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Kodiak National Wildlife Refuge Oil and Gas Resource Assessment

Robert J. Bascle, Aden Seidlitz and James Borkoski

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Abstract

Most of the Kodiak National Wildlife Refuge has No geologic potential for the accumulation of oil or gas, as most of the rocks are metamorphosed sedimentary rocks or igneous rocks. The southeastern edge of the Aliulik Peninsula has a Low geologic potential for the accumulation of oil or gas, but the geologic character and the small area indicate that this area has No economic development potential.

1. Introduction

The U.S. Bureau of Land Management (BLM) signed a Memorandum of Understanding with the U.S. Fish and Wildlife Service (FWS) to assess the oil and gas resource potential of the National Wildlife Refuge System in Alaska. Section 1008 of the Alaska National Interest Lands Conservation Act (ANILCA) requires the Secretary of the Interior to initiate an oil and gas leasing program on Federal lands in Alaska. ANILCA exempts ". . . those units of the National Wildlife Refuge System where the Secretary determines, after having considered the national interest in producing oil and gas from such lands, that the exploration for and development of oil and gas from such lands would be incompatible with the purpose for which such unit was established."

BLM's role is to help fulfill that part of Section 1008 that mandates:

"In such areas as the Secretary deems favorable for the discovery of oil or gas, he shall conduct a study, or studies, or collect and analyze information obtained by permittees authorized to conduct studies under this Section, of the oil and gas potential of such lands and those environmental characteristics and wildlife resources which would be affected by the exploration for and development of such oil and gas."

BLM intends for this report to assist the FWS in deciding which lands within the Kodiak National Wildlife Refuge (KNWR) should and should not be opened to oil and gas leasing and development.The original interagency version of this report was submitted to the FWS in April 1988.

2. Location and Physiography

The Kodiak National Wildlife Refuge occupies about 1,866,000 acres on Kodiak, Afognak, Uganik, and Ban islands *(Figure 1)* which lie to the south of Cook Inlet and to the east of the Alaska Peninsula. The mountains of the Kodiak islands range in elevation from 2,000 to 4,000 feet. Broad, smooth ridges extend to the northwest from the rugged northeast-trending divide of glacial horns and arêtes. A strong, northeast-trending grain, normal to the drainage, characterizes the topography southeast of the divide. The western part of Kodiak Island has many broad valleys. The islands have extremely irregular coastlines with many fjords and smaller islands. The northern part of Afognak Island is a hilly lowland (Wahrhaftig, 1965).

Swift, clear streams, generally less than 10 miles long, provide most of the drainage. Two rivers, each about 25 miles long, drain much of southwestern Kodiak Island.

The islands have numerous lakes. Afognak Island and the southwestern part of Kodiak Island have several lakes more than one mile long. The areas with glacially-sculptured topography have scattered small ponds. Chains of paternoster lakes bead the glaciated valleys which head in the main divide.

The firn line lies at 3,000 to 3,500 feet along the main divide and rises to more than 4,000 feet in the northwestern part of Kodiak Island (Wahrhaftig, 1965).

3. History of Geologic Exploration

Vitus Bering reported sighting the Kodiak islands in 1741, and Russian traders and trappers based some of their activities on the island. Glottof and his companions wintered on Kodiak Island in 1763. Twenty years later, Russians, led by Shelikof, established the first white settlement on the island (Capps, 1937a). In 1972, the Russians moved their headquarters settlement to Pavlosk Harbor, the present site of the town of Kodiak. Grewingk conducted a reconnaissance along the coast in 1848-1849 (Capps, 1937a and 1937b).

Dall and Harris (1892), representing the United States, collected concretions with plant remains and noted the existence of coal seams on Kodiak Island. Becker and Dall made a short visit to the islands in 1895 and briefly examined the geology. Becker examined gold-lode deposits and Dall studied coal and lignite resources. Dall recognized Tertiary beds and collected clay ironstones which contained plant remains that he considered referable to the Kenai group on the Kenai Peninsula (Dall, 1896; Atwood, 1911; Capps, 1937a and 1937b).

The Harriman Alaska Expedition, 1899, briefly visited in the vicinity of the town of Kodiak (Atwood, 1911) and collected a few fossils at Chiniak Bay.

Paige, in 1905, also collected fossils in the vicinity of Kodiak. Brooks' (1906) reconnaissance map showed undifferentiated Paleozoic and metamorphosed sediments of undetermined age on the northwest half of the island and some Triassic, Jurassic, and undifferentiated Mesozoic rocks in the vi-

