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GIS Geospatial Database of Oil-Industry and Other Human Activity (1979 – 1999) in the Alaskan Beaufort Sea

Volume 1

by

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The following is the brief description of the products for this study:

(1) Wainwright, P. (2002) GIS Geospatial Database of Oil-Industry and Other Human Activity (1979 – 1999) in the Alaskan Beaufort Sea, MMS OCS Publication 2002-071, **Volume 1**, 86pp. (this report)

Volume 1 of the study summarizes the results of the study and provides maps and graphs depicting oil and gas activity. This is the report that MMS has released for this study

(2) Wainwright, P. (2002) GIS Geospatial Database of Oil-Industry and Other Human Activity (1979 – 1999) in the Alaskan Beaufort Sea, MMS OCS Publication 2002-071, **Volume 2**, 233pp.

Volume 2 contains many more maps and detailed notes on the status and contents of study-specific information reviewed in the MMS Field Operations and Resource Evaluation vaults. Volume 2 contains proprietary information associated with the collection of information from the MMS Resource Evaluation Vault and therefore will not be released at this time.

(3) Wainwright, P. (2002) GIS Geospatial Database of Oil-Industry and Other Human Activity, (1979 – 1999) in the Alaskan Beaufort Sea, MMS OCS Publication 2002-071, **Volume 3**, Database Documentation.

Volume 3, the Database Documentation Report, contains a description of the database design and holds a copy of the GIS database on a CD within the inside cover. The Database Documentation Report will not be released to the public at this time since it contains a copy of the proprietary database and relates specifically to it.

(4) Wainwright, P. (2002) GIS Geospatial Database of Oil-Industry and Other Human Activity (1979 – 1999) in the Alaskan Beaufort Sea, MMS OCS Publication 2002-071, Human Activities **Database**.

The database contains all of the available spatial and attribute data on oil and gas activity for the Beaufort Sea collected for this study. The database contains proprietary data associated with the common-depth-point seismic navigation data extracted from the MMS Resource Evaluation Vault. The database will not be released to the public since the user can display and print out the CDP seismic navigation lines and shotpoints at their precise locations, which are proprietary.

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Abstract

The objective of this study was to compile detailed information describing the locations, timing, and nature of oil and gas related and other human activities in the Alaskan Beaufort Sea between 1979-1998. This information is stored in ArcView shapefiles and a Visual Foxpro database.

An important objective is the use of this database to assess concerns expressed by subsistence hunters and others living within the coastal villages of the Beaufort Sea about the possible effects that oil and gas activity, particularly seismic activity, drilling, and oil and gas support vessel activities, may have on the behavior of marine mammals, especially the bowhead whale. Such an analysis requires an adequate level of detail. However, only one oil company authorized access to proprietary information about seismic surveys and publicly available information lacks adequate detail. Information on these proprietary seismic surveys is presented in this report at a scale that does not compromise the proprietary nature of these data. The Human Activities Database is however proprietary because it includes these proprietary data in full detail.

The majority of the data in the database relate to seismic activity, drilling activity and ice management activity. The main sources for information were: Common Depth Point (CDP) surveys conducted under Federal OCS permit, geohazard surveys for Federal OCS wells, USGS geophysical surveys, and daily drilling reports for OCS and State of Alaska wells.

With the exception of ice management activity, the compiled information for the period 1990 to 1998 is relatively complete and considered adequate for the investigation of potential effects of disturbance on the fall bowhead whale migration. However, there are significant gaps in the data for the period 1979 to 1989.

1. Introduction

In September 1998, LGL Limited commenced a study to compile a GIS database of oil-industry and other human activities in the Alaskan Beaufort Sea between 1979 and 1998. The motivation for the study was the need for a quantitative description of human activities to support analysis of potential effects on the ecology and biota, particularly potential effects on the fall bowhead whale migration. The study area is illustrated in Figure 1 and includes the area from the shoreline extending North to 72ºN latitude and bounded on the East and West by 140ºW and 157ºW longitudes, respectively.

This report presents documentation of the human activities database, selected summaries of the database contents, a summary of the data compilation effort, discussion of completeness of the database and limitations the data, and recommendations. Some of the data in the database for seismic surveys are proprietary.

A chronology of the data compilation effort is presented below. The chronology of data compilation effort is of some importance because the contents and completeness of the database reflects decisions made during the data compilation process.

At commencement of the project the scope of the data compilation effort was broad. It became apparent that time, effort and data availability would limit the data compilation. Effort was focused on the fall bowhead whale migration period (September 1 to October 20) and the oil industry activities that were considered to be the greatest potential sources of noise and disturbance to bowhead whales: Common Depth Point (CDP) seismic surveys, geohazard and other high-resolution acoustic surveys, drilling, and ice management. Some activities that were potentially important sources of disturbance such as subsistence whale hunters and military activities were not within the scope of this compilation. Table 1 presents a comparison of noise levels associated with various activities. It is important to recognize that the response by whales to a noise source also depends on factors such as whether the sound is continuous or transient and the frequency of the sound.

2. Chronology of Data Compilation

An initial meeting was held in Anchorage to develop a preliminary database design and determine the scope of information to be included in the database. The next step was to request assistance from industry by authorizing release of information required for the database. An introductory letter was drafted and distributed in November 1998 to potential information sources (see Appendix 1, page 64).

At the outset, the scope of the study was broad and there was no special priority given to the period of fall bowhead whale migration. Priority was given to compiling information on drilling activity, geohazard surveys, CDP and high resolution seismic surveys, and ice-breaking activity because these activities were believed to be the most significant sources of industrial noise. The initial emphasis was to compile all available information from a single source, particularly the Daily Drilling Reports and Geohazard Surveys Reports held in the MMS Field Operations Vault (FOV).

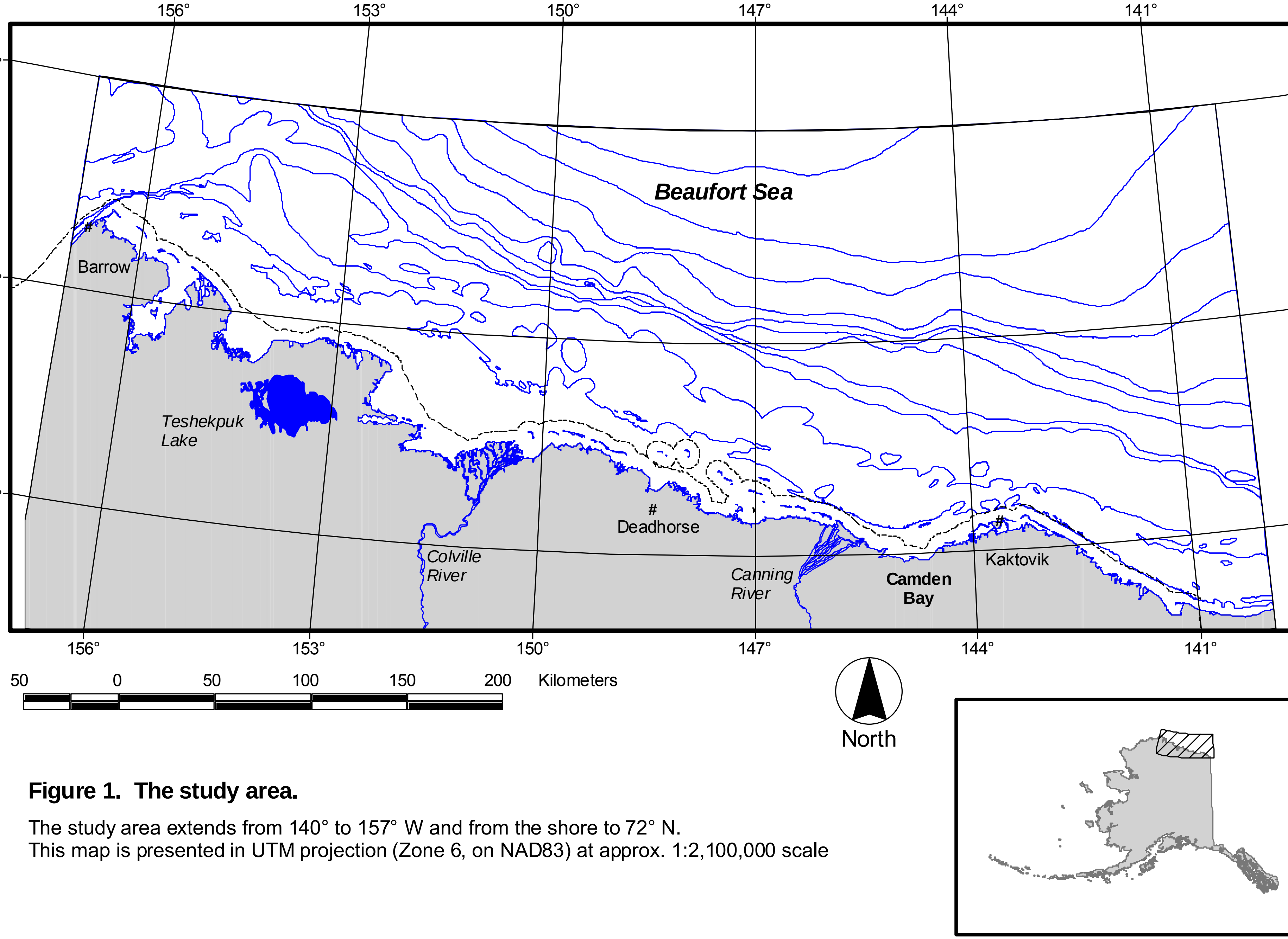


Figure 1. The study area.

The study area extends from 140° to 157° W and from the shore to 72° N.
This map is presented in UTM projection (Zone 6, on NAD83) at approx. 1:2,100,000 scale

Table 1. A comparison of sound levels from various sources
(from Richardson et al. 1995)

Source / Activity	dB at Source
Aircraft:	
Bell 212 helicopter	162
B-N Islander (2 prop)	157
Twin Otter (2 turboprop)	156
C-130 (4 turboprop)	175
Vessel activity:	
Tug pulling barge	171
Fishing boats	151 – 158
Zodiac (outboard)	156
Supply ship	181
Tankers	169 – 180
Supertankers	185 – 190
Freighter	172
Ice breaking:	
Ice-management	171 – 191
Ice-breaking (Robert Lemeur)	193
Dredging:	
Clamshell dredge	150 – 162
Aquarius (cutter suction dredge)	185
Beaver Mackenzie dredge	172
Drilling:	
Kulluk (conical drillship) – drilling	185
Explorer II (drillship) - drilling	174
Artificial island - drilling	125
Ice island (in shallow water) – drilling	86
Seismics and acoustics:	
Airgun arrays	235 – 259
Single airguns	216 – 232
Vibroseis	187 – 210
Water Guns	217 – 245
Sparker	221
Boomer	212
Depth sounder	180
Sub-bottom profiler	200 – 230
Side-scan sonar	220 – 230
Military	200 – 230
Ambient Noise: (Burgess and Greene 1999)	65 – 133

It was necessary to obtain approval from industry before gaining access to reports held in the FOV. All study team members were required to sign non-disclosure agreements before being authorized to work with any material from the FOV (Appendix 1, page 68). Due to delays in obtaining approvals we were unable to access any information from the FOV until early December 1998. At that time, we had received authorization from some companies allowing us to access specific reports.

The study team and Contracting Officer's Technical Representative (COTR), Warren Horowitz, expended considerable effort attempting to secure authorization to access information from industry. Several companies provided authorization to access Daily Drilling Reports. Only one company authorized the release of information from CDP seismic surveys.

As the work on the Daily Drilling Reports progressed, MMS decided that the information being compiled for the database did not involve sensitive information. Therefore, it was no longer necessary to obtain industry approval to access the Daily Drilling Reports.

Later (Summer 1999), MMS released all historical geohazard reports eliminating the need for specific authorizations to access these data.

Also in Summer 1999, the study team initiated compilation of environmental data for the database. Priority was given to compiling information on bathymetry and sediment properties because these data are critical for sound propagation modeling. A bathymetry coverage was completed from available NOS and USGS bathymetry data. Information on sediment properties, however, was limited and difficult to reconcile. The compilation of information on sediment properties is reported separately in Appendix 2, page 71.

By November 1999, we had compiled all available information from Daily Drilling Reports and Geohazard Reports in the FOV. However, the Daily Drilling Reports for some wells were incomplete. Also, some Geohazard Reports were not available from the FOV or were lacking both post-plot maps and digital navigation data or dates and times of survey lines. Therefore, some geohazard surveys could not be loaded into the database and some were loaded without dates. Volume 2, Appendix 3 presents additional details regarding the completeness of documentation accessed from the FOV and Resource Evaluation Vault (REV).

In early 2000, it was apparent that there were significant gaps in the database. It was determined that priority should be given to the fall bowhead whale migration period.

There were two possible options for obtaining information on the CDP seismic surveys: (1) publicly available information from the OCS and State permit records; and (2) proprietary data from the REV. The latter option would result in a data set that could not be publicly released.

We obtained copies of publicly available information from the OCS and State permit records to determine whether these could provide suitable information for the database. Unfortunately, the majority of the permits specified a broad geographic area (sometimes the entire Beaufort Sea) and a broad time period. With few exceptions, this information did not provide adequate spatial and temporal resolution for the intended use.

In July 2000 it was decided to evaluate the information on seismic surveys conducted under OCS permit from the REV for the years 1985, and 1990 to 1999 before proceeding.

This required MMS to notify each operator of the proposed disclosure of proprietary data to the study team (see Appendix 1, page 70).

It was found that the information from the REV was of varying degrees of completeness. In general, data from surveys conducted prior to 1990 did not include dates and times. Whereas, most data from 1990 and later either included dates and times in the digital data or these were available from an event log in the accompanying report. In most cases, the data submitted to MMS were only the lines which met survey specifications. Test shoots and survey lines which did not meet specifications commonly were not included. With the exception of two permits which were missing dates and times, the data for the period 1990 to 1999 were considered adequate.

A significant concern with respect to information on seismic activity was that information on surveys conducted under State Miscellaneous Land Use Permits (MLUP) remained proprietary and was not available to this project. On investigation, it was discovered that in all cases where a seismic survey had required both an OCS and MLUP permit, the final data submitted to MMS also included the lines shot in State waters. Therefore, complete information was available from the REV except for surveys under MLUP permit that did <u>not</u> require an OCS permit. A careful comparison of the publicly available information on MLUP permits was made against the data from the REV, matching vessels, companies, dates and general locations. It was determined that from 1990 to 1999 all seismic surveys which had been issued MLUP permits had also received OCS permits. However, prior to 1990, in most years MLUP permits had been issued for surveys that did not also receive OCS permits. As a consequence, prior to 1990 we were unable to obtain information for some seismic surveys.

In August 2000, a meeting was held to discuss options. It was recommended to focus on compiling as complete information as practical for a few years - 1992 and 1993 were recommended, with the remainder of the 1990s as a backup in the event that complete information could not be compiled for these years. It was decided to examine the feasibility of the proposed statistical analyses of the database before committing significant further effort towards the database. This latter task was directed by Dr. John Richardson and appears as a separate report (see Appendix 5). To undertake this feasibility assessment either required additional resources or internal reallocation. It was decided to reallocate resources by delaying work on implementation of the acoustic model component of the original project proposal. The rationale for this decision was that the acoustic model component would not be useful if there were not adequate data to describe the activities.

Lastly, it was decided to incorporate the proprietary CDP seismic data into the database and to investigate methods of presentation that would not compromise the confidential nature of the data.

A draft report was prepared incorporating the above and submitted to MMS in May 2001. This report was proprietary because it incorporated proprietary information from CDP seismic surveys.

Following a review of the 2001 report, it was decided to focus on compiling complete information for a few specific years. 1986 was identified as a primary interest, followed by 1992 and 1993, and the remaining years of the 1990s. It was also decided to direct remaining project effort towards compiling data on USGS seismic surveys, ice management activity, pipeline route surveys, and daily drilling reports for State wells.

Considerable effort was directed towards investigation of the fate of vessels which performed ice management functions in the Beaufort Sea. The majority of the vessels which had been performing ice management were owned by Canadian Marine Drilling Ltd. (Canmar) which was originally a subsidiary of Dome Petroleum and subsequently became a subsidiary of Amoco. Many of these vessels were sold in 1994 and 1995 by a broker, Marcon International Inc. Later Amoco sold its Canmar subsidiary to Livingston Marine Co. Ltd. Most of these vessels changed their names after purchase and are now in various locations from Europe to China. Don Conelley, Canmar's former Marine Supervisor, was working for Amoco at the time of the sale and was extremely helpful in tracking down these vessels (see Volume 2, Appendix 3-4).

We were able to confirm that the ship logs were transferred to the new owners and were not retained by Amoco at the time of sale in the mid-1990s. We were able to contact the current owners of the former Supplier III, IV, and VII and Kigoriak who confirmed that they no longer had log books from the time before they became owners and believe that these log books were discarded. Efforts were made to contact the current owners of the former Supplier V and VI and Robert Lemeur, but these efforts were not successful.

It does not appear possible to obtain access to the log books of the vessels involved in ice management. While there is some information about ice management activity in some reports and files, such information is limited and does not provide a complete summary of the fall migration period for any year.

Having determined that it would not be possible to obtain complete information on ice management activity, the remaining effort budgeted for compilation was directed towards compiling information about acoustic surveys in the 1990s, such as pipeline route surveys and surveys of the boulder patch, and compiling information about State wells in marine waters.

3. Completeness of Database and Limitations of Data

3.1 Status of Database

Documentation for the human activity database is presented separately (Wainwright, 2002). The human activity data are organized into “data sets” where a data set corresponds to a set of activities such as a series of lines in a seismic survey or a sequence of daily activities in a drilling program. At the time of writing, there are 296 data sets in the database.

Each data set consists of one or more “human activity” records. Each record describes a specific type of activity and its locations and the time period over which it was conducted. Where practical, the human activity records provide maximum detail, for example, one record may represent a single seismic line, an individual borehole location, or a specific activity such as tripping at a well. However, where such detail was not available, one human activity record may represent an entire seismic survey or an entire week of drilling activity. At the time of writing, there are 55,056 human activity records in the database. These are organized in 21 categories of activities, are represented to 59,792 spatial objects (points, lines, or polygons) and were compiled from 3242 unique "documents" where a document could be a computer data file, a published report, or a specific letter or form on file with a government agency.

3.2 Completeness of Database and Limitations of Data

It is best to discuss the completeness of the database and limitations in regards to specific types of activity:

- seismic activity,
- drilling,
- ice management,
- acoustic surveys, and
- other types of human activities.

Table 2 presents a summary of the completeness and quality of information in the database by year and by type of activity rated on a scale from 0 to 3, where "3" is the highest level of completeness and quality and "0" indicates significant data gaps. With the exception of information on ice-management, vessel activities and geophysical surveys in State waters, the information for the years 1990 to 1998 is complete and of adequate quality. Information for all years prior to 1990 is of variable completeness and quality and would be of limited use in statistical analyses. Information on ice-management is a significant data gap. The following sections provide additional details for each type of activity. Maps illustrating the data in the database, by the above categories are presented in Volume 2, Appendix 4.

3.2.1. <u>Seismic Activity</u>

Seismic surveys measure the structure of the seafloor or sub-surface by generating elastic energy waves (acoustic shock waves with a frequency less than 100 Hz) and measuring the reflected signals. Seismic surveys differ from other forms of acoustic survey by the frequency range of the acoustic source and consequently the depth of penetration of the seafloor. Higher frequency sources are typically used for bathymetric mapping and for surveys where the object is to provide a high level of detail about the seafloor and shallow sub-surface sediments. Table 3 presents a summary of seismic and acoustic survey methods used in the study area between 1980 and 1999.

Seismic and acoustic surveys are conducted on behalf of the oil industry for several purposes:

- Common Depth Point (CDP) or 3-dimensional surveys are conducted to explore and delineate potential hydrocarbon reserves and identify or assess drilling prospects. Such surveys always use seismic methods and sometimes conduct additional work using acoustic methods;

- Geohazard (or site clearance) surveys are conducted with the objective of locating and identifying hazards such as shallow gas, hydrates, unstable sea floors, active geologic features and potential shallow water flow-zones to enable exploration drilling, facilities installation (such as island construction) and production operations to be performed safely. Geohazard surveys often do not use seismic survey methods;

Table 2. Index of Completeness and Adequacy of Information in the Human Activities Database																				
	1979	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
CDP Seismic Surveys Under OCS Permit	0	0	0	0	0	0	2	2	0	0	0	3	3	3	3	3	3	3	3	3
OCS Geohazard and Pipeline Route Surveys	0	0	0	0	0	0	2	3	3	2	2	3	3	2	3	3	3	3	3	3
USGS Surveys	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Seismic Surveys Under State MLUP Permit	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	3	3	3
Seismic and Acoustic Surveys in State Waters Without Permits	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OCS Daily Drilling Reports	0	0	3	2	3	3	2	2	3	2	3	3	2	3	3	3	3	3	3	3
State Daily Drilling Reports	0	0	0	0	0	0	0	2	3	3	3	2	3	3	2	2	2	2	2	2
Ice-Management	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0
Other Vessel Activity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Data Rating System:

0	Significant data sets are missing. These data are not suitable for statistical analyses.	2	Information is complete, but some data sets lack important details that may limit analyses, i.e., some daily drilling reports during the fall migration period do not describe drilling activities; or, information for some seismic or geohazard survey lines does not all determination of whether the line was surveyed during the fall migration period.
1	Available data provides a poor level of detail. These data are unsuitable for statistical analyses.	3	Information is complete and considered suitable for use in analyses.

Table 3. Seismic and Acoustic Sources in Use Between 1980 and 1999		
Year(s)	**Seismic sources**	**Other acoustic sources**
1980 – 1981	Unknown	Side-scan sonar, uniboom, depth sounder
1982	None	Side-scan sonar, uniboom, depth sounder
1983 – 1984	Water gun array, airgun array, single water gun, unknown	Side-scan sonar, sub-bottom profiler, polar-scanning sonar, Geopulse system, boomer, depth sounder, unknown
1985	Single water gun, unknown	Side-scan sonar, sub-bottom profiler, polar-scanning sonar, boomer, depth sounder, multibeam bathymetry, unknown
1986 – 1987	Airgun array	Side-scan sonar, sub-bottom profiler, Geopulse system, uniboom, depth sounder
1988	Single airgun, unknown	Side-scan sonar, sub-bottom profiler, Geopulse system, depth sounder, unknown
1989	Sleeve gun array, single airgun, unknown	Side-scan sonar, sub-bottom profiler, Geopulse system, depth sounder, unknown
1990 – 1991	Unknown	Unknown
1992	None	Side-scan sonar, sub-bottom profiler, depth sounder
1993	Sleeve gun array, unknown	Side-scan sonar, sub-bottom profiler, mini-sparker, depth sounder, unknown
1994	None	None
1995	None	Side-scan sonar, sub-bottom profiler, multibeam bathymetry, depth sounder
1996	Airgun array	Side-scan sonar, sub-bottom profiler, multibeam bathymetry, depth sounder, unknown
1997	Airgun array, sleeve gun array, mini-sparker array, unknown	Side-scan sonar, sub-bottom profiler, multibeam bathymetry, depth sounder, unknown
1998 - 1999	Sleeve gun array	Side-scan sonar, multibeam bathymetry, depth sounder, unknown

- Surveys with specific objectives such as delineation of potential pipeline routes, bathymetric charting of the seafloor, locating and identifying man-made artifacts including debris, shipwrecks and sub-sea structures, profiling shallow geologic features to assist with engineering studies and facilities design. Such surveys typically do not use seismic methods.

Information on seismic activity (CDP, geohazard and USGS surveys) is relatively complete for the years 1990 to 1999. We are confident that all seismic surveys that were conducted in OCS waters during the open water season from 1990 to 1999 are represented in the database. However, for several surveys information describing test shoots or calibration activity, or lines that were shot off specifications was not available. Therefore, it is probable that some additional seismic activity was occurring in the vicinity of a survey either before or during the period described in the database.

Information on seismic activity (CDP surveys under OCS permit and seismic surveys under MLUP permit) prior to 1990 is known to be incomplete. In most years, the State issued at least one permit for which we could not obtain adequate details. Because of this, no effort was directed towards obtaining data on proprietary CDP surveys from the REV prior to 1990. Therefore, several seismic surveys during the open water period prior to 1990 are not represented in the database. In addition, many of the records of seismic surveys only provided the locations of the lines and the range of dates for the start and end of the survey. In some cases, only the year in which the survey was conducted was reported. As a consequence, for many survey lines it is not possible to determine whether they were shot during the fall migration period. Most surveys prior to 1990 did not report data on testing, calibration, or lines that were off specification. As a consequence, the information on seismic activity prior to 1990 is not considered adequate.

Seismic surveys for exploration purposes in State waters are authorized under MLUP permit (Matt Rader, DNR, pers. comm.). However, seismic surveys conducted for other purposes, such as shallow hazard assessments, do not require permits unless they are not conducted from the ice and or involve contact with the seafloor (Gary Schultz, DNR, pers. comm.). No information was available from the State about seismic surveys where no permits were issued. Therefore, it is possible that some seismic activity occurred in State waters during the open water period between 1990 and 1999 that is not represented in the database.

3.2.2. Drilling

Information on drilling activity is relatively complete. Operators have been required to submit regular reports of drilling activity for wells in both Federal OCS and State of Alaska waters. However, in the early 1980s the level of detail in the reports was at the discretion of the operator. Later, both agencies required a greater level of detail. In both cases, the reports generally start either at the point where the drillship is positioning over the well, where preparations are started to re-enter a suspended well, or where the rig is in position and ready to commence a new well. In general, there is no information about equipment mobilization, site and camp preparation, or island construction activities.

Drilling activities are organized in categories with consideration to underwater noise. The first level of classification is based on the type of drilling platform such as conventional drillship, SSDC, or artificial island.

Power generation is considered the primary contributor of sound to the water, and generally, the more power being used, the more noise produced. The effect of power generation on noise is perhaps most noticeable from drillships, which are coupled to the water so well. Bottom-founded structures such as the SSDC are well-coupled but the power generation and drilling equipment is generally on decks well above the water, so less vibration is manifest in the water. Artificial and natural islands do not conduct sound and vibration into the water very well.

The second level of classification is based on the type of activity reported. This second classification essentially considers sources of underwater noise such as power generation, the top drive, pumps and drawworks. The main categories used are the following:

- *Actively Drilling*, in which the drill string turns and depth generally increases, the mud pumps operate, and the drawworks operate. This category was also used to record reaming.
- *Cleaning*, in which the drill string probably turns and the mud pumps operate. Cleaning includes circulating, reverse circulating, washing. The drawworks also must operate. This category was also used to record pumping out of the hole.
- *Tripping*, which is either pulling the drillstring out of the hole, “POOH” (pulled out of hole), or running the drillstring into the hole, “RIH” (running in hole), changing rams.
- *Logging*, which involves running test equipment into and out of the hole or testing equipment.
- *Standby*, which generally involved conducting repairs, waiting on personnel or equipment, conducting safety meetings. “Waiting on whales” and “waiting on ice” were of special interest and were assigned separate categories.

The activities of "drilling" and "cleaning" use the most power and are therefore expected to produce the most underwater noise, followed by "tripping". "Logging" uses the least power, followed by “standby”.

For some wells, daily drilling reports provide a summary of all activities conducted during a 24-hour period, but are not specific about when these activities occurred. In such cases, if there is a mixture of different types of activities or if the activity was unknown the period was classified as “*Active*”. For a few wells, the drilling reports were filed on a weekly basis, or daily reports were filed for weekdays but a single report was filed covering weekends (including long weekends).

The terminology used in drilling reports varied between companies and over time and sometimes employed shorthand or technical jargon. Therefore, it was challenging to ensure consistency in assignment of activities to categories. The classification of drilling activities was performed by three individuals (including the Principal Investigator). All questions or issues about classifications were reviewed by the Principal Investigator and the classification of some daily drilling reports was blind replicated for quality assurance.

3.2.3. Ice Management

Information on ice management activity is extremely sparse. The data in the database consist of aerial observations of vessels at a specific date and time that were incidental to aerial surveys or monitoring of whales in 1986, 1991 and 1992. These observations do not describe vessel activity and do not describe the scope of ice-management activity during the period of drilling operations. Some additional information exists in relation to specific wells, such as tabular summaries of the number of hours of ice-breaking activity each day in the vicinity of a drillship (Hall et al. 1994), or a file of sketch maps of the status of ice in relation to Kuvlum in 1992. These additional information sources were not incorporated into the database because they lacked adequate location information.

It was not possible to identify any complete or systematic source of information on ice management. Attempts were made to obtain log books for the ships involved in ice management. However, this was not possible. These log books are believed to have been destroyed.

The available information on ice management is of extremely limited value. Information on ice management is a significant data gap.

3.2.4. Acoustic Surveys

For the purposes of this report "acoustic surveys" refers to a broad class of activities including the use of active acoustic sensors such as side-scan sonar, search-light and other sonars, sub-bottom profilers, and single and multi-beam bathymetry, but excluding seismic sources. Table 1 provides a comparison of the noise levels for some of these methods. Table 3 provides a summary of the acoustic survey methods used by the oil and gas industry in the study area. While many surveys of this nature of conducted in relation to oil and gas activity, such surveys are also conducted for other purposes such as military, navigation, hydrographic survey, research (including geology, archaeology, and oceanography), and construction.

The information of this nature contained in the database was compiled from specific sources including MMS records of geohazard surveys, pipeline route surveys, surveys of the boulder patch, and records of USGS surveys. No information was available on acoustic surveys in State waters.

The database is believed to provide a substantially complete description of oil industry related acoustic surveys in OCS waters since 1990. However, it is probable that depth sounders were used routinely by oil industry vessels for navigation. This activity is not described in the database. With the exception of USGS surveys, there is no information in the database on acoustic surveys for other purposes (e.g., geophysical surveys in State waters, military or hydrographic surveys). Therefore, it is probable that some acoustic activities after 1990 are not described in the database.

3.2.5. Other Human Activities

For the purposes of this report, all types of human activities not described above, are summarized as a single grouping of "other activities". However, in the database these activities are assigned to separate categories as appropriate, including:

- Aircraft, Aerial Survey
- Construction, Ice Island
- Geophysical, Borehole Drilling
- Vessel movement, In transit
- Vessel movement, Unknown activity

The information on other oil and gas related human activities is substantially incomplete. Examples of types of information missing from the database include helicopter activity, ice reconnaissance, supply boat and barge movements, oil spill response training and exercises, construction of islands, causeways, camps, etc., scientific and engineering surveys such as deployment of current meters, wave buoys, collection of water structure data and biological surveys. Many types of human activities not related to oil and gas activity are also not included in the database, such as vessel and barge activity to supply coastal communities, military activities, and subsistence whale hunting.

