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Engineering-geologic maps of northern Alaska, Meade River quadrangle

by

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Introduction

The Meade River quadrangle occupies an area of 12,634 km^2 between lat. 70° and 71° N. and long. 156° and 159° W. bordering the Chukchi Sea south and southwest of Point Barrow in northern Alaska. It lies entirely within the Arctic Coastal Plain province, the seaward or outer part of which is a flat, lake-dotted, tundra-covered lowland bounded on the south by the slightly higher and more rolling topography of the inner coastal plain. The coastal plain is broken by sea cliffs along the ocean and by escarpments inland that mark the position of former shorelines, the margin of dunefields, or river bluffs. Most of the area is drained by the Meade River and its major tributaries, Inaru, Usuktuk, and Nigisaktuvuk Rivers, by the Topagoruk River, by the Avalik River, and by smaller streams draining directly to the sea. The entire area of the quadrangle lies within the National Petroleum Reserve-Alaska. The only permanent settlement is Atkasook (Meade River Village); airstrips are located at Atkasook and at a former Government installation at Peard Bay. The area is criss-crossed by winter tractor trails that have been used for oil exploration and for hauling coal from the mine at Atkasook to Barrow, before a supply of gas was made available. Four exploratory oil wells and one core test (fig. 1) have not yielded economic oil and gas resources.

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

This report has been prepared with partial support of Minerals Management Service, Department of the Interior. It is based largely on interpretation of aerial photographs flown in 1955 and on fieldwork undertaken by the Geological Survey for the Bureau of Land Management land-use study under Chapter 105-C, Public Law 94-258 (Williams and others, 1977) between August 1 and 14, 1977, and between July 24 and August 9, 1978. During these periods about half of the 26 days of helicopter-supported fieldwork was used to visit about 160 sites in the Meade River quadrangle; the remainder was used for studies of the adjacent Barrow and Wainwright quadrangles. To supplement the field data, use has been made of unpublished field data collected by D. M. Hopkins (1976, 1981) and R. E. Nelson (1976, 1977) of the Geological Survey, chiefly along the coast where the very complex Quaternary stratigraphy is currently under study by Hopkins and J. K. Brigham (Brigham and others, 1980; Brigham, 1981). L. D. Carter of the Geological Survey accompanied the writer for two days in 1978 and has provided information from his 1982 fieldwork along the eastern boundary of the quadrangle. L. A. Morrissey accompanied the writer in the field in 1978 to obtain ground-truth data for application of Landsat imagery to vegetation cover maps being prepared by the Geological Survey

(Morrissey, 1979; Morrissey and Ennis, 1981). Naval Arctic Research Laboratory at Barrow provided meals, quarters, and logistic support on a cost-reimbursable basis in 1977 and 1978.

Previous studies of the Arctic Coastal Plain have been helpful in providing additional observations and developing concepts, and may be used by the reader seeking additional information. The early work along the arctic coast by Ray (1885), Leffingwell (1919), Dall (1921), and Meek (1923) was followed by early reconnaissance studies of Naval Petroleum Reserve No. 4, established in 1923 (Paige and others, 1925; Smith and Mertie, 1930). U.S. Geological Survey field investigations by Webber (1947), Stefansson and Mangus (1949), and reports on the test wells and core tests drilled by the Navy (Collins, 1958a, b, 1961) as part of its 1944-53 exploration of the Reserve were supplemented by regional and topical studies and compilations by MacNeil (1957), Tappan (1961), Swain (1961), Black (1964), Lathram (1965), Beikman and Lathram (1976), and Detterman (1978). Other geologic and permafrost studies, supported by various agencies and based at the Naval Arctic Research Laboratory at Barrow, included those of Black (1951, 1957a, b), MacCarthy (1952), Lachenbruch (1957, 1962), Brewer (1958), O'Sullivan and Hussey (1960), O'Sullivan (1961), Lachenbruch and others (1962), Geist (1962), Hussey and Reckendorf (1963), Hussey and Michelson (1966), Lachenbruch and Marshall (1969), Lewellen (1972), Sellmann and others (1972, 1975), Brown and Sellmann (1973), Sellmann and Brown (1973), and Short and Wright (1974). Soils studies by Tedrow and Hill (1955), Tedrow and Cantlon (1958), Tedrow and others (1958), Brown (1967, 1969a, b), and Brown and others (1980) and soil and botanical studies related to the Tundra Biome and RATE projects by Rickert and Tedrow (1967), Komarkova and Webber (1977, 1980), Everett and others (1978), Peterson and Billings (1978, 1980), Everett (1979, 1980), and Haugen and Brown (1980) have emphasized the soil-forming processes in the tundra environment. Britton (1957, 1967) described the vegetation and the thaw-lake cycle. The oriented lakes resulting from thawing of permafrost have been discussed by Cabot (1947), Black and Barksdale (1949), Brewer (1958), Livingstone and others (1958), Carson and Hussey (1960, 1962, 1963), and Carson (1968). Correlation of the Quaternary marine deposits of the coastal plain with the better-known regions around the Bering Sea rim has been made by Hopkins (1967, 1973, 1979), McCulloch (1967), Lewellen (1972), and Sellmann and Brown (1973). Engineering geology, geologic hazards, and construction techniques have been discussed by Black (1957b) and by Crory and others (1979). Shoreline processes have been described by Hume and Schalk (1964, 1967) and Hartz (1978). Erratic, ice-rafted boulders near the coast and in inland areas have been reported by Leffingwell (1919) and MacCarthy (1958) near Barrow, by Hopkins (unpublished field notes, 1976, 1981) along the Chukchi Sea coast, and by Paige (unpublished field notes, 1923), Webber (1947), and Hamilton (unpublished field notes, 1962) on Meade River. Water supply and hydrology are described by Johnson and Kistner (1967), Slaughter and others (1975), Nelson (1977), Sloan (1977), Childers and others (1978), Jones (1978), Sloan and Snyder (1978), and Sloan and others (1978), and the hydrologic information and processes in the nearby Barrow region have been summarized in Dingman and others (1980). Coal resources have been evaluated by Sanford and Pierce (1946), Toenges and Jolley (1947), Barnes (1967), and Martin and Callahan (1978). Reports of geophysical exploration and test drilling for oil and gas in both the Navy program and the one recently concluded by the Department of the Interior have been placed on open file (e.g., Bird, 1982) and are currently being summarized. Recent regional permafrost investigations have enabled Osterkamp and Payne (1981) to provide a regional pattern of permafrost thickness for the Prudhoe Bay area which could be applied to the Meade River region if more reliable subsurface data were available.

Transfer of the Petroleum Reserve from the Navy to the Department of the Interior in 1976, under P.L. 94-258, generated a new series of studies, supported by the Bureau of Land Mangement in exercising its responsibilities under the Act. The studies conducted by the U.S. Geological Survey in 1977 and 1978 resulted in a reconnaissance of the surficial deposits of the entire Reserve (Williams and others, 1977, 1978; Yeend, 1978), coastal erosion potential (Hartz, 1978), pingos (Galloway and Carter, 1978; Carter and Galloway, 1979a), slope characteristics (Johnson, 1978), additional work on the sand dunes, the western edge of which is in the Meade River quadrangle (Carter and Robinson, 1978; Carter and Galloway, 1979b; Carter, 1981a, b; and Carter and Hopkins, 1982), adaptation of LANDSAT imagery to vegetation cover mapping (Morrissey, 1979; Morrissey and Ennis, 1981), and stratigraphic studies at Skull Cliff (Williams, 1979) and at Topagoruk River (Williams and Yeend, 1979). These studies, supplemented in some cases by additional fieldwork, have formed the basis for the current series of quadrangle maps being prepared for Minerals Management Service.

