UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SUMMARY REPORT OF THE SEDIMENTS, STRUCTURAL FRAMEWORK, PETROLEUM POTENTIAL, ENVIRONMENTAL CONDITIONS, AND OPERATIONAL CONSIDERATIONS OF THE UNITED STATES BEAUFORT SEA, ALASKA AREA

U.S. DEPARTMENT OF THE INTERIOR
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Menlo Park, California
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U.S. DEPARTMENT OF THE INTERIOR
PROPOSED OIL AND GAS LEASE SALE
NO. 50

By

and others
Arthur Grantz, P. W. Barnes, S. L. Eittreim, Erk Reimnitz
E. W. Scott, R. A. Smith, George Stewart, and L. J. Toimil

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SUMMARY

Proposed OCS Oil and Gas Lease Sale #50, comprising approximately 20,000 sq km in the Beaufort Sea of northern Alaska, has good potential for petroleum in each of the three geologic provinces it contains. However, only about half of the proposed area underlies waters shallower than 20 m, the apparent present technologic limit for petroleum development in polar seas impacted by a drifting permanent ice pack.

The Arctic Platform province underlies most of the western half of the proposed sale area. Its coastal onshore extension has oil or gas pools or shows in nine geologic formations, which range in age from Mississippian to Tertiary. The oil and gas pools include those in the supergiant, multi-reservoir Prudhoe Bay field, which extends beneath state lands offshore. Large structural-stratigraphic traps may exist in the province on the OCS, but the proximity of Prudhoe Bay does not necessarily imply that Prudhoe-sized deposits also underlie the proposed sale area. The geologic history and structural geometry that produced Prudhoe may have been unique. The Western Beaufort Outer Shelf Province, which occupies a relatively small area in the western part of the proposed sale area, has good potential for medium-sized fields of oil and gas in primarily Cretaceous strata. The Camden Basin Province, which occupies the eastern third of the proposed sale area has good potential for medium to large petroleum accumulations in Cretaceous and Tertiary rocks. Potential structural traps include large linear northeast-striking folds in the easternmost part of the proposed sale area.

A geologic estimate of the undiscovered recoverable petroleum that may underlie the proposed area of lease sale #50 is 0 to 3.9 billion bbls of oil and 0 to 9.9 trillion cubic feet of gas at the 95 percent and 5 percent probability levels or confidence limits.

Sea ice and other aspects of the geologic environment, geographic remoteness, and the Arctic climate will impose severe constraints on the feasibility and safety of petroleum exploration and development in the Beaufort Sea. The dynamic shear zone (stamukhi zone), a relatively narrow belt wherein the drifting polar ice pack impinges the seabed and the coastal zone of comparatively stable shore- and bottom-fast ice, is apparently the present seaward technological limit for petroleum development. The stamukhi zone is generally in 10 to 20 m of water. Deep-keeled ice produced in the stamukhi zone and elsewhere in the polar pack extensively gouges the seabed to a depth of 0.5 to 1 m, and one gouge was measured to be 5.5 m deep. As many as 300 gouges per km of trackline have been counted. Rapid coastal sea-bluff retreat and barrier-island migration, annual spring meltwater floods, near- and onshore permafrost, storm surges in sea level, and a general shortage of fresh water in winter and of gravel for construction may also hinder development or create hazardous conditions at various times and places. On the other hand, only small-scale seabed slumping is anticipated in the sale area, and historically earthquakes are virtually absent from the western part of the proposed sale area and infrequent and of small to moderate magnitude in the eastern part.

Considerable research is being conducted by government and industry groups in Canada and the United States to extend the capability to explore and produce oil and gas in the arctic environment. The results will have immediate application to development in the Beaufort OCS area. Some conventional equipment may be utilized, with or without modification, to drill from artifical islands in shallow water. These islands may be designed for self destruction or can be reinforced to support permanent production facilities. Other equipment will have to be designed to cope with conditions at proposed operating sites.

Technology is currently available for operations in water depths less than 20 m.

Some skilled manpower for petroleum development in the Beaufort Sea may be available in Alaska, but much of it might have to be recruited from California and the Pacific Northwest. Availability will depend in large part on cyclical national economic factors.

Estimates of a time frame for development and production are conjectural at best. Present and near-term developing technology should provide for initial production within 5 to 10 years, but it is doubtful that peak production could be realized before 8 to 12 years. These figures assume the availability of pipeline outlets. Industry estimates indicate that at least 5 to 10 years of research and development of technology will be required before the capability to operate in waters deeper than 20 m is achieved.

INTRODUCTION

This report is a preliminary account of the geologic framework and consequent petroleum potential, the environmental hazards which might impact petroleum development, and the availability of exploration and production infrastructure in the area being considered for proposed OCS Oil and Gas Lease Sale #50 in the Beaufort Sea north of Alaska[1/]. Its purpose is to assist the Bureau of Land Management (BLM) in defining the area within which to call for nominations. A more detailed report, incorporating data to be obtained in the summer of 1976, will be issued about January, 1977.

The shoreward boundary of the Beaufort OCS is the 3-mile limit as shown on BLM protraction sheets; the seaward boundary is the 200-m isobath. The area under consideration encompasses about 60 percent of the OCS between 144° and 156° W. long., and includes all lands underlying waters shallower than 20 m. This water depth appears to be at the limit of present or imminent technology for drilling test wells in waters impacted by the main ice pack in the Arctic Ocean. Most proprietary and publicly available geophysical and geologic data pertinent to assessing the petroleum potential of the Beaufort shelf lies within the area being considered for proposed Lease Sale #50. The principal reports encompassing the publicly available data are listed in the Bibliography and References Cited. The relation of the proposed lease sale area to Naval Petroleum Reserve No. 4 (NPR-4); the Trans-Alaska Pipeline System (TAPS); onshore seeps and oil and gas fields, including the supergiant Prudhoe Bay field; and coastal airfields are shown in Figure 1. The area is adjacent to active petroleum exploration and drilling by industry on state lands between NPR-4 and the Arctic National Wildlife Range and by the U.S. Navy on NPR-4.

[1/] Grantz and Eittreim are responsible for the Introduction, Geologic Framework of Potentially Petroliferous Rocks and Petroleum Potential; Scott for Petroleum Resource Appraisal; Barnes, Reimnitz and Toimil for Environmental Geology and Smith and Stewart for Development Considerations.

