DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Engineering-geologic maps of northern Alaska, Barrow quadrangle

by

John R. Williams
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

and

L. David Carter
U.S. Geological Survey
4200 University Drive
Anchorage, AK 99508-4667

OPEN-FILE REPORT 84-124

CONTENTS

Illustrations

Engineering-geologic maps of northern Alaska, Barrow quadrangle

by

John R. Williams and L. David Carter

INTRODUCTION

Purpose

The purpose of this report is to describe and map bedrock and surficial deposits in order to provide a useful basis for environmentally sound land mangement. From this information an overview can be obtained of the availability of natural construction materials and potential foundation problems. In addition, the report includes data collected during this study on the paleontology of some of the marine deposits, a summary of the radiocarbon dates, subsurface data, and location of ice-rafted erratic stones. The section on previous investigations and references cited therein and elsewhere in the report will lead the reader to sources of information that will supplement data presented in this report. Much work is currently in progress on the land and on the continental shelf; this report covers only a small and selected part of the literature and does not discuss the extensive research that has been carried on in the undersea part of the quadrangle, other than a mention of the subsea permafrost.

General Setting

The Barrow quadrangle occupies a land area of about 2,330 km^2 between latitude 71^o and 71^o 23' 26" North and between longitude 154^o 32' and 156^o 53' West. The quadrangle lies entirely within the Arctic Coastal Plain Province (Wahrhaftig, 1965), which is flat, lake-dotted, and tundra-covered. Large oriented thaw lakes occupy 15 to 20 percent of the land area, including those along the Beaufort Sea coast that have been breached by the sea and are now lagoons. Much of the remainder of the area is occupied by drained thaw-lake basins. The highest ground, reaching nearly 20 m above sea level a few km south southwest of Barrow, occurs along the Chukchi Sea shore; the ground is only 2 to 7 m above sea level along the Beaufort Sea. Drainage is by small creeks which connect the lakes and drained lake beds and flow to the sea through small estuaries. Dease Inlet, a large estuary of the Meade River and Chipp River (a distributary of Ikpikpuk River) is the major indentation of the Beaufort Sea coast. The Inlet has been enlarged and shaped by the thaw and erosion of permafrost in its banks (Weller and Derksen, 1979).

The low, heavily indented, and rapidly-eroding shoreline of the Beaufort Sea contrasts with the straight, relatively unindented, and more stable coast of the Chukchi Sea. A prominent feature of the coastline is the 7-km long Barrow spit which extends, with some recent breaks, from the mainland near Barrow village to Point Barrow, the northernmost point in Alaska and in the United States. From Point Barrow a chain of barrier islands extends eastward, enclosing Elson Lagoon and Dease Inlet.

The principal settlement is Barrow, a city of about 3,000 persons, which is the principal commerical center and seat of borough government for northern Alaska. The Naval Arctic Research Laboratory is located on the spit north of

Barrow on the site of the former construction camp developed by the Navy for its 1944-53 exploration program of Naval Petroleum Reserve No. 4. Gas wells within the area of the quadrangle supply fuel to the city and to the Government facilities. Oil seeps at Cape Simpson in the eastern part of the quadrangle were test drilled but have not been developed as a source of oil. A modern paved airport serves Barrow, and a second landing strip on the Barrow spit serves the Government facilities there.

Previous Investigations

The earliest geologic investigations were those of the International Polar Expedition to Point Barrow in 1881-83 (Ray, 1885) during which a shaft 11 meters deep was dug in perennially frozen material (31, table 1, fig. 1) at a point just north of modern Barrow. Schrader (1904), Stefansson (1908, 1910), and Leffingwell (1908, 1915, 1919) in their trips along the coastline east of Barrow noted the extensive ground ice and the enclosing frozen sediments; Leffingwell was the first in Alaska to show that ice wedges are formed by contraction of the ground during winter freezing, later confirmed by Black (1963, 1974) and Lachenbruch (1962). Leffingwell (1919, p. 69-93) has summarized the early explorations and has abstracted the scientific results of those who traveled the coast between 1826 and 1912.

Local residents and early travelers in the region were aware of the oil seeps at Cape Simpson (summarized <u>in</u> Hanna, 1963). Knowledge of these seeps led President Harding in 1923 to issue an Executive Order establishing Naval Petroleum Reserve No. 4, which included all of the Barrow quadrangle. The seeps and the bedrock geology were studied by Paige and others (1925) and were summarized in a regional report on the geology of northwestern Alaska by Smith and Mertie (1930). Between 1944 and 1953 the U.S. Geological Survey assisted the Navy in evaluating the resources of the Reserve, including describing the test wells drilled near Barrow, where the South Barrow gas field was discovered in 1949, and near the Cape Simpson oil seeps (Robinson, 1959, 1964; Collins, 1961). Regional maps based on information from the exploratory surveys and drilling were prepared by Payne and others (1951) and by Lathram (1965).

Under Public Law 94-258, the National Petroleum Reserve Act of 1976, Naval Petroleum Reserve No. 4 was renamed National Petroleum Reserve--Alaska and was placed under jurisdiction of the Department of the Interior. The U.S. Geological Survey was assigned responsibility for exploration for oil and gas, and the Bureau of Land Management was given responsibility for land management in the Reserve, including preparation of land-use studies and evaluations. One of the provisions of the Act was for development and maintenance of a gas supply for the residents of Barrow. Several new wells were added to the South Barrow gas field, the East Barrow gas field was located and tested, and a promising new gas discovery was made southwest of Barrow (27[1/], table 1, fig. 1). Other exploratory wells were drilled along the Beaufort Sea coast eastward from Barrow, hoping to locate other structural and stratigraphic

---

[1/] Figure or letter, e.g. 27, refers to location of data in table and on figure cited.

traps on or just off the axis of the Barrow arch. A list of oil and gas exploratory holes is given in table 1; their location is shown in figure 1, based on data in Bird (1982). Much of the technical information connected with the 1976-81 exploration program is on file at National Oceanic and Atmospheric Administration, Boulder, Colorado, and is available for inspection.

In 1947, early in the period of Naval exploration for oil and gas, the Naval Arctic Research Laboratory was founded to carry out research related to the interests of the Federal Government and of the scientific community. A broad spectrum of research was conducted, including geologic studies, soils investigations, permafrost and geothermal measurements, and hydrologic studies, all of which are basic to construction and operations in the far north. A special 1:25,000-scale photo-mosaic base map (Brown and Johnson, 1966) was especially helpful in these studies.

The stratigraphy of the Gubik Formation was studied by O'Sullivan (1961), Black (1964), Faas (1962, 1964, 1966), Lewellen (1972b), Sellmann and Brown (1973), and correlations were attempted by Lewellen (1972b) and by Sellmann and Brown (1973) with the late Cenozoic chronologies worked out by Hopkins (1967a, b, 1973) and McCulloch (1967) for the Bering Sea region. Radiocarbon dating at Barrow (summarized, table 2, locations fig. 4) has been done to: (1) determine the age of the unconsolidated deposits of the Gubik Formation, (2) measure the rates of geologic and soil-forming processes, and (3) to date thaw-lake expansion and contraction (Coulter and others, 1960; Péwé and Church, 1962; Brown, 1965; Brown and Sellmann, 1966; Carson, 1968; Sellmann and Brown, 1973). More recently, studies of the Beaufort Sea coast by Hopkins and Hartz (1978), Black (1983), and by Carter are continually changing the geologic interpretation of the eastern part of the quadrangle. Similarly, the work of Brigham and others (1980), Brigham (1981, 1983a and b), and Brigham and Miller (1982, 1983) based on the use of amino-acid racemization of marine shells to correlate stratigraphic units from one location to another, has led to a revised stratigraphy of the Gubik Formation exposed in the Chukchi Sea Cliffs and extensive worldwide correlations. To date, however, the basic stratigraphy on which these correlations are based remains unpublished and is not available for use in figure 5, a cross section of these bluffs based on material, rather than chronological differences. Published data on marine fossils is scarce and is limited to works by Leffingwell (1919), Dall (1921), MacGinitie (1955), MacNeil (1957), Tappan (1961), Swain (1961), Faas (1962), Schmidt (1967), Schmidt and Sellmann (1966), and recently by McDougall (1983).

Engineering problems (Black, 1957) and utilization and stabilization of unconsolidated deposits for use as runways and roads (Carlson and others, 1959; O'Sullivan and Hussey, 1957; and O'Sullivan and others, 1959) have been considered. LaBelle (1973) has identified and estimated quantities of gravel near Barrow, as indicated by the figures and locations on figure 3 of this report, and has outlined resouces of some raised beaches (figs. 2 and 3) which have also been discussed by Rex (1964) and Rex and Taylor (1953). Erratic boulders presumed to be of glaciomarine origin were noted in the Gubik Formation at many points along the coast below an elevation of 8 m above sea level (Leffingwell, 1908, 1919; MacCarthy, 1958; Sellmann and Brown, 1973).

Tundra soils have been described, classified, and dated by Tedrow and Hill (1955), Drew (1957), Drew and others (1958), Tedrow and Cantlon (1958), Tedrow and others (1958), Douglas and Tedrow (1959, 1960), Drew and Tedrow (1962), Tedrow (1965, 1969, 1977), Brown and Johnson (1965), McNamara and Tedrow (1966), Brown (1967, 1969a, b, and 1972), and Brown and others (1980). The chronology of eolian events and deposits described by Black (1951), Carter (1981a, b; 1983b, c), Carter and Robinson (1978), Carter and Hopkins (1982) in other, more easterly sections of the coastal plain applies to the eolian history and soil forming processes in the Barrow quadangle.

Many studies have been made of the vegetation, for example, Britton (1957), other studies have been made on the pollen rain (Nelson, 1978) and paleobotany (Arnold, 1959; Colinvaux, 1964; Livingstone, 1955), on the tundra relief (Hussey and Michelson, 1966), the plant ecology (Potter, 1972), and the tundra environment (Batzli and Brown, 1976).

Important among the terrain conditions (Sellmann and others, 1972; Walker, 1973; Arctic Institute of North America, 1974) are the thaw lakes described by Black and Barksdale (1949), Black (1969), Sellmann and others (1975), and Tedrow (1969). The origin of these lakes, oriented N. 10^{o} W and formed by east-northeasterly winds, has been discussed by Black and Barksdale (1949), Livingstone (1954), Rosenfeld and Hussey (1958), Carson and Hussey (1959, 1960, 1962, 1963), Rex (1961), and Price (1963). Limnology of some of these lakes, with emphasis on their potential as a water source, has been discussed by Boyd (1959), and their thermal regime by Brewer (1958a). Mohr and others (1961) have studied the marine nature of Nuwuk Lake on the Barrow spit.

Basic research in permafrost has been undertaken by MacCarthy (1952), Brewer (1958b), Lachenbruch (1957a, b, 1959, 1962), Lachenbruch and Marshall (1969), Lachenbruch and others (1962), and by Black (1974). These studies have determined the heat flow in the Barrow and Simpson regions and its relation to permafrost, the effects of the ocean and bodies of fresh water on the temperature field and on permafrost, and have deduced certain information about climatic change and stability of shorelines based on the thermal gradient. The work on ice wedges has demonstrated the validity of Leffingwell's contraction-crack theory of origin. Nearshore permafrost beneath the Chukchi Sea has been discussed by Brewer (1958b), and the extent of permafrost beneath the rapidly eroding Beaufort Sea coast has been described by Lewellen (1973), Osterkamp (1976), and others. The relation of permafrost to the history of the coastal plain has been summarized by Brown and Sellmann (1973). Permafrost thickness data available through 1962 has been summarized by Ferrians (1965) and Williams (1965, 1970), and its variation with lithology, in the Prudhoe Bay region, has been described and accounted for by Osterkamp and Payne (1981). Ice wedges and their growth have been described by Leffingwell (1915, 1919) and have been measured by Black (1952, 1963, 1974) and their chemistry and that of the enclosing permafrost described by Brown (1966) and O'Sullivan (1966). The results of coring frozen ground near Barrow are reported by Sellmann and Brown (1965, 1973). Settlement estimates on the thawing of ice-rich permafrost have been made by Hussey and Michelson (1966), Sellmann and others (1975), and by Black (1974).