4. Summary of Data for the 1990s

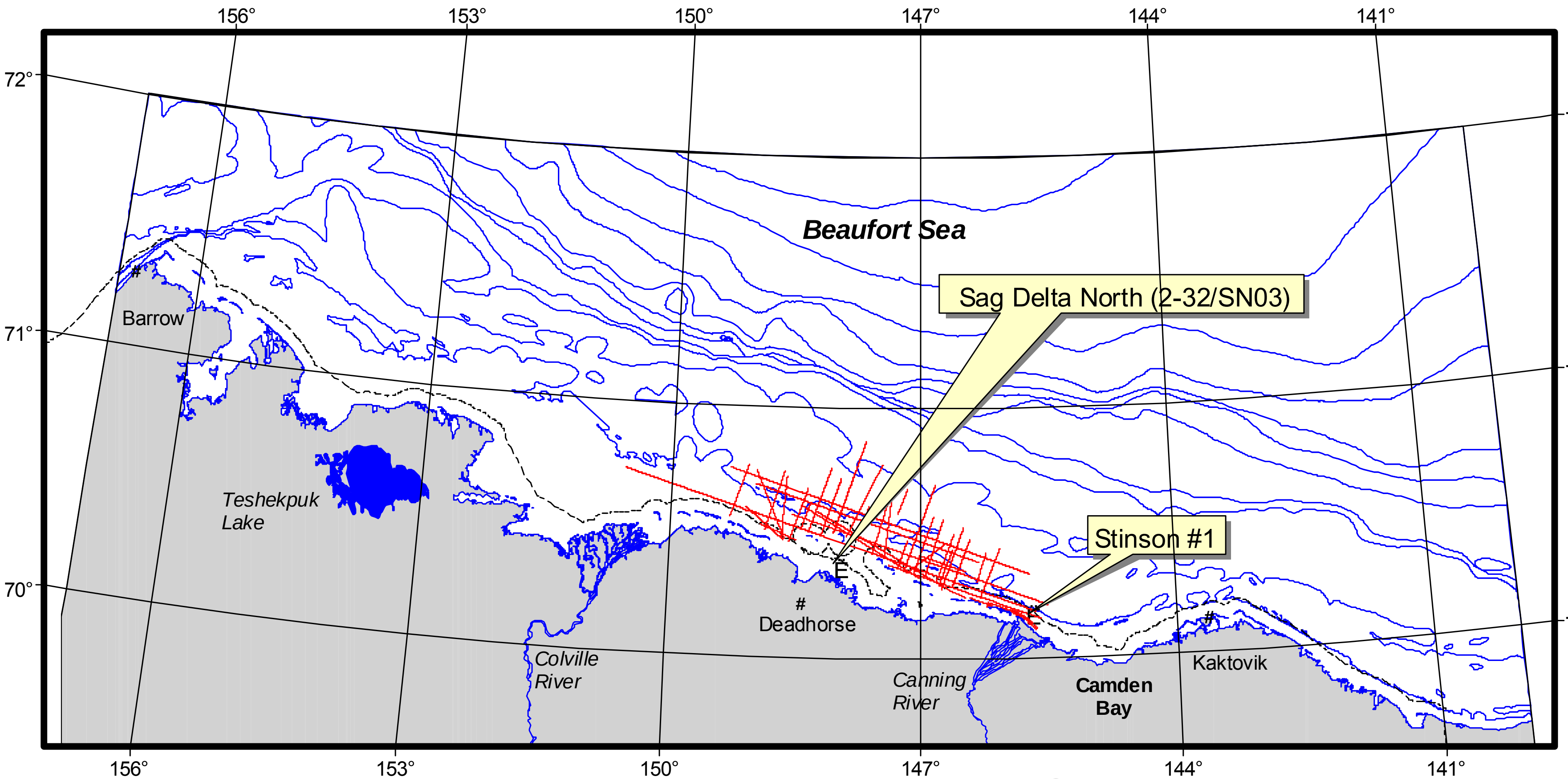
As discussed earlier, it was not possible to compile adequate information on seismic activity prior to 1990. Therefore, emphasis was placed on compiling as complete as possible information for the fall bowhead whale migration period in the 1990s. This section presents a summary of the information compiled for the 1990s.

The period of interest for the fall bowhead whale migration is the period from September 1st to October 20th (W.J. Richardson, pers. comm.). This range is from the earliest date that the migrating bowhead whales normally reach Point Barrow to when they normally have left the study area. For presentation purposes this period is divided into three periods: September 1 to 15, September 16 to 30, and October 1 to 20.

The maps presented here (Figures 2 to 10) illustrate the seismic, acoustic and drilling activity during the fall bowhead migration period for the 1990s. As mentioned earlier, the CDP seismic data are proprietary. There was only one non-proprietary seismic survey during the fall migration period in the 1990s, the USGS survey in 1993. There are no geohazard surveys using seismics during the fall migration period in the 1990s. However, one survey was conducted using acoustic methods.

Table 4 (page 45) provides summary information about the nature of the seismic and acoustic activity including kilometers of lines shot, the number of OCS blocks which include activity, and the number of 5-km cells which include activity. The number of 5-km cells provides a measure of the spatial extent of the activity while the ratio of line kilometers to 5-km cells provides a measure of the density of the line spacing.

It can be seen (Figure 11, page 41) that with the exception of two years, seismic activity was completed by September 30th. The year with the greatest level of seismic activity both in terms of kilometers of lines shot and areal extent of the surveys is 1990. There was no seismic activity during the fall migration period in 1992, 1994 and 1995.



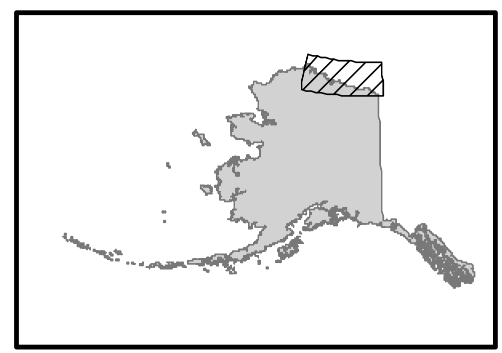
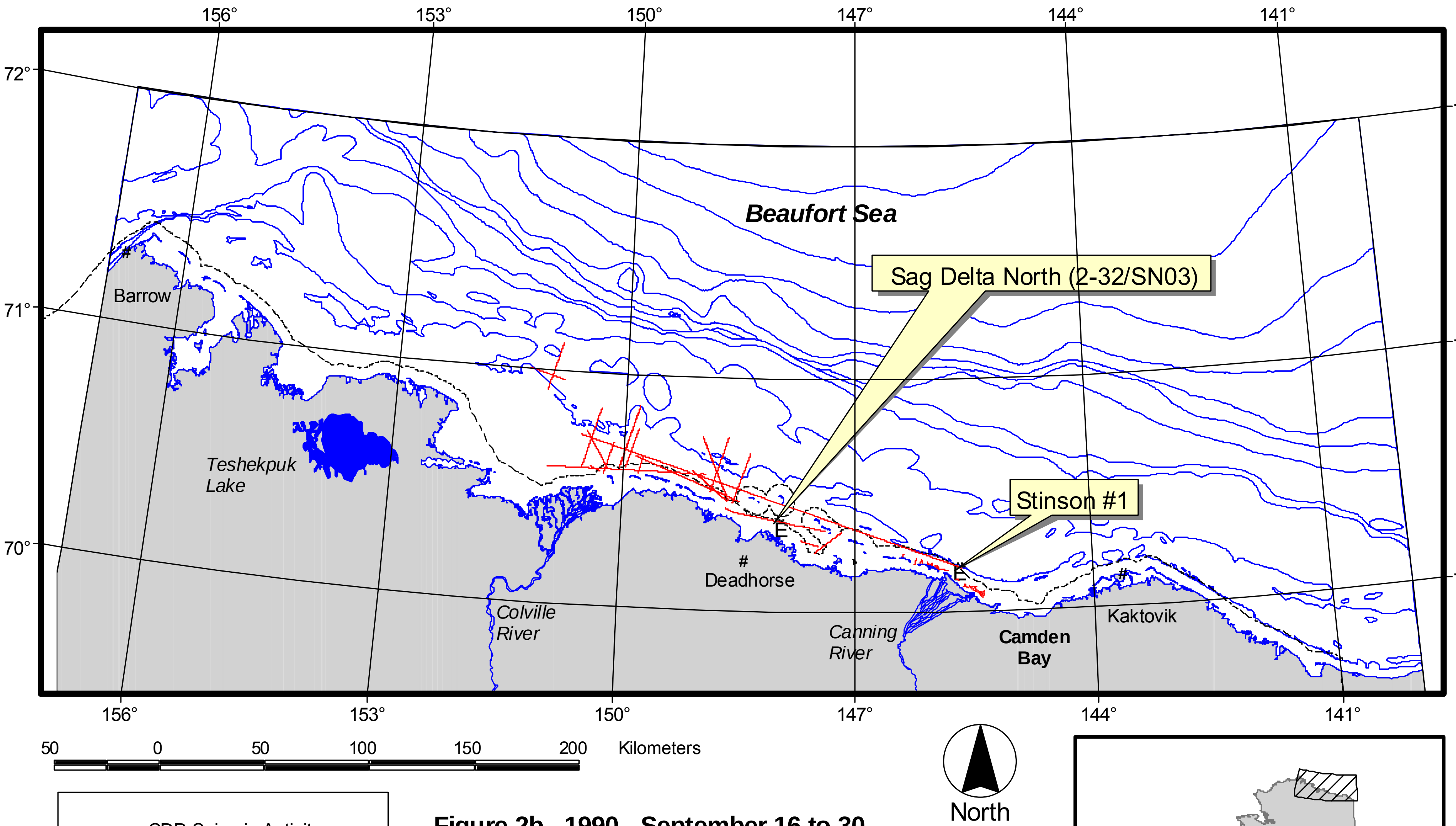
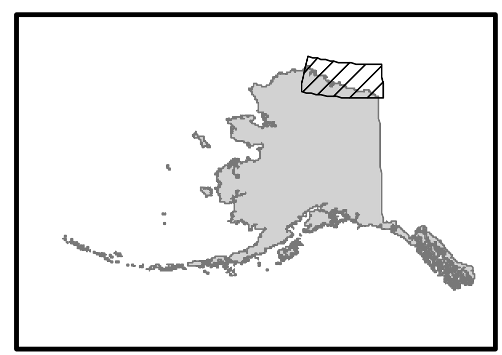


Figure 2a. 1990 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 2b. 1990 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



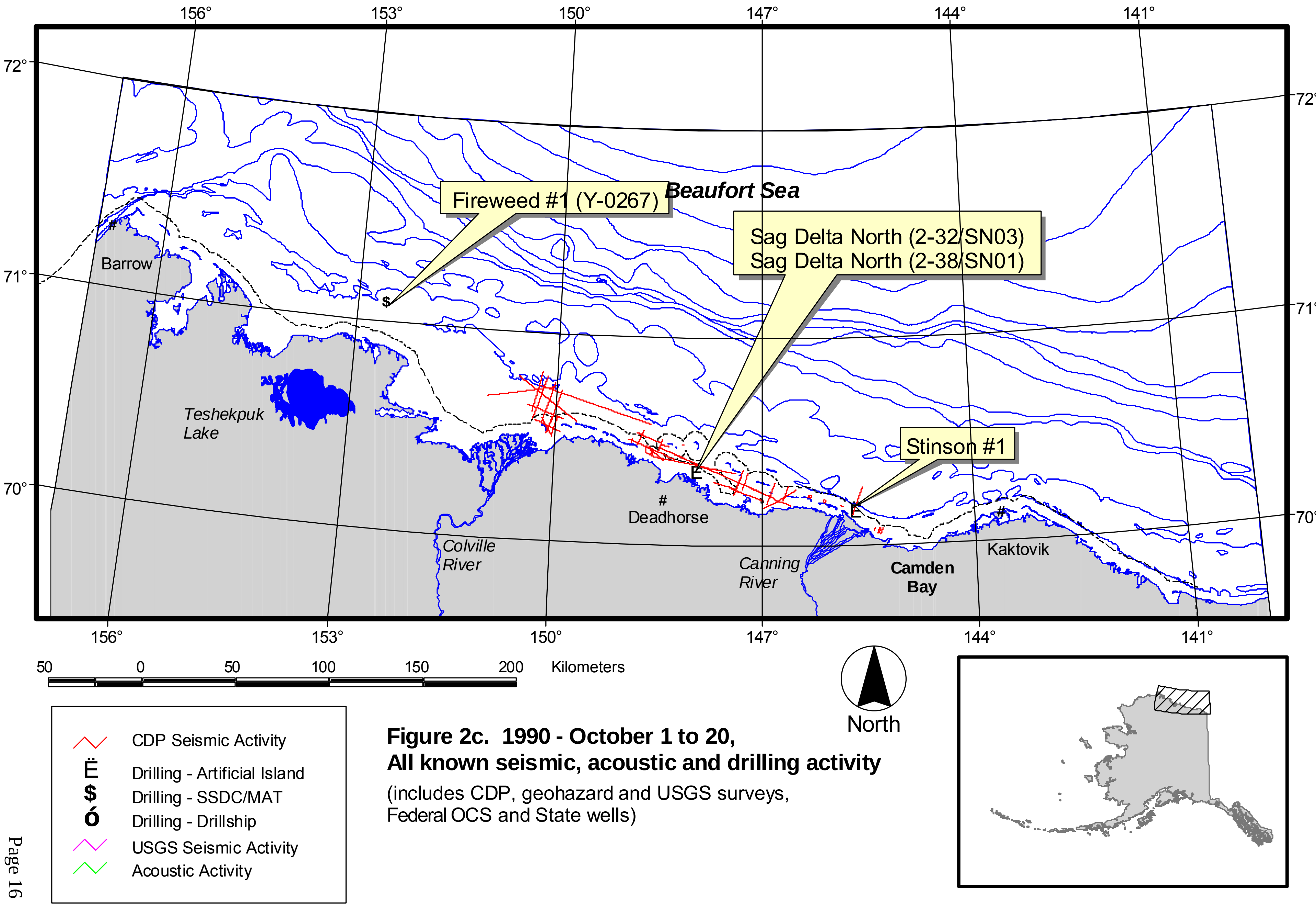
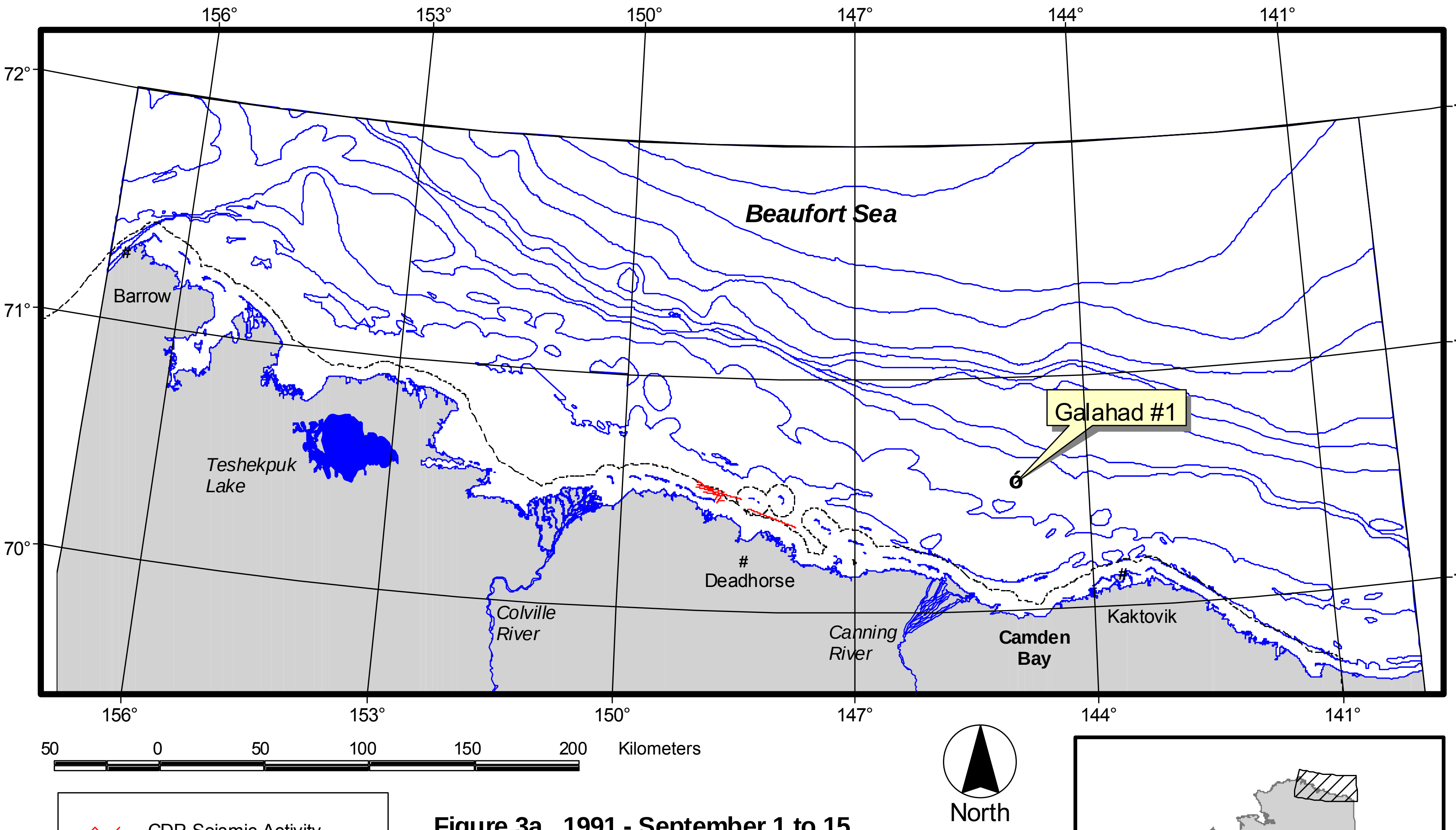
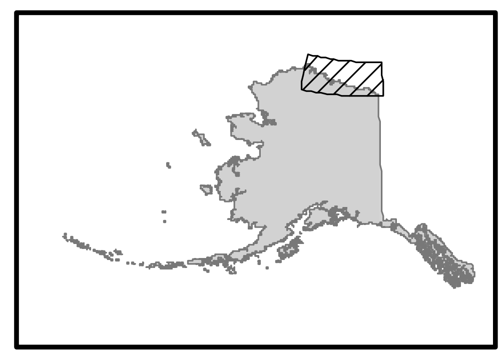


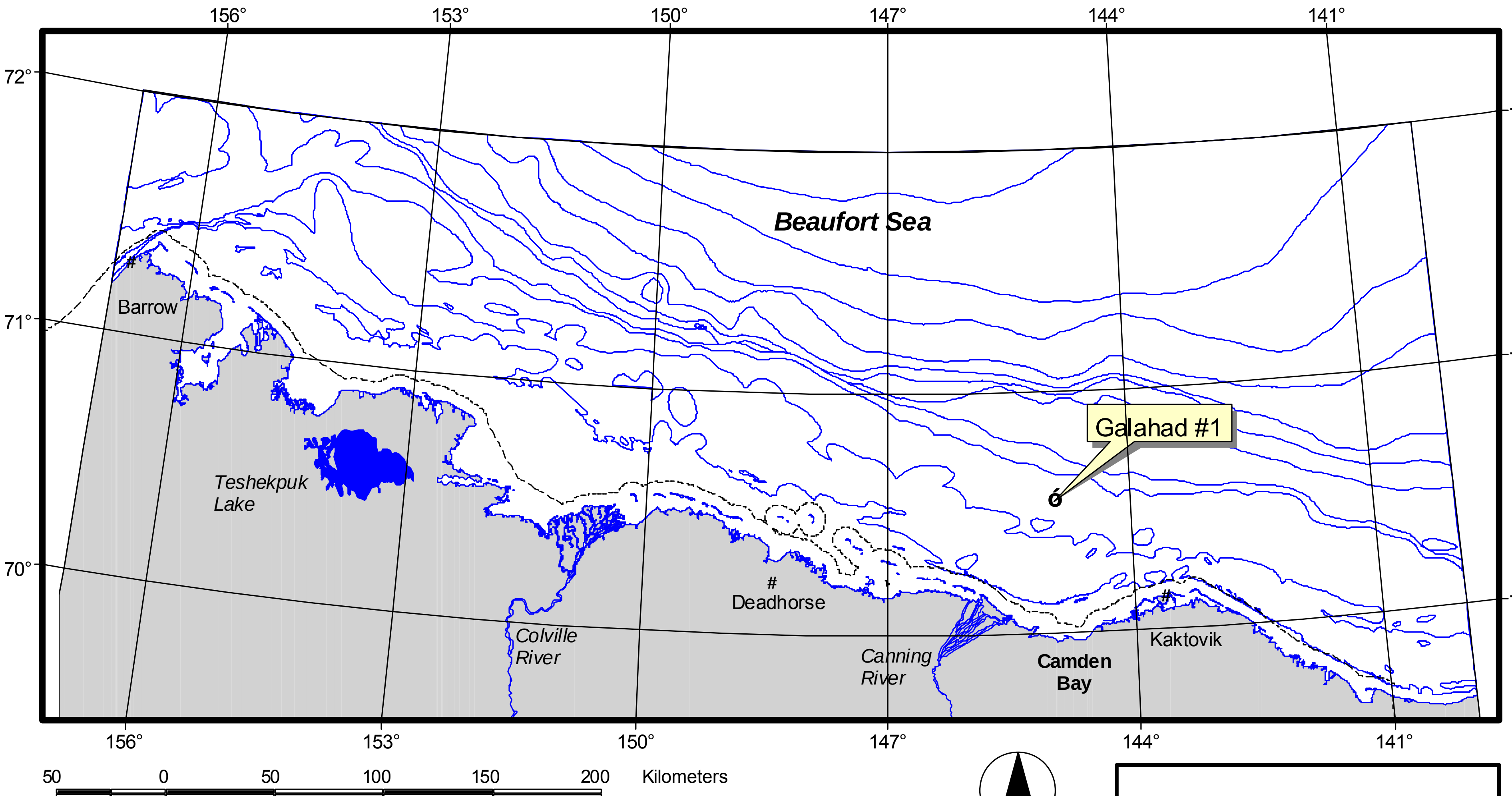
Figure 2c. 1990 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

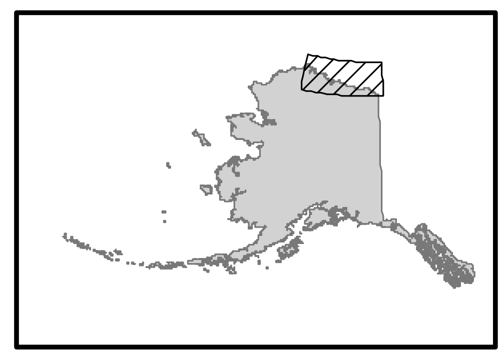
Figure 3a. 1991 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)

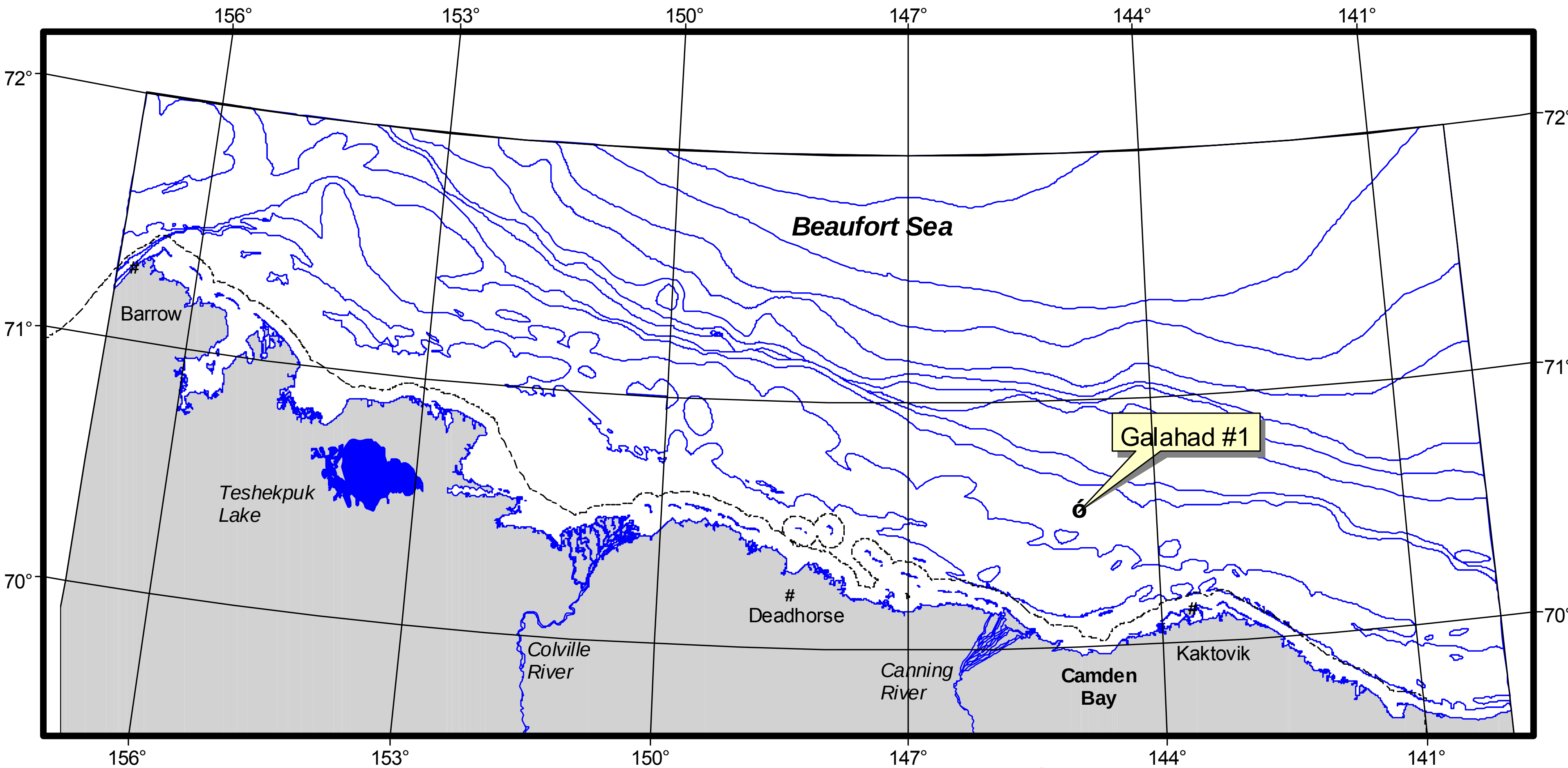


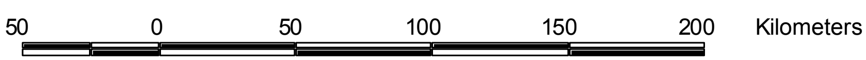


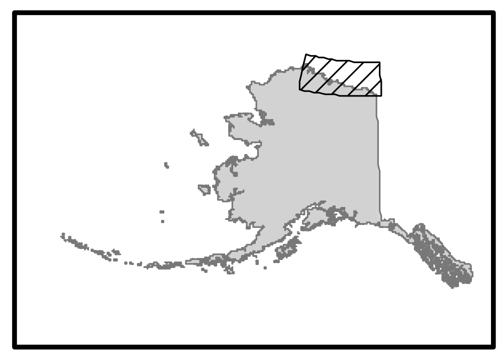
CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 3b. 1991 - September 16 to 30, All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys, Federal OCS and State wells)



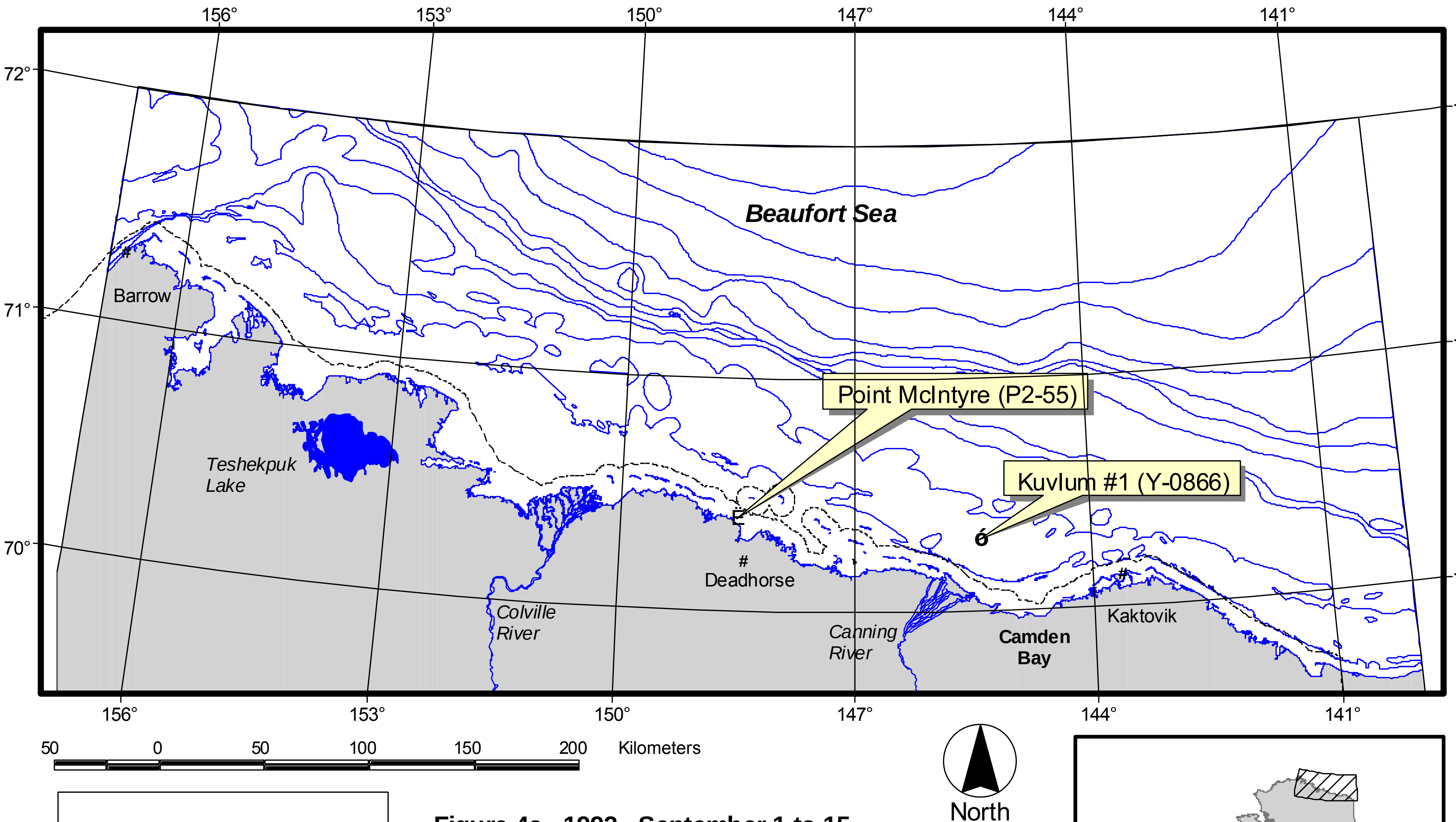






CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 3c. 1991 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



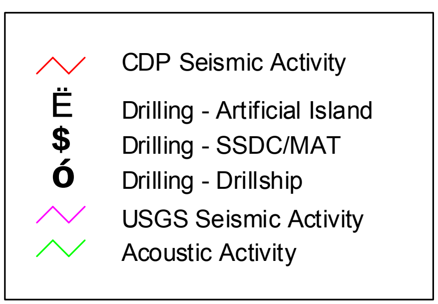
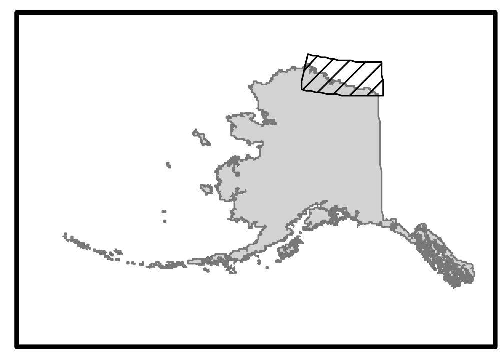
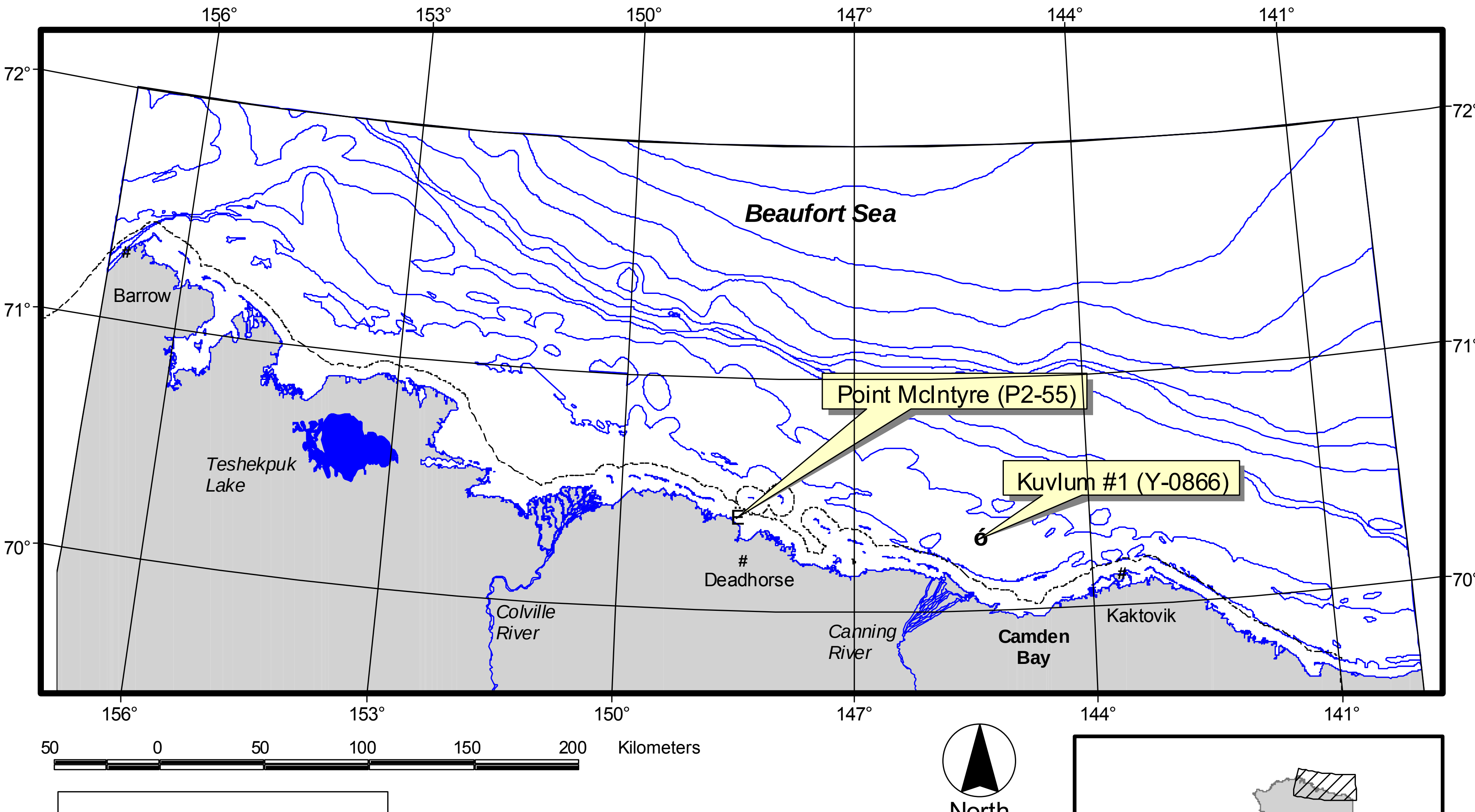