Bedrock

Sedimentary rocks of the Nanushuk Group of Early and Late Cretaceous age lie beneath the unconsolidated deposits in nearly all of the Meade River quadrangle (fig. 2) (Mayfield and others, in press). A small area of Torok shale of Early Cretaceous age is believed to lie beneath the unconsolidated deposits along the northern boundary of the quadrangle (Mayfield and others, in press), based on data from Walakpa Test Well No. 2, 4 km north of the quadrangle boundary; these rocks are not exposed in the Meade River quadrangle. Nanushuk Group rocks are exposed locally in river beds, in river and lake banks, and in sea cliffs; they are the uppermost bedrock formation in test wells, the core test, and in numerous seismic shot holes throughout the quadrangle (Bird, 1982; Martin and Callahan, 1978). Rocks of the Nanushuk Group are generally flat-lying and have dips of less than 10^{o}; they thicken from about 380 m at Kuyanak Test Well No. 1 in the northeastern corner of the quadrangle to about 1,050 m at Meade Test Well No. 1 near the southern border (Bird, 1982). These rocks are dominantly sandstone, shale, and coal, with lesser amounts of siltstone, ironstone, and conglomerate, as noted by appropriate symbols on figure 2, where the lithology is known from previous investigations (Webber, 1947; Stefansson and Mangus, 1949) and the present study. Webber reported limestone along Meade River and pointed out that the sandstone is more prominent in outcrop than the softer rocks because of its greater resistance to erosion. Coal content, expressed as a percentage of the stratigraphic thickness of the Nanushuk Group, increases from near zero at the boundary with the Torok shale in the northern part of the quadrangle to greater than 5 percent in the southwest quadrant of the map area; the coal is subbituminous, grading along the southern boundary of the quadrangle to bituminous (Martin and Callahan, 1978).

The bedrock surface beneath the outer coastal plain ranges from about 18 m above sea level along the Meade River south of Atkasook and 14 m along the southwestern end of the sea cliffs along Chukchi Sea to 3 m along the coast at the northern border of the quadrangle and 13 m below sea level at Kuyanak Test

Well No. 1 near the Meade River delta. Although bedrock has been gullied along the sea cliffs, the general northeastward slope of the bedrock surface is about 0.3 m/km; that along the northern border of the quadrangle is about 0.4 m/km eastward. Absence of bedrock outcrops on Usuktuk and Topagoruk Rivers within the belt of dunes and in the area of upland silt east of Meade River suggests that the bedrock surface is probably similar to or lower in altitude and slope to that along the Meade River, although covered with thicker unconsolidated deposits. Unfortunately, the seismic shot holes were not logged with the intent of defining the top of bedrock, nor are the ground control points accurate enough to portray with any degree of accuracy any breaks in the bedrock surface that might mark former ocean shorelines. However, the presence of gravel and clay, containing marine shells and erratic ice-rafted boulders on the bedrock surface along the Meade River and other streams suggests that the bedrock surface may have been planed by the sea along a slope close to that described above. At a number of localities the bedrock surface has been planed by the rivers as they have cut down into bedrock.

The bedrock surface of the inner coastal plain, west of Meade River, has greater relief than that of the outer coastal plain and is estimated to be between 30 and 50 m above sea level. Data on the transition between the bedrock surfaces of the inner and outer coastal plain are not available.

Unconsolidated deposits

Unconsolidated deposits of eolian, marine, and fluvial origin, the upper part of which has been largely reworked and redeposited in thaw-lake basins, cover bedrock in the Meade River quadrangle, except locally in near-vertical exposures of bedrock along rivers, lakes, and the ocean. 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 at Skull Cliff are marine deposits that may be of Pliocene age (MacNeil, 1957, p. 108-109; Brigham, 1981).

The unconsolidated deposits in this report are mapped on the basis of origin, as marine beach, bar, and spit deposits; marine sand; upland silt; eolian sand; alluvium; and thaw-lake deposits; they are described in the tabular description of map units. Their age and correlation are summarized in the correlation of map units. Fossil collections from this study are located on figure 1, and a check list of marine fauna identified by L. N. Marincovich, Jr., of the U.S. Geological Survey is given in table 1. Other fossil collections are reported by Dall (1921), Meek (1923), Smith and Mertie (1930), and MacNeil (1957). The marine deposits locally include basal gravel and clay that contain erratic, ice-rafted boulders that are described in table 2 and located in figure 1. Radiocarbon dates for samples collected as part of this study and by Everett (1979; written communication, 1978) (table 3) are located in figure 1. A cross section (fig. 3) showing the materials of the coastal bluffs facing the Chukchi Sea is provided to show the range of materials resting on bedrock in these complex deposits, which differ considerably from the thinner marine unconsolidated deposits inland.

Marine beach, spit, and bar deposits

Fine gravel, gravelly sand, and sand form low-lying offshore bars, barrier islands, and spits bordering Peard Bay on the north and east and narrow beaches bordering the sea cliffs south of Peard Bay and along the Chukchi Sea coast. These deposits are of Holocene age and are constantly being reworked by waves and currents. Older, raised beach deposits have been recognized only along the south shore of Peard Bay where they are about 10 m above sea level and are probably related to a high sea level at or below escarpment I (fig. 1) which probably marks the last major transgression of Pelukian age (Hopkins, 1967; McCulloch, 1967). Although other old beach deposits of this type probably exist, they are generally concealed by overburden of marine or eolian sand, and their form has been largely obliterated by the thaw-lake process.

Marine sand

Marine sand is a general term applied to the sand and silty sand containing scattered pebbles of quartz and chert that form the surficial deposits of much of the Meade River quadrangle. The sand is commonly underlain by marine gravel which lies on clay that is either marine mud or weathered bedrock; the gravel and underlying clay locally contain ice-rafted erratic boulders (table 2; fig. 1) and generally rest on bedrock. Fossil marine shells, although locally present in the pebbly sand, are much more common in the underlying marine gravel. As mapped, the marine sand may include terrace deposits bordering some streams because of the difficulty in identifying on aerial photographs terrace surfaces that have been extensively altered by the thaw-lake cycle, the small scale of the map, and general lack of good exposures.

Over most of the area of the quadrangle, outcrops of the marine sand and underlying gravel and clay expose only a single pulse of marine deposition. Only in the Chukchi Sea bluffs has the marine sand been seen overlying older marine deposits. The marine sand is locally covered by fine to medium-grained pebble-free sand of possible eolian origin, but these deposits have too patchy a distribution and insufficient thickness to be mapped. In some areas the pebbles from the marine sand have been concentrated at the surface beneath the turf, as though by wind deflation.

Relation of marine sand unit to escarpments: The marine sand unit is divided by or is bounded by escarpments or indistinct breaks in slope (I-IV, fig. 1), indicating a record of at least three marine transgressions. Numerous papers correlating these transgressions with the world-wide chronology have been published over the years (O'Sullivan, 1961; Black, 1964; McCulloch, 1967; Hopkins, 1967, 1973; Lewellen, 1972; Sellmann and Brown, 1973; and others). Many of these correlations have also discussed tilting of the various shoreline positions assigned to these escarpments and of the marine deposits by tectonic activity or isostatic adjustment. In the present study the sea levels indicated by some of these escarpments can only be approximated from topographic maps having a half-contour interval of 25 or 50 feet (8 or 15 m), and, with no exposures available to determine accurately the level of the sea forming these escarpments, only approximate levels can be given. Some of the escarpments seem to have a nonmarine origin. Fossil collections from the several levels of marine deposits are still too incomplete for regional correlation of the deposits or for comparison with the list of significant fossils used to correlate marine formations in better-known regions of Alaska (Hopkins, 1967, table 2). Amino-acid racemization studies to determine the relative age of the marine fauna are underway, but the results have not yet been published.

