Chapter Three: Description of the Beaufort Sea Lease Sale Area

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Chapter Three: Description of the Beaufort Sea Lease Sale Area

A. Property Description

The lease sale area contains approximately 2,000,000 acres in 573 tracts ranging in size from 640 to 5,760 acres. The area consists of state-owned tide and submerged land, located along the Beaufort Sea coast, between Point Barrow and the Canadian border within the three-mile offshore boundary between state and federal waters. The lease sale area is adjacent to the offshore boundaries of both the National Petroleum Reserve-Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR). The southern fringe of the area includes some state-owned uplands lying between the NPR-A and ANWR between the Colville River and the Canning River. The lease sale also includes numerous islands.

Prominent water bodies in the lease sale include Smith Bay, Harrison Bay, Simpson Lagoon, Gwyder Bay, Prudhoe Bay, Stefansson Sound, Foggy Island Bay, Mikkelson Bay, and Camden Bay. Important island groups include Plover, Jones, Return, Midway, McLure, Stockton, Maguire, and Flaxman Islands.

The state owns most of the uplands within the lease sale boundaries. Other landowners are the federal government, Native corporations, the North Slope Borough, and individuals. The mineral estate of seven onshore tracts within the Colville River Delta is owned jointly by the state and the Arctic Slope Regional Corporation (ASRC), with Kuukpik Village Corporation (Nuiqsut) as the owner of the land estate. There is one federal inholding, the DEW site at Bullen Point. Although surrounded by the lease sale, this acreage is excluded from state oil and gas leasing because the state does not own the mineral estate. Kaktovik Inupiat Corporation, the village corporation for Kaktovik, has inholdings within ANWR.

The uplands from the Stains River easterly to the Canadian border lie within ANWR, which is owned by the federal government and therefore not available for inclusion in state oil and gas lease sales. The uplands from the Colville River westerly to Barrow are within the NPR-A, which is also owned by the federal government. Portions of NPR-A are available for oil and gas exploration and development.

There are several Native allotments and parcels owned by the North Slope Borough. The state, as the mineral estate owner, may lease these lands.

The U.S. Department of State has notified the State of Alaska that the tide and submerged land within Tract 001 of the lease sale may be subject to a title dispute with the government of Canada. Potential bidders on Tract 001 should be prepared for possible delays in determining state title to lands within this tract.

The lease sale is within the North Slope Borough. This home rule borough, incorporated in 1972, extends from the Chukchi Sea to the Canadian border. The borough has the powers of taxation, land management, and zoning, and is responsible for providing borough communities with public works, utilities, education, health, and other public services. The lease sale is within Alaska's coastal zone and is subject to the Alaska Coastal Management Program.

ADNR plans to continue to defer from this lease sale all tracts from Pt. Barrow to Tangent Point (Tracts 555, 557-573) and from Barter Island to Pokok Bay (Tracts 27-39). Deferral means that these tracts will not be offered for lease in the 2009 Beaufort Sea Areawide sale, but may be included in future lease sales. Even though existing mitigation measures (Chapter Nine) provide the necessary protection for subsistence activities, ADNR is taking the extra precaution of continuing to defer these tracts from consideration at this time. It is possible that during the 10-year period covered by this finding, the prospects for developing these tracts will increase. ADNR will annually review the available information for these tracts to determine whether to offer them in a future lease sale.

1. Land and Mineral Ownership

The Alaska Statehood Act granted to the state of Alaska the right to select from the federal public domain 102.5 million acres of land to serve as an economic base for the new state. The Act also granted to Alaska the right to all minerals underlying these selections and specifically required the state to retain this mineral interest when conveying its interests in the land (AS 38.05.125). Therefore, when state land is conveyed to an individual citizen, local government, or other entity, state law requires that the deed reserve the mineral rights for the state. Furthermore, state law reserves to the state the right to reasonable access to the surface for purposes of exploring for, developing and producing the reserved mineral. Surface owners are entitled to damages under AS 38.05.130, but may not deny reasonable access. Mineral closing orders, which are commonly associated with surface land disposals, do not apply to oil and gas leasing.

The Alaska Native Claims Settlement Act (ANCSA), passed by Congress in 1971, also granted newly created regional Native corporations the right to select and obtain from the federal domain lands the land and mineral estates within the regional Native corporation boundaries. It also allowed Native village corporations and individual Native Alaskans to receive land estate interests. However, overlapping selections created conflicts and delays in conveying the land from the federal government, and some selected lands have yet to be conveyed.

In 1991 the State and Arctic Slope Regional Corporation (ASRC) executed a Settlement Agreement. In that agreement, the State and ASRC agreed to joint ownership of the land within the settlement area for the purposes of oil and gas leasing. The mineral estate of seven onshore tracts within the Colville River Delta is now owned jointly by the state and ASRC in various percentages, with Kuukpik Village Corporation (Nuiqsut) as the owner of the land estate. In accordance with the agreement, sections that are not "fully conveyed" from the federal government are not available for leasing. The State is the designated authority to offer the jointly owned lands for leasing, and issues leases on behalf of ASRC for their various ownership percentages.

There is one federal inholding, the DEW site at Bullen Point. The state has a selection topfiling on the parcel and is expected to receive title after the federal withdrawal has been lifted. However, there are contamination issues with the parcel that may need to be resolved before conveyance.

There are several parcels of which the surface estate was conveyed from the state through the federal government to Native allottees. The North Slope Borough also owns land as a result of the state's municipal entitlement program. Additional municipal conveyances are pending within the lease sale area. For the most part, the State, as the owner of the retained mineral estate, may lease these lands for oil and gas development.

The Beaufort Sea Areawide lease sale contains tracts in which the state owns both the land estate and the mineral estate; and tracts where the state owns just the mineral estate, while the land estate might be either privately owned or owned by a municipality. Only those free and unencumbered state-owned oil and gas mineral estates within the tracts will be included in any lease issued.

B. Historical Background

Evidence of human occupation and use of the Arctic Coastal Plain dates back to 10,000 B.C. Marine mammal harvesting on winter sea ice has occurred for at least four thousand years, and evidence of whaling is 3,400 years old (Langdon 1995). The record of human existence on the North Slope is characterized by several distinct cultural periods marked by changes in tool style (NSBCMP 1984).

The environmental characteristics of the Arctic shaped Inupiat culture into a semi-nomadic society with a tradition of whaling and an emphasis on seasonal inland hunting. This pattern of land use remained unchanged until the second half of the 19th century with the arrival of westerners, new tools, and due to natural events, such as caribou population decline (NSBCMP 1984; NSB 1979).

Numerous sites across the North Slope containing sod houses, graves, storage pits, ice cellars, bones and relics attest to the historical use and presence of Arctic people in the lease sale area, however, much of the archaeological record has been destroyed by erosion (Hoffman et al. 1988). For centuries, trading centers, such as Barter Island and Nigalik, at the mouth of the Colville River, were used by Canadian and Alaskan Eskimos (Jacobson and Wentworth 1982). Eskimos of the North Slope also traded with Asia across the Bering Strait as early as the mid-1700's (Langdon 1995) (NSBCMP 1984).

European explorers and fur traders began arriving in the lease sale area during the 1820s and 30s. This contact introduced metal tools, traps, and guns to support trading and hunting. Russian trading posts were established from Norton Sound southward. After bowhead whale migration paths were discovered, commercial whaling increased dramatically in the Arctic after 1850 and into the 1880s. Several whaling stations were built along the coast, providing for regular contact and trading with Natives. Steamships, later replaced sailing vessels, facilitating year round access. Increased hunting pressure and a natural decline reduced the population of the western caribou herd. This, coupled with western diseases, such as measles and influenza, resulted in an increase in the death rate of the inland Eskimo. Coastal Inupiat also suffered population decline from foreign diseases (NSBCMP 1984)

By World War I, declining whale populations and a decreased demand for whale oil and baleen brought an end to the commercial whaling period. However, demand for fur, particularly Arctic fox, resulted in the continued presence of westerners along the Beaufort Coast and North Slope. Native residents who were engaged in trapping provided income for non-subsistence resources. By 1914, trapping camps used in the thriving fur trade were established from Barrow to the Canadian border (NSBCMP 1984). In the 1930s, however, the price of fur plummeted, forcing many traders to leave the region near the lower Colville River. Many residents moved to other settlements in Alaska (Hoffman et al. 1988).

World War II brought an influx of military personnel into Alaska and the petroleum exploration period began. Inupiat were hired to work on construction projects, including the Naval Arctic Research Laboratory near Barrow in 1947, and the Distant Early Warning (DEW) line defense sites in the early 1950s (NSBCMP 1984). Before 1950, the lower Colville River supported many families, until the Bureau of Indian Affairs required that children attend schools, and most residents relocated to Barrow (NSB 1979).

The contemporary period of modernization and change began in the 1960s. The discovery of the Prudhoe Bay oil field in 1967 prompted a renewed interest in petroleum exploration and development, but before oil reserves could be developed, Native land claims had to be settled. "In response to rapid change that threatened Native land rights through land transfers, biological resource limitations, and natural resource leasing (primarily oil and gas), Inupiat political groups formed regional organizations to protect their rights and culture." The Alaska Native Claims Settlement Act, passed in 1971, created village and regional Native corporations and provided a mechanism for the transfer of land ownership to Native Alaskans (NSBCMP 1984).

Before the building period of the late 1970s and 1980s, few services were provided to residents, few jobs were available, and living conditions were austere across the Arctic Slope of Alaska. All communities lacked sanitation services, running water, telephones in homes, community centers and modern recreation facilities. The incorporation of the North Slope Borough (NSB) in 1972 provided residents with local government powers and a mechanism to assess and tax oil and gas infrastructure. Incorporation also created responsibilities of planning, zoning, education and utilities. Petroleum

N. Grewe, Community Photo Library, DCED

Community of Barrow.

revenues and other funding have provided the borough with resources to pay for schools, fire stations, medical clinics, health care services, utilities, public safety facilities, family assistance programs, workforce development programs, community centers, public housing, administrative facilities, and jobs for borough residents.

C. Communities

1. North Slope Borough

The North Slope Borough, incorporated in 1972, is Alaska's largest borough, covering more than 15 percent of the state's total land area. The area encompasses 88,817.1 mi^2 of land and 5,945.5 mi^2 of water. Communities located within the borough include: Anaktuvuk Pass, Atqasuk, Barrow, Deadhorse/Prudhoe Bay, Kaktovik, Nuiqsut, Point Hope, Point Lay, and Wainwright (DCCED 2006). The borough is located within the Barrow Recording District.

In 2007, the population of the North Slope Borough was 6,751. Approximately 70 percent of borough residents are Alaska Native or part Native. The majority of permanent residents are Inupiat Eskimos (DCCED 2008).

Air travel provides the only year-round access, while land transportation provides seasonal access. The Dalton Highway provides road access to Deadhorse/Prudhoe Bay, though it is restricted during winter months. "Cat-trains" are sometimes used to transport freight overland from Barrow during the winter (DCCED 2008).

2. Barrow

Barrow, which was incorporated in 1958, is located 10 miles south of Point Barrow on the Chukchi Sea coast. The area encompasses 18.4 mi^2 of land and 2.9 mi^2 of water. Formation of the North Slope

Borough in 1972, the Arctic Slope Regional Corporation, and construction of the Prudhoe Bay oil fields and the Trans-Alaska Pipeline have contributed to Barrow's development.

The population of Barrow is 4,054 (DCCED 2008). Fifty-seven percent of the population is Inupiat, who practice a traditional subsistence lifestyle dependent on marine mammal hunting and supplemented by inland hunting and fishing (EDAW/AECOM 2007). The North Slope Borough is Barrow's primary employer; however employment is also provided by state and federal agencies and numerous other businesses that provide support services to oil and gas field operations. The median household income in 1999 was $76,200 (City-Data.com 2008). Figure 3.1 and Figure 3.2 display Barrow's employment classes and employment rates from the year 2000.