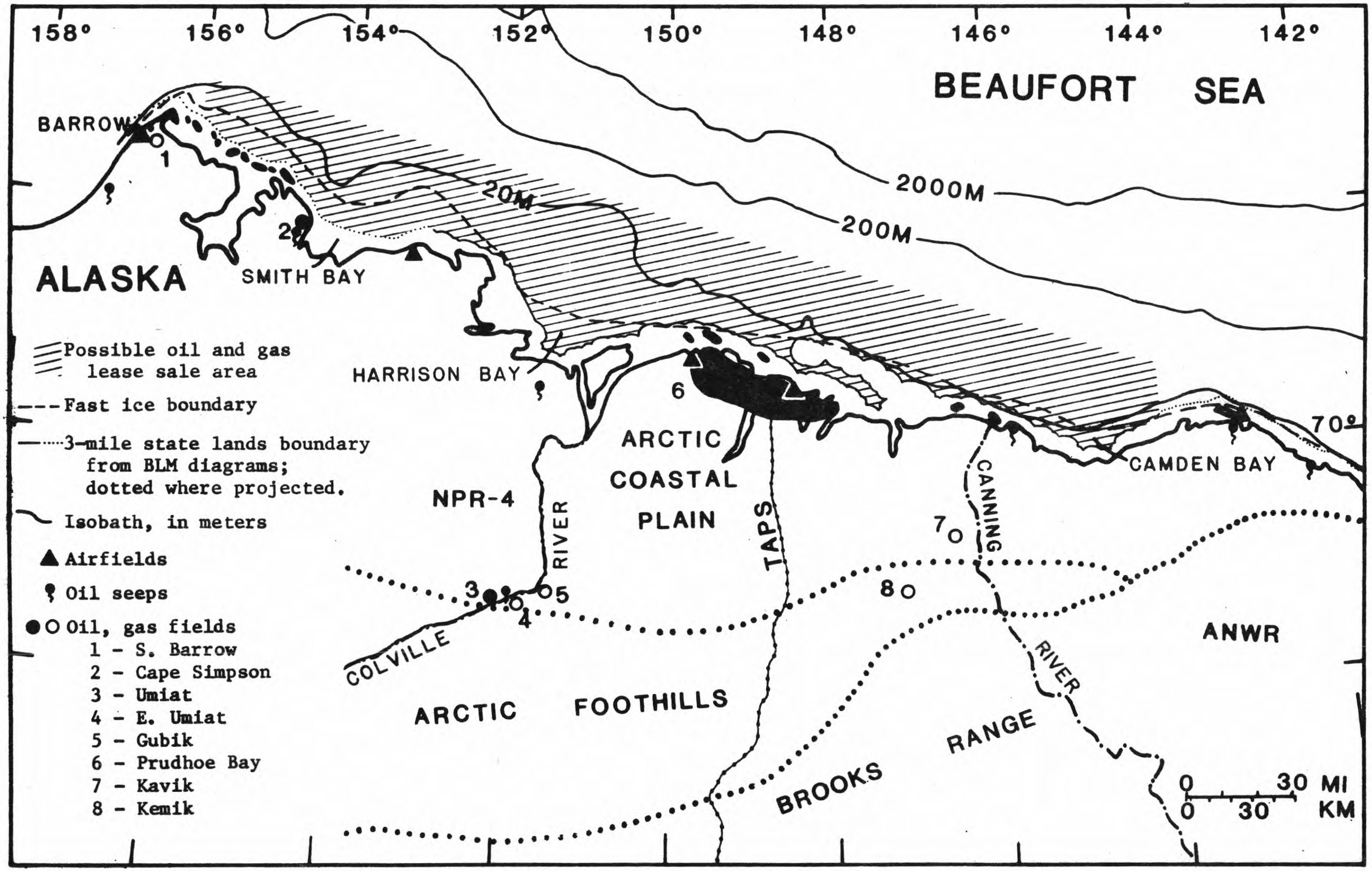

Figure 1. Proposed area of OCS oil and gas lease sale #50 in the Beaufort Sea showing bathymetric setting and the occurrence of petroleum on the adjacent North Slope of Alaska. Naval Petroleum Reserve No. 4 (NPR-4), the Arctic National Wildlife Range (ANWR), the Trans-Alaska Pipeline System (TAPS), principal airfields and physiographic provinces of the North Slope are also shown.

GEOLOGIC FRAMEWORK OF POTENTIALLY PETROLIFEROUS ROCKS

The proposed lease sale area encompasses parts of three geologic provinces or basins that are characterized by distinct, but overlapping sedimentary rock sequences and geologic structures. Accordingly, the specific location of the province boundaries is somewhat arbitrary. These provinces, the Arctic Platform, the western Beaufort Outer Shelf, and the Camden basin are shown in Figure 2. Typical, but generalized, columnar and cross sections are shown in Figures 2 and 3. The data for this discussion and that on Petroleum Potential, are mainly from Grantz, et al., 1975, and new data by Grantz and Eittreim offshore; and Alaska Geologic Society, 1971 and 1972, Brosgé and Tailleur, 1971, Jones and Speers, 1976, and especially Tailleur, et al., 1976, onshore.

<u>Arctic Platform</u>.--The Arctic coastal plan and foothills of the Brooks Range of northern Alaska and the southern one-half to two-thirds of the Beaufort Sea continental shelf are underlain by an extensive platform cut across mildly metamorphosed early Paleozoic (Cambrian to Devonian) sedimentary rocks. The platform maintained a remarkable stability for more than 200 m.y., which lasted through the Early Cretaceous epoch. During this major span of Phanerozoic time a lithologically varied suite of stable shelf clastic and carbonate sedimentary rocks representing all or most geologic epochs from Late Devonian to Early Cretaceous was deposited on the platform. This sequence contains organic-rich shale, texturally mature sandstone and conglomerate, and some dolomitized limestone. Beds of both marine and nonmarine origin are present. The clastic components were derived from a northerly source terrane that then lay north of the present Beaufort shelf. In the area under consideration, the Arctic Platform sequence ranges between 0 and a projected thickness of several hundred meters.

