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Geology Report for Proposed Norton Sound OCS Sand and Gravel Lease Sale

by

Gordon R. Hess and C. Hans Nelson

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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Introduction

The northern Bering Sea is a broad, shallow epicontinental shelf region covering approximately 200,000 km^2 of subarctic sea floor between northern Alaska and the U.S.S.R. (Fig. 1). The shelf can be divided into four general morphologic areas: (1) the western part, an area of undulating, hummocky relief formed by glacial gravel and transgressive - marine sand substrate (Nelson and Hopkins, 1972); (2) the southeastern part, a relatively flat featureless plain with fine-grained transgressive - marine sand substrate (McManus, et al, 1977); (3) the northeastern part, a complex system of sand ridges and shoals with fine- to medium- grained transgressive sand substrate (Nelson et al, 1978); and (4) the eastern part, a broad flat marine reentrant (Norton Sound) covered by Holocene silt and very fine sand (Nelson and Creager, 1977).

The northern Bering Sea is affected by a number of dynamic factors: winter sea ice, sea level setup, storm waves and strong currents (geostrophic, tidal, and storm). The sea is covered by pack ice for about half the year, from November to May. A narrow zone of shorefast ice develops around the margin of the sea during winter months. During the open water season, the sea is subject to occasional strong northerly winds, in the fall, strong southwesterly winds cause high waves and storm surges along the entire west Alaskan coast. Throughout the year, there is a continual northward flow of water with currents intensifying on the east side of strait areas (Coachman et al., 1975). Although diurnal tidal ranges are small, stong tidal currents are found in shoreline areas and within central Norton Sound (Fleming & Haggarty, 1966; Cacchione et al., 1982).

This report reviews the methodology employed and the data collected over a period of nearly 20 years in the northern Bering Sea. A brief geologic history and background are presented followed by a discussion of distribution of sediment types and distribution of specific sand and gravel bodies. The limitations of the data base and needs for further study are explained and a brief summary of resource potential and environmental considerations is given.

Methods and Data Base

The majority of data applicable to the evaluation of sand and gravel resources and environmental hazards of their exploitation, were collected on several U.S.G.S. cruises aimed at assessment of potential environmental hazards to exploration and production of oil and gas resources. Much of the data collected and analyses completed cannot be applied, however some studies of surficial sediment distribution, specific sediment bodies, and dynamics of sediment transport provide the data base for this report.

Geophysical Records

High-resolution seismic-reflection profiling data provide bathymetric information as well as subbottom information on sediment thickness and morphology. A qualitative assessment of the nature of the sediment can be made on the basis of acoustic character. Side-scan sonar imagery yields information on bottom morphology and lateral extent of discrete sediment bodies as well as another qualitative assessment of sediment nature. The trackline coverage of geophysical data used in this report is shown in Figures 2A & 2B.

Bottom sampling

An extensive array of bottom samples were analyzed to provide the sediment data used in this report. Figure 3 shows the location of all sample stations. The samples include simple grab samples of the surficial sediment, box cores penetrating up to several 10's of centimeters in substrate, and Kiel and Alpine vibracores penetrating up to 7 m into the seafloor. In addition, a series of deeper holes, up to 75 m in depth, were drilled within 3 miles of the coast off Nome, as part of a precious metal resource evaluation in the late 1960's.

Photographic data

TV and Black and White still photography were collected at numerous stations. This type of data provide qualitative information on sea floor morphology, active processes, and the nature of surficial sediment.

U.S.G.S. operated cruises were conducted with two broad emphases. The first being a regional, reconnaissance, survey to categorize and classify areas as to sediment type, sediment dynamics, active tectonics, and other regional characteristics. Secondly, cruises or portions of cruises, were devoted to discrete survey areas or objectives to delineate specific features and/or phenomena.

In addition to information from U.S. Geological Survey cruises, numerous data from University of Washington cruises are included in the data set. Similarly, data collected during operations by NOAA ships, U.S. Coast Guard ships, and research vessels of Scripps Institution were also incorporated into the data set.

Geologic Background

The northern Bering Sea is bounded by the Seward Peninsula on the north, Yukon-Koyukuk geologic province on the east, the Yukon delta and St. Lawrence Island on the south, and the Chukotsk Peninsula of Siberia on the west (Fig. 1). The United States - Russia Convention Line of 1867 marks the western end of the area that is likely to be included in any sand and gravel resource lease sale.

Three subbasins underlie the northern Bering Sea. The northwest Bering Sea is underlain by shallow basement, mainly Precambrian through lower Mesozoic rocks. Geophysical data show that the basement is overlain by an average of 1 km of rocks of late Neogene and Quaternary age (Fisher et al, 1982). The second and third subbasins are separated by a structure, the Yukon Horst (See Fisher et al., 1982, Fig. 10), which strikes northwest from near the mouth of the Yukon River. Rocks in the St. Lawrence subbasin, west of the horst, are locally as thick as 5 km. The subbasin east of the horst contains fill as thick as 6.5 km.

In terms of potential sand and gravel resources, the late Pleistocene (>10,000 years B.P.) and Holocene (≤10,000 years B.P.) sedimentation is the facet of geologic history of the greatest impact and interest. The distribution of late Pleistocene and Holocene surface sediment on the northern Bering Sea floor is patchy and dependent upon locations of seafloor bedrock, pre-late Pleistocene glacial debris, late Holocene river borne sediment influx, modern bottom currents, and past eustatic sea-level changes.

To assess the effect of these factors the northern Bering Sea can be divided into two provinces, Chirikov Basin on the west, and the shallower (Generally <20 m deep) Norton Basin in the central and east. The last late-

Pleistocene and Holocene transgression began about 12,000 to 13,000 years ago. A narrow seaway developed from Anadyr Strait (between St. Lawrence Island and Siberia) to Bering Strait (Hopkins, 1979), and then from Shpanberg Strait (between St. Lawrence Island and Yukon Delta) to Bering Strait (Nelson and Creager, 1977). The narrow seaways expanded to fill the deeper western area of Chirikov Basin until about 10,000 years ago.

The late Pleistocene to Holocene shoreline transgression deposited a thin sequence of transgressive deposits on the margins of Chirikov Basin. On some margins, only a thin gravel lag is found over bedrock outcrops or glacial deposits. These lags developed as the transgressive shoreline reworked bedrock or glacial deposits, removed finer grained sediment, and left a gravel lag (Nelson and Hopkins, 1972).

In other areas of Chirikov Basin, the typical sequence is late Pleistocene freshwater peaty silt overlain by transgressive sand. The tundra and freshwater silt developed where topographic elevations of bedrock or glacial moraines were not present. As the shoreline transgressed over the emergent freshwater peaty mud, a basal coarse- to medium-grained sand was deposited. A fine-grained inner shelf sand was deposited immediately off the shoreline as it transgressed; this generally overlies the basal coarser sand and forms a blanket deposit now covering most of the central and southern Chirikov basin.

The entire Norton Sound region remained emergent until about 10,000 years ago. Radiocarbon dates in Norton Sound show that from 10,000 to 9,500 years B.P., the shoreline rapidly transgressed eastward over Norton Sound and buried tundra peat deposits. Marine sandy silt interbedded with very fine sand layers overlie the freshwater peaty muds. Above this sequence in central

Norton Sound is bioturbated, sandy silt derived from the Yukon River (McManus et al., 1977; Howard and Nelson, 1982). The surficial Holocene deposits in Norton Sound vary from fine-grained sand surrounding the delta and in a trough along northern Norton Sound to very fine sand and coarse silt in central and eastern Norton Sound.

The thick blanket of Holocene silt and interbedded sand layers in Norton Sound differs from to the thin transgressive sequence of sand deposited in Chirikov Basin. Thick sections of Holocene sediment have been deposited in southern Norton Sound because of progradation of the Yukon Delta. Only 2 m or less of bioturbated mud has been deposited in the more distal areas of northern and eastern Norton Sound (Nelson and Creager, 1977).

Numerous subsurface alluvial channels, covered by the transgressive deposits, have been mapped in the Norton Sound region (Fig. 4). In Chirikov basin, the limited grid of seismic data does not permit detailed mapping of the subsurface channels, but major channels are known extending west of Port Clarence, in the sea valley extending south from King Island (Hopkins et al., 1976), and in the central part of Chirikov Basin. These channel deposits have not been identified in cores.

Early and middle Pleistocene continental glaciation extending off Siberia to the central Chirikov Basin, and local valley glaciation extending offshore from Seward Peninsula have been mapped by seismic reflection profiling and by sediment sampling (Grim and McManus, 1970; Nelson and Hopkins, 1972; Tagg and Greene, 1973; Hopkins, 1975, 1979). The glacial moraines are present in the subsurface of central Chirikov Basin (Fig. 5) and emerge toward land as gravel ridges. Sequences of moraines and outwash were documented in the nearshore areas off Nome and from drillholes (Nelson and Hopkins, 1972).

The other major geologic event that significantly influenced the distribution of late Pleistocene and Holocene deposits is the change in position of the active Yukon Delta lobe on the Bering Shelf. About 16,000 years ago, the Yukon River apparently crossed the present Bering shelf in the vicinity of Cape Romanzof, 100 km south of the present Yukon delta, and deposited a deltaic sequence south of St. Lawrence Island (Knebel and Creager, 1973). As sea level rose, various active lobes developed far south of Norton Sound (Nelson and Creager, 1977). The present active delta lobe first developed in southern Norton Sound after 2,500 years B.P. (Dupre, 1978). Since then the Yukon River has prograded significantly into Norton Sound.

Surficial Sediment Distribution

Analyses of surficial sediment samples from over 467 stations were compiled and computer-contoured maps of sediment distribution were prepared. The resulting maps are meant to be an extension and refinement of maps generated by McManus and others at the University of Washington (McManus et al., 1970, 1977).

Caution should be used in interpreting contoured data. Contours imply a gradation in value from one area to another that may not exist. In general, areas of relatively closely-spaced contours are suspect and may represent a sharp boundary between widely different sediment types.

The sand content maps (Fig. 6A and 6B) show sandy areas or shoals in central and western Shpanberg Strait, eastern Bering Strait, north-central and northeast Norton Sound, south of St. Lawrence Island, in shoals west of the mouth of the Yukon River, and over much of the central Chirikov basin. Figures 7A and 7B show a gravel distribution controlled by the presence of glacial moraines and outwash, bedrock, alluvial deposits, and adjacent terrestrial sources. The gravel concentrates are products of the winnowing of fine material by strong currents through the straits and along the Seward Peninsula. Areas of gravel abundance are reflected by areas of low sand content.

The mean sediment grain size (Fig. 8A and 8B) distribution map was prepared by calculating the first moment parameters for each sediment sample. This map is a composite of the areas of maximum content of each sediment size class, i.e., gravel, sand, silt, and clay. Again, caution must be used in interpretation. Apparent transition or grading from one average grain-size to another may not be real. The map of modal sediment size (Fig. 9A and 9B) is very similar to the mean grain-size map but in general shows values 1/2 ϕ coarser than the values of the mean grain-size map. To simplify interpretation and summarize the distribution of sediment on the northern Bering Seafloor, gravel, sand, and mud (silt and clay) abundances are portrayed on Figures 8B and 9B. Figure 8B is based on mean grain-size and figure 9B is based on modal analysis. Sand-size material characterizes the majority of both surficial sediment maps with a plume of muddy sediment extending northwest from the Yukon delta, mud-rich sediment in eastern Norton Sound, and gravel rich sediment off the Seward Peninsula and in the straits.

Discussion

Unconsolidated Surface Sediments

Lag gravel over bedrock

Very thin surficial covers of gravel over older Precambrian to Cretaceous bedrock outcrops (Fig. 10) occur in the area west of Nome near Sledge Island, northward toward Port Clarence, and in a large area from Port Clarence along the York coastline to Cape Prince of Wales (Nelson and Hopkins, 1972; Nelson, 1982). Sampling in these areas reveals only scattered occurrences of gravel suggesting that only small, thin (few cm thick) pockets of gravel are present over these bedrock locations and that distribution of the gravels is quite patchy. The sporadic, thin pockets of gravel over bedrock would not be a renewable resource because these relict gravels were produced by shoreline sedimentation during periods of lower sea level and are not being replenished.

Environmental change from mining, however, would leave a substrate of scattered pebbles over bedrock and would alter the already high concentration of suspended sediment. Also high values of suspended sediment already occur sporadically in the Alaskan coastal water of this region because of large quantities of suspended sediment created by storm events (Nelson, 1971; Nelson and Creager, 1977; Cacchione and Drake, 1982).

Lag gravel over glacial deposits

Gravels were deposited by the Holocene shoreline transgression as it reworked glacial till. A substantial surface area of this gravel type occurs out to the three mile limit off Nome, in a large area southwest of Cape Prince of Wales, and north and northwest of St. Lawrence Island (Fig. 10). The location of these gravels correlates with subsurface occurrence of glacial till. Where the gravel has been penetrated it is thin, less than 30 cm thick, and without a matrix of silt or mud. Beneath the thin veneer of relict lag gravel over glacial deposits, the till is composed of pebbly sandy silts.

The complete lack of any shallow coring in these regions, prevents detailed knowledge of the thickness of the gravel lags and the resource potential cannot be estimated. The techniques for mining would be difficult to ascertain because of unknown thicknesses and variability of gravel type. Additional complications exist in the Nome nearshore region because the relict gravels are rich in gold in certain locations. The gold resource should be considered along with the sand and gravel resource. Assessing the gold resource is complex because of the heterogeneity of deposits near Nome, especially where surface and subsurface alluvial channels have been in-filled by finer sands (Nelson and Hopkins, 1972).

The mining or skimming off of this clean relict lag gravel would change the substrate of the mined region. The new substrate would be one of muddy gravel that would not provide the same bouldery, clean gravel substrate as at present. The mining of such gravels and the generation of large sediment plumes by mining to some extent emulates the Seward Peninsula coast where coastal water frequently contains elevated levels of suspended sediment caused by storm surge ebb flow (Nelson, 1971; Nelson and Creager, 1977; Cacchione and Drake, 1982).

Basal transgressive medium sands

Coarse- to medium-grained sand covers regions paralleling the gravels; particularly along the western edge of Seward Peninsula from Sledge Island to Cape Prince of Wales and perhaps in bands through Bering Strait and Anadyr Strait (Fig. 10). They are poorly assessed in terms of thickness; where they have been penetrated they tend to be only a few centimeters (Fig. 11). The only exception to this is northwest of Port Clarence where large, linear ridges of this sand have been reworked by strong currents into sand wave fields (Field et al., 1981).

The resource potential of transgressive sands in most regions will be influenced by their thinness and interbedding with overlying finer-grained sands and underlying Pleistocene muds. In terms of environmental considerations this sand produces a distinct substrate for certain sets of fauna such as sand dollars (Nelson et al., 1981). If the well-sorted sands are mined out this substrate would no longer exist. At this point the relationships of these coarse- and medium-grained sands to biological food chains and mammals are not well assessed. Determination of long term effects of mining this substrate cannot be made with the present data base.

