n=122)

SCOUR DEPTH DISTRIBUTION



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sub-set of new scours observed during the ESRF 1990 survey indicates that local variations in the density of new scour events are most apparent when only 1 or 2 years have elapsed since a baseline survey was conducted. For example, the scour clusters observed along Line 6 and Line 15 on the plot of new scours recorded during the ESRF 1990 survey (Figure 4.2.3), are not apparent when all new scour events contained in NEWBASE are considered (Figure 4.2.2). Similarly, along ESRF 1990 survey lines where more time has elapsed since the previous survey (i.e. Line 45), the episodic nature of new scour distribution is not apparent (Figure 4.2.3). This suggests that in heavily scoured areas, progressive scouring activity over a number of years may result in what appears to be a more uniformly scoured seabed. More frequent surveys in such areas would likely show the scour population is comprised of scours formed during successive years of episodic scouring activity.

Scour density along adjacent survey lines for the sub-set of ESRF 1990 scours, is generally a function of the number of years since the previous baseline survey was conducted. For example, Figure 4.2.3 shows that Line 9 (six years since last survey) is much more heavily scoured than Line 4 (one year since last survey). Interestingly, only two new scours with extreme depths were formed along Line 9 since it was last surveyed in 1984. In contrast, although it is less heavily scoured, six of the new scours formed along Line 4, since it was last surveyed in 1989, have extreme scour depths.

Although the point-source plots are quite useful in understanding basic scour distribution trends, they do not provide the type of quantitative information required by design engineers. In many heavily scoured areas, individual scour symbols are too densely plotted to accurately determine the actual number of scours within an area of interest. Also, the point-source plots display scours from lines with contrasting re-survey interval times. For example, in Figure 4.2.3, Line 8 (one year time interval between surveys) shows many fewer scours than the adjacent Line 37 which has an eight year time interval between surveys. The lack of quantitative data from the point-source plots is resolved by using scour frequency (scours/km), and new scour impact rates (scours/km/yr), for each survey line.

4.2.2 SCOUR FREQUENCY, ESRF 1990 SCOURS

Scour frequency represents the number of new scours which occur along a known length of survey line, and is measured as the number of scours per line kilometre. Frequency calculations provide the type of quantitative reduction of new scour data which can be directly input into engineering design models. Calculations can be made using all new scour data, or a sub-set of the data base. Results can be obtained for any length of survey line segment although, for very short line segments, anomalously high frequencies may be calculated on the basis of relatively few scour events. For this study, the SIPS system was used to calculate scour frequency along survey line segments within 1.0 metre bathymetric intervals.

To accomplish this task, the ESRF 1990 navigation files were first overlain by a bathymetric coverage to calculate the length of survey line segments within each one metre bathymetric classification. Scour frequency was calculated by dividing the number of scour events recorded for each survey line segment by the length of that segment. The SIPS system provides a number of possible outputs for these calculations, including; hard copy printouts, large scale maps with numeric values plotted adjacent to each line segment, and digital maps which can be viewed on-screen or printed as page size colour plots such as those displayed in this section.

Figure 4.2.5 shows scour frequency calculated for 1.0 metre bathymetric intervals. Four frequency classifications are portrayed: blue (0.00<0.01 scours/km), green (0.01<1.0 scours/km), yellow (1.0<5.0 scours/km), and red (> = 5.0 scours/km). The actual scour frequency values for each 1.0 bathymetric interval are included on Map 6 (in back pocket). In Figure 4.2.5, scour frequencies included within the highest classification grouping (i.e. > = 5.0 scours/km) range from 5.0 to 15.0 scours/km for most line segments. A maximum scour frequency of 41.67 scours/km was calculated for a 0.12 km long segment which occurs at the end of Line 9, and partially crosses the 21-22 metre bathymetric interval. This is an anomalously high frequency value resulting from 5 new scour occurrences along a very short line segment. Excluding this anomalous value, scour frequency exceeds 15.0 scours/km for only 4 line segments with a maximum recorded scour frequency of 18.80 scours/km.

Two conclusions are immediately obvious from the scour frequency maps: the frequency of new scour events is highly dependent on water depth, as well as, on the elapsed time since a line was previously surveyed. In any given water depth, higher scour frequencies are more common for survey lines which were last surveyed four or more years prior to the ESRF 1990 survey. For example, Line 45 (last surveyed in 1984) has scour frequencies in excess of 5.0 scours/km in water depths of 5 to 15 metres. In contrast, scour frequencies observed in the same water depths along Line 5 (last surveyed in 1989), vary from 0.0 scours/km to in excess of 5.0 scours/km. It is evident that scour frequencies by themselves do not accurately reflect the scouring process, as they strongly relate to the elapsed time between successive surveys. New scour impact rates (scours/km/yr) address the problem associated with the variation observed on adjacent survey lines, by normalizing the scour frequency data.

4.2.3 SCOUR IMPACT RATES; ESRF 1990 SCOURS

Scour impact rates are calculated by dividing scour frequency by the number of years since a particular survey line segment was last surveyed. For survey lines in which only one year has elapsed, the scour impact rate is the same as scour frequency. For survey lines in which two or more years have elapsed since the previous survey, the resultant impact rates assume that equal numbers of new scours were formed in each year.

Scour impact rates for all new scour events recorded during the ESRF 1990 survey (n=2291) are presented in Figure 4.2.6 and Map 6 (in back pocket). Map 6 contains the individual impact rate values calculated for each 1.0 metre bathymetric interval. Four impact rate classifications are portrayed on Figure 4.2.6: blue (0.00<0.01 scours/km/yr), green (0.01<1.0 scours/km/yr), yellow (1.0<2.0 scours/km/yr), and red (> = 2.0 scours/km). Most line segments within the last classification have impact rates ranging from 2.0 to 5.0 scours/km/yr. Nine line segments were identified with impact rates in excess of 5.0 scours/km/yr (Table 4.2.2). Four of these are very short segments (<.35 km

FIGURE 4.2.5

NEW SCOURS OBSERVED
IN 1990 (n=2291)

SCOUR FREQUENCY
(# scours/km)

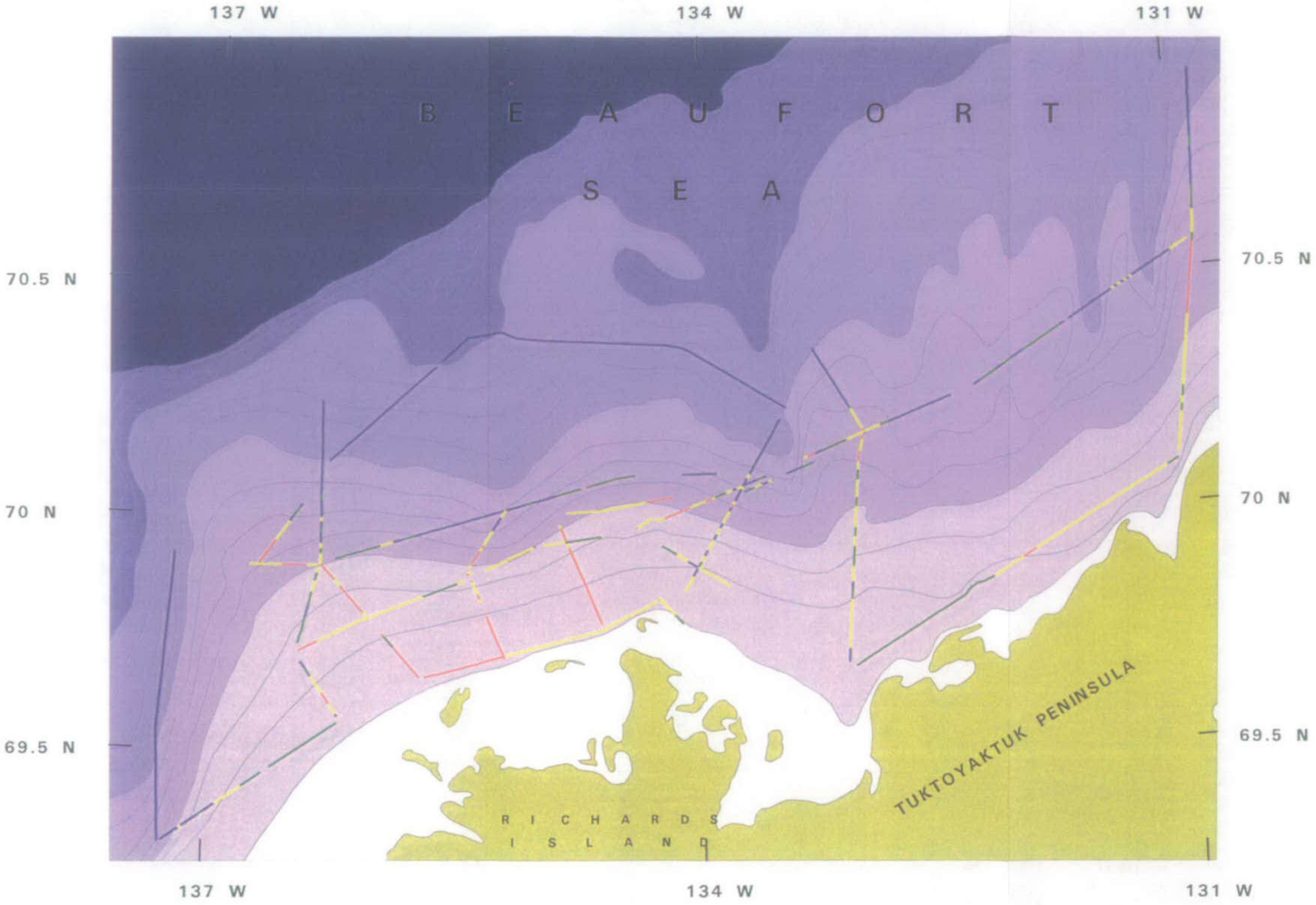

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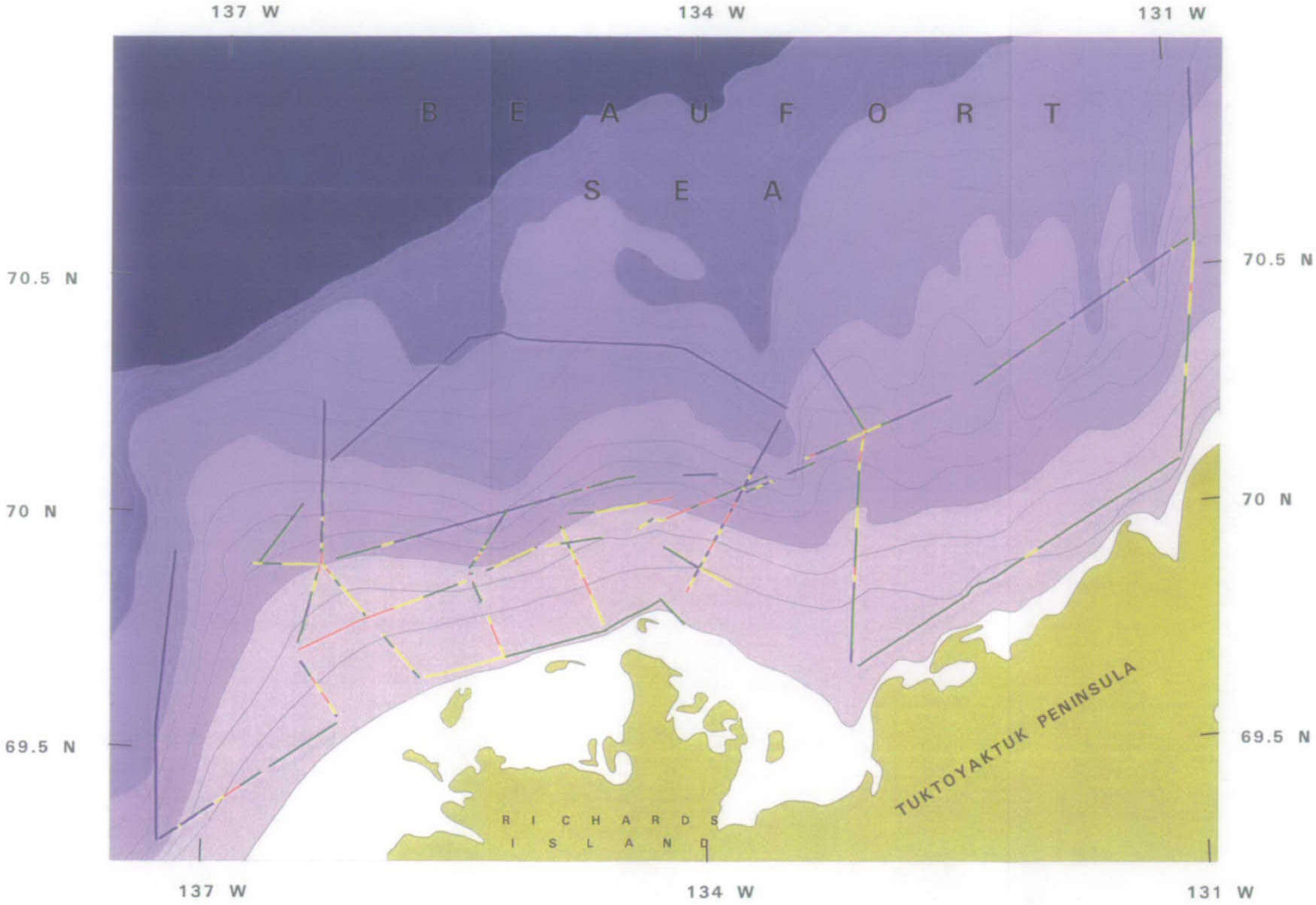
FIGURE 4.2.6

NEW SCOURS OBSERVED IN 1990 (n=2291)

SCOUR IMPACT RATES
(# scours/km/year)



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long) occurring at the end of a survey line or, at a break in the survey line. Excluding these short line segments, the maximum recorded impact rate, for a single line segment across a 1.0 metre bathymetric interval, is 6.42 scours/km/yr. This occurs along a line crossing the steeply-sloping eastern edge of Kugmallit Channel in 28 to 29 metres water depth.

Regional variations in scour impact rates are apparent along survey lines crossing the same bathymetric intervals. For example, impact rates are generally in excess of 1.0 scours/km/yr along most survey line segments in water depths of 5 to 20 metres for the area west of 133.5° W, including the Kringalik Plateau and Akpak Plateau physiographic provinces. In contrast, impact rates in excess of 1.0 scours/km/yr are much less common for the same water depths in the area east of Kugmallit Channel. Variations in scour impact rates are also associated with changes in water depth. West of 133.5°, impact rates are generally greater than 1.0 scours/km/yr, and commonly exceed 2.0 scours/km/yr, in water depths from 5 to 25 metres. Impact rates are generally less than 1.0 scours/km/yr in water depths greater than 25 metres, and 0.0 scours/km/yr for most line segments in water depths greater than 35 metres.

Survey lines for which only one or two years had elapsed since the previous survey generally display the greatest degree of local variability in impact rates, and often include the highest observed impact rates. The variability observed along these survey lines, including relatively high local impact rates, is probably typical of most scouring seasons. An example of local impact rate variations is observed along Line 32 (1 year since previous survey), in water depths of 10 to 14 metres. Along this segment of Line 32, impact rates range from 0.0 scours/km/yr to in excess of 2.0 scours/km/yr within adjacent 1.0 metre bathymetric intervals. An example of high impact rates associated with re-survey time intervals of one to two years is observed along three adjacent survey lines (Lines 32, 33, and 44), in water depths of 20 to 25 metres. Impact rates are predominantly greater than 2.0 scours/km/yr for these line segments. Most other survey lines crossing the 20 to 25 metre bathymetric interval have impact rates less than 2.0 scours/km/yr. Similarly, eight of the nine line segments with impact rates in excess of 5 scours/km/yr occur along survey lines which were last surveyed in 1988 or 1989 (Table 4.2.2). The seasonal variability in scour distribution may reflect the influence of scour clusters which are formed during a single scouring event, by an ice ridge with numerous keels (Shearer, 1996a). The effects of seasonal variability in impact rates may be overcome by using only line segments with a time interval of four or more years.

For scour depths exceeding a certain threshold (i.e. population of scours with extreme scour depth), the probability of more than one extreme scour occurring within each scour cluster decreases. Nessim and Hong (1992) conclude that a scour depth of 2.0 metres defines the lower threshold of extreme scour events, such that each extreme scour could be considered an independent event. Therefore, the episodic scour distribution caused by scour clusters may be eliminated by examining the impact rates of extreme new scour events. Scours with extreme depths also represent the greatest risk to a buried sub-sea installation. As such, impact rates calculated for a sub-set of extreme scours may be more useful to pipeline design engineers than impact rates calculated for the entire data base which is predominated by scours with depths less than 0.5 metres.

4.2.4 EXTREME SCOURS

Scours with an extreme depth (> =2.0 metres), as defined by Nessim and Hong (1992), are addressed in this section. It should be noted that the extreme scour depth threshold used by Nessim and Hong (1992), was determined as the depth at which scours were considered statistically independent events. Pipeline engineers may require analysis of a different extreme data sub-set, as defined by the specific design criteria applied. That is, the design engineer may only want to know the probability of new scour occurrence for scours with depths exceeding a pre-defined critical value. The spatial distribution of a sub-set of scours with depths exceeding any such pre-defined depth could be easily accommodated with the SIPS-GIS system.

The SIPS package was used to analyze the distribution of a subset of scours with depths of 2.0 metres or greater. Figure 4.2.4 shows the distribution of extreme scours in the entire new scour data base (NEWBASE). NEWBASE contains 122 records of extreme scour events in water depths ranging from 13 to 36 metres. Of these, 12 scours have depths between 3.0 metres and 4.0 metres, and one scour has a depth of 4.0 metres. All of the scours with depths greater than 3.0 metres are located in water depths ranging from 24 to 30 metres.

A comparison of the distribution of extreme scour distribution for the entire new scour data base (Figure 4.2.4), versus the ESRF 1990 sub-set (Figure 4.2.3), indicates that many of the extreme scour events recorded during the ESRF 1990 survey, do not occur in the same areas as those observed prior to the ESRF 1990 survey. Prior to the ESRF 1990 survey, extreme scours were observed in water depths ranging from 17 metres to 34 metres, and only three extreme events were observed in less than 20 metres water depth. Many more of the extreme scour events recorded during the ESRF 1990 were located in water depths of less than 20 metres. Most of the pre-ESRF 1990 extreme scours occur along the ESRF 1990 Line 3 and Line 8 corridors, in water depths of 20 to 30 metres. The pre-1990 extreme scours along the Line 3 corridor were recorded during surveys conducted in 1988 (baseline survey 1982) and 1989 (baseline survey 1988). In contrast, only one extreme scour was recorded along the Line 3 corridor during the ESRF 1990 survey. Thus, it appears that the overall distribution of extreme scour occurrences varies from year to year. These temporal distribution trends may be related to seasonal variations in the location of land-fast ice margin.

The spatial distribution of extreme scours does not appear to be entirely random. For example, groupings of several extreme scours with similar orientations were recorded along the western end of Line 32 during the ESRF 1990 survey (Figure 4.2.3). Similarly, the concentration of extreme scours along the western end of Line 37 and Line 38 on the Kringalik Plateau, while not displaying a single preferred orientation, contain several scours recorded on Line 37 that have similar orientations to scours on Line 38. This suggests that some extreme scours recorded on adjacent survey lines may have been formed by the same ice event. Two or more closely-spaced extreme scours (i.e. less than 1 km apart) with similar orientations are also apparent along several other survey lines (Figure 4.2.4). These examples suggest that extreme scours, with depths of 2.0 metres or greater, are not always formed by separate scouring events.

ESRF 1990 Extreme Scour Impact Rates

Figure 4.2.7 shows impact rates calculated for extreme new scour events recorded during the ESRF 1990 survey (n=72). Four impact rate classifications are portrayed; blue (<0.01 scours/km/yr), green (0.01< 1.0 scours/km/yr), yellow (1.0<2.0 scours/km/yr), and red (>=2.0 scours/km/yr). The majority of line segments crossing 1.0 metre bathymetric intervals have an impact rate of 0.0 scours/km/yr, reflecting the relative paucity of extreme scour events. Along line segments where extreme scour events were recorded, impact rates are most commonly less than 1.0 scours/km/yr. Only six survey line segments have impact rates greater than 1.0 scours/km/yr within a 1.0 metre bathymetric interval. These all occur west of 133.5° W, in water depths ranging from 19 to 30 metres.

Four of the line segments with impact rates in excess of 1.0 scours/km/yr occur on lines last surveyed in 1989, and two occur on lines last surveyed in 1988 (Table 4.2.3). For three of these segments, including the one segment with an impact rate exceeding 2.0 scours/km/yr, the higher impact rates result from only one or two extreme scour events over a short line segment. In contrast, the western ends of Lines 37 and 38, which were last surveyed in 1982 (Line 37) and 1986 (Line 38), contain a relatively large number of extreme scours but are characterised by average impact rates of less than 1.0 scours/km/yr. This suggests that for certain years, actual yearly extreme scour impact rates may greatly exceed the averaged impact rate calculated over a number of years. Therefore it is important to determine impact rates for each repetitive survey, as well as, for the entire NEWBASE scour population.

A larger population of extreme scours, and a more comprehensive GIS-based analyses of environmental factors, are required to adequately define the extreme scour distribution. Once further constrained, the extreme scour distribution may ultimately influence pipeline design specifications along a selected route, or perhaps be used in determining the most cost-effective pipeline route. For example, consider two pipeline routes in 7 to 30 metres water depth; one located along a corridor defined by ESRF 1990 Line 15 and Line 30 (Route 1), and a second along a corridor defined by ESRF 1990 Line 8, Line 4, and Line 5 (Route 2). Based on the ESRF 1990 extreme scour impact rates, only one extreme new scour, located in 27 metres water depth, would have cut across a pipeline along the Route 1 corridor between 1988 and 1990. In contrast, a pipeline along Route 2 would have been impacted by 8 extreme scours, in water depths ranging from 14 to 24 metres, between 1989 and 1990. Although the ESRF 1990 impact rates do not include extreme scours recorded prior to the ESRF 1990 survey, no pre-1990 extreme scours were observed along Route 1 dating back to 1984. Nine additional extreme scours, in water depths ranging from 22 to 27 metres, were recorded along Route 2 during a 1981 survey. Clearly, on the basis of extreme scour events recorded during the ESRF 1990 survey, a pipeline along Route 2 would be subject to more frequent extreme scour impacts over a larger distance, and would require greater protective design measures.

At present, given that there are only 122 events with a scour depth of 2.0 metres or greater, impact rates for extreme scours are less well-constrained than those calculated for the entire new scour database. Additional repetitive mapping of the existing baseline grid is recommended in order to more accurately predict the potential for extreme scour impacts.

Table 4.2.2 ESRF 1990 Scours (n=2291); Maximum Impact Rates

SURVEY LINE	SCOUR MAGE	BATHY CLASS	NUMBER OF SCOURS	LINE SEG. LENGTH	IMPACT RATE
4	1	20	6	1.28	4.69
44	2	21	32	3.38	4.74
44	2	22	30	3.09	4.86
5	1	9	15	2.97	5.05
33	2	20	29	2.80	5.18
33	2	24	18	1.55	5.81
15	2	26	4	0.33	6.06
13	1	25	5	0.81	6.17
14	1	29	12	1.87	6.42
9	6	21	5	0.12	6.95
3	1	27	2	0.28	7.14
14	1	28	1	0.08	12.50

Table 4.2.3 ESRF 1990 Extreme Scours (n=72); Maximum Impact Rates

SURVEY LINE	SCOUR MAGE	BATHY CLASS	NUMBER OF SCOURS	LINE SEG. LENGTH	IMPACT RATE
4	1	19	1	1.96	0.51
38	4	27	1	0.45	0.56
34	2	19	1	0.87	0.58
19	2	36	1	0.73	0.69
13	1	21	1	1.37	0.73
8	1	24	1	1.32	0.76
4	1	18	3	2.79	1.08
13	1	22	1	0.84	1.19
33	2	20	7	2.80	1.25
13	1	30	1	0.79	1.27
33	2	24	5	1.55	1.62
8	1	21	2	0.99	2.02

FIGURE 4.2.7

EXTREME NEW SCOURS
OBSERVED IN 1990 (n=72)

SCOUR IMPACT RATES
(# scours/km/year)

Geographic Control

Extreme Scour Impact Rates
- 0.00 - 0.01
- 0.01 - 1.00
- 1.00 - 2.00
- 2.00 +

Bathymetry (m)
- Above Sea Level
- 0 - 5
- 5 - 20
- 20 - 40
- 40 - 60
- 60 - 80
- 80 +

metres
0 20000 40000

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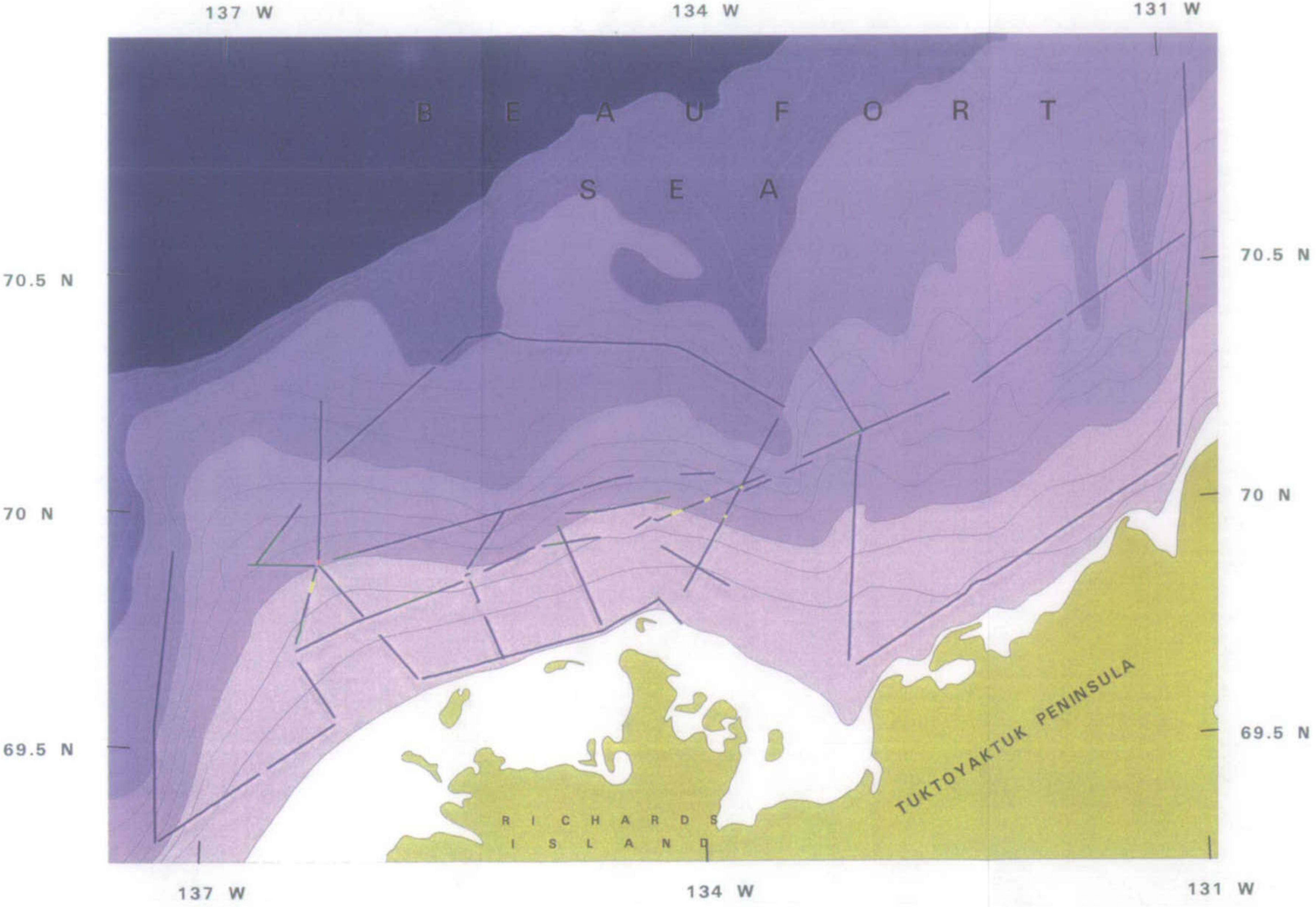


4.3 SCOUR TRACKING RESULTS

4.3.1 INTRODUCTION

This section presents the results of detailed scour tracking surveys conducted aboard the C.C.G.S. Nahidik in the summers 1989 and 1990 (Gilbert, 1989; Gilbert, 1990). Two scours were tracked during the 1989 survey. Six additional scours were tracked during the 1990 survey and one of the scours tracked in 1989 was surveyed again in 1990. The scours are named N89-1, and N90-1 through to N90-7. The prefix representing the principle survey on which they were tracked (i.e. N89 - Nahidik 1989 survey). The locations of each scour tracking survey are indicated in Figure 4.3.1.

Several criterion were used to select which scours would be surveyed, including extreme scour depth, sediment infill, scour age, and geographical location. Table 4.3.1 summarizes some of the key parameters associated with each of the scours. Analysis of key scour parameters such as scour width, scour depth, infill, berm size and scour rise-up are presented for each of the scours in Section 4.3.2. Synthesis of the analysis, focusing on scour depth variations and scour rise-up, are contained in Section 4.3.3.

Table 4.3.1 Summary of Key Scour Parameters

Scour Name	Water Depth (m)	Scour Depth (m)	Scour Infill (m)	Scour Length (km)	Total Rise-up (m)	Scour Age Since 1990 (yrs)
N90-1	28-34	3.6	<.1	19.9	3	10-11
N90-2	41-53	8.5	1-3	50.5	8	180-215
N90-3	16-20	2.6	<.2	12.5	3	10-25
N90-4	20-27	5.5	1-2	7.7	4	50-65
N90-5	26-29	2.9	<.1	4.5	1	1-2
N90-6	30-32	2.6	<.5	35	2	>10
N90-7	27-32	3.2	<.1	7.5	2	8
N89-1	48-56	6.9	<.5?	5.0	1	25-50

The present scour tracking study represents a continuation of similar work initiated in the 1984 field season (Shearer et al., 1986). None of the scours from the 1984 survey were examined in the present study. In the present study, scours of various sizes were tracked over a wide range of water depths. Most scour rise-up observations fall within the three broad stages of scouring outlined by Shearer et al. (1986). The 1989 and 1990 surveys data sets contain significantly more scour cross-overs (diagonal profiles across the scour) than the 1984 survey, and local variations are more apparent along the rise-up profiles contained in this report. Such variations occur along Scour N90-2 which penetrates near to the base of the Acoustic Unit A marine clays of O'Connor (1980). Locally, Scour N90-2 cuts slightly into the top of the more resistive Acoustic Unit B sediments, resulting in local variations in scour depth and scour rise-up. Such variations in scour rise-up were not documented in previous scour tracking surveys.

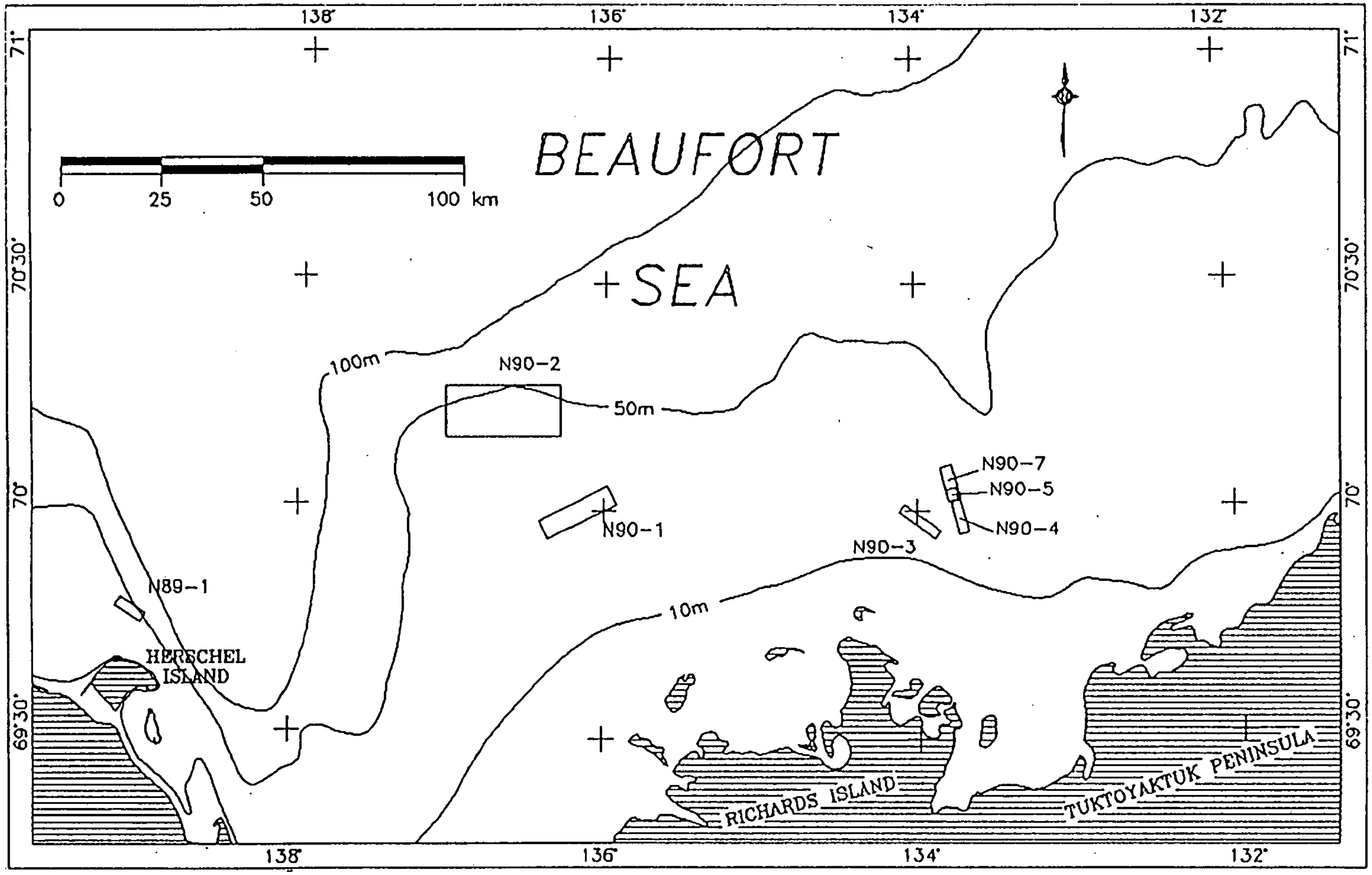


Figure 4.3.1 Location map outlining the areas of the scour tracking surveys.

Shearer et al. (1986) proposed a three stage scouring process based on their observations of scour rise-up. In Stage 1, beginning when the ice keel first touches down on the seabed, the base of the scour remains at a constant elevation and scour depth increases as the ice keel scours into progressively shallower water depths. During Stage 1, the resistance of the sediments to the scouring ice keel is apparently insufficient to prevent increased keel penetration.

The start point of Stage 2 rise-up coincides with the point along the scour where significant rise-up of the scour base elevation begins. As the ice keel continues to scour upslope during Stage 2, scour rise-up occurs at a rate less than the decrease in water depth. The ice keel continues to penetrate more deeply into the sediments and the scour depth increases. Shearer et al. (1986) propose that in stage two, increasing resistance to seabed penetration occurs as the scour depth increases. This results in the uplift or rise-up of the ice keel as it scours deeper into the sediments. However, progressive uplift of the ice mass creates an increasing lithostatic load on the seabed, allowing the keel to continue to penetrate progressively deeper.

As the ice keel continues to scour upslope, a point is reached where the scour depth remains relatively constant and Stage 3 of the scouring process begins. During Stage 3, the scour base elevation and seabed elevation rise-up at approximately the same rate. Apparently, during Stage 3, sediment resistance to scouring is such that progressive rise-up (increasing the lithostatic load on the seabed) does not result in additional keel penetration.

The range of scour depths at which each of the stages is active depends largely on the strength of the seabed sediments and the size of the scouring ice mass. For example, an ice floe would penetrate more deeply into soft clays during Stage 1, than would the same floe, scouring across more resistant sandy sediments. Variations in the sediment strength along the length of a scour would also be expected to alter the scour rise-up profile.

4.3.2 SCOUR DESCRIPTIONS

4.3.2.1 SCOUR N90-1

Scour N90-1 is a multi-keeled scour located on the Kringalik Plateau in 30 metres of water. The start point of the scour is located at 70° 02'11.4" N, 136° 00' 27.9" W. Scour N90-1 was tracked for almost 20 kilometres in water depths ranging between 28 metres and 34 metres. The depth of the deepest keel ranges from 1.3 metres to 3.6 metres. Total scour rise-up along the scour is approximately 3.0 metres. Stratified sediment infill was not observed within the base of the scour. Scour N90-1 was first observed as a new scour in 1981, while surveying a corridor initially surveyed in 1979, and was probably 10 years old at the time of the Nahidik 1990 survey.

Scour N90-1 was chosen for scour tracking in 1990 because of its known age, multi-keeled nature and its extreme scour depth. It is comprised of two primary keels; a broad, relatively flat bottomed, and steep sided scour (keel A) and a grouping of three narrow and closely spaced keels (keels B1,B2 and B3) referred to as the keel B complex (Figure 4.3.2). Two additional keels, keel C and a "western keel", were observed along portions of the scour. The principle keel of Scour N90-1, keel A, was profiled 32 times while minor keels were intersected only 10 times. Scour parameter measurements, obtained on keel A, are summarised in the Scour Parameter Table for Scour N90-1 (Appendix 2). Rise-up and Depth Profiles and representative sidescan/microprofiler records are contained in Enclosure 1. A smaller version of the along scour profiles is presented in Figure 4.3.3.

Scour Direction and Orientation

Scour N90-1 is linear to gently-arcuate along most of its length. Abrupt changes in scour orientation occur at Kilometre Point (KP) 2.9, KP 13.3, KP 19.2 and KP 19.4 (see Enclosure 1; Plan View). The direction of scouring was determined at KP 19.2 where N90-1 overlaps or cuts across itself (Enclosure 1: Plate 8). The overlapping observed at KP 19.2 indicates that Scour N90-1 originated in the northeast and was formed by ice moving initially towards the southeast, then changing direction and scouring towards the west-southwest.

Scour direction is initially 125° before abruptly changing direction to 250° at KP 2.9. Between KP 2.9 and KP 13.3, the scour is gentle arcuate, heading 250° for 2.1 km, then 280° for 2.5 km, 245° for 4.1 km and 220° for 1.7 km. Following an abrupt change in direction at KP 13.3, the scour is again arcuate and heads approximately 270° for 3.3 km, then 230° for 2.0 km, and 245° for 0.6 km. The scour changes direction abruptly at KP 19.2, then heads 110° until KP 19.4. There is another abrupt change in direction at KP 19.4, and the scour heads at 190°, until KP 19.9, at which point it is obscured by cross-cutting scours.

Examination of the widths and relative position of the N90-4 keels at the locations of the major changes in scour direction indicates that little, if any, rotation of the ice floe occurred at the abrupt direction changes (Enclosure 1: Plates 2 and 8). Instead, it appears that the ice floe changed direction without rotating, leaving the ice keels in the same position relative to one another (see below).

Scour Width and Incision Width

Ice keels responsible for multi-keeled scouring are connected in a rigid manner such that a change in ice flow direction may cause a relative re-positioning of component scours. Accordingly, component scours of a multi-keeled scour may appear to vary in width, to move closer or further away from one another, and even to disappear across a major change in scour direction. This appears to be the case for Scour N90-1. Changes in individual scour incision widths and scour spacing are associated with major changes in scour orientation. Table 4.3.2 summarises incision width measurements for keel A, the keel B complex, and the keel A-B separation distance. It is apparent that variations in relative scour spacing and changes in individual scour incision widths are associated with major changes in scour orientation. Along those segments of the scour with little or no

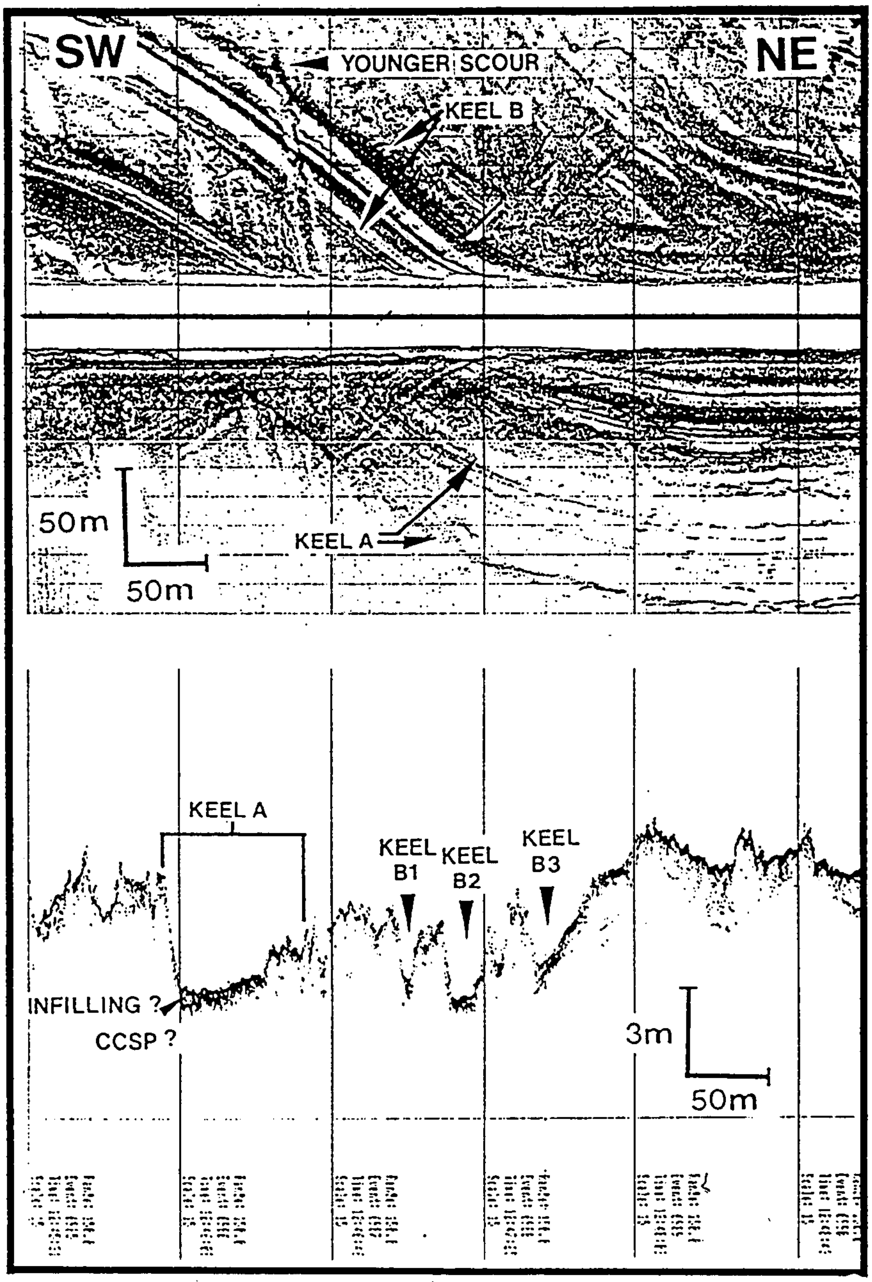


Figure 4.3.2: Sidescan and microprofiler record showing a cross-over of Keel A and the entire Keel B complex, near KP 7.8. Sub-bottom reflectors occur beneath each of the keels. The reflector beneath Keel A appears related to scour infilling (probably localized CCSP debris) rather than sub-scour deformation. Detailed striations, generally indicative of a lack of sediment infill, are present within the base of Keel A near the cross-over. A more recent scour cross-cutting scour near Event 6987, deposited CCSP debris within the base Keels B1 to B3, but does not appear to have incised the base of the keels.

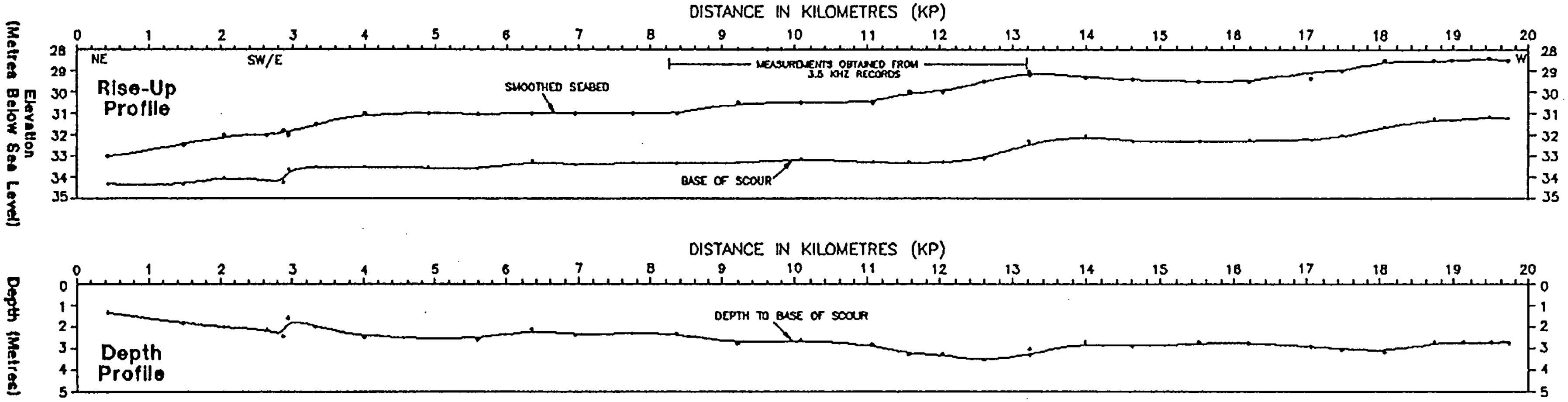


Figure 4.3.3 Scour rise-up and scour depth profiles along Scour N90-1.

orientation change, the width measurements remained fairly constant. Figure 4.3.4 illustrates how changes in scouring direction result in scour width variations similar to those observed along Scour N90-1.

Table 4.3.2 Scour Width Variations (Scour N90-1)

Scour Direction	Keel A Width (m)	Keel B Width (m)	Keel A-B Separation (m)	Multi-keel Width (m)
110	Keel A and B overlapping		0	80 (incl. C)
125	Keel A and B overlapping		0	55
190	45	40	30	195 (incl. C)
220	50	55	45	150
240-250	45	50	40	135
270-280	40	35	25	100

Between KP 0.0 and KP 2.9, keel A and the keel B complex were positioned one behind the other, forming a single resultant scour (Enclosure 1; Plate 1). A second keel, the western keel, occurs 150 metres west of the keel A-B composite scour along this interval. This keel parallels the keel A-B composite scour and appears to be part of Scour N90-1. However, it is not observed beyond the major change in scour direction at KP 2.9. This unnamed scour appears to be cross-cut by keels A and B just past KP 2.9 but could alternatively be masked beneath keel B (Enclosure 1: Plate 2).

Past KP 2.9, keel A and keel B separate and remain distinct entities until another major change in scour direction occurs at KP 19.2. Subtle variations in the incision widths of keel A and keel B, as well as, the keel A-B separation distance occur between KP 2.9 and KP 19.2. These variations are dependent on scour orientation. With scour orientation between 240° and 250°, keel A incision width is approximately 45 metres, the keel B complex incision width is 50 metres, and 40 metres separates keels A and B (Enclosure 1; Plates 2, 5, and 6). Beyond it's first observed occurrence at KP 8.5, keel C is only apparent when scour orientation is between 220° and 250° (Enclosure 1; Plate 7). When scour orientation is 270° to 280° (KP 5.0 to KP 7.5 and KP 13.3 to KP 16.6) keel A and keel B incision widths decrease to 45 metres and 35 metres respectively, keel B1 disappears, and the A-B separation distance is only 25 metres (Enclosure 1; Plate 4). Keel C also disappears when scour orientation is between 270° and 280°. It may be overlapped by keel B, although the exact locations where possible overlapping initiated or ended are not apparent.

Between KP 19.2 and KP 19.4 scour direction is 110° and keels A, B and C are all overlapping with a total scour width of 80 metres. Past KP 19.4, scour orientation is 190° and the component scours of N90-1 are no longer overlapping. Keel C width increases to 70 metres between KP 19.4 and the end of scour tracking at KP 19.9.

It is evident that an ice floe may change directions several times while scouring the seabed. Variations in the scour width observed along Scour N90-1 are predominantly the result of

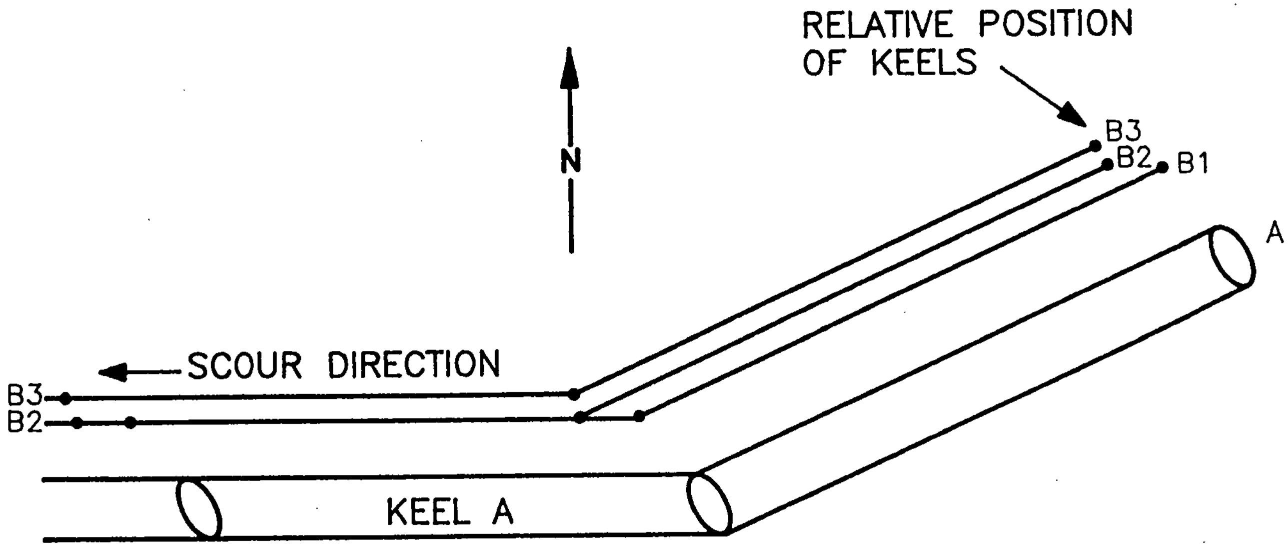


Figure 4.3.4 Schematic showing scour width variations resulting from relative ice keel positions and changes in scouring direction.

such changes in scour direction. No direct relationship between scour width and scour depth or water depth are apparent for Scour N90-1.

Berm Width and Berm Height

Berm width and height measurements for keel A, the principle scour of N90-1, are contained in the Scour Parameter Table for Scour N90-1 (Appendix 2). Between KP 0.0 and KP 1.5, the scour depth is approximately 1.0 metre and the scour berms are less than 1.0 metre high and 5.0 metres wide. Between KP 1.5 and KP 8.5, the scour depth increases to approximately 2.0 to 2.5 metres. Average berm heights along this portion of the scour are 2.0 metres (2.5 metres maximum) and 1.6 metres (2.4 metres maximum) for the northern and southern berms, respectively. Berm widths of 5-10 metres and 10-15 metres are most common for the northern and southern berms, respectively.

Beyond KP 8.5, scour depth varies between 2.7 metres and 3.8 metres. Average berm height decreases slightly to 1.9 metres (3.0 metres maximum) for the northern berm and increases to 2.0 metres (2.9 metres maximum) for the southern berm. Berm width is most commonly 5-10 metres (15-20 metres maximum) along the northern berm and 15-20 metres (25-30 metres maximum) along the southern berm.

On average, the southern or outer berm of keel A appears slightly wider than the northern or central berm. Berm heights are more variable, and display a considerable range in height along any given portion of the scour. There is an overall increase in berm size with increasing scour depth. This is most apparent in the initial stages of scouring where scour depth increases fairly rapidly to 2.0 metres. There does not appear to be any pronounced variation in berm size associated with changes in scour orientation.

Sediment Infill

Stratified sediment infill, commonly associated with older scours (i.e. Scour N90-4), was not observed along Scour N90-1. Significant accumulations of sediment infill were not expected for this scour, as it was only 9-10 years old at the time of the ESRF 1990 survey. The base of the scour was measured as the first arrival event on the microprofiler records which coincides with bottom return on the echo sounder records.

Sediment piles, resulting from more recent cross-cutting scour activity, were frequently within the base of Scour N90-1 (Enclosure 1; Plate 6). These sediment piles, herein referred to as cross-cut sediment piles (CCSP), are quite distinguishable on the microprofiler records and are generally associated with pronounced cross-cutting scours on the sidescan records. There were no cases where CCSP debris was so extreme as to prevent the measurement of the elevation of the scour base.

Sub-bottom reflectors were observed on the microprofiler records at the base of keel A and keel B (Enclosure 1; Plates 5 and 7). They are fairly common beneath the deepest portion of keel A (generally <0.5 metres sub-bottom) and less frequent at the base of the keel B complex. These sub-bottom reflectors suggest that either non-laminated sediment infill is present at the base of the scour, or that the sediments below the base of the scour were disrupted during the scouring process. At several N90-1 cross-overs, discontinuous sub-bottom reflectors appear to mark possible echelon failure planes within the sediments at the base of keel A (Enclosure 1; Plate 6).

The sediments overlying the sub-bottom reflectors are not stratified and rather than pinching out against the scour walls, appear to be continuous with the scour wall material (Enclosure 1; Plate 4). In addition, the thickness of sediments overlying the sub-bottom reflectors is sporadic and, in places, seems excessive for a relatively young scour, such as Scour N90-1. Scour infill rates more than 25 times the regional sedimentation rate would be required to produce the observed maximum infill thickness of 0.6 metres. These observations suggest that the sub-bottom reflectors may be related to sub-scour disturbance.

The scouring process, besides excavating a portion of the sea bottom, may significantly affect sediments within the scour base and walls (Comfort et al., 1990). Shearer (1981) presents acoustic evidence suggesting that the base and walls of some scours may be comprised of disturbed sediment (Figure 4.3.2). The apparent continuity of the material above the sub-bottom reflectors with scour wall material, as well as, the presence of what appear to be sub-scour sediment dislocation planes, suggest that the sub-bottom reflectors observed beneath Scour N90-1 may represent a zone of disturbed sediment formed during the scouring process.

Scour Depth and Rise-up

The start point of Scour N90-1 is only observed on the sidescan record. At the closest cross-over event, 400 metres away, the depth to the base of the scour is 34.3 metres and the scour is 1.0 metres deep (Enclosure 1 and Figure 4.3.3). This suggests that the initial contact of the ice keel with the seabed occurred at a water depth of approximately 34.3 metres. Between KP 0.0 and KP 2.9, scour base elevation remains relatively constant and scour depth increases to 2.4 metres, as the ice-keel scoured into progressively shallower water depths.

At KP 3.0 (the first cross-over past a major scour direction change at KP 2.9), the elevation of the base of the scour is 33.5 indicating a rise-up of 0.7 metres. This rise-up appears to be associated to a major change in scour direction. Prior to the direction change, keels A and B were aligned one behind the other. Keel B, the shallower of the two keels, trailed keel A and was not likely in full contact with the seabed. Following the change in scour direction, keel B scoured directly into the seabed. The increased surface area of ice in contact with the sediments may have resulted in the observed rise-up. Similar rise-up across a major change in scour direction was also observed on Scour N90-5.