The North Slope Borough provides utilities to Barrow. Water is derived from a dam on Isatkoak Lagoon and is stored in a holding tank. The Barrow Utilities & Electric Cooperative operates the water and sewage treatment plants, generates and distributes electric power, and distributes piped natural gas for home heating. The local power plant is fueled by natural gas (DCCED 2006).

Year-round access is provided by air travel. The state owns the Wiley Post-Will Rogers Memorial Airport, which serves as the regional transportation center for the borough. The airport has a 6,500-foot-long asphalt runway. Marine and land transportation also provide seasonal access (DCCED 2006).

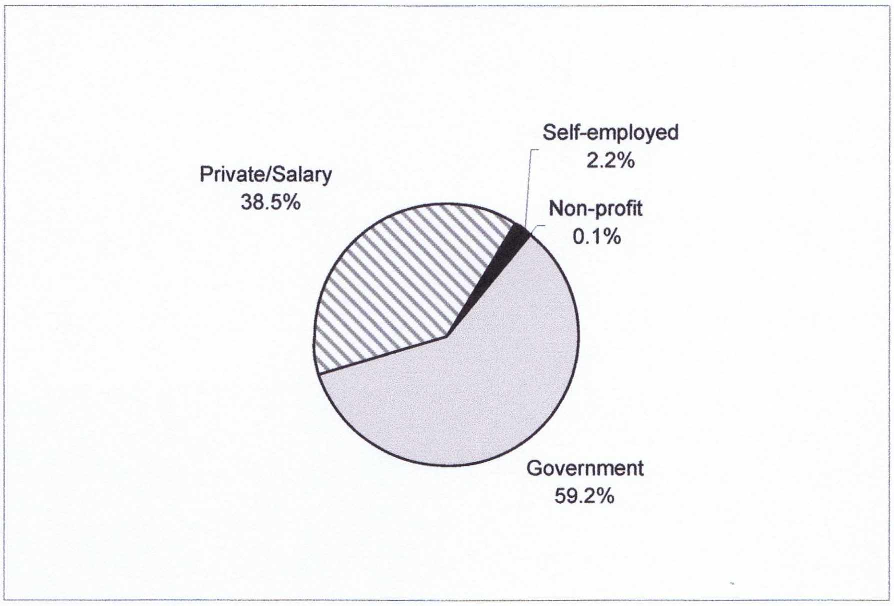
3. Kaktovik

Kaktovik, which was incorporated in 1971, is located on the north shore of Barter Island, between the Okpilak and Jago Rivers. The village encompasses 0.8 mi^2 of land and 0.2 mi^2 of water and lies within the Arctic National Wildlife Refuge. The island served as a major trade center for the Inupiat, particularly as a bartering place for Alaska Inupiat and Canadian Inuit (DCCED 2006).

The population of Kaktovik is 287 (DCCED 2008). The isolated village has maintained traditions and its subsistence is mainly dependent upon caribou (DCCED 2006). Unemployment is high in Kaktovik and economic opportunities are limited due to the isolation of the community. The median household income in 1999 was $55,625. The North Slope Borough and school provide most of the year-round employment; however, part-time seasonal jobs, such as construction, also provide income (USCB 2000b). Figure 3.3 and Figure 3.4 display Kaktovik's employment classes and employment rates from the year 2000.

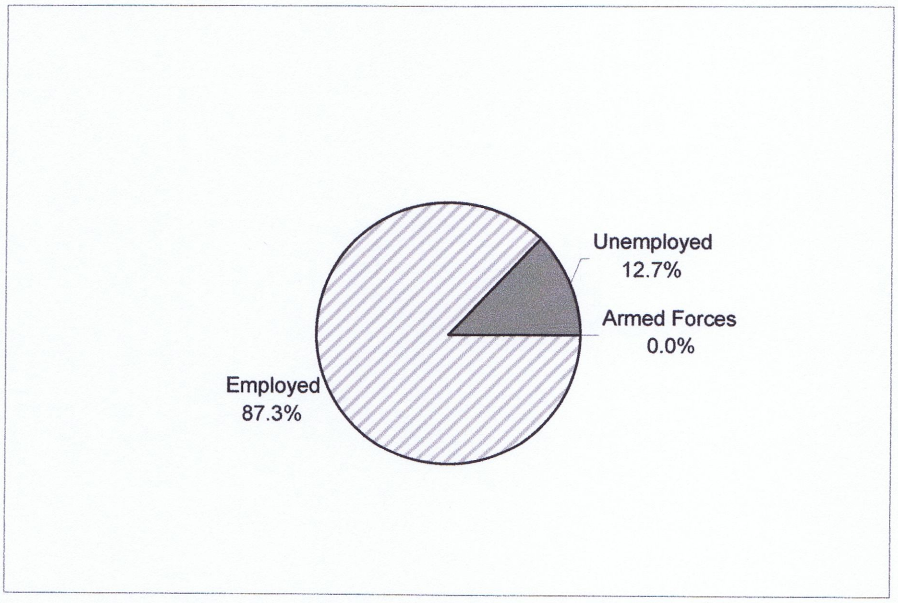
The North Slope Borough provides utilities to Kaktovik. Water is derived from a surface source, treated and stored in a 680,000-gallon water tank, and delivered by truck to home holding tanks. Approximately 80 percent of homes have running water in the kitchen. Homes that are not connected to the water and sewer system utilize holding tanks that are pumped and hauled on a regular basis (USCB 2000b).

Year-round access is provided by air travel. The Barter Island Airport is owned by the U.S. Air Force and operated by the borough. Marine and land transportation also provide seasonal access (DCCED 2006).



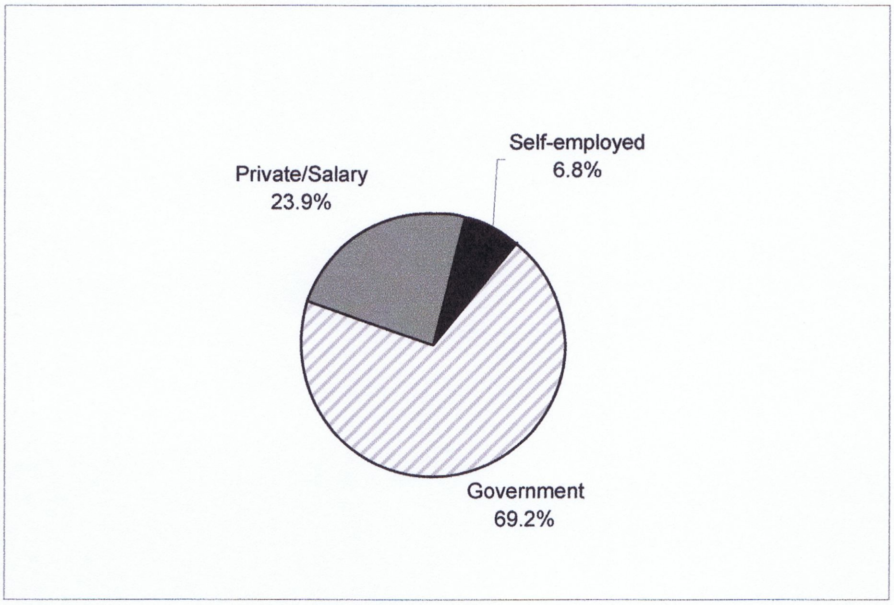
Source: (USCB 2000a)

Figure 3.1. Barrow employment classes, 2000.



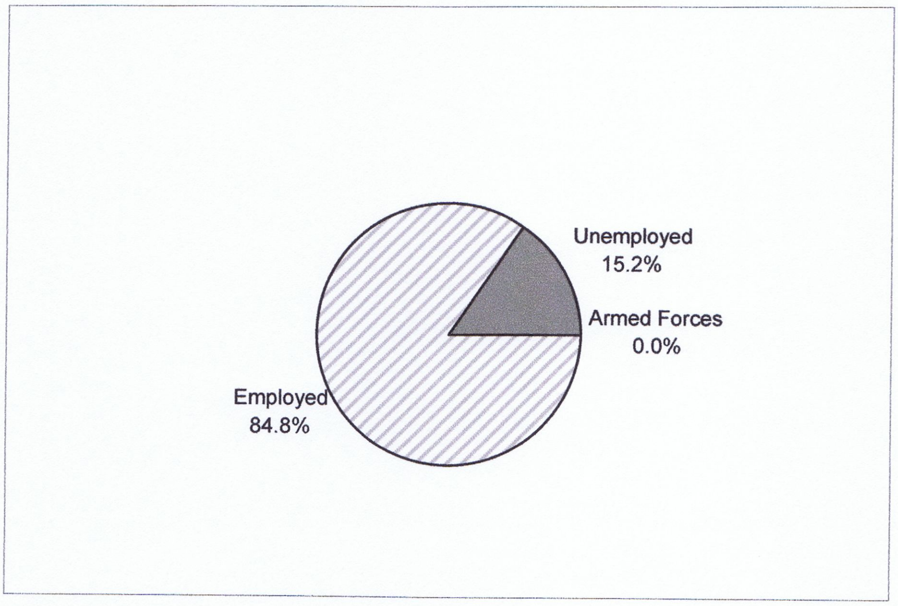
Source: (USCB 2000a)

Figure 3.2. Barrow employment rate, 2000.



Source: (USCB 2000b)

Figure 3.3. Kaktovik employment classes, 2000.



Source: (USCB 2000b)

Figure 3.4. Kaktovik employment rate, 2000.

Community Photo Library, DCED

Aerial view of Kaktovik.

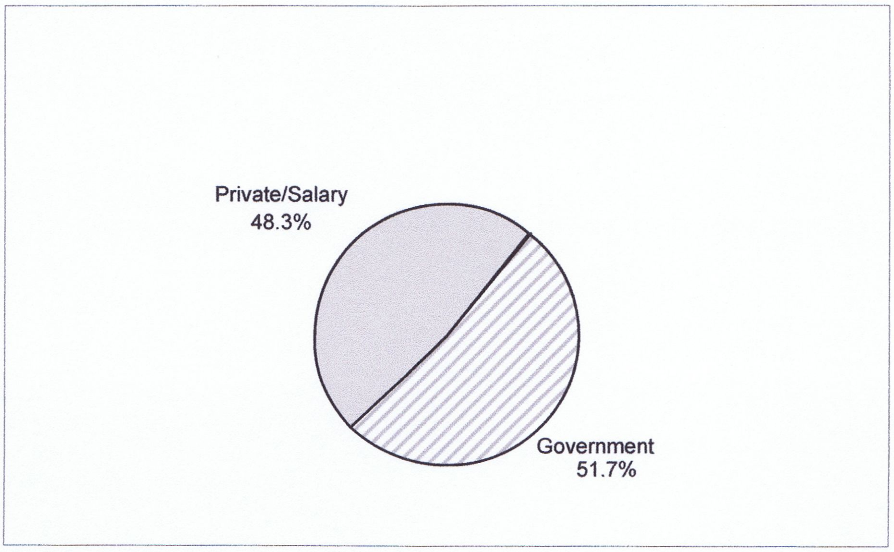
4. Nuiqsut

Nuiqsut, population 403 (DCCED 2008) is located approximately 35 miles from the Beaufort Sea on the west bank of the Nechelik Channel of the Colville River delta. It encompasses 9.2 mi^2 of land. The Colville delta has traditionally been a gathering and trading place for the Inupiat and offers good hunting and fishing. The old village of Nuiqsut was abandoned in the late 1940s for lack of a school. In 1973, the village was resettled by 27 families from Barrow. In 1973 and 1974, a school, housing, and other facilities were constructed by federal agencies. The City of Nuiqsut was incorporated in 1975 (DCCED 2006). The majority of the population is Inupiat, who practice a traditional subsistence lifestyle.

The median household income in 2000 was $48,036 (USCB 2000c). The Kuukpik Native Corporation, school, borough, and store provide most of the year-round employment in the village. Trapping and craft-making also provide some income. Caribou, bowhead and beluga whale, seal, moose, and fish are staples of the diet. Polar bears are also hunted (DCCED 2006). Figure 3.5 and Figure 3.6 display Nuiqsut's employment classes and employment rates from the 2000 census.

