GEOLOGIC INVESTIGATIONS IN THE CHUKCHI SEA, 1984, NOAA SHIP SURVEYOR CRUISE

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INTRODUCTION

Geologic processes on high latitude shelfs are poorly understood because of the harsh environment, sea ice, and the limited number of previous studies. Studies of the high latitude shelf environment of the Chukchi Sea were initiated to provide the Government and the public with adequate knowledge to safely lease offshore lands. This report presents preliminary findings from a study of the gelogic environment of the Chukchi Sea from Point Hope north to 71° 38′ on the western part of the shelf and to the vicinity of Point Franklin on the eastern shelf (figure 1).

Data were gathered from the NOAA ship SURVEYOR from August 26 to September 17, 1984. Pack ice conditions limited investigations north of 71 degrees in the eastern part of the study area. The pack ice front was approximately 5 to 7 miles northwest of Point Franklin when studies were started (figure 2). During the latter part of the season investigations were conducted north to 71° 38′ in the western part of the Chukchi Sea.

High-resolution seismic profiles, bathymetry and side-scan sonar surveys were collected along approximately 2440 km of trackline (figures 3 and 4). Forty box cores, 4 dredge samples and 2 gravity cores were also obtained (figures 5 and 6). Bottom drifters were deployed at 8 sites. During part of the study bad weather and ice hampered our research. Short period high northeast storm waves seriously interfered with the seismic and side-scanning sonar records and caused the termination of some lines on the outer and inner shelf. However, during periods of high wind and waves the nearshore areas protected by the capes allowed us to continue our investigations.

The objectives of the scientific program include the following: A) determination of the location, density and depth of modern sea floor ice gouging, B) Observe recent changes in bathymetry and sea bed morphology and determine their origins, c) Obtain seismic profiles of the modern sediment cover and of bedrock to determine the history of ice gouging, and D) identify potential sand and gravel resources.

METHODS

On the cruise we obtained analog recordings of side-scan sonar, 3.5 khz sub-bottom profiler, high resolution seismic system, and 12 khz and 3.5 khz bathymetry. A Kline Associates 100 khz and 500 khz side-scan fish towed approximately fifteen meters above the sea-bed was used as the source for the sea-bed

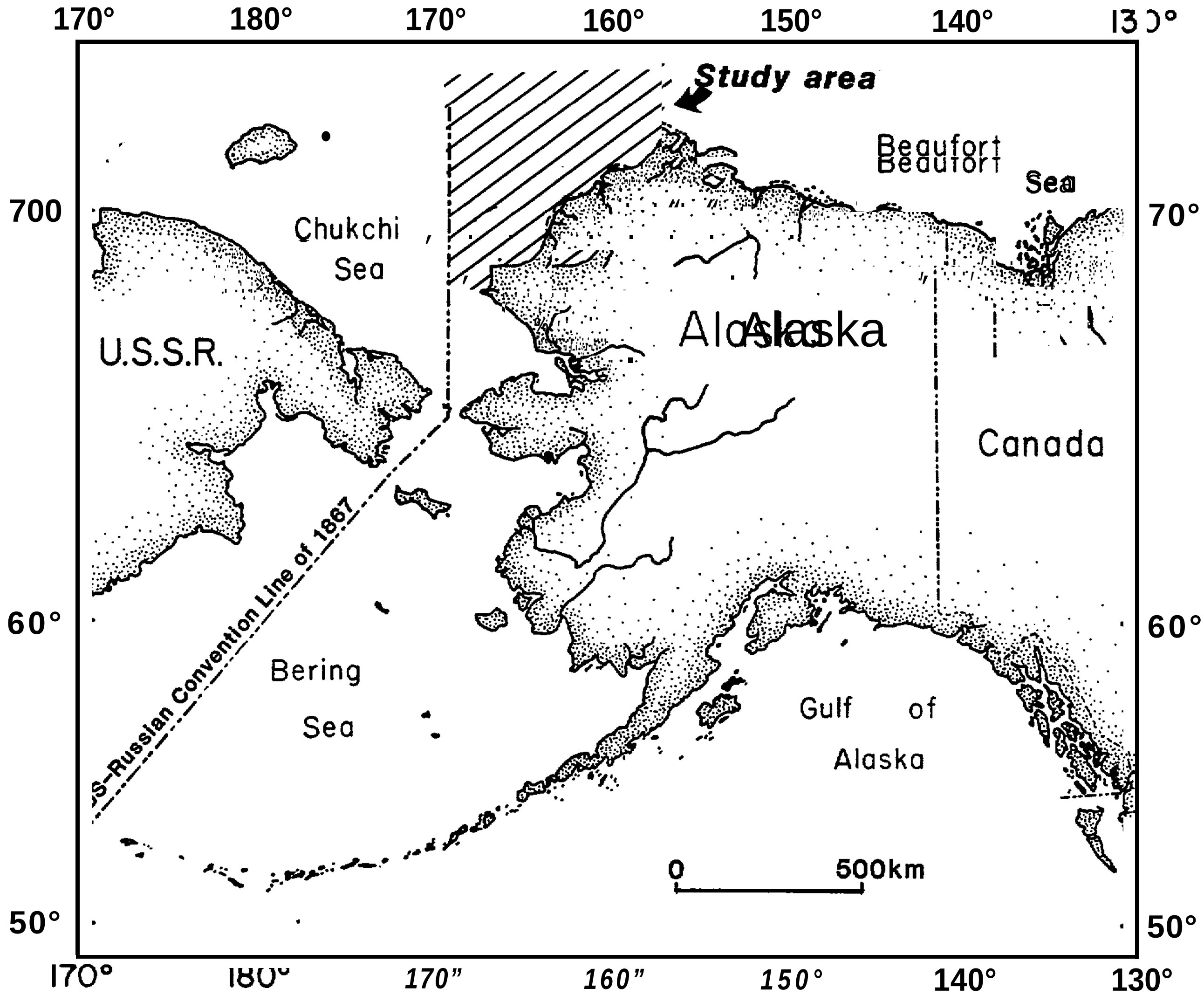


Figure 1. Location of study area in the northeastern Chukchi Sea.

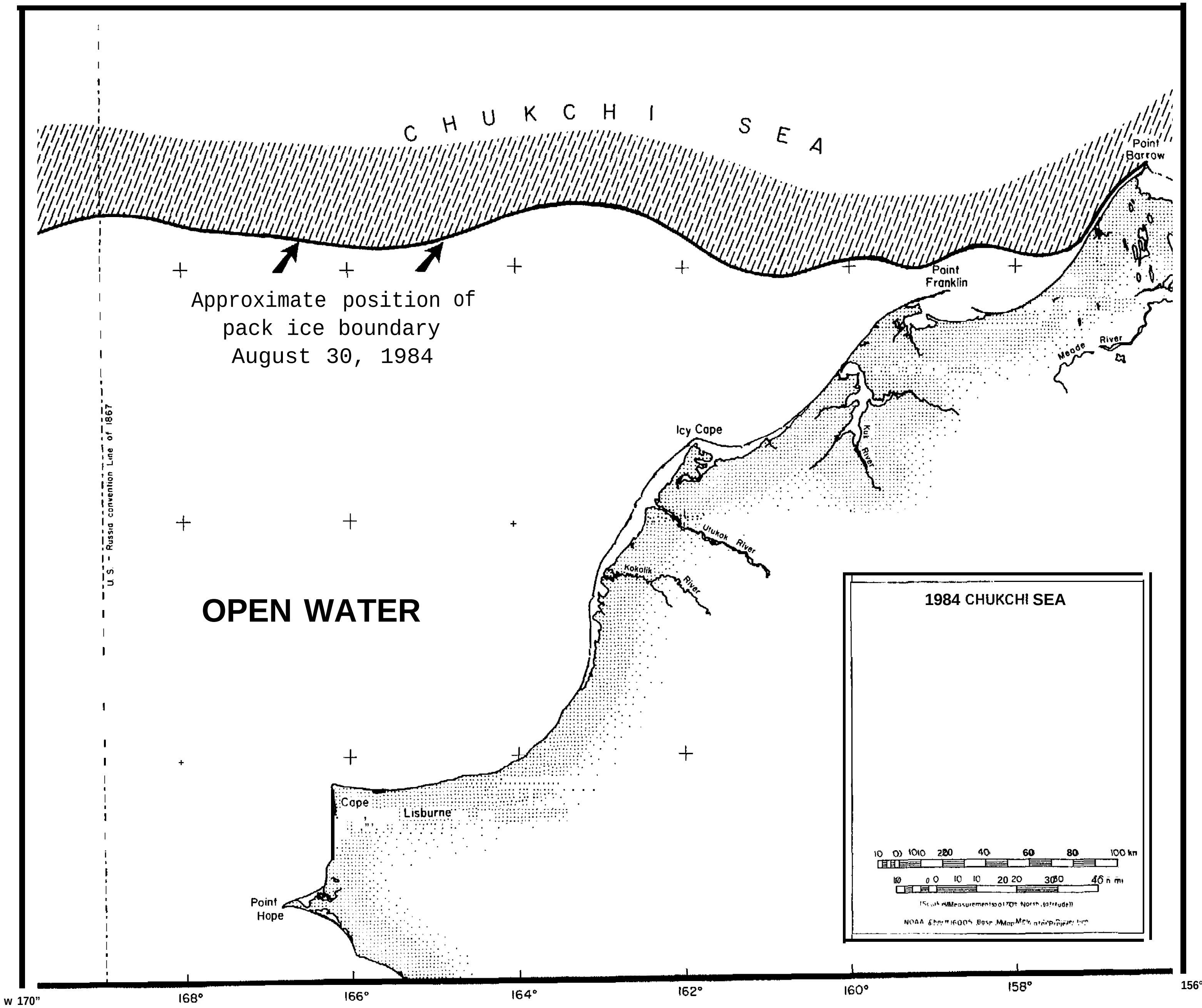


Figure 2. Approximate location of pack ice boundary at the start of the Chukchi Sea study, 1984.

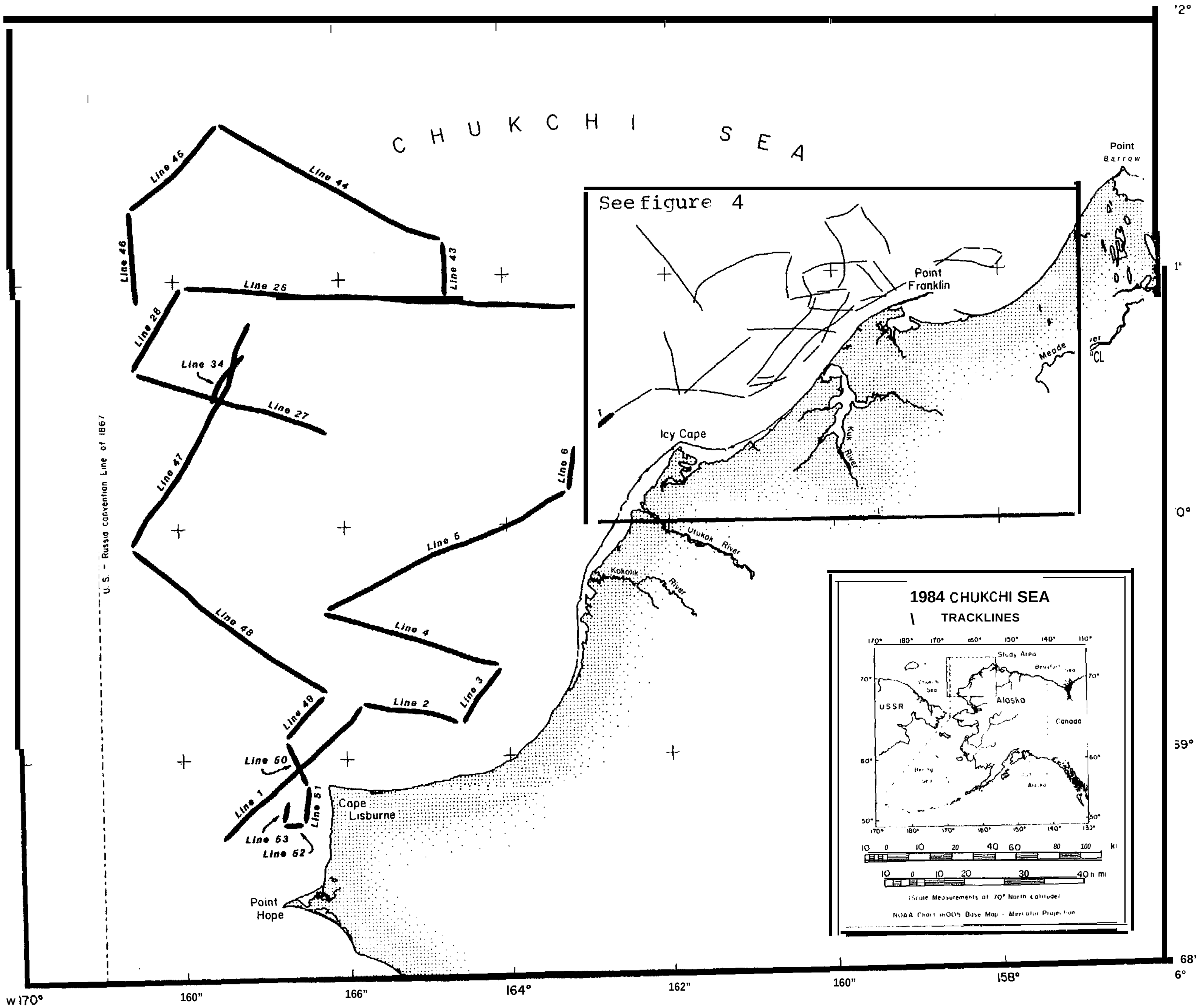


Figure 3. Track lines obtained in the outer part of the study area. See figure 4 for track line numbers in the nearshore region.

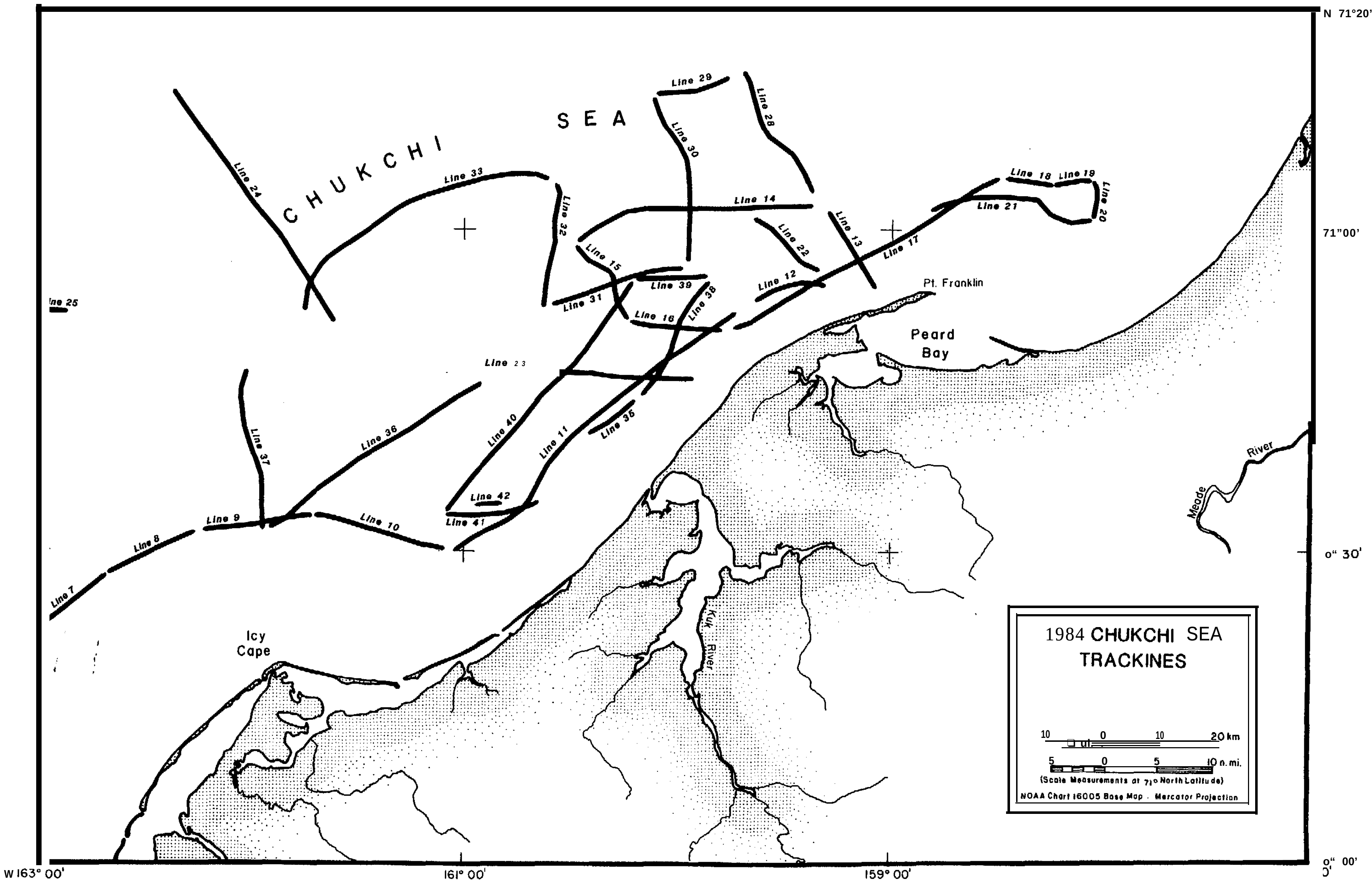


Figure 4. Track lines obtained in the northeastern part of the Chukchi Sea from Icy Cape to north of Point Franklin.

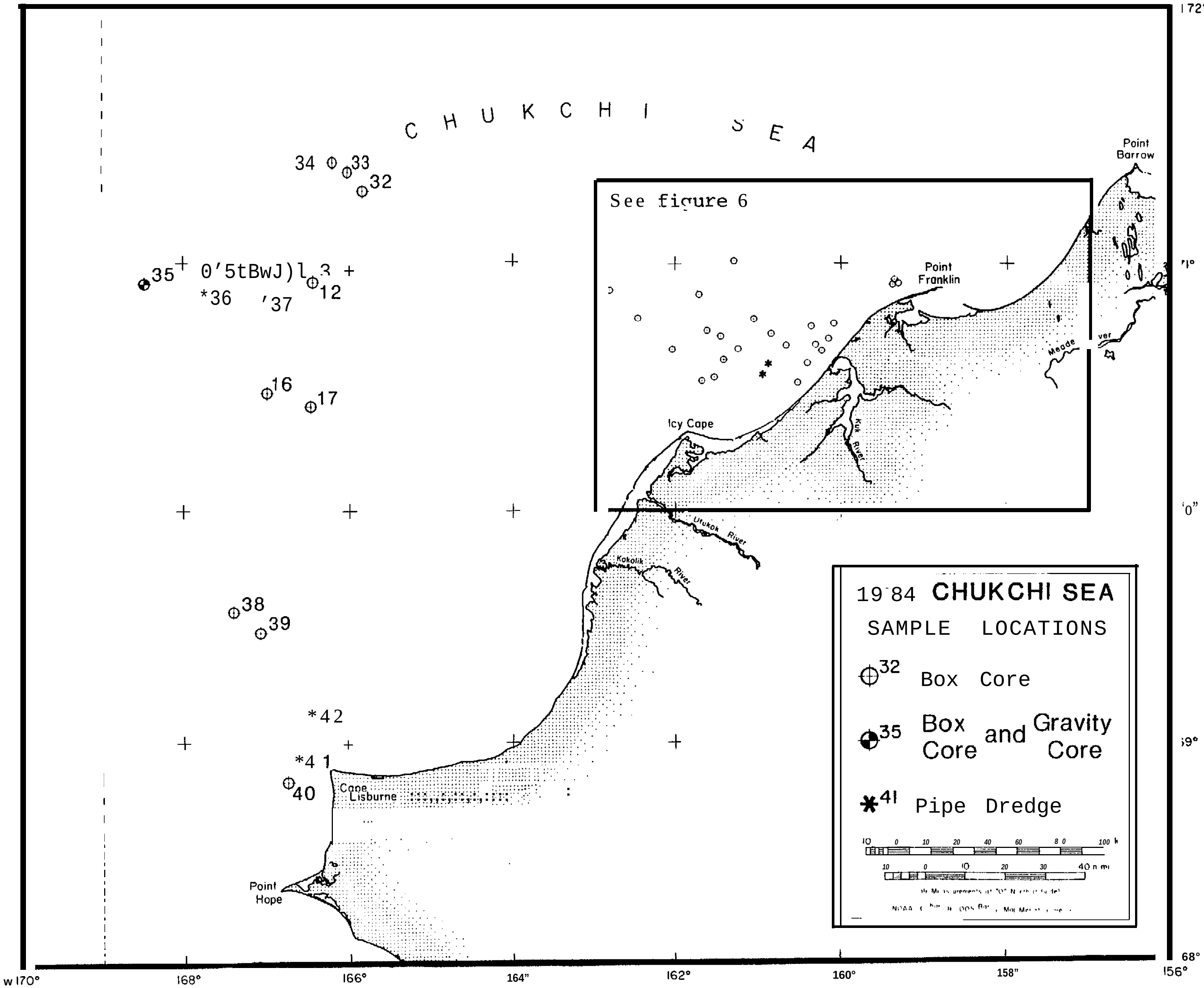


Figure 5. Sediment samples locations in the outer part of the study area. See figure 6 for sample numbers in the nearshore region.

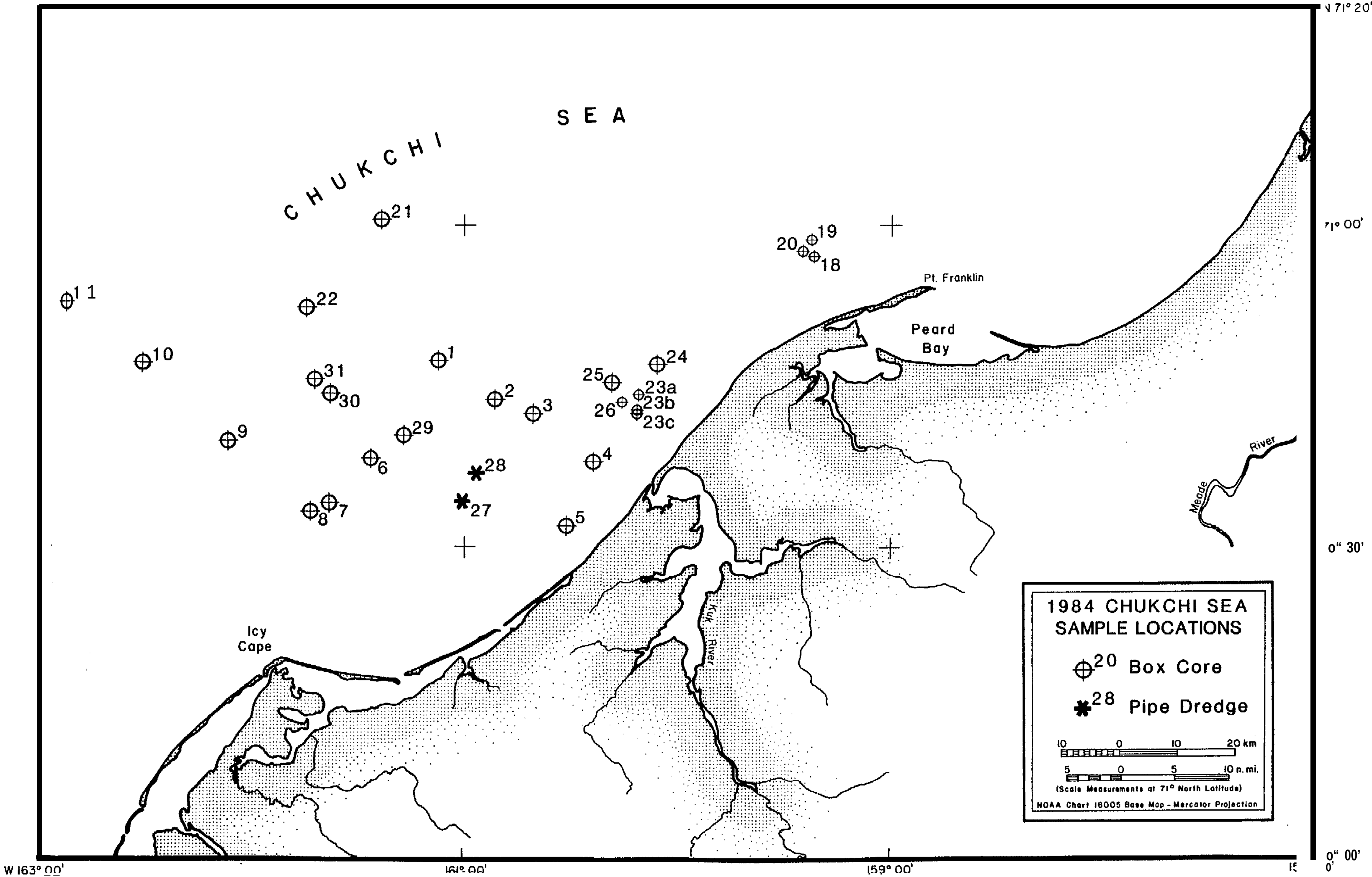


Figure 6. Sediment samples obtained in the northeast Chukchi Sea.

sonar data. The side-scanning fish also contains a 500 khz microprofiler and a a 3.5 khz sub-bottom profiler for viewing expanded sea-floor relief and shallow sub-bottom stratigraphy. Under optimum conditions subsurface reflections were obtained to depths of 15 meters below the sea-floor.

An ORE geopulse sub-bottom profiler was used at 100, 105, and 175 joules of power with the high resolution seismic signal pickup with a single channel, 25 element hydrophore. Under optimum conditions sub-bottom penetrations were obtained to 150 meters. Bathymetry was recorded with a hull-mounted transducer source.

The sea floor was sampled with a 60x31x22 cm box core, a 3 meter gravity core, and a pipe dredge. Recoveries of up to 56 cm were achieved with the box core.

Navigation for tracklines and sample sites consisted of Satelite Navigation, using a Magnavox Omega system, a Del Norte UHF transponder system and deduced reckoning.

BATHYMETRY

Much of the Chukchi Sea floor is relatively flat and shallow with depths averaging between 40 and 50 m. Locally, enclosed depressions and scattered highs contribute as much as 5 m of relief. Two areas contain bathymetric highs; the nearshore area off Icy Cape, Blossom Shoals, where migrating sand banks rise to within 10 m of the sea surface, and on the northern part of the shelf, Hannna Shoal which rises to within 25 m of the sea surface (Hill and others, 1984). Along the northeast part of the Chukchi Sea the Barrow sea valley forms a major erosional incision into the shelf starting west of Point Franklin and trending northeast parallel to shore. The sea floor rapidly drops to over 100 m depth within the sea valley (Hill and others, 1984). On the outer shelf, north of Hanna Shoal and Bank, the sea floor slopes north toward the shelf break where at approximately 60 m depth the shelf slope rapidly increases. Local gulleys and larger erosional features disect the outer shelf edge (figure 7).

CURRENTS

Surface wind-generated currents, the shore-parallel Alaska Coastal Current and shelf currents erode and transport sediment modifying the sea floor of the Chukchi Sea. The nearshore currents are generated mostly by winds, whereas, the offshore region is dominated by northeast- and southwest-directed storm currents and by the northeastward flowing Alaska Coastal Current (figure 8).

During the summer months, storms from the southwest commonly move across the Chukchi Sea. Their maximum fetch then developes across the open water (Wiseman and Rouse, 1980). The resulting storm waves and storm-generated currents erode and scour the sea

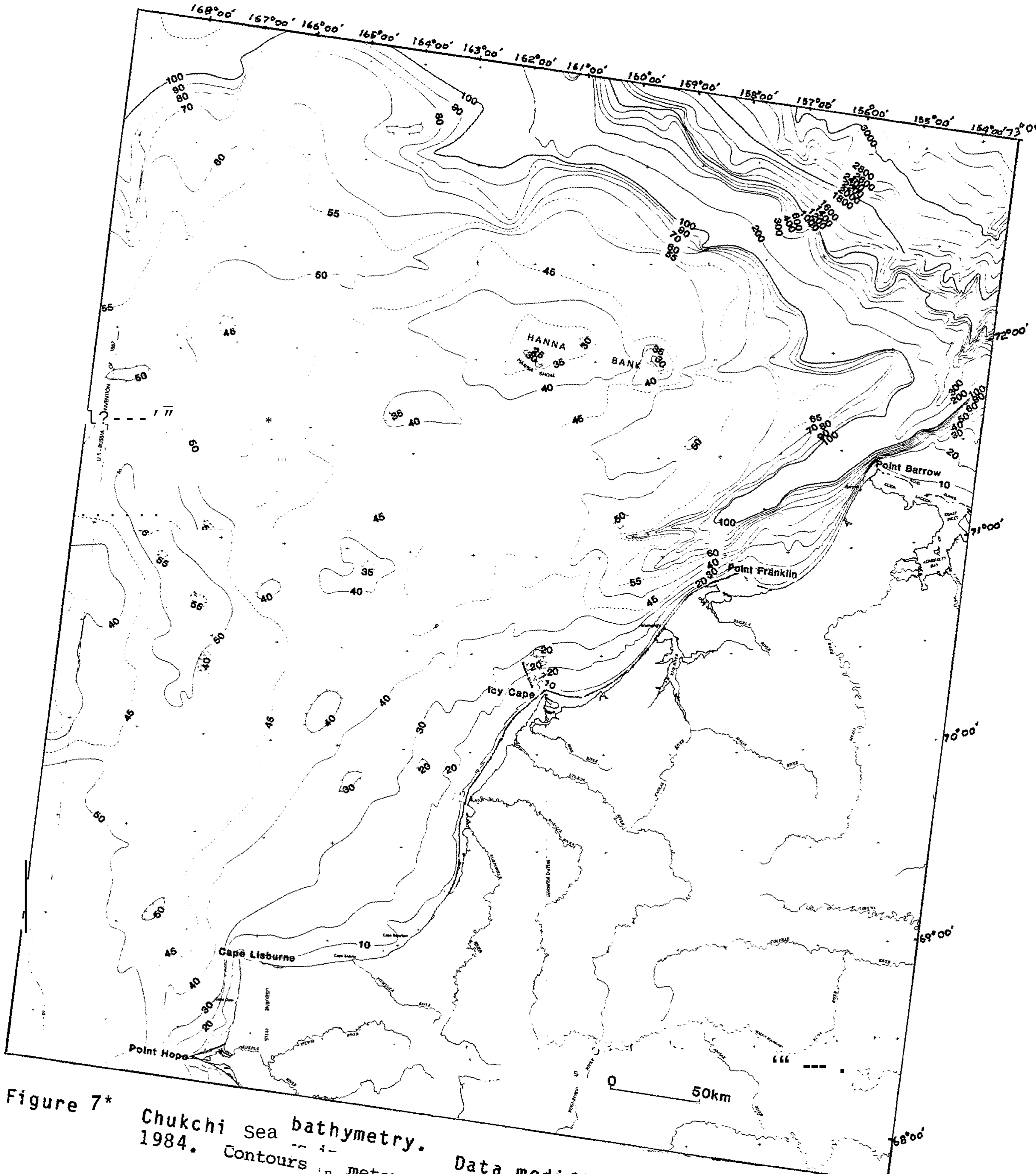


Figure 7* Chukchi Sea bathymetry. Data modified from Hill and others, 1984. Contours in meters.

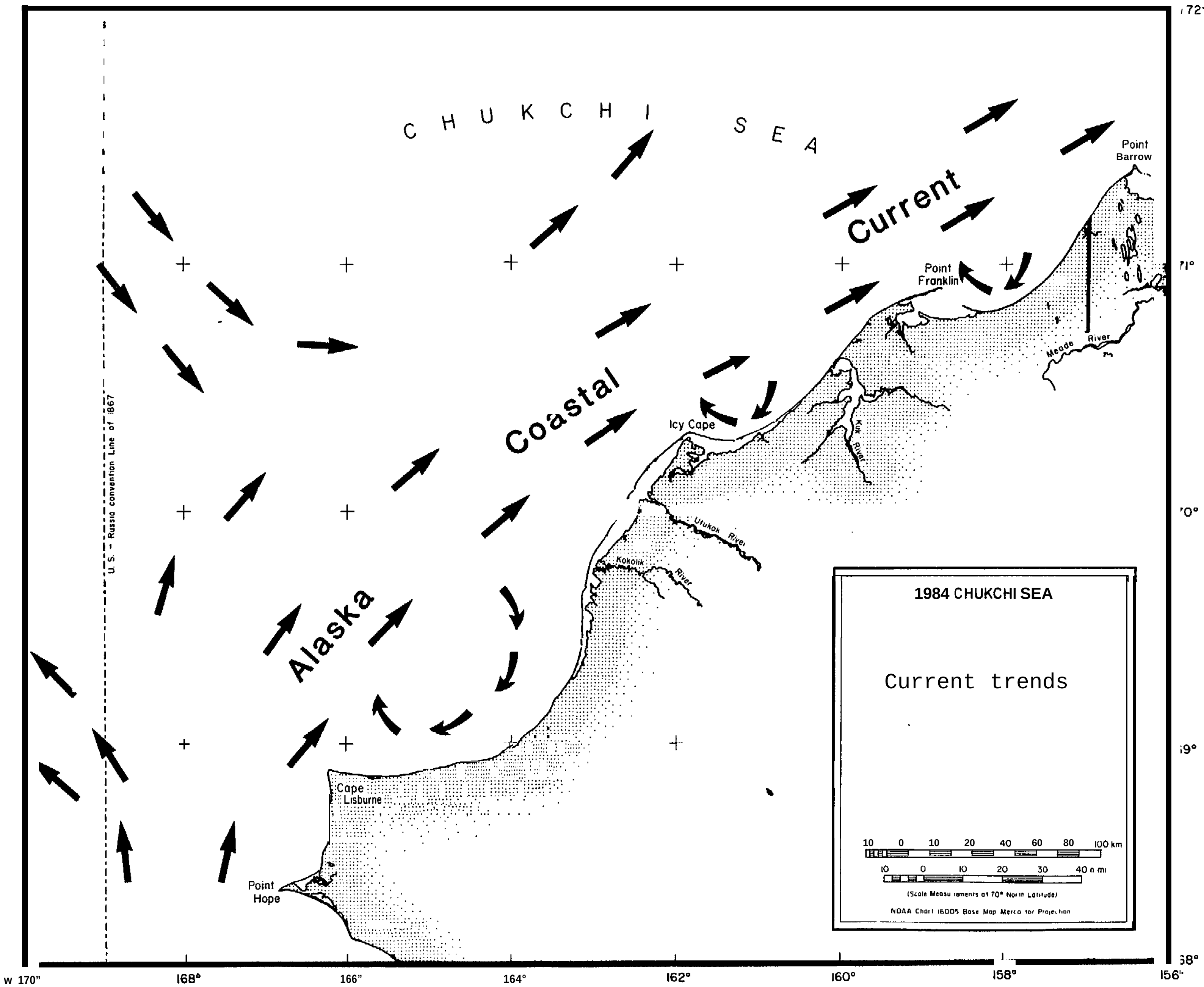


Figure 8. Current trends within the Chukchi Sea. The Alaska Coastal Current parallels the coastal region with clockwise rotating currents developing nearshore behind the capes. Current data modified from Coachman and others, 1975.

floor and transport sediment on the shelf and shoal regions. The storm-generated currents probably reinforce the normal shelf currents resulting in periods of bedform migration and sediment transport.

