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GEOLOGIC PROCESSES AND HAZARDS OF THE BEAUFORT AND CHUKCHI SEA SHELF AND COASTAL REGIONS

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TABLE OF CONTENTS

I. Summary of objectives, conclusions and implications with respect to OCS oil and gas development.

This study presents a continuation and expansion of our investigations of the arctic marine sedimentary environments off northern Alaska. We have concentrated within this report on understanding shelf processes within the chukchi Sea, correlating the shallow shelf stratigraphy on part of the Beaufort Sea, understanding rates of coastal erosion and shoreline evolution along the Beaufort coast, and on the rates of sediment disruption by sea ice and character of ice gouges in the Beaufort Sea. The observations, conclusions and implications of our studies summarizing these varied arctic environments are included in the following (The letters key to full topic discussions as attachments to this report):

A. Reconnaissance geophysical surveys of the Chukchi Sea show that a thin sediment cover, generally less than 6 m thick, overling folded bedrock over much of the shelf and that locally on the northwest part of the shelf an extensive filled channel system exists. The channels record a complex fill-history apparently related to multiple sea level changes. Side-scan sonar surveys record abundant ice gouging within the Barrow Sea Valley with decreasing gouge abundance occurring on the western shelf. Currents may rapidly fill in the gouges on parts of the shelf. The side-scan sonar surveys also define areas where both gray whales and walrus are feeding on the sea floor surface. The benthic mammal feeding areas are identified in regions containing sand and gravel along the eastern part of the shelf in areas dominated by the Alaska Coastal Current. Extensive gravel bedform fields also exist on the outer shelf to depths of 49 m suggesting that storm-generated currents do rework the shelf sediments but the periodicity of the storm events is unknown. Box cores show that the shelf surficial sediments on the outer shelf consist of mud or gravelly mud, whereas, the inner shelf is composed of sand and gravel. Bioturbation is abundant in all cores.

B. Gas samples from box cores in the Chukchi Sea contain light hydrocarbons but they are present in low concentrations in the surface sediments and are likely the result of biological processes.

C. Coastline erosion for part of the Beaufort Sea Coast records an average rate of 2.5 m/yr. In places the local long-term erosion can be up to 18 m/yr, while accretion rates near the active mouths of the Colville River are as high as 20 m/yr. The texture of the coastal plain sediments apparently controlls the erosion rates with fine-grained mud averaging high erosion rates of 5.4 m/yr, whereas, sandy to gravelly deposits erode at 1.4 m/yr. The difference in erosion rates suggests that the grain size of the bluff material exerts the dominate control on the coastal retreat rates.

D. Investigations of the inner shelf seismic stratigraphy between the Canning River and Prudhoe Bay identifies 4 unconformities in the subsurface strata as well as one on the present erosional sea floor surface. Identified seismic horizons within the western study area can be correlated with stratigraphic interpretations of more than 20 offshore boreholes. This then allows correlation of the unconformable surfaces to transgressive events.

E. Observations and measurements on recently formed ice gouges in eastern Harrison Bay indicate significant variability from year to year in ice gouge processes based on their number, size, and distribution. Ice gouge recurrence rates show that 3.7% of the sea floor is disrupted each year. This suggests that approximately 50% of the sea floor can be reworked in 20 years. Within" the study area, in water depths of 5-16 m, gouges > 1 m deep occur every 6+ years and account for 0.1-0.2% of all gouges in this area. In water depths > 10 m the sea floor can be completely disrupted to a depth of 1 m in approximately 800 years.

F. Repetitive side-scan sonar surveys between 1975 and 1980 in the Beaufort sea were used to assess sea floor changes due to ice gouging along 8 shore-perpendicular corridors. The percentage of sea floor area impacted annually by ice keels increases from the coast seaward to at least the 25 m isobath. Up to 6.8% of the total sea bed area scanned along the 15 km long corridors was disrupted in a single year. Total sea floor disruption in single km-long segments ranged as high as 60 %. High gouge densities are associated with wide, shallow "multiplet" gouging events, where long sections of pressure-ridge keels raked the bottom. Small annual variations in the amount and intensity of new gouges indicate rather consistent reworking of the inner shelf by this process.