Inner shelf sand sheets

Throughout most of central Chirikov Basin and extending toward Norton Sound and its western edge is a sheet of fine-grained sand of about 125 microns mean grain size diameter and consisting of about 80% sand and 20% coarse to medium silt (Fig. 10). This sand sheet consists of sands layed down by the shore line transgression throughout the Holocene and is a thin sheet overlying a very widespread area of Northern Bering Sea. Its thickness is not well assessed, since only a few vibracores have penetrated its entire thickness (Fig. 11, cores in Chirikov basin); indications are that it rarely exceeds more than 1 meter, except where it may fill in subsurface and surface channels (Fig. 4).

This widespread sand sheet is a potential resource if this very fine sand is of the proper grade for development purposes. It can be skimmed off over wide regions and is a very consistent material throughout the entire Chirikov Basin region. This uniformity means that little processing or sizing of the material might be required to provide fine sand sources.

If this substrate is stripped off to the coarser sands below or more likely to the underlying Pleistocene peaty mud, the surface substrate in such regions would be changed. Environmental effects of this are predictable because this fine sand sheet is a habitat for Ampilicid amphipods. The Ampilicid amphipods are a food source for whales, particularly the Grey whale species. If wide regions of this sand are used as a resource and it is stripped off completely the distribution of a major food source for the grey whales would be changed. In addition, mining operations causing large sediment plumes could alter the normal environment of this region which is not prone to high quantities of suspended sediment in the water column (Drake et al., 1979).

Holocene sediment covers the region of Norton Sound (Fig. 10). This deposit varies from 14 meters thickness, close to the Yukon Delta, to a thin (1-2 meter), very fine sand sheet over northern Norton Sound and may be absent in the north central region. Again this widespread sheet of very fine sand-coarse silt is a minable resource if such sands are required for any development purposes.

Like the inner shelf sands, if surficial Holocene deposits of Norton Sound are stripped off, the underlying Pleistocene peaty mud will form the new substrate. The food source and ecological relationships of this change in substrate are not well known and relationship to higher mammal food chains are not well established.

Distribution of sand and gravel bodies

A number of sand and gravel bodies have been defined in the Norton Basin area on the basis of topography and surface grain size. The thickness of these bodies and consequently total volumes cannot be estimated because there are only very shallow vibracores, generally less than 2 meters in penetration, available over these regions. Their geometry can only be determined from surface relief and estimates of their general thickness. This also holds true for the general grade of material since there are no shallow stratigraphic cores through these sand and gravel bodies. The homogeneity of the material is unknown and the only data available is in the upper 2 meters or from the surface samples collected over them. Table I summarizes the characteristics of these shelf sand bodies.

Two gravel bodies are known in the Northern Bering Sea area. The first lies west of St. Lawrence Island and appears to be a large old beach ridge formed by a Holocene still-stand of the sea level at approximately minus 30 meters of water depth (Fig. 12). The ridge consists of fine gravel and extends approximately 30 km to the northeast from the northwest Cape of St. Lawrence Island and has an undefined thickness because there are no shallow cores within this gravel body.

The second known gravel deposit occurs east of Nome off the Nome River area within 3 miles of shore. It is an outwash fan created during Pleistocene times of lower sea level (Nelson and Hopkins, 1972). This gravel body is well shown in the topography and seismic profiles of the region (ibid; Tagg and Green, 1973) and has been penetrated by drill holes providing core cuttings but no detailed stratigraphic sections. It appears to be at least several meters thick. However, there is not sufficient detail in the seismic profiling data nor in the drilling to assess the specific known volumes or size distribution of this outwash fan deposit.

The series of thin, relict, lag gravels over glacial till has been described in the previous section of this report. As has been noted, these cover wide areal regions over the northern Bering Sea but where they have been penetrated by vibracores or box cores they are quite thin, generally less than .5 m in thickness. They do not represent thick gravel deposits but do represent wide regions of a gravel occurrence. Outwash channels and alluvial channels in these relict glacial deposits have the greatest potential as gravel resources. In addition, the subsurface structure is poorly known because of the difficulty of obtaining good profile data in coarse-grained surficial deposits. The only good way to assess such alluvial channels is to have a shallow-core drilling program and such work has not yet been undertaken in the northern Bering Sea.

Large, deep, outwash and/or fluvial channels are observed on seismic reflection profiles collected over central Chirikov basin. These deep, filled, channels typically are incised 60 to 80 meters into the sea floor and occasionally over 100 meters. Assessment of the true width is somewhat difficult as the crossing angle is not known. Oblique crossings produce expansive cross-sections whereas more orthogonal crossings yield a narrow, steeper-sided record of the channel (Fig. 13 A & B).

Trackline density is not great enough to reliably connect these discrete crossings into a coherent drainage system. The channels are completely filled and show no surface expression, so sidescan records are of no aid in determining trend or continuity of channels. Their occurrence in Chirikov Basin suggests the upper part of the fill has been reworked during transgression and a thin veneer of coarse- to medium-grained sand deposited. A complete lack of deep core information from within the channels leaves the nature of the filling material unknown. The detail of internal structure seen within the channel fill suggests it is not coarse-grained but rather contains numerous silt and mud horizons. Good subsurface penetration in high-resolution seismic profiles is rarely observed in coarse-grained deposits.

Coarse-grained material would likely be present in the channel fill as channel-lag deposits and in point-bar portions of the fill. Exploitation of disseminated pockets of sand and gravel would require removal of fine-grained deposits to gain access to the target gravel lenses. Delineation of potential gravel zones would require detailed seismic surveys that at present do not exist. Working and removal of significant volumes of finer grained deposits would generate an extensive sediment plume in an area of typically low suspended sediment concentrations (Drake et al., 1979).

A series of large, linear, medium- to fine-grained sand shoals are present southeast of Bering Straits near Port Clarence (Fig. 14A). These sand shoals are well mapped in the surficial bathymetry and a number of shallow vibracores penetrating up to 6 m into the shoals have been taken. Some definition of these sand bodies is possible from surficial relief (Fig. 14B) and subsurface coring information (Fig. 14C) (Nelson et al., 1982).

These ancient shoreline shoals are 15-30 km in length, 3-7 km in width, and 10-15 m in relief with a known minimum thickness of 6 m of clean, very well sorted medium-to-fine-sand with a very low matrix content. They comprise a possible clean-sand source but it is a non-renewable source because these shoals were deposited as ancient shoreline sediments during a series of still-stands in the late Pleistocene-Holocene rise of sea level in the past 18,000 years (Field et al., 1981). At present, these sand bodies are not growing and sand is not being added to them because the grain size indicates the source is relict from past littoral drift processes and the grain size does not match with the modern very fine sand that has been deposited since sea level reached its present high level approximately 5000 years ago. Once these sand bodies are mined, they would not be replenished and the substrate in this region would be changed.

There are a series of other very large sand bodies that develop on the lee side of major landward projections into the strong northward currents (Nelson et al., 1982). These so-called leeside sand bodies have developed on both the east and west sides of Shpanberg Strait, on the north side of the Yukon delta, on the north side of King Island, and on the north side of Bering Strait (Fig. 12). Very little coring of these sand bodies has been done so estimates of their thickness cannot be made but their relief above the sea floor and general size can be estimated. These leeside shoals range from 25-100 km long, 5-25 km wide, and 10-20 m relief above the general level of the sea floor. They consist of very fine sand, approximately 100 microns in mean grain size, and contain coarse silt. This set of leeside sand bodies serves as a large source of very fine sand. These sand bodies also appear to be forming at present and if mined, could be replenished by the very fine sand suspended in the modern currents. Thus, these appear to be an extremely large, replenishable source of very fine sand (Nelson et al., 1982).

The last known types of sand bodies are the active subaqueous extensions of the modern Yukon River distributary channels (Fig. 12; Nelson et al., 1982). These surface and subsurface channels exist on the western side of the modern Yukon lobate delta. These delta-front channels extend 20-30 km from the delta, are 2-4 km wide, and have a relief of 5-15 m. It is impossible to assess the true nature of these sand sources which again are very fine (approx. 70 microns in diameter). These channel deposits are actively forming and provide a modern, replenishable source of sand. However, their location on the delta-front platform in water depths of only 2-3 m deep suggests that logistics for development may be difficult. Therefore, the resource potential is impossible to estimate using the present data base and available technology.

Data Limitations

The data base for this report is compiled from over 20 years of marine geologic investigation in the northern Bering Sea. The primary objective of these operations was the characterization of the sea floor on a broad reconnaissance level, recognition and delineation of potentially hazardous seafloor features, and detailed study of selected features, areas of unique character, property, or process. The assessment of potential sand and gravel resources was not a primary or even secondary objective and the data set is in large part not applicable to such an evaluation. The sediment analysis and characterization studies do provide some basic knowledge that sheds some light on presence and amount of sand and gravel.

One of the major limitations is lack of ground truth for interpretation of seismic data. No core information from deeper than 7 meters is included in the data. Shallow holes were drilled offshore Nome but do not provide detailed stratigraphy. A major drilling program is required to "calibrate" the seismic data and describe the units recognized in the seismic reflection profiles.

Coverage of seismic data is not extensive enough over much of the northern Bering to adequately and accurately define the morphology of various sediment bodies. Isolated crossings of channel deposits cannot be tied into a coherent pattern because the trackline separation is too great. Extensive portions of western Norton basin contain gas-charged sediment in the upper few meters (Cline and Holmes, 1977; Holmes and Thor, 1982). The presence of gas completely disrupts the ability of high resolution profiling systems to penetrate the subsurface. Therefore, the shallow, internal, structure of large portions of the sea floor of the northern Bering Sea is undetermined. Subbottom penetration of acoustic profiling systems is also decreased by coarse-grained sediment. Hence, the paradox of the presence of sand and gravel acting to prevent the determination, by seismic techniques, of their thickness, extent, nature, etc.

Coarse-grained sediment also reduces the effectiveness of conventional sampling methods. Gravel and coarse sand are resistant to penetration by all coring devices typically used. Refined and improved coring methods could provide needed information where present sampling methods are ineffective.

Summary

The sea floor of the northern Bering Sea features extensive areas of sand and gravel deposits. Additional detail is needed to define the exact limits of these deposits. In contrast to the lateral extent of such deposits, the thickness of such deposits is generally limited to a few cm to a few 10's of cm. Distinct sand and gravel bodies are known in some locales and the detailed surveys of some of these linear sand bodies allows definite constraints to be put on their size and thickness. These sand and gravel bodies are by-in-large relict or palimpsest deposits and as such represent a non-renewable resource. Once mined, the substrate would be changed.

The nature of the data base makes assessment of environmental impacts speculative and inferential. In areas where the underlying material differs from the sand and gravel, a change in substrate is one of the likely products of mining or stripping. Such a change affects bottom dwelling organisms that depend on a certain bottom character for their habitat. Disruption of this lower portion of the food chain could have an effect on the biologic community of a given area.

The generation of a suspended sediment plume will change the background suspended sediment levels. High levels of suspended sediment are not unusual in much of the northern Bering Sea, however, there are distinct areas of low suspended sediment values, and introduction of sediment laden water could increase suspended sediment concentrations.

Additional data aimed specifically at sand and gravel assessment is needed in much of the area. Once targeted as a potential resource area, detailed studies would be necessary to accurately define the resource and any potential environmental hazards associated with its exploitation.

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Figure Captions

Figure 1. Location map and generalized bathymetry of northern Bering Sea. Contour interval is 10 m.

Figure 2A. Tracklines and data type collected prior to 1980. Includes USGS, NOAA, and University of Washington.

Figure 2B. Survey lines and sample stations of 1980 USGS cruise.

Figure 3. Station location map. Locations of profiles of figure 11 shown by solid lines A-A' and B-B'.

Figure 4. Location of filled and buried channels.

Figure 5. Elements of pre-transgressive geologic history in northeastern Bering Sea showing locations of seafloor and near-surface bedrock outcrops, glacial moraines, and alluvial channels. (For complete coverage of alluvial channel distribution see figure 4).

Figure 6A. Percent sand in surface sediment. Contour interval 5%.

Figure 6B. Simplified map of sand-size material content of surficial sediment.

Figure 7A. Percent gravel in surface sediment. Contour interval 5%.

Figure 7B. Simplified map of gravel size material in surficial sediment.

Figure 8A. Mean grain size for surface sediment. Contour interval 0.5 ϕ.

Figure 8B. Gravel, sand, and mud content of surficial sediment based on mean grain size.

Figure 9A. Modal grain size for surface sediment. Contour interval 0.5 ϕ.

Figure 9B. Gravel, sand, and mud content of surficial sediment based on modal analysis.

Figure 10. Map of northeastern Bering shelf surficial geology.

Figure 11. Near-surface late Pleistocene and Holocene stratigraphy in Norton Sound (A-A') and Chirikov Basin (B-B'). (See figure 3 for locations). In profile A-A' the date of 1500 years BP in core C dates influx of freshwater and Yukon River Delta lobe. In profile B-B', the region of sand ridges in northeast Chirikov Basin extends from King Island shoal to Port Clarence.

Figure 12. Location of sand bodies on the eastern Bering epicontinental shelf.

Figure 13. High-resolution seismic reflection profiles over filled alluvial channels, central Chirikov Basin.

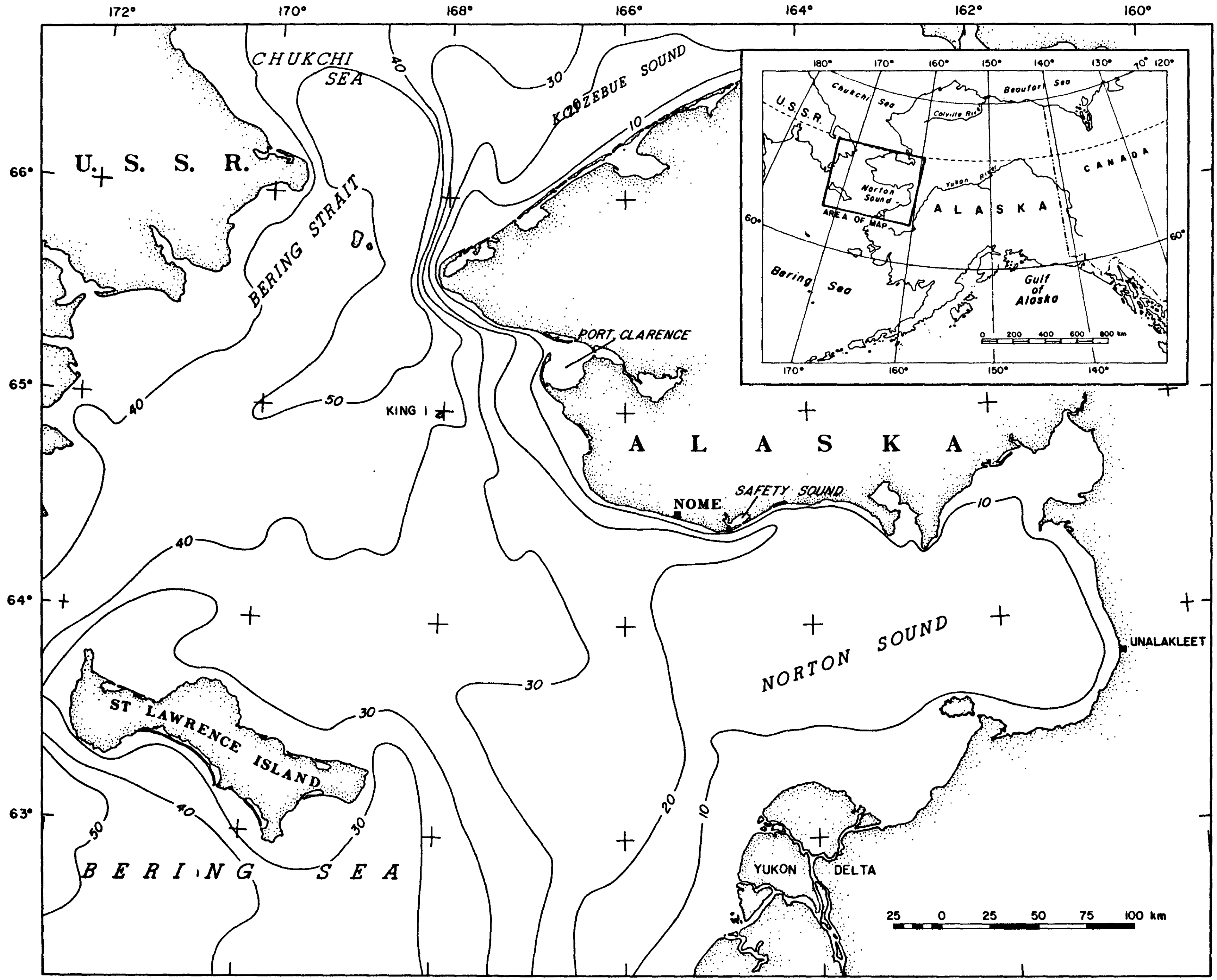
Figure 14A. Location map of active large sandwaves off Port Clarence. Bathymetric profiles of figure 14B shown by solid lines.