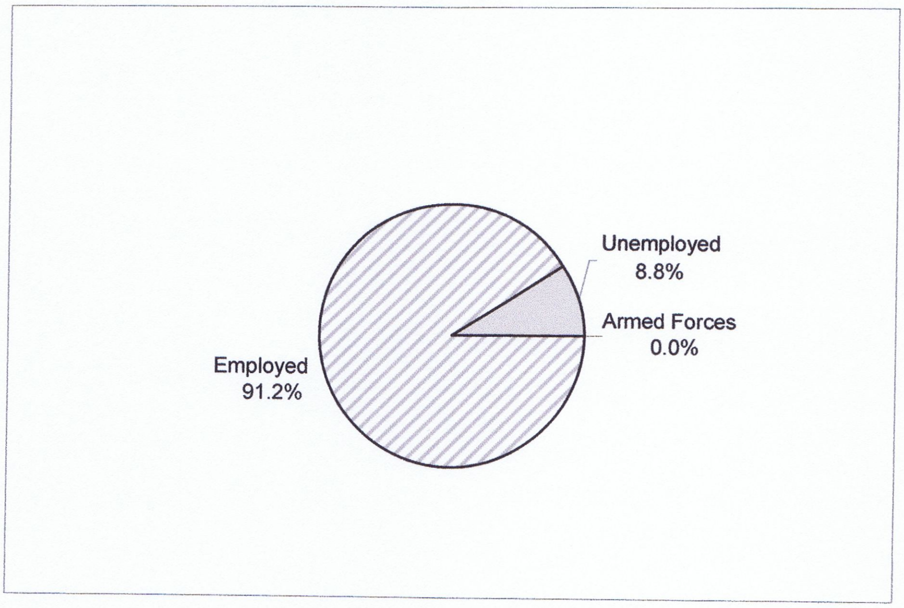
The North Slope Borough provides utilities to Nuiqsut. Water is derived from a lake, treated and delivered to individual resident's water tanks. Most homes have running water to the kitchen. The Alpine oil field will soon provide piped natural gas to Nuiqsut, which will lower the cost of running diesel electric generators for heating homes and other facilities (DCCED 2006).

The borough owns and operates a gravel airstrip and year-round access is provided by air travel. Marine and land transportation also provide local seasonal access and snowmachines are used for local transportation in winter months (DCCED 2006).



Source: (USCB 2000c)

Figure 3.5. Nuiqsut employment classes, 2000.



Source: (USCB 2000c)

Figure 3.6. Nuiqsut employment rate, 2000.

5. Prudhoe Bay/Deadhorse

Extensive development of the Prudhoe Bay/Deadhorse area for oil drilling operations began in the 1970s. Despite the low census figures—the population in 2007 was three—Prudhoe Bay is a very busy place and serves as a hub for oil and gas field workers. Population figures reflect only permanent residents of Deadhorse and Prudhoe Bay—most oil field workers travel home to Anchorage or the lower 48 states when off duty. The airport, lodging, a general store, and other facilities are clustered in Deadhorse (DCCED 2008).

The Prudhoe Bay oil fields provide approximately 20 percent of the nation's domestic oil supply. More than 5,000 individuals are employed in drilling, pipeline operations, cargo transportation, and a variety of support positions (DCCED 2006).

The airport at Deadhorse is the primary means of public transportation. The state owns a 6,500-foot-long asphalt airstrip and a heliport. The Dalton Highway is used year-round by trucks to haul cargo to the North Slope (DCCED 2006).

D. Cultural Resources

Historic use and archaeological sites: The ADNR, Office of History and Archaeology has researched the available sources and found 14 known historic and archaeological sites onshore within the lease sale area. There are several reported shipwreck sites within the lease sale area. It is very likely that there may be additional sites that have not been previously reported (DPOR 2008).

Cultural and historic resources are those sites and artifacts having significance to the culture of Arctic people. Historic and cultural sites are those identified by the National Register of Historic Sites, and include those identified in the NSB Traditional Land Use Inventory (TLUI), by the Commission on Inupiat History, Language and Culture, and sites identified in other published studies. Many places, such as ancient village locations along the tributaries of the Colville River, which contain archaeologically important relics, continue to be used today.

E. Climate

Surface conditions in the Arctic vary dramatically. In summer, the climate is generally mild. The three-month ice-free season is critical to biological productivity. In contrast, winters are severe, forcing many species to migrate south.

Since the late 19th century, average global temperatures have increased 0.5°F to 1.0°F (BLM 2005). Temperature increase in Alaska over the last 50 years averages 3.4°F, although the temperature changes vary greatly across the state and most of the change has occurred in winter and spring months. Little additional warming has occurred since 1977, with the exception of a few locations. Regional climatic change is difficult to quantify and much less reliable than global estimations (BLM 2005; ACRC 2008).

Changes that could accompany warming trends include melting glaciers, reduction in seasonal sea ice cover resulting in increased storm effects and higher coastal erosion rates, increased permafrost melting, shifting vegetation zones, increased fires, insect outbreaks, changing animal migration paths, and changing subsistence patterns (DGGS 2008a).

In 2006, the Alaska Climate Impact Assessment Commission was formed to assess the effects of climate change on citizens, resources, economy, and assets of the state of Alaska (ACIAC 2008). In September 14, 2007, Administrative Order 238 was signed, creating the Climate Sub-Cabinet to develop an Alaska Climate Change Strategy. The strategy will serve as a guide for responding to climate change and will identify immediate priorities as well as long-term strategies, including recommendations for saving energy and reducing greenhouse gas emissions (SOA 2008). On April

17, 2008, the Governor's subcabinet released its final report of recommended actions including emergency planning and training, erosion control, and village relocation planning (IAW 2008).

1. Precipitation

The mean annual precipitation ranges from 10.1 centimeters (cm) at Kuparuk to 15.7 cm at Barter Island. The precipitation maximum occurs in August for all stations while during the winter months (November through April), the precipitation is very light. The mean annual snowfall ranges from 78.2 cm at Kuparuk to 106.2 cm at Barter Island. The maximum snowfall, 211.7 cm, was recorded at Barter Island. A permanent snow cover normally is established in September. The depth of snow on the ground is influenced primarily by snowfall during the winter. However, due to blowing and drifting, the snow cover can be redistributed (MMS 2007).

2. Temperature

Subfreezing temperatures prevail for most of the year. Along the Beaufort Sea, the average mean temperature in February ranges from -18.0 °F at Prudhoe Bay. An extreme low temperature of -62 °F has been recorded at Prudhoe Bay. During winter, there may be prolonged periods of high winds, leading to extreme ice pressures and dangerous wind-chill conditions (MMS 2008).

There is a brief summer season from June through August, with temperatures generally above freezing and precipitation falling in the form of rain. Along the Beaufort Sea, the average mean temperature in July ranges from 39.8 °F at Barter Island to 47.6 °F at Prudhoe Bay. An extreme maximum temperature of 83 °F has been recorded at Prudhoe Bay and Kuparuk (MMS 2008).

3. Winds

The winds are fairly strong on the North Slope, with monthly mean values around 10 knots. There is no strong annual course in wind speed, but there is a slight indication of a maximum in the fall when the adjoining Beaufort Sea is still ice free and the land has already substantially cooled. This strong thermal contrast in the surface temperature of the ocean and land might at times enhance the wind speed. Winds are normally from an easterly direction, with westerly winds occurring more infrequently. Calms are very seldom, with annual values of less than 2 percent. Wind directions were bimodal, typically prevailing from an east northeasterly direction (approximately 45percent of the time) or from a west northwesterly direction (approximately 25percent of the time (MMS 2007).

F. Oceanography, Sea Ice, and Permafrost

Life, both residential and migratory in the lease sale area, is supported by the coastal habitat. The productivity and extent of coastal habitats are dependent on physical processes that shape and move the coast and barrier islands, and influence the circulation of marine waters. These coastal processes are driven by the changing seasons and the ever-present polar ice cap.

1. Oceanography

The sale includes a series of bays, lagoons, and a sound enclosed by barrier islands in the central Beaufort Sea. This region is highly influenced by the wind during the open-water season. Other influences include landfast ice, river discharge, and ice melt. This nearshore area is a repository for freshwater draining from rivers and streams, making it estuarine during parts of the seasonal cycle. During this seasonal cycle, nearshore waters are made up of freshwater, marine water, and a mixture of both (MMS 2008).

During the winter, under-ice water temperatures ranging from -2 to 0°C. During the open-water season water temperatures range from 0 to 9°C (MMS 2007). From early June to July, the landfast and sea ice melts. Open water first occurs next to the river deltas and is mostly river water and ice meltwater. This water is brackish, meaning a mixture of fresh- and saltwater. By midsummer, the open-water area becomes large enough for the wind to mix and circulate the water. The nearshore brackish water mixes to form a coastal watermass with a range of intermediate temperatures and salinity whose distribution is determined primarily by the wind. By late summer, freshwater discharge generally is low, and air temperatures fall. The water becomes marine and fairly uniform throughout the nearshore and offshore regions. The open-water area becomes the largest for the season (MMS 2008).

Tides in the Beaufort Sea are semidiurnal in nature, meaning that two high tides and two low tides occur each day. The National Ocean Service (NOS) reports a mean tide range of 16 cm and a diurnal range of 21 cm for the tide station located in Prudhoe Bay (MMS 2007). Tidal currents generally are weak, about 3-4 cm/sec. Both positive and negative storm surges occur (MMS 2008). Summer and fall storms frequently generate storm surges along the coast which can exceed 10 ft on the Beaufort Sea coast.

Sea temperatures are cold throughout the year, ranging from -1° to -2°C in winter under the ice to just above freezing in summer. Sea temperatures off all pack-ice zones are markedly cooler (AEIDC 1975). Seasonal freezing and melting are the major influences affecting surface water characteristics in the arctic seas (AEIDC 1975). Nearshore Beaufort Sea waters are relatively warm, turbid, brackish, and shallow. This zone of brackish water is formed each spring when coastal plain rivers discharge warm freshwater into the Beaufort Sea. The width and depth of this zone varies depending on freshwater input, water currents, winds, and topography (Craig et al. 1985). The mixing of these water masses results in a great diversity and abundance of zooplankton; these zooplankton and arctic cod support large numbers and species of fish and wildlife within the lease sale area.

The salinity of the Beaufort Sea varies both geographically and seasonally from 28 to 32 parts per thousand. The relatively warmer water of low salinity from large rivers affects the salinity in the vicinity of the deltas. Salinity is much higher in these areas in winter as river flow decreases or increases. Seawater samples from under the ice in spring show salinity values of 30 to 33 parts per thousand (ppt) in Harrison Bay and up to 40 ppt under the ice in the Colville River delta. Less saline waters exist behind barrier islands, in lagoons, and in river deltas. These estuarine type waters are enriched by terrestrial nutrients and support a productive biological community (AEIDC 1975).

Conversely, salinity for nearshore waters may be lower. During one summer, salinity for Mikkelsen Bay measured uniformly throughout the bay, and averaged between 16.9 and 23 ppt. During the 1994 study year, average salinity was lowered by 2 to 5 ppt after a rain storm. Historical data indicate that salinity levels, for example in Prudhoe Bay, vary considerably from year to year (Fechhelm and Griffiths 1990)

Sediments in the Beaufort Sea waters come from river runoff at spring breakup and the rains of late summer, coastal erosion, scour of the sea bottom by moving ice, and from freezing of bottom sediments into fast ice. The surficial sediments consist predominately of clay and silt-size particles underlain by ice-bonded sandy gravel in some areas (MMS 1996). The concentration and size of sediments vary greatly with local geological conditions and season. Largest sediment concentrations and coarsest sizes are carried during spring ice breakup and in severe storms. Coarse materials are often carried offshore by ice-rafting (AEIDC 1975).

