UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Engineering-geologic maps of northern Alaska, Wainwright quadrangle

John R. Williams[1]

Open-File Report 83-457

1. U.S. Geological Survey, Menlo Park, CA 94025

1983

Table of Contents

Illustrations

Tables

Engineering-geologic maps of northern Alaska,
Wainwright quadrangle

by

John R. Williams

Introduction

The Wainwright quadrangle occupies an onshore area of about 7,400 km^2 between latitude 70° and 71° North and longitude 159° and 163° West, southwest of Point Barrow in northern Alaska. It lies largely within the Arctic Coastal Plain Province which is a flat, lake-dotted, tundra-covered lowland bounded on the south by the slightly higher and more rolling topography that merges with the northern section of the Arctic Foothills Province (Wahrhaftig, 1965). The coastal plain is broken by sea cliffs along the Chukchi Sea coast, by escarpments inland that mark the position of former shore lines, by thaw-lake basins, and by river bluffs. Most of the area is drained by tributaries to Kuk River, a broad estuary discharging to the sea via Wainwright Inlet, by Kugrua, Avak, and Utukok Rivers and by shorter streams emptying into the Chukchi Sea or one of its lagoons, bays, and inlets. All of the quadrangle eastward of the meridian passing through Icy Cape lies within National Petroleum Reserve--Alaska. The major settlement is the village of Wainwright. Airstrips are located at Wainwright and a nearby Government installation, an abandoned Government installation at Icy Cape, and at the site of Tunalik Test Well No. 1 near Ongorakvik Creek. This well and Peard Test Well No. 1 near Kugrua Bay at the eastern edge of the quadrangle have yielded shows of gas. Coal for local use is available at three prospects on the east shore of Kuk River near Wainwright and two on Kugrua River.

The purpose of this report is to describe and map bedrock outcrops and surficial deposits of eolian, alluvial, and marine origin to provide a useful basis for environmentally sound land management. From this information an overview can be obtained of the potential construction materials and foundation problems. In addition, the report includes data on the paleontology of the marine deposits, location and description of ice-rafted erratic boulders, and radiocarbon dates of organic material in the surficial deposits.

This report has been prepared with partial support of Minerals Management Service, Department of the Interior. It is based largely on interpretation of aerial photographs flown in 1955 and on fieldwork undertaken by the Geological Survey for the Bureau of Land Management land-use study mandated by Chapter 105-C, Public Law 94-258 between August 1 and 14, 1977, and between July 24 and August 9, 1978. During these periods, about nine days of helicopter-supported fieldwork were used to visit about 110 sites in the Wainwright quadrangle. Fieldwork was concentrated in the inland part of the quadrangle to supplement the results of coastal studies furnished by D. M. Hopkins, R. E. Nelson, and J. K. Brigham of the Geological Survey (unpublished field notes 1976, 1977, 1981). L. D. Carter of the Geological Survey joined the writer for one day in 1978, and L. A. Morrissey accompanied the writer in 1978 to obtain ground-truth information for application of Landsat imagery to vegetation cover maps being prepared by the Geological Survey (Morrissey, 1979; Morrissey and Ennis, 1981). Naval Arctic Research Laboratory at Barrow

provided meals, quarters, and logistic support on a cost-reimbursible basis in 1977 and 1978. The report has benefited from discussions with D. M. Hopkins, L. D. Carter, J. K. Brigham, W. E. Yeend, and Reuben Kachadoorian of the U.S. Geological Survey.

Previous investigations

Although the coastline was first explored by Beechey (1831), Schrader (1904), and others passing to and from Point Barrow, the first comprehensive geologic and topographic studies of the quadrangle were made by the Geological Survey in 1923-1926 for the U.S. Navy, shortly after establishment of Naval Petroleum Reserve No. 4 in 1923. These studies, including establishment of topographic control and elevations, not only were along the coastline, but included traverses up the Kuk, Avalik, Kaolak, Utukok, and Kugrua Rivers (Paige and others, 1925; Smith and Mertie, 1930). A second and more detailed geologic investigation of the petroleum reserve, from 1944 to 1953, included studies of the bedrock in the Avalik, Ketik, Kuk and Kugrua River valleys (Webber, 1947; Stefansson and Mangus, 1949). After the Naval Petroleum Reserve was transferred to the Department of the Interior in 1976 and renamed National Petroleum Reserve--Alaska, additional geologic and geophysical studies were carried out in the search for oil and gas by the U.S. Geological Survey culminating in Peard Test Well No. 1 and Tunalik Test Well No. 1 in the Wainwright quadrangle (Bird, 1982). The bedrock geology has also been summarized in regional maps by Payne and others (1951), Lathram (1965), Beikman and Lathram (1976), and most recently by Mayfield and others (1978 and in press). Special studies have been made of the Cretaceous amber (Langenheim and others, 1960), flora (Dutcher and others, 1957; Smiley, 1966, 1969, 1979; Stanley, 1967), coal resources (Sanford and Pierce, 1946; Toenges and Jolley, 1947; Barnes, 1967; Martin and Callahan, 1978) and of the Nanushuk Group rocks (Ahlbrandt, 1979). Many of these reports on the bedrock of the quadrangle contain perceptive observations of the Quaternary deposits, for example those by Smith and Mertie (1930, p. 242) on the origin and distribution of ice-rafted erratic boulders.

Studies of the Quaternary deposits of northern Alaska have been largely based at the Naval Arctic Research Laboratory at Point Barrow and, although they have been concentrated in the Barrow region, many of the principles developed there are also applicable to the Wainwright quadrangle. Black (1974, 1976) studied the ice wedges in permafrost, the construction hazards posed by permafrost (1957), the eolian deposits (1951), and has summarized the Quaternary geology (1964). O'Sullivan (1961) developed the framework for Quaternary deposits of the Arctic Slope. Lachenbruch (1962) has investigated the origin of ice wedges and the thermal regime of permafrost, and Osterkamp and Payne (1981) have developed a regionalized picture of the permafrost thickness, based on subsurface data. Work by Sellmann and Brown (1973) on permafrost and coastal plain history, Hussey and Anderson (1963) and Hussey and Michelson (1966) on permafrost and relief forms, and by Black and Barksdale (1949), Livingstone and others (1958), Carson and Hussey (1962), and Sellmann and others (1975) on the oriented lakes is directly applicable to the Wainwright quadrangle. McCulloch (1967) traced and correlated marine shorelines northward from the Bering Strait region into the Wainwright quadrangle, using the general framework of reference summarized by Hopkins (1967). Results of work on the late Quaternary eolian and marine sequences east of the Meade River (Carter, 1981a, b; Carter and Robinson, 1978; Carter and Hopkins, 1982; Carter, 1983 in press) have been extended westward into the Meade River quadrangle by Williams (1983) and are applicable in the Wainwright quadrangle. Yeend (1978, 1983) has studied the Quaternary deposits of the Lookout Ridge quadrangle to the southeast and the Utukok River quadrangle to the south. Preliminary summary maps of the entire petroleum reserve by Williams and others (1977), and its coastal plain section (Williams and others, 1978), are part of the present investigation. Current and past work resulting from the Offshore Environmental Assessment project being done by the Geological Survey for Bureau of Land Management (unpublished field notes, D. M. Hopkins, 1976, 1977, 1980, 1981; R. E. Nelson, 1976; J. K. Brigham, 1981) have been used in compiling the map of the Wainwright quadrangle. Other studies that have provided information are those of Detterman (1978) and Johnson (1978) on the landforms, by Quaide (1955) on the fossil mammals, by Hume and Schalk (1967) and Hartz (1978) on the coastal erosion potential, by and Hopkins and others (1979), and Hopkins and Robinson (1979) on radiocarbon dating. Hydrology, including rivers, lakes, and snow cover, has been discussed by Sloan (1977), Sloan and Snyder (1979), Sloan and others (1978), and Childers and others (1979).

Bedrock

The Wainwright quadrangle is underlain by sedimentary rocks of the Nanushuk Group of Early to Late Cretaceous age (Langenheim and others, 1960; Smiley, 1966, 1969, 1979; Stanley, 1967; Ahlbrandt, 1979; Mayfield and others, in press). The rocks are best exposed along the Kuk River and its headwater streams and locally in sea cliffs. A south-north stratigraphic section along Kaolak and Kuk Rivers and Wainwright Inlet was measured by Smiley (1966) as follows:

Lithologic Unit	Thickness (m)	General lithologic character
7 (top of section, south)	85	Sandstone, sandy clay, coal; white bentonite and bentonitic clay; amber
6	168	Shale and hard sandstone in thick units; thin coal beds; white bentonite and bentonitic clay; rare amber
5	276	Clay shale and silty shale, with a few beds of hard sandstone; thin coal beds; bentonitic clay; rare amber
	205	Poor exposures; mixed sandstone, shale, coal based on correlation with Kaolak test well section.
4	134	Shale and hard sandstone in thick units; thin coal beds; like unit 6, but lacking bentonite and amber
3	234	Clay shale and silty shale, thin beds of sandstone; coal beds as thick as 2.75 m

2	40	Red to gray sandstone, with oscillation ripple marks, locally cross-bedded; local well-rounded white to gray chert pebbles up to 5 cm in diameter
1 (bottom of section, north)	205	Dark gray clay shale, some silty and some carbonaceous beds

The entire stratigraphic section dips about one degree southward and forms the north limb of an east-west trending syncline, the axis of which is near 70° N., the southern boundary of the quadrangle. Thus, the youngest beds are along the southern boundary of the quadrangle, and the oldest beds, the clay shale of unit 1, are in the north, bordering Wainwright Inlet. Study of the fossil plants by Smiley shows a change from warmer temperate gymnosperm-dominated forests in the older deposits to cooler angiosperm-dominated forests over a 30,000,000-year interval during Cretaceous time.

