Design Options for Offshore Pipelines in the US Beaufort and Chukchi Seas
APPENDIX B

Report R-07-078-519
MMS Contract M-07-PC-13015

Prepared for:
US Department of the Interior
Minerals Management Service

March 2008

Captain Robert A. Bartlett Building
Morrissey Road
St. John's, NL
Canada A1B 3X5

T: (709) 737-8354
F: (709) 737-4706

Info@c-core.ca
www.c-core.ca

This page is intentionally left blank

Design Options for Offshore Pipelines in the US Beaufort and Chukchi Seas

Prepared for:
Department of the Interior
Minerals Management Service

Prepared by:
C-CORE

Report R07-078-519 Appendix B

MMS Contract M-07-PC-13015

March 2008

Innovative Engineering Solutions
Captain Robert A. Bartlett Building
Morrissey Road
St. John's, NL
Canada A1B 3X5

T: (709) 737-8354
F: (709) 737-4706

Info@c-core.ca
www.c-core.ca

United States Department of the Interior
Minerals Management Service

Review of Existing Ice Gouge Data from the Eastern Chukchi Sea, Alaska

IMV Projects Atlantic Project No. C-0506-14
Technical Report No. TR-001

_____ Client _____ Project Manager

A	Mar. 12th, 2007	Re-Issued for Client Review	JC	MJP	MJP
0	Mar. 15, 2007	Issued for Use	JC	MJP	MJP
Rev.	**Date**	**Revision Description**	**By**	**Checked**	**Approved**

Table of Contents

Executive Summary……i

1. Introduction **1**
1.1 Scope of Work 1

2. Investigated Report Summaries **2**
2.1 USGS Open-File Report 60-123 2
2.2 USGS Open-File Report 82-1053 2
2.3 USGS Open-File Report 84-108 2
2.4 USGS Open-File Report 84-828 3
2.5 USGS Open-File Report 85-50 3
2.6 USGS Open-File Report 86-202 3
2.7 USGS Open-File Report 88-25 3
2.8 USGS Open-File Report 78-693 4
2.9 Ice Gouge Characteristics in the Alaskan Chukchi Sea (Toimil, 1979) .. 6

3. Ice Gouge Data **7**
3.1 Gouge Parameters and Characteristics 7
3.2 Gouge Depth 9
3.3 Gouge Width 9
3.4 Ice Gouge Density / Crossing Rate 10

4. Assessment of Available Data **11**
4.1 Data Set #1 – USGS Open-File Report 78-693 12
4.2 Data Set #2 – USGS Open-File Report 88-25 12

5. Analysis of Data **13**
5.1 Maximum Observed Parameters 13
5.2 Summary Plots 13

6. Summary **18**

7. Bibliography **19**

List of Tables

Table 4-1: Summary of Available Data.....11

List of Figures

Figure 2-1: Location of Side-Scan Sonar Tracklines as Determined by Satellite Navigation (Toimil, 1978). 5
Figure 3-1: Illustrated Single Keeled Ice Gouge Characteristics (Toimil, 1978). 8
Figure 3-2: Illustrated Trenched and Buried Pipeline Below an Ice Gouge Deformation (Lanan et al., 1986). 9
Figure 5-1: Maximum Ice Gouge Depth vs. Water Depth, USGS 78-693 Data Set.....14
Figure 5-2: Maximum Ice Gouge Width vs. Water Depth, USGS 78-693 Data Set.....14
Figure 5-3 Ice Gouge Crossing Rate vs. Water Depth, USGS 78-693 Data Set.....15
Figure 5-4: Ice Gouge Depth vs. Width, USGS 78-693 Data Set.....15
Figure 5-5: Ice Gouge Midclass Depth Frequency vs. Midclass Water Depth, USGS 88-25 Data Set, Northwest Chukchi Sea.....16
Figure 5-6: Ice Gouge Midclass Depth Frequency vs. Midclass Water Depth, USGS 88-25 Data Set, Barrow Sea Valley.....17

1. INTRODUCTION

A number of years of ice gouge statistical data are required for offshore pipeline design. Ice gouge statistics are normally reported as having a maximum depth and an overall or maximum width. This could be conservative as the maximum depth likely does not occur over the maximum width. Therefore, gouge widths associated with the depth measurements are important.

This report provides the preliminary research, results and analyses of existing ice gouge data for the Alaskan Chukchi Sea. Further investigation and analysis of this existing seabed gouge data is required to determine the appropriate data to be used in design and how widths should be related to design depths (either in a deterministic or a probabilistic design methodology).

1.1 Scope of Work

The current project scope of work is to conduct a preliminary review and analysis of existing ice gouge data from the Alaskan Chukchi Sea and compile relevant design data. Key information pertaining to ice gouges required from the assessment includes:

- Location
- Water Depth
- Maximum Gouge Depth
- Overall (maximum) Gouge Width
- Gouge Crossing Rate / Density

2. INVESTIGATED REPORT SUMMARIES

Numerous technical reports and studies of ice gouging occurring in the Alaskan Chukchi Sea have been researched and reviewed as part of the current project desktop study. Reports which have been reviewed were obtained from the United States Geological Survey (USGS), and references obtained from Memorial University of Newfoundland's Queen Elizabeth II library.

2.1 USGS Open-File Report 60-123

Marine Geology and Bathymetry of the Nearshore Shelf of the Chukchi Sea, Ogotoruk Creek Area, Northwest Alaska (Scholl & Sainsbury, 1959).

This report presents detailed marine geology and seabed bathymetry for the Ogotoruk sea valley area of the Chukchi Sea, but provides no tabulated ice gouge data of use within the current study.

2.2 USGS Open-File Report 82-1053

Geologic Framework, Hydrocarbon Potential, and Environmental Conditions for Exploration and Development of Proposed Oil and Gas Lease Sale 85 in the Central and Northern Chukchi Sea (Grantz et al., 1982).