The Alaska Coastal Current represents a northeastward flowing “warm” water mass derived from the Bering Sea (Paquette and Bourke, 1972). The northward flowing Bering Sea water bifiractes near Point Hope, one part flowing to the northwest around the south side of Herald Shoal and the other forming the Alaska Coastal Current which flows to the northeast parallel to the Alaska Coast (figure 8). The Alaska Coastal Current, which can be as narrow as 37 km, approaches the coast near Wainwright and Barrow. Surface velocities of up to 200 cm/sec. are reported for the Alaska Coastal Current southwest of Point Franklin (Hufford, 1977). Southward flowing clockwise gyres develope east of the Alaska Coastal Current north of the major promatories off Cape Lisburne, Icy Cape and Point Franklin (Flemming and Heggerty, 1966, Sharma, 1979, Lewbel and Gallaway, 1984). West of the Alaska Coastal Current off Point Franklin on the west side of the Barrow Sea Valley a southwest-directed current is reported with surface velocities of up to 80 cm/sec (Hufford, 1977). The southwest flowing currents are poorly defined in space and time. Southeast-directed bottom currents are also identified on the western part of the outer shelf (Coachman and others, 1975). Large clockwise rotating spiral currents are also reported northwest of Barrow and may represent interaction between the Alaska Coastal Current and the westward flowing current of the Beaufort Gyre [Solomon and Ahlmas, 1980).

ICE REGIME

The ice covers the Chukchi Sea for 8 to 10 months every year with 2 to 4 months of open-water during the summer-fall season. During September to early October the Arctic pack ice usually reaches its maximum northern retreat, near 72 to 73 degrees. The pack ice then advances to the south, and by January the entire Chukchi Sea is ice covered (Grantz and others, 1982). Nearshore, fast ice forms and reaches its maximum development in March and April (figure 9). Storms and winds from the northeast will move the pack ice to the west resulting in the formation of the persistent Chukchi Polynya usually by January (Stringer, 1982). However, the overall pack ice movement west of the Chukchi Polynya is to the west and northwest (Stringer, 1978, 1982, Lewbel, 1984) except for short periods during ice breakout when ice movement is to the south through the Bering Straits.

HOLOCENE-QUATERNARY SEDIMENT

Over much of the Chukchi Sea shelf a thin blanket of Holocene-Quaternary sediment overlies inclined and folded bedrock. The surficial sediment cover ranges in thickness from less than 1 m to over 12 m (Creager and McManus, 1967, Moore, 1964, Grantz and others, 1982). Thicker accumulations of

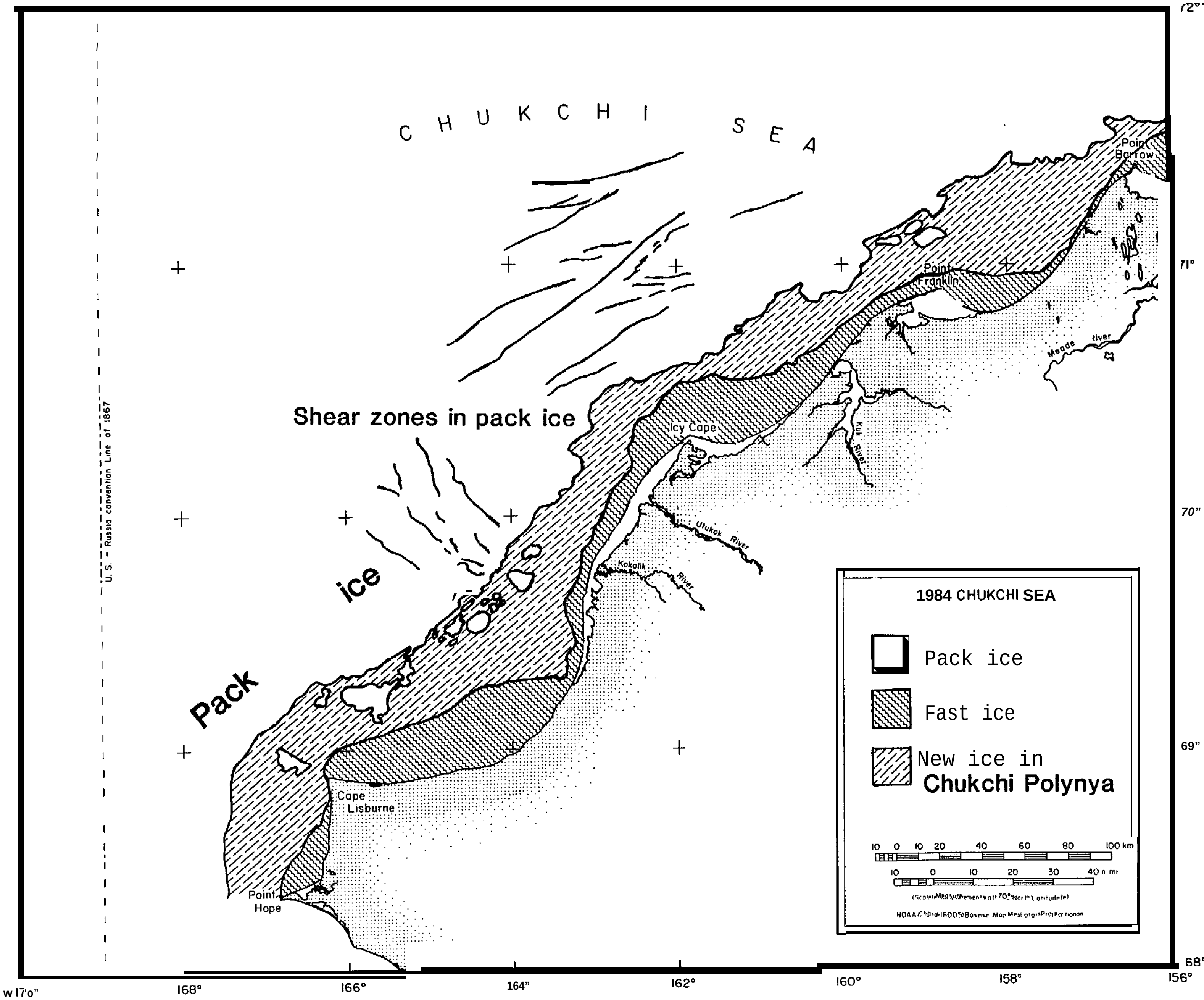


Figure 9. Ice zonation in the northeastern Chukchi Sea March-April, 1983. The ice field boundaries obtained from 1983 satellite photos. The maximum extent and development of shore-fast ice occurs during this time period. Northeast-directed storms form the Chukchi Polynya separating the fast ice from the offshore pack ice. The large pack ice blocks in the Chukchi Polynya were moving to the south during this period of observation.

Quaternary sediment are reported in channel-fill deposits of paleovalleys that were cut into the shelf during Pleistocene sea level lowstands (Grantz and others, 1982).

High resolution seismic profiles obtained during this study show that: 1) a thin sediment cover, generally less than 4 m thick, overlies folded bedrock over much of the Chukchi Sea; 2) local blanket sediment accumulations, greater than 6 m thick are limited and are only identified on the shelf southwest of Cape Lisburne (14 m sediment thickness), and at the head of Barrow Sea Valley northwest of Point Franklin (over 14 m of Quaternary sediment); and 3) in the northwest part of the Chukchi Sea a series of paleochannels cut into bedrock contain up to 64 m of channel-fill sediment. The age of the channel-fill deposits is uncertain.

In the southern part of the study area, south of 70 degrees N, bedrock is overlain by a thin blanket sediment deposit. Local accumulations of up to 14 m of sediment are found directly west of Cape Lisburne at depths of 32 m (figure 10). Horizontal and parallel almost transparent reflectors overly gently inclined stata under the thick sediment accumulation (figure ha). This sediment deposit thins toward shore near Cape Lisburne. To the north of Cape Lisburne a wide band of sediment approximately 4 m to 5 m thick trends to the northeast (figure 10). Landward, toward Cape Beaufort, the sediment cover rapidly thins to 1 to 2 m as the water depth shallows to 20 m (figures 11b, 12c). To the northwest of the northeast trending sediment band the Holocene-Quaternary deposits are thin, varying from 1 to 3 m in thickness (figure 10).

The northeast trending sediment band continues toward Icy Cape. Internally the sediment contains horizontal and parallel reflectors overlying inclined strata (figures 12d, 13a, 13b). This sediment band may have formed by sediment transportation and deposition by the northward flowing Alaska Coastal Current in combination with ice grounding and ice push. This sediment band also underlies an area of severe ice ridging (Stringer 1978). To the east in shallows water storm waves have eroded the sea bed removing part of the sediment cover. To the northwest of the sediment band, northeast flowing shelf currents have eroded the surficial sediment leaving a thin sediment cover over bedrock.

Nearshore, north of 70 degrees to Blossom Shoals, the Holocene-Quaternary sediment blanket varies from 2 to 5 m in thickness. Off Icy Cape the outer sand bank contains over 10 m of sediment overlying bedrock (figure 14). Nearshore, between Icy Cape and Point Franklin as well as north of Blossom Shoals, the Holocene-Quaternary sediment cover is also thin varying from less than 2 m to 3 m in thickness.

The thickest Holocene-Quaternary deposits are found at the head of the Barrow Sea Valley west of Point Franklin where the sediment is over 14 m thick. The sediment increases in thickness

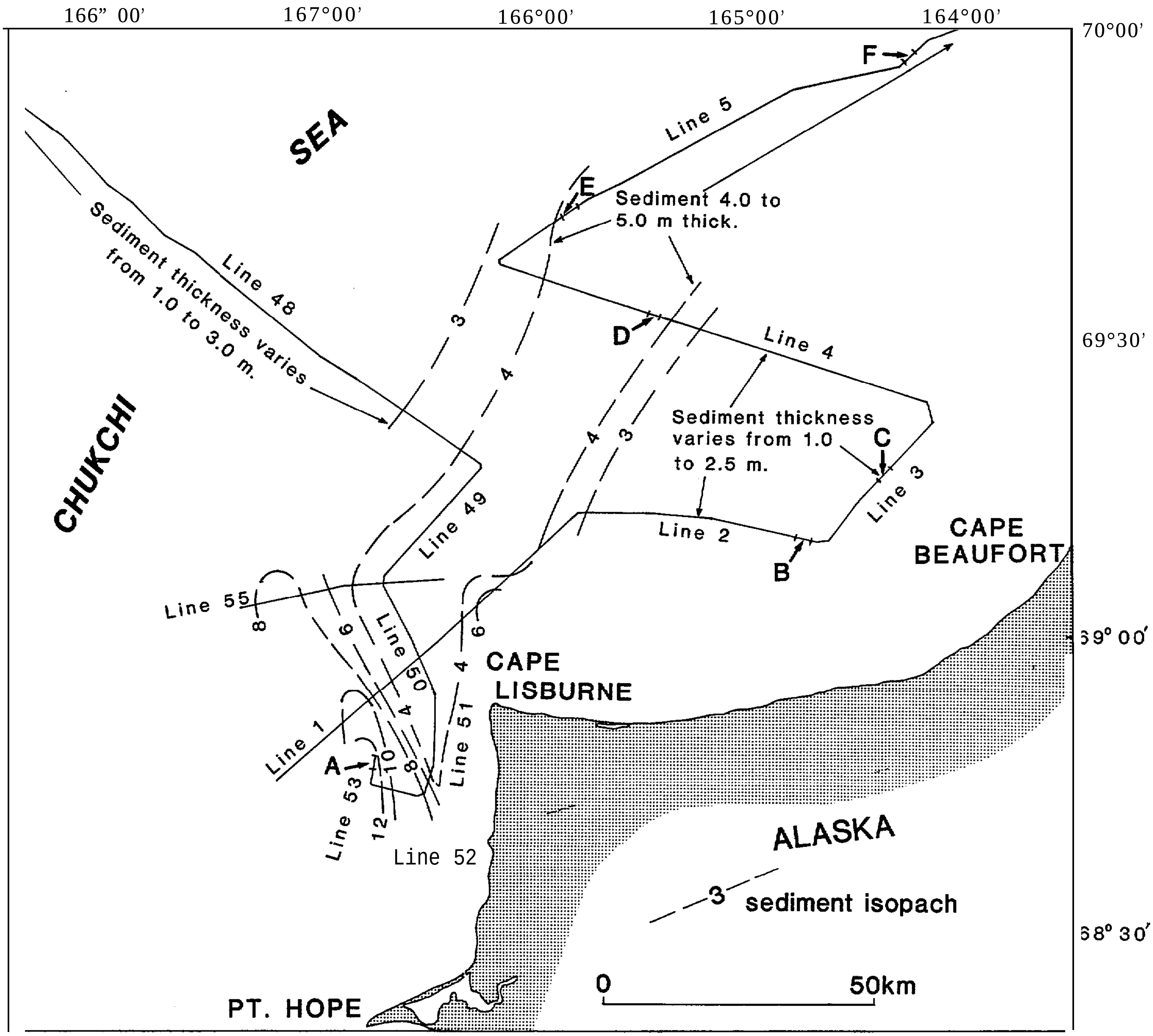
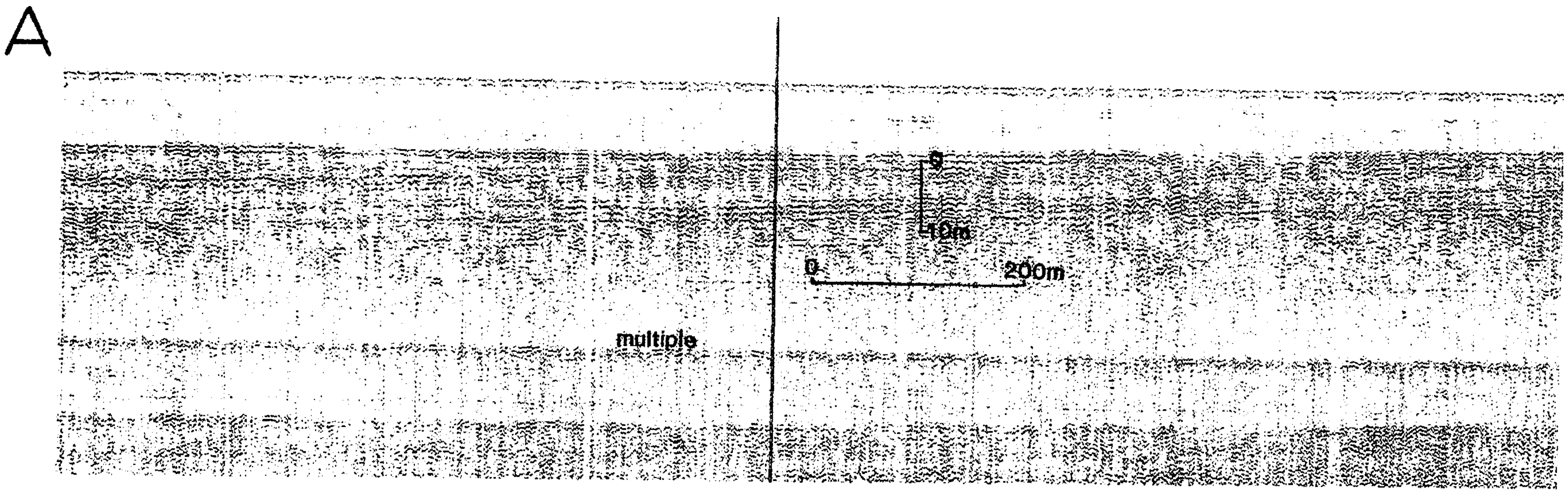


Figure 10. Isopachs of Holocene-Quaternary sediment near Cape Lisburne. The letters indicate seismic profile locations. Isopachs are in meters.



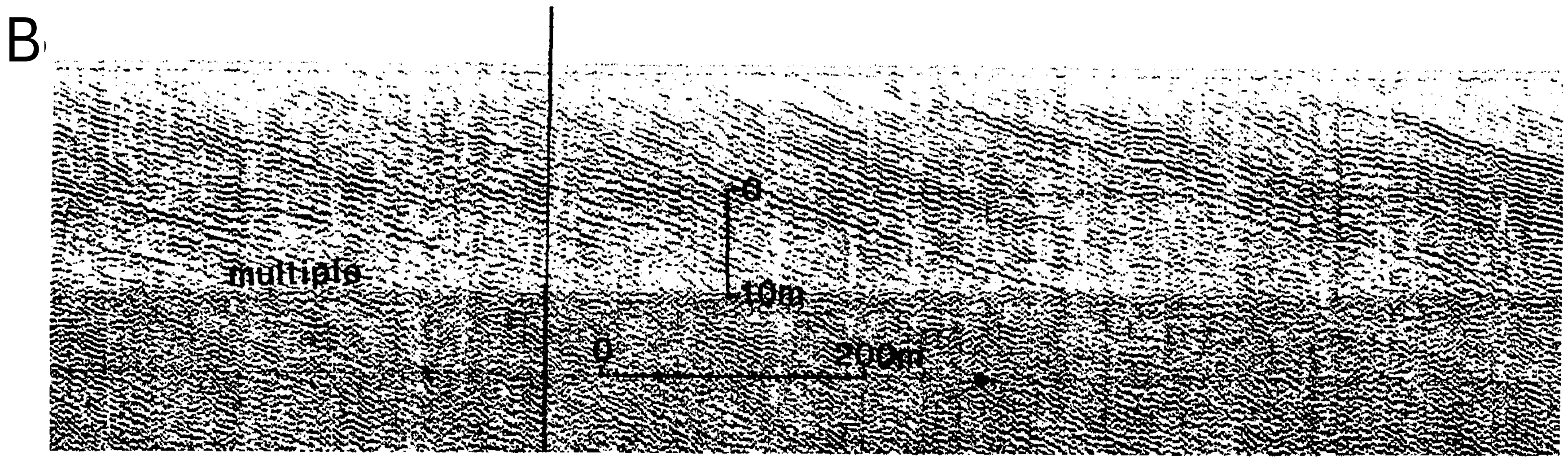


Figure 11. Seimic profiles near Cape Lisburne. A). An upper transparent (sand?) unit overlies slightly inclined strata. B). A thin, less than 2 m thick, sediment cover overlies dipping bedrock. See figure 10 for profile locations.

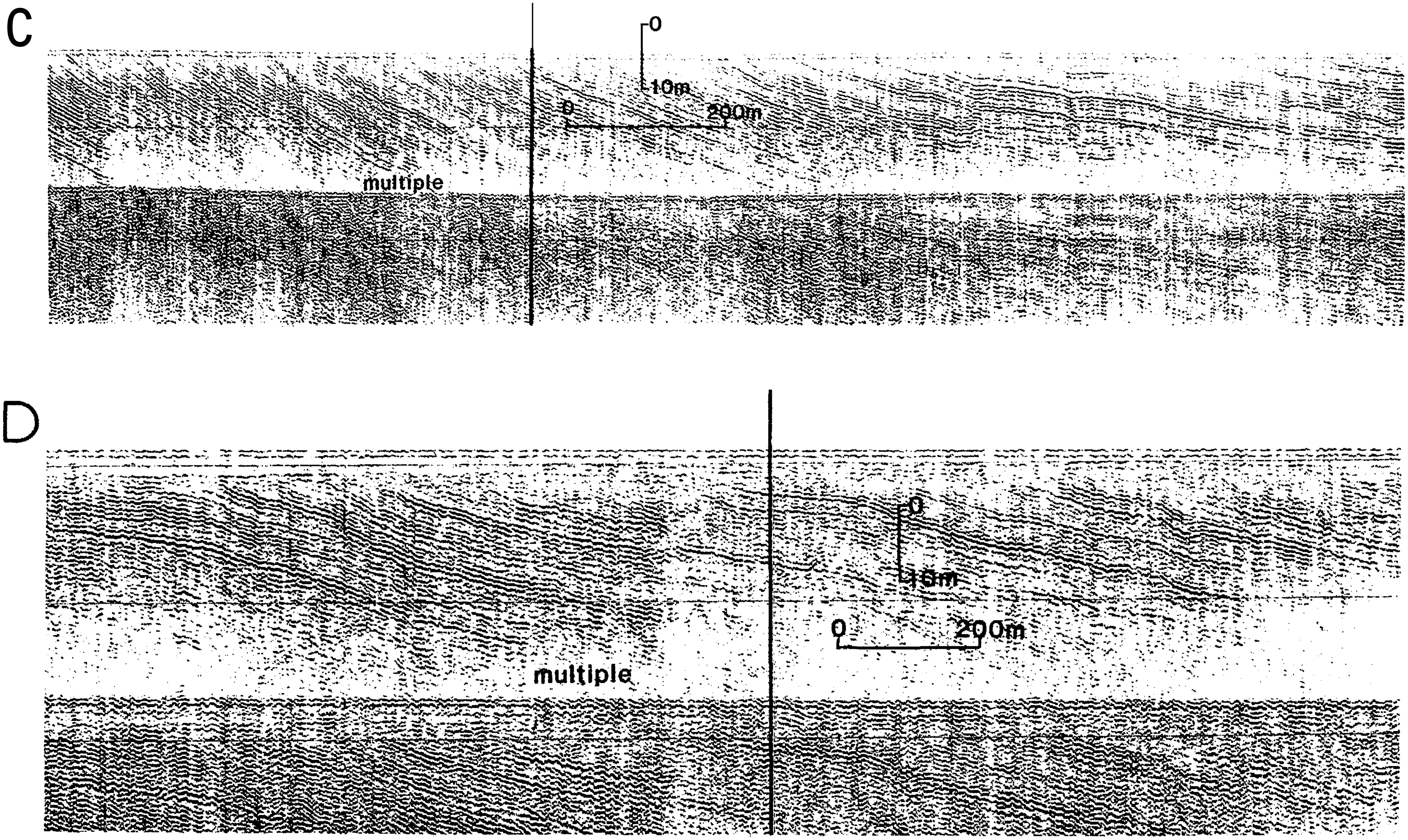


Figure 12. Seismic profiles north of Cape Lisburne. C) A thin sediment cover overlies bedrock west of Cape Beau fort. D). The upper seismic unit containing horizontal strata is approximately 4 m thick and may represent sediment deposited by the northward flowing currents. See figure 10 for profile locations.

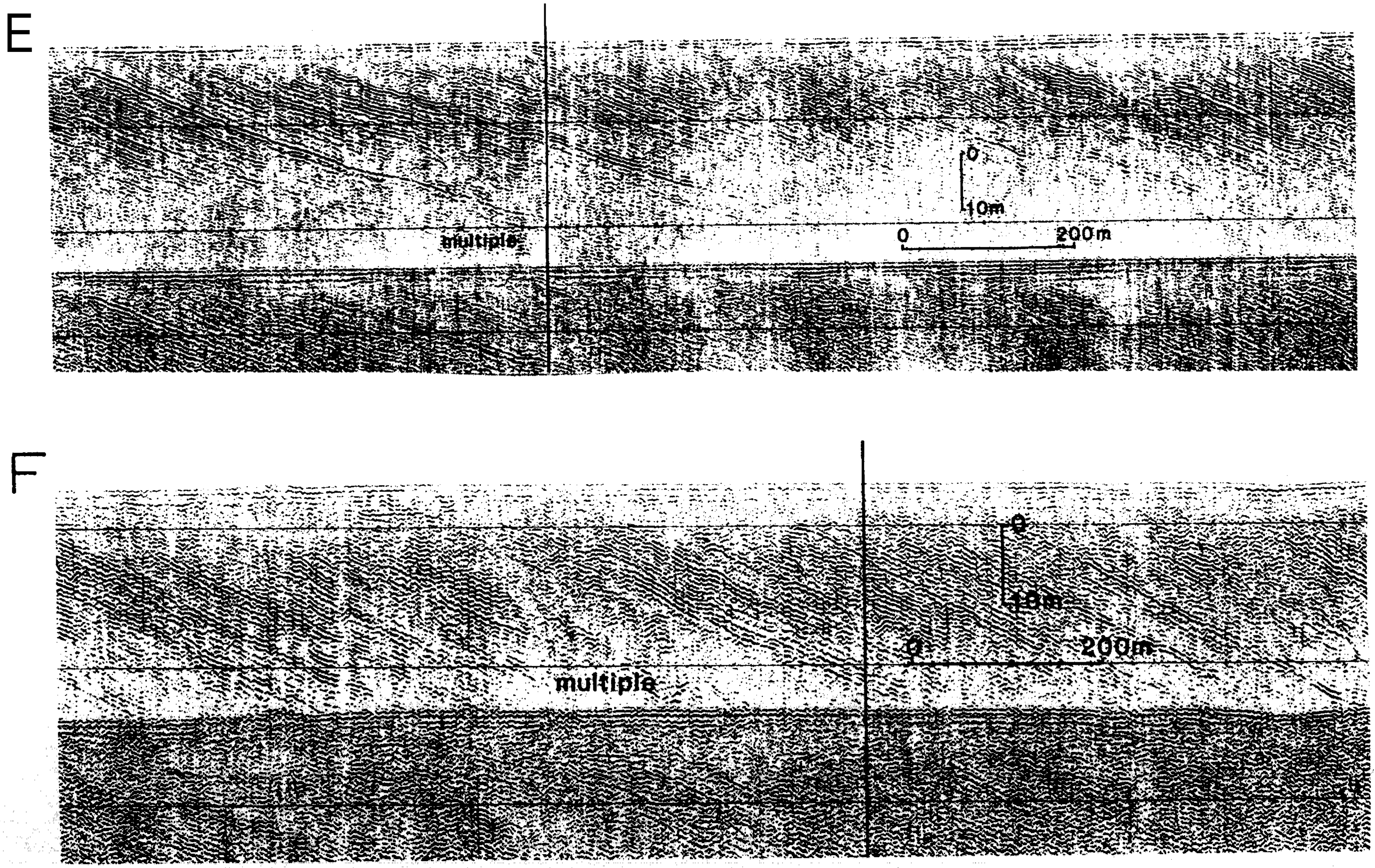


Figure 13 Seismic profile north of Cape Lisburne. Both profiles (E and F) show thin sediment cover over inclined bedrock which is typical for the southern Chukchi Sea. See figure 10 for location for (E) and figure 27 for location for (F).

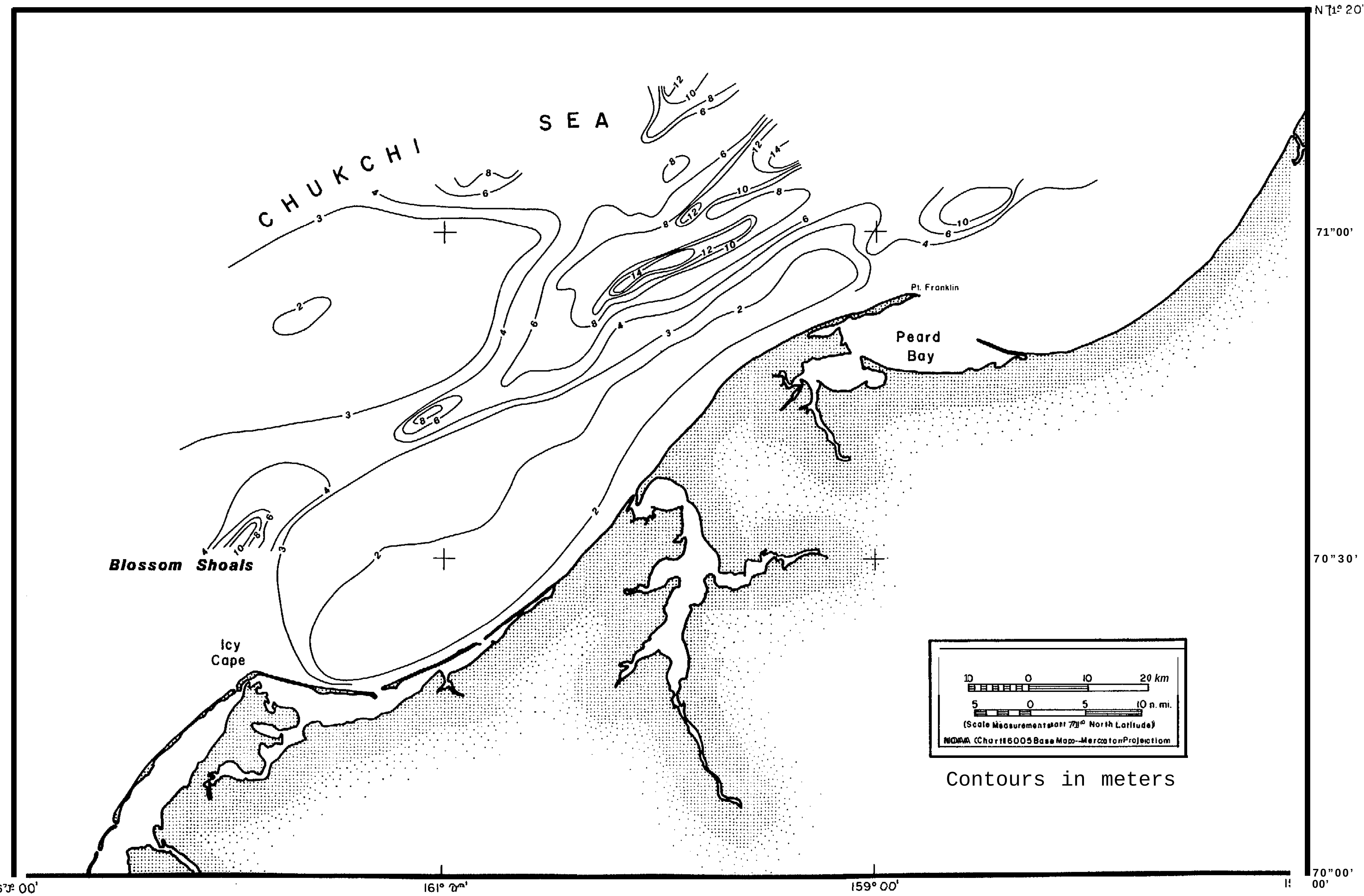


Figure 14. Isopachs, in meters, of Holocene- Quaternary sediment in the northeast Chukchi Sea. The nearshore isopachs are from Phillips and Reiss, 1984.

with increasing depth with most deposits greater than 6 m thick below 55 m. The thickest deposits trend to the northeast in linear bands parallel to the slope of the Barrow Sea Valley (figure 14). Within the sea valley modern channels are eroding the Quaternary deposits (figure 15).

On the west flank of the Barrow Sea Valley a series of paleochannels contain up to 13 m of sediment fill. The channeled sequence forms most of the Holocene-Quaternary sediment cover (figures 15, 16). However, to the east most of the Quaternary deposits within the head of the sea valley rarely contain coherent internal reflectors. The thickest deposits are found within the deeper parts of the sea valley adjacent to modern erosional channels. The Quarternary sediments are apparently being eroded by an internal drainage systems within the head of the sea valley (figures 17b, 17c). Channels cut through the Quaternary deposits down to bedrock (figures 18d, 18e).

To the west on the outer shelf the Holocene-Quaternary sediment blanket, which overlies folded to gently inclined bedrock, is thin varying from less than 1 m up to 5 m in thickness (figures 19a, 19b).

CHANNEL-FILL DEPOSITS (age unknown)

A series of filled paleochannels incised into bedrock are identified in the northwest part of the study area starting at approximately 70 30’N and 167 00’ west (figure 20). Based on limited trackline coverage, the largest channel system trends to the northwest. In water depths ranging from 45 to 50 m the channels are cut to depths of 10 m to over 64 m below the sea bed. The channels range up to 13 km in width. The channels may not represent a specific time event (same age) but represent multiple erosional and depositional events during different sea level lowerings. Evidence for different time events producing the channels is preserved in the distinct channel-fill stratigraphy, the superposition of stratigraphic units, and erosional contacts of some seismic units.

Four major seismic units containing distinctive depositional features are identified within the larger channel systems; 2 to 3 seismic units in the shallow channels.

The uppermost depositional sequence, seismic unit A, represents a thin blanket deposit ranging up to 6 m in thickness. This unit overlies all of the channeled and non-channeled deposits. Internally horizontal or gently inclined parallel reflectors characterize this sequence. The lower reflectors may truncate the underlying strata forming an undulatory contact.

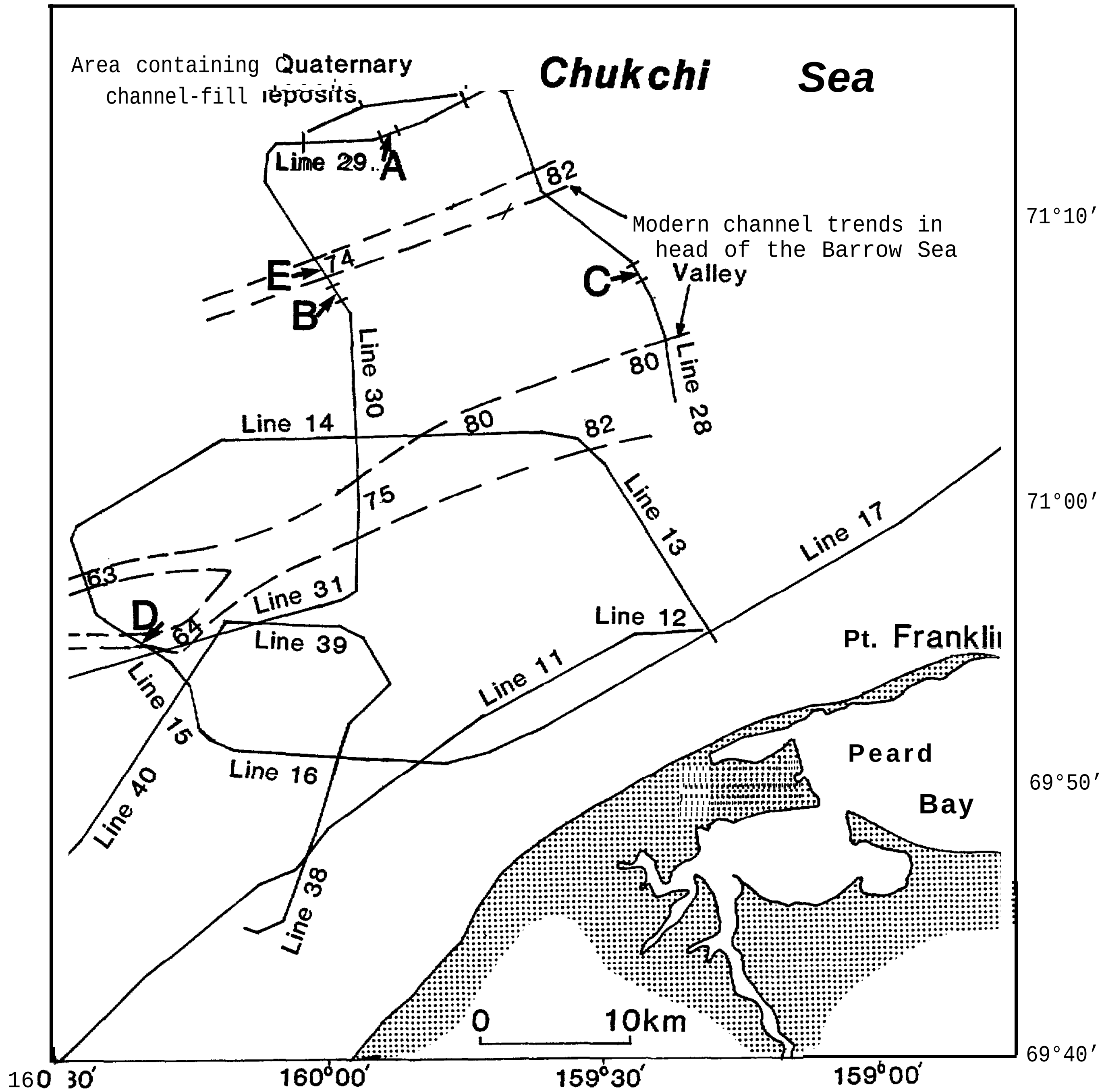


Figure 15. Modern channel trends in the head of the Barrow Sea Valley. The numbers within the channels indicate the maximum water depth in meters; the letters indicate seismic or bottom profile locations.