The distribution of bedrock is shown as a map unit on the geologic map (plate 1) and by a special symbol for bedrock that is exposed only in vertical banks along streams, lakes, and the ocean. The major lithologic types are shown on figure 1, as specifically noted by Paige and others (1925), Webber (1947), Stefansson and Mangus (1949), Langenheim and others (1960), and, in unpublished notes in the files of the Geological Survey at Menlo Park, California, by Hopkins (1976, 1981), Nelson (1976), Brigham (1981), and by the writer (1977, 1978). Rocks of the Nanushuk Group have been identified as the uppermost bedrock unit between 21 and 1,896 m below ground surface in Tunalik Test Well No. 1, between 16 and 744 m in Peard Test Well No. 1 (fig. 1), and between 29 and 1,582 m in Kaolak Test Well No. 1, about 13 km south of the quadrangle boundary at long. 160° 14' 50" W. (Bird, 1982). Seismic shot holes in which coal of the Nanushuk Group was identified by Martin and Callahan (1978) are located on figure 1. The coal, an important mineral resource, is discussed in a later section of this report.

Unconsolidated deposits

Unconsolidated deposits of marine, fluvial, and eolian origin, the upper part of which has been largely reworked in present and past thaw-lake basins, cover bedrock in the Wainwright quadrangle, except locally along river, lake, and ocean banks and in isolated hilltops where bedrock is exposed at the surface. The marine deposits have been subjected to the action of wind, as well as to thaw-lake activity, and they are covered in some areas by one or two meters of wind blown sand and have been deflated in others, leaving a thin layer of pebbles at the surface. In a few areas small dunes have been formed, particularly along some of the modern stream bars and on low terraces, but they are generally too small to be mapped at the scale of the map. Small landslides are common in river banks that are of bentonitic clay; the largest of these have been mapped, and others too small to be mapped are included in the bedrock map unit along the stream courses.

The unconsolidated deposits have been mapped as the Gubik Formation by Gryc and others (1951), who restricted the Formation to deposits of Pleistocene age, and by O'Sullivan (1961) and Black (1964), who broadened the definition of the Gubik Formation to include deposits of Holocene age. More recently, the Gubik Formation has been found to include or overlie late

Pliocene unconsolidated deposits at Ocean Point on the Colville River (Carter and others, 1977) and at Skull Cliff on the Chukchi Sea coast in the Meade River quadrangle (Brigham, 1981, 1982; Williams, 1979, 1983). Beds of Pliocene age comparable to those at Skull Cliff have not yet been positively identified in the Wainwright quadrangle. However, the marine sand that lies above the oldest wave-cut cliff (II, fig. 2) may be, in part, of Pliocene age, but no definitive data are available to support such an age assignment.

The unconsolidated deposits in this report are mapped (plate 1): as marine beach, bar, and spit deposits; marine sand; upland silt; eolian sand; alluvial deposits; landslide deposits; and thaw-lake deposits. They are described in the tabular description of map units. Their age and correlation are described in the text and summarized in the correlation of map units. Collections of marine fossils that were made during this study are located on figure 2, and a list of the marine fauna identified by L. N. Marincovich, Jr., of the U.S. Geologial Survey is given in table 1. C. A. Repenning of the U.S. Geological Survey identified a small collection of fossil bones discussed in the text. The marine deposits locally include basal gravel and clay. Erratic, ice-rafted boulders from these deposits are described in table 2 and located on figure 2. Radiocarbon dates for samples collected as part of this study and for those collected by others (Hopkins and Robinson, 1979; Hopkins and others, 1979) are listed in table 3 and located on figure 2.

Marine beach, bar, spit, and barrier island deposits

Fine gravel, gravelly sand, and sand form low-lying offshore bars, barrier islands, and spits, notably on the seaward side of Peard Bay and Kasegaluk Lagoon. Small spits and narrow beaches of sand and fine gravel border the cliffed shorelines on the landward side of Kasegaluk Lagoon, Peard Bay, and Kugrua Bay, as well as Wainwright Inlet and the Kuk River estuary. In many locations where the shores are backed by bedrock exposures, the beaches are largely of angular bedrock shingle. All of these beaches, bars, spits, and barrier islands are of Holocene age and are constantly being reworked by waves and currents, particularly those of violent storms that are commonly accompanied by storm surges as much as 3 m above normal sea level.

Older, elevated deposits of former beaches, offshore bars, and barrier islands (b_I, fig. 2) are 5.5 to 15 m above present sea level seaward of the youngest prominent wave-cut escarpment (I, fig. 2) which has been considered of Pelukian age, equivalent to the Sangamon interglacial (Hopkins, 1967; McCulloch, 1967). These deposits parallel the modern coastline from north of Wainwright to Atanik, enclosing Kugrua Bay. They follow the landward side of Kasegaluk Lagoon from near Pingoraruk Hill southwestward and westward to Icy Cape and from there southwestward toward the mouth of Utukok River.

A re-entrant in the shoreline of Pelukian age, at the former mouth of the Kugrua River estuary, is the site of an exposure of marine gravel, possibly a beach, or some form of spit or baymouth bar. The top of stratified sand and gravel containing marine shells and driftwood is 5.5 m above sea level; its base, resting on black clay (Cretaceous?) is 2.4 m above sea level. Fossils (M-7165, table 1, fig. 2) include Macoma balthica which inhabits marine waters of low salinity, such as those at the mouths of streams. The driftwood is more than 40,000 years old (I-10,272) (B, table 3, fig. 2).

Still older offshore bars and beach deposits, 20 to 30 m above sea level, are landward of and above wave-cut escarpment I (fig. 2) and appear to be related to the older wave-cut cliff (II, fig. 2) that has been correlated by McCulloch (1967) with a pre-Illinoian stand of the sea and is probably that of the Kotzebuan transgression of Hopkins (1967). The most prominent of these deposits are the offshore bars extending from Pingoraruk Hill northeastward to the west shore of Wainwright Inlet and Kuk River. Southwest of Pingoraruk Hill, marine beach or offshore bar gravel (b_{II}, fig. 2) as high as 30 m above sea level lies above and landward of the complex of wave-cut cliffs and terraces of Pelukian age (I, fig. 2). The deposits and form of these older marine beach and offshore bar deposits are difficult to recognize because of subsequent deposition by wind and modification by stream erosion and the thaw-lake process. For example, only one isolated knoll of beach gravel could be located along the base of the inland wave-cut cliff (II, fig. 1) marking the Kotzebuan shoreline; the beach deposit, about 30 m above sea level is located east of Irak Creek, 3.2 km south of its confluence with Mikigealiak River. Fossils collected from a former offshore bar now about 23 to 27 m above sea level, 7 km southwest of Kilimantavi (M-7308, table 1, fig. 2), included both *Neptunea* (*Neptunea*) *heros heros* (Gray) and *Neptunea* (*Neptunea*) *lyrata leffingwelli* (Dall), as well as *Natica* (*Tectonatica*) *janthostoma* Deshayes. The range of *N.* (*N.*) *lyrata leffingwelli* (Dall) is given as Beringian (Pliocene) to Kotzebuan, and *N.* (*N.*) *heros heros* Gray ranges from Kotzebuan to Holocene, suggesting that the deposits containing both forms may be of Kotzebuan age. *Natica* (*Tectonatica*) *janthostoma* Deshayes is now restricted to shallow seas in the northwestern Pacific Ocean from Hokkaido, Japan, to Kamchatka (L. N. Marincovich, Jr., written communication, 11/7/78).

Marine sand

Marine sand is a general term applied to the sand and silty sand containing scattered pebbles of quartz and chert that form the surficial deposits of much of the Wainwright quadrangle. The sand is underlain, in some places, by marine gravel which lies on clay that is either marine mud or weathered bedrock, although exposures in the Wainwright quadrangle demonstrate this sequence much less commonly than in the Meade River quadrangle. The basal marine sand, the underlying gravel, and the clay are the apparent source of ice-rafted erratic boulders (table 2, fig. 2) and generally lie on bedrock. Fossil marine shells, only locally present in the marine sand, are more common in the underlying gravel and in the marine beach, offshore bar, and spit deposits. As mapped, the marine sand may include terrace deposits bordering some streams because of the difficulty in identifying on aerial photographs terrace surfaces that have been extensively altered by the thaw-lake cycle, the small scale of the map, and the general lack of good exposures. The marine sand is locally covered by fine- to medium-grained pebble-free sand of possible eolian origin, but these deposits have too patchy a distribution and insufficient thickness to be mapped. In some exposures pebbles from the marine sand have been concentrated at the surface beneath the turf, as though by wind deflation.

Relation of marine sand unit to escarpments: The marine sand unit is divided by or is bounded by escarpments (I, II, fig. 2) and indicates a record of at least three marine transgressions. Numerous papers correlating these transgressioins with the world-wide chronology have been published over the years (O'Sullivan, 1961; Black, 1964; McCulloch, 1967; Hopkins, 1967, 1973;

Lewellen, 1972; Sellmann and Brown, 1973; Williams, 1983; and others). In the present study the sea level indicated by some of these escarpments and related marine raised beaches and offshore bars can only be approximated from topographic maps having a half-contour interval of 25 or 50 feet (8 or 15 m), and, with no exposures available to determine accurately the level of the sea forming these escarpments, only approximate levels can be given. Both of the escarpments are of marine origin and seem to mark the onshore limit of separate marine transgressions.

The marine sand unit can be divided into (1) deposits lower than 20 m above sea level that lie above the modern beaches seaward of the former sea cliff (I, fig. 2) already referred to as probably equivalent to the Pelukian shoreline of the Bering Sea region (McCulloch, 1967; Hopkins, 1967), (2) an area of Kotzebuan(?) marine sand on higher ground between the two wave-cut cliffs (I and II, fig. 2) the oldest and highest of which is probably pre-Illinoian or Kotzebuan in age (McCulloch, 1967; Hopkins, 1967), and (3) deposits of pre-Kotzebuan age, apparently of marine origin, that lie above and inland from the oldest (Kotzebuan?) shoreline and that merge gradually with the upland silt.