11. Introduction

A. General nature and scope of study

High-latitude continental shelves, where ice is present seasonally, comprise 25 percent of the total world shelf area. Yet the interaction of ice in the region of sedimentary processes and the influence of geology on the ice regime on North American arctic shelves and coasts is poorly understood. Investigations of the continental shelf and shores of the Chukchi and Beaufort Seas was initiated in 1970. The primary goal of this program has been to understand the processes unique to arctic coasts and shelves.

B. Specific objectives

Many questions have been raised on the basis of our past investigations, which apparently hold the key to an understanding of the seasonal cycle in the marine environment. It is these tasks that we address in our current research.

1. Location and extent of sea floor ice gouging, especially the maximum extent and intensity of modern ice gouging, including densities, depths, and directions of gouges, and statistical distribution of ice gouge depths.

2. Recent changes in bathymetry and shelf-edge morphology which may be related to shelf sediment transport by ice or other means.

3. Profiles of shallow sediment structures in selected regions with emphasis on studies that will provide information on past history of ice involvement with the sea floor and the potential for the presence of sand and gravel.

4. Develope cooperative studies with Canadian geoscientists to assess similarities and differences concerning ice seabed interactions on the Alaskan and Canadian Beaufort shelves.

C. Relevance to problems of petroleum development

The character of the arctic continental shelf and coastal area, with year round and seasonal sea ice and with permafrost, faces the developer with many special problems. The interaction of the arctic shelf with the arctic pack ice takes the form of ice gouging and the formation of a large stamukhi zone each winter. Furthermore, ice zonation is determined by sea bed morphology and textural character.

Oil drilling and production during the next several years will probably extend into the stamukhi zone seaward of the seasonal fast-ice zone. Of critical concern are ice gouging, ice zonation, strudel scour, storm-generated currents on the Chukchi shelf, and sand and gravel sources; all related to sea bed morpholgy and sea bed character. These are of concern to the government, in that an adequate understanding of arctic processes is needed to assure safe development and adequate environmental protection. Any structure which is to be mated with the ocean floor requires data concerning the strength and character of the ocean floor and its effect on the ice canopy. Likewise, the strength and effects of storm-generated currents is also unknown. Foundation materials in the form of gravels will be needed for work pads offshore. In addition, the offshore drilling operation may encounter unsupportive sediments with permafrost and associated gas hydrates which could be substantially altered during the process of pumping hot oil up to the sea floor or along the sea floor in gathering and transportation pipe lines.

III. Current state of knowledge

The current state of knowledge for the Beaufort Sea is summarized within this report. The availability of only small boats for the past field efforts has resulted in knowledge biasing the coastal regions, the very inner fringe of the continental shelf rather than the whole outer continental shelf.

On the middle and outer shelf big ship geophysical studies by the USGS provided considerable knowledge on structural framework, the stratigraphy, and certain hazards such as slumping. But very little work has been done here along the lines of research we and others conduct on modern processes and hazards relevant to the seaward thrust of petroleum development.

The current state of knowledge for the Chukchi Sea is increasing and to date approximately 50 percent of the shelf lease areas have been covered in reconnaissance studies. Ice gouging, migrating bedforms and sand banks, strong currents both coastal and storm-generated, and extensive filled paleochannels possibly containing permafrost or gas are hazards identified to date on the Chukchi shelf. North of 71°, however, limited data exists. The northern shelf will contain the most extensive ice gouged terrane on the Chukchi Sea shelf as well as contain extensive slump terranes. Large ship operations and favorable ice conditions are needed to complete the studies of the northern Chukchi Sea shelf.

IV. Study area

A. Chukchi Sea--The Alaska mainland between Cape Lisburne and Point Barrow slopes generally northward. The southern part of the mainland is hilly, whereas the northern part is a gently sloping coastal plain. The edge of the mainland, which faces the open sea in some places and faces lagoons, bays or barrier spits elsewhere, is marked in most places by cliffs or bluffs, which tend to gradually decrease in height northward. Barrier islands and spits are extensive along the Chukchi Sea coast from Point Barrow, Point Franklin, and Icy Cape, three of the major capes along this coastline.