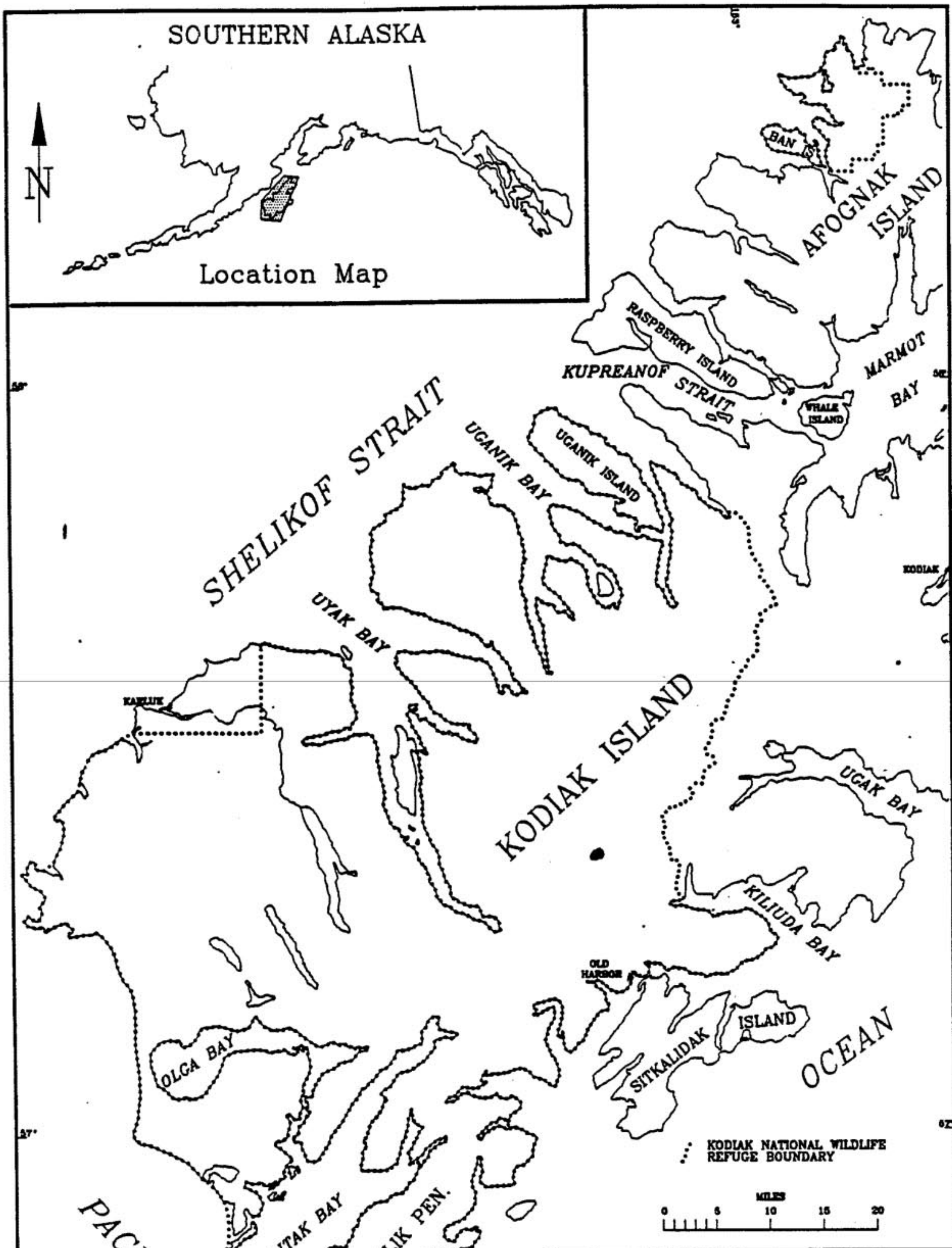

FIGURE 1.
KODIAK NATIONAL WILDLIFE REFUGE
LOCATION MAP

PREPARED BY: Robert Bascle

cinity of the town of Kodiak.

Brooks (1911) reported on active prospecting for lode-gold deposits and speculated that the metamorphic sediments of the Kodiak islands were equivalent to those of the Kenai Peninsula.

Maddren, in 1917, spent three weeks examining beach placer deposits in mainly Pleistocene and Recent deposits on the southwest side of Kodiak Island (Maddren, 1919).

Martin, in 1922, spent two months studying mineral deposits on Kodiak Island and compiled a geologic map based on his observations and on those of geologists who preceded him (Capps, 1937b). He noted that the islands consisted chiefly of slate and graywacke, and he recognized, but did not name, several of the major units recognized today (Martin, 1913).

Capps, in 1932, visited several points on the island and took several airplane flights over the island as part of a survey expedition with the U.S. Navy.

Fitzgerald, in 1932, conducted a topographic survey over a 720-square-mile portion of Kodiak Island in the vicinity of the town of Kodiak (Capps, 1937b).

Capps conducted geological field studies of the Kodiak islands in 1934 and produced a geologic map of the island group (Capps, 1937a and 1937b). He recognized most of the major rock groupings that are recognized today, but he did not name any of them.

In their 1959 survey of possible future petroleum provinces in Alaska, Miller et al. (1959) regarded the Mesozoic greenstone, graywacke, and slate belt bordering the Gulf of Alaska as unfavorable for petroleum because of the complex structure and the alteration caused by dynamic and thermal metamorphism. They noted, however, that the Chugach Mountains Geosyncline area, which by extension correlates with the central part of Kodiak Island (Kodiak Formation), has received some attention as a possible oil province in the past.

Moore conducted geologic mapping on the Kodiak islands in the 1960's. He first reported the ultramafic rocks on Kodiak Island and mapped the major structure of the island as an asymmetric anticline with the Cretaceous rocks northwest of the anticlinal axis dipping 45 degrees northwest and the Cretaceous and Tertiary rocks southeast of the axis approximately vertical (U.S. Geological Survey, 1964 and 1967; Moore, 1967).

Numerous investigators have studied Kodiak Island in the past couple of decades and some of these are cited throughout this report. No investigator has reported the occurrence of oil and gas seeps on the islands, and the petroleum industry has not drilled any exploratory wells.

4. Stratigraphy and Lithology

The geology of the Kodiak islands consists of subparallel to parallel bands of sedimentary and metasedimentary rocks with associated igneous plutons, dikes, and sills (*Figure 2*). These bands strike approximately northeastward and run nearly parallel to the coast of the Alaska Peninsula. In gen-