Studies of coastal morphology and processes have included work on local Holocene sea-level changes by Hume (1965), MacCarthy (1953), and Lewellen (1972a, b). A large number of reports have been written on coastal erosion and storm surges, particularly important because of inundation of the Naval facilities on the Barrow spit during the 1963 storm (Hume, 1964; Hume and Schalk, 1967; Lewellen, 1970, 1973; Wiseman and others, 1973; Hartz, 1978a, b; Hopkins and Hartz, 1978). Sediment transport by longshore currents moving northward along the Chukchi Sea coast toward Point Barrow has been of interest in studies of coastal erosion and of the effects of mining beach gravel to determine the rate of resupply of material (Hume and Schalk, 1963, 1967). Ice-push features on the modern beaches have been noted by Hume and Schalk (1964), and breakup and freeze-up processes have been studied by Short and Wiseman (1973, 1974, 1975).

Climate and hydrology have been summarized by Dingman and others (1980). These subjects include precipitation and snow cover (Black, 1954a; Benson, 1969, 1982; Slaughter and others, 1975; Sloan and others, 1979; Glude and Sloan, 1980; Sloan, 1983), microclimate (Mather and Thornthwaite, 1958), temperature (Hamilton, 1965; Haugen and Brown, 1980), and hydrology (Brown and others, 1962, 1968). Ground-water hydrology is summarized by Brewer (1958a) and Williams (1965, 1970).

Much of the work in the Barrow quadrangle has been a product of U.S. Geological Survey and U.S. Army Cold Regions Research and Engineering Laboratory programs and those funded by National Science Foundation and by (or through) Arctic Institute of North America. Iowa State University, University of Alaska, and the Coastal Studies Institute of the Louisiana State University have been prominent in earth sciences research in the Barrow area.

Present Study

Recent work, on which the present report is based, results from the mandate in the National Petroleum Reserves Act of 1976 (P.L. 94-258) that the Bureau of Land Management prepare a land-use study of National Petroleum Reserve--Alaska. This study included a surficial geologic map (Williams and others, 1977), an evaluation of the coal resources (Martin and Callahan, 1978), a slope map (Johnson, 1978), a map of coastal erosion (Hartz, 1978b), a map of the distribution of pingos (Galloway and Carter, 1978), a report on sand dunes (Carter and Robinson, 1978), a study of the electrical properties of permafrost near Barrow (Olhoeft, 1978; Olhoeft and others, 1978) and other studies, including some of metallic mineral deposits in the mountainous parts of the Reserve. In 1981 the Minerals Management Service of the Department of the Interior requested preparation of additional maps at 1:250,000-scale emphasizing the engineering geology; this agency and its successor for onshore work, the Bureau of Land Management, have provided funds for field and office work in 14 quadrangles, of which the Meade River (Williams, 1983a), Wainwright (Williams, 1983b), Lookout Ridge (Yeend, 1983), and Teshekpuk (Carter, 1983a), have been completed; this report is one of this series.

This report is based on extensive interpretation of aerial photographs flown in 1955 and on fieldwork at selected sites offering natural exposures of the unconsolidated deposits. Mapping by Williams, west of 156° W longitude, occupied about four days supported by helicopter between August 1 and 14, 1977, and between July 24 and August 9, 1978; L. A. Morrissey accompanied Williams in the field in 1978 to gather ground-truth data for interpreting Landsat imagery vegetation patterns (Morrissey, 1979; Morrissey and Ennis, 1981). Carter mapped the area east of 156° West longitude, assisted by J. P. Galloway in 1980 with brief visits or overflights in others years between 1975 and 1983. U.S. Geological Survey field notes of R. F. Black (1946-50), D. M. Hopkins (1976, 1981), and R. E. Nelson (1976-77) supplemented the data collected in the field by the authors. The very large literature, a selection of which is presented under the section of previous investigations and which is listed among the references cited, has provided much of the data used in this report.

Naval Arctic Research Laboratory at Barrow provided meals, quarters, and logistic support to Williams and party on a cost-reimbursable basis in both 1977 and 1978. Carter based at Camp Lonely, where similar support was furnished by arrangement with contractors for Office of National Petroleum Reserve--Alaska of the U.S. Geological Survey.

BEDROCK

The bedrock formations (fig. 1) that lie directly beneath the unconsolidated deposits are of early to late Cretaceous age (Mayfield, Tailleur, and Kirschner, unpublished mapping, 1983). Their distribution reflects their structural arrangement in the Barrow arch, the axis of which generally follows the Beaufort Sea coastline, and the Meade arch, intersecting the Barrow arch at right angles and trending southward from the Barrow area (Grantz and others, 1976; Lantz, 1981). The Cretaceous and underlying Jurassic and Triassic sedimentary rocks thicken eastward along the deepening crestline of the Barrow arch, and northward and southward down the flanks of the arch. These sedimentary rocks lie above the Devonian argillite and other rocks of the basement complex and are generally little deformed and of gentle dip. However, just southeast of Barrow in the area of pebble shale (fig. 1), steep dips and faulted rocks indicate considerable disturbance of the rocks (Kirschner, 1983). The South Barrow and East Barrow gas fields are located on structural highs respectively west and east of this disturbed zone (Lantz, 1981). The South Barrow gas field originally had about 25 billion cubic feet of recoverable gas, about half of which had been produced between 1949 and 1981, and the East Barrow field had about 12 billion cubic feet (Lantz, 1981), enough to meet the needs of the civilian and Government users at Barrow for several years, as mandated by the National Petroleum Reserves Act of 1976. Additional supplies remain to be developed from a promising discovery well west of Sukok Lake (27, table 1, fig. 1). The nearest known oil resources are in the Simpson area. The oil and gas resources that have been discovered so far in the quadrangle are too small to justify export to other parts of Alaska or to market outside Alaska.

The bedrock surface was probably formed by marine planation. The surface is known from the few bedrock exposures in the Chukchi Sea bluffs in the southwestern part of the quadrangle and from subsurface records of oil and gas exploratory wells (fig. 1, table 1; fig. 5). Northeastward along the Chukchi Sea coast the bedrock surface slopes, apparently with some gullying near Barrow, at about 0.45 m/km to the north and east. The median depth of the 38 holes in which the top of bedrock is logged is about 22 m below land surface, shallow in the southwest and as much as 41.5 m at the West Dease well (29, table 1, fig. 1).

UNCONSOLIDATED DEPOSITS
General Statement

Unconsolidated deposits of mostly marine origin, the upper part of which has been reworked by fluvial, eolian, and thaw-lake processes, cover bedrock in the Barrow quadrangle. These 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. Included in the subsurface as exposed along the Chukchi Sea coast are older marine sediments that in part are probably of Pliocene age (the lower marine deposits at Skull Cliff (Williams, 1979, 1983a) or the Killi Creek and Nulavik beds of the Gubik Formation (Brigham, 1983a, b)).

The unconsolidated deposits are mapped on the basis of origin, as marine beach, spit, and barrier island deposits; marine sand; marine silt and clay; thaw-lake deposits; eolian deposits; and alluvial deposits. The map units are described in the tabular description of map units, and their age and correlation are summarized in a separate diagram adjacent to figure 2 (plate 1). Collections of marine macrofossils are listed in the check list (table 4) and are located on figure 4; these were identified by Louie Marincovich, Jr., and Dale Russell of the U.S. Geological Survey. The marine deposits of several ages include silty clayey units that contain ice-rafted boulders that are erratic to the Brooks Range and the Alaskan Arctic in general, and must come from the Canadian north, perhaps Amundsen Gulf, as suggested by Rodeick (1975). Figure 4 shows pebble counts by Hopkins and Hartz (1978) along the shoreline of the Barrow quadrangle and illustrates the local dominance of Brooks Range rock types or those erratic to Alaska, from eastern sources. The erratic boulders are not only found in the surficial marine silt and clay east of Barrow, but also occur in one or more stratigraphic units in the lower part of the Gubik Formation along the Chukchi Sea. Erratics are also found as high as 30 m above sea level in the Meade River quadrangle (Williams, 1983a). More than 50 radiocarbon dates related to soils, permafrost, and geologic history are tabulated from the literature in table 2 and are located on figure 4. Four radiocarbon dates were obtained on samples collected for this study near Cape Simpson.

A cross section (fig. 5) showing the materials exposed in the coastal bluffs facing the Chukchi Sea is provided to show the range and general distribution of the materials and their relation to bedrock. In a number of short papers and abstracts, Brigham (1981, 1983a, b) and Brigham and Miller (1982, 1983) have published correlations of beds of the Gubik Formation with chronologies in the Bering Strait region and eastern Siberia. This revised stratigraphy is more detailed than the threefold division of the Gubik by Black (1964). The basic stratigraphic work and internal correlations of the newly proposed subdivisions of the Gubik Formation based on field observations, paleontological work, and amino-acid racemization still have not been published as this report is being written, and so this important revision in the mapping and stratigraphy of the Gubik deposits cannot be adopted.

Marine Beach, Spit, and Barrier Island Deposits

Modern landfoms and their deposits

Cobble to granule gravel, gravelly sand, and sand form low-lying beaches, spits, and barrier islands in the Chukchi and Beaufort Seas. Similar deposits, now above sea level, are located near Barrow, and extend from Barrow east-southeastward as a former set of beach and barrier islands that separate the marine sand from marine silt and clay units.

The modern beach along the Chukchi Sea cliffs is as much as 50 m wide, except where an even wider baymouth bar has formed across the mouth of an incised stream. The gravel is largely derived from erosion of the coastal bluffs, and it consists of sandy pebble and cobble gravel, with a few boulders as large as a meter in diameter. The large boulders, and some of the smaller material are apparently ice-rafted erratic material washed from glaciomarine deposits low in the stratigraphic section exposed in the cliffs. The beach gravel is transported northeastward past Barrow by currents to form the 7-km-long spit that terminates in Point Barrow. Studies of sediment transport along this shore (Hume and Schalk, 1967; Hume and others, 1972) indicate that a modest 7,600 m^3 of sediment is the net average yearly transport to the northeast, and that 3,500 m^3 of sediment is the net average yearly transport southeasterly from Point Barrow to Eliuktak Point.

Barrier islands enclose the seaward side of Elson Lagoon, protect the mouth of Dease Inlet, and merge with the coast near Cape Simpson. The western end of the barrier island chain, Eliuktak Pass, marks the boundary between gravel of Brooks Range lithologic types and gravel that is lithologically similar to rocks of the Canadian north (Rodeick, 1975) or from northern Greenland (Hopkins, 1979) (fig. 3). The gravel to the west of Eliuktak Pass is dominantly chert, graywacke, grit, and vein quartz. That to the east is largely dolomite with varying amounts of red quartzite, pyroxenite, red granite, and diabase (Hopkins and Hartz, 1978). The mainland side of Elson Lagoon and much of the shoreline of Dease Inlet and Cape Simpson lacks the source material for sand and gravel beaches. The sandy gravel beach deposits, therefore, are but a few cm thick, and a few m wide at the base of actively caving bluffs of fine soil material (chiefly thaw-lake deposits and marine silt and clay) and ice. In a few places thin gravelly sand deposits occur as cuspate spits along the mainland shoreline, but even these are generally insignificant as sources of granular material.

Drill holes for a dam across the lagoon north of Barrow (Esatkuak, Nerravak, or Village Slough or Lagoon) parallel to and about 200 m inland from the barrier beach provide a record (Faas, 1964, 1966) between sea level and 11 m below sea level of alternating lagoonal silt and clay deposits and sandy beach gravel. The base of the sequence of lagoonal deposits at 11 m below sea level contained wood, which was dated at 6,450 years (G, table 2, fig. 4). According to Faas (1966) this date for a former sea level 11 m lower than the present level is consistent with worldwide eustatic sea level records. The alternation of lagoonal and barrier beach deposits above the dated horizon is believed by Faas to be the result of brief periods of tectonic instability, intense storms, or slight variations in the rate of sea level rise. A storm such as that of October 3, 1963 might very well move beach gravel inland some 200 m to provide gravelly horizons like those recorded in the stratigraphic column.

A number of additional holes drilled from Browerville to Point Barrow to Eliuktak Point show that the fine to coarse sand, gravelly sand, and pebble to cobble gravel of the Barrow spit is as much as 8 m thick. At most locations (31, 32, 39, 50, 52, and 53, table 1, fig. 1) the beach sand and gravel is underlain by mud, black clay, peat, fine sand, and one or more of these materials alternates with sand and gravel. Some of these fine-grained and organic deposits were exposed in cuts made across the spit by man or by the action of storms.