Between KP 3.0 and KP 12.6, scour base elevation increases slightly, while bathymetry decreases gradually from 32.0 metres to 29.5 metres. Between KP 8.4 and KP 12.6, there is no echo sounder data and scour parameters were measured from corrected sub-bottom profiler records. At adjacent scour cross-overs, where both sub-bottom profiler and echo sounder data were recorded, measurements from the sub-bottom profiler records appear consistent with those obtained from echo sounder records. There are slight variations in scour base elevation along this portion of the scour and a net recorded rise-up of 0.4 metres. Scour depth increases from 1.6 to 3.6 metres along this portion of the scour. The maximum observed depth of 3.8 metres occurs along this portion of the scour. Up until this point, the scour appears to fall within the bounds of Stage 1 of the Shearer et al. (1986) scouring process.

The base of the scour begins to rise-up at KP 12.6. Beyond this point, Scour N90-1 is characterised by Stage 3 rise-up. Stage 2 of the Shearer et al. (1986) scouring process is not readily apparent along Scour N90-1. Between KP 12.6 and KP 13.3, the scour base elevation rises up more rapidly than the seabed elevation and the scour depth decreases slightly. Total rise-up across this interval is 0.8 metres. For some scours, this type of rapid rise up is indicative of imminent scour termination or partial termination (i.e. Scour N89-1). In the case of N90-1, the ice-keel changed direction immediately following the segment of rapid rise-up.

Beyond the scour direction change at KP 13.3, the scour base elevation closely follows seabed elevation and the scour depth remains relatively constant at approximately 3.0 metres. Between KP 13.3 and KP 17.1, bathymetry decreases slightly and the scour base elevation remains relatively constant near 34.0 metres. Between KP 17.1 and KP 18.1, there is a slight increase in scour depth as the base of the scour rises up more slowly than the seabed. There is a net rise-up in scour base elevation of 1.0 metres, between KP 17.1 and KP 18.7. Beyond KP 18.7, there is no significant change in either the seabed elevation or the scour base elevation.

No significant changes in rise-up are associated with the major changes in scour direction at KP 19.2 and KP 19.4. Although the limit of scour tracking occurs at KP 19.9, it is possible that Scour N90-1 continues past the more recent cross-cutting scours at KP 19.9, but is not recognised due, perhaps, to a change in character associated with another major change in scour direction. For most scours where termination has been observed, the scour base elevation rises up more rapidly than the seabed elevation, with a resultant decrease in scour depth prior to the termination event. Even up to the last cross-over event at KP 19.8, there are no apparent changes in rise-up, bathymetry, or scour depth within this interval which would imply imminent scour termination.

Scour Age and Cross-cutting Scours

Scour N90-1 is present on the sidescan records collected in the summer of 1981 but not on records from the same location during in 1979 field season. Accordingly, it must have been formed sometime between the summers of 1979 and 1981, and probably formed during a multi-year ice incursion that took place in this area in the fall of 1980 or winter of 1981. At the time of the ESRF 1990 survey, Scour N90-1 was probably 10 years old.

If the age of a scour is known, a count of the number of newer cross-cutting scours can be used to calculate the impact rate of new scours in the area. Impact rates for different water depth ranges are normally calculated from regional survey line data. These lines generally cross bathymetric contours at a considerable angle resulting in impact rate calculations that are based on very short line segments between the desired contours. Detailed studies of new scour impact rates across the Beaufort Sea indicate that scouring is quite episodic in nature (Shearer, 1996a). Certain areas may be heavily scoured in some years and relatively unscoured in other years.

Given that Scour N90-1 has been tracked for 16 kilometres in a relatively narrow range of water depths (28.5 to 31.5 metres) and that 10 years of scouring has occurred since its formation, the resultant impact rates for cross-cutting scours may more accurately reflect the probability of new scour occurrences for water depths of approximately 30 metres in this locality. Some 140 new scours were observed cross-cutting the 16 km long northeast-southwest portion of Scour N90-1, between KP 3.0 and KP 19.0. The resultant average re-scour frequency is 8.8 scours per kilometre. Individual 1.0 kilometre segments of Scour N90-1 have scour frequencies ranging from 4 scours per kilometre to 17 scours per kilometre. With the age of Scour N90-1 at 10 years, new scour impact rates calculated for this area range from 0.4 to 1.7 scours/km/yr, with an average impact rate of 0.9 scours/km/yr, for water depths between 28.5 metres and 31.5 metres. These rates fall within the bounds of the regional impact rates calculated by CSR for Shearer (1996a).

The cross-cutting scour impact rates represent an average over 10 scouring seasons and are not necessarily representative of scouring intensity in any one particular year. The re-scouring rate may have been quite high for one year (e.g. up to 17 scours per kilometre) with literally no scouring occurring in the remaining years.

4.3.2.2 SCOUR N90-2

Scour N90-2 is a double keeled scour located on the Kringalik Plateau, in water depths of 41 to 53 metres. The scour start point is located at 70° 14' 52.2" N, 137° 02' 24.6" W. At just over 50 kilometres in length and up to 8.5 metres deep, it is one of the longest and deepest scours observed in the Beaufort Sea to date. Sediment infill observed within the base of the scour ranges in thickness from 1.0 to 3.0 metres. Just over 8.0 metres of scour rise-up was recorded along the scour. The estimated age of Scour N90-2, based on sediment infill thickness and the frequency of cross-cutting scours, ranges from 180 to 215 years.

Scour N90-2 was first observed during a 1979 sidescan survey over the Tarsiut-Nektoralik corridor. The 1979 survey data revealed that the scour was a semi-smooth, single keel scour with an average scour depth of approximately 5.0 metres and a scour width of 50 metres. This early survey over N90-2 was of limited extent, and determination of sediment infill was not possible with the echo sounder system employed at that time.

Scour N90-2 was tracked for 50.5 kilometres during the 1990 scour tracking survey, providing 86 cross-overs of the scour. Figure 4.3.5 is an example of the combined sidescan and microprofiler record for one of the scour cross-overs. Scour parameter measurements obtained from each cross-over are summarised in the Scour Parameter Table for Scour

N90-2 (Appendix 2). The various scour measurements were used to construct Rise-up and Depth Profiles of Scour N90-2 (Enclosures 2a and 2b). Enclosure 2a contains the scour profiles along the northern scour leg along with representative sidescan records and scale-corrected cross-sections. Enclosure 2b provides the same display for the southern scour leg and scour loop segment. Page size plots of the scour profiles are presented in Figures 4.3.6 and 4.3.7.

Scour Direction and Orientation

Scour N90-2 is comprised of two distinct segments, the northern and southern scour legs, that describe a general V shape, opening to the west (see Plan View; Enclosures 2a and 2b). Detailed tracking at the apex of the V indicates that the scour loops across itself twice, forming a figure eight shape. The scouring direction of the ice ridge that formed Scour N90-2 can be inferred from cross-cutting relationships observed on the sidescan sonar records; both where Scour N90-2 cuts across itself, and where it cuts across older scours. Cross-cutting relationships within the scour loop segment indicate that the northern scour leg was formed prior to the southern scour leg. Accordingly, the ice ridge which formed Scour N90-2 touched down in the northwest, proceeded eastward forming the northern leg of the scour, abruptly changed course three times forming the scour loop, and then travelled westward forming the southern leg of the scour.

The northern leg of the scour shows evidence of formation from two ice keels, a main ice keel, which incised the deepest part of the scour, and an immediately adjacent auxiliary keel which did not penetrate as deeply into the sediments (Enclosure 2a; Plate 5). The southern leg of the scour, as well as, portions of the scour loop segment only show evidence of a single ice keel (Enclosure 2b; Plate 2). These changes in morphology are related to the direction of scouring and the relative position of the component ice keels. Along the northern leg, the ice keels scoured side by side, while along the southern leg, the ice keels were aligned one behind the other forming only a single scour (Figure 4.3.8).

Abrupt changes in scour direction at Kilometre Point (KP) 4.9 and KP 10.0, and a more gradual direction change near KP 14.8, separate the northern scour leg into four shorter segments. Average scouring direction along each of these segments is as follows; 100° (KP 0.0 to KP 4.9), 70° (KP 4.9 to KP 10.0), 135° (KP 10.0 to KP 14.8), and 100° (KP 14.8 to KP 29.1). Slight variations in scour direction occur along each of the four segments. These are most pronounced from KP 12.0 to KP 14.8, where the scour track is sinuous and several slight dislocations of the scour are apparent (Enclosure 2a; Plate 3).

Prior to KP 10.0, the main incision occurs north of the auxiliary incision. Past KP 10.0, the main incision is southwest of the auxiliary incision. This change in relative keel positions is due to the abrupt change in scour direction, at KP 10.0. Near KP 13.7, the relative position of the two incisions changes again, such that, the main incision occurs northeast of the auxiliary incision (Enclosure 2a; Plate 3). The juxtaposition of the keel incisions at this location suggests that significant rotation of the ice floe occurred near KP 13.7. The main incision is located just north of the auxiliary incision, until KP 25.0, at which point, the auxiliary incision becomes much less pronounced and may be absent.

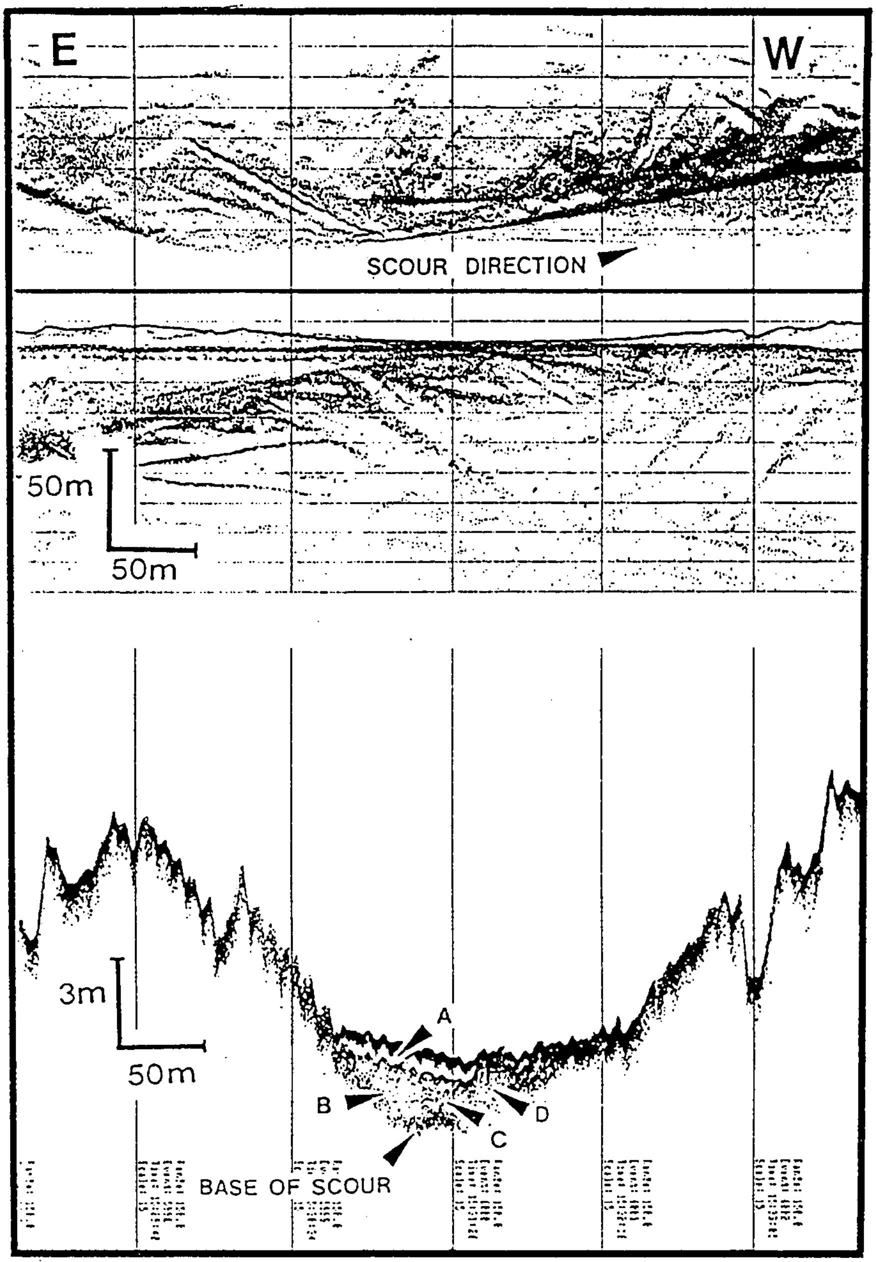


Figure 4.3.5: Low angle cross-over of scour N90-2, near KP 42.0 at approximately 42 metres water depth. A surface layer of infill (indicated by A) overlies a lower unit of infill that is largely unstratified (indicated by B) but does show some faint laminations (indicated by C). A cross-cut soil pile (indicated by D) rests directly on the base of the scour and must have been deposited shortly after scour N90-2 was formed. The apparent dip of the scour infill observed on the microprofiler record is due to slight variations in the tow-fish height and is not real. The infill is essentially flat lying.

From KP 29.1 to KP 31.8, the scour direction changes three times, forming the loop segment of the scour. The ice floe first moved at 020°, with the two ice keels aligned one behind the other, then for a short distance at 125° to 170° with the ice keels aligned side by side. Finally, the ice ridge began scouring the southern scour leg at 245°, once again with the ice keels aligned one behind the other but in reverse order to that in the earlier portion of the loop segment (Figure 4.3.8). The presence of what appears to be a wallow pit at one of the direction changes (Enclosure 2b; Plate 1), suggests that the ice ridge may have been temporarily grounded within the loop segment.

The southern leg of the scour has an overall orientation of approximately 80°-260°. Locally, scour direction is variable along the southern leg; heading 245° from KP 31.8 to KP 36.5, gradually changing to approximately 270° between KP 36.5 and KP 45.4, then heading 235° from KP 45.4 to KP 47.9, and finally heading 280° from KP 47.9 to KP 50.5. The direction changes at KP 45.4 and KP 47.9 are both fairly abrupt. The southern leg of the scour appears to be single-keeled. However, some segments of the southern leg are nearly parallel with portions of the northern scour leg, which exhibits two distinct incisions. This suggests that either the ice floe rotated gradually along the southern leg, keeping the two keels aligned one behind the other regardless of the scouring direction, or, the auxiliary keel was sheared off the ice floe, prior to the formation of the southern leg.

Scour Width and Incision Width

Scour width varies from 20 to 80 metres and incision width from 15 to 50 metres. Such variations in width measurements appear related to both scour depth and the positions of the ice keels during the scouring process. Along the first 10 kilometres of the scour, where changes in scour depth are most pronounced, scour width and incision width both increase as scour depth increases. Beyond KP 10.0, width variations are more closely related to the relative ice keel positions. Average scour width and incision width values were calculated along five separate segments of the scour (Table 4.3.3).

At the onset of scour tracking, scour depth is 2.0 metres, incision width is 15.0 metres and scour width is 20 metres. Between KP 0.0 and KP 10.0, average scour depth is just under 4.0 metres, while incision width and scour width average 26 metres and 42 metres, respectively. These average widths are less than those encountered along the remainder of the scour. Average scour depth is relatively constant beyond KP 10.0. Width changes along the remaining four scour segments are related to the relative positions of the scouring keels. For example, along segments 2 and 4, where the ice keels were aligned side by side, scour width and incision width are 66-78 metres and 40-50 metres respectively. In contrast, along segments 3 and 5, when the ice keels were aligned one behind the other, average scour width decreases to 52 metres, and incision width decreases to 34 metres.

Table 4.3.3 Average Scour Width and Berm Measurements

Scour Segment	(n)	KP	Water Depth	Scour Depth	Scour Width	Incis. Width	North Berm Width	South Berm Width	North Berm Height	South Berm Height
1) West N. leg	14	0-10	49-53	3.9	42	36	26	24	1.6	1.2
2) East N. leg	22	10-29	45-49	6.6	66	40	45	31	2.0	2.1
3) Loop seg.	9	29-30	45-46	5.7	50	34	23	26	1.8	2.2
4) Loop seg.	4	30-31	45-46	6.6	78	50	33	28	2.2	1.2
5) South leg.	36	31-50	41-45	6.8	54	34	24	27	1.8	1.9

Berm Height and Berm Width

Berm widths vary from, 5.0 metres to 75 metres, and berm heights vary from, less than 0.5 metres to 4.0 metres. Table 4.3.3 contains average berm heights and widths calculated for five scour segments. Slight variations in the average berm size occur along the length of the scour. The most dramatic change in the average berm size is related to a significant increase in scour depth that occurs along the northern leg of the scour near KP 10.0. Here average scour depth increases from 3.9 metres to 6.6 metres, while average berm width increases from 25 to 37 metres. Average berm height increases from 1.4 to 2.0 metres. Along portions of the scour where both scour keels are present, the berm adjacent to the main incision (northern berm) is slightly larger than the berm adjacent to the auxiliary keel (southern berm).

Along the entire southern scour leg, average berm height is approximately 1.8 metres. Average berm height is 2.5 metres along the deeper water portion of the southern leg (KP 31 to KP 39). Berms along this portion of the scour are slightly higher than in other areas. In water depths of less than 43 metres (KP 39 to KP 50), average berm height decreases to approximately 1.2 metres. This is primarily due to progressive berm alteration by more recent cross-cutting scouring activity.

Sediment Infill

Sediment infill is present along the entire length of Scour N90-2. The thickness of the sediment infill, as well as, the acoustic character of the infill, is variable along the length of the scour (Enclosure 2b; Plates 2 and 5).

Along most of the northern leg of the scour the sediment infill appears "opaque" or non-stratified. The base of the scour is often difficult to determine beneath a prolonged surface return on the microprofiler records and is not well-defined. At most cross-overs, the microprofiler record displays weak and discontinuous sub-bottom reflectors that appear to mark the base of the sediment infill (Enclosure 2a; Plate 5). The thickness of the opaque sediment infill generally ranges from 1.0 to 2.0 metres along the northern scour leg. The base of infill is poorly defined from KP 0.0 to KP 5.0, and KP 12.0 to KP 17.0, possibly due to higher angle cross-overs of the geophysical profiles along these intervals. Infill measurements obtained within these intervals probably represents minimum values.

Stratified infill was observed at one crossover of the northern leg, near KP 26.6 in 46 metres water depth (Enclosure 2a; Plate 6). The well-defined sub-bottom reflectors at this cross-over are similar to those observed along much of the southern scour leg. Cross-cutting soil pile debris is not extensive along most of the northern leg but does mask the base of the scour between KP 7.5 and KP 8.5. At KP 16.5, a sub-bottom reflector occurs beneath the ridge which separates the two scour keels along the northern leg (Enclosure 2a; Plate 4). This reflector appears to coincide with the base of the scour which suggests that the inter-keel ridge may, in places, be comprised of scoured sediments that were "squeezed" between the two ice keels during scouring.

Sediment infill is better defined along the southern scour leg. Small cross-cut sediment piles (CCSP) are commonly present within the scour. This CCSP debris was seldom extensive enough to mask the base of the scour (Enclosure 2b; Plate 5). In water depths greater than 44 metres, the acoustic character of the infill varies and, in places, the infill contains no internal reflectors and appears very similar to the opaque infill observed along most of the northern leg (Enclosure 2b; Plate 2). In water depths less than 44 metres, two distinct units of sediment infill were observed within the scour base.

The upper unit of sediment infill varies from 0.6 to 0.8 metres thick. The base of the unit is marked by a strong and continuous sub-bottom reflector. Although the upper unit does not generally display internal reflectors, as a whole, it appears very similar to some of the thicker individual strata observed within the stratified sediment infill of Scour N90-4. The upper unit sediments pinch out against the scour walls and have a fairly constant thickness across the central portion of the base of the scour (Enclosure 2b; Plates 4 and 6). These relationships are consistent with a process of preferential infill, resulting from preferred deposition in the "hydrodynamically quiet" base of the scour. The occurrence of the upper unit (in water depths of less than 44 metres) appears to coincide with a marked decrease in scour berm heights. More recent cross-cutting scours have repeatedly cut into the scour berms along this relatively shallow water portion of the scour, thereby, decreasing their height over time (Enclosure 2b; Plate 6). The upper unit of infill, within Scour N90-2, may be partially comprised of berm material placed into suspension by the more recent cross-cutting scours. Scouring of the N90-2 berms may also expose sediments which may be more easily winnowed for a period of time, resulting in increased deposition within the base of the scour.

The lower unit of infill along the southern scour leg typically appears similar to the opaque infill observed along the northern scour leg (Enclosure 2b; Plate 5). The lower unit is thickest at the extreme base of the scour and pinches out against the scour wall sediments. At several cross-overs this lower unit contains a series of weak reflectors. This suggests that, in places, the lower unit is partially comprised of stratified sediments. The thickness of this lower unit of "opaque" sediment infill ranges from 1.5 metres to 2.0 metres, similar to the infill thickness observed along the northern leg.

The opaque character of the lower unit, along parts of the southern leg, and the entire infill sequence along the northern leg is not completely understood. Such deposits are typically not observed, with the exception of Scour N90-4. The fairly constant thickness of the opaque sediments along the entire length of the scour suggests that it represents sediment infill. The lack of stratification may be the result of relatively rapid sedimentation shortly after the scour was formed, or possibly the result of bioturbation. Alternatively, the opaque material may represent a type of gravity flow deposit. There is no direct evidence to favour a gravity flow origin for the opaque infill and the mechanism for such a deposit is not well understood. If the displaced sediments were liquified during scouring, some of the sediment may flow back downslope to the centre of the scour once the ice keel has passed. The geotechnical properties of the sediments being scoured as well as the size, shape, and velocity of the ice keel may determine whether or not flow-back occurs. Another possibility is that, locally, the opaque unit may represent a disturbed sediment zone formed during the scouring process. This is suggested by a single cross-over profile along the southern scour leg, where the lower opaque unit appears continuous with the scour wall sediments (Enclosure 2b; Plate 4).

Scour Depth and Rise-up

Scour depth varies between 2.0 metres and 8.5 metres along the entire length of the scour. Past KP 10.0, scour depth most commonly varies between 6.0 metres and 8.0 metres. Two major stages of scour rise-up are apparent, corresponding to Stage 1 and Stage 3 rise-up of Shearer et al. (1986). Prior to KP 11, the scour depth increases as the ice keel scoured into progressively shallower water depths (Stage 1 rise-up). Beyond KP 11, scour depth remains relatively constant and the scour base elevation closely follows the seabed elevation (Stage 3 rise-up). Along some portions of the scour, past KP 11, the ice keel penetrated near to the base of the marine clays (Acoustic Unit A; O'Connor, 1980). Between KP 36.5 and KP 39.5, the keel appears to cut into the upper surface of the more resistive Unit B sediments. In some locations, as the marine clay thickness increases, drop-down of the base of the scour occurs. Therefore we can see that local variations in the scour base elevation, and scour depth, may be partially controlled by the physical properties of the scoured sediments.

KP 0.0 to KP 10.0

At the first cross-over location at KP 0.0, Scour N90-2 is already 2.0 metres deep and the scour base elevation is approximately 55.0 metres. The exact water depth at scouring began (beyond the limit of the scour tracking survey data) is not known. However, the scour base elevation remains relatively constant between KP 0.0 and KP 3.0, thus suggesting that the scour touched down in water depths of approximately 55 to 56 metres. The scour depth increases to 4.0 metres across the first 3 kilometres of tracking as the ice keel scoured into shallower water depths.

Poorly-defined infill thickness and CCSP debris within the base of the scour, hamper the measurement of rise-up along portions of the scour between KP 3.0 and KP 10.0. The scour base elevation appears to follow variations in the seabed elevation along this interval, first rising 2.0 metres, then dropping back down to its original elevation. Following a

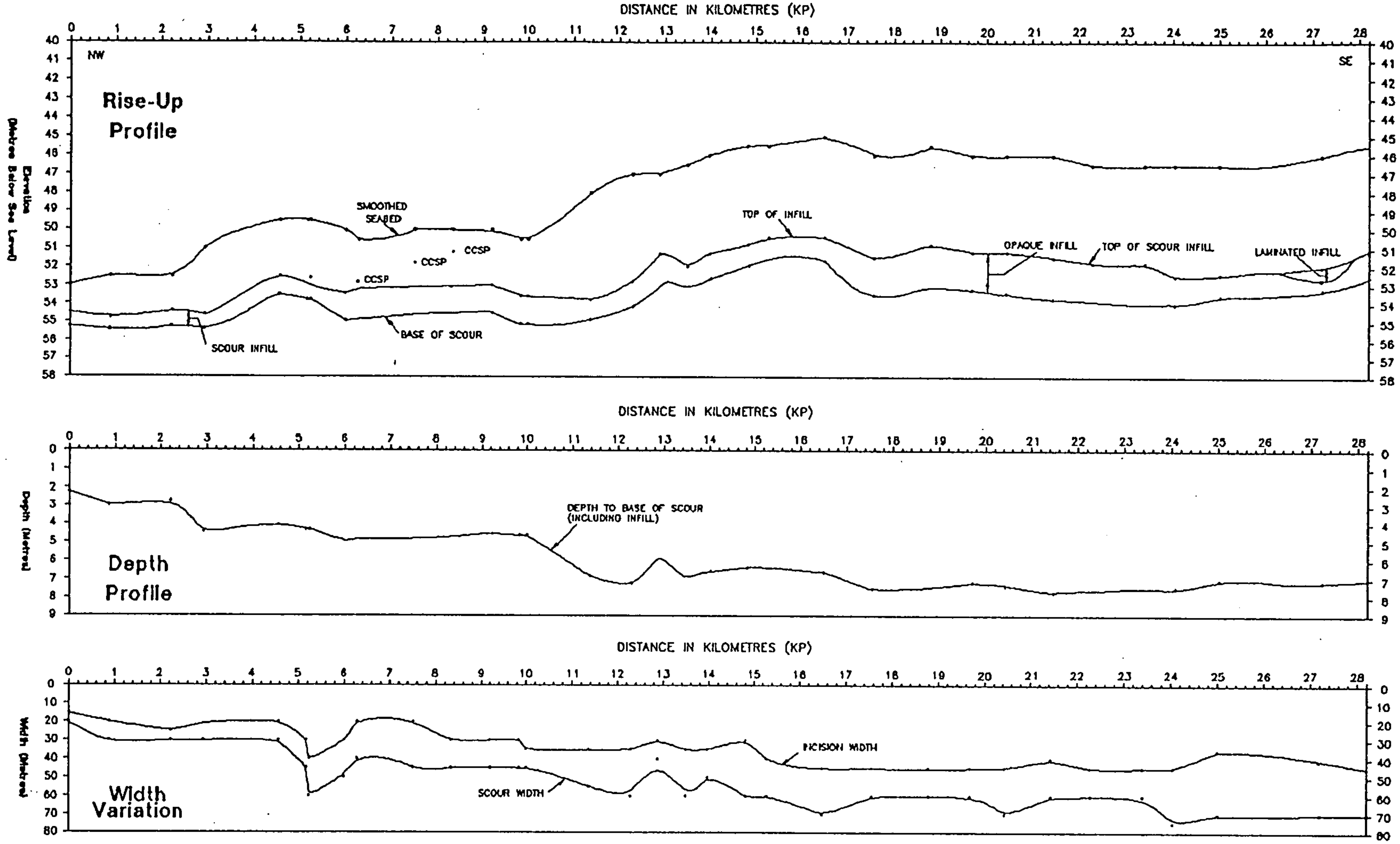


Figure 4.3.6 Scour rise-up profile, scour depth profile and scour width variation along the northern leg of Scour N90-2.

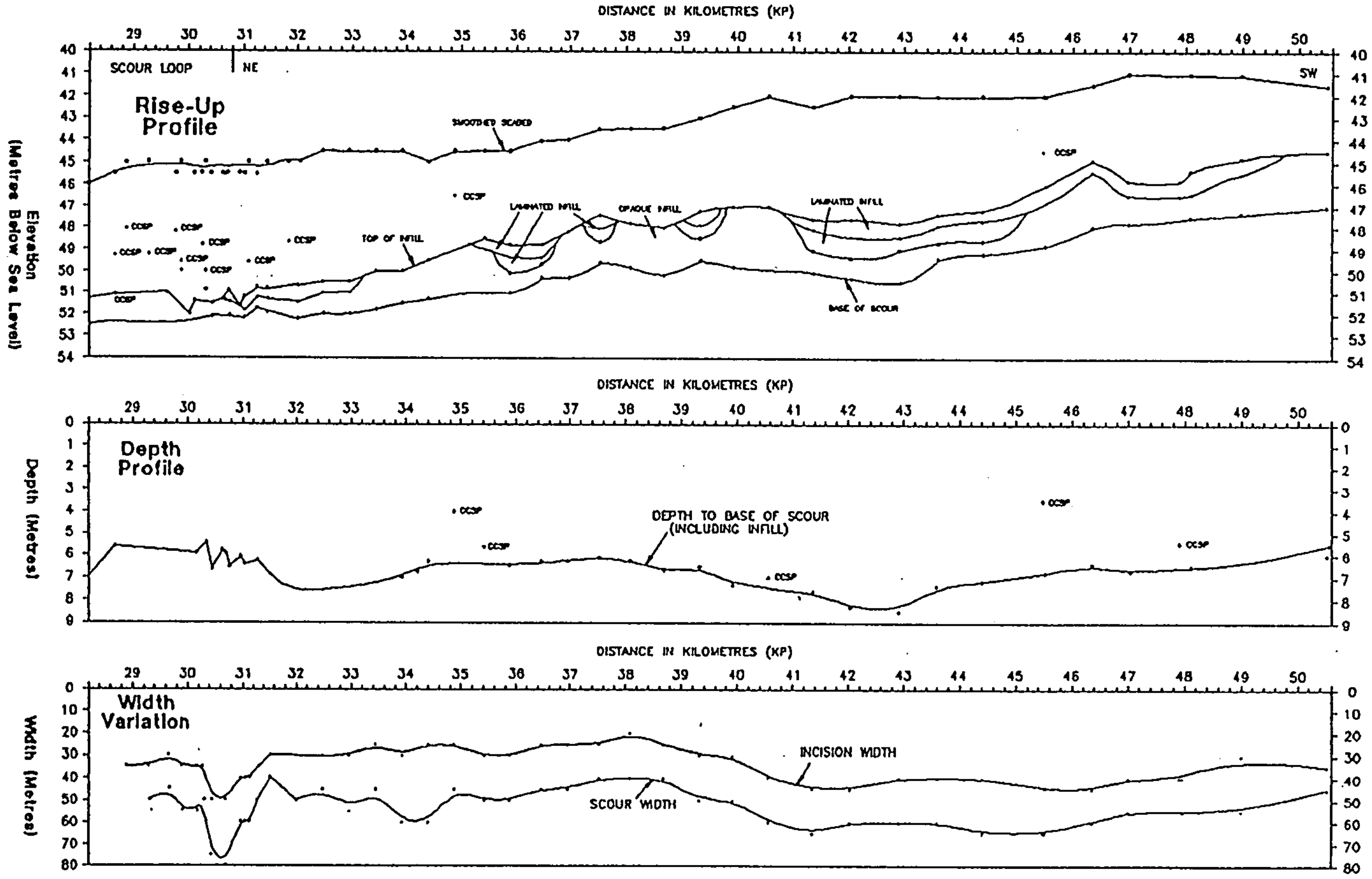


Figure 4.3.7 Scour rise-up profile, scour depth profile and scour width variation along the southern leg of Scour N90-2.

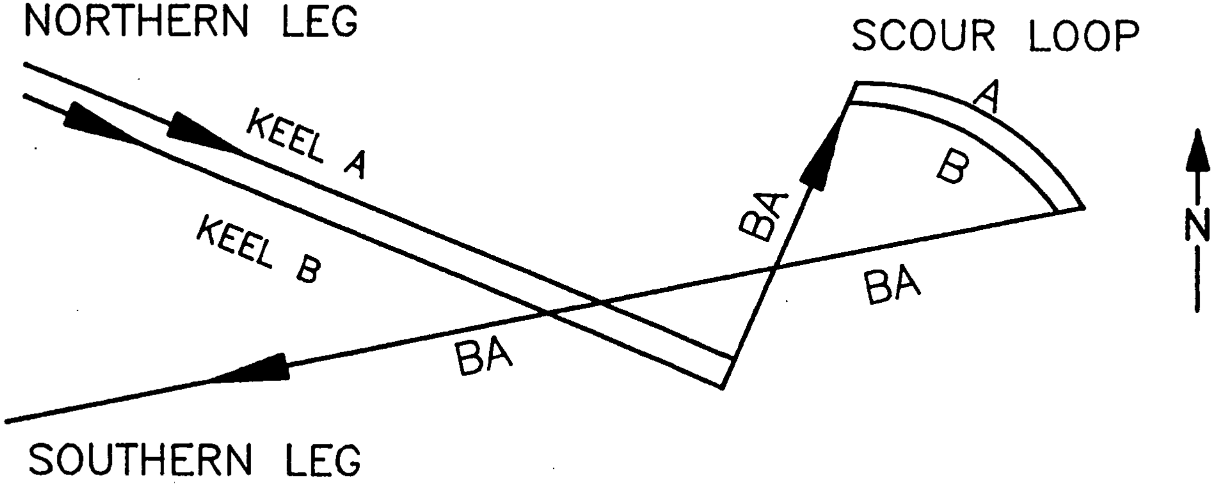


Figure 4.3.8 Reversal of ice keel positions across the scour N90-2 loop segment.

period of rise-up between KP 3.0 and KP 4.5, the ice keel changed direction near KP 5.0, and scoured nearly parallel to the bathymetric contours until KP 10.0. At this location, scour depth has increased to 4.6 metres. Up until this point, rise-up along Scour N90-2 appears to alternate between Stage 1 rise-up (KP 0-3 and KP 6-10) and Stage 3 rise-up (KP 3-6). Stage 2 rise-up, if present, occurs for a short distance between the cross-overs at KP 2.6 and KP 4.6.

KP 10.0 to KP 14.8

At KP 10.0, the ice keel changed direction, and scoured into shallower water across a relatively steep sloped seabed. Between KP 10.0 and KP 14.8, water depth decreases by 5.0 metres, and there is a total rise-up of the scour base elevation of 2.3 metres. However, this portion of the scour is characterized by several changes in scouring direction and alternating scour rise-up and scour drop-down (See below and Enclosure 2a). Within this region, the marine clays of acoustic unit A (O'Connor, 1980) thin to about 8.0 metres, and scour depth increases to approximately 7.0 metres. It appears that the ice keel penetrated very near to the upper surface of the more resistive Unit B sediments throughout this interval, perhaps accounting for the local irregularities in the scour rise-up.

Between KP 10.0 and KP 11.4, the scour depth increases from 4.6 metres to 6.8 metres, as the ice scoured into progressively shallower water. There is only a slight net rise-up of the scour base across this interval. Up until this point, the resistive forces within the scoured sediments were insufficient to prevent progressive ice keel penetration. Rise-up observations along this portion of the scour are consistent with Stage 1 of the scouring process.

Significant scour rise-up and abrupt changes in scour direction occur past KP 11.4, at the same location where the Acoustic Unit A marine clays begin to thin from 9.0 metres to 7.0 metres. Between KP 11.4 and KP 14.8, total scour rise-up is 2.3 metres. However, the rise-up observed along this portion of the scour is irregular, with alternating periods of rise-up and drop-down. The base of the ice keel penetrated near to the base of Unit A clays along this portion of the scour, suggesting that the rise-up variations may be associated with local changes in the physical properties of the sediments.

Between KP 12.2 and KP 13.5, the base of the scour first rises-up at a rate exceeding the decrease in water depth. This is an observation commonly associated with imminent scour termination. The scour then exhibits drop-down, even though the water depth continues to decrease. In plan view, the scour appears somewhat sinuous across this interval and, in some cases, abrupt directional changes over short distances are observed (Enclosure 2a; Plan View and Plate 2). The scour changes direction and becomes narrower just prior to the cross-over near KP 12.9, and at the crossover location, appears single keeled, rather than double-keeled (Enclosure 2a; Plate 2). The absence of the second auxiliary keel and the decrease in scour width both suggest that the ice floe rotated (aligning the keels one behind the other). Just beyond the crossover location the scour zig-zags before continuing off the sidescan record. The irregular scour rise-up and abrupt changes in scour direction may have formed as the ice keel penetrated near the base of unit A and, locally, cut into the more resistive Unit B sediments.

The scour may have been close to terminating along this segment due to increased resistance within the scoured sediments, but appears to have changed direction and scoured parallel to the seabed slope, for a short distance. The scour abruptly changed direction again near KP 13.8, across what appears to be a grounding pit feature (Enclosure 2a; Plate 3). The crossovers to either side of this pit show a reversal in the shape of the scour incision. This would imply that the ice floe rotated 180°, while temporarily grounded.

The sinuous plan shape of the scour, abrupt direction changes, and rise-up variations observed in this area suggest that the ice floe encountered stronger, and perhaps variable, resistive forces within the seabed sediments. The irregular rise-up might be partially explained by the keel alternately being founded in Unit A or Unit B sediments as it scoured upslope through a sediment assemblage of varying thickness. That is, as the ice keel continued to scour upslope and penetrated near to the base of Unit A marine clays, it encountered progressively more resistance and was forced to follow a "zig-zagging" path. Temporary grounding and ice floe rotation may be associated with possible penetration to the top of acoustic Unit B. However, Scour N90-2 was not observed to cut into Unit B at any of the cross-overs recorded across this interval.

KP 14.8 to KP 28.2

The elevation of the scour base tends to follow the bathymetric slope quite closely across most of this interval. Scour rise-up occurs along those segments where the water depth is decreasing, while slight scour drop-down occurs across bathymetric lows. The scour is 6.0 to 8.0 metres deep along most of this interval. There is a 1.0 metre decrease in water depth and a 3.0 metre scour drop-down between KP 16.5 and KP 25.0. The sub-bottom profiler records indicate a slight increase in the thickness of the soft clay sediments across this interval, ranging 8.0 to 9.0 metres in thickness. Variations in scour depth and scour base elevation along this portion of the scour appear to coincide with slight variations in the thickness of Acoustic Unit A marine clays.

KP 28.2 to KP 32.0

This is a complex area where Scour N90-2 changes direction three times and cross-cuts itself as it heads toward the southwest. Several of the cross-overs within this interval are masked by cross-cut sediment piles. The changes in scour direction are very abrupt, and a possible ice-wallow or grounding pit is apparent for at least one of the inflection points (Enclosure 2b; Plate 1). Water depth varies by 1.0 metre along the looped segment of the scour, while the observed scour depth varies between 4.3 metres and 8.3 metres. This suggests possible alternating periods of rise-up and drop-down of the scour base. However, cross-cutting scours are frequent within the area, and CCSP debris appears to have masked the base of the scour at many of the crossover locations.

KP 32.0 to KP 50.5

Water depth decreases gradually from 45 metres to 41 metres along the southern leg of the scour. The elevation of the base of the scour tends to generally follow the bathymetric profile along most of the southern leg. Total rise-up of approximately 5.5 metres occurs between KP 32.0 and the end of scour tracking, at KP 50.5. However, there are local variations in the scour depth, and the scour base elevation, which appear to be related to local thinning of the Unit A marine clays.

The effects of differences in the physical properties of scoured sediments are most pronounced between KP 36.5 and KP 39.5, where the scour depth decreases to approximately 6.0 metres and Unit A marine clays thin to between 5.5 and 6.5 metres. The ice keel penetrated to the base of the soft clays near KP 36.5, then followed along the top of the underlying stiff clays of acoustic Unit B, resulting in rise-up of approximately 2.5 metres. Between KP 39.5 and 42.9, the base of the scour drops down approximately 1.0 metre, and the scour depth increases to 8.5 metres, as the marine clays increase in thickness to approximately 10.0 metres. This portion of the scour represents one of the best examples of how variations in the physical properties of the scoured sediments may affect scour rise-up.

Beyond KP 42.9, the base of the scour rises up more rapidly than the decrease in water depth and the scour depth gradually decreases to 5.5 metres. Total rise-up of 3.5 metres occurs between KP 42.9 and KP 50.5. Unit A thins to between 5.0 and 8.0 metres across this interval. The close proximity of the keel to the base of Unit A may have influenced the scouring process along this portion of the scour. However, the ice keel does not appear to have penetrated into Unit B sediments beyond KP 39.5. At the limit of scour tracking, at KP 50.5, there is no indication of imminent scour termination. At this point the scour passed outside the swath of the sidescan record and could not be relocated amongst ubiquitous cross-cutting scours.

In summary, scour N90-2 was tracked in water depths ranging from 53 to 41 metres and exhibits a total rise up along it's entire length of just over 8.0 metres. This scour is also the deepest of the tracked scours, with a maximum observed scour depth of 8.5 metres. Scour N90-2 is unique among the tracked scours in that it penetrates near to the base of acoustic Unit A, and displays local variations in rise-up which appear related to changes in surficial marine clay thickness. Stage 1 rise-up predominates prior to KP 11, and scour depth increases from approximately 2.0 metres (depth at first cross-over) to 7.0 metres. Stage 3 rise-up predominates beyond KP 11, as the scour base elevation tends to mirror bathymetry. The ice keel penetrated close to the base of the Unit A marine clays, which are, on average, 8.0 metres thick in this area. Scour depth varies from 5.5 to 8.5 metres along this portion of the scour, in part due to local changes in the marine clay thickness along the scour. Occasionally, the ice keel cut slightly into the top of the more resistive sediments of acoustic Unit B. Where this occurred, the base of the scour closely follows the top of acoustic Unit B, locally rising up as the Unit A clay thickness decreased, and dropping down as the Unit A sediment thickness subsequently increased. These results indicate that scour N90-2 is an important scour, in terms of it's extreme scour rise-up and scour depth, and in displaying the influence of sediment type on the scouring process.

Scour Age and Cross-cutting Scours

At present, Scour N90-2 can not be dated directly. Scour smoothness, the degree of sediment infilling, and the frequency of younger cross-cutting scours are commonly used to provide an estimate of the relative age of scours. Each of these indicators suggests that Scour N90-2 is a relatively old scour, much older than the other scours tracked during this study.

Scour smoothness defines the degree of scour wall, berm and trough degradation, as observed on sidescan records. The degree of scour smoothness is a function bottom current erosion, bioturbation activity, the frequency of cross-cutting scours, and the rate of regional sedimentation. At any given location, the older the scour, the higher the degree of smoothing. However, for an area in which none of the scours has an absolute age determination it is difficult to assess scour age on the basis of scour smoothness alone. Nevertheless, both the northern and southern legs of Scour N90-2 fall into the semi-smooth category with fairly well-defined scour walls and berms. Most of the younger cross-cutting scours and older scours that are cut by Scour N90-2 also display a semi-smooth or smooth appearance. Given that none of the scours which cut N90-2 appear to be very fresh and that the frequency for new scour occurrences in these water depths is very low, it appears that Scour N90-2 is much older than the other scours tracked during this study.

Sediment infill can be used to estimate the age of a scour, by comparing the infill thickness to calculated sedimentation rates in the area. Only the well-defined upper unit of infill was used in estimating the age of N90-2. The lower opaque sediments are interpreted as an early sequence of rapidly deposited infill, perhaps related to storm-dominated activity, and are not directly related to regional rates of pelagic sedimentation.

Marine transgression of the N90-2 area occurred approximately 10,000 years ago (Hill et al., 1985). Significant sediment accumulation probably only occurred after water depths reached approximately 10 metres (some 1000 years later). The sub-bottom profiler data indicate that the thickness of the post-transgressive marine clays varies between 6.0 metres and 10.0 metres (8 metres average) along Scour N90-2. An average marine clay thickness of 8.0 metres suggests an average sedimentation rate of 0.9 mm/yr. However, the rate of sediment infilling for a scour at 50 metres water depth was observed to be as much as five times greater (i.e. 4.5 mm/yr) than that of the adjacent seabed (Shearer, 1981). Accounting for increased sedimentation rates within the base of the scour (4.5 mm/yr), the upper infill unit within N90-2 (0.7 metres average thickness) would have accumulated over 180 years. It is important to note that this age estimate assumes that the lower opaque unit was created by a "geological instantaneous" event, and is not included in the age calculation.

The age of Scour N90-2 can also be estimated by comparing the number of younger cross-cutting scours to scour impact rates obtained from repetitive mapping data. Updated scour impact rates, based on additional new scour occurrences recorded during the 1990 regional repetitive mapping survey, have been calculated by Shearer (1996a). This study represents the most comprehensive impact rate analysis conducted to date, and provides a basis for a more refined age estimate for Scour N90-2. Some 320 scours were observed to cross-cut Scour N90-2 over it's entire length. Because this scour traverses such a wide range in water depth, cross-cutting scour frequencies were calculated for 4 major water depth intervals (Table 4.3.4). The shallow water segment (41.0-42.5 metres water depth) is cut by 10.7 new scours/km, whereas the deepest water segment (49.0-53.0 metres water depth) is cut by 3.9 scours/km, roughly one-third the shallow water re-scour rate.

Table 4.3.4 Frequency of Scours Cross-cutting Scour N90-2

Water Depth (m)	Fix Numbers	Distance (km)	# Younger Scours	# Scours/Km
41.0-42.5	5977-6034) 6059-6082) 6111-6141)	10.8	116	10.7
43.0-45.0	5971-5880	9.1	78	8.6
45.0-48.0	6361-6537	17.8	87	4.9
49.0-53.0	6551-6604) 6624-6682)	11.1	39	3.9

In the past 10 years of repetitive mapping, no new scours have been recorded for water depths greater than 38 metres. Extrapolation of the impact rate curve developed in shallower water depths by Shearer (1996a), suggests that the impact rate at 41 metres water depth is approximately 0.05 scours/km/yr. At an impact rate of 0.05 scours/km/yr, and an observed scour frequency of 10.7 scours/km (Table 4.3.4) the age estimate for Scour N90-2 is approximately 215 years. This age estimate assumes that scour impact rates observed over the past 10 years are representative of the past 200 years.

Alternatively, if the age of scour N90-2 could be more accurately determined by independent methods, the frequency of younger cross-cutting scours along the length of the scour could be used to provide accurate long-term scour impact rates over a water depth range of 41 to 53 metres. Using the 215 year age estimate, a re-scour rate of approximately 0.02 scours/km/yr is indicated for water depths of 49-53 metres in this portion of the Kringalik Plateau.

4.3.2.3 SCOUR N90-3

Scour N90-3 is a single-keeled scour located within Kugmallit Channel, some 20 km southwest of the proposed Amauligak production site. Tracking for Scour N90-3 began at 70° 00' 15.9" N, 134° 03'52.5" W. This scour was tracked for 12.5 kilometres in water depths ranging from 16 metres to 20 metres. Scour direction is towards the southeast for the first 9 km, then towards the northwest for 3.5 kilometres. The scour varies in width from 12 to 23 metres, and has a maximum observed scour depth of 2.6 metres. Up to 0.2 metres of sediment infill is present within the base of the scour. Approximately 3.1 metres of scour rise-up, and 0.4 metres of scour drop-down, occur along the northern and southern scour legs, respectively. Scour impact rate and sedimentation rate calculations suggest that Scour N90-3 is between 10 and 25 years old.

Scour Orientation and Direction

Scour N90-3 is linear to gently arcuate in plan view, along most of its length. A 180° reversal in scour direction occurs at 16 metres water depth, separating the scour into a 9 km long northern leg and a 3.5 km long southern leg (Enclosure 3; Plan View). Both scour segments trend northwest-southeast, although several changes in scour orientation occur along the deeper water portion of the northern scour leg.

Neither end-point of N90-3 could be located, due to more recent scouring activity. As a result, actual direction of scouring is not certain. Cross-cutting relationships at the direction reversal event suggest the ice-keel initially travelled southeastward, forming the northern scour leg. The ice then changed direction and scoured towards the northwest, forming the southern scour leg.

Scour Width and Incision Width

Younger scours cross-cut extensive portions of N90-3 (Figure 4.3.9). These scours have severely modified the original N90-3 scour berms, and often deposited cross-cut soil-pile (CCSP) debris within the scour incision. As a result, scour width and scour incision width measurements were difficult to obtain. Scour width measurements could not be determined for every cross-over.

Scour width and incision width increase towards the southeast, along the northern scour leg. At the onset of scour tracking at KP 0, scour width is 12 metres and incision width is 7.5 metres. There appears to be a marked increase in scour width and incision width, to 15.0 metres and 20 metres respectively, at a major direction change near KP 3.3. Scour depth does not increase at this location, suggesting that the increase in width may be related to rotation of the ice-keel. Between KP 3.3 and the scour direction reversal event near KP 9.1, the incision width remains relatively constant at approximately 15.0 metres. Scour width increases slightly across along this portion of the scour, to a maximum of 23 metres. Maximum scour width measurements occur along the deepest portion of the scour between KP 7.0 and KP 8.0. This suggests that the increase in scour width is primarily related to an increase in scour depth, and an associated increase in berm size, along this portion of the scour. Scour width and incision width decrease along the southern scour leg. Scour width and incision width are 15.0 metres and 10.0 metres, respectively, at the northwestern end of the southern scour leg.

Berm Width and Berm Height

Berm width and berm height measurements were difficult to obtain because of the high degree of deformation caused by the younger cross-cutting scours. Nevertheless, relatively undisturbed berms were apparent at a number of cross-overs. The two scour berms appear to be similar in size, along any particular portion of the scour. The berms are roughly 5.0 metres wide at the northwest extent of the northern and southern scour legs. In other locations were measurements could be obtained, the berm widths averaged 10.0 metres. Berm heights range from 0.5 to 1.0 metres at cross-overs where younger scours are not apparent.

Sediment Infill

Most of the sediment infill observed along Scour N90-3 are cross-cut sediment pile debris (CCSP), deposited during more recent scouring activity. In many cases, this CCSP debris obscures the base of the scour (Enclosure 3; Plates 1 and 2).

Stratified sediment infill appears to be either absent at most scour cross-overs, or is beyond the resolution limit of the microprofiler (< 0.1 m). Thin deposits of stratified infill (approx. 0.1 m) are apparent at some cross-overs along the southeastern, shallow water, portion of the scour. Approximately 0.2 metres of poorly-defined sediment infill occurs at the scour direction reversal event in 16 metres water depth (Plate 4). The southern leg of Scour N90-3 cross-cuts an older scour with 0.2 metres of well-defined stratified infill.

At several cross-overs, discontinuous, poorly defined, sub-bottom reflectors are present beneath the scour (Enclosure 3; Plate 3). The origin of these reflectors is not certain. They may mark the base non-stratified sediment infill, the base of a zone of sub-scour deformation or, in some cases, the base of the scour beneath relatively thin CCSP debris. Similar sub-bottom reflectors are discussed more fully in the infill section of scours N90-2 and N90-4.

Scour Depth and Rise-Up

Key scour parameters were measured at 23 cross-overs along Scour N90-3; 19 along the northern scour leg and 4 along the southern scour leg. Cross-cut sediment piles are present at several of the cross-overs. This debris often masks the base of the scour, resulting in an incomplete scour rise-up profile. For example, scour base elevation measurements were obtained on only two of the four cross-overs along the southern scour leg. Nevertheless, three stages of scour rise-up were identified along the northern scour leg, while the scour base elevation appears to drop-down along the southern scour leg (Enclosure 3, and Figure 4.3.10). Total scour rise-up along the entire northern leg is 3.1 metres. The scour base elevation drops down at least 0.4 metres along the southern scour leg.

Stage 1 of scouring is apparent prior to KP 1.7. The scour base elevation remained relatively constant along this portion of the scour. Scour depth increased from less than one metre to 1.3 metres, as the ice keel scoured into progressively shallower seabed.

Stage 2 scouring occurred from KP 1.7 to KP 7.3. Scour rise-up occurred along this portion of the scour, but at a rate less than the decrease in bathymetry. As a result, scour depth continued to increase gradually from 1.3 metres (at KP 1.7), to 2.5 metres (at KP 7.3). Total rise-up across this interval is 1.1 metres.

At KP 7.3, the scour base elevation began to rise-up more rapidly bathymetry, and scour depth decreased. Scour rise-up of 2.0 metres occurred between KP 7.3 and KP 9.1, the last cross-over on the northern leg prior to the scour direction reversal event. Scour depth decreased to 1.0 metres at KP 9.1. The rise-up across this interval falls within the third stage of scouring outlined by Shearer et al. (1986). The relatively rapid rise-up, at a rate greater than the decrease in water depth, suggests that the strength of the sediments may have increased locally. Such rise-up is sometimes indicative of imminent scour termination. In the case of Scour N90-3, termination does not occur. Rather, the scouring direction changed almost 180° and the ice keel scoured into deeper water.

Only 2 scour base elevation measurements were obtained along the southern scour leg, due to CCSP debris. Scour depth appears relatively constant at approximately 1.0 metre. The scour base elevation drops-down 0.6 metres, at about the same rate as the increase in water depth. At the last cross-over with a scour base elevation measurement, water depth is 16.5 metres and the scour base elevation is 17.4 metres. At the same water depth on the nearby northern scour leg, the scour base elevation is 19.1 metres. This difference in scour base elevations may be indicative of local differences in the physical properties of the sediments along the two legs of the scour. Alternatively, the shape of the ice keel, relative to the scouring direction, may have influenced the degree of scour drop-down along the southern scour leg.

Scour Age

Sedimentation rate calculations, based on the thickness of stratified sediment infill and regional scour impact rates, suggest that Scour N90-3 is probably between 10 and 25 years old.

Stratified sediment infill, interpreted to be comprised of predominantly pelagic sediments, is 0.1 metre or less along most of Scour N90-3. Between 0.1 and 0.2 metres of infill were observed at one cross-over near the scour direction reversal event. Scour N90-3 also cross-cuts an older scour which contains 0.2 metres of well-defined sediment infill (Enclosure 3; Plate 5). Regional sedimentation rates within this area are approximately 2 mm/yr (Shearer, 1988). Preferential sedimentation rates within the base of scours may be up 5

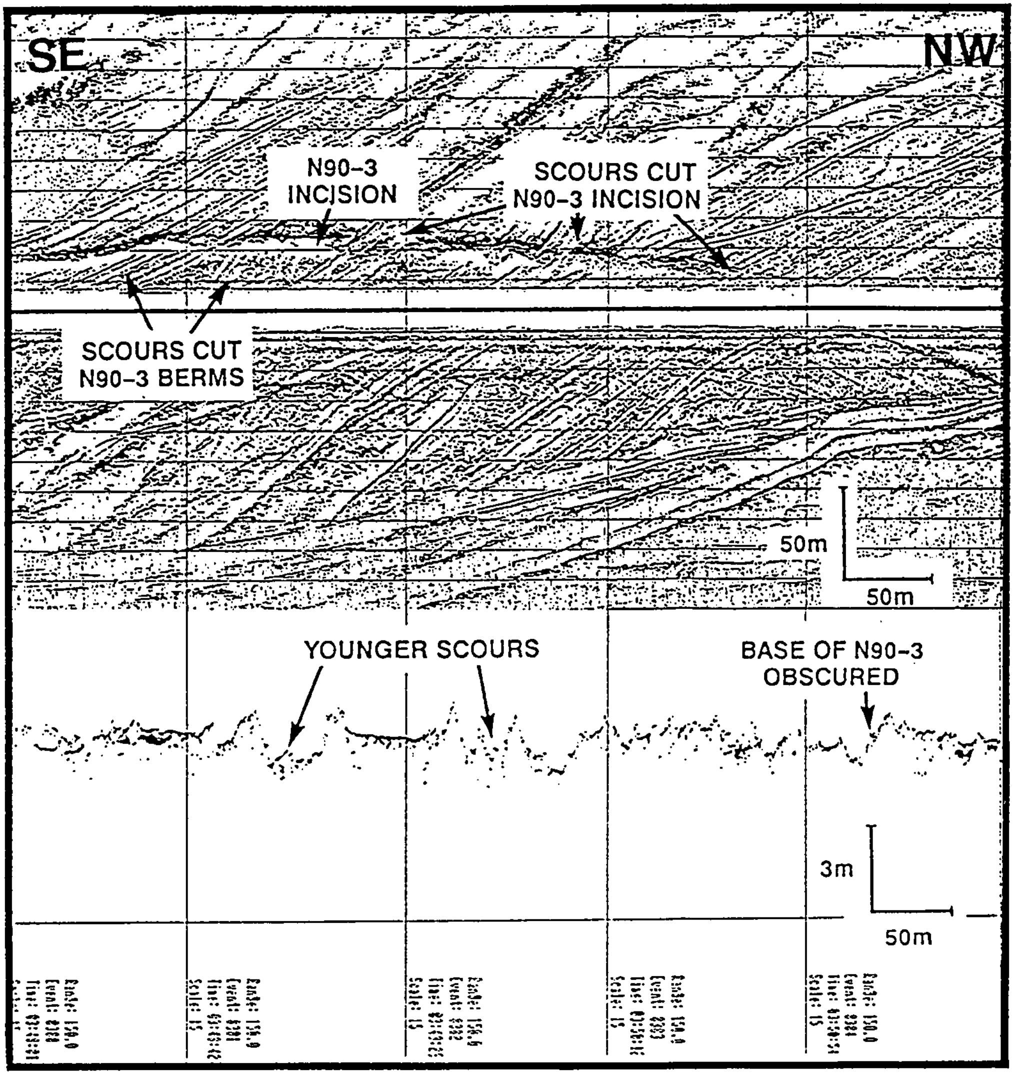


Figure 4.3.9: Sidescan and microprofiler record along a low angle cross-over of scour N90-3, near KP 2.4. Younger scours cross-cut this portion of N90-3, severely modifying the original scour morphology. Some of the larger cross-cutting scours cut across and obscure the N90-3 scour incision (i.e. cross-over at Event 8384). Other scours have destroyed the N90-3 scour berms, but appear to pass over the scour incision.