The marine deposits seaward of the inner Pelukian shoreline, the wave-cut cliff (I, fig. 2), consist of pebbly sand with beds of gravel in some areas. They generally lie below 20 m above sea level and are concentrated inshore of Icy Cape and around Kugrua Bay in an area protected by the offshore bars extending from north of Wainwright to Atanik. The Kugrua Bay deposits may include an important constituent of lagoonal fine sand and silt. Radiocarbon dates ranging from 6,234 to 9,535 years have been obtained from thaw lake sediments developed on the marine sand surface in the vicinity of Nokotlek Point (Hopkins and Robinson, 1979) and 8,295 years from ice-wedge deformed thaw-lake deposits above the marine deposits west of Kugrua Bay (table 3, fig. 2). A beach facies of these marine deposits, described previously, contains driftwood that is older than 40,000 years (B, table 3, fig. 2). The bulk of the marine sand lies between the inner Pelukian shoreline and systems of offshore bars and barrier islands (B_I, fig. 2) that are 10 to 15 m above sea level.

Pebbly sand, interpreted as of marine near-shore origin, also forms the surficial deposits between the shorelines of Pelukian and pre-Illinoian or Kotzebuan age (I and II, fig. 2). Similar deposits are found landward of the shoreline of pre-Illinoian or Kotzebuan age. Very few exposures in these deposits are available for study, and, in those visited, no marine shells were noted. However, erratic boulders, apparently from these deposits, are found along the shores of Kuk River (Smith and Mertie, 1930, p. 242), and in one place, above the Kotzebuan shore line in the adjacent Meade River quadrangle (Williams, 1983).

Upland silt

The upland silt of the Wainwright quadrangle lies at the western end of a belt that can be traced eastward through the Meade River, Lookout Ridge, and Ikpukpuk River quadrangles and on to the Colville River along a zone that is transitional between the Arctic Coastal Plain and the Arctic Foothills provinces (Williams and others, 1977). Within the Wainwright quadrangle the upland silt forms a cover that ranges from a few cm to as much as 13 m thick over bedrock on interfluves and over fluvial deposits in the valleys of Ivisaruk, Kaolak, and Ketik Rivers. In the one or two exposures examined along Avak and Avalik Rivers the silt apparently lies on pebbly sand or on bedrock. It has been mapped as the Foothills Silt by O'Sullivan (1961) and as upland silt by Williams and others (1977). The northern boundary has been relocated by the writer's fieldwork in 1978 but is still indefinitely located, for the silt grades without perceptible topographic break into the marine deposits of the coastal plain.

The upland silt consists of silt, fine sand, and silty sand, that resembles loess in other parts of Alaska. It is faintly bedded in some exposures, but is more commonly massive and uniform. Locally, it contains small pebbles of chert. The silt is similar to and in the same general geomorphic setting as fluvial silty sand in the Titaluk River valley, to the east, where the lower part of these deposits is from about 25,000 to 43,000 years old (Nelson, 1982). The top of these fluvial deposits is about 12,000 years old, and they are apparently the product of a mid- to late-Wisconsinan stream aggradation caused by an increase in sediment load brought about by increasing aridity (Carter, 1981b, p. 6). O'Sullivan (1961, p. 127-136) and O'Sullivan and Hussey (1960) argued that, instead of an eolian origin, the silt and the underlying coarser deposits were laid down in a marine-fluvial environment. The writer believes that the upland silt in the Wainwright quadrangle is largely of eolian origin because it is widely distributed as a mantle over valley alluvium and bedrock of the interfluves; its age is probably Wisconsinan, although some silt may have been blown into the upland by east-northeast winds sweeping across the coastal plain in Holocene time.

Fluvial sand and fine gravel beneath the upland silt in exposures along Ketik, Kaolak, and Ivisaruk Rivers are of particular interest because of the large number of land mammal bones found in the river at these locations, compared to their absence or rarity in areas underlain by marine deposits. These bones are also found along Avak and Avalik Rivers within the upland silt belt, although the underlying fluvial deposits were not seen at the few exposures studied. In general, exposures are poor and are commonly covered by silt. Studies by Fladeland (*in* Quaide, 1955) identified bone fragments of *Aquila* (eagle) on Avalik River 6 km west of lat. 159° W.; *Equus* cf. *caballus* (horse) and *Canis* (wolf) from Avalik River at 159° W.; *Rangifer* (caribou), a few km south of 70° N. on Kaolak River, *Bovidae*, as float, locality not indicated. The *Bovidae* was later identified as *Saiga tatarica* (Saiga antelope) and was reported to be located in the Kuk River drainage (Kaolak River?) 2.5 km downstream from Omingmaktosak River, just south of 70° N., (Harington, 1981, p. 207). A similar *Saiga* found on a bar of Usuktuk River a few km south of 70° N. at 156° 33' W. was 37,000 ± 990 (GSC-3050) years old (Harington, 1980, 1981, p. 224-225). Quaide (1955, p. 12) believes that the source of the mammal fossils in the Wainwright quadrangle was the 6 m terrace and that the fauna implies a temperate to cold plains-dwelling type. Hopkins (unpublished field notes, 1981) found two horse skulls (*Equus lambei*) at the base of an exposure of upland silt on Avak River at long. 161° 33' W.; the source, although unknown, could be the upland silt. O'Sullivan (1961, p. 185-186) reported a mammoth skull, apparently in place, near the base of a 1.8 m-thick sand bed that lies beneath the upland silt and above 7.6 m of fine gravel, containing sand beds near the top in the bank of Kaolak River at lat. 69° 57' 30" N. The writer found a tusk embedded in fine sand beneath the gravel bed of Ivisaruk River 3 km downstream from lat. 70° N.; *Rangifer* tarandus (caribou) from this locality was identified by C. A. Repenning of the Geological Survey. A ?Bison pelvis, also identified by Repenning, was collected on a bar of Ketik River 4 km above its mouth, and the skull of Ovibos moschatus (muskox) was similarly identified from the bed of the Kaolak River at long. 70° N. Of this fauna, caribou and wolf live in the area today, and the last muskox was killed in the mid 19th century (Harington, 1980, p. 825) although attempts have been made to reintroduce them in recent years. The remainder of the fauna is similar to that of the Ikpikpuk River quadrangle where five specimens, including horse, mammoth, and saiga, have radiocarbon ages greater than 28,000 years (Carter, 1981b, p. 7).

Although the fossil mammals of the Wainwright quadrangle have not been found in place in the alluvial deposits beneath the upland silt, the data suggest that these deposits are the probable source for the broken and water-worn bones and ivory found in the river terraces and on the river flood plains. However, the Avak River horse skulls may have come from the upland silt. The alluvial deposits beneath the upland silt, therefore, are probably of mid-Wisconsinan age, perhaps slightly older, based on similarity to the fauna older than 28,000 years in the Ikpikpuk River area (Carter, 1981b, p. 7).

Fossil logs as much as 18 cm in diameter were noted by Langenheim and others (1960, p. 1349) with the fossil mammal bones at several unspecified places along the Kaolak River, but it is not clear whether the logs were found on river bars or in the sections of Pleistocene deposits forming the river banks. O'Sullivan (1961, p. 117) found one log 15 cm in diameter on the Kaolak River which was identified as larch (probably Larix laricina) by Francis Kukachka of the U.S. Department of Agriculture Forest Products Laboratory. A larch log from the Kogosukruk River, tributary to the Colville, is greater than 36,000 years old (L-301) and is believed by O'Sullivan (1961, p. 118) to have come from gravel beneath the silt cover. Presumably, the Kaolak River larch came from the fluvial deposits beneath the silt, although no definitive information is available to locate these logs in the stratigraphy. The writer observed no logs from the fluvial deposits beneath the upland silt in the Kuk River drainage basin,but noted the presence of willow(?) logs 15 to 18 cm in diameter, larger than any growing today, in the Avak River terrace (C, table 3, fig. 2) where materials immediately below were dated at 10,200 ± 200 years.

Eolian sand

The extensive and easily identified dunes that characterize large segments of the Meade River, Teshekpuk, and Ipikpuk River quadrangles to the east are not found in the Wainwright quadrangle. Instead, the eolian sand appears to be a thin mantle that is discontinuously distributed over marine sand and beach deposits of the coastal plain. This sand sheet, generally less than 2 m thick, lacks dune form in most areas. In many other areas, pebble lag concentrated by wind action from the underlying pebbly sand is found at the base of the tundra mat. Dune forms, having a height of about 3 m were identified by Hopkins (unpublished notes, 1981) in the Tunalik River valley. Many more dunes could probably be located by more detailed fieldwork. The age of the sand sheet and local dunes is probably Wisconsinan to Holocene, by analogy to the areas to the east where Carter (1981a, b, 1982, 1983) has postulated desert conditions during Wisconsinan time and formation of a sand sheet and small parabolic and longitudinal dunes during Holocene time. Small areas of stabilized Holocene dunes and some that are still active are located on the north bank of Avalik River near its confluence with Ketik River and along the west shore of Kuk River, where broad sand bars in the delta at the head of the estuary provide a source of sand moved by the east-northeast wind. Other active dunes, too small to be mapped, are common along river cutbanks and in the largely unvegetated barrier island chains.

Alluvial deposits

As mapped, the alluvial deposits include the floodplain and adjacent low terrace systems along the major rivers. Escarpments bounding the higher terraces bordering the alluvial deposits are mapped by special hachured symbols where the scale of the map permits, but no investigations of their deposits or burial beneath alluvial fans, slope debris, or other cover have been made. Quaide (1955) recognized an older "open-valley" terrace into which have been cut the lower terraces and the floodplain. In many places, particularly along Kuk River, the breaks in slope that resemble terrace escarpments could reflect changes in lithology from hard, cliff-forming sandstone units to the lower coal-clay units which have been more easily eroded and have been subject to landsliding. The terraces cut into the "open-valley" terrace, according to Quaide (1955), probably reflect degradation, alluviation, and renewed degradation resulting from changes in sea level. All of the lower reaches of the larger rivers have been cut deeply into bedrock, presumably during the low stand of the sea during the Wisconsinan and earlier glacial stages. They now enter the sea through estuaries in which the modern deltas at the heads of the estauries reflect the rising base level caused by postglacial rise in sea level. The estuaries of the Kuk and Avak River have been enlarged after the rise in sea level by thaw activity which was terminated by interception of the bedrock surface in the former valley walls.