The marine sand unit can be divided into the (1) deposits that lie above the modern beaches and generally lower than about 20 m above sea level that lie seaward of the former sea cliff (I, fig. 1) that was recognized as a fragmental shoreline by O'Sullivan (1961, fig. 5) in the Peard Bay area and possibly northeasterly from an indistinct break in slope shown on topographic maps (II, fig. 1) between the coast and Meade River; (2) an area of high ground between wave-cut cliff I (fig. 1) and the the base of another wave-cut escarpment inland (III, fig. 1) which was recognized as a shoreline by O'Sullivan (1961) and McCulloch (1967), also at about 20 m above sea level; and (3) deposits generally above 30 m, the level of the top of escarpment III (fig. 1), that extend southward to merge with the inner coastal plain and foothills beyond the quadrangle boundary. Marine deposits beneath dune and terrace deposits along the Meade River south of Atkasook lie inland from the northeastward projection of shoreline III (fig. 1), but their relation to the marine deposits above 30 m in the southwestern part of the quadrangle is not clear.

The shoreline (I, fig. 1) that merges northeastward with the coastal bluffs southwest of Skull Cliff seems to indicate a sea level along the base of the cliff at about 20 m, or even less, above sea level. Hopkins (oral communication, Dec. 1982) believes this is the inner Pelukian shoreline, although its level is higher than that commonly ascribed to the Pelukian shoreline of the Bering Sea region (125,000 years, Sangamon interglacial) by Hopkins (1967) which is variously located at 7 $\pm$ 3 m above sea level (Hopkins and Carter, 1980) or about 13 to 14 m above sea level (McCulloch, 1967). Brigham (1981) has noted that the youngest beach deposits in the Peard Bay area are 9 m and 6 m above sea level. The older is correlated with the Pelukian and dated by radiocarbon methods on driftwood as older than 38,000 years; the younger is equivalent to a later interglacial (Pelukian) phase equivalent to the so-called Flaxman shoreline of the Beaufort Sea coast (Hopkins, 1979) or to a mid-Wisconsin event.

The escarpment east of Meade River near Atkasook (IV, fig. 1) was identified as a marine shoreline (Lewellen, 1972) because of its alignment with and its similarity in height above sea level to the escarpment (III, fig. 1) west of the Meade River. It could also be an extension of the indistinct break in slope (II, fig. 1) west of the Meade River, the base of which is also about 20 m above sea level. Under this interpretation, the gravel deposits at Barrow that rise to about 18 m above sea level could be interpreted as an offshore bar or spit of this stand of the sea. A third and currently more attractive interpretation is that the escarpment (IV, fig. 1) is not a shoreline at all, but merely the northern edge of the Holocene dune field that extends from the escarpment southward. The latter hypothesis seems substantiated by the lack of an appreciable break in slope or wave-cut notch in the marine deposits and the underlying bedrock surface between the area north of the escarpment and that along the Meade River to the south. Also, a shoreline that cuts dunes of Holocene age seems unreasonably young, considering the faunal characteristics of the marine deposits north of the escarpment and their pre-Holocene age.

The prominent escarpment rising from about 38 to 68 m above sea level in the southeastern part of the quadrangle (V, fig. 1) does not continue west of the Meade River. Its base is in the dune area, and its upper surface is underlain by upland silt that mantles a thick accumulation of fluvial deposits, the lower part of which contains reworked marine shells. Although the escarpment was identified as a shoreline by O'Sullivan (1961, p. 131), the lack of continuity west of the Meade River suggets that it may have been formed by streams diverted southward during the time of maximum dune formation. No evidence has been noted of any break in the bedrock surface that would indicate a marine shoreline. No bedrock or unconsolidated deposits other than fluvial deposits are exposed down to river level in sections through the escarpment along the Usuktuk and Topagoruk Rivers and along smaller streams. Formation of the escarpment must post-date the fluvial deposits beneath the upland silt, and these are 25,000 to 44,000 years old (middle(?) Wisconsinan age) (Carter, personal communication, 1982; Nelson, 1982) where exposed in the Ikpikpuk River quadrangle 42 km southeast of the southeast corner of the Meade River quadrangle. A middle Wisconsinan age for truncation by the sea at 38 m above sea level seems unreasonably young, and it is more likely that the bluffs were formed by streams diverted against it during the dune forming period.

In summary, two prominent former shorelines (I and III, fig. 1) have been recognized, together with an indistinct break in slope (II, fig. 1) recognized on topographic maps. The older of these shorelines (III, fig. 1) has been correlated with shorelines of pre-Illinoian age to the south (McCulloch, 1967, fig. 2) and may be equivalent to the inner limit of the Kotzebuan transgression of Hopkins (1967). The younger (I, fig. 1) is believed equivalent to the Pelukian shoreline of Hopkins (1967) and McCulloch (1967). No data are available on the age or even the validity of the indistinct break in slope (II, fig. 1), although it is possible that this break in slope marks the inshore edge of an embayment that is equivalent to the younger shoreline (I, fig. 1) of Pelukian age. Escarpment IV (fig. 1) is interpreted as the northern edge of the Meade River dune field and is not a marine shoreline. Escarpment V (fig. 1) is interpreted as a river-cut bluff in middle(?) Wisconsinan fluvial deposits and not a marine shoreline.

Coastal bluffs: Available information from the present study and from unpublished field notes by Hopkins (1976) and Nelson (1976, 1977) on the stratigraphy of bluffs facing the Chukchi Sea is summarized in figure 3, which cannot show at such a small scale the complexity of these sections. Few of the cliffs are exposed in complete sections from sea level to the top, some 25 m above the sea. The most complete section exposed in 1977-78 is 550 m southwest of VABM SKULL at Skull Cliff, where five stratigraphic units were noted (Williams, 1979). They include: (1) basal marine clayey silt and clay containing erratic boulders that lie unconformably on Cretaceous sandstone; (2) folded marine silty sand that is unconformable on the lower unit; (3) horizontal thin shell hash mixed with transgressive sandy gravel that is unconformable on the folded silty sand; (4) horizontal marine sand, silt, and fine gravel that is disconformable on the underlying unit; and (5) an upper thaw-lake deposit that lies disconformably on the underlying marine deposits. Further fieldwork by Hopkins and Brigham, and amino-acid racemization studies indicate that the stratigraphy is even more complicated than that reported previously (D. M. Hopkins, unpublished field notes, 1981; Brigham, 1981). Although fossils have been collected from these bluffs by

Leffingwell (in Dall, 1921; MacNeil, 1957, p. 110), Meek (1923), Hopkins (unpublished data), and by the writer (table 2; fig. 3), their stratigraphic position is too poorly known with respect to the stratigaphic column outlined above to comment on the paleontological content of the several stratigraphic units. The marine fauna from the coastal bluffs includes some of the characteristics indicative of Beringian, Anvilian, and Einahnutan ages (Hopkins, 1967, table 2). MacNeil (1957, p. 108) thought that the Skull Cliff fauna, as known at that time, was of equivalent age or younger than that of late Pliocene age on the Colville River at Ocean Point. Brigham (1981) stated that the oldest unconsolidated deposits in the coastal bluffs record marine transgressions that are more than 2 million years old (late Pliocene), similar to the age of the Ocean Point section (Carter and others, 1977). In the writer's opinion, the uppermost marine beds in the coastal bluffs are probably correlatable with the inland wave-cut cliff (III, fig. 1) which seems likely to be a northeastward extension of the pre-Illinoian shoreline of McCulloch (1967, fig. 2), or perhaps the Kotzebuan transgression of Hopkins (1967). The lower beds exposed in the bluffs, therefore, would be those of one or more of the older transgressions, Einahnutan, Anvilian, and Beringian of Hopkins (1967).