LaBelle (1973) has outlined potential sources of sand and gravel from the modern beaches, spits, and islands (fig. 3). Basically, the Chukchi Sea coast offers a few baymouth bars from which borrow may be made from the backshore deposits, and local areas on the Barrow spit. These sites probably are sensitive in that the material has to be replaced, and in the replacement other areas are depleted, either by erosion or starvation. The potential for developing gravel from Cooper Island and others in the barrier chain east of Point Barrow has been pointed out by LaBelle (1973). Certain places, such as the eastern end of Eliuktak spit, where sediment is accumulating, are suggested for sources of granular borrow by LaBelle. The islands between Eliuktak Pass and Ekilukruak Entrance are generally of sand, with some gravel. The largest of the Plover Islands is Cooper Island, southeast of Ekilukruak Entrance; this island contains more gravel than others in the chain. LaBelle believes the island has a potential yield of a large part of the more than 1.5 million m^3 of gravel that are above sea level, without destroying the island or seriously damaging its environment.

In a more recent study, however, Hopkins and Hartz (1978) have found the barrier islands and other shore features very sensitive to change. They have found that the gravel lithology (fig. 3) of the barrier islands changes abruptly at Ekilukruak Entrance from more than 90 percent eastern (Flaxman) provenance east of the Entrance, to 30 percent to the west. Similarly, at Eliutkak Pass the gravel changes abruptly westward across the pass from more than 50 percent to less than 40 percent eastern provenance. The passes and entrances, therefore, are apparently barriers to sediment transport and isolate the island groups, as is shown by the compound recurved spits terminating the islands as well as by the differences in gravel lithology. Hopkins and Hartz (1978) find that the eastern Plover barrier chain was probably fed from mainland erosion near Cape Simpson, that the sediment source for the islands between Eliutkak Pass and Ekilukruak Entrance may have disappeared, and that the islands are migrating with little loss of area and mass, but will eventually disappear. They regard the islands as mostly lag material derived from sand and gravel sources that have now disappeared, and, as such, are irreplaceable. If removed, or greatly reduced in volume, as by excavation of large quantities of borrow, they would not be replaced by natural processes, and their absence or reduction in size would affect the local oceanographic and biological regime. Use of the barrier islands and modern beach and spit deposits must be undertaken only with a full appreciation of the environmental consequences and a weighing of the benefits of the action against the short and long-term effects on the physical and biological environment.

Modern beaches, spits, and barrier islands described above are generally less than 3 m above sea level, and thus are swept by storms that are accompanied by surges as high as 3.5 m above sea level at Barrow and by waves described as much as 3 m high (Hume and Schalk, 1967). The storms occur when cyclonic disturbances move along the arctic or polar front and are most effective in the fall in years when the ice in the Chukchi Sea is far from shore. Major storms take place every few years. The greatest was that of October 3, 1963, when the Naval facilities on the Barrow spit were flooded with the loss or damage to 19 buildings and a dollar loss of more than $3,000,000 (Hume and Schalk, 1967). During this storm the Barrow spit was breached and major erosion took place along the cliffs southwest of Barrow where coarse beach material had been borrowed for use elsewhere. This storm in one day moved about 20 times the normal annual net sediment accumulation along the spit toward Point Barrow. The storms are, therefore, the major agent for erosion and deposition along the coast and they account for creation of new bars and islands and destruction of the old, and for opening and closing of passes between islands. Gravel in insignificant amounts is apparently placed along the top of cliffs by storms (Duguid, 1971).

The beach, bar, spit, and barrier island deposits freeze each winter, and in the higher, better drained areas, such as beach ridges, the frozen sand and gravel is locally dry and can be dug throughout the winter. Elsewhere, it is firmly cemented with ice. Permafrost has developed in these young sand and gravel deposits, and ice wedges are being formed by filling of winter frost cracks.

Radiocarbon dating of the Point Barrow end of the spit has been done by Pewe and Church (1962) and by Hume (1965) (U, V, table 2, fig. 4). Southwestward, at one of the breaks formed during the 1963 storm, Brown and Sellmann (1966) dated the upper, middle, and lower 25 cm of a 1.5-m core in frozen peat (Y, table 2, fig. 4). Hume (1965) states that the former Eskimo settlement at Birnirk, at the base of the spit, was in existence as early as 500 A.D., but because it is now partly submerged, the archaeological site must have been 2 m higher above sea level when it was occupied, or that sea level was 2 m below that of the present during the time of occupancy between 500 and 1,000 A.D. Hume finds that the age of the high beach ridge at Point Barrow, indicative of a sea level 0.6 to 1.0 m higher than the present must have been formed later than the youngest sample (V, table 2, fig. 4) dated by Hume (1965) which is 1,700 years, or about 265 A.D. He further finds that the next younger beach ridge must be younger than 1,100 years (865 A.D.) based on data reported by Pewe and Church (1962), and acknowledges conflict with the period of the low sea level during occupancy of Birnirk within this interval. The fact that Birnirk is partially submerged suggests a rise in sea level since it was occupied between 500 and 1,000 A.D. Dating of the freshwater bog deposits (Y, table 2, fig. 4) 1 km northeast of the base of the spit (Brown and Sellmann, 1966) at 2,650 to 4,570 years ago (700 to 2,600 B.C.) suggests that the ocean encroached on the bogs after that time, or, that sea level rose and the bogs were buried. Thus, the sea level has been close to that of the present for at least 2,000 years, but in general a net rise since some time before 6,450 years ago is recorded in the Barrow area. Lewellen (1972b, p. 168) agrees, based on fluvial deposits and levels along Avak Creek, that sea level has not been more than 1 m higher nor more than 2 m lower in the past 2,650 years.

Pleistocene beaches, bars, and barrier islands

The highest ground in the Barrow quadrangle lies along the Chukchi Sea, 1 to 4 km south of Barrow, angling inland from the coast to a point about 15 km south of Barrow. This ground is as high as 17 m above sea level. Exposures in the sea bluffs (fig. 5) and data from seismic shot holes and borings indicate that the material is largely gravel and sand that is underlain by older fine-grained marine deposits. The gravel and sand is well stratified and locally cross bedded and seems similar to a beach or offshore bar deposit, perhaps like the present Barrow spit. Wood and peat contained in both the gravelly and underlying fine-grained deposits are too old to be measured by the radiocarbon-dating method (O and T, table 2, fig. 4), and other samples were near the limit of the method (E, L, and S, table 2) (Coulter and others, 1960; Sellmann and Brown, 1973). Shells (FF, table 2, fig. 4) from the gravelly material have been dated at 31,200 years, which Brigham (1983a) believes is a minimum age for deposits which she designates as the Walakpa beds of the Gubik Formation, and correlates with the Pelukian (Sangamon interglacial) deposits of the Bering Strait region (Hopkins, 1967b; Brigham, 1983b).

At Barrow airport, on the northern end of the high ground, a shoreline at an elevation of about 10 m above sea level appears cut into the higher deposits. Although the deposits resemble a shoreline in many ways, Hussey and Michelson (1966) point out an alternate interpretation under which these gravelly sand deposits on low slopes could be marginal deposits of thaw lake basins, rather than ocean shorelines. The 10 m shoreline cannot be traced far, but it is at the same elevation above sea level as the barrier island chain (fig. 2) which extends east-southeastward from the Barrow area toward Dease Inlet. A younger shoreline at Barrow is the "inland" or "Central Marsh Ridge" shoreline, 7 to 8 m above sea level that extends from Browerville eastward around Central Marsh to Elson Lagoon in a recurved pattern similar to the end of the Barrow spit. It is not clear whether the barrier island chain (fig. 2) should be connected with this shoreline, or with the one at 10 m near the airport.

Radiocarbon dates of the 7- to 8-m shoreline around Central Marsh show that the organic material in surface soils ranges from 8,500 to 11,000 years old, and that material collected from near the top of the deposits was dated at about 18,500 years (Brown, Everett, and others, 1980, fig. 1-6; not listed in table 2). Samples within the beach gravel were split and sent to two laboratories; they were dated 25,300 and older than 44,000 years (L, table 2), and the sandy marine deposits beneath the beach gravel were 36,000 to 37,000 years old (L, table 2, fig. 4) (Sellmann and Brown, 1973, fig. 4). These dates led Sellmann and Brown to postulate a mid-Wisconsinan transgression about 35,000 years ago followed by uplift, regression, and deposition of the 7- to 8-m Central Marsh beach about 25,000 years ago. Field studies and collection of additional radiocarbon samples are underway to test the validity of these dates and the historical reconstruction of Sellmann and Brown.

Marine silt and clay

Marine silt and clay, including minor sandy lenses, and a glaciomarine facies containing erratic boulders, cobbles, and pebbles of eastern provenance (Canada or Greenland) lie beneath much of the Barrow quadrangle. Because of its widespread extent and fairly consistent elevation with respect to sea level, the deposits of this type were grouped together as the Skull Cliff unit of the Gubik Formation by Black (1964). More recent work (Williams and others, 1977, 1978; Carter and Robinson, 1981; Carter, 1983a) has disclosed that the marine silt and clay east of Point Barrow forms a surficial map unit that is younger than Pelukian barrier islands and an apparently related beach deposit and that its fossils are like the modern fauna. On the other hand, the deposits of the Chukchi Sea cliffs (fig. 5) lie beneath the Pelukian deposits and contain a few marine fossils that are either extinct or beyond their modern geographic limits; their age is estimated (Brigham, 1983a) to be early Pleistocene to late Pliocene.

Silt, clay, fine sand, sand, organic material, and glaciomarine deposits make up the silt and clay unit which is being rapidly eroded along the Beaufort Sea coastline. The deposits have been considerably modified by thaw-lake activity, and in many areas, the bottom of the lake basins extend below sea level. The main areas of exposed marine silt and clay are near the Cape Simpson Dewline Station and at the Kachiksuk Bluffs west of Christie Point; elsewhere the deposits are either below sea level or are exposed in the lower meter or two above sea level, where they are generally masked by slumped or caved material.

The marine silt and clay unit contains cobbles and boulders of rock types described by Leffingwell (1908, 1919) as characteristic of the Flaxman Formation at Flaxman Island far to the east along the Beaufort Sea coast. The locations of boulders in the Barrow quadrangle (table 3) are shown on figure 3; however, the impression conveyed about their density and distribution is biased because of the large number of observers near Barrow and the few elsewhere (MacCarthy, 1958). With some exceptions, most of the boulders seem localized in the area of marine silt east of Barrow, and along the Chukchi Sea shore where a much older marine and glaciomarine silt is exposed in the sea cliffs (fig. 5). The boulders are found as high as 30 m above sea level in the adjacent Meade River quadrangle (Williams, 1983a).

The coastal bluffs near Cape Simpson (J and BB, fig. 4) have been measured as follows by L. D. Carter:

Coastal bluffs near Cape Simpson

Unit 7 (top) — 0.25 to 0.50 m. Clay, olive-brown. Contains erratic pebbles, cobbles, and boulders. Appears to be a slope deposit derived from the low hill that lies behind the sea bluffs.

Unit 6 — 0 to 1.2 m. Peat and ice-rich organic silt and clay. Complex; highly deformed by ice wedges. Peat at base of unit is 6,000 to 7,000 yr old (see table 2). Peat at the top of the unit has radiocarbon dates of about 10,000 yr B.P. and has apparently been transported from a knoll immediately behind the bluff and redeposited at its present site.

Unit 5 — 0 to 1 m. Sand, pebbly, with some silty to clayey zones. Discontinuous. Contains shell fragments but no whole valves observed. Chunks of peat with small twigs occur locally at base, and may indicate redeposition. Microfossils.

Unit 4 0 to 0.30 m. Very fine sand, olive brown, discontinuous. Ostracodes.

Unit 3 1 to 2 m. Clay, gray, with sand stringers and lenses. Contains striated erratic cobbles and boulders in basal part of unit. Contains marine mollusk shells (listed in table 4) and microfossils.

Unit 2 1 to 2 m. Fine sand, brown, with layers, lenses, streaks, and blebs of clay. Pebbly in places. Contains marine mollusks (listed in table 4), but is barren of microfossils.

Unit 1 (base) Greater than 1 m (base not exposed). Clay, gray to olive-brown. Contains microfossils and marine mollusks (listed in table 4).

The section at Cape Simpson demonstrates at least three and perhaps four marine transgressions. Units 1 and 2 are the earliest recorded transgressive events. The fauna of units 3 and 4 indicate that these units are a transgressive-regressive couplet; unit 3 was deposited in water 10 m or more deep, and unit 4 is a nearshore, shallow-water sand. Units 3 and 4 are the Flaxman Formation (Leffingwell, 1919; Hopkins and Hartz, 1978). Unit 5 is probably a regressive beach deposit formed during the retreat of the Flaxman sea. However, unit 5 may alternatively be interpreted as a younger marine deposit, inasmuch as a 15-cm clayey sand to silt containing fine roots and blebs up to 2.5 cm in diameter of fine peat occurs at the top of unit 4 where overlying beds have been removed by mass wasting. This organic bed at the top of unit 4 contains plant debris and insect parts but lacks marine microfossils and is interpreted to be a paleosol. However, it could not be traced laterally to confirm that a subaerial horizon stratigraphically separates units 4 and 5, and that unit 5 must be a marine deposit distinct from and younger than the Flaxman.