Figure 4a. 1992 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)





CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

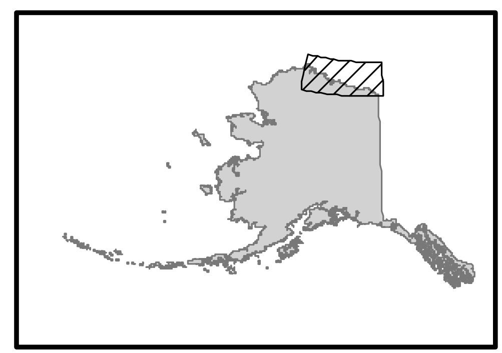
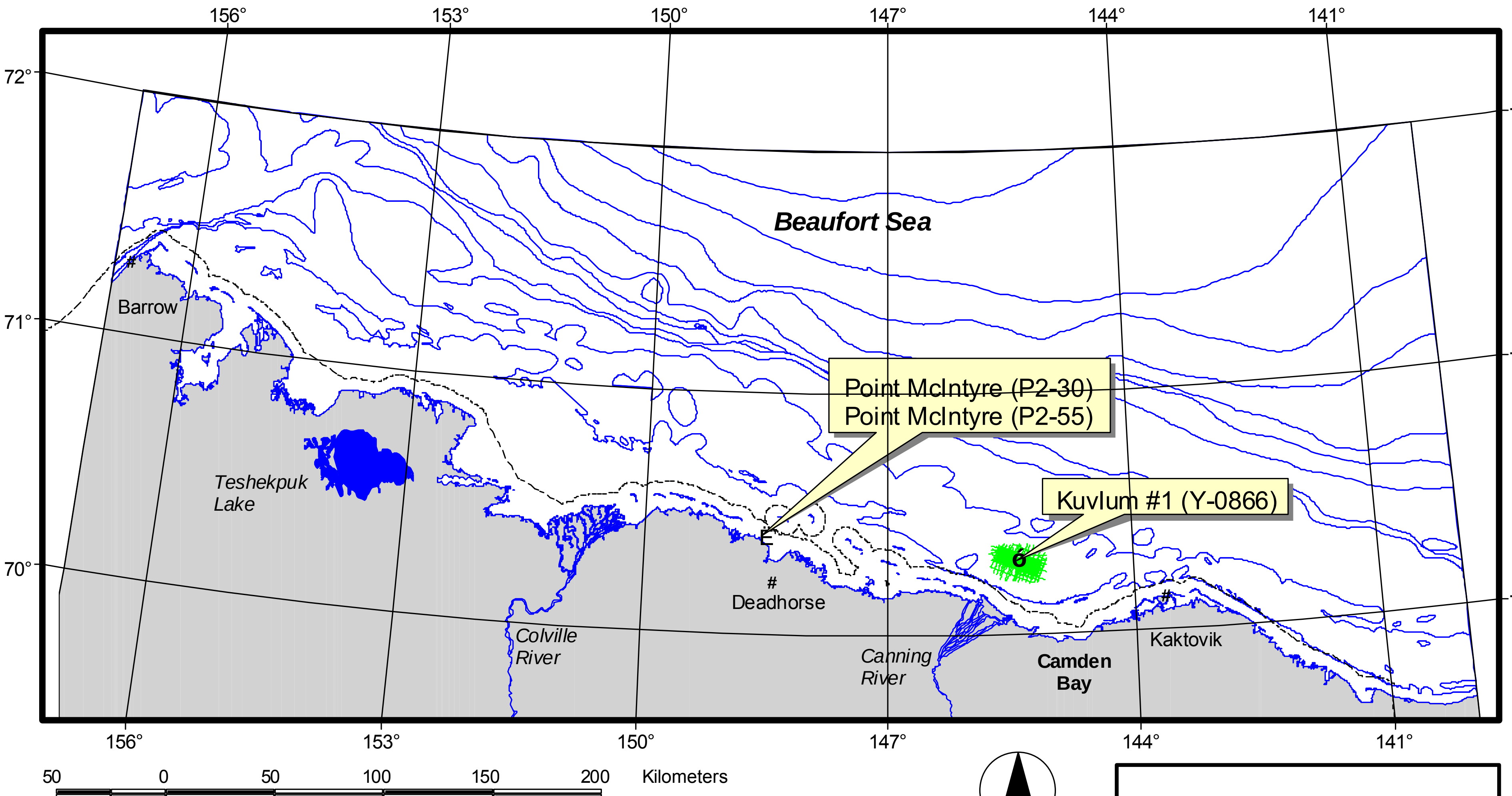


Figure 4b. 1992 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



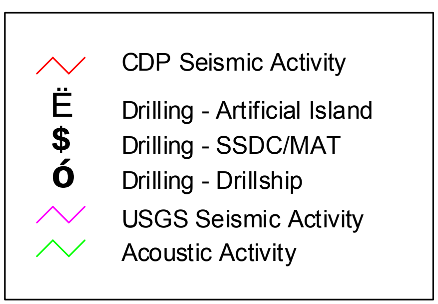
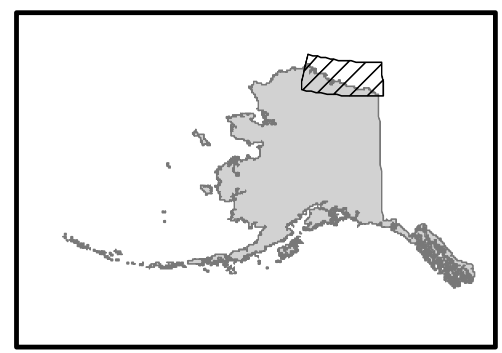
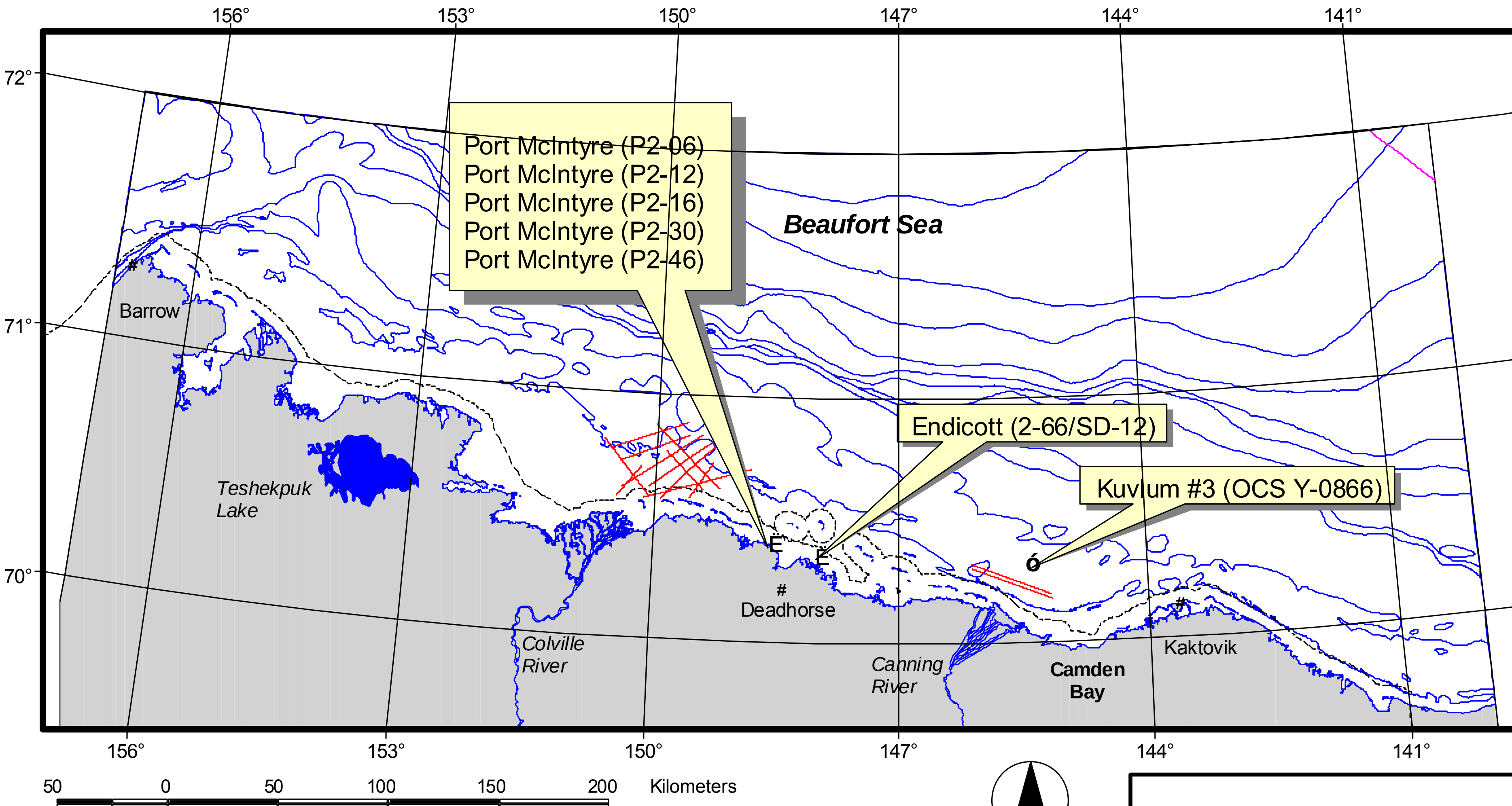
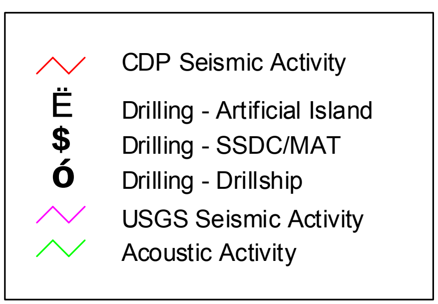


Figure 4c. 1992 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)







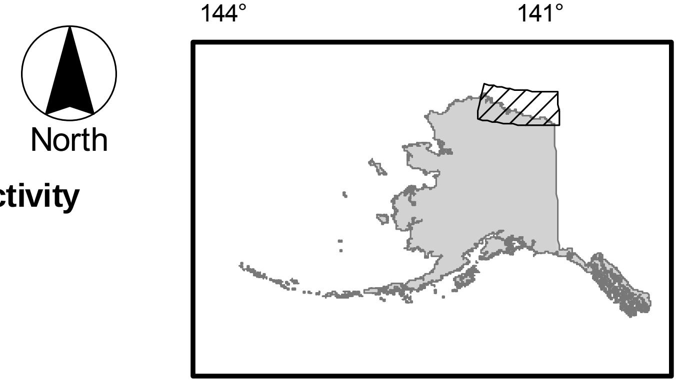
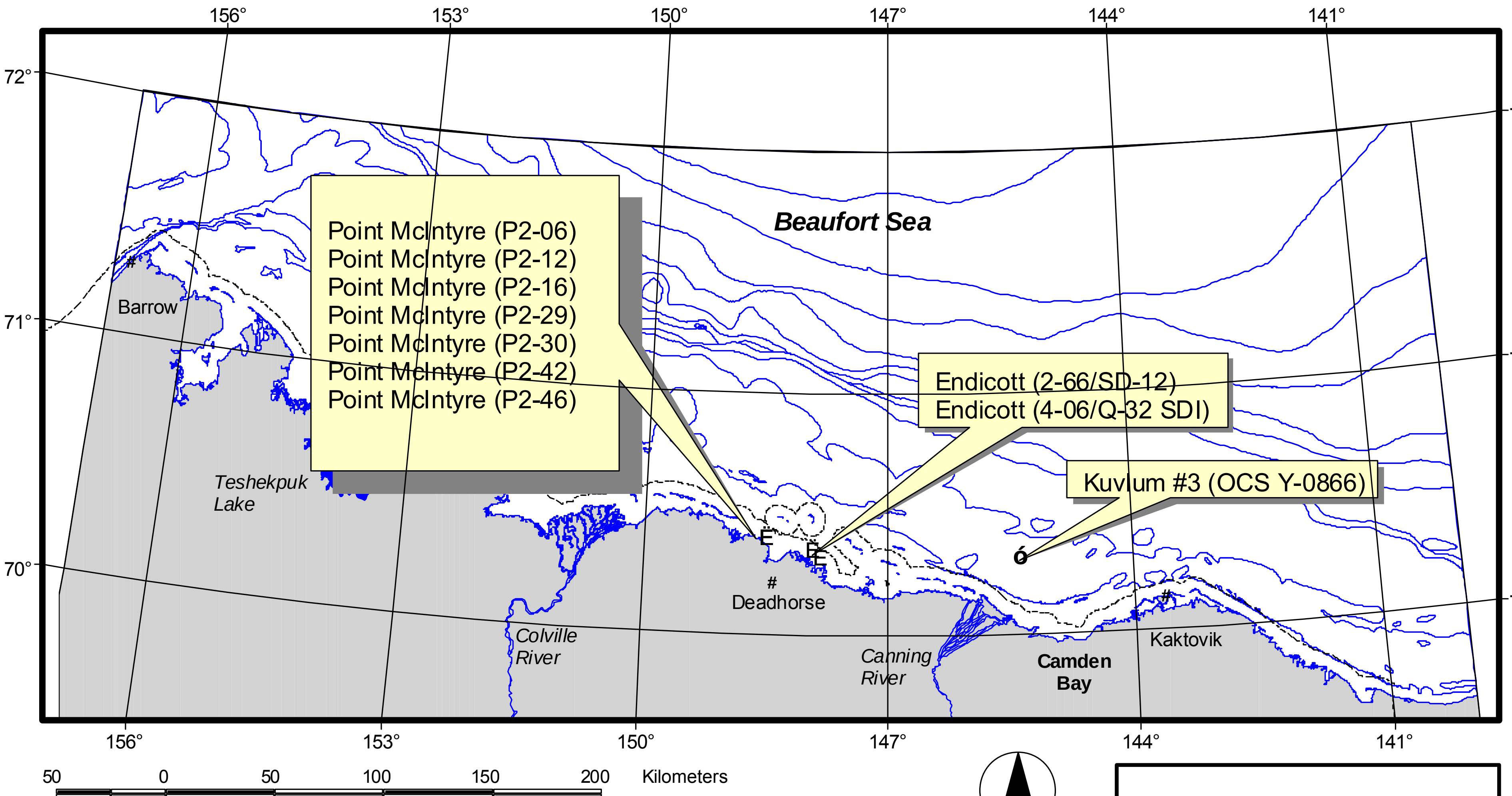


Figure 5a. 1993 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



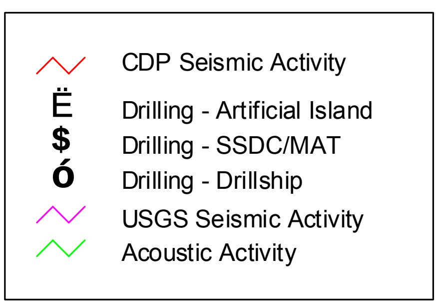
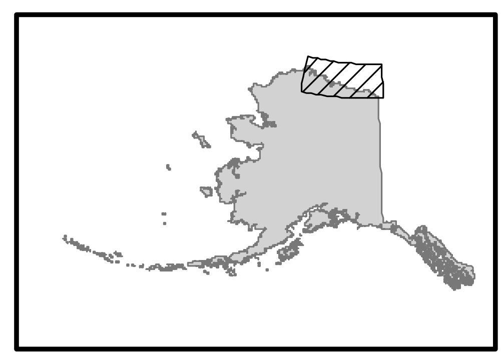
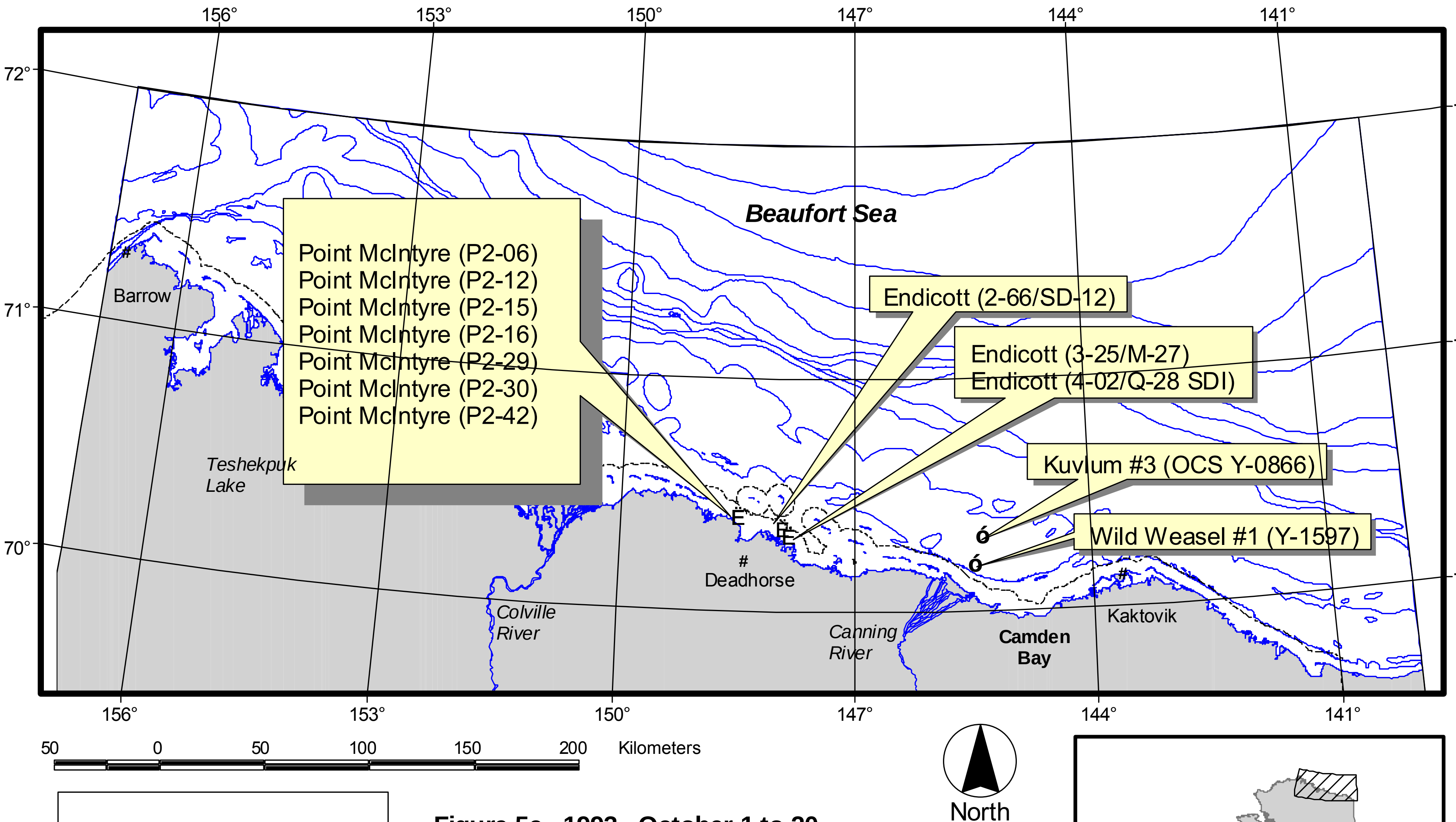


Figure 5b. 1993 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)





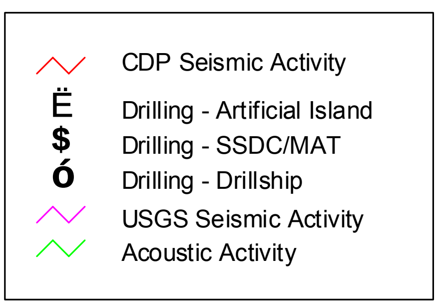
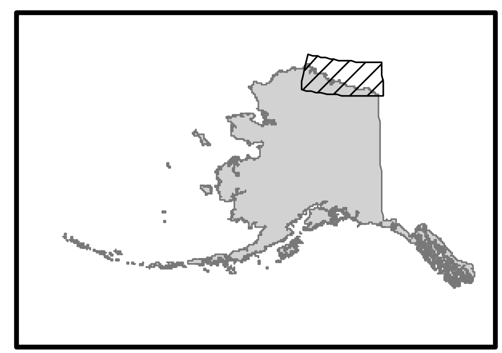


Figure 5c. 1993 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



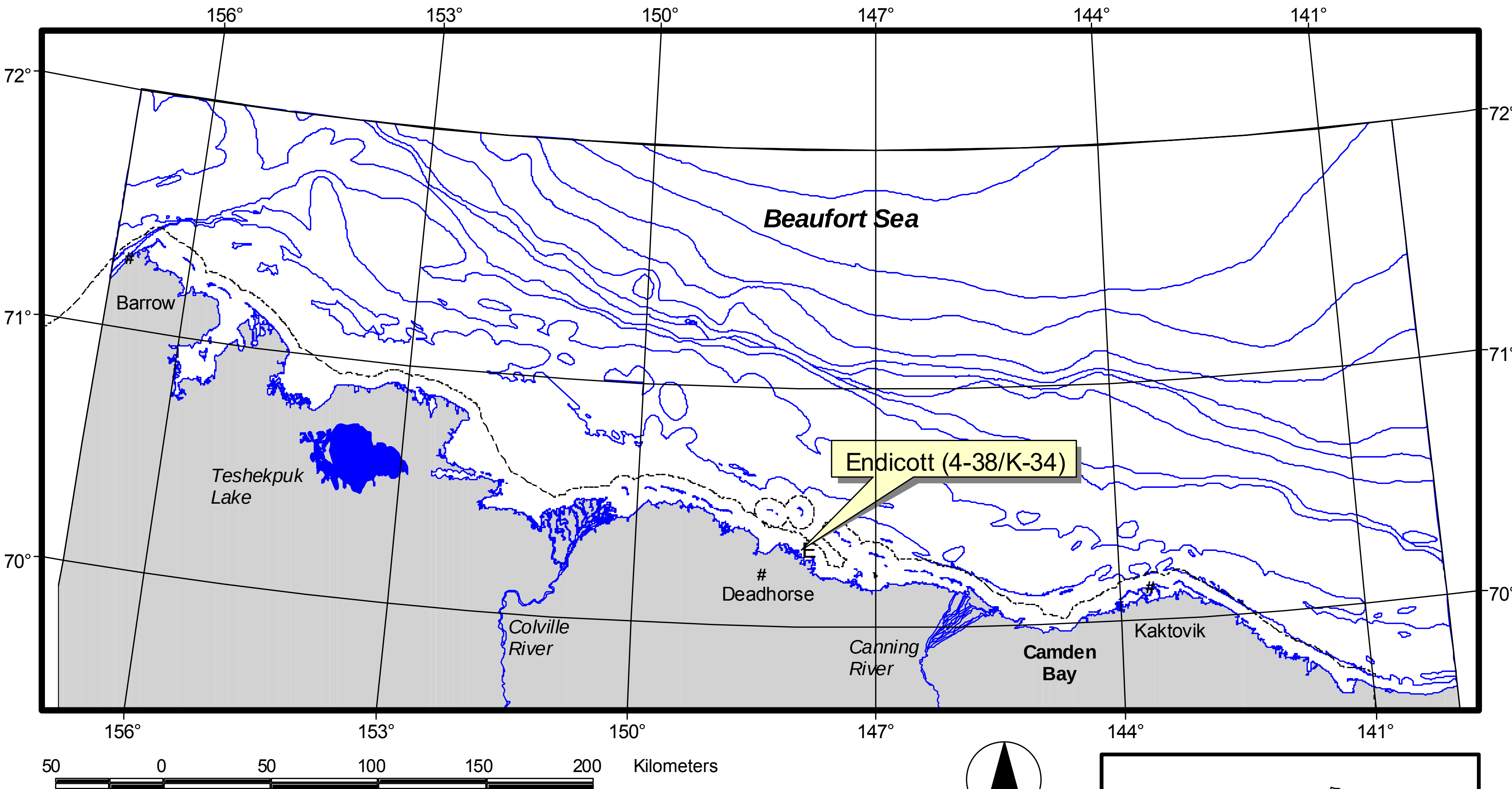
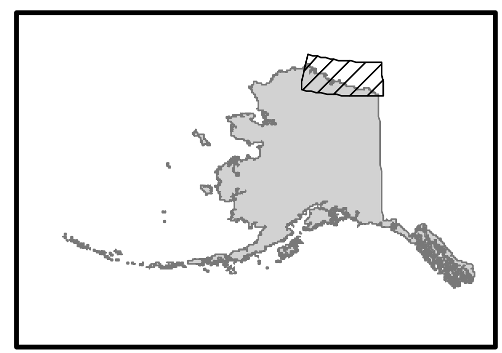
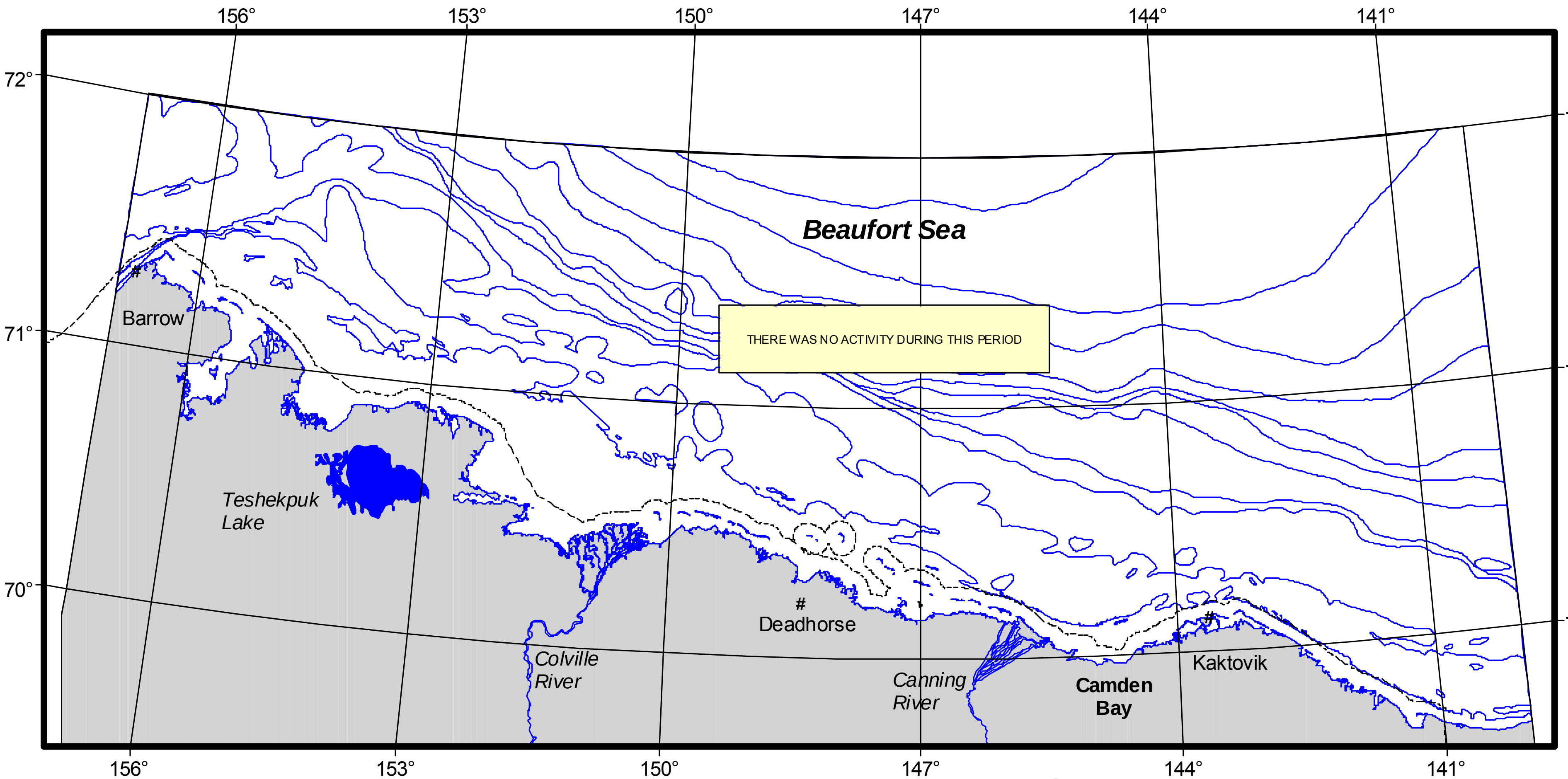
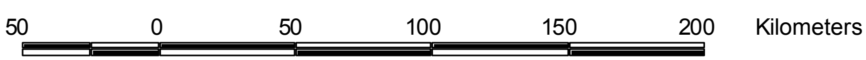


Figure 6a. 1994 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)

