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ICE SCOUR DATA BASE FOR THE BEAUFORT SEA

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TABLE OF CONTENTS

ï	Page
Project Personnel	ix x xi 1 3
Regional Setting and Background. Physiographic setting. Bathymetry Sea-ice zonation. Quaternary geology and related sea-bed process. Previous ice-scour studies. Canadian Beaufort Sea. American Beaufort Sea. Geophysical instrumentation for scour detection. Data-base overview Rationale for data base. Side-scan sonar data base. Echo-sounder data base.	8 8 8 10 14 15 16 18 19
Project Orientation. Selection of data-base parameters. Assessment of data quality. Data quality table. Factors constraining data quality. Data quality of specific data sets. Preparation of ice-scour bibliography. Environmental criteria for regional line selections. Bathymetry, shelf gradient, and sea-bed morphology. Geological and geotechnical factors. Ice-cover zonation. Oceanographic and meteorologic information. Evaluation of relative-age dating technique.	22 22 23 23 27 29 30 30 30 32 32
Methods Side-scan sonar Data preparation Digitizing	34 34

Echo-sounder	44
Data preparation	44
Digitizing	44
Data processing	45
Sub-bottom profile	47
Manual measurement technique	47
Entry to the data base	50
Mosaics (Relative-age study)	50
Criteria for selection	50
Data treatment	51
Corridor (study of additional new scours)	52
Rationale for study	52
Data treatment	52
Interpretation Methods	54
System configuration	54
Interpretive analysis	54
System algorithms	55
Brotem digoriemberen et en	
Results	57
Integrity of the data base	57
General quality-control measures	57
Statistical verification of echo-sounder data base against	
manual interpretation	57
Scour-depth comparison between echo-sounder data base and	
side-scan sonar data-base manual interpretations	62
Scour-depth comparison with APOA data	66
Methods	66
Results	67
Interpretation examples	67
Scour-parameter analysis using whole data base	68
Inter-relationship between scour parameters	68
Relationship of scour parameters to environmental	70
factors	70
Mosaics (relative-age study)	77 79
Corridors (study of additional new scours)	80
Unusual features	80
Geologic features	81
Man-made features	82
Unknown features	32
Discussion	83
Discussion Integrity of the data base	83
Interpretive flexibility of the data base	85
Mosaics (relative-age study)	86
Corridors (study of the additional new scours)	87
Advantages of the data-base system	88
Limitations of the data base	88

Recommenda	ations9	00
References	s	94
Appendices	5	9
Appendix	1 : Bibliography2 : Side-scan sonar and echo-sounder parameter descripti3 : Erratum	ons

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LIST OF TABLES

TABL	<u>.E</u>	PAG	SE
1.	Ice-scour parameters (side-scan sonar data base)	.	20
2.	Ice-scour parameters (echo-sounder data base)	• •	21
3.	General data quality summary ······	• •	24
4.	Mosaics and corridor data quality	• •	25
5.	Number code system used during digitizing phase	••	38
6.	Sub-bottom profile data derived from third-channel	• •	49
7.	Echo-sounder data base versus Geoterrex manual interpreter	••	58
8.	Echo-sounder data base versus independent interpreters	••	60
9.	Comparison of echo-sounder versus sub-bottom profile scour-depth measurements	• •	64
10.	Scour depth versus width	• • •	71
11.	Scour parameters versus bathymetric zonation	• •	73
12.	Relative-age study ······	• • •	78
13.	Study of additional new scours (corridor)	•••	79
14	Unusual features ····································		80

LIST OF ILLUSTRATIONS

Figure	<u>es</u>	ige	
1. 2. 3. 4. 5. 6.	BeaufortSea location map	9 10 12 13 17	*
8. 9. 10. 11. 12.	Flow diagram of data preparation	36 41 42 46	
14.	Computer versus manual comparison of echo-sounder data base from Gulf 1982	59	
15.	Comparison of scour-depth distributions by different		
16.	interpreters	61	
17. 18. 19. 20. 21. 22. 23. 24. 25.	interpreters	63 65 66 69 72 72 78 78 78	** ** ** ** **
26.	Tingmiark Plain: scouring over Pingo - like feature 40-50 m water depth (side-scan sonar record)	82	J.
27.	Tingmiark Plain: scouring over Pingo - like feature (echo-	82	93
28. 29. 30.	Scour orientation changes	82 82	5 ⁵
31.	Comparison of scour depths measured by sub-bottom profiler and echo-sounder	84	לכ

Plates	Facing	Page
2. 3.	Fix mark location map	30 52 52 52
5.	Ice-scour interpretation within 20 m bathymetric zones	72

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STATEMENT OF ACCESS

- This report and copies of the data base listings and/or 9-track tapes are available at duplication costs from the Geological Survey of Canada at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. Enlarged copies of the enclosed plates are also available at this location. Interested parties should contact Mr. S.M. Blasco at (902) 426-3932.
- 2) All software utilized for this project is the property of Geoterrex Ltd. in Ottawa and interested parties should contact Mr. W. Tschaikowsky for further information at (613) 731-9571.
- 3) Minor mistakes in data base values that have come to the authors attention are summarized and corrected in Appendix 3.

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SUMMARY

The grounding of sea ice on high-latitude continental shelves the world represents a geologic constraint to the safe installation of subsea petroleum facilities. To facilitate the assessment of seabottom ice scouring on marine design criteria, a computerized data-management system has been established for Sea. Side-scan Beaufort sonar, bathymetric, sub-bottom profile acoustic data are digitized computer-processed to produce various scour parameters that are incorporated into a comprehensive, location-referenced data file. The digitization process includes outlining the discrete scour events on sonographs and tracing the sea-bed profiles echographs. Individual scours are defined in a 27-column data base in which each is characterized by location, orientation, depth, length, width, area, form, morphology, smoothness, relative age, sediment infilling, associated sediment type and thickness, and the thickness of any sub-scour deformation, if present. Scour depths are derived by automatic measurement from computer-normalized echo-sounder profiles using a running average filter to determine the location of the smoothed sea-floor. The integrity of the data base was tested statistically within stringent confidence levels by comparing computer-generated scour distributions to those derived by conventional techniques of manual measurement.

The data base at present contains computer-derived scour parameters for over 11,400 scours from echo-sounder data and over 35,700 scours from side-scan sonar data. The nine separate data sets within this compilation were collected from 1970 to 1983 and represent about 5000 km of regional survey data from the principle petroleum operators in the Canadian Beaufort Sea (Dome Petroleum Ltd., Esso Resources Ltd., and Gulf Canada Resources Inc.) and from the Geological Survey of Canada. High-quality, sea-bed acoustic data was selected to accommodate the full range of physical conditions anticipated on the Beaufort shelf including sea-floor morphology and depth, sediment type, and geotechnical relationships and related environmental criteria, such as sea-ice zonation and oceanographic and meteorological considerations.

The creation of a digital data base lends great flexibility to traditional methods of interpreting ice-scour statistics. Three types of interpretive analyses were computed and graphically illustrated using Geoterrex software to demonstrate a full range of potential interpretive capabilities. The first analysis used the total echo-sounder data base and produced a scour-depth distribution for the whole Beaufort Sea that was successfully fitted to a negative exponential function. The second analysis showed the inter-relationship between two scour parameters (depth

versus width) for a selected subset of the side-scan sonar data base. The last example illustrated the correlation between various scour parameters and an environmental parameter (water depth). Statistical analysis of the data was found, in all cases, to be highly flexible, accurate, and rapid.

An evaluation was undertaken concerning two types of scour studies for potential incorporation into the data base. The first, relative age determination by crosscutting analysis was found to be somewhat subjective and therefore of limited value for future incorporation into the data base. The second, the study of new scours identified by repetitive mapping, however, was found to be important as statistical interpretation of these modern scouring events could be facilitated within the data base environment. A suitable procedure for corridor data analysis was established.

In summary, this computerized method of cataloguing ice-scour data from the Beaufort Sea was found to be accurate and highly efficient with the final product providing enhanced capabilities for data manipulation, interpretation, and plotting operations.

RESUME

L'échouage des glaces sur les plateaux continentaux des régions nordiques représente un péril naturel pour les installations pétrolières sous-marines. Afin d'évaluer l'influence des traces d'affouillement par les glaces sur le design des ouvrages pétroliers sur le fond de la mer, une approche informatisée de traitement des données d'affouillement par les glaces a été développée pour la partie canadienne de la mer de Beaufort. Des données de sonar à balayage latéral, d'écho sondeur et de sondeur de sédiment ont été traitées numériquement dans le but d'obtenir différents paramètres sur les traces d'affouillement. Ces paramètres ont été par la suite intégrés dans une banque de données, organisée à partir d'un système de référence géographique. L'étape de numération comprend le tracé des contours des traces individuelles d'affouillement sur les enregistrements de sonar latéral ainsi que le tracé du profil du fond marin sur les échogrammes. La banque de données est constituée de 27 colonnes contenant des informations sur la situation géographique, l'orientation, la profondeur, la longueur, l'apparence, la morphologie, le relief, l'âge relatif, le remplissage sédimentaire, la nature et l'épaisseur du sédiment affouillé, et la profondeur de la zone de déformation, si présente, de chaque trace d'affouillement par les glaces. La mesure de la profonduer des traces d'affouillement est effectuée par l'ordinateur à partir d'une reconstitution du profil moyen du fond de la mer qui est obtenu à l'aide d'un filtre numérique dont l'effet est d'effacer les traces d'affouillement. La validité de la banque de données a été vérifiée statistiquement afin d'assurer l'utilisateur que des marges d'erreur très strictes ont été respectées. Cette vérification a été effectuée en comparant des distributions de traces d'affouillement produites par ordinateur à celles obtenues par des techniques manuelles conventionnelles.

La banque de données contient des paramètres informatisés couvrant plus de 11,400 traces d'affouillement identifiées sur les échogrammes et plus de 35,700 traces d'affouillement visibles sur les enregistrements de sonar latéral. Les données obtenues suite à neuf campagnes de mesure, lesquelles ont été effectuées entre 1970 et 1983 par les principales compagnies pétrolières (Dome Petroleum Ltd, Esso Resources Ltd and Gulf Canada Resources Inc.) opérant dans la mer de Beaufort, ainsi que par la Commission Géoloquie du Canada, ont servi à cette compilation qui couvre environ 5000 km de profils régionaux. Une attention particulière a été accordée aux données acoustiques de haute qualité afin d'obtenir un éventail complet des conditions physiques qui peuvent se retrouver sur le plateau continental de la mer de Beaufort. Celles-ci incluent la profondeur d'eau et la morphologie des fonds marins, le type de sédiment, les conditions géotechniques, ainsi que des considérations environnementales telles que la distribution des glaces et des facteurs océanographiques et météorologiques.

L'accès à une banque informatisée de données permet une grande flexibilité par rapport aux méthodes traditionnelles d'étude statistique des traces d'affouillement par les glaces. Trois différents types d'analyses ont été effectués par ordinateur et illustrés graphiquement à l'aide d'un logiciel développé par la compagnie Géoterrex Ltée pour démontrer les possibilités de la banque des données. La première analyse a couvert toutes les données informatisées d'écho sondeur et a résulté en une distribution de la profondeur des traces d'affouillement pour toute la partie canadienne de la mer

de Beaufort; cette distribution respecte scrupuleusement une fonction exponentielle négative. La deuxième analyse a servi à démontrer les relations entre deux paramètres (profondeur versus largeur) d'un sous-échantillon de traces d'affouillement qui provenaient des données de sonar latéral. La troisième analyse a porté sur les corrélations entre différents paramètres des traces d'affouillement et un facteur environnemental donné (profondeur d'eau). L'analyse statistique des données s'est révélée, sans tous les cas, très flexible, précise et rapide.

En plus, une évaluation de deux autres types d'étude, dont les résultats auraient pu être intégrés dans la banque de données, a été effectuée sur les traces d'affouillement. La première étude, quie visait à déterminer l'âge relatif des traces d'affouillement à partir d'une analyse des entr-croisements des traces, s'est avérée quelque peu subjective et l'utilité d'inclure ces résultats dans la banque de données est douteuse. Cependant, la deuxième étude, quie se résume à identifier les nounelles traces d'affouillement sur des sections du fond de la mer qui furent l'objet de reconnaissances acoustiques à plus d'une occasion lors de différentes campagnes de mesure et dont les résultats ont été inclus dans la banque de données, sèst révélée un outil important pour l'interprétation statique des traces modernes d'affouillement. Cette seconde étude a permis d'établir une procédure appropriée pour l'analyse des données recueillies à des pédiodes différentes sur un même corridor du fond marin.

En résumé, cette méthode informatisée de classification des traces d'affouillement par les glaces dans la mer de Beaufort s'est avérée précise et très efficace. La produit final permet à l'utilisateur de meiux gérer, interpréter et présenter graphiquement des données informatisées de traces d'affouillement par les glaces.

INTRODUCTION

Ice-scour marks identified by side-scan sonar on the continental shelf of the Canadian Beaufort Sea (Figure 1) are evidence of ancient and recent ice/seafloor interactions (Pelletier and Shearer 1972). The grounding of sea ice (generally in the form of pressure ridges) represents a geologic constraint to the safe installation of subsea petroleum facilities. Adequate design for the protection of such facilities requires an understanding of ice scour processes and an engineering assessment of the scour parameters critical to design criteria.

Analysis of the ice-scour record for engineering purposes is problematic as the observed sea-bed distribution represents a cumulative history of scouring over geologic time which includes the effects of sea-level changes, geologic processes of scour degradation by sedimentation and/or erosion and temporal/spatial variations in sea-ice conditions. To fully address the problem of ice-scour, these effects including additional geographic and geotechnical factors relating to the Beaufort continental shelf must be considered.

The most critical phase preceding the statistical analysis of ice-scour data involves an accurate interpretive transfer of each scour parameter from the analogue acoustic data to a computerized data base. Traditionally, data analysis has been done manually using measuring scales for lengths, widths, and orientations. However this process is tedious, subjective, and costly, particularly for the large data sets that exist for the Beaufort Sea.

A computer analysis technique has recently been developed by Geoterrex Ltd. (Gilbert et al. 1985), whereby ice-scour data are first digitized by an experienced interpreter, are subsequently processed by specialized software to generate scour parameters, and are finally listed in a comprehensive, location-referenced data file. This technique was used in this project to process 5000 line kilometres of regional acoustic data from the Beaufort Sea. The integrity of the data was statistically evaluated by Shearer Consulting and Canada Marine Engineering Ltd.

The specific objectives of this project are:

- to create a regional ice-scour data base for scour parameters from side-scan sonar, echo-sounder and sub-bottom profile acoustic data;

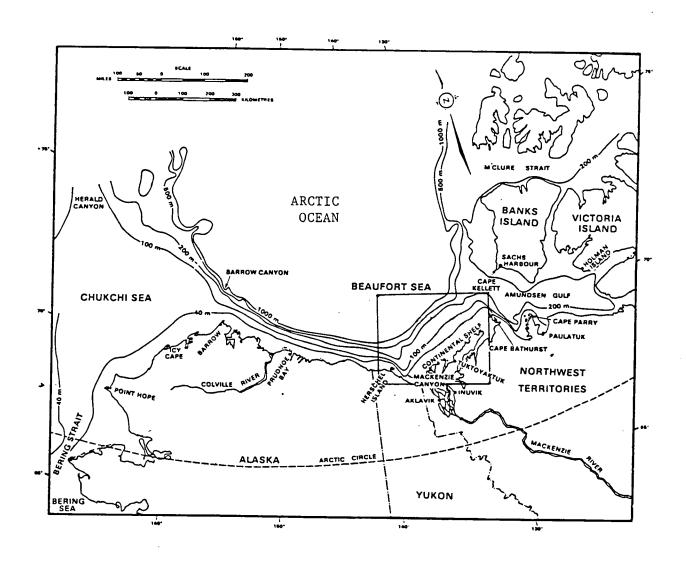


Figure 1. Beaufort Sea location map (after E.I.S. Beaufort Sea 1982).

- to process the existing regional acoustic data of sufficient quality to be incorporated into the data base (approximately 5000 km);
- to demonstrate the integrity of the data base and illustrate the interpretive flexibility; and
- to test the feasibility of incorporating relative scour age and repetitive surveys for new scours into the data base.

REGIONAL SETTING AND BACKGROUND

PHYSIOGRAPHIC SETTING

Bathymetry

The Beaufort Sea is located within the southern part of the Arctic Ocean (see Figure 1) and, more specifically, is contained within the Mackenzie Trough. Three major physiographic features are present on the floor of the Beaufort Sea region. The continental shelf is flat, moderately shallow (0 - 100 m) and slopes gently from the coast-line to the shelf edge at depths of about 100 m. The continental slope drops steeply from the shelf edge to depths of about 1000 m. The deep Mackenzie Trough interrupts the continuity of the western shelf extending to depths of 500 m and onwards to the upper slopes of the Canada Basin (Vilks et al. 1979). The reader is referred to Plate 1 for detailed bathymetry of the Beaufort Sea region.

Sea-Ice Zonation

The southern Beaufort Sea is typically ice-covered for 9 months of the year. It is this ice that directly affects the form and intensity of modern scouring on the Beaufort Shelf and therefore, should be described in some detail.

Kovacs and Mellor (1974) recognized three major ice zones within the continental shelf region known as the Fast-Ice Zone, Shear Zone, and the Polar Pack, (Figure 2).

- Fast-Ice Zone -generally limited to within the 18-20 m contour.
 -composed primarily of grounded first-year ice with inclusions of pressure ridges and some multi-year fragments.
- Shear Zone -formed by the interaction of the polar pack and the grounded fast-ice.
 this boundary zone is heavily ridged with multi-year ice and occasionally ice islands.
 - Polar Pack -permanent offshore pack ice that rotates in a clock-wise direction under the influence of the Beaufort gyre.

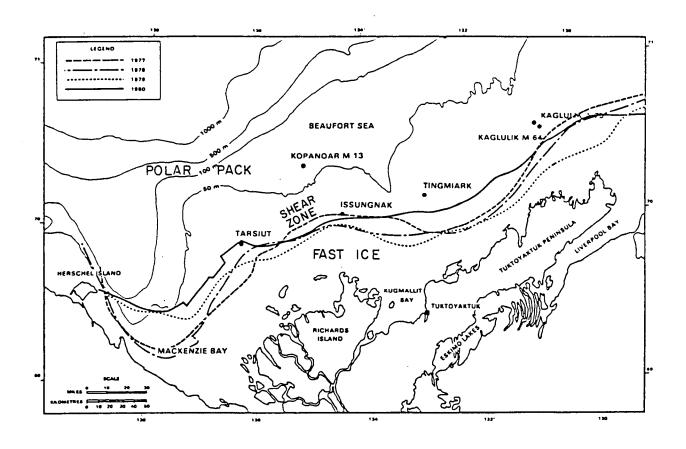


Figure 2. Maximum extent of Landfast ice in southeast Beaufort Sea (from E.I.S. Beaufort Sea 1982).

Quaternary Geology and Related Sea-bed Processes

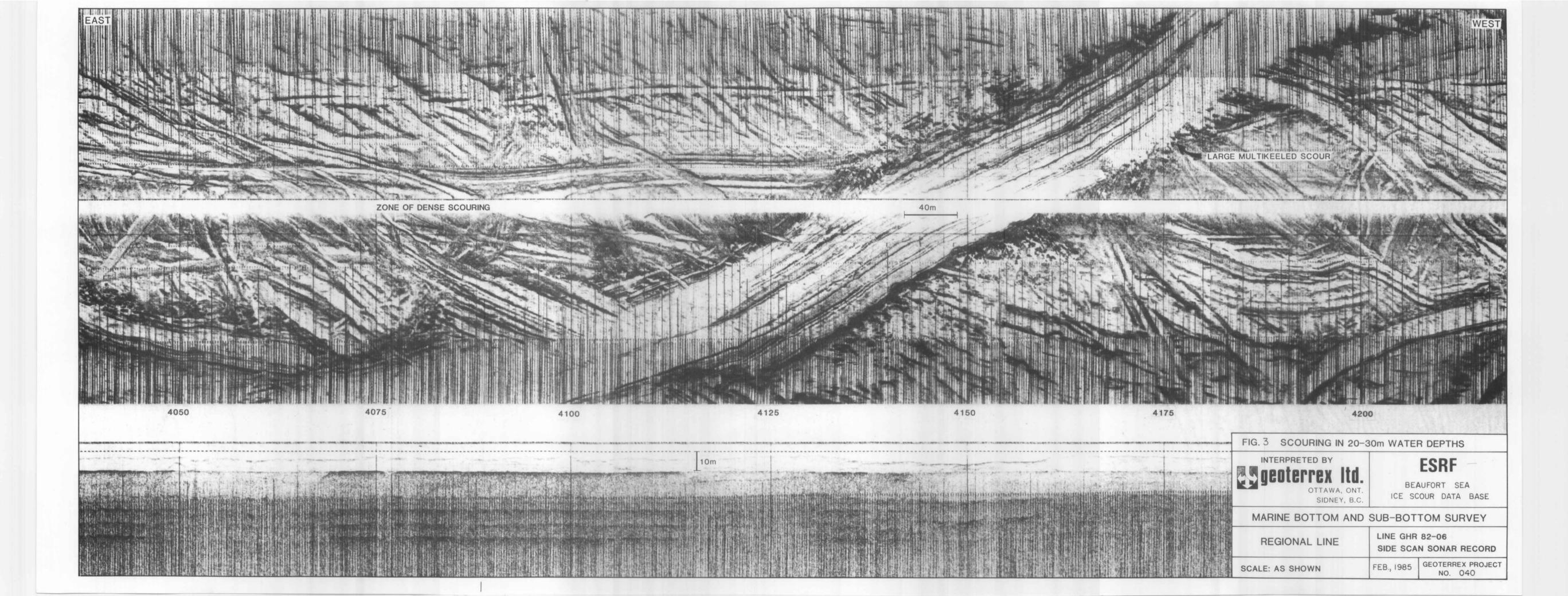
The Beaufort Sea is contained within the Mackenzie Basin which covers an area of about 90,000 square km. Throughout the Tertiary this basin was filled with marine, epicontinental, and fluviodeltaic sediments (Young et al. 1976). Continued deposition resulted in the present-day shallow Beaufort shelf of moderate relief and gradient with the exception of the Mackenzie Trough (a feature possibly carved out by an ice tongue during the early Wisconsin).

Late-Quaternary glacial processes generated the present-day sea-floor morphology and shallow stratigraphy within the coastal and marine regions of the Beaufort Sea. The continental shelf was exposed to subaerial erosion during the Wisconsin glaciation as sea-levels may have been more than 100 m lower during that time (Hill et al. 1985). Upon deglaciation, sea-level rose leading to transgression of the shelf and to the deposition of complex transgressive sedimentary units. water depth increased, a sequence of overlying marine silty clay was deposited that was particularly within thick the distributaries and the Mackenzie Trough. There are, therefore, three major units present on the Beaufort continental shelf; a regional, subaerially eroded plain underlying a transgressive, stratigraphic sequence followed by an overlying sequence of recent marine silty This glacial history is well summarized in a geological model with detailed illustrations and examples by O'Connor (1980).

An understanding of this glacial and post-glacial geological history will facilitate the interpretation of ice-scouring concepts within the framework of modern and historic geologic sea-floor processes. The presence of this scouring phenomena has been confirmed by geophysical surveying techniques as described later. In some cases, the sea-bed is completely incised by a network of troughs and berms producing a rugged, disturbed microrelief (Figure 3). Interpretation of the scour record is difficult as it portrays a cumulative history of events, complicated by the geologic processes of scour infill (sedimentation, erosion), sea-level changes, and temporal and spatial variations in sea-ice conditions.

For example, the transgression of both water and ice resulted in an ice-scoured sea-floor from the shelf edge directly to the modern coast-line. As the sea-level gradually rose to its present level, the sea-floor retained a progressive record of the effects of fast ice, shear zone ice and pack ice thereby creating a complex sea-floor pattern in which both older, relict scours and modern-day scours are found in spatial coexistence.

Along with the rise in sea-level the exposed coastal zone was progressively transgressed by a high-energy hydrodynamic environment that induced sea-bed erosion and infill of the the shallow-water scour population. It is noted by Harper and Penland (1982) that today, in



the shallow-water zone, bottom sediments (fine sands) are disturbed about 10 % of the time by waves having orbital velocities of 40 cm/s or greater.

By contrast, further offshore (greater than 10 m) a lower-energy environment persists that allows for the deposition of soft, silty clays, thereby infilling previously formed ice scours. It has been noted by Huggett et al. (1977) that near-bottom currents are weak and variable over the shelf and, therefore, are likely incapable of re-suspending sediments and degrading scours by erosion.