Radiocarbon dating of alluvial deposits is limited to the terraces of the Kaolak River near its confluence with the Kuk River and to a terrace of the Avak River. The terraces on the lower Kaolak River (Hopkins and others, 1979, p. B30) are 3.5 to 4.5, 7, and 14 m above the river at low water. The lowest terrace, 4.5 m above the Kaolak River, slopes northward more steeply than the present river and is only 3.5 m above the river at its confluence with Kuk River, 5 km downstream. A date for twigs 3.7 to 3.8 m below the top of the 4.5-m terrace upstream was 1,730 ± 40 years (E, table 3, fig. 2), and that for twigs in the foreset sand beds in the 3.5-m terrace downstream was 1,170 ± 45 years (D, table 3, fig. 2). The terrace deposits are believed (Hopkins and others, 1979) to have been formed during a storm-induced peak discharge that coincided with a storm surge that raised the Kuk River about 3 m above its normal height.

A terrace about 9 m above the Avak River (C, fig. 2) is composed of sandy gravel to about 5 m above the river with a surface mantle of about 4 m interbedded fine sand, silt, peat, and sticks. The fine-grained surficial deposits may be alluvial fan or slope-wash deposits carried to the surface of the gravel terrace from the adjacent valley walls, which are capped by 13 m of loess-like silt; a part may be fluvial overbank deposits. A zone of retransported organic material between two sand beds separates the fine surficial material from the underlying gravel at about 5 m above the river. The organic material contains willow(?) logs to 15 to 18 cm in diameter, larger than any tree growing today in the vicinity; peat and twigs are 10,200± 200 years old (C, table 3, fig. 2). This date probably is close to the age of the terrace overbank deposits and is older than the reworked material from the adjacent valley walls that caps the terrace. Although it cannot be proven much of the eolian silt on the valley walls is probably older than 10,000 years. Two horse skulls (*Equus lambei*) recovered from the valley wall above the terrace and apparently washed from the silt (Hopkins, unpublished field notes, 1981) seemingly substantiates the pre-10,000 year date for the silt because mammal remains found in the upland silt terrain further east (Harington, 1980, 1981; Carter, 1981b; Nelson, 1982) have generally given radiocarbon ages greater than 28,000 years.

Rocks of exotic lithology have been noted in the Kaolak and Ketik River alluvium. Cobbles of chert and other rocks not found in the Cretaceous bedrock are reportedly abundant on the Kaolak and Kuk Rivers; a cobble containing a coral of Paleozoic age was found on a sand bar of the Ketik River (Langenheim and others, 1960, p. 1348). This led Langenheim and others to suggest that the Kuk River system once extended to the Brooks Range before piracy by the Utukok River captured the former headwaters of the Kuk River. However, vari-colored chert and igneous rocks are common clasts in conglomeratic beds exposed south of the Wainwright quadrangle (Chapman and Sable, 1960, p. 87, 104). Chert is common in the sandstone throughout the Nanushuk Group (Bartsch-Winkler, 1979). The source for Nanushuk Group rocks was in the Brooks Range. The coral-bearing cobble could also have been a clast of Brooks Range provenance contained in conglomerates of the Nanushuk Group south of the quadrangle. Whether these conglomerates extend northward into the Wainwright quadrangle is unknown, however, Langenheim and others (1960, p. 1349) noted a well-cemented strongly cross-bedded conglomerate at a southern bend of Kaolak River in T. 8 N. at the boundary between R. 32 W. and R. 33 W.; these rocks were assigned a Pleistocene age, but may be a coarse channel deposit within the Nanushuk Group. The drainage history of the quadrangle is still largely unknown and awaits further study.

The studies of terraces by O'Sullivan (1961), Quaide (1955), and Langenheim and others (1960) were restricted by lack of the 1:63,360-scale maps now available, poor exposures, difficult access, and, within the upland silt unit, by the cover of silt that may mask some of the older terrace forms. The present study was a rapid reconnaissance of the major exposures that did not permit the detailed work necessary to map the terraces and to relate them to the several high sea levels recorded by the marine deposits.

Thaw-lake deposits and the thaw-lake cycle

The thaw-lake cycle is, perhaps, the dominant form of landscape modification in the permafrost environment of the Arctic Coastal Plain. The origin, orientation, and cyclic development of thaw lakes have been studied extensively in the Barrow area and to a lesser extent elsewhere in the coastal plain (Black and Barksdale, 1949; Brewer, 1958; Livingstone and others, 1958; Carson and Hussey, 1960, 1962, 1963; Brown, 1965; Hussey and Michelson, 1966; Britton, 1967; Carson, 1968; Black, 1969; Sellmann and others, 1975; Morrissey, 1979; Williams and Yeend, 1979; and others). The thaw-lake cycle is initiated by disruption of the vegetation or by collection of water at intersecting ice-wedge polygon trenches to form a pool at the surface. The pool is deepened and expanded laterally by thaw of near-surface ice-rich permafrost that is adjacent to or beneath the water. The pond or lake continues to expand laterally by thawing its ice-rich banks and becomes deeper by thawing the underlying ice-rich permafrost until it intercepts and drains to a lower lake or to a nearby stream. The depth of the thaw-lake basin is determined by the thickness of ice-rich permafrost and its potential for thaw settlement, which is approximately 3.4 m in that part of the coastal plain underlain by sandy material, and as much as 10 m in the upland silt. Orientation of the thaw lakes in a N. 10^{o} W. direction is derived from and is normal to the prevailing east-northeasterly winds (Carson and Hussey, 1962). Once drained the lake bed is refrozen. A new generation of ice wedges and ice-rich permafrost may be formed, which could, in time, regenerate a new cycle of thaw lakes, as noted by Hopkins and Robinson (1979, p. B44; L, M, table 3, fig. 2) near Nokotlek Point. The parts of the initial surface that have been unaffected by the thaw-lake cycle are called initial surface residuals. Permafrost beneath the initial surface residuals has a higher ice content than it does beneath the ancient lake beds, recently drained lake beds, and beds of existing lakes (Hussey and Michelson, 1966). The processes described above are discussed more fully in Carson and Hussey (1962), Lewellen (1972), and in Sellmann and others (1975).

Deposits within the thaw-lake basins vary with the map unit in which they occur and with the material available for redeposition. Thus, as explained in the description of map units, the deposits can include silt, sand, and pebbly beds and lenses. These materials incorporate organic material that has been redeposited from the banks of the lake and the remains of plants that grew _in situ_ in the lake basin. Carson (1968, fig. 4) illustrates sections through thaw lake basins in the Barrow area in which original sod is overlain by sand, organic fines and peat, and new sod. Because of the complexities of the stratigraphy and the intermixing of old and new organic material, interpretation of radiocarbon dates for thaw lake deposits is difficult (Brown, 1965).

Radiocarbon dates of thaw-lake deposits near Barrow may have applicability to similar deposits in the coastal plain of the Wainwright quadrangle. The oldest dated lacustrine basal peat, 12,160 ± 200 (I-3244) years old (Lewellen, 1972, p. 166) provides a maximum known age for operation of the thaw-lake process near Barrow (Sellmann and others, 1975; Brown and others, 1980). The dated peat is from the basal organic layer above marine sand. Whether this peat is an old turf that has been incorporated into younger thaw-lake sediments or whether it dates the deposits of the thaw lake is not known. Carson (1968) believes that the thaw-lake expansion at Barrow reached a maximum between 4,000 and 8,000 years ago and that the first of several cycles of thaw-lake basin intersection and drainage began after 3,500 years ago.

In the Wainwright quadrangle, Hopkins and Robinson (1979) have collected several samples that provide radiocarbon dates for thaw-lake deposits. The oldest date, 10,600 ± 180 years (H, table 3, fig. 2) for detrital peat in an ice-wedge pseudomorph at the base of the thaw-lake deposits shows that thaw lakes were in existence at that time. At Nokotlek Point the basal thaw-lake sediments are 9,125 ± 150 years old (L, table 3, fig. 2), and the basal peat of a younger thaw lake at the same site is 6,234 ± 120 years old (M, table 3, fig. 2); these dates indicate that the life of the older lake at this site was less than 3,000 years. Ice wedges 20 to 70 cm wide have formed since drainage of the younger lake. At another site near Nokotlek Point twigs in basal sediments near the margin of a thaw-lake basin are 8,435 ± 160 years old (I, table 3, fig. 2) and are slightly older than the date of drainage of the lake and subsequent formation of ice wedges 35 to 125 cm wide in the thaw-lake deposits. A peat sample collected 10 km southwest of Wainwright Inlet is 9,180 ± 150 years (A, table 3, fig. 2) and dates basal thaw-lake deposits in which ice wedges 70 to 250 cm wide have formed since drainage of the lake. These, and other dates, suggest that most, if not all of the thaw lakes are of Holocene age, that many of them seemed to have been formed between 8,000 and slightly more than 10,600 years ago, that some were drained after a fairly short life, and that ice wedges grew in their deposits, leading in some cases to a renewal of thaw-lake activity up to the present time. The thaw-lake process is still active and affects Holocene eolian and alluvial deposits, as well as the older marine deposits (Morrissey, 1979). The recent activity is shown by the 490 ± 50-year date (G, table 3, fig. 2) for twigs and grass from an ice-wedge pseudomorph at the base of sandy and gravelly thaw-lake deposits exposed on the shore of Kasegaluk Lagoon south of Icy Cape (Hopkins and Robinson, 1979). The regularities in expansion and drainage of thaw lakes noted by Carson (1968) in the Barrow area have not been recognized in the few records available for the Wainwright quadrangle. No dating has been done of the deposits of the relatively deep thaw lake basins in the upland silt, which, in the Meade River and Ikpikpuk River quadrangles to the east were about 2,500 years old (Williams and Yeend, 1979; Nelson, 1982).