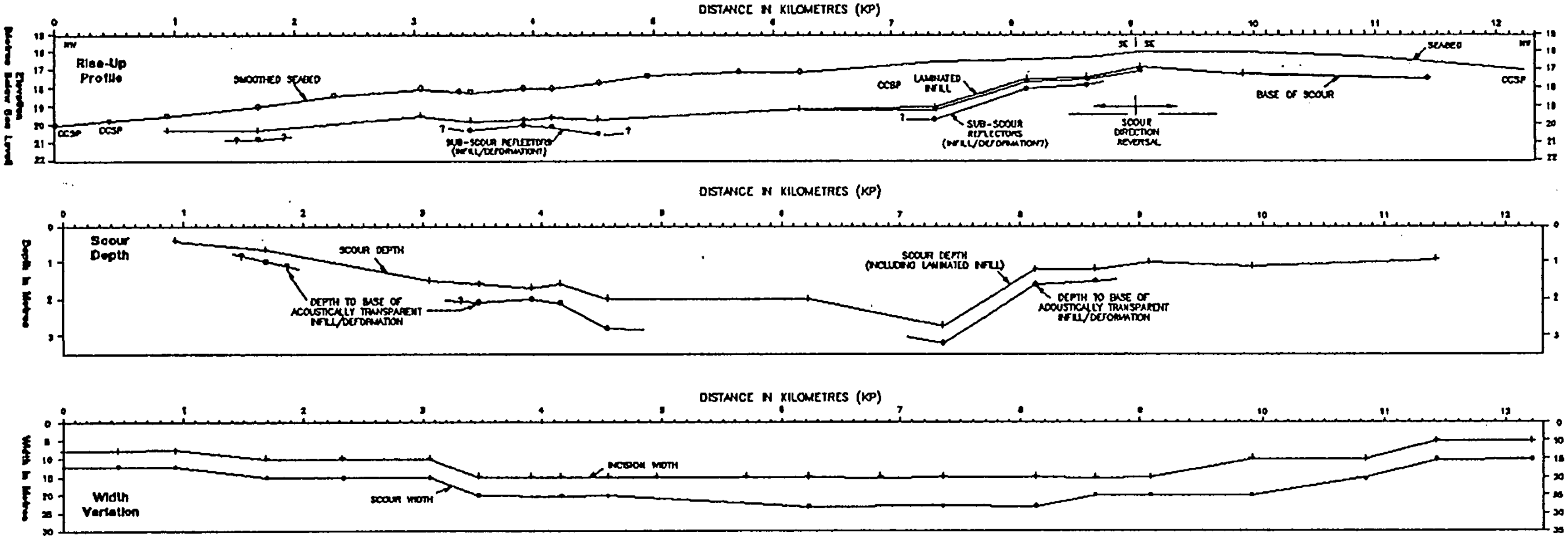


Figure 4.3.10 Scour rise-up profile, scour depth profile and scour width variation along Scour N90-3.

times the regional sedimentation rate in 50 metres water depth (see N90-4 discussion). At present, the ratio of preferential sediment infill within a scour located in shallow water depths can not be quantified, and may exceed this 5:1 ratio. For example, stratified sediment infill thickness increases as water depth decreases along Scour N90-4. Nevertheless, assuming a preferential infill ratio of 5:1 (i.e. 10 mm/yr), the 0.2 metres of sediment observed within the older scour would be deposited in approximately 20 years. Given that sediment observed within Scour N90-3 is between 0.1 and 0.2 metres thick, this scour probably formed 10 to 20 years ago.

Scour age can be estimated, by comparing the number of younger scours cross-cutting the scour in question, with regional new scour impact rates. In the case of Scour N90-3, the frequency of newer scour cross-cuts is quite high. It is difficult to determine the actual number of scours, due to superimposition of newer scours one on top of the other. As with Scour N90-4, estimates of the portion of the seabed unscoured since Scour N90-3 was formed, can be used to circumvent this problem.

Approximately 60% and 50% of the seabed is covered by scours younger than N90-3 in shallow water (16 metres) and in deeper water (20 metres), respectively. Assuming an average scour width of 25 metres, 40 scours/km would result in a 100% re-scouring of the seabed if none of the scours was superimposed. Impact rates in this region range from 2.0 scours/km/yr, in 16 metres of water, to 1.6 scours/km/yr in 20 metres of water (Shearer, 1988). These impact rates convert to a yearly re-scour rate of 5% in 16 metres water depth (2 scours/km/yr divided by 40 scours/km) and 4% in 20 metres water depth (1.6 scours/km/yr divided by 40 scours/km). In 16 metres water depth, 95% of the seabed would not be re-scoured after one year. In the second year, an additional 5% of the remaining unscoured seabed would be scoured (i.e. 5% of the 95% seabed unscoured after year one), leaving 90.25% of the seabed unscoured. It would take 18 years before 60% of the observed scours are younger than Scour N90-3. Likewise, in 20 metres water depth, where the re-scour rate is 4%, it would take 17 years before 50% of the observed scours are younger than N90-3. An increase in the estimated portion of the seabed that is not covered by scours younger than N90-3 from 50% to 60 % in 20 metres water depth and from 60% to 70% in 16 metres water depth would change the estimated age of Scour N90-3 from 17-18 years to 22-23 years. These age estimates, while somewhat subjective, are quite similar to the estimates obtained using sediment infill rates.

4.3.2.4 SCOUR N90-4

Scour N90-4 is a 50-65 year old, single-keeled scour located within the nearshore portion of Kugmallit Channel, approximately 15 km south of the proposed Amauligak production site. The start point of this scour is located at 70° 01' 42.0" N, 133° 45' 47.6" W. This scour was selected for scour tracking because of its extreme depth (3.5 to 5.5 metres) and significant post-scour sediment infill deposits (up to 2.3 metres thick)(Figure 4.3.11). It was first observed in 25 metres of water during re-surveying of the proposed Amauligak pipeline route and was subsequently tracked for 8 kilometres in water depths of 20 metres to 27 metres. Approximately 4.5 metres of scour rise-up was recorded along Scour N90-2. Sedimentation rate calculations and impact rate calculations suggest that the scour is 50-65 years old.

Two geophysical profiles were collected along Scour N90-4 with a combined total of 32 scour cross-over events. Key scour parameters such as depth, width, infill thickness and scour elevation were measured at each cross-over event and are compiled in Appendix 2. These measurements were used to construct scour depth and scour rise-up profiles along the scour (Enclosure 4 and Figure 4.3.12). Scale-corrected cross-sections and representative sidescan sonar records are also included on Enclosure 4.

Scour Orientation and Direction

Scour N90-4 is linear to gently arcuate in plan view. Scour orientation ranges from 170/350° in the north, to 180/360° along the southern portion of the scour (Enclosure 4; Plan View). No abrupt changes in scour orientation were observed along the tracked length of this scour. Scour direction could not be determined by locating a scour termination point. Neither of the N90-4 endpoints were observed due to the masking effect of a large number of younger cross-cutting scours. Evidence of Scour N90-4 cross-cutting older scours, commonly indicative of scouring direction, is also masked by more recent scours. Nevertheless, assuming that Scour N90-4 does not continue far beyond the limit of tracking and return to deeper water outside the survey area, the direction of scouring can be inferred from deeper water into shallower water. That is, Scour N90-4 is inferred to have been formed by an ice keel moving first at 170° then gradually changing course to 180°.

Scour Width and Incision Width

Scour N90-4 has a fairly smooth morphological appearance on sidescan records, consistent with most relatively old scours occurring at similar water depths. The reduced signal contrast, associated with smooth scours, is especially pronounced along the scour margin closest to the ship's track (Enclosure 4; Plate 4). More recent scouring activity has also severely modified and/or obliterated the N90-4 scour berms. As a result, berm crest to berm crest scour width measurements were not obtained, and incision width measurements were difficult to determine precisely.

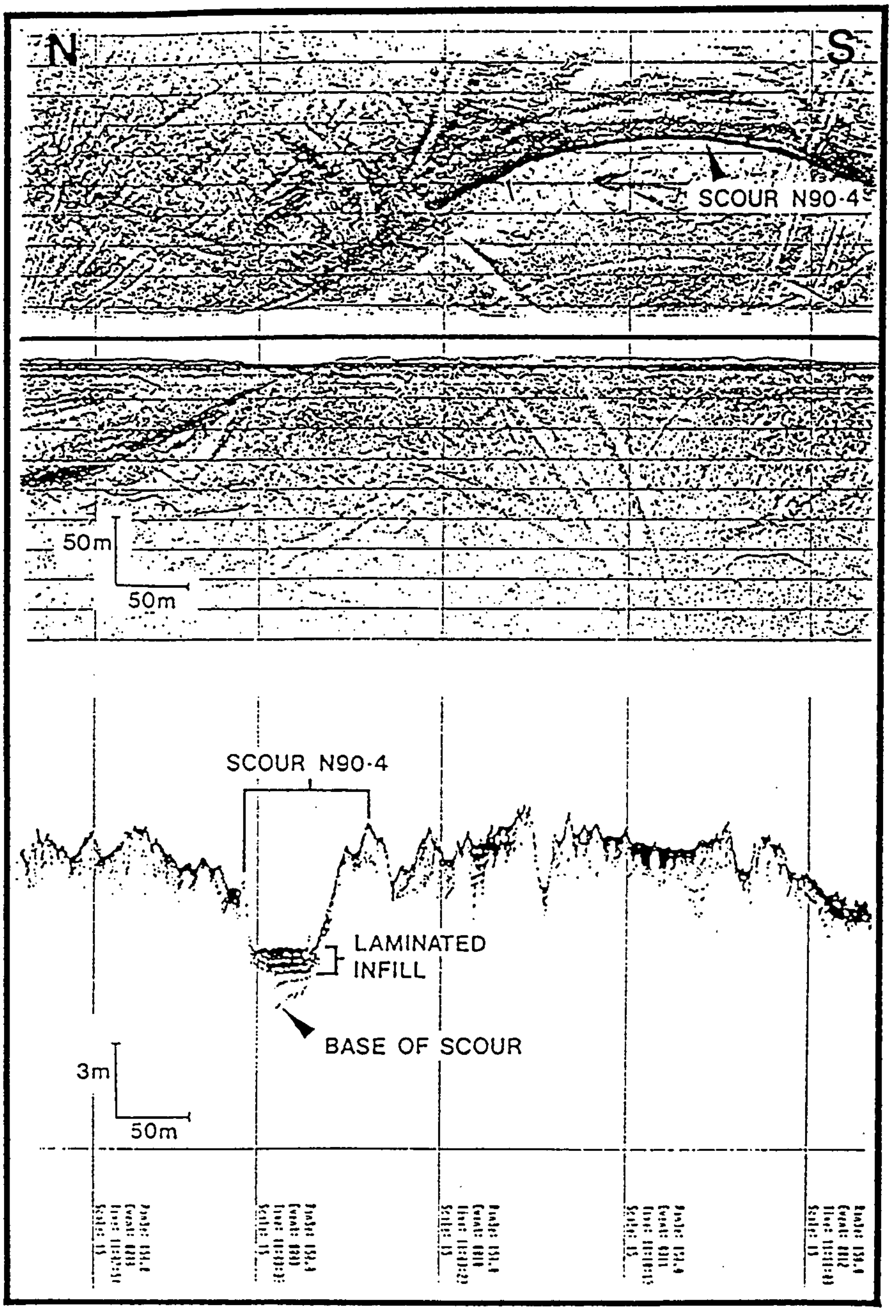


Figure 4.3.11: Sidescan and microprofiler record of scour N90-4, near KP 5.0 at approximately 23 metres water depth. Numerous younger scours cross-cut the scour, although the scour base is undisturbed at the cross-over location. None of the cross-cutting scours appears to cut entirely across the base of scour N90-4. An upper layer of laminated sediment infill, overlying two dipping reflectors, is apparent on the microprofiler record. The lowermost of the dipping reflectors is interpreted as the base of the scour.

Scour incision width varies from 20 to 30 metres along the tracked length of N90-4 with a slight overall increase in incision width with decreasing water depth. Incision width increases from 20 to 25 metres in water depths of 23-26 metres, to 25 to 30 metres in water depths of 20-23 metres. This increase in incision width coincides with an overall increase in scour depth. The incision width of N90-4 decreases to 20 metres again at the limit of tracking in 20 metres water depth.

Berm Width and Berm Height

A high degree of cross-cutting by younger scours has severely modified and/or obliterated the original berm configuration (Enclosure 4; Plate 6). As a result, Scour N90-4 berms are poorly defined and quite difficult to measure on the geophysical records, particularly in water depths of less than 25 metres where most berm heights are very small (<0.5 metres) and the berm manifestation on sidescan records is practically non-existent. The degree of cross-cutting scours does not appear to be as intense in water depths greater than 25 metres and Scour N90-4 berms are slightly more evident on sidescan records. Berm heights range from less than 0.5 metres to 2.0 metres along the deeper water portion of the scour while berm widths generally vary from 10.0 to 15.0 metres.

Sediment Infill

Scour N90-4 contains three types of sediment infill, each with a distinctive acoustic character on the microprofiler records. Acoustically transparent or non-stratified sediments occur at the base of the scour. These are overlain by acoustically well-stratified sediments (Enclosure 4; Plates 1 and 4). Irregular to mounded deposits of non-stratified sediments, interpreted as cross-cut sediment piles (CCSP), comprise the third type of infill observed along Scour N90-4 (Enclosure 4; Plates 3 and 6). As is the case with other infilled scours, the base of the scour beneath the infill is sometimes difficult to determine. This is especially true when sediment infill thickness approaches the penetration limit of the microprofiler system. The thickness of the stratified sediment ranges from 0.5 to 1.3 metres. The thickness of the non-stratified sediment infill is more constant, at approximately 1.0 metre.

The mounded morphology and the absence of internal stratification within the mounded deposits suggests they are comprised of dumped-in debris resulting from younger cross-cutting scour activity. These cross-cut sediment piles (CCSP) are not present at every cross-over. When present, they are located randomly at different stratigraphic levels within the sediment infill, depending upon the time when cross-cutting occurred (Enclosure 4; Plate 6).

The thickness of the stratified infill increases from 0.5 metres in 26 metres water depth (Enclosure 4; Plate 8) to 1.3 metres in 20.5 metres of water (Enclosure 4; Plate 1). At individual cross-overs, these sediments are thickest in the central part of the scour base and pinch-out against the scour walls. This unit is interpreted to be comprised of predominantly fine-grained sediments that are preferentially deposited within the base of the scour. Most of these sediments may be deposited during storm-related events. Cross-cutting scours may locally place sediment into suspension, which is subsequently deposited in the "hydrodynamically quiet" environment at the base of the scour. Assuming this unit is contemporaneous along the length of the scour, the rate of sedimentation varies by a factor of 2.5 across a 5.0 metre change in water depth. More rapid sedimentation in shallower water areas may result from the combined effects of more intense and more frequent storm wave activity, as well as, an increased frequency of post-N90-4 scouring activity.

In contrast to the stratified sediments, the non-stratified (acoustically transparent) unit appears more constant along the length of the scour, ranging from 0.9 to 1.3 metres in thickness. The non-stratified unit is separated from the overlying sediment infill by a strong well-defined reflector. A single internal reflector commonly divides the non-stratified sediments into an upper and lower sub-units. A third reflector, marking the apparent base of the lower sub-unit generally appears discontinuous (Enclosure 4; Plate 4). This reflector was not observed at several cross-overs. The poor definition of this lowermost reflector is probably due to the limited penetration ability of the microprofiler system.

The origin of the underlying non-stratified (acoustically transparent) sediments is less certain. The sediments appear to pinch-out against the scour walls (Enclosure 4; Plate 4). In contrast, sub-scour acoustic disturbance zones generally appear continuous beneath both the scour base and scour walls (Figure 4.3.13)(Shearer, 1981). This suggests that the non-stratified unit is the result of post-scouring sediment infill. The lack of well-defined internal stratifications may indicate that these lower sediments were deposited during an initial period of rapid sediment infilling, shortly after the scour was formed. These deposits may be related to slumping and spalling from newly formed scour walls and berms. Alternatively, these lower sediments may represent gravity-flow deposits formed by flow-back of liquified sediment down slope to the centre of the scour immediately following the passage of the ice keel. The relatively constant thickness of the non-stratified unit along the length of the scour (in contrast to the stratified infill) is consistent with a synchronous depositional event such as might be expected with immediate post-scour flow-back. Although the precise depositional mechanism is unclear, it appears that the non-stratified unit represents sediment infill rather than a zone of sub-scour disturbance.

Scour Depth and Rise-up

The rise-up profile of Scour N90-4 shows the depth below sea level of the seabed, the top of the sediment infill deposits, and the base of the scour for each cross-over location (Enclosure 4). At the onset of tracking at KP 0.0, water depth is 27 metres. The base of the scour, obscured by CCSP debris at the deepest water cross-overs, is probably between 30-31 metres at the onset of scour tracking. This suggests that the scouring began in at least 30-31 metres of water.

Scour N90-4 was tracked in water depths ranging from 27.2 metres to 20.3 metres. Two stages of scour rise-up are apparent. Between KP 0.9 and KP 1.9, there is no net rise-up and the scour depth increases from 3.5 metres to 5.2 metres. Between KP 2.9 and KP 7.4, the scour depth remains relatively constant at approximately 5.0 metres, and the base of the scour parallels the seabed. Total scour rise-up observed across this interval is 4.3 metres. A maximum observed scour depth of 5.5 metres occurs near KP 4.9. The scour termination event was not observed for this scour, due to the masking effect of numerous younger scours. As a result, it is uncertain how far Scour N90-4 continued beyond the limit of scour tracking in 20 metres of water.

Scour depth could not be measured at the cross-overs prior to KP 0.9 due to the presence of major CCSP debris. Between KP 0.9 and KP 2.9, bathymetry decreases by 1.7 metres, and the elevation of the scour base remains fairly constant. Scour depth increases from 3.5 metres to 5.2 metres across this interval. This scour depth increase formed as the ice keel scoured into progressively shallower water depths without experiencing scour rise-up. Up until this point, scouring is consistent with Stage 1 of the scouring process proposed by Shearer et al. (1986). Stage 2 scouring was not observed along Scour N90-4.

Between KP 2.9 and KP 7.4, bathymetry and the scour base elevation decreased at about the same rate, and scour depth remained fairly constant at approximately 5.0 metres. Total scour rise-up across this interval is 4.3 metres. Slight variations in the elevation of the scour base and in scour depth occur locally within this interval, with scour depth varying from 4.5 to 5.5 metres. These variations may reflect local differences in the physical properties of the sediments being scoured, although most variations are within the limits of acoustic profiling/measurement technique uncertainties. Scouring within this interval corresponds to Stage 3 of the scouring process outlined by Shearer et al. (1986). During Stage 3, the scouring forces of the ice keel are in balance with sediment resistance forces, and scouring continues with little change in scour depth.

Scour Age and Cross-cutting Scours

Scour N90-4 is a relatively old scour that predates the earliest geophysical surveys of ice scours in the Beaufort Sea. The age of N90-4 can be estimated by two independent techniques; the rate of the sediment infill within the base of the scour, and the impact rate or temporal frequency of younger cross-cutting scours.

Estimates of the regional sedimentation rate in this area were calculated by comparing the local thickness of post-transgression marine sediments observed on sub-bottom profiler records with the regional sea-level curves for the Beaufort Sea constructed by Forbes (1980) and by Hill et al. (1985). Between 14-16 metres of marine clay has accumulated in the N90-4 area since the marine transgression. Given that this occurred approximately 6,000 years (for 20 metre water depth) to 7,000 years (for 26 metres water depth) before present, the resultant sedimentation rates range between 2.1 mm/yr and 2.5 mm/yr for the deep and shallow water portions of the scour, respectively.

The acoustically transparent material at the base of the scour may represent an initial period of very rapid infilling, or possibly a type of gravity-flow deposit, and is probably not representative of long term scour infill. Consequently, only the upper unit of stratified sediment infill was used in calculating the age of Scour N90-4. This unit varies in thickness from 1.3 metres in shallow water to 0.5 metres along the deeper water portion of the scour,

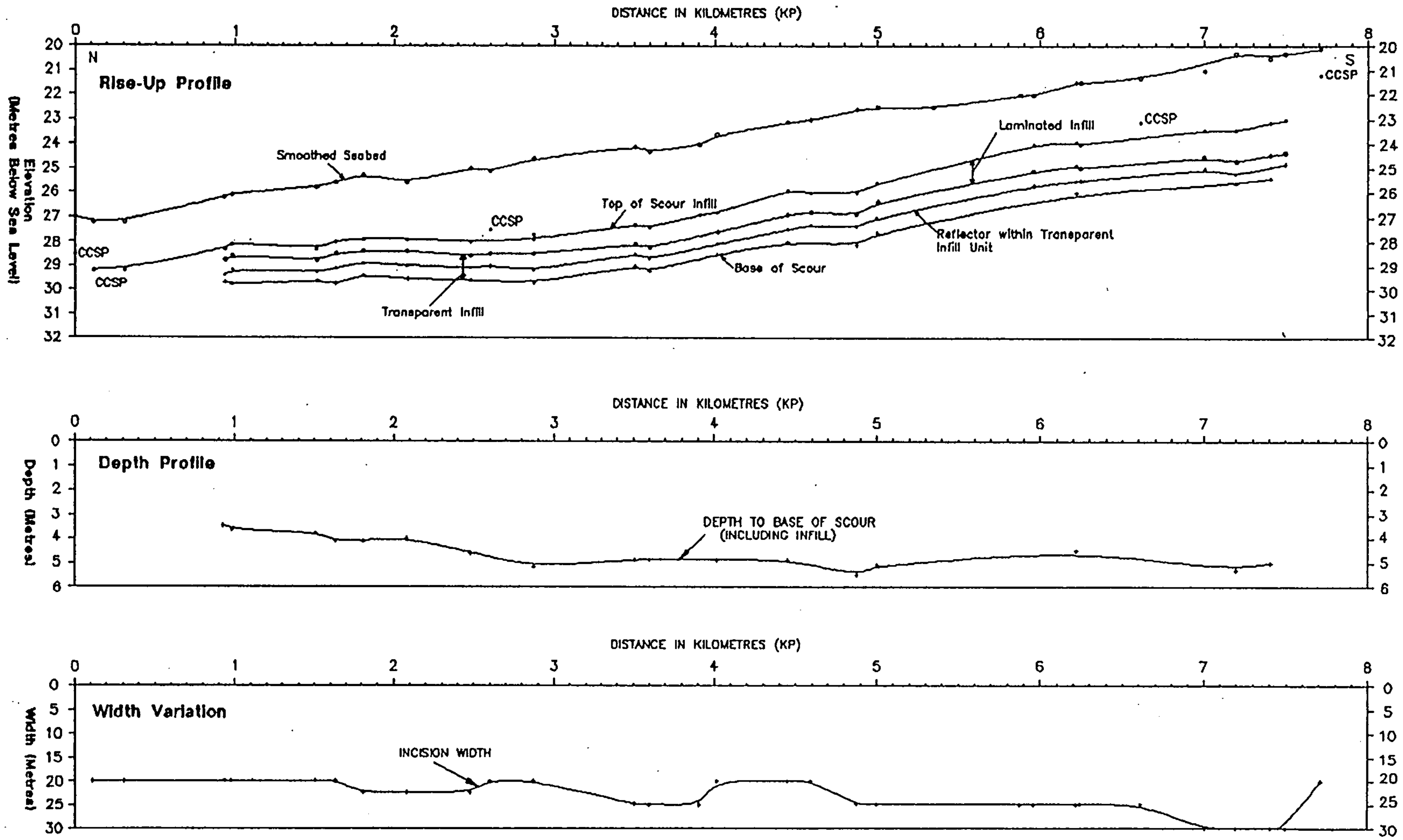


Figure 4.3.12 Scour rise-up profile, scour depth profile and scour width variation along Scour N90-4.

providing ages of 520 years and 238 years, respectively. However, these values do not take into account preferential deposition in the relatively protected scour base, during bottom current or storm wave related winnowing of seabed sediments. Shearer (1981) observed that the sedimentation rate in the base of scour, located at 45 metres water depth, was up to 5 times greater than the sedimentation rate for the adjacent seabed areas (Figure 4.3.13). Preferential sediment infilling may be more pronounced in shallower water, where the effects of storm activity on the bottom are more frequent and intense. For Scour N90-4, the rate of sediment infill at 20.5 metres water depth is approximately 2.5 times higher than that at 27.0 metres water depth (Enclosure 4; Plates 1 and 8). Given the marked difference in the sediment infill rates observed over a 6.5 metre change in bathymetry, it is unclear whether the 5:1 scour infill to seabed sedimentation ratio can be directly applied to Scour N90-4. Nevertheless, assuming that this ratio is 5:1 for the deeper water portion of the scour, the resultant age estimate for Scour N90-4 is 48 years. If the rate of preferential infill is greater than 5:1, Scour N90-4 could be significantly younger.

A second approach used to determine the approximate age of scours is to compare the frequency of younger cross-cutting scours, with regional new scour impact rates. Regional impact rates for the Beaufort Sea are calculated by Shearer (1996a). Due to the high number of younger scours cross-cutting N90-4, especially in shallower water, it is quite probable that younger scours may be superimposed on top of one another (Enclosure 4; Plate 2). Counting of individual cross-cutting scours in an area of intense scouring could result in an underestimate of the number of more recent scours. Instead, an estimate was made of the area of seabed unscoured since the occurrence of Scour N90-4 for water depths of 27.0 metres and 20.5 metres. These estimates (60% unscoured in 27.0 m and 40% unscoured in 20.5 m) can be used in conjunction with a calculated rate of re-scouring to obtain an age estimate which takes superimposition of younger scours into consideration.

Basic impact rates, excluding episodic events, calculated for this area by Shearer (1996a) range from 0.6 scours/km/yr to 0.3 scours/km/yr, in 20 metres and 27 metres water depth, respectively. Assuming an average width for the younger cross-cutting scours of 25 metres, the seabed re-scouring rate is approximately 1.5% per year in 20 metres of water and 0.75% per year in 27 metres of water (i.e. impact rate times average scour width in kilometres). With a re-scouring rate of 1.5% at 20 metres water depth, and considering that progressive superposition of scours will have occurred as the remaining percentage of unscoured seabed decreases, it would take 61 years until only 40% of the seabed was not re-scoured. Similarly, with a re-scour rate of 0.75% at 27 metres water depth, and 60% of the seabed unscoured since the time Scour N90-4 occurred, an approximate age of 65 years is indicated for Scour N90-4. However, the accuracy of these estimates is dependent on the assumption that episodic events of anomalous scouring have not occurred in this area since N90-4 was formed. If anomalous scouring has occurred, Scour N90-4 could be significantly younger.

Age estimates for Scour N90-4 range from 61 to 65 years based on scour impact rates and a minimum age of 48 years based on the thickness of sediment infill deposits within the scour base. A scour age in the range of 50 to 65 years is suggested. Although uncertainties are implicit in both methods used to determine scour age, it is significant that the resultant age estimates are fairly close.

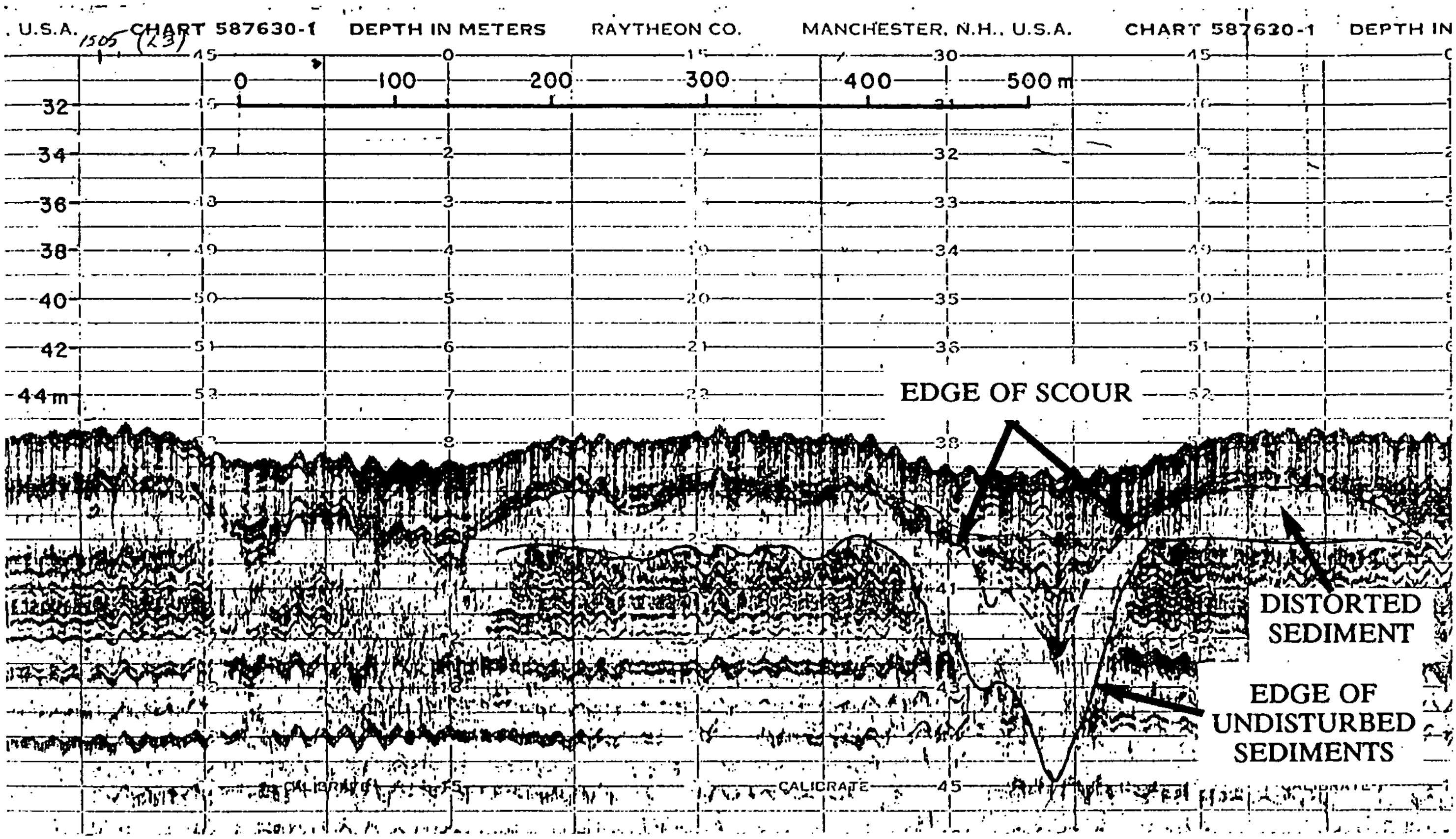


Figure 4.3.13 Seismic profile across an infilled scour, located in 46 metres water depth, within Mackenzie Trough. Post-scouring sediment infill is approximately 5 times thicker within the scour than in adjacent areas. A zone of acoustically disturbed sediments, characterised by a lack of reflectors surrounds the infilled scour, extending 5 metres beneath the base of the scour (after Shearer, 1981).

4.3.2.5 SCOUR N90-5

Scour N90-5 is a triple-keeled scour located within Kugmallit Channel, approximately 10 km southwest of the proposed Amauligak production site. At the start point of scour tracking (KP 0.0), Scour N90-5 is located at 70° 02' 32.4" N, 133° 47' 54.7" W. It was tracked for 4.5 kilometres in water depths of 26 to 29 metres. This scour appears to have been formed by an ice ridge which formed in situ, which subsequently scoured into deeper water. As such, it is unique among the scours examined in this study. The deepest keel (keel A) reaches a maximum observed scour depth of 2.9 metres. Scour width varies from 50 to 80 metres along the length of the scour. Total rise-up along Scour N90-5 is approximately 1.0 metre. This scour was observed as a new scour during repetitive mapping operations carried out in the 1989 summer field season. The previous survey operations were conducted in this area in 1987, indicating that N90-5 was formed either during the winter of 1988 or 1989.

Scour N90-5 was chosen for detailed scour tracking studies primarily because it was a very recent scour, with depths exceeding 2.0 metres. Sidescan records collected in 1989 revealed finely structured striations in the base of the scour. To closely examine the scour base for evidence of structural deformation, a sidescan range of 75 metres (and a higher sampling rate) was employed, instead of the more common 150 metre range setting.

Scour Direction and Orientation

Scour N90-5 is comprised of two distinct segments which, in plan view, delineate a general V shape which opens towards the north (Enclosure 5: Plan View). The western segment is oriented at 140/330°, and the eastern segment at 170/350°. Cross-cutting relationships at the direction reversal point (Enclosure 5; Plate 4) indicate that the ice keel started scouring in the northwest, moved southeast at 140°, then changed direction and scoured towards the north at 350°. Several minor adjustments in scouring direction are apparent along the first 200 metres of the scour.

It appears that the ice keels which eventually formed Scour N90-5 were created in situ (Enclosure 5; Plate 1), perhaps by ridging at the interface of the landfast ice and the polar ice pack. In situ ridging of this nature can create a lithostatic load on the sea bottom such that when breakup occurs and large ice pans are mobilized, appreciable scour depth may occur from the onset of scouring.

Scour Width and Incision Width

Scour N90-5 is comprised of three closely spaced keels; keels A, B, and C. At the onset of scouring in 28 metres water depth, the keels are already well-developed. The keels show little variation in incision width along the western scour leg. All three keels are between 10.0 and 15.0 metres wide. The keels are separated by inter-keel berms which are roughly the same width as the individual keels. Total scour width ranges from 70 to 80 metres along the western scour leg (Enclosure 5; Plate 2).

The scour changes character at a scour direction reversal event, located near Kilometre Point (KP) 2.2. Scour width decreases to approximately 50 metres at the start of the eastern scour segment. This appears to be largely due to a reduction in the size of the outer lateral berms. Along the shallow water portion of the eastern leg, the individual keels appear to have roughly the same width, and inter-keel separation distance, as on the western leg. Further along the eastern leg, in slightly deeper water depths, incision widths of the individual keels decrease slightly to 10.0 metres for keel A, and 5.0 metres for both keel B and keel C. Along the northern portion of the eastern segment, the two shallowest keels (keels B and C) are discontinuous, present only across local bathymetric highs (primarily older scour berms) (Enclosure 5; Plate 5).

Berm Width and Berm Height

Six berms are possible on a triple-keeled scour, one on either side of each keel. Along the western leg of Scour N90-5 the keels are quite closely spaced and scour depths are up to 2.5 metres. In these areas, the inter-keel berms often merge to produce a single 10-15 metres wide berm within each inter-keel area (Figure 4.3.14). The width of these inter-keel berms is controlled by the separation distance of the keels. In places, berm material appears to have fallen back into each of the keel incisions. Inter-keel berms are discontinuous along other portions of the scour. The two outer berms vary in width from 5.0 to 30 metres. Berm heights range from less than 1.0 metre to 1.5 metres along most of the western scour leg. The outer berm of keel A is generally the largest of the berms.

All of the scour berms decrease in size across the major directional change, near KP 2.2. The inter-keel berms are not merged along the eastern scour leg. For the first 500 metres along the eastern leg, the berms adjacent to keel A are 5-10 metres wide and up to 1.0 metre high. All other berms are smaller in size, and appear discontinuous. Along the deeper water portion of the eastern leg, only the outer berm adjacent to keel A appears continuous. The seabed in the inter-keel areas appears to be largely unmodified along the deeper water portion of Scour N90-5 (Enclosure 5; Plate 5).

Infill

No stratified sediment infill was observed within Scour N90-5. Occasionally, berm material has fallen back into the scour base, and CCSP is occasionally apparent within the base of the scour (Enclosure 5; Plate 4). The absence of infill is not unexpected, as the scour was only 2-3 years old when surveyed.

Scour Depth and Rise-up

Scour cross-cutting relationships indicate that scouring began at the northwest end of the western scour leg, in 28 metres water depth. The scour end-point at this location is very abrupt, and appears to be surrounded by berm material (Enclosure 5; Plate 1). This suggests that the ice keels which eventually formed Scour N90-5 were created in situ, perhaps due to ridging along the seaward edge of landfast ice. Sidescan images of the scour suggest that the keel depths at the onset of scouring are similar to the keel depths encountered at the initial keel cross-overs (Enclosure 5; Plate 1). At the first cross-over of each keel, occurring from KP 0.1 to KP 0.8; keel A is 2.5 metres deep, keel B is 1.5 metres deep, and keel C is 0.8 metres deep. These observations suggest that relatively deep scours may be formed by ice ridges which have formed in situ.

The depth of each of the keels remains relatively constant along the western scour leg, although there is a slight increase in scour depth as the ice scoured into shallower water depths (Enclosure 5, and Figure 4.3.15). Between KP 1.3 and the change in scour direction at KP 2.2, the base of the keels rises up approximately 0.3 metres. Maximum observed scour depth of 2.9 metres occurs along keel A, just prior to the change in scour direction. Since there is very little change in bathymetry or the scour base elevation, it is unclear whether the Stage 1 or Stage 3 scouring is active along this portion of the scour.

Approximately 1.2 metres of rise-up of the base of the keels occurs across the major change in scour direction at KP 2.2. Similar rise-up across a direction change along Scour N90-1 was attributed to an increase in the surface area of ice in contact with the sediments. However, in the case of Scour N90-5, there appears to be little change in incision width associated with the scour direction change. This suggests that the scour rise-up may be related to a change in the relative shape of the keels in the direction of scouring. At the first cross-over on the eastern scour leg, keel A is 1.5 metres deep, keel B is 0.8 metres deep and the depth of keel C could not be determined. The base of keel A drops down 0.6 metres along the first 600 metres of the eastern scour leg, as the ice scoured into deeper water. This may represent a re-adjustment of the scour base elevation, following the abrupt rise-up experienced at the direction change. The elevation of the base of the keels appears to remain constant beyond KP 2.8, and the depth of keel A decreases as the ice scoured into deeper water. Keels B and C are discontinuous along the deeper water portion of the eastern keel, as the ice keels alternately scoured across local bathymetric highs (primarily older scour berms) and passed over local bathymetric lows (primarily across the base of older scours).

Scour Age

Scour N90-5 was observed as a new scour during repetitive mapping operations carried out in the 1989 summer field season. It was not present on data collected during the previous survey of the area in 1987. This indicates that Scour N90-5 was formed either during the winter of 1988 or 1989, and was thus 1 or 2 years old at the time of the ESRF 1990 survey. The landfast ice edge was observed to extend to approximately 29 metres water depth during the winter of 1988. This suggests that the scour was probably formed during the winter or spring of 1988.

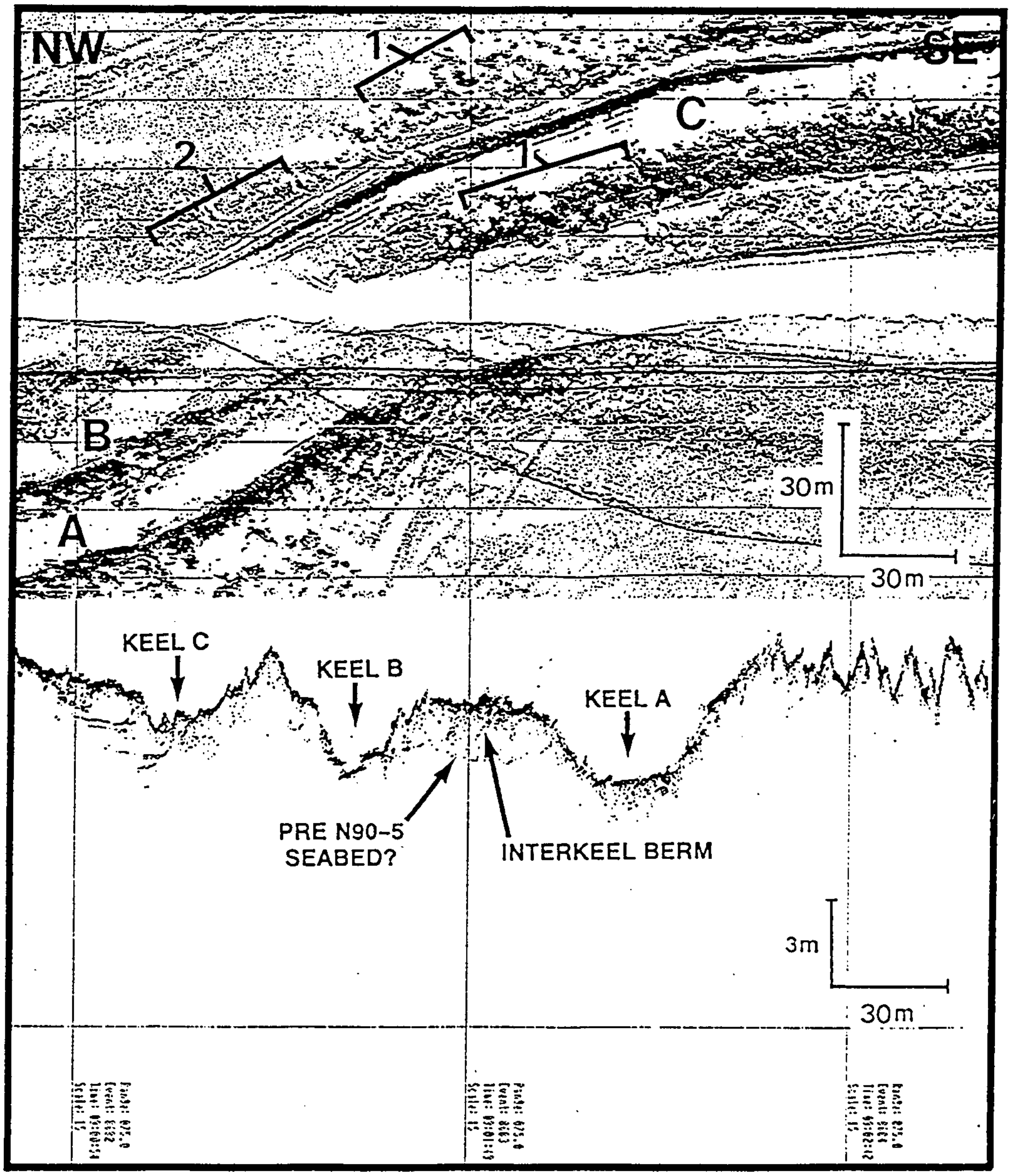


Figure 4.3.14: Sonogram and microprofiler record crossing over N90-5, near KP 1.6. Keels A, B, and C are indicated by A, B, and C on the sonogram, respectively. The A-B inter-keel berm and portions of the outer berm along keel C are well developed (indicated by 1). The outer berms are less well-developed along parts of the scour (indicated by 2). A sub-bottom reflector beneath the A-B inter-keel berm may mark the pre-N90-5 seabed location.

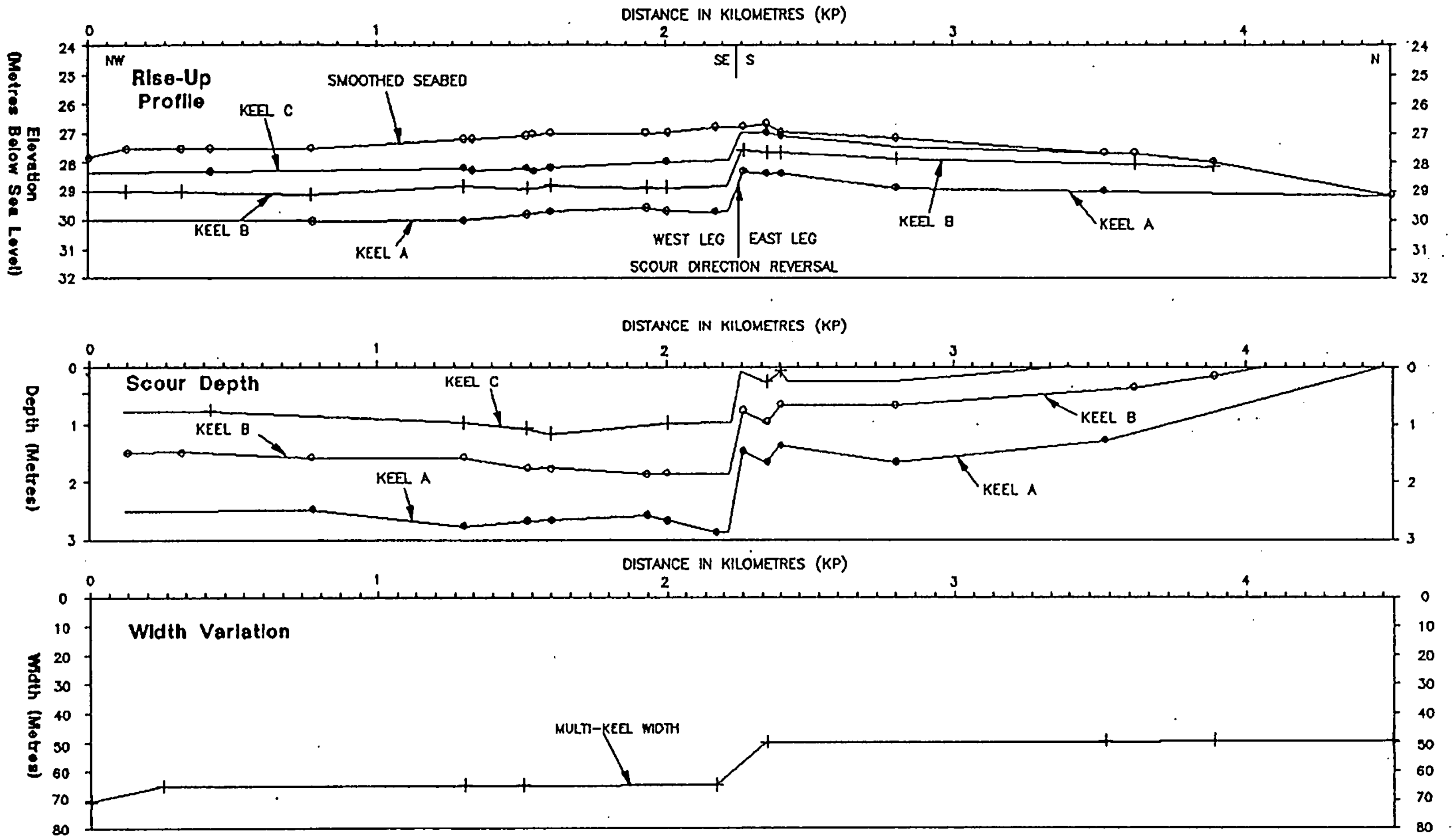


Figure 4.3.15 Scour rise-up profile, scour depth profile and scour width variation along Scour N90-5.

Scour Base Deformation

Studies combining sidescan imaging of ice scours with submersible and diver observations have been conducted on the Labrador Shelf and off Cornwallis Island (Woodworth-Lynas et al., 1991; Gilbert et al. 1993). Results of these scour morphology studies indicate that detailed basal structures, including possible tension cracks, are present within the scour base. Although micro-groove and ridge structures are commonly observed on sidescan records, little evidence of deformation features, such as tension cracks or stress fractures, has been reported for new scours in the Beaufort Sea. Scour N90-5 was surveyed at 75 metre range setting to better detect evidence of sediment deformation.

Micro-groove and ridge morphology was commonly observed within the base of Scour N90-5, and the scour berms often appear rough textured (Enclosure 5; Plates 1 through 4). Sharply defined scour blocks were occasionally recorded in some locations (Enclosure 5; Plate 3). A series of parallel linear features were observed partially cutting across the base of keel A, along a limited portion of the western scour leg (Enclosure 5; Plate 3). These features are oriented 45-60° off the axis of scouring direction. The separation distance between individual linear features ranges from 2.0 to 10.0 metres. Striations parallel to the scour direction (micro-groove and ridge morphology) terminate at the edge of the best developed series of lineations. Additional sidescan imagery and ground truth information, such as underwater video or diving observations, is required to confirm the exact origin of these features. Nevertheless, their orientation with respect to the scouring direction, their spacing along the scour, and their location at the edge of the scour base, are all consistent with similar features that have been interpreted as tension cracks or stress fractures.

4.3.2.6 SCOUR N90-6

Scour N90-6 is a multi-keeled scour located in the nearshore portion of Kugmallit Channel. This scour was tracked in 1990 as an apparent continuation of Scour N90-7. Subsequent investigation indicated that it was a separate scour which pre-dates Scour N90-7. The start point of tracking along this scour can be observed on the N90-7 panel (Enclosure 7; Plate 1). The starboard channel sidescan malfunctioned during tracking of this scour. Few complete cross-overs of the scour were obtained, due to concern that the scour could not be tracked on the starboard channel. Due to a lack of cross-overs and deteriorating data quality, scour profiles were not constructed for this scour.

The scour was tracked for approximately 35 km in water depths of 30 to 32.5 metres. The scour is oriented east-west and cuts obliquely across bathymetric contours. Scour depth, where observed, ranges from 0.7 metres to 2.6 metres. Scour width is generally 30-50 metres, increasing locally to 80 metres where additional discontinuous keels touched down adjacent to the main scour incision. Scour rise-up is approximately 2.5 metres from west to east along the length of the scour.

4.3.2.7 SCOUR N90-7

Scour N90-7 is a multi-keeled scour located within the nearshore portion of Kugmallit Channel, near the proposed Amauligak production site. The start point of Scour N90-7 is located at 70° 05' 23.2" N, 133° 50' 05.3" W. It was tracked for 7.4 kilometres in water depths of 27 to 32 metres. Scour depths along the scour range from 0.8 to 3.2 metres. Except for cross cut sediment pile (CCSP) debris, no sediment infill was recorded along this scour. The base of the scour rises up approximately 1.5 metres, prior to a partial scour termination event located near the end of the scour. The scour was formed in the winter of 1982, and was 8 years old at the time of the ESRF 1990 survey.

Scour N90-7 was first recognized as a short, but "very fresh looking" event on a 1982 mosaic of the West Amauligak site (Geoterrex, 1985). Preliminary investigation indicated that scour depth exceeded 2.0 metres along portions of this scour. The magnitude and proximity of this scour to the proposed Amauligak B-45 production site, led to detailed scour tracking surveys of Scour N90-7 during the summers of 1989 and 1990. Both the 1989 and 1990 surveys were unable to track N90-7 along its entire length, due to shallow water and possible navigation hazards associated with the Amauligak I-65 drill site. However, additional data collected at the I-65 site prior to development of the drilling berm was made available for the N90-7 study.

Key scour parameter measurements of Scour N90-7, such as scour depth, scour width, and scour base elevation are compiled in Appendix 2. Rise-up and Scour Depth profiles are displayed on Enclosure 7 and on Figure 4.3.16. Scale corrected cross-sections and representative sidescan sonar records are also contained on Enclosure 7.

Methods and Data Quality

This study combines results from the 1989 and 1990 surveys with additional scour crossover data, obtained during various geophysical surveys conducted from 1981 to 1988. A wide variety of equipment types were used over this time period. This variation in gear type, along with the prevailing weather conditions during the various surveys, have produced data sets of differing quality. Some of the sidescan data were not corrected for slant range and ship's speed distortions thus making scour interpretations very difficult.

Even with poor quality data rejected, there is an overall poor match between echo sounder data from different surveys. As a result, water depths recorded over the same portion of the seabed varied by as much as 3.0 metres. This is probably a combined result of uncorrected data (i.e. tidal and storm surge variations in sea level), and possible errors in the draft or velocity settings, on the various cruises. These variations in recorded water depth do not significantly affect scour depth measurements. However, if left uncorrected, they would preclude the construction of a meaningful rise-up profile. Bathymetric variations were corrected using the ESRF 1990 survey bathymetry as a datum. Seabed elevations from previous surveys were adjusted to best fit the smoothed seabed profile constructed from the ESRF 1990 data. Scour base elevations were adjusted by the same amount as the corresponding seabed elevation shift. These adjustments did not change scour depth or berm height measurements.

Scour depth measurements obtained from the ESRF 1990 survey are, in general .3 m to .5 m greater than measurements obtained from previous surveys in the same area. This appears to be more pronounced where the scour depth exceeds 2.0 metres. This apparent increase in scour depth resolution on the 1990 records may be due to a number of factors, including; a higher pulse frequency and narrower beam width, a faster chart speed on the echo sounder recorder, and a lower angle crossing of the scour (resulting in an increased crossing distance over the deepest part of the scour). In addition, the ESRF 1990 survey included high frequency microprofiler data which allowed the recognition of the true base of the scour, beneath locally occurring cross-cut sediment piles. In cases where the ESRF 1990 data indicate greater scour depth than previous survey data from the same location, the depth obtained from the 1990 data set was used preferentially in interpreting scour depth and rise-up.

Scour Direction and Orientation

Scour N90-7 is gently arcuate in plan view, along most of its length (Enclosure 7; Plan View). A partial scour-termination event at Kilometre Point (KP) 6.9 and a final scour-termination event at KP 7.4 (Enclosure 7; Plate 1) indicate that Scour N90-7 was formed by an ice keel which moved from northwest to southeast, and scoured into shallower water depths. Cross-cutting relationships with older scours also indicate a southeastward scouring direction.

A fairly rapid change in scouring direction, from 180° to 137°, occurs at the northwestern limit of tracking, near what appears to be the onset of scouring. Poor weather conditions, and the loss of the starboard channel on the sidescan system during the ESRF 1990 survey, hampered tracking of Scour N90-7 northeast of the Amauligak site (Enclosure 7; Plate 5). The scour gradually changes direction from 137° to 168° between KP 0.2 and KP 6.8. An abrupt change in scour direction, from 168° to 150°, occurs near KP 6.2 (Enclosure 7; Plate 2). Between KP 6.2 and KP 7.4 the scour is again gently arcuate, gradually changing direction from 150° to 165°. There is no appreciable change in the direction of scouring associated with the partial scour-termination event at KP 6.9.

