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GEOLOGICAL SURVEY

PRELIMINARY REPORT ON THE COAL RESOURCES OF THE NATIONAL PETROLEUM RESERVE IN ALASKA

by

G. C. Martin and J. E. Callahan

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CONTENTS

	Page
Abstract	1
Introduction	1
Geography	2
Physiography	2
Climate and vegetation	2
Settlements and accessibility	5
General Geology	5
Stratigraphy	5
Structure	7
Coal Resources	8
Coal geology	8
Coal quality	10
Coal classification system	15
Identified coal resources	15
Undiscovered coal resources	17
Significance of hypothetical resources estimates	19
Conclusions	20
References	21

ILLUSTRATIONS

Plate 1. Isopach and coal percentage map of the Nanushuk Group . . . in pocket

2. Map of identified coal resources . . . in pocket

Figure 1. Location map of the National Petroleum Reserve in Alaska (NPR-A) . . . 3

2. Physiography map of the NPR-A . . . 4

3. Major tectonic elements of the NPR-A . . . 4

4. Generalized stratigraphic correlations of Cretaceous rocks and surficial deposits of northwestern Alaska . . . 6

5. Classification of mineral resources . . . 16

TABLES

Page

Table 1. Analyses of coal cuttings from shallow seismic drill holes in NPR-A 11

2. Estimates of Coal Resources in NPR-A 18

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ABSTRACT

NPR-A, located on the Arctic slope of Northern Alaska, is underlain by a thick sequence of sedimentary rocks of Cretaceous age which attain a thickness of as much as 4600 m (15,000 feet). The bulk of the coal resources occurs in rocks of the Nanushuk Group of Early and Late Cretaceous age. The Nanushuk Group is a wedge-shaped unit of marginal-marine and nonmarine rocks that is as thick as 3300 m (11,000 feet) just west of NPR-A. Within the reserve, coal occurs primarily in the middle and thicker portions of this clastic wedge and occurs stratigraphically in the upper half of the section. Specific data on individual coal beds or zones are scarce, and estimates of identified coal resources of about 49.5 billion tons represent a sampling of coal resources too small to give a realistic indication of the potential resources for an area so large. Estimates of undiscovered resources suggest hypothetical resources of between 330 billion and 3.3 trillion tons. The wide range in the undiscovered resource estimates reflects the scarcity and ambiguity of the available data but also suggests the presence of a potentially large coal resource.

INTRODUCTION

The Naval Petroleum Reserves Production Act of 1976 directs the Secretary of the Interior to conduct a land-use study of the National Petroleum Reserve in Alaska (NPR-A, formerly Naval Petroleum Reserve No. 4). The U.S. Bureau of Mines was assigned the task of furnishing an assessment of all resource values other than oil and gas for this study and requested the Conservation Division of the U.S. Geological Survey to furnish an estimate of coal resources for inclusion in their preliminary assessment. An administrative report, including estimates of coal resources based mostly on previously published data, was furnished to the Bureau of Mines early in 1978. This open-file report is an updated version of that report. Slight adjustments in identified resource figures have been made based on new data obtained from seismic shot holes in the western part of the reserve during the late winter and spring of 1978 and from logs of two recent oil and gas test wells.

Further refinements in the identified resources should result from various geologic investigations during the 1978 summer field season; significant changes in the hypothetical resource figures also may result from a reinterpretation of depositional environments of the coal-bearing rocks.

NPR-A is located on the Arctic slope of northern Alaska (fig. 1) and extends from the crest of the DeLong Mountains in the Brooks Range northward to the Arctic coast and from the lower Colville River westward to the longitude of Icy Cape on the Chukchi Sea. It encompasses about 96,000 km^2 (37,000 miles^2), an area as large as the State of Indiana.

GEOGRAPHY

Physiography

The area can be divided into three physiographic provinces: the mountainous Brooks Range, which is generally considered the northwestern extension of the Rocky Mountain System; the Arctic Foothills; and the Arctic Coastal Plain (fig. 2). The mountainous province rims the southern boundary of NPR-A and is succeeded on the north by the foothills belt, which is characterized by treeless rolling hills, ridges, and valleys aligned east-west and parallel to the mountain front. The foothills belt is subdivided into a northern and a southern section, the southern section being hillier with more local relief and a higher overall altitude. Local relief in the foothills belt generally varies from 60 to 300 m (200 to 1000 feet) and altitudes range from 180 m (600 feet) along the northern boundary to 1200 m (4000 feet) along the mountainous southern border. North of the foothills is the coastal plain, an extensive practically featureless tundra plain containing numerous lakes and marshes and poorly defined streams.

Climate and Vegetation

The arctic climate of NPR-A is characterized by cold temperatures, strong winds and scant precipitation. Temperatures generally range from -54°C (-65°F) to 18°C (65°F). Summers are short and cool, and freezing temperatures are not uncommon. In winter, the temperature seldom rises above freezing. The area is within the zone of continuous permafrost that extends to depths of 305 m (1000 feet) or more.

The wind blows most of the time and is evenly distributed throughout the year. Average annual velocity at Barrow on the northern tip of Alaska and NPR-A is about 16 km/hr (10 miles per hour), and maximum velocities can be extreme. In 1951, during exploratory drilling of the Kaolak test well, the rig derrick was blown over in a high wind (Reed, 1958). Precipitation averages between 10-20 cm (4-8 inches) a year, principally in the form of snow. Although the small amount of precipitation suggests aridity, water, either in the form of snow and ice or as a liquid, is almost always present. The permanently frozen ground, dense mat-like tundra, and cold temperatures prevent or inhibit percolation, runoff, and evaporation.

Vegetation within NPR-A consists of typical tundra flora: grasses, sedges, flowering plants, mosses and flat bushes. The area is essentially devoid of trees, although stunted willows grow along the river valleys and infrequent stands of stunted alder and cottonwood are found in the foothills belt.