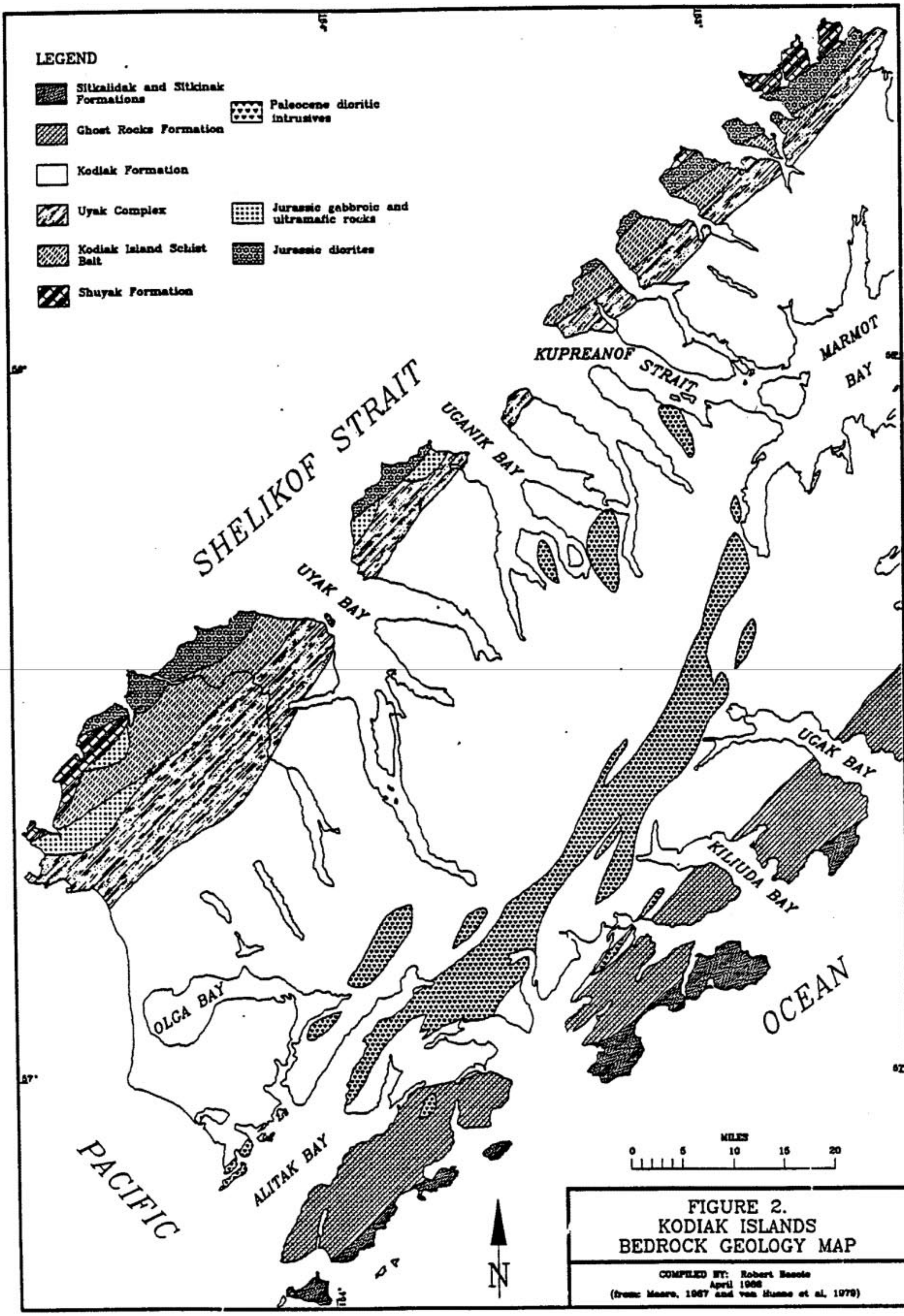

FIGURE 2.
KODIAK ISLANDS
BEDROCK GEOLOGY MAP

eral, these bands get younger from the northwest coast to the southeast coast.

"Older" Mesozoic Units

Shuyak Formation

The Shuyak Formation, of Late Triassic age, crops out on the western coast of Shuyak Island, on the northern and northwestern coasts of Afognak Island, and possibly on the southern end of the northwestern coast of Kodiak Island. The lower member of the Shuyak consists of massive and vesicular, pillowed greenstones, with inter-pillow limestone (Connelly, 1978; Moore and Connelly, 1979; Wilson et al., 1985; von Huene et al., 1985). A sequence of well-bedded tuff, volcaniclastic turbidites, massive sandstone, volcanic conglomerate, and siliceous mudstone, all metamorphosed to the prehnite-pumpellyite facies composes the upper member (Fisher, 1979; Moore and Connelly, 1979; Wilson et al., 1985). Several investigators have called this sequence of rocks a Late Triassic forearc sequence (Moore and Connelly, 1979; Forbes et al., 1979).

Kodiak Island Schist Belt

A belt of schist, the Kodiak island schist belt, composed of thinly layered and intricately folded quartz-mica schist, greenschist, blueschist, and marble lies along the northwest side of Kodiak Island, between Bear Island and Seven Mile Beach. The metamorphic rocks show apparent tectonic imbrication with virtually unmetamorphosed but highly deformed red chert and argillite. This schist belt has K-Ar ages of 190 million(+/-6 million) years before the present (m.y. BP; Early Jurassic). A fault juxtaposes the schist terrane with the Uyak Formation to the southeast, while a narrow dioritic intrusion separates it from the Upper Triassic forearc sequence (Carden and Forbes, 1976; Connelly, 1978; Moore and Connelly, 1979; Fisher, 1979; von Huene et al., 1985).

Dioritic Plutons

Lower Jurassic (187 - 193 m.y.) dioritic plutons intrude between the schist belt and the Upper Triassic forearc sequence (Fisher, 1979; Shew and Wilson, 1981; von Huene et al., 1985). These plutons form part of a string of Early Jurassic (184 - 193 m.y.) plutons of intermediate composition, which appear discontinuously from the northwest coast of Kodiak Island to the Kenai Peninsula (Pavlis, 1983 citing Hudson, 1979). The plutons comprise foliated and massive diorite and quartz diorite with abundant hornblende and little or no biotite. Thermally metamorphosed zones border the pluton and have locally prominent migmatites and aplitic dikes (Connelly, 1978).

Uyak Complex

The Uyak Complex, or Uyak Formation, contains blocks and slabs of ultramafic and gabbroic rocks, pillowed and massive greenstone, radiolarian chert and wacke, all enclosed in a matrix of gray chert and tuffaceous argillite. The Uyak Complex structurally underlies the Kodiak schist belt and the Afognak pluton along the Raspberry fault (Connelly, 1978). The Uyak crops out between the local equivalents of the Border Ranges fault (the Raspberry fault) and the Eagle River fault (the Uganik fault) and underthrusts the lower Mesozoic metamorphic, igneous, and sedimentary rocks to the northwest (Connelly, 1978; Nilsen and

Moore, 1979). The Kodiak Formation underthrusts the Uyak along the Uganik fault from the southeast (Connelly, 1978). Many researchers consider the Uyak Complex as equivalent to the McHugh Complex of the Kenai Peninsula. The ultramafic and gabbroic rocks, thought to represent the lower portion of the oceanic crust, have about the same age as the enclosing country rock. Most of the Uyak Complex shows metamorphism to the prehnite-pumpellyite facies in rocks of suitable composition (Connelly, 1978; Moore and Connelly, 1979; Forbes et al., 1979; Fisher, 1979).

Fossils in the Uyak range from mid-Permian to Early Cretaceous (Connelly, 1978; von Huene et al., 1987). Limestone lenses near the base and near the top of the formation contain marine fossils of Late Triassic age (Moore, 1969). One of the limestones found within the Uyak Complex has yielded fragments of gastropods, pelecypods, echinoderms, coral, and a Late Triassic hydrozoan (*Spongiomorpha*). Another limestone has yielded mid-Permian fusulinids, including *Neoschwagerina* sp., *Cancellina*? sp., and *Condonofusiella* (Connelly, 1978). The Uyak Complex appears to have accreted during Late Cretaceous subduction, but this remains uncertain.