Scour Width and Incision Width

Scour N90-7 is comprised of a major central incision, a discontinuous scoured area immediately east of the central incision ("eastern striated margin"), and a separate smaller keel to the west ("western keel")(Enclosure 7; Plan View). The central incision is continuous along the entire length of the scour. This incision is asymmetric in cross-section with a pronounced deepening along its eastern margin. All incision width measurements of Scour N90-7 were obtained from the central incision. The eastern striated margin is only present past KP 2.7 in water depths less than 31 metres. The N90-7 scour width measurements include the central incision and, where present, the eastern striated margin. The western outrider keel is present beyond KP 4.5, in water depths less than 29 metres. It is located approximately 40 metres west of the central incision. The multi-keel width parameter is a measurement of the distance from the eastern edge of Scour N90-7, including the eastern striated margin, to the outer edge of the western outrider keel.

The Scour N90-7 incision width remains fairly constant, at 40 to 50 metres, along most of the length of the scour. Near the onset of scour tracking, and beyond the partial termination event, incision width is approximately 30 metres. Between KP 0.0 and KP 0.1, incision width increases from 30 metres to 45 metres (Enclosure 7; Plate 5). Between KP 0.1 and KP 2.1 incision width measurements vary from 45 metres to 55 metres, with a mean incision width of 50 metres. Incision width appears to decrease to approximately 40 metres, near KP 2.1. Between KP 2.1 and KP 4.8, average incision width remains constant, at approximately 40 metres, even though water depth decreases from 31 metres to 29 metres and scour depth increases from 1.5 metres to 3.3 metres. Between KP 4.8 and KP 6.9, incision width measurements are more variable, ranging from 40 to 55 metres. This slight variation in incision width does not appear to be related to pronounced variation in scour depth, and is probably a result of measurement uncertainty. Incision width decreases abruptly, from 45 metres to 30 metres, across the partial termination point at KP 6.9 (Enclosure 7; Plate 1). This decrease is directly related to a decrease in the size of the ice keel, which occurs at the partial termination event.

Scour width increases from 50 metres, in water depths greater than 30.5 metres, to over 85 metres at a water depth of 28 metres. This increase in scour width is largely due to the presence of the eastern striated margin, and does not reflect a significant increase in the width of the central scour incision. Apparently, as the main ice keel scoured deeper into the seabed, adjacent ice keels that were previously just above the seabed, contacted the seabed immediately east of the main incision keel. This eastern portion of the scour appears somewhat discontinuous and varies in width form 10 to 35 metres (Enclosure 7; Plate 4). In places, it appears that the eastern striated margin may represent re-scoured berm material from the central keel. A maximum scour width of approximately 100 metres occurs near KP 6.9, just prior to the partial scour-termination event.

The western outrider scour has a fairly constant width of approximately 15.0 metres. It first appears as a discontinuous scour near KP 4.5, where it only occurs crossing the berms of older scours (Enclosure 7; Plate 3). The western keel is continuous in water depths less than 29 metres, beyond KP 5.0. Multi-keel scour width measurements vary from 130 to 145 metres. The western outrider scour terminates at the partial scour termination near KP 6.9.

Berm Width and Height

The eastern berm of N90-7 is generally wider and higher than the western berm. Between KP 0.0 and KP 0.1, the eastern berm width is approximately 5.0 metres. The eastern berm width varies from 10.0 to 15.0 metres along the remainder of scour, while the western berm ranges from 5.0 to 10.0 metres in width.

Between KP 0.1 and KP 3.5, the eastern berm varies from 1.0 to 1.8 metres high, while the western berm is generally 0.5 to 1.0 metres high. From KP 3.5, to the end of the scour,

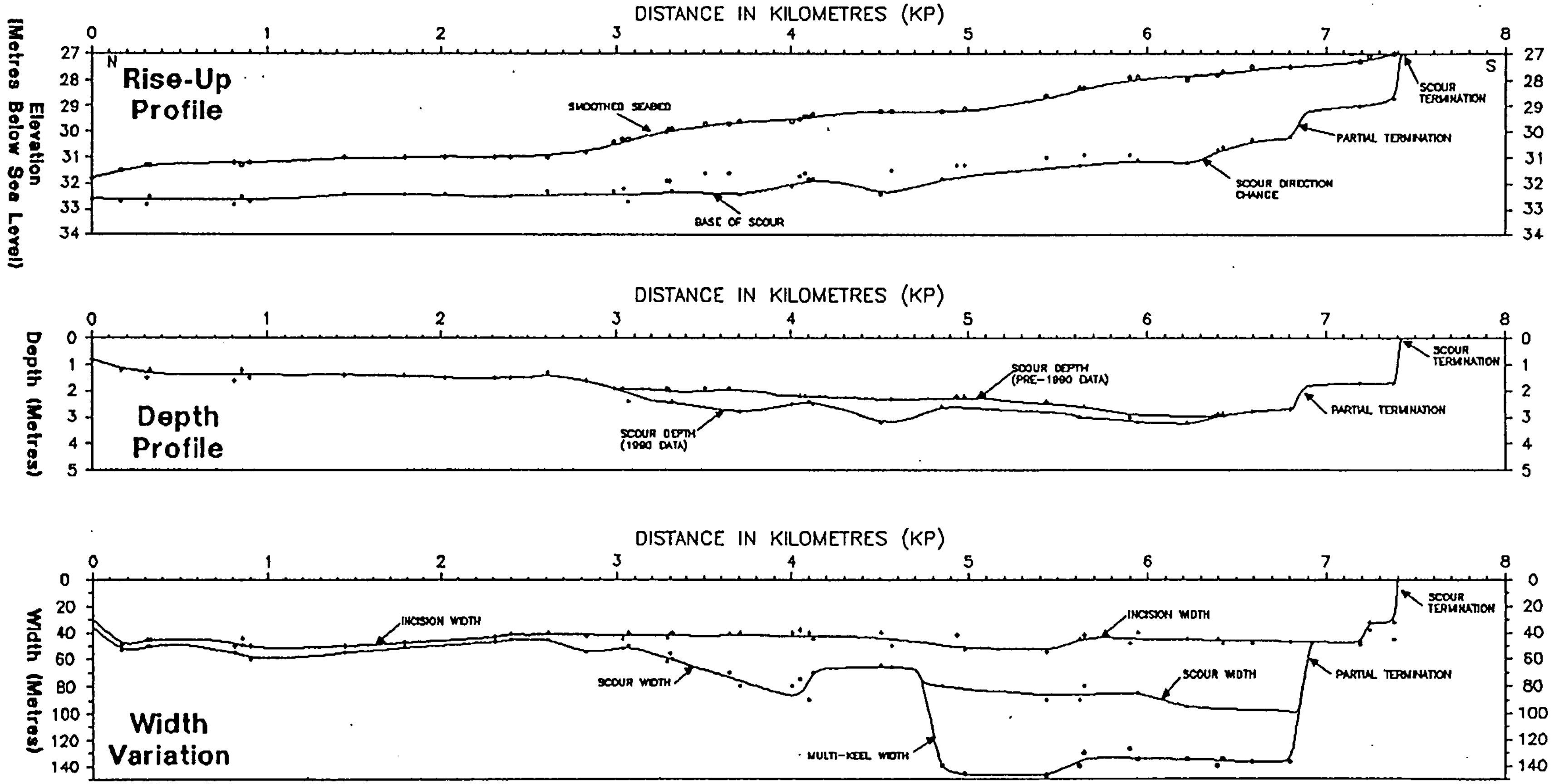


Figure 4.3.16 Scour rise-up profile, scour depth profile and scour width variation along Scour N90-7.

berm heights appear to be more variable. The western berm height varies from 0.0 to 1.5 metres, and the eastern berm height varies from, 0.0 to 2.5 metres. Maximum heights for both berms occur near the partial scour termination event, in water depths of 27.5 metres.

Between KP 5.1 and KP 6.2 the eastern berm height is less than that of the western berm. The decrease in the eastern berm height along this section may be caused by the discontinuous eastern portion of the scour. That is, the eastern striated margin appears to have re-scoured or smoothed out the berm created by the main incising keel. This process is suggested by the alternating striated and rubbly nature of the eastern scoured area (Enclosure 7; Plate 2).

The overall difference in berm sizes along the entire length of the scour probably results from the asymmetrical shape of the N90-7 incision, with the deepest scouring occurring along the eastern margin of the incision (Enclosure 7; Plate 2). The asymmetric profile and larger eastern berm may indicate that a significant component of the driving force for the ice-keel was oriented towards the east. Alternatively, the difference in berm sizes could be caused entirely by the shape of the ice-keel.

Sediment Infill

Stratified sediment infill was not observed within Scour N90-7. There are, however, occasional cross-cut sediment piles, formed by more recent cross-cutting scours. Approximately 16 metres of marine clay was deposited in this area since the Holocene marine transgression. Sea-level curves constructed by Hill et al. (1986) suggest that deposition of marine clays would have began 7,000 years before present. Average regional sedimentation rate over this time period is approximately 2.0 mm/yr. Assuming that preferential sediment infilling occurs at a rate 5 times that of regional sedimentation, less than 0.1 metre of infill would be deposited within Scour N90-7, in the 8 years since it was formed. Such a thickness is beyond the limit of resolution of the microprofiler system employed in the 1990 survey. Any sediment infill that may be present, must be very slight given the relatively young age of this scour.

Scour Depth and Rise-up

Stage 1 rise-up was active along the first 3.7 kilometres of Scour N90-7. At the start of scour tracking, the depth of Scour N90-7 increases from 0.7 metres to 1.4 metres, between KP 0.0 and KP 0.2. The scour base elevation remains constant at 32.5 metres in this area. Between KP 0.2 and KP 2.7, scour depth remains relatively constant at 1.5 metres and there is no net scour rise-up. Between KP 2.7 and KP 3.7, water depth decreases from 31 metres to 29.5 metres, scour depth increases to 2.8 metres and there is no appreciable rise-up. Up until KP 3.7, rise-up observations are consistent with observed by Shearer et al. (1986) during Stage 1 scouring.

Between KP 3.7 and KP 6.2, the scour base elevation rises up 1.2 metres, and water depth decreases by 1.6 metres. Rise-up within this interval is similar to Stage 2 of Shearer et al.

(1986) in that scour rise-up occurs at a rate less than the decrease in seabed elevation, and scour depth increases slightly. Scour depth increases from 2.8 to 3.2 metres across this interval. However, the rate of scour rise-up is not uniform across this interval. From KP 3.7 to KP 5.0, there appears to be two periods of rapid rise-up, separated by a period of drop-down near KP 4.5. Both periods of rapid rise-up correspond with increases in the multi-keel scour width. This suggests that increased surface area of ice in contact with the seabed contributed to the rise-up in these in areas. Alternating rise-up and drop-down may also result from local variations in the physical properties of the seabed sediments. This may be particularly apparent where the thickness of Unit A marine clays (O'Connor, 1980) is similar to the scour depth (see Scour N90-2 discussion). In the case of N90-7, however, the marine clay thickness exceeds 8.0 metres.

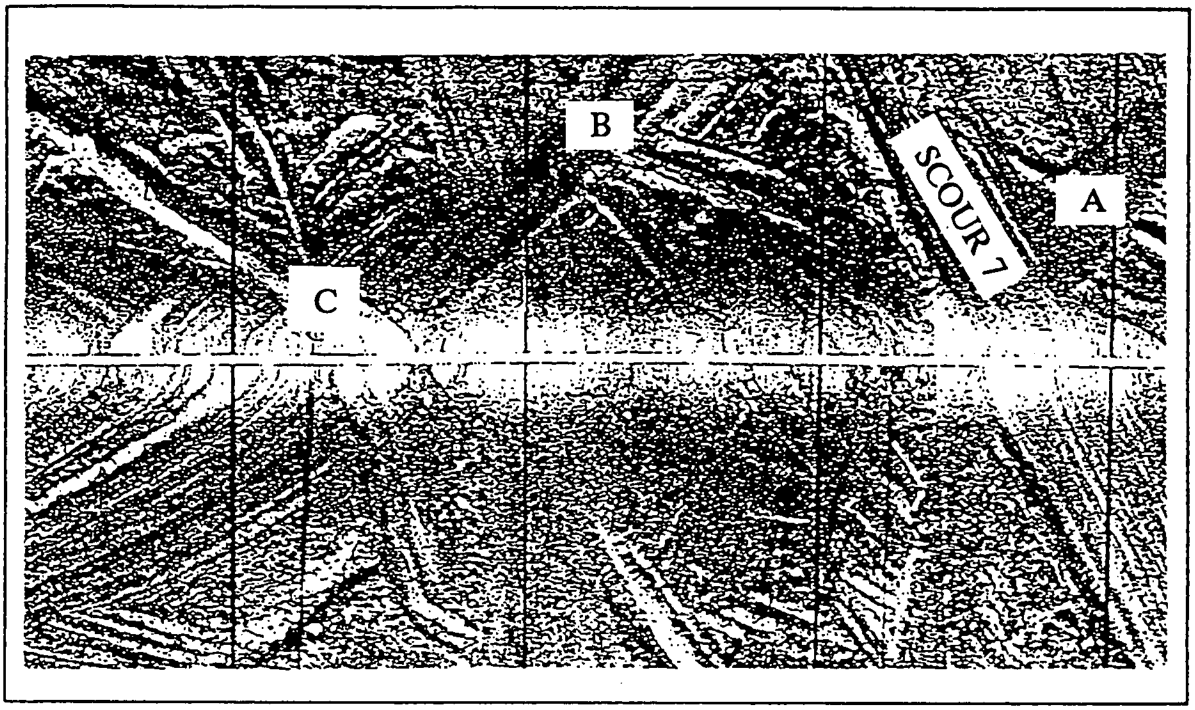
The rate of scour rise-up increases at KP 6.2, at the location of an abrupt change in scour direction (Enclosure 7; Plate 2). Between KP 6.2 and KP 6.9, the scour rises up more rapidly than the seabed elevation, and scour depth decreases from 3.3 metres to 2.7 metres. The increase in the rate of rise-up may be related to a change in the physical properties within the Unit A marine clays. Such changes can not be confirmed on the geophysical records. Scour rise-up across this interval is approximately 1.0 metre, with a total scour rise-up of 2.4 metres to KP 6.9.

At KP 6.9, the ice keel underwent a major change. The western outrider keel and the eastern striated margin both terminate at this point. It also appears that the deep eastern portion of the central incision terminates at this point (Enclosure 7; Plate 1). Incision width decreases to 30 metres across this partial termination, and scour depth measured at cross-overs to either side of this point decreases from 2.7 metres to 1.7 metres. It appears that this decrease in scour depth was instantaneous, resulting from a partial failure of the main incising ice keel. As such, the decrease in the scour base elevation at KP 6.9 is not rise-up in the classical sense, but rather a decrease in the size of the ice keel. Scour depth appears to remain constant at 1.7 metres, between the partial termination point and final termination at KP 7.4. A period of relatively rapid scour rise-up, prior to a partial termination event, was also observed on Scour N89-1. Such rise-up is often associated with a subsequent change in scour direction, or scour termination.

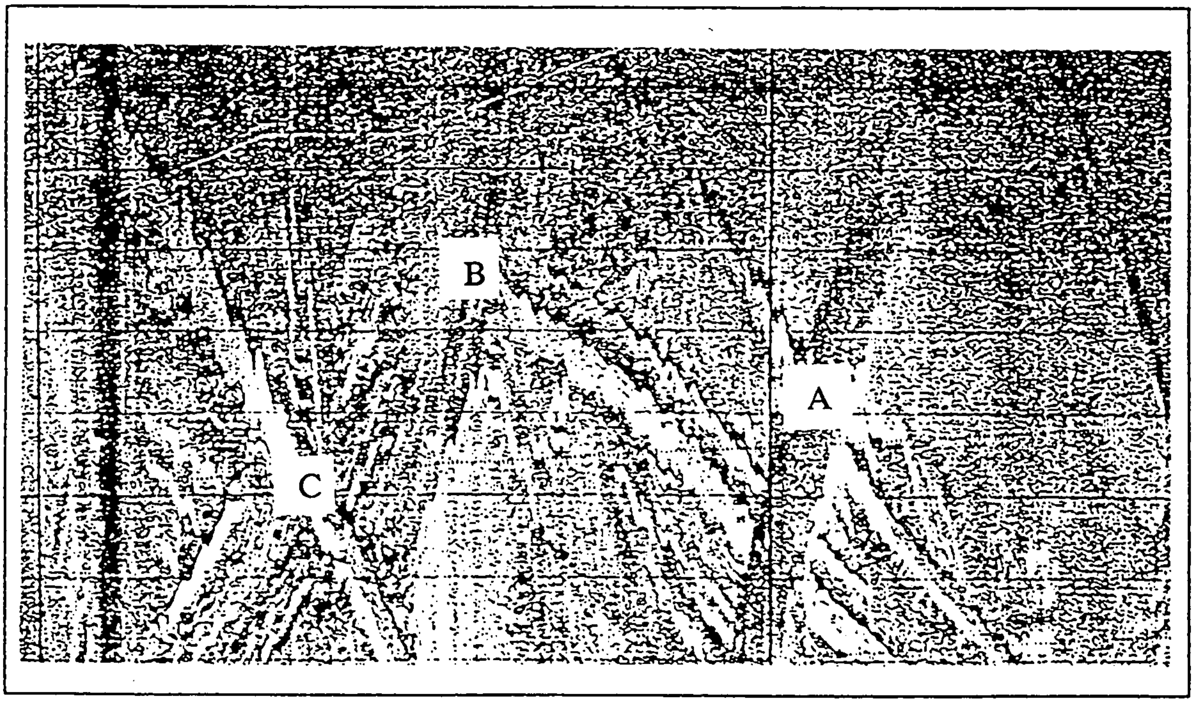
Scour Age and Cross-cutting Scours

Sidescan records collected over the Scour N90-7 area from 1981 to 1984 were examined to locate areas of overlapping coverage. Figure 4.3.17 shows the same seabed area surveyed in 1981 and 1984. Scour N90-7 is present only on the 1984 records, indicating that it formed sometime between the summers of 1981 and 1984. In contrast, the scour is present on sidescan records collected in 1982 and 1984 (Figure 4.3.18). This indicates that N90-7 was formed in the winter of 1981-1982, and was eight years old at the time of the ESRF 1990 survey.

Given that the age of Scour N90-7 is known, it is possible to determine new scour impact rates in this area, by observing the number of more recent scours cross-cut the scour. There are 7 new scours which were observed to cross-cut N90-7 on the ESRF 1990 data,

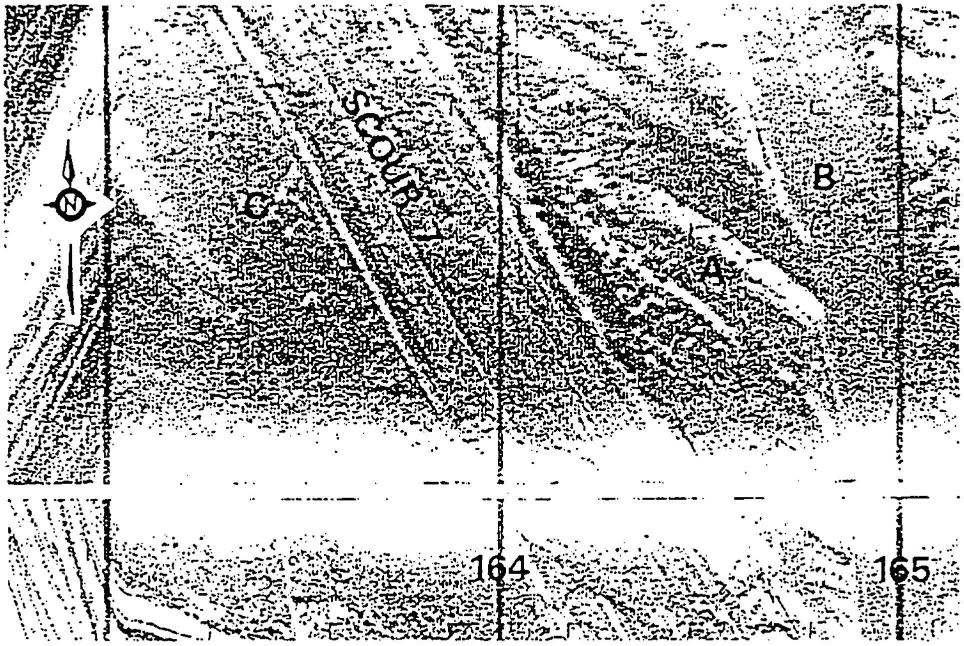


1984 SIDE SCAN SONAR DATA
SCOUR 7 PRESENT

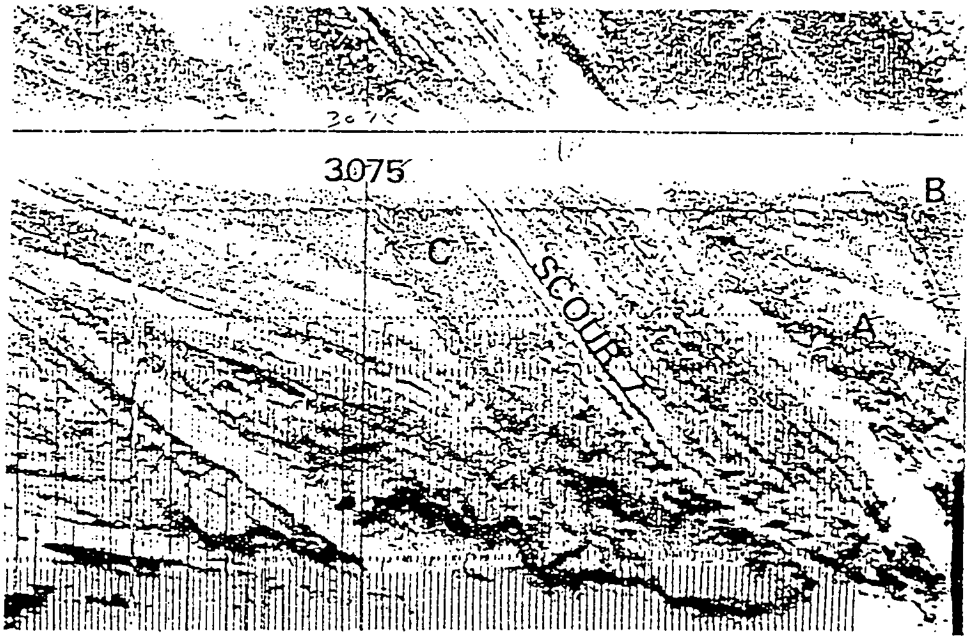


1981 SIDE SCAN SONAR DATA
SCOUR 7 ABSENT

Figure 4.3.17 Comparative 1981 and 1984 sonograms over the scour N90-7 area, showing that scour N90-7 formed after the summer of 1981.



GHR 1984 263 SIDE SCAN DATA SCOUR 7 PRESENT



GHR 1982 6104 SIDE SCAN DATA SCOUR 7 PRESENT

Figure 4.3.18 Comparative 1982 and 1984 sonograms over the scour N90-7 area, showing that scour N90-7 was formed prior to the 1982 survey.

and an additional 4 scours which possibly cross-cut the scour. The ESRF 1990 survey collected sidescan data along 5.4 kilometres of Scour N90-7. This provides impact rates of 0.16 new scours/km/yr for the known new scour events, and 0.25 new scours/km/year including the known and possible new scours. These rates are slightly lower than regional impact rates, calculated for the 1989 and 1990 repetitive mapping surveys, in this area.

Some of the cross-cutting scours appear to drop down partway into the base of Scour N90-7, while others appear to scour only the N90-7 berms. None of the cross-cutting scours appears to have scoured the deepest portion of the base of Scour N90-7. The ability of cross-cutting scours to drop-down into the base of a pre-existing may be largely a function of the amount of rise-up they have experienced prior to encountering the older scour. The difference in the pre-cross-cut scour base elevations for each of the scours may also play an important role in determining whether the cross-cutting scour incises the base of the older scour.

4.3.2.8 SCOUR N89-1

Scour N89-1 is a double-keeled scour located on the Yukon Shelf, approximately 12 kilometres north of Herschel Island. The start point of N89-1 scour tracking is located at 69° 43' 44.0" N, 138° 57' 17.0" W. The scour was tracked for 5 kilometres, in water depths of 48 to 56 metres. Maximum observed scour depth of the largest keel (keel A) is 6.9 metres. The base of keel A rises up 1.1 metres prior to a partial scour termination event, in which it appears that most of keel A was sheared off from the main ice floe. The age of Scour N89-1 is estimated to be less than 25-50 years.

This scour was first observed as a 6-7 metre deep, V-shaped feature, during a 1972 air-gun seismic survey. It was later confirmed as a linear ice scour feature in 1988, when six echo sounder profiles were collected across the feature. Although no sidescan data had been collected, the echo sounder profiles revealed steep scour walls, and well-defined berms, indicative of relatively fresh scours. As the deepest or near deepest scour observed in the Beaufort Sea, this scour was selected for scour tracking study.

In 1989, Scour N89-1 was surveyed using echo sounder, 7.0 kHz sub-bottom profiler and, for the first time, sidescan sonar equipment. During this survey, a 2-3 metre deep outrider scour was located 275 metres northeast of the main scour, the extreme depth of the main scour was confirmed, and a "very fresh" sidescan sonar morphology was observed. Scour N89-1 was tracked for 5 kilometres, and scour parameter measurements were obtained on 10 cross-overs of the major scour (keel A), and 7 cross-overs of the "minor" scour (keel B). These measurements are compiled in Appendix 2. Scour measurements were used to construct Scour Depth and Scour Rise-up profiles (Enclosure 6 and Figure 4.3.19). Scale-corrected cross-sections of keel A and portions of sidescan sonar records are also presented in Enclosure 6.

Scour Direction and Orientation

The keels comprising Scour N89-1 are linear in plan view, with an overall orientation of 120/300°. The scour does not cut across itself, and no clear directional indicators could be ascertained through cross-cutting scour relationships. However, based on bathymetric and scour rise-up relationships, particularly the apparent partial termination of keel A at the shallow water end of the scour, it appears that Scour N89-1 was formed by ice moving towards the northwest at approximately 300°.

Scour Width and Incision Width

Scour width and incision width were measured for both of the Scour N89-1 keels, along with the separation distance between the keels. Keel B is located 275 metres northeast of keel A. The keel separation distance remains fairly constant along the observed length of the scour.

Keel A is the widest of the two keels. It has an incision width ranging from 10 to 30 metres, and a scour width ranging from 20 metres and 70 metres. Incision width and scour width both increase as scour depth increases. This is not unexpected as most ice ridge features are narrowest at their base, and will produce a wider incision as they scour deeper into the seabed. The increase in the keel A scour width reflects the combined effect of increased scour incision dimensions, as well as, an increase in the amount of berm material excavated as the keel scoured deeper into the seabed.

Keels B is a narrow, sharp-sided scour comprised of two sub-keels, separated by a 1-1.5 metre high inter-keel ridge. Along the first 800 metres of keel B, only one of the sub-keels was in contact with the seabed, and incision width is 5.0 metres. Incision width remains constant at approximately 10.0 metres along the remainder of keel B. Keel B scour width varies from 15 to 25 metres, in areas where both sub-keels are present.

Berm Height and Berm Width

Although the keel A incision appears relatively symmetrical, the two lateral scour berms are very different in size. The northern berm is consistently much wider and higher than the southern berm (Enclosure 6; cross-sections). Along the length of the scour, the northern berm increases from 10.0 to 15.0 metres in width, and 1.0 metre in height (55.5 metres water depth), to approximately 40-45 metres in width and 3.2 metres in height (48 metres water depth). The corresponding southern berm widths increase from 5.0 metres to 10.0 metres across the same bathymetric interval. The height of the southern berm increases from 0.5 metres to 2.3 metres The overall increase in berm size is the result of a progressive increase in the size of the scour incision as the ice-keel scoured into progressively shallower water depths. Given the fact that the N89-1 scour is linear and the keel A incision appears symmetrical, the differences in the size of the two keel A berms may be accounted for by the shape of the ice keel. That is, in a manner analogous to a highway-plough, the shape of the ice keel may have ploughed sediments preferentially towards the northern berm.

Maximum berm height recorded on the echo sounder is 4.5 metres on the northern berm at KP 1.9. Scour depth at this cross-over is approximately 5.0 metres, nearly 2.0 metres less than the maximum recorded depth. However, the height of the northern berm of Keel A varies considerable along any given portion of the scour (Enclosure 6; Plates 1 and 2). The length of the acoustic shadow cast by the northern berm suggests that the berm may be as high as 8.0 metres along the deepest portion of the scour.

The relatively small lateral berms of keel B are difficult to identify on the sidescan records. Echo sounder records indicate that the berms are roughly equal in size. Berm heights are generally 1.0 metre or less and berm widths appear to be less than 5.0 metres.

Sediment Infill

Unlike the ESRF 1990 scour tracking surveys, during which a microprofiler was deployed in the sidescan sonar fish, high frequency seismic data were not collected over N89-1. As a result, unless a strong contrast exists between scoured seabed sediments and possible infilled sediments, the thickness of possible sediment infill deposits can not be determined from the echo sounder or sub-bottom profiler records. Examination of the available data sets did not reveal any indication of infill deposits. Scour N89-1 has a very rough scour morphology on the sidescan sonar records, including detailed ridge and groove striations along the scour base. It has a V-shaped profile on the echo sounder records, in contrast to the more flat bottomed profile of scours which contain thick infilled deposits. These observations suggest that only minor sediment infill is present within this scour. Future surveying of this scour should employ a high resolution profiling system to ascertain how much, if any, sediment infill is present within Scour N90-7.

Scour Depth and Rise-up

Scour depths were measured assuming that no sediment infill is present at the base of the scour (see infill section). Rise-up profiles for both keels of Scour N89-1 are plotted on a single rise-up profile presented in Enclosure 6. The major scour (keel A) has a maximum observed depth of 6.9 metres, while keel B has a maximum observed depth of 3.3 metres. The water depth at which scouring initiated (ice touchdown location) is different for the two keels; 57.2 metres for keel A, and 53.8 metres for keel B. This indicates that the ice keels responsible for each of the scours protruded at different depths beneath the ice ridge.

Rise-up relationships along the initial 1.8 km portion of Scour N89-1 are consistent with Stage 1 of the scouring process of Shearer et al. (1986). At the first cross-over event of keel A (KP 0.8), water depth is 55.5 metres and scour depth is already 1.7 metres. The depth to the base of the scour is 57.2 metres at this location and, based on the absence of scour rise-up along this portion of the scour, the ice keel probably touched down in

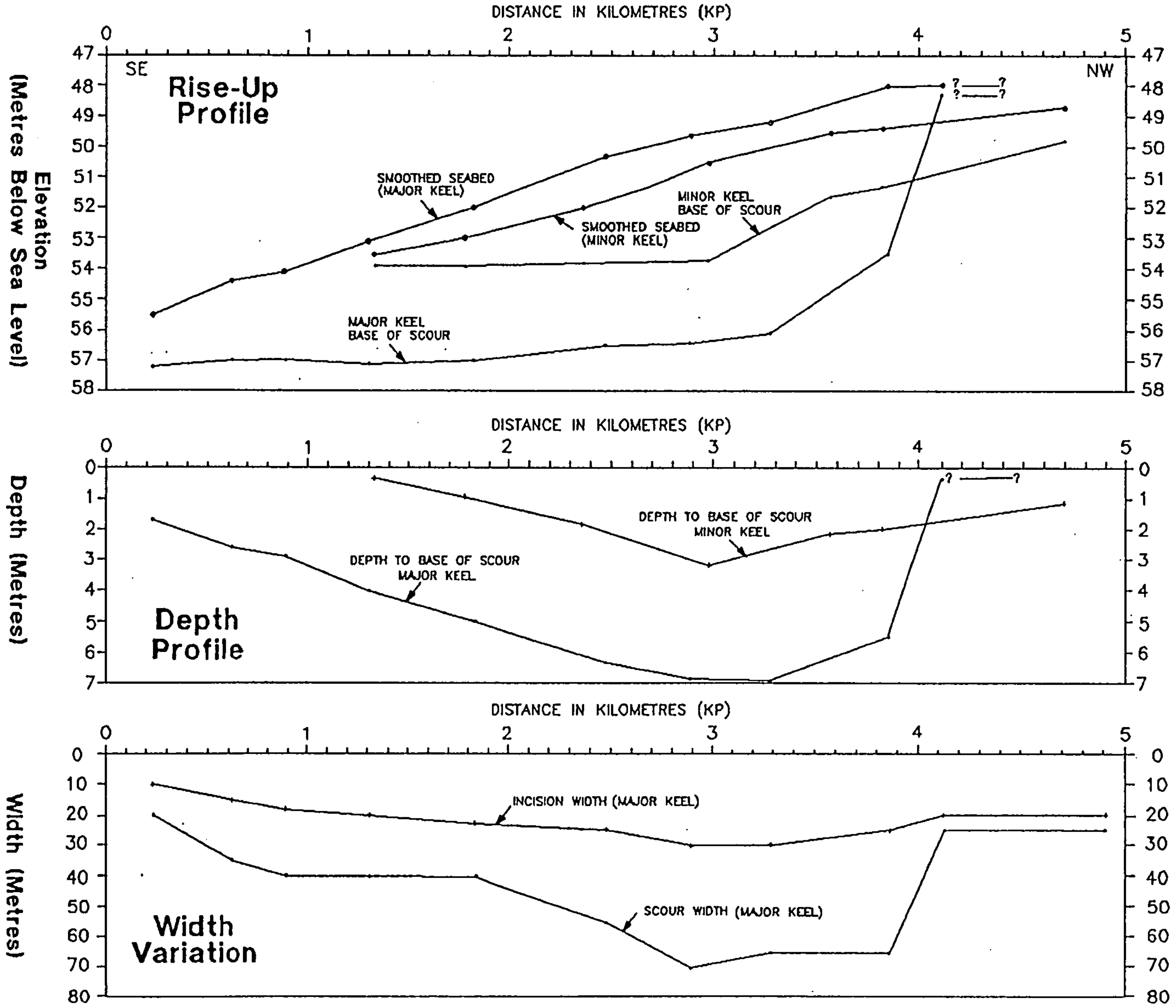


Figure 4.3.19 Scour rise-up profile, scour depth profile and scour width variation along Scour N89-1.

approximately 57 metres water depth. As scouring continued from KP 0.8 to KP 1.8, the bathymetry decreased from 55.5 metres to 52.0 metres and scour depth increased from 1.7 metres to 5.0 metres. The scour base elevation remains relatively constant near 57.0 metres across this interval, with no net increase in scour rise-up. During Stage 1, the resistive forces developed within the sediments being scoured are insufficient to prevent increased penetration of the ice keel into the seabed, as the ice keel scours into progressively shallower water depths.

At KP 1.8, the base of the scour begins rising up very gradually, accompanied by a more rapidly decreasing bathymetry, such that by KP 2.9 scour depth has increased to 6.8 metres. This is consistent with Stage 2 of the scouring process, in which increased resistive forces within the sediments being scoured (due to increased penetration of ice into the seabed) cause an uplift of the ice mass. However the amount of uplift or rise-up is less than the corresponding decrease in water depth, and the scour depth continues to increase (Shearer et al., 1986).

Between KP 2.9 and KP 3.3, the rate of rise-up and decreasing bathymetry are similar, and scour depth increases by only 0.1 metre to 6.9 metres. This corresponds to Stage 3 in the scouring process in which the increase in lithostatic loading which accompanies continued rise-up does not result in progressively deeper scouring. A significant increase in the rate of scour rise-up occurs, as Stage 3 scouring continues beyond KP 3.3. Rise-up exceeds the decrease in bathymetry along this portion of the scour, and the scour depth decreases to 5.5 metres at KP 3.9. The dramatic increase in rise-up across this interval may be related to a change in the physical properties of the sediments. Similar reductions in scour depth are often a sign of imminent scour termination (Shearer et al., 1986).

A dramatic change in scour character, interpreted as a partial scour termination event, occurs near KP 3.9 (Enclosure 6; Plate 2). This change in character corresponds to an abrupt decrease in the depth of keel A, as evidenced by the absence of an acoustic shadow within the scour. A decrease in scour width and the size of the northern berm also occur at KP 3.9. Berm rubble piles present within the base of the scour, near KP 3.9, probably represent surcharge or termination berms formed when the deepest portion of keel A broke off from the main ice mass (Enclosure 6; Plate 4). Echo sounder records are not available for the cross-overs immediately past the change in scour character. However, initial returns measured from the third channel sidescan display (expanded port channel sidescan) indicate that keel A is less than 0.5 metres deep at KP 4.1. These observations suggest that a major portion of the ice keel which scoured keel A became detached from the ice ridge, near KP 3.9. The remnant ice keel continued scouring beyond the partial termination event to the limit of scour tracking at KP 5. There are no cross-overs along the final 900 metres of scour tracking. The evidence outlined above suggests that a period of increased scour rise-up rates, perhaps related to an increase in sediment strength as the ice keel scoured deeper into the seabed, was followed by partial scour termination. At the point of partial termination, the sediment resistive forces and scour driving forces exceeded the internal strength of the ice keel, resulting in failure within the keel.

Keel A underwent at least 3.7 metres of rise-up prior to the partial termination event at KP 3.9. There is no direct evidence of final scour termination beyond this point. It seems probable that the scour continues a significant distance beyond the limit of scour tracking, perhaps into progressively shallower water with additional associated scour rise-up. The western extent of this scour should be investigated during future scour tracking surveys.

Except for the partial termination event on keel A, the rise-up profiles of keel A and keel B are similar in overall morphology. Keel B touches down near KP 1.1 (distances measured from start of tracking on keel A), and at the first cross-over, located near KP 1.3, the scour depth is 0.3 metres. From KP 1.3 to KP 1.8, water depth decreases slightly, the scour base elevation remains constant, and scour depth increases to 0.9 metres. Scour depth increases past KP 1.8, as scouring progressed into shallower water, reaching a maximum depth of 3.3 metres, near KP 3.0. The scour base elevation rises up very slightly within this interval, but at a rate less than the rise in seabed elevation. Beyond KP 3.0, the base of keel B rises up at a rate greater than seabed elevation, and scour depth decreases along the remainder of the scour. Net rise-up along the base of keel B is 0.2 metres prior to KP 3.0, and 3.9 metres between KP 3.0 and the last cross-over event at KP 4.7. Scour depth decreases from 3.3 metres at KP 3.0, to 1.1 metres at KP 4.7. Although scour rise-up along the latter portions of keel B occur at a rate greater than the rise in seabed elevation, there is no evidence of a partial termination event along keel B.

As the deepest of the keels, the ice keel which formed Keel A may have been responsible for determining most of the rise-up variations observed along both keels. The rate of maximum scour rise-up on keel B (3.5 m/km between KP 3.0 and KP 3.6) is similar to the rise-up rate observed on keel A just prior to the partial termination event (4.5 m/km). Past KP 3.6 on keel B, rise-up continues at a rate of 1.6 m/km. This decrease in the rate of scour rise-up along keel B, may coincide with the partial termination of keel A. That is, keel B may have been located at KP 3.6 when partial termination of keel A occurred. If so, the rise-up of keel A prior to the partial termination may have influenced the entire ice mass, partially causing the rise-up observed on keel B between KP 3.0 and KP 3.6. Once the partial termination of keel A had occurred, keel B may have been the predominant keel, with an associated decrease in the scour rise-up rate.

Scour Age and Cross-cutting Scours

Scour N89-1 was observed on survey data collected in the summer of 1972, and therefore has a minimum age at the time of the 1989 survey of 18 years. The thickness of sediment infill deposits, and the frequency of younger cross-cutting scour occurrences, are two qualitative methods that can be used to provide an age estimate for a scour, such as Scour N89-1, which pre-dates the earliest geophysical surveys in that area.

In the case of Scour N89-1, the thickness of sediment infill could not be determined directly, although significant sediment infill is not expected to be present (see Infill section). Sea level curves compiled for the Beaufort Sea by Hill et al. (1986) indicate that deposition of fine-grained sediments in this area would have began at 7500 years before present. The post-Holocene transgression marine sediments, observed on sub-bottom profiler records, average 15.0 metres in thickness in the area of Scour N89-1. This indicates a regional sedimentation rate of 2.0 mm/yr. Given that significantly less than 0.5 metres of sediment infill is probable within the base of Scour N89-1, and that the rates of preferential sediment infill may exceed the regional sedimentation rate by a factor of 5 times or more (i.e. 10 mm/yr), the age of this scour is probably less than 50 years.

A second method for estimating the age of a scour is to count the number younger cross-cutting scour events. In the case of Scour N89-1, no younger cross-cutting scours were observed. However, the regional impact rate calculations can still be used to provide an age estimate. In a regional study of ice scour impact rates in the Beaufort Sea, Shearer (1988) concludes that the rate of new scour occurrences decreases exponentially with increasing water depth. In the repetitive mapping surveys carried out date, no new scours were observed in water depths greater than 38 metres. Extrapolation of the observed impact rates in water depths of 20 to 40 metres, into deeper water depths, suggests an approximate re-scour rate of 0.01 scours/km/yr at 50 metres water depth. Given that Scour N89-1 was tracked for just over 4 kilometres, one new cross-cutting scour would be expected every 25 years assuming an impact rate of 0.01 scours/km/yr. The absence of cross-cutting scours suggests that Scour N89-1 is perhaps less than 25 years old.

In the fall of 1970, a major storm blew a number of large ice islands into the west side of Mackenzie Bay. Given that this Scour N89-1 formed prior to 1972, and is estimated to be less than 25 to 50 years old, it is possible that a multi-keeled ice island formed this scour during the 1970 ice incursion.

4.3.3 SCOUR TRACKING DISCUSSION

Section 4.3.3 contains a summary and discussion of the scour tracking study. Seven ice scours surveyed in 1989 and 1990 were analyzed in detail for this scour tracking study. Sidescan sonar, microprofiler, echo sounder and sub-bottom profiler data were collected along the length of each scour. The survey lines were run in a sinuous pattern, crossing over the scour at 0.5 to 1.0 kilometre intervals. The number of scour cross-overs recorded for each scour, varied from 10 to 86, depending on the length of the scour being tracked. Key parameters such as scour depth, scour infill, scour width, berm size, bathymetry and scour base elevation were measured at each cross-over. These measurements are compiled in Appendix 2. Scour depth and scour rise-up profiles were constructed for each scour. These are presented along with scale-corrected cross-sections and representative sidescan/microprofiler records in Enclosures 1 to 7.

Scour Width

Incision width and scour width vary along the length of most of the tracked scours. A gradual increase in the scour and incision width occurs along most scours, as the scour depth increases. The relationship between incision width and scour depth is dependent on the cross-sectional shape of the scouring ice keel. For example, a conical shaped ice keel scouring progressively deeper into the seabed would display a greater increase in incision width than would a more steeply sided ice keel. In general, scour width (the distance from berm crest to berm crest) increases at a slightly higher rate than incision width along any given scour. This is probably due to an increase in the amount of berm material excavated from the progressively larger incision. In a previous study of ice scour morphology, Gilbert (1989) indicates that berm width is strongly correlated to incision width. The relationship between scour width and scour depth is generally most apparent within Stage 1 of the scouring process, as scour depth increases more rapidly along the initial portion of the scour.

The most pronounced variations in width measurements, observed during the scour tracking study, are associated with scour direction changes along multi-keeled scours (i.e. scour N90-1; Figure 4.3.4). Depending on the relative ice keel spacing, component keels of multi-keeled scours may vary in width, or move closer or further away from one another, across major changes in scour direction. In some cases, if the keels become aligned one behind the other, individual keels may seem to disappear across such directional changes. Variations in scour rise-up and scour depth are also associated with some major changes in scour direction. These variations may be caused by changes in the ice-sediment surface area or, perhaps, by a change in the relative shape of the ice keels (i.e. the cross-sectional profile of an ice keel varies depending on the direction of scouring).

In the case of scour N90-1, where a change in scour direction resulted in an increase in scour width, a significant scour rise-up and a corresponding decrease in scour depth was observed. For Scour N90-5, a decrease in scour width and a sudden rise-up of the scour base occur across a major change in scour direction. The observed rise-up may be related to a change in the cross-sectional profile of the ice keel in the new scouring direction. It is apparent that scour width variations are sometimes associated with major changes in scouring direction, and that such variations may influence the depth to which an ice keel penetrates the seabed.

Significant increases in scour width are also associated with the onset of scouring by one or more additional ice keels, as a multi-keeled ice ridge scours into progressively shallower water depths (i.e. Scour N90-7). One or more additional scours, formed by ice keels that are slightly shallower than the deepest scour keel, appear part way along some scours. As the ice ridge scours into progressively shallower water depths, the primary keel penetrates deeper into the seabed and the shallower keels ultimately touch down and begin forming adjacent scours. These shallower keels may occur some distance from the primary keel, and form parallel, "outrider scours". If present directly adjacent to the primary keel, the shallower keels may appear to increase the width of the primary scour. In the case of Scour N90-7, slight scour rise-up and a minor decrease in the depth of the main incision coincide with the onset of scouring by additional ice keels. The onset of scouring by additional keels along a multi-keeled scour increases the surface area of the ice-sediment contact. This effectively distributes the lithostatic load of the ice ridge over a larger area and, in some cases, may influence the scour depth.

Scour Berms

Average berm widths and berm heights tend to increase as scour depth increases. This is due to the increased amount of sediment excavated by the ice keel as it scours progressively deeper into the seabed. Gilbert (1989) indicates a similar relationship between berm size and scour depth. The increase in average berm size is especially apparent along the initial scour segments where scour depths may increase relatively quickly to 2-3 metres.

Scour berms often appear to vary in width and height between adjacent cross-overs. Local variations in berm sizes are especially apparent along relatively young scours. The berms of these scours generally appear irregular in size and are typically blocky and rough textured on the sidescan records. Local variations in berm size are also influenced by the pre-scouring seabed morphology. Berm size increases locally as the scour cuts across local bathymetric highs and the berms of older scours, and decreases as the scour cuts less deeply across local bathymetric lows or the base of older scours. Scour berms may also be severely modified, and in some cases completely obliterated, along portions of scours which are cut by numerous younger cross-cutting scours.

The maximum berm height recorded on echo sounder profiles during the 1990 scour tracking project was 4.5 metres. This occurred at a cross-over of the northern berm of Scour N89-1. Acoustic shadows cast by this berm on sidescan sonar records suggest that it may be up to 8.0 metres high in places. Maximum berm widths recorded during the survey were 50-60 metres along Scour N90-2.

Sediment Infill

Accurate measurements of sediment infill deposits at the base of the scour are very important in determining the true scour depth and for subsequent construction of the scour rise-up profiles. The 100 kHz microprofiler system, employed during the 1990 survey, proved to be a very effective tool, providing high resolution profiles of sediment infill deposits. This represents a great improvement over previous surveys in which only echo sounder and lower frequency sub-bottom profiler systems were employed. A maximum of 3.0 metres of infilled sediments was observed during the scour tracking study. This occurred within one of the oldest scours (Scour N90-2).

Figure 4.3.20 depicts a conceptual model of sediment infilling, based primarily on observations made during the scour tracking study. Three acoustically-distinct types of scour infill are apparent on the microprofiler records; acoustically transparent/opaque (non-stratified to weakly stratified) sediments (Type A), acoustically stratified sediments (Type B), and mounded cross-cut sediment piles (CCSP)(Type C). The stratified sediment infill typically overlies the acoustically transparent sediments where both types of infill were observed. At cross-overs where CCSP debris was observed, its occurrence within the infill sequence is dependent on the frequency of scouring activity.

Type A Infill

Type A sediments generally occur at the base of the infill sequence. They are characterised by a general lack of acoustic reflectors, giving the sediments a transparent or opaque appearance on the microprofiler records. Occasionally, faint or discontinuous reflectors may occur within these

Model of Scour Infill

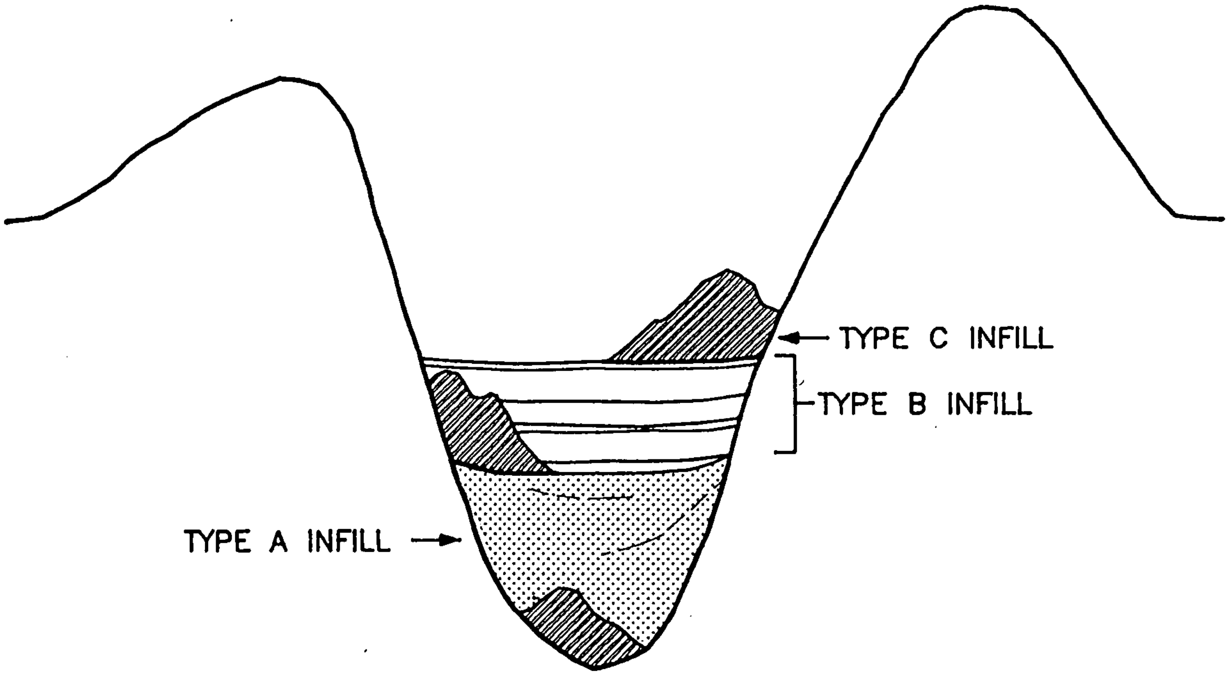


Figure 4.3.20 Conceptual model of scour infill showing three acoustically-distinct types of sediment infill: Type A (acoustically opaque sediments), Type B (well-stratified sediments), and Type C (cross-cut sediment piles).

sediments. Type C deposits seldom occur within or beneath Type A infill. This suggests that the Type A sediments may have been deposited relatively soon after the scour was formed. The origin of the Type A sediments is uncertain, due in part to discontinuous profiling (i.e. the base of unit approaches the penetration limitations of the microprofiler). Where the base of the Type A infill was observed, the sediments pinch out against the scour walls. This is in contrast to observations and models of sub-scour deformation reported in the literature, which propose that zones of sub-scour deformation continue into scour walls (Shearer, 1981; Lien, 1986; Gilbert, 1990; and Woodworth-Lynas and Guigne, 1990). This suggests that Type A deposits represent scour infill or back-fill, rather than a zone of disturbed sub-scour sediments. Although the deposition mechanism for Type A is uncertain, present observations suggest it is comprised of infilled sediments, emplaced shortly after scour formation.

Type B Infill

Type B infill generally occurs at the top of the infill sequence. It is characterised by two or more parallel, and generally well-defined, reflectors which pinch-out against the scour wall. Reflector spacing generally varies from approximately 0.1 metres (limit of microprofiler resolution) to 0.5 metres. The number of reflectors within Type B infill commonly varies between adjacent profiles along the same scour. Along Scour N90-4, the thickness of Type B sediments increases from 0.5 to 1.3 metres in water depths of 27 metres to 20 metres, respectively. This suggests that Type B infill is deposited by a process which is partially dependent on water depth. Type B infill is probably comprised of fine grained sediments winnowed from the adjacent scour berms and surrounding seabed, that are subsequently deposited in the "hydrodynamically quiet" base of the scour. This type of infill may be related to storm-dominated events.

Type C Infill

Type C infill is characterised by irregular-to-mounded deposits of non-stratified sediments. Type C deposits are observed at cross-overs where the tracked scour is cut by younger scour events, and are commonly referred to as cross-cut sediment piles (CCSP). Type C infill is comprised of sediments pushed into the scour base. These sediments are derived from the adjacent scour berm and those of the surrounding seabed, as the younger cross-cutting scour ploughs across the scour. In some cases, extensive deposits of Type C infill completely obscure the underlying infill and scour base reflectors. However, most Type C deposits are much less extensive. Type C deposits were observed at all stratigraphic levels within the infill sequence, but seldom occur within Type A infill. The location of the Type C deposits within the infill sequence is dependent on the age of cross-cutting scours.

The nature of the infill process can not be determined from the acoustic records alone. For example, within Type B infill, the individual strata bounded by the parallel reflectors may be interpreted as storm-related deposits. In this case, the majority of the infill is deposited during very short-lived, storm dominated events, and the reflectors separating the individual strata represent very thin deposits (beyond resolution limits) accumulated over a longer time period between individual storm events. Alternatively, the reflectors themselves may represent storm-dominated events. In this alternative interpretation, the sediments bounded by the reflectors represent long periods of preferential scour infill during relatively quiet conditions. In the case of the first interpretation, a relatively thick sequence of infill could be deposited in a relatively short time period, depending on the frequency or severity of major storms.

Similarly, uncertainties exist in the interpretation of Type A infill. However, it appears fairly certain that Type A represents sediment infill, rather than a zone of sub-scour disturbance. The poorly-stratified nature of these sediments may be indicative of an initial post-scour period of rapid infill deposition. The precise depositional mechanism for such infilling is not clear. Type A material may represent; sediments deposited during an extreme storm event shortly after the scour was formed (similar to individual strata within Type B infill), slumped sediments from the scour walls and berms, or a type of syn-scouring back fill. Such immediate back fill has been proposed for scours in sandy sediments (Woodworth-Lynas et al., 1986), but would probably require liquification of the marine clays in the Beaufort Sea. If Type A infill deposits are representative of extreme storm events, they should form useful time markers that may be evident within other older scours. A systematic analysis of the scour infill sequence for other older scours could be undertaken to determine whether the Type A infill is indeed storm-related. A carefully planned coring program, designed to sample the various types of scour infill, may also lead to a better understanding of the scour infill process.

Scour Rise-up and Scour Depth

Scour depth and scour rise-up profiles were constructed for seven scours (Enclosures 1 to 7). Rise-up profiles record variations in the scour base elevation which occur along the scour. Such profiles are important in understanding the scouring process and provide constraints for modelling of scour mechanics. Three stages of scour rise-up, following those outlined by Shearer et al. (1986), were observed along the scours examined in the present study. A conceptual model of scour rise-up, illustrating the key points for each of the three stages, is presented in Figure 4.3.21.

In Stage 1, the base of the scour remains at a constant elevation, and scour depth increases gradually as the ice keel scours into shallower water depths. The scour base elevation begins to rise-up in Stage 2, but at a rate less than the decrease in water depths such that scour depth continues to increase as the ice keel continues to scour upslope. During Stage 3 scouring, the scour base elevation and seabed elevation rise-up at the same rate, and the scour depth remains constant. Not every stage of rise-up was apparent along each individual scour. For example, Stage 2 rise-up was only observed along four of the seven tracked scours. Table 4.3.5 summarizes key rise-up observations, with respect to the proposed scour rise-up model, for each of the scours examined during the present study. Each of the primary stages is described as below.