This report contains general discussions of ice gouge observations, procedures and processes, but provides no tabulated data with respect to known ice gouge measurements. Report figures graphically provide generalized gouge data, including dominant ice gouge azimuths (orientations) and ice gouge concentrations. This report makes reference to USGS Open-File Report 78-693 as providing the most comprehensive ice gouge data available to date for the Chukchi Sea.

2.3 USGS Open-File Report 84-108

Nearshore Marine Geologic Investigations, Wainwright to Skull Cliff, Northeast Chukchi Sea (Phillips et al., 1984).

This report provides general ice gouge depth, orientation, and density observations for specified water depth ranges / contours located between

Wainwright and Skull Cliff, in the Chukchi Sea Region. Maximum width, depth and density observations are also provided, although no tabulated data is available.

2.4 USGS Open-File Report 84-828

Nearshore Marine Geologic Investigations, Icy Cape to Wainwright, Northeast Chukchi Sea (Phillips & Reiss, 1984).

This report provides general ice gouge depth, orientation and density observations for specified water depth ranges / contours located between Icy Cape and Wainwright in the Chukchi Sea Region. No tabulated ice gouge data is presented.

2.5 USGS Open-File Report 85-50

Nearshore Marine Geologic Investigations, Point Barrow to Skull Cliff, Northeast Chukchi Sea (Phillips & Reiss, 1985).

General ice gouge depth data is provided in this report for specified water depth contours (i.e. the maximum ice gouge depth observed is 1.7m, which is located in water depths of 12 – 30m). Survey areas range from Point Barrow to Skull Cliff in the Alaskan Chukchi Sea. No tabulated (individual) ice gouge data is provided.

2.6 USGS Open-File Report 86-202

1985 Field Studies, Beaufort and Chukchi Seas, Conducted from the NOAA Ship Discoverer (Miley & Barnes, 1986).

The observations and preliminary analysis of data collected during marine geological studies conducted in the Beaufort and Chukchi Seas is presented in this report. This report also contains a report entitled *Beaufort Sea Ice Gouge Studies*, by D.M. Rearic, which provides some basic, generalized ice gouge data and observations relevant to the western Beaufort Sea. Limited geotechnical data is provided (such as core samples, etc).

2.7 USGS Open-File Report 88-25

Geologic Investigations in the Chukchi Sea, 1984, NOAA Ship Surveyor Cruise (Phillips et al., 1988).

This report presents discussions and data related to ice gouge locations, density, depths and general ice gouge orientation for gouges located in the Chukchi Sea. Maximum and average range ice gouge parameters are discussed, with plots and tables of ice gouge depth frequency vs. water depth class provided. Soil data observations and measurements are also provided. This report provides substantial qualitative seabed sediment analysis for the study area, although no quantitative properties are discussed.

2.8 USGS Open-File Report 78-693

Ice-gouged Microrelief on the Floor of the Eastern Chukchi Sea, Alaska: A Reconnaissance Survey (Toimil, 1978).

This report provides tabulated Chukchi Sea ice gouge data for 10,200 individual ice gouge observations, which includes the observation date, time, maximum gouge depth, maximum gouge width, gouge density and direction / orientation (azimuth), which was recorded along 1800 km of survey trackline located in the Alaskan Chukchi Sea. A total of 83 separate tracklines were surveyed, which were subdivided into 1 km linear segments for ice gouge measurements. Refer to Figure 2-1 below, for a general location map of the survey tracklines.

Recorded ice gouge densities include every identifiable gouge produced within a multiple ice gouge event, and are normalized to represent the theoretical number of gouges that would have been observed in a direction normal to the dominant gouge orientation. The reported maximum ice gouge widths correspond to observed single-keeled ice gouge events. The recorded maximum ice gouge depth measurements are accurate to 0.5m. Report Appendix 1 provides survey trackline locations (geodetic coordinates of start and end points), whereas Appendix 2 provides tabulated ice gouge data.