Inaru River and Kucheak Creek: These streams locally have cut down to bedrock in the area southwest of the indistinct break in slope (II, fig. 1) that separates a marine surface higher than 20 m from lower levels. Downstream from the break in slope the Inaru River has not cut into bedrock. Sections exposed on Inaru River above the break in slope consist of pebbly sand underlain by thin shell-bearing gravel on clay or bedrock. Fossils (M-7175, M-7176, M-7177, table 1; fig. 1) are generally of the type of marine fauna that exists in the region today, except for *Astarte leffingwelli* Dall which is reported by L. N. Marincovich (written communication, Feb. 23, 1978) to be extinct but present in deposits of late Pliocene through Pelukian age. Marine fossils (M-7311, table 1, fig. 1) were collected on Kucheak Creek from basal sand and interbedded sand and clay, close to bedrock and, at exposures downstream, from the pebbly marine sand and from the gravelly mud at the base of the section. Other collections (M-7173, table 1, fig. 1) and in E. 1/2, T. 15 N., R. 24 W. have been made from lake banks in the Inaru River region. In all probability, the marine deposits are near-shore facies of the high sea level that terminated in shoreline III (fig. 1) and are probably of pre-Illinoian or Kotzebuan age. The relation of these deposits to those on the Meade River at and south of Atkasook, inland of the northeastward projection of this shoreline (III, fig. 1), was not determined. However, there is no obvious stratigraphic or topographic break between the marine deposits of the Inaru and those of the Meade River above and below Atkasook.

Lower Meade River: Marine sand is exposed between 10 and 13 m above sea level, according to topographic maps, at a number of places on the east bank of Meade River and in thaw-lake banks eastward to the quadrangle boundary. Some of the sand along Meade River lies on a thin gravel containing shells and clay that is believed to be the source of erratic boulders (table 2, fig. 1). Although not examined by a paleontologist, the fossils seem to be dominantly, but not exclusively, *Astarte* sp. along the Meade River and nearly exclusively *Astarte* sp. in the sandy banks of lakes near the quadrangle boundary in T. 15 N. and in T. 16 N. Erratic boulders (table 2, fig. 1) were found by L. D. Carter in 1982 in the northeast bank of a lake in SW 1/4 Sec.20, T. 14 N., R. 20 W. along the base of the northern edge of the dune field at a map elevation of about 20 m.

Meade River above confluence of Usuktuk River: This reach of the Meade River is largely within the area of Holocene dunes which have covered river terrace deposits and marine deposits, except for local exposures in the cut banks of the river. Exposures at Atkasook show that thin shell-rich gravel lies on clay at about 15 m above sea level. Erratic boulders noted by O'Sullivan (1961) and by Hamilton (unpublished field notes, 1962) near this point may have come from these marine deposits. Fossil collection 15929 (MacNeil, 1957, p. 110) from this bank included: Natica clausa Broderip and Sowerby, Volutopsius sp. aff. V. stefanssoni Dall, Neptunea ventricosa communis (Middendorf), Buccinum plectrum Stimpson, Astarte aff. A. vernicosa Dall, Astarte bennetti Dall, Astarte leffingwelli Dall, Cardita (Cyclocardita) cf. C. (C.) crebricostata (Krause), C. (C.) crassidens Broderip and Sowerby, Macoma calcarea (Gmelin), Saxicava arctica (Linne), and Balanus rostratus alaskensis Pilsbry. This collection is probably duplicated by M-7172 (table 1) which records only three of the species in MacNeil's list. MacNeil considered the Meade River fauna younger than that collected by Meek (1923) from the upper 7.6 m of the Skull Cliff section. Hopkins (1967, p. 81) once regarded these deposits as of Anvilian age, but now (oral communication, Dec. 1982) believes they may be of Kotzebuan age, based on his recent work and on preliminary amino-acid ratios.

Exposures in the west bank of Meade River between between 70^{o} 11' N. and 70^{o} 12' N. in T. 10 N., R. 21 W. (M-7309, table 1, fig. 1) show that 3.7 m of eolian sand covers pebbly sand of fluvial or marine origin that rests on clay and sandstone. Hiatella arctica Linnaeus seems the most common fossil in these exposures and in those upstream, but they have been broken and abraded, and perhaps have been redeposited in a terrace sand. The shell-rich deposit is about 17 to 18 m above sea level, based on map contours.

Shells were found as float on the shore of an oxbow lake on the east side of the Meade River floodplain adjacent to a cliff formed of stratified fluvial sand and detrital coal that lie beneath the upland silt (M-7310, table 1, fig. 1) and were presumably washed out of the cliff. Similar occurrences upstream on the Meade River were noted by Yeend (personal communication, Nov. 1982) and the presence of Hiatella arctica Linnaeus on bars of the Topagoruk River just south of the quadrangle boundary suggest that the marine deposits extend southward beyond the limits of the quadrangle and beyond the escarpment (V, fig. 1) that separates the upland silt from the eolian deposits mapped between Topagoruk and Meade Rivers.

High-level marine deposits: Pebbly sand in the southwestern part of the map area at elevations ranging from 30 m above sea level at the upper limit of the pre-Illinoian or Kotzebuan shoreline (III, fig. 1) to about 46 m near Avalik River seemingly are higher than the deposits along Meade River; their relation is obscured by the intervening cover of eolian sand and the general lack of exposures. The deposits may overlie marine beds that include erratic stones or may, themselves, include these stones as shown by the presence on the tundra surface of an erratic boulder of porphyritic granite (28, table 2, fig. 1) about 30 m above sea level on the southwest side of Kolipsun Creek. These deposits are clearly older than those at the base of the escarpment (III, fig. 1) which are correlated with the pre-Illinoian (McCulloch, 1967, fig. 2) or Kotzebuan high sea level. They seem to merge southward without appreciable topographic break into the inner coastal plain which, along Avalik and Avaliktok Rivers, is covered by only a thin mantle of upland silt above the sand. From the limited exposures, it is not even clear that all of these deposits are of marine origin, for they are non-fossiliferous and have been reworked by thaw-lake activity and by wind over a long period of time.

Erratic boulders: Erratic boulders, conspicuous by their presence in marine deposits and present as a lag concentration in alluvial deposits, have been noted along the arctic coastal zone in many localities (Leffingwell, 1919; MacCarthy, 1958; O'Sullivan, 1961; Hamilton unpublished field notes, 1962; Black, 1964; and Hopkins, unpublished field notes, 1976).

The boulders (table 2, fig. 1) are of a variety of lithologic types, some of which are not known in the area southward to the Brooks Range. They consist of gabbro or pyroxenite, red quartzite, red and gray granite, biotite schist, carbonate rocks, basalt, chert conglomerate, and other types. The boulders were apparently transported by floating ice, perhaps icebergs or ice islands calving from coastal glaciers along the Arctic Ocean.