With continued sedimentation, scours eventually become totally infilled and actually disappear from the modern sea-floor population. these scours can be identified in high-resolution (Occasionally profiles and are termed paleoscours in the literature). The rate of this scour infill is dependent on the prevailing sedimentation rates of that location on the shelf. Understanding the sedimentation rates are essential in ice-scour study because infilled scours found in zones with high rates of sedimentation may be interpreted incorrectly as older than those found in areas of low or normal sedimentation rates. Sedimentation rates as calculated by Harper and Penland (1982) show that, seaward of the 30 m isobath and east of Kugmallit channel sedimentation rates drop considerably (Figure 4). Harper and Penland (1982) suspects that the major portions of sediment loads are deposited in shallow water actually landward of the 10 m isobath.

Ice scouring may also be affected by the geological and geotechnical nature of the sea-floor sediments. For example, a more competent geologic horizon, such as the subaerially exposed plain (regional unconformity "C"), may influence the depth of extreme scouring. The thickness of sediments overlying this unit are known to vary considerably (Fortin and Laroche 1984; Meagher 1978) and, therefore, in some areas the proximity of this competent unconformable surface may influence scour-depth distributions (see Figure 22).

The relationship between wind and ice is also known to influence the ice-scour record. Wind roses in Figure 5 indicate annual winds are mainly from the west, northwest, east and southeast. Herlinveaux and deLange Boom (1975) also show that summer winds blow northwest and southeast roughly equal amounts of time. The latter wind direction pattern correlates well with the observed, dominant, scour-orientation data from the Beaufort Sea region (e.g., Lewis 1977a).

Another factor that should be considered in relation to ice scouring is that of ice cover which appears to be important in preserving the scoured sea-floor microrelief. The presence of nearly complete ice cover for 8-9 months of the year limits the level of hydrodynamic activity imparted to the sea-bed sediments as most current activity is wind-generated (Harper and Penland 1982). Despite comparatively shallow waters on the Beaufort continental shelf, the

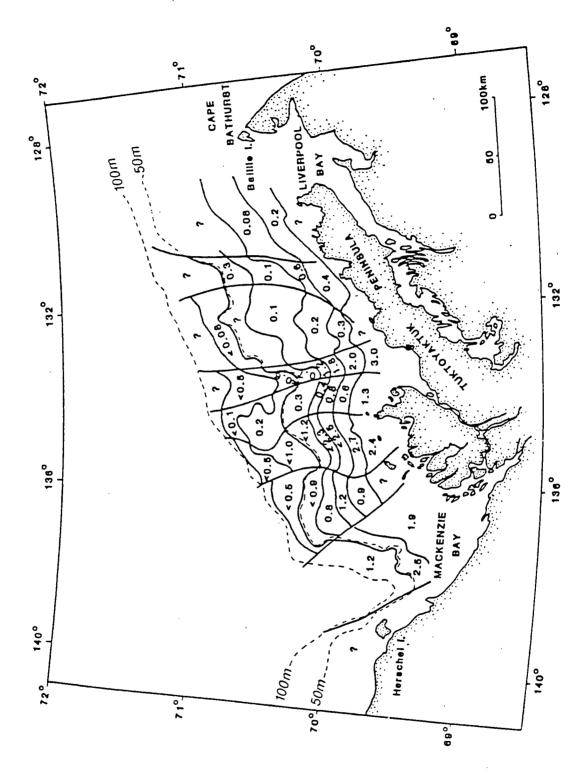


Figure 4. Sedimention rates (mm/yr) on the Beaufort Sea shelf (after Harper and Penland 1982).

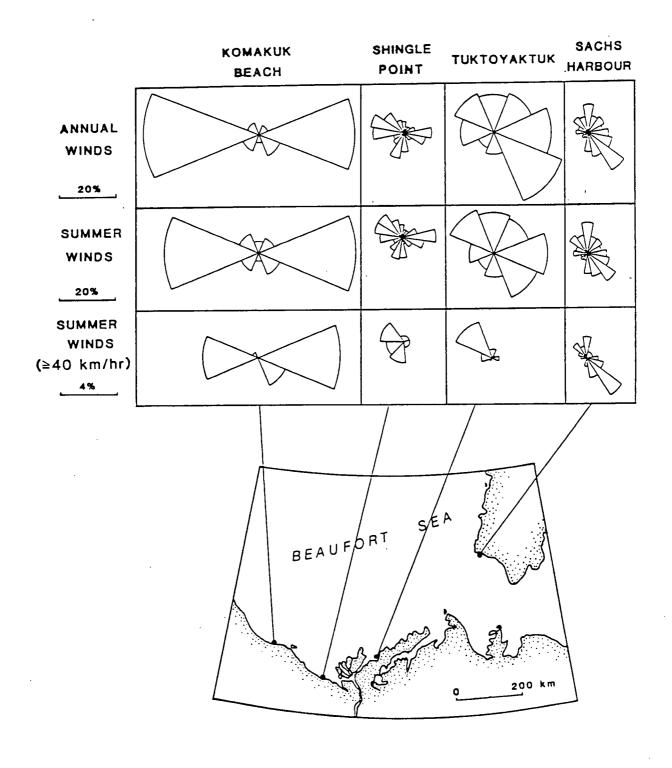


Figure 5. Wind distribution roses (from Harper and Penland 1982)

surficial sediments are not reworked hydrodynamically for most of the year, thus preserving scour morphology.

It is apparent therefore, that several environmental factors control the form and intensity of the ice-scouring process on the Beaufort Sea continental shelf.

PREVIOUS ICE SCOUR STUDIES

Canadian Beaufort Sea

Ice-scour research in the Canadian Beaufort Sea commenced in early 1970s. At an early stage, many of the persisting enigmas relating to ice-scour processes were identified (Pelletier and Shearer One such problem relates to scour age and the concept of "relict" scours; those preserved since the most recent Pelletier and Shearer (1972) observed that many of the transgression. scours on the Beaufort Shelf may be as old as 6,000 years based on sedimentation rates and infilled scours. This simplistic concept is likely complicated by variable sedimentation rates across the shelf producing infilled, old-appearing scours in areas of high sedimentation that may be contemporaneous with fresh-appearing scours in areas of low sedimentation (e.g., eastern Beaufort). Modern and relict scours are now believed to coexist spatially across the shelf. This problem seriously affects the ability to predict accurately the degree of risk to petroleum-related structures by modern ice-scour processes. increased exploration activity in the Beaufort Sea through the 1970s and 1980s a series of observational, statistical, and risk-related studies were undertaken by industry and government to help document and interpret some of these problems.

The largest undertaking was the Arctic Petroleum Operators Association (APOA) (Projects 19,32, and 69) contributions. A great many observational as well as statistical relationships were identified during this early work. Interpretive conclusions related to preferred scour orientations, scour frequency, scour depths, scour infill, and scour widths. Many useful observations relating to scour age and sedimentation rates were also presented.

Lewis (1977a,b) took the APOA data one step further and compared statistical relationships of various scour parameters with physical parameters such as water depth and geological zonations across the shelf. Lewis (1977b) also calculated yearly scouring rates and their return periods from repetitively mapped scour locations, however, as the data were somewhat limited, further time-series work was recommended. Further repetitive studies were undertaken by Shearer (1979, 1980a) and, as recently as 1984, by Shearer et al. (1985) where

a regional repetitive mapping framework has been surveyed for the Beaufort shelf.

Other statistical studies include those by Hnatiuk and Brown (1977) and Hnatiuk and Wright (1983). These papers summarize (using map sheets) various scour parameters, such as orientation, frequency, and depth, and also provide conceptual discussions relating to the problem of relict scours. Geoterrex ltd., under contract to Dome and Gulf, also produced numerous interpretations of scour parameters, such as depth, frequency, and widths, using site-specific mosaics from various locations across the Beaufort Sea. Shearer (1980b, 1983) under contract to Dome and Gulf, respectively, has documented scour depth statistics both regionally and for a site-specific location in the western Beaufort Sea. Much of Shearer's work contains useful interpretive "observations" relating to ice-scour, based on his extensive experience in the collection and interpretation of many years' ice-scour data.

Other useful observational studies include those by Wahlgren (1979) and Shearer and Blas ∞ (1975). Wahlgren examined a variety of scour relationships in relation to sea-bed slopes. Although many of the observations did not provide conclusive results, it is felt that this work has introduced important new concepts in ice-scour research that should be further tested with superior quality data sets that are now available. Shearer and Blasco (1975) presented several useful observations relating to ice and sea-floor scour morphologies. The problem of scour age was also addressed based on morphological criteria along with an introduction of the term "fresh" scours.

Studies related specifically to risk analysis include Pilkington and Marcellus (1981) and, more recently, a comprehensive summary by Morrison and Marcellus (1983); the latter under contract to Gulf Canada Resources. Additional ice-scour studies not mentioned here may be found in the bibliography (see Appendix 1).

American Beaufort Sea

The results of specific scour studies will not be discussed for the American Beaufort Sea. Rather than review the literature the more significant references are noted for the reader's use. Early work off the Alaskan coast took place in the early 1970s and is discussed by Skinner (1971), Reimnitz et al. (1972, 1973), Barnes and Reimnitz (1974) and Reimnitz and Barnes (1974). More recent work is described by Reimnitz et al. (1977, 1978), Barnes et al. (1978), and Barnes and Reimnitz (1979). As documented by Weeks et al. (1983) these studies provide observational descriptions of parameters, the characteristics of ice, and the general distribution and forces of scouring along the coast. A significant recent contribution by Weeks et al. (1983)

statistically documents many of the scour relationships occurring in the American Beaufort Sea.

It should be noted here that terminology varies between the American and Canadian researchers. The term "scour" used by Canadians is referred to as "gouge" by the American scientists. Also when picking scour depths from a known multi-keeled scour, the American researchers count each keel depth as a separate event, whereas, the Canadian group picks only a single, maximum scour depth as representative of the multi-keeled scouring event. Certain relationships such as scour frequency (number of scours per kilometre) and depth distributions can not be directly compared between countries.

GEOPHYSICAL INSTRUMENTATION FOR SCOUR DETECTION

The following acoustic equipment is commonly used in ice scour research programs:

- side-scan sonar
- echo-sounder
- sub-bottom profiler

The side-scan unit is a towed instrument that transmits high-frequency (10-500 kHz) sound pulses along narrow, fan-shaped beams slightly depressed from the horizontal (10 - 20 degrees). The recorded echoes produce an oblique, plan view of the sea floor's morphology and character as a function of acoustic reflectivity. This response is recorded using a chemical-treated wet paper on a dual-channel recorder producing a "photo-like" image of the sea-floor (see example; Figure 3).

The echo-sounder provides an accurate sea-floor profile by measuring the elapsed time between the transmission of a short, high-frequency (15-200 kHz) acoustic pulse and the return of a reflection or echo from the sea-floor. The recording device consists of a stylus-holding belt that sweeps across continuously advancing chart paper. It records both a transmission pulse (activation of transducer) and a generated, transducer pulse from the received acoustic "echo." The sounder profiles the sea-floor accurately thereby, defining ice scour morphology in cross-section as shown in Figure 6.

Like the echo-sounder system, sub-bottom profilers generate an accurate profile of the sea-floor in cross-section, but they generally operate within the 1.0 - 14.0 kHz frequency range. As their name implies, the lower frequency allows for penetration of the sea-floor sediments producing detailed seismic records of the sub-bottom geology, generally to depths of 20-30 m, see Figures 3 or 22.

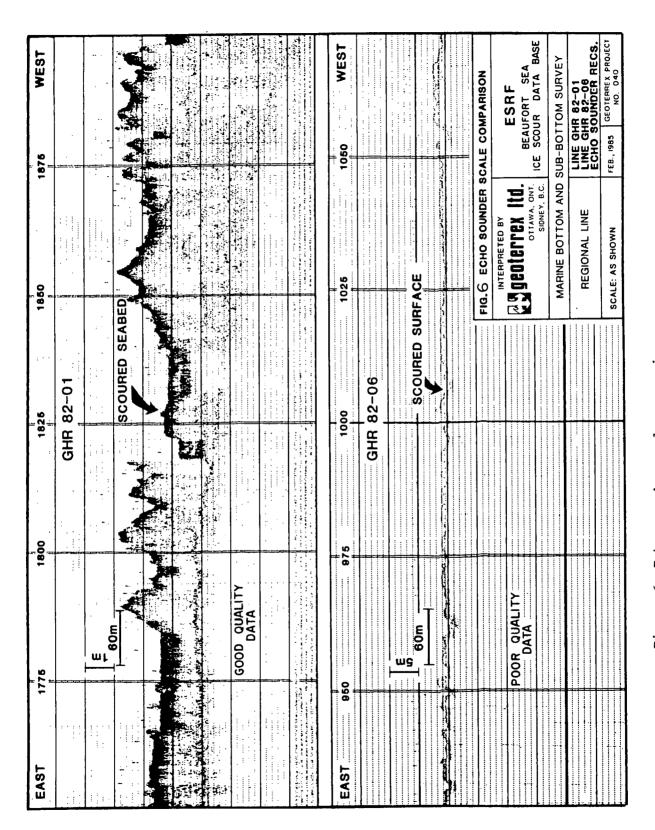


Figure 6. Echo-sounder scale comparison

The profiler also discriminates infilled scours and may show evidence of sub-scour deformation of the underlying sediments as a result of loading by a scouring keel. This profiling system is useful in correlating ice-scour relationships as it may be mounted on the side-scan fish and displayed simultaneously with the side scan plan view.

DATA-BASE OVERVIEW

Rationale for Data Base

With continued exploration for hydrocarbons in the Beaufort Sea, the petroleum operators and all concerned parties must assess the potential risks that ice scouring poses to petroleum-related sea-floor emplacements. During each exploration season more acoustic data applicable to this problem were collected. It became apparent that manual analytical and interpretation techniques were becoming inefficient for such a large data set and that these methods of analysis had limitations in terms of the flexibility of statistical studies and scour parameter re-evaluations. It was perceived that these data should be assimilated in an organized, reproducible format allowing for suitable flexibility in the later stages of interpretation for risk analysis.

The concept of a computer data base and digital input and processing techniques grew out of the recognition of some of the shortfalls of traditional interpretation techniques which include:

- the analysis of acoustic profiles is slow, tedious, and somewhat subjective;
- reanalysis and reinterpretation requires reassessment of the original analogue data; and
- the reproduceability of results by separate interpreters often is low.

It was thought that digitizing the data sets would provide a superior data package with advanced capabilities of display and statistical analysis. This technique would also provide for easy data storage, updates, and reinterpretations as well as a high degree of reproduceability between independent interpreters.

This description applies for both side-scan sonar and echo-sounder analogue records, but the methods of data treatment differ considerably. Unfortunately, scour depths measured from echo-sounder profiles could not be directly matched with those scours shown on

side-scan sonar records. This results mainly from the variable "layback" distance of the towed side-scan fish relative to the position of the echo-sounder.

It is important to recognize that the layback distance is potentially variable as the towed side-scan fish may be depth-compensated for changing bathymetry along a survey line. Resultantly, a one-to-one distance correlation between the two records is not possible and therefore two separate data bases are created; one for side-scan sonar data and one for echo-sounder data.

Side-Scan Sonar Data Base

An example of a side-scan sonar data base for ice scour is shown in Table 1. The data file contains 27 fields of data pertinent to the survey information and the particular ice-scour parameters measured. The structured format is such that various fields of data can be interpreted either in isolation or compared to other data fields as will be discussed in the Results. The interpretive advantages of such a system represent a significant step forward in ice-scour research for the Beaufort Sea region.

Echo-Sounder Data Base

An example of an echo-sounder data base is shown in Table 2. The data file contains fields of data relating to scour depth information. As with the side-scan data base the structured format allows easy comparison of the data fields; namely depth and bathymetry. The advantages of a digital data input method are many, perhaps the greatest of which is the concept of data reproduceability among independent interpreters. Made possible through a computerized sea-floor smoothing technique and automatic ice-scour detection software, this process establishes a common interpretation standard for the industry which will enhance data-pooling capabilities between independent research groups.

ICE-SCOUR PARAMETERS (SIDE-SCAN SONAR DATA BASE)

TABLE 1

NUMBER	PARAMETER	DESCRIPTION
1	Operator (company)	Operator who conduced survey
2	Year	Year survey was conducted
3	Line number	Regional line number
4	Part number	Reference number if line is subdivided
5	Fix number	Shot number input for each scour
6	Heading	Ship's heading
7	Easting	UTM co-ordinate for scour location
8	Northing	UTM co-ordinate for scour location
9	Scour number	Specific reference number
10	Orientation	Scour orientation (computed)
11	Standard deviation	Standard deviation of orientation (computed)
12	Form	Single keel, multi-keel, or multi-keel zone
13	Morphology	Straight, arcuate, sinuous, or crater
14	Smoothness	Rough, moderately rough, or smooth
15	Relative age	Old, recent, or uncut
16	Length	Scour length as computer from record
17	Width	Average scour width (computed)
18	Area	Area of scour (computed)
19	Depth	Scour depth; sub-bottom profile (S.B.P. if present)
20	Fix	Shot number for scour depth
21	Sediment fill	Thickness of scour infill (S.B.P)
22	Sub-scour deformation	Destruction of sub-scour stratigraphy (S.B.P.)
23	Sediment thickness	Thickness of surficial sediment (S.B.P.)
24	Sediment type	Clay, sand, or silt
25	Bathymetry	Bathymetric zonation (5.0-m intervals)
26	Quality	Data quality; good fair, or poor
27	Comments	Appropriate comments

TABLE 2

ICE-SCOUR PARAMETERS (ECHO-SOUNDER DATA BASE)

Number	<u>Parameter</u>	Description
1	Operator (company)	Operator who conducted survey
2	Year	Year survey was conducted
3	Line number	Regional line number
4	Part number	Reference number if line is
		subdivided
5	Fix number	Shot number input for each scour
6	Easting	UTM co-ordinate for scour location
7	Northing	UTM co-ordinate for scour location
8	Scour depth	Scour depth computed from filtered
		profile
9	Sea-bed depth	Bathymetry to filtered sea-floor
10	Quality	Data quality; good, fair, or poor
11	Comments	Appropriate comments

PROJECT ORIENTATION

In preparation for data analysis a number of preliminary assessments were undertaken:

- to establish an accepted format for the data base incorporating representative, good-quality data from across the Beaufort Shelf; and
- to ensure that compatible techniques for data measurement were correctly employed throughout the interpretive phase of the project.

As these preparatory studies revealed valuable observations influencing the analytical techniques employed and the evaluation of results obtained, each assessment warrants a brief summary description.

SELECTION OF DATA-BASE PARAMETERS

To evaluate the parameters chosen for the ice-scour data base, a meeting was held in Calgary, 19 January 1984, between geologic, geotechnical and engineering groups of the Beaufort Sea petroleum operators, Geoterrex Ltd., and the ESRF scientific adviser for this project. Participants reviewed the original data base (Gilbert et al. 1983) created in 1983 on behalf of Gulf Canada Resources and incorporated additional parameters based on comments of potential end users and associated experts from various marine disciplines. The final format (see Table 1) included the addition of relative age indicator, bathymetry, and a general denotation of data quality or confidence level; each of which is perceived to strengthen the interactive nature of the data array. Detailed description of each parameter used in the side-scan and echo-sounder data bases can be found in Appendix 2.

ASSESSMENT OF DATA QUALITY

Prior to picking lines for the data base, a complete review of data quality was undertaken to ensure the highest-quality data were incorporated in the 1984 Ice Scour Data Base. This was of importance for it was found upon comparing interpretive outputs that data quality was the factor most limiting in achieving accurate results. This especially held true for echo sounding and subbottom profile records that had compressed scales and low quality data. These records were more difficult to process than other data sets and accordingly have been assigned a lower confidence level in the data base. This section serves to remind the user that data quality does vary between and within data sets and also presents our estimate of data quality and confidence levels for each data package. Depending on the nature of

the interpretive analyses being performed, lower-quality data may, therefore, be rejected from the computation.

Data Quality Table

It is typical in geophysical surveys for the equipment and specifications to change from one season to the next, depending on the nature of the work and the current state of the technology. As a result, the data included in this compilation have differing parameters and degrees of quality. For example, one older data set has variable fix annotations in time, letters, and satellite fix passes. The data quality and navigation accuracy are resultantly low. Conversely, the more recent data sets, (e.,g. Dome 82, Gulf 82, Esso 83) are well annotated, have regular, accurate fix intervals, and are of superior quality largely resulting from removal of the water column and corrections to the slant range on the side-scan system.

The equipment and conditions used during each geophysical survey and the general data quality for each data set are summarized in Tables 3 and 4. The "General Quality" parameter in the table describes that data package as a whole. The judgement of GOOD, FAIR, or POOR for a data set is based on a number of physical factors (discussed in next section) that when considered together can adequately describe the general quality of one data set as opposed to another. These same conditions are also used as a field within the data base to define data quality on a line-by-line basis.

Factors Constraining Data Quality

Imperfect physical, environmental factors common to field operations often reduce data quality. Some of the limiting factors observed during the processing of the side-scan sonar and echo-sounder data for this project are summarized.

Side-scan sonar.

- i) The useable outer ranges of the channels may be diminished by the presence of thermocline/halocline interference and other seismic sources, or both, operating simultaneously during the survey generating interference patterns on the records.
- ii) Water surface multiples may be present.
- iii) Rolling, pitching, and yawing motions of the towfish because of the ship's motion during bad weather may distort data.

TABLE (3)

GENERAL DATA QUALITY SUMMARY

Parameter	Dome 80	Dome 81	Dome 82	Gulf 81	*Gulf 82	Gulf 83	Esso 83	Hudson 70	Beaufort Delta 76
SIDE SCAN SONAR									
Recorder sys. Frequency Scale Range Regular fixes? Slant range? Water col.? Speed correct? Navigation Regional interp.? Gonfidence	1694 Klein 421 100 kHz 150/250m NO NO NO NO Track Pit. YES GOOD HIGH	420 Klein 5317 100 kHz 100/150/250m NO YES YES YES YES YES GOOD HIGH	Klein 5117 100 kHz 150m YES YES YES TAPE COOD HIGH	924 Klein 401T 100 kHz 100 kHz 100/150m NO YES Tape NO GOOD HIGH	326 Klein 531T 100 kHz 150m YES YES YES YES YES YES YES HIGH	229 Klein 531T 100 kHz 100/150m YES YES YES YES TAPE NO FAIR	MIEIN 5317 100 KHZ 150m 150m YES YES YES YES TAPE NO NO FAIR	165 EG6G 100 kH2 1000' NO NO NO Track Plt. TO LOW	565 ECGG -1B 100 kHz 125' NO NO NO Track Plt. NO POOR
SUBBOTTOM PROFILE 1) Total Kms 2) Recorder sys. 3) Frequency 4) Vertical Scale 5) General Quality 6) Confidence		420 Klein 531T 100 kHz 50 m GCOD HIGH	217 Klein 531T 3.5 kHz 50m GOOD HIGH		326 Klein 531T 3.5 kHz 50/100m FAIR MOD.	229 Klein 531T 3.5 kHz 50m FAIR MOD.	92 Klein 531T 3.5 kHz 50m FAIR MOD.		
ECHO SOUNDER Kms Digitized	1354 50 kHz LAZ 17 NO YES NO GOOD	348 12 kHz Raytheon YES NO GOOD	217 33/210 kHz Atlas Deso 20 YES YES YES GOOD	808 30/210 kHz Atlas Deso 10 NO YES NO FAIR	326 33/210 kHz Atlas Deso 20 YES YES YES	229 208 kHz Raytheon YES YES YES GOOD	72 208 kHz Raytheon YES YES YES	* Gulf 82 Dat. processed for Gulf Canada Resources in	2 Data d for ada s in

TABLE (4)

MOSAICS and Corridor Data Quality

	Mosaics	Corridor
Parameter	Natiak W. Tingmiark Kringalik	E. Mackenzie 79
SIDE-SCAN SONAR		
1) Km digitized	300	150
2) Recorder system	Klein 531T	Klein 401T
3) Frequency	100 kHz	100 kHz
4) Scale range	1:10,000	1:10,000
5) Regular fixes	YES	ИО
6) Slant range	YES	NO
7) Water column	YES	NO
8) Speed correct	YES	NO
9) Navigation	Mosaic	TRACK PLOT
10) Regional interp	. NO	NO
11) General quality	GOOD	GOOD
12) Confidence	HIGH	HIGH

- iv) Discontinuities in data and recurring changes in range and depth scale hamper interpretation and processing.
 - v) Variable recorder settings for paper speed and signal gain may diminish image quality.
- vi) Changing towfish depths in uncorrected data introduces distortions.

Sub-bottom profile.