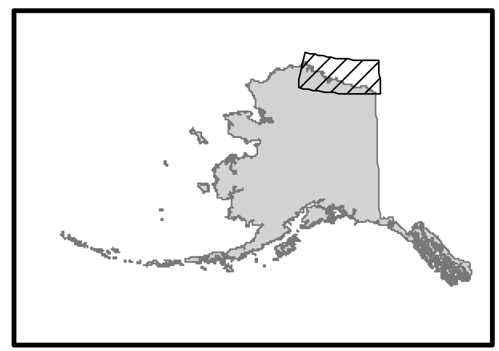


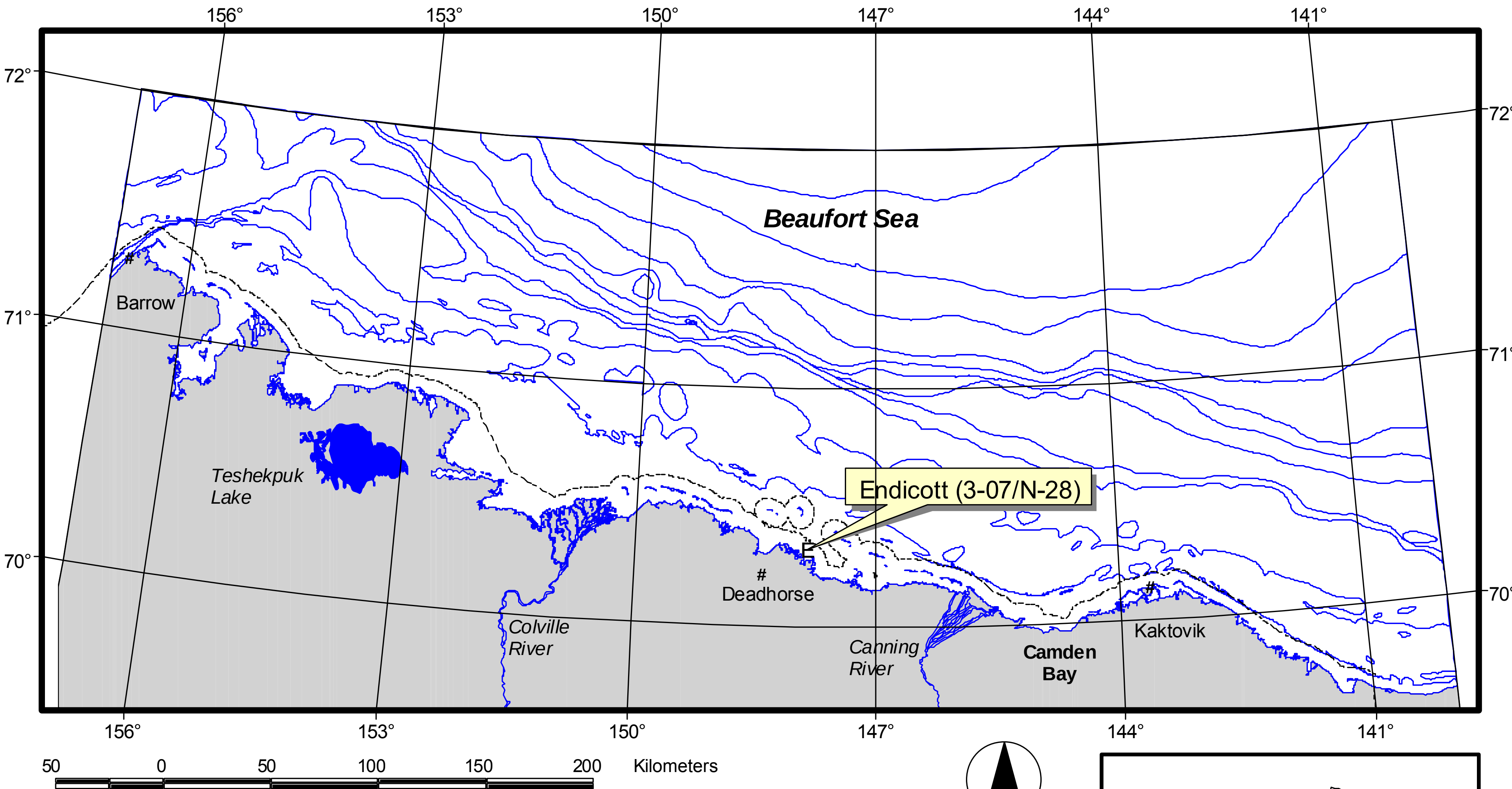


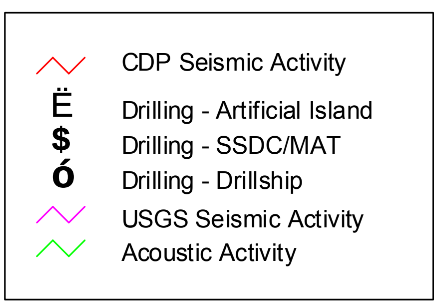


CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 6b. 1994 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)







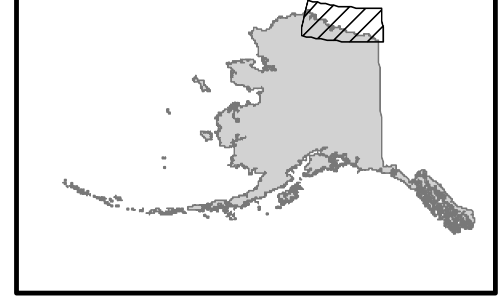
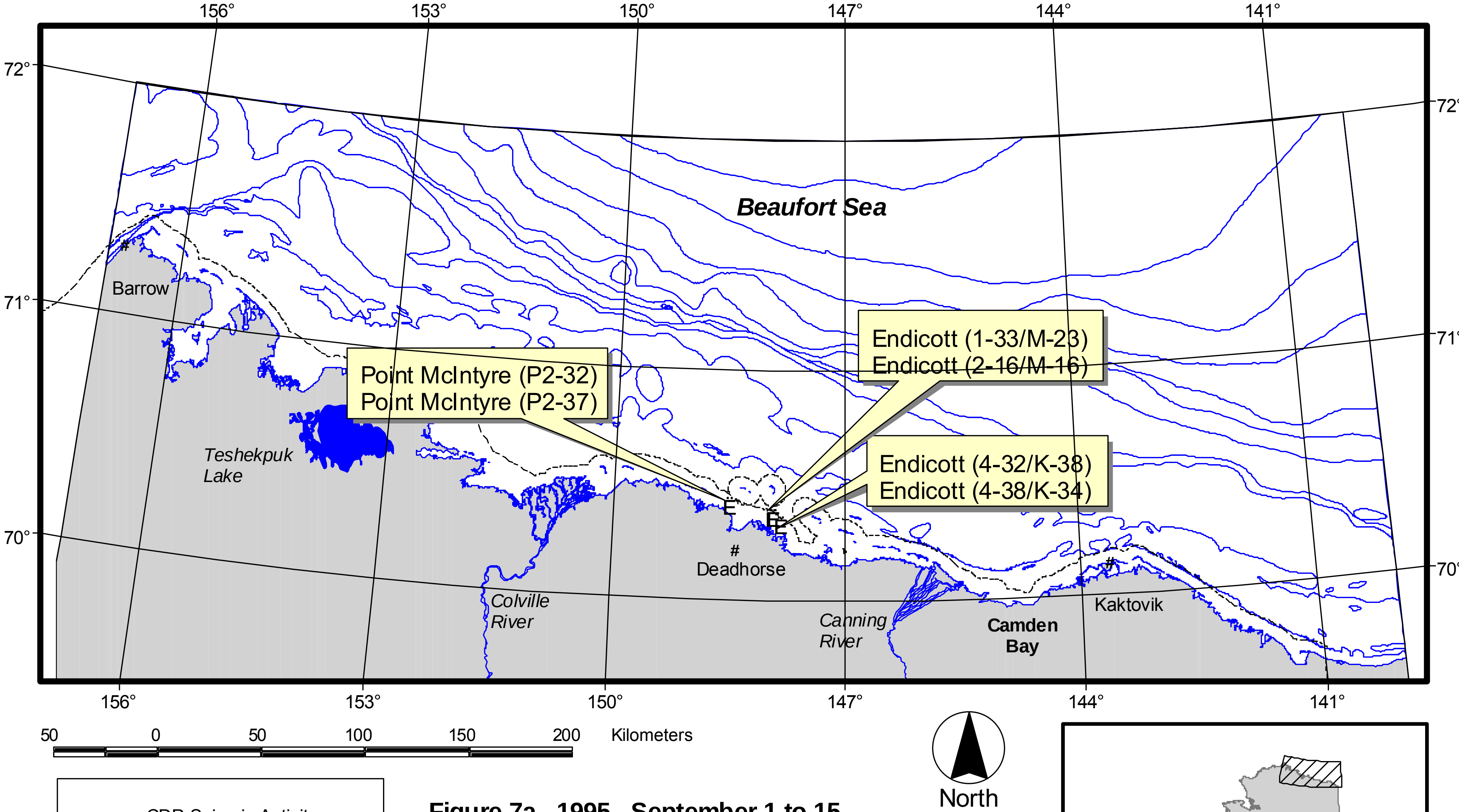
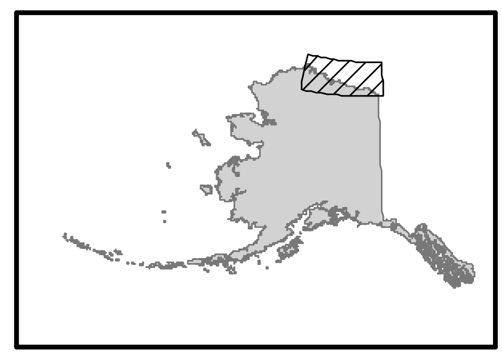


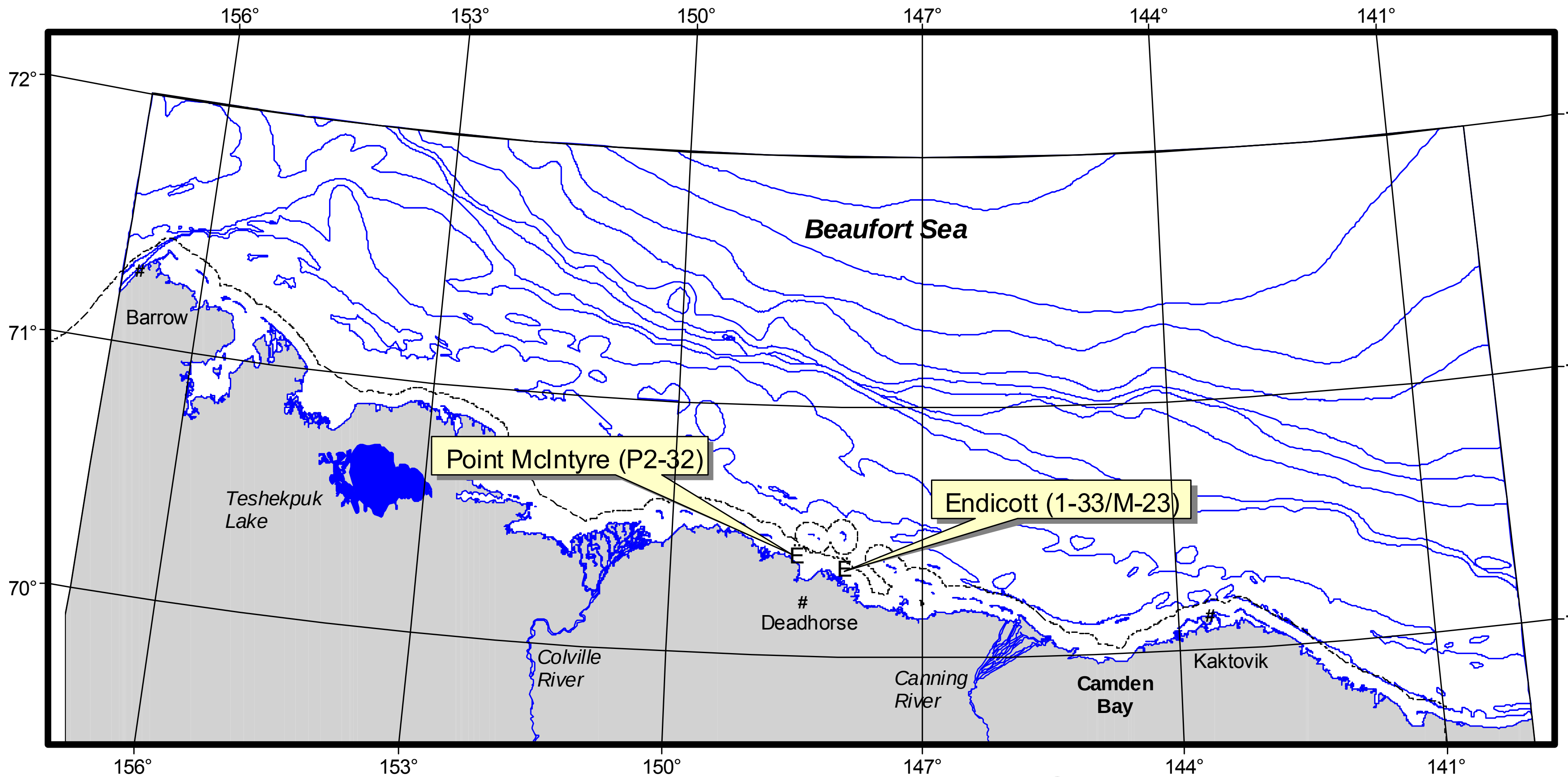
Figure 6c. 1994 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

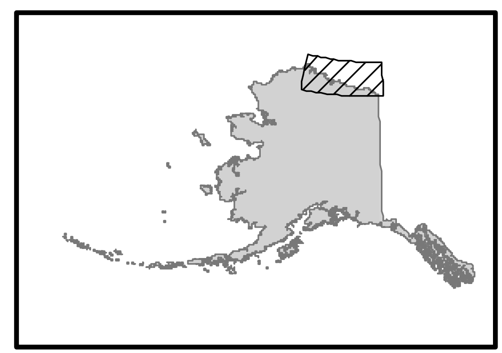
Figure 7a. 1995 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)

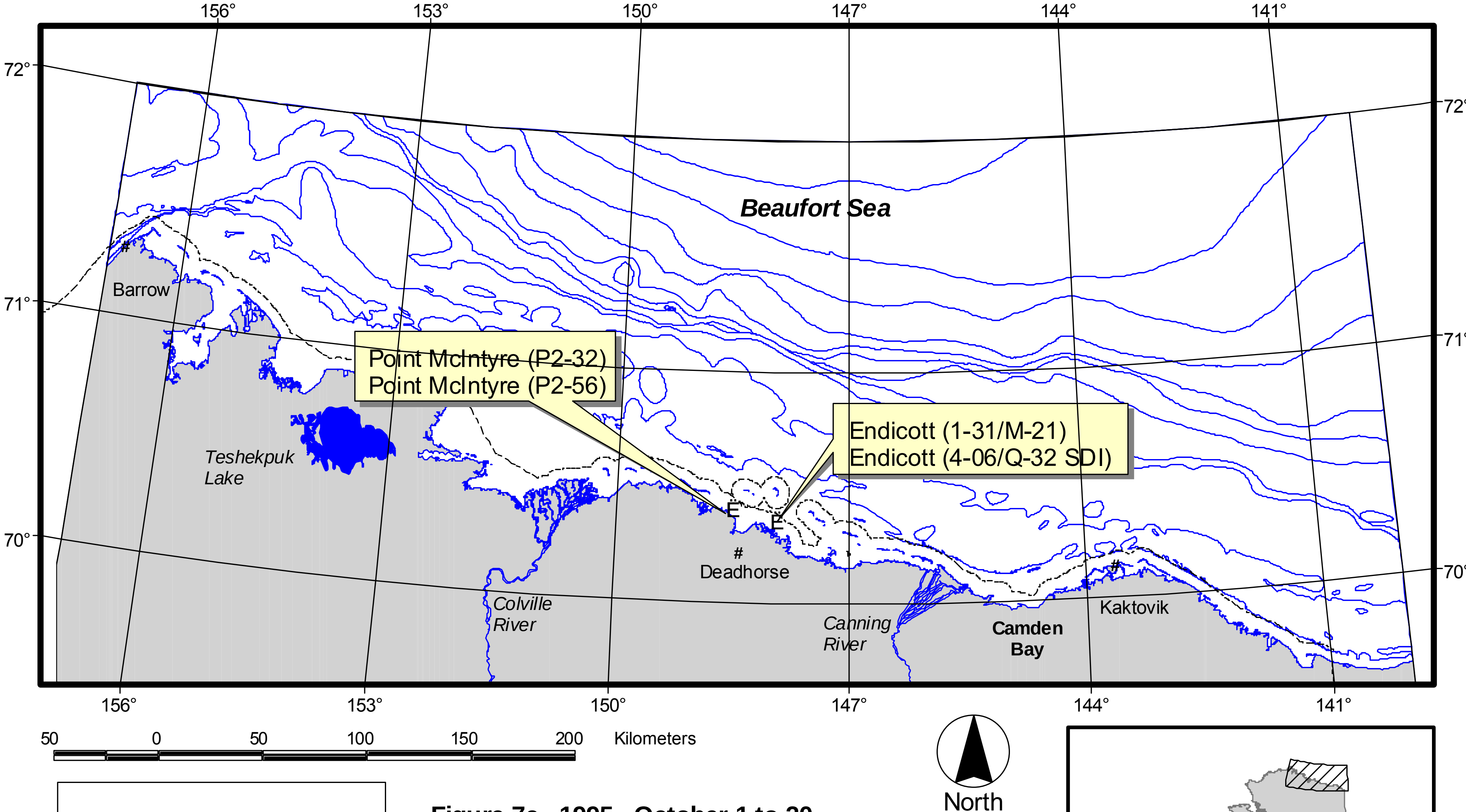




CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

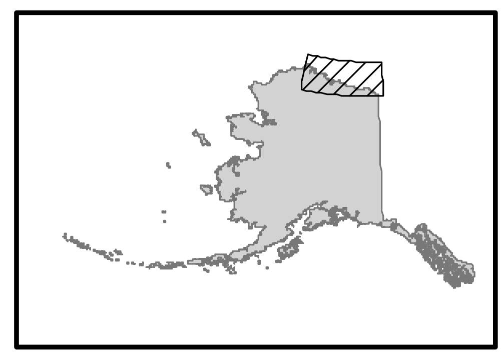
Figure 7b. 1995 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)

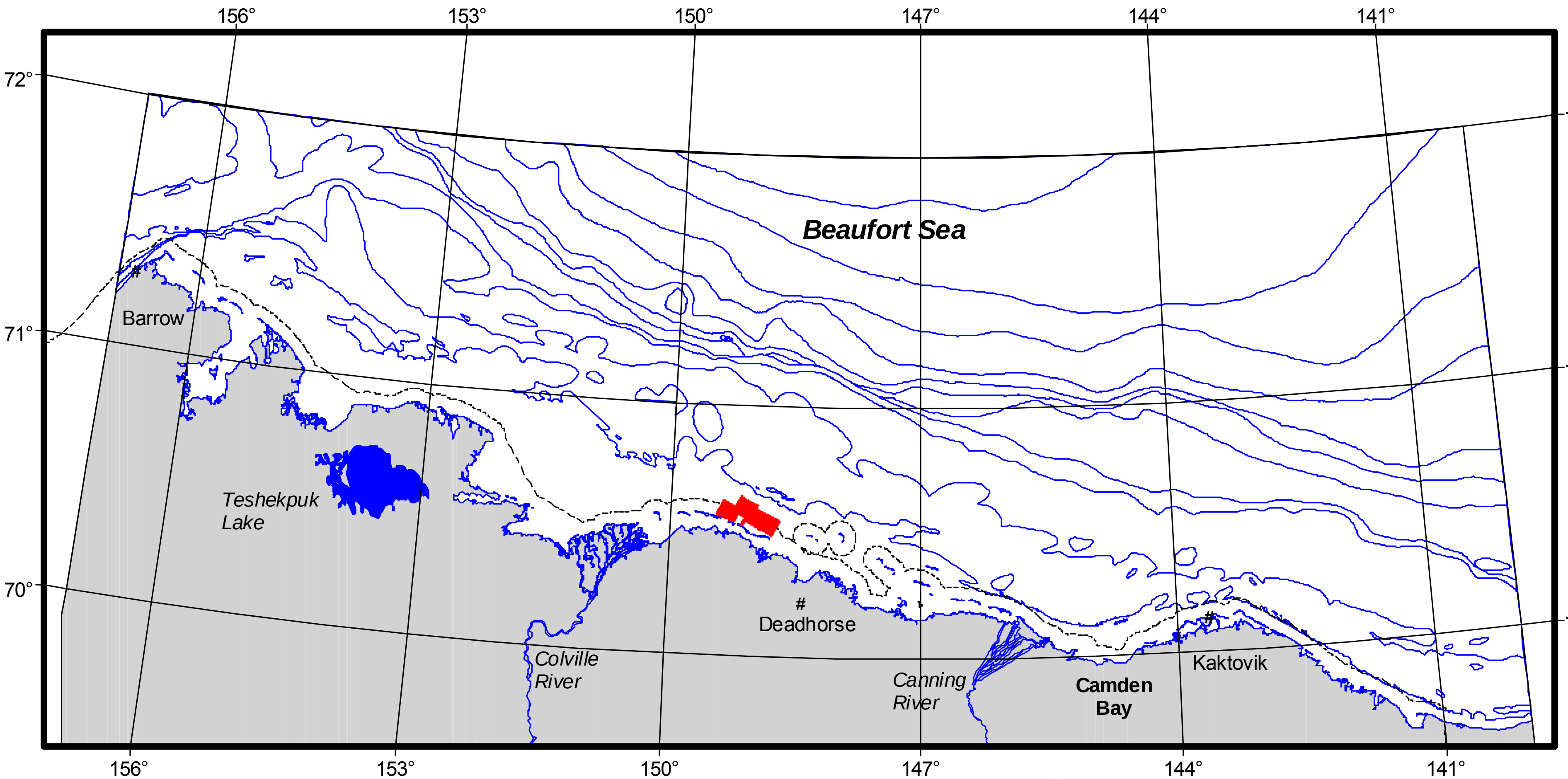


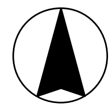


CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 7c. 1995 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)

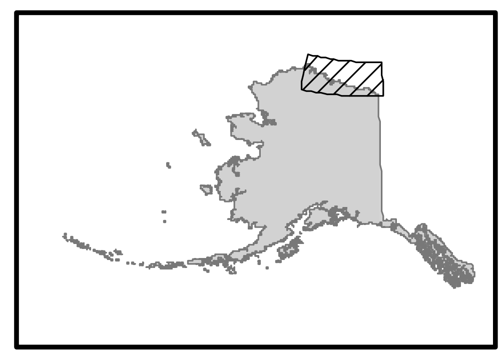






CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 8a. 1996 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



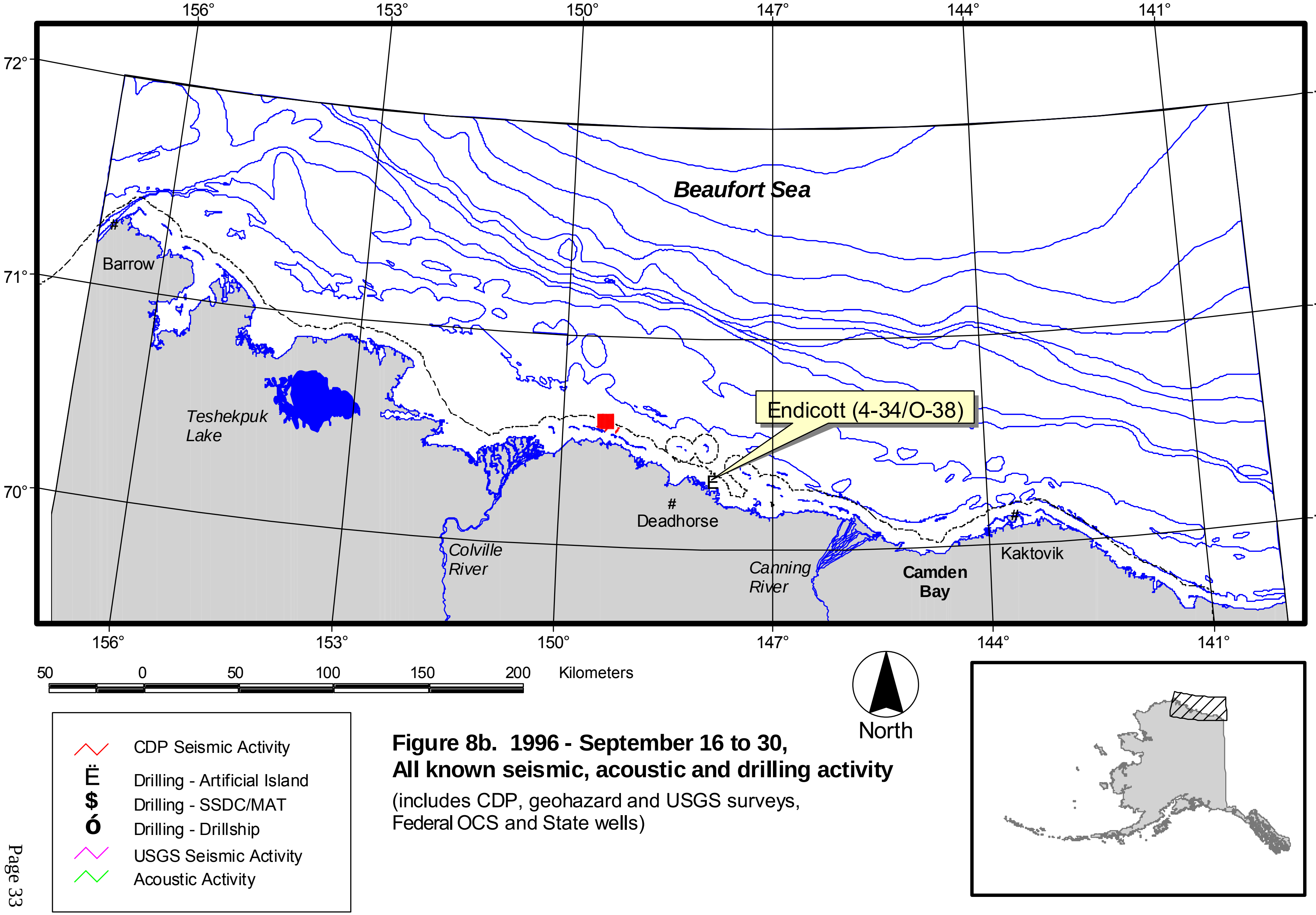
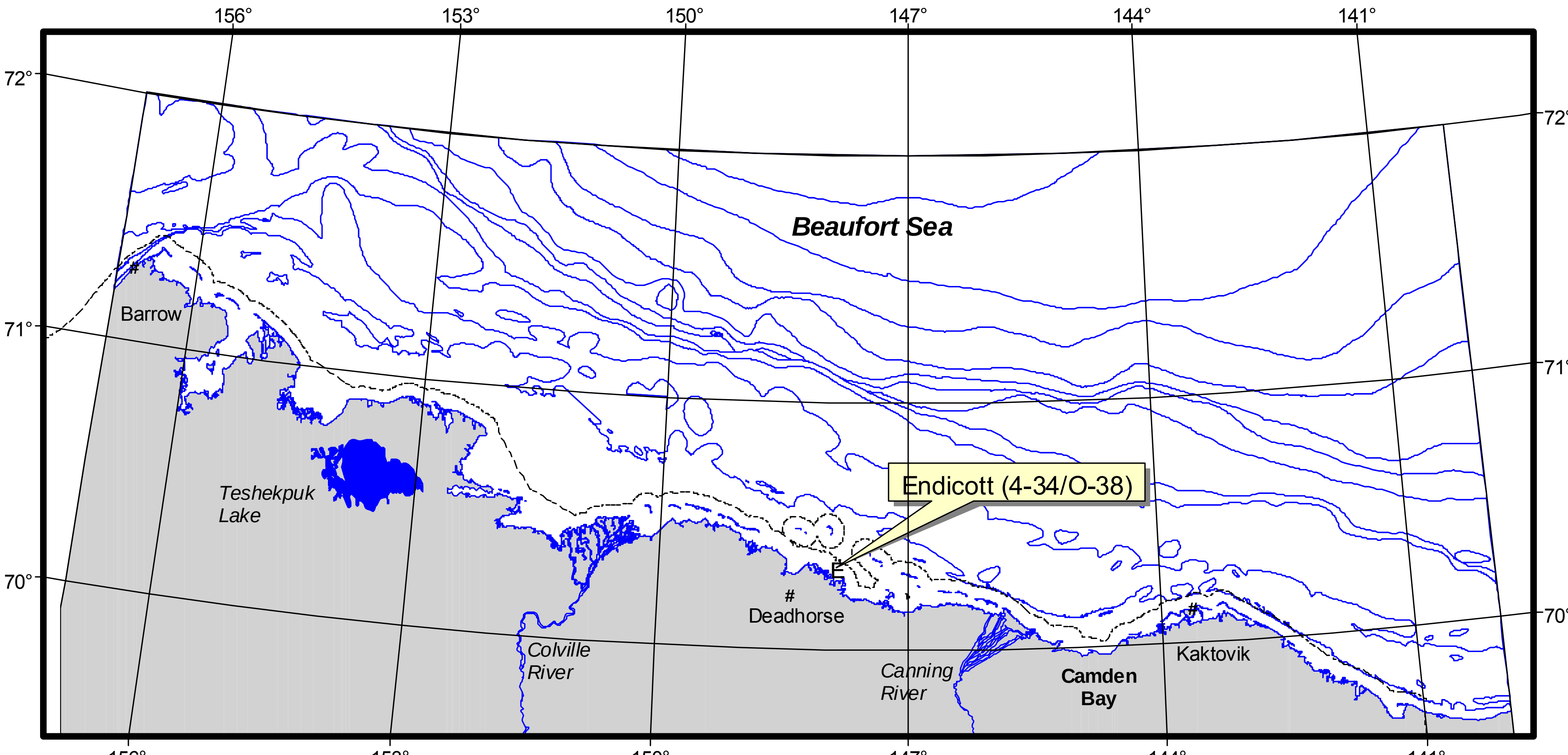
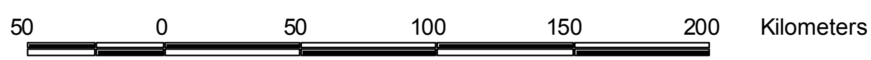
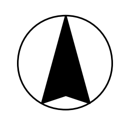
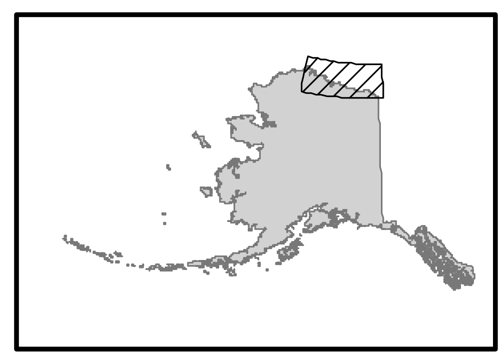


Figure 8b. 1996 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



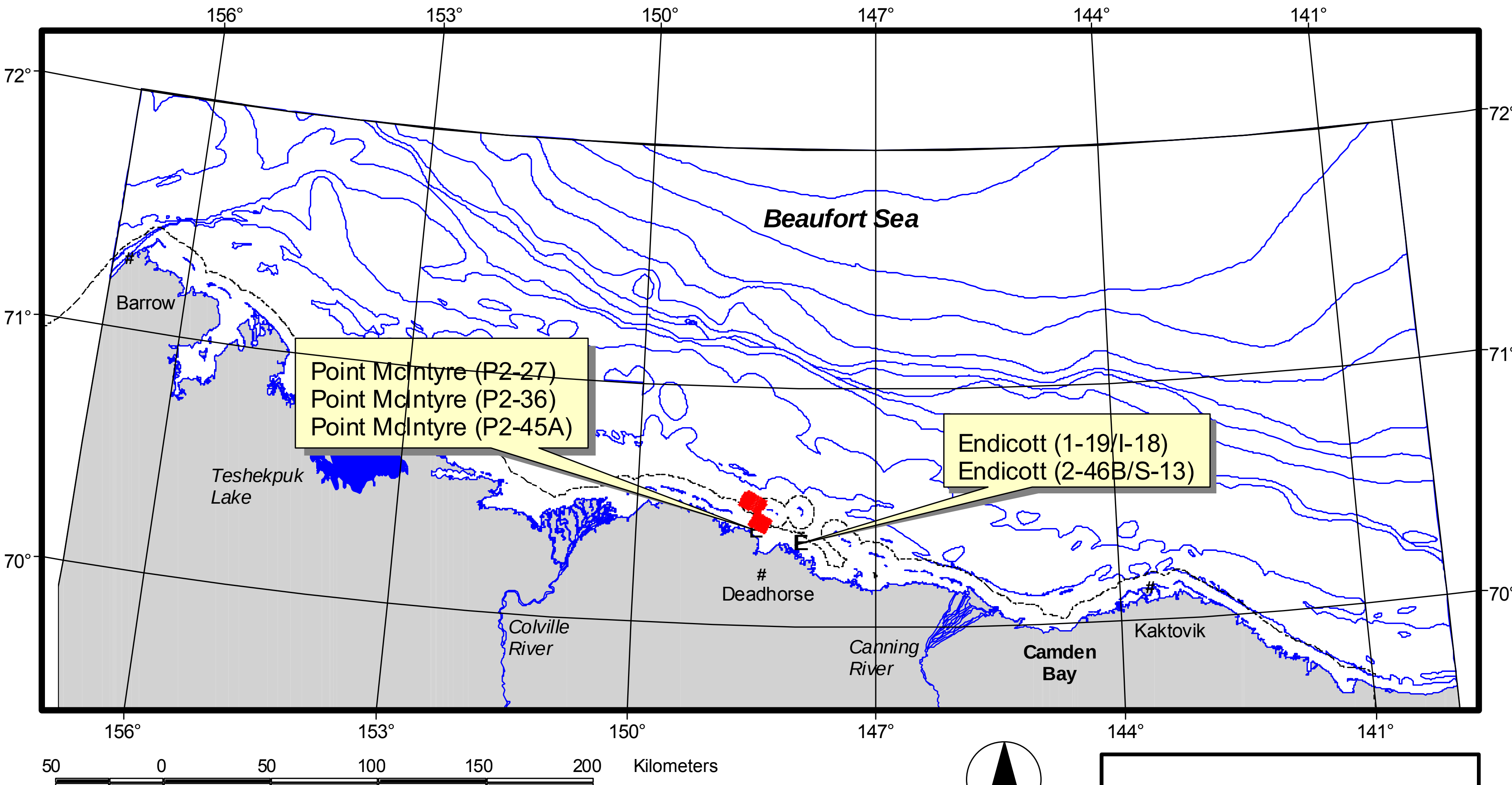






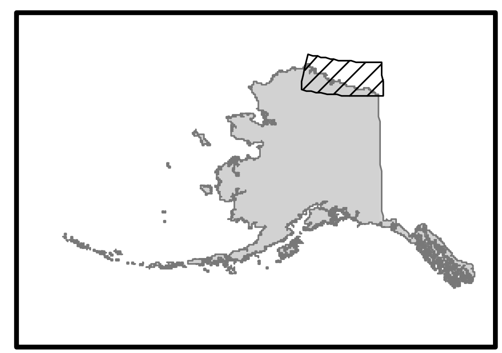
CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