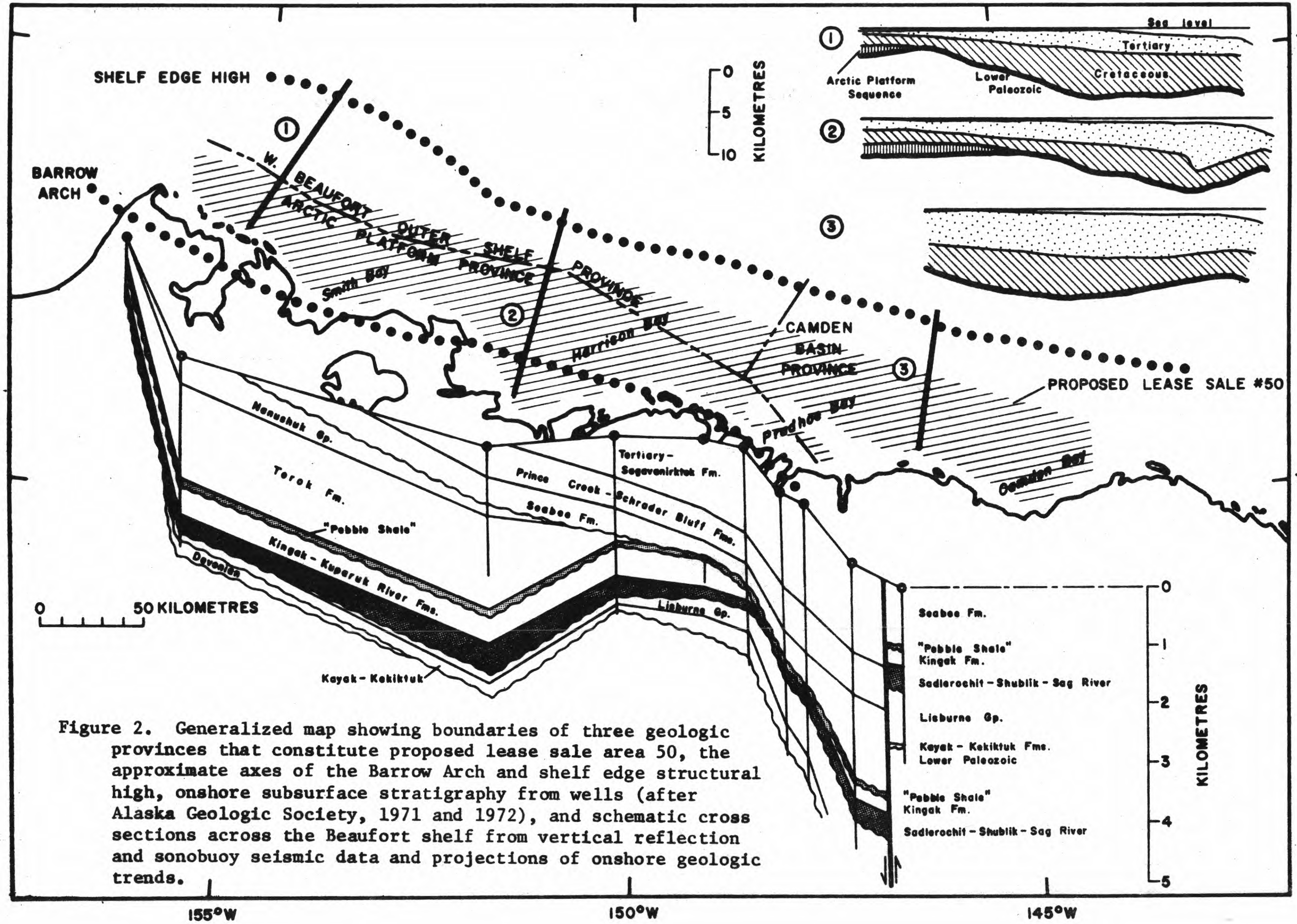

Figure 2. Generalized map showing boundaries of three geologic provinces that constitute proposed lease sale area 50, the approximate axes of the Barrow Arch and shelf edge structural high, onshore subsurface stratigraphy from wells (after Alaska Geologic Society, 1971 and 1972), and schematic cross sections across the Beaufort shelf from vertical reflection and sonobuoy seismic data and projections of onshore geologic trends.