A

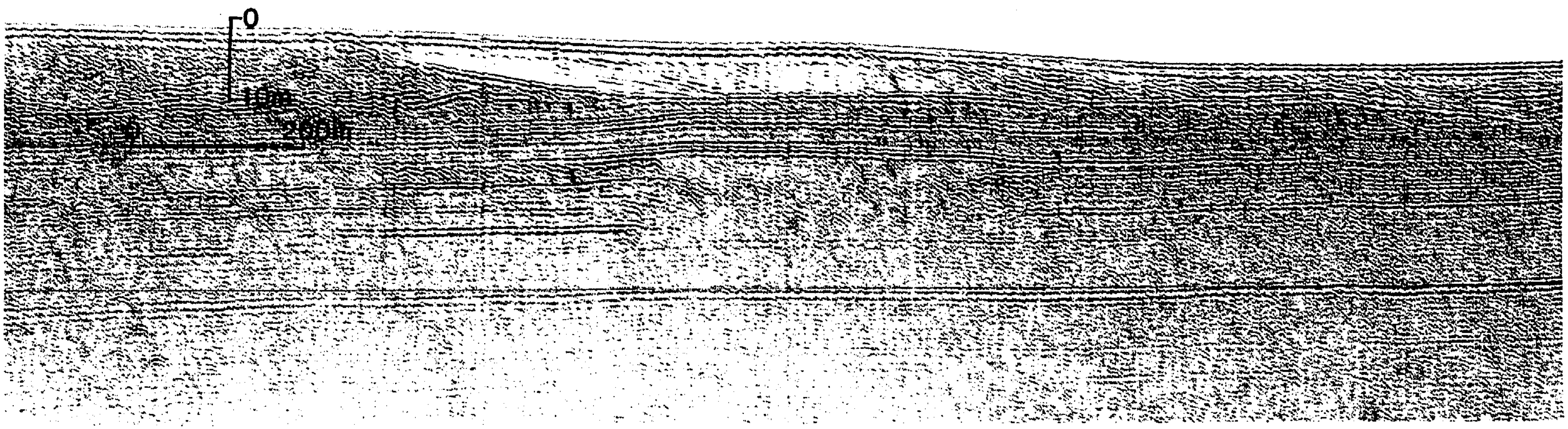


Figure 16. Seismic profile on the west side of the Barrow Sea Valley showing **fluvial** channel deposits overlying gently inclined bedrock. See figure 15 for profile location.

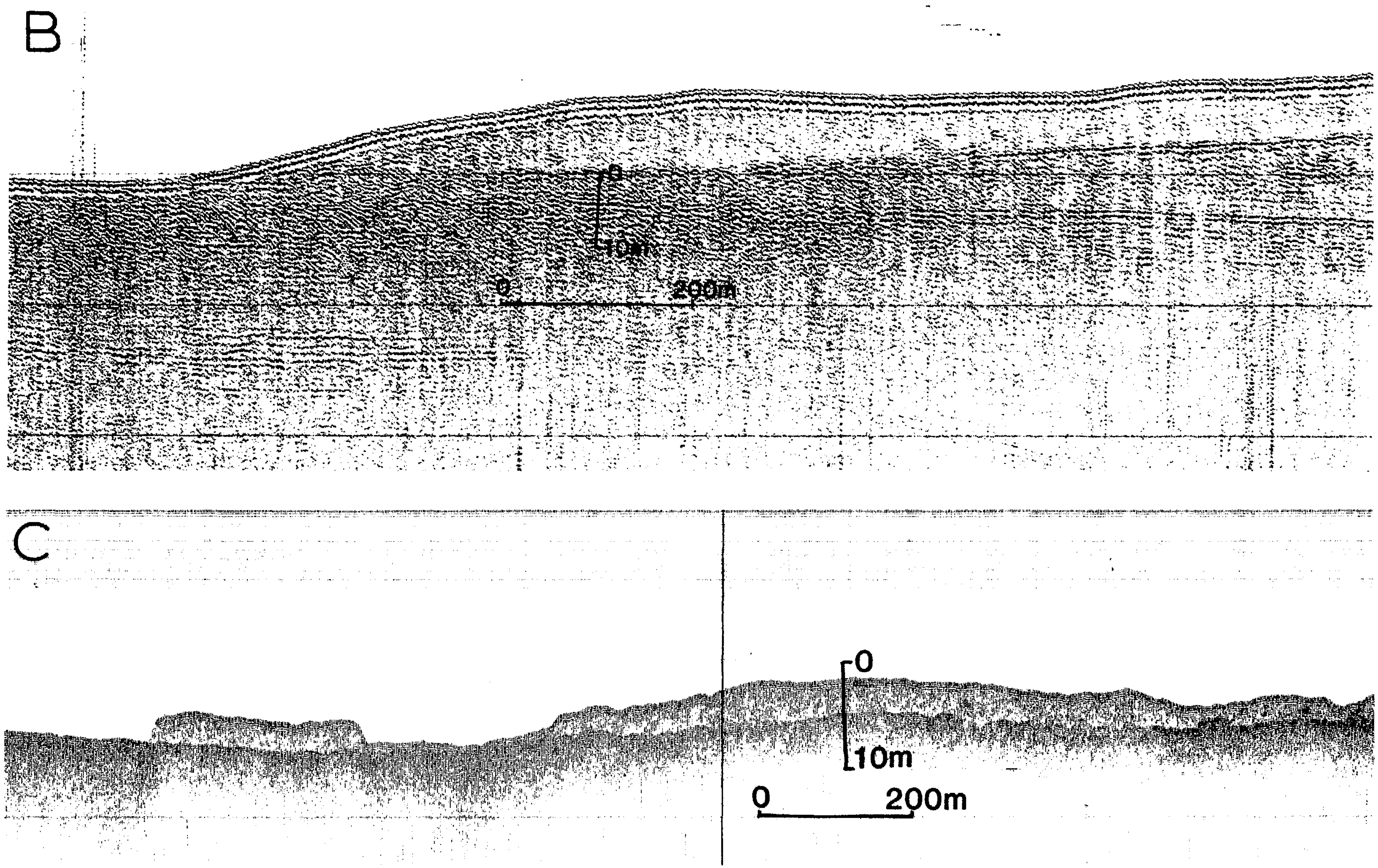


Figure 17. B). Seismic profile near the center of the Barrow Sea Valley showing eroded Quaternary deposits overlying gently inclined strata. A modern channel has cut through the young sediment down to bedrock. C). Bottom profile in the Barrow Sea Valley showing either eroded or slumped deposits overlying bedrock (water depth 68.5 m). See figure 15 for profile locations.

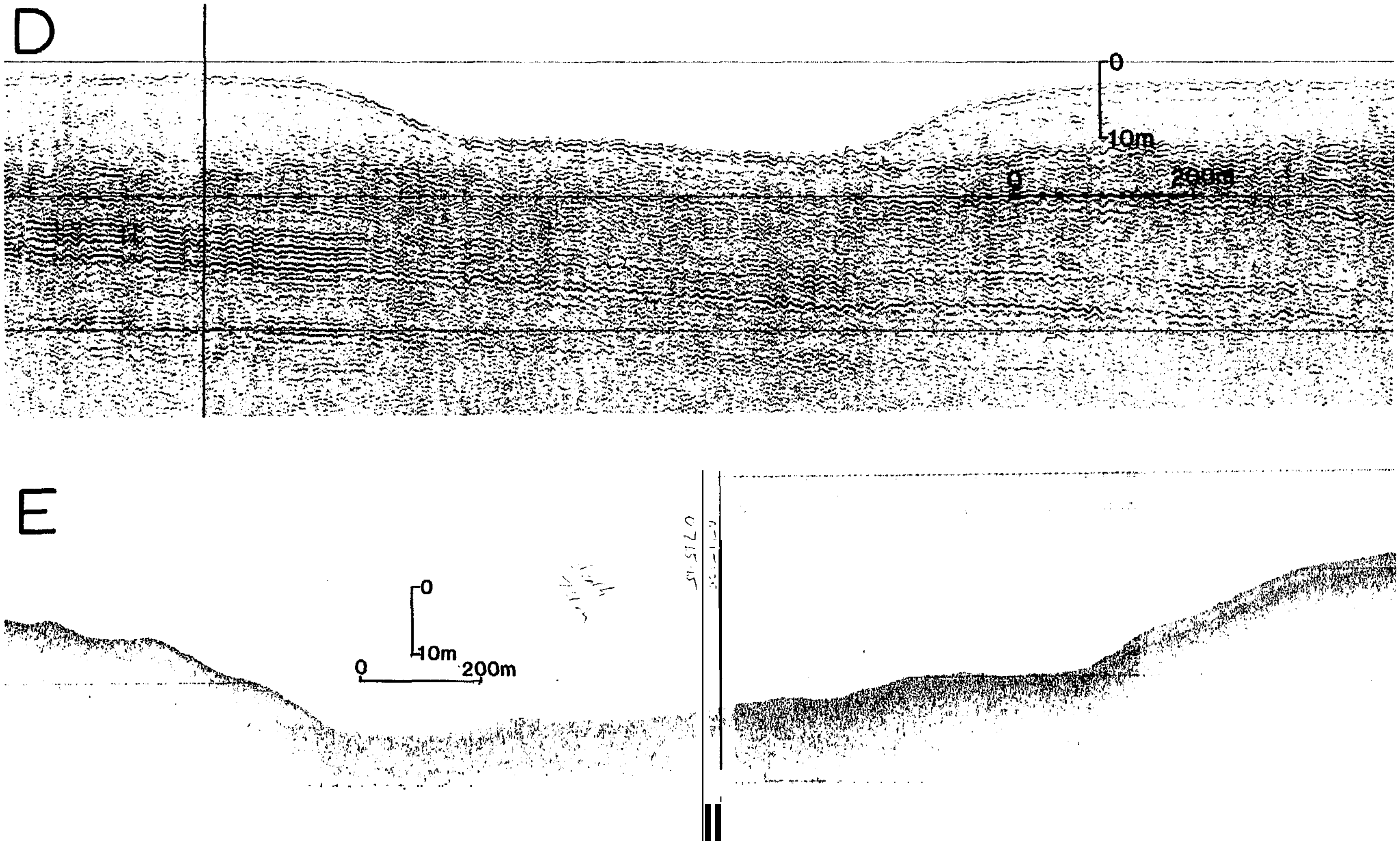


Figure 18. Modern channels at the head of Barrow Sea Valley. D). Seismic profile showing channel incised into Quaternary deposits which overly inclined bedrock. E). Bottom profile of channel. See figure 15 for profile locations.

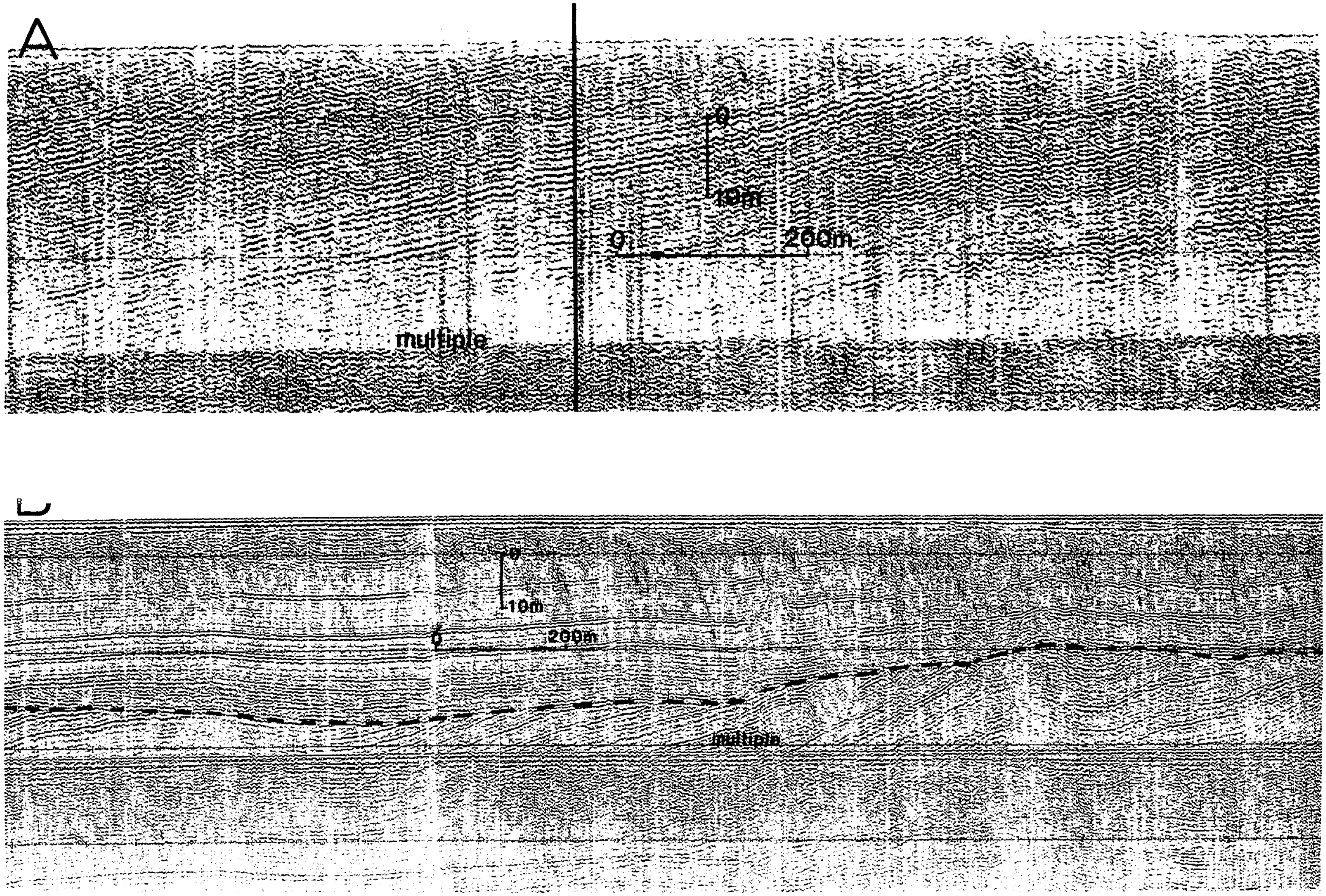


Figure 19. A). A thin sediment cover, locally containing gravel, overlies inclined bedrock on the outer shelf. B). An angular unconformity separates a lower folded and faulted bedrock sequence from an upper gently inclined (but also faulted bedrock sequence. A thin sediment cover overlies the bedrock. See figure 20 for profile locations.

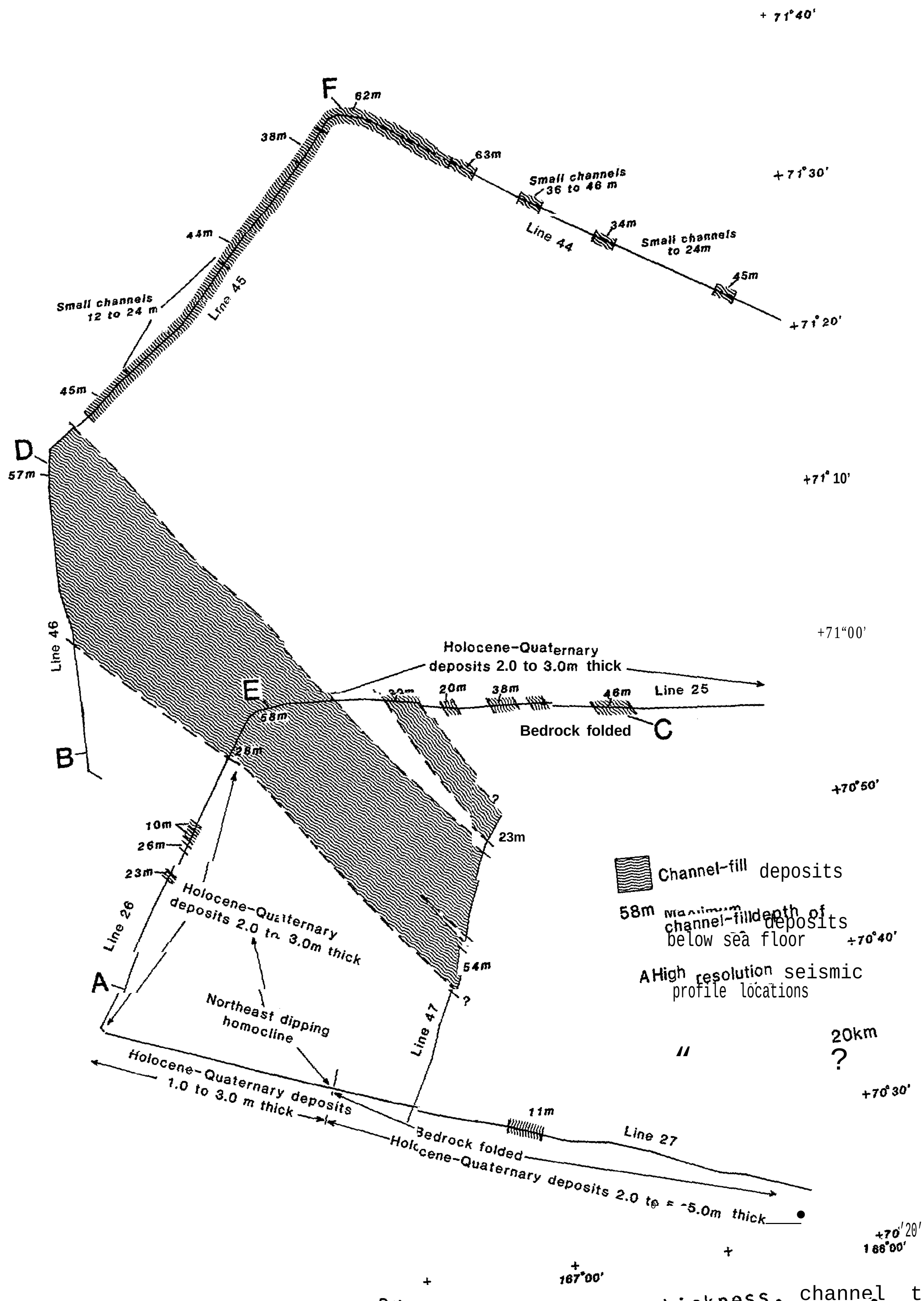


Figure 20. Holocene-Quaternary sediment thickness, channel trends and channel-fill deposits on the outer ... of the Chukchi Sea. The maximum depth of channel incision, expressed in meters, determined from seismic profiles.

The underlying sequence, seismic unit B, is also a blanket deposit varying from 14 to 32 m in thickness (averages about 18 m). The thicker depositional sequences represent local deep channels cut into underlying strata. Internally this unit exhibits complex sedimentation patterns. The reflectors can be discontinuous, contain abundant detraction hyperboles, or contain well defined parallel inclined reflectors. Truncation of the reflectors (due to channeling) can be locally common. The lower contact is usually undulatory and erosional.

The underlying sequence, seismic unit C, varies in thickness from 2 to over 28 m. Horizontal and parallel or slightly undulatory and parallel reflectors comprise the seismic section. The reflectors are parallel and continous throughout the seismic records. The basal reflectors of this sequence are usually drapped over an irregular erosional surface, likewise, the reflectors thin but are also drapped over channel flanks or other topographic irregulatories.

The basal seismic sequence, unit D, is usually discontinuous and poorly preserved. The strata vary in thickness from erosional pinchouts to over 16 m. Abundant hyperboles, locally inclined and parallel reflectors, or small-scale channeling characterizes the basal unit where preserved (figure 21).

The character of the reflectors within the seismic sequences identifies possible depositional environments. The channels record similar fill-stratigraphy even within multi-cyclic erosional -depositional events. Unit A represents fluvial to marine sedimentation and would include Holocene transgressive deposits. Unit B represents fluvial-dominated sedimentation as indicated by the abundant internal channel deposits but this sequence may also include some marine, estuarine, lagoonal and terrestrial facies. Unit C represents deposition of fine-grained sediment within a quite low energy environment. Marine conditions most likely prevailed during deposition of this sequence, however, bay or estuarine facies may also produce a similar depositiona? sequence. The basal sequence, unit D, represents mainly fluvial deposition probably related to the period of bedrock erosion when the deep channels were initially cut.

The channel-fill sequences can vary; most channels record an initial channel down-cutting (to 116 m below present sea level) and deposition of fluvial sediments (unit D). After deposition of the fluvial sediments a period of erosion followed. The drapped strata (unit C) overlying the fluvial sediments (unit D) represent marine sediment deposition during a transgression (figures 22, 23, 24, 25). The next depositional sequence, unit B, probably contains a variety of environments including fluvial, lagoonal, barrier island to possible marine (figure 24-). Within unit B a large channel over 28 m deep (103 m below sea level) has removed both underlying units C and D. The unit B channel is in

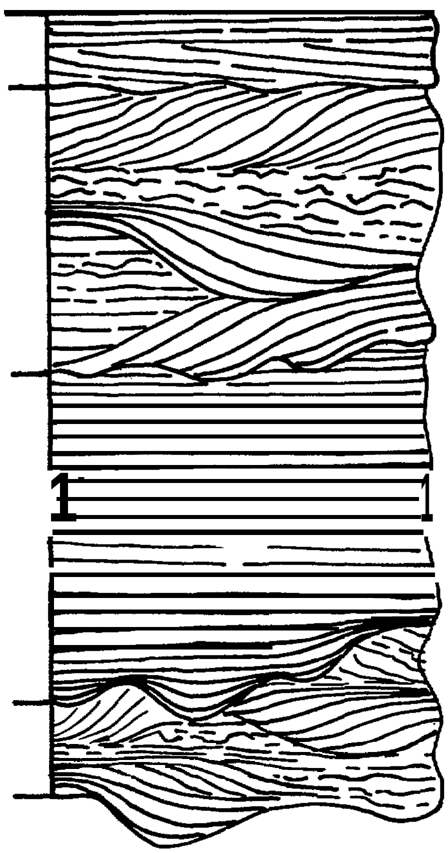


Figure 21. Major seismic units and interpretative deposit ional environments for channel-fill deposits northwest Chukchi Sea. Unit D rests on an erosional surface cut to 63 m into bedrock (116 m below present sea level); Unit C drapes an irregular erosional surface developed on Unit D and represents a probable marine depositional sequence; Unit B contains abundant channels but may also include estuarine to deltaic to terrestrial depositional environments; and Unit A contains fluvial to probable marine environments and would contain Holocene transgressive deposits.

C

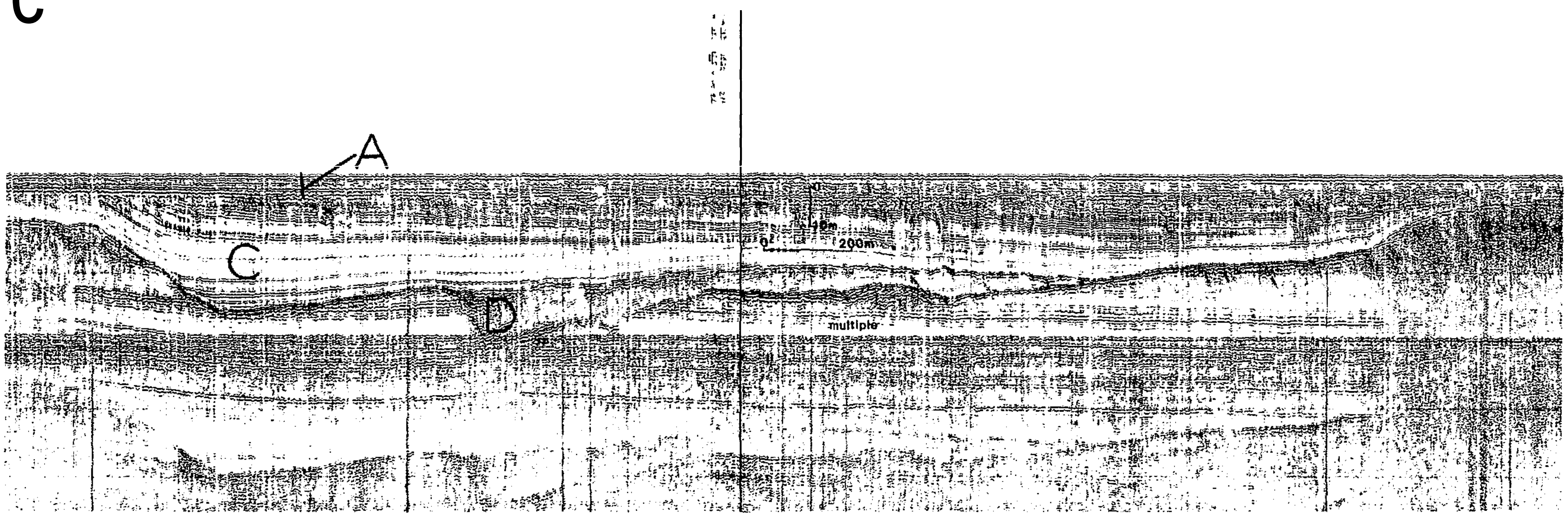


Figure 22. Channel-fill sequence containing 3 seismic units consisting of Unit D **fluvial** deposits, Unit C draped deposits (marine ?) and Unit A deposits **which** consist of a **fluvial** to marine sequence. See figure 20 for profile location C.

D

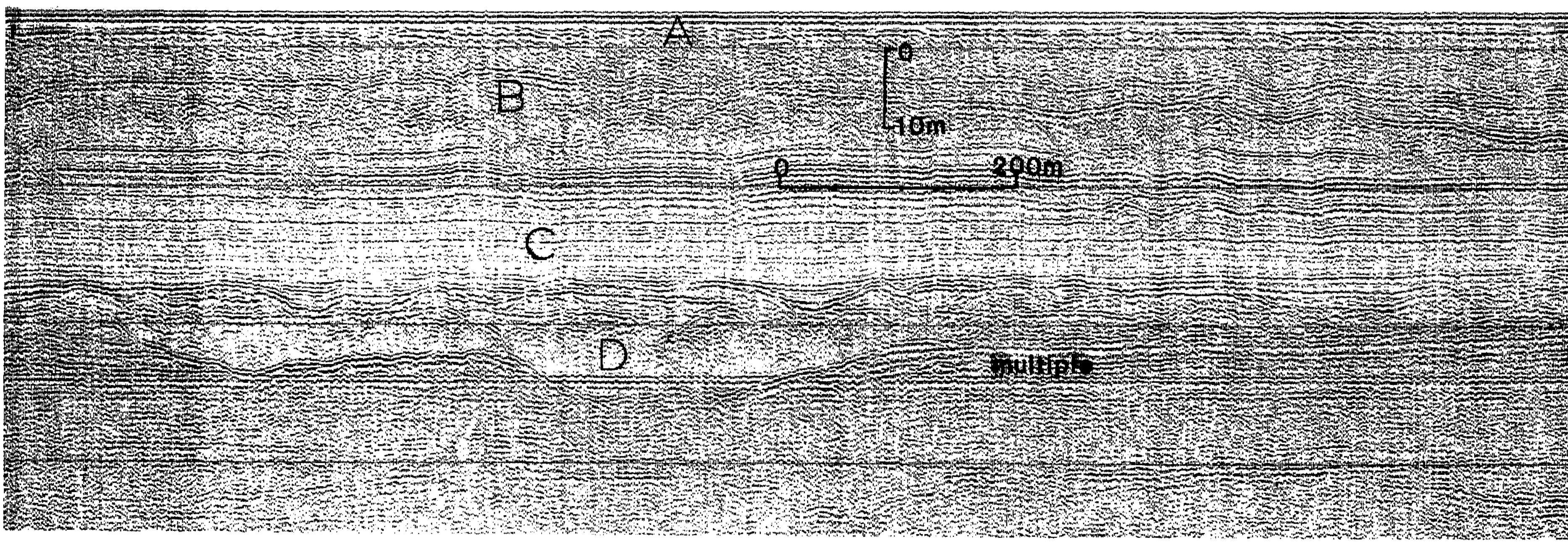


Figure 23. Channel-fill deposits within a large channel system, northwest Chukchi Sea. Four seismic units separated by erosional surfaces are identified and consists of a basal fluvial sequence (Unit D), a well-bedded draped sequence of probable marine origin (Unit C), a fluvial-dominated sequence (Unit B), and the uppermost sequence (Unit A) consisting of fluvial to marine beds. See figure 20 for profile location.

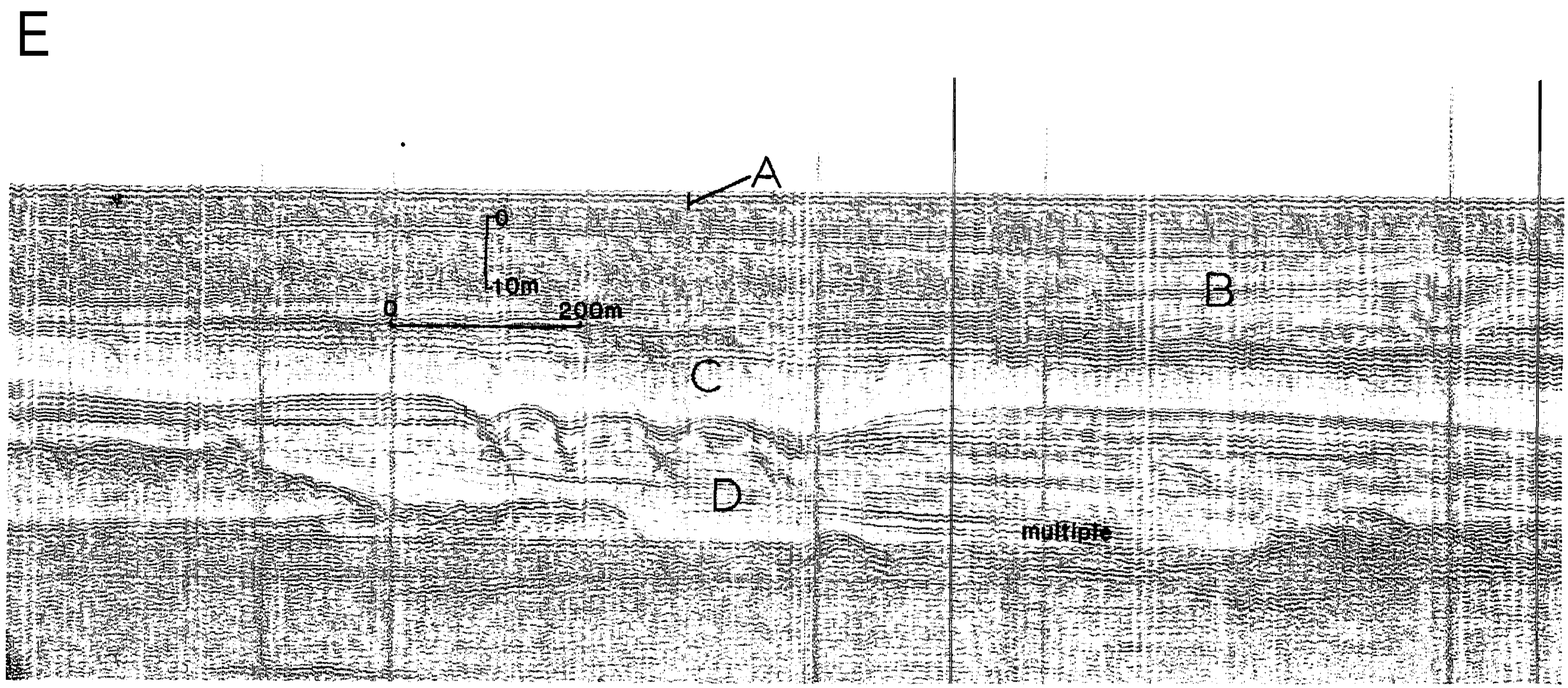


Figure 24. Channel-fill deposits within a large channel system containing a thick basal sequence of fluvial deposits (Unit D), a draped marine sequence (Unit C), a thick fluvial sequence (Unit B), and a thin fluvial-marine sequence (Unit A). See figure 20 for profile location.

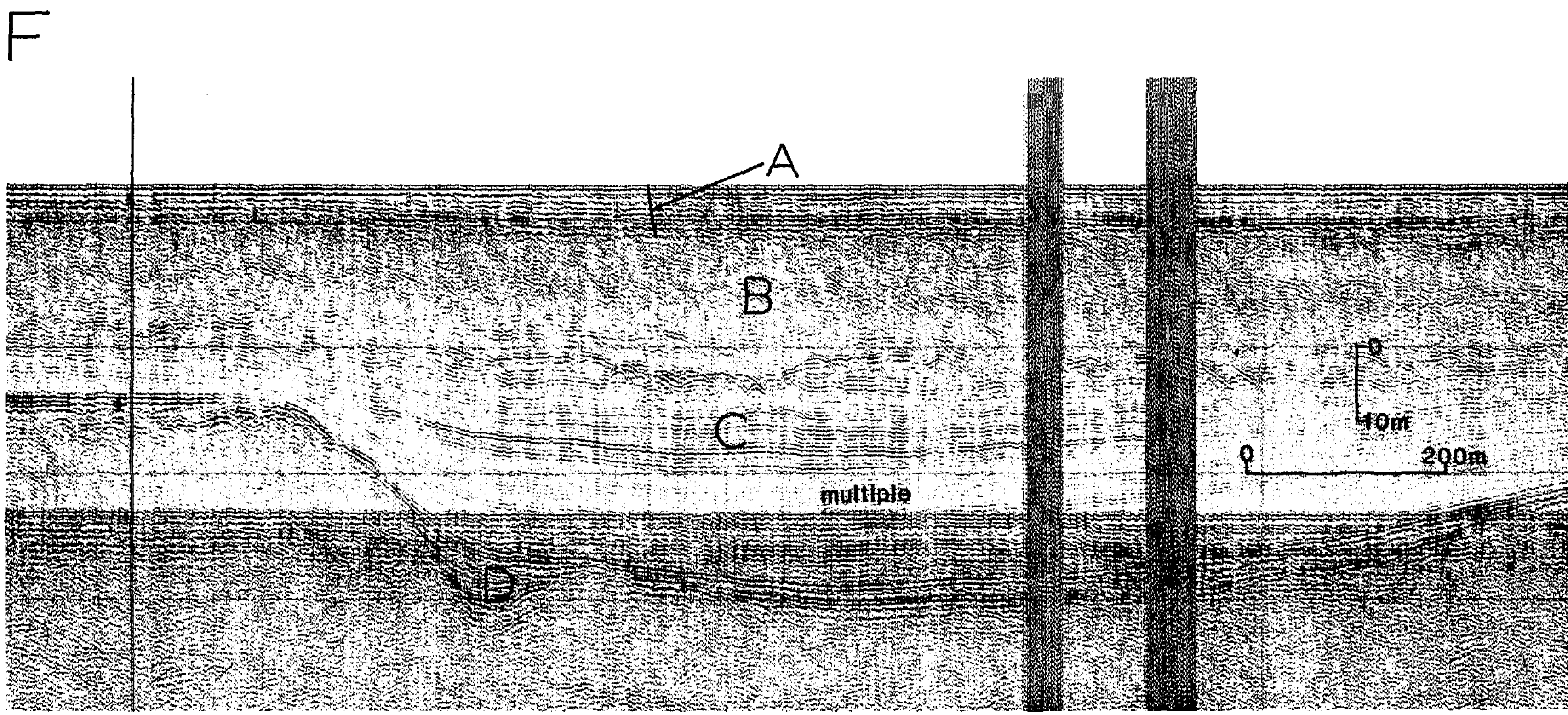


Figure 25. Channel-fill deposits recording a thin and discontinuous basal fluvial sequence (Unit D), a thick draped marine sequence (Unit C), a poorly defined fluvial sequence (Unit B), and a relatively thick fluvial-marine sequence (Unit A). See figure 20 for profile location.

turn filled with parallel draped reflectors. In much of this unit numerous shallow channels characterize the deposit ional sequences. The upper depositional unit contains only shallow, to 6 m thick, isolated channels suggesting fluvial deposition. Lagoonal, barrier island and marine environments may be found within this sequence.