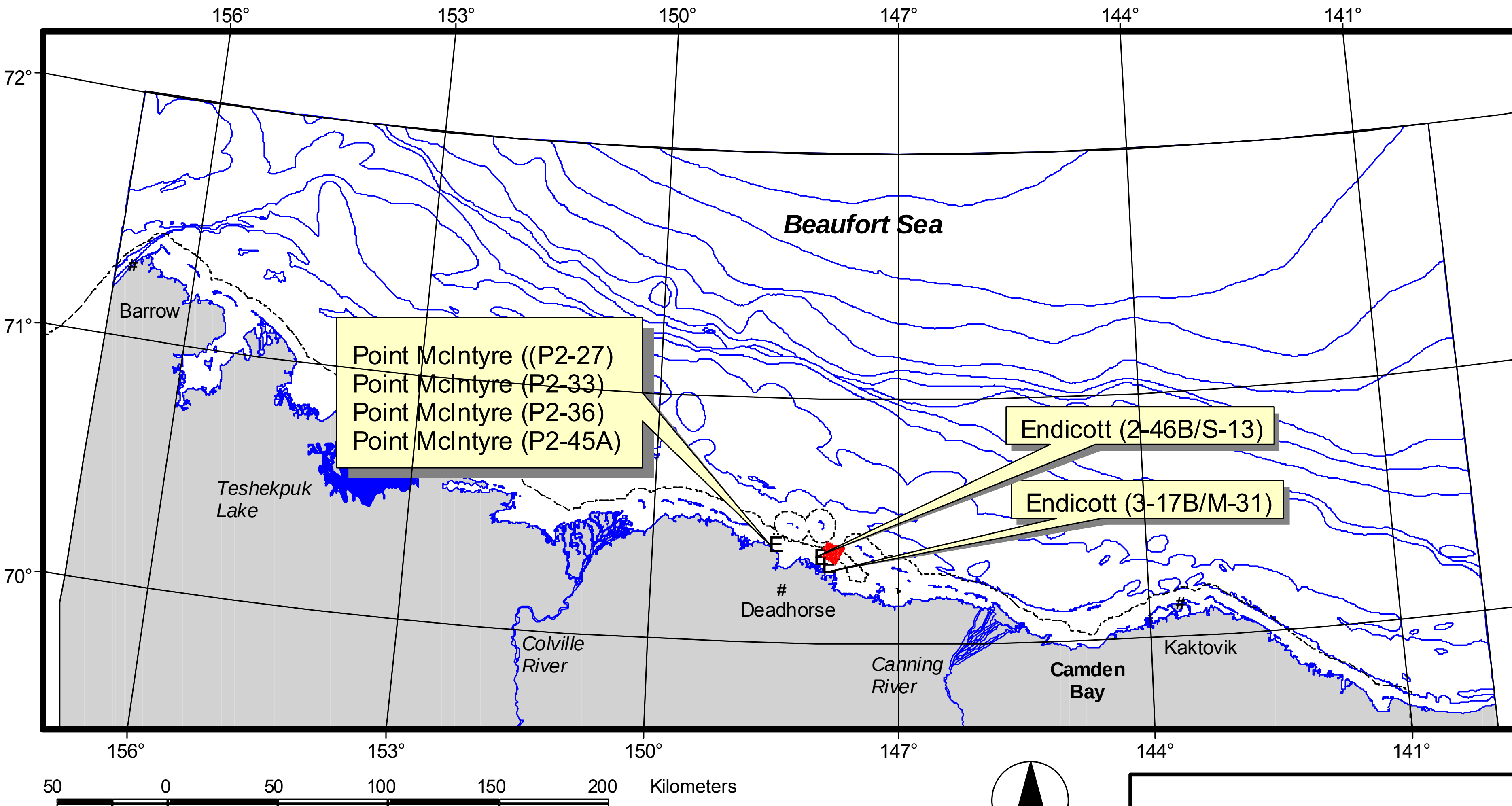
Figure 8c. 1996 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)

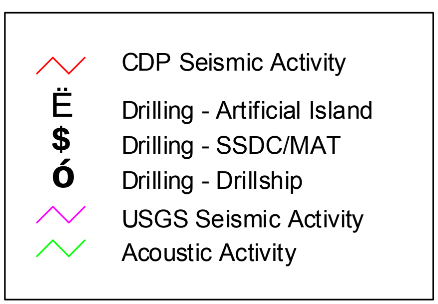


CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 9a. 1997 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)







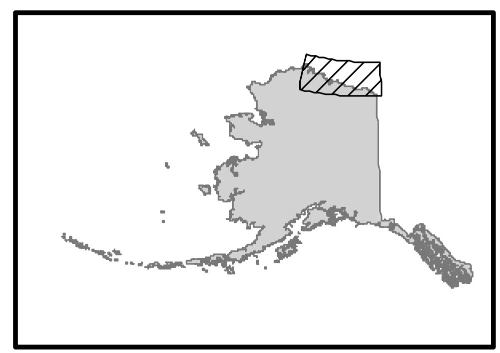
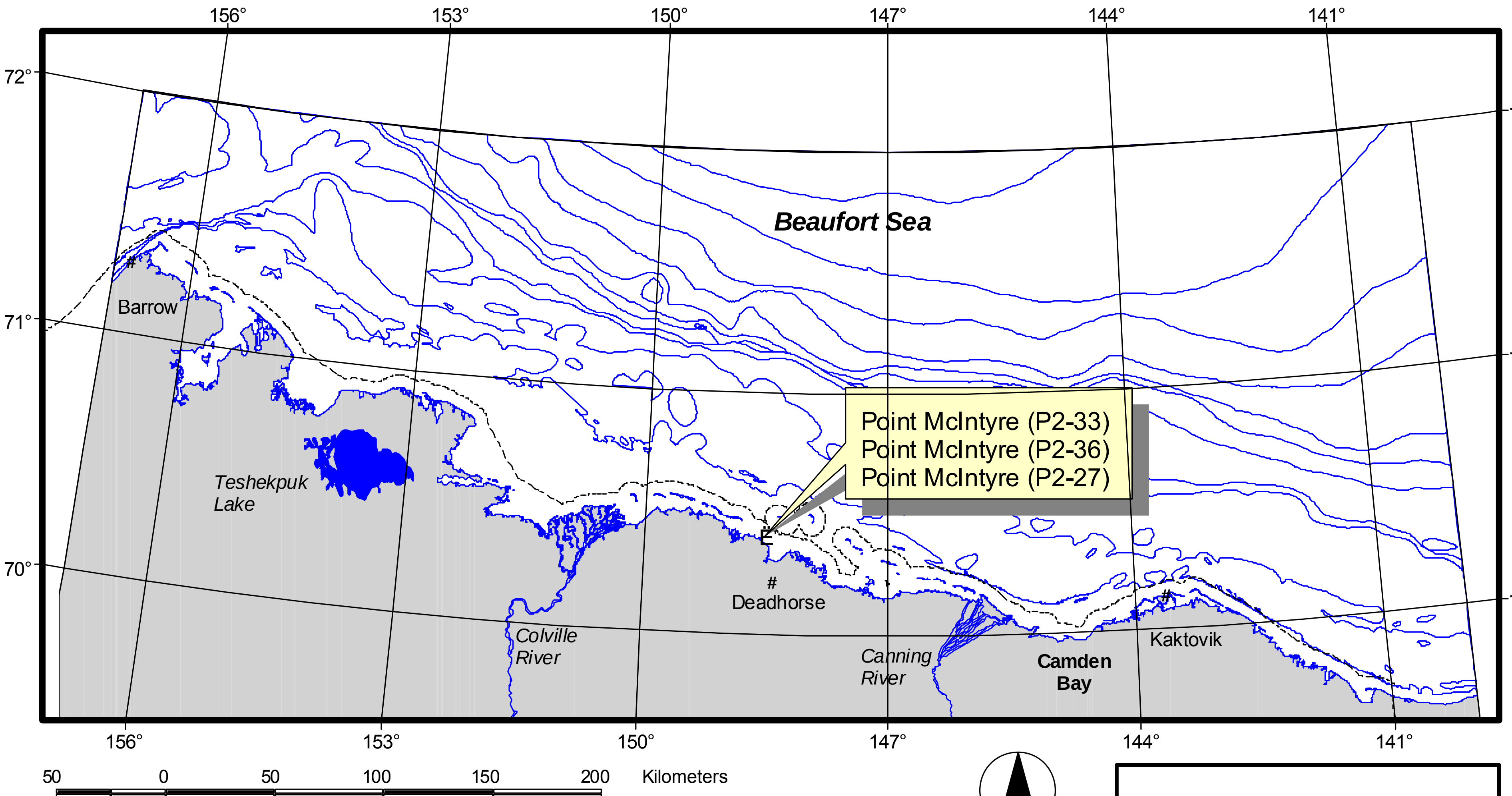


Figure 9b. 1997 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



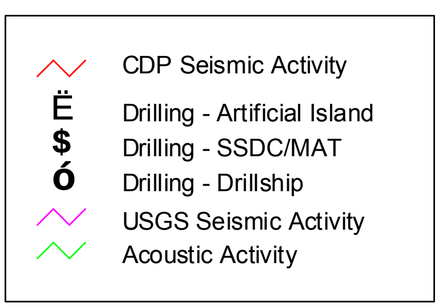
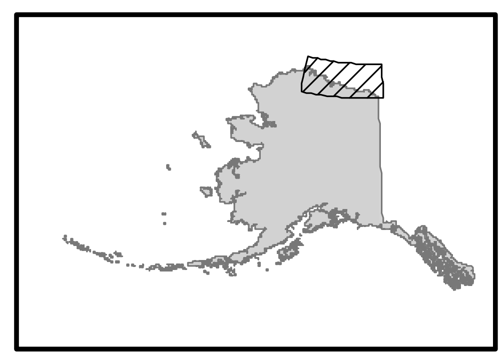
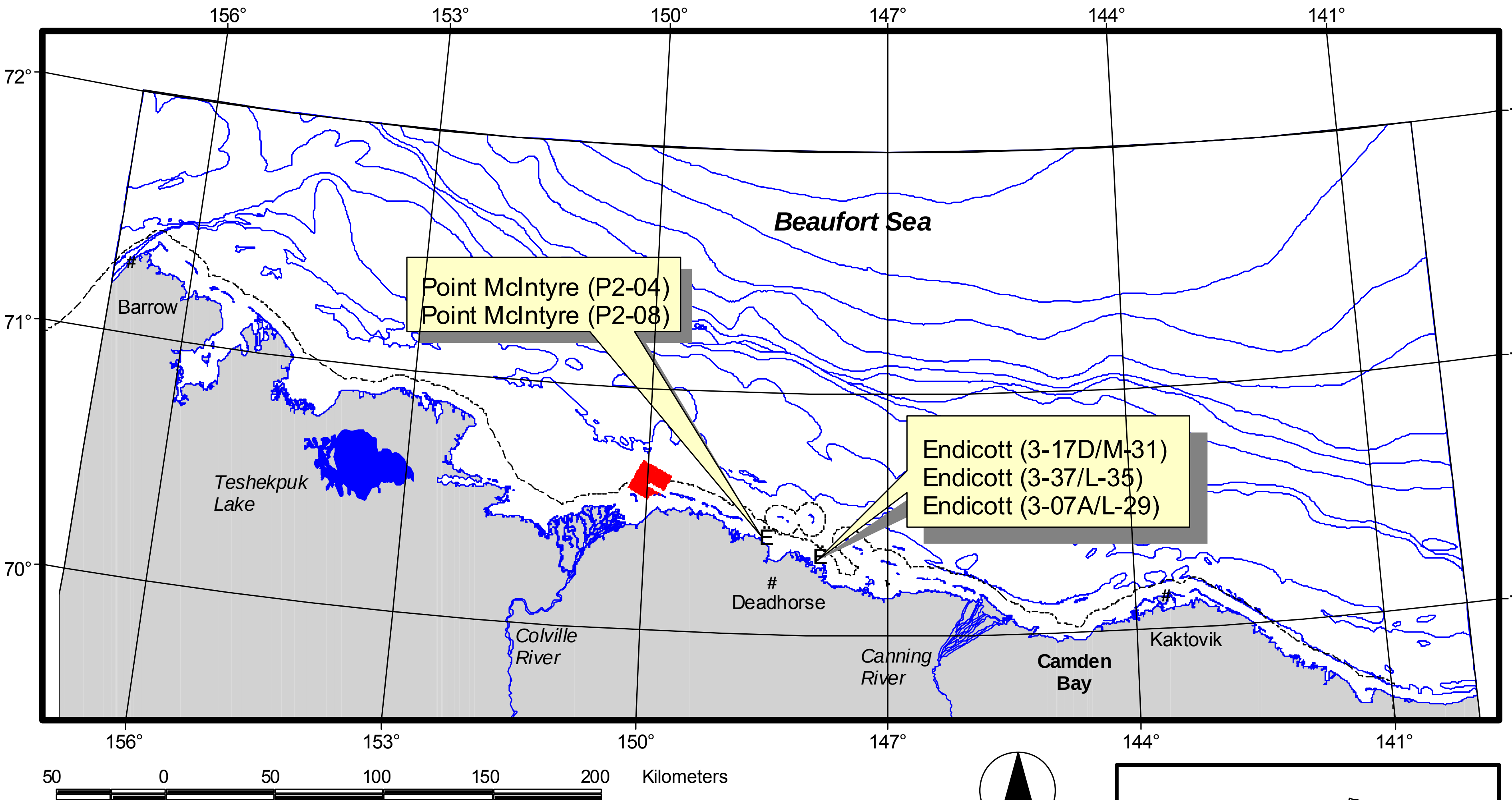
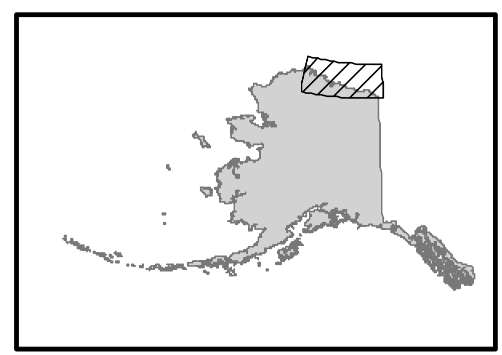


Figure 9c. 1997 - October 1 to 20,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)







CDP Seismic Activity
Ë Drilling - Artificial Island
$ Drilling - SSDC/MAT
Ó Drilling - Drillship
USGS Seismic Activity
Acoustic Activity

Figure 10a. 1998 - September 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)

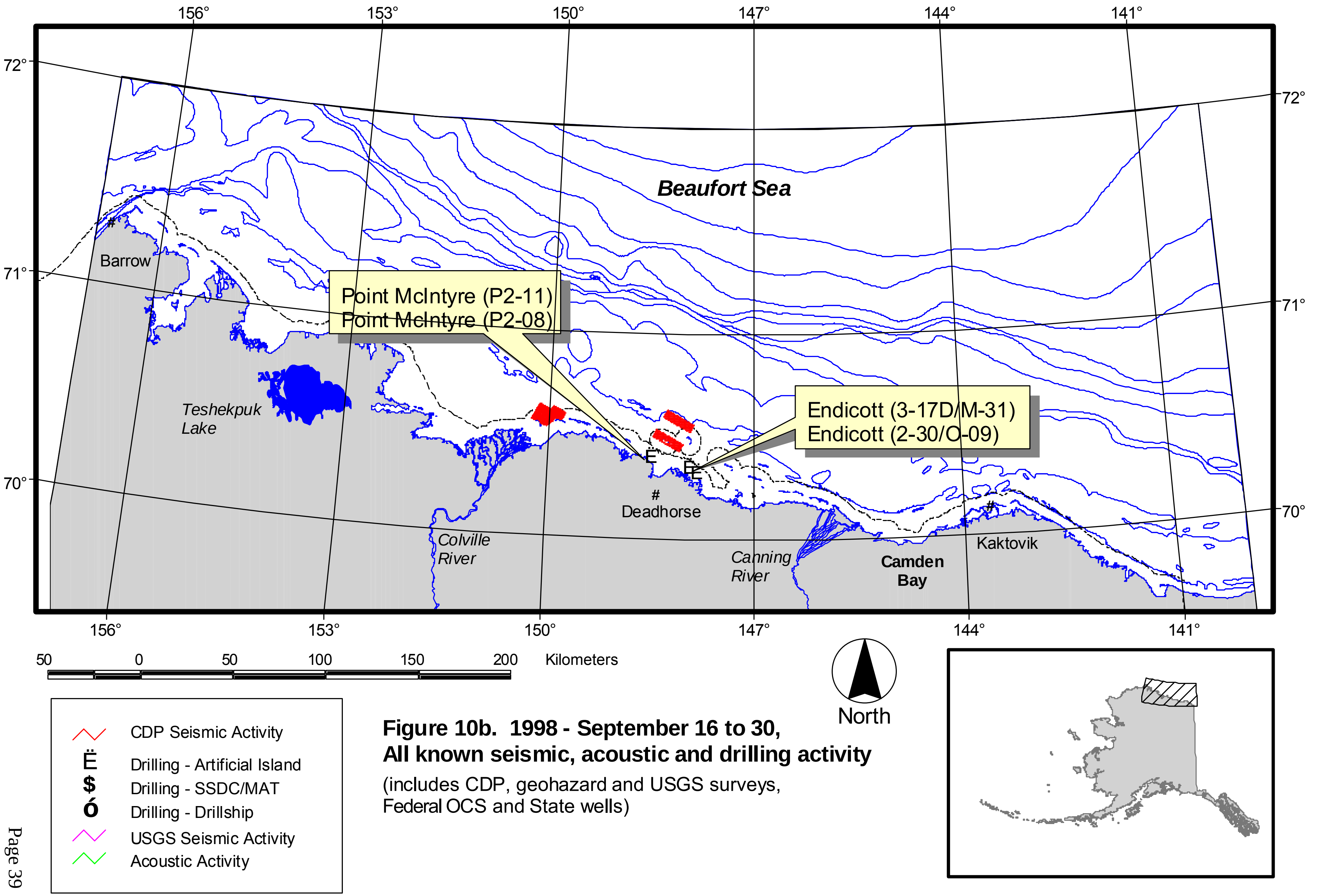
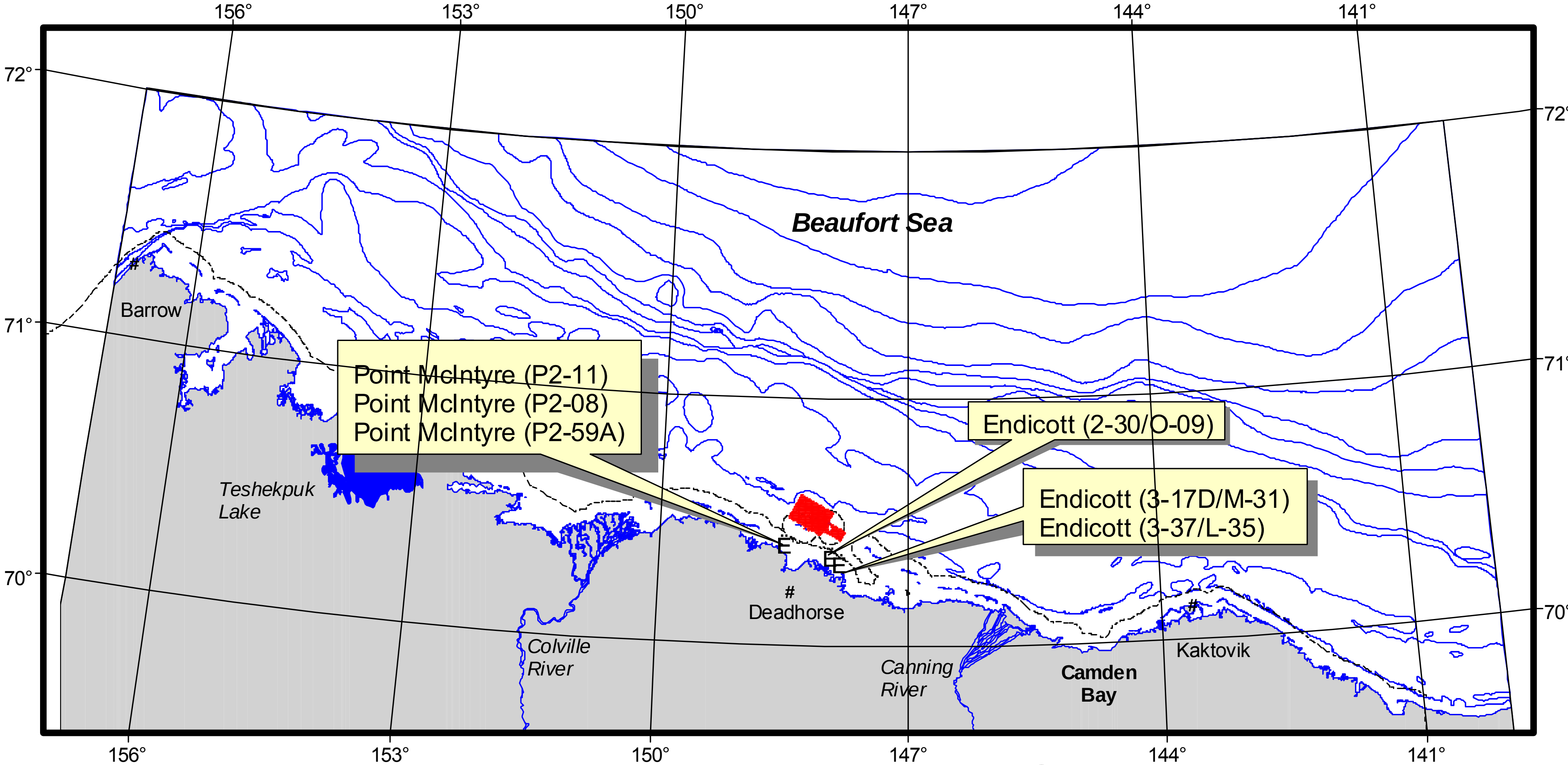
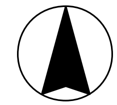


Figure 10b. 1998 - September 16 to 30,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)





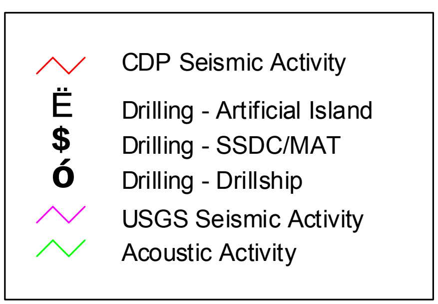
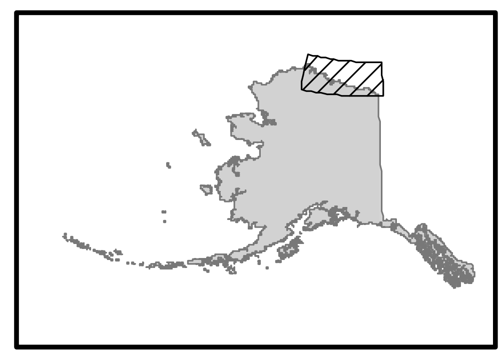


Figure 10c. 1998 - October 1 to 15,
All known seismic, acoustic and drilling activity
(includes CDP, geohazard and USGS surveys,
Federal OCS and State wells)



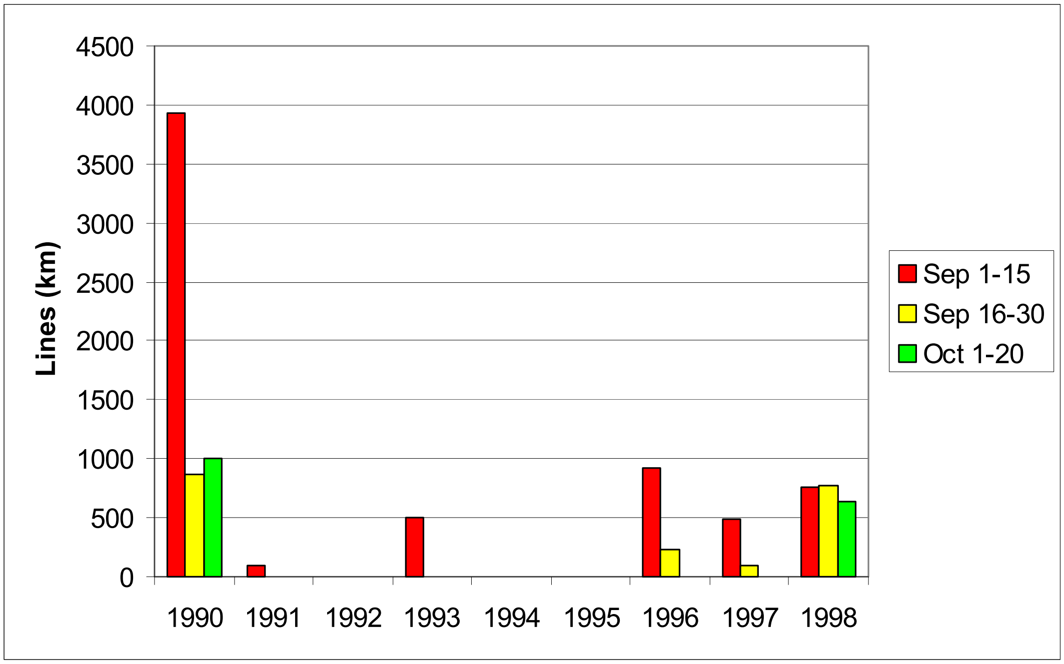


Figure 11a. Seismic activity (kilometers of lines surveyed) during the fall bowhead migration period from 1990 to 1998.

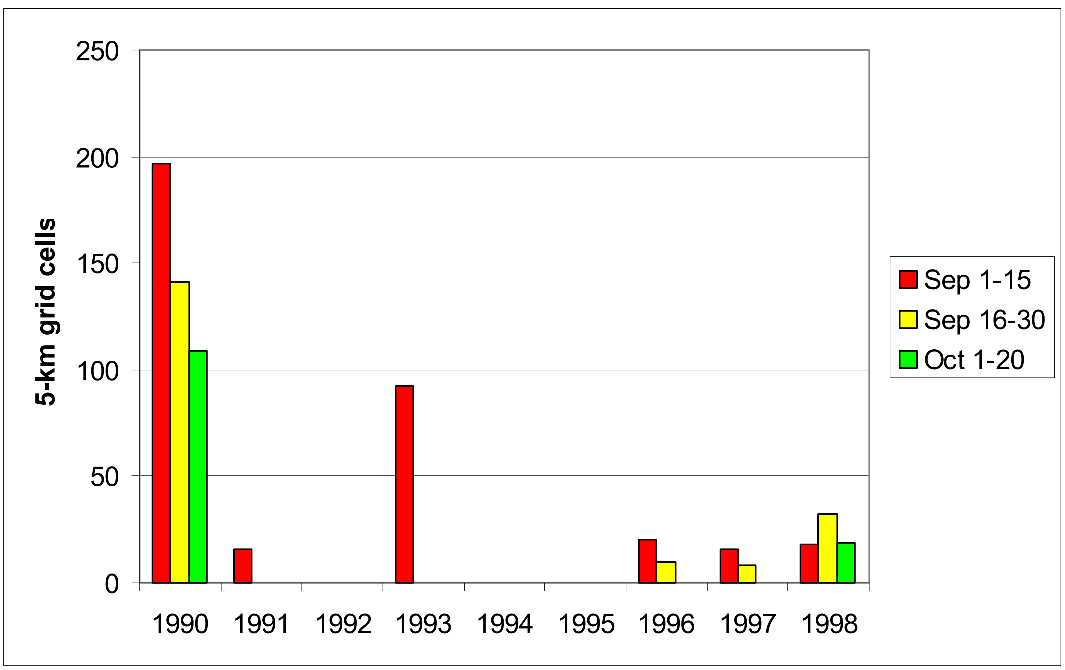


Figure 11b. Seismic activity (number of 5-km grid cells in which seismic activity occurred) during the fall bowhead migration period from 1990 to 1998.

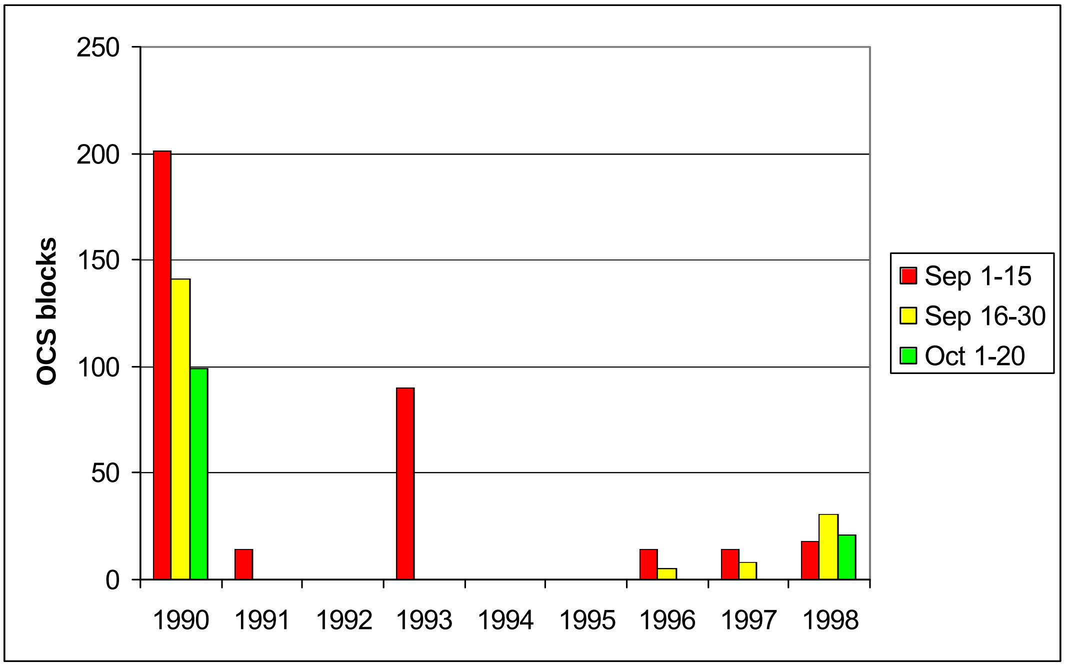
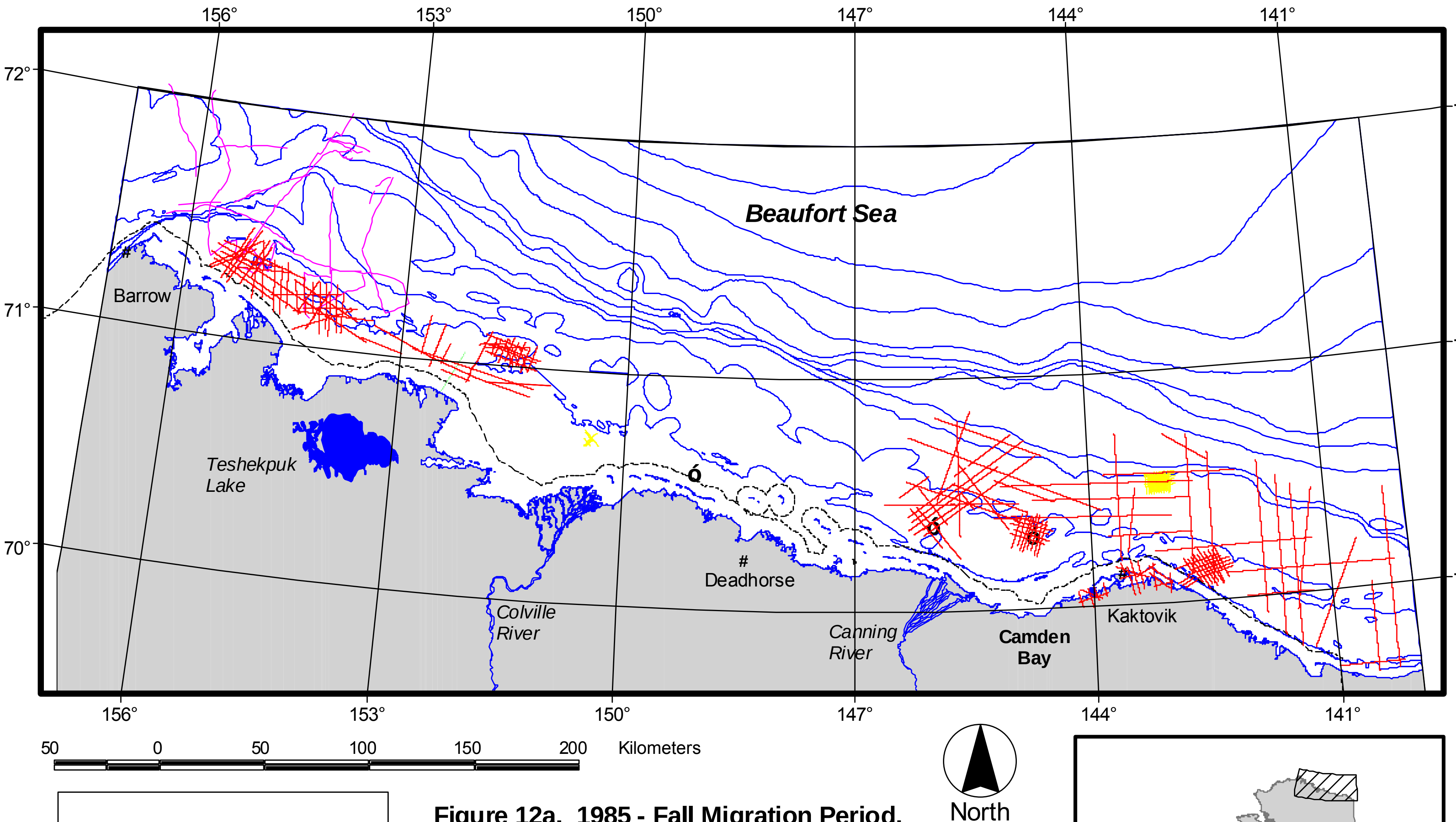


Figure 11c. Seismic activity (number of OCS lease blocks in which seismic activity occurred) during the fall bowhead migration period from 1990 to 1998.