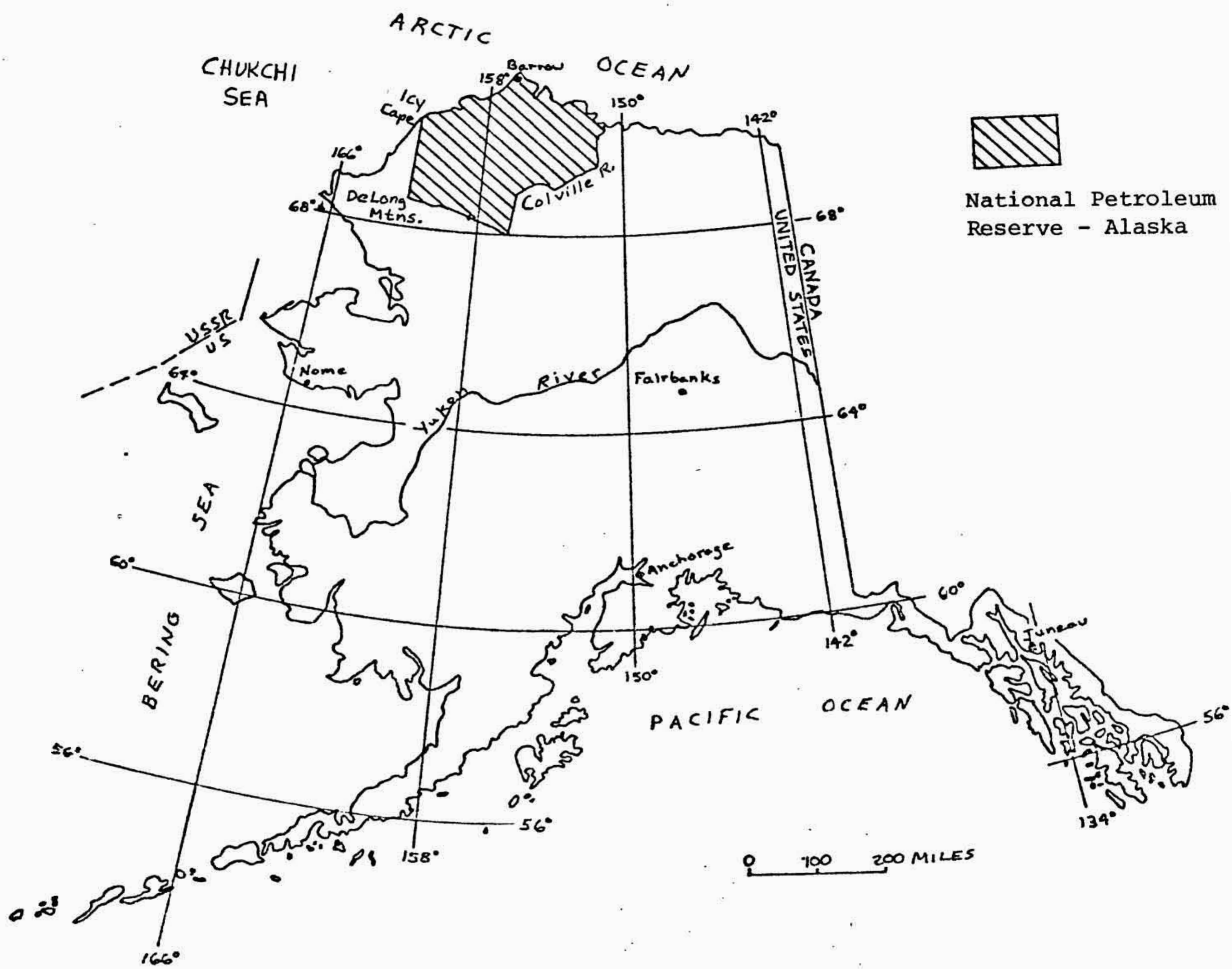

FIGURE 1.--Location of National Petroleum Reserve in Alaska (NPR-A).

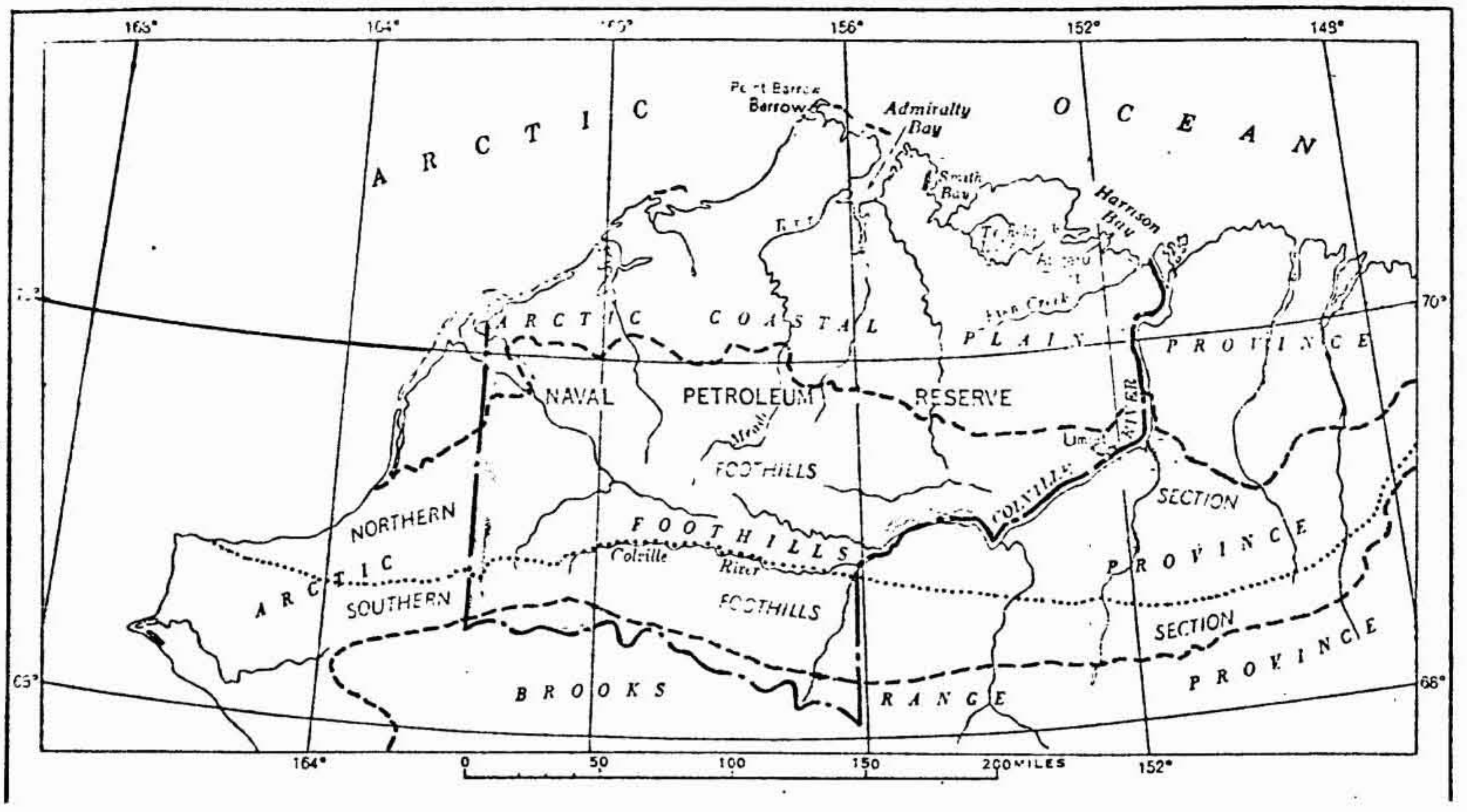

FIGURE 2.--Physiography of National Petroleum Reserve in Alaska (after Wahrhaftig, 1965, pl. 1).