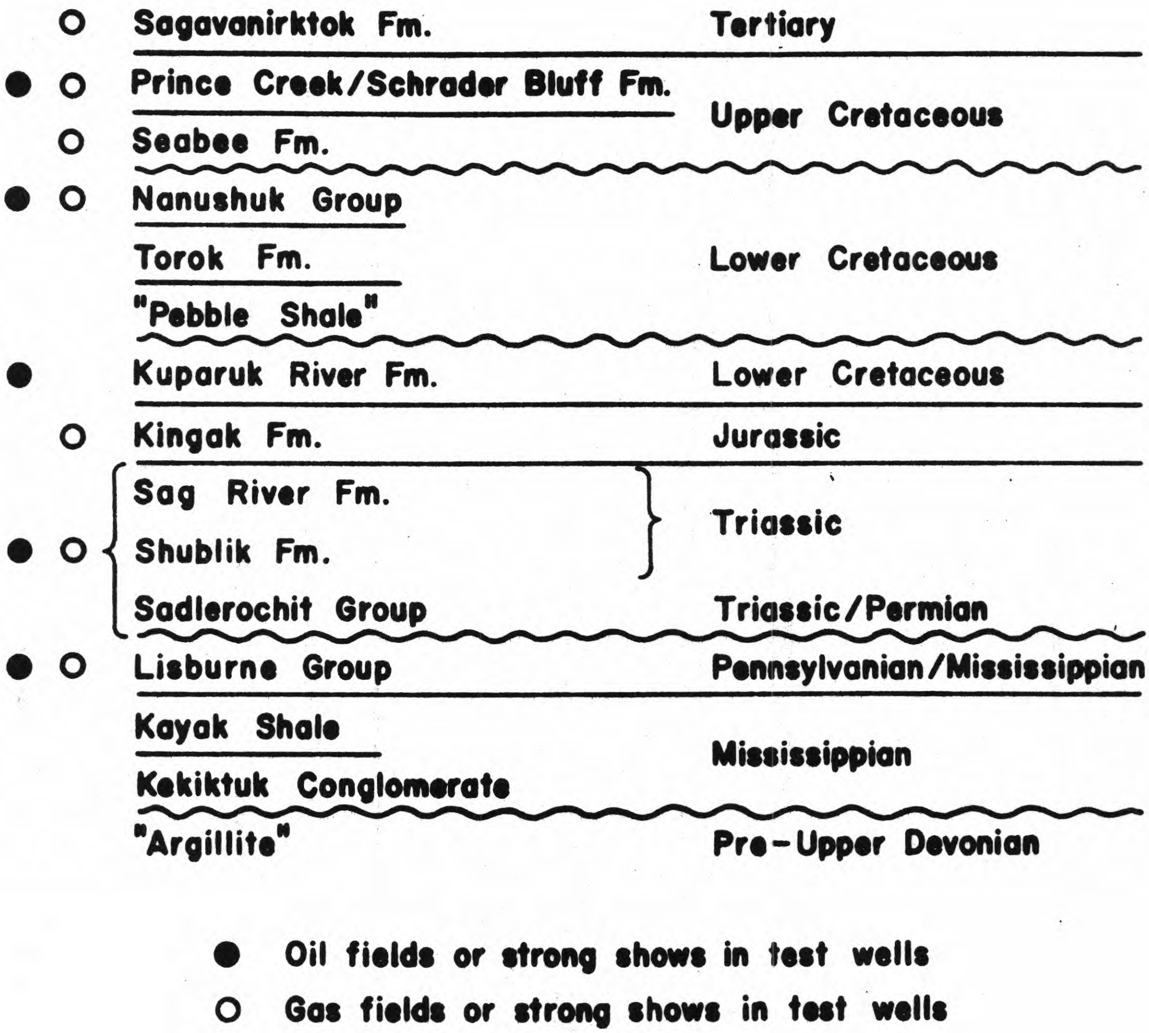

Figure 3. Generalized stratigraphic column beneath the Arctic coastal plain of northern Alaska, showing position of oil and gas fields and of strong snows of oil and gas in test wells. (Data from Alaska Geologic Society, 1971 and 1972, Brosgé and Tailleur, 1971, Jones and Speers, 1976).

In Late Jurassic and Early Cretaceous time the northern part of the Arctic Platform and the northerly source terrane for its shelf sediments was rifted away, leaving behind a continental margin typical of the rifted (Atlantic) type, with basement scarps facing northward, or oceanward. Concurrently, the Arctic Platform was tilted down to the south and overridden by nappes from newly formed tectonic highlands in the area of the present Brooks Range. An asymmetric foreland basin, the Colville geosyncline, formed north of the new mountains on the southward tilted platform.

The northern apex of the rifted and tilted Arctic Platform forms a broad structural culmination of regional extent, the Barrow Arch, that trends parallel to the Beaufort coast. This arch underlies the southern part of the Beaufort shelf, and structurally dominates the proposed lease sale area. The south flank of the arch is the southward tilted Arctic Platform; the north flank is the subsequently modified scarp left behind by the removal by rifting of the northern part of the Arctic Platform in Late Jurassic-Early Cretaceous time. Modification of the north flank was by partial collapse of the scarp into the newly created oceanic basin that now lay north of it. Post-rift tilting, folding and faulting have created some subsidiary geologic structures on the arch.

The Colville geosyncline was filled rapidly with Cretaceous and, on the eastern North Slope, Tertiary clastics from the newly formed highlands in the area of the Brooks Range. Southern sources now replaced the former northern sources of clastic sediment on the former Arctic Platform. The Cretaceous sedimentary rocks exceed 6,000 m in thickness in the southern part of the asymmetric Colville geosyncline, where they consist mainly of Early Cretaceous flysch and mid- and Late Cretaceous molasse. These sediments thin to thicknesses of 500 m to 2,000 m and rest on a major angular unconformity where they overlap the northern rim of the geosyncline and the Barrow Arch on the Arctic Coastal Plain and southern Beaufort shelf west of Camden basin. In this region the highly organic "Pebble Shale" of Early Cretaceous age, at the base of the Colville sequence, overlies the truncated edges of Mississippian to earliest Cretaceous beds of the Arctic Platform shelf sequence. The overlying Cretaceous beds on the arch are in paralic and neritic to upper bathyl marine facies.

Western Beaufort Outer Shelf.--The outer half of the continental shelf of the Beaufort Sea west of about 150°W. is underlain by a progradational sequence of thick Cretaceous and thinner Tertiary clastic sedimentary rocks derived from the Brooks Range. Although the Cretaceous beds are marine and nonmarine beneath the Arctic Coastal Plain they probably become increasingly, and perhaps dominantly or entirely, marine beneath the outer Beaufort shelf. The Tertiary beds are nonmarine onshore, but probably contain both marine and nonmarine beds offshore.

The Cretaceous and Tertiary sequence is relatively thin over the Barrow Arch (500 m to 2,000 m), but it thickens rapidly to more than 5,000 m where it progrades seaward over the rifted and down-faulted north flank of the arch. Near the Beaufort shelf edge the sequence thins again where it partly onlaps, and partly overarches a shelf edge structural high. This high is postulated to be a slab of the Arctic Platform that broke away from the Barrow Arch by normal faulting and rotation, and which has subsided a few kilometers more than the arch itself. The high forms the seawardmost extent of consolidated continental crust on the Beaufort shelf and slope. The core of the Outer Shelf high probably consists mainly of pre-Mississippian metasedimentary rocks, although it is at least possible that it locally includes thin wedges of the Mississippian to earliest Cretaceous Arctic Platform shelf sequence.

The western Beaufort Outer Shelf progradational sequence extends to a steep continental slope characterized by deep slumping. Similar conditions also existed during and after deposition of the Cretaceous and Tertiary progradational shelf sequence, for the sequence contains slumps, apparent growth faults and associated gentle folds, and normal faults, all of which moved north, or basinward. Except for arching over the Outer Shelf high, folding played a relatively minor role in the deformation of the progradational shelf sequence.

Camden Basin.-- The eastern Beaufort shelf is characterized by a deep basin that extends landward, beneath the Arctic Coastal Plain, between Prudhoe and Camden Bays. This, the Camden basin, overlies and deeply buries the Arctic Platform and the east end of the Barrow Arch (see Fig. 2). East of Camden Bay the basin is mainly an offshore feature.

The Camden basin is filled with Late Cretaceous and Tertiary sedimentary strata. It is essentially a landward embayment of the progradational sequence of the outer Beaufort shelf, and it is stratigraphically continuous with that sequence. However, Tertiary strata constitute a much larger proportion of the section in Camden basin than in the western Beaufort Outer Shelf. The Cretaceous beds are mixed marine and nonmarine; the Tertiary beds are mainly nonmarine but contain beds of shallow marine origin in at least the upper part of the section near the coast. The entire section presumably becomes increasingly, and perhaps dominantly marine seaward. It is about 4,000 m thick at the coast, and attains thicknesses considerably more than this offshore.

Structurally, the western Camden basin beneath the continental shelf resembles the progradational western Beaufort Outer Shelf in that its strata are relatively flat-lying. In the eastern half of the basin, however, are large east-northeast-striking folds that are postulated to be thrust folds. One of these has a strike length exceeding 100 km and an amplitude exceeding 1 km. These folds occur only in the eastern part of the proposed lease sale area.