During sea level lowerings multiple channeling events are proposed. At least 3 periods of sea level lowering and cutting of channels are recognized: 1) channels were initially incised to at least 116 m below present sea level, then filled during a transgressive event (deposition of seismic units D and C); 2) sea level lowering again resulted in channels cut to at least 103 m below present sea level (deposition of seismic unit B); and 3) a third sea level lowering event to at least 92 m below present sea level is recorded in channels lacking deposition of seismic unit B. The time relationship of the channels lacking unit B to the channels containing unit B is unknown.

The age of the channeling events is uncertain but may range from Quaternary to Tertiary. A "young" age is suggested for the channel-fill deposits based on the following: 1) the channels are incised into at least two stratigraphic bedrock units which are seperated by an angular unconformity, the gently inclined strata of the North Chukchi Basin which overlies older folded bedrock (figure 19 b); 2) the channels are not folded suggesting the channel-fill is younger then the folding event; 3) some channels appear to be bedrock controlled following the strike of underlying strata which also suggests the channels are younger than the bedrock they are incised into; 4) the channels must be younger than Late Cretaceus age because paleocurrent data and nonmarine channel trends (early to late Cretaceus age Nanushuk Group sandstones in the North Slope) are to the east to northeast (Bird and Andrews, 1979; Molenaar, 1985) over 90 degrees apart from the Chukchi Sea northwest trending paleochannels; 5) the channels are cut to at least 116 m below present sea level suggesting possible Quaternary sea level lowerings (however the channels may be incised to deeper depths to the north beyond the area of our track lines); and 6) some wide channels underly areas now containing sea floor depressions suggesting either compaction of unconsolidated sediment or the melting of permafrost to produce the sea floor depressions (figure 7).

The above evidence suggests a Quaternary to Tertiary age range for the channel deposits. However, the major problem of this "young" age is the identification of the channel's sediment source, because the major southern Holocene drainage pattern in the Chukchi Sea was to the west through the Chukchi Valley (McManus and others, 1983) (the present Hope Sea Valley located east of Wrangel and Herald Islands), and not where those ancient channels are located. Likewise, the Barrow Sea Valley" was probably the major Holocene drainage for streams and rivers from the east to at least south to Wainwright and the Kuk River because paleochannels trend north into the sea valley. The present lack of adequent drainage sources suggest that the outer shelf channels are pre-Holocene in age.

The Chukchi Sea channel deposits may be sources of sand and gravel. However, they may also represent geologic hazards if they contain permafrost or as in some cases where they contain gas (Appendix D). Drilling will be required to evaluate the channel deposits for a source of sand and gravel as well as establish the age of formation.

SURFICIAL SEDIMENTS

Sonographs along with bottom sampling can delineate the Chukchi Sea's major surficial sediment types. The sea floor texture ranges from sandy mud to muddy sandy gravel. Bedforms, current related sea floor processes, and mammal feeding areas can also be identified from monographs.

The surficial sediment distribution of the southern Chukchi Sea is fairly well defined from previous work (Creager and McManus, 1966, Barnes, 1970) and is summarized in Grantz and others (1982) and Lewbel (1984). This section summarizes new data obtained from box cores, dredges and sea floor monographs specifically of textures and sedimentalogic processes acting on the sea floor in the Chukchi Sea. The study is discussed in two sections, the outer shelf which includes the area from Cape Lisburne north, and the inner shelf located at the head of Barrow Sea Valley.

OUTER SHELF

The sediment texture in the outer shelf ranges from mud to gravelly muddy sand. Fifteen box cores are texturally classified as: 1) slightly gravelly sandy mud, 7 cores; 2) sandy mud, 4 cores; 3) slightly gravelly muddy sand, 2 cores; and 4) gravelly muddy sand, 2 cores (classification of Folk, 1974). The distribution of gravel, sand and mud components of the outer shelf cores show the areal variation in the sediment fractions on the shelf. The mud content Increases to the north (figure 26, Appendix A).

Monographs in conjunction with sampling defines the sea floor surface textures. Gravel- and sand-floored regions are readily identified by the presence of bedforms. However, mud appears to be the dominant surficial texture followed by slightly gravelly sandy mud on the outer shelf.

Gravel

Gravel is abundant in the southern part of the Chukchi Sea near Cape Lisburne and near Cape Beaufort (figure 27). In the northern shelf gravel patches are scattered and abundant only south of 71 degrees north (figures 28 and 29).

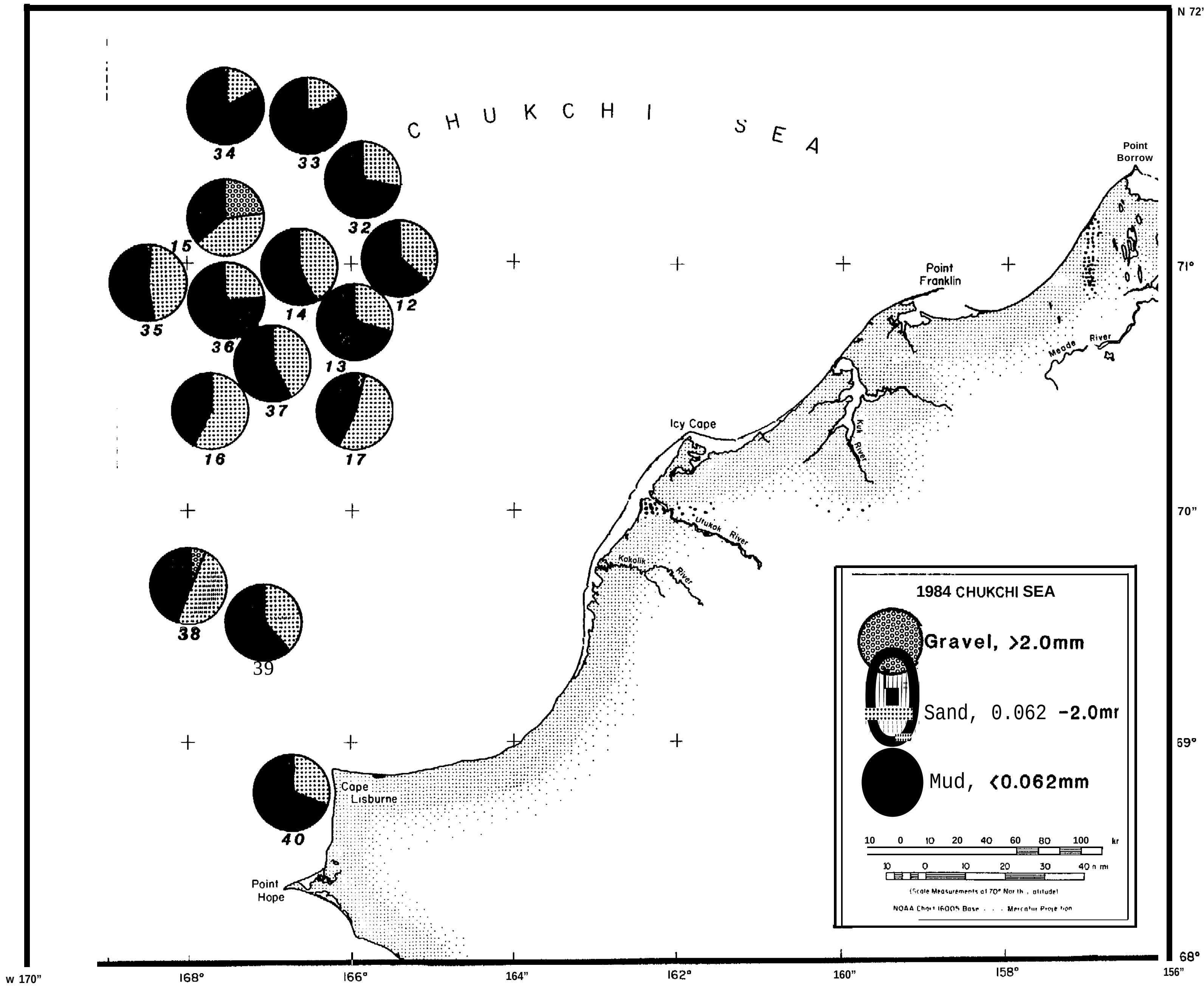


Figure 26. Phi diagram showing box core textural composition in percent for the outer shelf samples in the Chukchi Sea.

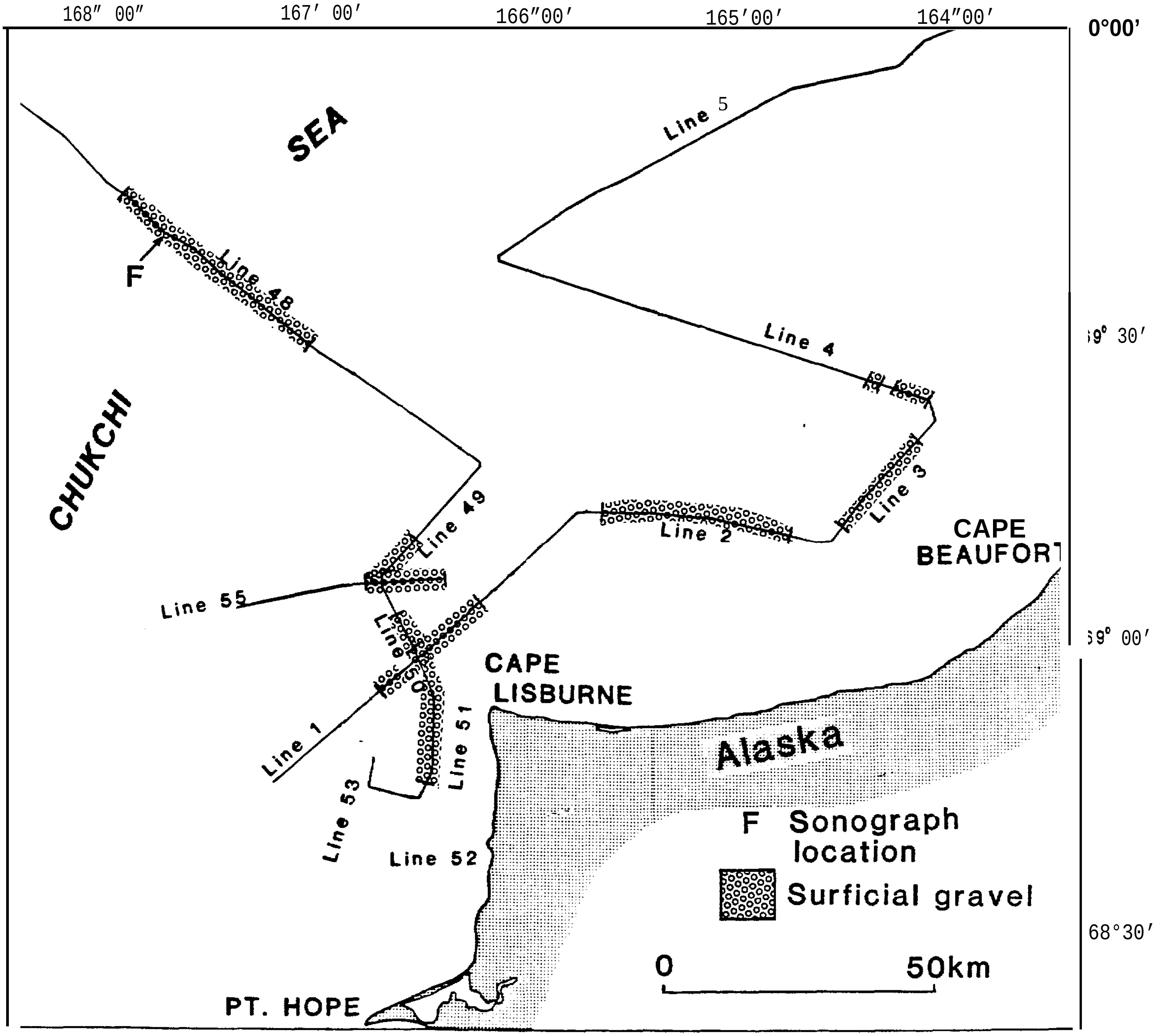


Figure 27. Surficial gravel deposits on the southeast Chukchi Sea determined from samples and side-scan sonar records.

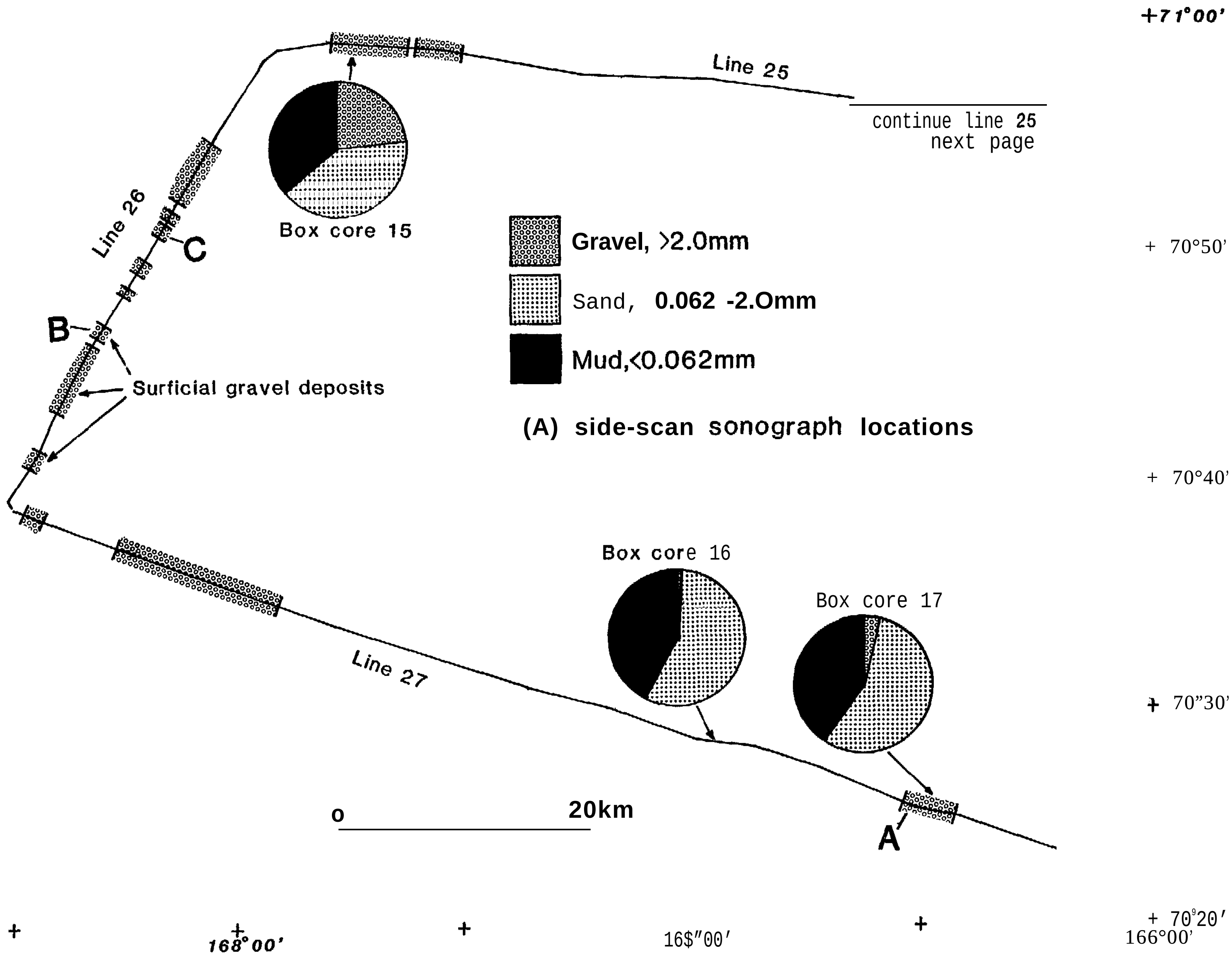


Figure 28. Surficial gravel deposits on the central Chukchi Sea. The distribution of gravel determined from monographs and box coring. See figure 3 for track line locations.

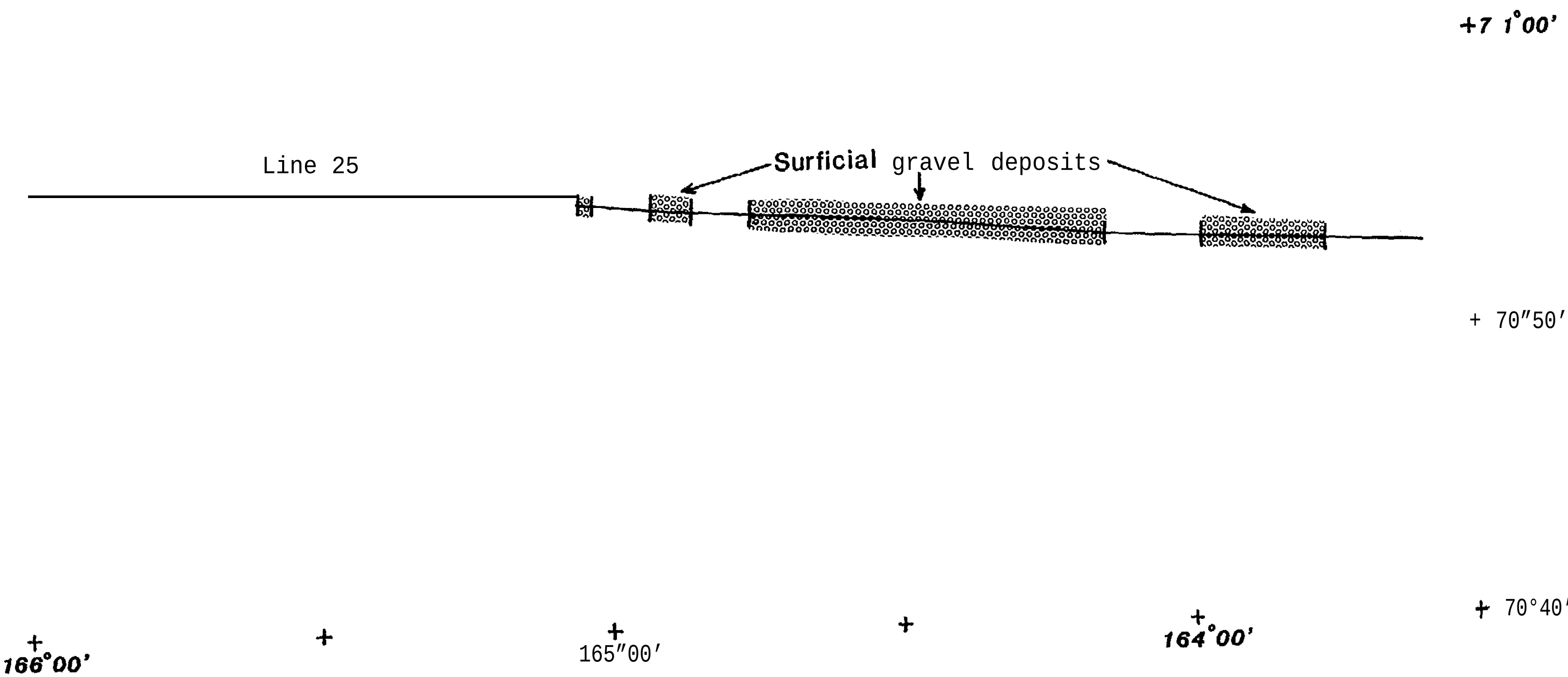


Figure 29. Continuation of line 25 (figure 28) showing the surficial gravel deposits identified on monographs in the outer Chukchi Sea. See figure 3 for track line locations.

Size analyses of the gravel fraction of 5 box cores and one dredge sample show that the gravel ranges up to 32 mm and falls in the pebble size range. A unimodal size distribution is present in 4 samples and a bimodal distribution in 2 samples (figure 30). The dominant pebble size mode of 5 of the samples is between 4 and 8 mm. The pebbles are either well-rounded (samples 15 and 17) or contain a population of rounded to angular clasts (sample 42). The composition of the pebble fraction varies depending on adjacent bedrock sources and transport distance. Marble and sandstone clasts are abundant near Cape Lisburne, whereas, well-rounded black siliceous clasts dominate in the northwest samples (samples 14,15,16). Sand size mica is abundant in the northern most gravels.

Surficial concentrations of gravel in the Chukchi Sea, reflects regions of active currents and subsequent sea floor erosion. In some examples the gravel is restricted to bathymetric highs. The pebbles occur either as extensive sheets ranging up to 45 km in length or as scattered patches separated by sandy mud. In all gravel-rich areas a thin, usually less than 2 to 4 m thick, Holocene-Quaternary sediment cover overlies bedrock which suggests that the gravels represent an erosional lag deposits.

The surficial gravel deposits exhibit a variety of bedforms. Widespread gravel sheets some covered with symmetrical gravel waves are the most common sea floor feature. Gravel waves also occur in areas where gravel sheets do not exist. Linear gravel ribbons(?) associated with mud or sand are also a common feature on the flanks of gravel sheet deposits especially near Cape Lisburne. The linear gravel ribbons are positive features with relief less than 30 cm, a width ranging from 2 to 4 m, and a spacing of between 5.5 and 6 m (figure 31A). The gravel ribbons usually lie at a slight angle to the ice gouge trend. With decreasing depth, abundant ice gouging can be associated with the gravel ribbons (figure 316) and at the shallowest depths the gravel ribbons change to gravel sheet deposits. Ice gouging is still common within the gravel sheet deposits (figure 31C).

Near Cape Lisburne besides the linear gravel bedforms nearly parallel to the ice gouge trend, transverse gravel waves oriented perpendicular to the ice gouge trend are common (figure 32D). Shore-parallel bedforms are found on the flanks of the gravel sheets (figure 32E). To the west of Cape Lisburne, at depths of 45 to 49 m, an extensive gravel sheet exists with scattered sand bedforms overlying the gravel (figure 32F). These sand bedforms indicate that active currents exist and are capable of moving sand-size particles at depths greater than 40 m.

In the northwest part of the outer shelf, gravel sheets are restricted to areas of thin sediment cover and to local broad bathymetric highs (less than 4m high). These gravel deposits also exhibit a range of bedforms types similar to those observed near Cape Lisburne.

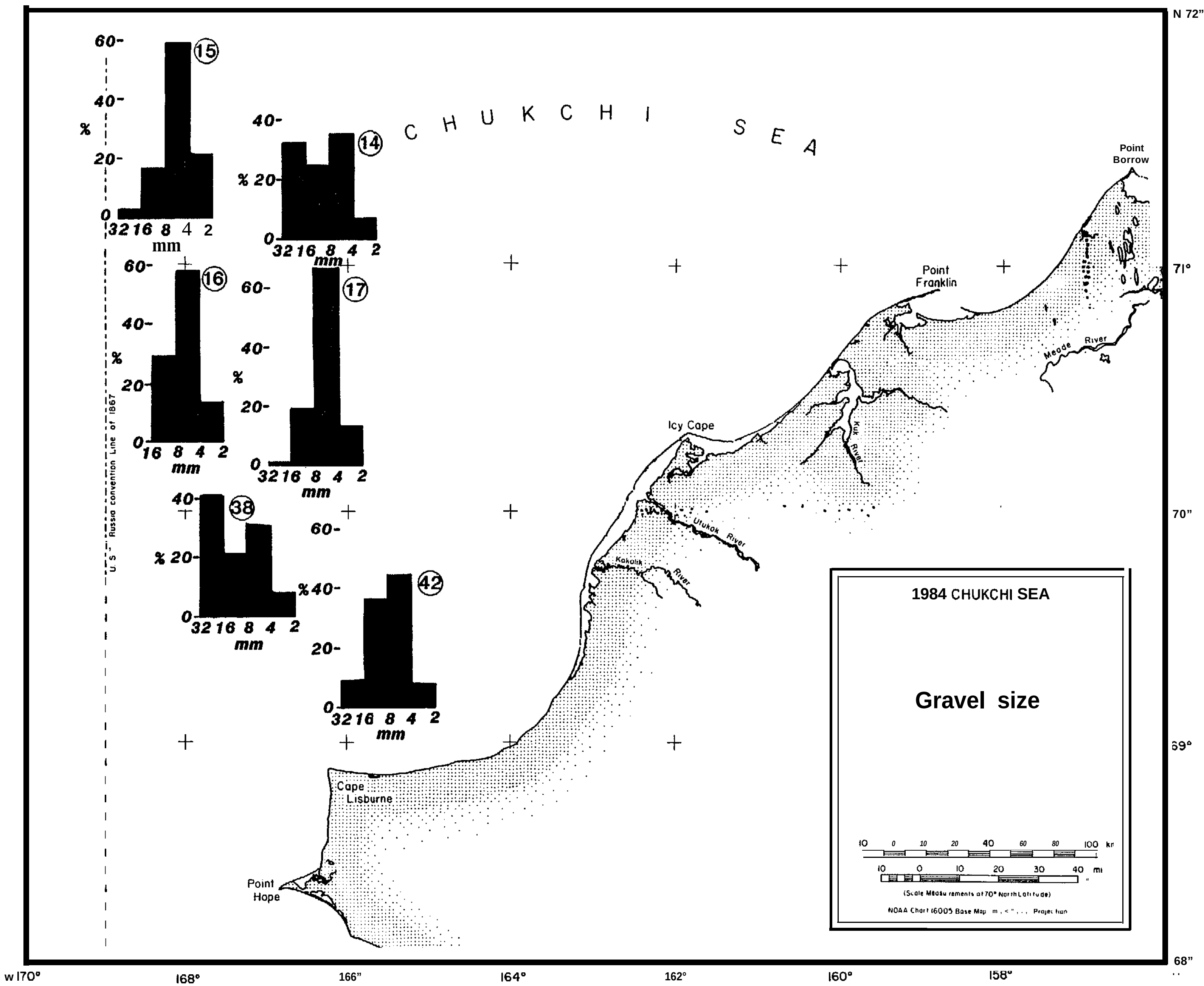


Figure 30. Gravel size analyses of coarse -grained fractions of box cores, outer Chukchi Sea. Sample 42 is a dredge sample. The sample numbers are indicated by circle.

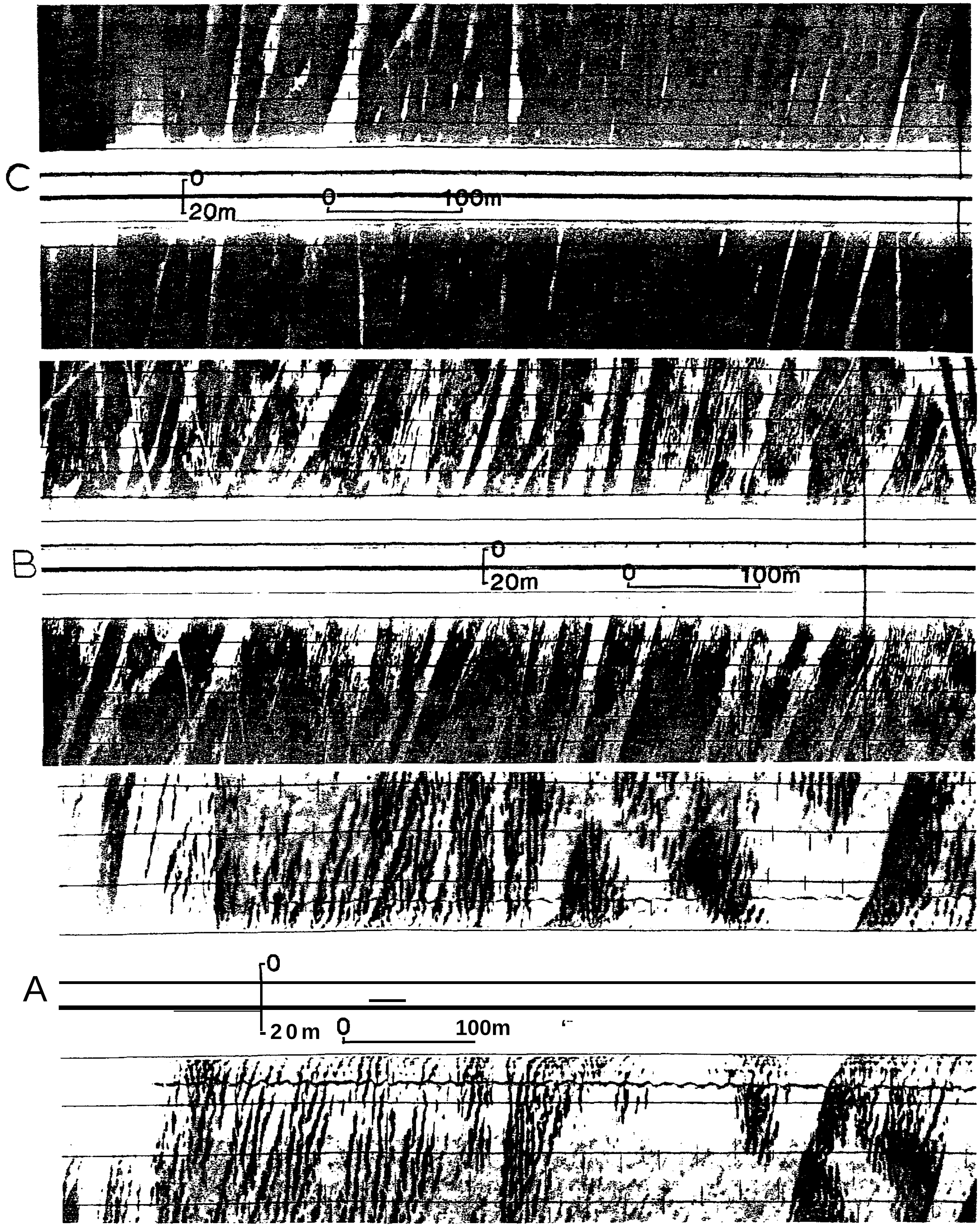


Figure 31. Gravel deposits northwest of Cape Lisburne, Chukchi Sea. A) Northward-trending gravel ribbons at 42 m depth cut by ice gouges. The gravel ribbons are <30 cm high, 2 to 4 m wide and spaced 5.5 to 6 m apart. B) gravel sheet and ribbons at 38 m depth cut by ice gouges. C). Gravel sheet deposit at 34 m depth cut by ice gouges. The transition from A to B to C is typical of gravel deposits in the outer shelf. See figure 35 for sonograph locations.

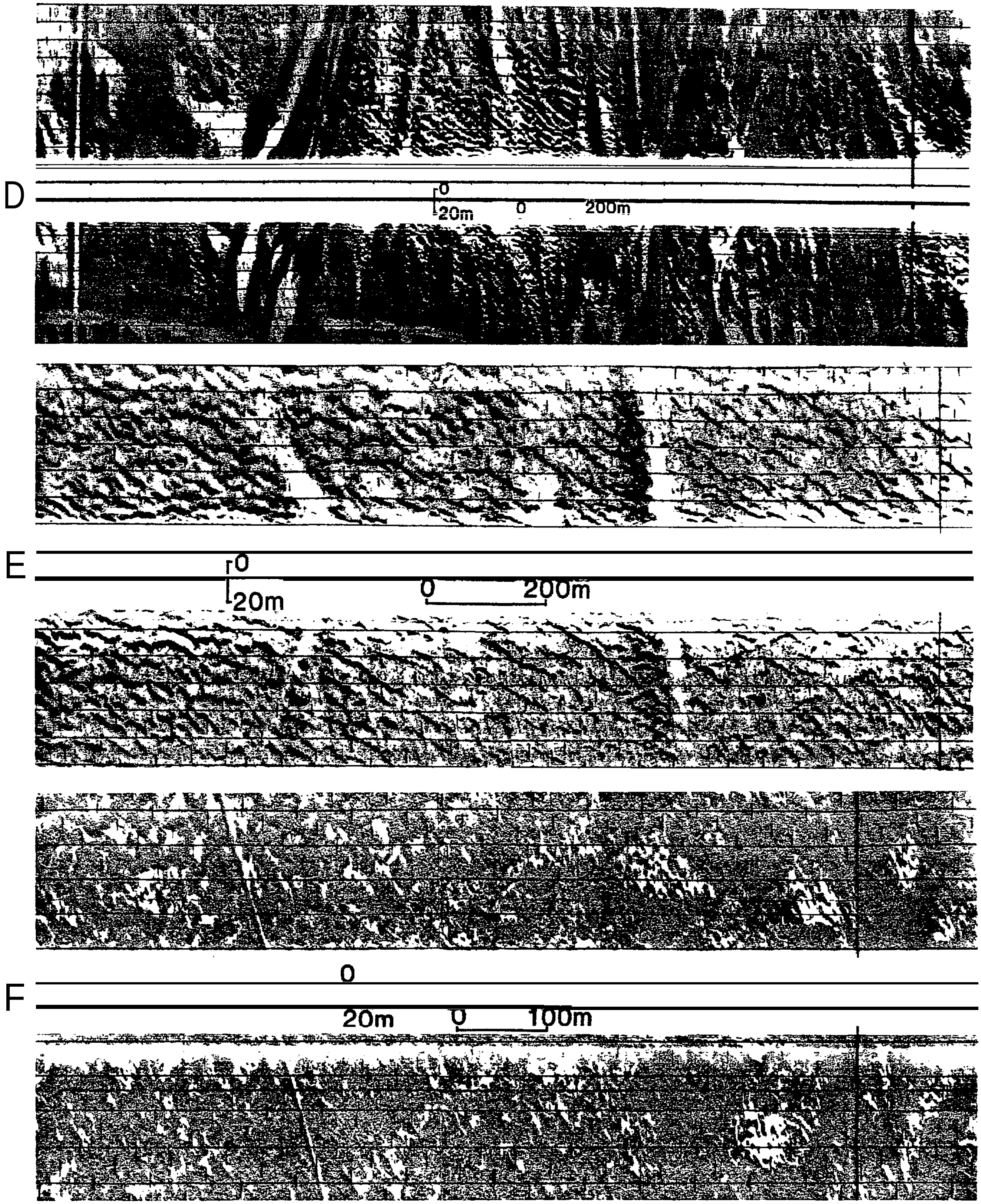


Figure 32. Gravel bed forms west of Cape Lisburne. D) Shore-normal gravel bed forms at 37.5 m depth (center of sonograph) and ice gouges oriented perpendicular to shore. E) Gravel waves at 39 m depth oriented normal to shore. The wave length is approximately 7 to 8 m. F) Scattered sandwaves on a gravel sheet deposit west of Cape Lisburne. See figure 35 for location of figures D and E and figure 27 for location of figure F.

