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PRELIMINARY ANALYSIS OF THE PETROLEUM POTENTIAL OF THE ARCTIC NATIONAL WILDLIFE RANGE, ALASKA

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Recent acquisition of 24-fold seismic reflection profiles on the Beaufort shelf by the U.S. Geological Survey permit a better analysis of the petroleum potential of the Arctic National Wildlife Range (ANWR) than could be made from previously available data. The new data, gathered in the fall of 1977, suggest that the principal potential of the Wildlife Range is for a number of medium to large gas and oil accumulations in Cretaceous and Tertiary rocks, rather than for a supergiant accumulation of oil and gas in Mississippian to Triassic rocks, as previously available data, considered alone, seemed to suggest.

The seismic data collected in the Beaufort Sea off the Wildlife Range in 1977 have been only partially processed and interpreted at the time of this writing. This analysis, therefore, depends heavily on preliminary interpretation of unprocessed single-channel seismic reflection monitor profiles and on one processed 24-fold CDP seismic line (fig. 4C). When the entire body of seismic profiles off the ANWR coast is processed and interpreted, a more complete report can be prepared. Figure 1 shows the location, geographic features, and petroleum development of ANWR and vicinity.

DATA BASE

A substantial, but in important aspects incomplete body of publicly available data exists from which an analysis of the petroleum potential of ANWR can be made. These data consist of:

1. Reconnaissance geologic mapping and gravity surveys in ANWR and adjacent areas by the Geological Survey (Reiser, and others, 1971, 1974; Detterman, and others, 1975; Barnes, 1977).
2. Compilations of subsurface (borehole) information derived from petroleum exploration in northern Alaska west of ANWR by oil industry and Geological Survey geologists (Alaska Geological Society, 1972; Tailleur and Pessel, in press).
3. Reconnaissance geologic mapping in northern Yukon Territory and geologic interpretation of two seismic profiles on the continental shelf north of Yukon Territory by the Geological Survey of Canada (Norris, 1977).
4. Multichannel seismic reflection surveys on the Beaufort shelf adjacent to ANWR obtained by the Geological Survey in 1977.

These data establish that the Arctic coastal plain and foothills north of the Brooks Range, constituting about a fourth of ANWR, are the only portions with significant petroleum potential. The coastal plain, however, contains relatively few exposures of the underlying geologic formations. These exposures, moreover, indicate that the geologic structure beneath the coastal plain is too complex to be adequately deciphered from the available outcrops. Accordingly, the present analysis was based on extrapolation of additional data now available from adjacent areas, including the continental shelf. The extrapolations were guided by the character of the limited outcrops and gravity data available on the coastal plain. No potential for significant upgrading of the data base exists short of performing selected seismic reflection survey lines across that portion of the Wildlife Range that lies north of the Brooks Range.

EXISTING ASSESSMENTS

Three estimates of the petroleum potential of ANWR are known to the writers. Two are in the published literature; the third is an undated administrative report by Geological Survey authors that was transmitted to the Fish and Wildlife Service on August 31, 1976. The substance of this latter report was presented as testimony in a staff workshop of the U.S. Senate Committee on Energy and the Environment held at Anchorage, Alaska, during the week of February 21, 1978.

1. Hartman, D. C., 1972 (Revised January, 1973), Geology and mineral evaluation of the Arctic National Wildlife Range, northeast Alaska: Alaska Div. Geol. and Geophys. Surveys, Open-File Rept. 22, 14 p.

   Hartman's principal conclusion is that Marsh anticline, which lies in the northwestern part of ANWR and about 5 to 10 km south of Camden Bay, may have an enormous reserve of oil and gas in Tertiary, Cretaceous, and Permian-Triassic (Sadlerochit Group) sands. He states (p. 8) that "...a reserve of nearly 14 billion barrels of oil can be calculated..." for Marsh anticline, given certain favorable assumptions.

2. Tailleur, I. L., and Pessel, G. H., 1976, Subsurface geology and some implications concerning future petroleum exploration in eastern Arctic Slope, Alaska (abs.): Am. Assoc. Petroleum Geologists Bull., v. 60, no. 12, p. 2190.