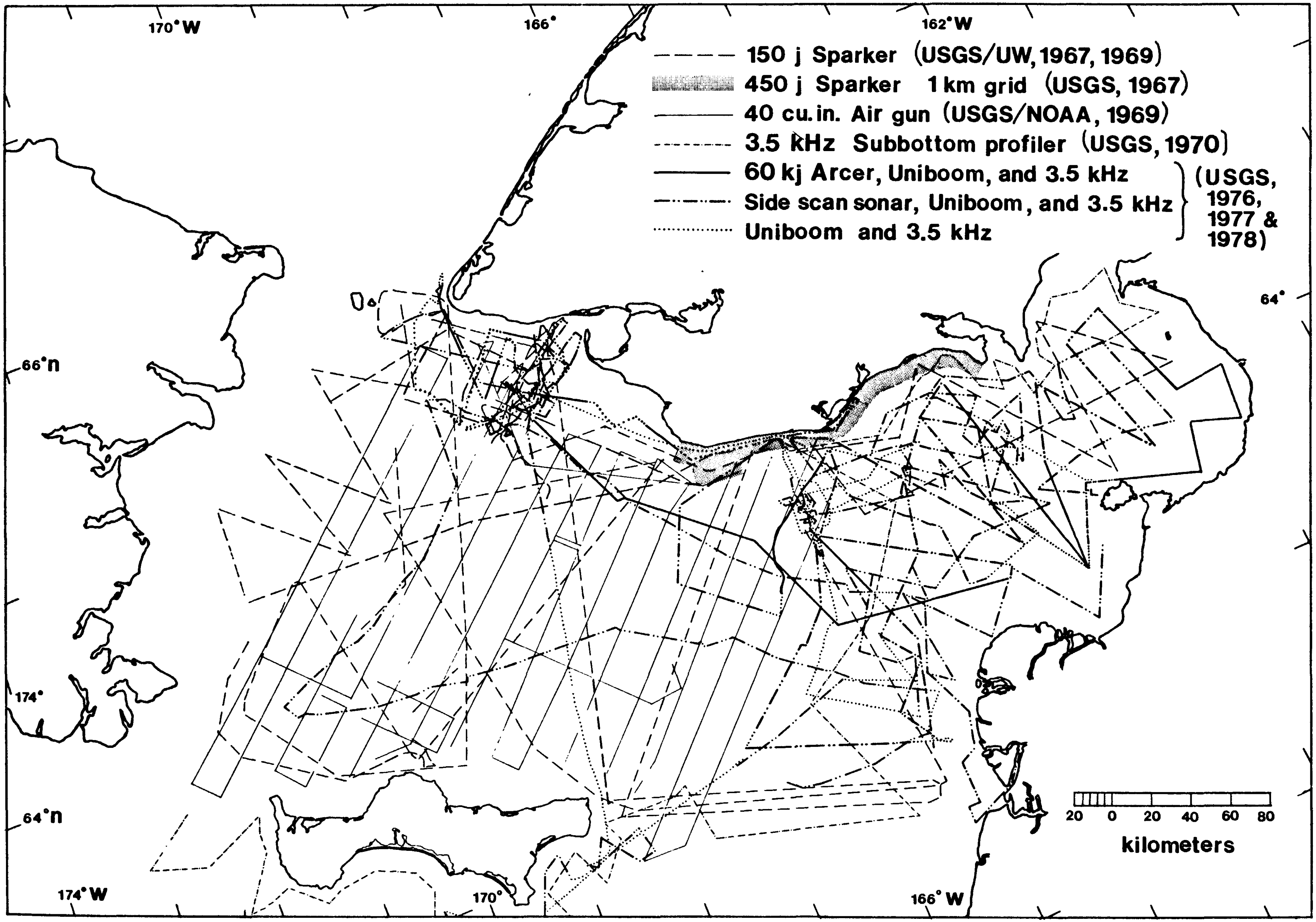
Figure 14B. Bathymetric profiles across area of large sandwaves.

Figure 14C. Mean grain size of surface sediment in area of large sandwaves.

Table 1. Characteristics of Bering Shelf Sand Bodies

AGE	TYPE	ENVIRONMENT OF DEPOSITION	LENGTH (KM)	WIDTH (KM)	RELIEF (M)	LITHOLOGY	SEDIMENTARY STRUCTURES	DISTINGUISHING FEATURES
Holocene - Modern	Linear tidal sand ridges	Macrotidal funnel-shaped bay and estuary.	5-35	1-3	4-32	Fine sand	Parallel lamination, surface ripple fields, sand waves observed	Enclosed by tidal flat and shelf mud, shore-perpendicular, varying in size and shape--sometimes sigmoidal.
	Shore-parallel shoals (+ barrier islands)	Outer edge of sub-tidal flats in mesotidal regions.	5-10	0.5-1	15	do.	Same as above	Enclosed by tidal flat and shelf mud, shore parallel, consistent limited size and shape.
	Delta front (sub-ice) channels	Offshore extensions of major distributaries.	20-30	2-4	5-15	Fine to very fine sand in thalweg, graded sand beds in overbank mud	Trough crossbedding graded sand beds with flat lamination, cross lamination in vertical sequence	Enclosed by graded overbank sand beds in mud, shore perpendicular, large-scale trough crossbeds in thalweg sand beds.
Pleistocene-Holocene Palimpsest	Leeside shoals	Lee of islands or peninsulas interrupting strong geostrophic bottom currents.	25-100	5-25	10-20	Very fine sand	Rhythmic flat laminations alternating with occasional thin ripple laminations	Enclosed by shelf sand and mud, orientation parallel to shelf currents not shoreline, widely varying shape and size, very fine sand size with rythmic flat lamination interrupted by ripples.
	Ancient shoreline shoals	Shoreline deposits formed during still-stands of sea level.	15-30	3-7	10-15	Fine to medium sand inter-interrupted near surface by pebble lags and mud drapes	Alternating ripple and trough cross-lamination with high-angle foreset beds, bioturbation common	Enclosed by shelf sand and mud, parallel to ancient strandlines, high angle foresets interrupted by ripple and trough crosslamination, storm pebble and shell lags, bioturbation in lower and offshore sequences.
Pleistocene Relict	Morainal features	Glacial deposition during lowstands of sea level.	5-75	5-25	10-15	Medium-coarse sand and gravel	Rare trough cross-lamination and shell laminations	Enclosed by shelf sand and mud, size and shape variable, not shore parallel or perpendicular, coarse and variable grain size.


172°
170°
168°
166°
164°
162°
160°
66°
65°
64°
63°
CHUKCHI SEA
KOTZEBUE SOUND
U. S. S. R.
BERING STRAIT
PORT CLARENCE
KING I
ALASKA
NOME
SAFETY SOUND
NORTON SOUND
UNALAKLEET
ST LAWRENCE ISLAND
BERING SEA
YUKON DELTA
10
20
30
40
50
25 0 25 50 75 100 km
Chukchi Sea
Beaufort Sea
Colville River
U.S.S.R.
CANADA
Yukon River
ALASKA
Norton Sound
AREA OF MAP
Bering Sea
Gulf of Alaska
0 200 400 600 800 km
180°
170°
160°
150°
140°
130°
120°
60°



150 j Sparker (USGS/UW, 1967, 1969)
450 j Sparker 1 km grid (USGS, 1967)
40 cu.in. Air gun (USGS/NOAA, 1969)
3.5 kHz Subbottom profiler (USGS, 1970)
60 kj Arcer, Uniboom, and 3.5 kHz
Side scan sonar, Uniboom, and 3.5 kHz
Uniboom and 3.5 kHz
(USGS, 1976, 1977 & 1978)
170°W
166°
162°W
64°
66°n
174°
64°n
174°W
170°
166° W
20 0 20 40 60 80
kilometers

Fig. 2A

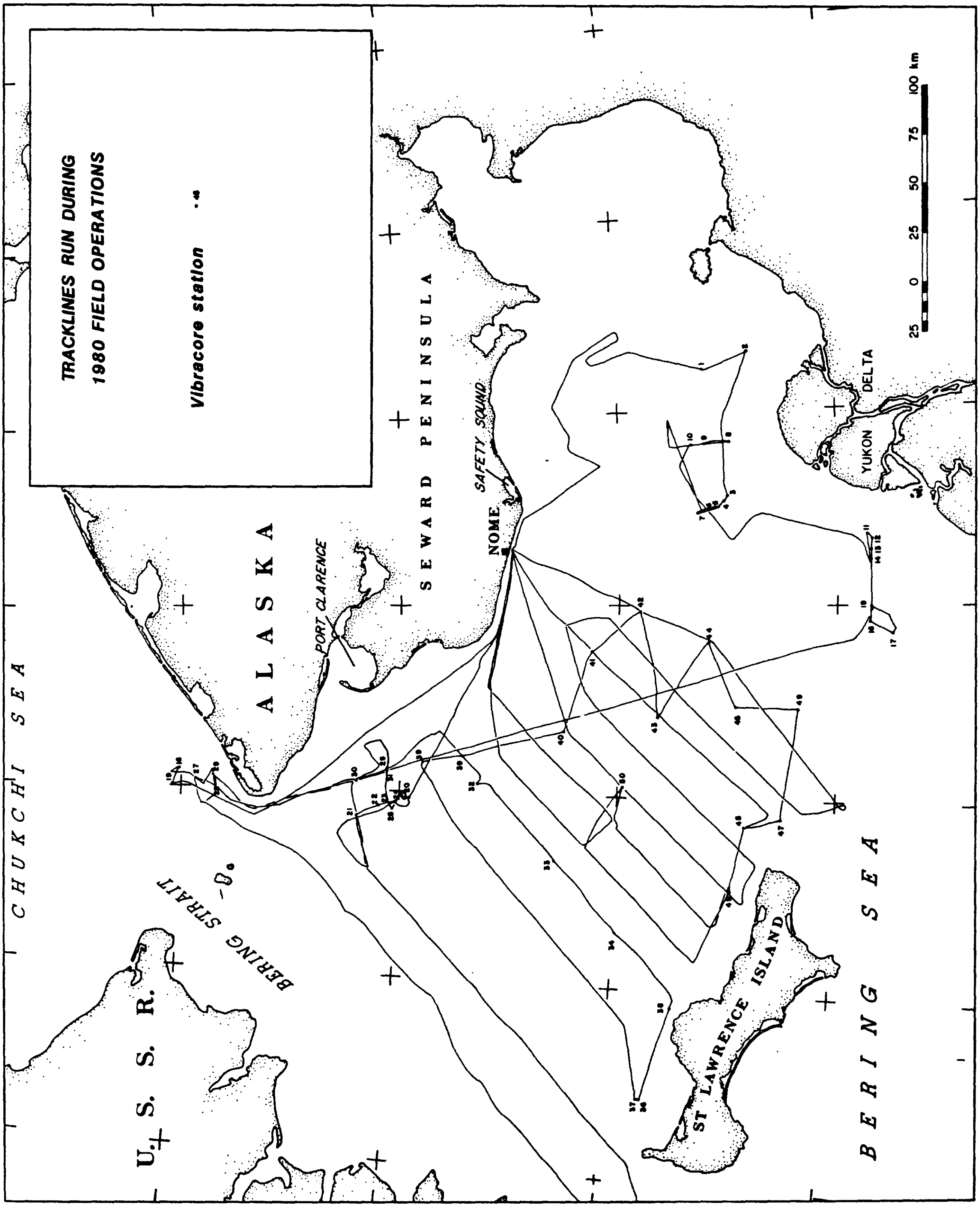

TRACKLINES RUN DURING
1980 FIELD OPERATIONS
Vibracore station
ALASKA
SEWARD PENINSULA
NOME
SAFETY SOUND
PORT CLARENCE
CHUKCHI SEA
BERING STRAIT
U. S. S. R.
ST LAWRENCE ISLAND
BERING SEA
YUKON
DELTA
25 0 25 50 75 100 km
160°
162°
164°
166°
168°
170°
172°
66°
65°
64°
63°