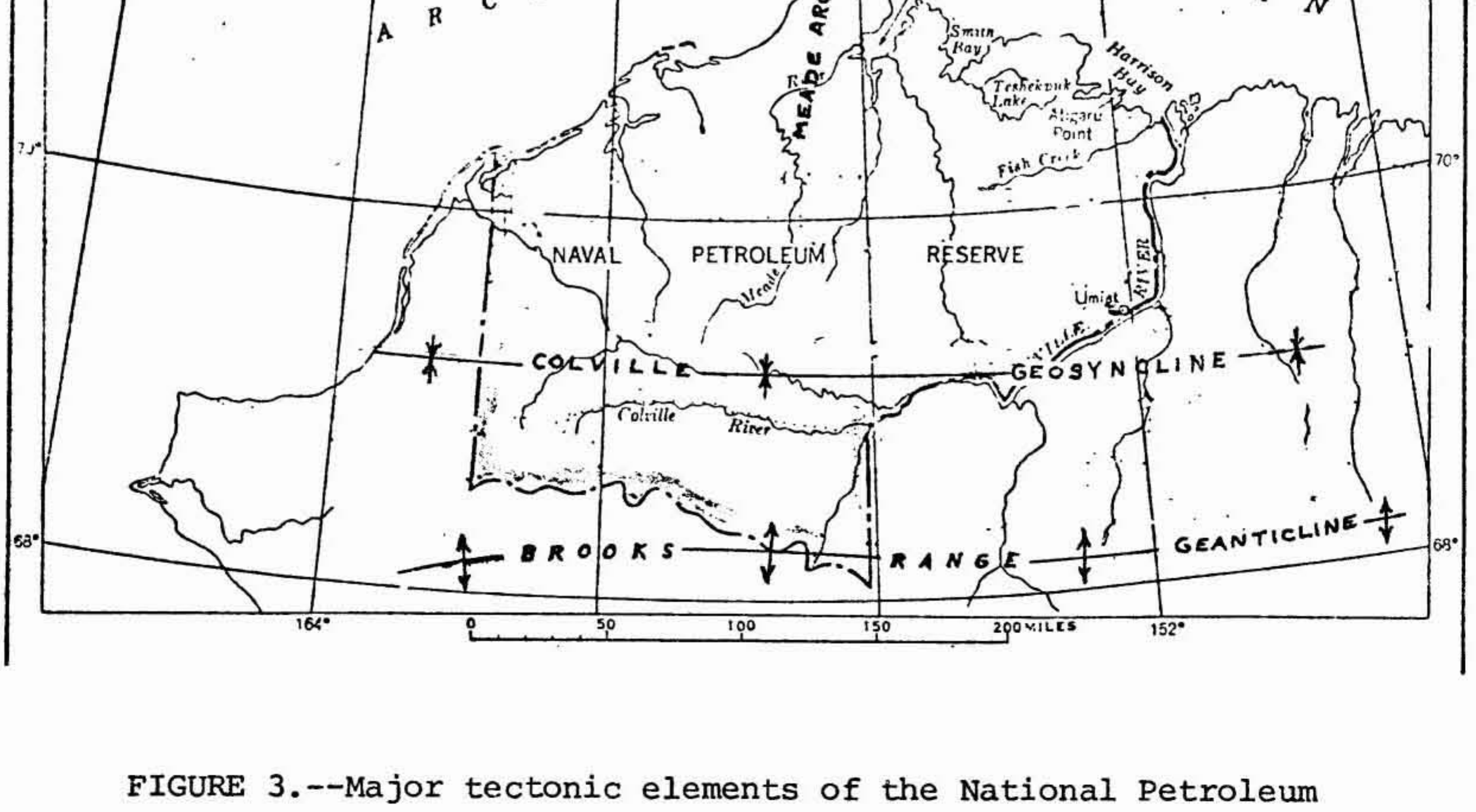

FIGURE 3.--Major tectonic elements of the National Petroleum Reserve in Alaska.

Settlements and Accessibility

Except for the town of Barrow and the three small Eskimo villages of Wainwright, Atkasook, and Nuiqsut, there are no permanent settlements in NPR-A. A longstanding base camp is located at Umiat along the Colville River on the east edge of the reserve. Government agencies, both civilian and military, and oil companies have used the base camp as a logistics center for petroleum exploration in northern Alaska.

The nearest road to the reserve is the Trans-Alaska pipeline haul road 100 to 110 km (60 to 70 miles) east of the reserve. Transportation to, from, and within the reserve is principally by air. Overland transportation is possible in the winter by tracked vehicles and sleds but not in summer, when such travel would scar, almost permanently, the exposed tundra. The coast is generally ice free and accessible by ship in August and September. However, there is a considerable variation in the ice-free season from year to year, and the ice pack may move in at any time, making shipping hazardous even during this short period.

GENERAL GEOLOGY

Stratigraphy

Most of NPR-A is underlain by a thick sequence of sedimentary rocks of Cretaceous age of the Colville geosyncline (fig. 3--see page 4). In the reserve, this sequence ranges in thickness from about 900 m (3000 feet) near Barrow along the Barrow Arch to at least 4600 m (15,000 feet) adjacent to the Brooks Range in the foothills belt (Brosgé and Tailleur, 1971). These rocks are roughly divisible into three groups that, in ascending order, are: a lower sequence of predominantly marine shales of Early Cretaceous age, the Nanushuk Group of marginal-marine and nonmarine coal-bearing rocks of Early and Late Cretaceous age, and the overlying Colville Group of intertonguing marine and nonmarine coal-bearing rocks of Late Cretaceous age (fig. 4).

The lower marine shale sequence comprises, in ascending order, the Okpikruak, the Fortress Mountain, and the Torok Formations. The Okpikruak (not shown on fig. 4), a dark shale unit containing pebbles and floating quartz grains, unconformably overlies Jurassic and older rocks and marks the base of the Cretaceous in the reserve. The Fortress Mountain and Torok Formations overlie the Okpikruak Formation. The Fortress Mountain Formation, a conglomeratic orogenic deposit present adjacent to the Brooks Range, rapidly grades laterally northward into a shaly facies that may be, in part, equivalent to the basinal shale and greywacke of the Torok Formation. Thrust faulting has obscured the exact relationship between these two formations. The Torok Formation overlies the Okpikruak Formation over most of NPR-A. The aggregate thickness of these three formations ranges from about 900 m (3000 feet) on the Barrow Arch to at least 3000 m (10,000 feet) in the foothills belt (Brosgé and Tailleur, 1971).

This Lower Cretaceous shale sequence is overlain by the Nanushuk Group, a sequence which grades upward from marginal-marine sandstone and