The surface circulation of the Beaufort Sea is dominated by a clockwise gyre in the Arctic basin, centered midway between Alaska and the North Pole. This prevailing current moves both water and ice shoreward throughout most of the year. However, over short periods of time nearshore surface currents are extremely variable. In late summer and fall easterly and offshore winds produce surface currents countering the prevailing Arctic gyre. This results in a variable period of relatively ice-free waters (AEIDC 1975).

The speed, direction, and persistence of summer winds determine whether freshwater river runoff accumulates or dissipates in the nearshore Beaufort Sea. The temperature, turbidity, and salinity of nearshore waters are also influenced by the level of mixing of nearshore water with colder offshore water in the shallow bays and lagoons; a process driven by summer winds. The presence or absence of prevailing winds in a given year has been correlated with anadromous fish migration (into the lease sale area) success in subsequent years (Griffiths et al. 1995). For more detail on the effects of coastal processes on Arctic fish, see Chapter Four.

2. Sea Ice

The Alaskan Beaufort Sea typically is ice-covered for about 9 months of the year. Breakup occurs from mid-May to mid-June and is initiated by river breakup and the overflow of freshwater onto the landfast ice. Open-water typically occurs by mid- to late July. Freeze-up ranges from late September to late October. The transition from freeze-up to winter ice conditions usually occurs in early to mid-November when the ice thickness is at least 30.5 cm (MMS 2007).

Seaward of the landfast ice is the shear zone or stamukhi. Shear zone ice forces are extremely dynamic and constantly produce open water ridges or leads that freeze and form new ice which in turn is deformed by pressure. The region of most intense ridging occurs in Beaufort Sea waters that are 15 to 45 m deep. As shear zone ice moves, it may gouge the sea bottom. The number and appearance of ice gouges depend on sediment type and age, the shape of the ice and depth of the water (AEIDC 1975; MMS 1996).

The pack ice zone lies beyond the shear zone and consists predominantly of multiyear ice floes from 6 to 12 ft thick that are constantly in motion. Multi-year ice is that which has survived more than one melt season. In summer they are surrounded by open water, thin ice or bits and fragments and in winter by first-year ice. The long-term ice movement is from east to west in response to the Beaufort Gyre. Often, the Beaufort Sea pack ice contains large ice floes or ice islands that originated from the Ellesmere Ice Shelf. They vary in size from a few thousand square yards to 300 square miles. When subjected to pack ice pressures in shallow waters, their keels extensively gouge the sea bottom (AEIDC 1975; MMS 1996).

3. Permafrost

Permafrost consists of any soil or other superficial deposit, including bedrock, that has been colder that 0° C for two or more years. Permafrost soils may be nearly ice free in coarse, unsaturated materials and may contain more than 50 percent water in finer grain saturated soils. Alaska has two types of permafrost classified as continuous or discontinuous. Continuous permafrost implies that the ground is frozen over nearly all the landscape and is colder than -5° C at the depth below annual seasonal temperature changes (depth varies based on rock type and water content but is about 15 m). Discontinuous permafrost is ground that is between 0° C and -5° C and as the term suggests, is not continuous. In discontinuous zones of permafrost, ground on south facing slopes and under large bodies of water are usually not frozen. Generally north of Atigun Pass (crest of the Brooks Range), the permafrost is continuous (Brown and Kreig 1983). Heading offshore the permafrost becomes progressively more discontinuous (MMS 1996).

Near Prudhoe Bay, permafrost extends to a depth of about 600 m which is the probable case for most all of the onshore portion of the lease sale area (Brown and Kreig 1983) (DGGS 1994, citing to Collett and others 1989). The depth of the active layer, or the layer of seasonal thaw is generally less than 0.9 m and 1.8 m beneath active stream channels. Ice content varies from minor segregated ice to massive ice in the form of ice wedges and pingos. Offshore, a large area of permafrost occurs off the Sagavanirktok River and possibly near Harrison Bay. Other areas of offshore permafrost include the 2-meter isobath zone, which is overlain by bottomfast ice in the winter; areas between the barrier islands and the shoreline; and on some of the barrier islands. However, permafrost may exist in other isolated places offshore to depths several hundred meters beneath the seafloor (MMS 1996). It is generally accepted that permafrost does not extend offshore beyond the 90-meter isobath.

G. Geologic Hazards

The primary geologic hazards in or near the lease sale area include faults and earthquakes; sea ice; ice gouging; ice movement; sub-sea permafrost; onshore permafrost, frozen ground, and Thermokarst; waves and erosion; coastal currents; flooding; overpressured sediments; unstable sediments; and shallow gas deposits and natural gas hydrates. These geologic hazards could impose constraints to exploration, production, and transportation activities associated with possible petroleum development, and should be considered before any siting, design, and construction of facilities.

1. Faults and Earthquakes

Surface faults[1] have been mapped throughout the Central Beaufort including high-angle faults, basement-involved[2] normal faults, listric growth faults[3], and north-dipping gravity faults[4]. Locally, two or more types may occur in close proximity to each other.

High-angle faults occur along the Barrow Arch extending into Harrison Bay. Along the Barrow Arch they are related to the basement tectonics of the Arctic Platform, while in Harrison Bay they offset the Tertiary and older units (Table 3.1). There has been little evidence of any Quaternary movement with no evidence of displacement in Pleistocene or Holocene sediments and there has been no recent seismicity associated with these faults. Thus, differential movement along these faults seems to have ended before the beginning of the Quaternary Period (DGGS 2008b, 2008 citing to Craig and Thrasher, 1982).

A number of shallow faults have been mapped north of the Arctic Platform. Included in these faults are the upper extensions of detached listric growth faults that exist deep in the Brookian section. These faults have been mapped in the greatest detail in the Camden Bay area where some of these faults may have been reactivated in the late Cenozoic and can have several tens of meters of offset. Shallow faults have also been mapped beneath the outer shelf, west of Cape Halkett and 15-50 km north of the lease sale area, and are reported to show from 3 to 10 m of Quaternary offset (DGGS 2008b, 2008 citing to Grantz and others, 1983).

In contrast to the western Beaufort shelf off Alaska, the Camden Bay area is still seismically active. This region is located at the northern end of a north-northeast trending band of seismicity that extends north from east-central Alaska (DGGS 2008b citing to Biswas and Gedney, 1979). Since monitoring began in 1978, a large number of earthquakes, ranging from magnitude one to over five, have been recorded in this area, with the majority of events clustering along the axis of the Camden anticline[5]. The largest earthquake recorded in the area was a magnitude 5.3 event 30 km north of Barter Island in 1968. In this region, the Tertiary and Quaternary strata dip away from and are truncated at the top of the Camden anticline, indicating that it has been growing in recent geologic

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[1] A fault is a surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale (American Geological Institute, Glossary of Geology, 1973).

[2] The term "basement" refers to the surface beneath which sedimentary rocks are not found (Encyclopedic Dictionary of Exploration Geophysics, 1991).

[3] A "listric" surface is a curvilinear, usually concave-upward surface of fracture that curves, at first gently and then more steeply, from a horizontal position. Listric surfaces form wedge-shaped masses, appearing to be thrust against or along each other (American Geological Institute, Glossary of Geology, 1973).

[4] A gravity fault is a normal fault in which movement is downward.

[5] An "anticline" is a fold, the core of which contains the stratigraphically older rocks; it is convex upward. The opposite is called a syncline (American Geological Institute, Glossary of Geology, 1973).

time. The faults in this region trend northwest-southeast, parallel to the hinge line[6] and as they approach and intersect the axis of the Camden anticline, they offset progressively younger strata. This suggests that these faults are older hinge line-related structures that were reactivated in late Tertiary and Quaternary by the uplift of the Camden anticline.

Table 3.1. Geologic time and formations.

Eras	Periods	Epochs	Began Approximate Number of Years Ago
Cenozoic	Quaternary	Holocene (Recent) Pleistocene (Glacial)	10,000 1.8 million
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	5.3 million 23.8 million 33.7 million 54.8 million 65 million
Mesozoic	Cretaceous Jurassic Triassic	Early and Late Early, Middle and Late	144 million 206 million 248 million
Paleozoic	Permian Pennsylvanian Mississippian Devonian Silurian Ordovician Cambrian		290 million 323 million 354 million 417 million 443 million 490 million 543 million

Source: http://www.geosociety.org/science/timescale/timescl.htm (accessed November 2008).

On the outer Beaufort shelf and upper slope, seaward of the 50-65 m isobaths, are gravity faults that are related to large rotational slump blocks[7] (DGGS 2008b citing to Grantz and Dinter, 1980; Grantz and others, 1982b). South of these slumps, which bound the seaward edge of the Beaufort Ramp, these faults have surface offsets ranging from 15 m to as high as 70 m (DGGS 2008b citing to Grantz and others, 1982b). Grantz and others (1982b) have inferred that these faults have been active in recent geologic time on the basis of the age of the faults and therefore pose a hazard to bottom-founded structures in this area. Large-scale gravity slumping of the blocks here could be triggered by shallow-focus earthquakes centered in Camden Bay or in the Brooks Range.

Throughout the region approximately 59 earthquakes of magnitude 4 and larger have been recorded between January 1968 and July 2008 (Map 3.1). Most of the seismicity in the region is shallow (less than 30 km deep), indicating near-surface faulting.

[6] Generally, a hinge line refers to a line or boundary between a stable region and a region undergoing upward or downward movement (American Geological Institute, Glossary of Geology, 1973).

[7] A "slump block" is the mass of material torn away as a coherent unit during a block slump. The rotation refers to the apparent fault-block displacement in which the blocks have rotated relative to one another, so that alignment of formerly parallel features is disturbed (American Geological Institute, Glossary of Geology, 1973).

Wesson and others estimate a 10 percent probability of exceeding 0.07 g[8] earthquake-generated peak ground acceleration in bedrock during a 50-year period in the lease sale area (DGGS 2008b citing to Wesson and others2007). For comparison, peak ground acceleration in Anchorage during the great 1964 earthquake was estimated at 0.16 g (DGGS 2008b, citing to Algemissen and others, 1991). In areas throughout the area underlain by thick, soft sediments, ground accelerations are likely to be higher than in bedrock due to amplification. However, thick localized permafrost may cause the earthquake response of sediments to be more like bedrock, which would limit amplification effects and would also tend to prevent earthquake-induced ground failure, such as liquefaction. Because of the periodic presence of sea ice along the Beaufort Sea Coast, consideration should be given to the combined effects of sea ice–earthquake interactions on any potential infrastructure in this region. Kato and Toyama suggest that earthquake load may be magnified by ice-structure interaction during a seismic event (DGGS 2008b, citing to Kato and Toyama 2004).

The USGS (U.S. Geological Survey) has a series of seismic hazard maps for Alaska, which are available on the USGS website at http://earthquake.usgs.gov/research/hazmaps/ . These maps depict earthquake hazard by showing, with contour values, the earthquake ground motions that have a given probability of being exceeded in 50 years. The ground motions being considered at a given location are those from all future possible earthquake magnitudes at all possible distances from that location. The ground motion coming from a particular magnitude and distance is assigned a probability based on the annual probability of occurrence of the causative magnitude and distance from the source. The method is based on historical earthquake occurrences and geological information on the recurrence rate of fault ruptures. To prepare these maps, the USGS analyzed all known seismic sources (surface faults, subduction zone and volcanic sources). Included in the computations are all historical and instrumental recordings of ground motions, gathered using a grid of 1-km^2 polygons. It is therefore possible to see the probabilistic ground motion for any location. The USGS seismic hazard maps are incorporated into the International Building Code for establishing the seismic design values for a selected location.

