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Surficial geology and morphology of the Alaskan central Arctic coastal plain

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SURFICIAL GEOLOGY AND MORPHOLOGY OF THE ALASKAN CENTRAL ARCTIC COASTAL PLAIN

A

DISSERTATION

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By

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SURFICIAL GEOLOGY AND MORPHOLOGY OF THE

ALASKAN CENTRAL ARCTIC COASTAL PLAIN

by

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ABSTRACT

Mapping and analyses have defined the distribution, morphology, character, and age of marine, fluvial, glacial, eolian, and lacustrine sediments of the late Cenozoic Gubik Formation in approximately 12,000 km^2 of the Alaskan central Arctic Coastal Plain, and allowed interpretations of the depositional, climatic, and tectonic histories.

Amino-acid analysis of wood and some shell materials has defined broad age groups: young, middle and old. The old group has been abandoned because of probable leaching of acids or other modification. These groups are the basis for correlation of deposits between areas and have been assigned minimum relative ages. The young group is at least Sangamonian and the middle group is probably at least middle Pleistocene.

Notable among interpretations of the surficial geology and morphology are:

1. Transgression of early Wisconsinan and perhaps Sangamonian seas as far as 9 km inland from the present coast.
2. Tertiary glacial advances as far north as uplands near Kavik airstrip and perhaps the headwaters of the Kachemach and Miluveach Rivers.
3. Three marine terraces as old as middle to late Pliocene and three late Pleistocene alluvial terraces east of the Colville River.
4. Middle Pleistocene minimum age for the Ugnuravik gravel is indicated by wood of the middle amino-acid group.
5. Coexistence of coniferous and nonconiferous wood on the Coastal Plain in middle to early Pleistocene time is possibly explained by greater accumulation of summer warmth associated with a continental climate resulting from greater exposure of the continental shelf.
6. Late Pliocene through Pleistocene outwash and alluvium and Holocene alluvium compose the Canning gravel.

7. Folding of the Coastal Plain in western ANWR and up to 95 m of uplift in the Sadlerochit Mountains since latest Pliocene time.

8. Late middle through late Wisconsinan age for the Beechey sand.

9. Late Wisconsinan through early Holocene age for thaw lakes in which broad-based mounds formed.

While other findings and interpretations may be less significant, collectively they have allowed a start toward definition of the surficial geology.

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ACKNOWLEDGEMENTS

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Among the many colleagues who provided valuable information on the processes and geology of the Arctic Coastal Plain or Beaufort Sea Shelf, Sathy Naidu of the University of Alaska Institute of Marine Sciences and Peter Barnes and Erk Reimnitz, both of the USGS in Menlo Park, California, deserve special recognition.

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CHAPTER 1 - INTRODUCTION

Location

The primary area of study of the surficial geology and morphology comprises about 12,000 km^2 in 24 quadrangles that cover the near-coastal, central part of the Arctic Coastal Plain[1] in northern Alaska (figures 1.1, 1.2, and 1.3). The Colville and Canning Rivers, which approximately bound the state-owned part of the study area on the west and east, respectively, flow northward from headwaters in the Brooks Range, through Foothills of the Brooks Range, and across the Arctic Coastal Plain to the Beaufort Sea. The Brooks Range, Arctic Foothills, and Arctic Coastal Plain are three of 12 physiographic divisions of Alaska described by Wahrhaftig (1965). The Arctic Coastal Plain is the northernmost of these divisions and described as a broad, level plain underlain by continuous permafrost.

The west side of the Colville River and delta is the east boundary of the National Petroleum Reserve, Alaska (NPRA), which includes most of the Coastal Plain westward to the Chukchi Sea. The west side of the Staines River, the westernmost distributary of the Canning River, is the west boundary of the Arctic National Wildlife Refuge (ANWR), which includes the Coastal Plain eastward to the Canadian border (figure 1.1). State land between these two areas of federal land, and inland to 70^0 north latitude and to 69^0 45' north latitude near and within ANWR (variable distances between 25 and 65 km), composes most of the study area; the east study-area boundary has been extended into ANWR to allow a better understanding of the geology within the adjacent state land (figure 1.3). All

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[1]Harrison Bay A-1, A-2, B-1, B-2; Beechey point A-1, A-2, A-3, A-4, A-5, B-2, B-3, B-4, B-5, C-4, C-5; Flaxman Island A-1, A-3, A-4, A-5; Mount Michelson D-1, D-2, D-3, D-4, D-5.

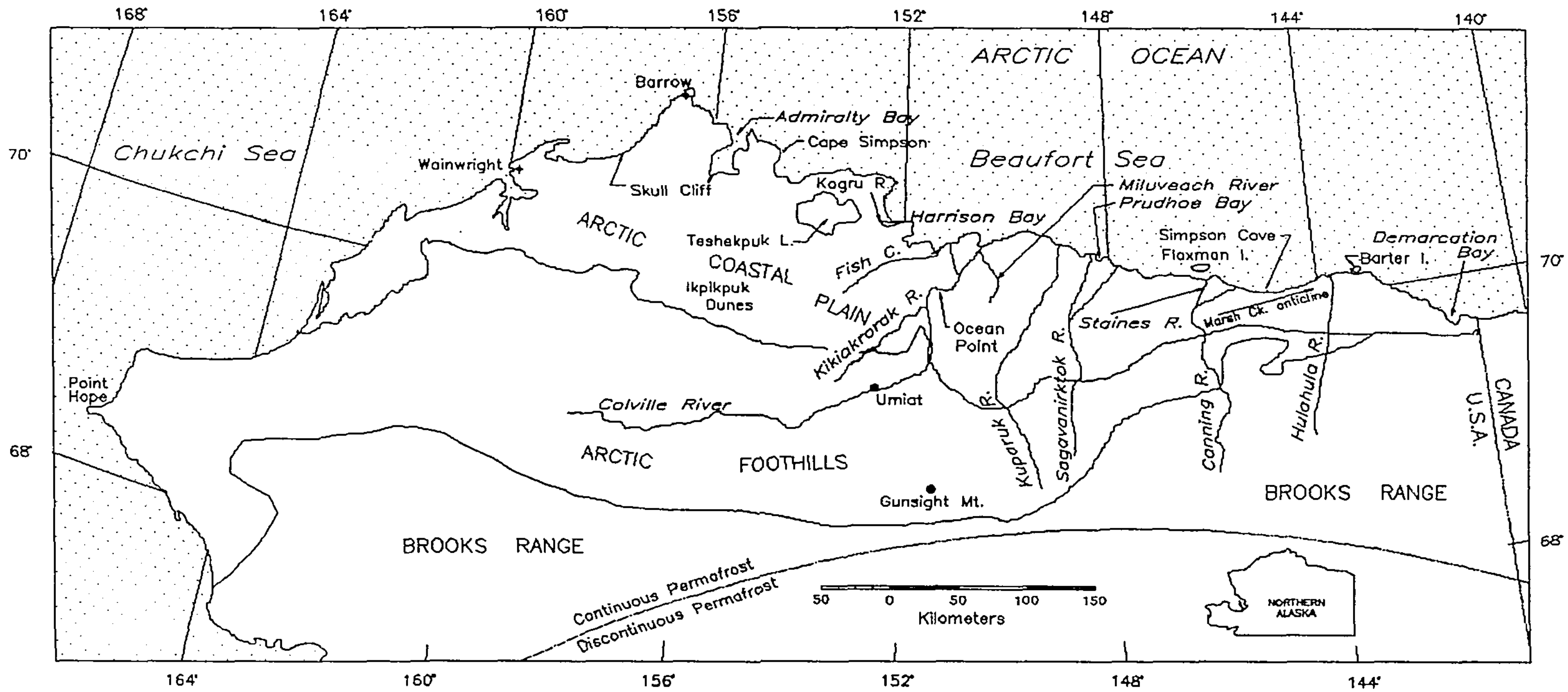

Figure 1.1 Map of the Arctic Coastal Plain of Alaska showing locations discussed in the text.

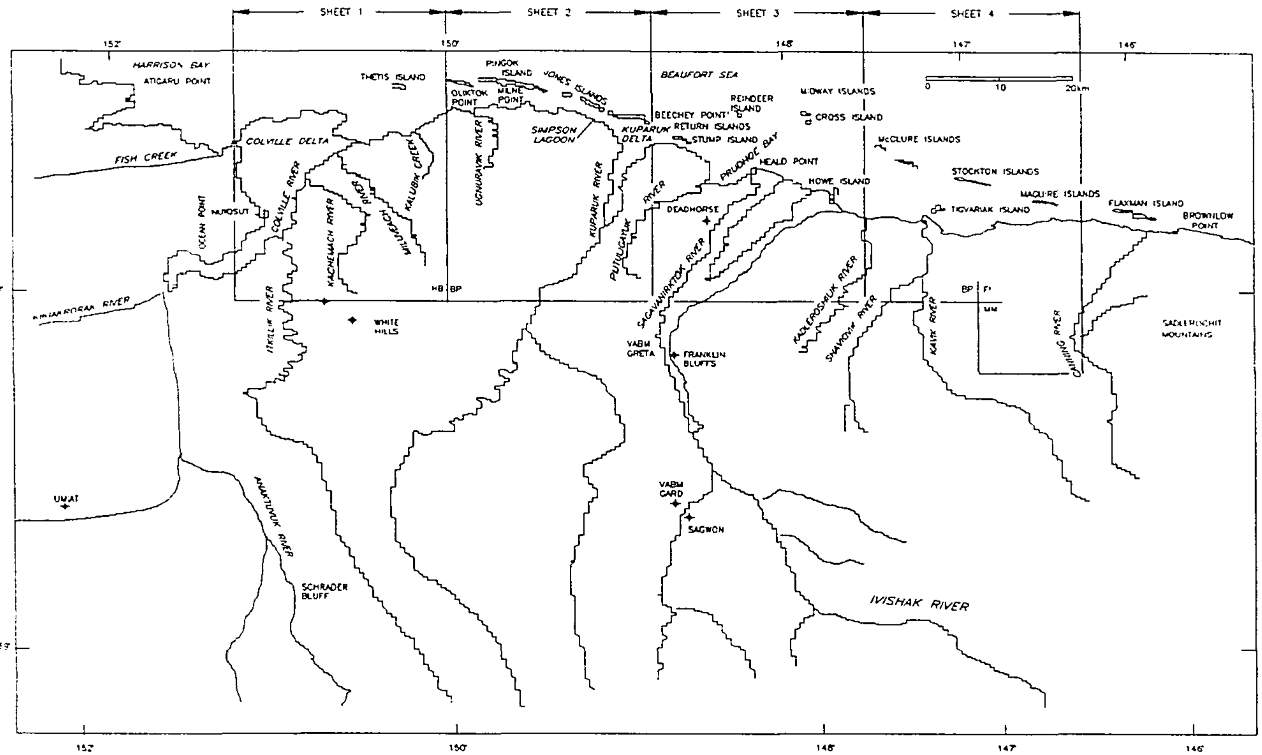

Figure 1.2 Map of the western part of the study are.. showing locations discussed in the text. Stars near the White Hills mark locations of erratic boulders.

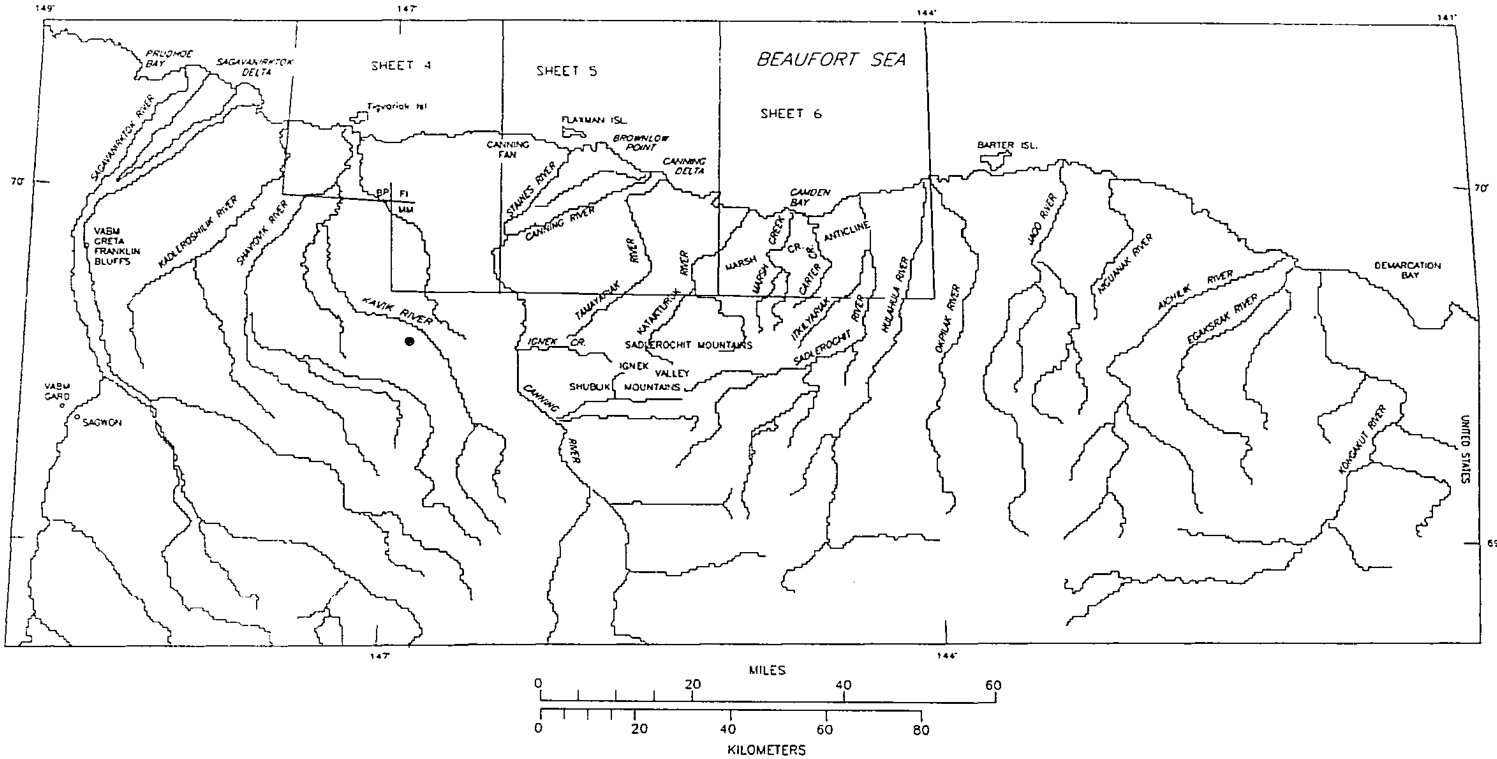

Figure 1.3 Map of the eastern part of the study area showing locations discussed in the text. Dot south of the Kavik River marks the location of erratic boulders.

of these lands are within the North Slope Borough, which includes the land north of the Brooks Range (figure 1.1).

Problem and Objectives

Little was known of the surficial geology of the Alaskan Arctic Coastal Plain until the past decade. However, beginning late in the 1970s and continuing into the 1980s, federal land west and, to a lesser extent, east of state-owned areas being explored and developed for petroleum was studied through systematic mapping, topical research, and new analytical techniques. These studies added considerably to the base of knowledge; in particular, marine and eolian depositional histories were defined. However, interest in the central Coastal Plain during that time was largely oriented toward recovery of petroleum resources. Lacking in studies were systematic and detailed mapping and characterization of the unconsolidated surficial sediments, without which the late Cenozoic depositional, paleoclimatic, and tectonic histories could not be defined.

The purpose of this study is to define the late Cenozoic depositional, climatic, and tectonic histories in the central part of the Alaskan Arctic Coastal Plain. Because a large percentage of sediments within the study area is fluvial, this work provides a link with marine and eolian depositional histories that are important in adjacent areas. The study is based on the primary objectives of mapping and characterization of surficial sediments in that area. A further objective is to systematically present baseline sediment data such as: grain size, age, and included microfossils, pollen, and wood taxa. Such data for the Alaskan central Arctic Coastal Plain are not available systematically and in quantity in any other source.

Primary users of information collected in this study are (1) state agencies and the North Slope Borough for area plans, permitting, land leases, and geologic-materials sales; (2) geotechnical and environmental consultants working for these agencies and the petroleum industry; (3) the petroleum industry; and (4) researchers interested in understanding the geologic history of the area during the late Cenozoic Era.

Scope

Field work within the state-owned part of the study area was done each summer from 1981 through 1985 and a short winter project to log boreholes was done in 1985. Field work on the Arctic Coastal Plain in the Canning River Delta area and elsewhere within ANWR was also done in 1985 in a cooperative study with L. David Carter of the USGS. In 1987, another cooperative study with Carter in the Colville River Delta and eastern NPRA provided additional data on the delta and allowed extension of the study area farther west. Maps of surficial sediments in quadrangles within ANWR[2] that were done in the 1985 cooperative study are included as part of the study area; however, discussion of the geology in these quadrangles is not emphasized to avoid preempting interpretations and probable publication of these interpretations by Carter.

Organization

The dissertation consists of three parts: narrative, appendices, and sheets. The narrative provides introductory information in Chapter 1, including previous work; geographic information in Chapter 2, including location, topography, climate, permafrost

[2]Flaxman Island A-1, A-3, A-4; Mount Michelson D-1, D-2, D-3, D-4.

and related features, vegetation, and soils; and geologic information on pre-late Cenozoic sediments in Chapter 3. Discussion of pre-late Cenozoic sediments is included to establish an understanding of the rocks that underlie, or by being eroded, have contributed to the late Cenozoic unconsolidated sediments of the Gubik Formation.

In Chapters 4 through 8, emphasis is given to the unconsolidated sediments of the Gubik Formation, primarily because these are most prevalent within the study area. Each of these chapters discusses a different type of unconsolidated sediment of the Gubik Formation: marine, fluvial or glaciofluvial, glacial, eolian, and lacustrine. Fluvial and glaciofluvial sediments discussed in Chapter 5 compose the greatest percentage of the unconsolidated sediments within the study area, yet had been among the least studied. The relative great abundance of these sediments and general paucity of information regarding them, prompted their emphasis in this dissertation; hence, the apparent disproportionate coverage of these sediments within the narrative.

One or more literature-derived summaries of relevant information (e.g., marine transgressions on the Coastal Plain in Chapter 4, or glaciations in the central Brooks Range in Chapter 6) are included in frontal sections of each chapter to familiarize readers with the nomenclature, general distribution, character, or chronology of the particular type of sediment on the Coastal Plain.

Chapter 9 summarizes and correlates the Cenozoic events and deposits based on previous discussions and presents an integrating conceptual model for these events and deposits. Chapter 10 concludes the dissertation with a listing of key findings and interpretations. Appendices A through D present information relevant to included maps, and appendices E through K present analytical data relevant to samples collected in the study. Sheets 1 through 6 are the maps, usually in blocks of four quadrangles, of the study area from west to east, respectively.

Methods

Interpretations of surficial geology and morphology in the study area are based on: (1) detailed geologic mapping and observations (sheets 1 through 6 and appendices A through D); (2) grain-size analysis, radiocarbon and thermoluminescence dating, analysis of amino acids in mollusk shells and wood, identification of wood types, and microfossil and pollen contents (appendices E through K); and (3) review of literature and discussions with colleagues.

The surficial geology was mapped from 1:60,000-scale, color-infrared photographs while consulting 1:250,000-scale, black-and-white and false-color Landsat images and 1:18,000-scale, natural-color photographs. Mapping was transferred from the photographs to 1:63,360-scale base maps using a zoom-transfer scope. Surficial-geology units and the morphology were field checked and boundaries were revised as necessary. Field activities were concentrated along the coast and rivers where surficial deposits are best exposed, and in gravel pits that exposed sediments to about 19 m below the ground surface. During field operations, 464 stratigraphic sections or locations were measured or described, or both, and 678 samples were collected for various analyses. Grain-size analysis was done to aid interpretation of depositional environments and to characterize or compare sediments; all other analyses were done to aid interpretations of chronology, paleoclimates, or paleoenvironments.

Grain-size analysis and determination of whether wood was coniferous or nonconiferous were done in the DGGS sediment laboratory by staff under supervision. Grain-size analysis included sieving at quarter-phi intervals for coarse fractions, and pipetting and later use of a Rapid Sediment Analyser for fine fractions, in accordance with established laboratory procedures. Data reduction was done using a computer program written by DGGS staff. Determination of whether wood was coniferous or nonconiferous was based on microscopic examination of the wood structure, in particular, presence or absence of marginal pits.

All other analyses were done by commercial, university, or governmental laboratories as appropriate; with one exception, these laboratories are listed on the appendix cover sheet. The exception is Micropaleo Consultants in San Diego, California because they did not assign an internal laboratory number to each submitted sample.

Background

The western part of the area was first geologically studied when Schrader (1904) traversed the Brooks Range and Anaktuvuk and Colville Rivers, and proceeded westward along the coast to Cape Lisburne on the Chukchi Sea (figure 1.1). Leffingwell (1919) spent nine summers and six winters on the Arctic Coastal Plain between 1906 and 1914, making traverses inland across the Coastal Plain, east along the coast to Herschel Island, and west along the coast to Barrow to document the geology and morphology. Although not the earliest, his was the first systematic geological study.

The area is included in regional map reports by Payne and others (1952) and Lathram (1965) that resulted from work done between 1944 and 1953 to evaluate the petroleum resources of the Coastal Plain west of the Colville River, the area then called Naval Petroleum Reserve 4 (Reed, 1958). As part of this resource evaluation in 1949 and 1950, Black (1964) studied surficial deposits in the Petroleum Reserve and the western part of the study area. O'Sullivan (1961) also studied deposits of the western Coastal Plain, and made interpretations of late Cenozoic sea levels that extend into the western part of the study area. Walker (1983) summarized his work since 1966 on the morphology and processes of the Colville River Delta.

The primary focus in the central and eastern parts of the Coastal Plain during the 1960s was exploration for petroleum resources; there was little work on the surficial sediments. Yeend (1973a,b) mapped surficial sediments in a proposed transportation corridor that crossed the study area southeast from Prudhoe Bay to near the Sadlerochit Mountains (and on to the Canadian border in subsequent reports). A terrain analysis by Sellman and others (1975) was based on the size and orientation of thaw lakes and included the central part of the Coastal Plain. Updike and Howland (1979) mapped the surficial geology and discussed processes specific to the Prudhoe Bay oil field.

Geologic and other scientific investigations of the central part of the Coastal Plain accelerated with initiation of the Outer Continental Shelf Environmental Assessment Program (OCSEAP) in the mid to late 1970s. As part of OCSEAP, Hopkins and Hartz (1978) discussed deposits and morphology of the Coastal Plain and erosion of the coast. In subsequent studies reported in quarterly and annual OCSEAP publications, Hopkins and colleagues expanded geological knowledge of the area and established a base for further studies in the 1980s. Concurrently, Cannon and Rawlinson (1981) investigated surficial sediments and processes within the study area and mapped the geomorphology and flood hazard in the Colville, Kuparuk, Sagavanirktok, and Canning River Deltas.

In 1976, Naval Petroleum Reserve 4 was placed under jurisdiction of the U.S. Department of the Interior and renamed the National Petroleum Reserve, Alaska. Systematic mapping and exploration for petroleum resources were consequently done by personnel of the USGS between 1976 and 1981. Carter and Galloway (1985a) mapped surficial sediments in the Harrison Bay Quadrangle, which includes the western part of the study area, and Carter and others (1986c) mapped surficial sediments in the eastern part of the area.

Other mapping and topical research (e.g., Carter and Robinson, 1981; Carter and Galloway, 1982, 1985a,b; Carter, Brouwers, and Marincovich, 1988); amino-acid studies (e.g., Brigham and Miller, 1983; Brigham, 1984, 1985), and fossil studies (e.g., Hopkins and others, 1981a; Brouwers and others, 1984; McDougall and others, 1986) advanced understanding of the late Cenozoic marine transgressions and regressions on the Coastal Plain. Studies of offshore stratigraphy (e.g., Dinter, 1982, 1985; Smith, 1985; Wolf and others, 1985, 1987; and Foster, 1988) aided interpretations of the onshore stratigraphy.

Mapping of coastal morphology has been done over the past two decades (e.g., Short, 1973; Wiseman and others, 1973; Short and others, 1974; Barnes and others, 1977; Lewellen, 1977; Harper, 1978; Naidu and others, 1984; and Reimnitz and others, 1988).

Between 1981 and 1985, Rawlinson (1986b,c,d,e,f) mapped surficial deposits within the central Beechey Point Quadrangle, which includes the Prudhoe Bay and Kuparuk oil fields. Hickmott (1986a,b) mapped surficial deposits in the eastern Beechey Point Quadrangle. A field trip to these oil fields and other parts of Arctic Alaska, led by Rawlinson for the Fourth International Conference on Permafrost held in Fairbanks in 1983, was the impetus for a guidebook on permafrost and related features in the Prudhoe Bay area (Rawlinson, 1983).

Cooperative mapping between Carter of USGS and Rawlinson of DGGS was done in the western Coastal Plain of ANWR in 1985 and in the Colville Delta area in 1987. Results of these studies not previously published are included as part of this dissertation.

CHAPTER 2 - GEOGRAPHY

Topography

The Arctic Coastal Plain becomes narrower eastward, reflecting a northeast bend in the trend of the Arctic Foothills and Brooks Range. With this narrowing, the gradient of the Coastal Plain also increases eastward. Discounting areas of higher elevation along the southern boundary of the study area that are underlain by Tertiary deposits of the Sagavanirktok Formation and locally by Pliocene deposits of the Gubik Formation, the southern boundary of the Coastal Plain within the study area is about 60-m elevation in the west and about 300-m elevation in the east. The Coastal Plain slopes northward to elevations of only a few meters at the Beaufort Sea coast and is underlain by Quaternary deposits of the Gubik Formation. Low-lying barrier islands, also underlain by sediments of the Gubik Formation, are discontinuously present along the coast in the study area (figures 1.2 and 1.3).

The Colville River and delta incise higher terrain to the west and east. East of the river and delta, marine and alluvial terraces are cut into this high terrain (sheet 1). The northern front of this terrain grades into a rolling alluvial plain, which becomes nearly flat near the coast (sheet 2). The Coastal Plain between a distinct scarp of an alluvial terrace west of the Kuparuk River and the east bank of the Sagavanirktok River is nearly flat (sheets 2 and 3). East of the Sagavanirktok River, the terrain is again a rolling alluvial plain that becomes nearly flat along the coast. This alluvial plain is incised by the Kadleroshilik and Shaviovik Rivers, which have associated flood plains and terraces (sheets 3 and 4). East of the Shaviovik River, a gently sloping outwash fan stretches to the Canning River and its terraces (sheets 4 and 5). Near the Sadlerochit Mountains, moraines on both sides of the Canning River create a rolling topography that grades northward east of the river to a gently sloping outwash plain. Both the outwash plain and the moraines have been folded into northeast-southwest trending anticlines and synclines by late Cenozoic tectonism (sheet 5) (Carter and others, 1986c). Folded terrain and gravel-covered bedrock extend east approximately to the Sadlerochit River. Near the east end of the Sadlerochit Mountains, the Sadlerochit and Hulahula Rivers incise moraines, and to the north, incise sand-covered outwash (sheet 6). All of sheet 5 and most of sheet 6 join mapping of Robinson and others (1989). However, Quaternary sediments are mapped in less detail in Robinson and others (1989), so not all contacts or units match across the map boundary.

Climate

The central part of the Arctic Coastal Plain is within the Arctic Climatic Zone as defined by Koppen (1936), and has a modified Arctic coastal maritime climate (Brown, 1975). Details of the climate are presented by Searby and Hunter (1971), Selkregg (1975), and Dingman and others (1980). Mean monthly temperatures between 1970 and 1979 at the ARCO Alaska Camp at Prudhoe Bay ranged from 7° C in July to minus 30° C in February; the mean annual temperature was minus 13° C. The lowest recorded temperature during that time was minus 49° C in February 1971 and 1976, and the highest temperature was 28° C in July 1975. Temperatures along the coast are cooler than inland temperatures during spring and summer, and warmer during fall (Walker, 1980). Soil temperatures are up to 10° C higher than air temperatures 1 m above the ground (Conover, 1960; Kelly and Weaver, 1969; Weller and Holmgren, 1974).

Total annual precipitation on the Coastal Plain ranges between 10 and 22 cm, of which 35 to 50 percent is rain. These recorded amounts may be 100 to 400 percent low, because of stormy conditions during snowfalls (Black, 1954; Benson, 1982; Woo and others, 1983). Rainfall occurs between June and September, with the greatest amounts in late summer. Snowfall is greatest in October, with half of the annual snowfall occurring by the end of December (Carter and others, 1987).

Winds on the Coastal Plain are generally from the east and northeast in summer and from the west and northwest in winter. A summer high-pressure center to the north and a winter low-pressure center to the south dictate these wind directions. The mean annual wind velocity is 22 km/hr, with the highest means in spring, early summer, and fall, and the lowest means in late winter (Gamara and Nunes, 1976). Westerly summer winds are generally associated with storms and are responsible for surge waters that sometimes inundate low areas of the Coastal Plain inland to several kilometers (Reimnitz and Maurer, 1979).

Permafrost

The Arctic coastal maritime climate maintains permafrost, which is essential to development of ice wedges and ice-wedge polygons, thaw lakes, pingos, and thaw streams. Permafrost and seasonal freezing and thawing are conducive to frost processes that develop frost boils, peat rings, hummocks, and reticulate ground.

The distribution and amount of ice in permafrost on the Coastal Plain greatly affect the surface morphology. Ice there tends to be concentrated in the top few meters of the permafrost (Sellman and others, 1975). Of several types of ice in the near-surface sediments, segregated ice and ice wedges represent as much as 85 percent of the ground by volume, with the former contributing a much greater amount (75 percent) than the ice wedges (Brown, 1967). Natural and man-induced differential thawing of this near-surface ice generally results in uneven lowering of the ground surface, which may lead to ponding of water or preferential erosion, or both.

Coastal Plain Permafrost

The Coastal Plain is within the zone of continuous permafrost (Ferrians, 1965) where the ground is perennially frozen except locally beneath bodies of water that do not freeze to the bottom during the winter (those deeper than about 2 m). At Prudhoe Bay, the mean ground-surface temperature is about minus 10^0 C (Lachenbruch and others, 1982b). Water bodies there represent relatively warm spots that thaw or warm underlying ice-rich permafrost and cause extreme modification of the landscape (Lachenbruch and others, 1982b). Little data are available on the depth of thaw and degree of warming below bodies of water on the Coastal Plain, although Sellman and others (1975) reported thawing to 58 m below a lake near Barrow. The depth of seasonal thaw, the active layer, is largely dependent on soil texture and varies between about 0.5 and 1.0 m on the Coastal Plain (Everett, 1980b).

Gold and Lachenbruch (1973) suggested that permafrost first formed beneath the Coastal Plain during the first glacial episode of the Pleistocene and has existed continuously since that time. However, the base and top of the permafrost have likely risen and fallen in response to climatic variations. Presently, permafrost on the Coastal Plain typically extends to depths of several hundred meters with little variance in individual thermal gradients (figure 2.1). At Prudhoe Bay, however, permafrost reaches a depth of about 600 m (Lachenbruch and others, 1982a,b; Osterkamp and others, 1985). At this depth the thermal gradient flattens significantly, representing a probable change in thermal conductivity caused by the presence of interstitial water rather than ice (figure 2.1). Lachenbruch and others (1982a) suggested that the significantly thicker permafrost at Prudhoe Bay results from the presence of highly conductive, siliceous, ice-rich sediments in that area. Other factors, such as long-term exposure during extreme cold periods, or the lack of extensive and long-term marine inundation could also have contributed to development of thick permafrost.

Offshore Permafrost

Hopkins (1979) suggested that permafrost formed beneath the Beaufort Sea about 18 ka ago during the peak of the last Wisconsinan glacial stade when the continental shelf was exposed to about the minus-90-m isobath, about 70 to 80 km north of the present coast. However, between the early Wisconsinan Simpsonian transgression and the start of Holocene time, sea level probably did not rise higher than the 25-m isobath (Hopkins, 1982), a distance of about 25 km from the present coast (Lachenbruch and others, 1982b). Even in mid-Holocene time, when sea level reached near its present level, the Coastal Plain probably extended considerably north of its present coast (Naidu and others, 1984), maintaining conditions for preservation of permafrost in an area since inundated by the sea. Thus, much of the offshore permafrost probably is as old as early Wisconsinan (Lachenbruch and others, 1982b), postdating the Simpsonian transgression; or if this and

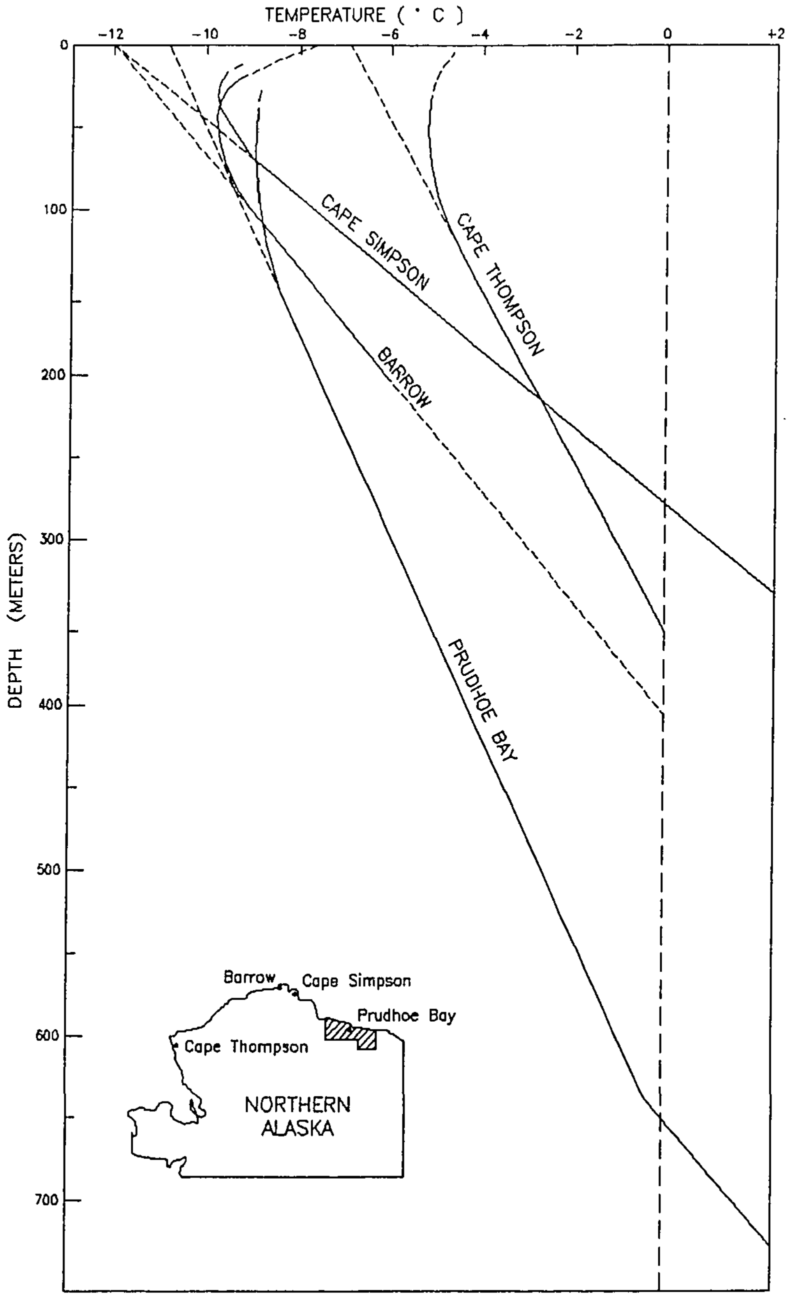

Figure 2.1 Plot of subsurface thermal gradients at various locations on the Arctic Coastal Plain. Small-dashed lines are extrapolated. Lined area on inset map is the study area. From Gold and Lachenbruch (1973).

earlier transgressions were of insufficient duration to completely thaw the existing permafrost, some of the offshore permafrost could be much older.

The rise of the base of offshore permafrost from a depth of 600 m at Prudhoe Bay following inundation by seawater was estimated by Lachenbruch and others (1982b) to be 10 m during the first 2 ka, and 15 m/ka thereafter. These investigators indicated that the base of permafrost would be between 400 and 500 m deep if inundation occurred since the beginning of the Holocene, and in excess of 300 m if inundation occurred as a result of rising sea level after the peak of the last Wisconsinan glacial stade. According to Lachenbruch and others (1982b), 40 ka is the approximate maximum time required to thaw 600 m of permafrost following inundation by the sea. This implies that under present conditions offshore permafrost will remain, albeit continuously thinning, for up to 30 ka.

Island Permafrost

Islands along the coast of the central Arctic Coastal Plain are of two types: tundra-covered islands and constructional sand-and-gravel barrier islands. The tundra-covered islands are mostly remnants of once more extensive coastal plain. Parts of the apparently constructional islands may actually be lag deposits of remnant islands; examples of such islands are Stump Island and Long Island, both of which are in the Return Islands group west of Prudhoe Bay (figure 1.2). On the basis of borehole and seismic data, ice-bonded permafrost is pervasive under the tundra-covered islands and generally absent under constructional islands (Rogers and Morack, 1978; Harrison and Osterkamp, 1979; Morack and Rogers, 1981). However, permafrost is indicated by thermal-contraction cracks in older parts of constructional islands where repeated freezing and thawing reduce salt brines in the sediments and allow them to freeze. Permafrost generally forms in 40 to 50 years in these islands (Hopkins and Hartz, 1978). Permafrost under Stump Island is thought to be relic permafrost (Hopkins and Hartz, 1978; Rogers and Morack, 1978), perhaps formed when the island was covered with tundra.

Permafrost- and Seasonal-frost-related Landforms

Variations in the climate, and in the stability, width, surface gradient, and types of sediments of the Coastal Plain play an important role in creating and modifying landforms. Permafrost and seasonal freezing and thawing are primary controlling factors of landforms, vegetation, and soils which, in the Prudhoe Bay area, are strongly correlated (Everett, 1975; Webber and Walker, 1975; Everett and others, 1978, 1980; Walker and others, 1980). Common permafrost-related forms on the Coastal Plain are ice-wedge polygons and pingos; common seasonal-frost-related forms are nonsorted circles and nets.

Ice-wedge Polygons. Ice wedges are masses of ice that taper downward and develop by water or snow repeatedly filling thermal-contraction cracks and subsequently freezing or refreezing (Lachenbruch, 1962). Ice wedges are generally less than 6 m wide and 10 m deep (Black, 1976). However, syngenetic ice wedges on the Coastal Plain are known to be as much as 3 m wide and 26 m deep (Carter, 1988). Ice wedges are typically linked in polygonal forms, which initially may exceed 100 m in diameter. Through time, these polygons subdivide into secondary polygons commonly 4 to 8 m in diameter, which further subdivide into tertiary polygons commonly 1 to 3 m in diameter (Black, 1952).

Orthogonal ice-wedge polygons are common in drained lake basins, river flood plains, and river terraces; the shorelines act as anisotropic borders where first cracks are oriented normal to the greatest tension, which is either perpendicular or parallel to the shoreline depending on the temperature field and distance from shore. Because these cracks are oriented, subsequent orthogonal cracks are oriented (Lachenbruch, 1966). Nonorthogonal ice-wedge polygons are common in areas that show little modification by lacustrine or fluvial processes.

Ice-wedge polygons are high centered or low centered depending on whether the center is high or low relative to the rim. Leffingwell (1919) first described low-centered and high-centered polygons and Black (1952) noted gradations between these extremes. Lachenbruch (1966) and French (1974) suggested that the occurrence of low- or high-centered, ice-wedge polygons is largely determined by the type of material in which they form. Low-centered, ice-wedge polygons form in material that has finite shear strength when thawed, e.g., long-fiber peat and some silt. This material is extruded into the active layer where it accumulates as peripheral ridges. High-centered, ice-wedge polygons form in material that is fluid when thawed, e.g., silt and clay. When this material flows and disperses into the active layer, it leaves either no surface trace of the polygon, or a trough over the ice wedges. High-centered, ice-wedge polygons may also form when polygonal troughs are deepened by erosion and peripheral ridges, when present, are destroyed (Lachenbruch, 1966).

Pingos. Pingos are ice-cored conical mounds that grow and persist in areas of permafrost (Washburn, 1980). On the Arctic Coastal Plain, pingos form in drained lake basins where moisture-rich lacustrine sediments are exposed to freezing temperatures

(Muller, 1959). The substrate must be permeable and sufficiently thick that the thawed basin extends into permafrost. Pore water is expelled from below the freezing front as permafrost aggrades into the thaw bulb and freezes at the front, forming an ice core (Mackay, 1973, 1978). The ice core grows and pushes up the ground surface as pore water is continually supplied to the ice core. The tops of some pingos may alternately rise or fall in response to the rate of the accumulation and loss of pore water (Mackay, 1977). Closed-system pingos stop growing when unfrozen pore water is gone.

Walker and others (1985) mapped two types of closed-system pingos in the Prudhoe Bay area: those with large basal diameters, gentle slopes, and not occurring within distinguishable lake basins; and those with small basal diameters, steep side slopes, and occurring within distinguishable lake basins. These investigators termed the former type broad-based mounds because of the uncertainty of origin. On the basis of morphology and one borehole in a broad-based mound (C-60 pingo) east of the KUP C gravel pit (Brockett, 1982), many of the broad-based mounds apparently are true pingos and thus formed within lake basins that have subsequently been destroyed by younger thaw lakes. The mean diameter of the broad-based mounds is 242 m and the mean slope is 3°. The height of these mounds ranges approximately from 2 to 12 m, with the mode being approximately 5 m (Walker and others, 1985).

The mean diameter of the steep-sided pingos is 72 m and the mean slope is 8°. The height of the steep-sided pingos ranges approximately from 2 to 13 m, with the mode being approximately 4 m (Walker and others, 1985). The distribution of the steep-sided pingos is more uniform across the study area than is the distribution of broad-based mounds. Because the steep-sided pingos occur within well-defined lake basins and most show little sign of collapse, they are probably not older than several thousand years.

Williams and others (1977) and Galloway and Carter (1978) mapped pingos in the NPRA, and Hickmott (1986a,b) and Rawlinson (1986b, c, d, e, f; sheets 1 through 6) mapped the surficial geology, including both types of pingos, in the area between the Colville River Delta and the Hulahula River in ANWR. The obviously smaller number of thaw lakes and pingos in the eastern part of the Coastal Plain is adequately explained by the generally coarser sediments, greater slope, and better drainage, which preclude thaw-lake and pingo development.

Nonsorted Circles. Nonsorted circles are those that have a marked uniformity in the distribution of grain sizes between the border and the interior (Washburn, 1956). These circles range from 0.5 to 5 m in diameter (Washburn, 1980). Excavations of nonsorted circles typically show sandy, silty clay laterally surrounded by humic peat and sand at and near the surface, and marginal disturbance; the central fine-grained soil is continuous with fine-grained soil below the sandy, peaty border (Washburn, 1969). These relationships indicate displacement of underlying fine-grained soil into overlying coarse-grained soil.

Two types of nonsorted circles are frost boils, also referred to as frost scars (Hopkins and Sigafoos, 1951) or mud boils (Shilts, 1978), and peat rings, which evolve from frost boils. Frost boils generally occur on well-drained surfaces, whereas peat rings occur where a peaty substrate and shallow permafrost inhibit drainage. Upward heaving along with lateral thrusting during freezing (and pushing aside of peat deposits to form a peat ring) has long been thought to be the formative mechanism (Hopkins and Sigafoos, 1951); although diapirism of poorly sorted, silty soil with low liquid and plastic limits during periods of thaw is also a probable mechanism (Shilts, 1978; Washburn, 1980).

Nets. A net is patterned ground with a mesh that is intermediate between a circle and a polygon. Two common nonsorted types are hummocks and reticulate ground. Hummocks range from 0.3 to 2 m in diameter and have a convex or flattened top that is 0.2 to 0.8 m high (Zoltai and Pettapiece, 1973; Walker and others, 1980). Hummocks generally occur on slopes greater than 6° and have been documented on slopes up to 20° (Sharp, 1942). Development of hummocks is not well understood. Washburn (1969) concluded that hummocks in Greenland formed by downslope movement at the net border with concurrent upward displacement of the central mineral soil by frost processes, termed cryoturbation. According to Zoltai and Pettapiece (1973), cryoturbation is a factor in the development of most hummocks. Although the presence of permafrost is conducive to development of hummocks in some localities (Zoltai and Tarnocai, 1974), it is not essential (Washburn, 1980).

Reticulate ground includes nonsorted, high-centered polygons that are generally less than 1 m in diameter and have a hummocky microrelief (Walker and others, 1980). This form is common in moderately well-drained areas. Excavations of reticulate ground show that underlying silt, silty sand, and fine sand generally intrude a peaty layer below the surface troughs. The formative mechanism is thought to be frost heaving followed by convective overturn of light, saturated sediments near the frost table under denser, drier, overconsolidated material at the surface (Hallet and Prestrud, 1986). Because reticulate ground often grades downslope into hummocks, Walker and others (1980) proposed that hummocks are derived from reticulate ground; they suggested that thermal and slope-runoff erosion accentuate the relief of the polygons and modify the polygonal pattern to a net pattern.

Vegetation

Walker and Webber (1980) distinguished four groups of vegetation in the Prudhoe Bay area as defined by the moisture regime at various sites (table 2.1). Of 42 types of vegetation recognized within the four groups, 22 types are common and have distinctive taxa (table 2.2). This vegetation is probably representative of lowlands within the study area.

Table 2.1. Vegetation groups at Prudhoe Bay as defined by site moisture regime. From Walker and Webber (1980).

B	Vegetation on dry, barren, or exposed sites
U	Vegetation on moist, well-drained upland sites or well-drained microsites
M	Vegetation on wet or lowland sites
E	Vegetation on sites where lowland water is present during the entire growing season

Table 2.2. Common vegetation types and characteristic taxa in the Prudhoe Bay area, as defined by site moisture regime. From Walker and Webber (1980).

Vegetation type	Common taxa
B1	*Dryas integrifolia, Oxytropis nigrescens*
B2	*Dryas integrifolia, Saxifraga oppositifolia*
B3	*Saxifraga oppositifolia, Juncus biglumis*
B4	*Epilobium latifolium, Artemisia arctica*
B5	*Dryas integrifolia, Kobresia myosuroides*
B6	*Dryas integrifolia, Astragalus alpinus*
B7	*Braya purpurascens, Anemone parviflora*
B9	*Elymus arenarius* var. *mollis, Dupontia fisheri*
B13	*Salix ovalifolia, Artemisia borealis*
U1	*Carex aquatilis, Ochrolechia frigida*
U2	*Eriophorum vaginatum, Dryas integrifolia*
U3	*Eriophorum angustifolium, Dryas integrifolia*
U4	*Carex aquatilia, Dryas integrifolia*
U8	*Salix lanata, Carex aquatilis*
U9	*Dryas integrifolia, Eriphorum angustifolium*
M1	*Carex aquatilis, Carex rariflora*
M2	*Carex aquatiiis, Drepanocladus brevifolius*
M4	*Carex aquatilis, Scorpidium scorpioides*
M5	*Carex aquatilis, Salix rotundifolia*
E1	*Carex aquatiiis*
E2	*Arctophila fulva*
E3	*Scorpidium scorpioides*

Table 2.3 shows 12 landforms in the Prudhoe Bay area and the associated vegetation types as mapped by Everett (1980a).

Soils

Four soil orders in the Prudhoe Bay area, which is probably representative of much of the study area and especially the lowland areas, are Entisols, Inceptisols, Mollisols, and Histosols. Entisols, including Psamments and Orthents, are poorly developed soils. Inceptisols, including Aquepts, are mineral soils that have horizons with distinctive chemical

Table 2.3. Common landforms and associated vegetation types in the Prudhoe Bay area. Compiled from Everett (1980a) and Walker and Webber (1980).

Landform	Vegetation type
High-centered polygons (center-trough relief >0.5 m)	B1, B2, U3
High-centered polygons (center-trough relief ≤0.5 m)	B1, B2, U2, U3
Low-centered polygons (rim-center relief >0.5 m)	U3, U4, M2, M4
Low-centered polygons (rim-center relief ≤0.5 m)	U3, U4, M2, M4
Mixed high- and low-centered polygons	B1, B2, U3, U4, M2, M4
Frost-boil tundra	B3
Strangmoor or disjunct polygon rims, or both	U4, M3, M4, U1, U2, M1
Hummocky terrain	B1
Reticulate ground	U2, U3
Nonpatterned ground	M1, M2, M4
Alluvial flood plain	B4, U8, M5, B6, B7, U9
Pingo	B1
Sand dunes	B9, B13, B5

and physical characteristics. Mollisols, including Borolls and Aquolls, are dark base-saturated soils. Histosols, including Fibrists and Saprists, contain organic material in the top 0.4 m of the soil profile.

Suborders of the soil orders reflect a soil-forming factor and are prefixed by the great-group designator, which describes aspects of the center soil profile. A prefix of "Cry" indicates a soil with a mean annual temperature between 0 and 8° C. Subordinate soil-forming processes that modify characteristics of the dominant process are emphasized by the subgroup. In the nomenclature, the subgroup precedes other descriptions. The terms "pergelic", "ruptic", and "histic", apply to soils in the Prudhoe Bay area. Pergelic denotes permafrost, ruptic denotes soil interruption, and histic denotes organic material (Everett, 1980b).

Everett (1980b) mapped eight soils as distinct morphologic entities in the Prudhoe Bay area and described a ninth for dunes near the mouth of the Sagavanirktok River. These soils are typically associated with specific landforms (table 2.4). Association of soils with landforms in the Prudhoe Bay area illustrates, in part, the interdependence of many environmental factors active on the Coastal Plain.

Table 2.4. Common soils and associated landforms in the Prudhoe Bay area. From Everett (1980b).

Soil unit	Associated landforms
Pergelic cryoboroll	Pingos, high-centered polygons
Pergelic cryaquoll	Steam banks, slightly convex interfluves
Pergelic ruptic aqueptic cryaquoll	Frost boils
Histic pergelic cryaquept	Low-centered polygons, disjunct polygon rims and strangmoor
Pergelic cryohemists	Low-centered polygons (center)
Pergelic cryosaprists	Low-centered polygons (rim), high-centered polygons
Pergelic cryorthent	River flood plains and terraces
Pergelic cryopsamments	Active or partially stabilized sand dunes

CHAPTER 3 - GEOLOGIC FRAMEWORK

Introduction

Pre-late Tertiary sediments discontinuously surround the study area, underlie sediments of the Gubik Formation in the study area, or by being eroded, have contributed to the unconsolidated sediments of the Gubik Formation. Sediments of the Gubik Formation are by far the most widespread within the study area, and thus are the primary focus of this dissertation.

The pre-late Tertiary sediments represent several depositional environments and probably range in age from Late Cretaceous through Oligocene (figure 3.1). These sediments are designated from oldest to youngest, the Prince Creek and Schrader Bluff Formations, and the Sagavanirktok Formation. Sediments of the Sagavanirktok Formation underlie considerably more of the study area than those of the other two formations and are thus emphasized in this chapter.

Prince Creek and Schrader Bluff Formations

Gryc and others (1951) named the Prince Creek Formation for poorly consolidated nonmarine conglomerate, sandstone, siltstone, shale, carbonaceous shale, and coal exposed along Prince Creek, a tributary of the Colville River. The Prince Creek Formation and its intertonguing marine equivalent, the Schrader Bluff Formation, underlie the Foothills of the Brooks Range south of the Arctic Coastal Plain. The Schrader Bluff Formation is named

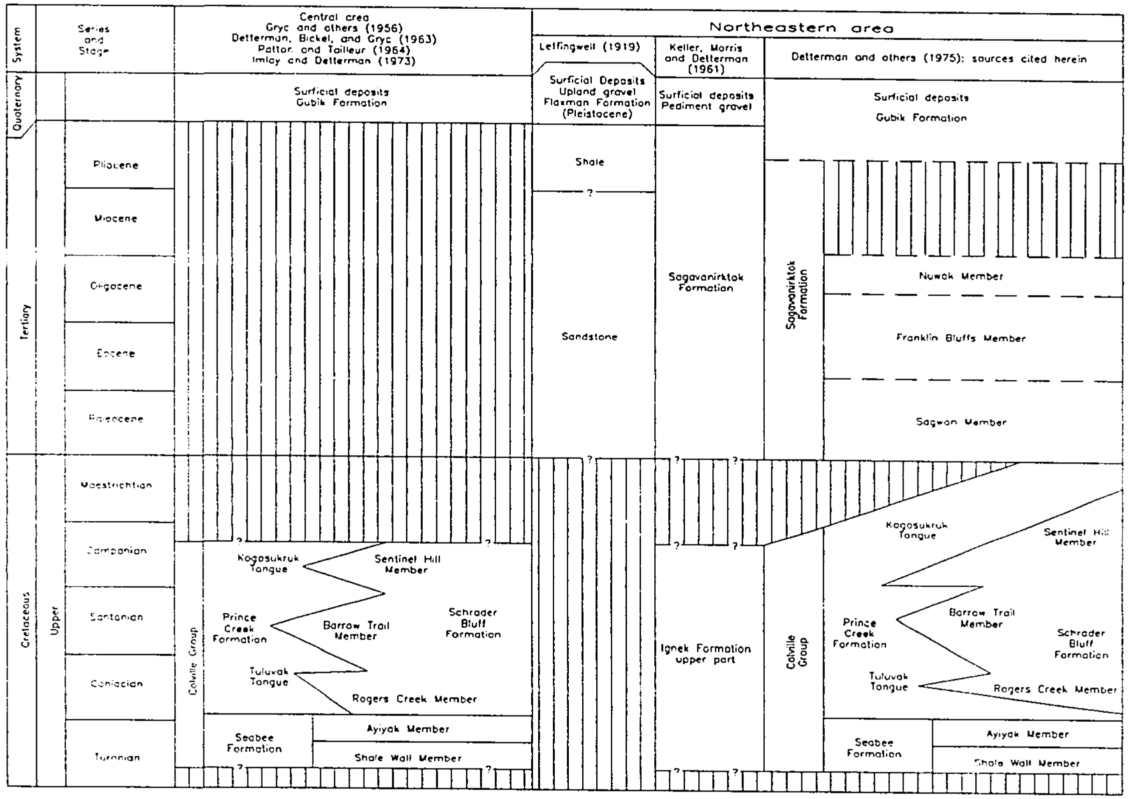

Figure 3.1 Stratigraphic column of late Mesozoic and Cenozoic geologic formations of the central and eastern Arctic Coastal Plain of Alaska.

for marine sandstone, siltstone, and shale exposed at Schrader Bluff on the lower Anaktuvuk River.

Exposures of the Prince Creek and Schrader Bluff Formations are isolated but widespread. In addition to the type sections, these formations are well exposed along the lower Colville River. The Prince Creek Formation is also exposed near Sagwon on the Sagavanirk'uk River and along the Kavik River. The most complete section of the Schrader Bluff Formation is along the Canning River west of the Sadlerochit Mountains (figure 1.3); most exposures of this formation occur between the Sagavanirktok and Jago Rivers (Detterman and others, 1975).

Brosgé and Whittington (1966) assigned nonmarine sediments exposed along the west side of the Colville River from south of the southern boundary of the study area northward to Ocean Point to the Kogosukruk Tongue of the Prince Creek Formation (figure 1.2). Fluvial and flood-plain sediments, especially channel-fill and overbank sediments, compose most of the Kogosukruk Tongue, but lacustrine and palustrine sediments are also present (Spicer and Parrish, 1987). Nonmarine sediments near Ocean Point interfinger up section with fine-grained interdistributary bay sediments, which are overlain by marine sediments; both the bay sediments and marine sediments are assigned to the Schrader Bluff Formation (Phillips, 1988). Frederiksen and others (1988) reported a stratigraphically higher nonmarine sand, perhaps of the Kogosukruk Tongue, on the Colville River 6 km east of Ocean Point. Possibly correlative Late Cretaceous marine sediments of the West Sak sands and an overlying shale-mudstone unit, and the overlying nonmarine Ugnu sands, all units that underlie the Kuparuk and Prudhoe Bay oil fields (Werner, 1987), are considered to be part of the Sagavanirktok Formation by Collett and

Bird (1990). However, because most recent literature discusses the Sagavanirktok Formation as being Tertiary, this convention is used herein to avoid confusion.

Late early Eocene was once considered a near-maximum age for the Prince Creek Formation based on a fission-track date of 50.9 +/- 7.7 Ma on tephra near the base of the Kogosukruk Tongue sediments exposed near Ocean Point (Carter and others, 1977) (figures 1.1 and 1.2). However, based on spores, pollen grains, and dinoflagellate cysts, Frederiksen and others (1988) assigned a Maestrichtian age to sediments of the Kogosukruk Tongue near Ocean Point. Hadrosaurian dinosaur remains present in these sediments are not diagnostic of age (Parrish and others, 1987). Macbeth and Schmidt (1973) considered benthic foraminiferal assemblages from the intertonguing Schrader Bluff Formation at Ocean Point to be late Campanian. However, re-examination of the foraminifers indicates an early Maestrichtian age (McDougall, 1986). Brouwers and others (1984) and Marincovich and others (1985, 1986) considered the marine beds to be Paleocene to early Eocene based on mollusk and ostracode faunas and palynological data. Frederiksen and others (1988) placed the Cretaceous-Tertiary boundary along the Colville River 8 km northeast of Ocean Point and assigned a mid-Maestrichtian age to nonmarine sediments below this boundary.

Sagavanirktok Formation

Subdivision to Members

Gryc and others (1951) named the Sagavanirktok Formation for poorly consolidated conglomerate, sandstone, siltstone, and lignitic coal exposed along the east side of the Sagavanirktok River at Franklin Bluffs.

Increased investigations on the Arctic Coastal Plain brought on by discovery of oil at Prudhoe Bay provided disparate data that resulted in confusion as to which strata to include in the Sagavanirktok Formation. To eliminate confusion, Detterman and others (1975) assigned all Tertiary sediments overlying the Prince Creek Formation but underlying the Gubik Formation to the Sagavanirktok Formation. These investigators also subdivided the formation into three members, from oldest to youngest, Sagwon, Franklin Bluffs, and Nuwok.

Sagwon Member. The type section of the Sagwon Member begins along the west side of the Sagavanirktok River at Benchmark Gard, about 1.4 km northwest of Sagwon, and continues northward along the river bluff for about 1.6 km (figure 1.2). At the type section, the member is 143 m thick. Sediments of the Sagwon Member are not exposed east of the Canning River, and the westernmost sediments occur in the White Hills, 32 km northwest of the type section (Detterman and others, 1975).

Lignite and carbonaceous shale, interbedded with dark gray and brown shale and siltstone containing ironstone nodules compose the lower part of the Sagwon Member.

The upper part of the member consists of poorly consolidated sandstone and conglomerate. The sandstone is dominantly quartz and chert, but includes feldspar and carbonaceous material. Cross-bedding in the sandstone is suggestive of a nonmarine shallow water to deltaic depositional environment (Detterman and others, 1975).

Floras from the coal-bearing part of the Sagwon Member are correlated with Paleocene and Eocene beds elsewhere in Alaska (Detterman and others, 1975). This age range is consistent with ages determined for stratigraphically higher members.

Franklin Bluffs Member. The type section of the Franklin Bluffs Member is along a stream that cuts the west side of Franklin Bluffs 1.8 km southwest of Benchmark Greta (figure 1.2 or 1.3). The member is 105 m thick at the type section, but other exposures along stream banks in the northernmost low hills on the Arctic Coastal Plain between the White Hills and the Niguanak River (figures 1.2 and 1.3) indicate a total thickness of between 900 and 1,500 m (Detterman and others, 1975).

The Franklin Bluffs Member consists of four or five cycles of laminated brown and gray clay and silt composed of quartz and feldspar overlain by thick beds of pink, brown, orange, and yellow sand and gravel. The fine-grained part of a cycle is dominantly clay but includes mud lumps and organic material along bedding planes, and randomly distributed small pebbles and zones of limonite. Desiccation cracks are preserved in some of these beds. The composition, textures, and structures of the fine-grained part of the cycle suggest a semiarid lacustrine environment. The coarse-grained part of the cycle includes interbedded volcanic ash and limonitic zones, and large cross-bedding. The composition, textures, and structures of this part of the cycle suggest deposition by fluvial and eolian processes in a semiarid environment (Detterman and others, 1975).

Ager and others (1986) suggested an Eocene age for the sediments at Franklin Bluffs based on included pollen grains.

Nuwok Member. The type section of the Nuwok Member is east of Carter Creek in the core of the Marsh Creek anticline 2.4 km south of Camden Bay (figure 1.3), and is represented by the upper 80 m of strata at this location. Detterman and others (1975) placed the contact with the Franklin Bluffs Member between a 3-m-thick, poorly consolidated sandstone and an underlying 10-m-thick clayey silt and indicated that the contact is gradational and conformable. However, both Brouwers and Marincovich (1988) and McNeil and Miller (1990) included the basal clayey silt with the Nuwok Member.

Fouch and others (1990) have identified at least 220 m of Nuwok-like strata on the north limb of the Marsh Creek anticline, significantly adding to the previously described 80-m-thick type section. Brouwers and Marincovich (1988) indicated that Nuwok Member sediments are also present on Barter Island and at Manning Point based on ostracodes at both localities and mollusks at Manning Point. Brigham (1985) described a widespread marine clay at Skull Cliff, termed the Papigak clay, and suggested that it may correlate with sediments of the Nuwok Member. The Papigak clay has since been shown to be Campanian and thus not correlative (W. Elder, personal communication to D. Hopkins, 1990).

The basal clayey silt and overlying sandstone in the Nuwok Member type section contain mollusk shells that suggest normal marine salinity, temperate water, and deposition on the deeper inner shelf to middle shelf (Brouwers and Marincovich, 1988). The sandstone is capped by a pebble conglomerate, which is overlain by pebbly siltstone and mudstone with interbeds of silty limestone (Detterman and others, 1975). These fine-grained sediments contain glendonite crystals, which are calcite pseudomorphs after original minerals of unknown composition, perhaps calcium carbonate hexahydrate. This precursor mineral is probably diagnostic of organic-rich sediments rapidly accumulating in cold bottom waters (Suess and others, 1982). A high-latitude lagoonal environment was suggested by Detterman and others (1975) for the fine-grained sediments. Faunas included in these sediments do indicate a cold temperate marine climate, but are more indicative of deposition on the middle shelf in the lower part and on the deeper inner shelf in the upper part (Brouwers and Marincovich, 1988). Pebbly sandstone about 15 m thick caps the fine-grained sediments. This sandstone is unconsolidated except where locally cemented by limonite; Detterman and others (1975) suggested that the texture and cross-bedding of these sediments indicate a barrier island environment. However, Brouwers and Marincovich (1988) suggested that included faunas indicate environmental conditions and a depositional environment like those of the bottom part of the section.

Age estimates for the Nuwok Member based on included mollusks range from Miocene to Pliocene (MacNeil, 1957; Brouwers and Marincovich, 1988). A Pliocene age was based on ostracodes and mollusks (Brouwers and Marincovich, 1988) and ages based on benthic foraminifers range from Oligocene to Pliocene (Todd, 1957; Detterman and others, 1975; Young and McNeil, 1984; McNeil, 1989). Re-evaluation of ages based on foraminifers indicates a late Oligocene age (McNeil and others, 1982; Young and McNeil, 1984; McNeil, 1989). Strontium-isotope ratios calculated from three samples of benthic foraminifers and a single mollusk substantiate a late Oligocene age (McNeil and Miller, 1990).

Sediments Not Assigned to Members or Informal Units

Carter and Galloway (1985a) discussed nonmarine and marine sediments of the Sagavanirktok Formation exposed along the west side of the Colville River, and nonmarine sediments exposed along the Miluveach and Kachemach Rivers, that have not been assigned to members or units. The marine sediments have since been shown to be Maestrichtian and were assigned to the Schrader Bluff Formation by Frederiksen and others (1988). On the basis of well-correlation sections, Collett and Bird (1990) discussed nonmarine and marine sediments of the Sagavanirktok Formation that overlie the early Tertiary, nonmarine Ugnu sands below the Kuparuk and Prudhoe Bay oil fields.

Nonmarine Sediments. Unassigned nonmarine sediments of the Sagavanirktok Formation, consist of conglomerate, gravelly sand, sand, and pebbly shale with subbituminous coal and lignitic wood. These sediments overlie marine sediments along the Colville River that were discussed by Carter and Galloway (1985a) and that are now assigned to the Maestrichtian Schrader Bluff Formation. A late Paleocene to early Eocene age for the nonmarine sediments is indicated by fungal spores (Lentin, 1984, written communication cited in Carter and Galloway, 1985a); however, pollen assemblages are like those of early Paleocene assemblages in Siberia and northwest Canada. The pollen assemblage includes many coniferous taxa, along with other deciduous broadleaf and shrub taxa, that suggest a temperate, moist climate (T. Ager, written communication cited in Carter and Galloway, 1985a).

The finer grained sediments typically have zones of oxidation near the top of a given stratigraphic section and zones of disseminated sulfur deeper in the section that give the beds a mottled orange and gray or yellow and gray appearance. Gravel-sized clasts of schist, gneissic granite, granite, greisen, rhyolite, rhyolite tuff, and andesite in these sediments do not occur in potential source drainage basins to the south. Older sediments that might have been reworked to contribute these clasts are also known not to exist in these drainage basins (Carter and Galloway, 1985a). Probable correlative sediments are exposed along the Ublutouch River west of the Colville River and along the Miluveach and Kachemach Rivers east of the Colville River (Carter and Galloway, 1985a). The source and full extent of these sediments are unknown.

A pebble, cobble, and boulder gravel, informally termed the Kuparuk gravel by Carter (1983b), overlies the unassigned nonmarine Paleocene to Eocene sediments. This gravel forms bluffs on the upper slopes of valleys in the upper drainage areas of the Miluveach and Kachemach Rivers but is truncated at a scarp that probably represents the shoreline and maximum inland extent of one or both of the two oldest marine transgressions represented by the Gubik Formation. These transgressions likely occurred between 2.4 and 3.5 Ma ago (Carter and Galloway, 1985a; Carter and others, 1986a). Fluvial terraces associated with erratic boulders of the late Tertiary Gunsight Mountain glaciation (Hamilton, 1979a,b) are younger than the Kuparuk gravel (Carter and Galloway, 1985a).

Clasts of the Kuparuk gravel include chert, quartz, quartzite, chert-pebble conglomerate, and siliceous sandstone, types common to potential source basins in the Brooks Range. Clasts up to several meters in diameter may be glacial erratics, a concept supported by diamicton sediments at one location in the Miluveach and Kachemach Rivers area. If so, a Tertiary advance of ice from the Brooks Range reached farther north than previously thought (Carter and Galloway, 1985a).

Collett and Bird (1990) discussed a 250- to 300-m-thick, subsurface interval of many upward-fining, channel sandstone and overbank siltstone units. This nonmarine interval reportedly overlies the Ugnu sands and predates overlying Eocene marine beds. How this interval, and perhaps part of the Ugnu sands, correlate with outcropping probable Paleocene and Eocene sediments discussed by Carter and Galloway (1985a) is unknown.

Marine Sediments. No Tertiary marine sediments that have not been assigned to a member or informal subsurface unit crop out in the study area. A 200- to 300-m-thick sequence of interbedded marine sandstones and mudstones reportedly overlies the nonmarine fluvial sediments that overlie the Ugnu sands (Collett and Bird, 1990). According to Collett and Bird (1990), this sequence was deposited during a basin-wide marine transgression in Eocene time. In the Sagavanirktok River Delta area, the upper boundary of the marine unit is an erosional unconformity; the unconformity apparently disappears to the southwest into the Kuparuk River area. The apparent proximity of the age of these marine sediments to the age of the Nuwok Member sediments prompts the notion of possible correlation. Overlying rocks are nonmarine and represent a delta-plain environment (Collett and Bird, 1990).

Gubik Formation

Gryc and others (1951) assigned all Pleistocene sediments on the Coastal Plain to the Gubik Formation. Black (1964) included Holocene sediments in the formation and subdivided the formation into three lithologic units, from oldest to youngest: Skull Cliff, Meade River, and Barrow. These units are now known to be facies of the Gubik Formation that differ both in age and distribution across the Coastal Plain based on field work by personnel of the USGS between 1976 and 1981 (Brigham, 1985).

The Gubik Formation as presently defined includes all late Pliocene and Quaternary unconsolidated marine and nonmarine sediments on the Coastal Plain. Marine sediments in part of the type section along the west side of the Colville River are now known to be Pliocene (Repenning, 1983). Brigham subdivided marine sequences of the Gubik Formation in western Alaska into five informal members based on amino-acid signatures of mollusk shells; each member corresponds to an aminozone, which represent a period of transgression and deposition. Leffingwell (1919) assigned glaciomarine sediments exposed on Flaxman Island and elsewhere along the coast to the Flaxman Formation, but Dinter (1985) reduced this formation to a formal member of the Gubik Formation.

Rawlinson (1986a) subdivided nonmarine sediments approximately between the Colville and Canning Rivers into lithologic units. The names Ugnuravik gravel and Ugnuravik sand were coined for widespread gravel and overlying sand between the Colville and Kuparuk Rivers. On the basis of surface morphology and apparent similar stratigraphy and age, these names were also used for sediments approximately between the Sagavanirktok and Shaviovik Rivers. Outwash gravel between the Shaviovik and Canning Rivers was named the Canning gravel. The names Put alluvium and Put outwash, collectively the Put gravel, were coined for alluvium and outwash between the Kuparuk and Sagavanirktok Rivers. Herein, the Ugnuravik sand has been renamed the Beechey sand to avoid confusion with the Ugnuravik gravel.

CHAPTER 4 - MARINE SEDIMENTS OF THE GUBIK FORMATION

Introduction

Prior to the last decade, the number and extent of late Cenozoic marine transgressions on the Coastal Plain were only hypothesized and based mainly on study of a few outcrops of marine sediments and elevation contours (figure 4.1). Within the last decade, however, knowledge of marine transgressions on the Coastal Plain and their correlation with transgressions recognized along the Bering Sea coast has been considerably increased by David M. Hopkins, Julie Brigham-Grette, L. David Carter, and Darrell S. Kaufman (Hopkins, 1967; Hopkins and others, 1981a; Brigham, 1984, 1985; Carter and others, 1986a; Carter and others, 1988; Kaufman and others, 1989; and Kaufman and others, 1990).

Marine Transgressions

Six late Cenozoic marine transgressions have been well defined and correlated across the Coastal Plain by analysis of amino acids in mollusk shells (table 4.1), and two additional transgressions may be represented in deposits of the Gubik Formation (Carter and others, 1986a). Sediments of certainly four and probably five of these transgressions have been recognized within the study area[3]. In order of decreasing age, these are the Colvillian, Bigbendian, Fishcreekian, Pelukian, and Simpsonian; the presence of Pelukian sediments

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[3]The terms Colvillian I and Colvillian II were first used by Carter and Galloway (1982), and subsequently by Rawlinson (1986a) and Carter and others (1986a, Table 9-1). However, the latter paper also described the Colvillian and Bigbendian transgressions, the terms now preferred for the Colvillian I and II transgressions, respectively.

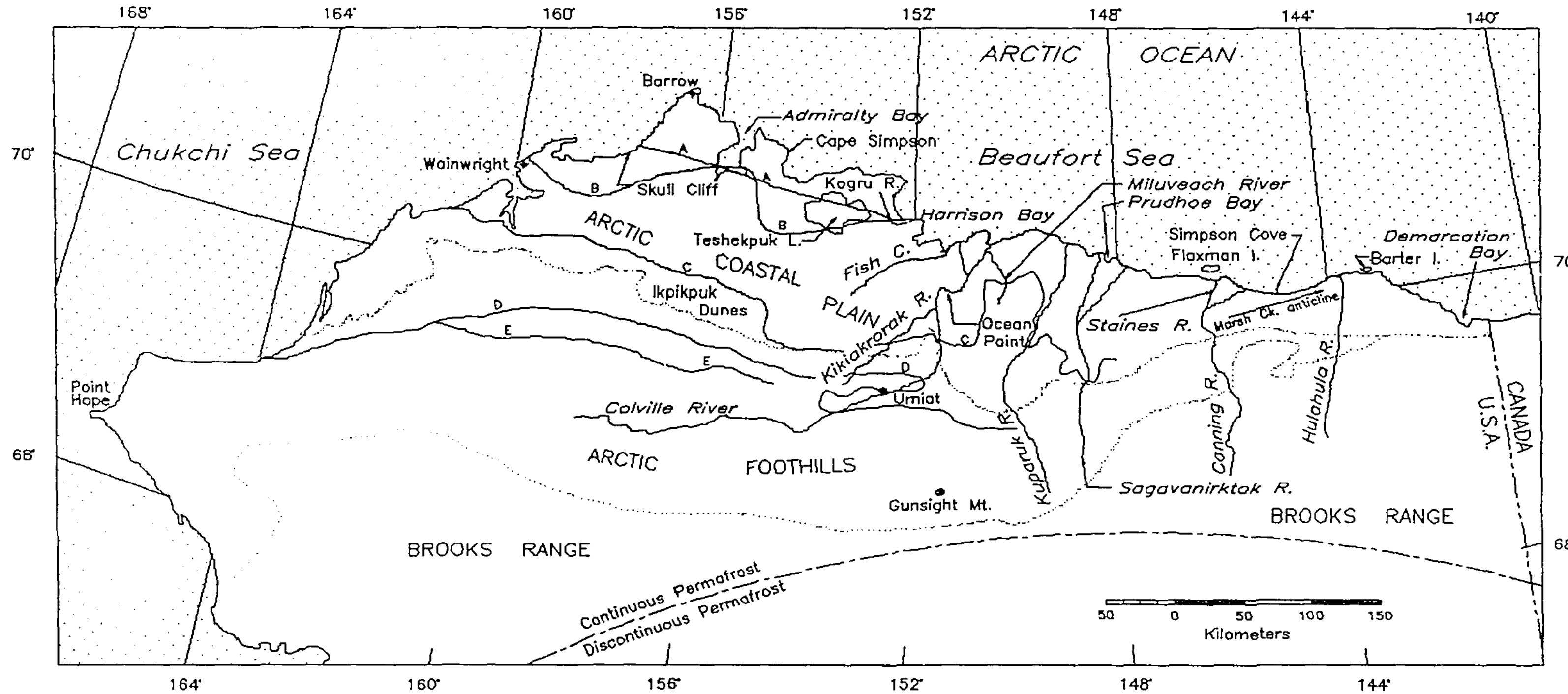

Figure 4.1 Map of the western Arctic Coastal Plain showing marine shorelines proposed prior to 1973: (A) Late Sangamonian or mid-Wisconsinan (O'Sullivan, 1961); (B) Wisconsinan (Black, 1964); (C) Sangamonian (O'Sullivan, 1961); (D) middle Pleistocene (O'Sullivan, 1961); and (E) late Pliocene (O'Sullivan, 1961). Map modified from Sellman and others (1975).

Table 4.1 Correlation chart of marine sequences of the Gubik Formation in northern Alaska based on amino-acid analysis of marine mollusks. Modified from Carter and others (1986a).

Transgression	Maximum Elevation Reached (m)	Age	aIle/Ile[1]: Colville River/ Fish Creek Area	aIle/Ile[1]: Chukchi Sea Coast Area[2]	Probable Correlation with Hopkins (1967)
Simpsonian	7	70 to 80 ka	———	———	———
Pelukian	10	120 to 130 ka	———	0.014 ± 0.002	Pelukian
Wainwrightian	20	500 ka[4]	———	0.038 ± 0.007	Anvilian[4]
Fishcreekian	>20, <60	1.87 to 2.48 Ma	0.086 ± 0.004 (6)[3]	0.086 ± 0.009	}
Bigbendian	>35, <60	>2.19 Ma	0.0136 ± 0.014 (12)[3]	0.15 ± 0.007	} Beringian[4]
Colvillian	>40, <60	<3.5 Ma	0.236 ± 0.022 (8)[3]	0.22	}

1. Ratios for the total fraction of Hiatella arctica.
2. From Brigham, 1983 and 1984. A single value indicates that only one valve was analyzed.
3. Number of analyses.
4. Hopkins (personal communication, 1990).

is uncertain. The following summaries of these transgressions are derived entirely from published literature.

Colvillian Transgression. West of the study area, sediments of the Colvillian transgression unconformably overlie Cretaceous or lower Tertiary sediments along the Colville River from the Kikiakrorak River downstream for about 10 km; this exposure of Colvillian sediments is the type section. The sediments are a basal gravelly sand up to 1 m thick and an overlying clayey silt up to 2.5 m thick. Unconsolidated fluvial and eolian sediments 11 to 12 m thick overlie the Colvillian sediments except in the northern part of the exposure, where 1 to 1.5 m of sediments of the Bigbendian transgression overlie the Colvillian sediments and separate them from the fluvial and eolian sediments (Carter and others, 1986a).

The gravelly base of the Colvillian sediments includes cobbles and boulders of well-indurated sandstone and chert-pebble conglomerate, and of metamorphic, intrusive, and volcanic rocks. Grain sizes of the sandstone and conglomerate resemble those of similar clasts in the Kuparuk gravel and are derived from like rocks nearby in the Brooks Range. The other rock types do not occur in potential source areas of the Brooks Range, but are present in Paleocene boulder-bearing beds exposed along the Colville River and that underlie the Kuparuk gravel. These boulders were likely eroded from the Paleocene boulder-bearing beds and the Kuparuk gravel during the Colvillian transgression and incorporated with other Colvillian sediments (Carter and others, 1986a).

Sediments of the Colvillian transgression are also present along the Miluveach River east of the Colville River; at the Marsh Creek anticline in ANWR; and at Skull Cliff near

Barrow. Colvillian sediments at Skull Cliff were mapped by Brigham (1985) as the Nulavik allomember (table 4.1). Colvillian sediments at Marsh Creek contain distinctive ostracode faunas, which include an Atlantic form that does not presently inhabit Arctic waters. The climate during the Colvillian transgression was apparently much warmer than today (Carter and others, 1986a).

Minimum and maximum ages for the Colvillian transgression are provided by taxa found in the deposits. Samples of the marine mollusk *Hiatella arctica* from these deposits yielded a mean alloisoleucine (aIle)/isoleucine (Ile) ratio of 0.236 +/- 0.022 (table 4.1) (Carter and others, 1986a). Such a ratio indicates correlation with Brigham's (1985) aminozone 5, which is >2.2 Ma. Taxa of Pacific origin in the deposits indicate that the Bering Strait was open and thus provide a maximum age for the Colvillian transgression; the Bering Strait opened between 3 and 3.5 Ma ago (Hopkins, 1972; Gladenkov, 1981).

Bigbendian Transgression. Along the big bend of the Colville River from near Ocean Point upstream for about 10 km, sediments of the Bigbendian transgression unconformably overlie Cretaceous or lower Tertiary rocks, or locally a thin deposit of Colvillian sediments; this exposure is the type section. Type Bigbendian sediments are a 1-m-thick basal gravelly sand with cobbles and boulders like those in the basal Colvillian sediments, and overlying sandy silt about 4 m thick (Carter and others, 1986a).

The pollen assemblage from the Bigbendian sediments is dominated by *Picea*, but includes a significant amount of *Betula*, and minor amounts of *Pinus* and *Abies*. Such floras suggest a mild climate much like that of present-day, south-central Alaska (Nelson, 1981; Nelson and Carter, 1985). Fossil remains of a sea otter (*Enhydra*?) (Repenning, 1983) and the mollusks *Littorina squalida* (Rosewater, written communication to Marincovich cited in Carter and Galloway, 1985a) and *Clinocardium californiense* (Deshayes) (Marincovich, oral communication cited in Carter and Galloway, 1985a) also indicate a mild climate. The present northern limit of these mollusks is the Bering Strait and sea otters are not tolerant of severe sea ice, which suggests that the Beaufort Sea may have been only seasonally frozen during the Bigbendian transgression (Carter and others, 1986a).

Shells of *Hiatella arctica* from Bigbendian sediments in the type section yielded a mean aIle/Ile ratio of 0.136 +/- 0.014. This value indicates correlation with the Killi Creek allomember defined by Brigham (1983); with sediments exposed along part of the Miluveach River; and with sediments on St. George Island attributed to the second Beringian transgression defined by Hopkins (1967) (Repenning, 1983). Marine beds on St. George Island are at least 2.19 Ma old based on radiometric dates of overlying basalt flows (Hopkins, 1967). On the basis of evolutionary development of the sea otter remains, Repenning (1983) suggested that the Colvillian and Bigbendian sediments at Ocean Point are between 1.7 and 2.2 Ma old. Carter and others (1986a), however, indicated that this evidence is not sufficiently precise to preclude a greater age. Repenning and others (1987) indicated that a rodent fauna from stratigraphically higher Fishcreekian sediments indicates a minimum age of 2.4 Ma. If Repenning and others are correct, then both the Bigbendian and Fishcreekian transgressions occurred between 2.4 and 3.0 Ma ago, the older limit being the earliest time that the Bering Strait opened.

Fishcreekian Transgression. Type sediments of the Fishcreekian transgression are exposed on the north side of Fish Creek about 6 km west of the confluence with Judy Creek. Sediments at this location were grouped by Carter and others (1979) into four units, the bottom two of which are marine. The basal marine sediments are 3 to 4 m of dark gray silt with granules of chert and quartz, some interbeds of sand and sand-filled burrows, scattered mollusk fragments, and some woody stems. Overlying marine beds are 5 to 9 m of fossiliferous brown to gray sand, pebbly sand, and silt, all with detrital wood and fine organic debris. The lithology, stratigraphy, and faunas of these marine sediments suggest a bay-mouth or estuary depositional environment (Carter and others, 1979; Carter and Galloway, 1985a).

Amino-acid analysis of *Hiatella arctica* from these sediments yielded a mean aIle/Ile ratio of 0.086 +/- 0.004 (Carter and Galloway, 1985a). On the basis of amino-acid analysis, the type Fishcreekian sediments correlate with sediments exposed in the Marsh Creek anticline and with the Tuapaktushak allomember mapped by Brigham (1983) along the Chukchi Sea coast (Carter and others, 1986a).

The extralimital mollusks *Natica janthostoma* and *Littorina squalida* (L. Marincovich, Jr., written communication cited in Carter and others, 1986a) and femur and molar of a fossil sea otter (*Enhydra*?) collected from the marine sediments provide evidence that Fishcreekian marine waters were warmer than present Arctic waters (Carter and Galloway, 1985a).

Interpretable pollen assemblages from the upper marine sediments include herbaceous taxa, Ericaceae, *Betula* (dwarf birch ?), *Larix*, *Alnus*, *Picea*, and *Pinus*; the last three genera probably represent reworking of older sediments or long-distance transport. These assemblages suggest a severe terrestrial climate, in contrast to the postulated mild marine conditions. Vegetation was shrub-herb tundra with scattered *Larix* trees, much like the modern taiga of northeast Siberia (Carter and Galloway, 1985a). The Fishcreekian transgression may have been nearly coincident with glaciation in the Brooks Range, perhaps the Gunsight Mountain advance of Hamilton (1981). Glacial dropstones, striated-boulder pavements, and deformational structures in the correlated Tuapaktushak beds of Brigham (1983) support this hypothesis (Carter and Galloway, 1985a).

Pollen assemblages in the basal marine sediments are similar, but the amounts of *Betula*, *Picea*, and *Pinus* are greater. During deposition of the basal sediments, *Picea* and *Pinus* were either growing nearby or regional wind directions were different, or both (Carter and Galloway, 1985a). Paleomagnetic and amino-acid data suggest that the basal and upper marine sediments were deposited during a single marine transgression. Differences in pollen assemblages of the two units probably result from minor variations in climate (Carter and Galloway, 1985a).

Carter and Galloway (1985a) proposed that the Fishcreekian transgression likely occurred between 1.87 and 2.48 Ma ago, based on paleomagnetic, palynologic, and paleontologic data. Reversed magnetic polarity of the sediments limits them to the Matuyama Superchron, which began 2.48 Ma ago. This maximum age is corroborated by the presence of tundra or *Larix* taiga vegetation indicated by pollen assemblages. This vegetation is unlikely to have been present on the Arctic Coastal Plain during an interglaciation prior to a world-wide cooling trend that occurred near the Gauss-Matuyama boundary (Carter and Galloway, 1985a). The mollusk faunas are more similar to boreal mollusks in the Tjornes beds in Iceland than to Arctic mollusks in the overlying Breidavik beds, which are interbedded with tillites (Carter and Galloway, 1985a). According to Gladenkov (1981), the top of the Tjornes beds is about 2 Ma old and the base of the

Breidavik beds is stratigraphically just above the Olduvai Chron, which began 1.87 Ma ago. Carter and others (1986b) suggested that the Fishcreekian transgression corresponds to a 2.41-Ma O^{18} minimum recorded in North Atlantic deep-sea cores, the only such minimum in these cores that predates 2.4 Ma.

However, strontium-isotope dates of mollusk shells from Fishcreekian and corresponding Taupaktushak beds suggest that the Fishcreekian transgression occurred between 1 and 1.5 Ma ago (Kaufman and others, 1990; J. Brigham-Grette, personal communication, 1990). This age range is coincident with that proposed by Brigham (1985) based on possible long-term rates of amino-acid epimerization. Brouwers and others (1984) used the rates of epimerization and a tenuous correlation with unfossiliferous marine sediments on the Pribilof Islands to propose an age of 1.2 Ma[4].

Pelukian Transgression. Hopkins (1967) defined the Pelukian transgression as occurring during the Sangamonian Interglaciation and producing shoreline features and sediments at elevations up to 10 m above the present mean level. Carter and Robinson (1981) reported beach sand and gravel from this transgression at elevations between 1 and 10 m from near Barrow eastward to Harrison Bay. Sediments of the Pelukian transgression near Barrow and along the Chukchi Sea coast were termed the Walakpa allomember by Brigham (1983).

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[4]In this text, the Fishcreekian transgression is considered to have occurred between 1.87 and 2.48 Ma ago. Events or deposits discussed herein that are bracketed by the Fishcreekian transgression will have to be pushed forward if the transgression is eventually confirmed to have occurred between 1 and 1.5 Ma ago.

Hopkins and others (1981a) suggested that foraminifera and ostracode faunas in the Pelukian sediments indicate a warmer climate and more open-water conditions than today. Brigham (1983), however, indicated that these faunas and the molluskan faunas are similar to those in the modern Arctic nearshore environment, and thus that conditions were similar to modern conditions. Carter and others (1986a) concurred with interpretations of Hopkins and others (1981a) based on the faunas and abundant *Picea* driftwood in the Pelukian sediments. Abundant *Picea*, if derived from the Arctic Coastal Plain, supports an interpretation of warmer climate because the modern northernmost extent of *Picea* in Alaska is south of the continental divide in valleys of the Brooks Range based on investigations for the Trans-Alaska Pipeline System (Viereck and Little, 1972; R. D. Reger, personal communication, 1990).

Carter and others (1986a) cited four lines of evidence that the Pelukian transgression correlates with oxygen-isotope stage 5e of Shackleton and Opdyke (1977): the mean aIle/Ile ratio (0.014 +/- 0.002) of *Hiatella arctica* shells from Pelukian (Walakpa) sediments along the Chukchi Sea is essentially the same as that of modern specimens, precluding an age older than the Sangamonian Interglaciation (Brigham, 1983); the O^{18} contents of *Astarte borealis* shells from Pelukian sediments are very similar to O^{18} contents in modern *Astarte borealis* shells (J.R. O'Neill, written communication to Carter, 1984); thermoluminescence dates of the Pelukian beach and underlying sediments average 123.5 ka (Carter and Galloway, 1985a); and the 10-m-maximum elevation of the Pelukian sediments is essentially the same as the maximum eustatic sea level cited for oxygen-isotope stage 5e (Cronin and others, 1981).

Simpsonian Transgression. As defined by Dinter (1985), the Flaxman Member of the Gubik Formation was deposited during the Simpsonian transgression. The type section for the member is on Flaxman Island; however, Flaxman sediments are also well exposed at Cape Simpson and Simpson Cove, and discontinuously along much of the Beaufort Sea Coast up to 7 m elevation. The Flaxman Member consists of clayey silt and silty sand with exotic erratic clasts of dolomite, diabase, pyroxenite, granite, and quartzite. The granite typically has red or pink feldspar, and the quartzite is typically pink or purple; both lithologies are very distinctive. Regressive marine sand, beach sand and gravel, deltaic silt and sand, or fluvial sand and gravel typically overlie the Flaxman sediments. The regressive marine sand may be deposits of a younger transgression (Carter and others, 1988).

The erratic clasts have been the subject of many papers primarily addressing lithologies, distribution, process, and provenance (MacCarthy, 1958; Rodeick, 1979; Hopkins, 1982). Hopkins (1982) indicated that erratic clasts were being supplied at the peak of the transgression as shown by their occurrence to within a few hundred meters of the inland extent of transgressive marine sediments. Breakup of an ice sheet in the Canadian Arctic and rafting of the erratic clasts on icebergs is now widely accepted.

Repenning (1983) reported remains of a ribbon seal, *Histriophoca fasciata*, and a gray whale, *Eschrichtius* sp., both Pacific mammals, in sediments of the Flaxman Member, indicating connection of the Arctic Ocean with the Bering Sea. Even though these water bodies were connected, benthic macrofaunas and microfaunas in the Beaufort Sea during the Simpsonian transgression were sparse. Hopkins and others (1981a) reported 16 taxa of foraminifera in the Flaxman Member, and Carter and others (1988) reported 15 taxa of ostracodes and only seven bivalve-mollusk taxa.

Mollusk shells from the Flaxman Member are enriched in O^{18} relative to modern specimens from the Beaufort Sea, suggesting that during the Simpsonian transgression more glacial ice was present than exists today (Carter and others, 1986a). An apparent large volume of glacial ice concurrent with eustatic transgression was explained by Cronin and others (1984) by floating ice in the polar regions. The erratic clasts of the Flaxman Member corroborate floating ice. Carter and others (1986a) proposed a surge of polar ice as a possible mechanism for providing a large volume of floating ice. A rapid rise in sea level resulting from such a surge (Mercer, 1978; Hollin, 1982) could break up unstable marine-based ice over the central Canadian Shield (Denton and Hughes, 1983) and release it to the polar region.

Faunas also suggest that water less than 20 m deep during the Simpsonian transgression may have been slightly warmer than today. Turbidity was also high relative to present day. However, seasonal variations in temperature and salinity were probably similar to the present. East of Flaxman Island, salinities were less than today, perhaps from a high influx of fresh meltwater from icebergs (Carter and others, 1988).

Carter and Galloway (1985a) reported 11 thermoluminescence dates for sediments of the Flaxman Member that range from 53 to 81 ka. Six of these dates range between 71 and 76 ka, and a uranium-series date on the whale bone is 75 ka. Finite radiocarbon dates reported by Carter (1983b) for organic material from Flaxman sediments are apparently erroneous. Carter (personal communication, 1989) indicated that an Accelerator Mass Spectrometer radiocarbon analysis done at the University of Arizona yielded a date of >55 ka, corroborating erroneous finite radiocarbon dates.

The Simpsonian transgression apparently represents an eustatic high stand of sea level, which is corroborated by marine sediments that were deposited near sea level on the Atlantic Coastal Plain about 75 ka ago (Cronin and others, 1981; Cronin and others, 1984).

Sediment Distribution, Character, and Age

Colviile River Marine Terraces

Carter and Galloway (1982) described three terraces that bound the east side of the Colville River Delta, and suggested that the oldest and youngest, respectively Terraces I and III, have counterparts on the west side of the delta. Carter and Galloway (1985a) showed that on the east side of the Colville River Delta, the oldest and youngest terraces can be further subdivided, giving a total of five terraces. Mapping for this study concurs with subdividing the oldest and youngest terraces but subdivides the youngest terrace into three terraces, giving a total of six, herein and on the sheets referred to as Terraces A through F, from oldest to youngest. Mapping for this study also differs as explained below in assignment of sediment types mapped by Carter and Galloway (1985a) for Terrace II (Terrace C) and Terrace III (Terraces D, E, and F) (figure 4.2).

On the basis of field mapping with Carter of the USGS, Terrace A probably was cut by and includes sediments of the Colvillian and perhaps Bigbendian transgressions; Terrace B was probably cut by and certainly includes sediments of both these transgressions and perhaps the Fishcreekian transgression; and Terrace C was possibly cut by and may

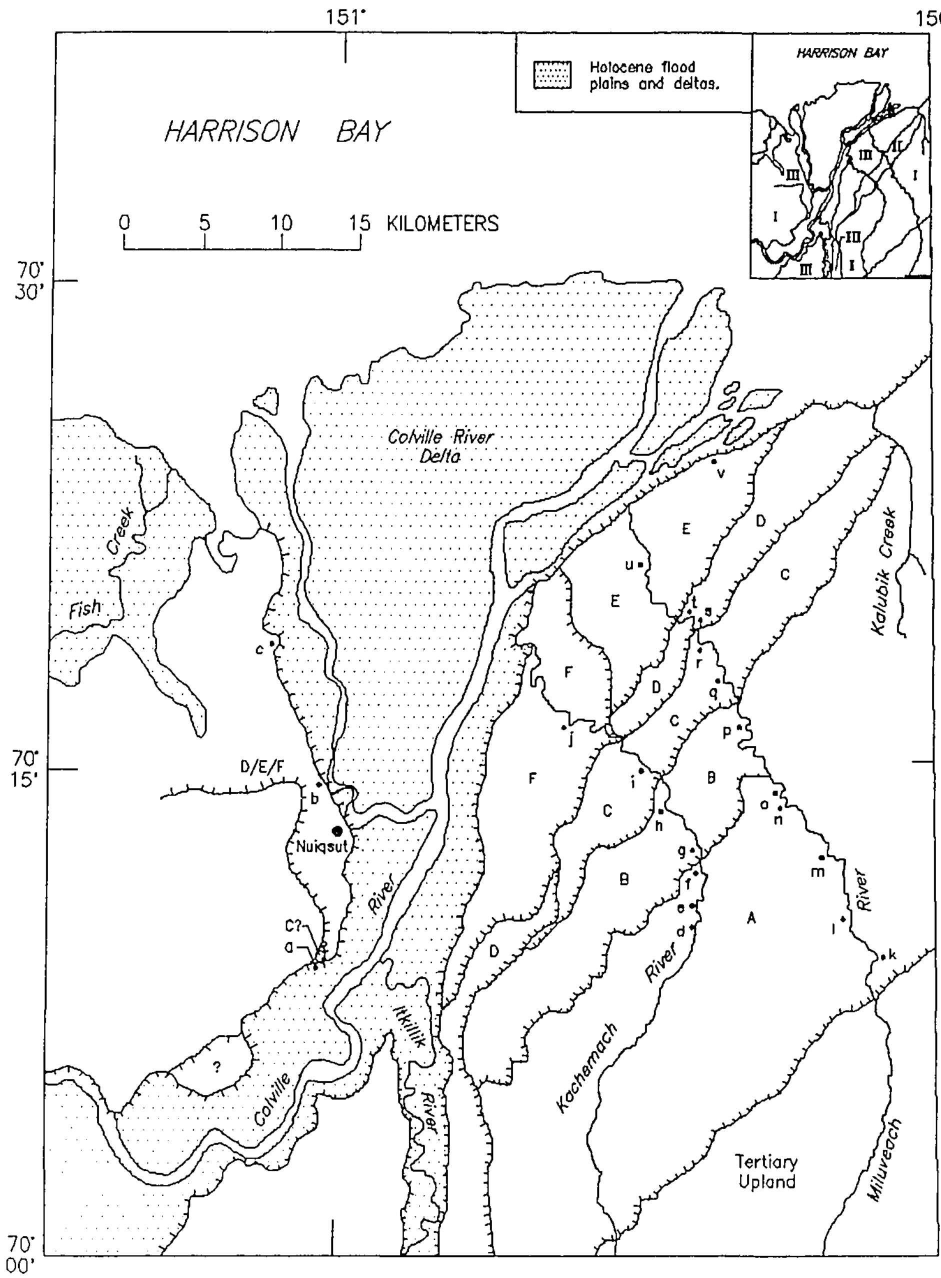


Figure 4.2 Map of the Colville River Delta and vicinity showing marine (A, B, and C) and alluvial (D, E, and F) terraces. Lower case letters denote stratigraphic sections measured on these terraces: a. HBA2-2, b. HBA2-4, c. HBB2-1, d. HBA1-1, e. HBA1-2, f. HBA1-3, g. HBA1-4, h. HBA1-5, i. HBA1-6, j. HBB2-13, k. HBA1-8, l. None, m. HBA1-10, n. HBA1-11, o. HBA1-12, p. HBB1-9, q. HBB1-10, r. HBB1-11, HBB1-12 s. HBB1-13, t. HBB1-14, u. HBB1-4, v. HBB1-7. Map is based on Carter and Galloway (1982) (Inset), Carter and Galloway (1985a), and this study.

include sediments of the Fishcreekian transgression. Terraces D, E, and F are composed primarily of alluvial or deltaic, or both, types of sediments (figure 4.3) and are discussed under "Colville River Alluvial Terraces" in Chapter 5.

Terrace A is the oldest and most extensive of the Colville River Delta terraces and has, perhaps along with Terrace B, a counterpart west of the river. East of the Colville River Delta, approximately 32 km upstream on the Miluveach River, Terrace A truncates a Tertiary upland along a remarkably straight, but degraded scarp that trends approximately 50^0 azimuth and can be traced to a point about 30 km south of the Beaufort Sea coast, where it intersects nonmarine sediments of the Gubik Formation at an elevation of 40 m (Rawlinson, 1986a). The elevation across the scarp changes from about 60 m on the terrace tread to 100 m on the upland. The upland is composed of probable Paleocene nonmarine sediments and Kuparuk gravel of the Sagavanirktok Formation, and of overlying eolian deposits of the Gubik Formation (Carter and Galloway, 1985a).

On the basis of mapping for this study, marine sediments near the base of section HBA1-11 (figures 4.2 and 4.4) are those exposed most upstream along the Miluveach River and probably represent the Colvillian or Bigbendian transgressions, or both. This location is approximately 23 m above mean sea level, 17 m lower than the highest confirmed occurrence of Colvillian sediments (40 m), and about 12 m lower than the highest confirmed occurrence of Bigbendian sediments (35 m) along the west side of the Colville River. (Carter and Galloway (1985a) cited maximum elevations shown in parentheses above). However, fragments of mollusk shells are present in measured section HBA1-10 (figures 4.2

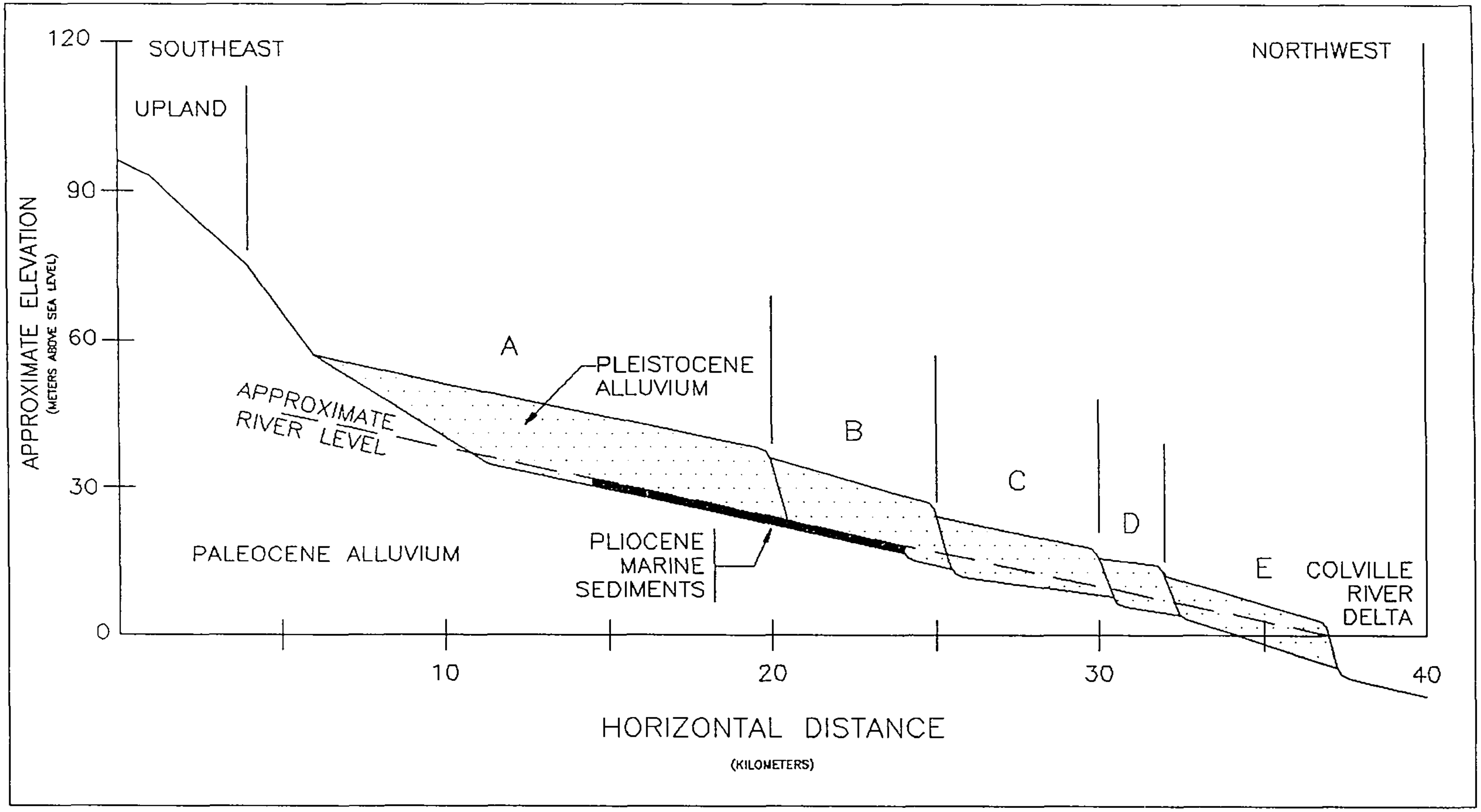


Figure 4.3 Cross-sectional diagram along the Miluveach River of Colville River Terraces A through E. View is to the southwest.

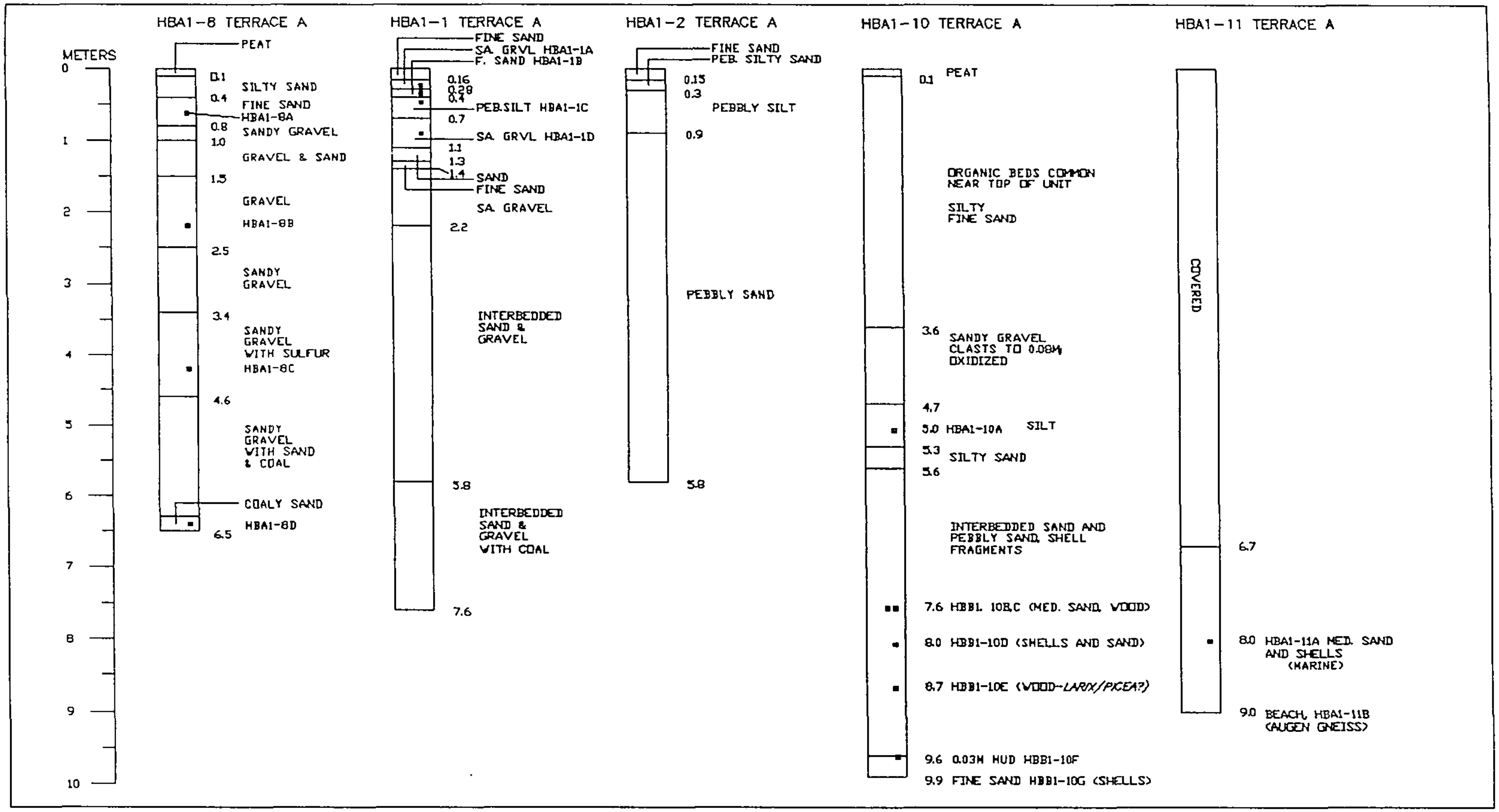


Figure 4.4 Stratigraphic sections HBA1-8, HBA1-1, HBA1-2, HBA1-10, and HBA1-11 measured along the Kachemach and Miluveach Rivers on Terrace A. The small black squares represent samples; sample numbers are adjacent to the right (e.g., HBA1-8A). Locations of sections are indicated on figure 4.2 and sheet 1.

and 4.4) and were found by the author on channel bars of the Miluveach River on Terrace A with decreasing frequency to an elevation of about 27 m within about 5 km of the degraded scarp (figure 4.2, point l). These shell fragments and the straight scarp along the upland suggest that the terrace is a bench cut by marine waters into nonmarine silt, sand, and gravel sediments of the Sagavanirktok Formation, and that marine sediments are present below the level of exposure. The bench has since been covered with alluvium and eolian sediments (figures 4.3 and 4.4).

Cobbles and boulders of rock types characteristic of the Kuparuk gravel (Carter, 1983b; Carter and Galloway, 1985a) and the underlying Paleocene gravel (Carter and Galloway, 1985a) are associated with sediments known to be Bigbendian and Colvillian based on amino-acid analysis. Schist and sandstone cobbles characteristic of these gravels are associated with marine sediments in section HBA1-11 and in similar sediments in section HBA1-12 (figures 4.2 and 4.5). A 0.9-m-diameter boulder of gneissic granite, a rock type and size characteristic of the Kuparuk gravel, is on the river shore at section HBA1-12 and presumably eroded from the adjacent bluff. Presence of these types and sizes of clasts within or near the marine sediments corroborates that the deposits are from the Colvillian or Bigbendian transgressions, or both. Downstream of sections HBA1-11 and HBA1-12 and along the Kachemach River, alluvial sediments are rich in fragments of marine mollusk shells, which presumably were reworked from these sediments or from older marine sediments, perhaps of the Colvillian transgression, farther upstream.

Terrace B, the older of the two more recently mapped terraces, is marked by an indistinct and discontinuous scarp that trends southwest to northeast, roughly parallel to the

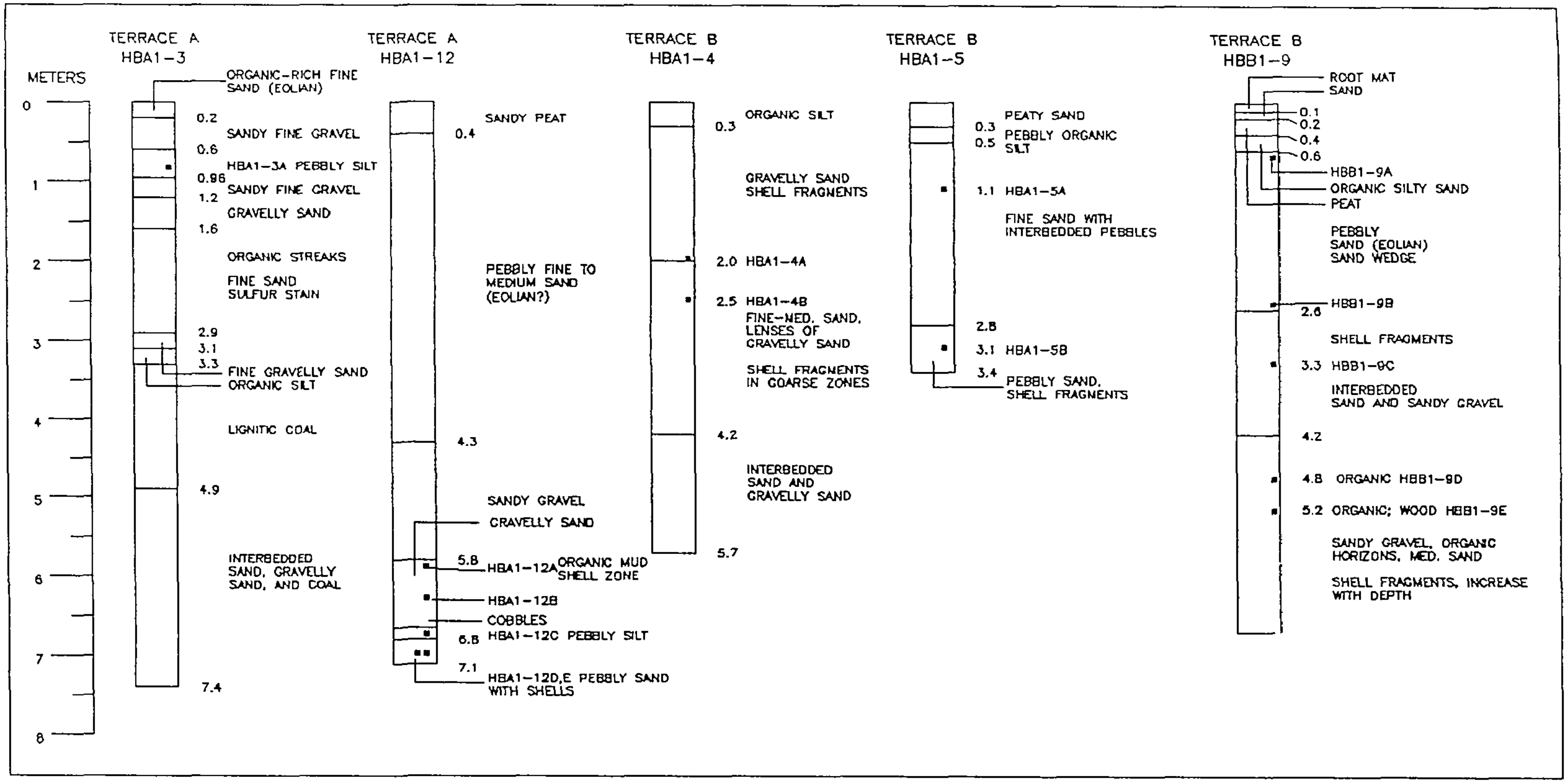


Figure 4.5 Stratigraphic sections HBA1-3 and HBA1-12 measured along the Kachemach and Miluveach Rivers on Terrace A, and sections HBA1-4, HBA1-5, and HBB1-9 measured along the Kachemach and Miluveach Rivers on Terrace B. The small black squares represent samples; sample numbers are adjacent to the right (e.g., HBA1-3A). Locations of sections are indicated on figure 4.2 and sheet 1.

other terraces, from a scarp bounding the Itkillik River flood plain to at least the Kachemach River, and with less certainty to the Miluveach River (figure 4.2 and sheet 1). The elevation of the terrace tread adjacent to the Itkillik River flood plain is approximately 38 m; the lowest elevation of the terrace tread is 30 m.

Terrace B is also likely a bench cut by marine waters. Carter (personal communication, 1989) reported amino-acid ratios indicative of both the Colvillian and Bigbendian transgressions from shells in sections measured on Terrace B. Unequivocal marine sediments were not found on Terrace B in this study, although reworked shell fragments are common in measured sections HBA1-4, HBA1-5, and HBB1-9 (figures 4.2 and 4.5).

Terrace C (Terrace II) is 3 to 4 km wide and bounded by well-defined scarps that trend roughly parallel to the other terraces (figure 4.2). The highest elevation of the terrace tread along the back scarp is approximately 30 m; the elevation decreases northeastward to about 15 m near Kalubik Creek. At the Miluveach River, the elevation of the tread at the back scarp is about 23 m. Across the tread, the elevation varies generally less than 5 m and is especially uniform northeast of the Miluveach River. Carter and Galloway (1982) assumed that at least the northeastern part of the terrace resulted from a single marine transgression based on uniform elevation.

Sediments exposed along the Kachemach and Miluveach Rivers on Terrace C, however, provide little support for the concept of a marine origin. Of four measured stratigraphic sections along the Kachemach and Miluveach Rivers on Terrace C (figures 4.2 and 4.6), only section HBA1-6 has sediments that may be marine; this section includes thin

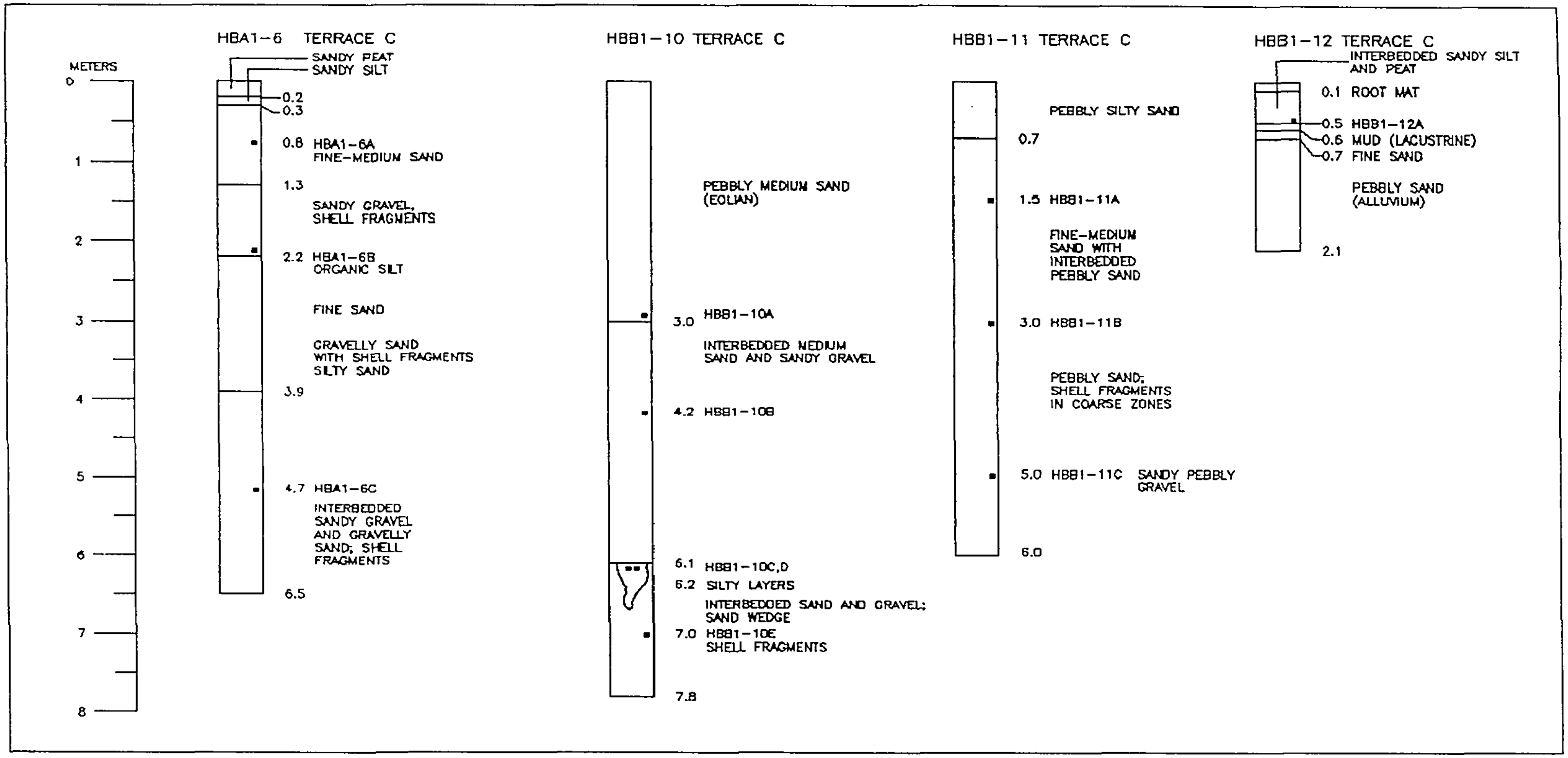


Figure 4.6 Stratigraphic sections HBA1-6, HBB1-10, HBB1-11, and HBB1-12 measured along the Kachemach and Miluveach Rivers on Terrace C. The small black squares represent samples; sample numbers are adjacent to the right (e.g., HBA1-6A). The downward-tapering form shown in section HBB1-10 represents a sand wedge. Locations of sections are shown on figure 4.2 and sheet 1.

beds of sandy gravel with abundant fragments of marine mollusk shells. However, the absence of intact shells suggests nonmarine redeposition.

Two additional sections on Terrace C, both along the Miluveach River, contain fragments of marine mollusk shells. However, shell fragments in these sections are distributed throughout the sediments, which are likely fluvial and were probably reworked from older sediments.

Marsh Creek Anticline

On both the north and south limbs and along the crest of the Marsh Creek anticline, sediments of the Colvillian and Fishcreekian transgressions (Carter and others, 1986c; Dinter and others, 1987), and of the Bigbendian transgression based on amino-acid analysis of shells collected in this study, overlie marine and nonmarine sediments of the Sagavanirktok Formation and underlie a gravel sheet (e.g., sections MMD2-11 and MMD2-25, sheet 6). The composition of the gravel sheet that overlies the sediments of the Fishcreekian transgression differs from the composition of a younger gravel sheet elsewhere within ANWR. Details of the Gubik Formation stratigraphy and character in this area have yet to be determined and are being considered by L. David Carter. However, the entire sequence of sediments is undoubtedly folded in the anticline.

Coastal Outcrops

Rodeick (1975, 1979) recognized a chert facies and a dolomite facies for gravels along the Beaufort Sea coast. The chert facies includes chert of various colors, brown and black being dominant; sandstone; siltstone; shale; limestone; coal; and occasional igneous clasts. Clasts of this facies are derived from the Brooks Range. The dolomite facies includes exotic clasts belonging to or reworked from the Flaxman Member; within the study area along the coast, sediments from other marine transgressions have not been identified. Dolomite from this member composes up to 80 percent of the gravel clasts along the Beaufort Sea coast (Hopkins and Hartz, 1978).

Along the modern beaches from a point about half the distance between Oliktok Point and Milne Point to Howe Island off the mouth of the Sagavanirktok River Delta, and on adjacent barrier islands, the presence of Flaxman Member sediments is most obviously indicated by individual or patches of exotic erratic clasts of pink granite, red and purple quartzite, and black diabase. Within the study area, these clasts have not been observed along the coast west of a point half the distance between Oliktok Point and Milne Point or within the Colville River Delta.

Occurrences of individual or patches of erratic clasts resume east of the Sagavanirktok River Delta and continue intermittently along the coast to beyond the Canadian border; these occurrences have been mapped as part of this study to the Canning River Delta (sheets 2 through 5). Notable patches of erratic clasts between Oliktok Point and the Canning River occur at an unnamed estuary southeast of Milne Point, Heald Point, Tigvariak Island, and Flaxman Island. The "boulder patch" is a well-documented and publicized occurrence of erratic clasts offshore from the Sagavanirktok River Delta that represents lag deposits derived from erosion of Flaxman Member sediments (Reimnitz and Ross, 1979).

West of Flaxman Island, outcrops of gray clayey silt of the Flaxman Member are sometimes associated with the coastal patches of erratic clasts. These outcrops are typically at or just below beach level and were originally thought to be modern accumulations of sediments formed from beach processes. However, these sediments at Heald Point are present in the base of the exposed bluff and extend below beach level as exposed in trenches dug across the beach.

Sediments of the Flaxman Member on Flaxman Island are best exposed on the seaward side of the island. There, bluffs are typically between 5 and 6 m high and the beach, when present, is very narrow. Waves often undercut the bluff resulting in failure of large blocks of sediment along ice wedges and collapse into the sea. This type of erosion along the seaward side of the island results in rapid retreat of the shore, approximately 3.5 m/yr averaged over 19 years (Lewellen, 1977), and continually presents fresh exposures of sediment.

Stratigraphic section FIA4-4 is typical of exposures on the seaward side of Flaxman Island (figure 4.7). The bottom 1.4 m of this section is pebbly clayey silt (sample FIA4-4B, appendix E), or what is commonly termed Flaxman mud. The overlying 1.4 m of pebbly medium sand is regressive marine and the top 2.8 m of interbedded peat and sand are thaw-lake sediments. The modal diameter of exotic pebbles in the marine units is less than 1 cm, but diameters range up to 6 cm. Cobble- and boulder-sized clasts are present on the beach but not in the section at this location.

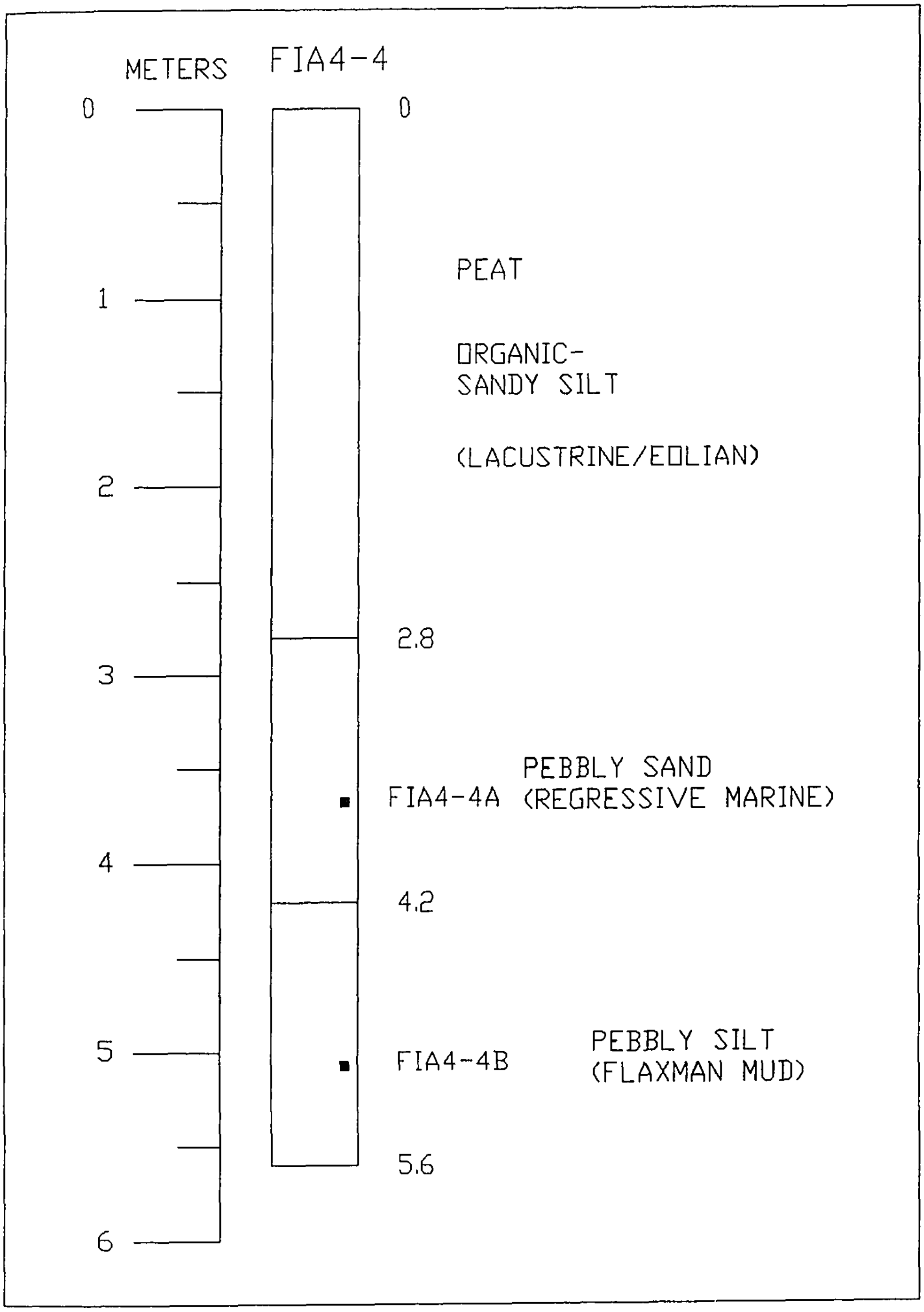


Figure 4.7 Stratigraphic section FIA4-4 measured on the seaward side of Flaxman Island. The small black squares represent samples; sample numbers are adjacent to the right (e.g., FIA4-4A). The location of this section is shown on sheet 5.

Elsewhere, exotic boulders are typically distributed throughout the section. Indentation of boulder-sized clasts into underlying marine sediments and draping of sediments over the clasts indicate that the boulders sank into the marine deposits and were subsequently covered. The presence of boulder-sized clasts on the ground surface, such as on Tigvariak Island and elsewhere, suggests that many of the boulders have moved upward in the section, probably by frost heaving. Boulders present in thaw-lake deposits have either been heaved up-section or indicate reworking of marine sediments, or both.

Inland Outcrops

The inland extent of the Simpsonian transgression is uncertain except in a few areas where Flaxman mud or regressive marine sediments, or both, are present; and in areas where exotic erratic clasts are present or there is a change in ground surface wetness that suggests a variation in the subsurface lithology. One measured stratigraphic section about 5 km inland includes Flaxman mud in the bottom part of the section based on the presence of exotic lithologies on the river berm, sediment texture like that of the type Flaxman mud, and similar altitude with Flaxman mud along the coast (figure 4.8, section FIA4-8). This stratigraphic section is on a topographically high area that diverts the Canning River eastward and then northward where it empties into the Beaufort Sea, and which is probably underlain by Flaxman mud.

Five additional stratigraphic sections within the study area include sand or gravel, or both, and exotic clasts that are interpreted to be regressive marine sediments: MMD3-15, FIA3-5, and BPA1-12 (figure 4.8), BPA2-13 and BPA2-14 (figure 4.9). Stratigraphic section BPA1-12 is approximately 1 km inland along the east side of the first

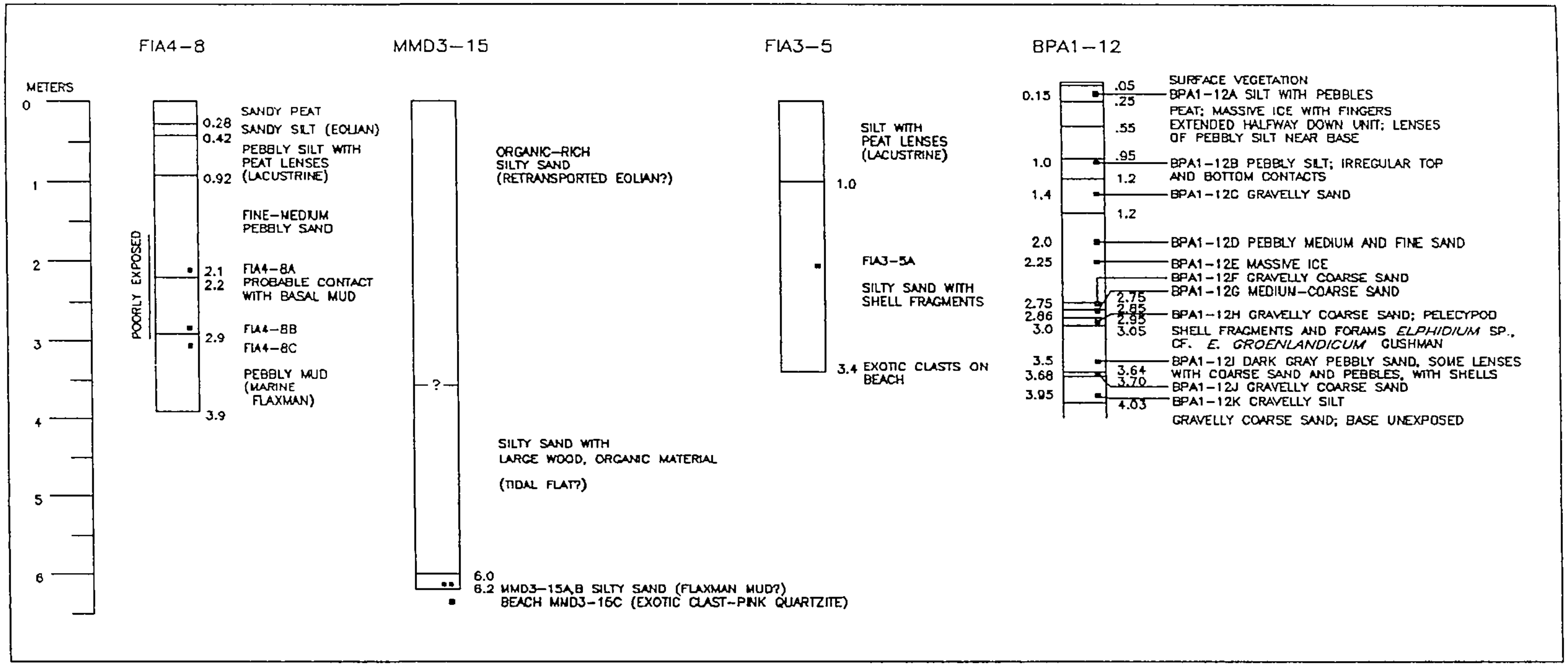


Figure 4.8 Stratigraphic sections FIA4-8, MMD3-15, FIA3-5, and BPA1-12 measured east of the Sagavanirktok River. Stratigraphic sections east of the Sagavanirktok River include sediments deposited during the Simpsonian or possibly Pelukian marine transgression. The small black squares represent samples; sample numbers are adjacent to the right (e.g., FIA4-8A). Locations of the first three of these sections are shown on sheet 5 and the location of section BPA1-12 is shown on sheet 4.

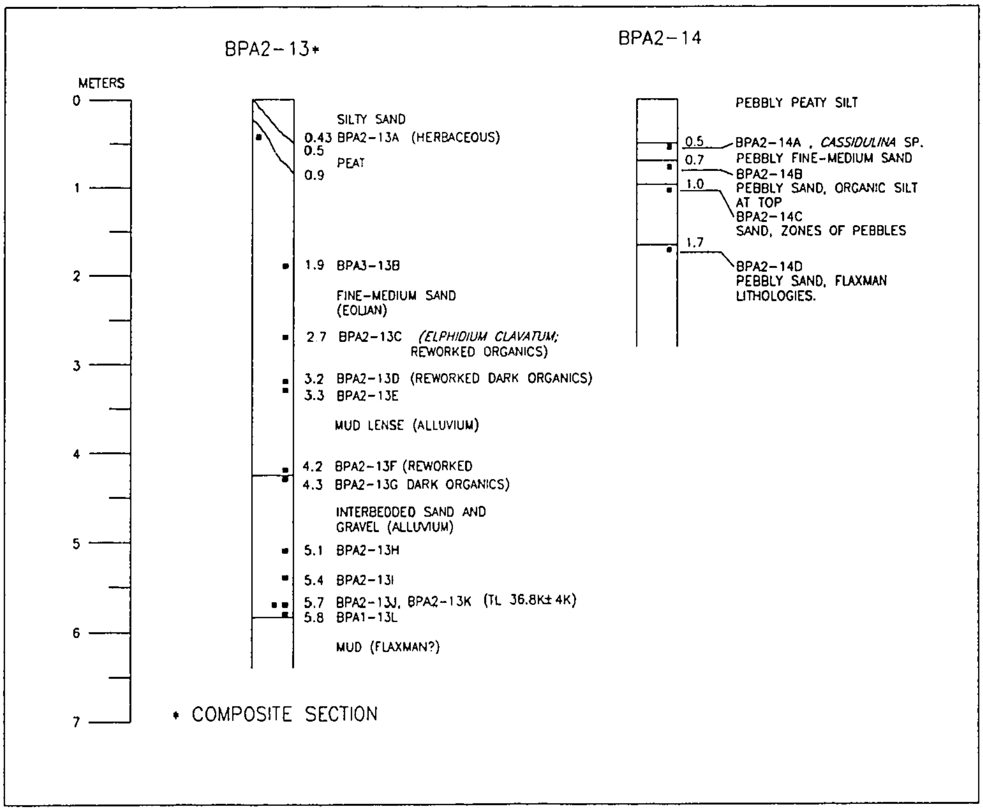


Figure 4.9 Stratigraphic sections BPA2-13 and BPA2-14 measured east of the Sagavanirktok River. The small black squares represent samples; sample numbers are adjacent to the right (e.g., BPA2-13A). TL denotes a thermoluminescence date. Locations of these sections are shown on sheet 3.

unnamed stream east of the Shaviovik River. The bottom part of this section includes sandy gravel that is overlain by pebbly silt. Whether this silt, which is only 0.3 m thick, is the Flaxman mud is uncertain. Approximately 1 m of regressive marine sediments overlie the silt and a thin gravelly sand bed within this part of the section yielded *Elphidium* sp., cf. *E. groenlandicum* Cushman. Stratigraphic section MMD3-15 is near the southern end of an unnamed estuary that empties into Camden Bay and section FIA3-5 is on a lake shoreline about 2.5 km east of the Tamayariak River. Both sections are approximately 5 km inland from the present coast.

Two remaining stratigraphic sections that may represent the Flaxman Member, BPA2-13 and BPA2-14 (figure 4.9), are between 8 and 9 km inland on the east side of the Sagavanirktok River. Within several hundred meters south of section BPA2-13, a slight but distinct break in topography trends perpendicular to the Sagavanirktok River for several kilometers (sheet 3). Whether this topographic break represents an ancient shoreline is undeterminable because of the lack of exposure. However, no marine sediments have been found south of this break.