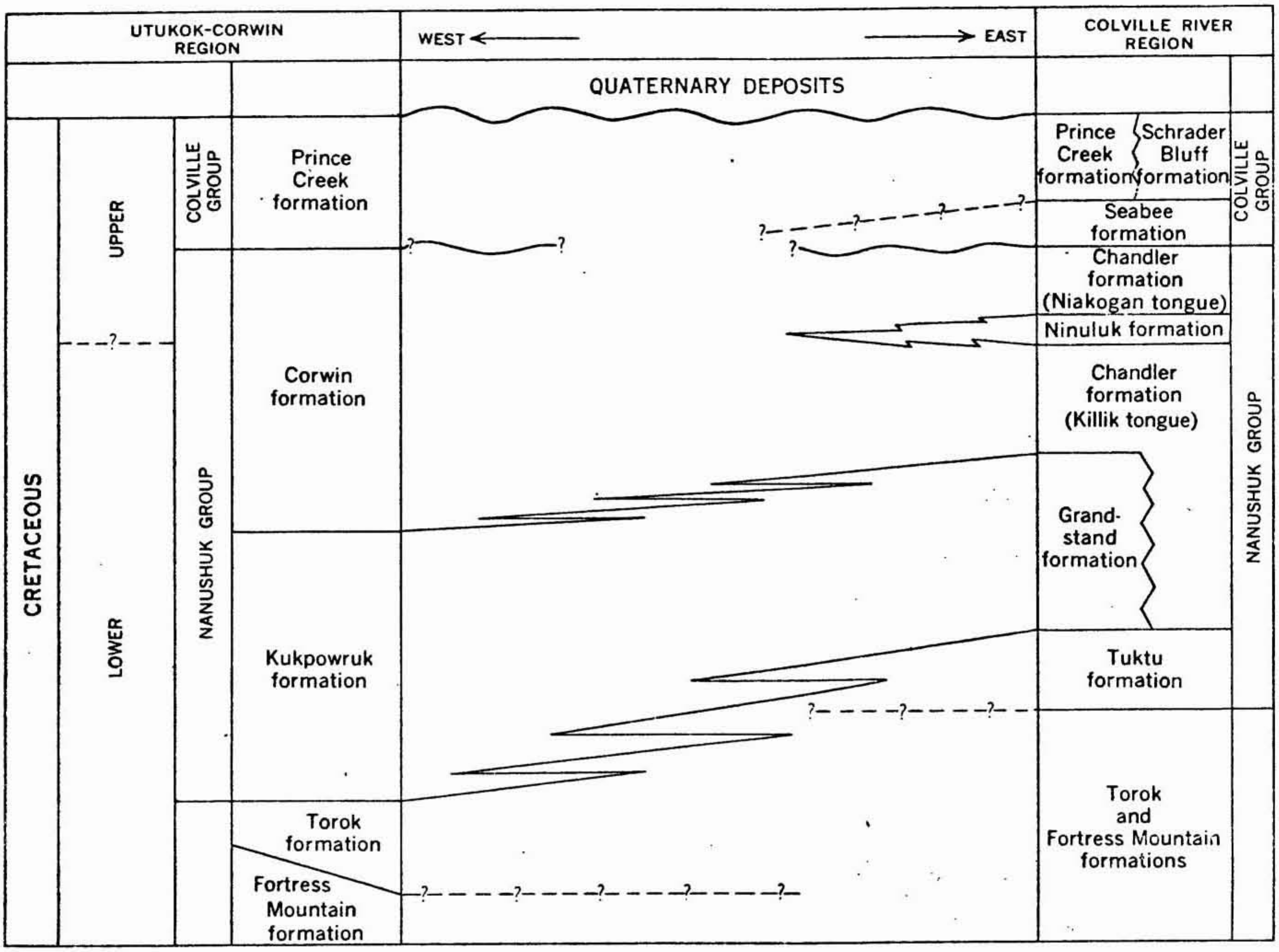

Figure 4.--Generalized stratigraphic correlations of Cretaceous rocks (in part) and surficial deposits of northwestern Alaska. Wavy lines represent unconformities. Modified from Chapman and Sable (1960, p.70).

shale into nonmarine coal-bearing sandstone and shale. The Nanushuk Group, the principal coal-bearing rocks in northern Alaska, was deposited as a clastic wedge which progressively filled the downwarping Colville geosyncline and prograded to the northeast causing the Cretaceous shoreline to retreat in a northeasterly direction (Detterman, 1973). The Nanushuk sediments become increasingly more marine in character away from their source in the Brooks Range, and intertonguing of marine and nonmarine sediments along a wide northwest-trending belt between the Peard Bay-Wainwright Inlet area and Maybe Creek-Prince Creek area indicates broad fluctuations of shoreline at this time. Northeastward from their Brooks Range source area, the Nanushuk rocks thin from more than 3300 m (11,000 feet) west of the reserve to a paleo-erosional edge on the Barrow Arch along the reserve's northeastern coastline.

The Nanushuk Group has been subdivided into formations primarily on the basis of marine or nonmarine character of its rocks where it has been mapped along exposures in the foothills belt. The nonmarine facies contains the majority of coal found in the reserve.

In the western section of the foothills belt, near the Utukok River, the lower marginal-marine facies comprise the Kukpowruk Formation, and the upper nonmarine facies comprise the Corwin Formation. To the east, along the foothills belt from the Etivluk River and eastward, the lower marginal-marine facies is mapped as the Tuktu Formation and the nonmarine facies is mapped as Chandler Formation, with an upper tongue of marine facies overlying the Chandler mapped as the Ninuluk Formation. Beyond the northeastern paleoshoreline where the Nanushuk section is predominantly marine to marginal-marine, it is referred to as the Grandstand Formation. For the purposes of this report, the Nanushuk Group is divided into a lower sequence of predominantly marginal-marine facies and an upper nonmarine facies sequence. During subsequent uplift and deformation, part of the Nanushuk rocks were removed by erosion, particularly in the foothills belt and in the eastern Arctic.

In the eastern part of NPR-A, in the Umiat area and along the lower course of the Colville River, the Colville Group unconformably overlies the Nanushuk and reaches a maximum thickness of about 900 m (3000 feet) (Brosgé and Tailleur, 1971). The Colville Group consists of a basal marine shale and sandstone unit referred to as the Seabee Formation, and an overlying sequence of intertonguing marine and nonmarine clastic sediments. These nonmarine rocks of the Colville Group are known as the Prince Creek Formation and occupy a small area in the vicinity of Umiat. A thin unit of nonmarine rocks equivalent in age to the Colville Group overlies the Nanushuk Group in the western part of NPR-A along the lower courses of the Utukok and Kokolik Rivers. Known coals in the Colville Group in NPR-A are poorer and less abundant than coals in the Nanushuk; thus no estimates of resources were made.

Structure

The major structural features of NPR-A are shown in Figure 3. In general, the structure of the Cretaceous coal-bearing and associated rocks is characterized by folding and faulting along east-west axes which parallel the Brooks Range, with the intensity of deformation diminishing northward away from the mountains. The topography of the foothills belt reflects this folding and faulting.

Seismic data indicate that the folding of the Nanushuk Group in the foothills does not continue with depth to the basal Cretaceous rocks, indicating a regional décollement or detachment in the thick, incompetent Lower Cretaceous shale of the Torok Formation. The deformation of Cretaceous rocks was slight in the coastal plain, resulting generally in gentle open folding and little faulting. The Barrow Arch is a structural high that persisted through Cretaceous time, and Cretaceous rocks thin onto its flank.

COAL RESOURCES

Coal Geology

As noted above, the bulk of the coal resources in NPR-A is in rocks of the Nanushuk Group. Nanushuk rocks are among the most studied in the reserve. Data have come from exploratory petroleum test holes, seismic studies, logs of shallow seismic shotholes, and surface mapping in the foothills belt where exposures are present.

Most Cretaceous coal-bearing formations of the western United States are interpreted as deltaic or paralic in origin. The coal-bearing rocks of the Nanushuk Group are in a similar geologic setting and thus most likely have a similar origin.

The isopachs of the Nanushuk Group shown on Plate 1 are modified from Brosgé and Tailleur (P. 85, fig. 16, 1971) and illustrate the regional wedge shape of this rock unit. It should be noted, however, that the coarsest nonmarine sediments and the trend of greatest thickness occur in the proximal portion of the wedge; this is not the normal deltaic pattern in which the coarsest sediment and the trend of least thickness occur in the proximal portion. Also, the thicker Nanushuk coals are mainly present in the middle and upper part of the sequence and are widely separated stratigraphically from the underlying marginal-marine facies, indicating deposition considerably inland from the sea. This is in contrast to the Cretaceous deltaic and paralic coals of the western United States which are normally found within the first 30 m (100 feet) of nonmarine section above the marine facies even though the nonmarine rocks may be hundreds of meters thick (Weimer, 1977). The presence of thick sandstone and conglomerate in the southern and southwestern borders of the Nanushuk Group reflects high stream gradients scarcely typical of delta associations. Furthermore, the bentonitic shales and claystones, which indicate volcanic activity, and the conglomerates imply the proximity to an orogenic source. Downwarping and sedimentation apparently took place concurrently with, and probably as a result of, the northward-directed thrust faulting and uplifting that formed the Brooks Range (Carter and others, 1977). Thus, rather than a deltaic association, the coals of the Nanushuk Group appear to have been deposited in a broad piedmont plain between the sea and elevated mountains, a depositional setting typical of a clastic wedge association.