2. Sea Ice

The Beaufort Shelf is covered with ice most of the year, with a typical ice-free period during August and September only. The sea ice first forms in late September to early October and becomes continuous nearshore by mid-October. This ice will remain through the winter and start breaking up in July. It is not until early August that the nearshore region is largely ice free (DGGS 2008b, citing to Barry 1979). In recent years, breakup occurred earlier with a difference of 6 and 21 days along the Chukchi and Beaufort Sea coasts, respectively. Ice-free coastlines now occur over a month earlier along the Beaufort Sea coast (DGGS 2008b, citing to Mahoney, et al. 2007). During the winter months, the offshore ice can be divided into three main zones: the landfast zone, the shear zone (or Stamukhi zone), and the pack ice zone (DGGS 2008b, citing to Reimnitz and Barnes 1974). The landfast ice forms along the shore and develops seaward in the early fall. Small movements of this ice can be related to storm fronts which cause narrow leads and rubble fields in this zone. In late winter, the fast ice can extend out to the 25-meter to 30-meter isobath.

The shear zone, or Stamukhi zone, is between the landfast ice and the pack ice zone. It is a transition zone between the relatively stationary landfast ice and the highly mobile pack ice. Fragments of seasonal ice, multi-year ice and ice ridges up to tens of meters high exist in this zone. It is here where there is an intense interaction between the ice and the seabed, where the ice can gouge the seabed to depths of several meters (DGGS 2008b, citing to Reimnitz and Barnes 1974).

[8] Gravitational acceleration. One g equals an acceleration rate of 9.806 m per second per second.

The pack ice zone, seaward of the Stamukhi zone, is the shoreward edge of the permanent polar ice cap. It consists of multi-year ice, ice ridges, and ice island fragments that migrate westward in response to the clockwise circumpolar gyre (DGGS 2008b, citing to Reimnitz and Barnes 1974). During summer, the ice can move up to 20 km/day. Summer pack ice usually occurs tens to hundreds of kilometers offshore and so will not affect the lease sale area.

The National Ice Center currently monitors, analyzes, publishes current conditions and forecasts the ice conditions along the Beaufort coastline. They use visual, infrared, passive microwave and Synthetic Aperture Radar imagery, as well as ship reports and aerial reconnaissance to produce these data (DGGS 2008b, citing to Andrews and Benner 1996). Since the central Beaufort is characterized by significant, rapid changes in ice conditions, mathematical modeling of the evolution of the sea ice cover has been developed to help predict the ice conditions more precisely. By using these data it is possible to determine different ice characteristics such as: ice concentration, thickness distribution, edge configuration, drift velocity, zones of divergence and compacting, distribution of ice floe sizes, and their strength and motion (DGGS 2008b, citing to Appel 1996).

A massive iceberg or ice island could present a danger to structures beyond state territorial waters where depths are great enough to allow for large ice masses to approach the coastal zone. Ice islands are produced by the break-up of portions of the Ellesmere Ice Shelf and are the tabular icebergs of the Arctic Ocean. They are usually 40 to 50 m thick with lateral dimensions that range from tens of meters to tens of kilometers. If an ice island became imbedded in the arctic ice pack and hit an offshore production facility, the facility would likely be destroyed. This geologic hazard poses no threat to exploration or development in the lease sale area because of the shallow water depth.

Sea ice poses a potential hazard to offshore and coastal structures if they are not properly designed; a concrete island drilling structure could be pushed off location, ice could override a fixed structure, or a marine pipeline could be damaged where it comes ashore. Facilities exposed to the potential risks of each sea ice zone must be designed to accommodate ice forces.

Structures exposed to ice forces are fortified with sheet piling, concrete armor, and large bags filled with dense material placed in the path of moving sheets of ice. Existing steel and concrete island drilling structures placed in multi-year ice are durable and can accommodate closely spaced well designs. Gravel islands are designed with 10:1 slopes above sea level, and 5:1 slopes as deep as 20 ft below sea level. They are also constructed with a sheet pile retaining ring. Slopes are protected by fabricated blocks and filter fabric anchored to sheet pile.

All offshore structures in state waters must be bottom-founded (NSBMC 19.70.040(A) (NSB 2008), which considerably reduces the risk of damage to oil and gas facilities from sea ice movements. Exploratory drilling in winter is conducted with ice pads frozen to the sea bottom. This method of exploratory drilling is expected to be used throughout the lease sale area. Most of the area, and the entire region shoreward of the barrier islands, are seasonally covered by stable fast ice, generally ridge free. Thus, the risk of damage to facilities is reasonably predictable, and can be accounted for in the design. Sea ice remains stable throughout the drilling period. However, severe winter storms, such as one in November 1978, have been known to break-up landfast ice and create large pressure ridges (DGGS 2008b, citing to Thomas 1984:447). Therefore, contingency plans must be in place to demobilize a drill rig in a short period of time if weather becomes adverse.

All operations must comply with NSB municipal Code offshore development policies (NSBMC 19.70.040) (NSB 2008) which include measures to prevent an uncontrolled release of oil. Drilling below threshold depth must be conducted during winter (November 1 through April 15) and be completed as early in this period as practicable (NSBMC 19.70.040(C) (NSB 2008) to minimize the risk of an oil spill caused by ice movements.

NSB municipal code requires plans for offshore drilling activities to include a relief well drilling plan and an emergency countermeasures plan. The emergency countermeasures plan must identify the steps that will be taken to protect human life and minimize environmental damage in the event of loss of a drilling rig; ice override; or loss or disablement of support craft or other transportation systems (NSBMC 19.70.050(I)(6)(NSB 2008).

"Offshore structures must be able to withstand geological hazards and forces which may occur while at the drill site. Design criteria must be based on actual measurements or conservative estimates of geological forces. In addition, structures must have monitoring programs and safety systems capable of securing wells in case unexpected geophysical hazards or forces are encountered" (NSBMC 19.70.050(I)(2) and NSBCMP Policy 2.4.4(b)(NSB 2008).

3. Ice Gouging

Nearshore areas of the Beaufort Sea bed can potentially come in direct contact with icebergs, potentially resulting in ice gouging of the seafloor and infrastructure damage. Based in part on a USGS study in the mid 1980's suggest that ice gouge characteristics (density, depth and width) are related to water depth and shelf bottom morphology (DGGS 2008b, citing to Rearick and Ticken1988). Density, width and depth of ice gouges tend to increase with increasing water depth away from shore, attaining their maximum values in the Stamukhi zone, generally between the 18-meter and 30 meter isobaths, and then decreasing toward the shelf edge. Ice gouging is primarily active at mid-shelf and inner-shelf water depths although gouges can be found across the entire shelf. On the mid-shelf, ice ridges can scour the seafloor to depths of several meters. Reimnitz and Barnes found gouges as deep as 5.5 m, with ridges up to 2.7 m high just west of the lease sale area in Smith Bay (DGGS 2008b, citing to Reimnitz and Barnes 1974). Barnes has measured the average ice gouge on the Beaufort shelf at 50 cm deep, ridges 40 cm high, and 7.5 m wide. Ice gouges have been found to range between 1 and 10 m of relief (DGGS 2008b, citing to Barnes 1981).

At water depths less than 18 m, inshore of the Stamukhi zone, the ice gouging is much less severe. In this region, any ice gouges which form are rapidly buried by sand waves or sediment sheets. Since the nearshore sediments tend to be coarser grained than those farther offshore, any ice gouges in this region will degrade more rapidly than in the more cohesive, fine-grained sediments farther offshore (DGGS 2008b, citing to Barnes and Reimnitz 1979).

As the water depth increases offshore of the Stamukhi zone, the number of ice keels large enough to reach the bottom decreases, although ice gouges have been reported in water as deep as 58 m. Closer to the outer shelf edge, strong geostrophic currents exist which smooth the older ice gouges by eroding and filling them (DGGS 2008b, citing to Reimnitz and others, 1982).

Shoals and islands often show little or no evidence of ice gouging on their down-drift side with the highest intensity of gouging occurring on the up-drift side (DGGS 2008b, citing to Reimnitz and others, 1982; Rearic and Ticken 1988). In the Prudhoe Bay area, there is very little ice gouging due to the location of the barrier islands, while in Harrison Bay, where there are no barrier islands, high-intensity ice gouging occurs.

In general, the ice gouges throughout the central Beaufort shelf are oriented east-west, although they vary considerably more on the inner shelf where the shoals and other bottom features can deflect the ice. This east-west orientation reflects the directions of the surface current as well as the prevailing wind throughout the region.

Ice gouging poses little hazard to offshore exploration or production structures but does pose a significant risk to oil and gas transportation, particularly sub-sea pipelines (DGGS 2008b, citing to Younan 2007). Potential for damage to pipelines and offshore facilities depends on structural configuration; structural resistance of the pipe as well as the physical dimensions of and frequency of gouges (DGGS 2008b, citing to McKenna and others, 2003). Pipelines should be trenched deep beneath the deepest predicted scour depth, and covered with protective material. This could constitute backfill of in-situ or other material. Protective armament at all locations is not necessarily warranted, but could be a site-specific requirement. Additionally, pipelines should be designed to withstand both the horizontal and vertical forces associated with the gouging process which may cause significant soil displacement (DGGS 2008b, citing to McKenna 2003).

4. Ice Movement

Ice movement (ice ride-up and override) can result from wind, current, waves or temperature changes. Continuous, large scale ice movements are caused by major current systems (e.g., the Beaufort Gyre in the Arctic Ocean), tidal currents, or geostrophic winds. Major contributions to local, short term movements are wind, wave, and current action during storms. Ice movements during a single ice season create zones of landfast and pack ice. Zone boundaries are not static, but change with seasonal ice growth and movement. Ice movements at a given site may have a predominant direction due to geography and environmental conditions (DGGS 2008b, citing to API 1995).

Throughout the Beaufort Sea, both ice ride-up and ice override can transport and erode significant amounts of sediment. Ice ride-up is the process whereby ice blocks are forced onshore by strong wind or currents and push the sediment from the coast into the ridges farther inland. It is most important on the outer barrier islands where ice ride-up ridges up to 2.5 m high, extending 100 m inshore from the beach have been identified (DGGS 2008b, citing to Hopkins and Hartz 1978). Over most of the Arctic coast, ice ride-up rubble is found at least 20 m inland with boulders in excess of 1.5 m in diameter (DGGS 2008b, citing to Kovacs 1984). A number of accounts of ice ride-up events have been documented where man-made structures have been damaged along the Beaufort coast. In January of 1984, ice over-topped the Kadluck, an 8 m-high caisson-retained drilling island located in Mackenzie Bay (DGGS 2008b, citing to Kovacs 1984). Ice ride-up has the potential to alter shorelines and nearshore bathymetry, which in the longer term may pose a threat to nearshore facilities with increased erosion.

Ice override can occur offshore or onshore. Ice can override itself, rafted ice, or can override the coastline and ride-up onto a shore. Ice override onshore will add an additional dead load (ice on top of a buried pipeline) to a buried pipeline in the transition area from offshore to onshore beginning where the ice contacts the sea floor. This dead load, along with the force being exerted by the ice and the strength of soil, should be considered in pipeline design (DGGS 2008b, citing to Rice 1999; Younan 2007).

5. Sub-Sea Permafrost

Numerous refraction, borehole and conductivity surveys indicate that permafrost is widespread beneath the Beaufort inner shelf. A number of seismic refraction surveys have been run (DGGS 2008b, citing to Rogers and Morack ,1981, Neave and Sellmann, 1983, and Morack and others, 1983). Additional data have been obtained from boreholes (DGGS 2008b, citing to Harding-Lawson 1979) and thermal probes (DGGS 2008b, citing to Hopkins and Hartz 1978b; Rogers and Morack 1981; Harrison and Osterkamp 1981). The depth to the surface of the subsea permafrost is highly variable, which reflects the varying degrees of ice-bonding before the Holocene marine transgression as well as the degree of subsequent thawing due to the advection of saline groundwater. A study in the Laptev Sea region, (DGGS 2008b, citing to Grigoriev and Rachold 2005) concludes that evolution of upper layers of sub-sea permafrost depends on near bottom water temperature and salinity, coastal retreat rate (or accumulation/accretion rate), bathymetric features and shoreline inclination, general coastal morphology and shoreline configuration, coastal and shore-face sediment composition, ice content of deposits submerged below sea level, and near-shore hydrodynamics and sea ice regime.