PETROLEUM POTENTIAL

The proposed lease sale area has good potential for large petroleum accumulations. The area is everywhere underlain by a significant thickness of unmetamorphosed and probably dominantly marine sedimentary rocks. Many of these rocks or their correlatives contain seeps and petroleum accumulations on the adjacent coast (see Figs. 1 and 3). The latter include the supergiant, multi-pool Prudhoe Bay oil and gas field, which extends beneath state waters on the Beaufort shelf.

Prudhoe Bay field has industry-estimated reserves of 9.6 billion bbls of recoverable oil in Permo-Triassic reservoirs, and total recoverable reserves from these plus Carboniferous and Cretaceous reservoirs that probably exceed 15 billion bbls. It is not valid, however, to assume from its proximity to the multi-reservoir Prudhoe Bay field that the Beaufort shelf necessarily contains similar large accumulations. The specific geometric and temporal conditions that created the Prudhoe Bay field may not have recurred elsewhere in the sub-crop area. Nevertheless, many of the key rock units and geologic structures and events that combined to produce Prudhoe Bay do extend into the proposed lease sale area. Therefore, Prudhoe-like accumulations or other types of large hydrocarbon accumulations are possible in the proposed lease sale area.

Arctic Platform.--The potential reservoir strata of the Arctic Platform that extend offshore beneath the Beaufort shelf, in general, improve in porosity and permeability northward toward the crest of the Barrow Arch and the Beaufort OCS. Concomitantly, however, most of the strata thin northward and in places wedge out before they reach the OCS. The principal source bed, the richly organic Lower Cretaceous "Pebble Shale," appears to extend undiminished beneath the OCS.

The reservoir rocks that appear to offer atractive petroleum prospects on the Beaufort OCS are dolomitized limestones in the Lisburne Group, the Ivishak Formation of the Sadlerochit Group, the Sag River Formation, sandy facies of the Kingak Formation and the Kuparuk River Formation, all of which contain hydrocarbons on the North Slope (see Fig. 3 for the stratigraphic position of these units). Updip wedgeouts of these formations on the south flank of the broad Barrow Arch, particularly between Prudhoe and Smith Bays, and structural closures in these rocks on the crest and flanks of the arch would offer viable drilling prospects. Such prospects would be especially attractive if it can be demonstrated that significant volumes of potential reservoir rocks lie updip of fault-plane, unconformity or bedding-plane contacts between the potential reservoir rocks and the highly organic "Pebble Shale" or organic facies in the Kingak and Shublik Formations. A preliminary assessment of available data indicates that there is a good chance that such prospects exist on the Arctic Platform in the proposed lease sale area. Many seeps, shows, and some petroleum accumulations have been found in post-Arctic Platform marine Cretaceous rocks on the Arctic Coastal Plain. These rocks extend offshore into the lease sale area, where they offer prospects on the flanks and crest of the Barrow Arch.

<u>Western Beaufort Outer Shelf.</u>--The Beaufort Outer Shelf north of the relatively steep north flank of Barrow Arch contains petroleum prospects in Cretaceous and Tertiary progradational shelf sedimentary rocks. Seismic records and onshore geologic conditions suggest that both marine sandstones and shales, including the organic carbon-rich "Pebble Shale" are present. Numerous stratigraphic and structural traps related to down-to-the-basin faulting and possible growth faulting may be present. It is possible, though not likely, that significant

thicknesses of reservoir rocks of the pre- "Pebble Shale" Arctic Platform sequence underlie the Cretaceous progradational shelf sequence.

Camden Basin.--Within the proposed lease sale area the Camden basin contains petroleum prospects in thick marine and nonmarine Cretaceous and Tertiary sedimentary sequences. Potential source rocks for oil and gas include the Lower Cretaceous "Pebble Shale", Upper Cretaceous organic carbon-rich fissile shale, and Miocene or Pliocene marine claystone. Dry gas may have been generated in the many coal beds known to be present in the Upper Cretaceous and Tertiary beds of the basin. Potential reservoir beds are likely among the many paralic and neritic sandstones that can be inferred in both the Cretaceous and Tertiary parts of the sequence. In the area of the proposed lease sale these rocks contain very attractive structural prospects in down-to-the-basin normal faults and fault blocks and, east of 146° W. long., in large east-northeast-trending anticlines. On the OCS Arctic Platform rocks can be projected beneath the Camden basin only in a relatively small area near Prudhoe Bay field where they may be prospective for hydrocarbons.

RESOURCE APPRAISAL ESTIMATE

Geological estimates of the undiscovered recoverable oil and gas resources of offshore northern Alaska between the 0 and 200 m isobaths were reported in U.S. Geological Survey Circular 725 (1975). Estimates for the Beaufort Sea province, which includes the proposed lease sale area, are:

	Probability 95%	Probability 5%	Statistical Mean
Oil (billions of barrels)	0*	7.6	3.28
Gas (trillions of cubic feet)	0*	19.3	8.2

* The possibility of the occurrence of no commercial oil or gas in a frontier province such as the Beaufort Sea is very real, consequently a marginal probability is assigned. In this instance, the probability of no commercial oil or gas is estimated to be 25 percent, consequently estimates of the quantity of resource to be found at the 95-percent probability level are '0'.

A specific geological resource assessment of a restricted portion of the Beaufort Sea province, such as the proposed sale area, is not realistic because of the paucity of necessary geological information. An allocation can be made, however, on the basis of the proportion of the total area judged to be prospective which lies within the 20 m isobath, about 60 percent. It was determined that Federal acreage comprised about 85 percent of this restricted area. On the basis of these calculated ratios, the ranges of estimates of undiscovered recoverable oil and gas resources for the proposed sale area are:

Oil (billions of barrels)	0 to 3.9
Gas (trillions of cubic feet)	0 to 9.9

This estimate represents the range within which the undiscovered resources are expected to fall; though probability levels or confidence limits have not been assigned, they may approximate 5 and 95 percent.

Much of the Federal acreage in the proposed sale area and the adjoining state acreage is believed to be amenable to drilling and producing operations under conditions of present-day economy and technology. Both Federal and state lands are also considered favorable from a resource standpoint on the basis of the restricted amount of geological information available and on the basis of proximity to known reserves. Thus, the assumptions and the resultant estimates are considered to be reasonable.

ENVIRONMENTAL GEOLOGY

The modern geologic environment of the Beaufort OCS is unique in that a major role is played by sea ice and ice-related processes. Information gained in studying recent geologic processes of temperate latitudes is not strictly applicable to the Beaufort OCS due to this unique influence.