Both sections BPA2-13 and BPA2-14 yielded marine microfaunas, which in both cases were probably reworked from underlying deposits, respectively by lacustrine processes and by fluvial and eolian processes. A single specimen of *Elphidium clavatum* was collected about 4 m below the surface in section BPA2-13 and ostracodes were collected about 0.6 m below the surface in section BPA2-14. Exotic clasts (e.g., pink quartzite) were also present on the river berm adjacent to section BPA2-14. Analysis of sediments from throughout section BPA2-13 for palynomorphs yielded mostly dark brown to black organic material, a variety of single pollen grains undoubtedly reworked from older deposits, and several rarely

(2 to 5 grains) and frequently (6 to 15 grains) occurring taxa. Rarely occurring taxa include undifferentiated bisaccates, Tasmanaceae, Caryophyllaceae, *Lycopodiumsporites* sp., *Sphagnumsporites* sp., *Laevigatosporites* sp., and *Osmundacidites* sp. A frequently occurring taxum is *Ilexpollenites* sp. (appendix K).

A 1-m-thick silt bed at the base of section BPA2-13 is at least 36.8 ka old based on a thermoluminescence date of overlying probable fluvial sediments, which in turn are overlain by eolian sediments. Whether the silt represents the Flaxman mud or earlier marine sediments is unknown.

Exotic erratic clasts on the ground surface at many locations within the study area suggest that marine sediments may be present in the shallow subsurface. Most occurrences of erratic clasts are within a few kilometers of the coast (MacCarthy, 1958). However, at section BPA1-30, approximately 9 km inland on the east bank of the Shaviovik River (sheet 4), a boulder of pink granitic rock in the river adjacent to the section suggests that marine sediments underlie the exposed eolian sediments. These occurrences suggest that the Coastal Plain north of an imaginary line connecting sections BPA2-13 and BPA1-30 may be underlain with marine sediments of the Simpsonian and perhaps older transgressions. This part of the Coastal Plain has a higher density of small thaw lakes than on the Coastal Plain south of this line.

Exotic erratic clasts, numerous thaw lakes, and occurrences of Flaxman mud (e.g., section FIA4-8) strongly suggest that topographically high ground north of the Canning River and between Brownlow Point and the mouth of the Canning River, and on the Coastal Plain east of the Canning River to an unnamed estuary that empties into Camden

Bay south of Konganevik Point (sections MMD3-15 and FIA3-5), is underlain by sediments of the Simpsonian transgression and perhaps by sediments of the Pelukian transgression. A lower slope and the presence of marine sediments in the latter area undoubtedly are factors controlling the greater number of thaw lakes there than on the Coastal Plain adjacent to the south.

The inland extent of the Simpsonian transgression in the vicinity and west of Prudhoe Bay is more uncertain than to the east of the bay. Exotic clasts and Flaxman mud at Heald Point and along the east side of Prudhoe Bay, and exotic clasts along the coast between the Putuligayuk River and the Kuparuk River (sheet 3), imply a shoreline somewhere south of the present coast in these areas. No shoreline is obvious and for mapping purposes the marine sediments are assumed to extend to the boundaries of surrounding fluvial sediments.

Marine pebbly sand (appendix E, sample BPB3-25T) was dredged from a lake at the bottom of the northernmost (PUT 2) of three gravel pits along the east side of the Putuligayuk River, but near the west side of the broad Putuligayuk River flood plain (sheet 3). PUT 2 gravel pit is 2.9 km inland from the shore of Prudhoe Bay at a surface elevation of 3 m above mean sea level. Sediments are exposed in section BPB3-25 to approximately 12 m below the surface, or 9 m below sea level: 0.5 m peat and fluvial sandy silt overlying 11.5 m of fluvial and glaciofluvial interbedded pebbly sand, sandy gravel, and gravel (figure 4.10). The fluvial sediments are discussed in Chapter 5. The marine sediments were adjacent to the lake and stratigraphic relationships had been obscured by digging. Although disturbed, the sediments are not believed to be from significantly lower in the pit because the lake is shallow.

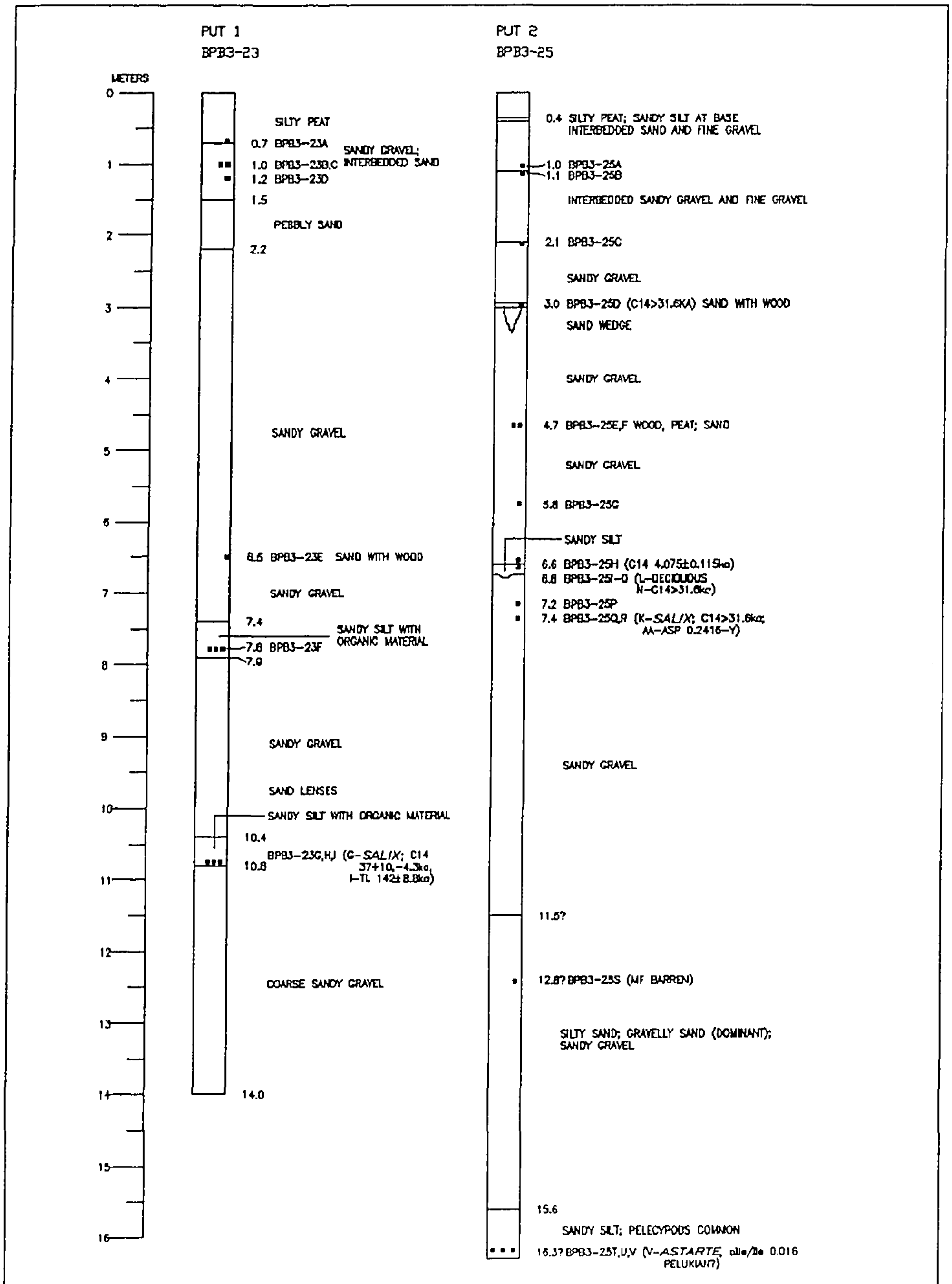


Figure 4.10 Stratigraphic section BPB3-23 measured in the PUT 1 gravel pit and section BPB3-25 measured in the PUT 2 gravel pit. The small black squares represent samples; sample numbers are adjacent to the right (e.g., BPB3-23A). The downward-tapering form shown in section BPB3-25 represents a sand wedge. C14 denotes radiocarbon; TL denotes thermoluminescence; and AA denotes amino acid; the letter after AA ratio indicates the assigned age group. Locations of these gravel pits are shown on figure 5.6 and sheet 3.

The pebbly sand contains *Macoma calcarea* (Gmelin), *Astarte borealis* (Shumacher), *Yoldia arctica* (Gray), *Musculus niger* (Gray), and *Cyrtodaria kurriana* (Dunker), all of which are extant species that typically inhabit cold, shallow, marine waters (R. Allison, personal communication, 1985). Sample BPB3-25U from the pebbly sand was analyzed for microfossils and yielded calcispheres, shell fragments, *Guttulina* sp., *Elphidium clavatum* and frequent ostracodes. These faunas suggest a marginal marine to inner neritic environment.

Amino-acid analysis of three *Astarte borealis* specimens yielded a tight group of aIle/Ile ratios with a mean ratio of 0.016 +/- 0.002 (appendix H, sample BPB3-25V), which suggests that the specimens are no older than the Sangamonian Interglaciation (G. Miller, written communication, 1986).

Significant Findings, Implications, and Interpretations

Geologic mapping, observations, and analyses of samples from marine deposits across the study area collectively allow interpretations regarding the age of the Colville River Terrace C; correlation of boulders along the mainland coast with those on adjacent islands; the relationship between lake population, broad-based mounds, and substrate; and the inland extent of Quaternary marine transgressions.

Fishcreekian Age for Colville River Terrace C

Carter and Galloway (1982) suggested that at least part of their Terrace II, Terrace C of this study, was formed as a result of the middle Pleistocene Kotzebuan transgression of Hopkins (1967). However, the middle Pleistocene transgression is now considered the Anvilian transgression of Hopkins (1967) and tentatively correlated with the Wainwrightian transgression (Kaufman and others, 1989; Kaufman and others, 1990), which is named for fine-grained marine sediments exposed at Karmuk Point near Wainwright (Carter and others, 1986a). Sediments from this transgression are known eastward to the Kogru River and up to 20 m above sea level (Carter and others, 1986a; Dinter and others, 1987). Because the Wainwrightian transgression reached a maximum elevation of 20 m, association with the next older and higher reaching marine transgression, the Fishcreekian, seems more plausible to have formed the northeastern part of Terrace C. This assumes validity of Carter and Galloway's (1982) assumption that the terrace resulted from marine transgression. Amino-acid analysis of shells from the west side of the Colville River indicates the presence of Fishcreekian seas in the vicinity of the Colville River and delta (Carter, personal communication, 1989). The Fishcreekian transgression may have cut this or higher terraces, but associated sediments apparently have been eroded.

Correlation of Coastal Exotic Boulders

Exotic erratic boulders, pebbly silty sand, or sandy silt, or combinations of these representing the Flaxman Member, are present on most of the nearshore, tundra-covered islands as far west as Pingok Island. Contrarily, Hopkins and Hartz (1978) suggested that some of the Jones and Return Islands that bound Simpson Lagoon are cored with Pelukian beach sediments; and Hopkins (personal communication, 1984) suggested that these islands are a continuation of a Pelukian beach ridge that extends eastward from Barrow to Harrison Bay (Carter and Robinson, 1981). This interpretation, though, is inconsistent with the presence of exotic clasts from the Flaxman Member on the islands and the adjacent mainland coast. If the exotic clasts were ice rafted from the Canadian Arctic, which all evidence seems to indicate, the probability of a berg bypassing a high-standing beach ridge and grounding further inland seems prohibitively low.

Alternatively, the island chain may not represent a high-standing Pelukian beach ridge and the mainland and island chain may have been joined, perhaps until only a few thousand years ago (Naidu and others, 1984). These authors suggested that Simpson Lagoon formed from coalescence of Coastal Plain thaw lakes followed by thaw subsidence. Although Reimnitz and others (1985, 1988) disagreed, perhaps correctly so, with the mechanism presented by Naidu and others (1984) for the formation of coastal Arctic lagoons, the two groups of authors agree that within the past 1 ka the Coastal Plain was continuous and extended offshore well beyond the present coast. Thus, exotic clasts or fine-grained marine sediments, or both, present on the islands are correlative with similar sediments discontinuously present along the mainland coast.

Inland Extent of Quaternary Marine Transgressions

The apparent Sangamonian or younger age and the 9-m depth below sea level of marine sediments in the PUT 2 gravel pit suggest that the sediments were deposited in an embayment, perhaps a precursor to Prudhoe Bay. These sediments could have been deposited during either the Pelukian or Simpsonian transgressions; or as suggested by L. David Carter (personal communication, 1986), they may be only slightly older than the overlying alluvium. Radiocarbon analysis of wood (sample BPB3-23G) from a sandy-silt horizon in probably corresponding overlying alluvium in the PUT 1 gravel pit upstream yielded a date of 37 +10/-4.3 ka. This date should be considered infinite because of the large counting error and is a minimum age for the underlying marine sediments.

In addition to the marine sediments exposed at the bottom of PUT 2 pit, two exotic clasts were found but not in place. One clast, a cobble of pink granite, was found near the bottom of the PUT 2 pit; the other clast, a boulder of light-purple quartzite, was found on a ramp that provided access into the pit, approximately two-thirds of the distance up the stratigraphic section from the bottom of the pit. Even though these clasts were not in place, they indicate that sediments of the Simpsonian transgression might be present in the stratigraphic section above the highest occurring clast, or in the vicinity of the pit. In-place marine sediments have not been found in the section, leaving only the possibility that the clasts were reworked from upstream of the pit. This being the case, the presence of exotic clasts in pit PUT 2 does provide a maximum age of early Wisconsinan for sediments in the top one-third of the section.

Marine sediments apparently do not extend inland much beyond pit PUT 2 because they have not been recognized in either of the two gravel pits farther inland along the Putuligayuk River. Nonrecognition of the marine sediments in these pits may have occurred because the pits have not been excavated sufficiently deep to expose the sediments. Another possibility is that Carter's hypothesis, that the marine sediments are relatively young (personal communication, 1986), is correct. Radiocarbon dating of the shells or thermoluminescence dating of the sediments, or both, should be done in future studies to resolve the uncertain age. However, based on available evidence, marine deposits in PUT 2 pit are thought to have been deposited during the Pelukian transgression.

The Coastal Plain adjacent to the west of the Putuligayuk flood plain is the most likely source for the exotic clasts in PUT 2 pit. The discontinuous occurrence of exotic clasts along most of the coast there, and in the area between the Kuparuk and Colville

Rivers, indicates that the Simpsonian transgression reached an undetermined distance inland in both areas. Marine sediments are not exposed in either of the MP or KUP E gravel pits, which are located approximately within 5 km of the coast between the Kuparuk and Colville Rivers. These pits are sufficiently deep to have encountered marine sediments emplaced near or slightly above sea level; that is, sediments of the Simpsonian and Pelukian transgressions. Thus, these pits mark the maximum possible inland extent of these transgressions between the Kuparuk and Colville Rivers.

On the basis of stratigraphic relationships in the western part of the Coastal Plain, the Pelukian transgression reached elevations perhaps as high as 10 m (Carter and Galloway, 1985a). This suggests that mean sea level, typically 3 m lower than the maximum elevation (Hopkins, personal communication, 1990) was close to the plus 6 +/- 2 m maximum eustatic sea level cited for oxygen-isotope stage 5e (Cronin and others, 1981). Thus little, if any, tectonism has occurred in the western part of the Coastal Plain since at least about 124 ka ago (Carter and others, 1986a); however, ongoing minor tectonism might account for linear features that cut Holocene sediments in the study area.

West of the Colville River, sediments of the Pelukian and Simpsonian transgressions are superposed, and the existence of a Pelukian beach ridge that extends from near Barrow to Harrison Bay is well accepted. Why then, are Pelukian sediments not found inland of the probable maximum inland extent of the Simpsonian transgression east of the Colville River? One possibility is that the Coastal Plain extended sufficiently north during the Sangamonian Interglaciation to preclude transgression onto this area. Alternatives are that Pelukian marine sediments are still present but have since been buried, perhaps in conjunction with subsidence; or that these sediments once were present, but have since been eroded, perhaps in conjunction with uplift.

A combination of the first two alternatives is most probable. As shown by absence of Pelukian sediments in the KUP E and MP gravel pits, the inland extent of inundation between the Colville and Kuparuk Rivers was not as great as east of the Kuparuk River. Subsidence, especially east of the Kuparuk River, followed by alluviation may have buried Pelukian sediments well below sea level as is the probable case in the PUT 2 gravel pit. Absence of Pelukian marine sediments in the SAG C and END pits may have resulted from delta development at the mouth of the Sagavanirktok River. Pelukian marine sediments probably underlie the Coastal Plain between the Sagavanirktok River and Canning River fan.

Lake Number and Marine Substrate

A large number of relatively small thaw lakes and a small number of broad-based mounds as far as 9 km inland in the area between the Sagavanirktok River and the Canning River fan may be tied to a marine substrate. Whether this is a function of a lower gradient, and thus poorer drainage, is unknown. The gradient certainly is less there than to the south, and in continuous permafrost, poor drainage is expected where the gradient is lower.

A definite demarcation between parts of the Coastal Plain with numerous lakes and with few lakes occurs approximately 3 to 5 km inland along the front of the Canning River fan between Bullen Point and the Staines River (sheets 4 and 5). Although gradient probably influences the number of lakes near the coast, the many occurrences of exotic clasts suggest that the primary control is a substrate of marine sediments.

CHAPTER 5 - FLUVIAL, DELTAIC, AND OUTWASH SEDIMENTS OF THE GUBIK FORMATION

Introduction

Fluvial, deltaic, and outwash sediments share the attribute of being transported and deposited by running water, whether by precipitation or melting of snow or glacial ice. Thus, regardless of a glacial, interstadial, or interglacial climate, the process and effects of running water have been ongoing on the Coastal Plain through time, albeit at different rates and locations. These sediments compose a large percentage of sediments present on the Coastal Plain, yet have received only a small percentage of the attention given to the Coastal Plain.

During the winter, fluvial processes on the Coastal Plain are greatly diminished and commonly restricted to sub-bed flow (Harden and others, 1977). Spring ice-breakup on the rivers occurs over the first few days of a three-week period of flooding in late May through early June. Up to 80 percent of the flow occurs during this period (Walker, 1973). Spring flood waters inundate large areas of the deltas, and upon reaching the coast, spread over stable grounded and floating ice up to 15 km from shore (Arnborg and others, 1967; Walker, 1974; Barnes and others, 1988).

The boundary between fluvial and deltaic sediments in a river and delta system is frequently arbitrary. The term "delta" implies that the transition from river to delta environment is where distributary streams first occur. For the Sagavanirktok and Canning Rivers, this point is far inland and the area between there and the coast can better be described as a flood plain. Nevertheless, the first occurrence of distributary streams has been used by some researchers, including the author, to define boundaries of the deltas (e.g., Alaska Outer Continental Shelf Office, 1979). In this text and on the accompanying sheets, the transition from river to delta is approximately where distributary streams first occur and modern accumulations of fine sediment are laterally extensive. An exception is the Colville River Delta where only the first criterion is used.

Amino-acid Analysis

The extent of amino-acid diagenesis (epimerization or racemization) in shell material, and perhaps also in wood, is a means of determining absolute and relative ages beyond the limits of other dating techniques. Temperature is the most critical of several variables that affect the rate of amino-acid racemization (Brigham, 1985). Despite demonstrated temperature variations on the Coastal Plain during the Pleistocene (Carter and others, 1986b), reproducible and consistent results have been realized for samples of shells from the Coastal Plain that date to several million years (Brigham, 1985).

Brigham (1985) indicated that the potential for amino-acid analysis providing useful age data on wood samples much older than 100 ka has not been thoroughly demonstrated. According to Rutter (1986), results are commonly erratic and dextrorotary/levorotatory (D/L) ratios lower than expected. Some data suggest that samples greater than that age have undergone diagenetic changes involving mineralization, selective leaching of acids, bacterial attack, or variations of the rate of racemization. However, D/L ratios for aspartic acid in wood are sufficiently consistent to differentiate late to middle Wisconsinan samples from early Wisconsinan to Sangamonian samples and to correlate and determine relative ages of Pleistocene sediments within a given area. Rutter (1986) further indicated that the rate of racemization in wood tends not to be greatly sensitive to variations in temperature or genera of taxa.

Realizing probable limitations of amino-acid dating on wood, samples of wood from fluvial sediments and of shell from marine sediments underlying fluvial sediments were analyzed for amino acids to correlate sediments between areas and to tentatively assign minimum relative ages to groups within which the samples fall. Most of the samples are from relatively old sediments exposed in deep gravel pits between the Colville and Sagavanirktok Rivers, and from exposed bluffs within ANWR.

Amino-acid analysis conducted by staff of the University of Alberta on the submitted samples suggests three age groups defined by the D/L ratio of aspartic acid in the total hydrolysate: (1) a young group with a mean ratio of 0.2037 +/- 0.0536; (2) a "relatively old" middle group with a mean ratio of 0.3156 +/- 0.0156; and (3) an "old" group with an anomalously low mean ratio of 0.0543 +/- 0.0182 (figure 5.1). The aspartic-acid ratios within each group are consistently higher with age except in the old samples, which revert to very low ratios. This reversal is apparently common (N. Rutter, written communication, 1986) and may be attributable to leaching of acids or other modification of the samples (J. Brigham-Grette, personal communication, 1990). The old samples, without exception, are from locations within ANWR, and are probably significantly older than samples of the middle group. However, location of all the old samples in ANWR probably reflects preferential collecting, and does not imply that old samples do not exist elsewhere. Four additional samples that had unexpectedly low ratios (mean 0.2202 +/- 0.0239) for perhaps the same reason were assigned to the middle group based on stratigraphic position. If these

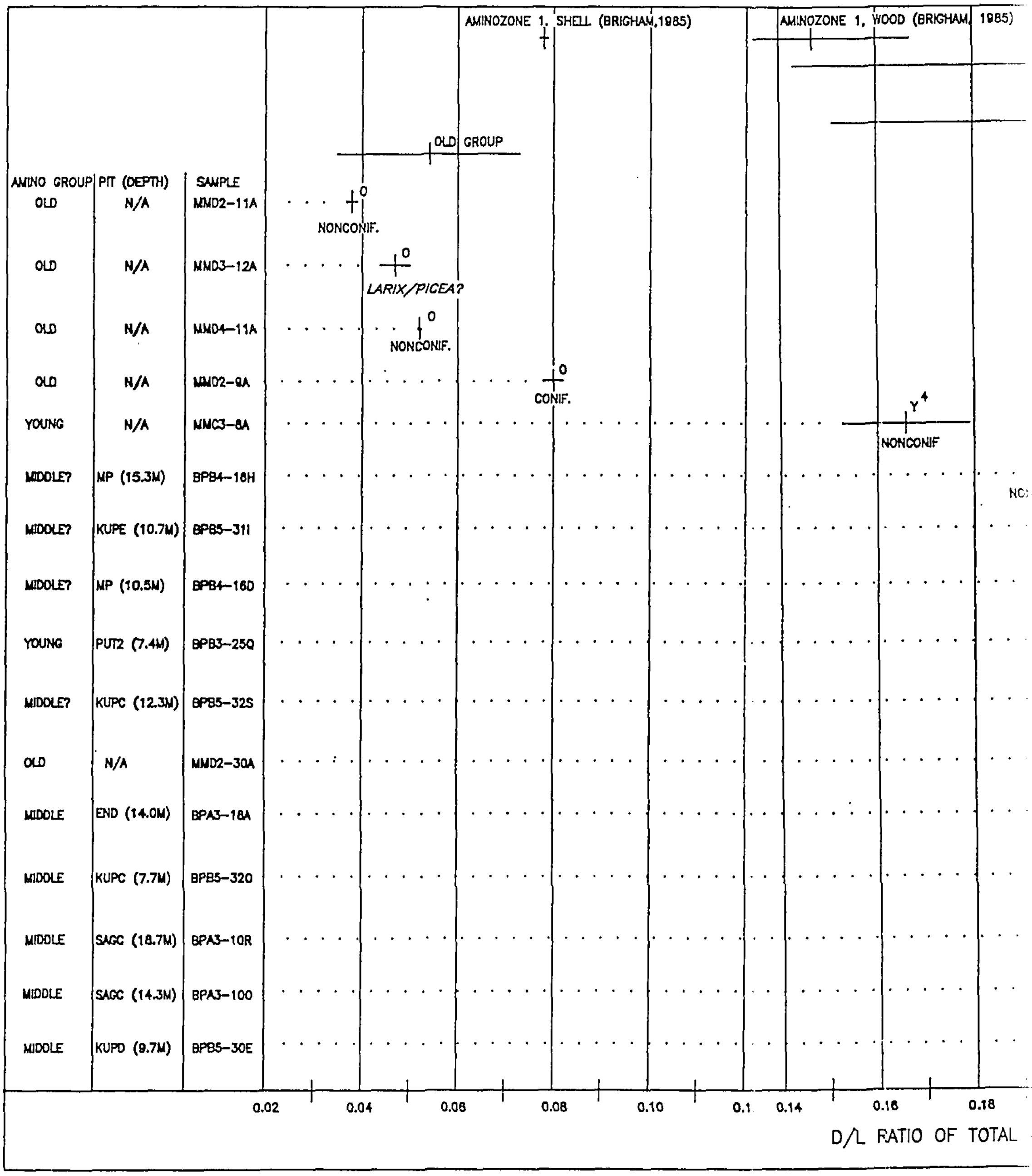
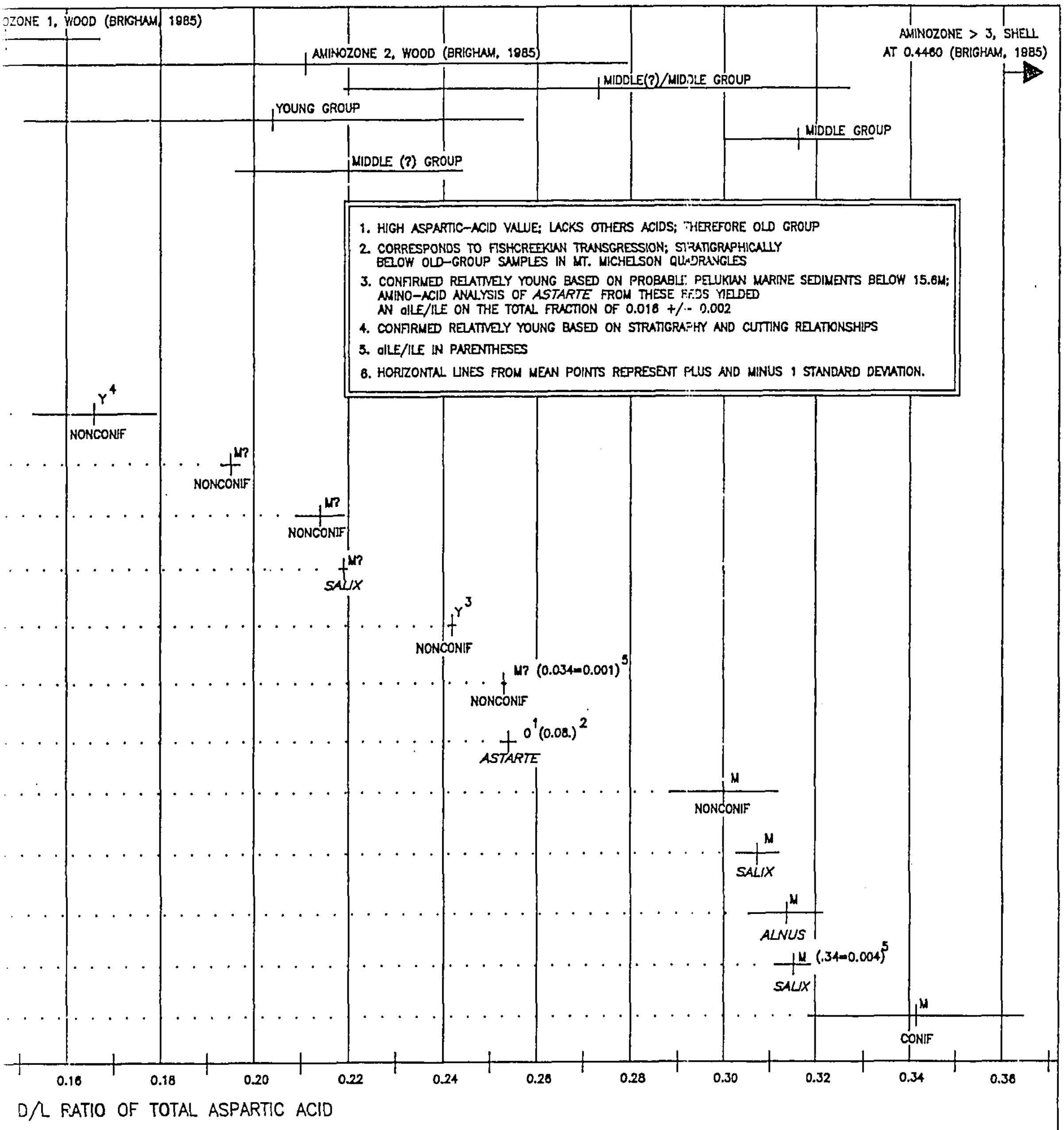


Figure 5.1 Plot of dextrorotary/levtory ratios for aspartic acid i ratios cited in Brigham (1985).ters on the top right of each M - middle; M? - queried middd O - old.



...tios for aspartic acid in wood and shells collected in this study, and of ... the top right of each point denote the assigned group: Y - young; ...ld.

are considered part of the middle group, the mean ratio becomes 0.2732 +/- 0.0535, showing significant overlap with the young group.

Information in figure 5.1 suggests that the old group should be abandoned, except perhaps in cases when other acids are absent. Absence of other acids may indicate a very old age; however, leaching of these acids is certainly a possible alternative. The middle and young groups are retained, albeit with caution, because the mean values are widely separated and one standard deviation is not excessively large. Even if the anomalous samples are considered, the mean ratio of the middle group is greater than that of the young group.

Brigham (1985) established temporal aminozones numbered 1 through 5 based on aIle/Ile ratios for mollusk shells from the Gubik Formation and estimated absolute ages for these aminozones of 125 ka, 475 ka, 1 to 1.4 Ma, >2.4 Ma, and >3.8 Ma, respectively. Correlation of the young and middle groups of this study with these aminozones can be approximated by aspartic-acid D/L ratios reported by Brigham (1985) for wood and shells from the Gubik Formation. Wood samples known to correspond to aminozone 1 yielded a mean D/L ratio of 0.1464 +/- 0.0200; shell samples that correspond to aminozone 1 yielded a mean ratio of 0.0785 +/- 0.0078; wood samples that correspond to aminozone 2 yielded a mean ratio of 0.2110 +/- 0.0686; and a shell sample that corresponds to aminozone 3 or an older aminozone yielded a mean ratio of 0.4460 (figure 5.1). Further, Rutter (1986) cited Sangamonian (aminozone 1) ratios to range between 0.13 and 0.16 and mid-Pleistocene ratios (aminozone 2) to range between 0.18 and 0.29; these ratios were determined for aspartic acid in wood from the Coastal Plain.

The mean ratio of the young group falls between the mean ratios that correspond to aminozones 1 and 2, suggesting an approximate minimum relative age of 125 ka for the young group (figure 5.1). The young group is probably slightly less than 125 ka old based on infinite radiocarbon dates and on an aIle/Ile ratio indicative of a Sangamonian age for shell material from a location stratigraphically below where a young-group sample was collected. The mean aspartic acid D/L ratios of the queried middle group and the middle group both exceed the ratio that corresponds to aminozone 2, suggesting that the assigned age of 475 ka for aminozone 2 could represent a minimum age for the middle group.

Sediment Distribution, Character, and Age

West of Colville River

With the exception of sediments of small modern streams and terrace deposits discussed as part of the Colville River, most fluvial sediments that crop out adjacent to the study area west of the Colville River belong to the Sagavanirktok Formation.

Colville River and Delta

The Colville River drains 60,000 km^2, 29 percent of the Coastal Plain, and has the largest delta, 600 km^2, of rivers within the study area (Wright and others, 1974; Walker, 1983) (sheet 1). Distributary channels from the Colville River first occur about 40 km upstream of its eastern mouth; the confluence of the Itkillik River and the Colville River is just south of this point. The former head of the Colville River Delta was about 5 km upstream of its present position as shown by abandoned flood plains of distributary channels. This shift in the position of the delta head and the lobate morphology of the delta front indicate that the delta is river-dominated and prograding.

The delta is morphologically similar to other river-dominated deltas around the world; the delta is dissimilar by being subject to arctic processes and the presence of seasonal sea ice and continuous underlying ice-rich permafrost. Arctic processes and underlying permafrost are responsible for many features on the delta and influence the nature of deposition and erosion on the delta, and the timing, volume, and character of river discharge (Naidu and Mowatt, 1975; Walker, 1983). Exposure of these ice-rich sediments to the sun, currents, and waves during summer months results more in melting than in mechanical removal; these bluffs tend to be dominated by ice-related, mass-wasting processes: ground-ice slumps and thermoerosional falls.

During the spring flood, up to 65 percent of the Colville River Delta may be inundated and with this comes considerable deposition of organic-rich, fine-grained sediment. Deposition of nearly 0.3 m of sediment in only a few weeks is not uncommon. Most of the sediment is deposited on point bars, in lake beds that are connected to a channel, and on the delta front (Walker, 1983). Sediments exposed in a deep cold-storage cellar at the Helmricks' homestead near the delta front are similar both in texture and structure to sediments exposed in a shallow test pit dug on the delta front. Alternating laminae of organic material, silt, and dominantly very fine sand typically show current-ripple structure. These sediments at the delta front are unvegetated, whereas at the Helmricks' about 1 m of peat and fine sand form a continuous cover.

Upstream from the delta front, channel bars and point bars are fine to medium sand and typically unvegetated; slightly elevated areas sometimes have a sparse vegetative cover. Gravel-sized clasts are rare on bars throughout the delta. The few exceptions are in locations where a channel has cut into probable Paleocene nonmarine deposits of the Sagavanirktok Formation. At these locations (e.g., approximately 100 m north of section HBA2-4, sheet 1), fine gravel and cobbles up to 30 cm in diameter are present on the channel shore. Gravel clasts at this locality include sandstone, conglomerate, schist, limestone, and gneiss.

Many stratigraphic sections measured on the Colville River Delta show alluvial sand overlain by eolian sand (figure 5.2, section HBB1-2). A lens of peat approximately 0.4 m below the contact of alluvial and eolian sand in section HBB1-2 is probably a remnant of vegetation that existed on this abandoned flood plain prior to deposition of eolian sand. This peat (sample HBB1-2A) yielded a radiocarbon date of 7.440 +/- 0.100 ka (BETA 23739), which is a minimum age for the alluvial sediments and a maximum age for the overlying eolian sediments.

Fibrous reddish-brown peat is a primary constituent of abandoned flood plains in the Colville River Delta. Many measured stratigraphic sections show almost exclusively peat, which may be overlain by eolian sand (figure 5.2, section HBB1-1), or interbedded peat and sand (figure 5.2, section HBB2-5). Sand interbedded with peat is typically fluvial in the bottom part of the section and eolian in the top part of the section. Distinction of these depositional modes is made based on a finer grain size, parallel laminae, and inclusion of fine organic material in the alluvial sand; the eolian sand is commonly cross-bedded.

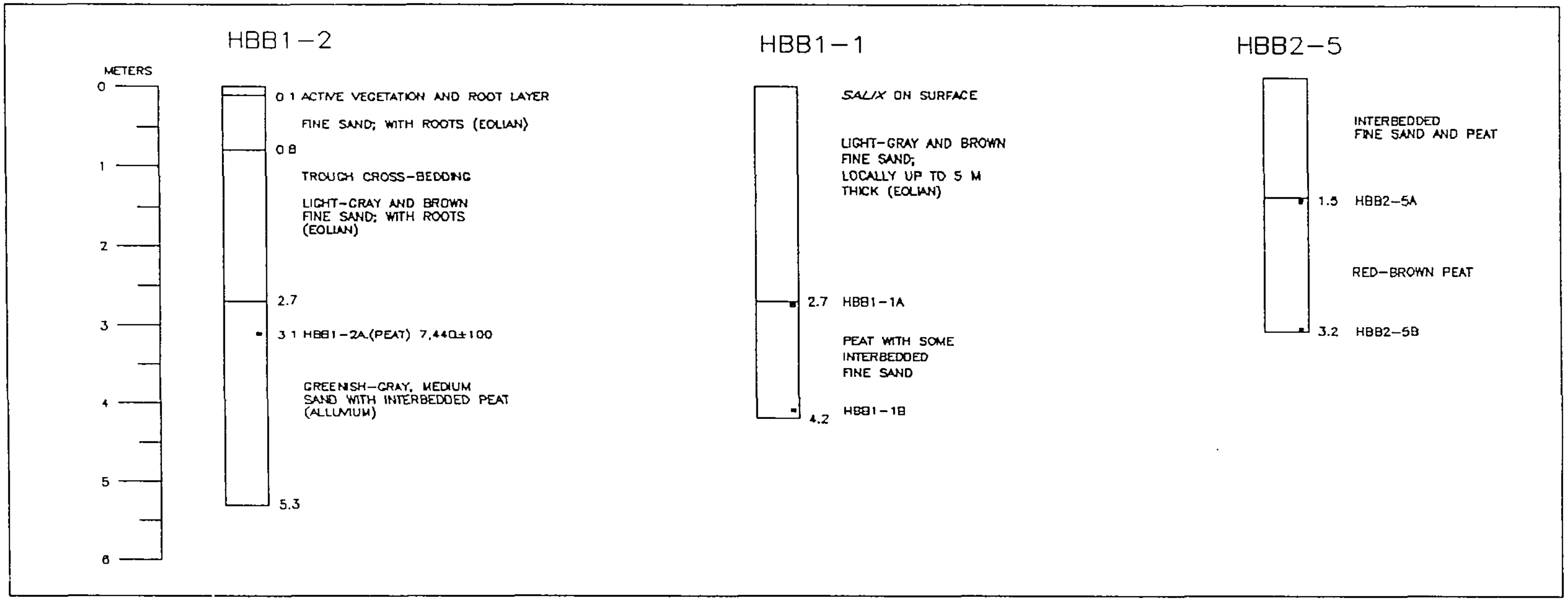


Figure 5.2 Stratigraphic sections HBB1-2, HBB1-1, HBB2-5 in the Colville River Delta, each showing a typical stratigraphic relationship. The small black squares represent samples; sample numbers are adjacent to the right (e.g., HBB1-2A). Locations of these sections are shown on sheet 1.

Radiocarbon ages of peat in the Colville River Delta suggest that all emergent sediments and features of the delta are Holocene.

Colville River Alluvial Terraces

Terraces D, E, and F on the east side of the Colville River Delta are composed of alluvial (deltaic) sediments presumably of the Colville River (figure 4.2 and sheet 1). This presumption is based on southwest to northeast trends of the terrace scarps, roughly parallel with the adjacent modern Colville River channel. The southeasternmost scarp of these terraces, that between Terraces C and D, terminates near the mouth of Kalubik Creek.

A probable remnant of Terrace D is present southwest of the Kachemach River, near where several of the terraces originate northeast of the Itkillik River. Terrace D is well defined northeast of the Kachemach River by scarps that separate it from Terrace C to the southeast and Terrace E to the northwest. The scarp separating Terraces D and E is traceable to near the mouth of Kalubik Creek, where it meets the mouth of the Colville River at Harrison Bay. Elevations on Terrace D vary between approximately 18 and 2 m, and the width increases from about 2 km near Kachemach River to about 4 km at Kalubik Creek.

Terraces D and E coincide roughly with the northeast half of Terrace III defined by Carter and Galloway (1982) and with Quaternary alluvium and marine sediments east of the Colville River mapped by Carter and Galloway (1985a). Terrace F coincides with the southwest half of Terrace III and with Quaternary alluvium mapped by Carter and Galloway (1985a). The boundary between Terraces E and F is marked by a well-defined scarp that trends southeast to northwest across Terrace III from the approximate downstream point where the Kachemach River leaves Terrace D to the main channel of the Colville River (figure 4.2). Elevations on both Terraces E and F vary approximately between 15 and 2 m; although elevations are slightly more uniform and lower on Terrace F.

Stratigraphic sections along the Miluveach River on Terrace D show dominantly pebbly sand with interbeds of fine gravel; shell fragments are also present (figure 5.3, sections HBB1-13 and HBB1-14). However, sediments in these sections are interpreted to be fluvial or deltaic based on the presence of reworked sediments and organic-rich beds, some with detrital wood. Coal fragments in beds of sand in these sections are almost certainly derived from the Sagavanirktok Formation. Sections on Terrace E include interbeds of peat and are similar to sections in the Colville River Delta (figure 5.3, sections HBB1-4 and HBB1-7). A section on the Kachemach River on Terrace F (figure 5.3, section HBB2-13) is primarily gravelly sand; shell fragments are absent, but organic-rich beds with detrital wood are present.

Carter and Galloway (1982) reported *Picea*, *Alnus*, and *Populus* wood from various sites on Terrace III, all of which yielded radiocarbon dates greater than 48 ka. These investigators indicated that these genera suggest deposition of the terrace during an interglacial or relatively warm interstadial, and proposed the Sangamonian, but did not rule out one or more interstadials during Illinoian or early Wisconsinan time.

Terrace III (Terraces D, E, and F of this study) of Carter and Galloway (1982) has a counterpart on the west side of the Colville River Delta. The western counterpart is apparently a single terrace tread. On the basis of sediment types reported by Carter and

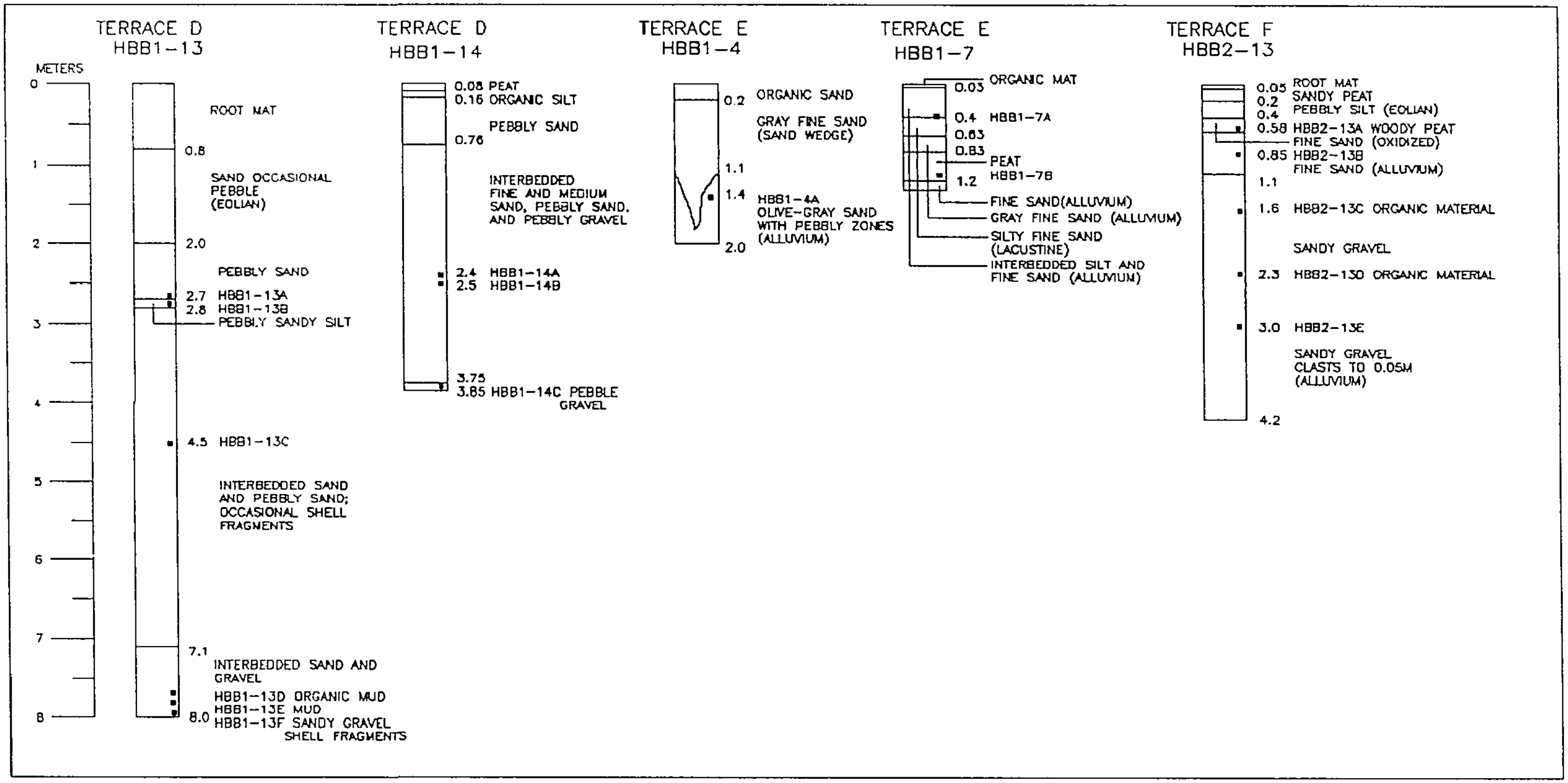


Figure 5.3 Stratigraphic sections HBB1-13 and HBB1-14 measured along the Kachemach and Miluveach Rivers on Terrace D; sections HBB1-4 and HBB1-7 on Terrace E; and section HBB2-13 on Terrace F. The small black squares represent samples; sample numbers are adjacent to the right (e.g., HBB1-13A). The downward-tapering form shown in section HBB1-4 represents a sand wedge. Locations of these sections are shown on figure 4.2 and sheet 1.

Galloway (1985a), Terraces D and E may correspond to the northwestern part of the western counterpart and Terrace F may correspond to the southern and northeastern parts of the western counterpart. However, Terraces D and E are most like the western scarp in terms of elevation, but the differences in elevation are slight and may not be significant.

According to Carter and Galloway (1985a), Terraces D and E and the northwestern part of the western counterpart consist of alluvium overlying marine sediments, and Terrace F and the southern and northeastern parts of the western counterpart consist only of alluvium. However, mapping for this study provided no unequivocal evidence of marine sediments in Terraces D and E, and no exposures of marine sediments are known on the western counterpart within the study area. The presence of marine sediments presumably was inferred from such sediments west of the Ublitok River.

A remnant of a terrace older than Terrace D/E/F, but younger than A or B, is present at the south end of the western counterpart of Terrace D/E/F. Stratigraphic section HBA2-2 (figure 5.4) is representative of this terrace and shows a 0.5 m veneer of fine sand, probably eolian, overlying 1.5 m of sandy gravel, which in turn overlies 2 m of interbedded gravelly sand and sandy gravel. Wood (sample HBA2-2A) collected 0.3 m below the contact of the sandy gravel and the interbedded sand and gravel is most probably *Larix*[5], but may be *Picea*, and yielded a radiocarbon date of >40.730 ka (BETA 23741). The presence of *Larix* wood in this section may indicate that the terrace remnant is Fishcreekian,

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[5]Wood taxa collected in this study were identified by personnel of the U.S. Department of Agriculture, Forest Products Laboratory, Center for Wood Anatomy Research in Madison, Wisconsin; determinations of coniferous and nonconiferous wood were made by personnel of the Alaska Division of Geological and Geophysical Surveys using procedures and literature supplied by the Center.

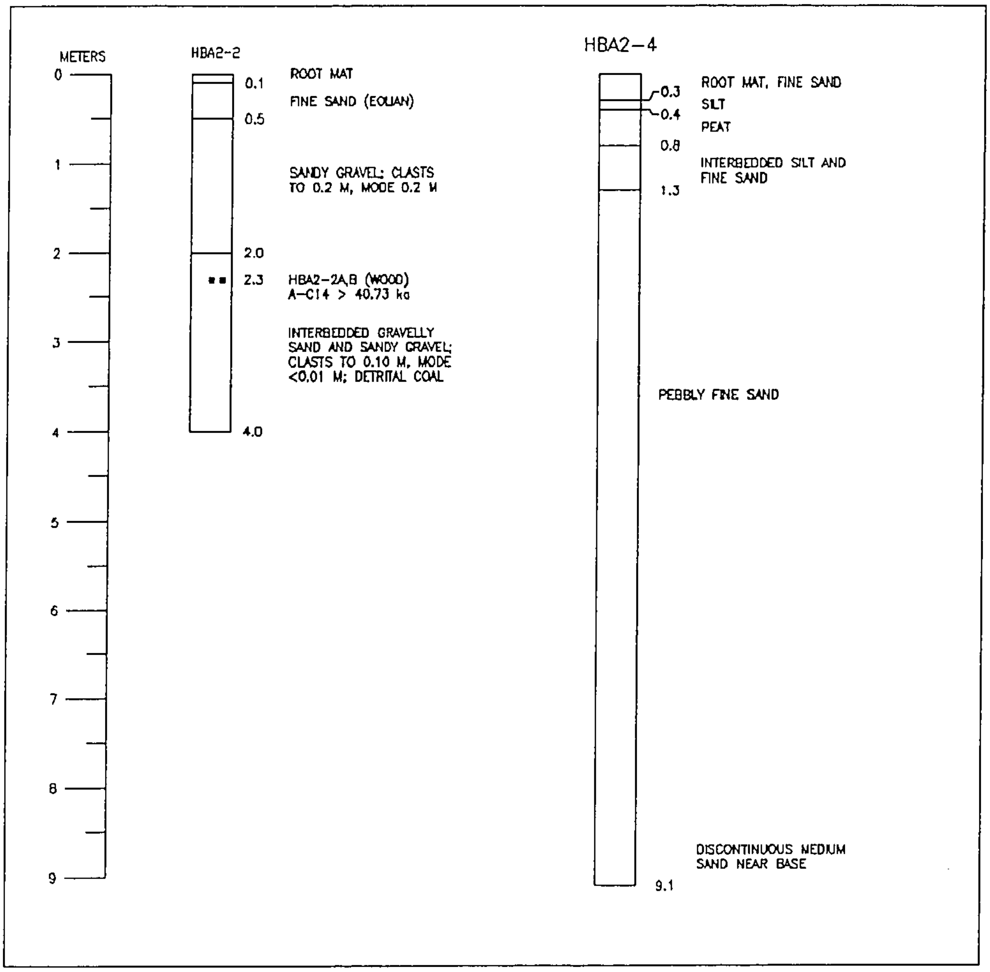


Figure 5.4 Stratigraphic sections HBA2-2 and HBA2-4 measured west of the Colville River. The small black squares represent samples; sample numbers are adjacent to the right (e.g., HBA2-2A). C14 denotes radiocarbon date. Locations of these sections are shown on figure 4.2 and sheet 1.

because sediments of this age contain much *Larix* pollen and wood. If so, the terrace remnant probably corresponds to Terrace C on the east side of the Colville River.

Stratigraphic sections representative of the western counterpart of Terraces D, E, and perhaps F collectively, are HBA2-4 and HBB2-1 (figures 5.4 and 5.5). Section HBA2-4 is on the west bank of Nechelik Channel, 2.5 km directly northwest of Nuiqsut (sheet 1). The top 1.3 m of the section consists of eolian and probable lacustrine sand and silt, with peat; the remainder of the section, to 9 m below the terrace surface, is alluvium consisting of pebbly fine sand. This pebbly sand yielded no datable material. Sediments here presumably overlie unnamed Paleocene or Eocene sediments of the Sagavanirktok Formation. About 100 m downstream from section HBA2-4, fine gravel and cobbles up to 0.3 m in diameter of exotic lithologies typical of that unit crop out near river level.

Section HBB2-1 is 8.8 km directly northwest of HBA2-4, adjacent to a side channel of Nechelik Channel (sheet 1). The section exposes an 8-m-wide sand wedge that tapers downward into alluvial sand of the terrace (figure 5.5). The unusually large width of this sand wedge compared with a maximum width of 3 m reported by Carter (1983c) for sand wedges west of the Colville River suggests that it may be a composite ice and sand wedge. The sand wedge is split by two ice-wedge pseudomorphs that have been filled with organic-rich lacustrine sediments. Detrital *Salix* (sample HBB2-1G) collected 0.2 m below the top of the terrace alluvium yielded a radiocarbon date of 29.100 +/- 0.860 ka (BETA 23743). This date represents a maximum limiting age for cessation of alluviation on the terrace and for the start of development of the sand wedge. Organic silt (sample HBB2-1E) collected from within one of the ice-wedge pseudomorphs yielded a radiocarbon date of 9.400 +/- 0.110 ka (BETA 23742). This date represents a minimum age for the sand wedge and

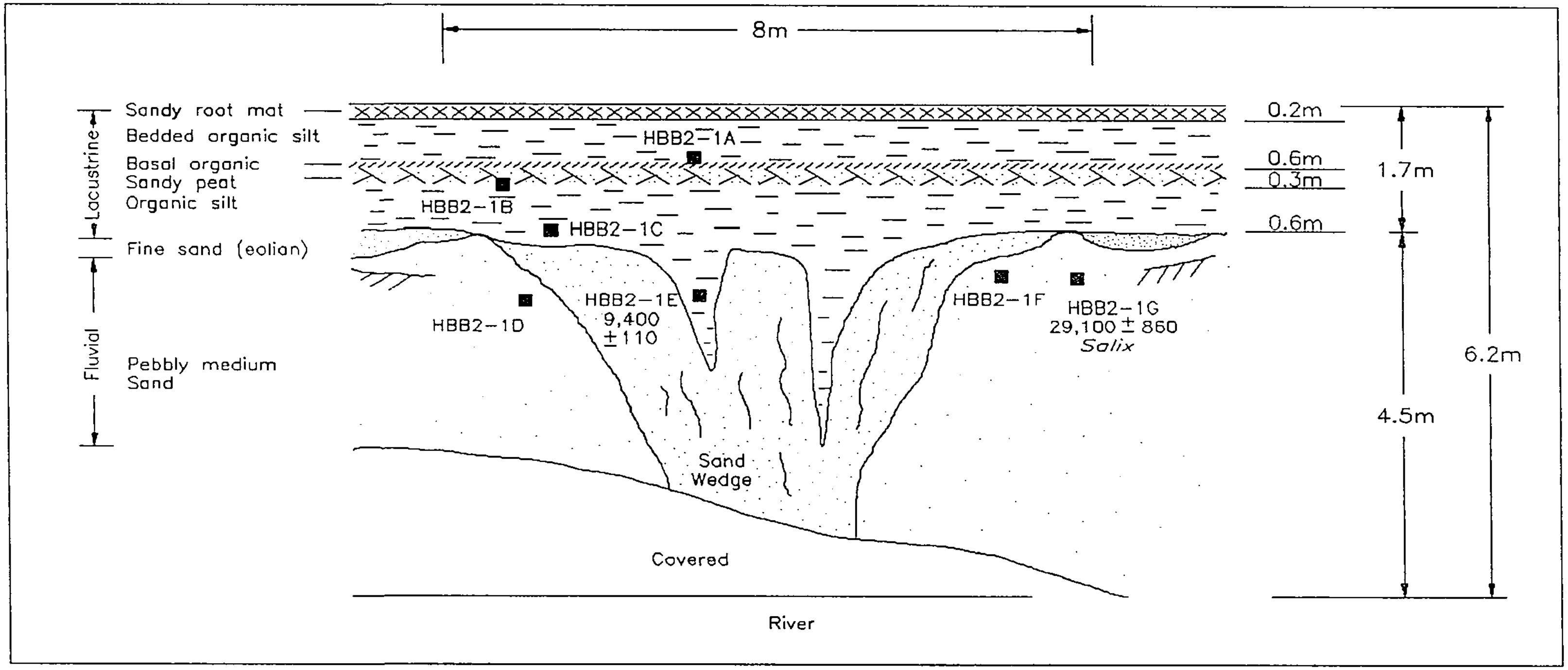


Figure 5.5 Stratigraphic section HBB2-1 measured on Terrace D/E/F west of the Colville River Delta showing alluvium, a sand wedge, and lacustrine sediments. The small black squares represent samples; sample numbers are adjacent to the squares (e.g., HBB2-1B). All dates are radiocarbon. The location of this section is shown in figure 4.2 and on sheet 1.

an approximate maximum age for the thaw lake.

Kalubik Creek to Kuparuk River West Terrace

Kalubik Creek approximately marks the boundary between sediments of Colville River Terraces A through C and dominantly old fluvial sediments that extend eastward to a well-defined, alluvial-terrace scarp 2 to 5 km west of the Kuparuk River (figure 5.6 and sheet 2). The boundary is uncertain because of overlying eolian and lacustrine sediments and poor exposure. Deep exposure of the old fluvial sediments is provided in five gravel pits designated KUP C, D, E, and F, and MP. KUP C, D, and F are inland, whereas KUP E and MP are within several kilometers of the Beaufort Sea coast (figure 5.6 and sheet 2). Stratigraphic sections were measured in each of these pits and samples were collected for various analyses.

KUP C Gravel Pit. KUP C pit is along the Ugnuravik River about 21 km from the coast. The elevation of the Coastal Plain at the pit is 18 m above sea level and the pit was excavated to 15 m below the surface. The general stratigraphy exposed in KUP C (section BPB5-32) is given in figure 5.7.

Section BPB5-32 is the type section for the informally designated Ugnuravik sand (eolian sediments) and Ugnuravik gravel (fluvial or glaciofluvial sediments, or both) defined by Rawlinson (1986a). Sangamonian and Illinoian ages originally assigned to the Ugnuravik gravel are now considered to be minimum ages based on further field and laboratory studies, and on recent studies that suggest the thermoluminescence dating technique tends to underestimate actual ages, especially in samples greater than 100 ka (Wintle, 1987; Lu

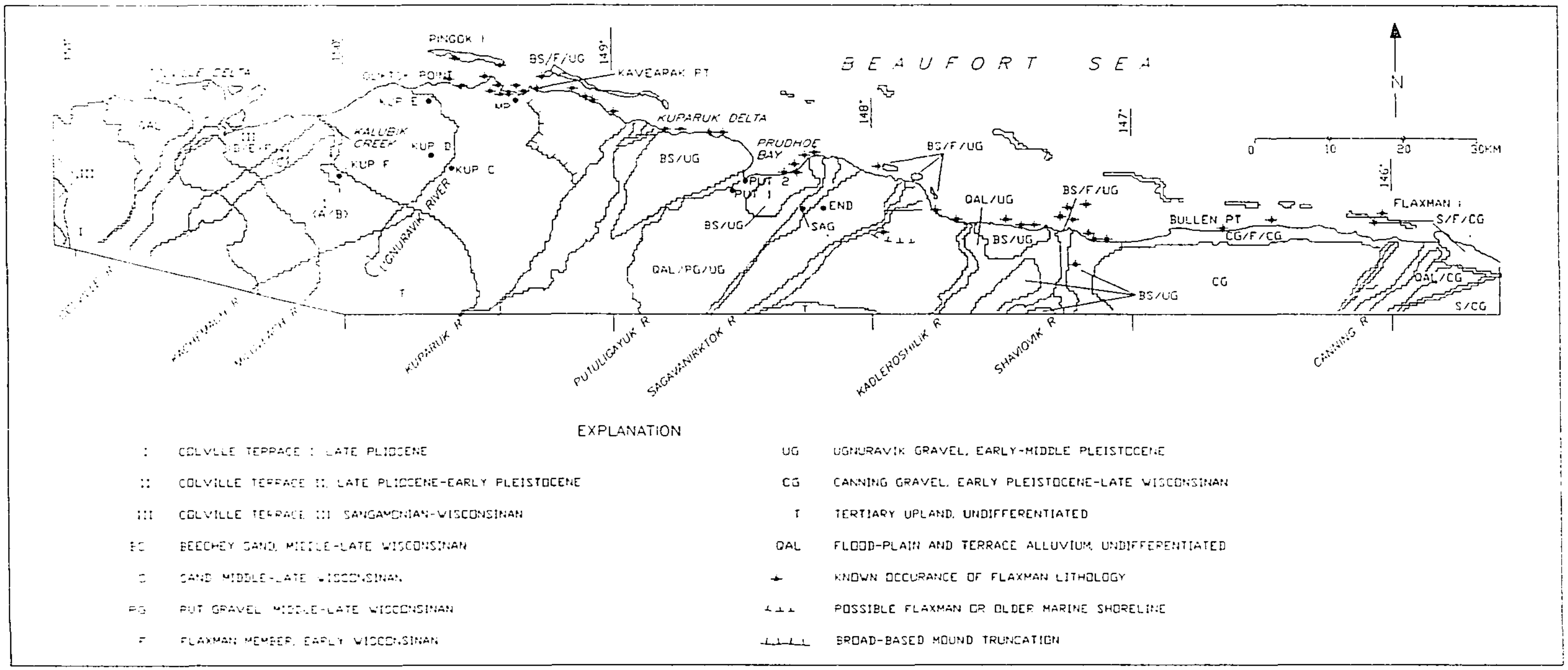


Figure 5.6 Map of the Coastal Plain between the Colville and Canning Rivers, showing proposed lithologic-unit and other boundaries and locations of gravel pits.

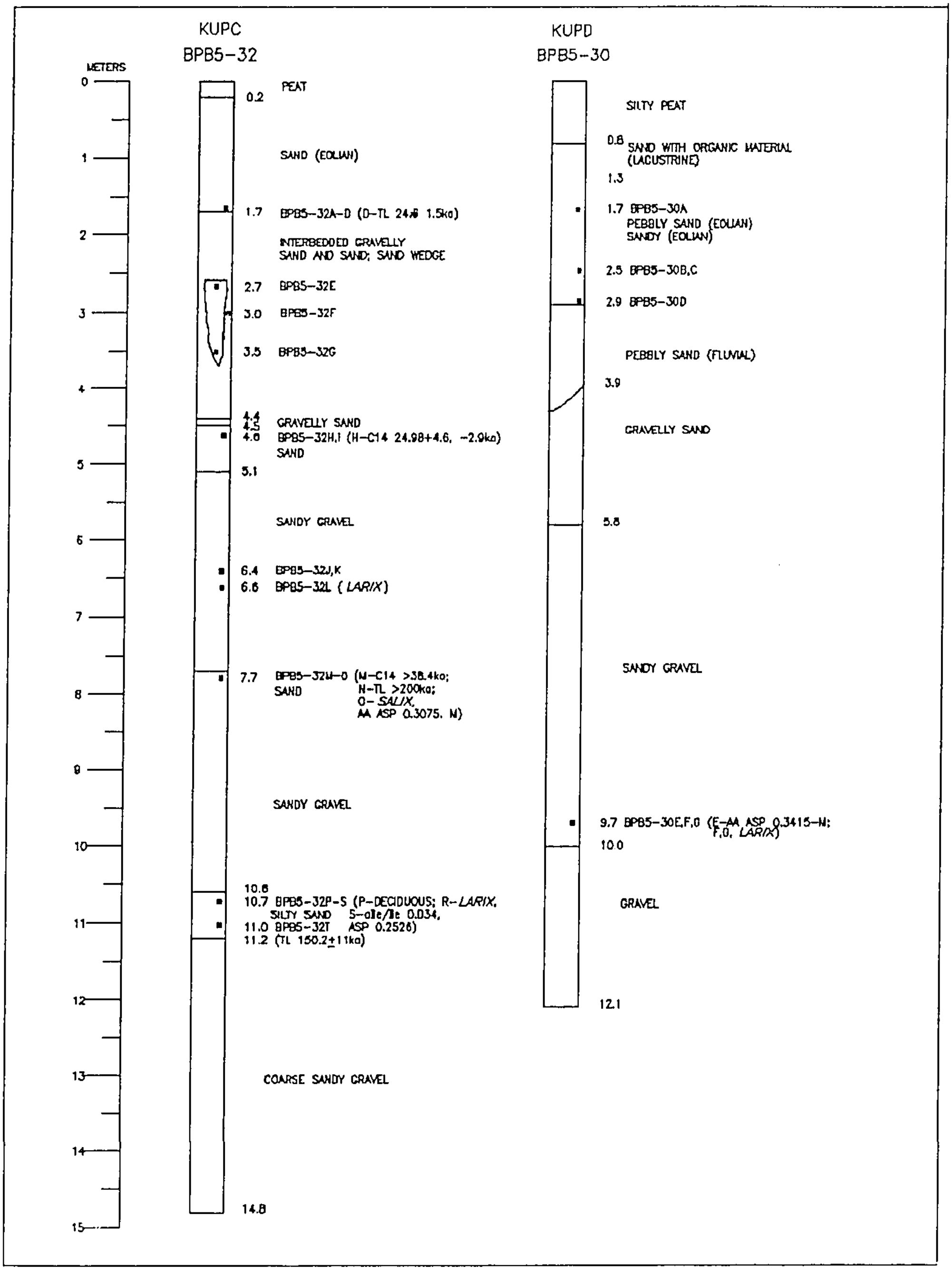


Figure 5.7 Stratigraphic section BPB5-32 measured in the KUP C gravel pit and section BPB5-30 measured in the KUP D gravel pit. Section BPB5-32 is the type section of the Beechey sand (formerly Ugnuravik sand) and the Ugnuravik gravel. The small black squares represent samples; sample numbers are adjacent to the right (e.g., BPB5-32A). The downward-tapering form shown in section BPB5-32 represents a sand wedge. C14 denotes radiocarbon; TL denotes thermoluminescence; and AA denotes amino acid; letter after AA ratio indicates the assigned age group. Locations of these gravel pits and sections are shown in figure 5.6 and on sheet 2.

and others, 1988; Rendell and Townsend, 1988; Wintle and Packman, 1988; Berger, 1989). The original age assignments were based on apparently finite thermoluminescence ages. The overlying Ugnuravik sand is herein changed to the Beechey sand to avoid confusion with the gravel unit.

A sand wedge is present at the top of the interbedded pebbly sand and sandy gravel unit in section BPB5-32. The underlying sandy-gravel unit contains thin ice wedges, ice-wedge pseudomorphs, and thin, discontinuous silty-sand and fine-sand beds. These thin beds typically fill cut-and-fill structures and mark changes of modal and maximum grain sizes. Abundant detrital wood is associated with these fine-grained beds. Two wood samples, BPB5-32L and BPB5-32R, collected 6.6 m and 12.3 m, respectively, below the ground surface are *Larix*. Two other wood samples, BPB5-32P and BPB5-32Q, both collected 12.3 m below the ground surface, are nonconiferous, probably *Salix*. The Beechey sand and the sandy gravel below 12.4 m deep are not oxidized; the interbedded pebbly sand and sandy gravel is oxidized, and the sandy gravel above 12.4 m deep has both oxidized and unoxidized zones.

Wood (sample BPB5-32M) collected 8.8 m below the ground surface yielded a radiocarbon date of >38.4 ka (GX 10657); sediment (sample BPB5-32N) collected from the same bed yielded a thermoluminescence date of >200 ka (ALPHA 2599). Thermoluminescence analysis of sediment (sample BPB5-32T) collected 12.4 m below the ground surface, yielded a date of 150.2 +/- 0.011 ka (ALPHA 1528). Although apparently finite, this date is not in stratigraphic sequence with the infinite date on sample BPB5-32N and is beyond the reliable limit of thermoluminescence dating. Thus, it is also considered a minimum age. Sample BPB5-32D was collected at the base of the eolian sand in section

BPB5-32 for thermoluminescence analysis to provide a maximum age for the sand; results of this analysis are discussed in Chapter 7.

Amino-acid analysis of *Salix* wood (samples BPB5-32O and BPB5-32S) collected respectively from 8.8 m and 12.3 m below the ground surface yielded respective aspartic-acid D/L ratios of 0.3075 +/- 0.0045 (UA 1769) and 0.2526 +/- 0.0004 (UA 1770); sample BPB5-32S also yielded an aIle/Ile ratio of 0.034 +/- 0.004 (AAL 4643), which is identical to the aIle/Ile ratio determined for *Salix* wood (sample BPA3-10O) from 14.3 m below the ground surface in the SAG C gravel pit to the east. Sample BPB5-32S was questionably assigned to the middle group, with the caveat that the 0.2526 aspartic-acid D/L ratio was low (suggesting a younger age). However, based on stratigraphic position this and other gravel-pit samples with unexpectedly low aspartic-acid D/L ratios (mean 0.2202 +/- 0.0239) belong in the middle group.

KUP D Gravel Pit. KUP D pit is about 3 km northwest of KUP C at an elevation of 15 m (sheet 2). The pit reportedly reached a depth of 19 m (4 m below sea level), but a section could only be measured to 12 m because of flooding (figure 5.7, section BPB5-30). An occurrence of shells at the bottom of the pit, as reported by oil-field workers, remains unsubstantiated because of the lake in the pit. Similar to KUP C, the bottom two units are oxidized above the organic-rich, silty-sand and fine-sand bed 12.4 m below the surface (figure 5.7).

Wood (samples BPB5-30F and BPB5-30G) from 9.7 m below the ground surface in KUP D is *Larix*; wood (sample BPB5-30E) from the same level is coniferous and probably also *Larix*. Amino-acid analysis of sample BPB5-30E shows that the aspartic-acid D/L ratio is 0.3415 +/- 0.0230 (UA 1767), putting this sample in the middle group.

KUP E Gravel Pit. KUP E pit is actually two adjacent pits along the Ugnuravik River about 5 km inland from the Beaufort Sea coast (figure 5.6). The elevation of the ground surface at the easternmost of the two pits is 6 m, and the pit is excavated 14 m deep. The general stratigraphy exposed in KUP E is given in figure 5.8, section BPB5-31. Similar to the KUP C and D pits, the interbedded pebbly sand and sandy gravel unit is oxidized and sand-filled, ice-wedge pseudomorphs are present near the middle of the unit. The underlying interbedded sandy-gravel and gravel unit contains sand wedges.

The top of section BPB5-31 is partially covered with colluvium emplaced during excavation of the pit. Sand and pebbly silty sand (appendix E, samples BPB5-31B and BPB5-31D, respectively; sample BPB5-31D termed pebbly silt prior to analysis; pre-analysis term used in figure 5.8) between 2.0 and 2.9 m below the surface were initially thought to be coarse variations of Flaxman mud because their colluvium obscures the lateral extent. The texture, color, proximity to the coast, and 3.8-m elevation supported this concept. However, thermoluminescence analysis of sample BPB5-31F from the pebbly silty-sand bed yielded a thermoluminescence date of 11.9 +/- 1.8 ka (ALPHA 1493), which if correct, precludes the sediment from being emplaced by the Simpsonian transgression. Subsequent excavation confirmed that the bed is not laterally extensive and it is now considered to be eolian. The underlying sand, most of which is covered, may also be eolian but is considered to be fluvial based on stratigraphic position.

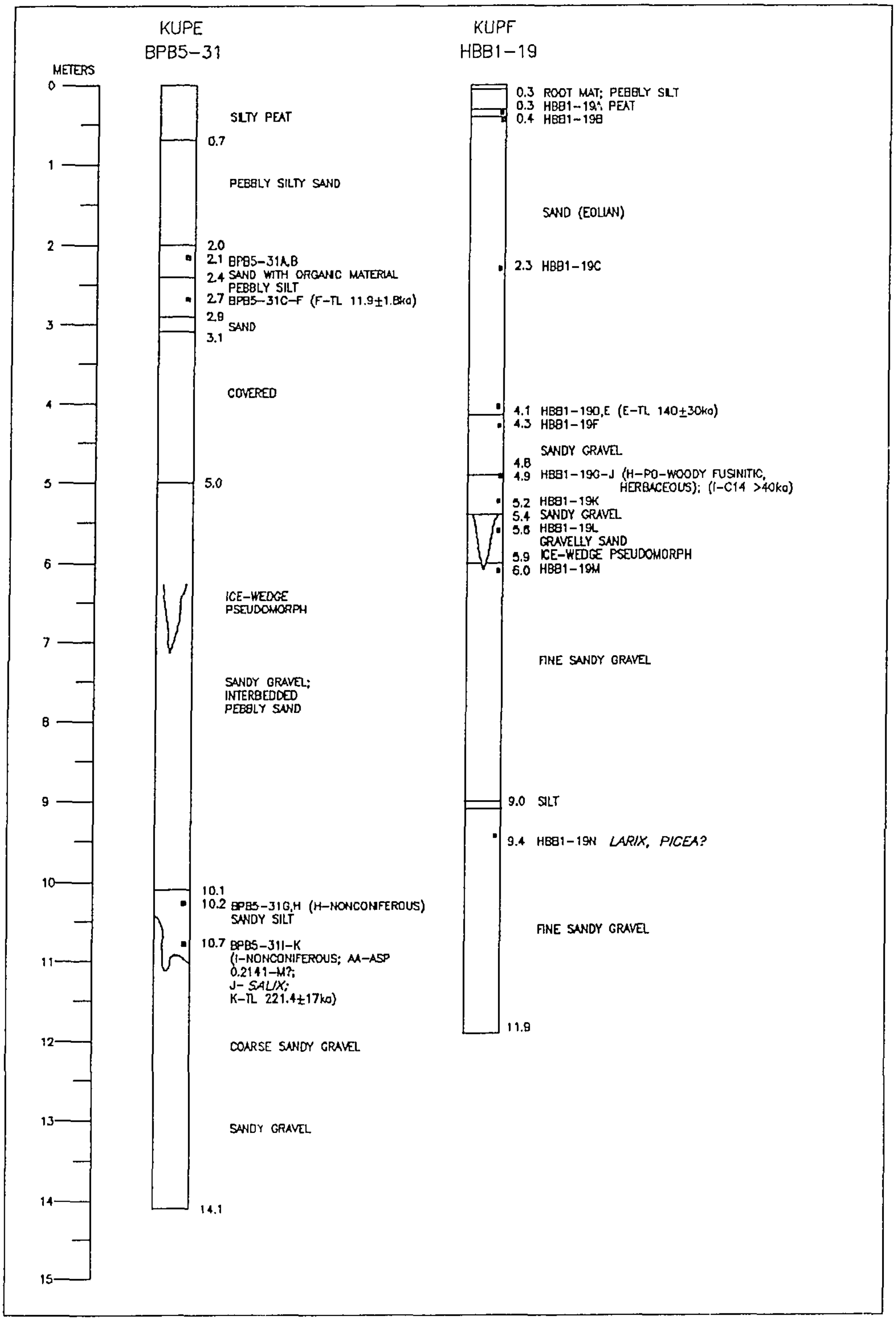


Figure 5.8 Stratigraphic section BPB5-31 measured in the KUP E gravel pit and section HBB1-19 measured in the KUP F gravel pit. Black squares represent samples; sample numbers are adjacent to the right (e.g., BPB5-31A). Locations of the gravel pits and sections are shown in figure 5.6; and on sheets 2 and 1, respectively.

A wood-rich, silty-sand bed similar to those in other KUP pits is also present in section BPB5-31; it fills cut-and-fill structures and an ice-wedge pseudomorph 10.2 m below the ground surface.

Thermoluminescence analysis of sediment (sample BPB5-31K) from this bed yielded a date of 221.4 +/- 17 ka (ALPHA 1529). Even though the date is apparently finite, it is considered a minimum for reasons previously discussed. Wood (sample BPB5-31H) collected 10.2 m below the surface and wood (sample BPB5-31I) collected at 10.5 m are both nonconiferous, probably *Salix*. Wood (sample BPB5-31J), also collected at 10.5 m, is definitely *Salix*. Rawlinson (1986a) incorrectly reported the presence of *Larix* in this bed. Amino-acid analysis of sample BPB5-31I yielded an aspartic-acid D/L ratio of 0.2141 +/- 0.0052, which places it in the young group. However, the sample was assigned to the middle group based on similarity of these sediments with those exposed in other gravel pits in the Kuparuk area; perhaps the sample has been subjected to bacterial attack or other modification.

KUP F Gravel Pit. KUP F pit is located west of the east fork of Kalubik Creek, approximately 11 km inland from Harrison Bay (figure 5.6). The elevation of the ground surface at pit KUP F is 21 m and the pit is excavated approximately 14 m deep. A lake fills the deepest part of the pit so that the exposed stratigraphic section is 12 m high (figure 5.8, section HBB1-19). Section HBB1-19 provides a view of the Coastal Plain approximately at the proposed boundary between the Colville River marine and alluvial terraces and alluvial-plain sediments to the northeast. The section consists entirely of nonmarine sediments and is most like sections exposed in the other KUP gravel pits, suggesting that the location of the approximate boundary is correct.

The 3.8-m-thick sand near the top of section HBB1-19 is uniform throughout except for occasional zones of pebbles and alternating zones of oxidation and nonoxidation. Eolian sediments near the top of other KUP gravel pits are typically about half this thickness; therefore, this unit may in part be fluvial or glaciofluvial. Thermoluminescence analysis of sand (sample HBB1-19E) from the base of the unit, 4.1 m below the surface, yielded a date of 140 +/- 30 ka (ALPHA 2600). If this is considered a minimum age, it is consistent with at least part of the sand being fluvial or glaciofluvial. Prior to obtaining the thermoluminescence date on sample HBB1-19E, wood (sample HBB1-19I) from 4.9 m below the surface yielded a radiocarbon date of >40 ka. This date supports the minimum thermoluminescence date on sample HBB1-19E and the concept of at least part of the "eolian" sand being fluvial or glaciofluvial. Data suggest that eolian sediments near the top of sections exposed in the other gravel pits are Wisconsinan.

Pollen analysis of sediment (sample HBB1-19H), also from 4.9 m, revealed a mixture of woody fusinitic and herbaceous materials, and only rare occurrences of undifferentiated bisaccates. Reworking of Tertiary and perhaps older sediments likely contributed the woody fusinitic material and herbaceous tundra probably contributed the herbaceous material. Consistent with most of the other gravel pits, ice-wedge pseudomorphs, alternating zones of oxidation and nonoxidation, and large woody material are present in the deeper exposed gravelly sediments of section HBB1-19. Sample HBB1-19N, from 9.3 m below the surface, is a 0.1-m-diameter log of *Larix* or possibly *Picea*.

MP Gravel Pit. The MP pit is 3.8 km inland from the Beaufort Sea coast west of an unnamed stream that empties into the Beaufort Sea as an estuary west of Kavearak Point (figure 5.6). The Coastal Plain surface there is 5 m above sea level and the pit was excavated approximately 18 m deep. Walls of the MP pit are exceptionally steep and as in most of the other gravel pits, a lake occupies the deepest part. Stratigraphic section BPB4-16 (figure 5.9) is a composite of two sections. Most of the section was measured near the southwest corner of the pit but the basal 2 m were measured near the northeast corner. Samples BPB4-16H and BPB4-16I were also collected from the northeast corner of the pit. Sand near the top of the section may be fluvial overbank sediments; however, an eolian interpretation is more likely based on the presence of similar sediments near the tops of all other gravel pit sections. All sediments below 0.7 m are interpreted to be fluvial or glaciofluvial based on sediment textures and structures.

Section BPB4-16 includes discrete beds of sandy gravel and organic silt between the eolian sand and the underlying interbedded sand and gravelly sand. The organic silt (sample BPB4-16B) yielded a radiocarbon date of >44 ka, which is a minimum age for the underlying interbedded sand and gravelly sand or sandy gravel. Wood collected from the sand and sandy gravel beds between 10.3 and 16.3 m below the surface is all nonconiferous, some of which (samples BPB4-16D and BPB4-16F) have been determined to be *Salix*. Amino-acid analysis of samples BPB4-16D and BPB4-16H, respectively from 10.3 m and 15.1 m below the ground surface, yielded respective aspartic-acid D/L ratios of 0.2189 +/- 0.0008 and 0.1952 +/- 0.0021. These ratios place both samples in the young group. However, the samples were assigned to the middle group based on similarity of these sediments with sediments exposed in other gravel pits in the Kuparuk area; perhaps these samples have been subjected to bacterial attack or other modification.

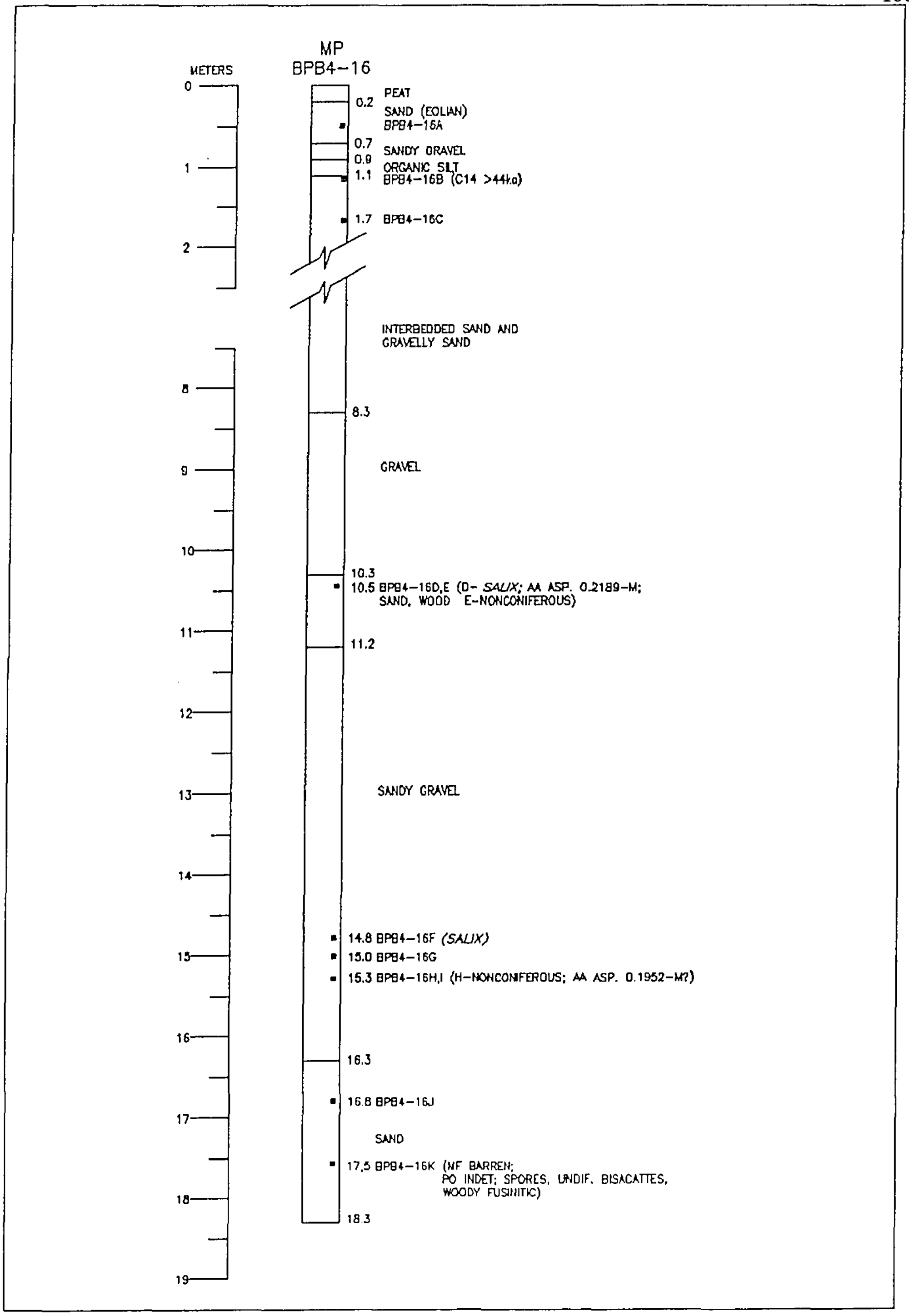


Figure 5.9 Stratigraphic section BPB4-16 measured in the MP gravel pit. The small black squares represent samples; sample numbers are adjacent to the right (e.g., BPB4-16A). PO denotes pollen; MF denotes microfossil; C14 denotes radiocarbon; and AA denotes amino acid; letter after AA ratio indicates the assigned age group. The location of this section is shown in figure 5.6 and on sheet 2.

A distinct change in the color, from gray to oxidized yellowish brown, and texture, from sandy gravel to medium sand, of sediments below 16.3 m in the stratigraphic section prompted microfossil and pollen analyses on sample BPB4-16K, one of two samples collected from this unit. Sample BPB4-16K was barren of microfossils but included black woody fusinitic and amorphous materials and undifferentiated bisaccates and indeterminate spore fragments. The fusinitic material is probably coal reworked from Tertiary coal-bearing sediments of the Sagavanirktok Formation.

Kuparuk River West Terrace to Sagavanirktok River East Shore

The Coastal Plain between a 2- to 5-km-wide alluvial terrace immediately west of the Kuparuk River and the Sagavanirktok east shore generally includes thicker sections of younger sediments, chiefly alluvium and outwash, compared with adjacent areas to the west and east. Three areas between the Kuparuk River and the east shore of the Sagavanirktok River that do not fit this generalization of younger sediments were mapped by Rawlinson (1986a); however, one of these areas, between the west and east channels of the Sagavanirktok River, is now interpreted to be Holocene (figure 5.6). The remaining two large areas of older sediments are near the coast and were discussed in Chapter 4 as being associated with Simpsonian marine sediments west of the Putuligayuk River and at Heald Point.

Inland between the Kuparuk and Sagavanirktok River, younger alluvial sediments are separated by small isolated areas of older sediments capped by Holocene sediments similar to areas near the coast and the area west of the Kuparuk River.

Walker and Acevedo (1987) mapped most of the area between the Kuparuk west terrace and the east shore of the Sagavanirktok River as flat thaw-lake plain and indicated only one broad-based mound. This mound, and vegetation similarities with the rolling thaw-lake plain west of the Kuparuk River, are presumed to be the basis for designating areas on either side of the Kuparuk River Delta as rolling thaw-lake plain. However, based on morphology, this assignment seems incorrect; and the author considers the area east of the Kuparuk River Delta (and west, as will be explained later) to be flat thaw-lake plain.

Deep exposure of the Coastal Plain between the Kuparuk and Sagavanirktok Rivers is provided in two gravel pits along the Putuligayuk River and two gravel pits along the Sagavanirktok River. Another gravel pit along the Putuligayuk River has since been converted to a sanitary landfill. The two accessible pits along the Putuligayuk River from south to north are designated PUT 1 and PUT 2; and the two pits on the Sagavanirktok River are designated SAG C and END (figure 5.6).

Kuparuk River West Terrace. The alluvial terrace west of the Kuparuk River truncates rolling thaw-lake plains at a well-defined scarp. Thaw lakes have obscured the terrace scarp north of where it meets the line of truncation of broad-based mounds and the terrace tread cannot be distinguished from flat thaw-lake plains adjacent to the west. Rather than turning to the east as postulated by Walker and Acevedo (1987), the terrace is interpreted to continue its trend to the present coast (figure 5.6 and sheet 3).

Stratigraphic sections measured in the more upstream positions on the terrace west of the Kuparuk River (e.g., sheet 2, sections BPA4-6 and BPA4-10) typically show from top to bottom about 0.5 m each of organic silt or peat and overbank sand, both overlying sandy gravel. In downstream positions on the terrace (e.g., section BPB4-31), sand dominates the section but interbeds of silt and pebbly sand are also present. The terrace tread is typically 3 to 6 m high above the adjacent Kuparuk River flood plain.

Samples of peat collected from on top or near the top of the gravel in two different stratigraphic sections yielded radiocarbon dates that approximately represent the end of active flood-plain deposition. Peat (sample BPA4-6A) collected 0.6 m below the terrace surface between underlying overbank sand and overlying flood-basin pebbly silt yielded a radiocarbon date of 5.120 +/- 0.235 ka (GX 10660). Peat (sample BPA4-10A) collected from within a 0.5- to 0.8-m-thick bed of sandy gravel about 2.0 m below the surface yielded a radiocarbon date of 4.320 +/- 0.100 ka (BETA 23740). Gravel of this bed filled cut-and-fill structure in the underlying gravel and so may represent a second period of deposition resulting from migration of the stream channel. The upper 1.5 m of the section consists of interbedded organic-rich silt, fine sand, and peat that probably represent fluvial, lacustrine, and eolian deposition in a flood-basin environment.

PUT 1 Gravel Pit. PUT 1 pit is 5.2 km up the Putuligayuk River from Prudhoe Bay at an elevation of 6.1 m above sea level. The pit exposes sediments to a depth of 14 m: 0.7 m peat and fluvial sandy silty overlying 13.3 m of fluvial or glaciofluvial interbedded pebbly sand, sandy gravel, and gravel; sandy gravel is dominant (figure 4.10). Hopkins and others (1981b) reported more than 4 m of "Sagavanirktok River" alluvium below 0.9 m of bedded oxbow-lake sediments in this pit. Detrital peat 0.9 m below the top of this alluvium, 1.8 m below the surface, yielded a radiocarbon date of 5.470 +/- 0.110 ka (USGS I-10642).

Sandy-silt beds that Hopkins and Robinson (1979) considered to be interstadial or interglacial horizons are present 7.5 and 10.5 m below the ground surface in PUT 1 pit. These beds contain peat and detrital wood and likely correspond to organic horizons in the landfill pit that yielded radiocarbon dates of 26.3 +/- 0.370 ka (USGS 505) (Hopkins and Robinson, 1979) and 35.6 +/- 0.550 ka (USGS 504), respectively (Hopkins and others, 1981b).

The lower sandy-silt bed in PUT 1 pit overlies and often fills cut-and-fill structures. Gravel below the lower sandy-silt bed is oxidized and coarser grained than sandy gravel higher in the section. Detrital wood also occurs in lenses of pebbly sand in the bottom half of the section. *Salix* wood (sample BPB3-23G) from the lower sandy-silt bed yielded a radiocarbon date of 37 +10/-4.3 ka (GX 10656), which because of the wide standard deviation is considered a minimum age. If this bed correlates with the lower sandy-silt bed in the landfill pit, the apparently finite age of 35.6 ka reported by Hopkins and others (1981b) should also be considered a minimum age. Thermoluminescence analysis of sediment (sample BPB3-23I) from the lower of the two organic-rich horizons yielded a date of 142 +/- 8.8 ka[6] (ALPHA 2601). Although possibly unreliable and apparently too old, the thermoluminescence date suggests that the lower sandy-silt bed and underlying oxidized gravel are Sangamonian. Thaw probably reflecting an interglacial climate is essential to oxidation of the sediments. Such an age is consistent with probable Sangamonian marine sediments at the bottom of the PUT 2 gravel pit.

[6]This age was determined using only the Regen technique. The thermoluminescence within the sample was saturated, therefore negating use of the Residual and Rbeta techniques. Without these techniques, zeroing of the sample in nature cannot be determined. However, if the sediment was of primary deposition and the sensitivity to bleaching is high, as suggested by the analysis, the probability of being zeroed is high. If these assumptions are valid, the age would be a minimum.

PUT 2 Gravel Pit. PUT 2 pit is 2.3 km northeast of PUT 1 pit at an elevation of 3 m (figure 5.6). The general stratigraphy of sediments exposed in the pit and discussion of marine sediments at the base of PUT 2 pit were presented in Chapter 4 (figure 4.10). Most of the section consists of fluvial or glaciofluvial sediments.

A thin, pebbly-sand bed with abundant detrital wood overlies and fills cut-and-fill structure 6.8 m below the surface. Rawlinson (1986a) reported this bed at 8.3 m below the surface. This depth was based on a section measured in a topographically higher part of the pit; the bed in both sections is the same. The pebbly-sand bed likely corresponds to the bottom sandy-silt bed in PUT 1 pit because they differ only slightly in depth below sea level (4.2 m in PUT 1 and 3.8 m in PUT 2) and gravel below this bed is oxidized as in PUT 1. As expected because of the elevation difference, a counterpart to the upper sandy-silt bed in PUT 1 pit is not present in PUT 2 pit. An ice-wedge pseudomorph is present 3.2 m below the surface and thin sand lenses with small pieces of detrital wood and peat are present in the middle one-third of the section.

Wood from 3 m (sample BPB3-25D), 6.8 m (sample BPB3-25N), and 7.4 m (sample BPB3-25Q, *Salix*) below the surface all yielded radiocarbon dates of >31.6 ka (respectively GX 11762, GX 11761, and GX 11766). Peat (sample BPB3-25H) from 6.6 m below the surface yielded a radiocarbon date of 4.075 +/- 0.115 ka (GX 10781). If this date is valid[7], Holocene alluvium composes almost one-third of the section and disconformably overlies probable Sangamonian fluvial sediments; wood (sample BPB3-25D) from 3 m that yielded and infinite date was likely reworked from older sediments. In addition to the infinite

[7]Dates on peat tend to be reliable in terms of representing the approximate age of the enclosing sediment, because reworking would disaggregate the peat in a short time.

radiocarbon dates of samples BPB3-25N and BPB3-25Q, amino-acid analysis of sample BPB3-25Q yielded an aspartic-acid D/L ratio of 0.2416 +/- 0.0006 (UA 1774), which places it within the young group of analyzed samples.

Sediments in PUT 2 pit between an uncertain contact 11.5 m below the surface and marine sediments adjacent to the lake at the bottom of the pit are presumed to be in place. These sediments were exposed adjacent to the lake, separate from the continuous section. Salt efflorescence on the surface of these sediments suggests a marine origin; however, gravelly sand (sample BPB3-25S) from the approximate middle of this unit was barren of microfossils. The sediments are likely fluvial and the efflorescence resulted from exclusion of salt as brackish pore-water froze. Amino-acid analysis of marine mollusks from sediments at the bottom of PUT 2 pit suggests that the sediments are not older than Sangamonian.

Sediments exposed in the Putuligayuk River gravel pits are likely of equivalent ages based on the presence of the sandy-silt bed and underlying oxidized gravel in both pits. Sediments exposed in approximately the bottom one-half of PUT 1 pit were deposited during the Sangamonian Interglaciation, the middle Wisconsinan nonglacial Boutellier interval, and into the Duvanny Yar interval of Hopkins (1982) based on radiocarbon dates on peat and wood in both pits, a thermoluminescence date in the PUT 1 pit, and amino-acid dates in the PUT 2 pit. This alluvium is overlain by outwash derived from late Wisconsinan glaciation in the Brooks Range and by Holocene alluvium. Approximately the bottom one-half of PUT 2 pit is alluvium deposited during the Sangamonian Interglaciation; no Wisconsinan alluvium or outwash overlies this alluvium.

Rawlinson (1986a) termed the older alluvium exposed in the PUT 1 and 2 pits, and the landfill pit, the Put alluvium; and termed overlying outwash exposed in PUT 1 pit and the landfill pit, the Put outwash. To avoid confusion between the two units, and because the units cannot always be visually distinguished from each other, the collective term of Put gravel defined by Rawlinson (1986a) is now preferred.

SAG C Gravel Pit. The SAG C pit is within the active flood plain of the Sagavanirktok River 11.2 km south of the Beaufort Sea coast and about the same distance southeast of PUT 1 gravel pit (figure 5.6). The flood-plain surface at SAG C pit is between 3 and 4 m above mean sea level. SAG C pit is the deepest on the Coastal Plain, exposing sediments to 19 m below the surface. As in the other pits, a lake occupies the deepest part.

The general stratigraphy of the SAG C pit is given in figure 5.10 (section BPA3-10). A thin paleosol 5.1 m below the surface separates unoxidized gravel and underlying oxidized gravel. The interval with sand beds and lenses contains some small chips of detrital wood; whereas the interval between 14 m and the bottom of the pit contains abundant large pieces of wood. Salt efflorescence is present on the sediments below 7.5 m and, as for nonmarine sediments in the PUT 2 pit, possibly resulted from exclusion of salt as brackish pore-water froze. The possibility that the salt efflorescence is associated with marine deposition was checked by a series of samples analyzed for microfossils. Sediment collected at 7.7 m (sample BPA3-10S) was barren of microfossils.

Samples for pollen analysis were also collected throughout the section. Sediment (sample BPA3-10D) from 7.7 m below the surface contained indeterminant spores and one occurrence of the Devonian spore *Hymenozonotriletes lepidophytus*, which presumably was

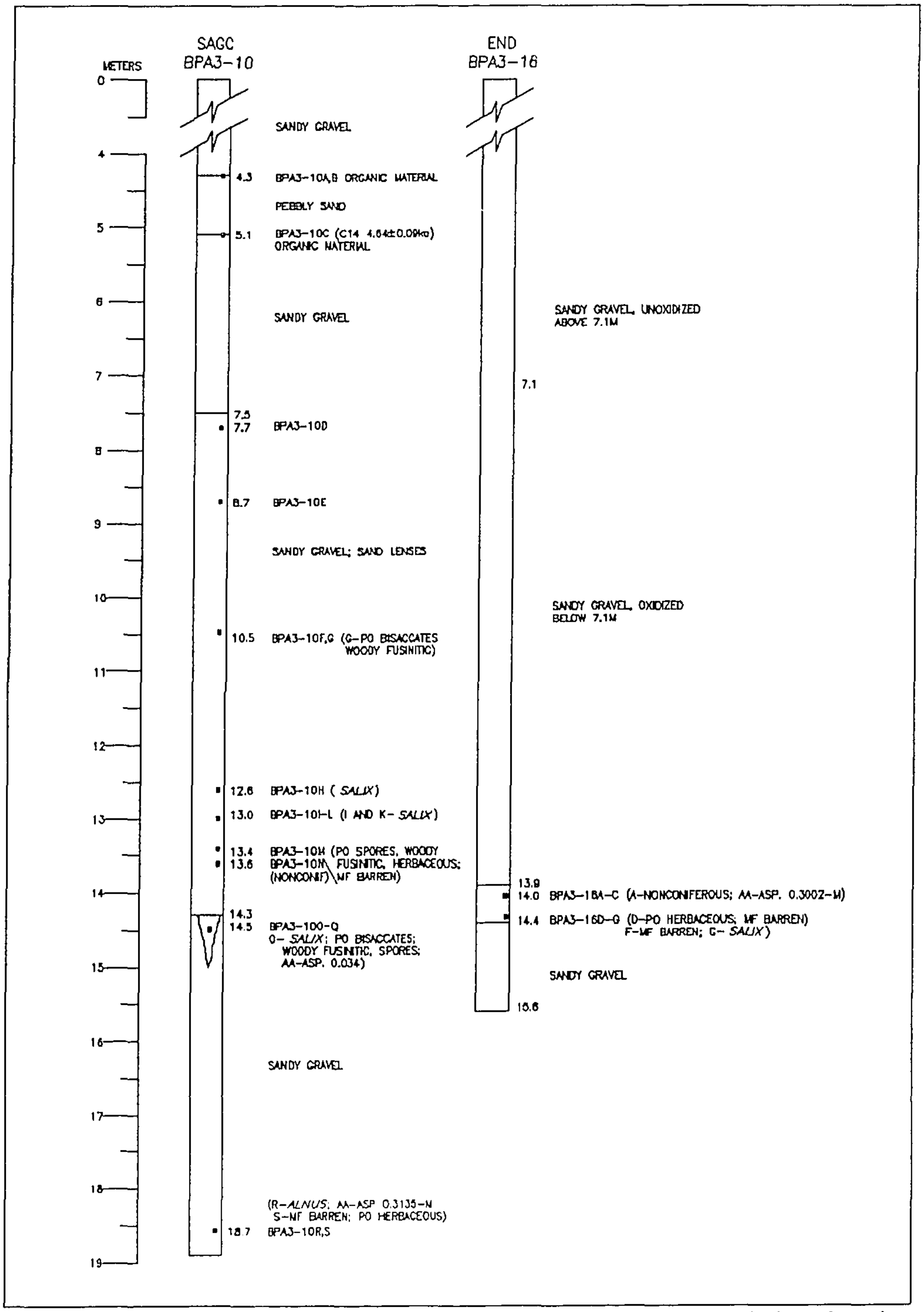


Figure 5.10 Stratigraphic section BPA3-10 measured in the SAG C gravel pit and section BPA3-16 measured in the END pit. Black squares represent samples; sample numbers are adjacent to the right (e.g., BPA3-10A). Form in section BPA3-10 is an ice-wedge pseudomorph. PO denotes pollen; MF denotes microfossil; C14 denotes radiocarbon; and AA denotes amino acid; letter after AA ratio indicates assigned age group. Locations of these sections are shown in figure 5.6 and on sheet 3.

reworked from Devonian rocks that crop out along the crest of the Brooks Range (Payne and others, 1952). This sample also contained woody fusinitic material.

Sediment (sample BPA3-10G) from 10.5 m contained undifferentiated Bisaccates and woody fusinitic material. Sediment (sample BPA3-10M) from 13.4 m contained indeterminant spores and woody fusinitic and herbaceous materials. Sediment (sample BPA3-10O) from 14.5 m contained undifferentiated Bisaccates and indeterminant spores, as well as woody fusinitic and herbaceous materials. Sediment (sample BPA3-10S) from 18.7 m contained mostly herbaceous material and was barren of palynomorphs. Woody fusinitic material in these samples is suggestive of reworking of older deposits, probably coal-bearing sediments of the Sagavanirktok Formation.

Peat (sample BPA3-10C) from the paleosol 5.1 m below the ground surface yielded a radiocarbon date of 4.640 +/- 0.090 ka (GX 10779). Because this horizon marks the boundary between unoxidized and underlying oxidized alluvial gravels, it probably also represents the boundary between the Holocene alluvium and older sediments. Wood (sample BPA3-10E) from 8.7 m below the surface yielded a radiocarbon date of >38.4 ka (GX 10658); however, as suspected for similar detrital samples from other sections, this wood may have been reworked from older deposits.

Amino-acid analysis of *Salix* wood (sample BPA3-10O) from an ice-wedge pseudomorph 14.5 m below the surface yielded an aspartic-acid D/L ratio of 0.3152 +/- 0.0040 (UA 1766), and an aIle/Ile ratio of 0.034 +/- 0.004 (AAL 4642). These ratios place the wood in the middle age group; they are perhaps broadly correlative with sediments exposed in the KUP and MP pits. *Alnus* wood (sample BPA3-10R) from 18.7 m below the surface corroborates this age group with an aspartic-acid D/L ratio of 0.3135 +/- 0.0080 (UA 1775). In addition to wood mentioned above, wood from 12.6 m (sample BPA3-10H) and 13.0 m (samples BPA3-10J and BPA3-10L) is *Salix*. Wood (BPA3-10N) from 13.6 m is nonconiferous.

END Gravel Pit. The END pit is within the Sagavanirktok River abandoned flood plain approximately 2 km east of the SAG C pit and 12 km inland from the Beaufort Sea coast (figure 5.6). The elevation of the flood plain at the pit is 3 m and the pit is excavated to 16 m below the surface. The general stratigraphy of sediments exposed in the END pit is given in figure 5.10 (section BPA3-16).

Undisturbed exposure of sediments is limited to near the base of the pit. All samples were collected from a 0.6-m-thick, organic-rich sand that crops out between 13.9 and 14.5 m below the surface. Organic material in places consists of matted deciduous leaves. Wood samples are nonconiferous (sample BPA3-16A) or *Salix* (sample BPA3-16G). Amino-acid analysis of sample BPA3-16A yielded an aspartic-acid D/L ratio of 0.3002 +/- 0.0117 (UA 1773), which places it in the middle age group. Sediment (sample BPA3-16D) contained herbaceous material and was barren of pollen. Sediment (sample BPA3-16F) was barren of microfossils.

Inland Exposures. Exposures of younger sediments between the Kuparuk and Sagavanirktok Rivers are limited to cut banks of streams and thaw lakes. Stratigraphic section BPA4-1 (sheet 2) on the east bank of the Kuparuk River shows 0.5 m of lacustrine and eolian silty peat and sand overlying more than 3 m of alluvial sand and sandy gravel. A radiocarbon date of 8.475 +/- 0.335 ka (GX 10659) on a basal peat (sample BPA4-1A) is the minimum age for underlying alluvial sediments. Banks of thaw lakes in the area typically provide little, if any, exposure of the subsurface. An exception is section BPA3-2, which exposes 0.7 m of lacustrine peat and pebbly sand overlying about 1 m of fluvial silty sand. Peat (sample BPA3-2C) from 0.7 m below the surface yielded a radiocarbon date of 10.540 +/- 0.310 ka (GX 10780), which is a minimum age for underlying alluvial sediments. Walker and others (1985) and Hopkins and others (1981b) reported radiocarbon dates that range between 1.2 and 3.5 ka for basal peat from flood plains to the north.

Sagavanirktok River to West Edge of Canning River Fan

The Coastal Plain between the east shore of the Sagavanirktok River and the western edge of the Canning River fan has much the same morphology as the Coastal Plain west of the Kuparuk River west terrace. Walker and Acevedo (1987) mapped this area as rolling thaw-lake plain. However, near-coastal parts of this eastern area should be classed as flat thaw-lake plain along with the area north of the line of truncation of broad-based mounds west of the Kuparuk River.

No gravel pits that provide deep exposure have been excavated in the area between the east bank of the Sagavanirktok River and the western edge of the Canning River fan. However, cut banks of streams and a few thaw lakes in this area provide relatively good exposure.

Sagavanirktok River Outcrops. Perhaps the best exposure is along the east bank of the Sagavanirktok River, where sections range up to 12 m thick but most are less than half this thickness. Stratigraphic sections along the Sagavanirktok River from the coast to about

9 km inland generally consist of lacustrine, eolian, and fluvial sediments, and sometimes underlying marine gravelly sand and silt.

More than 9 km inland, a typical stratigraphic section representative of alluvial-plain sediments is much like the top part of a section in the Kuparuk oil field and consists from top to bottom of lacustrine peat and silt, eolian sand, and fluvial or glaciofluvial sandy gravel or gravelly sand, or both. Stratigraphic sections BPA2-8, BPA2-9 and BPA2-10 (figure 5.11 and sheet 3) illustrate this approximate consistency from south to north along the east bank of the Sagavanirktok River.

In addition to sediment samples collected for grain-size analysis (appendix E), samples were collected from several of the Sagavanirktok River sections to ascertain chronology and depositional environment. Organic-rich silt (sample BPA2-8D) from a bed near the base of thaw-lake sediments in stratigraphic section BPA2-8 yielded a radiocarbon date of 11.180 +/- 0.430 ka (GX 10321). This bed probably represents the basal organic-rich layer typical in a sequence of thaw-lake sediments and suggests that the overlying sediments were deposited during a second cycle of thaw-lake activity.

Organic material from thaw-lake sediments above the dated organic bed consists almost entirely of light-colored herbaceous material, indicative of tundra growing on the Coastal Plain. Rarely occurring palynomorphs from these upper sediments include *Sphagnumsporites* sp., and *Lejeunia* sp.; frequently occurring palynomorphs include an indeterminant large spore and fungal hyphae. Organic material from thaw-lake sediments below the dated organic-rich bed consists almost entirely of dark-brown, woody fusinitic

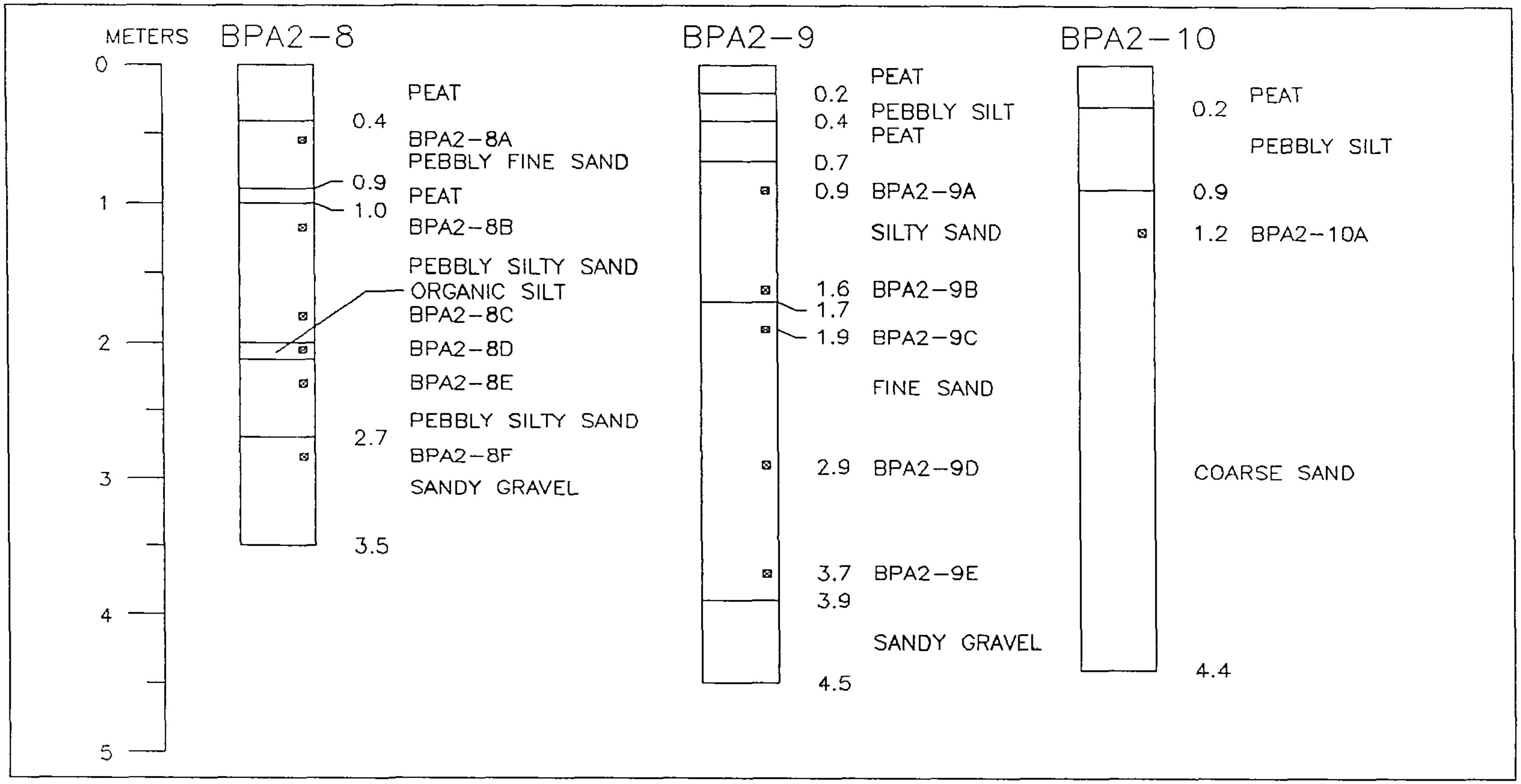


Figure 5.11 Stratigraphic sections BPA2-8, BPA2-9, and BPA2-10 measured along the east bank of the Sagavanirktok River, showing consistency of deposits. The small squares represent samples; sample numbers are adjacent to the right (e.g., BPA2-8A). Locations of these sections are shown on sheet 3.

material that is almost certainly reworked from older deposits. Rarely occurring, reworked palynomorphs from these lower sediments include indeterminant forms, *Striatites richteri*, and *Micrhystridium* sp.; a frequently occurring reworked palynomorph is *Laciniadinium biconiculum*.

The first cycle of thaw-lake sediments overlies sandy gravel from which no datable material was recovered. Analysis of the sandy gravel for palynomorphs yielded only poorly preserved indeterminant pollen, precluding inferences of age, and an equal mix of amber amorphous organic material and dark-brown, woody fusinitic material. The fusinitic material is probably reworked from coal-bearing sediments of the Sagavanirktok Formation.

Alluvial-terrace sediments in sections BPA3-13, BPA3-14, and BPA3-15 (figure 5.12 and sheet 3) differ little from the alluvial-plain sediments in that they show approximately the same sequence of sediments; albeit, sand-sized sediments in section BPA3-13 were more fluvial than eolian. With this exception, these sections show 0.4 to 2 m lacustrine peat and silt overlying 1.5 to 2 m eolian sand. Section BPA3-15 exposes sandy gravel below the eolian sand and sandy gravel is presumed to be also present below the depth of exposure in section BPA3-14. No datable material was recovered from nonlacustrine sediments in either section BPA3-14 or PBA3-15.

A bed of silt with peat 7 m below the ground surface in section BPA3-13 (figure 5.12) is laterally discontinuous and varies up to 1 m thick over the approximate distance of 20 m that it could be traced. Caution should be taken in interpreting the stratigraphy in cases where the adjacent river may have cut and filled a niche with modern sediments; these sediments, especially once frozen, are often difficult to distinguish from in-place sediments. Top and bottom contacts of the silt bed with adjacent sediments suggest

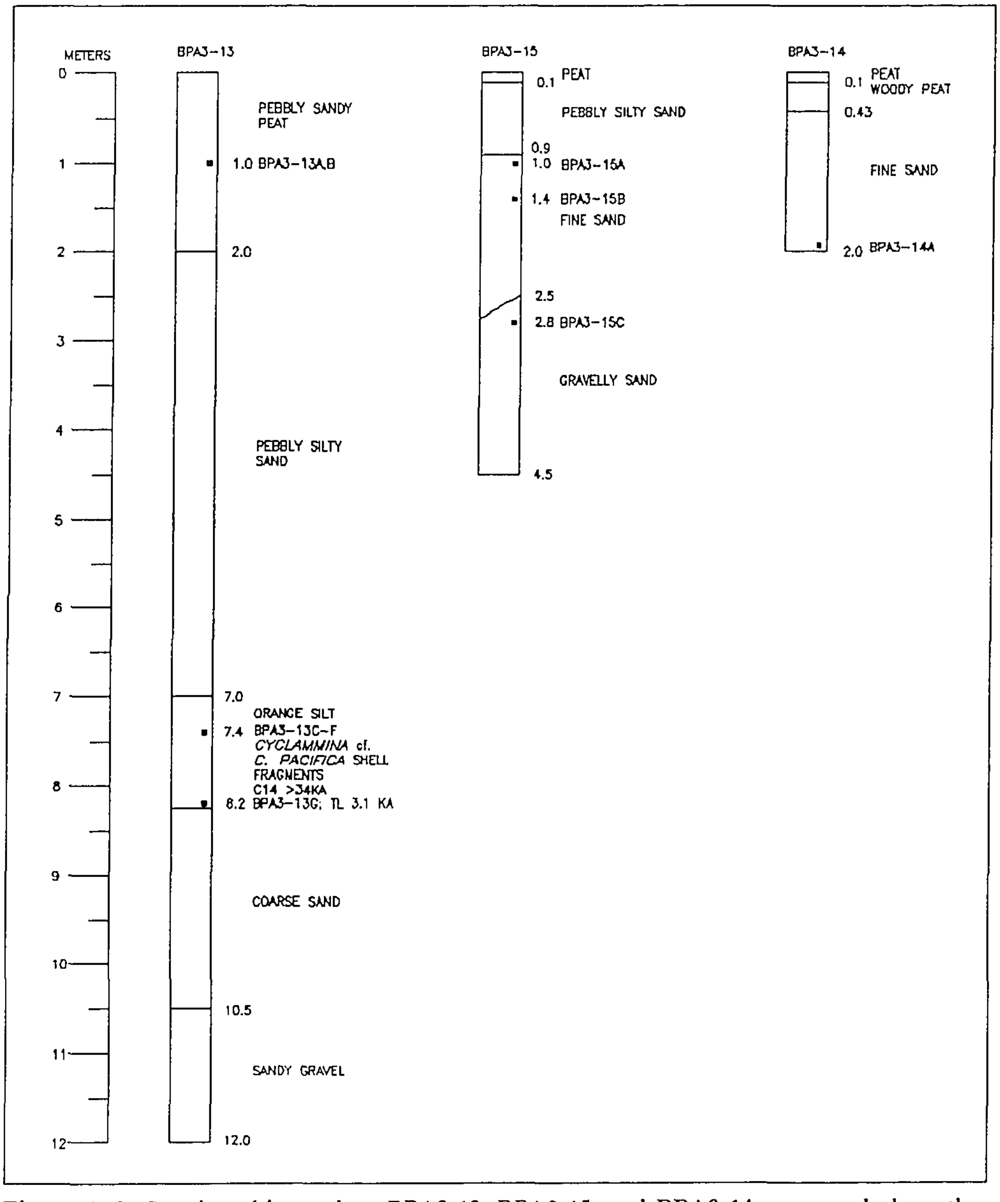


Figure 5.12 Stratigraphic sections BPA3-13, BPA3-15, and BPA3-14 measured along the east bank of the Sagavanirktok River, showing similarity of alluvial-terrace sediments with alluvial-plain sediments to the west and east. The small black squares represent samples; sample numbers are adjacent to the right (e.g., BPA3-13A). C14 denotes radiocarbon and TL denotes thermoluminescence. Locations of these sections are shown on sheet 3.

that the bed is in place. Analysis of the silt for microfossils and palynomorphs indicated one specimen of the foraminifer *Cyclammina* cf. *C. pacifica*, which was undoubtedly reworked from older deposits, and freshwater shell fragments. Rarely and frequently occurring palynomorphs included *Lycopodiumsporites* sp. and Betulaceae, respectively.

Peat (sample BPA3-13D) from the top part of the silt bed, 7.4 m below the surface, yielded a radiocarbon date of >34.8 ka (GX 10319), which is not unexpected considering similar dates from approximately this depth elsewhere on the Coastal Plain. A thermoluminescence date of the silt (BPA3-13G) from 8.1 m below the surface, however, yielded the unexpectedly young date of 3.140 +/- 0.500 ka (ALPHA 1494). The analysis is reported to have run well and showed excellent internal agreement between the three thermoluminescence dating methods used (Regen, Residual, and R-Beta). This young date can be explained by one of several alternatives. The simplest explanation is that for some unknown reason the thermoluminescence date is incorrect and the sediments are >34.8 ka as shown by the radiocarbon date. This explanation assumes that the radiocarbon date is valid; there is no reason to believe otherwise.

An alternative is that the silt bed is Holocene, having been deposited in a niche cut during the time that the river level was approximately 5 m higher than at present, or during a time when flood stage reached that height above present mean stage. This alternative assumes that the peat date is either incorrect or that it is correct and the peat is reworked from older deposits, and that lateral erosion by the river has been less than the depth of the niche. The alternative is less likely than the simple explanation for two reasons: (1) fibrous peat typically yields reliable radiocarbon dates because unless frozen, it disaggregates rapidly; and (2) most modern stream-cut niches are only a few meters deep, probably less than the lateral erosion of the bluff over a period of several thousand years based on modern erosion rates.

Kadleroshilik River and Shaviovik River Outcrops. Stratigraphic sections similar to those along the Sagavanirktok River are exposed along the Kadleroshilik River (e.g., sections BPA2-20, BPA2-23, BPA2-24) and Shaviovik River (e.g., sections BPA1-22, BPA1-25, and BPA1-27) and illustrate the consistency of sediments across this part of the Coastal Plain (figure 5.13). Sediments for grain-size analysis were collected from each of these sections (appendix E). Datable organic material is sparse with the exception of such material associated with lacustrine sediments at the top of each of these sections. Peat (sample BPA2-20A) from the base of lacustrine sediments 0.4 m below the surface in section BPA2-20 yielded a radiocarbon date of 12.360 +/- 0.410 ka (GX 10320). This date is the oldest of all the lacustrine basal peat samples collected as part of this study and among the oldest of reported dates for lacustrine sediments on the Coastal Plain.

Canning River Fan

The coastline of the Canning River fan forms a symmetrical convex-northward arc that stretches approximately 60 km from an unnamed stream 5 km east of the Shaviovik River eastward to near the confluence of the Tamayariak and Canning Rivers (sheets 4 and 5). The apex of the fan is approximately 35 km inland from the coast, where the trend of the Canning River turns from northwesterly to northeasterly. There, outwash terraces cut into glacial till have been dissected by more recent alluvial terraces, some of which are exposed to approximately 14 m below the ground surface. Northward along the river, exposed sections of the fan are less high. On the fan surface, the only exposure is along

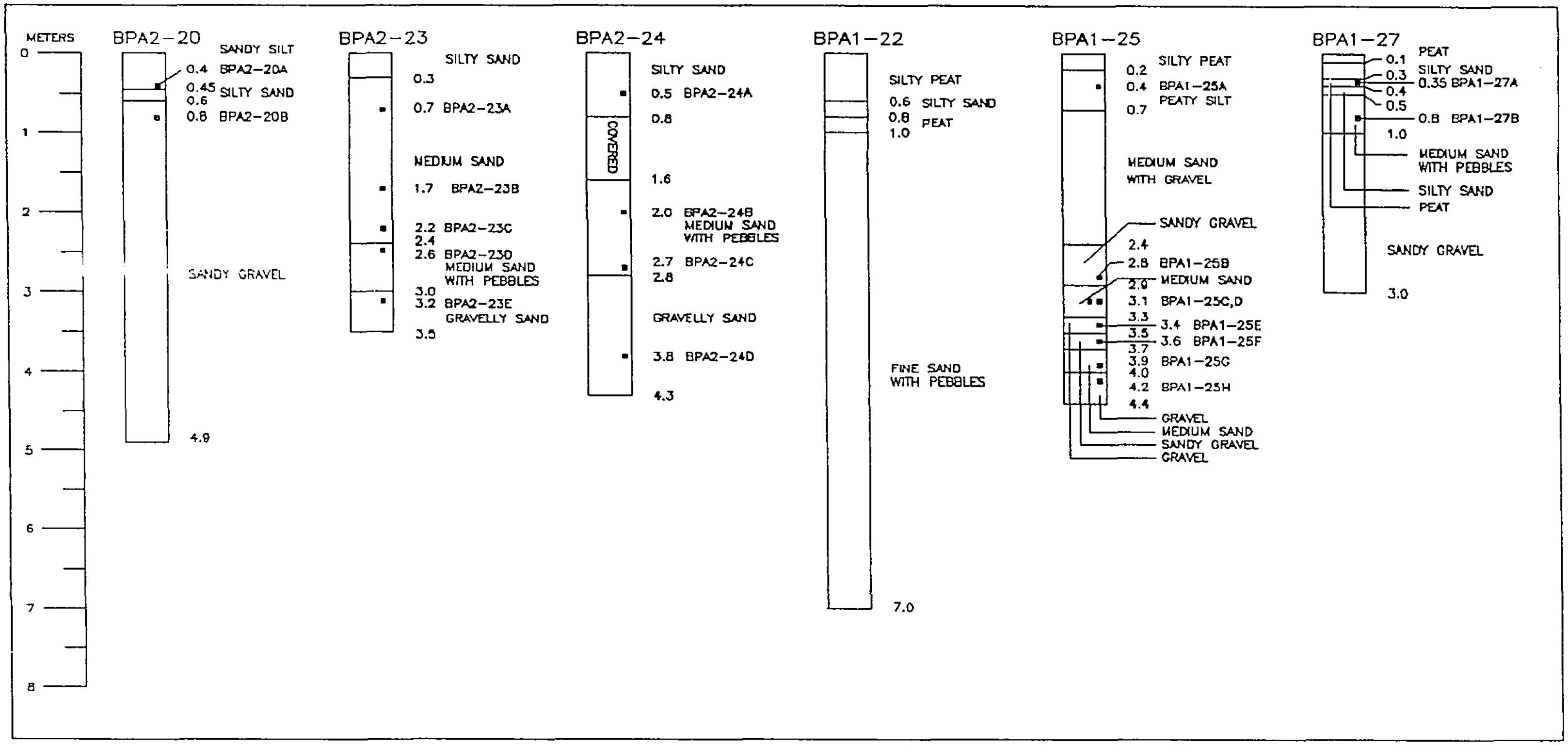


Figure 5.13 Stratigraphic sections BPA2-20, BPA2-23, BPA2-24, BPA1-22, BPA1-25, and BPA1-27 measured between the Sagavanirktok River and Canning River fan, showing consistency of sediments. The small black squares represent samples; sample numbers are adjacent to the right (e.g., BPA2-20A). Locations of the first three sections are shown on sheet 3 and locations of the last three sections are shown on sheet 4.

banks of small stream and thaw lakes. Exposure of the fan along the coast is typically less than 1 m high except where originally higher areas have not been dissected by flow. These areas typically stand several meters above sea level and expose lacustrine silt, sand, and organic material overlying eolian sand, which in turn overlies marine Flaxman mud.

The eastern part of the fan is currently active, with the Canning River and associated alluvial terraces covering approximately one-third of the fan surface. The central part of the fan is inactive except for drainage that originates on the fan surface, and consists of sandy-gravel outwash covered with a thin veneer of fluvial and eolian sand. The western part of the fan is sandy-gravel outwash covered with eolian sand that was deposited as subtle southwest-trending longitudinal dunes presumably when the central part of the fan was active and unvegetated. Elongated thaw lakes with long axes parallel to the trend of the dunes are present between the dunes. As in the central part of the fan, drainage that originates on the fan surface cuts transversely through the dunes to the Beaufort Sea.

Canning Gravel. Rawlinson (1986a) termed outwash sediments of the Canning River fan the Canning gravel and indicated that these sediments were questionably underlain by sediments equivalent to the Ugnuravik gravel. Rawlinson further suggested a late Wisconsinan age for the Canning gravel. This age was contested by Dinter and others (1987); however, with clarification given below, views presented by Rawlinson and Dinter and others are not conflicting.

On the basis of offshore seismic investigation, Wolf and others (1985) suggested that the Canning River fan extends into the submarine environment as a delta and that deposition of the fan has been more or less continuous through at least several marine transgressions and regressions. Because the apex of the fan is nearly coincident with the northernmost limit of recognizable glacial till, deposition of the fan can probably be extended back at least to the onset of presumed early Pleistocene glaciation in the Canning River drainage. Apparent deposition from a focus inland on the Canning River since at least the early Pleistocene makes it unlikely that the Ugnuravik gravel extended eastward to the Canning River.

Wolf and others (1985) suggested that the Canning River fan and delta includes five unconformities: surface 3, surface 4, bottom of the Flaxman Member, top of the Flaxman Member, and the present sea floor and isolated areas within the lagoons. Surfaces 3 and 4 are two erosional surfaces of seven seismic reflectors identified by Wolf and others (1985). Foster (1988) recognized six stratigraphic units, which he termed sequences A through E based on offshore seismic investigations between the Colville River and Prudhoe Bay, and correlated Wolf and others' unit between surfaces 3 and 4 with his sequence C, and the unit below surface 3 with his sequence D (table 5.1). Foster also correlated his sequence E, which underlies sequence D, with the upper part of Rawlinson's (1986) Ugnuravik gravel. Foster suggested that these units represent the latter half of the middle Pleistocene, but reiterated the argument that the presence of *Larix* in the Ugnuravik gravel may imply a Fishcreekian age. However, he also indicated that the Ugnuravik gravel may be deposited over Fishcreekian-aged sediments.

Eolian or lacustrine sediments, or both, which unconformably overlie Flaxman mud near the coast and outwash inland of the coast, are present on topographically high areas along the seaward margin of the fan, and on Flaxman Island and the adjacent topographically high area that includes Bullen Point. Topographically high areas stand as

Table 5.1 Correlation chart of offshore and onshore stratigraphic units. Modified from Foster (1988).

QUATERNARY TIME SCALE YEARS (ka)	+ HOPKINS (1967) * CARTER AND GALLOWAY (1985a)	SMITH (1985 AND 1986)	WOLF & OTHERS (1985)	FOSTER (1988)	CRAIG AND THRASHER (1982)	DINTER (1982)	SMITH & OTHERS (1980)	RAWLINSON (THIS STUDY)
HOLOCENE		STEFANSSON SOUND UNIT	UNIT ABOVE 5?	SEQUENCE A	ABOVE UNIT A	UNIT A	QHd QHm QHb	
LATE PLEISTOCENE – WISCONSIN – Late 23		MIKKELSON BAY UNIT		SEQUENCE B	UNIT A	UNIT B	QPa	BEECHEY SAND
LATE PLEISTOCENE – WISCONSIN – Middle 64			UNIT BELOW 5? AND ABOVE 4	ATB? DELTA?	PALEO–SHORELINE?			
LATE PLEISTOCENE – WISCONSIN – Early 115	*Simpsonian (70–80 ka)	CROSS ISLAND UNIT		SEQUENCE A/B?			FLAXMAN	FLAXMAN
LATE PLEISTOCENE – SANGAMON 128	+Pelukian (120–130 ka)	MAGUIRE ISLAND UNIT		SEQUENCE B			SANGAMON MARINE	
MIDDLE PLEISTOCENE 730	+Kotzebuan *Wainwrightian (> 158 ka)	LEFFINGWELL LAGOON UNIT	UNIT BETWEEN 3 AND 4 UNIT BELOW 3	SEQUENCE C SEQUENCE D SEQUENCE E	UNIT B		QPa	UGNURAVIK GRAVEL
EARLY PLEISTOCENE 1.85 Ma	*Fishcreekian (1.87–2.48 Ma)							

remnants of post-Flaxman fan sediments that correlate with Wolf and others' (1985) unit above surface 4 (or possibly below surface 5), and with Rawlinson's (1986a) Beechey (formerly Ugnuravik) sand (table 5.1). Post-Flaxman fan sediments were eroded (Wolf and others, 1985) and replaced with more recent sandy gravel and gravel, which compose most of the near surface part of the fan and, as suggested by Rawlinson (1986a), are probably outwash associated with late Wisconsinan glaciation within the Canning River drainage. The sand sheet on the western part of the fan may have developed during and shortly after deposition of this outwash.

Terrace Deposits. Terraces near the apex of the Canning River fan are capped by Holocene alluvial sand and sandy gravel (figure 5.14, section MMD5-10, and sheet 4), or consist entirely of such sediments. The terrace represented by stratigraphic section MMD5-10 is among the oldest of several terraces cut into older outwash sediments. From top to bottom, this section shows 4.6 m of interbedded alluvial sand and sandy gravel unconformably overlying 6.3 m of presumably Wisconsinan outwash sandy gravel. The modal diameter of clasts in the outwash is approximately 0.2 m, but some are up to 0.7 m in diameter. No organic material was found, which is typical of outwash sediments.

Detrital wood (sample MMD5-10A) from 0.6 m above the outwash contact yielded a radiocarbon date of 8.455 +/- 0.195 ka (GX 11753). Other detrital wood (sample MMD5-10B) from 0.3 m above the contact with the underlying outwash yielded a radiocarbon date of 7.300 +/- 0.440 ka (GX 11752), which is not in expected sequence. Thus, one or the other, or both, wood samples have apparently been reworked from older sediments; the youngest date can be taken as a maximum age for the upper alluvial sediments.

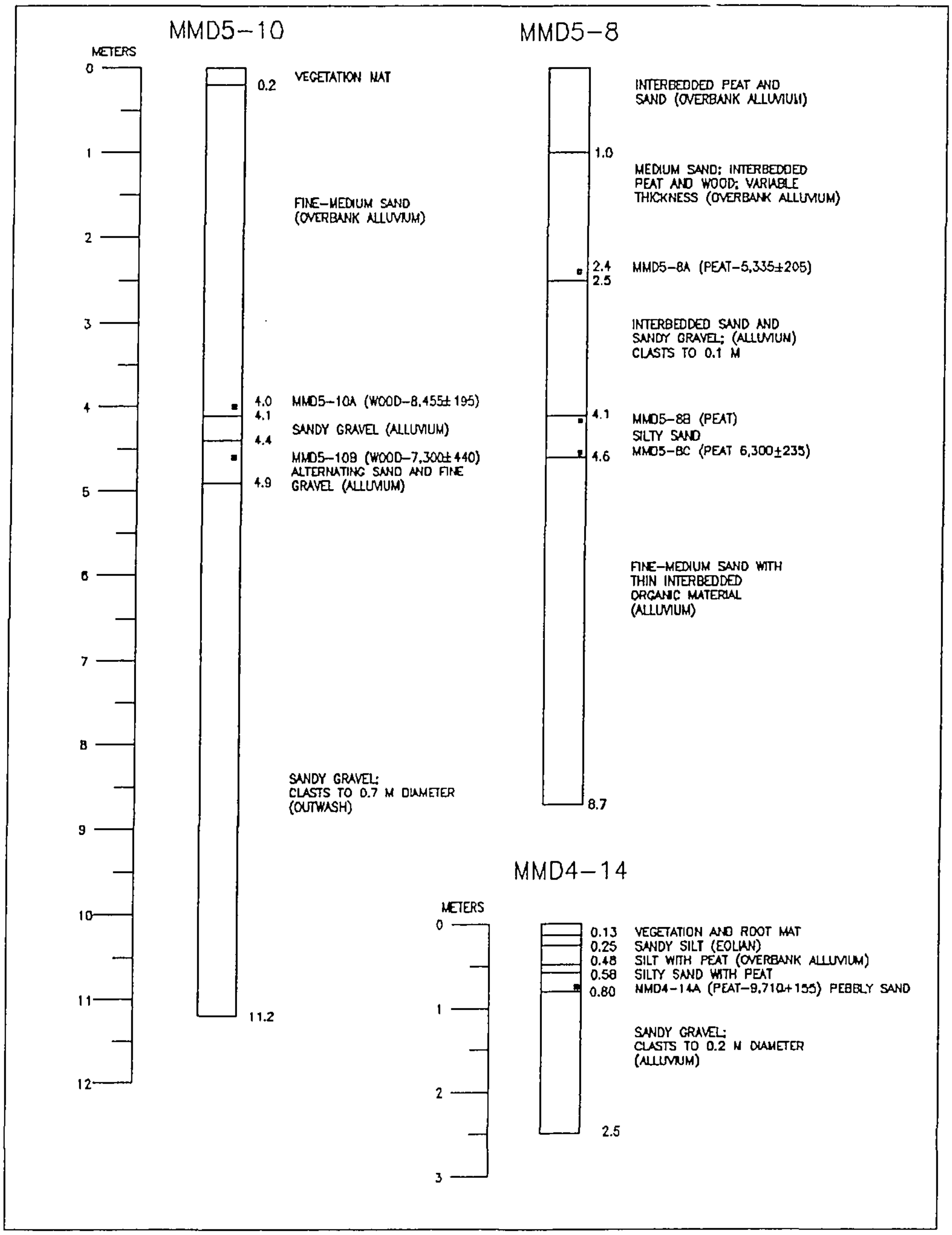


Figure 5.14 Stratigraphic sections MMD5-10, MMD5-8, and MMD4-14 measured near the apex of the Canning River fan and downstream of the fan apex, showing alluvial-terrace or abandoned flood-plain sediments. The small black squares represent samples; sample numbers are adjacent to the right (e.g., MMD5-10A). All dates are radiocarbon. Locations of the first two of these sections are shown on sheet 4 and the location of MMD4-14 is shown on sheet 5.

The span of time represented by most of the terraces near the fan apex is provided by radiocarbon dates of peat in a section representing an abandoned flood-plain surface about 5 km upstream of section MMD5-10. Section MMD5-8 (figure 5.14) shows 1 m of peat capping 7.7 m of interbedded alluvial sand, sandy gravel, silty sand, and sand. Peat (sample MMD5-8A) from 2.5 m below the surface yielded a radiocarbon date of 5.335 +/- 0.205 ka (GX 11755), and peat (sample MMD5-8C) from 4.6 m below the surface yielded a radiocarbon date of 6.300 +/- 0.235 ka (GX 11754). Thus, most alluvial terraces near the apex of the Canning River fan were deposited approximately between 9 and 5 ka ago.