The Beaufort shelf has been subaerially exposed to the Arctic climate during several Pleistocene lowstands of sea level followed by subsequent highstands (DGGS 2008b, citing to Wang and others, 1982). During these episodes, the permafrost formed to depths of several hundred meters during the lowstands followed by highstand periods where it was partially melted by saline advection from the seawater into the underlying sediment and by geothermal heating. In a study by Harding-Lawson (DGGS 2008b, citing to Harding Lawson 1979), boreholes encountered ice at depths shallower than 9 m to more than 30 m over a distance of less than 12 km. Hopkins and Hartz estimate that well-bonded permafrost (permafrost having a greater ice crystal matrix) will form in a subaerial Arctic environment in only 40 to 50 years (DGGS 2008b, citing to Hopkins and Hartz 1978a).

Permafrost can therefore be expected to occur in the core of some of the barrier islands and artificial islands. On Reindeer Island, the Humble Oil C-1 well encountered two layers of permafrost at depths of 0 to 18.9 m and 91 to 128 m. The shallower layer may have formed under modern Arctic conditions while the deeper layer was probably formed during the Pleistocene (DGGS 2008b, citing to Sellmann and Chamberlain 1979).

Sub-sea permafrost can pose a hazard to bottom-founded drilling structures via thaw and subsidence, if its presence is not considered in design and construction. Geophysical data acquired before development can reveal the presence and distribution of sub-sea permafrost. Structures placed on top of permafrost must be designed to prevent heat loss into the substrate. The presence of sub-sea permafrost is a major consideration in the siting and design of sub-sea pipelines. The effect of heat loss to the surrounding substrate can be minimized by trenching and backfilling along the pipeline corridor, and by insulating the pipe. Chilling the oil or gas in pipelines may also reduce the potential effects posed by the presence of sub-sea permafrost.

6. Onshore Permafrost, Frozen Ground, and Thermokarst

Permafrost exists throughout most of the onshore portion of the sale and is, for the most part, overlain by an active layer[9] of unconsolidated sediment. The thickness of permafrost has been measured from numerous onshore wells indicating that it thins from east to west. East of Oliktok Point, it has been measured to be 500 m thick, whereas west of the Colville River it has been measured to be 300 to 400 m thick (DGGS 2008b, citing to Osterkamp and Payne 1981). The depth of seasonal thaw is generally less than 1 m below the surface and 2 m beneath most active stream channels and is dependent on site-specific hydrological and geotechnical water crossing conditions. Borings along the Colville River, for example, show it remains thawed year-round. The ice content varies throughout the region from segregated ice to massive ice in the form of wedges and pingos, and is the highest in the fine-grained, organic-rich deposits and the lowest in the coarse granular deposits and bedrock (DGGS 2008b, citing to Collett and others, 1989).

Ground settlement, due to thawing, occurs whenever a heated structure is placed on ground underlain by shallow, ice-rich permafrost, and proper engineering measures are not taken to adequately support the structure and prevent the structure's heat from melting the ground ice. Settlement is a function of the original thickness of the active layer, the increase in the active layer as it adjusts to the surface disturbance and the thaw strain of the underlying permafrost. In general the magnitude of settlement depends on the nature and abundance of ice and the severity of the disturbance. The potential for thaw settlement is least in areas of active river deposits and eolian sand and can be greater than 1 meter in areas of alluvial marine deposits (DGGS 2008b, citing to Pullman and others, 2007).

In addition to settlement, seasonal freeze-thaw processes will cause frost jacking of nonheated structures placed on any frost-susceptible soils unless the structures are firmly anchored into the

[9] An "active layer" refers to a surface layer of ground or soil above permafrost that is alternately frozen each winter and completely thawed each summer. It represents the seasonally frozen ground (American Geological Institute, Glossary of Geology, 1972).

frozen ground with pilings or supported by non-frost-susceptible fill (DGGS 2008b, citing to Combellick 1994). The frost susceptibility of the ground is highest in fine-grained alluvium, colluvium, thaw-lake deposits, and coastal-plain silts and sands; moderate in alluvial-fan deposits and till; and lowest in coarse-grained flood-plain deposits, alluvial terrace deposits and gravely bedrock (DGGS 2008b, citing to Carter and others, 1986; Ferrians, 1971; Yeend, 1973a, b). Thermokarst is caused by the disturbance or removal of vegetation resulting in local melting of ground ice. This causes development of uneven topography in the form of mounds and sink holes. Even small disturbances such as a vehicle driven across the tundra can create thermokarst features. In the past off-road and seismic trail disturbances associated with oil development activities have led to the development of thermokarst (DGGS 2008b, citing to Pullman and others, 2007).This can be mitigated through seasonal and area restrictions on vehicles.

Increased thawing of permafrost is commonly initiated by both natural (forest fire, floods, and erosion) and manmade ground disturbances (DGGS 2008b, citing to Richter-Menge et al. 2006). Surface response to permafrost melting is not uniform and is related to the interactions of slope position, soil texture, hydrology and vegetation over time. Arctic lowland areas are particularly at risk for thaw subsidence because of the high volume of ground ice at the top of the permafrost (DGGS 2008b, citing to Jorgenson and others, 2008).

Other potential impacts from thawing permafrost include liquefaction and the development of slides, flows, slumps and increased erosion along rivers and coasts (DGGS 2008b, citing to Nelson and others, 2001; Hobson 2006; ACIA 2006). Additionally, Lilly and others suggest that changes in the distribution of ice in soil pore space can impact sediment strength on both seasonal and long term scales. Generally, soil strength is greater during the winter when soil water is frozen than during summer months when melting occurs (DGGS 2008b, citing to Lilly and others, 2008).

Many geologic processes in areas of permafrost and seasonally frozen ground are related to seasonal and long term variability of climate, and long-term records indicate that permafrost temperatures at the depth of zero seasonal temperature variations in permafrost (20 m) are warming on the North Slope (DGGS 2008b, citing to Richter-Menge et al. 2006; Pavlov and Malkova 2008). Ground subsidence, increased erosion, change in the hydrologic regime, and the other potential impacts of permafrost degradation described above will negatively impact infrastructure as climate warms unless new mitigation techniques are adopted (Report of the Alaska Regional Assessment Group, 1999). As a result, continued monitoring of permafrost stability, including water content and temperature variability of soils, and continued assessment of mitigation techniques are necessary. Frozen-ground problems can be successfully mitigated through proper siting, design, and construction, as demonstrated at Prudhoe Bay and elsewhere. Structures such as drill rigs and permanent processing facilities should be insulated to prevent heat loss into the substrate. Pipelines can be trenched, back-filled, and chilled (if buried) or elevated to prevent undesirable thawing of permafrost. In addition, ADNR regulates winter travel across the tundra and authorizes travel only after determining that the tundra is sufficiently frozen and protected by ample snow cover so that the travel will not have major environmental effects such as permafrost degradation (DGGS 2008b, citing to Bader and Guimond 2004).

7. Waves and Erosion

Wave heights along the Beaufort coastline are low throughout most of the year because of the short fetch resulting from the pervasive ice cover. However, in the fall open-water season, a considerable fetch can develop both seaward and shoreward of the barrier islands. During this time, storm waves can reach up to 7 to 9 m when the fetch is equal to 800 km and can become effective erosive agents both onshore and along the exposed faces of the barrier islands (DGGS 2008b, citing to Appel 1996). Also, wind-induced storm surges can force the ice and water onshore and can raise sea level as much as 3 m, with an additional meter added to this due to low atmospheric pressures associated with the

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Erosion along the coastline of Barrow.

storms (DGGS 2008b, citing to Barnes and Reimnitz 1974). During the most extreme surges, the coastal islands can become completely flooded, and major changes in the size and shape of these islands can occur during a very short time period (DGGS 2008b, citing to Reimnitz and Maurer 1978b).

Even with the short open-water season along the Beaufort coastline, the wave action, in combination with melting of coastal permafrost and gravity induced mechanisms, can cause dramatic rates of coastal erosion (DGGS 2008b, citing to Walker 1988; Hoque and Pollard 2008; Aguirre and others, 2008). The highest rates of erosion occur along coastal promontories where the bluffs are composed of fine-grained sediments and ice lenses, and where thermal erosion, a dynamic process involving the wearing away by thermal means (melting ice) and by mechanical means (hydraulic transport), are the dominant processes. In some areas, beaches have been formed from the gravel eroded from bluffs composed of coarse-grained deposits and act to partially protect those bluffs from further wave action. In other areas, where the bluffs are composed of fine sediment, the sand eroded from the bluffs does not form protective beaches and the bluffs erode more rapidly. In the Harrison Bay area, where the bluffs are composed primarily of coarser-grained sediments, the average retreat rates are between 1.5 and 2.5 meters per year (DGGS 2008b, citing to Craig et al. 1985).

Average rates of erosion across the Beaufort coastline range from 1.5 to 4.7 meters per year, although short term rates can be higher. In one case, near Oliktok Point, the coastline eroded 11 meters during one two-week period (DGGS 2008b, citing to Hopkins and Hartz 1978a). West of Harrison Bay, erosion occurred at a rate of 1.08 kilometers per year during the period 1985-2005, compared to 0.48 kilometers per year from 1955-1985. In this area, removal of offshore islands and spits left coastal bluffs exposed to direct wave impact. Thermokarst lakes along the coast were subsequently breached, leading to accelerated rates of erosion (DGGS 2008b, citing to Mars and Houseknecht 2007).

The only prograding (advancing) shoreline areas along the Beaufort coastline occur off the deltas of major rivers. In those areas, the rate of progradation is very slow. The progradation rate of the Colville River delta was estimated to be 0.4 meters per year (DGGS 2008b, citing to Reimnitz et al. 1985).

Factors influencing erosion along the North Slope coastline also affect erosion along the region's rivers, although the driving forces (currents, waves with a short fetch) are somewhat different. Sediment cohesiveness, influenced by the degree and depth of seasonal frost, and permafrost, are important factors in determining river bank erodibility (DGGS 2008b, citing to Veldman and Ferrell 2002).High erosion rates occur along braided channels, which usually develop in areas composed of noncohesive sediment (DGGS 2008b, citing to Scott 1978). In a study along the Sagavanirktok River, aerial photographs showed a maximum erosion rate of 4.5 meters per year during a 20-year period. In this area, most of the erosion appeared to occur in small increments during breakup flooding and was concentrated in specific areas where conditions were favorable for thermo-erosional niching (DGGS 2008b, citing to Combellick 1994).

Erosion rates, river bank and shoreline stability, and the potential impacts of waves and storm surge must all be considered in determining facility siting, design, construction, and operation especially with recent studies indicating that the extent of seasonal ice-free seas in the arctic has been increasing and could potentially result in increased rates of erosion along Arctic coastlines (DGGS 2008b, citing to Aguirre and others, 2008; Mahoney and others, 2007) Facility siting, design, construction and operation must also be considered in determining the optimum oil and gas transportation mode. Structural failure can be avoided by proper facility setbacks from coasts and river banks. Docks and road or pipeline crossings can be fortified with concrete armor, and by placing retainer blocks and concrete-filled bags in areas subject to high erosion rates, such as at the Endicott causeway breaches.

8. Coastal Currents

Marine currents along the central Beaufort shelf are primarily wind driven and are strongly regulated by the presence or absence of ice. Sediment is transported by these currents along the barrier islands and the coastal promontories, although, due to the short open-water season, the annual rate of longshore sediment transport is relatively low. The currents along the inner shelf generally flow to the west in response to the prevailing northeast wind, with current reversals occurring close to shore during storms. Further from the shoreline, on the open shelf, the currents average between 7 and 10 cm/sec (DGGS 2008b, citing to Matthews 1981). During storms, east-flowing currents have been measured with velocities of up to 95 cm/sec, although typical storm current velocities are an order of magnitude lower (DGGS 2008b, citing to Kozo 1981). Under the ice, in the winter, the currents are usually less than 2 cm/sec, although some currents have been measured at up to 25 cm/sec in areas around grounded ice blocks (DGGS 2008b, citing to Matthews 1981).