Much of the Chukchi Sea north of Point Hope consists of a broad, nearly flat, shallow shelf. The average depth is 50 m. Herald Shoal, which lies in the central shelf area, rises up to 14 m depth; Hanna Shoal, on the northern part of the shelf, rises to approximately 20 m depth. The Barrow Sea Valley lies near the northern edge of the shelf. Nearshore, in depths less than 25 m, shore-parallel shoals are developed off the capes. Actively migrating longshore bars form adjacent to the beaches.

The high sea cliffs at and near Cape Lisburne are cut in bedrock of Permian and Triassic age. Cretaceus bedrock, mostly sandstone and shale, forms the sea cliffs aroung Ledyard Bay, east of Cape Lisburne. Cretaceus bedrock is exposed in the lower parts of sea cliffs as far north as Skull Cliff, between Peard Bay and Barrow. The upper parts of the sea cliffs at Skull Cliff and elsewhere on the coastal plain are made up of unconsolidated Quaternary deposits.

Tidal currents, storm currents and the offshore, shore-parallel Alaska Coastal Current modify the sea floor along the eastern Chukchi Sea by erosion and transportation of sediment as migrating bed forms. The nearshore currents are generated mostly by winds, and the offshore region is dominated by northeast-directed storm currents and by the northeast-flowing Alaska Coastal Current.

The tides are small in the Chukchi Sea, and the tidal range along the eastern coast is generally less than 10 cm. The tides are of the semi-diunal type. The tidal wave moves from north to south in the Chukchi Sea. Tide-generated currents can be expected to be of limited velocity along the open coast.

Storms during the summer months usually result in winds from the southwest which move across the Chukchi Sea. The maximum fetch then developes across the open water. The resulting storm waves and storm-generated currents may erode and scour the sea floor as well as result in intense sediment transport on the shelf and on the shoals.

Wind-generated currents are extremely variable both in velocity and in direction of movement for the nearshore region. The predominant summer winds are from the northeast, generating nearshore current velocities of 4 to 20 cm/sec. The wind generated currents generally follow the bottom contours. Daily variations in the current direction are reported for the nearshore region.

The Alaska Coastal Current represents a northeast flowing “warm” water mass derived from the Bering Sea. The current bifurcates at Cape Lisburne, one branch flowing north and the other branch flowing to the northeast parallel to the coast. The current varies in width and can be as narrow as 20 to 37 km. The velocities of the coastal current vary from 50 cm/sec. near Cape Lisburne, to 5 to 87 cm/sec. south of Icy Cape, to 55 cm/sec. north of Wainwright. Surface velocities of up to 200 cm/sec. and mid depth velocities of 70 cm/sec. are reported north of Wainwright. To the northwest of Wainwright near the Barrow Submarine Canyon head, a returning southwest-directed current is reported west of the Alaska Coastal Current with surface velocities of 80 cm/sec. The southwest-flowing current is poorly defined in space and time. Large clockwise rotating spiral currents are reported west of Barrow and may represent interaction between the Alaska Coastal Current and the westward flowing current of the Beaufort Gyre.

B. Beaufort Sea--The primary study area includes the Beaufort Sea shelf between Barter Island on the east and Point Barrow on the west with emphasis on an inshore segment between Flaxman Island and Cape Halkett. The adjacent land is a broad, flat coastal plain composed mainly of Quaternary deposits of tundra silts, sands, and gravels. In much of the area, the coast is being eroded by the sea at a rapid rate forming coastal bluffs as much as 6 m high. The line of bluffs is interrupted by low mud flats at the mouths of major rivers. Much of the coast is marked by islands at varying distances from the shore. Most of the islands are less than 3 m in elevation, narrow, and comprised of sand and gravel. Others are capped by tundra and are apparently erosional remnants of the inundated coastal plain. Coast-parallel shoals are also a feature of the inner shelf.