The Kachiksuk Bluffs and the Christie Point area are the second major area of outcrop of marine silt, including the Flaxman glaciomarine deposits (Hopkins and Hartz, 1978). As described by Black (1964, p. 69) the bluffs consist of a sandy clayey silt unit with some lenses of coarser sediments, the gravel members of which contain erratic clasts such as dolomite, red granite, and quartzite. In 1946 Black (field notes) measured the section as follows:

> 0 to 0.3 m (top), active layer consisting of peat, brown silt; 0.07 to 0.10 m thick, and basal peat; ice-rich peat and silt; yellow-brown silt; olive-brown silt having 30 to 40 percent ice; and 0 to 1.83 m of gray silt that dips northwestward from the bench mark into the sea. The top of the gray silt (Black's Skull Cliff unit) is 2.44 to 3.05 m below the top of the bluff.

In 1978 Carter examined a part of the bluff that is 5.2 m high and found clay exposed from the base to 60 cm above the base where it was overlain by 3.9 m of silty very fine sand with scattered pebbles and containing a 15-cm-thick bed of clay; turf 15 cm thick was at the top of the bluff.

Lewellen (1972b) collected a radiocarbon sample (Z, table 2) that reportedly came from 2.1 m below the land surface in Kachiksuk Bluffs (fig. 4), in that part of the 3.7-m thick section that is composed of thaw-lake deposits; the 9,330-yr date is similar to dates of thaw-lake deposits elsewhere on the coastal plain.

Marine sand

The term marine sand is applied to the sand and silty sand containing scattered pebbles of quartz and chert and organic matter that form the surficial deposits of areas that are generally higher than 10 m above sea level. Marine sand continues northward into the Barrow quadrangle from the Teshekpuk (Carter, 1983a) and the Meade River quadrangles (Williams, 1983a). Over that part of the map unit occupying ground less than 12 m above sea level, exposures are not good enough to allow direct determination of the presence of marine sand beneath the surficial peat and silt. However, the presence of marine sand is inferred because the beaches of some of the lakes are composed of pebbly sand that locally contains marine shells. In some locations, however, as at Walakpa Test Well 1 (26, table 1, fig. 1), foundation borings encountered fine silty sand or silt at shallow depth beneath the turf. The northern limit of the marine sand unit is the former chain of barrier islands (unit Qb, fig. 2) that separates it from the marine silt and clay unit.

Pebbly sand about 2.4 m thick covers the offshore bar or beach deposits along the sea coast south of the Barrow airport. Elsewhere, in the Barrow area, the sand (and underlying marine gravel of the former bar), named the Barrow unit of the Gubik Formation by Black (1964), is known through drill-hole records and coastal exposures to cover marine silt and clay which locally contains stones of glaciomarine origin--the Skull Cliff Unit of the Gubik Formation of Black (1964). The contact between the upper marine sand unit and the lower marine silt unit was delineated from seismic shot holes by Black (1964, fig. 11), from coastal exposures (fig. 5), and from drilling by the U.S. Army Cold Regions Research and Engineering Laboratory along a transect from Barrow eastward to Elson Lagoon and at other locations (Sellmann and Brown, 1973). Subsurface data that would identify the character of unconsolidated deposits beneath the marine sand are not available inland. In the adjacent Meade River quadrangle the sand mantles marine gravel, clay, and Cretaceous bedrock in exposures along the Inaru River.

A part of the sand may be a sand sheet of Wisconsin to Holocene age, a part of the extensive sand sheet that covered the coastal plain (Carter, 1981a, b, 1983b, c), but the thickness of any such deposit is not known, owing to the lack of exposures.

Eolian sand

Modern eolian activity is limited to a few small dune areas and related blow outs in a former lake bed in the southwestern part of the map area. However, the upper meter of the marine sand may have been reworked by the wind during past periods of increased aridity, the most significant of which was late Wisconsinan time (Carter, 1981a, b, 1983b, c).

Alluvial deposits

Alluvial deposits, chiefly sand with minor silt and gravel, border most of the small streams and underlie their beds. Generally, however, the deposits from too narrow a zone to be shown on the map, and their thickness above underlying marine deposits is generally too little to be of significance as a source of materials. The deposits form floodplains and low terraces and are shown principally along Avak Creek, where they have been described in detail by Lewellen (1972b).

Thaw-lake deposits and the thaw-lake cycle

Away from rivers and streams the thaw-lake cycle is perhaps the dominant form of landscape modification in the permafrost environment of the western part 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; Britton, 1957; Brewer, 1958a; Livingstone and others, 1958; Carson and Hussey, 1960, 1962, 1963; Brown, 1965; Hussey and Michelson, 1966; Carson, 1968; Black, 1969, 1976; Morrissey, 1979, and others). Thaw lakes have been classified (Sellmann and others, 1975) into several categories, of which the Barrow quadrangle has large to intermediate-sized lakes with moderate to well-developed orientation (10^{o} to 15^{o} west of north).

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 marginal 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 either intercepts and is drained to another 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, about 3.4 m in the Barrow area (Hussey and Michelson, 1966). Lakes are oriented with their long axes normal to the prevailing east-northeast and west-southwest winds as a result of wind-induced waves and currents which build protective shelves on the downwind shores and concentrate erosion on the north-northwest and south-southeast shores (Carson and Hussey, 1962). Once drained, the lake bed is refrozen and a new generation of ice wedges and ice-rich permafrost may be formed, which could, in time, regenerate a new cycle of thaw lakes. The parts of the initial surface that have been unaffected by the thaw-lake cycle are called initial surface residuals, and, as is shown later, have a higher ice content than do 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), Black (1969), Lewellen (1972b), and Sellmann and others (1975).

Deposits within the thaw-lake basins depend upon the materials available for redeposition in the bed and banks, and therefore have grain size parameters similar to those of the map unit in which they occur. 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 materials that grew _in situ_ in the lake basin. Carson (1968, fig. 4) illustrates sections through thaw-lakes 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 dating of thaw-lake deposits is difficult (Brown, 1965).

Radiocarbon studies of thaw-lake deposits near Barrow show that the oldest dated deposit is 12,160 years old (Lewellen, 1972b; Sellmann and others, 1975; Brown and others, 1980; table 2, fig. 4). The deposit is exposed along Footprint Creek and consists of organic silt that immediately overlies marine sand.

SOIL DEVELOPMENT

Soils of the Barrow area have been under investigation by J. C. F. Tedrow (1977) and many of his students for more than 25 years. Drew (1957) identified four major soil types near Barrow; the rare arctic brown soil on well-drained sites; meadow tundra; upland tundra; and bog soils. Each soil type has wet, normal, and dry phases. Soils investigations were combined with permafrost, radiocarbon, and geologic investigations by Brown and Sellmann in a program undertaken by U.S. Army Cold Regions Research and Engineering Laboratory. This study also included special emphasis on the ice wedges and the geochemistry of ground ice, as well as on arctic hydrology. The relation between soils, ice content of surficial deposits, microrelief, lakes, and tundra vegetation has been studied by Hussey, Carson, O'Sullivan, and others of Iowa State University.

Organic horizons in the soils near Barrow are interpreted to consist of peat that has been cryogenically worked into the soil, possibly down ice-wedge cracks, or by heaving processes, rather than by burial in a sequence of wind- or water-laid deposits (Brown, 1969b). Three generations of buried peat were recognized by Brown along the transect between Barrow and Elson Lagoon: 9,155 to 10,430 years, 6,690 to 7,860 years, and 2,450 to 4,595 years based on seven dates at locations F, CC, DD, and EE (table 2, fig. 4). The youngest peat occurs over active ice wedges. Brown (1969b, p. 165-166) concluded that the tundra soils have a wide variation between deeply-thawed sandy soils and organic-rich soils that thaw only a few cm each summer. The average seasonal thaw for 80 locations was between 33 and 43 cm. Differences in depth of seasonal thaw are apparently related to the differences in moisture content, which depend on the differences in organic content. But, no correlations were discovered between micorelief and thaw depth and moisture content. Chemical depletion of permafrost is apparently related to freshening of lake-bottom sediment that has been refrozen subsequently, or, it has been accomplished by sustained leaching of soils in the thawed condition.

PERMAFROST

Permafrost, or perennially frozen ground, is defined as earth materials having a temperature below $0^{o}C$ for two or more years. The permafrost is considered continuous (Black, 1954b), if (1) its temperature at the level of zero annual amplitude is lower than $-5^{o}C$, (2) its areal extent is unbroken by zones having a temperature of $0^{o}C$ or above, and (3) its thickness is great over a large area. The prime example of the continuous-permafrost zone is the Barrow area where numerous geothermal studies (MacCarthy, 1952; Brewer, 1958b;

Lachenbruch, 1957a, b, 1959, 1962; Lachenbruch and others, 1962; Lachenbruch and Marshall, 1969; Gold and Lachenbruch, 1973) have been undertaken. With the advent of oil exploration, the thickness of ice-bearing permafrost became of practical importance in interpreting surface and downhole geophysical records and logs. The difference in depth between the base of ice-bearing permafrost and the $0^{o}C$ isotherm depends on freezing-point depression of the pore water in the formation caused by pressure, chemical (salt content), and soil particle effects (Osterkamp and Payne, 1981, p. 14). For example, the greatest thickness of permafrost recorded in the Barrow quadrangle is 405 m (7, table 1, fig. 1) based on geothermal measurements (Brewer, 1958b), but the thickness of ice-bearing permafrost is only 360 m in the same well (Osterkamp and Payne, 1981). Osterkamp and Payne suggest (1981, fig. 2), despite an admission of inadequate information, that the Barrow quadangle probably has more than 300 m of ice-bearing permafrost in locations that are remote from the thermal disturbance caused by the ocean and lakes. They also point out that ice-bearing permafrost thins rapidly or is absent off the stable Chukchi Sea coast, a statement that agrees with early work by MacCarthy (1952) and Brewer (1958b). These authors noted that permafrost at Barrow thins from 405 m beneath a point 13 km from the Chukchi Sea coast (7, table 1, fig. 1) to 305 m at a point on land 355 m from shore, and 204 m about 118 m from the shore. They concluded that ice-bearing permafrost does not exist beneath the Chukchi Sea floor more than a few hundred m from shore, assuming that the pore water has the salinity of sea water. A 96-m hole, drilled 115 m offshore near the Naval Arctic Reseach Laboratory (near Point Barrow airfield on maps) is entirely in permafrost (below $0^{o}C$), except for the upper few meters. The driller's log, however, indicates no ice-bearing permafrost, except possibly between 29.5 and and 61 m. By contrast, the rapidly-eroding Beaufort Sea coast has subsea permafrost. Drill holes and temperature measurements by Lewellen (1973, 1974, 1977b) in traverses across Elson Lagoon (62-65, table 1, fig. 1) have shown the presence of negative temperatures and ice-bonded permafrost beneath the barrier islands where the ground water is relatively fresh.

Lakes and streams also affect the thermal regime of underlying permafrost. Based largely on studies by Brewer (1958a), a commonly used rule of thumb has been developed that states that lakes deeper than 2 m have a perennial thaw bulb beneath their beds, and those less than this depth freeze to the bottom each winter and refreeze the active layer in the sediments beneath the lake, although even these shallow lakes will affect underlying permafrost temperatures. This rule is of importance in the search for winter water supplies, either from unfrozen lake or stream water below the ice cover or from unfrozen sediments below the lake or stream. Experience has shown, however, that these sources are quite limited in volume by mid-winter and that the dissolved-solids content of the water has been considerably, and often unpleasantly, increased by concentration of these solids during the annual freezing process. Side-looking radar techniques (Sellmann and others, 1975; Sellmann, Weeks, and Campbell, 1975) have potential for identifying water bodies that do not freeze to the bottom in winter.