Tailleur and Pessel report that the petroleum potential of the prolific reservoir formations of Prudhoe Bay are best in the northern part of the Arctic coastal plain and may improve to the north, in the offshore area. They state that similar favorable conditions in these formations may be found in the ANWR unless the principal of these formations, the Ivishak sandstone, was truncated there by Early Cretaceous erosion. Post earliest Cretaceous sandstones, which have good reservoir characteristics and oil shows, but few structural traps west of the Canning River, are folded and faulted in ANWR. Tailleur and Pessel therefore postulate that these younger rocks are an attractive exploration target in the Wildlife Range.

3. Mull, C. G., and Kososki, B. A. (undated), Hydrocarbon potential of the Arctic National Wildlife Range, Alaska: U.S. Geol. Survey Admin. Rept., transmitted to the U.S. Fish and Wildlife Service, Aug. 31, 1976, 26 p., 4 pl., 1 fig.

Mull and Kososki conclude that in ANWR only the northern two-thirds of the Arctic coastal plain is prospective for petroleum. The southeastern 20 percent of the prospective area is held to be slightly prospective with petroleum accumulations possible but none likely to be large. The western 60 percent of the prospective area, lying west of Barter Island, <u>and including</u>

Marsh anticline, is held to have moderate prospects, with petroleum accumulations possible but probably smaller than in the area of highest potential. The area of highest potential is held to lie southeast of Barter Island in the northern half of the coastal plain as far east as Beaufort lagoon. This area, some 40 percent of the terrain with petroleum potential, is held to be very highly prospective, with multi-billion-barrel oil accumulations possible.

SYNOPSIS OF PETROLEUM GEOLOGY OF ANWR

Rock sequences

The major sedimentary rock formations in ANWR are shown schematically in figure 2. Almost all have petroleum potential. Basement for the occurrence of significant deposits of petroleum is the heterogeneous assemblage of rocks of the Franklinian sequence. In northern Alaska and northwestern Yukon Territory these rocks are generally strongly deformed or metamorphosed. However, in western Canada, and particularly Alberta, Devonian rocks correlative with the upper part of the Franklinian sequence contain very large oil and gas deposits.

The Ellesmerian sequence of sedimentary rocks was deposited upon the Franklinian rocks following an episode of structural geologic deformation and deep erosion. The sequence consists of sandstone, conglomerate, shale, limestone, and dolomite deposited in coastal lowlands and on a stable continental shelf with shallow to moderate water depths. The sandstone, shale, and conglomerate consist of detritus brought to the Ellesmerian shelf by rivers draining highlands lying north of the present coast. The limestones are dominantly lime muds containing fossil shell debris. The depositional environment, slow sedimentation on a stable shelf, has given suitably located portions of the Ellesmerian sequence the excellent reservoir characteristics that made the supergiant Prudhoe Bay field possible. An episode of regional erosion recorded as a widespread unconformity at the base of the Lower Cretaceous Kemik Sandstone and Kongakut Formation, and of the correlative "Pebble Shale" encountered in boreholes west of ANWR, has removed older Ellesmerian strata from significant areas of the northern Arctic coastal plain. The Kongakut Formation and the "Pebble Shale," the highest formations of the Ellesmerian sequence, are highly organic and contain excellent source rocks for petroleum. Following the deposition of these formations the highlands to the north, from which the Ellesmerian sediments were largely derived, were removed by rifting and subsidence and Ellesmerian deposition ceased.

The Brookian sequence was laid down under quite different conditions than the preceding Ellesmerian sequence, which it overlies with unconformity. The Brookian sequence consists of sandstone, shale, conglomerate, and coal formed mainly of detritus brought to a subsiding basin by streams flowing from the newly formed ancestral Brooks Range to the south. The detritus was deposited on coastal plains and in a shallow to modestly deep marine basin. The sequence contains, in places, good reservoir sands and also highly organic shales that are thought to be excellent source rocks for petroleum. These shales, which occur in the Colville Group, and the "Pebble Shale" at the top of the Ellesmerian sequence, are considered by most geologists to have been the principal sources for petroleum at Prudhoe Bay. Both oil and gas have been found in Brookian rocks west of ANWR, and also in generally similar, age-equivalent strata in the Mackenzie delta region of northwestern Canada.