Alluvial terraces on the fan surface downstream of the apex are also probably Holocene. On the basis of elevation above stream level and a consistent surface morphology, an alluvial terrace along the east side of the Canning River is perhaps among the oldest of such terraces on the fan. The stratigraphy of this terrace is shown in figure 5.14 (section MMD4-14). Peat (sample MMD4-14A) from 0.1 m above the contact with the sandy gravel yielded a radiocarbon date of 9.710 +/- 0.155 ka (GX 11749), which is approximately the time when channel deposition was replaced by overbank deposition at this locality.

Flood-plain surfaces on the Canning River fan are presumably mid-Holocene or younger based on the approximate 5.335 ka date obtained for sample MMD5-8A.

Canning River East Bank to the Hulahula River

Sediments on the Coastal Plain within approximately the western half of the ANWR are dominated by outwash and fluvial sandy gravel and gravel. As with the Canning River fan, outwash sediments underlie or have been cut by erosion and subsequently covered with Holocene alluvium. Walker and others (1982) mapped much of the area covered by outwash sediments as foothills and by the more recent alluvium as river flood plains. Between the east bank of the Canning River and the Katakturuk River, these outwash and fluvial sediments are primarily present from the coast inland 15 to 20 km. Holocene alluvium approximately 13 km south of the mouth of the Canning River is cut by northeast- to southwest-trending lineaments similar to those observed on aerial photographs of the area between the Kuparuk and Sagavanirktok Rivers. These lineaments, which are discernable on the ground as a slight drop in elevation on the north side of the lineament, are probably faults. Biswas and Gedney (1978) indicated that the northeast part of the Coastal Plain is seismically active. Such seismicity may result from continuing tectonism in the area and perhaps much of ANWR. Between Itkilyariak Creek and the Hulahula River, fluvial and outwash sediments extend inland to the Sadlerochit Mountains, approximately 35 to 40 km. The area between the Tamayariak River and Itkilyariak Creek has been folded and uplifted, and with a few exceptions, alluvium caps underlying sediments of the Sagavanirktok Formation or older formations.

Outwash Deposits. Outwash deposits in ANWR vary considerably in age and composition. Most outwash deposits between the Canning and Tamayariak Rivers are north of and probably associated with an extensive moraine that was likely deposited during an early Pleistocene glaciation. However, within this area some outwash, such as that at locality MMD4-21, has been folded and includes older, metamorphosed rocks not found in later outwash; thus it may be associated with an older, perhaps Tertiary, glacial advance. Locality MMD4-21 is on the north limb of the northern of two parallel anticlines (sheet 5). Outwash there is composed of subrounded to rounded clasts of rock types present in drainage basins of the Canning River south of the Sadlerochit Mountains: argillite; sandstone presumably of the Sadlerochit Group; and lesser amounts of quartz-pebble conglomerate; chert-pebble conglomerate; limestone presumably of the Lisburne Group; mafic volcanic rock with green vug filling, possibly Katakturuk greenstone; and mafic, aphanitic rock. The modal diameter of these clasts is 0.05 m and the maximum clast observed is 0.3 m in diameter.

Outwash probably associated with the early Pleistocene glaciation was deposited around the areas uplifted in the anticlines and on the Coastal Plain north of the northern anticline. Folding of these anticlines must have been concurrent with deposition of the moraine to have resulted in folding of the moraine and selective deposition of the associated outwash. The early Pleistocene outwash is exposed at locality MMD3-3 on the east end of the northern anticline. Clasts present at locality MMD3-3 include rock types common in the Sadlerochit and Shublik Mountains: sandstone presumably of the Sadlerochit Group; chert-pebble conglomerate; limestone presumably of the Lisburne Group; dolomite presumably of the Katakturuk Dolomite; and the mafic, aphanitic rock. Metamorphosed rocks are absent in the younger outwash. As at locality MMD4-21, these clasts are subrounded to rounded, have a modal diameter of 0.05 m, and a observed maximum diameter of 0.4 m.

Outwash sediments on the Coastal Plain north of the northern anticline are covered by eolian sand overlain by lacustrine silt and peat. This sand is well exposed at locality MMD4-18. There, the lacustrine sediments are 0.4 m thick and the underlying eolian sand is 4.1 m thick. A basal sample of the sand (MMD4-18B) yielded a thermoluminescence date of 26 +/- 2.9 ka (ALPHA 2602), a probable young minimum age for the underlying outwash sediments.

Outwash sediments covered by eolian sand are also present between the Sadlerochit River and Nataroarok Creek, and east of the Hulahula River. Dominant clast types in outwash there are common to drainage basins of the Sadlerochit and Shublik Mountains and of the Brooks Range south and east of these mountains: gray and brown sandstone presumably of the Sadlerochit Formation; schist; and granitic rock. Present in lesser amounts are dolomite presumably of the Katakturuk Dolomite; limestone presumably of the Lisburne Group; and gray-green volcanic rock . The outwash and overlying eolian sand are probably equivalent in age to these types of sediment between the Canning and Tamayariak Rivers. The rationale for the proposed age equivalency is that, as in the Canning River drainage, outwash in the vicinity of the Sadlerochit and Hulahula Rivers is north of and probably associated with a moraine of early Pleistocene till. This moraine was left by a glacial advance down the Hulahula River drainage and is the most extensive recognizable moraine in that drainage.

Flood-plain surfaces and constituent gravels in the vicinity of the Sadlerochit and Hulahula Rivers, as in other parts of ANWR and on the Canning River fan, are mid-Holocene or younger. These surfaces are incised into older terrace deposits, which at locality MMD1-7, are capped by peat that yielded a maximum age of 5.870 +/- 0.090 ka (GX 11747).

Gravel Sheets. Elevated terrain between the east fork of the Tamayariak River and the Sadlerochit River, and in particular, fan-shaped surfaces with apices near the Sadlerochit Mountains, are capped with alluvial gravel. On the basis of topography and cross-cutting relationships, this gravel predates adjacent till, outwash, and alluvial sediments (Carter and others, 1986c; sheets 5 and 6). Variations in composition and clast size in two sections in particular, MMD2-4 and MMD2-18 (figure 5.15), suggest that two distinctly different gravel sheets are present.

Stratigraphic section MMD2-4 clearly shows the two gravel sheets superposed. The underlying gravel at this locality is estimated to be 5 m thick, which is generally representative of many locations. This older gravel consists chiefly of rocks common to the core of the eastern Sadlerochit Mountains and drainage basins of the Brooks Range: metamorphic rocks like those of the Neruokpuk Formation, but including lesser amounts of Sadlerochit Formation sandstone; Lisburne Group limestone; shale; quartz-pebble conglomerate; and dolomite. Clasts are subrounded to rounded and, as at many other localities, have a modal diameter of 0.05 m; the observed maximum clast diameter is 0.2 m. The younger gravel is chiefly rock types common in the Sadlerochit Mountains: Sadlerochit Formation sandstone and Lisburne Group limestone, but including lesser amounts of Katakturuk Dolomite. The modal diameter of clasts is 0.05 m and the observed maximum is 0.4 m. The thickness of the younger gravel at this location is approximately 20 m.

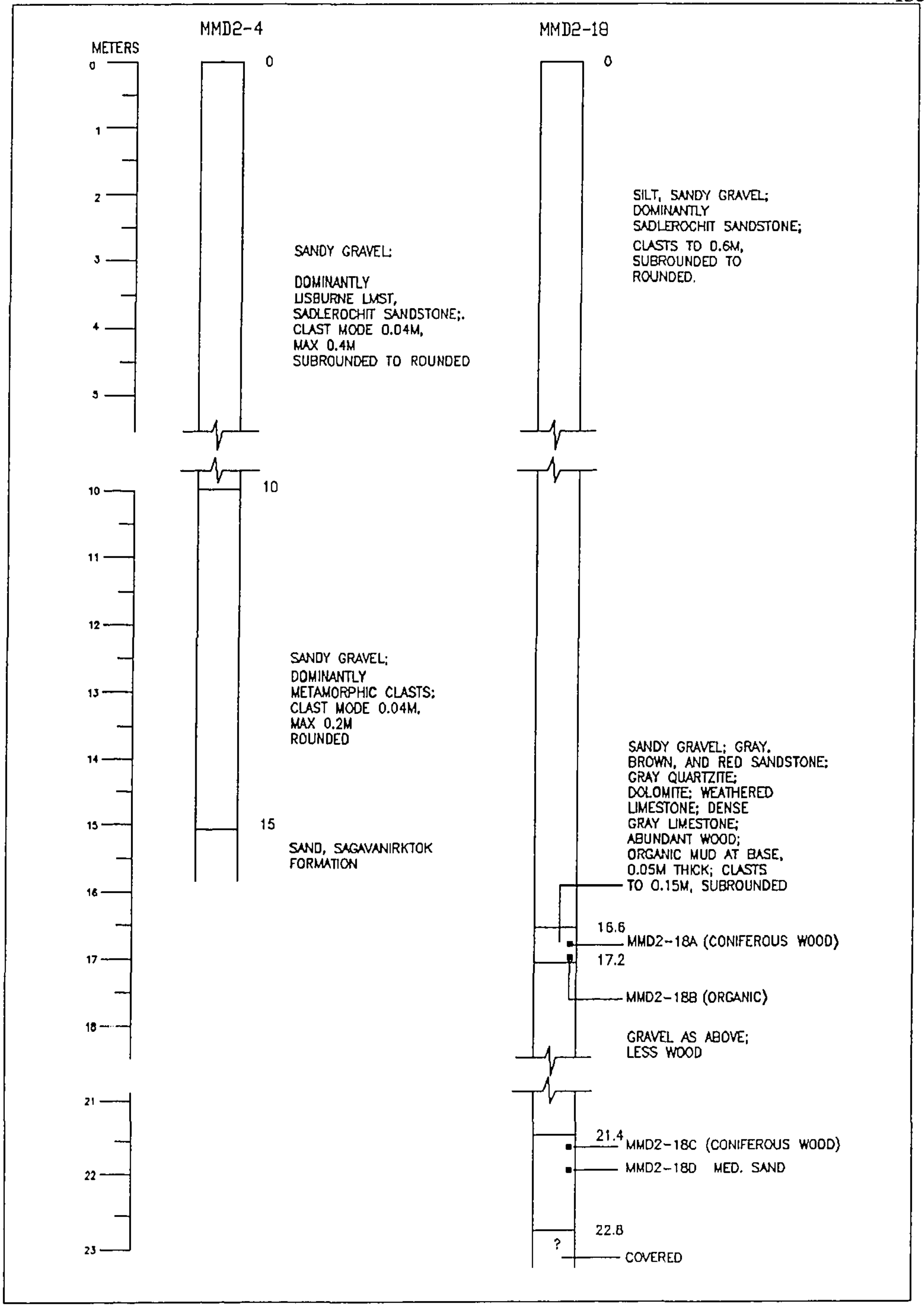


Figure 5.15 Stratigraphic sections MMD2-4 and MMD2-18 measured north of the Sadlerochit Mountains, suggesting that two distinctly different aged gravel sheets are present on some surfaces north of these mountains. The small black squares represent samples; sample numbers are adjacent to the right (e.g., MMD2-18A). Locations of these sections are shown on sheet 6.

In section MMD2-18, 16.6 m of gravel like that capping section MMD2-4, but with clasts up to 0.6 m in diameter, apparently disconformably overlie the older gravel. However, the older gravel in section MMD2-18 includes rock types common to drainage basins in the Brooks Range south of the Sadlerochit and Shublik Mountains: quartzite but none of the other metamorphic rocks typical at other representative older gravel localities; gray and brown sandstone; and limestone, all of which are deeply weathered. Clasts are up to 0.2 m in diameter. The top 0.8 m of the older gravel contains abundant coniferous wood and is separated from underlying similar but wood-free sediments by a 0.05-m-thick, organic-rich mud. The underlying gravel is 4.2 m thick and overlies sand that is rich in coniferous wood and at least 1.4 m thick; colluvium covers the section below this point. The sand may be part of the Sagavanirktok Formation.

Gravel along the tops of ridges in the Marsh Creek anticline is the older of the two gravel sheets based on inclusion of metamorphic clasts and other rock types not typical of the younger gravel sheet. In stratigraphic sections MMD2-30 and MMD2-25 (sheet 6), which are on the north and south limbs of the Marsh Creek anticline, respectively, the older gravel overlies marine sediments of the Gubik Formation, which in turn overlie silty sand of the Sagavanirktok Formation. The Gubik Formation marine sediments in section MMD2-30 consist of 3 m of sand underlain by 2 m of silt; both the sand and silt contain marine shells.

Specimens of *Astarte borealis* (sample MMD2-30A) from the silt were analyzed for aspartic acid and other amino acids, and for aIle/Ile; the aspartic-acid D/L ratio is 0.2544 +/- 0.0016, and some other acids are absent, suggesting an old age. The free (naturally hydrolyzed) and total (free plus peptide bound) acid hydrolysate fractions in each of three *Astarte* valves were analyzed and yielded the aIle/Ile ratios given in table 5.2.

Table 5.2 Results of amino-acid analysis on *Astarte borealis* (sample MMD2-30A). Analyses were conducted by staff of the University of Alberta.

Sample No.	Lab No.	Free	Total
MMD2-30A	UA 1781A	0.721 +/- 0.039	0.080
	UA 1781B	0.681	0.139 +/- 0.008
	UA 1781C	0.643	0.120

Despite the high aIle/Ile ratio of the free hydrolysate fraction of sample UA 1781A, the aIle/Ile ratio of the total hydrolysate fraction indicates an age equivalent to the Fishcreekian type section. The 0.139 and 0.120 aIle/Ile ratios of the total fractions of lab samples UA 1781B and UA 1781C indicate a Bigbendian age, suggesting that the specimens are probably reworked (J. Brigham-Grette, written communication, 1986). These ages agree with separate amino-acid analyses previously conducted on shells from this locality (Carter, personal communication, 1985).

The older of the two gravel sheets, then, postdates the Fishcreekian transgression, which perhaps occurred between 1.87 and 2.48 Ma ago. Wood from the older of the two gravel sheets at localities MMD2-27 and MMD2-9 is coniferous. Wood (sample MMD2-9A) from the second of these localities yielded an aspartic-acid D/L ratio of 0.0802 +/- 0.0016. Nonconiferous wood (sample MMD2-11A) from silt underlying the old gravel at locality MMD2-11 yielded an aspartic-acid D/L ratio of 0.0379 +/- 0.0011. Such low ratios in obviously old samples based on stratigraphic position suggest bacterial attack or other modification. Wood from the Nuwok Member of the Sagavanirktok Formation in section MMD2-8 is nonconiferous. The single wood sample (MMD3-12A) analyzed from the younger gravel sheet yielded an aspartic-acid D/L ratio of 0.0471 +/- 0.0026; this sample too has probably been subjected to bacterial attack or other modification.

Significant Findings, Implications, and Interpretations

Geologic mapping, observations, and analysis of samples from fluvial sediments across the study area collectively allow interpretations regarding or relating to drainage history, vegetation and climate, correlation of sediments, and tectonism.

Drainage History

Alluviation in the Prudhoe Bay area and presumably in nearby areas has been ongoing since the Tertiary Period as shown by nearly 500 m of alluvium overlying Cretaceous bedrock (Sohio Alaska Petroleum Company, 1982).

In addition to obvious sources of sediments in the area between the Colville River and the Canning River fan, Tertiary uplands to the south and drainage basins of the Kuparuk, Sagavanirktok, Kadleroshilik, and Shaviovik Rivers, sediment may have been derived from the Colville River drainage basin. On the basis of terraces identified on aerial photographs and satellite images, Cannon and Rawlinson (1979) hypothesized that the Colville River once continued its northeastward trend south of the White Hills and Franklin Bluffs uplands and drained across the Coastal Plain, rather than turning northward near Umiat as it does today. This drainage was hypothesized to first drain across the Coastal Plain in the vicinity of the modern Kadleroshilik and Shaviovik River drainages, and later in the vicinity of the Sagavanirktok River drainage.

Such a former trend of the Colville River was corroborated by Carter and Galloway (1985b), who mapped an extensive gravel terrace along the Colville River near Umiat that can be traced eastward to where it merges with the gravel surface across which the Kuparuk River now flows. Capture of the Colville River and later the Itkillik River by north-flowing streams northeast of Umiat resulted in abandonment of the eastward channel (Dinter and others, 1987). The time of capture probably postdates the early Pleistocene Anaktuvuk River glaciation because major downcutting on tributaries of the Colville River west of the Anaktuvuk River postdates this glacial advance (Hamilton, 1986b). The probable post-Fishcreekian age of the highest alluvial terrace east of the Colville River corroborates an early Pleistocene age for the time of stream capture.

Surface morphology identified on aerial photographs and satellite images further suggests a complex drainage history for the area between the Kuparuk and Sagavanirktok Rivers. Sheet 3 shows cross-cutting relationships of streams in this area. Drainage from the Sagavanirktok River area appears to have once flowed northwest to the Kuparuk and Putuligayuk drainages. The present Putuligayuk River is underfit relative to the size of the flood plain and associated terraces, which near the mouth at Prudhoe Bay are collectively 4 km wide, essentially the width of Prudhoe Bay (sheet 3). The width of these terraces suggests that they are more the result of greater drainage from the Sagavanirktok River area than of drainage solely from the Putuligayuk River basin. Analysis of the compositions of clasts in the Putuligayuk and Sagavanirktok drainages has not been done to test this hypothesis. Further, correspondence of the terrace width with the width of Prudhoe Bay suggests that the formation of Prudhoe Bay is related to the terrace sediments (Cannon and Rawlinson, 1979). Prudhoe Bay may have started as an estuary of a larger stream, or may have formed from preferential erosion of the terrace sediments, or both.

The time when the Sagavanirktok River drained into the Kuparuk and Putuligayuk drainages may be indicated by dates obtained for the organic-rich, fluvial beds exposed deep in the gravel pits along the Putuligayuk River. These dates suggest active alluviation in that area back to the Sangamonian Interglaciation.

Probable Pelukian marine sediments exposed at depth near the mouth of the Putuligayuk River may push the time of drainage from the Sagavanirktok River area to pre-Sangamonian. An embayment in which these sediments were likely deposited may have been an early Prudhoe Bay formed from preferential erosion of the terrace sediments, or an estuary of a larger river. The latter interpretation would also have terrace sediments in place at the time of the Pelukian transgression.

On the basis of amino-acid analysis of wood exposed near the base of the SAG C, END, KUP, and MP gravel pits, deeper sediments in the Sagavanirktok River drainage and perhaps underlying most of the area between the Kuparuk and Sagavanirktok Rivers, correlate with the Ugnuravik gravel exposed deep in the KUP and MP pits. The probable exception is the Putuligayuk River drainage, as suggested by radiocarbon, thermoluminescence, and amino-acid dates. Although most of the deposits in these areas are correlative, and perhaps date to the middle Pleistocene or older, no coniferous wood has been found in the gravel pits along the Sagavanirktok or Putuligayuk Rivers.

Coniferous and Nonconiferous Wood

During at least part of the time that the Ugnuravik gravel was deposited, both *Larix* and perhaps *Salix* were growing north of the Brooks Range, suggesting a climate much like that of interior Alaska today. The wood-rich zones in these sediments tend to be associated more with oxidized beds, supporting association of the wood with a warmer climate. If nonoxidation of some beds implies freezing soon after deposition and a continuous frozen state since that time, the stratigraphic section records alternating conditions conducive and not conducive to development of permafrost.

Hopkins (personal communication, 1985) suggested that because *Larix* seems to be an important palynomorph in sediments associated with the Fishcreekian transgression, *Larix*-bearing sediments in the Kuparuk and Milne Point oil fields may be of that age. The probable cross-cutting relationship of sediments in the Kuparuk oil field with sediments in Terrace C on the east side of the Colville River argues against this interpretation and suggests that the oil-field sediments are younger than Fishcreekian. Reworking of Fishcreekian sediments could have contributed *Larix* to sediments of the Kuparuk and Milne Point oil fields; however, the apparent abundance of this taxon argues against this interpretation. Amino-acid analysis suggests a minimum relative age of middle Pleistocene.

Growth of certain taxa in specific areas, perhaps controlled by local microclimates, is one alternative to reworking of older sediments to provide coniferous wood to fluvial or glaciofluvial sediments in the Kuparuk and Milne Point areas. Presumably, microclimates are responsible for stands of nonconiferous trees in a few modern North Slope drainage basins. This alternative falters when considering the modern distribution of *Larix* in Alaska. Today *Larix* is restricted to moist soils in drainages north to the Brooks Range and south to the Alaska Range (Viereck and Little, 1972), indicating less tolerance to dry soils and cold than *Salix*. The distribution of *Larix* and *Salix* wood in the gravel pits suggests that *Larix* and *Salix* were concurrently present on the Coastal Plain, except in the Sagavanirktok and Kuparuk drainages, where *Larix* was not present. This distribution is opposite that expected based on the modern distribution of these taxa in Alaska.

Perhaps the best alternative explanation for the apparent lack of *Larix* in sediments exposed deep in the area between the Kuparuk and Sagavanirktok Rivers is that sediments there are younger than sediments in the adjacent area to the west, and were deposited during a warmer, moister climate. The correlation based on amino-acid analysis is sufficiently wide that sediments exposed in the KUP and MP pits could be older than sediments exposed in the SAG and END pits. This interpretation implies that coniferous trees, including *Larix*, were growing on the Coastal Plain later than suggested by other investigators (Ager and Brubaker, 1985).

The presence of tree taxa, but especially *Larix*, deep in any of the gravel pits presents a paradox: how could locally warmer temperatures necessary to establish tree taxa on the Coastal Plain coexist with the colder global temperatures associated with lower sea level? Assuming that the gradient of the Coastal Plain has not varied significantly since the early Pleistocene, or perhaps as far back as the Fishcreekian, sea level would have to be lower by at least the same depth as wood in the pits; that is, between 10 and 15 m.

Carter and others (1986b) may provide a solution to the paradox. These investigators concluded that 85 percent of the period since Fishcreekian time has been dominated by cold climates. Fifteen percent of that period, however, was brief intervals (5 to 10 ka) of climate as warm as or warmer than today. The time required for tree taxa to move into an area following climatic amelioration is on the order of hundreds of years (Haugen and others, 1971; Viereck and Van Cleve, 1984); whereas, the time required for sea level to respond to climatic change is greater. On the basis of the Bermuda sea level curve, sea level rose from minus 121 +/- 5 m during the last glacial maximum to near the present level at rates between 4 and 24 m/ka (Fairbanks, 1989). Additionally, even though the mean annual temperature was low, exposure of the continental shelf could have resulted in a more continental climate with summers warmer than present. The northern limits of tree species of *Larix*, *Betula*, *Alnus*, and *Salix* are largely controlled by threshold amounts of accumulated summer warmth (Hopkins and others, 1981c). Thus, during brief warm intervals, especially during the summer months, these tree taxa could have been established while sea level rose only a small amount.

Correlation of Rolling Thaw-lake Plains

Coastal Plain sediments between the Sagavanirktok River and the western edge of the Canning River fan are thought to be approximately equivalent in age to sediments west of the Kuparuk River west terrace. Only a minimum radiocarbon date (>34.8 ka, at minus 7.4 m, sample BPA3-13D) and a thermoluminescence date (36.8 +/- 4.0 ka, at minus 5.7 m, sample BPA2-13J) are available for sediments deep below the surface east of the Sagavanirktok River. These dates are associated with eolian or fluvial sands that either overlie or probably overlie sandy gravel and gravel. Abundant wood and old dates reported from the Kuparuk and Milne Point areas are associated with sandy gravel and gravel that underlie the eolian or fluvial sandy sediments.

Most gravel pits west of the Kuparuk River have been sited adjacent to existing streams after extensive exploratory borehole programs for gravel resources. These preferred sitings may indicate that sediments exposed in the pits were deposited by streams coincident with modern streams. This interpretation implies that sediments of the Coastal Plain between the streams may be different from in the pits. However, KUP D pit is an exception to siting adjacent to existing streams. The stratigraphy of this pit, along with proprietary borehole logs, suggest that the Coastal Plain between the streams in the area is not significantly different.

Surface morphology also suggests correlation of sediments west of the Kuparuk River with those east of the Sagavanirktok River. Both areas are rolling thaw-lake plains and exhibit numerous broad-based mounds. Broad-based mounds in the area between the Sagavanirktok River and the Canning River fan are abundant near the base of upland Tertiary sediments (Walker and Acevedo, 1987; sheets 3 and 4). The number of these mounds decreases northward. North of an imaginary line where marine sediments perhaps are present in the subsurface, mounds are either not present or only a few are present. Only one such mound was mapped in this study north of this line; this occurrence is between the Sagavanirktok and Kadleroshilik Rivers. Walker and Acevedo (1987) mapped five broad-based mounds in this area and one between the Kadleroshilik and Shaviovik Rivers. The distribution of the mounds east of the Sagavanirktok River suggests that marine inundation or the presence of marine sediments, or both, might have some relation with the distribution of the mounds.

Gravel Sheets and Tectonism

Because the Fishcreekian marine sediments and the overlying gravel were uplifted in the Marsh Creek anticline, the range of 1.87 to 2.48 Ma (Carter and others, 1986a) or possibly 1 to 1.5 Ma (Kaufman and others, 1990; J. Brigham-Grette, personal communication, 1990), is a maximum age for uplift of the anticline, and presumably for deformation and uplift of terrain to the south. The concept of recent and rapid uplift in the area was initiated by L. David Carter based on his USGS geological mapping program in ANWR. Carter will likely publish his concept with considerably more data than presented here and may or may not concur with this preliminary interpretation of age and extent of uplift.

A series of five terraces in the Katakturuk River canyon in the Sadlerochit Mountains provides further evidence of recent rapid uplift in the ANWR. The Katakturuk River is an antecedent stream that flows from Ignek Valley south of the Sadlerochit Mountains, through the Sadlerochit Mountains, and onto the Coastal Plain of ANWR. The highest of the terraces is approximately 95 m above the river flood plain and capped by the younger of two gravel sheets. On a profile roughly parallel to the Katakturuk River, this terrace falls along the slope angle of the highest terrain between the mountain front and the southern apex of a fan-shaped, gravel-covered bedrock surface between the Katakturuk River and the east fork of the Tamayariak River; the terrace and bedrock surface were presumably once connected (figure 5.16). Thus, since deposition of the younger gravel, the Sadlerochit Mountains have been uplifted as much as 95 m. The older gravel, which is present east of the Katakturuk River, may be from sources south of the Sadlerochit Mountains.

Southwest- to northeast-trending linear features identified on aerial photographs between the Kuparuk River and the Sagavanirktok River (sheet 3) and in several areas within ANWR (sheets 4 and 5) suggest structural instability during Holocene time. Although ground investigation showed no indication of such features south of Prudhoe Bay, the possibility of recent tectonism there should not be dismissed. Such tectonism could

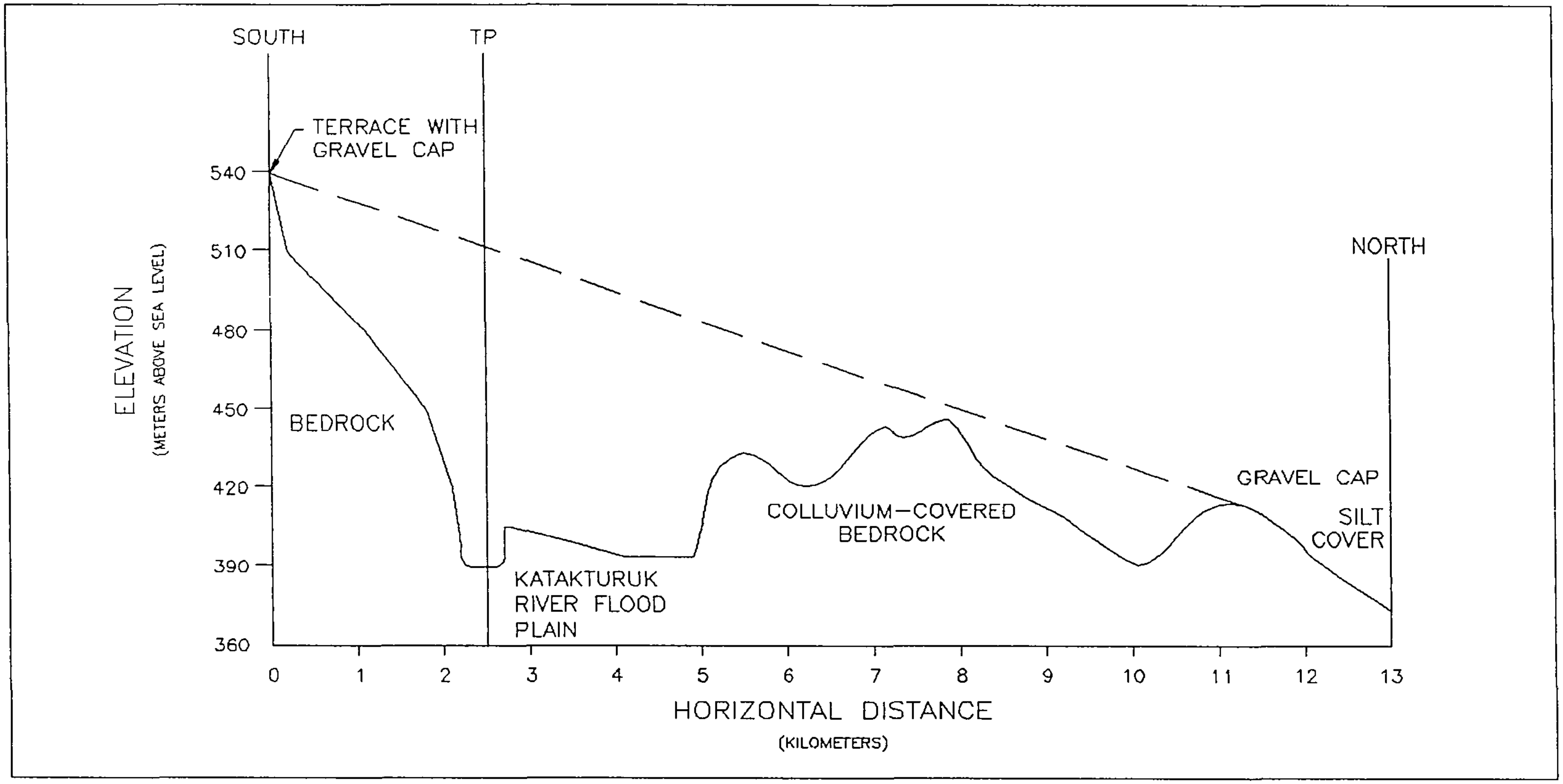


Figure 5.16 Profile of terrain west of the Katakturuk River in the Sadlerochit Mountains and northern Foothills, showing positions of a gravel-capped terrace and surface capped with gravel. Dashed line suggests past slope of surface and TP refers to a turning point in the profile.

account for possible subsidence in the Prudhoe Bay area since at least Sangamonian time as suggested by the minus-9-m elevation of Pelukian sediments in the PUT 2 pit.

CHAPTER 6 - GLACIAL SEDIMENTS OF THE GUBIK FORMATION

Introduction

Glacial sediments in the central Brooks Range have been studied in considerable detail by personnel of the USGS. Presumably correlative glacial sediments occur within or near the study area. These correlative sediments had previously received only reconnaissance study, essentially only small-scale mapping of the distribution and general descriptions of the characteristics. Detail is still lacking because of the enormity of the task of interpreting complex glacial sediments over this broad area.

With the exception of erratic boulders, unequivocal till is present in the study area only in the vicinity of the Sadlerochit Mountains. Elsewhere within the study area, erratic boulders and diamicton sediments hint at one or possibly two pre-Quaternary glaciations that extended well beyond the previously identified maximum limit of glacial advance on the Arctic Coastal Plain.

Glacial Episodes in the Brooks Range

Hamilton (1986a, 1986b) discussed four major glaciations in the Brooks Range and Foothills based primarily on investigations of till complexes and erratics in the central part of the range. Each glacial phase was apparently separated by long periods of weathering and erosion, as the degree of denudation of each till complex is distinctly different. Multiple glacial advances presumed to have occurred during each of the four glaciations are only distinguishable among the younger till complexes.

Gunsight Mountain Glaciation. Hamilton (1979a) informally named the Gunsight Mountain glaciation for localized till with little topographic expression and erratic boulders near Gunsight Mountain on the north side of the Brooks Range (figure 1.1). The erratic boulders are present on pediments and uplifted plateaus, according to Detterman and others (1963) up to 25 km north of the limits of recognizable Pleistocene till; Gunsight Mountain till, therefore, is considered to be late Tertiary. The boulders are generally found weathering from alluvial gravel in which they were redeposited during a long period of stream erosion and pedimentation. During that time, stream courses north of the Brooks Range stood 50 to 100 m above present levels (Hamilton, 1986a). Surfaces formed by erosion after the Gunsight Mountain glaciation are related to extinct tributaries of the Colville River (Hamilton, 1986a), when it flowed from near Umiat eastward toward the Kuparuk and Sagavanirktok drainages.

Anaktuvuk River Glaciation. Detterman (1953) named the Anaktuvuk River glaciation for erratic boulders and till with subdued, yet easily recognizable morainal topography that extend 65 km north of the range along the Anaktuvuk River (Hamilton, 1986b). Till of this glaciation is considered to be early Pleistocene (Hamilton, 1986a). Extensive moraines are continuous but subdued and show mature drainage and complex lake basins (Hamilton, 1986a). Till in the terminal moraine at the type locality is covered with silt and few erratic boulders are exposed (Hamilton, 1986b). Drainage channels in the Brooks Range during the Anaktuvuk River glaciation were approximately 100 m higher than modern channels. Subdued and discontinuous scarps visible on aerial photographs of terrain east of the headwaters of the Miluveach River (sheet 2) are perhaps also related to this elevated drainage.

Sagavanirktok River Glaciation. Detterman (1953) named the Sagavanirktok River glaciation for till with morainal topography that extends approximately 50 km north of the Brooks Range along the Ivishak River, which on older maps was incorrectly labeled the Sagavanirktok River (Hamilton, 1986b). Till of this glaciation is considered to be middle Pleistocene and was deposited after a long period of valley enlargement and pedimentation that followed the Anaktuvuk River glaciation (Hamilton, 1986a). Some valleys contain two distinct sheets of till, which are thought to have been deposited early and late during the Sagavanirktok River glaciation. Moraines of the Sagavanirktok River glaciation, although subdued by mass wastage, retain much of the original topography and have immature drainage. Erratic boulders are also more prevalent than on older till (Hamilton, 1986a).

Itkillik and Walker Lake Glaciations. The fourth major glaciation occurred in the late Pleistocene and included two distinct advances, the older of which is termed the Itkillik glaciation (Detterman, 1953; Detterman and others, 1958), while the younger is designated the Walker Lake glaciation (Fernald, 1964). The Walker Lake glaciation is equivalent to the Itkillik II and late Itkillik II glacial phases of Hamilton and Porter (1975) and Hamilton (1979a). Tills of these glaciations are generally little eroded and can be distinguished from each other based on soil development, the degree of solifluction, and sharpness of morphology. Moraines of Itkillik glaciation till are oxidized to 1 m below the ground surface where drainage is good, and have been modified by solifluction and formation of patterned ground; whereas moraines of Walker Lake age show negligible solifluction and in many locations are still cored with ice (Hamilton, 1986a).

Hamilton (1979a, 1982) showed that the Itkillik glaciation is older than 50 ka. The glaciation is suspected to not be older than early Wisconsinan because some of the till included ice until the Holocene and some mountain valleys in the Brooks Range retained glacial ice between the Itkillik and Walker Lake glaciations. Radiocarbon dates of organic material in till of the Walker Lake glaciation are late Wisconsinan, ranging from 29 to 11.5 ka (Hamilton, 1986a).

Sediment Distribution, Character, and Age

Sadlerochit Mountains Area

Glacial till is unequivocally present within the study area in the vicinity of the Sadlerochit Mountains (figure 6.1). Four distinctive moraines are present within or associated with the Canning River drainage west of these mountains and are presumed to correspond to the four Pleistocene glaciations recognized elsewhere in the Brooks Range. The oldest two moraines, presumably from the Anaktuvuk River and Sagavanirktok River glaciations, extend into the study area (Carter and others, 1986c; Robinson and others, 1989; sheets 4 and 5). The extent of the Itkillik (?) moraine adjacent to the west of the Canning River, as indicated by Robinson and others (1989), is now thought to be about 2 km too great; the moraine actually extends about as far north as on the east side of the river.

Tills presumably from the Anaktuvuk River and Sagavanirktok River glaciations are also present within Ignek Valley between the Sadlerochit and Shublik Mountains to the south, and within the Sadlerochit and Hulahula River drainages east of these mountains as isolated outcrops and well-defined moraines. Robinson and others (1989) indicated that the oldest two moraines in the Sadlerochit and Hulahula River drainages presumably correspond to the Sagavanirktok River and Itkillik River glaciations. However, these moraines more likely correlate with the Anaktuvuk River and Sagavanirktok River moraines

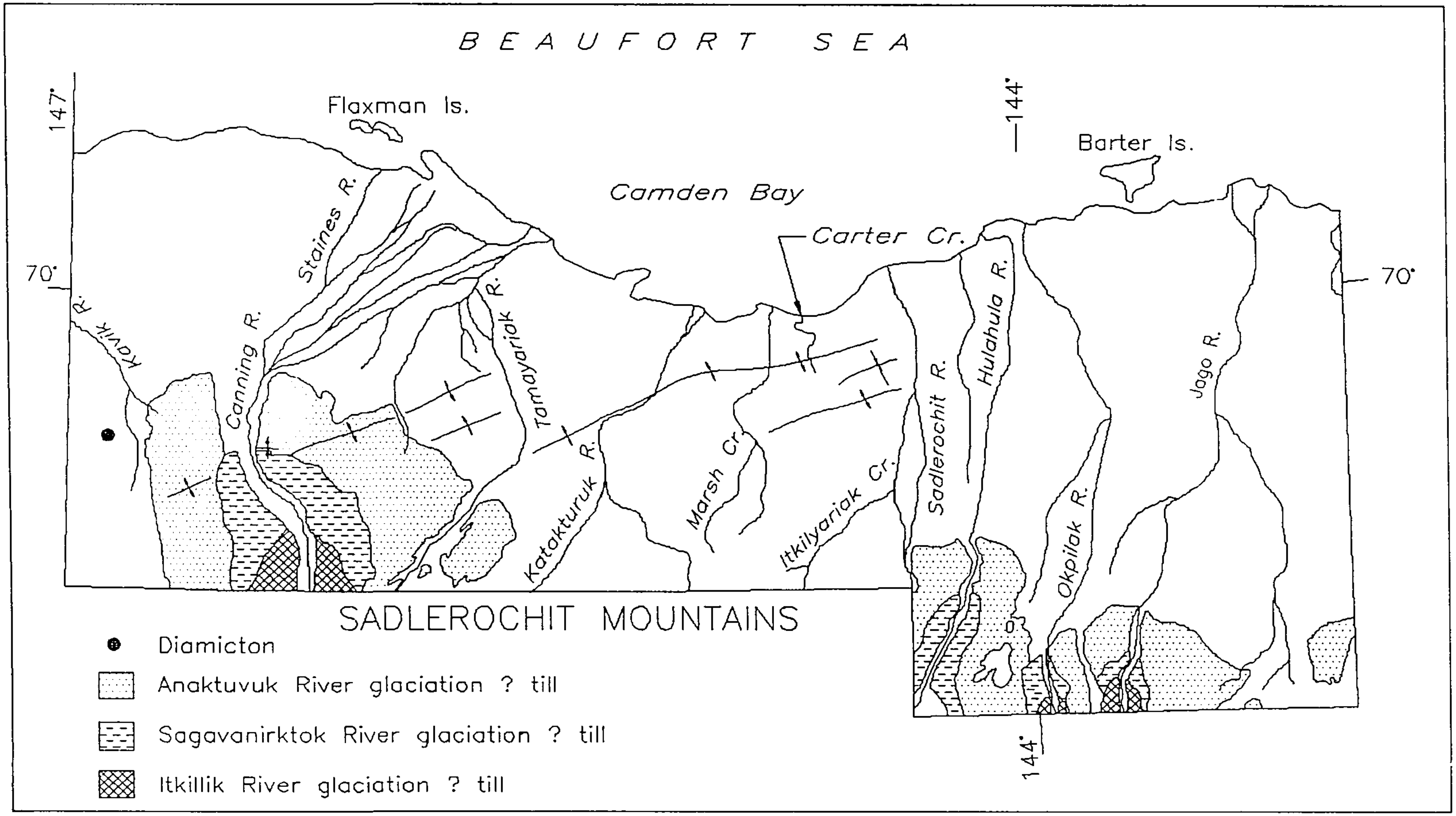


Figure 6.1 Map showing locations of glacial sediments in the vicinity of the Sadlerochit and Shublik Mountains. The location of erratic boulders in this area is shown on figure 1.3.

in the Canning River drainage based on similar morphology and extent.

Tills of the Anaktuvuk River and Sagavanirktok River glaciations are not well exposed in the study area in the Canning River drainage. Cuts made into these tills by the Canning River and tributaries are generally colluviated and vegetated. As with moraines of this presumed age in the central Brooks Range (Hamilton, 1986b), eolian, colluvial, and in some places lacustrine silts fill topographically low areas. However, the sediments are well exposed in sections MMD4-11 and MMD4-9, both of which are within the Anaktuvuk River till (figure 6.1 and sheet 5).

Section MMD4-11 is 12 m of till with the exception of a zone of bedded silt in the middle of the section that may represent intercalated ice-contact lacustrine sediments. This silt, collected 5.8 m above the Canning River flood plain by Carter and Rawlinson in 1985, has normal magnetic polarity (L. David Carter, personal communication, 1986).

Section MMD4-9 is lacustrine silt overlying probable ice-contact lacustrine sediments (figure 6.2). The topmost lacustrine silt varies in thickness up to 5 m and unconformably overlies the ice-contact sediments. Peat (sample MMD4-9A) from the base of the upper lacustrine silt yielded a radiocarbon date of 9.640 +/- 0.510 ka (GX 11746), indicating that the silt probably represents an early Holocene thaw lake that formed in a depression in the moraine. The underlying probable ice-contact lacustrine sediments are sandy gravel with tillstones and other clasts up to 0.6 m in diameter with zones of bedded silt. Peat (sample MMD4-9C) from a 0.6-m-thick silt about 2 m below the contact with the upper lacustrine silt (7 m below the surface) yielded a radiocarbon date of >25 ka (GX 11745).

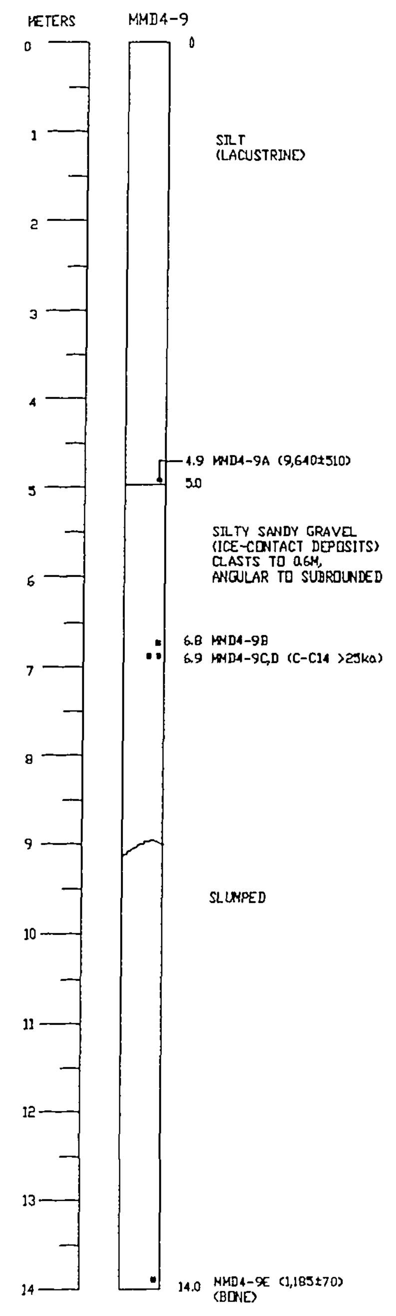


Figure 6.2 Stratigraphic section MMD4-9 measured along the east bank of the Canning River, showing lacustrine silt overlying probable ice-contact lacustrine sediments. The small black squares represent samples; sample numbers are adjacent to the right (e.g., MMD4-9A). All dates are radiocarbon; C14 denotes radiocarbon. The location of this section is shown on sheet 5.

Slope failure below where the peat was sampled precludes further stratigraphic inferences. Bones, including a 0.2-m-long femur (sample MMD4-9E), scattered on top of the slumped deposits were initially thought to be from those deposits. The femur, however, yielded a radiocarbon date of 1.185 +/- 0.070 ka (GX 11937), which suggests that it was derived from the upper lacustrine silt.

Probable pre-Pleistocene erratic boulders, some 2 m in diameter, are present several kilometers south of the Kavik River airstrip in the hills west of the Kavik River (figure 6.1). Approximately 16 km north of Kavik River airstrip, diamicton sediments crop out on an upland at locality MMD5-3 (sheet 4). The sediments north of Kavik airstrip consist of iron-stained gravel, chiefly deeply weathered pebbles and cobbles of sandstone, in a muddy matrix.

Kachemach and Miluveach Rivers Area

Carter (1983b) first reported erratic boulders within and south of the study area in the headwater basins of the Miluveach and Kachemach Rivers. These erratic boulders occur in the Kuparuk gravel, which may be till or alluvium into which the erratics have been redeposited. One erratic boulder of chert-pebble conglomerate is 10 m in diameter. David M. Hopkins (personal communication to L. David Carter, 1986) suggested that this boulder may not be an erratic, but formed by secondary cementation of in-place gravel (Carter, personal communication, 1987). Whether the boulder is an erratic is unknown; if it is eventually determined to be so, the till versus alluvium origin of the Kuparuk gravel will be resolved because a boulder of that size certainly exceeds the competence of nearly all streams.

The Kuparuk gravel is truncated by Colville River marine Terrace A. However, erratic boulders occur as erosional lag at least 10 km north of the southern Terrace A scarp, indicating that glacial ice extended to within 30 km of the present coast (Carter and Galloway, 1985a; Dinter and others, 1987). When this glacial advance occurred is uncertain. The maximum age is established by Paleocene sediments that underlie the Kuparuk gravel; the minimum age is established by the late Tertiary Colvillian marine transgression, which occurred between 2.4 and 3.5 Ma ago and formed the Terrace A southern scarp. The Kuparuk gravel is further known to be older than fluvial terraces associated with the Gunsight Mountain glaciation (Carter and Galloway, 1985a; Dinter and others, 1987).

Significant Findings, Implications, and Interpretations

Pre-Pleistocene Till and Tectonism

Erratic boulders in the hills south of Kavik airstrip are well beyond the western limit of the early Pleistocene till in the Canning River drainage, but must have been associated with glaciers in the Canning River drainage because the Kavik River drainage basin seems too small to have supported such a large advance of glacial ice.

Whether pre-Pleistocene till was ever present in the study area north of the Pleistocene tills associated with the Canning, Sadlerochit, and Hulahula Rivers is unknown. However, the presence of erratic boulders west of Kavik River suggests that pre-Pleistocene till, perhaps in association with the Gunsight Mountain glaciation, may have been present in those areas. If so, that till has since been covered or reworked. Further, outwash from pre-Pleistocene glaciation probably represents much of the older subsurface parts of the

Canning River fan and adjacent areas, and of fans associated with the Sadlerochit and Hulahula Rivers.

Diamicton sediments in the upland north of Kavik airstrip have always been assumed to be older Tertiary because of the deformation, deep weathering, and iron staining. Outwash sediments covered with silt occur north of these diamicton sediments. The diamicton and outwash sediments have been uplifted and may be part of the north limb of an eroded anticline.

The upland is immediately north of the trend of an anticlinal axis that can be traced discontinuously from west of the Tamayariak River to west of the Canning River. The anticline has folded the Anaktuvuk River till, but not the Sagavanirktok River till in the Canning River drainage. Uplift of the anticline, and perhaps the upland north of the Kavik River airstrip, thus predates the middle Pleistocene Sagavanirktok River glaciation. Uplift of the anticline was likely initiated in the late Tertiary and continued through the early Pleistocene. Uplift of the upland during this time would not preclude association of the diamicton and outwash sediments exposed in the upland with the late Tertiary Gunsight Mountain glaciation or the earlier Tertiary glaciation with which the Kuparuk gravel is associated. Whether the diamicton is associated with the Gunsight Mountain glaciation, or is older Tertiary, has yet to be determined.

Anaktuvuk River Glaciation and the Olduvai Chron

On the basis of morphology and extent, the most extensive recognizable moraine in the Canning River drainage correlates to the early Pleistocene Anaktuvuk River glaciation.

Normal magnetic polarity of the sediments thus restricts the age to either the Olduvai or Jaramillo chrons. The Olduvai chron, which occurred between 1.72 and 1.88 Ma ago (Harland and others, 1982) seems more probable because of better representing early Pleistocene time; the Jaramillo chron occurred late in the early Pleistocene. Alternatively, the modern normal polarity may have over-printed an earlier polarity. Nonconiferous wood (sample MMD4-11B) from the slope about 2 m above the Canning River flood plain at this locality yielded an aspartic-acid D/L ratio of 0.0518 +/- 0.0003 (UA 1776). Such a low ratio in an obviously old sample based on stratigraphic position suggests bacterial attack or other modification.

CHAPTER 7 - EOLIAN SEDIMENTS OF THE GUBIK FORMATION

Introduction

Although eolian sediments are ubiquitous within the study area, they had received little study. In contrast, considerable attention has been given to eolian deposits in the Foothills of the Brooks Range and on the Coastal Plain west of the study area by personnel of the USGS. These USGS studies have resulted in interpretations on past climates that are certainly applicable to the study area.

Eolian sediments on the Coastal Plain range from loess and very fine sand in sheets, to fine and medium sand in sheets, dunes, and sand wedges. The loess and very fine sand are primarily present on the Foothills of the Brooks Range and adjacent inner edge of the Coastal Plain up to several tens of meters thick (Carter, 1988) and have been termed "Foothill Silt" (O'Sullivan, 1961) and "Upland Silt" (Williams and others, 1978; Carter and others, 1986c). With the exceptions of the coastal zone west of Harrison Bay and some Holocene alluvial terraces, the fine and medium sand is present elsewhere on the Coastal Plain up to several tens of meters thick (Dinter and others, 1987).

Eolian Sediments and Past Climates

Carter and others (1984) described four periods during the Wisconsinan and early Holocene of contrasting seasonal climate in Arctic Alaska based on studies of upland loess and of extensive sand deposits in NPRA, termed the Ikpikpuk dunes (e.g., Carter, 1981, 1983a,c). These periods emphasize eolian sand transport, soil development, and contrasting fluvial regimes, and roughly correlate with Beringian climatic periods defined by Hopkins (1982) (table 7.1).

Sediment Distribution, Character, and Age

Beechey Sand

Rawlinson (1986a) named as the Ugnuravik sand eolian sediments that overlie the Ugnuravik gravel in the KUP C gravel pit. Herein, to avoid confusion with the Ugnuravik gravel, the Ugnuravik sand is renamed the Beechey sand, after the Beechey Point Quadrangle where it is most widespread. The new term follows the old term in its application to widespread eolian sediments on the Coastal Plain between the Colville River and the westernmost terrace scarp of the Kuparuk River, between the Sagavanirktok and Shaviovik Rivers, and along the coast between the Shaviovik and Canning Rivers. Additionally, the new term applies to the area adjacent to the east of the Canning River, but north of the Pleistocene till, and to isolated areas near the coast and inland between the Kuparuk River and the east bank of the Sagavanirktok River. The isolated areas were not specified in Rawlinson (1986a), although they were shown in figure 11-1 of that report as being covered by the sand.

Figures 7.1 and 7.2 show envelopes of cumulative-frequency-percent curves or individual curves and a gravel-sand-mud plot, respectively, based on grain-size analysis of Beechey sand from gravel pits in the area between Kalubik Creek and the Kuparuk River, section BPA2-23 east of the Sagavanirktok River, and section MMD4-18 east of the Canning River (appendix E). The following textural categories are apparent: samples consisting

Table 7.1 Conditions during Wisconsinan and Holocene periods of contrasting seasonal climate recognized by Carter and others (1984).

	Period 1	Period 2	Period 3	Period 4
Chronology	? - 36 ka	36 - 13.5 ka	13.5 - 11 ka	11 - 8 ka
Hopkins (1982) Interval	Mid-Boutellier	Mid-Boutellier - Duvanny Yar	Early Birch	Late Birch
Temperature	Equal to or slightly less than present	Cold	Warming; warmer than present	Warmer than present
Precipitation	Drier than present; wetter than period 2; moderate snow cover	Drier than period 1 and present; patchy snow cover	Wetter than present	Drier than present
Flora	Abundant wood and organic debris; discontinuous shrub tundra on interfluves	Very little wood; dwarf birch gone	Abundant wood and organic debris	Abundant wood and organic debris
Fauna	-----	Herbivores prior to 28 ka; few remains between 28 and 14.5 ka	-----	-----
Eolian	Ikpikpuk dunes active; upland loess deposition	Eolian processes dominated landscape development; Ikpikpuk dunes upland loess deposition	Ikpikpuk dunes stable at 12 ka	Sand movement; sand sheet on much of Coastal Plain; ceased 8 ka ago
Drainage	----	Not through-flowing in Foothills	Through-flowing in Foothills	Through-flowing in Foothills
Other	Ice wedges; paleosols; ice-wedge pseudomorphs	Syngenetic ice wedges; sand wedges, most active late in period	Organic soil development; ice wedges initiated north and east of Ikpikpuk dunes	Organic soil development

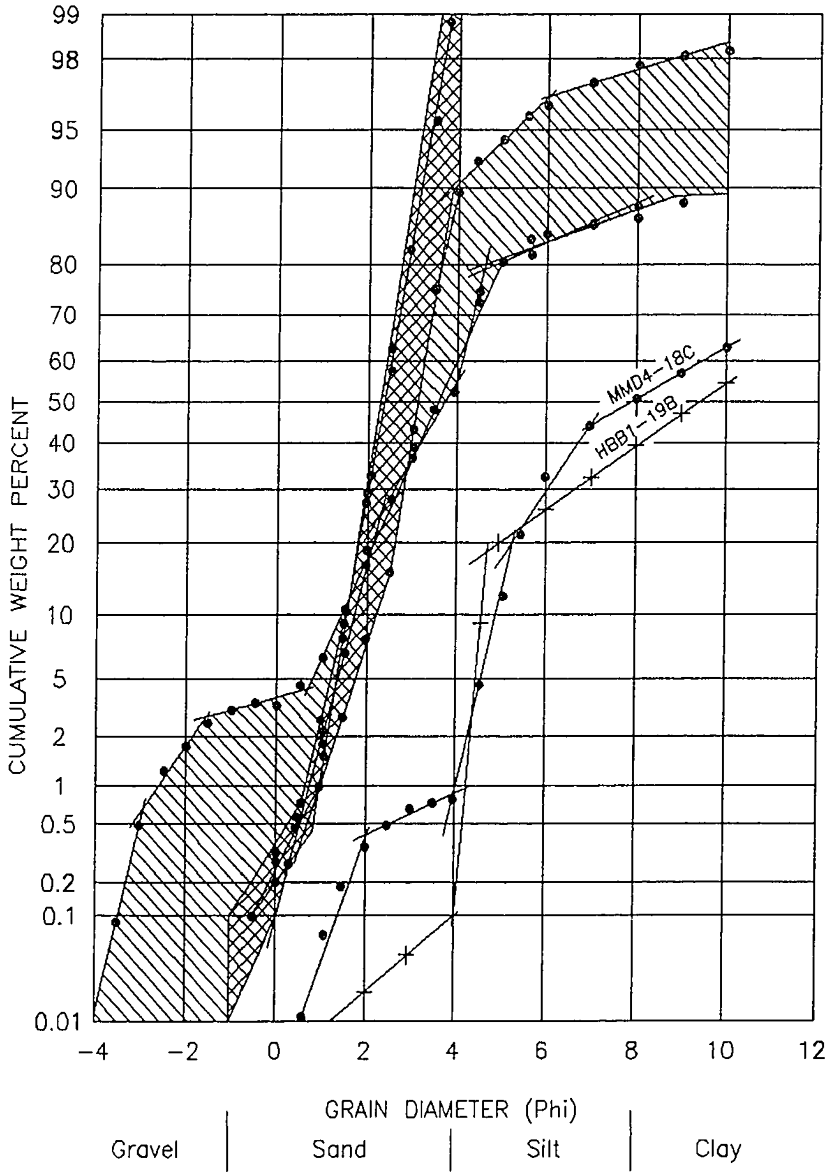


Figure 7.1 Envelopes of cumulative-frequency-percent curves for 11 Beechey sand samples and plots of curves for Beechey sand samples MMD4-18C and HBB1-19B. Most of the samples are sand with insignificant percentages of coarser and finer grains (cross-hatched pattern); some samples are sand with small percentages of coarser and finer grains (diagonal pattern); and samples MMD4-18C and HBB1-19B are gravelly muds. Locations of sections MMD4-18 and HBB1-19 are shown on sheets 5 and 1, respectively.

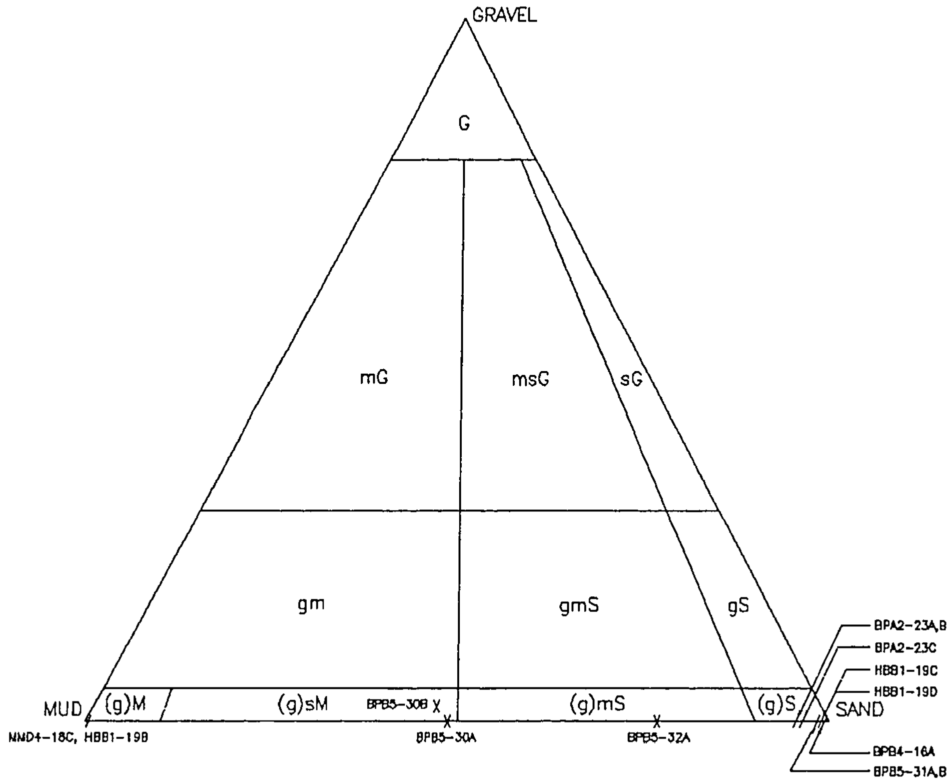


Figure 7.2 Gravel-sand-mud plot of Beechey sand samples shown in figure 7.1. G - gravel; sG - sandy gravel; msG - muddy sandy gravel; mG - muddy gravel; gS - gravelly sand; gmS - gravelly muddy sand; gM - gravelly mud; (g)S - slightly gravelly sand; (g)mS - slightly gravelly muddy sand; (g)sM - slightly gravelly sandy mud; (g)M -slightly gravelly mud; S - sand; mS - muddy sand; sM - sandy mud; M - Mud. Diagram and nomenclature are from Folk (1980).

dominantly of silt and clay; dominantly of sand and silt; and dominantly of sand. Samples of silt and clay typically have less than one percent sand, and samples of sand and silt generally include up to five percent of fine gravel. Amounts of silt and clay, and of sand and silt, respectively, in samples of the first and second categories, each vary between 40 and 60 percent of the total sample by weight. Eight of 13 samples (62 percent) of Beechey sand are composed of between 90 and 99 percent sand, most of which is fine or very fine; medium sand is present in lesser amounts and gravel may be present in trace amounts. The remaining five samples are either mud, sandy mud, or muddy sand, all of which but two have a trace amount of gravel. Gravel in the Beechey sand is typically polished or ventifacted and probably was introduced into the sand from underlying deposits by frost-related processes.

The silt and clay sample HBB1-19B occurs at the top of the inland KUP F pit, which also yielded two dominantly sand samples. The other dominantly sand samples are from the near-coast MP and KUP E pits. Thus, position within the area west of the Kuparuk River seems not to be a factor in determining the distribution of each textural category. The other silt and clay sample, MMD4-18C, is from a location on the east bank of the Canning River and may be representative of most eolian sediments in that area. Redeposited eolian sediments that overlie gravel sheets and outwash deposits east of the Canning River are qualitatively described as organic silt.

The Beechey sand is essentially barren of dateable organic materials, suggesting that when it was deposited conditions were not conducive to propagation or preservation of such materials. Such a time was the second climatic regime proposed by Carter and others (1984), which occurred between 36 and 13.5 ka ago (table 7.1). The few thermoluminescence dates of basal Beechey sand indicate that it was deposited primarily during the latter part of this climatic regime. Sample BPB5-32D from the base of the Beechey sand in the type section, 1.7 m below the surface, yielded a thermoluminescence date of 24.6 +/- 1.5 ka (ALPHA 2598). A similar thermoluminescence date of 26.0 +/- 2.9 ka (ALPHA 2602) was obtained from a basal eolian sand sample in section MMD4-18, adjacent to the east of the Canning River. There, the sand is 4.1 m thick and overlies sandy-gravel outwash.

Thermoluminescence analysis of probable fluvial sand (sample BPA2-13J) 5.7 m below the surface in section BPA2-13 yielded a date of 36.8 +/- 4.0 ka (ALPHA 1530). The dated sand is the lowest of several such beds interbedded with fine sandy gravel over a stratigraphic interval of 1.4 m. Eolian sand 3.4 m thick overlies this interval of interbedded sediments. A date for the basal part of the eolian sand is not available; however, the 1.4-m-thick interval between this sand and the dated horizon may account for the approximate 13 ka age difference of other basal Beechey sand samples.

Although of similar thickness, the 1.7-m-thick eolian sand exposed near the top of the KUP E gravel pit (figure 5.8, section BPB5-31; samples BPB5-31A and BPB5-31B) is apparently younger than the Beechey sand elsewhere. Silt (sample BPB5-31F) underlying this sand yielded a thermoluminescence date of 11.9 +/- 1.8 ka (ALPHA 1493), suggesting that the sand is Holocene. Eolian sand exposed near the top of MP gravel pit (figure 5.9, section BPB4-16) is only 0.5 m thick. No age data are available for this sand; however, underlying organic silt (BPB4-16B) yielded a radiocarbon date of >44.0 ka.

Upland Loess

Wide, unvegetated flood plains on the Coastal Plain during the Wisconsinan are undoubtedly responsible for much of the loess that mantles upland areas within and south of the study area. Radiocarbon and thermoluminescence dates from materials in stratigraphic sections south and west of the study area show that loess deposition was ongoing in the middle Wisconsinan, but was particularly active during the Walker Lake glaciation (Carter, 1988). Although no age information is available, silt that overlies gravel sheets and early Pleistocene till in ANWR is probably of equivalent age; much of this silt has been retransported and thus includes a large Holocene organic component.

Holocene Sand Deposits

Following stabilization of Coastal Plain eolian sediments approximately 8 ka ago, small parabolic and longitudinal dunes were deposited over the Ikpikpuk dunes west of the Colville River. This renewed sand deposition may have resulted from destabilization of the sand surface brought on by a cooler and drier climate associated with late Holocene neoglaciation in the Brooks Range (Dinter and others, 1987).

Similar Holocene dunes, some of which have been stabilized by vegetation or a thin tundra mat, are present within or downwind of nearly all the active river and delta systems and along the seaward edge of tundra-covered barrier islands that have a beach. Such deposits associated with the Sagavanirktok and Colville River Deltas are particularly well developed. Longitudinal dunes downwind of the Sagavanirktok River Delta and river flood plains are up to 4.5 km long and 6 m high, although most are smaller. These dunes and a veneer of sand downwind of the dunes locally fill thaw-lake basins and low-centered, ice-wedge polygons. Unstabilized dunes associated with the Sagavanirktok River Delta are commonly eroded into yardangs.

Dunes on the Colville River Delta occur as transverse ridges along the upwind margin of abandoned flood-plain surfaces adjacent to active channels. The longitudinal component of these dunes is relatively small, often because of spatial constraints. Examples of such a surface and overlying dunes are exposed at sections HBB2-4 and HBB1-2 (sheet 1). At section HBB2-4, eolian sand up to 5 m thick overlies 2 m of peat with interbedded fluvial sand. The eolian sand includes organic interbeds that indicate alternating periods of stability and renewed deposition, probably the result of channel migration. At section HBB1-12, 0.8 m of interbedded roots and peat overlies approximately 2 m of eolian sand, which in turn overlies 2.6 m of sandy alluvium. A lens of peat (sample HBB1-2A) in the alluvium 0.4 m below the contact with the eolian sand yielded a radiocarbon date of 7.440 +/- 0.100 ka (BETA 23739). This maximum age for the eolian sand is consistent with the concept of renewed eolian activity associated with Holocene neoglaciation.

Significant Findings, Implications, and Interpretations

Beechey Sand and Broad-based Mounds

A truncation of broad-based mounds 3 to 15 kilometers inland between the Colville and Kuparuk Rivers, and a similar truncation between the Sagavanirktok and Shaviovik Rivers may result from an insufficient thickness of Beechey sand near the coast (figure 5.5 and sheets 2 and 3). However, marine sediments, which are possibly part of the substrate between the Sagavanirktok and Shaviovik Rivers, may also be involved with the truncation in that area. The broad-based mounds contribute to the gently rolling thaw-lake plains of Walker and others (1985). Thus, the line of truncation also separates gently rolling thaw-lake plains from flat thaw-lake plains, contrary to mapping by Walker and Acevedo (1987).

Williams and others (1977) and Galloway and Carter (1978) indicated that pingos preferentially form in thaw-lake basins that have formed in ice-rich eolian sand or eolian sand that has been reworked by fluvial processes. Hopkins (personal communication, 1990) also suggested that pingos form readily when gravel (e.g., the Ugnuravik gravel) underlies such ice-rich sediments. Radiocarbon dates of basal organic material in thaw-lake sediments indicate that thaw lakes, and thus pingos, did not exist on the Coastal Plain prior to about 12 ka ago. On the basis of morphology and one borehole in a broad-based mound (C-60) east of the KUP C gravel pit (Brockett, 1982), many of the broad-based mounds apparently are true pingos and thus formed within lake basins that have subsequently been destroyed by younger thaw lakes. If the Beechey sand was sufficiently thick to preferentially support thaw lakes only south of the line of truncation in the latest Wisconsinan and early Holocene, that area might have been where thaw lakes first developed and consequently where the oldest of the pingos are now located.

Thermoluminescence dates and the absence of organic material in the Beechey sand indicate that the sand is late middle to late Wisconsinan. Relatively young eolian sand at the top of the KUP E pit (section BPB5-31) and the thin eolian sand at the top of the MP pit (section BPB4-16) suggest deposition later than most of the Beechey sand. The few broad-based mounds north of the line of truncation might be explained by isolated areas of early deposition of sand.

The orientation of the oldest of the Ikpikpuk dunes west of the Colville River shows that the wind direction has been northeasterly since at least the first climatic period proposed by Carter and others (1984). The geometry of the Coastal Plain undoubtedly provides sufficient area upwind to supply sand to the area south of the line of truncation and increasing thickness of sand at the foot of downwind uplands is expected.

Eolian sand deposited during the first climatic period discussed by Carter and others (1984) is apparently limited or absent east of the Colville River. Paucity of these sediments there suggests either that such sand was present and subsequently eroded, or that sand composing the early Ikpikpuk dunes was derived from the Colville River flood plain and delta, and areas to the east. The apparently long hiatus between deposition of the Ugnuravik gravel and the Beechey sand suggests that erosion rather than deposition has been the dominant process on interfluves east of the Colville River since the middle Pleistocene. Further, proximity of Foothill and mountainous areas to the coast and steeper topographic gradients east of the Colville River undoubtedly provided a setting conducive for braided outwash streams during the Wisconsinan; such streams still dominate the Coastal Plain east of the Colville River. The wide, typically unvegetated flood plains of braided streams are recognized to be sources of enormous amounts of eolian sand and loess, especially during glacial climates (Washburn, 1980).

CHAPTER 8 - LACUSTRINE SEDIMENTS OF THE GUBIK FORMATION

Introduction

Thaw lakes and associated sediments are ubiquitous on much of the Coastal Plain including the study area. These lakes have received considerable attention by previous investigators, especially in the vicinity of Barrow and on the western part of the Coastal Plain; this preferential attention is more related to proximity of the former Naval Arctic Research Laboratory rather than unique attributes of lakes at that location. Although simple in concept, an adequate description of the ideal and typical stratigraphic section through thaw-lake sediments had not been presented until recently (Hopkins and Kidd, 1988).

Water bodies on the Coastal Plain range from ponds several meters long to elongated lakes typically up to 15 km long and 5 km wide (Black and Barksdale, 1949). The depth of these lakes ranges from 0.6 to 6 m and is related to the volume of ice in the ground, local relief, and possibly the age of the basin (Sellman and others, 1975). Teshekpuk Lake, the largest lake on the Coastal Plain, is 40 km long and 28 km wide, and formed by coalescence of several large lakes. Flat surfaces underlain by fine-grained sediments that contain a high percentage of ground ice are conducive to development of large lakes (Sellman and others, 1975); such conditions exist in the area around Teshekpuk Lake.

Thaw-lake Cycle

A thaw-lake cycle originally presented by Britton (1957) is fundamental to development of the regional landscape of the Coastal Plain. Through the thaw-lake cycle, lakes tend to form, drain, and reform in different places over the Coastal Plain, resulting in an overall lowering of the ground surface from loss of ground ice. Billings and Peterson (1980) elaborated on the thaw-lake cycle by noting: (1) emergence of the Coastal Plain sediments; (2) development of permafrost; (3) formation of thermal contraction cracks in permafrost; (4) growth of ice wedges; and (5) development of low-centered, ice-wedge polygons (figure 8.1).

Formation of thaw lakes is related to melting of permafrost, which can be caused by disruption of the vegetation mat by mass movement, the action of wind or water, or accelerated thaw beneath pools at intersections of ice wedges or the centers of ice-wedge polygons (Hopkins, 1949; Billings and Peterson, 1980). Pools of water coalesce by thawing to form thaw ponds; once formed, they continue to enlarge by thawing and slumping at the pond margins. Most shorelines of the ponds and lakes are scalloped because of preferential erosion along ice wedges. Wave erosion of thawed banks becomes an important process after the lake has attained a diameter of about 30 m (Hopkins, 1949; Black, 1969).

In flat, undissected terrain, expansion of the lake by thaw and erosion removes interlake divides, resulting in coalescence of lakes. In dissected or rolling terrain, lakes usually expand into lower ground. Expansion of a given lake continues until drainage lines open and the lake is partially or completely drained. A surface pattern of ice-wedge polygons rapidly develops in the drained basin if previously existing ice wedges were not completely

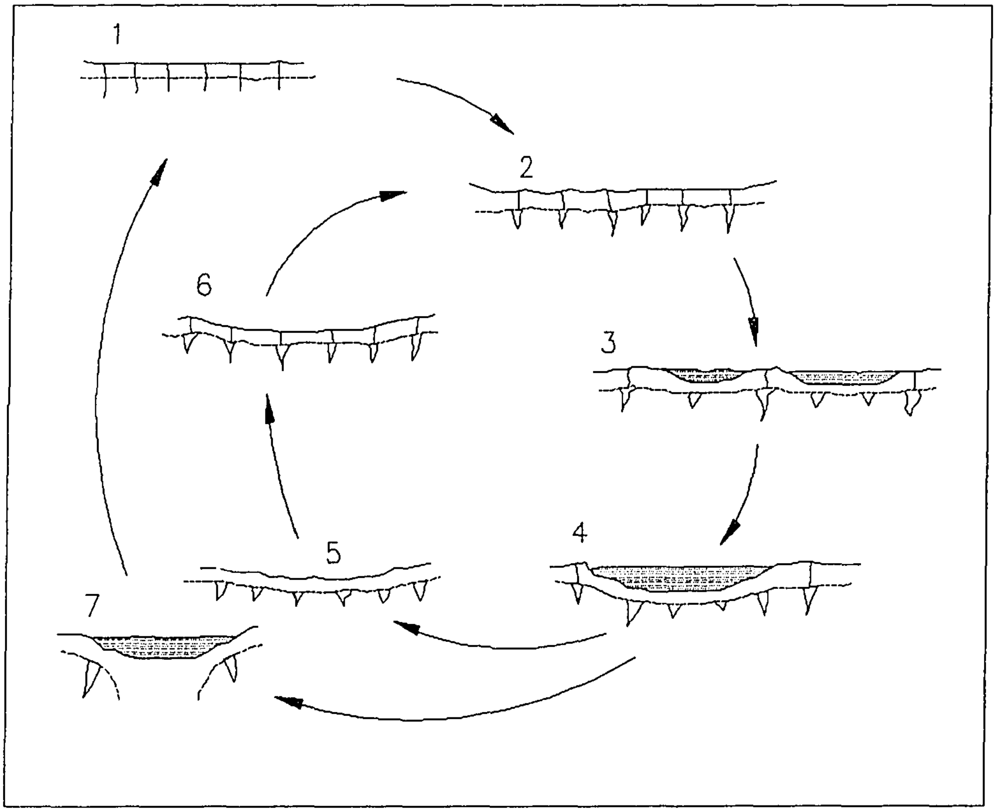


Figure 8.1 Diagram of the thaw-lake cycle: (1) newly exposed sediments develop thermal-contraction cracks in permafrost, the top of which is shown by the dashed line; (2) ice wedges and low-centered, ice-wedge polygons develop in the sediments; (3) thaw ponds form by erosion and coalescence of low-centered, ice-wedge polygons; (4) a mature, but shallow thaw lake with benches; polygons remain visible on the benches because of persistence of ice wedges; (5) a drained, shallow thaw lake; (6) a shallow thaw-lake basin in which old ice wedges are re-established; (7) a deep, large thaw lake with underlying thaw bulb. Diagram is modified from Billings and Peterson (1980).

thawed earlier in the cycle (Walker and others, 1980). In lakes less than 2 m deep, where seasonal ice freezes to the bottom, incomplete thawing may result; conversely, a perennial thaw bulb rapidly develops under lakes sufficiently deep to have water present all year. Even when ice wedges are completely thawed, permafrost and ice-wedge polygons are eventually re-established in the basin. Subsequent thawing of these ice wedges and permafrost, and displacement of the soil, results in a pool of surface water that may eventually become another lake.

Orientation of Thaw Lakes

Elongated thaw lakes on the Arctic Coastal Plain are generally oriented between 9 and 21° west of north (Rex, 1961). Cannon and Rawlinson (1979) reported that lakes in the Prudhoe Bay area are oriented 10° west of north. Field observations, hydrodynamic theory, mathematical and experimental models, and wind records most support the concepts of Rex (1961) and Carson and Hussey (1962) presented below. The concept of Carson and Hussey (1962) was most recently supported by Kaczorowski (1977).

Rex (1961) concluded that elongation [and thus orientation] of a lake on the Coastal Plain results from relative differences in rates of littoral drift, and thus rates of erosion, around the margin of the lake. Maximum rates of erosion occur at the ends of a lake perpendicular to the prevailing wind, where littoral drift is highest, causing a deficit in sediment supply. Rex's conclusion was based primarily on conclusions of Bruun (1953) that minimum littoral drift along a curved beach occurs directly downwind, and maximum drift occurs at a 50° angle between the deep-water angle of the waves and a line perpendicular to the shoreline. Rex (1961) explained the square to rectangular shape of lakes on the

Coastal Plain by considering the wave orthogonals as an array from a sector, rather than as unidirectional.

Through detailed field investigations, Carson and Hussey (1960, 1962) determined that the zones of maximum current velocity and littoral drift in a lake on the Coastal Plain, as predicted by Rex (1961), are valid in lakes with a fetch greater than 550 m. Carson and Hussey also validated Rex's interpretation of lake shores as equilibrium forms adjusted to variations in the rate of wind-induced littoral drift.

Carson and Hussey (1962) further showed that wave-generated, equilibrium bottom profiles off downwind shores are quickly established in small, enlarging lake basins and that these profiles rapidly adjust to changes in lake depth. The result of this process is sublittoral shelves that insulate permafrost and damp storm waves, thus limiting lake expansion parallel to the prevailing wind, but not impeding expansion perpendicular to the wind. Carson and Hussey (1962) proposed that these sublittoral shelves are the most important factor in lake elongation during nearly all stages of lake enlargement.

Carter and others (1987) provided a historical overview of studies and explanations for the orientation of thaw lakes on the Arctic Coastal Plain, beginning with the initial study by Cabot (1947).

Sediment Distribution, Character, and Age

Multiple Lake Sequences

Multiple sequences of lake sediments are often preserved in the stratigraphic record. Section HBB2-1 west of the Colville River (figure 5.5) provides evidence of two thaw lakes. Deposits of the first lake lack a basal organic horizon; organic silt directly overlies late Wisconsinan alluvium, eolian sand, and a sand wedge that has intruded the alluvium. The organic-rich lake sediments are 0.6 m thick and fill two ice-wedge pseudomorphs in the sand wedge; these pseudomorphs presumably formed when the lake thawed the wedge ice. Organic silt (sample HBB2-1E) from one of the pseudomorphs yielded a radiocarbon date of 9.400 +/- 0.110 ka (BETA 23742). Sandy peat, 0.3 m thick and containing freshwater gastropods, overlies the organic silt of the first thaw lake.

The second lake is represented from bottom to top by a thin organic bed, which overlies the peat of the first lake, 0.6 m of bedded organic-rich silt, and 0.2 m of sandy root mat. A sample of the basal organic layer (HBB2-1A) was collected for eventual radiocarbon dating.

The radiocarbon date obtained from the first of the two lake cycles exposed at section HBB2-1 is consistent with other dates for lake sediments in the Prudhoe Bay area. These dates suggest that thaw lakes have existed on the Coastal Plain only since about 12 ka ago (Lewellen, 1972; Everett, 1975, 1980a; Hopkins and others, 1981b; Rawlinson, 1983; Walker and others, 1985), when the climate ameliorated from previous glacial conditions; most of the dates tend to be younger than 9 ka. Hopkins and Kidd (1988) reported that the oldest of existing lakes on the Coastal Plain are between 4 and 5 ka, but that most lakes typically persist 2.5 to 3 ka.

Ideal Thaw-lake Section

As the margins of a lake erode, massive blocks of peat are moved short distances into the lake; fine-grained organic materials and sediments are carried to the lake center resulting in a peripheral zone of peat that grades laterally to a fine-grained sediment zone. This sequence is also preserved in the vertical stratigraphic section as the lake enlarges (Britton, 1957). The lower part of the ideal thaw-lake section thus has a basal zone of organic material that is commonly overlain by organic-rich silt or fine sand (Hopkins and Kidd (1988). The thickness of this part of the section is generally less than 1 m. The presence or absence of the basal organic component, and the composition of the clastic component, depend greatly on the character of the sediments being reworked by the thaw lake.

Lake-fill processes typically establish a cap of peat or roots, or both, up to 1.5 m thick above the clastic component. Fresh-water gastropods, commonly *Physa* sp. (R. Allison, personal communication, 1985) are sometimes present in the peat. The peat is generally vertically foliated, presumably from compressional and tensional stresses associated with thawing and freezing of the sediments between bounding ice wedges. The contact of the peat and the underlying fine-grained sediments is often irregular, with the peat interfingering into the sediments in the form of apex-down cones. Small lenses of peat are usually present in the underlying sediments, or less often, lenses of sediment are present in the base of the peat.

In areas where thaw lakes are prevalent, gravelly muddy sand or similar sediment commonly overlies or, less commonly, is interbedded with the peat (figure 4.8, section BPA1-12; and figures 8.2 and 8.3). This muddy sand is widespread and usually less than 0.5 m thick. When wet, the muddy sand is gray; when dry, it is very light gray and shows a horizontal platy parting. Thin segregated ice is common in the muddy-sand bed; when thawed, the void space exhibits a boxwork structure. The origin of the muddy sand is uncertain.

Significant Findings, Implications, and Interpretations

Coastal Erosion and Coastline Reconstruction

The relatively young lake basins that have been truncated by erosion along the Beaufort Sea coast attest to the reported rapid rates of coastal retreat (e.g., Dygas and Burrell, 1976; Lewellen, 1977; Hartz, 1978; Hopkins and Hartz, 1978; Cannon and Rawlinson, 1981; Kovacs, 1983; and Naidu and others, 1984). Thaw-lake basins that are truncated by coastal erosion are generally the sites of higher erosion rates (Cannon and Rawlinson, 1979). Because the basins are lower than the surrounding terrain, they are more subject to inundation by surge waters during storms. This inundation has the effects of thawing more ground ice, which lowers the surface even more, and of killing the wave-resistant tundra. Once the lake basin is near or below base level and much of the tundra is gone, wave impact results in mechanical erosion.

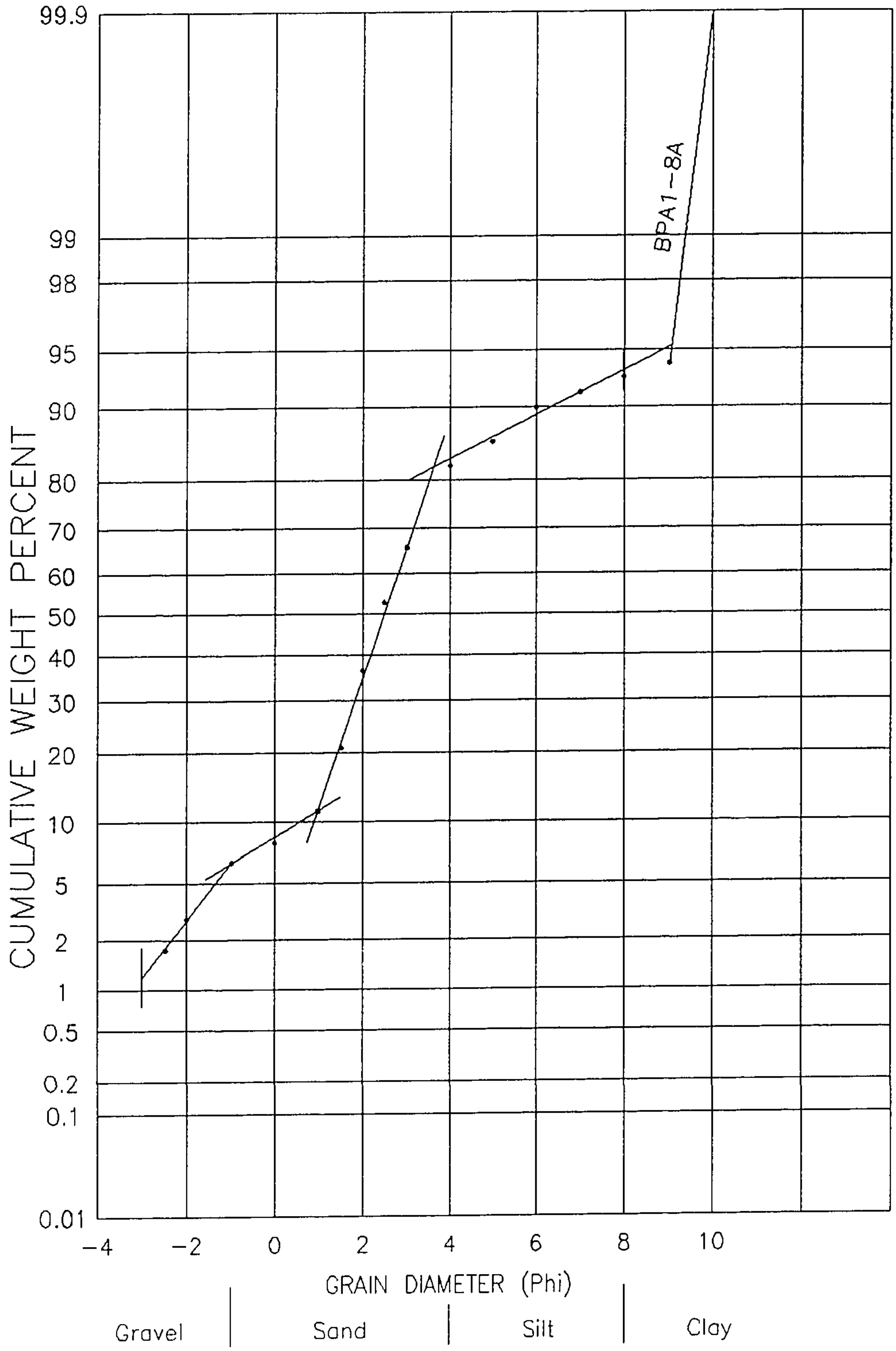


Figure 8.2 Plot of cumulative-frequency-percent curve for muddy-sand sample BPA1-8A in section BPA1-8. The location of this section is shown on sheet 4.

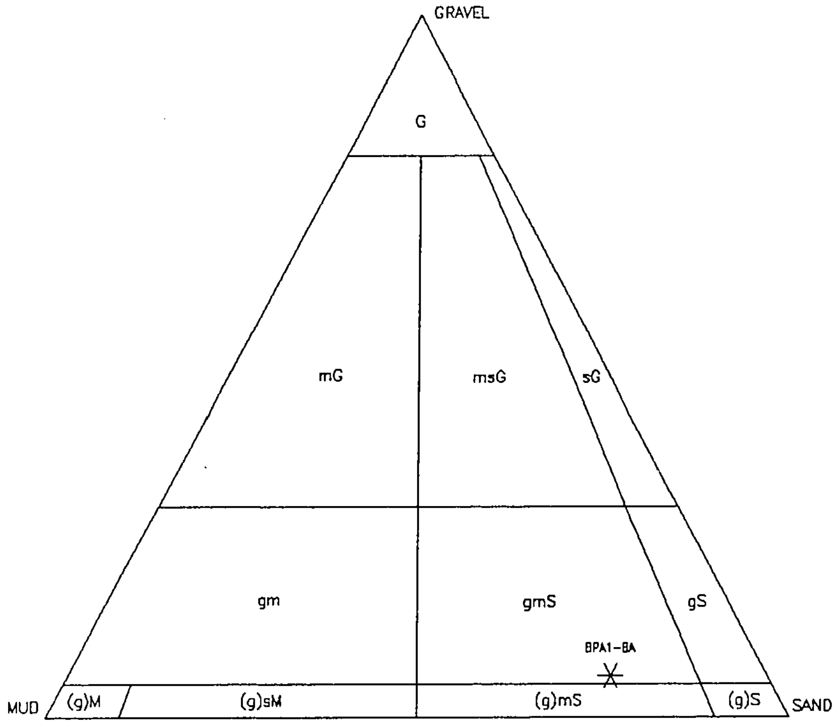


Figure 8.3 Gravel-sand-mud plot of muddy-sand sample BPA1-8A in section BPA1-8; sheet 4. Refer to figure 7.2 for an explanation of the nomenclature. The diagram and nomenclature are from Folk (1980).

Reconstruction of the outline of truncated lakes based on the remaining basinal outline, in conjunction with radiocarbon dates of enclosed organic material, may allow time-series reconstruction of the past coastline. Such reconstruction assumes that radiocarbon dates could be obtained that closely estimate the time of lake drainage.

Lake Orientation by Dunes and Structure

Some thaw lakes, especially in the eastern part of the Coastal Plain, tend to be oriented parallel to the prevailing northeasterly wind direction, or tend to be less elongate and roughly square. Many lakes on the west side of the Canning River fan are oriented parallel to the prevailing wind. There, the orientation is apparently controlled by low-relief longitudinal dunes. Small sand dunes or irregularities in the topography of eolian deposits may also account for some square lakes on the Coastal Plain. A few elongated lakes on the eastern part of the Coastal Plain are within synclines and thus trend parallel to the synclinal axis.

Widespread Muddy Sand

Hopkins (personal communication, 1984) suggested that the muddy sand commonly present at the top of exposed thaw-lake sediments is eolian and derived from deflation of drained lake basins. Although this interpretation is probable, most drained thaw-lake basins when not frozen tend to be moist and thus relatively stable. The muddy sand is more likely to have been derived from deflation of active and inactive flood-plain sediments, especially those deposited during spring flooding. The muddy sand is generally overlain by a thin layer of active vegetation and the associated root mass. Depending on location, a thin layer of fine eolian sand may be present between the vegetation and the muddy-sand bed.

CHAPTER 9 - SUMMARY OF AGES AND CORRELATIONS

Introduction

One objective of nearly all mapping-oriented geologic investigations, including this study, is to define the past events and sediments for the area of study. Such definition provides for better understanding of present geological and environmental conditions and information can be used to better understand a larger area such as the Coastal Plain bordering the Beaufort Sea.

Cenozoic Events and Sediments Within the Study Area

The past several million years on the Alaskan Arctic Coastal Plain, particularly the central part, have been a time of considerable change. Few places have experienced marine transgressions and regressions, glaciations, tectonism, major drainage changes and associated deposition and erosion, development of permafrost, desertification, and lake development within such a short period of time. Such events are recorded by the unconsolidated sediments of the Sagavanirktok and Gubik Formations at or the near the ground surface or by surface morphology within the study area (table 9.1).

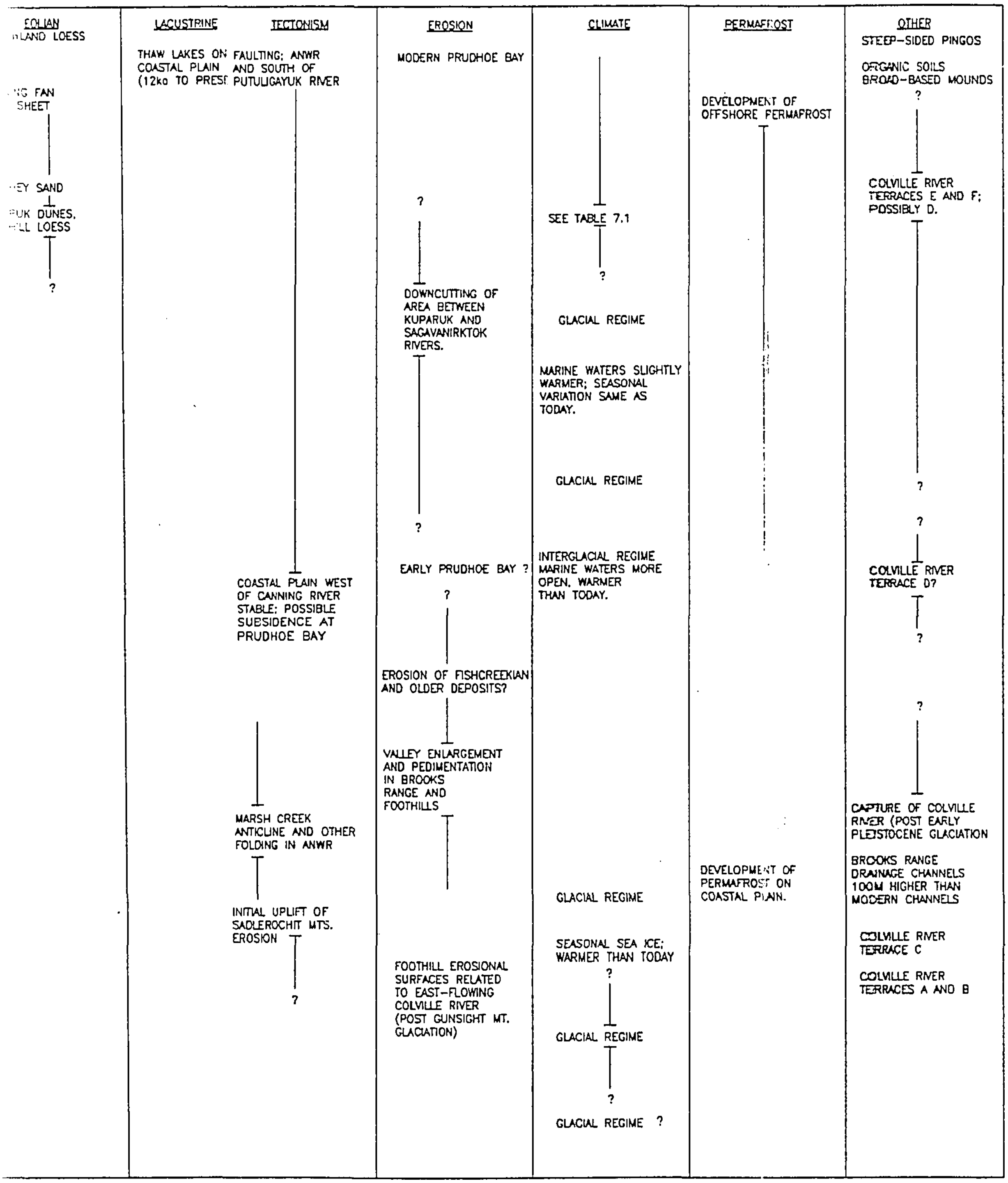
Marine Transgressions and Regressions

Certainly four and perhaps five of six late Cenozoic marine transgressions are recorded within the central part of the Coastal Plain. The Colvillian transgression and the younger

Table 9.1 Correlation chart of events aiment...

Age	MARINE	FLUVIAL	GLACIAL	EOLIAN	LACUSTRINE	...
QUATERNARY — HOLOCENE		MODERN STREAM ALLUVIAL TERRACES		LOWLAND LOESS	THAW LAKES ON COASTAL PLAIN (12ka TO PRESE...	FAULTIN... AND SO... PUTULIG...
10 ka						
LATE PLEISTOCENE — LATE WISCONSINAN		PUT OUTWASH ?	WALKER LAKE GLACIATION 29–11.5 ka	CANNING FAN SAND SHEET		
23 ka						
MIDDLE WISCONSINAN		PUT ALLUVIUM; DRAINAGE FROM SAGAVANIRKTOK RIVER TO KUPARUK AND PUTULIGAYUK RIVERS. ENCLOSED WOOD ASSIGNED TO "YOUNG" AMINO-ACID GROUP. PUT GRAVEL		BEECHEY SAND; IKPIKPUK DUNES, FOOTHILL LOESS ?		
64 ka			ITKILLIK GLACIATION; SECOND ADVANCE (BETWEEN 75–55ka)			
EARLY WISCONSINAN	SIMPSONIAN TRANSGRESSION FLAXMAM MEMBER (BETWEEN 80–70ka)		ITKILLIK GLACIATION; FIRST ADVANCE (BETWEEN 105–87ka)			
115 ka						
SANGAMONIAN	PELUKIAN TRANSGRESSION (BETWEEN 130–120ka)	? ?	?			
128 ka						
MIDDLE PLEISTOCENE		? UGNURAVIK GRAVEL ENCLOSED WOOD ASSIGNED TO "MIDDLE" AMINO-ACID GROUP.	SAGAVANIRKTOK RIVER GLACIATION; TWO ADVANCES. ?			COASTA... OF CA... STABLE... SUBS... PRUD...
730 ka						
EARLY PLEISTOCENE	POSSIBLY FISHCREEKIAN TRANSGRESSION	? ? DEVELOPMENT OF CANNING FAN; GRAVEL SHEETS IN ANWR	ANAKTUVUK RIVER GLACIATION. (BETWEEN 1.88 AND 1.72ka?)			MARSH... ANTICLI... FOLDIN...; INITIAL SADLER... EROSIO...
1.85 Ma						
TERTIARY — PLIOCENE	FISHCREEKIAN TRANSGRESSION; BIGBENDIAN TRANSGRESSION; COLVILLIAN TRANSGRESSION	?	? GUNSIGHT MT. GLACIATION; ERRATIC BOULDERS SOUTH OF KAVIK?			
5.1 Ma						
MIOCENE			? ?			
OLIGOCENE			DIAMICTON NORTH OF KAVIK			
EOCENE		KUPARUK GRAVEL; UNASSIGNED NONMARINE SEDIMENTS	UNASSIGNED MARINE SEDIMENTS WEST OF COLVILLE RIVER			
PALEOCENE						

relation chart of events aiments within the study area.



Bigbendian transgression, both probably between 2.48 and 3.5 Ma old (Carter and others, 1986a), are recorded by sediments east and west of the Colville River and at Marsh Creek within ANWR, and by Terraces A and B east of the Colville River. The Fishcreekian transgression, between 1.87 and 2.48 Ma old (Carter and others, 1986a) or possibly between 1 and 1.5 Ma old (Kaufman and others, 1990; J. Brigham-Grette, personal communication, 1990), is recorded by sediments at Marsh Creek and perhaps by Terrace C east of the Colville River.

The Pelukian transgression, which probably correlates with oxygen-isotope stage 5e and is between 120 and 130 ka old (Carter and others, 1986a), is probably represented by marine sediments approximately 15 m below the ground surface near the mouth of the Putuligayuk River and may underlie younger marine, eolian, and lacustrine sediments as far as 9 km inland between the Sagavanirktok and Canning Rivers. Correlation of the sediments at the Putuligayuk River with the Pelukian transgression is uncertain because dating control is limited to infinite radiocarbon dates and amino-acid analysis of *Astarte* valves for which the aIle/Ile ratios do not differ significantly from modern values (G. Miller, written communication, 1986). However, these sediments are certainly not older than Pelukian.

The Simpsonian transgression, which probably correlates with oxygen-isotope stage 5a between 70 and 80 ka ago (Carter and others, 1986a), is represented by glaciomarine sediments, including exotic clasts, of the Flaxman Member. These sediments are discontinuously present in the study area along the coast generally inland to several kilometers, but are as much as 9 km inland between the Sagavanirktok and Canning Rivers.

Glaciations

The oldest two of four distinct moraines, presumably from the early Pleistocene Anaktuvuk River and middle Pleistocene Sagavanirktok River glaciations (Hamilton 1986a,b), extend into the study area in the Canning River drainage west of the Sadlerochit Mountains. Assuming an early Pleistocene age, normal magnetic polarity of ice-contact lacustrine silts interbedded with till near the terminus of the oldest moraine suggests an age of one of several normal-polarity chrons, perhaps the Olduvai chron, which occurred between 1.72 and 1.88 Ma ago (Harland and others, 1982).

Erratic boulders, which may correspond to the pre-Pleistocene Gunsight Mountain glaciation, or perhaps an older Tertiary glaciation, west of the Kavik River suggest that pre-Pleistocene till may have been present north of the Pleistocene till associated with the Canning, Sadlerochit, and Hulahula Rivers. If so, outwash from that glaciation probably represents much of the older subsurface parts of the Canning River fan and adjacent areas, and of the fans associated with the Sadlerochit and Hulahula Rivers.

Diamicton sediments cropping out on an upland north of Kavik River airstrip may be associated with the Gunsight Mountain glaciation; or more likely, with an older Tertiary glaciation, perhaps the glaciation that deposited possible erratic boulders in the Kuparuk gravel in the headwater basins of the Miluveach and Kachemach Rivers. The age of the Kuparuk gravel, which may be till or alluvium into which the possible erratics have been redeposited, is bracketed by underlying Paleocene sediments and formation of Colville River Terrace A by the late Tertiary Colvillian transgression (Carter and Galloway, 1985a).

Drainage, Alluviation, and Erosion

Deltaic, fluvial, and outwash sediments compose a large percentage of sediments present on the Coastal Plain, yet have received only a small part of the total attention given to the Coastal Plain.

Drainage from more than one-fourth of the Coastal Plain crosses the Colville River Delta in the western part of the study area (Walker, 1983). Upstream from the delta front, channel bars and point bars are fine to medium sand. Gravel-sized clasts are rare on bars throughout the Colville Delta and other deltas within the study area. Stratigraphic sections of banks on the Colville River Delta typically show almost exclusively alluvial sand or peat, or interbedded sand and peat overlain by eolian sand. Radiocarbon dating of organic material in the Colville River Delta sediments suggests that all emergent sediments and features of the delta are Holocene. This age is also applicable to deltaic, flood-plain, and most low terrace sediments elsewhere on the Coastal Plain.

Terraces D, E, and F on the east side of the Colville River (Terrace III of Carter and Galloway, 1982) comprise alluvial or deltaic, or both, sediments presumably of the Colville River. These terraces have a counterpart west of the Colville River Delta that is apparently represented by a single terrace tread. On the basis of sediment type, Carter and Galloway (1985a) related Terraces D and E to the northwestern part of the single tread and Terrace F to the southern and northeastern parts of the single tread. However, based on elevation, Terraces D and E are most like the western single tread.

Plant genera from Terraces D, E, and F suggest deposition during an interglacial or relatively warm interstadial according to Carter and Galloway (1982) who proposed the Sangamonian Interglaciation, but did not rule out one or more interstadials during Illinoian or early Wisconsinan times. Radiocarbon dates from the northeastern part of the single tread west of the Colville River (possibly correlative with Terrace F) suggest that the age is middle to late middle Wisconsinan.

Deep exposure of the Coastal Plain between the Colville River terraces and the Sagavanirktok River is provided in nine gravel pits designated KUP C, D, E, and F; MP; PUT 1 and 2; SAG C; and END.

The section exposed in KUP C pit is the type section for the informally named eolian Ugnuravik sand, herein renamed the Beechey sand, and the fluvial or glaciofluvial, or both, Ugnuravik gravel defined by Rawlinson (1986a). These units are exposed in all the gravel pits within the area west of the Kuparuk River, possibly in the SAG C gravel pit, and are thought to underlie the area east of the Sagavanirktok River to the Canning River fan. The Ugnuravik gravel was originally thought to be Sangamonian to Illinoian based on thermoluminescence dates of several hundred-thousand years; these dates are now considered minimum relative ages. Amino-acid analysis of wood samples from the gravel pits suggests a minimum age of middle Pleistocene. Deposition of sediments exposed in the pits may have been coincident with the latter part of a long period of erosion in the Brooks Range (Hamilton, 1986a).

The Coastal Plain between an extensive terrace west of the Kuparuk River and the east shore of the Sagavanirktok River includes thicker sections of younger sediments, chiefly alluvium and outwash, than the adjacent areas to the west and east. Alluvium, termed the Put alluvium (Rawlinson, 1986a), in approximately the bottom one-half of PUT 1 pit was deposited during the Sangamonian Interglaciation, the middle Wisconsinan nonglacial Boutellier interval, and into the Duvanny Yar interval of Hopkins (1982) based on radiocarbon dates on peat and wood in both the Put 1 and 2 pits, a thermoluminescence date in the PUT 1 pit, and amino-acid dates in the PUT 2 pit. This alluvium is overlain by outwash derived from late Wisconsinan glaciation in the Brooks Range and by Holocene alluvium. Approximately the bottom one-half of PUT 2 pit is alluvium deposited during the Sangamonian Interglaciation; no Wisconsinan alluvium or outwash overlies this alluvium.

Aerial photographs and satellite images suggest that the Sagavanirktok River once flowed northwest to the Putuligayuk and Kuparuk Rivers. Dates from organic-rich fluvial beds exposed deep in the PUT 1 and 2 gravel pits suggest active alluviation in the intermediate area since the Sangamonian Interglaciation. Probable Pelukian marine sediments exposed at depth near the mouth of the Putuligayuk River may indicate drainage from the Sagavanirktok River as early as pre-Sangamonian time. The embayment in which these marine sediments were likely deposited may have been an early Prudhoe Bay formed from preferential erosion of Putuligayuk River terrace sediments. The modern Prudhoe Bay likely correlates with the rise of sea level into the Putuligayuk River flood plain and terraces following the late Wisconsinan Walker Lake glaciation.

Rawlinson (1986a) applied the term Canning gravel to outwash sediments of the Canning River fan and indicated that these sediments were questionably underlain by sediments equivalent to the Ugnuravik gravel. However, apparent deposition from a focus inland on the Canning River since at least the early Pleistocene Anaktuvuk River glaciation makes it unlikely that the Ugnuravik gravel extended eastward to the Canning River. Eolian sand unconformably overlying Simpsonian Flaxman mud at the coast and outwash near the coast was eroded and replaced with more recent sandy gravel and gravel. This gravel composes most of the near-surface part of the fan and is probably outwash associated with late Wisconsinan glaciation within the Canning River drainage.

The dominant sediments on the Coastal Plain within the approximate western half of ANWR are outwash and alluvial sandy gravel and gravel. Most outwash sediments between the Canning and Tamayariak Rivers are north of and probably associated with an extensive early Pleistocene moraine. However, within this area some outwash sediments may be associated with a Tertiary glacial advance, perhaps correlative with the Gunsight Mountain glaciation. The northernmost outwash is overlain by late Wisconsinan eolian sand and Holocene lacustrine silt and peat. A similar, probably equivalent-aged sequence exists between the Sadlerochit River and Nataroarok Creek and east of the Hulahula River.

Alluvial gravels of two distinctly different compositions and ages cap elevated and folded surfaces between the east fork of the Tamayariak River and the Sadlerochit River and, in particular, fan-shaped surfaces with the apices near the Sadlerochit Mountains. The older of the two gravel sheets is younger than the Fishcreekian transgression. The younger gravel sheet is older than the early Pleistocene Anaktuvuk River glaciation based on topography and cross-cutting relationships.

Tectonism

The maximum elevation of Pelukian sediments on the western part of the Coastal Plain is perhaps as much as 10 m (Carter and others, 1986a). Similarity of this elevation with the maximum eustatic sea level estimated for oxygen-isotope stage 5e suggests little (2 to 6 m), if any, uplift of that part of the Coastal Plain since at least 124 ka ago. However, recorded seismicity (Biswas and Gedney, 1978) and demonstrated late Cenozoic folding suggest that the eastern part of the Coastal Plain is tectonically active. Where the Coastal Plain becomes relatively inactive to the west is uncertain. Tectonism as far west as the Kuparuk River may be indicated by photolineaments that cross Holocene sediments near the southern boundary of the study area between the Kuparuk and Sagavanirktok Rivers. Subsidence may be indicated in the Prudhoe Bay area based on the presence of Pelukian marine sediments 9 m below sea level near the mouth of the Putuligayuk River.

Folding west of and within ANWR apparently was most pronounced following the Fishcreekian transgression through early Pleistocene time, but possibly also occurred in the Tertiary. Uplift of the upland north of Kavik airstrip has always been assumed to have occurred early in the Tertiary, but possible association with anticlinal folding could place the deformation much later. An anticline that can be traced discontinuously from west of the Tamayariak River to west of the Canning River folds Anaktuvuk River till but not Sagavanirktok River till in the Canning River drainage. Uplift of the anticline and perhaps the upland north of the Kavik River airstrip is thus restricted to the time between latest Tertiary and middle Pleistocene.

The older of the two alluvial gravel sheets overlies Fishcreekian marine sediments; these in turn, overlie silty sand of the Sagavanirktok Formation. Because the Fishcreekian marine beds and the overlying gravel were uplifted in the Marsh Creek anticline, the range of 1.87 to 2.48 Ma (Carter and others, 1986a) or possibly 1 to 1.5 Ma (Kaufman and others, 1990; J. Brigham-Grette, personal communication, 1990), is a maximum age for uplift of the anticline and presumably for deformation and uplift of terrain to the south.

Recent rapid uplift in ANWR, a concept initiated by L. David Carter of the USGS, is indicated by a series of terraces in the Katakturuk River canyon in the Sadlerochit Mountains. The highest terrace is capped by the younger of the two alluvial gravel sheets. The Sadlerochit Mountains apparently have been uplifted as much as 95 m after deposition of the younger gravel. The older gravel, present east of the Katakturuk River, may be from sources south of the Sadlerochit Mountains based on composition.

Desertification and Eolian Activity

Eolian sediments are nearly ubiquitous on the Alaskan Arctic Coastal Plain. Most were deposited during four periods of contrasting seasonal climate identified by Carter and others (1984). The first period started during the Wisconsinan and ended 36 ka ago; the second period occurred between 36 and 13.5 ka ago; the third period occurred between 13.5 and 11 ka ago; and the fourth period occurred between 11 and 8 ka ago. The Beechey sand was deposited primarily during the latter half of Carter's second climatic regime. Following stabilization of Coastal Plain eolian sediments approximately 8 ka ago, small parabolic and longitudinal dunes were deposited in the Colville River Delta and over the Ikpikpuk dunes west of the Colville River. Similar Holocene dunes are present within or downwind of nearly all the active river and delta systems and along the seaward edge of tundra-covered barrier islands that have a beach.

Lacustrine Activity and Deposits

Radiocarbon dates suggest that thaw lakes have existed on the Coastal Plain only since about 12 ka ago, when the climate ameliorated from previous glacial conditions. Most of the dates tend to be younger than 9 ka and the oldest of existing lakes on the Coastal Plain are about 5 ka old.

Integrating Conceptual Model

Table 9.1 identifies events and sediments relative to time but does not identify how they relate to each other. A conceptual model that integrates events and sediments, time, and cause and effect is presented below not withstanding that much data are lacking and time intervals are poorly known.

Tectonism and processes influenced by climate, that is, temperature are primarily responsible for development and modification of the Coastal Plain. Temperature variations result in wind and precipitation, which relate to glaciation, which relates to sea level. Each of these processes affects erosion, sediment transport, and deposition, the rates and timing of which are also affected by tectonism.

Middle Tertiary

During part of the middle Tertiary, temperatures were sufficiently cold and precipitation was sufficiently great to result in glaciation on the Coastal Plain. The time and extent of this glaciation are poorly understood, but associated glacial ice may be responsible for transporting and depositing probable erratic boulders of the Kuparuk gravel present near the headwaters of the Miluveach and Kachemach Rivers and diamicton sediments exposed in an upland north of Kavik airstrip. Whether the Kuparuk gravel is till or outwash from this glaciation has not been determined. This glaciation is more extensive than any later glaciations recognized on the Coastal Plain. With such an extensive glaciation, sea level was likely much lower than that estimated for the most extensive of the Pleistocene glaciations, minus 90 m, and the Coastal Plain extended far offshore beyond its present position. Outwash sand and gravel from this glaciation likely represent a large percentage of the deep fluvial sediments of the Coastal Plain.

Late Tertiary

Early during the late Tertiary, temperatures were again sufficiently cold to initiate glaciation. The Gunsight Mountain glaciation may be responsible for erratic boulders present in an upland south of the Kavik airstrip and outwash sand and gravel from this glaciation likely compose deeper, older sediments of the Coastal Plain between the Colville and Shaviovik Rivers, the Canning River fan, and the Coastal Plain within ANWR.

Late during the late Tertiary, the climate ameliorated and sea level rose to well above its present level on three separate occasions: the Colvillian, Bigbendian, and Fishcreekian[8] transgressions. Waters of these transgressions cut three marine benches, Terraces A, B, and C, on uplands in the vicinity of the present Colville River Delta; marine sediments remain on the two higher benches, but have been eroded from the lower bench. The inland extent of the Colvillian, Bigbendian, and Fishcreekian transgressions between the Colville River terraces and the Canning River fan is unknown; however, sediments from these transgressions are present on uplifted terrain to 10 km inland south of the Marsh Creek anticline. The Colville River at this time flowed eastward at least to the present Kuparuk River drainage, possibly extending south of Franklin Bluffs to the present Kadleroshilik River and Shaviovik River drainages, where it emptied into these transgressed seas; the Canning River fan likely was a delta during the marine transgressions.

Erosion of mountainous terrain south of the Sadlerochit Mountains and fluvial transport of metamorphic and other rock types resulted in a gravel sheet that overlies uplifted Fishcreekian marine sediments in and near the Marsh Creek anticline. Uplift of the Sadlerochit Mountains, northern Foothills, and eastern Coastal Plain apparently started after the Fishcreekian transgression. Coniferous wood present in the gravel suggests a climate similar to that of interior Alaska today. A relatively warm, regressing Fishcreekian sea adjacent to a relatively cold landmass (Carter and others, 1986b) resulted in increased precipitation and thus active erosion of the uplifted terrain and fluvial transport of sediment necessary to deposit the gravel sheet. Continued uplift of the Sadlerochit Mountains,

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[8]In this text, the Fishcreekian transgression is considered to have occurred between 1.87 and 2.48 Ma ago. Events or deposits discussed herein that are bracketed by the Fishcreekian transgression will have to be pushed forward if the transgression is eventually confirmed to have occurred between 1 and 1.5 Ma ago.

Foothills, and eastern Coastal Plain in this climate conducive to fluvial processes resulted in erosion of bedrock, sediment transport, and deposition of another gravel sheet composed primarily of limestone and sandstone common in these mountains.

Permafrost possibly began to develop at this time where the sea had regressed, but probably did not become thick until initiation of Pleistocene glaciation.

Early Pleistocene

Onset of the Anaktuvuk River glaciation resulted in sea level dropping and ice advancing well onto the Coastal Plain down the Canning and Hulahula Rivers, leaving distinct terminal moraines. Anticlinal folding was initiated in the eastern part of the Coastal Plain concurrently with the onset of glaciation. The moraine in the Canning River drainage was deformed as folding continued.

Glaciofluvial processes associated with the Anaktuvuk River glaciation began to erode marine sediments between the Colville and Canning Rivers and on low terrain within ANWR, and to deposit outwash sediments in their place and on the Canning River fan.

Early Pleistocene glaciation was followed by a long period of fluvial processes in the Brooks Range and on the Coastal Plain; these processes continued to erode the marine sediments. Valleys were enlarged in the Brooks Range, the eastward-flowing Colville River was captured and began flowing northward, and alluvium was deposited on low areas of the Coastal Plain including the Canning River fan. Fluvial processes associated with the north-flowing Colville River possibly eroded Fishcreekian sediments on Terrace C and deposited alluvium in their place. Alluvium deposited between the Colville and Canning Rivers is the basal Ugnuravik gravel, which interfingers with alluvium deposited on the Canning River fan. During this time, uplifted terrain in ANWR was dissected by fluvial processes and eroded sediments were deposited on the Coastal Plain, which then extended far beyond the present shoreline.

Middle Pleistocene

Fluvial process eroded any remaining marine sediments and alluviation on the extensive Coastal Plain continued; this alluvium represents much of the Ugnuravik gravel and sediment wedges recognized offshore between the Colville River and Canning River fan. Even though the mean annual temperature was low, exposure of the Coastal Plain resulted in a continental climate with summers warmer than today. During brief intervals of warm climate, especially during the summer months, coniferous and nonconiferous trees coexisted on the Coastal Plain.

The climate became significantly colder later during the middle Pleistocene, and ice of the Sagavanirktok River glaciation advanced onto the Coastal Plain down the Canning River, leaving a distinctive moraine. Outwash sand and gravel were deposited on the Canning River fan and elsewhere on the Coastal Plain. Folding in the eastern Coastal Plain had either stopped or slowed by this time.

Late Pleistocene

Sangamonian. The climate ameliorated and Pelukian seas inundated the Coastal Plain between 130 and 120 ka ago depositing marine sediments as far inland as 9 km between the Colville River and the Canning River fan and to unknown distances in low terrain in ANWR. Pelukian sediments in the vicinity of modern Prudhoe Bay were deposited in an embayment, perhaps an early analog of the modern bay. Colville River Terrace D may have formed at this time in response to an elevated base level. The Coastal Plain west of the Canning River was either stable or subject to minor tectonism, possibly including subsidence; whereas, the eastern Coastal Plain probably continued to be slowly uplifted. Such tectonic conditions have not changed to the present.

Early Wisconsinan. The climate again began to deteriorate and between 105 and 97 ka ago ice of the Itkillik glaciation advanced in the Brooks Range and down the Canning River drainage to near the Coastal Plain, leaving a distinctive moraine. Sea level fell to well below the present level and permafrost that exists today in the offshore began to form. Glaciofluvial processes associated with the Itkillik glaciation began to erode sediments between the Kuparuk and Sagavanirktok Rivers and on low terrain within ANWR, and to deposit outwash sediments in their place and on the Canning River fan. Deposition over Pelukian marine sediments probably also started this time.

Between 80 and 70 ka ago, an apparent surge of polar ice resulted in a rise of sea level and breakup of unstable marine-based ice (Carter and others, 1986a). Simpsonian seas inundated the Coastal Plain typically less than a few kilometers inland of the present coastline except between the Sagavanirktok River and Canning River fan, where the sea transgressed as much as 9 km inland. Colville River Terrace E may have formed at this time in response to an elevated base level. Between 75 and 55 ka ago, glaciofluvial processes associated with a second advance of Itkillik ice continued to erode and deposit sediments as during the first advance.

Middle and Late Wisconsinan. The climate early during this time was similar to that of today except for being drier. Alluviation continued in the area between the Kuparuk and Sagavanirktok Rivers, and elsewhere on the Coastal Plain. Discontinuous vegetation on interfluves allowed deflation, initiating deposition of loess in upland areas and of sand on the Coastal Plain. Late during this time, the climate turned cold and even drier eventually resulting in the Walker Lake glaciation between 29 and 11.5 ka ago, and hence deposition of outwash sediments. Vegetation was also sparse. Eolian processes dominated the landscape, resulting in considerable deposition of loess and sand derived from broad, unvegetated flood plains.

Holocene. Amelioration of climate after 11.5 ka ago to conditions warmer than today resulted in development of shrub tundra and organic soils by 8 ka ago. Extensive sand sheets were stabilized and thaw lakes developed where eolian deposits were best developed. Pingos formed in these early thaw lakes are the broad-based mounds common on the Coastal Plain. Also at this time, sea level rose to near its modern level. Prudhoe Bay formed from inundation of low flood-plain and terrace sediments associated with Wisconsinan streams that drained northwest and north from the Sagavanirktok River area. The nearshore islands also formed from this inundation. Cooler, drier climate associated with neoglaciation in the Brooks Range resulted in destabilization of the surface after 8 ka ago and renewed deposition of sand. Many of the dunes formed at that time have since been stabilized by a thin tundra mat or sedge vegetation. Thaw lakes remained present on the Coastal Plain throughout the Holocene; steep-sided pingos have developed in relatively recent lakes.

Holocene variations in climate and sea level may be reflected in alluvial terraces along the major rivers. Limited data suggest that most of the terraces near the apex of the Canning River fan formed near or soon after the middle Holocene deterioration of climate. An extensive terrace west of the Kuparuk River is middle Holocene and perhaps Terrace F along the Colville River Delta also formed at this time.

Lineaments that cross Holocene sediments on the Coastal Plain within ANWR and as far west as the Kuparuk River may indicate renewed tectonism in those areas.

Cenozoic Events and Sediments Along the Beaufort Sea Margin

In 1984, investigators from the United States and Canada participated a workshop in Calgary to present and synthesize current knowledge of late Cenozoic events and sediments of the margin of the Beaufort Sea. Creation of a detailed correlation chart of events and sediments for this region was a major goal. A correlation chart, supporting discussions, and references were published by Heginbottom and Vincent (1986). Table 9.2[9] presents a version of the regional correlation chart that incorporates events and sediments identified

[9]References specific to Table 9.2: American Commission on Stratigraphic Nomenclature, 1970; Ashley and others, 1984; Begèt and others, 1990; Black, 1964; Brigham, 1985; Carter, 1981, 1983a,b; Detterman, 1953; Detterman and others, 1958; Dinter, 1985; Fernald, 1964; Hamilton, 1969, 1979b, 1980, 1982; Hamilton and Porter, 1975; Hopkins, 1967; Hopkins and others, 1980; Keroher and others, 1966; MacNeil, 1957; North American Commission on Stratigraphic Nomenclature, 1983; Porter, 1964; Repenning, 1983; Smith, 1985; Westgate and others, 1983.

Table 9.2 Correlation chart of events and sediments around the
and Vincent (1986).

GENERAL CHRONOSTRATIGRAPHY (age in ka)	OXYGEN ISOTOPE STAGES	YUKON CORDILLERAN ICE SHEETS (O.L. Hughes)	YUKON BASINS (O.L. Hughes J.V. Matthews, Jr., N.W. Rutter and C. Schweger)	BROOKS RANGE AND BASINS TO SOUTH AND NORTH (T.D. Hamilton)	ALASK COAST (J.K. Br L.D. Carte D.M. Hopkins and
LATE PLEISTOCENE – WISCONSINAN STAGE – LATE (23)	2	McCONNELL GLACIATION = MACAULEY GLACIATION	Upper glaciolacustrine (12–30 ka–14C) Interstadial fluctuation? Hanging Lake Interval (at about 18–20 ka–14C)	WALKER LAKE GLAC. (13–24 ka–14C)	PUT RIVER C UNIT A marin outer sh Ikpiks F
LATE PLEISTOCENE – WISCONSINAN STAGE – MIDDLE (23–64)	3	THOM CREEK INTERSTADIAL (28 ka–14C) BOUTELLIER NONGLACIAL INTERVAL (29,>37 ka–14C)	*Alternating warm and cold intervals within stage 5d to 3 and including*	*Unnamed paleosol* (24–34 ka–14C)	PUT RI BEEC marine UNIT B on
LATE PLEISTOCENE – WISCONSINAN STAGE – EARLY (64–115)	5d–4	Sheep Creek Tephra (>42 ka–14C, 73, 78 ka–U/Th) MIRROR CREEK GLACIATION = REID GLACIATION	Koy–Yukon Thermal Event	ITKILLIK GLACIATION (Chebanika advance) *Forest beds (>55 ka–14C)* ITKILLIK GLACIATION *(maximum advance)*	SIMPSON = FLAXMAN MEMBER = Cross island = mid = UNIT C m
LATE PLEISTOCENE – SANGAMONIAN STAGE (115–128)	5e			Bettles gravel	PUT PELUKIAN = Walakpa = MCGUIRE IS = UNI
MIDDLE PLEISTOCENE (128–730)		Old Crow Tephra	Old Crow Tephra *Interlacustrine alluvium with multiple paleosols*	Old Crow Tephra SAGAVANIRKTOK RIVER GLACIATION *Long interglacial*	WAINWRIGHTIA = Kormuk Membe = ANVI = LEFFINGWELL LAG = UNIT = UG
EARLY PLEISTOCENE (730–)		KLAZA GLACIATION Fort Selkirk Tephra (.94 Ma–Ft and 1.08 Ma–KAr) NANSEN GLACIATION Klondike gravels Flat Creek beds White Channel gravels	Little Timber Tephra (1.2 Ma–Ft) Lower lacustrine (in Old Crow Basin) *Sands containing permafrost structures (in Bluefish Basin)*	ANAKTUVUK RIVER GLAC. (+) *High terraces*	= OLDUVAI (?) = CAN FISHCRE = Tuapaktushak Me (1.87– BIGBEN = Killi Creek Me (>2.19 Ma
LATE TERTIARY			*Paleosol with extinct Larix minuta type, Picea and Pinus?*	Gunsight Mountain erratics	COLVILLIAN TRANSG = BE = Nulavik Erratics (K Ko

(1) a) Names in upper case letters are published and in the Alaskan columns are formal names that are published and/or have the approval of the U

b) Names in lower case are informal and in the Alaskan column, if formal, have not yet been published and do not have the approval of the USG

c) Names and comments in italics are quite informal and are included for the sake of completeness of the chart.

d) The correlation chart is a working document. Readers will note the lack of consistency in the nature of the units discussed. Few formally defi are used. Geologic–climate units (glaciations, interglaciations, stades, and interstades) are used even though these have been abandoned by the on Stratigraphic Nomenclature, and are now recognized only as informal units.

(2) According to Hughes, the Buckland Glaciation is correlative with the Hungry Creek Glaciation.

(COMPILED by J.S. VINCENT, from data provided by S.M. Blasco
N. Catto, D.A. Dinter, T.D. Hamilton, P.R. Hill, D.M. Hopkins,
S.E. Rawlinson, N.W. Rutter, V.N. Rampton, C. Schweger,

…iments around the Beaufort Sea margin. Chart modified from Heginbottom

	ALASKAN ARCTIC COASTAL PLAIN (J.K. Brigham-Grette, L.D. Carter, D.A. Dinter, D.M. Hopkins, S.E. Rawlinson and P.A. Smith)	YUKON COASTAL PLAIN AND MACKENZIE DELTA AND VALLEY (N. Catto, O.L. Hughes, V.N. Rampton and J.S. Vincent)	MACKENZIE DELTA OFFSHORE (P.R. Hill and S.M. Blasco)	WESTERN ARCTIC ISLANDS (J-S. Vincent)
	PUT RIVER OUTWASH AND ALLUVIUM UNIT A marine wedge on middle and outer shelf (9–15 ka–14C) Ikpikpuk sand sea Foothill loess	Sitidgi Lake stade = Tutsieta Lake phase (13 ka–14C) HUNGRY CREEK GLAC. (16–25 ka–14C)	*Sea level drop or standstill–Mackenzie Delta progradation in west and outwash plain in east (8.8 to 21.6 ka–14C)* *Sea Level rise from mid or early(?) Wisconsinan minimum* *Delta progradation in west (21.6 to 27.4 ka–14C)*	AMUNDSEN GLACIATION (RUSSELL STADE) = PRINCE OF WALES FM (incl. SCHUYTER POINT SEA SEDS–12.6 to 9 ka–14C; and PASSAGE POINT SEDS)
	PUT RIVER ALLUVIUM BEECHEY SAND; marine UNIT B on middle and outer shelf	*Nonglacial beds* (33.8 and 38.9 ka–14C)	*Outwash plain in east, off Tuktoyaktuk Peninsula*	*Unnamed interstadial* (>41 and >49 ka–14C)
…4C)	SIMPSONIAN TRANSG. = FLAXMAN MEMBER OF GUBIK FM (75 ka–TL) = Cross Island Unit on inner shelf? = mid shelf deltas = UNIT C marine wedge (?)	Deception glaciation = BUCKLAND GLACIATION (2) = Toker Point stade (>35 and >39 ka–14C) *Deformed ground ice* *Sabine grey member?*		AMUNDSEN GLACIATION (MCLURE STADE) = PRINCE OF WALES FM (incl. MEEK POINT SEA SEDS. and EAST COAST SEA SEDS–51 ka–U/Th; CARPENTER, BAR HARBOUR, MERCY, SACHS and JESSE TILLS; and PRE AMUNDSEN SEA SEDIMENTS–106 ka–U/Th)
	PUT RIVER ALLUVIUM PELUKIAN TRANSG. (125 ka–TL) = Walakpa Member of GUBIK FM = MCGUIRE ISLAND UNIT on inner shelf = *UNIT E marine wedge*	*Sabine oxidized member?;* *Mason River driftwood (>38 and >39 ka–14C)* *Maitland brown sand?* *Peel fluvial deposits?*		CAPE COLLINSON INTERGLAC. = CAPE COLLINSON FM (>61 ka–14C and 83.3 ka–U/Th)
	WAINWRIGHTIAN TRANSG. (210 ka–TL) = Karmuk Member of GUBIK FM (500 ka–Aa) = ANVILIAN TRANSG. = LEFFINGWELL LAGOON unit ON INNER SHELF (?) = UNIT 1 MARINE WEDGE (?) = UGNURAVIK GRAVEL	Mason River Glaciation Maitland thinly bedded silts? Maitland lower brown sands and silts? Peel gravels? Maitland clay		THOMSEN GLACIATION =NELSON RIVER FM (incl. BIG SEA SEDS. 116 and 118 ka–U/Th; KELLETT, BAKER and KANGE tills; and PRE THOMSEN SEA SEDS) MORGAN BLUFFS INTERGLAC. =MORGAN BLUFFS FM (>300 ka–U/Th)
… (+)	= OLDUVAI (?) GEOMAGNETIC EVENT? = CANNING GRAVEL FISHCREEKIAN TRANSG. = *Tuapaktushak Member of GUBIK FM (–?)* (1.87–2.48 Ma–Aa) BIGBENDIAN TRANSG. = Killi Creek Member of GUBIK FM (+) (>2.19 Ma–Aa, Mammals)			BANKS GLACIATION =DUCK HAWK BLUFFS FM (incl. POST BANKS SEA SEDS.; BERNARD, PLATEAU and DURHAM HEIGHT TILLS; and PRE BANKS SEA SEDS– *magnetically reversed in Duck hawk Bluffs)* *Old erratics* ?
…tics	COLVILLIAN TRANSG. (<3.5 Ma–Pacific mollusks) = BERINGIAN TRANSG.? = Nulavik Member of GUBIK FM Erratics (?) in Kuparuk gravel Kavik erratics Kavik diamicton			WORTH POINT FORMATION *(preglacial)* BEAUFORT FORMATION

…have the approval of the USGS Geologic Names Committee.

…ve the approval of the USGS Geologic Names Committee.

…scussed. Few formally defined names of lithological units …have been abandoned by the North American Commission

Aa age estimate from amino-acid analysis
14C age estimate from radiocarbon analysis
Ft age estimate from fission-track analysis
TL age estimate from thermoluminescence analysis
U/Th age estimate from Uranium-Thorium analysis
KAr age estimate from potassium-argon analysis
(+) magnetically normal
(–) magnetically reversed

Alaskan marine units are from Dinter (1982, 1985)

…ata provided by S.M. Blasco, J.K. Brigham-Grette, L.D. Carter, …on, P.R. Hill, D.M. Hopkins, O.L. Hughes, J.V. Matthews, Jr., V.N. Rampton, C. Schweger, P.A. Smith and J.S. Vincent)

in table 9.1. Changes in the chart that reflect information provided by this study are: re-assignment of the Canning gravel to the early Pleistocene; renaming of the Ugnuravik sand to the Beechey sand; reassignment of the Ugnuravik gravel to the middle Pleistocene; assignment of the Canning gravel to the early Pleistocene; and assignment of erratic boulders south of Kavik airstrip and diamicton sediments north of Kavik airstrip to the late Tertiary. Normal polarity of the Anaktuvuk River glaciation is also indicated. The area influenced by glaciations recognized in the Brooks Range has been changed to include basins to the north; such basins specific to this study are drainages of the Canning, Sadlerochit, and Hulahula Rivers in the vicinity of the Sadlerochit Mountains. The Foothill loess has been assigned to the late Wisconsinan based on Carter (1988). The Old Crow Tephra has been reassigned to the late middle Pleistocene, based on Begèt and others (1990).

The provisional nature of this updated chart and the chart in Table 9.1 is emphasized herein as the editors did for the first Beaufort Sea margin correlation chart. The intent is that these charts will be corrected, updated, and expanded based on future investigations within Alaska and Canada. Reassignment of events and sediments applicable to Canadian locations in Table 9.2 are beyond the scope of this dissertation.

CHAPTER 10 - CONCLUSIONS

Introduction

Mapping and analyses have defined the distribution, morphology, character, and age of marine, fluvial, glacial, eolian, and lacustrine sediments of the late Cenozoic Gubik Formation in approximately 12,000 km^2 of the Alaskan central Arctic Coastal Plain, and allowed interpretations of the depositional, climatic, and tectonic histories. Further, considerable baseline data have been compiled on grain size; radiocarbon, thermoluminescence, and amino-acid dates; microfossils; pollen; and wood taxa. Additional information such as field notes, lab reports, and complete grain-size analysis has been deposited and is available for viewing at DGGS in Fairbanks, Alaska.

Key Findings and Interpretations

Laboratory Analyses

Radiocarbon, thermoluminescence, and amino-acid analyses have yielded information on the chronology of deposition, although some data have to be accepted with caution, or be considered in stratigraphic context. This need is most apparent with the thermoluminescence and amino-acid analyses. With only two exceptions, Wisconsinan thermoluminescence dates seem reliable; one date was apparently far too young and one date was too old based on other analyses. Post-Wisconsinan thermoluminescence dates, many of which are apparently finite, have to be considered minimum ages in most cases based on stratigraphic position and results of amino-acid analysis.

Amino-acid analysis of wood and some shell materials from within the study area has defined broad age groups: young, middle, and old. The old group has been abandoned because of the high probability that amino acids in the samples have been leached or some other modification has occurred. On the basis of the aspartic-acid D/L ratio, the young group is probably at least Sangamonian and the middle group is probably at least middle Pleistocene.

Field Observations and Mapping

Interpretations of the surficial geology are based on the laboratory analyses and on field observations and mapping. Some of these interpretations are new and some are contrary to previously held notions. Notable among these interpretations are:

1. **Extensive transgression of early Wisconsinan and perhaps Sangamonian seas.** Pelukian sediments were likely deposited in an embayment in the vicinity of present day Prudhoe Bay. The inland extent of the Simpsonian transgression in this area was not great, probably only a few kilometers south of the present coast. However, the Simpsonian transgression and possibly the Pelukian transgression extended as far as 9 km inland in the area between the Sagavanirktok River and the west side of the Canning River fan.

2. **Glacial advances in excess of previous known limits.** Probable extensive Tertiary glaciation in parts of the Coastal Plain is indicated by diamicton sediments in an upland north of Kavik airstrip and probable erratic boulders near the headwaters of the Kachemach and Miluveach Rivers. Similar erratic boulders in an upland south of Kavik

airstrip may represent extensive late Tertiary glaciation, perhaps correlative with the Gunsight Mountain glaciation.

3. **Colville River marine and alluvial terraces.** Six terraces are identified east of the Colville river and designated A through F from oldest to youngest. Terraces A and B correlate with Carter and Galloway's (1982) Terrace I; Terrace C correlates with their Terrace II; and Terraces D, E, and F correlate with their Terrace III. Terraces A and B formed during the Colvillian and Bigbendian marine transgressions and Terrace C probably formed during the Fishcreekian transgression. Terraces D, E, and F are alluvial and probably formed during the late Pleistocene.

4. **Middle Pleistocene minimum age for the Ugnuravik gravel.** Fluvial sediments of the Ugnuravik gravel include wood of the middle amino-acid group, and underlie the near-surface part of the Coastal Plain between the Colville River marine terraces and the western edge of the Canning River fan. These sediments abut older marine and overlying alluvial and eolian sediments of the Colville River marine terraces approximately along the trend of Kalubik Creek.

   The Ugnuravik gravel has been eroded and is overlain by Wisconsinan and Holocene fluvial sediments approximately between the Kuparuk and Sagavanirktok Rivers.

5. **Coexistence of coniferous and nonconiferous wood on the Coastal Plain in middle to early Pleistocene time.** Wood from coniferous trees (specifically *Larix)* and nonconiferous trees (specifically *Salix)* is included in sediments now thought to be at least middle Pleistocene, but probably younger than early Pleistocene. A Fishcreekian

age based on the abundance of *Larix* seems not to be viable. The particular taxa present suggest a climate similar to that of present-day interior Alaska. Oxidation of the wood-rich beds exposed in deep gravel pits suggests that the sediments remained thawed for some time following deposition or were subsequently thawed.

There is a paradox here: how did locally warmer temperatures necessary for these tree taxa coexist with the generally colder global temperatures at that time? This might be explained by greater accumulation of summer warmth associated with a continental climate. Such a climate could result from greater exposure of the continental shelf related to lower sea levels.