Gravel ribbons also occur associated with and parallel to ice gouges. Gravel waves, up to 20 to 30 cm high, can be oriented transverse to the ribbons or occur as distint fields (figure 33A). Scattered sand or gravel bedforms without a distinct orientation may be formed on the flanks of the bathymetric highs (figure 33B). The gravel sheet deposits can also exhibit a variety of bedform types (figure 33C). Most of the gravel sheets in the outer shelf contain symmetrical bedforms oriented essentially transverse to the adjacent ice gouge trend.

The gravel deposits in the Chukchi Sea exhibit a variety of bedforms suggesting that active currents exist possibly during storm periods which reinforce the shelf currents. The currents then are capable of moving pebble-size clasts on the sea floor.

Box cores show gravel scattered throughout the cores. A slight increase in gravel content at the top of some cores suggests an erosional lag deposit (figure 34). Bedding is poorly defined within the gravel-rich cores. Vertical and horizontal burrows are also abundant suggesting biological disruption of the substrate.

The gravel deposits identified in the outer shelf represent erosional storm-lag deposits. The gravels are found either where a thin Holocene-Quatenary sediment cover exists, or, especially, on local bathymetric highs. The gravels may represent exposed parts of the Holocene transgressive lag deposit which now is being eroded.

The source of the gravel is uncertain, however, prime candidates are bedrock and ice rafting. However, the well-rounded siliceous pebbles are similar to the suite present on the beaches north of Icy Cape. This may suggest that fluvial transport to the west occurred across the exposed coastal plain during sea level lowstands.

Discussion

The variety of gravel bedforms found to depths of 49 m, are the result of a combination of factors including: 1) current erosion and sediment transport by the northward flowing Alaska Coastal Current (along the east side of the Chukchi Sea) and east or west flowing shelf currents (the northwest part of the shelf), and 2) westward flowing storm-generated currents on both the inner and outer shelf regions. Evidence for currents is best demonstrated in the area of geatest gravel accumulation off Cape Lisburne. Here, the gravel ribbons and symmetric gravel bedforms are oriented north-south, essentially parallel to shore (figure 35) and to the northward flowing coastal current. The dominant ice gouge trend in this same region is northeast-southwest with a secondary component oriented east-west normal to the gravel ribbons and gravel waves. Ice can only move to the west, upslope, when storms come from the west. During periods of open water the symmetric shore-parallel gravel waves may be initially

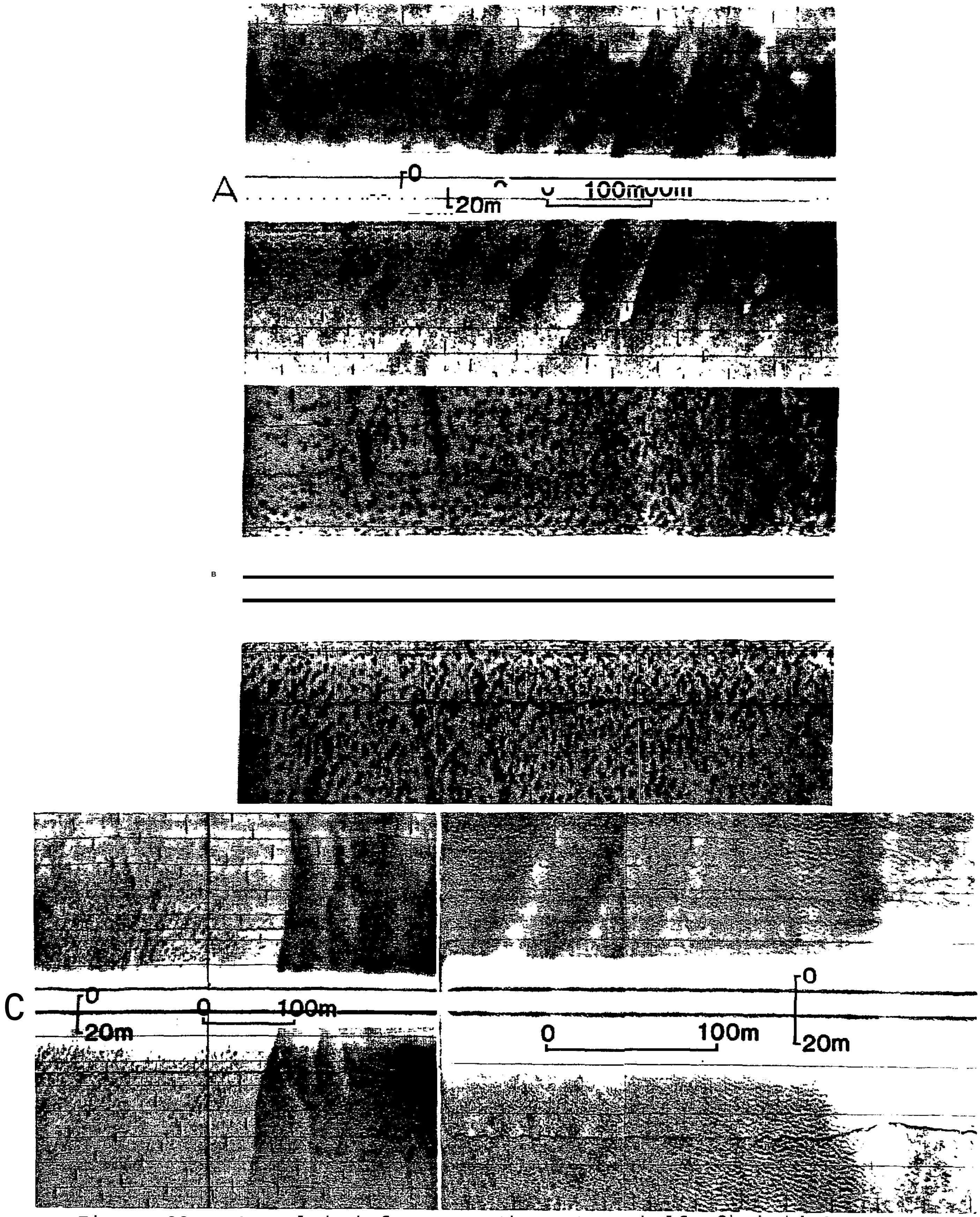


Figure 33. Gravel bed forms on the outer shelf, Chukchi Sea. A) Gravel waves at 45.5 m depth migrating to the west. B) Gravel bedforms (?) at 43.5 m depth on flank of a gravel sheet. The gravel bedforms rise above the sea floor. C) Gravel bedforms at 49 m depth. Scatted gravel bedforms change to gravel sheet deposits with a slight decrease in depth. An expanded view of gravel sheet (right side sonograph) shows symmetrical gravel waves covering the deposit. See figure 28 for profile locations.

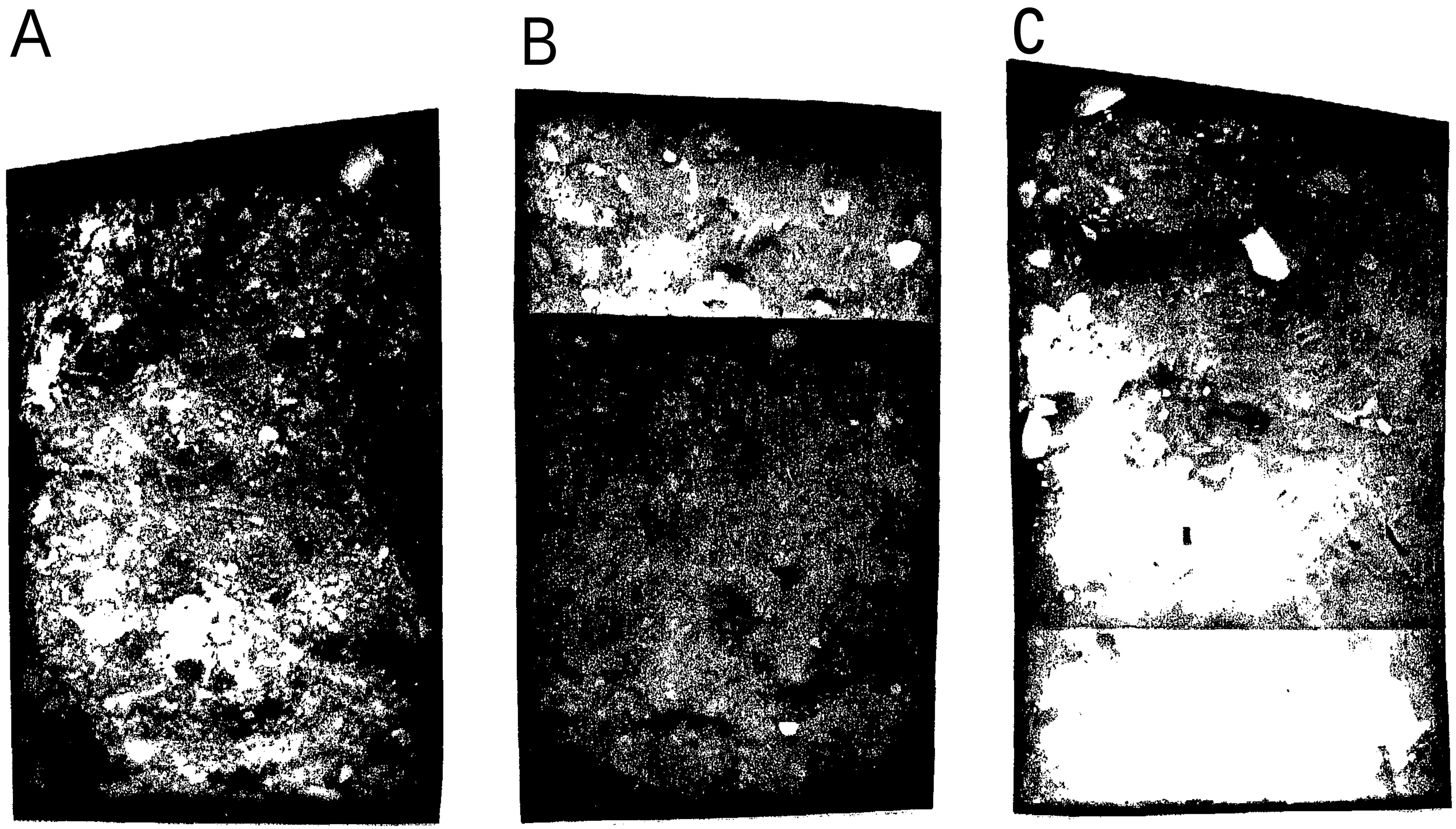


Figure 34. Radiographs of outer shelf box cores containing gravel. A) Core 15 (44.4 m) contains abundant gravel throughout core as well as burrows. B) Core 17 (43.2 m) shows both shells and gravel mixed in a mud substrate. C) Core 38 (45.7 m) contains bioturbated mud with gravel as a surficial lag and in burrows. See figure 26 for core locations. The cores are 19 cm wide.

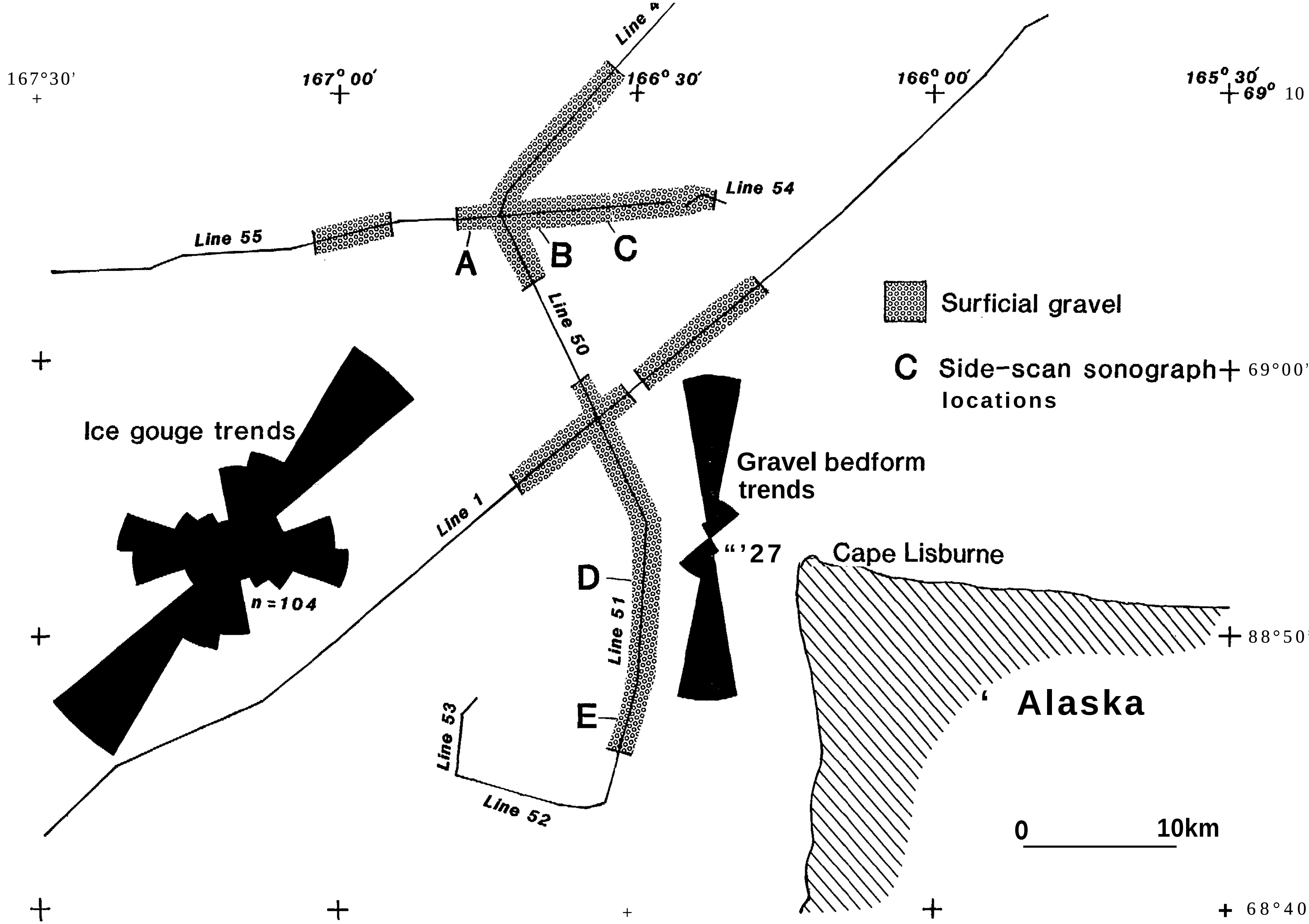


Figure 35. Ice gouge and gravel bedform trends (gravel ribbons and symmetrical gravel wave crest trends) off Cape Lisburne, Chukchi Sea. The gravel bedforms lie at an angle to the ice gouges suggesting a combination of processes produced and maintained the gravel bedforms including storms from the west initially forming the gravel bedforms and the northward flowing Alaska Coastal Current maintaining the bedforms.

produced by storm waves moving from the west to the east (allows maximum fetch). The shore-parallel bedforms are then further maintained by the northward flowing coastal current. The gravel waves in the northwest part of the study area, likewise, are oriented north-south and transverse to the gravel ribbons suggesting currents from the east or west produced the bedforms. Storms from the west may also have reinforced the shelf currents moving gravel on the sea bed.

The reoccurrence interval of the storm events capable of moving pebbles at 49 m depth is unknown, but the presence of gravel bedforms on the shelf indicates bottom currents of up to 150 cm/sec (8 mm quartz clasts at 20° C, Miller and others, 1977) do occur periodically.

Mud

Sandy mud to slightly gravelly sandy mud is the common texture on the outer shelf. The sand fraction contains abundant mica. Internally the box cores record crude bedding, disrupted strata, abundant bioturbation, scattered pebbles, filled clay lined and oxidized burrows, as well as bivalves and gastropod remains (figures 36 and 37). Gravel is rare in the 3 cores north of 71 degrees and the mud fraction increases to 83 percent (Appendix A).

The biological composition of the outer shelf box cores, when compared to the inner shelf cores, show low species diversity and abundance. The living organisms found on the surface and within the cores include brittle stars, aneomies, crustaceans (shrimp), a variety of polychaete worms, and a few pelcypods and gastropod. The shell fraction of all cores only contains pelcypod and gastropod remains. In the upper part of cores 33 and 34 the shells are thin and fragile suggesting dissolution of calcium carbonate; where as in the bottom 30 cm pelcypods are leached and are identified by molds. Leached shells within 20 cm of the sea floor surface suggests the deposits are of considerable age.

In all cores bioturbation is abundant. Based on the apparent low abundance of infauna but the presence of intense biotubation suggest that the outer shelf is an area of low sediment input. Biological pocesses dominate over physical processes on the outer shelf.

INNER SHELF

Based on core analyses and grab samples the sediment texture of the inner shelf, at the head of the Barrow Sea Valley west of Icy Cape to Point Franklin, ranges from gravelly muddy sand to gravelly sand to sand to muddy sand to sandy mud (classification of Folk, 1974). The distribution of gravel, sand and mud components of the samples show an abundant sand fraction containing gravel and some mud throughout the inner shelf (figure

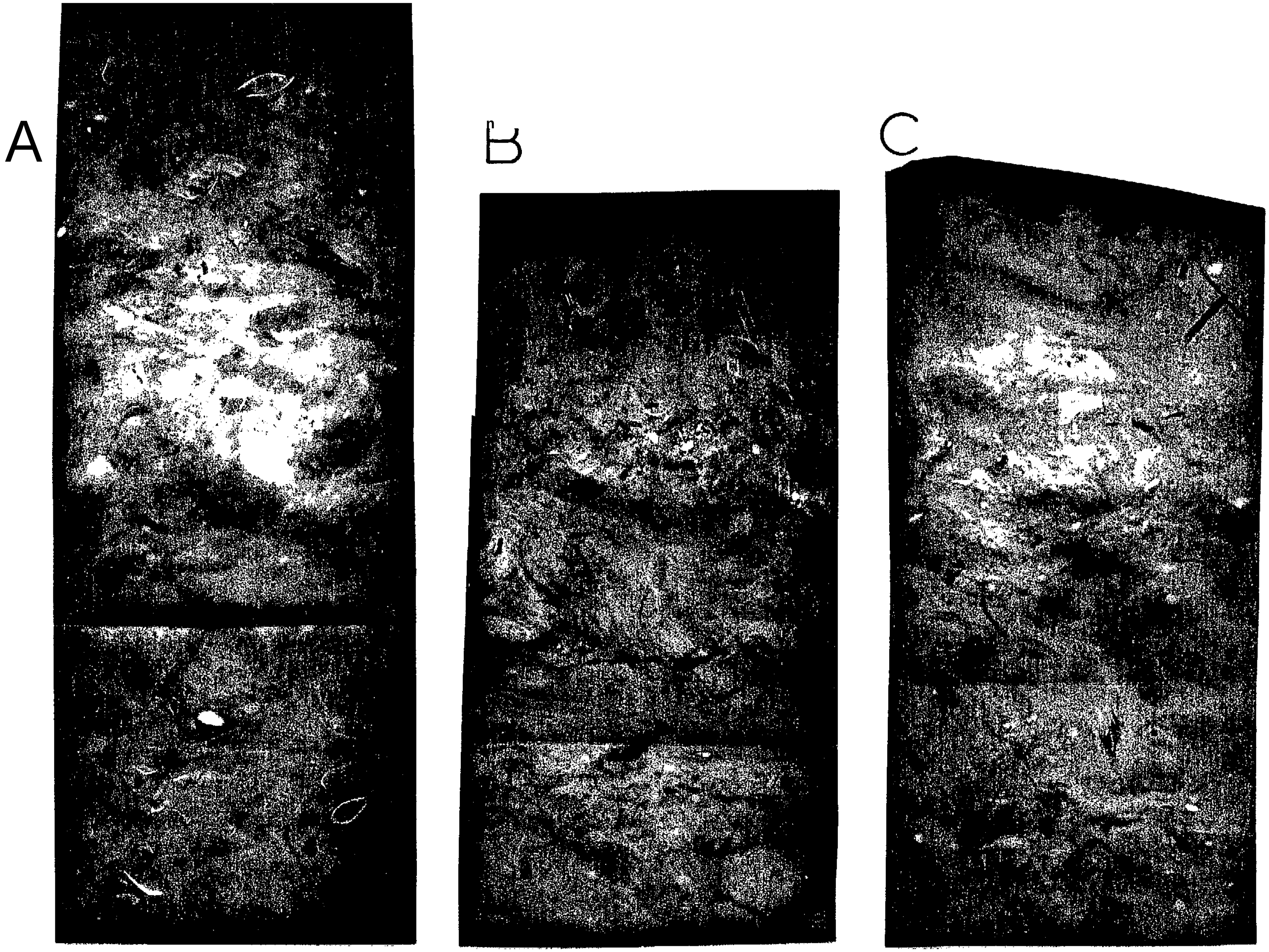


Figure 36. Radiographs of outer shelf box cores. A) Core 36 (53.5 m), B) core 16 (49.5 m), C) core 14 (44.8 m); all cores show bioturbated to disrupted strata, burrows, poorly defined bedding, shells, and scattered pebbles in sandy mud to muddy sand matrix. See figure 26 for core locations. The cores are 19 cm wide.

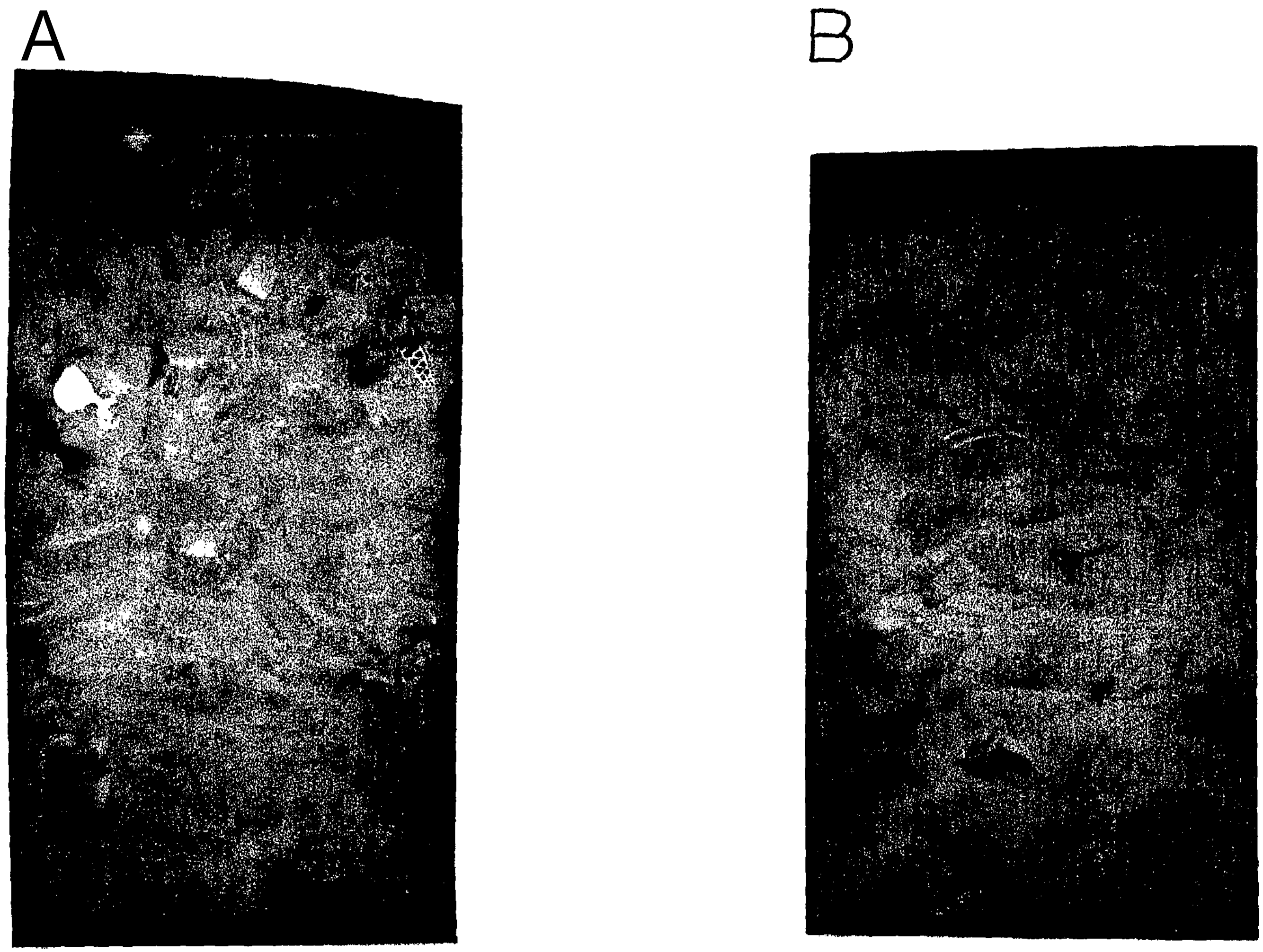


Figure 37. Radiographs of outer shelf, box cores. A) C (41.2 m); both cores consist of bioturbated and shells. See figure 26 for core locatio wide.

38, Appendix A). The highest mud content is found off Point Franklin. Sediment analyses of cores found no readily distinct sediment patterns. However, core x-rays, core "peels, and monographs do reveal distinct surficial sediment patterns. The surficial textural distribution defines extensive erosional areas as well as areas of sediment transport within a region influenced by strong shelf currents. Shelf currents and specifically the Alaska Coastal Current has an affect over a 60 km wide area of the sea floor parallel to shore. Within this area at least 4 major textural-biological facies are identified: 1) an outer sand, 2) outer gravel, 3) coastal current sand, and 4) an inner gravel (figure 39).

Outer sand facies

The outer sand facies occupies the western flank of the Barrow Sea Valley. The sea floor is flat in the southern region changing to a gently eastward slope to the north. The depths range from 42 to over 48 m. An extensive gravel field, the outer gravel facies, and overconsolidated mud in the northern part of the sea valley bounds most of the eastern flank of the outer sand facies.

From monographs and box cores, gravel patches are identified in this facies (figure 39). Gravel is present in the 4 box cores and contributes up to 15 percent of the sediment (sample 22, Appendix A). The texture ranges from slightly gravelly sand to gravelly mud. Micaceous sand is abundant in all cores.

Internally the box cores exhibit abundant bioturbation with scattered pebbles, crude pebble bedding (core 22) or shell layers (core 21) (figure 40).

The fauna of the outer sand facies is dominated by bivalves and gastropod, similar to the composition of the outer shelf fauna (figure 41, Appendix C). Barnacles, bryzoans, echinoids and worm tubes are a minor component of the biological community. The greatest numbers of barnacles occurred in the core containing the highest gravel content (core 22).

Outer gravel facies

The outer gravel facies occurs inshore from the outer sand facies. It represents a surficial gravel-shell lag deposit that is at least 165 km long. The width varies from 11 km at the south to 27 km at Its maximum width. The depths of the deposit range from 40 m west of Icy Cape to over 60 m in the north. The eastern flank of this facies southwest of Point Franklin is as shallow as 28 m. The thickness of the gravel varies and can be as thin as 4 cm where it overlies over-consolidated mud (cores 3, 4, 20, and 25) or as thick as 8 to 10 cm over gravelly" sand. Within the sea valley over-consolidated mud outcrops at the northwest part of this facies (figure 39). Based on box cores, over-consolidated mud underlies the northern gravel deposits south to near Wainwright.

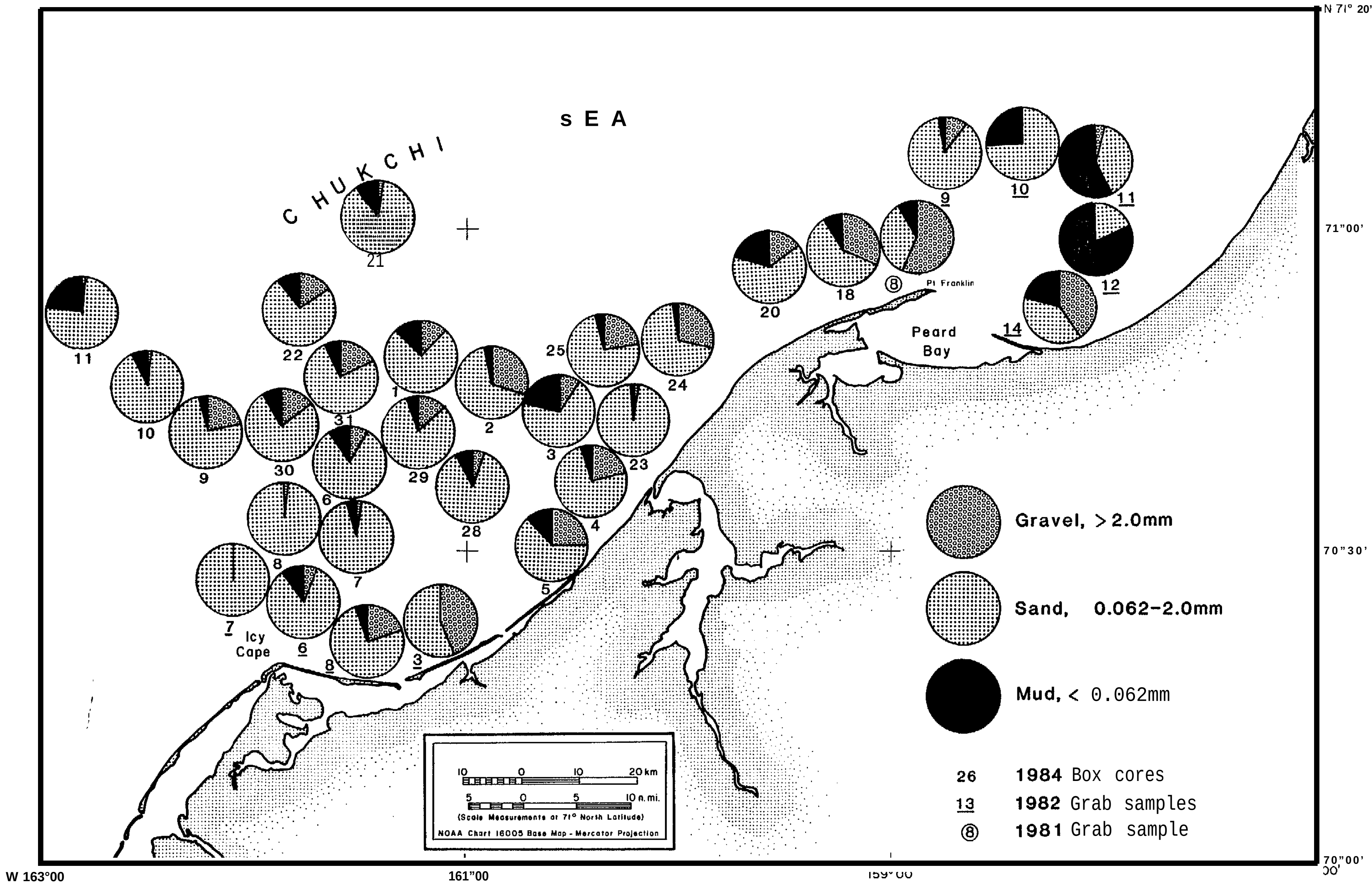


Figure 38. Sediment components from channel samples of box cores in the northeast part of the Chukchi Sea.

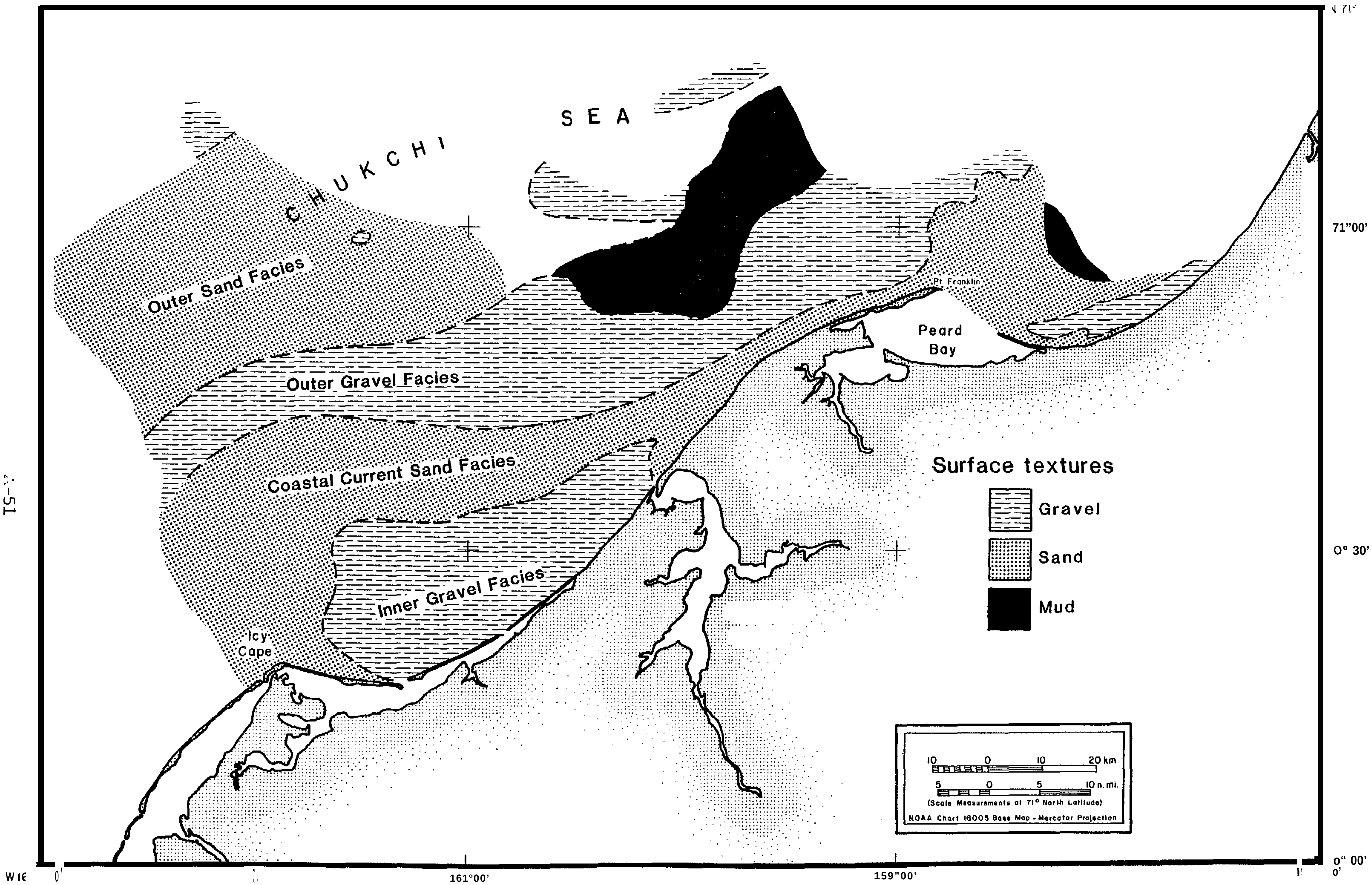


Figure 39. Major surficial sediment facies observed in the northeast part of the Chukchi Sea. The three outer facies contain distinctive fauna dominated by bivalves and gastropod in the Outer Sand; barnacles, bryzoans and brachiopods in the Outer Gravel; and echinoids in the Coastal Current Sand. The greatest faunal abundance and diversity occurs in the Outer Gravel facies.