Distribution of rocks

The Franklinian sequence crops out over much of the mountainous part of the Wildlife Range (see fig. 3), including the core of the Sadlerochit and Shublik Mountains. Where it is covered by younger rocks it is inferred to lie at shallow to moderate depths (0 to roughly 1 or 2 km) beneath the mountains and southern part of the Arctic coastal plain, and at moderate to great depths (1 or 2 to more than 6 km) beneath the central and northern parts of the coastal plain. The Ellesmerian sequence crops out in large areas of the mountains, also, and in the foothills to the north. In the mountains, and locally in the foothills, the Ellesmerian rocks are deeply cut by erosion related to the present landscape. In many places this erosion has also cut deeply into the underlying Franklinian sequence. The Brookian sequence underlies almost all of the Arctic coastal plain and most of the foothills in ANWR, but it is present in only a few scattered areas in the mountains to the south. The rocks of this sequence constitute volumetrically all or most of the strata prospective for petroleum in ANWR.

In the northern part of the Wildlife Range a major question is: are the rocks of the Ellesmerian sequence preserved beneath the Arctic coastal plain? There they might have escaped erosion and intense deformation, came in contact with petroleum source rocks, and perhaps acquired large petroleum deposits. Regional stratigraphic trends, indicated both by outcrop data and by subsurface data west of the Wildlife Range, indicate that the Ellesmerian rocks were removed by earliest Cretaceous erosion from at least a significant part of the coastal plain north of the Sadlerochit Mountains (see figs. 1 and 4A). Mapping in northern Yukon Territory (Norris, 1977), east of the Wildlife Range, shows that the Ellesmerian formations there are near their northern depositional limits. These rocks have, in addition, been truncated by erosion at the base of the Kingak Shale (Jurassic) and to some extent at the base of older Ellesmerian units. The trends of the lines of zero thickness that appear to limit these formations on the north in the Yukon lie generally within the northern foothills of the Brooks Range. They follow the trend of the mountain front northwest, then west-northwest toward the southern part of the Arctic coastal plain in ANWR. A simple interpolation of these lines of northward truncation and pinchout would trend across the southern part of the coastal plain, suggesting that Ellesmerian formations are absent farther north. The question is not so simply resolved, however, because these interpolations are made across 150 km, and for some formations across more than 250 km of terrain almost without Ellesmerian exposures and entirely lacking in subsurface information.

The only Ellesmerian exposures on the Arctic coastal plain north of the foothills consist of Kingak Shale and Kongakut Formation about 30 km southeast of Barter Island. The Kingak, of Jurassic age, lies high in the Ellesmerian sequence. It has been commonly assumed that the Kingak Shale outcrop indicated that the older beds of the Ellesmerian sequence, including the Sadlerochit Group which is prolifically oil-bearing at Prudhoe Bay, were also present in that area of the coastal plain. If stratigraphic relations southeast of Barter Island are like those at Prudhoe Bay, where the Sadlerochit and other Ellesmerian beds underlie the Kingak, the Sadlerochit would be expected in the subsurface. However, geologic mapping by Norris (1977) in northern Yukon Territory, and his interpretation of two seismic lines on the continental shelf to the north, indicate that the Kingak in that area extends far north of the northern depositional and erosional edge of the older Ellesmerian formations. If stratigraphic relations southeast of Barter Island are like those in the northern Yukon the Kingak Shale outcrop would not necessarily be underlain by older Ellesmerian beds; and regional trends of the northern depositional and erosional edges of Ellesmerian rocks in northern Yukon and Alaska would suggest that they are likely to be absent. The question cannot be resolved with available data, however, and the presence of pre-Kingak Ellesmerian rocks southeast of Barter Island must be considered a possibility.

