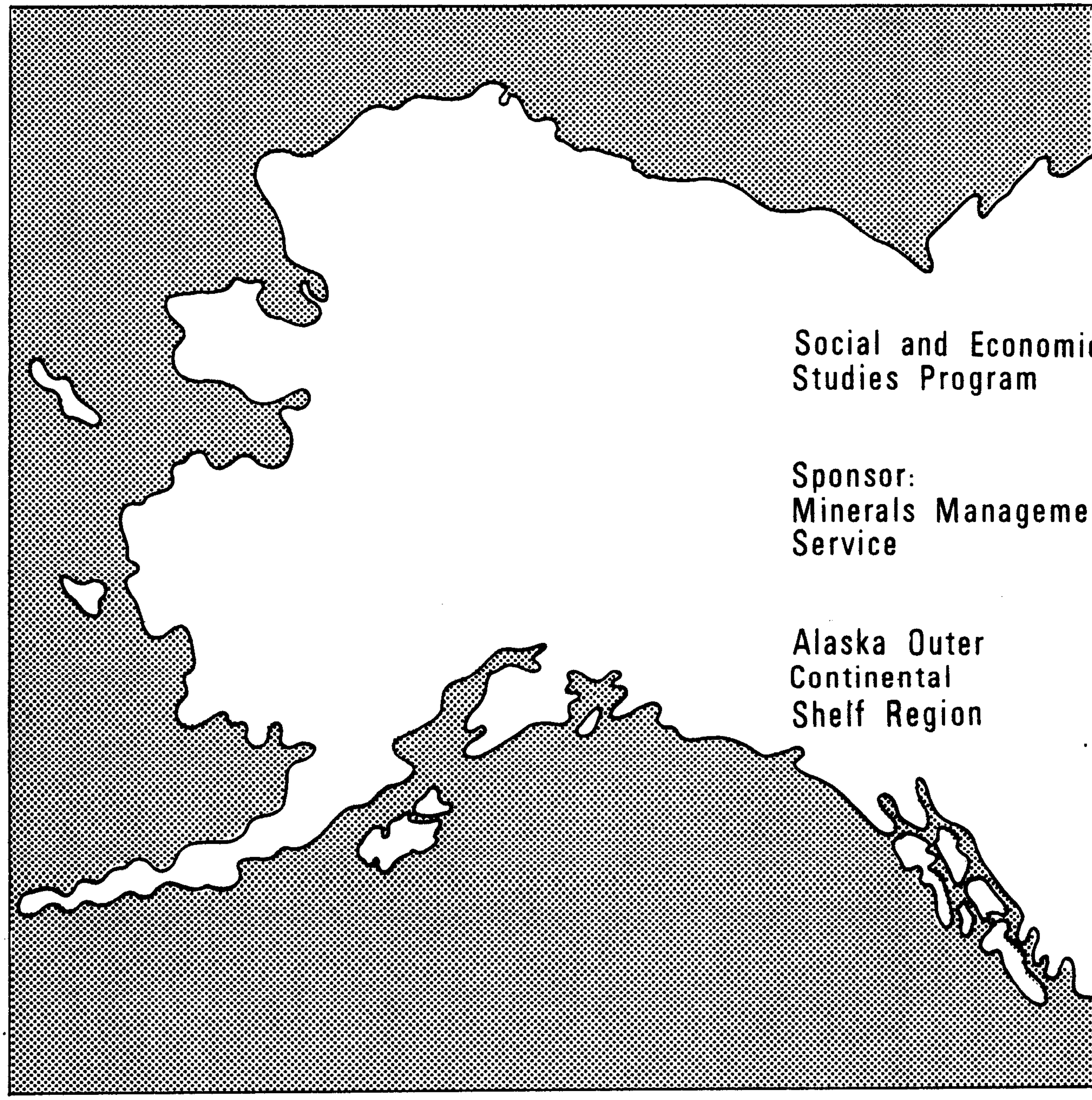
Technical Report
Number **81**



Social and Economic
Studies Program

Sponsor:
Minerals Management
Service

Alaska Outer
Continental
Shelf Region

HOPE BASIN PETROLEUM TECHNOLOGY ASSESSMENT

Technical Report

ALASKA OCS SOCIOECONOMIC STUDIES PROGRAM
HOPE BASIN PLANNING AREA
PETROLEUM TECHNOLOGY ASSESSMENT

Prepared for

MINERALS MANAGEMENT SERVICE
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JULY, 1983

Contract No. AA851-CT1-37

Job No. 08699-026-20

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ABSTRACT

Based on data available to date, petroleum resources in the Hope Basin OCS Planning Area have been assessed as low and marginal fields appear likely. The area has been deleted from the current five-year OCS Leasing Schedule. Hope Basin is to the south of the adjacent Barrow Arch (Chukchi Sea) Planning Area and an earlier companion study reported on that area's related technology and economics.

Hope Basin petroleum development will be restricted primarily by the expected low reserves, associated small field sizes and, to some extent, by greater average water depths than other arctic areas. Environmental constraints to Hope Basin development are similar to those described in the Barrow Arch report, but usually (except for seismic exposure) slightly less severe, e.g. the sea ice conditions are reduced and the open-water season is longer. Exploration could likely be done with more floating rigs than other arctic areas.

Unlike other planning areas examined during these Alaska OCS Socioeconomic Studies Program analyses, Hope Basin petroleum development will probably be more significantly dependent on developments in the adjacent region. Important outside facilities include potentially re-usable drilling structures and other arctic equipment already available and proven to be efficient for marginal fields, and an oil transportation infrastructure established to serve adjacent areas' production.

1.0 INTRODUCTION

1.1 Purposes

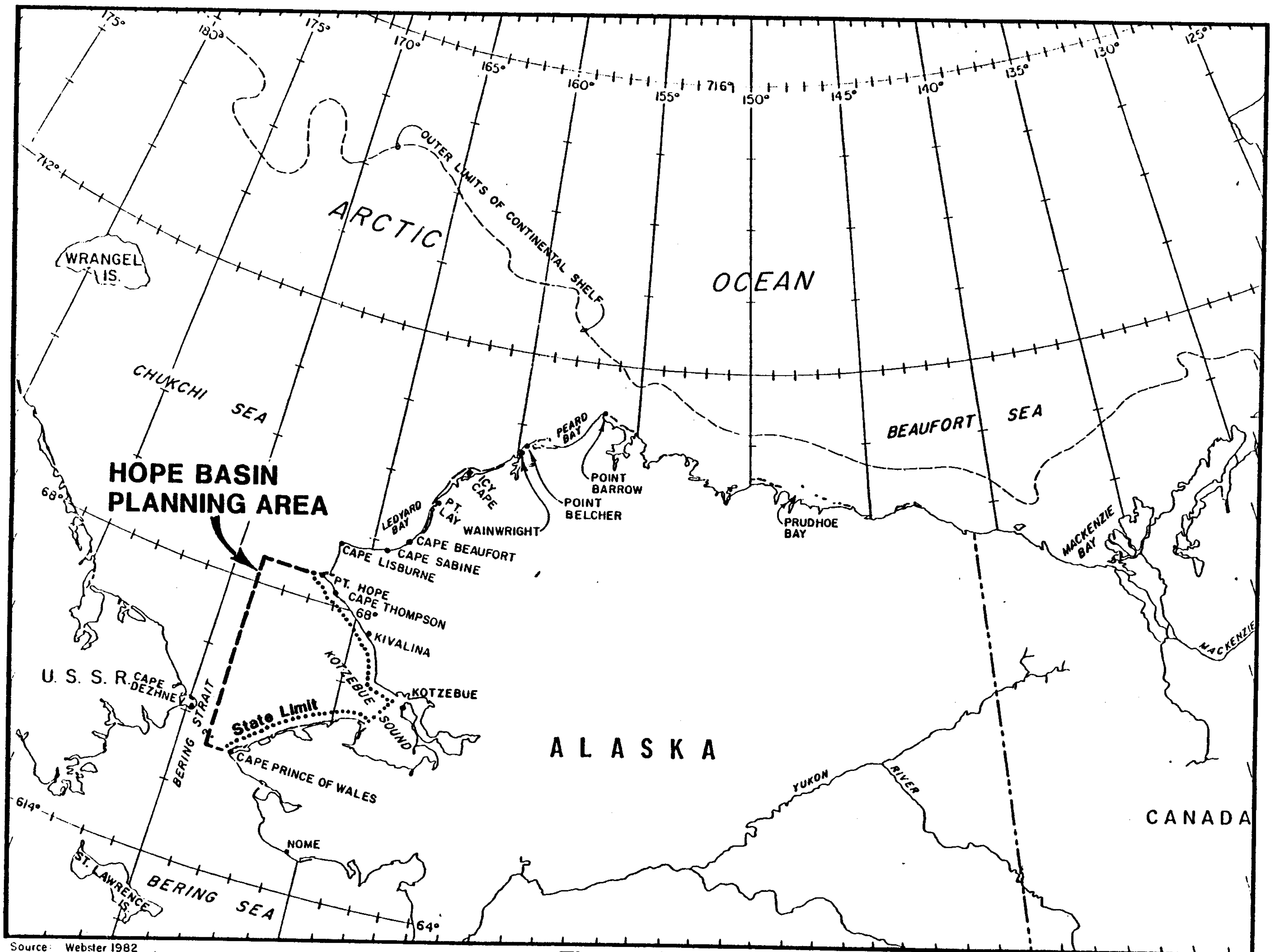
The principal purpose of this study is to identify the petroleum technology that may be used to develop oil and gas resources for the Hope Basin OCS Lease Sale. This analysis focuses on both the individual field development components (types of platforms, pipelines, etc.) and the overall field development and transportation strategies. An evaluation of the environmental constraints (oceanography, geology, etc.) defines the most suitable engineering strategies. In addition, the manpower required to construct and operate the facilities selected for analysis was estimated.

The emphasis in this discussion is on arctic production technologies for marginal fields. This is in response to the low total hydrocarbon resources estimate and the likely small field sizes, coupled with somewhat less harsh arctic offshore conditions.

Unlike other studies in this series, an economics assessment is not included in this report. This was requested by Minerals Managmement Service because this lease area was taken off the 5-year OCS leasing schedule and an economic analysis at this time would be too dated when, and if, this sale is held.

1.2 Background and Scope

This petroleum technology assessment is for the Hope Basin OCS Planning Area, one of three arctic planning areas. A proposed lease sale for the Hope Basin was recently dropped from the 5-year OCS oil and gas leasing schedule. The Hope Basin planning area encompasses the area in the southern Chukchi Sea shown in Figure 1-1, which is bounded on the south by a line westward from Cape Prince of Wales (about 65° 35'N latitude), on the east by the 3-mile limit of the State of Alaska waters; it is bounded on the north by a line westward from Point Hope (about 68° 15'N latitude) and to the west by the U.S.-Russia Convention Line of 1867 (about 169° W longitude).



Source: Webster 1982

Figure 1-1

GENERAL LOCATION MAP

OF PROPOSED HOPE BASIN OCS PLANNING AREA IN THE SOUTHERN CHUKCHI SEA

This report is the second of two reports assessing oil and gas development technologies for the two Chukchi Sea lease sale planning areas (Barrow Arch and Hope Basin). The first report was a technology assessment for the Barrow Arch (formerly Chukchi Sea) OCS Planning Area, and it will be helpful for the reader to be familiar with this companion document. While this report does not include a time-sensitive economic analysis, a general appreciation for Hope Basin economic considerations may be gained by reviewing the Barrow Arch report.

This study is structured to provide "building blocks" of the petroleum facilities, equipment, costs, and employment that can be used by Minerals Management Service Alaska OCS Region staff to evaluate nominated lease tracts. Scenarios involving probable feasible field development strategies for oil and gas (types of platforms, transportation options, etc.) are described.

Petroleum technology, in conjunction with the regulatory framework and any stipulations, will influence or determine the scheduling of offshore and onshore activities, the local employment and infrastructure support requirements, and the potential risks involved in the production and transportation of hydrocarbons and related potential for environmental impacts. Thus, this petroleum technology assessment provides a key part of the necessary framework to assess the environmental and socioeconomic impacts of petroleum development in the Hope Basin Planning Area.

This report provides early information for the Minerals Management Service to initiate planning for a lease sale. As such, this is part of the regulatory process for OCS development, but specific stipulations regarding this possible lease sale are not known at this time.

It should be emphasized that this report is specifically designed to provide petroleum development data for the Alaska OCS socioeconomic studies program. This study, along with other studies conducted by or for the Minerals Management Service, including environmental impact statements, is required to use U.S. Geological Survey estimates of recoverable oil and gas.

However, at the time this report was prepared, no U.S. Geological Survey resources report was available specifically for the Hope Basin Planning Area. Therefore, estimates of recoverable oil and gas were obtained from the recent National Petroleum Council's report on U.S. Arctic Oil and Gas (1981) and an independent evaluation of the area's petroleum geology (Chapter 3.0). The assumptions used in the analysis may, therefore, be subject to revision as new resources data become available.

The principal components of this study are:

- A review of the petroleum geology of the Barrow Arch Planning Area to formulate reservoir and production assumptions (Chapter 3.0).

- An evaluation of the environmental constraints (oceanography and geology) that will influence or determine engineering field development and transportation strategies (Chapter 4.0).

- A review of state-of-the-art and conceptual technology for exploration, production and transportation of oil and gas from arctic regions (Chapter 5.0).

- A description of various field development components, strategies and related technical problems (Chapter 5.0).

- A discussion of facilities siting to identify suitable shore sites for petroleum facilities such as crude oil terminals and support bases (Chapter 6.0).

- A discussion of petroleum development strategy considerations, resulting in identification of specific alternative scenarios for Hope Basin development (Chapter 7.0).

- Estimates of the manpower requirements to explore, develop, and produce Hope Basin petroleum resources in the context of projected technology, and environmental and logistical constraints. This includes classification of manpower requirements by individual tasks and facilities (Appendix A).

- Appendix B gives estimates of petroleum development costs upon which an economic analysis may be based.

The study methodology is basically the same as that employed by Dames & Moore in preparing previous petroleum technology assessments for other Alaska OCS lease sale planning areas, with the exception of time-sensitive economic analyses. However, this study's analytical approach was structured to accommodate both Chukchi Sea study areas. While appropriate sections of previous studies in this series are incorporated by reference, the basic data set for this analysis is unique to the Chukchi Sea and was specifically assembled for this report. Contrasts between this area and other Alaska OCS lease sale areas have been identified where appropriate.

1.3 Data Gaps and Limitations

Results of this study are preliminary and should be reviewed in the context of the constraints imposed on the analysis by significant data gaps. This study is based upon available public data such as the geophysical records of the U.S. Geological Survey (USGS) and the results of the oceanographic surveys conducted by the National Oceanic and Atmospheric Administration (NOAA) and other agencies. No proprietary data were available to this study, although both agency and industry reviews of important technical and geologic assumptions were made.

The principal data gaps include:

- Oceanography -- Data on the seasonal extent and annual variation of landfast ice and multiyear pack ice coverage for the Chukchi Sea are still limited. Even more limited are data on dynamic ice movement and forces generated, critical data for platform design and overall production feasibility.

- Petroleum Geology -- Geophysical data for the geologically complex Hope Basin Planning Area are extremely limited. Seismic data is reconnaissance level only.

- Facility Cost -- The petroleum facility cost estimates (for platforms, pipelines, terminals, etc.) are tentative; no petroleum exploration and production has yet taken place with the same conditions that may provide direct operational and cost experience.

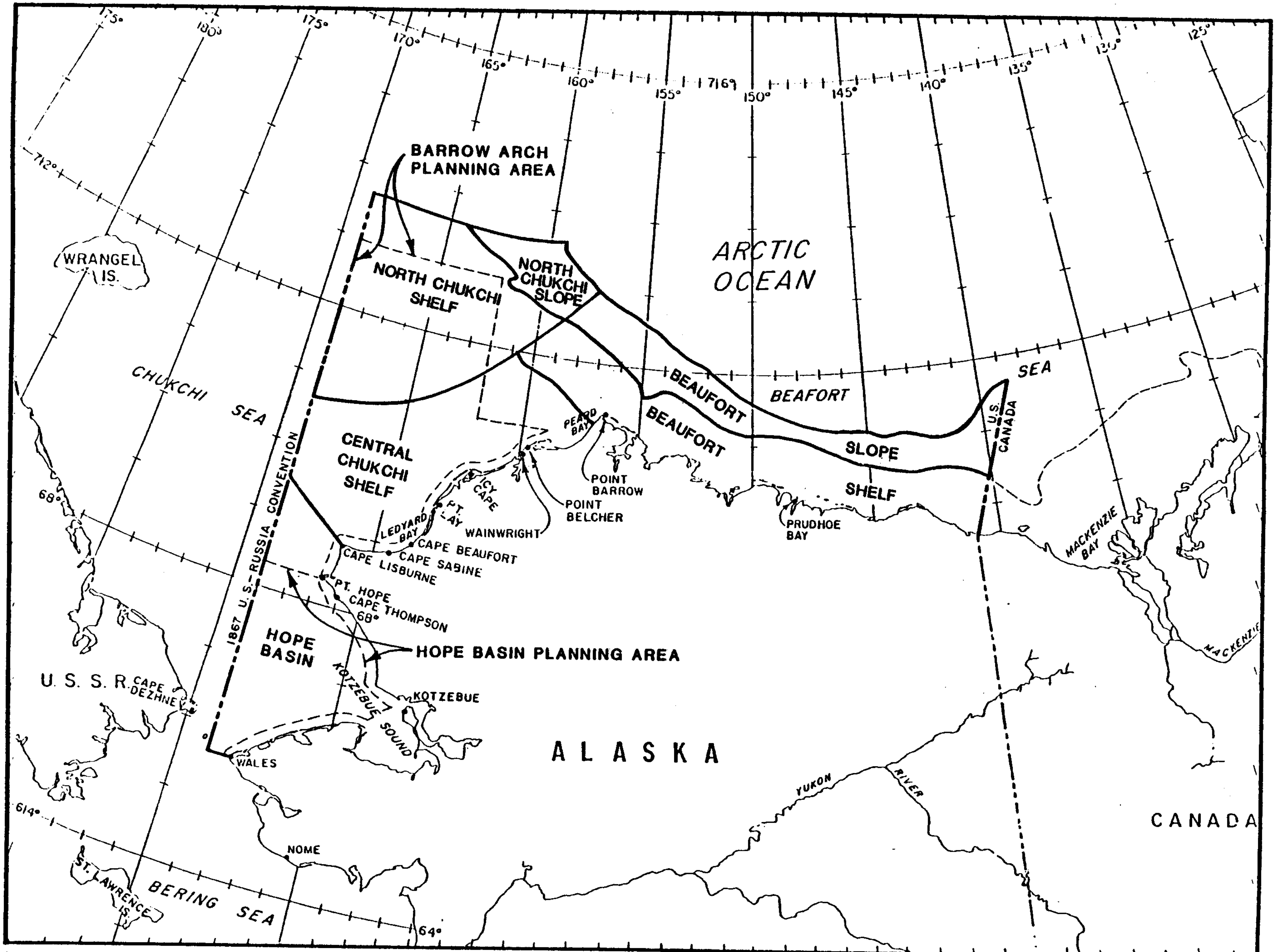
2.0 SUMMARY

The Hope Basin Petroleum Technology Assessment is the second of two reports describing Chukchi Sea OCS areas; the earlier Barrow Arch Planning Area study described the northern portion of the Chukchi Sea. The present report focuses on the geological Hope Basin sedimentary deposits in the southern Chukchi Sea. There are similarities between the two areas of the Chukchi Sea (but not in their petroleum geology) and this study incorporates and references material of the earlier Barrow Arch study. This summary focuses on information that is unique to the Hope Basin Planning Area; the reader is encouraged to also review the Barrow Arch report for more detailed context and additional perspective regarding the Hope Basin OCS Planning Area.

Petroleum Geology

The relationship of the Hope Basin province to Barrow Arch and other petroleum provinces in arctic Alaska is shown on Figure 2-1. The lack of information about the Hope Basin makes comparison to other basins difficult. The Hope Basin does not have significant similarities to the North Slope province. A full description of the petroleum geology of the Hope Basin suffers from a lack of data: limited seismic work has been published and no COST wells have been drilled. The studies that have been conducted indicate thick sections of sediment over acoustic basement. The basin probably developed in two stages, a late-Tertiary subbasin less than a hundred kilometers wide resulting from extensional tectonism. This lies within a broader mid-Tertiary or early-Tertiary basin that is more than two hundred kilometers wide. The basin crosses over the U.S./Russia treaty line, however, the areas of greatest potential lie within the U.S. portion of the basin.

There are no formations in the Hope Basin that are known to contain oil or gas reservoir rocks. Reservoir qualities of the basin can only be generalized from geophysical characteristics and regional stratigraphic relationships. Extensive faulting is present and seismic data indicates that trap-producing faults could be expected about every 20 kilometers (12 miles). This implies a tendency to smaller field sizes.



Source: National Petroleum Council 1981; Webster 1982.

Figure 2-1
ARCTIC OFFSHORE OIL & GAS PROVINCES

An USGS resources report is not available for Hope Basin at this time, and the limited information regarding the Hope Basin makes the study's assessments of recoverable reserves and other production parameters very speculative. Initial production is estimated at 1,000 barrels per day per well. Well depths will range 1,000 to 3,000 meters (3,000 to 10,000 feet) with an average reservoir depth of approximately 1,200 meters (4,000 feet). Recoverable reserves of forty thousand barrels per acre of primary recovery with twenty thousand barrels from secondary recovery are assumed. Assuming fifty percent fill-up, an up-scale field size of 50 to 100 million barrels is projected.

Environmental Constraints

In general, the environment contraints of the Hope Basin are similar to those presented in the Barrow Arch study. Sea ice will be a predominate design constraint. The Hope Basin Planning Area affords a longer probable open-water season, approximately 85 days, benefiting floating equipment use for drilling and construction. Overall ice design factors will be somewhat less than those for equivalent Barrow Arch structures.