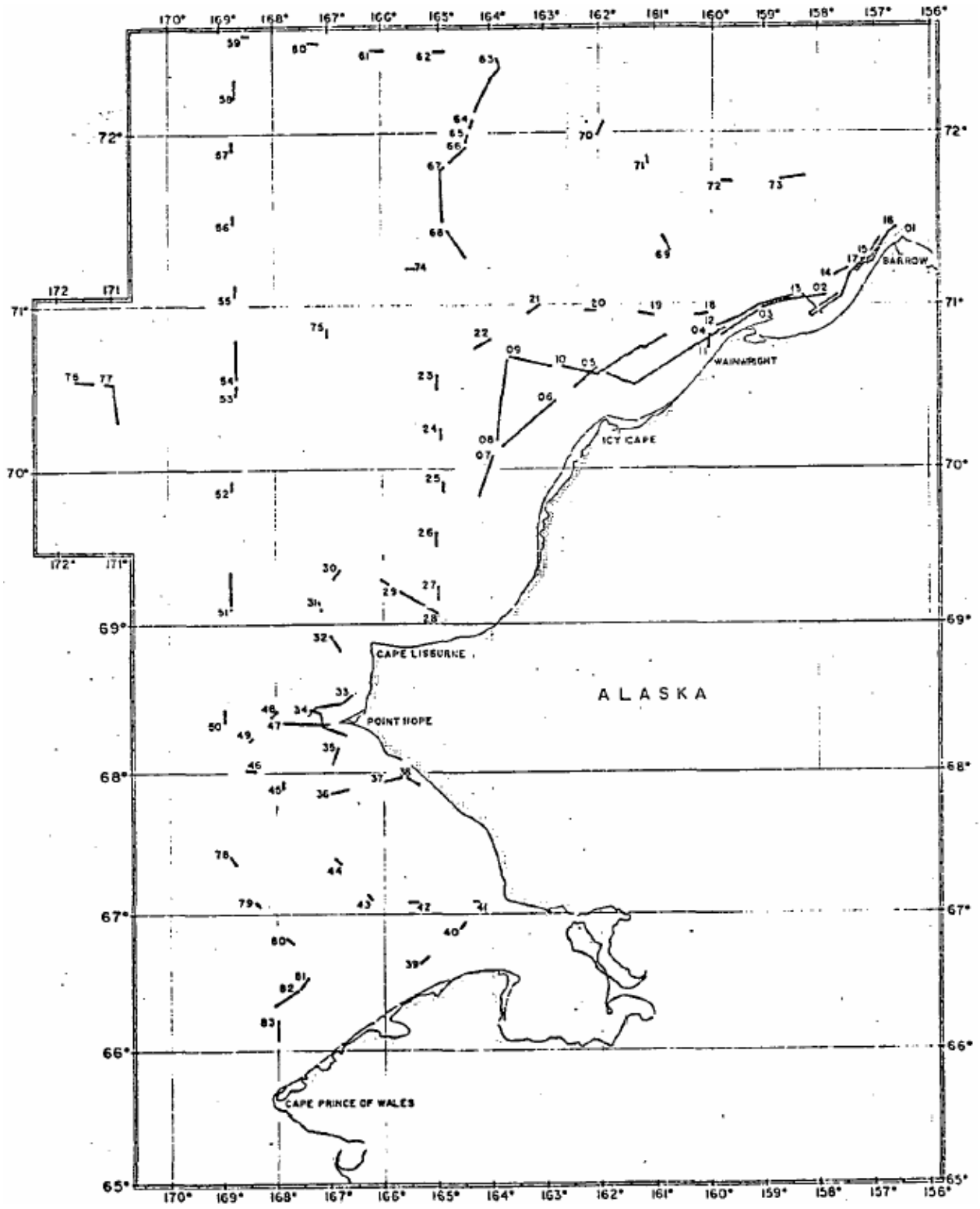

Figure 2-1: Location of Side-Scan Sonar Tracklines as Determined by Satellite Navigation (Toimil, 1978).

2.9 Ice Gouge Characteristics in the Alaskan Chukchi Sea (Toimil, 1979)

Presented in: *Proceeding of the Specialty Conference, Civil Engineering in the Oceans IV., Vol.II., American Society of Civil Engineers, 1979.*

This paper presents a general discussion of ice gouge procedures, distributions and evidence of contemporary ice gouging observed in the eastern Chukchi Sea. 10,000 individual ice gouges observed along 1800 km of survey trackline were analyzed and maximum ice gouge measurements and corresponding water depths are presented in the paper. Frequency plots (% distribution per water depth interval) of maximum ice gouge depth, width and density vs. water depth are also provided. No tabulated data is provided in this paper, and no source for the data presented in the paper is provided; the United States Geological Survey is credited as the source of the data, although the specific report number is not provided.

3. ICE GOUGE DATA

3.1 Gouge Parameters and Characteristics

The dynamic process of an ice keel impacting and scraping along the seabed often produces many characteristic seabed deformations that may be observed and measured for further analysis through marine surveying techniques. The impact and grounding of an ice keel upon the seabed typically produces 'pock mark' indentations upon the seafloor, which become noticeable once the ice has sufficiently melted to allow the indenting ice keel to dislodge and move off of the grounding site.

If the grounded ice possesses enough momentum or driving force to facilitate further movement, the impacting ice keel may scrape along the seabed and thus create a noticeable ice gouge (or ice scour) on the seafloor. Single-keeled ice features have a single keel projection contacting the seafloor, which generally creates gouge deformations that produce a localized ridge berm and furrowed seabed micro-topography with associated vertical and horizontal sediment displacement and redistribution (Rearic & Ticken, 1988). 'Multiplet' ice gouges are created by multi-keeled ice features, which possess multiple keel projections contacting and gouging the seafloor. These gouge deformations typically exhibit a characteristic multiplet gouge deformation which simulates rake marks upon the seabed surface (Rearic & Ticken, 1988).

Common ice gouge deformation parameters and associated characteristics are presented below. Figure 3-1 presents single keeled ice gouge characteristics. The geotechnical conditions, morphology and localized bathymetry of the seabed areas subject to ice gouging events influences gouge attributes, thus producing gouge characteristics that may fluctuate along the length of the gouge with changing seabed conditions. Annual variations in ice concentrations also strongly affect the distribution of seabed gouges.

The scraping of an ice keel along the seabed poses a significant threat to subsea pipelines, among other facilities, which may be damaged by the gouging ice keel. Subsea pipelines are generally trenched and buried beneath the seabed in areas prone to ice gouging and sediment reworking events caused by grounding ice keels. The required burial depth for the protection of pipelines from interactions

with ice keels and the associated pressure ridges formed during gouging is a function of the maximum gouge depth that may be expected to occur in a specific area, during the installation's designed lifetime. Figure 3-2 presents a schematic of a trenched and buried pipeline located below an ice gouge deformation.

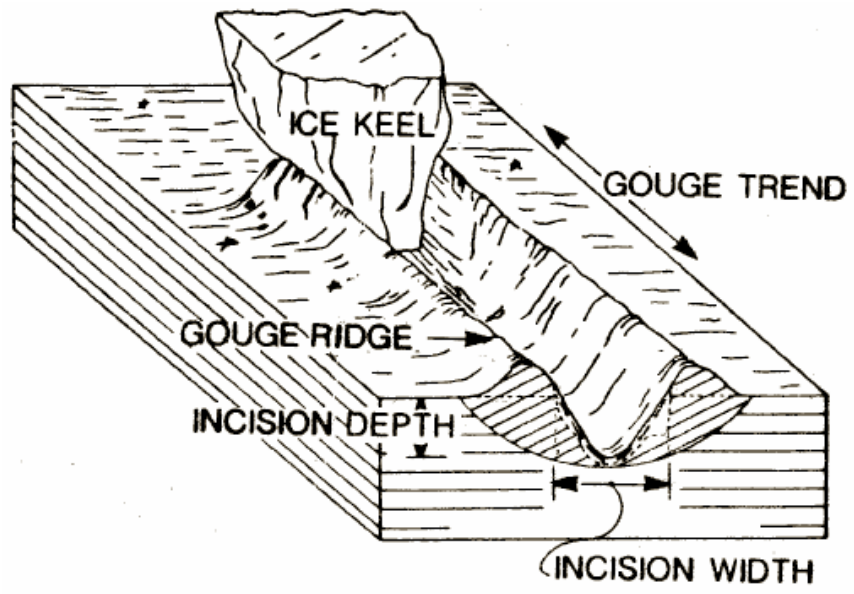

Figure 3-1: Illustrated Single Keeled Ice Gouge Characteristics (Toimil, 1978).