Geologic structure

The geologic structure of ANWR and adjacent continental shelf is unique in northern Alaska. The Wildlife Range occupies most of the Alaskan portion of a structurally controlled northward "bulge" in the eastern Brooks Range and a terrain of large, long thrust-fault-cored anticlines (thrust folds) that have deformed the Brookian rocks of the Arctic coastal plain in front of the "bulge". At least three thrust folds can be interpreted to underlie the coastal plain of ANWR. Preliminary interpretation of seismic data (see fig. 3 and 4C) suggests that the long anticlinal features, or arches, found to underlie the continental shelf off ANWR are also cored by thrust faults. Some of the thrust folds have deformed strata as young as Pliocene, and probably Pleistocene, age. The largest thrust fold so far delineated onshore, Marsh anticline, exceeds 50 km in length and the longest analogous structure offshore exceeds 150 km in length.

The great length of the thrust folds and their geologic character as inferred from limited outcrops onshore and from seismic profiles offshore (fig. 4C), supports the preliminary interpretation that they are rootless and do not involve the underlying basement. In this respect they would resemble the elongate thrust folds of the foothills north of the Brooks Range west of the Sagavanirktok River. Such folds form where low angle thrust faults give up their displacement (and their identity) to long anticlines with steep dips and structural disorder at their cores. The disordered cores commonly penetrate the overlying strata to some extent, and the isolated Kingak Shale outcrop 30 km southeast of Barter Island may represent such an upward displaced core of a thrust fold. This Kingak Shale outcrop also indicates that the thrust fold in which it occurs is breached through the entire Brookian sequence, which seriously diminishes the potential of the fold as a trap for oil and gas.

The depth and configuration of basement beneath the sedimentary rocks of the coastal plain in ANWR are critical to its petroleum potential. If the thrust folds inferred to underlie the coastal plain are indeed rootless, then the top of the underlying basement rocks might slope more or less uniformly seaward, from the mountains to the coast, as it does just west of ANWR (see cross section fig. 4A). In this case, the large thrust folds inferred to underlie the ANWR coastal plain would represent "bunching up" or thickening mainly or entirely within the overlying Brookian rocks at the leading edge of thrust faults. Trapping structures for petroleum would then have to be sought in the folded rocks, and similar traps would not occur in any strata which might lie beneath the thrust folds.

Seismic reflection profiles recorded in the Beaufort Sea as close as 11 km off ANWR indicate that basement there lies beneath more than 6 km of Brookian rocks and Kingak Shale. The thickness of these superincumbent beds may, in places, exceed 8 km. The profiles also show structural thickening of the Brookian rocks in the cores of the offshore thrust-cored arches, or large regional folds. Of particular significance is the observation that an area of maximum thickening of inferred lower Brookian rocks offshore lies opposite a large positive gravity anomaly onshore east of Barter Island. This gravity anomaly also coincides in part with a shallow depth to basement inferred from a proprietary aeromagnetic survey by Aero Services, Inc. These anomalies were interpreted by Mull and Kososki (ibid.) as evidence for a broad structural high that brought basement, and possibly Ellesmerian rocks, to within 2 km of sea level. The offshore data suggest, instead, that the gravity anomaly represents a large thrust fold mainly or entirely within the Brookian sequence plus the Kongakut Formation and Kingak Shale of the upper part of the Ellesmerian sequence. The fold is interpreted to contain Cretaceous and probably Jurassic beds at the core and Tertiary beds on the flanks. This alternative interpretation is plausible because the greatest density contrast between the geologic formations of ANWR occurs between the Tertiary, and to a lesser extent the Upper Cretaceous, and all older formations (see fig. 2). There is apparently a smaller density contrast between the Lower Cretaceous and older rocks, including the sedimentary and metasedimentary rocks of the Franklinian sequence.

The geologic structure of the mountainous areas of ANWR, south of the Arctic coastal plain and foothills, is dominated by an older series of broad synclinoria and anticlinoria which have been breached through the only potentially petroliferous rocks, those of the Ellesmerian sequence, which occur there in significant thickness.