Fig. 2B

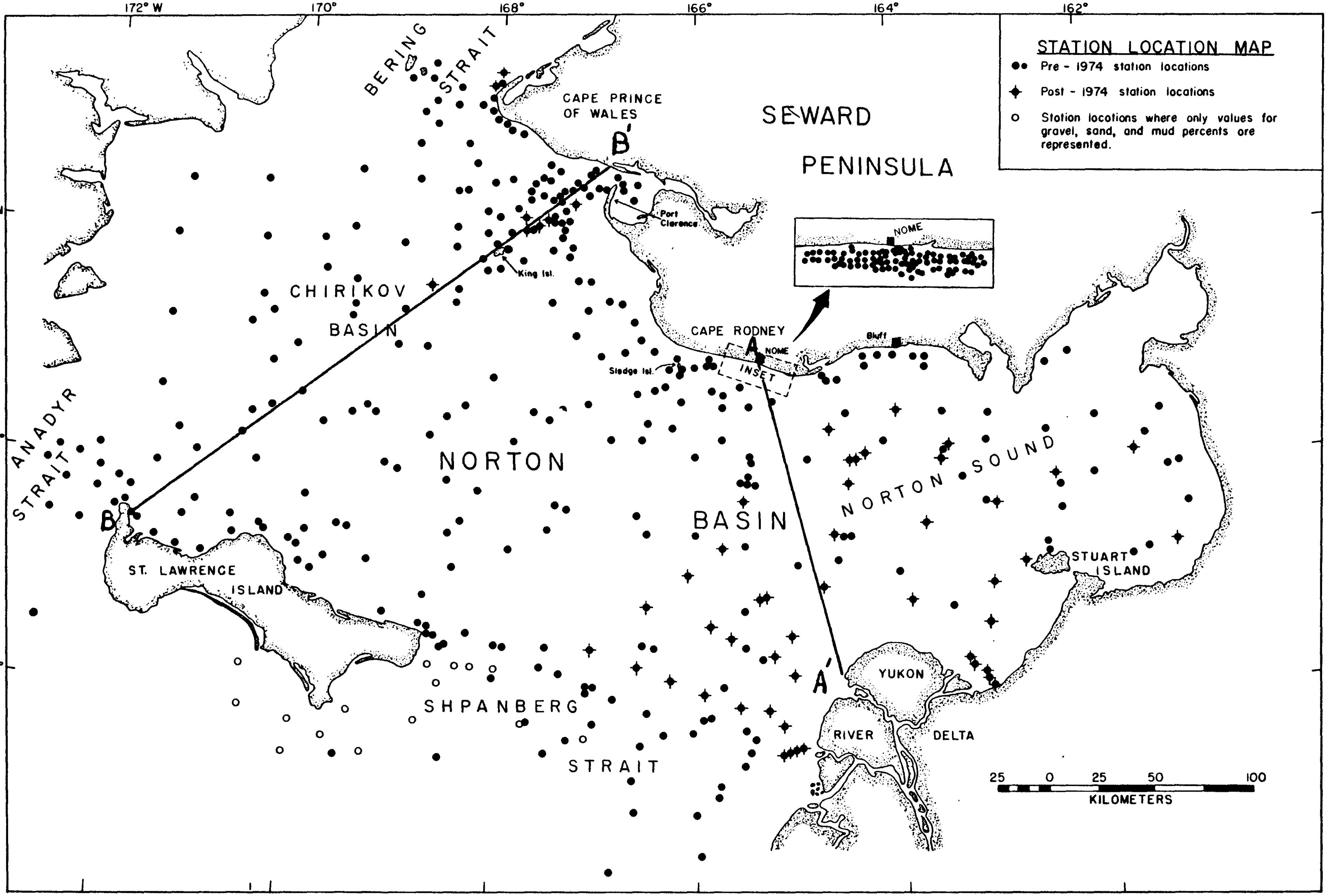
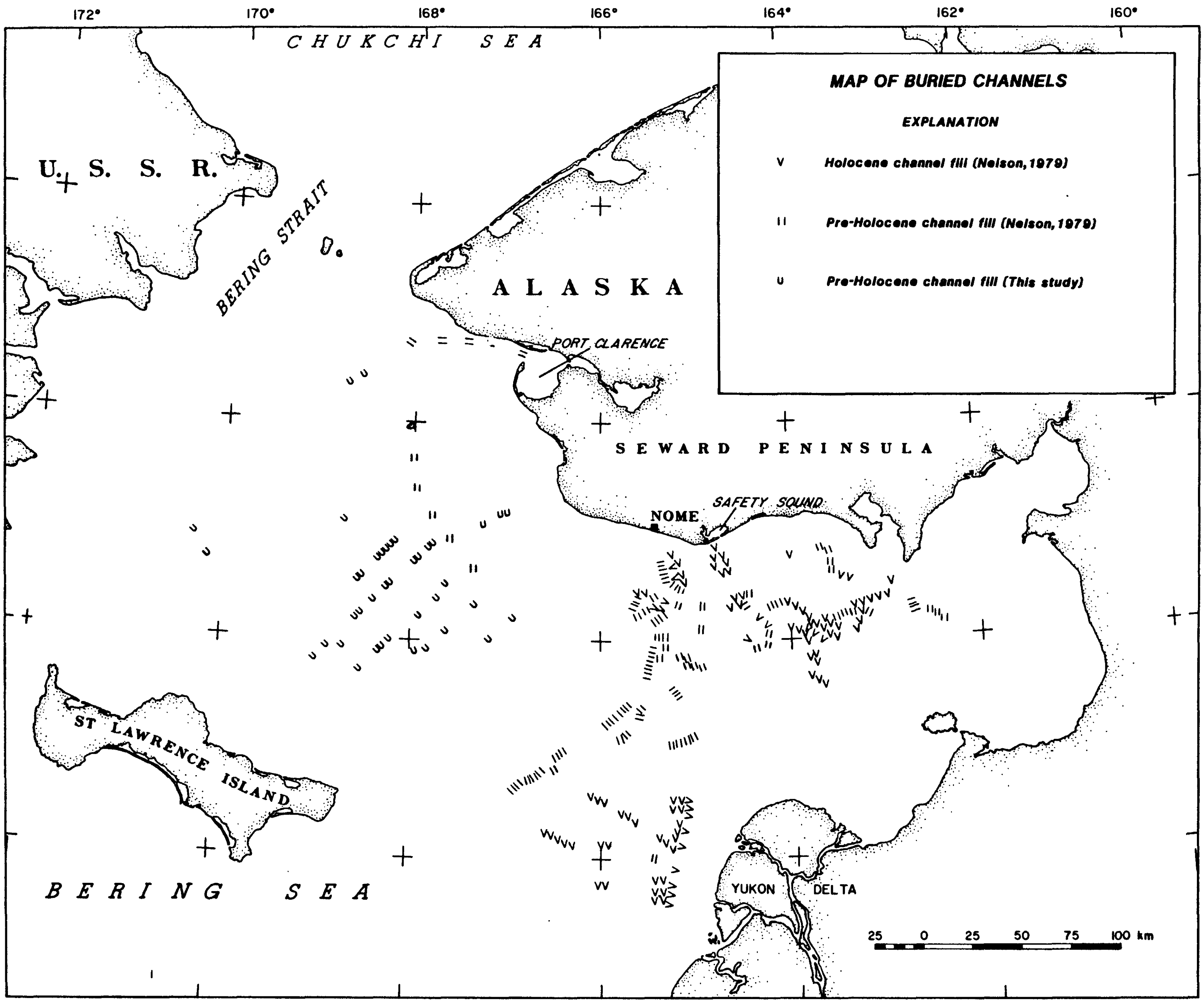
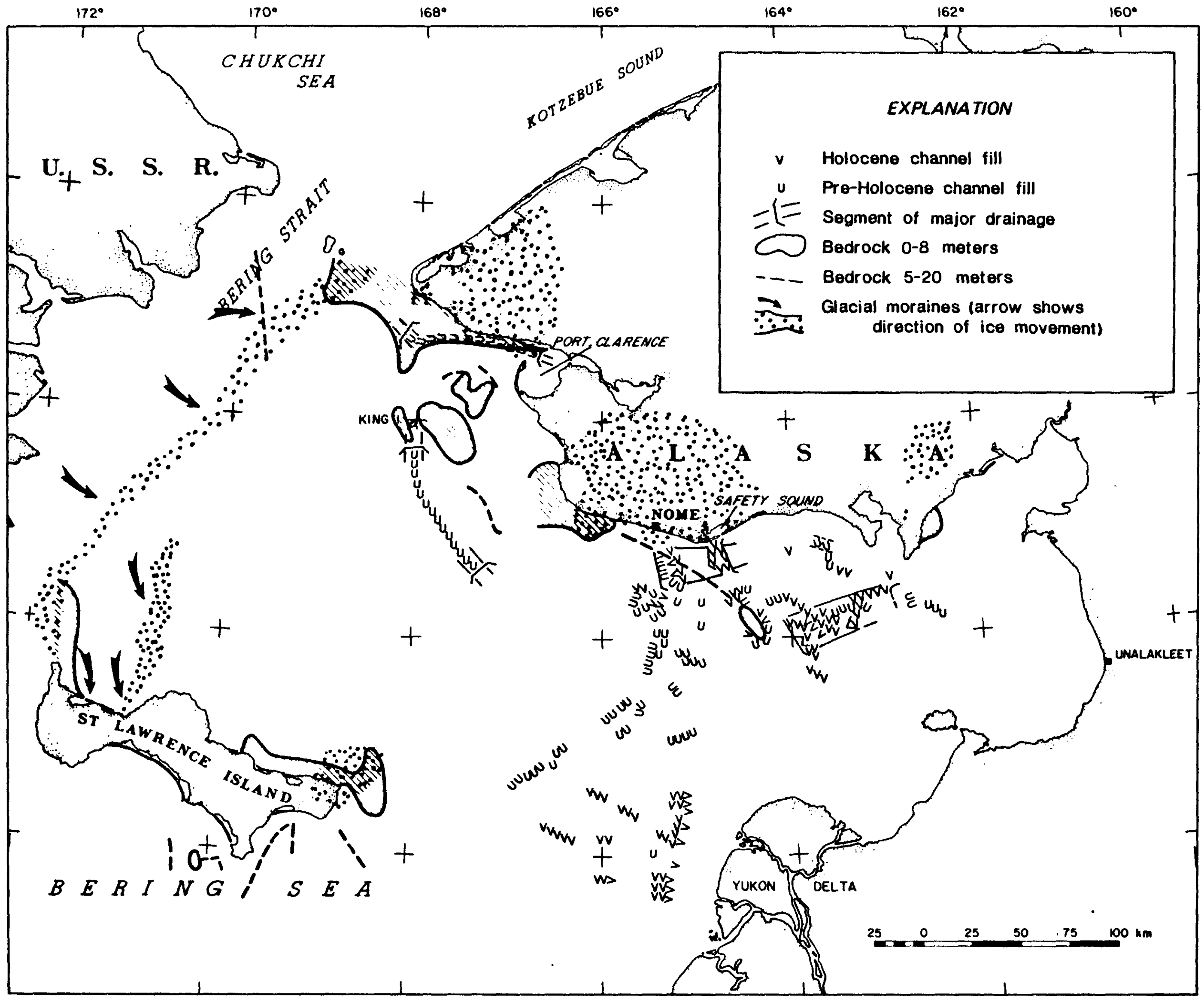

STATION LOCATION MAP
Pre - 1974 station locations
Post - 1974 station locations
Station locations where only values for gravel, sand, and mud percents are represented.
172° W
170°
168°
166°
164°
162°
65°N
64°
63°
BERING STRAIT
CAPE PRINCE OF WALES
SEWARD PENINSULA
B'
Port Clarence
NOME
King Isl.
CHIRIKOV BASIN
CAPE RODNEY
Bluff
NOME
INSET
A
Sledge Isl.
ANADYR STRAIT
NORTON
NORTON SOUND
B
BASIN
ST. LAWRENCE ISLAND
STUART ISLAND
YUKON
A'
SHPANBERG
RIVER
DELTA
STRAIT
25 0 25 50 100
KILOMETERS

Fig. 3



MAP OF BURIED CHANNELS
EXPLANATION
Holocene channel fill (Nelson, 1979)
Pre-Holocene channel fill (Nelson, 1979)
Pre-Holocene channel fill (This study)
172°
170°
168°
166°
164°
162°
160°
66°
65°
64°
63°
CHUKCHI SEA
U. S. S. R.
BERING STRAIT
ALASKA
PORT CLARENCE
SEWARD PENINSULA
NOME
SAFETY SOUND
ST LAWRENCE ISLAND
BERING SEA
YUKON
DELTA
25 0 25 50 75 100 km

Fig. 4



172°
170°
168°
166°
164°
162°
160°
66°
65°
64°
63°
CHUKCHI SEA
KOTZEBUE SOUND
U. S. S. R.
BERING STRAIT
PORT CLARENCE
KING
A L A S K A
SAFETY SOUND
NOME
UNALAKLEET
ST LAWRENCE ISLAND
BERING SEA
YUKON
DELTA
25 0 25 50 75 100 km
EXPLANATION
v Holocene channel fill
u Pre-Holocene channel fill
Segment of major drainage
Bedrock 0-8 meters
Bedrock 5-20 meters
Glacial moraines (arrow shows direction of ice movement)