- i) Scale is essential when making manual scour measurements. For example, on a Klein 531T recorder, the third channel recorded profile with a scale of 100 m (over 12 cm of chart paper) is too compressed for accurate scour depth measurement. A larger scale of 50 m displayed over 12 cm of chart paper is of more value. The scale lines must be accurately calibrated.
- ii) Gaps in data, frequent gain variations and interference from other seismic sources degrade image quality.
- iii) The 5-m timing line on the profile data does not always track the sea-floor accurately and therefore does not reflect a true 5-m value.
- iv) Frequent changes in fish height decrease data quality as the sea-floor display is artifically distorted by physically altering the signal travel times from source to target.
 - v) Towfish motion during bad weather introduces distortions to the sea-bed profile thereby degrading ice scour recognition.

Echo-sounder.

- i) Wave motion may introduce artificial undulations on the analogue profile thereby distorting the sea-floor morphology.
- ii) Frequent scale changes slows digitization.
- iii) A compressed vertical depth scale minimizes sea-floor relief, therefore, making it very difficult to digitize smaller scours in the range of 0.5 1.0 m (see Figure 6 for scale comparison).
 - iv) Slow paper speeds produce poor horizontal scales for

digitization by horizontally compressing the data making it difficult to recognize discrete events.

- v) An output frequency that is too low may result in some sea-floor penetration and a profile that favours deeper scour depths especially for scours that may be infilled by "soft" sediment.
- vi) Data gaps on the analogue records are often attributed to air pockets trapped under the echo-sounder transducer during rough weather conditions. The presence of these gaps (often referred to as "bubble noise") slow digitizing and processing stages of the data reduction.

The "degree of confidence" qualifier which is included in the Data Quality Table therefore reflects the confidence placed in the interpreted data set. It is based on the cumulative effect of these constraining physical factors for each acoustic data set.

Data Quality of Specific Data Sets

Specific problems related to data quality and characteristics of certain data sets are described briefly.

Beaufort Delta Oil Project 1976. The original analogue records could not be located, so photocopied versions of requested lines were substituted. Poor record resolution may have been a result of both the copying technique and the quality of the original analogue records. Consequently, determination of scour smoothness, age, and uncut scours was difficult. As with all data sets or line portions of marginal quality, conservative interpretation was placed upon the data. For example, uncertainty over scour smoothness would result in the scour being labelled "moderately smooth," rather than "rough" or "very smooth." Echo-sounder records were of poor quality and were rejected for data processing.

Hudson 70. In addition to irregular fix intervals, annotation problems, and uncertain navigation co-ordinates, gain changes across the analogue records masked some of the data. Wide scale ranges of 1000 ft compress the data, thereby reducing scour sizes and lowering the interpreter's confidence in the accuracy of scour smoothness, age, and uncut codes. Echo-sounder records were rejected for processing.

<u>Dome 81</u>. These side-scan sonar analogue records were of good quality although some irregular fix intervals occurred. The towfish-mounted profiler was a 100 kHz pinger and, therefore, no sea-floor penetration was obtained. This third-channel data was used to derive scour depth data only. The 12 kHz sub-bottom profiler was hull-mounted and was used during this survey for bathymetry. This data set was digitized and was used to produce scour depths for the echo-sounder data base. Both profiler data sets were generally of good quality.

<u>Dome</u> 82. Quality was generally of high standard for both side-scan and echo-sounder data. It is worthy of note that fast chart speeds were used on the echo-sounder for the entire survey which increased the accuracy of digitizing and scour depth analysis.

<u>Dome</u> <u>80</u>. Side-scan and echo-sounder analogue records were of high quality, however, irregular fix intervals occurred on some lines and line 80-521E had fix annotations in time, rather than in numeric, units. Much of the 50-kHz echo-sounder data was not available until a substantial portion of 7-kHz data had been digitized. To maximize accuracy, the higher-frequency echo-sounder data were digitized which gave good quality, however, vertical scales were such that digitizing was slow.

Esso 83. Problems with these data were related to environmental conditions during the survey. Thermocline/halocline interference because of shallow water and fresh-water discharge from the MacKenzie River, or both, decreased the useable outer ranges of the side-scan sonar channels. An inability to decouple the ship's motion from the towfish resulted in wave "noise" on many of the side-scan analogue records. Echo sounder records were similarly affected and slow chart speeds hindered good horizontal scour definition.

Gulf 81. Side-scan records were generally of good clarity however irregular fix intervals and numerous paper feed problems slowed data processing. Echo-sounder records were similarly affected. Wave noise and "bubble gaps" decreased the record quality.

Gulf 82. Side-scan data were generally of good quality, however, the third channel 3.5-kHz sub-bottom profile data were often set at a compressed (0-100 m) vertical scale. This severely affected the scour depth measurements making correlations with echo-sounder values extremely difficult. The echo-sounder similarly was set at a compressed (0-100 m) scale for part of the survey as the scale adjustment setting was malfunctioning. The resulting data for both

sub-bottom and echo-sounder is of low quality for comparisons of scour depth distribution.

<u>Gulf 83.</u> Some irregular fix intervals on side-scan analogue records increased processing time. Sub-bottom profile data on the side-scan analogues was very faint and sea-floor relief was quite close to the zero time line for much of lines 83-06, 83-16, and 83-17. This minimized the amount of sub-bottom profile information that could be interpreted. Wave motion and vertical scale ratios decreased the quality of echo-sounder data somewhat.

Corridor. The 1974 base year corridor mosaic for the E. Mackenzie site was difficult to interpret because of the older, less superior analogue records from which it was compiled. Data quality was reduced by masked data in the outer channel edges of the sonograms, by very faint contrast in scour signatures, by other source interference on sonograms, and by gaps in the data. The 1979 resurvey corridor mosaic was of much higher quality. Because of the higher reliability of the newer data composing the 1979 resurvey, this corridor mosaic was digitized as if it were the base year (with the exception of any new scours). The mosaic was then digitized a second time for new scour additions only.

Mosaics. Data was generally of high quality for the mosaics used in relative age dating. Imperfect alignment between adjacent sonogram strips did at times, however, degrade the accuracy of determining cross-cutting relationships.

PREPARATION OF ICE-SCOUR BIBLIOGRAPHY

Prior to picking lines for the data base, a literature review was conducted incorporating papers and reports pertaining to the various aspects of ice scouring in the Beaufort Sea. Included in this bibliography are scientific publications by government and industry together with many unpublished reports originating mainly from the Canadian petroleum operators and associated consulting firms. The bibliography is presented (see Appendix 1) under the following major headings:

- 1) Ice Scour; Canadian Beaufort
- 2) Ice Scour; American Beaufort and Europe
- 3) Beaufort Geology
- 4) Oceanographic: Currents, Winds, Ice Conditions

The reader is also referred to the Ice Scour Bibliography produced as a joint ESRF/ASTIS project through the Arctic Institute of North America (Goodwin et al. 1985).

ENVIRONMENTAL CRITERIA FOR REGIONAL LINE SELECTIONS

The spatial and temporal frequency of sea-floor disturbance by ice scour in the Beaufort Sea cannot be solely related to any one It is well documented from the Beaufort environmental variable. (Pelletier and Shearer 1972) and other high-latitude, scoured shelves of the world (Bornhold and Guilicher 1984) that sea-floor signature geological/geotechnical bathymetry, with changes in sea-bed relationships, sea-ice zonation patterns, and More realistically, combinations of these transport variables. variables may interact ultimately to dictate the modern-day sea-floor signatures we observe on marine geophysical survey data. each environmental variable is represented by line coverage in the data base, specific criteria were addressed. The final line selections are shown as Plate 1. The projection used was Universal Transverse mercator (UTM) with the central Meridian at 135 degrees longitude.

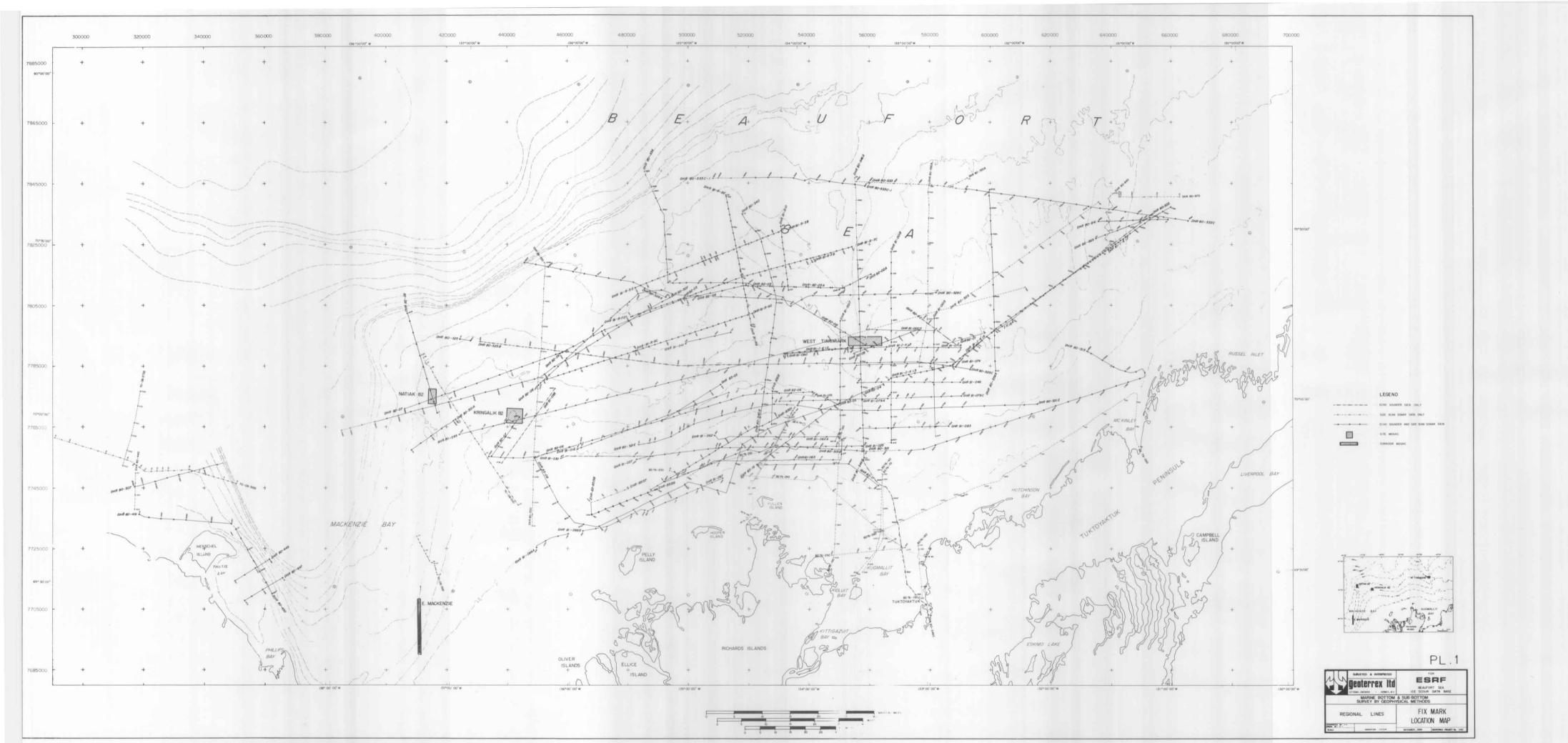
Bathymetry, Shelf Gradient and Seabed Morphology

Survey data were selected to optimize bathymetric coverage of the Beaufort Sea continental shelf. Most of these data originate in 20-60 m water reflecting the areas of current exploration interest by the operators. Accordingly, priorities were given to data outside these bounds, but especially for data in water depths less than 20 m where data are sparse and scour frequency is suspected to be quite high. Subdivision of the data was such that long isobathimetric lines were favoured within each 20-m contour zone as shown by Plate 1. Factors related to bathymetry such as regional shelf gradients (as scour depths are predicted (Wahlgren 1979) to change with slope) and localized sea-bed morphology were also considered in selecting survey lines.

Geological and Geotechnical factors

Ice scouring may be influenced by geologic factors such as grain-size distributions, geotechnical relations (e.g., high shear stress due to consolidation), and the thickness of surficial sediments overlying a more competent substrate. The available literature has been reviewed to ensure that all such factors in the Beaufort Sea have been identified and considered.

Pelletier (1975) and Vilks et al. (1979) published grain-size distribution maps of the Beaufort Sea (Figure 7a) showing the great



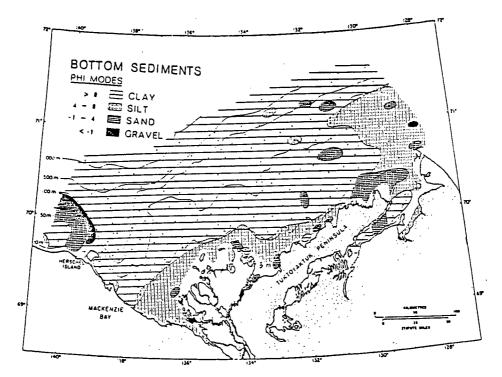


Figure 7a

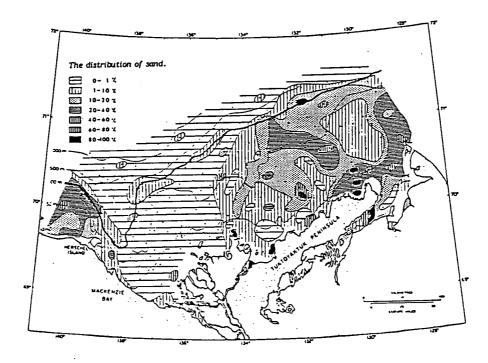


Figure 7b. Bottom sediment distributions (from Pelletier 1975).

majority of the surficial sediments to be marine clays at the surface. Figure 7b shows, however, that sediment coarsens both towards the inshore (roughly tracing the 10-m contour) and east of 133 degrees longitude with silts and sands increasingly present. Data coverage is notably poor in the shallow water (less than 10 m) zone where a 1976 poor data-quality survey is the only representative.

Geologic and physiographic zonations proposed by Swan Wooster Engineering Company (1982) and O'Connor (1982) define regions of similar sea-bed conditions across the shelf and have been addressed to ensure representative line coverage within each zone. The data base was also designed to accommodate the regional variations in the thickness of the thin Holocene silty clays as already discussed.

Other considerations included data from the Mackenzie Canyon area, from locations with differing sedimentation rates, and from unusual geologic features.

Ice-Cover Zonation

It is evident that any zonation of ice cover across the shelf would directly affect the form and intensity of modern scouring populations and, therefore, should be considered to ensure representative coverage. Data were selected to accommodate three different types of ice regimes, as discussed previously (Kovacs and Mellor 1974); the Fast-Ice zone, the Shear zone, and the Polar Pack.

Oceanographic and Meteorologic Information

The properties and motions of water in the shelf region of the southeastern Beaufort Sea are largely controlled by winds, as a result of relatively low speeds of residual and tidal currents (LGL Limited 1982). Data were broadly spaced across the Beaufort Shelf to cover the variable nature of the oceanographic and meteorologic data.

EVALUATION OF RELATIVE AGE DATING TECHNIQUE

The concept of "scour age" remains one of the most fundamental problems existing in ice-scour research on scoured continental shelves. It is well known that populations of both modern and relict scours coexist under certain conditions (Pelletier and Shearer, 1972; Lewis 1977a,b) which significantly influences engineering models of risk analysis for sea-floor emplacements (e.g. Morrison and Marcellus 1983).

Although not an absolute measurement technique, the concept of relative age dating by scour cross-cutting analysis may help to define

scour relationships between parameters and age and, thereby, may aid in estimating scour age. A test was performed using the method outlined by Woodworth-Lynas (1983) on side-scan sonar analogues and a side-scan mosaic produced by Jim Shearer and Geoterrex Ltd. for Dome Petroleum.

Scours were identified as members of age groups which lie within discrete domains. Identification of cross-cutting relationships was based on morphological criteria at the scour intersection points as discussed more fully in "Methods." Ice scours were traced on a mylar overlay to simulate a digitizing procedure. The length of the sonogram record which was traced approximated the length of a digitizing table (150 cm). Two sections of Gulf 82-03 data were chosen to represent both good and fair data. As well, to compare the east and accuracy of identification of scour relationships, a mylar trace of a Dome mosaic It was noted that poor data quality (thermocline, made. was crosstalk), compressed scales (reduced mosaic scale), and imperfectly aligned adjacent side-scan data for mosaics could decrease the degree of certainty over a cross-cutting relationship. As expected the mosaic provided the most reliable relationships, as single scours could be studied over many sonogram widths helping to clarify the cross-cutting relationships. Based on the results of this test, three mosaic sites were chosen for detailed analysis.

METHODS

SIDE SCAN SONAR

Data Preparation

Side-scan sonar and echo-sounder data received for interpretation and processing included a wide range of data formats of varying quality (see Table 3). As the records were received they were examined, documented, and processed following the steps outlined in the digitizing flow diagram (Figure 8).

Records were catalogued and filed by company name, survey year, and regional line number into separate data package boxes. Each side-scan sonar and echo-sounder record was then checked for correct record annotation. This information was recorded on data description sheets which were kept for both types of data for each regional line. Survey parameters were also noted, such as survey date, general location, fix intervals, start of line (SOL) and end of line (EOL) fixes, scale ranges, type of survey system, and corrections applied to data. The availability of other data types for corresponding lines was A section of each sheet was dedicated to special also listed. information such as the occurrence of geological or man-made features on the sea-floor. The effects of environmental variables on data (such data. and conditions), discontinuities in quality-related effects were also noted.

Selected regional lines for the data base were then re-evaluated using the data description sheets, taking into account the general quality of the data as well as the availability of matching echo-sounder or side-scan sonar data. Each regional line chosen was plotted on a 1:250,000 base map (see Plate 1).

Digitizing

The analogue-side scan records were digitized using a 40x50-in backlite digitizing table with a resolution of 0.005 in. Continuous-point digitization mode is used with a sample increment of 1.5 mm. The real distance this increment represents varied from one data set to another because of scale changes. Data are output on 9-track tape as 26-byte ASCII records with a blocking factor of 150 records/block.

The side scan records are taped to the digitizing table and are covered by a thin sheet of plexiglas to remove wrinkles (Figure 9).

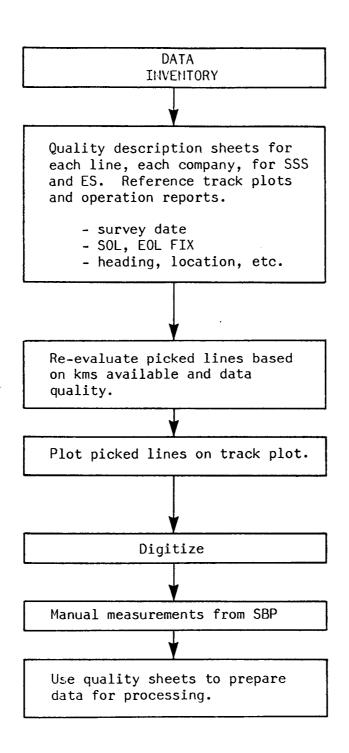


Figure 8. Flow diagram of data preparation.

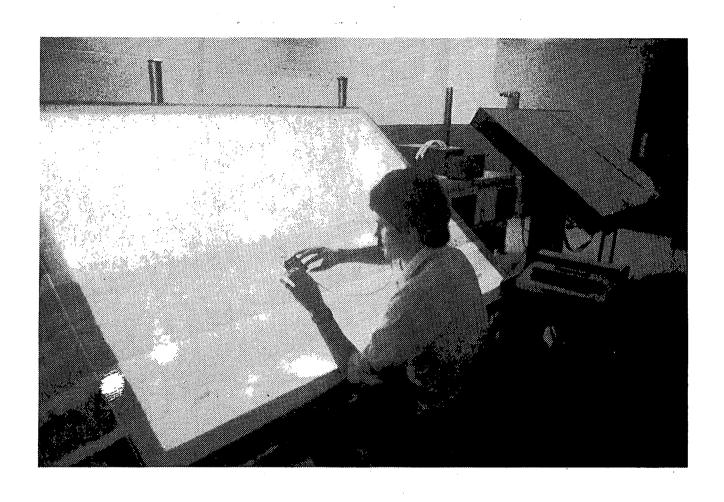


FIG. 9 Side-scan sonar digitizing method.

For each table segment (approximately 1.5 m) all navigation fix marks are entered along with scale points for computing X and Y scaling factors. Ice scours are numbered at a "pivot point" corresponding to the mid point of the left-most portion of the scour and their outlines are digitized using the keypad cursor. The outlined scour width generally includes both the berms as the boundaries of a sonified scour are gradational and, therefore, difficult to identify uniquely. Depending on data quality and scales, this boundary may represent slightly different values from one data set to another. Scours that extended beyond the length of the digitizing surface are digitized in half segments to be merged at a later stage.

During the digitizing phase, four main scour parameters - form, morphology, smoothness, and relative age - are interpreted by the operator and are input to the data file via a number code system as outlined in Table 5.

TABLE 5
Number code system used during digitizing phase

<u>Parameter</u>	Code	Description
Form:	1 2 3	Single-keel event Multi-keel event Zone of multi-keel: this descriptor is used in cases where multi-keeled scours cannot be distinguished from each other
Morphology	4 5 6 7	Linear: undirectional scours Arcuate: curved Sinuous: changes orientation more than once Crater: generally not present in Beaufort Sea
Smoothness:	8	Note: Smoothness is a subjective descriptor based on the sharpness of acoustic returns which may vary with angle of scour sonification and recording scale Rough: strong acoustic signature, evidence of rubble on berm or in scour
	9 0	Moderately smooth Smooth: reduced signal contrast, no rubble, smoothed scour walls
Relative Age	.	Note: This parameter is based on smoothness and general morphology in relation to background scouring; it is input only rarely when a high degree of confidence exists for the age of unusually distinct scours
	+	Old: smooth appearing, likely infilled and crosscut
	-	Recent: rough-appearing, uniquely distinct amongst background scouring
	•	Uncut: input for only those Recent scours that are not crosscut by other scouring events

It should be noted that a number of control checks were carried out to enhance the consistency of some of these interpreted parameters between different geographic areas, different data-quality records, and different geologic characteristics.

For example:

- a) shallow sub-bottom profile and echo-sounder records were used whenever possible to aid in determining the smoothness, degree of infilling, and relative age of scours.
- b) scours in areas of regional line intersections with similar sea-floor conditions but with varying angles of ensonification and differing data quality were compared.
- c) comparisons were made of scours in similar geographic areas between various lines of different survey years and companies.

Based on these checks, some interpretive inconsistencies were noted within data sets that were updated accordingly. Other valuable observations that the data base user should be aware of are as follows:

- a) In highly scoured areas where the sea-bed is completely saturated it was impossible to distinguish and digitize each discrete scouring event. In such cases, although the sea-floor is completely scour-saturated, the data base portrayed only the significant recognizable features.
- b) Scours that crossed a data gap on the side-scan records could not be digitized in their entirety. In these cases only the largest or deepest portion of the scours were digitized and were treated as a single, closed event.
- c) Some older side-scan records were not corrected for water column removal. Scours crossing under the ship's path were, therefore, digitized by interpretation through the water column gap. The data quality was consistently good enough that matching scours between channels was not a problem.
- d) For those older data sets that did not have correction equipment for slant range and ship's speed, the processing software automatically rescaled the digitized scour points to a corrected format. Scour data is therefore referenced to scale-corrected UTM co-ordinates with the exception of the variable layback distance.

Data Processing

Following digitization of the side-scan data, a series of steps involving specific software utilities are taken in processing the digital acoustic data. These steps are summarized in a data flow block diagram (Figure 10) and are discussed below.

Quality Control and Processing Preparation. The first stage following digitization is to deblock (DIGBRK) the 26-byte ASCII data into separate files, one for each table segment of data. At this time the data are thoroughly quality-controlled in three distinct stages. Initially, the data were checked to ensure that the format was correct; i.e., line headings, fix co-ordinates, and morphology codes were verified. Any scours flagged as having been digitized incorrectly were corrected at this time.

After the initial edit was complete, the table segments were plotted (Figure 11). Because each digitized ice scour is represented by a long string of x,y co-ordinates, certain errors were difficult to detect without graphical output. For example, duplicate digitized scours, missing table end scours, unclosed scours, and scours extending beyond the table segment borders could be pinpointed and corrected using the plots. Errors found at this quality-control stage were corrected in the data files at this time. Subsequently, the data were usually written to tape and stored for later processing.

In some cases, however, the format of the different analogue data sets necessitated a unique, digitizing format. These data files required further processing to conform with the format required by the processing software. For example, some data contained irregular fix intervals or fixes in time rather than distance which required a great deal of manual editing.

The data were further prepared for insertion into the geophysical data base by "mapping" the digital data that defined unique, closed individual scours using the 'SSSMAP' routine. Those "half" scours digitized over one or more table-end boundaries were merged through specialized processing techniques. Scours that did not match at this stage were identified by their fix position, redigitized, and later merged back into the data yielding a final file containing completely enclosed scours.