General Description.--The Alaskan Beaufort Sea coastline is characterized by low tundra bluffs and a complex of river estuaries, bays, barrier island chains and coastal lagoons. The continental shelf ranges in width between 35 and 90 km, slopes gently to the north, and is essentially flat except for the extensive micro-relief caused by the plowing and churning action of drifting ice in contact with the seafloor. Landward of the 20 m isobath subtle linear topographic highs parallel the coast. Nearshore, a prominent bench inside the 2 m isobath is apparently related to the seasonal growth of sea ice.

Shelf Deposits.--The shelf of the Beaufort Sea is essentially a seaward extension of the low, flat coastal plain and is probably underlain by shallow water marine and terrestrial sediments of the Gubik Formation. These sediments crop out in scour depressions and where the Holocene sediments are absent. Surficial Holocene deposits generally consist of 5 to 15 m of fine-grained marine mud and sand deposited since the post-glacial rise in sea level. Sedimentation rates are low even off river deltas. Local accumulations of gravel and boulders, mainly along the shelf break, apparently represent relict ice rafted materials. Modern ice rafting does not appear to be a significant process of sediment transport.

The thin veneer of Holocene sediments and the low regional slopes of the shelf indicate that the materials are not subject to large-scale slumping. Steep, but short, slopes at ice gouges and scours are, however, subject to small-scale slumping. The surficial sediments in these areas are frequently disrupted and reworked. Large-scale slumps and slides do occur along the continental slope. Likewise, the coastal bluffs show evidence of slumping and mass wasting, primarily due to the erosion of ground ice and frozen soil by surface water during the summer months. This process has resulted in bluff retreat at average rates of 3-5 m per year along the entire coast. Extreme rates of 30 to 50 m have been recorded at coastal promontories during major storm events.

Ice Regime.--The seasonal freeze thaw cycle along the coast starts with the formation of river and sea ice during September. By the end of December the ice is commonly more than a meter thick, and it thickens to a maximum of about 2 m in May. In late May and early June, 24-hour insolation aids rapid thawing and river flow is initiated. Most of the lagoonal and open shelf fast ice inside the 10 m contour melts in place by the middle of July. The ice-melt zone off rivermouths can reach a width of 10-15 km in response to the influx of warm river water. The remaining sea ice continues to melt and move offshore through the completion of the cycle in late July, August and early September.

The winter ice canopy overlying the shelf can be divided into three broad categories: (1) seasonal floating and bottomfast ice of the inner shelf; (2) a brecciated shear (stamukhi) zone consisting of grounded ice ridges that marks the zone of interaction between the stationary fast ice and the moving polar pack; (3) the polar pack of new and multi-year flows, ridges and ice-island fragments that are in almost constant motion.

The fast ice zone is composed mostly of seasonal first-year ice, which, depending on the coastal configuration, extends out to the 10 to 20 m isobath. By the end of the winter, the ice inside the 2 m isobath rests on the bottom over extensive areas. In early winter the location of the boundary between undeformed fast ice and the westward drifting polar pack is controlled predominantly by the location of major coastal promontories. Pronounced linear pressure and shear ridges form along this boundary and are stabilized by grounding, generally between the 10 to 20 m isobaths. Slippage along this boundary occurs intermittently during the winter forming new grounded ridges in a widening zone (the stamukhi zone) which ultimately extends out to about the 40 m isobath by late winter. A causal relationship is seen between major ridge systems of the stamukhi zone and the location of offshore shoals downdrift of major coastal promontories. These shoals, which absorb a considerable amount of the kinetic energy during the arctic winter, appear to have migrated shoreward up to 400 m over the last 25 years.

The polar pack consists of floes 2-4 m thick and pressure ridges with maximum observed draft of 47 m. The general drift of the pack is to the west under the influence of the Pacific Gyre.

Ice Gouging.--Ice moving in response to wind, current, and pack ice pressures often plows through and disrupts the shelf sediments, forming gouges. Gouges are generally oriented parallel to the shore and incisions commonly range from 0.5 to 1 m deep. However, gouges cut to a depth of 5.5 m have been measured on the outer shelf. The density of gouges may be as high as 300 or more per kilometer of survey trackline. Regions of high-gouge density are commonly found within the stamukhi zone and along the steep seaward flanks of topographic highs. Inshore of the stamukhi zone, seasonal gouges may be abundant but can be smoothed over during a single summer by wave and current activity.

Oceanographic Regime.--The overall movement of water on the shelf off northern Alaska is toward the west. On the inner shelf, the oceanographic regime is strongly influenced by winds and the presence or absence of ice. Sub-ice current observations reveal less than 2 cm/second flow velocities in the absence of wind stress, except in areas where the tidal prism is constricted by ice growth and in inlet channels where velocities up to 25 cm/second have been recorded.

The normal tidal range is only 15 to 30 cm, but storm conditions during late summer and fall commonly create several fluctuations of a meter or more each season. During major storms, fluctuations of more than 3 m have been observed.

Permafrost.--The distribution of subsea permafrost and its ice content are poorly known. Drill-hole and thermoprobe data indicate that bottom sediment temperatures are commonly below 0° C. on the inner shelf. Where ice rests on the bottom it can conduct heat away and may result in local temperature anomalies. Ice-bonded sediments apparently do not occur at the seafloor on the shelf. The top of the ice-bonded sediments is close to the seafloor out to the 2 m isobath, beyond which it drops off sharply.

Development Problems and Constraints.--The geologic environment imposes problems and impresses constraints on petroleum development. An understanding of the relevant geology and geologic processes is necessary to avoid or mitigate such problems during development.

Stamukhi Zone - The intense ice-bottom interaction and ice ridging associated with this zone will probably limit initial offshore development to areas within the fast ice. However, the location of the stamukhi zone, and therefore the extent of the fast ice, may to some extent be deflected seaward by artificial structures.

Ice Gouging - The integrity of bottom-mounted structures will depend heavily on the maximum depth, distribution and recurrence interval of ice-bottom interactions.

Erosion - Coastal thermokarst erosion and barrier island migration will be a significant factor during the lifetime of structures built in these areas. Construction of causeways, and mining of barrier islands for sand and gravel, will require a thorough prior understanding of nearshore sedimentary processes and the origin of the sand and gravel in the islands.

River Flooding - The initial snow melt and river flooding of the sea ice, followed by flood-water drainage has the potential to transport and widely distribute within a few days any pollutants and debris accumulated throughout the winter. Scour activity at sinkholes in shore and bottomfast ice could be significant. A sudden impulse of river water interacting with an offshore (sub-ice) oil spill would probably enlarge the area affected.