The Cretaceous Frontier Formation of Wyoming that has been described by Krumbein and Sloss (1963) and others as a clastic wedge exhibits lithofacies associations, regional geometry, and a tectonic setting generally analogous to that of the Nanushuk Group. The coals of the two sequences would therefore be expected to be similar, and the available data seem to agree with this inference. The stratigraphic distribution of coal in the Frontier Formation is present mainly in the middle and top parts of the formation (Glass, 1977), and areally the thicker and more numerous coals are present in the predominantly nonmarine facies of the formation, with thinner less numerous coals occurring in the thinner more distal portions of the wedge where marine and nonmarine rocks intertongue (Krumbein and Sloss, 1963). As these are the same regional relationships observed in the Nanushuk Group, the more detailed knowledge of the Frontier Formation may provide a guide for future coal exploration in NPR-A.

The coal percentage contours (pl. 1) illustrate the areal distribution of coal in the Nanushuk Group. The control for the coal percentage contours was derived by calculating, from published reports, the relative percentage of coal in the Nanushuk Group at each test well and measured stratigraphic section which contained a relatively complete and detailed stratigraphic record of individual coal beds. Contouring of coal percentages was partly mechanical and partly interpretive. Due to the scarcity of the control points, strictly mechanical contouring would probably not reveal the coal distribution as well as interpretive contouring, which takes into account probable sedimentation patterns discussed previously.

Along the northwest-trending belt of intertonguing marine and nonmarine rocks, the coals were probably deposited in coastal-plain swamps, and strandplain-lagoons. In this area, the coal percentage contours trend parallel to the paleoshoreline, and the zero contour marks the approximate northeasternmost edge of shoreline retreat, beyond which the Nanushuk Group is predominantly marine. In general, the lower coal percentages indicate depositional environments which were only marginally favorable to coal accumulation. However, locally favorable conditions did occur, as demonstrated by the high coal percentage in the marginal-marine rocks of the Topagoruk test well.

West of the paleoshoreline in the northwestern part of NPR-A, the depositional setting of the bulk of the Nanushuk section probably consisted of a lower to middle alluvial plain consisting of a complex of shifting distributary channels, flood plains, and swamps. The vertical distribution of coal in the Nanushuk sequence indicates this setting was apparently the most favorable for the formation of coal swamps; areally, the greater frequency of coal reported in the seismic drill holes, as well as the high coal percentages reported in the Meade, Kaolak and Kugrua test wells, also favor this interpretation. Thus, in this area the coal percentage reaches a maximum, and the contours are interpreted as trending slightly normal to the depositional strike, and parallel to the probable major paleodrainage systems.

Farther south and west in the foothills belt, nearer the sediment source where greater rates of subsidence and sedimentation occurred, conditions during deposition of most Nanushuk sediments were probably less favorable for coal swamp formation than the lower to middle alluvial plain but were more favorable than in the coastal plain and strandplain-lagoon setting. In middle to upper alluvial plain environments, coal swamps would be more subject to the deleterious effects of contamination by sediment-laden water and to more frequent fluctuations in the water table. Coal percentages calculated from three stratigraphic sections in the foothills are lower and seem to support this inference, although the lower percentage may be primarily a function of the difference between subsurface and surface sampling techniques used in the two areas and the selective effect of the greater removal of the upper coal-rich section by erosion within the foothills.

Coal Quality

The geographic division between bituminous and subbituminous coal shown in this report (pl. 2) is based primarily on recent analyses of coal cuttings from shallow holes drilled for seismic exploration. A northward shift in plotted position of the boundary considerably enlarges the bituminous-coal category from Barnes' 1967 calculations. Barnes had to depend on weathered surface samples, which generally yield lower heating values than unweathered samples. Also, Barnes attributed the increase in rank in the foothills coals primarily to greater deformation. This is probably true to some extent; however, it is likely that higher temperatures, due to greater depth of burial and greater age, were significant in increasing the rank. The rocks exposed in the foothills are older, and the original thickness of rock was probably greater than for the rocks exposed farther north in the coastal plain.

No attempt was made to determine the vertical distribution of coal beds by rank; however, this may be possible after petrographic rank determinations of organic matter from oil and gas test drilling that is planned for several localities in NPR-A. A vertical change in rank could account for the anomalously lower subbituminous heating values of some samples occurring in the bituminous area if they were actually collected stratigraphically higher than most of the bituminous-heating-value samples. A plot of the vertical (stratigraphic) distribution of coal rank, which will be possible after more data are collected, may prove to be more useful than the tentative bituminous-subbituminous geographic boundary shown in this report.

Table 1 contains some of the analyses of coal cuttings from seismic shotholes used in determining the bituminous-subbituminous boundary of this report. The shothole samples were collected under less than ideal conditions. Faulty sampling techniques ordinarily have a deleterious effect on analytical results; therefore, the quality of the coal is probably at least as good as the analyses indicate.

Analyses with ash contents greater than 30 percent are not shown in Table 1. However, for these high-ash samples, coal rank (moist, ash-free basis) was calculated to provide additional data points for the bituminous-subbituminous boundary determination shown in Plate 2. All of the analyses indicate the coal is low in sulfur, with as-received samples

TABLE 1.--Analyses of coal cuttings from shallow seismic drill holes in NPR-A

[Analyses by U.S. Department of Energy; samples collected by U.S. Bureau of Mines]

Sample Location	Laboratory Number	Rank	Calculated Moist Mineral-Free Heating Value (Btu)	Condition of sample[1]	Moisture (%)	Volatile Matter (%)	Fixed Carbon (%)	Ash (%)	Sulfur (%)	Heating Value (Btu)
T. 2 S., R. 30 W.	K78882	Subbituminous (?)	11,125	1	7.6	35.5	45.7	11.2	0.2	9,767
				2	--	38.4	49.5	12.1	0.2	10,568
				3	--	43.7	56.3	--	0.2	12,026
T. 3 S., R. 13 W.	K78889	Subbituminous	10,425	1	10.0	29.3	40.2	20.5	0.2	8,106
				2	--	32.6	44.6	22.8	0.2	9,010
				3	--	42.2	57.8	--	0.3	11,669
T. 3 S., R. 17 W.	K78890	Bituminous	13,155	1	4.2	29.9	52.4	13.5	0.2	11,221
				2	--	31.2	54.7	14.1	0.2	11,711
				3	--	36.4	63.6	--	0.2	13,626
T. 3 S., R. 17 W.	K78891	Bituminous	13,776	1	5.2	31.1	43.5	20.2	0.1	9,995
				2	--	32.8	45.9	21.3	0.2	10,548
				3	--	41.7	58.3	--	0.2	13,402
T. 4 S., R. 12 W.	K78776	Bituminous	13,506	1	3.1	34.8	48.7	13.4	0.3	11,526
				2	--	35.9	50.3	13.8	0.3	11,894
				3	--	41.6	58.4	--	0.4	13,802
T. 4 S., R. 39 W.	K81746	Bituminous	12,396	1	6.9	23.5	44.6	25.0	0.6	9,040
				2	--	25.2	48.0	26.8	0.7	9,714
				3	--	34.5	65.5	--	0.9	13,280
T. 4 S., R. 39 W.	K81748	Bituminous	14,882	1	2.1	33.0	47.7	17.2	0.7	12,095
				2	--	33.7	48.8	17.5	0.7	12,359
				3	--	40.9	59.1	--	0.8	14,985
T. 4 S., R. 40 W.	K81753	Bituminous	14,701	1	0.8	28.4	42.2	28.6	0.2	10,154
				2	--	28.6	42.6	28.8	0.2	10,237
				3	--	40.2	59.8	--	0.3	14,379
T. 4 S., R. 40 W.	K81754	Bituminous	14,871	1	1.3	36.6	49.4	12.7	0.3	12,822
				2	--	37.1	50.0	12.9	0.3	12,989
				3	--	42.6	57.4	--	0.4	14,904