Geothermal studies of heat-flow (MacCarthy, 1952; Lachenbruch, 1957a, b, 1959; Brewer, 1958a, b; Lachenbruch and others, 1962; Lachenbruch and Marshall, 1969) based on many years of temperature measurements in abandoned oil exploratory holes near Barrow and Cape Simpson and in specially-drilled holes in the Barrow area have provided the data needed for development of basic theories about the origin of permafrost and its sensitivity to disturbance by lakes, the ocean, and man's works. These studies also demonstrate a stable coastline on the Chukchi Sea side of Point Barrow, and point to a 4°C increase in the mean annual surface temperature since the mid 19th century at Barrow, with perhaps a subsequent 1°C decrease in the decade prior to 1969.

Perhaps the most important practical consideration about permafrost is its ice content, particularly the amount expressed as a percentage of the volume of frozen material by which the ice content exceeds the natural voids in the material. Ice-saturated material and that which contain excess ice are both strongly bonded, but, in a few places, material undersaturated with ice may occur. The ice-saturated material and undersaturated material will not yield excess water upon thawing. On the other hand, material containing excess ice, either as wedges or as disseminated masses, blebs, and lenses, will produce excess water which can render the thawed material a slurry subject to flowage and liquefaction and which generally produces settlement of the ground because of the excess volume of ice and the volume change from ice to water on thawing and runoff of the excess water.

Non-wedge ice that occurs as lenses, layers, blebs, and large grains is apparently formed by water migration to the freezing front as permafrost formed perhaps in the manner described by Taber (1943). Non-wedge ice is widespread, and, according to Hussey and Michelson (1966), forms about 95 percent of the ground ice. They found that the non-wedge ice is in excess of the void volume of the permafrost from the top of permafrost down to about 6 m, below which the permafrost was saturated or undersaturated by ice. Similar studies by Sellmann and others (1975, p. 14-18) revealed that wedge-ice content was 10 to 20 percent of the total amount of ground ice and that the excess ice not including wedge ice decreased from about 75 percent of the volume of the frozen sediments at a depth of 1 m to zero at about 8.5 m. The figures developed by Hussey and Michelson (1966) for excess ice are expressed as percentage of volume as settlement and as minimum action settlement in meters in four types of terrain, not including the five percent of ice as wedges:

	Initial surface residual (high surface showing no thaw-lake activity) (33, table 1, fig. 1)	Ancient drained thaw lake	Recently-drained lake (34, table 1, fig. 1)	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

As has been noted elsewhere the above estimates show that the thaw settlement possible from the ice-rich permafrost beneath initial residual surfaces is adequate to create thaw lakes and depressions in the flat coastal plain.

Ice wedges are produced by the formation of thermal contraction cracks in winter and subsequent filling of the cracks with hoar frost, snow, and meltwater. The vertical to near-vertical cracks tend to form at the same sites each winter, and repeated cracking and filling form wedges that can be as large as several meters across at the top, tapering downwards to apices that can be deep as 10 m (Leffingwell, 1919; Lachenbruch, 1962; Black, 1974, 1976). The wedges intersect to form a reticulate surface pattern enclosing polygons 5 to 30 m in diameter. The polygons can be high or low centered, or flat (Black, 1974). Active wedges extending downward from the top of the permafrost table can be contrasted to relict or fossil ice wedges which are still present at some depth below the top of permafrost, but are apparently now inactive. Studies of the ice content of the ground in an area of ice wedges indicate that wedge ice makes up less than 5 percent (Hussey and Michelson, 1966) to 8 percent of the ground volume (Sellmann and Brown, 1975) or even 10 to 20 percent (Sellmann and others, 1975). Ice wedges grow at such a slow rate that those 1 to 3 m wide studied by Black (1974, fig. 25) are 3,400 years old, ages that seem consistent with the radiocarbon dating by Carson (1968), Brown and Sellmann (1973), Sellmann and Brown (1973), according to Black (1974, p. 270).

Brown (1965) has summarized studies of three generations of ice wedges on an initial surface residual that is probably part of the Central Marsh beach ridge complex, located east of Esatkuat Lagoon (H, table 2, fig. 4). The largest complex ice wedge contains organic material, apparently fallen from the ground surface through the contraction crack during formation of the wedge; this material is 8,200 to 14,000 years old (H, table 2). A peat horizon above the wedge is 10,525 years old (H, table 2). The top of this wedge is beveled off at a depth of about 3 m, suggesting thaw due to surface disturbance or climatic warming. The large wedge occurs in a soil in which the matrix is generally ice poor. The refrozen soil above the top of the large wedge, however, is ice rich and contains smaller ice wedges. One of these, a small fissure-like wedge, is adjacent to an elongated mass of peat that was derived from an overlying zone of buried peat. The peat is 9,550 years old (H, table 2), and the peat that overlies the near-surface active ice wedges is 1,775 years old (H, table 2). Pewe and Church (1962) found that small active ice wedges at Point Barrow were younger than the beach gravel dated at about 1,100 years (U, table 2, fig. 4). Black (1974, fig. 25, p. 270) provides a method for estimating age of ice wedges based on their percentage of cracking, their width, and the average annual increment of ice added. Apparently his results are reasonable with respect to radiocarbon dating by Carson (1968), Brown and Sellmann (1973), and Sellmann and Brown (1973). Using an average increase in the width of ice wedges of 1 mm per year, the larger wedges of the Barrow area may grow in 5,000 to 7,000 years (Black, 1974, p. 274).

Although the permafrost is continuous vertically and laterally, the ice-bonded permafrost is broken by lenses or zones of brine, so concentrated in salts that it remains liquid at temperatures well below $0^{\circ}C$. Imikpuk Lake, for example, some 5 km north of Barrow, is the water supply for the Naval Camp on the Barrow spit. The lake is separated from the Chukchi Sea by a 3-m high gravel ridge beneath which the ice-bearing permafrost extends about 10 m to an unfrozen layer having a brine that is saline enough to remain liquid at temperatures below $-7^{\circ}C$ (Brewer, 1958a, p. 259). The saline water beneath the gravel ridge is apparently hydraulically connected to that beneath the sea floor and to saline water beneath the fresh surface water of Imikpuk Lake. A 59-m deep hole drilled in the lake bottom did not reach ice-bearing permafrost until a depth of 56 m, suggesting that the thermal effect of the lake, which is locally deeper than 2 m, and the high salinity of the ground water have combined to prevent ice formation to that depth. Similar fresh water on salt water has been noted at 5-m deep Nuwuk Lake at Point Barrow (Mohr and others, 1961) and in Sinclair Lake near Cape Simpson where the minimum ground temperature of -2.7°C would have been too high to freeze the ground if the ground water had the same salinity as that of the lake (MacCarthy, G. R., cited by Williams, 1970, p. 61). Thus, within the coastal belt of large lakes, lagoons, and unstable shoreline east of Point Barrow, the pattern of ice-bearing permafrost is probably more complex, windows of unfrozen ground more common, brines and stratified fresh/saline lakes more common than in the inland areas, some 8 km or so back from the coast.

Studies of the ionic concentration gradient in permafrost at the U.S. Army Cold Regions Research and Engineering Laboratory research transect extending from the lagoon at Barrow eastward toward Brant Point show that none of the salt concentrations approached those of the modern lagoons (Brown, 1969c, p. 6). In fact, some samples from drained lake basins show relatively low concentrations, as though the soil was freshened by lake water before being frozen, even below sea level. High ground along the traverse, on the other hand, retained relatively high concentrations to within 1 to 3 m of the surface, suggesting a lack of major thawing of the permafrost since deposition of the sediments. Seasonal frost has 24 times fewer extractable ions than underlying permafrost (Brown, 1969c).

FLOODS AND STORM SURGES

Discharge records for Nunavak Creek, Esatkuat Creek, and Esatkuat Lagoon near Barrow, measured by the Geological Survey during 1972-1976, included years having 48 to 167 percent of normal precipitation (Dingman and others, 1980, table 2-6). A hydrograph of Avak Creek (Lewellen, 1972b) for 1968 illustrates the creek stage and the tidal fluctuations at the gaging station. The records are too short for flood-frequency analysis and for estimating maximum flood events during the breakup or during heavy rains in fall storms. During the years of measurement more than half the annual runoff was concentrated in periods ranging from 5 to 13 days in June, and the maximum daily runoff as a percentage of the annual runoff ranged fom 8 to 14 percent (Dingman and others, 1980, table 2-6). The streams in the Barrow quadrangle are small, have low gradients, and generally have drainage areas less than 10 sq km. These small brooks, from all information available, flood the low terraces and their bottomlands or floodplains during the snow-melt period when most of the thaw-lake basins and lakes are at a high stage.

Storm surges generally accompany late summer or fall cyclonic storms when the arctic ice pack is far from the coast. The storms are intense low pressure areas which tend to raise sea level, and the strong southwest to west winds pile the water onto shore, raising sea level even more. The total surge in sea level may be as much as 3.5 m (Hume and Schalk, 1967) as it was during the October 3, 1963 storm. During a storm in 1954, the surge was 2.7-3.0 m. The height of these surges is indicated by driftwood and windrows of smaller vegetation along gullies that indent the cliffed coastline and along low-lying shores. The 1963 storm damage at the Government camp on the spit, which was nearly completely inundated, was about $3,000,000, including contamination of the water supply lake, destruction of the airstrip, and loss of six buildings and damage to others (Hume and Schalk, 1967, p. 96). In Barrow village 17 houses were badly damaged and 15 were completely destroyed, many because of the severe bluff erosion by the high waves. Also, an oil tank and its contents and several airplanes were destroyed. In addition, many changes were made in the configuration of the shorelines, on the cliffs along Chukchi Sea, in Barrow spit, and in the barrier islands east of Point Barrow. Hume and Schalk (1967) calculated that at least 20 times the normal annual load of sediment had been deposited on the west side of the Barrow spit, but that even more had been carried through the breached areas of the spit and carried seaward beyond Point Barrow.

Cliff erosion is accomplished by high sea level and large waves and is probably several times more rapid during these storms than during normal years. Average values of coastal retreat have been determined by comparison of 1949 aerial photographs and those taken later (Lewellen, 1970; Hartz, 1978). Although the erosion of the seabluffs along the Chukchi coast was about 3 m during the 1963 storm, the average coastal retreat in this area is 0 to 2 m, based on comparison of photographs. The south shore of Elson Lagoon and the mainland coast eastward to Cape Simpson are undergoing attack by the thermo-erosional processes in which cliffs are rapidly undercut by thawing of ice-rich permafrost and removal of sediment by small waves. Eventually the removal of material at water level extends horizontally beneath the bluff so far that the weight of the overhanging frozen material collapses the bank, commonly along an ice wedge crack. The process has been described by Hartz (1978), and by Lewellen (1965, 1970, 1972a, 1977a), who estimated that the erosion rate along the Beaufort Sea coast is 2-6 m/yr at Point Barrow, less than 1 m/yr in Elson Lagoon west of Tekegakrok Point, where protected by a bar from the point north-northwestward to Barrow spit; 2-6 m/yr eastward from Tekegakrok Point to near Cape Simpson airstrip, where it is slightly greater than 6 m/yr. Points and promotories are subject to even more rapid erosion, e.g., the 10 m/yr recorded on Ross Point (Lewellen, 1972a).

ECONOMIC GEOLOGY

The area of the quadrangle, which is entirely within National Petroleum Reserve--Alaska, has been examined by geophysical methods for potential structural and stratigraphic traps that might yield economic amounts of oil and natural gas. This work led to drilling of 34 holes, including 7 core tests, 14 gas wells, 10 dry holes or holes having small shows of gas or oil, 3 edge or marginal gas wells and no oil wells (Bird, 1982) south and southeast of Barrow and along the coast toward Cape Simpson, following the axis of the Barrow arch (Table 1, fig. 1). Basically, three gas fields were found, the south Barrow field (originally 25 bcf), currently in production located on a structure on the west side of the "disturbed zone" (an area of faulted and folded rocks within the area mapped as pebble shale, fig. 1), the East Barrow field (12.5 bcf), in reserve, on the east side of the disturbed zone, and a potential gas field still to be evaluated by further drilling around Walakpa test well 2 (27, table 1, fig. 1) south of Barrow. Production is from the Barrow gas sand of Jurassic age that lies at depths of 648 to 832 m, beneath the Cretaceous pebble shale and the Torok Formation (table 1). Lantz (1981), Kirschner (1983), and Bird (1983), among others, have described the history of development and details of the field and its production problems. Under the

National Petroleum Reserves Act (P.L. 94-258), the Congress mandated that the Department of the Interior provide a supply of natural gas to the city of Barrow, and, for this reason, these small gas fields of 12 and 25 billion cubic feet are being utilized, even though not economical for development for export from the region. Data on the U.S. Geological Survey investigations on behalf of the Department of the Interior and on previous exploration programs have been placed on open file with the Environmental Data Service of the National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado; much information is also available in Geological Survey reports, e.g., logs of the test holes in Bird (1982).