Fig. 5

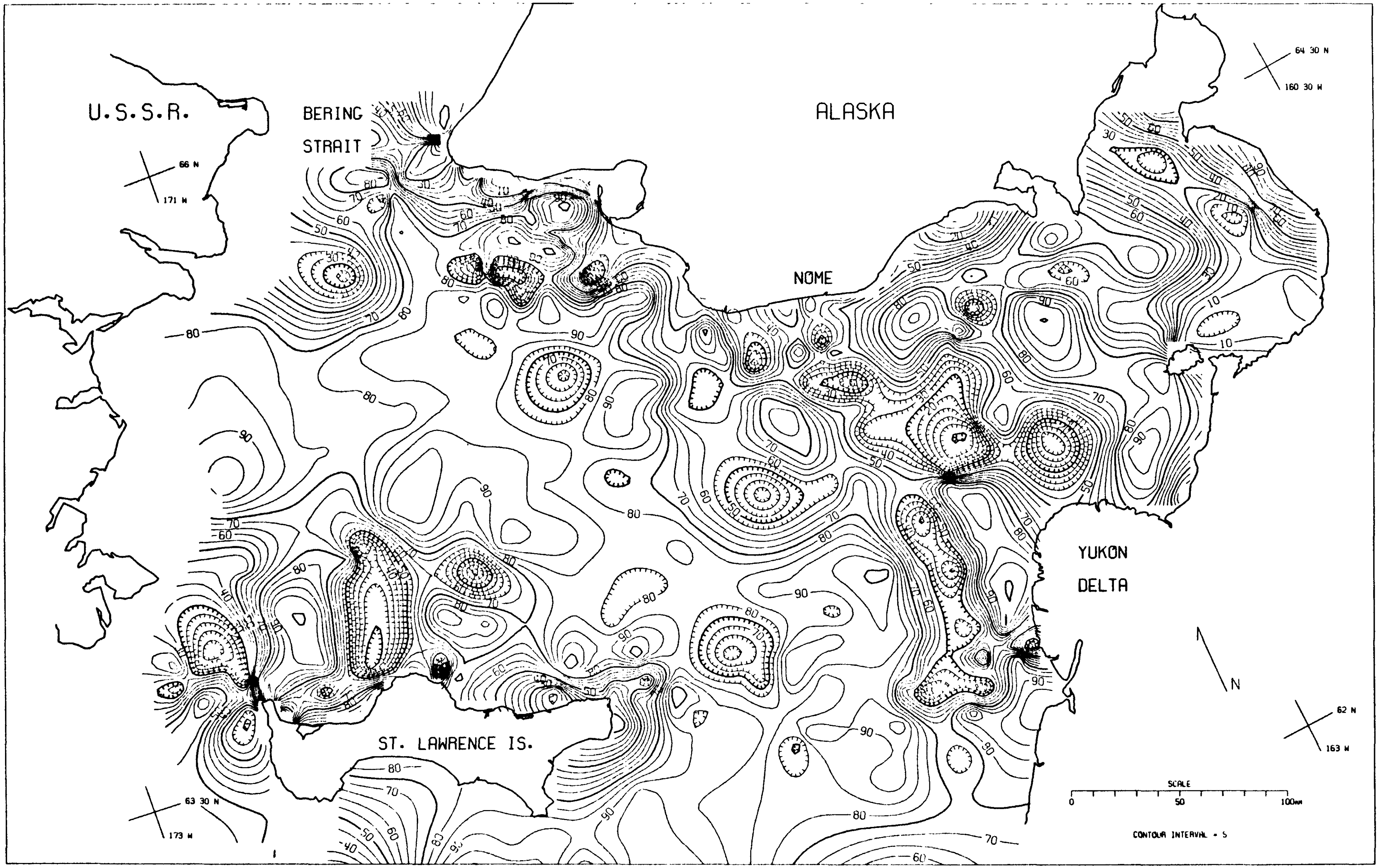


Fig. 6A % SAND IN SURFACE SEDIMENT OF NORTON BASIN, NORTHERN BERING SEA

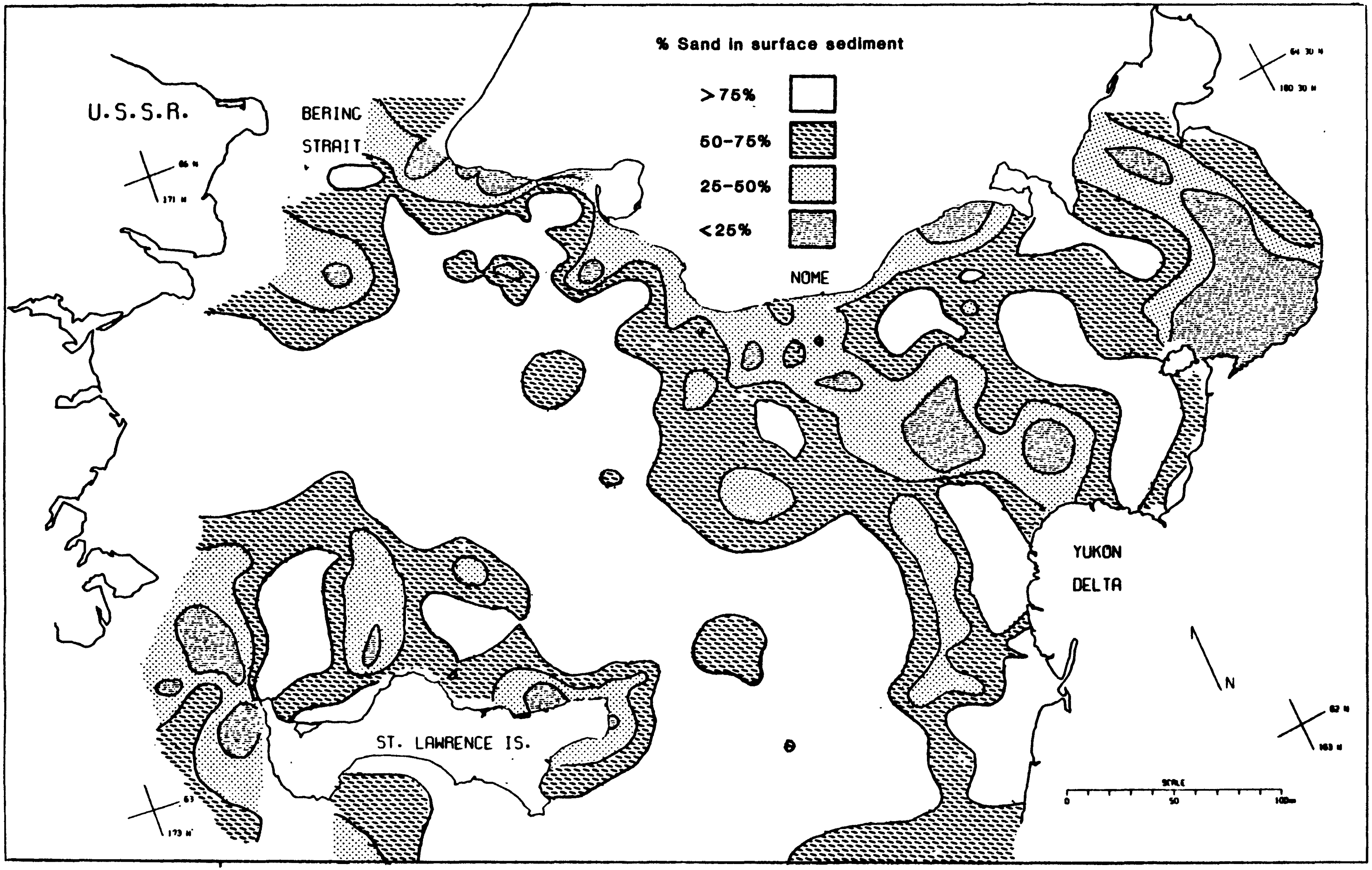

% Sand in surface sediment
>75%
50-75%
25-50%
<25%
NOME
U.S.S.R.
BERING
STRAIT
ST. LAWRENCE IS.
YUKON
DELTA
N
SCALE
0
50
100

Fig. 6B

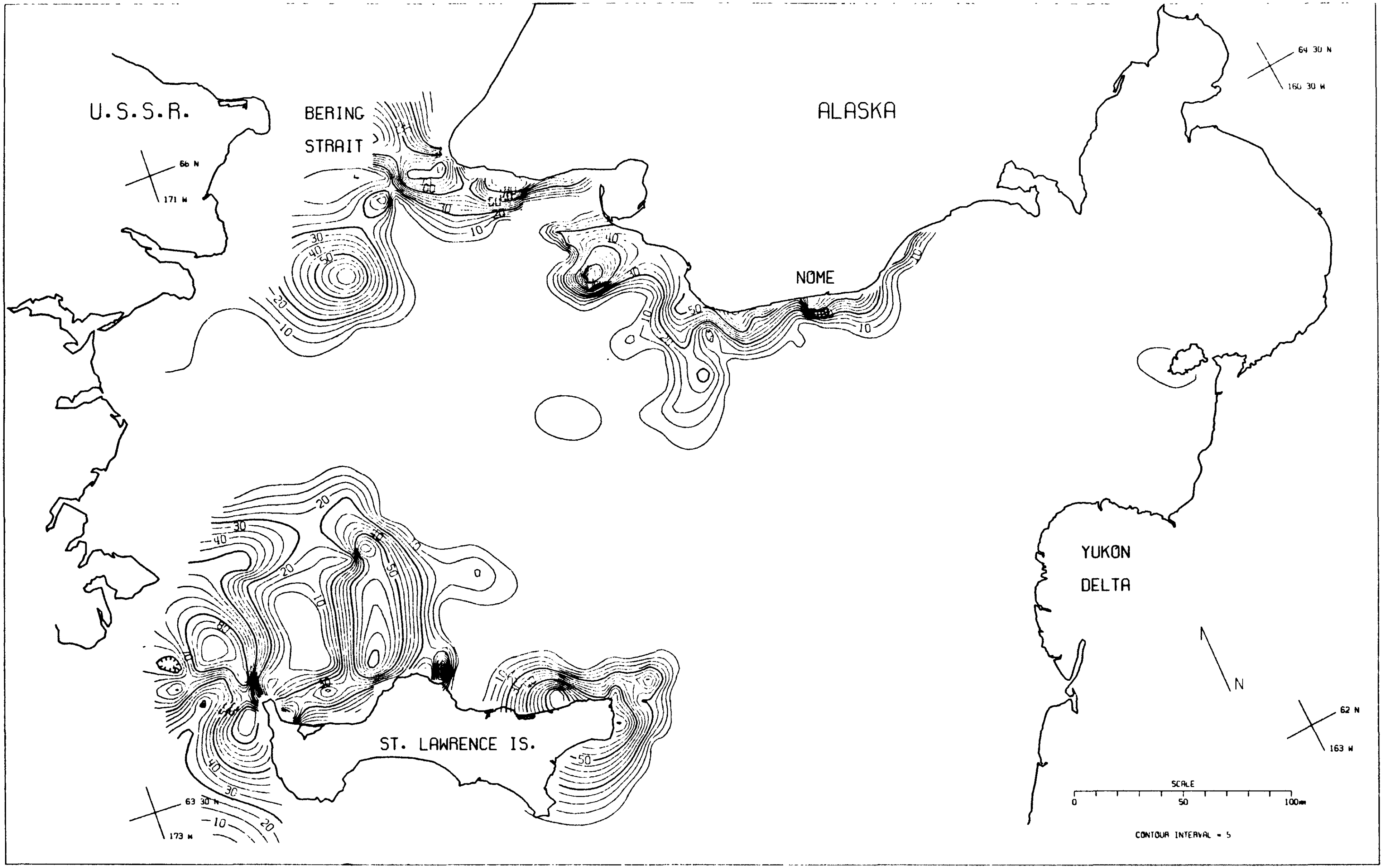
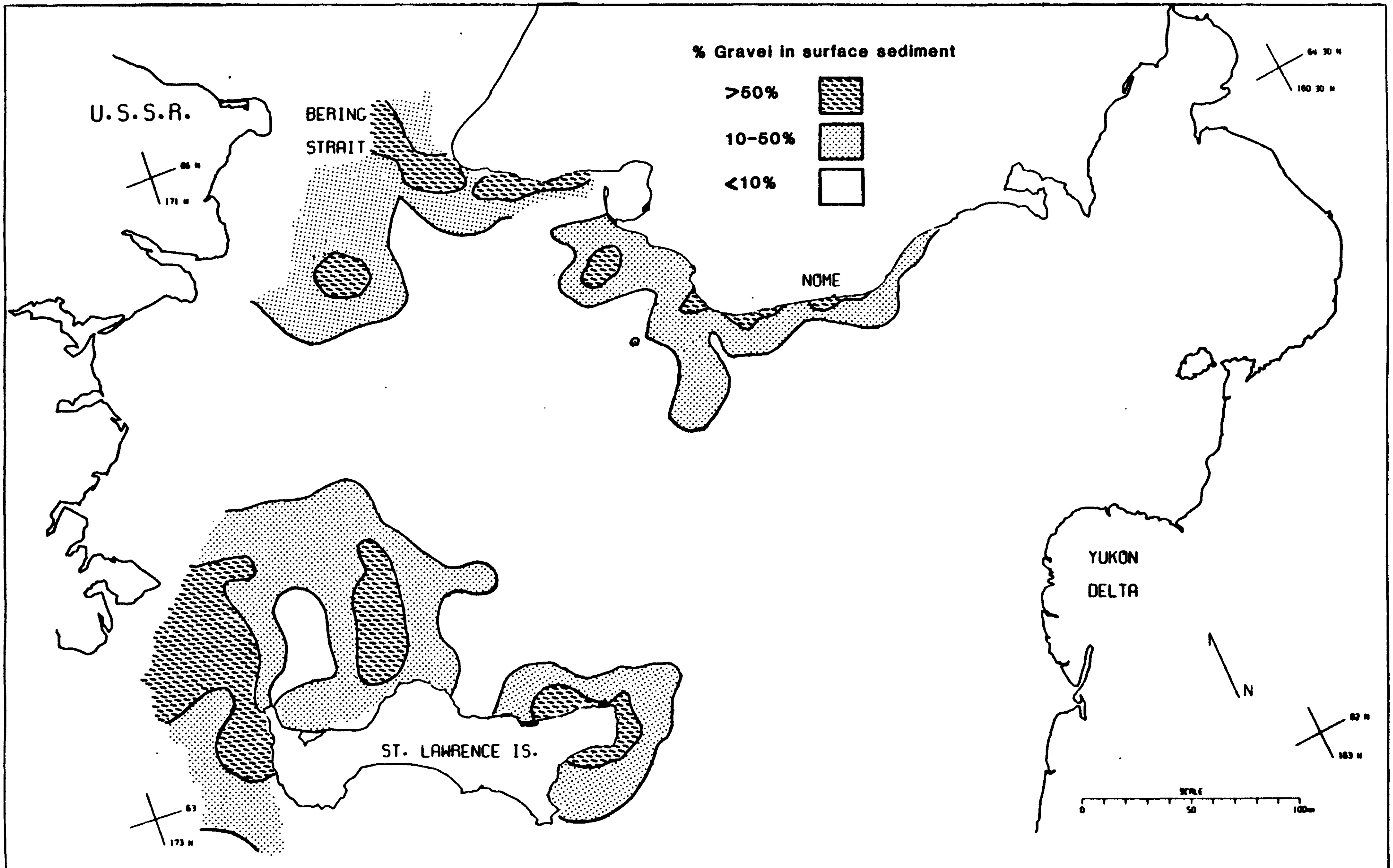


Fig. 7A % GRAVEL IN SURFACE SEDIMENT OF NORTON BASIN, NORTHERN BERING SEA



% Gravel in surface sediment
>50%
10-50%
<10%
U.S.S.R.
BERING
STRAIT
NOME
ST. LAWRENCE IS.
YUKON
DELTA
N
0
50
100km