The clastic sedimentary rocks of the accretionary terrane contain no known Late Jurassic to Middle Cretaceous fossils. This suggests that either the arc shed no sediments during this interval or erosion or subsequent tectonic processes removed deposits of these ages (Connelly, 1978; Moore and Connelly, 1979). The Uyak Complex appears to have accreted during Late Cretaceous subduction, but this remains uncertain.

Kodiak Formation

The Kodiak Formation comprises a thick sequence of highly deformed, flysch-like metasandstones, slate, and argillite (Jones and Clark, 1973). It underthrusts the Uyak formation to the northwest along the Uganik fault (Fisher, 1979). The Uganik fault bounds the formation to the northwest and the Contact fault bounds it on the southeast (Nilsen and Moore, 1979). The sandstones commonly exhibit graded bedding, sole markings, and complete Bouma sequences indicative of deposition by turbidity currents. It shows primarily a slope-facies turbidite sequence along its northwestern margin and primarily a basin-plain facies along its southeastern margin (Nilsen and Moore, 1979). Thick mudstone sequences with chaotically-oriented blocks, slabs and disordered fragments of hemipelagic mudstone characterize the slope facies association. The sandstone:shale ratios run from about 1:30 to 1:10. Thick beds of conglomerate (up to 50 meters thick) and sandstone, associated with thin beds of channel-margin turbidites crop out locally within the slope facies.

Repetitively interstratified, graded-sandstone beds and hemipelagic shales, typically about 30 cm thick, characterize the basin-plain facies. Some of the sandstones show calcite cementation, and the sandstone:shale ratio ranges from about 1:1 to 1:5. The interstratified hemipelagic shales show general bioturbation. Sedimentary structures evident in this facies include sole markings, parallel and wavy lamination, convolute lamination, current-ripple markings, and, rarely, ripple-drift lamination (Nilsen and Moore, 1979).

Fisher and Byrne (1987) identify a tectonic melange unit that ranges from tens of meters to over one kilometer wide along the northwest margin of the Kodiak Formation where it underthrusts the Uyak formation along the Uganik Fault. To the southeast, this melange grades into a structurally coherent unit. Paleocurrent data indicate currents flowed to the southwest and west at Kodiak Island (Moore and Connelly, 1979; Sample and Fisher, 1986; Sample and Moore, 1987).

Inoceramus-bearing fossil localities crop out on the northwest shore of Woody Island, Kodiak Harbor. This locality also contains *Terebellina palachei* Ulrich and trace fossils. Moore and Connelly (1979) cite the widespread occurrence of *Inoceramus kusiroensis* on Kodiak Island. These fossils indicate a Late Cretaceous (Maastrichtian) age (Jones and Clark, 1973; Moore and Connelly, 1979; Sample and Moore, 1987).

Unfolded Paleocene (60 m.y.) dioritic plutons intrude the Kodiak Formation and suggest that the Kodiak accreted in latest Cretaceous or earliest Paleocene time (Wilson, 1980; von Huene et al., 1985).

"Younger" Tertiary Units

Ghost Rocks Formation

The Ghost Rocks Formation of Paleocene and Eocene age consists predominantly of turbidites preserved in a tectonic melange unit and as coherent units (Fisher, 1979). It contains zeolite-bearing tuffaceous sandstones, pillow basalt, hard claystone, sandstone, tuff, and graded sandstone beds in the form of wildflysch (Moore, 1969). Nilsen and Moore (1979) studied the Ghost Rocks Formation at a few locations and did not find enough evidence to designate the turbidite facies associations. The Ghost Rocks has veins, fractures, minor faults, and melange-like features (Nilsen and Moore, 1979).

The Ghost Rocks Formation underthrusts the Kodiak Formation to the northwest along the Contact fault (Fisher, 1979; Vrolijk, 1987). Fisher and Byrne (1987) identify a one to two kilometer wide melange unit along the southeast margin of the Ghost Rocks Formation. A poorly exposed fault separates the melange unit from more coherent Ghost Rocks Formation to the northwest. To the southeast, the intensely disrupted melange grades into more coherent strata. Pressure-temperature experiments on the fluid inclusions and estimates of vitrinite reflectance temperatures indicate prehnite-pumpellyite metamorphism (Vrolijk, 1987; 1069). Von Huene et al. (1976) identified zeolite grade metamorphism for the formation.

The formation contains a Paleocene assemblage of foraminifera including *"Globigerina" pseudobulloides*, *Planorotalites* sp., and *Subbotina triangularis* or *S. triloculinoides* (Lyle et al., 1978; Nilsen and Moore, 1979). Early Paleocene batholiths intrude the Ghost Rocks Formation. This implies the assemblage, deformation, and intrusion of the Ghost Rocks Formation in the earliest Tertiary (von Huene et al., 1985).

Paleocene Plutons

Paleocene batholiths of intermediate, i.e., dioritic, composition intrude the Kodiak and Ghost Rocks formations (Fisher, 1979; Nilsen and Moore, 1979; von Huene, 1985). These plutons have a K-Ar age of about 60 m.y. (Nilsen and Moore, 1979; Wilson, 1980; Shew and Wilson, 1981; Wilson, 1981; Sample and Moore, 1987, citing Davies, 1987). These plutons may have formed by anatexis (i.e., metamorphism or melting) of the turbidites at depth (Fisher, 1979).

Coeval rocks, of similar petrographic and geochemical character, which intrude the Uyak Complex, the Kodiak Formation, and the Ghost Rocks Formation suggest that all these formations formed a cohesive unit by the early Paleocene. These dikes, sills, and plutons do not greatly deform or metamorphose the surrounding country rock. Contact aureoles around plutons vary from only a few tens of meters to a few hundreds of meters wide (Sample and Moore, 1987).

Kienle and Turner (1976) suggested that the Kodiak batholith may constitute part of a 760-km long batholith that may extend from the Sanak Islands to Kodiak Island and possibly to the Kenai Peninsula. They further proposed that this Shumagin-Kodiak batholith represents the locus of a Paleocene magmatic arc similar to the Jurassic magmatic arc on the Alaska Peninsula.