Although originally noted only along the coastline, erratic boulders are as high was 30 m above sea level, above the pre-Illinoian/Kotzebuan shoreline (28, table 2, fig. 1) and in the bed of the Meade River south of the northeastward projection of that shoreline, as well as in the lower units of the Skull Cliff stratigraphic column (fig. 3). The boulders, therefore, are found in marine deposits of probable Kotzebuan age and in those of at least one pre-Kotzebuan high sea level. The boulders have also been found on the north shore of Sisgravik Lake near sea level in the Meade River delta and inland from a shoreline which separates marine sand from boulder-rich muds along the Beaufort Sea Coast. All of the boulders seem to be inland from or higher than the Flaxman deposits of Hopkins (1979) which are believed to be post-Pelukian in age or a late phase of the Pelukian.

Tilting and crustal warping of marine deposits: Differential uplift of the older marine surfaces described in the literature south of the Meade River quadrangle is reported to have been about 100 to 200 m greater in the region due south of Barrow than in that along the Chukchi Sea coast (O'Sullivan, 1961; Black, 1964; McCulloch, 1967, p. 115; Hopkins, 1967, p. 67). No data from the present study seem to bear on this problem, and the solution must await more detailed studies of the region to the south.

Tilting or warping of the shorelines (I and III, fig. 1) identified in the Meade River quadrangle cannot be estimated until detailed stratigraphic information fixing the height of sea level along the escarpments and accurate topographic information become available. The marine surface between these shorelines, however, exhibits a strongly asymmetrical drainage system, having short streams draining to the Chukchi Sea that head against much longer streams draining to the Meade River. This asymmetry, and the abrupt shift in direction of Meade River north of Atkasook, led O'Sullivan (1961, p. 145) to suggest that the western part of the coastal plain had been uplifted differentially with respect to that along Meade River. Meek (1923, p. 414) also suggested a slight upwarping of the coastal plain at Skull Cliff. Estimated gradients of the bedrock surface, 0.3 m/km northeastward along the coast, and 0.4 m/km eastward along the northern edge of the quadrangle, are very flat, although the gradients do support O'Sullivan's postulated uplift of the western part of the coastal plain.

The record of tilting and crustal warping of the marine surfaces will become clear only when the topographic, stratigraphic and paleontologic data are used to produce a regional record for the Arctic Coastal Plain that can be compared with similar records for other regions.

Upland silt

The upland silt of the inner coastal plain generally mantles fluvial deposits along the southern boundary of the quadrangle east of the Meade River between 40 and 70 m above sea level. In this area the silt thickness may reach 10 m, but exposures are lacking from which accurate measurements may be made. West of the Meade River the silt cover is in many places very thin, and it mantles pebbly sand that is probably of marine origin, although a fluvial origin is possible. At Meade Test Well No. 1 (Collins, 1958a) the silt cover is scarcely 1 m thick, and, according to the log of the test well, it is underlain by 2.5 to 3 m of silt, sand, and gravel that contain a few Foraminifera, possibly reworked from the underlying bedrock of the Nanushuk Group. Exposures along Avalik and Avaliktok Rivers also indicate relatively thin deposits of silt. The upland surface merges imperceptibly with the outer coastal plain west of the Meade River, and its boundary has not been precisely defined. The upland silt was called the Foothills Silt by O'Sullivan (1961); its boundaries in this report differ from those shown by O'Sullivan and from the upland silt mapped by Williams and others (1977), based on additional fieldwork in 1978.

The upland silt and underlying fluvial deposits can be traced eastward from the Meade River into the Teshekpuk quadrangle to the east and into the Ikpikpuk River quadrangle to the southeast where radiocarbon dating of the lower part of these deposits (Nelson, 1982, p. 21-23) indicates an age range from about 25,000 to 43,000 $\pm$ 1400 years (USGS-746) on the Titaluk River. The gravel at the base of this section is 44,100 $\pm$ 1700 years old (USGS-747). At the Titaluk site the deposits above the basal gravel are fluvial fine silty sand that encloses a lens of sand (Nelson, 1982). Even though the Titaluk section is in the same general geomorphic unit as the upland silt east of the Meade River, it is not absolutely clear whether the upland silt in the Meade River quadrangle is the equivalent of the fine silty fluvial sand of the Titaluk section or whether it is a separate, younger silt mantle. The fluvial deposits, seen beneath the silt in only a few exposures on the Meade, Usuktuk, and Topagoruk Rivers include medium to coarse sand and granule gravel, both of which include partings of detrital coal, and silt. Oxidized gravel similar to that at the base of the Titaluk section was not seen in the Meade River quadrangle. Although the upland silt of the Meade River quadrangle is probably loess because of its texture and position downwind from a large area of sand dunes, it is possible that the silt is part of the fluvial sequence that is better exposed on Titaluk River. O'Sullivan and Hussey (1960) and O'Sullivan (1961) pointed out that the upland silt was not eolian, and suggested a marine-fluvial origin in which the silt was deposited by streams that aggraded as sea level rose and advanced into the inner coastal plain. If the upland silt is a part of the fluvial deposits in the Meade River quadrangle, it may be about 25,000 years old, or even older, depending on its equivalency with the dated Titaluk River section. If a part of the silt is eolian, it is perhaps equivalent to the sand sea to the east, thought by Carter (1981a) to be of Late Wisconsinan age, or equivalent to Holocene eolian activity that took place in forming the dunes north of the escarpment (V, fig.

1) in the Meade River quadrangle. The fact that the fluvial deposits contain reworked marine shells on the Meade and Topagoruk Rivers suggests that the deposits may, at depth, contain or overlie marine beds, as suggested by O'Sullivan and Hussey (1960).

Although the fluvial deposits were not found exposed in the Meade River quadrangle west of Meade River, they reappear beneath the upland silt in the Wainwright quadrangle to the west. Mammal remains, common in the Titaluk River section and older than 28,000 years (Carter, 1981b, p. 7), are also reported from the Meade River south of the quadrangle boundary (Webber, 1947, p. 10), from the Avalik River (Quaide, 1955; O'Sullivan, 1961), and are plentiful at the base of exposures of fluvial deposits beneath the upland silt in the Kaolak River valley in the Wainwright quadrangle. A date of 37,000 $\pm$ 990 years (GSC-3050) was reported for bone collagen from the skull of a saiga antelope found on a bar of Usuktuk River at 156° 33'W, 3 km south of the quadrangle boundary (Harington, 1981, p. 224-225). Although its stratigraphic position was not evident, the date is consistent with those of mammal remains from the Ikpikpuk-Titaluk River region. O'Sullivan (1961, p. 87-136) has discussed at length the silt and underlying fluvial deposits for most of the Arctic Coastal Plain region; his report deserves careful study for those planning further study of these deposits.

Eolian sand

A belt of eolian sand extends across the southern part of the coastal plain from the Colville River to a point 32 km west of the Meade River, where the obvious dune forms can no longer be recognized on aerial photographs. These eolian deposits, first delineated by Black (1951) and also observed by O'Sullivan (1961), have been studied in detail by Carter and Robinson (1978), Carter and Galloway (1979b), Carter (1981a), and by Carter and Hopkins (1982). These studies, in the area east of the Meade River quadrangle, have identified an older set of linear dune ridges of a sand sea that was active between 12,000 and 36,000 years ago, but which are not known to be present in the Meade River quadrangle, a sand sheet formed between 8,000 and 11,400 years ago, and small longitudinal and parabolic dunes that have been formed in the last 3,500 years (Carter, 1981b; personal communication, 1982). All of these eolian deposits have been formed by winds that were essentially parallel to the east-northeasterly winds that prevail today.