The shelf is generally rather flat and remains shallow for a considerable distance from shore. Off the Colville River the 2-m isobath is up to 12 km from shore. The width of the shelf is variable, ranging from, 55 km in the east to 110 km in the west. The shelf break lies at depths of 50 to 70 m. The shallowness of the shelf break and the presence of elevated Pleistocene beach lines suggests broad regional uplift. The Holocene marine sediments on the inner shelf are generally 5 to 10 m thick and composed of complex textural and compositional character, Ice and oceanographic factors interact to form a complex. sediment section composed of wave and current-bedded sequences intensely churned and disrupted by ice.

The rivers flood in early June, delivering 50 to 80 percent of the yearly runoff in a 2-3 week period. The bulk of sediment input from rivers is associated with this flood. No river gravels presently reach the ocean. Initial flooding seaward of the river delta occurs on top of the unmelted sea ice, although the influx of warmer water eventually leads to ice-free areas off the deltas early in the sea-ice melt season. River drainage basins are located in the Brooks Range and the eastern rivers drain directly into the ocean while the western rivers meander across the broad coastal plain.

Sea ice is a ubiquitous feature in the study area. New ice starts to form in late September and grows to a thickness of 2 m through the winter, welding remnant older ice into more or less solid sheets. Where forces are sufficient, ice fractures and piles into hummocks and ridges. By June, sea-ice melting is well underway and usually sometime in July enough ice has melted so that the protected bays and lagoons are free of ice, and temperate latitude processes of waves and wind-driven currents are active. Ice remains on the shelf in the study area throughout the summer. Its location and concentration depend on the degree of melting and winds. The prevailing northeasterly wind tends to carry drifting summer ice away from the shore while the westerlies pile ice against the coast. Ice commonly remains grounded throughout the summer on many of the shoals on the inner shelf.

Currents and waves are a function of the winds during the open-water season. Waves are generally poorly developed due to the limited fetch which results from the presence of ice during most of the summer. Water circulation is dominated by the prevailing northeasterly winds which generate a westerly flow on the inner shelf. In winter, currents under the ice are generally sluggish although restrictions of the tidal prism by ice, at tidal inlets and on the broad, shallow, 2-m bench cause significantly higher velocities.

V. Sources, methods and rationale of data collection

A. Equipment operated routinely from the R/V KARLUK and other scientific vessels includes box cores, dredges, gravity and vibracores, water salinity, temperature and turbidity sensors, fathometers, a high and medium resolution seismic system, camera and TV system, and a side-scan sonar system. Precision navigation is maintained to 3 m accuracy with a range-range system.

Special techniques include (a) repetitive sonar and fathometer surveys of ice gouges, (b) diving observations and bottom photography, (c) measurements of sediment thicknesses within ice gouges by combined use of narrow beam echo sounder, and (d) a near-bottom tow package incorporating sub-bottom profiler and television, (e) nearsurface stratigraphic studies using a vibracores capable of obtaining 2 and 6 m long sediment cores," and {f) detailed surveys of bathymetry in river and lagoonal channels and in the vicinity of man-made structures. Coastal observations of rates of bluff erosion and the distribution and elevation of storm surge strand lines carried out by helicopters. Winter ice observations involve ice coring, diving observations along with modified system of upward-looking fathometer and side-scan sonar.

VI. Results, discussions and conclusions--(as attachments to this report)

A. Geologic investigations in the Chukchi Sea, 1984, NOAA ship SURVEYOR cruise.

B. Hydrocarbons in surface sediments of the Chukchi Sea.

C. Beaufort Sea coastal erosion, shoreline evolution and sediment flux.

D. Pleistocene and Holocene seismic stratigraphy between the Canning River and Prudhoe Bay, Alaska.

E. Temporal and spatial character of newly formed ice gouges in eastern Harrison Bay, Alaska, 1978-1982.

F. Rates of sediment disruption by sea ice as determined from characteristics of dated ice gouges created since 1975 on the inner shelf of the Beaufort Sea, Alaska.