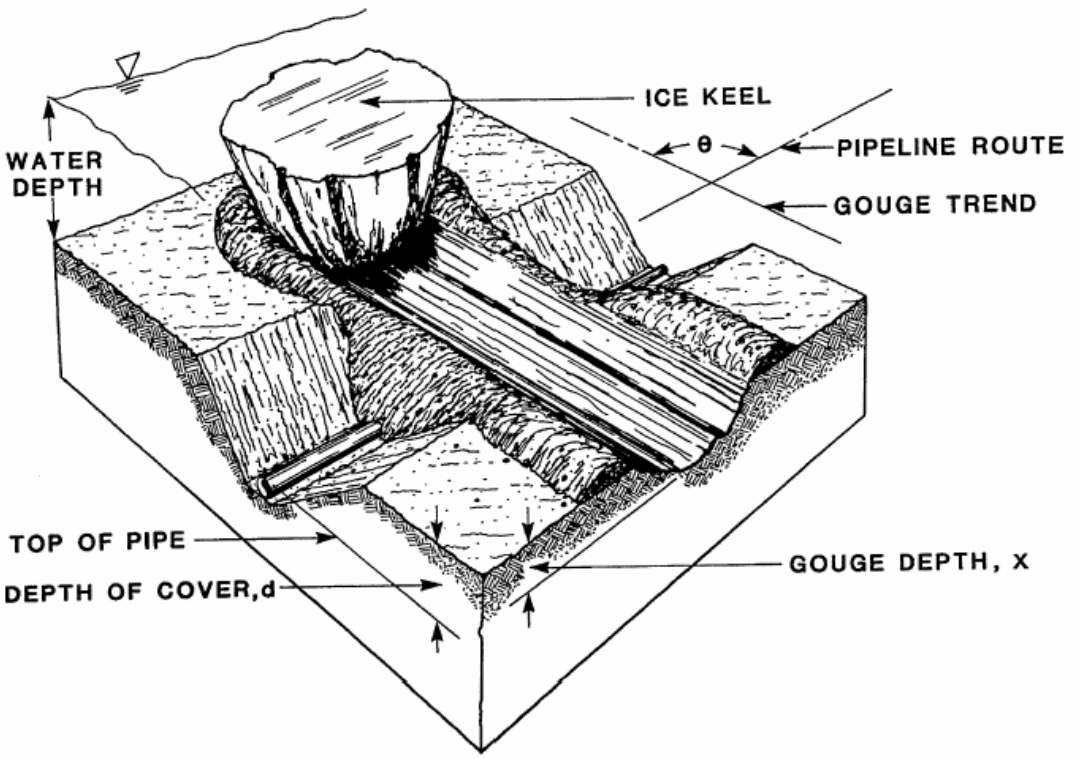

Figure 3-2: Illustrated Trenched and Buried Pipeline Below an Ice Gouge Deformation (Lanan et al., 1986).

3.2 Gouge Depth

The measured ice gouge incision depth is the vertical distance between the average gouge trough (or floor) and the undisturbed seabed. This measurement practice allows the minimum penetration of the impacting ice keel into the seabed to be accurately measured and recorded. The total gouge relief height, as measured from the gouge trough to the maximum berm height is a misleading ice gouge characteristic as it may lead to over-estimation of the size of the gouging ice keel.

3.3 Gouge Width

The gouge width is the horizontal distance across the ice gouge, measured at the undisturbed seabed level. The gouge width thus excludes the width of the gouge berm, or ridge, and is a characteristic of the impacting ice keel. More detail is provided in Appendix A, Section 3.

3.4 Ice Gouge Density / Crossing Rate

Ice gouge density is commonly presented for base year or single-year surveys, which fundamentally do not present dated new gouge occurrence data. In such cases, the ice gouge density (or crossing rate) is often reported as the number of gouges observed per linear kilometer of surveyed trackline or the number of gouges observed per survey area (km^2). The survey area is dependent upon the visible width of the seabed reconnaissance equipment used. More detail is presented in Appendix A.

4. ASSESSMENT OF AVAILABLE DATA

The USGS Open-File Reports 60-123, 82-1053, 84-108, 84-828, 85-50 and 86-202 do not provide comprehensive data sets with respect to ice gouges. The reports, however, do make some general observations with regards to ice gouge parameters. These are summarized in Table 4-1.

Table 4-1: Summary of Available Data

Report / Study Reviewed	Gouge Depth		Gouge Width		Max. Gouge Density (gouges/km)	Dominant Soil Type
	Max. (m)	Water Depth (m)	Max. (m)	Water Depth (m)		
USGS 84-108	1.6	8.0	175	22.0	N/A	Sand
USGS 84-828	2.5	19.0	N/A	N/A	6 – 9	Coarse Sand / Gravel
USGS 85-50	1.7	12 – 30	N/A	N/A	N/A	Sand / Gravel Nearshore, Silt Offshore
USGS 88-25	2.9	45	N/A	N/A	24	Sandy – Muddy Gravel
USGS 78-693	4.5	38	110	36.5	364	Silt, Sand & Gravel
Toimil, 1979	4.5	35 – 40	>100	36 – 40	>200	N/A

Electronic data files of available ice gouge data have been compiled from USGS Open-File Reports 78-693 and 88-25. The individual data sets are discussed below, with particular attention to the data extracted from each report and the method of data assessment. The data set(s) for the current study have been assessed on the basis of the relevant ice gouge parameters, including ice gouge depths, widths and crossing rates (or density), among other pertinent characteristics. Section 5.2 of this report presents summary plots of the various ice gouge parameters extracted from each data set and these plots are discussed within the following subsections of this report.