Data Base Processing. The ice scours mapped by the SSSMAP routine were stored in a geophysical data-base (FLTLIB) by the program "CRESS." Each scour is treated as a separate entry in the FLTLIB data-base. Initially four parameters are stored in unique fields for each ice scour; namely a simple sequential counter; a fix number; the Y-scale analogue value in inches for each sample defining the scour outline;

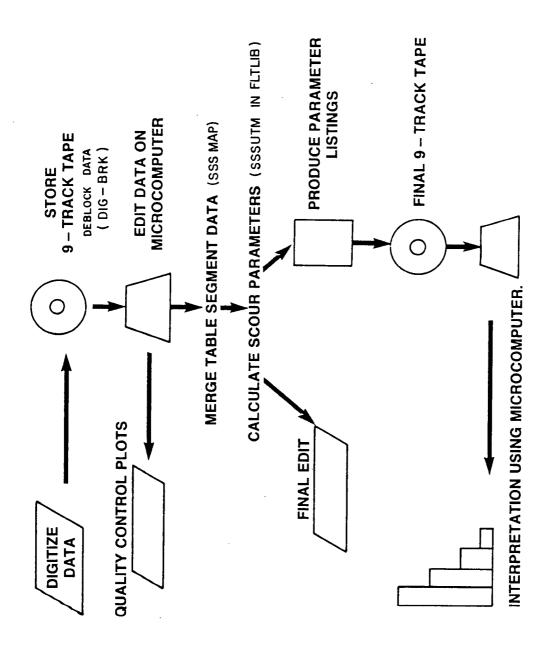


Figure 10. Flow diagram for processing side-scan sonar data.

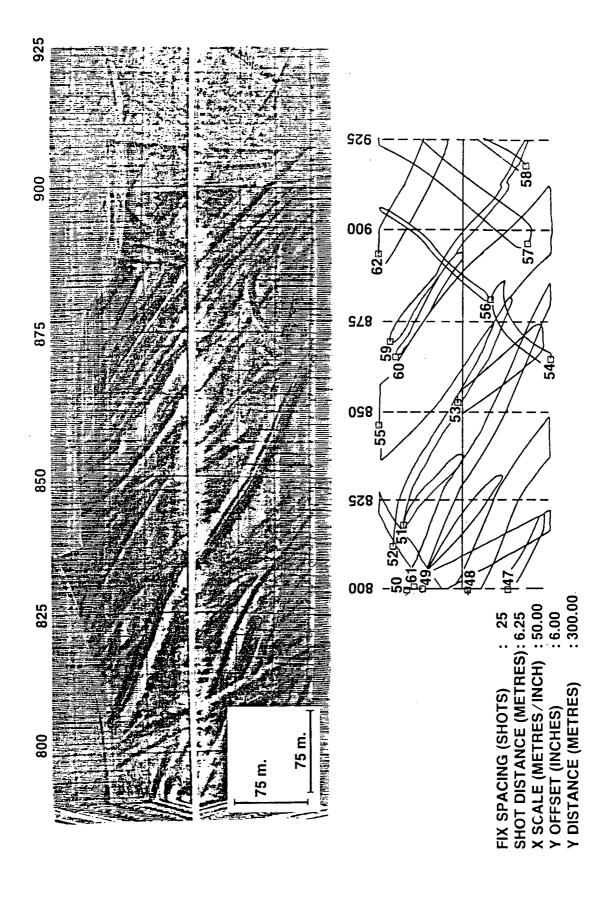


Figure 11. Side-scan sonar quality-control plot.

and a field reserved for information pertinent to the individual ice scour, such as company name, year of survey, codes defining relative age, form, smoothness, and morphology. Other statistical parameters related to the ice scour will be stored in this latter field in future processing steps. The speed of all further data retrieval, storage, and manipulation is greatly increased by the use of the "FLTLIB" data-base software.

The utility "SSSUTM" computes the UTM easting and northing for each sample in the data-base file and also computes and stores the statistical parameters for each ice scour.

The navigation data are accessed, and the UTM co-ordinates along the ships track are determined, from the stored fix value. The analogue Y-scale values are converted into metres to either port or starboard side, normal to the ships track and this adjustment is applied to the previously determined scour co-ordinates to obtain the correct easting and northing position of each data sample.

The scour statistics, which are computed, listed, and stored in the data-base file, include scour orientation, length, width, area, and standard deviation. They are derived in this program through the use of the pivot point as the centre of a detailed co-ordinate system within the digitized scour outline defined as a polygon. From the pivot point, rays extend out to all other digitized points of the scour outline. The orientation parameter is derived by a weighted average of the angles between each ray and a co-ordinate system referenced to the ship's heading. Scour orientations are, therefore, referenced to true north and are shown by convention as values ranging from 0-180 degrees. Standard deviation of scour orientation is computed as a product of the moments about the mean. This parameter is useful in defining scour shape because short, wide scours were found to have high standard deviations, whereas long, narrow scours had lower values. remaining parameters, length is derived as the longest ray; area by an equation using the digitized X,Y points of the scour polygon, and width by area divided by length.

The proprietary FLTLIB data-base was designed, written, and implemented by Geoterrex Limited, specifically for fast and efficient storage, manipulation, and retrieval of geophysical data. A wide variety of software utilities for mapping, editing, and general data manipulations exist and have been tested on data sets from several geophysical disciplines. With the ice-scour data stored in the FLTLIB data-tise, development of dedicated software utilities is greatly simplified by the use of existing data-base subroutines. Also all geophysical data manipulation routines can be used on the ice-scour data when required.

ECHO-SOUNDER

Data Preparation

Echo-sounder data were catalogued and data quality was assessed in much the same way as those procedures described in the side-scan sonar data preparation section. Those lines selected for the echo-sounder data base are identified by a unique symbol on the regional base map (see Plate 1).

Digitizing

The echo-sounder analogue records are digitized in a similar way as are the-side scan records. The operator enters the line number, fix number, and then digitizes the sea-bed profile by very carefully moving the cursor along the irregular sea-floor trace. The sample increment found to be most representative was 1.2 mm per sample. This value in terms of real distance on the sea-floor varied between data sets because of scale changes.

Interpretation of the profile data by the operator at the table is minimal and so processing is relatively rapid. However, the correct treatment of data quality and scale-related factors were significant in maintaining fairly consistent production and accuracy. For example:

- a) Analogue records with greatly expanded vertical scales could be processed more rapidly by "smoothing" insignificant (less than 0.25 m) undulations in the sea-floor. Conversely, data that were vertically compressed into the same chart width (e.g., 0-100 m scale) required slow, tedious digitization with a magnifying glass attachment (see Figure 6).
- b) Data voids or acoustic blanking of a minimal nature (i.e., less than 1 cm) were interpreted through the gaps to preserve data continuity wherever possible. Data voids greater than this, as occurred at paper change breaks, meant that digitized echo-sounder profiles had to be broken into a series of discontinuous line parts.
- c) A large amount of poor-quality data within a line segment would similarly be omitted and would be considered a separate line part.

Data Processing

Subsequent to digitization the data were incorporated into the GMAPS data base (Geoterrex Marine and Airborne Processing System). This software contains comprehensive programs for the manipulation of geophysical data including a filtering package that was used to produce a computer-smoothed sea-floor.

The complete processing sequence and data flow for the echo-sounder program is summarized in Figure 12. When the digitizing is completed, the tape produced is read into an ASCII file and stored on computer disc. As the data are still in ASCII at this stage of the processing the resultant file may be examined by means of the text editor. Obvious mistakes can be edited out from the data and profile plots can be produced to check the accuracy of the digitizing. Sections of the profiles can be redigitized if required.

The data then enters the GMAPS data base in a scale-corrected format where further quality control checks are performed. These consist of running programs, which automatically check for spikes and steps in the profile data. Few problems are generally found at this stage.

The next stage involves filtering the sea-bed profile using a running average filter program (DSCFLT) to produce a computer smoothed datum from which scour depths are referenced. Tests were conducted with different running average filters to evaluate which filter produced the most accurate reproduction of the undisturbed sea-bed. With this type of filter an N point window is moved across the data. The filtered output is the average of the input point centred at the middle of the window plus (N-1)/2 points from before and after that point. It was found that the number of points used in the filter depends on the horizontal fix interval of the data in relation to the echo-sounder chart speed and the sampling interval of the digitizing For example, slow chart speeds compress the data horizontally requiring a shorter processing filter. Generally, however, it was determined that the 41-point filter generated the most consistent reproduction of the sea-bed in areas of moderate relief, as is the case for most of the Beaufort Sea. In areas where sea-floor relief was more pronounced, detailed manual checks were performed to ensure that correct scour depth parameters were being generated.

The final program (EKODEP) merges X,Y location data from the navigation tape to each sample point and subtracts the filtered data from the raw, digitized, echo-sounder data. The resultant data field contains those departures from the sea-bed caused by ice scouring. Scour depths are detected automatically if they exceed a preselected threshold (set at 0.5m). The program reads the echo-sounder data points until it finds a value that is less than, or equal to, the threshold. This point on the profile is assumed to be the falling bank

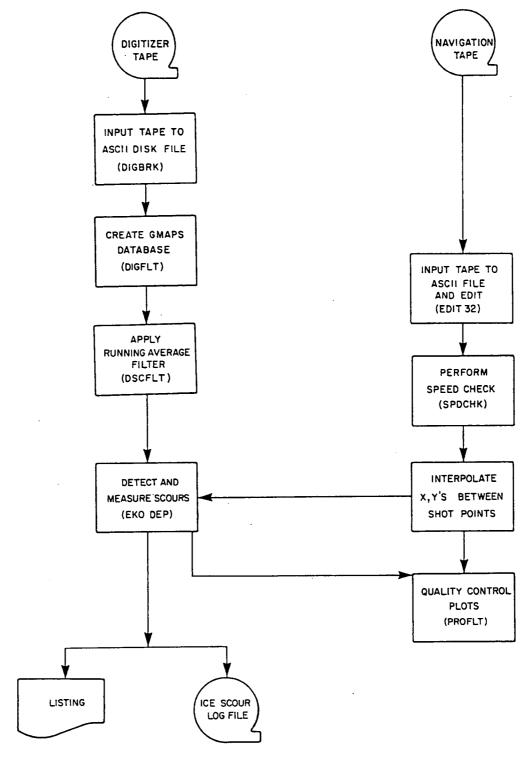


Figure 12. Data flow diagram for echo-sounder analysis.

of an ice scour. The data is then read to find the point at which the trace exceeds the threshold, the rising bank on the opposite side of the ice scour. The program then interpolates between these two points to find the maximum depth and, at this point, reads the location and bathymetric fields to obtain the scour position and the sea-bed depth. Plots of the digitized analogue data with the 41-point filter and scour depth departures are produced for quality control (Figure 13).

SUB-BOTTOM PROFILE

Manual Measurement Techniques

Sub-bottom profile data displayed as the side-scan sonar third channel was present for five data sets (Esso 83, Dome 82, Gulf 82, Gulf 83, and Dome 81) out of the total regional compilation. This sub-bottom data was useful in providing scour depths that could be matched uniquely to a scour seen in plan view on the side-scan sonar record. The data-base parameters in Table 6 were derived from the third-channel data and were entered manually into the final data listings. (Note: Dome 81 third-channel profiles did not achieve sea-floor penetration and, therefore, scour depths only are recorded.)

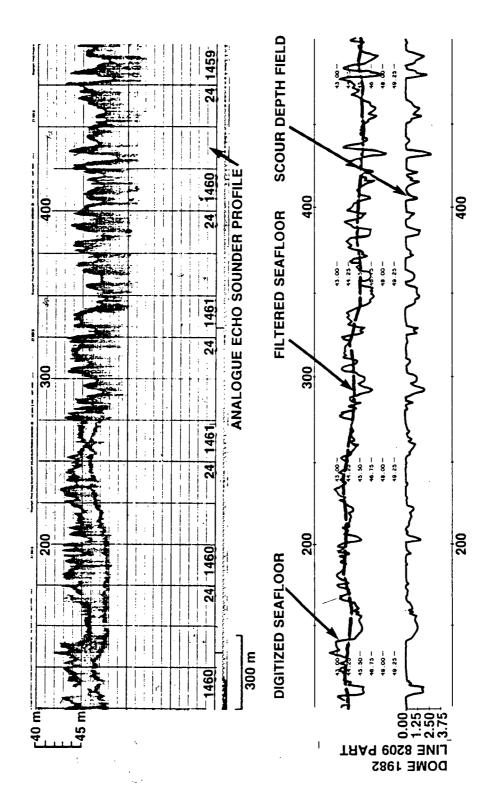


Figure 13. Echo-sounder quality-control plot.

TABLE 6
Sub-bottom profile derived from third-channel data

Parameter	<u>Value</u>	Description	
Scour depth	. 5m	Scour depths were picked at 0.5-m intervals (e.g., 1.0, 1.5, 2.0 m) because of the resolution limitations of the sub-bottom profiler system	
Fix	100	This scour depth fix records the position of the scour where it transects the ship's path	
Sediment fill	.5m	Records the value of observable scour infill in 0.5 m intervals	
Sub-scour deformation	. 5m	Records the depth of sub-scour disruption of stratigraphy by ice loading Note: This parameter was very difficult to recognize confidently as bedding distortions may be produced as seismic artifacts rather than real phenomena	
Sediment thickness	5.0m	Measured to the Unit "C" regional unconformity. This boundary was chosen as it is the most common and distinct reflector regionally across the Beaufort Shelf. The base of the recent marine clays for example is not always obvious as in some cases it is a gradational lithofacies. Thickness was measured up to 10.0 m beyond which 10.0+appears in the data base	
Sediment type	С	Clay	
	S	Sand	
	CS	Clay over sand	
		Note: Sediment type was interpreted from a combination of side-scan and sub-bottom records and pre-existing site interpretation reports	

To accurately record values for each of these parameters, the sub-bottom interpretation was often performed at the end of the digitizing phase of that data set. At this time regional line interpretation reports, grain-size maps, regional isopach maps and pertinent echo-sounder data were assembled and used in the interpretation of these geologic parameters.

As mentioned previously and discussed in detail later, the 5.0 m timing reference scale line for making depth measurements from the sub-bottom profile initially produced results that were inconsistent. As a result, echo-sounder data were used wherever possible to check the scour depth measurements before their transfer to the data listings, however, it should be noted that a bias towards higher scour depths persists within the sub-bottom profile data entries.

Entry to the Data Base

The parameters derived from the sub-bottom profile data were entered into the data base via a formatted FORTRAN program. The final output was quality controlled to ensure that the correct record entries were achieved.

MOSAICS (RELATIVE AGE STUDY)

Criteria for Selection

Three mosaic sites were chosen to evaluate the theory of relative age studies by cross-cutting relationships. The mosaics that were chosen for this analysis were Natiak, Kringalik, and West Tingmiark (see Plate 1). The most important criteria affecting the choice was data quality as it was found in the test described in Data Quality Assessment that record gaps and poor data resolution made cross-cutting relationships hard to distinguish. The mosaics chosen for this analysis have superior data quality.

The second criteria was geographic and bathymetric location to ensure that a broad range of conditions were covered. The criteria are summarized as follows:

Mosaic	Bathymetry	Location
Natiak	45 m	Western Beaufort shelf
Kringalik	30 m	Western Beaufort shelf
W. Tingmiark	30-50 m	Eastern Beaufort shelf

The final consideration was that of unique geologic environments for observing ice scour/geologic relationships. For example, the West Tingmiark site traverses the Kugmallit Channel where scour frequency drops sharply from the shallower shelf to the channel floor. Natiak is unique as it is situated in the far western central Beaufort Shelf in relatively deep water; here exposed to the initial contact environment between pack ice and the sea-floor. Kringalik is a shallower, "shelf proper" representative that bears a slight surficial lithological contrast from north to south across the grid.

Data Treatment

The methods of data treatment are as follows:

- a) Cross-cutting relationships were interpreted on a mylar overlay. Scours of different age classes were given unique colours and were numbered alphabetically,
- b) The mylar interpretation was then digitized as if it were a single, side-scan sonar record. A reference trackline with start and end fixes and a heading was created to derive scour X,Y position values. Data-base entries for Heading, Part, and Fix are for data-processing purposes only. The scours were digitized in a normal fashion (closed polygons) to produce the parameters; orientation, length, width, and area. Age-class letters were keyed into the relative age column for each scour and data were later sorted by these values alphabetically. The morphology codes were input as usual, however, all smoothness values are shown as moderately smooth as the reduced scale made this interpretation difficult.
- c) Scour statistics were processed in a similar fashion as for single side-scan data.
- d) Cross-cutting relationships interpreted on the mylar sheet were drafted and appear as Plates (2, 3, & 4). The relative frequency of each age class was derived from the output listing and was drafted on the Plates.

CORRIDOR (STUDY OF ADDITIONAL NEW SCOURS)

Rationale for Study

The E. Mackenzie resurvey corridor was chosen to establish a suitable method for incorporating new scours into the data base by the digitization technique. The E. Mackenzie resurvey corridor is a north-south trending grid that is separated by Shearer (1980a) into a number of different sections. New scours are found on the southern section (1 and 2) and the adjacent section (3 and 4) to the north; correspondingly these are the sections chosen for analysis. They are referenced in the data base as follows,

Corridor Data Base Part

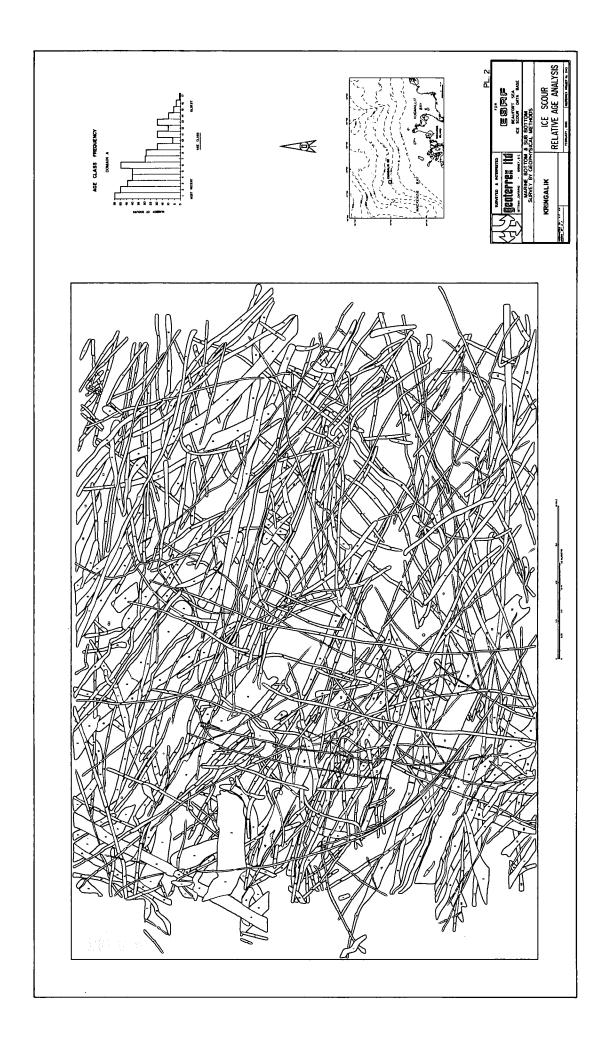
E. Mackenzie South (1 + 2)

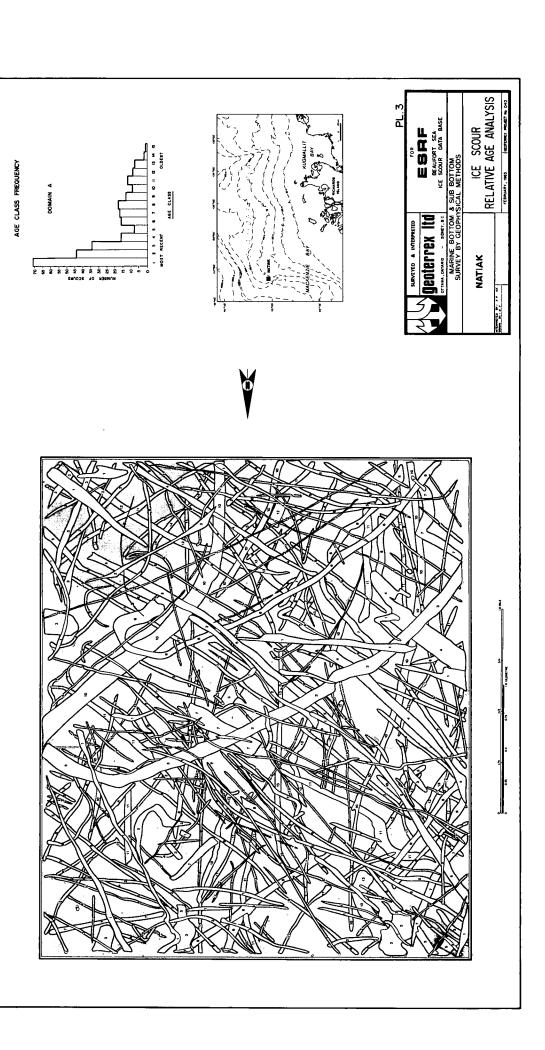
E. Mackenzie North (3 + 4)

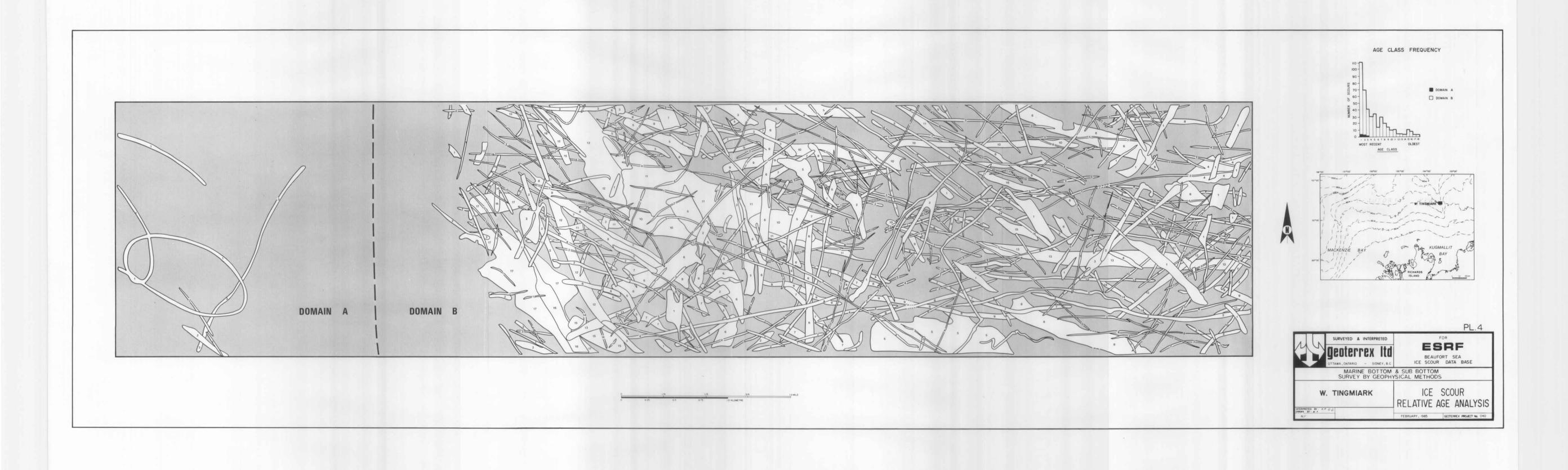
It was originally hypothesized that by digitizing the 1974 base and the 1979 resurvey data, the computer alone would be able to identify new scours. As described in the Results this is not the case for a number of reasons. New scours must be identified manually by an experienced interpreter and then digitized in a similar fashion as the normal side-scan sonar records. The East Mackenzie corridor was chosen for analysis as these data were previously interpreted by J. Shearer for new scours on behalf of Gulf Canada Resources Inc. (Shearer 1980a) and the corridor was subsequently resurveyed for new scours in 1984.

Data Treatment

The 1974 base-year corridor mosaic was difficult to interpret because of the older, poorer-quality analogues from which it was compiled. The 1979 resurvey mosaic provided much higher-quality data than the original base-year data. Because of the higher reliability of the newer data, this mosaic was digitized as if it were the base-year data. New scours as identified by Shearer (1980a) were not included in the base year digitization, but were incorporated into a separate file reflecting new scour data only. The corridor data base therefore contains scours interpreted from an original base year and a separate file for those identified as new scour additions. Scour parameters for both the base year and new scours were derived in a similar fashion as for the repetitive mosaics and side-scan sonar data base, however, it







is noted that as for mosaics the smoothness code is designated "9" or relatively smooth for all data for the same reason as stated previously.