The apparent absence of coniferous wood in deep gravel pits along the Sagavanirktok River may indicate slightly younger sediments (but still within the middle amino-acid group) and a warmer, moister climate. Alternatively, coniferous wood may be present but has yet to be identified.

6. **Late Pliocene through Holocene age for the Canning gravel.** Sediments of the Canning River fan, termed the Canning gravel, include outwash from the Pleistocene glaciations and probably include outwash from late Tertiary glaciations. Terraces near the apex of the fan and near-surface alluvial and eolian sediments of the fan are Holocene.

7. **Recent and rapid uplift and folding in western ANWR.** Bedrock surfaces and folded terrain within ANWR are capped by one or both of two gravel sheets that differ in age and composition. The older gravel sheet and underlying Fishcreekian marine beds are folded in the Marsh Creek anticline, indicating post-Fishcreekian tectonism. Similarly,

early Pleistocene till but not middle Pleistocene till is folded in anticlines to the west, suggesting latest Pliocene to middle Pleistocene folding. The younger of the two gravel sheets caps terraces now 95 m above the present flood plain of the Katakturuk River in the Sadlerochit Mountains, suggesting up to that amount of uplift since latest Pliocene time.

The western part of the Coastal Plain has previously been considered tectonically inactive, but this may not be entirely true. Linear features that cut Holocene alluvium in ANWR and south of Prudhoe Bay are thought to be fault terraces. If so, they suggest modern tectonism on the Coastal Plain at least as far west as the Kuparuk River. Such tectonism may be associated with subsidence in the Prudhoe Bay area since at least Sangamonian time.

8. **Late middle through late Wisconsinan age for the Beechey Sand.** Thermoluminescence analysis of basal samples of Beechey sand indicate a maximum age of approximately 26 ka in the area between the Colville River and western edge of the Canning River fan. The Beechey sand north of the limit of broad-based mounds is thin and probably younger. Sand wedges in the Beechey sand indicate a cold, dry climate.

9. **Late Wisconsinan to early Holocene age for thaw lakes in which broad-based mounds formed.** A borehole in one of the broad-based mounds suggests that these features are true pingos. If these mounds formed as closed-system pingos in drained lake basins, as do modern pingos on the Coastal Plain, they indicate a warm climate similar to today. There is no evidence to indicate that thaw lakes were present on the Coastal Plain prior to climatic amelioration of the latest Wisconsinan and Holocene; their age

is further constrained by late middle through late Wisconsinan ages for the Beechey sand, on which the lakes formed. The much larger size of the mounds relative to modern pingos, and the fact that they have been modified by existing thaw lakes, suggest that the broad-based mounds formed in the earliest late Wisconsinan and Holocene lakes.

Findings and interpretations itemized above are highlights of numerous others within the text. While the others may be less significant, collectively they have allowed a start toward definition of the depositional, climatic, and tectonic histories of the area. Interpretations herein are considered to be provisional; it is intended that other investigators will revise interpretations as new data become available.

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APPENDICES

Information pertinent to Appendices A through K, is consolidated below.

Lithologic designations, from Folk (1980); parentheses indicate small amount:

S = Sand	cS = Clayey sand
sC = Sandy clay	mS = Muddy sand
sM = Sandy mud	M = Mud
zS = Silty sand	sZ = Sandy silt
Z = Silt	G = Gravel
msG = Muddy sandy gravel	sG = Sandy gravel
gM = Gravelly mud	gmS = Gravelly muddy sand
gS = Gravelly sand	g(s)M = Gravelly sandy mud
(g)S = Gravelly sand	mS = Muddy sand
g(m)S = Gravelly muddy sand	sM = Sandy mud

Sample numbers are derived as follows:

First two letters designate the quadrangle name; third letter and number designate the quadrangle; and, the last letter is the stratigraphic position from top to bottom.

Quadrangle Names:

BP = Beechey Point	FI = Flaxman Island
HB = Harrison Bay	MM = Mount Michelson
SG = Sagavanirktok	

Laboratory names:

AAL = University of Colorado
ALPHA = Alpha Analytical Incorporated
BETA = Beta Analytical, Incorporated
GX = Krueger Enterprises Incorporated - Geochron Laboratories Division
UA = University of Alberta

Abbreviations:

Nonconif. = Nonconiferous wood
Conif. = Coniferous wood
Decid. = Deciduous
ND = Not Determined
unk. = Unknown; sample taken from slope
NA = not available

Depth: All depths are in meters

Field notebooks are on deposit at the Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys; 3700 Airport Way, Fairbanks, Alaska 99709-4699. Map numbers are cross-referenced to field numbers in Appendix C.

APPENDIX A

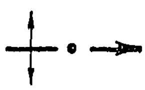
MAP SYMBOLS AND UNIT DESCRIPTIONS

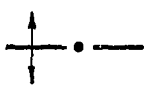
Map Symbols

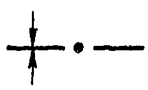
 Contact.

 Inferred Contact.

 Scarp; commonly separates like units. Tick marks on lower surface.

 Plunging anticlinal axis.

 Anticlinal axis.

 Synclinal axis.

 Photolineament.

 Measured section or observations, or both, with number.

 Facility or disturbed area.

 Broad-based mound.

 Pingo.

Map Unit Descriptions

Active Marine Sediments

Qb **BEACH DEPOSITS** - Gravelly sand and fine to medium sand deposited along the coast and nearshore islands by mass-wasting and marine processes. Along the coast and on tundra-covered islands these deposits include detrital peat. The mode size of pebbles is 3 cm. The deposits are continuously frozen but seasonally thawed to about 1 m. The surface is barren or has sparse halophytic vegetation.

Qtf **TIDAL-FLAT DEPOSITS** - Moderately to well-sorted silt and fine sand with organic material deposited by wave action. Deposits are laterally continuous and unvegetated, and commonly occur along the shore of lake basins that have been breached by the sea. The thickness of these deposits is uncertain, but probably less than several meters.

Qsm **SALT-MARSH DEPOSITS** - Moderately to well-sorted silt and fine sand, with organic material deposited by inundation of marine waters during storms. Deposits are laterally discontinuous, generally less than 0.5 m thick, and occur over peat or lacustrine sediments in lake basins that have been breached by the sea. Deposits may be sparsely covered with hylophytic vegetation.

W **WATER** - Indicated when necessary to clarify a boundary between units.

Deltaic Sediments

Qd **ACTIVE DELTA DEPOSITS** - Silt, fine sand, and finely disseminated peat deposited in channels and flats of modern deltas by deltaic processes; these deposits are moderately sorted. Subrounded to rounded pebbles are sometimes present on these deposits especially in areas of the delta proximal to the adjoining river. The unit is continuously frozen but seasonally thawed to about 1 m deep; it is also thawed in thin zones below channels with water greater than 2 m deep. Surfaces are unvegetated or support sparse covers of halophytic vegetation.

Qdi **INACTIVE DELTA DEPOSITS** - Peat and silt or fine sand, or mixtures or interbeds of all three, deposited in deltaic overbank environments by fluvial, eolian, and lacustrine processes. These deposits generally consist of a topmost bed of peat up to 0.5 m thick, underlain by interbedded silt or fine sand and peat. Exposures of these deposits rarely exceed 2 m high and are generally less than 1 m high. The unit is continuously frozen but seasonally thawed to about 0.6 m deep. Surfaces support thin covers of halophytic and tundra vegetation.

Qda **ABANDONED DELTA DEPOSITS** - Peat and silt or fine sand, or mixtures or interbeds of all three, deposited in deltaic overbank environments by fluvial, eolian, and lacustrine processes. These deposits generally consist of a topmost bed of peat up to 1 m thick, which is often cryoturbated and vertically foliated, and underlying interbedded silt or fine sand and peat. Exposures of these deposits rarely exceed 3 m high and are generally less than 2 m high. Segregated ice and massive ice in the form of wedges are common in these deposits; the unit is continuously frozen but seasonally thawed to about 0.6 m deep. Surfaces support tundra vegetation and are marked by low-centered, ice-wedge polygons. Centers of polygons support sedges and grasses.

Lacustrine Sediments

Qt **THAW-LAKE DEPOSITS** - Peat and pebbly silt or fine sand, or mixtures or interbeds or all three, deposited in basins of thaw lakes by lacustrine and eolian processes. A topmost bed of peat and often a basal bed of peat bound interbeds of peat and silt or fine sand. These beds rarely exceed 2 m total thickness and are generally less than 1 m thick; superposition of deposits accounts for the thicker deposits. The deposits are often cryoturbated. The unit is continuously frozen but seasonally thawed to 0.6 m. deep. The surface is featureless or marked by indistinct large-diameter, ice-wedge polygons and very wet. Aquatic vegetation is common.

Qti **ICE-RICH THAW-LAKE DEPOSITS** - Peat and pebbly silt or fine sand, or mixtures or interbeds or all three, deposited in basins of thaw lakes by lacustrine and eolian processes. A topmost bed of peat and often a basal bed of peat bound interbeds of peat and pebbly silt or fine sand. These beds rarely exceed 2 m total thickness and are generally less than 1 m thick; superposition of deposits accounts for the thicker deposits. Cryoturbation is common. The deposits are continuously frozen but seasonally thawed to 0.6 m deep. They contain segregated ice and massive ice in the form of wedges. The surface is marked by low-centered, ice-wedge polygons and ranges from wet to dry. Tundra is the dominant vegetation.

Fluvial Sediments

Qf **ACTIVE FLOOD-PLAIN DEPOSITS** - Fine to medium sand or sandy gravel, or both, deposited in channels of modern flood plains by fluvial processes. Sandy gravel is the dominant type of these deposits. When present, sand deposits are moderately sorted and generally 0.5 m or less thick, and overlie poorly sorted sandy gravel with a sharp contact. Subrounded to rounded pebbles and cobbles are common in the sandy gravel. Deposits extend up to 1 m above the mean stream surface. The unit is continuously frozen but seasonally thawed to about 1 m deep. It is also thawed in zones below channels with water greater than 2 m deep. Surfaces of sandy gravel are unvegetated. Sandy surfaces are unvegetated or support sparse covers of grasses, sedges, and willow. Surfaces flood annually.

Qfi **INACTIVE FLOOD-PLAIN DEPOSITS** - Peat and pebbly silt or fine to medium sand, or mixtures or interbeds of all three, deposited in flood plain overbank environments by fluvial, eolian, and lacustrine processes, and underlying sand, sandy gravel, or gravel, or interbeds of all three, deposited in channels by fluvial processes; sandy gravel is the dominant type of these underlying deposits. Overbank deposits generally consist of a topmost bed of peat up to 0.5 m thick and underlying pebbly silt or sand about 0.5 m thick. These deposits are in sharp contact with underlying channel deposits. Subrounded to rounded pebbles and cobbles are common in the channel deposits; these clasts are sometimes imbricated. Exposures of these deposits rarely exceed 2 m high and are generally less than 1 m high. The unit is continuously frozen but seasonally thawed to about 0.6 m high. Surfaces support thin covers of sedges, grasses, and tundra, and flood annually.

Qfa **ABANDONED FLOOD-PLAIN DEPOSITS** - Peat and pebbly silt or fine to medium sand, or mixtures or interbeds of all three, deposited in flood plain overbank environments by fluvial, eolian, and lacustrine processes, and underlying sand, sandy gravel, or gravel, or interbeds of all three, deposited in channels by fluvial processes; sandy gravel is the dominant type of these underlying deposits. Overbank deposits generally consist of a topmost bed of peat up to 1 m thick that is often cryoturbated and vertically foliated, and underlying interbedded pebbly silt, pebbly fine sand, and peat all up to 2 m thick. These overbank deposits generally contain segregated ice and massive ice in the form of wedges. The overbank deposits are in sharp contact with underlying channel deposits. Subrounded to rounded pebbles and cobbles are common in the channel deposits; these clasts are sometimes imbricated. Exposures of these deposits rarely exceed 3 m high and are generally less than 2 m high. Scarps that bound the unit are indistinct. The unit is continuously frozen but seasonally thawed to 0.6 m deep. Surfaces support tundra and are marked by low-centered, ice-wedge polygons. Centers of polygons support sedges and grasses. Surfaces flood infrequently, although low areas may flood annually.

Qat **ALLUVIAL-TERRACE DEPOSITS** - Peat and pebbly silt or fine to medium sand, or mixtures or interbeds of all three, deposited in flood plain overbank environments by fluvial, eolian, and lacustrine processes, and underlying sand, sandy gravel, or gravel, or interbeds of all three, deposited in channels by fluvial processes; sandy gravel is the dominant type of these underlying deposits. Overbank deposits generally consist of a topmost bed of peat up to 1 m thick that is often cryoturbated and vertically foliated, and underlying interbedded pebbly silt and fine sand and peat up to 2 m thick. These overbank deposits generally contain segregated ice and massive ice in the form of wedges. The overbank deposits are in sharp contact with underlying channel deposits. Subrounded to rounded pebbles and cobbles are common in the channel deposits; these clasts are sometimes imbricated. Exposures of these deposits rarely exceed 4 m high and are generally less than 3 m high. Scarps that bound the unit are distinct. The unit is continuously frozen but seasonally thawed to 0.6 m deep. Surfaces support tundra and are marked by low-centered, ice-wedge polygons. Centers of polygons support sedges and grasses. The surface is not subject to flooding by the adjacent river.

Qaf **ALLUVIAL-FAN DEPOSITS** - Poorly to moderately sorted silt, sand, and gravel deposited at valley mouths by fluvial processes. Surface generally smooth; dissected by a few stream channels. Suiface slopes less than 20^0 and slightly concave upward. Gravel clasts are subangular to subrounded and range up to boulder size; cobbles and boulders are common. Compositions of clasts match rock types in the associated drainage basin. Inactive fan surfaces often capped by overbank silt and sand.

Qau **UNDIFFERENTIATED ALLUVIUM** - Peat and silt or fine sand, or mixtures or interbeds of all three, deposited in flood plain overbank environments by fluvial, eolian, and lacustrine processes, and underlying sand, sandy gravel, or interbeds of all three, deposited in channels of flood plains by fluvial processes; sandy gravel is the dominant type of these underlying deposits. Overbank deposits are up to 5 m thick but average 2.5 m thick. Peat and peat-rich pebbly silt compose up to 4.5 m of the top of these deposits but the average thickness is 1 m. These deposits are often cryoturbated and vertically foliated. Pebbly silt, silty sand, and fine sand compose up to 3.5 m of the bottom of these deposits but the average thickness is 1.5 m. Channel deposits are poorly to moderately sorted; pebbles and cobbles are common and subrounded to rounded. Scarps that bound the unit are indistinct. The unit is continuously frozen but seasonally thawed to 0.6 m deep. The ground surface is marked by low-centered ice-wedge polygons and generally wet.

Qsg **ALLUVIAL-PLAIN DEPOSITS** - Pebbly fine eolian sand, and underlying interbedded pebbly fine to medium sand and gravel, and sandy gravel deposited by braided-river processes on an alluvial plain. The topmost part of the section often consists of peat 0.3 to 1.3 m thick, with an interbed of pebbly sandy silt 0.1 to 0.4 m thick, and sometimes underlying thaw-lake deposits. The pebbly sandy silt is dark grayish brown when wet and light gray when dry. When dry, it shows a boxwork structure caused by melting of segregated ice. The pebbly sandy silt is most likely loess because its distribution is extensive. Thaw-lake deposits undoubtedly often overlie the pebbly fine sand, but are not mapped because they cannot be recognized outside lake-basin boundaries on aerial photographs. The pebbly fine sand is gray to olive gray but often oxidized brownish yellow. Pebbles in the sand are most commonly brown and black chert; all are polished and some are ventifacted. These deposits are up to 4 m thick including the peat, loess, and thaw-lake deposits. The top part of the alluvial-plain deposits often consists of interbedded pebbly fine and medium sand and sandy gravel. When present, the interbedded interval is up to 6 m thick, but the average is 3 m thick. The modal size of the gravel is 3 cm; pebbles are subrounded to rounded. The bottom part of the alluvial-plain deposits is dominantly sandy gravel, although thin beds of gravel, sand and organic-and wood-rich silt are present. Alluvial-plain deposits have been measured in deep gravel pits to 16 m below the surface. The modal size of the gravel varies from 2 to 5 cm; cobbles are common and boulders are sometimes present near the base of the section. Thin beds of sand and organic- and wood-rich silt sometimes mark changes in the clast mode. Discontinuously along the coast and up to 9 km inland, pebbly marine mud, interbedded sand and gravelly sand, and cobbles and boulders of the Flaxman Member crop out at or near sea level. These deposits are generally less than 1 m thick and are overlain by the eolian pebbly fine sand. The unit is continuously frozen but seasonally thawed to 0.6 m deep. Segregated ice and massive ice in the form of wedges are concentrated in the top 3 m. The surface is moist to dry and marked by low- and high-centered ice-wedge polygons.

Eolian Sediments

Qs **SAND COVER DEPOSITS** - Fine to medium sand derived from dune deposits (Qsd) and deposited downwind in a sheet by eolian processes. Deposits proximal to the dunes are several meters thick, and thin downwind from the dunes. The deposits are mapped only where they can be seen on aerial photographs to infill low-centered ice-wedge polygons, thaw ponds, and small thaw lakes. The deposits are continuously frozen but seasonally thawed to about 1 m deep. Surfaces support grasses, sedges, and tundra.

Qsd **SAND DUNE DEPOSITS** - Fine and medium sand derived from barren flood plain, delta, and beach deposits and deposited in dune form by eolian processes. Dune deposits are up to 6 m thick but generally range from 1 to 4 m thick. The dunes are most commonly longitudinal and trend northeast to southwest. Vegetated dunes are continuously frozen and often contain pore ice; they are seasonally thawed to about 1 m deep. Unvegetated dunes are actively being reworked and yardangs are common.

Colluvial Sediments

Qrg **RETRANSPORTED GRANULAR DEPOSITS** - Poorly to moderately sorted silt and sand retransported from the site of initial deposition by colluvial and fluvial processes. At most localities, the primary cause of retransport is thawing of constituent massive and segregated ice, resulting in subsidence and movement downslope. These deposits are typically several meters thick.

Qc **UNDIFFERENTIATED COLLUVIUM** - Very poorly to moderately sorted silt, sand and gravel on steep slopes, derived from underlying or nearby bedrock or unconsolidated deposits and left on slopes by frost creep and gelifluction. Size distribution of clasts is dependent on source deposit or bedrock. Where present, gravel clasts are subangular to subrounded and range up to boulder size. The sediments include disseminated, fine-grained organic material, and in some places, detrital wood, or chunks of peat, or both. Deposits are typically 1 to 10 m thick. Topography generally smooth, and follows the contour of the underlying bedrock surface (modified from Carter and Galloway, 1985a; and Carter and others, 1986c.)

Terrace Sediments

QtF **ALLUVIAL-TERRACE F DEPOSITS** - As QtE deposits; however, deposits are younger.

QtE **ALLUVIAL-TERRACE E DEPOSITS** - Predominantly fluvial gravelly sand, sand, silty sand and peat, overlain by eolian sand. Pelecypod shell fragments are not present.

QtD **ALLUVIAL-TERRACE D DEPOSITS** - As QTtC deposits, but without basal possible marine sediments.

QTtC **ALLUVIAL- AND MARINE-TERRACE C DEPOSITS** - Predominantly fluvial silty sand with granules and pebbles, but includes minor sandy pebble gravel and peat, overlain by eolian sand and peat. Fluvial sediments contain pelecypods fragments throughout; however, basal gravelly sand in more upstream sections along Terrace C that is particularly rich in shell fragments may be marine. Terrace C is hypothesized to have been cut by the Fishcreekian transgression (modified from Carter and Galloway, 1985a.)

QTtB **ALLUVIAL-AND MARINE-TERRACE B DEPOSITS** - Variable composition, but deposits generally consist of stratified marine gravelly sand, silty sand, silt and minor clay, overlain by fluvial gravelly sand, silty sand, and minor organic silt, which in turn is overlain by eolian sand. The marine deposits are absent in some exposures; where present, they are fossiliferous. Amino-acid analysis of enclosed shells suggests that the marine deposits are from the Colvillian and Bigbendian transgressions. The fluvial deposits typically contain fragments of pelecypod shells, presumably reworked from the marine deposits, peat, and logs of coniferous and nonconiferous trees. Tsg deposits are exposed below the fluvial deposits along the more upstream part of the Kachemach River on Terrace B (modified from Carter and Galloway, 1985a.)

QTtA **ALLUVIAL-AND MARINE-TERRACE A DEPOSITS** - Deposits consist of Tsg deposits along the Kachemach River and the more upstream part of the Miluveach River on Terrace A, overlain by fluvial gravelly sand, silty sand, and silt and minor clay, which in turn is overlain by eolian sand. The fluvial deposits typically contain peat and logs of coniferous and nonconiferous trees. Marine deposits are absent; however, fragments of pelecypod shells in the stream channel along the more downstream part of the Miluveach River on Terrace A suggest their presence below exposed levels. Marine deposits, if present, would likely be from the Colvillian or Bigbendian, or both transgressions (modified from Carter and Galloway, 1985a.)

Tgs **UNDIFFERENTIATED GRAVELLY SAND** - Moderately sorted gravelly sand to sandy gravel. Clasts are predominantly pebble-sized, well-rounded chert and quartz. Unit is poorly exposed, but is estimated to be 1 to 3 m thick (modified from Carter and Galloway, 1985a.)

Outwash sediments

Qso **SILT AND SAND OVER OUTWASH GRAVEL** - Eolian silt and fine sand overlying glaciofluvial gravel, gravelly sand, and minor silty sand. The eolian deposits are stratified, include disseminated organic material, and range in thickness between 2 and 10 m. Sand is generally predominant over silt within a few kilometers of the coast. The underlying outwash gravel is described as unit Qo. Along parts of the coast, marine pebbly mud interfingers with the outwash gravel to several kilometers inland (modified from Carter and others, 1986c.)

Qo OUTWASH GRAVEL - Stratified pebble, cobble, and boulder gravel, gravelly sand, and minor silty sand deposited by proglacial streams. Clasts are subrounded to well rounded and composed of a wide varity of rock types derived from within the Brooks Range. Clast size decreases northward. Wood is absent or rare. Along parts of the coast, marine pebbly mud interfingers with the outwash gravel to several kilometers inland, except where post-transgression outwash has eroded and replaced the marine deposits (modified from Carter and others, 1986c.)

Glacial Sediments

$Qsgt_3$ **SILT AND SAND OVER MIDDLE PLEISTOCENE (?) TILL** - Middle Pleistocene till (Qgt_3) covered by eolian and colluvial silt and sand in layers up to several meters thick.

Qgt_3 **MIDDLE PLEISTOCENE (?) TILL** - Presumed to correspond to the middle Pleistocene glacial episode. Present in Ignek Valley and as large lobate moraines on Canning and Hulahula Rivers. Moraines are gently irregular, but not as subdued as moraine of early Pleistocene till along the Canning River. Rounded ridges are discernable, and lakes are present in Canning River moraine. Moraines on Hulahula River are possibly early Pleistocene.

$Qsgt_4$ **SILT AND SAND OVER EARLY PLEISTOCENE (?) TILL** - Early Pleistocene till (Qgt_4) covered by eolian and colluvial silt and fine sand in layers up to several meters thick.

Qgt_4 **EARLY PLEISTOCENE (?) TILL** - Presumed to correspond to the early Pleistocene glacial episode. Present in Ignek Valley and as large lobate moraine extending eastward along Canning River to Tamayariak River. Lobate moraine subdued and rolling, with lakes near its terminus. Till deposits to the east more subdued and possibly older. Based on extent, early Pleistocene (?) till should occur along streams east of the Sadlerochit Mountains. These correlate with similar deposits on the coastal plain. However, available evidence indicates that early Pleistocene (?) till is not present (see discussion of middle Pleistocene (?) till); it may have been reworked or is covered by later outwash and eolian deposits.

Tg **GRAVEL** - Poorly to moderately sorted pebble, cobble, and boulder gravel termed the Kuparuk gravel. Clasts are predominantly rock types common in nearby parts of the Brooks Range, including chert, quartz, sandstone, and chert-pebble conglomerate. Glacial erratics to 1.5 m in diameter are common. Parts of deposit may have silty matrix and may be till. Deposits are poorly exposed, but estimated to be up to 20 m thick (modified from Carter and Galloway, 1985a.)

Gravel Sheet Sediments

QTsg **SILT AND SAND OVER GRAVEL, GRAVELLY SAND, AND SAND** - Eolian silt and fine sand overlying fluvial and possibly glaciofluvial, gravel, gravelly sand, sand, and silty sand. The silt and fine sand contains disseminated fine-grained organic material and is indistinctly stratified. Underlying fluvial deposits are stratified and include clasts of a wide range of rock types derived from the interior of the Brooks Range. The eolian deposits are up to 15 m thick and the underlying fluvial deposits range between 10 and at least 25 m thick (modified from Carter and others, 1986c.)

QTg(') **SAND AND GRAVEL** - Poorly to moderately sorted sand and gravel deposited on high-level bedrock surfaces by fluvial processes. Subangular to rounded pebbles, cobbles, and boulders with a matrix of fine sand is the dominant texture. Modal gravel sizes range from 0.03 to 0.05 m, with clasts to 0.6 m in diameter; in general, clast size decreases northward away from the Sadlerochit Mountain front. Three lithologies are dominant: Sadlerochit Group sandstone or Lisburne Group limestone, or both, plus or minus Katakturuk Dolomite. Lithologic sequences represented by clasts indicate selective exposure over time or change of source, or both. Maximum measured thickness is 21 m; most deposits about half this thickness. In some localities, wood is abundant in sand lenses; some coniferous wood is present. Deposits mapped and indicated with a prime (') mark are the most recent of these deposits. Best exposed on ridges adjacent to river valleys and on knolls (modified from Robinson and others, 1989.)

QTgm **GRAVEL OVER SAND, SILT, AND CLAY** - Poorly to moderately sorted pebble, cobble, and boulder gravel of fluvial and possibly glaciofluvial origin overlying marine sand, silt, and clay. The gravel is stratified and contains clasts composed of a wide range of rock types derived from the interior of the Brooks Range. These deposits are up to 10 m thick. The marine deposits are stratified and includes sediments of the Bigbendian and Fishcreekian marine transgressions. The marine deposits are about 10 m thick (modified from Carter and others, 1986c.)

Bedrock

Ts **UNDIFFERENTIATED SILTSTONE, SHALE, AND SANDSTONE** - Poorly to moderately sorted marine and nonmarine siltstone, shale, sandstone, and minor conglomerate. The deposits are poorly indurated and thin to medium bedded. The thickness of these deposits is unknown (modified from Carter and others, 1986c.)

Tmg **MUDDY CONGLOMERATE (DIAMICTON)** - Very poorly sorted, poorly indurated pebble to cobble conglomerate with a silty to clayey matrix; matrix locally may be bentonitic. Clast rock types include siliceous sandstone, siltstone, quartz, and possibly tuff. These deposits are at least 50 m thick (modified from Carter and others, 1986c.)

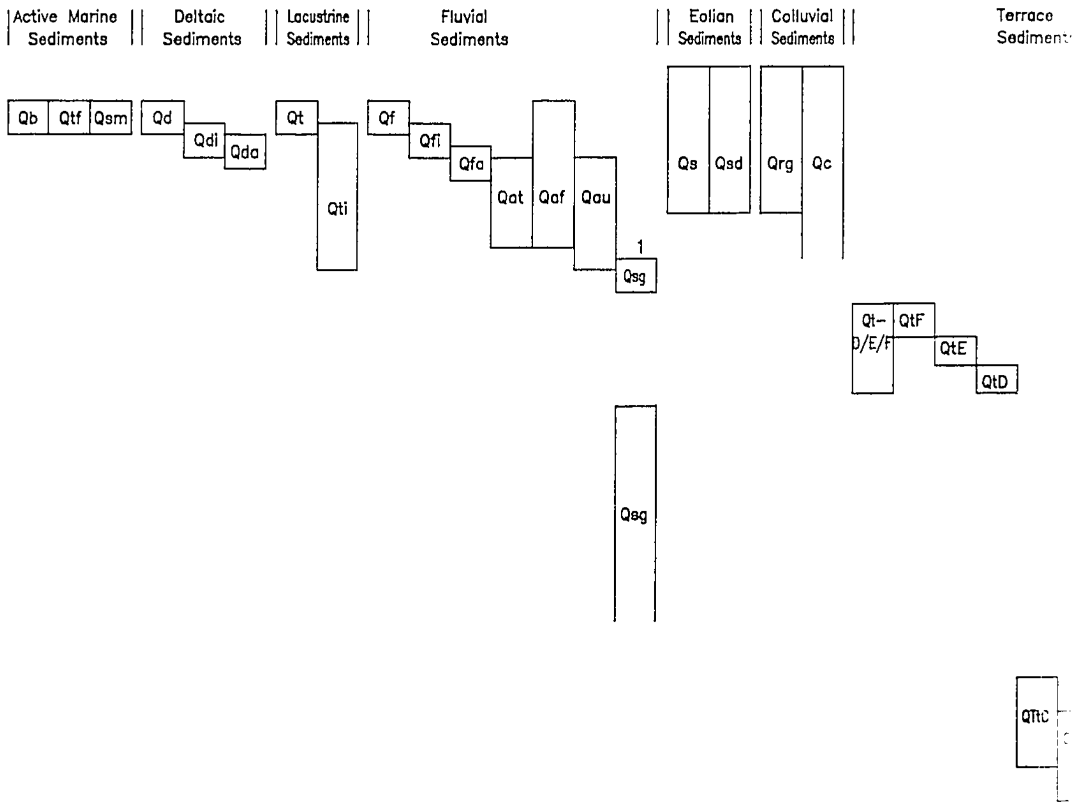
Tsmg **SILT AND MUDDY CONGLOMERATE** - Quaternary eolian and retransported silt and fine sand overlying Tmg deposits. Silt and fine sand deposits include disseminated organic material, are indistinctly stratified, and range up to 10 m thick.

Tsg

UNDIFFERENTIATED SAND, GRAVELLY SAND, CONGLOMERATE, AND PEBBLY MUD - In the western part of the study area, the composition of the deposits varies from conglomerate to sandy gravel, gravelly sand, sand, and pebbly mud. Some of the deposits include clasts up to 1.2 m in diameter composed of metamorphic, intrusive, and volcanic types that do not occur in nearby parts of the Brooks Range. The deposits locally contain lignitized logs of large coniferous trees, and disseminated sulfur. The exposed thickness of these deposits ranges between 2 and 8 m; the total thickness is much greater, but unknown. These deposits are overlain by predominantly eolian silt and fine sand up to 10 m thick. In the central and eastern parts of the area, the deposits consist of poorly sorted and poorly indurated pebble to cobble conglomerate with a sandy matrix. Clast rock types include siliceous sandstone, silicified siltstone, chert, and quartz. These deposits are at least 85 m thick (modified from Carter and Galloway, 1985a; and Carter and others, 1986c.)

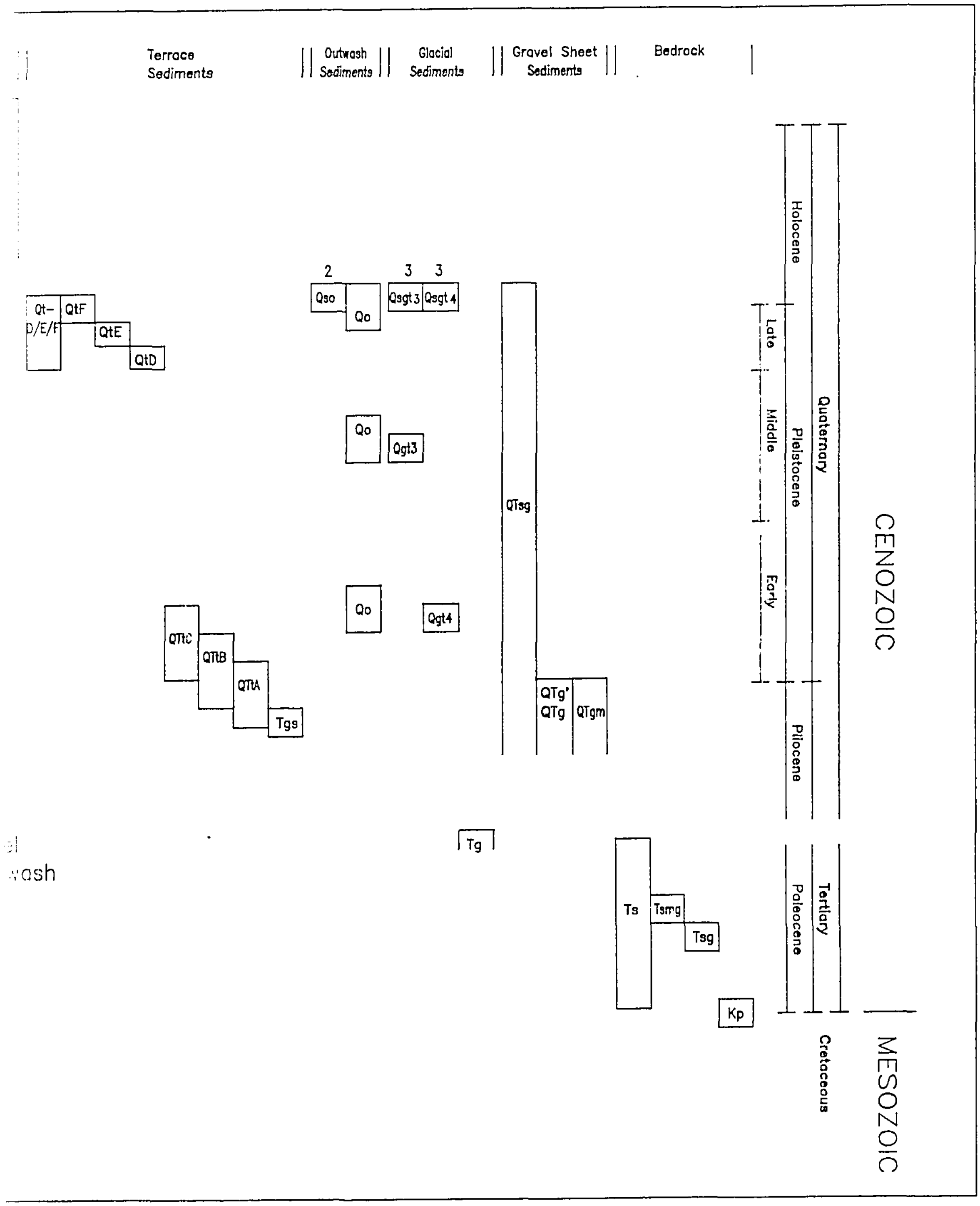
Kp

SANDSTONE, SILTSTONE, SHALE, AND PYROCLASTIC ROCKS - In the western part of the study area, deposits are moderately sorted nonmarine sandstone, siltstone, and shale with minor coaly beds and thin tephra layers. The deposits are thin to thickly bedded and poorly to moderately indurated. These beds are part of the type section for the upper part of the Kogasukruk Tongue of the Prince Creek Formation (Brosgè and Whittington, 1966). In the eastern part of the area, the deposits consist of silicified tuff and bentonitic shale with minor silty shale (modified from Carter and Galloway, 1985a; and Carter and others, 1986c.)



1. Represents the Beechey sand; overlies Ugnuravik gravel
2. Represents silt and sand that overlies Pleistocene outwash
3. Represents silt that overlies corresponding till

B - MAP-UNIT CORRELATION



APPENDIX C

STRATIGRAPHIC SECTIONS OR FIELD OBSERVATIONS

Log: Y = stratigraphic section measured
N = observations only

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPA1	81TIG1	BPA1-1	N 70°12'32"	W 147°14'12"	Y
BPA1	82KAD1	BPA1-10	N 70°10'42"	W 147°18'20"	Y
BPA1	83SHAV1	BPA1-11	N 70°10'04"	W 147°18'46"	Y
BPA1	82SHAV1	BPA1-12	N 70°09'02"	W 147°11'08"	Y
BPA1	82SHAV2	BPA1-13	N 70°09'12"	W 147°10'04"	Y
BPA1	82SHAV3	BPA1-14	N 70°09'24"	W 147°08'24"	Y
BPA1	82SHAV4	BPA1-15	N 70°09'22"	W 147°07'02"	Y
BPA1	84COA2	BPA1-16	N 70°09'20"	W 147°06'30"	Y
BPA1	82SHAV5	BPA1-17	N 70°09'14"	W 147°05'14"	Y
BPA1	84COA1	BPA1-18	N 70°09'17"	W 147°00'41"	Y
BPA1	83SHAV20	BPA1-19	N 70°07'37"	W 147°00'13"	Y
BPA1	81TIG2	BPA1-2	N 70°12'37"	W 147°14'08"	Y
BPA1	84SHAV4	BPA1-20	N 70°06'27"	W 147°27'17"	Y
BPA1	83SHAV9	BPA1-21	N 70°00'34"	W 147°29'24 "	Y
BPA1	81SHAV6	BPA1-22	N 70°00'54"	W 147°27'18"	Y
BPA1	82SHAV7	BPA1-23	N 70°01'54"	W 147°17'30"	Y
BPA1	83SHAV8	BPA1-24	N 70°02'15"	W 147°09'52"	Y
BPA1	83SHAV14	BPA1-25	N 70°04'06"	W 147°15'34"	Y
BPA1	83SHAV5	BPA1-26	N 70°04'48"	W 147°12'30"	Y
BPA1	81SHAV4	BPA1-27	N 70°09'06"	W 147°15'30"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPA1	81SHAV5	BPA1-28	N 70°05'07"	W 147°15'48"	Y
BPA1	84SHAV3	BPA1-29	N 70°05'25"	W 147°16'52"	Y
BPA1	81TIG3	BPA1-3	N 70°12'34"	W 147°13'52"	Y
BPA1	83SHAV6	BPA1-30	N 70°06'20"	W 147°14'25"	Y
BPA1	83SHAV7	BPA1-31	N 70°06'24"	W 147°12'16"	Y
BPA1	83SHAV4	BPA1-32	N 70°07'06"	W 147°14'00"	Y
BPA1	83SHAV3	BPA1-33	N 70°07'19"	W 147°12'42"	Y
BPA1	82SHAV6	BPA1-34	N 70°07'29"	W 147°14'11"	Y
BPA1	83SHAV2	BPA1-35	N 70°08'00"	W 147°14'08"	Y
BPA1	87SR35	BPA1-36	N 70°06'10"	W 147°14'30"	Y
BPA1	81TIG4	BPA1-4	N 70°12'49"	W 147°14'20"	Y
BPA1	82KAD4	BPA1-5	N 70°11'52"	W 147°28'42"	Y
BPA1	82KAD3	BPA1-6	N 70°11'28"	W 147°26'28"	Y
BPA1	81SHAV2	BPA1-7	N 70°11'13"	W 147°24'12"	Y
BPA1	81SHAV1	BPA1-8	N 70°11'12"	W 147°24'26"	Y
BPA1	82KAD2	BPA1-9	N 70°11'07"	W 147°21'48"	Y
BPA2	83ESAG4	BPA2-1	N 70°14'11"	W 147°51'48"	Y
BPA2	82SAG9	BPA2-10	N 70°08'56"	W 148°08'20"	Y
BPA2	84ESAG6	BPA2-11	N 70°10'50"	W 148°00'20"	Y
BPA2	84ESAG5	BPA2-12	N 70°11'02"	W 147°59'50"	Y
BPA2	83ESAG10	BPA2-13	N 70°12'57"	W 147°59'17"	Y
BPA2	83ESAG9	BPA2-14	N 70°11'52"	W 147°58'12"	Y
BPA2	81SAG9A-C	BPA2-15	N 70°13'04"	W 148°01'26"	Y
BPA2	83ESAG6	BPA2-16	N 70°12'56"	W 147°56'20"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPA2	83ESAG1	BPA2-17	N 70°13'03"	W 147°53'00"	Y
BPA2	83ESAG2	BPA2-18	N 70°13'02"	W 147°52'56"	Y
BPA2	83ESAG5	BPA2-19	N 70°13'56"	W 147°53'28"	Y
BPA2	82SAG5	BPA2-2	N 70°13'03"	W 147°45'48"	Y
BPA2	83ESAG3	BPA2-2	N 70°13'53"	W 147°50'20"	Y
BPA2	82KAD6	BPA2-20	N 70°01'30"	W 147°44'32"	Y
BPA2	83KAD6	BPA2-21	N 70°02'30"	W 147°42'03"	Y
BPA2	83KAD5	BPA2-22	N 70°04'55"	W 147°43'00"	Y
BPA2	83KAD4	BPA2-23	N 70°08'27"	W 147°39'24"	Y
BPA2	83KAD3	BPA2-24	N 70°10'20"	W 147°39'21"	Y
BPA2	82KAD5	BPA2-25	N 70°11'34"	W 147°36'22"	Y
BPA2	87SR34	BPA2-26	N 70°11'02"	W 147°59'50"	Y
BPA2	82SAG3	BPA2-3	N 70°13'36"	W 147°49'24"	Y
BPA2	82SAG4	BPA2-4	N 70°13'20"	W 147°48'22"	Y
BPA2	82SAG6	BPA2-6	N 70°12'38"	W 147°42'40"	Y
BPA2	83KAD1	BPA2-7	N 70°11'38"	W 147°39'24"	Y
BPA2	83ESAG7	BPA2-8	N 70°01'51"	W 148°11'41"	Y
BPA2	83ESAG8	BPA2-9	N 70°07'47"	W 148°10'22"	Y
BPA3	84WSAG3	BPA3-1	N 70°02'55"	W 148°45'42"	Y
BPA3	85SAGC	BPA3-10	N 70°14'33"	W 148°15'47"	Y
BPA3	81SAG5	BPA3-11	N 70°00'56"	W 148°30'18"	Y
BPA3	81SAG7	BPA3-12	N 70°03'50"	W 148°20'56"	Y
BPA3	82SAG7	BPA3-13	N 70°00'24"	W 148°27'30"	Y
BPA3	82SAG8	BPA3-14	N 70°04'51"	W 148°15'16"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPA3	83ESAG11	BPA3-15	N 70°05'20"	W 148°13'24"	Y
BPA3	84WSAG2	BPA3-2	N 70°06'35"	W 148°37'58"	Y
BPA3	81SAG1	BPA3-3	N 70°01'30"	W 148°40'32"	Y
BPA3	81SAG3	BPA3-4	N 70°00'27"	W 148°34'16"	Y
BPA3	84WSAG4	BPA3-5	N 70°01'45"	W 148°37'32"	Y
BPA3	81SAG6	BPA3-6	N 70°03'46"	W 148°28'02"	Y
BPA3	84WSAG1	BPA3-7	N 70°06'14"	W 148°29'00"	Y
BPA3	81SAG8A	BPA3-8	N 70°12'18"	W 148°18'34"	Y
BPA3	81SAG8B	BPA3-9	N 70°12'24"	W 148°18'18"	Y
BPA4	84KUP2	BPA4-1	N 70°03'02"	W 149°13'47"	Y
BPA4	84KUP4	BPA4-10	N 70°06'05"	W 148°59'59"	Y
BPA4	87SR26	BPA4-10	N 70°10'35"	W 149°06'50"	Y
BPA4	87SR26-1	BPA4-10	N 70°10'40"	W 149°07'04"	Y
BPA4	84KUP3	BPA4-2	N 70°03'09"	W 149°13'44"	Y
BPA4	83KUP1	BPA4-3	N 70°05'35"	W 149°14'18"	Y
BPA4	84KUP1	BPA4-4	N 70°05'34"	W 149°13'18"	Y
BPA4	82KUP2	BPA4-5	N 70°10'29"	W 149°06'48"	Y
BPA4	84KUP5	BPA4-6	N 70°10'29"	W 149°07'04"	Y
BPA4	84WSAG6	BPA4-7	N 70°00'04"	W 149°14'06"	Y
BPA4	84WSAG5	PBA4-8	N 70°00'36"	W 149°08'16"	Y
BPA5	82KUP5	BPA5-1	N 70°03'03"	W 149°48'00"	Y
BPA5	82KUP6	BPA5-2	N 70°03'34"	W 149°44'08"	Y
BPA5	82KUP4	BPA5-3	N 70°00'02"	W 149°34'04"	Y
BPA5	87SR27	BPA5-4	N 70°00'35"	W 149°31'18"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPB2	82SAG2	BPB2-1	N 70°19'45"	W 148°03'38"	Y
BPB2	82SAG1	BPB2-2	N 70°17'34"	W 148°11'40"	Y
BPB2	81SAG10	BPB2-3	N 70°15'44"	W 148°03'20"	Y
BPB3	81SR01	BPB3-1	N 70°24'42"	W 148°42'50"	Y
BPB3	81WDOCK2	BPB3-10	N 70°22'43"	W 148°31'24"	Y
BPB3	81WDOCK5	BPB3-11	N 70°21'21"	W 148°28'04"	Y
BPB3	81WDOCK7	BPB3-12	N 70°21'04"	W 148°27'58"	Y
BPB3	81WDOCK8	BPB3-13	N 70°21'01"	W 148°27'50"	Y
BPB3	81WDOCK9	BPB3-14	N 70°20'04"	W 148°27'25"	Y
BPB3	7/18/81-1	BPB3-15	N 70°18'28"	W 148°19'30"	Y
BPB3	7/18/81-2	BPB3-16	N 70°18'33"	W 148°19'17"	Y
BPB3	7/16/81-1	BPB3-17	N 70°19'02"	W 148°18'08"	Y
BPB3	7/16/81-2	BPB3-18	N 70°19'07"	W 148°17'44"	Y
BPB3	7/16/81-3	BPB3-19	N 70°19'16"	W 148°17'18"	Y
BPB3	81SR02	BPB3-2	N 70°24'38"	W 148°42'24"	Y
BPB3	84PRU1	BPB3-20	N 70°20'42"	W 148°12'32"	Y
BPB3	84PUT3	BPB3-21	N 70°15'50"	W 148°38'08"	Y
BPB3	84PUT4	BPB3-22	N 70°16'06"	W 148°37'18"	Y
BPB3	84PUT1	BPB3-23	N 70°16'45"	W 148°32'36"	Y
BPB3	81WRD10	BPB3-24	N 70°17'29"	W 148°31'16"	Y
BPB3	85PUT2	BPB3-25	N 70°17'45"	W 148°30'44"	Y
BPB3	PUOWR2	BPB3-26	N 70°15'08"	W 148°19'02"	Y
BPB3	81SAG3	BPB3-27	N 70°16'19"	W 148°15'48"	Y
BPB3	87SR36	BPB3-28	N 70°20'29"	W 148°13'06"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPB3	81SR03	BPB3-3	N 10'24'19"	W 148°40'42"	Y
BPB3	81SR04	BPB3-4	N 70°24'05"	W 148°70°40"	Y
BPB3	81SR05	BPB3-5	N 70°23'59"	W 148°40'25"	Y
BPB3	81SR06	BPB3-6	N 70°24'11"	W 148°38'20"	Y
BPB3	81SR07	BPB3-7	N 70°23'38"	W 148°37'12"	Y
BPB3	81SR08	BPB3-8	N 70°23'54"	W 148°36'00"	Y
BPB3	81WDOCK1	BPB3-9	N 70°22'44"	W 148°32'00"	Y
BPB4	81KAV2	BPB4-1	N 70°29'44"	W 149°20'34"	Y
BPB4	81BEE2	BPB4-10	N 70°27'51"	W 149°03'50"	Y
BPB4	81WRD3	BPB4-11	N 70°19'14"	W 149°22'42"	Y
BPB4	81WRD4	BPB4-12	N 70°19'18"	W 149°22'40"	Y
BPB4	81WRD5	BPB4-13	N 70°19'22"	W 149°19'24"	Y
BPB4	81WRD1	BPB4-14	N 70°19'47"	W 149°23'38"	Y
BPB4	81WRD2	BPB4-15	N 70°19'52"	W 149°23'58"	Y
BPB4	85MP1	BPB4-16	N 70°27'23"	W 149°21'20"	Y
BPB4	81KAV1	BPB4-17	N 70°27'56"	W 149°20'42"	Y
BPB4	81WRD6	BPB4-18	N 70°19'02"	W 149°13'02"	Y
BPB4	81WRD7	BPB4-19	N 70°18'49"	W 149°10'00"	Y
BPB4	81KAV3	BPB4-2	N 70°29'59"	W 149°20'20"	Y
BPB4	82KUP1	BPB4-20	N 70°16'19"	W 148°56'30"	Y
BPB4	81KUP4	BPB4-21	N 70°17'31"	W 148°57'48"	Y
BPB4	81KUP5	BPB4-22	N 70°17'45"	W 148°56'58"	Y
BPB4	81KUP1	BPB4-23	N 70°18'04"	W 148°56'50"	Y
BPB4	81KUP2	BPB4-24	N 70°18'15"	W 148°57'20"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPB4	81KUP3	BPB4-25	N 70°18'04"	W 148°58'00"	Y
BPB4	81KUP11	BPB4-26	N 70°18'06"	W 149°00'18"	Y
BPB4	81KUP10	BPB4-27	N 70°18'15"	W 149°00'38"	Y
BPB4	81KUP9	BPB4-28	N 70°18'19"	W 149°00'50"	Y
BPB4	84KUPB	BPB4-29	N 70°19'51"	W 148°59'30"	Y
BPB4	81KAV4	BPB4-3	N 70°29'54"	W 149°19'40"	Y
BPB4	84KUPA	BPB4-30	N 70°20'00"	W 149°00'40"	Y
BPB4	84KUPC	BPB4-31	N 70°20'08"	W 149°01'06"	Y
BPB4	81KUP6	BPB4-32	N 70°22'25"	W 148°52'34"	Y
BPB4	81KUP7	BPB4-33	N 70°23'01"	W 148°55'28"	Y
BPB4	81KUP8	BPB4-34	N 70°23'12"	W 148°56'40"	Y
BPB4	81KAV5	BPB4-4	N 70°29'33"	W 149°18'28"	Y
BPB4	81KAV6	BPB4-5	N 70°29'30"	W 149°18'10"	Y
BPB4	81KAV7	BPB4-6	N 70°29'32"	W 149°17'42"	Y
BPB4	81KAV8	BPB4-7	N 70°29'19"	W 149°14'40"	Y
BPB4	81KAV9	BPB4-8	N 70°29'25"	W 149°14'14"	Y
BPB4	81BEE1	BPB4-9	N 70°29'14"	W 149°10'02"	Y
BPB5	82OLIK3	BPB5-1	N 70°27'50"	W 149°59'59"	Y
BPB5	81OLIK9	BPB5-10	N 70°29'32"	W 149°48'22"	Y
BPB5	81OLIK10	BPB5-11	N 70°29'35"	W 149°47'50"	Y
BPB5	81OLIK11	BPB5-12	N 70°29'32"	W 149°47'38"	Y
BPB5	81OLIK12	BPB5-13	N 70°29'15"	W 149°46'58"	Y
BPB5	81OLIK13	BPB5-14	N 70°29'06"	W 149°46'30"	Y
BPB5	81OLIK14	BPB5-15	N 70°28'51"	W 149°46'00"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPB5	81UGR1	BPB5-16	N 70°28'57"	W 149°45'40"	Y
BPB5	81UGR2	BPB5-17	N 70°29'04"	W 149°45'53"	Y
BPB5	81UGR3	BPB5-18	N 70°29'24"	W 149°45'59"	Y
BPB5	81UGR4	BPB5-19	N 70°29'33"	W 149°45'52"	Y
BPB5	82OLIK4	BPB5-2	N 70°29'59"	W 149°59'16"	Y
BPB5	81UGR5	BPB5-20	N 70°29'46"	W 149°45'40"	Y
BPB5	81UGR6	BPB5-21	N 70°29'36"	W 149°44'40"	Y
BPB5	81UGR7	BPB5-22	N 70°29'46"	W 149°44'06"	Y
BPB5	81UGR8	BPB5-23	N 70°29'47"	W 149°43'04"	Y
BPB5	81UGR9	BPB5-24	N 70°29'51"	W 149°43'00"	Y
BPB5	81UGR10	BPB5-25	N 70°29'49"	W 149°41'56"	Y
BPB5	81UGR11	BPB5-26	N 70°29'52"	W 149°40'10"	Y
BPB5	81UGR2-2	BPB5-27	N 70°29'59"	W 149°37'20"	Y
BPB5	81UGR2-4	BPB5-28	N 70°29'57"	W 149°35'40"	Y
BPB5	81UGR2-5	BPB5-29	N 70°29'45"	W 149°33'59"	Y
BPB5	82OLIK5	BPB5-3	N 70°28'15"	W 149°58'59"	Y
BPB5	84KUPD	BPB5-30	N 70°20'28"	W 149°42'40"	Y
BPB5	84KUPE	BPB5-31	N 70°27'41"	W 149°41'18"	Y
BPB5	85KUPC	BPB5-32	N 70°19'20"	W 149°38'00"	Y
BPB5	81UGPIT1	BPB5-33	N 70°19'15"	W 149°37'30"	Y
BPB5	81UGPIT2	BPB5-34	N 70°19'15"	W 149°37'30"	Y
BPB5	81UGPIT3	BPB5-35	N 70°19'15"	W 149°37'30"	Y
BPB5	81UGPIT4	BPB5-36	N 70°19'15"	W 149°37'30"	Y
BPB5	82OLIK6	BPB5-4	N 70°28'55"	W 149°57'00"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
BPB5	81OLIK4	BPB5-5	N 70°28'08"	W 149°50'10"	Y
BPB5	81OLIK5	BPB5-6	N 70°29'56"	W 149°49'54"	Y
BPB5	81OLIK6	BPB5-7	N 70°29'51"	W 149°49'44"	Y
BPB5	81OLIK7	BPB5-8	N 70°29'41"	W 149°49'34"	Y
BPB5	81OLIK8	BPB5-9	N 70°29'30"	W 149°49'10"	Y
BPC4	81BOD3	BPC4-1	N 70°31'32"	W 149°15'22"	Y
BPC4	81BOD2	BPC4-2	N 70°31'52"	W 149°15'59"	Y
BPC4	81BOD1	BPC4-3	N 70°31'51"	W 149°15'06"	Y
BPC5	81OLIK1	BPC5-1	N 70°30'22"	W 149°51'10"	Y
BPC5	81PIN4	BPC5-10	N 70°33'22"	W 149°34'08"	Y
BPC5	81PIN5	BPC5-11	N 70°33'20"	W 149°32'56"	Y
BPC5	81PIN6	BPC5-12	N 70°33'36"	W 149°32'16"	Y
BPC5	81PIN7	BPC5-13	N 70°33'06"	W 149°28'31"	Y
BPC5	81OLIK2	BPC5-2	N 70°30'16"	W 149°51'04"	Y
BPC5	81OLIK3	BPC5-3	N 70°30'02"	W 149°50'20"	Y
BPC5	81UGR2-1	BPC5-4	N 70°30'04"	W 149°38'26"	Y
BPC5	81UGR2-3	BPC5-6	N 70°30'04"	W 149°36'40"	Y
BPC5	81PIN1	BPC5-7	N 70°33'18"	W 149°34'40"	Y
BPC5	81PIN2	BPC5-8	N 70°33'22"	W 149°34'28"	Y
BPC5	81PIN3	BPC5-9	N 70°33'22"	W 149°34'08"	Y
FIA1	85SR134	FIA1-1	N 70°01'45"	W 144°19'54"	N
FIA3	85SR165	FIA3-1	N 70°01'59"	W 145°45'40"	Y
FIA3	85SR164	FIA3-2	N 70°03'04"	W 145°43'00"	Y
FIA3	85SR166	FIA3-3	N 70°00'23"	W 145°43'00"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
FIA3	85SR167	FIA3-4	N 70°01'20"	W 145°39'59"	N
FIA3	85SR168	FIA3-5	N 70°01'04"	W 145°35'42"	Y
FIA4	85SR157	FIA4-1	N 70°08'22"	W 146°15'22"	Y
FIA4	81CAN10	FIA4-10	N 70°01'56"	W 145°54'30"	Y
FIA4	81CAN12	FIA4-11	N 70°01'10"	W 145°52'12"	Y
FIA4	81CAN8	FIA4-12	N 70°01'15"	W 145°51'18"	Y
FIA4	81CAN9	FIA4-13	N 70°01'15"	W 145°51'08"	Y
FIA4	85SR158	FIA4-2	N 70°08'21"	W 146°07'00"	N
FIA4	81FLAX1	FIA4-3	N 70°11'10"	W 145°57'32"	Y
FIA4	84FLAX1	FIA4-4	N 70°11'00"	W 145°57'48"	Y
FIA4	85SR159	FIA4-5	N 70°02'35"	W 146°01'30"	Y
FIA4	85SR161	FIA4-6	N 70°05'14"	W 145°56'30"	Y
FIA4	85SR160	FIA4-7	N 70°05'19"	W 145°53'00"	N
FIA4	85SR162	FIA4-8	N 70°04'49"	W 145°48'20"	Y
FIA4	81CAN11	FIA4-9	N 70°01'49"	W 145°54'32"	Y
FIA5	83SHAV17	FIA5-1	N 70°03'35"	W 146°52'48"	Y
FIA5	83SHAV18	FIA5-2	N 70°05'57"	W 146°56'24"	Y
FIA5	83SHAV19	FIA5-3	N 70°07'02"	W 146°58'48"	Y
FIA5	83SHAV21	FIA5-4	N 70°08'20"	W 146°59'42"	Y
FIA5	84COA3	FIA5-5	N 70°10'14"	W 146°51'24"	Y
FIA5	84COA4	FIA5-6	N 70°10'32"	W 146°40'12"	Y
FIA5	84COA5	FIA5-7	N 70°11'07"	W 146°31'30"	Y
HBA1	84KAC1	HBA1-1	N 70°07'43"	W 150°28'00"	Y
HBA1	84MIL4	HBA1-10	N 70°11'56"	W 150°11'18"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
HBA1	87SR21	HBA1-11	N 70°13'36"	W 150°15'20"	Y
HBA1	87SR19	HBA1-12	N 70°13'55"	W 150°15'54"	Y
HBA1	87SR22	HBA1-2	N 70°08'34"	W 150°26'24"	Y
HBA1	84KAC2	HBA1-3	N 70°11'35"	W 150°23'40"	Y
HBA1	84KAC3	HBA1-4	N 70°11'56"	W 150°23'40"	Y
HBA1	84KAC4	HBA1-5	N 70°13'26"	W 150°26'30"	Y
HBA1	84KAC5	HBA1-6	N 70°14'52"	W 150°29'30"	Y
HBA1	83MIL1	HBA1-7	N 70°05'11"	W 150°05'08"	Y
HBA1	84MIL3	HBA1-8	N 70°08'49"	W 150°06'16"	Y
HBA1	87SR20	HBA1-9	N 70°09'59"	W 150°08'50"	N
HBA2	87SR33	HBA2-1	N 70°08'45"	W 151°03'19"	Y
HBA2	87SR37	HBA2-2	N 70°09'00"	W 151°01'48"	Y
HBA2	87SR38	HBA2-3	N 70°07'47"	W 151°01'08"	Y
HBA2	87SR40	HBA2-4	N 70°14'17"	W 151°01'00"	Y
HBA2	87SR30	HBA2-5	N 70°02'43"	W 150°52'52"	Y
HBA2	87SR31	HBA2-6	N 70°05'15"	W 150°53'59"	Y
HBA2	87SR32	HBA2-7	N 70°08'12"	W 150°50'50"	Y
HBA3	87SR39	HBA3-1	N 70°04'43"	W 151°14'00"	Y
HBA3	87SR46	HBA3-2	N 70°13'48"	W 151°17'00"	N
HBB1	87SR14	HBB1-1	N 70°22'45"	W 150°35'30"	Y
HBB1	84MIL2	HBB1-10	N 70°17'32"	W 150°21'36"	Y
HBB1	84MIL5	HBB1-11	N 70°18'23"	W 150°23'15"	Y
HBB1	84MIL6	HBB1-12	N 70°18'25"	W 150°23'22"	Y
HBB1	84MIL7	HBB1-13	N 70°19'10"	W 150°23'40"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
HBB1	84MIL8	HBB1-14	N 70°19'25"	W 150°24'28"	Y
HBB1	87SR03	HBB1-15	N 70°19'42"	W 150°05'45"	N
HBB1	84KAL3	HBB1-16	N 70°20'11"	W 150°03'56"	N
HBB1	87SR02	HBB1-17	N 70°20'31"	W 150°04'20"	N
HBB1	84KAL2	HBB1-18	N 70°21'20"	W 150°03'24"	N
HBB1	87SR01	HBB1-19	N 70°20'16"	W 150°00'10"	Y
HBB1	87SR12	HBB1-2	N 70°25'47"	W 150°34'12"	Y
HBB1	84KAL1	HBB1-20	N 70°24'52"	W 150°04'08"	N
HBB1	87SR04	HBB1-21	N 70°24'52"	W 150°05'18"	Y
HBB1	82OLIK1	HBB1-22	N 70°25'57"	W 150°05'38"	Y
HBB1	82OLIK2	HBB1-23	N 70°27'38"	W 150°00'18"	Y
HBB1	87SR11	HBB1-3	N 70°25'54"	W 150°32'52"	Y
HBB1	87SR08	HBB1-4	N 70°20'17"	W 150°30'12"	Y
HBB1	87SR10	HBB1-5	N 70°26'57"	W 150°26'18"	Y
HBB1	87SR09	HBB1-6	N 70°26'40"	W 150°25'00"	Y
HBB1	87SR06	HBB1-7	N 70°24'22"	W 150°23'32"	Y
HBB1	87SR05	HBB1-8	N 70°25'09"	W 150°19'15"	Y
HBB1	84MIL1	HBB1-9	N 70°16'03"	W 150°19'28"	Y
HBB2	81COL6	HBB2-1	N 70°18'22"	W 151°07'00"	Y
HBB2	87SR15	HBB2-10	N 70°24'21"	W 150°40'22"	Y
HBB2	81COL8	HBB2-11	N 70°24'46"	W 150°39'00"	Y
HBB2	81COL9	HBB2-12	N 70°25'18"	W 150°38'28"	Y
HBB2	84KAC6	HBB2-13	N 70°16'10"	W 150°37'10"	Y
HBB2	87SR07	HBB2-14	N 70°21'05"	W 150°37'14"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
HBB2	87SR41	HBB2-2	N 70°16'38"	W 151°00'38"	Y
HBB2	81COL5	HBB2-3	N 70°17'04"	W 150°55'42"	Y
HBB2	87SR16	HBB2-4	N 70°19'47"	W 150°49'50"	Y
HBB2	87SR17	HBB2-5	N 70°21'08"	W 150°49'25"	Y
HBB2	81COL3	HBB2-6	N 70°16'03"	W 150°48'10"	Y
HBB2	81COL4	HBB2-7	N 70°16'07"	W 150°47'59"	Y
HBB2	81COL7	HBB2-8	N 70°21'37"	W 150°42'18"	Y
HBB2	87SR13	HBB2-9	N 70°23'17"	W 150°40'40"	N
HBB3	87SR45	HBB3-1	N 70°15'25"	W 151°43'00"	N
HBB3	87SR43	HBB3-2	N 70°21'26"	W 151°24'50"	Y
HBB4	87SR44	HBB4-1	N 70°24'55"	W 151°49'22"	Y
MMC2	85SR101	MCC2-2	N 69°36'15"	W 144°45'45"	N
MMC1	85SR153	MMC1-1	N 69°44'48"	W 144°29'30"	Y
MMC1	85SR150	MMC1-2	N 69°44'00"	W 144°15'40"	N
MMC2	85SR102	MMC2-1	N 69°35'32"	W 144°50'00"	N
MMC2	85SR100	MMC2-3	N 69°39'07"	W 144°44'34"	N
MMC2	85SR144	MMC2-4	N 69°44'36"	W 144°49'50"	N
MMC3	85SR65	MMC3-1	N 69°43'03"	W 145°47'20"	N
MMC3	85SR73	MMC3-2	N 69°39'22"	W 145°38'53"	N
MMC3	85SR74	MMC3-3	N 69°39'58"	W 145°35'47"	N
MMC3	85SR70	MMC3-4	N 69°36'40"	W 145°35'34"	N
MMC3	85SR71	MMC3-5	N 69°37'03"	W 145°35'00"	N
MMC3	85SR72	MMC3-6	N 69°38'31"	W 145°35'41"	N
MMC3	85SR78	MMC3-7	N 69°39'06"	W 145°31'25"	N

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
MMC3	85SR77	MMC3-8	N 69°39'49"	W 145°28'44"	Y
MMC3	85SR135	MMC3-9	N 69°42'01"	W 145°19'15"	Y
MMC4	85SR103	MMC4-1	N 69°30'02"	W 146°18'30"	Y
MMC4	85SR44	MMC4-1	N 69°34'15"	W 146°08'01"	N
MMC4	85SR36	MMC4-1	N 69°37'06"	W 146°05'44"	N
MMC4	85SR35	MMC4-12	N 69°37'33"	W 146°05'59"	N
MMC4	85SR37	MMC4-13	N 69°37'40"	W 146°04'30"	N
MMC4	85SR40	MMC4-14	N 69°37'11"	W 146°03'51"	N
MMC4	85SR41	MMC4-15	N 69°37'36"	W 146°02'08"	N
MMC4	85SR43	MMC4-16	N 69°37'49"	W 146°02'27"	N
MMC4	85SR42	MMC4-17	N 69°37'50"	W 146°03'22"	N
MMC4	85SR39	MMC4-18	N 69°37'41"	W 145°59'51"	N
MMC4	85SR38	MMC4-19	N 69°37'46"	W 145°59'14"	N
MMC4	85SR105	MMC4-2	N 69°30'41"	W 146°15'54"	N
MMC4	85SR45	MMC4-20	N 69°34'53"	W 146°02'15"	N
MMC4	85SR46	MMC4-21	N 69°34'23"	W 145°58'27"	N
MMC4	85SR47	MMC4-22	N 69°35'15"	W 145°56'30"	N
MMC4	85SR48	MMC4-23	N 69°33'56"	W 145°55'04"	N
MMC4	85SR49	MMC4-24	N 69°34'35"	W 145°53'25"	Y
MMC4	85SR56	MMC4-25	N 69°40'06"	W 145°54'20"	N
MMC4	85SR57	MMC4-26	N 69°40'16"	W 145°53'30"	N
MMC4	85SR58	MMC4-27	N 69°40'26 "	W 145°53'21"	N
MMC4	85SR59	MMC4-28	N 69°41'09"	W 145°54'39"	N
MMC4	85SR60	MMC4-29	N 69°42'14"	W 145°52'42"	N

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
MMC4	85SR104	MMC4-3	N 69°30'42"	W 146°14'39"	N
MMC4	85SR63	MMC4-30	N 69°38'49"	W 145°49'47"	N
MMC4	85SR64	MMC4-31	N 69°39'20"	W 145°48'10"	N
MMC4	85SR62	MMC4-32	N 69°40'05"	W 145°48'32"	N
MMC4	85SR61	MMC4-33	N 69°40'18"	W 145°49'15"	N
MMC4	85SR52	MMC4-4	N 69°37'05"	W 146°16'35"	N
MMC4	85SR106	MMC4-5	N 69°35'01"	W 146°17'38"	Y
MMC4	85SR33	MMC4-6	N 69°44'06"	W 146°18'04"	Y
MMC4	85SR32	MMC4-7	N 69°44'00"	W 146°14'20"	N
MMC4	85SR51	MMC4-8	N 69°14'25"	W 146°14'02"	Y
MMC4	85SR50	MMC4-9	N 69°34'46"	W 146°10'31"	N
MMC5	85SR10	MMC5-1	N 69°42'59"	W 146°57'00"	Y
MMC5	85SR06	MMC5-2	N 69°36'54"	W 146°54'41"	N
MMC5	85SR01	MMC5-3	N 69°39'14"	W 146°51'26"	Y
MMC5	85SR07	MMC5-4	N 69°38'05"	W 146°49'38"	Y
MMC5	85SR08	MMC5-5	N 69°36'45"	W 146°40'45"	N
MMC5	85SR09	MMC5-6	N 69°31'42"	W 146°32'24"	N
MMD1	85SR146	MMD1-1	N 69°52'56"	W 144°31'20"	N
MMD1	85SR155	MMD1-10	N 69°51'40"	W 144°02'00"	Y
MMD1	85SR17	MMD1-2	N 69°56'22"	W 144°27'26"	N
MMD1	85SR148	MMD1-3	N 69°50'07"	W 144°26'08"	N
MMD1	85SR149	MMD1-4	N 69°50'08"	W 144°25'04"	N
MMD1	85SR147	MMD1-5	N 69°51'47"	W 144°24'20"	N
MMD1	85SR133	MMD1-6	N 69°58'41"	W 144°23'35"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
MMD1	85SR152	MMD1-7	N 69°45'39"	W 144°21'58"	Y
MMD1	85SR154	MMD1-8	N 69°49'34"	W 144°15'22"	N
MMD1	85SR151	MMD1-9	N 69°45'12"	W 144°08'59"	Y
MMD2	85SR95	MMD2-1	N 69°45'21"	W 145°09'11"	N
MMD2	85SR80	MMD2-10	N 69°54'54"	W 144°55'42"	N
MMD2	85SR79	MMD2-11	N 69°55'32"	W 144°55'05"	Y
MMD2	85SR131	MMD2-12	N 69°57'45"	W 144°57'01"	Y
MMD2	85SR137	MMD2-13	N 69°49'55"	W 145°03'19"	N
MMD2	85SR138	MMD2-14	N 69°48'41"	W 145°00'20"	N
MMD2	85SR141	MMD2-15	N 69°46'50"	W 144°54'08"	N
MMD2	85SR143	MMD2-16	N 69°49'24"	W 144°51'11"	N
MMD2	85SR91	MMD2-17	N 69°49'31"	W 144°50'42"	Y
MMD2	85SR140	MMD2-18	N 69°49'31"	W 144°50'42"	Y
MMD2	85SR142	MMD2-19	N 69°50'23"	W 144°53'40"	N
MMD2	85SR136	MMD2-2	N 69°45'59"	W 145°04'44"	N
MMD2	85SR139	MMD2-20	N 69°50'29"	W 144°55'07"	Y
MMD2	85SR89	MMD2-21	N 69°51'46"	W 144°54'45"	Y
MMD2	85SR90	MMD2-22	N 69°51'57"	W 144°55'44"	N
MMD2	85SR88	MMD2-23	N 69°52'25"	W 144°50'10"	N
MMD2	85SR145	MMD2-24	N 69°51'24"	W 144°37'38"	N
MMD2	85SR86	MMD2-25	N 69°54'23"	W 144°39'20"	Y
MMD2	85SR22	MMD2-26	N 69°56'39"	W 144°42'43"	N
MMD2	85SR18	MMD2-27	N 69°56'42"	W 144°39'47"	Y
MMD2	85SR20	MMD2-28	N 69°57'02"	W 144°40'58"	N

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
MMD2	85SR87	MMD2-29	N 69°57'09"	W 144°42'00"	N
MMD2	85SR92	MMD2-3	N 69°50'40"	W 145°11'25"	N
MMD2	85SR21	MMD2-30	N 69°57'16"	W 144°42'37"	Y
MMD2	85SR19	MMD2-31	N 69°57'17"	W 144°39'13"	N
MMD2	85SR132	MMD2-32	N 69°57'49"	W 144°38'00"	N
MMD2	85SR93	MMD2-4	N 69°51'32"	W 145°09'40"	N
MMD2	85SR85	MMD2-5	N 69°51'52"	W 145°03'12"	N
MMD2	85SR84	MMD2-6	N 69°53'45"	W 145°03'02"	N
MMD2	85SR82	MMD2-7	N 69°54'33"	W 145°02'17"	N
MMD2	85SR83	MMD2-8	N 69°55'04"	W 144°58'08"	N
MMD2	85SR81	MMD2-9	N 69°55'18"	W 144°58'07"	N
MMD3	85SR120	MMD3-1	N 69°46'15"	W 145°40'20"	Y
MMD3	85SR121	MMD3-10	N 69°51'20"	W 145°25'20"	N
MMD3	85SR123	MMD3-11	N 69°45'54"	W 145°22'59"	N
MMD3	85SR76	MMD3-12	N 69°47'30"	W 145°18'46"	N
MMD3	85SR94	MMD3-13	N 69°49'48"	W 145°21'30"	N
MMD3	85SR122	MMD3-14	N 69°51'37"	W 145°17'05"	Y
MMD3	85SR130	MMD3-15	N 69°58'11"	W 145°19'59"	Y
MMD3	85SR119	MMD3-2	N 69°46'42"	W 145°41'00"	N
MMD3	85SR75	MMD3-3	N 69°58'32"	W 145°42'12"	N
MMD3	85SR128	MMD3-4	N 69°58'15"	W 145°45'16"	N
MMD3	85SR129	MMD3-5	N 69°58'31"	W 145°37'24"	N
MMD3	85SR68	MMD3-6	N 69°50'06"	W 145°33'12"	N
MMD3	85SR69	MMD3-7	N 69°50'30"	W 145°34'00"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
MMD3	85SR118	MMD3-8	N 69°50'25"	W 145°33'08"	Y
MMD3	85SR117	MMD3-9	N 69°52'48"	W 145°33'00"	N
MMD4	81CAN1	MMD4-1	N 69°59'12"	W 146°17'24"	Y
MMD4	85SR30	MMD4-10	N 69°53'35"	W 146°21'26"	Y
MMD4	85SR28	MMD4-11	N 69°53'55"	W 146°22'00"	Y
MMD4	85SR116	MMD4-12	N 69°53'00"	W 146°12'34"	Y
MMD4	85SR124	MMD4-13	N 69°66'57"	W 146°14'44"	Y
MMD4	85SR125	MMD4-14	N 69°56'57"	W 146°07'38"	Y
MMD4	85SR114	MMD4-15	N 69°51'34"	W 146°03'58"	N
MMD4	85SR115	MMD4-16	N 69°55'30"	W 146°02'14"	Y
MMD4	85SR126	MMD4-17	N 69°57'30"	W 145°59'36"	Y
MMD4	85SR127	MMD4-18	N 69°59'33"	W 145°54'38"	Y
MMD4	85SR112	MMD4-19	N 69°48'26"	W 145°56'32"	N
MMD4	81CAN2	MMD4-2	N 69°59'01"	W 146°16'00"	Y
MMD4	85SR113	MMD4-20	N 69°51'27"	W 145°57'06"	Y
MMD4	85SR67	MMD4-21	N 69°53'22"	W 145°48'40"	N
MMD4	85SR66	MMD4-22	N 69°47'19"	W 145°49'30"	N
MMD4	81CAN3	MMD4-3	N 69°58'55"	W 146°16'51"	Y
MMD4	81CAN4	MMD4-4	N 69°59'30"	W 146°11'41"	Y
MMD4	81CAN5	MMD4-5	N 69°59'11"	W 146°11'02"	Y
MMD4	81CAN6	MMD4-6	N 69°57'35"	W 146°08'32"	Y
MMD4	81CAN7	MMD4-7	N 69°56'50"	W 146°07'28"	Y
MMD4	85SR34	MMD4-8	N 69°45'38"	W 146°23'00"	Y
MMD4	85SR109	MMD4-9	N 69°52'36"	W 146°22'28"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
MMD5	83SHAV16	MMD5-1	N 69°57'08"	W 146°59'59"	Y
MMD5	85SR108	MMD5-10	N 69°49'14"	W 146°27'10"	Y
MMD5	85SR26	MMD5-11	N 69°49'50"	W 146°24'22"	N
MMD5	85SR25	MMD5-12	N 69°50'01"	W 146°26'20"	Y
MMD5	85SR24	MMD5-13	N 69°50'55"	W 146°27'59"	N
MMD5	85SR27	MMD5-14	N 69°51'05"	W 146°26'42"	N
MMD5	85SR23	MMD5-15	N 69°54'04"	W 146°25'14"	N
MMD5	85SR11	MMD5-2	N 69°45'08"	W 146°52'28"	Y
MMD5	85SR12	MMD5-3	N 69°49'20"	W 146°51'20"	N
MMD5	85SR13	MMD5-4	N 69°50'48"	W 146°53'48"	N
MMD5	85SR14	MMD5-5	N 69°53'31"	W 146°54'00"	N
MMD5	85SR111	MMD5-6	N 69°50'39"	W 146°42'02"	N
MMD5	85SR107	MMD5-8	N 69°46'47"	W 146°24'48"	N
MMD5	85SR31	MMD5-9	N 69°48'58"	W 146°24'30"	N
SGC1	85SR05	SGC1-1	N 69°37'31"	W 147°01'55"	N
SGC1	85SR04	SGC1-2	N 69°38'34"	W 147°02'55"	N
SGC1	85SR03	SGC1-3	N 69°40'39"	W 147°06'04"	N
SGC1	85SR02	SGC1-4	N 69°40'59"	W 147°03'30"	N
SGD1	83SHAV11	SGD1-1	N 69°57'24"	W 147°32'10"	Y
SGD1	83SHAV10	SGD1-2	N 69°59'15"	W 147°31'16"	Y
SGD1	83SHAV12	SGD1-3	N 69°57'26"	W 147°17'10"	Y
SGD1	83SHAV13	SGD1-4	N 69°59'43"	W 147°16'00"	Y
SGD1	85SR15	SGD1-5	N 69°52'39"	W 147°00'40"	N
SGD1	85SR16	SGD1-6	N 69°54'04"	W 147°05'16"	Y

QUAD	FLD NO.	MAP NO.	LATITUDE	LONGITUDE	LOG
SGD1	83SHAV15	SGD1-7	N 69°58'07"	W 147°02'40"	Y
SGD2	83KAD8	SGD2-1	N 69°56'59"	W 147°49'04"	Y
SGD2	83KAD7	SGD2-2	N 69°59'39"	W 147°46'05"	Y
SGD3	81SAG2	SGD3-1	N 69°59'45"	W 148°43'00"	Y
SGD3	81SAG4	SGD3-2	N 69°59'25"	W 148°32'16"	Y
SGD5	83KUP3	SGD5-1	N 69°58'39"	W 149°51'56"	Y
SGD5	83KUP2	SGD5-2	N 69°59'06"	W 149°43'10"	Y
UMD1	87SR28	UMD1-1	N 69°57'35"	W 150°31'48"	N
UMD2	87SR25	UMD2-1	N 69°58'28"	W 150°50'35"	Y
UMD2	87SR24	UMD2-2	N 69°57'36"	W 150°46'29"	N
UMD2	87SR29	UMD2-3	N 69°59'52"	W 150°45'40"	N

APPENDIX D

SAMPLES

Analyses:

TX = grain-size analysis
C14 = carbon-14 analysis
MF = microfossil analysis
PO = pollen analysis
WO = wood analysis
AA = amino-acid analysis
TL = thermoluminescence analysis

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA1-11A	83SR55	0.7	zS	TX
BPA1-11B	83SR56	1.4	S	
BPA1-11C	83SR57	1.5	S	TX
BPA1-11D	83SR58	1.5	zS	TX
BPA1-11E	83SR59	2.6	Organic	
BPA1-12A	82SR13	0.2	(g)sM	TX
BPA1-12B	82SR14	1.1	gmS	MF/TX
BPA1-12C	82SR15	1.4	sG	TX
BPA1-12D	82SR16	2.0	g(m)S	TX
BPA1-12E	82SR17	2.3	S	TX
BPA1-12F	82SR18	2.8	gS	TX
BPA1-12G	82SR19	2.9	(g)S	TX
BPA1-12H	82SR20	3.0	gS	MF/TX
BPA1-12I	82SR21	3.5	(g)S	TX
BPA1-12J	82SR22	3.7	msG	TX
BPA1-12K	82SR23	3.9	gmS	TX
BPA1-14A	82SR24	0.3	Peat	
BPA1-14B	82SR25	0.9	mS	TX
BPA1-14C	82SR26	3.4	gmS	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA1-18A	84SR108	1.7	sG	TX
BPA1-19A	83SR119	0.1	(g)mS	TX
BPA1-19B	83SR120	0.7	gmS	TX
BPA1-19C	83SR121	1.5	(g)mS	TX
BPA1-1A	81SR96	0.3	sM	TX
BPA1-1B	81SR97	1.0	g(m)S	TX
BPA1-20A	84DH38	0.3	Peat	
BPA1-21A	83SR78	2.2	(g)mS	TX
BPA1-21B	83SR79	2.8	(g)mS	TX
BPA1-21C	83SR80	3.4	gS	TX
BPA1-21D	83SR81	4.2	gmS	TX
BPA1-21E	83SR82	4.7	msG	TX
BPA1-23A	82SR52	1.5	g(s)M	TX
BPA1-23B	82SR53	1.8	g(m)S	TX
BPA1-23C	82SR54	2.4	msG	TX
BPA1-23D	82SR55	3.0	msG	TX
BPA1-24A	83SR76	0.6	(g)mS	TX
BPA1-24B	83SR77	1.1	(g)mS	TX
BPA1-25A	83SR95	0.4	(g)mS	TX
BPA1-25B	83SR96	2.8	msG	TX
BPA1-25C	83SR97	3.1	(g)S	TX
BPA1-25D	84DH37	3.1	(g)S	TX
BPA1-25E	83SR98	3.4	G	TX
BPA1-25F	83SR99	3.6	sG	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA1-25G	83SR100	3.9	(g)S	TX
BPA1-25H	84DH36	4.2	sG	TX
BPA1-26A	83SR71	0.6	gmS	TX
BPA1-26B	83SR72	0.9	msG	TX
BPA1-27A	81SH06	0.4	Peat	
BPA1-27B	81SH07	0.8	g(m)S	TX
BPA1-28A	81SH08	0.9	Peat	
BPA1-29A	84SR113	0.6	Peat	
BPA1-2A	81SR98	0.7	Peat	
BPA1-30A	83SR74	0.3	gmS	TX
BPA1-30B	83SR101	1.6	sG	TX
BPA1-31A	83SR75	0.6	(g)mS	TX
BPA1-32A	83SR68	0.7	gS	TX
BPA1-32B	83SR69	1.1	msG	TX
BPA1-32C	83SR70	1.5	gmS	TX
BPA1-33A	83SR64	1.4	gS	TX
BPA1-33B	83SR65	2.0	sG	TX
BPA1-33C	83SR66	2.4	sG	TX
BPA1-33D	83SR67	2.7	gmS	TX
BPA1-34A	82SR50	0.5	S	TX
BPA1-34B	82SR51	0.7	msG	TX
BPA1-35A	83SR61	0.8	Peat	
BPA1-35B	83SR62	0.9	sG	TX
BPA1-35C	83SR63	1.1	Peat	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA1-37A	81SH05	0.1	zS	TX
BPA1-4A	81SR99	0.2	sM	TX
BPA1-5A	82SR46	2.6	mS	TX
BPA1-7A	81SH02	0.4	mS	TX
BPA1-7B	81SH03	0.6	(g)S	
BPA1-7C	81SH04	0.9	mS	TX
BPA1-8A	81SH01	0.3	gmS	TX
BPA1-9A	82SR45	2.0	gS	
BPA2-10A	82SR44	1.2	mS	TX
BPA2-11A	84SR66	5.9	sZ	
BPA2-11B	84SR67	5.9	sZ	TX
BPA2-11C	84SR65	6.0	sG	TX
BPA2-12A	84DH01	3.6	sG	TX
BPA2-12B	84DH03	5.4	Z	TX
BPA2-12C	84DH02	6.3	sG	TX
BPA2-13A	83SR22	0.5	S	MF/PO
BPA2-13A	84SR63	3.3	(g)S	TX
BPA2-13B	84SR64	1.9	gM	TX
BPA2-13C	83SR23	2.7	S	MF/PO
BPA2-13D	83SR24	3.2	Z	PO
BPA2-13F	83SR25	4.2	Z	PO/TX
BPA2-13G	83SR26	4.3	sG	PO/TX
BPA2-13H	84SR60	5.1	msG	TX
BPA2-13I	84SR62	5.4	(g)mS	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA2-13J	84TL07	5.7	Z	TL
BPA2-13K	84SR51	5.7	sZ	TX
BPA2-13L	84SR61	5.8	G	TX
BPA2-14A	83SR18	0.6	(g)S	MF/TX
BPA2-14B	83SR19	0.8	gmS	TX
BPA2-14C	83SR20	1.1	(g)S	TX
BPA2-14D	83SR21	1.8	gS	
BPA2-15A	81SR137	0.1	zS	TX
BPA2-15B	81SR138	0.1	sZ	TX
BPA2-15C	81SR139	0.4	(g)S	
BPA2-17A	83SR01	0.3	(g)S	
BPA2-17B	83SR02	0.7	Peat	
BPA2-18A	83SR03	0.7	(g)mS	TX
BPA2-19A	83SR04	0.2	M	TX
BPA2-19B	83SR05	0.5	M	TX
BPA2-20A	82SR56	0.4	Peat	C14
BPA2-20B	82SR57	0.8	gmS	TX
BPA2-21A	83SR46	0.7	(g)S	TX
BPA2-21B	83SR45	1.2	Wood	C14
BPA2-23A	83SR40	0.7	S	TX
BPA2-23B	83SR41	1.7	S	TX
BPA2-23C	83SR42	2.2	S	TX
BPA2-23D	83SR43	2.6	gmS	TX
BPA2-23E	83SR44	3.2	msG	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA2-24A	83SR36	0.5	sZ	
BPA2-24B	83SR37	2.0	(g)mS	TX
BPA2-24C	83SR38	2.7	gmS	TX
BPA2-24D	83SR39	3.8	sG	TX
BPA2-25A	83SR33	1.6	Peat	
BPA2-25B	82SR47	1.7	Wood	
BPA2-25C	83SR34	2.1	sZ	
BPA2-25D	83SR35	3.8	zS	TX
BPA2-3A	82SR11	1.3	g(s)M	TX
BPA2-3B	82SR12	1.4	Peat	
BPA2-7A	83SR30	0.8	(g)mS	TX
BPA2-7B	83SR31	1.1	gS	
BPA2-7C	83SR32	1.7	gmS	TX
BPA2-8A	83SR06	0.6	(g)S	TX
BPA2-8B	83SR07	1.3	gS	PO
BPA2-8D	83SR09	2.1	Organic	C14
BPA2-8E	83SR10	2.4	gS	PO
BPA2-8F	83SR11	2.9	sG	PO
BPA2-8G	83SR12	3.0	Peat	
BPA2-9A	83SR13	0.9	(g)sM	TX
BPA2-9B	83SR14	1.6	gmS	TX
BPA2-9C	83SR15	1.9	(g)S	TX
BPA2-9D	83SR16	2.9	(g)S	TX
BPA2-9E	83SR17	3.7	(g)S	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA3-10A	84SR02	4.3	Wood	
BPA3-10B	84SR03	4.3	gS	TX
BPA3-10C	84SR01	5.1	Peat	C14
BPA3-10D	85SAGC-3	7.7	gS	MF/PO/TX
BPA3-10E	84SR68	8.7	Peat	C14
BPA3-10F	84SR09	10.5	(g)S	MF/TX
BPA3-10G	84SR10	10.5	Organic	PO
BPA3-10H	84SR69	12.6	Wood	WO
BPA3-10I	84SR08	12.9	gS	TX
BPA3-10J	84SR04	13.0	sG	TX/WO
BPA3-10K	84SR05	13.0	Organic	WO
BPA3-10L	84SR06	13.0	gS	WO
BPA3-10M	84SR07	13.4	gS	MF/PO
BPA3-10N	84SR70	13.6	gS	WO
BPA3-10O	84SR11	14.5	gS	AA/PO
BPA3-10P	84SR12	14.5	gS	
BPA3-10Q	84SR13	14.5	gS	TX
BPA3-10R	85SAGC-1	18.7	Wood	AA/WO
BPA3-10S	85SAGC-2	18.7	Z	MF/PO/TX
BPA3-11A	81SR127	0.1	M	TX
BPA3-12A	81SR131	0.2	(g)S	
BPA3-12B	81SR132	0.3	gM	TX
BPA3-13A	82SR39	1.0	mS	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA3-13B	82SR40	1.0	gmS	TX
BPA3-13C	82SR41	7.4	sZ	MF/PO/TX
BPA3-13D	82SR42	7.4	Organic	C14
BPA3-13E	84SR52	7:4	Wood	
BPA3-13F	84SR53	7.4	Z	TX
BPA3-13G	84TL08	8.1	Z	TL
BPA3-14A	82SR43	1.9	g(m)S	TX
BPA3-15A	83SR27	1.0	gmS	TX
BPA3-15B	83SR28	1.4	(g)S	TX
BPA3-15C	83SR29	2.8	g(s)M	TX
BPA3-16A	85END3	14.0	Wood	AA/WO
BPA3-16B	85END4	14.0	Z	TL
BPA3-16C	85END5	14.0	M	TX
BPA3-16D	85END1	14.4	Organic	PO
BPA3-16E	85END2	14.4	Organic	
BPA3-1A	84SR76	0.1	Peat	
BPA3-1B	84SR77	0.4	Peat	
BPA3-2A	84SR73	0.4	Peat	
BPA3-2B	84SR74	0.5	g(s)M	TX
BPA3-2C	84SR75	0.7	Peat	C14
BPA3-3A	81SR121	0.5	Peat	
BPA3-4A	81SR124	0.5	(g)S	
BPA3-5A	84SR78	0.2	(g)S	
BPA3-6A	81SR128	0.4	sM	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA3-6B	81SR129	0.5	Peat	
BPA3-6C	81SR130	0.6	M	TX
BPA3-7A	84SR72	0.3	(g)S	
BPA3-8A	81SR133	0.1	Peat	
BPA3-8B	81SR134	0.4	(g)S	
BPA3-9A	81SR135	0.2	mS	TX
BPA3-9B	81SR136	0.3	sZ	TX
BPA4-10A	87SR26-2	1.6	Peat	
BPA4-10B	87SR26-1	1.7	Peat	C14
BPA4-1A	84SR81	0.4	Peat	C14
BPA4-2A	84SR82	0.9	Peat	
BPA4-3A	83SR124	0.7	S	TX
BPA4-3B	83SR125	1.2	sG	TX
BPA4-4A	84SR33A	0.6	Peat	
BPA4-4B	84SR33	0.7	Peat	
BPA4-5A	82SR31	0.3	gmS	TX
BPA4-5B	82SR32	0.6	gmS	TX
BPA4-5C	82SR33	1.2	msG	TX
BPA4-5D	82SR34	1.5	msG	TX
BPA4-6A	84SR85	0.6	zS	C14/TX
BPA4-6B	84SR86	1.7	Peat	
BPA4-6C	84SR86A	1.7	Organic	
BPA4-7A	84SR80	0.2	Peat	
BPA4-8A	84SR79	0.1	Peat	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPA4-9A	84SR83	0.6	(g)S	
BPA4-9B	84SR84	0.7	sM	TX
BPA5-1A	82SR36	1.6	Wood	
BPA5-1B	82SR37	1.8	Wood	
BPA5-1C	82SR38	2.2	Wood	
BPA5-2A	82SR35	1.7	Wood	
BPA5-4A	87SR27-2	0.7	(g)S	
BPA5-4B	87SR27-1	2.6	gS	
BPB2-1A	82SR10	1.6	zS	TX
BPB2-2A	82SR07	0.5	zS	TX
BPB2-3A	81SR140	1.8	zS	TX
BPB3-10A	81SR15	0.2	sZ	TX
BPB3-10B	81SR29	0.2	g(m)S	TX
BPB3-10B	81SR30	0.3	Peat	C14
BPB3-10C	81SR31	1.0	(g)S	
BPB3-11A	81SR32	0.2	sM	TX
BPB3-12A	81SR33	0.2	Peat	
BPB3-12B	81SR34	0.4	Peat	
BPB3-12C	81SR35	0.8	Peat	C14
BPB3-14A	81SR36	0.3	sM	TX
BPB3-15A	81SR20	0.3	(g)S	
BPB3-15B	81SR21	0.5	sZ	TX
BPB3-15C	81SR22	0.6	(g)S	
BPB3-15D	81SR23	1.0	Peat	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB3-15E	81SR24	1.4	mS	TX
BPB3-16A	81SR125	0.2	zS	TX
BPB3-16A	81SR25	0.8	sM	TX
BPB3-16B	81SR126	0.2	zS	TX
BPB3-16B	81SR26	1.4	mS	TX
BPB3-16F	85END6	14.4	Organic	MF
BPB3-16G	85END7	14.4	Organic	WO
BPB3-17A	81SR01	0.1	mS	TX
BPB3-17B	81SR02	0.3	(g)S	
BPB3-17C	81SR03	0.6	Peat	C14
BPB3-17D	81SR04	1.6	g(m)S	TX
BPB3-17E	81SR05	1.8	gmS	TX
BPB3-18A	81SR06	0.2	sZ	TX
BPB3-18B	81SR07	0.6	g(m)S	TX
BPB3-18C	81SR08	1.2	g(m)S	TX
BPB3-19A	81SR10	0.4	zS	
BPB3-19B	81SR11	0.4	sZ	TX
BPB3-19C	81SR09	0.8	Peat	
BPB3-1A	81SR88	0.2	sZ	TX
BPB3-1B	81SR89	0.6	gmS	TX
BPB3-21A	84DH04	0.1	Peat	
BPB3-22A	81SR118	0.3	Peat	
BPB3-22B	84DH05	0.3	Peat	
BPB3-22C	84DH06	0.6	Wood	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB3-22D	84SR119	0.6	(g)S	
BPB3-22E	81SR120	1.4	sM	TX
BPB3-23A	84SR14	0.7	Peat	
BPB3-23B	82SR03	0.8	Z	TX
BPB3-23B	84SR15	1.0	Wood	
BPB3-23C	81SR108	1.0	mS	TX
BPB3-23D	81SR109	1.2	sG	TX
BPB3-23E	84SR19	6.5	Wood	WO
BPB3-23F	84SR18	7.8	Wood	C14/WO
BPB3-23G	84SR16	10.7	Wood	C14/WO
BPB3-23H	84SR17	10.7	Wood	
BPB3-23I	84TL10	10.7	Z	TL
BPB3-24A	81SR110	0.5	Z	TX
BPB3-24B	81SR111	1.0	sZ	TX
BPB3-25A	85PUT2-1	1.0	S	TX
BPB3-25B	85PUT2-2	1.1	Organic	
BPB3-25C	85PUT2-3	2.1	Peat	
BPB3-25D	85PUT2-10	3.0	Wood	C14
BPB3-25E	85PUT2-4	4.7	Wood	AA
BPB3-25F	85PUT2-5	4.7	Peat	
BPB3-25G	85PUT2-6	5.8	sG	TX
BPB3-25H	84SR58	6.6	Wood	C14
BPB3-25I	84SR54	6.8	Wood	
BPB3-25J	84SR55	6.8	Wood	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB3-25K	84SR56	6.8	sZ	TX
BPB3-25L	84SR57	6.8	Wood	WO
BPB3-25M	84TL09	6.8	Z	
BPB3-25N	85PUT2-7	6.8	Organic	C14
BPB3-25O	85PUT2-8	6.8	Z	TX
BPB3-25P	85PUT2-9	7.2	sG	
BPB3-25Q	85PUT2-11	7.4	Wood	C14
BPB3-25R	85PUT2-12	7.4	Z	
BPB3-25S	85PUT2-13	12.8	sG	MF/TX
BPB3-25T	85PUT2-14	16.3	Z	TX
BPB3-25U	85PUT2-15	16.3	Z	MF
BPB3-25V	85PUT2-16	16.3	Shell	AA
BPB3-26B	81SR17	0.7	zS	
BPB3-28A	87SR36-1	Beach	M	
BPB3-29A	81SR12	Surface	sZ	TX
BPB3-2A	81SR90	0.3	g(m)S	TX
BPB3-32A	81SR13	Surface	zS	TX
BPB3-34A	81SR14	0.2	zS	
BPB3-35A	81SR107	1.0	g(m)S	TX
BPB3-6A	81SR91	0.4	cS	TX
BPB3-6B	81SR92	0.5	Peat	
BPB3-8A	81SR93	0.1	S	TX
BPB3-8B	81SR94	0.3	(g)S	
BPB3-8C	81SR95	0.5	g(m)S	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB3-9A	81SR27	Beach	gS	TX
BPB3-9B	81SR28	0.4	sM	TX
BPB4-11A	81SR102	0.2	mS	TX
BPB4-11B	81SR103	0.3	g(m)S	TX
BPB4-14A	81SR100	0.3	zS	TX
BPB4-15A	81SR101	0.3	sM	TX
BPB4-16A	85MP6	0.3	S	TX
BPB4-16B	85MP5	1.3	Z	C14
BPB4-16C	85MP4	1.7	gS	TX
BPB4-16D	85MP3	10.5	Wood	AA/WO
BPB4-16E	85MP2	10.5	Wood	WO
BPB4-16F	85MP1	14.8	Wood	WO
BPB4-16G	85MP11	15.0	S	MF
BPB4-16H	85MP9	15.3	Wood	AA/WO
BPB4-16I	85MP10	15.3	Organic	
BPB4-16J	85MP7	16.8	S	TX
BPB4-16K	85MP8	17.5	S	MF/PO/TX
BPB4-17A	81SR65	0.4	zS	TX
BPB4-17B	81SR66	10.0	g(m)S	TX
BPB4-18A	81SR104	0.5	g(m)S	TX
BPB4-19A	81SR105	0.2	zS	
BPB4-1A	81SR67	0.8	g(m)S	MF/TX
BPB4-20A	82SR30	10.0	cS	TX
BPB4-21A	81SR116	0.6	zS	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB4-21B	81SR117	1.0	gS	TX
BPB4-23A	81SR112	0.7	Peat	
BPB4-23B	81SR113	0.2	mS	TX
BPB4-23C	81SR114	0.4	mS	TX
BPB4-24A	81SR115	0.6	Peat	
BPB4-26A	81SR148	0.5	Peat	
BPB4-27A	81SR147	0.2	zS	TX
BPB4-28A	81SR146	0.5	S	
BPB4-29A	84DH08	0.5	S	
BPB4-2A	81SR68	0.9	gmS	TX
BPB4-30A	84DH07	0.3	S	
BPB4-31A	84DH10	0.2	Peat	
BPB4-31B	84DH09	5.4	Organic	
BPB4-32A	81SR141	0.3	Peat	
BPB4-33A	81SR143	0.5	Peat	
BPB4-33B	81SR142	10.0	sZ	TX
BPB4-34A	81SR144	0.7	Organic	
BPB4-34B	81SR145	1.1	Peat	
BPB4-4A	81SR69	0.5	gmS	TX
BPB4-6A	81SR70	0.3	Peat	C14
BPB4-6B	81SR71	0.8	S	TX
BPB4-7A	81SR72	0.4	gmS	TX
BPB4-9A	81SR82	0.5	Peat	
BPB4-9B	81SR73	2.0	sZ	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB5-10A	81SR47	2.0	mS	TX
BPB5-13A	81SR48	0.2	mS	TX
BPB5-13B	81SR49	10.0	Peat	
BPB5-14A	81SR50	0.8	Peat	C14
BPB5-15A	81SR51	0.9	zS	TX
BPB5-15B	81SR52	1.0	Peat	
BPB5-16A	81SR53	0.3	zS	
BPB5-17A	81SR54	0.2	sM	TX
BPB5-18A	81SR56	0.2	mS	TX
BPB5-1A	82SR29	0.5	g(s)M	TX
BPB5-26A	81SR58	0.3	cS	TX
BPB5-28A	81SR61	0.3	mS	
BPB5-28B	81SR62	1.2	g(m)S	
BPB5-30A	84SR20	1.7	sZ	TX
BPB5-30B	84SR21	2.5	g(s)M	TX
BPB5-30C	84TL1	2.5	S	
BPB5-30D	84SR22	2.9	gS	TX
BPB5-30E	84SR23	9.7	Wood	AA/WO
BPB5-30F	84SR24	9.7	Wood	WO
BPB5-30G	84SR25	9.7	Wood	WO
BPB5-31A	84SR44	2.1	S	TX
BPB5-31B	84SR90	2.1	S	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB5-31C	84SR45	2.7	zS	TX
BPB5-31D	84SR87	2.7	zS	TX
BPB5-31E	84SR88	2.7	G	
BPB5-31F	84SR89	2.7	Z	TL
BPB5-31G	84SR47	10.2	S	TX
BPB5-31H	84SR48	10.2	Wood	WO
BPB5-31I	84SR49	10.7	Wood	AA/WO
BPB5-31J	84SR50	10.7	Wood	WO
BPB5-31K	84TL06	10.7	Z	TL
BPB5-32A	84SR26	1.7	sZ	TX
BPB5-32B	84TL01	1.7	S	
BPB5-32C	85KUPC-1	1.7	gS	TX
BPB5-32D	85KUPC-2	1.7	S	TL
BPB5-32E	84TL02	2.7	S	
BPB5-32F	82SR06	3.0	S	TX
BPB5-32G	84SR27	3.5	S	TX
BPB5-32H	85KUPC-3	4.6	Organic	C14
BPB5-32I	85KUPC-4	4.6	S	
BPB5-32J	84SR28	6.4	(g)S	TX
BPB5-32K	85KUPC-5	6.4	S	
BPB5-32L	84SR32	6.6	Wood	WO
BPB5-32M	84SR29	7.7	Wood	C14
BPB5-32N	84TL03	7.7	S	TL
BPB5-32O	85KUPC-6	7.7	Wood	AA/WO

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPB5-32P	84SR30	10.7	Wood	WO
BPB5-32Q	84SR31	10.7	Wood	WO
BPB5-32R	84SR32A	10.7	Wood	WO
BPB5-32S	85KUPC-7	10.7	Wood	AA
BPB5-32T	84TL04	11.0	Z	TL
BPB5-33A	81SR38	0.8	S	TX
BPB5-33B	81SR39	1.0	mS	TX
BPB5-33C	81SR40	10.0	sG	TX
BPB5-5A	81SR44	0.3	S	
BPB5-7A	81SR45	0.2	g(s)M	TX
BPB5-7B	81SR46	0.8	gmS	TX
BPC4-1A	81SR78	0.5	gmS	TX
BPC4-1B	81SR79	0.9	gmS	TX
BPC4-1D	81SR81	0.0	S	TX
BPC4-2A	81SR76	1.2	g(m)S	TX
BPC4-2B	81SR77	1.6	gM	TX
BPC4-3A	81SR74	0.4	Peat	C14
BPC4-3B	81SR75	0.5	mS	TX
BPC4-1C	81SR80	1.1	gmS	TX
BPC5-10A	81SR85	0.6	Peat	C14
BPC5-10B	81SR86	0.6	S	TX
BPC5-10C	81SR87	1.0	sZ	TX
BPC5-1A	81SR41	0.2	Z	
BPC5-1B	81SR42	0.7	g(m)S	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
BPC5-3A	81SR43	0.5	M	TX
BPC5-5A	81SR59	0.4	mS	TX
BPC5-6A	81SR60	0.4	mS	TX
BPC5-8A	81SR83	0.1	gM	TX
BPC5-8B	81SR84	1.6	g(s)M	TX
FIA3-5A	85SR168-1	1.7	M	TX
FIA4-11A	81SH23	0.2	Peat	
FIA4-1A	85SR157-1	0.9	Peat	
FIA4-3A	81SH24	0.4	g(m)S	TX
FIA4-3B	81SH25	0.9	Peat	
FIA4-3C	81SH26	1.8	mS	TX
FIA4-4A	84SR112	3.5	(g)S	TX
FIA4-4B	84SR111	4.9	C	
FIA4-5A	85SR159-1	1.0	Peat	
FIA4-8A	85SR162-1	2.1	gS	
FIA4-8B	85SR162-2	2.9	gS	
FIA4-8C	85SR162-3	3.0	gS	
FIA5-1A	83SR111	0.2	gmS	TX
FIA5-2A	83SR112	0.3	msG	TX
FIA5-3A	83SR113	0.2	gmS	TX
FIA5-3B	83SR114	0.7	Organic	
FIA5-3C	83SR115	0.8	Ash	
FIA5-3D	83SR116	0.9	Organic	
FIA5-3E	83SR117	1.0	gmS	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
FIA5-3F	83SR118	1.3	sG	TX
FIA5-4A	83SR122	0.4	Z	
FIA5-4B	83SR123	0.8	G	TX
FIA5-6A	84SR109	2.3	sZ	TX
FIA5-6B	84SR110	4.2	S	TX
FIA5-7A	84DH34	0.6	S	TX
FIA5-7B	84DH35	1.9	sG	TX
HBA1-10A	84DH20	5.0	M	TX
HBA1-10B	84DH17	7.6	S	TX
HBA1-10C	84DH18	7.6	Wood	
HBA1-10D	84DH15	8.0	gS	TX
HBA1-10E	87SR18-1	8.7	Wood	WO
HBA1-10F	84DH16	9.6	sZ	TX
HBA1-10G	84DH19	Beach	Shell	
HBA1-11A	87SR21-1	8.0	S	
HBA1-11B	87SR21-2	Beach	Rock	
HBA1-12A	87SR19-5	5.8	S	
HBA1-12B	87SR19-4	6.2	Shell	
HBA1-12C	87SR19-3	6.8	gS	
HBA1-12D	87SR19-2	6.9	Shell	
HBA1-12E	87SR19-1	6.9	gS	
HBA1-1A	84SR91	0.2	gS	TX
HBA1-1B	84SR92	0.4	gS	TX
HBA1-1C	84SR93	0.4	gM	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
HBA1-1D	84SR94	0.9	sG	TX
HBA1-3A	84SR95	0.8	sM	TX
HBA1-4A	84SR96	2.0	sG	TX
HBA1-4B	84SR97	2.5	S	TX
HBA1-5A	84SR98	1.6	S	TX
HBA1-5B	84SR99	3.1	gS	TX
HBA1-6A	84SR100	0.8	S	TX
HBA1-6B	84SR101	2.2	gS	TX
HBA1-6C	84SR102	4.5	gS	TX
HBA1-7A	83SR131	1.1	sZ	TX
HBA1-7B	83SR132	1.6	sM	TX
HBA1-7C	83SR133	3.7	sZ	TX
HBA1-7D	83SR134	4.2	gM	TX
HBA1-7E	83SR135	4.6	S	TX
HBA1-7F	83SR136	5.3	S	TX
HBA1-7G	83SR137	7.0	sZ	TX
HBA1-8A	84DH11	0.5	S	TX
HBA1-8B	84DH12	2.0	sG	TX
HBA1-8C	84DH13	4.0	sG	TX
HBA1-8D	84DH14	6.3	gS	TX
HBA2-2A	87SR37-1	2.3	Wood	C14
HBA2-2B	87SR37-2	2.3	Wood	
HBA2-3A	87SR38-1	3.9	Wood	
HBA3-1A	87SR39-1	6.0	Shell	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
HBB1-10A	84SR43	2.9	(g)S	TX
HBB1-10B	84SR42	4.2	gS	TX
HBB1-10C	84SR41	6.2	S	TX
HBB1-10D	84TL05	6.2	Z	
HBB1-10E	84SR40	7.0	Shell	
HBB1-11A	84DH21	1.5	gS	TX
HBB1-11B	84DH22	3.0	sG	TX
HBB1-11C	84DH23	5.0	sG	TX
HBB1-12A	84DH24	0.4	Peat	
HBB1-13A	84DH30	2.6	sG	
HBB1-13B	84DH28	2.8	gS	TX
HBB1-13C	84DH29	3.5	Coal	
HBB1-13D	84DH27	7.8	Organic	
HBB1-13E	84DH26	7.9	sZ	TX
HBB1-13F	84DH25	8.0	sG	TX
HBB1-14A	84DH31	2.4	gS	TX
HBB1-14B	84DH32	2.5	Wood	
HBB1-14C	84DH33	3.8	gS	TX
HBB1-19A	85KUPF-1	0.3	S	TX
HBB1-19B	85KUPF2	0.4	M	TX
HBB1-19C	85KUPF3	2.3	gS	TX
HBB1-19D	85KUPF4	4.1	S	TX
HBB1-19E	85KUPF5	4.1	S	TL
HBB1-19F	85KUPF6	4.3	sG	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
HBB1-19G	85KUPF7	4.9	sG	
HBB1-19H	85KUPF8	4.9	sG	PO
HBB1-19I	85KUPF9	4.9	sG	C14/TX
HBB1-19J	85KUPF10	4.9	Wood	WO
HBB1-19K	85KUPF11	5.2	sG	TX
HBB1-19L	85KUPF12	5.6	gS	TX
HBB1-19M	85KUPF13	6.0	sG	TX
HBB1-19N	87SR01-1	9.4	Wood	WO
HBB1-1A	87SR14-2	2.8	Peat	
HBB1-1B	87SR14-1	4.2	Peat	
HBB1-21A	87SR04-2	4.4	S	
HBB1-21B	87SR04-1	4.8	Organic	
HBB1-22A	82SR27	0.4	zS	TX
HBB1-23A	82SR28	0.2	Organic	
HBB1-2A	87SR12-1	3.1	Peat	C14
HBB1-4A	87SR08-1	1.4	Organic	
HBB1-5A	87SR10-1	0.4	Z	
HBB1-5B	87SR10-2	1.0	Organic	
HBB1-7A	87SR06-2	0.4	Organic	
HBB1-7B	87SR06-1	1.2	Peat	
HBB1-8A	87SR05-1	0.3	S	
HBB1-9A	84SR34	2.6	S	
HBB1-9B	84SR35	4.1	S	TX
HBB1-9C	84SR36	4.8	sG	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
HBB1-9D	84SR37	6.3	Organic	
HBB1-9E	84SR38	6.7	Wood	
HBB1-9F	84SR39	7.4	sG	TX
HBB2-13A	84SR103	0.5	Peat	
HBB2-13B	84SR104	0.9	zS	TX
HBB2-13C	84SR105	1.6	Organic	
HBB2-13D	84SR106	2.3	Organic	
HBB2-13E	84SR107	3.0	sG	
HBB2-14A	87SR07S-1	0.7	Peat	
HBB2-15A	87SR07N-2	0.5	Peat	
HBB2-15B	87SR07N-1	0.8	S	
HBB2-1A	87SR42-4	0.8	Organic	
HBB2-1B	81SH14	1.5	Peat	
HBB2-1C	87SR42-5	1.7	Z	
HBB2-1D	81SH15	2.0	mS	TX
HBB2-1E	87SR42-1	2.0	Organic	C14
HBB2-1F	87SR42-2	2.0	S	
HBB2-1G	87SR42-3	2.0	S	C14/WO
HBB2-2A	87SR41-2	2.2	Wood	
HBB2-2B	87SR41-1	5.0	Peat	
HBB2-3A	81SH13	2.4	Peat	
HBB2-5A	87SR17-1	1.6	Peat	
HBB2-5B	87SR17-2	3.3	Peat	
HBB2-7A	81SH12	0.4	S	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
HBB2-7B	81SH12A	1.3	Z	
HBB2-8A	81SH16	0.5	sZ	TX
HBB3-2A	87SR43-2	1.0	Organic	
HBB3-2B	87SR43-1	2.6	Organic	
HBB4-1A	87SR44-2	2.6	Peat	
HBB4-1B	87SR44-1	4.3	Peat	
MMC3-8A	85SR77-2	2.5	Peat	C14
MMC3-8B	85SR77-3	4.7	Peat	
MMC3-8C	85SR77-1	10.1	Organic	AA/WO
MMC4-24A	85SR49-1	18.3	Organic	
MMC5-1A	85SR10-1	Surface	Wood	
MMC5-1B	85SR10-2	20.8	Rock	
MMC5-3A	85SR01-1	Unknown	Coal	
MMD1-7A	85SR152-1	1.7	Peat	C14
MMD2-11A	85SR79-1	Unknown	Wood	AA/WO
MMD2-12A	85SR131-1	4.4	Z	
MMD2-17A	85SR91-1	20.0	Wood	
MMD2-18A	85SR140-1	16.8	Wood	WO
MMD2-18B	85SR140-2	17.2	Z	
MMD2-18C	85SR140-3	21.5	Wood	WO
MMD2-18D	85SR140-4	21.5	S	TX
MMD2-20A	85SR139-1	2.6	Wood	C14/WO
MMD2-21A	85SR89-1	0.3	Peat	
MMD2-24A	85SR145-1	Unknown	Rock	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
MMD2-27A	85SR18-1	Unknown	Wood	WO
MMD2-30A	85SR21-1	7.4	Shell	AA
MMD2-8A	85SR83-1	Unknown	Wood	WO
MMD2-8B	85SR83-2	Unknown	Wood	
MMD2-9A	85SR81-1	Unknown	Wood	AA/WO
MMD3-12A	85SR76-1	Unknown	Wood	AA/WO
MMD3-12B	85SR76-2	Unknown	Wood	
MMD3-15A	85SR130-1	6.2	Peat	
MMD3-15B	85SR130-2	6.2	zS	
MMD3-15C	85SR130-3	Beach	Rock	
MMD3-7A	85SR69-1	7.9	gS	TX
MMD4-11A	85SR28-2	6.0	Z	
MMD4-11B	85SR28-1	10.0	Wood	AA/WO
MMD4-12A	85SR116-1	0.8	Peat	
MMD4-13A	85SR124-1	0.3	S	
MMD4-13B	85SR124-2	0.4	sG	C14
MMD4-14A	85SR125-1	0.7	Z	C14
MMD4-16A	85SR115-1	0.8	sG	TX
MMD4-18A	85SR127-1	2.0	Bone	
MMD4-18B	85SR127-2	4.4	(g)S	TL
MMD4-18C	85SR127-3	4.4	M	TX
MMD4-19A	85SR112-1	Surface	Rock	
MMD4-2A	81SH17	0.2	msG	TX
MMD4-4A	81SH18	0.6	zS	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
MMD4-4B	81SH19	1.0	Peat	
MMD4-5A	81SH20	0.8	Peat	
MMD4-6A	81SH21	0.2	mS	TX
MMD4-7A	81SH22	0.8	(g)S	
MMD4-9A	85SR109-2	4.9	Peat	C14
MMD4-9B	85SR109-5	6.8	gS	TX
MMD4-9C	85SR109-4	6.9	Organic	C14
MMD4-9D	85SR109-3	6.9	Z	
MMD4-9E	85SR109-1	14.0	Bone	C14
MMD5-10A	85SR108-2	4.0	Wood	C14
MMD5-10B	85SR108-1	4.6	Wood	C14
MMD5-13A	85SR24-2	1.9	Organic	C14
MMD5-13B	85SR24-1	12.6	Wood	
MMD5-1A	83SR106	0.7	zS	
MMD5-1B	83SR107	0.9	Ash	
MMD5-1C	83SR108	0.9	mS	TX
MMD5-1D	85SR110-1	1.6	sG	C14
MMD5-1E	85SR110-2	1.6	sG	
MMD5-2A	85SR11-2	0.2	Peat	C14
MMD5-2B	85SR11-3	0.3	Z	
MMD5-2C	85SR11-1	0.6	Peat	C14
MMD5-3A	85SR12-1	Unknown	Rock	
MMD5-8A	85SR107-3	2.5	Organic	C14
MMD5-8B	85SR107-2	4.1	Peat	

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
MMD5-8C	85SR107-1	4.6	Peat	C14
SGD1-1A	83SR88	0.4	mS	TX
SGD1-1B	83SR89	1.4	(g)S	TX
SGD1-1C	83SR90	2.9	S	TX
SGD1-1D	83SR91	5.8	S	TX
SGD1-2	83SR83	0.7	M	TX
SGD1-2B	83SR84	1.7	Peat	
SGD1-2C	83SR85	1.8	M	TX
SGD1-2D	83SR86	2.9	M	TX
SGD1-2E	83SR87	3.4	(g)mS	TX
SGD1-3A	83SR92	0.5	gS	TX
SGD1-3B	83SR93	1.0	sG	TX
SGD1-4A	83SR93.5	0.9	gmS	TX
SGD1-4B	83SR94	1.4	sG	TX
SGD1-6A	85SR16-1	0.4	Peat	
SGD1-7A	83SR102	0.6	(g)S	TX
SGD1-7B	83SR103	1.0	gmS	TX
SGD1-7C	83SR104	1.3	gmS	
SGD1-7D	83SR105	1.6	G	
SGD1-8B	83SR109	3.1	zS	TX
SGD2-1A	83SR48	0.8	sZ	TX
SGD2-1B	83SR49	1.5	Organic	C14
SGD2-1C	83SR50	1.7	zS	TX
SGD2-1D	83SR51	2.3	S	TX

SPL NO	FLD SPL	DEPTH	MATL	ANALYSES
SGD2-1E	83SR52	2.6	cS	
SGD2-2A	83SR47	0.4	gS	TX
SGD3-1A	81SR122	0.2	Peat	
SGD3-1B	81SR123	0.4	sM	TX
SGD5-1A	83SR128	0.5	sZ	TX
SGD5-1B	83SR129	1.1	Peat	
SGD5-1C	83SR130	1.4	S	
SGD5-2A	83SR126	1.6	sZ	TX
SGD5-2B	83SR127	2.3	msG	TX
UMD2-3A	87SR29-2	3.3	zS	
UMD2-3B	87SR29-1A	4.6	zS	

APPENDIX E

GRAIN-SIZE ANALYSIS

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPA1-11A	0.0	83.7	12.3	4.0	16.3	zS
BPA1-11C	0.0	95.2	3.0	1.8	4.8	S
BPA1-11D	0.0	64.6	26.7	8.7	35.4	zS
BPA1-12B	15.5	55.6	20.1	8.7	28.8	gmS
BPA1-12C	38.7	57.1	2.2	2.0	4.2	sG
BPA1-12D	2.0	87.1	6.7	4.3	11.0	g(m)S
BPA1-12E	1.0	93.4	3.5	2.1	5.6	S
BPA1-12F	9.3	86.4	2.6	1.8	4.40	gS
BPA1-12G	2.1	95.3	1.2	1.4	2.6	(g)S
BPA1-12H	10.0	87.1	2.5	1.1	3.6	gS
BPA1-12I	4.4	91.8	1.7	2.1	3.8	(g)S
BPA1-12J	36.7	52.7	6.4	4.2	10.6	msG
BPA1-12K	10.6	70.1	12.8	6.4	19.20	gmS
BPA1-14C	16.6	73.1	4.6	5.7	10.3	gmS
BPA1-18A	44.6	54.9	0.5	0.0	0.5	sG
BPA1-19A	5.0	53.6	22.0	19.4	41.4	(g)mS
BPA1-19B	6.6	77.3	10.7	5.4	16.1	gmS
BPA1-19C	0.8	88.4	6.8	4.0	10.8	(g)mS
BPA1-1A	0.5	48.1	27.6	23.8	51.4	sM
BPA1-21C	5.3	86.0	2.8	5.9	8.6	gS
BPA1-21D	10.2	69.0	13.9	6.9	20.8	gmS
BPA1-21E	56.9	29.3	8.6	5.2	13.8	msG

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPA1-1B	1.0	87.7	5.5	5.9	11.4	g(m)S
BPA1-21A	1.7	79.1	10.5	8.7	19.2	(g)mS
BPA1-21B	3.7	68.6	16.1	11.6	27.7	(g)mS
BPA1-23A	3.8	25.4	37.5	33.3	70.8	g(s)M
BPA1-23B	3.2	76.2	10.1	10.5	20.6	g(m)S
BPA1-23C	37.4	51.7	7.0	4.0	11.0	msG
BPA1-23D	59.5	34.0	3.6	2.8	6.4	msG
BPA1-24A	4.4	57.5	25.7	12.4	38.1	(g)mS
BPA1-24B	4.4	78.1	10.8	6.7	17.5	(g)mS
BPA1-25A	2.0	73.3	12.3	12.5	24.8	(g)mS
BPA1-25B	46.7	45.7	4.7	2.9	7.6	msG
BPA1-25C	0.0	100.0	0.0	0.0	0.0	(g)S
BPA1-25D	0.5	98.1	1.4	0.0	1.4	(g)S
BPA1-25E	91.4	8.0	0.6	0.0	0.6	G
BPA1-25G	56.3	43.2	0.5	0.0	0.5	sG
BPA1-25H	0.8	98.8	0.4	0.0	0.4	(g)S
BPA1-25I	55.5	43.2	1.3	0.0	1.3	sG
BPA1-26A	5.6	80.8	7.6	6.0	13.6	gmS
BPA1-26B	72.7	23.8	3.5	0.0	3.5	msG
BPA1-27B	4.0	75.7	9.3	11.0	20.3	g(m)S
BPA1-30A	8.2	72.0	11.6	8.2	19.8	gmS
BPA1-30B	77.2	21.9	0.9	0.0	0.9	sG
BPA1-31A	1.7	84.6	8.4	5.3	13.7	(g)mS
BPA1-32A	6.1	85.1	4.5	4.3	8.8	gS

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPA1-32B	53.3	40.5	2.6	3.6	6.2	msG
BPA1-32C	10.2	73.8	6.0	10.0	16.0	gmS
BPA1-33A	8.8	82.2	6.3	2.7	9.0	gS
BPA1-33B	34.4	61.5	4.1	0.0	4.1	sG
BPA1-33C	50.4	45.1	1.7	2.8	4.5	sG
BPA1-33D	27.1	58.1	9.3	5.5	14.8	gmS
BPA1-34A	0.1	90.1	4.4	5.4	9.8	S
BPA1-34B	72.9	22.7	1.5	3.0	4.5	msG
BPA1-35B	32.9	66.0	1.1	0.0	1.1	sG
BPA1-37A	0.0	57.2	29.6	13.2	42.8	zS
BPA1-4A	0.1	35.0	26.5	38.4	64.9	sM
BPA1-5A	0.8	81.1	7.0	11.0	18.0	mS
BPA1-6A	1.0	85.0	6.6	7.5	14.1	mS
BPA1-7A	0.1	83.9	7.7	8.2	15.9	mS
BPA1-8A	6.1	73.2	13.9	6.9	20.8	gmS
BPA2-10A	0.1	85.0	8.7	6.3	15.0	mS
BPA2-11B	0.0	23.0	69.3	7.7	77.0	sZ
BPA2-11C	40.2	58.8	1.0	0.0	1.0	sG
BPA2-12A	39.8	58.7	1.5	0.0	1.5	gM
BPA2-12B	0.0	0.0	70.5	29.5	100.0	Z
BPA2-12C	49.9	50.1	0.0	0.0	0.0	sG
BPA2-13A	0.1	94.9	2.5	2.5	5.0	(g)S
BPA2-13B	13.9	15.8	38.6	31.7	70.3	gM
BPA2-13F	0.0	0.0	73.7	26.3	100.0	Z

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPA2-13G	60.3	38.3	1.4	0.0	1.4	sG
BPA2-13H	52.2	36.7	6.8	4.3	11.1	msG
BPA2-13I	1.3	88.9	4.6	5.2	9.8	(g)mS
BPA2-13K	0.0	27.2	51.9	20.9	72.8	sZ
BPA2-13L	84.0	4.5	5.9	5.6	11.5	G
BPA2-14A	3.3	92.0	3.4	1.3	4.7	(g)S
BPA2-14B	23.3	65.6	6.1	5.0	11.1	gmS
BPA2-14C	0.4	95.5	2.5	1.6	4.1	(g)S
BPA2-15A	0.0	61.7	28.0	10.2	38.2	zS
BPA2-15B	0.0	47.2	37.9	15.0	52.9	sZ
BPA2-18A	0.5	47.2	32.9	19.4	52.3	(g)mS
BPA2-19A	0.0	0.0	54.2	45.8	100.0	M
BPA2-19B	0.0	0.0	61.0	39.0	100.0	M
BPA2-20B	6.2	84.2	4.1	5.5	9.6	gmS
BPA2-21A	4.9	94.4	0.7	0.0	0.7	(g)S
BPA2-23A	0.0	95.4	4.6	0.0	4.6	S
BPA2-23B	0.0	95.2	4.8	0.0	4.8	S
BPA2-23C	0.0	96.4	2.0	1.6	3.6	S
BPA2-23D	17.2	70.2	7.9	4.7	12.6	gmS
BPA2-23E	58.1	35.0	4.6	2.3	6.9	msG
BPA2-24B	2.5	86.7	6.5	4.3	10.8	(g)mS
BPA2-24C	8.3	80.1	7.7	3.9	11.6	gmS
BPA2-24D	66.3	31.1	2.6	0.0	2.6	sG
BPA2-25D	0.0	50.7	37.1	12.2	49.3	zS

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPA2-3A	4.4	45.8	26.3	23.5	49.8	g(s)M
BPA2-7A	4.9	61.5	23.6	10.0	33.6	(g)mS
BPA2-7C	6.2	80.6	7.7	5.5	13.2	gmS
BPA2-8A	0.5	90.7	5.5	3.3	8.8	(g)S
BPA2-9A	0.1	87.7	7.6	4.6	12.2	(g)sM
BPA2-9B	8.1	78.2	8.5	5.2	13.7	gmS
BPA2-9C	1.1	93.4	3.1	2.4	5.5	(g)S
BPA2-9D	2.8	90.2	2.8	4.2	7.0	(g)S
BPA2-9E	0.4	95.6	2.1	1.9	4.0	(g)S
BPA3-10B	5.9	92.0	2.1	0.0	2.1	gS
BPA3-10D	0.0	99.9	0.1	0.0	0.1	gS
BPA3-10F	2.8	93.0	4.2	0.0	4.2	(g)S
BPA3-10I	9.8	89.0	1.2	0.0	1.2	gS
BPA3-10J	55.9	44.0	0.1	0.0	0.1	sG
BPA3-10Q	5.3	90.8	3.9	0.0	3.9	gS
BPA3-10S	0.0	0.2	71.7	28.1	99.8	Z
BPA3-12B	12.6	12.5	64.5	10.4	74.9	gM
BPA3-13A	0.7	87.8	5.0	6.5	11.5	mS
BPA3-13B	25.8	61.7	5.4	7.1	12.5	gmS
BPA3-13C	0.0	41.9	42.6	15.6	58.2	sZ
BPA3-13F	0.0	0.0	88.2	11.8	100.0	Z
BPA3-14A	2.0	80.5	8.4	9.2	17.6	g(m)S
BPA3-15A	9.4	75.2	8.6	6.8	15.4	gmS
BPA3-15B	1.5	91.1	5.1	2.3	7.4	(g)S

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPA3-15C	39.6	53.9	2.0	4.5	6.5	g(s)M
BPA3-16C	0.0	0.0	75.7	24.2	99.9	M
BPA3-2A	3.5	40.4	48.6	7.5	56.1	g(s)M
BPA3-6A	0.0	14.2	49.1	36.7	85.8	sM
BPA3-6C	0.0	8.6	42.5	48.9	91.4	M
BPA3-9A	0.0	58.1	23.3	18.6	41.9	mS
BPA3-9B	0.0	25.3	52.7	22.0	74.7	sZ
BPA4-14B	0.4	84.5	6.6	8.6	15.2	mS
BPA4-3A	0.0	98.5	1.5	0.0	1.5	S
BPA4-3B	64.3	35.7	0.0	0.0	0.0	sG
BPA4-9B	11.6	38.1	37.6	12.7	50.3	sM
BPB2-1A	0.0	50.0	33.4	16.6	50.0	zS
BPB2-2A	0.0	69.4	22.1	8.5	30.6	zS
BPB2-3A	0.0	44.8	45.2	10.0	55.2	sZ
BPB3-10A	3.6	53.6	17.7	25.1	42.9	g(m)S
BPB3-11A	0.2	48.6	24.2	27.0	51.2	sM
BPB3-14A	0.4	40.1	27.8	31.7	59.5	sM
BPB3-15B	0.0	17.0	56.3	26.8	83.1	sZ
BPB3-15D	0.0	14.3	45.0	40.7	85.7	sM
BPB3-15E	0.7	77.1	11.1	11.1	22.2	mS
BPB3-16A	0.2	15.9	33.8	50.2	84.0	sM
BPB3-16B	0.6	88.3	5.3	5.9	11.2	mS
BPB3-17A	0.0	81.3	12.1	6.5	18.6	mS
BPB3-17D	2.8	77.1	11.4	8.68	20.1	g(m)S

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPB3-17E	5.2	74.1	15.4	5.3	20.7	gmS
BPB3-18A	0.0	18.5	73.0	8.6	81.6	sZ
BPB3-18B	2.3	62.9	31.2	3.7	34.9	g(m)S
BPB3-18C	2.3	78.9	12.1	7.0	19.1	g(m)S
BPB3-19B	0.0	37.4	56.2	6.4	62.6	sZ
BPB3-1A	NA	NA	NA	NA	NA	sZ
BPB3-1B	8.6	63.8	14.8	13.2	28.0	gmS
BPB3-22E	0.0	49.2	23.9	26.9	50.8	sM
BPB3-23C	0.0	87.6	6.7	5.5	12.2	mS
BPB3-23D	55.1	43.0	0.9	1.0	1.9	sG
BPB3-24A	0.0	8.9	59.0	32.2	91.2	Z
BPB3-24B	0.0	11.2	70.2	18.7	88.9	sZ
BPB3-25A	0.0	100.0	0.0	0.0	0.0	S
BPB3-25G	79.3	20.7	0.1	0.0	0.1	sG
BPB3-25K	0.0	27.2	60.8	12.0	72.8	sZ
BPB3-25O	0.0	0.0	83.0	17.0	100.0	Z
BPB3-25P	70.8	29.1	0.1	0.0	0.1	sG
BPB3-25S	45.7	53.8	0.6	0.0	0.6	sG
BPB3-25T	0.6	0.9	70.4	28.1	98.5	Z
BPB3-26A	0.0	31.2	46.6	22.2	68.8	sC
BPB3-29A	0.0	29.5	65.2	5.3	70.5	sZ
BPB3-2A	1.4	65.0	10.5	23.1	33.6	g(m)S
BPB3-32A	0.0	81.7	18.3	0.0	18.3	zS
BPB3-35A	1.3	83.2	7.7	7.7	15.4	g(m)S

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPB3-6A	0.6	60.0	12.4	27.0	39.4	cS
BPB3-8A	0.4	91.4	2.5	5.7	8.2	S
BPB3-8C	1.8	54.7	16.6	26.9	43.5	g(m)S
BPB3-9A	21.5	78.4	0.0	0.0	0.0	gS
BPB3-9B	0.8	48.8	23.6	26.8	50.4	sM
BPB4-11A	0.8	75.1	12.0	12.0	24.0	mS
BPB4-11B	2.8	77.8	7.5	11.8	19.3	g(m)S
BPB4-14A	0.0	59.7	27.7	12.6	40.3	zS
BPB4-15A	0.2	29.5	40.0	30.3	70.3	sM
BPB4-16A	0.0	98.8	1.2	0.0	1.2	S
BPB4-16C	5.9	94.0	0.1	0.0	0.0	gS
BPB4-16J	4.4	95.6	0.0	0.0	0.0	S
BPB4-16K	0.0	99.6	0.4	0.0	0.4	S
BPB4-17A	0.3	77.7	16.0	6.0	22.0	zS
BPB4-17B	2.9	85.0	9.7	2.4	12.1	g(m)S
BPB4-18A	1.5	77.8	8.9	11.9	20.8	g(m)S
BPB4-1A	2.4	83.7	5.2	8.7	13.9	g(m)S
BPB4-20A	0.4	76.8	7.1	15.8	22.9	cS
BPB4-21A	0.0	61.7	31.8	6.5	38.3	zS
BPB4-21B	11.9	83.2	2.2	2.8	5.0	gS
BPB4-23B	0.0	59.8	23.9	16.3	40.2	mS
BPB4-23C	0.1	78.1	12.7	9.2	21.9	mS
BPB4-27A	0.0	70.1	21.5	8.4	29.9	zS
BPB4-2A	7.2	65.8	16.9	10.1	27.0	gmS

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPB4-33B	0.3	34.8	52.5	12.5	65.0	sZ
BPB4-4A	5.3	51.1	16.6	27.0	43.6	gmS
BPB4-5A	2.9	66.7	21.7	8.7	30.4	gmS
BPB4-5B	9.9	70.3	14.2	5.6	19.8	gmS
BPB4-5C	52.9	38.7	5.7	2.8	8.5	msG
BPB4-5D	52.4	40.8	4.5	2.3	6.8	msG
BPB4-6B	0.4	90.4	4.2	5.1	9.3	S
BPB4-7A	8.1	67.3	7.6	17.0	24.6	gmS
BPB4-9B	0.0	20.8	54.5	24.8	79.3	sZ
BPB5-10A	0.6	89.9	5.0	4.5	9.5	mS
BPB5-13A	0.0	67.5	19.1	13.4	32.5	mS
BPB5-15A	0.0	70.2	20.3	9.5	29.8	zS
BPB5-16A	0.0	72.2	22.6	5.2	27.8	zS
BPB5-17A	0.5	46.5	23.6	29.4	53.0	sM
BPB5-18A	0.1	80.3	13.1	6.5	19.6	mS
BPB5-1A	2.7	52.5	37.5	7.3	44.8	g(s)M
BPB5-26A	0.1	55.1	14.8	30.1	44.9	cS
BPB5-28A	1.0	47.5	2.9	22.9	25.8	mS
BPB5-28B	4.9	77.1	9.0	9.0	18.0	g(m)S
BPB5-30A	0.0	48.2	40.2	11.7	51.9	sZ
BPB5-30B	1.9	45.2	41.7	11.2	52.9	g(s)M
BPB5-30D	13.9	84.2	1.9	0.0	1.9	gS
BPB5-31A	0.0	98.6	1.5	0.0	1.5	S
BPB5-31B	0.0	98.5	1.5	0.0	1.5	S

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPB5-31C	0.0	62.7	26.3	11.0	37.3	zS
BPB5-31D	0.0	55.3	32.2	12.5	44.7	zS
BPB5-31G	0.0	96.8	3.3	0.0	3.3	S
BPB5-32A	0.0	75.8	22.2	2.0	24.2	sZ
BPB5-32C	0.0	95.9	4.1	0.0	4.1	gS
BPB5-32F	0.0	95.4	4.7	0.0	4.7	S
BPB5-32G	0.0	99.3	0.7	0.0	0.7	S
BPB5-32J	3.0	96.6	0.3	0.0	0.3	(g)S
BPB5-33A	0.0	95.1	2.6	2.3	4.9	S
BPB5-33B	0.0	87.9	6.8	5.3	12.1	mS
BPB5-33C	58.7	38.8	1.2	1.3	2.5	sG
BPB5-7A	3.0	50.4	22.5	24.1	46.6	g(s)M
BPB5-7B	12.5	67.6	13.0	7.0	20.0	gmS
BPC4-1A	3.1	72.5	10.1	14.2	24.3	gmS
BPC4-1B	5.6	84.9	3.4	6.6	10.0	gmS
BPC4-1C	14.9	60.6	19.4	5.1	24.5	gmS
BPC4-1D	0.0	99.8	0.2	0.0	0.2	S
BPC4-2A	1.8	81.4	11.7	5.2	16.9	g(m)S
BPC4-2B	21.4	55.2	9.5	14.1	23.6	gM
BPC4-3B	0.1	85.6	7.4	6.9	14.3	mS
BPC5-10B	0.0	99.7	0.3	0.0	0.3	S
BPC5-10C	0.0	40.4	50.2	9.4	59.6	sZ
BPC5-1B	1.1	64.2	17.9	16.8	34.7	g(m)S
BPC5-3A	0.0	2.6	34.0	63.4	97.4	M

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
BPC5-5A	0.0	79.6	11.8	8.6	20.4	mS
BPC5-6A	0.0	55.8	19.9	24.3	44.2	mS
BPC5-8A	5.9	38.3	25.4	30.5	55.9	gM
BPC5-8B	2.4	41.3	26.8	29.4	56.2	g(s)M
FIA3-5A	0.0	0.0	60.4	39.5	99.9	M
FIA4-3A	1.8	39.9	24.4	33.9	58.3	g(m)S
FIA4-3C	0.2	83.2	7.7	8.8	16.5	mS
FIA4-4A	2.9	89.4	4.4	3.3	7.7	(g)S
FIA5-1A	11.2	55.5	18.4	14.9	33.3	gmS
FIA5-2A	50.6	25.1	13.6	10.7	24.3	msG
FIA5-3A	5.1	59.1	19.1	16.7	35.8	gmS
FIA5-3E	11.4	73.1	9.6	5.9	15.5	gmS
FIA5-3F	68.4	30.3	1.3	0.0	1.3	sG
FIA5-4B	84.4	14.6	1.0	0.0	1.0	G
FIA5-6A	0.0	43.3	45.9	10.8	56.7	sZ
FIA5-6B	0.0	92.6	7.4	0.0	7.4	S
FIA5-7A	0.0	94.1	5.9	0.0	5.9	S
FIA5-7B	40.5	57.7	1.8	0.0	1.8	sG
HBA1-7E	0.0	98.1	1.9	0.0	1.9	S
HBA1-10A	0.0	0.3	67.2	32.5	99.7	M
HBA1-10B	0.0	99.2	0.8	0.0	0.8	S
HBA1-10D	8.2	91.0	0.8	0.0	0.8	gS
HBA1-10F	0.0	57.2	32.7	10.1	42.8	sZ
HBA1-1A	25.5	73.9	0.7	0.0	0.7	gS

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
HBA1-1B	7.4	83.8	7.4	1.4	8.8	gS
HBA1-1C	18.1	46.2	18.5	17.2	35.7	gM
HBA1-1D	34.0	65.7	0.3	0.0	0.3	sG
HBA1-3A	0.0	25.8	50.5	23.7	74.2	sM
HBA1-4A	39.9	59.9	0.3	0.0	0.3	sG
HBA1-4B	0.0	99.5	0.6	0.0	0.6	S
HBA1-5A	0.0	98.8	1.2	0.0	1.2	S
HBA1-5B	26.0	73.8	0.2	0.0	0.2	gS
HBA1-6A	0.0	91.4	8.6	0.0	8.6	S
HBA1-6B	18.4	81.5	0.1	0.0	0.1	gS
HBA1-6C	23.4	76.4	0.3	0.0	0.3	gS
HBA1-7A	0.0	25.6	68.9	5.6	74.5	sZ
HBA1-7B	0.0	30.3	51.4	18.5	69.9	sM
HBA1-7C	0.0	24.6	70.6	4.9	75.5	sZ
HBA1-7D	28.3	32.1	32.9	6.8	39.7	gM
HBA1-7F	0.0	99.6	0.4	0.0	0.4	S
HBA1-7G	0.0	18.6	67.4	14.0	81.4	sZ
HBA1-8A	0.0	94.4	5.6	0.0	5.6	S
HBA1-8B	43.0	57.0	0.1	0.0	0.1	sG
HBA1-8C	42.3	57.7	0.0	0.0	0.0	sG
HBA1-8D	28.8	71.0	0.2	0.0	0.2	gS
HBB1-10A	2.8	96.1	1.1	0.0	1.1	(g)S
HBB1-10B	14.5	84.5	1.0	0.0	1.0	gS
HBB1-10C	0.0	92.6	7.4	0.0	7.4	S

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
HBB1-11A	24.9	75.9	0.1	0.0	0.1	gS
HBB1-11B	37.1	62.1	0.8	0.0	0.8	sG
HBB1-11C	58.8	41.0	0.2	0.0	0.2	sG
HBB1-13B	26.9	72.5	0.6	0.0	0.6	gS
HBB1-13E	0.0	38.7	44.8	16.5	4.3	sZ
HBB1-13F	68.1	31.6	0.4	0.0	0.4	sG
HBB1-14A	12.3	87.7	0.0	0.0	0.0	gS
HBB1-14C	23.2	76.7	0.1	0.0	0.0	gS
HBB1-19C	0.0	99.3	0.7	0.0	0.7	gS
HBB1-19D	0.0	99.0	1.0	0.0	1.0	S
HBB1-19F	54.8	45.1	0.1	0.0	0.1	sG
HBB1-19K	73.8	25.5	0.7	0.0	0.7	sG
HBB1-19L	8.3	91.6	0.1	0.0	0.1	gS
HBB1-19M	52.5	47.5	0.1	0.0	0.1	sG
HBB1-22A	0.0	62.9	25.6	11.5	37.1	zS
HBB1-9B	0.0	97.2	2.8	0.0	2.8	S
HBB1-9C	56.7	43.1	0.2	0.0	0.2	sG
HBB1-9F	35.7	64.1	0.2	0.0	0.2	sG
HBB1-19B	0.0	0.1	47.4	52.6	100.0	M
HBB2-13B	0.0	85.5	13.0	1.6	14.6	zS
HBB2-13E	NA	NA	NA	NA	NA	sG
HBB2-1D	0.4	81.1	11.5	7.0	18.5	mS
HBB2-7A	0.0	91.2	4.3	4.4	8.7	S
HBB2-8A	0.0	24.3	64.1	11.6	75.7	sZ

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
MMD2-18D	1.3	98.1	0.6	0.0	0.6	S
MMD3-7A	0.0	0.6	77.0	22.4	99.4	gZ
MMD4-16A	73.1	26.8	0.1	0.0	0.1	sG
MMD4-18C	0.0	0.8	56.9	42.3	99.2	M
MMD4-2A	37.4	31.7	27.0	3.8	30.8	msG
MMD4-4A	0.0	80.6	13.8	5.6	19.4	zS
MMD4-6A	0.0	70.1	13.7	16.2	29.9	mS
MMD4-9B	0.0	0.5	67.6	32.0	99.6	gZ
MMD5-1C	0.0	87.0	8.5	4.5	13.0	mS
SGD1-1A	0.0	57.0	25.8	17.2	43.0	mS
SGD1-1B	0.8	93.4	4.0	1.8	5.8	(g)S
SGD1-1C	0.0	94.9	4.0	1.1	5.1	S
SGD1-1D	0.0	97.2	2.8	0.0	2.8	S
SGD1-2A	0.0	0.0	38.0	6.2	100.0	M
SGD1-2C	0.0	0.0	59.0	41.0	100.0	M
SGD1-2D	0.0	0.0	51.3	48.7	100.0	M
SGD1-2E	1.5	80.5	11.5	6.5	18.0	(g)mS
SGD1-3A	8.4	82.7	4.4	4.5	8.9	gS
SGD1-3B	76.9	22.0	1.1	0.0	1.1	sG
SGD1-4A	14.1	73.9	7.1	4.9	12.0	gmS
SGD1-4B	71.5	28.0	0.5	0.0	0.5	sG
SGD1-7A	0.5	91.4	4.8	3.3	8.1	(g)S
SGD1-7B	23.8	57.8	12.0	6.4	18.4	(g)S
SGD1-7C	10.3	77.5	8.0	4.2	12.2	gmS

SPL NO	GRVL	SAND	SILT	CLAY	MUD	LITH
SGD1-7D	98.6	1.2	0.2	0.0	0.2	G
SGD1-8B	0.0	68.3	21.4	10.3	31.7	zS
SGD2-1A	2.0	85.1	8.8	4.1	12.9	sZ
SGD2-1C	0.0	88.3	8.7	3.0	11.7	zS
SGD2-1D	0.0	93.3	4.8	1.9	6.7	S
SGD2-2A	8.5	82.5	5.6	3.4	9.0	gS
SGD5-1A	0.0	16.9	68.1	15.1	83.2	sZ
SGD5-2A	0.0	25.6	63.3	11.1	74.4	sZ
SGD5-2B	31.2	39.1	20.1	9.7	29.8	msG

APPENDIX F

RADIOCARBON ANALYSIS

SPL NO	LAB SPL	MATL	DEPTH	AGE
BPA2-20A	GX10320	Organic	0.4	12,360 +/- 410
BPA2-21B	GX10322	Wood	1.2	3,585 +/- 320
BPA2-8D	GX10321	Organic	2.1	11,180 +/- 430
BPA3-10C	GX10779	Peat	5.1	4,640 +/- 90
BPA3-10E	GX10658	Wood	8.7	>38,400
BPA3-13D	GX10319	Organic	7.4	>34,800
BPA3-2C	GX10780	Peat	0.7	10,540 +/- 310
BPA4-10B	BETA23740	Peat	1.7	4,320 +/- 100
BPA4-1A	GX10659	Peat	0.45	8,475 +/- 335
BPA4-6A	GX10660	Peat	0.6	5,120 +/- 235
BPB3-10B	BETA4801	Peat	0.3	7,700 +/- 100
BPB3-12C	BETA4802	Peat	0.8	4,830 +/- 65
BPB3-17C	BETA4800	Peat	0.55	2,900 +/- 60
BPB3-23F	GX11763	Wood	7.8	>33,100
BPB3-23G	GX10656	Wood	10.5	37 +10/-4.3 ka
BPB3-25D	GX11762	Wood	3.0	>31,600
BPB3-25H	GX10781	Peat	6.6	4,075 +/- 115
BPB3-25N	GX11761	Wood	6.8	>31,600
BPB3-25Q	GX11766	Wood	7.4	>31,600
BPB4-16B	GX11760	Organic	1.3	>44,000
BPB4-6A	BETA4804	Peat	0.3	4,815 +/- 85
BPB5-14A	BETA4803	Peat	0.8	7,640 +/- 75

SPL NO	LAB SPL	MATL	DEPTH	AGE
BPB5-32H	GX11765	Wood	4.6	24.9 +4.6/-2.9 ka
BPB5-32M	GX10657	Wood	7.7	>38,400
BPC4-3A	BETA4805	Peat	0.4	5,785 +/- 100
BPC5-10A	BETA4806	Peat	0.6	4,195 +/- 75
HBA2-2A	BETA23741	Wood	2.3	>40,730
HBB1-19I	GX11764	Wood	4.8	>40,000
HBB1-2A	BETA23739	Organic	3.1	7,440 +/- 100
HBB2-1E	BETA23742	Organic	2.0	9,400 +/- 110
HBB2-1G	BETA23743	Wood	2.0	29,100 +/- 860
MMC3-8A	GX11756	Peat	2.5	6,345 +/- 90
MMD1-7A	GX11747	Peat	1.7	5,870 +/- 90
MMD2-20A	GX11748	Wood	3.4	7,330 +/- 175
MMD4-13B	GX11750	Wood	0.4	Insufficient Sample
MMD4-14A	GX11749	Peat	0.7	9,710 +/- 155
MMD4-9A	GX11746	Peat	5.0	9,640 +/- 510
MMD4-9C	GX11745	Peat	7.0	>25,000
MMD4-9E	GX11937	Bone	Unknown	1,185 +/- 70
MMD5-10A	GX11753	Wood	4.0	8,455 +/- 195
MMD5-10B	GX11752	Wood	4.6	7,300 +/- 440
MMD5-13A	GX11757	Organic	2.2	Laboratory Error
MMD5-1D	GX11751	Organic	1.7	9,790 +/- 345
MMD5-2A	GX11758	Peat	0.17	1,430 +/- 95
MMD5-2C	GX11759	Peat	5.3	3,160 +/- 255
MMD5-8A	GX11755	Peat	2.5	5,335 +/- 205

SPL NO	LAB SPL	MATL	DEPTH	AGE
MMD5-8C	GX11754	Peat	4.6	6,300 +/- 235
SGD2-1A	GX10323	Organic	1.5	>34,900

APPENDIX G

THERMOLUMINESCENCE ANALYSIS

SPL NO	FLD SPL	LAB SPL	DEPTH	AGE
BPA2-13J	84TL07	ALPHA1530	5.7	36.8 +/- 4.0 ka
BPA3-13G	84TL08	ALPHA1494	8.1	3.14 +/- 0.5 ka
BPB3-23I	84TL10	ALPHA2601	10.7	142.0 +/- 8.8 ka
BPB5-31F	84SR89	ALPHA1493	2.5	11.9 +/- 1.8 ka
BPB5-31K	84TL06	ALPHA1529	10.4	221.4 +/- 17.2 ka
BPB5-32D	85KUPC-2	ALPHA2598	1.7	24.6 +/- 1.5 ka
BPB5-32N	84TL03	ALPHA2599	7.7	>200,000
BPB5-32T	84TL04	ALPHA1528	11.0	150.2 +/- 11.0 ka
HBB1-19E	85KUPF-5	ALPHA2600	4.1	140.0 +/- 30.0 ka
MMD4-18B	85SR127-2	ALPHA2602	4.4	26.0 +/- 2.9 ka

APPENDIX H

AMINO-ACID ANALYSIS

aIle/Ile = D- alloisoleucine/L- isoleucine ratio of total amino-acid hydrolysate
Aspartic = D- aspartic/L- aspartic ratio of total amino-acid hydrolysate
Age Group: Y = young group
M = middle group
M? = middle group, uncertain
O = old group

Sample No.	Lab. Sample No.	Material	aIle/Ile	Aspartic	Age Group
BPA3-10O	AAL4642	*Salix*	0.034	NA	
BPA3-10R	UA1775	Wood	NA	0.3135	M
BPB2-1A	UA1773	Nonconif.	NA	0.3002	M
BPB3-25Q	UA1774	*Salix*	NA	0.2416	Y
BPB3-25V	AAL4641	*Astarte*	0.016	NA	P
BPB4-16D	UA1771	*Salix*	NA	0.2189	M?
BPB4-16H	UA1772	Nonconif.	NA	0.1952	M?
BPB5-16N	UA1769	Nonconif.	NA	0.3075	M
BPB5-17E	UA1767	Conif.	NA	0.3415	M
BPB5-18I	UA1768	Nonconif.	NA	0.2141	M?
BPB5-32S	AAL4643	*Salix*	0.034	NA	
	UA1770	Nonconif.	NA	0.2526	M?
FIA4-4B	UA1766	*Salix*	NA	0.3152	M
MMC3-8A	UA1778	Nonconif.	NA	0.1658	Y
MMD2-9A	UA1780	Conif.	NA	0.0802	O
MMD2-30A	UA1781(A)	*Astarte*	0.745	0.2544	O
MMD3-12A	UA1777	Conif.	NA	0.0471	O
MMD4-11A	UA1779	Nonconif.	NA	0.0379	O
MMD4-11B	UA1776	Nonconif.	NA	0.0518	O

APPENDIX I

WOOD ANALYSIS

SPL NO.	FLD SPL	DEPTH	DECID/CONIF	TAXA
BPA3-10H	84SR69	12.6	Decid	*Salix*
BPA3-10J	84SR04	13.0	Decid	*Salix*
BPA3-10L	84SR06	13.0	Decid	*Salix*
BPA3-10N	84SR70	13.6	Decid	ND
BPA3-10O	84SR11	14.5	Decid	*Salix*
BPA3-10R	85SAGC1	18.7	Decid	*Alnus*
BPA3-16A	85END3	14.0	Decid	*Larix*
BPA3-16G	85END7	14.4	Decid	*Salix*
BPB3-10K	84SR05	13.0	Decid	ND
BPB3-23E	84SR19	6.5	Decid	*Salix*
BPB3-23F	84SR18	7.8	Decid	*Salix*
BPB3-23G	84SR16	10.5	Decid	*Salix*
BPB3-25L	84SR57	6.8	Decid	ND
BPB4-6D	85MP3	10.5	Decid	*Salix*
BPB4-16E	85MP2	10.5	Decid	ND
BPB4-16F	85MP1	14.8	Decid	*Salix*
BPB4-16H	85MP9	15.3	Decid	ND
BPB5-16P	84SR31	10.7	Decid	ND
BPB5-30E	84SR23	9.7	Conif	*Larix*
BPB5-30F	84SR24	9.7	Conif	*Larix*
BPB5-30G	84SR25	9.7	Conif	*Larix*

SPL NO.	FLD SPL	DEPTH	DECID/CONIF	TAXA
BPB5-31H	84SR48	10.2	Decid	ND
BPB5-31I	84SR49	10.7	Decid	ND
BPB5-31J	84SR50	10.7	Decid	*Salix*
BPB5-32L	84SR32	6.5	Conif	*Larix*
BPB5-32O	85KUPC6	7.7	Decid	*Salix*
BPB5-32P	84SR30	10.7	Decid	ND
BPB5-32Q	84SR31	10.7	Decid	ND
BPB5-32R	84SR32A	10.7	Conif	*Larix*
HBA1-10E	87SR18-1	8.7	Conif	*Larix/Picea*?
HBA2-2B	87SR37-2	2.3	Conif	*Picea/Larix*?
HBB1-19N	87SR01-1	9.4	Conif	*Larix/Picea*?
HBB2-1G	87SR42-3	2.0	Decid	*Salix*
MMC3-8C	85SR77-1	unk.	insuf. spl.	insuf. spl.
MMD2-8A	85SR83-1	unk.	insuf. spl.	insuf. spl.
MMD2-8B	85SR83-2	unk.	Decid	ND
MMD2-9A	85SR81-1	unk.	Conif	ND
MMD2-11A	85SR79-1	unk.	Decid	ND
MMD2-18A	85SR140-1	16.8	Conif	ND
MMD2-18C	85SR140-3	21.5	Conif	ND
MMD2-20A	85SR139-1	2.6	Decid	ND
MMD2-27A	85SR18-1	unk.	Conif	ND
MMD3-12A	85SR76-1	unk.	Conif	ND
MMD4-11B	85SR28-1	10.0	Decid	ND

APPENDIX J

MICROFOSSIL ANALYSIS

SPL NO.	FLD SPL	MATL	DEPTH	TAXA
BPA1-12B	82SR14	gmS	1.1	Barren
BPA1-12H	82SR20	gS	3.0	*Elphidium* sp.
BPA2-13A	83SR22	S	0.5	Barren
BPA2-13C	83SR23	S	2.7	*Elphidium* sp.
BPA2-14A	83SR18	(g)S	0.6	*Cassidulina* sp.
BPA3-10F	84SR09	(g)S	10.5	Barren
BPA3-10M	84SR07	gS	13.4	Barren
BPA3-13C	82SR41	sZ	7.4	*Cyclammina* sp.
BPA3-16F	85END6	Organic	14.4	Barren
BPB3-25S	85PUT2-13	sG	12.8	Barren
BPB3-25U	85PUT2-15	Z	16.3	*Guttulina* sp.
BPB4-16D	85SAGC-3	gS	7.7	Barren
BPB4-16G	85MP11	S	15.0	Barren
BPB4-16K	85MP8	S	17.5	Barren
BPB4-16S	85SAGC-2	Z	18.7	Barren
BPB4-1A	81SR67	g(m)S	0.8	Shell fragments

APPENDIX K

POLLEN ANALYSIS

Symbols used in this appendix to show abundance of taxa represent the following quantities: V = very rare (single grain); R = rare (2-5 grains); F = frequent (6-15 grains).