TABLE 1.--Analyses of coal cuttings from shallow seismic drill holes in NPR-A (continued)

Sample Location	Laboratory Number	Rank	Calculated Moist Mineral-Free Heating Value (Btu)	Condition of sample[1]	Moisture (%)	Volatile Matter (%)	Fixed Carbon (%)	Ash (%)	Sulfur (%)	Heating Value (Btu)
T. 5 S., R. 16 W.	K78864	Subbitiminous	10,440	1	6.1	34.6	38.3	21.0	0.3	8,056
				2	--	36.8	40.8	22.4	0.4	8,575
				3	--	47.5	52.5	--	0.5	11,047
T. 5 S., R. 17 W.	K78863	Subbituminous	8,609	1	15.4	29.5	31.5	23.6	0.3	6,404
				2	--	34.9	37.3	27.8	0.4	7,566
				3	--	48.4	51.6	--	0.5	10,486
T. 5 S., R 41 W.	K81757	Bituminous	12,525	1	5.1	32.0	50.9	12.0	0.4	10,894
				2	--	33.7	53.7	12.6	0.4	11,477
				3	--	38.6	61.4	--	0.4	13,137
T. 2 N., R. 34 W.	K78885	Bituminous	14,468	1	1.8	31.8	45.5	20.9	0.2	11,184
				2	--	32.4	46.3	21.3	0.2	11,387
				3	--	41.1	58.9	--	0.3	14,470
T. 2 N., R. 34 W.	K78886	Bituminous	14,495	1	2.0	35.2	58.6	4.2	0.2	13,818
				2	--	35.9	59.8	4.3	0.2	14,097
				3	--	37.6	62.4	--	0.2	14,730
T. 2 N., R. 39 W.	K78884	Bituminous	13,913	1	3.0	34.6	50.1	12.3	0.5	12,020
				2	--	35.7	51.6	12.7	0.5	12,394
				3	--	40.9	59.1	--	0.6	14,198
T. 4 N., R. 28 W.	K78881	Bituminous	11,939	1	10.1	28.8	50.5	10.6	0.2	10,558
				2	--	32.1	56.1	11.8	0.2	11,740
				3	--	36.4	63.6	--	0.2	13,315
T. 6 N., R. 21 W.	K78867	Bituminous	12,181	1	6.4	29.9	44.6	19.1	0.2	9,654
				2	--	32.0	47.6	20.4	0.3	10,315
				3	--	40.1	59.9	--	0.3	12,955

TABLE 1.--Analyses of coal cuttings from shallow seismic drill holes in NPR-A (continued)

Sample Location	Laboratory Number	Rank	Calculated Moist Mineral-Free Heating Value (Btu)	Condition of sample[1]	Moisture (%)	Volatile Matter (%)	Fixed Carbon (%)	Ash (%)	Sulfur (%)	Heating Value (Btu)
T. 8 N., R. 16 W.	K78869	Subbituminous	10,140	1	18.5	27.8	44.6	9.1	0.4	9,123
				2	--	34.2	54.6	11.2	0.4	11,195
				3	--	38.5	61.5	--	0.5	12,606
T. 8 N., R. 16 W.	K78775	Subbituminous	9,614	1	19.1	24.9	32.4	23.6	0.2	7,154
				2	--	30.8	40.0	29.2	0.2	8,848
				3	--	43.5	56.5	--	0.3	12,498
T. 10 N., R. 28 W.	K70231	Subbituminous	10,217	1	16.7	28.7	44.1	10.5	0.3	9,043
				2	--	34.5	52.9	12.6	0.3	10,862
				3	--	39.5	60.5	--	0.4	12,432
T. 10 N., R. 28 W.	K70232	Subbituminous	10,202	1	18.3	28.2	43.7	9.8	0.3	9,107
				2	--	34.5	53.5	12.0	0.4	11,148
				3	--	39.2	60.8	--	0.5	12,664
T. 10 N., R. 30 W.	K70241	Subbituminous	9,752	1	17.1	21.0	35.0	26.9	0.2	6,909
				2	--	25.3	42.2	32.5	0.3	8,333
				3	--	37.5	62.5	--	0.4	12,338
T. 11 N., R. 28 W.	K70233	Subbituminous	9,745	1	20.7	31.2	40.7	7.4	0.4	8,947
				2	--	39.3	51.4	9.3	---	11,276
				3	--	43.4	56.6	--	0.5	12,438
T. 11 N., R. 28 W.	K70235	Subbituminous	9,749	1	20.5	26.7	40.7	12.1	0.3	8,461
				2	--	33.5	51.2	15.3	0.3	10,642
				3	--	39.6	60.4	--	0.4	12,560
T. 11 N., R. 30 W.	K70238	Subbituminous	10,380	1	17.9	29.9	45.4	6.8	0.3	9,607
				2	--	36.4	55.3	8.3	0.3	11,708
				3	--	39.7	60.3	--	0.3	12,762
T. 11 N., R. 30 W.	K70239	Subbituminous	9,910	1	20.9	30.0	42.8	6.3	0.2	9,226
				2	--	37.9	54.2	7.9	0.3	11,661
				3	--	41.2	58.8	--	0.3	12,668

TABLE 1.--Analyses of coal cuttings from shallow seismic drill holes in NPR-A (continued)

Sample Location	Laboratory Number	Rank	Calculated Moist Mineral-Free Heating Value (Btu)	Condition of sample[1]	Moisture (%)	Volatile Matter (%)	Fixed Carbon (%)	Ash (%)	Sulfur (%)	Heating Value (Btu)
T. 11 N., R. 32 W.	K78753	Subbituminous	11,330	1	6.9	28.5	40.5	24.1	0.1	8,375
				2	--	30.6	43.5	25.9	0.1	9,000
				3	--	41.3	58.7	--	0.1	12,146
T. 12 N., R. 30 W.	K70236	Lignite	7,108	1	30.9	27.5	28.3	13.3	0.7	6,072
				2	--	39.8	41.0	19.2	1.0	8,786
				3	--	49.2	50.8	--	1.3	10,879
T. 12 N., R. 30 W.	K70237	Subbituminous	10,168	1	16.5	25.2	35.6	22.7	0.2	7,665
				2	--	30.2	42.6	27.2	0.3	9,183
				3	--	41.5	58.5	--	0.4	12,609
T. 13 N., R. 32 W.	K78761	Subbituminous	8,946	1	19.1	32.8	44.3	3.8	0.3	8,567
				2	--	40.5	54.8	4.7	0.4	10,589
				3	--	42.5	57.5	--	0.4	11,113
T. 13 N., R. 32 W.	K78762	Subbituminous	10,003	1	17.0	25.2	40.2	17.6	0.3	8,087
				2	--	30.4	48.3	21.3	0.3	9,744
				3	--	38.6	61.4	--	0.4	12,375
T. 13 N., R. 33 W.	K78756	Subbituminous	10,104	1	17.2	29.1	41.1	12.6	0.4	8,709
				2	--	35.1	49.7	15.2	0.5	10,520
				3	--	41.4	58.6	--	0.6	12,408

[1] 1 - As-received
2 - Moisture free
3 - Moisture and ash free

showing values of less than 1.0 percent sulfur and the majority of the samples showing less than 0.5 percent sulfur.