The Meade River has cut its valley through the younger dunes and the underlying sand sheet to basal pond deposits and alluvium that rests on marine gravel, clay, and bedrock. The basal pond deposits, 2 m above river level in the east bank of Meade River 5 km east of Atkasook (E, table 3, fig. 1), are 11,200 $\pm$ 220 years old (I-10,785). Basal peat beneath the tundra turf, about 10 m above the dated pond deposits, is 3,610 $\pm$ 90 years old (I-11,124). Dating of the eolian deposits (Everett, 1979, p. 220) on the west side of the Meade River near Atkasook gives an age of 9,470 $\pm$ 145 years (DIC-464; C, table 3, fig. 1) for organic material at a depth of 1.22 m below the top of the river bank, and several younger dates, mostly between 4,000 and 6,000 years, from surface soils that bear on the stabilization of the dunes. A prominent and horizontally continuous peat horizon on the east bank of Usuktuk River (L, table 3, fig. 1) indicates a period of stabilization or the beginning of local dune formation 11,460 $\pm$ 200 years ago (I-11,496). The radiocarbon dating is consistent with Carter's reconstruction of the eolian history and shows that most of the eolian sand is equivalent in age with his 8,000 to 11,400-year old sand sheet and that most of the surficial eolian deposits are of Holocene age.

Active dunes and blowouts are common on the larger streams both within the belt of eolian sand and north of it. Dune and blowout activity is greatest on the downwind (west) side of the rivers. Downwind from the active dunes and blowouts are stabilized dunes and a thin sheet of eolian sand, as noted on the lower Meade River by Rickert and Tedrow (1967) and by Peterson and Billings (1978). Local modern dunes are generally too small to be shown on the geologic map, except along Meade river.

The eolian sand is fine to medium grained and contains no coarse material, in contrast to the pebbles that are scattered through the marine sand and to beds and lenses of coarse material in fluvial deposits. The eolian sand is massive to stratified and is locally cross bedded. Exposures are generally poor, and none were observed where the sand could be studied in the frozen state. However, thaw lakes are numerous, indicating that the sand or underlying deposits are ice rich in many places.

<u>Alluvial deposits</u>

Alluvial deposits that are transported downstream consist largely of sand redeposited from erosion of river banks and bed scour. Fine gravel transported down the Meade River from the fluvial deposits beneath the upland silt and coarser gravel, largely of subangular pieces and angular slabs of the local bedrock, occur locally on bars and in shoals along the river downstream to the confluence with Usuktuk River. Below the Usuktuk River, the Meade River alluvial deposits are largely sand, grading in the delta region to fine sand and silty sand. Gravel on the Avalik and lower Avaliktok Rivers is largely of the local rock, including large amounts of coal. The Usuktuk and Topagoruk Rivers have fine gravel beds a few km downstream from the southern boundary of the quadrangle, beyond which the alluvium is sand. The smaller streams, such as the Inaru, Kucheak, Kugrua, and Nigisaktuvuk Rivers, generally flow on sandy bed material similar to that in which the valleys are cut, except in local areas similar to those indicated on the map (fig. 2) where the stream is close to bedrock and fragments of the local rock form gravelly bars and shoals, some of which have fractured bedrock in poor outcrop. Commonly the larger sizes form an armor over finer-grained materials, including clay.

Radiocarbon ages of the alluvial deposits of the Meade River at Atkasook show that they are, in general, less than 4,000 years old, or late Holocene. Everett (1979, p. 220) obtained dates of 3,740 ± 110 years (DIC-694) for sedge, fragments of leaves, and stems at a depth of 63 cm, and 2,560 ± 75 years (DIC-695) for fine fibrous materials at a depth of 48 cm in a terrace (B, table 3, fig. 1) that is 5 to 6 m lower than the level of the eolian sand deposits into which the Meade River has cut. The terrace is probably one of the oldest and highest of the complex of alluvial surfaces that is grouped in the alluvial deposits map unit. Two other dates adjacent to the Meade River (A and I, table 3, fig. 1) were 2,180 ± 65 for a lower alluvial surface that is slightly higher than one dated at 930 ± 70 (K. R. Everett, written communication, Jan. 8, 1978). The ages are generally consistent with the concept discussed in the section on eolian sand in which the age of the sand sheet into which the Meade River has cut its channel is 8,000 to 11,400 years. Apparently, the alluvial surfaces are slightly younger than or are equivalent in age to the late Holocene parabolic and longitudinal dunes.

A small dune on the Meade River delta (K, table 3, fig. 1) included willow sticks, perhaps transported by the river and rolled by the strong winds of that region into peat beds that were incorporated into the dune deposits. A radiocarbon age of 6,990 $\pm$ 125 years (I-11,123) favors this interpretation because the dunes are still actively being built and reworked by the wind and because the date is older than those described above from terraces near Atkasook.

Thaw-lake deposits and the thaw-lake cycle

The thaw-lake cycle is, perhaps, the dominant form of landscape modification in the permafrost environment of the Arctic Coastal Plain. The origin, orientation, and cyclic development of thaw lakes have been studied extensively in the Barrow area and to a lesser extent elsewhere in the coastal plain (Black and Barksdale, 1949; Britton, 1957; Brewer, 1958; Livingstone and others, 1958; Carson and Hussey, 1960, 1962, 1963; Brown, 1965; Hussey and Michelson, 1966; Carson, 1968; Black, 1969; Morrissey, 1979; Williams and Yeend, 1979; and others). Thaw lakes have been classified (Sellmann and others, 1975) into several categories, of which the Meade River quadrangle has large- to intermediate-sized lakes with moderate to well-developed orientation (10^{o} to 15^{o} west of north) in the outer coastal plain, and intermediate to small sized, poorly-oriented, low-density lakes in the inner coastal plain underlain by upland silt.

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 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 outer coastal plain and as much as 21 m in parts of the inner coastal plain. Orientation of the thaw lakes by wave-induced currents is derived from and is normal to the prevailing east-northeasterly winds (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 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), Lewellen (1972), and in Sellmann and others (1975).

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

Radiocarbon studies of thaw-lake deposits near Barrow may have applicability to similar deposits in the outer coastal plain of the Meade River quadrangle. The oldest dated lacustrine peat, 12,160 ± 200 years old (Lewellen, 1972), provides a maximum known age for operation of the thaw-lake process at Barrow (Sellmann and others, 1975, p. 18; Brown and others, 1980). It is not known whether this peat is an old turf that has been incorporated into younger thaw-lake sediments, or whether it dates the deposits of the thaw lake. Carson (1968) believed that the lacustrine expansion reached a maximum between 4,000 and 8,000 years ago and that the first of several cycles of basin intersection and drainage began after 3,500 years ago. The process of formation and drainage of thaw lakes continues today in the Meade River quadrangle (Morrissey, 1979), and it has affected oxbow lakes of the young alluvial deposits and the late Holocene dunes.

Thaw-lake activity in the inner coastal plain is continuing today, and the larger, deep thaw lakes developed on upland silt seem to have formed about 2,500 years ago (Williams and Yeend, 1979; Nelson, 1982). For example, a radiocarbon sample from in situ peat in the bottom of a 21-m deep thaw lake in the upland silt (M, table 3, fig. 1) was dated at 2,640 ± 85 years (I-10,273) (Williams and Yeend, 1979), but retransported twigs, from the same stratigraphic level, were 8,980 ± 140 years old (I-10,787). Nearly identical results were obtained from the Titaluk River section, about 42 km to the southeast, where the in situ peat at the base of the thaw-lake deposits was 2,500 ± 50 years old (USGS-628) and the woody material apparently retransported from the lake banks was 6,960 ± 80 years old (USGS-1271) (Nelson, 1982). In the latter case, the fluvial sediments beneath the thaw-lake deposits are between about 25,000 and 43,000 years old. The age of these thaw lakes seems to be late Holocene, although further study may identify others that have a greater age.