Coal, largely of subbituminous rank, occurs in the wedge of marginal marine to nonmarine sedimentary rocks of the Nanushuk Group of Early and Late Cretaceous age, but is neither an important constituent of the overlying Colville Group nor of the underlying marine Torok Formation (fig. 1). Although the Nanushuk group rocks contain much coal in the adjacent Meade River quadrdangle (Martin and Callahan, 1978; Williams, 1983a), none has been noted in outcrops in the southwestern part of the Barrow quadrangle nor in borehole records within the area of outcrop of Nanushuk rocks (fig. 1). Except for these outcrops, the bedrock is concealed beneath 10 to 41 m of frozen unconsolidated deposits which would make prospecting and development difficult.

Bedrock, as mentioned above, is buried by at least 10 m of unconsolidated deposits except for small exposures in the coastal bluffs in the southwestern corner of the quadrangle (fig. 5). These exposures consist of shale, sandstone, and clay. Although no tests have been done on the sandstone, it is probably neither strong enough nor abundant enough to serve as a source of rip rap, crushed stone, or dimension stone.

Gravel resources of the Barrow quadrangle are in short supply, largely because the widely scattered small deposits onshore are frozen and commonly buried by overburden and because development of the limited beach, bar, and barrier island deposits creates adverse environmental impact to the delicate littoral system. Past gravel borrowing from the beach southwest of Barrow has apparently resulted in removal of material protecting the sea cliffs and has accelerated bluff retreat during storms (Hume and Schalk, 1967). Borrow of gravel from the Point Barrow spit had been halted for fear that the material would not replaced and its loss would alter littoral processes (LaBelle, 1973). LaBelle has made a careful, quantitative survey of baymouth bars, high parts of islands, and has suggested certain inland sites (fig. 3) for future development of gravel needed for construction projects at Barrow. The most promising of LaBelle's sites are the barrier islands, particularly Cooper Island. However, Hopkins and Hartz (1978) regard the offshore barrier chain as a set of individual migrating sediment cells that are not losing or gaining sediment across the passes that separate them; therefore, removal of any sediment from these islands is bound to affect the size and shape of the island as it migrates.

The largest onshore source of gravel appears to be the former offshore bar or spit deposit which is exposed in the sea bluffs from Barrow airport to a point 4 km south, and which is suggested by subsurface data to extend about 15 km south of Barrow, though largely covered by frozen overburden. This deposit has already been opened in the pits south of Barrow airport.

Extensive development in this area would require consideration of the effect of gravel removal on bluff retreat, of the cost of confirmatory test drilling, and consideration of the time and money required for thawing of the deposit and stripping and removal of the overburden. Quite likely, the cost would be greater than the cost of obtaining gravel from one of the barrier islands, even from a source as far away as Cooper Island.

LaBelle (1973) suggested developing sand and gravel beneath certain artificially drained lakes, such as Footprint Lake and one other near Barrow which he believed would yield 765,000 m^3 of material. Certainly this kind of development could take advantage of the thawed condition of materials beneath a lake deeper than 2 m and could be combined with the development of a winter reservoir for storage of potable water pumped from a lake or stream during summer. A thorough subsurface investigation is needed to ensure a yield of materials of the desired quality.

Minor sources of sand, gravelly sand, and some gravel are the former barrier island deposits that lie parallel to the Beaufort Sea coast a short distance north of Lake Tusikvoak. These deposits are probably thin and lens shaped in plan and section, just as are the modern barrier islands. Other former barrier chains parallel to the one shown on figures 2 and 3, may be present nearer the shoreline of Elson Lagoon.

Sand is common throughout the Barrow quadrangle, but is mixed with silt in many areas, and locally contains pebbles. Relatively thick and extensive deposits of pure sand, like the dunes of the Meade River (Williams, 1983a) and Teshekpuk quadrangles (Carter, 1983a) are not present in the Barrow quadrangle. Within the map unit designated, "marine sand," the few exposures are limited to surface peat and thaw-lake deposits, and boreholes suggest that the sand may give way at shallow depth in many areas to fine-grained deposits. Sand also is plentiful, with lenses of fine gravel and silt, in littoral deposits, where the annual thaw approaches 2 m. Inland, however, the older beach, bar, and spit deposits are frozen fom 0.5 m downward, except in especially well-drained sites where the ground thaws to 1 to 2 m each summer.

Clay, as well as silt and silty clay, is exposed in the bluffs bordering the Chukchi Sea (fig. 5), generally near the base of the section. Its maximum thickness, 3.5 m, would be suitable as a source of binder, brick clay, or other uses, were it not for the 5 m or more of frozen overburden and the difficulty of working a cut without discharging suspended sediment into the ocean. The clayey deposits range from oily, plastic clay, to silty and sandy clay, and clay or silt containing erratic stones. Similar deposits are found at or below sea level along the shore of Elson Lagoon and have been noted at a depth of 2 to 7 m below sea level in drill holes at depth beneath the transect between Barrow and Brant Point (Sellmann and Brown, 1973, p. 173).

Peat is largely confined to the surface mat of living and dead vegetation that seldom exceeds 0.5 m in thickness. Peat sod has been used for building material, in the absence of any other, but it appears to have no special value because it is too thin to work economically.

WATER RESOURCES

Average annual precipitation at Barrow, the only meteorological station, corrected for estimated errors caused by windblown snow and rain and to sum the trace amounts, is approximately 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; see also Black, 1954a). The processes of heat balance and the effect on snow cover, evaporation, transpiration, microclimate, and hydrology are explained in some detail by Dingman and others (1980). Basically, runoff is concentrated during the breakup period in June when between 61 and 98 percent of the annual stream flow occurs during the snowmelt flood, as determined by scattered short-term gaging records on Esatkuat Creek and Lagoon, and Nunavak Creek. Heavy summer rains cause secondary peak discharges in some years. During the winter months streams 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, and the small amount of liquid water that remains unfrozen beneath occasional river channels and lakes that are deeper than 2 m or as 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 dissolved solids are concentrated in the unfrozen liquid as they are expelled during the freezing process. Techniques of deepening existing lake basins to create reservoirs that are capable of providing 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 Barrow quadrangle, although the water would have to be pumped in during spring high water in the small creeks (or diverted from these creeks) to provide enough to fill large reservoirs.

Potable 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 beneath lakes and rare stream channels that are deeper than 2 m, and except where the ground water is a brine so highly concentrated that it can remain liquid even at temperatures as low as -10°C. The brines noted by Brewer (1958a, b, p. 259) at places along the Chukchi Sea shore between Barrow and Point Barrow between 3 and 47 m below the surface were a problem in his geothermal studies of permafrost for which he used strings of thermistors in drill holes. The water in the bedrock beneath the base of the frozen layer, or ice-bearing permafrost, is generally saline throughout the quadrangle, where data were collected (Holes 4, 5, and 8, table 1, fig. 1) (Williams, 1970, table 3). Water in lakes within 8 km of the coast is commonly saline to brackish (Brewer, 1958a) and is stratified with a fresh layer on top, the salinity increasing with depth. In lakes of this type the thermal disturbance due to the body of water extends to a greater depth than would be the case if the water were entirely fresh and the freezing point were not depressed (Holes 31, 43, 66, table 1, fig. 1).

REFERENCES CITED

Aitken, G. W., 1965, Ground temperature observations, Barrow, Alaska: U.S. Army Cold Regions Research and Engineering Laboratory Technical Report 105, 15 p.

Arctic Institute of North America, 1974, The Alaskan Arctic coast, a background study of available knowledge: prepared for Department of the Army, Corps of Engineers, Alaska District, contract DACW-85-74-C-0020, 551 p.

Arnold, C. A., 1959, Some paleobotanical aspects of tundra development: Ecology, v. 40, no. 1, p. 146-148.

Batzil, G. O., and Brown, Jerry, 1976, RATE - the influence of grazing on arctic tundra ecosystems: Arctic Bulletin, Interagency Arctic Research Coordinating Committee, v. 2, p. 153-160.

Beal, M. A., 1957, Barrow sea valley study and tide gage installations: Arctic Institute of North America contract ONR-165 to Scripps Institute of Oceanography, University of California, Final Report, 22 p.

Benson, C. S., 1969, The seasonal snow cover of Arctic Alaska: Arctic Institute of North America Research Paper 51, 85 p.

____1982, Reassessment of winter precipitation on Alaska's arctic slope and measurements on the flux of wind-blown snow: Geophysical Institute University of Alaska, Report UAG R-288, 26 p.

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.

____1983, Oil and gas resources of the North Slope, Alaska (abs): U.S. Geological Survey Circular 911, p. 27-30.

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

____1952, Growth of ice-wedge polygons in permafrost near Barrow, Alaska (abs): Geological Society of America Bulletin, v. 63, no. 12, p. 1235-1236.

____1954a, Precipitation at Barrow, Alaska, greater than recorded: American Geophysical Union Transactions, v. 35, no. 2, p. 203-207.

____1954b, Permafrost - a review: Geological Society of America Bulletin, v. 65, no. 9, p. 839-856.

____1957, Some problems in engineering geology caused by permafrost in the Arctic Coastal Plain, northern Alaska: Arctic, v. 10, no. 4, p. 230-240.

____1963, Les coins de glace et le gel permanent dans le Nord de l'Alaska (Ice wedges and permafrost in northern Alaska): Annales de Geographie, v. 72, p. 257-271.

Black, R. F., 1964, Gubik Formation of Quaternary age in northern Alaska: U.S. Geological Survey Professional Paper 302-C, p. 59-91.

____1969, Thaw depressions and thaw lakes, a review: Biuletyn Peryglacjalny, v. 18, p. 131-150.

____1974, Ice-wedge polygons of northern Alaska, in, Coates, D. R., ed., Glacial geomorphology: Annual Geomorphology Series, 1974, 5th, Proceedings: Binghamton, New York, State University of New York, p. 247-275.

____1976, Periglacial features indicative of permafrost: Ice and soil wedges: Quaternary Research, v. 6, no. 1, p. 3-26.

____1983, Ice wedge diapirs, northern Alaska, are produced mainly by horizontal compression (abs.): Geological Society of America Abstracts with Programs, v. 15, no. 6, p. 527, Abstract 28622.

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

Boyd, W. L., 1959, Limnology of selected arctic lakes in relation to water-supply problems: Ecology, v. 40, no. 1, p. 49-54.

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

____1958b, Some results of geothermal investigations of permafrost in northern Alaska: American Geophysical Union Transactions, v. 39, p. 19-26.

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

____1983a, Marine stratigraphy and amino acid chronology of the Gubik Formation, western Arctic Coastal Plain, Alaska: U.S. Geological Survey Circular (in press).

____1983b, Correlation of Late Cenozoic marine transgressions of the Arctic Coastal Plain with those in western Alaska and Northeastern Russia (abs): U.S. Geological Survey Circular 911, p. 47-52.

Brigham, J. K., Hopkins, D. M., Carter, L. D., and Miller, G. H., 1980, Application of amino-acid geochronology to deposits of the Arctic Coastal Plain, Alaska; Preliminary results and implications: Ninth Annual Arctic Workshop, April 4 and 5, 1980, Institute of Arctic and Alpine Research, University of Colorado, Boulder, p. 34-35.

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

Brigham, J. K., and Miller, G. H., 1983, Paleotemperature estimates of the Alaskan Arctic Coastal Plain during the last 125,000 years: Fourth International Conference on Permafrost, Fairbanks, July 18-22, 1983, Proceedings, Washington, D.C., National Academy Press, p. 80-85.

Britton, M. E., 1957, Vegetation of the Arctic tundra: Arctic Biology, 18th Annual Biology Colloquium, Oregon State College, Corvallis, p. 26-61.

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

____1966, Ice-wedge chemistry and related frozen-ground processes, Barrow, Alaska: International Conference on Permafrost, Proceedings, National Academy of Sciences-National Research Council Publication 1287, p. 94-98.

____1967, Tundra soils formed over ice wedges, northern Alaska: Soil Science Society of America, Proceedings, v. 31, p. 686-691.

____1969a, Buried soils associated with permafrost: Symposium on Pedology and Quaternary Research, University of Alberta, Edmonton, Canada, p. 115-127.

____1969b, Soil properties developed on the complex tundra relief of northern Alaska: Biuletyn Peryglacjalny, no. 18, p. 153-167.