Fig. 7B

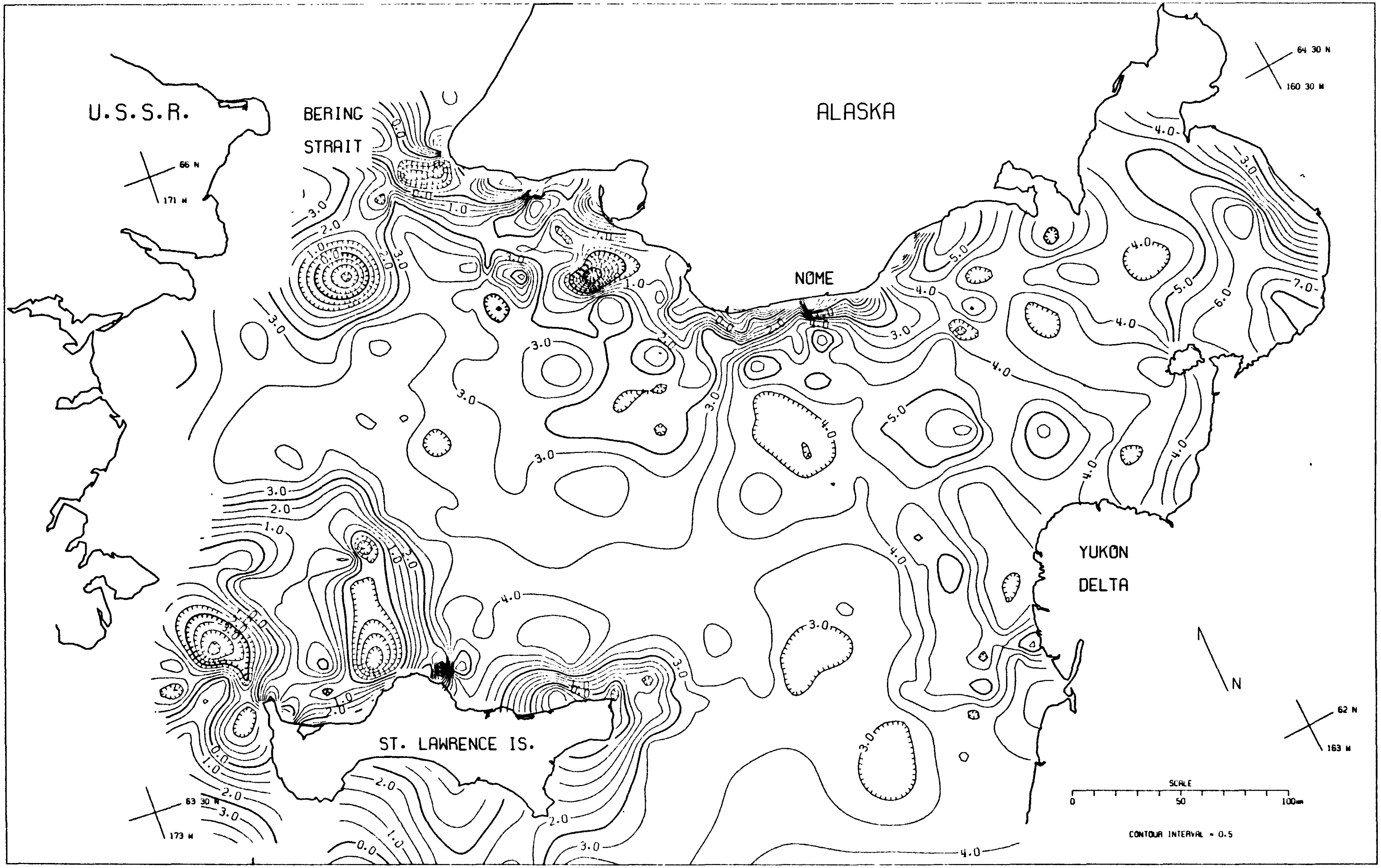


Fig. 8A MEAN GRAIN SIZE (FIRST MOMENT) FOR SURFACE SEDIMENT IN NORTON BASIN, NORTHERN BERING SEA

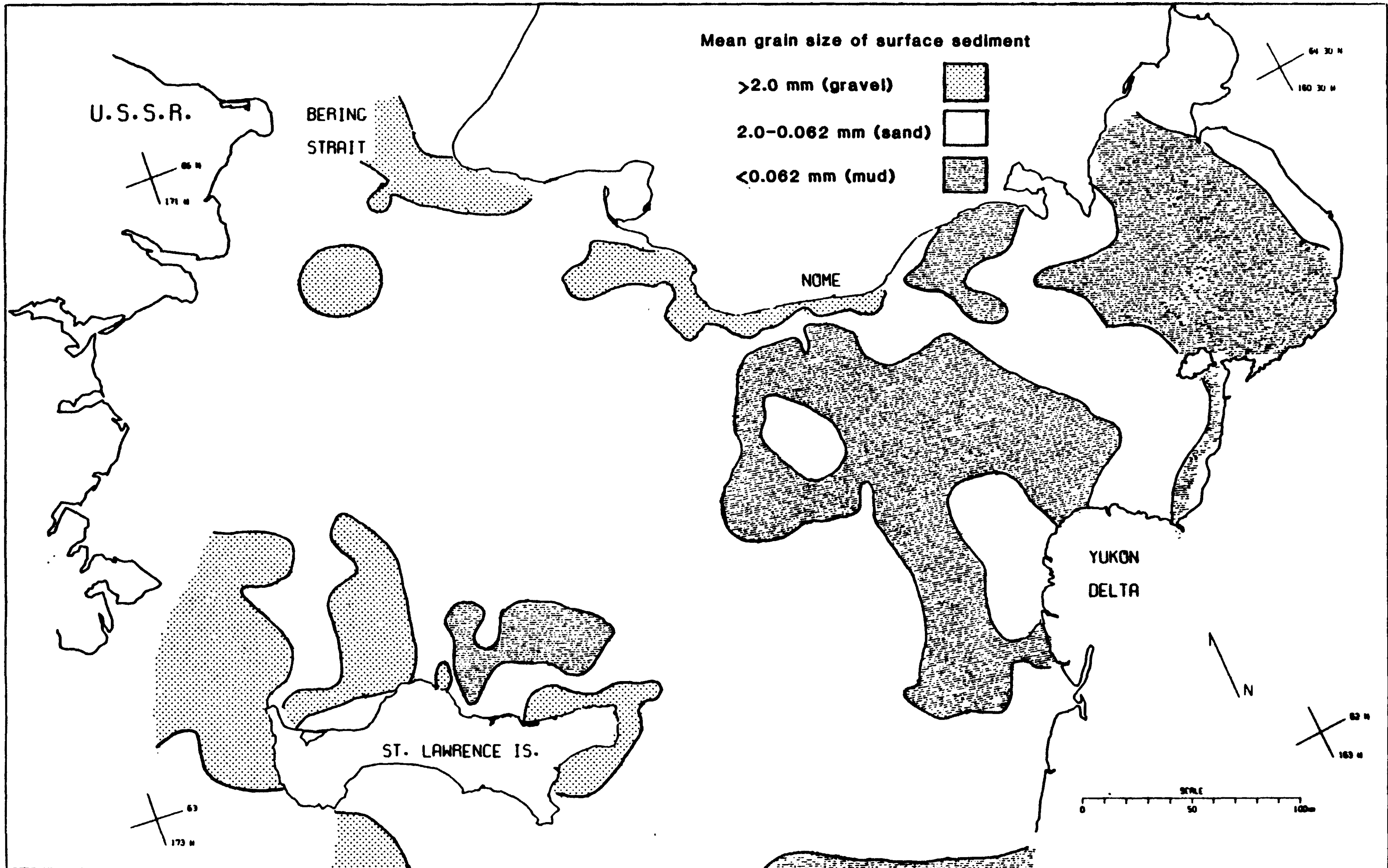

Mean grain size of surface sediment
>2.0 mm (gravel)
2.0–0.062 mm (sand)
<0.062 mm (mud)
U.S.S.R.
BERING
STRAIT
NOME
YUKON
DELTA
ST. LAWRENCE IS.
N
0
50
100

Fig. 8B

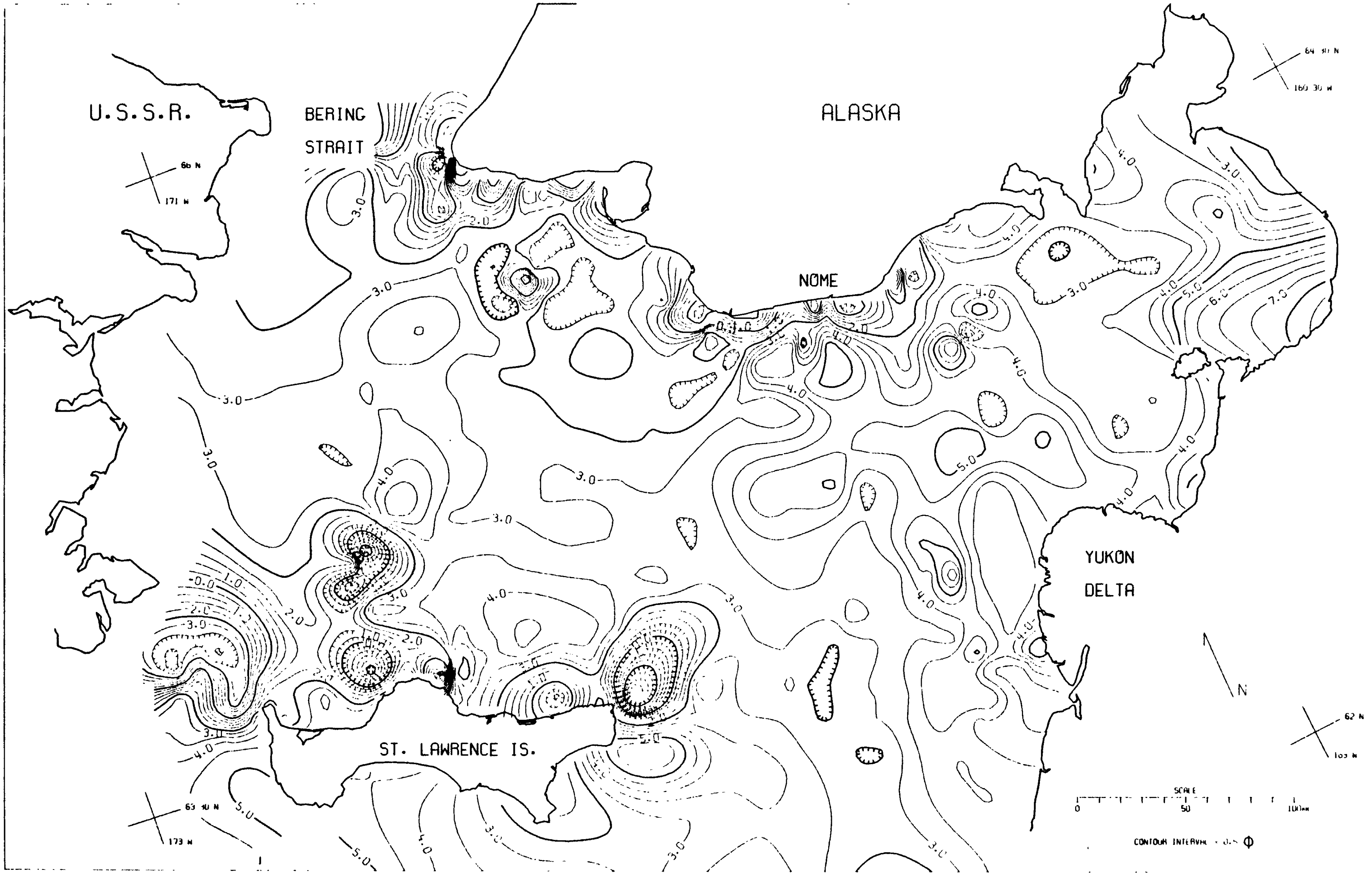


Fig. 9A PLOT OF MODAL CLASSES (IN PHI) FOR SURFACE SEDIMENT IN NORTON BASIN, NORTHERN BERING SEA

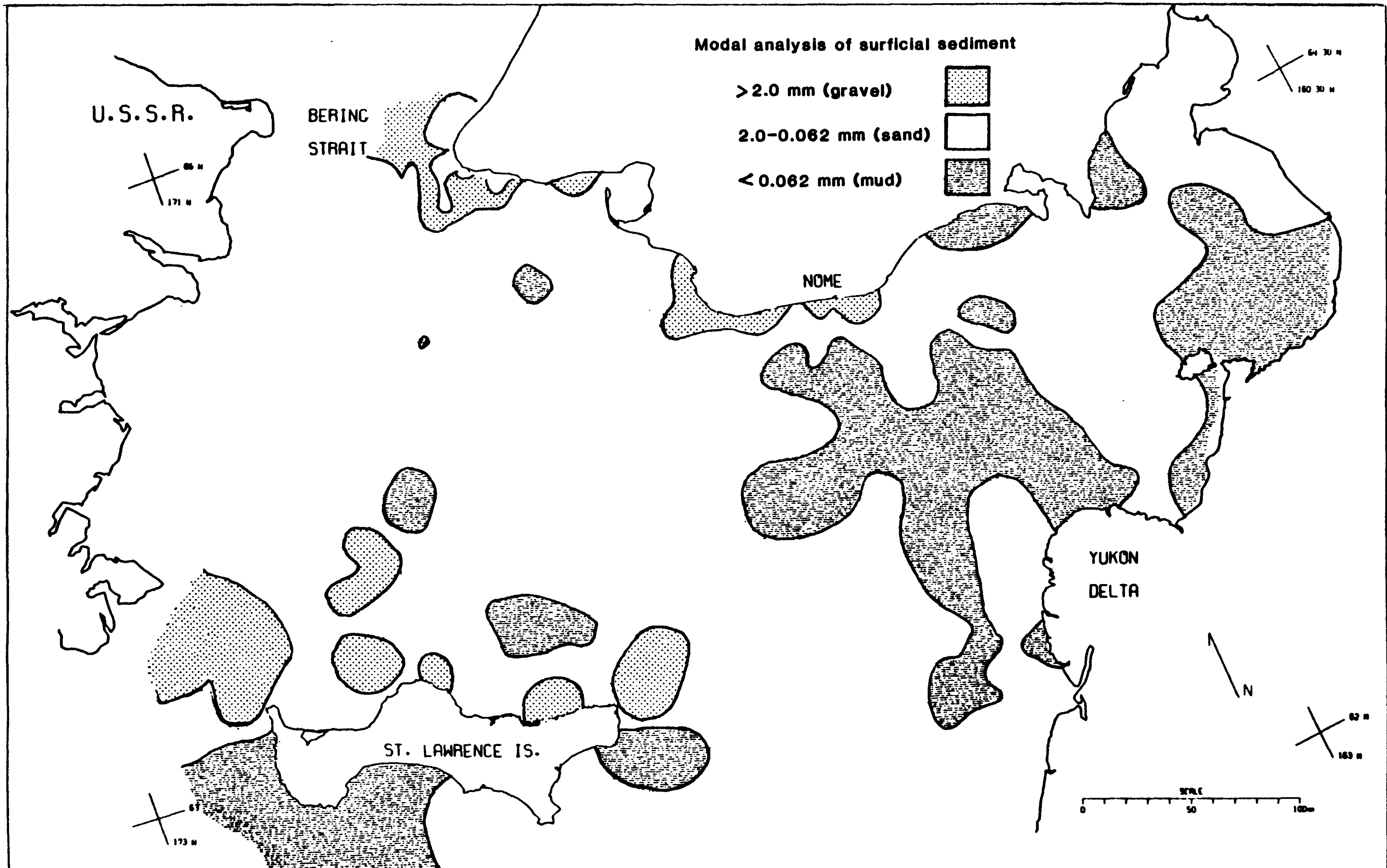

Modal analysis of surficial sediment
>2.0 mm (gravel)
2.0-0.062 mm (sand)
<0.062 mm (mud)
U.S.S.R.
BERING
STRAIT
NOME
YUKON
DELTA
ST. LAWRENCE IS.
N