During the open-water season storms and waves will be the dominant environmental constraint. Other hazards include local coastal erosion rates greater than one meter per year and permafrost conditions. The geologic structural history of the basin suggests shallow gas may be a drilling hazard. There is some low seismic activity in the region.

On the average, water depths in Hope Basin Planning Area are deeper than Barrow Arch . The shallowest zone, along the state boundary, is on the order of 30 meters (100 feet), which covers only a thin coastwise strip of seafloor. The majority of the area of interest for petroleum can be characterized by a depth of about 37 meters (120 feet), and there are some potential oil basins in deeper waters, averaging 50 meters (165 feet). The generally greater water depths of the Hope Basin area increase the cost of platforms, especially gravel islands, but also provide better clearance for floating drilling rigs to operate, due to greater riser/drillstring flexibility. While these depths are deepwater in the persective of present arctic petroleum production technologies, the somewhat reduced ice constraints and promising future achievements of arctic offshore technology should combine to make Hope Basin production feasible by the time it might be leased.

The remoteness and lack of infrastructure in the area will place added demands on petroleum operations and projects. Pipeline distances northward to a Lisburne Peninsula landfall (the most likely direction) are generally shorter that Barrow Arch distances. The lower latitude of this arctic area makes it the easiest to support using floating equipment, such as drilling rigs and dredges.

Petroleum Technology Assessment and Development Scenarios

Exploration in Hope Basin is most likely to be done predominately from floating drilling platforms. This is in contrast to other arctic areas, and is the result of several characteristics: deeper water, smaller and shallower targets and longer open-water season.

Offshore production systems will tend towards ice-resistance drilling platform structures that are bottom-founded on natural seafloor or dredge-and-fill berms. Monocone-type structures should prove attractive. The water depths are too deep to favor gravel islands without caisson structures to retain the upper portion (through the wave and ice zone).

An important aspect of Hope Basin petroleum development is its timing relative to other OCS lease sale areas in the arctic. The Hope Basin Planning Area may benefit from the future availability of re-usable production platforms (and related support construction and transportation equipment) from adjacent areas. This may prove essential to the economic viability of Hope Basin.

Similarily, oil transportation scenarios for production of Hope Basin's marginal fields will likely depend upon the existence of infrastructure already in place in an adjacent region. Outside components needed to facilitate Hope Basin oil movement are those facilities that support the final transport to market, e.g., ice-breaking shuttle tankers, transshipment terminal, or overland pipeline to TAPS. Therefore the transportation components constructed in Hope Basin will be mainly pipelines to collect and consolidate production to a location and system type (overland pipeline or tanker terminal) that is in fact determined by neighboring production areas (e.g. Barrow Arch, NPR-A, Norton Sound) and the characteristics of that existing transportation system.

Economics of Petroleum Development

The economics of Hope Basin petroleum development and its technologies were not included in this study because this planning area has been removed from the current OCS 5-year leasing schedule. However, cost estimates for technological components are included in this report (Appendix B) and the reader's reference to the companion Barrow Arch report's economic analysis will provide a basis for judging the important economic aspects of Hope Basin development.

The following general comments provide a perspective on key economic characteristics of Hope Basin that at this time are expected to dominate a future economic analysis:

- The low resources forecasted for the basin and the small field sizes and shallow reservoirs estimated imply that major new development will not be supported by Hope Basin, and that whatever development might occur would tend towards smaller production platforms.

- The above point implies a potential for higher costs per barrel (more production units per barrel are needed compared to the large field sizes and high productions of the Barrow Arch platforms).

- Hope Basin shows a potential to be more of a gas-producing than oil-producing province, and recent evaluations of marketability of Alaska gas suggest very little economic incentive to develop gas for the near future.

- The postponement of the Hope Basin OCS Lease Sale offers a potential for re-utilization of drilling and production structures originally built and installed for other arctic areas. (The area's tendency towards smaller fields with shallow reservoirs might even make conversion of arctic exploration drilling structures into small production platforms a feasible option.)

- The small scale of petroleum resources implies that shared facilities outside the Hope Basin OCS Planning Area will probably be critical to the area's economic feasibility.

3.0 PETROLEUM GEOLOGY, RESERVOIR, AND PRODUCTION ASSUMPTIONS

3.1 Introduction

Published geology of the Hope Basin is known mainly from single channel seismic data interpreted by the USGS and published in several reconnaissance-type reports. A current project of the USGS is to process and interpret multi-channel seismic reflection data for a more detailed determination of the geologic framework and petroleum potential. The multi-channel data indicate considerably thicker sections of sediments over the acoustic basement and more faulting than previously thought to exist (Reed 1982).

There have been no Continental Offshore Stratigraphic Test (COST) wells drilled in the Hope Basin and the sedimentary section in the two onshore oil and gas exploratory wells drilled on either side of Kotzebue Sound by SOCAL are thought not to represent sediments that are known (from geophysical interpretation) in the offshore basin (personal communication, Steven May, USGS, Menlo Park, CA).

Water bottoms lying within 3 miles of the Alaska coastline are owned by the State of Alaska. Approximately 250 kilometers (155 miles) of Alaska coastline adjoin the northeast limb of the Hope Basin between Point Hope and Cape Krusenstern.

Part of the Hope Basin lies west of the U.S.-Russia Treaty line but, on the basis of the reconnaissance seismic information now available, it appears that the most interesting portion of the basin is well within the U.S. boundary.

The hydrocarbon potential of this basin is of interest because it contains a thick sequence of Tertiary and perhaps Cretaceous sedimentary rocks and numerous structures, many of which appear to have had episodes of active growth shortly after periods of deposition early in the history of the basin.

Section 3.2 reviews the petroleum geology of the Hope Basin to provide the geologic specifications for the reservoir and production parameters and assumptions. The assumptions are presented in Section 3.3. The reader will also find related geological background information in sections 4.2.2 and 4.2.3.

3.2 Summary of Hope Basin Petroleum Geology

3.2.1 Regional Framework

The geological structure of Hope Basin, (Figure 3-1), is thought to be much less complicated than the Barrow Arch Planning Area adjoining it on the north. Most of the faults, anticlines and synclines are oriented in a sub-parallel fashion and in a general way radiate into the southern Chukchi Sea from Cape Krusenstern. On the north, the sediments lap on the Herald Arch, which forms the northern geologic boundary of Hope Basin, and on the south, they overrun the Kotzebue Arch and thin out on the north coast of the Seward Peninsula. The young basin-fill sediments lap on the Kotzebue Arch, a prominent eastwest feature that appears to connect topographically with the southern Brooks Range through the Igichuk Hills at Cape Krusenstern. This connection is clearly seen in gravity data as a positive anomaly along the Kotzebue Arch and extends inland to about 160° W longitude (Eittreim 1977) a distance of about 200 kilometers (124 miles).

The sediments of the Hope Basin have not been dated and their correlation with the bedded rocks of adjacent land areas is conjectural. However, the rocks filling the Hope Basin are probably late Cretaceous or Tertiary in age and the sequence was deposited in local intracontinental basins south of the Brooks Range. These rocks are tectonically distinct from the Brookian sequence of Tertiary age lying north of the Brooks Range.

The very dense rocks representing the core of the Brooks Range mountains probably underlie the younger basin fill and extend across the Bering Strait to the Chukotsk Peninsula of Siberia.

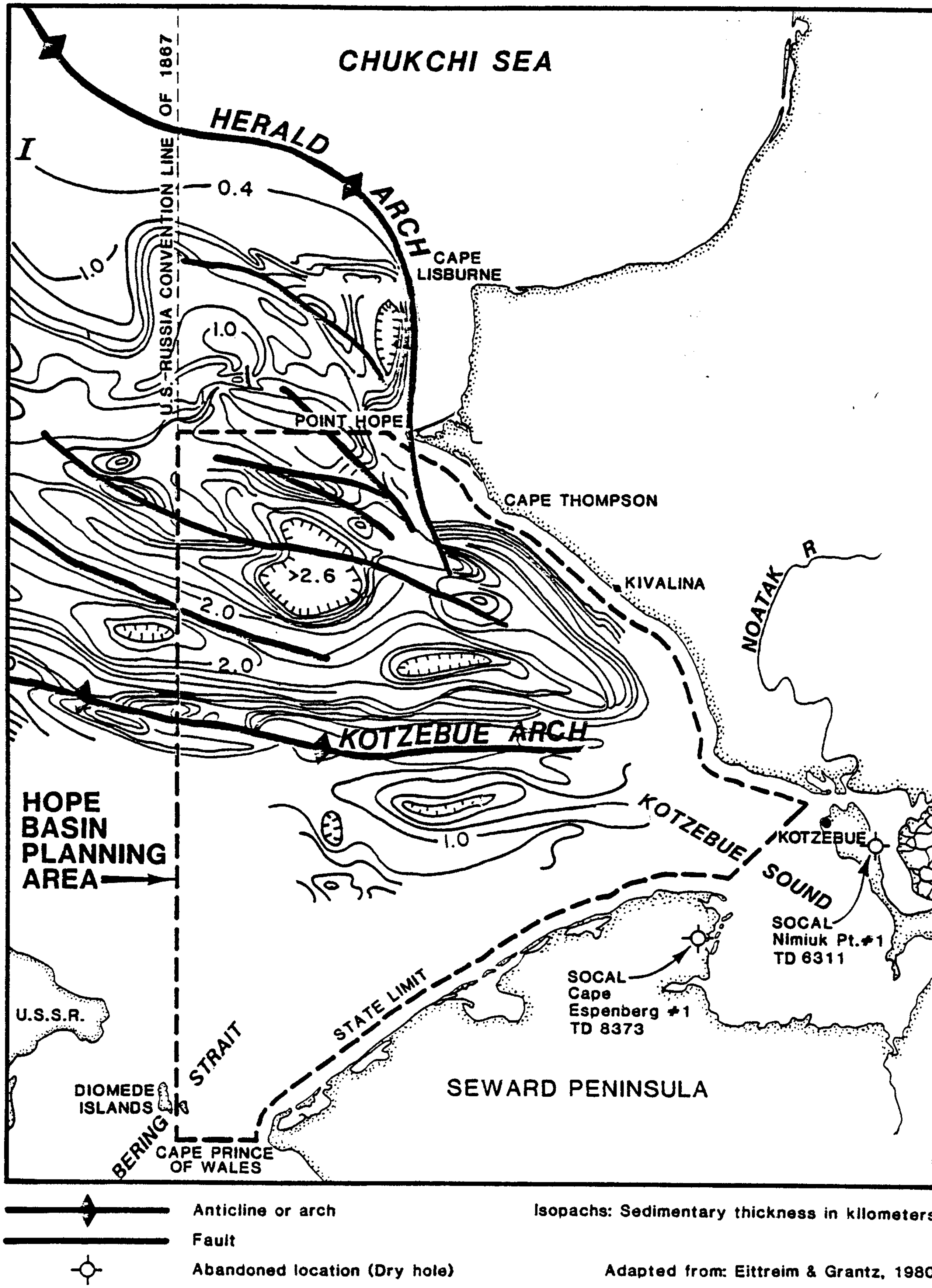


Figure 3-1

PRELIMINARY TECTONIC MAP OF HOPE BASIN

3.2.2 Structure

A series of basement ridges and faults subdivides the Hope Basin into a number of east-west troughs in which sediment thicknesses locally may exceed 5 kilometers (16,000 feet). The longest of the basement ridges is the Kotzebue Arch, a structural high that trends westerly across the southern part of the basin.

The Kotzebue Arch probably forms the Hope Basin's southern boundary of areas with sediment thicknesses of interest to hydrocarbon exploration. Interpretation of multi-channel seismic data suggests that the Kotzebue Arch is a more subtle feature than the earlier single channel data indicated.

During the late Tertiary period, a deep, east-west elongate sub-basin developed in eastern central Hope Basin north of Kotzebue Arch. The axis of the sub-basin is defined by a thickening of the sedimentary section above a key regional seismic reflector believed to approximate the late Cretaceous-early Tertiary boundary. Subsidence of the sub-basin was accommodated by numerous faults and the Kotzebue Arch itself was concurrently uplifted several hundred meters. Between Point Hope and Cape Krusenstern, the late Tertiary sub-basin is bounded by normal faults parallel to the coast that also form the western boundary of the DeLong Mountains and the western Brooks Range. The northern boundary of the sub-basin is a series of monoclines and normal faults that bring older rocks to the surface on the Herald Arch. Westward, the sub-basin gradually diminishes in depth, and near 171°W longitude on the Soviet side of the U.S.-Russia Treaty line its ridge and trough structures end.

An episode of volcanic and tectonic activity strongly affected the Seward Peninsula and lower Kobuk Valley. Plio-Pleistocene basalts flooded a large area south of Kotzebue Sound and tectonic warping and faulting offset Miocene gravels and Pleistocene glacial deposits. These displacements were accompanied by the formation of sizable non-marine sedimentary basins and by block faulting in and adjacent to the Kigluaik and Bendeleben Mountains of the Seward Peninsula and the Waring Mountains of the lower Kobuk Valley. This tectonism may also have been responsible for the late Tertiary subsidence, arching, and faulting in Hope Basin.

In summary, Hope Basin developed in two steps. A late Tertiary sub-basin less than 100 kilometers (60 miles) wide resulting from extensional tectonism formed within a broader mid-Tertiary or early Tertiary basin more than 200 kilometers (120 miles) wide that was produced by late Cretaceous-early Tertiary subsidence.

3.2.3 Stratigraphy

Regional onshore stratigraphy suggests that both the sub-basin and the greater Hope Basin consist, at least partly, and perhaps largely, of non-marine rocks. However, a few marginal outcrops of late Tertiary marine strata and the periodic migration of late Tertiary marine fauna across Bering Strait indicate that some marine beds must occur in the sub-basin, which subsided rapidly. In both the older and younger basins, marine rocks may replace non-marine rocks away from shore.

It must be emphasized that the deep basin stratigraphy is actually unknown as no wells have been drilled in the basin. Correlation to surface geology in the Selewik area to the southeast and to the Seward Peninsula in the south are conjectural because multi-channel seismic profiling indicates that these onshore rock units wedge out near the perimeter of the Hope Basin. This means that the onshore wells drilled at Cape Espenberg and Nimiuk Point by SOCAL in 1977 may not be relevant to the central Hope Basin stratigraphy because the sedimentary section these wells penetrate appears not to exist in the Hope Basin except in the shallow southern margins (Figure 3-1). This conclusion is drawn because a prominent reflective seismic horizon seen at depth in the subsurface seismic interpretations in the area of the onshore exploratory wells rises to the surface of the Hope Basin in its southern perimeter. This does not mean that the Hope Basin does not contain the typical non-marine section found in the upper part of the SOCAL wells but does cast doubt on a direct correlation.

There are indications that post Tertiary, poorly consolidated sediments containing a large quantity of plant remains cover a wide area of the Hope Basin at very shallow depth due to the great abundance of shallow gas indicated by a high resolution Uniboom geophysical survey. These sediments are thought to be derived from Pleistocene age river and stream channels (personal communication, David Dinter, USGS, Menlo Park, CA).

3.2.4 Reservoir Rocks and Traps

Since there are no formations known to exist in the Hope Basin that contain recognized oil and gas reservoir rocks, it is only possible to generalize about reservoir qualities of the basin filling sediments from geophysical characteristics and regional stratigraphic relationships.

Seismic velocities are slow and of above average acoustic transparency compared to typical shelf sediments. Both characteristics suggest a relatively young age. In the northwest part of the Hope Basin more reflectors appear in the seismic data, perhaps indicating a lithology change.

Coal, shale, conglomerate and sandstone could be expected in the nonmarine rocks. Shales and sandstones are likely in the marine section.

A study of formation density logs (Fisher 1982) from the Cape Espenberg and Nimiuk Point wells suggests that on a regional basis, sandstone porosity decreases rapidly with depth so that mean porosities below 3 kilometers (9,800 feet) are less than 5 percent.

Faulting is very extensive in the Hope Basin and provides the greatest possibilities for hydrocarbon traps. Normal faulting, mostly parallel to the long axis of folds, is very common. Seismic data interpretation of lines run about 25 kilometers (15 miles) apart and indicate that a trap producing fault can be expected about every 20 kilometers (12 miles). The reconnaissance type of seismic surveys run by the USGS are not intended to define traps. Numerous "bright spot" zones are seen in the geophysics but gas seeps have not been reported. A disadvantage of the extensive faulting is that the fetch area providing hydrocarbons to each trap is small where the number of traps is large in a given area.

The eastern Hope Basin comprises three successively northward migrated overlapping clastic depocenters of possible late Cretaceous, early Tertiary, and late Tertiary age, giving rise to the possibility of stratigraphic traps in these rocks as they onlap the rise of the Herald Arch to the north.

3.2.5 Source Rocks

The nature of basin margin outcrops suggests that the Hope Basin was filled mainly by non-marine rocks. However, the presence of some marginal late Tertiary marine outcrops and the periodic exchanges of late Tertiary marine fauna across the Bering Strait indicate that at least part of the later Tertiary section is marine. Indeed, given a marine connection and a suitable interplay between subsidence and sedimentation, the Hope Basin could contain a significant section of late Tertiary, shallow water marine sediments (Grantz 1975).

The extensive normal faulting and nature of the sedimentary deposition, as interpreted from the geophysics, indicates that the Hope Basin is an extensional basin formed by separation of the basin flanks. Extensional basins are associated with high geothermal heat flow that could result in the ultimate generation of gas rather than oil from deeply buried carbonaceous sediments. Methane gas is expected to be the hydrocarbon derived from the non-marine rocks thought to fill most of the Hope Basin.

3.2.6 Comparison to Other Basins

It is difficult to make positive comparisons of the Hope Basin to any other basin because so little specific information is known about the Hope Basin at this time. When the U.S. Geologic Survey Resource Report is published it will provide more definitive information than the presently available raw data. Arthur Grantz and Steven May of the USGS have been most helpful in providing previews of how more sophisticated recent data may affect presently held and published concepts.

The Hope Basin does not bear important similarities to the North Slope province and the Hope Basin may have less oil potential than the Norton Basin. It is unlikely that the basement rocks in Hope Basin have any oil generating capacity, whereas Triassic rocks underlying part of the Norton Basin may be thermally mature, thus providing another possible source rock below the younger basin fill of the Norton Basin.

The Anadyr Basin of western Siberia, which lies southwesterly across the Bering Strait, is similar to Hope Basin in that non-marine rocks are thought to occur deep within each basin and marine rocks are thought to occur at shallow depths within each basin. Wells drilled in the Anadyr Basin have produced up to 10 million cubic feet of gas per day but continued testing led to sharp drops in pressure and volume. The Miocene (late Tertiary) producing sections were relatively shallow (1470 meters [4,800 feet]). An oil strike was recently reported by the Soviets in the west central Anadyr Basin at 1,650 meters (5,400 feet) but volumes were not reported.

3.3 Production Parameters and Assumptions

3.3.1 Initial Production Rate

3.3.1.1 Oil

Initial well production rate is used as an index of reservoir performance in the absence of specific data about reservoir characteristics (pay thickness, porosity, permeability, drive mechanism, etc.). Initial production rate refers to the sustained average productivity of a well over the first 45 percent of its total production, after which exponential decline occurs. The initial productivity per well influences the number of wells that have to be drilled to efficiently drain a reservoir. Assuming well spacing and the maximum number of wells that can be drilled from a single platform or drilling vessel (dictated by the reservoir depth and well spacing limitations), the peak throughput of a producing system can be estimated using the initial well productivity assumption.

Initial production rate for wells on fault traps in the Hope Basin Planning Area is assumed to average 1,000 barrels per day. The estimated depth of wells should range between 1,000 meters (3,000 feet) and 3,000 meters (10,000 feet). An overall average of 1200 meters (4,000 feet) is used as a base case in view of the rapid regional decrease of porosity with depth mentioned in Section 3.2.4. At this depth, the most favorable ratio of porosity, permeability, and pressure is anticipated to occur.

The initial productivity assumed for wells producing from stratigraphic traps will vary widely as depths of these traps range from very shallow to moderately deep. Considering that some of the productive potential may originate from clean clastics in truncation traps, an initial well productivity of 1,000 barrels of oil per day is also assumed for stratigraphic and combination structural and stratigraphic traps.

Within certain technical and economic constraints, the number of wells and their spacing can be varied, depending upon the initial well productivity, to optimize the recovery or take-off rate. These are trade-offs between the investment in additional wells, and the increased revenue streams from a higher offtake rate. (Increasing the number of wells will decrease the well spacing.) In general, the deeper the reservoir the more expensive are the development wells and the longer the drilling time. Thus, it is more advantageous to increase the number of wells in shallow reservoirs (1,000 meters [3,000 feet] or less) to overcome low initial well productivities than it is for deeper reservoirs.

3.3.1.2 Non-Associated Gas

Non-associated gas is thought to be the principal hydrocarbon of the Hope Basin because of the high heat flow of the extensional sub-basin and because much of the basin fill is thought to be non-marine sediments, which favors gas generation. Total reserves may be large but some suspected traps, which appear to contain gas on the basis of seismic interpretation, are extremely shallow (less than 300 meters [1,000 feet]) and are more likely to be avoided as drilling hazards than exploited as gas reserves.

Geochemical data are needed on shale well cuttings to determine the ability of a given potential source rock unit to generate oil or gas in the Hope Basin. This critical information is not avialable to us. For economic analysis, we will assume a gas well productivity of 10 million cubic feet per day.

3.3.2 Reservoir Depth

The available geophysical records indicate reservoir depths may range from 300 to 3,000 meters (1,000 to 10,000 feet). We assumed a single reservoir depth of 1,200 meters (4,000 feet). Analysis of the USGS seismic data provides limited control for the reservoir depth assumptions.

Reservoir depth defines the number of producing systems required to efficiently produce a given field size and, in combination with optimal well spacing, the maximum number of production wells that can be housed in a single producing system whether it be a platform, gravity structure or sub-sea system. All other factors being equal, a shallow field with a thin pay reservoir covering many square kilometers and requiring several systems to produce is less economic than a field of equal reserves with a deep, thick pay zone that can be reached from a single producing system. The well completion rate also affects the development drilling employment.