____1969c, Ionic concentration gradients in permafrost, Barrow, Alaska: U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Research Report 272, 24 p.

____1972, Buried soils associated with permafrost: Pedology and Quaternary Research Symposium Proceedings, Edmonton, Alberta, May 13-14.

Brown, Jerry, Dingman, S. L., and Lewellen, R. I., 1968, Hydrology of a drainage basin on the Alaskan Coastal Plain: U.S. Army Cold Regions Research and Engineering Laboratory, Research Report 240, 18 p.

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: Stroudsburg, Pennsylvania, Dowden, Hutchinson, and Ross, p. 1-29.

Brown, Jerry, and Johnson, P. L., 1965, Pedo-ecological investigations, Barrow, Alaska: U.S. Army Cold Regions Research and Engineering Laboratory, Technical Report 159, 32 p.

____1966, U.S. Army CRREL topographic map, Barrow, Alaska (1:25,000): U.S. Army Cold Regions Research and Engineering Laboratory, Special Report 101.

Brown, Jerry, and Sellmann, P. V., 1966, Radiocarbon dating of coastal peat, Barrow, Alaska: Science, v. 153, no. 3733, p. 299-300.

____1973, Permafrost and coastal plain history of Arctic Alaska: Arctic Institute of North America Technical Paper 25, p. 31-47.

Brown, Jerry, and others, 1962, Mineral composition of some drainage waters from Arctic Alaska: Journal of Geophysical Research, v. 67, no. 6, p. 2447-2454.

Carlson, P. R., Roy, C. J., Hussey, K. M., Davidson, D. T., and Handy, R. L., 1959, Geology and mechanical stabilization of Cenozoic sediments near Point Barrow, in, Davidson, D. T., Roy, C. J., and others, The geology and engineering characteristics of some Alaskan soils: Iowa State University Bulletin, Iowa Engineering Experiment Station, Bulletin, 186, p. 101-128.

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., 1959, The method of multiple working hypotheses applied to the oriented lakes of northern Alaska: Iowa Academy of Sciences, Proceedings, v. 66, p. 334-349.

____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, 13, and 14, 1981, Institute of Arctic and Alpine Research, University of Colorado, Boulder, p. 5-9.

____1983a, Engineering-geologic maps of northern Alaska: Teshekpuk quadrangle: U.S. Geological Survey Open-File Report 83-634, 1 sheet, scale 1:250,000.

____1983b, Fossil sand wedges on the Alaskan arctic coastal plain and their paleoenvironmental significance: Fourth International Conference on Permafrost, Fairbanks, July 18-22, 1983, Proceedings, Washington, D.C., National Academy Press, p. 109-114.

____1983c, A Pleistocene sand desert in Arctic Alaska (abs): U.S. Geological Survey Circular 911, p. 36.

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, 12, and 13, 1982, Institute of Arctic and Alpine Research, University of Colorado, Boulder.

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.

____1981, Minimum age of beach deposits north of Teshekpuk Lake, Alaskan Arctic Coastal Plain, in, Albert, N. R. D., and Hudson, Travis, eds., The U.S. Geological Survey in Alaska: Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B8-B9.

Colinvaux, P. A., 1964, Origin of Ice Ages; pollen evidence from Arctic Alaska: Science, v. 145, no. 3633, p. 707-708.

Collins, F. R., 1961, Core tests and test wells, Barrow area, Alaska: with a section on temperature measurement studies by M. C. Brewer: Exploration of Naval petroleum Reserve No. 4 and adjacent areas, Northern Alaska, 1944-53, part 5, Subsurface geology and engineering data: U.S. Geological Survey Professional Paper 305-K, p. 569-644.

Coulter, H. W., Hussey, K. M., and O'Sullivan, J. B., 1960, Radiocarbon dates relating to the Gubik Formation, northern Alaska: U.S. Geological Survey Professional Paper 400-B, p. B350-351.

Dall, W. H., 1921, Pliocene and Pleistocene fossils from the Arctic coast of Alaska and the auriferous beaches of Nome, Norton Sound, Alaska: U.S. Geological Survey Professional Paper 125, p. 23-37.

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, Miller, P. C., Tieszen, L. L., and Bunnell, F. L., eds., An Arctic ecosystem : the coastal tundra at Barrow, Alaska: Stroudsburg, Pennsylvania, Institute of Ecology, Dowden, Murchinson, and Ross, p. 30-65.

Douglas, L. A., and Tedrow, J. C. F., 1959, Organic matter decomposition rates in Arctic soils: Soil Science, v. 88, no. 6, p. 305-312.

____1960, Tundra soils of Arctic Alaska: International Congress of Soil Science, 7th, Repr. Trans., v. IV, p. 291-304.

Drew, J. V., 1957, A pedologic study of Arctic Coastal Plain soils near Point Barrow, Alaska: Doctoral dissertation, New Brunswick, New Jersey, Rutgers University, 117 p.

Drew, J. V., and Tedrow, J. C. F., 1962, Arctic soil classification and patterned ground: Arctic, v. 15, no. 2, p. 109-116.

Drew, J. V., Tedrow, J. C. F., Shanks, R. E., and Koranda, J. J., 1958, Rate and depth of thaw in Arctic soils: American Geophysical Union Transactions, v. 39, no. 4, p. 697-701.

Duguid, J. O., 1971, Thin gravel deposits on wave-eroded cliffs near Barrow, Alaska: Arctic, v. 24, no. 4, p. 304-306.

Fairbridge, R. W., 1960, The changing level of the sea: Scientific American, v. 202, no. 5, p. 70-79.

Faas, R. W., 1962, Micropaleontology of some Quaternary sediments from the Barrow area, northern Alaska: Master of Science thesis, Ames, Iowa, Iowa State University of Science and Technology, 38 p.

Faas, R. W., 1964, A study of some late Pleistocene estuarine sediments from Barrow, Alaska: Doctoral dissertation, Ames, Iowa State University of Science and Technology, 190 p.

____1966, Paleoecology of an Arctic estuary: Arctic, v. 19, no. 4, p. 343-348.

Ferrians, O. J., Jr., compiler, 1965, Permafrost map of Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-445, 1 sheet, scale 1:2,500,000.

Galloway, J. P., and Carter, L. D., 1978, Preliminary map of pingos in National Petroleum Reserve in Alaska: U.S. Geological Survey Open-File Report 78-795, 1 sheet, scale 1:500,000.

Glude, W. J., and Sloan, C. E., 1980, Recannaissance snow survey of the National Petroleum Reserve in Alaska, April-May, 1979: U.S. Geological Survey Water-Resources Investigations 80-49, 13 p.

Gold, L. W., and Lachenbruch, A. H., 1973, Thermal conditions in permafrost a review of North American literature, in, Permafrost, North American Contribution to Second International Conference on Permafrost, Yakutsk, U.S.S.R., Washington, D. C., National Academy of Sciences, p. 3-25.

Grantz, Arthur, Holmes, M. L., and Kososiki, B. A., 1976, Geologic framework of the Alaskan continental terrace in the Chukchi and Beaufort Seas, in, Canada's continental margins: Canadian Society of Petroleum Geologists, Memoir 4, p. 669-700.

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.

Hamilton, T. D., 1965, Alaskan temperature fluctuations and trends: an analysis of recorded data: Arctic, v. 18, no. 2, p. 105-117.

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.

Hartz, R. W., 1978a, High spindrift and storm surge limits, Icy Cape to the Colville River, in, Hopkins, D. M., and Hartz, R. W., Shoreline history of Chukchi and Beaufort Seas as an aid to predicting offshore permafrost conditions: U.S National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaskan Continental Shelf, Annual Report, Task D-9, Research Unit 473, April 1977 to March 1978, Appendix IV, 1 p., 4 maps.

Hartz, R. W., 1978b, 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., approx. scale 1:817,300.

Haugen, R. K., and Brown, Jerry, 1980, Coastal-inland distribution of summer air temperature and precipitation in northern Alaska, in, Batzli, G. O., ed., Patterns of vegetation and herbivory in Arctic tundra, results from the research on Arctic tundra environments (RATE) program: Arctic and Alpine Research, v. 12, no. 4, p. 403-412.

Hopkins, D. M., ed., 1967a, The Bering Land Bridge: Stanford, Califonia, Stanford University Press, 445 p.

____1967b, Quaternary marine transgressions in Alaska, in, Hopkins, D. M., ed., The Bering Land Bridge, Stanford University Press, Stanford, California, p. 47-90.

____1973, Sea level history in Beringia during the past 250,000 years: Quaternary Research, v. 3, no. 4, p. 520-540.

____1979, The Flaxman Formation of Northern Alaska; record of early Wisconsinan shelf glaciation in the high Arctic? (abs): 14th Pacific Science Conference, Khabarovsk, U.S.S.R., Proceedings, Additional volume, p. 15-16.

Hopkins, D. M., and Hartz, R. W., 1978, Shoreline history of Chukchi and Beaufort Seas as an aid to predicting offshore permafrost conditions: U.S. National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaska Continental Shelf, Annual Report, Task D-9, Research Unit 473, April 1977 to March 1978, 3 p., 5 appended reports.

Hume, J. D., 1964, Shoreline changes near Barrow, Alaska, caused by the storm of October 3, 1963: Science in Alaska, 15th Alaskan Science Conference, College, Alaska, Proceedings, p. 96.

____1965, Sea level changes during the last 2,000 years at Point Barrow, Alaska: Science, v. 150, no. 3700, p. 1165-1166.

Hume, J. D., and Schalk, Marshall, 1963, The effects of beach borrowing in the Arctic (abs): American Geophysical Union Transactions, v. 44, no. 1, p. 67.

____1964, The effects of ice push on Arctic beaches: American Journal of Science, v. 262, no. 2, p. 267-273.

____1967, Shoreline processes near Barrow, Alaska, a comparison of the normal and the catastrophic: Arctic, v. 20, no. 2, p. 86-103.

Hume, J. D., Schalk, Marshall, and Hume, H. W., 1972, Short-term climate changes and coastal erosion, Barrow, Alaska: Arctic, v. 25, no. 4, p. 272-278.

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.

Kirschner, C. E., 1983, The Arctic Platform in the National Petroleum Reserve in Alaska - deposition, deformation, and petroleum potential (abs): U.S. Geological Survey Circular 911, p. 24-27.

LaBelle, J. C., 1973, Fill materials and aggregate near Barrow, Naval Petroleum Reserve No. 4, Alaska: Arctic Institute of North America, Contract NOd-9915 (72-2), Office of Naval Petroleum and Oil Shale Reserves, 147 p.

Lachenbruch, A. H., 1957a, Thermal effects of the ocean on permafrost: Geological Society of America Bulletin, v. 68, no. 11, p. 1515-1530.

____1957b, Three dimensional heat conduction beneath heated buildings: U.S. Geological Survey Bulletin 1052-B, 69 p.

Lachenbruch, A. H., 1959, Periodic heat flow in a stratified medium with application to permafrost problems: U.S. Geological Survey Bulletin 1083-A, 34 p.

____1962, Mechanics of thermal contraction cracks and ice-wedge polygons in permafrost: Geological Society of America Special Paper 70, 69 p.

Lachenbruch, A. H., Brewer, M. C., Greene, G. W., and Marshall, B. V., 1962, Temperatures in permafrost, _in_ Temperature - its measurement and control in Science and Industry, v. 3, pt. 1: New York, Reinhold Publishing Company, p. 791-803.

Lachenbruch, A. H., and Marshall, B. V., 1969, Heat flow in the Arctic: Arctic, v. 22, no. 3, p. 300-311.

Lantz, R. L., 1981, Barrow gas fields - N. Slope, Alaska: Oil and Gas Journal, March 10, 1981, p. 197-200.

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.

Leffingwell, E. deK., 1908, Flaxman Island, a glacial remnant: Journal of Geology, v. 16, no. 1, p. 56-64.

____1915, Ground-ice wedges the dominant form of ground ice on the north coast of Alaska: Journal of Geology, v. 23, no. 7, p. 635-654.

____1919, The Canning River region, northern Alaska: U.S. Geological Survey Professional Paper 109, 251 p.

Lewellen, R. I., 1965, Characteristics and rates of thermal erosion, Barrow, Alaska: Master's thesis, University of Denver, Denver, Colorado, 181 p.

Lewellen, R. I., 1970, Permafrost erosion along the Beaufort Sea coast, Littleton, Colorado, 25 p. (Published privately).

Leffingwell, E. deK., 1972a, The occurrence and characteristics of nearshore permafrost, northern Alaska: Arctic Institute of North America, contract N00014-70-A-0219-001, subcontract ONR-433, Progress Report dated November 1, 77 p.