INTERPRETATION METHODS

System Configuration

The creation of a computerized ice-scour data base lends great flexibility to traditional methods of ice-scour interpretation. The facility for rapid data-sorting routines greatly increases the information potential from the scour data base. For example, the data could be sorted to list the orientations and widths of all multi-keeled scours showing scour depths greater than 3.0 m within a particular geographic location.

Such specialized ice-scour interpretation software has been developed by Geoterrex Ltd. This software can be configured on an IBM-XT microcomputer with a 10-MB fixed disk drive and executed using the DOS Version 2.1 operating system. The system is, therefore, portable and can be taken to the field and used for on-board data analysis and survey planning.

The data-base software product, DBase II, was used to build the interpretation software. It offers both an on-line query language for single-parameter answers and a programming language which was useful for the execution of multiple-interpretation routines. Input-output processing was found to be relatively slow in DBase II, although with the batch-processing utility much of the interpretation could be run after hours. Lotus 1-2-3 was used to graph selected results such as the scour-depth histograms for various bathymetric distributions.

Interpretive Analysis

Three types of interpretive analyses can be computed and graphically illustrated using the appropriate software routines.

- Specific scour-parameter distributions can be analysed using the whole data base or a selected subset, such as a scour-depth distribution for the whole Beaufort Sea data set (shown in the Results).
- 2) The inter-relationships between scour parameters can be examined for the entire data set or any subset, such as scour depth versus scour width (shown in the Results).
- 3) The correlation of one or more scour parameters with different environmental parameters such as scour depth versus bathymetry at 10 m bathymetric intervals (shown in the Results).

System Algorithms

The interpretation software may be broken down into a number of subsets, each containing a group of routines. Each set performs some basic calculation, manipulating one or more data-base parameters or variables specified by the user through an interface program. The calculation is implemented by a Basic Algorithm program.

In addition to the calculation performed, the Basic Algorithms control access to the data base and decide upon the output format. The purpose of confining access to this level was to "protect" the data base from the user, and more important, to increase the ease of program modification and extension. If the format of the data base changes, modifications to the Basic Algorithms will be necessary. If a new interpretation routine is to be added, it is likely that an existing Basic Algorithm program can be used and that only the simplistic interface program need be created.

The Basic Algorithms separate into four classes:

1) Distribution algorithm:

- calculates a distribution based upon one or more data-base fields (e.g., calculates scour depth distribution);
- the interface program specifies which field or fields are to be examined.

2) Event occurrence and percentage:

- counts the number of occurrences of one or more "events"
 (e.g., counts number of "smooth" scours);
- calculates the percentage of this occurrence;
- the interface program specifies what event or events

3) Maximum values:

- Searches for the maximum value in one or more data base fields (e.g., searches for longest scour in each data file);
- isolates all records with those values;
- the interface program specifies which field or fields.

- a collection of independent programs which perform a specialized computation (e.g., Scour depth versus width distribution);
- influenced only by user input values passed by the interface program.

RESULTS

INTEGRITY OF THE DATA-BASE

General Quality-Control Measures

The integrity of the data-base results were verified by both a number of manual quality-control checks throughout the processing stages and by statistical comparisons of interpretive results with an independent manual interpreter. Manual control checks were performed directly after digitization to ensure data input formats were correct. This was facilitated by plotting the digital data and by re-editing the data files. Small digitizing errors were often found at this control check. Quality-control checks were also performed subsequent to the production of the final scour-parameter listings. At this stage virtually every field of information was checked on a spot check basis for any irregularities. In particular, the values for FIX, UTM co-ordinates, orientation, morphology codes, scour depth, and the codes for bathymetry and data quality were checked in detail. correlation between the computer-derived values for orientation, length, width, and area were found to be consistent with those measured manually from the side scan analogue data. Any problems found at this stage were edited manually in the data base.

Some of these basic parameters were confirmed independently by an external interpreter (J. Shearer). Shearer reviewed a quality control plot of a side scan sonar example in relation to the original data and generally found a high degree of correlation between scour parameters.

The echo-sounder data were similarly quality-controlled by plots (see Figure 13) and by the actual scour-depth listings. The listings and original data were scanned for "scours" that might be caused by the filter's inability to respond to a sharp break in the sea-floor slope or to "artificial" scours caused by petroleum-related activity (e.g., dredging).

Statistical Verification of Echo-Sounder Data-Base against Manual Interpretation

A number of statistical checks on scour-depth distributions were performed. The philosophy of these tests was to compare a scour-depth distribution produced by the computer data base with a distribution produced by manual interpretation of the same data set. The results of these tests were analysed statistically by Canada Marine Engineering

Ltd. (C.M.E.L.) using a standard chi-squared analysis with a stringent 5% confidence estimate. This test compares the distribution at every point and creates a statistic based on the different probability distributions.

Test a) Echo-sounder data-base versus Geoterrex manual interpreter. A portion of the 1982 Gulf echo-sounder data was chosen for this analysis. Scour depths were picked accurately and then grouped at 0.5 m intervals as shown in Table 7. The data were sampled for scours greater or equal to 1.5 m. The results (shown also as histograms in Figure 14 were quite close and compared well at the 5% confidence level as tested by C.M.E.L.

TABLE 7

Echo-sounder data base versus Geoterrex manual interpreter

Interval:			Geoterrex
(0.5 m)		Echo Sounder	Echo Sounder
		(Computer)	(Manual)
1.5 - 2.0		64	56
2.0 - 2.5		29	36
2.5 - 3.0		9	11
3.0 - 3.5		5	7
3.5 - 4.0		4 .	2
4.0 - 4.5		. 1	2
4.5 - 5.0		1	1
	TOTAL	113	115

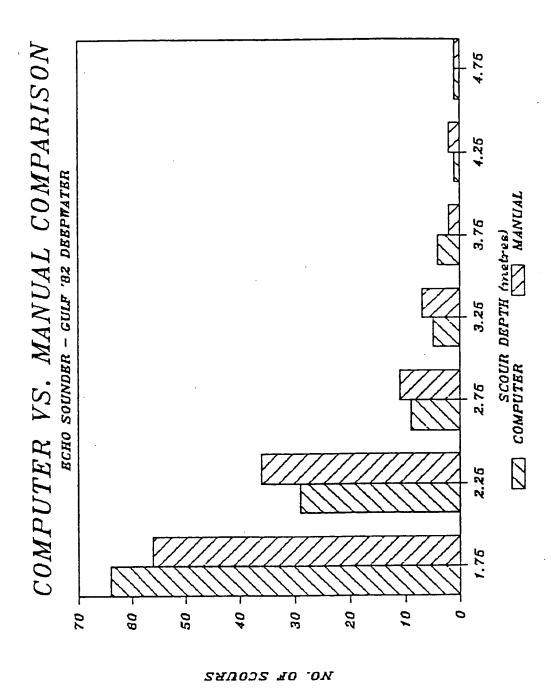


Figure 14. Computer versus manual comparison of echo-sounder data base from Gulf 1982.

Test b) Echo-sounder data-base versus independent external interpreter. This comparison was performed independently between the computerized scour detection system at Geoterrex and a manual interpretation by an external ice-scour specialist. Dome 1982 echo-sounder data were sent to J. Shearer for scour-depth analysis. Both parties independently sent their results to C.M.E.L. for statistical analysis. The results as shown in Table 8 and graphically illustrated in Figure 15 compare favourably and again pass the chi-squared analysis.

TABLE 8

Echo-sounder data-base versus independent interpreters

Bin internal	Echo sounder		Average of
(0.5 m)	(Computer)	J. Shearer	9 Interpreters
1.0 - 1.5	36	34	37.7
1.5 - 2.0	19	19	16.6
2.0 - 2.5	8	9	7.1
2.5 - 3.0	3	4	2.7
3.0 - 3.5	1	1	2.0
3.5 - 4.0	4	4	2.4
TOTAL	71	71	68.5

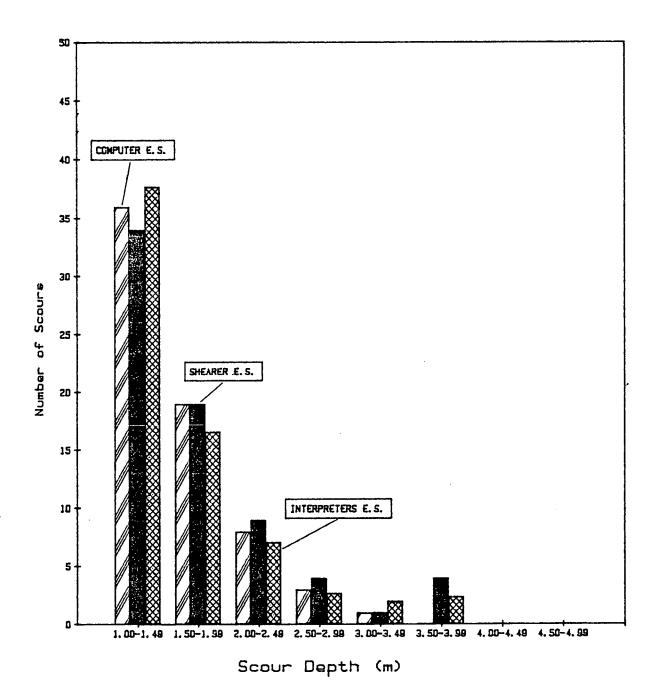


Figure 15. Comparison of scour-depth distributions by different interpreters (Dome line 82-06).

Test c) Echo-sounder data-base versus the average of nine interpreters. This test was performed to assess the variability between scour-depth distributions of nine different interpreters and how closely the computer-derived distribution approximated the resulting average. The same Dome 1982 good-quality echo-sounder data were used. These were circulated among nine interpreters, seven of whom were experienced in picking scour-depths from echo-sounder data. The averaged values (see Table 8) and Figure 15 compared statistically at the 5% level. It is interesting to note, however, that the individual plotted distributions show a fair degree of variation (Figure 16). This variance is notably highest in the first depth class interval where the decision must be made of whether or not to pick a marginal scour.

Scour-Depth Comparison Between the Echo-Sounder Data-Base and Side-Scan Sonar Data-Base Manual Interpretations

This test was undertaken to examine the correlation between

- two, independent, manual, scour-depth interpretations based on a single, sub-bottom profile data set; and
- a manual, sub-bottom profile, scour-depth distribution and one produced by the echo-sounder computer data-base.

This latter test was undertaken with the knowledge that a number of problems exist in attempting such a comparison. For example, in analysing echo-sounder scour depths one cannot discriminate between single and multi-keeled scouring events and, therefore, each departure from the filtered sea-floor is recorded as a single scour. Conversely, this distinction can be made using the third-channel sub-bottom profile data and only one maximum scour depth is recorded for a multi-keeled scouring event (See Discussion).

The following discussion of the test is taken in part from a report submitted to Geoterrex Ltd. by C.M.E.L. who performed the statistical analysis.

Methods. Because of the compressed vertical scale of the sub-bottom profile only those scours greater than, or equal to 1.5 m were picked and "grouped" at 1.0 m intervals. The computer-derived echo-sounder distribution was similarly grouped at 1.0 m intervals to match the manual measurements. The chi-squared contingency table test was used to analyse the distributions. This test compares the distributions at every point and creates a statistic based on the different probability distributions. The Dome 1982 scour data provided to C.M.E.L. for comparison are as follows;

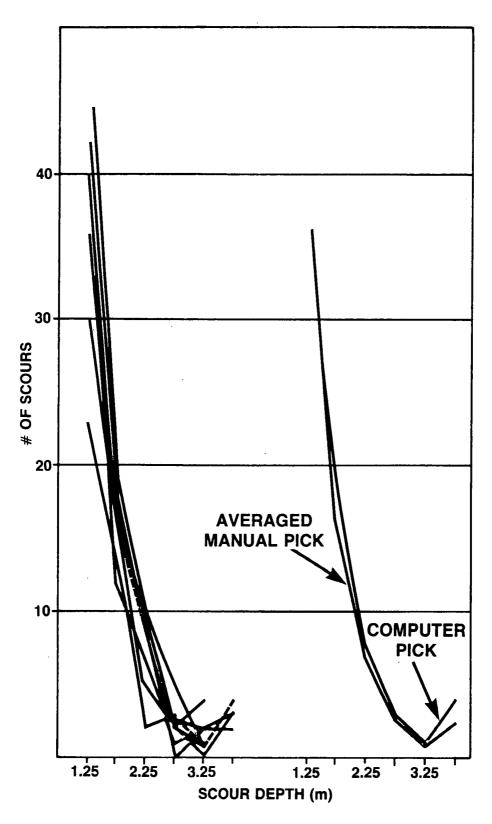


Figure 16. Manual versus computer scour-depth comparison from nine interpreters.

- Manually analysed sub-bottom profiler distribution (analysed by Geoterrex);
- Computer-analysed echo-sounder data-base distribution; and
- Manually analysed sub-bottom profiler distribution (analysed by J. Shearer).

The objective was to compare these three distributions statistically to determine if they came from the same population.

Results of the Analysis. Because the chi-squared test only compares the probability distributions and not the number of scours in each data set, it was felt that for the test to be positive the total number of scours from each population must be within 10%. This was chosen by C.M.E.L. as an arbitrary limit. If however, two population totals differed by more than 10% but the majority of the difference was in the smallest scour depth class, the data were accepted as scours from this depth class are often very difficult to confidently recognize.

The data shown in Figure 17 are summarized in Table 9.

TABLE 9

Comparison of echo-sounder versus sub-bottom profile

scour-depth measurements

Bin (Interval)	Shearer SBP	Geoterrex SBP	<u>Database ECS</u>
1.5 - 2.5	235	206	238
2.5 - 3.5	45	54	55
3.5 - 4.5	11	13	20
4.5 - 5.5	2	9	4
5.5 - 6.5	0	1	0
Totals	293	283	317

SBP - Sub-bottom profile

ECS - Echo-sounder

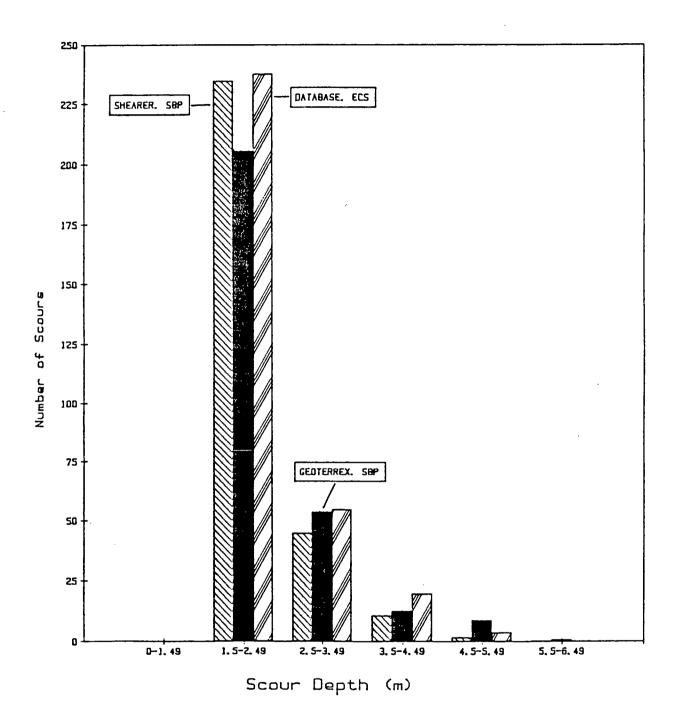


Figure 17. Scour-depth distribution from Dome 1982 data (based on manually derived values from sub-bottom profile data - Geoterrex SBP, Shearer SBP - and on computer-derived values from the echo-sounder data base.

Three comparisons using the chi-squared test were conducted. These were:

- Shearer SBP vs Geoterrex SBP
- Shearer SBP vs Data-base ECS
- Geoterrex SBP vs Data-base ECS.

Comparison #1 passed at the 5% level (just barely) when all the scours deeper than 3.5 m were put into the same group. Comparisons numbers 2 and 3 passed at the 5% level very well when all the scours deeper than 4.5 m were put into the same group. All tests were made at the 5% confidence level, which means that the results will generally be the same 19 out of 20 times. This level of comparison is felt to be adequate for the purpose of comparing manual and computer analysis of the same data sets.

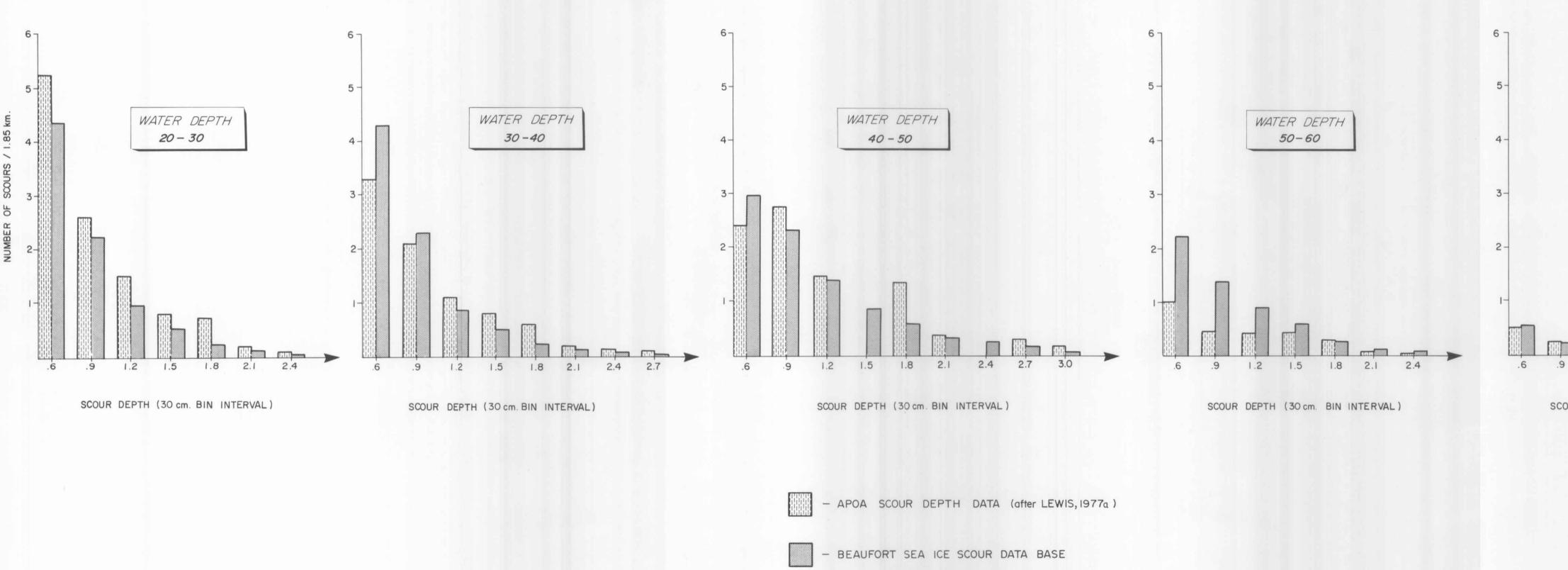
Both manually analysed data sets are fully compatible with the computer-analysed data, however the manually measured data sets are barely consistent with each other. This may be an indication of the variability introduced by manually analysing the data. Based on these scour-depth distributions passing the contingency table test we would conclude that the data-base is capable of rendering the same scour-depth distributions as manual analysis. However, for scour depths we recommend that a manual check be conducted for site-specific areas because we cannot base total acceptance of the data base on a single comparison of data in five 1 m groups with a cutoff of 1.5 m, (e.g., thousands of scours versus 300 scours analysed into five groups).

SCOUR DEPTH COMPARISON WITH APOA DATA

Methods

Scour-depth distributions derived from the echo-sounder data-base were compared to APOA scour-depth data as interpreted over 10 m bathymetric intervals by Lewis (1977a). The APOA acoustic data (echo-sounder) was analysed every third mile (1.85 km) and scour depths were measured in feet rather than in metres. A simple program was written within the scour analysis software system to count scour depths within the same 0.3 m intervals as used by Lewis (1977a). The comparative histograms (Figure 18) begin with the first group ranging from 0.45-0.75 m as values less than 0.5 m are not recorded in the echo-sounder data-base. In checking the group representing scours less than 0.5 m in Lewis (1977a) it is evident that the data have been undersampled at this value.

Subsequent to deriving the 0.3 m group counts for the echo-sounder data the total line distances from each bathymetric



(NOTE: DATA RECONFIGURED TO FIT APOA UNITS)

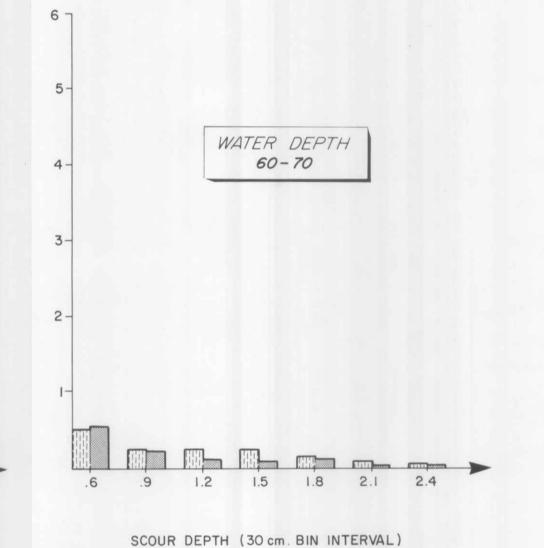
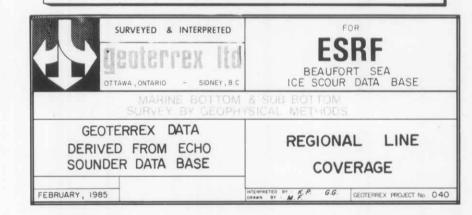


FIG. 18 SCOUR DEPTH COMPARISON WITH A.P.O.A. DATA (LEWIS, 1977 a)



interval were used to produce frequency of scouring values in number of scours per 1.85 km so as to compare to the APOA data.

Results

The results as shown in Figure 18 show a high level of computer-derived the APOA and Geoterrex correlation between distributions for all water-depth classes. This example illustrates the rapid decrease in scour numbers as scour-depth classes increase meaning that shallow scours are significantly more prevalent than deeper ones on the Beaufort Shelf. The relationship between total spatial scour frequency and water depth is shown in Figure 18, for spatial frequency is high in shallow waters and drops incrementally with increasing water depth. The nature of each distribution also changes with water depth. Within shallow water the frequency curve is highly peaked in the shallow scour-depth classes, however, as water depth increases the frequency curve flattens as shallow scours become less common in the distribution.

Two interesting aspects of the comparative Figure 18 are noted as The first is the striking similarity in the scour depth distributions of the 20-30 and 30-40 m bathymetric comparisons suggesting possible similar scouring mechanisms and frequencies within this geographic partition of the continental shelf. The second involves the divergence of the Geoterrex versus APOA. data in the 50-60 m bathymetric zone. Here the Geoterrex computer data base has significantly greater scour frequencies for the shallow scour depth classes than does the APOA data set. This may result from differing geographic locations for the data packages or the relative sample sizes used in each analysis. For example, the echo-sounder data from the APOA study (Lewis 1977a) incorporated data within the 50-60 bathymetric range from the far eastern Beaufort Sea where scouring frequency may be lower than the central and western shelf regions where data from the current study is preferentially concentrated.

INTERRETATION EXAMPLES

The creation of a computerized data base lends great flexibility to traditional methods of ice-scour interpretation. The capacity for computerized manipulation of ice-scour data greatly increases the information "potential" from the digitized acoustic data. This section illustrates the flexibility of the data base by presenting different examples of three main types of interpretive analyses that can be computed and graphically illustrated.

Scour Parameter Analysis Using Whole Data-Base

In this example the total echo sounder data base (over 11,400 scours) was used to produce a scour-depth distribution at 0.5 m intervals. This type of scour depth analysis is perhaps one of the most important in assessing risk to engineering seafloor emplacements. Previous work (Lewis 1977a) has shown that the scour depth distribution can be approximated by the negative exponential function in the following form.

exp (-kd)

where: K is the inverse of the mean scour depth and d is the scour depth.

The data, as shown in Figure 19 were plotted on semi-log graph paper and a negative exponential function was fit to the data by computer. The linear fit of the function to the scour-depth data was extremely close as was confirmed by a high correlation coefficient of 0.988.

The least-square negative exponential fit to the echo-sounder data-base scour-depth distribution is:

- number of scours (of depth d) = $19400 \exp(-1.73d)$
- the general k value is 1.73 (inverse of the mean scour depth)
- the Y intercept is 19400 scours
- the scour depth is d. (metres).

Distributions could also be fit to selected subsets of the data base; for example, a particular geographic region like the Kugmallit Channel could be isolated for this type of analysis.