3.3.3 Estimate for Hope Basin

An assessment of recoverable reserves in a virgin basin such as Hope Basin is very speculative as all of the many reservoir parameters must be assumed or estimated.

Recovery factors range greatly in the Alaska North Slope oil province, which is the nearest area of established oil production. The Kuparuk Oil Field will yield about 31 barrels per acre foot on primary recovery and 62 barrels per acre foot on secondary for a total of 93 barrels per acre foot. At the high end of the range, the Prudhoe Bay Sadlerochit sands will probably yield 350 barrels per acre foot on primary and an additional 250 barrels per acre foot on secondary for a total of 600 barrels per acre foot. Geologically, the Kuparuk River and Prudhoe Bay oil field areas are very different than the Hope Basin area but the great range in recovery factors is demonstrated. A more typical example might be the Tertiary reservoirs of productive Pacific Margin basins in California, which contain considerable clay derived from unstable feldspars and usually yield about 200 barrels per acre foot.

Assuming a recovery factor of 200 barrels per acre foot and net pay thicknesses of 200 feet, recoverable reserves per acre approximate 40,000 barrels for primary recovery. Secondary recovery would add an additional 50 percent to the primary recovery amount.

We suggest 60,000 barrels per acre for use in future analyses. This assumes that a secondary recovery program (e.g., water injection) is initiated early in the development schedule. The field development plan should incorporate secondary recovery in the producing system and process equipment design since retrofitting for a secondary recovery program could be exceedingly expensive.

3.3.4. Field Size and Distribution

Three types of traps of economic importance may be present in this planning area. These are:

1. High angle normal faults generally oriented east-west.

2. Closed anticlines associated with normal faulting.

3. Updip pinchouts, onlap and erosional truncation traps on the rise of the Herald Arch.

Indications of all potential trap types are visible on the USGS seismic lines in the Hope Basin area but detailed seismic surveys would be necessary to provide a higher degree of certainty of structural closure. Only drilling will actually confirm closure.

Assuming that traps will be hydrocarbon-bearing, and assuming seismic data were available to identify structures and estimate the areas of closure, etc., the all-important resource question would be the prediction of percent fill-up. The approach used to predict fill-up would be an analogy based on statistical comparisons with known productive basins. It should be emphasized, however, that any analogical approach to prediction of petroleum resources is extremely hazardous. Each basin is unique. One critical difference in geologic parameters can completely negate the effect of many similarities.

Factors affecting percent fill-up are the richness of the source rock and quality of reservoir rock. In addition, trap density is also an important factor. Generally, the greater the trap density, the smaller the fill-up. As examples, the average percent fill-up of productive closures in the Pacific Margin Los Angeles and Ventura Basins are 40 and 15 percent full, respectively. On the less deformed Coastal Plain province of the North Slope, fill up is thought to be nearly 100 percent in the Kuparuk oil field. The high density of fault traps indicated on the seismic profiles in the Hope Basin should minimize the fetch area for each trap.

Unfortunately, there is no reliable way to estimate percent fill-up. We assume that fill-up of 50 percent would be a proper compromise between the extremes that are likely to be encountered.

The field sizes selected for economic screening were consistent with, or reflect, the following factors:

- U.S. Geological Survey resources estimates.
- Geology (discussed above).
- Anticipated economic conditions and the requirement to examine a reasonable range of economic sensitivities.

The field sizes evaluated in this study, therefore, ranged from 50 million barrels to 100 million barrels for oil and 0.5 trillion cubic feet for non-associated gas. It should be noted that once a number of field sizes (with a certain reservoir characteristic and matched engineering) have been evaluated, minimum economic field sizes could be calculated.

4.0 ENVIRONMENTAL CONSTRAINTS TO PETROLEUM DEVELOPMENT

This chapter discusses an evaluation of environmental constraints. It is important to note that this discussion is based upon current, publicly available data. In comparison to other OCS lease sale planning areas, this data base is very limited. In particular, data on sea ice characteristics and behavior--critical factors affecting exploration and production concepts--are very limited. Our study team includes industry expertise in sea ice engineering to provide experienced judgment regarding ice design parameters. Several proprietary data collection efforts by industry have been completed or are being planned; however, these were not available for this analysis, hence our conclusions should be regarded as preliminary.

4.1 Meteorology and Oceanography

4.1.1 Meteorology

The climate of Alaska's northwestern coast is classified as arctic by the National Weather Service. Summer weather is characterized by cool marine winds, frequent but light precipitation and considerable cloudiness and fog. In winter the cloudiness decreases and very cold winds prevail. Snow cover is established by mid-September and persists until June or July. Below-freezing air temperatures are the rule except in June, July, August and early September.

Although meteorological information has been systematically collected in the Arctic from coastal stations since World War II, available data records are still somewhat limited, relative to sub-arctic OCS areas. Particularly lacking are data from offshore areas due to the limited vessel traffic in the area.

Air temperatures in the lease sale region tend to be persistently low for most of the year. The U.S. Coast Pilot for the Arctic Ocean area provides a general description of the region's weather. Winters are cold and summers are cool. In November, average daily maximums drop to around -10°C (14°F) or below, while average minimums are around -18°C (0°F). February is generally the coldest month. Average maximums range from just above -17°C (1°F) at Kotzebue to -25°C (-13°F) east of Cape Lisburne. Low temperatures in the -30°C (-22°F) range are common. Extremes of -45°C (-49°F) or colder have been recorded.

Table 4-1 lists representative temperature information for several coastal stations along the Hope Basin and southern Chukchi Sea coast. While air temperatures over the arctic land mass are less stable than those over the polar ice pack, air temperatures over the pack ice are usually uniform and deviate little from day to day. In summer, the temperature over the pack ice remains relatively stable, near the freezing point.

Annual precipitation over most of the arctic coastal region is very light ranging from 20 to 50 centimeters (8 to 20 inches) annually in the southern Chukchi Sea and Hope Basin. Annual snowfall can range from 120 to 190 centimeters (47 to 75 inches) depending upon location and elevation. Some form of measurable precipitation falls on about 200 to 300 days per year, with heaviest precipitation in July, August and September, averaging 5 to 10 centimeters (2 to 4 inches) each month (U.S. Coast and Geodetic Survey 1979). Snow can appear in any month and usually predominates beginning in September (Arctic Institute of North America 1974). Table 4-2 provides data on precipitation measurements at coastal stations.

The relative humidity is generally high with values averaging from 60 to 90 percent throughout the year. However, the absolute humidity is very low due to the low air temperatures, which prevent water vapor buildup in the atmosphere, and the ice cover, which limits evaporation. Other types of precipitation experienced include rime or granular ice, which occurs over most arctic coastal regions throughout the year, and hoarfrost, which occurs in winter (Arctic Institute of North America 1974).

Wind conditions tend to be fairly constant along the Arctic coast year-round. The Arctic Institute of North America (1974) reports that a

TABLE 4-1

AIR TEMPERATURES AT ARCTIC COASTAL STATIONS

Station	Mean Annual °C (°F)	Summer Seasonal Maximum °C (°F)	Winter Seasonal Maximum °C (°F)	Record High °C (°F)	Record Low °C (°F)	Mean Number of Days 0°C (32°F) or Below
Tin City	-6.7 (19.9)	10.0 (50)	-23.9 (-11)	23.9 (75.0)	-42.2 (-44.0)	--
Kotzebue	-6.2 (20.8)	61.1 (61)	-24.9 (-13)	29.4 (84.9)	-46.7 (-52.1)	251

Sources: Brower et al. (1977)
Swift et al. (1974)

TABLE 4-2

PRECIPITATION AT ARCTIC COASTAL STATIONS

Station	Liquid Precipitation (cm) Annual Mean	Liquid Precipitation (cm) Monthly Maximum	Liquid Precipitation (cm) 24-Hour Maximum	Snow (cm) Annual Mean	Snow (cm) Monthly Maximum	Snow (cm) 24-Hour Maximum
Tin City	48.8	19.5 (Aug.)	5.0 (July)	190.5	62.7 (Sep.)	21.8 (Apr & Sep)
Kotzebue	20.8	13.2 (Aug.)	4.5	119.3	153.6 (Jan.)	21.8 (March)

Source: Swift et al. (1974)

general yearly average for the coastal zone is 24.2 to 32.2 kilometers/hour (15 to 20 miles/hour) at relatively exposed locations. Table 4-3 summarizes surface wind data compiled by Swift et al. (1974) for coastal stations along the Hope Basin and southern Chukchi Sea. Observational data summarized by Brower et al. (1977) indicates that 45 percent of all observations reported winds less than 19 kilometers/hour (12 miles/hour) and 5 percent of all observations reported winds less than 6 kilometers/hour (4 miles/hour).

High winds may occur at any time of the year although maximum velocities have historically occurred in the coldest months. Gales blow less than 1 percent of the time in the Hope Basin and southern Chukchi Sea, although winds reach 52 kilometers (32 miles/hour) or more up to 5 percent of the time. The Tin City coastal station most frequently reports strong steady winds. Gale force winds are experienced up to 5 percent of the time during winter (Energy Interface Associates 1979).

Brower et al. (1977) estimates that the 100-year wind speed may exceed 177 kilometrers/hour (110 miles/hour) in the Hope Basin and southern Chukchi Sea. Sustained winds of 93 to 105 kilometers/hour (58 to 65 miles per hour) have been recorded with gusts going much higher (Swift et al. 1974). In addition to the design parameters affected by surface winds, ambient wind conditions during the summer occasionally drive the pack ice into nearshore areas. This relatively rapid shift in the pack ice can adversely affect vessel and barge movements or other offshore activity associated with oil and gas exploration and development.

Fog is the major restriction to visibility in the Arctic. Dense fog can be expected to occur from 30 to 100 days each year along the coast. Offshore and inland areas are much less prone to fog. Advection or sea fog is the primary restriction to visibility during the warmer months of the year. It is most prevalent from June through September, and is most dense during the morning hours. Areas along the coast may have advection fog for up to 15 to 20 days per month in summer (Arctic Institute of North America 1974). In July and August visibilities drop below 3.2 kilometers (2 inches) 10 to 25 percent of the time (U.S. Coast and Geodetic Survey 1979). Advection fog,

TABLE 4-3

SURFACE WINDS AT ARCTIC COASTAL STATIONS

Station	Winter		Summer		Maximum Recorded	
	Prevailing Direction	Mean Speed (km/hour)	Prevailing Direction	Mean Speed (km/hour)	Prevailing Direction	Speed (km/hour)
Tin City	E, NE	32	N, S, SE	24	NW	105
Kotzebue	E, SE, NE	21	W	21	SE	150

Source: Swift et al. (1974)

provided by relatively warm, moist air moving over a cold surface, tends to persist due to strong temperature inversions that prevent turbulent dissipation (Energy Interface Associates 1979).

During winter, radiation fog, ice fog and steam fog can all reduce visibility. Table 4-4 presents annual and monthly data on fog conditions at coastal stations. It is apparent from the data that wide variations in visibility limitations are imposed by fog due to both season and location. In general summer fogging conditions tend to be about twice as severe as winter conditions at coastal stations. However, winter visibilities can be reduced to less than 0.8 kilometers (0.5 miles) by snow or blowing snow (U.S. Coast and Geodetic Survey 1979). Cloudiness is another prevalent condition along the entire arctic coast that tends to reduce visibility. Energy Interface Associates (1979) report that over 60 percent of the days are cloudy on an annual basis. During the summer and early fall, cloudiness occurs more than 70 percent of the time.

4.1.2 Bathymetry

The Hope Basin Planning Area extends west from Kotzebue Sound to the U.S.-Russian Convention Line of 1867. The Hope Shelf falls within the southern Chukchi Sea and is dominated by a submarine valley trending northwest towards Wrangel Island (Aagaard and Coachman 1964). Some seafloor scarps exist in the vicinity of Point Hope (Woodward-Clyde 1978).

Figure 4-1 illustrates the general bathymetry of the planning area. The southern section of the planning area extends southward to the Bering Strait at approximately 65 1/2°N.

4.1.3 Circulation

The circulation within the Chukchi Sea is known only in the most general terms, having been inferred from water mass studies reinforced by infrequent, short-term current meter measurements with some support from the concepts of bathymetric steering (Paquette and Bourke 1981).

TABLE 4-4

FOG CONDITIONS AT ARCTIC COASTAL STATIONS
(Percent Frequency of Occurrence Based on Hourly Observations)

Station	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tin City	31.9	26.4	31.7	30.4	38.4	42.1	44.4	48.6	37.4	23.1	13.9	16.4	25.5
Kotzebue	5.5	4.9	6.5	5.7	7.2	6.9	9.6	5.4	4.7	3.0	3.0	3.6	5.0

Source: Brower et al. (1977)

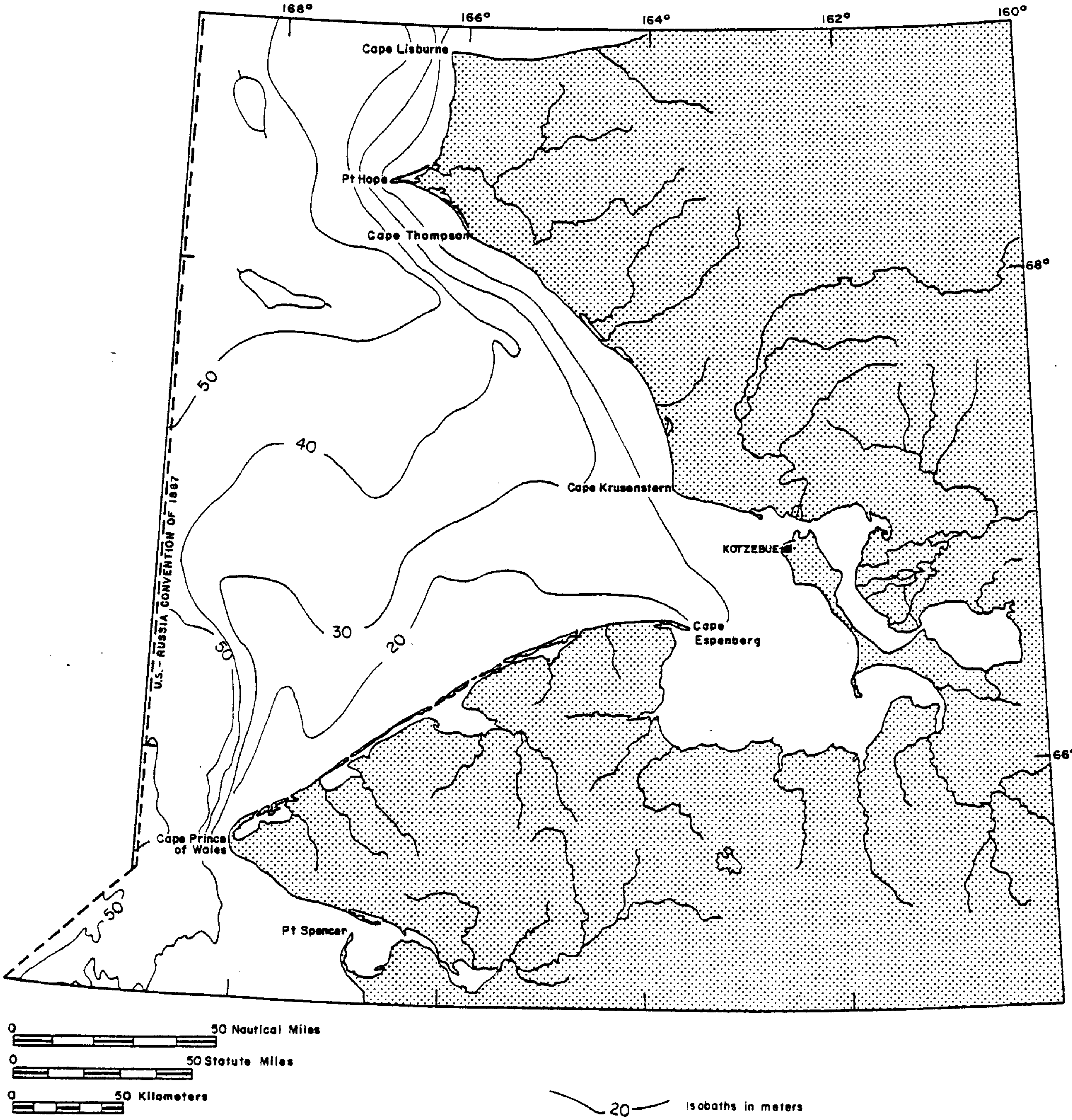


Figure 4-1

BATHYMETRY IN THE SOUTHEAST CHUKCHI SEA

Source: Adapted by Dames & Moore from Schumacher(1976)

Although the Chukchi Sea is part of the Arctic Basin, its currents are dominated by the northward flow of water from the Bering Sea. Detailed measurements show that the flow is predominately barotropic, with speeds and directions uniform from top to bottom (Arctic Institute of North America 1974). A pressure-induced, north-sloping sea surface is thought to cause the northward flow of water from the Bering Sea to the Arctic Basin (Coachman and Aagaard, 1966). In 1945, Russian scientists reported average current speeds of 45 centimeters/second (1.5 feet/second) during summer and 10 centimeters/second (0.8 feet/second) in winter. The direction of the primary current is generally parallel to the coast, with eddies and reversals noted in nearshore areas. Winds have been observed to slow the current, occasionally reversing its direction through the Bering Strait (Arctic Institute of North America 1974).

Figure 4-2 illustrates the surface currents in southeast Chukchi Sea. In general, Coachman et al. (1975) indicate that warm waters enter the Chukchi Sea through the eastern side of the Bering Strait at estimated flow speeds from 30 to 150 centimeters/second (1to 5 feet/second) and then flow northward and turn west-northwest in a broad stream starting from south of Point Hope. Near shore, a northeasterly stream branches from this flow in the vicinity of Cape Lisburne. The westerly branch, moving at 15 centimeters/second (0.5 feet/second), enters the Arctic Ocean by way of Herald Canyon. The northeasterly branch narrows into a high-speed jet-like stream moving at 25 to 30 centimeters/second (1 foot/second), approximately along the 40-meter (130-foot) isobath north of Cape Lisburne and then close to the Alaskan Coast between Wainwright and Point Barrow, where it flows eastward into the Beaufort Sea. Named the Alaskan Coastal Current by Paquette and Bourke (1974), currents on the outer shelf form a regime that is highly energetic over a broad band of sub-tidal frequencies, with a mean eastward flow (Coachman et al. 1975).

Within this general picture of the circulation regime, significant uncertainties and variations exist. Ingham et al. (1972), based on observations in the fall of 1970, indicated that currents were strongly influenced by the northeasterly winds and showed the expected northeastward set only

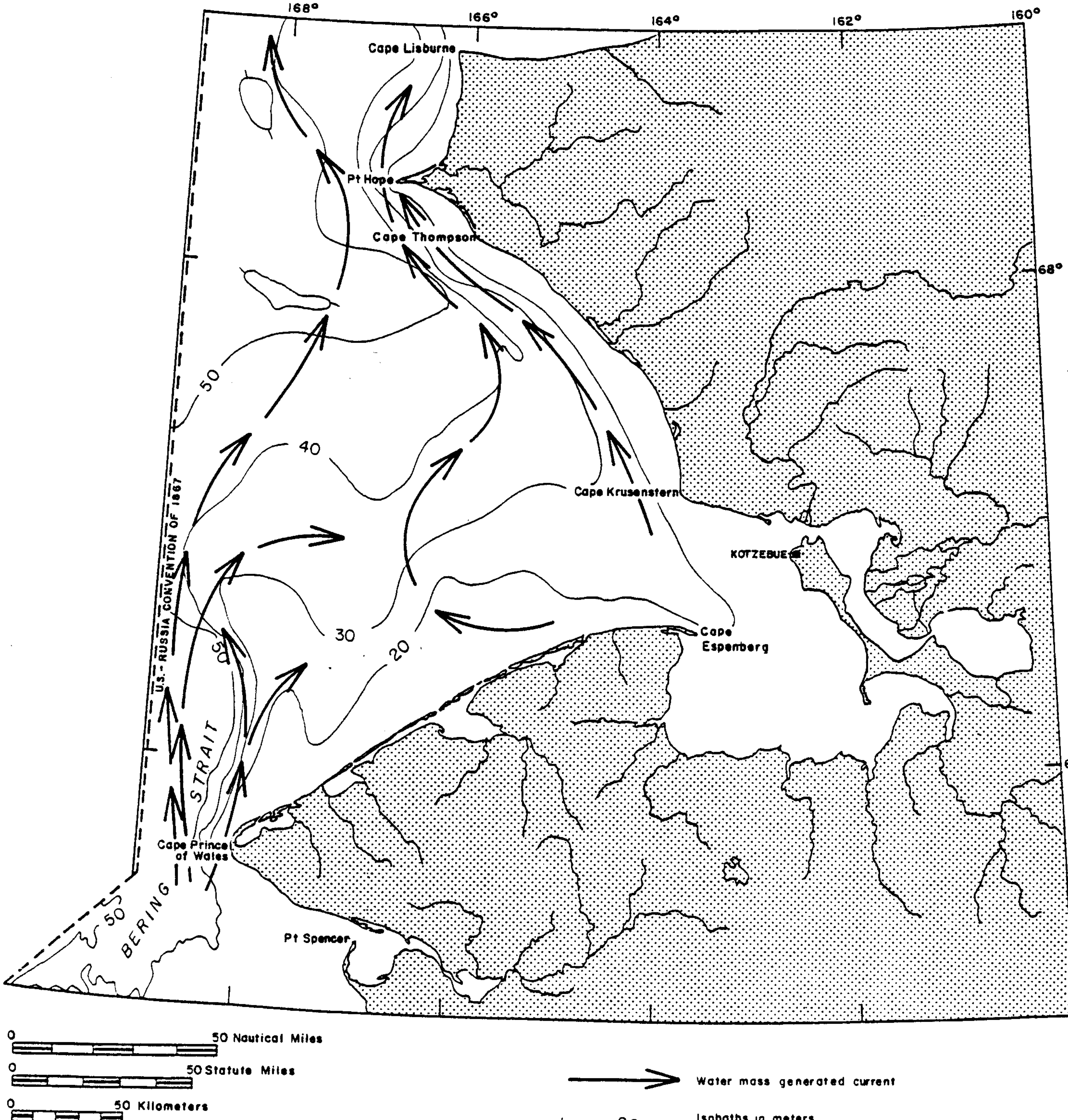


Figure 4-2

SURFACE CURRENTS IN THE SOUTHEAST CHUKCHI SEA

Source: Adapted by Dames & Moore from Schumacher (1976); Coachman, Aagaard and Tripp (1976).

when winds were weak and variable. Their observations also indicated that returning nearshore southwesterly currents between Cape Lisburne and Icy Cape were weak and variable. Hufford (1977) reports the existence of a significant offshore southwesterly current beyond the Alaska Coastal Current in the vicinity of Point Franklin. The U.S. Coast and Geodetic Survey (1979) reports that another current moves northwest out of Kotzebue Sound adjoins the Alaska Coastal Current in the vicinity of Cape Krusenstern, producing a resultant velocity of 75 to 100 centimeters/second (2.5 to 32.5 feet/second) at Point Hope in July and August. They report that during summer months, the Alaska Coastal Current moves at 50 centimeters/second (2 feet/second) after rounding Point Hope. They indicate that currents are influenced not only by the wind, but also by moving pack ice and by landfast ice.