Permafrost

Permafrost, or perennially frozen ground, extends from a depth of about 0.5 m below the ground surface to depths estimated from limited data (Osterkamp and Payne, 1981, fig. 2, table 1) to be less than 200 m to greater than 300 m. Osterkamp and Payne noted a tendency for thickening of permafrost in the northern part of the quadrangle. Data on the base of permafrost are limited to the Kugrua Test Well No. 1 (207 m), Skull Cliff Core Test No. 1 (greater than 236 m), Topagoruk Test Well No. 1 (335 m), 4 km east of the quadrangle boundary, and Kaolak Test Well No. 1 (259-299 m), 48 km west-southwest of the southwestern corner of the quadrangle. The upper surface of permafrost, or the permafrost table, is depressed by the thermal disturbance of bodies of surface water that are deeper than 2 m (Brewer, 1958). Almost all of the lakes are shallow and freeze to the bottom each winter. No subsurface information is available on the thickness of the thaw bulb beneath deep lakes and rivers.

The ice content of permafrost that exceeds the natural voids of the frozen sediments determines the amount of settlement to be expected when permafrost thaws. This is an important consideration in building roads, airfields, and structures on permafrost terrain because even a slight disturbance of the ground cover can raise the mean annual ground-surface temperature and cause thawing of permafrost. In the Meade River quadrangle construction methods that prevent thaw of permafrost should be employed, for, as far as is known, all of the perennially frozen materials contain near-surface excess ice that will produce undesirable settlement upon thawing. Very few natural exposures of permafrost were available for study because those exposed by storm waves and river erosion are rapidly thawed and become slumped. However, drilling in the Barrow area, in terrain very similar to that of the outer coastal plain section of the Meade River quadrangle, shows that segregated ice, exclusive of wedge ice, decreases from about 75 percent of the volume of the frozen sediments at a depth of about 1 m to zero at about 8.5 m (Sellmann and others, 1975, p. 14-18). Hussey and Michelson (1966, p. 167-168) made a similar analysis for the upper 6.6 m of frozen ground and concluded that if the upper 6.6 m of permafrost in the Barrow area were thawed in various terrain units, the following amounts of settlement would take place. These amounts are based on four test holes and, excluding wedge ice, estimated as 5 percent of the volume of the sediments, are:

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

The actual settlement resulting from thaw of permafrost that is ice rich only in the upper 6 to 8 m accounts for the numerous shallow thaw-lake basins in the outer coastal plain at Barrow and in the Meade River quadrangle. The much deeper thaw lake basins in the inner coastal plain along the southern border of the quadrangle indicate that the sediments containing ice in excess of the void ratios of the materials may extend to greater depths than in the outer coastal plain and at Barrow. A deep basin along Topagoruk River at the southeastern corner of the quadrangle, 21 m below the original land surface, is estimated to have had an average ice content (including wedge ice) of about 78 percent before thaw of the permafrost (Williams and Yeend, 1979, p. B36), a value that compares with the ice content (excluding wedge ice) of the uppermost part of the Barrow sections (Sellmann and others, 1975) and with an ice content approaching 80 percent in Yakutia (Are, 1973) and 68 percent at East Oumalik Lake in the upland silt terrain 42 km east of the Topagoruk River locality (Livingstone and others, 1958). Processes of formation of thick sections of segregated ice described by Mackay (1971) or deeper more numerous ice wedges than in the Barrow area may account for these thick ice-rich areas, but, unfortunately, no exposures were available for study.

Ice wedges, expressed at the surface as raised- and depressed-center polygons, generally extend 2 to 5 m below the permafrost table in the inner coastal plain. They contribute an amount of ice ranging from 5 percent of the volume of the soils at Barrow (Hussey and Michelson, 1966) to 10 to 20 percent according to Sellmann and others (1975). In Siberia, in an area somewhat like the upland silt unit of the Meade River quadrangle, ice wedges make up as much as 50 percent of the ground volume (Are, 1973). Wedge ice was not included in the settlement figures tabulated above.

Floods and storm surges

Flood surveys have been made on the Meade River at Atkasook and on Avalik River near its mouth west of the quadrangle boundary (Childers and others, 1979, table 1). Bankfull discharge of the Meade River is computed at 246 m^3/s (cubic meters per second) and for Avalik River, it is 2,642 m^3/s. The maximum evident flood is 2,973 m^3/s for the Meade River and 2,585 m^3/s for Avalik River. The two-year flood for Meade River is 425 m^3/s, the 50-year flood 934 m^3/s. The duration of spring floods is brief and depends on the rate of snow melt, which varies from year to year. Normally, during the snow-melt period lake levels are high and much of the area of thaw-lake basins is temporarily flooded by meltwater. Breakup on the rivers is, at first, streamflow over the ice, then, as the river rises, the ice cover is lifted to float downstream where it causes local ice jams. Ice jams are broken when the river is backed up enough to provide the necessary flotation to lift the jam or when the river overtops the jam and cuts a channel through it.

Storm surges generally accompany late summer or fall cyclonic storms when the arctic ice pack is far removed from the coast. The surges are as much as 3 m above normal sea level (Hartz, 1978), compared to the normal tidal range at Barrow of about 0.3 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 interval between storms during which ice conditions favor a surge and high waves is several years. The storms are believed to cause most of the coastal erosion, which averages 0 to 2 m per year along the Chukchi Sea coast (Hartz, 1978). Erosion is relatively slow because the coastal bluffs are defended by consolidated rock; in other areas, notably the Beaufort Sea coast, erosion of the frozen marine sediments is much more rapid.

Water resources

Average annual precipitation at Barrow, the nearest meteorological station, corrected for estimated errors caused by windblown snow and rain and to sum the trace amounts, is estimated at about 170 mm, of which 106 mm is snow and 64 mm is rain; monthly maxima are in August and January (Dingman and others, 1980, p. 52). The processes of heat balance and the effect on snow cover, evaporation, transpiration, microclimate, and hydrology are explained in some detail by Dingman and others (1980). Basically, runoff is concentrated during the breakup period in June when between 61 and 98 percent of the annual streamflow occurs during the snowmelt flood. Heavy summer 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 is 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. Techniques of deepening existing lake basins to create reservoirs that are capable of providing winter storage for water pumped in from rivers during the summer have been used at Prudhoe Bay to provide water for camp and industrial needs. Similar techniques could be used in the Meade River quadrangle.