Inter-relationship Between Scour Parameters

In this analysis, the distribution of one scour parameter can be examined in relation to another scour parameter. If a high degree of correlation was obtained the data could then be tested statistically, although statistics were not used for this example. The side-scan sonar data base has been subsampled for three data bases (Gulf 82, Dome 82, and Esso 83) that possess the third-channel sub-bottom profile data. Scour-depth information can, therefore, be referenced directly to the scour parameters of the same scour as digitized on the side-scan sonar data.

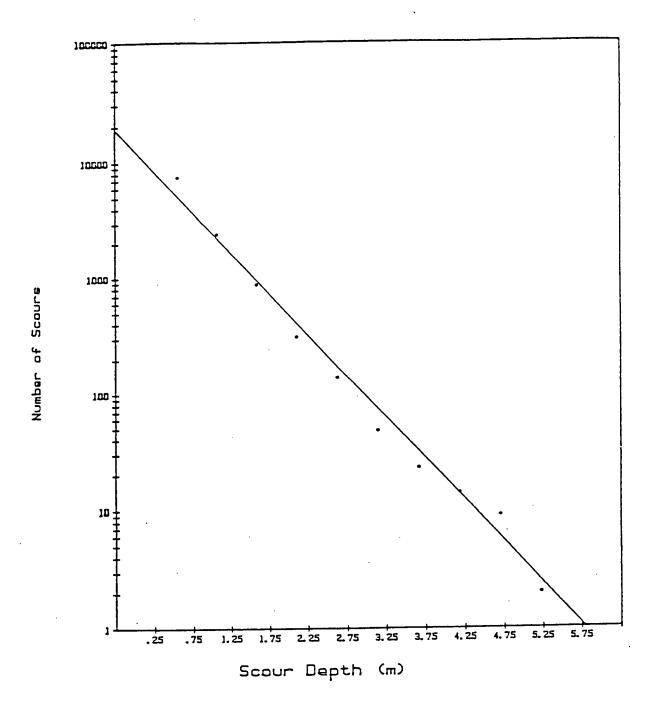


Figure 19. Scour-depth distribution from total echo-sounder data base.

In this case, depth was compared to scour width. The scour-width distribution (50-m intervals) was calculated in percentages over each 1.0 m scour-depth class, thereby producing a scour depth versus width two-way table (Table 10). The general trend shown by this analysis is that shallow scours (0.5 m - 1.5 m) typically are narrow with 80% of the total number of scours less than 50 m wide. As scour depths increase to 3.5 m, scour widths increase accordingly. The relationship between scour depth and width appears to be proportional; deeper ice keels contacting the sea-floor produce statistically wider scours as observed on side scan records. This analysis was based on over 1500 scours. The last two scour-depth classes, however, (3.5-4.5 m) and (4.5-5.5 m) may show somewhat spurious results because of the reduced sample size with only 30 and 15 scours (respectively) represented.

Relationship of Scour Parameters to Environmental Factors

This type of analysis is important as changes in scouring relationships can be studied within different environmental settings whether it be bathymetric, geologic, oceanographic, or ice zonation. Interpretive examples from both the echo-sounder and side-scan sonar data bases are used here to illustrate the flexibility of the data base analysis system.

Scour depth versus bathymetric zonation (echo-sounder data-base). this analysis the total echo-sounder data base (more than 11,400 scours) was subdivided into subsets for each 10 m bathymetric interval. Within each bathymetric zone a scour-depth distribution was calculated as the number of scours per kilometre (spatial frequency) within each 0.5 m scour depth interval. The results (Figure 20) illustrate the changes in scour-depth signatures in relation to water depth. The spatial frequency of scours is high within the shallower scour depth classes for the shallow bathymetric zones (e.g., 20-30 m and 30-40 m). It is noted that scour depth information from waters shallower that 20 m was not presented for lack of data. As water depths increase, the frequencies are more evenly distributed over the range of scour depth intervals as shallow scours become less common in deeper water. This relationship between scour frequency and bathymetry is well illustrated by one survey line that transcends the Kugmallit Channel (50 m depths) rises onto the Tingmiark Plain (30 m depths). Although this example (Figure 21) refers to bathymetric variations associated with sea-bed morphology rather than gross continental shelf water depth changes, it illustrates well the marked increase in scour frequency from deep to shallow water. Note also the increased "roughness" or acoustic contrast of the shallower water scours. The corresponding sub-bottom profile record (Figure 22) not only shows this frequency relationship but also illustrates the change in scour depth with

TABLE 10

Scour depth versus width

Scour width (2)

æ	881	240	126	30	15
24	100.0	100.0	100.1	6.66	100.1
150-200 200-250 250-300 300-350 350-400 (m)					6.7
300-350					
250-300		0.2		3.3	
200-250	0.3	6.0		3.3	
150-200	1.3	1.9	3.2	3.3	6.7
100-150	2.8	3.3	6.4	10.0	6.7
0-50 20-100 100-120	15.0	18.0	23.0	10.0	40.0
0-50	9.08	75.7	67.5	70.0	40.0
Scour depth (m)	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5	4.5-5.5

1592

TOTAL

bathymetric change. Deeper scours are more common in the deeper Kugmallit Channel than in shallower waters on the Tingmiark Plain.

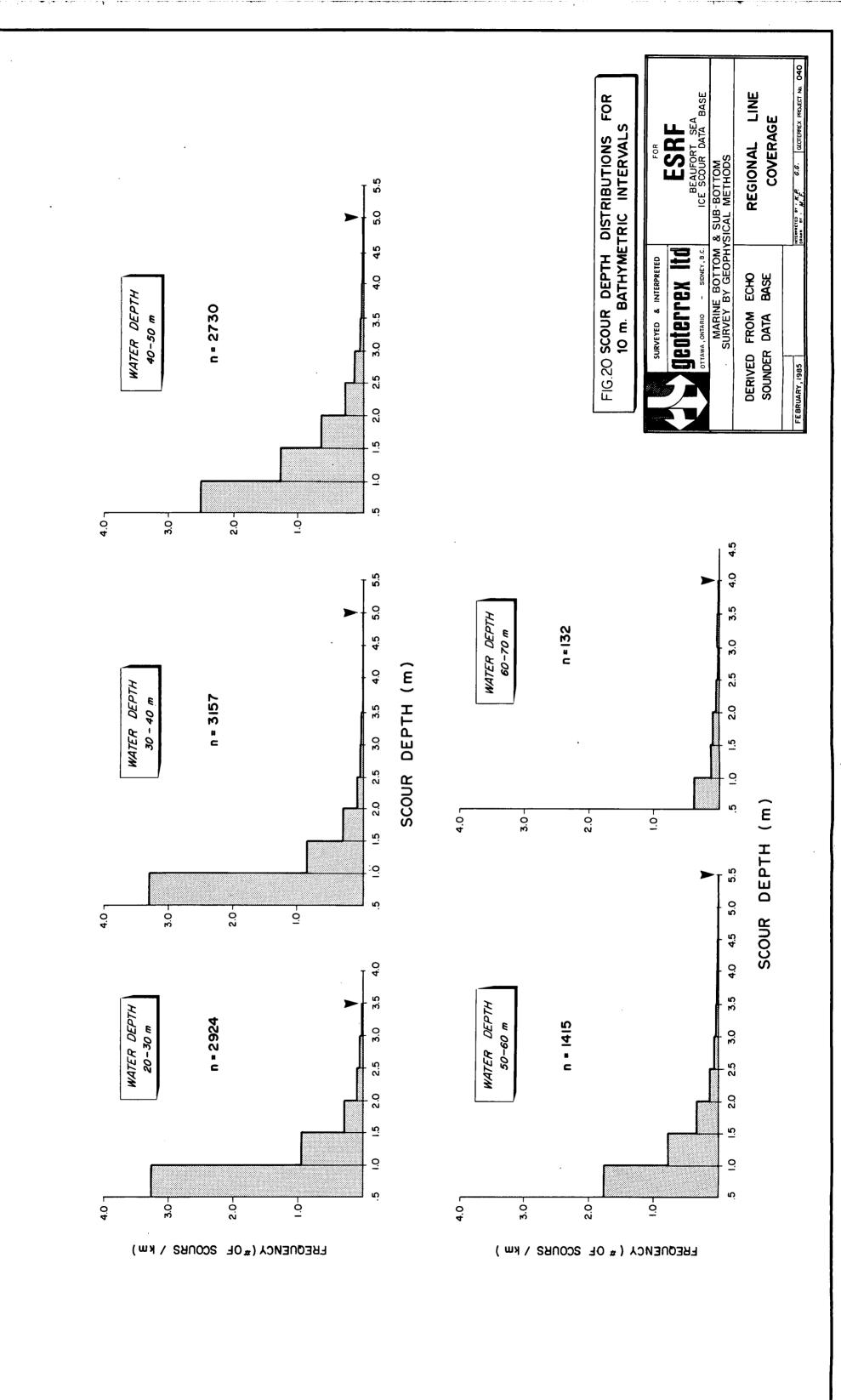
Scour parameter versus bathymetric zonation (side-scan This analysis illustrates the flexibility of deriving a data-base). number of scour parameters from the side-scan sonar data base relative For this study the data base was to an environmental factor. subsampled (over 5,700 scours) to provide three good-quality data packages (Gulf 82, Dome 82, and Esso 83) bearing the third-channel sub-bottom profile information. A number of scour parameters were extracted from these data in relation to 20 m bathymetric intervals. The major results, summarized in Table 11 and shown by Plate 5, are discussed separately in this section.

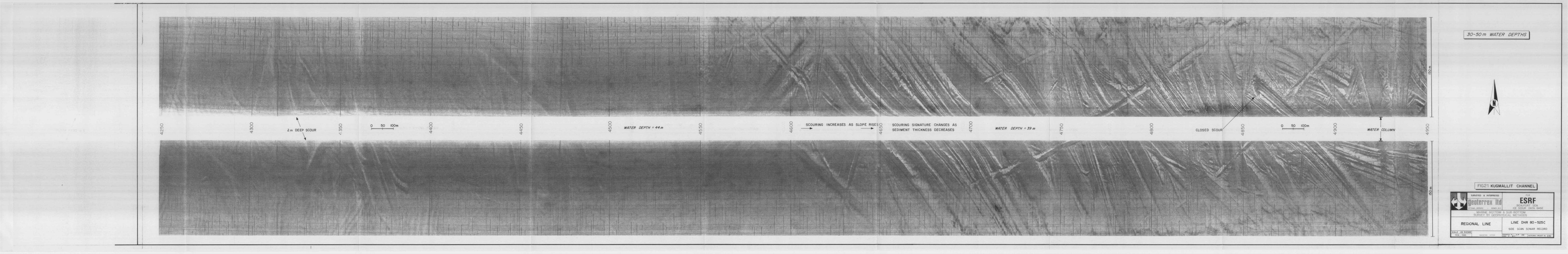
1. Scour spatial frequency:

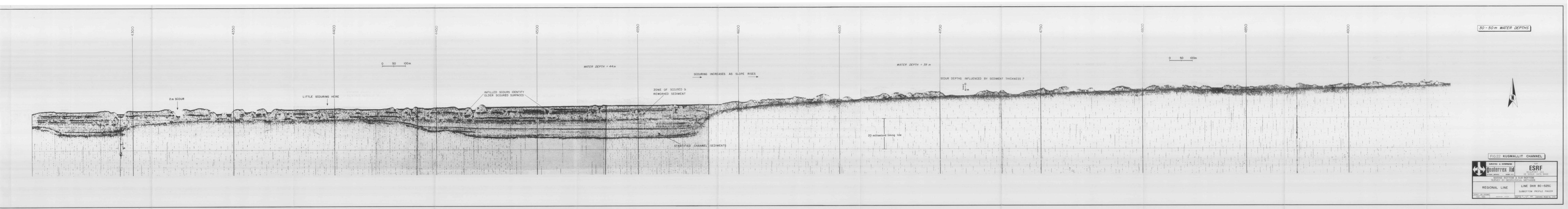
Scour spatial frequency is calculated as the total number of scours seen on side-scan sonar records divided by the total line-kilometre distance of survey data within each 20 m bathymetric zone. As shown in Plate 5, spatial frequency is highest in the shallow water zone and drops considerably in deeper water. These data are consistent with studies concerning depth measurement of ice keels by submarines (e.g., Wadhams 1982) and well illustrated by Figure 21.

2. Percentage sea-floor disturbance:

This parameter is calculated as the total sum of the areas of each scour divided by the total area of the side-scan data for the survey lines within a particular bathymetric zone. discussed previously, it is noted that this is a relative measurement only as all the small "background" scours making up the record cannot all be included in the digitization. This interpretation does, however, give interesting results. As shown in Plate 5 the sea-floor disturbance is highest in shallow water where scour frequency is known to be high and drops off with decreasing scour frequency in deeper waters. fact that the disturbance percentage increases only marginally in the shallow water from the mid-water zone may higher percentage of narrower scours in the a reflect shallow-water zone.







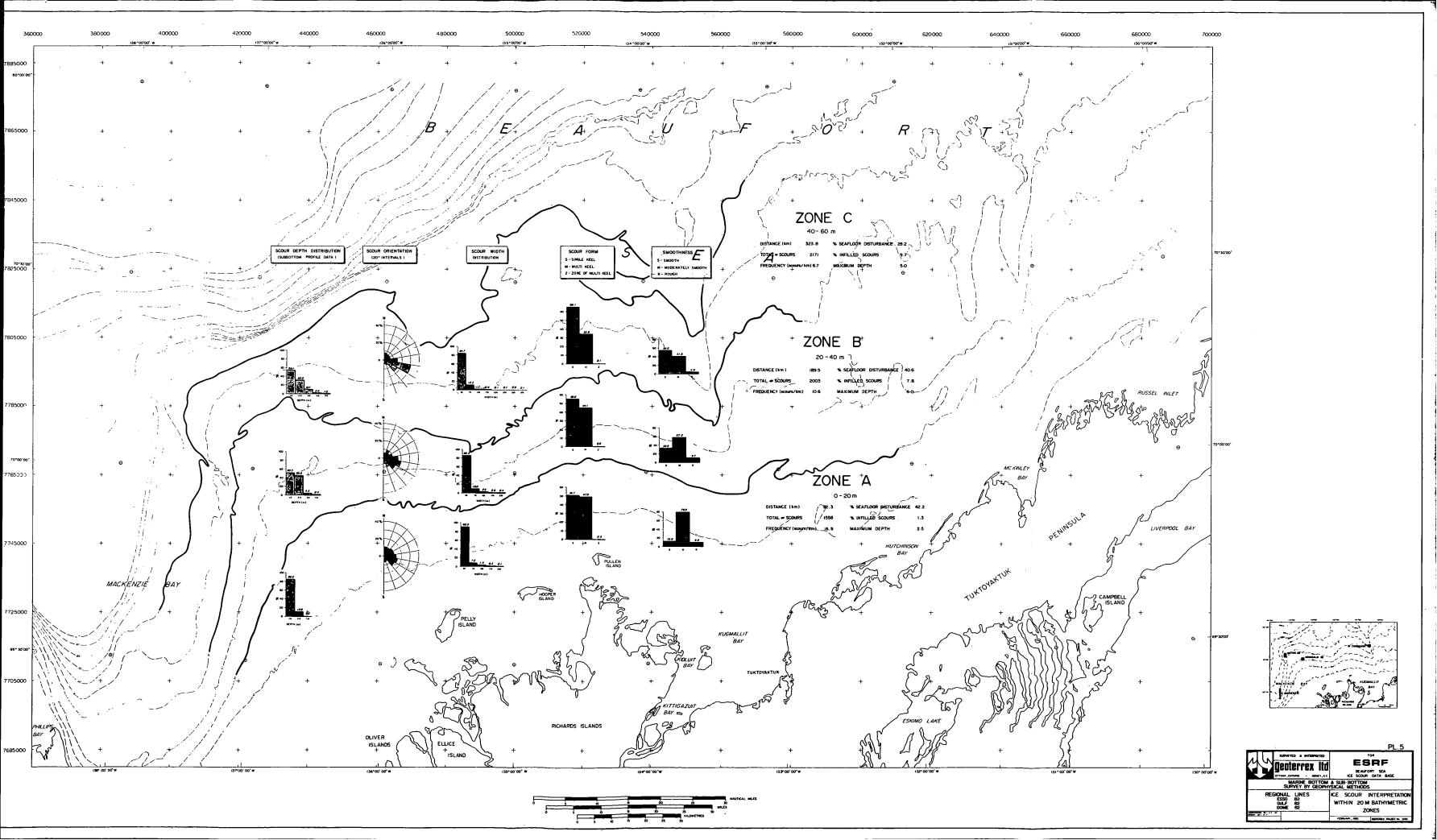


TABLE 11

Scour parameter versus bathymetric zonation (side-scan sonar data-base)

Parameter	<u>0-20</u> <u>m</u>	20-40 m	<u>40-60 m</u>	Total data set
Distance (km)	92.3	189.5	323.8	605.5
Total # of scours Frequency (S/km)	1558 16.9	2003 10.6	2171 6.7	5732 9.5
Single-keeled (%)	51.7	55.0	66.1	58.3
Multi-keeled (%) Multi-keel zone (%)	47.8 0.5	44.1 0.9	33.8	41.2 0.5
Smooth (%) Moderately	12.8	32.9	54.0	35.4
smooth (%) Rough (%)	78.0 9.2	57.3 9.7	41.5 4.5	56.9 7.6
% Sea-floor				
disturbance % of scours	42.2	40.6	28.2	34.2
w. infill Maximum scour	1.3	7.8	9.7	6.7
depth (m) Maximum scour	2.5	4.0	5.0	5.0
width (m) Maximum scour length (m)	247 2896	229 5905	375 4317	375 5905
Tenden (m)	2070	J90J	3311	3703

3. Percentage of infilled scours:

This relationship is determined as the percentile of all scours with depths greater than, or equal to, 0.5 m that show some degree of measurable sediment infill. The data illustrate that the highest percentage of infilled scours occur in deeper water even though it is known that sedimentation rates are quite low in these areas. These scours probably reflect an older, or "relict" scour population that displays the cumulative effect

of many years of sedimentation. If this is so, much of the infill likely occurred during lower sea-level stands when the distance to source was closer and when, sedimentation rates were correspondingly greater. The large disparity between the shallow and mid water zone is probably because of the virtual lack of deep scours in the shallow-water zone (see Plate 5). Thus it is difficult to determine infilling values within the limits of the sub-bottom profiler's resolution, but it appears that scours in the shallow-water zone are being more actively infilled than is portrayed here both by sedimentation processes (discussed earlier) and by yearly rescouring by ice.

4. Scour smoothness percentage:

This relationship simply portrays the percentage of scours that appear smooth, moderately smooth, or rough within bathymetric zone. It is noted that this parameter is based on acoustic reflectivity characteristics from each scour which is known to vary based on the angle of ensonification, recorder scales, data quality, and towfish depth. It is, therefore, only a relative indication of scour morphology. The data show that the percentage of smooth scours increase from a low in shallow-water to a high in deeper water. Even though this is a relative relationship it correlates well with the higher percentage of infilled scours in the deeper-water zone that would have scours of smoother-appearing scour morphologies. The high percentage of moderately smooth scours in the shallow-water zone rather than rough scours (as might be expected) may relate to the shallower, narrow nature of most of these scours. Both these characteristics do not favour sharp, strong acoustic returns. It is within this zone as well that more dynamic sea-bottom oceanographic conditions prevail which contribute to scour degradation and to infill. Figure 21 shows one example of the change in scour smoothness with increased water depth.

5. Scour form percentage:

This relationship portrays the relative percentage of single-keeled, multi-keeled, or zone of multi-keeled scours found within each bathymetric zone. The indicator for the zone of multi-keeled scours is used only infrequently when a number of multi-keeled scours are difficult to discriminate as unique entities. Their percentge is so low in all zones that they virtually can be eliminated from this analysis. The data show a roughly equal percentage of single and multi-keeled scours in

shallow-water, however, in deeper water, single scours become dominant especially in water 40-60 m deep. This divergence may reflect a transition in ice zonation patterns from the fast ice to the shear zone as discussed earlier or the progressive incorporation of single-keeled relict scours into the population with increasing bathymetry. At this stage it is difficult to explain this unequivocally, however, several processes may be combining to produce the observed relationship.

6. Scour width distribution:

Scour widths were calculated as percentages within 50 m width intervals for each bathymetric zone. The observed data show that scour width appears not to vary significantly with differing water depths. The only trend of note is for slightly wider scours to occur in the deep water zone as might be expected in conjunction with observed deeper scours in deeper water as discussed previously.

7. Scour orientation percentage:

Scour orientations are presented as percentages of scours within 20 degree intervals referenced to true north. The data generally describe a NW-SE preferred directionality which agrees with wind-rose diagrams as discussed earlier. A closer look at the data shows that scours in the shallow-water zone appear to have no preferred orientation. Conversely, with increasing water depth a preferred directionality appears especially within the 100-120 degree interval in the deep water (40-60 m) zone. This trend likely represents the two different ice regimes the fast-ice zone from 0-20 m depths and the shear zone beyond 20 m into deeper water. The presence of relict scours in the distribution complicates this relationship by recording preferred orientations from historically different oceanographic or sea ice regimes, or both.

8. Scour depth distribution:

Scour depths were taken from sub-bottom profile data and are illustrated as percentages of scours within 1.0 m scour depth categories. The data reflect a similar pattern as witnessed from the echo-sounder scour-depth distributions within bathymetric intervals (see Figure 20). Scours in shallow water

are typically less than 2.0 m in depth, but, as water depth increases, scour depth increases accordingly. It is noted here that these depth values were picked manually and that the lower resolution of the sub-bottom profile system did not allow for precision measurement techniques. Scour depths were therefore picked within 0.5 m intervals as values of 1.0 m, 1.5 m, 2.0 m, and so on and in some cases the "interpretive bias" favoured the 1.0 m, 2.0 m, 3.0 m categories. Consequently, some problems in grouping these data in 0.5 m categories have resulted. For precision scour-depth analyses the interpretor should use the echo-sounder data-base.

MOSAICS (RELATIVE-AGE STUDY)

Side-scan sonar mosaics of the Kringalik, Natiak, and W. Tingmiark sites (Figures 23, 24, and 25) were interpreted and were included in the data base. In addition to the standardized data base parameters, a relative-age code was input for each scour (see Methods). The interpreted cross-cutting relationships which determine the relative age of scours are shown by Plates 2,3, and 4.

Age-class frequency histograms were created for each of the three digitized mosaics and are also presented on each plate. At each site the most recent age class has the greatest number of scours whereas the oldest age classes have the fewest. As discussed later this may reflect an inherent bias built into this type of analysis because the older scours are progressively more obliterated by newer scours. The results are expressed in Table 12 that presents the percentge of scours within each relative age class.

The Kringalik site is situated in water 30-35 m deep where scouring is known to be common. A high percentage of small "background" scours exist (Figure 23) giving the impression of 100% scour saturation. The age-class frequencies for Kringalik are fairly evenly distributed within the first eight age classes, which reflect roughly equal proportions of scour generation groups.

Conversely, Natiak and Tingmiark have high percentages of "recent" scour groups. The Natiak site is in water 40-50 m deep located on the northwest edge of the shelf which might result in a high percentage of "recent" scours where the sea-floor is initially contacted by free-drifting ice moving shorewards.

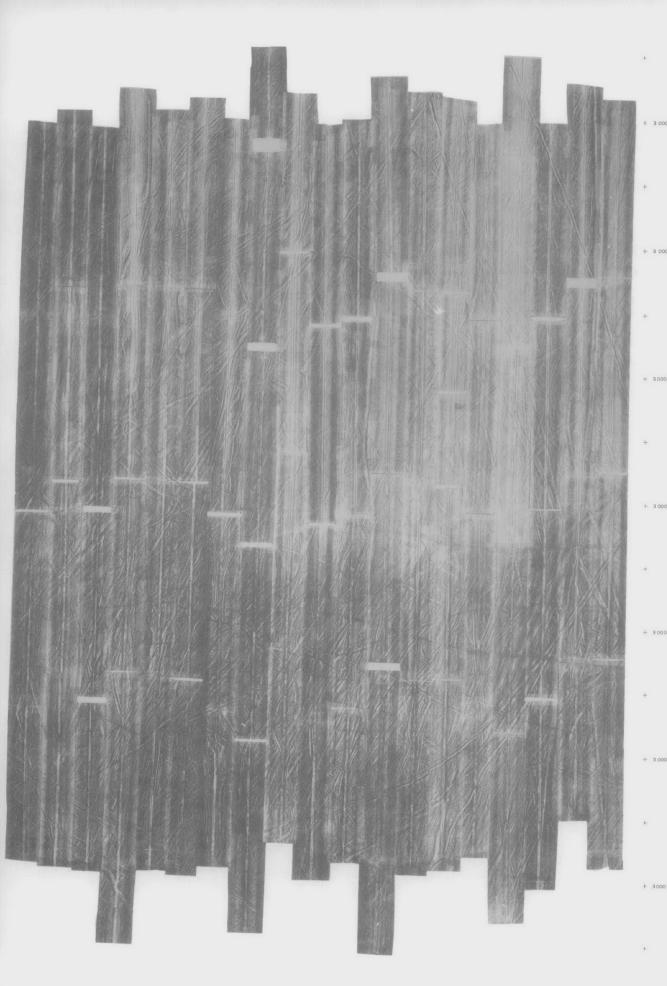
The West Tingmiark site similarly has deep water to the west. It is situated on the eastern flank of the Kugmallit Channel and spans two bathymetric zones, which coincide with two discrete domains within the mosaic area (see Plate 4). Domain A, containing only five scours, is in water 45-55 m deep. Domain B is in water 30-45 m deep and is highly scoured. It has the highest percentage of "recent" scours and the greatest number of older scours. This wide range in age classes may result from the gradual rise in sea-floor and the accompanying increase in scouring in shallower water. A more detailed analysis could be made to determine if "recent" scours are most predominant in shallower water and older scours in deeper water. The relationship of relative-age class to other scour parameters can be easily examined as codes for relative-age are part of the standard data-base format for the mosaic sites. To access these data the reader is referred to Appendix 2.