VII. Needs for further study

As petroleum exploration and development continues to press into deeper water and further from shore in both the Beaufort and Chukchi Seas the geologic environment and hazards of these regions will need better defining. In particular the impact of the transportation phase of development is poorly understood. As yet no offshore pipeline or coastal crossing have bee attempted except by use of causeways which will become unfeasible at greater distances from shore and at greater depths. From this perspective we see the following needs for additional geologic information within the Beaufort Sea. 1) A definitive study of coastal and barrier island stabilities and the sedimentary dynamics of the nearshore environment. We understand a good deal about this environment, however, there are still major questions

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such as the fate of river sediments (none are presently deposited off the Sagavanirktok River), 2) Continued studies of ice gouging directed toward understanding the energy expended at the sea floor and the quantities of sediment disturbed and displaced. This would allow us to estimate the relative saftey of various pipeline schemes of seabed structures.

Several other areas of study will be needed to keep abreast of the present state of knowledge. A) Studies of the shelf edge slump and slide terrain and its associated gasses. B) Cooperative studies, including cruises with the Canadian geoscience community will allow for a increased rate of learning and will keep us informed of Canadian advancements (they may be first to develop resources far from shore). C) Studies of the "recovery" rates of offshore drilling sites, such as CIDS, to determine the seabed response to artificial alteration.

Our view of the needs for future study in the Chukchi Sea is based on the present state of knowledge which continually improves and may well raise new questions. As seen at present, the primary emphasis of future work should include the following: (a) investigation of ice gouging on the northern shelf (area north of 71°) as well as slumping along the shelf break and on the west side of the Barrow Sea Valley; (b) using vi bracores establish the sediment depth of ice interaction on the present shelf; (c) establish potential sand and gravel resources using vibracores (d) define the Chukcki Sea biofacies in relation to fauna, current regime, sediment texture, and identify major benthic feeding areas of walrus and gray whales; (e) identify processes forming and moving major bedform fields on the shelf; and (f) identify origin and reoccurrence rates of movement of storm-generated (?) gravel waves on the outer shelf.

As our work and the work of others progresses, new thoughts and questions will develope and need to be incorporated into future research.

VIII. Published reports since last annual report

Rearic, D. M., Barnes, P. W., and Reimnitz, Erk, 1981, Ice gouge data, Beaufort Sea, Alaska, 1972-1980; U.S. Geological Survey Open-file Rept. 81-950, 8 microfiche cards.

Reimnitz, Erk and Barnes, P. W., 1981, Depositional complexities in the sea-ice environment of arctic shelves: Example from Harrison Bay, Alaska: American Assoc. Petrol. Geol . Bulletin, San Francisco, California, AAPG-SEPM Annual Convention, May 31-June 2, (abs), v. 65, p.978.

Weeks, W. R., Barnes, P. W., Rearic, D. M., and Reimnitz, Erk, 1981, Statistic of ice gouging on the Alaskan Shelf of the Beaufort Sea: EOS, Transactions of the American Geophysical Union, v. 62, no. 45, p. 902.

Barnes, P. W., and Minkler, P. W., 1982, Sedimentation in the vicinity of a causeway groin Beaufort Sea, Alaska, 1982, U.S. Geol. Survey Open-file Rept. 82-615, p. 12