4.1 Data Set #1 – USGS Open-File Report 78-693

Ice-gouged Microrelief on the Floor of the Eastern Chukchi Sea, Alaska: A Reconnaissance Survey (Toimil, 1978).

Ice gouge data provided in this data set includes water depth, gouge density, and maximum ice gouge depths and widths. No ice gouge recurrence rate, infilling rate or obliteration rate data could be obtained from this data set as it does not represent a repetitive ice gouge survey and no record of any subsequent survey is indicated.

Maximum ice gouge measurements were recorded for 1 km linear segments of each survey trackline, as provided in the USGS 78-693 report. Therefore, although a reported 10,200 individual ice gouges were observed during the survey procedures, the total number of observations presented is significantly less than 10,200. The corresponding data set thus presents the maximum ice gouge data observations for each 1 km linear trackline segment.

Data extraction for this data set was limited to the export and recreation of the original tabulated data into Microsoft Excel spreadsheets for analysis.

4.2 Data Set #2 – USGS Open-File Report 88-25

Geologic Investigations in the Chukchi Sea, 1984, NOAA Ship Surveyor Cruise (Phillips et al., 1988).

Ice gouge depth class data is presented as a function of water depth class range for two areas within the Alaskan Chukchi Sea; the Northwest Chukchi Sea and the Barrow Sea Valley.

Data extraction for this data set was limited to the export and recreation of the original tabulated data into Microsoft Excel spreadsheets for analysis.

5. ANALYSIS OF DATA

5.1 Maximum Observed Parameters

Analysis of the ice gouge information applicable to the Alaskan Chukchi Sea has indicated the following maximum observed ice gouge parameters:

- A maximum depth of 4.5m was observed for an ice gouge event that occurred at a water depth of 38m with no corresponding gouge width reported (Toimil, 1978). This depth was observed during the single-year ice gouge survey corresponding to USGS Open-File Report 78-693 and is thus of unknown age.

- The maximum exhibited ice gouge width was 175m, and was observed at a water depth of 22.0m (Phillips et al., 1984). This width was observed during the single-year ice gouge survey corresponding to USGS Open-File Report 84-108 and is thus of unknown age.

- The maximum observed linear ice gouge density provided in Data Set #1 (corresponding to USGS Open-File Report 78-693) is 364 gouges / km (Toimil, 1978). This gouge density was observed for a survey trackline segment located in 25.5m water depth, with an associated maximum ice gouge depth of 1.5m and no reported width measurement.

5.2 Summary Plots

Summary plots of Maximum Ice Gouge Depth vs. Water Depth, Maximum Ice Gouge Width vs. Water Depth, Ice Gouge Crossing Rate vs. Water Depth and Ice Gouge Depth vs. Width were generated from the analysis of the USGS 78-693 data set. A plot of Ice Gouge Midclass Depth Frequency vs. Midclass Water Depth was generated from the USGS 88-25 data set. These summary plots are presented within the following figures (Figure 5-1 through Figure 5-6).