Fig. 9B

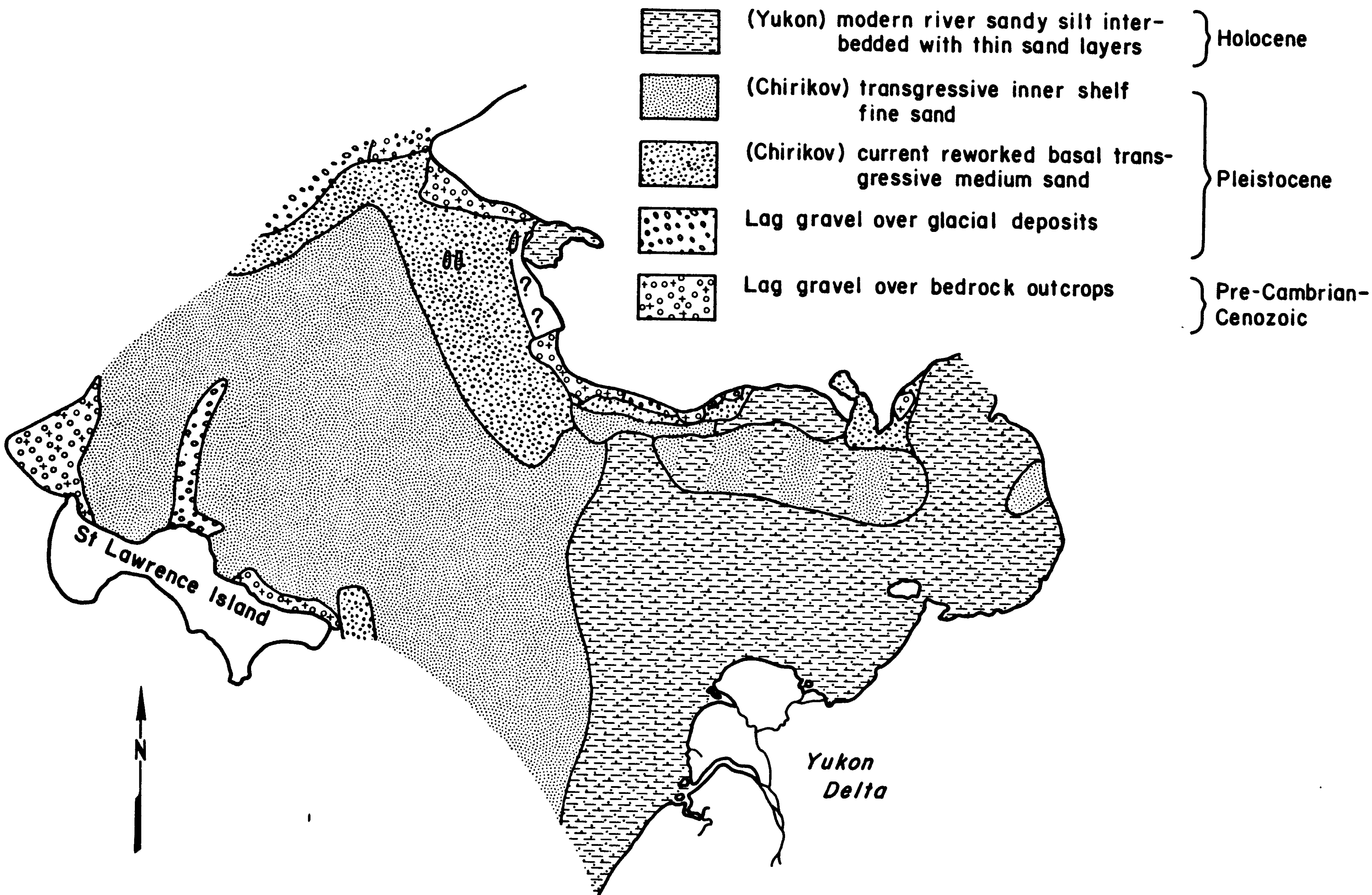

(Yukon) modern river sandy silt inter-bedded with thin sand layers
Holocene
(Chirikov) transgressive inner shelf fine sand
(Chirikov) current reworked basal trans-gressive medium sand
Lag gravel over glacial deposits
Pleistocene
Lag gravel over bedrock outcrops
Pre-Cambrian-Cenozoic
St Lawrence Island
Yukon Delta
N

Fig. 10

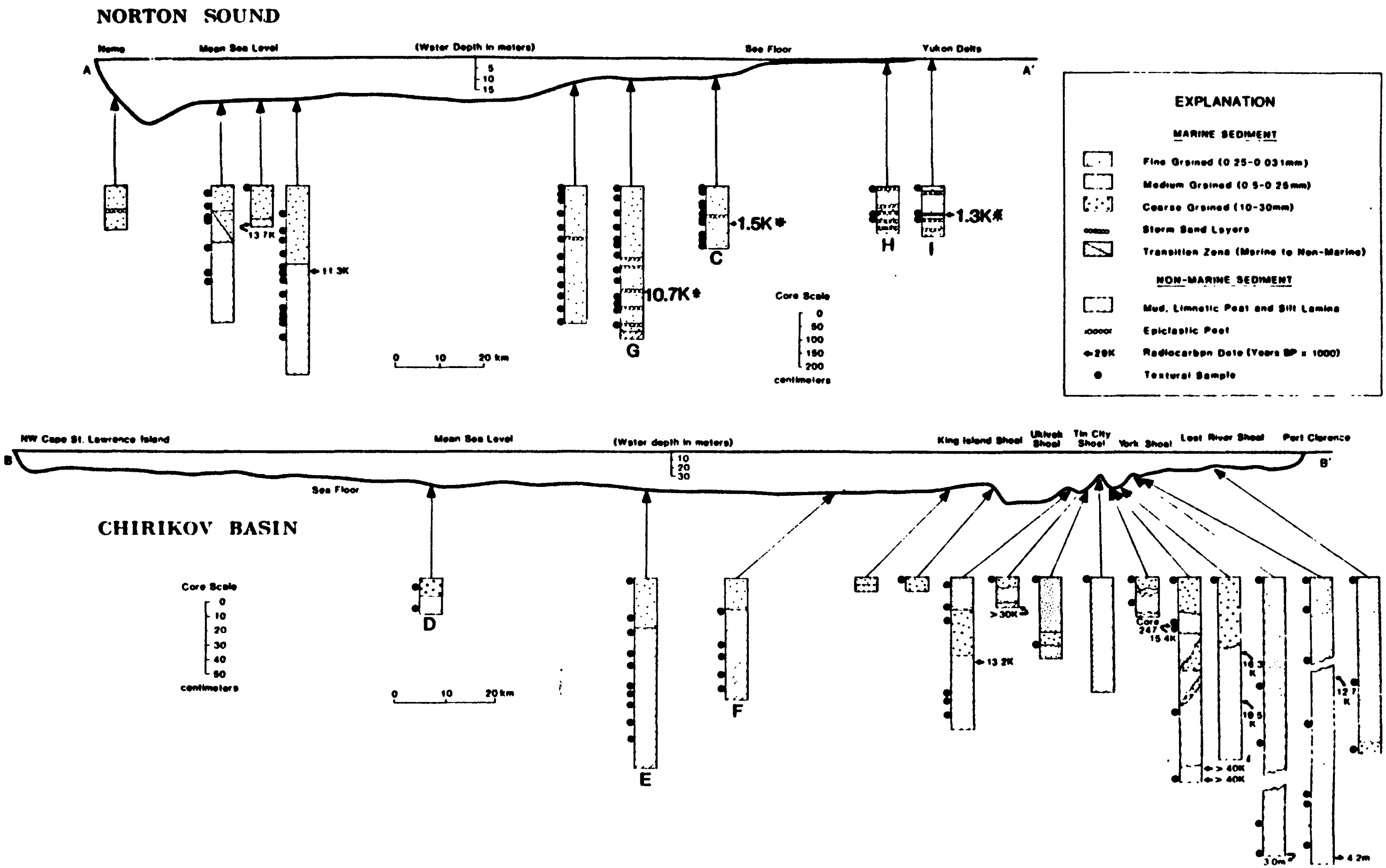
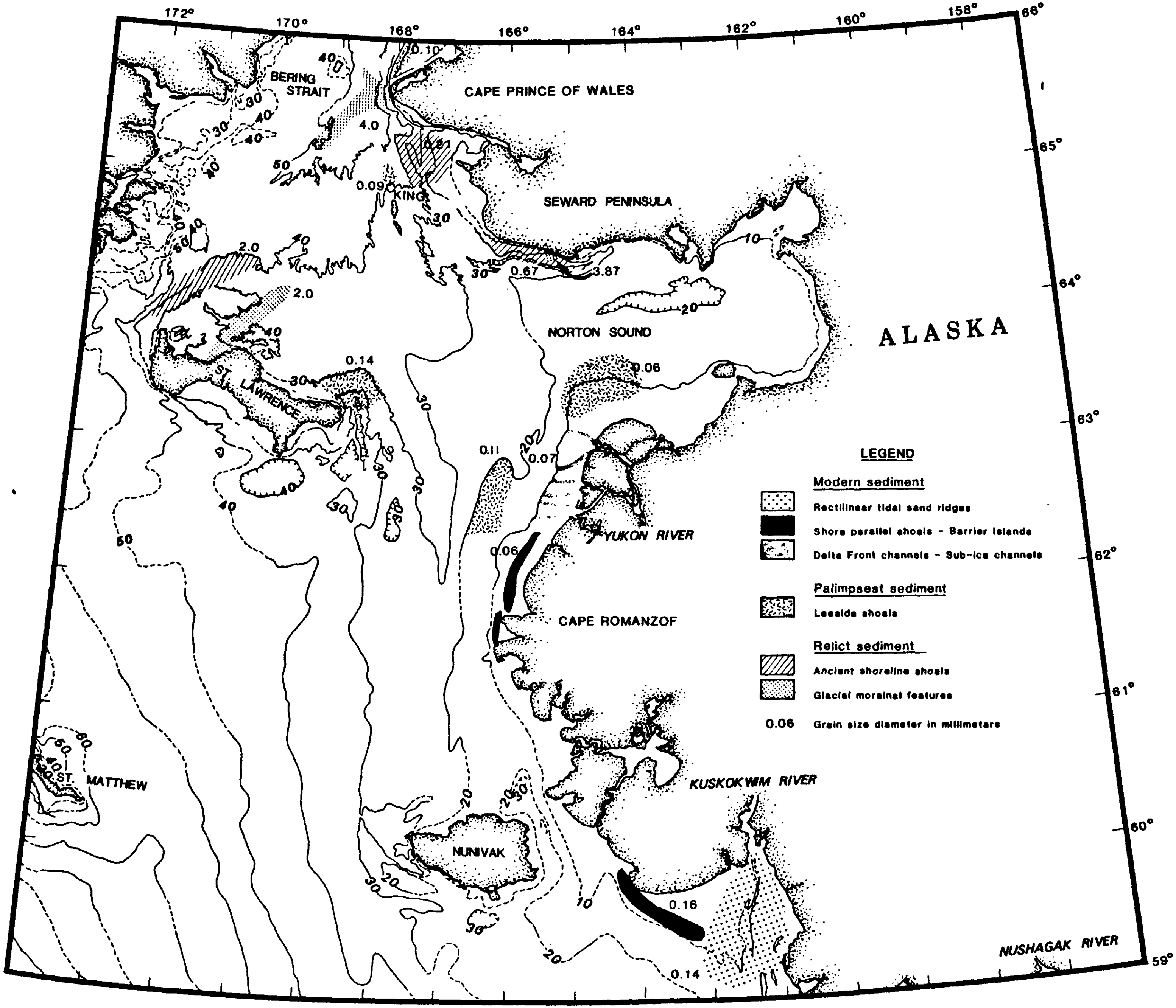
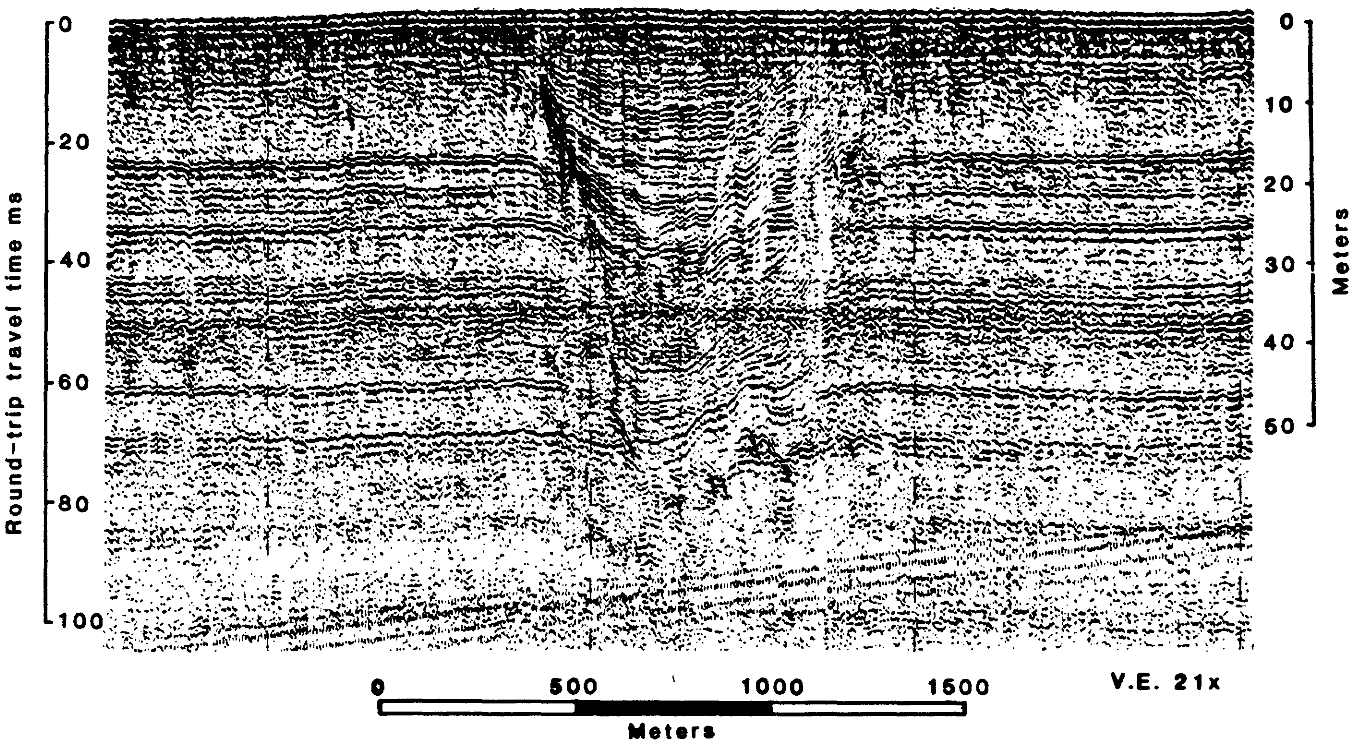

NORTON SOUND
Nome
Mean Sea Level
(Water Depth in meters)
5
10
15
Sea Floor
Yukon Delta
A
A'
13.7K
11.3K
10.7K*
1.5K*
1.3K*
G
C
H
I
Core Scale
0
50
100
150
200
centimeters
0 10 20 km
EXPLANATION
MARINE SEDIMENT
Fine Grained (0.25-0.031mm)
Medium Grained (0.5-0.25mm)
Coarse Grained (10-30mm)
Storm Sand Layers
Transition Zone (Marine to Non-Marine)
NON-MARINE SEDIMENT
Mud, Limnetic Peat and Silt Lamina
Epiclastic Peat
Radiocarbon Date (Years BP x 1000)
Textural Sample
NW Cape St. Lawrence Island
Mean Sea Level
(Water depth in meters)
10
20
30
King Island Shoal
Ukivok Shoal
Tin City Shoal
York Shoal
Lost River Shoal
Port Clarence
B
B'
Sea Floor
CHIRIKOV BASIN
Core Scale
0
10
20
30
40
50
centimeters
0 10 20 km
D
E
F
13.2K
>30K
Core 247
15.4K
>40K
>40K
12.7K
3.0m
4.2m