Barnes, P. W., Rearic, D. M., and Reimnitz, Erk, 1982, Ice

gouge characteristics and their relation to ice zonation, Beau fort Sea, Alaska, Abstract vol. llth International Congress on Sedimentology, Hamilton, Ontario, Canada, p. 75.
Barnes, P. W., Reimnitz, Erk, and Fox, D., 1982, Ice rafting of fine-grained sediment, a sorting and transport mechanism, Beaufort Sea, Alaska, Jour. Seal. Petrol. , v. 52, p. 493-502.
Barnes, P. W., and Reimnitz, Erk, 1982, Sediment content of nearshore facies-Fall, 1980, Beaufort Sea, Alaska, U.S. Geol . Survey Open-file Rept. 82-716, 18 p.
Barnes, P. W., and Reimnitz, Erk, 1982, Net flow of near-bottom waters on the inner Beaufort Sea Shelf as determined for sea bed drifters, U.S. Geol. Survey Open-file Rept. 82-717, 9 p.
Barnes, P. W., and Reiss, Tom, 1982, Erosion and migration of an artificial sand and gravel island, NIAKUK XII, Beaufort Sea, Alaska, U.S. Geol. Survey Open-file Rept. 82-608, 9 p.
Barnes, P. W., and Ross, C. R., 1982, Marine ice-pushed boulder ridge, Beaufort Sea, Alaska, Arctic, V. 35, p. 312-316.
Dunton, K. H., Reimnitz, Erk, and Schonberg, S., 1982, An arctic kelp community in the Alaskan Beaufort Sea, Arctic, v. 35, no. 4, p. 465-484.
Kempema, E. W., Barnes, P. W., Reimnitz, Erk, Asbury, J. L., and Rearic, D. M., 1982, A summary of U.S. Geological Survey marine geological data collected in the Beaufort Sea, Alaska, 1982, U.S. Geol. Survey Open-file Rept. 83-493, 2 rolls microfilm, 9 p.
Reimnitz, Erk, and Kempema, E. W., 1982, Dynamic ice-wallow relief of northern Alaska's nearshore - a dynamic bedform, Jour. of Seal. Petrol. , v. 52, no. 2, p. 451-462.
Minkler, P. W., Reimnitz, Erk, and Barnes, P. W., 1982, A summary of U.S. Geological Survey marine geologic data collected in the Beaufort Sea, Alaska, July through August, 1981, U.S. Geol. Survey Open-file Rept. 82-586.
Reimnitz, Erk, Barnes, P. W., Rearic, D. W., Minkler, P. W., Kempema, E., and Reiss, T., 1982, Marine geological investigations in the Beaufort Sea in 1981 and preliminary interpretations for region from the Canning River to the Canadian border, U.S. Geol. Survey Open-file Rept. 82-974.
Reimnitz, Erk, Kempema, E. W., and Ross, C. R., 1982, Observations on the mode and rate of decay of an artificial ice island in the Alaskan Beaufort Sea, OTC #4310, Offshore Tech. Conf. Proceedings, v. 3, p. 121-132.
Reimnitz, Erk, and Kempema, E. W., 1982, High rates of bedload transport measured from filling rate of large strudel scour craters in the Beaufort Sea, Alaska, U.S. Geol . Survey Open-file Rept 82-588, 22 p.
Barnes, P. W., and Reimnitz, Erk, 1983, Sedimentary facies on an ice dominated shelf, Beaufort Sea, Alaska, U.S. Geol. Survey Circular 917, 37 p.
Reimnitz, Erk, and Kempema, E. W., 1983, High rates of