In summary of the geologic structure, offshore seismic reflection profiles and limited onshore outcrop data suggest that the Arctic coastal plain beneath ANWR is underlain by a thick section of Brookian rocks plus Kingak Shale and Kongakut Formation of the upper part of the Ellesmerian sequence. The extent of the remainder of the Ellesmerian sequence under the coastal plain is unknown, but it is absent from at least a significant part of this area. The Brookian rocks thicken from a wedge edge at the mountain front to more than 6 or 8 km near the coast. Of particular interest for petroleum is the observation that on the offshore seismic lines the large thrust folds are flanked by sedimentary prisms of Tertiary and, perhaps, Upper Cretaceous sedimentary rocks that appear to have been deposited while the folds were growing (fig. 4C). The resulting geometry and early development of large folded structures in sedimentary basins is considered favorable for the accumulation and entrapment of petroleum.

PETROLEUM POTENTIAL

There is a general agreement that the petroleum potential of ANWR south of the Arctic coastal plain is low. On the other hand a range of options have been expressed for the potential of the coastal plain itself. The coastal plain would appear to have potential because it contains at least three oil seeps and two outcrops of oil-stained sandstone; and because promising, although not yet fully evaluated, discoveries of oil and gas have been found at Flaxman Island and Point Thomson, both at the coast immediately west of ANWR. In addition, apparently modest-sized gas fields have been found at Kavik and at Kemik, 10 km and 40 km west of the Wildlife Range, on the southern part of the Arctic coastal plain, and the supergiant Prudhoe Bay field lies on the coast 80 km west of ANWR.

Potential in Ellesmerian rocks

The Ellesmerian sequence contains the most favorable reservoir rocks in northern Alaska, a consequence of the stable sedimentary environment in which its rocks were deposited. Oil and gas occurs in four main stratigraphic units of the sequence in the supergiant Prudhoe, the incompletely evaluated Kavik and Kemik, and the small South Barrow fields (see fig. 2).

In the western part of the ANWR, the prospects for large oil or gas deposits in rocks of the Ellesmerian sequence, including traps of the Prudhoe type, is very low. Outcrop relations in the Sadlerochit Mountains, regional subsurface trends, and the #1 Alaska State "A" well at Flaxman Island indicate that Ellesmerian rocks are absent from the northern two-thirds of the coastal plain south of Camden Bay, including the area of Marsh anticline (see figs. 1 and 3). Several boreholes have tested the Ellesmerian rocks near the mountains southwest of Camden Bay, just west of ANWR, and found apparently moderate amounts of gas, but no oil. The gas discoveries, the Kemik and Kavik fields, apparently have not been drilled out and fully evaluated. The area of prospective Ellesmerian rocks south of Camden Bay is greatly constricted in the Wildlife Range by the Sadlerochit and Shublik Mountains, which are underlain by large thrust-faulted folds that bring basement rocks to the surface opposite the gas discoveries at Kemik and Kavik.

The prospects for Ellesmerian petroleum deposits beneath the coastal plain east of Camden Bay cannot be conclusively evaluated from existing data, but the wright of evidence is that the prospects are poor. It is possible that no Ellesmerian reservoir units occur beneath the northern and central parts of the coastal plain east of Camden Bay (see figs. 1 and 3). If the geologic structure seen offshore in seismic data (fig. 4C) projects onshore beneath the coastal plain east of Camden Bay, as here interpreted, the prospects may be poor even if Ellesmerian rocks are present. These data suggest that any Ellesmerian rocks under the central and northern coastal plain east of Camden Bay are so deeply buried that their reservoir properties would be diminished by compaction unless they were filled with oil or gas before deep burial. The offshore data also suggest that any Ellesmerian rocks that might underlie the coastal plain dip generally northward, without major structural reversal such as was crucial to the entrapment of oil and gas at Prudhoe Bay. These beds, if present, and the underlying Franklinian basement are inferred in the offshore to lie beneath the thrust-fault related folds developed in the overlying Brookian rocks. The gross structure of any Ellesmerian beds that might underlie the coastal plain is therefore thought to generally resemble that shown in Figures 4B and 4A, which are structural cross sections lying east and immediately west of the Wildlife Range. The offshore seismic data strongly suggest that shallow basement, which might provide structurally favorable conditions for trapping oil and gas in Ellesmerian reservoirs, does not exist southeast of Barter Island, as postulated by Mull and Kososki (ibid.).