SAMPLE NO.	TAXA	MATERIAL
BPA2-8B	*Sphagnumsporites* sp. (R) *Lejeunia* sp. (R)	herbaceous
BPA2-8C	*Indeterminate large spore (F)* *Fungal hyphae (F)* *Sphagnumsporites* sp. (R) Compositae (Taraxacum-type) (V)	herbaceous amorphous organics
BPA2-8E	*Laciniadinium biconiculum* (F) Indeterminate pollen (R) *Striatites richteri* (R) *Micrhystridium* sp. (R) *Baltisphaeridium* sp. (V)	70% woody-fusinitic
BPA2-8F	Indeterminate pollen? (R)	50% woody-fusinitic 50% amber amorphous organics
BPA2-13A	Undifferentiated bisaccates (R) Compositae (Helianthus-type) (V)	70% herbaceous 20% woody-fusinitic
BPA2-13C	Undifferentiated bisaccates (R) *Lycopodiumsporites* sp. (R) Tasmanaceae (R) Compositae (Helianthus-type) (V) Compositae (Taraxacum-type) (V) *Lycospora* sp. (V)	70% dark, reworked
BPA2-13D	Undifferentiated bisaccates (R) *Lycopodiumsporites* sp. (R) *Sphagnumsporites* sp. (R) Caryophyllaceae (R) *Micrhystridium* sp. (V)	50% brownish, reworked

SAMPLE NO.	TAXA	MATERIAL
BPA2-13F	*Laevigatosporites* sp. (R) Caryophyllaceae (V) Polemoniaceae (V) *Paraalnipollenites confusus* (V)	60% dark, reworked
BPA2-13G	*Ilexpollenites* sp. (F) *Osmundacidites* sp. (R)	80% dark, reworked
BPA3-10D	*Hymenozonotriletes Lepidophytus* (F) Indeterminate pollen (V)	woody-fusinitic spore fragments
BPA3-10G	Undifferentiated bisaccates (V)	woody-fusinitic
BPA3-10M	Indeterminate spore frag- ments (R)	woody-fusinitic spore fragments herbaceous-amorphous
BPA3-10O	Indeterminate spores? (R) Undifferentiated bisaccates (V)	60% woody-fusinitic 40% herbaceous
BPA3-10S	Barren	herbaceous
BPA3-13C	Betulaceae (F) *Lycopodiumsporites* sp. (R) Ericaceae (V)	herbaceous
BPA3-16D	Barren	herbaceous
BPB4-16K	Indeterminate spore frag- ments (R) Undifferentiated bisaccates (R)	spore fragments woody-fusinitic amorphous
HBB1-19H	Undifferentiated bisaccates (R)	woody-fusinitic herbaceous

PLEASE NOTE:

Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

Black and white photographic prints (17" x 23") are available for an additional charge.

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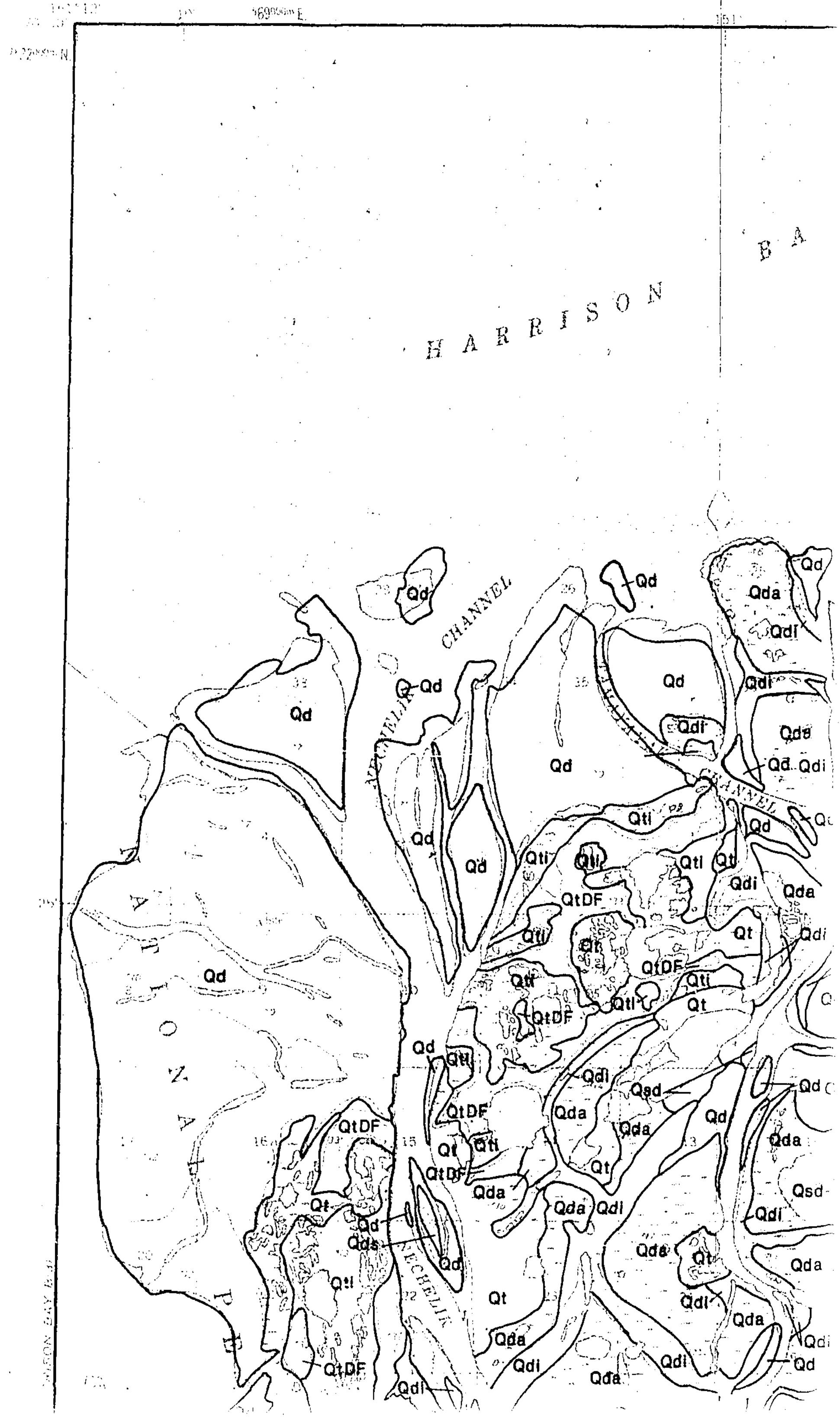
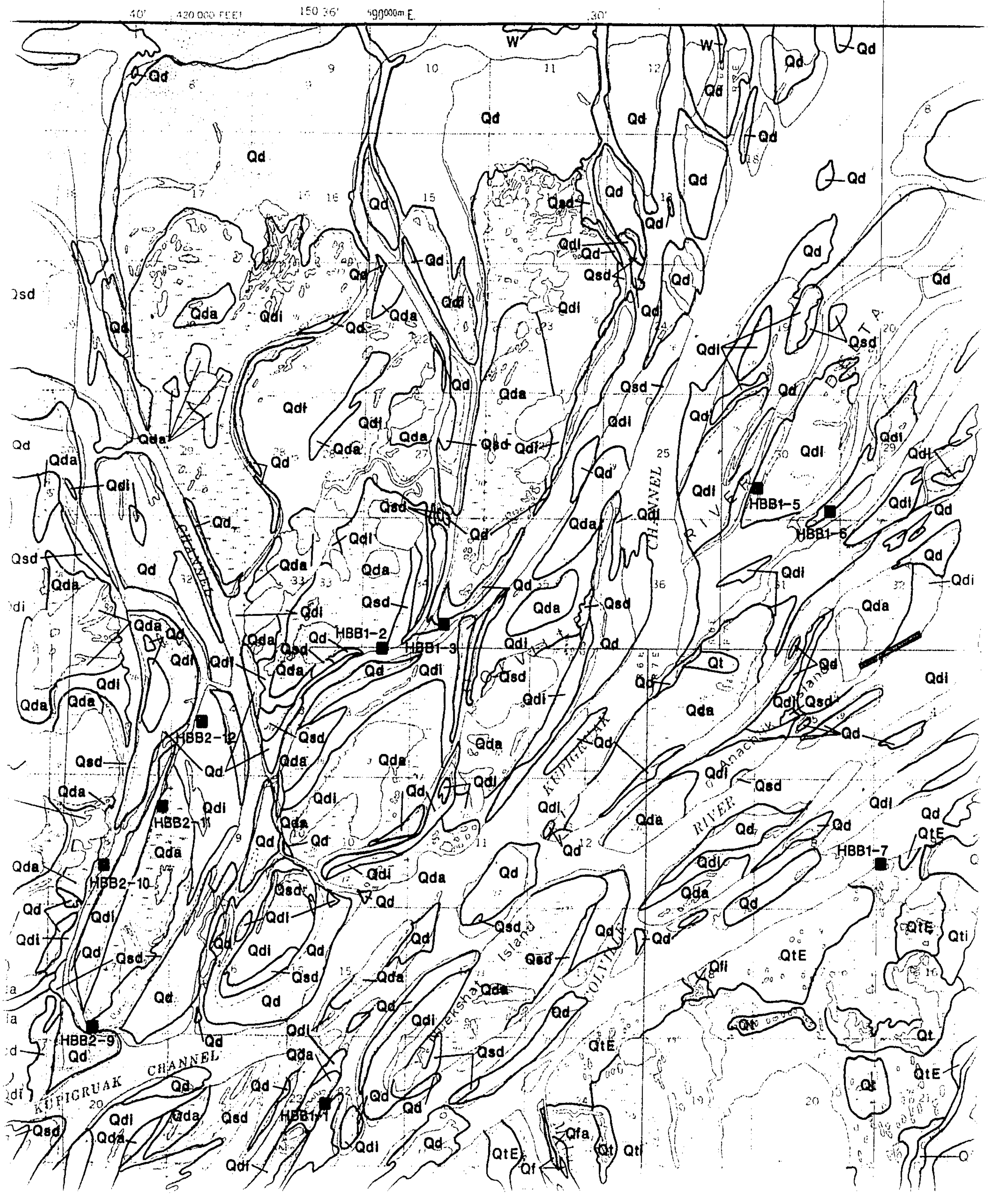
MAP SYMBOLS AND MAP-UNIT DESCRIPT
CORRELATION OF MAP UNITS IN APPEND



ESCRIPTIONS IN APPENDIX A

APPENDIX B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Anachlik Island
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RIVER
Pueksha Island
DELTA
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HBB1-3
HBB1-5
HBB1-6
HBB1-7
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HBB2-10
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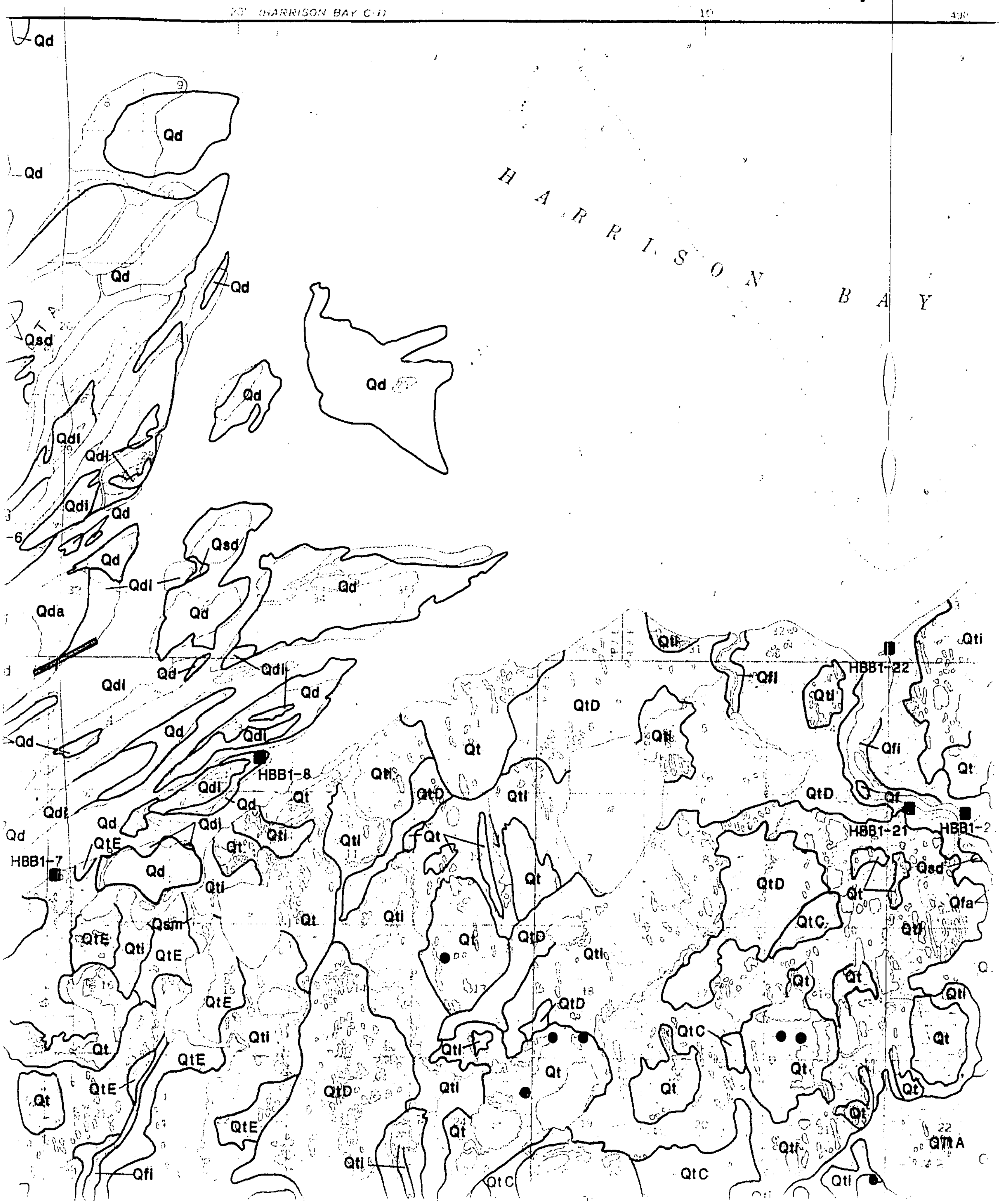
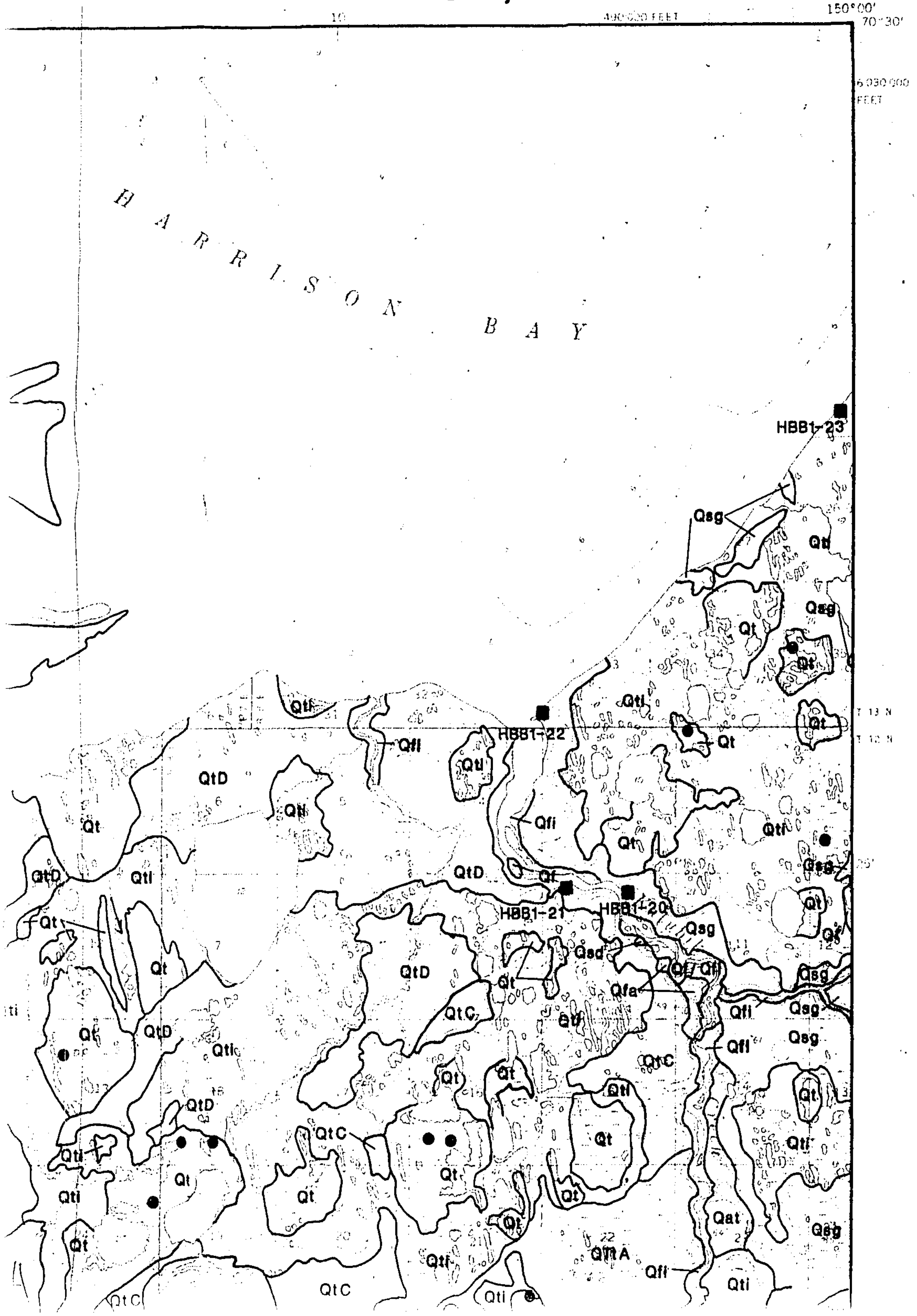
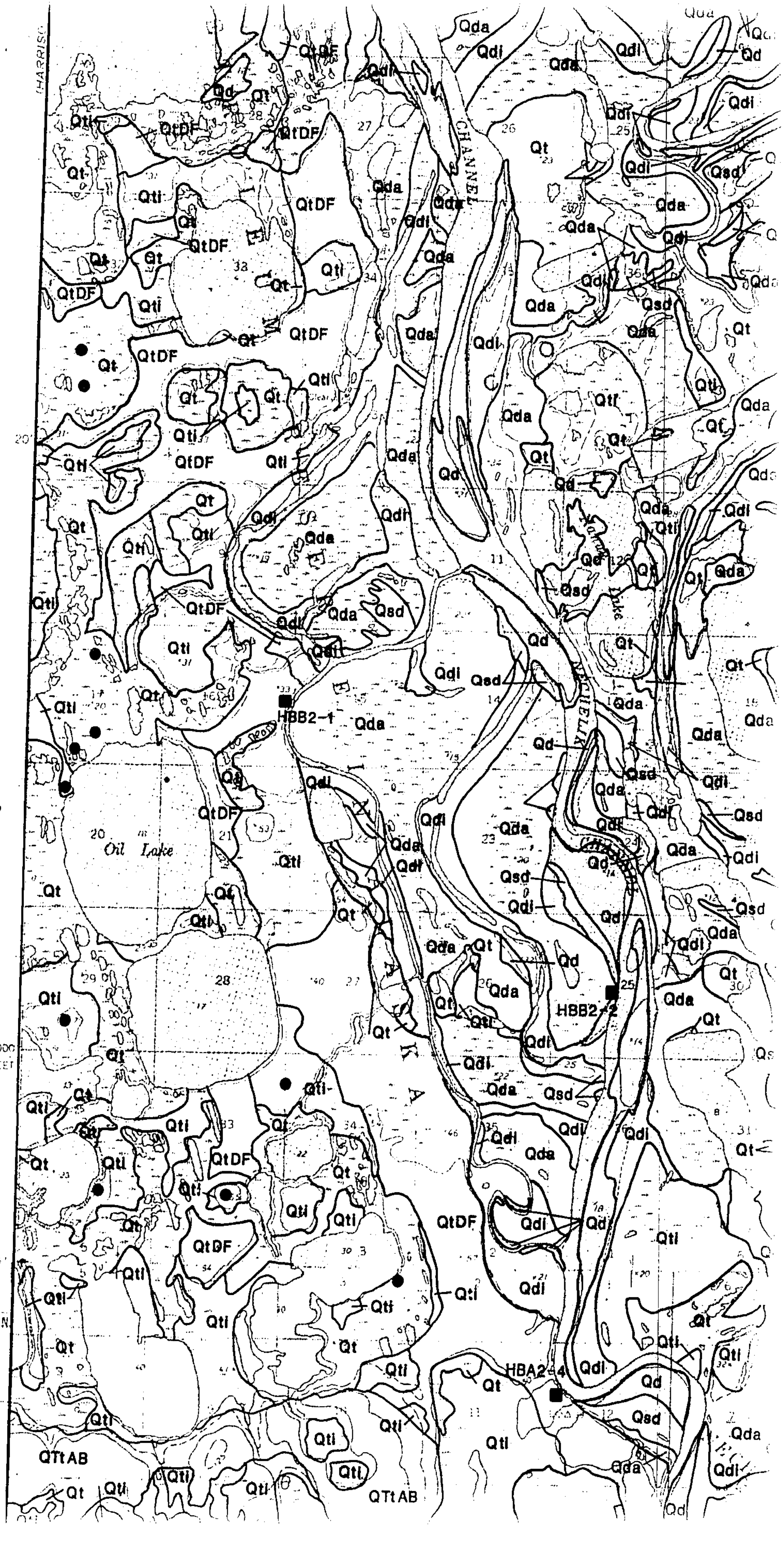
RAWLINSON, 1990 S



RAWLINSON, 1990 SHEET 1 OF 6

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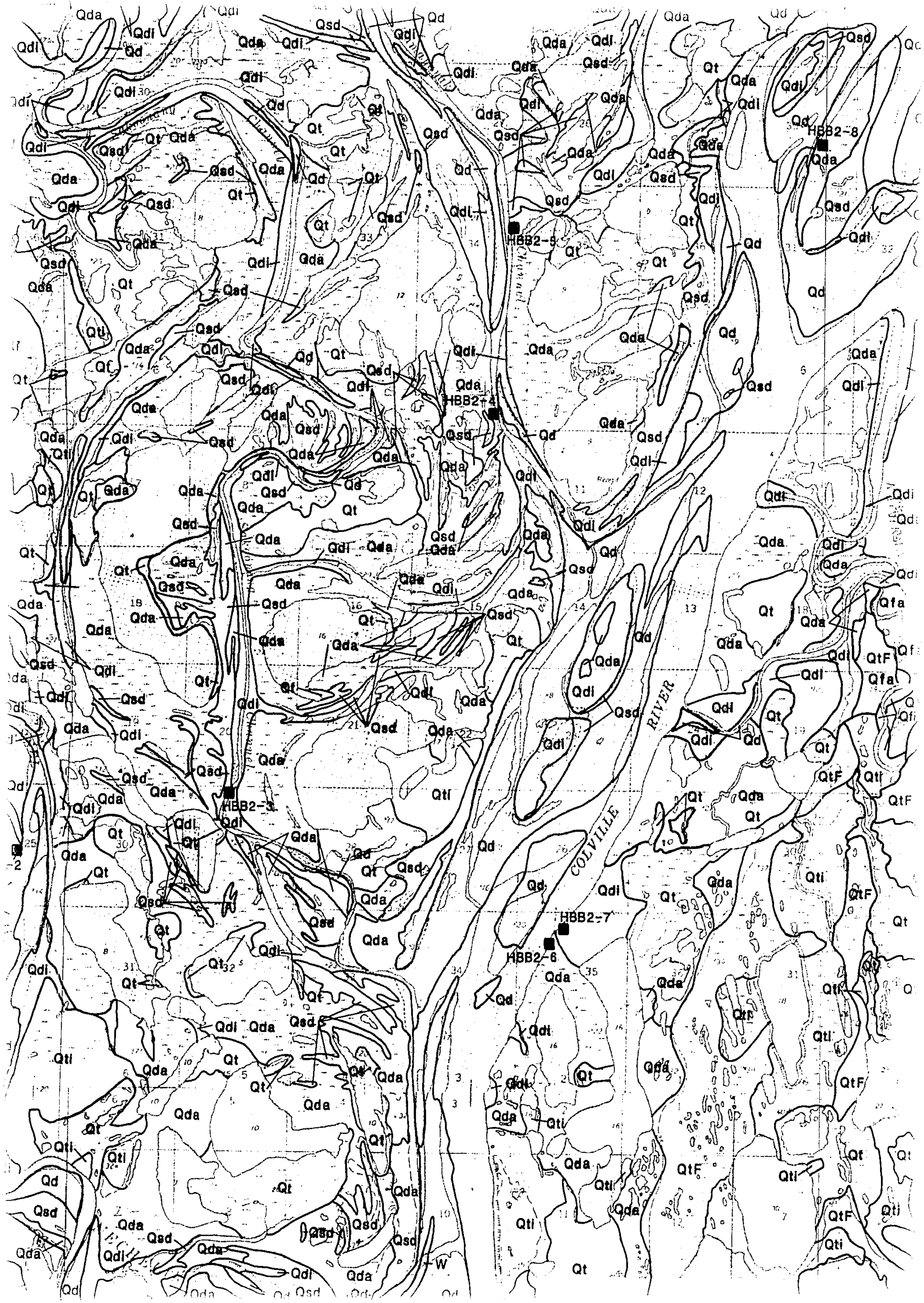
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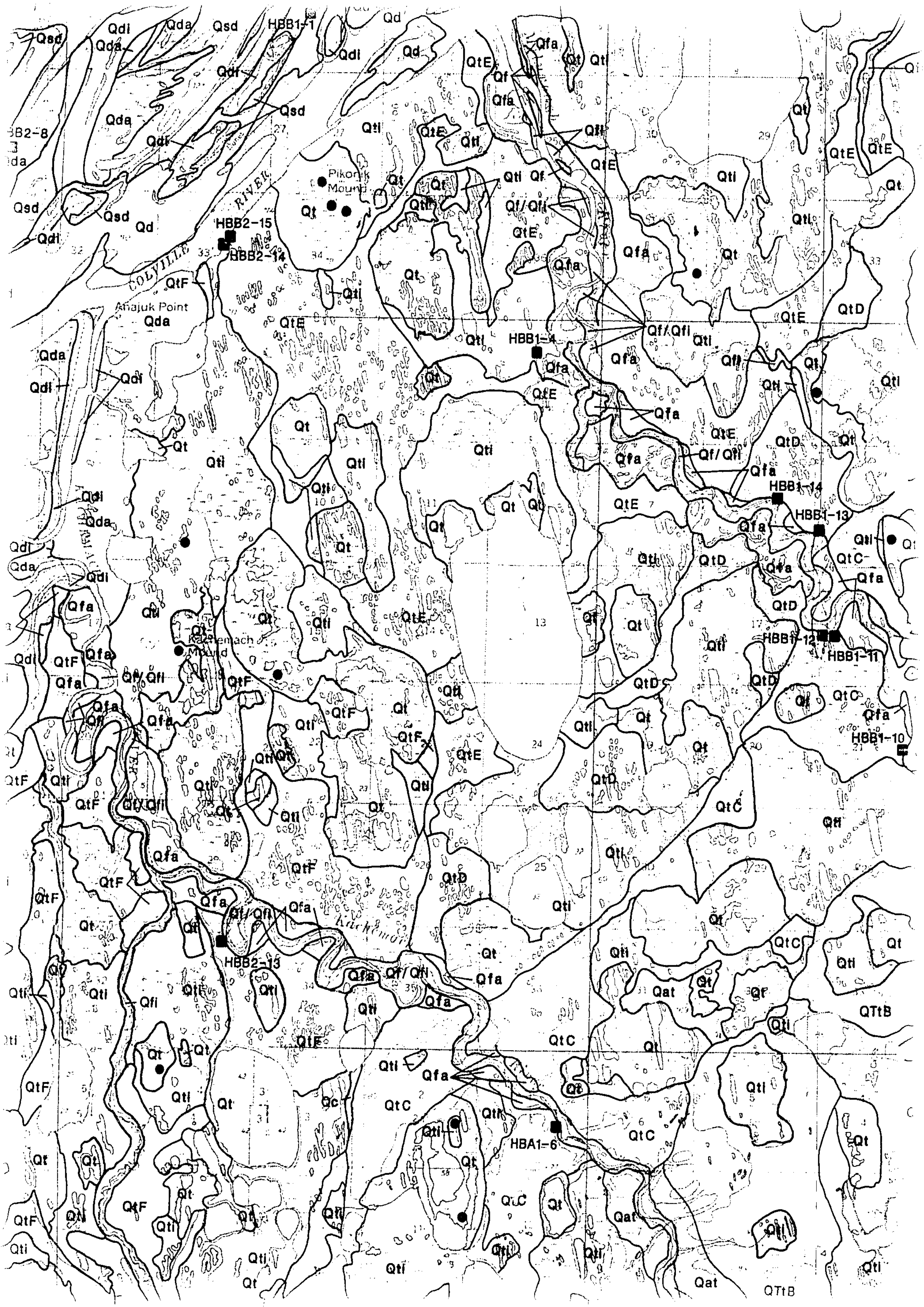
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Mound
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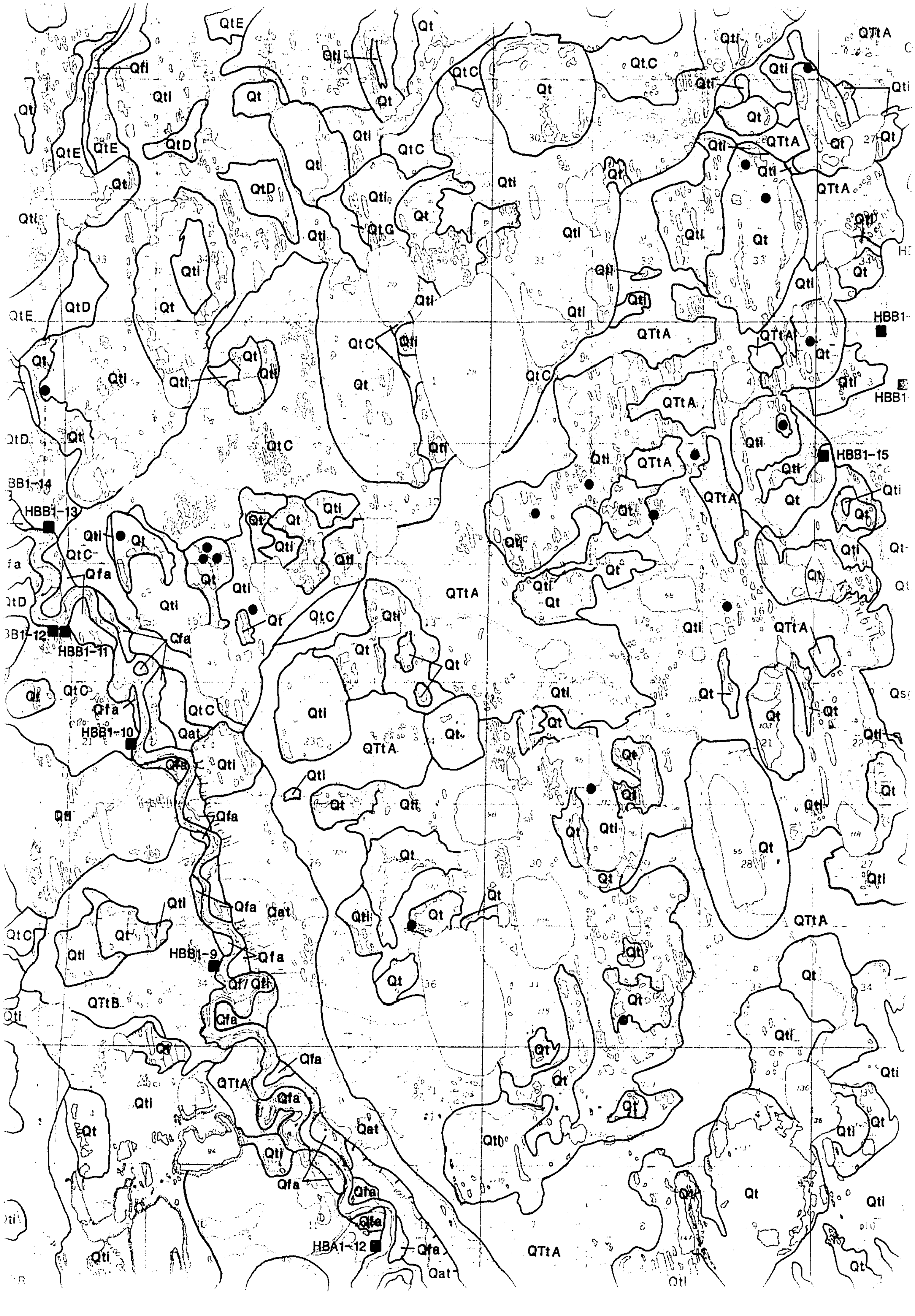
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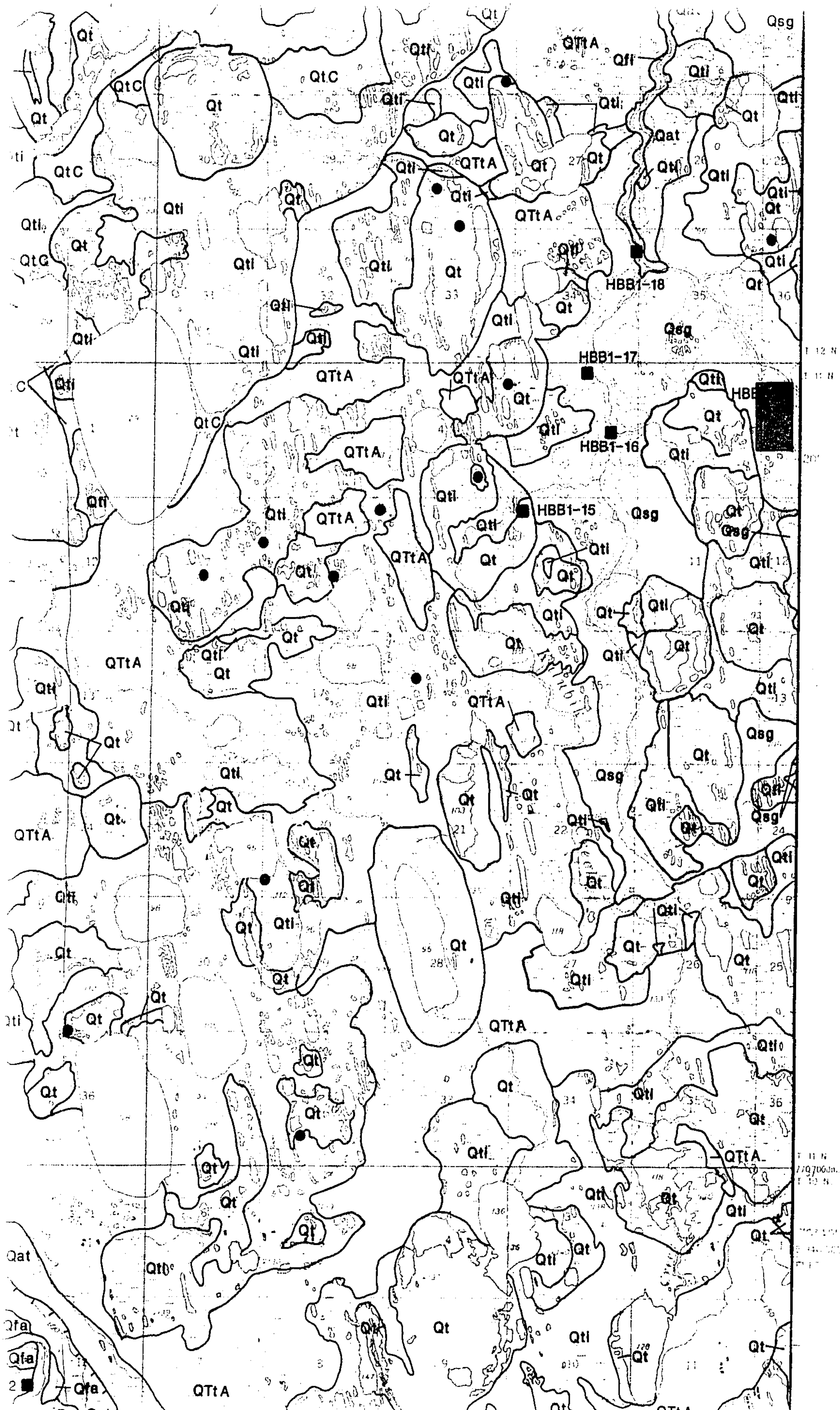
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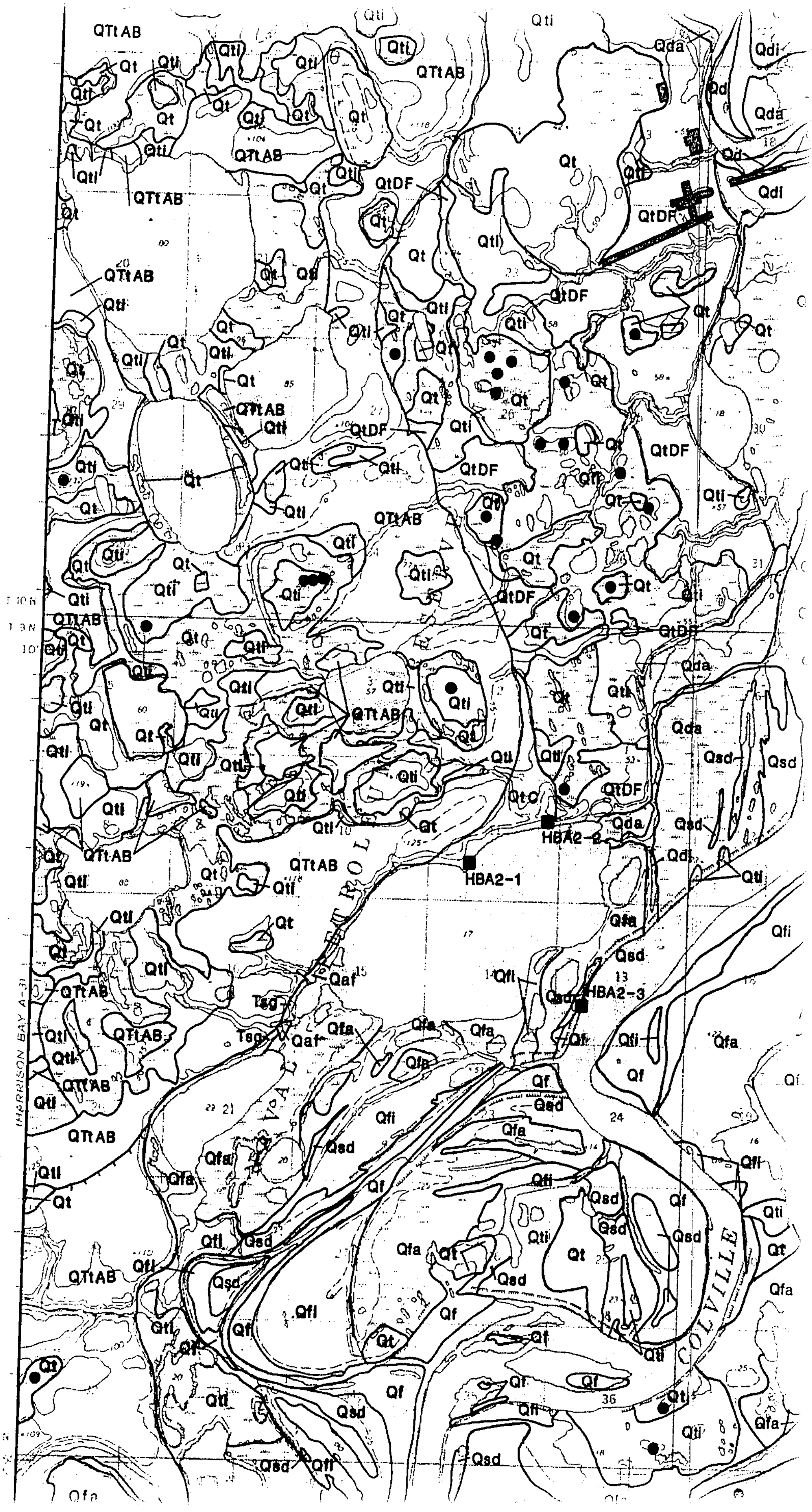
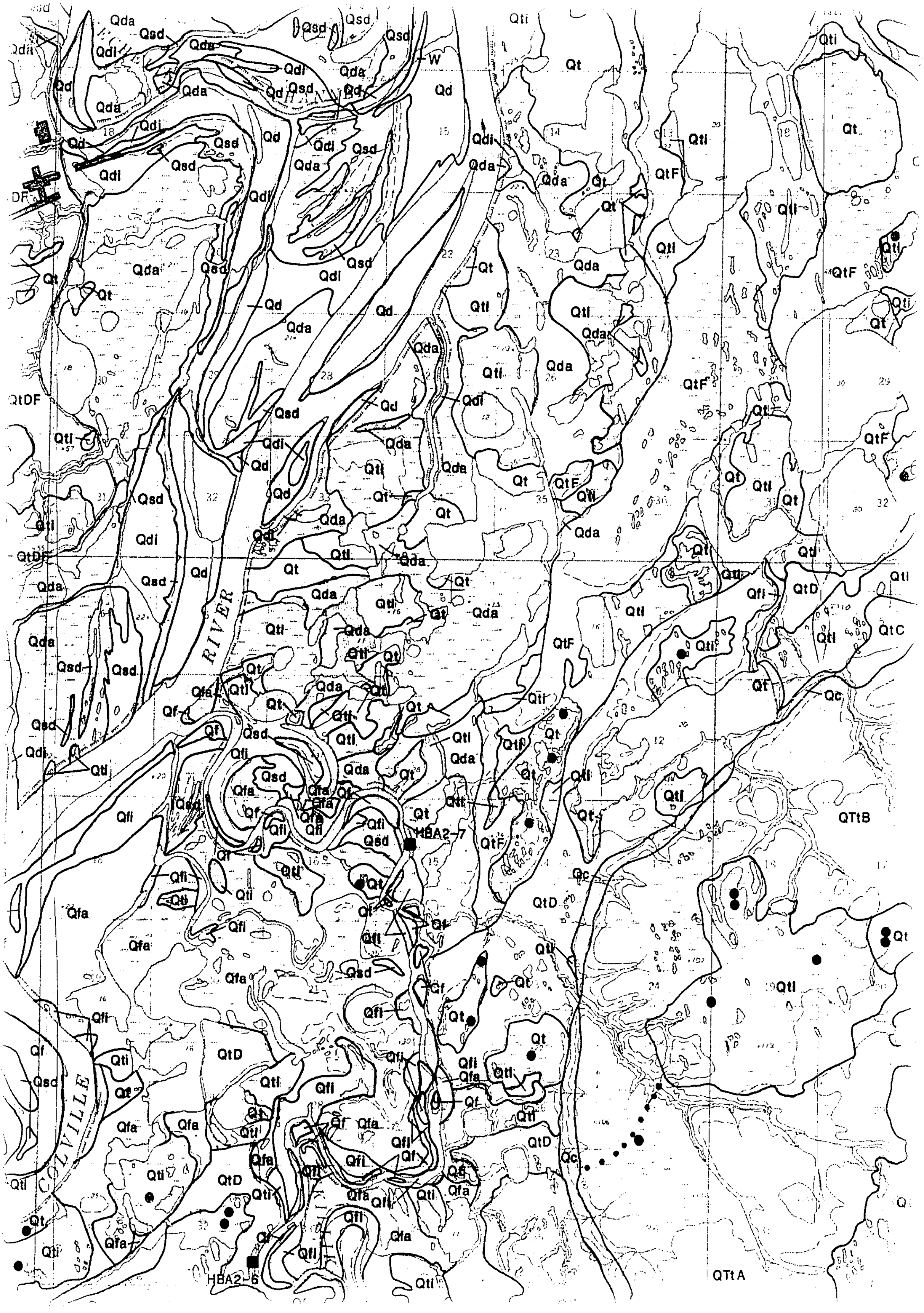
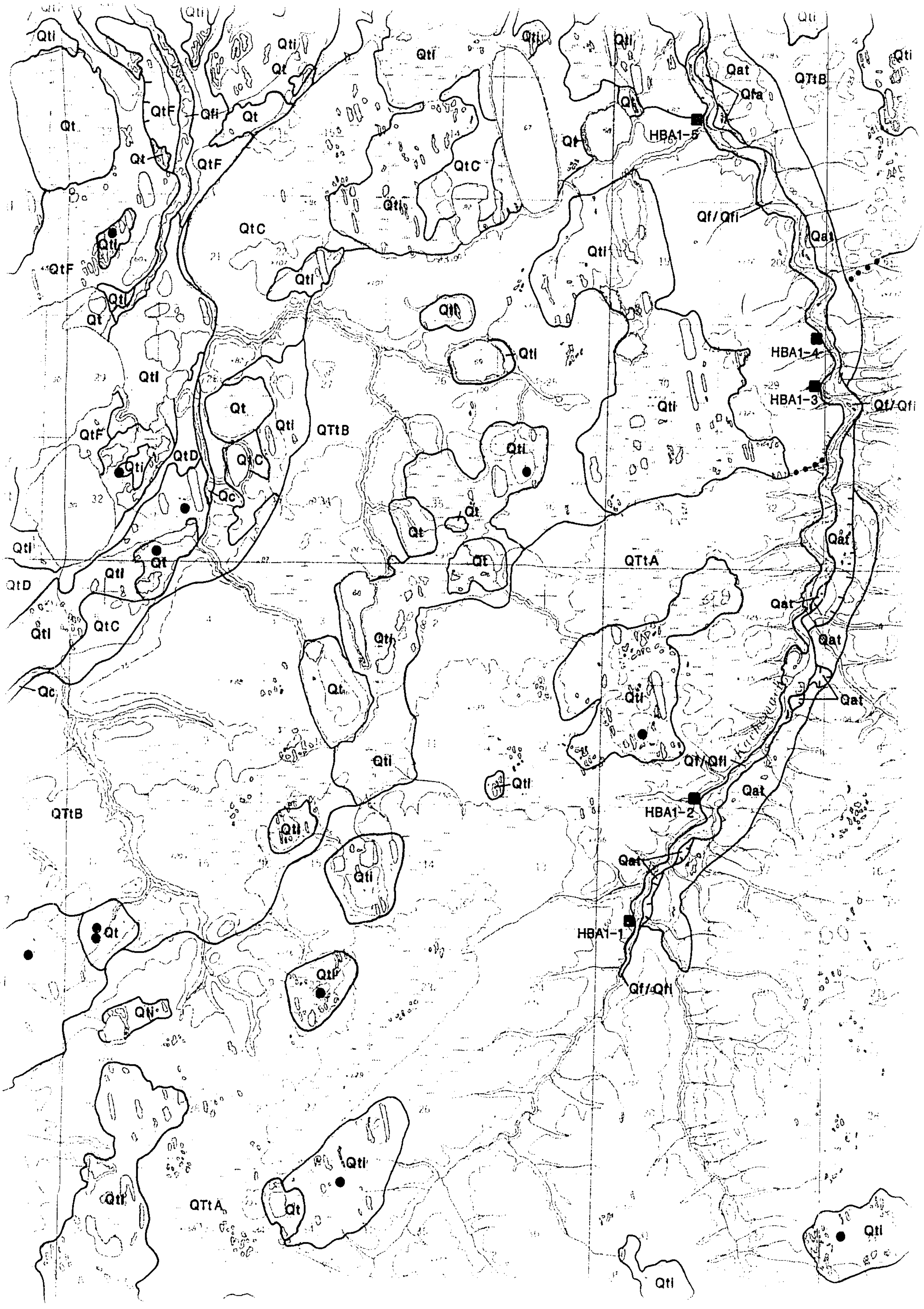
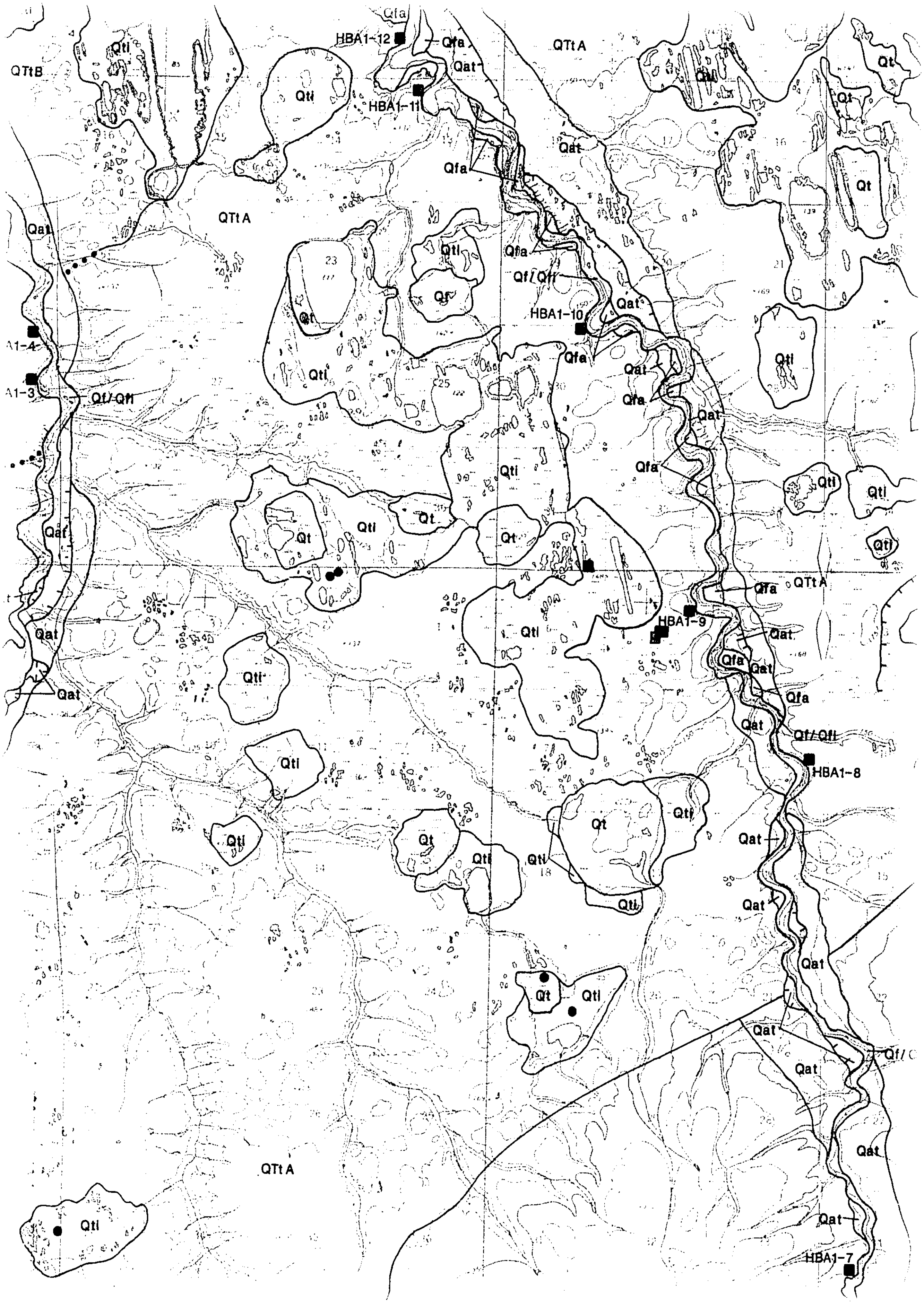
HBB1-15


QTtAB
Qt
Qtl
Qti
QtDF
Qda
Qdi
Qd
Qfa
Qfi
Qf
Qsd
Qaf
Tsg
QtC
HBA2-1
HBA2-2
HBA2-3
COLVILLE
HARRISON BAY A-3


COLVILLE
RIVER
HBA2-7
HBA2-6
QTtB
QTtA
QtDF
QtD
QtF
QtC
Qda
Qdi
Qsd
Qd
Qt
Qti
Qfa
Qfi
Qf
Qc
W


Qtl
QtF
Qt
QtC
QTtB
Qat
Qfa
HBA1-5
Qf/Qfl
HBA1-4
HBA1-3
Qt/Qfl
QtD
Qc
QTtA
Qtl
HBA1-2
HBA1-1
QTtA


Qfa
HBA1-12
Qfa
QTtA
Qt
Qtl
QTtB
Qtl
Qat
HBA1-11
Qt
Qat
Qfa
QTtA
Qat
Qt
Qtl
Qfa
Qtl
Qf/Qfl
Qat
Qtl
Qt
HBA1-10
A1-4
Qfa
Qtl
Qat
Qtl
A1-3
Qf/Qfl
Qfa
Qat
Qfa
Qtl
Qtl
Qtl
Qt
Qtl
Qt
Qt
Qat
Qtl
Qfa
QTtA
HBA1-9
Qtl
Qat
Qat
Qfa
Qat
Qtl
Qat
Qfa
Qat
Qat
Qf/Qfl
Qtl
HBA1-8
Qt
Qtl
Qtl
Qt
Qat
Qtl
Qtl
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Qt
Qtl
Qat
Qf/C
Qat
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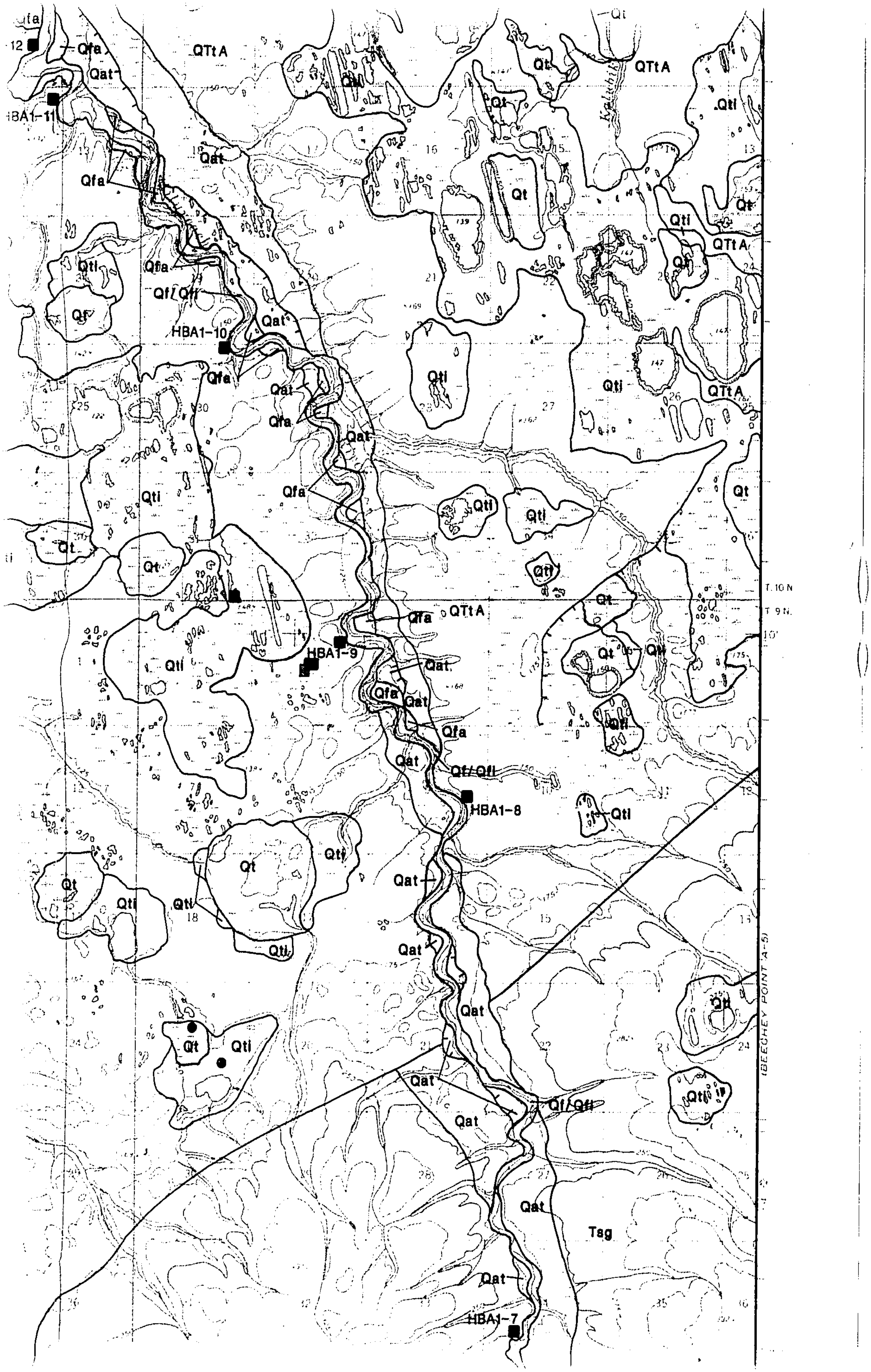
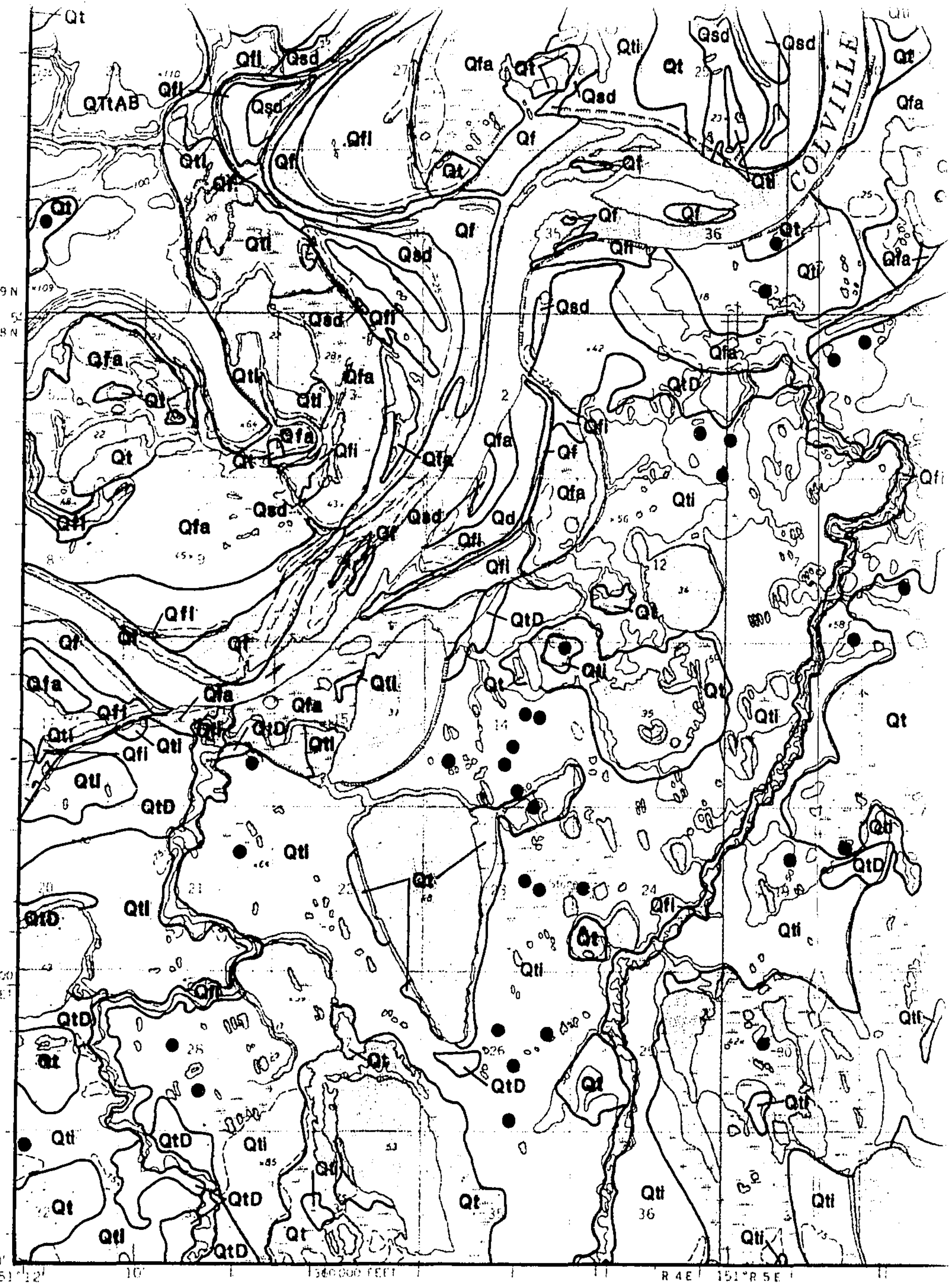
Qtl
Qat
HBA1-7

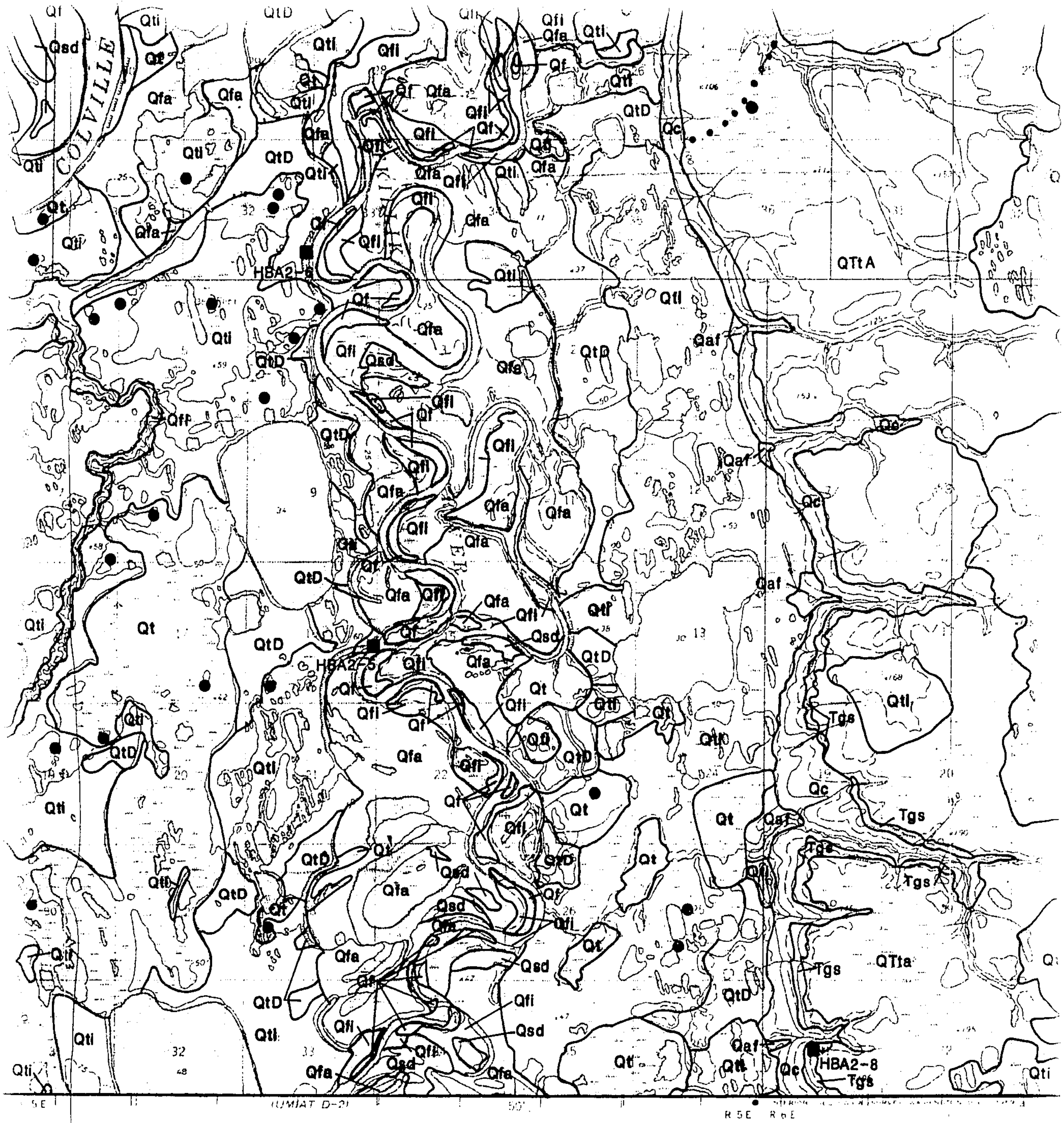


QTtA
Qfa
Qat
HBA1-11
Qfa
Qt
Qtl
QTtA
Qt
Qtl
Qfa
Qf/Qfl
Qf
Qat
HBA1-10
Qfa
Qat
Qfa
Qtl
Qtl
QTtA
Qat
Qfa
Qtl
Qtl
Qtl
Qt
Qt
Qt
Qtl
Qfa
QTtA
HBA1-9
Qtl
Qat
Qt
Qtl
Qfa
Qat
Qfa
Qtl
Qat
Qf/Qfl
HBA1-8
Qtl
Qt
Qtl
Qt
Qtl
Qtl
Qtl
Qat
Qat
Qat
Qtl
Qt
Qtl
Qat
Qat
Qf/Qfl
Qtl
Qat
Tsg
Qat
HBA1-7
T.10N
T.9N.
(BEECHEY POINT A-5)



GEOLOGY MAPPED BY L.D. CARTER AND J.P. GALLOWAY, 1977–1982; S.E. RAWLINSON, R.A. COMBELLICK, AND D.R. HICKMOTT, 1983–1984; RAWLINSON, CARTER, AND COMBELLICK, 1987; AND RAWLINSON, 1988–1989

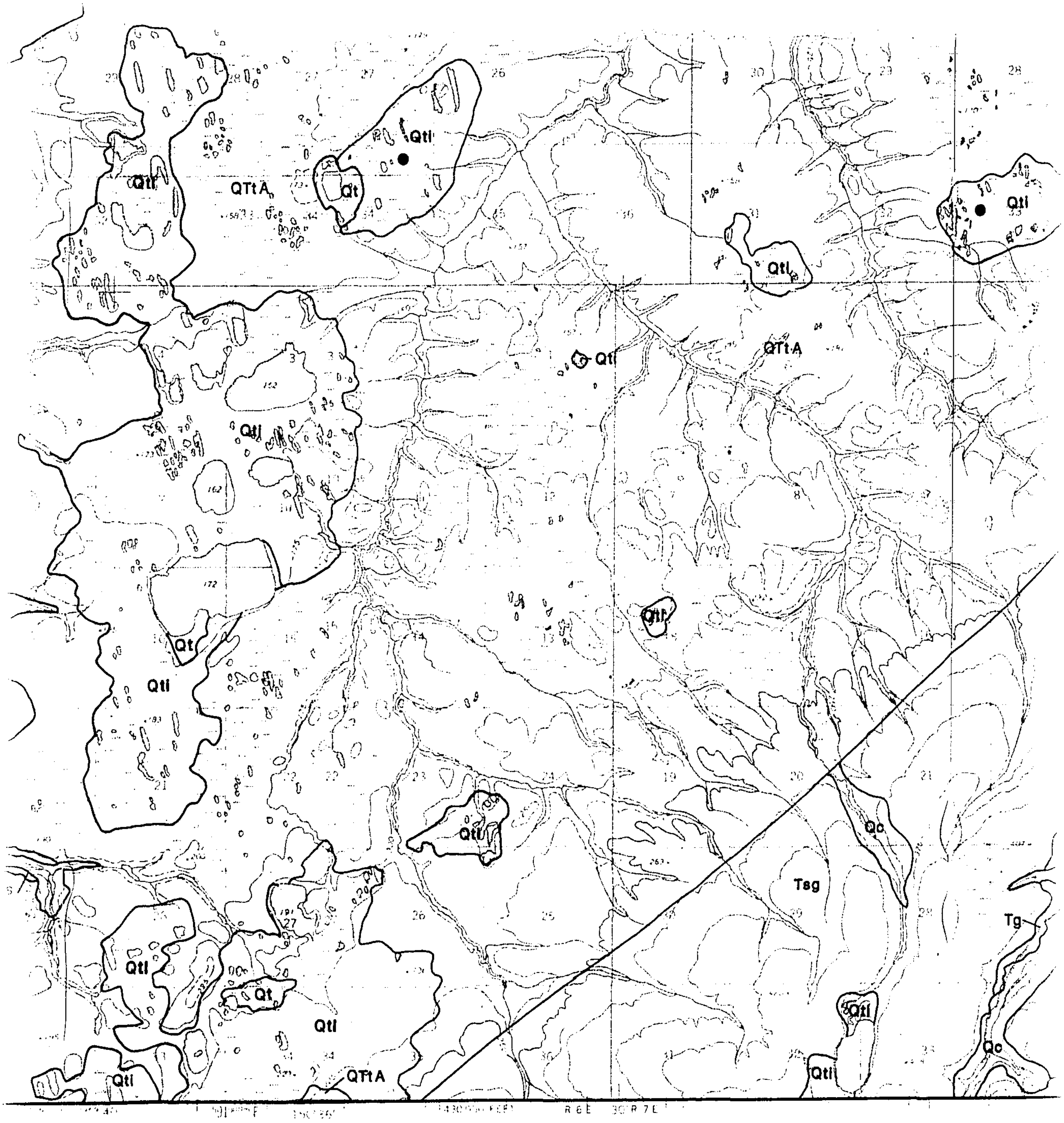
BASE MAP FROM U.S. GEOLOGICAL SURVEY HARRISON BAY A-1, 1955; A-2, 1955; B-1, 1955; AND B-2, 1955.



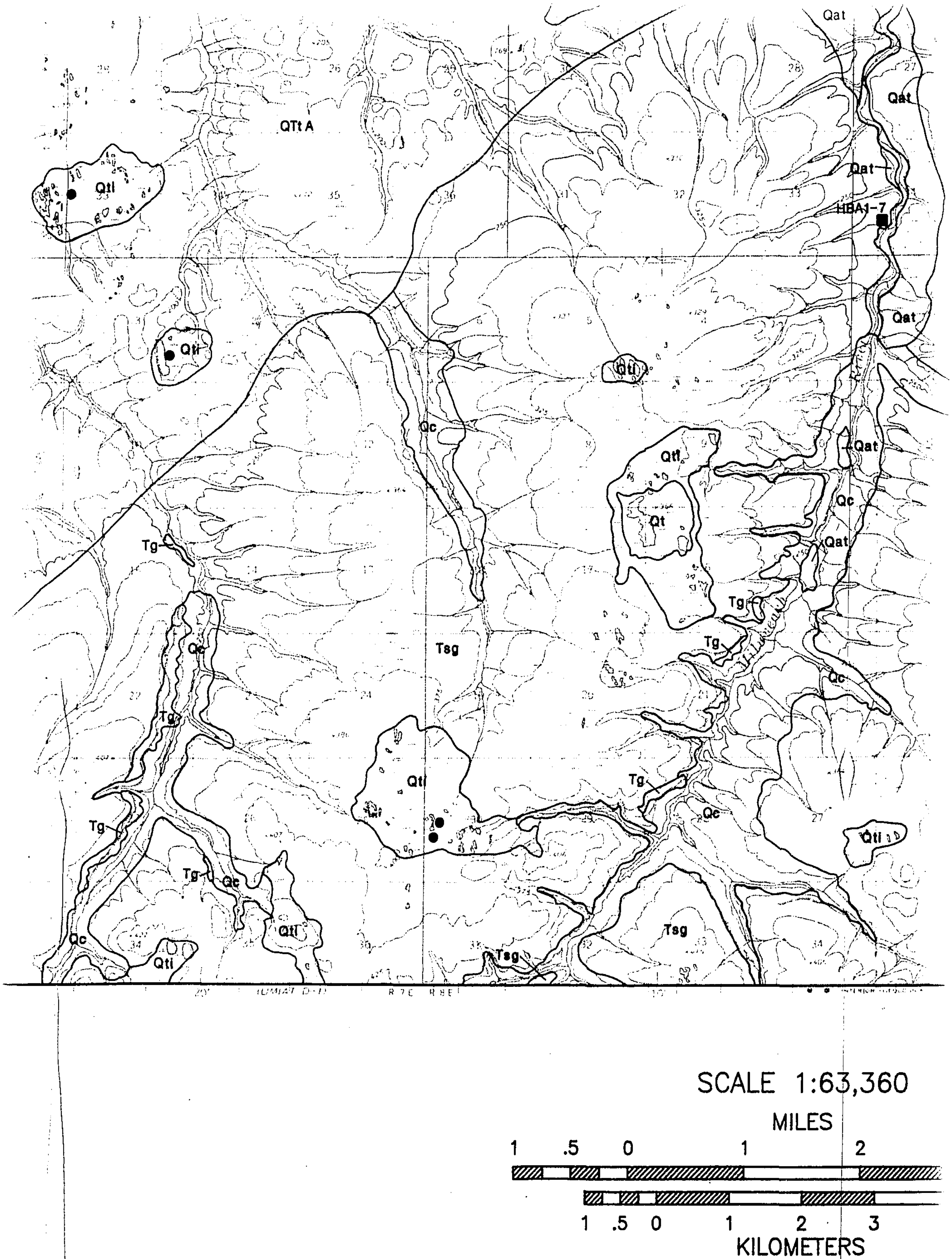
1989

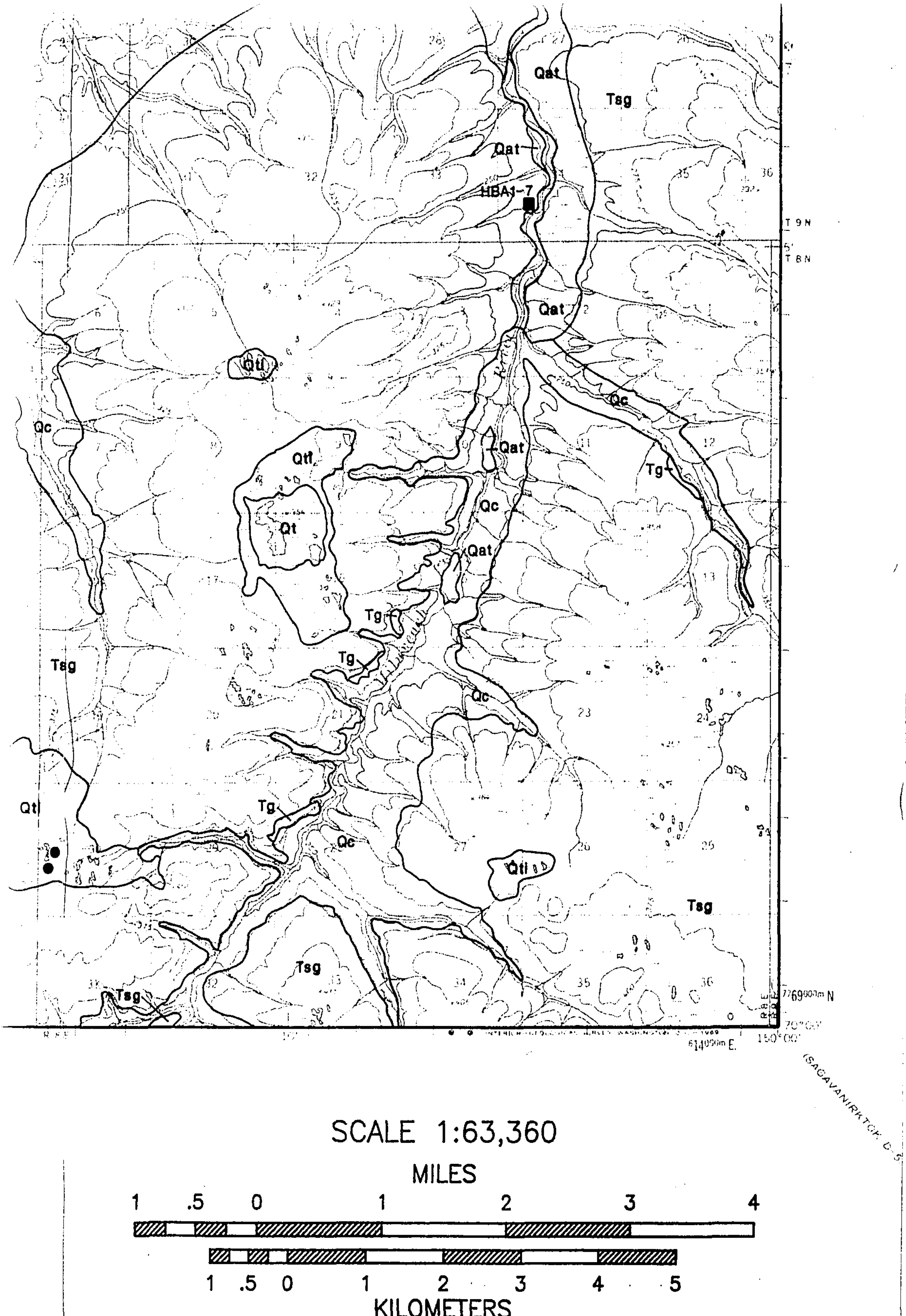
SURFICIAL-GEOLOGY

AND B



:OLOGY MAP OF THE HARRISON BAY A-1, A-2, B-1, AND B-2 QUADRANGLES, ALASKA


Qat
QTt A
Qtl
HBA1-7
Qc
Qt
Tg
Tsg
SCALE 1:63,360
MILES
1 .5 0 1 2
1 .5 0 1 2 3
KILOMETERS


Qat
Tsg
Qat
HBA1-7
T 9 N
T 8 N
Qat
Qtl
Qc
Qc
Qtl
Qat
Qt
Qc
Tg
Qat
Tg
Tg
Tsg
Qc
Qt
Tg
Qc
Qtl
Tsg
Tsg
Tsg
7769000m N
614000m E.
150°00'
(SAGAVANIRKTOK D-5)
SCALE 1:63,360
MILES
1 .5 0 1 2 3 4
1 .5 0 1 2 3 4 5
KILOMETERS

PLEASE NOTE:

Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

Black and white photographic prints (17" x 23") are available for an additional charge.

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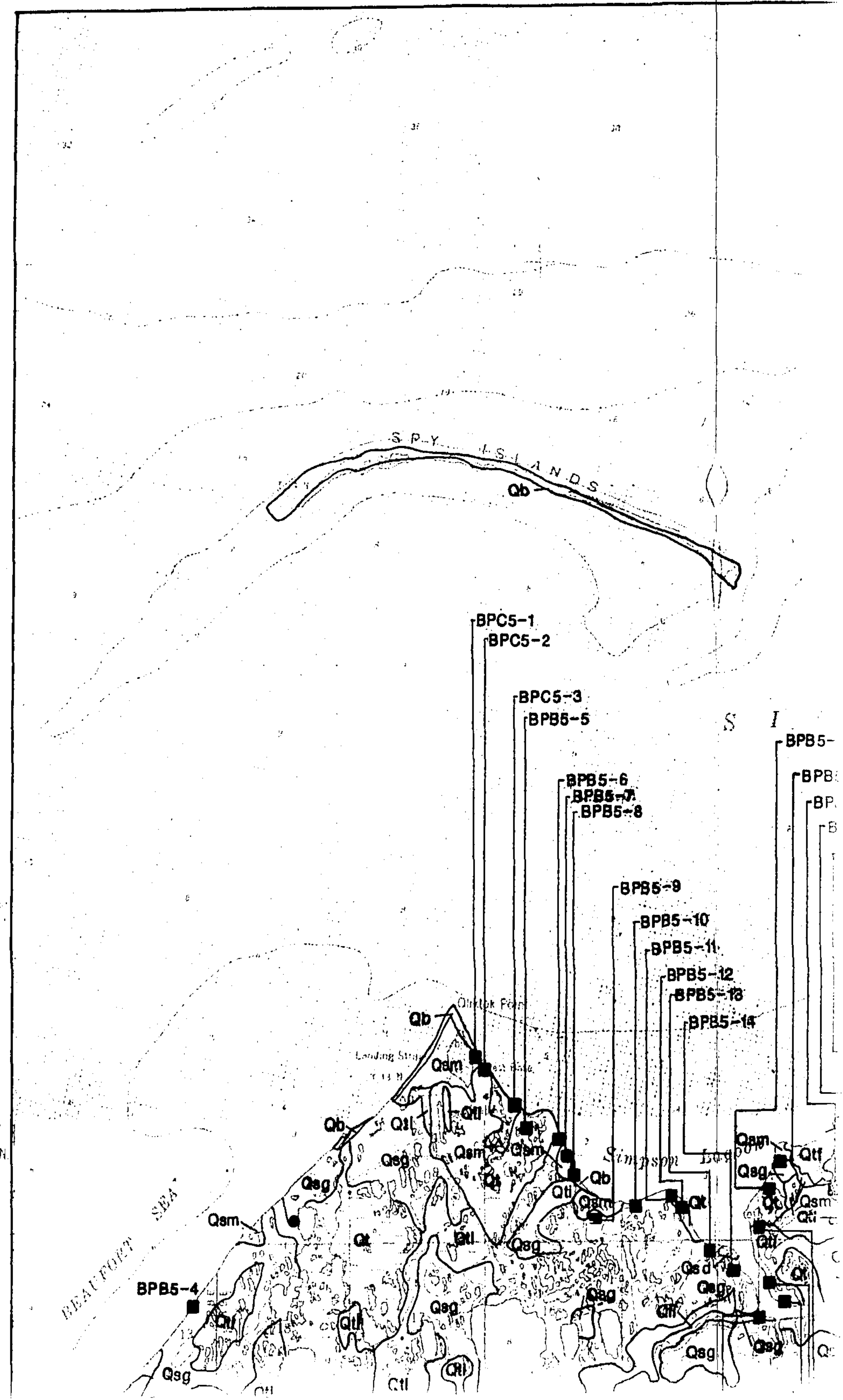
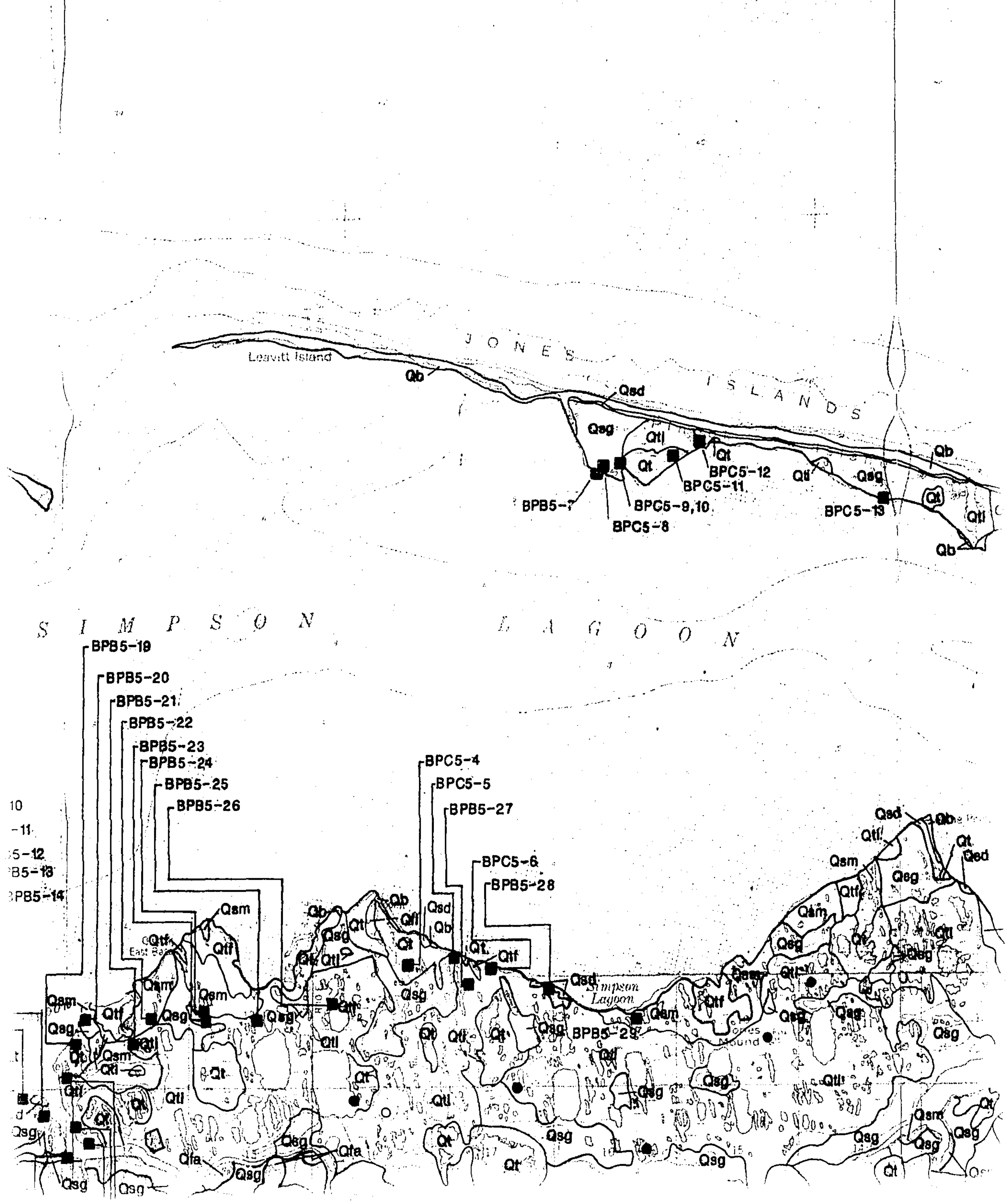
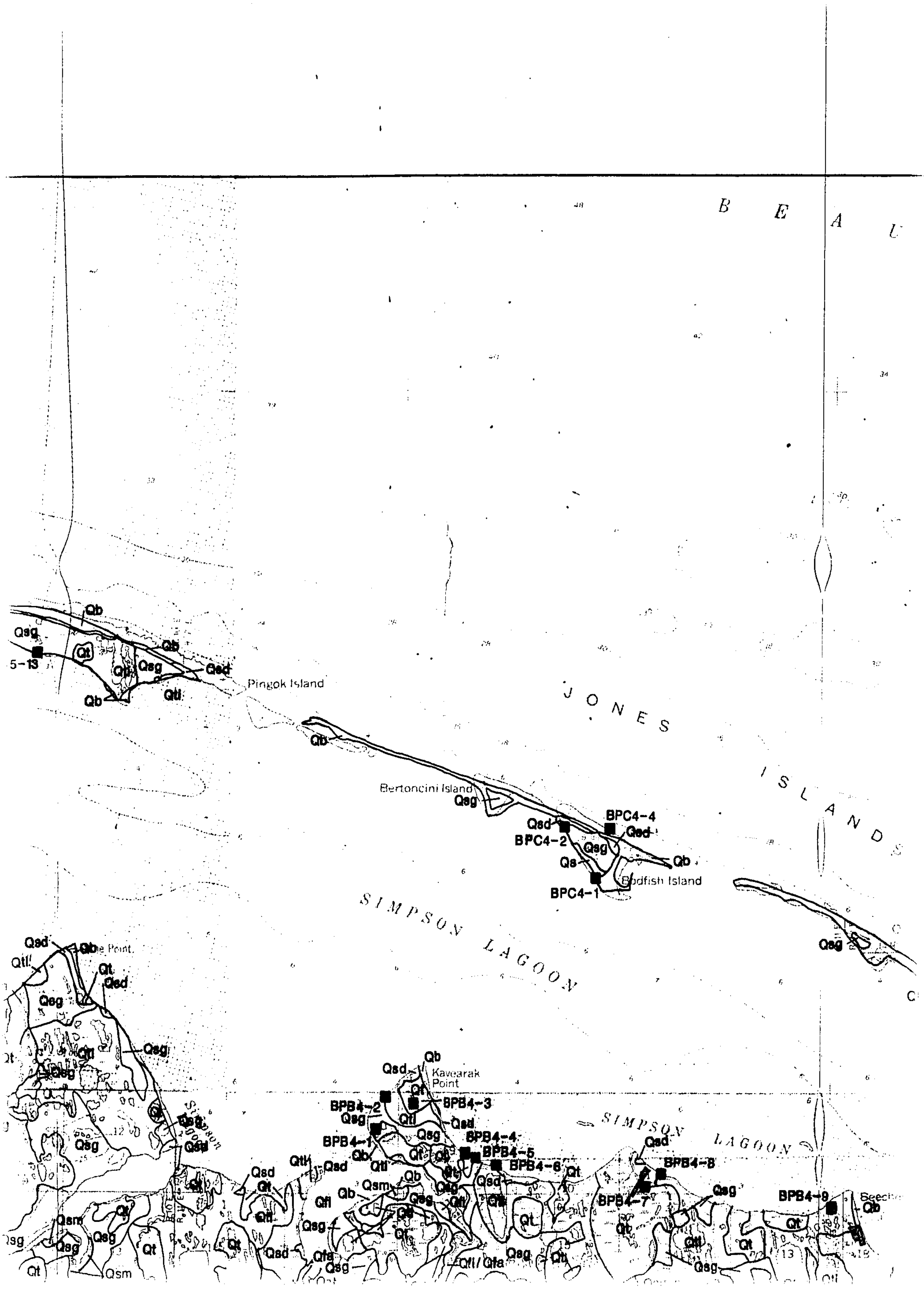
MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS
CORRELATION OF MAP UNITS IN APPENDIX B



ƎIPTIONS IN APPENDIX A

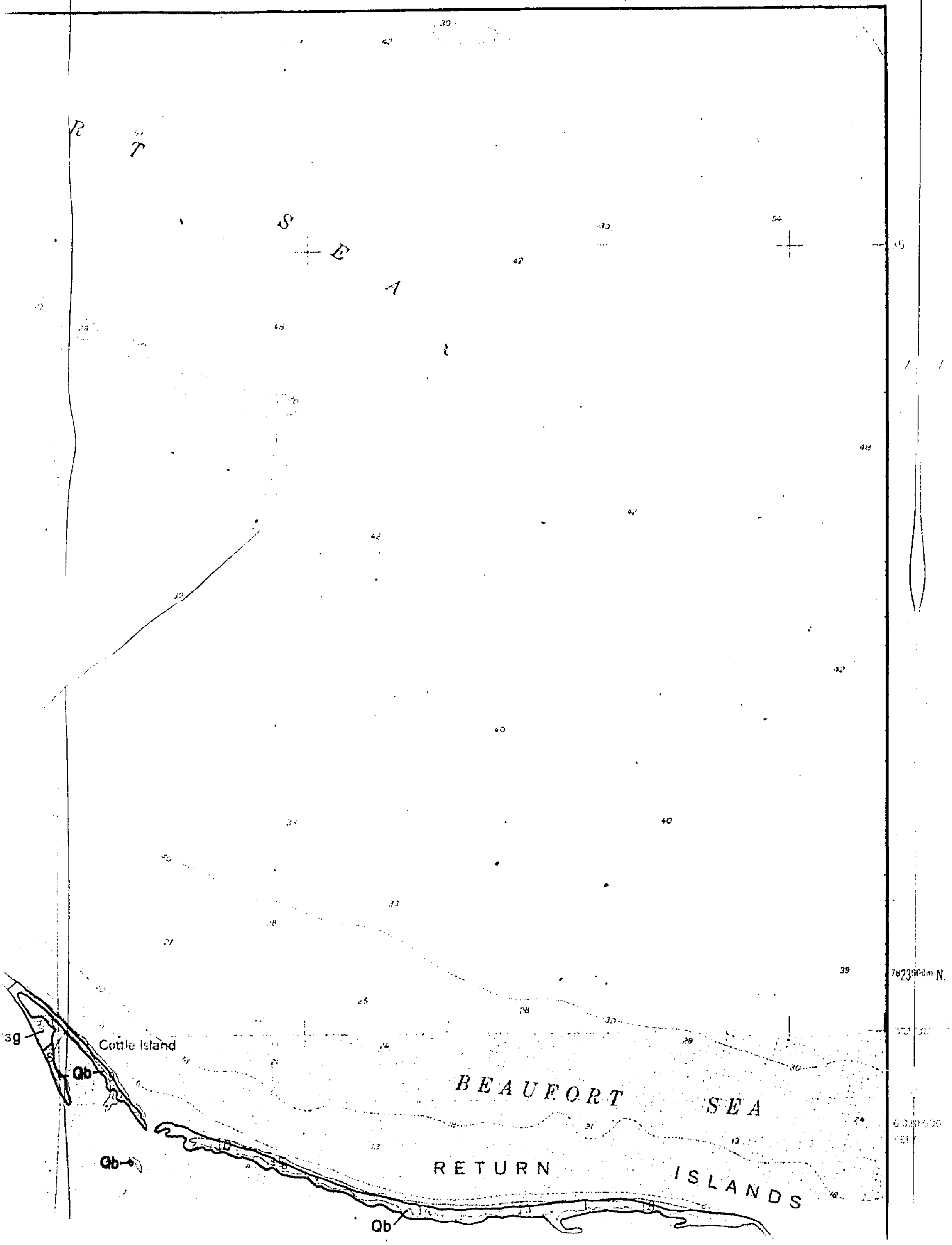
ƎNDIX B

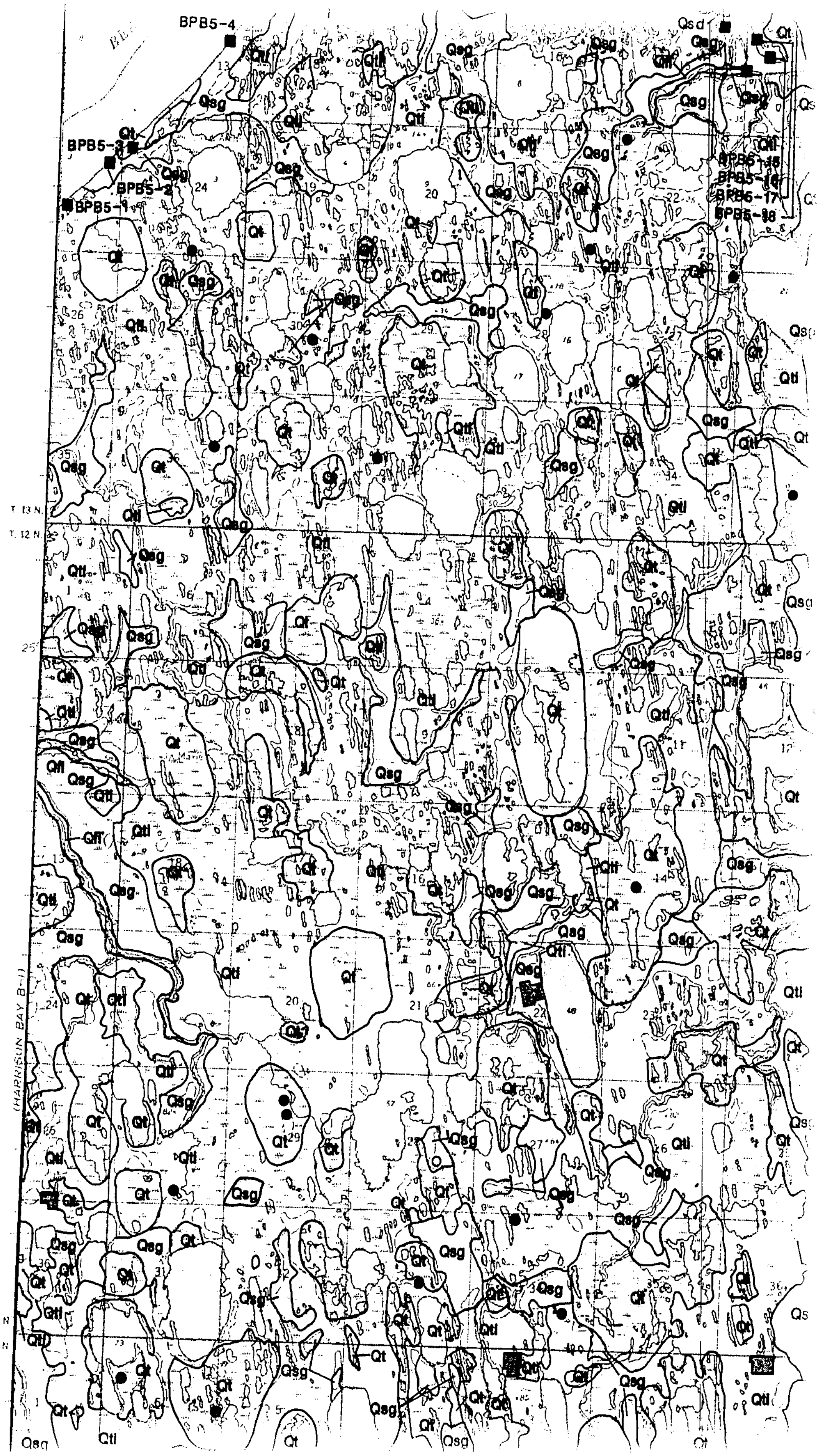


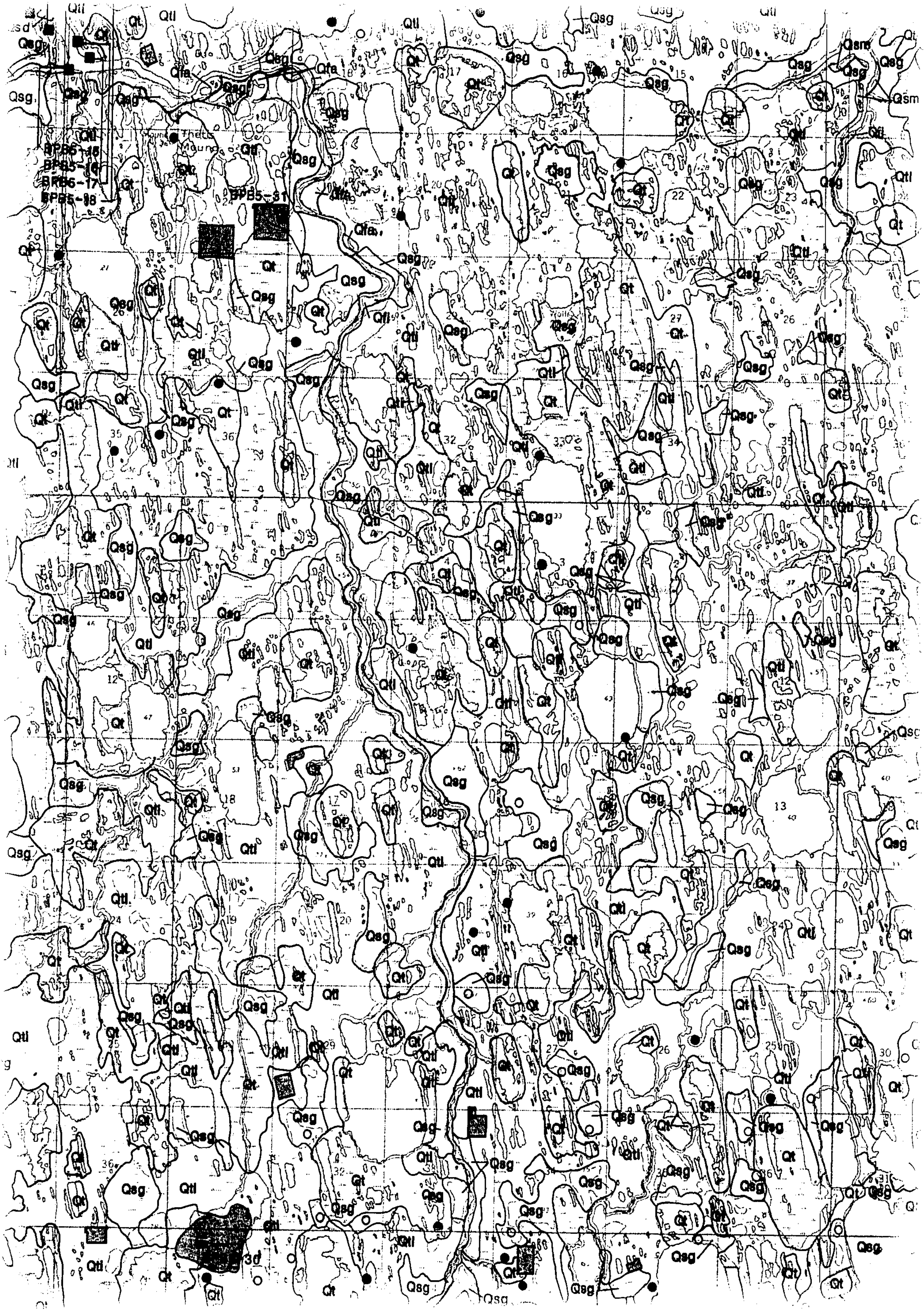

B E A U
J O N E S
I S L A N D S
Pingok Island
Bertoncini Island
Bodfish Island
SIMPSON LAGOON
Kavearak Point
BPC4-4
BPC4-2
BPC4-1
BPB4-1
BPB4-2
BPB4-3
BPB4-4
BPB4-5
BPB4-6
BPB4-7
BPB4-8
BPB4-9
5-13
Qb
Qsg
Qt
Qsd
Qtl
Qs
Qsm
Qfa

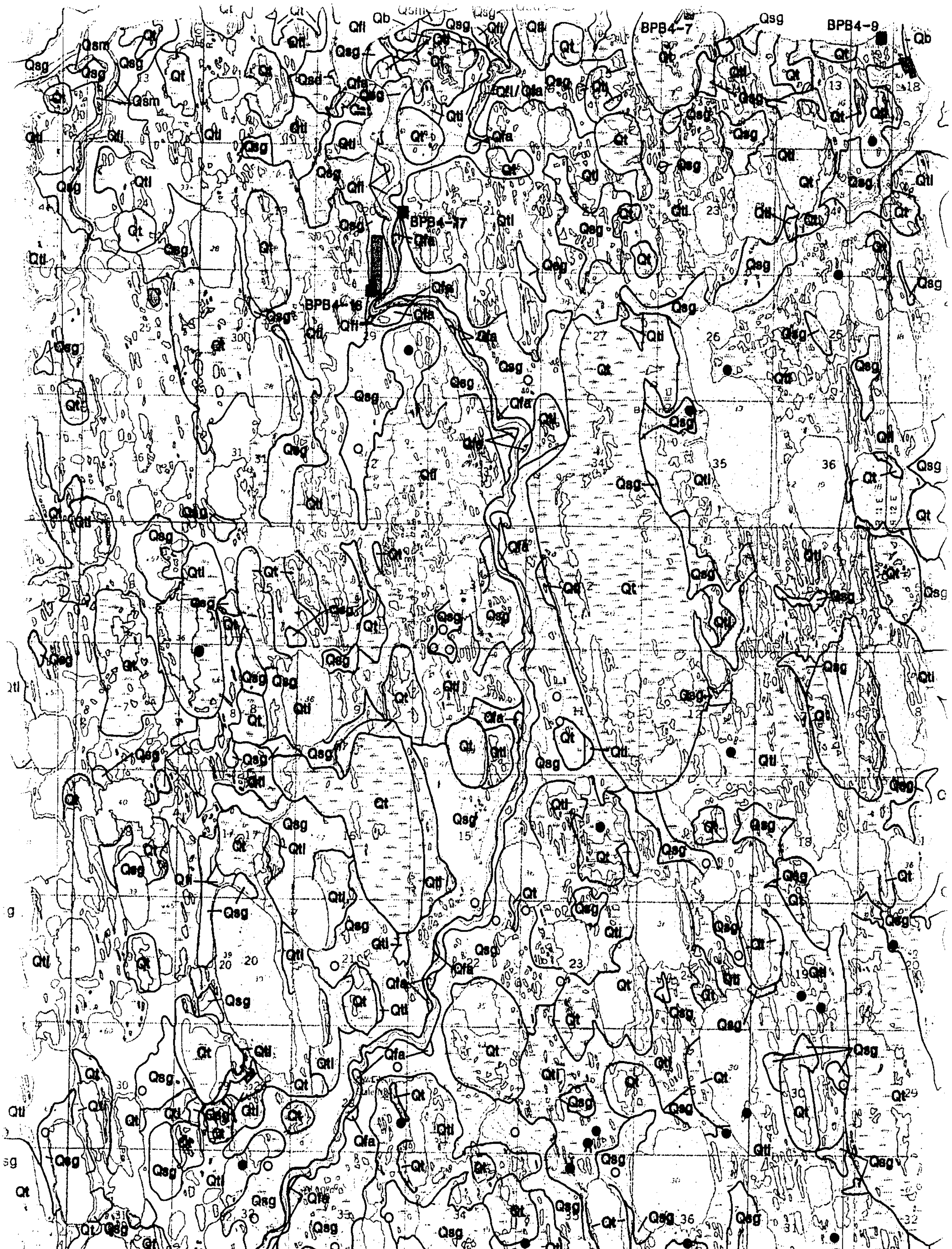

RAWLINSON, 1990 SHEE
BEAUFORT SEA
SLANDS
Cottle Island
Qsg
Qb
Cottle Island
BEAUFORT SE
RETURN ISLA
BPB4-9
Beechey Point
Qt
Qsd

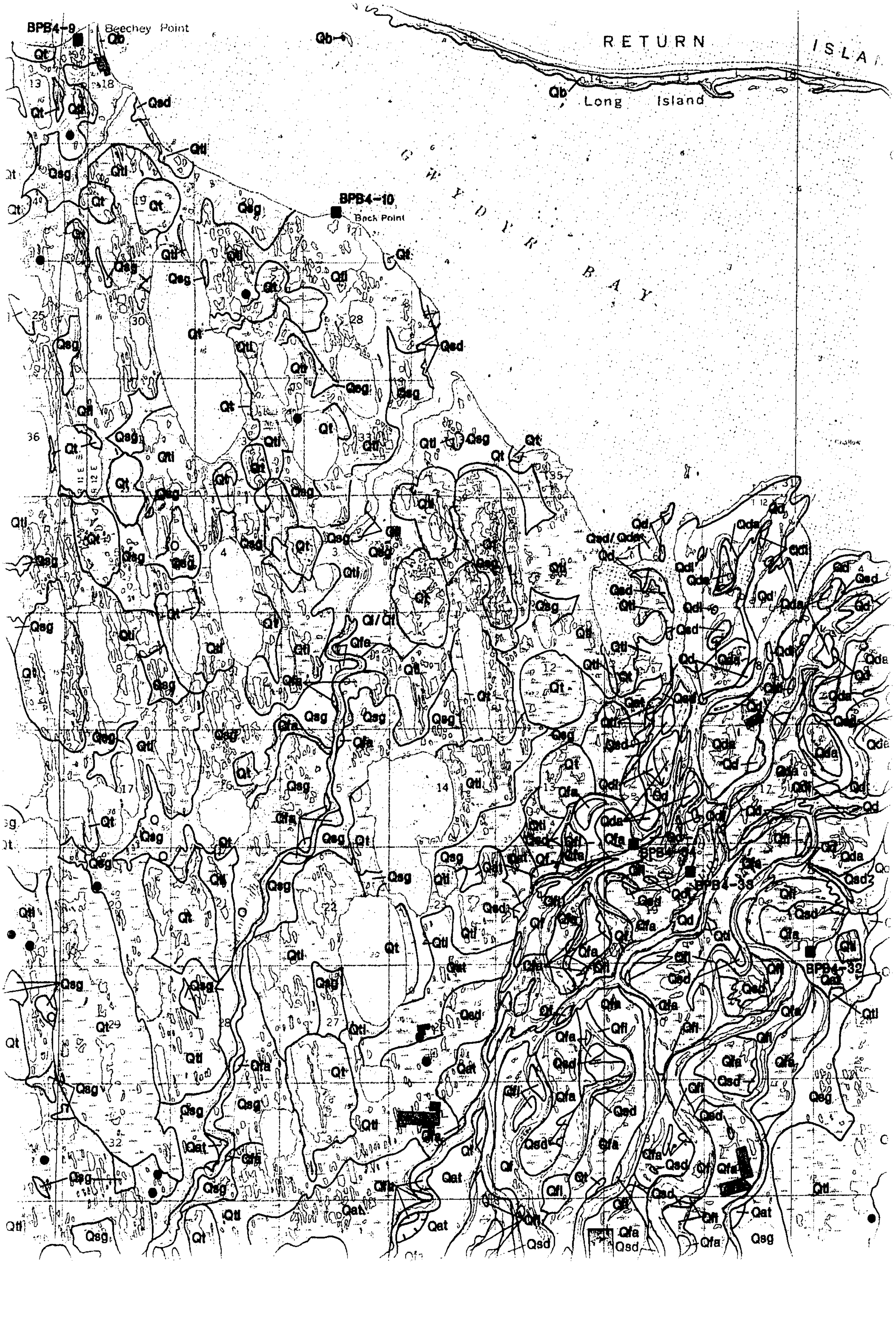
RAWLINSON, 1990 SHEET 2 OF 6

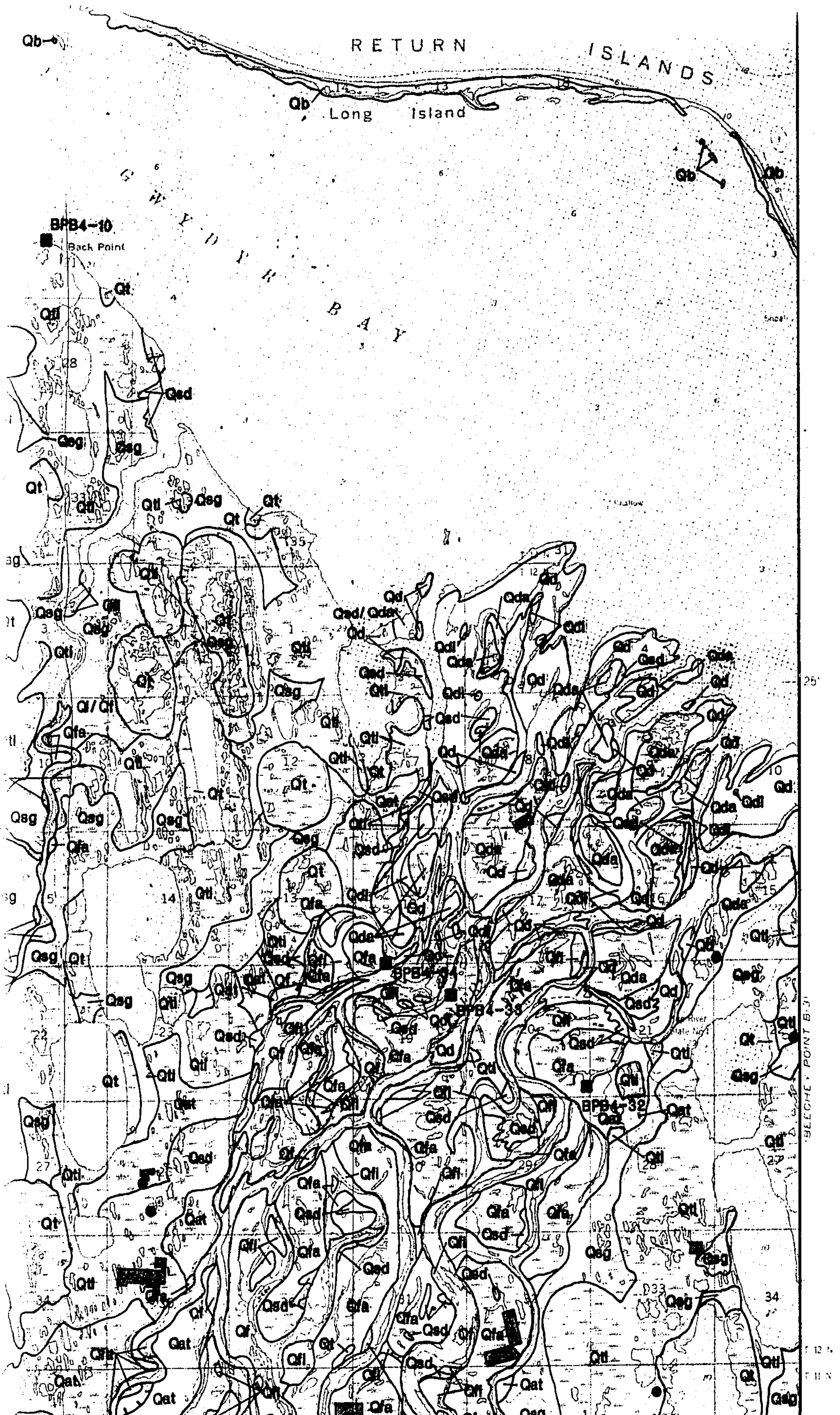


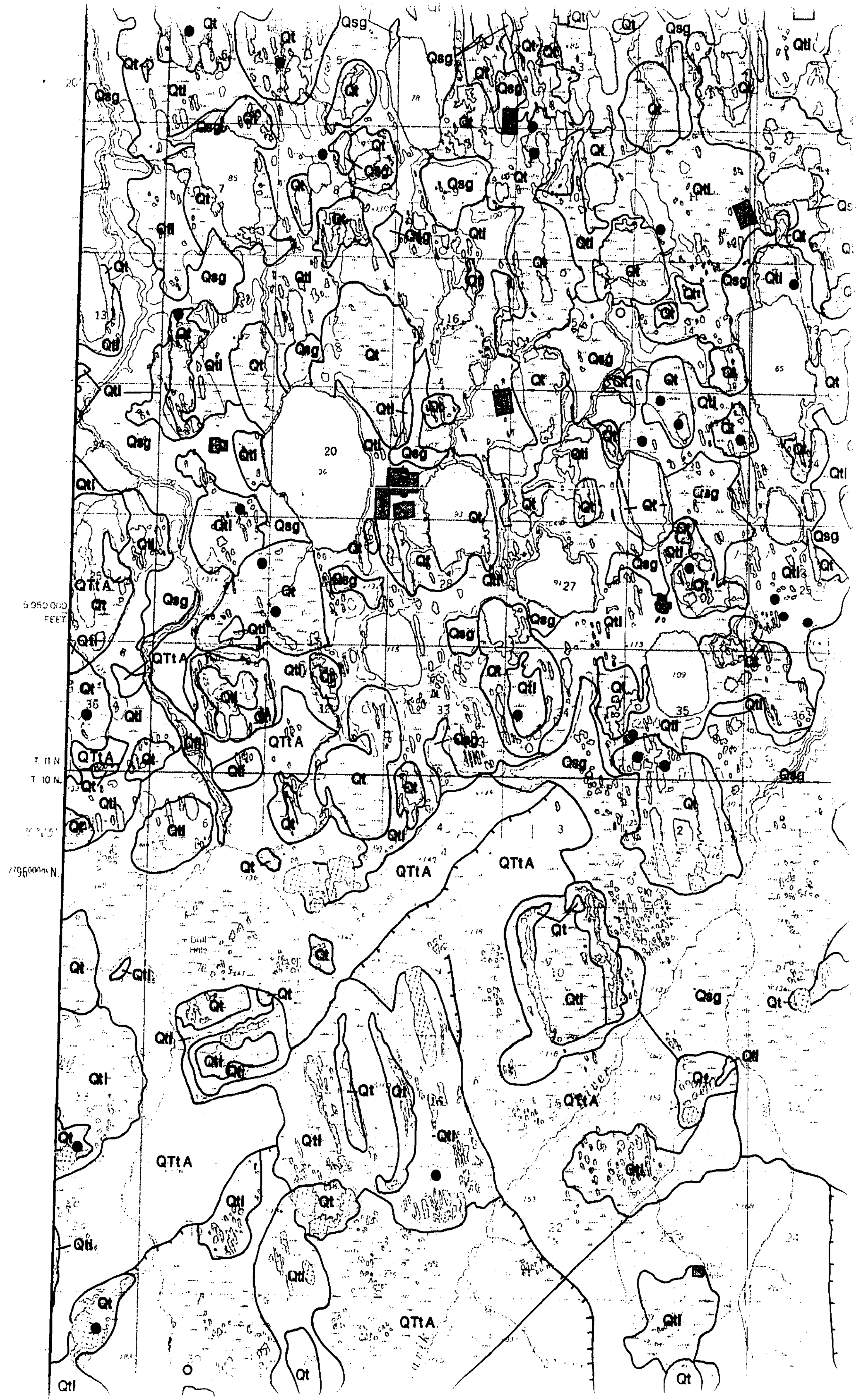

BPB5-4
BPB5-3
BPB5-2
BPB5-1
BPB5-17
Qsd
Qt
Qtl
Qsg
Qfl
T 13 N.
T 12 N.
T 12 N
T 11 N
(HARRISON BAY B-1)