Fig. 11

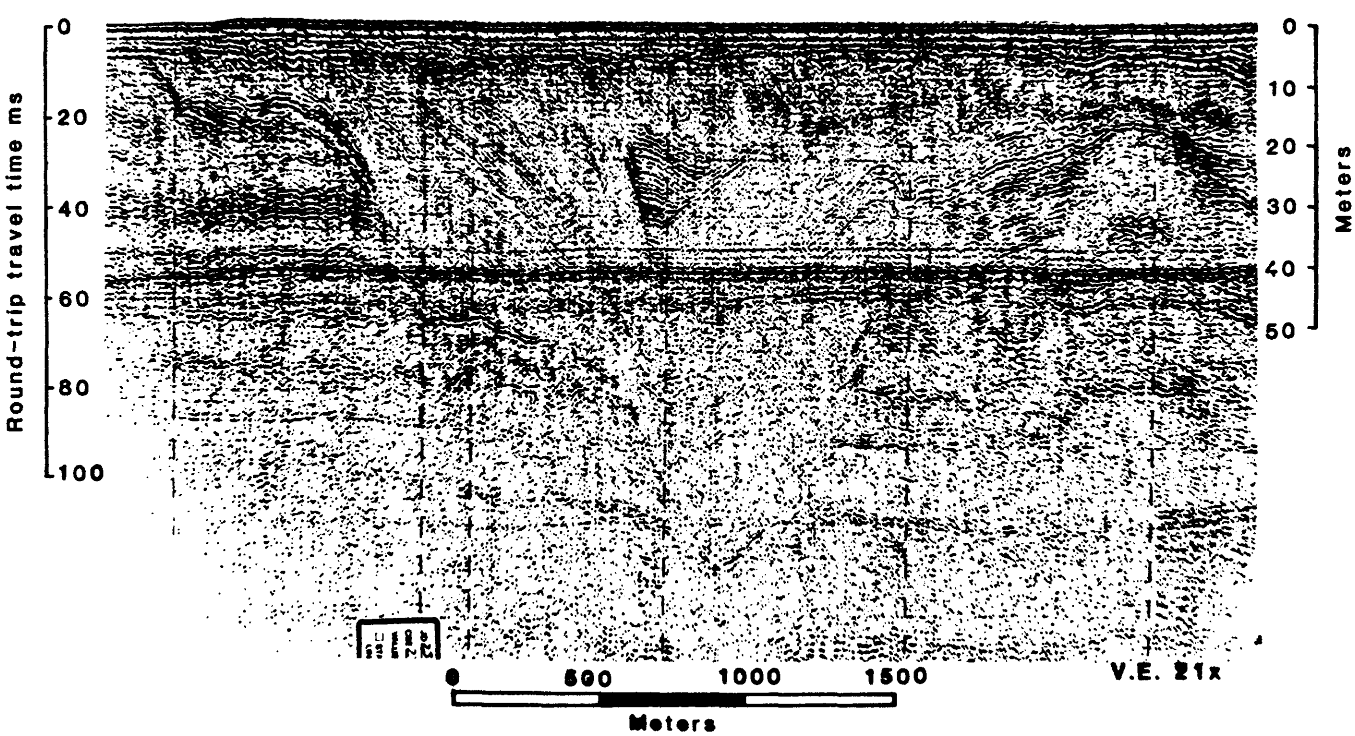


ALASKA
CAPE PRINCE OF WALES
BERING STRAIT
SEWARD PENINSULA
KING
NORTON SOUND
ST. LAWRENCE
YUKON RIVER
CAPE ROMANZOF
KUSKOKWIM RIVER
NUNIVAK
ST. MATTHEW
NUSHAGAK RIVER
LEGEND
Modern sediment
Rectilinear tidal sand ridges
Shore parallel shoals - Barrier islands
Delta Front channels - Sub-ice channels
Palimpsest sediment
Leeside shoals
Relict sediment
Ancient shoreline shoals
Glacial morainal features
0.06 Grain size diameter in millimeters

Fig. 12



Round-trip travel time ms
0
20
40
60
80
100
0
10
20
30
40
50
Meters
0
500
1000
1500
Meters
V.E. 21x



Round-trip travel time ms
0
20
40
60
80
100
0
10
20
30
40
50
Meters
0
500
1000
1500
Meters
V.E. 21x

Fig. 13

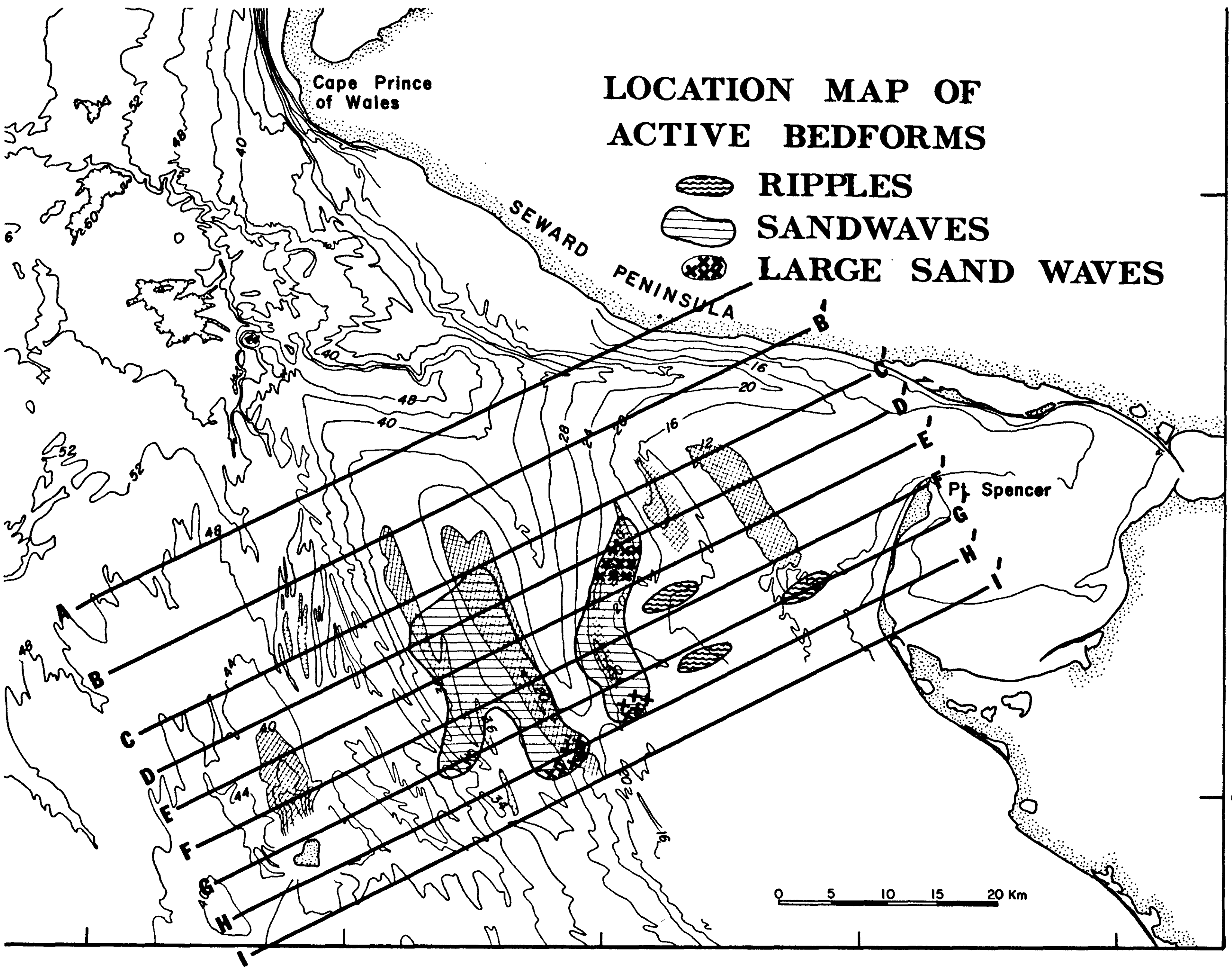

LOCATION MAP OF
ACTIVE BEDFORMS
RIPPLES
SANDWAVES
LARGE SAND WAVES
Cape Prince of Wales
SEWARD PENINSULA
Pt. Spencer
65°30'
65°
0 5 10 15 20 Km

Fig. 14A

BATHYMETRIC PROFILES

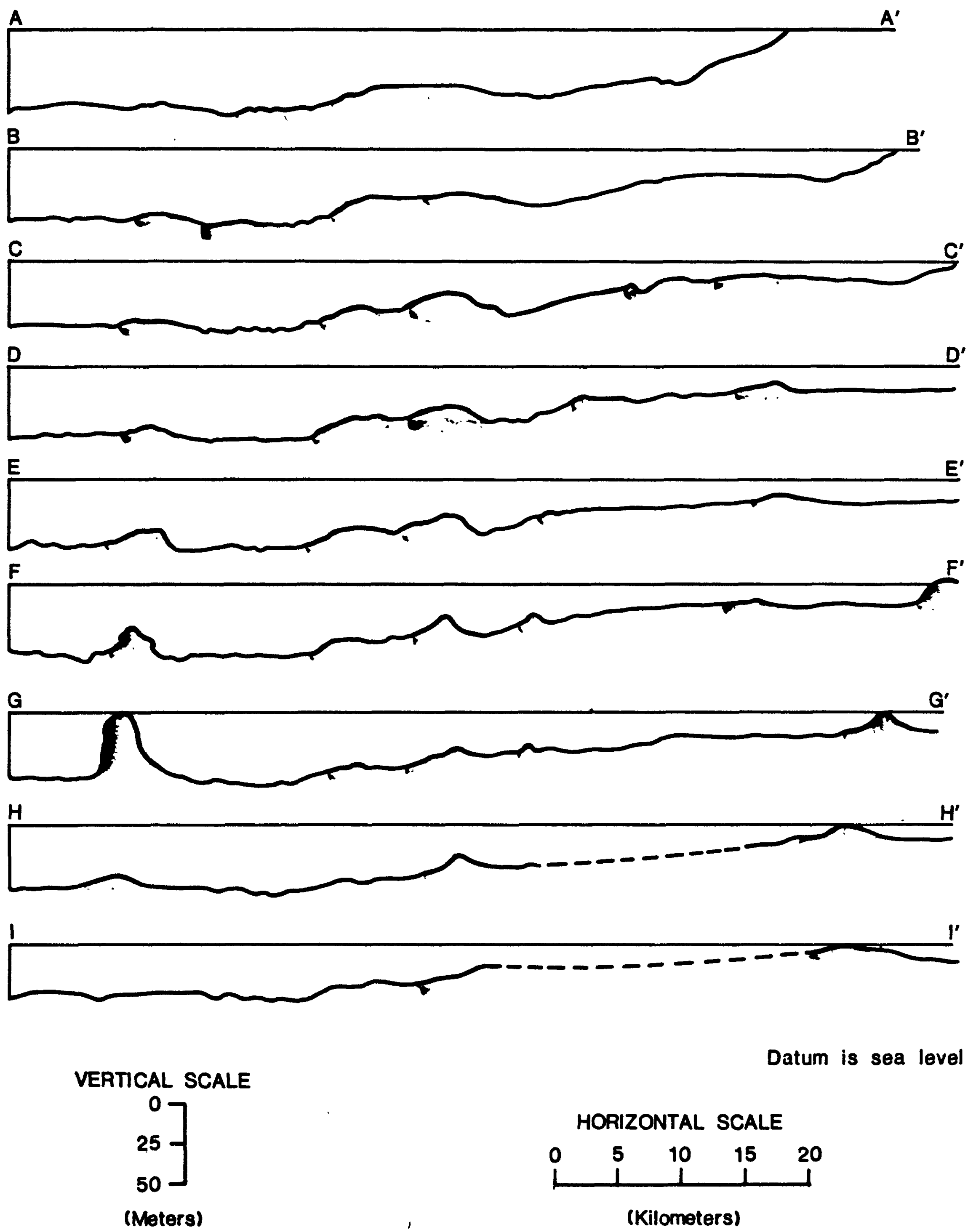


Fig. 14B

SEDIMENT DISTRIBUTION

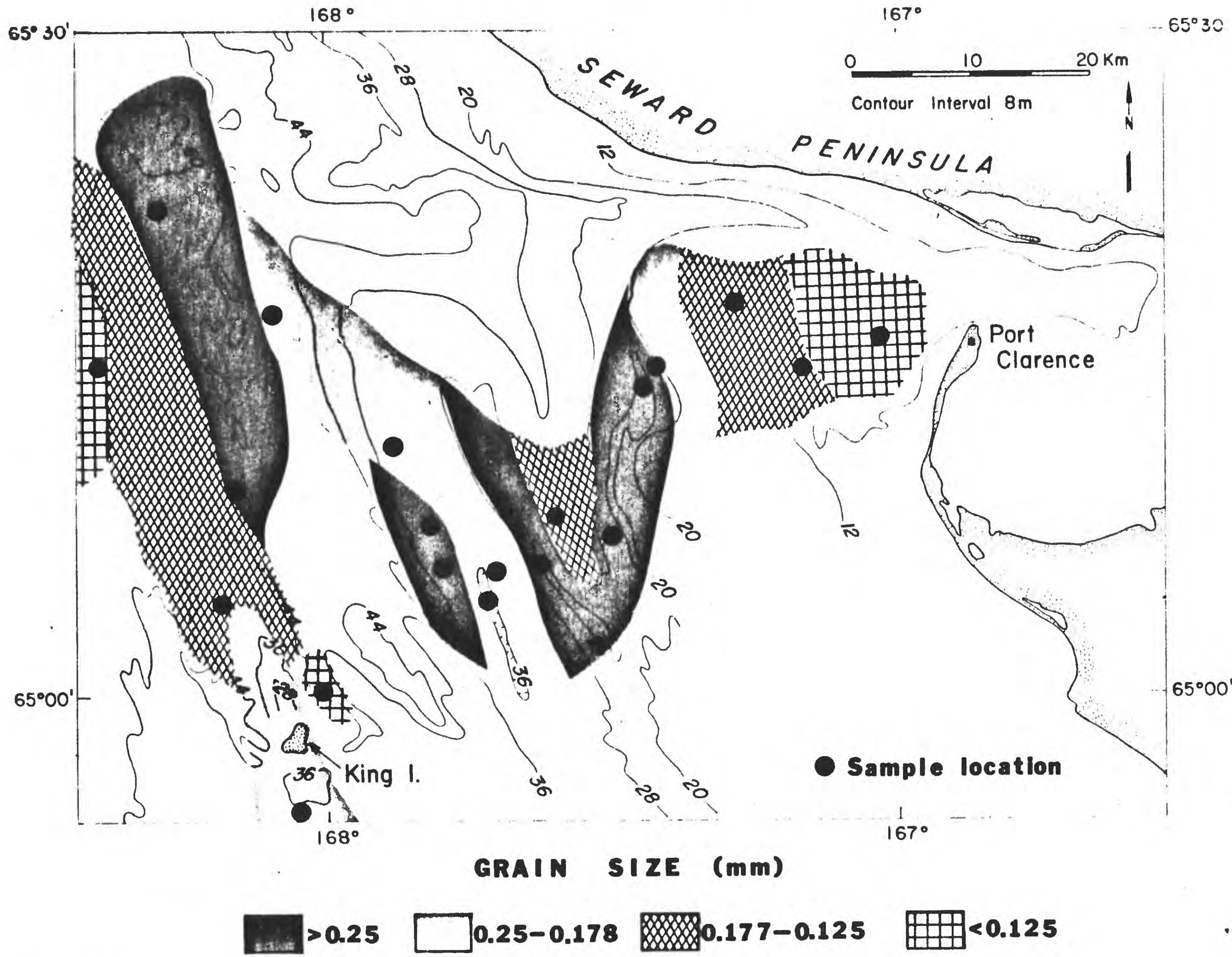


Fig. 14C