Stage 1

Stage 1 is characterised by a constant scour base elevation. There is no scour rise-up, and scour depth increases, as the ice keel scours into progressively shallower water depths. During Stage 1, the vertical resistance developed within the scoured sediments (F_4 on Figure 4.3.21) is insufficient to prevent progressive penetration of the ice keel into the seabed. Since scour rise-up does not occur within Stage 1, the ice ridge remains neutrally buoyant in the water and no lithostatic load is developed. The Stage 1 scouring process may be analogous to a ploughing action with little, if any, load on the sub-scour soils. The distance over which Stage 1 scouring occurs is primarily a function of seabed slope. An ice keel scouring parallel to the bathymetric contours may continue for tens of kilometres without experiencing scour rise-up. For an ice keel moving upslope, the scour depth increases gradually, as the ice keel scours into progressively shallower water depths, ultimately reaching a depth at which rise-up begins.

The depths to which an ice keel can penetrate without experiencing rise-up is dependent on a number of factors, including; the mass of the ice ridge, the shape of the ice keel, and the physical properties of the seabed sediments. A change in any of these factors may result in local scour rise-up or drop-down. In the present study, scour depths within Stage 1 exceed 5.0 metres for three of the seven scours, with a maximum observed depth of 6.8 metres.

Stage 2

During Stage 2 rise-up, the scour base elevation rises up at a rate less than the decrease in water depths, such that scour depth continues to increase as the ice keel continues to scour upslope. As scour depth increases during Stage 1, resistive forces acting against the ice keel begin to build (F_4 in Figure 4.3.21). At the onset of Stage 2, the F_4 forces are sufficient to prevent further penetration of the ice keel into the seabed sediments. The point at which this occurs is a function of the strength of the sediments, which tends to increase with depth, as well as, the surface area of the ice-sediment contact. As scouring continues during Stage 2, scour rise-up occurs and the ice ridge is pushed up slightly out of the water. This in turn increases the vertical load on the sediments, which allows the keel to penetrate slightly deeper into the sediments. The F_3 and F_4 forces increase throughout Stage 2 as the keel penetrates deeper into the seabed, and further scour rise-up occurs. Eventually, a point is reached (marking the onset of Stage 3) where further

SCOUR RISE-UP MODEL

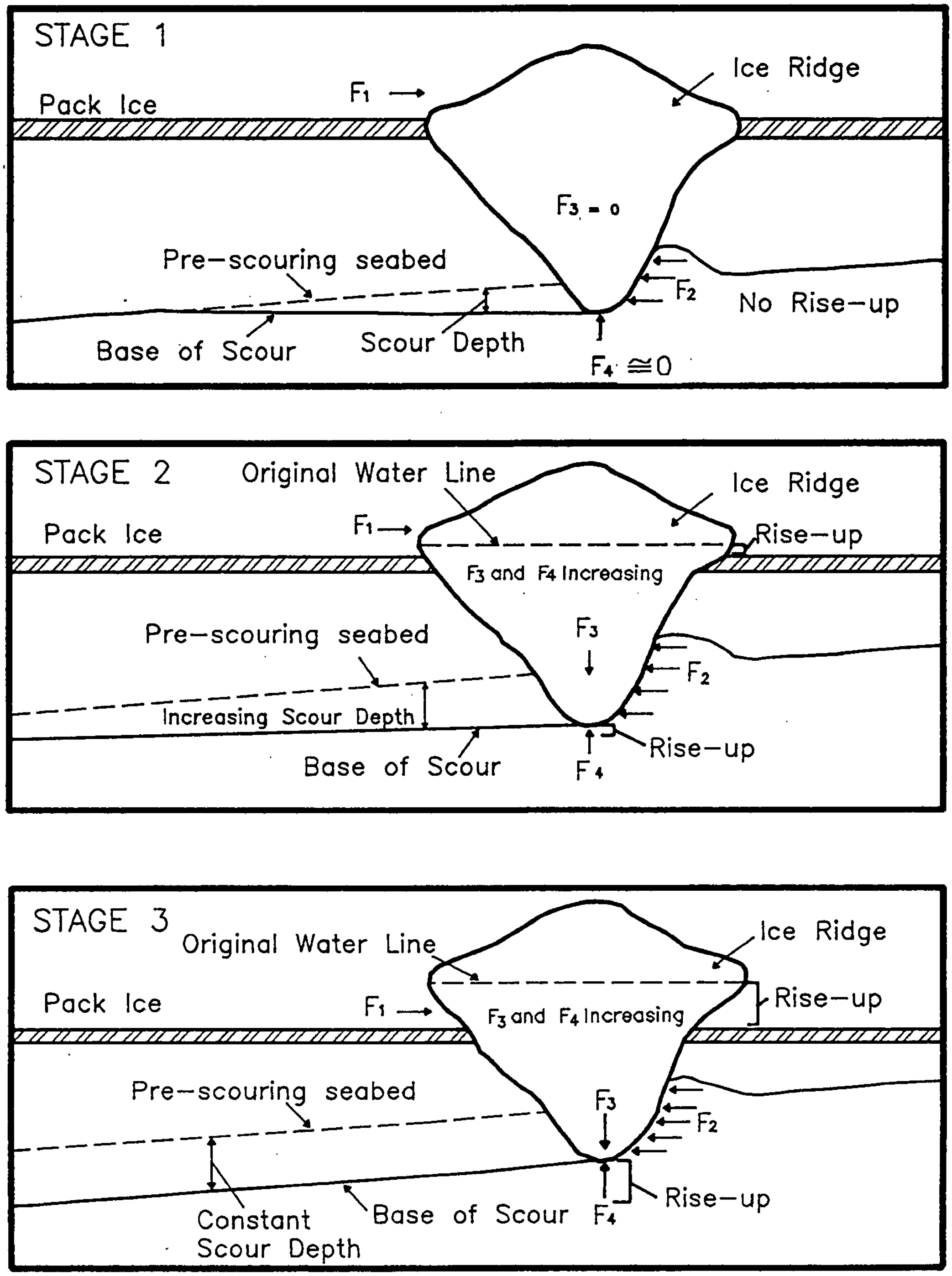


Figure 4.3.21 Conceptual model of the various stages of scour rise-up; F_1= driving force, F_2= horizontal resistance to scouring, F_3= lithostatic load resulting from scour rise-up, and F_4= vertical resistance to keel penetration. See text for details.

rise-up does not result in deeper scouring.

Given that the F_4 forces are already sufficient to initiate scour rise-up at the onset of Stage 2, the transition to Stage 3 may occur following a relatively small increase in scour depth. The increase in scour depth observed within Stage 2 along individual scours ranges from 0.3 metres (scours N90-1 and N90-2) to 1.9 metres (Scour N89-1). The distance during which Stage 2 is active depends on seabed slope. The increase in scour depth required to initiate Stage 3 scouring will occur very quickly across a steep seabed slope, and the evidence for Stage 2 scouring may not be recorded on adjacent cross-overs. Stage 2 rise-up was not apparent along scours N90-4 or N90-5, and appears to be present only along relatively short segments of three other scours (Table 4.3.5). Scour depths recorded within Stage 2 rise-up range from 1.0 to 7.1 metres. Total rise-up observed within Stage 2 ranges from 0.2 to 1.2 metres. Stage 2 is a transitional stage of scour rise-up which occurs as the scouring forces and resistive forces within the seabed sediments approach an equilibrium. The scour base elevation increases at a rate less than the seabed elevation, and scour depths increase in Stage 2, as the ice keel scours progressively into shallower water depths.

Stage 3

During Stage 3 rise-up, the scour base elevation and the seabed elevation change at the same rate, and scour depth remains relatively constant. Locally, alternating periods of scour rise-up and scour drop-down may occur, as the ice keel scours upslope and downslope, respectively. As scouring continues into shallower water, progressive scour rise-up increases the lithostatic load acting on the seabed sediments (F_3 in Figure 4.3.21). In Stage 3, an apparent equilibrium is achieved such that the increasing lithostatic load does not result in a significant increase in scour depth. Maximum scour rise-up and scour depth observed within Stage 3 scouring are 7.8 metres and 8.5 metres, respectively (Table 4.3.5).

The inability of the ice keel to penetrate significantly deeper into the seabed, despite the increased vertical load, is related to the strength of the sediments, the surface area of the ice-sediment contact, and perhaps, the short-term compaction limit of the sediments beneath the keel. In a previous study of scour morphology, Gilbert (1989) observed that the berm area/scour area ratio decreases with increasing scour depth. This may suggest that some portion of the scour area in the later stages of scouring (i.e. Stage 3 where lithostatic loads are significant) is formed by sediment compaction. This relationship could not be confirmed in the present study, given the limited number of cross-overs within Stage 3, as well as, the post-scour berm alteration observed along most of the tracked scours.

A change in the physical properties of the seabed sediments may alter the rise-up profile, and produce a local increase or decrease in scour depth. Periods of relatively rapid scour rise-up during Stage 3, at a rate greater than the decrease in water depths (i.e. scour depths decreasing), are often followed by a major change in the scouring process. This occurred along four of the seven tracked scours. Such rise-up preceded a partial termination event along two of the scours, while a major change in scouring direction immediately followed the period of rapid rise-up along two additional scours. It is thought that increased resistance to scouring, perhaps related to a local change in sediment properties, caused the higher rates of scour rise-up and subsequent partial termination events or direction changes. Only where an ice keel penetrates into the more resistive sediments of acoustic Unit B (O'Connor, 1980) is there evidence on the geophysical records, for a major change in sediment type. In the case of Scour N90-2, significant scour rise-up and a corresponding decrease in the scour depth occurred across an area where Unit A marine clays thinned and the keel cut into the more resistive Unit B sediments. A subsequent increase in Unit A thickness coincides with drop-down of the keel elevation and a 2.0 metre increase in scour depth. Nevertheless, if there are no significant changes in the seabed sediments, Stage 3 rise-up is characterised by similar scour base elevation and seabed elevation profiles, and a relatively constant scour depth.

The ultimate fate of a scouring ice keel depends on a number of factors, including; the direction and magnitude of the forces driving the scouring, the strength of the surrounding ice pack, and the internal integrity of the ice keel. If an ice keel is moving into deeper water during the final stages of scouring, the base of the keel will simply lift-off the seabed. If the scour driving forces decrease in magnitude during Stage 1 or Stage 2 scouring, and are insufficient to overcome the horizontal resistance to scouring, the ice ridge will become grounded. This may result in the formation of a temporary wallow pit, depending on whether or not there is a subsequent change in the magnitude or the direction of the driving forces.

Grounding of an ice ridge or partial termination of a scour event may also occur, independent of a decrease in the magnitude of the driving force, particularly during Stage 3 scouring. As progressive rise-up occurs during Stage 3, the vertical force on the seabed results in increasing horizontal resistance to scouring. Eventually, this resistance is great enough to result in partial scour termination or the grounding of the ice mass. In the case of partial scour termination, a portion of the ice keel is sheared off, effectively reducing or eliminating the resistive forces developed within the sediments. Alternatively, ice ridges become grounded upon failure within the surrounding ice pack. Whether excessive horizontal resistance results in partial scour termination or a grounding of the ice ridge may be dependent on the size of the ice ridge, the strength of the surrounding ice pack, and the integrity of the ice keel. For example, partial scour termination is likely in cases where the ice ridge is extremely large, the surrounding ice pack is relatively strong, and the ice keel is relatively weak. In contrast, if the surrounding ice pack is relatively weak, and the internal strength of the keel is high, grounding is more likely.

Table 4.3.5 Scour Rise-up Summary

	N90-1	N90-2	N90-3	N90-4	N90-5	N90-7	N89-1
Stage 1 Present	Yes[1]	Yes[2]	Yes	Yes	Yes?[5]	Yes	Yes
Length (km)	12.6	11.4	1.7	2.9	4.5	3.7	1.8
Water Depths (m)	29.5-33	48-53	19-20	24.5-26	27-29	29.5-32	52-55.5
Scour Depths (m)	1.3-3.6	2.2-6.8	0.8-1.3	3.5-5.2	0.0-2.9	0.8-2.8	1.7-5.0
Rise-up (m)	1.0[1]	0.4	0.0	0.0	0.9[3]	0.2	0.2
Stage 2 Present	No	Yes	Yes	No	No	Yes	Yes
Length (km)	-	0.9	5.6	-	-	2.6	1.1
Water Depths (m)	-	47-48	16.5-19	-	-	28-29.5	49.5-52
Scour Depths (m)	-	6.8-7.1	1.3-2.6	-	-	2.8-3.2	5.0-6.8
Rise-up (m)	-	0.7	1.2	-	-	1.2	0.6
Stage 3 Present	Yes	Yes	Yes	Yes	No	Yes	Yes
Length (km)	7.3	40.1	1.7	4.8	-	1.2	1.1
Water Depths (m)	29.5-28.5	41-48	16-16.5	20-24.5	-	27-28	48-49.5
Scour Depths (m)	2.7-3.6	5.5-8.5	1.0-2.6	4.5-5.5	-	2.7-3.2[4]	5.5-6.9[4]
Rise-up (m)	2.1	7.8	2.1	4.3	-	1.0[4]	2.6[4]
Stage 3 Modifications	Minor	Yes	Yes	Minor	-	Yes	Yes
Rise-up>Seabed Slope	Yes	Yes	Yes	No	No	Yes	Yes
Local Scour Drop-down	No	Yes	Yes	No	Yes	Yes	No
Rise-up At Direction Change	Yes	Yes	No	No	Yes	No	No
Scour Termination Evident	No	No	No	No	No	Yes	Yes
Change in Sediment Type	No	Yes	No	No	No	No	No

[1] Rise-up of 0.7 metres occurs across a major change in scour direction within Stage 1.

[2] Local rise-up/drop-down occurs within Stage 1 interval. However, there is very little net change in scour base elevation.

[3] Rise-up of 1.4 metres occurs across a major change in scour direction. Scour drops down 0.6 metres along eastern scour leg.

[4] Does not include rise-up across partial termination events in which part of the ice keel appears to have been sheared off the main ice floe. Rise-up, including that across the partial termination event, is 2.5 metres for Scour N90-7 and approximately 8.0 metres for Scour N89-1.

[5] Scour N90-5 was formed by an ice ridge which formed in situ. Since there is little variation in the scour base and the seabed elevations, it is difficult to ascertain whether Stage 1 or Stage 3 rise-up is active along this scour.

For any given scour, the predominant factors controlling the maximum scour depth are the physical properties of the sediments being scoured, the size of the ice ridge, and the shape or cross-sectional area of the ice keel. For a given sediment type, the greater the size of an ice ridge, and the smaller the ice keel-seabed sediment surface area, the deeper the maximum possible scour depth. The shape of the ice keel may also influence maximum scour depth. For example, a pinnacle protruding beneath the main portion of the ice keel, while not affecting the cross-sectional area of the ice keel within the sediments, would result in a deeper scour than would the same ice keel without the protruding ice pinnacle. Probably the most important factor in controlling maximum scour depth is the sediment type.

The forces driving the ice (wind, current, pack ice, etc.) ultimately determine whether or not Stage 3 of the scouring process occurs, but probably have little influence on the maximum possible scouring depth for a given ice ridge. That is, if the driving forces are insufficient to overcome the increasing horizontal resistance to scouring during Stages 1 and 2, the keel will ground prior to reaching its maximum possible scour depth. Once an ice keel progresses to Stage 3 scouring, driving forces will influence the total amount of scour rise-up, but will not result in significant increases in scour depth unless there is a significant change in the physical properties of the scoured sediments. The most pronounced scour depth variations observed within Stage 3 scouring in the present study are related to changes in the type of sediment being scoured.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 SUMMARY OF RESULTS

1. The ESRF 1990 field program was conducted from August 30 to September 17, 1990 aboard the C.C.G.S. Nahidik. A total of 1389.6 km of the regional repetitive mapping grid was surveyed using sidescan sonar, microprofiler, echo sounder and 3.5/7.0 kHz sub-bottom profiler. The ESRF 1990 survey grid was designed by CSR to provide repetitive coverage for previous surveys conducted from 1982 to 1989. An additional 7.8 km of survey data were collected during a small survey at the Tingmiark glory hole site. Detailed scour tracking surveys, designed to reveal along-track, process-related information over the entire length of individual scouring events, were conducted along six extreme ice scour events. This resulted in an additional 254.2 line kilometres of data, for a total of 1651.6 km for the entire survey.

2. A total of 2291 new scour events, formed over a one to eight year time interval, were identified on the 1390 line km of repetitive sidescan sonar coverage obtained during the ESRF 1990 survey data. Scour measurements and survey information were added to the new scour data base (NEWBASE) for each of these new scours. Extreme events, defined as scours with a depth of 2.0 metres or greater, account for approximately 3% of the new scours identified on the ESRF 1990 data.

3. The Beaufort Sea New Scour Database (NEWBASE) was updated to include the 2291 new scours identified during the 1990 ESRF survey, as well as, 1373 new scours recorded during the Tully 1988 survey and 783 new scours recorded during the Nahidik 1989 survey. The updated version of NEWBASE now contains 5329 geographically referenced scour events that have been recorded on repetitive mapping surveys conducted between 1978 and 1990. Each new scour record includes key scour parameters such as scour depth, width, orientation and water depth. New scour events recorded in NEWBASE occur in water depths ranging from 2 metres to 38 metres. Prior to the ESRF 1990 survey, new scours were observed in water depths up to 37 metres. Average and maximum scour depths recorded in NEWBASE are 0.57 metres (for all scours with a recorded depth of greater than 0.0 metres) and 4.0 metres, respectively. Average scour width is approximately 31 metres, with a maximum recorded scour width of 1281 metres.

4. One of the main highlights resulting from a preliminary exploration of the updated version of NEWBASE (N=5329) is the relationship between water depth and scour depth distribution. In water depths of less than 17 metres, more than 90% of the scour population have scour depths of less than 1.0 metres. In contrast, for water depths ranging from 18 to 30 metres, 20% to 40% of the scours (within any given 1.0 metre bathymetric interval) have scour depths of 1.0 metres or greater. Also, only 5 of 122 extreme scours (depths of 2.0 metres or greater) recorded in NEWBASE, occur in water

depths less than 17 metres, and none were recorded in water depths less than 13 metres. The keels of first year ice ridges are poorly consolidated, and most deep scours are thought to be formed by multi-year ice. The influx of deeper scours in water depths greater than 18 metres is probably related to a major boundary in the sea-ice regime, such as the seaward edge of landfast ice. The 18 metre contour may therefore mark the average landward limit of significant multi-year ice incursions within the transition zone.

5. In order to display and analyze the spatial distribution of the new scour data sets, CSR developed the Scour Information Processing System (SIPS) which is based on the Arc/Info GIS Platform. SIPS can be used to effectively analyze a single scour parameter, a sub-set within a parameter field, or a combination of scour parameters. Spatial scour distribution maps were constructed for all NEWBASE scour events, as well as, for the various sub-sets of the database, including; the sub-set of all recorded extreme scour events and sub-sets of new scours recorded during repetitive surveys conducted in 1988, 1989, 1990. These plots illustrate local, and regional, variations in the spatial and temporal occurrence of new scour events, and demonstrate the utility of the SIPS system. For example, clusters of new scour events with very similar orientations often occur. This suggests that numerous individual scours may be formed during a single scouring event. Scour clusters are especially apparent on the plot of ESRF 1990 new scour events. This is likely due to the fact that only one or two years have elapsed since many of the 1990 lines were previously surveyed. Typically, the largest scour clusters are dominated by scours which are less than 0.5 metres deep. However, the SIPS plot of the extreme scour data sub-set, shows that pairs and small clusters of extreme scour events (depths of 2.0 metres or greater) may also occur.

6. New scour impact rates, based on the sub-sets of new scours observed during the Tully 1988 survey (n=1373), the Nahidik 1989 survey (n=783), and the ESRF 1990 survey (n=2291), were calculated for survey line segments crossing 1.0 metre bathymetric intervals. The major factor controlling new scour impact rates is water depth. For the ESRF 1990 survey, most line segments in water depths less than 25 metres have impact rates exceeding 1.0 scours/km/yr, and many segments have impact rates exceeding 2.0 scours/km/yr. Impact rates generally drop-off in water depths greater than 25 metres, and seldom exceed 1.0 scours/km/yr in areas greater than 30 metres water depth. Significant local variations in impact rates were observed, especially along lines for which only one or two years have elapsed since the previous survey. These variations are likely caused by highly episodic scouring activity (i.e. scour clusters) that occurs on a yearly basis.

   Given that the majority of new scours observed to date are less than 1.0 metres deep, impact rates based on a sub-set of deeper scour events may be of greater use to design engineers. However, as the sub-set is limited to fewer and fewer scours events, the resultant impact rates become less well constrained. For the sub-set of extreme scours (depths of 2.0 metres or greater) recorded during the ESRF 1990 survey (n=72), the majority of line segments crossing 1.0 metre bathymetric intervals have an impact rate of 0.0 scours/km/yr. These values reflect the relative paucity of extreme scour events within this subset. Along line segments where extreme scour events were recorded, impact rates are commonly less than 1.0 scours/km/yr (i.e. one extreme impact along a line segment which is greater than 1 km long). Six survey line segments, in water depths between 19 and 30 metres, have impact rates greater than 1.0 scours/km/yr. The maximum observed impact rate for extreme scours is 2.02 scours/km/yr, calculated for a 0.99 km long line segment crossing the 20-21 metre bathymetric interval on the Kringalik Plateau.

7. Seven ice scours surveyed in 1989 and 1990 were analyzed in detail for the scour tracking portion of this project. Sidescan sonar, microprofiler, echo sounder and sub-bottom profiler data were collected along the length of each scour. The survey lines were run in a sinuous pattern, crossing over the scour at 0.5 to 1.0 kilometre intervals. The number of scour cross-overs recorded varied from 10 to 86, depending on the length of the scour being tracked. Key parameters such as scour depth, scour infill, scour width, berm size, bathymetry and scour base elevation were measured at each cross-over. Scour depth and scour rise-up profiles were constructed for each scour.

   Three stages of scour rise-up were observed along scours formed by ice keels which scoured into progressively shallower water depths. In Stage 1, the base of the scour remains at a constant elevation, and scour depth increases gradually as the ice keel scours into shallower water depths. During Stage 2, a typically short-lived transitional period of rise-up, the scour base elevation begins to rise-up, but at a rate less than the decrease in water depths such that scour depth continues to increase as the ice keel scours upslope. During Stage 3 scouring, the scour base elevation and seabed elevation rise-up at the same rate, and the scour depth remains relatively constant. The maximum depth to which an ice keel can penetrate the seabed is dependent on the physical properties of the seabed sediments, the size of the scouring ice mass, the surface area of the ice in contact with the seabed, and the shape of the ice keel. Scour N90-2, a 180-215 year old scour, is the deepest of the tracked scours, with a maximum observed scour depth (including 3.0 metres of sediment infill) of 8.5 metres. The maximum observed scour rise-up is 8.2 metres over a scour length of approximately 50 kilometres for Scour N90-2.

   A change in the physical properties of the seabed sediments may result in a significant change in the scour rise-up profile. Only where an ice keel penetrates into the more resistive sediments of acoustic Unit B (O'Connor, 1980), do the geophysical records collected in 1990 provide evidence for such changes in sediment properties. In the case of Scour N90-2, significant scour rise-up and a corresponding decrease in the scour depth occurred across an area where Unit A marine clays thinned and the keel cut into the more resistive Unit B sediments. A subsequent increase in Unit A thickness coincides with drop-down of the keel elevation and a 2.0 metre increase in scour depth. Less pronounced variations in scour rise-up and scour depth profiles may result from; local variation in the physical properties of Unit A sediments (not resolved on acoustic data), tidal and/or storm surge related variations during scouring, or a change in scouring direction.

Average scour width values increase slightly along the length of a scour, as scour depth increases. However, the most pronounced variations in width measurements are associated with scour direction changes along multi-keeled scours. Significant width variations are also associated with the onset of scouring by one or more additional ice keels as a multi-keeled ice ridge scours into shallower water depths. Local variations in berm size are influenced by the pre-scouring seabed morphology. Berm size increases as the scour cuts across local bathymetric highs, such as the berms of older scours, and decreases as the scour cuts less deeply across local bathymetric lows (i.e. the base of older scours). Scour berms may be severely modified, and in some cases, completely obliterated, along portions of scours which are cut by numerous younger cross-cutting scours.

8. A model has been presented which illustrates sediment infill deposits that were profiled within the base of infilled scours. Three types of acoustically-distinct infill deposits are described in the model; stratified sediments, acoustically transparent/opaque (non-stratified) sediments, and mounded cross-cut sediment piles (CCSP). The stratified sediment infill typically overlies the acoustically transparent sediments where both types of infill were observed. At cross-overs where CCSP debris was observed, it occurs randomly within the infill sequence. The thickness of the sediment infill sequence ranged from 0.1 metres to 3.0 metres, depending on the age of the scour profiled. The Klein 100 kHz microprofiler provided high resolution profiles of scour infill, as well as, detailed records of seabed/scour morphology. As such, the microprofiler was an extremely valuable addition to the survey, and should be incorporated into future surveys.

5.2 RECOMMENDATIONS

1. Additional data currently exists which have not been analyzed for new scour events. This includes scour tracking data, where younger scours cross-cut some of the tracked scours of known age, as well as, new scours present along the outlier survey lines shot along the proposed Amauligak pipeline route. New scours identified on these lines should be measured and included into NEWBASE.

2. The repetitive mapping grid should be surveyed again in 1996 or 1997. Another survey would increase the size of the extreme scour population for more reliable statistical and GIS analyses, and provide longer term average

scour impact rate information. The longer the time interval between surveys, the greater the likelihood of superimposed new scours, and loss of new scour data, especially in heavily scoured areas. The episodic nature of the scouring process is also lost as the time interval between surveys increases. In this regard, consideration should be given to surveying a small portion of the grid on a yearly basis.

3. A major GIS spatial analysis study is recommended to achieve a better understanding of the scour process, in terms of all the environmental parameters. Such parameters should include; sediment type and thickness, geotechnical borehole data, seabed slope, ice zonation data, and oceanographic information, such as current and ice trajectories. At present, Canadian Seabed Research Ltd. has used the SIPS GIS-platform to conduct spatial analyses of scour depth distribution and scour impact rates. These analyses, while valuable, do not fully utilize the analytical capabilities of GIS systems. Additional information coverages would provide more comprehensive modelling and analysis capabilities. The upgraded system would help model scour occurrence in terms of controlling environmental factors, and ultimately predict the return rates of scours with extreme dimensions in different spatial locations.

4. The frequency of new scour events is one of the most critical factors to be considered in designing sub-sea installations. Scour impact rates (scours/km/yr) calculated for a single year (i.e. along lines surveyed in successive years) generally display a greater local variability, and often include the highest observed values within a given area, compared to those averaged over a number of years (i.e. 4 or more years between repetitive surveys). We recommend that NEWBASE be used to calculate both the long-term average and the extreme yearly impact rates along each of the survey corridors.

5. The scour tracking surveys conducted during the ESRF 1990 survey have provided important scour process information. This information should provide useful constraints to future scour modelling research. Detailed scour tracking surveys should be continued in conjunction with future repetitive mapping surveys. Emphasis should be placed on scours with extreme depths and known age, and should include scours on the Tingmiark plain where the surficial marine clays are thin or absent. If possible, it would also be useful to identify and track scours formed by an ice keel/ridge of known size and magnitude.

6. The potential for scour drop-down into an open pit or trench is of concern to designers of sub-sea installations such as pipelines. Younger scours were observed cross-cutting six of the seven scours examined in the scour tracking portion of this project. Preliminary observations made during the scour tracking study indicate that most younger scours only cut the berms and push debris into the scour base of the tracked scours. However, a significant number of cross-cutting scours appear to have scoured right across the scour

base, indicating possible scour drop-down. Up to three metres of scour drop-down across bathymetric depressions has been observed by Myers (1994), in a scour study conducted off Cornwallis Island. A systematic study of the existing scour tracking data should be undertaken to determine whether cross-cutting scours actually drop-down into the base of the tracked scours and, if so, under what conditions drop-down occurs.

7. Preferential deposition at the base of scours during specific storm-related events is proposed as one probable mechanism for the sediment infill observed within older scours. In this regard, a study of scour infill is recommended. Existing data should be examined to recognize common markers or patterns within the sediment infill sequences. Such patterns should be present regionally if sediment infill is, in fact, related to storm-events. Scours with well-defined sediment infill could be selected for a geological/geotechnical coring program to determine the origin of each type of acoustically-identified sediment infill. A repetitive survey of one of the existing tracked scours following a major storm could also help to define the extent of storm-related infilling.

8. New scour impact rates for water depths greater than 38 metres are presently extrapolated from results in shallower water depths where new scour events have actually been observed. Scour N90-2 (estimated to have formed 180-215 years ago) has been tracked in water depths of 41 to 53 metres. The frequency of younger scours which cross-cut N90-2 varies along the length of the scour from 4.0 scours/km (49-53 metres water depth), to 11.0 scours/km (41-43 metres water depth). Methods for precise age dating of this scour should be examined. This would provide long-term scour impact rates for deeper water areas of the Beaufort Sea where, to date, no new scours have been observed by repetitive mapping techniques. Alternatively, longer repetitive mapping corridors established in the 40 to 50 metre water depth range may eventually record sufficient new scour impacts to establish rescour rates in deeper water.

9. Repetitive mapping data could be examined for maximum end member years (i.e. 1984-1990) to determine acoustical change as a function of scour degradation, thereby establishing a relationship between scour age and acoustic signature that could be utilized in previously unsurveyed areas.

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APPENDIX 1

NEWBASE AND NNAVBASE; DATA BASE DESCRIPTIONS

FORMAT: NEWBASE

Total Number of Records 5329
Total FOXBASE Space 928,496 Bytes

FIELD	NAME	TYPE	WIDTH / DECIMAL
1	Comp	Character	4
2	Year	Numeric	3
3	Line	Character	5
4	Opart	Numeric	3
5	Fix	Numeric	7.1
6	Head	Numeric	4
7	East	Numeric	7
8	North	Numeric	8
9	Orient	Numeric	4
10	Form	Numeric	2
11	Morph	Numeric	2
12	Smooth	Numeric	2
13	Mage	Numeric	2
14	Len	Numeric	6
15	Wid	Numeric	4
16	Area	Numeric	7
17	Inwid	Numeric	4
18	Inwidql	Character	2
19	Mknum	Numeric	2
20	Mkwid	Numeric	4
21	Depth	Numeric	4.1
22	Sbp	Numeric	3
23	Sfill	Numeric	4.1
24	Ssdef	Numeric	3.1
25	Sthk	Numeric	5.1
26	Stype	Character	3
27	Bathy	Numeric	4
28	Qual	Character	2
29	Pdepth	Numeric	4.1
30	Duyear	Numeric	3
31	Pcomp	Character	4
32	Pyear	Numeric	3
33	Source	Character	2
34	Comments	Character	23

PARAMETER DESCRIPTIONS: NEWBASE

FIELD NAME DESCRIPTION

1) COMP COMPANY

Reference name for each major data set. Refers to the company/institution funding the survey or the name of the survey vessel. Identifiers contained in this field are:

Govt - 78 data
Dome - 81 data
Esrf - Environmental Studies Revolving Funds 1984
Ty85 - Tully 85 EMR data
Ty86 - Tully 86 EMR data
Emr - EMR 84 & 85 comprised of Banksland 84 & Tully 85 data for the Yukon Shelf. (Processed by Shearer)
Ty88 - Tully 88 data
Na89 - Nahidik 1989
Esrf - Environmental Studies Research Funds 1990

2) YEAR

The year of data acquisition.

3) LINE

Identifies the survey line. Most identifiers are numeric. The occasional alphanumeric identifiers usually indicate that the original line was aborted and re-shot due to poor weather, equipment malfunctions, or ice conditions. The alphanumeric notation retains the relationship between these lines. In 1990's data an example of this would be lines 43 and 43B.

4) OPART OVERLAP PART

This parameter refers to the sections of the current year's data that overlaps completely with previous surveys, for comparison and identification of new scours. An opart value is assigned to navigation where overlap occurs. Opart values increment as overlap breaks and then is re-established. The most common reasons for breaks in comparison, or opart, is poor data quality from the previous year, bad weather, equipment paper changes or diversion from course due to ice or islands. Breaks, due to paper changes, of less than 500 meters have not been used to determine opart.

5) FIX

Indicates the reference fix location from which the scour co-ordinates are derived. Fix numbers for new scours are taken at the midpoint of the scour where it crosses the ships path or the closest location for scours that do not cross the path. Measurements made from sidescan sonar records to the nearest one-tenth of a fix. For the original ESRF data, fix is taken at the "left-most" position of each scour. Fixes recorded in time were changed to cumulative minutes that keep accumulating after 2400 hours.

DATA	FIX TYPE
ESRF 84	Numeric
EMR 84	Numeric
TY85 85	Time
EMR 85	Time
TY86 86	Time
TY88 88	Numeric
NA89 89	Numeric
ESRF 90	Numeric

6) HEAD HEADING

General value for the ship's heading obtained from navigation plot. The heading may change several times along a survey line. Exact heading values can be calculated using northing and easting positions.

7,8) EAST, NORTH EASTING, NORTHING

Precise UTM scour position as calculated from the decimal FIX value in data field 5. UTM's for new scour locations are interpolated from fix locations utilizing Navbase information. Yukon Shelf data was measured manually from the track plot while original ESRF 84 data was interpolated from navigation files. All data is referenced to UTM zone 8 (central meridian 135 degrees longitude).

9) ORIENT ORIENTATION

Scour orientation value referenced to true north and expressed, by convention, between 0-179 degrees inclusive. This value was measured manually from data for all previous surveys with the exception of ESRF 84 where the data was measured digitally. Scour orientation is determined by establishing a best fit line (chord) that joins the two termini of the observed scour feature. The orientation value is measured in degrees relative to True North; and recorded, with an accuracy of +/- 5.0 degrees, as a number ranging from 0 to 179 degrees. It is also important to note that the orientation value infers no actual directionality of ice movement.

10) FORM

Type of scour. Determined manually from data sets.

1 - Single keeled scour
2 - Multi keeled scour
3 - Zone of multi-keels...used when it is not possible to isolate separate events.

11) MORPH MORPHOLOGY

Shape of scour in plan view. Determined manually from sidescan sonar records.

4 - Linear scour
5 - Arcuate or Curved Scour
6 - Sinuous Scour changes orientation more than once.

12) SMOOTH SMOOTHNESS

Smoothness is highly subjective description based on the sharpness of acoustic returns which may vary dependant on; angle of scour sonification, data quality, water depth and sediment type.

7 - Very rough: opaque reflectance from scour floor with sharply defined berm walls. This value may relate to the most recent scour events.

8 - Rough: strong acoustic signature, evidence of rubble on berm or in scour.

9 - Moderately smooth.

10 - Very smooth: reduced signal contrast, no rubble, often infilled.

13) MAGE MAXIMUM AGE

This refers to the maximum scour age in years as determined by time lapsed since the previous repetitive scour mapping survey.

14) LEN LENGTH

Scour length as measured manually along scour's longest axis. Scour length unfortunately is limited to the range of the side scan system and therefore is of limited value.

15) WID WIDTH

Scour width is measured manually from sidescan sonar records and represents an average value of the distance between the tops of the berms, perpendicular to the long axis of the scour. Estimated measurement accuracy of +/- 5 metres.

16) AREA

Scour area is calculated by scour length times scour width. Area for original ESRF 84 data was computed as the polygonal area of the digitized scour points.

17) INWID INCISION WIDTH

Scour incision width is measured manually from the data as an average value between the inner edges of the scour at the approximate level of the seabed as if it had been unscoured. Estimated accuracy of +/- 5 metres.

18) INWIDQL INCISION WIDTH QUALITY

A subjective description of the quality of the incision width measurement.

19) MKNUM MULTI KEELED NUMBER

This field is used by the interpreter to link together new scour events that are not conclusively one event but may be related, and therefore warrant further investigation. Values assigned to these related events are only unique to each line, therefore these same values may appear on other lines.

20) MKWID MULTI KEELED WIDTH

This field is used in conjunction with MKNUM and records the total width of the related scour events. The width value will be the same for each related event.

21) DEPTH SCOUR DEPTH

For ESRF 90 this value was obtained from microprofiler data that provided a more accurate scour depth value. Previous to ESRF 90 depths were measured from echo sounder data. An effort has been made to update the majority of the previously recorded new scour depths from ESRF 90 data because of the increased accuracy of the microprofiler. This was felt justified in light of the importance the scour depth parameter plays in the design of sub-sea pipelines. Accuracy of scour depth measurement is dependant on the pick of the smoothed seabed datum. Estimated accuracy of +/- 0.25 metres.

22) SBP SUB BOTTOM PROFILER

SBP refers to the type of instrument utilized in recording the data from which depth measurements were taken.

1 - sub-bottom profiler
2 - echo sounder
3 - echo sounder on third channel
4 - no echo sounder or sub-bottom profile available
5 - microprofiler

These numbers may be prefixed by 1 (eg. 15). This code indicates that a scour cuts the ship's path, thus has been sampled by the profiling device and therefore has the potential to record a measurable scour depth.

23) SFILL SEDIMENT INFILL

Records the thickness of scour infill in 0.5m intervals as measured from micro profiler and third channel sub-bottom profile data. It should be noted that echo sounding devices mounted in the side scan fish, such as those used prior to ESRF 90, will not likely not reveal sediment infill values due to lack of penetration.

24) SSDEF SUB-SCOUR DEFORMATION

Records the depth of the of sub-scour disruption of stratigraphy. This parameter is highly speculative at present and therefore is rarely input. Apparent sub-scour disruption of continuous beds may result from acoustic focusing/unfocusing of seismic energy. Note this is only recognizable on sub-bottom profiler records in areas where the scoured sediments are stratified.

25) STHK SEDIMENT THICKNESS

Thickness of surficial sediment to the Unit C unconformity. Most values are based on a map published by O'Connor (1982). Values are input to 10.0m only, therefore thickness greater than 10 metres are referenced by 10.0 in the data base. Unknown values where data is unavailable or as yet not interpreted are referenced as 99.0.

26) STYPE SEDIMENT TYPE

Sediment type is interpreted from acoustic data sets and site interpretation reports.

C - Clay
S - Sand
SI - Silt
CS - Clay over Sand

27) BATHY BATHYMETRY

Water depth is derived from overlaying navigational data with a digital bathymetric map with values at one metre intervals. Coded at one metre intervals, according to the larger water depth value for each interval (i.e. Code 23 represents 22-23 metre interval)

28) QUAL DATA QUALITY

A subjective description of general data quality which may vary dependant on weather conditions and equipment malfunctions.

G - Good
F - Fair
P - Poor

29) PDEPTH PREVIOUS DEPTH

This field is used retain the previous depth measurement of any scour that has had it's depth updated using microprofiler records. Scours that were new prior to ESRF 90 and not updated will have no value entered in this field.

30) DUYEAR DEPTH UPDATE YEAR

Should a scour depth be updated the year of update would be listed in this field.

31) PCOMP PREVIOUS COMPANY

PCOMP identifies the previous company/survey used as a baseline for the present survey. This value may change on a line to line basis or during a line depending on the coverage of the present survey.

32) PYEAR PREVIOUS YEAR

PYEAR indicates the year of the previous survey being used for comparison with the current survey. This information is used to determine maximum scour age.

33) SOURCE DATA SOURCE LOCATION

SOURCE identifies whether the repetitive mapping information has been ascertained from a mosaic site area, or one of the regional corridor location on the Beaufort Shelf.

M - Mosaic
C - Corridor

34) COMMENTS

Comments pertaining to anomalies appearing on the data sets which are of interest (i.e. sand bodies, pingos, gas seeps, etc.) or which hamper the scour measurements. Abbreviations used in commenting on scours are:

PSDD	- Poor scour depth definition
PSDW	- Poor scour definition width
PSDL	- Poor scour definition length
PSD	- Poor scour definition
IN/OUT	- Scour travels in and out
TERM.	- Termination visible
X-SCOUR	- Depth measurement obscured by another scour
NOISE	- Surface noise that degrades data quality

FORMAT: NNAVBASE

TOTAL # of records = 13802
TOTAL FOXBASE SPACE = 0.93 megabytes

FIELD	FIELD NAME	TYPE	WIDTH
1	COMP	Character	4
2	YEAR	Numeric	3
3	LINE	Character	5
4	ESPART	Character	2
5	SSPART	Character	2
6	FIX	Numeric	5
7	EAST	Numeric	7
8	NORTH	Numeric	8
9	BATHY	Numeric	4
10	REGION	Character	3
11	ORIGIN	Character	3
12	COMMENT	Character	20

TOTAL FORMAT LENGTH = 66

PARAMETER DESCRIPTIONS: NNAVBASE

FIELD NAME	DESCRIPTION	DATA TYPE (WIDTH)
1) COMP	COMPANY	Character (4)

The operator who collected the field data, or the name of the vessel used during the survey. The company parameters are listed as follows:

GOVT	Government Research Cruise
DOME	Dome Petroleum Ltd.
ESRF	Environmental Studies Revolving Funds (1984)
NAHI	1986 Nahidik Survey
TY86	1986 Tully Survey
TY88	1988 Tully Survey
NA89	1989 Nahidik Survey
ESRF	Environmental Studies Research Funds (1990)

2) YEAR YEAR Numeric (3)

Year of data acquisition. Range 1978-1990

3) LINE LINE Character (5)

Survey line number.

4) ESPART ECHO SOUNDER PART NUMBER Character (2)

Not utilized in NNAVBASE.

5) SSPART SIDE SCAN SONAR PART NUMBER Character (2)

Records the exact location of overlap between repetitive survey line data. If one line or the other is broken for any reason (eg. data quality) this break will be reflected by a blank part number in the SSPART field. When complete overlap is restored, the successive part number will record the exact fix and UTM position where this occurs.

6) FIX REFERENCE FIX MARK Numeric (5)

The reference shot number. Most data types have sequential increments of whole numbers with the exception of Government surveys where fixes were in time. These data are converted to cumulative minutes. Distance increments vary with type of survey and navigation equipment used.

7,8) EAST, NORTH EASTING AND NORTHING Numeric (7,8)

The x,y position of each fix position expressed in the Universal Transverse Mercator system. Data collected in Latitude/Longitude has been changed using conversion software. All positions are in Zone 8, which is based on a Central Meridian of 135 degrees West. Note that with the extension of this coordinate system into the two adjoining zone, errors of scale increase.

9) BATHY BATHYMETRY Numeric (4)

The charted water depth corresponding to the position of that record, to the nearest meter. Note that this is derived from corrected Hydrographic charts, and therefore may differ from ECHOBASE or SCOURBASE values for that same fix. There are duplicate records in NNAVBASE containing bathymetry values which differ by 1m (eg. 39m and 40m), which are used to delimit bathymetry contour crossover points.

10) REGION PHYSIOGRAPHIC AREA Character (3)

Physiographic area in the Beaufort Sea as defined by O'Connor (1982). Codes for the different areas are as follows:

AK - Akpak Plateau
BA - Baillie Plain
IK - Ikit Trough
KR - Kringalik Plateau
KU - Kugmallit Channel
MA - Mackenzie Trough
NI - Niglik Channels
TI - Tingmiark Plain
YU - Yukon Shelf

When a survey line crosses a border of one of these areas, duplicate records are placed in NAVBASE. These can be identified by the comment ' AREA BORDER' in the COMMENT field.

11) ORIGIN ORIGIN OF DATA Character (3)

Original source of the navigation data corresponding to each record in the data file. Codes for the different origins are as follows:

NT - Navigation tape.
TP - UTM positions derived manually from trackplot.
DC - Fix and UTM position digitized from trackplot.
E - Fix and UTM position taken directly from ECHOBASE.
S - Fix and UTM position taken directly from SCOURBASE.
XS - UTM positions extrapolated from SCOURBASE records.
XE - UTM positions extrapolated from ECHOBASE records.
I - UTM positions extrapolated from NAVBASE records.

12) COMMENT	COMMENT	Character (20)

Comments pertinent to NAVBASE. Commonly used comments are:

xx RECORDS USED - This indicates that the position of that record was extrapolated from ECHOBASE or SCOURBASE, with the number of records used to form a least-squares line for the extrapolation (see section on Extrapolation/Interpolation).

AREA BORDER - This comment indicates the position of the survey line where it crosses an area border.

APPENDIX 2

SCOUR PARAMETER TABLES
SCOUR TRACKING STUDY

SCOUR N89-1
SCOUR PARAMETER TABLE

FIX	KP: DIST ALONG SCOUR (Km)	DEPTH TO TOP OF INFILL (A)	BATHY (B)	INFILL (C)	DEPTH TO BASE OF INFILL (A+C)	SCOUR DEPTH TO TOP (A-B)	SCOUR DEPTH TO BASE (A-B+C)	SCOUR WIDTH	INCISION WIDTH	NORTH BERM WIDTH	SOUTH BERM WIDTH	NORTH BERM HEIGHT	SOUTH BERM HEIGHT
MAJOR SCOUR (KEEL A)													
251.6	0.23	57.2	55.5	2	57.2	1.7	1.7	20	10	15	5	1	<1
253.9	0.62	57.0	54.4	2	57.0	2.6	2.6	35	15	20	8	2.5'	<0.5
242.6	0.89	57.0	54.1	2	57.0	2.9	2.9	40	18	20	8	1.2	0.6
233.0	1.31	57.1	53.1	2	57.1	4.0	4.0	40	20	20	8	1.2	0.6
225.0	1.82	57.0	52.0	2	57.0	5.0	5.0	40	23	30	8	4.5	0.9
218.8	2.48	56.5	50.3	2	56.5	6.3	6.3	55	25	40	8	3.3	1.8
211.1	2.89	56.4	49.6	2	56.4	6.8	6.8	70	30	45	10	3.5	1.2
199.5	3.27	56.1	49.2	2	56.1	6.9	6.9	65	30	35	10	3.2	1.4
190.0	3.85	53.5	48.0	2	53.5	5.5	5.5	65	25	40	10	3.2	2.1
177.1	4.11	-	-	-	-	0.3	-	25	20	<5	<5	<1	<1
MINOR SCOUR (KEEL B)													
234.5	1.34	53.8	53.5	0	53.8	0.3	0.3	10	5	<5	<5	<1	<1
224.3	1.77	53.9	53.0	0	53.9	0.9	0.9	10	5	<5	<5	<1	<1
220.2	2.36	53.8	52.0	2	53.8	1.8	1.8	25	10	<5	<5	<1	<1
209.6	2.98	53.7	50.5	2	53.7	3.2	3.2	20	10	<5	<5	<1	<1
201.7	3.58	51.6	49.5	2	51.6	2.1	2.1	25	10	<5	<5	2	<1
188.6	3.82	51.3	49.3	2	51.3	2.0	2.0	20	10	<5	<5	<1	<1
179.0	4.23	0.0	0.0	1	0.0	0.0	0.0	15	10	<5	<5	<1	<1
163.7	4.72	49.8	48.7	2	57.1	1.1	1.1	15	10	<5	<5	<1	<1

SCOUR N90-1 (KEEL A)
SCOUR PARAMETER TABLE

FIX (KEEL A)	KP: DIST ALONG SCOUR (Km)	DEPTH TO TOP OF INFILL (A)	BATHY (B)	INFILL (C)	DEPTH TO BASE OF INFILL (A+C)	SCOUR DEPTH TO BASE (A-B)	NORTH BERM WIDTH	SOUTH BERM WIDTH	NORTH BERM HEIGHT	SOUTH BERM HEIGHT	SCOUR DIRECTION
7078	0.43	34.3	33.0	0.0	34.3	1.3	5	5	0.9	-	125
7067	1.48	34.3	32.5	0.0	34.3	1.8	5-10	5-10	-	0.9	125
7059	2.05	34.0	32.0	0.0	34.0	2.0	10-15	10-15	2.4?	1.6?	125
7054	2.65	34.1	32.0	0.0	34.1	2.1	-	-	-	1.9	125
7051	2.95	33.6	32.0	0.0	33.6	1.6	5-10	15-20	1.8	-	125
7036	2.88	34.2	31.8	0.0	34.2	2.4	15-20	15-20	1.6	1.0	250
7032	3.33	33.5	31.5	0.0	33.5	2.0	15-20	10-15	2.5	2.3	250
7025	4.01	33.5	31.0	0.0	33.5	2.5	5-10	10-15	-	2.0	250
7016	4.90	33.5	31.1	0.0	33.5	2.5	5-10	10-15	-	2.2	280
7009	5.60	33.6	31.0	0.0	33.6	2.6	-	10-15	2.3	1.0	280
7001	6.36	33.2	31.0	0.0	33.2	2.1	-	15-20	1.1	2.1	280
6996	6.96	33.4	31.0	0.0	33.4	2.4	-	15-20	-	1	280
6986	7.76	33.3	31.0	0.0	33.3	2.3	5-10	10-15	-	1	245
6980	8.38	33.3	31.0	0.0	33.3	2.3	15-20	15-20	-	1	245
6971	9.23	33.3	30.5	0.0	33.3	2.8	5-10	15-20	-	1.5	245
6962	10.10	33.1	30.5	0.0	33.1	2.6	5-10	15-20	-	1.8	245
6952	11.09	33.3	30.5	0.0	33.3	2.8	10-15	15-20	2.4	2	245
6947	11.60	33.3	30.0	0.0	33.3	3.3	15-20	15-20	-	2.9	220
6942	12.06	33.3	30.0	0.0	33.3	3.3	5-10	15-20	-	2.6	220
6936	12.63	33.1	29.5	0.0	33.1	3.6	5-10	20-25	3	2.2	220
6929	13.25	32.3	29.0	0.0	32.3	3.3	10-15	15-20	1	1.8	220
6906	13.25	32.3	29.2	0.0	32.3	3.0	5-10	20-25	3.0	2.3	270
6898	14.01	32.0	29.3	0.0	32.0	2.7	10-15	15-20	-	1.9	270
6891	14.65	32.3	29.4	0.0	32.3	2.9	15-20	15-20	1.9	2.7	270
6882	15.55	32.2	29.5	0.0	32.2	2.7	5-10	15-20	1.5	2.5	270
6875	16.23	32.2	29.5	0.0	32.2	2.7	5-10	25-30	1.4	1.6	270
6866	17.08	32.2	29.3	0.0	32.2	2.9	5-10	15-20	0.9	1.4	240
6862	17.50	32.0	29.0	0.0	32.0	3.0	5-10	15-20	-	2	240
6856	18.08	31.6	28.5	0.0	31.6	3.1	5-10	15-20	1.6?	1.0	240
6849	18.75	31.2	28.5	0.0	31.2	2.7	5-10	15-20	-	2.2	240
6737	19.00	31.3	28.5	0.0	31.3	2.8	5-10	5-10	1.8	2.6	240
7093	19.50	31.1	28.4	0.0	31.1	2.7	5-10	5-10	1.7	2.0	190
7112	19.75	31.2	28.5	0.0	31.2	2.7	-	10-15	1.7	2.2	190

SCOUR N90-2
SCOUR PARAMETER TABLE (part 1 of 2)

FIX	KP DIST ALONG SCOUR (Km)	DEPTH TO TOP OF INFILL (A)	BATHY (B)	INFILL (C)	DEPTH TO BASE OF INFILL (A+C)	SCOUR DEPTH TO TOP (A-B)	SCOUR DEPTH TO BASE (A-B+C)	SCOUR WIDTH	INCISION WIDTH	NORTH BERM WIDTH	SOUTH BERM WIDTH	NORTH BERM HEIGHT	SOUTH BERM HEIGHT	ANGLE	COMMENTS
NORTHERN SCOUR LEG															
6682	0.00	54.5	53.0	0.7?	55.2	1.5	2.2	20	15	15	10	2.0	1.0	10	
6672	0.88	54.8	52.5	0.6	55.4	2.3	2.9	30	20	30	15	0.5	0.5	23	
6658	2.24	54.4	52.5	0.8?	55.2	1.9	2.7?	30	25	30	5	1.5	0.5	18	MINOR CCSP
6650	2.94	54.6	51.0	0.8?	54.4	3.6	4.4?	30	20	20	30	0.8	1.0	45	
6624	5.24	52.6	49.5	1.2	53.8	3.1	4.3	60	40	30	25	2.0	0.5	23	MINOR CCSP
6610	4.58	52.5	49.5	1.0	53.5	3.0	4.0	30	20	30	0	1.5	0.7	85	MINOR CCSP
6604	5.18	53.3	49.5	0.5?	53.8?	3.8	4.3?	45	30	30	30	1.5	1.8	29	
6595	6.00	53.4	50.0	1.4	54.8	3.4	4.8	50	30	45	40	3.0	2.6	30	
6592	6.28	52.6	50.5	?	?	2.1	?	40	20	20	40	4.0	1.5	59	MINOR CCSP
6580	7.52	51.8	50.0	?	?	1.8	?	45	20	20	30	2.0	1.4	62	MAJOR CCSP
6571	8.34	51.2	50.0	1.8*	53.0*	1.2	3.0	45	30	15	30	1.4	0.4	81	MAJOR CCSP
6562	9.20	53.0	50.0	1.5	54.5	3.0	4.5	45	30	30	20	1.5	1.3	23	
6555	9.84	53.6	50.5	1.5	55.1	3.1	4.6	45	30	20	25	0.4	1.4	~30	
6553	10.00	53.6	50.5	1.5	55.1	3.1	4.6	45	35	30	30	0.3	1.5	<10	
6539	11.36	53.8	48.0	1.0	54.8	5.8	6.8	55	35	30	20	1.5	1.8	13	
6529	12.28	52.8	47.0	1.3	54.1	5.8	7.1	60	35	30	30	1.1	2.2	50	
6522	12.88	51.3	47.0	0.5?	51.8?	4.3	4.8	40	30	30	30	1.2	0.9	85	
6515	13.48	52.3	46.5	0.7?	53.0?	5.8	6.5	60	35	50	20	3.2	2.5	65	
6510	13.96	51.2	46.0	1.1	52.5	5.2	6.5	50	35	30	30	2.0	3.0	28	
6501	14.80	50.8	45.5	0.8	51.8	5.3	6.3	60	30	45	15	2.5	2.0	48	
6496	15.28	50.4	45.5	0.7?	51.1?	4.9	5.6	60	40	30	40	1.5	2.0	15	
6484	16.48	50.4	45.0	1.2	51.6	5.4	6.6	70	45	30	45	1.4	2.0	106	
6473	17.56	51.5	46.0	2.0	53.5	5.5	7.5	60	45	45	35	2.0	3.0	15	
6460	18.78	50.8	45.5	0.8*	51.6*	5.3	6.1	60	45	45	30	2.5	1.2	99	PARTIALLY COVERED BY FIX MARK
6451	19.68	51.2	46.0	2.0	53.2	5.2	7.2	60	45	60	60	1.8	3.2	17	
6443	20.44	51.2	46.0	2.2	53.4	5.2	7.4	70	45	45	45	2.0	2.8	15	
6433	21.44	51.5	46.0	2.2	53.5	5.5	7.7	60	40	40	40	1.5	1.8	8	
6425	22.28	51.8	46.5	0.8*	52.6*	5.3	6.1	60	45	35	50	2.5	2.5	48	PARTIALLY COVERED BY FIX MARK
6412	23.40	51.8	46.5	0.8*	52.6*	5.3	6.1	60	45	45	30	3.5	1.5	29	PARTIALLY COVERED BY FIX MARK
6404	24.04	52.5	46.5	1.5	54.0	6.0	7.5	75	45	40	45	2.0	3.0	25	
6395	25.00	52.4	46.5	1.2?	53.6	5.9	7.1	70	35	45	45	2.5	2.0	19	
6372	27.20	52.0	46.0	1.2	53.2	6.0	7.2	70	40	35	35	1.5	0.0	<10	
6239	28.20	51.2	45.5	0.8	53.2	5.7	6.5	70	45	45	30	1.3	3.0	130	CCSP
6362	28.20	51.0	45.5	1.5	53.0	5.5	7.0	70	45	40	30	3.0	2.0	115	
5891	28.68	49.3	45.5	1.8?	51.1	3.8	5.6?	45	30	20	25	-	-		CCSP, DEPTH FROM M. PROFILER
SCOUR LOOP SEGMENT															
6355	28.88	48.1	45.0	?	?	3.1	?	-	35	-	-	-	-		CCSP
6352	29.28	49.2?	45.0	-	49.2	4.2?	?	50	35	25	25	1.8	1.8	019	DISC. E/S; POSS. CCSP
5862	29.64	51.0	45.5	0.6	51.6	5.5	6.0	45	30	15	25	-	-	019	POOR E/S, POSS. CCSP
6229	29.84	48.2	45.5	?	?	2.7	?	-	-	-	-	-	-	019	MAJOR CCSP (NO PENETRATION)
6155	29.88	50.0	45.0	-	50.0	5.0	5.0	-	35	?	30	?	2.8	019	POOR BATHY; POSS. CCSP
5884	29.88	49.6	45.0	?	?	4.6	?	55	35	20	30	3.0	1.6	019	CCSP
6314	30.04	52.0	45.5	?	?	7.0	?	-	-	-	-	-	-	019	
6274	30.15	51.4	45.5	-	51.4	5.9	5.9	55	35	25	30	1.2	2.0	019	