Sitkalidak Formation

The Sitkalidak Formation crops out as a series of patches at the southeastern tips on Kodiak, Sitkalidak, and Sitkinak islands. It consists of a thick, rather uniform series of sandstone and siltstone graded beds with a few conglomerate beds (Moore, 1969). These sediments lack volcanic rocks and probably accumulated as submarine fans in a trench or trench slope setting (von Huene et al., 1980; von Huene et al., 1985). The Sitkalidak Formation, of Eocene and Oligocene (?) age, consists of turbidites in fault contact with the Ghost Rocks Formation (Moore, 1969; Fisher, 1979). It has a gradational upper contact with the Sitkinak Formation, except at the type section where a fault juxtaposes the two formations (Moore, 1969). A fossil clam found about 300 meters below the top of the formation and a fossil crab, *Callianassa* aff. *C. porterensis*, from the same location, indicate an Oligocene age.

On Sitkalidak Island, some of the turbidites have calcite cement with abundant coalified plant debris in most sandstone beds. Sandstone:shale ratios run 10:1 to 1:6 in the various megasequences (Nilsen and Moore, 1979). According to von Huene et al. (1976), the lower part of the formation shows nearly as much alteration and cementation as the underlying Ghost Rocks Formation. The induration decreases near the top where the shoreline facies of the Sitkinak Formation overlies the Sitkalidak.

Sitkinak Formation

The Sitkinak Formation crops out as isolated patches along a 250-km belt from Chirikof Island to Dangerous Cape on Kodiak Island (Moore, 1969; Nilsen and Moore, 1979). The basal part of the formation includes beach and shallow-marine deposits while the bulk of the formation consists of continental coal-bearing siltstones, sandstones, and conglomerates. On Sitkinak Island, it consists of alternating conglomerate-sandstone units and fine-grained sandstone and siltstone units with some coal and carbonaceous-shale strata (Nilsen and Moore, 1979).

The conglomerate-sandstone units account for up to 70 percent of the formation with the siltstone-coal intervals getting relatively more numerous upwards. Siltstone-coal units probably represent interchannel, lagoonal, and interdistributary bay environments within the conglomerate-sandstone units. The coal-bearing beds contain fossilized tree trunks in vertical and horizontal position (Nilsen and Moore, 1979).

In its type section on Sitkinak Island, several half-meter-thick coal beds are associated with well-preserved fossil leaves which indicate a middle or late Oligocene age. Here, its base interbeds with the graded beds of the underlying Sitkalidak Formation, and its top interbeds with marine siltstone which contains lower Miocene fossils (Moore, 1969; von Huene et al., 1976). On Sitkalidak Island, the conglomerates, which contain rounded clasts of volcanic rocks, graywacke, chert, and carbonate rocks up to 50 cm long, form most of the basal part of the sequence. Turbidite sandstones and interbedded shale make up the upper part of the sequence. A poorly exposed shale overlies the turbidite sequence (Nilsen and Moore, 1979).

At many of its exposures, no younger bedrock overlies the Sitkinak. Von Huene et al. (1985) identify a principally Oligocene sequence of nonmarine to shallow marine rocks that unconformably overlie the Eocene turbidites of the Sitkalidak Formation. This unconformity documents that complex deformation and uplift of the turbidites occurred by about middle Oligocene time.

The Sitkinak contains no marine fossils in the type section, but mollusk-bearing Narrow Cape Formation conformable upon the Sitkinak may indicate a marginal-marine depositional setting. Based on the fossilized, broad-leaved, deciduous flora and its position beneath well-dated marine megafossil invertebrates of the Narrow Cape Formation, Wolfe (1966) and Wolfe et al. (1966) assigned the Sitkinak a middle to late Oligocene age. Fossil plants identified in the coal-bearing part of the sequence include *Metasequoia* cf. *M. glyptostroboides* and *Alnuevidens* (Nilsen and Moore, 1979).

Narrow Cape Formation

The Narrow Cape Formation (not exposed within the refuge), as exposed in its type section at Narrow Cape on Kodiak Island, consists, in its lower two-thirds, of sandstone and a few beds of conglomerate and, in its upper one-third, of siltstone. It rests unconformably on the Sitkalidak Formation at Narrow Cape (Moore, 1969) and occupies a small area in the trough of a syncline on Sitkinak Island. At Narrow Cape, the section consists of a fossiliferous breccia and conglomerate overlain by a highly-bioturbated, massive, silty, fine-grained sandstone and siltstone that forms more than 90 percent of the formation. The bioturbated sandstone contains gastropod, pelecypod, scaphopod, and echinoid fossils. Coarser deposits interlayer with the silty sandstone and siltstone at irregular intervals. These contain well-rounded megafossil fragments. Nilsen and Moore (1979) interpret these as storm deposits of a transgressive inner-shelf sequence deposited in generally quiet water beyond the surf zone.

The Narrow Cape Formation has abundant marine fossils but a low species diversity (Nilsen and Moore, 1979). A collection from the Middle Miocene fossils, and a collection from near the base of Sitkinak Island contains early Miocene fossils (Moore, 1969; von Huene et al., 1976). At Narrow Cape, the Narrow Cape Formation is early and middle Miocene and rests with angular unconformity on the Sitkalidak and Ghost Rocks formations. On Sitkinak Island, it is Oligocene or early Miocene and is exposed in two northeast-trending synclines. Von Huene et al. (1976) claim that on Sitkinak Island it contains early Miocene mollusks. Allison and Addicott (1976) date the Narrow Cape as middle Miocene based on the presence of the bivalve *Mytilus middendorffi*.

5. Structure

The structure of the Kodiak islands, overall, strikes northeast. The formations appear in subparallel to parallel bands separated by faults that run the length of the island group and probably extend northeastward and southwestward beyond the islands (Fisher, 1979). The intensity of deformation shows a general decrease from the northwestern coasts to the southeastern coasts of the islands.

The Shuyak Formation is coherent and either dips homoclinally to the northwest or is flexed into open folds (Moore and Connelly, 1979). The Shuyak fault separates the Shuyak Formation, on the northwest, form the Kodiak islands schist terrane, on the southeast, with the Afognak pluton obscuring the fault (Connelly, 1978). The schists have an isoclinal, overturned fold style with the fold axes trending northeast and the axial planes dipping steeply to the northwest (Carden and Forbes, 1976).