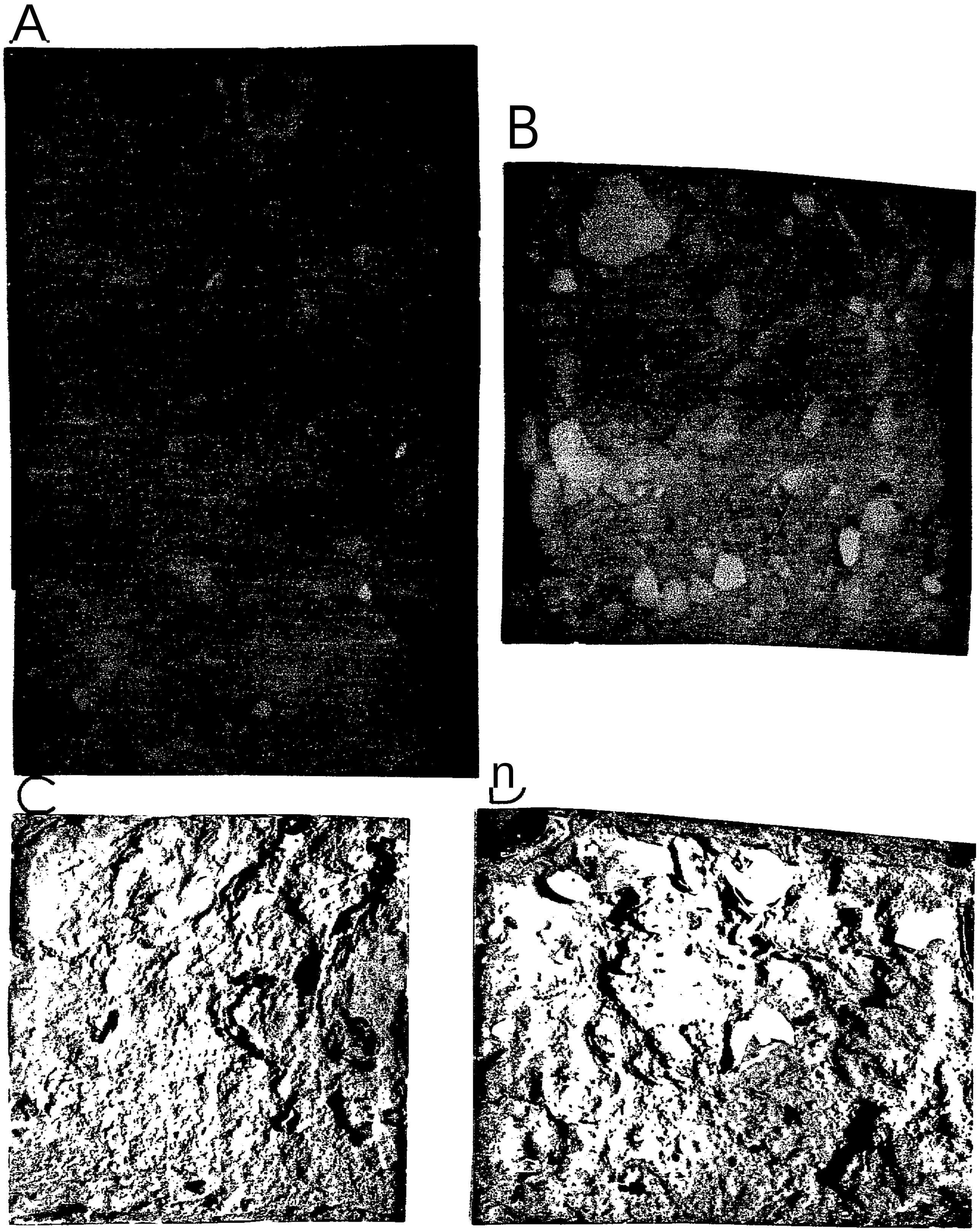


Figure 40. Outer Sand facies box cores. A) Radiograph of core 11 (42.5 m) containing scattered gravel and shells as well as abundant bioturbation; B) radiograph of core 22 (42.1 m) containing abundant gravel with crude bedding; C) photo of core 10 (42.9 m) which contains bioturbated sand with a few scattered pebbles; D) photo of core 21 (47.7 m) containing a shell lag, scattered pebbles and abundant bioturbation. See figure 38 for core locations. The cores are 19 cm wide.

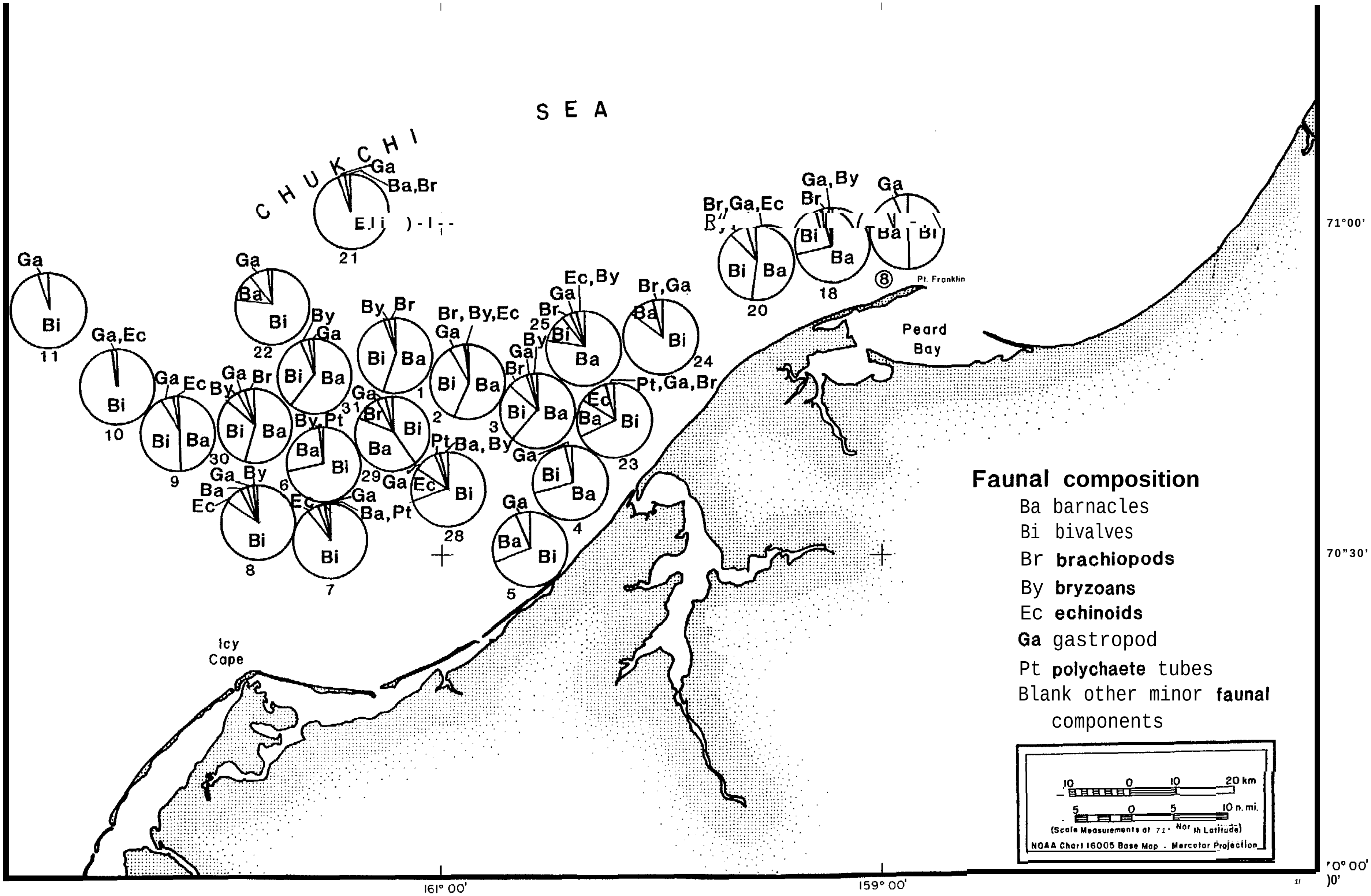


Figure 41. Faunal composition of inner shelf box cores. Includes only material from within the core and not the living fauna on the box core surface. The faunal analyses conducted on the >2.0 mm size fraction of washed samples of most of the core following the method of Wilson, 1979.

In this facies monographs record either a scattered mottled pattern or distinctive dark patches (figure 42) and box cores confirm the presence of gravel. No gravel bedforms have been identified within this facies.

The gravel content of the box cores ranges from 9.4 to 31.7 percent (Appendix A, figure 38). Of the 10 box cores taken in this facies; 7 are classified texturally as gravelly sand, 3 as gravelly muddy sand and 1 as muddy sandy gravel. Gravel is present in all cores. The gravel clasts range in size up to 24 cm, however, most clasts are less than 10 cm. The clast composition also varies and consists of igneous, sandstone, siltstone and dolomite. Red granite clasts are found in most cores. The gravel clasts vary from well-rounded to angular.

Box cores show both the sea floor surface and the distribution of the clasts, fauna, and internal bedding. The sediment surface can vary in concentrations of shells, clasts, and animals (figures 43a, 44a, 45a). Internally, however, the cores and radiographs show a gravel-shell lag, up to 10 cm thick, in the upper part of the cores (figures 43, 44, 45, 46). Gravel can also be scattered throughout the core sediment. Coarse-grained lag deposits may also be present at the base of some samples. Bedding is usually indistinct. Bioturbation, however, is abundant with preserved burrow structures.

The benthic fauna can be exceedingly rich especially towards the north. The fauna consists of; sponges, barnacles, bryzoans, brittle stars, urchins, brachiopods, sea cucumbers, hermit crabs, shrimp, isopods, and tube worms. Large polychaete worms are also present in some cores (figure 45a). The death assemblage contains in order of decreasing abundance; barnacles, bivalves, gastropod, bryzoans, brachiopods, echinoids, and chitonplates (figure 41, Appendix C). Barnacles, many stained and oxidized, are the most abundant component within the cores. Living barnacles, however, are not common within the samples. The widespread gravel substrate provides a habitat for the extensive epifauna that exists within this facies.

Coastal current sand facies

The coastal current sand facies lies to the east of the outer gravel facies. It forms a northeast trending textural band from Icy Cape to north of Point Franklin. Inshore, northeast of Icy Cape, the facies is bounded by the inner gravel facies. North of Wainwright the coastal current sand facies merges with the nearshore sand. The textural band ranges in width from 20 km to less than 4 km (figure 39). The depths vary from 40 m to less than 20 m. This facies is distint in that it contains abundant echinoids, records active northward sediment transport represented by sand wave fields, and is a major feeding ground for Gray whales.

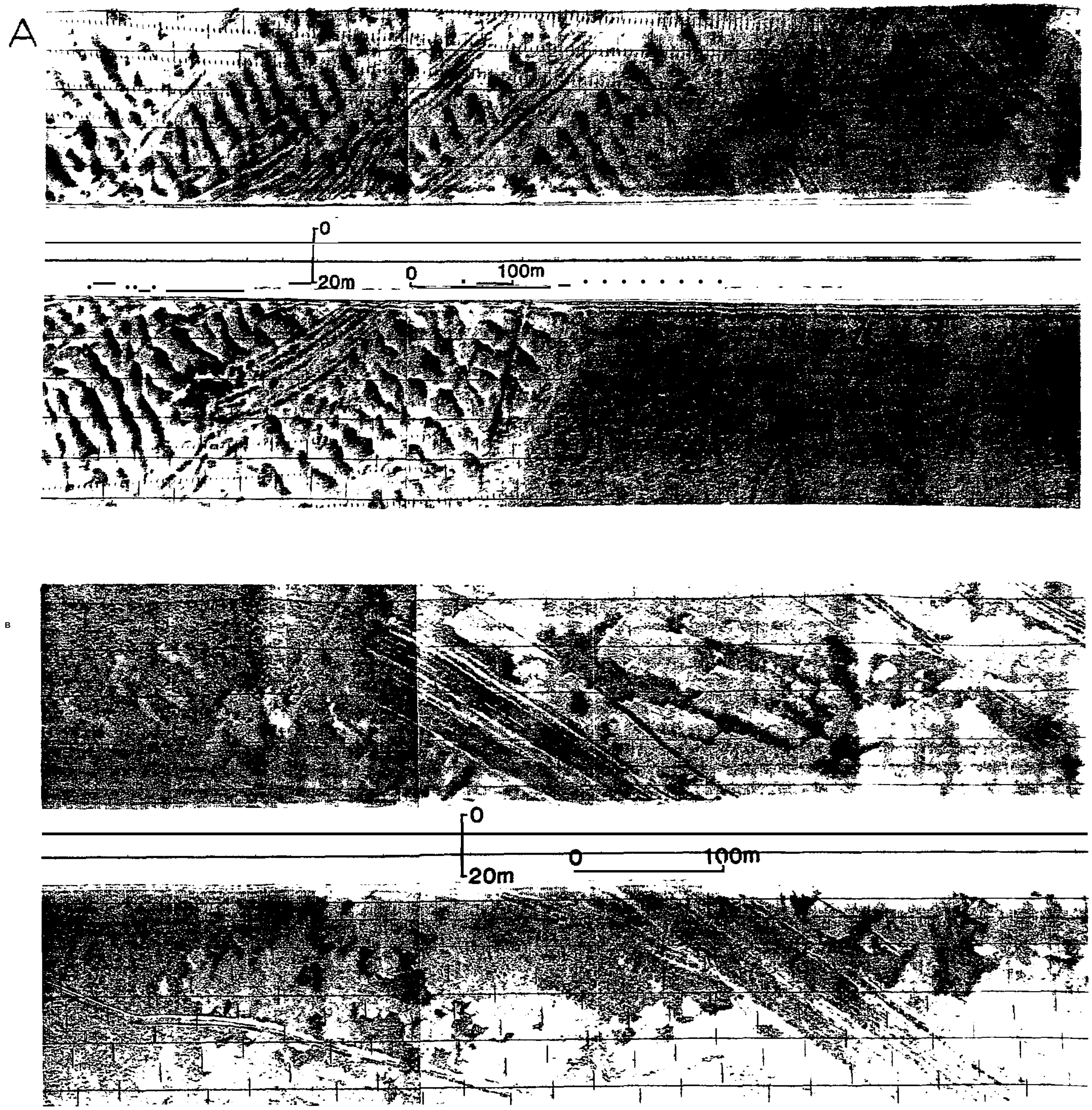


Figure 42. A) Transition between the Outer Gravel facies (right side of sonograph) and sandwaves in the Coastal Current Sand facies directly west of Wainwright. The depth is 28.5 m. B) Outer Gravel facies west of Point Franklin. The gravel sheet (left side of sonograph) changes to scattered gravel deposits locally covered by sand.

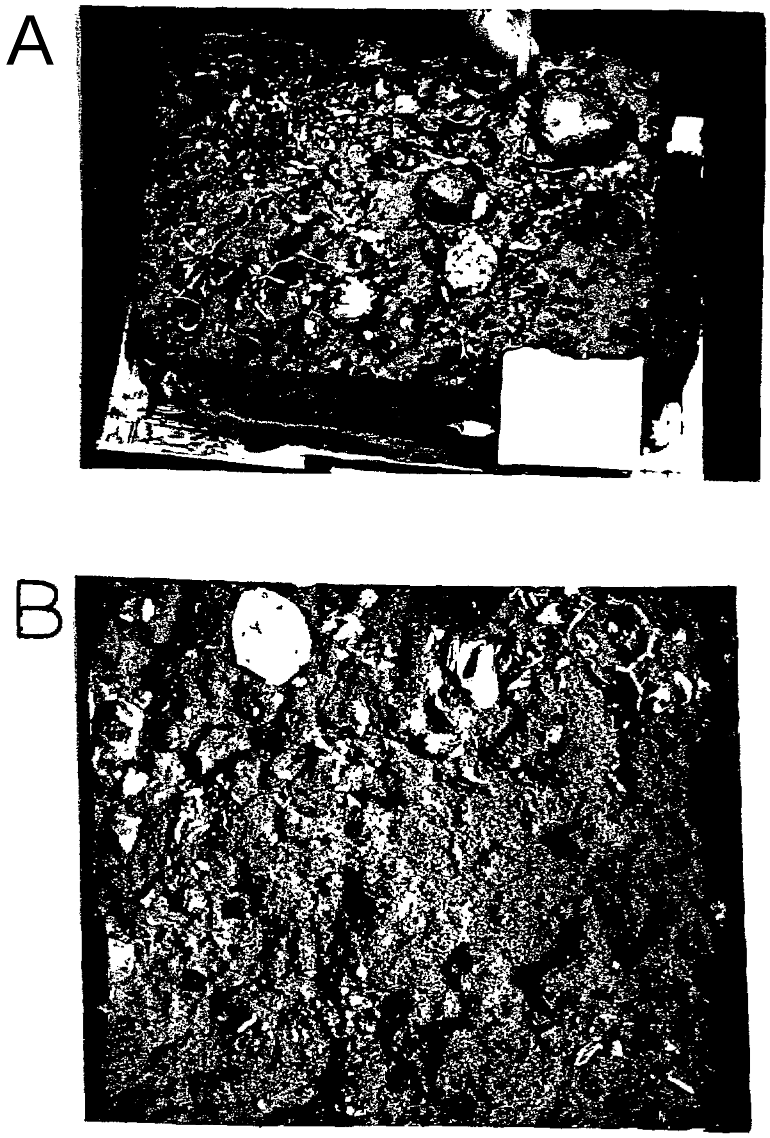


Figure 43. Outer Gravel facies box core 30 (40.2 m). A) photograph of core top which contains scattered pebbles and cobbles as well as branching bryzoans. Tunicates cover some of the cobbles here. B) Peel of core showing the upper erosional gravel-shell lag deposit and scattered gravel in the lower part of the core. The box core is 31 cm in maximum length; the peel is 19 cm wide. See figure 38 for core location.

A

B

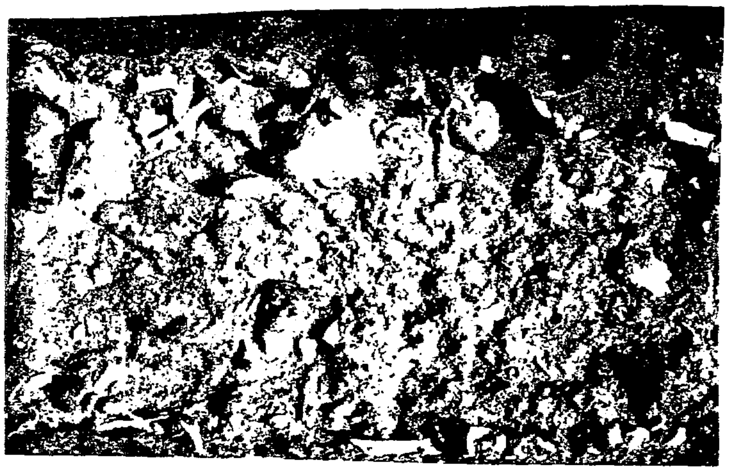


Figure 44. Outer Gravel facies box core 25 (40.2 m). A) Photograph of top of core showing the surficial gravel lag and biology. Sponges, bryzoans, urchins, and barnacles are common. B) Core peel showing the upper gravel-shell lag and bioturbated sediment. Most biogenic fragments in core are barnacles. The box core is 31 cm in length; the peel is 19 cm wide. See figure 38 for location.

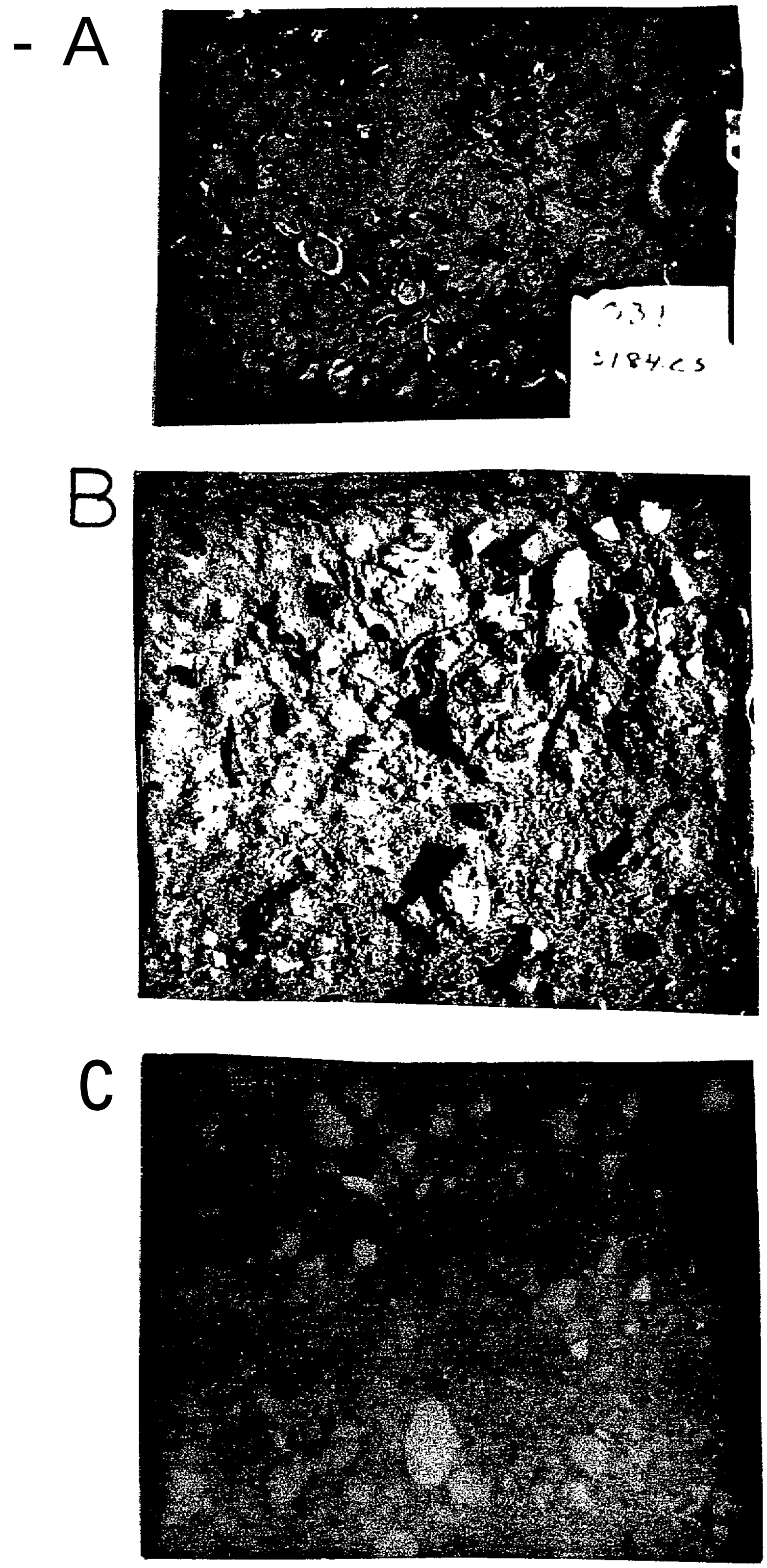


Figure 45. Outer Gravel facies box core 31 (42.0 m). A) Photograph of top of core showing the surface gravel-shell lag with a large worm on right side of core. B) Core peel showing the gravel-shell lag and bioturbated sediments. C) X-ray of core peel showing the gravel distribution and crude bedding.

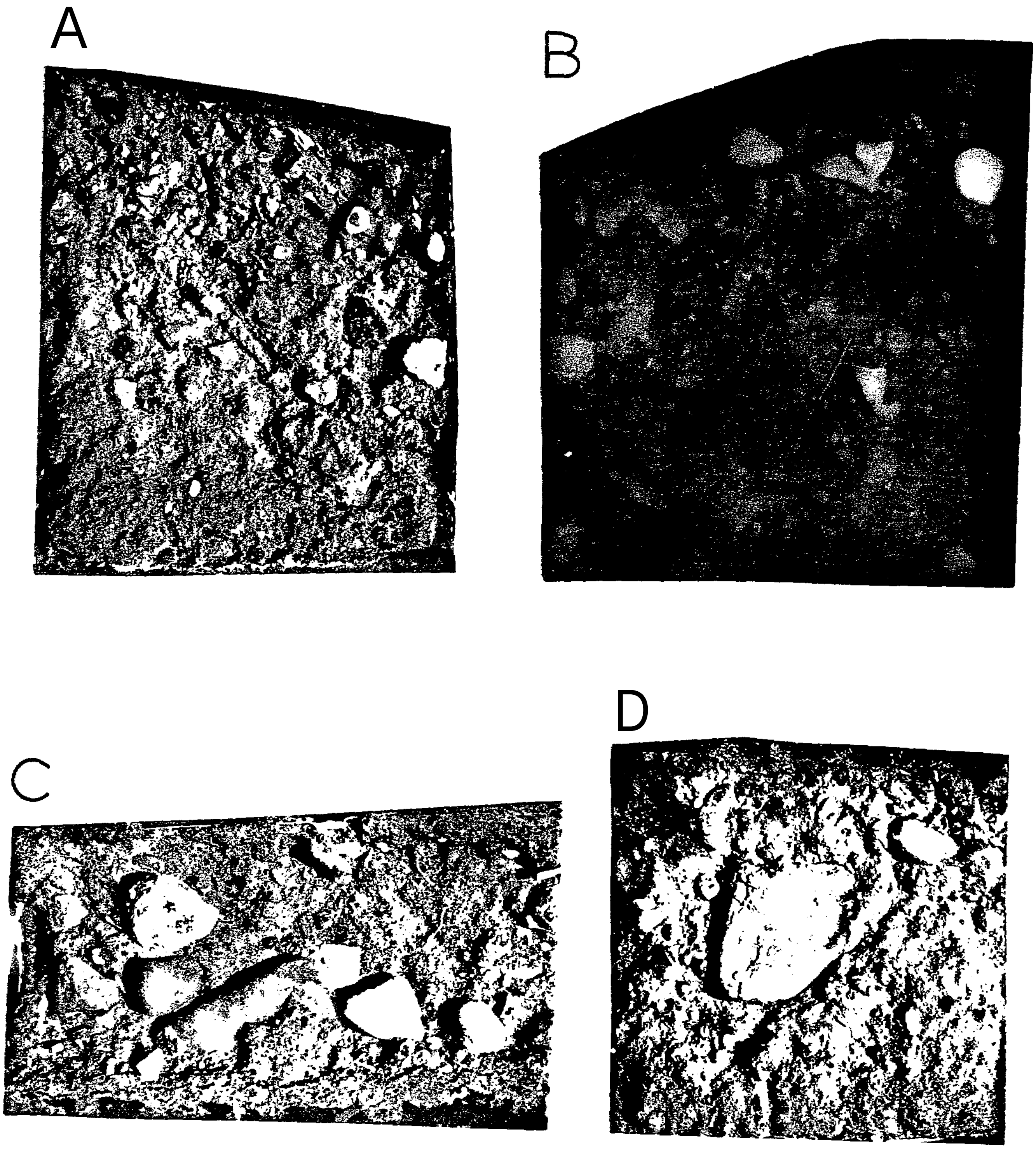


Figure 46. Outer Gravel facies. A) Core 2 (45.3 m) peel showing bioturbated sediment and upper gravel-shell lag. B) X-ray of core peel showing the surficial gravel concentration. C) Core 24 (36.6 m) peel contains scattered shells and cobbles. D) Core 1 (43.5 m) with a surficial gravel-shell lag. The cores are 19 cm wide.

The contact with the outer gravel facies can be abrupt where large-scale sand waves exist (figure 42a) or can be apparently gradational. Sandwave fields occur within this facies off Icy Cape, Wainwright, and Point Franklin (figures 47, 48). Where large bedforms are not evident on the monographs small-scale bedforms (height less than 5 cm) are expected as ripples were observed on the surface of some box cores. The large-scale bedforms are found to depths of 39 m off Icy Cape, between depths of 23 and 38 m west of Wainwright, and 18 to 30 m off Point Franklin. Most bedforms contain northward facing slip faces indicating northward bedform migration and sediment transport. The sand waves represent straight- to sinuous-crested bedforms ranging in height from 0.5 to 1.3 m (figures 47, 48).

The sand content of the box cores varies from 82 to 98 percent. The texture classification for samples in this facies ranges from slightly gravelly muddy sand, to gravelly muddy sand, to gravelly sand, to sand (figure 38, Appendix A). The high gravel content in core 29, which is located near the western boundary of the coastal current sand facies, may reflect a transition zone between the facies or may represent lateral shifting of the facies because of currents or sediment supply.

All box cores contain abundant bioturbation, scattered invertebrates, and exhibit some crude bedding (figure 49). Echinoids are abundant both on the sea floor surface, as observed on the top of cores 7 and 8, and are also abundant within the cores (figure 49d, Appendix C).

Living echinoids in this facies range in size from 2 mm up to 4 cm. The sea floor surface where box core 7 and 8 were taken contain, respectively, 103 and 110 echinoids per square meter. The echinoid is identified as Echinarachnius parma and has been reported from southwest of Icy Cape at depths of 31 m (Haidu and Sharma, 1970). Bivalves, barnacles, echinoids, gastropod, and polychaete tubes (Pectinara) form the major invertebrate members of this community.

The sea bed contains abundant pits that in places cover most of the sea floor. The pits are attributed to benthic feeding by Gray whales (Eschrichtius robustus) and will be discussed in-a following section.

Inner gravel facies

The inner gravel facies occupies the area east of the coastal current sand facies from northeast of Icy Cape to near Wainwright. The contact with the coastal current sand facies is gradational. The gravel band is over 70 km long and is up to 28 km wide. The depths range from approximately 30 m to less than 5 m nearshore. Most of the gravel is found at depths less than 25 m.

In contrast with the outer gravel facies, gravel bedforms

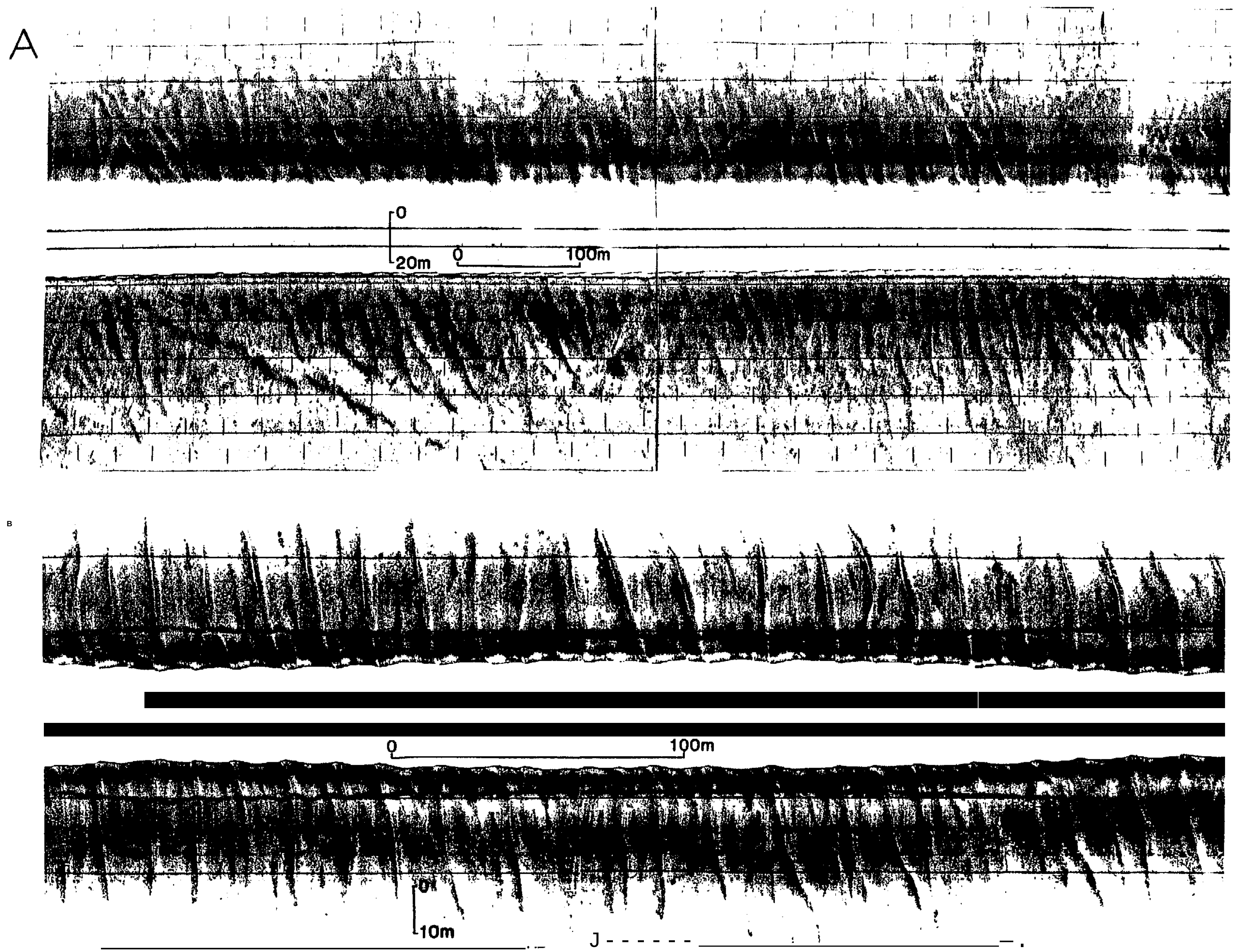


Figure 47. A) Coastal Current Sand facies containing sandwavesat 28 m depth on northwest part of Blossom Shoals off Icy Cape. The sandwaves range up to 0.9 m in height. B) Straight-crested sandwaves at 23 m depth west of Wainwright. The sandwaves range in height from 1.0 to 1.3 m and have a wave length of approximately 38 m.