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

Economic geology

The area of the quadrangle, 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. Four test wells and one core test have been drilled. Meade Test Well No. 1, 1,660 m deep, and producing no oil and a small amount of gas (Collins, 1958a, p. 342) and Skull Cliff Core Test No. 1, 237 m deep and encountering no oil nor gas (Collins, 1961, p. 575) were drilled by the U.S. Navy. South Meade Test Well No. 1, 3,031 m deep and yielding only poor gas shows, Kugrua Test Well No. 1, 3,858 m deep and dry, and Kuyanak Test Well No. 1, 2,039 m deep and yielding minor oil and gas shows, were drilled by the U.S. Geological Survey. However, Walakpa Test Well No. 2, only 4 km north of the quadrangle boundary, was drilled 1,329 m deep and was completed as a gas well by the Geological Survey. Peard Test Well No. 1, 0.1 km west of the quadrangle boundary, was drilled 3,117 m by the Geological Survey and encountered only poor shows of gas. Topagoruk Test Well No. 1 was drilled by the U.S. Navy 4 km east of the quadrangle boundary to a depth of 3,202 m and was essentially a dry hole, except for a small show of oil and a slight blow of gas (Collins, 1958b); East Topagoruk Test Well No. 1, located nearby, was drilled to 1,094 m by the Navy and yielded no shows of oil and no commercial shows of gas. Data on the Geological Survey exploration program has been placed on open file with the Environmental Data Service of the National Oceanic and Atmospheric Administration (NOAA), Boulder, Colorado; logs of the formations penetrated are summarized by Bird (1982).

Coal, 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 which lies beneath the unconsolidated deposits in all but the northern edge of the Meade River quadrangle (Martin and Callahan, 1978; Mayfield and others, in press). Coal in the Nanushuk Group ranges from near zero at its contact with the underlying Torok Shale to more than 5 percent of the thickness of the Nanushuk rocks in the southwest quadrant of the area (Martin and Callahan, 1978). These coal deposits are a significant part of the 45 billion metric tons of identified coal resources and of the 300 billion to 3 trillion metric tons of hypothetical undiscovered coal resources of National Petroleum Reserve--Alaska, as estimated by Martin and Callahan.

The coal resources have been developed only at the Meade River coal mine, at Atkasook, where coal was first mined in a pit in the river bank and later (1944) the coal mined in an 18 by 20 m room was hoisted to the surface through a shaft. This method enabled winter work and allowed direct loading into tractor trains hauling the coal to Barrow where it was used in Government facilities and was sold to the local residents (Sanford and Pierce, 1946) in the days before development of the Barrow gas field that now supplies fuel to the village. The coal beds, 0.3 to 2 m thick, are frozen, as is the 7.5 to 9 m of clay and sand overburden. The coal is subbituminous and has a rating of 10,330 to 12,960 Btu. Although this mine is no longer operating, the more than 62,000 metric tons identified by drilling can be developed, providing equipment can be brought in and the coal taken out economically and without adverse environmental impact. Other deposits of coal in the quadrangle as thick as that in the Meade River mine have not been identified close to the surface.

Rock that is suitable for use as a construction material is limited to sandstone beds in the Nanushuk Group because the shale, clay, and coal generally have insufficient strength for most uses. The sandstone is exposed in the bed or low in the banks of the Meade, Avalik, lower Avaliktok Rivers, and locally on the middle Inaru and other streams. The sandstone breaks along shaly partings and bedding planes to form thin, flat fragments, the size of which is controlled by the joint system in the rock. The sandstone is believed too weak, in many areas, to pass the abrasion tests required for its use as rip rap, or would pass only marginally. Locating thick-bedded sandstone with widely-spaced joints suitable for quarrying for rip rap is expected to be difficult. Even where exposed in river banks the sandstone is covered by frozen overburden that is generally 3- to 20-m thick.

Gravel of any type is in short supply. It occurs in offshore bars, spits and beaches along the Chukchi Sea coast, in the beds and bars of the larger streams in the southern part of the area, and in the marine deposits as a thin layer on clay or bedrock and as former beach deposits. The principal source of well-sorted, washed gravel and gravelly sand is the offshore bars that bound Peard Bay and some of the narrow beaches and spits that form the shore line of Peard Bay and occur in indentations in the cliffed coastline farther northeast, where streams enter the sea. The gravel of these deposits is more likely to be unfrozen to a greater depth than at any other site during the summer, but in pit run the deposits are likely to contain a large amount of sand. Excavation of bar, spit, and beach deposits incurs responsibility for evaluating the environmental consequences of altering the shoreline. The beach deposits are long and narrow, and, where adjacent to cliffs, contain erratic boulders, broken blocks of bedrock, and fine material washed down gullies to the beach. Former beaches are difficult to identify on aerial photographs and are of limited size and thickness; those identified from study of air photos (Williams and others, 1977) along the base of the pre-Illinoian shoreline (III, fig. 1) have proved, upon inspection in 1978, to be marine sand, not former beaches. Gravelly material at the base of the marine sand and over the bedrock and clay is seldom more than 1-m thick and is generally buried by frozen overburden; it is not a viable source of gravel.

Even more limited are deposits of gravel in the seasonally-thawed bars and bed of Meade River south of 70° 30' N., the Avalik and lower Avaliktok Rivers, and the southernmost 5 km of Usuktuk and Topagoruk Rivers. The thin alluvial gravel on Inaru River and smaller streams is generally concentrated from local bedrock exposures and from the basal marine gravel exposed in the river banks; these local occurrences would yield an insignificant amount of gravel. Even on the larger rivers the gravel probably does not extend below the depth of stream scour or, at many places, is merely an armor that mantles finer-grained deposits. The gravel of streams which are cutting into bedrock, like the Meade River, includes angular pieces of sandstone, ironstone, shale, and coal. Gravel is seldom available from terraces bordering the streams and seems generally confined to the present stream courses; this raises the problem of environmental impact of mining the gravel on fisheries and on water quality. In addition, the presence of large amounts of chert and coal in the marine and alluvial gravel makes the material generally unsuitable for aggregate. In general, the river gravel may be available in quantities of less than 1,000 m^3 for local use, but no deposits large enough for major construction projects have been found.

Sand is the most abundant construction material of the Meade River quadrangle; it forms a widespread mantle at the surface and extends to depths as great as 30 m. It generally ranges from fine to medium eolian sand to fine to medium silty marine sand that contains scattered pebbles and granules of quartz and chert. The sand grains are largely quartz and chert with minor amounts of other minerals and coal. In general the deposits are frozen downward from a depth of about 0.5 m and in a few well-drained sites downward from a depth of 1 to 2 m. Locally, the upper part of the dune sand contains peat beds. The sand is easily worked by wind when thawed, and, in opening any area as a borrow or construction site, the effect of wind in redepositing the sand across undisturbed tundra downwind and the potential for wind-enlargement of the borrow area by blow-out action should be considered.

Clay is common above and below the coal beds of the Nanushuk Group and is exposed in beds and banks of the Meade, Avalik, and Avaliktok Rivers and locally along Kucheak Creek, Inaru River, and Kugrua River. It is also exposed near the base of the unconsolidated deposits along the Chukchi Sea bluffs. Although no tests have been made of its properties, the clay appears to have some plasticity when saturated and to be hard when dry; it may, thus, be a possible source of brick clay. The clay, found with coal in Meade Test Well No. 1, formed a natural drilling mud during most of the drilling of that well (Collins, 1958a, p. 351-352). Whether these deposits could be developed as a source of drilling mud would require further tests of their properties and location of a suitable source near proposed drill sites. Even if suitable clay were available in the beds and banks of the rivers, excavation of these deposits may cause an adverse environmental impact by adding suspended sediment to the stream. The cost of overcoming environmental problems might eliminate any savings to be achieved by using local sources of drilling mud.

Peat is largely confined to the surface mat of living and dead vegetation that seldom exceeds 0.5 m in thickness. Locally, within cliffhead dunes along streams, peat reaches thicknesses of 3 to 5 m. In these locations the peat is normally not well enough compressed for use as a building material or fuel, and it contains sand and is interbedded with sand. No estimates of the fuel value of peat are available.

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