Landslide deposits

Landslides are limited to rocks of the Nanushuk Group where failure has taken place along clay beds that commonly occur with coal. The clay is bentonitic and, in some areas, is of nearly pure bentonite. Only a few landslides are large enough to be shown at the scale of the map, but many others occur in areas mapped as Cretaceous bedrock. Landslide processes are especially active along the Kaolak and Ivisaruk Rivers where cutbanks in bedrock have cracks well back from the edge of the bluff, indicating incipient failure planes. The east bank of Kuk River exposes slumped coal and clay that is backed by a break in slope that may mark the position of a cliff-forming sandstone unit, beneath which the clay has slid toward the river. Some of the banks of Avalik River, in which coal and clay are exposed, also appear to have been subject to landsliding. Careful consideration of the potential for landsliding along river bluffs and valley walls is required as part of foundation investigations.

Permafrost

Permafrost, or perennially frozen ground, extends from the permafrost table at a depth of about 0.5 m below the ground surface to depths estimated from exploratory test wells in the region to be in the range 200 to 300 m. Data on the base of permafrost are limited to the Kugrua Test Well No. 1 (207 m) 12 km east of the quadrangle boundary and Kaolak Test Well No. 1 (259 to 299 m) 16 km south of the quadrangle boundary. Information on permafrost thickness for Tunalik Test Well No. 1 and Peard Test Well No. 1 is not available.

The upper surface of permafrost is depressed by the thermal disturbance of bodies of surface water that are deeper than 2 m (Brewer, 1958). Almost all of the lakes are shallow and freeze to the bottom each winter, including Sikolik Lake, one of the largest in the quadrangle (Childers and others, 1979, table 2). The winter water supply lake at Wainwright, however, had 0.3 m of water beneath 2 m of ice. In all likelihood, lacking a detailed depth survey, some of the larger lakes may have sections that are more than 2 m deep. Kuk River, reported to be about 5 m deep in places, probably has a thaw bulb beneath the river bed. However, no subsurface information is generally available on the thickness of the thaw bulb beneath the few lakes and rivers that do not freeze to the bottom each winter.

The ice content of permafrost that exceeds the voids of the sediments determines the amount of settlement to be expected when permafrost thaws. This is an important consideration in building roads, airfields, and structures on permafrost terrain because even a slight disturbance that results in reduction of the insulating properties of the ground cover can raise the mean annual ground-surface temperature and cause thawing of permafrost. In the Wainwright quadrangle, as far as is known, nearly all of the perennially frozen materials contain near-surface excess ice that will produce undesirable settlement upon thawing. Therefore, construction methods that prevent thaw of permafrost should be employed everywhere unless test drilling at a site shows that ice-rich permafrost is not a problem. Very few natural exposures of permafrost were available for study because those exposed by storm waves and river erosion are rapidly thawed. However, drilling in the Barrow area, in terrain very similar to that occupied by the marine sand unit of the Wainwright quadrangle, shows that the volume of segregated ice in excess of the voids of the soil, exclusive of wedge ice, decreased from about 75 percent at a depth of 1 m to zero at about 8.5 m (Sellmann and others, 1975, p. 14-18). Hussey and Michelson (1966, p. 167-168) made a similar analysis for the upper 6.6 m of frozen ground, based on four test holes and excluding the estimated 5 percent as wedge ice, and concluded that if the upper 6.6 m of permafrost in the Barrow area were thawed in various terrain units the following amounts of settlement would take place:

	Initial surface residual (highest surface)	Ancient drained thaw lake	Recently drained lake	Present lake
Average percent settlement	55.4	19.0	11.5	2.0
Minimum actual settlement (m)	3.4	1.2	0.7	0.1

The actual settlement resulting from thaw of permafrost that is ice rich only in the upper 6 to 8 m accounts for the numerous shallow thaw-lake basins in the coastal plain near Barrow and in the Wainwright quadrangle. The much deeper thaw-lake basins in the upland silt unit along the southern border of the Wainwright quadrangle and those more spectacularly developed in the Meade River quadrangle to the east indicate that the sediments containing ice in excess of the void ratios of the materials may extend to greater depths than in the area of marine sand of the coastal plain. The ice-rich upland silt of the Wainwright quadrdangle is not as thick as that in the Meade River quadrangle where thaw-lake basins as deep as 21 m have been reported (Williams and Yeend, 1979; Williams, 1983). However, the ice content of the upland silt in the Wainwright quadrangle probably approaches the 78 percent, including wedge ice, that was noted in similar deposits in the Meade River quadrangle. Thaw-lake basins as deep as 10 m may be expected in the thicker deposits of ice-rich silt in the Wainwright quadrangle. More often, however, the upland silt is thin and the thaw-lake basins are relatively shallow. They have coalesced to form vast meadowlands (alassi) bordered by a low scarp separating them from the undisturbed residual surface. As in the Soviet Union, where thaw lake basins (alass terrain) are favored locations for settlement and agriculture, much but not all of the ground ice has been melted and further ground settlement is minor when compared to the devastating settlement to be expected by clearing the vegetation and disturbing the thermal regime of permafrost in the undisturbed residual surfaces between the thaw-lake basins. Ice wedges probably constitute 50 percent of the ground volume in these undisturbed areas in Siberia (Are, 1973) and extend to greater depths than the 2- to 5-m long wedges of the marine deposits of the Alaskan arctic coastal plain, where wedge ice is estimated at 5 percent of the volume of the frozen soils by Hussey and Michelson (1966) or 10 to 20 percent by Sellmann and others (1975).

A detailed account (Lawson, 1982) of the impact of the construction-disturbed vegetation on the permafrost in upland silt at the site of East Oumalik Test Well No. 1, 250 km east of the Wainwright quadrangle points out the many potential problems of construction on permafrost. At the test well site ground ice occurs as wedges of two generations, the younger of which forms the surface polygonal ground, and as lenses in silt that is similar to the upland silt of the Wainwright quadrangle. The ground ice composes 42 to 90 percent of the volume of the upper 15 m of frozen silt. Disturbance was probably greatest during the first 10 to 15 years of the 33 years that has elapsed since construction. Since 1950 the relief at the site has been increased from about 2 m then to 8 m now; the maximum surface depression has been about 5 m directly over a shallow ice wedge. The site is now an irregular hummocky area with numerous depressions, some filled with water. Lawson concludes that construction site evaluation requires an analysis of the content and distribution of ground ice to determine the behavior of the sediment upon thawing. The lessons learned at the East Oumalik site are that adverse physical changes will occur over two to three decades if the vegetation is removed or even severely compacted during construction.

Water resources

At Barrow, the nearest station with significant meteorological records, the average annual precipitation, corrected for estimated errors caused by windblown snow and rain and to sum trace amounts, is estimated at about 170 mm, of which 106 mm is snow and 64 mm is rain; monthly maxima are in August and January (Dingman and others, 1980, p. 52). The processes of heat balance and the effect on snow cover, evaporation, transpiration, microclimate, and hydrology are explained in some detail for the Barrow area by Dingman and others (1980). Basically, runoff is concentrated during the breakup period in June when between 61 and 98 percent of the annual streamflow occurs during the snowmelt flood. Heavy summer or autumn rains cause secondary peak discharges in some years. During the winter months streams in the Wainwright quadrangle have no flow for significantly long periods, and the area lacks icings, which are indications of year-round ground-water discharge. Accordingly, the only source of water in winter is ice and snow, the small amount of liquid water that is beneath occasional river channels and lakes that are deeper than 2 m, or ground water stored within the thaw bulb beneath these incompletely-frozen bodies of water. Not only are supplies of water beneath the ice cover extremely limited, but the water quality deteriorates in winter as downward freezing concentrates the dissolved solids. Techniques of deepening existing lake basins to create reservoirs that are capable of providing winter storage for water pumped in from rivers during the summer have been used at Prudhoe Bay to provide water for camp and industrial needs. Similar techniques could be used in the Wainwright quadrangle.

Ground water is not available within the usual economic depth range of water wells. The ground is frozen from less than 1 m to depths of at least 200 m in bedrock, except for occasional lakes and streams channels deeper than 2 m, beneath which a small thaw bulb develops. Thaw bulbs beneath the deep pools on the Sagavanirktok River near Prudhoe Bay have proven to have only limited storage which is not replenished by inflow during the winter. Water can be obtained from bedrock below the base of the frozen layer, but the well yield would be low because of low permeability of the Nanushuk Group rocks. Experience over most of the Petroleum Reserve shows that formation water below the permafrost is generally too high in salinity and dissolved solids to be suitable as a potable supply (Williams, 1970).

Economic geology

Oil and gas

All of the quadrangle east of the meridian passing through Icy Cape is in National Petroleum Reserve--Alaska, formerly Naval Petroleum Reserve No. 4 which was established by Executive Order in 1923, based on oil seepages at Cape Simpson and other locations near Barrow. The only oil seepage reported in the Wainwright quadrangle was an indirect report of an oil seep near Wainwright given to Brooks (1916); Hanna (1963) believes that the informant may have referred to the Skull Cliff seepage, east of the Wainwright quadrangle, for subsequent work has located no oil or gas seepages in the Wainwright quadrangle.

During exploration of Naval Petroleum Reserve No. 4 by the Navy between 1944 and 1953, no test wells were drilled in the Wainwright quadrangle. The westernmost test well in this exploration program, Kaolak Test Well No. 1, was drilled 13 km south of the quadrangle boundary at long. 160° 14' 51" W. on a buried east-west trending anticline discovered by seismic methods. The well reached 2,119 m, but encountered only slight shows of oil and some methane gas from the coal beds (Collins, 1958). Two wells in the quadrangle were drilled by the Geological Survey after 1976 when the reserve was transferred from the Navy to the Department of the Interior; both have been plugged and abandoned. Peard Test Well No. 1, located on the eastern boundary of the quadrangle (fig. 1), was drilled 3,117 m, reaching the basement complex at 2,938 m (Bird, 1982); it encountered poor shows of gas. Tunalik Test Well No. 1, in the west-central part of the quadrangle (fig. 1) was drilled 6,503 m, reaching the Lisburne Group at 5,238 m (Bird, 1982); it had gas shows, none of which were large enough to develop. Data on the Geological Survey exploration program has been placed on open file with the Environmental Data Service of the National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado; logs of the formations penetrated are summarized by Bird (1982).