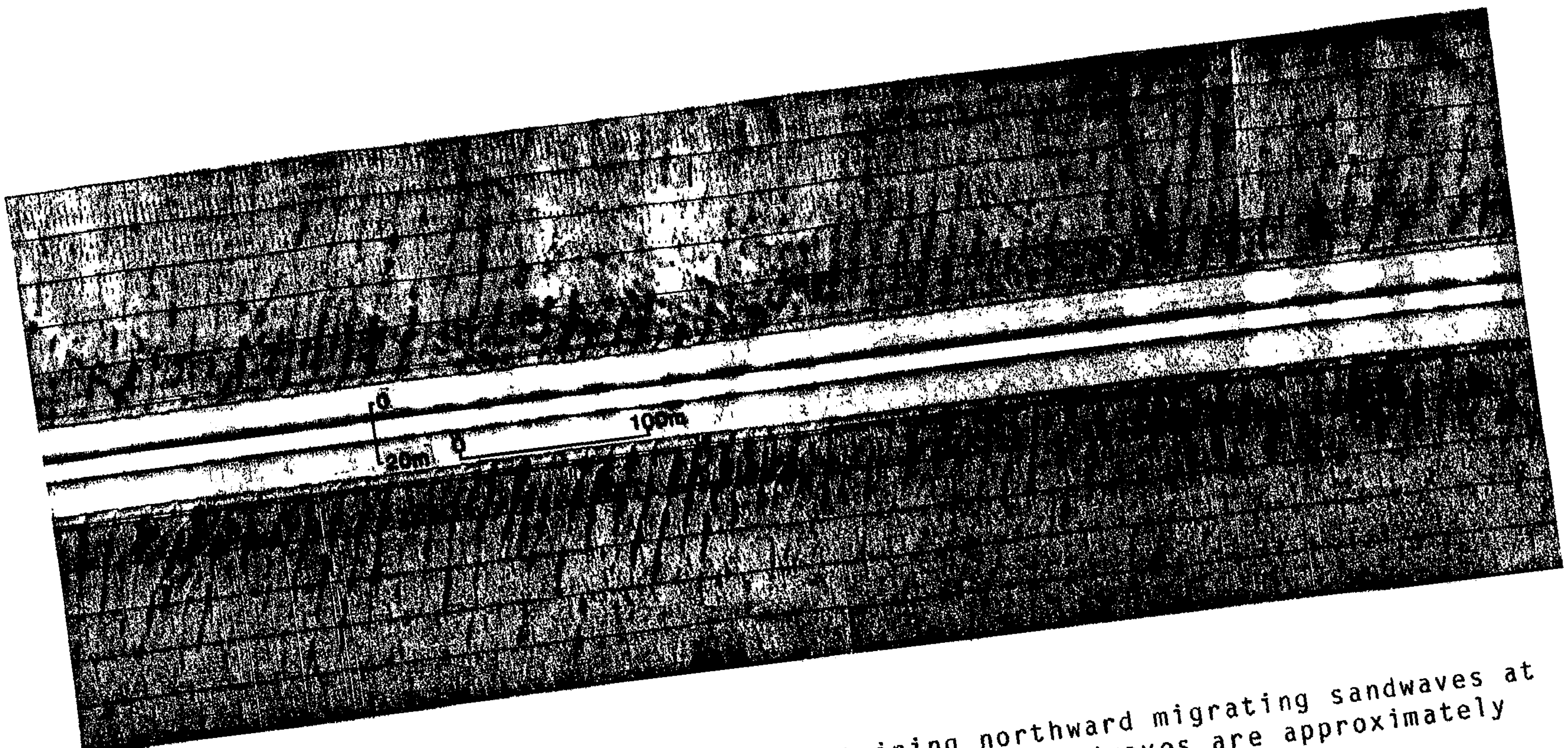


Figure 48. Coastal Current Sand facies containing northward migrating sandwaves at 28 to 30 m depth off Point Franklin. The sandwaves are approximately 0.5 m high.

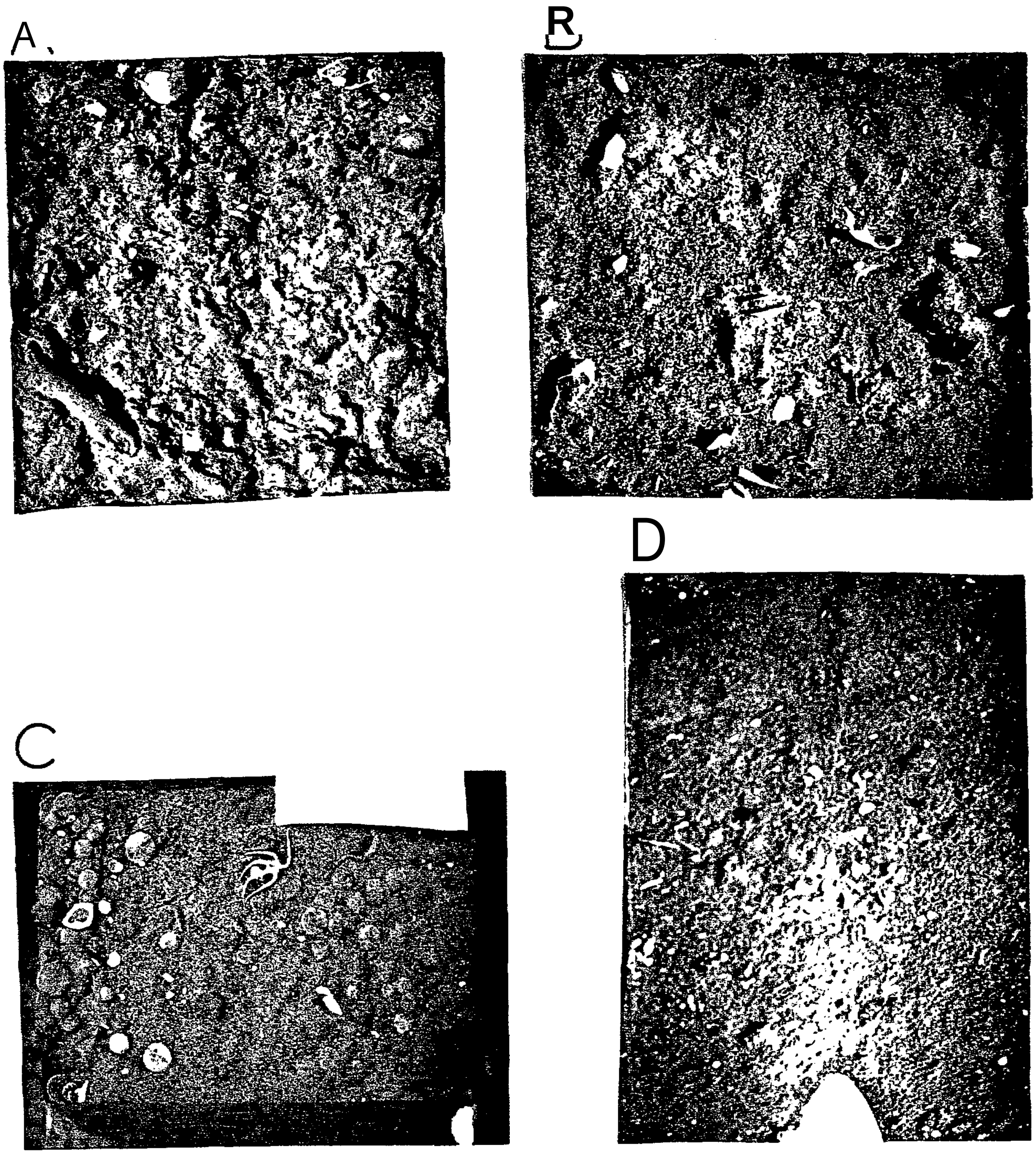


Figure 49. Coastal Current Sand facies. A) Core 29 (35.0 m) taken near the seaward boundary with the Outer Gravel facies. The peel shows a surficial gravel-shell lag overlying bioturbated sand. B) Core 7 (28.7 m) core peel contains bioturbated sand with scattered shells and echinoid fragments. C) Core 8 (24.6 m) photograph of top of core showing the distribution and abundance of echinoids. D) Peel of core 8 which contains bioturbated sand with scattered echinoid and shell fragments. The core peels are 19 cm wide; the box core is 31 cm in length.

are observed on monographs. Gravel sheets, gravel-sand patches, and shore-normal symmetrical gravel bedforms characterize the sea foor surface in this facies. Irregular shore-parallel gravel-sand patches occur offshore changing to shore-normal gravel bedforms nearshore (Phillips and Reiss, 1984).

Limited box core data record bioturbated gravel, sand and mud (figure 50). The gravel consists of rounded to angular clasts of sandstone, siltstone, coal as well as black siliceous pebbles.

The core fauna is somewhat restricted (based on limited samples) and consists of barnacles, bivalves and gastropod (Appendix C).

Discussion

The inner shelf at the head of the Barrow Sea Valley is greatly influenced by two processes; 1) the northeastward flowing Alaska Coastal Current, and 2) storm-generated currents. The distribution of the surficial sediments in this region is the result of sediment transport and on-going. erosion of the sea bed by these currents (figure 39).

The outer sand facies represents an area of thin sediment cover (less than 3 m thick), contains erosional gravel patches, with bioturbation a dominant process. Local storm-generated currents and shelf currents flowing into as well as up the Barrow Sea Valley (Garrison and Becker, 1976; Mountain and others, 1976) erode the sediment.

Within the outer gravel and coastal current sand facies the Alaska Coastal Current and shelf currents flowing into the Barrow Sea Valley erode and transport sediment to the north. The outer gravel facies represents an erosional surficial gravel-shell lag deposit produced by the northward flowing currents. It also overlies areas of thin sediment cover over bedrock and grades laterally to the northeast into apparently erosional deposits within over-consolidated mud. Evidence for erosion and currents is found in the over-consolidated mud where fields of linear, northeast-trending sediment furrows are abundant to depths of at least 80 m (figure 51a). Sediment furrows form in mud between velocities of 20 cm/sec for deep sea sediments to >40 cm/sec for shelf environments (Flood, 1984). Velocities probably with this range most <likely produced the sediment furrows in the head of the Barrow Sea Valley. This facies also records low sediment deposition with erosion apparently the major process.

The coastal current sand facies is an area of northward sediment transport. It forms the seaward part of a sediment circulation cell between Icy Cape and Wainwright. Sand bedforms cover a series of arcuate shoals off Icy Cape (Phi nip-s and Reiss, 1984). These shoals migrate seaward where ice grounding and the Alaska Coastal Current erode the banks. Fields of northward migrating large-scale bedforms then form as a result of

Figure 50. Inner Gravel facies box core 5 (18.3 m). X-ray of core peel showing bioturbated gravel.

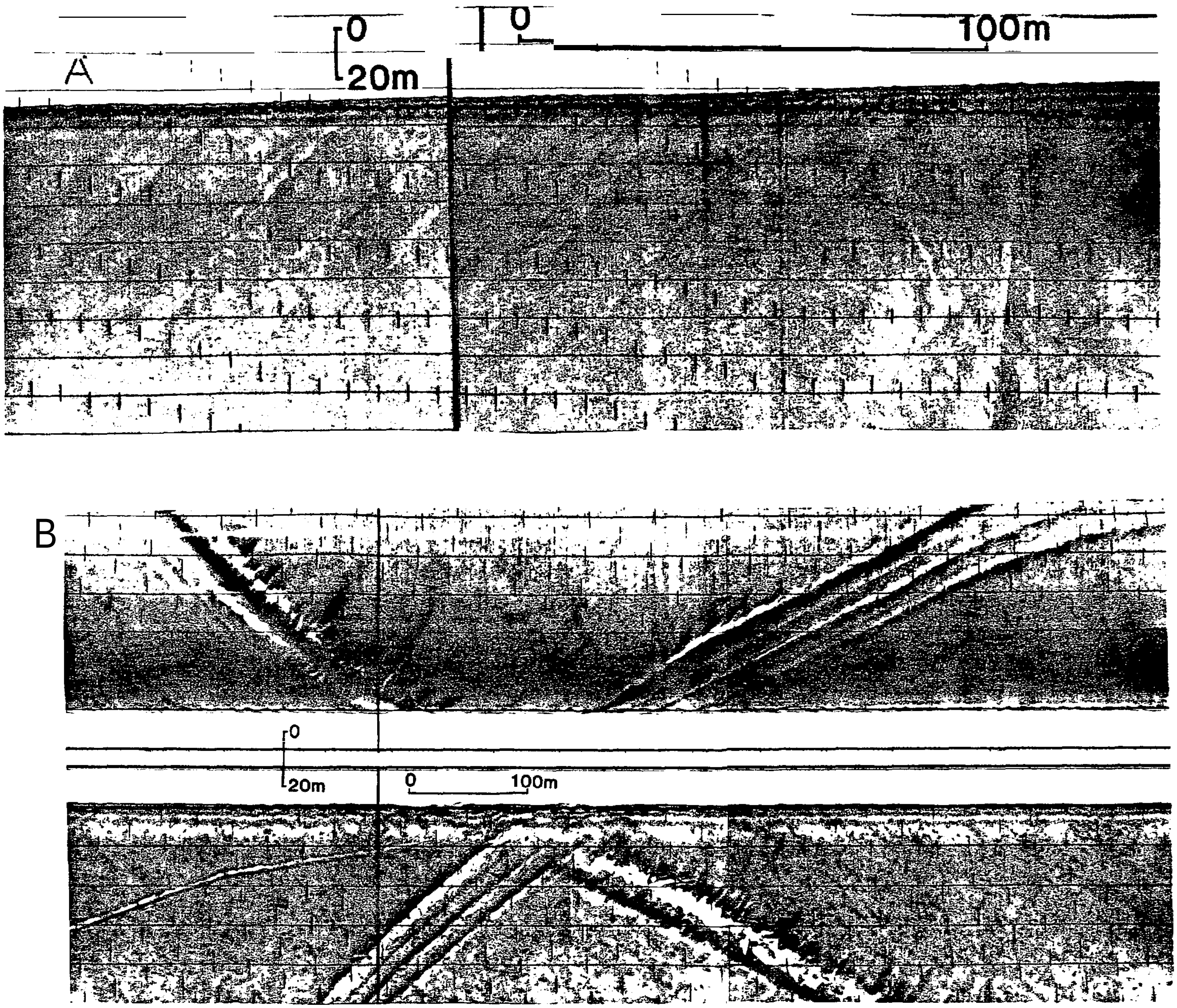


Figure 51. Inner shelf bottom current features. A) Linear furrows at depths of 69 m are erosional bed forms cut into mud. The dark streaks on the sonograph represent the base of the furrow and probably consist of gravel or shell debris. These furrows occuppy most of the region of over-consolidated mud at the north end of the Outer Gravel facies (figure 38). B) Northeast-directed sediment "streaming" from ice gouges indicate bottom current direction in regions where sandwaves are not observed on monographs.

the coastal currents eroding the shoals. As the water deepens to the north the large-scale sandwaves change to rippled sand. Where the sea floor shallows and the coastal current impinges against the coast off Wainwright and Point Franklin, large-scale sandwave fields occur again. Northward flowing currents are still evident where large-scale bedforms are not observed on monographs. Ice gouge flanks may also contain northward streaming sediment which are similar to comet marks observed on other non-gouged shelfs (figure 51b). Northward flowing currents form these features.

The inner gravel facies represents an area of erosion by storm-generated waves and currents as well as longshore sediment transport nearshore. The shore-normal symmetrical gravel waves, starting at depths of 10 to 15 m, reflect the direct effects of shoaling waves acting on the sea bed. At deeper depths both wave-generated currents as well as the northward flowing Alaska Coastal Current erode the sea bed producing the surficial gravel lags. Sediment erosion results in a thin sediment cover of 2 m or less. Nearshore, shore-parallel currents transport the finer sediment fractions towards Icy Cape.

BENTHIC MAMMAL FEEDING AREAS

Caifornia gray whales have been observed on the inner shelf for the past 3 summers in the region west of Icy Cape to north of Point Franklin. Gray whales are very abundant throughout this area as individuals and in pods, especially within the region of the Alaska Coastal Current. The gray whales feed on benthic amphiopods and isopods in the the Coastal Current Sand facies. Gray whales have been observed surfacing surrounded by sediment plumes indicating active benthic feeding. Locally scattered, rounded sea floor pits, attributed to gray whale benthic feeding, characterize parts of the sea floor in the Coastal Current Sand facies. The greatest sea floor disturbance is in the inner shelf west of Wainwright and north to Point Franklin (figure 52). Here, a variety of apparently freshly-produced and current modified feeding pits are observed (figure 53). Elliptical multiple feeding pits to wide elliptical oval pits characterize the sea bed (Type I and Type II feeding pits of Nelson and Johnson, 1984). The pits range in length from 1.0 to 3.8 m and in width from 1.0 to 2.5 m. Near Wainwright the depths where the sea floor pits have been observed vary from 23 to 34 m. A sandwave field bounds the landward flank of the feeding area.

Three box cores (cores" 23a, b, c), taken in succession where sediment plumes were observed surrounding surfacing gray whales, record coarse pebbly sand in all cores. Abundant amphipods and some isopods were found in the cores.

The feeding traces also record varying sea foor modification of ice gouges (figure 54a). Fresh gouges did not contain feeding pits whereas some gouges contained scattered feeding traces both in the gouge troughs and on internal ridges within the gouges

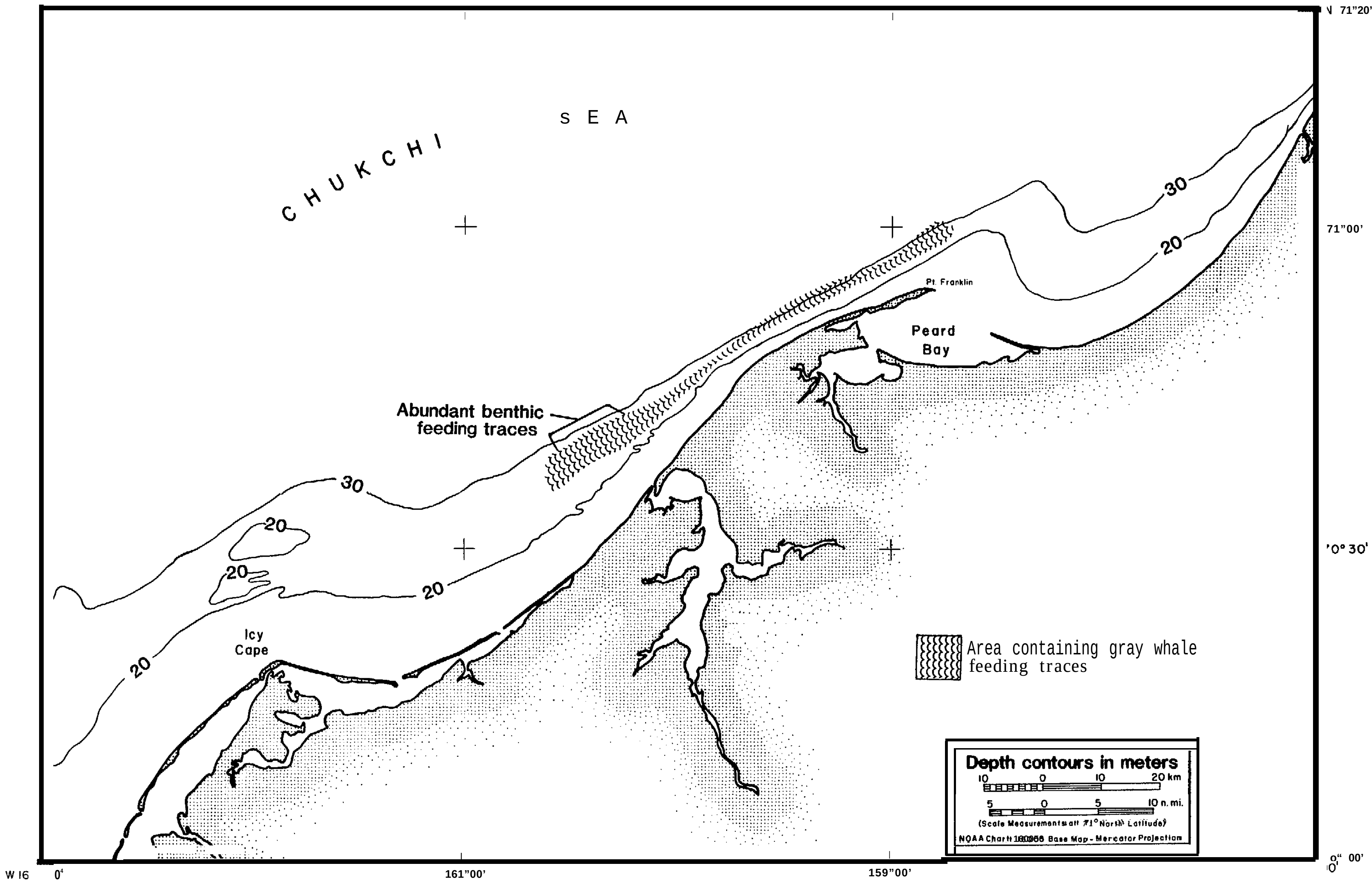
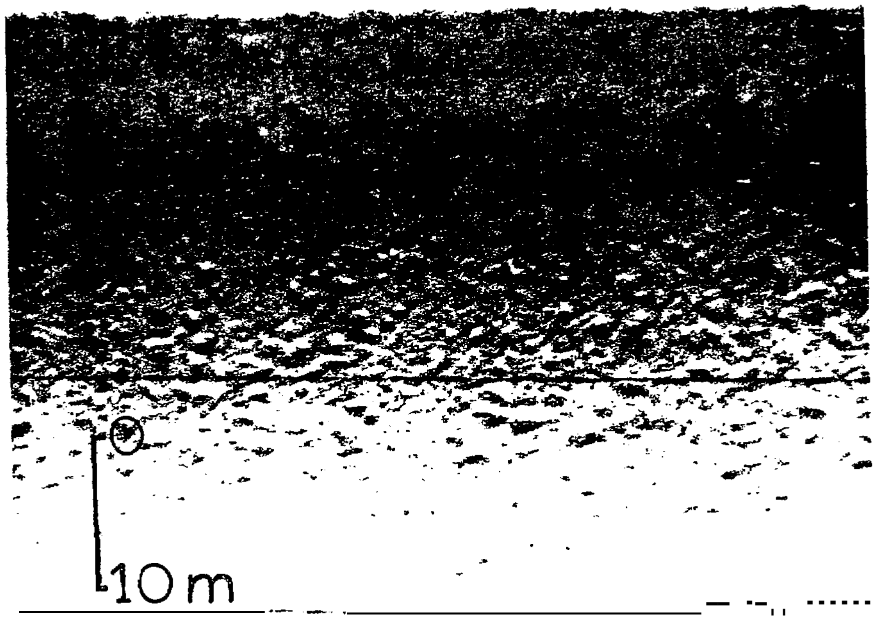


Figure 52. Major location of gray whale feed traces along the eastern boundary of the Alaska Coastal Current. The boundary limits of the feeding areas are only approximate. Scattered sea floor pits are also observed south of Icy Cape between depths of 20 to 35 m as well as east of Point Franklin. Some of the scattered feeding pits may also represent walrus feeding traces.

A



B

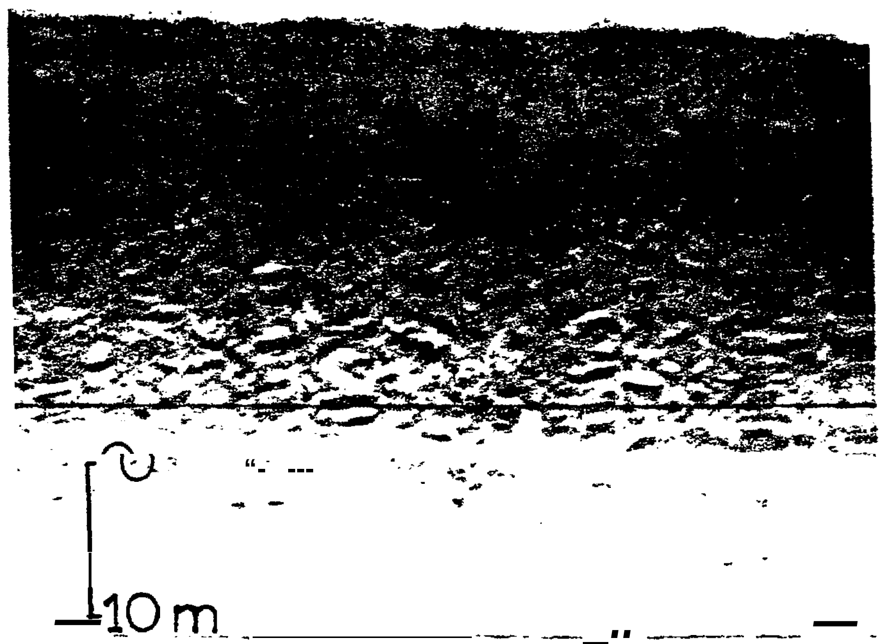
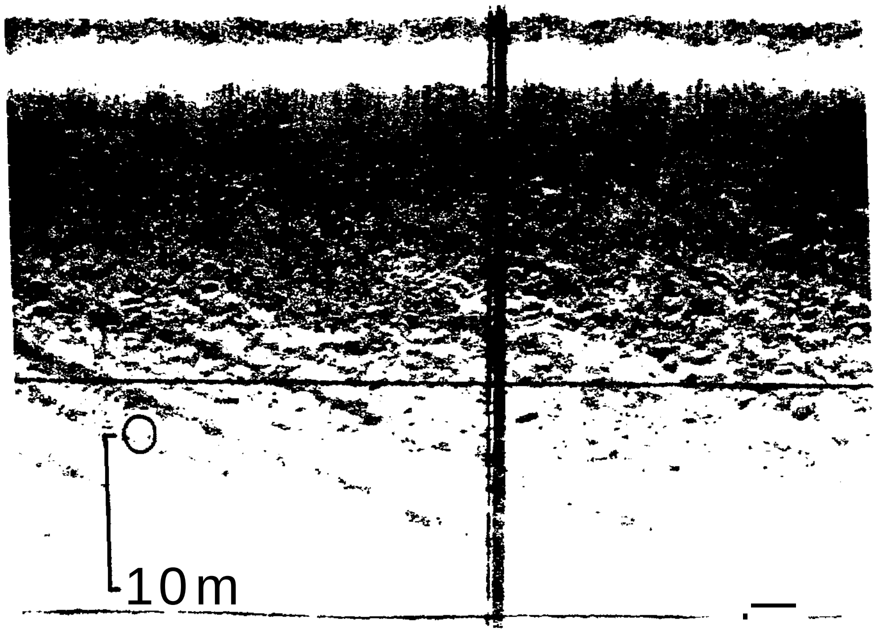


Figure 53. Gray whale feeding traces west of Wainwright, Chukchi Sea. A) Rounded and eliptical to current-modified feeding traces. B) Current-modified whale feeding traces at 24 m depth. A sandwave field bounds the feeding area (sandwaves start off right side of photo). Both monographs are 500 Khz records.

A



B

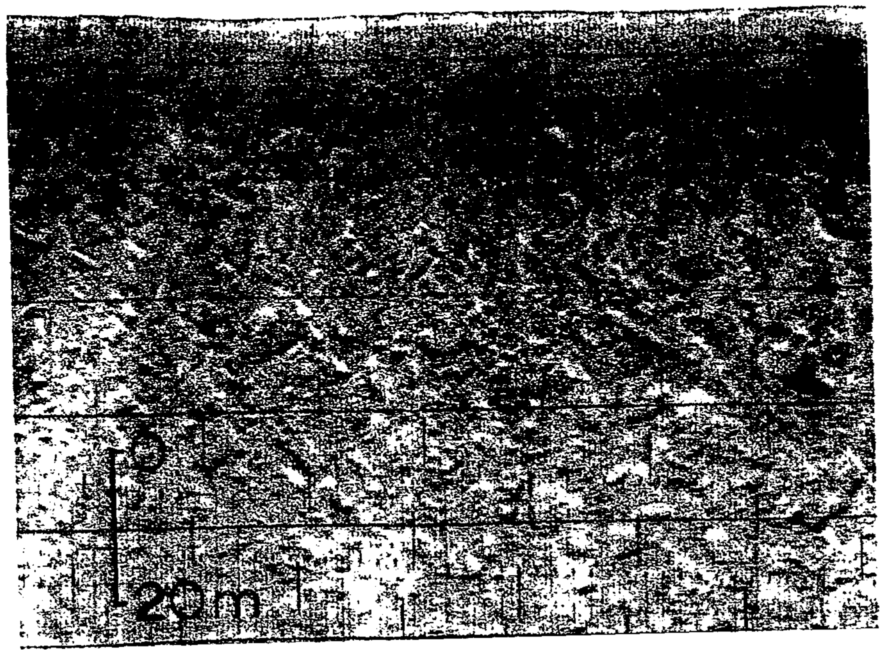


Figure 54. A) Gray whale feeding traces within an ice gouge off Wainwright. B) Round to elongate scattered feeding traces in coarse sand and pebbles west of Point Franklin. Monographs are 500 Khz (A) and 100 Khz (B) records.

while other gouges were completely pitted. This may suggest that some of the intensely pitted ice gouges are over one season old.

North of Point Franklin adjacent to a sandwave field scattered rounded pits in coarse pebbly sand are also observed in the monographs (figure 54b). These pits may represent either whale feeding traces in a coarser sediment type then found in the southern feeding area or it may represent possible walrus feeding traces. South of Icy Cape within the area dominated by the Alaska Coastal Current scattered sea floor pits are also observed (figure 55a). These pits may represent areas where gray whales are "test" feeding or they may represent an area of active bottom currents filling in the feeding pits resulting in a low density of feeding traces.

Benthic feeding traces of unknown origin are also observed as scattered patches on the outer shelf (figure 55b). These feeding traces are represented by linear to curved pits and they occur adjacent to gravel patches on the sea bed. These feeding traces may be produced by walrus.

Walrus feeding traces are found in the northeast Chukchi Sea to depths of at least 53 m. Long narrow linear furrows, gently curved furrows, or S-shaped to irregular sea bed furrows characterize the feeding traces. The sea floor furrows are less than 1 m wide and range in length from 10 m to 40 m. The furrows can be solitary features or they may be found as groups of linear parallel traces. The feeding traces generally parallel the Alaska Coastal Current suggesting the walrus use the currents during feeding. The greatest concentration of these feeding traces were preserved within the Outer Gravel Facies.

The reconnaissance surveys on the Chukchi Sea show that gray whale and walrus feeding areas do exist on and adjacent to the region bounded by the Alaska Coastal Current. Other feeding areas can be expected on the outer shelf and on the west side of the Barrow Sea Valley adjacent to Hanna Shoal. The areal distribution of the feeding areas as well as the total sea floor ulitilized by mammals in feeding in the northern Chukchi Sea is unknown.

ICE GOUGING

Sea it-s plays an active role in the reworking and transport of sediments on the Chukchi Sea shelf. The seasonal ice canopy can be divided into three distinct zones. Along the coast and extending from promontory to promontory is the quasi-stable, often uniform ice of the fast ice zone. Immediately seaward of this zone, pressure and shear ridges develop in response to the interaction between the stationary fast ice and moving ice further offshore. The ice ridges in this zone are often grounded. Further offshore pack ice and ice ridges are essentially free to drift guided by winds and currents. Unequal pressures within the yearly ice pack gives rise to numerous

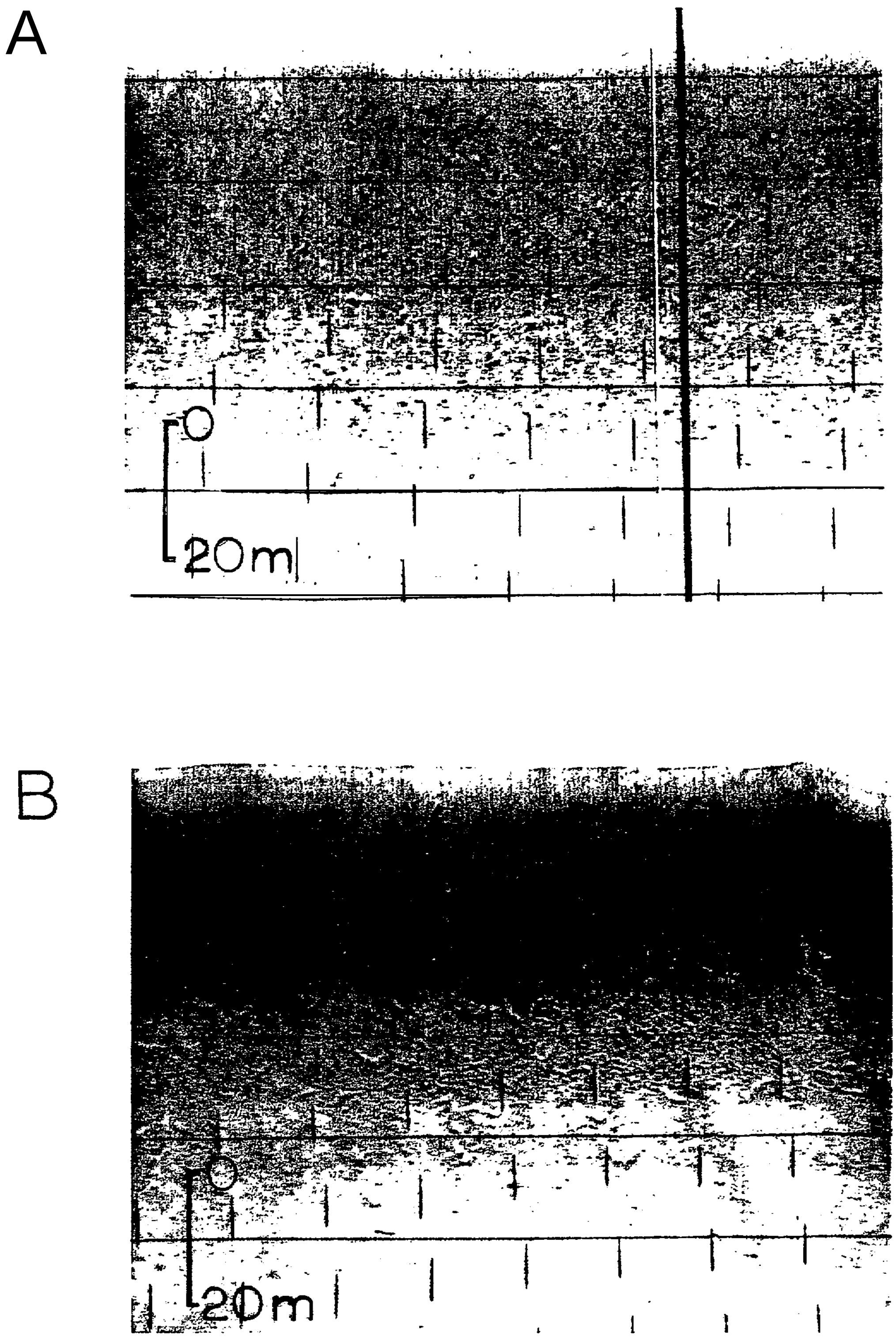


Figure 55. A) Scattered feeding traces within an area dominated by the Alaska Coastal Current south of Icy Cape.
B) Outer shelf feeding traces of unknown origin (possibly walrus) at depth of 48 m. This type of feeding trace commonly occurs adjacent to gravel patches. Monographs are 100 Khz records.

pressure ridges of varying heights. Ice keels extend to varying depths beneath the shear and pressure ridges in the ice canopy. Ice keels to 50 m have been observed from limited data sets in the Arctic Basin to the north and even deeper keels have been statistically predicted. When keels of sufficient draft to ground are incorporated in a moving ice canopy the sea floor sediment is disrupted and bulldozed forming linear plow marks or gouges.

TERMINOLOGY

An ice gouge is defined as a single sea floor groove or plow mark generated by one protrusion of an ice keel. A single ice keel having more than one protrusion may create many parallel gouges. This results in a multiplet or set of closely spaced gouges generated by the same ice keel. Gouge depth is the measured depth of a gouge below the surrounding sea floor. This measurement does not necessarily indicate the depth of ice incision as sediment may have infilled the gouge since its inception. Ridges usually flank one or both sides of a gouge and represent the plowed debris from the gouge event. Gouge relief refers to the vertical distance from the floor of the gouge to the crest of the ridge. The gouge orientation refers to the trend of linear gouges and, as used here, is the dominant trend within our observational segment on the sonograph. Orientation trends of gouge lineations do not necessarily imply the direction of motion of ice which created the gouge.