The bituminous coals in Table 1 are all high volatile, ranging from A to C, and the coals below this rank range from subbituminous A through C. In one case, an analysis yielded a lignite A rank.

Coal studies by the U.S. Bureau of Mines (Warfield and Boley, 1969) and the U.S. Geological Survey (Callahan and Sloan, 1978) of the area between the western boundary of NPR-A and Cape Beaufort indicate that the Nanushuk Group contains coking coals comparable in quality to coking coals of the western United States. Additional study of bituminous coals in NPR-A will probably disclose coals of metallurgical quality.

Coal Classification System

The coal resource classification system officially adopted by the U.S. Bureau of Mines and the U.S. Geological Survey is a function of (1) the degree of economic feasibility and (2) the degree of geologic assurance. Figure 5 shows the basic features of this system. All the coal in NPR-A is now classified as subeconomic, and most, if not all, falls under the submarginal heading defined as resources which would require a price more than 1.5 times the current market conditions in order to be economic.

In terms of geologic assurance, the coal in NPR-A falls into both the identified and undiscovered categories. Identified resources are defined by this sytem as resources "whose location, quality, and quantity are known from geologic evidence supported by engineering measurements." Undiscovered resources in NPR-A fall under the hypothetical subcategory: "resources that may reasonably be expected to exist in a known mining district under known geologic conditions." Although this area is not formally regarded as a mining district, small-scale coal mining operations have been conducted in the past in the coastal areas of northern Alaska, some by Eskimos and some for the purpose of supplying coal to whaling ships. The regional geologic aspects of the Nanushuk Group are fairly well known.

Identified Coal Resources

Barnes (1967) estimated identified resources to be about 13 billion tons of bituminous coal and 110 billion tons of subbituminous coal; however, he used less restrictive criteria for identified resources than allowed by the system subsequently adopted by the U.S. Bureau of Mines and the U.S. Geological Survey (1976). The identified resources tabulated in Table 1 reflect a readjustment of the resource figures of Barnes to comply with the officially adopted standards plus some additional data collected by the U.S. Bureau of Mines and U.S. Geological Survey in the Kokolik River-Elusive Creek area in the western part of NPR-A. For bituminous coal, the identified resources also include tonnages calculated from seismic shotholes, where any coal beds greater than, or equal to, 0.6 m (2 feet) in thickness were reported on the drillers' logs, although the specific thicknesses were not noted. Therefore, these resources were

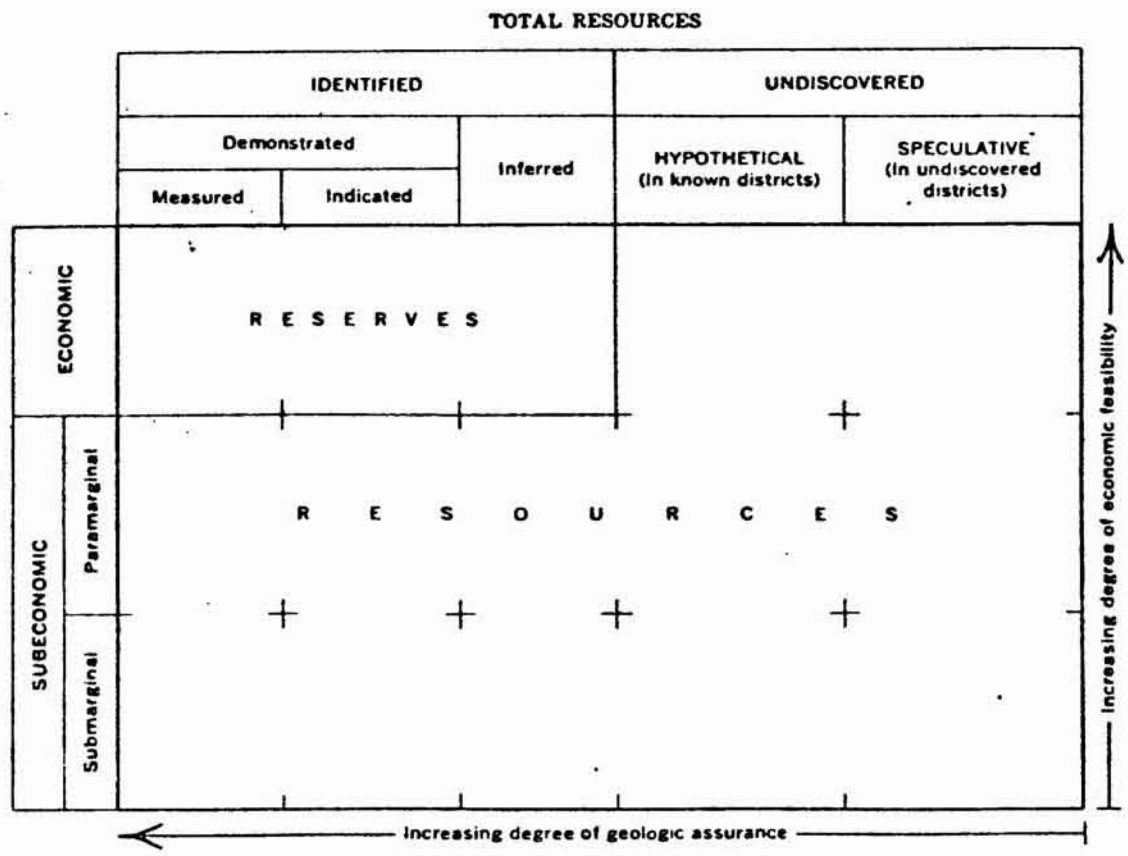

FIGURE 5.--Classification of mineral resources. (After U.S. Bureau of Mines and U.S. Geological Survey, 1976a, fig. 1.)

calculated on the basis of a 0.6-m (2-foot) thickness and represent a minimum figure. Identified coal localities are shown in Plate 2.

Due to the large extent and volume of coal-bearing rocks in NPR-A, the amount of coal resources is probably quite large. However, the subeconomic character of the resource, combined with the remoteness, harsh climate, scarcity of exposures, and subsequent high cost of exploratory field work, has resulted in a very sparse sampling of coal in the region. Consequently, the present identified resources figures probably do not realistically indicate the potential resource base of NPR-A.

Undiscovered Coal Resources

A realistic estimation of potential coal resources in NPR-A must employ some method of estimating the undiscovered resources. Exploratory petroleum test wells and a few stratigraphic sections that are constructed from exposures and logs of shallow seismic shotholes in the foothills represent the only relatively complete, detailed stratigraphic records of the Nanushuk Group in the reserve. Estimates of undiscovered resources must, therefore, be based on these data.

For this report, the undiscovered hypothetical resources were estimated from the map (pl. 1) that shows the geometry and areal distribution of coal in the Nanushuk Group. Individual areas bounded by isopach and coal percentage contours were measured by planimeter, and the area was multiplied by the average thickness and coal percentage to yield coal volume. Resource figures were then derived by multiplying coal volume by conversion factors of 0.147 tonnes/km^2-m (1.13 million tons per square mile-foot) for subbituminous coal and 0.149 tonnes/km^2-m (1.15 million tons per square mile-foot) for bituminous coal. The resulting figures are shown in Table 2.