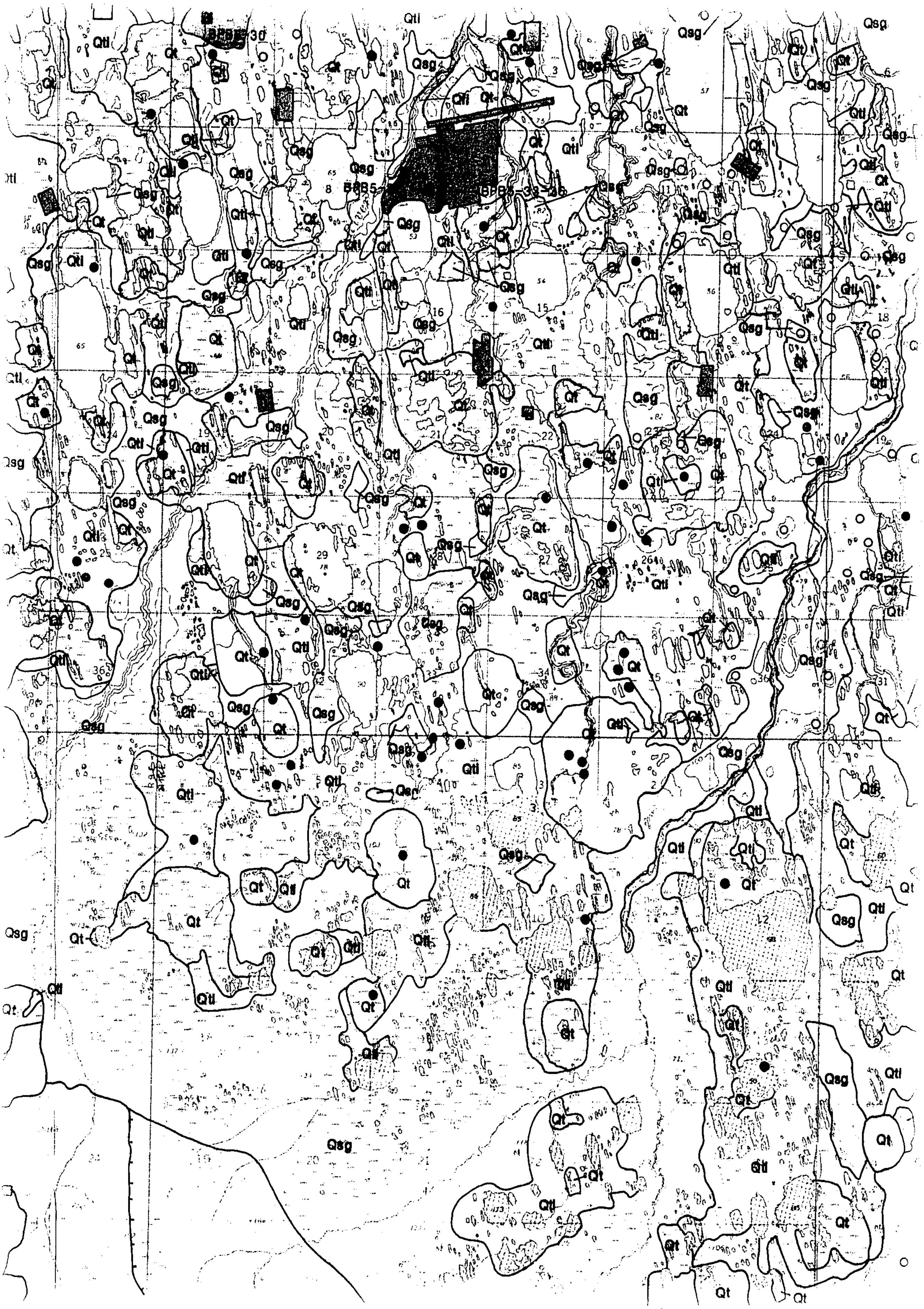

Qsg
Qt
Qtl
Qfa
Qsm
BPB5-31

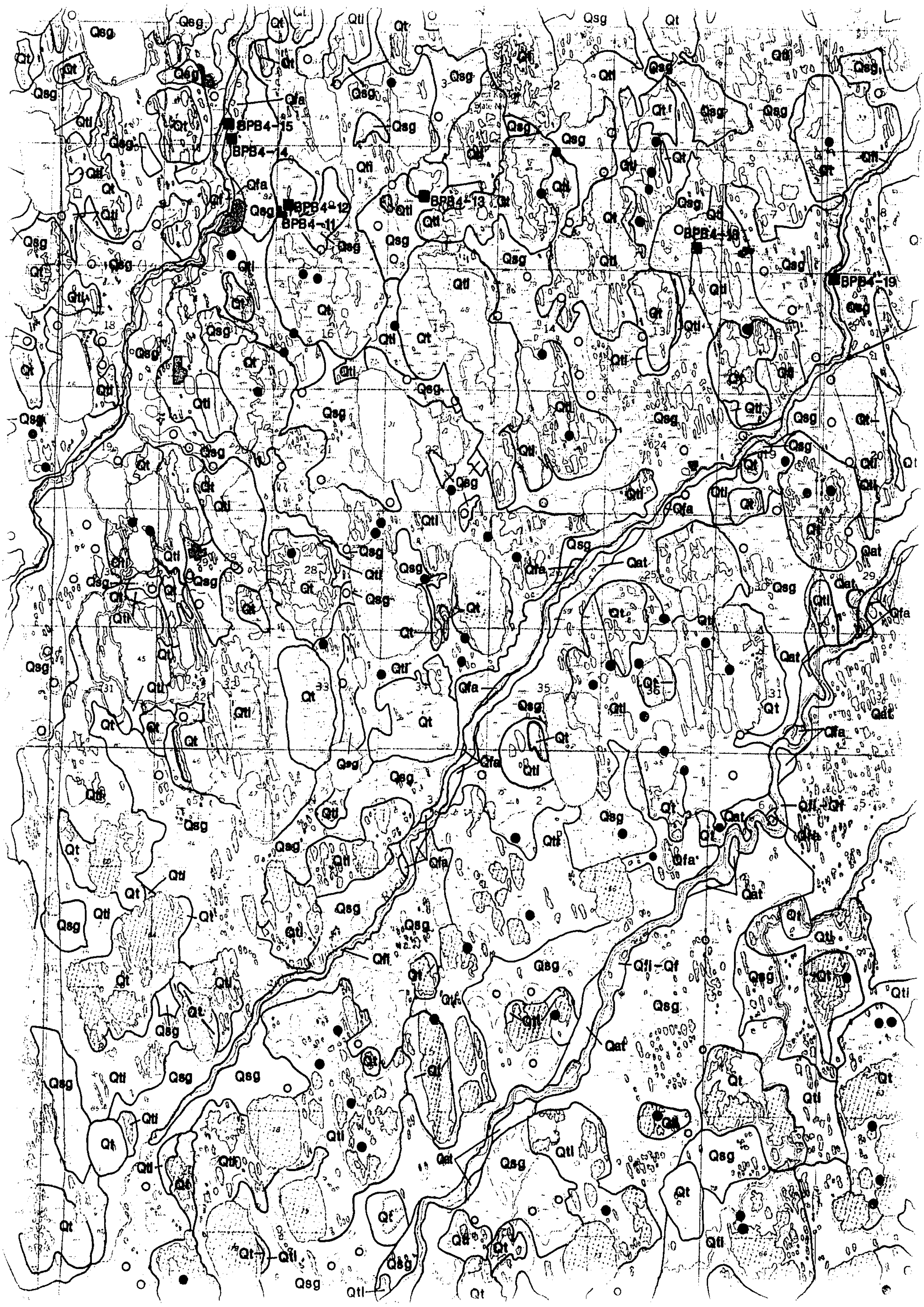

BPB4-7
BPB4-9
BPB4-37
BPB4-16
Qb
Qsm
Qsg
Qt
Qtl
Qfa

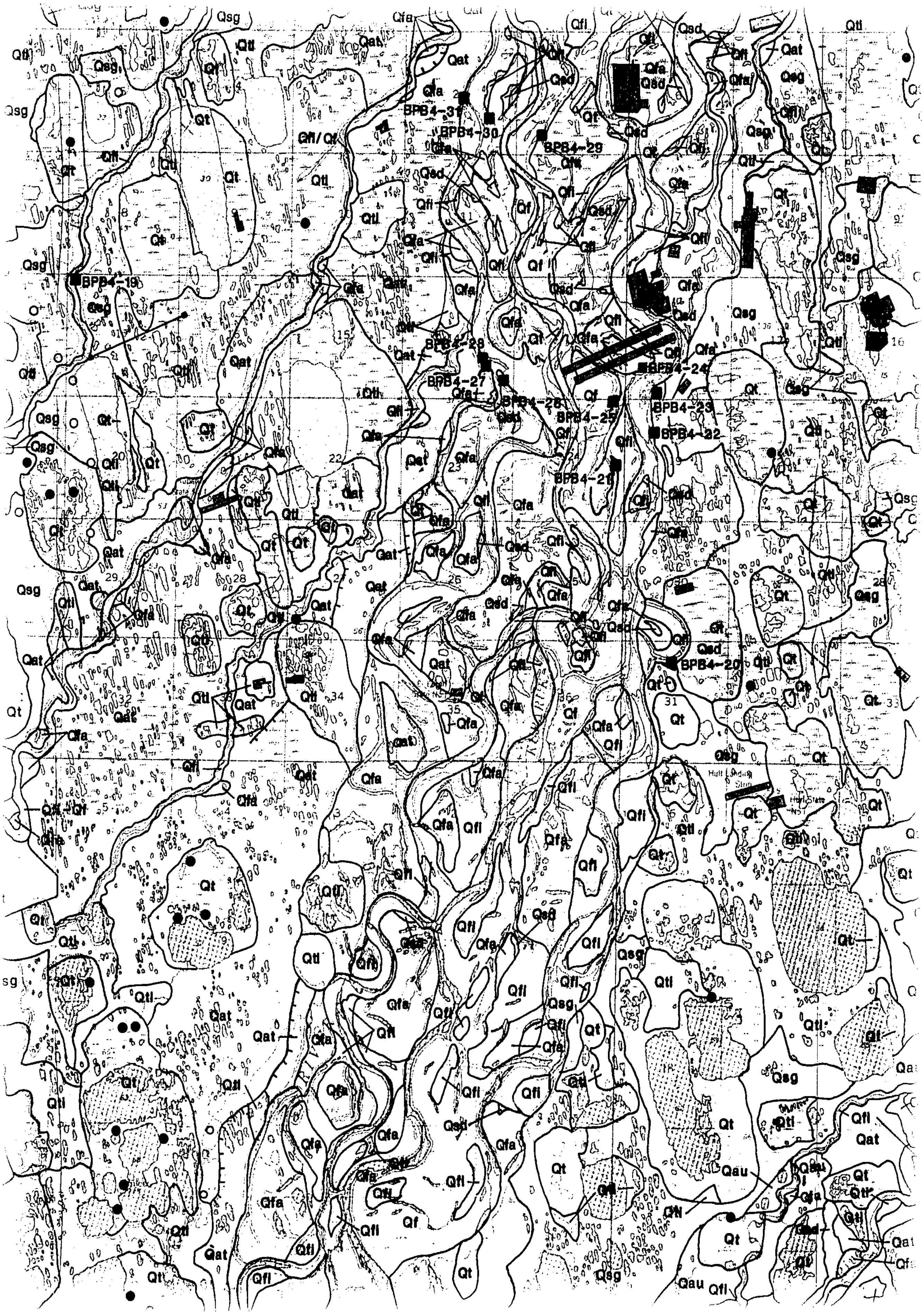

BPB4-9
Beechey Point
RETURN
ISLA
Long Island
BPB4-10
Back Point
G W Y D Y R B A Y
BPB4-33
BPB4-32

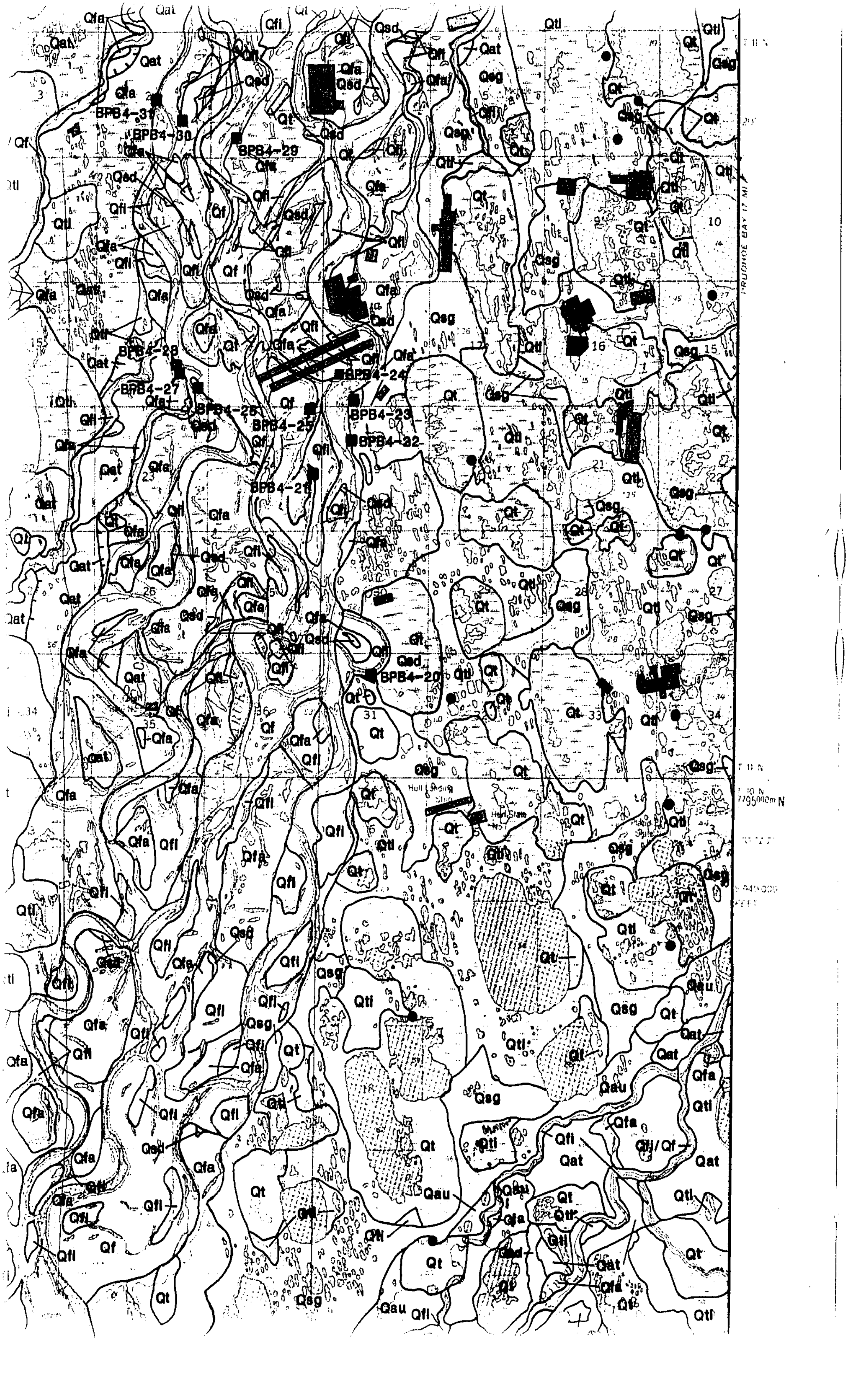

RETURN ISLANDS
Long Island
BPB4-10
Back Point
BAY
BPB4-33
BPB4-32

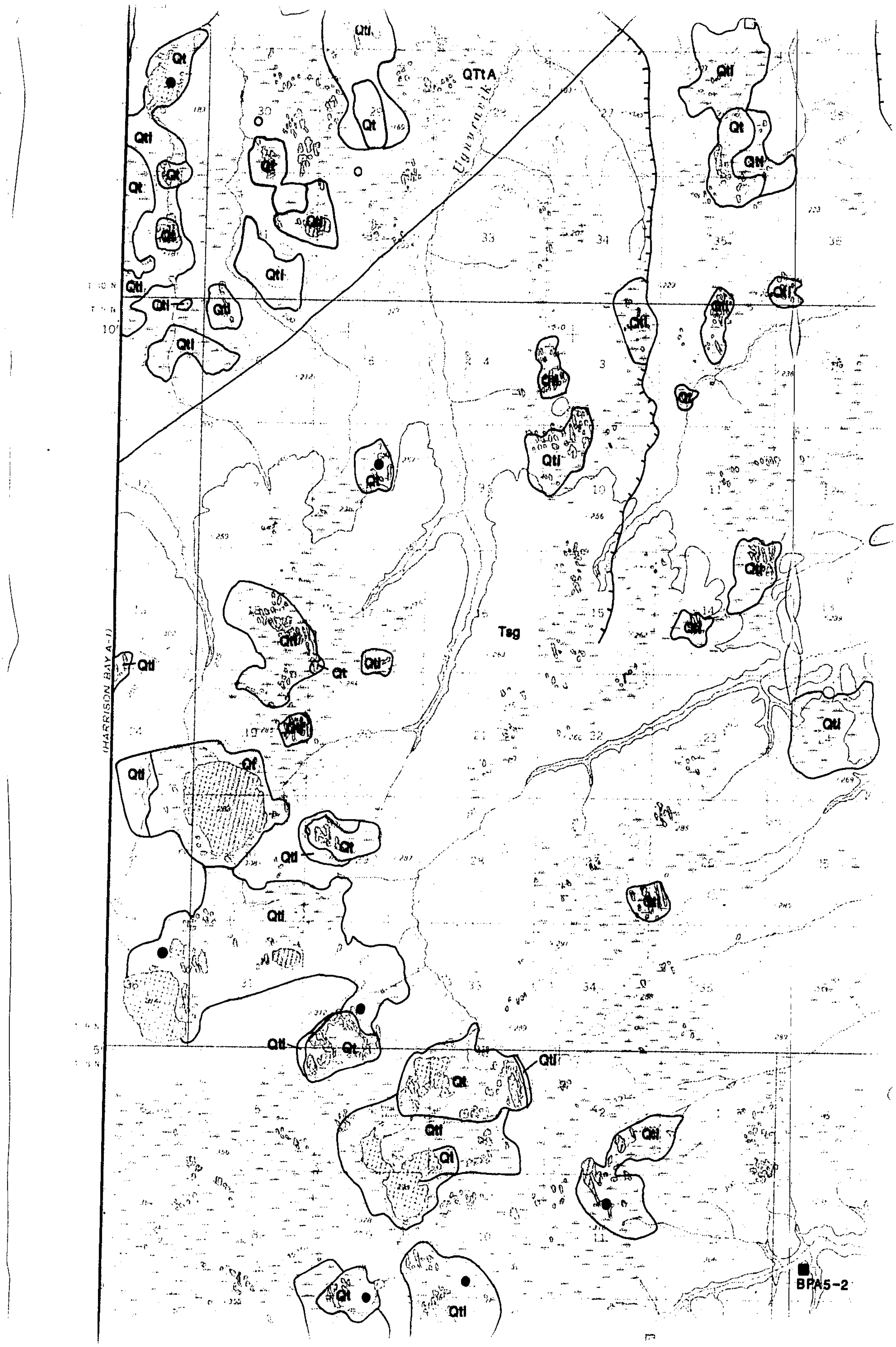

Qt
Qtl
Qsg
QTtA
5950000 FEET
T. 11 N.
T. 10 N.
796000m N.
20
27
35

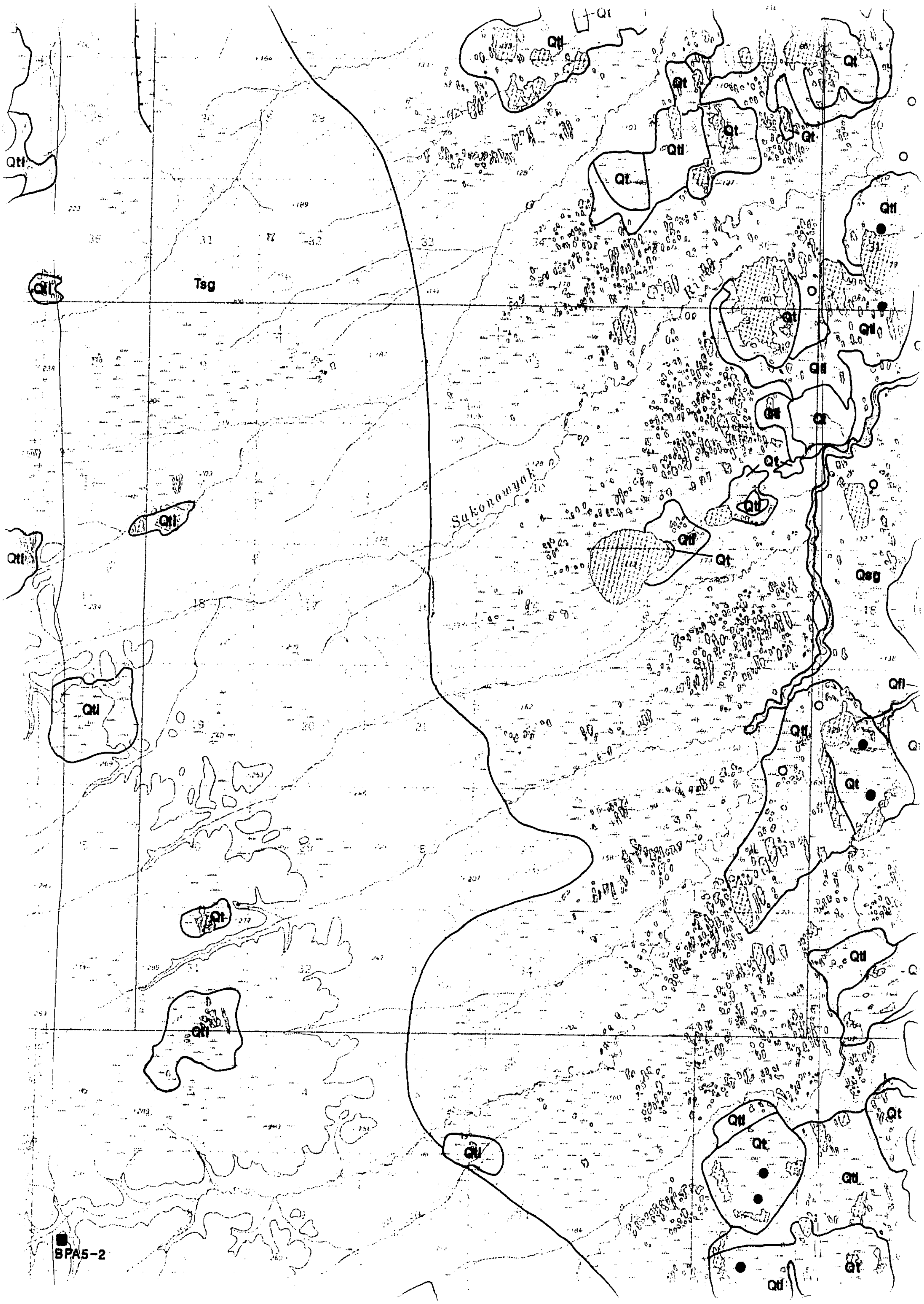

Qtl
Qt
Qsg
BPB5-30
BPB5
BPB5-33-36

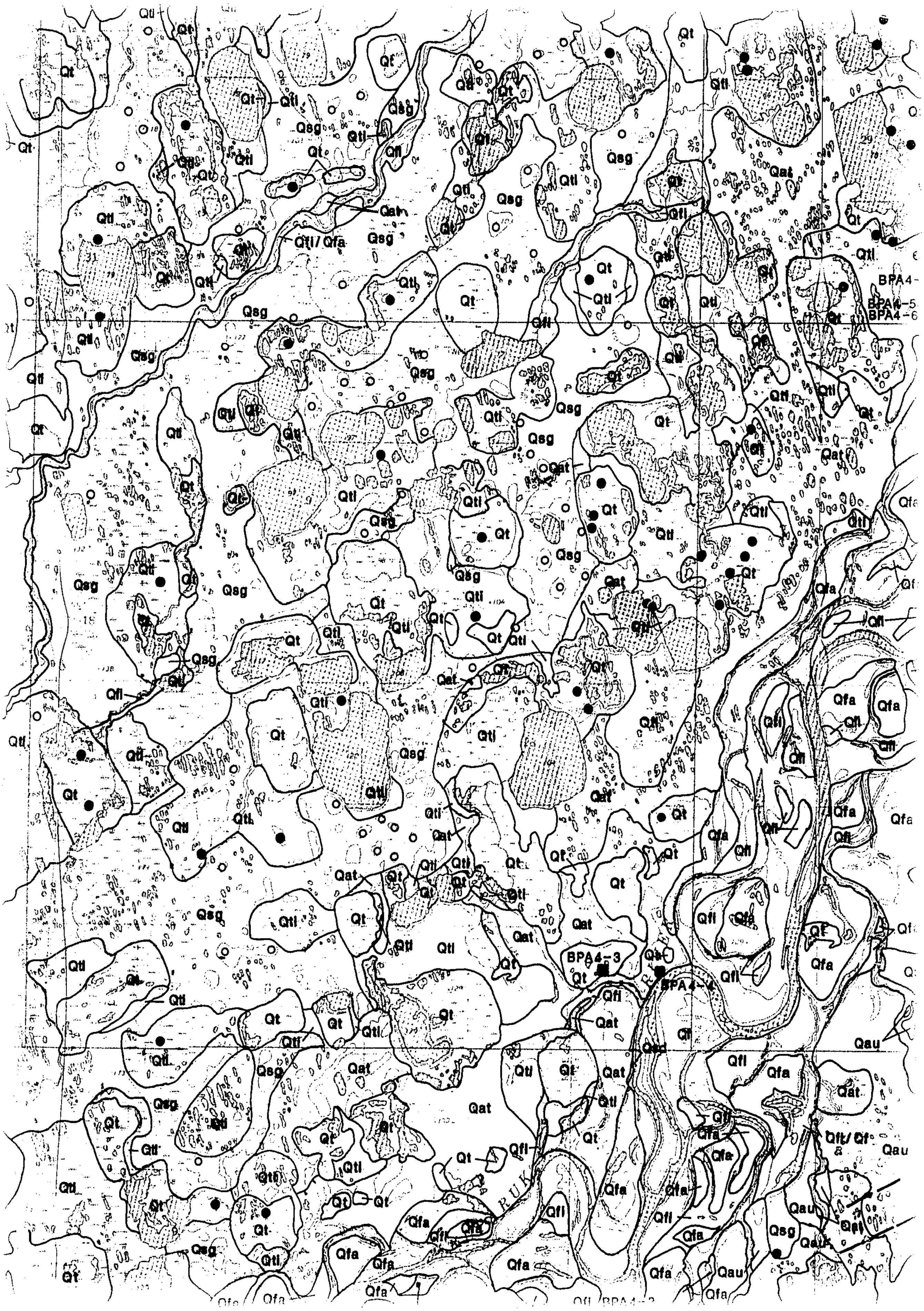

BPB4-15
BPB4-14
BPB4-12
BPB4-11
BPB4-13
BPB4-19
Qsg
Qt
Qtl
Qfa
Qat
Qfl
Qf
Qfl-Qf

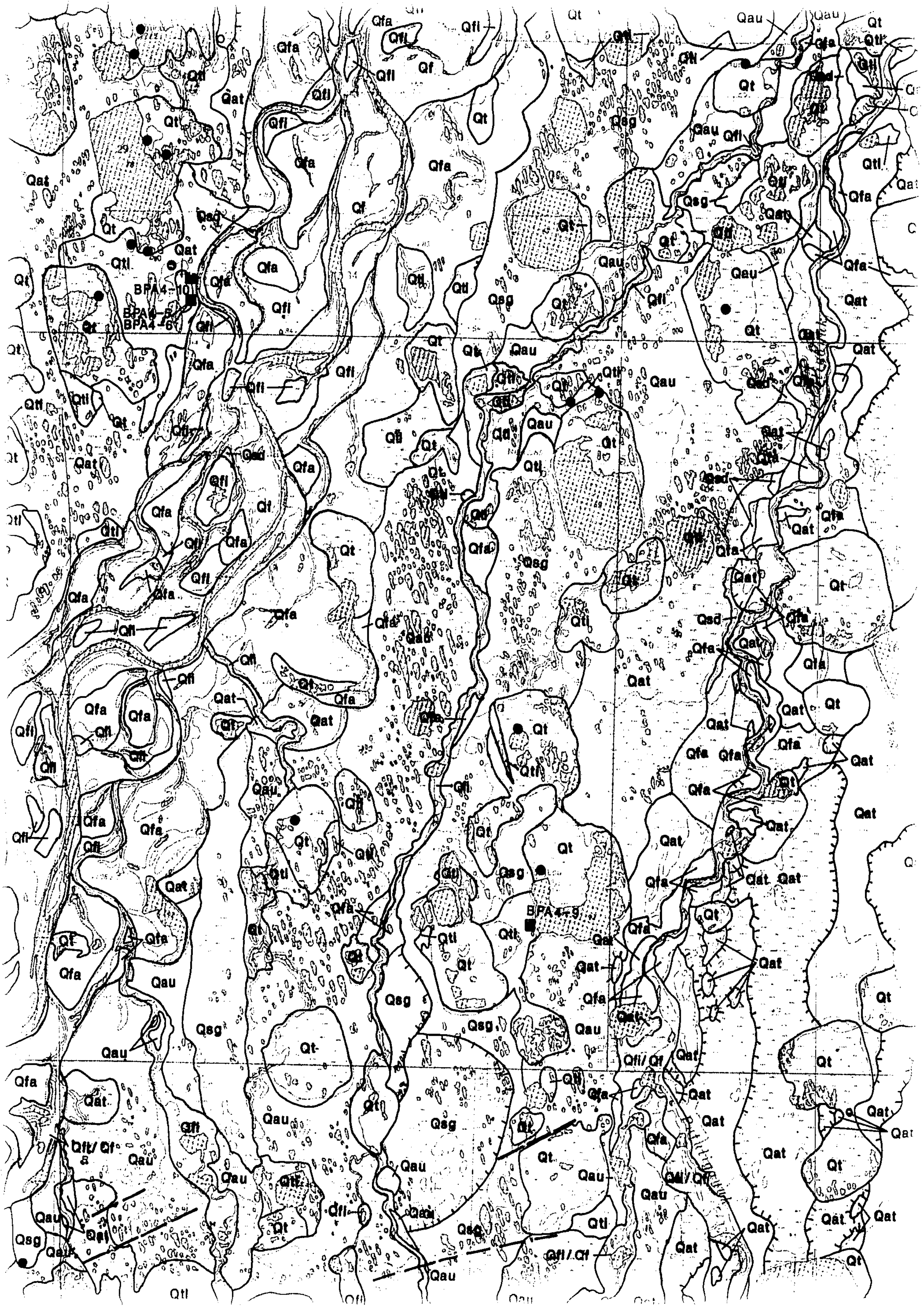

Qsg
Qtl
Qt
Qfa
Qat
Qsd
Qfl
Qf
Qau
BPB4-31
BPB4-30
BPB4-29
BPB4-19
BPB4-28
BPB4-27
BPB4-26
BPB4-25
BPB4-24
BPB4-23
BPB4-22
BPB4-21
BPB4-20

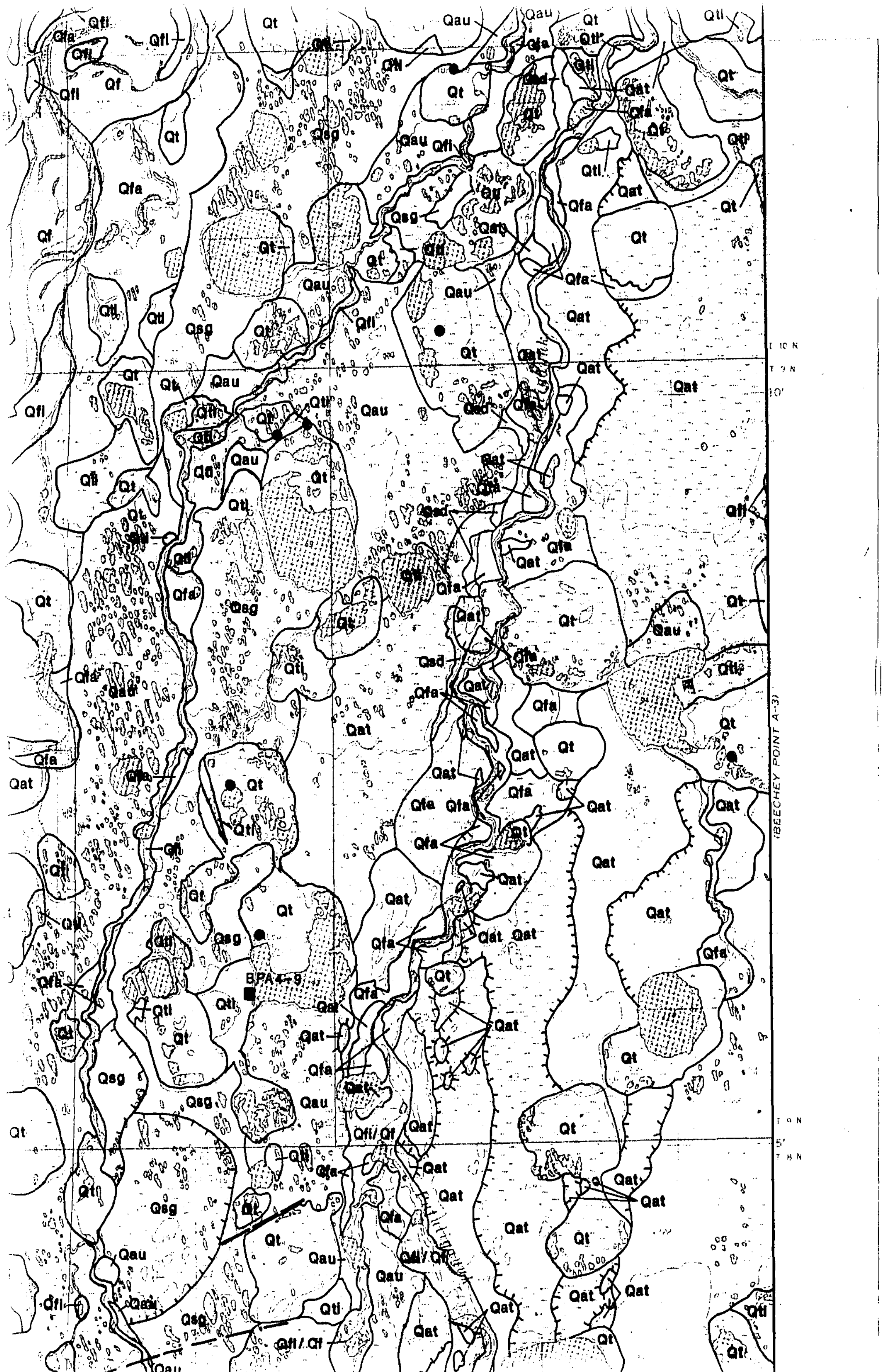

BPB4-31
BPB4-30
BPB4-29
BPB4-28
BPB4-27
BPB4-26
BPB4-25
BPB4-24
BPB4-23
BPB4-22
BPB4-21
BPB4-20
PRUDHOE BAY 17 MI
Qfa
Qat
Qfl
Qsd
Qf
Qt
Qtl
Qsg
Qau
Qtl/Qf

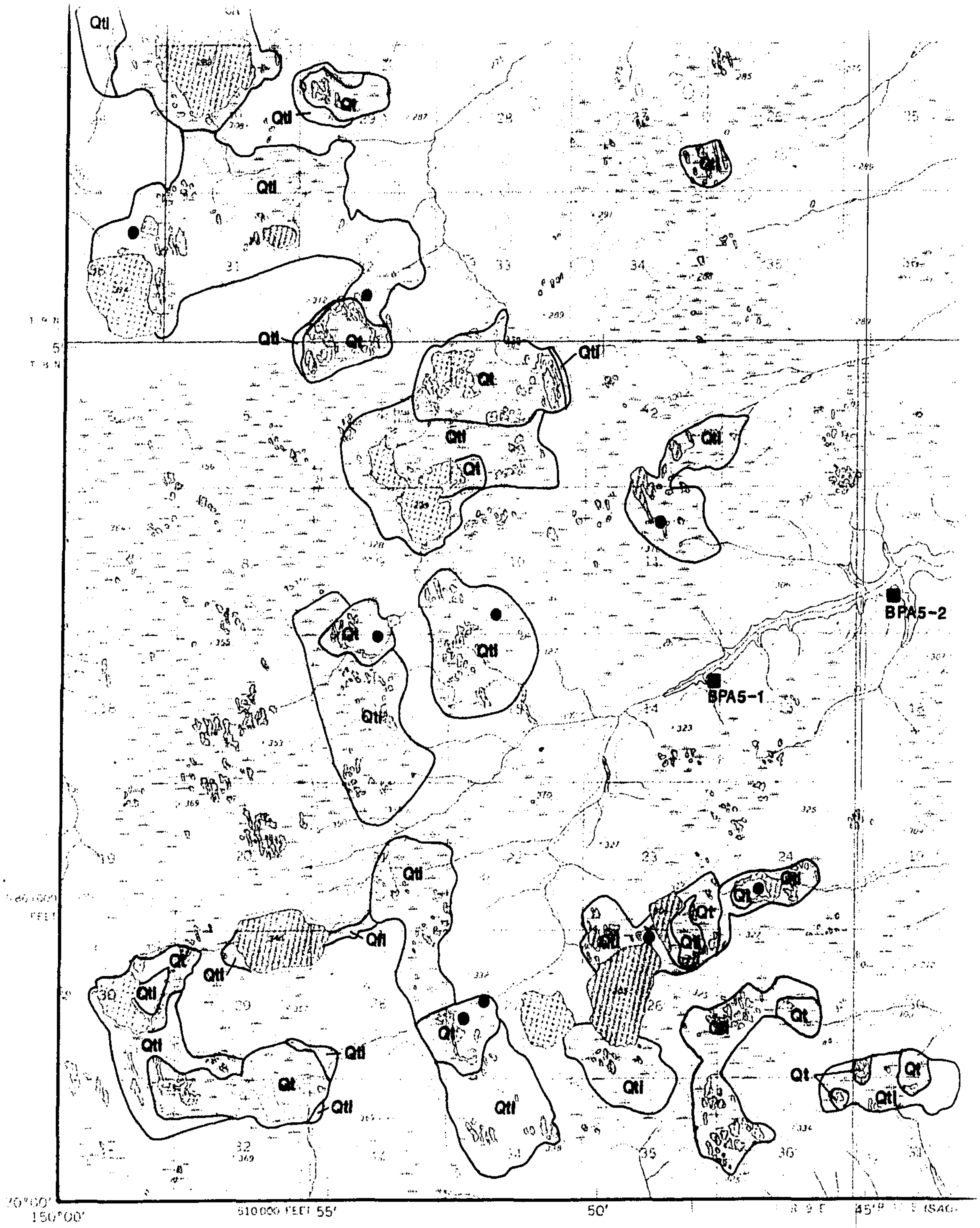

QTtA
Qt
Qtl
Tsg
Qf
(HARRISON BAY A-1)
Ugnuravik
BPA5-2


Qtl
Qt
Tsg
Sakonowyak River
Qsg
Qfl
BPA5-2


Qt
Qtl
Qsg
Qat
Qfl
Qfa
Qau
Qtl/Qfa
BPA4-3
BPA4-4
BPA4-5
BPA4-6

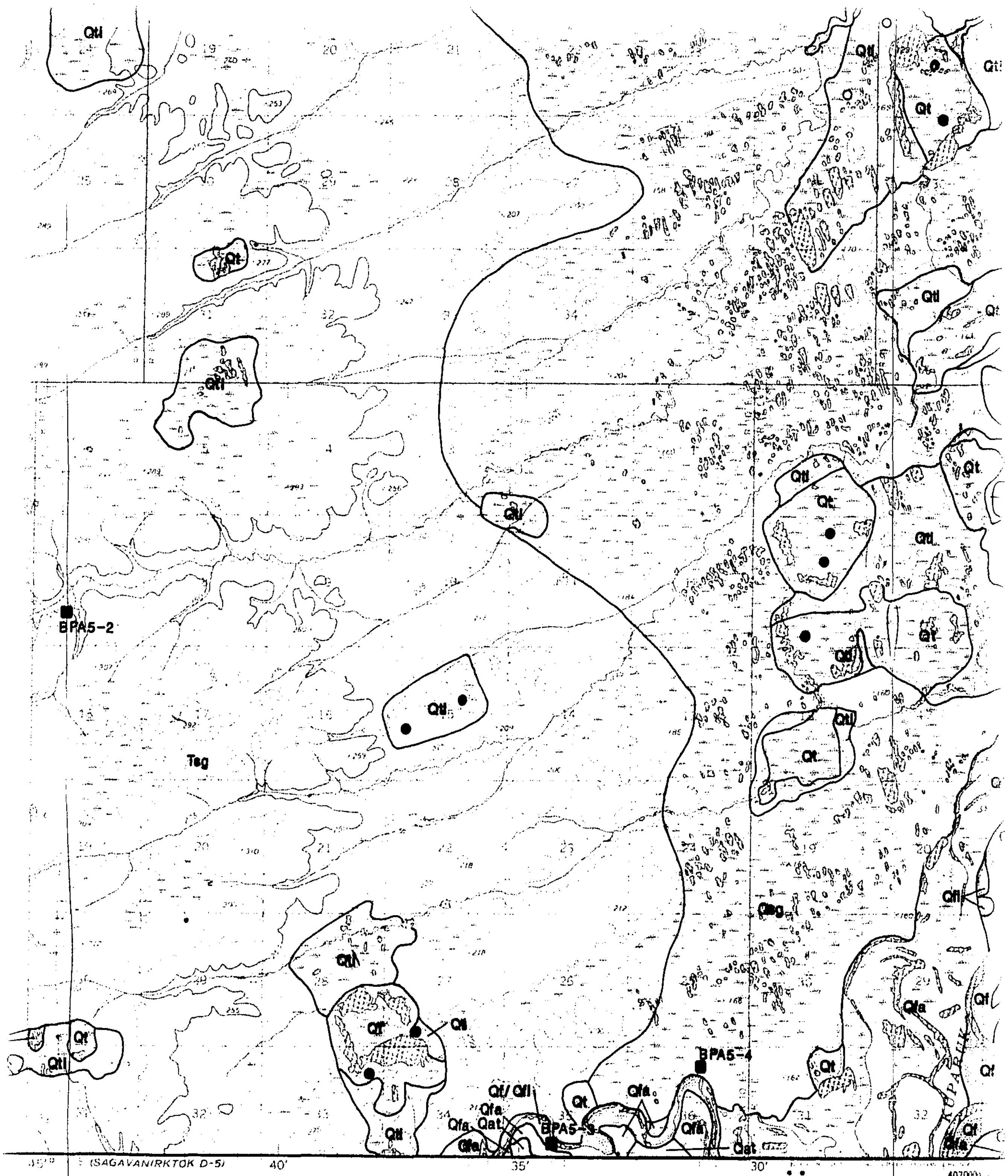

BPA4-10
BPA4-8
BPA4-6
BPA4-9
Qfa
Qfl
Qf
Qt
Qtl
Qat
Qau
Qsg
Qsd
Qfl/Qf


Qt
Qat
Qau
Qfa
Qfl
Qtl
Qsg
Qsd
Qf
Qfl/Qf
BPA4-9
(BEECHEY POINT A-3)
T 10 N
T 9 N
10'
T 9 N
5'
T 8 N



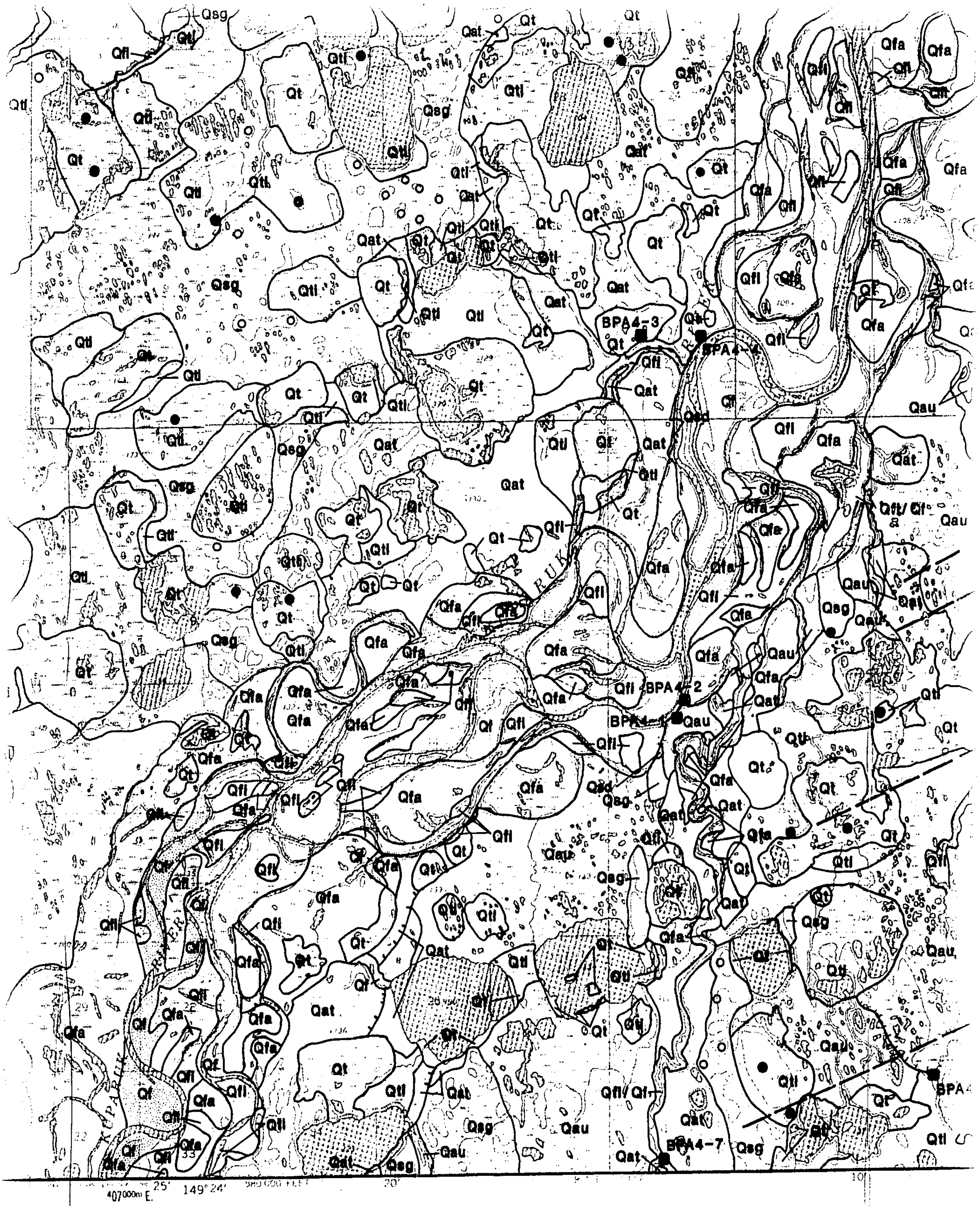
GEOLOGY MAPPED BY S.E. RAWLINSON AND S.B. HARDY, 1981-1982; RAWLINSON AND D.R. HICKMOTT, 1983-1985; AND RAWLINSON 1988-1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY BEECHEY POINT A-4, 1955, REVISED 1981; A-5, 1955; B-4, 1955, REVISED 1975; B-5, 1955; C-4, 1955; AND C-5, 1955, REVISED 1981.

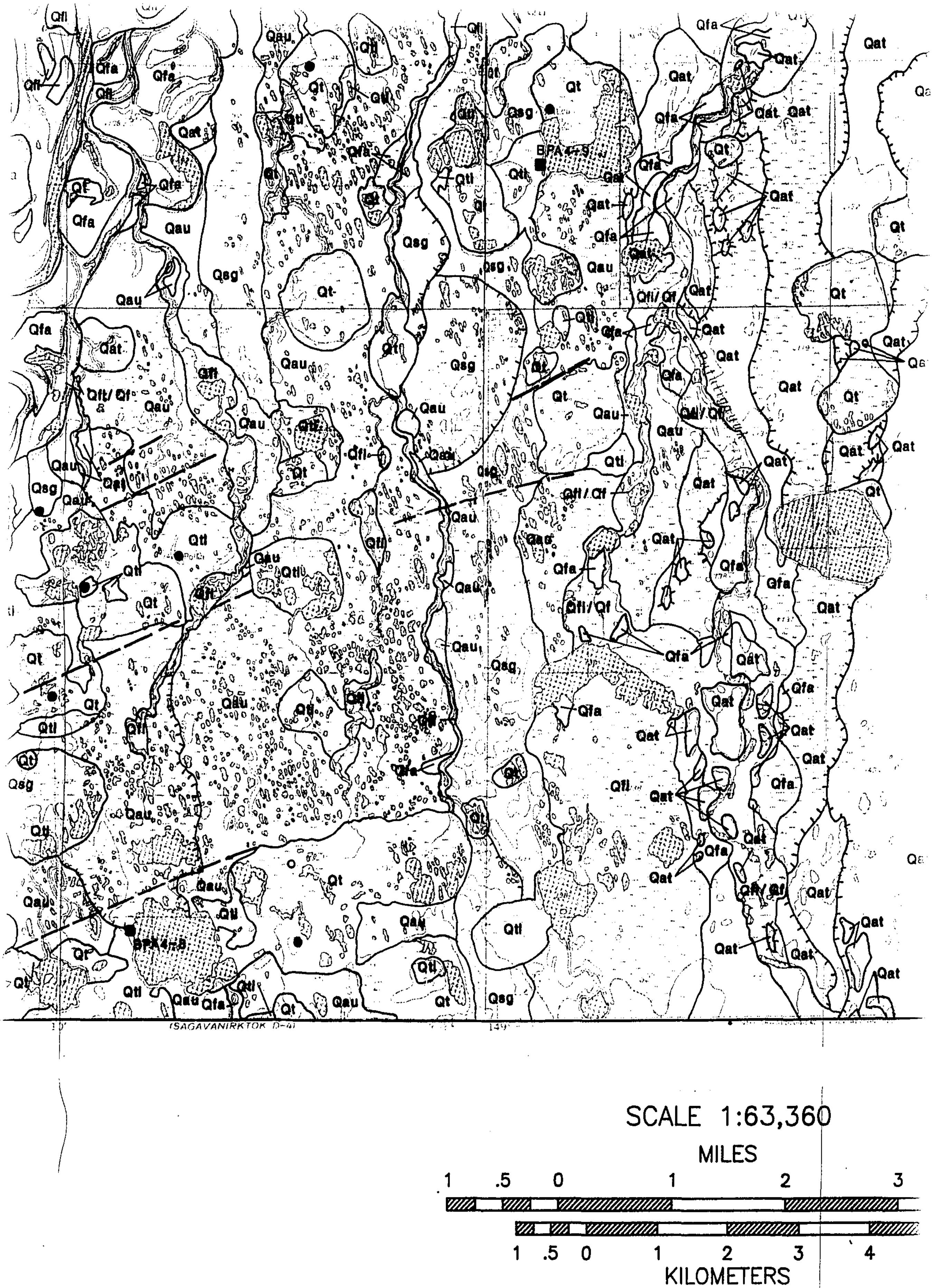


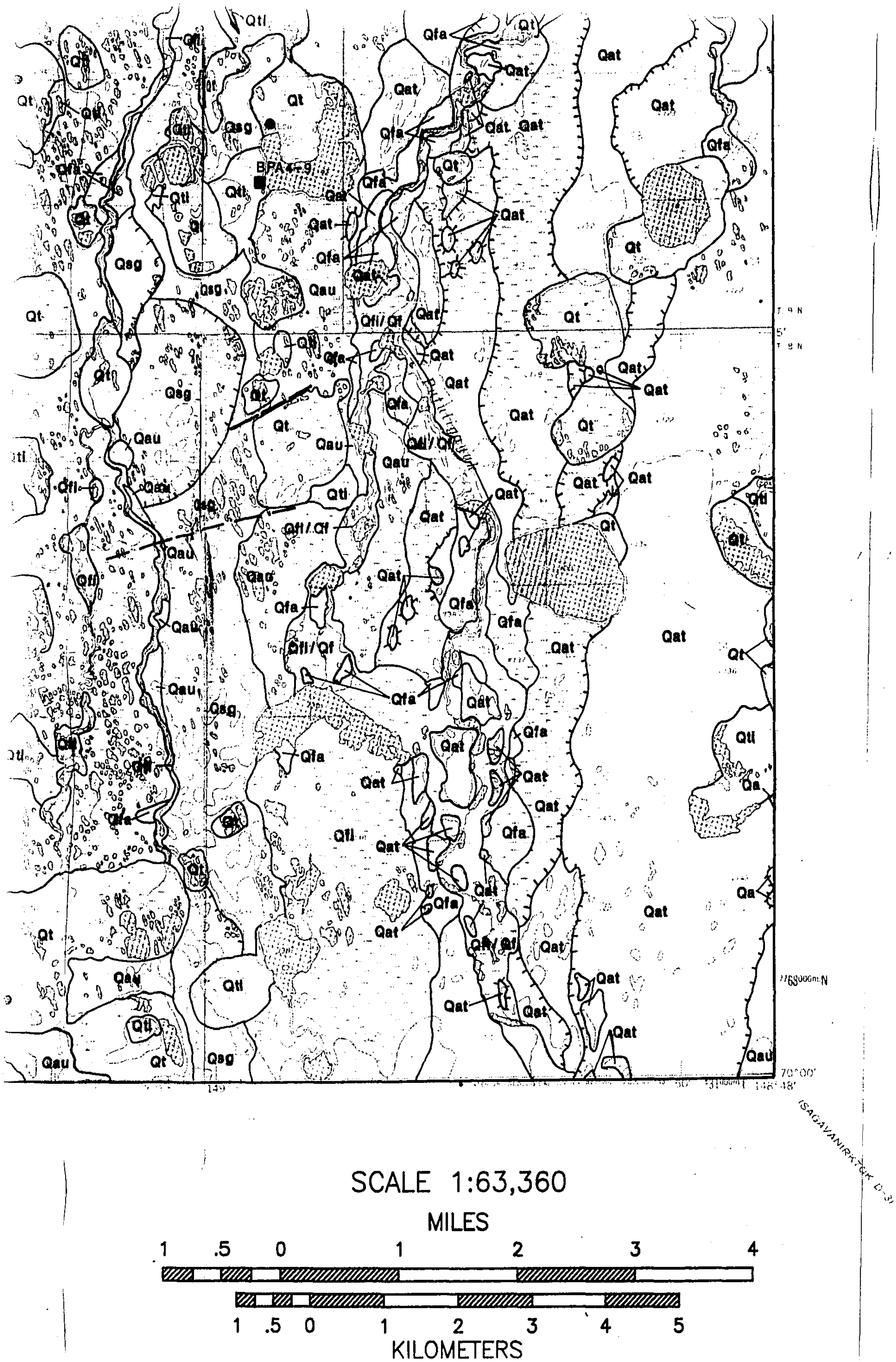
A-5, 1955;

SURFICIAL-GEOLOGY MAP OF
B-4, B-5, C-4, AND C-



Y MAP OF THE BEECHEY POINT A–4, A–5,
4, AND C–5 QUADRANGLES, ALASKA


Qfl
Qfa
Qat
Qau
Qsg
Qt
Qtl
Qfl/Qf
BPA4-5
BPA4-8
(SAGAVANIRKTOK D-4)
149°
SCALE 1:63,360
MILES
1 .5 0 1 2 3
1 .5 0 1 2 3 4
KILOMETERS


(SAGAVANIRKTOK D-3)
SCALE 1:63,360
MILES
1 .5 0 1 2 3 4
1 .5 0 1 2 3 4 5
KILOMETERS

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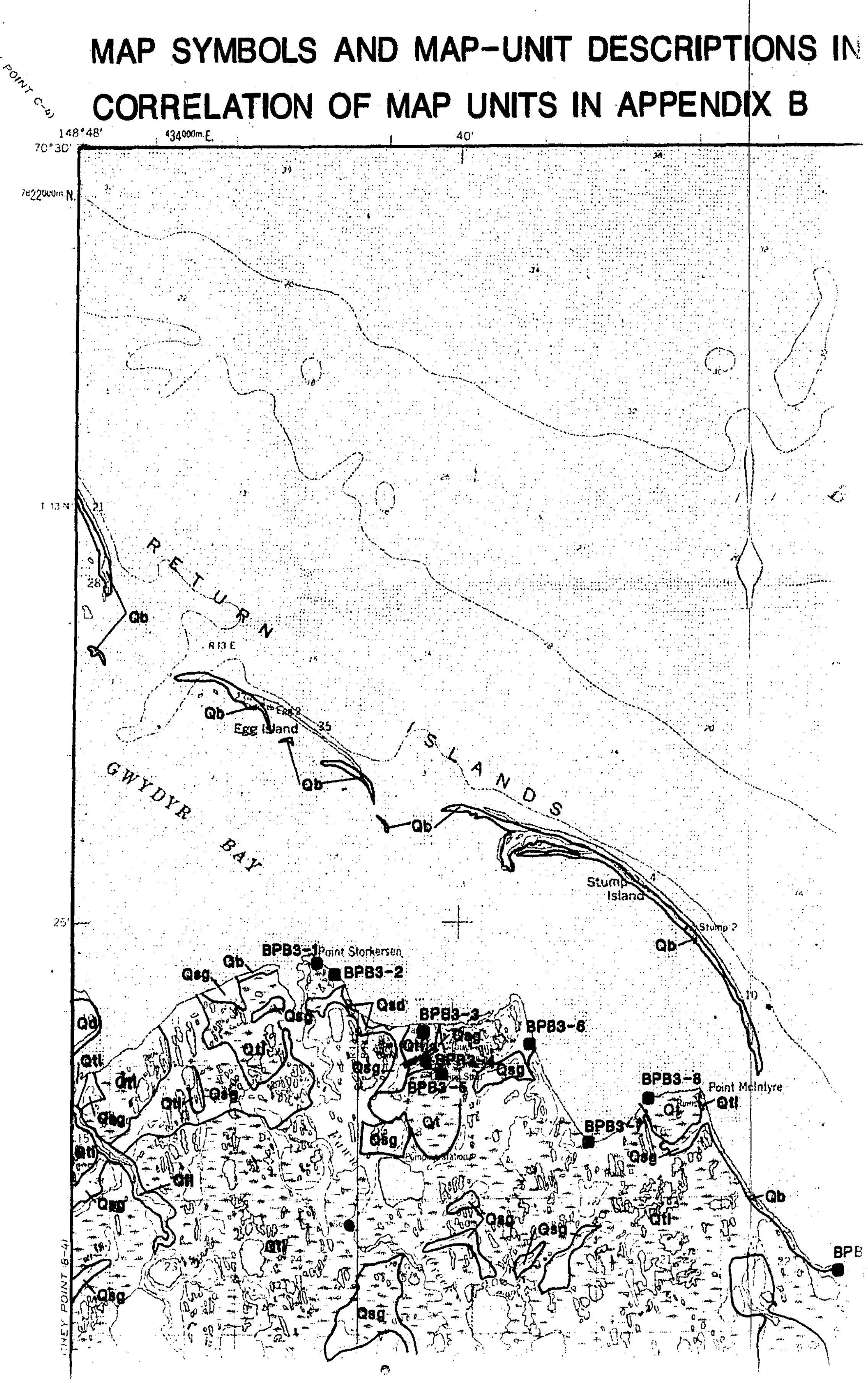
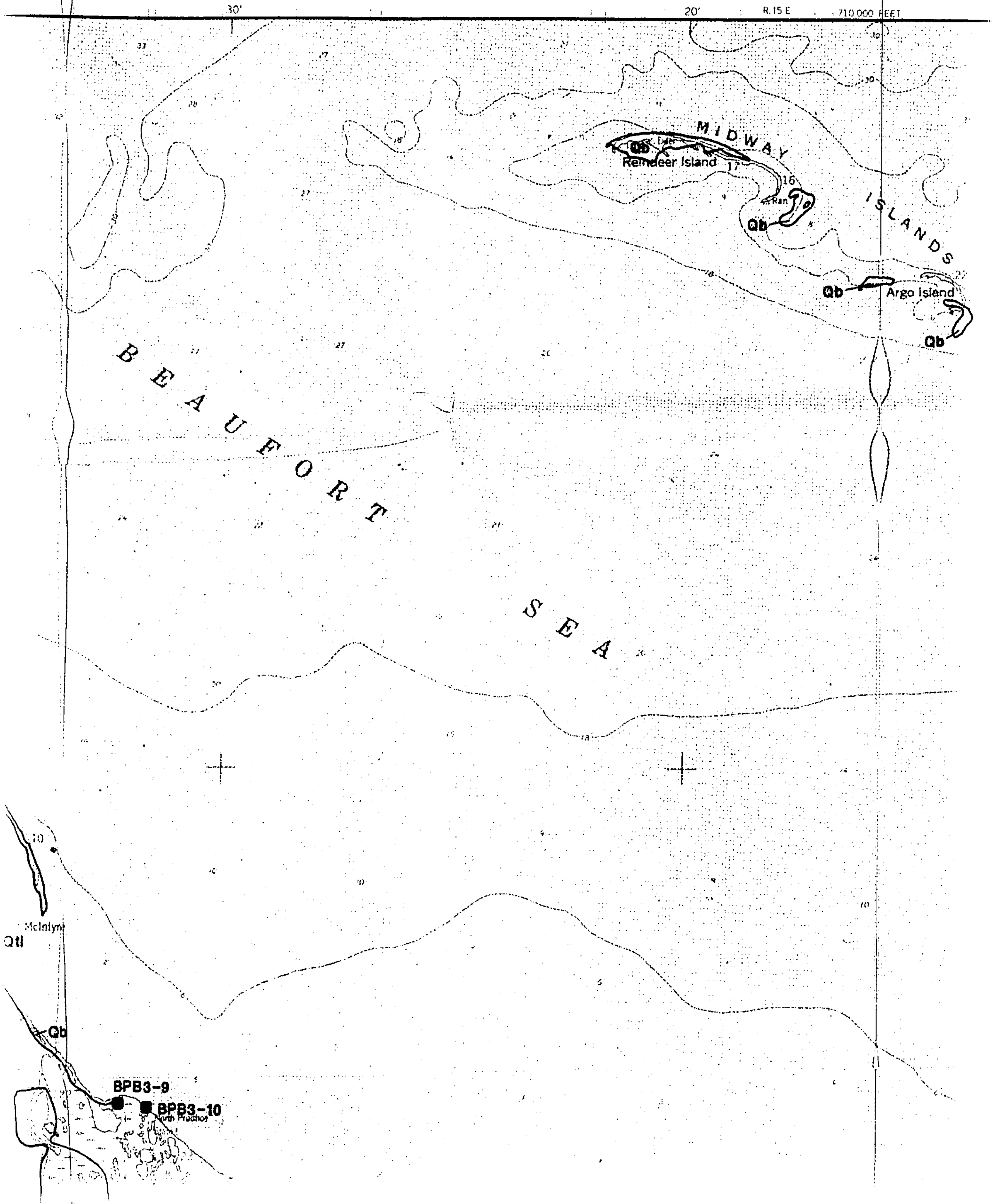
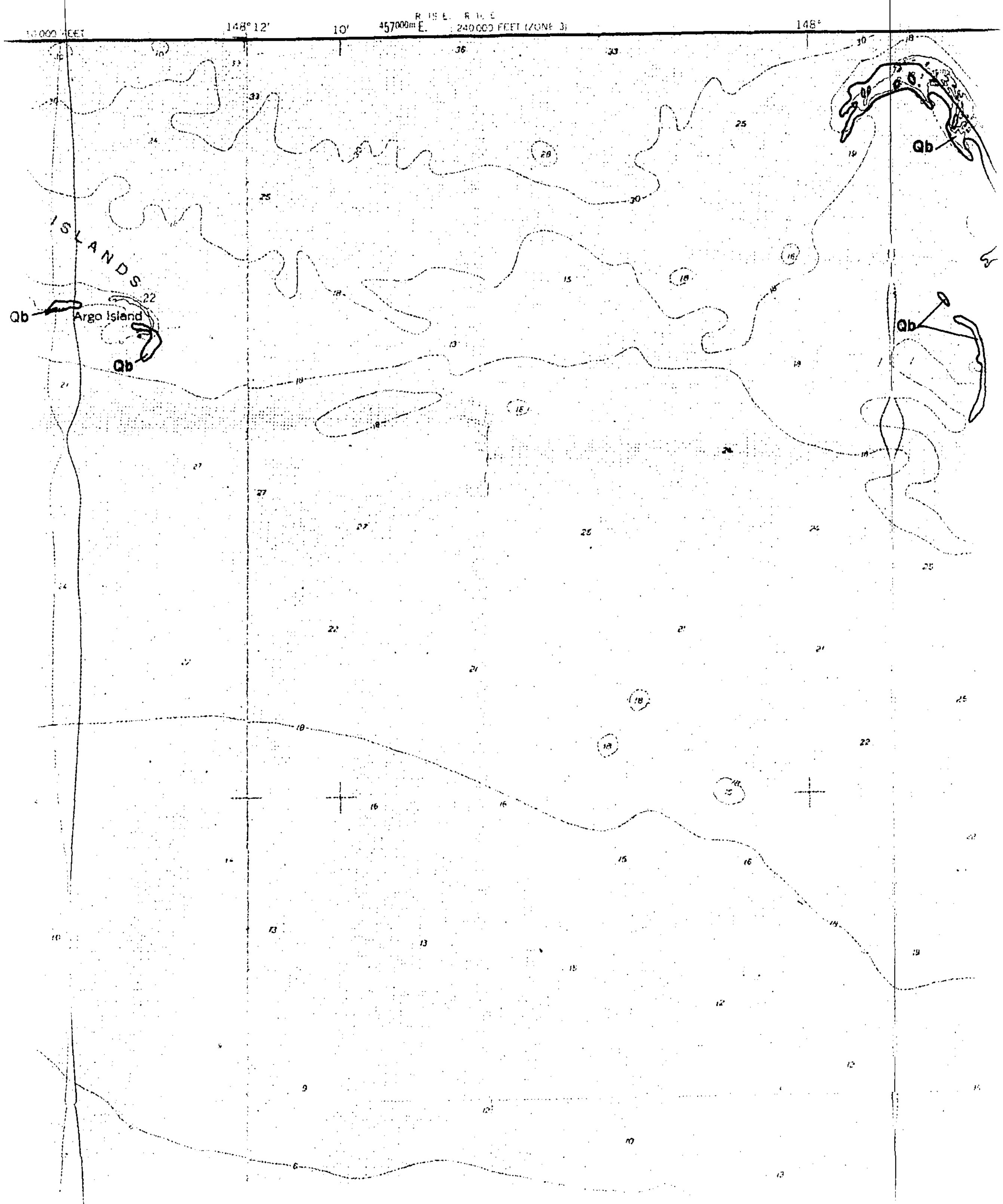
MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN
CORRELATION OF MAP UNITS IN APPENDIX B



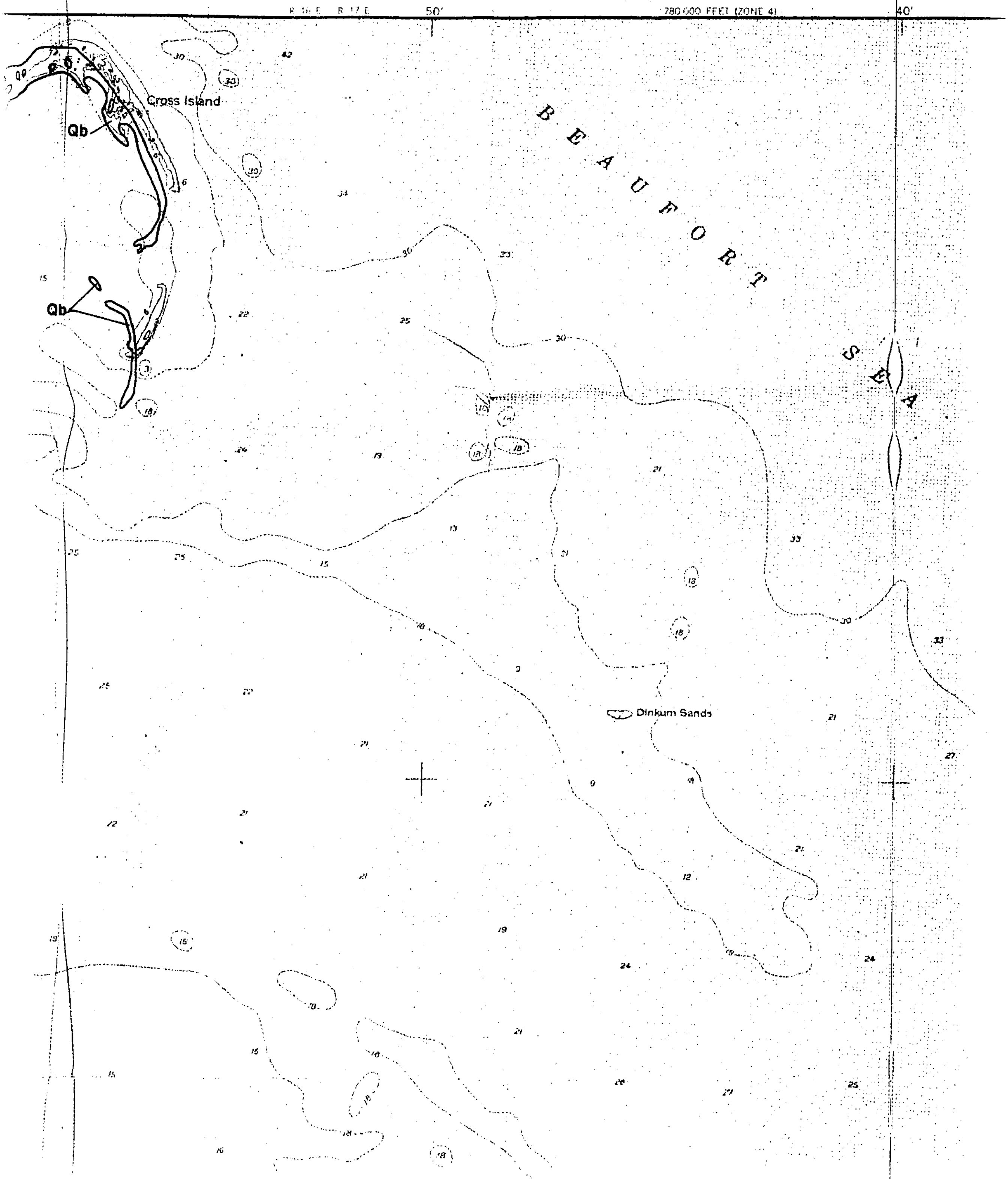
ᑭTIONS IN APPENDIX A

NDIX B

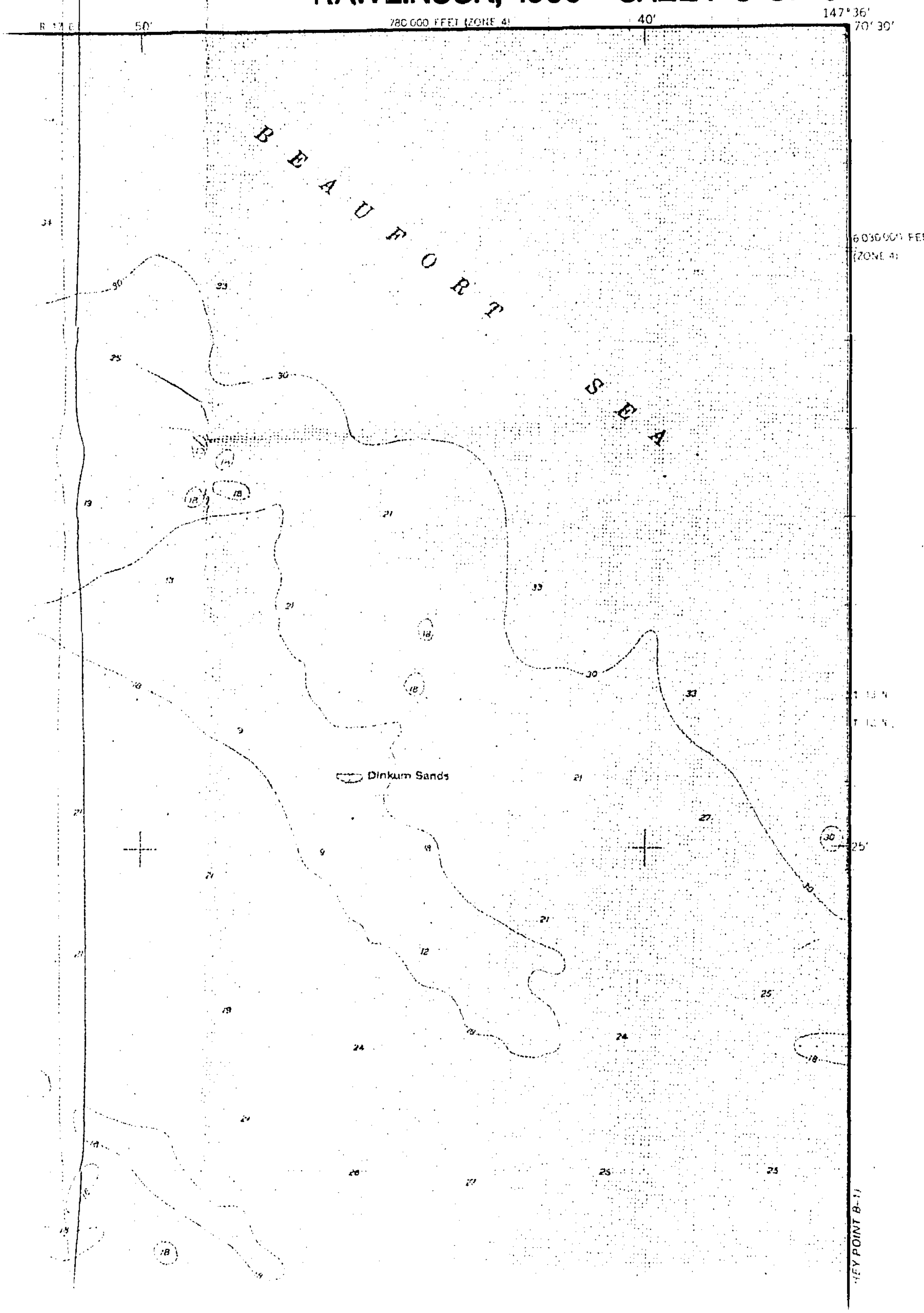


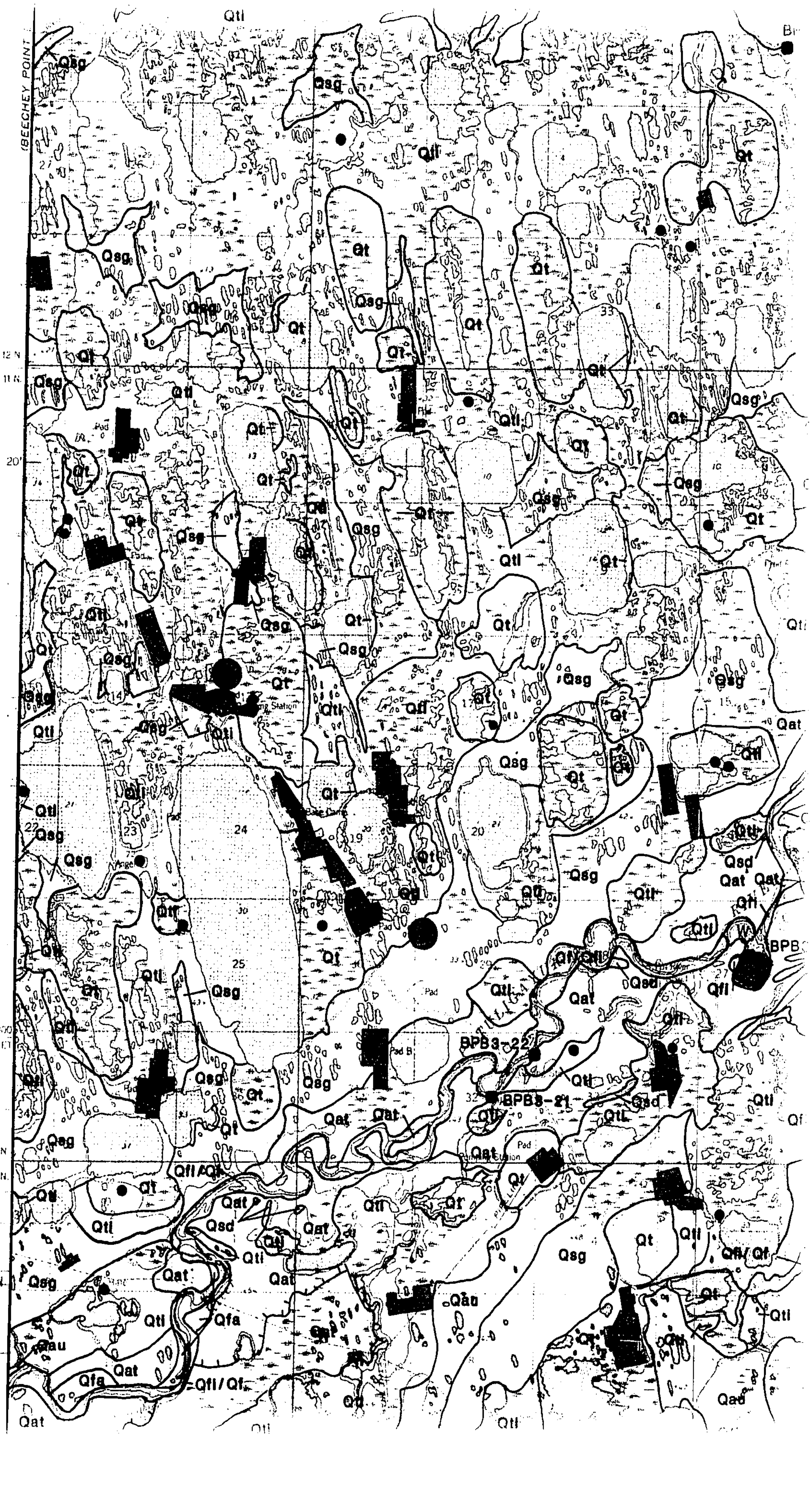

148° 12'
10'
148°
I S L A N D S
Argo Island
Qb
Qb
Qb
Qb
22

RAWLINSON, 1990 SHEET 3

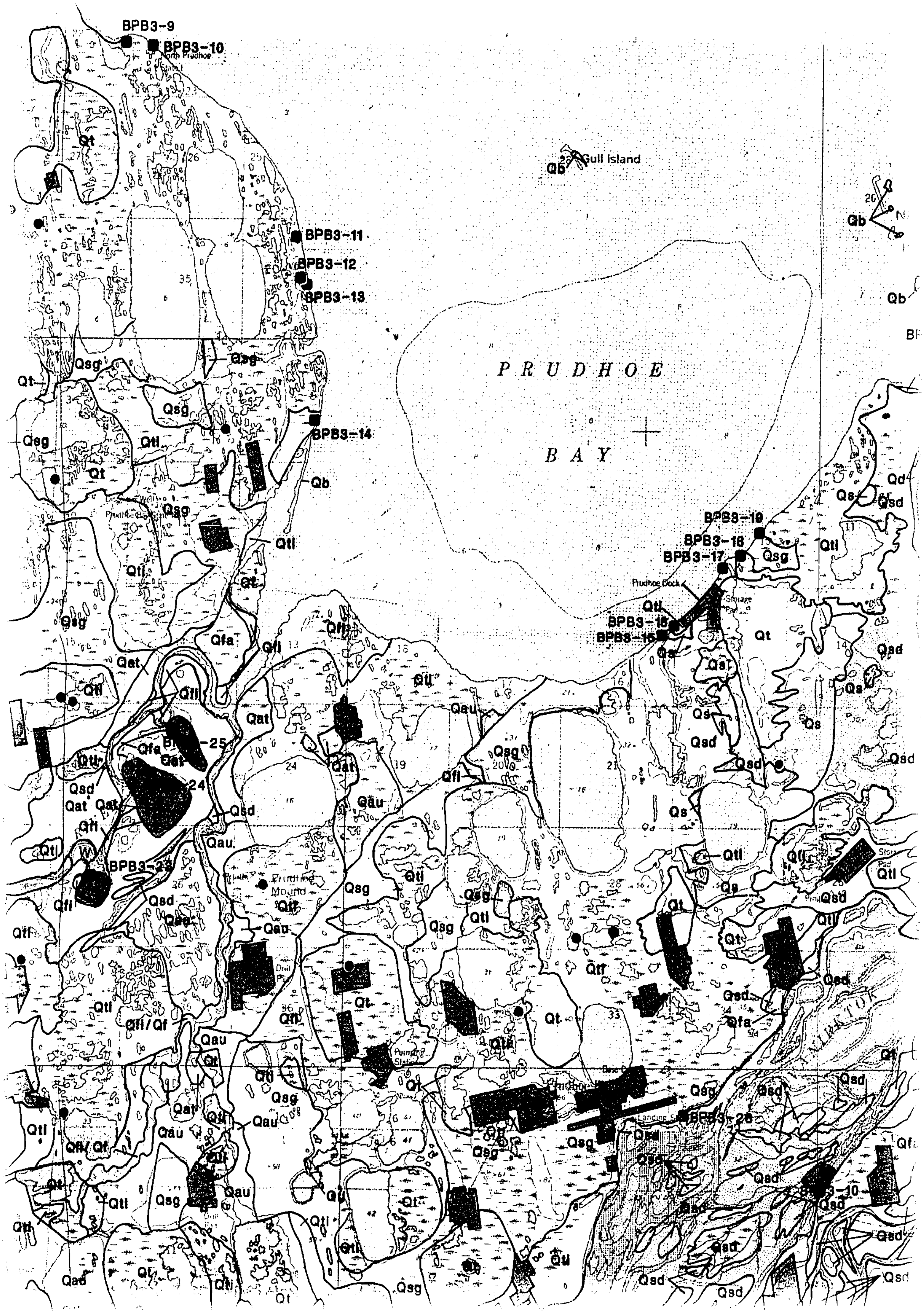


RAWLINSON, 1990 SHEET 3 OF 6



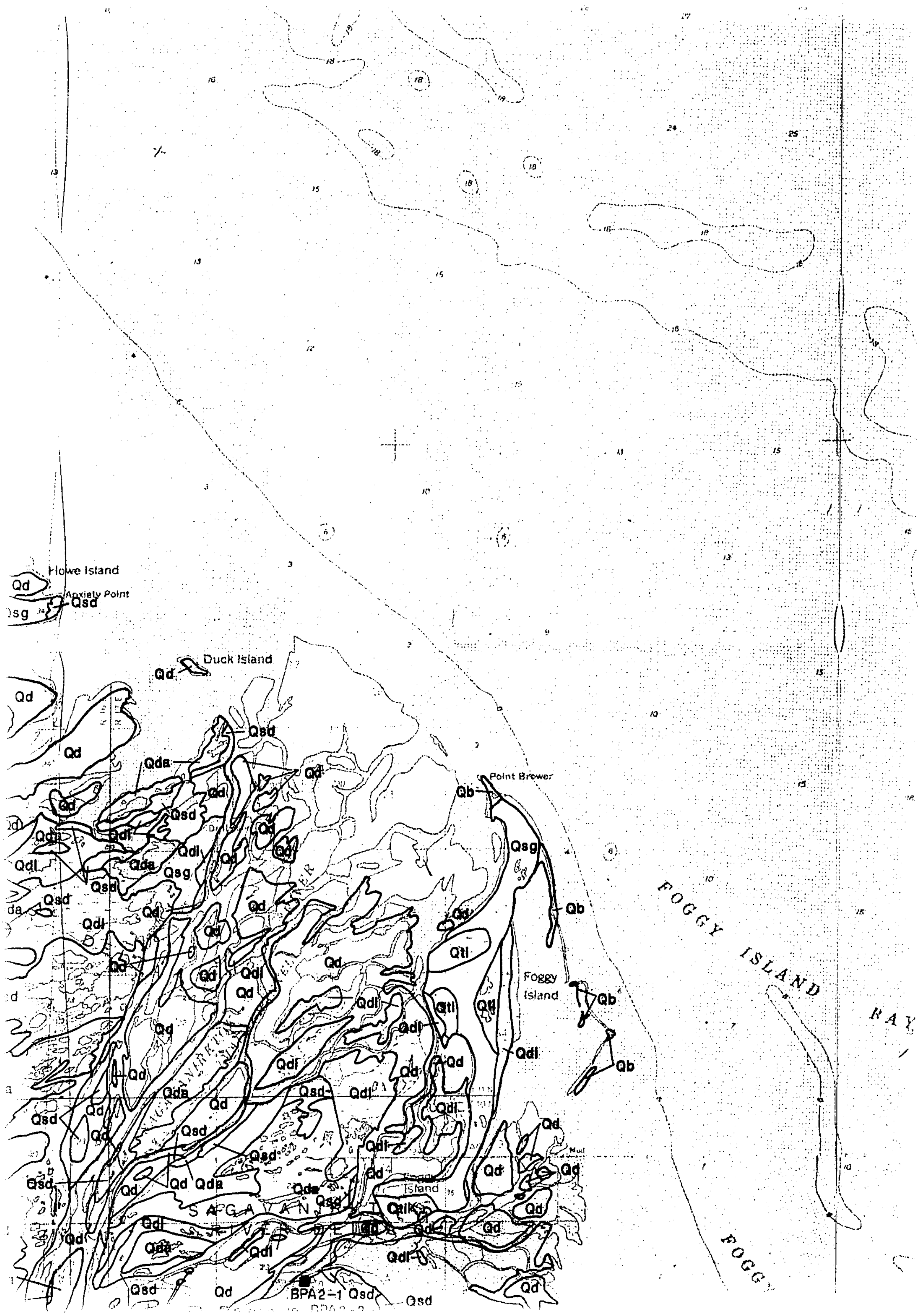


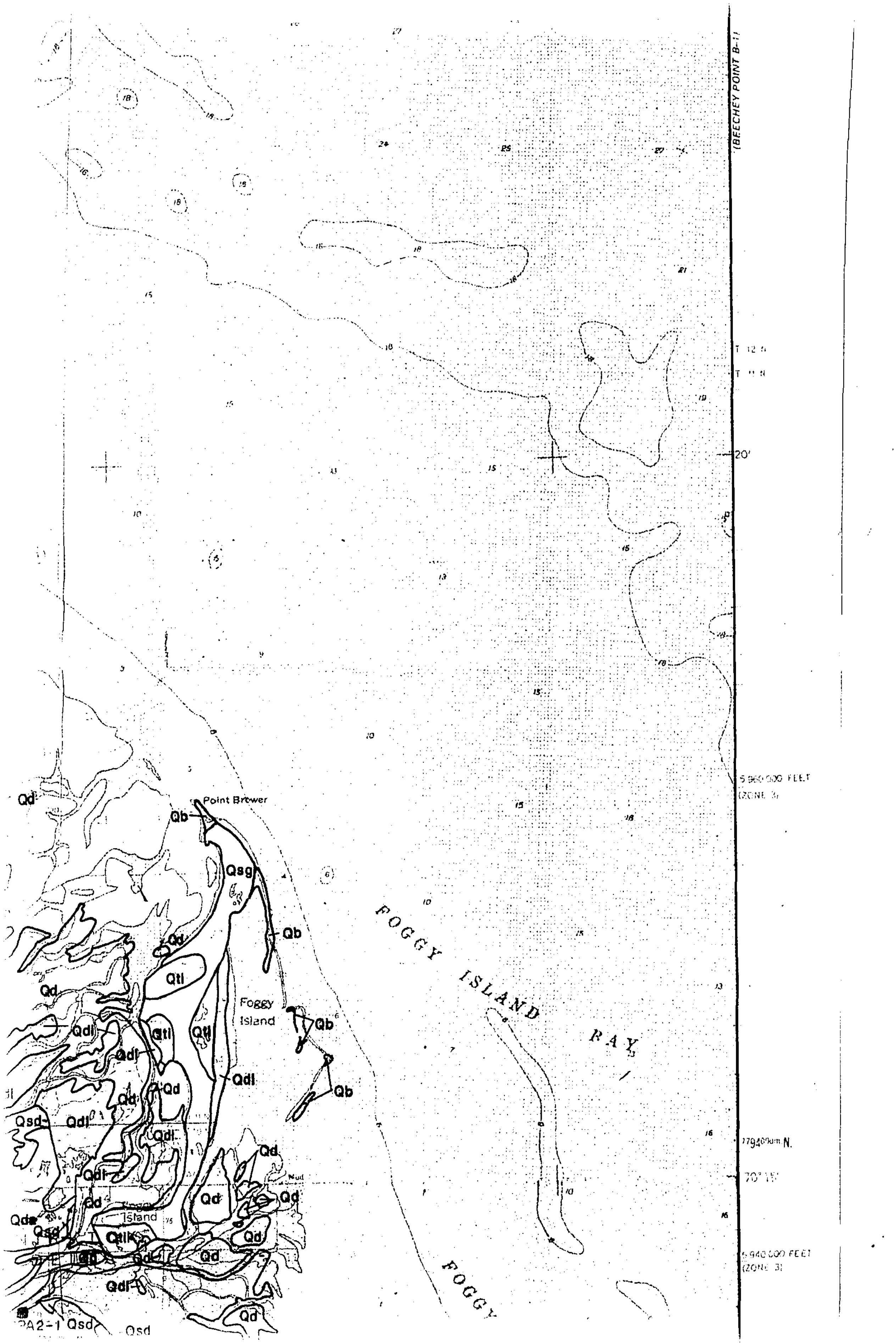
BEECHEY POINT
T 12 N
T 11 N
T 10 N
20'
Qtl
Qsg
Qt
Qat
Qsd
Qfa
Qau
Qfl/Qf
Pad
Pad B
BPB3-22
BPB3-21
5 950 000 FEET
794000m N.

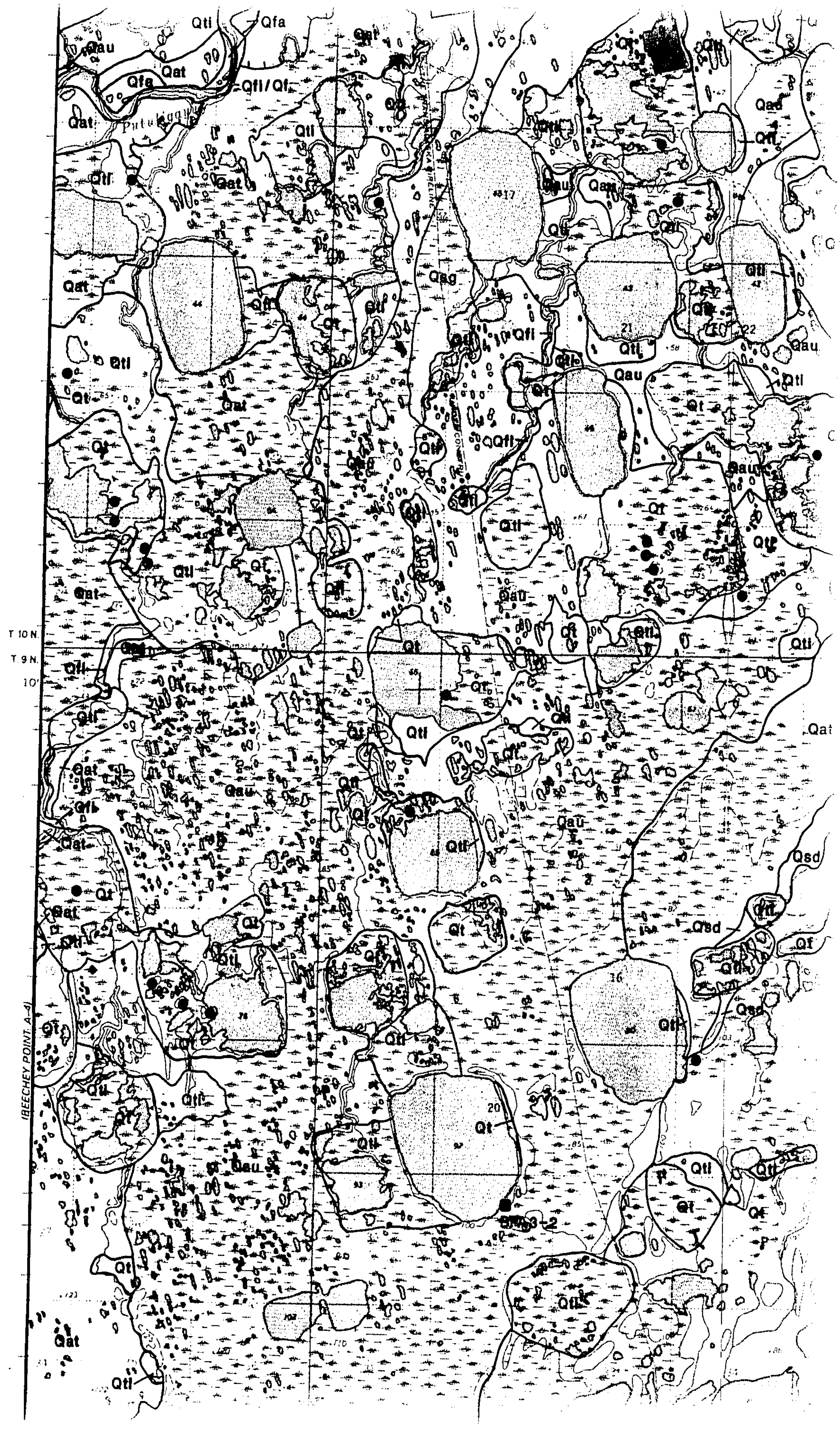


BPB3-9
BPB3-10
Gull Island
BPB3-11
BPB3-12
BPB3-13
PRUDHOE
BAY
BPB3-14
BPB3-19
BPB3-18
BPB3-17
Prudhoe Dock
BPB3-16
BPB3-15
Prudhoe Mound
Pumping Station

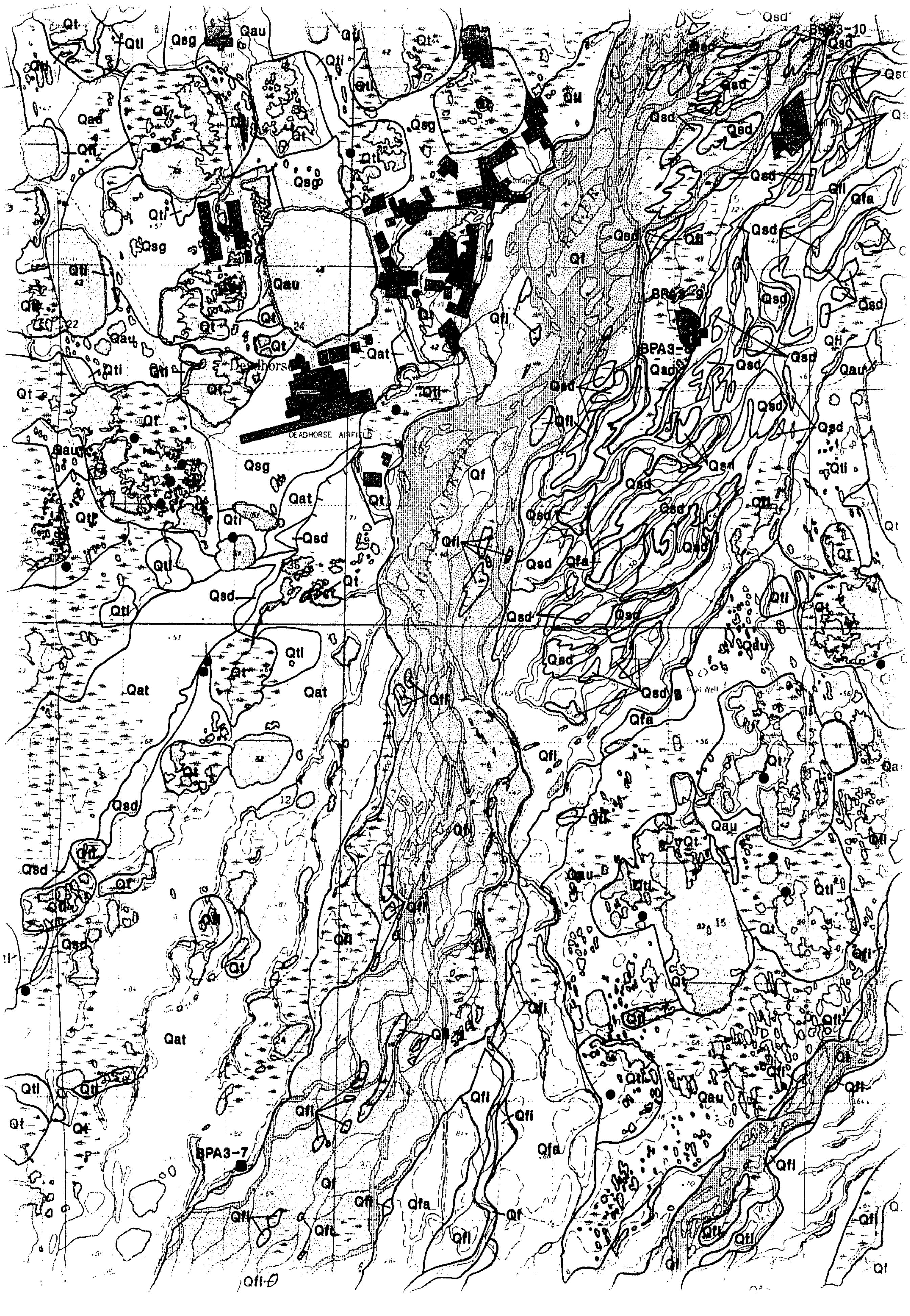

Niakuk
Islands
Qb
Heald Point
BPB3-27
T12 N
Qd
Qsg
Qtl
Qda
Qf
BPR2-1
Qdl
Qsd
Howe Island
Anxiety Point
Qs
BPB2-2
Qfl
Qau
Qt
BPB2-3
Qfa
Drill Hole

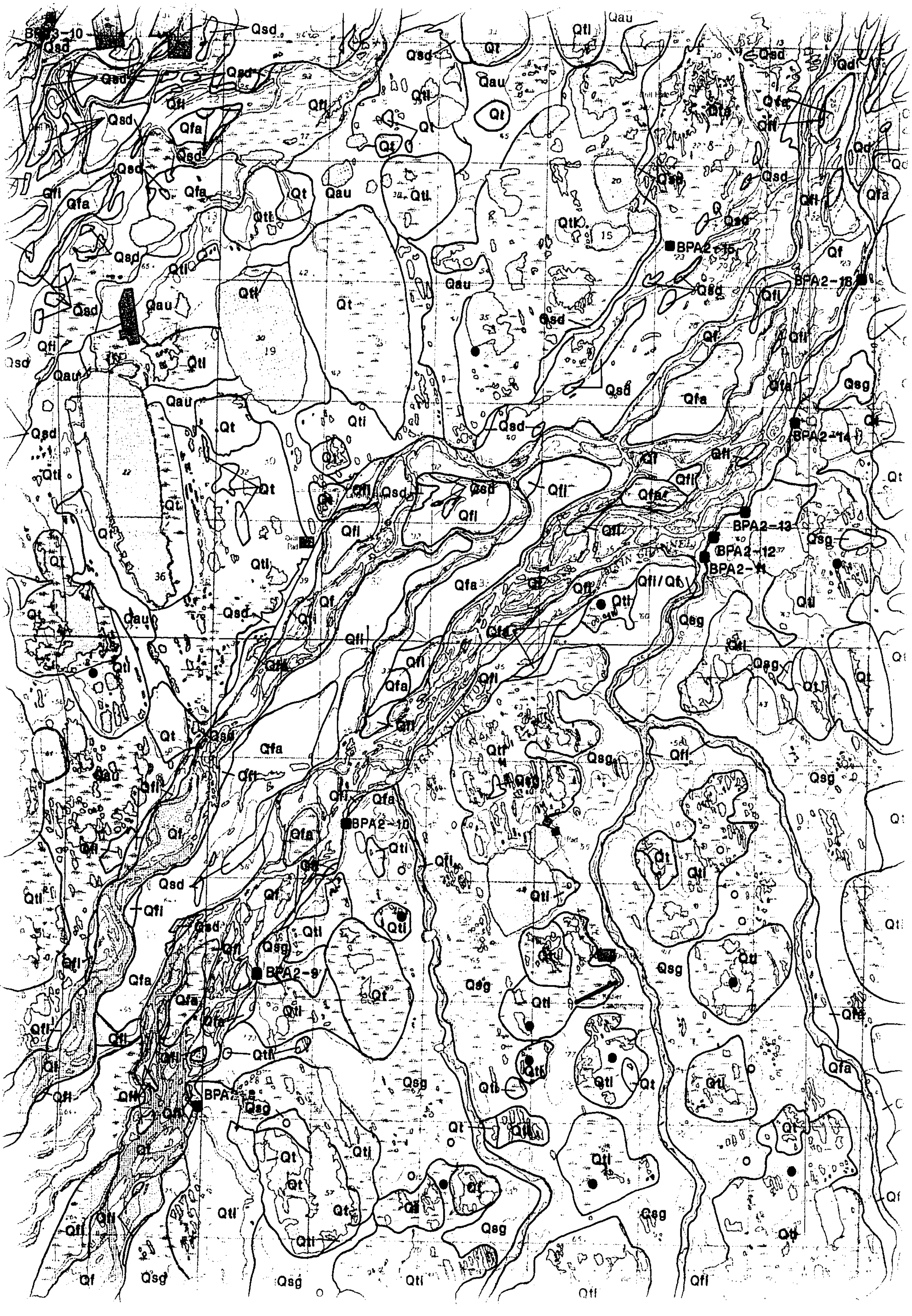

Howe Island
Anxiety Point
Duck Island
Point Brower
Foggy Island
FOGGY ISLAND BAY
SAGAVANIRKTOK RIVER DELTA
BPA2-1
Qd
Qsd
Qda
Qdl
Qsg
Qb
Qtl

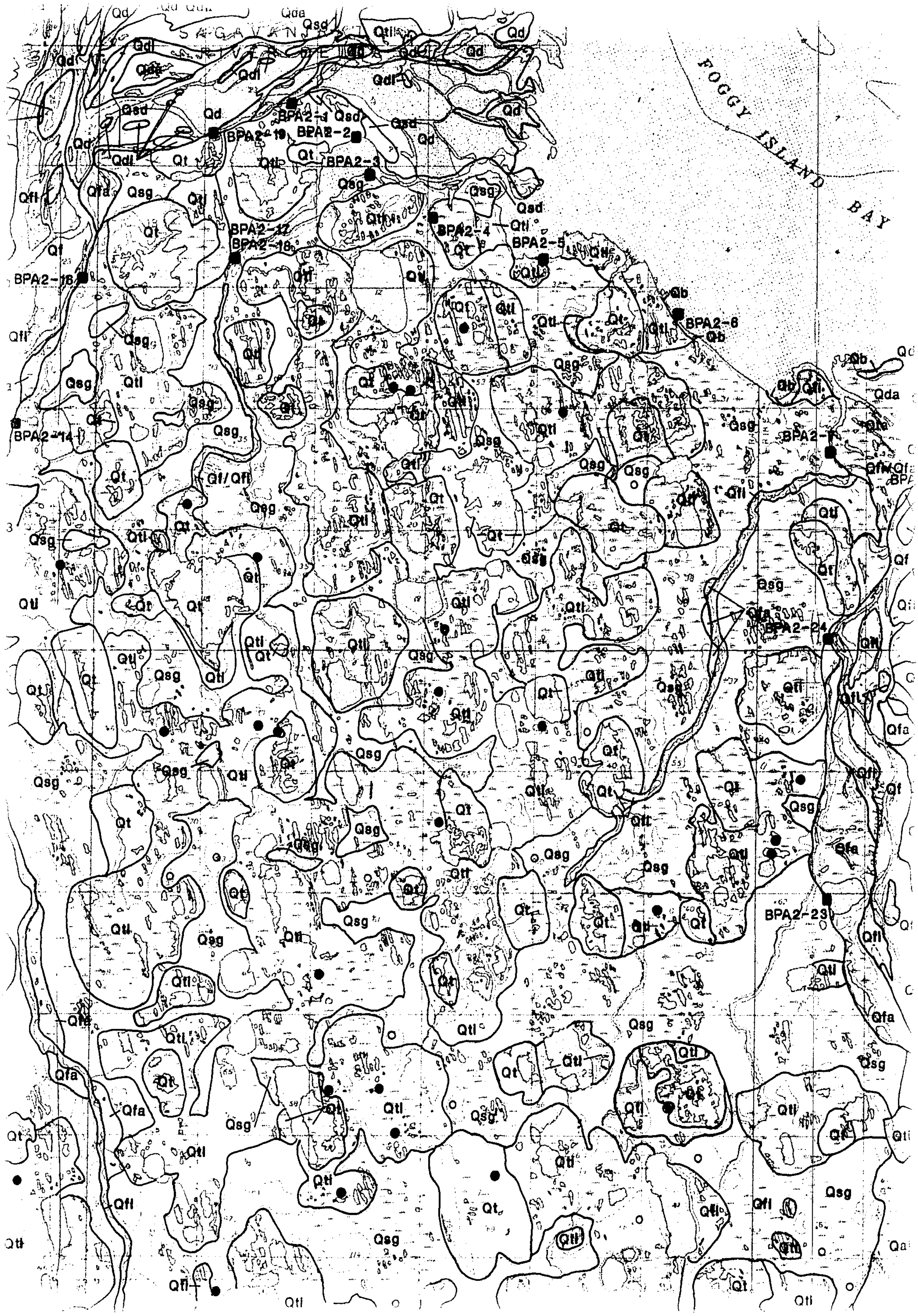

(BEECHEY POINT B-1)
T 12 N
T 11 N
20'
5 960 000 FEET
(ZONE 3)
Point Brower
Qb
Qsg
Qd
Qtl
Foggy
Island
Qdl
Qsd
Qlk
FOGGY ISLAND BAY
FOGGY
70° 15'
5 940 000 FEET
(ZONE 3)
Qsd
PA2-1

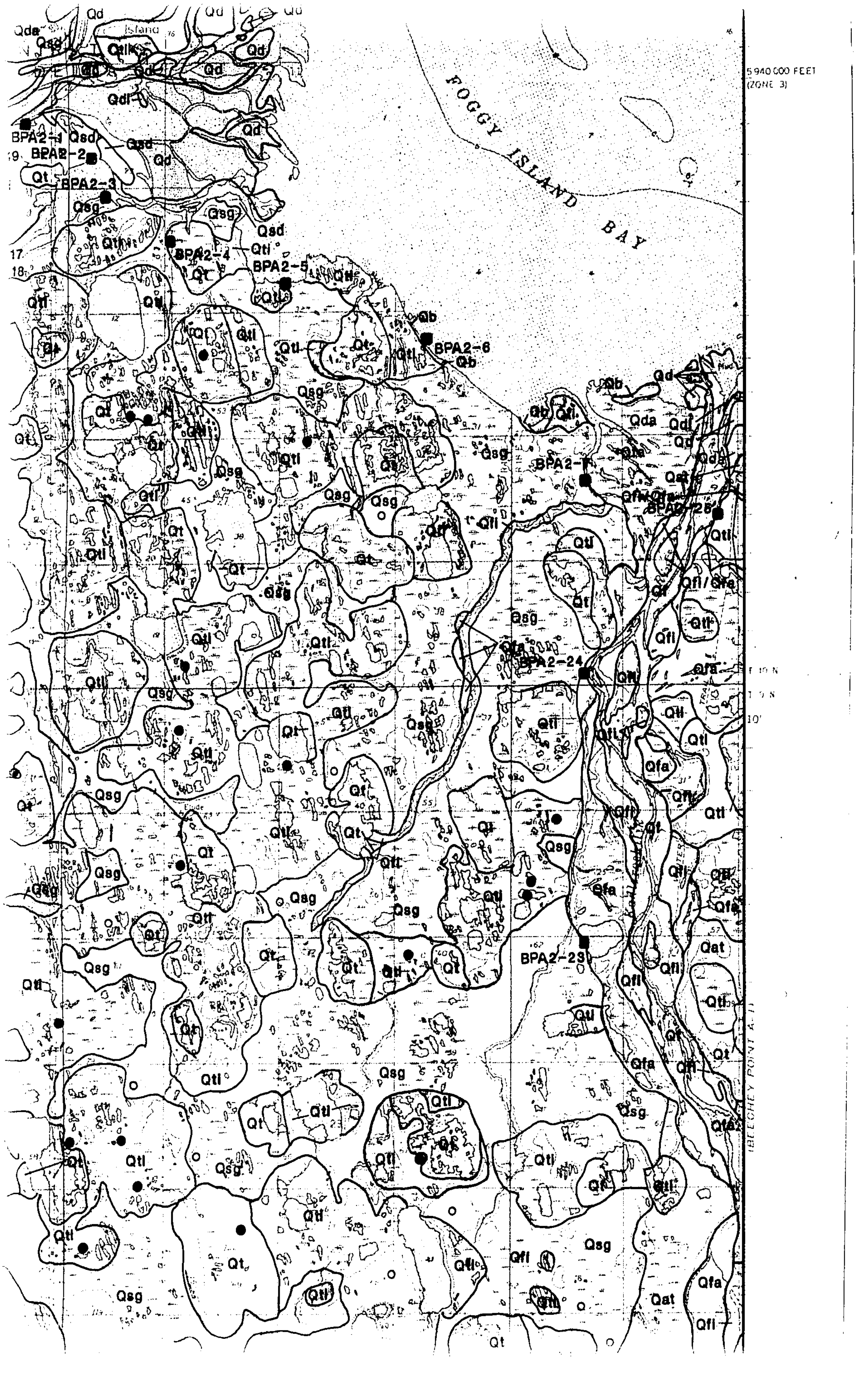


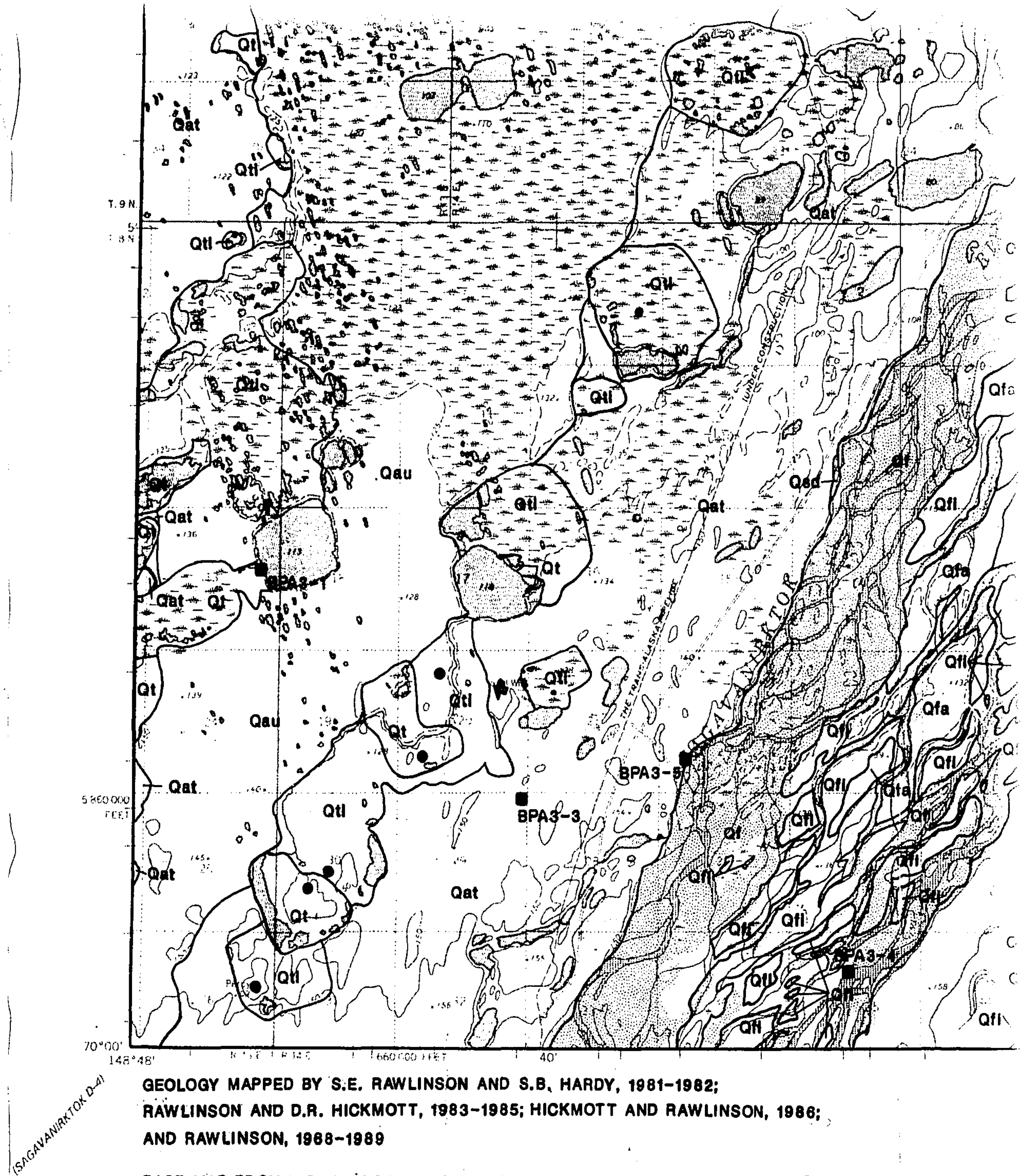
T 10 N.
T 9 N.
10'
(BEECHEY POINT A-4)
Qtl
Qfa
Qau
Qat
Qfl/Qf
Qt
Qag
Qfl
Qsd
Qf


Deadhorse
DEADHORSE AIRFIELD
BPA3-10
BPA3-7
Qt
Qtl
Qsg
Qau
Qat
Qsd
Qf
Qfa
Qfl


BPA2-10
BPA2-9
BPA2-11
BPA2-12
BPA2-13
BPA2-14
BPA2-15
BPA2-16
Qsd
Qfl
Qfa
Qt
Qtl
Qau
Qsg
Qf
Qfl/Qt

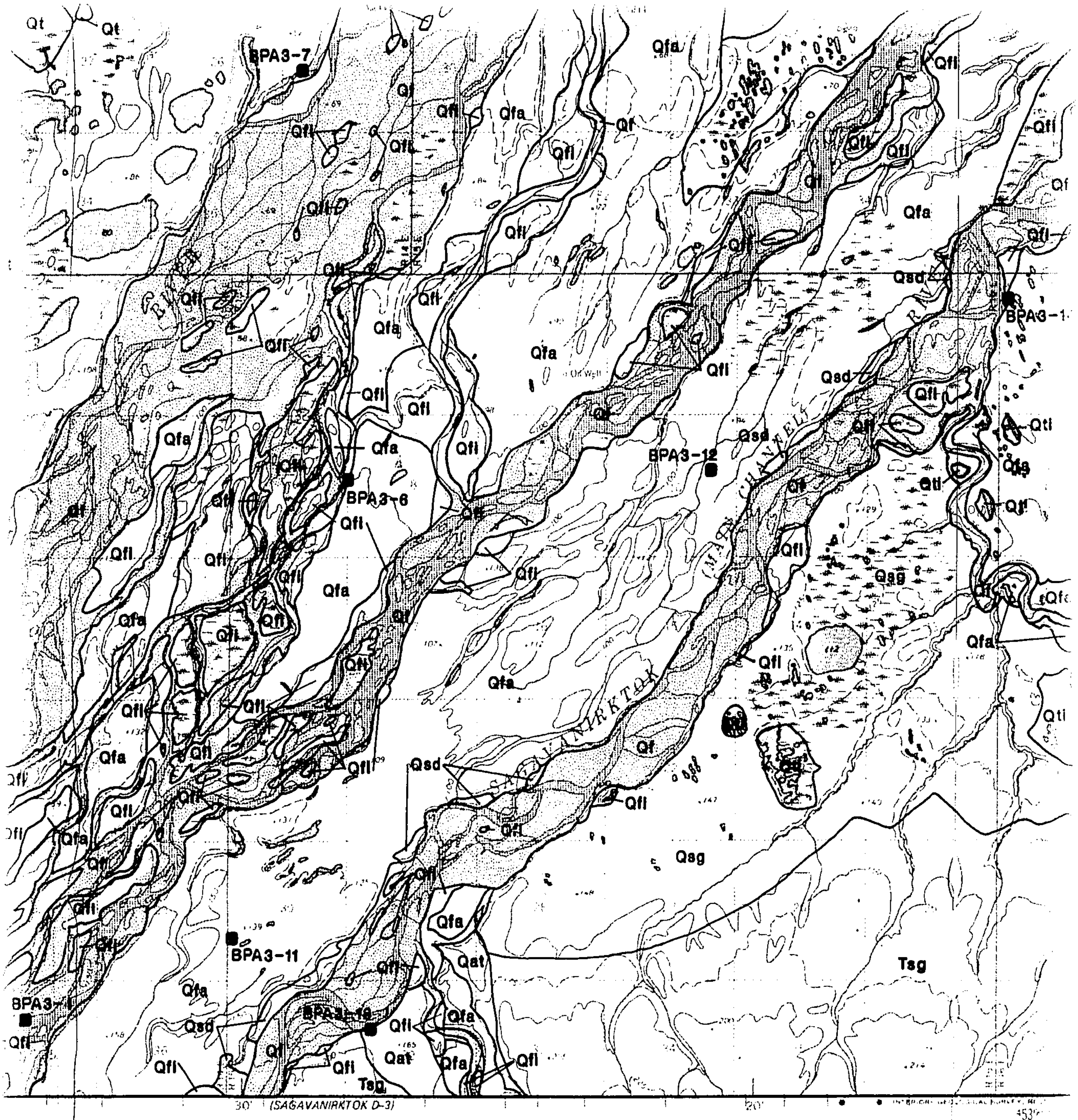

FOGGY ISLAND BAY
BPA2-1
BPA2-2
BPA2-3
BPA2-4
BPA2-5
BPA2-6
BPA2-7
BPA2-14
BPA2-16
BPA2-17
BPA2-18
BPA2-19
BPA2-23
BPA2-24
Qd
Qdl
Qsd
Qda
Qsg
Qt
Qtl
Qfl
Qfa
Qb
Qf
Qtl/Qfl


FOGGY ISLAND BAY
BPA2-1
BPA2-2
BPA2-3
BPA2-4
BPA2-5
BPA2-6
BPA2-7
BPA2-24
BPA2-23
5 940 000 FEET
(ZONE 3)
Qd
Qda
Qdl
Qsd
Qsg
Qt
Qtl
Qb
Qfa
Qfl
Qat



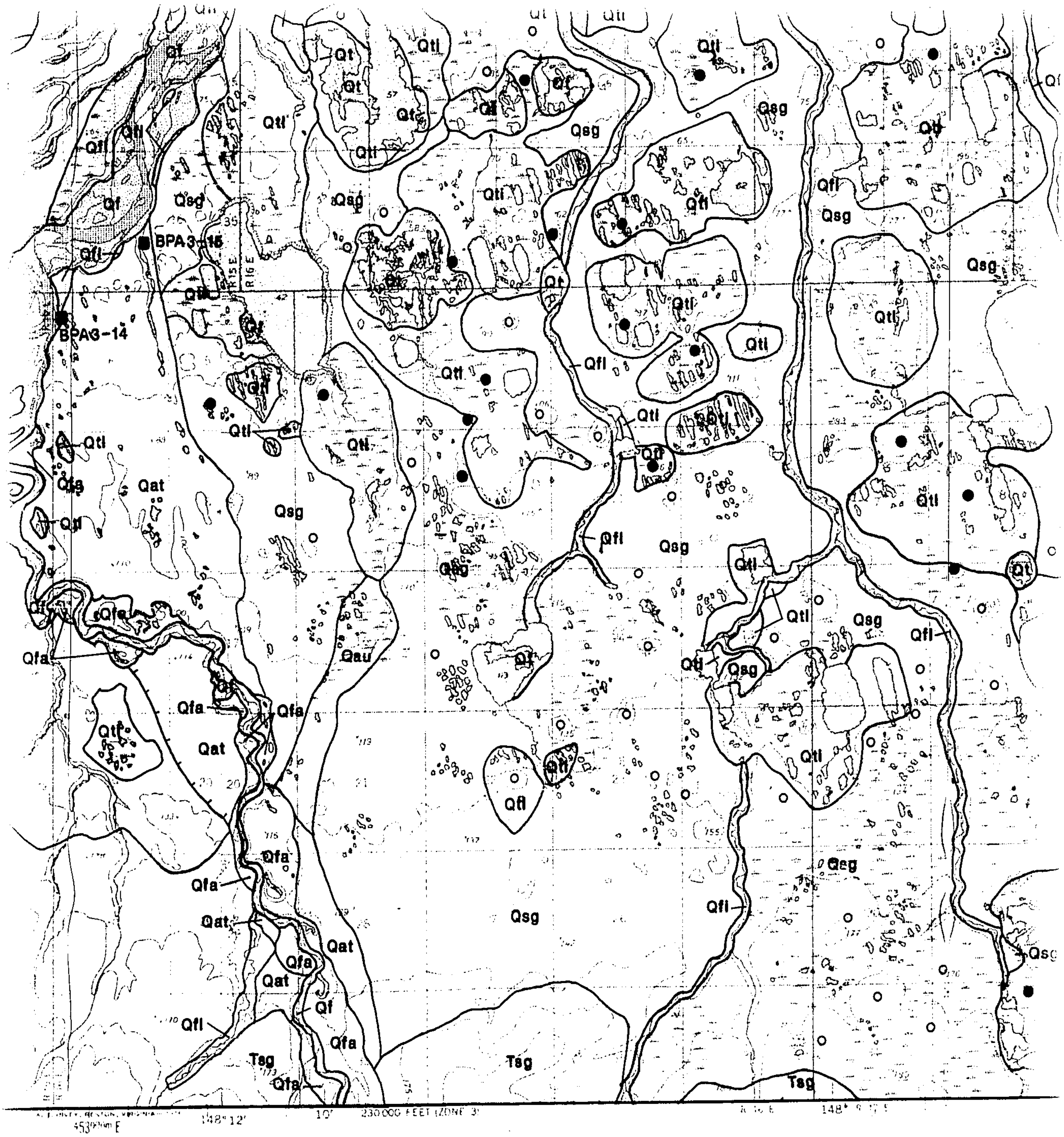
GEOLOGY MAPPED BY S.E. RAWLINSON AND S.B. HARDY, 1981-1982; RAWLINSON AND D.R. HICKMOTT, 1983-1985; HICKMOTT AND RAWLINSON, 1986; AND RAWLINSON, 1988-1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY BEECHEY POINT A-2, 1955, REVISED 1975; A-3, 1955, REVISED 1975; B-2, 1955, REVISED 1977; B-3, 1955, REVISED 1975.

