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THE HOLOCENE PALEOENVIRONMENT OF CLEMENTS MARKHAM INLET, NORTHERN ELLESMERE ISLAND, N.W.T., CANADA

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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....
Supervisor

John Shaw ....

....

Date ....April 6, 1981........

ABSTRACT

This study outlines a provisional Holocene paleoenvironmental model for Clements Markham Inlet, a major northeast trending reentrant on the northern coast of Ellesmere Island, N. W. T., Canada. Specific evidence dealt with includes: 1)the general depositional environment of certain raised marine deposits of postglacial age; 2)the identification and interpretation of macrofossils (marine molluscs and terrestrial plants) reported from these deposits; 3)the history and significance of driftwood penetration into the inlet head; 4)radiocarbon dates on collected macrofossils and driftwood which provide a provisional time framework for 1-3 above.

Abundant fossil plants were collected from the proximal bottomset beds of a local marine delta graded to a 43m relative sea level which is dated 6400 BP on the provisional emergence curve. The fossil plants also dated 6400±60 BP (SI-4314) and contain a highly diverse bryophyte flora with a minimum of 21 genera and 25 species. *Limatula (Lima) subauriculata*, a small marine pelecypod, was collected in deposits laterally continuous with the dated plants. This species' contemporary distribution is predominantly Atlantic-Mediterranean extending to Jan Mayen Island and into the subarctic waters along west Greenland. Its disjunct (?) occurrence here is interpreted as a range extension in response to ameliorated (warmer) marine conditions resulting in less abundant summer sea ice and thus more available

summer moisture. The abundant fossil plants are therefore interpreted to represent the commencement of increased plant productivity in response to increased summer precipitation in this arid polar environment. This interpretation is consistent with driftwood zonation within inner Clements Markham Inlet.

Driftwood penetration or exclusion from Clements Markham Inlet is primarily dependent upon the stability of the landfast sea ice cover at the inlet mouth. Periods of driftwood exclusion indicate cold summers when the landfast sea ice remains in place. Conversely, periods of driftwood abundance indicate warm summers when the landfast sea ice decays. Four postglacial driftwood abundance zones are indicated on emerged shorelines below the local Holocene marine limit: sporadic driftwood *ca.* 7800 BP to 6500 BP; abundant driftwood *ca.* 6500 BP to 4500 BP; greatly reduced driftwood 4500 BP to *ca.* 500 BP (?); and abundant driftwood on the present shoreline with penetration beginning as early as 500 BP (?). This zonation is similar to that demonstrated on southern Ellesmere Island and a histogram of driftwood radiocarbon dates from the Canadian and Greenlandic High Arctic indicate that this is likely a regional trend.

The collective data presented here - driftwood, fossil plants, marine molluscs - suggests consistent intervals of amelioration and cooling on northern Ellesmere Island. This provisional model shows much greater variability during the Holocene than previously interpreted Arctic Ocean deep sea cores and is directly comparable to isotopic records of high latitude ice cores.

ACKNOWLEDGEMENTS

First I would like to thank my advisor, Dr. John England, for his energy, interest and guidance throughout this project. Especially worthwhile was his heavy handed editing which added immeasureably to the quality of this thesis. Special thanks also to Jan Bednarski whose constant cynicism forced a reevaluation of many pet theories while we were still in the field. Don Lemmon provided able field assistance often under gastronomically gruelling circumstances.

Conversations with Dr. Robert L. Christie, Geological Survey of Canada, Calgary aided in preparation for field work. His provision of the original field notes from his work in Clements Markham Inlet was especially helpful.

Identification and verification of fossil materials discussed in this thesis was provided by several individuals. Jim Vaness, Department of Zoology, University of Alberta, showed great interest and aided in my initial identification of the marine molluscs. Final identification of these was provided by Dr. Irene Lubinsky (pelecypods) and Elizabeth Macpherson (gastropods) and their help is greatly appreciated. Special thanks go to Jan A. Janssens, Department of Botany, University of Alberta, for his extensive work on the bryophytes. In addition, conversations with Dr. Robert McGhee, Archaeological Survey of Canada, Ottawa assisted in understanding of some driftwood radiocarbon dates. Dr. McGhee also arranged identification and age placement of man made spikes in cultural debris.