4.1.4 Tides and Storm Surges

Almost no work on the tides of the Alaska arctic coast has been published. Astronomic tides are very much smaller than meteorological tides (OCSEAP 1978). Along the southern Chukchi coast, astronomic tides are reported to be small. Tide range at Kiwalik in Kotzebue Sound is reported at 80 centimeters (2.7 feet) by Stringer (1978a,b).

Deviations in sea level produced by meteorological forces are a significantly greater problem than tides in the Hope Basin Planning Area. These deviations, known as storm surges or storm tides, are produced by wind stresses and barometric pressure gradients acting on the water surface (Energy Interface Associates 1979). The dominant storm track producing storm surges is to the northeast, from storm systems originating in the Aleutian chain and moving through the Bering Strait (U.S. Navy 1968). An occasional storm moving eastward from the Siberian Shelf may produce surges. The most severe surges, often accompanied by high waves, occur during September and October when storm frequencies are highest and open water exists (OCSEAP 1978).

Along the Chukchi Sea coast and Kotzebue Sound coast, surges are possible from mid-June through November. The Chukchi Sea coast is most susceptible to storm surge damage from northward moving storms from the Bering Strait, while Kotzebue Sound is affected by storm surges and coastal flooding from westerly Siberian storms with winds in excess of 75 kilometers/hour (45 miles/hour; Brower et al. 1977). Storms causing the most extensive flood damage require a long fetch and little or no ice cover. Storm surges are also greater when the air temperature is colder than the water.

Negative surges, which are usually smaller than positive surges, also occur and appear to be more frequent in winter. Negative surges are potentially hazardous to vessel traffic in the Arctic due to the relatively shallow water depths that provide limited draft clearance in many areas. Negative surges on the order of 1 meter (3 feet) or less have been observed (Energy Interface Associates 1979).

There are no direct measurements of storm surge elevations, but secondary observations of strandlines above the coastal beaches provide evidence of their general magnitude. The most severe recorded storm in 1963 produced a storm surge of 3 meters (10 feet) plus waves of the same height (Brower et al. 1977). The surge produced extensive coastal flooding, ice grounding and shoreline erosion in the vicinity of Barrow (Hunkins 1965).

Thirteen storm surges have been documented in the Chukchi Sea area since 1960. Although insufficient data exist to develop recurrence intervals for storm surges, Reimnitz and Barnes (1974) record that local Eskimos report such severe positive surges at around 25-year intervals.

4.1.5 Waves

Wave generation in the Hope Basin and southern Chukchi Sea is limited to the summer open-water season. No significant wave activity exists from November to May when the Hope Basin and southern Chukchi Sea are under ice. Wave heights of 6 meters (20 feet) or more occur less than 1 percent of the time during the ice-free season (Brower et al. 1977).

Extreme wave conditions for the Hope Basin and southern Chukchi Sea have been calculated (Brower et al. 1977). These data suggest that the 10-year storm (i.e., a storm with an average recurrence interval of once every 10 years) will have sustained winds of 73 knots and extreme wave heights of 24.10 meters (79 feet). The 50-year storm will have corresponding values of 88 knots and 31.5 meters (104 feet). Calculated 100-year return period values are as follows:

- 100-year storm winds: 1-minute sustained speed of 96 knots.

- 100-year wave heights for the Hope Basin and southern Chukchi Sea (south of 70° N. latitude)
  - Significant: 20.0 meters (65 feet)
  - Maximum: 35.5 meters (117 feet)

These significant and maximum 100-year wave heights are only possible in water depths of >25 meters (82 feet) and >44 meters (144 feet) respectively. Then the waves become depth limited.

The extreme wave heights for the Hope Basin and southern Chukchi Sea were calculated based on the work of Thom (1973a,b) and do not include the possibility that the open-water fetch and resultant wave heights are reduced by the presence of ice cover. Heideman (1979) indicates that they should therefore be discounted. He calculates that for a 100-year return period at a 9-meter (30-foot) water depth inside a Beaufort Sea barrier island, a storm surge of 2 meters (6.3 feet) is accompanied by a maximum wave height of only 8.2 meters (27 feet). Heideman's analysis relied on two proprietary storm hindcast studies prepared by Joy (1978, 1979).

Bechtel (1979) in a conceptual design study of an arctic terminal for ice-breaking tankers, arrived at similarly scaled oceanographic design data for 36.5-meter (120-foot) water depths off of Wainwright on the northern Chukchi Sea coast. They calculated a storm surge of 3.3 meters (11 feet), a significant wave height of 5.4 meters (18 feet), and a maximum wave height of 10.3 meters (34 feet) based in part on oceanographic survey data collected near the proposed terminal site.

Seasonal wave activity is summarized in Table 4-5 based on Brower et al. (1977). Several observers, including Sellman et al. (1972) and Wiseman et al. (1974), confirm the mild wave climate that predominates during summer, ice-free periods. Much more severe waves can occur under certain conditions, particularly during periods of pack ice retreat. Energy Interface Associates (1979) reports that during some summers the pack ice has retreated as far as 190 to 260 kilometers (120 to 160 miles) off the coast. Under these conditions, severe and rapidly moving storms proceeding across the shelf can generate waves over a long fetch. They report a shipboard observation of average wave heights on the order of 4 to 5 meters (13 to 17 feet) during a storm in the vicinity of Point Barrow in 1951.

4.1.6 Sea Ice

Expected ice conditions in the Hope Basin planning area are briefly described based on several public and proprietary sources. Ice data for this area remains very limited; additional data from ongoing and future surveillance projects should be used directly when they become available. Alaska arctic seas and extent of sea ice is shown in Figure 4-3. Typical ice conditions in the Hope Basin are characterized by:

- o Ice coverage of close to 100 percent for most of the year.
- o Multi-year ice floes transported to the region from the Arctic.

The general ice movement is to the south through the Bering Strait under influences of wind and current (Ahlnas and Wender 1979; and Reimer et al. 1981).

Freeze-up generally starts in early October. The first-year ice thickness grows to a maximum of about 1.4 meters (4.5 feet) in early May. For the Kotzebue Sound area, which is closer to the land mass, the maximum first-year ice thickness is about 1.5 meters (5 feet). Ice decay generally does not start until mid-May and is completed by mid-July. See section 5.2 for discussion of the operational significance of the limited open-water season.

TABLE 4-5

SEASONAL WAVE ACTIVITY FOR HOPE BASIN PLANNING AREA

PERCENT FREQUENCY OF OBSERVED WAVE HEIGHT THRESHOLDS
(NON-HAZARDOUS SEA CONDITIONS) IN HOPE BASIN AND SOUTHERN CHUKCHI SEA
(SOUTH OF 70°N LATITUDE)

	Wave Height						
	Meters	0 -.5	1 - 1.5	2 - 2.5	3 - 3.5	4 - 5.5	6 - 7.5
Month	Feet	0 - 2	3 - 6	7 - 9	10 - 12	13 - 19	20 - 25
May		57%	43%				
June		69%	28%	3%			
July		49%	42%	7%	1%		
August		41%	44%	10%	3%	1%	
September		32%	46%	16%	3%	2%	
October		29%	41%	24%	5%	*	1%

* <.5% but >0

Source: Brower et al., 1977.

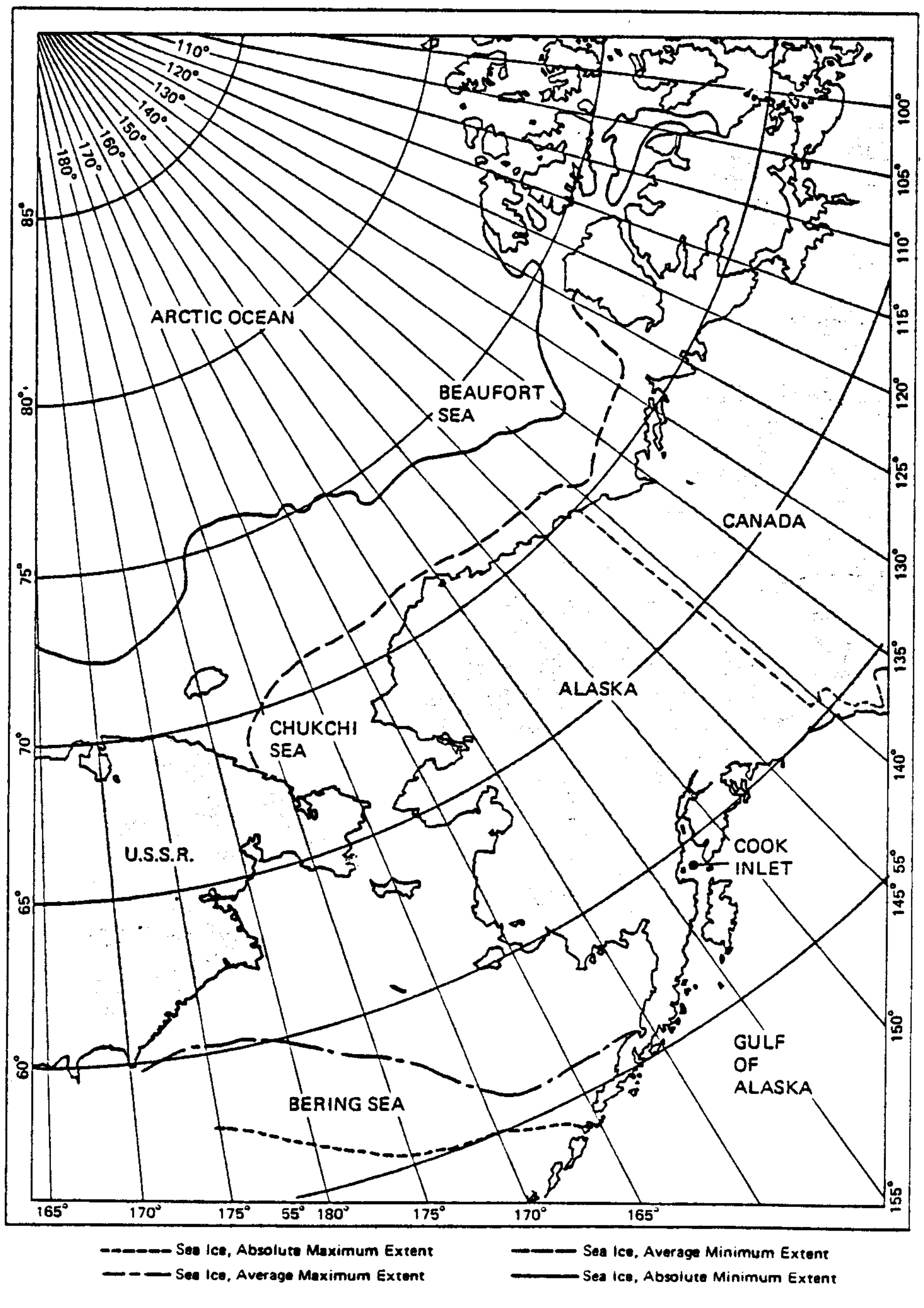


Figure 4-3

ALASKA ARCTIC SEAS & EXTENT OF SEA ICE

Source: National Academy of Sciences 1982

The ice coverage is close to 100 percent during the months of November through May. Multi-year ice may account for as much as 20 percent of the total ice cover. The multi-year floe thickness ranges from 1.2 to 2.1 meters (4 to 7 feet).

A probable range of the ridge size and frequency has been extrapolated in Table 4-6 for the Hope Basin Planning Area from some limited data assembled by the Cold Regions Research and Engineering Laboratory (1970), John J. McMullen Associates (1980), and Voelher et al. (1981). Pressure ridges can contain both first-year and multi-year ice. Based on a heat-flow analysis, first year ridges are estimated to have a consolidated zone thickness (i.e. with ice bonding) of less than 3.9 meters (13 feet). Multi-year pressure ridges probably can have a consolidated zone thickness exceeding 13.7 meters (45 feet) but the probability of encountering such a feature cannot yet be estimated.

Surface temperature data from infrared satellite images, as well as ice motion simulation developed by Reimer et al. (1981), indicate that the ice in the nearshore area along the northern coast of Hope Basin (Point Hope to Cape Krusenstern) and Kotzebue Sound is sheltered from colder ice from the arctic pack. The probability of encountering multi-year floes and ridges in this region would therefore be quite small (Ahlnas and Wendler 1979).

Structures supporting drilling and production facilities in the areas of interest will most probably include gravel islands and conical gravity structures (National Petroleum Council 1981). The design total ice forces will depend not only on the ice features but also on the configuration and contact surface characteristics of the structure. For the purposes of this planning study, the loads on Table 4-7 are suggested as examples for fixed structures that are to be located in the zone of large ice movement and where large multi-year ice features can be expected.

In the floating landfast ice zone, ice movement will be significantly less and multi-year ice features will be less likely to be encountered. In this zone, a load of 350 kips per foot of waterline diameter (horizontal) for a vertical cylindrical structure or gravel island seems appropriate.

TABLE 4-6

EXTRAPOLATED PRESSURE RIDGE CHARACTERISTICS AND FREQUENCY

Sail Height (meters)	Keel Depth (meters)	Number of Ridges per kilometer
0.6	2.1	14.8
0.6 - 1.2	2.1 - 4.2	14.8
1.2 - 1.8	4.2 - 6.4	3.7
1.8 - 3.0	6.4 - 10.6	1.9
3.0	10.6	1.9

Source: Brian Watt Associates

TABLE 4-7

GENERALIZED ICE LOADS FOR REPRESENTATIVE DRILLING STRUCTURES IN DEEPER WATER[1]

Structure Type	Total Horizontal Load[2] (1000 kips)	Vertical Load (1000 kips)
Gravel Island	200[3]	0
Vertical Cylinder	140 - 200	0[4]
45° Cone	135 - 180	100 - 135
20° Cone	60 - 80	100 - 135

(1) See text for explanation.

(2) Total load includes both static (widely distributed) and impact (locally distributed) loads.

(3) For a 400-foot island, using 500 kips/foot of waterline diameter.

(4) Assumes no adfreeze plus tidal movement.

Source: Brian Watt Associates

It is expected that engineering structures for the Chukchi Sea will have to be designed for very high and localized ice loads; selecting appropriate design ice pressure criteria for these structures is a difficult task due to the lack of data and industry experience. Bruen et al. (1981) discuss the complications involved in criteria selection and suggest a tentative relationship between the design ice pressure and the contact area under consideration. The suggested design ice pressure starts at 1600 psi for a 5 square foot area decreasing to 1200 psi for a 100 square foot area, and 500 psi for a 1000 square foot area.

4.2 Geology and Geologic Hazards

4.2.1 Major Data Sources and Reference Materials

The Chukchi Sea shelf, as a geographic and geologic unit, has received intermittent study from researchers over the last two decades, and a reasonable amount of knowledge has been accumulated about the structural, tectonic and environmental geology of the area. However, the Chukchi Sea has received considerably less attention than the Beaufort Sea, due to its remoteness from existing petroleum development and transportation infrastructure. Nevertheless, a limited amount of magnetic, gravity and seismic data is available, primarily from research conducted by the U.S. Geological Survey. At the time of this writing, little of the available data had been synthesized although a geohazards report is currently in preparation by the U.S. Geological Survey.

4.2.2 Geologic Setting

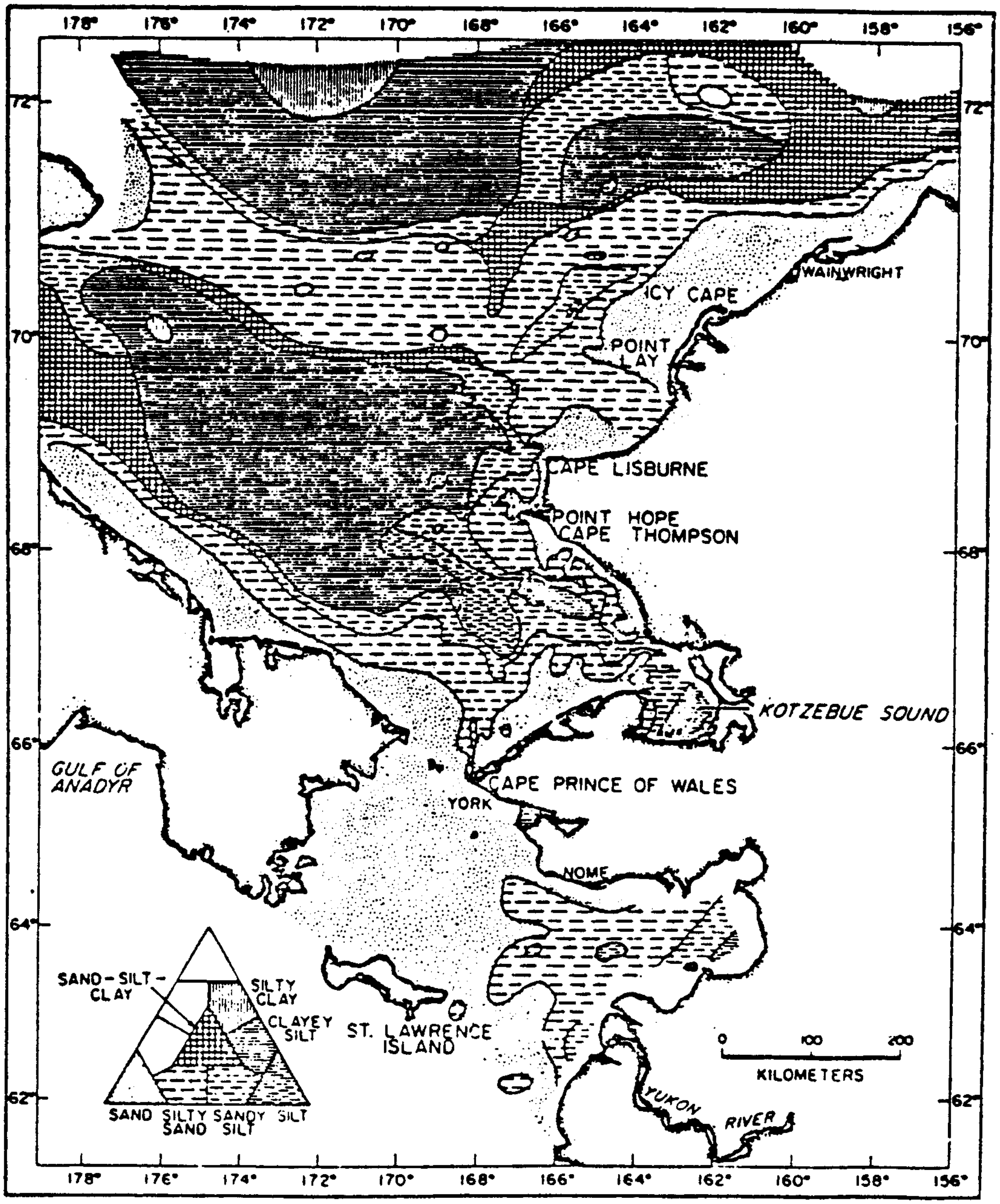
The Chukchi Shelf is a peneplained, infolded sedimentary remnant. The extension of the Colville geosyncline beneath the Chukchi Sea shelf is comprised of lower Cretaceous and older sedimentary rocks with a presumed average thickness of 5 kilometers (3 miles) and a maximum thickness speculated at 8 kilometers (5 miles). It has been estimated that as much as 6,000 meters (20,000 feet) of Cretaceous sediments interbedded with volcanics may lie immediately offshore beneath the Chukchi Sea (Arctic Institute of North America 1974).

The thickness and stratigraphy of the pre-Cretaceous interval is in question. A great deal depends on the nature, age and extent of apparent basement highs indicated by gravity and magnetic surveys. Sub-bottom reflections of the Tigara uplift area off Point Hope and Cape Lisburne indicate no stratification but strongly suggest buried sedimentary rock. Rocks are generally believed to be complexly folded and faulted rocks of Devonian, Carboniferous, and early Mesozoic age (Moore 1964).

The sediment character of the Chukchi Shelf seafloor is fairly well known, primarily from the work of Creager and McManus (1967). In general, the Chukchi Shelf displays very low relief and is covered by thin relict and residual sediments with a minimal input of new fine sands, silt and clay from the Bering Strait and Kotzebue Sound (U.S. Coast Guard 1970). Extreme diversity, even over short distances, is the most distinctive characteristic of arctic shelf sediments. The sediment cover rarely exceeds 10 meters (33 feet) and frequently is on the order of 3 to 5 meters (10 to 17 feet; Moore 1964). Sediments are predominantly Holocene silts and clays with widespread Pleistocene gravel sheets occuring at depths from 3 to 10 meters (10 to 33 feet; OCSEAP 1978). In water depths of 30 meters (100 feet) and more, bedrock is frequently exposed with only patches of sediment filling depressions (Moore 1964).