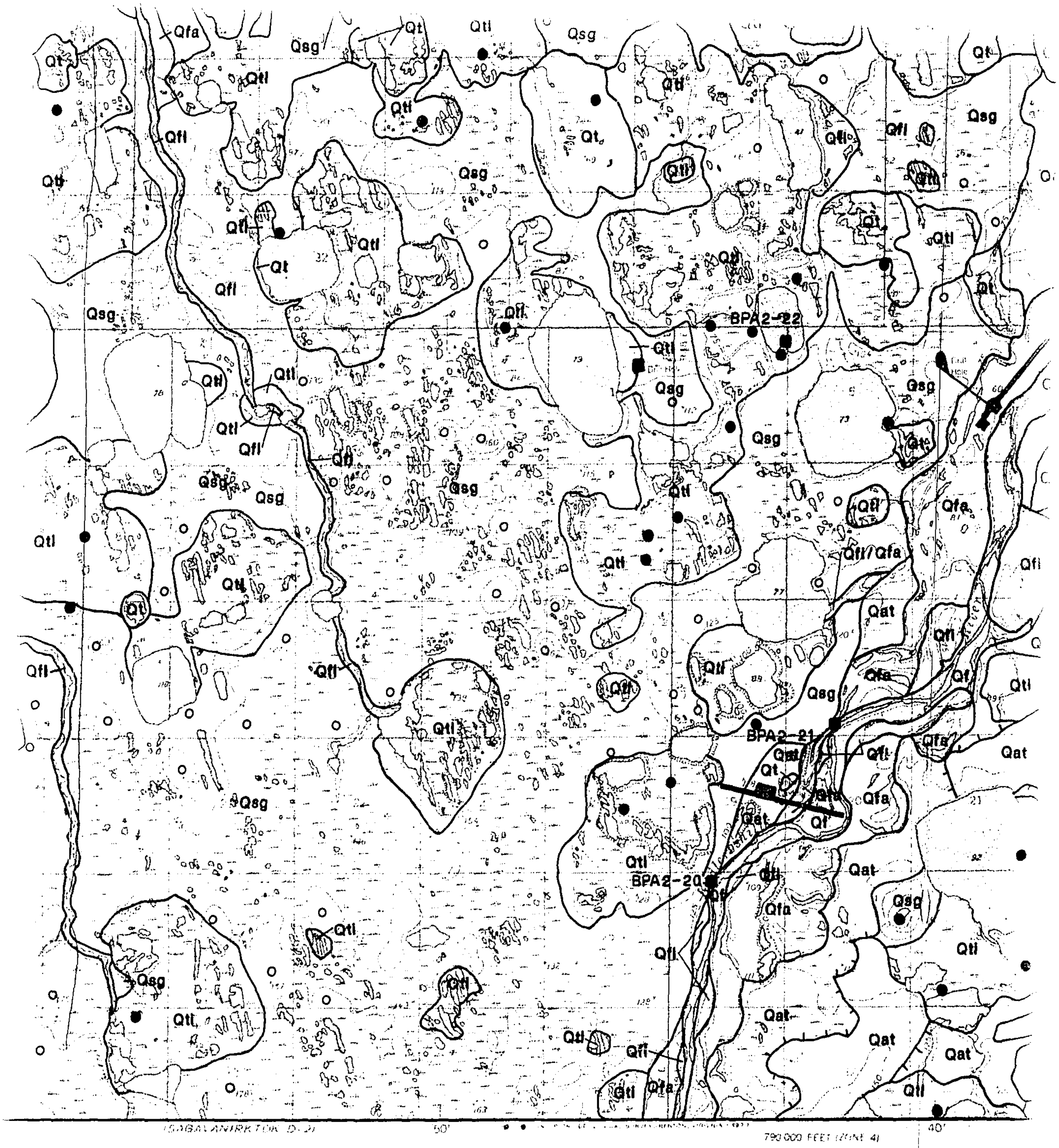


1975;

SURFICIAL-GEOLOGY MAP
AND B-3 Q



Y MAP OF THE BEECHEY POINT A-2, A-3, B-2, B-3 QUADRANGLES, ALASKA



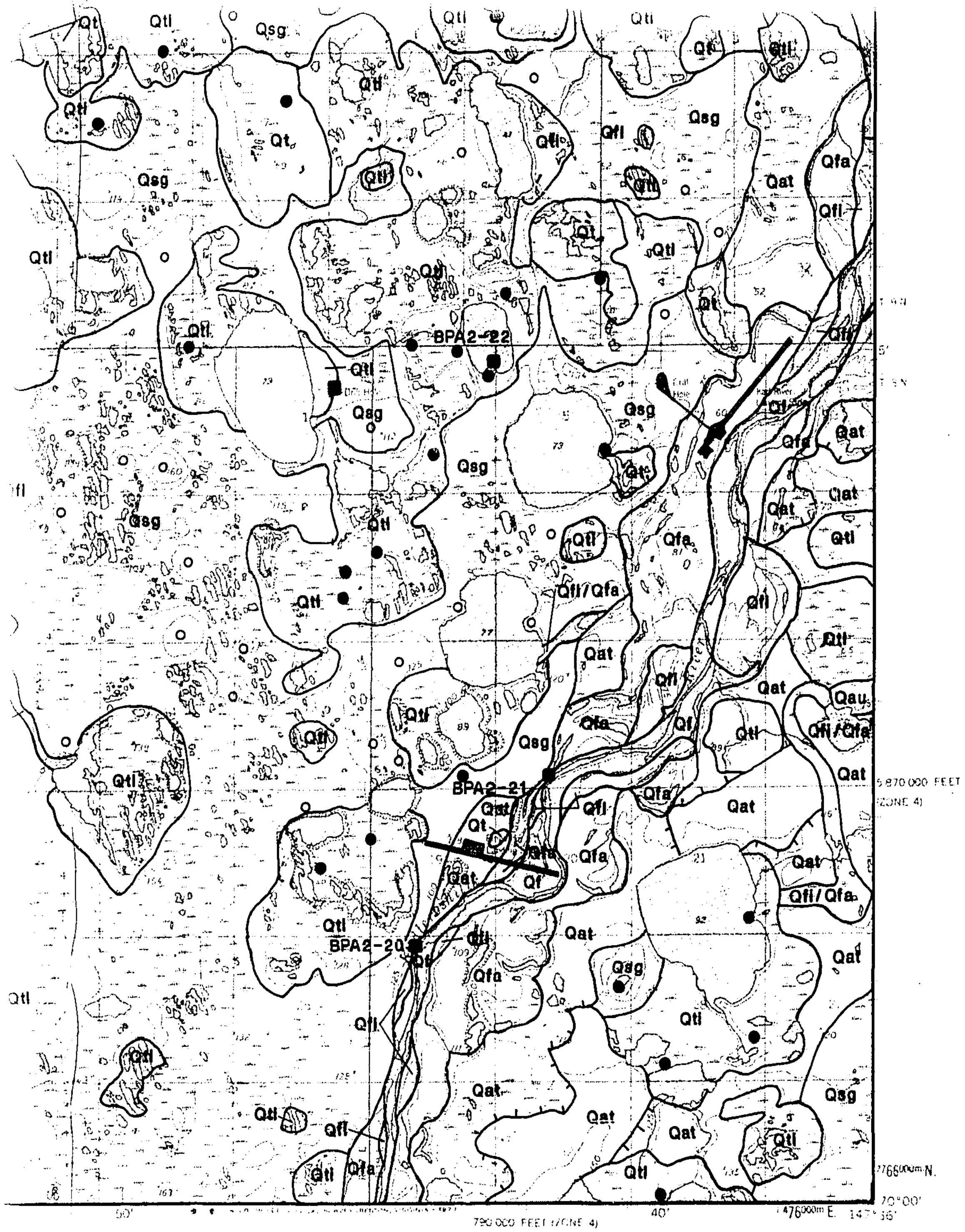
SCALE 1:63,360

MILES

1 .5 0 1 2 3

1 .5 0 1 2 3 4

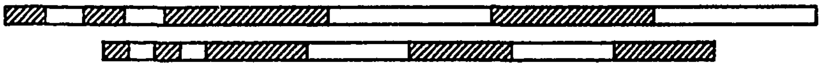
KILOMETERS



SCALE 1:63,360

MILES

1 .5 0 1 2 3 4



1 .5 0 1 2 3 4 5

KILOMETERS

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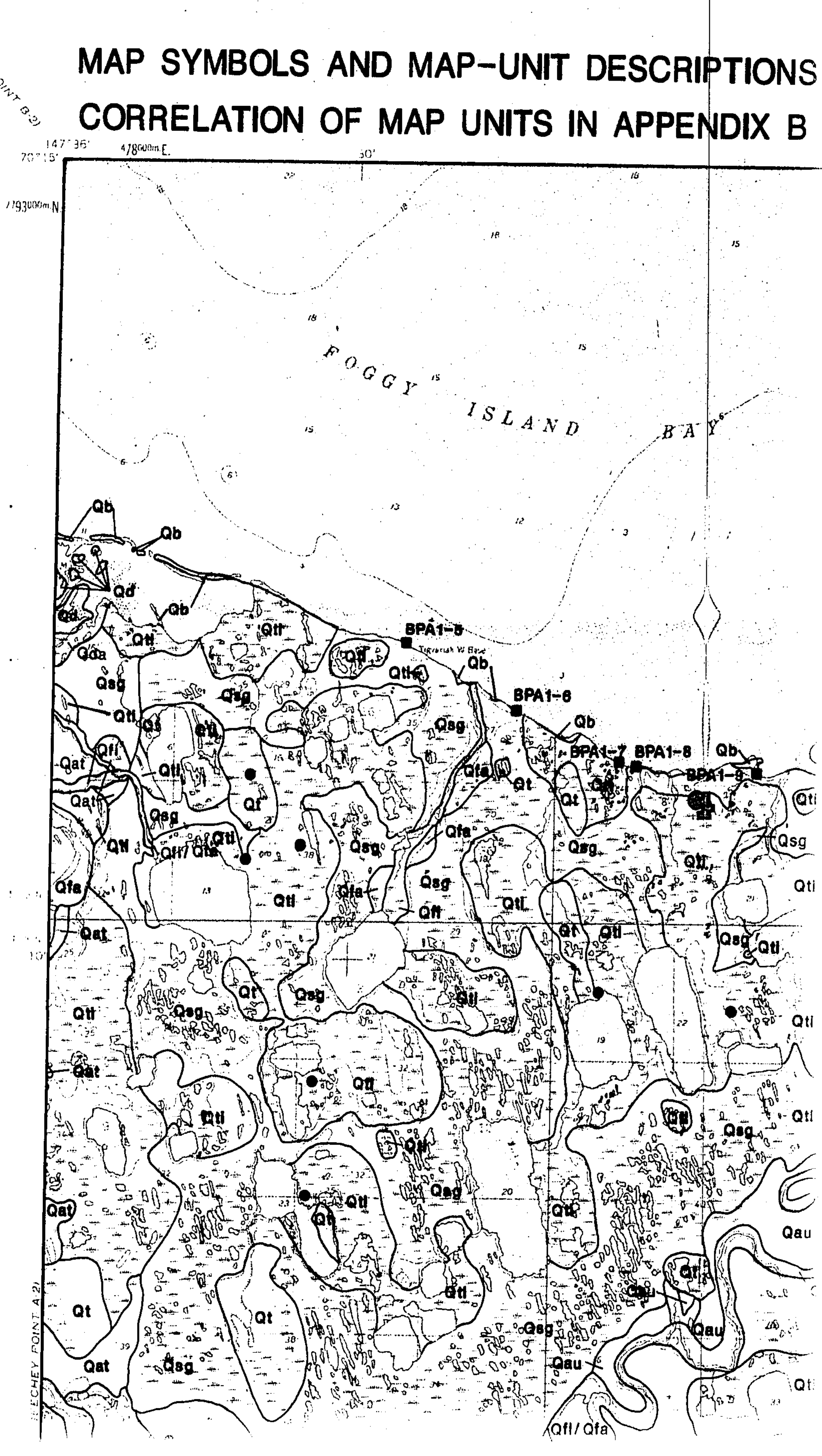
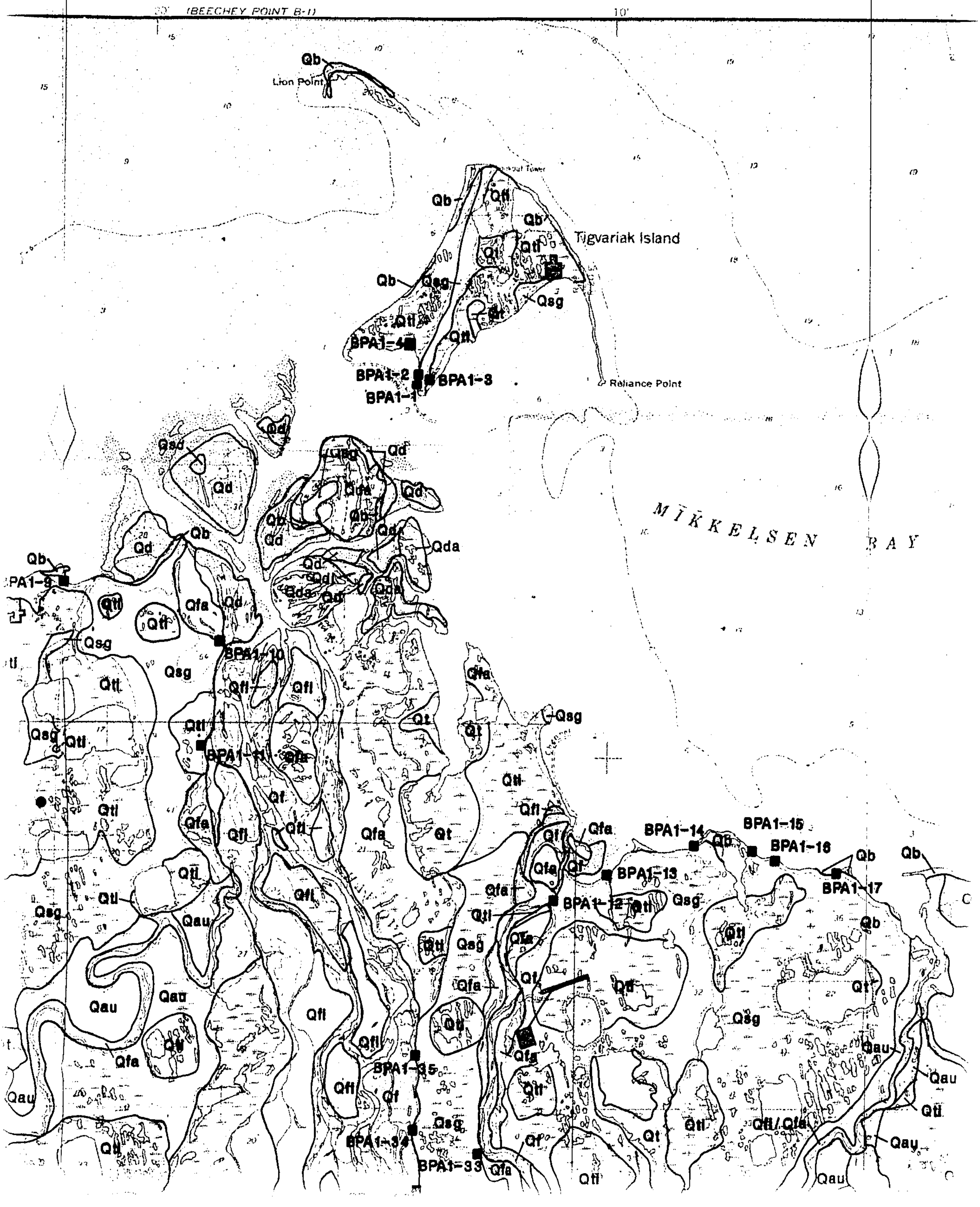
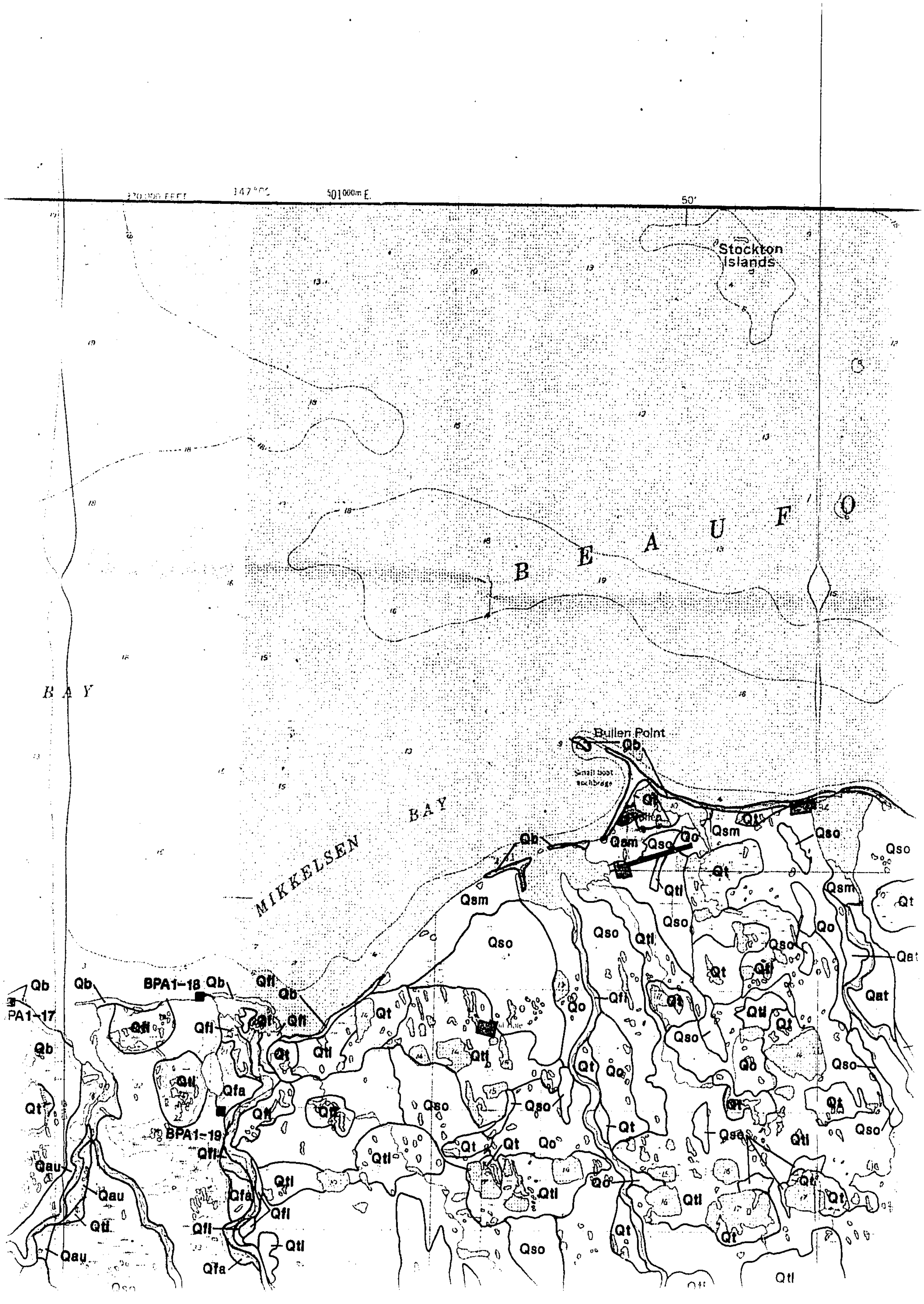
MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS
CORRELATION OF MAP UNITS IN APPENDIX B



IPTIONS IN APPENDIX A

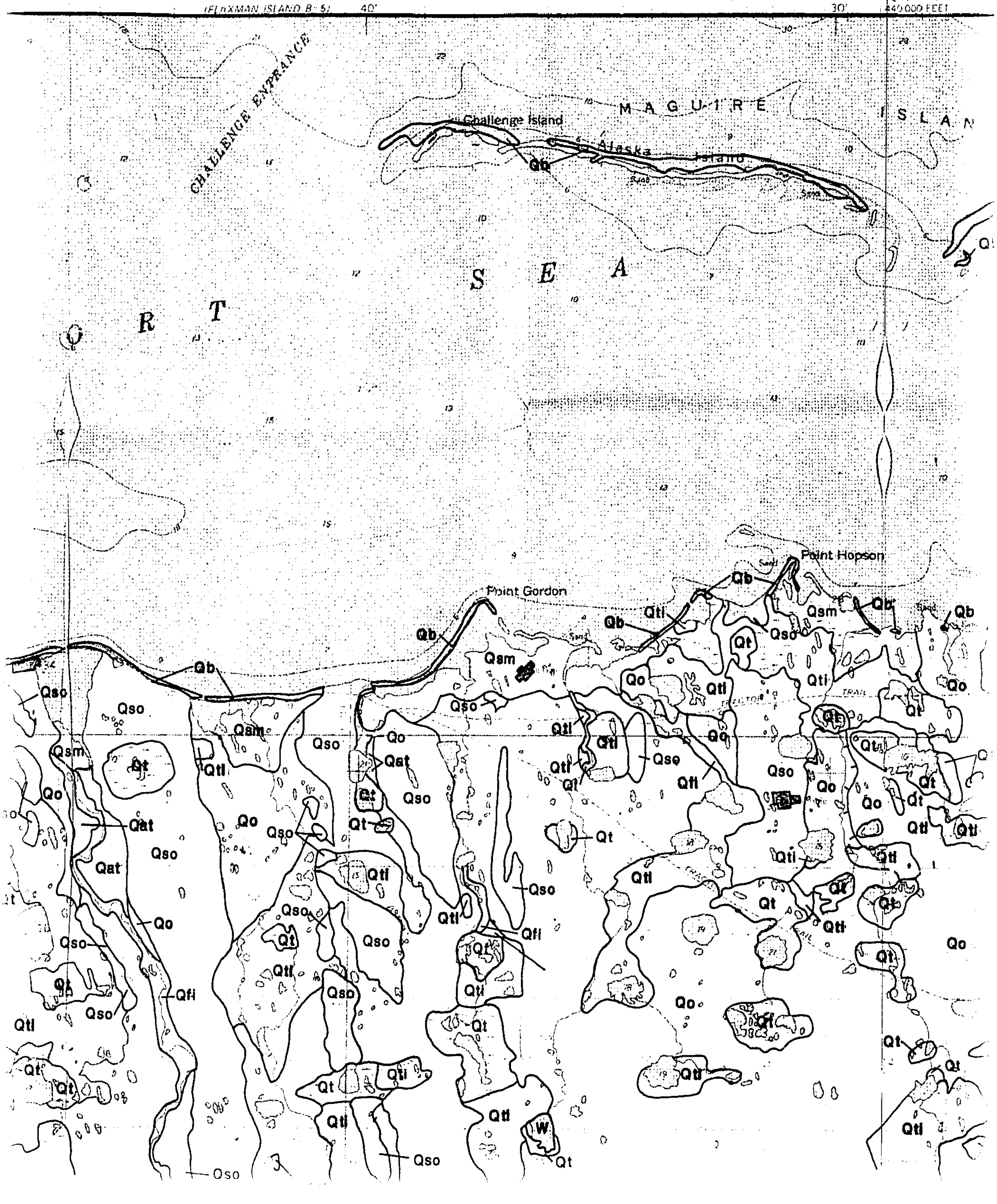
NDIX B



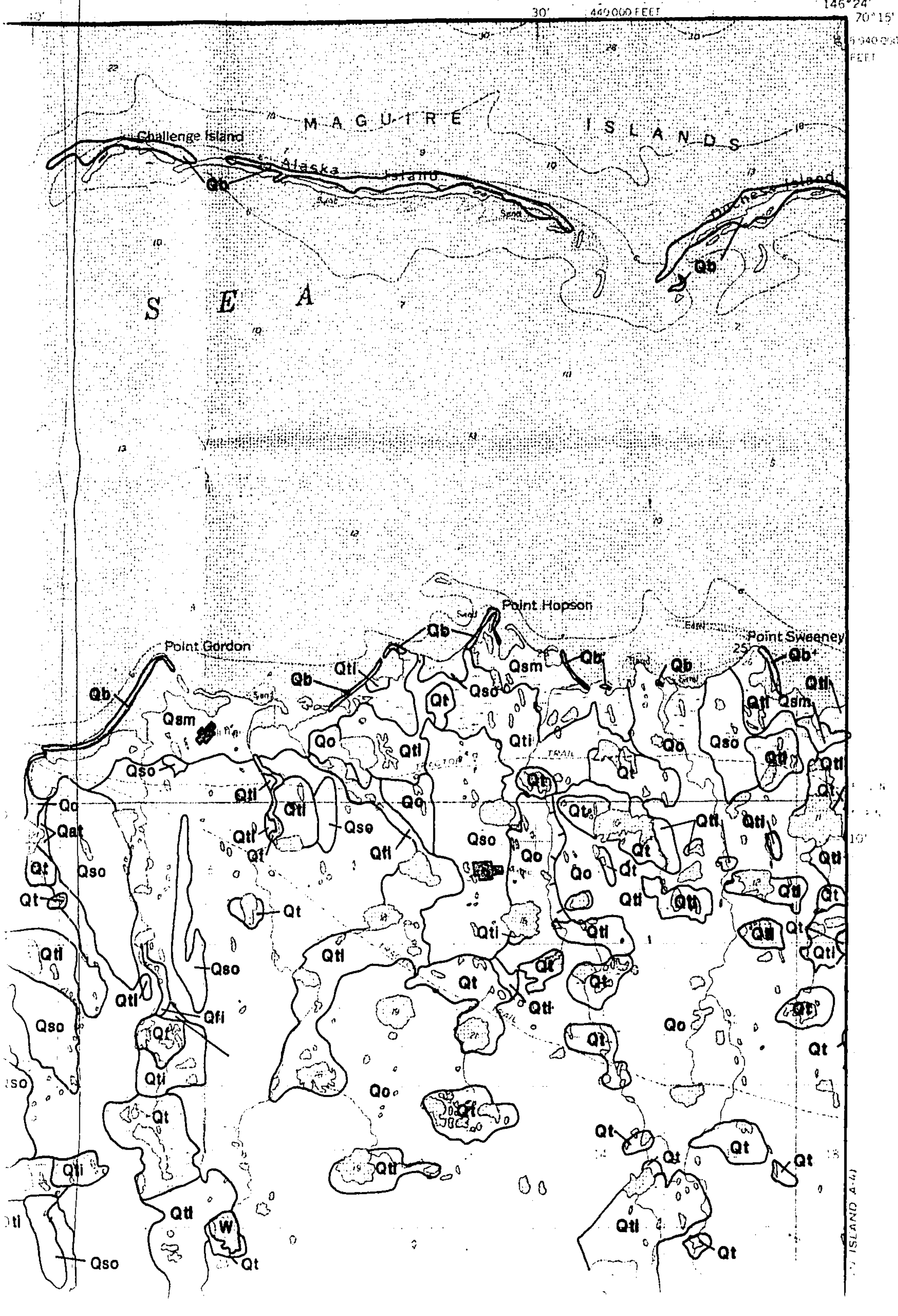


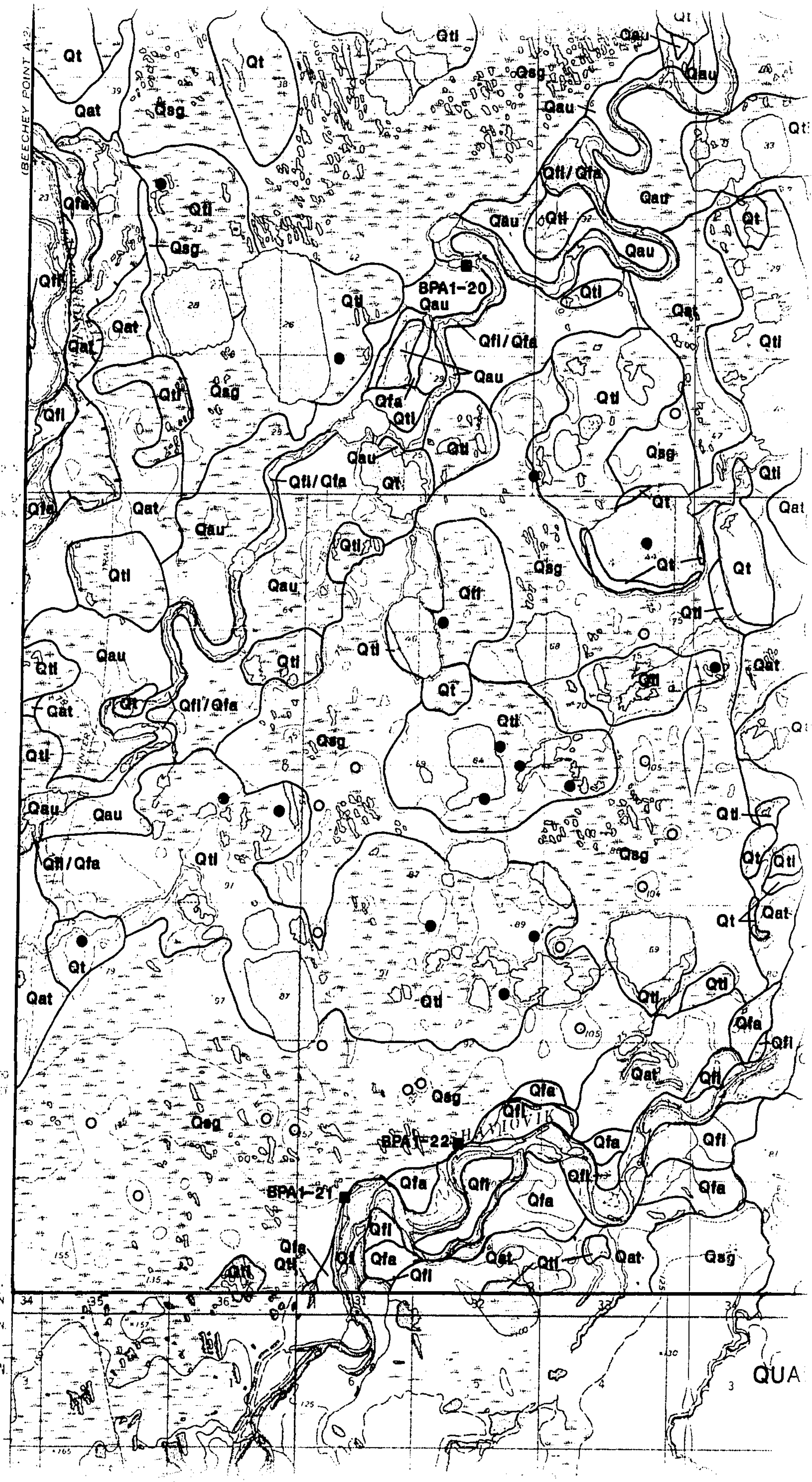
50'
Stockton Islands
B E A U F O
BAY
MIKKELSEN BAY
Bullen Point
Qb
Qfl
Qsm
Qso
Qo
Qt
Qtl
Qat
Qfa
Qau
BPA1-17
BPA1-18
BPA1-19

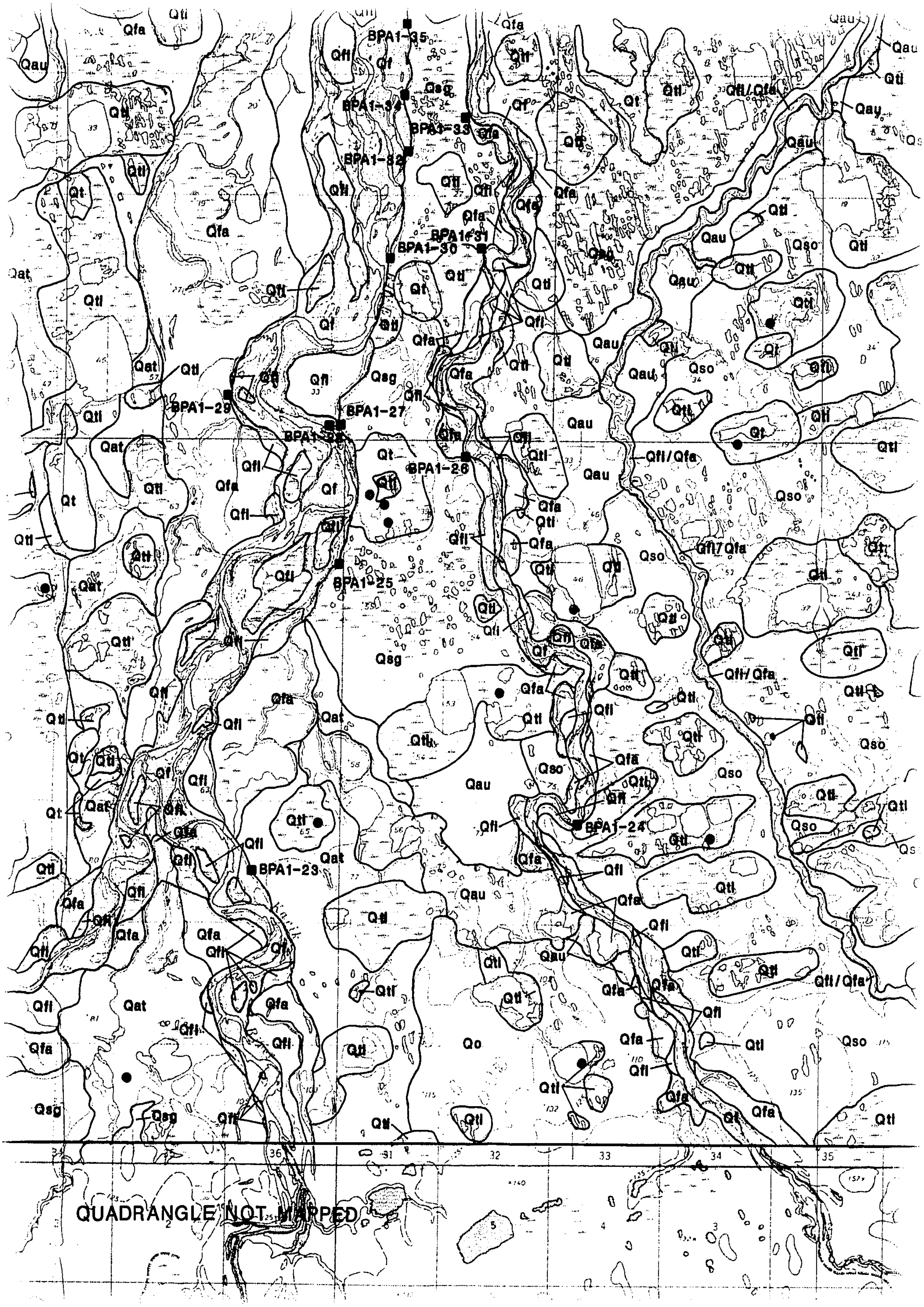
RAWLINSON, 1990 SHEET

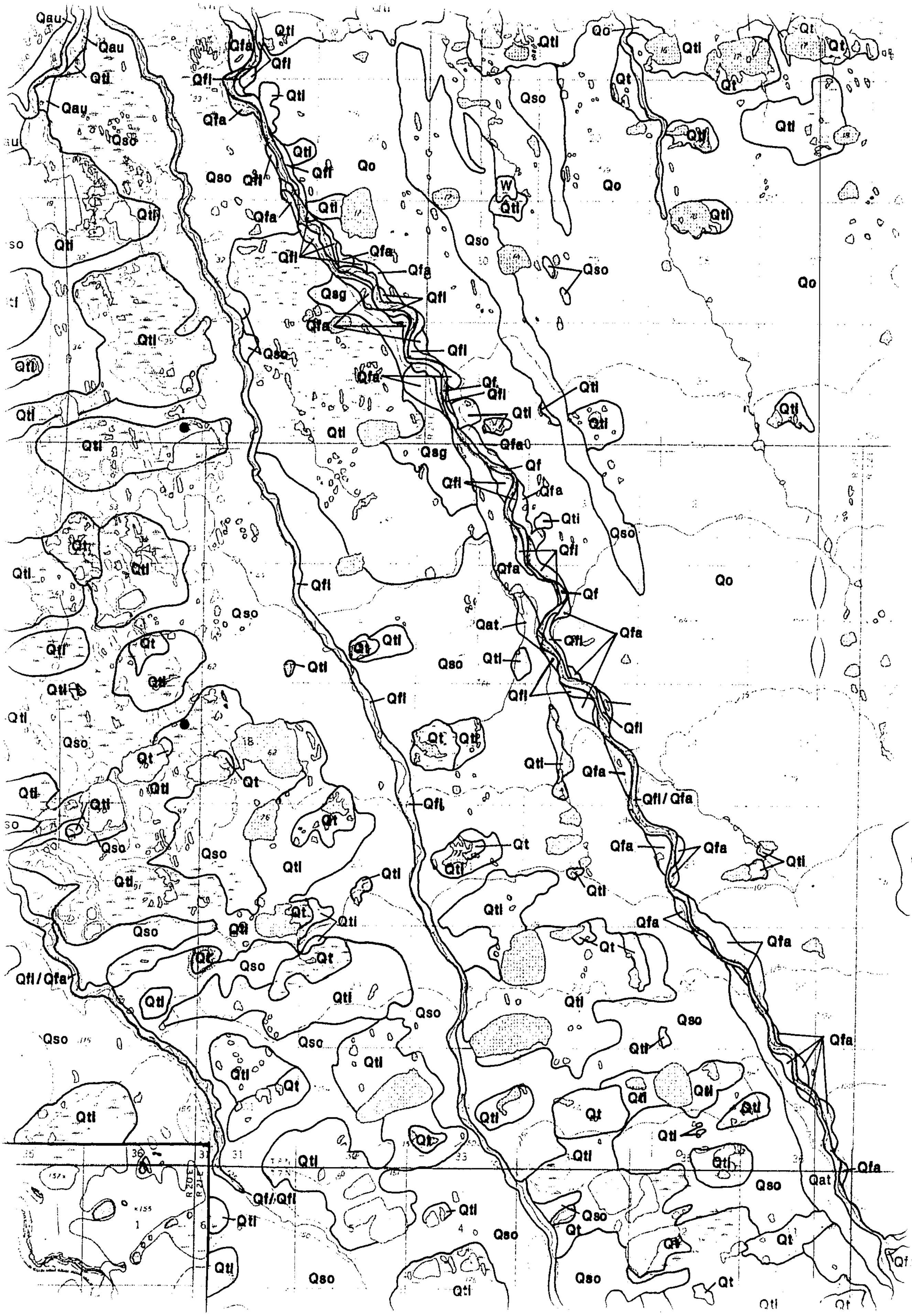


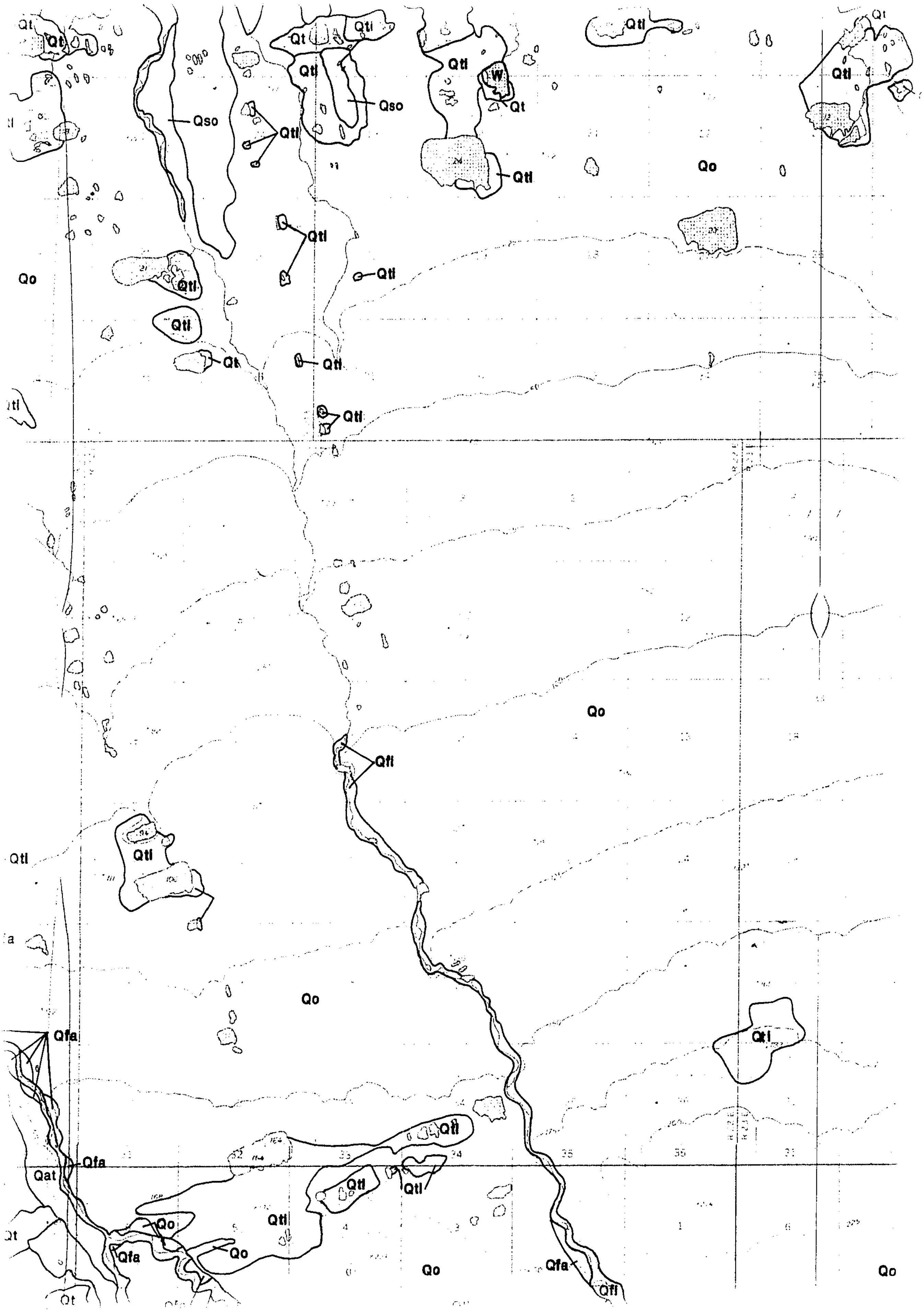
RAWLINSON, 1990 SHEET 4 OF 6

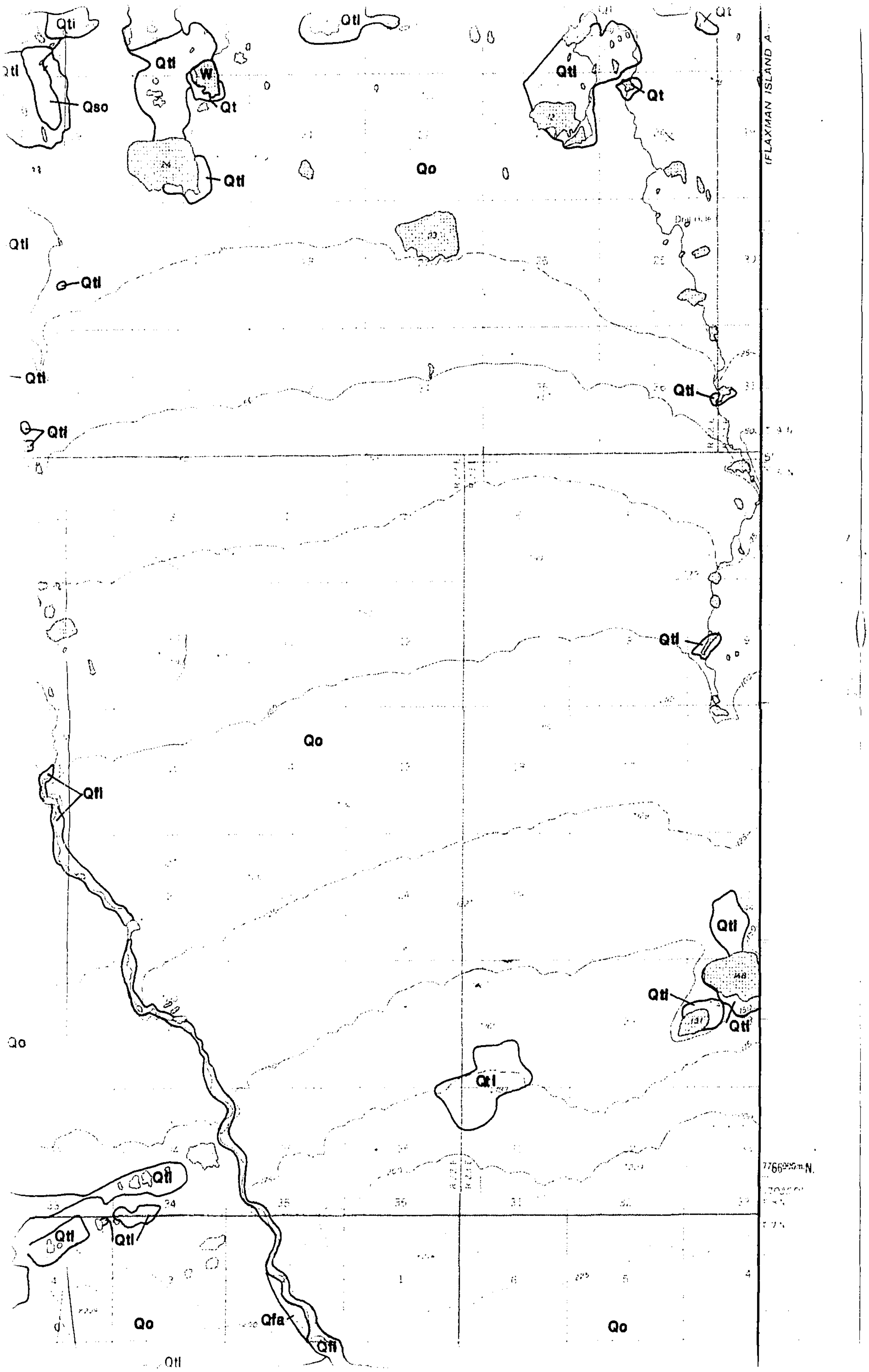


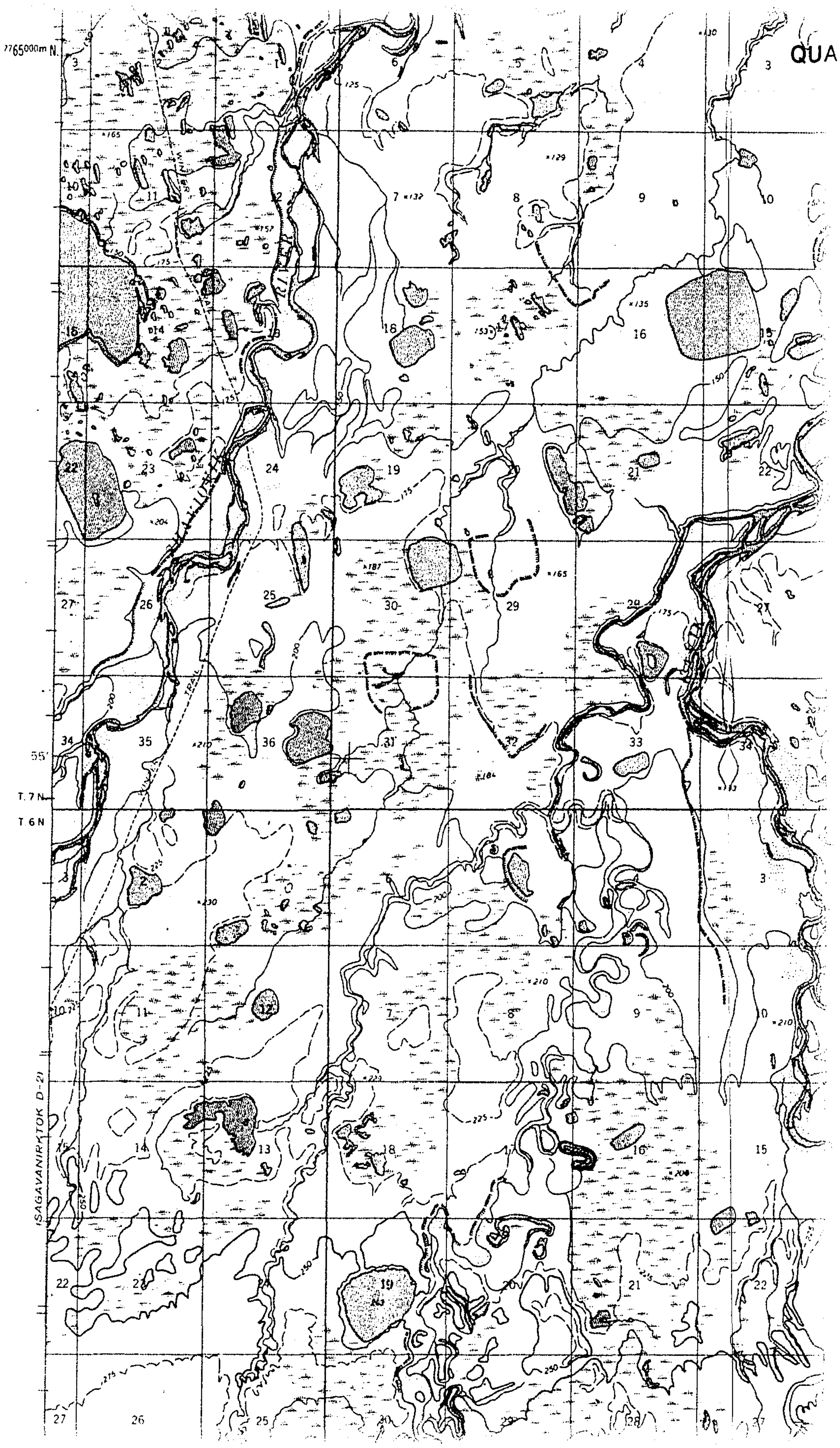

(BEECHEY POINT A-2)
Qt
Qat
Qsg
Qtl
Qfa
Qau
Qtl/Qfa
BPA1-20
BPA1-22
BPA1-21
T. 8 N.
T. 7 N.
QUA

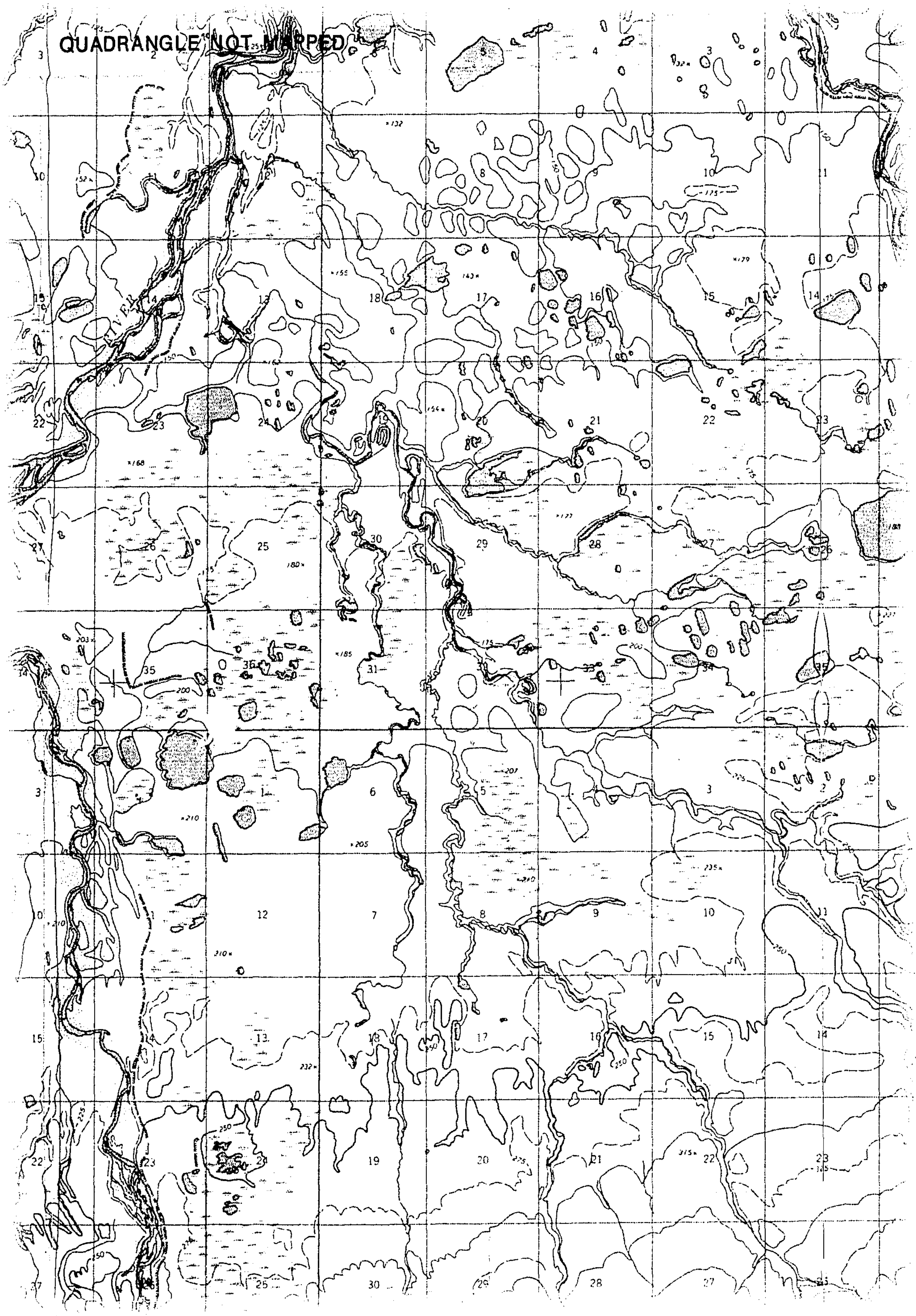

BPA1-35
BPA1-34
BPA1-33
BPA1-32
BPA1-31
BPA1-30
BPA1-29
BPA1-28
BPA1-27
BPA1-26
BPA1-25
BPA1-24
BPA1-23
Qfa
Qau
Qtl
Qt
Qfl
Qf
Qsg
Qat
Qso
Qtl/Qfa
Qfl/Qfa
Qo
31
32
33
34
35
36
QUADRANGLE NOT MAPPED

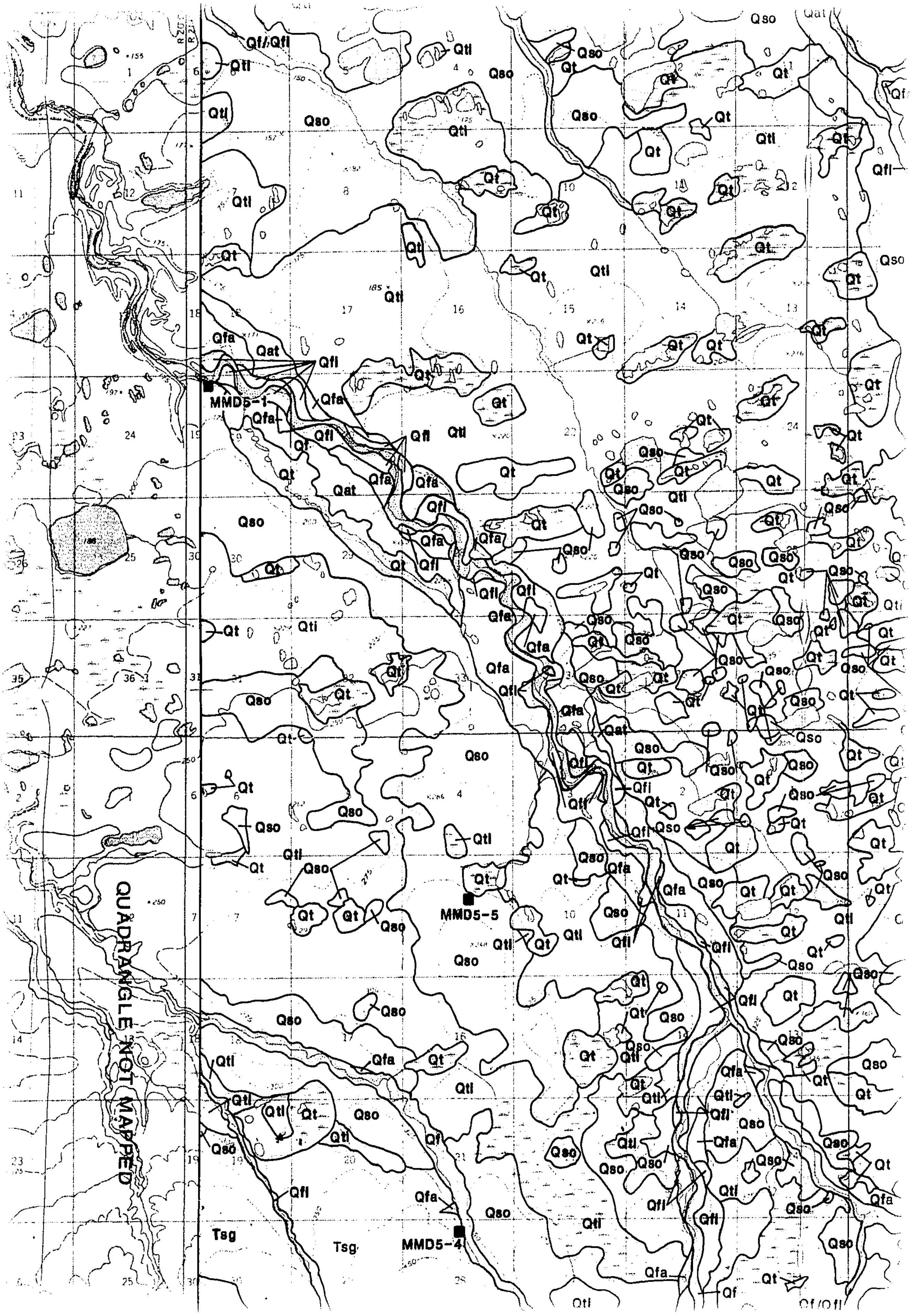

Qau
Qtl
Qfa
Qfl
Qo
Qso
Qsg
Qt
W
Qf
Qat
Qfl/Qfa
Qf/Qfl

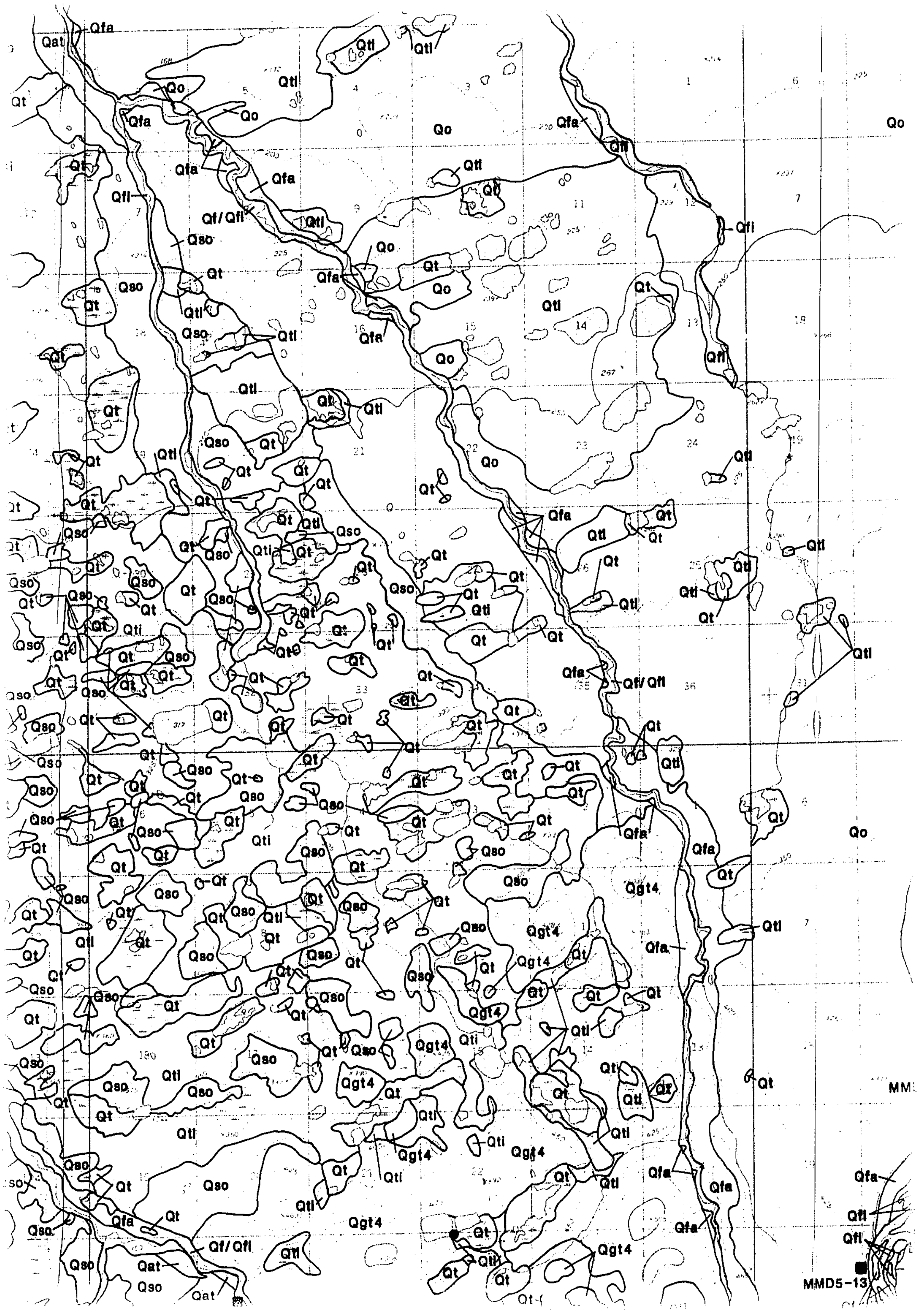

Qt
Qtl
Qt
Qtl
Qtl
Qso
Qtl
Qso
Qtl
W
Qt
Qtl
Qtl
Qo
Qtl
Qo
Qtl
Qtl
Qtl
Qtl
Qt
Qtl
Qtl
Qtl
Qo
Qfl
Qtl
Qo
Qfa
Qtl
Qtl
Qfa
Qat
Qtl
Qtl
Qo
Qfa
Qo
Qo
Qfa
Qfl
Qt
Qo

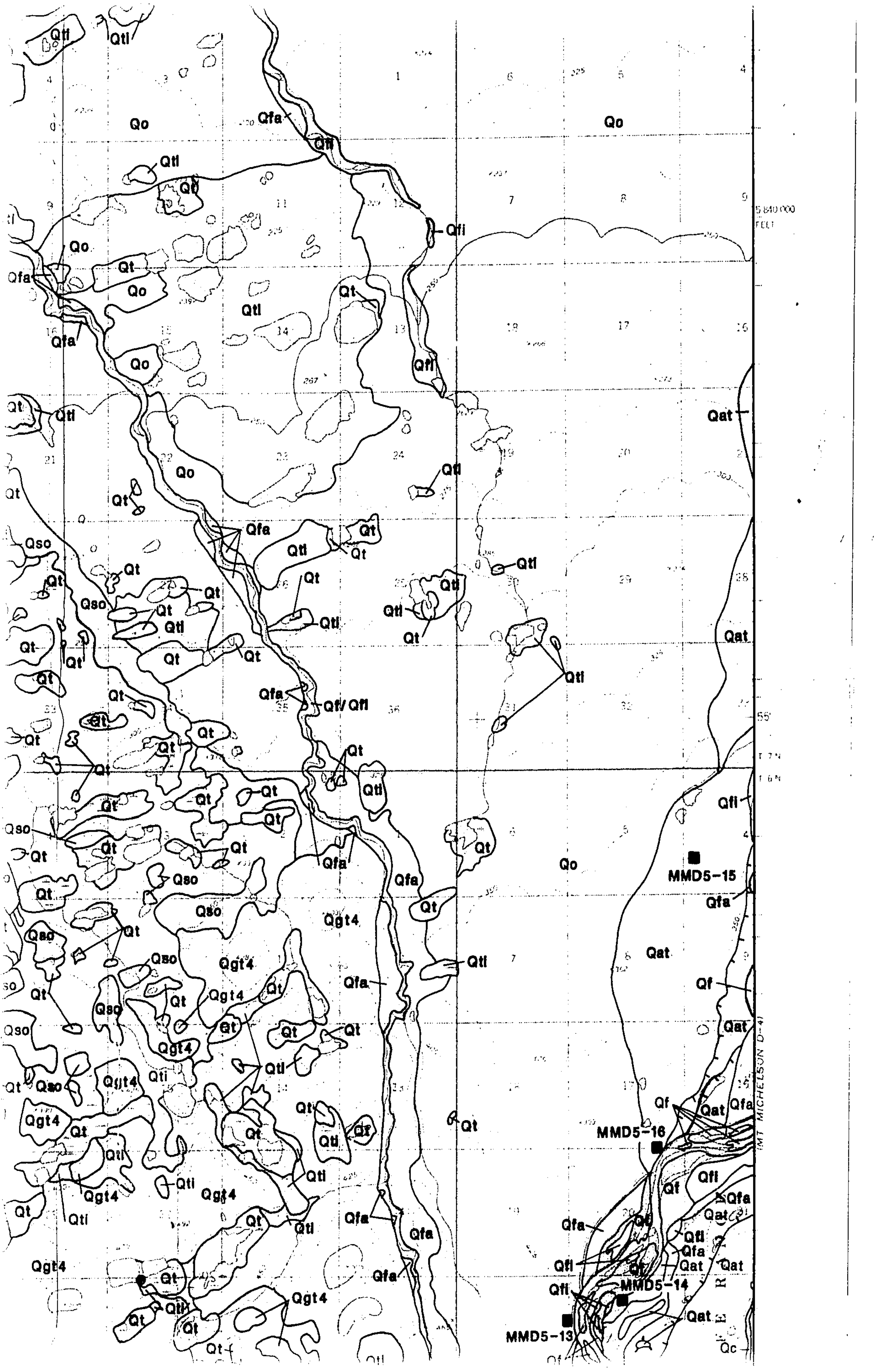

Qtl
Qso
Qtl
W
Qt
Qtl
Qtl
Qt
Qo
Qtl
Qtl
Qtl
Qtl
Qtl
Qtl
Qo
Qfl
Qtl
Qtl
Qtl
Qo
Qtl
Qfl
Qtl
Qtl
Qo
Qfa
Qfl
Qo
Qtl

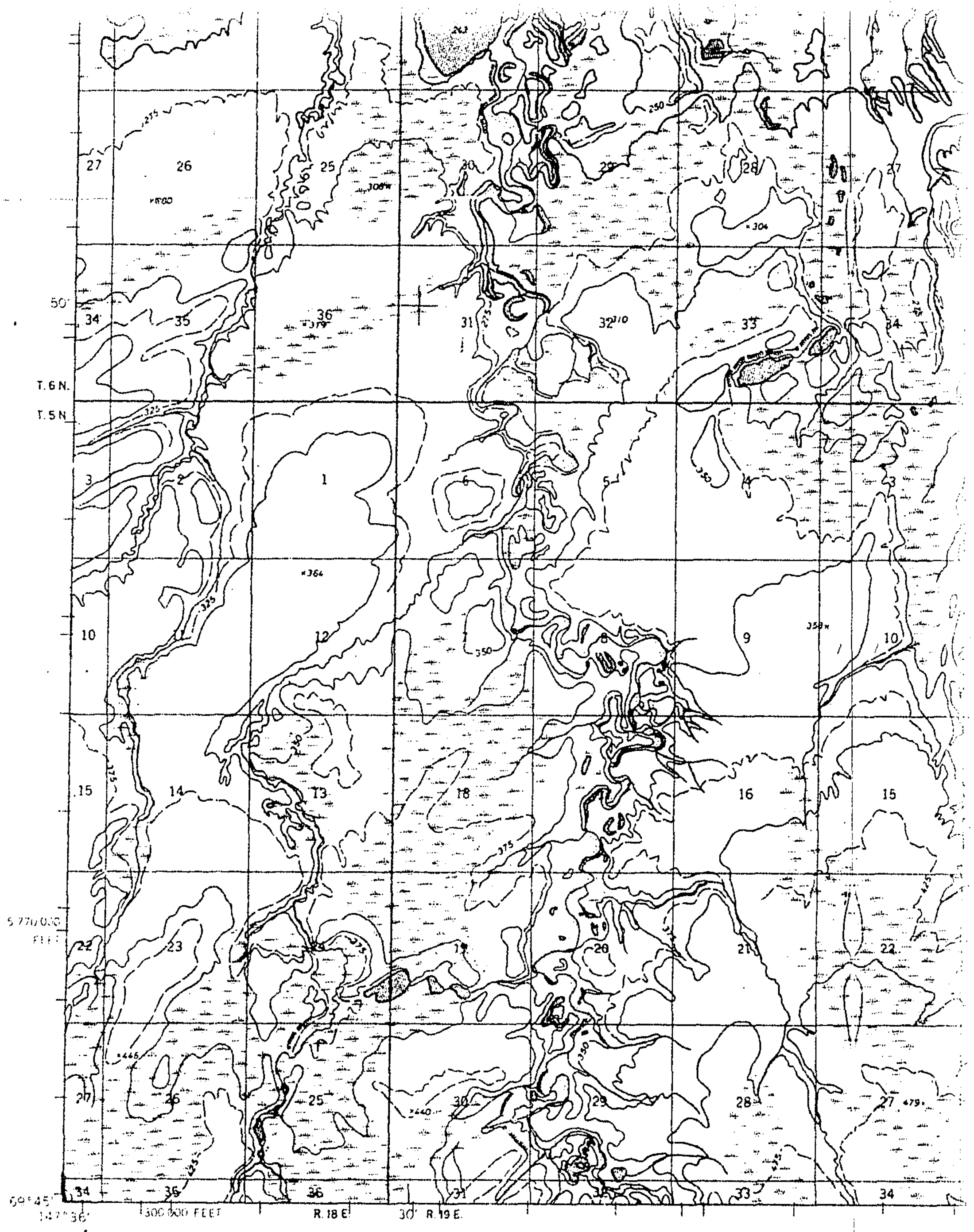

7765000m N.
QUA
55'
T. 7 N.
T. 6 N
ISAGAVANIRKTOK D-2)
TRAIL


QUADRANGLE NOT MAPPED


QUADRANGLE NOT MAPPED
MMD5-1
MMD5-5
MMD5-4

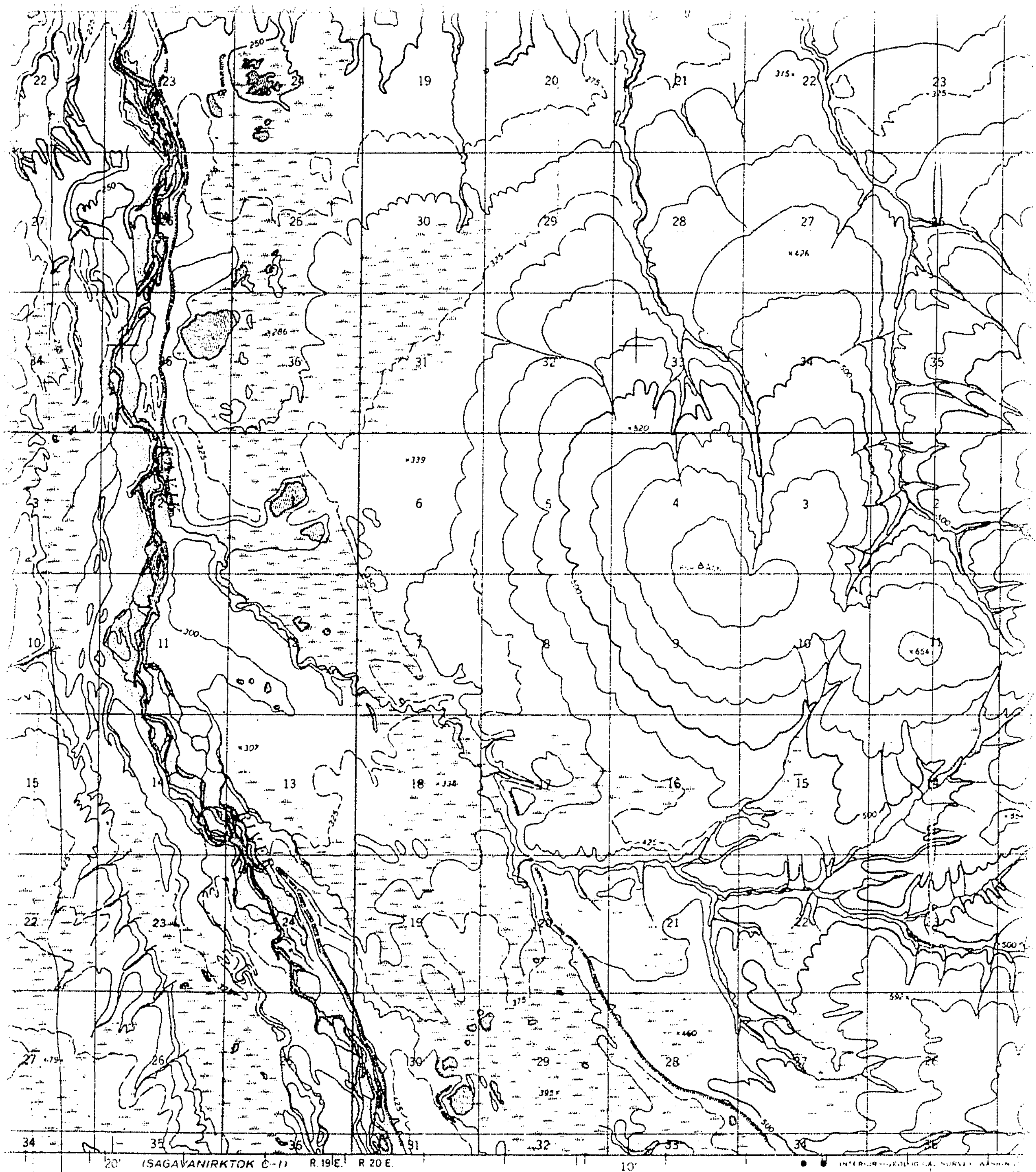

MMD5-13


Qo
Qfa
Qtl
Qt
Qso
Qgt4
Qat
Qf
Qc
Qf/Qfl
MMD5-13
MMD5-14
MMD5-15
MMD5-16
5 840 000 FEET
55'
T 7 N
T 6 N



GEOLOGY MAPPED BY O.J. FERRIANS, JR., 1973, 1975; L.D. CARTER AND J.P. GALLOWAY, 1983-19
S.E. RAWLINSON, CARTER, AND D.R. HICKMOTT, 1985; AND RAWLINSON, 1988-1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY MT. MICHELSON D-5, 1955; FLAXMAN ISLAND A-5, 19
AND BEECHEY POINT A-1, 1955, REVISED 1975.

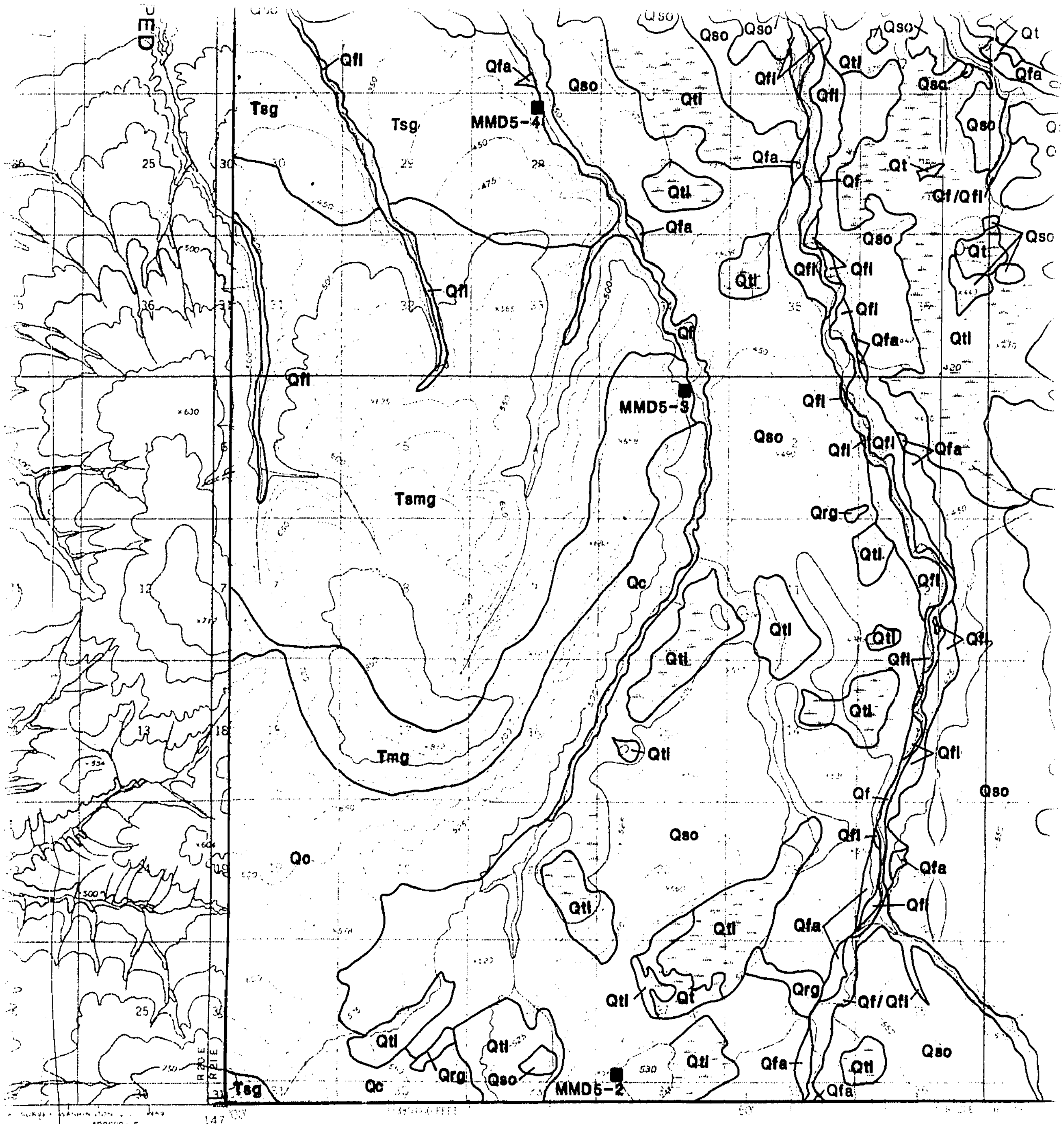


.OWAY, 1983-1984;

SLAND A-5, 1955, REVISED 1981;

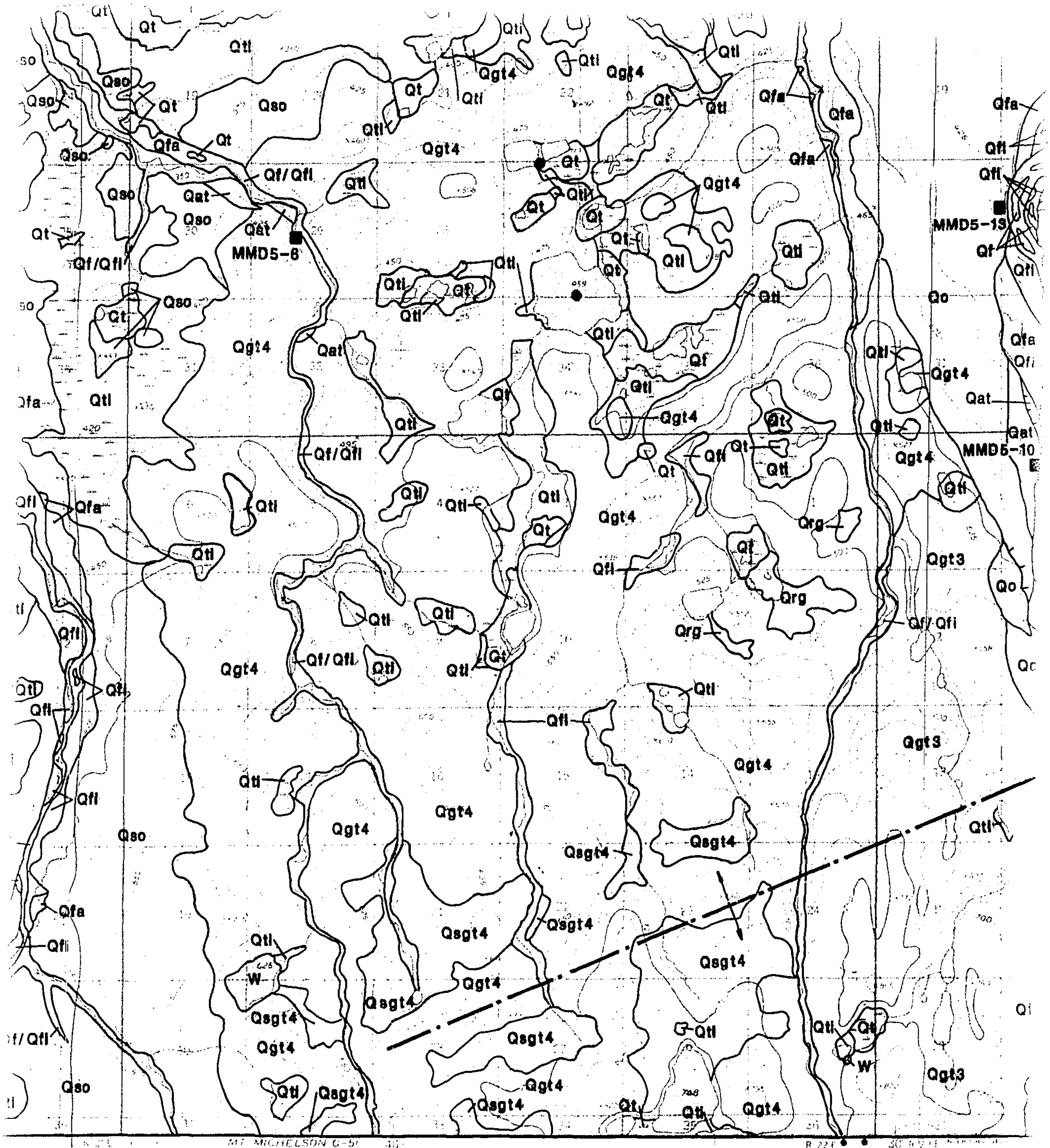
SURFICIAL-GEOLOGY MAP OF T

AND BEECHEY PO



AP OF THE MT. MICHELSON D-5, FLAXMAN ISLAND A-5,

HEY POINT A-1 QUADRANGLES, ALASKA



-5,

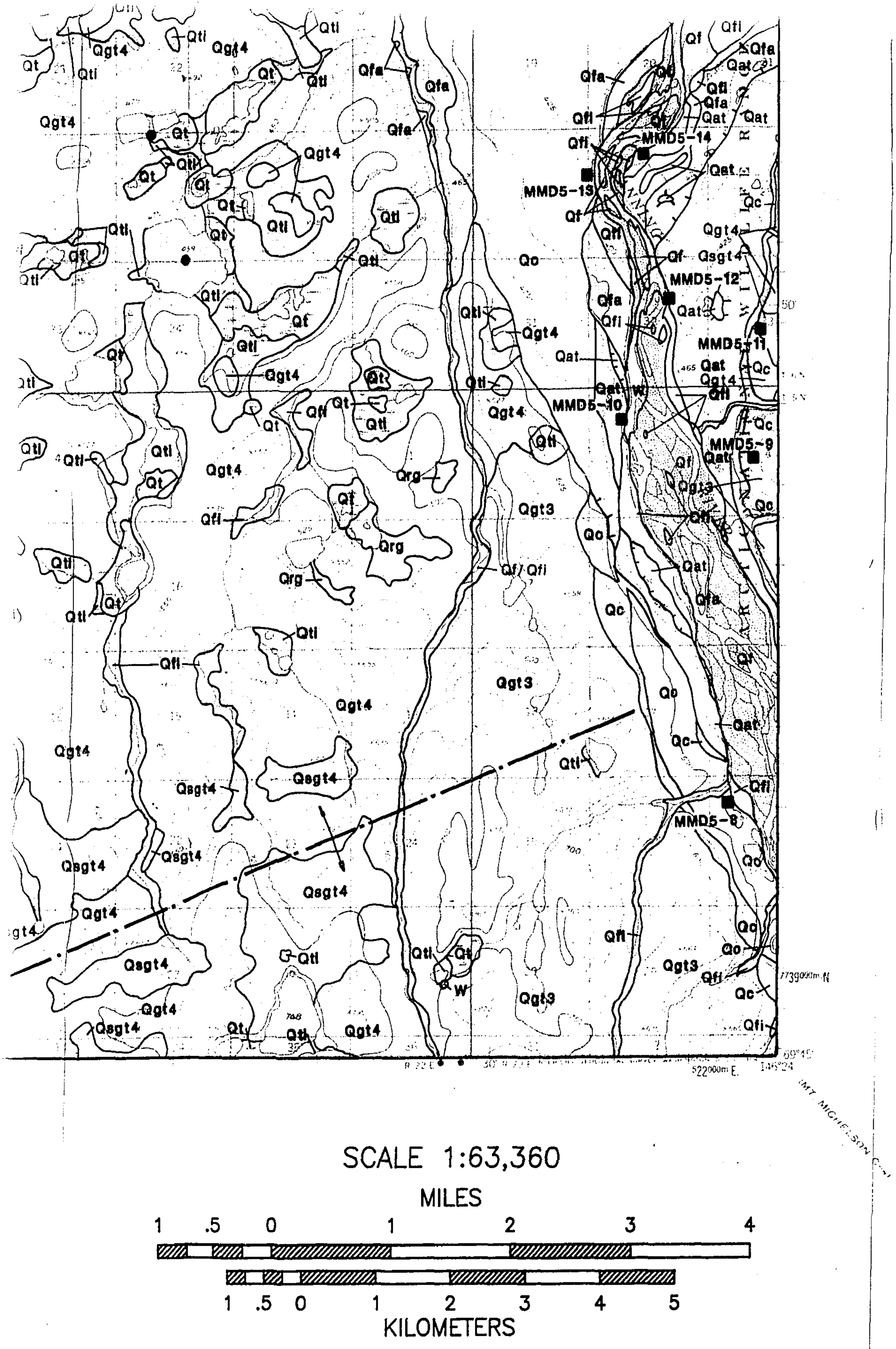
SCALE 1:63,360

MILES

1 .5 0 1 2

1 .5 0 1 2 3 4

KILOMETERS


Qt
Qtl
Qgt4
Qfa
Qo
Qf
Qfl
Qat
Qc
Qsgt4
Qgt3
Qrg
Qf/Qfl
MMD5-14
MMD5-13
MMD5-12
MMD5-11
MMD5-10
MMD5-9
MMD5-8
W
7739000m.N
522000m.E.
MT. MICHELSON
SCALE 1:63,360
MILES
1 .5 0 1 2 3 4
1 .5 0 1 2 3 4 5
KILOMETERS

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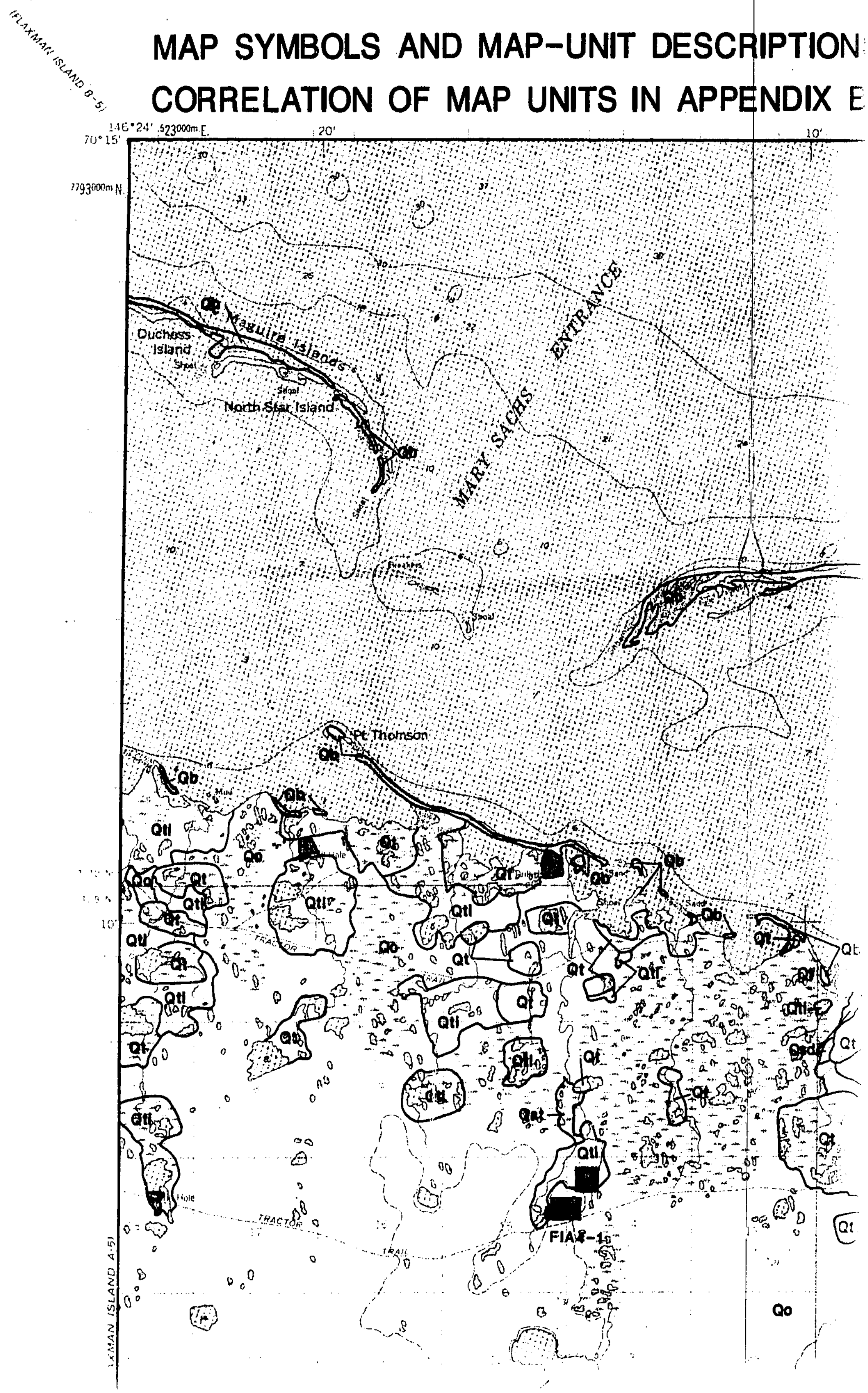
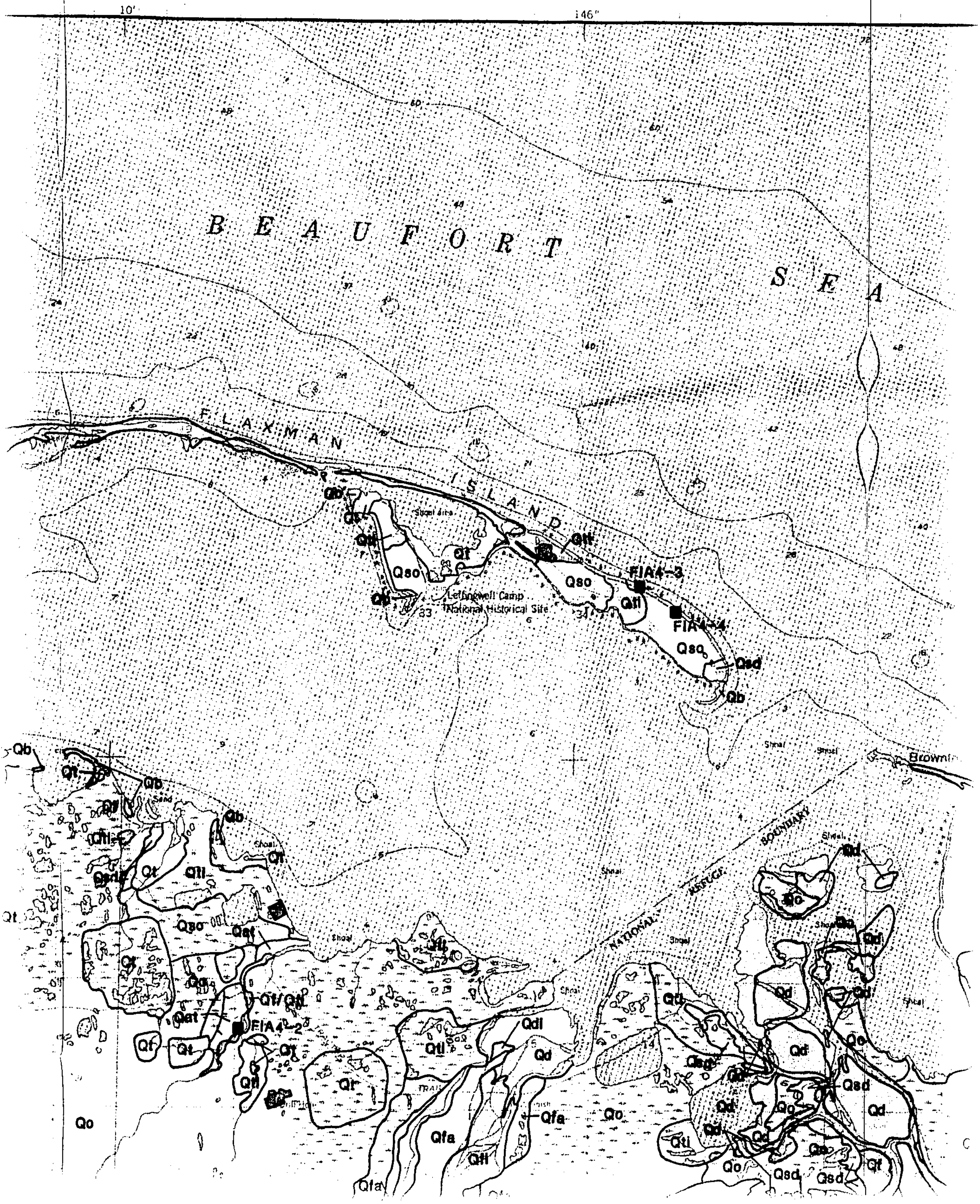
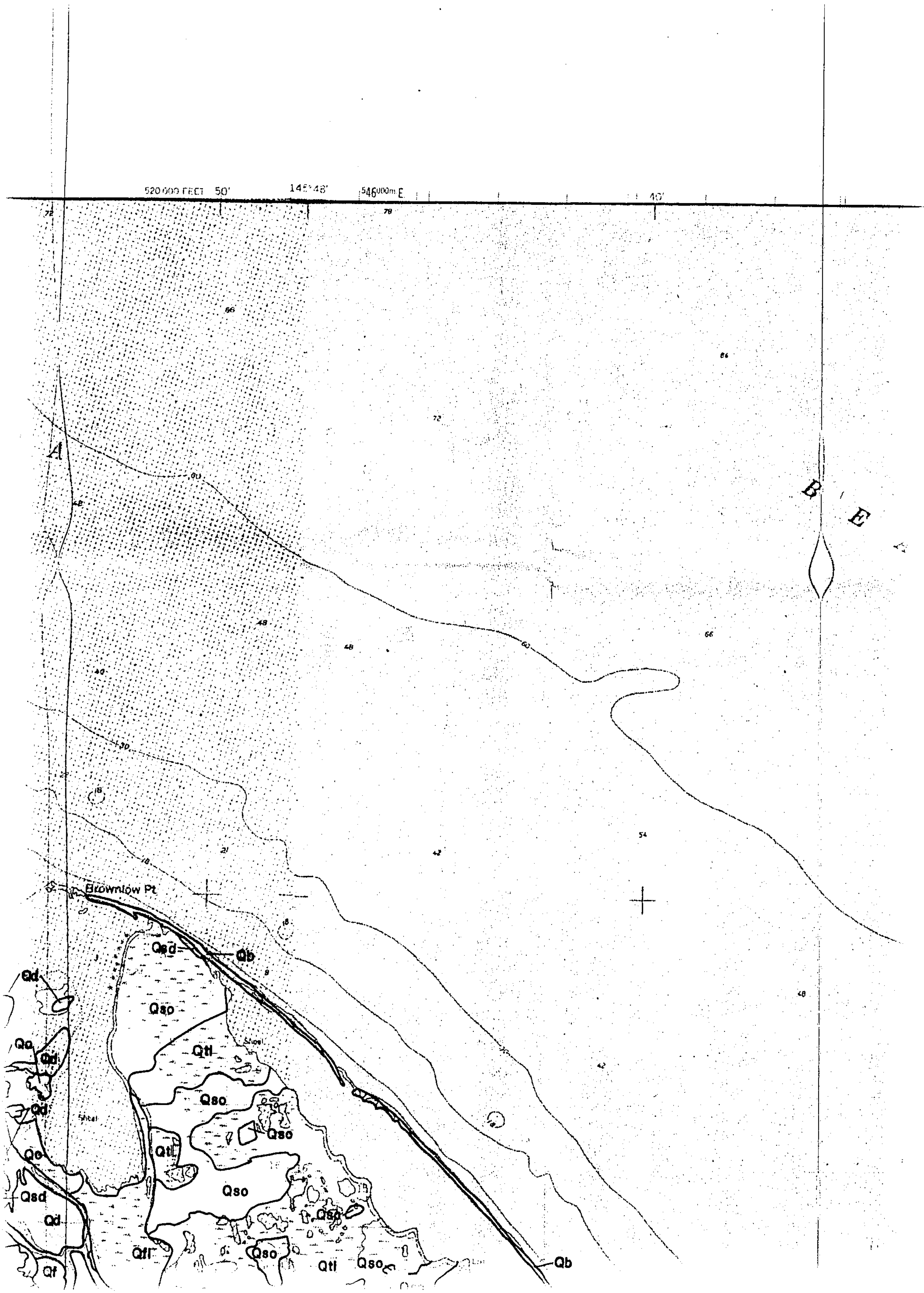
MAP SYMBOLS AND MAP-UNIT DESCRIPTION
CORRELATION OF MAP UNITS IN APPENDIX E



:SCRIPTIONS IN APPENDIX A

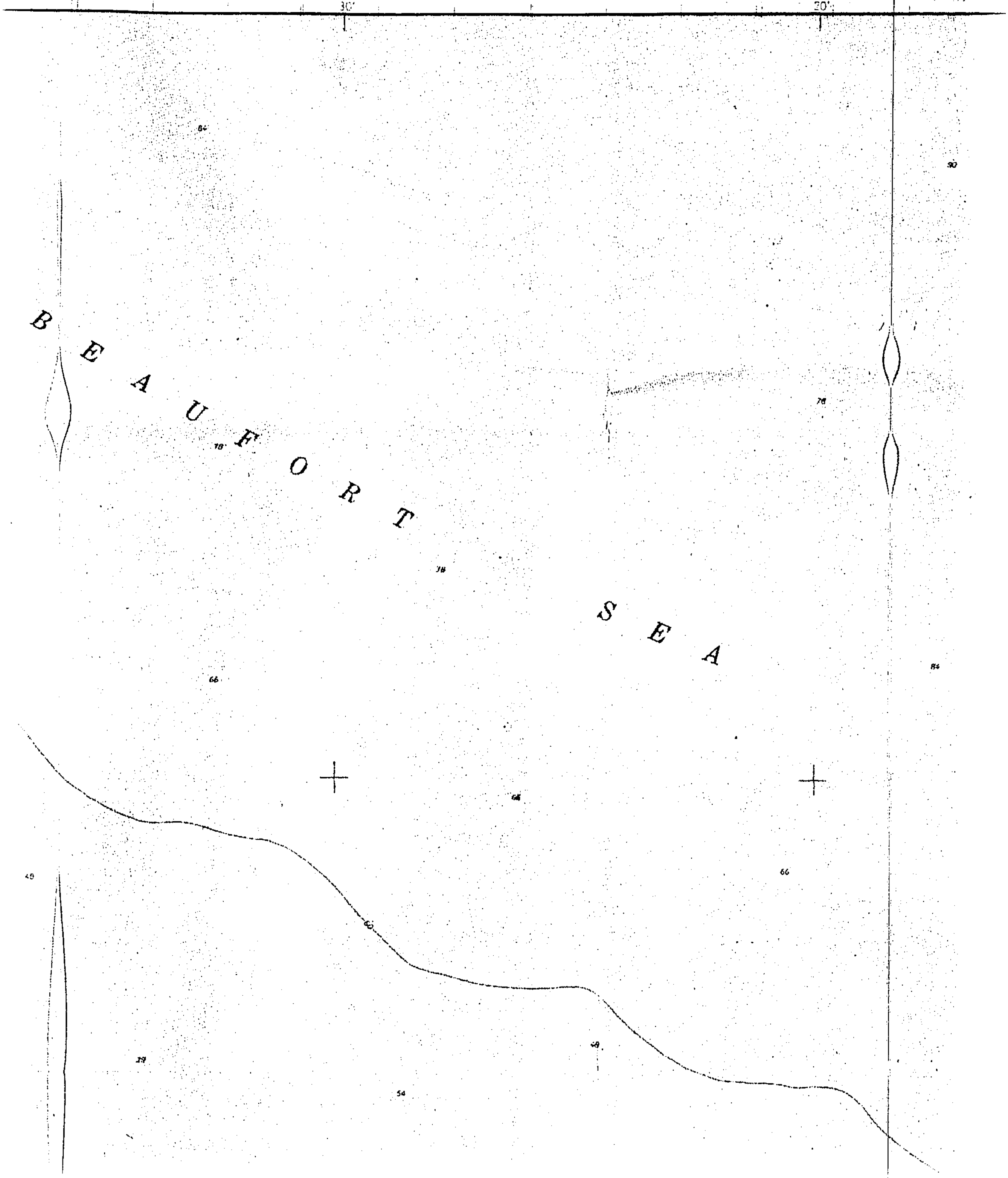
\PPENDIX B



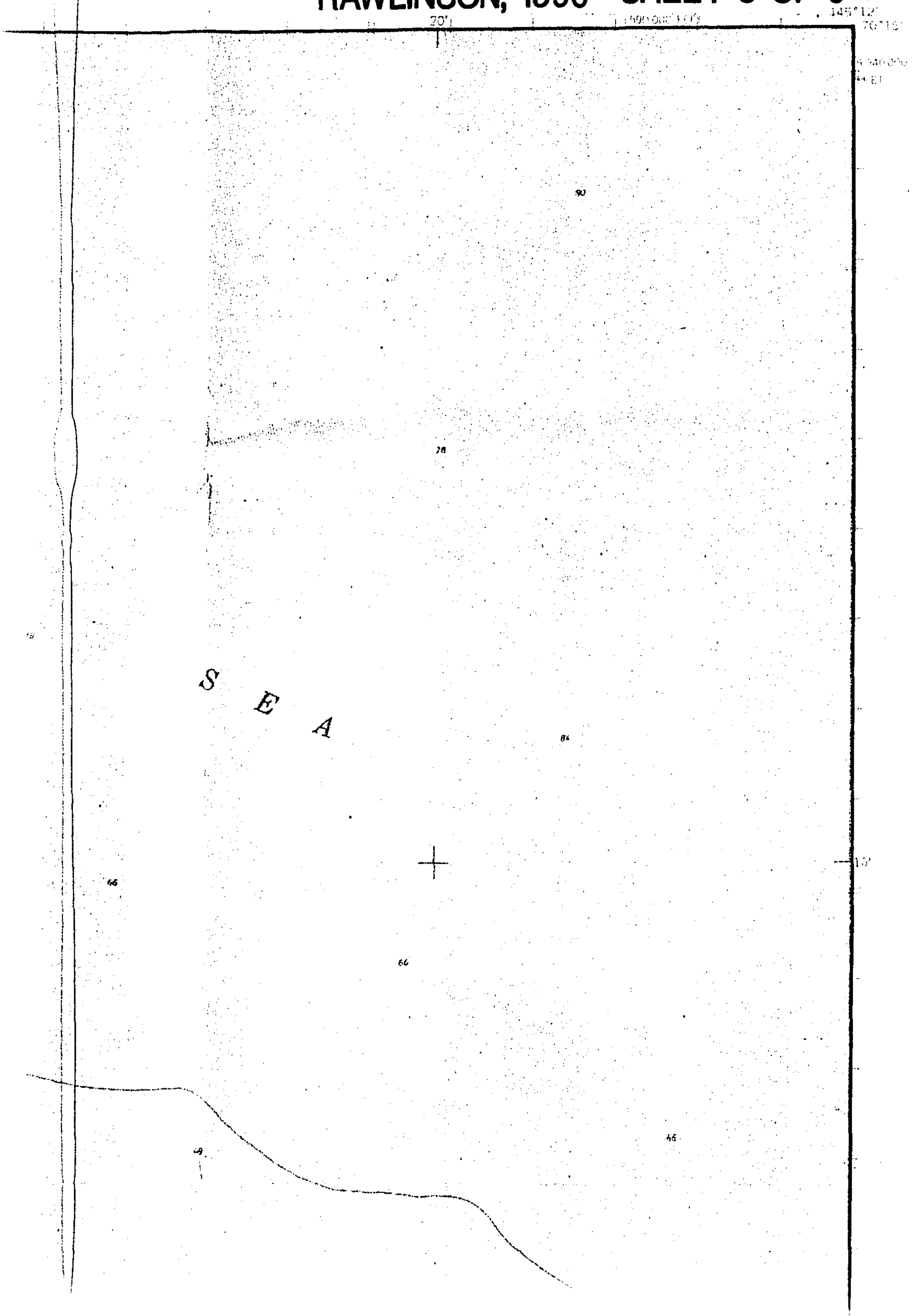


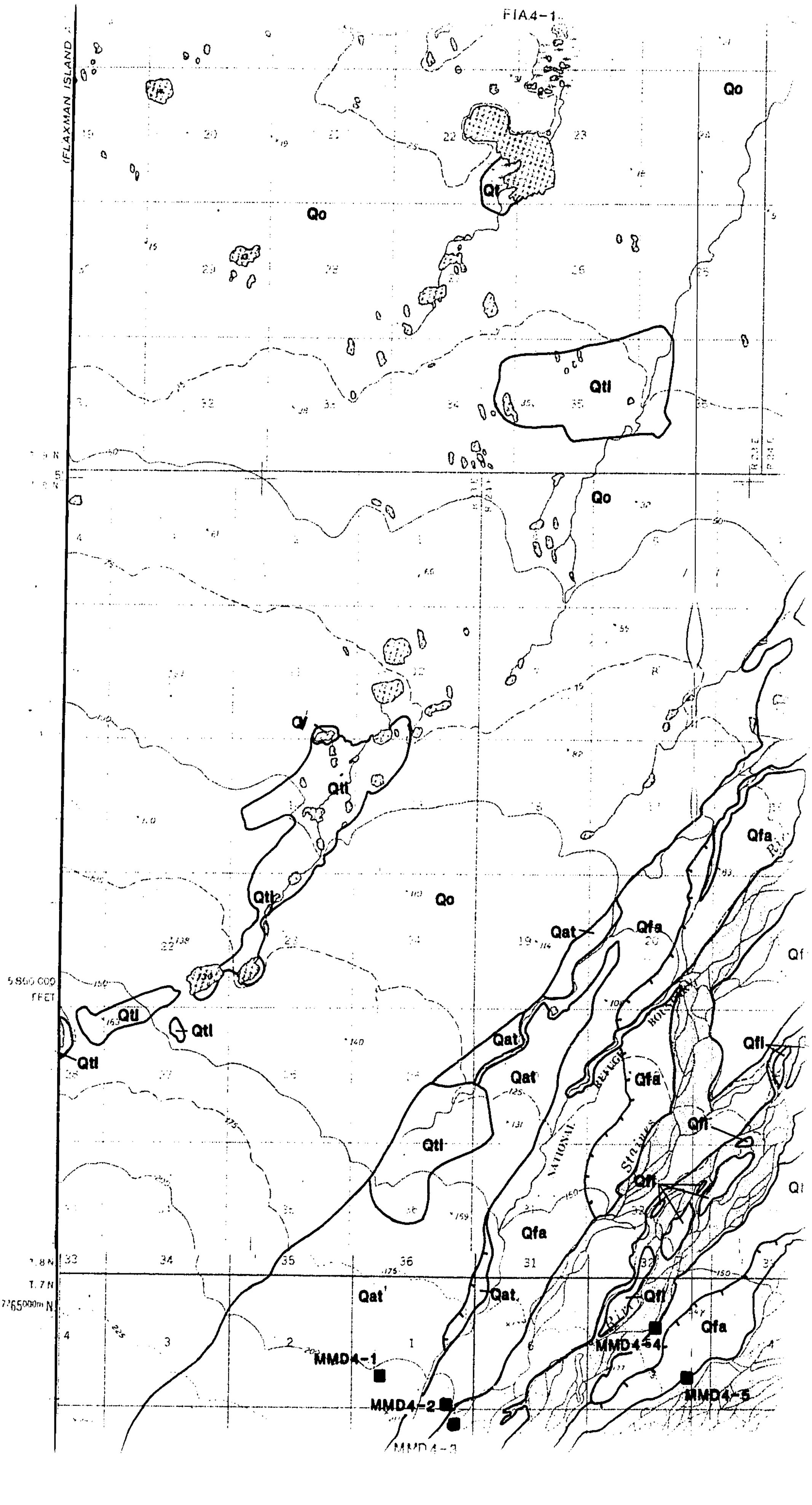
520 000 FEET
50'
145°48'
546000m E
40'
Brownlow Pt
Qsd
Qb
Qd
Qso
Qtl
Qo
Qsd
Qd
Qf
Qso
Qtl
Qso
Qb

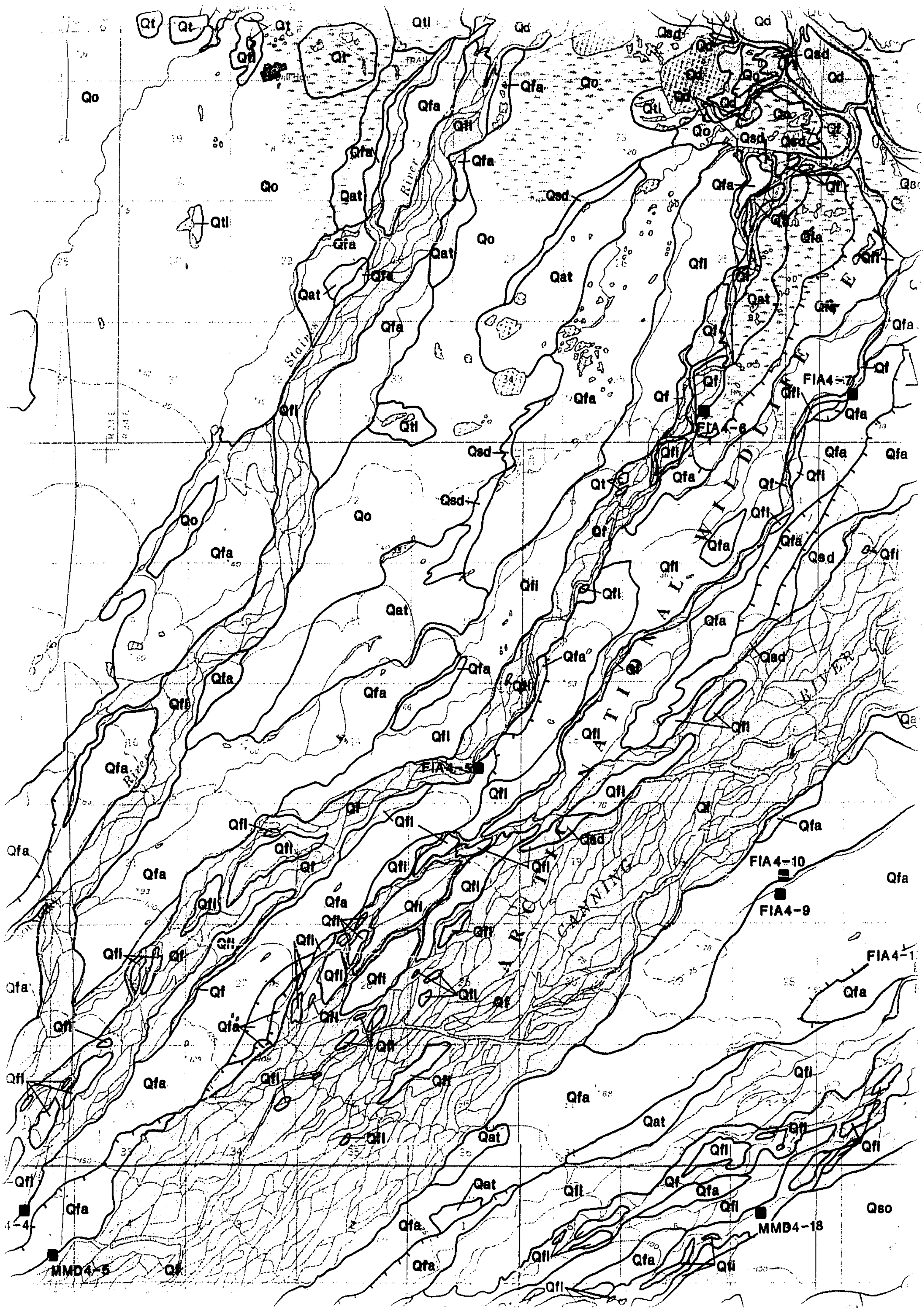
RAWLINSON, 1990

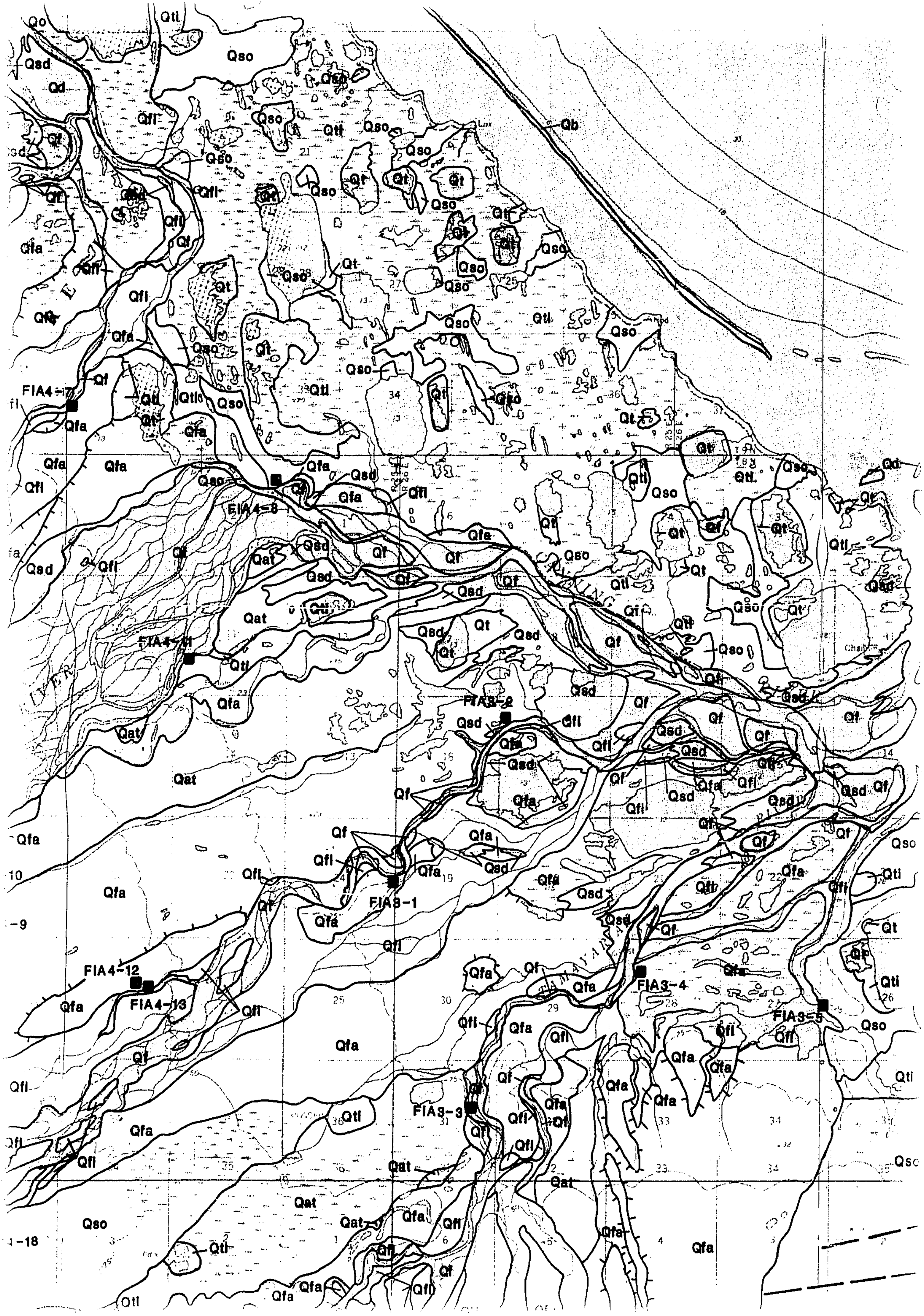


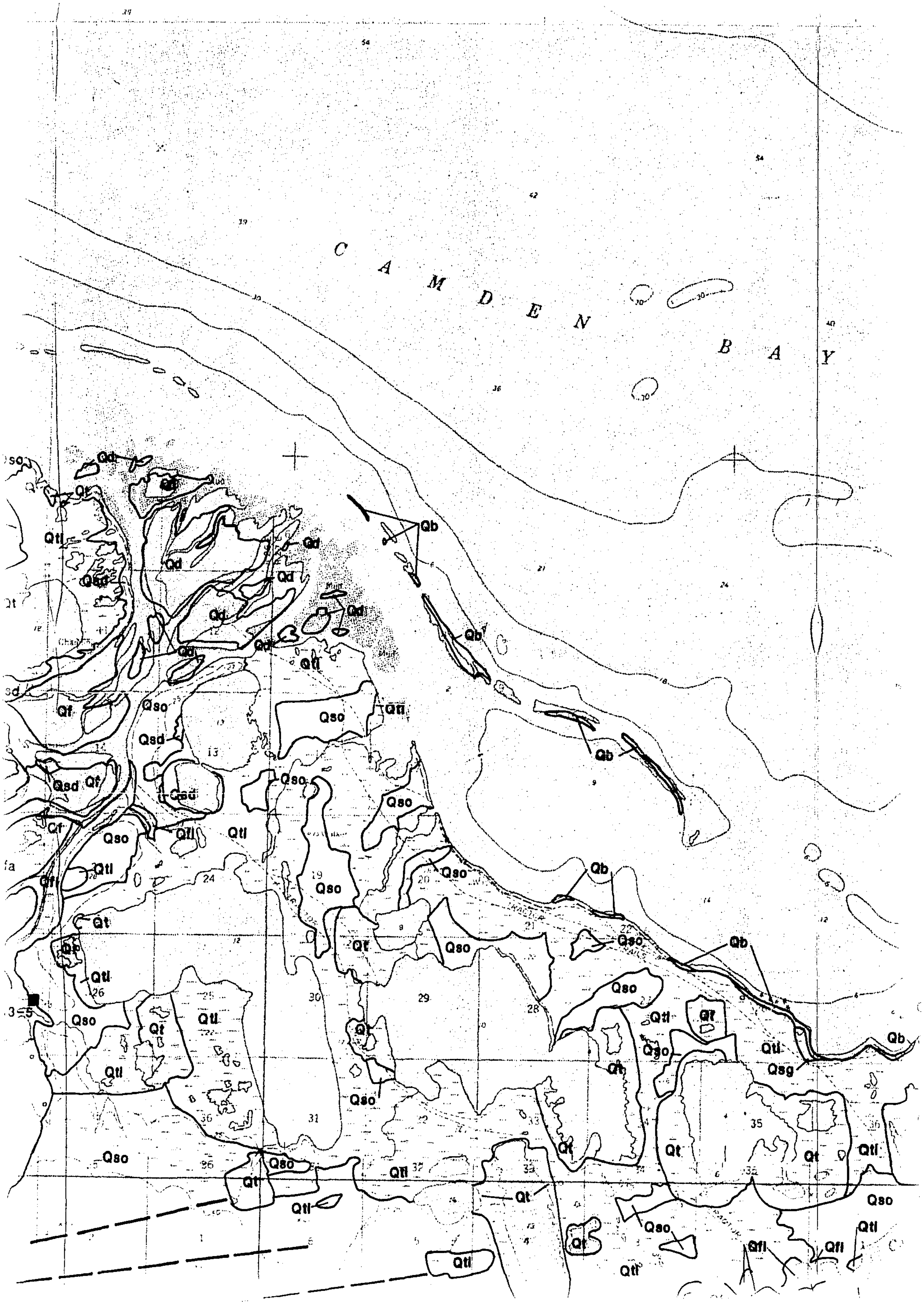
RAWLINSON, 1990 SHEET 5 OF 6

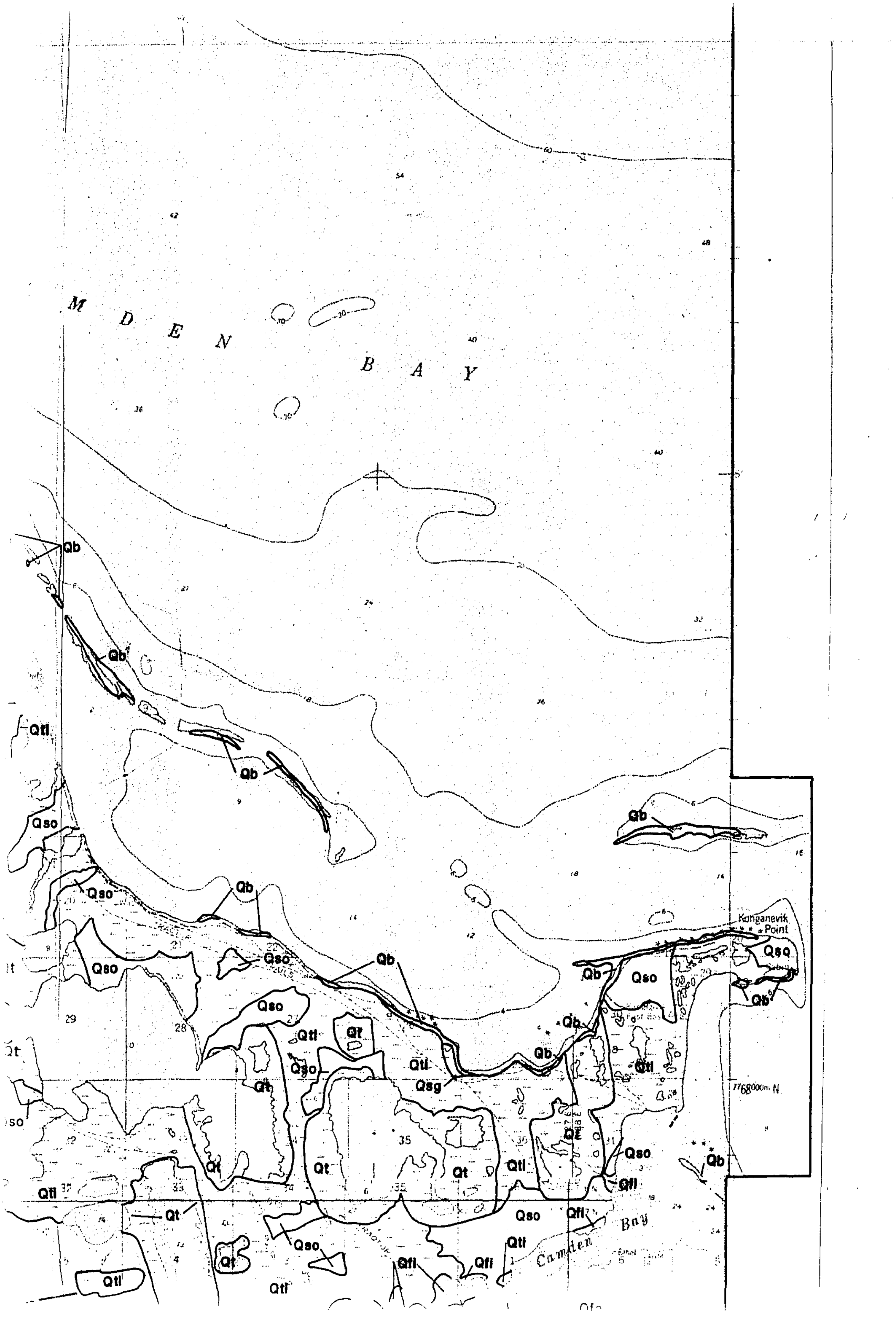


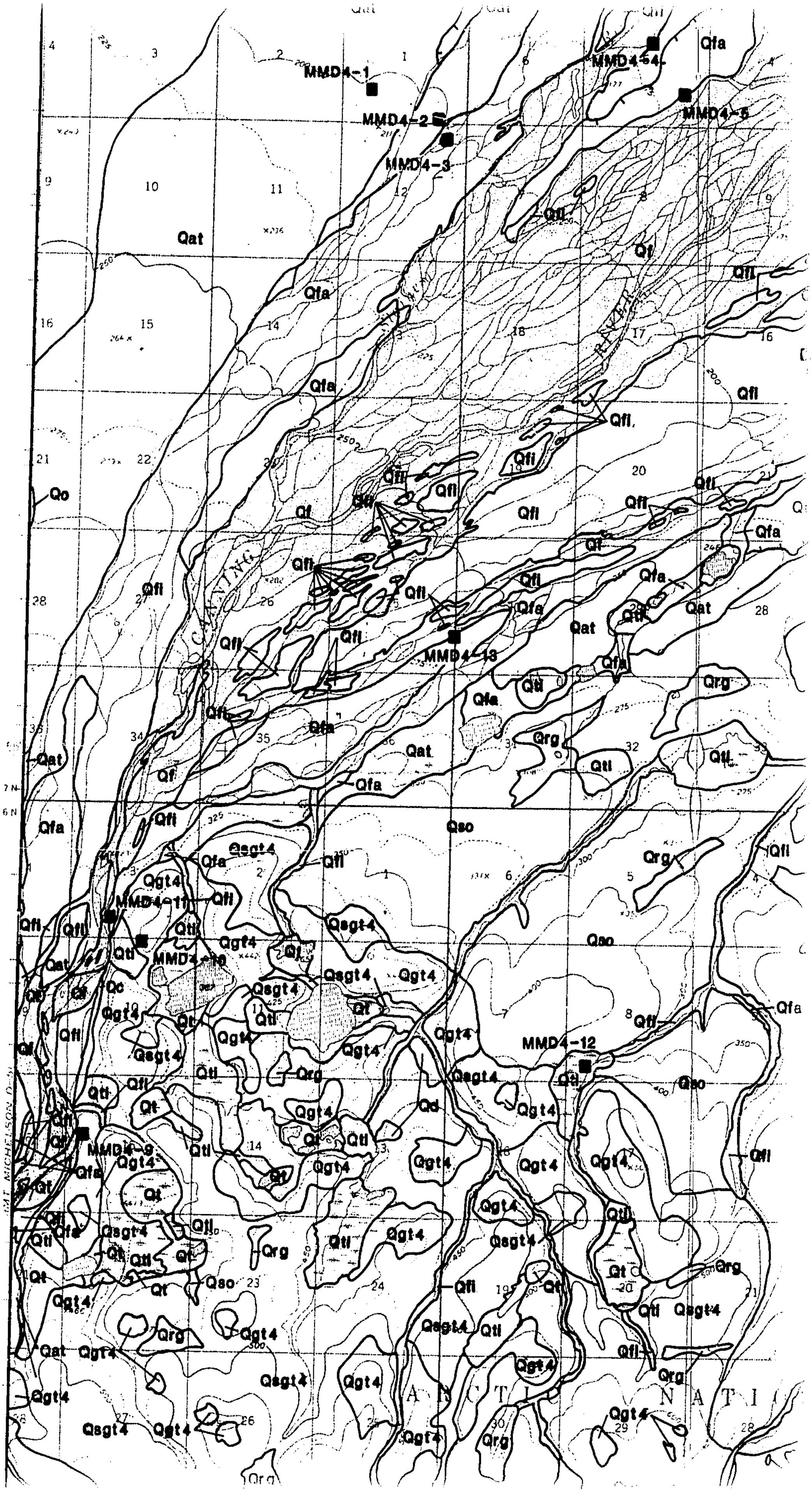

FIA4-1
FLAXMAN ISLAND
Qo
Qtl
Qo
Qtl
Qo
Qtl
Qtl
Qo
Qtl
Qtl
Qtl
Qat
Qfa
Qat
Qat
Qfa
Qfl
Qtl
Qfl
Qfl
Qfa
Qat
Qat
Qfl
Qfa
MMD4-1
MMD4-2
MMD4-4
MMD4-5
NATIONAL
T.8 N
T.7 N
5,860,000 FEET
765000m N


Qt
Qtl
Qo
Qfa
Qfl
Qat
Qsd
Qd
Qf
Qso
Stain River
FIA4-7
FIA4-6
FIA4-5
FIA4-10
FIA4-9
FIA4-1
MMD4-18
MMD4-5
4-4
CANNING
RIVER
ARCTIC NATIONAL WILDLIFE

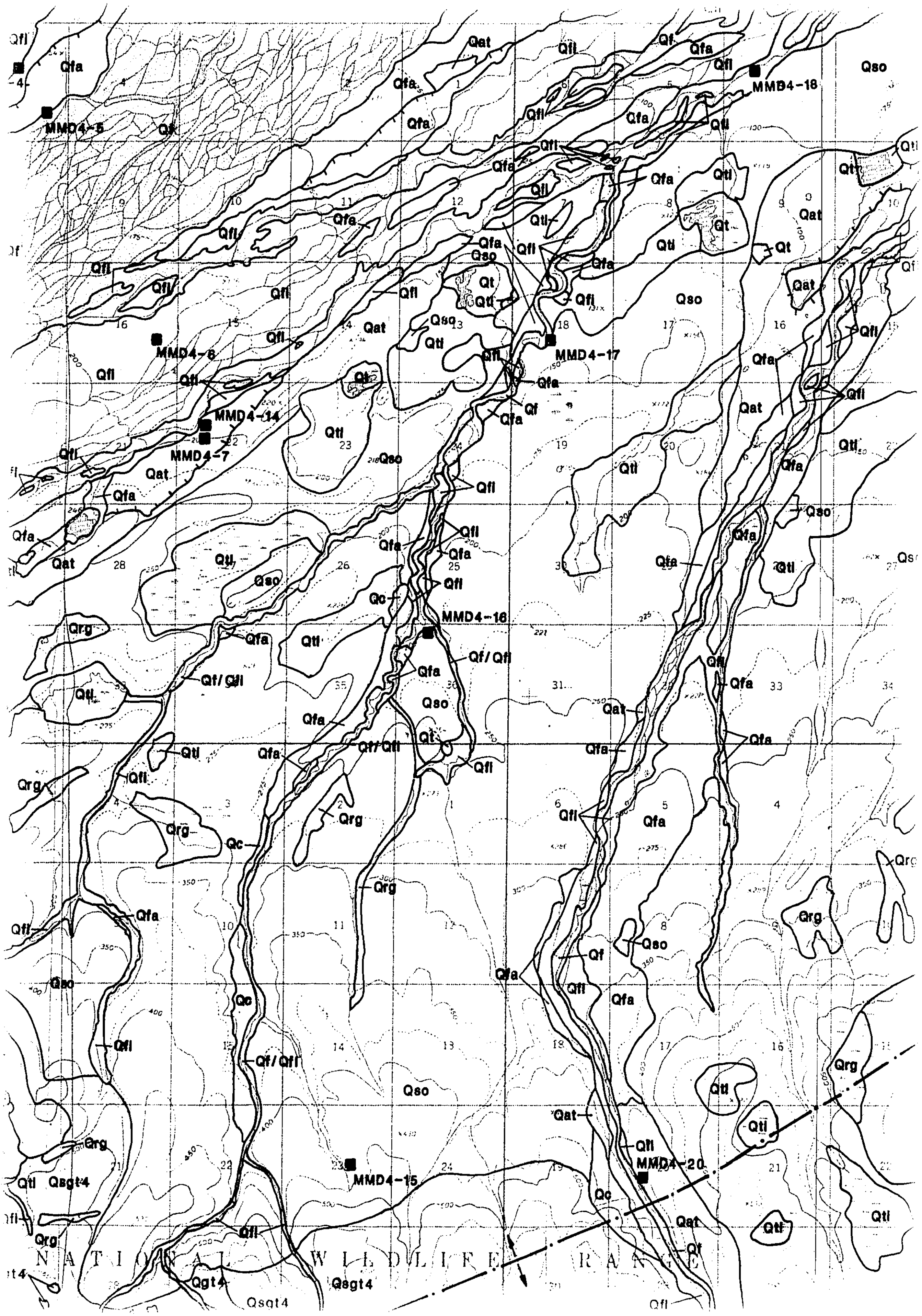

FIA4-7
FIA4-8
FIA4-11
FIA3-2
FIA3-1
FIA4-12
FIA4-13
FIA3-4
FIA3-5
FIA3-3
Qso
Qsd
Qd
Qfl
Qt
Qtl
Qf
Qfa
Qat
Qb
Qo

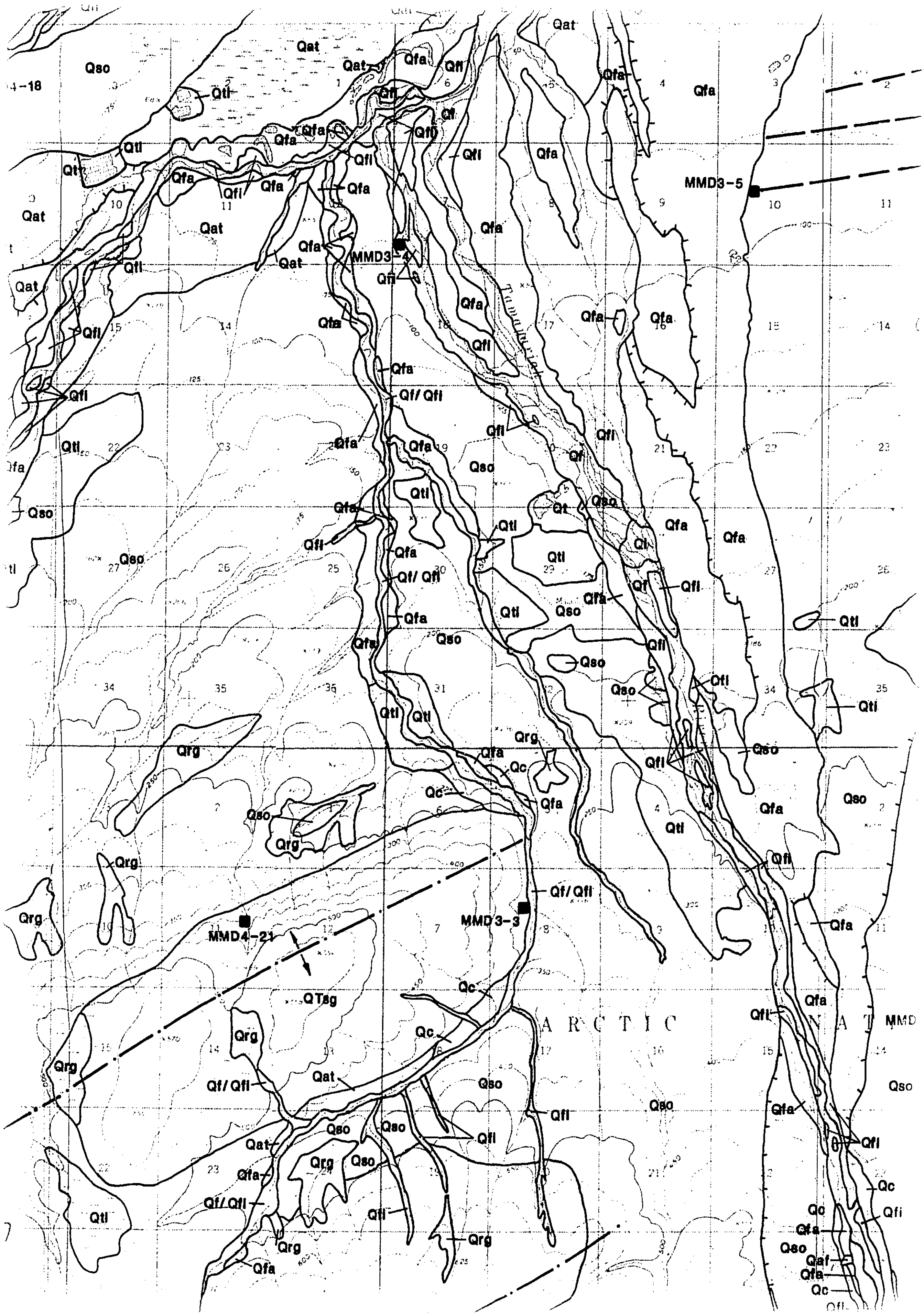

C A M D E N B A Y
Qb
Qd
Qsd
Qt
Qtl
Qf
Qso
Qsg
Qfl

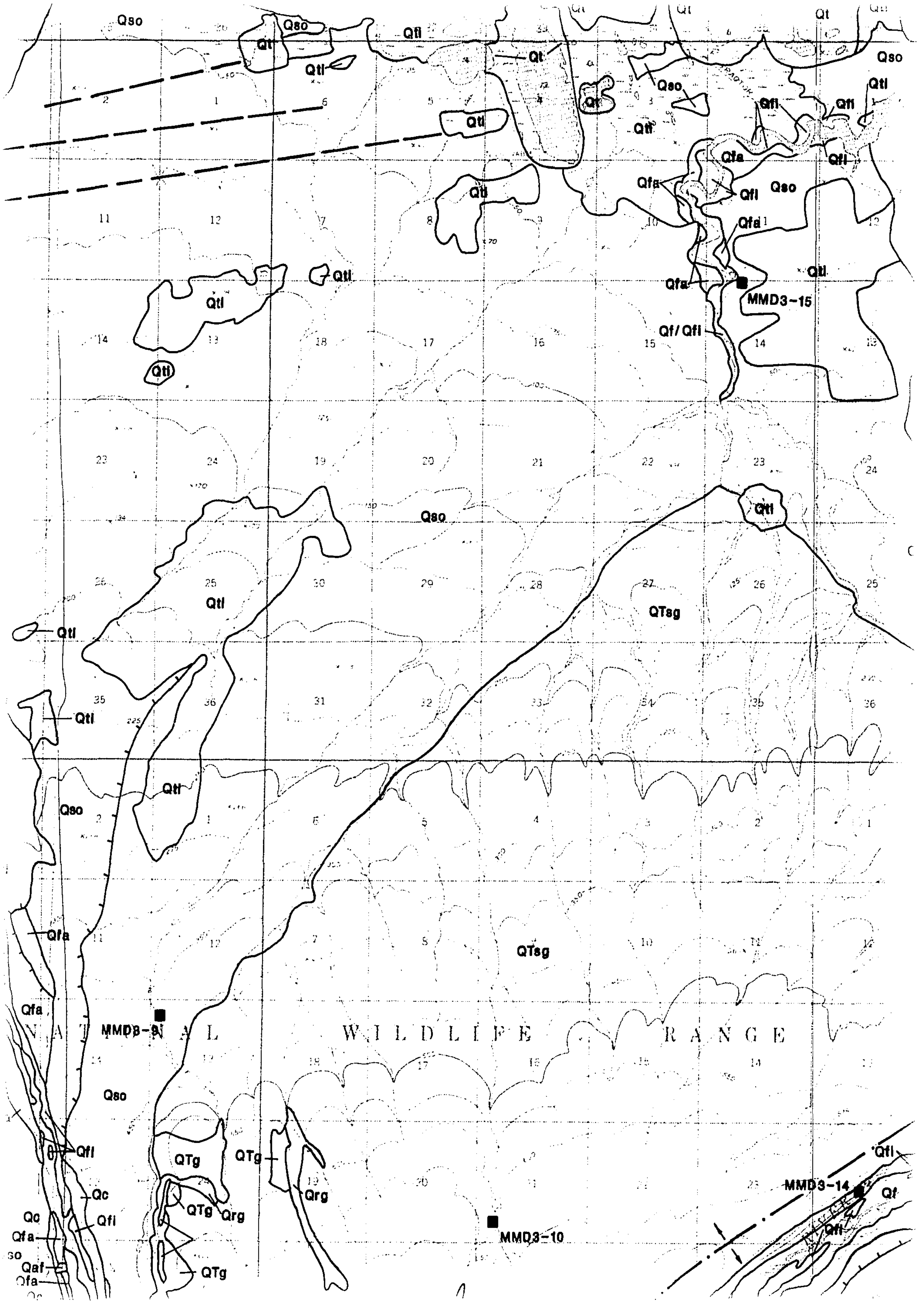

M D E N B A Y
Qb
Qtl
Qso
Qsg
Qt
Qfl
Konganevik Point
Camden Bay
7768000m N

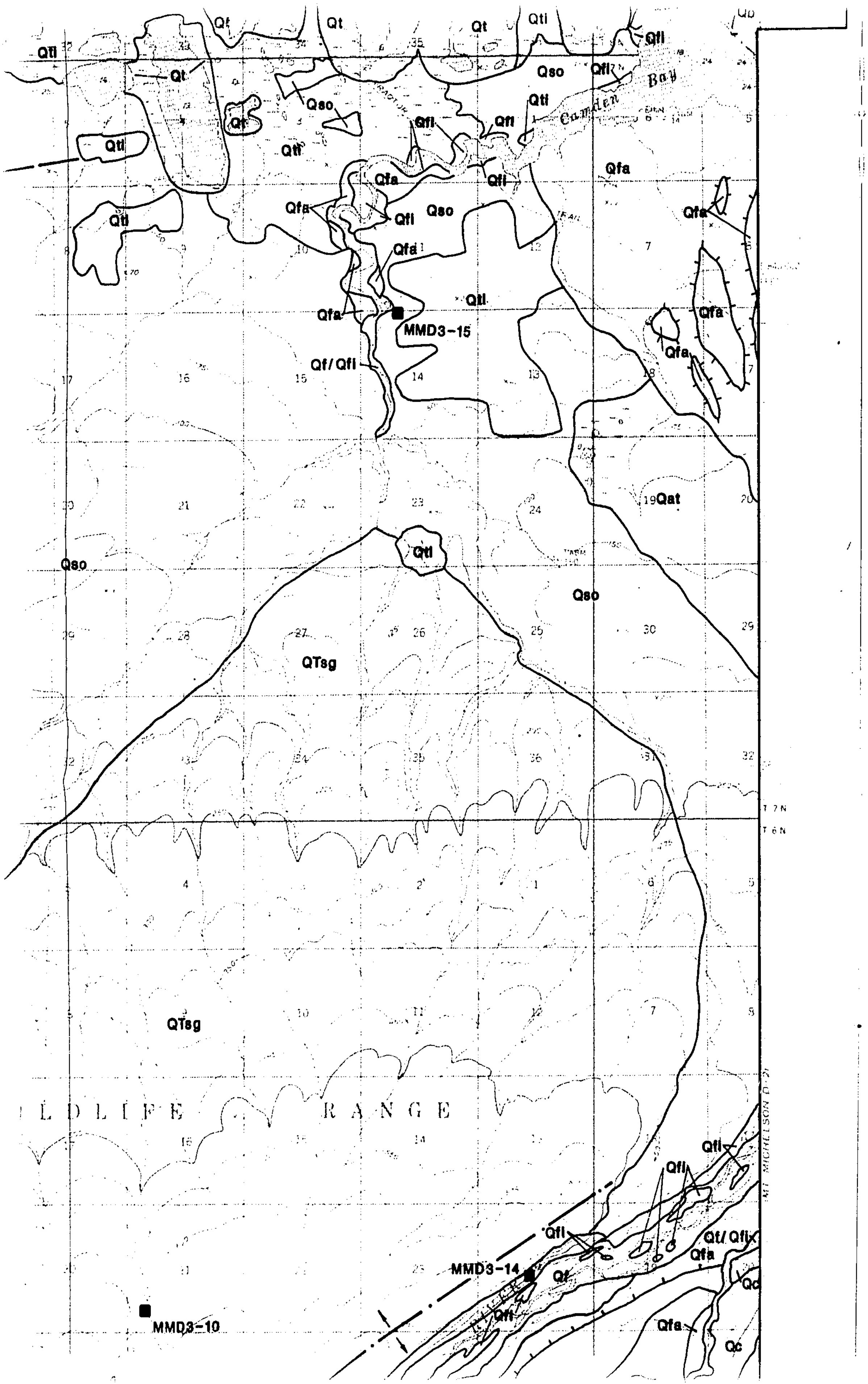


MMD4-1
MMD4-2
MMD4-3
MMD4-4
MMD4-5
MMD4-9
MMD4-10
MMD4-11
MMD4-12
MMD4-13
Qat
Qfa
Qfl
Qf
Qo
Qso
Qgt4
Qsgt4
Qrg
Qtl
Qt
Qc
Qd
T. 7 N
T. 6 N
CANNING

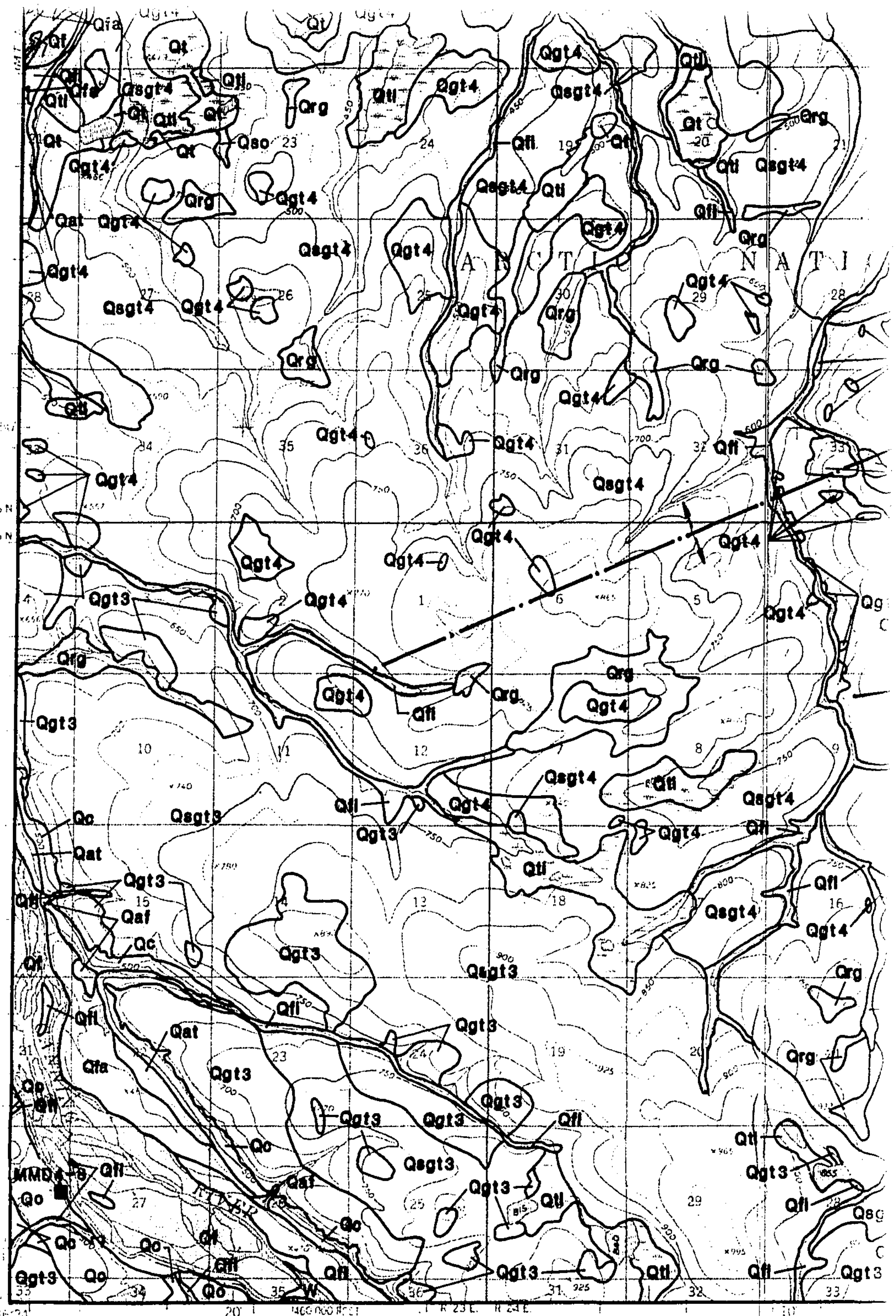

MMD4-5
MMD4-6
MMD4-7
MMD4-14
MMD4-15
MMD4-16
MMD4-17
MMD4-18
MMD4-20
Qfl
Qfa
Qat
Qso
Qtl
Qt
Qf
Qc
Qrg
Qf/Qfl
Qsgt4
Qgt4
NATIONAL WILDLIFE RANGE


Qso
Qat
Qfa
Qfl
Qtl
Qf
MMD3-5
MMD3-4
MMD3-3
MMD4-21
Qf/Qfl
Qc
Qrg
QTsg
Qaf
A R C T I C
N A T
MMD


Qso
Qt
Qfl
Qtl
Qso
Qfa
Qf/Qfl
MMD3-15
QTsg
Qc
Qaf
QTg
Qrg
MMD3-9
MMD3-10
MMD3-14
Qf
W I L D L I F E
R A N G E

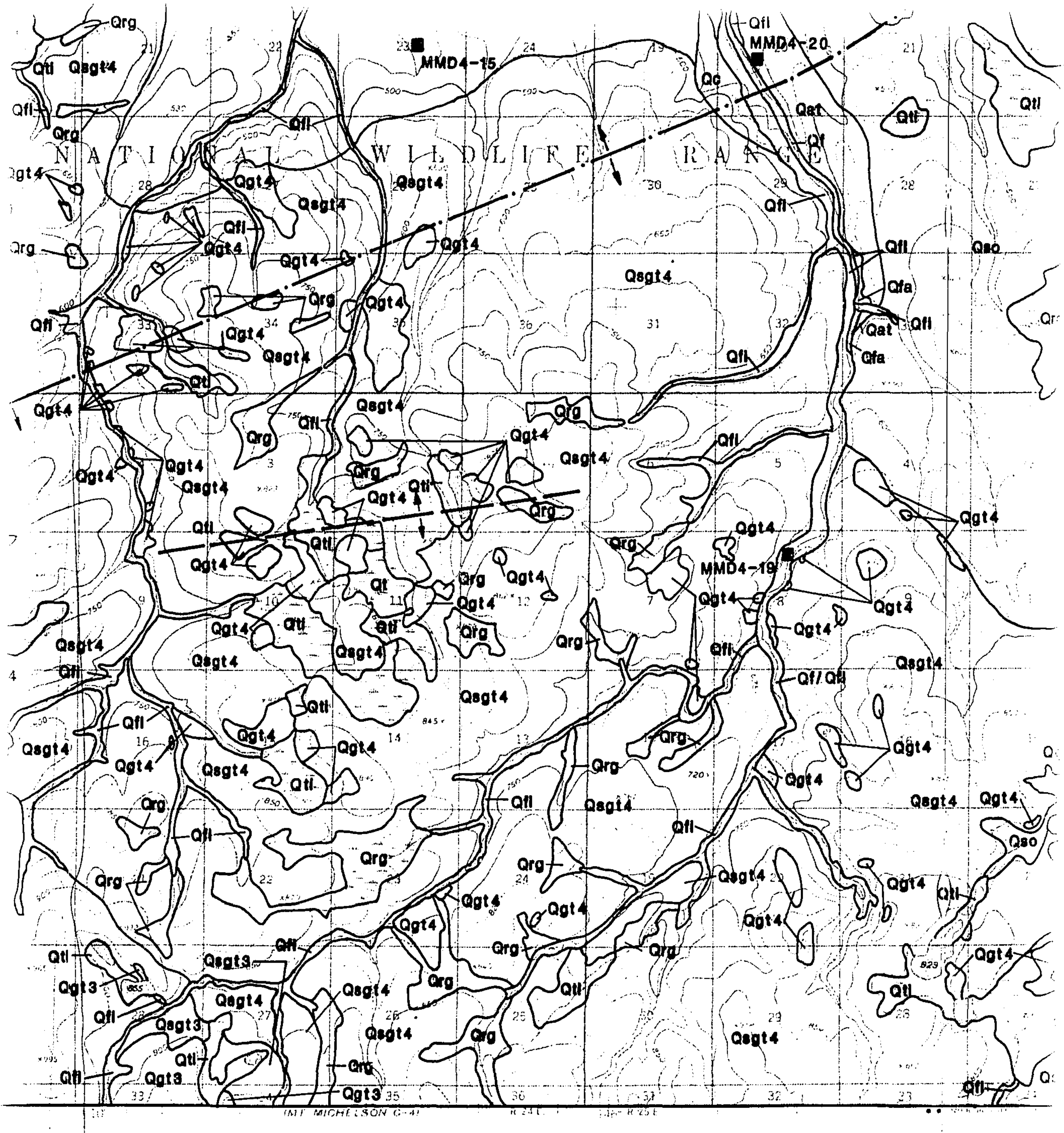


Qtl
Qt
Qso
Qfl
Camden
Bay
Qfa
Qti
MMD3-15
Qf/Qfl
Qat
QTsg
T 7 N
T 6 N
R A N G E
Qt/Qfl
MMD3-14
Qf
Qc
MMD3-10



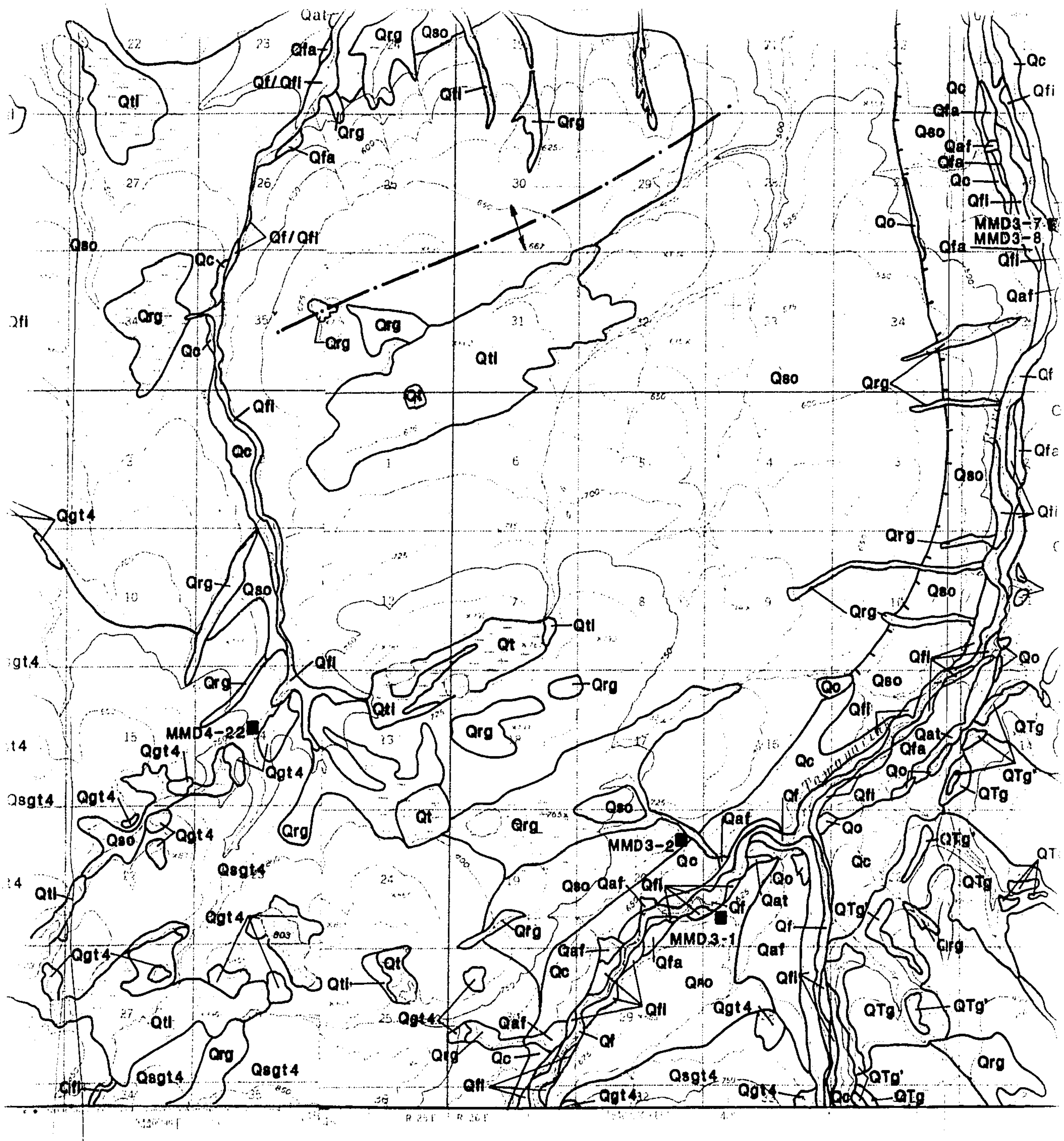
GEOLOGY MAPPED BY O.J. FERRIANS, JR., 1973, 1975; L.D. CARTER AND J.P. GALLOWAY, 1983
S.E. RAWLINSON, CARTER, AND D.R. HICKMOTT, 1985; AND RAWLINSON, 1988–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY MT. MICHELSON D-3, 1955; D-4, 1955;
FLAXMAN ISLAND A-3, 1955; AND A-4, 1955.