Geostrophic currents can occur north of the lease sale area on the outer shelf, flowing parallel to the shelf-slope break. These currents have been measured at up to 50 cm/sec and can occur in both easterly and westerly directions (DGGS 2008b, citing to Craig and others, 1985). Since the tidal range on the central Beaufort shelf is small, approximately 15 to 30 cm, the tidal currents exert only minor influences on the sedimentary regime (DGGS 2008b, citing to Matthews 1981). When the water flow on the shelf is restricted by bottomfast ice, these currents can act as important scouring agents (DGGS 2008b, citing to Reimnitz and Kempema 1982b).

Offshore structures are designed to withstand variable marine currents in the Beaufort Sea. Additionally, all drilling structures are bottom founded and fortified to counteract any current-induced scouring. Artificial or natural gravel islands must be fortified and built to withstand coastal currents as well as the forces of moving sea ice for the life span of the producing field. To this end, they may require periodic maintenance in response to heavy storms.

9. Flooding

Floods occur annually along most of the rivers and many of the adjacent low terraces due to seasonal snowmelt and ice jams (DGGS 2008b, citing to Rawlinson 1993; Walker and Hudson 2003). Spring ice breakup on rivers in the region often occurs over the first few days of a three-week period of flooding in late May through early June. Up to 80 percent of the flow occurs during this period (DGGS 2008b, citing to Walker 1973). The geologic impact of flooding is in large part related to the magnitude and timing of seasonal ice breakup. The formation of ice jams is especially associated with catastrophic flooding (DGGS 2008b, citing to Walker and Hudson 2003). Some of the most damaging floods are associated with an above-average snowpack that is melted by rainstorms and sudden warming.

During flooding, small changes in river flow can be caused by changes in sediment bars. Consequently, areas of significant bank erosion can be variable. The amount of erosion depends on factors such as sediment character, amount of water and its level with respect to the river bank (DGGS 2008b, citing to Veldman and Ferrell 2002). Ice carried along by rivers can also produce significant erosion, especially if breakup occurs during lowering river stage, allowing the ice to erode stream banks (DGGS 2008b, citing to Walker and Hudson 2003).

Spring floodwaters inundate large areas of the deltas, and on reaching the coast spread over stable ground and floating ice up to 30 km from shore (DGGS 2008b, citing to Arnborg et al. 1967; Barnes et al. 1988; Reimnitz et al. 1974; Walker 1974). When floodwater reaches openings in the ice often associated with tidal cracks, thermal cracks and seal breathing holes), it rushes through with enough force to scour the bottom to depths of several meters by a process called strudel scouring (DGGS 2008b, citing to Reimnitz and others, 1974; Leidersdorf and others, 2001; Reimnitz 2002).

Along the Beaufort shelf, strudel scour craters have formed up to 6 m deep and 20 m across, as mapped by shallow bathymetric surveys and scuba diving observations (DGGS 2008b citing to Reimnitz and others, 1974). In a study for the Northstar Pipeline, strudel scours were found in water depths of 2.2-5.4 meters with the greatest scour occurring at depths of 3-4 meters (DGGS 2008b, citing to Leidersdorf and others, 2001). Sheltered coastal areas and bays adjacent to major rivers such as the Colville, Sagavanirktok, and Canning are particularly susceptible to this type of scouring. In these areas deltas can be totally reworked by strudel scouring in several thousand years, although the scours can be infilled very rapidly (DGGS 2008b, citing to Reimnitz 2002; Reimnitz and Kempema 1982a). Areas of strudel scour that have been measured along the Beaufort shelf are shown in Map 3.2.

Strudel scouring has the potential to undermine substrate upon which a nearshore structure is placed, such as an artificial island placed in a river mouth or delta. It is unlikely that such a structure would be permitted as it may violate NSBCMP Best Effort Policies regarding alteration of shoreline dynamics by mining, and placing of structures subject to a 50-year recurrence level (NSBCMP 2.4.5(i) and (j) (NSB 2008).

In addition to seasonal flooding, many rivers along the coast are subject to seasonal icing before spring thaw. This is due to overflow of the stream or groundwater under pressure, often where frozen or impermeable bed sections force the winter flow to the surface to freeze in a series of thin overflows, or where spring-fed tributaries overflow wide braided rivers (DGGS 2008b citing to Veldman and Ferrell, 2002). In areas of repeated overflow, residual ice sheets often become thick enough to extend beyond the flood-plain margin. These large overflows and residual ice sheets have been documented on the Sagavanirktok, Shaviovik, Kavik, and Canning Rivers (DGGS 2008b citing to Dean, 1984; Combellick, 1994).

Storm surges along the Beaufort coast frequently occur in the summer and fall. Sea level increases of 1 to 3 m have been observed, with the largest increases occurring on westward-facing shores. Storm surges can also occur from December through February, although sea level elevation changes are generally less than in summer and fall. Winter storm surges of as much as 1.4 m amplitude have been recorded for the period of complete ice cover in the Beaufort Sea (DGGS 2008b citing to Reimnitz, 2002). Decreases in the elevation of sea level can occur, and these occur more frequently during the winter months.

Seasonal flooding of lowlands and river channels is extensive along major rivers that drain into the lease sale area. Thus, measures must be taken before facility construction and field development to prevent losses and environmental damage. Pre-development planning should include hydrologic and hydraulic surveys of spring break-up activity as well as flood-frequency analyses. Data should be collected on water levels, ice floe direction and thickness, discharge volume and velocity, and suspended and bedload sediment measurements for analysis. Also, historical flooding observations should be incorporated into a geologic hazard risk assessment. All inactive channels of a river must be analyzed for their potential for reflooding. Containment dikes and berms may be necessary to reduce the risk of flood waters that may undermine facility integrity.

10. Overpressured Sediments

Along the central Beaufort region, extremely high pore pressures can be expected to be found where Cenozoic strata (sedimentary layers) are very thick, such as in the Kaktovik, Camden, and Nuwuk Basins. Onshore, in the Camden Basin, high pore pressures have been measured in both the Tertiary and Cretaceous formations where the burial depths of the Tertiary strata exceeded 3 km (DGGS 2008b citing to Craig and others, 1985).

In the Point Thomson area, the pore pressure gradients were measured as high as 0.8 pounds per square inch per foot (psi/ft) in sediments at burial depths of 4 km. In this area a pore pressure gradient of 0.433 psi/ft is considered normal (DGGS 2008b citing to Hawkings and others, 1976). High pore pressures have also been measured throughout the Cenozoic strata of the Mackenzie Delta in the Canadian Beaufort. Here, the pore-pressure gradients were measured as high as 0.76 psi/ft and have been observed at depths as shallow as 1.9 km (DGGS 2008b citing to Hawkings and others, 1976).

Drilling mud in the well-bore is mixed to a specific density that will equal or slightly exceed the pressure in the formation. When formation pressures exceed the weight of the drill mud in the well-bore, the result can be a kick[10] or blow-out. Thus, encountering over-pressured sediments while drilling can result in a blow-out or uncontrolled flow. The risk of a blow-out is reduced by identifying locations of overpressured sediments via seismic data analysis, and then adjusting the mud mixture accordingly as the well is drilled. If a kick occurs, secondary well control methods are employed. The well is shut-in using the blow-out prevention (BOP) equipment installed on the wellhead after surface casing is set. The BOP equipment closes off and contains fluid pressures in the annulus and the drillpipe. BOP equipment is required for all wells and surface and sub-surface safety valves are required to automatically shut off flow to the surface.

11. Unstable Sediments

The distribution of unconsolidated sediments on the central Beaufort is greatly affected by the density of ice gouging, wave and current activity, and the composition of sediment delivered from rivers and coastal bluffs. The ability of these sediments to support the weight of bottom-founded structures and to resist sliding when sea ice interacts with the structure can vary greatly. The sediments consist predominantly of coarser grained material (sand and gravel sized particles) in

[10] A kick is a condition where the formation fluid pressure (pressure exerted by fluids in a formation) exceeds the hydrostatic pressure (pressure exerted by mud in the borehole) resulting in a 'kick'; formation fluids enter the borehole.

nearshore areas, near offshore barrier islands and on shoals and along the shelf break. Further offshore, at depths of 20 m and greater, the sediments consist primarily of mud (clay and silt sized particles) (DGGS 2008b citing to Craig and others, 1985).

Overconsolidated surface sediments are widespread on the Beaufort shelf (Map 3.3)(DGGS 2008b, citing to Chamberlain 1978; Reimnitz and others, 1982; Watt 1984). This type of sediment is one that is consolidated beyond what is expected from the present overburden pressure, and is produced by freeze-thaw action (DGGS 2008b, citing to Chamberlain 1978) and compaction by ice gouging (DGGS 2008b citing to Reimnitz and others, 1980). The freeze-thaw action requires the sediment be frozen after deposition, which for the central Beaufort has been measured at depths greater than 1 to 2 m (DGGS 2008b, citing to Hunter and Hobson 1974).

Unstable sediments can move unexpectedly and pose a risk to improperly sited and constructed facilities. Shallow seismic data can reveal some information about the stability of sediments, and shallow core samples profiling sediment type can be taken for geotechnical analysis in an area where a facility is to be sited, such as along a proposed pipeline route.

Potential instability and mass movements of sediment in the area are also related to the seafloor gradient, low sediment strength where fine-grained sediments retain high amounts of water, sediment loading from waves during storms, and ground motion during earthquakes. Along the shelf, inshore of the 50-meter isobath, the seafloor slope is generally low and, except in the vicinity of Camden Bay, ground motions associated with earthquakes are very low. Thus, except for Camden Bay, the mass movements in water less than 50 m are generally not considered to be a significant hazard to offshore operations (DGGS 2008b, citing to MMS 1995).

12. Shallow Gas Deposits and Natural Gas Hydrates

Shallow pockets of natural gas have been encountered in boreholes both onshore and offshore throughout the Arctic. This gas usually exists in association with faults that cut Brookian (Aptian through Miocene) strata, and as isolated concentrations in the Pleistocene coastal plain sediments (DGGS 2008b citing to Grantz and others, 1982b). The presence of shallow gas has been inferred from studies. Sediments in which gas has accumulated are a potential hazard if penetrated during drilling, as well as for any man-made structures on top of them. The presence of gas may lower the shear strength of the sediments and reduce their ability to support structures (DGGS 2008b citing to MMS, 1995).

Natural gas hydrates are unique compounds consisting of ice-like substances composed of gas trapped within water molecules (DGGS 2008b, citing to Nixon and Grozic 2007). They commonly occur offshore under low-temperature, high-pressure conditions (DGGS 2008b, citing to Macleod 1982), as well as at shallower depths associated with permafrost (DGGS 2008b, citing to Kvenvolden and McMenamin 1980). Within the lease sale area, gas hydrates have been found at shallow depths under permafrost along the inner shelf (DGGS 2008b citing to Sellmann and others, 1981) and onshore at Prudhoe Bay (DGGS 2008b, citing to Kvenvolden and McMenamin 1980) and at the Mount Elbert well in Milne Point where downhole coring and logging operations were recently completed (DGGS 2008b, citing to Collett 2008).