____1972b, Studies on the fluvial environment, Arctic Coastal Plain Province, northern Alaska: Littleton, Colorado, 2 v., 282 p. (Published privately).

____1973, The occurrence and characteristics of nearshore permafrost, northern Alaska, in Permafrost: The North American Contribution to the Second International Conference on Permafrost, Yakutsk, U.S.S.R.: Washington, D. C., National Academy of Sciences, p. 131-136.

____1974, Offshore permafrost of the Beaufort Sea, Alaska, in, Reed, J. C., and Sater, J. E., eds., The coast and shelf of the Beaufort Sea: proceedings of a symposium on Beaufort Sea Coast and shelf research: Arctic Institute of North America, 750 p.

____1977a, A study of Beaufort Sea coastal erosion, northern Alaska: U.S. National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaskan Continental Shelf, Annual Reports, Principal Investigators for the year ending March 1977, v. 15, p. 491-527.

Lewellen, R. I., 1977b, Subsea permafrost research techniques: Geosience and Man, v. 18, p. 29-34, 4 figs.

Livingstone, D. A., 1954, On the orientation of lake basins: American Journal of Science, v. 252, p. 547-554.

____1955, Some pollen profiles from Arctic Alaska: Ecology, v. 36, no. 4, p. 587-600.

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.

MacCarthy, G. R., 1952, Geothermal investigations on the Arctic slope of Alaska: American Geophysical Union Transactions, v. 33, no. 4, p. 589-593.

____1953, Recent changes in the shoreline near Point Barrow, Alaska: Arctic, v. 6, no. 1, p. 44-51.

____1958, Glacial boulders on the Arctic coast of Alaska: Arctic, v. 11, no. 2, p. 71-85.

MacGinitie, G. E., 1955, Distribution and ecology of the marine invertebrates of Point Barrow, Alaska: Smithsonian Miscellaneous Collections, v. 128, no. 9, 201 p.

MacNamara, E. E., and Tedrow, J. C. F., 1966, An Arctic equivalent of the grumusol: Arctic, v. 19, no. 2, p. 145-152.

MacNeil, F. S., 1957, Cenozoic megafossils of northern Alaska: U.S. Geological Survey Professional Paper 294-C, p. 99-125, pls. 11-17.

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.

McDougall, Kristin, 1983, Quaternary microfossils on the Arctic shelf (abs): U.S. Geological Survey Circular 911, p. 39-40.

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 pl., scale 1:500,000.

Mather, J. R., and Thornthwaite, C. W., 1958, Microclimate investigations at Point Barrow, Alaska, 1957-58: Centerton, New Jersey, Drexel Institute of Technology, Laboratory of Climatology, Publications in Climatology, v. 9, no. 2.

Mohr, J. L., Reish, D. J., Barnard, J. L., Lewis, R. W., and Geiger, S. R., 1961, The marine nature of Nuwuk Lake and small ponds of the peninsula at Point Barrow, Alaska: Arctic, v. 14, no. 4, p. 211-223.

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., 1978, Modern pollen rain on the Chukchi and Beaufort Sea coasts, Alaska, in, Hopkins, D. M., and Hartz, R. W., Shoreline history of Chukchi and Beaufort Seas as an aid to predicting offshore permafrost conditions: U.S. National Oceanic and Atmospheric Administration, Environmental Assessment of the Alaskan Continental Shelf, Annual Report, Task D-9, Research Unit 473, April 1977 to March 1978, Appendix III, 8 p.

Olhoeft, G. R., 1978, Electrical properties of permafrost: International Conference on Permafrost, 3rd, Edmonton, Alberta, July 10-13, 1978, Proceedings: Ottawa, National Research Council of Canada, p. 127-131.

Olhoeft, G. R., Watts, Ray, Frischknecht, Frank, Bradley, F., and Dansereau, D., 1978, Electromagnetic geophysical exploration in the National Petroleum Reserve in Alaska, in, Symposium on Permafrost Field Methods, Saskatoon, Saskatchewan, October 4, 1977, Proceedings: Ottawa, National Research Council of Canada Technical Memorandum.

Osterkamp, T. E., 1976, A conceptual model of offshore permafrost: The Northern Engineer, v. 7, no. 4, p. 5-10.

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, Ames, Iowa State University of Science and Technology, 191 p.

____1966, Geochemistry of permafrost, Barrow, Alaska: International Conference on Permafrost, 11-15 November 1963, Lafayette, Indiana: National Academy of Sciences - National Research Council Publication 1287, p. 30-37.

O'Sullivan, J. B., Davidson, D. T., Roy, C. J., Handy, R. L., and Hussey, K. M., 1959, Crude oil for stabilization of soil materials at Point Barrow, in, Davidson, D. T., and others, The geology and engineering characteristics of some Alaskan soils: Iowa State University Engineering Experiment Station Bulletin 186, p. 129-149.

O'Sullivan, J. B., and Hussey, K. M., 1957, Problems associated with soils stabilization in the vicinity of Point Barrow, Alaska: Iowa Academy of Sciences Proceedings, v. 64, p. 429-442.

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.

Péwé, T. L., and Church, R. E., 1962, Age of the spit at Barrow, Alaska: Geological Society of America Bulletin, v. 73, no. 10, p. 1287-1292.

Potter, L. D., 1972, Plant ecology of the Walakpa Bay area, Alaska: Arctic, v. 25, no. 2, p. 115-130.

Price, W. A., 1963, The oriented lakes of Arctic Alaska; a discussion: Journal of Geology, v. 71, no. 4, p. 530-532.

Ray, P. H., 1885, International Polar Expedition to Point Barrow: 48th Congress, 2nd Session, House Executive Document 44.

Rex, R. W., 1961, Hydrodynamic analyses of circulation and orientation of lakes in northern Alaska, in, Raasch, G. O., ed., Geology of the Arctic: Toronto, University of Toronto Press, p. 1021-1043.

____1964, Arctic beaches, Barrow, Alaska, in, Miller, R. L., ed., Papers in Marine Geology (Shepard Commemorative volume): New York, Macmillan Company, p. 384-400.

Rex, R. W., and Taylor, E. J., 1953, Uplifted beach ridges and first generation lakes in the Barrow area, Alaska: Unpublished final report to NONR Contract NONR 225(09), Palo Alto, California, Department of Geology, Stanford University.

Robinson, F. M., 1959, Test wells, Simpson area, Alaska, with a section on core analyses by S. T. Yuster: U.S. Geological Survey Professional Paper 305-J, p. 523-568.

____1964, Core tests, Simpson area, Alaska, with, a section on temperature measurement studies by M. C. Brewer: U.S. Geological Survey Professional Paper 305-L, p. 645-730.

Rodeick, C. A., 1975, The origin, distribution, and depositional history of gravel deposits on the Beaufort Sea continental shelf, Alaska: Master's thesis, San Jose State University, California, 87 p.

Rosenfeld, G. A., and Hussey, K. M., 1958, A consideration of the problem of oriented lakes: Iowa Academy of Sciences, Proceedings, v. 65, p. 279-287.

Schmidt, R. A. M., 1967, New generic assignments for some Pleistocene Ostracoda from Alaska: Journal of Paleontology, v. 41, p. 487-488.

Schmidt, R. A. M., and Sellmann, P. V., 1966, Mummified Pleistocene ostracods in Alaska: Science, v. 153, no. 3732, p. 167-168.

Schrader, F. C., 1904, A reconnaissance in northern Alaska across the Rocky Mountains, along the 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, 1965, Coring of frozen ground, Barrow, Alaska: U.S. Army Cold Regions Research and Engineering Laboratory Special Report 81, 8 p.

____1973, Stratigraphy and diagenesis of perennially frozen sediments in the Barrow, Alaska, region, in North American Contribution to 2nd International Conference on Permafrost, Yakutsk, U.S.S.R.: 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 Cold Regions Research and Engineering Laboratory Research Report 344, 21 p.

Sellmann, P. V., Carey, K. L., Keeler, Charles, and Hartwell, A. D., 1972, Terrain and coastal conditions on the arctic Alaskan coastal plain: U.S. Army Cold Regions Research and Engineering Laboratory Special Report 165, 74 p.

Sellmann, P. V., Weeks, W. F., and Campbell, W. J., 1975, use of side-looking airborne radar to determine lake depth in the Alaskan North Slope: U.S. Army Cold Regions Research and Engineering Laboratory Special Report 230, 6 p.

Short, A. D., and Wiseman, W. J., Jr., 1973, Freezing effects on Arctic beaches: Louisiana State University Coastal Studies Bulletin 7, Technical Report 128, p. 23-32.

Short, A. D., and Wiseman, W. J., Jr., 1974, Freezeup processes on Arctic beaches: Arctic, v. 27, no. 3, p. 215-224.

____1975, Coastal breakup in the Alaskan Arctic: Geological Society of America Bulletin, v. 86, no. 2, p. 199-202.

Slaughter, C. W., Mellor, Malcolm, Sellmann, P. V., Brown, Jerry, and Brown, L., 1975, Accumulating snow to augment the fresh water supply at Barrow, Alaska: U.S. Army Cold Regions Research and Engineering Laboratory Special Report 217, 21 p.

Sloan, C. E., 1983, Hydrology of the North Slope, Alaska (abs): U.S. Geological Survey Circular 911, p. 44.

Sloan, C. E., Trabant, Dennis, and Glude, William, 1979, Reconnaissance snow surveys of the National Petroleum Reserve in Alaska, April 1977 - May 1978: U.S. Geological Survey Open-File Report 79-1342, 31 p.

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

Stefansson, Vilhjalmur, 1908, Underground ice sheets of the arctic tundra: American Geographical Society Bulletin, v. 40, p. 176-177.

____1910, Ground ice in northern Alaska: American Geographical Society Bulletin, v. 42, p. 337-345.

Swain, F. M., 1961, Ostracoda from the Pleistocene Gubik Formation, Arctic Coastal Plain, Alaska, in, Raasch, G. O., ed., Geology of the Arctic: Toronto, University of Toronto Press, p. 600-606.

Taber, Stephen, 1943, Perennially frozen ground in Alaska: its origin and history: Geological Society of America Bulletin, v. 54, p. 1433-1548.

Tappan, Helen, 1961, Foraminifera from Pleistocene Gubik Formation of northern Alaska (abs): American Association of Petroleum Geologists Bulletin, v. 45, no. 1, p. 132.

Tedrow, J. C. F., 1965, Concerning genesis of the buried organic matter in tundra soil: Soil Science Society of America Proceedings, v. 29, p. 89-90.

____1969, Thaw lakes, thaw sinks, and soils in northern Alaska: Biuletyn Peryglacjalny, no. 20, p. 337-344.

____1977, Soils of the Polar Landscapes: New Brunswick, New Jersey, Rutgers University Press, 638 p.

Tedrow, J. C. F., and Cantlon, J. E., 1958, Concepts of soil formation and classification in Arctic regions: Arctic, v. 11, no. 3, p. 166-179.

Tedrow, J. C. F., Drew, J. C., Hill, D. E., and Douglas, L. A., 1958, Major genetic soils of the Arctic Slope of Alaska: Journal of Soil Science, v. 9, p. 33-45.

Tedrow, J. C. F., and Hill, D. E., 1955, Arctic brown soil: Soil Science, v. 80, p. 265-275.

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

Walker, H J., 1973, Morphology of the North Slope, in, Britton, M. E., ed., Alaskan Arctic tundra: Arctic Institute of North America Technical Paper 25, p. 49-92.

Weller, M. W., and Derksen, D. V., 1979, The geomorphology of Teshekpuk Lake in relation to coastline configuration of Alaska's coastal plain: Arctic, v. 32, no. 2, p. 152-160.

Williams, J. R., 1965, Ground water in permafrost regions, with emphasis on Alaska - an annotated bibliography, including a glossary of terms: U.S. Geological Survey Water-Supply Paper 1792, 297 p.

____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. 31-33.

____1983a, 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.

____1983b, Engineering-geologic maps of northern Alaska, Wainwright quadrangle: U.S. Geological Survey Open-File Report 83-457, 28 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., 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.

Wiseman, W. J., Jr., Coleman, J. M., Gregory, A., Hus, S. A., Short, A. D., Suhayda, J. N., Walters, C. D., Jr., and Wright, L. D., 1973, Alaskan arctic coastal processes and morphology: Louisiana State University Coastal Studies Institute, Technical Report 149, 171 p.

Yeend, W. E., 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.