TABLE 12

Relative-age study

PERCENTAGE OF TOTAL NUMBER SCOURS BY AGE CLASS

	(most	(most recent)	it)														(oldest)	st)	
-	~		3	4	5	t 5 6 7 8 9 10 11 12 13 14 15 16 17 18	7	8	6	9	=	12	13	14	15	9	17	81	u
12.9 11.8 10.4 9.4 9.4 11.5 7.0 6.8 4.7 1.6 4.7 2.3 4.7 2.3 1.4 0.7 0.2	_	8.	10.4	9.4	7.6	11.5	7.0	8.9	4.7	9.1	4.7	2.3	4.7	2.3	1.4	0.7	0.2		425
25.2 16.0 12.1	_	0.9	12.1		2.4	5.3 2.4 5.7 6.0 6.7 5.0 3.5 4.6 3.5 2.5 0.7 0.3	0.9	6.7	5.0	3.5	4.6	3.5	2.5	0.7	0.3				282
W. Tingmiark 27.0 16.9 9.7 7	_	6.9	7.6	7.2	1.7	.2 7.7 2.9 7.2 5.0 2.8 2.4 2.7 0.7 0.7 0.5 2.7 1.7 0.5 0.5	7.2	5.0	2.8	2.4	2.7	0.7	0.7	0.5	2.7	1.7	0.5	0.5	415



SCAN SONAR SURVEY - SEAFLOOR MOSAIC 1982

-137*15' -137*12'

NATIAK 0-44

1982 SIDE SCAN SONAR SURVEY - SEAFLOOR MOSAIC

CORRIDORS (STUDY OF ADDITIONAL NEW SCOURS)

The original 1974 base-year scours (digitized in this case from the 1979 mosaic) are filed separately from the side-scan sonar data base. This allows the corridors to be kept separate from the main data base as they are somewhat different from single-line regional survey data. They can, however, be easily merged with the-side scan sonar data-base if so desired as the data formats are similar. The additional new scours are stored as well in a unique file, so the data base user may quickly isolate that file and apply statistical routines to the data.

The results of this study (see Table 13) show that 283 base-year scours and 14 additional new scours are now present in the corridor files. It is noted that this new scour value likely reflects a maximum value as the data quality reduced the interpreters ability to identify separate or related scouring events.* In fact the better resolution of the 1979 resurvey data may, in itself, contribute to discriminating events that previously were present but not resolved on the 1974 data. This study has illustrated a suitable method for the future incorporation of new scour information into the data base, but it is evident that high data quality is imperative for such studies.

TABLE 13
Study of additional new scours (corridor)

Corrid	<u>lor</u>	Part	Base ye	ear scours		scour tions
E. Mackenz (south)	•	A		139		5
E. Mackena (north)	· · · · · · · · · · · · · · · · · · ·	В		144		9
Note: The	e individual	Totals sections	of the E.	283 Mackenzie	'	l4 are

cross-referenced in the data base as Part A and B.

^{*} J. Shearer, Shearer Consulting, personal communication, 1985.

UNUSUAL FEATURES

Sea-floor features that were observed on echo-sounder and side-scan sonar records have been catalogued in Table 14 and include those which are geologic, man-made, or artificial in nature and those which cannot be confidently identified.

TABLE 14
.
Unusual features

Data set	Geologic	Man-made	Unknown
Dome 81	16	-	3
Esso 83	6	-	2
Hud. 70	4	-	-
Gulf 81	26	6	10
Dome 82	31	1	3
Dome 80	104	12	12
Beau.76	. 9	5	7
Gulf 83	8	1	4
Total	204	25	41

Geological Features

Geologic features can be further subdivided as shelf-edge features, thermokarst topography, lithological features, and unusual scouring examples.

Shelf-edge features. These are most evident in the northwestern area of the Beaufort Shelf. Possible mud diapirs occur between the Natiak and Kringalik sites in the 50-m bathymetric zone. Some linear depressions (fault traces) are visible around the Natiak site which do

not exhibit the berms typical of ice scours. Slumping, is commonly visible on side-scan data which extends over the shelf edge. Slump units create depressions which could be identified as scours on echo-sounder records unless recognized with the aid of side-scan sonar records.

Thermokarst topography. There are many instances of pingo-like features (PLFs) on side-scan and echo-sounder records, particularly in the northeastern portion of the shelf. Figures 26 and 27 illustrate one pingo from the Tingmiark Plain as observed on side-scan sonar and echo-sounder records. Scouring is clearly evident on the higher slopes of this PLF, and is noticeably absent in deeper water on the lower edges and surrounding sea-floor. Figure 27 also displays a trench or moat skirting the pingo, which is similar to its morphologic equivalent on the Tuktoyaktuk Peninsula.

Lithology. Sand bodies and sand ridges occur in isolated cases most typically in shallow water and in the eastern Beaufort Sea. Sand waves are evident in a few places such as the Akpak Plateau (40-50 m bathymetry) and the northeastern flank of the Kugmallit Trough (40-50 m bathymetry). The regional unconformity (Unit "C") is exposed or covered by thin, surficial sediment in the eastern area of the shelf. Figure 22 illustrates the changes in scour signature as ice grounds on this more-resistant stratigraphic unit.

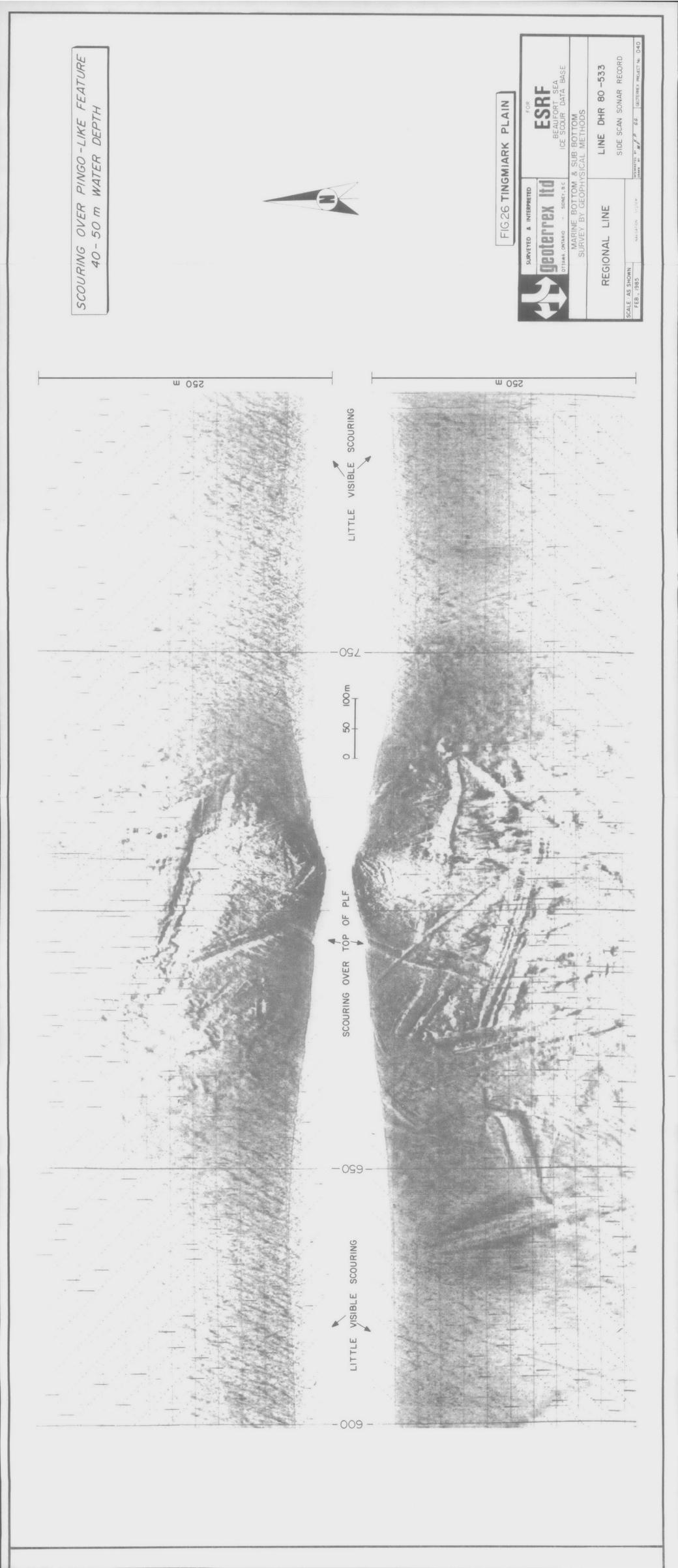
<u>Unusual scours.</u> Paleoscours are frequently preserved within well-stratified sediments on survey lines extending into deeper watr, such as sea-floor channels and towards the shelf edge. Figure 22 illustrates completely buried paleoscours revealing older, scoured surfaces as well as more recent scours in various stages of infill. Another example of unusual scouring is shown in Figure 28 which illustrates a well-defined, multi-keeled scour that has changed direction several times.

Man-Made Features

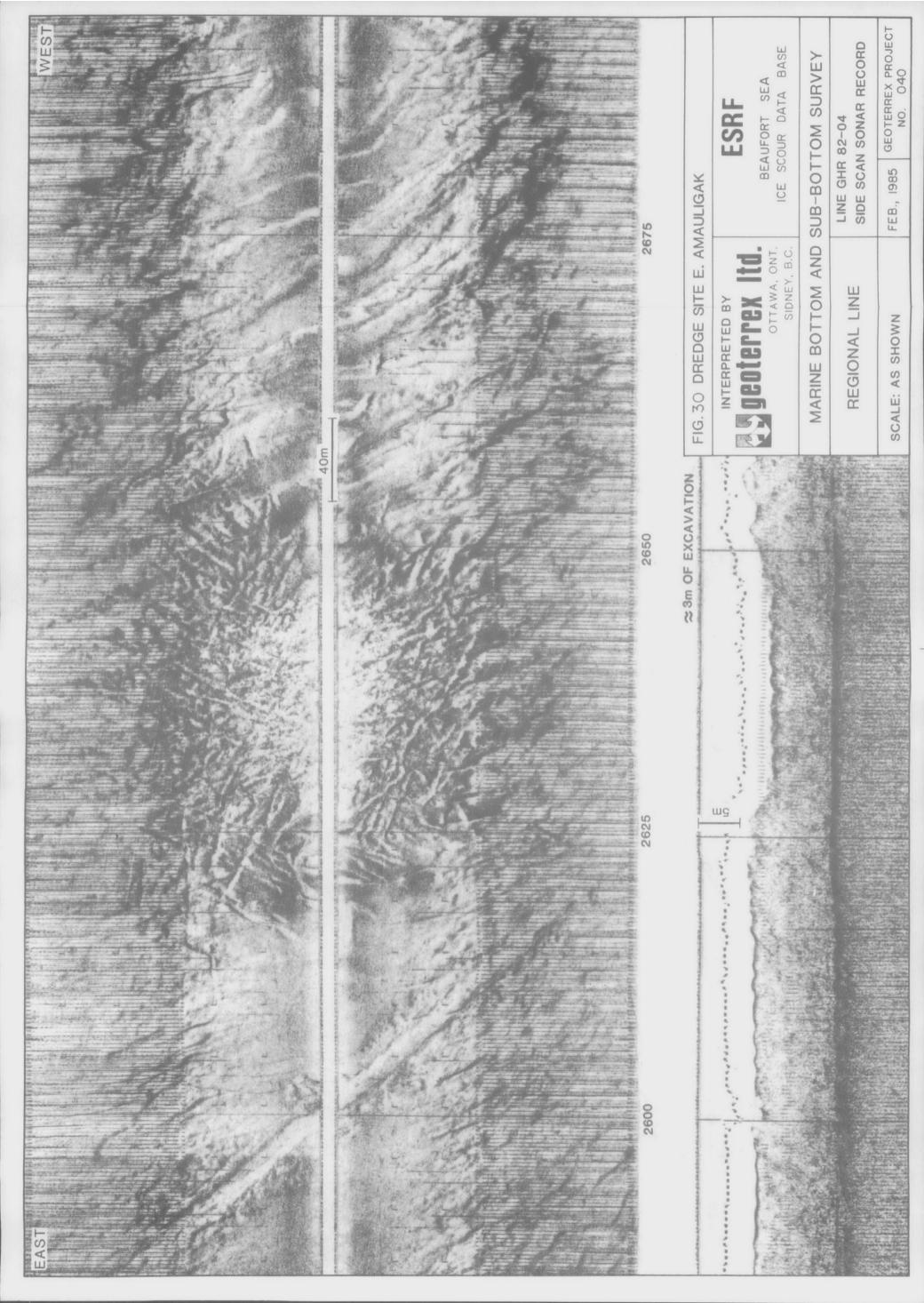
Man-made features include glory holes,, dredging holes and scours created by anchor drag (Figures 29 and 30). These features occur near well sites and borrow areas. They are useful because their creation can be dated allowing for time series study of degradation rates. For example, comparison of man-made features on side-scan sonar and echo-sounder recorders in years following their occurrence can aid in understanding local sedimentation rates and, therefore, rates of ice-scour infill.

Unknown Features

Unknown features are those which have an acoustically reflective surface but cannot be positively attributed to sea-floor relief. Such surfaces could be related to ice, to sea-floor gas seepage, to biological material in the water column, or to possible equipment abnormalities.



EEAUFORT SEA ECHO SOUNDER PROFILE LINE DHR 80-533 FIG. 27 TINGMIARK PLAIN PLF SCOURING OVER geoterrex Itd SURVEYED & INTERPRETED REGIONAL LINE SCALE: AS SHOWN FEB., 1985 006 098 008 AROUND PLF DEPRESSION 094 36 m 21m 002 31 m 099 PLF SCOURING OVER 009 32m 46 44 68



DISCUSSION

GENERAL

A comprehensive, computerized ice-scour data base has been created for Beaufort Sea acoustic data. The data base at present contains computer-derived scour parameters for over 11,400 scours from echo-sounder data and 35,700 scours from side scan sonar data. The nine separate data packages that now reside in the data base range in age from 1970-1983 and represent data from the three principle petroleum operators (Dome Petroleum Ltd., Esso Resources Ltd., and Gulf Canada Resources Inc.) and from the Geological Survey of Canada.

Data are input into the data base by a series of steps. The side-scan sonar and echo-sounder acoustic data are digitized and subsequently are quality-controlled using a graphics terminal or hard-copy plots. A number of specific ice-scour programs process the digital data to produce the various ice-scour parameters. Manually interpreted data and accurate navigation information are merged with the results as a final step, thus producing an accurate and comprehensive data base. Its format and file structure information is given in Appendix 2.

INTEGRITY OF THE DATA BASE

The integrity of the data base has been verified by statistically comparing results produced by the data base with those produced by an impartial external interpreter using conventional measuring techniques. The test comparing the Echo-sounder data base both to J. Shearer and the average of nine interpreters (see Figure 15) is perhaps the most definitive. This shows that within a high confidence interval, the observed data-base results are as good as those produced by nine, independent, manual interpretations.

If we explore this comparison in more detail, Figure 16 shows that the nine interpreters visually judge the position of the smoothed sea-floor somewhat differently, thus producing the variable scour-depth distributions. The outer limit bounds of these distributions should, therefore, define an error range for manual interpretation of the data. As the computer-derived data fall well within these bounds and, in fact, closely approximate the average of the interpreters, the integrity of the data base is felt to be confidently established. In fact, the poor agreement between manual interpreters argues in favour of using an unbiased, reproducible, computerized technique to locate the sea-floor reference datum.

As a further measure of confidence in the data base, scour-depth information compared favourably to that produced by the APOA data taken from Lewis (1977a) (see Figure 18). This serves as a useful general check as each data set was derived roughly within similar geographic localities on the Beaufort shelf (see Lewis 1977a and Plate 1).

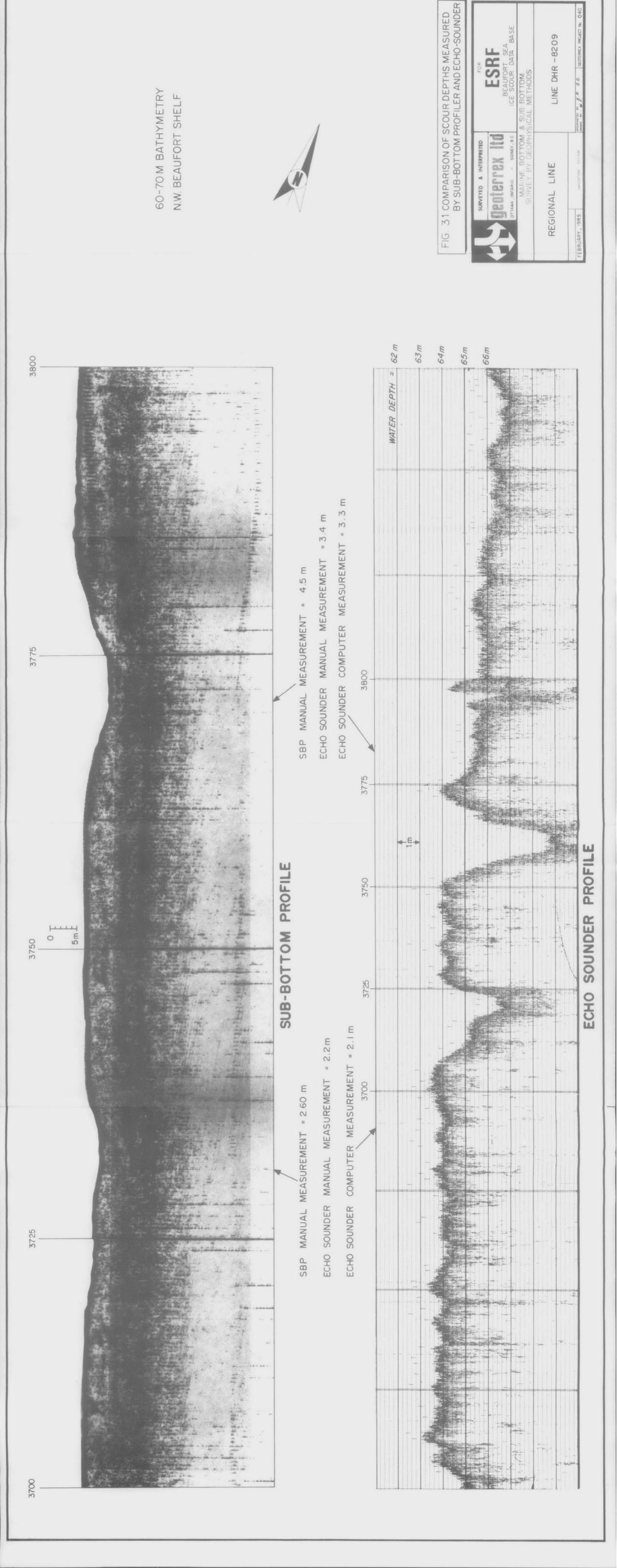
The integrity between the echo-sounder and side-scan sonar data base was tested by comparing manual scour-depth measurements from the third-channel sub-bottom profile data to those taken from echo-sounder data base. As discussed in the Results, although this comparison passed the chi-squared test, there are inherent problems in making such a correlation. First, any interpretation taken from the echo-sounder cannot identify multi-keeled scour events and, therefore, events would be identified as separate keel depths of a multi-keeled scour. Conversely, in picking depths from the "matched" third-channel sub-bottom profile data, multi-keeled scours are recognized on the side-scan data and only the deepest keel depth is manually recorded into the side-scan data base from the sub-bottom profile data. This feature would bias the data towards more scour depth values in the echo-sounder data base than in the side-scan sonar data base.

A second and complicating relationship exists that favours deeper scours being picked from the sub-bottom profile data. Throughout the various quality-control checks performed during this project a statistical variation towards greater scour depths recorded by sub-bottom profile data than by echo-sounder data has been observed. Often this relationship would be evident for larger scours only. Figure 31 shows scour-depth measurements for two scours recorded by echo sounder and sub-bottom profile data. Clearly in this case scour depths measured from the sub-bottom profile are greater than those from echo-sounder. Accurate picking of scour depths from the sub-bottom profile data was further constrained if data quality was poor or if the instruments were set on compressed vertical scales (e.g., 0-100 m across the width of the chart paper).

A number of factors may be in operation to explain this variation. Perhaps the simplest explanation results from the "towed" nature of the side-scan/sub-bottom profile fish. This layback potentially allows the fish to track at a divergent angle from that of the ship's heading, thus, the sub-bottom profile may simply cross the scour at a different (possibly deeper) section of the scour than the echo sounder had recorded.

A number of technical factors have also been considered in explaining this divergence. These as summarized follows:

a) The 5-m reference scale line which locks on the sea-bottom was tested by McQuest Marine Sciences Ltd. They felt that



there was a calibration adjustment required and that this marker possibly represents $4.5\ m_{\star}$

- b) The frequency of the two sources is different and therefore the lower-frequency sub-bottom profiler (3.5 kHz) might not to respond to any "soft" scour infill as readily as the higher-frequency echo-sounder. Effectively, it is possible that the sounder profiles the top of the infilled scour and the sub-bottom profiler, the base of the scour.
- c) The respective beam angles are different for the two sources; echo sounders have angles of about 9 degrees and the sub-bottom profiler an angle of 45 degrees. The resulting area of the sea-floor "footprint" of the two sources would be dependent on their relative position in the water column (as the profiler is a towed instrument). It is evident however, that the echo-sounder's narrower beam should descriminate the sea-floor's microrelief with a higher degree of accuracy.
- d) The speed of sound used in the two sources is different as well. The sub-bottom profiler is calibrated for 1500 m/sec and the echo-sounder for 1,463 m/sec. This might account for small differences in the depth measurements of the two sources as the scale lines are generated using these values.

During the summer of 1985, Geoterrex Ltd., under contract to ESRF undertook a short, field, calibration test of the two instruments. Unique scours were profiled by both instruments and the scour depth measurements were found to correlate reasonably well for those scours measured. However, it is possible that shallower scours were used in this test where the differences might not be as readily apparent. As a result of these observations, it is recommended that the echo sounder data base be used when dealing with scour depth distribution analyses.

INTERPRETATIVE FLEXIBILITY OF THE DATA BASE

The interpretive flexibility of the data base has been illustrated in the Results by using three examples of different types of analyses. These relationships were derived with relative ease using Geoterrex' ice-scour interpretation system described in Methods. At present, more than 20 ice-scour statistical routines are in place within this system.

The first interpretive example produced a scour-depth distribution at 0.5 m intervals for the whole Beaufort Sea echo-sounder data base. Data points from over 11,400 scours were fitted successfully to a negative exponential curve, producing a general k value of 1.73. This interpretation establishes a base-line value for

the whole of the Beaufort Sea, derived from the largest data set now available. It is noted that these data could be grouped at a user-selected interval (e.g., 5.0 cm if required).

The second interpretive example compared two scour parameters to each other using a selected data set from the side-scan sonar data base. The relationship of scour depth versus width illustrated that as scour depth increased, scour-width percentages increased similarly. This test was carried out relatively simply and the technique could be applied to any of the parameters for the whole data set or to a particular subset.

The third example of the interpretive flexibility of the data base compared a number of different scour parameters to an environmental parameter; in this case, water depth. The echo-sounder data base was used to derive scour-depth distributions at 0.5 m intervals for a number of 10 m water depth zones across the Beaufort shelf. The data illustrate a high correlation between scour depth and water depth. As water depths increase, spatial scour frequency decreases and scour depths increase statistically.