Bottom sediments in the area range from silt and clay through well-sorted sands to muddy or to clean gravels. The bottom sediment distribution of the Chukchi Sea, as described by Creager and McManus (1967,) are illustrated in Figure 4-4. In general, grain size decreases away from the shore or downstream from the sediment source.

In the nearshore waters of the Chukchi Sea and on the Chukchi shelf, sedimentary depositional structures are largely absent. A combination of ice bottom interaction and bioturbation is being considered the primary process, replacing older explanations that emphasized wave and current action (Barnes and Reimnitz 1974). Ice gouge phenomena are discussed in greater detail in Section 4.2.3).



Source Creager & McManus 1967

Figure 4-4

DISTRIBUTION OF BOTTOM SEDIMENTS, CHUKCHI SEA

Toimil and Grantz (1976) speculate that the anomalously coarse sediments reported on many shoals of the Chukchi Shelf by Creager and McManus (1967) may in part result from seabed-sediment winnowing by processes related to repeated massive ice groundings or bergfields. They recognize, however, that the coarseness of sediments on some of the shoals can be more directly attributed to nearby outcrops or to wave and fluvial erosion and deposition during times of eustatically lowered sea level.

4.2.3 Geologic Hazards

Types of potential geologic hazards to petroleum development exist in the proposed lease sale area include ice gouging, subsea permafrost, seismicity, and coastal erosion. Based on evidence reviewed for this report, volcanism and seafloor instability do not appear to be major risks in this region.

Sea ice reworks sediments and modifies bottom topography by impaction, plowing and gouging. Ice gouging or ice scour, as it is also called, may be caused by any type of ice with sufficient draft and momentum to penetrate the seafloor. Pressure ridges are probably the most common type of ice feature to produce major depressions in the seafloor although ice islands and their fragments are capable of scour as well. According to Barnes and Reimnitz (1974), ice processes appear to dominate the entire shelf of the Chukchi Sea, including the beach, during the winter season.

Reimnitz and Barnes' (1974) studies of the Beaufort Sea ice gouges indicate that ice-scoured relief tends to dominate the small-scale shelf morphology between depths of 8 to 10 meters (26 to 33 feet) with the greatest intensity of gouging corresponds to depths where the zone of grounded ridges (Stamukhi zone) is formed in 10 to 20 meters (33 to 66 feet) of water. Ice gouging is also especially intense on the seaward slopes of bathymetric highs.

Toimil's (1979) reconnaissance study of ice scour in the Chukchi Sea produced the following observations:

- The density of ice scour increases with increasing latitude, increasing slope gradients and decreasing water depth.

- Scour was observed to occur at least as far south as Cape Prince of Wales.

- Densities of over 200 gouges per kilometer (320 per mile) were encountered in water depths less than 30 meters (100 feet).

- No values higher than 50 per kilometer (80 per mile) were found in water depths deeper than 50 meters (165 feet).

- The maximum depth at which evidence of scour was observed was 58 meters (192 feet).

- Maximum incision depths were found in water depths of 36 to 50 meters (120 to 165 feet).

- An extreme incision depth of 4.5 meters (15 feet) was encountered at a depth of 35 to 40 meters (115 to 130 feet).

Toimil (1978) also noted several differences between gouging in the Beaufort and Chukchi Seas:

- The maximum water depth of ice gouging occurrence appears to be shallower in the Chukchi Sea than the Beaufort Sea.

- In the Chukchi, ice scour is associated with and may be modified by strong currents.

- Gouge trends in the Beaufort Sea are generally parallel to shore, reflecting the westward drift of pack ice, but the trend is poorly developed in the Chukchi.

- In the Chukchi Sea, gouge densities are variable and patchy under otherwise uniform conditions.

While the general level of seismicity in the Hope Basin Planning Area is relatively low, as indicated by its designation by the American Petroleum Institute (1982b) in seismic risk zone 2, several epicenters have been recorded over the last 30 years (Eittreim and Grantz 1977). In terms of its general tectonic setting, the Hope Basin lies within an area dominated by pre-existing tectonic structures that are not likely to be major earthquake-producing structures at the present time (Woodward-Clyde 1978). Some apparent Holocene scarps are evident south of Point Hope but the tectonic significance of these features has not been evaluated (Grantz et al. 1976). Many faults have been recognized on seismic profile data within the basin and especially along the Kotzebue Arch at the southern edge of the basin. However, no displacements are known in unconsolidated Holocene sediments, nor are any scarps known on the extremely flat sea floor (Grantz et al. 1976).

A recent study for the Alaska Subarctic Offshore Committee (Woodward-Clyde 1978) examined potential ground motion characteristics that might be associated with earthquakes in the Hope Basin area. Assuming a random earthquake source and a seismic event with a 100-year return period of magnitude 6.5, the study computed various ground motion parameters and their associated return periods. It was found that ground accelerations of 0.03 to 0.12 g could be expected to occur on an average of once every 100 years. The associated maximum velocities were approximately 2.2 to 9.0 centimeters/second (0.4 to 3.5 inches per second) in the Hope Basin. However, the analysis is very sensitive to the seismicity level and if a larger earthquake were to occur, the accelerations and velocities would be significantly increased.

Although ice-bonded permafrost is known to be widely distributed on the Beaufort Sea shelf, little is known about conditions on the Chukchi Shelf (Weeks et al. 1978). The Arctic Institute of North America (1974) indicates that while relict permafrost is known to occur beneath the coastal waters of the Chukchi Sea, little is known about its areal distribution, thickness, nature and equilibrium conditions.

According to Barnes and Hopkins (1978), subsea relict permafrost is most likely to be encountered in shallow, inshore areas where ice rests directly on the seabed. Relict permafrost may be encountered on any part of the shelf inshore of the 90-meter (300-foot) isobath. While several OCSEAP investigators continue to study the pattern of subsea permafrost occurence on the Chukchi Sea shelf, no more recent data is available.

Frozen gas hydrates or clathrates are a geological feature often encountered in association with or below ice-bonded permafrost zones. They occur as a latticework of gas and water molecules with a typical ratio of one gas molecule to six water molecules (Energy Interface Associates 1979). When heated, clathrates may decompose, releasing gas with a much greater volume and/or pressure than it had in the frozen state. Because of the high pressures that may accompany thawing, frozen hydrates are of concern to offshore drilling operations in arctic waters.

Little is known about the distribution of clathrates on the Chukchi Sea shelf. Indirect evidence from seismic reflection records indicates that clathrates may be widespread in the Beaufort Sea (Weeks et al. 1978).

The coast along the Chukchi Sea is generally a narrow transition zone between the tundra surface and the sea (Arctic Institute of North America 1974). It ranges from steep, nearly continuous sea cliffs with gullies and narrow valleys to low, gentle slopes where the sea meets the plain with little discernible shoreline break. The nearshore regime is composed of both semi-enclosed lagoons and open embayments with common coastal landform features such as beaches, barrier islands, barrier bars, spits, dunes and river deltas. During the short summer when sea ice moves off the coast, thermal and wave erosion form steep sea cliffs, and a marked annual retreat of shorelines occurs.

Studies of coastal erosion in the Barrow region show that annual rates of cliff retreat east of Barrow in Elson Lagoon generally exceed 1 meter/year (3 feet/year) and occasionally exceed 10 meters/year (33 feet/year; Harper 1978). However, west of Barrow along the Chukchi Sea coast, cliff erosion rates have been measured at 0.3 to 3.0 meters/year (1 to 10 feet/year) with a long-term retreat rate of over 2 meters/year (7 feet/year; Harper 1978).

Harper (1978) speculates that temporal variations in erosion rates may result from variations in annual wave energy levels associated with storms, migratory bar-attachment points, and localized beach borrow activity.

An additional concern affecting not only coastal erosion rates but also the siting of onshore support facilities is ice pile-up or ride-up events. Described by Kovacs and Kovacs (1982), shore ice pile-up and over-ride are frequent events along arctic shorelines. Events generally occur between March and June in the Chukchi Sea. Ice over-ride events can affect structures up to 25 meters (82 feet) from water at elevations of 6 meters (20 feet), even within barrier islands. Shore ice pile-ups along the Chukchi Sea coast in 1981 were found to be massive, some reaching heights of 20 meters (66 feet) and extending continuously along several kilometers of shoreline. Ice over-ride events of more than 30 years ago produced inland ice movements of at least 125 meters (410 feet) near Camden Bay in the Beaufort Sea (Kovacs and Kovacs 1982). Ice pile-up events can also produce extensive soil berms and tundra scars.

4.3 Biology

The Hope Basin Planning Area is characterized by significant seasonal and year-round populations of mammals, birds and fish. The area has year-round populations of marine mammals including ringed seals and bearded seals. Polar bears are also found on pack ice and occasionally den in the area from Point Hope to the Kuparuk River. Some barren-ground caribou overwinter in the Icy Cape to Point Lay area. Seasonal populations of bowhead whales, belukha whales, spotted seals, walruses and gray whales are common. Some 13 other species of marine mammals are occasional or rare inhabitants of the region. The endangered bowheads migrate in the ice leads in the northern Chukchi Sea in April and May, and return westward in the fall. Bowheads have been sighted off Barrow as late as November. Walruses use the pack ice edge of the northern Chukchi Sea as summer habitat, migrating in spring and fall within several miles of shore and feeding in mollusk beds (Arctic Institute of North America 1974).

Birds are transient in the Chukchi Sea. Sea birds are seasonally present from May through September and their colonies are of minor importance in the area north of Cape Lisburne. The northernmost nesting sea bird colony in the Arctic is located at Cape Beaufort. The largest concentrations are found in coastal areas between July and September. Large late summer concentrations are found at Peard Bay and on Solovik Island near Icy Cape. Nesting seabird colonies are found at Capes Thompson and Lisburne and in Kotzebue Sound. The endangered arctic peregrine falcon is found between Cape Lisburne and Point Lay (Arctic Institute of North America 1974).

In the Chukchi Sea, waterfowl make extensive use of shore leads in May. Significant year-to-year variations exist in habitat use by post-breeding migrants, making delineation of critical habitat difficult. Potential OCS development conflicts with birds include use of open ice leads by barge and tanker traffic, aircraft overflights and onshore support facilities. Major bird nesting colonies are located south of Cape Beaufort (OCSEAP 1978).

The majority of the fish found in the Chukchi Sea area are one of five species: arctic cod, arctic cisco, least cisco, arctic char, and fourhorn sculpin. The arctic cod is the major secondary consumer in the arctic marine food chain. A few small commercial salmon runs are present in Kotzebue Sound (Arctic Institute of North America 1974).

Arctic ecosystems display considerable resilience, effectively coping with extremes of temperature, light and salinity, and inconstancy in ice cover and length of the growing season. However, sensitivities to disturbance do exist. Arctic species are generally long-lived and slow to reproduce. Disturbed communities may repopulate, but over a relatively long time period as recruitment rates are generally low (OCSEAP 1978).

5.0 PETROLEUM TECHNOLOGY ASSESSMENT

5.1 Introduction

The technology assessment for the Hope Basin OCS Planning Area has three major components:

- An assessment of the environmental forces and operating conditions (Chapter 4.0) influencing the design, selection and location of offshore facilities, including platforms and pipelines, and the overall field development and transportation strategies.

- A description of selected field development components, their design parameters and installation techniques (this Chapter and Chapter 6.0). Included in this evaluation is a discussion of trade-offs between artificial islands and other platforms, ice-breaker tanker transport vs. pipelines to ice-free ports, techniques to develop marginal fields, and the application of subsea systems.

- Identification of field development strategies that may be adopted to develop oil resources in the southern Chukchi Sea. The field development strategy involves the sum of the various field development components (platforms, wells, process equipment, pipelines, terminals, etc.) and the transportation system(s) (Chapter 7.0).

In previous technology assessments in this series, Dames & Moore already has presented detailed descriptions of different types of arctic and sub-arctic petroleum technologies. The reports on Beaufort Sea Petroleum Development Scenarios (Dames & Moore 1978) and Bering-Norton Petroleum Development Scenarios (Dames & Moore, 1980a) contain an extensive discussion of arctic and sub-arctic petroleum technologies. These reports presented descriptions of artificial islands, caissons and monocones that are relevant to this study. Rather than reiterate these descriptions, the reader is referred to these technical discussions that provide background for this report. From this broad evaluation of arctic oil and gas technologies, a subset of specific exploration, production and transportation technologies and systems tailored to the environment and operational conditions of the southern Chukchi Sea was selected.

5.2 Hope Basin Design and Operational Considerations

While industry has not yet constructed and operated exploration and development concepts in ice-infested waters analogous to those of the Chukchi Sea, its experience in designing and constructing ice-reinforced platforms for Cook Inlet and artificial islands for ice conditions in the U.S. and Canadian Beaufort Seas provides a technological base for extension of oil and gas recovery to the Chukchi Sea. Existing arctic and subarctic designs are being improved and optimized, and structural designs for more severe sea ice conditions have been under investigation by the industry. Suitable platform types have been identified and, in many cases, advanced through model tests.

The presence of sea ice in Chukchi Sea waters poses a significant challenge in the design of offshore field development components for the exploration and production of oil and gas. Water depth is also an important factor, but present technological capabilities for arctic areas are on a different scale from those for ice-free OCS areas. Water depths from 10 to 60 meters (30 to 200 feet) are found across the relatively shallow Chukchi Sea shelf. Due to industry's relatively limited experience in open-coast sea ice environments, the term "deepwater" may be appropriate for arctic water depths beyond 30 meters (100 feet).

The progressively severe ice conditions found as one moves north in the Chukchi Sea, substantially limits the summer season during which conventional open-water drilling and construction techniques can be used. Ice-capable vessels can somewhat extend the drilling/construction season for floating equipment. Ice limitations are such that only bottom-founded, ice-resistant concepts have been seriously considered as first-generation technologies for year-round exploration drilling and oil field development.

The presence of multi-year pack ice and its dynamic movement poses the most severe constraint on drilling activities. Although pack ice retreats during July, August, September and October, multi-year pack ice can move back onshore due to shifting winds. While conventional exploration drilling techniques such as jack-ups, drill ships and semisubmersibles have been utilized in sub-arctic and arctic offshore areas during open-water seasons, significant advantage is derived by extending the drilling season into the winter months. For this area, a reasonable working estimate of the open-water season, for conventional planning purposes, is 85 days per year. The actual period will vary significantly from year to year and with location. Open-water periods with 50 percent ice coverage or less vary between 4 and 5 months (National Petroleum Council 1981). Estimates of working period for floating operations must allow for downtime due to weather.

Statistically, there is only a 35 percent chance of the working time in any specified year being as great as the mean open-water period. Thus, considerable potential for a short work season exists in planning and costing offshore operations in the Arctic; it is unreasonable to count on something close to the mean open-water period being available for summertime drilling or construction (Jahns 1980).

All structures emplaced in Hope Basin are vulnerable to some degree (risk) of impact by multi-year ice and will have to be capable of resisting the dynamic forces developed by moving ice. Beyond the landfast ice zone, multiple ridges or ice pile-ups form in the shear zone of transition between the stationary ice and the moving multi-year ice. Exploration and production systems will have to deploy slope protection systems or employ passive design concepts to survive in the shear zone and the multi-year ice beyond. Bottom-founded systems must be flexible enough to absorb the initial concentrated loading from large irregular ice shapes while spreading the load over a large enough area to mobilize the concept's mass resistance and thus develop the forces required to cause failure of the largest ice features (Downie and Coulter 1980).

Weather will also play a role in affecting exploration programs. Limited visibility due to fog can occur anytime, and is most prevalent in the open-water season. High wind and waves, particularly those associated with early fall storms may shorten exploration seasons or affect the construction period for exploration concepts such as artificial islands. Any year-round exploration operations may also be adversely affected by the severe cold of winter and the limited visibility due to fog and snow.

The remoteness of the Hope Basin Planning Area from developed ports and industrial centers and its lack of in-place shore facilities capable of supporting an offshore program is another constraint. The great supply distances will make crew rotations and resupply more difficult and costly. Crew rotations and critical spares will be transported by air. An airstrip and forward base, possible temporary facilities, could be established in close proximity to the exploration effort. Resupply of bulky materials such as mud and water and any material required for construction or emplacement of exploration platforms will probably be barged from an expanded regional supply center such as Nome or Kotzebue. Desalination units might be installed for water supply.

No absolute engineering constraint exists in the development of platforms or production concepts for recovery of oil and gas from severe ice conditions such as those found in the Chukchi Sea. Rather it will be questions of cost and recoverable reserves that determine whether the large investments of industry's capital and engineering know-how required to develop Hope Basin fields will be made. The basic engineering tools needed to design and operate oil and gas field development components for Chukchi Sea waters presently exist. While suitable field development components are not all currently available, they are either analogous to existing ice-design exploration and production concepts constructed in other arctic areas or represent an extension of engineering experience that is justified by previous technological development within the oil and gas industry.

In addition, by the time industry begins to develop lease blocks in the Hope Basin planning area, many years of additional experience will have been accumulated through development in deeper waters of the ice-infested Beaufort Sea. This will include potential development of Diapir Field lease tracts and continuing development of fields discovered in Canada's Mackenzie Delta area.

It is impossible to forecast with precision the individual exploration and production concepts that will be employed in development of a planning area. Different industry operators may favor different approaches to developing the same or similar areas, as has been the case in the Canadian Beaufort Sea. Therefore, this report discusses selected technological options that appear most feasible for selected water depths based on current information about concept design engineering, actual industry experience to date, and specific environmental parameters of the Hope Basin area. It is entirely conceivable that a different set of exploration and development technologies may ultimately be used to develop Hope Basin oil or gas, based on intervening developments in arctic OCS technologies, or site-specific environmental characteristics and regulatory requirements that are currently unforeseen.

It should be emphasized that any of the concepts to be employed for exploration of the Chukchi Sea will be considerably more expensive than similar functions for sub-arctic or non-arctic OCS regions. At this writing new purpose-built equipment for operation in arctic regions is just becoming available and being applied in the Beaufort Sea. While some conventional equipment can be employed in Hope Basin on a seasonal basis, the requirement for ice-survivable platform concepts and supporting equipment for year-round operation implies considerable costs for design and construction of new equipment. Also, due to the high costs and risks of developing fields in offshore basins with sea ice conditions, more exploratory delineation drilling than is normal may be required to evaluate the economic potential of a prospect.

This points up an important aspect of Hope Basin offshore technology: development of new and proven arctic drilling systems. There should be a considerable base of design and operations experience available in the future to help make the lower reserves of Hope Basin more attractive to exploration. Further, most of these systems for exploration are constructed for re-use (unlike gravel islands) and may be applicable and cost-effective for Hope Basin exploration and production. There should be interesting opportunities for cost savings for future Hope Basin programs.

5.3 Exploration Platforms

5.3.1 Platforms Selected for Representative Water Depths

Based on a review of the Hope Basin Planning Area's petroleum geology and bathymetry, two water depths were selected as representative for the whole area, to be the basis on which to define suitable exploration and production concepts. The selected water depths are 37 meters (120 feet) and 50 meters (165 feet). One additional water depth, 30 meters (100 feet) was examined less rigorously. This shallower depth occurs only over a limited area of the federal waters just beyond the State of Alaska (3-mile) jurisdiction zone and this inshore strip of seafloor appears less likely to contain geologic structures of interest.

The 37-meter (120-foot) depth was selected because it is most typical for a zone identified with promising geological structures that would be the least costly for offshore construction. The 50-meter (165-foot) depth represents the largest geological structures and thickest sedimentary sections in Hope Basin and hence the maximum potential field size.

The following are the exploration concepts appropriate to each selected water depth for the Chukchi Sea:

30 meters (100 feet)

- o Caisson-retained gravel drilling island [1]

(1) The widely used term "gravel island" is generally used in this report to refer to any type of artificial island or underwater berm for structural foundation support constructed from fill materials that can have a wide range of grain sizes.

- o Jack-up rig
- o Mobile caisson rig
- o Conical drilling unit

37 meters (120 feet)

- o Caisson-retained gravel drilling island
- o Jack-up rig
- o Mobile caisson rig
- o Conical drilling unit, other ice-strengthened floating platform

50 meters (165 feet)

- o Conical drilling unit/round drillship
- o Ice-reinforced semi-submersible, drillship and turret-moored drillship
- o Jack-up rig
- o Mobile caisson rig

5.3.2 Description of Selected Exploration Concepts

The various types of exploration drilling platforms identified in the preceding section are described in detail in the Barrow Arch report (Dames & Moore, 1982d; section 3.3.1). That discussion also addresses the technical tradeoffs that an operator must make in selecting an arctic drilling rig concept for a specific play. Critical points in the selection decision include:

- o Fill source quality and quantity - free-draining materials are needed for gravel islands, underwater berms or ballast.

- o Fill source distance and depth - dredging concept and transport distance can vary widely, but are very sensitive and site-specific economic factors.

- o Draft depth clearances - floating drillships, semi-submersibles, or conical drilling units all require a certain minimum water depth to provide for flexibility in the riser/drillstring to accommodate vessel motions; bottom-founded concepts must also be able to be floated to the drill rig site without grounding at a shallow depth enroute (e.g. for Hope Basin the Bering Strait conditions control).

- o Seafloor conditions - soft sediments must be allowed for in founding structures that are to resist wave and ice loading, or even to accept placement of a fill berm; also placement of a structure directly onto the seafloor requires an even surface.

- o Ice forces and season - either a drilling platform must be able to resist the expected winter ice movements or it must be quick enough to drill and move within design constraints for the open-water season.

The factors summarized above have been incorporated into several current conceptual designs, a few of which have been deployed, and some are under construction, and others are designs-in-progress. Two of the key aspects of assessing technologies for Hope Basin are:

1. The economics of its petroleum resources are very marginal for the near future.

2. The delayed schedule for its lease sale provides for development of technologies, including the benefits of greater operational and design experience.