MacKevett and Plafker (1974) identify the Border Ranges (locally termed the Raspberry (?) fault by Connelly, 1978) fault as discontinuously traceable, for over 1,600 km, from west of Kodiak Island eastward to the St. Elias Mountains. It cuts across northwestern Kodiak and Afognak islands as a nearly vertical fault that juxtaposes the Kodiak islands schist terrane, to the northwest, with the Uyak Complex, to the southeast.

Connelly (1978) described the Uyak Complex dislocated and pervasively sheared with mesoscopic shear fractures and innumerable faults of unknown magnitude. This complex structure juxtaposes contrasting sedimentary and igneous rocks. The more brittle rocks occur as angular blocks that either juxtapose against other tectonic blocks or are enclosed in the highly deformed gray chert and argillaceous matrix.

The Kodiak Formation underthrusts the Uyak Complex along the steeply dipping Uganik thrust (Connelly, 1978; Moore and Connelly, 1979). Connelly (1978) correlates the Uganik thrust with Chugach Bay fault of the Kenai Peninsula and the Eagle River fault near Anchorage. Tectonic mixing along the Uganik fault inserted kilometer-size "slivers" of, what appears to be, Kodiak Formation turbidites as far as three kilometers structurally above the thrust contact and mixed smaller blocks of Uyak lithology as far as 0.5 km into the Kodiak Formation (Connelly, 1978). The Kodiak Formation typically shows tight folding with a well-developed axial-plane slaty cleavage and common transitions to broken formation.

Sample and Fisher (1986) divided the Kodiak Formation into three litho-stratigraphic units based on structure: 1) a 13-km-wide landward belt, 2) a 20-km-wide central belt, and 3) a 35-km-wide seaward belt. In general, planar structures dip steeply in the landward and seaward belts and have shallower dip in the central belt.

Outcrops of the Tertiary rocks on Kodiak and adjacent islands show a general decrease in intensity of deformation with decreasing age. The Paleocene Ghost Rocks Formation underthrusts the Kodiak Formation along the Contact fault and shows intense fracturing and folding. It has been described as a tectonic melange. The Eocene-Oligocene Sitkalidak Formation rocks are overturned in isoclinal folds. The Oligocene Sitkinak Formation rocks form close folds with some overturning. The Miocene Cape Narrow Formation rocks dip at about 30 degrees (von Huene et al., 1976).

6. Tectonic Setting

The rocks of southwestern Alaska represent "one of the most complete and straight forward records of ancient plate convergence known anywhere in the world." This sequence includes a magmatic arc, a forearc sequence, and a highly-deformed, deep-sea, accretionary terrane.

The Alaska-Aleutian Range batholith represents the magmatic arc; the area between the batholith and the Kodiak islands schist terrane represents the forearc sequence; and the area from the schist terrane and extending to the southeast represents the highly-deformed, deep-sea, accretionary terrane (Moore and Connelly, 1977).

Nilsen and Moore (1979) identify five tectonostratigraphic terranes for the Kodiak islands. From northwest to southeast, these consist of the Peninsular terrane northwest of the Border Ranges fault (Raspberry fault), the Uyak formation (corresponding to the McHugh Complex) between the Border Ranges fault and the Eagle River fault, the Chugach terrane (corresponding to the Kodiak Formation) between the Eagle River fault (Uganik fault) and the Contact fault, a terrane consisting of folded and faulted Paleogene turbidites and mafic volcanic rocks (corresponding to the Orca Group) of the Ghost Rocks, Sitkalidak, and Sitkinak formations, and the most oceanward terrane which consists of less-deformed, upper Paleogene and Neogene, shallow-marine deposits.

7. Geologic Setting

The fossiliferous limestones, tuff beds, and volcaniclastic rocks of the Upper Triassic Shuyak Formation indicate deposition in a warm sedimentary environment regularly subjected to fall out from volcanic eruptions during the Late Triassic. The abundant volcanic rock fragments and the common presence of clinopyroxene suggest an andesitic and basaltic source area (Connelly and Moore, 1979).

The 190 m.y. ages of the Kodiak Island schist belt and the Lower Jurassic plutons exposed to the southeast of the Shuyak Formation indicate that a period of regional metamorphism and plutonic intrusion occurred during the Early Jurassic (Connelly and Moore, 1979).

The Uyak Complex contains Permian and Early Cretaceous fossils. But, the clastic sedimentary rocks of the accretionary terrain contain no known late Jurassic to middle Cretaceous fossils. This suggests that the arc shed no sediments during this interval of that subsequent erosion or tectonic processes have removed deposits of this age. Accretion during the late Cretaceous accounts for the Early Cretaceous fossils of the Uyak Complex (Connelly and Moore, 1979).

The sedimentation, deformation, and accretion of the Kodiak Formation turbidites took about 10-13 million years during the Late Cretaceous, and the sedimentation, deformation, and accretion of the Ghost Rocks Formation turbidites required less than 5 million years in the early Paleocene. The Paleocene plutons intruded the Kodiak and Ghost Rocks formations subsequent to their deformation during the Paleocene (Fisher and Byrne, 1987).

The turbidites of the Sitkalidak Formation collected in submarine fans during the Eocene and Oligocene. The complex deformation and uplift of the Sitkalidak Formation turbidites took place by about middle Oligocene time (von Huene et al., 1985).

The near-shore marine and coal-bearing continental deposits of the Sitkinak Formation collected mostly during the middle to late Oligocene.

The Narrow Cape Formation formed as a shallow marine deposit during the Miocene with subsequent uplift.

8. Oil Geology

Reservoir Rocks

Von Huene et al. (1980) classify the potential reservoir rocks as having poor quality. The lower and middle Miocene rocks have the best reservoir quality, but these have only fair permeability and poor porosity. Diagenetic changes have caused the poor reservoir quality, probably because the rocks contain chemically unstable volcano-lithic fragments and plagioclase feldspar.

Tertiary sandstones with intergranular porosity and permeability would make the most likely reservoir rocks on the Kodiak islands. Rocks of Miocene and younger are the most likely to fit this category. In the Sitkalidak Formation, these sandstones would most likely have one of three geometries: 1) shoestring turbidites that occupy channels, 2) turbidite fans, or 3) turbidite sheets. The Sitkinak Formation would most likely have elongated bar-finger units and broad, lobate, sandy, delta-front deposits. The Narrow Cape Formation would most likely have linear clastic shoreline deposits, such as beach or barrier deposits paralleling the shoreline. Little is known about the relationship between described potential reservoir sand bodies and the geologic structure of the area (Lyle et al., 1978).