RESULTS

A summary of ice gouge trends in the Chukchi Sea record a dominant northeast-southwest orientation (figure 56). Tomi 1 (1978) also notes local dominant ice gouge trends that parallel the bathymetric contours which agrees with our data. The ice gouge trends in the Chukchi Sea apparently reflect the effects of shelf currents, storms and pack ice movement. The northwest-southeast ice gouge trend (C, figure 56) may reflect ice movement by shelf currents as a southeast-directed current is reported for area "C" (figure 8) (Coachman and others, 1975). Likewise, the shore-parallel ice gouge trends along the eastern part of the Chukchi Sea reflect ice movements by the Alaska Coastal Current. Ice generally moves 45 degrees to the right of the wind (Thorndike and Colony, 1982). The winds in the Chukchi Sea region are from the northeast with summer storms generally from the southwest or west which, should move ice to the northwest and to the east respectively. The summer storms may account for the onshore trends of gouges off Cape Lisburne (G, figure 56) and on the east side of the Barrow Sea Valley (H, figure 56). However, the dominant northeast-southwest ice gouge trend on the Chukchi Sea shelf must reflect the pack ice movement to the south during the fall as well as the effects of shore parallel shelf currents. Whereas, the dominant pack ice movement to the west and northwest (Springer, 1978, 1982) apparently does not readily affect the sea floor on the outer shelf.

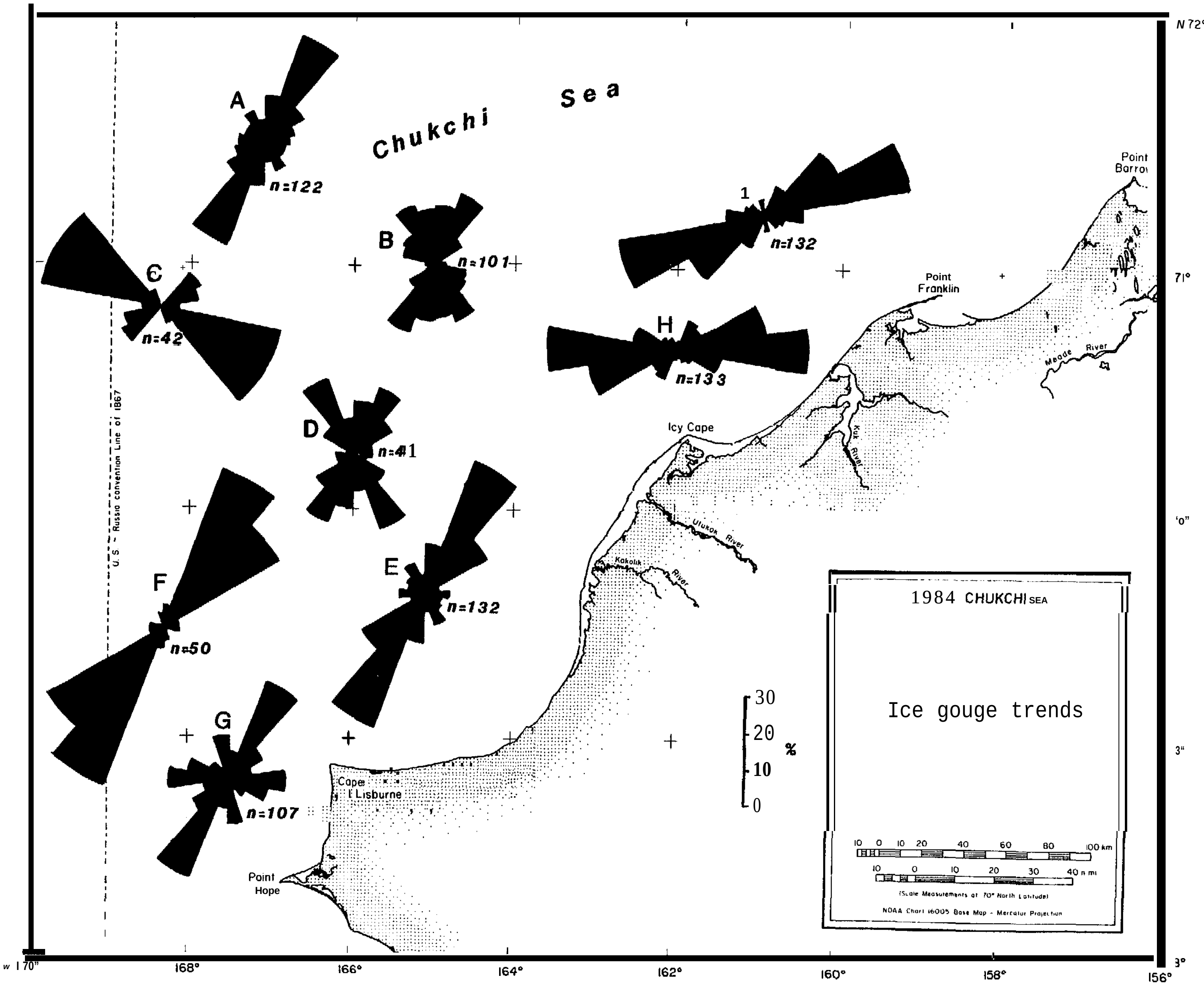


Figure 56. Rose diagram of ice gouge orientations in the northeast Chukchi Sea. H) Ice gouge trends on the east side of the Barrow Sea Valley. I) Ice gouge trends on the west side of the Barrow Sea Valley.

On the outer shelf (northwest part) of the Chukchi Sea the maximum ice gouge incision depth is 1.3 m (table 1). Most of the ice gouges are shallow, 0.3 m of less in depth below the sea floor. The "shallow" gouges may represent "older" gouge events that are now being filled with sediment or they may also reflect the thin sediment cover over bedrock (ice is not cutting into bedrock).

The maximum ice gouge density for lines 25, 26, 27, and 44 (figure 3) are 5 gouges per km with these values only found on gravel-covered bathymetric highs. The adjacent low regions average 1 gouge per km on line 44, 1 gouge per 3 km on line 27, 1 gouge per 4 km on line 26, whereas, line 45 varies from 1 gouge per 3 km to 1 gouge per 7 km. The ice gouge abundance rapidly decreases with increasing depth (table 1).

On the inner shelf (northeast part of the Chukchi Sea) within and adjacent to the Barrow Sea Valley ice gouging is identified to 58 m depth. The maximum ice gouge incision depth, 2.9 m with 3.9 m ice gouge relief, occurs on line 23 (figure 4) at the head of the Barrow Sea Valley. The water depth is 45 m where the maximum ice gouge incision is located. Multiple, parallel ice gouges formed by large ice sheets or ridges account for the abundance of shallow, 0.3 m depth or less, bottom disturbances in shallow water areas (24 to 34 m water depth) (table 2). The ice gouges at deeper depths tend to represent solitary grounding events, especially within the deeper parts of the sea valley.

The maximum ice gouge density within the Barrow Sea Valley ranges from 19 gouges per km at 44 to 46 m depth (line 24, outer sand facies) on the east flank of the sea valley, to 24 gouges per km at 28 m depth (line 17, inner sand facies) directly west of Point Franklin. Low ice gouge densities, 1 gouge in 10 km (35 m depth) to 1 gouge per km (24 to 29 m depth) are recorded on the shoreward part of the outer gravel facies and in the coastal current sand facies respectively. These low gouge densities are apparently the result of active currents filling in the gouge traces within these two facies as at deeper depths and at shallow depths ice gouging ranges from 14 per km to 12 per km respectively.

In the-southern part of the Chukchi Sea, north of Cape Lisburne (line 4), ice gouge incision depths are also shallow with most gouges 0.3 m or less. The gouge densities are greatest on the shoreward regions ranging up to 6 gouges per km between 24 to 28 m depth.

DISCUSSION

Although ice gouging is pervasive on the Chukchi shelf, but away from topographic highs and the nearshore slopes, gouging is

Water depth (m) \ Ice gouge depth (m)	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1.0	1.0–1.1	1.1–1.2	1.2–1.3	1.3–1.4
50–52	5	4		1								
48–50	10	23	1	1			2		1		1	
46–48	39	36			2	2						
44–46	29	102	1	2		1	1					1
42–44	20	132		1								
40–42	15	65		6			1			1		
38–40	32	196	43	1	3		1		1			1

Table 1. Maximum ice gouge incision depth verses water depth for the northwest Chukchi Sea. Numbers in boxes represent number of gouges in class. Data from line 25, 26, 27, 44, 45 and 46 (see figure 3 for track line locations). Most of the ice gouge incisions are shallow, 0.3 m of less below the sea floor, however, the shallow gouges may represent “older” gouges that are filling with sediment. The ice gouge abundance also decreases with increasing depth with most of the gouges found between 38 to 44 m on gravel covered bathymetric highs.

Water depth (m) \ Ice gouge depth (m)	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1.0	1.0–1.1	1.1–1.2	1.2–1.3	1.3–1.4	1.4–1.5	1.5–1.6	1.6–1.7	1.7–1.8	1.8–1.9	1.9–2.0
58–60	5																
56–58	11	1															2
54–56	26	1															1
52–54	35	3															
50–52	52	1							1								
48–50	30																
46–48	77	2	4	1	1												
44–46	113	1	1	2	1	2	1	1								2	
42–44	6	2															
40–42	39		1														
38–40	118	2	3														
36–38	49																
34–36	68	1			1	1											
32–34	199	4	1	2	1												
30–32	74																
28–30	299	1			1	1		1									
26–28	203	2	2	3	2	3	1	1	1								
24–26	236	4	3	3		1	1	2	1						1		

One ice gouge to 2.9 m depth.

Table 2. Maximum ice gouge incision depths verses water depth for the Barrow Sea Valley region. Numbers in boxes represent number of gouges in class. Data obtained from tracklines in figure 4. The maximum ice gouge incision depth is 2.9 m at 45 m water depth near the center of the Barrow Sea Valley. Most of the ice gouges are shallow, 0.3 m or less in depth below the sea floor. Multiple ice gouge incisions are common to 32-34 m water depth; at deeper depths the ice gouges are usually solitary events.

rare and gouge depths are shallow. Furthermore, in the deep water areas gouge relief is commonly subdued indicating that waves, currents and biological activity are perhaps the dominant surface reworking processes, since gouging is less frequent.

The highest gouge intensities (most numerous and deepest) are found on the east facing slopes of bathymetric highs and along the steeper slopes of the coastal margin. The bathymetric highs and inshore areas comprise a relatively small portion of the shelf area yet are subject to higher gouge intensities. Gouging occurs here because a greater number of ice keels exist with shallower draft which Interact with the shallow sea floor. The broad flat areas, depths of 40 to 50 m, provide the rarer deep draft ice a large surface to gouge.

Over the broad and generally flat regions of the study area gouging increases northward. This is because of the incursion of ice ridges and ice island fragments from the Arctic Basin to the north and to the greater period of ice cover. Conversely longer periods of open water in the southern parts of the study area allow greater sediment reworking by storm waves and currents. Additionally the shoals and broad expanse of the northern shelf filter out southward moving ice of sufficient draft to gouge the sea floor. This implies that much of the gouging in the study area may be the result of locally generated ice ridges. From studies in the Beaufort Sea we know that gouges from locally generated ice ridges are shallow due to the general incompetence of newly created ridges and their keels.

Ice gouging is a process that is constantly reworking the surface sediment of the Chukchi Sea shelf. However, currents, waves, and biological processes are also active in reworking the this surficial sediment layer at a higher rate in the deeper and southern portion of the study area masking the effects of gouging. Inshore of about 30 m water depth and on the flanks and the crests of bathymetric highs ice gouging dominates the surficial sediment processes except in areas where the Alaska Coastal Current actively impinges on the sea floor.

CONCLUSIONS

1) A thin sediment cover, less than 4 to 5 m thick, overlies folded bedrock over much of the Chukchi Sea shelf.

2) Channel-fill deposits of unknown age occur in the northwest part of the Chukchi shelf. These channel deposits may represent possible hazard if they contain gas or permafrost. They may also represent a potential source of sand and gravel on the outer shelf.

3) The outer shelf surface sediment is composed of micaceous sandy mud with scattered surficial gravel on bathymetric highs.

4) The surface sediment in the southern part of the Barrow Sea Valley can be divided into 4 facies, an outer sand, an outer gravel, a coastal current sand, and an inner gravel. Distinctive benthic biological communities inhabit these facies.

5) Storm-generated currents, shelf currents, and biological processes dominate on the outer shelf; storm-generated currents, the shore-parallel Alaska Coastal Current, and biological processes rework the eastern shelf regions.

6) Sand waves, gravel waves, gravel ribbons, extensive gravel sheet deposits, and linear erosional furrows are the common bedforms on the Chukchi shelf that indicate active bottom currents.

7) Gray whale feeding areas are identified within the coastal current sand facies off Wainwright; walrus feeding traces are identified in the outer gravel facies as well as on the outer shelf.

8) Ice gouging, to 58 m water depth, occurs throughout the Chukchi shelf, however, most of the gouges are shallow, less than 0.3 m in depth below the sea floor, and scattered. High ice gouge densities are identified on the northern shelf areas investigated and on the flanks of the Barrow Sea Valley.

REFERENCES

Barnes, P. W., 1970, Preliminary results of geologic studies in the eastern central Chukchi Sea, U. S. Coast Guard oceanographic rept., no. 50,, p87-110.

Bird, K. J., and Andrews, J., 1979, Subsurface studies of the Nanushuk Group, North Slope, Alaska, in Ahlbrandt, T. S., cd., Preliminary geologic, petrologic, and paleontologic results of the study of Nanushuk Group rocks north slope, Alaska, U. S. Geol. Survey circular 794, p. 32-41.

Coachman, L. K., Aagaard, K., and Tripp, R. B., 1975, Bering Strait- -the regional physical oceanography, Univ. Wash. Press, Seattle, 172 p.

Creager, J. S., and McManus, D. A., 1966, Geology of the Chukchi Sea, in Wilimovsky, N. J., and Wolf, J. N., eds., Environments of the Cape Thompson region, Alaska, U. S. Atomic Energy Commission, Div. of Technical Information, p* 755-786.

Creager, J. S., and McManus, D. A., 1967, Geology of the floor of the Bering and Chukchi Seas--American studies, in Hopkins, D. M., cd., The Bering land bridge: Stanford Univ. Press, Stanford, Calif., p. 7-31.

Flemming, R. H., and Heggarty, D., 1966, Oceanography of the southeastern Chukchi Sea, in Wilimovsky, N. J., and Wolf, J. N., eds. , Environment of the Cape Tompson region, Alaska, U. S. Atomic Energy Commission, Div. of Technical Information, p. 697-754.

Flood, R. D., 1984, Classification of sedimentary furrows and a model for furrow initiation and evolution, Geol. Sot. of America Bull., v. 94, p. 630-639.

Folk, R. L., 1974, Petrology of sedimentary rocks, Hemphill Publishing Co., Austin, Texas, 182 p.

Garrison, G. R., and Becker, P., 1976, The Barrow submarine canyon: a drain for the Chukchi Sea, Jour. of Geophysical Res., v. 81, p. 4445-4453.

Grantz, A., Dinter, D. A., Hill, E. R., Hunter, R. E.,May,S. D., McMullin, R. H., and Phillips, R. L., 1982,Geologic framework, hydrocarbon potential, and environmental conditions for exploration and development of proposed oil and gas lease sale 85 in the central and northern Chukchi Sea, U. S. Geol. Survey Open-file rept. 82-1053, 84 p.

Hill, E. R., Grantz, A., May, S. D., and Smith, M., 1984, Bathymetric map of the Chukchi Sea, Miscellaneous investigation series map I-1182-D.

Hufford, G. L., 1977, Northeast Chukchi Sea coastal currents, Geophys. Res. Letters, v. 4, no. 10, p. 457-460.

Lewbel, G. S. ,1984, Environmental hazards to petroleum industry development, in Truett, J. C., ed, Proceedings of synthesis meeting: The Barrow Arch environment and planned offshore oil and gas development, NOAA/OCSEAP, p. 31-46.

Lewbel, G. S., and Gallaway, B. J., 1984, Transport and fate of spilled oil, in Truett, J. C., ed, Proceedings of synthesis meeting: The Barrow Arch environment and planned offshore oil and gas development, NOAA/OCSEAP, p. 7-29.

McManus, D. A., Creager, J. S., EchoIs, R. J., and Holmes, M. L., 1983, The Holocene transgression of the flank of Beringia: Chukchi valley to Chukchi estuary to Chukchi Sea, in Masters, P. M., and Flemming, N. C., eds., Quaternary coastlines and marine archaeology: towards the prehistory of land bridges and continental shelves, Academic Press, p. 365-388.

Miller, M. C., McCave, I. N., and Komar, P. Do, 1977, Threshold of sediment motion under unidirectional currents, Sedimentology, v. 24, p. 507-525.

Molenaar, C. M., 1985, Subsurface correlations and depositional history of the Nanushuk Group and related strata, North Slope, Alaska, in Huffman, A. C., cd., Geology of the Nanushuk Group and related rocks, North Slope, Alaska, U. S. Geol. Survey Bull. 1614, p. 37-59.

Moore, D. G., 1964, Acoustic reflection reconnaissance of continental shelves: the Bering and Chukchi Seas, in Miller, R. I., cd., Papers in Marine Geology, Shepard Commemorative Volume, MacMillan press, New York, p. 319-362.

Mountain, D. G., Coachman, L. K., and Aagaard, K., 1976, On the flow through Barrow Canyon, Jour. Phys, Oceanography, v. 6, p. 461-470.

Naidu, A. S., and Sharma, G. D., 1970, Geologic, biological, and chemical oceanography of the eastern central Chukchi Sea, U. S. Coast Guard oceanographic Rept., no. 50, p. 173-195.

Nelson, C. H., and Johnson, K. R., 1984, Gray whales, tillers of the sea floor, in Clarke, S. H., cd., Highlights in Marine Geology, U. S. Geol. Survey circular 938, p. 99-107.

Paquette, R. G., and Bourke, R. H., 1974, Observations" on the coastal current of Arctic Alaska, Jour. Marine Res., v. 32, no. 2, p. 195-207.

Phillips, R. L., and Reiss, T. E., Kempema, E., and Reimnitz, E., 1982, Marine geologic investigations, Wainwright to Skull Cliff, northeast Chukchi Sea, U. S. Geol. Survey Open-file rept. 84-108, 33 p.

Phillips, R. L., and Reiss, T. E., 1984, Nearshore marine geologic investigations, Icy Cape to Wainwright, northeast Chukchi Sea, U. S. Geol. Survey Open-file rept. 85-50, 22 p.

Sharma, G. D., 1979, The Alaska shelf: hydrographic, sedimentary and geochemical environment, Springer-Verlag, New York.

Solomon, H., and Ahlnas, K., 1980, Ice spirals off Barrow as seen by satellite, Arctic, v. 33, no. 1, p. 184-188.

Stringer, W. J., 1978, Morphology of Beaufort, Chukchi, and Bering Seas nearshore ice conditions by means of satellite and aerial remote sensing, v. 1, Geophy. Inst. Univ. of Alaska, Fairbanks, 34 p.

Stringer, W. J., 1982, Width and persistence of the Chukchi Polynya, NOAA/OCSEAP Rept., 17 p.

Thorn dike, A. S., and Colony, R., 1982, Sea ice motion in response to geostrophic winds, Jour. Geophy. Res., v. 87, no. C8, p. 5845-5852.

Toimil, L. J., 1978, Ice gouge microrelief on the floor of the eastern Chukchi Sea, Alaska: a reconnaissance survey, U. S. Geol. Survey Open-file Rept., 94 p.

Wilson. J. B., 1979, Biogenic carbonate sediments on the Scottish continental shelf and on Rockall Bank, Marine Geol., v. 33, p. M85-M93.

Wiseman, W.J., Jr., and Rouse, L. J., Jr., 1980, A coastal jet in the Chukchi Sea, Arctic, v. 33, no. 1, p. 21-29.

Appendix A

1984 Chukchi Sea Samples							
Sample #	Sample Type	Latitude (North)	Longitude (West)	Depth (m)	Gravel (%)	Sand (%)	Mud (%)
001	Box Core	70.79330	161.12830	43.5	12.1	75.0	12.9
002	Box Core	70.73330	160.84670	45.3	29.4	66.3	4.3
003	Box Core	70.70830	160.65500	43.9	9.4	69.3	21.3
004	Box Core	70.64170	160.40170	22.3	20.5	74.5	5.0
005	Box Core	70.52670	160.57330	18,3	24.2	63.6	12.1
006	Box Core	70.64670	161.41OMI	37.0	7.6	82.6	9.7
007	Box Core	70.55170	161.64830	28.7	2.0	94.7	3.2
008	Box Core	70.54330	161.78330	24.6	0.8	98.4	0.8
009	Box Core	70.65830	162.16330	39.2	21.1	74.5	4.4
010	Box Core	70.77170	162.54330	42.9	2.2	89.7	8.0
011	Box Core	70.88330	162.86170	42.5	1.8	74.3	23.9
012	Box Core	70.93330	166.34000	42.1	—.	36.0	64.0
013	Box Core	70.95500	166.94830	45.5		29.2	70.8
014	Box Core	70.97320	167.39670	44.8	----	42.4	57.6
015	Box Core	70.98000	167.73670	44.4	22.9	40.9	36.1
016	Box Core	70.47170	166.95330	49.5	- F F -	57.1	42.4
017	Box Core	T0.41000	166.47500	43.2	3.5	53.2	43.3
018	Box Core	70.94500	159.35330	39.2	31.7	60.3	7.9
019	Box Core	70.97500	159.37170	52.2	ROCK	—.-	- - -
020	Box Core	70.96000	159.42670	49.4	157	64.9	19.3
021	Box Core	71.02000	161.36330	47.7	1.7	88.9	9.4
022	Box Core	70.88330	161.75670	42.1	15.1	74.2	10.7
023 A	Box Core	70.72670	160.17500	23.7	3.8	95.3	0.9
023 B	Box Core	70.69670	160.20830	23.7	2.9	96.8	0.3
023 C	Box Core	70.69330	160.20830	23.7	19.3	79.9	0.8
024	Box Core	?0 77670	160.09000	36.6	28.0	69.6	m -
025	Box Core	70.76000	160.33170	40.2	22.7	73.2	4.1
026	Box Core	70.71170	160.27000	29.3	23.4	74,6	1.9
027 START	Pipe Dredge	70.57000	160.98330	31.3	0.7	93.6	5.7
027 END		70, 57000	160.99170				
028 START	Pipe Dredge	70.61330	160.93670	35.0	5.3	87.1	7.6
028 END		70.61500	160.93930				
029	Box Core	70.67920	161.26850	40.3	12.8	82.5	4.7
030	Box Core	70.73170	161.57500	40.2	14.3	77.5	8.2
031	Box Core	70 7600(	161.70670	42.0	17.3	75.6	7.1
032	Box Core	71.2883(	165.72670	41.2	0.3	27.4	72.3
033	Box Core	71.3733(	166.12830	42.4		16.7	83.3
034	Box Core	71.4083(	166.35330	43.0	1.0	15.9	83.0
035	Box Core	70.9150(	168.46670	43.0	1.3	45.7	52.9
035G	Gravity Core	70.9150(	168.4667(	43.0			
036	Box Core	70.8800(	167.7817(	53.5	0.2	23.3	76.5
036G	Gravity Core	70.8800(	167.7817(	53.9			
037	Box Core	70,8400(	167.103M	46,0	0.6	41.6	57.8
038	Box Core	69.5783(	167.4117(	45.7	6.3	48.9	44.8
039	Box Core	69.4933(	167.0617(	45.0	0.1	37.6	62.3
040	Box Core	68.82001	166.7450(	40.5	0.5	30.2	69.3
041 START	Pipe Dredge	68.9183(	166.5600(	36.5			
041 END		68.9213	166.5605(				
042 START	Pipe Dredge	69. 1017(	166.415a	31.1			
042 END		69. 1017(	166.4218:				

Appendix B

X981 Chukchi Sea Samples							
;ample #	Sample Type	Latitude (North)	Longitude (weat)	Depth (m)	Gravel (%)	Sand (%)	Mud (%)
)08	Grab	70.96104	158.98534	28.6	59.6	345	5.5

1982 Chukchi Sea Samples

;ample #	Sample Type	Latitude (North)	Longitude _&!Ell-	Depth 44-	Gravel (%)	Sand (%)	Mud (%)
001	Grab	70,43645	161.31513	22.0	4.1	88.8	6.9
002	Grab	70.57261	160.88451	27.0	9.7	72.5	17.8
003	Grab	70.30769	161.38040	6.7	43.5	55.6	0.8
004	Grab	70.32925	161.44785				
005	Grab	70.36929	161.60620				
006	Grab	70.40710	161.77314	16.7	5.9	84.1	9.9
007	Grab	70.45207	161.96241	16.5	0.1	98.8	1.0
008	Grab	70.35409	161,75108	10.8	19.7	75.7	4.6
009	Grab	70.99737	158.54305	19.0	5.9	90.9	3.1
010	Grab	70.98577	158.38219	21.0	0.1	70.8	28.1
011	Grab	70.95229	158.28459	19.0	4.0	38.3	57.7
012	Grab	70.90994	158.21192	17.0	0.4	18.6	80.7
013	Grab	70.87287	158.19676	14.0	3.7	40.8	55.5
014	Grab	70.84760	158.17605	14.0	40.0	39.6	20.4
015	Grab	70.83480	158.23021				
016	Grab	70.98072	157.42988				
017	Grab	70.93045	157.61289				
018	Grab	70.93518	157,62725				
019	Grab	70.87266	157.87974				

Appendix C

Biological Composition of Inner Shelf Samples

Biological Environment	Sample #	Biological Specimen *								Depth (m)
		Ba	Bi	By	Br	Ec	Cp	Ga	Pt	
Outer Sand Facies	84-10		99.5			0.2			0.2	42.0
	84-11		96.1					3.9		42..5
	84-21	0.4	98.2		0.2			1.2		47.7
	84-22	12.6	78.5					8.9		42.1
Outer Gravel Facies	84-1	54.9	36.7	4.4	2.3			1.7		43.5
	84-2	56.4	34.5	0.9	1.2	0.1	0.1	6.8		45.3
	84-3	61.8	25.0	0.5	9.5	1.7		1.5		43.9
	84-9	50.2	42.1			0.6		6.7		39.2
	84-18	71.3	25.6	0.1	2.5	0.1		0.4		39.2
	84-20	52.0	36.7	9.3	1.3	0.1		0.6		494
	84-24	10.8	86.0	2.9				0.3		36.6
	84-25	77.7	16.0	0.2	3.9	0.6	0.1	1.5		40.2
	84-26	19.6	'?8.3	0.1	0.1	1.2		0.7		29.3
	8430	55,5	34.5	7.0	0.9			2.1		40.2
	8431	60.0	33.8	3.7	0.3			2.2		42.0
	81-8	43.9	50.5					5.5		28.6
Coastal Current Sand Facies	84-6	26.4	72.3	1.1					0.2	37.0
	84-7	0.5	90.7			6.0		2.7	0.1	28.7
	84-8	3.5	85.2			8.3		3.0		24.6
	84-23	15.5	68.6		0.3	11.6		1.6	2.5	23.7
	84-28	1.9	69.9	1.3		14.7		10,9	1.9	31.3
	84-29	36.2	45.7	2.6	11.4	0.3		3.7		35.0
Inner Gravel Facies	84-4	70,8	26.9	0.4				1.9		22.3
	84-5	24.9	69.6					5.5		18.3

Biological Composition of Outer Shelf Samples

Biological Environment	Sample #	Biological Specimen *								Depth (m)
		Ba	Bi	By	Br	Ec	Cp	Ga	Pt	
Outer Shelf Facies	84-34		89.1					10.9		43.0
	84-36		100.0							53.5
	84-37		89.9					10.1		46.0
	84-39		28.5					71.5		45.0
Cape Lisburne	84-42	6.4	75.1		0.2			18.3		31.1

* Biological specimens: Percentage (by weight) of biological fraction of sediment sample. Codes used are as follows:

Ba - Barnacles
Bi - Bivalves
By - Bryzoans
Br - Brachiopods
Ec - Echinoids
Cp - Chitons
Ga - Gastropod
Pt - Polychaete (*Pectinaria* sp.) tubes

APPENDIX D

BOX CORE STATIONS 32-33 IN RELATION TO HIGH-RESOLUTION SEISMIC PROFILES

High-resolution reflection seismic profiles on line 44 on the northwest part of the Chukchi Sea where box cores 32 and 33 obtained show different acoustic signatures. Where box core 32 obtained the sub-bottom reflectors show well-defined parallel strata cut by a fluvial channel deposit (figure 1). In contrast, where box core 33 taken continous reflectors only occur in the upper part of the section with apparently acoustic impenetrable zones throughout the lower part of the section (figure 2). The acoustic "turbid" zone may possible be due to gas within the sediment as high methane values were obtained in box core 33 (see following report). However, the acoustic "turbid" zone may be caused by other physical features as uniform sediment texture or lack of bedding or textural contrasts.

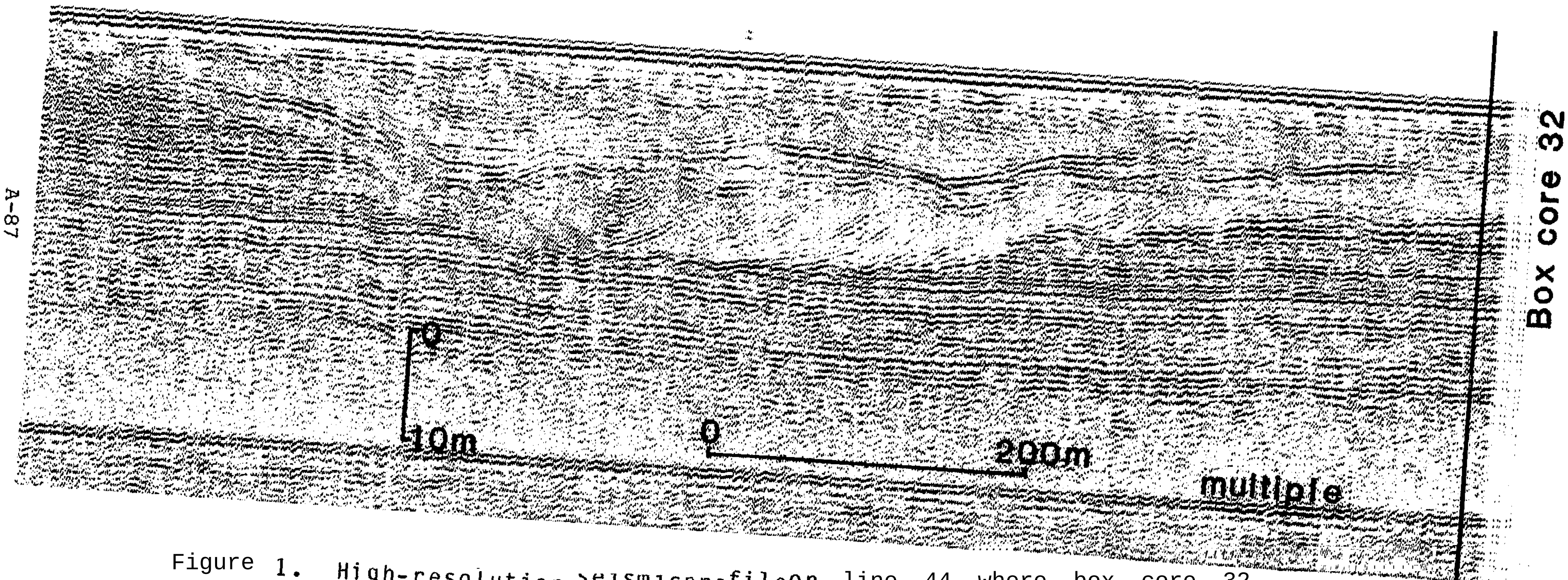


Figure 1. High-resolution seismic profile on line 44 where box core 32 obtained. See figure 3 for track line location and figure 5 for box core location. Bedrock consists of parallel and gently inclined strata cut by a fluvial channel deposit. Box core 32 taken where seismic record ends on right.

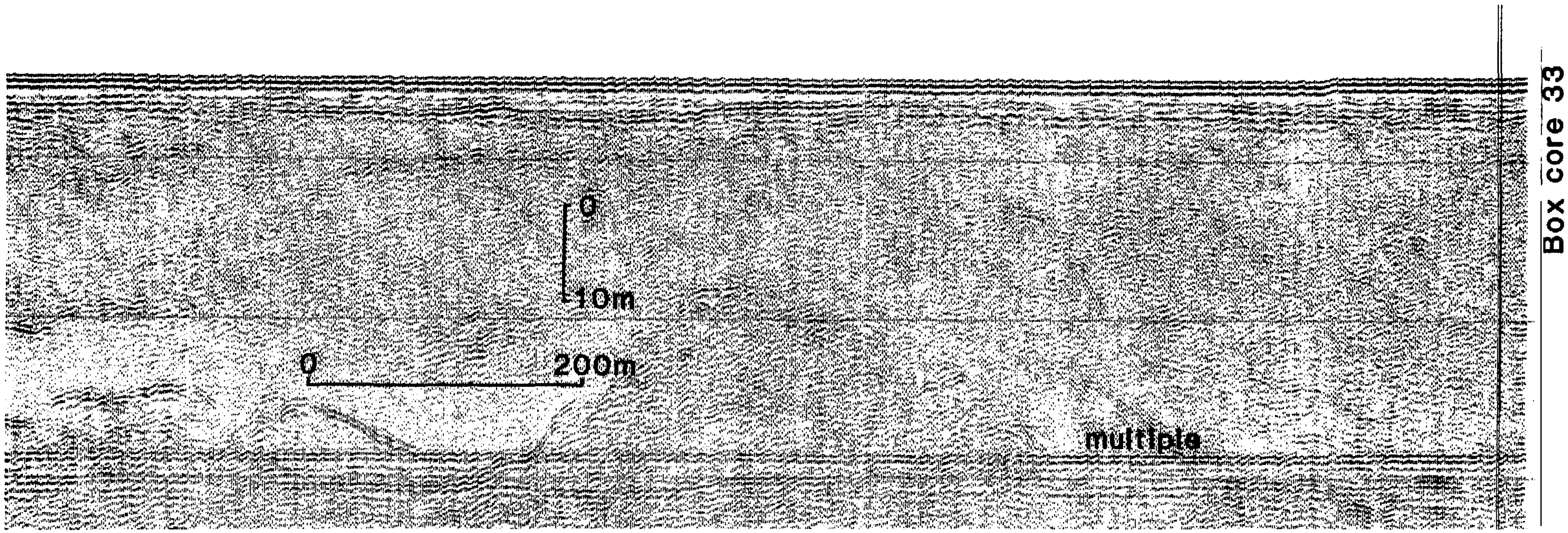


Figure 2. High-resolution seismic profile on line 44 where box core 33 obtained. Parallel reflectors are present only in the upper part of section. The lower acoustic "turbid" zone may be due to gas-charged sediment as high values of methane were found in box core 33. Box core 33 taken where seismic record ends on right.