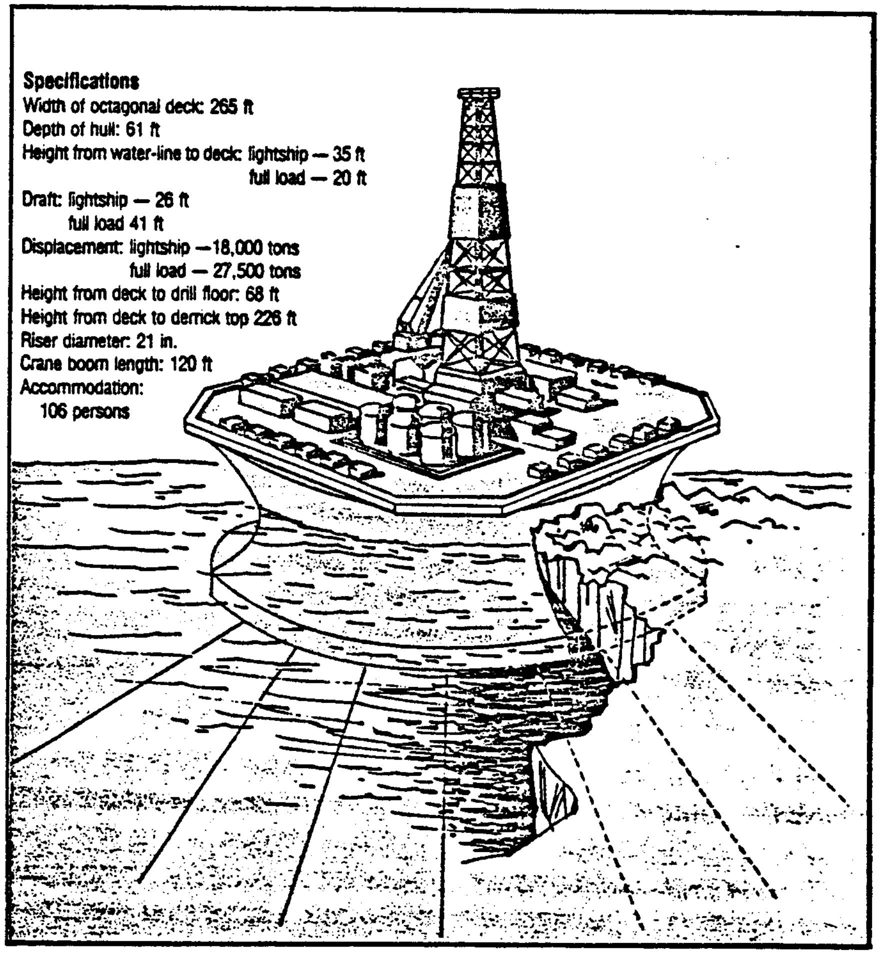
These two factors point to a potentially important economic aspect of Hope Basin technology: re-use of systems built for other arctic offshore areas. Therefore, this section will conclude with a brief description of the state of development of offshore arctic drilling platforms at this writing. Most of these systems are described in the Barrow Arch report.

Deployed arctic drilling platforms at this writing are all bottom-founded (if ice-reinforced conventional floating drilling vessels are excepted). Several gravel islands have been constructed in the Beaufort Sea of Canada and Alaska. Two caisson-retained concepts are also found in Canada. The first was installed one year ago (Summer 1982) at Tarsuit, and consists of four concrete sections joined together and placed on an underwater berm. The second is Esso Canada's eight-section concrete caisson system that is being (Summer 1983) installed at the Kadluk site (also on a berm). One mobile caisson system, Dome's Single Steel Drilling Caisson (SSDC), placed in late 1982 at the Uviluk site, is now working. It is a water-ballasted structure derived from a truncated super-tanker hull.

Systems under construction are both floating and bottom-founded types. Gulf's circular ("conical") semi-submersible, the Kulluk, is ready to move into the Beaufort Sea this year (Figure 5-1). An ice-strengthened and enclosed conventional semi is being outfitted by Sonat-Wilhelmsen. Gulf also plans to have its eight-sided steel mobile caisson ready for 1984 work; Sohio's arctic mobile structure (SAMS) is currently being designed. It is a gravel-ballasted structure with steel spuds added to resist lateral ice forces when installed on weak Beaufort seafloor sediments.

Newly designed units on long-term design or awaiting contracts or approval from operator committees prior to construction include SF/Braun's jack-up drilling barge (Figure 5-2), Shell's Cossac platform, Brian Watt Associates' arctic cone exploration structure, Anglo Energy-Nabors Drilling's stacked steel caisson, Global Marine's trio of a shallow-water steel ballast structure, a concrete island drilling system and a monopod jack-up, Exxon's concrete production island, Zapata Offshore's BWACS caisson system, and Dome's arctic production and loading atoll (APLA). Mobile rig contractors will require a minimal three-year contract to procede with construction of a design (Offshore, 1983).

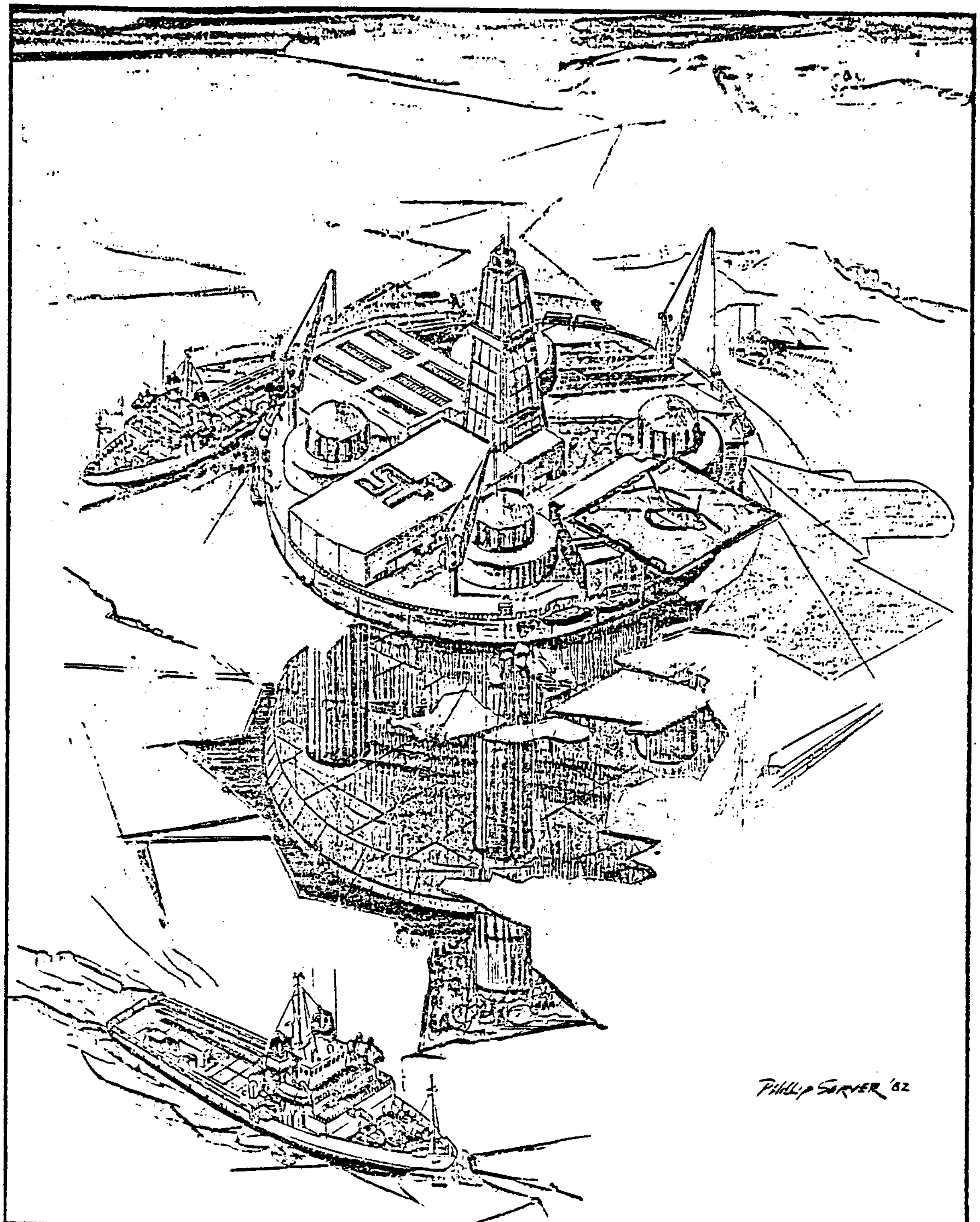
Relative to these developments in the Beaufort Sea, Hope Basin exploration operations will more likely favor the floating concepts for several reasons:



Source: Offshore 1981

Figure 5-1

GULF CANADA BEAUFORT SEA DRILLING BARGE "KULLUK"



Source SF/Braun 1982

Figure 5-2

MOBILE ARCTIC DRILL BARGE JACK-UP CONCEPT

- o Vessels can transit to and from the area on a seasonal basis more easily.

- o The open-water season is longer, and marginal ice conditions somewhat less.

- o Water depths are generally greater.

Although ice-breaker drillships or ice-reinforced drillships supported by ice-breakers can extend the open-water drilling season somewhat, there is a minimum water depth at which drillships can operate due to limitations on lateral motion or vessel excursion, which are dictated by the riser angle. This depth limitation lies between 15 to 20 meters (50 to 66 feet). Dome Petroleum has been successful in extending the open-water drilling season with its ice-reinforced Canmar fleet, and this Canadian approach may be applicable in the Chukchi Sea despite the more severe and dynamic ice conditions occurring in the deeper waters in which drillship operations appear desirable.

A second generation of arctic drillships incorporating special hull forms and mooring features to minimize hull forces from moving pack ice, including special features to reduce ice resistance between ice masses and the hull of the ship, once appeared likely. However, the decisions of Gulf Canada and Dome Petroleum to order more ice-resistant, conservative designs, indicates the direction in which mobile exploratory drilling concepts are likely to move in years ahead.

5.4 Production Platforms for Hope Basin

5.4.1 Background

Selection of production platforms for Hope Basin offshore fields will also depend on several factors, but a key consideration for Hope Basin is the expected small field size and shallow reservoir depth. Production platforms must be positioned over reservoirs in a manner to most efficiently develop hydrocarbon resources. The number of platforms needed to tap a reservoir depends on the area, shape and depth of the reservoir, and how much of it can be drained by a single platform using directionally drilled wells. Drilling and production systems must be concentrated into the fewest number of locations possible to be economic in the Hope Basin area.

No production has, at this writing, occurred from an offshore arctic find anywhere in the world. Although several Canadian operators are currently designing production systems for oil and gas finds that may be produced by 1985 or 1986, and Exxon and Sohio plan to produce from Duck Island/Sag Delta area in 1988, there is not the reservoir of experience to draw upon as exists for arctic exploratory drilling technologies. The design concepts presented in the Barrow Arch report (Dames & Moore, 1982d) are based on current knowledge and expertise. As more research, field data, and operational experience accumulates, design concepts will undoubtedly be modified as necessary by industry operators to improve the technologies available in the future for Hope Basin.

The various tradeoffs, limitations, and design considerations associated with the artifical island (fill-based) concepts and the rigid platforms (structures), and hybrids of both, are covered in the Barrow Arch report (Dames & Moore, 1982d, section 3.3.2) to which the reader is referrred for more detailed background information.

5.4.2 Selection of Platform Concepts

Selection of production platforms for Hope Basin reflects a combination of factors including: ice conditions, geographic location, field size, water depth, and distance from shore. Any production platform must provide adequate space not only for development drilling but also for processing facilities and crew accommodations.

As expected, ice loading forces on Hope Basin production platforms are the controlling design factor. Structures must be able to survive in moving ice and impacts of the multi-year pack ice itself. Natural ice floes or islands also present a potential hazard risk in the Chukchi Sea. Feasibility of different structural concepts is principally predicated on their ability to resist ice loads effectively.

The Hope Basin generally represents arctic "deepwater" -- water depths beyond 30 meters (100 feet), which reflects industry's current experience with exploration concepts in the Arctic. Reservoir areas with water depths of 200 feet are a distinct possibility in Hope Basin. The water depths considered for this study are range from 30 to 60 meters (100 to 200 feet). This water depth range is very similar to the depth ranges of proposed Alaska outer Beaufort Sea platforms as well as some of the platforms presently being designed for Canada's Beaufort Sea finds. The following types of production platforms all appear feasible for the Hope Basin planning area at these water depths, but are listed in sequence from shallower-to-deeper-favored concepts:

- o Caisson-retained gravel production island
- o Mobile caisson production rig platform
- o Concrete gravity island
- o Steel or concrete monocone/gravity island

Artificial islands are anticipated to predominate as production concepts possibly out to water depths as great as 45 meters (150 feet; Harrison 1979). In deeper waters beginning at approximately 37 meters (120 feet), stiff gravity-type structures of steel or concrete are the expected alternative concept. Such production platforms would include a cone-shaped form at and below the waterline to break advancing ice through flexural failure and to promote ridge clearing without ice pile-up (Harrison 1979).

The caisson-retained concept was developed to reduce costs by decreasing fill requirements, simplifying construction methods and eliminating the need for elaborate slope protection. It also offers several other advantages over all-gravel artificial islands. The steeper side slopes make it easier to maneuver barges or other vessels in close, facilitating lifts of equipment. Caisson-retained islands also offer a potential for reusability, since the caisson might be removed and floated onto another site.

One of the technical constraints of the monocone platform design with its conductors located within the vertical throat or shaft is a limitation on the number of well slots that can be accomodated in the production platform.

For this analysis, the diameter of a monocone shaft was calculated by SF/Braun to be on the order of 14 to 15 meters (45 to 50 feet). In this range, the total number of slots would be limited to on the order of 30 wells depending on the size of the conductors and design criteria.

The production technologies selected in the Hope Basin Planning Area will be influenced to a large extent by the exploratory technique used to discover the field when gravel islands or underwater berms are part of the discovery technique. No experience in expanding an artificial island from an exploration base into a production mode has yet been obtained. It is unclear in advance what advantage if any, hybrid production concepts emplaced on exploratory artificial islands may have. Such trade-offs will be site-, design- and operator-specific. Clearly, a successful exploration gravel island at a newly discovered producible reservior represents a valuable asset for oil recovery from at least a portion of the field.

5.4.3 Arctic Early Production Systems

Another production-related factor that may be of importance in later development of Chukchi Sea hydrocarbons will be establishing the feasibility of early production systems for arctic conditions. Early production systems have been used in other parts of the world to shorten the lead-time in bringing production on-stream and to allow extended reservoir evaluations prior to commitment of capital for permanent production systems. Such systems assume the existence of a suitable transportation infrastructure.

A number of concepts have been advanced for arctic production platforms. Many of these concepts are discussed in detail in the Barrow Arch planning petroleum technology assessment study (Dames & Moore 1982d). Please refer to that study for a more detailed description of available technology.

5.4.4 Marginal Field Development

High costs of facilities and equipment required to develop oil and gas resources in a remote arctic area such as the Hope Basin Planning Area will cause some significant discoveries to remain undeveloped because they cannot economically justify production. Such "marginal fields" will remain shut-in pending higher oil prices, cost-saving technological advances, or further discoveries close-by with which pipelines and other facilities can be shared. Delayed development of marginal fields has occurred in the North Sea. As noted in a series of articles on marginal fields in Offshore (April, 1978, p. 76):

> The factors which determine whether a field is marginal include the obvious producing characteristics such as reservoir size, shape, and depth below the ground, well producing rates, oil and/or gas quality, and the existence of production problems such as H_2S or CO_2 and sand productions. The status of technology required for development, availability of competent and efficient construction facilities in the area, nearness to market, accessibility for supplies and transport of production to market, plus environmental problems such as earthquakes and hurricanes must also be taken into account.

While the search for more cost-effective engineering solutions to develop marginal fields has been focused on the extension of offshore petroleum development into deeper waters where the cost of fixed platforms rises exponentially with water depth, many of the same principles will eventually be applied to arctic oil and gas development. Some possible solutions and trends in petroleum technology for marginal field development are listed below. While not all of these will be directly applicable to producing marginal fields in the Chukchi Sea, the underlying concepts such as using cheaper, faster and less material-intensive production techniques will be used. The trends and solutions include:

- o Use of subsea production systems either as an adjunct to fixed platforms or as part of floating production systems (see Barrow Arch report for more detailed discussion).

- o Two-stage development programs using an early (temporary) production system while further reservoir evaluation assesses the viability of a development plan employing fixed platforms, pipelines and major shore facilities.

- o Employment of offshore loading in conjunction with a floating system, subsea system, or fixed platform with storage when long pipelines cannot be struction time. Several factors, such as transportation distance, volume of fill required, water depth, length of work season and anticipated weather, will influence the type of dredging equipment employed. The relatively deep waters of potential Hope Basin reservoirs and distance from possible shallow water borrow sites accentuates these constraints.

Very larger dredges (super dredges) are one method of generating sufficient dredging capacity to cope with a short open-water season. The super dredge incorporates the following special features (Cottrill 1981):

- o Operation in transition ice without ice-breaker support, through an arctic Class VI hull, bow reamers and ice-breaking devices.

- o Capacity of at least 25,000 cubic meters (33,000 cubic yards).

- o Dredgable depth that can be extended to 80 meters (260 feet) using a retractable tower amidships, allowing high accuracy for subsidiary tasks like trenching and removal of fine overburden.

- o Power plant of 60,000 horsepower allowing 25,000 cubic meters (33,000 cubic yards) to be loaded in two hours and 16 knots of sailing speed.

- Drag head and suction pipe in a moon pool, protected from ice.

It is unlikely that a super dredge would be cost-effective for Hope Basin conditions. The open-water season is probably long enough to allow smaller capacity units time to complete a project. Further, the need for very large islands is not forseen in terms of expected site production. However, the Hope Basin water depths could demand large fill volumes, and if such a dredging capability is available in the future, it may be a viable option for Hope Basin.

Trailer suction hopper dredges offer advantages over stationary suction dredges in rough sea conditions. They are capable of operating in up to 3-meter (10-foot) waves and 65-kilometer (40-mile) per hour winds and can rapidly mobilize after a shutdown due to storms. In addition to several trailing suction hopper dredges of approximately 6,500-cubic meter (8,500-cubic yard) capacity, a stationary suction dredger/crane/work barge with a large crane mounted is desirable to build up the island or base berm from a stockpile deposited adjacent to the island site by the trailing suction hopper dredgers. If open-water season weather conditions permit, an alternative technique is use of a pontoon floating pipe to move the stockpile onto the island site. The same stationary suction dredger with mounted crane can be used to overbuild the sacrificial beach to provide for maintenance requirements. The same unit can also provide the lifting capacity for many miscellaneous tasks and the location of a floating construction camp at the island site (Downie and Coulter 1980).

In its construction of the Issungnak sand island in 20 meters (66 feet) in 1978-1979 in the Canadian Beaufort Sea, Esso Resources Canada (formerly Imperial Oil Ltd.) used two stationary suction dredges to move fill from borrow pits on site. One dredge, the Beaver Mackenzie, provided the backbone of the fill movement with its 70,000-cubic meter (90,000-cubic yard) per day capacity. One smaller cutter suction dredge was employed to fill 1500-cubic meter (2,000-cubic yard) capacity split-bottom dump barges with sand from a remote borrow site. The dump barges stockpiled this material at the island site for use in completing the island. Floating pipelines with alternating rubber and steel pipe sections were used. Several pipeline breaks did take place without significantly disrupting operations. Average dredge production over a 69-day ice-free season was 23,400 cubic meters (30,600 cubic yards) per day (Boone 1980).

An assessment during this study by Ogden Beeman and Associates for conditions in the Chukchi Sea suggests use of sea-going hopper dredges or tug/self-loading hopper barge combinations for berm or island building. The exposed nature of the potential sites and the distance to protected areas precludes use of conventional cutterhead pipeline dredges. As used in this report, "hopper dredge" refers to a sea-going, self-contained ship equipped with capabilities to load material through hydraulic pumps to hoppers and to discharge this material by bottom dumping or by pumping ashore to fixed pipeline systems. A tug/self-loading hopper barge has similar capabilities but consists of a tug pushing a hopper barge that has the capability to load through hydraulic pump(s) and drag arms. These dredges are self-powered and have the capability of working in sea heights up to 2 meters (7 feet), riding out storms and transferring material over some distance from borrow area to island construction site.

This analysis suggests that the tug/self-loading hopper barge could be less than one-half the cost of alternative dredging schemes, and is especially feasible for Hope Basin conditions. A major benefit is the fact that the capital equipment need not be amortized over a full year for a project or projects. This is because of the accessibility to the Hope Basin area through the Bering Strait and the use of conventional tugs and other equipment that may be employed in other areas.

6.0 PETROLEUM FACILITIES ONSHORE SITING

6.1 Overview of Onshore Facilities

Siting of onshore facilities is an important element in cost-effective oil development in the Hope Basin Planning Area. Development of such facilities along the northwest coast of Alaska will be a challenge, not only due to the severe weather and ice conditions prevailing during most of the year, but also because the existing physical infrastructure in the area is so limited. The effort required will be analogous to establishment of the Prudhoe Bay facilities, however, Hope Basin is not thought to offer large enough potential reserves to support enclave development.

Transportation distances to inhabited areas and supply base sites are much greater in northwest Alaska than in comparable offshore fields in other parts of Alaska with the exception of the Navarin Basin. Long distances and severe weather will make ready transport difficult. Personnel may be required to live on location for longer periods, requiring recreation and medical facilities. Critical supplies and spare parts must be stored on-site.

At present, the northwest coast of Alaska in the Hope Basin planning Area offers only limited potential to support the marine and onshore activities necessary for oil and gas exploration and development. Kotzebue has a population of approximately 2,300 and is 125-150 miles from the nearest likely reservoir areas. The other established coastal community, Kivalina, is extremely small (several hundred population). Neither are equipped to support oil industry operations. Both are isolated by lack of overland transportation and lack of marine transportation in the winter. While a few small airstrips exist along the coast, any would require expansion or modernization to handle anticipated air activities associated with oil and gas development. Ship transport is limited by the absence of adequate port facilities, and natural protected deepwater and by shallow water depths near the coast. Barge unloading sites, at present, exist only at Kotzebue, however there are preliminary plans for a future ore-loading facility on the coast near the Hope Basin reservoirs.