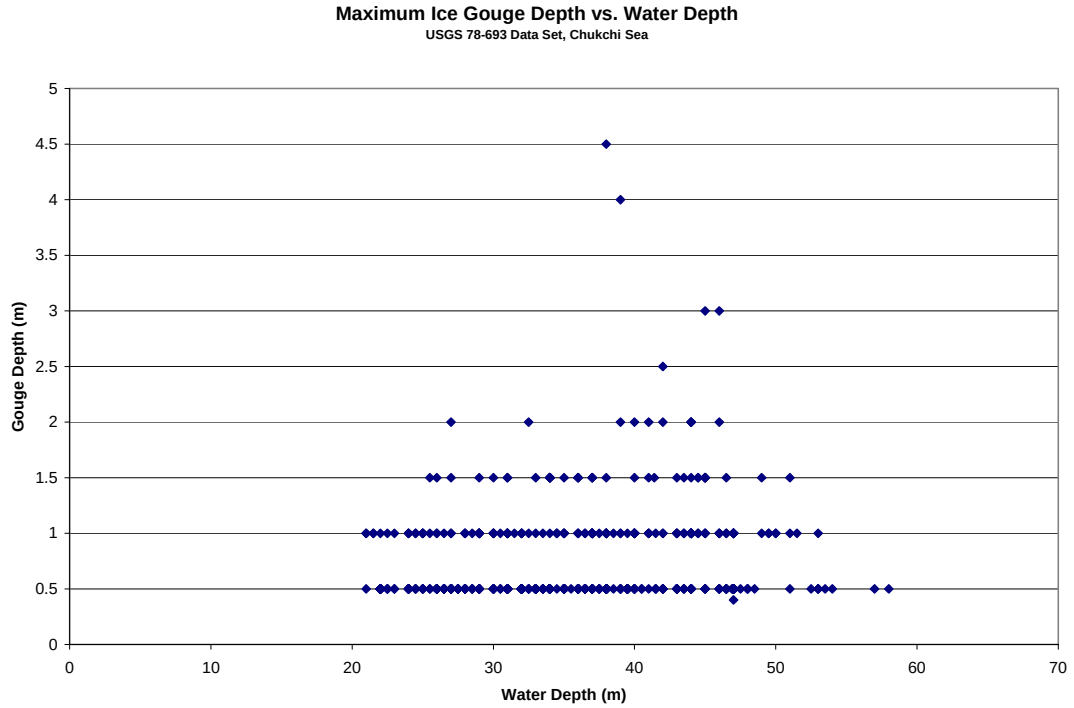

Figure 5-1: Maximum Ice Gouge Depth vs. Water Depth, USGS 78-693 Data Set

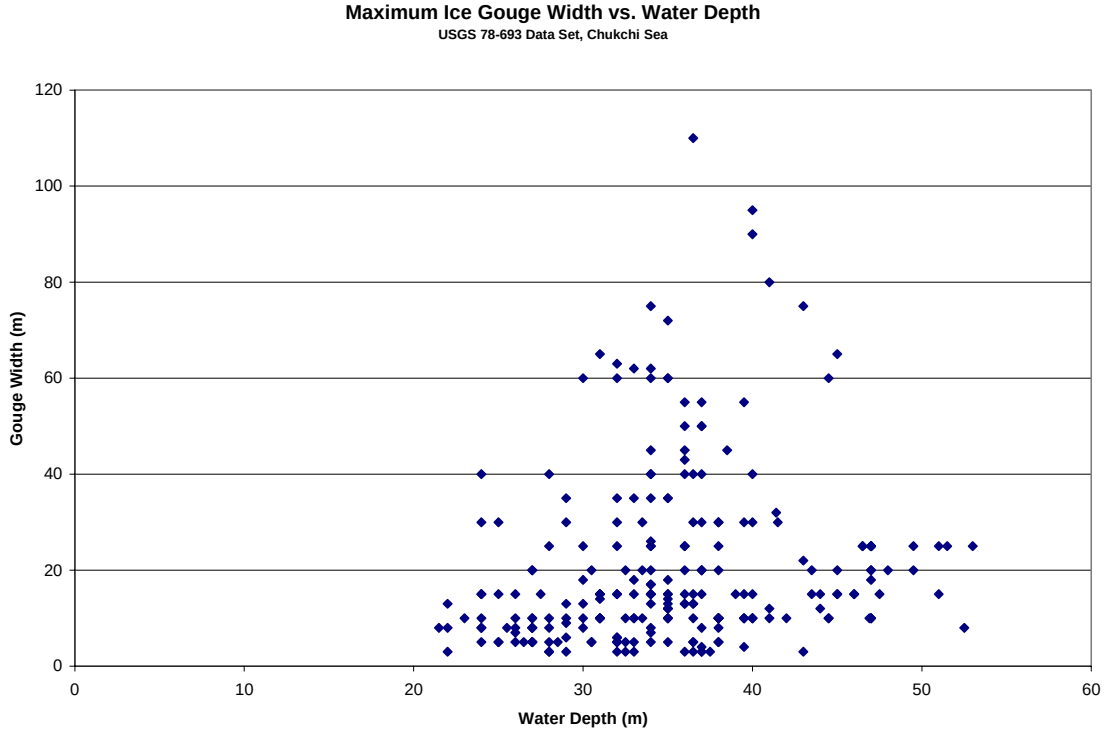

Figure 5-2: Maximum Ice Gouge Width vs. Water Depth, USGS 78-693 Data Set

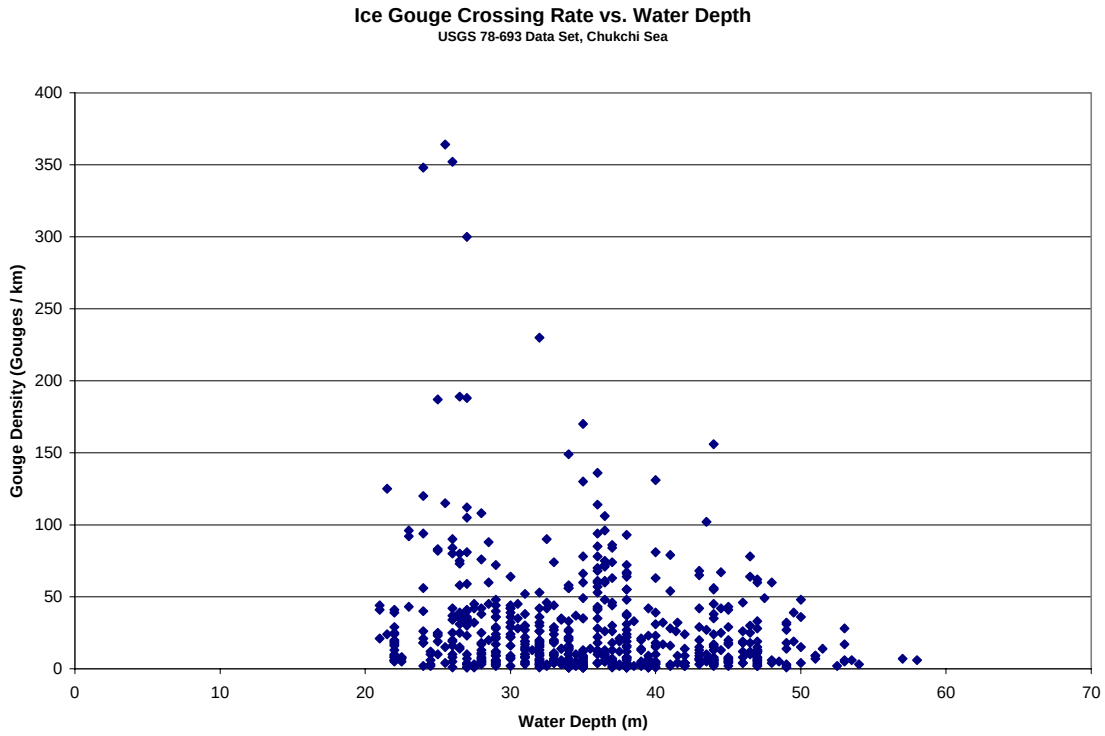