Coal

Coal of subbituminous rank in the Nanushuk Group within the Wainwright quadrangle constitutes a significant part of the estimated 45 billion metric tons of identified coal resources and of the 300 billion to 3 trillion metric tons of hypothetical undiscovered coal resources of National Petroleum Reserve--Alaska (Martin and Callahan, 1978). Coal beds make up about 3 to nearly 10 percent of the thickness of the Nanushuk Group and are found in beds as much as 2 m thick along the eastern shores of Wainwright Inlet and Kuk River and locally on its tributaries, and along Kugrua River and its estuary.

The coal has been collected from beach shingle and dug from three prospects on the east bank of Kuk River and from two on Kugrua River for use by the local residents (fig. 1). These coal outcrops have been described by Paige and others (1925) and by Smith and Mertie (1930), and have been further examined by the Bureau of Mines during the mid 1940's (Sanford and Pierce, 1946). The coal deposits are frozen and are interrupted in some places by ground-ice wedges. Two flat-lying coal beds at the northernmost Kugrua River prospect and another at the southern prospect were found upon trenching to be 1.52 to 1.83 m thick. A 30-m wide strip along the 488-m long outcrop would yield about 29,900 metric tons of coal at the northern prospect and about 10,900 metric tons at the southern prospect from a bed 137 m long and 1.83 m thick (Sanford and Pierce, 1946, p. 16). The Bureau of Mines also examined the middle of the three coal prospects on the east bank of Kuk River south of Wainwright (Sanford and Pierce, 1946, p. 12-13) and located two coal beds, 1.67 and 1.83 m thick, interbedded with clay. No estimates of reserves were made of this long exposure of coal or of the prospects to the north and south.

Further details on these coal prospects and results of analysis of samples can be obtained from Sanford and Pierce (1946), Paige and others (1925), Smith and Mertie (1930), and Martin and Callahan (1978). Smith and Mertie observed that coal beds exposed on the Avalik and Kaolak Rivers were not as thick as those on Kuk and Kugrua Rivers. Locations of these beds from unpublished field notes and published reports and the location of seismic shot holes which penetrated coal (Martin and Callahan, 1978) are plotted on figure 1 as a general guide for further detailed studies. For obvious reasons, the prospects that have been used by local people are located along navigable waterways, so that these prospects, also along the routes used for geological exploration, have received the most notice. Away from these waterways the coal and related sedimentary rocks are generally concealed beneath a mantle of unconsolidated deposits and tundra vegetation, so that subsurface work is needed to locate the thickest beds and to estimate the coal reserves.

Gravel

Deposits of sandy gravel that are near the surface and easily worked are scarce in the Wainwright quadrangle. They are limited to modern beaches, spits, offshore bars and barrier islands in which the sandy gravel is generally less common than gravelly sand, to raised beaches, bars, and barrier islands related to the Pelukian and Kotzebuan shorelines, and to bars and beds of streams within a few kilometers north of the upland silt unit. Elsewhere, the deposits are generally of sand. Beneath the sand are isolated thin gravel deposits which are generally difficult to locate and to develop.

A nearly continuous chain of barrier islands fringes Kasegaluk Lagoon south of Wainwright and a long barrier bar extends from Point Belcher northeastward, enclosing Peard Bay. The deposits range from sand to sandy gravel, and, in pit run, the most common product would be gravelly sand that is generally low in silt, because all these materials have been extensively worked and cleaned by wave action. These barrier islands and the spits, beaches and bars elsewhere can be easily searched for the desired material; they have little vegetation, and a local cover of small dunes. They are subject to ice shove and are inundated during storm surges, and, therefore, are not suitable locations for permanent facilities. Passes separating the barrier islands are opened and closed from time to time with the storms. Excavation of material from these shore features carries with it the responsibility for evaluating the potential effect of the work on sediment transport and beach erosion.

The modern beaches along the inshore side of Kasegaluk Lagoon and those at the base of the cliffed shoreline elsewhere are narrow and thin and are generally of sand or sand and fine gravel that is largely washed from the cliffs by waves and retransported along shore; they include sand contributions from streams draining the regions inland. The most productive locations for mining sand and gravel are the spits formed at points in the cliffed shoreline.

Raised beaches and wave-cut cliffs of Pelukian and Kotzebuan age are plotted on figure 2, where it is possible to show the inferred general trends of the beach lines as a guide to gravel prospecting that may not be readily apparent from examining the geologic map. Beaches of gravelly sand of Pelukian age lie inshore from Kaseguluk Lagoon between the mouth of Utukok River and that of Nokotlek River. These deposits are narrow and linear and are not more than a few meters thick. Raised beaches of Pelukian age that back the modern beach northeastward of Point Belcher are of fine to coarse sandy gravel. A stream cutting through these deposits exposed about 2 m of coarse sandy gravel, the best quality seen in the entire quadrangle. Gravel has been found in only one location at the base of Kotzebuan shoreline (II, fig. 2), 3.2 km south of the confluence of Irak Creek and Mikigealiak River, and less than 0.5 km east of Irak Creek. No gravel deposits were found in the unsuccessful aerial and ground search for the shoreline as inferred by queried lines (fig. 2) from the Irak Creek site westward to Pingoraruk Hill and along the well defined shoreline from Irak Creek northeastward to the quadrangle boundary.

Beach deposits of Kotzebuan age lie inshore of the wave-cut cliff of Pelukian age from a point northeast of Sikolik Lake to Pingoraruk Hill and extend northeastward as a series of offshore bars to Wainwright Inlet and Kuk River (fig. 2). These beaches were visited at three locations. High banks on the west side of Kuk River, 1 to 3 km south of Karmuk Point, have as much as 7 m of coarse gravel near the top, overlain by 1 to 3 m of sand of possible eolian origin; the gravel is well washed, well sorted, and lacks fine-grained material. A raised beach, 7 km southwest of Kilimantavi, has been eroded by a brook, the banks of which expose about 5 m of similar washed gravel that is mantled with 1.5 m of pebbly sand and 1 m of peat. The southernmost location is the gravel pit (Kachadoorian and others, 1978) developed on either side of a brook that drains through the Pelukian wave-cut cliff, but high enough above the brook to be part of the Kotzebuan beach deposits. The pit and the material taken from it is gravelly sand. When observed by the writer in 1978 the pit had been rehabilitated by grading, and no exposures were available for study. At that time nearly 1 m of relief had developed in the floor of the pit from thawing of polygonal ice wedges in the underlying sediments. The beach deposits, located on the map and on figure 2, between these deposits are favorable locations for prospecting for gravel, although the deposits are linear, of only limited thickness, and are commonly covered by sandy overburden.

Alluvial deposits of the larger streams within the upland silt unit are generally of sandy fine gravel. These deposits become finer downstream, and, a few km beyond the northern limit of the upland silt unit, the alluvium is generally sand. High bars bordering the stream channel locally are as much as 2.5 m thick and may provide as much as 10,000 m^3 of washed fine gravel. Gravel in the stream beds is generally thin where the streams are scouring bedrock, and the deposits locally contain angular cobbles and boulders derived from the local bedrock. In some places the gravelly stream beds are underlain by fine sand. The source of the gravel is believed to be gravel beds within the alluvium that lies beneath the upland silt on either side of the stream. These gravel beds are commonly interlayered with sand and finer-grained materials and are overlain by frozen silt. The best quality and most productive sites are the high bar deposits. The Utukok River has a gravel bed in its broad floodplain near the southern edge of the quadrangle. The gravel extends a few km downstream into the Wainwright quadrangle before grading into sand and sandy silt as the river approaches its delta in Kasegaluk Lagoon. Excavation of streambed material requires consideration of environmental impacts on the stream regimen and fish habitat. An advantage in utilizing alluvial deposits along rivers is the potential for a thicker active layer than is found in near-surface deposits away from the rivers.

The quality of the gravel for use as concrete aggregate is affected by the presence of coal and chert, which has a deleterious effect on concrete. Otherwise, the gravel is generally subrounded to subangular, is of relatively resistant rock types, and generally has a sandy matrix that contains less than 12 percent silt.

Sand

Sand is the most abundant foundation material; it forms a widespread mantle at the surface and commonly extends to depths of 3 to 5 m, rarely to 10 m. It generally ranges from fine to medium eolian sand to fine to medium marine silty sand that contains scattered pebbles and granules of quartz and chert. The sand grains are largely quartz and chert with minor amounts of other minerals and coal. In general, the sand is frozen below a depth of about 0.5 m and in a few well-drained sites below a depth of 1 to 2 m. Once the vegetation is stripped and the underlying sand thawed and dried, the sand is subject to wind erosion.

Silt

Silt in large quantities is available at various places in the upland silt unit of the southern part of the quadrangle. Locally, the silt is as thick as 13 m. The silt has been incorporated with organic material where reworked by running water or locally by solifluction on slopes. It is generally frozen below a depth of 0.5 m and has a very high ice content, as wedges, masses, and interstitial ice approaching 78 percent of the volume of the deposit.