Of the three formations, the Sitkalidak probably has the least potential for having reservoir rocks. Lyle et al. (1978) measured a total of 2,036 m (6,680 feet) of sandstone and conglomerate in 110 beds for an average bed thickness of 22 m (73 feet). The low-porosity range (0.2 to 13.6 percent) and the low permeability (less than 0.01 millidarcy), however, indicate poor- reservoir potential. In the Sitkinak Formation, they measured 381 m (1,250 feet) of sandstone and conglomerate for an average bed thickness of 14.3 m (47 feet). The porosity measurements in the Sitkinak ranged from 2.5 percent to over 10 percent, but averaged a low 4.4 percent. These rocks did, however, show a better permeability range (0.1 to 1.88 millidarcy) and average permeability (0.52 millidarcy) than did the rocks of the Sitkalidak Formation.

The Narrow Cape Formation showed the most promise for having reservoir-quality rocks. Lyle et al. (1978) measured 448 m (1,470 feet) of sandstone and conglomerate with an average bed thickness of 22.5 m (74 feet). Porosity ranged from 1 percent to 17 percent for a 7.4 percent average. Permeability ranged from 0.01 millidarcy to 30 millidarcy and averaged 7.59 millidarcy.

Hydrocarbon Indicators, Geochemistry, Source Rocks

The only source rock potential appears to be in Miocene or younger strata while the older rocks show enough alteration to have destroyed any oil that may have been generated (von Huene et al., 1976).

Sample and Moore (1987) measured illite crystallinity and vitrinite reflectance values for argillite samples from the Kodiak Formation. Illite, a diagenetic clay mineral, shows better crystallinity with increasing temperatures. Illite-crystallinity values show no progressive change across the formation and suggest a regional metamorphism equivalent to the prehnite-pumpellyite facies of the metabasite system. Vitrinite-reflectance values mostly ranged from 3.5 to 4.0 (R_o) with an average of 3.73. These values correspond to a burial temperature of 225°C if a burial time of 10 m.y. is assumed (Sample and Moore, 1987). Von Huene et al. (1980) stated that the rocks on Kodiak Island have poor source potential with an average organic- carbon content in the Paleogene rocks of less than 0.5 weight percent. The Sitkinak Formation, Tugidak Formation (not discussed here), and the Plio-Pleistocene rocks contain less than 0.6 weight percent organic carbon. Only the Eocene through middle Miocene rocks show thermal maturity and organic carbon of a type conducive to the production of gas and gas condensate. That is, the indigenous organic matter consists mainly of herbaceous and coally kerogen.

Lyle et al. (1978) reported that the C_{15+} extractable organic carbon content of the Sitkalidak Formation ranged from 155 parts per million (ppm) to 620 ppm. Thermal alteration for the Miocene and post-Miocene formations range from 1+ to 2+, dominantly in the 2- to 2+ range. This indicates a submature to mature stage of organic alteration that would generate either "wet" or "dry" associated hydrocarbons, depending on the type of hydrocarbon present (Lyle et al., 1978).

9. Geophysics

Bouguer gravity anomalies follow the general northeast trend shown by the geology of the Kodiak islands. Gravity highs parallel the northwestern and southeastern shorelines and may indicate that oceanic basement rises near these coastal areas or that denser rock intruded the rocks near the coastlines. A gravity low extends northeastward over the central part of Kodiak Island and northwest of most of the portion of the pluton exposed along the axis of the island (Barnes, 1977). This gravity low may represent a thrust-fault-thickened section of relatively low-density turbidites of the Kodiak Formation.

Case et al. (1986) reported on magnetic anomalies over Afognak and Shuyak islands. High-amplitude, steep-gradient anomalies align with the northwest side of Afognak Island and the southeastern two-thirds of the mapped area is almost magnetically featureless. Between these two areas lies an area with a subdued magnetic pattern having a series of small oval highs.

The high-amplitude, steep-gradient anomalies appear to correlate with exposures of the Afognak pluton or with shallowly-buried (within 1 kilometer of the surface) bodies of rock having a high-magnetic susceptibility. The magnetic anomalies over the Kodiak Formation (southeastern two-thirds of the mapped area) have small extent and low amplitude. Isolated bodies of volcanic rock, either unmapped or not exposed, may cause these small positive anomalies. The gentle magnetic gradients indicate that magnetic basement lies at a relatively great depth (5 kilometers or more).

The subdued magnetic pattern correlates with the melange of the Uyak Complex. A series of small, oval highs with steep gradients and a discontinuous distribution interrupt this subdued pattern. Many of these highs have a close spatial association with greenstone bodies, and Case et al. (1986) infer that greenstone or ultramafic bodies cause these oval anomalies. The southeastern limit of the oval anomalies closely parallels the major, mapped, fault which separates the Uyak Complex from the Kodiak Formation. Locally, this limit diverges from the previously mapped trace of the fault in areas where the geology is poorly known.

The Kodiak islands schist shows little difference in magnetic expression from the Uyak Complex. Magnetic rocks (amphibolite ?), concealed masses of the Afognak pluton, ultramafic bodies, or greenstone layers may cause the low-amplitude highs associated with the schist belt. Conspicuous magnetic highs and lows occur over the Triassic mafic volcanic rocks. Remanent magnetism or alteration of original magnetite may cause some of the lows. Steep gradients, caused by Triassic volcanic rocks, bound the northwest side of the northern belt of anomalies. These gradients closely parallel the mapped contact of the volcanic sequence with the relatively nonmagnetic Triassic sedimentary sequence.

Whether these magnetic patterns extend to the southeast is unknown, but the geology appears quite similar.

10. Conclusions

Geologic Potential

We classify most of the KNWR *(Figure 3)* as having No potential for the accumulation of oil and gas. This area has an O/D classification according to the BLM's mineral resource potential classification scheme (Appendix A). Igneous, metamorphic, and metasedimentary rocks underlie a large portion of the refuge and these rocks are unlikely to contain oil or gas deposits.

We classify the southeastern edge of the Aliulik Peninsula as having a Low potential for the accumulation of oil and gas. This is an L/C classification according to BLM's classification scheme. The Sitkalidak Formation, which crops out here, has low potential for having reservoir-quality sandstones and source rocks.