The actual onshore facilities required to support oil and gas development will depend greatly on the magnitude of offshore fields, their location, whether oil and gas or only oil is actually produced, and the transportation systems selected to service field production. For the purposes of this report, a representative range of required onshore support facilities is presented.

6.2 Physical Environment of the Region

The land surrounding likely onshore facility sites is generally inhospitable. The area has been referred to as one of the most uncomfortable in the world (Wilimovsky and Wolfe 1966).

The region is characterized by strong winds which are common during the coldest months. Observations made between 1943-1944 at Point Hope reported an average wind speed of approximately 16 miles per hour. Only 5 percent of the observations were less than 4 miles per hour.

The average depth of the southern Chukchi Sea is only 30 meters (100 feet). The 18-meter (60-foot) contour lies roughly 5 kilometers (3 miles) offshore. Observations in the Kivalina area report wave heights exceeding 5 meters (15 feet) are extremely rare. At Kotzebue, the frequency of occurrence for waves greater than 2 meters (6 feet) increases from 0 percent in May to 27 percent in October. Tides, in general, are semidiurnal with a mean range of approximately .3 meters (1 foot).

The coastline of the area is characterized by a string of longshore gravel bars that form shallow lagoons on the shoreward side. The littoral environment is dynamic but seems to have reached equilibrium along much of the coast. Clearly, the introduction of man-made structures along this coast will have a direct effect on the littoral transport process. The net transport of sediment is toward the southeast. Cape Thompson serves as a primary material source.

Onshore subsurface conditions generally contain a thick permafrost layer, often several hundred feet thick.

For geographic reasons, two general sites are appealing: Point Thompson and a coastal site on the Seward Peninsula. Point Thompson is geographically the closest landfall to the likely reservoir areas. It is also possible that development of reserves at the southern end of the Barrow Arch Planning Area may result in the construction of marine terminal facilities at Point Thompson. A Seward Peninsula landfall, near Shishmaref Inlet for example, would be almost 120 kilometers (75 miles) from the likely reservoir area. This would allow an inshore pipeline of approximately 200 kilometers (125 miles) to Nome. This alternative may be attractive if the Norton Sound oil development occurs.

6.3 Types of Onshore Facilities Required

Onshore support facilities will be required at several stages of oil and gas development in the area. The main requirements that must be accommodated in nearshore areas of the Hope Basin Planning Area are:

- Basic shorebase facilities to service exploration, development and long-term production.

- Temporary shore facilities to handle peak construction activities associated with artificial island construction, structure emplacement and assembly, terminal construction and pipeline construction.

- Appropriate airport or airstrips and heliport facilities to service exploration and development activities.

- A basic port facility to accommodate:
  - service vessels and tugs
  - supply barges
  - construction vessels (dredges, pipelay barges, etc.)
  - ice-breakers for winter port and terminal ice management.

- A marine terminal to receive produced crude oil for treatment, storage and off-loading via a single-point mooring (SPM) to ice-breaking tankers.

6.3.1 Marine Service Bases

Marine service bases are an integral part of any offshore exploration and development program. Their construction will involve staging areas, operating around the clock to provide drilling materials and support equipment from the coast to the offshore oil fields. Size and function will vary considerably with offshore activity. However, the marine service base will be the longest-lived activity related to offshore development. Marine service bases need to be carefully conceived and efficiently planned so as to aid the stability and economic diversification of northwestern Alaska.

Service bases are required from the time crude oil or natural gas exploration is initiated to the point where production ceases and the equipment is dismantled. The entire range of activities offshore in the exploration and the production of oil and gas resources requires support from onshore facilities.

6.3.1.1 Exploration-Related Facilities

Depending upon the magnitude of the exploration program and the types of rigs used, base camps could approach the size of a development/production camp, or could be very modest. High costs and low reserves estimates for Hope Basin would normally favor a minimal level of development or the use of existing facilities.

Seismic survey or other early exploration efforts will most probably be conducted from self-sufficient vessels with no need for onshore facilities in the area. Onshore support needs will commence with the exploratory drilling phase.

Prior to the start of exploratory drilling, an onshore camp and an operating port must be constructed to house workers and provide storage space and fabrication areas for materials and equipment. If floating rigs are used for exploration drilling, onshore support requirements will be reduced and may not be initially located in the immediate vicinity of the Hope Basin area. Surveys of gravel and water resources are required prior to construction of facilities and excavation of gravel borrow areas. Transportation facilities to be constructed will include an adequate boat harbor, runways to land fixed-wing supply aircraft and a helipad for cargo and crew helicopters. Appropriate docks and roads will also be constructed to service the harbor and support base complex.

If exploratory drilling in the area is conducted from artificial islands, adequate onshore construction of support base facilities will require a sophisticated planning and mobilization effort to ensure material delivery prior to the short summer construction season. Although as much work as possible will be conducted off-site to avoid the high costs of labor, low productivity, and weather delays that are inherent in the Arctic, a considerable amount of onshore construction will be required. Onsite activities are likely to include: mining and transporting gravel; filling and grading; construction of roads, workpads, foundations and causeways; and installation of utility distribution systems, prefabricated modules and interconnecting pipework. Care must be taken in all construction activities to minimize the impacts on tundra, waterbodies and wildlife.

If exploratory drilling in the area is to be conducted from artificial islands, adequate space must be incorporated into the base camp to accommodate peak manpower and material loads associated with island construction. Also, because of the severe weather prevailing during most of the year and the criticality of maintaining schedules to complete exploration efforts, ample spares will need to be stockpiled to prevent delays.

Harbor facilities will be required at the outset of the exploratory drilling program. In addition to the need to receive construction loads for shore base fabrication, harbor facilities will be required to service the large amount of marine activity associated with artificial island construction, re-supply and maintenance. Use of floating drilling platforms will greatly reduce this requirement. Although enclosed lagoon systems occur along much of the lease area's coastline, all of these protected waters are extremely shallow and the entrances are not navigable. Therefore, due to the lack of suitable natural harbor facilities, a dredged and/or breakwater harbor may have to be created, possibly as far away as Kotzebue. At a minimum, the harbor should have the physical dimensions to allow maneuvering, anchoring and berthing of a number of supply boats, barges and other vessels supplying the base.

The harbor must be deep enough at dockside to accommodate supply boats and barges to load or unload all various items of cargo necessary to support an offshore operation. The supply boats must operate around the clock throughout the year taking into account the range of possible ocean and ice conditions. During the exploration and construction phases, they may also be used to haul anchors in support of pipelaying, and operate other support missions from towed rigs or platforms.

6.3.1.2 Production-Related Facilities

Facilities required in support of field development and production operations will be significantly greater and more permanent than those required for exploration. The exploration base camp could be expanded to accommodate development and production, or a new marine production support base could be constructed in closer proximity to the actual offshore development fields.

Incorporated as part of the marine service base should be several types of facilities in addition to the harbor and crew quarters and mess. The physical plant is likely to include: a pipe marshalling or terminal yard; warehousing for tubular drilling goods and drilling muds and cements; storage tanks for chemicals, fuel and water; fabrication yards; communications facilities; office accommodations; mud and cement make-up facilities; vehicle and machinery maintenance and repair shops; power plant; sewage facilities; and oil spill response and clean-up equipment.

The major activities to be serviced by the marine service base in the post-exploration period are:

- o Construction
- o Development
- o Production
- o Post-Production

Construction

The construction stage involves constructing production islands or expanding exploration islands into production islands, installing towed production facilities, building oil collection stations or gas processing plants and tanker terminals, and laying of trunk and feeder marine pipelines to shore and land pipelines to a terminal or pump stations. A marine service base plays an active role in the installation of production concepts through its support of tugs, barges and other vessels required for the platforms, pipelines, and production equipment. This generally does not involve a large tonnage or volume of material except in support of pipelaying operations where a large volume of pipe may have to be stored and distributed.

Development

The development stage consists of drilling numerous wells from the production platforms. Generally this phase represents the height of service base activity in terms of tonnages and volumes of materials supplied offshore.

Production

Production commences with the flow of oil or gas and continues through the life of the field. The volume and tonnage supplied offshore are substantially reduced. Also, operations and manpower requirements are reduced at the shore station.

Post-Production

After the fields are exhausted, the service base may support the dismantling of production platforms and other offshore facilities.

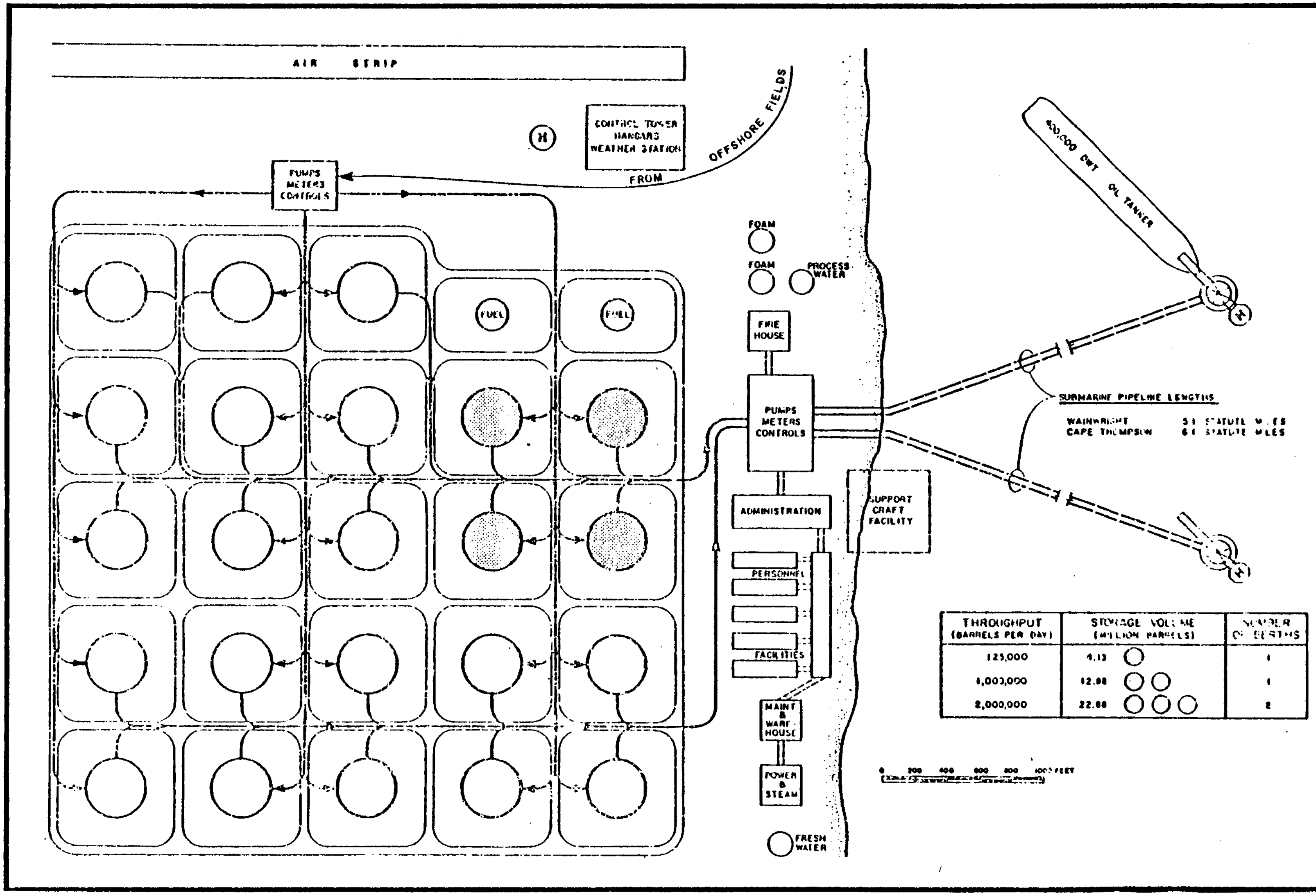
6.3.2 Marine Terminal

In addition to the marine service base, a marine terminal to receive, treat, store, and transfer crude oil to ice-breaking tankers may be constructed. Conceptual designs for such arctic facilities have been developed by Global Marine (1978), Bechtel (1979), and McMullen (1980). In addition, several proprietary studies of arctic marine terminals have been prepared for industry operators.

The onshore facilities associated with a marine terminal include storage tanks, a topping plant, a power plant, a tubular and equipment yard, a warehouse, and storage areas and shops. Figure 6-1 illustrates the layout of such a facility. The terminal will be connected to the offshore fields by marine pipelines and to two SPM structures, each located in deep water at the end of a several kilometer marine pipeline and capable of off-loading into ice-breaking tankers.

The most optional marine terminal site for Hope Basin is near Cape Thompson, where deep water approaches close to shore and ice conditions are less severe. A site at either Kisimilok Creek or Ogotoruk Creek seems feasible. Depending on the actual terminal site and the size of the tankers used, pipeline lengths to a SPM in deep water would be between 5 to 10 kilometers (2.5 and 3.5 nautical miles; McMullen 1980).

Figure 6-2 illustrates the location of representative offshore oil fields, platforms, offshore and onshore pipeline corridors, marine terminal sites, LNG plant sites, and marine support base sites in the Hope Basin planning area.



Source: McMullen 1980

Figure 6-1
CRUDE OIL MARINE TERMINAL

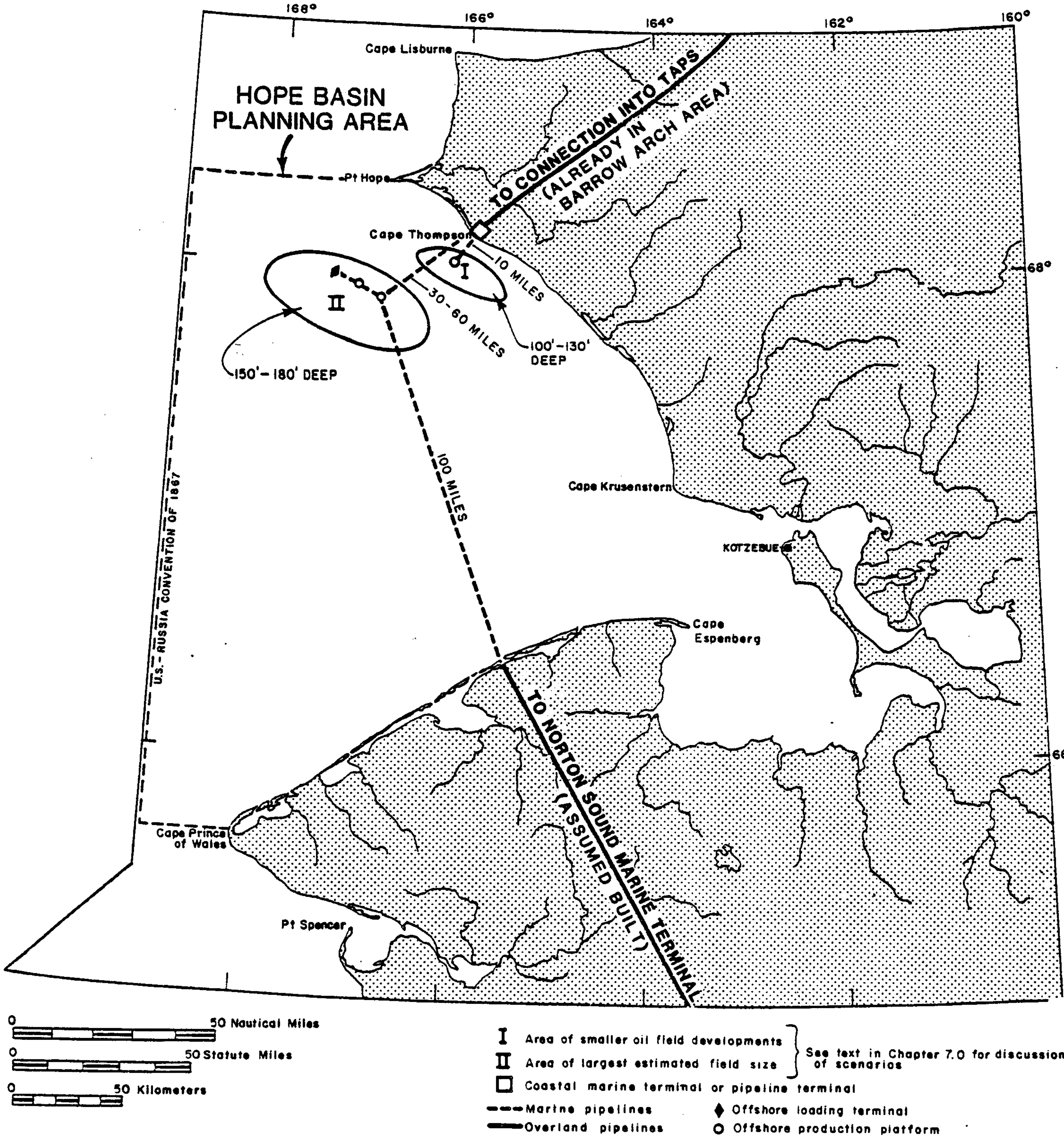


Figure 6-2

ONSHORE FACILITIES & OFFSHORE DEVELOPMENT COMPONENTS

6.3.3 Natural Gas Liquefaction Plants and Terminals

In the event that a pipeline is not constructed to transport natural gas, a liquefaction plant and marine terminal would be constructed to liquefy natural gas (LNG), store the produced LNG and transfer it to ice-breaking LNG tankers at an SPM. The Arctic Pilot Project being undertaken by PetroCanada to produce Mackenzie Delta natural gas is one such project.

6.4 Onshore Facilities Siting Constraints and Criteria

Table 6-1 illustrates some representative siting requirements for the major onshore facilities required to develop the oil and gas resources of the Chukchi Sea.

A variety of technical and environmental constraints and criteria must be taken into account selecting sites for onshore oil and gas facilities. Among the constraints to be considered in selecting onshore sites for support facilities are the following:

- o Landfast ice
- o High rates of coastal erosion
- o Nearshore permafrost
- o Gravel deposits
- o Sediment dynamics (littoral drift)
- o Freshwater supplies

TABLE 6-1

SUMMARY OF PETROLEUM FACILITY SITING REQUIREMENTS

Facility	Land Hectares (Acres)	Harbor Entrance	Channel	Turning Basin	Berthing Area	No. of Jetties/ Berths	Jetty/ Dock Frontage Meters (Feet)	Minimum Turning Basin Width Meters (Feet)	Comments
Crude Oil Terminal									
Small-Medium (<250,000 B/D)	30 (75)	15-23 (50-75)	14-20 (46-66)	13-19 (42-61)	12-18 (40-58)	1	457 (1500)	1220 (4000)	Required space in turning basin can be reduced substantially should tug-assisted docking and departures be required
Large (500,000 B/D)	138 (340)					2-3	914-1371 (3000-4500)	1220 (4000)	
Very Large (<1,000,000 B/D)	300 (740)					3-4	1371-1829 (4500-6000)	1220 (4000)	
LNG Plant									
(400 MMCFD)	24 (60)	13-16 (43-54)	11-14 (37-46)	10-13 (34-42)	10-12 (33-40)	1	304-610 (1000-2000)	1220 (4000)	In addition to thoroughput, size of plant will also depend on amount of reconditioning required for gas
(1,000 MMCFD)	80 (200)	13-16 (43-54)	11-14 (37-46)	10-13 (34-42)	10-12 (33-40)	2			
Construction Support Base	16-30 (40-75)	9.1 (30)	6 (20)	6 (20)	5.5 (18)	5-10	304-610 (1000-2000)	304-457 (1000-1500)	Requires additional 61 m of dock space for each pipelaying activity being conducted simultaneously and each additional 4 platform installation per year

Source: Dames & Moore 1980c.

B/D - barrels per day

MMCFD - million cubic feet per day

7.0 HOPE BASIN PETROLEUM STRATEGY AND SCENARIOS

7.1 Strategy Considerations

The characteristics of the Hope Basin OCS Planning Area that influence the nature of its future petroleum development are discussed here relative to the Barrow Arch OCS Planning Area. The latter is analyzed in detail in a preceding companion study (Dames & Moore, 1982d), which included an economic evaluation. Therefore, this present study provides comparison and contrasts between the two areas allowing for judgments about the economic considerations which might affect the Hope Basin Planning Area.

Key parameters that will influence the character of Hope Basin petroleum development have been identified as follows:

- Estimated small reserves
- Likely small field sizes
- Shallow reservoir depths
- Deep water
- Seasonal sea ice
- Remote location
- Postponed lease sale

The effects that these have on Hope Basin are discussed below, especially with respect to the Barrow Arch area immediately to the north.

Small Estimated Reserves

Although a final resources estimate report has not yet been completed by the USGS, earlier government and industry forecasts have identified Hope Basin as having low overall prospects. This will reduce and delay exploration activities relative to more prospects. This will reduce and delay exploration activities relative to more promising Alaska areas. It makes it more likely that floating drill platforms will be used for exploration and, that production platforms would be smaller and fewer, as would transportation facilities. Most importantly these factors favor development of the Hope Basin area only in conjunction with successful petroleum projects outside this planning area.

Small Field Sizes

Due to geological conditions, such as extensive faulting, it is likely that individual field sizes in Hope Basin will be small, at least relative to other arctic areas. This strains economic viability because of the higher amortized cost per unit of production.

Shallow Reservoirs

Although the range of potential reservoir depths is great, the most probable hydrocarbon accumulations are shallow. This allows for somewhat lower costs per well, but could still adversely impact the overall economics because of the limited reach possible using directional drilling. The result in Hope Basin could mean that more smaller platforms, or perhaps subsea completions, would be needd to effectively drain a given field area.

Deep Water

Average water depths in federal waters over Hope Basin are "deep" by arctic development standards at this time. Costs for arctic platforms rise dramatically with increasing water depth. Further, the more favorable geological structures identified for use in scenarios are in deeper (though not deepest) portions of the area.