Figure 5-3 Ice Gouge Crossing Rate vs. Water Depth, USGS 78-693 Data Set

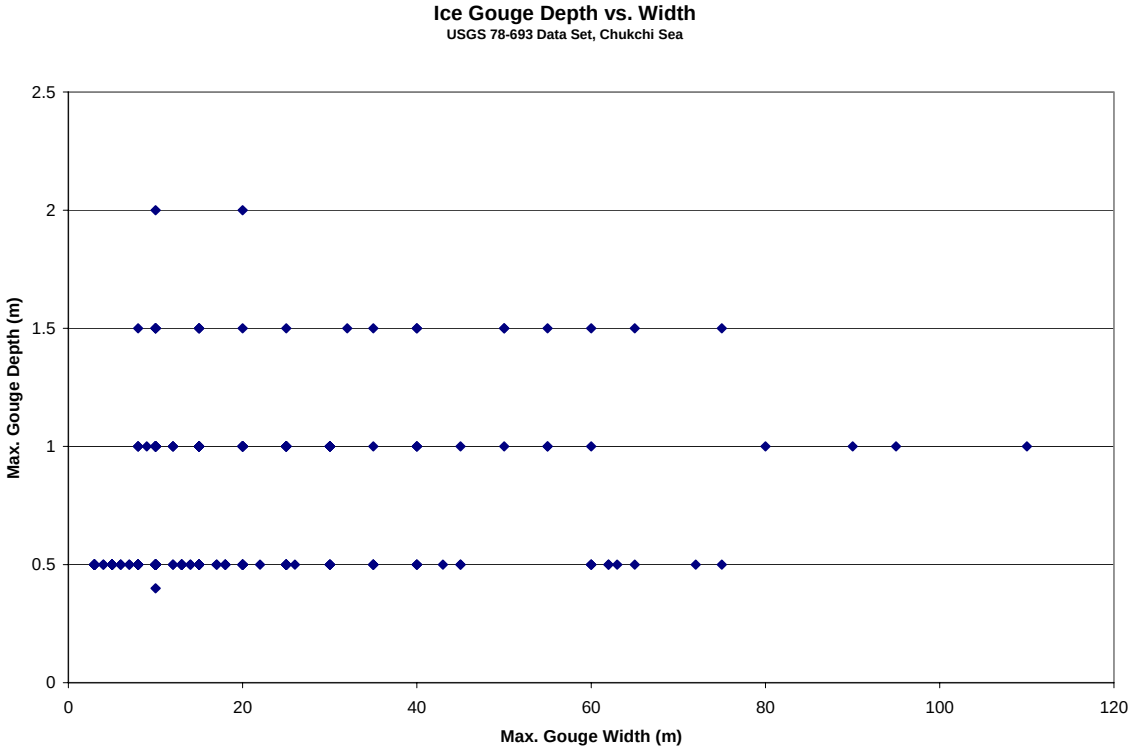

Figure 5-4: Ice Gouge Depth vs. Width, USGS 78-693 Data Set

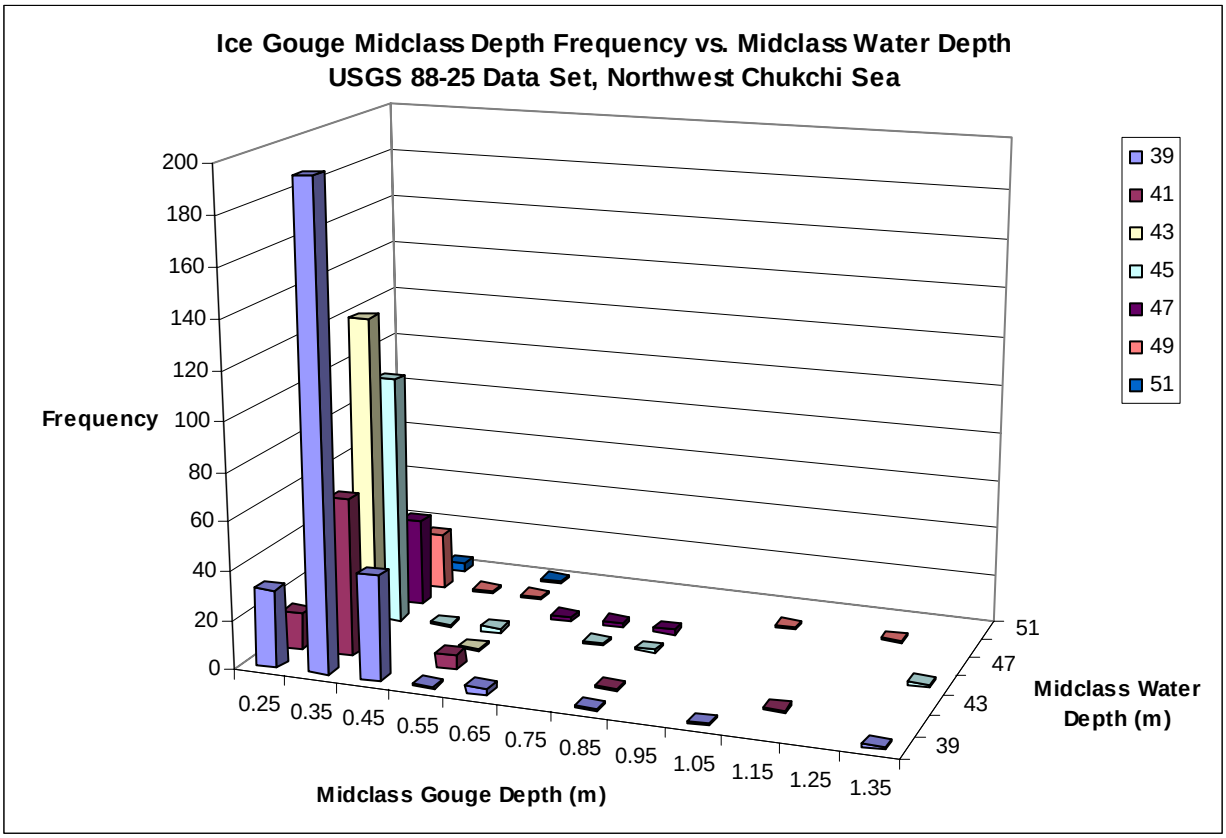

Figure 5-5: Ice Gouge Midclass Depth Frequency vs. Midclass Water Depth, USGS 88-25 Data Set, Northwest Chukchi Sea