Permafrost - Coastal structures inshore of the 2 m water isobath, especially heated or refrigerated pipelines, will influence the permafrost regime. Nearsurface, ice-rich permafrost will probably not be encountered farther offshore. But the presence of deeper, possibly gas-rich, permafrost must be anticipated.

Suspended Sediments - Water clarities, highest in winter, could be altered by construction activities, which may serve to resuspend particulate matter. This would have a direct adverse effect on the productivity of benthic communities on the seafloor and sub-ice surfaces.

Storm Surges - Erosion, sea level set up of several meters, and major onshore ice movements associated with storm-related sea-level changes occur unpredictably, but primarily during the fall.

Fresh Water - Due to permafrost and the annual freezing of most streams to the bottom, fresh water sources have already become over-used. Utilization of ice melt, storage of river flow and substitution of sea water are possible alternatives.

Because of geological problems, development on the Beaufort OCS appears to be technically feasible at present only inshore from the stamukhi zone. Within and seaward of the stamukhi zone, the forces and rate of ice-sea interaction are not well understood. Of particular concern are the poorly documented dynamics and size of shelf ice deformational features. These deformational features commonly form during storms and may be larger than when those formed during the intervening quiet periods.

DEVELOPMENT CONSIDERATIONS

Sea ice and its movement are major factors to be overcome in offshore oil and gas development in the proposed Beaufort Sea lease sale area. The Arctic climate and geographic location are additional factors which will influence the technology, operating procedures, timing and cost of offshore operation in this area. Following is a brief description of some of these conditions which are of prime importance in the design of equipment and planning for this area.

1. Sea Ice - The one environmental condition which most affects offshore operations and development in the Beaufort Sea is sea ice. Variable ice conditions occur over the proposed lease sale area ranging from relatively stable land-fast ice in shallow water to multi-year polar pack ice which is in nearly constant motion and contains large ice flows or ice islands. The ice regime and some related development problems are described in the previous section under environmental geology. Design criteria and operational limitations will vary over the proposed lease area with varying ice conditions, and basic information for developing these criteria and limitations include:

    a. The extent and thickness of ice cover on a seasonal and long term basis.

    b. The ice behavior including the amount, direction and velocity of ice movement for the various ice zones.

    c. Ice strength information.

    d. Characteristics of pressure ridges and ice islands and the area and probability of occurrence.

e. Area, extent and degree of ice scoring or gouging from moving ice and the probability of occurrence.

f. The possible occurrence of offshore permafrost, ice lenses and frozen gas (hydrate) below the seafloor.

2. Arctic Climate - While considerable experience has been gained in recent years in oil and gas exploration and development in the Arctic areas of Alaska, Canada and other countries, the Arctic climate continues to be a major factor in the feasibility of year round operations in this area. Cold temperatures and chill factors as a result of strong prevailing winds and subzero temperatures combine with long periods of darkness in the winter season to create an environment which greatly reduces human efficiency and greatly increases the demand for equipment, materials and energy, including specialized equipment and materials for subzero temperatures.

3. Geographic Location - The proposed sale area in the Arctic Ocean is one of the farthest removed proposed OCS sale areas. The distance and routes to industrial areas and supply centers, combined with the Arctic climate, make logistics of exploration and development activities formidable and expensive, requiring careful planning and scheduling and large investments. Likewise, the transportation of oil and gas from this area to a market involves special technology; large investments of time, material and money; and political involvement on a statewide, national and international basis.

OFFSHORE EXPERIENCE

To date, offshore oil and gas exploration and development in the Arctic has been limited to drilling from shore and natural islands by directional drilling methods, drilling from artifically constructed islands, and drilling from thickened ice platforms. Also, a program underway utilizing mobile drill ships to drill during the ice free season from off the Mackenzie Delta, and drilling and production operations in the ice affected areas of the Upper Cook Inlet have some analogous application. Information on these techniques and some of their limitations is summarized below:

1. Direction drilling - wells directionally drilled to bottom offshore have been drilled using conventional onshore drilling techniques from shore and from offshore islands in both the Alaskan and Canadian Beaufort Sea areas. Directional drilling permits exploratory drilling and production from a subsurface location for 1-3 miles laterally distant from the surface location. However, the technological limitations of directional drilling of less than the 3 nautical mile distance, required to cross State submerged lands to the shoreward boundary of OCS lands, makes this procedure inapplicable to exploration and development of OCS lands except from offshore artificial islands or fixed or mobil structures.
2. Artificial islands - several artificial islands constructed from gravel and/or silt have been successfully used for exploratory drilling in the Mackenzie Delta area of the Beaufort Sea. Experience gained from eight artificial islands in water depths to 7 m shows that this is a feasible method of exploration in shallow water areas. The islands can be designed for self destruction or can be reinforced for permanent

production facilities. At least one artificial island is proposed for exploration drilling on Alaska state submerged lands over the 1976-1977 season and several additional artificial islands are planned or under construction in the Canadian Beaufort Sea area.

3. Ice strengthened platforms - Pan Arctic Ltd. has drilled nine exploratory and delineation wells in as much as 286 m of water and 22 km from shore off Ellef Ringnes and Melville Islands in the Canadian Arctic from artificially thickened ice platforms. This technique combines conventional land drilling equipment with the use of offshore subsea wellheads and riser equipment. The ice platforms are thickened to 4.8 to 5.5 m by alternate flooding and freezing of natural sea ice to support drilling equipment. The application of ice strengthened platforms for oil and gas exploration drilling is controlled by horizontal ice movement and to areas of shorefast ice with little or no movement. Such platforms are also limited to seasonal use between December and May to be able to build and maintain the necessary ice strength.

4. Upper Cook Inlet - The offshore oil and gas platforms in the Upper Cook Inlet were designed to withstand fast moving ice flows up to 1.2 m thick. Ice loads were the controlling design factors for these platforms and resulted in a special design of one, three and four legged, tower-type platforms with wells protected inside the legs and minimum exposure in the zone of ice action. Considerable design and operating information and data in this ice affected area have been gained from 14 platforms and production pipelines which have been installed and operated on a year around basis since the first platform installation in 1964.