SCOUR N90-2
SCOUR PARAMETER TABLE (part 2 of 2)

FIX	KP DIST ALONG SCOUR (Km)	DEPTH TO TOP OF INFILL (A)	BATHY (B)	INFILL (C)	DEPTH TO BASE OF INFILL (A+C)	SCOUR DEPTH TO TOP (A-B)	SCOUR DEPTH TO BASE (A-B+C)	SCOUR WIDTH	INCISION WIDTH	NORTH BERM WIDTH	SOUTH BERM WIDTH	NORTH BERM HEIGHT	SOUTH BERM HEIGHT	ANGLE	COMMENTS
6338	30.28	48.8	45.5	?	?	3.3	?	50	35	25	30	1.0	2.7	019	MAJOR CCSP
6176	30.36	50.0	45.5	0.9*	50.9	4.5	5.4	-	-	-	-	-	-	119	MINOR CCSP
6340	30.44	51.5	45.5	0.6*	52.1	6.0	6.0*	75	50	30	15	?	0.7	119	SCOUR DEPTH FROM M. PROFILER
6311	30.64	51.3	45.5	?	?	5.8	?	-	-	-	-	-	-	170	
6271	30.70	51.4	45.5	0.7?	51.4	5.9	6.6?	80	50	35	35	1.9	1.7	170	PARIALLY COVERED BY FIX MARK
6174	30.76	50.9	45.5	1.2?	51.4	5.4	6.0	80	50	35	35	2.5	?	170	
SOUTHERN SCOUR LEG															
5883	30.96	51.6	45.5	?	51.6?	6.1	6.1?	60	40	25	30	?	?	241	POOR BATHY, S.B.P. OFF RECORD
6227	31.04	51.2	45.5	0.7	51.9	5.7	6.4	60	40	30	45	1.5	1.8	241	MINOR CCSP INFILL
6154	31.12	49.6	45.0	?	?	4.6	?	60	40	25	25	1.0	2.8	241	CCSP, POOR BATHY
5860	31.28	~50.8	45.5	0.9	51.7	5.3	6.2	50	35	25	35	-	-	241	POOR E/S; LAM. INFILL
5889	31.52	50.8	45.0	1.1	51.9	5.8	6.9	40	30	25	25	?	1.5	241	DEPTH FROM M. PROFILER (POOR E/S)
6356	31.88	48.6	45.0	?	48.6?	3.6	?	?	30	-	-	-	-	241	POSS. CCSP, NUM. X-CUTTING SCOURS
5894	32.00	50.7	44.5	1.5*	52.2	6.2	7.7	50	30	15	20	2.2	4.5	241	LAM. INFILL; DEPTH FROM M. PROFILER
5899	32.48	50.5	44.5	1.5	52.0	6.0	7.5	45	30	30	40	3.6	2.3	241	LAM. INFILL; DEPTH FROM M. PROFILER
5904	32.96	50.5	44.5	1.5	52.0	6.0	7.5	55	30	35	40	3.2	2.5	241	
5909	33.44	50.0	44.5	1.5	51.5	5.5	7.0	45	25	25	20	2.5	2.5	241	
5914	33.92	50.0	44.5	1.5	51.5	5.5	7.0	60	30	20	20	3.0	1.0	241	
5919	34.40	49.5	45.0	1.8	51.3	4.5	6.3	60	25	15	15	2.5	2.5	241	CCSP
5924	34.88	46.5	44.5	?	48.5*	2.0	4.0*	45	25	15	15	0.8	1.0	241	CCSP
5930	35.42	48.5	44.5	1.6*	50.9	4.0	5.6*	50	30	15	20	2.5	3.0	245	CCSP
5935	35.88	48.8	44.5	2.3	51.0	4.3	6.5	50	30	20	20	2.0	1.0	245	
5941	36.46	48.8	44.0	1.5	50.3	4.8	6.3	45	25	30	15	2.5	3.0	263	
5946	36.96	48.2	44.0	2.1	50.3	4.2	6.3	45	25	20	20	3.8	3.5	263	CCSP
5952	37.52	47.4	43.5	2.2	49.6	3.9	6.1	40	25	30	30	3.0	2.5	263	
5958	38.08	47.8	43.5	2.0	49.8	4.3	6.3	40	20	30	40	0.5	3.0	266	
5964	38.68	48.0	43.5	2.2	50.2	4.5	6.7	40	25	30	30	2.5	2.5	266	CCSP
5971	39.32	47.2	43.0	2.3	49.5	4.2	6.3	50	30	15	20	3.5	2.2	270	
5977	39.92	47.0	42.5	2.8	49.8	4.5	7.3	50	30	35	30	1.0	1.0	275	
5984	40.56	47.0	42.0	2.0	49.0	5.0	7.0	60	40	20	45	2.5	1.4	270	CCSP
5992	41.36	47.6	42.5	2.5	50.1	5.1	7.6	65	45	30	20	0.5	1.0	270	
5999	42.04	47.6	42.0	2.7	50.3	5.6	8.3	60	45	20	30	0.6	0.0	270	
6008	42.92	47.8	42.0	2.7	50.5	5.8	8.5	60	40	25	20	0.0	0.2	282	
6015	43.60	47.4	42.0	2.0	49.4	6.4	7.4	60	40	25	30	0.5	1.5	282	
6023	44.40	47.2	42.0	2.0	49.2	5.2	7.2	65	40	30	30	1.8	2.0	285	
6034	45.48	44.5	42.0	0.8	45.3*	2.5	3.3*	65	45	20	30	1.0	0.2	243	CCSP
6061	45.52	46.0	42.0	2.8	48.8	4.0	6.8	65	30	30	30	2.0	2.0	240	
6067	46.36	44.9	41.5	3.0	47.9	3.4	6.4	60	45	30	30	1.5	2.5	238	
6074	47.00	45.8	41.0	2.0*	47.8	4.8	6.8	55	40	25	30	1.5	2.0	238	CCSP
6083	47.90	45.8	41.0	0.7	46.5*	4.8	5.5	60	40	30	20	3.0	1.6	290	CCSP
6113	48.10	45.4	41.0	2.1	47.5	4.4	6.5	55	40	30	30	0.0	2.5	290	
6122	49.00	44.8	41.0	2.5	47.3	3.8	6.3	55	30	20	15	1.0	0.5	275	
6138	50.52	44.5	41.5	2.5	47.0	3.0	5.5	45	35	10	20	0.5	1.5	250	

SCOUR N90-3
SCOUR PARAMETER TABLE

FIX	KP: DIST ALONG SCOUR (Km)	DEPTH TO TOP OF INFILL (A)	BATHY (B)	INFILL (C)	DEPTH TO BASE OF INFILL (A+C)	SCOUR DEPTH TO TOP (A-B)	SCOUR DEPTH TO BASE (A-B+C)	SCOUR WIDTH	INCISION WIDTH	WEST BERM WIDTH	EAST BERM WIDTH	WEST BERM HEIGHT	EAST BERM HEIGHT	COMMENTS
NORTHERN LEG														
8408.2	0	?	20	<0.1	?	?	?	12	7.5	5	5	<1	<1	MAJOR CCSP
8403.4	0.45	?	19.8	<0.1	?	?	?	12	7.5	5	5	<1	<1	MAJOR CCSP
8398.9	0.93	20.3	19.5	<0.1	20.3	0.8	0.8	10	7.5	5	5	<1	<1	
8390.6	1.69	20.3	19	<0.1	20.3	1.3	1.3	15	10	5	5	<1	<1	SUB-SCOUR REFLECTORS TO 0.5 m
8384.2	2.33	?	18.4	<0.1	?	?	?	15	10	-	-	-	-	MAJOR CCSP
8359	3.05	19.5	18	<0.1	19.5	1.5	1.5	15	10	-	-	-	-	
8374.6	3.38	?	18.2	<0.1	?	?	?	-	-	-	-	-	-	MAJOR CCSP
8349.3	3.47	19.8	18.2	<0.1	19.8	1.6	1.6	20	15	-	-	-	-	SUB-SCOUR REFLECTORS TO 0.5 m
8345	3.92	19.7	18	<0.1	19.7	1.7	1.7		15	-	-	-	-	SUB-SCOUR REFLECTORS TO 0.3 m
8342.6	4.16	19.6	18	<0.1	19.6	1.6	1.6	20	15	-	10	-	<1	SUB-SCOUR REFLECTORS TO 0.5 m
8338.9	4.55	19.7	17.7	<0.1	19.7	2.0	2.0	20	15	-	10	-	<1	SUB-SCOUR REFLECTORS TO 0.8 m
8334.3	4.95	?	17.3	<0.1	?	?	?	-	15	-	-	-	-	MAJOR CCSP
8326.8	5.71	?	17.1	<0.1	?	?	?	-	15	-	-	-	-	MAJOR CCSP
8321	6.23	19.1	17.1	<0.1	19.1	2.0	2.0	23	15	-	10	-	<1	
8315	6.84	18.0?	16.8	<0.1	18.0?	?	?	-	15	-	-	-	-	MAJOR CCSP
8309.8	7.36	19.0	16.5	0.1	19.1	2.5	2.6	23	15	10	15	<1	<1	SUB-SCOUR REFLECTORS TO 0.6 m
8249.7	8.13	17.5	16.4	0.1	17.6	1.1	1.2	23	15	15	10	<1	<1	SUB-SCOUR REFLECTORS TO 0.4 m
8255.2	8.63	17.4	16.3	0.1	17.5	1.1	1.2	20	15	10	-	<1	-	SUB-SCOUR REFLECTORS TO 0.3 m
8259.5	9.08	16.8	16	0.2	17.0	0.8	1.0	20	15	10	10	<1	<1	
SOUTHERN LEG														
8277	9.92	17.2	16	<0.1	17.2	1.2	1.2	20	10	-	10	-	<1	
8286.8	10.85	?	16.2	<0.1	?	?	?	15	10	-	10	-	<1	MAJOR CCSP
8292.8	11.43	17.3	16.5	0.1	17.4	0.8	0.9	10	5	5	5	<1	<1	
8301	12.21	?	17	<0.1	?	?	?	10	5	-	-	-	-	MAJOR CCSP

SCOUR N90-4
SCOUR PARAMETER TABLE

FIX	KP DIST ALONG SCOUR (Km)	DEPTH TO TOP OF INFILL (A)	BATHY (B)	INFILL (C)	DEPTH TO BASE OF INFILL (A+C)	SCOUR DEPTH TO TOP (A-B)	SCOUR DEPTH TO BASE (A-B+C)	SCOUR WIDTH	INCISION WIDTH	WEST BERM WIDTH	EAST BERM WIDTH	WEST BERM HEIGHT	EAST BERM HEIGHT	COMMENTS
8928	0.00	28.5	27.0	?	?	1.5	?	?	?	0	0	<0.5	1-1.5	MAJOR CCSP
8759	0.12	29.2	27.2	?	?	2.0	?	25	20	0	0	<0.5	1-1.5	MAJOR CCSP
8761	0.31	29.2	27.2	?	?	2.0	?	25	20	15	15	<0.5	1-1.5	MAJOR CCSP
8918	0.94	28.3	26.2	1.4	29.7	2.1	3.5	30	20	10	0	1-1.5	1-1.5	
8768	0.98	28.1	26.1	1.7	29.8	2.0	3.7	25	20	10	15	0.5-1	<0.5	
8912	1.51	28.3	25.8	1.3	29.6	2.5	3.8	30	20	10	15	<0.5	1-1.5	
8775	1.63	28.0	25.6	1.8	29.8	2.4	4.2	25	20	15	15	1.5-2.0	<0.5	
8909	1.81	27.9	25.3	1.5	29.4	2.6	4.1	30	20-25	10	15	0.5-1	0.5-1	
8780	2.08	27.9	25.6	1.7	29.6	2.3	4.0	30	20-25	10	10	0.5-1	0.5-1	
8902	2.48	28.0	25.0	1.6	29.6	3.0	4.6	25	20-25	10	15	<0.5	0.5-1	
8786	2.60	27.5	25.1	1.5*	29.0*	2.4	3.9*	30	20	10	10	<0.5	0.5-1	LOWER INFILL NOT OBSERVED
8898	2.87	27.9	24.5	1.8	29.7	3.4	5.2	25	20	5	5	<0.5	<0.5	
8788	2.87	27.7	24.6	2.0	29.7	3.1	5.1	25	20	10	10	<0.5	1.0-1.5	
8795	3.51	27.3	24.1	1.7	29.0	3.2	4.9	30	25	15	10	0.5-1	<0.5	
8890	3.60	27.4	24.3	1.8	29.2	3.1	4.9	30	25	10	10	0.5-1	<0.5	
8887	3.91	26.9	24.0	-	-	2.9	-	30	25	10	15	<0.5	<0.5	POOR WEATHER
8800	4.02	26.8	23.6	1.7	28.5	3.2	4.9	25	20	10	10	<0.5	<0.5	
8805	4.49	25.9	23.1	2.1	28.0	2.8	4.9	25	20	10	15	<0.5	<0.5	
8880	4.59	26.0	23.0	1.3*	27.3*	3.0	4.3*	25	20	5	10	<0.5	<0.5	
8809	4.88	26.0	22.6	2.1	28.1	3.4	5.5	30	25	10	15	<0.5	<0.5	
8876	5.00	25.6	22.5	2.0	27.6	3.1	5.1	30	25	5	10	<0.5	<0.5	
8814	5.34	-	22.0											MAJOR CCSP
8820	5.88	-	22.0											MAJOR CCSP
8866	5.96	24.0	22.0	1.7*	25.7*	2.0	3.7	30	25	5	10	<0.5	<0.5	LOWER INFILL NOT OBSERVED
8824	6.22	23.9	21.5	2.1	26.0	2.4	4.5	25	25	10	0	<0.5	0.5-1	
8863	6.24	24.0	21.5	1.5*	25.5*	2.5	4.0	30	25	5	5	<0.5	<0.5	LOWER INFILL NOT OBSERVED
8828	6.61	23.1	21.3			1.8				0	0			MAJOR CCSP
8832	7.01	23.4	20.7	1.6*	25.0*	2.7	4.3*	30	30	5	5	<0.5	<0.5	LOWER INFILL NOT OBSERVED
8853	7.20	23.4	20.3	2.2	25.6	3.1	5.3	30	30	5	5	<0.5	<0.5	
8837	7.41	23.1	20.4	2.3	25.4	2.7	5.0	30	30	5	5	<0.5	<0.5	
8850	7.50	23.0	20.3	1.8*	24.8*	2.7	4.5	30	30	5	10	<0.5	<0.5	LOWER INFILL NOT OBSERVED
8849	7.71	21.1	20.1						20					MAJOR CCSP

SCOUR N90-5
SCOUR PARAMETER TABLE

FIX	KP: DIST ALONG SCOUR (Km)	-DEPTH TO TOP OF INFILL–			BATHY	INFILL	——SCOUR DEPTH——			SCOUR WIDTH
		KEEL A	KEEL B	KEEL C			KEEL A	KEEL B	KEEL C	
WESTERN SCOUR LEG										
8417.0	0.13	-	29.0	-	27.5	-	-	1.5	-	-
8419.0	0.32	-	29.0	0.0	27.5	-	-	1.5	-	-
8420.5	0.42	-	-	28.3	27.5	-	-	-	0.8	-
8423.5	0.77	30.0	29.1	-	27.5	-	2.5	1.6	-	-
8679.5	1.30	30.0	28.8	28.2	27.2		2.8	1.6	1.0	65
8739.0	1.33	-	-	28.3	27.0	-	-	-	1.3	65
8737.0	1.54	-	-	28.3	27.0	-	-	-	1.3	65
8431.0	1.52	29.8	28.9	28.2	27.1	-	2.7	1.8	1.1	-
8682.5	1.60	29.7	28.8	28.2	27.0		2.7	1.8	1.2	65
8513.5	1.93	29.6	28.9	-	27.0		2.7	1.9	-	65
8436.0	2.00	29.7	28.9	28.0	27.0	-	2.7	1.9	1.0	-
8688.5	2.15	29.7	-	-	27.0	-	2.7	-	-	65
8606.5	2.17	29.7	-	-	26.8	-	2.9	-	-	65
EASTERN SCOUR LEG										
8689.0	2.27	28.3	27.6	-	26.8	-	1.5	0.8	-	-
8607.0	2.35	28.4	27.7	27.0?	26.7	-	1.7	1.0	0.3?	-
8730.0	2.40	28.4	27.7	27.1?	27.0	-	1.4	0.7	0.1?	-
8611.5	2.80	28.9	27.9	-	27.2	-	1.7	0.7	-	50
8620.0	3.62	-	28.1?	-	27.7	-	-	0.4?	-	-
8619.0	3.52	29.0	-	-	27.7	-	1.3	-	-	50
8527.0	3.89	CCSP	28.2?	-	28.0	-	-	0.2?	-	50

SCOUR N90-7
SCOUR PARAMETER TABLE

SURVEY LINE	FIX	KP DIST ALONG SCOUR (Km)	DEPTH TO TOP OF INFILL (A)	BATHY (B)	INFILL (C)	DEPTH TO BASE OF INFILL (A+B-C)	SCOUR DEPTH TO BASE OF INFILL	INCISION WIDTH	SCOUR WIDTH	MULTI-KEEL WIDTH
N90 52B	9246.5	0.000	32.6	31.8	-	32.6	0.8	30	35	-
G267		0.165	32.7	31.5	-	32.7	1.2	49	53	-
N90 52	9206.8	0.315	32.8	31.3	-	32.8	1.5	45	50	-
G204		0.330	32.5	31.3	-	32.5	1.2	45	50	-
N90 52A	9213.0	0.810	32.8	31.2	-	32.8	1.6	50	55	-
G263		0.855	32.5	31.3	-	32.5	1.2	44	49	-
N90 52B	9237.8	0.900	32.7	31.2	-	32.7	1.5	50	60	-
G259		1.440	32.4	31.0	-	32.4	1.4	50	55	-
G257		1.785	32.9	31.0	-	32.5	1.4	47	51	-
G225		2.025	32.5	31.0	-	32.4	1.5	-	-	-
G203B		2.310	32.5	31.0	-	32.5	1.5	43	47	-
G210		2.400	32.5	31.0	-	32.5	1.5	41	45	-
SUR1		2.610	32.3	31.0	-	32.3	1.3	40	45	-
G251		2.838	32.4	30.8	-	32.4	1.6	43	55	-
N90 50A	9039.5	2.985	32.3	30.4	-	32.3	1.9	-	-	-
N89 16-9		3.035	32.2	30.3	-	32.2	1.9	45	52	-
N90 50A	8974.8	3.068	32.7	30.3	-	32.7	2.4	40	50	-
N89 16-1		3.285	31.9	30.0	-	31.9	1.9	44	62	-
SUR2		3.300	31.9	29.9	-	31.9	2.0	41	56	-
N90 50A	9043.6	3.315	32.3	29.9	-	32.3	2.4	40	60	-
G247		3.510	31.6	29.7	-	31.6	1.9	-	-	-
N89 16-2		3.645	31.6	29.7	-	31.6	1.9	41	70	-
N90 50A	8967.9	3.705	32.4	29.6	-	32.4	2.8	40	80	-
N90 50A	9049.5	4.005	31.5	29.6	0.6 (CCSP)	32.1	2.5	40	80	-
SUR3		4.050	31.7	29.5	-	31.7	2.2	38	75	-
N89 16-3		4.080	31.6	29.4	-	31.6	2.2	-	-	-
N90 50A	8963.8	4.103	31.8	29.4	-	31.8	2.4	40	90	-
N90 49A	8642.3	4.125	31.8	29.3	-	31.8	2.5	45	70	-
N90 49A	8638.1	4.508	32.4	29.2	-	32.4	3.2	40	65	-
N89 16-4		4.568	31.5	29.2	-	31.5	2.3	50	66	-
N90 50A	8955.7	4.853	31.8	29.2	-	31.8	2.6	50	80	140
SUR4		4.935	31.3	29.1	-	31.3	2.2	42	-	-
N89 16-5		4.980	31.3	29.1	-	31.3	2.2	53	-	146
N89 16-6		5.438	31.0	28.6	-	31.0	2.4	55	90	147
N90 50A	9066.5	5.625	31.3	28.3	-	31.3	3.0	45	90	140
SUR5		5.648	30.9	28.3	-	30.9	2.6	42	80	130
N89 16-7		5.903	30.9	27.9	-	30.9	3.0	48	-	127
N90 49A	8564.6	5.948	31.1	27.9	-	31.1	3.2	40	85	135
N90 50A	9072.5	6.225	29.4	28.0	1.8 (CCSP)	31.2	3.2	45	95	135
SUR6		6.398	30.7	27.8	-	30.7	2.9	45	-	140
G225		6.428	30.6	27.7	-	30.6	2.9	48	-	135
G223B		6.593	30.3	27.5	-	30.3	2.8	48	-	137
G201		6.803	30.2	27.5	-	30.2	2.7	47	-	137
G219		7.193	29.0	27.3	-	29.0	1.7	47	49	-
SUR7		7.245	-	27.1	-	-	-	32	38	-
N89 16-8		7.380	28.7	27.0	-	28.7	1.7	32	45	-
TERMINATION										

APPENDIX 3

REPETITIVE MAPPING DOCUMENT

CONSIDERATIONS FOR A SIDE SCAN SONAR REPETITIVE MAPPING PROGRAM

1.0 INTRODUCTION

A side scan sonar repetitive mapping survey is one that obtains a time series of seafloor image data in exactly the same region. The reason such surveys are undertaken is usually to obtain temporal information relating to a geological process (eg. ice scouring or seafloor erosion) or an anthropogenic activity (eg. bottom trawling or mine laying by hostile militaries).

The time interval between the base year (first survey) and subsequent re-surveys should be selected to best represent the process you are attempting to monitor.

The types of information that a repetitive mapping program can yield are quite varied. Some of the more important processes are as follows;

> The rate of addition of a seabed feature. This can lead to calculations of spatial density and ultimately to the temporal frequency of that process.
>
> As a long time series builds up, the data may reveal seasonal or yearly variability in the process.
>
> The rate of removal or erosion of a seabed feature. Such information leads to indicators of seabed erosion, sedimentation or removal by some other process, such as over-scouring.
>
> The seabed textures, geologic topography and any sediment transport features in the region.

To undertake a repetitive mapping program, a number of important aspects must be considered. ***In general, it is important to consider long range planning and ensure that there is continuity and consistency of equipment selected and personnel for sonar operations and data interpretation.***

The following document outlines several operational considerations in designing and executing a repetitive mapping program.

2.0 NAVIGATION AND POSITIONING

ACCURACY

The minimum repeatable survey accuracy should be no less than 25-50m. Such accuracies are acceptable only if the field sonar operators are regularly "feature matching" and steering the vessel down the repetitive corridor. A system with a survey accuracy of 10-15m should be used whenever possible.

Survey accuracy for different systems varies greatly with respect to a number of factors, however, the following accuracies can be used as a rule of thumb.

SYSTEM	REPEATABLE ACCURACY
Loran C	200-500m
Stand Alone GPS	50-150m
Differential GPS	5-10m
Syledis/Argo	5-10m

GPS alone is quite noisy with regular jumps in positions. Selective availability (induced by the military) will decrease positional accuracy to 100m or more. By contrast, Loran C is quite smooth, however, this is largely due to the heavy filtering required, which in turn decreases accuracies.

Differential GPS involves a base station (a known location on land) that can calculate the pseudoranges and transmit these corrections to the ship. This can be done by VHF radio for 25 mile ranges or HF radio for longer ranges, such as Scotian Shelf regions. In order that accuracy is maintained, corrections must be transmitted very 5 seconds.

Ideally, DGPS should be used for repetitive mapping surveys. Failing that, stand alone GPS can be used, whereas, Loran C alone is unacceptable.

GENERAL DATA LOGGING

Positional fixes should be logged to disk and to the side scan system at least every 200m or 2:00 min of travel time.

The helmsman will require an offtrack indictor display in order to steer the line. The lab should have the same monitor in order to ensure overlap.

The Navigation system should have ability to send a fix closure and filtered ship speed information to the sonar device for record marking.

All nav data should be digitally logged in standard ASCII format along with real-time paper copy backup.

OPERATIONAL CONSIDERATIONS

The Base Year, subsequent re-surveys and any experimental seabed markings that are laid down should have consistent and repeatable navigation.

Bottom referencing may be achieved by the use of 100 kHz bottom trisponders at the start and end of key line positions. These units, however, are $2500 US each and have a life span of 2 years. Utilization of Differential GPS navigation, or a navigation system with similar accuracy, should negate any requirement for bottom positioning systems in most survey applications.

An experienced navigation person should be responsible for positioning in the field.

3.0 SIDE SCAN SONAR

The two most important aspects of Sonar considerations are first to select a top end system that produces high resolution images on thermal paper (not video) and secondly to maintain consistency in the use of that exact tool for subsequent re-surveys.

The use of different systems for the base year and the first repetitive re-survey complicates the interpretation process to the point that, for some applications, the data will not be of value. For example, if one wanted to monitor the degradation rate of a trawl mark or ice scour over time, very detailed morphological data on the berm and scour acoustic signatures would be required. Many cases have been documented where such subtle differences were caused by equipment differences alone rather than erosional processes.

The data should also be speed and slant range corrected so that measurement of seabed mark orientations and width characteristics can be made each for each repetitive survey, if required.

The following system is being utilized by CSR for their repetitive mapping programs.

KLEIN 595 DIGITAL SIDE SCAN SONAR

This is a state-of-the-art, digital side scan sonar system recently purchased by CSR. The system offers very high resolution, 100 or 500 kHz seafloor imaging with the added ability to display a profile channel, such as the 3.5 kHz sub-bottom data or the high resolution 100 khz microprofiler. Contrary to most side scan systems, the Klein 595 system offers complete slant range and speed correction in order that the dimensions and orientations of all seabottom features such as pipelines, ice scours, megaripples etc. can be accurately measured.

KLEIN 100 KHZ MICROPROFILER

This option represents a unique capability of the Klein 595 system. CSR has integrated a very narrow beam Microprofiler into the side scan fish such that real-time, very high resolution bathymetric profiles can be obtained that are directly linked to the plan view side scan data. CSR used this system for the ESRF 1990 Beaufort Sea Mapping program where very detailed measurements were required from seafloor features. This system is also a useful in helping to interpret surficial geology in the region.

CSR recommends that the following side scan sonar equipment be utilized for the repetitive trawl experiments.

- Klein 595 Digital Side Scan Sonar
- Both 100 khz and 500 khz tow-fish
- Klein 100 khz Microprofiler
- Winch with suitable cable length for the intended water depths (allowing anywhere from 3-5 to 1 scope).
- Klein K-Wing depressor to achieve deeper depths
- Consider the use of tape recorder to tape all data in the field. The data can also be replayed at different scales.
- Suitable backups for tow-fish, winches and spare boards in the event of problems.

OPERATIONAL CONSIDERATIONS

SELECTION OF SONAR OPERATORS

It is important to maintain personnel continuity from one survey to the next in order to generate similar results. Although all operational settings should be documented in the filed, it is most desirable to maintain the same sonar operator from one year to the next.

The operator should understand the objectives of the survey and have experience in repetitive mapping and steering the vessel using real-time side scan sonar data. (The objective here is to minimize overshoots and loss of base year line data).

Similar gain and slope settings should be used from one survey to the next, in order to optimize data.

Optimization fish height off bottom in order to improve the resolution of trawl marks.

RECORDER SETTINGS

We recommend that the maximum range scale should be 100m although smaller scales should be experimented with (ie. 50 and 75m).

Channel 4 should be the microprofiler and channel 3 should be expanded out port side scan data. This expanded out data is quite useful in obtaining useful morphological data on seabed marks.

Ship speed and slant range corrections should be available for use.

DOCUMENTATION OF CALIBRATION POINTS

Each repetitive line should have a series of calibration points or highly recognizable features taken from the base year data set. Ideally these points should have a suitable longevity to match the time frame of the survey program. These points will be used in the field to confirm that overlap is being achieved as the line progresses. All base data or photocopies should be used in the field.

Such calibration points may be geologic features or if such features are not available, sonar reflectors could be set at critical points along the line. We recommend that such reflectors be tested before the repetitive mapping cruise.

GENERAL

It is important to have direct communications with the bridge for steering down repetitive corridors.

All equipment laybacks should be recorded in order to optimize the recording of trawl mark position.

4.0 SURVEY LOGISTICS

CRUISE PLANNING

The setup of line directions should be made in consideration of prevailing currents, surficial geology, etc.

Bathymetric constraints on sonar equipment, winch cable lengths, fish positioning etc. should be evaluated.

Preparation of all SOL/EOL coordinates, as well as, calibration points well in advance of survey. These lines should also be prioritized. If possible, attempt to optimize survey timing for weather, thermoclines etc.

AT SEA OPERATIONS

Attempt to run KEY lines under ideal conditions for comparative purposes. If this is not possible, the interpreter must consider relative data quality in reducing the information.

Record all operational settings, equipment types and navigation information in a detailed operations report.

5.0 POST-SURVEY DATA REDUCTION

GEOSCIENCE PERSONNEL

It is recommended that the interpreters who are responsible for data reduction also take an active part in collecting the sonar data in the field. This always enhances both the quality of the data collected in the field and the quality of the subsequent data reduction.

DIGITAL TRACK PLOTS FOR CONFIRMATION OF OVERLAP

A digital GIS system would be a useful tool to store all field program information for planning and implementation purposes while on station. The same system would provide a base for storage and evaluation of all spatial data results. Since we expect that degradation rates will depend on a number of variables, such a system would be an extremely valuable tool for spatial correlation purposes. This system would produce track plots for interpretive purposes.

APPENDIX 4

ESRF 1990 SURVEY; OPERATIONS REPORT

SUMMARY SURVEY SPECIFICATIONS

ESRF 1990 Repetitive Ice Scour Mapping Survey
Aug. 30 - Sept. 17 1990

Client:	**Environmental Studies Research Funds**
Prime Contractor:	Cdn. Seabed Research Ltd.
Survey Vessel:	C.C.G.S. Nahidik
Length:	175 ft
Beam:	50 ft
Draft:	4-6 ft
Navigation Contractor:	Challenger Surveys and Service Ltd.
Navigation Type:	Syledis/Argo Network
General Line Spacing	Regional Repetitive Lines
Fix Interval:	200m

GEOPHYSICAL EQUIPMENT	TYPICAL SETTINGS
Klein 595, 100 kHz Sidescan	150m range scale
3rd. Channel Display	100 Khz Microprofiler
HP 3968 Tape Recorder	3 3/4 i.p.s.
RTT-1000 3.5/7.0 kHz Profiler	7.0 kHz
EPC 1600 Recorder for SBP	10 msec.
Raytheon DE 719 200kHz Sounder	0-15m * 2
TSS 312 Record Annotator	Triggered by Navigation
SCOURBASE Microcomputer System	

Typical Survey Conditions:	Fair-Good Sea Conditions
Total # of Lines:	79
Total # of Kilometres:	1651.6
Total # of Survey Days:	14
Average # of Kilometres/Day	118.0

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ACKNOWLEDGEMENTS

We are grateful to Captain F. Ali and the officers and crew of the C.C.G.S. Nahidik for their contributions to the overall success of the ESRF 1990 Repetitive Ice Scour Mapping Survey. In particular, we acknowledge the help of Ryan in helping mobilize the survey gear and the deck crew in general for providing willing assistance especially during equipment recovery operations.

The scientific authority, Steve Blasco and Geoscience technicians Bob Harmes and Mike Hughes provided clear instruction and logistical support throughout the cruise, thereby, helping to achieve the scientific objectives of the 1990 program.

Shore-based logistical support was provided by Gary White at the Inuvik Scientific Resource Centre.

Finally, the contributions of all the survey participants in the ESRF 1990 program are acknowledged. In closing, we would like to wish Captain Ali all the very best success with his new posting on the West Coast of B.C.

1.0 INTRODUCTION

A repetitive ice scour mapping survey was carried out during the period of August 30/90 to September 17/90 in the Canadian Beaufort Sea (See Figure 1). This program was funded by the Environmental Studies Research Funds of Ottawa in response to a request for proposal that was distributed across Canada in April 1990. Under competitive bid, Canadian Seabed Research Ltd. (CSR) of Halifax was awarded the contract and given permission to proceed with planning on July 13/90. It is noted that this project represented a cooperative effort with the Geological Survey of Canada providing logistical support, the Canadian Coast Guard providing a vessel and the Beaufort Sea petroleum operators providing logistical and financial support.

As prime contractor for the survey, Canadian Seabed Research Ltd. (CSR) was responsible for planning the regional network, providing geophysical equipment and personnel and organizing a suitable commercial navigation package. A SYLEDIS/ARGO navigation system was provided under subcontract by Challenger Surveys and Service Ltd. of Edmonton. The navigation chain and signals were provided by Halliburton Geophysics Ltd.

The primary objective of the survey was to resurvey specific corridors across the Beaufort Shelf using high resolution geophysical instrumentation to identify and document new scour events. (See Background). This objective was fully realized through the collection of over 1600km of data along regional and scour specific survey lines. The success of this year's survey can be attributed to the excellent weather and clear ice conditions that were experienced, as well as, the provision of new and 100% backed-up geophysical equipment to minimize downtime.

1.1 BACKGROUND

The seafloor of the Canadian Beaufort Sea retains a unique historical record of ice/sediment interaction that is expressed morphologically in the form of complex linear gouges found on the sea bottom. These features termed "ice scours" (see Figure 2) may extend linearly for tens of kilometres, have widths of 400 or more metres, and incise up to 8.5m into the seabed sediments. Such characteristics have been recognized as potential threats to safe petroleum operations in the Beaufort Sea. It is thus important to understand the modern day scour phenomena, especially in terms of recurrence rates and standard parametric measurements of extreme events. Yearly repetitive mapping is the only method of documenting and measuring scour features that are known to result from modern-day populations. Work to date has illustrated that scour frequency can be highly variable from one year to the next. This episodicity can only be documented by continued yearly resurvey of the repetitive scour network.

The first major scour survey initiative was undertaken in 1984 by the ESRF to establish a baseline repetitive mapping network from which new scour events could be identified and statistically documented (Shearer et al, 1986). Information such as distribution and impact rate data for known new events (critical to engineering design) resulted from this study. This information is now stored as part of the Beaufort Sea Ice Scour Base SCOURBASE system (Gilbert et al., 1989, Gilbert and Pedersen, 1986). In 1988, the survey network was partially resurveyed by CSR under a joint GULF/GSC program. That survey yielded many important new scour results (Gilbert, 1988). The network was further resurveyed in 1989 by CSR under funding from the Geological Survey of Canada (Gilbert,1989).

The present ESRF 1990 program represents a continuation of resurvey efforts to map the repetitive mapping network, especially in regions not covered by the 1988 and 1989 surveys. The resulting data will enhance our knowledge of the recurrence rate of extreme ice scour events across the shelf and thereby aid in defining safe risk protection strategies for petroleum-related seafloor emplacements.

1.2 SURVEY OBJECTIVES

The ESRF 1990 Nahidik program represented a multi-disciplinary ice scour mapping survey. Although the main priority was to resurvey specific corridors for new scour additions (especially the Gulf pipeline route), many additional objectives were outlined and planned for, given sufficient time. The main survey objectives, and the status of each, are as follows:

- Resurvey the major repetitive scour mapping corridors across the Beaufort Shelf established from 1984 to 1989. Focus on both the shallow and deeper water regions if ice conditions are favourable. This objective, was very successfully met by the 1990 program due to excellent weather and ice conditions.

- Profile the Gulf Pipeline Route, extended to 50m water depths, only under ideal conditions for the collection of high quality data. Re-run two outer lines (1 and 7) of the pipeline route to identify new events. Perform detailed studies on extreme events along the route. This priority was very successfully achieved with a complete resurvey of the pipeline route and the tracking of four scours around the pipeline region: Scour 7, SCPIP16, SCPIP26 and SCPIPEA.

- Conduct scour tracking operations to yield process-related information for major features such as the deepest, longest scours in both the Historical and New Scour data base. This objective was met by tracking the scours SCTARN2 and SCNEWDP.

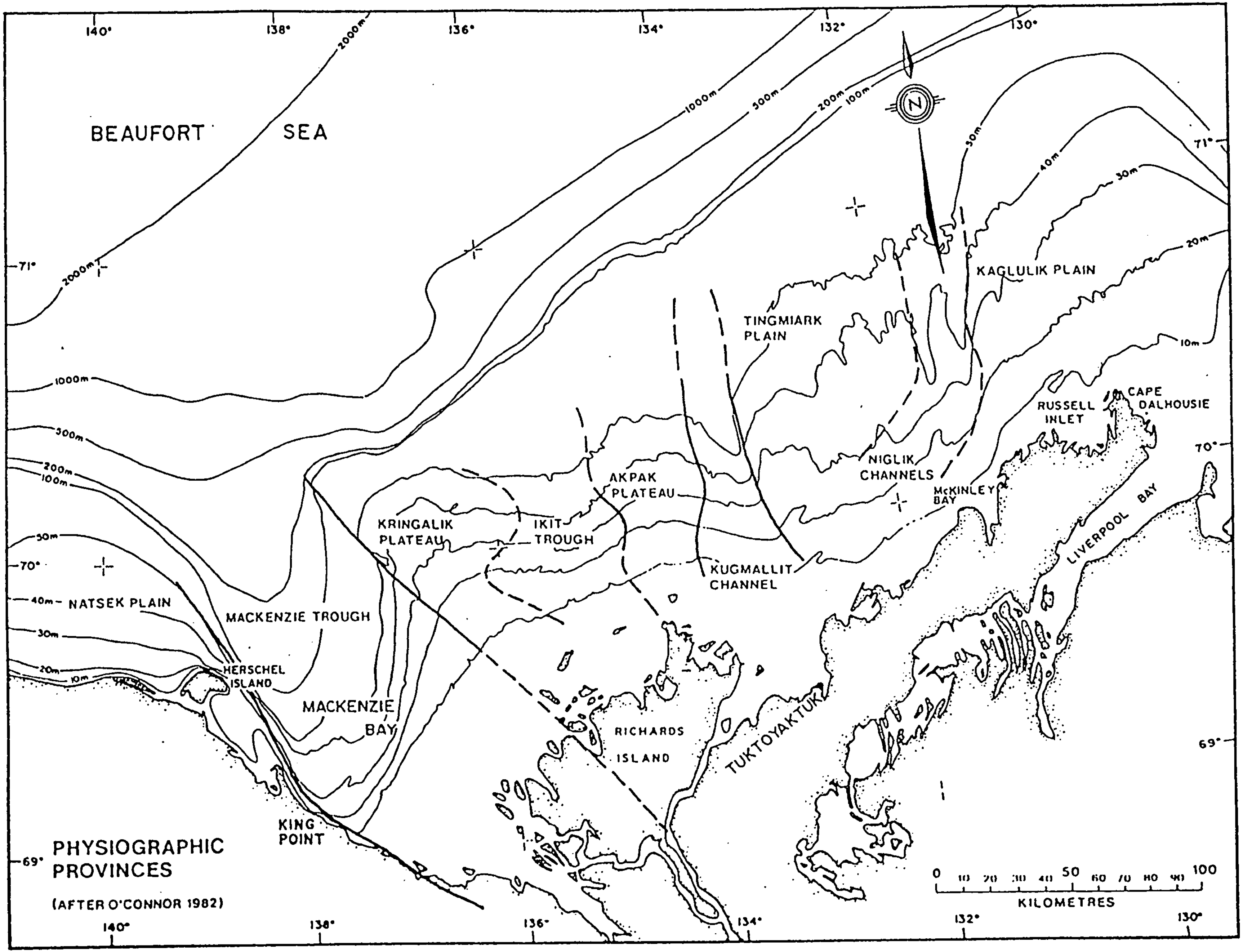


FIG 1 BEAUFORT SEA LOCATION MAP

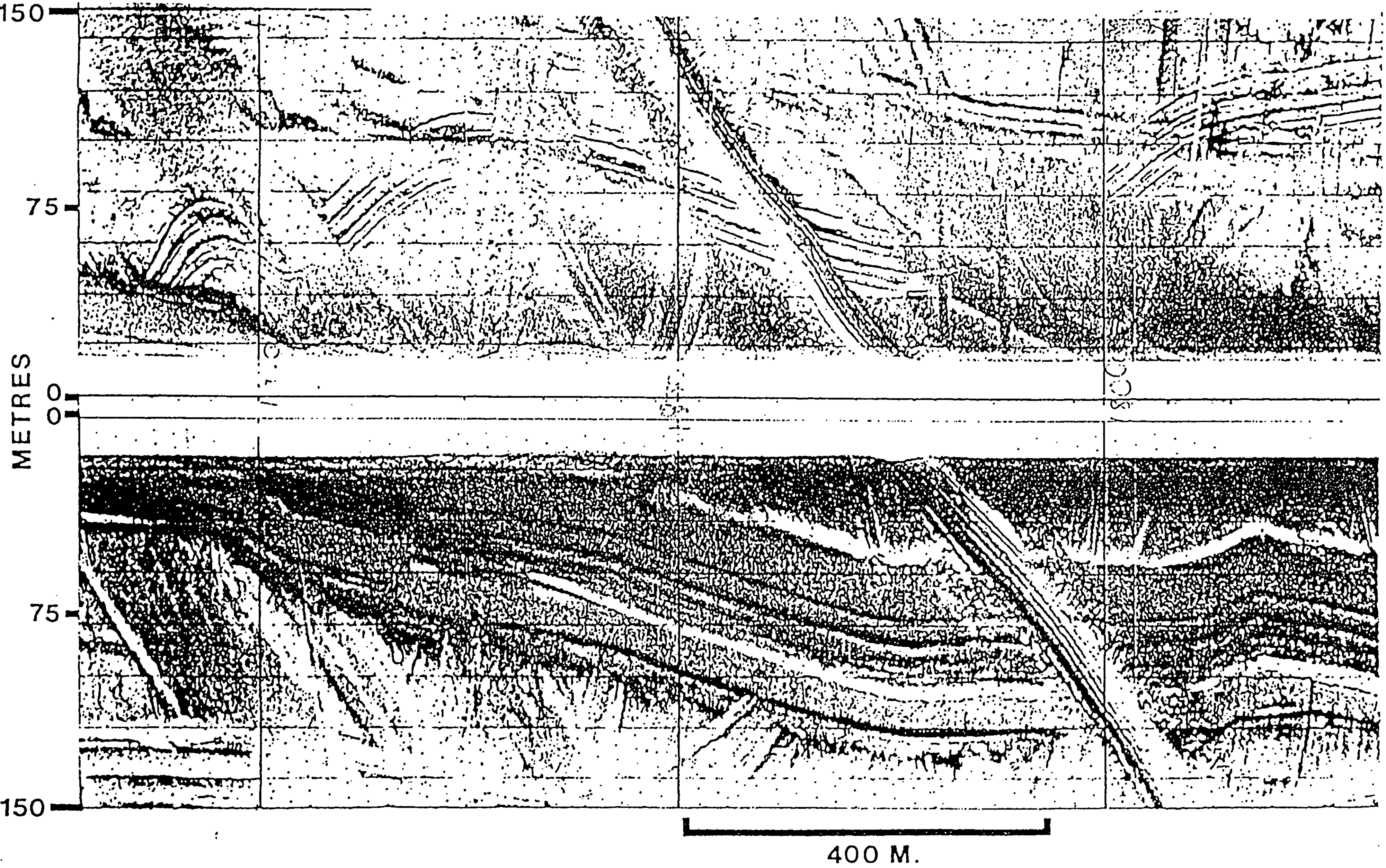


FIG 2 BEAUFORT SEA SCOURED SEABED

- Attempt to mosaic the Tingmiark glory hole to determine if there is a drill pipe protruding from the glory hole. This objective was achieved and the presence of the pipe confirmed.

- Test and evaluate the new Klein 595 digital sidescan sonar system configured with the narrow beam microprofiler for accurate scour depth definition. This system, provided by CSR, was successfully used throughout the survey with very high quality images generated.

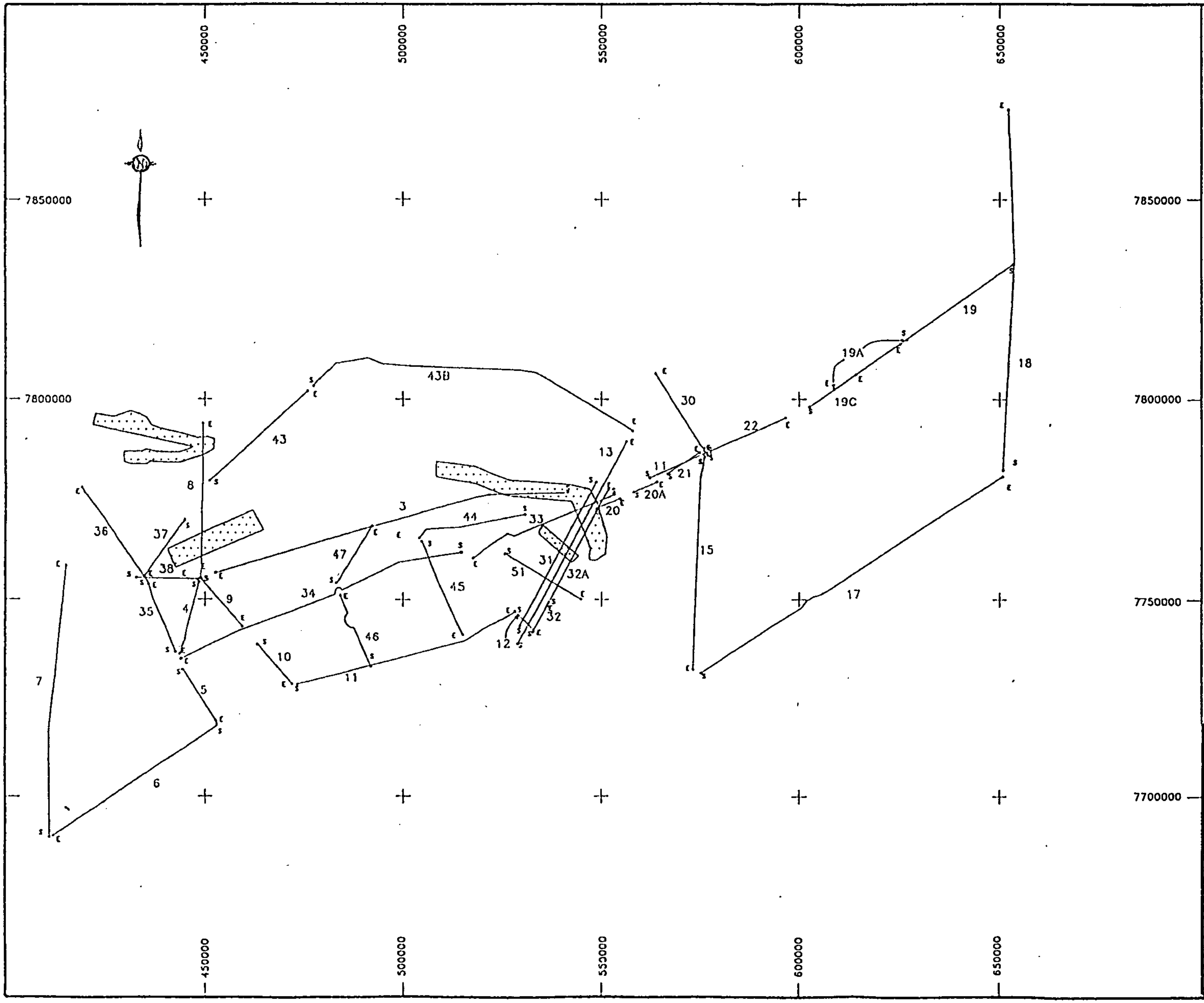
- Collect high resolution, 500 kHz sidescan sonar data over New scour features to identify potential soil failure features along the scour base. This objective was not realized due to weather problems at the scheduled time for this program.

1.3 SURVEY COVERAGE

The ESRF 1990 program collected 79 survey lines that resulted in a total kilometre distance of 1651.6 km. A general breakdown of these survey lines is shown in Table 1. The bulk of the survey data were regional repetitive scour mapping lines that accounted for over 1300 km of data. These lines were shot in many diverse environments encompassing most of the major physiographic and bathymetric regions of the Beaufort continental shelf. The location of these regional lines are displayed in Figure 3.

TABLE 1 GENERAL BREAKDOWN OF ESRF 1990 LINE DISTANCES

LINE TYPE	TOTAL LINES	DISTANCE (KM)
Regional	44	1389.6
Tingmiark Survey	7	7.8
Scour Tracking Studies		
SCTARN2	13	81.2
SCNEWDP	3	48.2
SCPIP16	5	17.4
SCPIP26	2	33.7
SCPIPEA	2	32.8
SC7	3	40.9
TOTALS	**79**	**1651.6**



NOTES:

1.

LINE NUMBER	START FIX	END FIX
3	214	674
4	675	768
5	769	845
6	846	1100
7	1101	1445
8	1446	1640
9	1641	1720
10	1721	1788
11	1789	2081
12	2082	2123
13	2124	2415
14	2416	2495
15	2496	2784
17	2781	3241
18	3242	3695
19	3696	3861
19A	3872	3982
20	3997	4031
20A	4032	4064
21	4065	4114
22	4115	4224
19C	4225	4294
30	4341	4462
31	4463	4667
32	4668	4707
32A	4708	4869
33	4870	5069
34	5070	5456
35	5457	5549
36	5550	5694
37	5695	5780
38	5781	5858
43	7169	7332
43B	7340	7776
44	7777	7918
45	7919	8046
46	8047	8152
47	8153	8237
51	9086	9196

▨ Detailed Scour Tracking Survey Site

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MARINE GEOPHYSICS AND GEOLOGY

ESRF 90
NAVIGATION TRACKPLOT

DATE : May 11, 1991	FIGURE 3
CHKD. BY : G.G.	SCALE : 1: 1,000,000
DRN. BY : K.H.M.	PROJECTION : U.T.M. Zone 8
CSR PROJECT# : 8933	FILE : NAV90.DWG

A series of 7 lines were also shot to profile the Tingmiark glory hole site. This glory hole may represent a hazard to shipping as it is reported to have the remains of a drilling pipe protruding from the site's dredged depression. Search lines were initially run in a nearby, but incorrect location. The site was subsequently located at a position of 7,786,671N and 576,358E and the protruding pipe successfully identified and profiled by sidescan.

A total of 28 lines were also run to profile and track six unique scours on the Beaufort Shelf. These scour tracking operations are utilized to reveal along track, process-related information over the entire length of the scouring event.

Table 2 is a summary of the survey line statistics and a record of which historical lines were re-shot. For additional information refer to the daily log in Appendix 1.