Potential in Brookian Rocks

The thick sequence of Cretaceous and Tertiary marine and nonmarine sedimentary rocks of the Brookian sequence, which underlies the coastal plain of ANWR, contains most of the Range's petroleum potential. The Brookian rocks of ANWR contain good to excellent source beds, at least adequate reservoirs, and large folds - albeit probably with faulted cores. However, the petroleum potential of the large fold that lies some 30 km south-southeast of Barter Island is seriously diminished because it is breached by erosion down to the Kingak Shale of the upper Ellesmerian sequence. A deep Tertiary (and possibly Upper Cretaceous) Brookian sedimentary basin was found offshore of the eastern part of ANWR that exhibits evidence of structural growth during sedimentation (see fig. 4C). Such early growth is favorable for the migration and entrapment of oil and gas. This basin trends into the Wildlife Range near Beaufort Lagoon between Barter Island and Demarcation Bay. Similar growth during sedimentation can also be inferred for the geologically recent (Pliocene--Pleistocene) history of Marsh anticline, but whether this was a significant factor during the deposition of the main body of underlying sedimentary rock is not known.

The Brookian rocks are prospective because of their character and because oil and gas have been found in correlative strata of similar type both to the west, in northern Alaska and to the east in the Mackenzie delta area. These deposits include apparently large oil accumulations in lower Tertiary (Eocene) strata at Flaxman Island, immediately adjacent to the Wildlife Range, and in beds of unreported age at Pt. Thomson. In addition, the oil seeps and oil-stained sandstones that have been found on the coastal plain of ANWR occur in areas underlain by Brookian rocks.

Magnitude of the Petroleum Potential of ANWR

The main potential for multi-billion-barrel oil fields in ANWR appears to lie in finding pre-Kingak Shale Ellesmerian rocks in structurally high positions in the central or northern parts of the Arctic coastal plain. The weight of evidence from available data, which cannot be conclusive, indicates that the potential for such large Ellesmerian oil or gas fields beneath the coastal plain is low. Moderate-sized gas fields might occur in the wedge of Ellesmerian rocks remaining beneath the southern part of the coastal plain north of the Sadlerochit Mountains.

The Brookian rocks in ANWR have good potential for a number of moderate, and perhaps large, gas and oil deposits in both Tertiary and Cretaceous strata. Experience on the North Slope west of ANWR and in the Mackenzie delta to the east suggests that accumulations in Tertiary rocks will most likely consist of gas, but that those in Cretaceous rocks will likely be more equally divided between oil and gas. The expected size of oil and gas fields in Brookian rocks in ANWR cannot be confidently estimated from available data, but some insight may be derived from experience in the Mackenzie delta. There, 13 fields found through 1975 contained an estimated 6.5 trillion cubic feet of gas and 400 million barrels of oil- for an average of 0.5 trillion cubic feet of gas and 30 million barrels of oil per field (Canada Dept. Energy, Mines and Resources, 1977). However, one field, Taglu, is reported to contain 3 trillion cubic feet of gas (Bowerman and Coffman, 1975). In northern Alaska, announced Brookian discoveries range up to 70 million barrels of oil and 0.3(?) trillion cubic feet of gas. As a rough estimate, based partly on these figures and partly on the offshore seismic data, typical Brookian fields in ANWR might contain in the range of 0.1 to 5 trillion cubic feet of gas and 10 to 200 million barrels of oil. Recent discoveries by Dome Petroleum of gas and oil in mainly Brookian rocks on the continental shelf north of the Mackenzie delta are reportedly much larger than these, but the trend of geologic structures offshore of ANWR suggests that Dome's discoveries are more relevant to the potential of the continental shelf north of ANWR than to the potential of the Wildlife Range itself. If the reported Dome discoveries have relevance for the potential of the Wildlife Range, or if the Flaxman Island and Point Thomson discoveries are as large as their initial rates of flow during testing (1,175 and 2,300 barrels of oil per day) suggest, then the potential of the ANWR coastal plain could be significantly larger than indicated above. In any case, the geology of the ANWR coastal plain and adjacent areas permits the speculation that a number of Brookian fields could occur there, and available knowledge does not preclude the possibility that some of these might be very large.