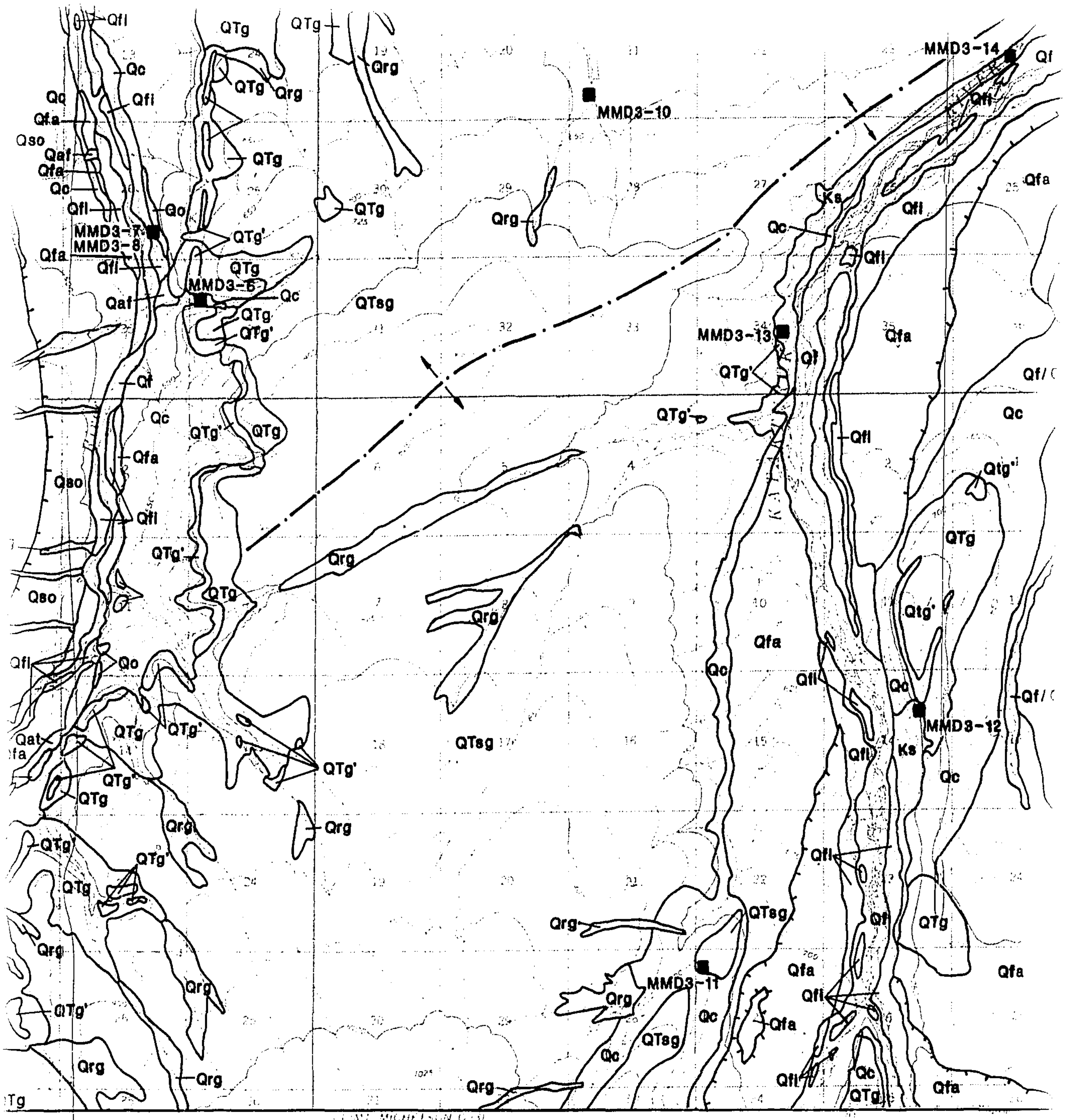
J.P. GALLOWAY, 1983–1984;
1988–1989
–4, 1955;

SURFICIAL–GEOLOGY M
AND FLAXMAN ISLAN



OLOGY MAP OF THE MT. MICHELSON D-3 AND D-4,

N ISLAND A-3 AND A-4 QUADRANGLES, ALASKA



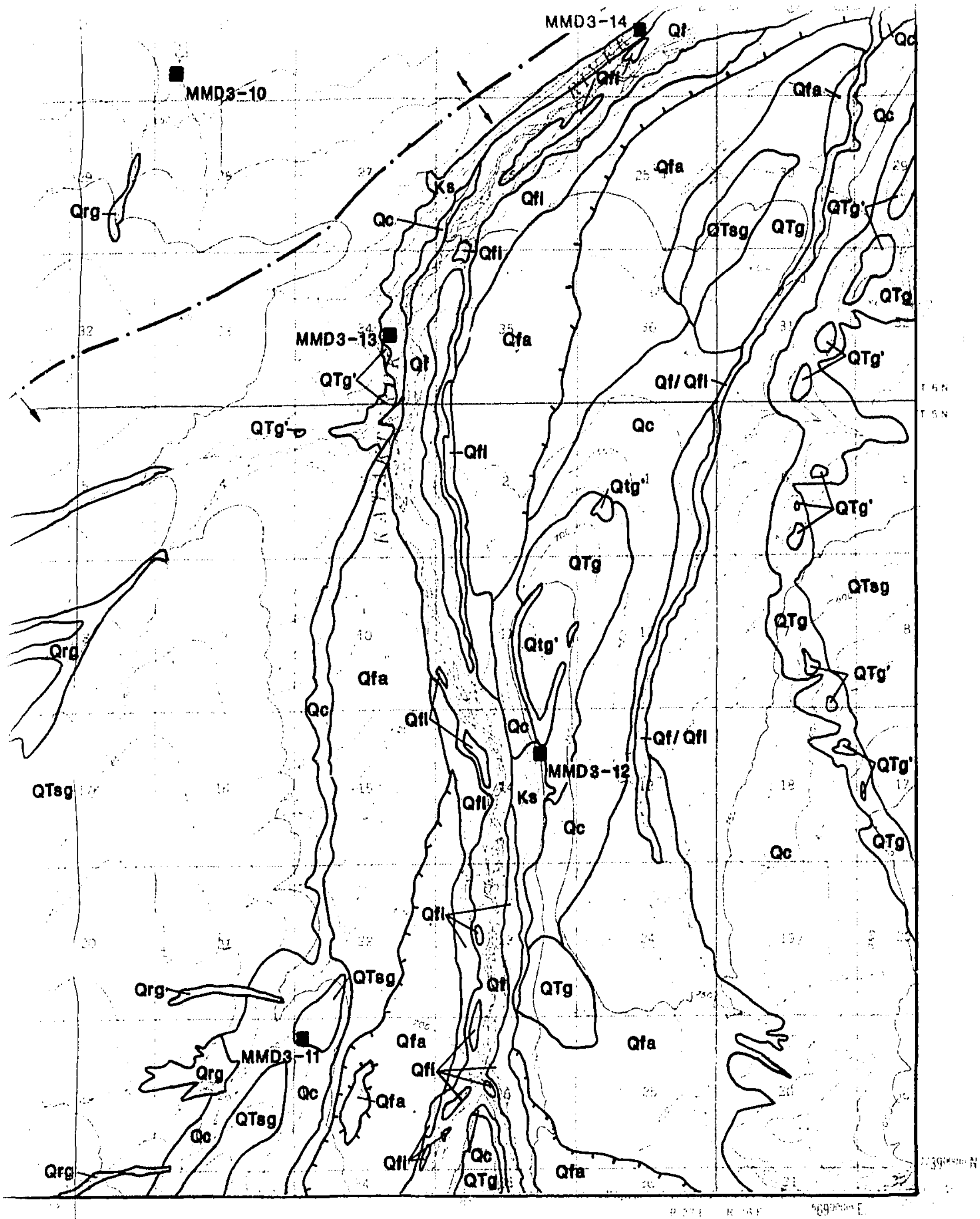
SCALE 1:63,360

MILES

1 .5 0 1 2

1 .5 0 1 2 3

KILOMETERS



SCALE 1:63,360

MILES

1 .5 0 1 2 3 4

1 .5 0 1 2 3 4 5

KILOMETERS

PLEASE NOTE:

Oversize maps and charts are filmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

The following map or chart has been refilmed in its entirety at the end of this dissertation (not available on microfiche). A xerographic reproduction has been provided for paper copies and is inserted into the inside of the back cover.

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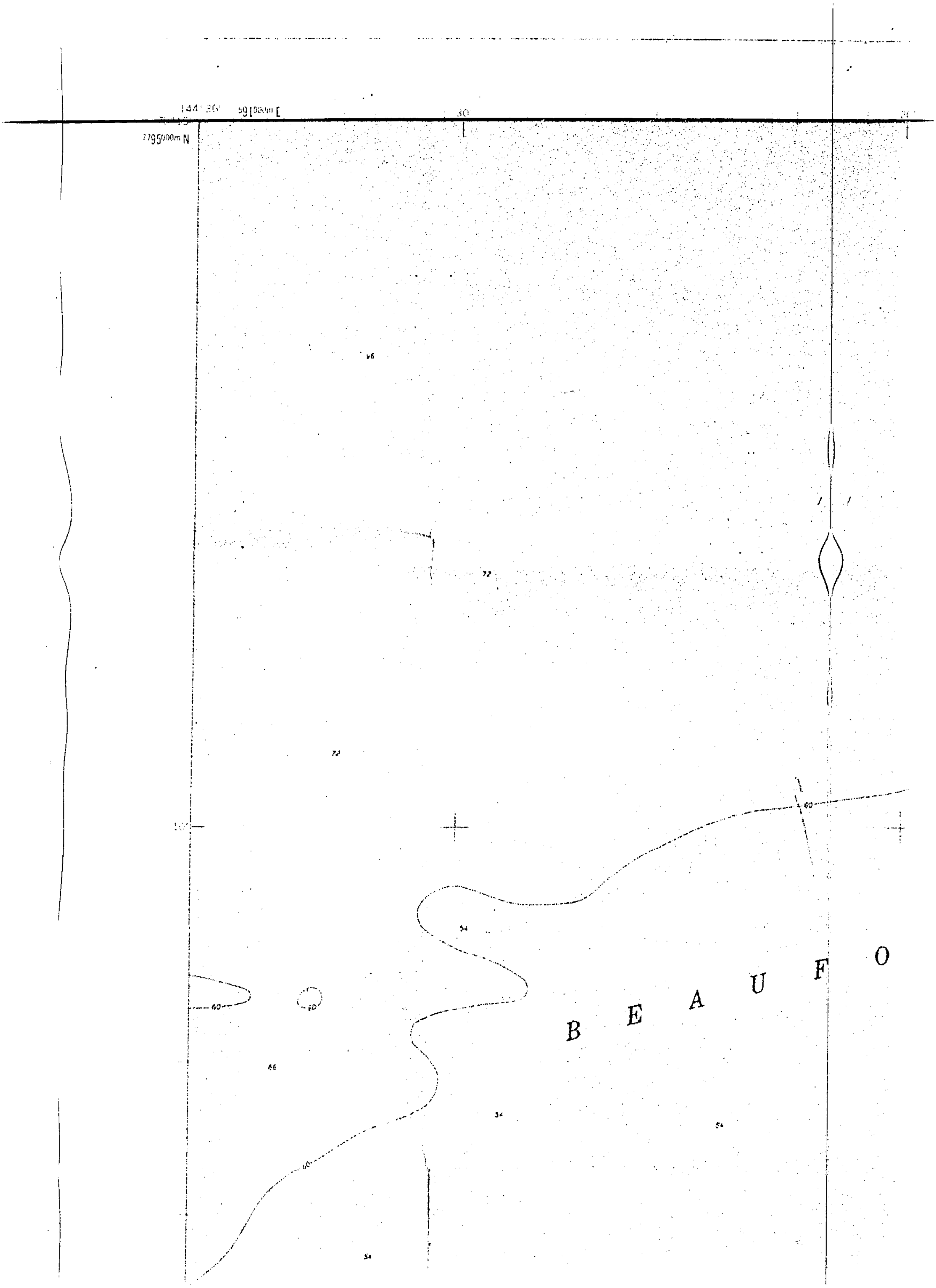
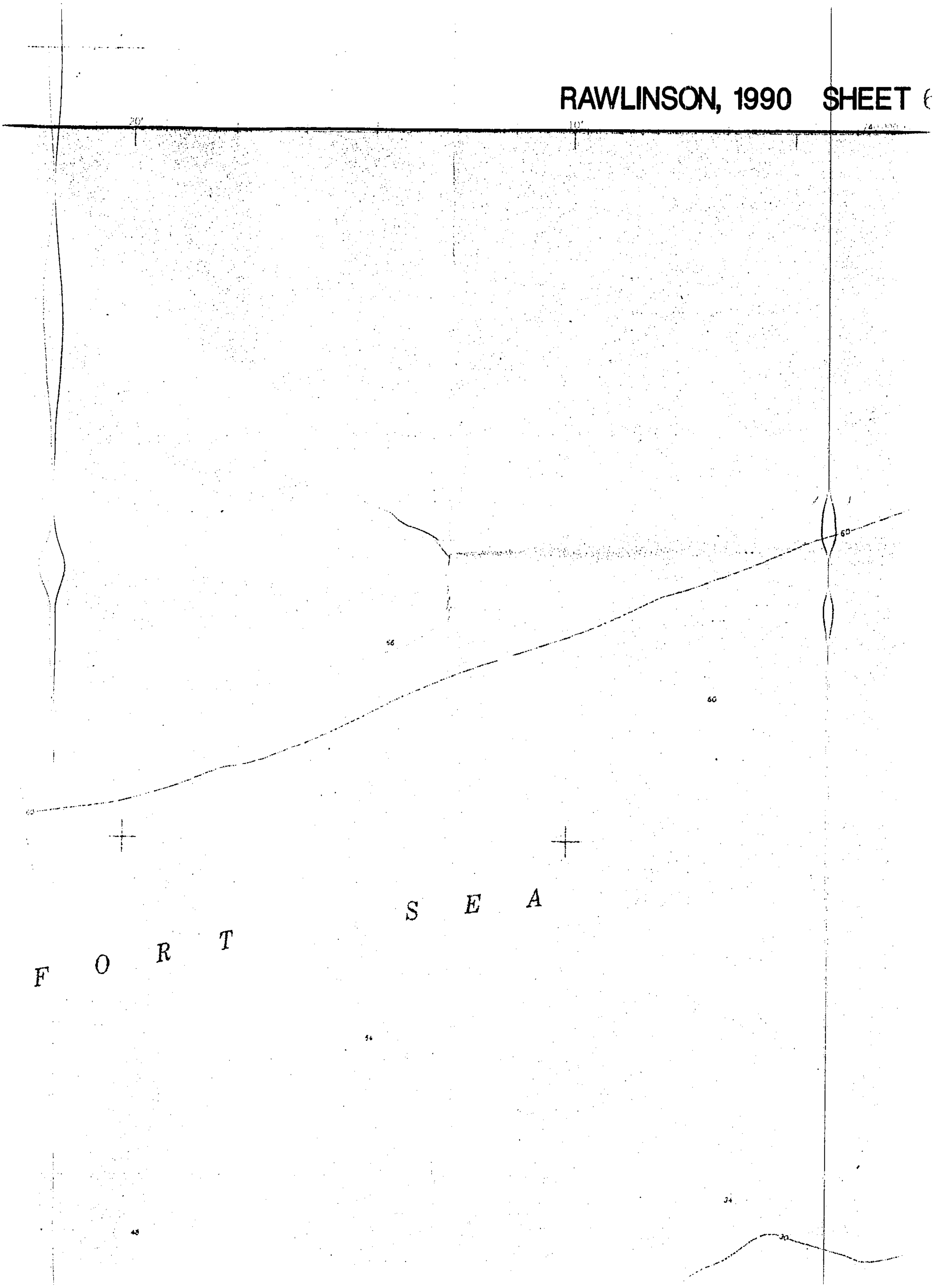
MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN A
CORRELATION OF MAP UNITS IN APPENDIX B

ONS IN APPENDIX A

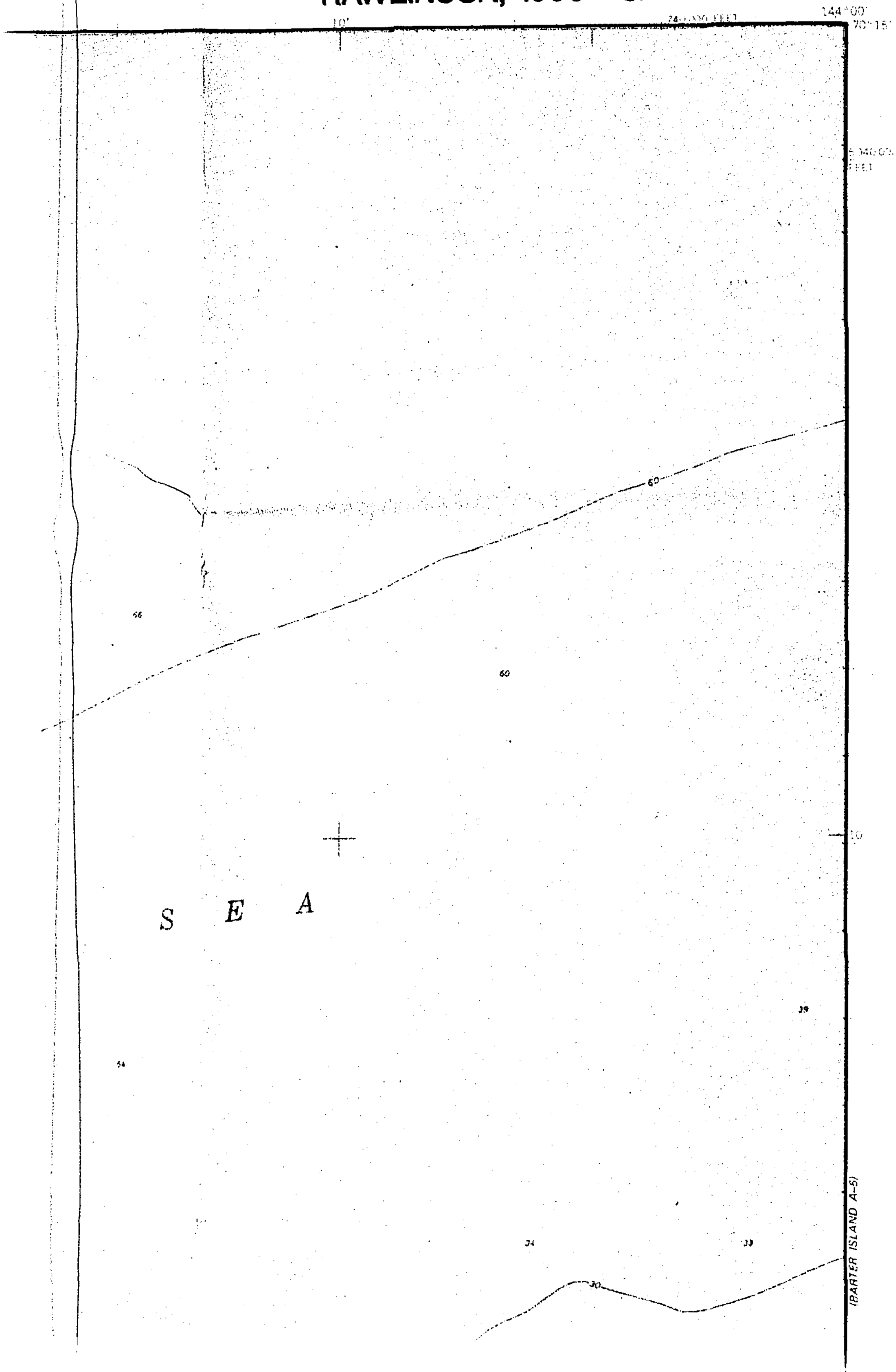
X B

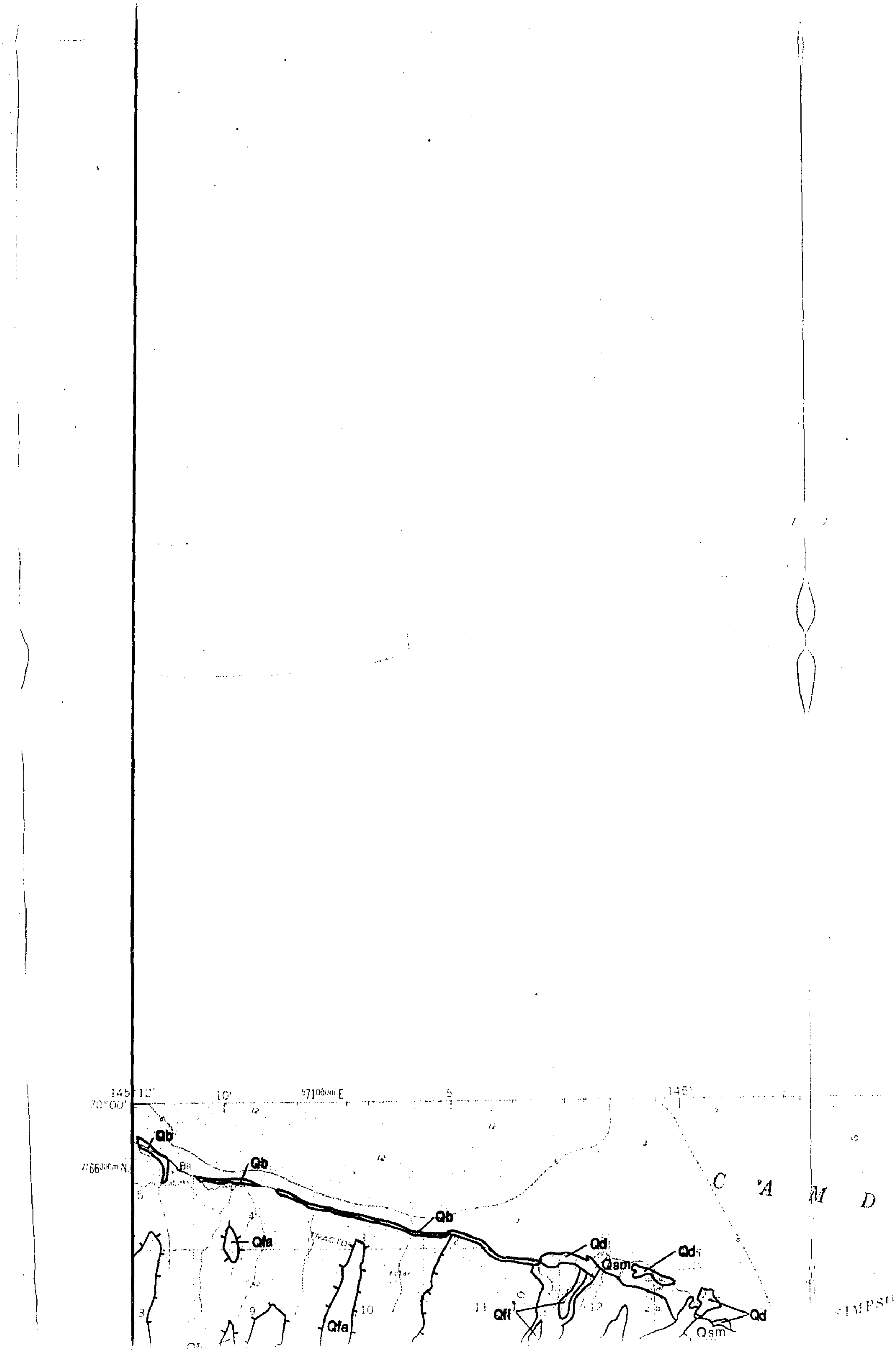

B E A U F O

RAWLINSON, 1990 SHEET 6

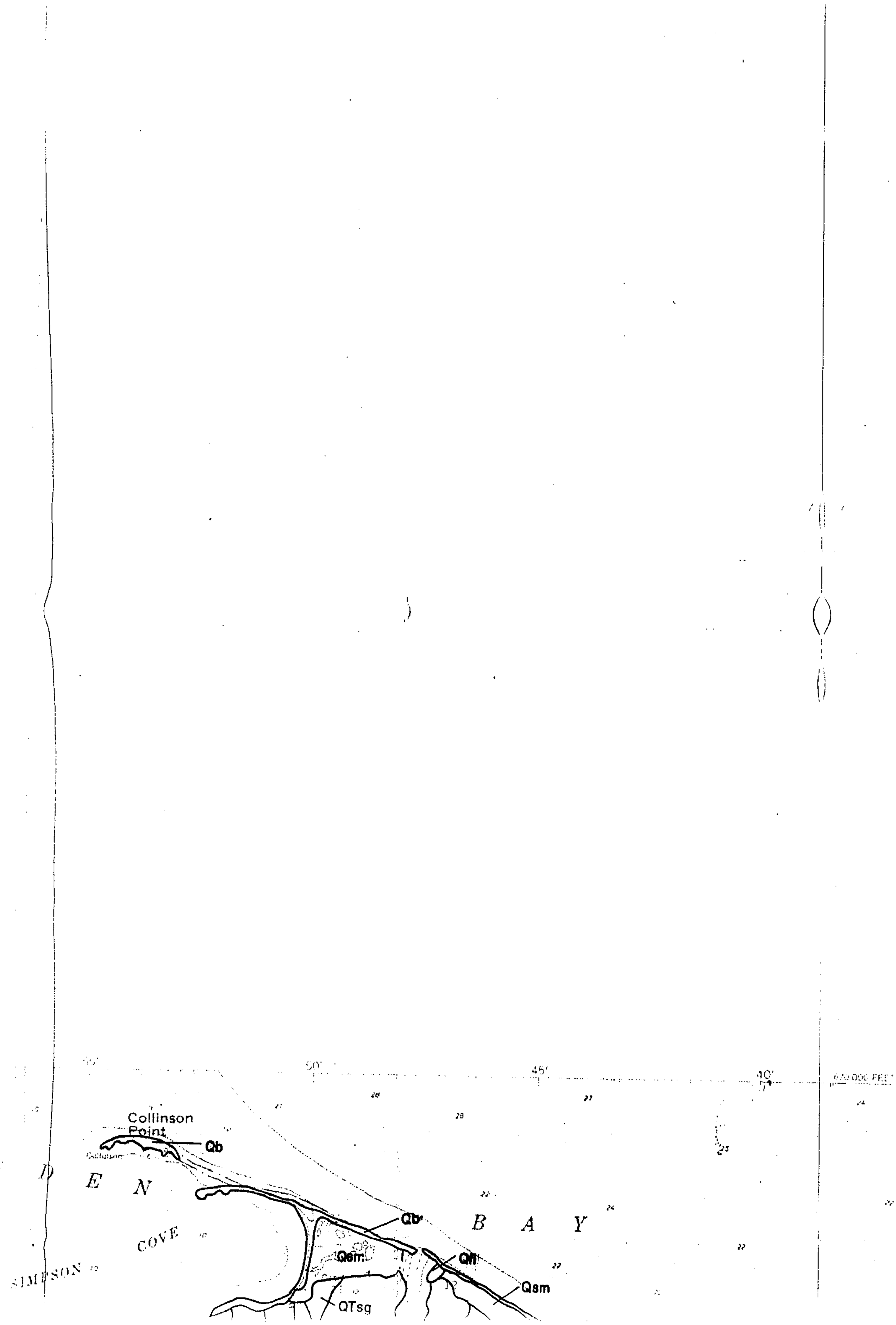


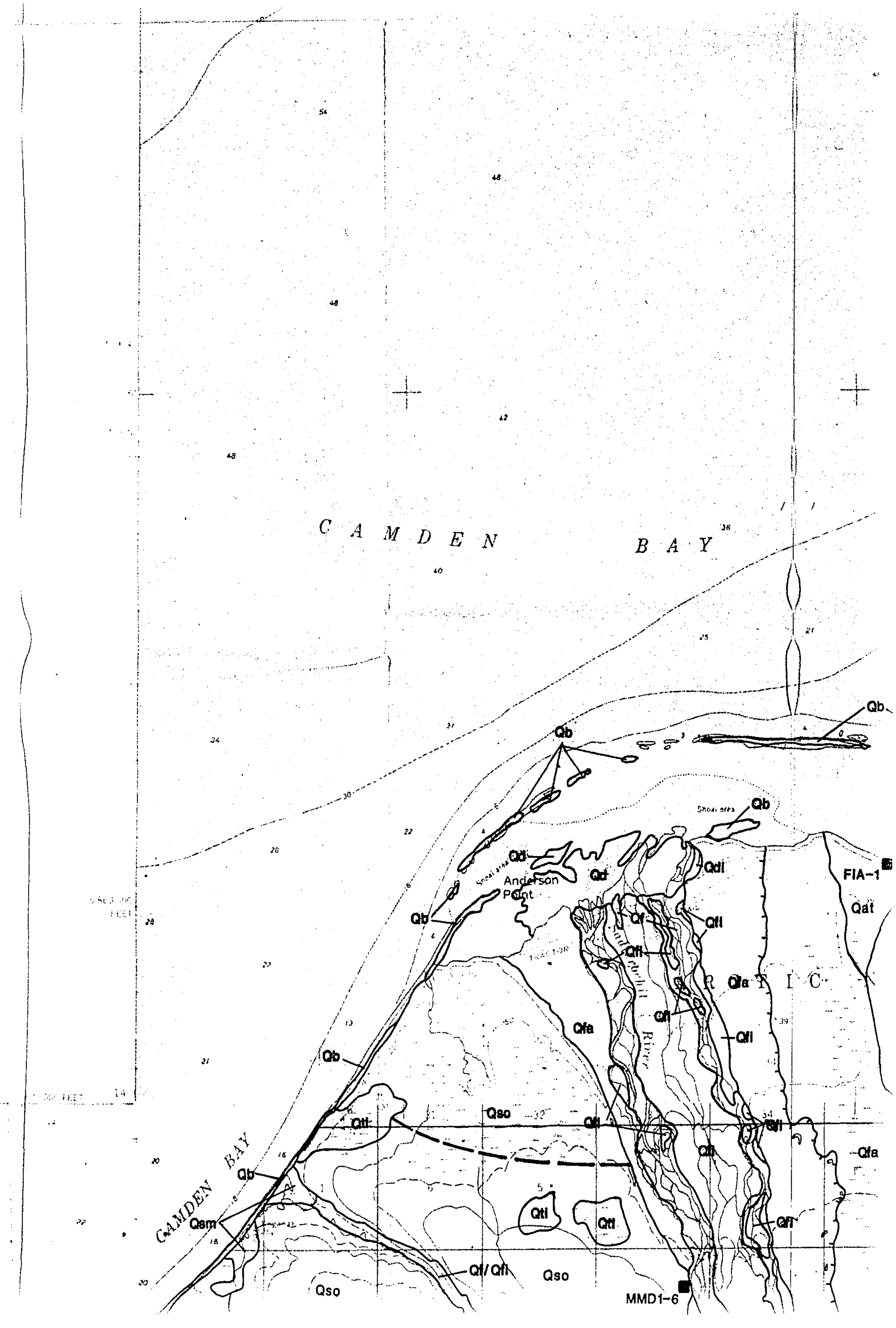
RAWLINSON, 1990 SHEET 6 OF 6

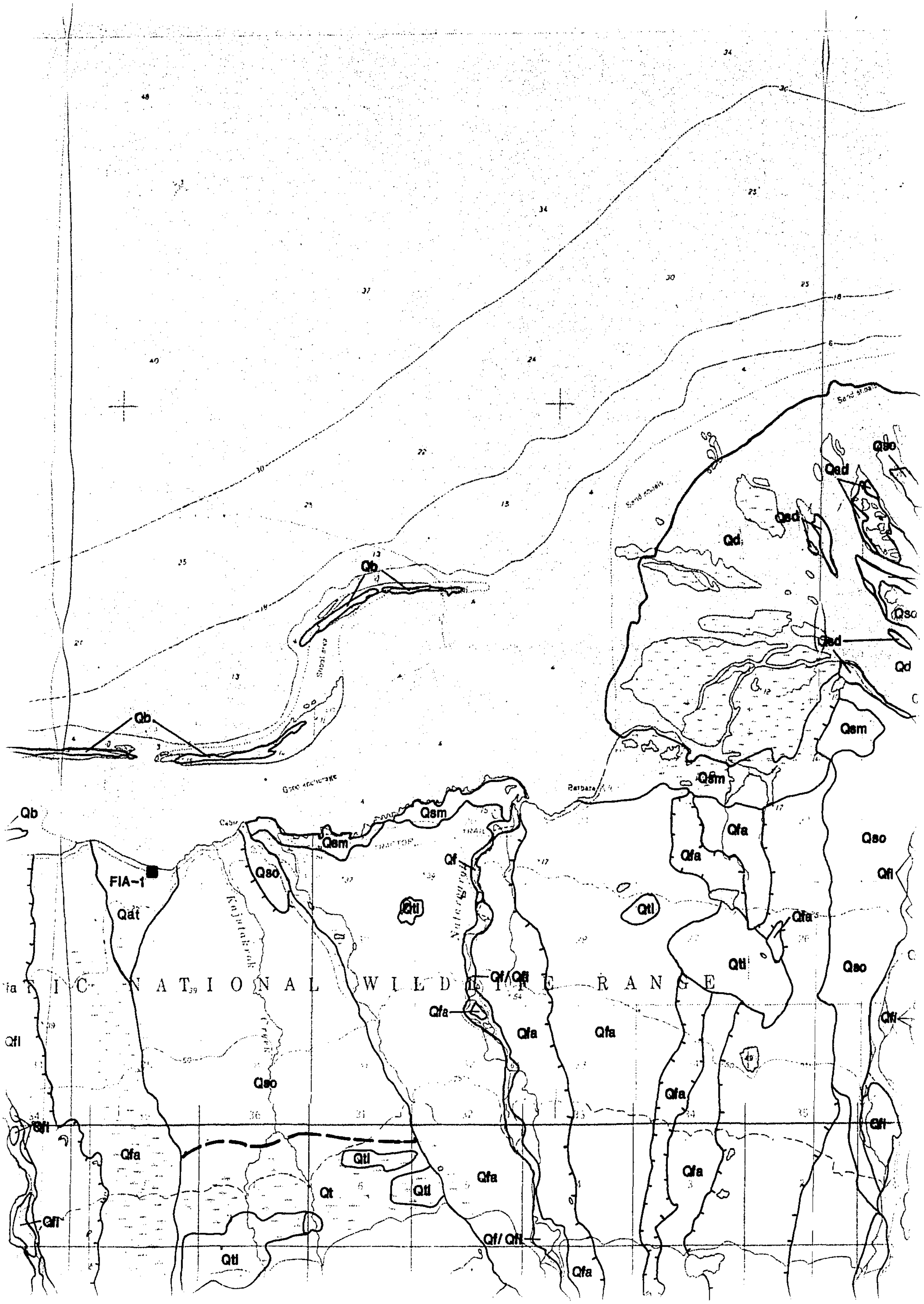


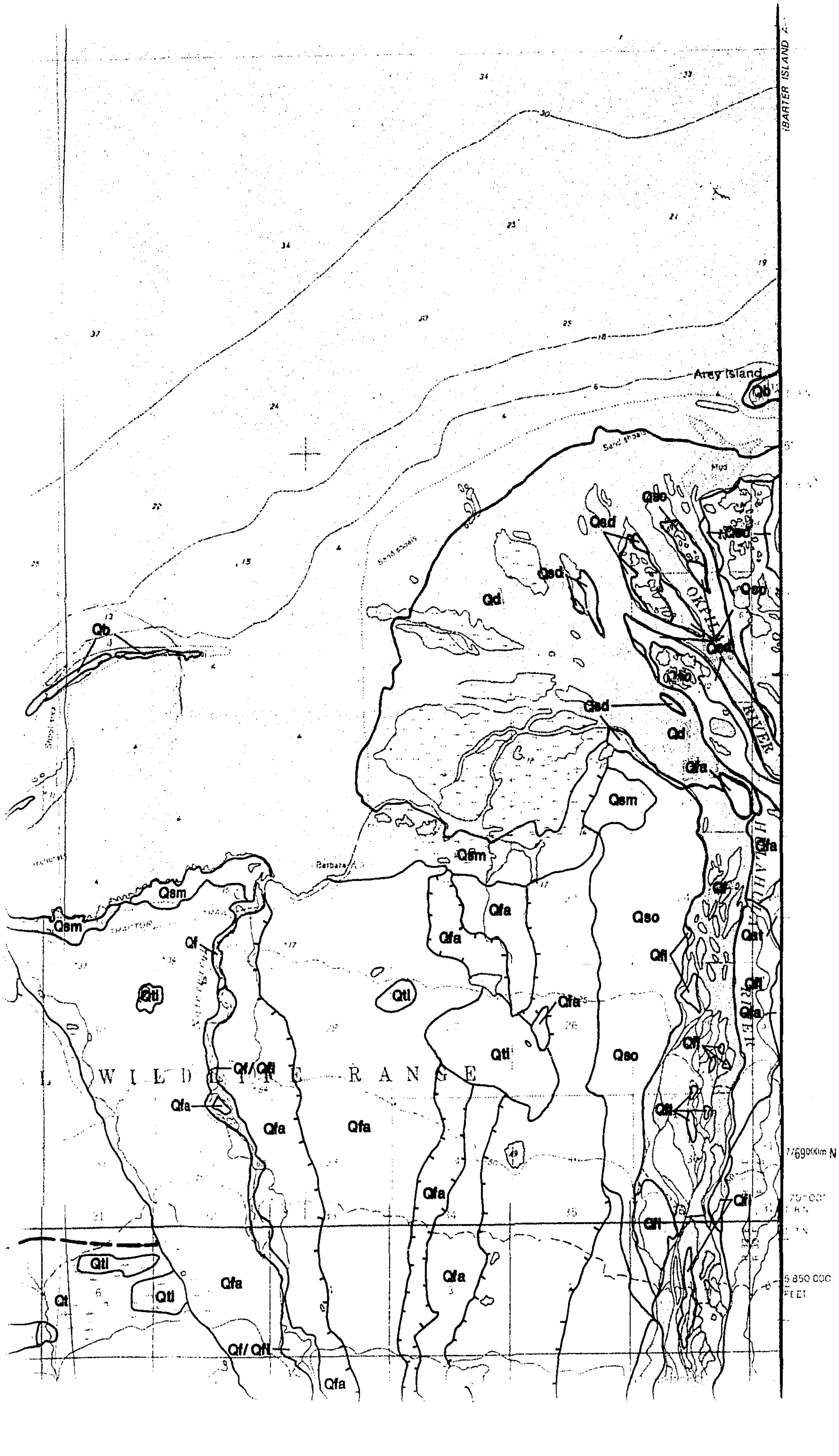


Qb
Qb
Qb
Qfa
Qfa
Qd
Qd
Qd
Qsm
Qsm
Qfl
C A M D

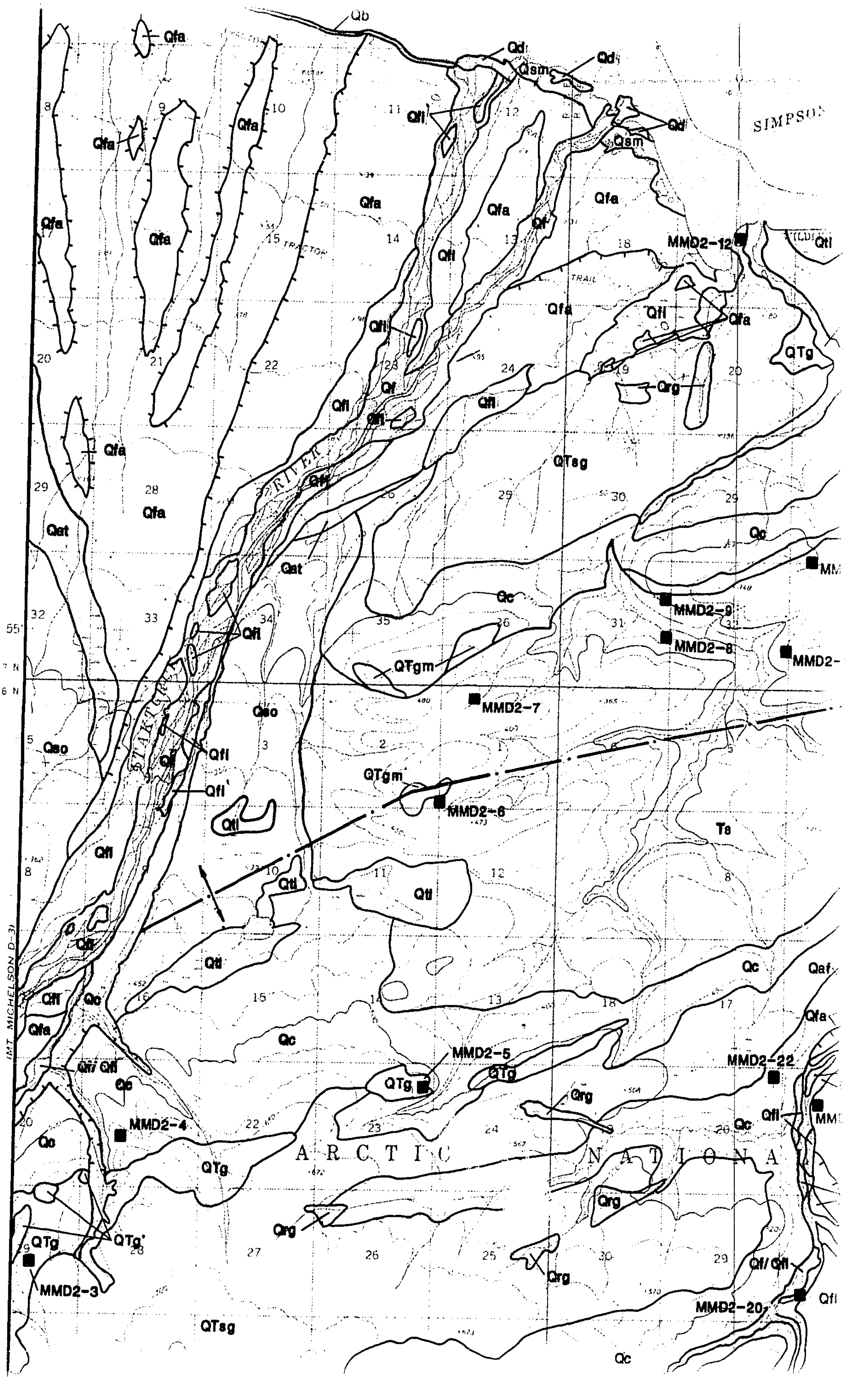

Collinson Point
Qb
Qb'
Qsm
Qsm
QTsg
COVE
SIMPSON
B A Y
50'
45'
40'

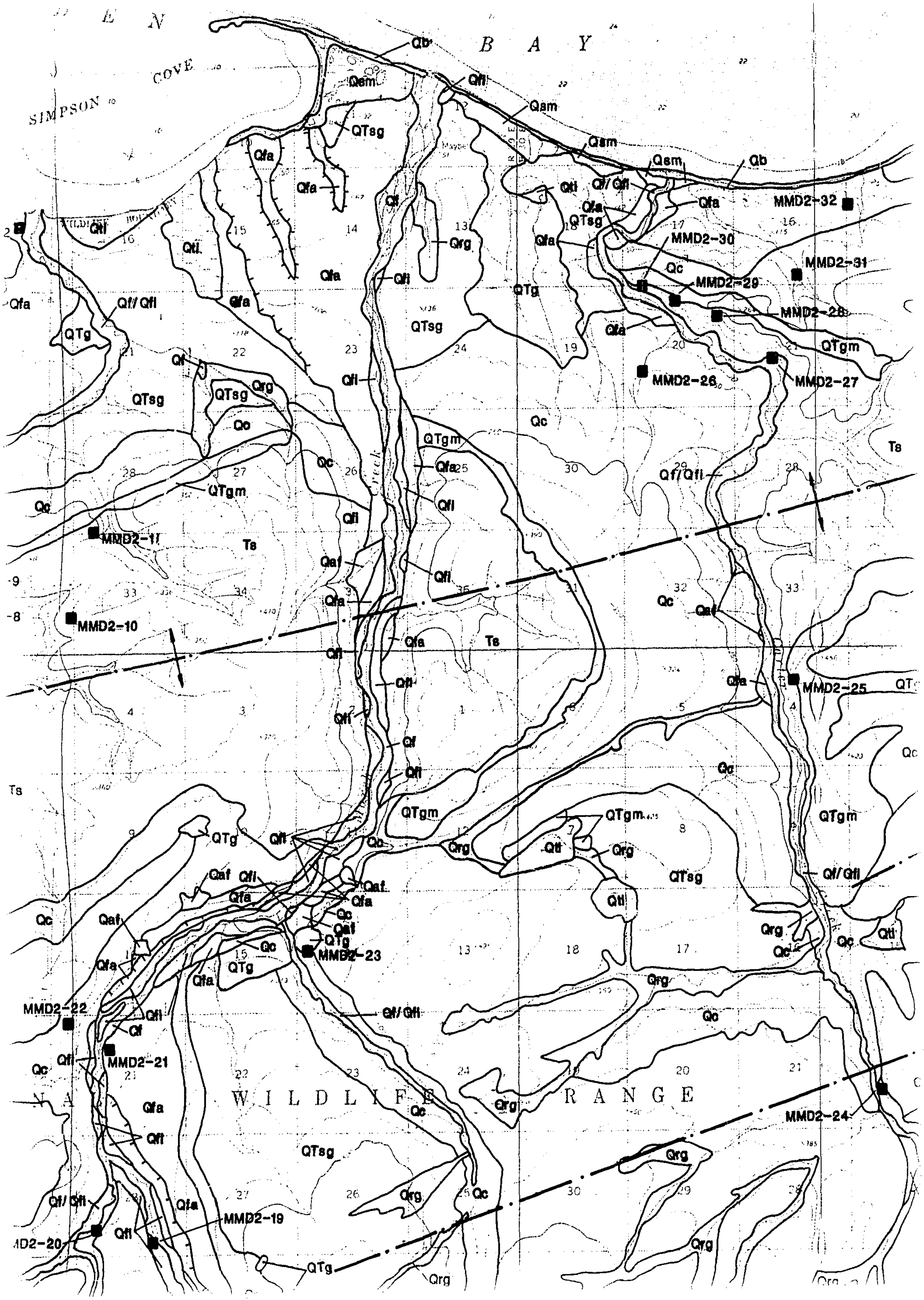

CAMDEN BAY
Qb
Shoal area
Qd
Qdl
Anderson Point
FIA-1
Qat
Qfl
Qfa
River
Qso
Qtl
Qsm
Qf/Qfl
MMD1-6
CAMDEN BAY


Qb
Qsm
Qso
Qad
Qd
Qfa
Qtl
Qf
Qf/Qfl
FIA-1
Qat
Qfl
Qt
N A T I O N A L W I L D L I F E R A N G E
Sand shoals



BARTER ISLAND
Arey Island
Qb
Sand shoals
Mud
Qso
Qsd
Qd
Qb
Qsm
Qf
Qtl
Qfa
Qf/Qfl
W I L D L I F E R A N G E
Qfl
Qt
Qf/ Qfl
7769000m N
5 850 000 FEET
RIVER


Qb
Qfa
Qd
Qsm
Qfl
SIMPSON
Qf
MMD2-12
Qtl
TRACTOR
TRAIL
QTg
Qrg
RIVER
QTsg
Qat
Qc
MMD2-9
MMD2-8
MMD2-7
QTgm
T 7 N
T 6 N
Qso
MMD2-6
Ts
Qaf
MMD2-5
MMD2-22
MMD2-4
A R C T I C
N A T I O N A
MMD2-3
MMD2-20
(MT. MICHELSON D-3)


B A Y
SIMPSON
COVE
W I L D L I F E
R A N G E
Qb
Qfl
Qsm
QTsg
Qfa
Qfl
Qrg
QTg
Qtl
Qf/Qfl
Qc
QTgm
Ts
Qaf
Qf
MMD2-32
MMD2-31
MMD2-30
MMD2-29
MMD2-28
MMD2-27
MMD2-26
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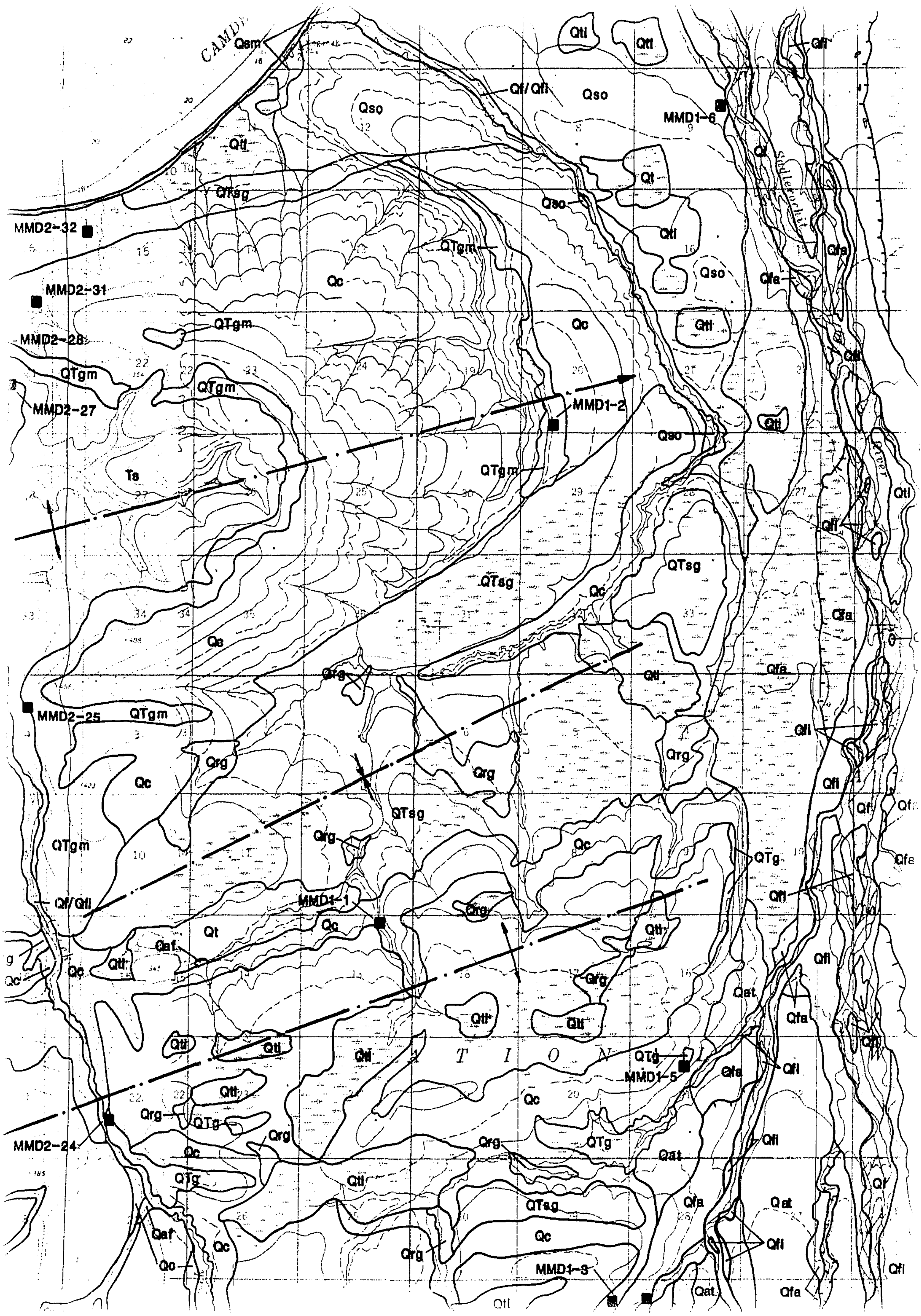
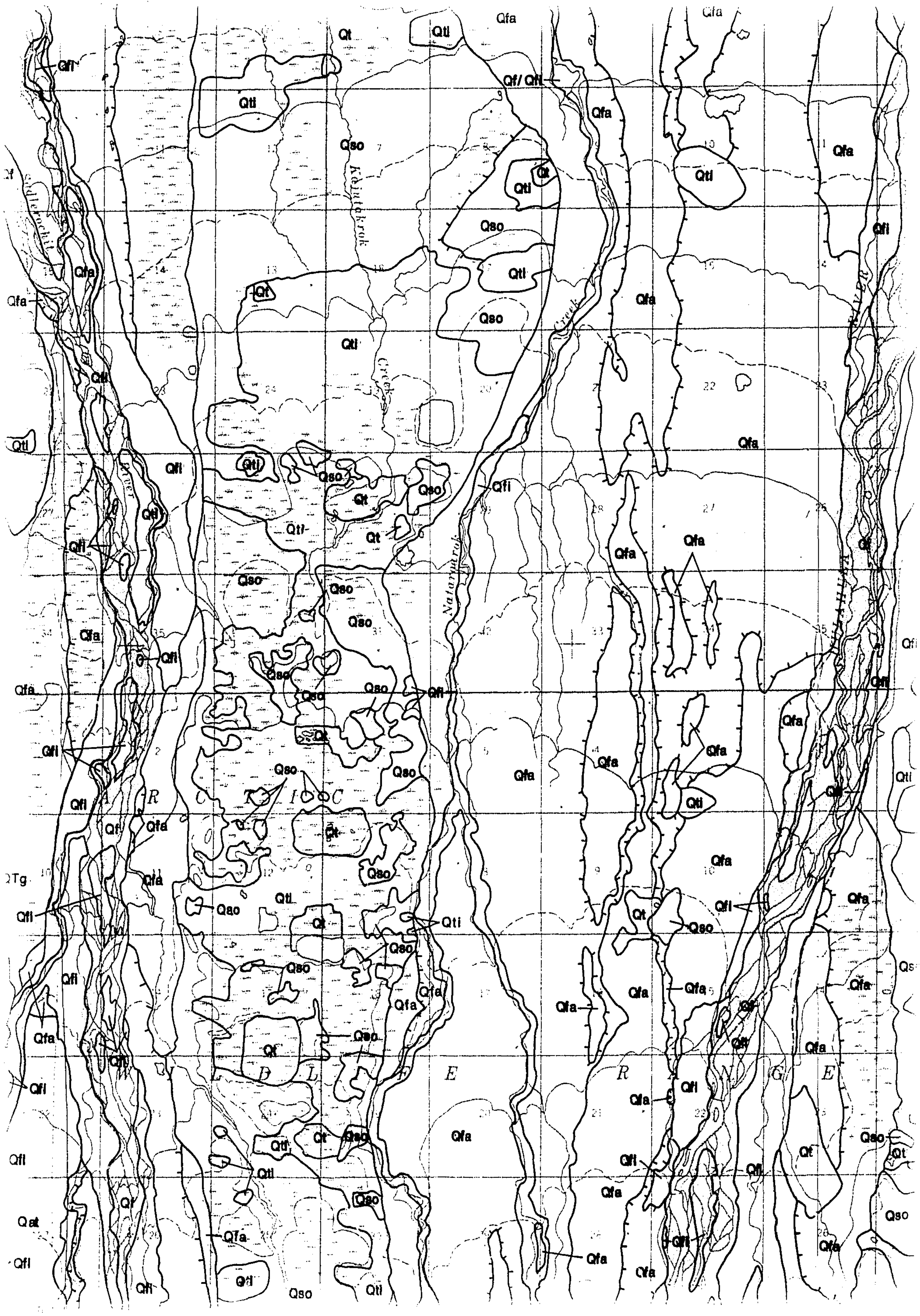
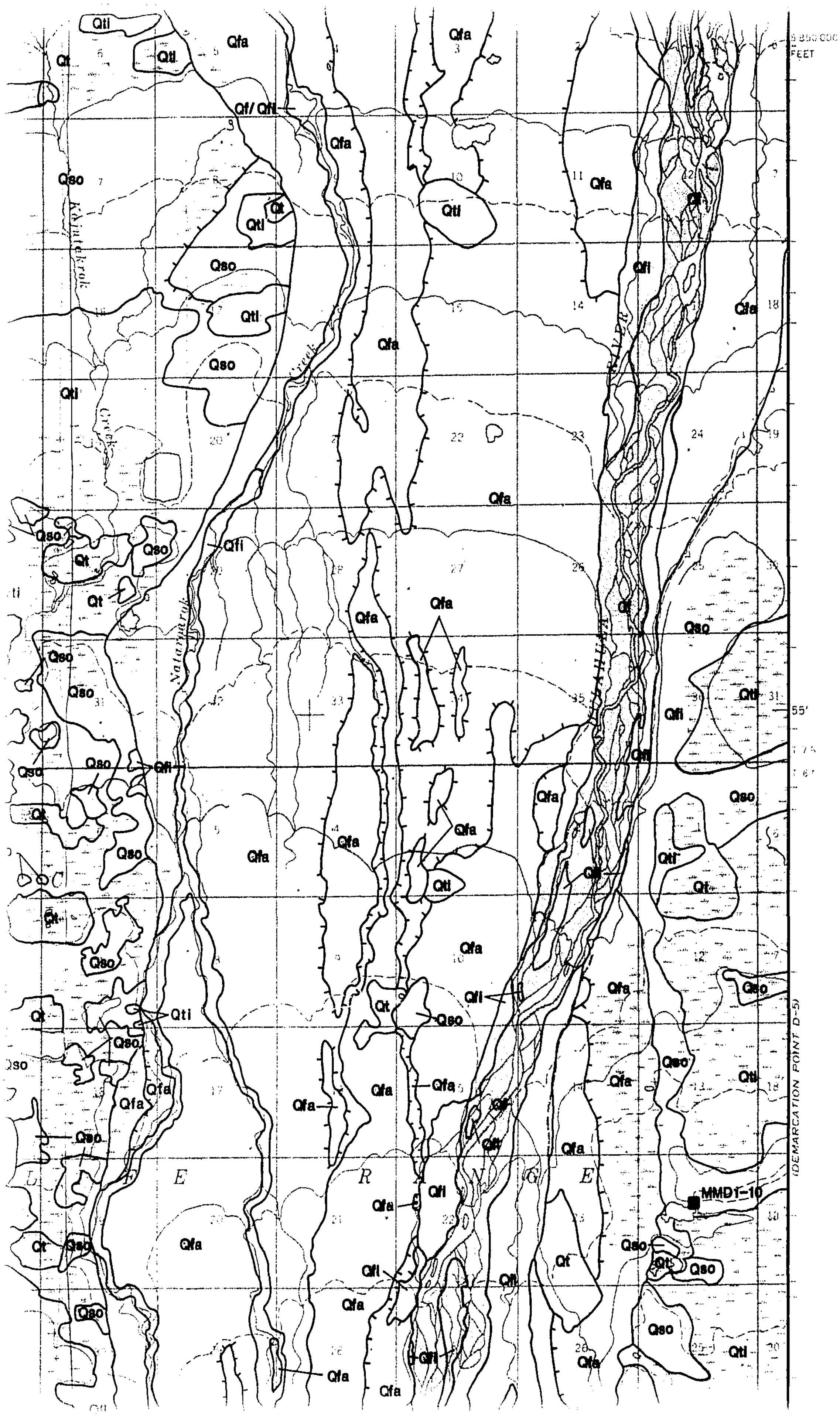
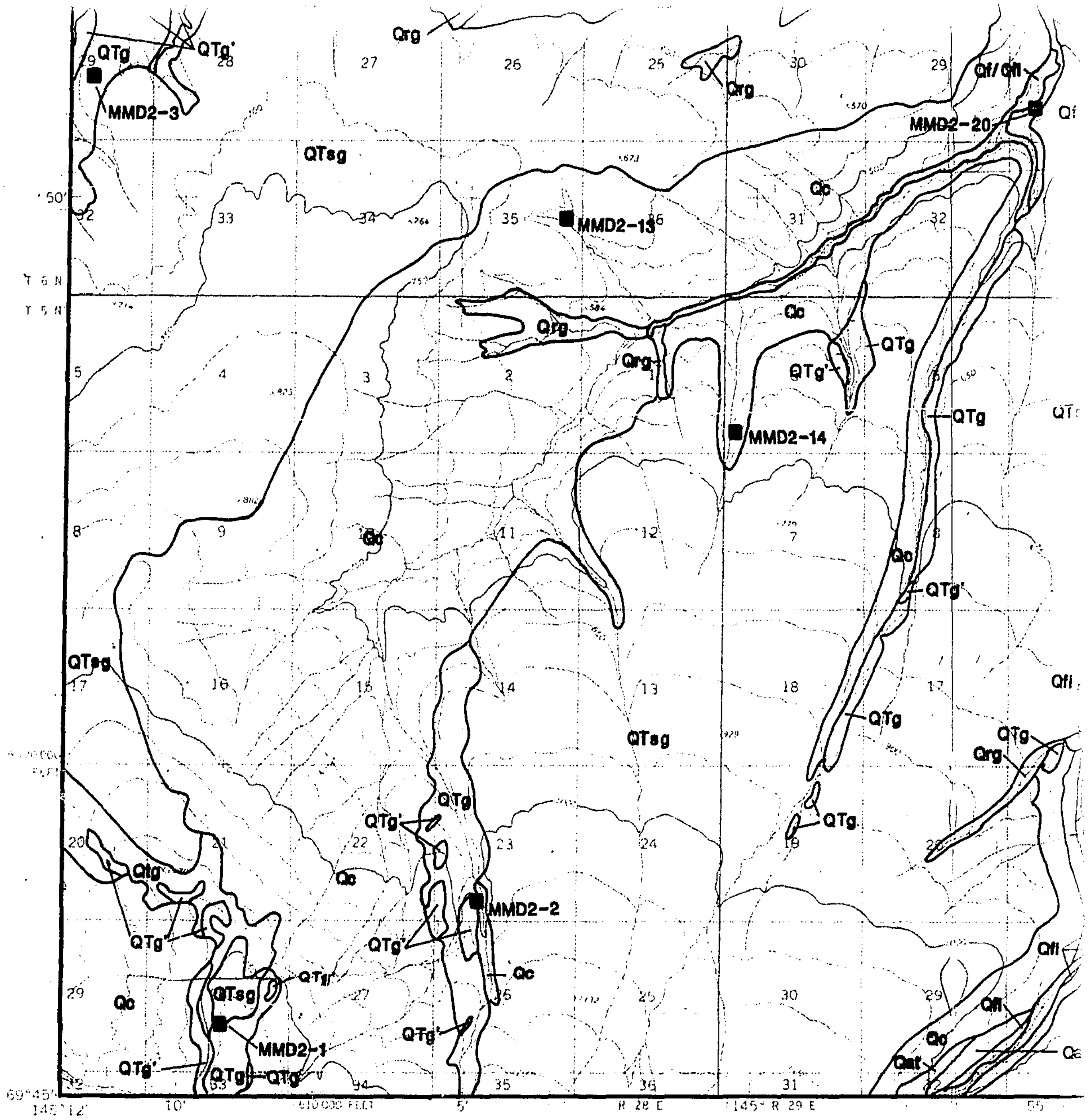
MMD2-19
MMD2-11
MMD2-10


Qsm
Qtl
Qso
Qf/Qfl
MMD1-6
Qtl
QTsg
MMD2-32
Qc
QTgm
Qtl
Qfa
MMD2-31
QTgm
MMD2-28
QTgm
MMD2-27
MMD1-2
Qso
Ts
QTgm
QTsg
Qc
Qtl
Qfl
Qfa
MMD2-25
QTgm
Qrg
Qc
QTsg
QTgm
Qf/Qfl
MMD1-1
Qc
Qt
Qaf
Qtl
QTg
Qfl
Qfa
Qat
QTg
MMD1-5
MMD2-24
Qrg
QTg
Qc
QTsg
Qrg
MMD1-3
Qaf
Qfl
Qat

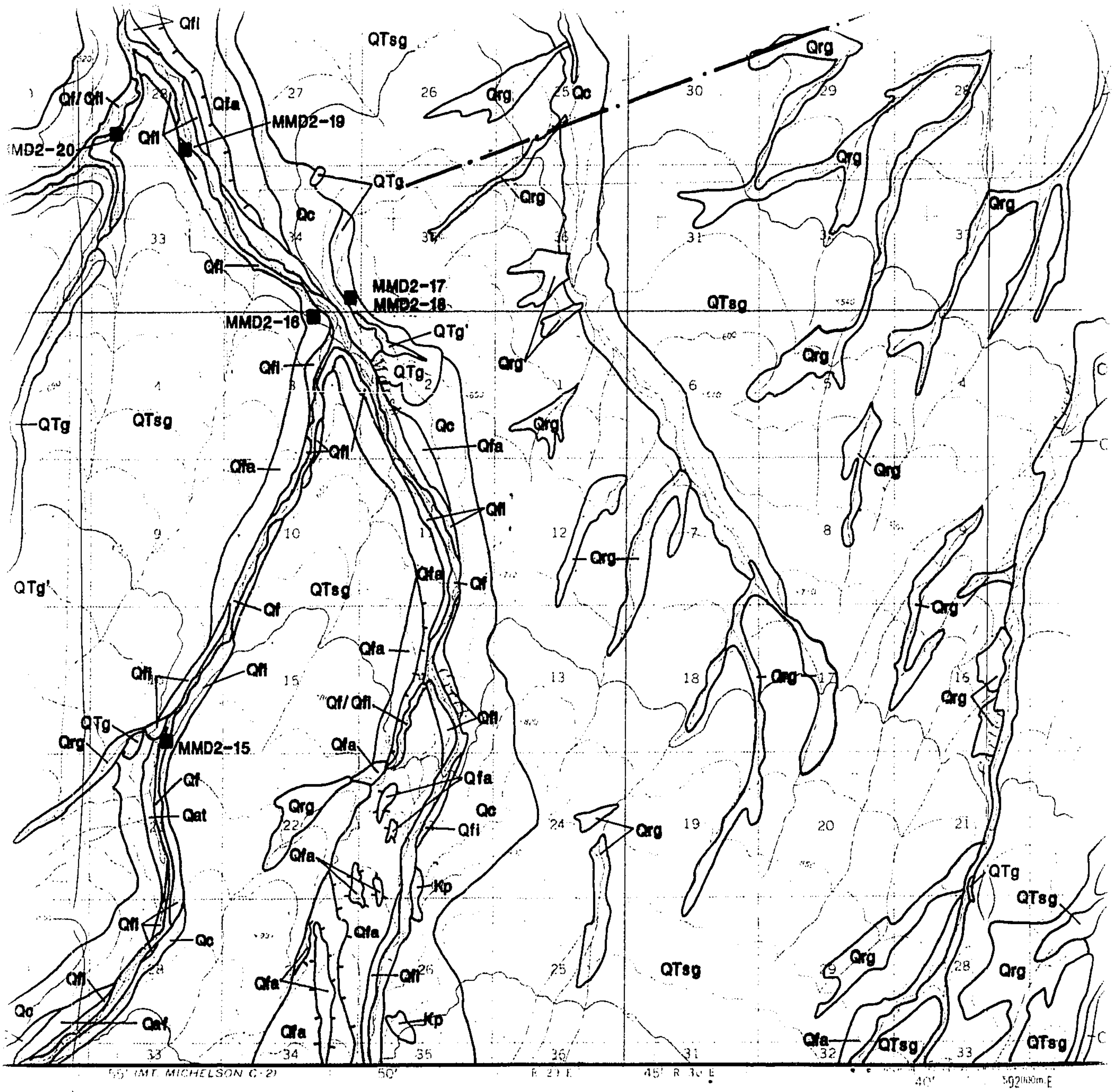

Qfa
Qtl
Qt
Qfl
Qf/ Qfl
Qso
Creek
Qat
Qso


Qtl
Qfa
Qf/Qfl
Qso
Qt
Qfl
Qti
Qfa
Qf/Qfl
Qso
MMD1-10
FEET
55'
(DEMARCATION POINT D-5)
R
A
N
G
E
Natarvarok
Creek



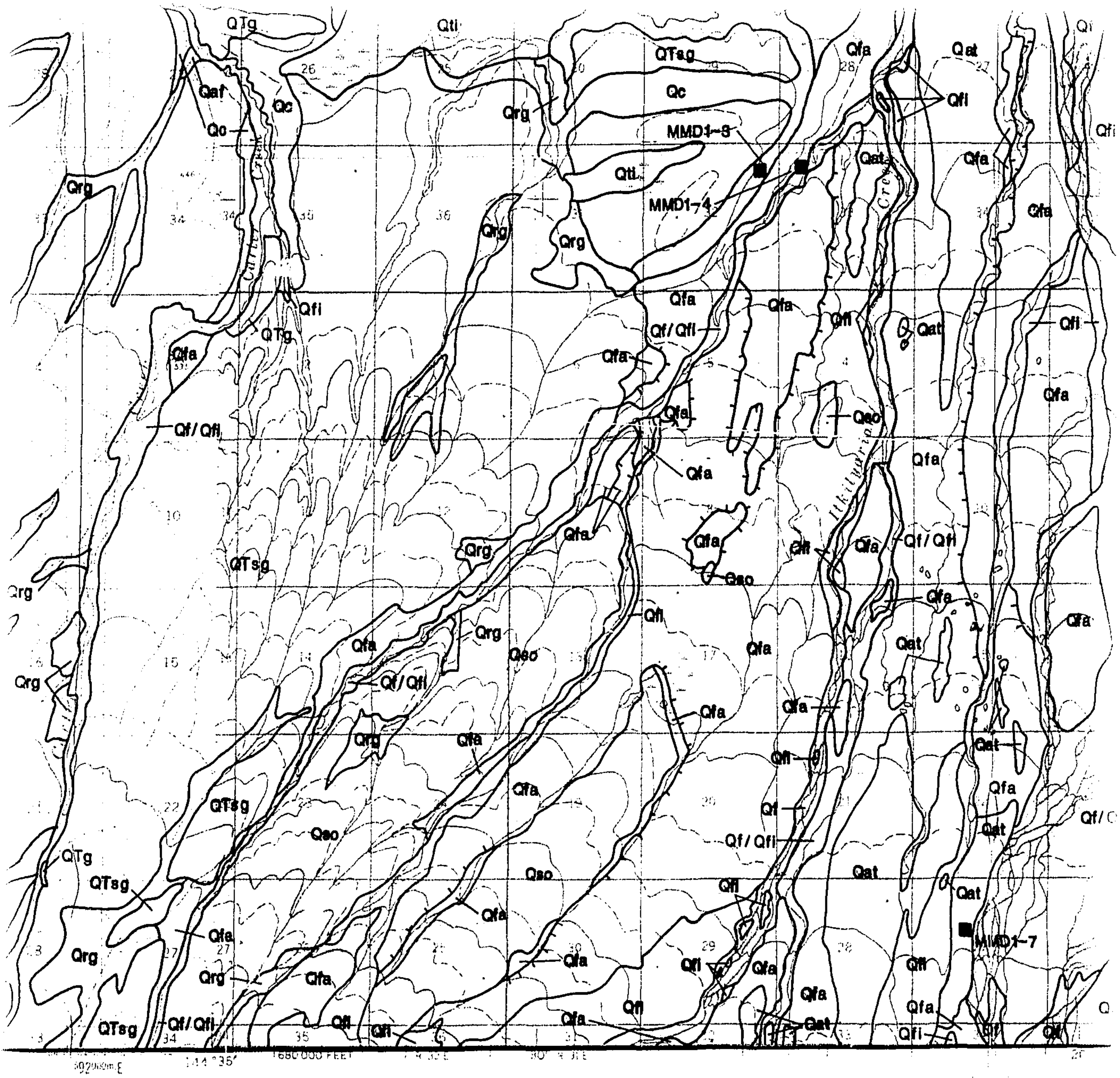
GEOLOGY MAPPED BY O.J. FERRIANS, JR., 1973, 1975; L.D. CARTER AND J.P. GALLOWAY, 1983–1984; S.E. RAWLINSON, CARTER, AND D.R. HICKMOTT, 1985; AND RAWLINSON, 1988–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY MT. MICHELSON D-1, 1955; D-2, 1955; AND FLAXMAN ISLAND A-1, 1955, REVISED 1977.



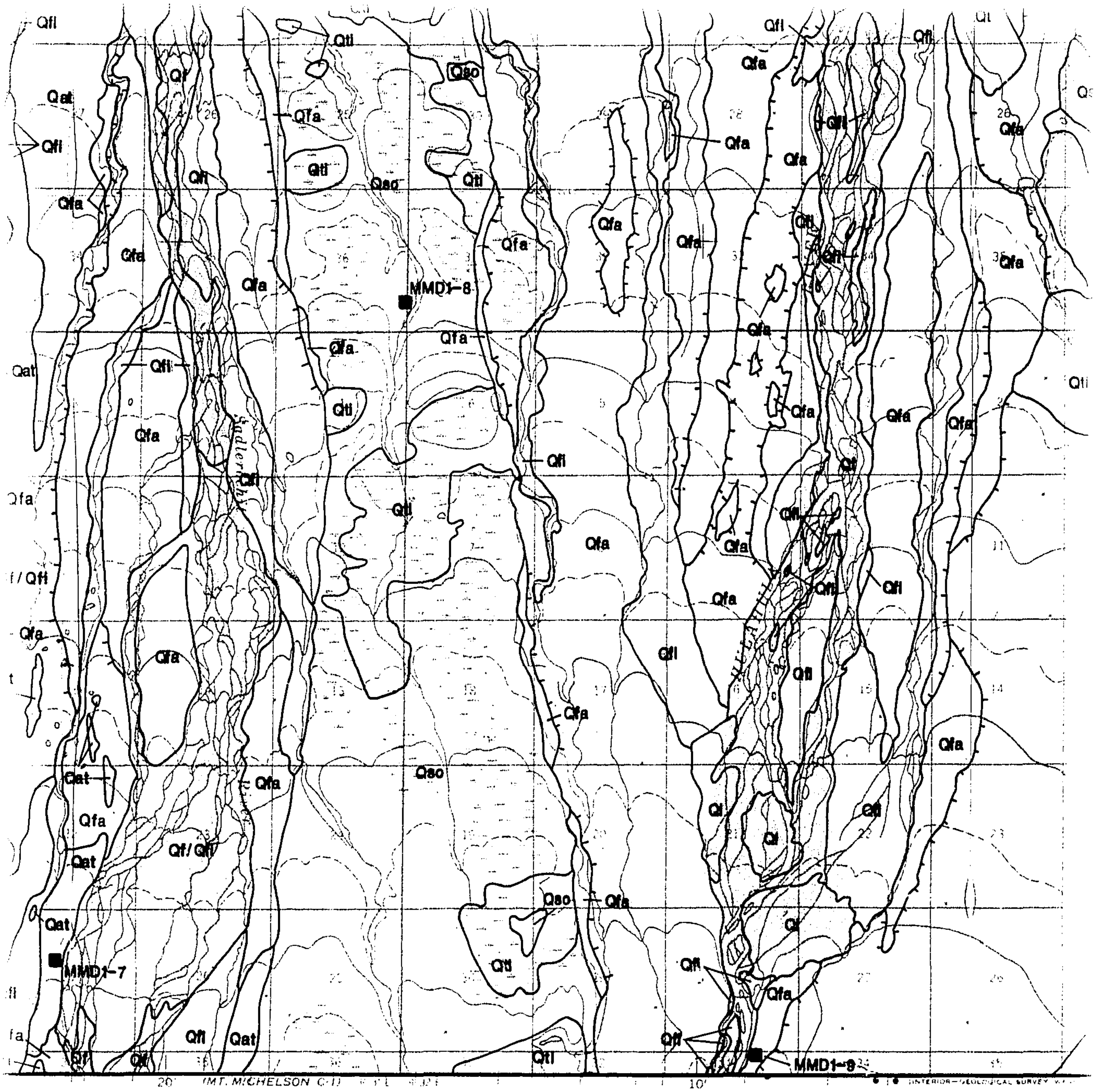
983-1984;

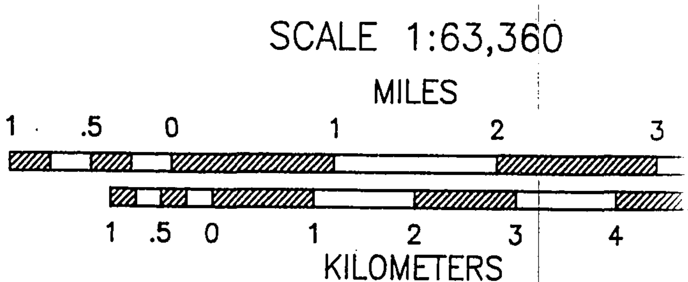
SURFICIAL-GEOLOGY MAP OF
AND FLAXMAN ISLAND A-

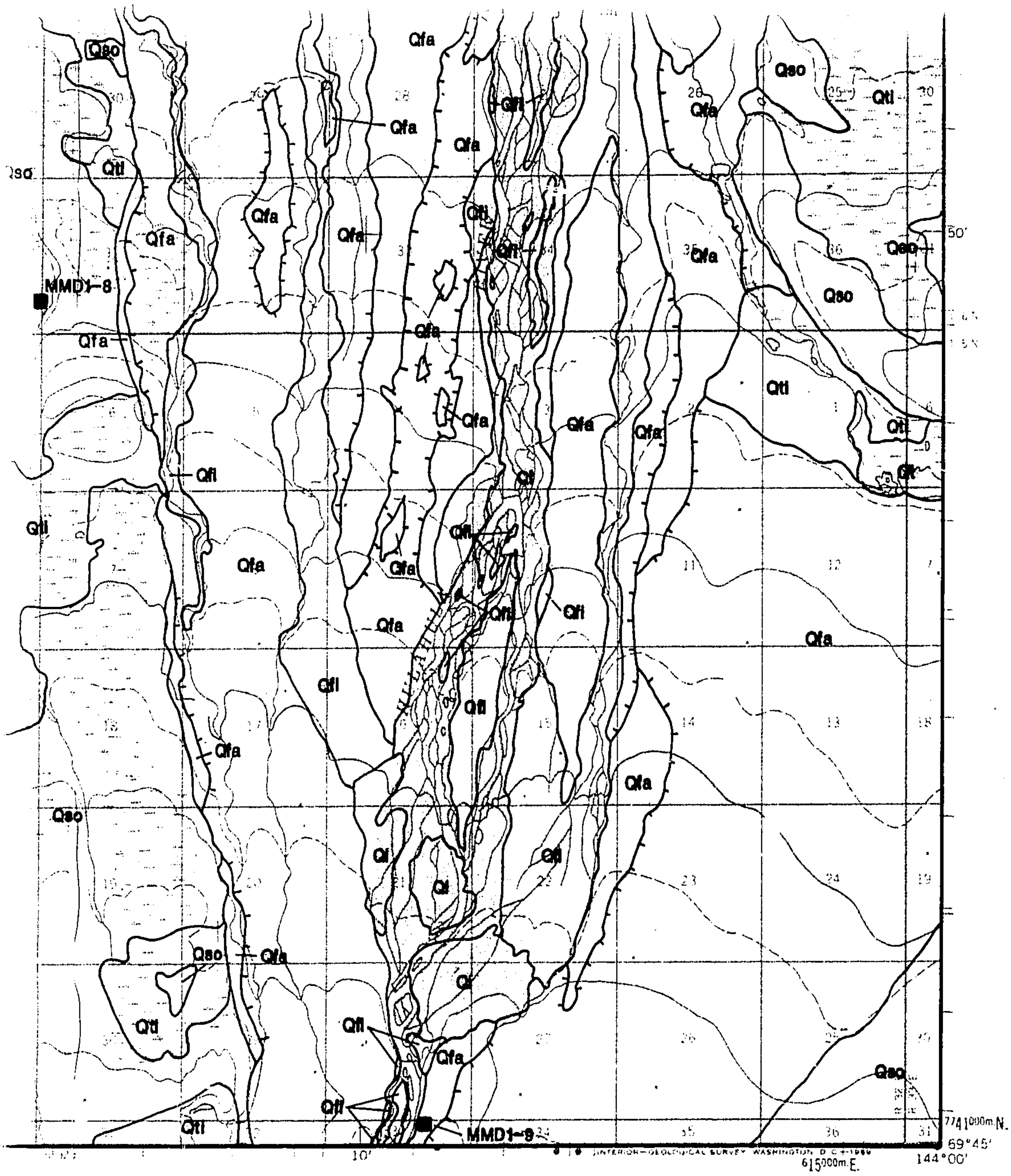


MAP OF THE MT. MICHELSON D-1 AND D-2,

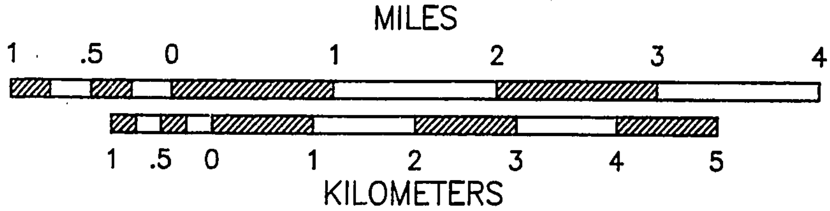
SLAND A-1 QUADRANGLES, ALASKA


Qfl
Qat
Qfa
Qtl
Qso
Qf/Qfl
MMD1-8
MMD1-7
MMD1-9
(MT. MICHELSON C-1)


SCALE 1:63,360
MILES
1 .5 0 1 2 3
1 .5 0 1 2 3 4
KILOMETERS

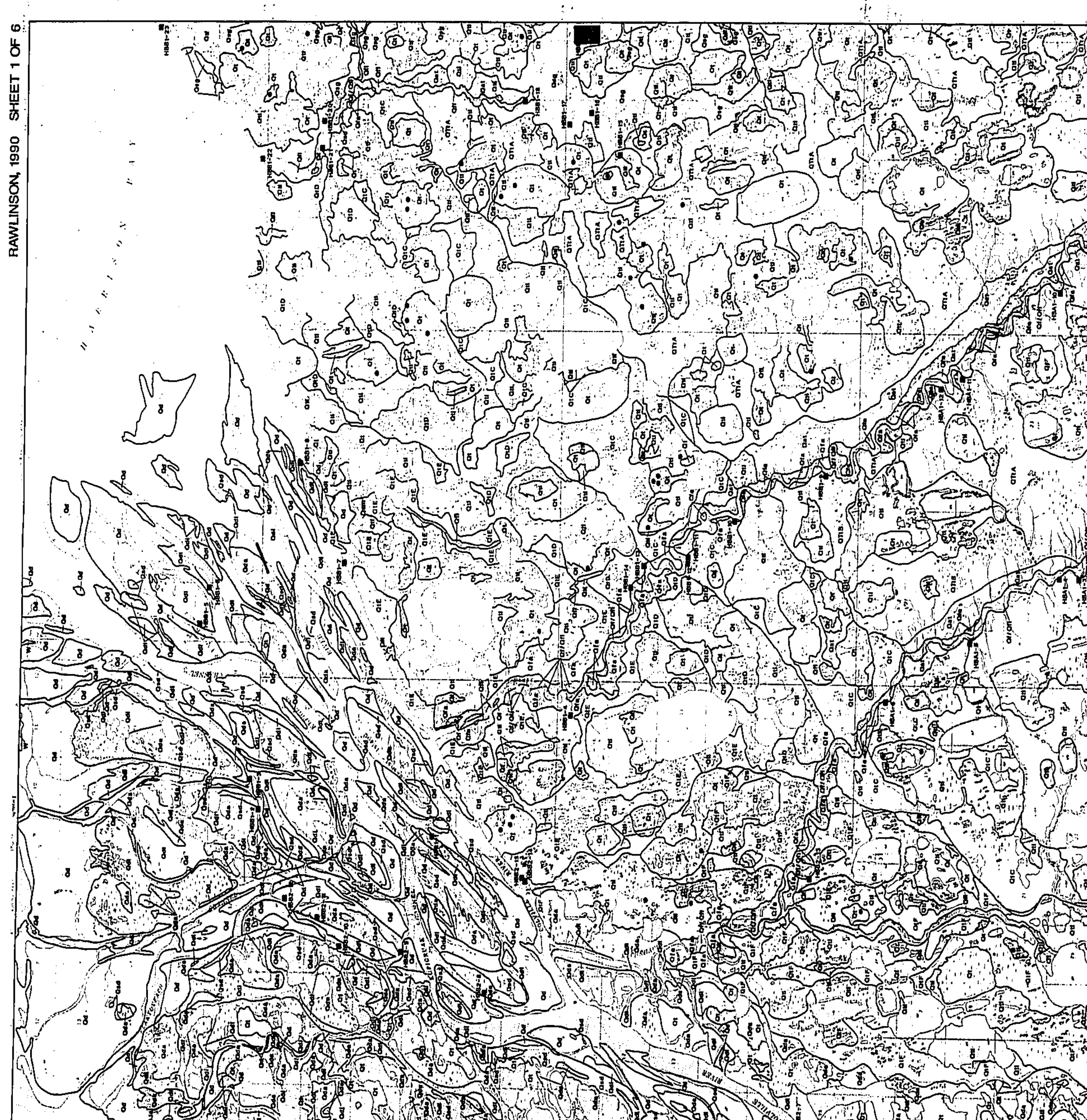


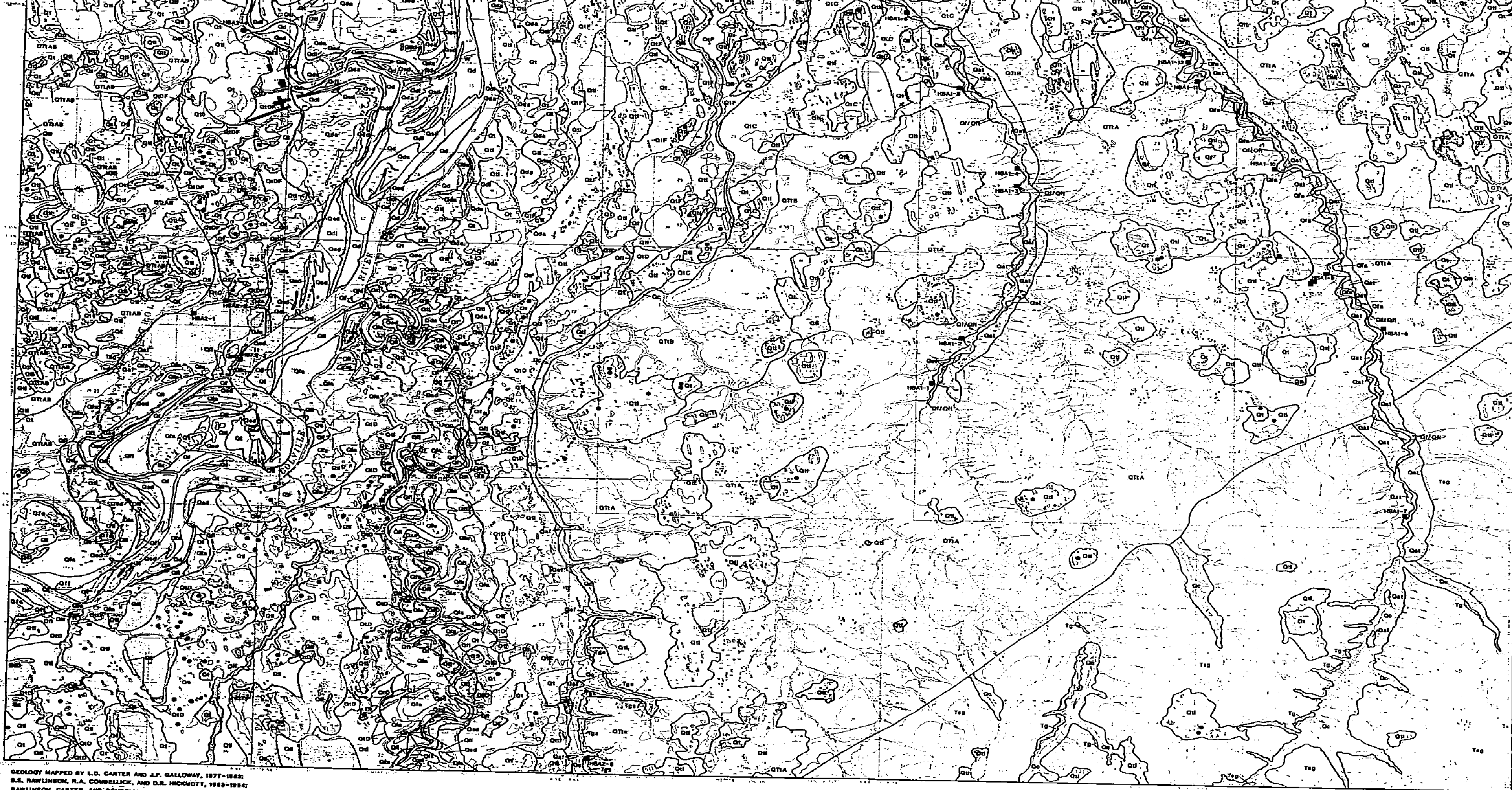
SCALE 1:63,360



RAWLINSON, 1990 SHEET 1 OF 6

MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN APPENDIX A
CORRELATION OF MAP UNITS IN APPENDIX B

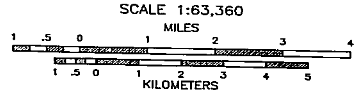




GEOLOGY MAPPED BY L.D. CARTER AND J.P. GALLOWAY, 1977–1982; S.E. RAWLINSON, R.A. COMBELLICK, AND D.R. HICKMOTT, 1983–1984; RAWLINSON, CARTER, AND COMBELLICK, 1987; AND RAWLINSON, 1988–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY HARRISON BAY A-1, 1955; A-2, 1955; B-1, 1955; AND B-2, 1955.

SURFICIAL–GEOLOGY MAP OF THE HARRISON BAY A–1, A–2, B–1, AND B–2 QUADRANGLES, ALASKA



RAWLINSON, STUART E.
9209705 ©1990

MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN APPENDIX A
CORRELATION OF MAP UNITS IN APPENDIX B

GEOLOGY MAPPED BY S.E. RAWLINSON AND S.B. HARDY, 1981–1982; RAWLINSON AND D.R. HICKMOTT, 1983–1985; AND RAWLINSON 1988–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY BEECHEY POINT A–4, 1955, REVISED 1981; A–5, 1955; B–4, 1955, REVISED 1974; B–5, 1955, C–4, 1955, AND C–5, 1955, REVISED 1981.

SURFICIAL–GEOLOGY MAP OF THE BEECHEY POINT A–4, A–5, B–4, B–5, C–4, AND C–5 QUADRANGLES, ALASKA

SCALE 1:63,360

MILES 1 .5 0 1 2 3 4

KILOMETERS 1 .5 0 1 2 3 4 5

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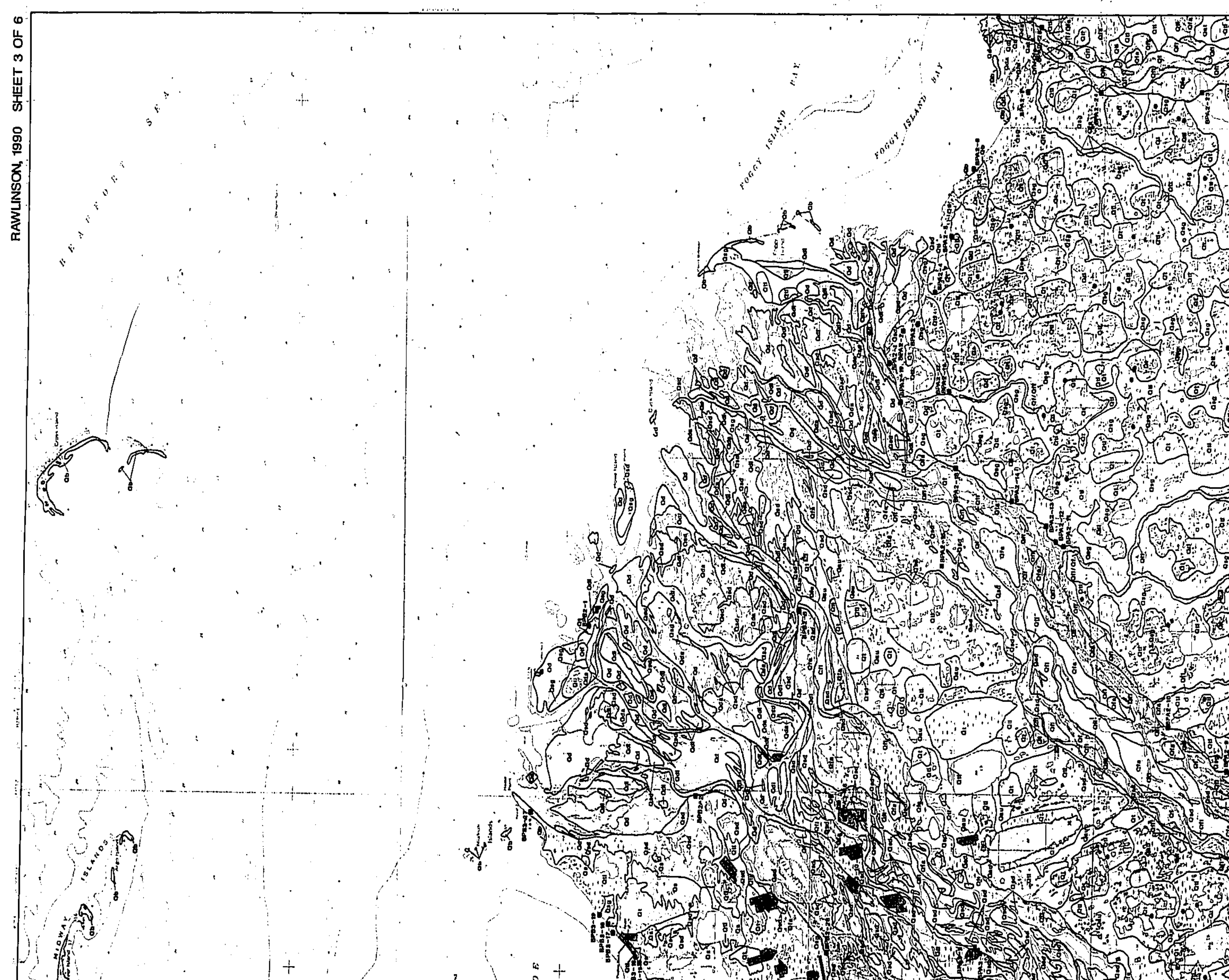
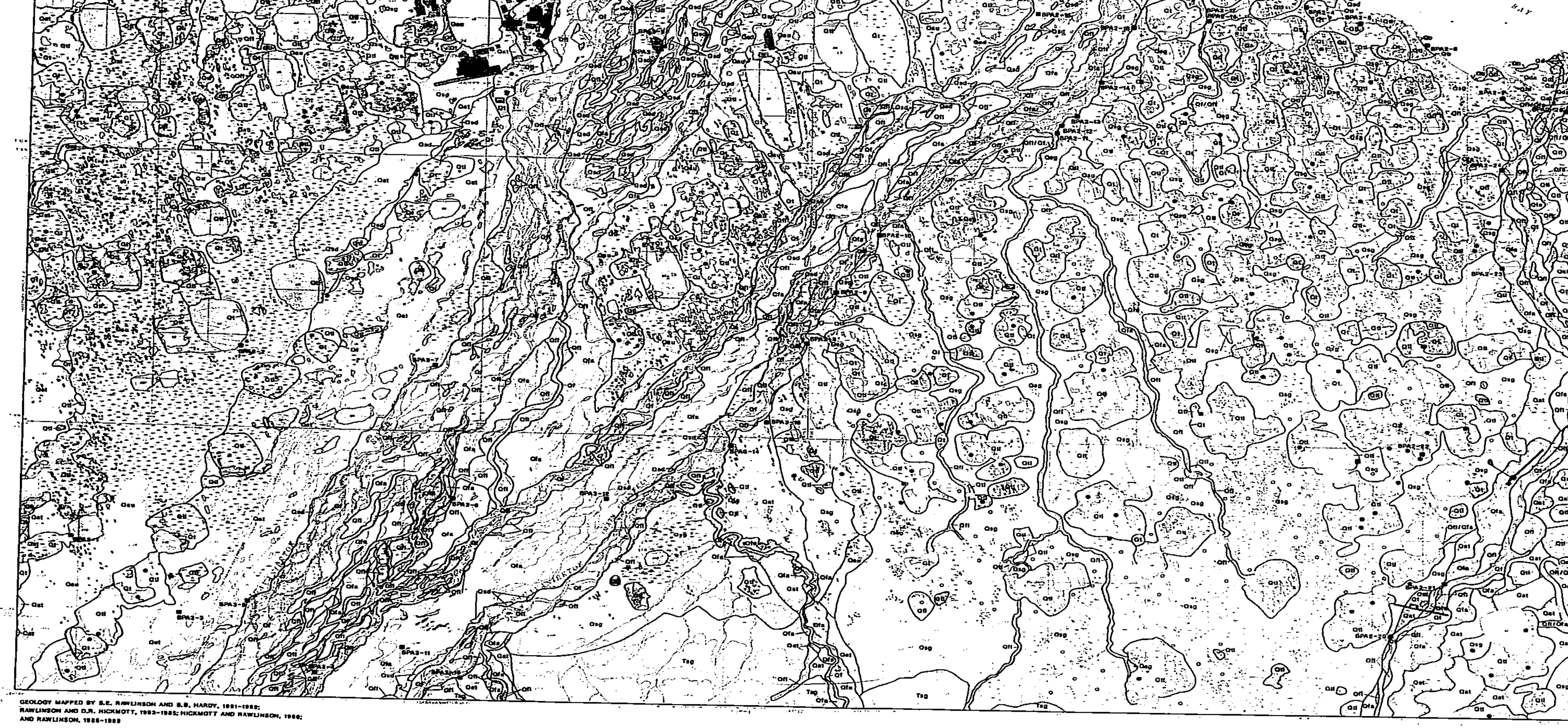
RAWLINSON, 1990 SHEET 3 OF 6

MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN APPENDIX A
CORRELATION OF MAP UNITS IN APPENDIX B





GEOLOGY MAPPED BY S.E. RAWLINSON AND S.B. HARDY, 1981–1982;
RAWLINSON AND D.R. HICKMOTT, 1983–1985; HICKMOTT AND RAWLINSON, 1986;
AND RAWLINSON, 1986–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY BEECHEY POINT A-2, 1955, REVISED 1979;
A-3, 1955, REVISED 1979; B-2, 1955, REVISED 1977; B-3, 1955, REVISED 1975.

SURFICIAL–GEOLOGY MAP OF THE BEECHEY POINT A–2, A–3, B–2,
AND B–3 QUADRANGLES, ALASKA

SCALE 1:63,360

MILES

1 .5 0 1 2 3 4

1 .5 0 1 2 3 4 5

KILOMETERS

RAWLINSON, STUART E.
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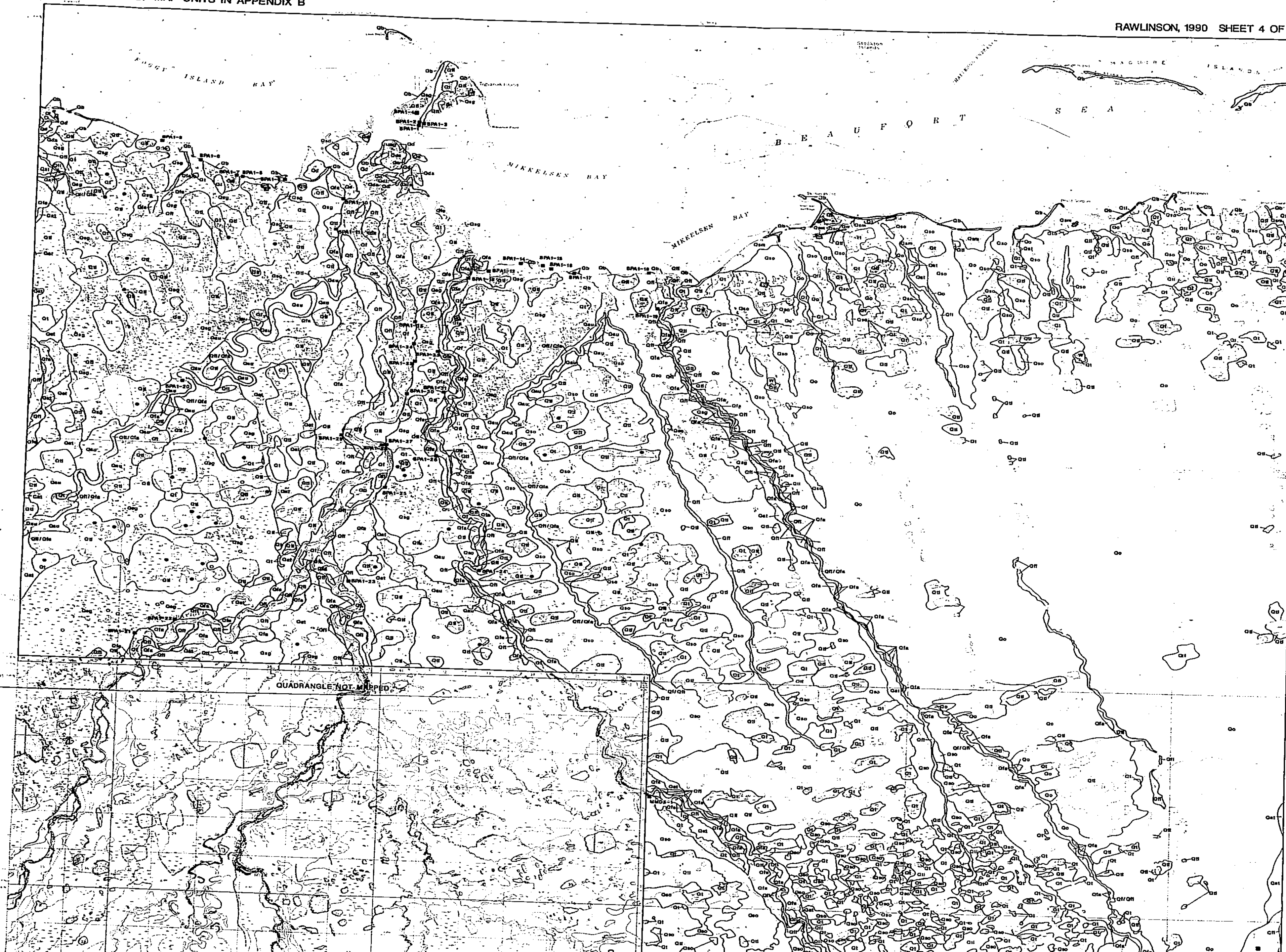
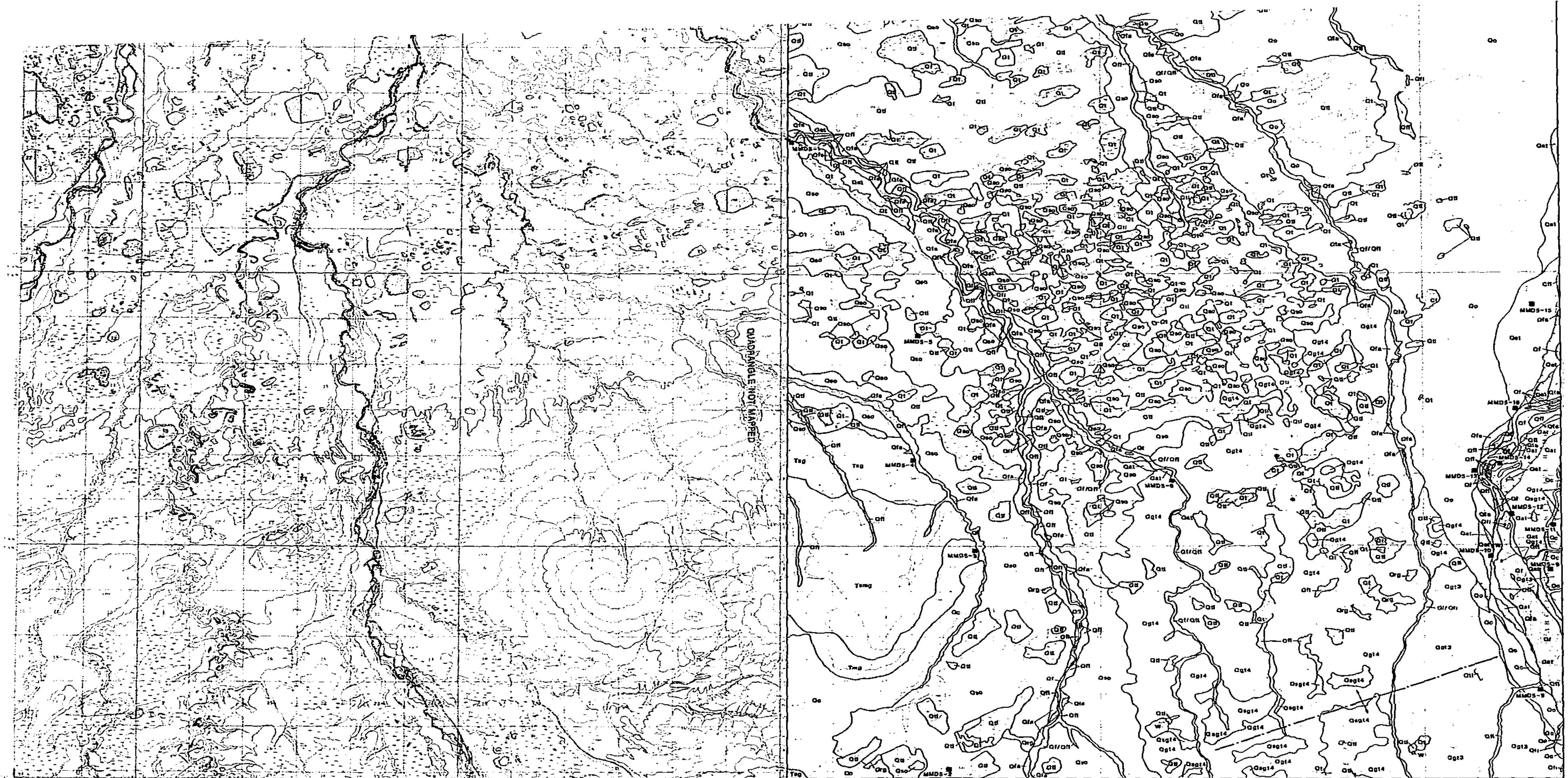
MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN APPENDIX A
CORRELATION OF MAP UNITS IN APPENDIX B





GEOLOGY MAPPED BY O.J. FERRIANS, JR., 1973, 1976; L.D. CARTER AND J.P. GALLOWAY, 1983–1984; S.E. RAWLINSON, CARTER, AND D.R. HICKMOTT, 1985; AND RAWLINSON, 1986–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY MT. MICHELSON D-5, 1955; FLAXMAN ISLAND A-5, 1955, REVISED 1981; AND BEECHEY POINT A-1, 1955, REVISED 1975.

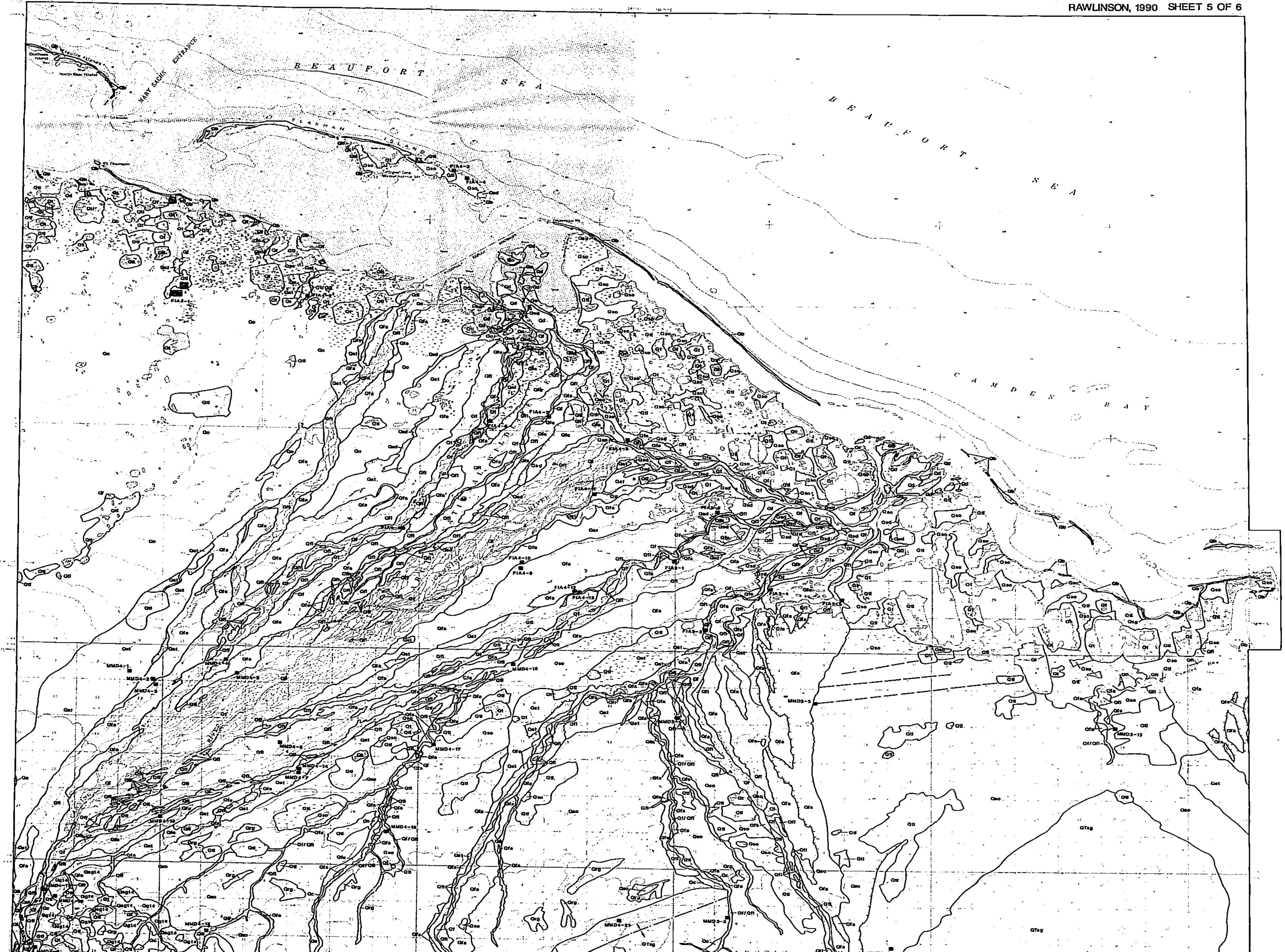
SURFICIAL-GEOLOGY MAP OF THE MT. MICHELSON D-5, FLAXMAN ISLAND A-5, AND BEECHEY POINT A-1 QUADRANGLES, ALASKA

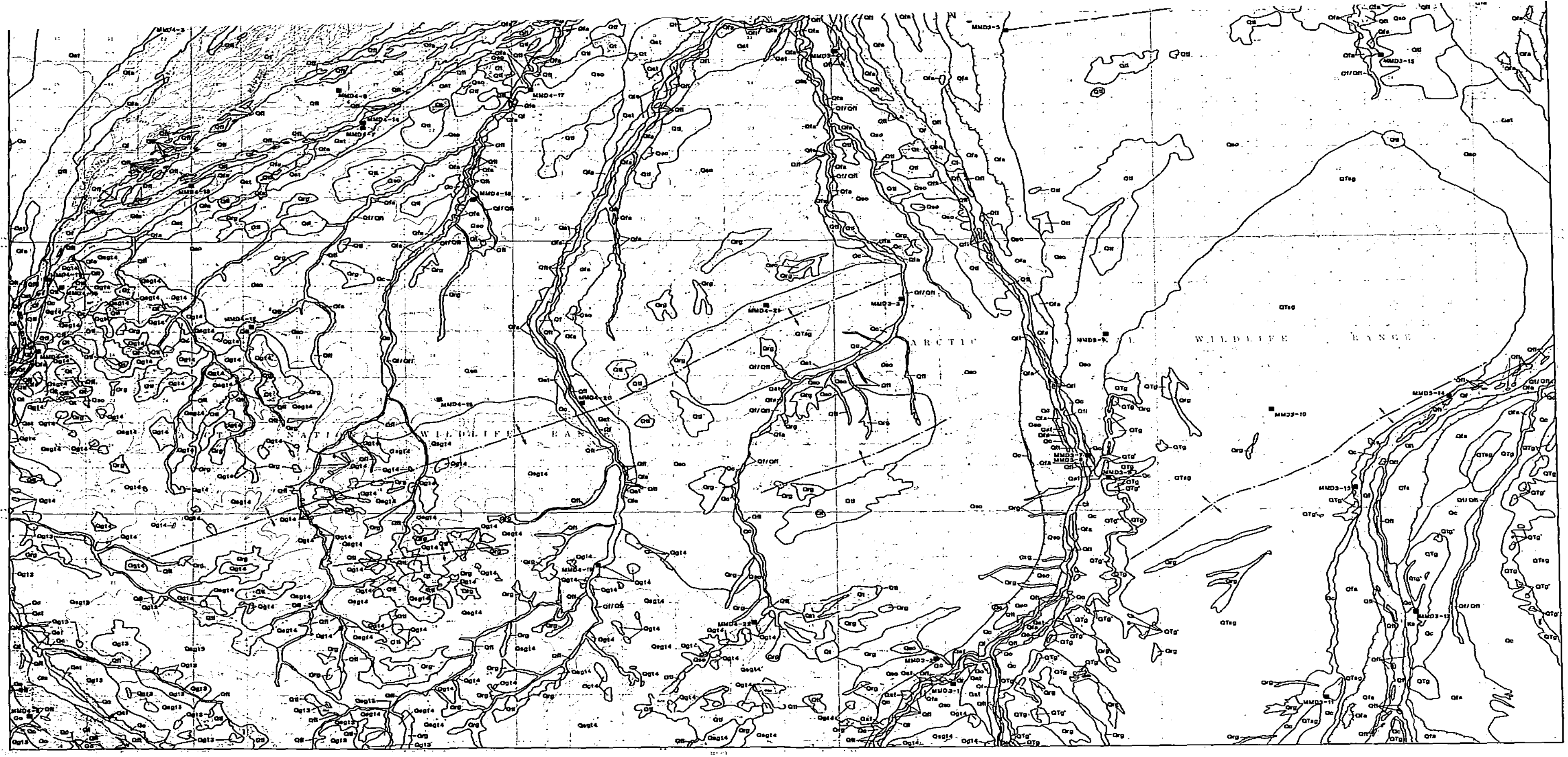
SCALE 1:63,360

MILES: 1 .5 0 1 2 3 4

KILOMETERS: 1 .5 0 1 2 3 4 5

MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN APPENDIX A
CORRELATION OF MAP UNITS IN APPENDIX B





GEOLOGY MAPPED BY O.J. FERRIANS, JR., 1973, 1978; L.D. CARTER AND J.P. GALLOWAY, 1983–1984; S.E. RAWLINSON, CARTER, AND D.R. HICKMOTT, 1985; AND RAWLINSON, 1988–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY MT. MICHELSON D–3, 1955; D–4, 1955; FLAXMAN ISLAND A–3, 1955; AND A–4, 1955.

SURFICIAL–GEOLOGY MAP OF THE MT. MICHELSON D–3 AND D–4, AND FLAXMAN ISLAND A–3 AND A–4 QUADRANGLES, ALASKA

SCALE 1:63,360

MILES: 1 .5 0 1 2 3 4

KILOMETERS: 1 .5 0 1 2 3 4 5

RAWLINSON, STUART E.
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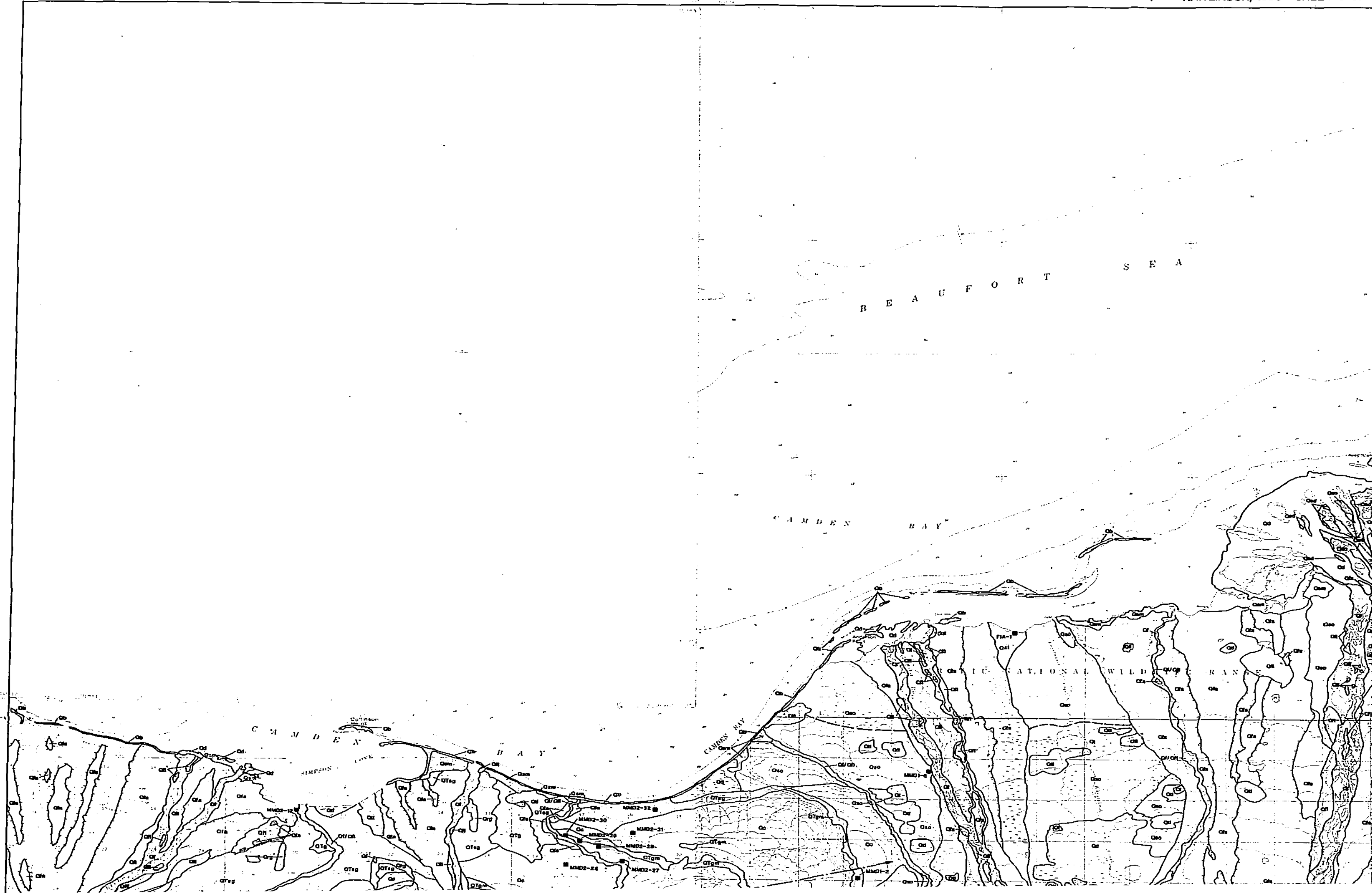
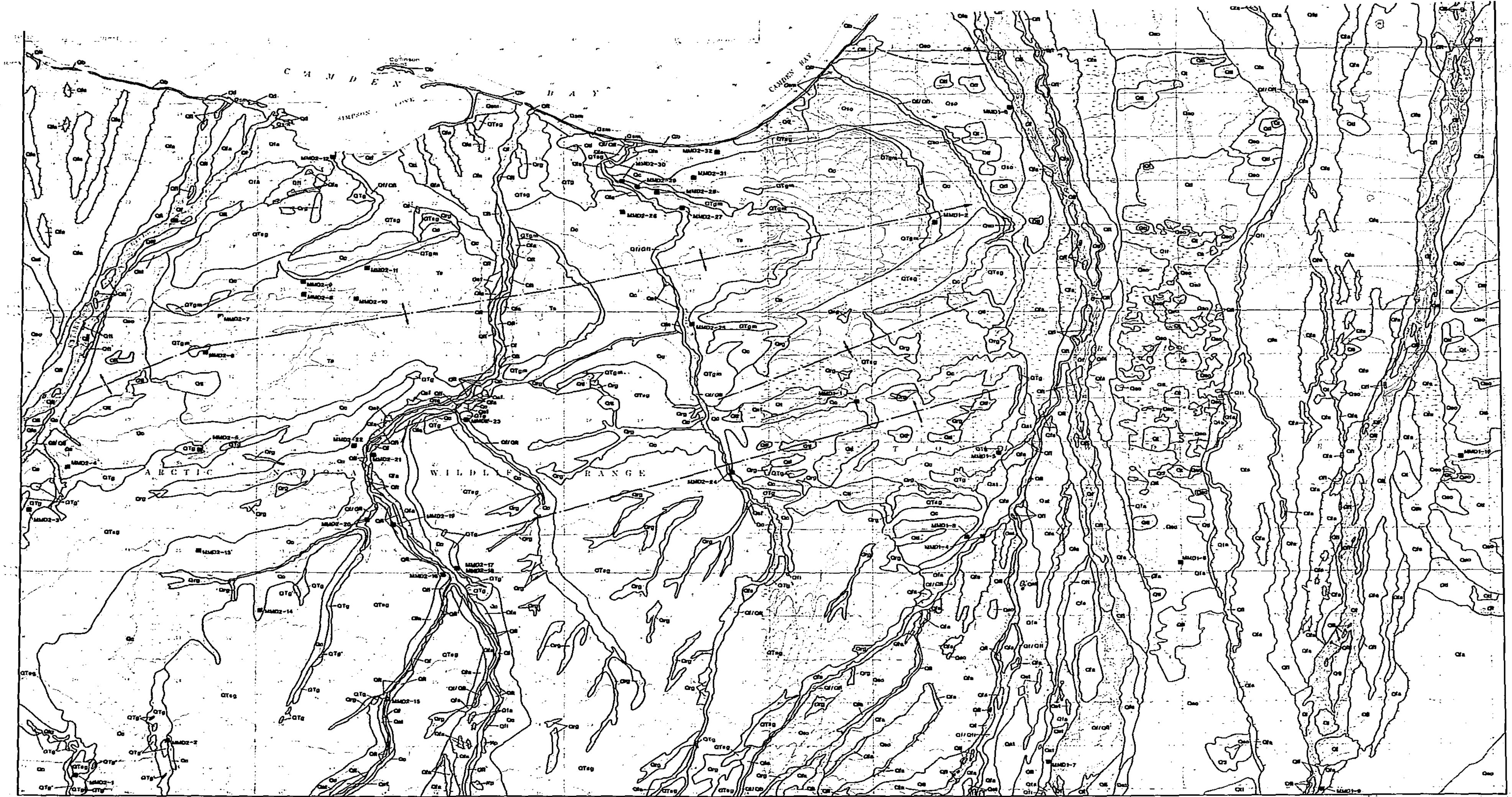
MAP SYMBOLS AND MAP-UNIT DESCRIPTIONS IN APPENDIX A
CORRELATION OF MAP UNITS IN APPENDIX B





GEOLOGY MAPPED BY O.J. FERRIANS, JR., 1973, 1978; L.D. CARTER AND J.P. GALLOWAY, 1982–1984; S.E. RAWLINSON, CARTER, AND D.R. HICKMOTT, 1985; AND RAWLINSON, 1986–1989

BASE MAP FROM U.S. GEOLOGICAL SURVEY MT. MICHELSON D-1, 1955; D-2, 1955; AND FLAXMAN ISLAND A-1, 1955, REVISED 1977.

SURFICIAL-GEOLOGY MAP OF THE MT. MICHELSON D-1 AND D-2, AND FLAXMAN ISLAND A-1 QUADRANGLES, ALASKA

SCALE 1:63,360

MILES: 1 .5 0 1 2 3 4

KILOMETERS: 1 .5 0 1 2 3 4 5

RAWLINSON, STUART E.
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