While it is possible to compare the pattern of seismic activity in the 1990s with that for the 1980s, care must be used when making this comparison because the information on seismic activity in the 1980s for several years is substantially incomplete and in many cases dates of the surveys are not known. In general, the surveys are substantially larger in spatial coverage with a lower density of lines in the 1980s. The data for 1985 (Figure 12a, page 43) indicate an extensive area in which seismic activity occurred during the fall migration period.

Table 5 (page 46) and Figure 13a, b and c (page 49-50) provide a summary of drilling activity during the fall migration period by platform (caisson systems, drillships and artificial islands). Drilling from drillships (Explorer II and Kulluk) occurred only during 1991 to 1993 and only in OCS waters. The SSDC, a single caisson drilling system, was active in 1990 in OCS waters. The remaining active well locations were all artificial islands in State waters.

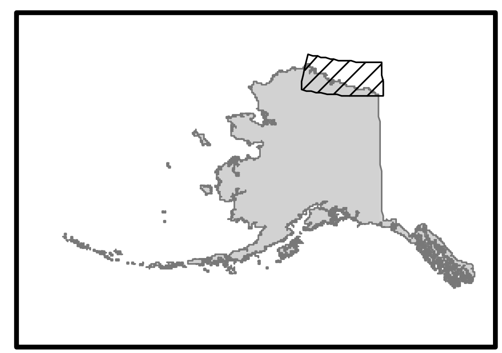
As discussed in Section 3.2.2, drilling from drillships is associated with more underwater noise that drilling from the SSDC or artificial islands. In addition to noise from drilling activity, drillships require ice ma nagement support during operations while the caisson systems and artificial islands only require ice management during construction and abandonment. It should also be noted that 1992 was considered a “bad” ice year in which significant ice management support was required and the Kulluk experienced frequent shutdowns because of the proximity of ice.

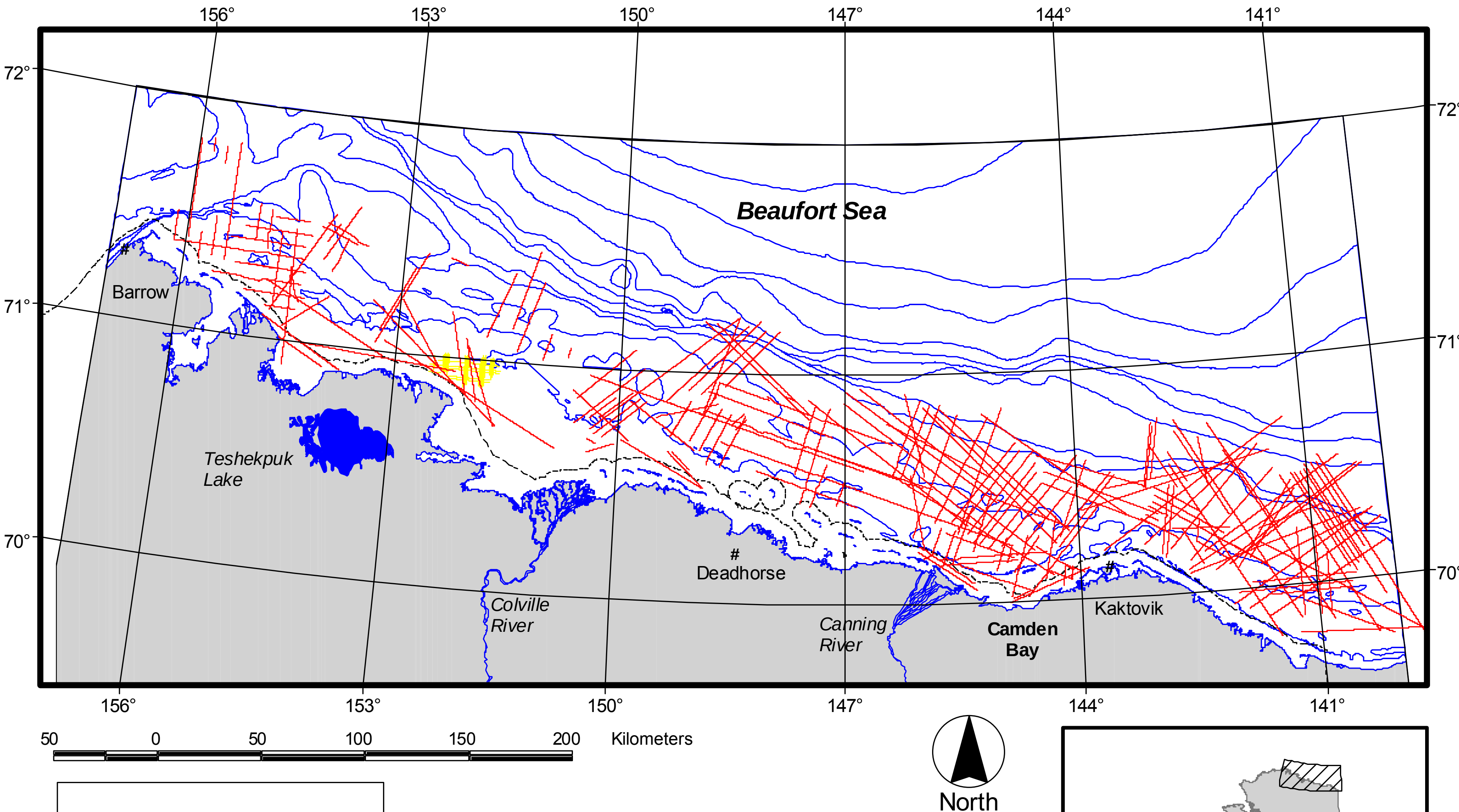


CDP Seismic Activity
ó Drilling - Drillship
Geohazard Seismic Activity
USGS Seismic Activity
USGS Acoustic Activity

Figure 12a. 1985 - Fall Migration Period, A significant amount of additional activities have uncertain dates and may also have occurred during this period.

(includes CDP, geohazard and USGS surveys, Federal OCS and State wells)





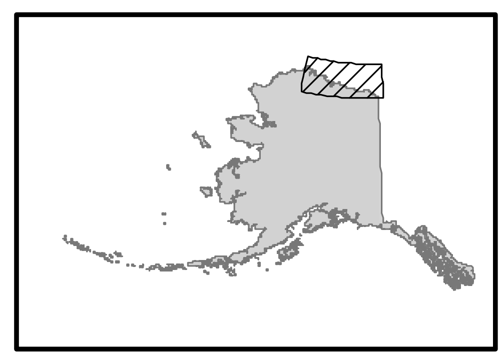


Figure 12b. 1985 - Uncertain Dates, Activities with uncertain dates that may have occurred during the fall migration period.

(includes CDP, geohazard and USGS surveys, Federal OCS and State wells)

Table 4. Summary of Seismic and Acoustic Activity During the Fall Bowhead Migration Period in the 1990s

		Seismic Activity[1]					**Acoustic Activity**	
		CDP Surveys			**USGS Surveys**		**Geohazard Surveys**	
		Sep 1-15	Sep 16-30	Oct 1-20	Sep 1-15	Sep 16 - Oct 20	Sep 1-30	Oct 1-20
1990	Line km	3934	867	1001	-	-	-	-
	5-km blocks	197	141	109	-	-	-	-
	OCS blocks	201	141	99	-	-	-	-
1991	Line km	94	-	-	-	-	-	-
	5-km blocks	16	-	-	-	-	-	-
	OCS blocks	14	-	-	-	-	-	-
1992	Line km	-	-	-	-	-	-	1213
	5-km blocks	-	-	-	-	-	-	26
	OCS blocks	-	-	-	-	-	-	29
1993	Line km	464		-	38	-	-	-
	5-km blocks	81		-	11	-	-	-
	OCS blocks	90	-	-	-	-	-	-
1994	Line km	-	-	-	-	-	-	-
	5-km blocks	-	-	-	-	-	-	-
	OCS blocks	-	-	-	-	-	-	-
1995	Line km	-	-	-	-	-	-	-
	5-km blocks	-	-	-	-	-	-	-
	OCS blocks	-	-	-	-	-	-	-
1996	Line km	917	224	-	-	-	-	-
	5-km blocks	20	10	-	-	-	-	-
	OCS blocks	14	5	-	-	-	-	-
1997	Line km	493	93	-	-	-	-	-
	5-km blocks	16	8	-	-	-	-	-
	OCS blocks	14	8	-	-	-	-	-
1998	Line km	761	779	637	-	-	-	-
	5-km blocks	18	32	19	-	-	-	-
	OCS blocks	18	31	21	-	-	-	-

[1] Some seismic surveys also employed acoustic survey methods. Acoustic surveys did not employseismic survey methods.

Table 5. Summary of Drilling Activity During the Fall Bowhead Migration Period in the 1990s

Year	Well Name	Platfrom	Activity	Hours Drilled Sep 1-15	Hours Drilled Sep 16-30	Hours Drilled Oct 1-20
1990	Fireweed #1	Canmar SSDC/MAT	Actively drilling	0	0	9.8
			Cleaning	0	0	4
			Stand by	0	0	11.3
			Tripping	0	0	17
			Total for Well	0	0	42.1
	Sag Delta North (2-32/SN03)	Artificial Island	Active (unknown)	360	360	66
	Sag Delta North (2-38/SN-01)	Artificial Island	Active (unknown)	0	0	385.5
			Pre drilling activity	0	0	40.5
			Totals for Well	0	0	426
			Totals for 1990	360	360	534
1991	Galahad	Explorer II	Abandonment	0	0	10.5
			Active (unknown)	0	24	0
			Actively drilling	8.5	127.5	200
			Cleaning	0	72.5	52
			Logging	0	74.5	78.5
			Pre drilling activity	9.5	43.5	0
			Tripping	6	18	2
			Waiting On Ice	0	0	3.5
			Totals for Well	24	360	346.5
			Totals for 1991	24	360	347
1992	Kuvlum #1	Kulluk	Abandonment	0	9.5	39
			Actively drilling	139.5	0	0
			Cleaning	12.5	0	0
			Logging	96.5	44	56.5
			Pre drilling activity	0	76	44.5
			Stand by	1.5	1.5	39.5
			Tripping	110	0	106
			Waiting On Ice	0	229	72.5
			Totals for Well	360	360	358
	Point McIntyre (P2-30)	Artificial Island	Active (unknown)	0	0	456
	Point McIntyre (P2-55)	Artificial Island	Active (unknown)	360	360	288
			Totals for 1992	720	720	1102
1993	Endicott (2-66/SD-12)	Artificial Island	Active (unknown)	360	360	20.5
	Endicott (3-25/M-27)	Artificial Island	Active (unknown)	0	0	41.5
	Endicott (4-02/Q-28 SDI)	Artificial Island	Active (unknown)	0	0	203
	Endicott (4-06/Q-32 SDI)	Artificial Island	Active (unknown)	0	6.5	0
	Kuvlum #3	Kulluk	Abandonment	0	0	16
			Actively drilling	138	112	0

Year	Well Name	Platfrom	Activity	Hours Drilled Sep 1-15	Sep 16-30	Oct 1-20
			Cleaning	22	27	8
			Logging	33	47.5	28
			Stand by	116.5	31.5	31.5
			Tripping	50.5	87.5	42.5
			Waiting On Whales	0	54.5	0
			Totals for Well	360	360	126
	Point McIntyre (P2-06)	Artificial Island	Active (unknown)	360	360	480
	Point McIntyre (P2-12)	Artificial Island	Active (unknown)	360	360	480
	Point McIntyre (P2-15)	Artificial Island	Active (unknown)	0	0	192
	Point McIntyre (P2-16)	Artificial Island	Active (unknown)	360	360	480
	Point McIntyre (P2-29)	Artificial Island	Active (unknown)	0	24	480
	Point McIntyre (P2-30)	Artificial Island	Active (unknown)	360	360	480
	Point McIntyre (P2-42)	Artificial Island	Active (unknown)	0	216	480
	Point McIntyre (P2-46)	Artificial Island	Active (unknown)	72	360	0
	Wild Weasel #1	Kulluk	Actively drilling	0	0	119
			Cleaning	0	0	67
			Logging	0	0	17
			Stand by	0	0	86.5
			Tripping	0	0	47
			Totals for Well	0	0	336.5
			Totals for 1993	2232	2767	3800
1994	Endicott (3-07/N-28)	Artificial Island	Active (unknown)	0	0	42
	Endicott (4-38/K-34)	Artificial Island	Active (unknown)	13	0	0
			Totals for 1994	13	0	42
1995	Endicott (1-31/M-21)	Artificial Island	Active (unknown)	0	0	7.5
	Endicott (1-33/M-23)	Artificial Island	Active (unknown)	350	324.5	0
	Endicott (2-16/M-16)	Artificial Island	Active (unknown)	3.5	0	0
	Endicott (4-06/Q-32 SDI)	Artificial Island	Active (unknown)	0	0	8.6
	Endicott (4-32/K-38)	Artificial Island	Active (unknown)	7.5	0	0
	Endicott (4-38/K-34)	Artificial Island	Active (unknown)	9.5	0	0
	Point McIntyre (P2-32)	Artificial Island	Active (unknown)	360	360	72
	Point McIntyre (P2-37)	Artificial Island	Active (unknown)	288	0	0
	Point McIntyre (P2-56)	Artificial Island	Active (unknown)	0	0	48
			Totals for 1995	1019	685	136
1996	Endicott (4-34/O-38)	Artificial Island	Active (unknown)	0	276	480
			Totals for 1996	0	276	480
1997	Endicott (1-19/I-18)	Artificial Island	Active (unknown)	5.7	0	0
	Endicott (2-46B/S-13)	Artificial Island	Abandonment	0	19	0
			Actively drilling	249.5	86.5	0

Year	Well Name	Platfrom	Activity	Hours Drilled		
				Sep 1-15	Sep 16-30	Oct 1-20
			Cleaning	9.5	35	0
			Logging	7.3	5	0
			Stand by	54.8	51.5	0
			Tripping	39	97	0
			Totals for Well	360.1	294	0
	Endicott (3-17B/M-31)	Artificial Island	Active (unknown)	0	12.3	0
	Point McIntyre (P2-27)	Artificial Island	Active (unknown)	360	360	480
	Point McIntyre (P2-33)	Artificial Island	Active (unknown)	0	144	480
	Point McIntyre (P2-36)	Artificial Island	Active (unknown)	360	360	480
	Point McIntyre (P2-45A)	Artificial Island	Active (unknown)	360	216	0
			Totals for 1997	1446	1386	1440
1998	Endicott (2-30/O-09)	Artificial Island	Active (unknown)	0	38	39
			Cleaning	0	0	10
			Logging	0	0	11
			Stand by	0	0	84
			Tripping	0	0	33
			Totals for Well	0	38	177
	Endicott (3-07A/L-29)	Artificial Island	Abandonment	18	0	0
			Actively drilling	122.1	0	0
			Cleaning	22.8	0	0
			Logging	17.9	0	0
			Stand by	54.4	0	0
			Tripping	109.3	0	0
			Totals for Well	344.5	0	0
	Endicott (3-17D/M-31)	Artificial Island	Abandonment	0	0	17.5
			Actively drilling	0	122.5	129.5
			Cleaning	0	20	21.5
			Logging	0	31	17.3
			Pre drilling activity	15.5	75	0
			Stand by	0	33.5	43.1
			Tripping	0	78	113.8
			Totals for Well	15.5	360	342.7
	Endicott (3-37/L-35)	Artificial Island	Active (unknown)	1.5	0	0.7
	Point McIntyre (P2-04)	Artificial Island	Active (unknown)	144	0	0
	Point McIntyre (P2-08)	Artificial Island	Active (unknown)	360	360	480
	Point McIntyre (P2-11)	Artificial Island	Active (unknown)	0	144	480
	Point McIntyre (P2-59A)	Artificial Island	Active (unknown)	0	0	312
			Totals for 1998	866	902	1792

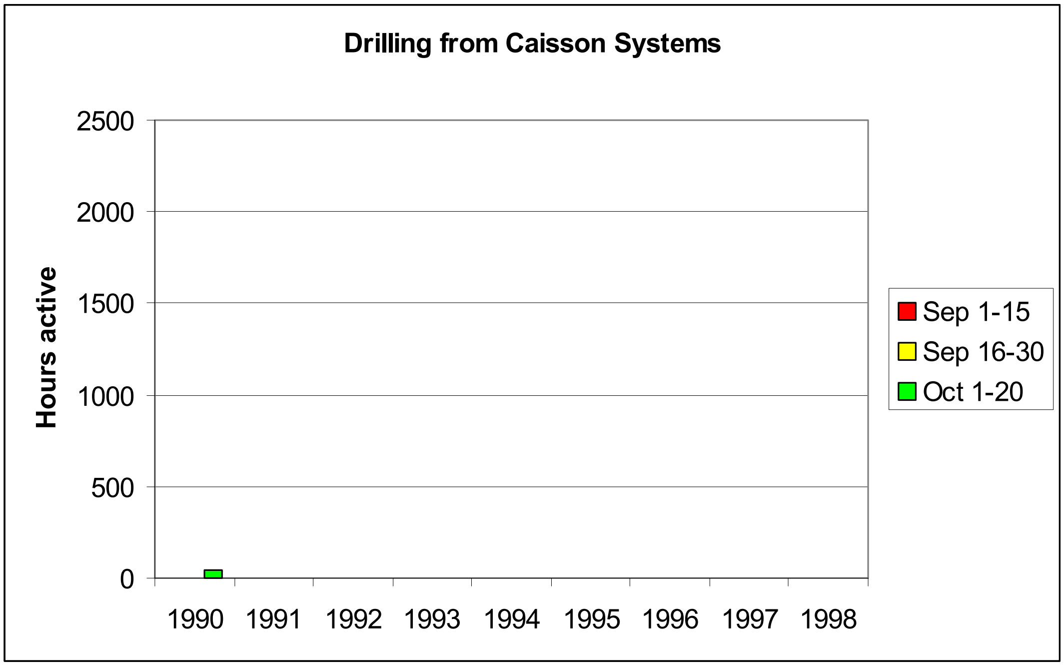


Figure 13a. Drilling activity from caisson systems (*i.e.* SSDC/MAT) during the fall bowhead migration period from 1990 to 1998 (hours of activity, excluding "waiting on ice" and "waiting on whales").

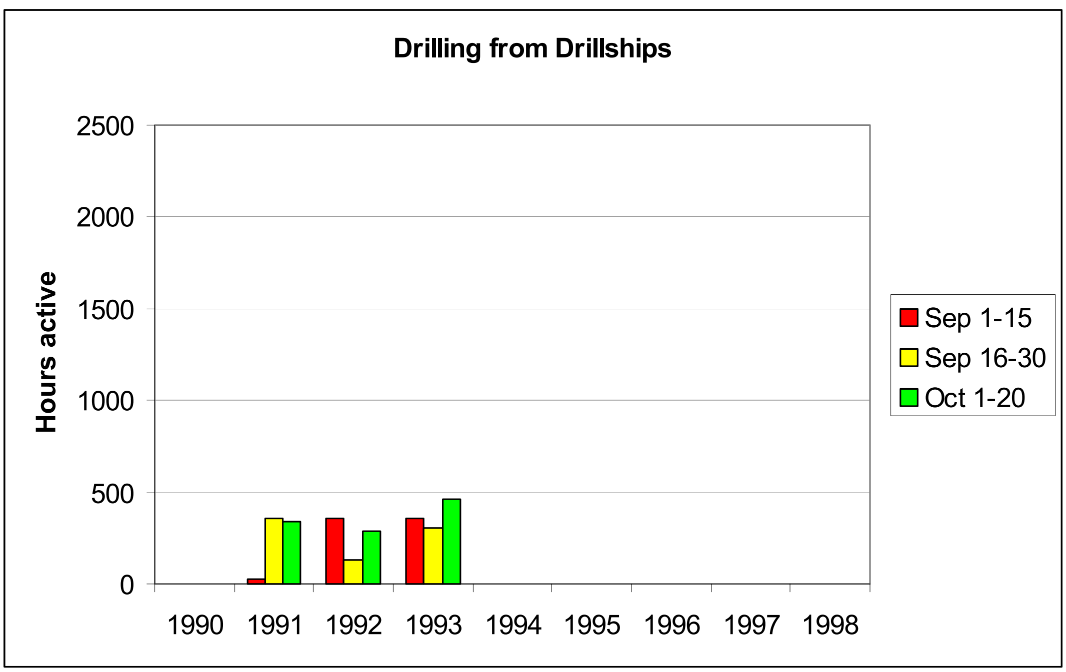


Figure 13b. Drilling activity from drillships (Explorer II and Kulluk) during the fall bowhead migration period from 1990 to 1998 (hours of activity, excluding "waiting on ice" and "waiting on whales").

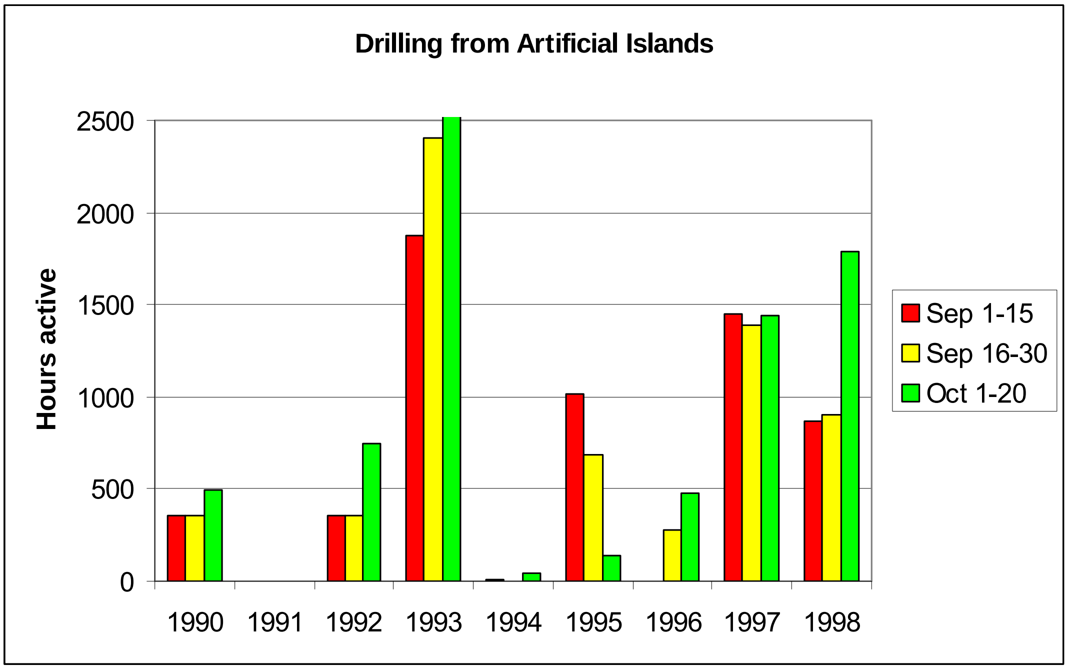


Figure 13c. Drilling activity from artificial islands (in State waters) during the fall bowhead migration period from 1990 to 1998 (hours of activity, excluding "waiting on ice" and "waiting on whales").

5. Discussion and Recommendations

Seismic Data (CDP and Geohazard Surveys):

1 MMS has relatively complete information describing seismic activity conducted since 1990. However, this is the result of fortuitous circumstance. Adequately detailed information about seismic activities conducted in State waters under MLUP permit is not publicly available and this study was unable to access proprietary information held by the State. Therefore, there was a significant potential that information about seismic activity since 1990 would be incomplete. However, it was fortunate that in all cases all seismic activities since 1990 where a MLUP permit was issued had also received an OCS permit and that the companies had chosen to provide MMS with details of the activity conducted in State waters.

It is inevitable that some activities will receive a MLUP permit and not require an OCS permit. Therefore, unless a data sharing agreement is reached with the State, one expects that MMS will have some data gaps in future years. ***It is recommended that MMS initiate discussions with the State regarding access to proprietary seismic data for inclusion into the HAD.***

2 In many cases, the data on seismic activities submitted by companies to MMS documents only the seismic lines and shots that were completed to specifications. For environmental assessment purposes it is also important to consider the lines that were not shot to specifications, any activity associated with testing or calibration of the seismic source, and "ramping" (source firing at reduced levels)

between lines. During calibration or between lines it is possible that the source is firing at different levels than during normal production lines. Such differences in source levels may also be important for environmental assessment.

It is recommended that MMS consider requiring companies to submit more complete documentation of seismic activity including location coordinates, shotpoint number, date, time, type of source and source levels for all shots including off specification, between lines, testing and calibration. Documentation should consist of two data sets: a "raw" data set with the above information for <u>all</u> shotpoints; and a "cleaned" data set with only the shotpoints that were completed to specifications.

3 **<u>Navigation Data (CDP, Geohazard and Pipeline Surveys)</u>**:

In loading the electronic data on seismic activity from the MMS Field Operations Vault it became apparent that the data submitted to MMS varied significantly in formats and completeness of documentation. With few exceptions none of the data were formatted in a manner that allows easy inspection using GIS. This presents obstacles to quality assurance or inspection of the data as received. This is of concern because the time of submission would be when companies can most effectively address questions or deficiencies.

Some of the problems observed with the data from the Vault included lack of documentation of UTM Zone or whether coordinates were in feet or meters, some invalid dates and times and missing coordinate information were also encountered. In one case, the data submitted did not appear to be complete. Some data sets were mislabeled.

It is our opinion that if data were submitted in a common GIS format, such as ESRI shapefiles, that this would not be a burden on the companies and would greatly facilitate inspection by MMS at the time of submission. ESRI shapefiles are a public (open source) format that is widely supported by commercial and public domain GIS software***. It is recommended that MMS consider requiring companies to submit electronic data as ESRI shapefiles with documentation of map projection and attribute data. Required attribute data are described in recommendation #2 above.***

4 <u>Drilling Activity:</u>

Information on drilling activity was relatively complete. Information submitted to MMS and the State in daily drilling reports since 1990 provided sufficient detail for this study. Almost all cases where there was less detail than considered adequate were prior to 1990. The few problems that were encountered in reports since 1990 were cases of illegible fax copies or a few missing pages in the files. It seems likely that existing procedures will continue to provide a source of adequate information on drilling activity.

Submission of daily drilling reports in electronic format could facilitate loading data into the HAD. This could consist of a simple spreadsheet format where each row would include start date (GMT), start time (GMT), end date (GMT) end time (GMT) and a description of the activities conducted. However, it is recommended that companies not be required to report activities using the HAD classification at this time. This would require documentation, training, and support and could interfere with timely submission of daily drilling reports.

5 Ice-Management Activity:

Very limited information was obtained on ice management activity (ice-breaking). The only information available is incidental records of ice-breaker positions recorded during aerial surveys. It was not possible to obtain access to the log books of the vessels involved in ice-management. These log books are believed to have been destroyed. It was not possible to identify any other information source that might provide significant information on ice management activity. **Since ice management activity (at least one vessel) is routinely associated with drillship operations, this represents a substantial level of activity which is not adequately described.** Ice management activity represents a substantial level of activity which is missing from the database and from the maps (*e.g.*, Figure 2 through Figure 10), especially for the years 1991, 1992 and 1993. This remains a significant data gap.

It is not likely that information on future ice management or ice-breaking activity will become available unless there is a directed effort towards ensuring that these data are collected in future. ***If investigation of potential effects of disturbance from ice management and ice-breaking is considered a priority, it is recommended that MMS consider working in cooperation with operators to ensure that these data are collected.***

6 Seismic and Acoustic Data (CDP, Geohazard and Pipeline Surveys):

Some information describing the nature of acoustic sources (source levels and frequency distribution) was compiled and loaded in the database. However, higher priority was given to compilation of basic information describing location, date and time. Therefore, a substantial body of acoustic data (source and ambient observations) exists and was not loaded into the database. Much of these data are in hard copy tabular formats or stored in analogue format on magnetic tapes. It is not likely that the compilation of these data would be of short-term benefit for the statistical analysis of potential effects of human activities on bowhead whale migrations. However, there is a potential that some data may be lost if no effort is made to archive them.

7 Acoustic Properties of Sediments:

The efforts in this study to produce a GIS data set on sediment properties to support acoustic modeling based on existing information met with limited success (Appendix 2). This is due to three factors: (1) There is a lack of consensus on the general composition and origins of the upper layers of the regional continental shelf. (2) The available information does not provide complete spatial coverage of the study area. (3) The estimation of acoustic properties (sound velocities, attenuation coefficients and densities) based on stratigraphy is based on limited data.

The limitations of the current GIS data set on acoustic properties of the seafloor limit the ability to model underwater sound propagation with confidence. This presents an information gap that could potentially be addressed by a large-scale compilation of existing data and synthesis analysis. However, it is likely that a substantial amount of proprietary industry data exist that were not considered in previous analyses of regional stratigraphy and/or may be relevant to estimation of acoustic properties. The success of such a synthesis analysis likely depends on the access to these proprietary data.

Of particular interest would be additional data for areas identified by this study as having substantial contents of Categories A, A/B, B and B' (*i.e.*, Appendix 2, layers 1 and 2) should be analyzed to both further confirm the distinctions made between the Holocene and Holecene/Late Pleistocene species and to quantify the validity of extrapolations of category thicknesses and sequencing into areas not included in the earlier studies. Additional information on the locations and acoustic properties of the internal reflectors (B') characteristic of category B are also of interest.

Better information on acoustic properties of the seafloor would improve the ability to model underwater sound propagation. However, this may be of limited benefit to MMS without information to characterize the location, timing and nature of industrial noise sources. Further, this would not eliminate the need for direct observations of sound in future site-specific studies.

It is recommended that MMS give modest priority to a large-scale compilation of existing sediment data and a synthesis analysis of stratigraphy and acoustic properties provided that access to relevant proprietary industry data can be secured. A sensitivity analysis of sound levels at various ranges from sources as functions of both the composition of the sea floor and the above acoustic parameters would be useful in assessing the priority that should be given to improving this data set.