Sea Ice

Seasonal sea ice over Hope Basin is of course estimated to be less severe than the more northerly arctic areas, such as Barrow Arch. However, this does not make it an easy area to operate in, and all constraints described in the earlier companion study apply to Hope Basin. These are somewhat mitigated, however, by its more southerly location. Significantly, the open-water season should be marginally longer on average. This is most beneficial for dredging, island construction and pipelaying operations, as well as favoring floating drilling during exploration. Another favorable aspect with respect to Hope Basin sea ice is that design forces should be less than the other areas at the same risk level. Stated differently, the probability of severe design events (pack ice incursion, ice islands) is less for Hope Basin (although the maximum possible ice forces may be very close to the other areas).

Remoteness

Hope Basin is an isolated, relatively undeveloped region. There is virtually no infrastructure to support petroleum development or exploration operations. The area is somewhat closer (in terms of air and water distances) to supply labor sources, however, the differences represent only a modest reduction relative to the Barrow Arch area and the same basic facilities (air fields, camps, docks, marshalling yards, etc.) must still be constructed.

Kotzebue is the closest large community in the region, however, it is far from suited for much more than peripheral logistics support to exploration operations. No deepwater harbor facilities of significance are available anywhere in the Hope Basin area.

Postponed Sale

Since Hope Basin is no longer on the current 5-year OCS lease sale schedule, exploration and possible development would occur after activity has occurred in most other arctic areas. This may provide the single most favorable aspect regarding its economic viability. The delay offers the possibility that other petroleum infrastructure will have been developed around the region. Possible facilities outside the planning area, which could reduce total investment costs and risks, are primarily an oil terminal serving Norton Sound to the south, or a trans-North Slope pipeline linking northwest Alaska with TAPS. If the Barrow Arch area proves economic using marine terminals, these are less likely to benefit Hope Basin because these would either be offshore terminals or a coastal facility located at Point Belcher, at the northern end of that area. However, some tanker transport capacity might be shared.

The prospect of Hope Basin's development occurring later in the overall petroleum development of the Arctic offers a potential for proven, used equipment to be available. Perhaps most significant of such equipment would be re-usable production platforms, such as caissons; however, available dredging systems, ice-breaking tankers, drill rigs and ice-capable workboats are all possible benefits to Hope Basin's future economics. An existing transshipment terminal, probably in the Aleutians Islands, is a reasonable expectation, and perhaps necessary to make Hope Basin marine transport economically viable.

Finally, market conditions at the time of Hope Basin development are likely to be far different than at present, characterized mainly by higher oil prices.

7.2 Possible Petroleum Development Scenarios

The preceding strategic considerations have been consolidated in defining reasonable and likely scenarios for Hope Basin petroleum development. Unlike earlier studies, facilities and activities outside this OCS planning area are considered important in the overall picture of the area's development.

Regarding exploration, it appears likely that most OCS drilling in Hope Basin will be done from floating platforms. The water depths area amenable, ice season conditions less demanding than the other arctic areas, drill depths should average less, and target structures will generally be smaller than needed to justify installing a bottom-founded platform for exploration.

Gas production scenarios are not developed here in light of the recent Dames & Moore (1983) economic analysis of the marketability of Alaska (Bering

Sea) gas. The study suggests that significant changes in the natural gas supply and price picture are needed to improve the marketability of even large gas reserves. The much smaller gas resources predicted for Hope Basin do not support serious consideration of such development at this time. Suffice it to note that any viable future gas projects in Hope Basin would require changes in the current gas market conditions that are highly speculative at this time, and would still require other gas projects in the vicinity.

<u>Oil Production Scenarios</u>

Four transportation scenarios define the range of reasonable options available for Hope Basin petroleum development. Two of these involve construction of marine terminals within the area, and two entail using pipelines to move oil to facilities presumed to exist out of the planning area (see Figure 6-2). The scenarios include:

- Coastal marine terminal located at Cape Thompson that receives oil from one or several oil gathering marine pipelines; treats and stores oil; and offloads into ice-breaking shuttle tankers year-round and/or conventional tankers during open-water periods.

- Offshore loading terminal located on a central production and storage island with oil flows augmented by pipelines from smaller production islands in the vicinity; offloads into tankers as above.

- From Cape Thompson marine pipeline landfall terminal northward via overland pipeline to connect with existing North-Slope-to-TAPS trunk line (latter already constructed to serve Barrow Arch or NPR-A area).

- From Hope Basin offshore platform(s) southward via marine pipeline across outer Kotzebue Sound to Seward Peninsula with overland crossing to marine terminal in Norton Sound (latter already constructed to serve local production there).

In terms of offshore facilities feeding these transport systems, two cases should bracket the technology and economics:

- Largest field size (100 million barrels) in Hope Basin area assumed located further offshore 50 to 100 kilometers (30 to 60 miles) and in deeper water 45 to 55 meters (150 to 180 feet).

- Smaller field(s) nearer to shore (Cape Thompson 25 to 40 kilometers [15 to 25 miles]), shallower 30 to 40 meters (100 to 130 feet) and somewhat more protected from sea ice movements than above case.

The larger field might be amenable to any of the four transportation options described. The smaller field case nearshore is more likely to be associated with either of the marine terminals than with the pipeline options.

It is difficult to judge which of these possible scenarios would be most feasible in terms of costs, particularly because of the hypothetical possibility of reusing platforms from other lease areas, and the uncertain pace development of petroleum-related infrastructure in the northwest Alaska region. With the small resources estimated for Hope Basin, such related development outside the planning area will be important to its economic viability for oil production.

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APPENDIX A
MANPOWER REQUIREMENTS

Introduction

The purpose of this appendix is to provide estimates of manpower requirements for several major tasks involved with the exploration, development, and production of petroleum for the Hope Basin OCS Planning Area. The estimates are presented here in the same format used in the Barrow Arch (Chukchi Sea) Petroleum Technology Assessment (Dames & Moore 1982d). Manpower estimates for Hope Basin for each major exploration, development, and production task are presented in Table A-1. Transportation support services associated with these major offshore operations are the same as were presented in the Barrow Arch report Table 5-2.

The southern Chukchi Sea (Hope Basin) has several characteristics which distinguish it from the northern Chukchi Sea (Barrow Arch). The open water season is on the order of 90 days as opposed to 70 days in the northern Chukchi Sea. Water depths are greater in the likely reservoir area but the target drilling depths are shallower. The likely reservoir size is smaller, which will reduce the size of production and transportation facilities. The relatively close proximity to Kotzebue and the Seward Peninsula alters logistic and siting considerations.

Our estimates reflect previous research on manpower requirements for offshore petroleum development; for example, "Beaufort Sea Petroleum Development Scenarios" (Dames & Moore 1978a), which discusses background on arctic labor considerations and specifically covers Prudhoe Bay experience with opening an arctic frontier area. Also see St. George Petroleum Technology Assessment (Dames & Moore 1980c) for general factors affecting offshore labor force size and productivity (Sections 4.2 and 5.3 of that report). Our manpower estimates for this study also benefited from consultation with engineers from SF/Braun about specialized arctic structures and operations that will be used in the development of resources in the Hope Basin planning area.

General background information regarding employment factors for this region are discussed in Chapter 5 of the Barrow Arch report; the specific differences and characteristics of Hope Basin mentioned above should be kept in mind when reading that background chapter. Hope Basin dredging and fill construction will usually require similar construction spreads and crews, but conditions offer a longer working period that might reduce crews somewhat. Smaller island areas would be needed for lesser production, but the deeper water may offset volume reductions. The probability of smaller fields will also force economies in shorebase construction (perhaps Kotzebue could play a role), use of shared and/or re-useable platforms, and virtually requires that the construction of a regional transshipment facility be carried by development of another OCS lease area. The Barrow Arch discussion of arctic labor expense, efficiency and potentials for labor-saving also apply to Hope Basin.

TABLE A-1

ESTIMATES OF LABOR REQUIREMENTS FOR SPECIFIC TASKS OF PETROLEUM DEVELOPMENT IN THE HOPE BASIN OCS PLANNING AREA

Activity	Onsite Labor (Number of Jobs)	Duration of Onsite Employment
Exploration Drilling	40/cone or island	2 months/well
Geophysical Survey	30/year of exploratory drilling	during exploration phase
Shorebase Construction		
Exploration Phase	100/mo. (peak) 40/mo. (average)	4 months
Development Phase(1)	150/mo. (peak) 40/mo. (average)	27 months
Oil Terminal Construction		
Arctic Site(2)	1300/mo. (peak) 400/mo. (average)	45 months
Aleutian Site	1000/mo. (peak) 550/mo. (average)	24 months
Early Production System (temporary)	200/mo. (average)	9 months
LNG Plant Construction (barge-mounted)	200/mo. (peak) 50/mo. (average)	24 months
Offshore Fill Construction(3)		
Gravel Island (50' depth)		
Exploration	430/mo.	3 months
Production (add-on)	450/mo.	3 months
Production (new)	620/mo.	3 months
Caisson-retained (50' depth)		
Exploration	400/mo.	3 months
Production (add-on)	445/mo.	3 months
Production (new)	575/mo.	3 months
Production Monocone	350/mo.	3 months
Production Equipment Installation and Hook-up		
Monocone	200/mo. (peak) 150/mo. (average)	7 months
Gravel/Caisson Island	250/mo. (peak) 200/mo. (average)	7 months

TABLE A-1 (Continued)

Activity	Onsite Labor (Number of Jobs)	Duration of Onsite Employment
Development Drilling Production Wells(4)		
Monocone	112/mo.	(4)
Gravel/Caisson Island	112/mo.	(4)
Submarine Pipeline Construction(5)		
Trunk	350/spread/mo.	0.75 mi/day
Feeder	350/spread/mo.	1.25 mi/day
On-Shore Pipeline Construction(6)		
Cross-Country	220/mo.	0.75 mi/day
Short-Distance	110/mo.	0.25 mi/day
Shorebase Operation		
Exploration Phase	32/mo.	exploration phase
Development Phase	160/mo.	development phase
Production Phase		
Year-round	40/mo.	12 months
Seasonal	80/mo.	3 months
Production Platform Operation, Cone and Island	64/mo.	12 months
Production Island Maintenance		
Gravel	44/mo.	3 months
Caisson	16/mo.	3 months
Production Equipment, Pipeline Maintenance; Cone and Island	24/mo.	3 months
Oil Terminal Operations		
Arctic Site(7)	52/mo.	12 months
Aleutian Site	40/mo.	12 months
LNG Plant Operation	48/mo.	12 months

Source: Dames & Moore and SF/Braun

NOTES TO TABLE A-1

(1) It is assumed that the development shorebase will be located at the terminal site near Cape Thompson. It is also assumed that the shorebase will be incorporated into the terminal site; therefore, shorebase construction has been phased with terminal construction. Shorebase construction could be completed much more quickly if done on a separate basis.

(2) Arctic terminal construction duration has been estimated by SF/Braun and by Bechtel (1979). The long total construction period to completion is predicated on the assumption that year-round construction would not be utilized due to the high inefficiency of outdoor winter construction in arctic regions. Therefore, the bulk of construction must be accomplished during the open-water season of several successive years.

(3) An existing exploration island could be expanded for use as a production island. The estimates shown for production islands "add-on" represent the incremental labor required for expansion. Caisson island assumes a Gulf-IHI-type steel structure. Monocone assumes gravel ballasting.

(4) Two rigs, one month/well on monocone; two rigs, one-half month/well on islands. For Barrow Arch area, the maximum number of wells per platform (60 on monocone and 100 on island) were assumed. Number of wells for Hope Basin platforms is difficult to predict because of generally shallower reservoirs (lower number wells), low initial production rate (need for more wells to increase production) and smaller field sizes.

(5) Oil or gas pipeline. Duration of employment for pipeline construction can be estimated for each scenario based on average rates of progress. Crew sizes are the same for trunk and feeder lines because it is reasonable to assume that the same lay barge will be used for both.

(6) Estimate for cross-country pipeline includes pump station; one spread is required. Short-distance pipeline construction would use smaller crew to avoid the high cost of mobilizing a large crew for a short period.

(7) Includes pipeline operation.

APPENDIX B

FIELD DEVELOPMENT COMPONENT COSTS AND SCHEDULES

B.1 Cost Data Base

This appendix presents cost estimates for Hope Basin field development and operations. The cost estimates given were developed by engineering staff of SF/Braun and supplemented by Dames & Moore. These are based primarily on modifications to the earlier analysis given in Appendix B of the Barrow Arch technology assessment report (Dames & Moore 1980d).

Several important qualifications were discussed with respect to estimating petroleum facility and equipment costs for frontier areas where no exploration has yet occurred, such as the Hope Basin planning area, in that companion report.

The approach in this study involved cost estimating by petroleum, drilling, pipeline and marine engineers. In the course of earlier Alaska OCS studies on the Gulf of Alaska (Dames & Moore 1979a and b), lower Cook Inlet (Dames & Moore 1979c), Norton Sound (Dames & Moore 1980a), St. George Basin (Dames & Moore 1980c), and Navarin Basin (Dames & Moore 1982a), a considerable data base on petroleum facility costs for offshore areas was obtained that provided supplemental information for this study. Those data were based on published literature, interviews with oil companies, construction companies, and government agencies involved in OCS research. Where primary source data for Hope Basin were unavailable, cost estimates were obtained from the National Petroleum Council's recent report U.S. Arctic Oil and Gas (1981).

The difficulties in obtaining relevant and comparable cost data, the extreme ice conditions and lack of comparable development experience in arctic regions imposed great cost estimation uncertainty.

B.2 Cost and Field Development Schedule Uncertainties

The purpose of this cost analysis is not to evaluate site-specific prospects with relatively well-known reservoir and hydrocarbon characteristics, but to bracket the development economics of the Hope Basin lease area. This would comprise a number of prospects that will have a range of reservoir and hydrocarbon characteristics, requiring a set of assumptions on petroleum geology and on characteristics of technology, given in Chapters 3 and 5, respectively. The facilities cost data, presented in Tables B-1 through B-8 use these assumptions.

The costs presented in Tables B-1 through B-8 reflect our estimates of the facility and equipment costs, based on simplifying assumptions that are the same as those stated in the Barrow Arch report (Dames & Mooe 1980d). All the cost figures are given in 1983 dollars.

Briefly discussed below are the principal uncertainties relating to the cost estimates for the various facility components. Important assumptions are noted in the tables.

B.2.1 Platform Fabrication and Installation (Table B-1)

Cost estimates are presented for two types of offshore production systems--concrete monocones and caisson-retained gravel islands -- in water depths representative of the high interest areas in the Hope Basin. These costs include design, manufacture, tow-out, and installation of monocones and retaining structures and mobilization and operation of gravel dredges.

B.2.2 Platform Process Equipment (Tables B-2 and B-3)

There is little difference in costs related to the decision to produce or reinject associated gas. For the range of figures and type of construction we have assumed, the major cost is equipment installation, not the cost of hardware. Costs for waterflood are included as are costs for drilling equipment. Drilling supplies and operating costs are included in the cost of wells. The gas-oil ratio is assumed to be 500:1 for all oil fields.

As the gas-oil ratio increases, the size of the pressure or production vessels and pipelines increase. Larger, more sophisticated equipment is required to handle the gas. At some point, depending on the amount of gas handled, the amount of entrained liquids, and costs, it becomes economical to take the natural gas liquids, stabilize them, and inject this stream into the oil pipeline. Associated gas may be reinjected into the reservoir to maintain pressure and to prolong the flowing life of the field. If natural gas production is not economically feasible, reinjection of associated gas is the only viable solution to the flaring ban imposed upon producing fields.

The costs for platform process equipment for a secondary recovery program (e.g., water injection) are much reduced if planned from the beginning. When water is injected, some of the drilling slots must be used, thus reducing the number available for production and, in turn, reducing the production rate and revenue flow.

B.2.3 Production Wells (Table B-4)

Production wells are assumed to be drilled from platform-mounted rigs. Two rigs would be used initially in developing oil fields. Once the initial drilling period is over, one rig would be removed, while the second would remain on the platform for workovers.

Gas wells are similar in design and cost to oil wells. Since fewer wells are assumed drilled from each platform, only a single rig would be installed on each gas platform.

B.2.4 Marine Pipelines (Table B-5)

Because of the unique considerations of landfalls, hook-ups, trenching, burying, and mobilization and demobilization, it was necessary to cost out the pipeline requirements of each scenario individually; these costs appear in Table B-5. The costs for pipeline in the Chukchi Sea are much higher than those reported in technology assessments for the sub-arctic due to the shorter (estimated 85-day) open-water working season.

B.2.5 Oil Terminal Costs (Table B-6)

Terminal costs vary more as a function of tanker size than throughput itself. This is primarily due to differences in storage capacities. Since Hope Basin would probably be viable only at its upper throughput, only that quanity was estimated. Further, Hope Basin would likely draw upon services of existing ice-capable tankers rather than a dedicated fleet for its small production. Therefore, a range of tanker sizes might need to be accomodated, and this is reflected Table B-6.

Particular uncertainty exists regarding crude oil terminal costs in the more remote areas of Alaska. Oil terminal costs will vary as a function of throughput; quality of crude; upgrading requirements of crude for tanker transport; terrain and hydrographic characteristics of the site; type, size, and frequency of tankers; and many other factors. Remote location will impose significantly greater costs on terminal construction than a similar project in the Cook Inlet area or Lower 48.

B.2.6 Costs Estimates for Tankers, Tugs and Workboats (Table B-7)

Year-round production of the Hope Basin's oil resources requires ice-breaking oil tankers, workboats and tugs. Workboats with ice-breaking capability would be required at a Hope Basin terminal and to serve the offshore platforms. Costs on Table B-7 are based on a 290-foot 2,000-DWT vessel developing 18,000 horsepower. These estimates were provided by SF/Braun.

TABLE B-1

COST ESTIMATES FOR INSTALLED PLATFORMS AND ARTIFICIAL ISLANDS[1]

PLATFORM TYPE	WATER DEPTH METERS	FEET	INSTALLED COST ($ Millions 1983)
Concrete Monocones:	37	120	430
	60	200	600[2]
Caisson-Retained Gravel Islands	30	100	280

Notes: (1) In addition to fabrication of the gravity structure in a Lower 48 yard, these estimates include the cost of platform installation, which involves site preparation, tow-out, set-down and pile driving. The above estimates do not include any allowance for the installation or hook-up of topside facilities (see Tables B-2 and B-3).

(2) At this depth, a 37-meter (120-foot) water depth monocone would be placed on a submerged berm island 23 meters (80 feet) high.

Source: SF/Braun

TABLE B-2

COST ESTIMATES FOR PLATFORM EQUIPMENT[1]
AND FACILITIES FOR OIL PRODUCTION

PEAK CAPACITY OIL (Barrels Per Day)	COST[2] ($ Million 1983)
30,000 to pipeline	100[3]

Notes: (1) The cost of topside facilities would be essentially the same for both the platform types being considered.

(2) The above cost estimates include installation, hook-up, and commissioning. It is assumed that module installation would be concurrent with platform installation, thus avoiding a second mobilization and demobilization of the equipment.

Source: SF/Braun

TABLE B-3

COST ESTIMATES FOR PLATFORM EQUIPMENT(1)
AND FACILITIES FOR GAS PRODUCTION

PEAK CAPACITY GAS (Thousand MCF Per Day)	COST(2) ($ Million 1983)
100 (production equipment)	120

Notes: 1. The cost of topside facilities would be essentially the same for both the platform types being considered.

2. The above cost estimates include installation, hook-up, and commissioning. It is assumed that module installation would be concurrent with platform installation, thus avoiding a second mobilization and demobilization of the equipment.

3. This cost only applies to offshore equipment. Onshore LNG equipment is discussed under terminals.

Source: National Petroleum Council (1981).

TABLE B-4

COST ESTIMATES OF PRODUCTION WELLS
(OIL OR GAS)

WELL TYPE	RESERVOIR DEPTH METERS	RESERVOIR DEPTH FEET	COST ($) MILLION (1983)
Production Well from Platform	1,200	4,000	2.0

Source: SF/Braun

Notes: 1. Includes mobilization costs, operating cost, and consumables.
2. Well is asumed to be directionally drilled (below the mud line).

TABLE B-5

COST ESTIMATES FOR PIPELINES

For Largest Hope Basin Oil Field Scenario:

	Cost ($ Million 1983)
Offshore Pipelines	
Feeder lines between platforms - 5 miles	30
Trunk line to shore - 50 miles (12- to 16-inch)	250
Onshore Pipelines (16-inch)	
Cape Thompson to TAPS at Wainwright, including one pump station	650
Cape Thompson to Cape Sabine, including one pump station	350

For Smaller Nearshore Oil Field Scenario:

Offshore Pipeline (4)	
Platform to shore - 10 miles (10-inch)	60

Notes:
1. Trenching and/or insulation is assumed where required.
2. Includes mobilization/demobilization of a ship-type lay barge.
3. Includes cost of landfalls and hookups.
4. No offshore feeder lines nor onshore lines needed.

Source: SF/Braun

TABLE B-6

ESTIMATED COST OF OIL TERMINAL

Peak Throughput (Thousand Barrels Per Day)	Tanker Size Capability (1000 DWT)	Hope Basin(1) Terminal Capital Cost ($ Million 1983)
30	60	480
30	150	610

Notes: (1) Including facilities for any final crude stabilization, storage of 10 days' throughput and docking and loading for shuttle tankers.

Source: SF/Braun and Dames & Moore

TABLE B-7

ESTIMATES OF COSTS AND ANNUAL OPERATING EXPENSES FOR TANKERS AND WORK BOATS

VESSEL TYPE	CAPITAL COST ($ MILLION 1983)	ANNUAL OPERATING COST ($ MILLION 1983)
1. Ice-Capable		
Oil Tankers - 60,000 DWT	160	19
- 150,000 DWT	240	25
2. Ice-Breaking Workboats (support vessels) - 140 feet	79	29
3. Tugs - Port Duty	63	23
Sea Duty	63	37

Sources: SF/Braun and National Petroleum Council.