The relative vertical distribution of coal resources within the Nanushuk Group, as shown in the depth column, was estimated by calculating the relative center of gravity and standard deviation of the coal in each test well using the methods of Krumbein and Libbey (1957). The center of gravity reflects the relative weighted mean vertical position of coal in the section in terms of the distance above the base of the Nanushuk Group, and the standard deviation indicates the relative vertical spread of the coal about the center of gravity expressed in terms of a percentage of the total thickness of the Nanushuk. The mean relative center of gravity and standard deviation of 75 and 15 percent, respectively, indicate that coal in the Nanushuk Group occurs primarily in the stratigraphic interval centered about three-fourths of the way above the base and spreads over 15 percent of the total section.

The relative distribution of the hypothetical coal resources by individual bed thickness categories, as shown in Table 2, was estimated by calculating the percentage of the total resource in each bed thickness category from the identified resources in Table 1 and applying this to the hypothetical resources. Data on discrete bed thicknesses from Table 1 represent the largest sample available and should provide the most reliable estimate.

TABLE 2.--Estimates of Coal Resources in NPR-A

IDENTIFIED SUBECONOMIC RESOURCES
(in millions of tons)[1]

Depth (ft)[2]	Bituminous: Bed Thickness (in inches)[3] 14-28	28-42	>42	≥24[4]	Totals	Subbituminous: Bed Thickness (in feet)[2] 2.5-5	5-10	>10	Totals
0-1000	1,019	1,259	3,280	4,613	10,171	4,995	7,420	2,055	14,470
1000-2000	343	868	7,934	---	9,145	1,434	4,096	1,248	6,778
2000-3000	748	308	4,555	---	5,611	96	29	15	140
3000-4000	455	292	1,300	---	2,047	---	---	---	---
4000-5000	65	97	910	---	1,072	---	---	---	---
5000-6000	---	65	---	---	65	---	---	---	---
Totals	2,630	2,889	17,979	4,613	28,111	6,525	11,545	3,318	21,388

UNDISCOVERED HYPOTHETICAL RESOURCES
(in billions of tons)[1]

Depth (ft)[2]	Bituminous: Bed Thickness (in inches)[3] 14-28	28-42	>42	Totals (rounded)	Subbituminous: Bed Thickness (in feet)[2] 2.5-5	5-10	>10	Totals (rounded)
0-1000	39.2	42.7	274	356	241	434	128	803
1000-2000	148	162	1,040	1,350	143	258	76.3	477
2000-3000	10.3	11.3	72.3	93.9	23.1	41.5	12.3	76.9
3000-4000	6.2	6.8	43.4	56.4	9.5	17.1	5.0	31.6
4000-5000	2.0	2.2	14.3	18.5	1.6	2.9	.8	5.4
5000-6000	1.1	1.2	8.0	10.3	---	---	---	---
Totals (rounded)	207	226	1,450	1,880	418	754	222	1,390

[1] tonne = (tons) x (0.9718)
[2] meters = (feet) x (0.3048)
[3] centimeters = (inches) x (2.54)
[4] Calculated using exactly 24 inches

In the bituminous coal category, about 77 percent of the resources are estimated to occur in beds more than 107 cm (42 inches) thick, and 12 percent and 11 percent are estimated to occur in beds 71-107 cm (28 to 42 inches) and 36-71 cm (14 to 28 inches) thick, respectively. In the subbituminous category, about 54 percent of the resources are inferred to occur in 1.5 to 3.05 m (5 to 10 feet) thick beds, 30 percent in 0.8 to 1.5 m (2.5 to 5 feet) thick beds, and 16 percent in beds over 3.05 m (10 feet) thick. Maximum reported coal bed thickness in NPR-A is about 9.1 m (30 feet).

Hypothetical resources (table 2) are about 1.9 trillion tons of bituminous coal and about 1.4 trillion tons of subbituminous coal, for a total of 3.3 trillion tons. Of this total, more than 95 percent occurs at depths of less than 914 m (3000 feet) and 35 percent, or about 1.2 trillion tons, occur at depths of 305 m (1000 feet) or less. Assuming a 50-percent recoverability factor for coal of minimum thickness within 305 m (1000 feet) of the surface, recoverable resources are about 600 billion tons.

Significance of Hypothetical Resource Estimates

Estimates of undiscovered coal resources suggest a potentially large resource base in the range of trillions of tons. Hypothetical coal resource estimates by others in northern Alaska also range upward to a trillion tons or more. Tailleur and Brosgé (1976) reported hypothetical resources in northern Alaska to be in the range of 115 billion to 3.7 trillion tons. Wanek and Callahan (unpublished data, 1971) calculated resources of 970 billion tons in NPR-A.

All of these resource estimates, as well as those of this report, are based primarily on well records of petroleum test holes. Unfortunately, the coal identifications in the well records, as shown in the published reports, are based primarily on interpretations of the drill cuttings of the rocks penetrated, and in some instances the geophysical log does not show the response characteristic of coal. Some coal identifications in the well records are therefore suspect.

Interpretations of coal bed thicknesses from drill cuttings are prone to be exaggerated because coal tends to wash or cave more readily than other lithologies in the borehole. When a coal bed is penetrated in a borehole, its presence is indicated by coal appearing in the drill cuttings. As the drill bit continues through a coal bed and penetrates underlying lithologies, the coal may continue to appear in the cuttings and mask other lithologies because the coal continues to cave from the side of the hole. The result is a false impression of the lower boundary of the coal bed. This situation is often aggravated by rapid drilling rates and the consequent large sampling intervals in the shallow portion of holes where the coal-bearing strata occur. Consequently, these hypothetical coal resource estimations may be too high.

Furthermore, calculation of more than 75 percent of the resources was based on results from only two test wells: the Meade No. 1 and Kaolak No. 1. Judged mainly from the response of the geophysical logs of these two wells, coal thickness may be exaggerated from five to eight times. Tailleur and Brosgé (1976) suggested that the exaggeration may be as much as twenty to seventy times based on amounts calculated from outcrop data.

But, in our opinion, direct comparisons with outcrops may be invalid for two reasons. First, most of the outcrops occur in the foothills where depositional environments may have been less favorable for coal accumulation than in the rocks underlying the coastal plain. Second, coal percentage calculations based on stratigraphic sections constructed from outcrop data contain a considerable percentage of unsampled section where the rocks are covered by vegetation, soil and other surficial material, and automatically considering these to be barren of coal and including them in the stratigraphic section may produce a negative bias. If, as in this report, these covered parts of the section are excluded from the stratigraphic sections, relative coal percentages calculated from outcrop data are only from five to ten times less than percentages reported in the Meade and Kaolak wells, a range compatible with that previously indicated from the interpretation of the geophysical logs. Thus, coal resource estimates in Table 2, if reduced by a factor of ten, should represent the minimum resource figure consistent with the present data.

CONCLUSIONS

The identified coal resources of NPR-A are about 49.5 billion tons, and, are probably too small to give a realistic indication of the potential resources of an area so large. Estimates of undiscovered coal resources based on current data indicate hypothetical resources of between about 330 billion and 3.3 trillion tons, of which about 18 percent or 60 to 600 billion tons are inferred to be recoverable.

The wide range of estimates of potential undiscovered coal resources reflects the scarcity and ambiguity of the available data. A reasonably accurate and realistic appraisal of the coal resources in NPR-A cannot be made without obtaining additional reliable subsurface data, primarily from drilling and coring.

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