Clay

Clay above and below the coal beds of the Nanushuk Group is commonly exposed in the banks of Kugrua, Kuk, Ketik, Kaolak, Avalik, and Ivisaruk Rivers, as well as in places along the sea coast south of Wainwright (fig. 1). Bentonitic clay is reportedly widespread in the Kuk River drainage basin (Langenheim and others, 1960, p. 1349; Smiley, 1966), and probably elsewhere, although no special study has been made of these deposits. In its pure form bentonite is a white, putty-like material containing visible biotite flakes, as noted from two locations on the Kaolak River by Langenheim and others (1960). It expands when wet. The clay is especially susceptible to flowage and slope failures, which are common along river bluffs. Properties of the clay deposits of the quadrangle have not been tested for their suitability for brick clay or for drilling mud. The clay found with coal beds in Meade River Test Well No. 1 in the Meade River quadrangle (Collins, 1958, p. 351-352) formed a natural drilling mud during drilling of that well.

Peat

Peat is largely confined to the surface mat of living and dead vegetation that seldom exceeds 0.5 m in thickness. The peat is normally not well enough compressed for use as a building material or for fuel.

References cited

Ahlbrandt, T. S., ed., Preliminary geologic, petrologic, and paleontologic results of the study of Nanushuk Group rocks, North Slope, Alaska: U.S. Geological Survey Circular 794, 163 p.

Are, F. E., 1973, Development of thermokarst lakes in Central Yakutia: International Conference on Permafrost, 2nd, Yakutsk, U.S.S.R., Field trip guidebook, 29 p.

Barnes, F. F., 1967, Coal resources of the Cape Lisburne-Colville River region, Alaska: U.S. Geological Survey Bulletin 1242-E, p. E1-E37, 1 pl.

Bartsch-Winkler, Susan, 1979, Textural and mineralogical study of some surface and subsurface sandstones from the Nanushuk Group, western North Slope, Alaska, _in_ Ahlbrandt, T. S., ed., Preliminary geologic, petrologic, and paleontologic results of the study of Nanushuk Group rocks, North Slope Alaska: U.S. Geological Survey Circular 794, p. 61-76.

Beechey, F. W., 1831, Narrative of a voyage to the Pacific and Bering's Straits: London.

Beikman, H. M., and Lathram, E. H., 1976, Preliminary geologic map of northern Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-789, 2 sheets, scale 1:1,000,000.

Bird, K. J., 1982, Rock-unit reports of 228 wells drilled on the North Slope, Alaska: U.S. Geological Survey Open-File Report 82-278, 106 p.

Black, R. F., 1951, Eolian deposits of Alaska: Arctic, v. 4, no. 2, p. 89-111.

_____1957, Some problems in engineering geology caused by permafrost in the Arctic Coastal Plain, northern Alaska: Arctic, v. 10, no. 4, p. 230-240.

_____1964, Gubik Formation of Quaternary age in northern Alaska: U.S. Geological Survey Professional Paper 302-C, p. 59-91.

Black, R. F., 1969, Thaw depressions and thaw lakes, a review: Biuletyn Peryglacjalny, v. 19, p. 131-150.

_____1974, Ice-wedge polygons of northern Alaska, _in_ Coates, D. R., ed., Glacial geomorphology: Annual Geomorphology Series, 1974, 5th, Binghamton, New York, State University of New York, Proceedings, p. 247-275.

_____1976, Periglacial features indicative of permafrost: ice and soil wedges: Quaternary Research, v. 6, p. 3-26.

Black, R. F., and Barksdale, W. L., 1949, Oriented lakes of northern Alaska: Journal of Geology, v. 57, no. 2, p. 105-118.

Brewer, M. C., 1958, The thermal regime of an arctic lake: American Geophysical Union Transactions, v. 39, p. 278-284.

Brigham, J. K., 1981, Amino-acid geochronology of Late Pliocene and Pleistocene marine transgressions on the Arctic Coastal Plain, northern Alaska (abs.): Geological Society of America Abstracts with Programs, v. 13, no. 7, p. 417.

Brigham, J. K., and Miller, G. H., 1982, Late Cenozoic history of high sea level stands and Pleistocene temperature estimates, northwestern Alaska (abs.): Geological Society of America Abstracts with Programs, v. 14, no. 7, p. 451.

Britton, M. E., 1967, Vegetation of the arctic tundra, in Hansen. H. P., ed., Arctic Biology: Corvallis, Oregon State College, p. 67-130.

Brooks, A. H., 1916, The Alaska mining industry in 1915: U.S. Geological Survey Bulletin 642-A, 71 p.

Brown, Jerry, 1965, Radiocarbon dating, Barrow, Alaska: Arctic, v. 18, no. 1, p. 36-48.

Brown, Jerry, Everett, K. R., Webber, P. J., MacLean, S. F., and Murray, D. F., 1980, The coastal tundra at Barrow, in Brown, Jerry, and others, eds., An Arctic ecosystem: the coastal tundra at Barrow, Alaska: Institute of Ecology, Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, p. 1-29.

Carson, C. E., 1968, Radiocarbon dating of lacustrine strands in Arctic Alaska: Arctic, v. 21, no. 1, p. 12-26.

Carson, C. E., and Hussey, K. M., 1960, Hydrodynamics in three Arctic lakes: Journal of Geology, v. 68, no. 6, p. 585-600.

_____1962, The oriented lakes of Arctic Alaska: Journal of Geology, v. 70, no. 4, p. 417-439.

_____1963, The oriented lakes of Arctic Alaska, a reply: Journal of Geology, v. 71, no. 4, p. 532-533.

Carter, L. D., 1981a, A Pleistocene sand sea on the Alaskan Arctic Coastal Plain: Science, v. 211, no. 4480, p. 381-383.

_____1981b, Middle Wisconsinan through Holocene climate in the Ikpikpuk River region, Alaska: Tenth Annual Arctic Workshop, March 12-14, 1981, Boulder, Colorado, Institute of Arctic and Alpine Research, University of Colorado, Proceedings, p. 5-9.

_____1983, Engineering-geologic maps of northern Alaska: Teshekpuk quadrangle: U.S. Geological Survey Open File Report, 1 sheet, scale 1:250,000 (in press).

_____in press, Fossil sand wedges on the Alaskan arctic coastal plain and their paleoenvironmental significance: Fourth International Conference on Permafrost, Fairbanks, Alaska, July 18-22, 1983, Proceedings.

Carter, L. D., and Hopkins, D. M., 1982, Late Wisconsinan winter snow cover and sand-moving winds on the Arctic coastal plain of Alaska: Eleventh Annual Arctic Workshop, March 11-13, 1982, Boulder, Colorado, Institute of Arctic and Alpine Research, University of Colorado, Proceedings, p. 8-10.

Carter, L. D., Repenning, C. A., Marincovich, L. N., Hazel, J. E., Hopkins, D. M., McDougall, Kristin, and Naeser, C. W., 1977, Gubik and pre-Gubik Cenozoic deposits along the Colville River near Ocean Point, North Slope, Alaska, in Blean, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1976: U.S. Geological Survey Circular 751-B, p. B12-B14.

Carter, L. D., and Robinson, S. W., 1978, Eolian sand and interbedded organic horizons at Kealok Creek on the Arctic Coastal Plain of Alaska: possible regional implications: U.S. Geological Survey Open-File Report 78-320, 26 p.

Chapman, R. M., and Sable, E. G., 1960, Geology of the Utukok-Corwin region, northwestern Alaska: U.S. Geological Survey Professional Paper 303-C, p. 47-167.

Childers, J. M., Kernodle, D. R., and Loeffler, R. M., 1979, Hydrologic reconnaissance of western Arctic Alaska, 1976 and 1977: U.S. Geological Survey Open-File Report 79-699, 70 p.

Collins, F. R., 1958, Test wells, Meade and Kaolak areas, Alaska, with micropaleontology of Meade Test Well 1 and Kaolak Test Well 1, northern Alaska, by Harlan R. Bergquist: U.S. Geological Survey Professional paper 305-F, p. 341-376.

Detterman, R. L., 1978, The Arctic Lowland region, potential landform and lifeform natural landmarks: U.S. Geological Survey Open-File Report 78-329, 411 p., 26 figs., scales 1:63,360 and 1:3,720,000.

Dingman, S. L., Barry, R. G., Weller, Gunter, Benson, C. S., LeDrew, E. F., and Goodwin, C. W., 1980, Climate, snow cover, microclimate, and hydrology, in Brown, Jerry, and others, eds., An Arctic ecosystem: the coastal tundra at Barrow, Alaska: Institute of Ecology, Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, p. 30-65.

Dutcher, R. R., Trotter, C. L., and Spackman, William, 1957, Petrography and palynology of certain coals of the Arctic Slope of Alaska: Mineral Industries Experiment Station, College of Mineral Industries, Pennsylvania State University, University Park, Pennsylvania, Results of research July 1, 1956 to June 30, 1957, submitted to Arctic Institute of North America, 37 p., 6 appendices.

Gryc, George, Patton, W. W., Jr., and Payne, T. G., 1951, Present Cretaceous stratigraphic nomenclature of northern Alaska: Washington Academy of Sciences Journal, v. 41, p. 159-167.

Hanna, G. D., 1963, Oil seepages on the Arctic coastal plain, Alaska: California Academy of Sciences Occasional Papers, no. 38, 18 p., 1 fig., 1 pl.

Harington, C. R., 1980, Radiocarbon dates on some Quaternary mammals and artifacts from northern North America: Arctic, v. 33, no. 4, p. 815-832.

_____ 1981, Pleistocene Saiga antelope in North America and their paleoenvironmental implications, in Mahaney, W. C., ed., Quaternary paleoclimates, Norwich, England, Geo Abstracts, p. 193-225.

Hartz, R. W., 1978, Erosional hazards map of the Arctic coast of the National Petroleum Reserve--Alaska: U.S. Geological Survey Open-File Report 78-406, 7 p., 1 pl., scale 1:817,300.

Hopkins, D. M., 1967, Quaternary marine transgressions in Alaska, in Hopkins, D. M., ed., The Bering land bridge: Stanford, California, Stanford University Press, p. 47-90.

_____ 1973, Sea level history in Beringia during the past 250,000 years: Quaternary Research, v. 3, p. 520-540.

Hopkins, D. M., Hartz, R. W., and Robinson, S. W., 1979, Record of a prehistoric storm surge in the Wainwright Inlet-Kuk River area, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska--Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B29-B31.