The-side scan sonar data base was also used to produce a number of relationships between various scour parameters and 20 m bathymetric intervals. Scour frequency, percentage sea-floor disturbance, percentage of infilled scours, smoothness percentage, form percentage, scour width, orientation, and scour depth were the parameters analysed. The scour parameters, smoothness, form, infill, and area of disturbance are important parameters that to the authors knowledge have not previously been documented for the Beaufort Sea.

MOSAICS (RELATIVE-AGE STUDY)

The theory of identifying relative-age relationships by cross-cutting analysis was evaluated for three sites using methods described previously. The results illustrate that all sites have the highest percentage of scours in the most recent age class and the lowest in the oldest age classes. It is not likely that this observation results from any increased scouring activity in recent times, but rather, reflects the interpreters inability to identify the increasingly older, and therefore more cross-cut, scours. A second factor complicating the interpretation of cross-cutting relationships is that if a preferred scour orientation was in operation throughout the time frame for the total age class time series, fewer cross-cutting relationships would be observed (statistically) thereby creating an artificial paucity of scours in older age classes.

As an analogy, consider a completely random system where the probability of witnessing a scour with a random orientation is equal over a particular time series. Such a system would produce a high

percentage of cross-cutting relationships (hence age classes) and, therefore, would infer a certain older "relative age" for the older age class scours. Alternatively, if this same system were constrained by an outside physical force (e.g., wind) that caused many scours to be similarly oriented, a lower number of cross-cuts would occur producing fewer age classes and the impression of more-recent scouring activity even despite the same time series and perhaps the same scour ages.

A realistic model for the Beaufort Sea may lie within these two extreme endpoints, however it is noted that preferred wind directions and scour orientations exist in the Beaufort Sea and, therefore, the latter relationship could be more probable. The axiom then for the Beaufort geologic environment may be that as water depths increase, scour orientations become more directional (see Plate 5) thus producing fewer cross cuts and an abnormally high, first age-class value. In shallower waters, where the sea-floor may commonly influence pack-ice directionality, scour orientations are more random (see Plate 5). It is interesting to note also that the shallow shelf site Kringalik has fairly equal age frequency distributions for the first eight classes illustrating, perhaps, an increase in orientation variability rather than scour age. It also follows that to identify a cross-cut the two scours must have divergent orientations and therefore the data are somewhat constrained for statistical orientation frequency study.

This technique is highly relative and perhaps of limited value, but further analyses of scour parameter relationships within the age classes may reveal interesting trends. The relative-age technique may also prove useful in comparing the relationships observed at different site locations and physical environments.

CORRIDORS (STUDY OF ADDITIONAL NEW-SCOURS)

The results of this study, using the East Mackenzie corridor data, have established a framework for incorporating new-scour data into the data base. The base-year data are first digitized as a reference in a separate file. New scours must then be identified manually from the repetitive year, digitized, and entered into a unique "new scour file." The computer alone could not identify new scours if both the base - and repetitive-year corridors were fully digitized. As discussed previously every digitization session is, in essence, an interpretation where the operator chooses the major scour events until a "background" level is reached. This level may vary from one session to the next and most certainly between different interpreters. Pattern recognition software utilities as well are difficult to troubleshoot and bring on-line.

ADVANTAGES OF THE DATA-BASE SYSTEM

Several advantages of a digital ice-scour data base are summarized.

- The data parameters are catalogued in an organized format that can be statistically analysed using appropriate software.
- 2) A digital archive of each scour outline is stored in Geoterrex' in-house data base, thereby alleviating the need for reviewing the original analogue records.
- 3) The data base is easily modified and updated as new data and possibly new parameters become available.
- 4) Scour depths derived from the echo-sounder data base are referenced to a reproduceable sea-floor datum. Scour-depth re-interpretations may be undertaken by experimenting with different filtering routines or by modelling the digitized sounder profile within the frequency domain.
- 5) The data-base system is compact (less than 10 megabytes) and may be taken to the field on a microcomputer for on-board analysis and survey planning.
- 6) The digitization technique has been found to be both highly accurate and time efficient.
- 7) A wide variety of software utilities such as mapping, editing, and general data manipulations that reside within the Geoterrex in-house (FLTLIB) data base can be developed further and applied to the ice scour data.

LIMITATIONS OF THE DATA BASE

Five limitations of the data base are noted as follows:

- 1) Due to the "layback" differences between the echo-sounder and side-scan sonar, the scour depths observed on echo-sounder cannot be easily correlated with those scours seen on side-scan sonar. Two data bases, therefore must be used.
- 2) As discussed previously, there exists problems in the correlation of both the number of scours and the actual scour-depth values measured manually from sub-bottom profile data and by the computer from echo-sounder data.

- 3) Poor data quality; especially irregular navigation data, poor scale selections and "bad weather" data may produce results of a lower quality in both data bases.
- 4) Some of the manual interpretive inputs into the data base are somewhat subjective and, therefore, may not be always consistent as data quality and water depths change regionally. These parameters are: smoothness, relative age and data quality.
- 5) The analysis of additional new scours requires that new scours first be identified manually and then be digitzed into the data base. If all the scours were digitized from a base-year and a resurvey-year corridor, the computer alone could not be trusted to pick new scours at the present level of technology.

RECOMMENDATIONS

A number of suggestions are recorded in this section to improve the results of the collection, processing, and final presentation of the ice scour data.

1) Standardize Equipment Scales

Data acquisition techniques should be standardized in the future with respect to scales, chart speeds, and navigation fixing techniques. Side-scan sonar scales should not be changed intermittently along a survey line. One standard scale (e.g., 150 m slant range scale) should be employed throughout the survey duration. Similarly echo-sounder and sub-bottom profile vertical scales should maximize sea-floor relief, thereby speeding up the latter stages of digital processing. Echo-sounder paper speeds should be fast enough to isolate deep narrow scours accurately and heave-compensated systems are strongly recommended to reduce wave noise.

2) Ship-board Digitizer

Echo-sounder data have been digitized by on-board digital samplers during various surveys. A study could be initiated to recover these data, to identify their sampling increment, and to evaluate the possibility of streamlining the echo-sounder software to use this data format. If the sampling increment were unsuitable, recommendations for future survey equipment and formats could be presented. Successful use of the digital field data would eliminate the labour-intensive step of manual digitization of echo-sounder data.

3) Third Channel Echo-Sounder

Based on the scale measurement problems of the third-channel, fish-mounted sub-bottom profile, it is recommended that a high-frequency, narrow-beam echo-sounder be used in its place. The sub-bottom profiler could be towed or hull-mounted to provide sub-bottom penetration, whereas, the fish mounted echo-sounder would provide accurate scour depths referenced to the plan-view, side-scan sonar.

4) Echo-Sounder/Sub-bottom Profile Calibration

A study could be undertaken to calibrate the differences in measurable resolution between these two analogue data sets. Sub-bottom profile data could be digitized, scale corrected to match that of the echo-sounder, and subsequently processed for scour-depths or digitally

modelled in the frequency domain to remove noise. The statistical differences between the resulting two scour-depth distributions may identify a calibration factor that could be rerun through the data base values to improve the correlation between sub-bottom profile and echo-sounder for scour-depth measurements. This technique might also establish a suitable method for the automatic referencing of scours seen on echo-sounders to those on side-scan sonar using the digitized, third-channel profile (sub-bottom profiler) as the fundamental link. The variable "layback" distance is the inherent problem with this correlation, however, computer modelling and goodness of fit-testing between the two digital profiles may identify suitable processing methods.

5) Error Estimates

The echo-sounder data base provides scour-depth values for good - fair, - and poor-quality data. Some degree of margin of error for differing qualities of data could be established by statistically comparing repeated digitizing sessions with several manual interpretations of the same data sets (for GOOD, FAIR, and POOR data). This could establish a numeric confidence interval that could be incorporated into future updates of the echo-sounder data base.

6) Filter Modelling for Echo Sounder

The principle advantage of the recovery of the sea-bed by filtering is the repeatibility of the process. When interpreters hand sketch the sea-bed, often there is a different result for each person. Standardized computer filtering will always give comparable results. One problem with the present filtering methodology is that interpreters evaluate the results. The choice of filters could be based on a frequency analysis of the echo-sounder profile data. By producing fast fourier transforms (FFTs) of echo-sounder data, the frequency of the noise (ship heave) and signals can be readily identified. The filter could then be designed to reject the noise and to retain the maximum amount of the signal as possible. This study could be expanded to include the best choice of filters depending on the sea-floor "roughness" and regional slope gradients. Different geologic environments may require specific filter characteristics.

7) Regional Gradient Inclusion

Scour parameters are known to change with respect to local sea-floor gradients. A program could be written to calculate gradients from the digitized echo-sounder data over a preselected interval (e.g., 500 m). This field could be input into both data bases so that scour parameters could be easily compared to regional or local slope values.

8) Regional Plotting of Data Base

The scour data exists in a navigation-referenced format that can be processed for purposes of visual plotting. The scale could be 1:250,000, however, it is suggested a number of 1:50,000 sheets be produced to illustrate the scour polygons as distinctly as possible. Research could be undertaken to plot bathymetric contours on these map sheets to produce an accurate visual presentation of scour density and bathymetric relationships. Plotting capabilities could then be further refined to plot certain scours only, for instance, generating a map of scours across the Beaufort shelf that are longer than 1 km or deeper than a user-selected threshold, such as all the scours greater than 3 m deep.

9) Unusual Features Report

Throughout the digitizing phase of the side-scan and echo-sounder data, a number of interesting geologic features were observed and recorded. These features alone could be catalogued and described in a pictorial-type atlas of the Beaufort Sea.

10) Regional Ice-Scour Interpretation

Scouring signatures have been demonstrated in this study to vary significantly with bathymetric zonation. These relationships could be documented further by partitioning the shelf into geologic, bathymetric, and perhaps oceanographic sub-units and by studying the resulting scour distributions in detail. Such a regional analysis would provide the engineer with a better capability for prediction based on the interpreted scour distributions.

ll) Field Testing

The data base can now be fitted on a microcomputer with a 10-MB hard disc and, therefore, may be taken to the field for on-board interpretive analyses during ice-scour research programs. The envisioned system could be updated with advanced plotting capabilities for on-board visual presentation and the interpretation software could be improved for rapid handling of data.

12) Sediment Thickness Study

Sediment thickness values are now referenced to the Unit "C" unconformity as it is the most consistent regional marker. These values have been input for those data sets bearing sub-bottom profile information only. A regional study could be undertaken to input

sediment—thickness values into the data base for all data sets. A second sediment thickness data field could also be incorporated into the data base to reference the thickness of recent marine clays to the first significant reflector which may be "resistive" to scouring. Because of transitional facies changes across the shelf this boundary may alternate between Unit "B," "C," or undefined unconformable surfaces that are known to exist within the inshore regions. As an extension, perhaps, sedimentation rates could be included in the data base because as this information, coupled with sediment—thicknesss information, may be coupled with scour morphology to define more accurately the relationship between morphology and scour age.

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APPENDICES

Appendix 1 : Bibliography

Appendix 2 : Side-scan sonar and echo-sounder parameter descriptions

Appendix 3 : Erratum

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APPENDIX 1

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APPENDIX 2

SIDE-SCAN SONAR AND ECHO-SOUNDER PARAMETER DESCRIPTIONS

The data base at present contains five files on 9-track tape.

- 1) Side Scan Sonar Data Base
- 2) Mosaics (Relative Age Study)
- 3) Corridors Base Year
- 4) Corridors New Scours
- 5) Echo Sounder Data Base

Format for all tapes is as follows:

9 Track

1600 BPI

ASCII Format

132 Byte Records

A. Side Scan Sonar Data Base Format

<u>Parameter</u>	Fortran Format	Column #
Company	A4	1-4
Year	IX,12	6-7
Line	15	8-12
Part	13	13-15
Fix	15	16-20
Heading	14	21-24
Easting	17	25-31
Northing	18	32-39
Scour #	15	40-44
Orient.	14	45-48
Std. Dev.	14 ·	49-52
Form	lx,Al	53-54
Morph.	lx,Al	55-56
Smth.	lx,Al	57-58
R. Age	lx,Al	59-60
Length	16	61-66
Width	14	67–70
Area	17	71-77
Depth	A4	78-81
Fix	A 5	82-86
s. Fill	. A5	87-91
SS. Def.	A3 .	92-94
S. Thk	A5	95-100
S. Type	A4	101-103
Bathy.	A4	104-107
Qual.	A2	108-109
Comments	A23	110-132

B. Side Scan Sonar Data Base Parameter Descriptions

Parameter 1 - Company

Description: The operator who collected the field data.

Comments: The company parameters are listed as follows:

DOME - Dome Petroleum Ltd.

ESSO - Esso Resources Ltd.

GULF - Gulf Canada Resources Inc.

BEAU - Beaufort Delta

HUDN - Government Hudson 70

MAC - Corridor E. MacKenzie Site.

Parameter 2 - Year

Description: Year of data acquisition.

Comments: Year for E. MacKenzie base year corridor is 1979 (see

Methods).

Parameter 3 - Line

Description: Survey line number.

Comments: Due to the restriction of 5 integers to describe line #, the following line numbering methods were used (by

data set):

a) Hudson 70: Last four numbers of line same,

i.e. "70-08-3110" = "3110".

b) Beaufort Delta: Original survey line numbers were used, i.e. "76-08" = "120".

c) Dome 81: Letters "R" and "I,K" which preceded numerals were omitted, i.e. "I,K - 1.5" = "1.5".

d) Gulf 82: Zeroes do not appear before line #
in data base, i.e. "02" = "2".

e) E. MacKenzie Corridor: The site area name is substituted for a line # since the mosaiced corridor area is composed of several lines which scours cross over.

f) Mosaics: The site area name is substituted for a line # for the same reason as MacKenzie Corridor.

Parameter 4 - Part

Description: Refers to a break in the line due to a paper break or poor data quality.

Comments: Generally not important to the user but was incorporated throughout the processing stages.

If a part number of a line does not occur in the data base, it is because

- a) the record quality was too poor for digitizing;
- b) there are no visible scours on that line part.
- a) E. MacKenzie Corridor: Because the corridor mosaic was compiled as two separate sheets, the south area of the mosaic is referred to as Part A and the north area as Part B.

Parameter 5 - Fix

Description: The reference shot number taken at the left hand portion of each scour at the "pivot point".

Comments:

- a) Fixes for Dome 81 on the acoustic data were one numeral value per fix. Decimal values for fix could not be incorporated as five integer values were allocated for this field.
- b) Dome 80: Part c: Line 80-521E had fixes in time rather than counter units on the original record. These were converted to counter units to enable processing of this line. All fixes for this line are shown on the track plot as counter units.
- c) Beaufort Delta: All fixes on side scan records were recorded as time rather than counter units. To enable processing of this data, software was written to convert the fixes from time in hours and minutes to minutes only. (i.e. 2300 hrs = 138 mins). Pivot point fixes in the data base are thus in minutes only, while fixes on track plot regional lines remain as they are on the side scan records in hours and minutes.
- d) Mosaics and Corridors: Since these mosaiced areas were digitized with reference to corner point UTM values rather than ship path navigation fixes, the symbol "-" replaces fix numbers.
- e) Hudson 70: Line 2722 fixes converted from hours/minutes to minutes/minutes.

Parameter 6 - Heading

Description: This is a general reference ship's heading interpolated from the S.O.L. UTM to the E.O.L. UTM position.

Comments:

a) Mosaics and Corridors: heading value reflects an artificially generated heading created for processing purposes.

Parameters 7 & 8- Easting and Northing

Description:

The x,y position of each scour "pivot point" expressed in real distance units from the track line. UTM values are derived from the track plot (Plate 1) that uses 135 degrees longitude as a central meridian. Data beyond a 3 degree to either side of 135 degrees is interpolated.

Comments:

Nil.

Parameter 9 - Scour

Description:

Arbitrary reference number input for data processing purposes only. Scours within each line part are renumbered and data is sorted by fix for the whole line.

Comments:

- a) Dome 82 and Esso 83 may have some duplicate scour numbers due to digitization errors.
- b) Gulf 82: Some scours found on the subbottom profiler and not on side scan are labelled as "*00". Late scour additions may be prefixed by "99".

Parameter 10 - Orientation

Description:

Line vectors are drawn to each digitized point of the scour polygon from the pivot point.

Length of vectors = Vec i

The orientation of each vector is measured from 0 to 360 degrees.

PH1 = Orientation of each vector.

The weighted scour orientation is calculated as: Scour orientation = Sum of Phi /Sum of Vec;

Orientations are expressed by convention as values less than 180 degrees.

Comments:

Data sets that are not speed corrected on the original records are corrected by the processing stages. Orientations are therefore corrected for ship speed distortion within the processing and therefore may not "appear" correct when directly checking from analogue to data base.

Parameter 11 - Standard Deviation

Description: The variance of the orientation values is calculated

and expressed as standard deviation.

Comments: Nil.

Parameter 12 - Form

Description:

1. Single-keel event

2. Multi-keel event

3. Zone of multi-keel: This descriptor is used in cases where multi-keeled scours cannot be

distinguished from each other.

Comments:

Nil

<u>Parameter 13</u> - Morphology

Description:

4. Linear: unidirectional scours

5. Arcuate: curved

6. Sinuous: changes orientation more than once

7. Crater: generally not present in Beaufort Sea.

Comments:

Nil.

Parameter 14 - Smoothness

Description:

Smoothness is a subjective descriptor based on the sharpness of acoustic returns which may vary with angle of scour sonification, data quality and water depth.

- 8. Rough: strong acoustic signature, evidence of rubble on berm or in scour.
- 9. Moderately smooth.
- 10.Smooth: reduced signal contrast, no rubble, smoothed scour walls.

Comments:

Mosaics and corridors have smoothness values of "9" due to the difficulty in estimating this parameter at a reduced scale.

Parameter 15 - Relative Age

Description:

This parameter is based on smoothness and general morphology in relation to background scouring. It is input only rarely when a high degree of confidence exists for the age of unusually distinct scours.

- + Old: smooth appearing, likely infilled and crosscut.
- Recent: rough appearing, uniquely distinct amongst background scouring.
- , Uncut: input for only those recent scours that are not crosscut by other scouring events.

Comments:

For mosaics only, all scours have an alpha character

indicating relative age.

i.e.: A=1 most recent age class

B=2 most recent age class

C=3 etc., older age class

Parameter 16

- Length

Description:

Length is measured as the longest vector value of the rays drawn to all digitized points. This is an apparent value due to the small viewing window which is further constrained by loss of resolution in the outer

edges of the channels.

Comments:

Scour lengths from the mosaic and corridor areas are longer on average than scours digitized from single width sonographs. Scour lengths over several sonograph widths on mosaics can be digitized in full.

Parameter 17

- Width

Description:

Width is calculated as an average value by the area of the scour divided by length. Low values may occur for narrow scours due to rounding errors. The digitized perimeter of the scour generally included the berms as precise scour width discrimination is difficult within the resolution limits of the equipment used.

Comments:

Nil.

Parameter 18

- Area

Description:

Area is calculated as the simple area of a polygon as

follows:

Xl = X.pivot

Yl = Y pivot

Xi = Xi - X1

Yi = Yi - Yl

AREA =

Comments:

Nil.

NOTE: The Parameters 19-24 are taken from subbottom profile records (3rd channel fish mounted) available for Esso 83, Dome 82, Gulf 82 and Dome 81 data.

Parameter 19 - Depth

Description: Scour depth value for those scours that cross the ship's path only on side scan sonar records. Scour depths were picked at 5m. intervals due to resolution limitations of the profiling system. If a scour is identified as a multikeel on side scan, the deepest keel depth only is recorded.

Comments:

Dome 81 third channel data utilized on higher frequency (100 kHz) acoustic sourcer and therefore may give different depth values than the other three data packages.

Vertical scales are very important for accurate depth measurements.

Esso 83 - 0-50m scale

Gulf 82 - 0-50/0-100m scale

Dome 82 - 0-50m

Dome 81 - 0-50m

Gulf 83 - 0-50m

Parameter 20 - Fix

Description:

This scour depth fix records the positions of the scour where it transects the ship's path.

Comments:

- a) Fixes for Dome 81 SBP scour depths are given to one decimal place in the comments field because of the large distance between fixes.
- b) Gulf 82: SBP fixes are not included in the data base since they were not a part of the earlier Gulf 82 data base format.

- Sediment Fill Parameter 21

Description:

Records value of scour infilling by sediments in .5m intervals. Note: Some values may be quite high due to completely infilled large scours.

Comments:

- a) Dome 81: not measurable because of no seafloor penetration on SBP
- b) Gulf 82: absence of infill is denoted by "0.0".

- Sub-Scour Deformation Parameter 22

Description:

Records the depth of sub-scour disruption stratigraphy by ice loading. Note: This parameter was very difficult to confidently recognize within the subbottom profiling resolution of the Distorted sub-scour stratigraphy may also be created by seismic "artifacts".

Nil. Comments:

Parameter 23 - Sediment Thickness

Description:

Measured to the Unit C regional unconformity. This boundary was chosen as it is the most common and distinct reflector regionally across the Beaufort Shelf. The base of the recent marine clays, for example, is not always obvious as in some cases it is a gradational lithofacies. Thickness was measured up to 10.0m beyond which 10.0+ appears in the data base. This measurement is taken from the smoothed seafloor.

Comments:

Where sediment thickness values are uncertain, this is noted in the comments field.

Dome 81 - no values are input as penetration was not achieved with the 100 kHz sounder.

Parameter 24 - Sediment Type

Description:

Sediment type was interpreted from a combination of side scan and subbottom records and pre-existing site interpretation reports.

C - Clay

S - Sand

CS - Clay Over Sand

Comments: Nil.

Parameter 25 - Bathymetry

Description:

The bathymetric value as derived from the regional track plot was input into the data base at 5.0m intervals. The alpha code for bathymetric cross reference is as follows:

Α	0-5	K	50-55	
В	5-10	L	55-60	
С	10-15	M	60-65	
D	15-20	N	65-70	
E	20-25	0	70-75	
F	25-30	P	75-80	
G	30-35	Q	80-85	
Н	35-40	R	85-90	
I	40-45	S	90-95	
J	45-50	T	95-100	etc.

Comments:

a) Corridors and Mosaics: bathymetric zone represents an average. The actual bathymetric range over the area is noted in the comments field.

Parameter 26 - Data Quality

Description:

A subjective descriptor of general data quality along the length of a survey line. Quality may vary due to poor weather conditions or equipment malfunctions.

G - Good

F - Fair

P - Poor

Comments:

Nil.

Parameter 27 - Comments

Description: Pertinent comments for certain aspects of the data set

may be inserted within this field. Possible comments include:

- l) Data Quality
- 2) Unusual Scours
- 3) Geologic Features; slumping, pingoes
- 4) Artificial Features

Comments:

The full fix values for Dome 81 subbottom profile scour depth FIX values are recorded in the comments field due to lack of space in the FIX field.

C. Echo Sounder Data Base Format

Parameter	Fortran Format	Column #
Company	3X,A4	1-6
Year	3X,I2	7-11
Line	18	12-19
Part	14	20-23
Fix	16	24-29
Easting	. 19	30-38
Northing	IlO	39-48
Scour Depth	F6-1	49-54
Seabed Depth	F9-1	55-63
Data Quality	A7	64-70
Comments	A62	71-132

D. <u>Echo Sounder Data Base Parameter Descriptions</u>

Parameter 8 - Scour Depth

Description: Scour depth measured in meters as derived by the echo

sounder processing software discussed in Methods.

Comments: Nil.

Parameter 9 - Seabed Depth

Description: Water depth referenced to the smoothed seafloor value

produced by the running average filter.

Comments: Nil.

APPENDIX 3

ERRATUM

Minor errors that have come to the attention of the authors are corrected as follows:

SIDE SCAN SONAR DATA BASE

Company & <u>Year</u>		<u>Fix</u>	Type of Error	Corrected Value
Dome 80	521E	5692	Easting = 529A06	Easting = 529306
Dome 80	529C	6749	Easting = 529C50	Easting = 529250
Dome 30	529C	6772	Easting = 529A77	Easting = 529177
Dome 80	449	452	Easting = 3529A2	Easting = 352902
Dome 80	530	7426	Area = 529A	Area = 5290
Dome 80	540	4100	Easting = 529A05	Easting = 529005
Dome 80	515B	6580	Northing = 77529A9	Northing = 7752909
Gulf 83	05	1504	Sediment thickness = 10.5+	Shift (10.0+) one column to the right.

The last record in this file is duplicated and should be deleted.

CORRIDOR DATA BASES

Water depths should be corrected as follows for both the base year and new scour data files.

		Bathymetry
E. Mackenzie Corridor	Part A	F
E. Mackenzie Corridor	Part B	G