8 Human Activities Database:

Substantial effort has been expended on the development of the Human Activities Database. However, the structure of the database and the classification of data records have not yet been evaluated by attempting to use the database for specific purposes, such as hypothesis testing. ***It is recommended that before substantial additional effort is expended to expand the database or make the database available in a distributed, multi-user environment (such as Oracle/SDE), that the structure, completeness and standards used in the database be evaluated by attempting to use the database on a pilot basis for practical applications.***

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Appendix 1.
Selected Documents Pertaining to the Data Compilation

Letter of Introduction Requesting Assistance by Authorizing Release of Information

November 3, 1998

Re: Request for Assistance on a Project to Develop a GIS Database of Oil and Gas Related and Other Human Activities in the Beaufort Sea Between 1979 - 1998

Gentlemen;

Recently MMS awarded a contract to LGL Limited to develop a GIS database of oil and gas related and other human activities in the Alaskan Beaufort Sea between 1979-1998. We plan to use this database to analyze potential effects of oil industry activity on subsistence whale hunting and to test hypotheses related to factors affecting bowhead whale distribution and relative abundance as described in the MMS Bowhead Whale Aerial Survey Program (BWASP) reports.

We first would like to explain the background of our project, provide a brief project description, and request your assistance in making information available to the study team.

Background

Subsistence hunters and others living within the coastal villages of the Beaufort Sea have voiced concerns about the possible effects that oil and gas activity may have on the behavior of marine mammals, especially the bowhead whale. Their concerns involve seismic activity, drilling, and oil and gas support vessel activities within the Beaufort Sea. Concerns related to seismic activity were raised at an MMS sponsored workshop on seismic noise in the Beaufort Sea (OCS Study MMS 97-0014).

Residents expressed concerns that past seismic and other industrial activity from the oil industry has shifted the migration route of the bowhead whale farther offshore. Also, there are concerns that noise from drilling activities associated with ice breakers, resupply ships, tugs, helicopters, and noise from the seismic vessel and instrumentation from the seismic source may have altered the normal whale migration route.

Maps of prior oil industry activity shown at the seismic workshop were inconclusive and had not resolved the temporal relationship between past seismic activity and possible bowhead displacement. Previous studies in evaluating the effects of marine mammals on oil industry activity have also been inconclusive, because they pertained to individual instances, within a brief window, over a small geographic area. Therefore, we need an historical database for oil and gas industry activity and other human activities in order to determine any long term disturbance effects on the bowhead whale in the Beaufort Sea.

<u>Project</u>

The objective of this study is to compile detailed information describing the locations, timing, and nature of these human activities in the Alaskan Beaufort Sea between 1979-1998. This information will be stored in ArcView and an application will be developed to analyze and display this information graphically, particularly in regards to potential noise and disturbance associated with human activities.

<u>Data Request</u>

We need your assistance in obtaining the human activity data for this project in order for us to address the concerns of the subsistence hunters on the North Slope of Alaska. We recognize that information on some oil industry activities, such as details of recent exploration activities, may be sensitive. The information of interest to this project is of a non-sensitive nature (e.g. locations of helicopters, icebreakers, timing of drilling activity), except for CDP shotpoint seismic navigation survey files under Permit. ***We will ensure that sensitive information is protected***. This will be accomplished by:

All members of the study team will sign appropriate non-disclosure agreements.

The "data owners" will be given the opportunity to review the contents of the draft database and will be able to veto the inclusion of any proprietary information prior to project completion.

The database will be maintained by MMS in Oracle/SDE. Proprietary data can be included and appropriately identified so that access to sensitive information is restricted.

Where practical, specific location information can be generalized to a broader area. In this manner, specific location information which may be sensitive can be protected, but information about timing and nature of activity is still made available.

The objective of the study is to compile as complete and detailed information on oil industry related activities as possible, because decision making is improved when complete information is available. However, we respect the need to protect sensitive information.

We seek your help to achieve the project objectives by (1) authorizing access to information held in the MMS security vault and other repositories, for the purpose of allowing the contractors to compile *non-sensitive* information, and (2) providing access to additional specific information, particularly information concerning the collection of High-Resolution, CDP seismic shotpoint data and their daily activity logs. These data are collected during geophysical surveys conducted under State of Alaska and OCS Federal Permits for the Beaufort Sea, held by your organization and/or contractors on behalf of your organization.

Therefore, we ask that:

You respond in writing <u>as soon as practical</u> providing authorization for access to information in the MMS security vault and other repositories for the compilation of *non-sensitive* information contained in geohazard reports, navigation tapes, daily drilling reports, oceanographic/meteorological data, daily seismic logs, and post plot maps, pertaining to your company's operations between 1979-1998 on all leases within the Beaufort Sea solely for use in this project as described in this letter (attachment 1).

You respond in writing providing authorization for access to *non-sensitive* information from geophysical surveys and daily drilling reports held by the State of Alaska pertaining to your company's operations between 1979-1998 within the Beaufort Sea solely for use in this project as described in this letter (attachment 1).

You forward a copy of this letter to relevant contractors before November 16th 1998 authorizing them to release shotpoint navigation file and daily seismic activity log information about specific CDP and HRD geophysical surveys under Permit (attachment 1) to the study team for this project and requesting that they provide reasonable assistance.

On completion of the study we will be pleased to send a copy of the final report and a subset of the database containing the information describing your organization's activities to the organization that cooperated with the study.

The study team for the project consists of LGL Limited (prime contractor), Environmental Systems Research Institute Inc. (ESRI), Greeneridge Sciences Inc., Charles I. Malme Engineering and Scientific Services and ASL Environmental Sciences Ltd. We expect that the project will take up to two years to complete.

For your convenience an example letter of authorization with respect to non-sensitive information held by MMS is found in attachment 2. It would be of considerable benefit to the study if you would provide verbal authorization to access non-sensitive information in daily drilling reports held in the MMS Field Operations Vault by calling Mr. Jeff Walker, Regional Supervisor for Field Operations, Alaska Region, at (907) 271-6190. This would allow the study team to begin to the compilation process.

Thank you in advance for your cooperation and timely response. If you have any questions about the project or this request for assistance or wish to discuss the project and its objectives, please contact Warren Horowitz at (907) 271-6554. Questions of a technical nature about the database and protection of sensitive information can be directed to the consultant's Project Manager, Peter Wainwright at (250) 656-0127.

Yours Sincerely,

John Goll
Regional Director MMS

cc. Warren Horowitz
Peter Wainwright

(Attachment 2)

Date:

Warren Horowitz
Minerals Management Service
Alaska OCS Region
949 E. 36th Avenue
Anchorage, AK 99508-4363
fax: (907) 271-6504

Re: Request for Assistance on a Project to Develop a GIS Database of Oil and Gas Related and Other Human Activities in the Beaufort Sea Between 1979 - 1998

This letter is to authorize access to information in the MMS security vault and other repositories for the compilation of *non-sensitive* information contained in geohazard reports, navigation tapes, daily drilling reports, oceanographic/meteorological data, daily seismic logs, and post plot maps, pertaining to Company's _____ operations between 1979-1998 on all leases within the Beaufort Sea solely for use in this project as requested in Mr. John Goll's letter of November 3, 1998.This letter is to authorize access to information in the MMS security vault and other repositories for the compilation of *non-sensitive* information contained in geohazard reports, navigation tapes, daily drilling reports, oceanographic/meteorological data, daily seismic logs, and post plot maps, pertaining to Company's _____ operations between 1979-1998 on all leases within the Beaufort Sea solely for use in this project as requested in Mr. John Goll's letter of November 3, 1998.This letter is to authorize access to information in the MMS security vault and other repositories for the compilation of *non-sensitive* information contained in geohazard reports, navigation tapes, daily drilling reports, oceanographic/meteorological data, daily seismic logs, and post plot maps, pertaining to Company's _____ operations between 1979-1998 on all leases within the Beaufort Sea solely for use in this project as requested in Mr. John Goll's letter of November 3, 1998.This letter is to authorize access to information in the MMS security vault and other repositories for the compilation of *non-sensitive* information contained in geohazard reports, navigation tapes, daily drilling reports, oceanographic/meteorological data, daily seismic logs, and post plot maps, pertaining to Company's _____ operations between 1979-1998 on all leases within the Beaufort Sea solely for use in this project as requested in Mr. John Goll's letter of November 3, 1998

Yours Sincerely,

NONDISCLOSURE AGREEMENT

In connection with the employment of ____________________ a resident of _______________ (the "Employee") by LGL Alaska Research Associates Inc. and the performance of work required under contract 1435-01-98-RP-30915: "Reference Manual and GIS Geospatial Database of Oil-Industry and Other Human Activity (1979-1998) in the Beaufort Sea" (the "Contract") between LGL Limited and the Minerals Management Service (MMS), the Employee has requested access to certain information held in the MMS Field Operations Vault which MMS has agree to provide under this nondisclosure agreement (the "Agreement") on the following terms and conditions:

1. As a condition to MMS allowing the Employee access to such information, MMS requires that the Employee agree as set forth below to treat confidentially any and all information pertaining to current and historical oil and gas exploration and production activities in the Alaskan Beaufort Sea including daily drilling reports, navigation tapes, and records of geophysical permits, which MMS or its officers, employees, counsel, or agents (hereinafter collectively "Representatives") furnishes to the Employee in connection with the performance of this Contract, whether furnished before, on or after the date of this agreement, and all notes, analyses, compilations, studies, reports, or other documents prepared by the Employee, which contain or otherwise reflect such information (collectively, the "Information").
2. The Employee hereby agrees that the Information will not be used by the Employee expect for the purpose of performing the work specified in the Contract, and will be kept confidential by Employee for a period of twenty-five (25) years from the date hereof; provided however, that:
   i) any of such information may be disclosed to other employees of LGL Alaska Research Associates Inc or LGL Limited who need access to such information for the purpose of completion of the Contract, all of whom shall be informed by the Employee of the confidential nature of such information and shall be directed by the Employee to treat such information confidentially;
   ii) any disclosure of such information may be made to which MMS consents in writing; and
   iii) the obligation of confidentiality and non-use contained herein shall not extend to such of the Information which (a) at the time of its receipt by the Employee is already in, or subsequently comes into, the public domain through no fault of the Employee, LGL Alaska Research Associates Inc. or LGL Limited (but only to the extent that it so becomes available), or (b) becomes available to the Employee without restriction on disclosure from a third party who has a lawful right to make a disclosure thereof.
3. The Employee will promptly upon the request of MMS return to MMS all of the Information furnished by, or on behalf of, MMS, without retaining any copy thereof, and any analyses, compilations, studies, reports, or other documents which may be prepared by the Employee which reflect Information will be kept confidential by the Employee and will not be used in any way, or shall be destroyed upon request of MMS, such destruction to be certified in writing to MMS by the Employee.

4. It is acknowledged that MMS does not make any representations or warranties as to the accuracy or completeness of the Information. It is agreed that neither the MMS nor its Representatives shall have any liability to the Employee resulting from the use of the Information.
5. It is acknowledged that the Agreement and the obligations created under this Agreement survive beyond the term of the Contract.
6. In the event that the Employee is requested or required by oral questions, interrogatories, requests for information or documents subpoena, civil investigative demand, by order of any governmental authority, or similar legal process to disclose any of the Information supplied to by MMS in the course of the completion of the Contract, it is agreed that the Employee will provide MMS with prompt written notice of such request(s) so that MMS may seek an appropriate protective order and/or waive compliance by the Employee with the provisions of this Agreement. It is further agreed that if, in the absence of a protective order or the receipt of a waiver hereunder, the Employee is nonetheless, in the opinion of its counsel, compelled to disclose any of the Information to any tribunal or else stand liable for contempt or suffer other censure or penalty, the Employee may disclose such information to such tribunal hereunder, provided the information so disclosed is clearly marked as confidential to MMS.
7. The Employee acknowledges and agrees that a breach of the provisions of this Agreement would cause MMS to suffer irreparable damage that could not be adequately remedied by an action at law. Accordingly, the Employee agrees that MMS shall have the right to seek specific performance of the provisions of this Agreement if necessary to prevent disclosure of the Information, such right being in addition to all other rights and remedies that are available to MSS at law, in equity, or otherwise.
8. If any provision of this Agreement or its application is held to be invalid, illegal, or unenforceable in any respect, the validity, legality, or enforceability of any of the other provisions and applications therein shall not in any way be affected or impaired.

This Agreement shall be governed and construed in accordance with the laws of the State of Alaska.

IN WITNESS WHEREOF, this Agreement has been signed on this ____________, 2000

By: ____________________________	By: ____________________________
Printed Name: ___________________	Printed Name: ____________________
Title: ___________________________	Title: ____________________________
Organization: ____________________	Organization: _____________________
Address: ________________________	Address: _________________________
_______________________________	________________________________

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Name
Company
Street Address
City, State, Zip

Dear Name:

The Minerals Management Service (MMS) has contracted with LGL Limited (hereafter referred to as the contractor) to compile a Geographic Information System database of oil and gas activities (drilling, vessel, seismic operations, and aircraft traffic) in Federal and State waters in the Beaufort Sea, Alaska. These data, as well as ice coverage data, will be used within a future study to correlate any possible effect on the migration of the bowhead whale. Specifically, the contractor will have access to navigation tapes, the weekly progress reports, and the final completion reports from the seismic surveys on the following list. The purpose of these data is to determine where vessels were operating at any given time.

MMS Permit Number	Nature of Survey

Prior to the MMS disclosing any proprietary information to the contractor, the contractor or the contractor's agent will be required to execute a written commitment not to transfer or to otherwise disclose any information or data to anyone.

Following completion of the study, the MMS may wish to publish certain generalized information concerning the location of seismic vessels. This generalized information will not be published without your written consent.

If you care to comment on the use of these data, please contact this office within 10 working days of receiving this letter. Thank you for your assistance in this manner. It is our hope that this study will be part of a more analytical approach to whether or not oil and gas activities have had any effect on the bowhead whale and to what degree.

If you have any questions, please call Rance Wall at (907) 271-6060.

Sincerely,

Larry W. Cooke
Acting Regional Supervisor
Resource Evaluation

Appendix 2.
Preparation Of A Sediment Stratigraphy Representative Of The Alaskan North Slope

by

John R. Marko

ASL Environmental Sciences Inc.
1986 Mills Road, R.R. 2
Sidney, B.C.
V8L 5Y3

March, 2001

File No. 61-394-M

Abstract

Acoustic sounding and geohazard drilling data as well as analytic studies of seafloor stratigraphy based upon such data were reviewed to develop a basis for setting up a subsea sediments database capable of supporting modeling of acoustic propagation in waters shallower than about 80 m on the continental shelf between 141°W and 152.5°W. Our approach identified 5 major categories of sediment layers recognized in earlier studies which appear to form a basis for describing the subfloor down to depths relevant to acoustic propagation in the overlying ocean. These categories were largely based upon identifications made by Foster in the western part of the study area and appeared consistent with observations made by other workers in the same and other areas. Occurrences of theses categories was documented in a 3-layer GIS database which also included surface characterizations for local areas known to have anomalous surface showings of boulders gravel etc. A fourth layer, semi-infinite in extent, forms the foundation for all other overlying layers is assumed to be composed on one of the identified categories.

Acknowledgements

This project was heavily reliant on key inputs of reports, anecdotal information and insights from the U.S. Geological Survey and its present or past personnel. Particularly key individuals in this regard, were Stephen Wolf, Erk Reimnitz and David Foster. Their patience and active cooperation were greatly appreciated.

2-1. Background

Development of an MMS model of sound propagation in marine areas on the North Slope of Alaska requires realistic descriptions of variations in sound speed (c_s), mass density (ρ) and dissipation or attenuation rates (a) in both the water column and in the upper layers of the regional seafloor sediments. Such descriptions allow specification of characteristic acoustic impedances for plane wave propagation:

$$Z_s = \rho c_s ,$$

which, together with attenuation rates, determine reflected and refracted sound levels in the presence of non-uniform propagation in the marine and underlying terrestrial layers.

Given the relatively narrow temporal windows of interest, namely, the late summer-early fall marine mammal migration periods, approximate water column acoustic specifications are available from accumulated CTD (conductivity, temperature and density) profiles and established relationships between sound speed and attenuation rates and the latter parameters. Some difficulties in this regard are anticipated in shallower waters and in the vicinity of major river mouths where factors, such as wind direction, states of ice clearance and melt, impact directly on the character of the water column. On the other hand, such circumstances also diminish the relative importance of the in-water portions of the acoustic propagation paths, reducing sensitivity to water column variability and allowing generic seasonal profiles to be used with moderate accuracy.

Equivalent generic characterizations of sub-sea floor portions of acoustic paths are more problematic because of both the extremely complicated and spatially inhomogeneous nature of North Slope geology and the greater technical and logistical challenges involved in ascertaining its details. Specifically, the present sea floor and its underlying sediment structures are a consequence of terrestrial- and marine-depositions and sub-aerial- and sub-marine-erosion-processes acting during the numerous cycles of sea level advance and retreat associated with the past million years or so of the Earth's history. The resulting sequences of large-scale, relatively uniform sediment layers or stratigraphic types also typically show local idiosyncrasies or modifications associated with nearby terrestrial geology, ancient estuaries or paleovalleys and past effects of sea ice movement and sub-aerial exposure to freezing temperatures. Unfortunately, characterizations of larger scale stratigraphic structures and their local modifications must be deduced from data which are very limited in spatial extent: usually comprised of at most, several dozen borehole sediment profiles and recorded echo returns of "boomer" acoustic impulses periodically transmitted downward along relatively narrow survey vessel tracks. Interpretations of these returns in terms of distinct sediment layers, each associated with a relatively common set of geological origins and physical properties, are often ambiguous and dependent upon simple constant sound speed assumptions which have only approximate validity. Some non-uniformities internal to individual stratigraphic units, associated with, for example, relict permafrost and gas pockets, introduce particularly large discontinuities in acoustic impedance which produce acoustic reflections strong enough to prevent meaningful probing of deeper layers. Actual assignments of sound speed, density and attenuation rate values to the identified distinct layers must eventually be made using results from a small number of detailed studies (Hamilton, 1980) of such properties or from standard listings of "typical parameters" for various categories of sediment type (Urick, 1983).

2-2. Methodology

2-2.1 General Approach and Definition of Categories

Our characterizations of the acoustic properties of sub-sea portions of the North Slope draw upon bodies of acoustic sounding or stratigraphic data and accompanying borehole drilling results which have been collected since the early 1970's by USGS researchers and independent geological consultants in conjunction with hydrocarbon exploration activities. Data and analyses were obtained in the form of reports and charts for selected portions of the inshore continental shelf (Figure 2-1) between, roughly, Cape Halkett (152.5°W) and Demarcation Bay (141°W). Major contributions to this body of knowledge date back to 1972 (Reimnitz and Bruder, 1972; Reimnitz et al., 1974) with research activity peaking in the 1980's in preparation for actual North Slope hydrocarbon production. Results obtained in this and subsequent periods have led to a slowly evolving and still fairly tentative consensus picture of the composition and origins of the upper layers of the regional continental shelf.

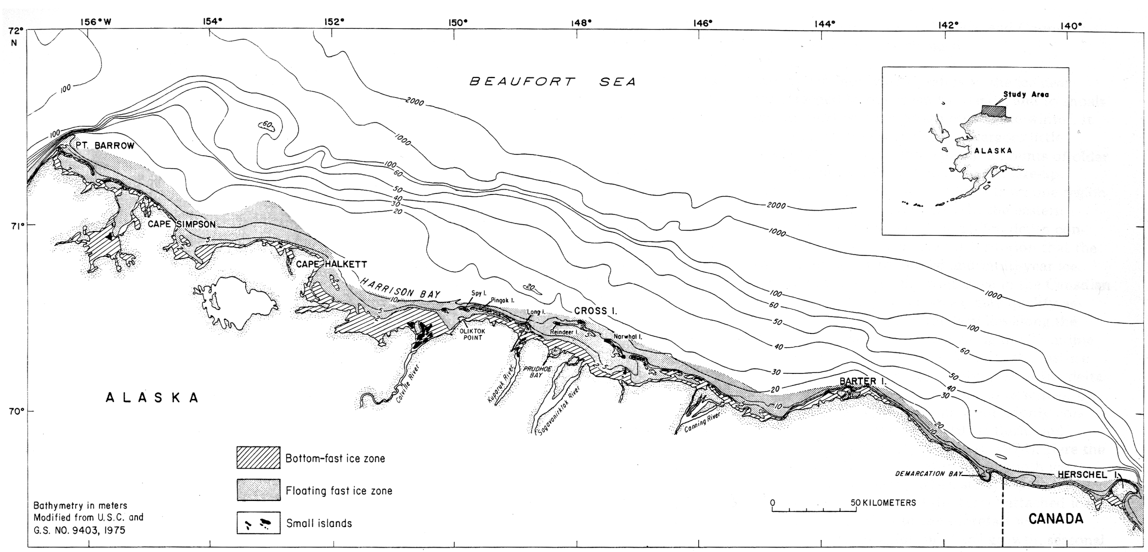
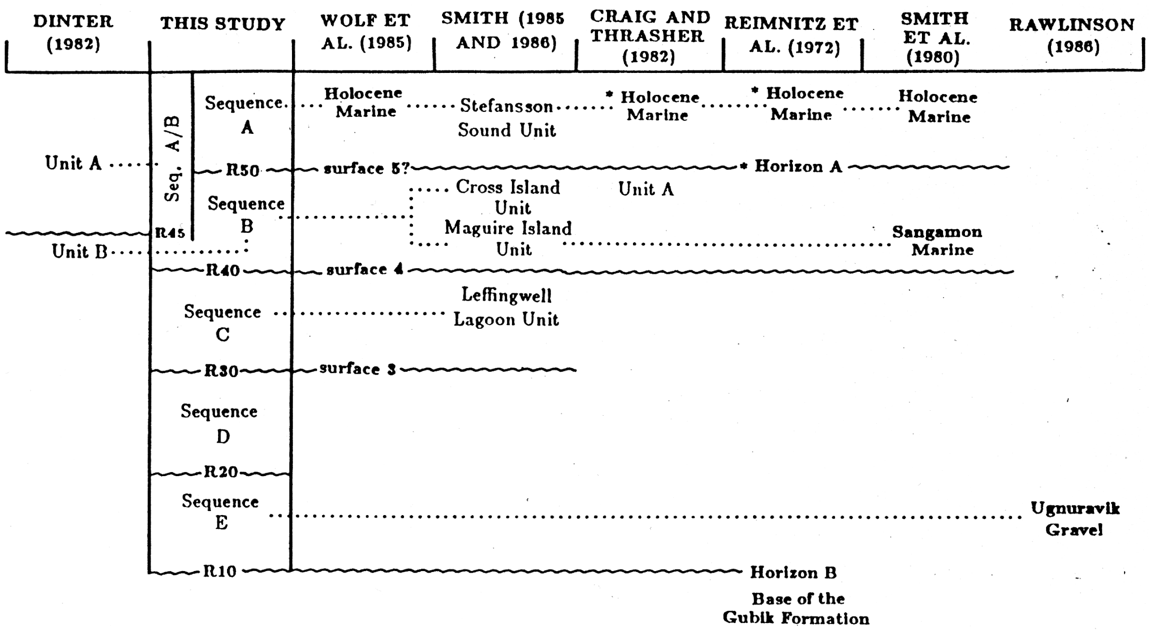


Figure 2-1. Bathymetric features and place names of the greater North Slope study region (Reimnitz et al., 1978).

Particular difficulties were encountered in characterizing the uppermost regional sediment layers, with early workers (Reimnitz et al., 1972; Craig and Thrasher, 1982; Dinter, 1982) associating such layers with Holocene deposits which thicken in offshore directions to reach layer depths as large as several tens of meters on the middle and outer continental shelves. Subsequent work by Wolf et al. (1985), Foster (1988) and Reimnitz and Wolf (1998) has reinterpreted these data in the light of later recognitions of the highly erosional nature of the regional shelves. In this view, true Holocene sediments are presently confined only to a relatively small number of inner shelf areas and protected embayments. Even in such areas there is abundant evidence of physical mixing of these and older sediments by ice gouging and hydraulic processes. This conception of the sea floor was first offered by Foster (1988) based upon analyses of data recorded between western Prudhoe Bay and Cape Halkett at the west end of Harrison Bay as well as from earlier data from more eastern areas analyzed by Wolf et al. (1985). Foster's work included specific efforts to establish connections or cross-linkages between the derived identifications and previous classifications of stratigraphy in both the same study area and in other portions of the North Slope shelf and on the adjacent Alaskan Coastal Plain. Numerous additional discussions of the resulting cross-linkages, illustrated in Table 2-1, were held with S. Wolf of the USGS during the present study to maximize the compatibility of our descriptions with current "state of the science" understandings.

Table 2-1. Correlation of stratigraphic units on the Beaufort Sea shelf and the adjacent Arctic Coastal Plain. Dotted lines show correlation between units and wavy lines show correlation of reflectors (Foster, 1988).



Our decision to use the stratigraphic units and notation developed by Foster as the principal basis of our classification scheme was dictated by a motivating need to extract acoustic modelling data on a fairly wide regional basis from a very patchy body of previous classifications derived from highly localized individual studies. This approach allowed coverage of shelf areas between the Canadian border in the east and 152.5°W in the west based upon the 5 independent studies or reports listed in Table 2-2, each of which provide information on different but sometimes overlapping portions of the overall area of interest.

Table 2-2. Principal sources for stratigraphic mapping in this study

Study	Spatial Boundaries: western (°W); eastern (°W): range of water depth (m).
Craig and Thrasher, 1982	152.5, 150; 5-30
Foster, 1988	151; 148; 0-50
Wolf et al., 1985	149; 145.5; 0-40
Dinter, 1982	147.5; 141; 20-100
Wolf et al., 1989	146; 141; 0-50

An additional summary of: Foster's stratigraphic categories; their connections with earlier studies; and their times of deposition (both in terms of geological epochs and in thousands of years (ka)) is presented in Table 2-3.

Table 2-3. Identifications of stratigraphic units made in regional studies. Broken – lines are used to make tentative cross-identifications between units of similar age and properties identified in different studies (Reproduced from Foster, 1988)

QUATERNARY TIME SCALE YEARS (ka)	+ HOPKINS (1967) * CARTER AND GALLOWAY (1985)	SMITH (1985 AND 1986)	WOLF ET AL. (1985)	THIS STUDY	CRAIG AND THRASHER (1982)	DINTER (1982)	SMITH ET AL. (1980)	RAWLINSON (1986)
HOLOCENE		STEFANSSON SOUND UNIT	UNIT ABOVE 5?	SEQUENCE A	ABOVE UNIT A	UNIT A	QHd QHm QHb	
LATE PLEISTOCENE, WISCONSIN, Late 23		MIKKELSON BAY UNIT		SEQUENCE B	UNIT A	UNIT B	QPa	UGNURAVIK SAND
LATE PLEISTOCENE, WISCONSIN, Middle 64			UNIT BELOW 5? AND ABOVE 4	ATB? DELTA?	PALEO-SHORELINE?			
LATE PLEISTOCENE, WISCONSIN, Early 115	*Simpsonian (70-80 ka)	CROSS ISLAND UNIT		SEQUENCE A/B ?			FLAXMAN	FLAXMAN
LATE PLEISTOCENE, SANGAMON 128	+Pelukian (120-130 ka)	MAGUIRE ISLAND UNIT		SEQUENCE B			SANGAMON MARINE	UGNURAVIK GRAVEL
MIDDLE PLEISTOCENE 730	+Kotzebuan *Wainwrightian (> 158 ka)	LEFFINGWELL LAGOON UNIT	UNIT BETWEEN 3 AND 4 UNIT BELOW 3	SEQUENCE C SEQUENCE D SEQUENCE E	UNIT B		QPa	
EARLY PLEISTOCENE 1.65 Ma	* Fishcreekian (1.87 Ma -2.48 Ma)							

The linkages indicated in Table 2-1 and Table 2-3 illustrate the above-noted tendency of earlier studies to overestimate the horizontal and vertical extent of the Holocene layer deposited during the most recent period of sea level transgression. This confusion was most apparent in the Craig and Thrasher (1982) and Dinter (1982) interpretations of areas at, respectively, the western and eastern ends of our study region. Difficulties appeared to arise primarily from the earlier workers' neglect of differences between the shallow Holocene layer (Foster's Sequence A) which tends to <u>thin</u> in the offshore direction and Foster's Sequence A/B which <u>thickens</u> in a seaward direction on the middle and outer shelf. Sequence A/B, believed to be a late Pleistocene deposit, overlies a relatively ubiquitous, more definitively late Pleistocene layer, Sequence B, in the latter areas and, thus, would be expected to be a still younger layer associated with times closer to the start of the Holocene transgressions. On the other hand, ^{14}C results showing a Holocene component within the upper portions of Sequence B on the inner shelf also make it possible that sequence A/B was deposited within sequence B, not above. In the absence of additional age determinations and other information, it is, therefore, probably most appropriate to tentatively identify A/B as a Holocene/Late Pleistocene sequence and sequence B as a somewhat older Late Pleistocene layer. This confusing situation undoubtedly accounted for spatially-detailed geohazard mappings (*e.g.,* the Comap, 1985 Torgisl survey) in which Holocene layer thicknesses greater than 60 m were reported. In other instances, higher spatial resolution stratigraphic mappings failed to distinguish between Holocene and Pleistocene layers, focusing instead upon providing estimates of the depths associated with transitions from soft, clayey sediments to harder, coarser sediment horizons.

Although in some cases it may be difficult to unambiguously distinguish between the acoustic properties of sediments in adjacent stratigraphic layers, our classification efforts tried, as much as possible, to both retain geological distinctions noted by the actual acoustic data set analysts and draw on the cross-linkages identified by Foster (Table 2-1 and Table 2-3). The 6 distinct stratigraphic classifications of the Foster scheme included the aforementioned Holocene and Holocene-like Pleistocene sequences A and A/B as well as four distinguishable Pleistocene layers, B, C, D and E which are described below.

The first of these layers, Sequence B, is the predominant late Pleistocene species identified in most early regional studies. It consists of mixtures of marine silt, clay and pebbly mud deposited during both the Pelukian (Sangamon) and Simpsonian (Early Wisconsin) transgressions along with, especially on the middle and outer shelf, sediments of terrestrial origin associated with coalescing river fan deltas which were built up during earlier sea level lowstands. This sequence often hosts strong internal reflectors associated with ice-bonded sediments and gas concentrations which, by decreasing depths of acoustic penetration, locally limit capabilities for measuring layer thicknesses or for extracting details of deeper layers. The spatial uniformity of this layer is also frequently disrupted by its abundant content of cut and fill channels and paleodelta sequences.

Sequences C and D are also transgressive marine deposits created during at least two distinctive middle Pleistocene periods associated with rising sea levels. Sequence C is believed to have been associated with the Wainwrightian transgression onto the adjacent coastal plain more than, roughly, 160,000 years ago. Sequence D is, of course, still older. These sequences have similar, acoustically transparent, characteristics and appear to be associated with mixtures of gravelly sand and gravelly mud.

Finally, the deepest (oldest) sequence in the Foster scheme (E) is of non-marine fluvial origin. Limited data suggests it thins in an offshore direction and is composed primarily of heavy sand and gravel deposited sometime after the Fishcreekian trangression of, approximately, 1.9 to 2.5 million years ago. The age of this deposit was estimated as no greater than 1.8 M years and no younger than Middle Pleistocene. It is clearly the deepest layer likely to be of relevance to acoustic propagation in the overlying ocean layer.

Unfortunately, classification of submarine sediments into the 6 discussed categories is feasible only in that small fraction of the study region associated with Foster's own studies. Even in those areas, large gaps in coverage were produced by the local opacity of sequence B introduced by the noted presence of strong internal reflectors associated with ice-bonded sediments, gas pockets and other local layer anomalies. In such areas, it was, thus, necessary to specifically identify the widespread prevalence of such reflectors by the designation of a sub-category B'. It is to be recognized that because of the minimal penetration of the acoustic beams to depths much greater than a few meters from the surface of this subcategory, all estimates of the depths this and deeper layers have had to be obtained by extrapolation or interpolation from adjacent B'-free areas.