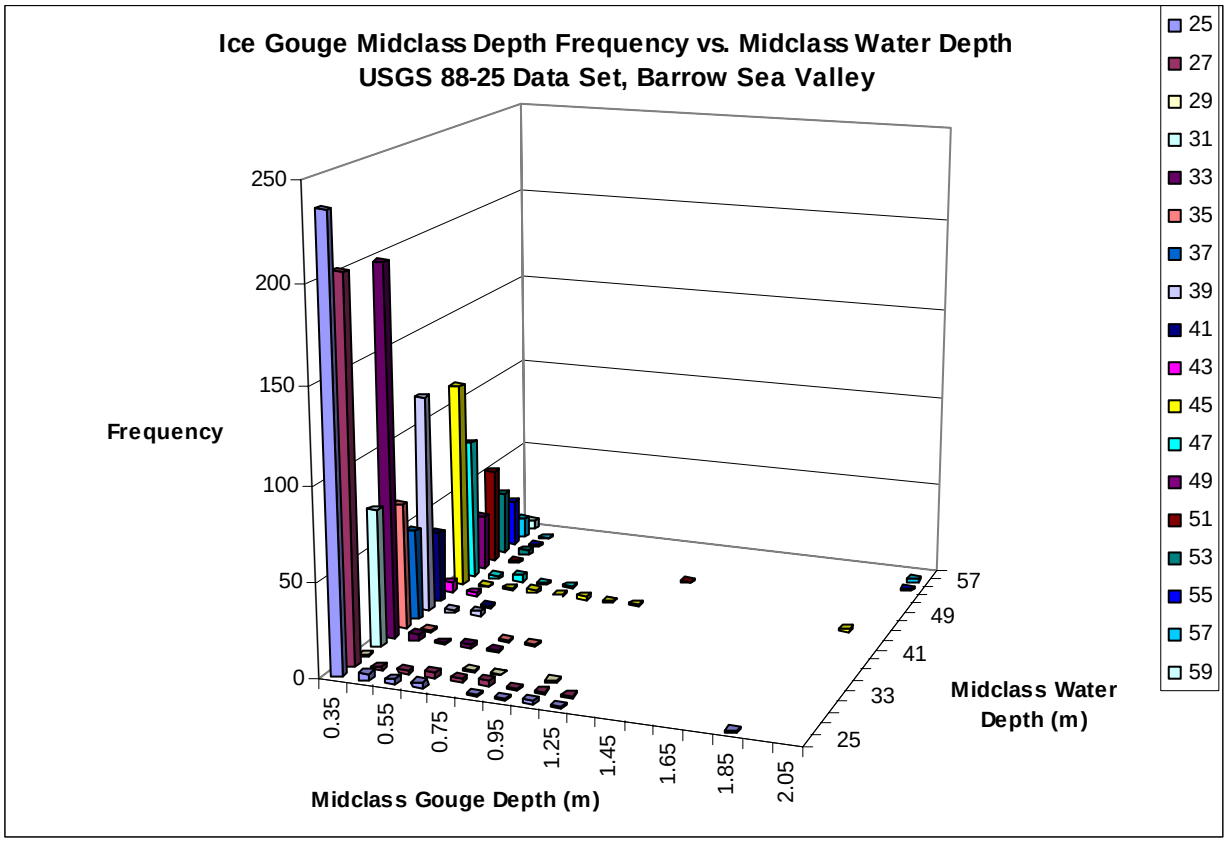

Figure 5-6: Ice Gouge Midclass Depth Frequency vs. Midclass Water Depth, USGS 88-25 Data Set, Barrow Sea Valley

6. SUMMARY

Preliminary research, review and analyses have been conducted relating to existing ice gouge data available for the Alaskan Chukchi Sea.

7. BIBLIOGRAPHY

Grantz, A., Dinter, D.A., Hill, E.R., Hunter, R.E., May, S.D., McMullin, R.H. & Phillips, R.L. (1982). *Geologic Framework, Hydrocarbon Potential, and Environmental Conditions for Exploration and Development of Proposed Oil and Gas Lease Sale 85 in the Central and Northern Chukchi Sea.* USGS Open-File Report 82-1053.

Lanan, G.A., Niedoroda, A.W. & Weeks, W.F. (1986). *Ice Gouge Hazard Analysis.* Offshore Technology Conference, paper OTC 5298.

Miley, J.M, & Barnes, P.W., editors. (1986). *1985 Field Studies, Beaufort and Chukchi Seas, Conducted from the NOAA Ship Discoverer.* USGS Open-File Report 86-202.

Phillips, R.L. & Reiss, T.E. (1984). *Nearshore Marine Geologic Investigations, Icy Cape to Wainwright, Northeast Chukchi Sea.* USGS Open-File Report 84-828.

Phillips, R.L. & Reiss, T.E. (1985). *Nearshore Marine Geologic Investigations, Point Barrow to Skull Cliff, Northeast Chukchi Sea.* USGS Open-File Report 85-50.

Phillips, R.L., Reiss, T.E., Kempema, E. & Reimnitz, E. (1984). *Nearshore Marine Geologic Investigations, Wainwright to Skull Cliff, Northeast Chukchi Sea.* USGS Open-File Report 84-108.

Phillips, R.L., et al. (1988). Geologic Investigations in the Chukchi Sea, 1984, NOAA Ship Surveyor Cruise. USGS Open-File Report 88-25.

Rearic, D.M. & Ticken, E.J. (1988). *Ice Gouge Processes in the Alaskan Beaufort Sea.* Reprinted from *Arctic Coastal Processes and Slope Protection Design, TCCR Practice Report, American Society of Civil Engineers (ASCE), May 1988.*

Scholl, D.W. & Sainsbury, C.L. (1959). *Marine Geology and Bathymetry of the Nearshore Shelf of the Chukchi Sea, Ogotoruk Creek Area, Northwest Alaska.* USGS Open-File Report 60-123.

Toimil, Lawrence J., (1978) *Ice-gouged Microrelief on the Floor of the Eastern Chukchi Sea, Alaska: A Reconnaissance Survey.* USGS Open-File Report 78-693.

Toimil, Lawrence J., (1979) Ice Gouge Characteristics in the Alaskan Chukchi Sea. Presented in: *Proceeding of the Specialty Conference, Civil Engineering in the Oceans IV., Vol.II., American Society of Civil Engineers, 1979.*