TABLE 2 LINE PRODUCTION SUMMARY

JUL. DAY	1990 LINE	PREV. LINE	SOL TIME	SOL FIX	EOL FIX	FIX INT	DIST (KM)	COMMENTS
246	1	5C	0633	1	103	200	20.4	TEST LINE
246	2	5C	0919	104	213	200	21.8	PARTIAL LINE N TO S, STARTING AT LEG 5
247	3	8206	0207	214	674	200	92.0	
247	4	2E	1240	675	768	200	18.6	
247	5	2DA	1554	769	845	200	15.2	
247	6	10WEST	1744	846	1100	200	50.8	START OF LINE 6 IS OFFLINE SOMEWHAT
248	7	EMAC	0000	1101	1445	200	68.8	
248	8	TARNEK	1050	1446	1640	200	38.8	
248	9	2B	1609	1641	1720	200	15.8	FINISH LINE AT KADLUK ARTIFICIAL ISLAND
248	10	2B	1825	1721	1788	200	13.4	START LINE ON SOUTH SIDE OF KADLUK
248	11	10WEST	2000	1789	2081	200	58.4	
249	12	10EAST	0244	2082	2123	200	8.2	
249	13	PIPELINE	0511	2124	2415	200	58.2	
249	14	8BN	1252	2416	2495	200	15.8	
249	15	5C	1440	2496	2764	200	53.6	
249	16	10D,DA	2210	2765	2780	200	3.0	FIXES 2765-2769 ARE GOOD, FIXES 2769-2780 ABORTED DUE TO SYLEDIS
249	17	10D,DA	2228	2781	3241	200	92.0	FIXES 3089, 3096 BAD POSITIONS
250	18	11B,A	0837	3242	3695	200	90.6	FIX 3413 BAD POSITION
250	19	9F	2026	3696	3871	200	35.0	FIXES 3696-3861 ARE GOOD, FIXES 3862-3871 ARE ABORTED AS TOO FAR OFFLINE.
251	19A	9F	0059	3872	3982	200	22.0	ABORT LINE DUE TO POOR WEATHER
251	19B	9F	1759	3983	3996	200	2.6	ABORT LINE DUE TO POOR WEATHER
253	20	8204	0543	3997	4031	200	6.8	LINE TERMINATED EARLY DUE TO ICE
253	20A	8204	0706	4032	4064	200	6.4	
253	21	K1	0811	4065	4114	200	9.8	
253	22	9F2	0924	4115	4224	200	21.8	
253	19C	9F	1254	4225	4294	200	13.8	LINE MIS-LABELLED AS 23 IN FIELD. FIX 4270 BAD POSITION
253	24	TING	1645	4295	4300	200	1.0	TINGMIARK GLORY HOLE SURVEY
253	25	TING	1706	4301	4306	200	1.0	TINGMIARK GLORY HOLE SURVEY
253	26	TING	1729	4307	4318	200	2.2	TINGMIARK GLORY HOLE SURVEY
253	27	TING	1750	4319	4324	200	1.0	TINGMIARK GLORY HOLE SURVEY
253	28	TING	1810	4325	4330	200	1.0	TINGMIARK GLORY HOLE SURVEY
253	28A	TING	1833	4331	4334	200	.6	TINGMIARK GLORY HOLE SURVEY. RE-RUN OF LINE 28
253	29	TING	1851	4335	4340	200	1.0	TINGMIARK GLORY HOLE SURVEY
253	30	TINGNERL	1938	4341	4462	200	24.2	LINE TERMINATED EARLY DUE TO ICE
254	31	SUR8801	0026	4463	4667	200	40.8	
254	32	SUR8807	0529	4668	4707	200	7.8	BAD FIX AT 4707
254	32A	SUR8807	0624	4708	4869	200	32.2	
254	33	TY8802	1026	4870	5069	200	39.8	
254	34	TY8801	1509	5070	5456	200	77.2	DETOUR AROUND KAUBVIK FIXES 5226-5246 (NO NAV. BREAK)
254	35	TY8521	2335	5457	5549	200	18.4	
255	36	TY8520	0213	5550	5694	200	28.8	LINE TO END AT FIX 5686, BUT WAS EXTENDED TO TRACK A SCOUR TO 5694
255	37	GHR8207	0713	5695	5780	200	17.0	
255	38	SAUVC	0949	5781	5858	200	15.4	
255	39	SCTARN2	1315	5859	6151	100	29.2	SCOUR TRACKING EVENT, DURING LINE SWITCH FROM 200M TO 100M FIXING.
255	39A	SCTARN2	1906	6152	6165	100	1.3	SCOUR TRACKING EVENT, ABORTED DUE TO LOSS OF SCOUR
255	39B	SCTARN2	1935	6166	6181	100	1.5	SCOUR TRACKING EVENT, ABORTED DUE TO LOSS OF SCOUR
255	39C	SCTARN2	2011	6182	6192	100	1.0	SCOUR TRACKING EVENT, ABORTED DUE TO LOSS OF SCOUR
255	40A	SCTARN2	2040	6193	6213	100	2.0	SCOUR TRACKING GRID TO FIND DIRECTION
255	40F	SCTARN2	2116	6214	6239	100	2.5	SCOUR TRACKING GRID TO FIND DIRECTION
255	40B	SCTARN2	2147	6240	6260	100	2.0	SCOUR TRACKING GRID TO FIND DIRECTION
255	40E	SCTARN2	2215	6261	6279	100	1.8	SCOUR TRACKING GRID TO FIND DIRECTION
255	40C	SCTARN2	2244	6280	6300	100	2.0	SCOUR TRACKING GRID TO FIND DIRECTION
255	40EE	SCTARN2	2307	6301	6325	100	2.4	SCOUR TRACKING GRID TO FIND DIRECTION
255	40D	SCTARN2	2337	6326	6349	100	2.3	SCOUR TRACKING GRID TO FIND DIRECTION
256	41	SCTARN2	0124	6350	6618	100	26.8	SCOUR TRACKING, DIRECTION FOUND THEN LOST
256	41A	SCTARN2	0500	6619	6683	100	6.4	SCOUR TRACKING, CONTINUE ON SCOUR THEN LOST
256	42	SCNEWDP	0815	6684	6841	100	15.7	SCOUR TRACKING
256	42A	SCNEWDP	1103	6842	7087	100	24.5	SCOUR TRACKING
256	42B	SCNEWDP	1508	7088	7168	100	8.0	SCOUR TRACKING
256	43	GHR8208	1704	7169	7320	200	30.2	LINE TERMINATED EARLY DUE TO ICE
256	43A	GHR8208	2026	7321	7339	200	3.6	LAST GOOD FIX WAS 7332
256	43B	GHR8208	2057	7340	7776	200	87.2	
257	44	8B	0833	7777	7918	200	28.2	LINE ENDED 8KM EARLY TO MERGE WITH NEXT LINE
257	45	M2A	1202	7919	8046	200	25.4	
257	46	3DA	1713	8047	8152	200	21.0	
257	47	3D	1955	8153	8237	200	16.8	
258	48	SCPIP16	0024	8238	8265	100	2.7	SCOUR TRACKING, PIPELINE ROUTE, CENTRE LINE 16M
258	48A	SCPIP16	0059	8266	8304	100	3.8	SCOUR TRACKING, PIPELINE ROUTE, CENTRE LINE 16M
258	48B	SCPIP16	0202	8305	8352	100	4.7	SCOUR TRACKING, PIPELINE ROUTE, CENTRE LINE 16M
258	48C	SCPIP16	0258	8353	8370	100	1.7	SCOUR TRACKING, PIPELINE ROUTE, CENTRE LINE 16M
258	48D	SCPIP16	0343	8371	8416	100	4.5	SCOUR TRACKING, PIPELINE ROUTE, CENTRE LINE 16M
258	49	SCPIP26	0534	8417	8444	100	2.7	SCOUR TRACKING, PIPELINE ROUTE, CENTRE LINE 26M, NEW
258	49A	SCPIP26	0615	8445	8755	100	31.0	SCOUR TRACKING, PIPELINE ROUTE, CENTRE LINE 26M, NEW
258	50	SCPIPEA	1031	8756	8848	100	9.2	SCOUR TRACKING, PIPELINE ROUTE, EASTERN LINE
258	50A	SCPIPEA	1152	8849	9085	100	23.6	SCOUR TRACKING, PIPELINE ROUTE, EASTERN LINE
258	51	M3	1647	9086	9196	200	22.0	BACK TO REGIONAL LINES
258	52	SC7	2103	9197	9211	100	1.4	SCOUR TRACKING, PIPELINE ROUTE, SCOUR 7 TO EAST
258	52A	SC7	2121	9212	9234	100	2.2	SCOUR TRACKING, PIPELINE ROUTE, SCOUR 7 TO EAST/SCOUR LOST
258	52B	SC7	2159	9235	9608	100	37.3	SCOUR TRACKING, PIPELINE ROUTE, SCOUR 7 TO WEST

TOTAL LINE DISTANCE (KM): 1651.6

2.0 SURVEY PERSONNEL

The success of this survey was realized through the competence of the individuals involved in the ship's operations and in the acquisition of the scientific data sets.

The scientific team was composed of 3 geophysical operators, 2 Syledis/Argo operators and 2 geoscience technicians. This combination of personnel (especially the number of geophysical operators) was found to be desirable such that equipment downtime could be minimized and the collection of high quality data sets could be assured. The following list documents the names, functions and affiliations of the key personnel involved in the 1990 program.

STATUS	NAME	FUNCTION	AFFILIATION
SHIP'S CREW			
Gov't	F. Ali	Captain	Coast Guard
"	Don Sweeny	First Officer	"
"	Garry Mc Donnel	Second Officer	"
"	Yvette Myers	Third Officer	"
"	Mark Decker	Chief Engineer	"
"	Wayne Woo	First Engineer	"
"	Rinhart Veltheer	Bosun	"
"	Jack Roberts	Seaman	"
"	Greg Locke	Seaman	"
"	Ray Lapinski	Seaman	"
"	D. Carriere	Seaman	"
"	Bob Comin	Oiler	"
"	K. Proudman	Oiler	"
"	Ed Helbig	Cook	"
"	Eloise Sweeny	Steward	"
SCIENTIFIC CREW			
Gov't	Steve Blasco	Scientific Authority	AGC Dartmouth
"	Bob Harmes	Geoscience Technician	AGC Dartmouth
"	Mike Hughes	Geoscience Technician	AGC Dartmouth
Contractors	Glen Gilbert	Survey Manager	CSR Halifax
"	John Lewis	Geophysicist/Tech	CSR (Consult)
"	Jim Shearer	Geophysicist	CSR (Consult)
"	Christy Thompson	Syledis Operator	Challenger
"	Dave Johnson	Syledis Operator	Challenger
"	Tim Harding *	Systems Engineer	Challenger

* Mr. Harding was present during the mobilization phase of this survey only.

3.0 LOGISTICS

Logistical support for the ESRF 1990 field program was provided through the combined efforts of the Geological Survey of Canada and Canadian Seabed Research Ltd.

During the mobilization phase, most of the rental equipment was organized and crated by CSR at their Halifax offices. The gear was then picked up and shipped by air freight to Inuvik by AGC. As the date for mobilization approached, late shipments were handled commercially at guaranteed rates direct to Inuvik. The navigation equipment was mobilized and shipped totally out of Edmonton by Challenger Surveys. All equipment arrived undamaged and on schedule at the Inuvik Scientific Research Centre. CSR's sidescan winch arrived later than the rest of the gear but still on time. All gear was subsequently trucked and offloaded onto the Nahidik at her berth on the MacKenzie River. This year all mobilization took place at Inuvik, and no equipment had to be shipped to Tuktoyaktuk.

The heavy and bulky equipment, such as the AGC sidescan sonar winch and generator were trucked to Inuvik, where they were transferred to the Nahidik by crane. The new AGC seismic shack was fitted out in Halifax in the spring and later trucked north. It was stored in the yard at the Research Centre and then transferred to the Nahidik using a flat bed truck and crane. The accommodations modules were stored in Tuk at Polar Shelf and were installed at this location before the Nahidik came up river.

Upon survey completion, all gear was packed for shipping by CSR/AGC personnel. In order to reduce costs, all contract personnel departed out of Tuk rather than take the long trip upriver. The Nahidik was demobilized by AGC personnel in Inuvik with all contract gear being shipped south by airfreight. The equipment rental charges were thus minimized by effective shipping both ways with AGC personnel monitoring the transferral of the gear. (Some rental navigation equipment, however, did manage to get side tracked in Inuvik by Points North upon demobilization). Heavier equipment such as the sidescan sonar winch and generator were trucked south. The AGC seismic shack and accommodation trailers were stored in Inuvik and Tuk respectively.

4.0 SURVEY VESSEL AND EQUIPMENT LAYOUT

4.1 MAIN SURVEY VESSEL

The main operations vessel utilized for the ESRF 1990 repetitive mapping program was the C.C.G.S. Nahidik, a Canadian Coast Guard vessel based out of Hay River, N.W.T. (See Figure 4). This vessel was used as the main operations vessel responsible for running the regional line network established for the Beaufort Shelf region. The shallow draft nature (4-6 ft) of the Nahidik proved to be advantageous for surveys of this nature as it could be safely navigated throughout coastal regions and thereby collect data in difficult shallow water areas. This vessel was also outfitted with comfortable accommodations modules on the Helicopter deck allowing for 8 scientific personnel to be housed.

Noteworthy specifications of the Nahidik are documented below.

C.C.G.S. NAHIDIK

Official #:	347496
Class of Voyage:	Home Trade Class II
Date Built:	1974
Dimensions:	
Length:	175 ft
Beam:	50 ft
Depth:	10 ft
Draft:	4-6 ft
Gross Tonnage:	855.86
Propulsion:	2-GM 12-645E5 Engines @ 4300 BHP
Speed Cruising:	13.5 Knots
Navigation:	Racon Radar Navigation Magnavox Mx 5102 Satellite Receiver ELAC Echo Sounder

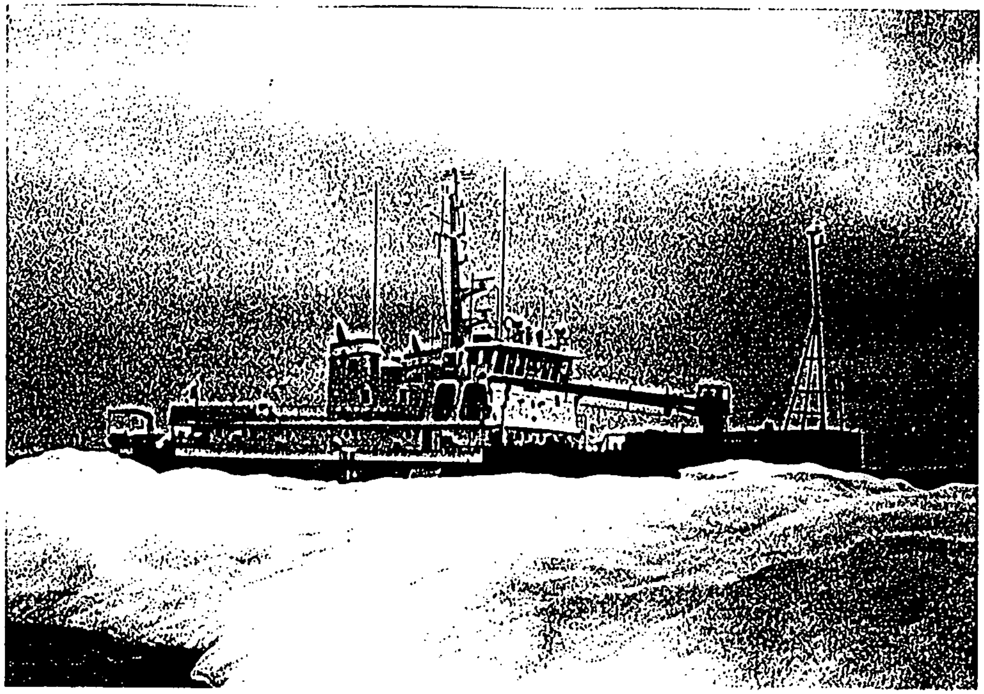

FIGURE 4 CCGS NAHIDIK

4.2 DECK EQUIPMENT AND LAYOUT

A scaled plan of the fore-deck and equipment layout (Figure 5) illustrates the spatial relationships of the seismic container, equipment locations and power generator, relative to the ship's bulkheads and 10-ton crane.

Note that all equipment was located in the bow section of the Nahidik for the ESRF 1990 survey. The sidescan system was boomed off the port side using the 10-ton crane. The length of the crane arm facilitated the launch and recovery operations of the sidescan tow-fish. The primary sidescan winch was positioned adjacent to the crane boom on the fore-deck. The CSR back-up winch was also chained down on the fore deck in a position where it could be utilized if necessary. We did not have a problem with the primary winch system for the duration of the survey. The 20 Kw generator used to power the winch was mounted forward on the starboard side. This unit was completely self-contained and worked well throughout the survey.

This year the AGC seismic container was mounted cross-ship directly forward of the main bulkhead. This location proved quite suitable, although it is also noted that this year we had relatively calm weather compared to previous survey seasons. Last year, for example, the container received a lot of spray and, on occasion, "green water", with some damage occurring. This forward location did prove ideal for proximity to the sidescan winch and for cabling operations between the container and the wheelhouse.

The over-the-side mount for the sub-bottom profiler and the echo sounder transducer was mounted on the starboard side as close to the container as possible to minimize signal loss due to excess cabling. This year we had a problem with the SBP/mount coupler. The transducer broke free onto it's safety strap in rough seas. This problem was solved by cable wiring the transducer mount onto the pipe fitting. The threaded pipe coupler should be replaced for future surveys. Other than this, the mount worked quite well, especially since it has been extended deeper, thus achieving better records in poor sea conditions.

RECOMMENDATIONS

Fix threaded pipe coupler for Sub-bottom profile mount.

4.3 AGC SEISMIC CONTAINER AND EQUIPMENT LAYOUT

This year a new seismic container was provided by the GSC. This container measured 8'x 20' and was outfitted with tables, power supplies/transformers, power bars, and heat and lights. This new container proved quite suitable for geophysical operations mainly since it had adequate space, regulated power, and was dry and comfortable.

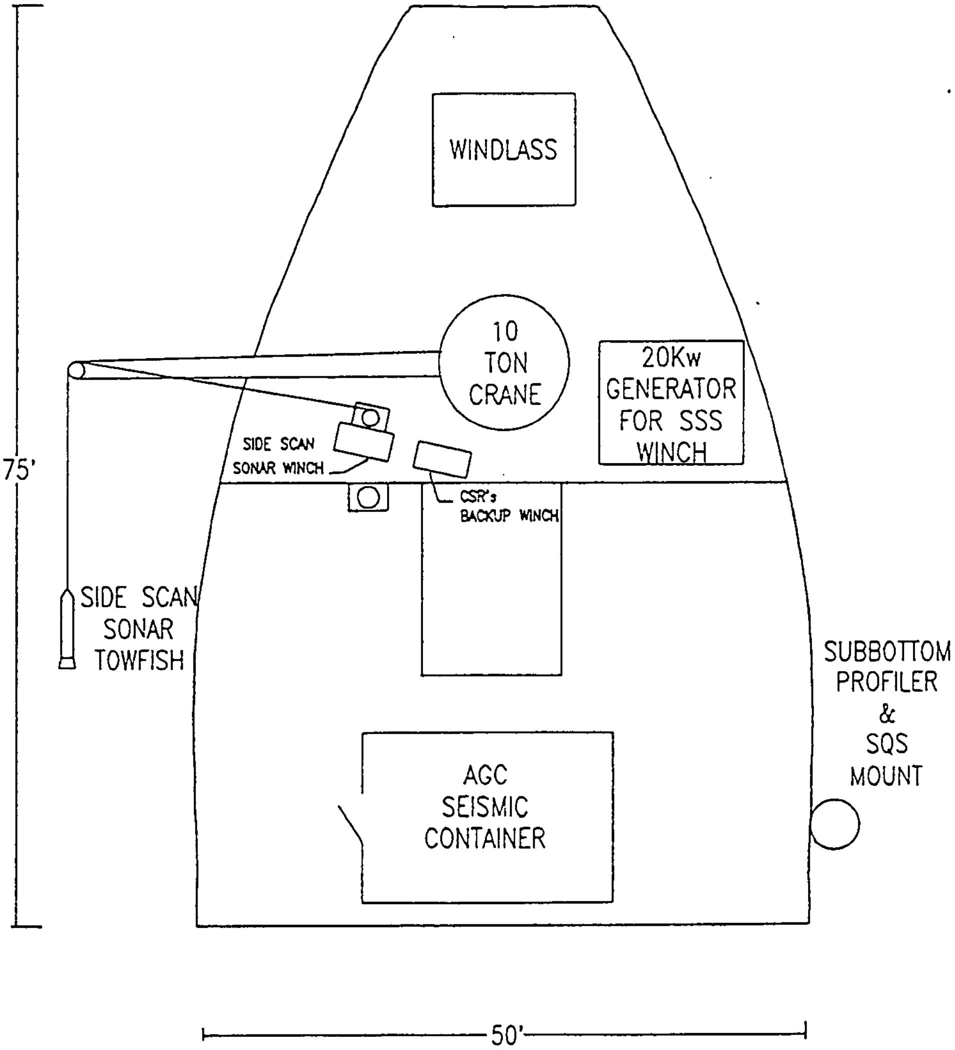

FIGURE 5 CCGS NAHIDIK DECK LAYOUT

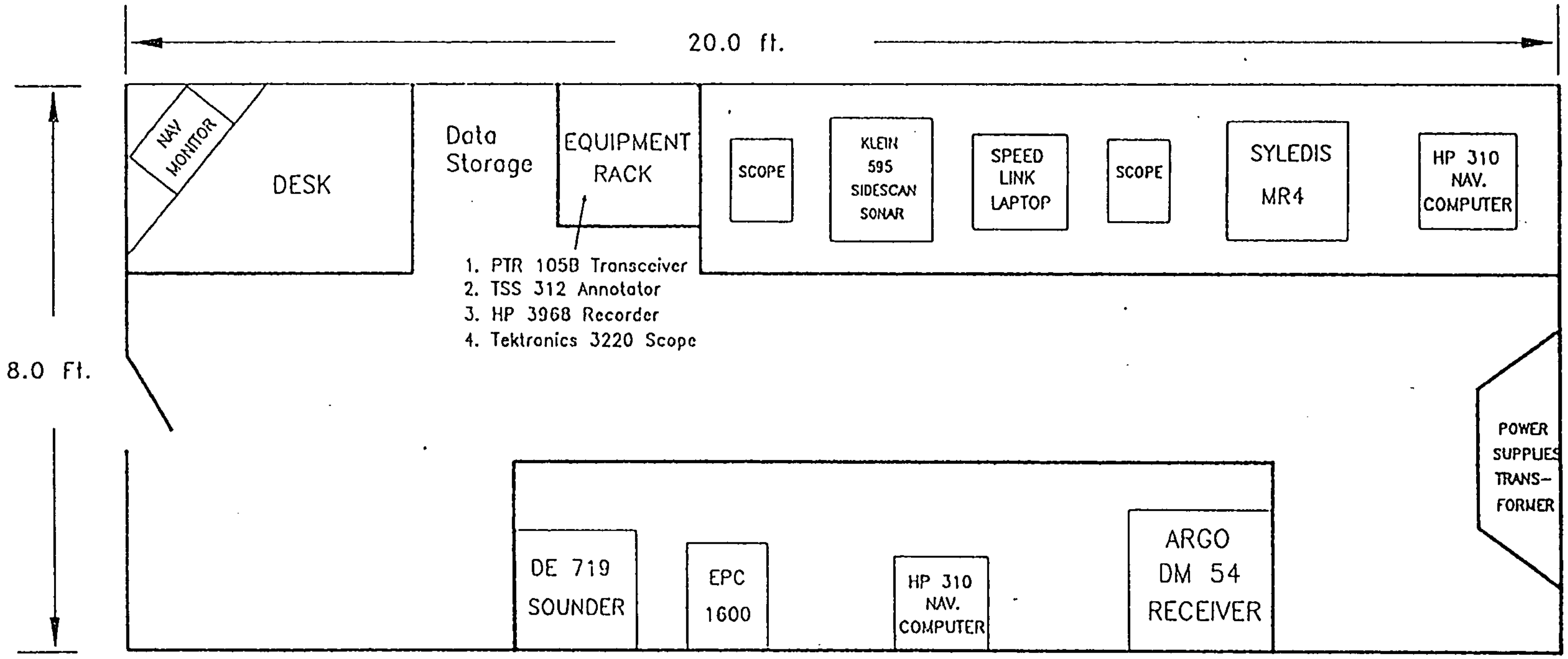

FIGURE 6 SEISMIC CONTAINER AND EQUIPMENT LAYOUT

Cdn Seabed Research Ltd.

A schematic layout of the AGC seismic container and the geophysical equipment is shown in Figure 6. As can be seen in this figure, little space is available for survey planning using large maps in the container. Ultimately, Gilbert set up the SCOURBASE computer in an empty ship's cabin and undertook all survey planning at that location.

RECOMMENDATIONS

Some power fluctuations were experienced which sent the Navigation computers down. This problem should be examined in more detail.

The exhaust fan capacity should be increased to effectively clear the container of EPC smoke and stale air.

Additional overhead shelf space for equipment manuals/equipment etc. would be useful.

5.0 GEOPHYSICAL EQUIPMENT

5.1 SIDESCAN SONAR SYSTEM

A Klein sidescan system was used to produce scale rectified images of the seafloor in order that detailed scour measurements could be made with the resultant data. The Klein system was chosen due to its scale correction capability, its third channel capability, its high resolution at 100khz frequencies and its demonstrated reliability during previous surveys.

The sidescan system setup was an integrated package that was designed and configured to accommodate navigation speed input, data output for taping purposes, AGC winch and cable wiring anomalies, and a new third channel microprofiler system. The overall sidescan system diagram is presented in Figure 7. This figure also indicates the comprehensive level of backup systems that were available in the event of equipment malfunction. This level of backup is one of the primary reasons for the success of the ESRF 1990 program.

5.1.1 KLEIN 595 SIDESCAN SONAR RECORDER

CSR provided their new state-of-the-art, four channel, 595 Klein sidescan sonar system for the 1990 ESRF Repetitive Mapping Survey. The system offers complete real-time, scale rectification, as well as, water column removal and aspect ratio correction. CSR configured this system with manual, rather than digital tuning such that the operator has complete control over enhancing contrast and gain settings for optimal resolution. Tape output and speed input are standard for this system.

This self-contained system has a four channel display which can be used to considerable advantage for ice scour surveys. CSR configured the recorder to display sidescan and profile data in either of two modes. The first method displayed the sidescan data across channels 1 and 2, expanded out port sidescan data (similar to altimeter data) across channel 5 and simultaneous microprofiler data across channel 6. This configuration proved useful in order to compare the scour depth differences between the two profiling devices. Once enough comparative data had been collected, channels 5 and 6 were selected to display the full range of the very accurate microprofiler data. This was desirable in order to maximize the scale presentation of the scour depth data and to illustrate sediment infill details where applicable.

Range scale selections used during this survey were typically 150m and sometimes 100m in shallower waters. Additional specifications of this recorder are provided in Appendix 2.

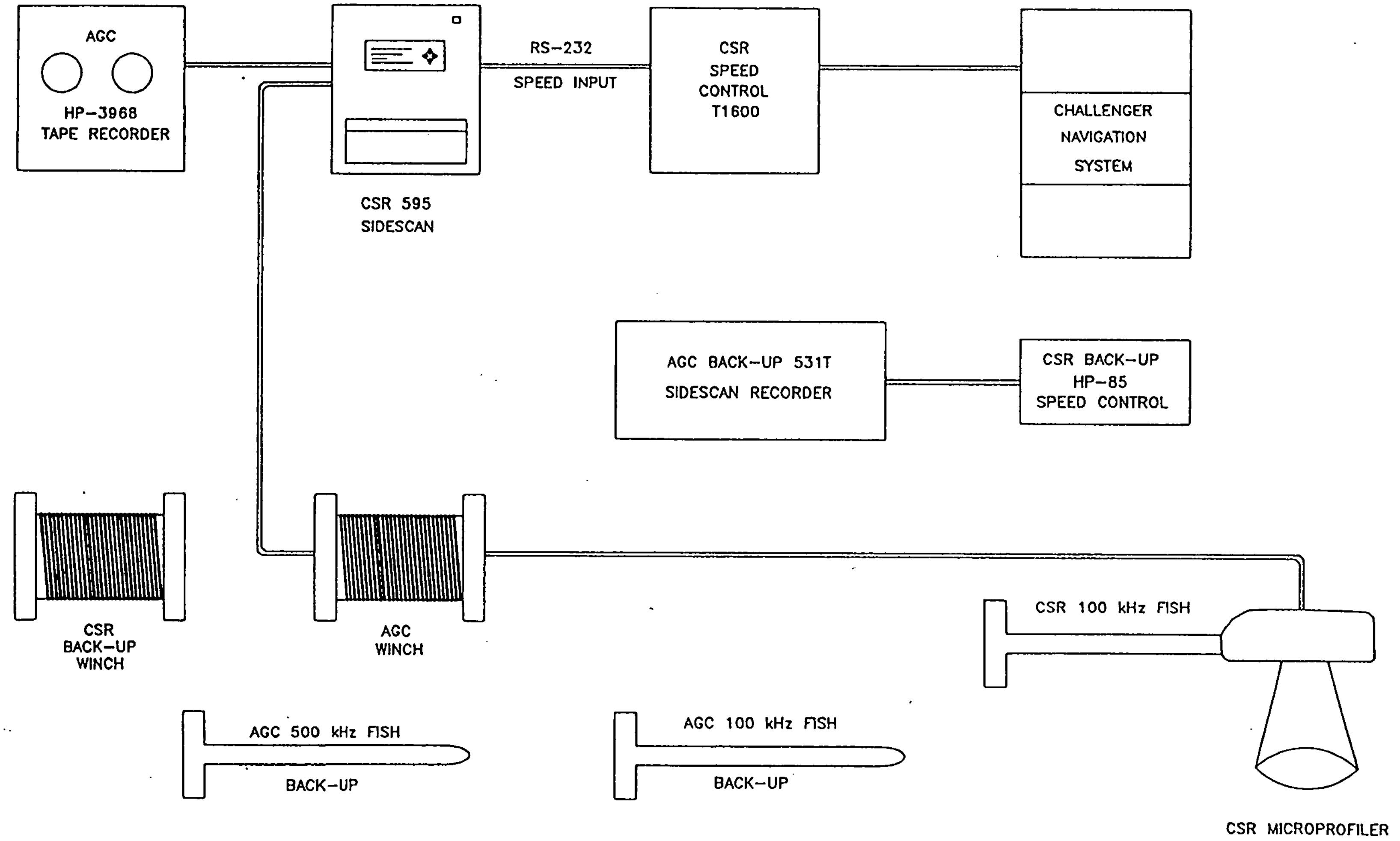

FIGURE 7 SIDE SCAN SONAR SYSTEM COMPONENT DIAGRAM.

A complete backup sidescan system was provided by AGC which was composed of the following components.

KLEIN 531T Recorder
KLEIN 606 Slant Range/Speed Correction
KLEIN 611 Record Expander
KLEIN 100 kHz Tow-fish (AGC)
KLEIN 500 kHz Tow-fish (AGC)
KLEIN K Wing Fish Depressor (AGC)

PERFORMANCE

Operationally, the Klein 595 system worked flawlessly throughout the survey, producing high quality acoustic images such as those presented in Figure 8. The moderate sea states this year allowed the collection of very good quality images. Since the system operates using thermal paper, rather than the old helix blade system, little maintenance was required and no down time of the sidescan system was experienced.

One problem that did occur during the survey, resulted in a poor contrast and gain range to be displayed only on the starboard channel. This was eventually tracked to the AGC winch/cable and did not result from the Klein recorder. Another problem involved the speed transfer to the Klein. This resulted in the paper drive speeding up or slowing down for about 1 sec. which would distort the paper records slightly. This minor problem could not be traced and rectified during the survey.

5.1.2 SIDESCAN SONAR TOW-FISH AND MICROPROFILER

The "wet end" of the sonar system included a range of 3 different tow-fish types and a new Microprofiler System mounted in the sub-bottom profiler pod. The appropriate specifications of these tools are listed below with additional information presented in Appendix 2.

KLEIN EQUIPMENT	SPECIFICATIONS	OWNER	USED
100 kHz Fish	1 degree beam	CSR	yes
100 kHz Fish	3/4 degree beam	AGC	1 day
500 kHz Fish	3/4 degree beam	AGC	no
100 kHz Microprofiler	8 degree beam	CSR	yes

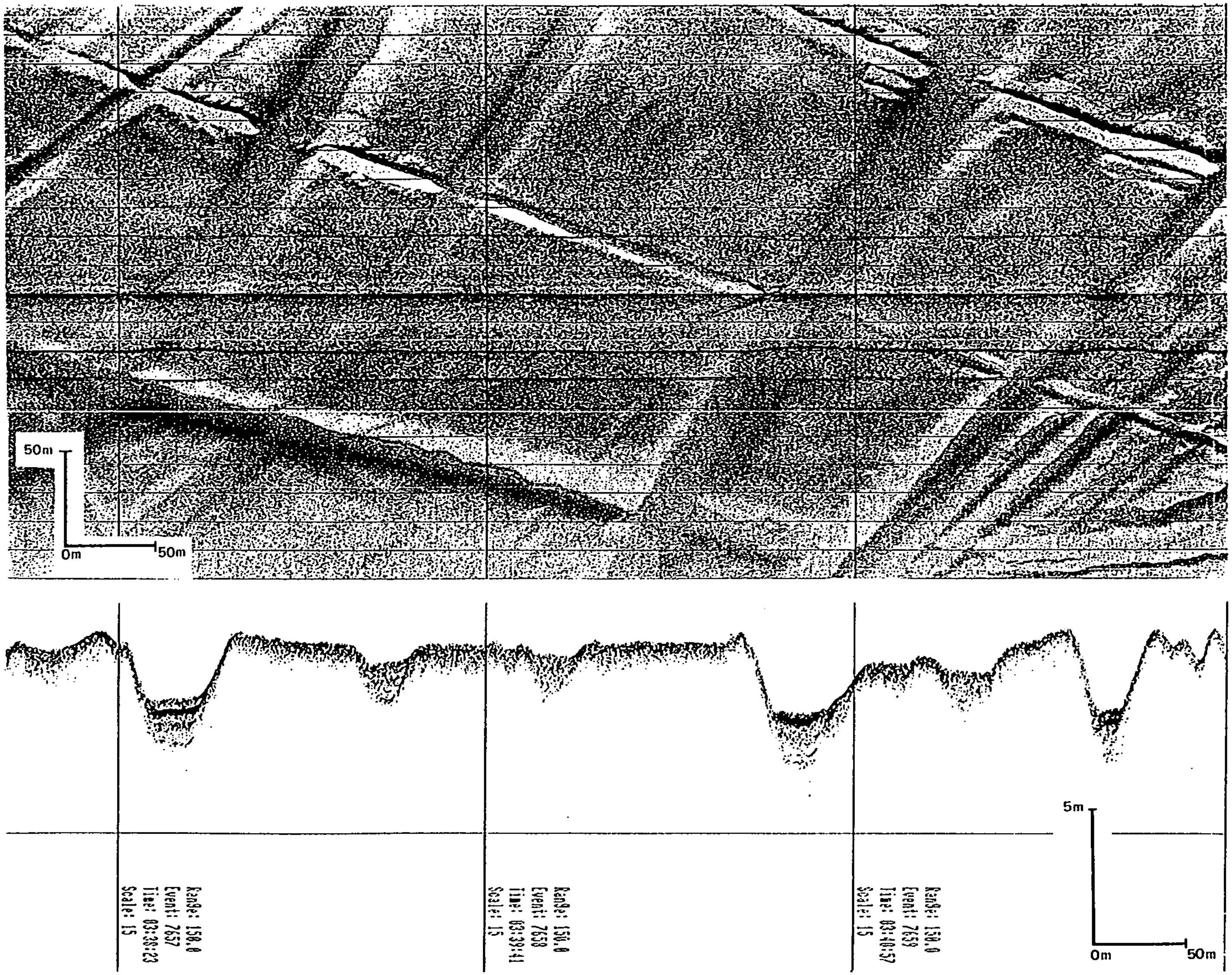

Figure 8 EXAMPLE OF KLEIN 595 SIDE SCAN AND MICROPROFILER DATA

The Klein microprofiler is a high resolution echo sounder which is used to produce sharp detail of the seafloor topography. This system differs from conventional sounders in that it uses a narrower beam, shorter pulse length and it is towed closer to the seafloor. Consequently, the Microprofiler is able to detect very subtle seafloor features and is therefore an ideal tool for scour depth determination.

The system was configured by CSR in conjunction with Klein. The microprofiler transducer replaced the 3.5 kHz sub-bottom profiler transducer in the sub-bottom towing pod as shown in Figure 9. The wiring setup included the use of a spare CSR 100 kHz tow-fish and a series of jumper cables to correctly configure the system to AGC wiring. A detailed wiring diagram is shown in Figure 10.

PERFORMANCE

The records produced by the microprofiler system proved to be so accurate, that scour depths derived from all our previous surveys may have to be revised. The resolution of sediment infill in many of the scours, as shown in Figure 8, was also not expected. This system clearly resolves fine bands of clay infill in many of the scours which implies that scour depths are actually deeper than those previously measured. A small study is presently underway at CSR to evaluate the implications of this excellent data set in light of previous measurements.

Minor problems occurred with the Microprofiler system. The recorder display board must be the 100 kHz TVG board in order to correctly represent the frequency band of the data. It is also important to pull out the starboard pre-amp board in the tow-fish electronics bottle in order to eliminate high voltage arcing in the water. Plugging the Kintec connecters was not sufficient. Transducer grounding problems may also have to be re-evaluated.

5.1.3 SIDESCAN SONAR SPEED LINK SYSTEMS

Speed transfer from the navigation system to the Klein is required for accurate aspect ratio correction. This year, CSR introduced a new speed interface for the Klein 595 recorder which was designed to read the navigation string from the data logging computer and transfer the speed word to the Klein (about every 3 seconds) in an acceptable format string.

Figure 9 KLEIN MICROPROFILER SYSTEM

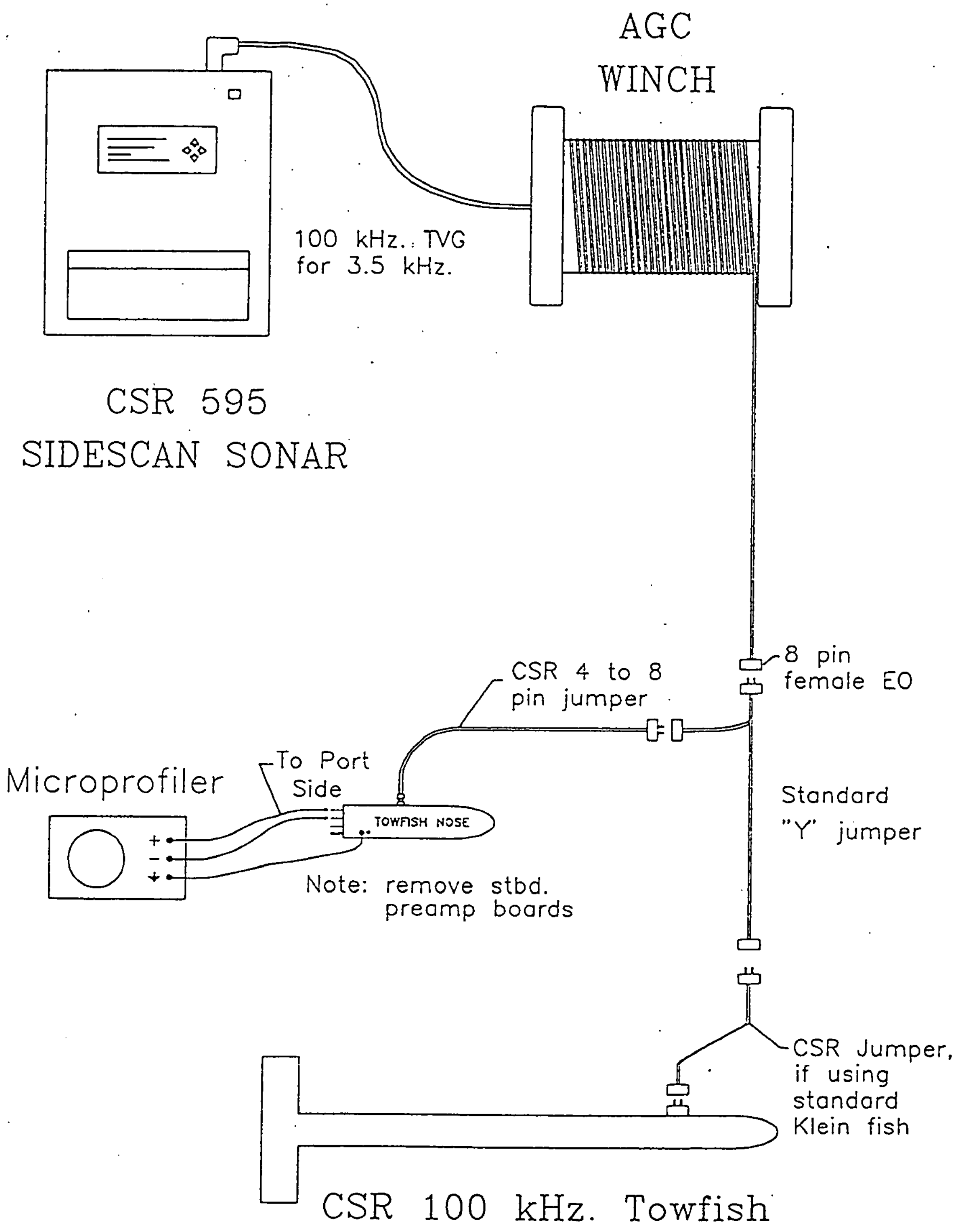

FIGURE 10 MICROPROFILER/TOWFISH WIRING DIAGRAM

The communication parameters for this program are as follows;

Baud Rate: 9600
Data Bits: 8
Stop Bit: 1
Parity: none

Navigation String Format:

```
#####Y+#######.#X+#######.#V####
Fix  Northing   Easting    Velocity (Knots)
```

This MS-DOS based program was also designed to simultaneously log the navigation data on a Laptop computer. This routine functioned well throughout the survey, with the only problem being intermittent speed fluctuations causing small compressions or expansions in the paper data. This problem could not be isolated during the survey, although we suspect that either the Recorder is at fault or electrical noise along the RS-232 cables may have caused the problem.

A backup speed link system for the 531 T Klein system was also provided by CSR in the event that this sidescan was required. This system is composed of a HP-85 computer and Speed2 software and has been successfully used during the Nahidik89 survey. This backup Klein 531 T recorder and this speed control system were not utilized during the ESRF 1990 survey.

5.1.4 SIDESCAN SONAR WINCHES

The primary sidescan sonar winch was supplied by GSC. This Klein electro-hydraulic winch was fitted out with a remote control switch this year which helped facilitate quick fish height changes. However, one problem with this remote switch was that if the power was left on to the winch, it would slowly pay out. This resulted in the fish hitting the bottom on more than one occasion. Another problem that occurred throughout the duration of the survey was very poor transmission on the starboard channel sidescan record. This problem was isolated to somewhere in the winch/cabling system but could not be further traced while at sea. It is recommended that this fault be rectified for future surveys as the sonar data was considerably degraded by this problem especially near the end of the survey.

CSR provided a small electrical backup winch in event of failure of the primary system. This winch holds 150m of cable and has a remote control system. It's lifting capacity is capable of handling the sidescan fish along with a K Wing depressor, but due to it's small motor and gear reduction it is not capable of lifting the heavy sub-bottom profiler pod.

5.1.5 HP 3968 DATA TAPING SYSTEM

An HP 3968 8 channel tape recorder was provided by AGC for the survey. This unit has functioned well during previous surveys, however, considerable problems were experienced this year. The main problem related to the boards being FM positive or negative, in relation to the Klein 595 output. This unit was utilized during the survey, but also examined in detail between survey lines to clarify the validity of the taped data. Most of these checks revealed poor signal lock for synchronization. It is recommended that this unit be given a complete checkout before going out into the field next year. The following channel allocations were utilized this year.

HP 3968 TAPE DECK CHANNEL ALLOCATIONS

CHANNEL	SYSTEM
1.	Trigger Sync SSS
2.	n/a
3.	Port SSS
4.	Starboard SSS
5.	-
6.	-
7.	Direct SSS Profiler
8.	FM Bipolar Annotation and Voice

5.2 RAYTHEON RTT-1000 SUB-BOTTOM PROFILER

The RTT-1000 sub-bottom profiling unit was used to record seabed substrate and shallow sub-bottom geological conditions for later correlation with ice scour data acquired by sidescan. The primary advantage of this system is that it can distinguish between sand and clay sediments and also offer penetration to identify sub-bottom geological units.

The system consisted of a PTR model 106A transceiver unit driving a TC-7 transducer mounted on an over-the-side mount. This unit features a dual frequency 3.5/7.0 khz capability, automatic initial and bottom triggered time variable gain, a no-ring transducer and a receiver tailored to high resolution profiling requirements in shallow water. The data was displayed on an EPC Model 1600 graphic recorder using a typical sweep speed of 10 msec. See Figure 11 for a wiring diagram.

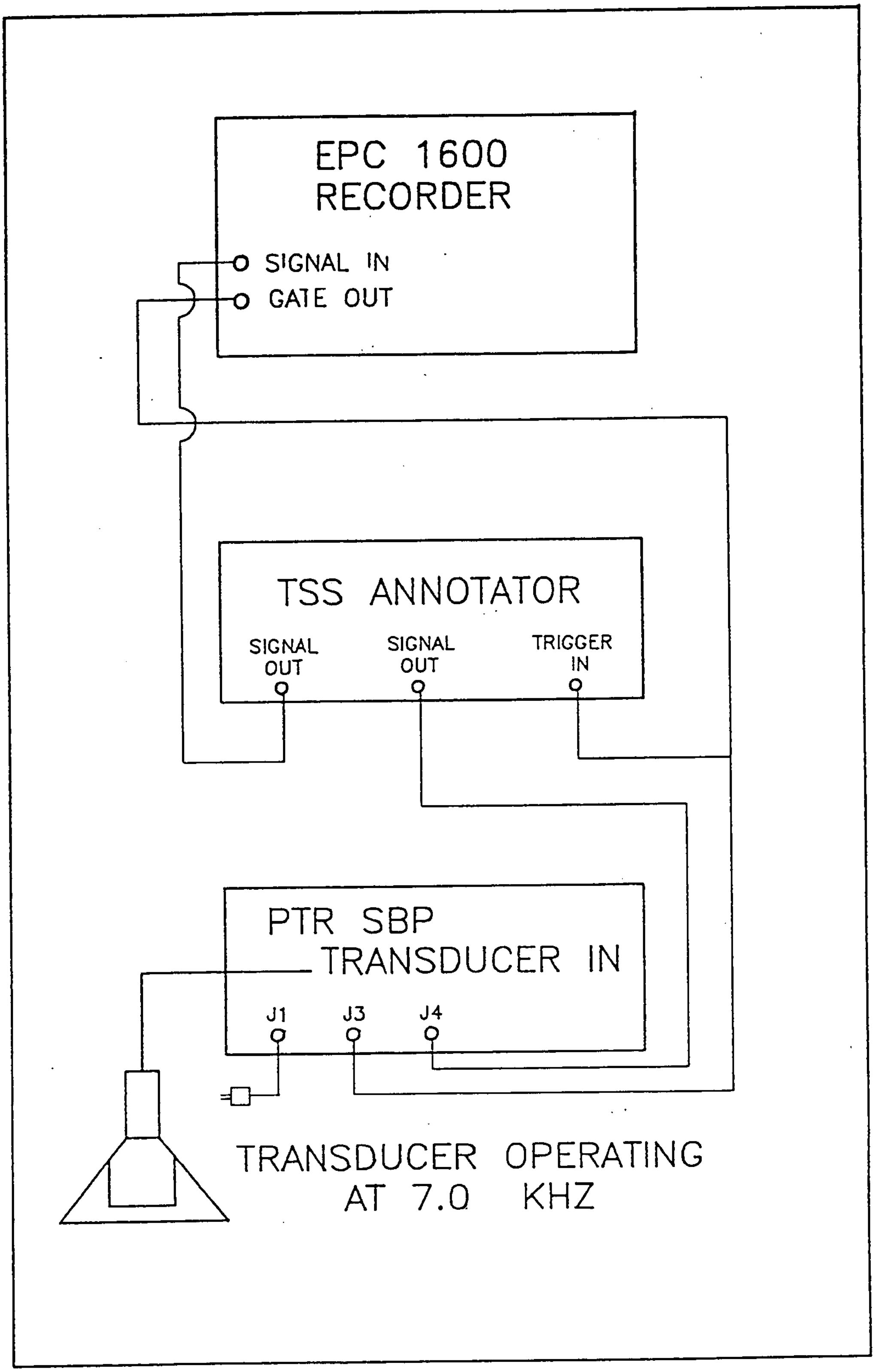

Figure 11 PTR Subbottom Profile System

The system components are listed below with more detailed specifications in Appendix 2.

SYSTEM COMPONENTS

PTR 106A Transceiver
Model TC-7 Transducer (Mounted over the side, draft 1.4m)
EPC Model 1600 Analogue Graphic Recorder
Interface to TSS Record Annotator

TYPICAL SETTINGS

Pulse Width:	0.1ms
Bottom Ramp Slope:	2-3
Frequency:	7 kHz
Gain Level:	2-5
BT-TVG	Low Out
Power Output:	0db

PERFORMANCE

The RTT-1000 sub-bottom profiler performed quite well throughout the duration of the survey. This system proved itself to be a good shallow water profiler and required low gain and power output settings for the whole survey. The 7.0 khz frequency was used as this frequency provided the best quality data. The 3.5 khz setting produced slightly better penetration but also a considerable amount of noise on the records that could not be removed by tuning. It is possible that this system was not correctly set up for dual frequency operation.

The over-the-side mount for the sub-bottom profiler and the echo sounder transducer was installed on the starboard side as close to the container as possible to minimize signal loss due to excess cabling. This year we had a problem with the SBP/mount coupling where on one occasion the transducer broke free onto it's safety strap in rough seas. This problem was solved by cable wiring the transducer mount onto the pipe fitting. The threaded pipe coupler should be replaced for future surveys. Other than this, the mount worked quite well, especially since it had been extended deeper since last year, thus achieving better records in poor sea conditions.

The sub-bottom data was recorded on an EPC 1600 graphic recorder set at a sweep speed of 10 msec. This compact recorder worked very well throughout the survey with only minor belt changes required. It is important to note that these recorders often malfunction and complete backup is a definite requirement.

5.3 ECHO SOUNDER

A Raytheon DE 719B echo sounder was supplied by AGC to monitor bathymetry and record scour depth throughout the survey. This sounder is a high resolution survey fathometer which utilizes an 8 degree transducer transmitting at 208 kHz. The transducer was mounted on the over-the-side mount just forward of the large sub-bottom profiler transducer (draft 1.4m).

Bar checks were performed at the beginning and end of the survey sessions and the sounder calibrated if necessary. It was found that this unit did not drift appreciably and little calibration was required. Navigation tagging was accomplished by a closure transmitted from the navigation to the Raytheon recorder for each fix event.

This system worked well with the exception of two problems. First there was an inadequate supply of metric sounder paper which required us to utilize slow paper speeds (1"/min) and eventually imperial paper (starting at Line 17). Secondly, the chart paper take-up spool kept slipping which negatively effected the data quality and operation of the sounder in general. This unit should be checked out and the take-up unit replaced if necessary.

CSR has developed a bathymetry package called the SQS system which is an integrated software and hardware package that stores and processes echo sounder data received from the seafloor to yield accurate bottom feature measurements. More specifically, the signals are digitized, filtered and numerically processed to yield precise scour depth data and downloaded to a data base or GIS environment. It is recommended that this system be used for future scour surveys and that further integration of this unit with the microprofiler data stream be supported. This digital concept will eliminate a series of tedious steps towards scour depth measurement and will make those readings more accurately and with a greater degree of repeatability.

5.4 SCOURBASE SYSTEM

SCOURBASE is a microcomputer based software system that stores and manipulates the Beaufort Sea Ice Scour Data Base System. The SCOURBASE system was used onboard the ESRF 1990 survey as a tool for accessing and retrieving relevant survey track and scour data required during the cruise. This system is the property of CSR and is composed of the following hardware and software components.

AST Premium\286 Microcomputer 70 Meg Hard drive.
HP 7475A Pen Plotter
EPSON FX-85 Printer
Microsoft Mouse
SCOURBASE\FOXBASE Software
GEOCAD Mapping Software
Contouring/3-D Display Software
GIS Software (can be added)

PERFORMANCE

The SCOURBASE system proved very useful in rapidly selecting the specific x,y line coordinates required for repetitive survey, while in an active survey mode. This data was posted to a digital file and a hard copy printout. The print out was utilized by the navigators for manual input to the HP 310 navigation computer and by the bridge for plotting purposes. The system also contains routines for conversion of UTM to Geographic coordinates so that the ship's navigators could plot the proposed lines on hydrographic charts.

SCOURBASE was also used to perform online queries for extreme scour events in the data base. Events such as the longest, deepest scours etc. could be readily located and important attributes such as UTM coordinates posted to the printer. Many of these scours were then tracked to confirm the data values residing in the data base and to reveal information regarding rise-up.

Other products such as distributions, regressions, rose diagrams, contour and 3 dimensional data plots are all possible for certain regions, sediment types or water depths of the Beaufort Shelf using this system.

It is recommended that this system be upgraded with CSR's new GIS and SQS capabilities and be utilized in the future on high resolution geophysical surveys. It is also recommended that this system and the SQS system be distinct so that each can operate independently, while in an active survey mode.

5.5 TSS RECORD ANNOTATOR

The TSS record Annotator is a microprocessor based electronics unit which allows for automatic annotation of up to 4 geophysical instruments using graphic recorders. The time, date, fix number and a 40 character comment string may be applied to each fix annotation on the record. This system is microprocessor controlled and therefore automatically increments the fixes and keeps track of time on it's own clock. The system is composed of the following components which are described in more detail in Appendix 2.

SYSTEM COMPONENTS

Electronics unit with 12 key keypad, LED display and microprocessor.
External Touch Sensitive Keyboard

The TSS system provided a useful interface providing fix marks and annotation from the Navigation system to the EPC sub-bottom recorder and the Raytheon echo sounder. Besides the record keeping abilities of this system, a very useful function was to provide an easy interface between the navigation system and the graphic recorders. Through the appropriate delay and text height settings, the TSS system could redirect the desired annotation to each of the geophysical recorders.

PERFORMANCE

In general the system worked well if set up correctly at the start of the survey and operated by experienced personnel. The system was found to be a bit "touchy" and often was the cause of some "dismay" generally to those not so familiar with it's operation. Too often, however, the fixes got out of synchronization, which may have been the result of radio interference.

6.0 NAVIGATION AND POSITIONING SYSTEM

6.1 INTRODUCTION

Challenger Surveys and Services Ltd. was subcontracted by Cdn. Seabed Research Ltd. to provide navigation and positioning services for the 1990 Environmental Studies Research Fund, Beaufort Sea Repetitive Mapping. A Hewlett Packard-based, real time, interrupt driven system and two surveyors were provided for the project. High accuracy positioning was required as pre-existing survey lines were being re-run to identify background and new geological features along those corridors. This system was capable of providing video read-out, to both the AGC seismic container and the bridge, that illustrated the ship's position and state vector, including heading and velocity.

On the evening of August 30th a systems engineer and a surveyor travelled from Edmonton to Inuvik to begin mobilization of the C.C.G.S. Nahidik, on the following day. System installation included Argo and Syledis receivers, and real time navigation (along with interfacing) to CSR's Klein Sidescan and Toshiba laptop navigation data logging system.

Challenger leased signals for Argo and Syledis from Haliburton Geophysical Services (HGS) who maintains both networks to support their offshore seismic activities in the Canadian Beaufort. HGS mounted the Argo receiver and tuned the antenna onboard the Nahidik.

The second surveyor arrived on September 1st and mobilization was completed on the same day. On September 3rd, after running test lines in Kugmallit Bay, the systems engineer was dropped off in Tuktoyaktuk and the C.C.G.S. Nahidik sailed for the Beaufort Shelf.

6.2 SURVEY SYSTEM

A Hewlett Packard 300 series computer loaded with custom navigation software formed the basis of the navigation and positioning system. This software version used was one specifically adapted for seismic surveying. The system was capable of taking up to three syledis ranges and up to four Argo ranges to resolve an accurate position fix. Operating hardware onboard the Nahidik included the following:

2 HP 310 Computers
1 HP Interface Extender
2 HP 9122 Disk Drives
2 HP 35731 Monochrome Monitors
1 ICS 4874 Relay Interface

1 Syledis MR3 c/w antenna
1 Seitz 6450A GPPI
1 S.I.A. Gyro Interface
1 DM54 ARGO c/w antenna, ALU,CDU and RPU
1 Topaz Line Conditioner
1 Lamarche Power Supply
2 12 Volt batteries
2 21" Sony Monitors
1 Thinkjet Printer
1 HP7475A Plotter

The shooting specifications for the repetitive mapping program were as follows:

Fix interval:	200m
Fix increment:	1 unit, starting at 1 and incrementing throughout the survey.
Line Numbering:	90-01 etc., with A,B parts for navigation breaks (especially when skirting islands or ice etc.)

6.3 SHORE NETWORKS

Three networks were used for positioning which consisted of an eastern Syledis network, a western Syledis network and an Argo network. Shore station locations and antenna heights are shown in Appendix 3.

6.4 SYSTEM PERFORMANCE

The navigation and positioning system performed well, providing coverage in the area predicted. This was demonstrated by comparing photocopies of sidescan images collected previously, with the sidescan data collected along that same corridor. These checks (made periodically throughout the survey) yielded excellent overlap characteristics. This also can be attributed to the line keeping of the helmsmen and the use of an autopilot.

Having a systems engineer onboard for mobilization proved to be quite worthwhile to resolve interfacing difficulties. The Argo DM54 came without a serial output, which has been standard since the early eighties, but the systems engineer was able to utilize the spare computer to send Argo data to the real-time system. A major disadvantage of this configuration was that we were without a backup computer, if required. Additionally, the engineer completed the navigation interface to the data logger and the Klein recorder, as well as, monitoring the navigation setup, during the completion of a test line.

The combination of Argo and Syledis was found necessary to achieve positioning throughout the survey region. The majority of the program was surveyed using Argo, however, it was necessary to periodically correct Argo lane counts by using the Syledis position. One disadvantage of the network set-up was that an HGS vessel (E.O. Vetter) maintained the master for the Argo system. In order to work, we had to remain within the general region of where the Vetter was operating.

Syledis was also used for calibration of the Argo system. These calibrations were performed north of Kugmallit Bay (69° 37'N, 133° 30'W) from the control monument Tuk Doppler. By measuring distances to shore stations from this location both at the beginning of the project, and again during the project, the navigation system could be calibrated to ensure accurate results.

6.5 NAVIGATION RECOMMENDATIONS

1. The requirement for a combined ARGO/Syledis configuration should be evaluated for future surveys. Differential GPS should also be explored as a possible alternative.

2. Given an ARGO combination, it is most desirable to have the master control onboard.

3. A systems engineer should be available for installation and to run a test line to quickly accommodate any hardware or software modifications.

4. On-line plotting capabilities should be present in order to evaluate the lines surveyed.

5. Direct communication between the HP navigation computer and the IBM computer would allow for transmission of x,y data files directly to the navigation system from SCOURBASE, thus avoiding keypunching of coordinates by the navigators.