As well, it proved infeasible to utilize all 6 (exclusive of the B' subcategory) Foster categories since the majority of prior and subsequent classifications in the region as a whole utilized smaller numbers of stratigraphic categories (see Table 2-1 and Table 2-3) Nevertheless, efforts were made in the present study to use the general trends and parameters associated with these categories to provide coverage of the major stratigraphic transitions out to, roughly, the 80 m depth contour on the Alaskan shelf between 141°W and 152.5°W. Retained categories: A, A/B, B, C/D were designed to allow characterization of: the most common surface layers (A (Holocene), A/B and B (late Pleistocene)); the immediately underlying Pleistocene C and D layers comprised of similar, coarser sediments; and, finally, the very coarse Middle to Early Pleistocene sediments of Sequence E. For ocean acoustics purposes, Sequence E can be considered as the basement layer of the submarine acoustic environment. Additional local details on surface features of note, including gravel and boulder patches, were retained as additional characteristics of the uppermost sediment layer.

Actual representation of the regional stratigraphy utilized just 3 layers in an ARCINFO GIS database. The contents of these layers are listed below.

Layer 1 Contents: Thickness contours of the Holocene and Holocene-Pleistocene transition Categories A and A/B, respectively as well as polygons delineating notable characteristics of the sea floor such as the presence of boulders, gravel beds or other features relevant to description of the acoustic environment.

Layer 2 Contents: Thickness contours of the late Pleistocene Categories Band B'.

Layer 3 Contents: Thickness contours of the Middle Pleistocene Category C/D.

The basement or "floor" of these layers is assumed be composed of a semi-space of infinite depth containing Category E sediments. The actual thickness of this category which directly overlies the terrestrial Gubik Formation was about 35 m in Simpson Lagoon (near 150°W) (See Figures 5-3 and 5-5 (Foster, 1988)). Even such a thickness, at the thin, shoreward, end of this seafloor constituent is comparable to or larger than the sum of thickness of all overlying layers in many portions of the study area, thus justifying its treatment as an infinite half-space.

Polygons representing sediment Category thicknesses and/or surface material character were constructed using 3 different line types according to the following coding.

1. Solid line: data taken from previously reported/graphically represented data.

2. Dashed broken line: data obtained by extrapolation or interpolation over small gaps or by extensions (usually over distances shorter than 10 km) of previously reported/graphically represented data into adjacent areas.
3. Dotted broken line: data extrapolated/interpolated over very large spatial gaps in the available data sets.

This additional information offers the user representative measures of the reliability of the individual layer data provided for any particular portion of the region of interest.

2-2.2 Data Assembly and Assumptions within Individual GIS Layers

2-2.2.1 <u>Layer 1</u> (Figure 2-3)

Relatively reliable mapping of Holocene Category A layer thicknesses on the inner and middle shelf were available between, roughly 151°W and 145.5°W from the work of Foster (1988) and Wolf et al. (1985). Layer thicknesses in the 148°W-149°W area of overlap between these two bodies of work are in reasonable agreement, giving us a fair degree of confidence in the 1- 7 m thickness values deduced for these areas. Similarly, mappings by Wolf et al. (1989) in discontinuous sections of the shelf between 141°W and 146°W delineated other concentrations of Category A equivalent sediments. The specified concentrations of this material were confined to areas within a few kilometers of the shoreline in Beaufort, Nunagapak and Demarcation Lagoons (Figure 2-1) Potentially similar material was also reported by Wolf et al. (1989) in slightly thicker coast-paralleling bands roughly 10 km offshore in western Camden Bay and east of, roughly, 143° 30’W. The latter, spatially discontinuous, features were identified as overlying central portions of a similarly coast paralleling band at least 15-20 km in width comprised of Unit 2 material which, by description showed continuity with the Unit A identified by Dinter (1982) (Table 2-1 and Table 2-3) in immediately adjoining western areas. These bands were therefore assumed to be composed of Category A/B materials. In the light of Wolf et al.’s (1989) own uncertainty regarding the origins of their identified Unit 1 material, it was also assumed to be a variant of the sequence A/B so frequently misidentified as Holocene elsewhere in the region and, hence, not specifically delineated in our mappings.Finally, the discrepancy between the alternative seaward thinning and thickening of the Holocene layer inferred for eastern and western Harrison Bay by Foster (1988) and Craig and Thrasher (1982), respectively, was resolved by assuming that the latter report of thickening in western areas was, yet, another consequence of misidentification of A/B material as Category A material. This inferred presence of A/B material as well as evidence for local ice bonded sediments in the vicinity of the stamukhi-grounding region near the 20 m depth contour motivated a decision to retain Craig and Thrasher’s Holocene thickness estimates for our Category A mappings only in waters shallower than 20 m.

Mappings of Category A/B layer thickness provided estimates of the spatial distribution of this stratigraphic element as first documented by Foster in the NE corner of his study region (between 148°W and 149°W and in waters deeper than about 30 m) in terms of two-way travel times (TWTs) to the bottom bounding surface of this material. The actual depths of such interfaces below the sea floor were established from the conventional geophysical rule that such depths were obtained by subtracting local water depth from 0.8 times the measured two-way travel time. In the absence of data at equivalent depths in the adjacent Wolf et al. (1985) study region, the presence of compatible thicknesses of Dinter's Unit A (Category A/B) material at comparable depths further east was taken as a reasonable justification for interpolating and connecting A/B layer thickness contours between the two regions. This step, when combined with the shoreward boundaries delineated for Wolf et al.'s (1989) 'pre-Holocene" Unit 2/Category A/B material allowed mapping of the thicknesses of a band of the latter material which appeared to comprise the uppermost layer of the sea floor on the basis of most acoustic data gatherered in waters deeper than 25- 30 m in the study area. The available data and our interpolations into the region of the Wolf et al. (1985) study extended the prevalence of this sediment layer, which thickens to seaward, as the principal sea floor constituent out to at least the 80 m water depth contour.

Surface details going beyond the Category A and A/B stratifications were obtained for areas east of Tigvariak Island (°146.2W) from Wolf et al. (1985 and for more western areas east of 148° W from Reimnitz and Ross (1979). In the former case polygons were defined using designations from the original references as "bouldery", "mottled", and "platy" deposits on the silt and sand sea floor surfaces. With the exception of the bouldery categories, these terms are primarily derived from the appearances of the reflected acoustic signals. The Reimnitz and Ross data give much more detail of the structure of the "bouldery" areas, presenting separate designations of areas with high and moderate densities of boulder and cobble coverage and distinguishing these categories from nearshore "beach boulders" and areas associated with "broad, fuzzy bottom echoes".

2-2.2.2 **Layer 2** (Figure 2-4)

The late Pleistocene layer associated with our defined Category B, was only mapped directly by Foster and given in terms of layer thickness values for areas west of 148°W. Identification of this same layer with materials bounded by Wolf et al.'s (1985) surfaces 4 and 5? in adjacent areas as far east as 145.5°W and with the Unit 3 materials mapped by Wolf et al. (1989) in areas still further east, likewise, provided a quantitative basis for estimating Category B stratigraphy between 141°W and 151°W. Unfortunately, however, data in the latter two studies only extended out to approximately 40 m water depths, necessitating eastward extrapolation of Foster's data to obtain estimates of related structures in out to roughly the 80 m depth contour. West of 145.5°W, this extension of Foster's results is readily justified by the agreement achieved near the 40 m depth contour with thicknesses reported for the equivalent layer by Wolf et al. (1985).

Further east, data on the most equivalent of the layers identified by Wolf et al. (1989), Unit 3, are less detailed, particularly in Camden Bay west of Barter Island, where the defining local lower bound (Horizon A') of this layer was rarely unambiguously detectable in the available acoustic sounder datasets. Nevertheless, except in the eastern portion of the Bay, where tectonic activity has raised older material to the upper sea floor, it is clear that, as in adjoining western areas near 145°W, Category B material comprises the sea floor out to distances of 15-20 km from shore and to water depths of about 25m. In slightly deeper waters in this area, the Category B layer underlies a relatively narrow strip of Category A/B material before appearing again on the sea floor surface at distances more than 25 km from the coastline. East of Barter Island mappings presented by Wolf et al. (1987) again showed Category B (Unit 3) material to be the uppermost seafloor layer for distances ranging out to 6 km to 15 km from the coastline. Further offshore the Category B layer again was overlaid with strips of Category A/B material. In this case, however, particularly near 142 °W, the outer boundaries of the latter layers were not well defined and the adjoining more offshore surface species were not specified. Details on the underlying Category B/Unit 3 material were limited to TWT contours corresponding to its local lower bounding surface (Horizon A) in waters inshore of, roughly, the 40 m depth contour. Under these circumstances, we chose to assume a rough continuity in the structure of the upper sea floor layers exclusive of the narrow area of East Camden Bay (near 144 °W) where tectonic activity in waters shallower than 40 m apparently replaced eroded near-surface bodies of Category A/B and B materials with older strata. Elsewhere, neglecting Wolf et al.'s (1987) reported small showing of Category B (Unit 3) material on the sea floor at depths of 30 m in western Camden Bay, we assumed Category A/B material to be the surface species in all areas seaward of the 25 m bathymetric contour. Contours of TWTs for the Category B bottom boundary were then interpolated and extrapolated among: the Wolf et al. (1989) data sets inshore of the 40 m bathymetric contour and outside the tectonic region of Camden Bay; from Wolf et al.'s (1986) results for areas west of 145.5 °W and from Foster's (1986) results obtained further west. Since only the later results extended out beyond the 40 m bathymetric contour it was also necessary to use Wolf et al.'s estimates of the seaward slope of Horizon A in areas east of Barter Island to estimate the thickness of the category B layer as a function of offshore distance at water depths as large as 80 m east of 148°W.

Values of Category B thickness in the Foster study area, which supported the described eastward extrapolation were themselves derived from acoustic travel times to the bases of both this and the immediately overlying layers (Category A or A/B material). The "onlapping" of Category B material on successive older layers dictated that various portions of the lower Category B boundary were associated with transitions to Sequence C, D and E materials in the Foster nomenclature scheme. Other difficulties in extending thickness estimates throughout the full Foster study area arose from the presence of so-called "acoustic transmission boundaries" (Foster, 1988) which delineated areas containing internal (to the sequence B layer) reflectors of sufficient strength to preclude both estimation of the full depth of Category B material and observation of transitions associated with deeper layers. Our procedure was to obtain layer thickness estimates in such areas by interpolating acoustic travel times to the bottom of the Category B into these regions from the abundant transparent zones in, respectively, the eastern and western portions of the Foster study region.

2-2.2.3 **Layer 3** (Figure 2-5)

As was the case for the Category B mappings of Layer 2, there was no common source of data for the defined Category C/D material capable of supporting coverage for all areas of interest. Data on this material are essentially non-existent for areas west of the 151° W limit of the Foster (1988) study. Specific C, D or C/D information for areas in the rest of our area of interest are listed in Table 2-4. Even in these cases, however, inspection indicates that, with the exception of data on the depth of the upper surface of E, most of the compiled data is directly usable only in characterizing C layer thicknesses. The most useful results on a region-wide basis were the observation by Foster (1986) that:

1) D tends to thicken in a seaward direction from zero on the inner shelf, reaching maximum thicknesses on the middle and outer shelf; and
2) C thins in a seaward as well as landward directions and extends to the outer shelf.

Table 2-4. Sources and content of information available for estimating C/D layer thickness

W. Longitude Range	Data Source	Data Type
148°-151°	Figures 5.3 and 5.5 (Foster, 1988); Figure 5.6 (Foster, 1988)	Depth to top of material E and thickness of its "overburden"; Depth to upper boundary of D
145.5°-149°	Figure 15 (Wolf et al., 1985)	Depth to upper boundary of material D
141°-146°	Figure 5 (Wolf et al., 1989)	Areal coverage of surface exposures of "Units 4 and 5" in an area just west of Barter Island (by a process of elimination, these units can be identified with C and D, respectively.)

Estimation of C-layer thicknesses from the difference in the depths of Foster's R30 and R40 surfaces indicated that, near 148°W, these thicknesses increase from negligible values nearshore to a 15 m maximum near the 30 m bathymetric contour and slowly tailed off into deeper waters. Similar results were deduced from Wolf et al.'s (1986) data along two offshore lines about 0.5 ° and 1° further east. In this case, substantial (6-8 m) layer thicknesses persisted in inshore areas. Direct estimates of D-material distributions were available only from a small area between 148°W and 149 °W where Foster (1988) presented TWT data for the upper surfaces of both Sequence D and E. These data suggest that the D-layer only slowly increases in thickness in the offshore direction, reaching a maximum observed thickness of about 4m near the 25 m bathymetric contour. As well this material and the normally overlying C-layer is totally removed from an area south of, roughly 70.7 °n between 148.5 °W and 149.5 °W, where the surface of the E-layer is separated from the sea floor only by a few m of overburden, which we have assumed to be Category B material.

Given the dearth of data and the, generally, lessened importance of Category C/D relative to higher-lying species as a determinant of the acoustic environment in the overlying ocean, we chose to provide descriptions of Category C/D thickness in terms of direct relationships between layer thickness, $T_{C/D}$, and water depth, d, which are, with one exception, universal in the study region at depths inside the 80 m bathymetric contour. The specific exclusion in this case is the area noted near 149 °W above where neither of the C or D constituents of this layer were observed to be present (Foster, 1988). These relationships are:

$T_{C/D}$ = 10 (1 + (d)/20) m, for d< 20m;

$T_{C/D}$ = 20 + 5(d-20)/10 m, for 20m ≤ d ≤ 30m; and

$T_{C/D}$ = 25 - 10(d-30)/50 m, for 30m < d ≤ 80m.

This choice allows the C/D layer to rise gradually in a seaward direction from a 10 m nearshore value, reaching a broad peak thickness of 25 m at the 30 m bathymetric contour and thinning slowly to 15 m in waters 80 m deep.

These relationships and the boundaries of the identified C/D-free area constitute the information content of Layer 3.

2-3. Use of Stratigraphy and Bottom Type Data for Assessing the Ocean Acoustic Environment

Combined use of all three layers should allow a reasonably realistic representation of regional variations in sea floor composition relevant to acoustic environmental investigations. Areas of poor reliability included both: those areas west of 150 °W where the presence of strong reflectors internal to the Category B layer (usually 5-15 m below the surface of this layer) precluded extraction of details on all but the uppermost surface layer: and areas including and seaward of the strongly tectonically modified areas near 144 °W where upheavals have left older materials (assumed to be Category C/D) as the sea floor surface species and clearly distorted the stratigraphy in all adjoining areas. In the latter case, the availability of good layer 1 and 2 data east and west of the older surface material still enabled development of a fairly representative database in such areas. On the other hand, much more limited data in areas further offshore, particularly in the elements of Layer 2, necessitated heavy reliance on extrapolation and consequent uncertainties in data quality or total absences of information.

As indicated in Section 2-1, actual use of stratigraphy data in characterizing an ocean acoustics environment still requires assignment of sound speeds, densities and attenuation coefficients to each of the component of the defined sediment layers. Such assignments are clearly significant simplifications since, even within the identified layers, drillhole data are indicative of considerable site to site variability in layer composition and in the internal sequencing of constituents. The category progression A, A/B, B, C/D, E was assumed to correspond to a similar progression in the relative presence of silt, mud, clay, sand and gravel, with Category A comprised primarily of silt, clay and mud and with the sand and gravel contents of the subsequent categories progressively rising to a peak in the deepest, oldest material of Category E. Within this picture, reviews of the related literature (Hamilton, 1980, Urick, 1983, Akal and Jensen, 1983) and of the recent work of VerWest and Bremner (1997) on the North Slope were used to derive the set of density, sound speed and attenuation coefficients listed in Table 2-5.

Table 2-5. Suggested parameters for acoustic propagation modelling in the idealized description of the Alaskan North Slope.

Category	Density (g/cm^{3})	Speed (m/s)	Attenuation (dB/wavelength)
A	1.75	1600	1
A/B	1.8	1700	0.5
B	1.85	1725	0.4
C/D	1.95	1830	0.15
E	2.0	1900	0.1

For widespread use in the study region, these listings should be supplemented by additional representations of effects arising from:

a) the various patches of boulders, gravel and other designations included as surface descriptors in layer 1;

b) the presence of strong reflectors internal to the variety of Category B material designated by the sub-Category B' which is commonly present at the western end of the study region.

In the first instance, it is feasible to locally replace say the first m of the uppermost material with a 1m thick layer of a material with appropriately higher values of density and sound speed (i.e. for concentrated boulders a density of 2.5 g/cm^3 and a 2500 m/s sound speed) as well as comparably lowered attenuation coefficients. Adjustments for the internal reflectors associated with B' are more problematic. These reflectors can have multiple sources associated with gas pockets, frozen sediments and mechanically modified sediment structures produced by interactions with ice keels. In the absence of detailed information at a given site, a general representation of related effects may be obtained by assuming the internal reflectors occupy the bottom half of the B' layer and have the large 2500 m/s to 3000 m/s sound speeds reported for ice bonded sediments by Rogers and Morack (1979) in the same area. This assumption, in conjunction with allowing the standard B parameters to prevail in the upper half of B' will naturally give the enhanced reflections and diminished downward propagation characteristic of this sub-category.

Ultimately, of course, it would be desirable to obtain acoustic propagation data in all general areas of interest in order to provide the comparisons with models needed to refine the assignment of Table 2-5.

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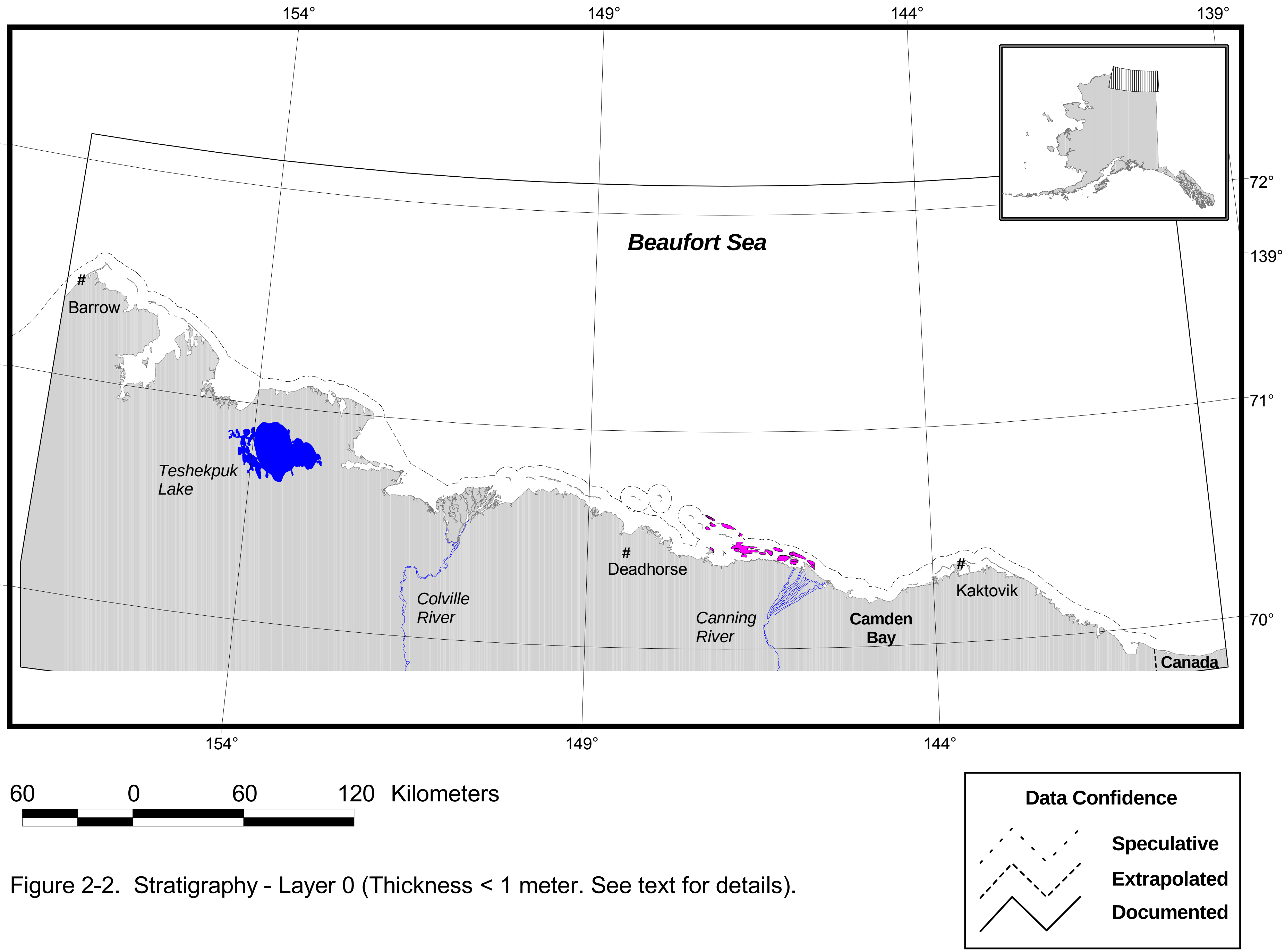

Figure 2-2. Stratigraphy - Layer 0 (Thickness < 1 meter. See text for details).

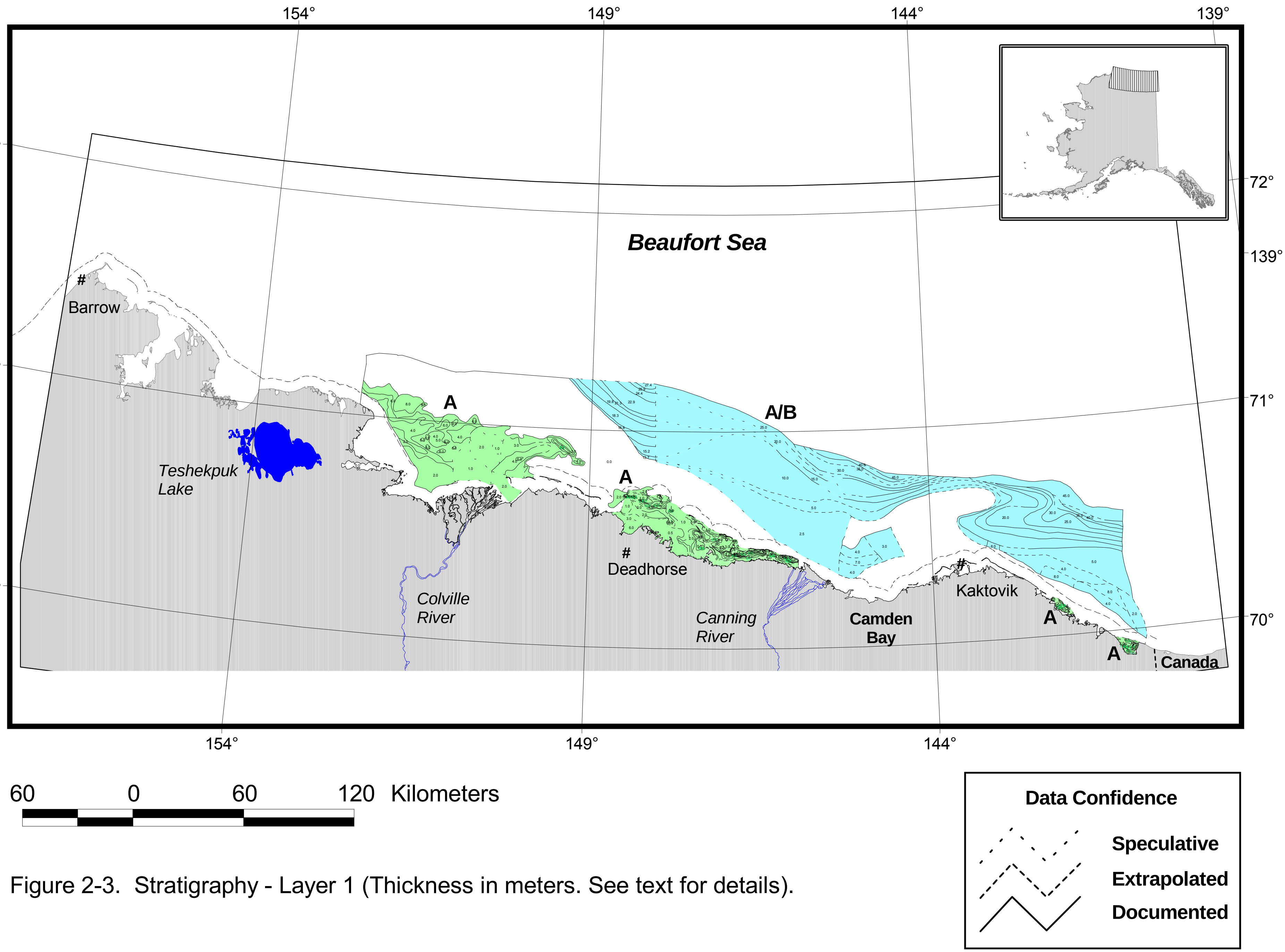

Figure 2-3. Stratigraphy - Layer 1 (Thickness in meters. See text for details).

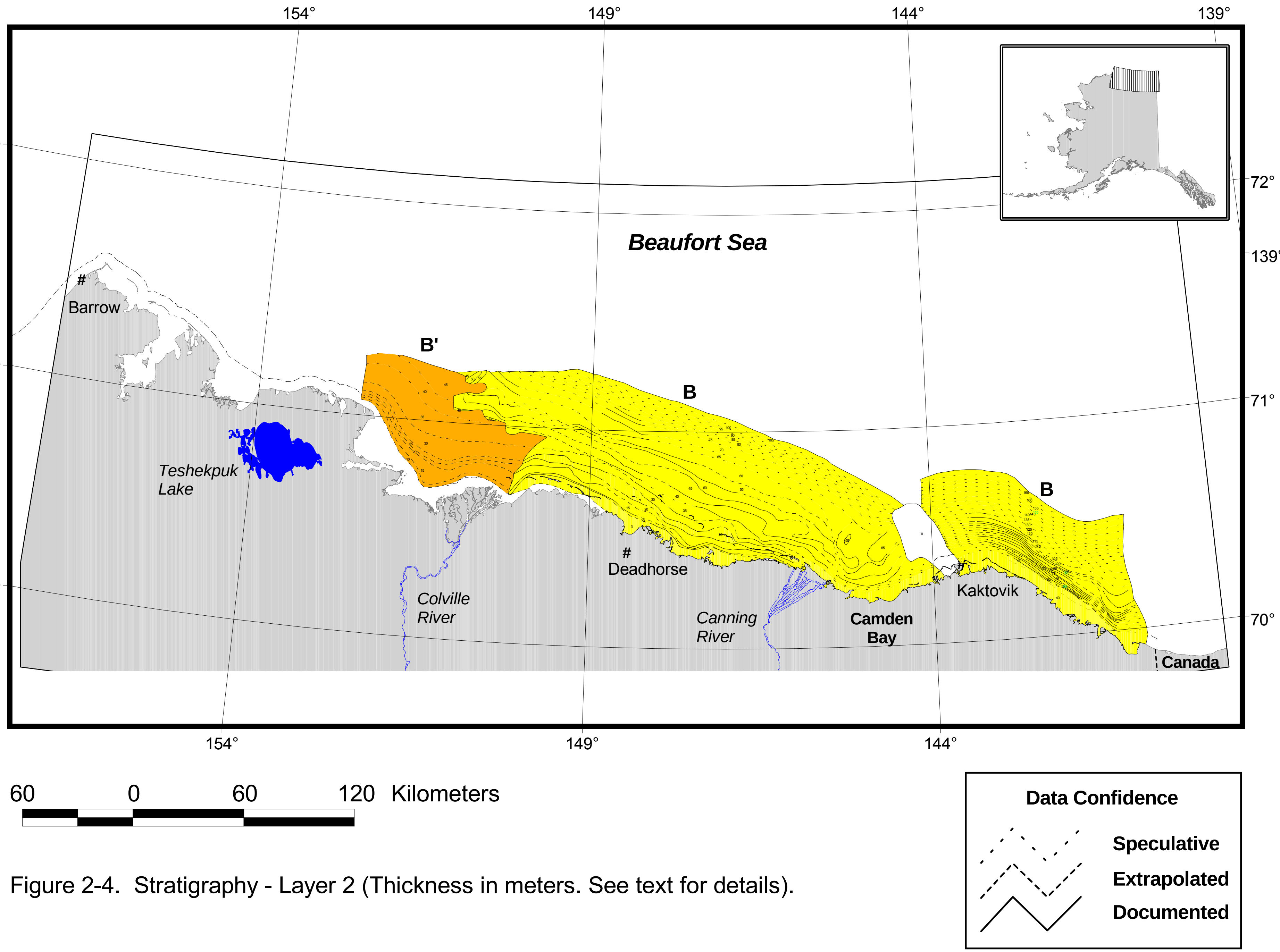

Figure 2-4. Stratigraphy - Layer 2 (Thickness in meters. See text for details).

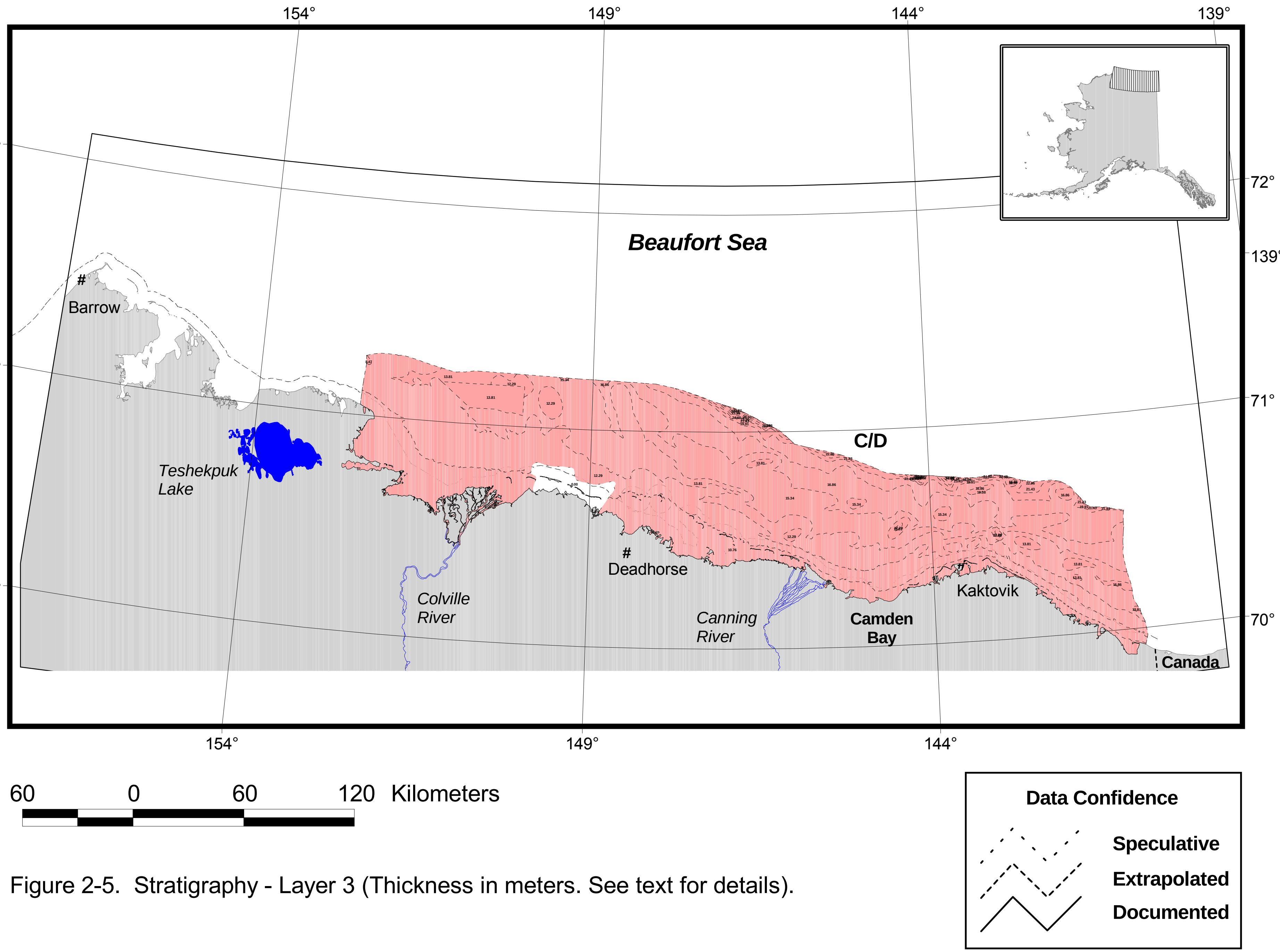

Figure 2-5. Stratigraphy - Layer 3 (Thickness in meters. See text for details).