Economic Potential

We classify all of the KNWR area as having No potential for having economic deposits of oil and gas. This is based on the area's low potential for having reservoir and source rocks and because of its small size.

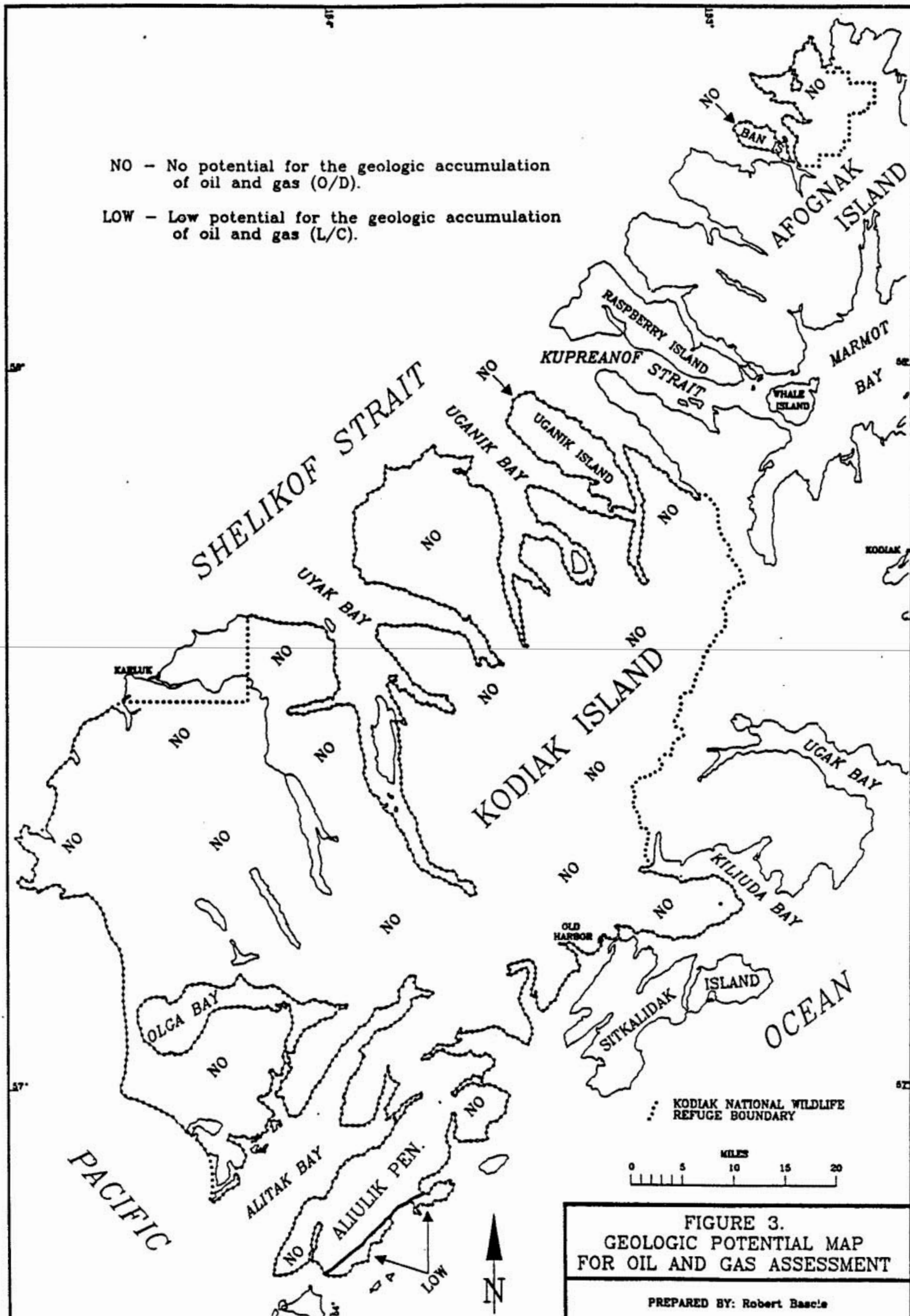

FIGURE 3.
GEOLOGIC POTENTIAL MAP
FOR OIL AND GAS ASSESSMENT

PREPARED BY: Robert Bascle

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Appendix A

3031 - Energy and Mineral Resource Assessment

Mineral Potential Classification System *

I. Level of Potential

O. The geologic environment, the inferred geologic processes, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences of valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines and deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.

ND. Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

II. Level of Certainty

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B. The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C. The available data provide direct evidence but are quantitatively minimal to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

For the determination of No Potential use O/D. This class shall be seldom used, and when used it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholithic (igneous intrusive), one can conclude, with reasonable certainty, that the area does not have potential for coal.

* As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and/or mineral resources. It does not refer to or imply potential for development and/or extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

Consideration of the Potential for Development and the Economic Potential

Whenever known, the quality, quantity, current, and projected development potential or economic potential should be part of the mineral resource assessment. Although this is not necessary or required for most BLM actions, it is often useful to the decision maker. Assessments of economic potential should not be attempted for actions requiring low levels of detail, or when data are scant.

Development potential means whether or not an occurrence or potential occurrence is likely to be explored or developed within a specified timespan under specific geologic and nongeologic assumptions and conditions. Economic potential means whether or not an occurrence or a potential occurrence is exploitable under current or foreseeable economic conditions. The time period applicable to the economic or development potential assessment should be specified in the assessment report (e.g., the occurrence is likely to be exploited in the next 25 years). Conditions that could change the economic potential, such as access, world energy prices, or changing technology, shall be an important part of every economic potential assessment. Determining the economic or development potential of either an actual or an undiscovered mineral occurrence is a matter of professional judgment based on an analysis of geologic and nongeologic factors. The rationale for that judgment shall be part of the mineral Assessment Report, when the economic potential is assessed. The rationale may include data on the current marketing exploitability, distance from roads, anticipated capital costs, etc. In other words, if the economic or development potential is assessed, the rationale for the conclusions regarding that potential must be thoroughly documented.

Calculating the quality and quantity of an occurrence, where the quality and quantity are not known from existing data, is only done for actions requiring a high level of detail. These calculations involve methods appropriate to the type of action and are described in the pertinent Bureau Manual (e.g., appraisal, validity, etc.).