5. Beaufort Sea Project - Important exploration operations are scheduled in the Canadian part of the Beaufort Sea later this summer (West, 1976). Two wells will be drilled 64 to 80 km off the Mackenzie Delta in about 30 to 65 m of water during the ice free late summer. These wells are part of a planned five-year exploration program that may include a total of 15 exploration wells in the Canadian Beaufort Sea. The consortium has invested more than $200 million in three ice-strengthened drillships. The drilling fleet consists of nine vessels consisting of a work barge, four icebreaker supply boats, a bulk carrier, and a tug in addition to the drill ships. The rigs will be left in the area during the winter to allow quick mobilization for the short summer operating season. The Geological Survey has been invited to participate as observers. It is anticipated that this exploration program will generate a great deal of technological data and experience that will be useful in exploration activities off the coast of Alaska.

STATUS OF RESEARCH

Research projects - Arctic Research and data gathering has been conducted for many years by various U.S. agencies and institutions, including CRREL, USGS, NSF, Arctic Institute of North America, the Navy, U.S. Coast Guard and many others. Also there has been considerable Beaufort Sea research and studies conducted by Canadian government agencies and universities. Oil companies and industry cooperative groups have been active in recent years in conducting research related to oil and gas exploration and development in the offshore arctic including studies on oceanography and sea ice, environmental baseline, ice and structures, bottom sediments, ice scour, permafrost, drilling structures and systems, oil spill and clean up, etc. The Arctic Research Subcommittee of the Alaska Oil and Gas Association is the U.S. organization with 27 member companies which has sponsored 24 research projects. The Arctic Petroleum Operators Association, the Canadian industry group, consisting of 37 companies has sponsored over 75 projects related to oil exploration and development in the Arctic. A recent cooperative effort between the Canadian industry organization and the Canadian government for the Beaufort Sea Project has involved such research and development of information pertinent to the environment and oil and gas activities in the Beaufort Sea and the publication of some 39 project reports. Technology and concepts for exploration and development in the Beaufort Sea area are progressing and a number of these concepts and further developments are in the testing phase.

New concepts - The development of new concepts and technology for offshore Arctic oil and gas operation is following the pattern of offshore oil and gas development which has been a step-by-step process. First directional drilling from shore and the construction of artificial islands in shallow water followed by new technological innovations for possible use in deeper water and areas of heavier ice coverage. These innovations involve various proposed concepts for exploration and production within the ice affected areas including the use of moored ships and mobile structures with ice breaking capability, fixed structures of conical or other monopod designs with ice breaking or ice cutting capability, air cushion barges with ice-melting capability, and under-the-ice drilling vessels. Most of these concepts are in the design or research phase while some are now in the prototype and testing phase. Most industry estimates indicate at least five to ten years of research and development of technology for exploration and development capability in water depths deeper than 20 m.

Table 1, is a summary of "present and future water depth capabilities and earliest dates for exploration drilling and production for United States Outer Continental Shelf Areas" (the Beaufort and Chukchi Sea areas) projected by the National Petroleum Council in their report "Ocean Petroleum Resources", March 1975.

MANPOWER

Most of the skilled manpower for exploratory drilling will have to come initially from other areas. The reservoir of manpower needed for the drilling, development, and production, including the installation of platforms, pipelines and onshore facilities, is relatively small owing to 1) the low population density in Alaska and 2) the continued need of and competition for qualified people in other OCS development areas. Some of the skilled manpower may be available in Alaska, depending on the stage of construction of the Trans-Alaska or other pipelines and of the Prudhoe Bay oil field. Also it is expected that replacements will be recruited from the local labor market and trained in the skills required. A large potential supply of manpower, available for training, exists in the Pacific Northwest and California. Availability will depend in large part on the relative state of the national economy and in finding a sufficient number of individuals willing to work far from home in harsh climatic conditions for long periods of time.

TIME FRAME FOR DEVELOPMENT

Estimates of a time frame for development and production from a new area are conjectural at best. This is expecially true in an area such as the Beaufort Sea where technology for the development of the ice pact areas in water depths of more than 20 m remains to be developed. Speculative factors

Table 1 -- Presnet and Future Depth Capabilities and Earliest Dates
Exploration Drilling and Production for United States Outer Continental Shelf Areas

		Maximum Water Depth Capabilities		Earliest Date	
		Exploration Drilling *	Production	Exploration Drilling	Production #
17.	Beaufort Sea	Gravel islands and island-type structures 50 feet. Land fast ice (as in Kotzebue Sound) may be drilled. Conventional offshore rigs not usable in areas of heavy moving ice. Anticipate that current R & D projects such as ice-breaking drillships will extend present capabilities.	Gravel islands and island-type structures 50 feet. Concrete or steel cone structures may be feasible to 200 feet. Drillship capability may permit UWC if latter can be designed for potential bottom ice conditions.	Now, selectively, with some modifications to existing equipment for specific areas	At present, production from gravel islands and island-type structures 4 to 5 years after field discovery and delineation, provided development drilling from same island as exploration drilling. In the future, development cycle periods for deeper water dependent on current R & D. Additional overland pipelines required for moving petroleum to southern ports, since the pipeline presently under construction will be fully used by projected North Slope production forecasted from current discoveries.

* All jackup rigs derated from indicated maximum water depth capability during severe seasons.
\# "Ready for production" assumes all development wells drilled before initial production; one rig per platform. Development period related to number of wells, drilling depth, drilling conditions. Number of wells not limited to examples given.

Source: National Petroleum Council, 1975 which can affect development of water areas 20 m or less in depth include the ready availability of needed equipment and materials, discovery success, reservoir and hydrocarbon character, economic climate and other conditions which can cause unforeseen delays (labor disputes, environmental matters, etc.). Development of the National Petroleum Reserve of Alaska and State of Alaska offshore leases, should such development occur with similar timing, would provide some additional logistical support to the movement of material and equipment in the area.

Testimony provided by the Alaska Oil and Gas Association to the Alaska State Division of Lands, January 23, 1975, estimated 4 to 8 years to initial production and 6 to 10 years to maximum production for development of the nearshore State lands in the Beaufort Sea area. This was with the assumption that pipeline outlets would be available. It is estimated that initial production from OCS leases with water depths less than 20 m could be attained within 5 to 10 years, but it is doubtful that peak production from the lease sale area could be realized before 8 to 12 years. These figures also assume availability of pipeline outlets.

Projection of timing for development in deeper water areas affected by the polar ice pack are highly speculative. Most industry estimates indicate at least 5 to 10 years of research and development of technology for exploration and development capability for waters deeper than 20 m.

The expensive operating conditions and the expected high cost of equipment for Alaska operations will likely restrict development to lease areas within reach of present and near term developing technology and to fields having very large recoverable reserves and sufficient potential for economic development.

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