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ILLUSTRATIONS

Figure 1. Geographic features and petroleum development near the Arctic National Wildlife Range, Alaska, and location of northern depositional or erosional truncation edges of principal Ellesmerian rock units beneath the Arctic coastal plain.

2. Sedimentary rock sequences in the vicinity of the Arctic National Wildlife Range, showing occurrence of oil and gas and bulk rock densities. Bulk densities from data compiled by B. A. Kososki, U.S. Geological Survey.

3. Generalized geologic map of the Arctic National Wildlife Range and vicinity, showing location of structural cross sections shown in Figure 4. Overlay Figure 1 for location of geographic features.

4. Structural cross sections of areas adjacent to the Arctic National Wildlife Range.

A. Kemik gas field to Flaxman Island. Data from a compilation of geologic formations encountered in boreholes between the Canning and Colville Rivers (Tailleur and Pessel, in press). The control points for the cross section (boreholes) would not suffice to delineate any small scale geologic structures that might be present.

B. Alaska-Yukon boundary near Firth River to the continental shelf northeast of Herschel Island. Data from geologic field mapping in northern Yukon and interpretation of CDP seismic reflection records on the Beaufort shelf by Norris, (1977).

C. Beaufort shelf between 6 km and 53 km offshore along $141^{\circ}00'$W. longitude. Data from interpretation of U.S. Geological Survey 1977 CDP seismic reflection profiles (present study).

SEQUENCE	GEOLOGIC AGE		FORMATION	KNOWN FOSSIL FUEL		BULK DENSITIES
				OIL	GAS	No. of samples
BROOKIAN	TERTIARY		SAGAVANIRKTOK FORMATION	●	☼	2 ‡
BROOKIAN	CRETACEOUS	UPPER	COLVILLE GROUP	●	☼	10
	CRETACEOUS	LOWER	NANUSHUK GROUP ˣKONGAKUT FORMATION- "Pebble shale" *			20
ELLESMERIAN	JURASSIC		KUPARUK RIVER SANDSTONE KINGAK SHALE *	●	☼	4
ELLESMERIAN	TRIASSIC		SHUBLIK FORMATION- KAREN CREEK SANDSTONE *	●	☼	38
ELLESMERIAN	PERMIAN		SADLEROCHIT GROUP *	●	☼	
ELLESMERIAN	PENNSYLVANIAN		LISBURNE GROUP	●	☼	6
ELLESMERIAN	MISSISSIPPIAN		ENDICOTT GROUP			10
FRANKLINIAN	DEVONIAN & OLDER		SEDIMENTS & METASEDIMENTS; VOLCANICS AND METAVOLCANICS			65 34

Bulk density scale: 2.0, 2.5, 3.0, 3.2

* *These unconformities record important erosion and local removal of underlying beds of the Ellesmerian Sequence.*

ˣ*Includes Kemik Sandstone.*

‡ – – ✱ – Range and rough estimate of mean value from #1 Alaska State "A" testwell.

FIGURE 2. SEDIMENTARY ROCK SEQUENCES IN THE VICINITY OF THE ARCTIC NATIONAL WILDLIFE RANGE, SHOWING OCCURRENCE OF OIL AND GAS AND BULK ROCK DENSITIES. BULK DENSITIES FROM DATA COMPILED BY B. A. KOSOSKI, U.S. GEOLOGICAL SURVEY.