Hopkins, D. M., and Robinson, S. W., 1979, Radiocarbon dates from the Beaufort and Chukchi Sea coasts, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska--Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B44-B46.

Hume, J. D., and Schalk, Marshall, 1967, Shoreline processes near Barrow, Alaska, a comparison of the normal and the catastrophic: Arctic, v. 20, no. 2, p. 86-103.

Hussey, K. M., and Anderson, G. S., 1963, Environment and distribution of thermal relief features in the northern foothills section, Alaska: Ames, Iowa, Iowa State University of Science and Technology, Department of Geology, unpublished report.

Hussey, K. M., and Michelson, R. W., 1966, Tundra relief features near Point Barrow, Alaska: Arctic, v. 19, no. 2, p. 162-184.

Johnson, K. M., 1978, Map showing slopes and selected geomorphic features, National Petroleum Reserve--Alaska: U.S. Geological Survey Open-File Report 78-206, 1 sheet, scale 1:500,000.

Kachadoorian, Reuben, Crory, F. E., and Berg, R. L., 1978, Studies of proposed airfields at the Inigok and Tunalik well sites, NPRA, in Johnson, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B22-B24.

Lachenbruch, A. H., 1962, Mechanics of thermal contraction cracks and ice wedge polygons in permafrost: Geological Society of America Special Paper 70, 69 p.

Langenheim, R. L., Jr., Smiley, C. J., and Gray, Jane, 1960, Cretaceous amber from the Arctic Coastal Plain of Alaska: Geological Society of America Bulletin, v. 71, p. 1345-1356.

Lathram, E. H., 1965, Preliminary geologic map of northern Alaska: U.S. Geological Survey Open-File Report 65-254, 2 sheets, scale 1:1,000,000.

Lawson, D. E., 1982, Long-term modifications of perennially frozen sediment and terrain at East Oumalik, northern Alaska: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Report 82-36, 33 p.

Lewellen, R. I., 1972, Studies on the fluvial environment, Arctic Coastal Plain Province, northern Alaska: Littleton, Colorado, published privately, 2 v., 282 p.

Livingstone, D. A., Bryan, Kirk, Jr., and Leahy, R. G., 1958, Effects of an arctic environment on the origin and development of freshwater lakes: Limnology and Oceanography, v. 3, p. 194-214.

Martin, G. C., and Callahan, J. E., 1978, Preliminary report on the coal resources of the National Petroleum Reserve in Alaska: U.S. Geological Survey Open-File Report 78-1033, 23 p., 2 pls., scale 1:500,000.

Mayfield, C. F., Tailleur, I. L., and Kirschner, C. F., in press, Geologic map of National Petroleum Reserve--Alaska: U.S. Geological Survey, 2 sheets, scale 1:500,000.

Mayfield, C. F., Tailleur, I. L., Mull, C. G., and Sable, E. G., 1978, Bedrock geologic map of the south half of National Petroleum Reserve in Alaska: U.S. Geological Survey Open-File Report 78-70B, 2 sheets, scale 1:500,000.

McCulloch, D. S., 1967, Quaternary geology of the Alaskan shore of Chukchi Sea, in Hopkins, D. M., ed., The Bering land bridge: Stanford, California, Stanford University Press, p. 91-120.

Morrissey, L. A., 1979, Succession of plant communities in response to thaw lake activity on the Arctic Coastal Plain, Alaska: Master's thesis, Department of Geography, San Jose State University, San Jose, California, 71 p.

Morrissey, L. A., and Ennis, R. A., 1981, Vegetation mapping of the National Petroleum Reserve in Alaska using LANDSAT digital data: U.S. Geological Survey Open-File Report 81-315, 25 p.

Nelson, R. E., 1982, Late Quaternary environments of the western Arctic slope, Alaska: Doctoral dissertation, University of Washington, Seattle, 90 p.

Osterkamp, T. E., and Payne, M. W., 1981, Estimates of permafrost thickness from well logs in northern Alaska: Cold Regions Science and Technology, v. 5, p. 13-27.

O'Sullivan, J. B., 1961, Quaternary geology of the Arctic coastal plain, northern Alaska: Doctoral dissertation, Iowa State University of Science and Technology, Ames, Iowa, 191 p.

O'Sullivan, J. B., and Hussey, K. M., 1960, Noneolian origin for silts of the Arctic slope, Alaska (abs.): Geological Society of America Bulletin, v. 71, no. 12, pt. 2, p. 1940.

Paige, Sidney, Foran, W. T., and Gilluly, James, 1925, Reconnaissance of the Point Barrow region, Alaska: U.S. Geological Survey Bulletin 772, 32 p.

Payne, T. G., and others, 1951, Geology of the Arctic slope of Alaska: U.S. Geological Survey Oil and Gas Investigations Map OM-126, 3 sheets.

Quaide, William, 1955, Enquiry into the paleontologic and geologic history of the Naval Petroleum Reserve No. 4 and adjoining areas: Unpublished report prepared for Arctic Institute of North America under project number ONR-118, 26 p.

Sanford, R. S., and Pierce, H. C., 1946, Exploration of coal deposits of the Point Barrow and Wainwright areas, northern Alaska: U.S. Bureau of Mines Report of Investigations 3934, 17 p.

Schrader, F. C., 1904, A reconnaissance in northern Alaska across the Rocky Mountains, along Koyukuk, John, Anaktuvuk, and Colville Rivers and the Arctic coast to Cape Lisburne in 1901: U.S. Geological Survey Professional Paper 20, 139 p.

Sellmann, P. V., and Brown, Jerry, 1973, Stratigraphy and diagenesis of perennially frozen sediments in the Barrow, Alaska region: North American contribution to 2nd International Conference on Permafrost, Yakutsk: Washington, D.C., National Academy of Sciences, p. 171-181.

Sellmann, P. V., Brown, Jerry, Lewellen, R. I., McKim, H., and Merry, Carolyn, 1975, The classification and geomorphic implication of thaw lakes on the arctic coastal plain, Alaska: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Research Report 344, 21 p.

Sloan, C. E., 1977, Arctic hydrology studies, in Blean, K. M., ed., The United States Geological Survey in Alaska--accomplishments during 1976: U.S. Geological Survey Circular 751-B, p. B30-B31.

Sloan, C. E., and Snyder, R. F., 1978, Hydrologic reconnaissance of lakes in NPRA, 1977, in Johnson, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B28-B29.

Sloan, C. E., Trabant, Dennis, and Glude, William, 1978, Reconnaissance snow survey of NPRA, April, 1977, in Johnson, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B28.

Smiley, C. J., 1966, Cretaceous floras from Kuk River area, Alaska: stratigraphic and climatic interpretations: Geological Society of America Bulletin, v. 77, no. 1, p. 1-14.

Smiley, C. J., 1969, Floral zones and correlations of Cretaceous Kukpowruk and Corwin Formations, northwestern Alaska: American Association of Petroleum Geologists Bulletin, v. 53, no. 10, p. 2079-2093.

_____ 1979, Some Cretaceous plant megafossils and microfossils from the Nanushuk Group, northern Alaska: a preliminary report, in Ahlbrandt, T. S., ed., Preliminary geologic, petrologic, and paleontologic results of the study of Nanushuk Group rocks, North Slope, Alaska: U.S. Geological Survey Circular 794, p. 89-111.

Smith, P. S., and Mertie, J. B., Jr., 1930, Geology and mineral resources of northwestern Alaska: U.S. Geological Survey Bulletin 815, 351 p.

Stanley, E. A., 1967, Cretaceous pollen and spore assemblages from northern Alaska: Review of Paleobotany and Palynology, v. 1, p. 229-234.

Stefansson, Karl, and Mangus, M. D., 1949, Stratigraphy and structure of the area of the Avalik and Ketik Rivers: U.S. Geological Survey, Geologic Investigations Naval Petroleum Reserve No. 4, Alaska, Report 28, 4 p. (Open-File Report, 1954).

Toenges, A. L., and Jolley, T. R., 1947, Investigation of coal deposits for local use in the Arctic regions of Alaska and proposed mine development: U.S. Bureau of Mines Report of Investigations 4150, 19 p.

Wahrhaftig, Clyde, 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 52 p., 6 pls.

Webber, E. J., 1947, Stratigraphy and structure of the area of the Meade and Kuk Rivers and Point Barrow, Alaska: U.S. Geological Survey, Geologic Investigations of Naval Petroleum Reserve No. 4, Alaska, Report 6, 14 p., 3 pls. (Open-File Report, 1954).

Williams, J. R., 1970, Ground water in the permafrost regions of Alaska: U.S. Geological Survey Professional Paper 696, 83 p.

_____ 1979, Stratigraphy of the Gubik Formation at Skull Cliff, northern Alaska, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska--Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B31-B33.

_____ 1983, Engineering-geologic maps of northern Alaska, Meade River quadrangle: U.S. Geological Survey Open-File Report 83-294, 29 p., 1 pl., scale 1:250,000.

Williams, J. R., Carter, L. D., and Yeend, W. E., 1978, Coastal plain deposits of NPRA, in Johnson, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B20-B22.

Williams, J. R., and Yeend, W. E., 1979, Deep thaw lake basins of the inner Arctic Coastal Plain, Alaska, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska--Accomplishments during 1978: U.S. Geological Survey Circular 804-B, p. B35-B37.

Williams, J. R., Yeend, W. E., Carter, L. D., and Hamilton, T. D., 1977, Preliminary surficial deposits map of National Petroleum Reserve--Alaska: U.S. Geological Survey Open-File Report 77-868, 2 sheets, scale 1:500,000.

Yeend, W. E., 1978, Surficial geology of the foothills and mountains of NPRA, _in_ Johnson, K. M., ed., The United States Geological Survey in Alaska--Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B19-B20.

_____1983, Engineering-geologic maps of northern Alaska, Lookout Ridge quadrangle: U.S. Geological Survey Open-File Report 83-279, 2 sheets, scale 1:250,000.