One of the main problems associated with gas hydrates is dissociation, which occurs when the compound becomes unstable. Dissociation occurs by both natural and man-made activity and can lead to an increase in fluid pressure and reduction of effective stress of sediment as volume increases (DGGS 2008b, citing to Nixon and Grozic 2007). Potential for dissociation in marine environments is a function of water depth, sea floor temperature, availability of gas and availability of water in adequate quantities. Natural mechanisms leading to gas hydrate dissociation include sea level decrease and sediment temperature increase. Man-made mechanisms include heat transfer during petroleum production leading to melting of hydrates. During drilling, rapid decomposition of gas hydrates can cause a rapid increase in pressure in the wellbore, gasification of the drilling mud, and the possible loss of well control. If the release of the hydrate gas is too rapid, a blowout can occur, and the escaping gas could be ignited. In addition, the flow of hot hydrocarbons past a hydrate layer could result in hydrate decomposition around the wellbore and loss of strength of the affected sediments (DGGS 2008b, citing to Nixon and Grozic 2007). If this happened and the well was shut-in for a period, the reformation of the hydrates could induce high pressures on the casing string (DGGS 2008b, citing to MMS 1995).

An additional geologic hazard associated with gas hydrates is the potential for submarine slope failures associated with decreased sediment strength occurring during dissociation (DGGS 2008b, citing to Nixon and Grozic 2007). Acoustic records indicate a stretch of slumps in the Beaufort Sea along the shelf-edge break. The slumps extend for at least 500 km in an area of known gas hydrates and should be considered during exploration and development activities.

Because gas hydrates and shallow gas deposits pose risks similar to overpressured sediments, the same mechanisms for blow-out prevention and well control are employed to reduce the danger of loss of life or damage to the environment. For a discussion of oil spill prevention and response, see Section F of Chapter Six.

13. Mitigation Measures and Other Regulatory Protections

Several geologic hazards exist in the Beaufort Sea area that could pose potential risks to oil and gas installations both onshore and offshore. As discussed above, these potential hazards include earthquakes, sea ice, shore-ice movement, permafrost and frozen-ground phenomena, waves, coastal and river erosion, offshore currents, flooding, strudel scour, overpressured and unstable sediments, and shallow gas deposits and hydrates.

The risks from earthquake damage can be minimized by siting onshore facilities away from potentially active faults and unstable areas, and by designing them to meet or exceed national standards and International Building Code seismic specifications specific for Alaska. National industry standards help assure the safe design, construction, operation, maintenance, and repair of pipelines and other oil and gas facilities. Sometimes referred to as "technical standards" they establish standard practices, methods, or procedures that have been evaluated, tested, and proven by analysis and/or application. These standards are intended to assure the safe design, construction, operation, maintenance, and repair of infrastructure. National consensus standards, such as the American Petroleum Institute (API), American Society of Mechanical Engineers (ASME), National Fire Protection Association (NFPA), and National Association of Corrosion Engineers (NACE), can carry the equivalent weight of law. In fact, many of them are codified by incorporation of all or parts of them into regulations by reference. They are constantly reviewed and upgraded by select committees of engineers and other technical experts (PHMSA 2008).

Design for offshore drilling and production platforms should consider all environmental events which influence the design of an arctic structure (API Recommended Practice 2N). Design conditions are those environmental conditions to which the structure is designed. Additional precautions should be taken to identify and accommodate site-specific conditions or events that can act on a structure such as unstable ground, flooding, and other localized hazards. Proper siting and engineering will minimize the detrimental effects of these natural processes.

Safe design of offshore drilling and production platforms use design codes and recommended practices that assist the engineer by setting out procedures for achieving acceptable levels of safety. Recommended practices provide guidance for the design of arctic structures and pipelines considering the environment, sea ice, and permafrost. Once the design conditions have been established for each process, they become the basis for that system's design. The primary goal of codes is safety, which is accomplished by providing a minimum set of rules which must be incorporated into a sound engineering design concerning materials, fabrication, testing, and examination practices used in the construction of these systems. All of these are intended to achieve a set of engineering requirements deemed necessary for safe design and construction of these structures and their associated piping systems.

Although geologic hazards could damage oil and gas infrastructure, measures in this final best interest finding, along with regulations imposed by state, federal, and local agencies, in addition to design and construction standards discussed above, are expected to avoid, minimize, or mitigate those hazards. Mitigation measures address siting of facilities, design and construction of pipelines, and oil discharge prevention and contingency plans. A complete listing of mitigation measures is found in Chapter Nine.

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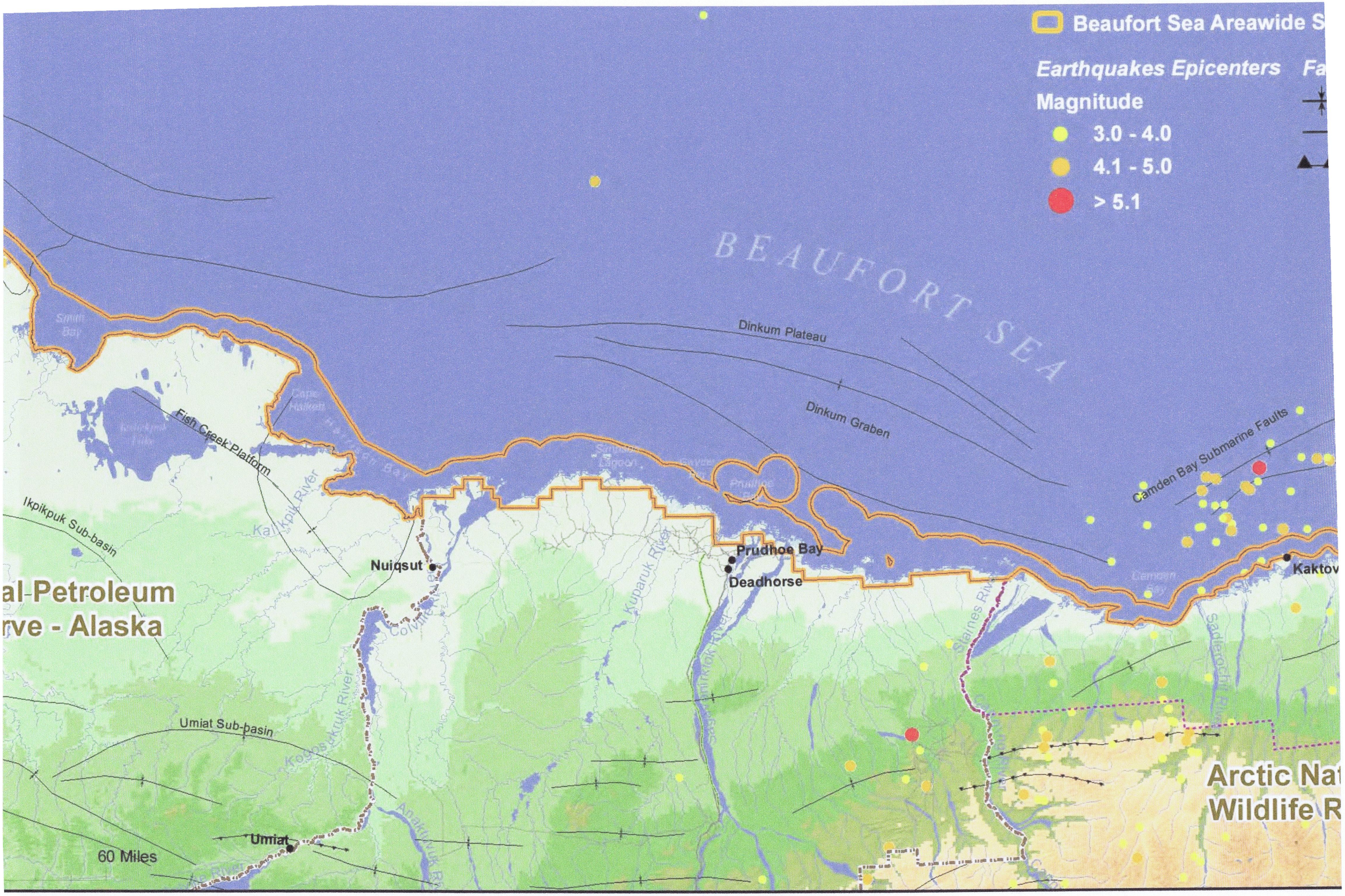
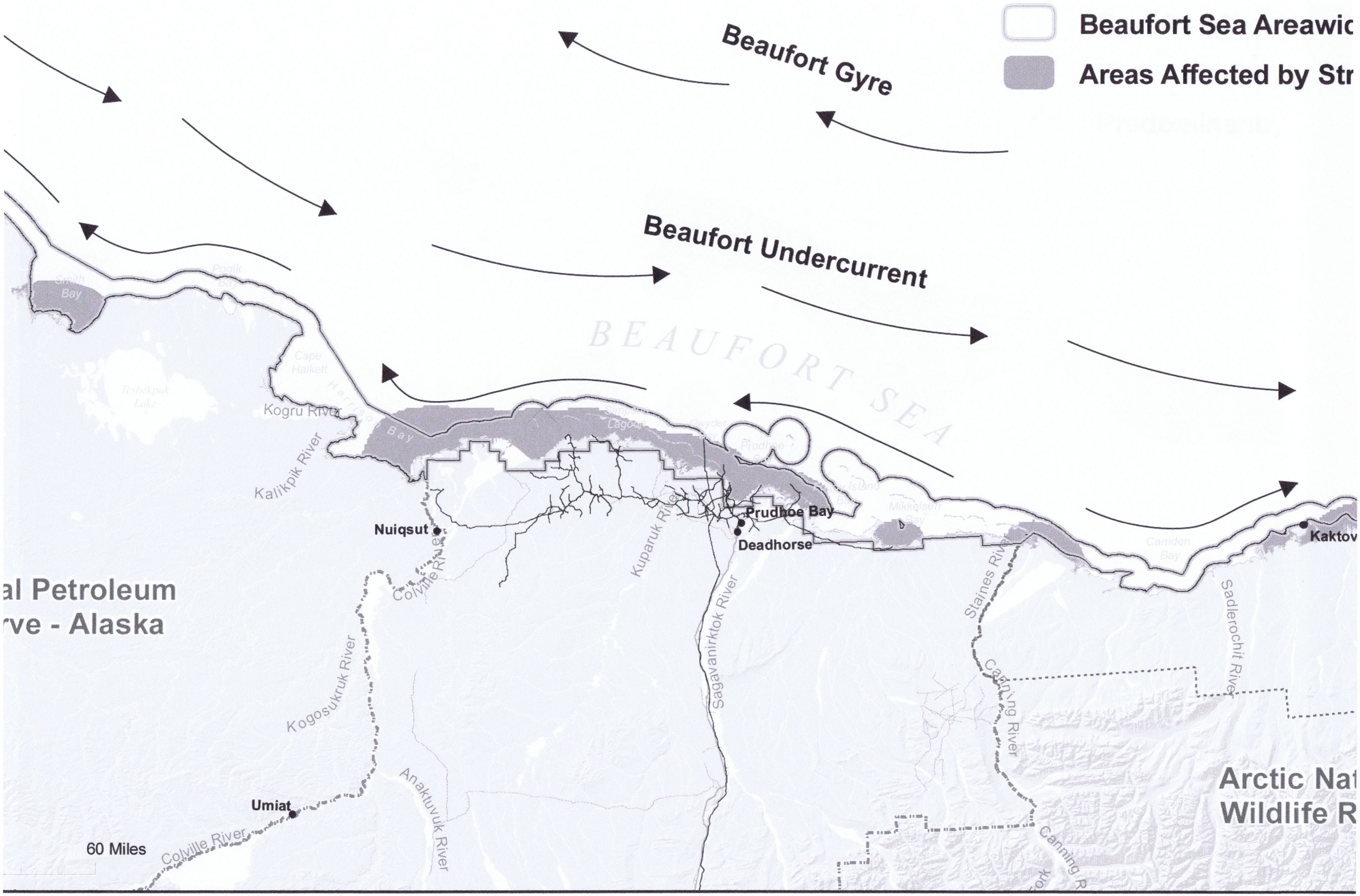
Maps



is depicted only at a township or section level resolution. For detailed information regarding any specific area, interested individuals may consult the land records of one or more of the following agencies: ADNR, BLM, MMS, NOAA, A
. Sedimentary basins and faults. Discrepancies in boundary alignments are the result of merging multiple data sets from these various sources.



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distribution of surface sediments, Beaufort Sea area