bedload transport measured from infilling rate of large strudel-scour craters in the Beaufort Sea, Alaska, Continental Shelf Reasearch, v. 1, no. 3, p. 237- 251.
Reiss, T., Phillips, R. L., Hunter, R. E., and Barnes, P. W ., 1983, A summary of U.S. Geological Survey marine geologic studies on the inner shelf of the Chukchi Sea, Alaska, 1975 and 1981, U.S. Geol. Survey Open-file Rept. 83-71, 11 p.
Weeks, W. F., Barnes, P. W., Rearic, D. M., and Reimnitz, Erk, 1983, Statistical aspects of ice gouging in the Alaskan shelf of the Beaufort Sea, CRREL Rept. 83-21, Hanover, NH, U.S. Army Corps of Engineers, 34 p.
Barnes, P. W., Rearic, D. M., and Reimnitz, Erk, 1984, Ice gouge characteristics and their relation to ice gouging and ice dynamics, in P. W. Barnes, D. M. Shell, and E. Reimnitz (eds.), The Alaskan Beaufort Sea - Ecosystems and Environment, Academic Press, San Francisco, California, 466 p.
Barnes, P. W., Shapiro, L. and Reimnitz, Erk, 1984, Control concepts for mid-shelf-shear zone, in Abstracts," Arctic Energy Technologies Workshop, Nov. 14-15, 1984, U.S. Dept. of Energy, Office of Fossil Energy, Morgantown Energy Technology Center, Morgantown, West Virginia, 5 p.
Graves, S. M., Reimnitz, Erk, and Barnes, P. W., 1984, A summary of U.S. Geological Survey marine geological data collected in the Beaufort Sea, Alaska, 1983, U.S. Geol. Survey Open-file Rept. 84-117, 13 p.
Phillips, R. L., Reiss, T. E., Kempema, E. W., and Reimnitz, Erk, 1984, Nearshore marine geologic investigations, - Wainwright to Skull Cliff, northeast Chukchi Sea, U.S. Geol . Survey Open-file Rept. 84-108, 33 p.
Reiss, T. E., Hunter, R. E., and Phillips, R. L., 1984, A summary of Us. Geological Survey marine geologic studies on the inner shelf of the Chukchi Sea, Alaska, summer 1982, U.S. Geol. Survey Open-file Rept. 84-116, 12 p.
Phillips, R. L., and Reiss, T. E., 1984, Nearshore marine geologic investigations, Icy Cape to Wainwright, northest Chukchi Sea, U.S. Geol. Survey Open-file Rept. 84-828, 27 p.
Phillips, R. L., and Reiss, T. E., 1984, Nearshore marine geologic investigations, Point Barrow to Skull Cliff, northeast Chukchi Sea, U.S. Geol. Survey Open-file Rept. 85-50, 22 p.
Phillips, R. L., 1984, Current-dominated sedimentation in the northeastern Chukchi Sea, Alaska, in research sysposium, Sedimentology of shelf sands and sandstones, Canadian Sot. of Petrol. Geologists, p. 86.
Reimnitz, Erk, Barnes, P. W., and Phillips, R. L., 1984, Geologic evidence for 60 m deep pressure-ridge keels in the Arctic Ocean, Ice Symposium, August 27-31, 1984, Hamburg, Germany, v. II, p. 189-206.
Reimnitz, Erk, and Barnes, P. W., 1984, Determining the maximum ice keel depth in the Beaufort Sea, in Abstracts, Arctic Energy Technologies Workshop, Nov. 14-15, 1984, U.S.

Dept. Energy, Office of Fossil Energy, Morgantown Energy Tech. Center, Morgantown, West Virginia, 8 p.

Reimnitz, Erk, and Kempena, E. W., 1984, Pack ice interaction with Stamukhi Shoal, Beaufort Sea, Alaska, in P. W. Barnes, D. M. Schell and Erk Reimnitz (eds.), The Alaskan Beaufort Sea - Ecosystem and Environment, Academic Press, San Francisco, California, p. 159-184.

Weeks, W. F., Barnes, P. W., Rearic, D. M., and Reimnitz, Erk, 1984, Some probabilistic aspects of ice gouging in the Alaskan shelf of the Beaufort Sea, in P. W. Barnes, D. M. Schell, and Erk Reimnitz (eds.), The Alaskan Beaufort Sea - Ecosystem and Environment, Academic Press, San Francisco, California, p. 213-236

Barnes, P. W., Reimnitz, Erk, and Rearic, D. M., 1984, Ice gouge characteristics related to sea-ice zonation, Beaufort Sea, Alaska, Montebel lo, Quebec, Canada, National Research Council of Canada, Ice Scour Workshop, Feb. 15-19, 1982, 32 p.

Barnes, P. W., Ross, C. R., and Reimnitz, Erk, 1984, Correlation between an ice ridge and sea bed geologic boundary, Montebel lo, Quebec, Canada, National Research Council of Canada, Ice Scour Workshop. Feb. 15-19, 1982, 15 p.

Bea, R. G., Puskar, F. J., Barnes, P. W., and Reimnitz, Erk, 1985, The role of ice gouging in determining global forces on arctic structures, Proceedings, American Sot. of Civil Engineers, Arctic, 85, p. 251-266.