6. Duplicate printing could be performed real time so that one hard copy is immediately available to the party manager.

7. Intermediate positioning data should be available to the data logger

between fix intervals.

8. A digital depth sounding system should be used and interfaced with the navigation system to tag each location with a depth.

7.0 SUMMARY AND RECOMMENDATIONS

The ESRF 1990 Repetitive Mapping program was highly successful, with over 1600km of high-resolution acoustic data collected in a total of 14 days of available ship time. A large part of this success can be attributed to the moderate weather and ice conditions experienced this year, although it is noted, that such conditions are not typical for this time period in the Beaufort. If it is possible, it is recommended that future surveys be undertaken earlier in the season in order to minimize downtime due to weather. The success of this survey can also be attributed to the provision of both new and 100% backed-up equipment for most of the major items. If any problems were encountered, additional gear could simply be swapped in with no loss in overall survey production.

The primary objective to resurvey the major repetitive scour mapping corridors established from 1984 to 1989 was very successfully met. Virtually the entire network was re-surveyed, including the high priority shallow and deeper water survey regions. The data quality for most of this coverage ranges from good to excellent.

The Gulf Pipeline Route was also re-surveyed during a good weather window when calm seas were encountered. The combination of good weather and the use of the high resolution Klein 595 sidescan produced excellent data along the route. This was very apparent in shallow water where new features were resolved that had not been previously recognized. Two outer lines (SURV88 1 and 7) of the route were also run for new scours, and a series of four scour tracking operations were achieved in the region.

Many other of our survey objectives were successfully achieved. These included; additional scour tracking operations for a total of 6 scours, locating and mosaicing the protruding pipe at the Tingmiark glory hole, and the successful test and evaluation of CSR's new Klein 595 digital sidescan sonar and microprofiler combination.

From an operations standpoint, the program ran very smoothly; with all gear arriving on time, efficient shipboard mobilization and demobilization operations, minimal downtime due to equipment malfunction and an overall positive working relationship between all concerned onboard. Excellent support from the crew of the Nahidik was especially instrumental in achieving the overall objectives of the survey.

The data collected on the ESRF 1990 program has already yielded important results. A total of 2291 new scours have been found as a result of detailed analysis of the 1990 data. The pipeline route alone produced 45 new events that are known to have formed between 1989 and 1990. Very high scour impact rates are now apparent in the Beaufort Sea which supports the concept that repetitive mapping studies should be undertaken on a yearly basis. The detailed scour tracking data is also presently being reduced and is yielding important scour process-related information.

In addition, the microprofiler data is being examined in detail. This data set achieved very high resolution of sediment infill and thereby has increased the overall depth of many of the scour events, previously profiled.

Not all of the 1990 objectives could be met. These along with other ideas relating to possible scour projects are listed below.

STUDY RECOMMENDATIONS

1) Work up all detailed scour tracking data in order to evaluate scour process-related information. Provide as many illustrations of original data as possible to show the changes in scour morphology over the extent of the feature.

2) Perform detailed scour tracking analysis on specific extreme scour events along the pipeline route, the Yukon shelf and the Mackenzie Trough. Data sets should be pre-viewed to identify specific scour events especially those showing infill and scour termination berms.

3) Collect high resolution 500 kHz sidescan sonar data over New scour features to identify potential soil failure features along the scour base. This objective was not realized during the 1990 program due to weather problems at the scheduled time for this program.

4) Undertake a detailed sub-scour deformation survey on selected scour events in the MacKenzie Trough region. Evaluate and recommend the types, frequencies and geometries of sub-bottom profiling devices to be used for this survey. Under ideal conditions, the original scour profile may be distinguished from the backfilled or infilled sediments.

5) Upgrade the SQS System to integrate with the Klein microprofiler system in order to digitize the third channel profile data for automated scour depth determination. Continue to enhance the system for digitization in deeper waters and process the present data sets to yield a complete scour depth distribution including those scours with depths less than 0.5m.

6) Make a mosaic of the 1990 Tingmiark site data to illustrate the drilling pipe protruding from the glory hole. Forward these data to Coast Guard for evaluation.

7) The high scour recurrence rate found along the Gulf pipeline route, in only one year, supports the observation that repetitive scour mapping field surveys should be

undertaken on a yearly basis. The detailed new scour statistics within the Gulf route should be worked up in the form of graphic distributions and interpretations.

8) Undertake a review of all repetitive mapping data collected to date to identify scour degradation rates for different bathymetric regions.

TECHNICAL RECOMMENDATIONS

Several technical survey recommendations are noted below based on observations from this year's program.

1) In general, the major systems should have complete back-ups and adequate spare parts. The Klein 595 Digital sidescan sonar system is recommended for future surveys. This system, combined with the 100khz microprofiler produced excellent records. It also utilized less consumable spare parts and produced speed and slant range corrected records such that mosaics may be constructed from the data. An automated speed link from the navigation system to the Klein is also required.

2) The Raytheon RTT-1000 Sub-bottom Profiler and analogue EPC 1600 recorder should be utilized in the future. This system worked very well, especially in shallow water regions, with no downtime incurred at all. A telescopic over-the-side mount is recommended in order to adjust the draft of the system for rough weather conditions.

3) The SQS system should be utilized for future surveys, especially if this system can be configured for the Klein Microprofiler. Separate computers for SQS and SCOURBASE systems should be provided such that they are stand-alone systems. Integrate SCOURBASE with the HP navigation computer for automatic file transfer.

4) Fix problems with the HP Tape Recorder or consider the use of a Digital Audio tape system such as the Teac RD 101T system. Fix the gain and threshold problems with the starboard channel on the AGC winch/cable system.

8.0 REFERENCES

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APPENDIX 1

DAILY FIELD LOG

NAVIGATION DAILY LOG REPORT

Note: Up till Sept 3/90 all times are given in local Mountain Time. After that, the Julian Day/GMT system is utilized.

AUGUST, 29, 1990

Gilbert departs Halifax.

AUGUST, 30, 1990

Gilbert arrives Inuvik. Shearer arrives @ 12:30. John Lewis already in Inuvik.

AUGUST, 31, 1990

Two navigators (Tim Harding and Dave Johnson) in. They install antenna and set up equipment in lab.

John and Glen work on Klein microprofiler assembly all afternoon. Confirm that CSR jumper can not be used with AGC cable and fish.

Glen tracks winch to Edmonton. Should be in tomorrow. Continue to work on speed transfer programs with navigators.

SEPT., 1, 1990

Mobilization of seismic container proceeding well. Winch has been located at Canadian Air Freight. Speed transfer program has some minor problems. Every 3-4 minutes the Klein either defaults to 1.0 knot or speeds up to around 8.0. Continue to evaluate.

The 3.5 khz sub-bottom profiler also has an intermittent connector. John is looking at this problem.

Problem with navigation system. GPIO boards and not serial boards were shipped with the ARGO system. Tim Harding has re-configured the system to work with GPIO boards, however, this also utilizes the spare computer. Harding to sail with us tomorrow to Tuk to test all systems.

SUNDAY, SEPT.2, 1990 (Winds: Maximum 22, Low Temp: 9)

08:05 Depart Inuvik for Tuk. Navigators T. Harding, D. Johnson and C. Thompson onboard. Day spent completing mobilization in preparation for a test line.

Gilbert preparing line coordinates to shoot. Plan to calibrate navigation and geophysical gear in Kugmallit Bay at site 69° 37'N, 133° 30'W. Watches established as 12-12.

19:15 Stop to deploy sidescan tow-fish. AGC fish seems to have loss of gain to outer channel for starboard transducer. CSR fish swapped in with CSR jumper and worked well. HP 3968 tape deck experiencing problems. Also test echo sounder and sub-bottom profiler.

START GMT TIME (6 HOURS ADDED TO LOCAL MOUNTAIN TIME)

DAY 246 SUNDAY, SEPT.3, 1990 (Winds: Maximum 35, Low Temp: -1.6)

06:33 Start running test line # 1 through Kugmallit Bay. Sidescan working well with some minor speed fluctuations. Navigation also operative and all data being saved on CSR's Laptop. AGC's Tape deck and echo sounder not operational.

08:53 End of test Line 1.

09:19 Begin running Line 2 to South, starting at 7739551N and 573415E. This is Line #1 in reverse.

12:22 End of partial Line 2.

13:55 Arrive in Tuk. (Tim Harding ashore)

15:00 Set anchor in Tuk Bay. Perform bar check for echo sounder. Weather is poor. Plan to head West and hope conditions improve. CSR's Navigation data logger is working well.

John working on TSS Record Annotator fixes to echo sounder. Tape recorder still not functioning. Glen organizing line coordinates.

18:00 Depart Tuk Bay.

DAY 247 TUESDAY, SEPT.4, 1990 (Winds: Light, Low Temp: -2)

02:07 Started Line#3 (Gulf 8206) Offtrack at start of line. Still speed fluctuations on Klein recorder. Microprofiler working well since we swapped in the 100 khz TVG card for the 3.5 khz card. This removed a lot of the noise on the record.

04:53 Glen has line coordinates for the evening's program. Weather has moderated considerably and data is quite good.

06:10 Contacted the Edward O. Vetter and confirmed that it was okay for us to take over master control of the Western Syledis network.

11:55 Completed Line #3.

12:40 Started running Line #4, North to South.

15:00 Problem with Syledis and Argo switch to Western Network. Set up Line #5.

15:54 Start Line #5, 2400m South of start.

17:43 Finish Line #5, Fix #845.

17:44 Start Line #6 off line OR+1226, Fix #846. Raytheon sounder paper take-up problems at SOL. CSR data logger did not start until Fix 851. Back on line by Fix 853.

18:40 Weather is calm and sunny. Sidescan data is good although still some problems with starboard channel. SBP is working well. Tape deck still not operative. Gilbert to organize lines for rest of Western program.

23:15 End Line #6, Fix #1100. Set-up line #7. Pullen down since start of survey.

DAY 248 WEDNESDAY, SEPT. 5, 1990 (Winds: Maximum 20, Low Temp: 1.5)

00:00 Started Line #7 (Eastern MacKenzie Corridor) at Fix #1101. Line #7 South to North, Azimuth 359.

04:02 Weather and sea state are good and therefore data is very good. Glen installed the jumper cable to get expanded out port sidescan data on channel 5 along with microprofiler data on channel 6. So far there appears to be a reasonable correlation between the two profiling methodologies.

06:00 Still running survey on Line #7.

07:25 Completed Line #7. Picked up fish and start steaming to Line #8.

10:15 Deployed fish 1.5km from end of Line #8.

10:50 Start Line #8, North to South.

15:09 End Line #8 and begin set up for Line #9.

16:09 Line #9, North to South.

17:42 End Line #9 to sail around Kadluk artificial island. Begin setup for Line #10. Stopped Line #9 to go around Kadluk.

18:25 Start Line #10, Fix #1721. Sidescan data has been excellent so far with the microprofiler showing good penetration and resolution. Attempted tape replay on HP 3968 but with no success. The recorder could not lock onto trigger pulse and changed the range display to 25m rather than 150m.

Navigation data logger is working well but has a carriage return in the wrong location. AGC winch is experiencing some problems with the remote switch. Last night the EPC 1600 paper take-up stopped working. A spare EPC was swapped in.

19:50 End Line #10, Fix #1788.

20:00 Start Line #11, Fix #1789, Azimuth 75', West heading East. Re-shoot of ESRF84 10B(West).

DAY 249 THURSDAY, SEPT.6, 1990 (Winds: Maximum 20, Low Temp: 0)

02:00 Switch syledis to Eastern Network and pick-up TOKS.

02:27 Finish Line #11, Fix 2081. Ship turned port side to start Line #12.

02:44 Start of Line #12, Fix 2082, Azimuth 136'. Running on TOKS syledis, PITA, TOKA & PULA (Argo). Residuals fair.

03:50 Navigation computer locked up due to ERROR 314. Receive buffer overflow, Argo was not disabled.

04:30 Tried to switch from Western network Argo to Eastern Argo. Calibration seems to be off, residuals seem to be running high twenties. Syledis residuals Eastern network seem to be good.

05:11 Start Line #13, the GULF Pipeline route. Start at shallow end of the route and starboard channel of sidescan has problems since it is shadowed by ship's hull. Problems with Tape deck at SOL. Using ATKS, TOKS, ATKA. Fix #2124.

05:30 Spoke with Tim on the Edward O. Vetter. If the computer locks up again type CONT START. He said that Argo residuals are often higher than normal when close to shore. Tim is leaving Vetter tomorrow at 1:00 p.m.

10:00 Running Line #13 near Amauligak. Tried to Bring in Garry Argo (Gara and residuals went large.) Compute lanes and found GARA had lost one lane. Corrected lane count and brought Gara into the solution. Sidescan sonar data quality is very good.

10:47 Running Northerly on Line #13 on TOKS, ATKA, TOKA, and GARA. Approx. 4 km to complete line.

11:13 Completed Line #13 and started sailing for Line #14.

11:25 Shut down generator for service and knocked out computer. Servicing Argo. HP LaserJet Series II (ADDITIONAL)HLSEIIAD.PRS ATKA, TOKA, and GARA. Out of range of Syledis.

14:25 Complete Line #14.

14:40 Start Line #15. Re-shoot of ESRF84 5C North to South. Plan to shut down survey at EOL for two hours to calibrate navigation system. Engine room also has a repair to perform.

Sounder has paper take-up problems at SOL. Glen working on by cleaning gears and bending out electrical contact points on take-up relay. Sidescan data quality is very good.

16:30 Syledis receiving Sync. but all three stations down.

19:00 Started tuning ARGO antenna.

20:15 Finish Line #15, Fix #2764.

21:30 Finish calibrating Argo.

22:10 SOL Line #16.

22:16 Residuals went high into the thousands. Disable Argo and aborted Line #16 due to Navigation. Syledis was the problem; disabled syledis; enabled Argo.

22:16 Glen calculates amount of sidescan paper required. Running at 5 Knots one roll lasts 7.5 hours. For continuous operations, we would require 3.2 rolls/day * 12 days = 38.4 rolls. We have 33 rolls which should be enough as we expect to get weathered out.

John identifies Tape Player requirements for 595 Klein system.

* Port and Starboard FM negative to record Positive signals.
* Trigger; FM negative to record positive signal.
* Annotation: FM Bipolar.

22:28 Started Line #17, fix 2781 as a continuation of Line 16. Using Argo, ATKA, TOKA,PULA, GARA disabled Syledis. All the metric echo sounder paper has been consumed. Switching to imperial for the rest of survey, although additional paper has been ordered and may appear before end.

DAY 250 FRIDAY, SEPT.7, 1990 (Winds: Maximum 30, Low Temp: -4)

03:38 Running Line #17.

04:36	Lost Argo station GARA.
05:08	Syledis went down totally. Last good Fix #3088 residuals for Argo were running high. Stopped survey.
05:11	Started survey again at Fix #3097, but still maintain Line #17 designation.
08:10	Complete Line #17 and set-up Line #18.
08:37	Begin running Line #18, South to North.
11:19	Start of second leg of Line #18.
12:10	Positioning down. Found Syledis had dropped out and residuals high on Argo. Took filter off after disabling Syledis and residuals returned to normal. Surveying line #18 ranging on ATKA, TOKA and PULA. Fix #3413.
17:23	Started deviation on Line #18 at Fix 3662 around ice pans.
17:31	End deviation at 3669. Working through ice pans which could affect Argo accuracies.
18:04	Finish Line #18, Fix #3695.
18:05	Haul Fish out of water set sail South to start Line #19.
20:10	Syledis back in sync and receiving ATKA.
20:26	Start Line #19, Fix #3696.

DAY 251 SATURDAY, SEPT.8, 1990 (Winds: Maximum 25, Low Temp: 0)

00:22	Abort Line #19, at Fix #3871. Last good fix was fix 3861. Line was aborted since we were 150m off line.
03:36	Abort Line #19A at Fix #3982, due to bad weather.
05:14	Glen working on speed control software for Klein.

16:50	Riding out storm.
17:51	Start Line #19B, Fix #3983. Started off-line by 81m (still in rough sea).
18:15	Stop Line #19B at Fix #3996 due to poor data.
18:40	Depart for Tuk.

DAY 252 SUNDAY, SEPT.9, 1990 (Winds: Maximum 22, Low Temp: -2)

02:00	Tied up at NTCL dock in TUK. AGC crew off to locate metric echo sounder paper from RCMP. Glen off to make calls re: Hudson's Bay job. Discover that SBP transducer has been sheared off due to vibration of the mount in heavy seas. John to look at.
05:41	John and Glen re-epoxy SBP transducer housing. Echo sounder cable also scotch coated and taped.
15:00	Shut down Navigation computers while generator was serviced. Re-started computers with no problems incurred.
17:10	Still standing by in Tuk.
19:45	Test CSR's auxiliary winch with 3.5 khz pod and fish. Winch is not powerful enough to lift this combination off the deck but is suitable for use with the fish only. Over the side mount is now repaired and seized in position with steel banding wire.
21:42	Heading to fairway buoy to check weather. Suspect we'll have to run SW-NE with following seas. Determine that SBP can be run on Klein recorder through the auxiliary input. The trigger out relates to the range scale of the sidescan 150m = 200msec. Presently we are using .1sec on the EPC which is 100msec. The Klein functions of display and delay can than be used on this data. Best to use AUX in and re-direct AUX XMB into channel 6. This allows a display of channels 1,2, and 6 rather than 1,2,5, and 6.

DAY 253 MONDAY, SEPT.10, 1990 (Winds: Maximum 20, Low Temp: -3.5)

O1:49	Ready to start line Gulf 8204, however, Navigation is down.
03:30	Positioning still down. Syledis has very high residuals. Problem with Argo losing lanes. Sail East towards ATKS to try to pick up signal.
05:00	Problem with syledis was that the ship's TV antenna was touching syledis antenna. Re-calibrate Argo, sail to start of Line #20.
05:43	Start of Line #20, Fix #3997.
06:26	Terminated Line #20 due to ice. Sailing around ice on starboard side of Line #20. Re-deploy gear.
07:06	Start of Line #20A after going around broken ice.
07:49	Completed Line #20A and set up for Line #21.
08:11	Start of line #21.
09:13	Complete Line #21 and begin set-up Line #22.
09:24	Begin running Line #22 Easterly.
11:47	Ended/Aborted Line #22, 3.5 km before end due to ice. Begin set up for Line #23.
13:52	Bad Fix #4270 due to Toker syledis dropping out. No fixes occurred for 760m. Reloaded line segment to activate the fixing again. Did not shut down navigation.
14:26	Complete Line #23. This line should have been labelled (19C). Set target to sail back to Tingmiark.
16:45	Start Line #24 with co-ordinates given by Glen for Tingmiark (K-91) 7,786,671N, and 576,894E but did not find site. Run Line #25 and Line #26; still no site. New co-ordinates from Jim are as follows; Tingmiark(K-91) 7,786,671N, 576,358E.

17:50 Run Line #27. Found glory hole (K-91) on Line #27. Run Lines #28, 28A, 29 using a 100m North/South grid in order to make a small mosaic.

18:58 Finish Line #29, Fix 4340.

20:58 Start Line #30, fix #4341, Azimuth 327°. Re-shoot of Tingnerl.

22:16 End Line #30, Fix #4462. Aborted line as ice pack too close. Heading to start GULF 8208. The E.O. Vetter reports ice in their vicinity.

23:00 Sailed to Line Gulf 8208. Can not shoot line due to proximity of ice in the region. Sailed to pipeline route region, Line #31(Surv 8801A) to run South.

DAY 254 TUESDAY, SEPT. 11, 1990 (Winds: Maximum 15, Low Temp: 2.1)

00:26 Started Line #31, Fix 4483, Azimuth 208°. Started using TOKS, ATKA, TOKA, PULA, low residuals. Amauligak I-65 berm is within the region of this line. It is approximately 8.0m deep and therefore the sidescan operators should be careful with fish.

05:01 End of Line #31, Fix #4667, Azimuth 208°.

05:29 Start of Line #32, Fix 4668, Azimuth 28°.

06:25 While surveying Line #32, PULS dropped out giving a bad fix at #4707. Since next fix would not occur, survey was stopped and later re-started at Line #32A.

09:53 Completed Line #32A and start set-up for Line #33.

10:26 Start of Survey for Line #33 from East to West.

13:35 Running Line #33, ranging on TOKS,ATKA,TOKA, and PULA. Residuals are notably larger as boat is rocked from wave action.

14:48 Complete Line #33 and begin set-up for Line #34.

15:09 Start Line #34. Running line East to West.

19:29 At Fix #5226, we go off line to traverse around Kaubvik Island. Survey remained on for this detour. At Fix 5246, back on Line #34. All data quality is very good. Sidescan sonar altitude tracker has been functioning well.

23:21 Finish survey Line #34 approximately 1 km short, due to presence of Minuk Island.

23:36 Start survey Line #35, Fix #5427, Azimuth 339°, using Argo stations only. This line is a re-shoot of TY8521 to the . Weather is calm and the data quality is good. Starboard sidescan channel still weak. We suspect problem is in the cable or winch.

DAY 255 WEDNESDAY, SEPT.12, 1990 (Winds: Maximum 12, Low Temp: 2)

01:42 Finished Line #35, Fix #5549.

01:50 Stopped to check out equipment, still no syledis, ATKA down.

02:13 Started Line #36, Fix #5550.

04:05 Glen finishes working up lines for the evening's program.

05:22 End of Line #36, Fix #5694. Line #36 was to end at Fix #5686 but was extended to track Ice scour to Fix 5694.

05:35 Pull all equipment out onto deck for sail to start of Line #37.

07:01 Prepared to run Line #37.

07:14 Start of Line #37 ranging on TOKA, PULA, and GARA with good residuals.

09:11 Complete Line #37 and start set-up for Line #38.

09:49 Start Line #38 West to East.

11:25 End Line #38 and set target for Western end of Line#39.(Gulf 8202).

12:30 Change of plans. Line #39 will be a scour tracking investigation.

13:15	Start tracking deep scour that crosses Tarsiut-Nektoralik corridor as Line #39. After several fixes went to a fixing interval of 100m from 200m.
17:06	Recorded several fixes using TOKS along with TOKS, PULA, and ATKA. Toker coming in at over 160 kms on Syledis with small residuals.
17:33	End Line #39, and start steaming back to Line #39A to follow scour beyond change in direction.
19:06	Back at the start of Line #39 looking for scour going in other direction. Abort Line #39A.
19:35	Tried again to track ice scour. Aborted Line #39B could not find direction.
20:11	Tried once more to track Ice scour. Aborted Line #39C, could not find direction.
20:20	Start running a 200m Grid E/W direction 2 km long to find scour direction.

DAY 256 THURSDAY, SEPT.13, 1990 (Winds: Maximum 12, Low Temp: 2)

00:00	Finish running 200m grid. Shot line 40A, 40B, 40C, 40D, 40EE, 40F
01:00	With information from grid determine direction of ice scour.
01:24	Started tracking Ice Scour Line #41, Fix #6350 in other direction. Scour tracking continues for many kilometres.
04:33	Aborted Line #41, lost track of ice scour at Fix #6605. However, did track scour for over 20km.
05:00	Start Line #41A, continue to follow Ice Scour with not too much luck.
05:45	Stop the survey on Line #41A, last Fix 6683.
05:59	Load equipment on deck to prepare to sail to new ice scour.

06:15	Steaming towards next scour location; 7763361N, 449027E.
08:15	Start Line #42 following the deepest New scour in the data base.
10:24	End Line #42 and start back to trace the scour in the other direction. Set-up for Line #42A.
11:03	Start of line #42A ranging on TOKA,PULA, and GARA.
14:02	Complete Line #42A and start back to Line #42B which will be a different line on the same scour.
15:08	Start Line #42B.
16:05	End Line #42B and begin set-up for Line #43 (Gulf 8208). Confirm Argo position with Syledis.
17:04	Start Line #43 from West to East.
20:22	Abort Line #43 due to ice.
20:26	Decided to continue fixing even if we are detouring around ice. Start Line #43A.
20:38	Navigation down. Calculated lane count for ATKA but mistakenly set Lane count for GARA not ATKA. Abort survey Line #43A.
20:40	Argo back to low residuals by using syledis TOKS.
20:57	Start survey of Line #43B about 100m off Line. Line #43B changes Azimuth 45° to Azimuth 80°. Survey line continued in an Easterly direction.

DAY 257 FRIDAY, SEPT.14, 1990 (Winds: Maximum 16, Low Temp: 4)

02:37	Continuing on Line #43B. We have veered offline only once due to ice. Weather is sunny and flat calm with the close proximity of the ice pack. Bowhead whales sited in this region and feeding pits on the sidescan sonar are recognized.
06:14	End Line 43B and begin set-up for Line 44. (Re-shoot of Line ESRF84

8b).

08:34 Start Line #44 West to East.

11:55 End Line #44 and begin set-up for Line #45. Line #44 was ended approximately 8 km early to allow for an easy merge with Line #45.

14:49 End Line #45 and begin set-up for Line #46.

17:13 Start Line #46 from South to North.

18:22 Going around Nipterk artificial island with a 1 mile radius. Last Fix 8100 on Line #46.

19:30 Stopped survey Line #46, 1 km short of end to avoid Kaubvik Island.

19:55 Start Line #47 from South to North.

21:52 Completed survey on Line #47 and begin set-up for tracking ice scour in 16m water on Gulf Pipeline route at Fix #2254, Line #13. Steaming to Line #48.

DAY 258 SATURDAY, SEPT.15, 1990 (Winds: Maximum 25, Low Temp: 1.6)

00:00 Stop to deploy equipment.

00:24 Start of Line #48, Fix #8238, following ice scour. Shoot a series of lines to track this event including 48, 48A, 48B 48C, and 48D.

04:00 End of tracking shallow ice scour. Steaming to deep water (26m) on pipeline route to track ice scour. Line #49.

05:34 Start survey of Ice Scour. Line #49, Fix 8417. Lost scour, start another line #49A.

09:54 End Line #49A and start set-up for Line #50.

10:31 Start Line #50. Scour tracking of event on East leg of pipeline route.

11:42 End Line #50 and begin set-up for Line #50A.

11:52 Start Line #50A and continue on same scour.

14:38 Completed Line #50A and begin setup for Line #51.

16:47 Start Line #51 running from North to Southeast.

19:18 End of Line #51, Fix 9186. Start to steam for Scour 7.

21:03 Start of Line #52, West to East. Scour 7 located and tracked, but eventually lost. Seas rough with poor data quality.

21:21 Start Line #52A. This is a line run around Amauligak to locate Scour 7. Scour 7 located northwest of Amauligak site.

21:59 Start Line #52B to track Scour 7 to the North and then West. Starboard sidescan channel very poor and therefore we didn't risk crossing over scour (for depth information) for fear of losing scour on sidescan.

DAY 259 SUNDAY SEPT 16, 1990 (Winds: Maximum 25, Low Temp: 1.1)

02:33 Stopped Line 52B after tracking scour 7 for many kilometres. End of Survey!

02:45 All gear aboard and sailing for Tuk.

07:45 Arrive at Coast Guard dock in Tuk. Day spent packing all gear. Jim, John and 2 navigators out from Tuk.

SWITCH BACK TO LOCAL MOUNTAIN TIME

MONDAY SEPT. 17, 1991

09:30 Gilbert and Blasco leave Tuk by plane for Inuvik. Glen out to Edmonton to overnight at Nisku. Departs next day for Montreal and Hudson's Bay job.

APPENDIX 2

GEOPHYSICAL EQUIPMENT SPECIFICATIONS

KLEIN 595 DIGITAL SIDESCAN SONAR

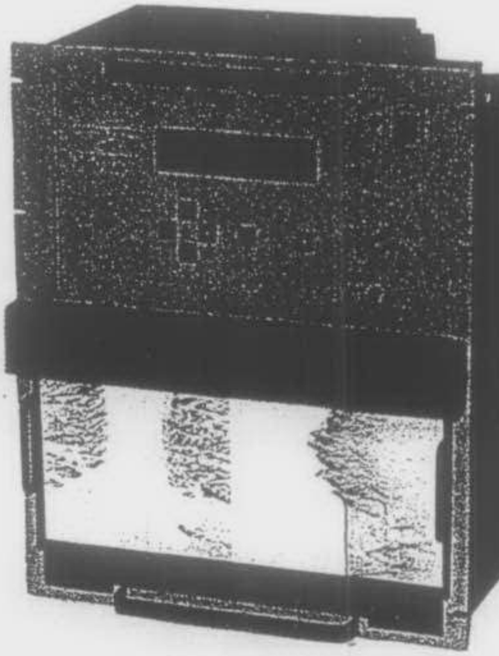
KLEIN MICROPROFILER SYSTEM

RAYTHEON RTT-1000 SUB-BOTTOM PROFILER

RAYTHEON DE-719 ECHO SOUNDER

KLEIN DIGITAL GRAPHIC RECORDER

The Klein 595 Digital Graphic Recorder produces a continuous permanent graphic record of the sea floor and sub-bottom topography. The recorder generates a trigger pulse which is sent down the tow cable to energize the side scan sonar and/or sub-bottom profiler transducers. When the sonar echoes are received, they are sent up the tow cable to the recorder. The signals are electronically processed and printed line by line to produce the sonar image. The 595 is controlled by a powerful microprocessor and includes a wide variety of capablities including image correction, record expansion, sophisticated annotation and menu-driven operation. A versatile display format allows the operator to print up to four channels with a wide variety of options as listed in the Menu Options below. The 595 also features a totally new, fixed head, high resolution, high speed dry thermal printer in which each dot is individually digitally addressed to produce 16 distinct gray shades. The modular design of the 595 allows the customer to easily expand existing sonar systems. Current Klein customers can obtain the 595 only and use it with their present towfish and cable. New customers can start out with a single frequency sonar towfish and later, as the budget permits, expand the system with a dual frequency unit, a sub-bottom profiler or other options.



SPECIFICATIONS:

MODEL NUMBER	595
DOT DENSITY	8 Dots/mm (203 Dots/in)
RECORDING PAPER	
TYPE	Direct Thermal, Dry, Odorless, Archival
COLOR	Black and White
WIDTH	43.2 cm (17 in)
LENGTH OF ROLL	46 meters (150 feet)
GRAY SCALE	16 Shades, Each Pixel Digitally Controlled
OPERATING TEMPERATURE	0° C to +50° C
STORAGE TEMPERATURE	-40° C to +80° C
POWER INPUT, SWITCHABLE A.C. OR D.C.	
A.C. Switchable	105-125 Volts or 210-250 Volts, 47-420 Hz, Single Phase, 100 Watts Average
D.C.	23-30 Volts, 100 Watts Average (Input Protected From Reverse or Overvoltage)
CASE SIZE	
WIDTH	44.8 cm (17.6 in)
HEIGHT	55.9 cm (22.0 in)
DEPTH	29.2 cm (11.5 in)
FRONT PANEL SIZE	
WIDTH	48.3 cm (19.0 in)
HEIGHT	57.8 cm (22.8 in)
WEIGHT	34.0 kg (75 lbs)

MENU OPTIONS:

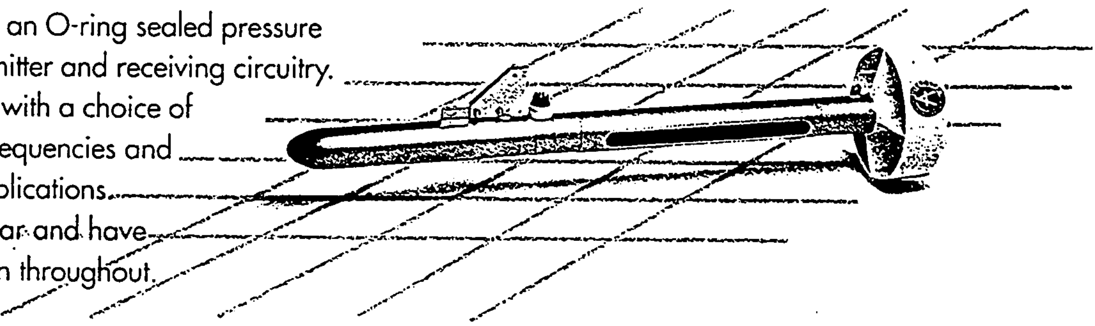
DEFAULT VALUES ARE UNDERLINED

RANGE SCALES	12.5, 25, 37.5, 50, 75, 100, 150, 200, 250, 300, 400, 500, 600, 750 meters
SCALE LINES	OFF 5 10 15 20 25 50 meters
CHANNELS	
1 2 | 3 4	NOTE-CHANNEL ASSIGNMENT IS:
1 | 2	1: Port 100 kHz Side Scan
3 | 4	2: Starboard 100 kHz Side Scan
1 2 | 6	3: Port 500 kHz Side Scan
3 4 | 6	4: Starboard 500 kHz Side Scan
1 2 | 5 6	5: Auxilliary 6. Sub-Bottom Profiler
MAPPING MODE	OFF ON (Image Correction)
SOURCE	TAPE MONITOR FISH TAPE
ALTITUDE	AUTO 0.0 - 75.0 meters, MAN 0.0 - 75.0 meters
ALTITUDE ALARM	OFF ON 2 - 30 meters
SPEED	MANUAL 1.0 - 20.0 knots EXTERNAL 1.0 - 20.0 knots
AUTO MARK	OFF, ON 0:10 - 10:00 in 10 second increments
EVENT COUNT	OFF UP DOWN
EVENT NUMBER	0 - 9999
SIDE SCAN EXPAND	OFF ON
SIDE SCAN DELAY	0 - 600 meters in 5 meter increments
SIDE SCAN DISPLAY	10 - 200 meters in 5 meter increments
PROFILER EXPAND	OFF ON
PROFILER DELAY	0 - 600 meters in 1 meter increments
PROFILER DISPLAY	10 - 200 meters in 5 meter increments
NAVIGATION SOURCE	PARROT, LORAN-C, GPS, MINI RANGER, TRISPONDER
FAST FEED	(Rapid Paper Advance)
TIME	HH:MM:SS in 24 hour format
DATE	DD:MM:YY
GREY SCALE	0 - 15
CHARACTER HEIGHT	1 - 7
CHARACTER WIDTH	1 - 7

THE KLEIN TOWFISH AND SUB-BOTTOM PROFILER

The Klein Towfish contains transducers which send out high intensity, high frequency bursts of acoustic energy in fan shaped beams to both sides of the Towfish.

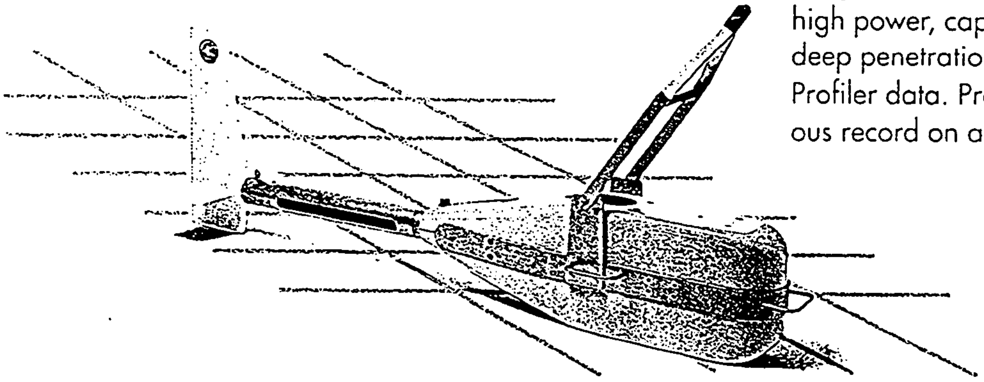
The nose of the Towfish is an O-ring sealed pressure housing containing the transmitter and receiving circuitry. Towfish models are available with a choice of single or dual simultaneous frequencies and beam patterns to suit user applications. Towfish are completely modular and have 316 stainless steel construction throughout.



Model Number	Output Frequency	Horizontal Beamwidth	Vertical Beamwidth	Vertical Beam Depression Angle	Pulse Length (Milliseconds)	Acoustic Output db (Peak) Ref. 1 µ Pascal at 1 meter	Maximum Range Per Side	Weight		Dimensions		Tow Speeds		Standard Depth Rating (12,000 m Units Available)
								In Air	In Water	Length	Diameter	Operational	Maximum	
422S-101HF	100/ 500 kHz	1°/0.2°	40°	0°, 10° or 20°	0.1/0.02	228/216	75-150/ 200-500	27.0 kg 60 lbs	23.0 kg 50 lbs	145 cm 57 in	8.9 cm 3.5 in	1 to 8 kt	16 kt	1000 m 3280 ft
422S-101EF	500 kHz	0.2°	40°	10°	0.02	216	75-150	21.7 kg 48 lbs	16.3 kg 36 lbs	122 cm 48 in	8.9 cm 3.5 in	1 to 8 kt	16 kt	1000 m 3280 ft
422S-101AF	100 kHz	1°	40°	10°	0.1	228	200-500	21.7 kg 48 lbs	16.3 kg 36 lbs	122 cm 48 in	8.9 cm 3.5 in	1 to 8 kt	16 kt	1000 m 3280 ft
422S-101F	100 kHz	0.75°	40°	10°	0.1	228	200-500	26.7 kg 59 lbs	2.08 kg 46 lbs	143 cm 56 in	8.9 cm 3.5 in	1 to 8 kt	16 kt	1000 m 3280 ft
422S-101GF	50 kHz	1.5°	40°	10°	0.2	228	500-750	28.1 kg 62 lbs	21.7 kg 48 lbs	147 cm 58 in	8.9 cm 3.5 in	1 to 8 kt	16 kt	1000 m 3280 ft

The Klein Sub-Bottom Profiler provides a high resolution profile of seafloor sediments.

Modular in design, the Sub-Bottom Profiler can be integrated with the Klein Side Scan Sonar Towfish. A high power, capacitance discharge transmitter provides deep penetration and high resolution Sub-Bottom Profiler data. Processed data is displayed as a continuous record on a hard copy recorder or video display.



Model Number	Output Frequency	Beam Angle	Pulse Length (Milliseconds)	Acoustic Output db (Peak) Ref. 1 µ Pascal at 1 meter	Penetration	Weight		Dimensions (without SSS Towfish)			Standard Depth Rating (12,000 m units Available)	Maximum Operational Tow Speed
						In Air	In Water	Length	Width	Height		
532S-101	3.5 kHz	50° Conical	0.40	205	0-60m	79.4 kg 145 lbs	64.4 kg 142 lbs	85.0 cm (33.5 in)	21.6 cm (8.5 in)	33.0 cm (13.0 in)	300 m 1000 ft	7 kt

KLEIN SUB-BOTTOM PROFILER AND MICROPROFILER

SPECIFICATIONS:

MODEL NUMBER (Note 1)	532S-101	532S-201	532S-202
DESCRIPTION	SUB-BOTTOM PROFILER ATTACHMENT	MICROPROFILER™ ATTACHMENT	COMBINED SUB-BOTTOM & MICROPROFILER ATTACHMENT
OUTPUT FREQUENCY	3.5 kHz	500 kHz	3.5 & 500 kHz
BEAM ANGLE	50° conical	2° conical	50° & 2° conical
PULSE LENGTH, Milliseconds	0.40	.02	0.4 & 0.02
RESOLUTION, approx. in water	60 cm	3 cm	60 cm & 3 cm
ACOUSTIC OUTPUT, db(Peak) Ref. One Micropascal at one meter	205	216	205 & 216
DEPTH RATING (Note 1)	300 m (1,000 ft) or 12,000 m (39,000 ft)	300 m (1,000 ft) or 12,000 m (39,000 ft)	300 m (1,000 ft) or 12,000 m (39,000 ft)
DIMENSIONS			
LENGTH (Attachment only)	85.0 cm (33.5 in)	120.7 cm (47.5 in)	120.7 cm (47.5 in)
LENGTH (Including sonar towfish)	152.4 cm (60.0 in)	189.2 cm (74.5 in)	189.2 cm (74.5 in)
MAXIMUM LENGTH (With Towish and with tow bridle extended forward)	163.9 cm (64.5 in)	200.7 cm (79.0 in)	200.7 cm (79 in)
WIDTH	21.6 cm (8.5 in)	36.8 cm (14.5 in)	36.8 cm (14.5 in)
HEIGHT	33.0 cm (13.0 in)	50.8 cm (20.0 in)	50.8 cm (12.0 in)
TAIL HEIGHT	66.0 cm (26.0 in)	66.0 cm (26.0 in)	66.0 cm (26.0 in)
WEIGHT (with Towfish) IN AIR (Note 2) IN WATER (Note 2)	 79.4 kg (175 lb) 64.4 kg (142 lb)	 85.0 kg (187 lb) 68.3 kg (150 lb)	 92.5 kg (204 lb) 74.4 kg (164 lb)

NOTE 1: Deep-tow models are indicated by the letter D following the model number (e.g., 532S-101D).

NOTE 2: Weight specifications are for the 300 m models only. Deep units are heavier.

Specifications are subject to change without notice.

RTT-1000 Portable Survey System

1. System Description

The RTT-1000 is a dual purpose portable system designed for shallow water sub-bottom profiling and high resolution bathymetry. Sub-bottom penetration is achieved with a powerful transceiver and a low frequency transducer mounted over the side. Results are displayed on a compact, dry paper recorder capable of one foot resolution. The recorder's high frequency transmitter and transducer enable precise depth sounding to be conducted simultaneously. Advanced system features such as automatic initial and bottom triggered time variable gain, a no-ring transducer, and a receiver tailored to high resolution profiling requirements assure optimal performance under the difficult conditions posed by shallow water. All items are packaged in rugged carrying cases and can be set up and operating in minutes. The system is ideally suited to the survey of lakes, rivers, and coastal regions.

2. Specifications

The general specifications and features of the three main components are listed below. For detailed information, consult the operation manual for each unit.

	Model TC-7 Transducer	Model PTR-106A Sounder Transceiver	Model DE-719-RTT Survey Fathometer®
SPECIFICATIONS	Material: Lead zirconate titanate Input power capability: 2000 watts maximum Pulsed at 1 ms Frequency: 7 kHz Bandwidth: 2.6 kHz Beamwidth: 36 degrees Dimensions: 17" dia. x 8 " high Weight: 36 pounds Cable length: 50 feet	Power Output: 2000 watts maximum Frequency: 7 kHz (others available in Model PTR 105A) Voltage input: 115AC or 12 volts DC with optional inverter Pulse Width: .1 ms - 1.0 ms Electronics: All solid state Dimensions: 19" x 17" x 5 1/4" Weight: 55 pounds	Accuracy: 0.5% + 1" of depth Voltage input: 12 VDC or 115AC with optional power supply Electronics: All solid state Chart paper: 7" by 60' Calibration: feet or meters Operating frequency: 7 kHz and/or 200 kHz Dimensions: 18" x 15 3/8" x 9 1/16" Weight: 47 pounds
FEATURES	Accepts extremely short pulses. Wide band width minimizes ringing. Light weight/portable. Easy to mount. Heavy duty mounting hardware. Rugged carrying case.	Manual gain, initial time variable gain, and automatic bottom triggered TVG for optimal performance in shallow water. High power for maximum penetration. Variable pulse lengths. Coherent keying for sharp pulses.	Eight selectable depth scales. Four chart speeds. Tide, draft, and speed of sound adjustments. Center or edge keying. Integral transmitter/transducer for high resolution survey.

DE-719C Recording Fathometer® Depth Sounder

High-resolution chart recordings provide extremely accurate bathymetric charts.

The DE-719C recording Fathometer® depth sounder is a portable, survey instrument that provides an accurate detailed and permanent record of underwater topography. It is easy to set up and easy to use. Its rugged construction and low power consumption make it ideal on smaller boats. To operate, simply mount the transducer on the sectional tube supplied, secure the tube to the side of the boat, and connect the battery cable. The unit is ready to operate. When not in use, the transducer mount and rigging are stored in the recorder case.

The DE-719C offers solid state circuitry throughout, with magnetic keying and electronically-controlled stylus speed. An extremely narrow transducer beamwidth, a high sounding rate, fast stylus speed and fast chart paper speed give you exceptionally high resolution recordings.

Additional flexibility is provided by front panel tid and draft adjustment, speed of sound control, and four paper speeds. Calibration markers indicating phase in use, tide draft, and sound speed compensation, are permanently recorded on the chart for future reference. You can select either foot or metri scales, depending on the chart paper used.

The DE-719C can also be interfaced with the SSD-100, Raytheon's microprocessor-based Surve Sounder Digitizer, to provide survey grade, four-dig digital depth display and BCD depth output for data logging and integration in hydrographic survey systems.

OCEAN SYSTEMS COMPANY RAYTHEON

DE-719C Specifications

SPECIFICATIONS

Depth Range: 0-55', 50-105', 100-155', 150-205', 0-16.5, 15-31.5, 30-41.5, 45-61.5 meters (All basic depth ranges can be multiplied 2 times by use of the range doubling switch.)

Sounding Rate: 534 Sounding per min.

Voltage Input: 12 volts DC (operates between 11.5 and 14.8 VDC. Optional converter available for operation 115/230 VAC, 50-60 Hz.)

Current Drain: 2.5 Amperes.

Accuracy: ±0.5% ±1" of indicated depth.

Operating Frequency: 208 kHz.

Transducer: Barium Titanate—Model 200T5HAD. Optional Model 7245A.

Transducer Beamwidth: 8° at the half-power points.

Chart Paper Speed: 1, 2, 3 or 4 inches per minute.

Chart Paper: 7 inches (17.8 cm) wide by 60 feet (18.3 meters).

Recorder Dimensions: Height (including handle): 18 inches (46 cm).

Width: 15 3/8 inches (39 cm).

Depth: 9 1/6 inches (23 cm).

Weight of recorder and rigging, with transducer: 47 pounds (21.3 kg)

Recorder alone: 38 pounds (17.2 kg).

TRANSDUCER

Model 200T5HAD

Frequency: 208 kHz.

Transmit sensitivity: 170 dB re 1 μPa/V (typical).

Receive sensitivity: −190 dB re 1 V/μPa (typical).

Beam width at −3 dB: 8° typical.

Transformer: Built-in.

Pulse power: 300 watts.

Weight: 1.4 pounds.

Impedance: 50 ohms ±15% at operating frequency.

Cable: 2 conductor shielded, No. 18 AWG.

Connector: Cannon XLR-3-12C.

Model 7245A.

Narrow beam, silicon bronze housing, urethane window.

Frequency: 204 to 210 kHz.

Transmit sensitivity: 171 dB re 1 μPa/V (typical).

Receive sensitivity: −180 dB re 1 V/μPa (typical).

Beam width at −3 dB: 2.75° typical.

Transformer: Built-in.

Pulse power: 300 watts.

Weight: 7 1/2 pounds.

Cable: 2-conductor shielded, No. 18 AWG Neoprene jacket, thirty feet long.

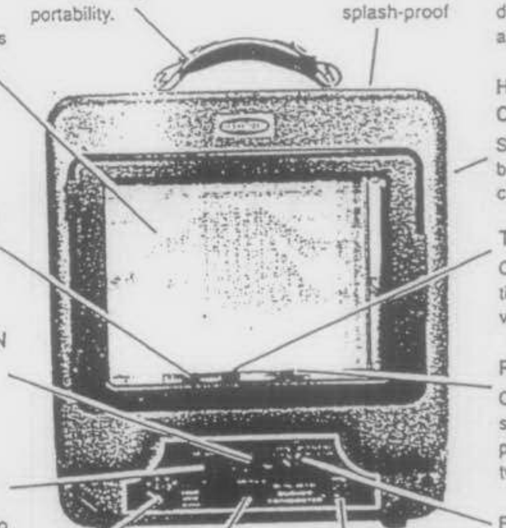
Connector: Cannon XLR-3-12C.

ENVIRONMENTAL TESTING

The Model DE-719C has passed tough Raytheon environmental tests for shock, vibration, temperature extremes and resistance to corrosion, fungus and water penetration.

FEATURES

- Portable, compact, lightweight
- Four selectable chart speeds
- Hinged chart window for manual chart notations
- Operation with up to 1500 feet of transducer cable
- Standby switch
- Plug-in printed circuit boards
- Phase marker
- Remote fix-mark receptacle
- Adjustable chart paper speed
- All solid state
- Available for 12 VDC, 115/230 VAC operation, 50-60 Hz
- Belt driven stylus
- Stylus designed for long life, quick, easy replacement.



HINGED WINDOW
Opens for easy access to chart paper and controls for speed of sound, tide and draft and range.

CARRYING HANDLE
Provides easy portability.

CASE
Rugged aluminum, splash-proof

CANVAS ZIPPER CASE
Protects unit during transport and stowage

HINGED REAR COMPARTMENT
Stores transducer, brackets and cable.

SPEED OF SOUND
Compensates for salinity and temperature of water.

TIDE/DRAFT
Compensates for tide and draft variations.

OFF/STDBY/ON
Turns unit on and off or keeps unit warmed up.

RANGE X1, X2
Changes stylus speed to multiply phase scale by two.

CAL. ZERO
Adjusts first marker line to zero on chart.

FEET
Selects desired depth ranges.

CHART SPEED
Selects 1, 2, 3 or 4 inches per minute.

SENSITIVITY
Adjusts receiver gain.

FIX MARK
Places reference mark on chart.

Completely self-contained with stowage for transducer and rigging.

For specific information on price and delivery, or for applications assistance, contact:
Raytheon Ocean Systems Company,
Westminster Park, Risho Avenue,
East Providence, Rhode Island 02914
Telephone: (401) 438-1780 TELEX: 6814078

RAYTHEON

Outside U.S.A and Canada, contact:
Raytheon Company, International Affairs,
141 Spring Street, Lexington, Mass. 02173.
Telephone: (617) 862-6600. TWX:
710-324-6568. Cable: RAYTHEONEX.

All specifications subject to change without notice

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APPENDIX 3

NAVIGATION SHORE STATION CONSTANTS

```
|==========================================================================|
|                                                              15 SEP 1990|
|    S H O R E   S T A T I O N   C O N S T A N T S  (DETAILED)  20:45:44  |
|--------------------------------------------------------------------------|
| (1) FILE NAME    :  TOKS                                                 |
|     STATION NAME :  Toker Pt. Syledis, slot 10                           |
|     HARDWARE     :  Syledis Beacon                                       |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                            |
|     COORDINATES  :  N  7 728 461.99     LAT    69-39-10.479 N           |
|                     E    583 523.75     LONG  132-50-50.402 W           |
|     ANT. HEIGHT  :   18         CONSTANT :  -235.2     STATUS : ENABLED  |
|--------------------------------------------------------------------------|
| (2) FILE NAME    :  ATKS                                                 |
|     STATION NAME :  Atkinson Pt. Syledis, slot 09                        |
|     HARDWARE     :  Syledis Beacon                                       |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                            |
|     COORDINATES  :  N  7 763 669.88     LAT    69-56-46.710 N           |
|                     E    635 907.58     LONG  131-26-49.490 W           |
|     ANT. HEIGHT  :   15         CONSTANT :  -235.2     STATUS : DISABLED |
|--------------------------------------------------------------------------|
| (3) FILE NAME    :  PULS                                                 |
|     STATION NAME :  Pullen Island Syledis, slot 12                       |
|     HARDWARE     :  Syledis Beacon                                       |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                            |
|     COORDINATES  :  N  7 740 810.90     LAT    69-46-33.020 N           |
|                     E    522 929.57     LONG  134-24-20.500 W           |
|     ANT. HEIGHT  :   30         CONSTANT :  -235.2     STATUS : DISABLED |
|--------------------------------------------------------------------------|
| (4) FILE NAME    :  ATKA                                                 |
|     STATION NAME :  Atkinson Pt. Argo Fix 1 EVEN                         |
|     HARDWARE     :  Argo RPU freq. 1750/1925 Khz                         |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                            |
|     COORDINATES  :  N  7 763 645.28     LAT    69-56-45.969 N           |
|                     E    635 880.30     LONG  131-26-52.185 W           |
|     ANT. HEIGHT  :   15         LANE CORR:    +.16     STATUS : DISABLED |
|--------------------------------------------------------------------------|
| (5) FILE NAME    :  TOKA                                                 |
|     STATION NAME :  Toker Pt. Argo Fix 2 ALL                             |
|     HARDWARE     :  Argo RPU freq. 1750/1925 Khz                         |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                            |
|     COORDINATES  :  N  7 728 440.83     LAT    69-39-09.847 N           |
|                     E    583 478.64     LONG  132-50-54.652 W           |
|     ANT. HEIGHT  :   17         LANE CORR:    +.17     STATUS : DISABLED |
|--------------------------------------------------------------------------|
| (6) FILE NAME    :  PULA                                                 |
|     STATION NAME :  Pullen Is. Argo Fix 3 ALL                            |
|     HARDWARE     :  Argo RPU freq. 1750/1925 Khz                         |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                            |
|     COORDINATES  :  N  7 740 834.23     LAT    69-46-33.767 N           |
|                     E    522 951.07     LONG  134-24-18.472 W           |
|     ANT. HEIGHT  :   35         LANE CORR:    +.30     STATUS : DISABLED |
|--------------------------------------------------------------------------|
| (7) FILE NAME    :  GARA                                                 |
|     STATION NAME :  Garry Is. Argo Fix 4 ALL                             |
|     HARDWARE     :  Argo RPU freq. 1750/1925 Khz                         |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                            |
|     COORDINATES  :  N  7 709 154.23     LAT    69-29-28.350 N           |
|                     E    469 381.90     LONG  135-46-58.980 W           |
|     ANT. HEIGHT  :   46         LANE CORR:    -.16     STATUS : DISABLED |
```

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|===========================================================================|
|                                                               16 SEP 1990|
|    S H O R E   S T A T I O N   C O N S T A N T S (DETAILED)   04:12:51   |
|---------------------------------------------------------------------------|
| (1) FILE NAME    :  KUGS                                                  |
|     STATION NAME :  Kugmallit Bay Syledis, slot 11                        |
|     HARDWARE     :  Syledis Beacon                                        |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                             |
|     COORDINATES  :  N  7 697 009.75      LAT     69-22-43.550 N           |
|                     E    553 310.60      LONG  133-38-37.100 W           |
|     ANT. HEIGHT  :   12         CONSTANT :  -235.2     STATUS : DISABLED  |
|---------------------------------------------------------------------------|
| (2) FILE NAME    :  GARS                                                  |
|     STATION NAME :  Garry Island Syledis, slot 09                         |
|     HARDWARE     :  Syledis Beacon                                        |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                             |
|     COORDINATES  :  N  7 709 178.65      LAT     69-29-29.136 N           |
|                     E    469 377.07      LONG  135-46-59.454 W           |
|     ANT. HEIGHT  :   62         CONSTANT :  -235.2     STATUS : DISABLED  |
|---------------------------------------------------------------------------|
| (3) FILE NAME    :  PITS                                                  |
|     STATION NAME :  Pitt Island Syledis, slot 10                          |
|     HARDWARE     :  Syledis Beacon                                        |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                             |
|     COORDINATES  :  N  7 672 840.70      LAT     69-09-47.196 N           |
|                     E    452 196.45      LONG  136-12-15.130 W           |
|     ANT. HEIGHT  :   18         CONSTANT :  -235.2     STATUS : DISABLED  |
|---------------------------------------------------------------------------|
| (4) FILE NAME    :  PITA                                                  |
|     STATION NAME :  Pitt Is. Argo Fix 1 ODD                               |
|     HARDWARE     :  Argo RPU freq. 1750/1925 Khz                          |
|     COORD. SYST. :  UTM: NAD 1927, CLARK 1866                             |
|     COORDINATES  :  N  7 672 892.04      LAT     69-09-48.835 N           |
|                     E    452 168.06      LONG  136-12-17.795 W           |
|     ANT. HEIGHT  :   18         LANE CORR:    +.16     STATUS : DISABLED  |
|---------------------------------------------------------------------------|
```