Financial assistance for this research was furnished by a grant from the Boreal Institute for Northern Studies, University of Alberta. Transportation into the field and able logistical support was provided by the Polar Continental Shelf Project, Department of Energy, Mines and Resources, Ottawa.

Radiocarbon dates were provided courtesy of Dr. Weston Blake Jr., Geological Survey of Canada, Ottawa and Dr. Robert Stuckenrath, Smithsonian Institution, Washington D.C. Their interest in the present study is gratefully acknowledged.

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1. STUDY AREA AND PURPOSE

1.1 Introduction

The first impetus for Quaternary research on northern Ellesmere Island followed upon the discovery of 'ice islands' in the Arctic Ocean during the late 1940's. These ice islands were found to be fragments of the (sea ice) ice shelves which exist along the north coast of Ellesmere Island today and much work was subsequently concentrated on the genesis, chronology and dynamics of these features (Koenig *et al.* 1952; Marshall 1955; Crary 1956, 1958, 1960; Hattersley-Smith 1957, 1963b; Lyons *et al.* 1972; Dorrer 1971; Holdsworth 1971; Lyons and Mielke 1973). Knowledge of the surrounding environment expanded with the establishment of the Alert Weather Station in 1950 and the numerous studies conducted by the Defence Research Board (DRB, Ottawa) during, and subsequent to, the International Geophysical Year (IGY, 1957/58) at Lake Hazen (Figure 1; Jackson 1959, 1960; Maxwell 1960; Powell 1961; Oliver and Corbet 1966; Leech 1966). Investigation of the contemporary glacierization and glacial history of the region began with these previous studies (e.g. Hattersley-Smith 1960a, 1963a, 1969; Christie 1967) and remains in progress (England 1974, 1976a, 1976b, 1978; England and Bradley 1978). In addition, isotopic studies of ice cores from northern Ellesmere Island are also being conducted (cf. Koerner 1979).

The present study is a result of field investigations in Clements Markham Inlet, northern Ellesmere Island (Figures 1 and 2). This particular inlet was first examined in 1953 (Blackadar 1954; Hattersley-Smith *et al.* 1955) and a reconnaissance of the Quaternary deposits and present glacier margins was conducted in conjunction with other DRB/IGY investigations in 1958 (Christie 1964, 1967; R.L. Christie, personal communication, 1979). Since these initial investigations of Clements Markham Inlet a great deal of research has been conducted on the isotopic and stratigraphic record of high latitude ice cores which provides considerable resolution on late Quaternary climatic change (Dansgaard *et al.* 1969, 1971; Paterson *et al.* 1977; Hammer *et al.* 1978). However, despite continually expanding Quaternary research throughout the Canadian arctic very little Holocene paleoenvironmental information exists for the northernmost portion of Ellesmere Island. Such information is particularly pertinent to the continuing isotopic studies in this area (cf. Koerner 1979) and it compliments investigations in other areas of Ellesmere Island and the High Arctic in general. The present study provides new Holocene paleoenvironmental information from inner Clements Markham Inlet and is specifically concerned with:

1)The general depositional environment of certain raised marine deposits of postglacial age.

2)The identification and interpretation of macrofossils (marine molluscs and terrestrial plants) reported from these deposits.

3)The history and significance of driftwood penetration into the inlet head.

4)Radiocarbon dates on collected macrofossils and driftwood which provide a provisional time framework for 1-3 above.

1.2 Study Area

The study area is located at the head of Clements Markham Inlet, northern Ellesmere Island, Northwest Territories, Canada (82° 37′ N latitude, 68° 30′ W longitude; Figures 1 and 2). Clements Markham Inlet is a major reentrant, 45km long and 7km wide, which extends southwestward from the Arctic Ocean-Lincoln Sea into the northern flank of the United States Range. Surrounding the the inlet head is a large lowland plain (*ca.* 200km²) occupied by the contemporary sandurs of the Clements Markham, Gypsum, Piper Pass and Arrowhead (unofficial name) rivers Postglacial raised marine deltas and silt deposits are also extensive here and much of the present investigation focused on these sediments.

The mouth of the inlet forms a broad opening into the Arctic Ocean which in turn exerts considerable influence on temperature, moisture availability, cloud cover and sea ice severity. Near the central portion of the inlet the mountain ridges average about 700m asl (above sea level) rising to about 1600m asl near the inlet head. The higher peaks in the

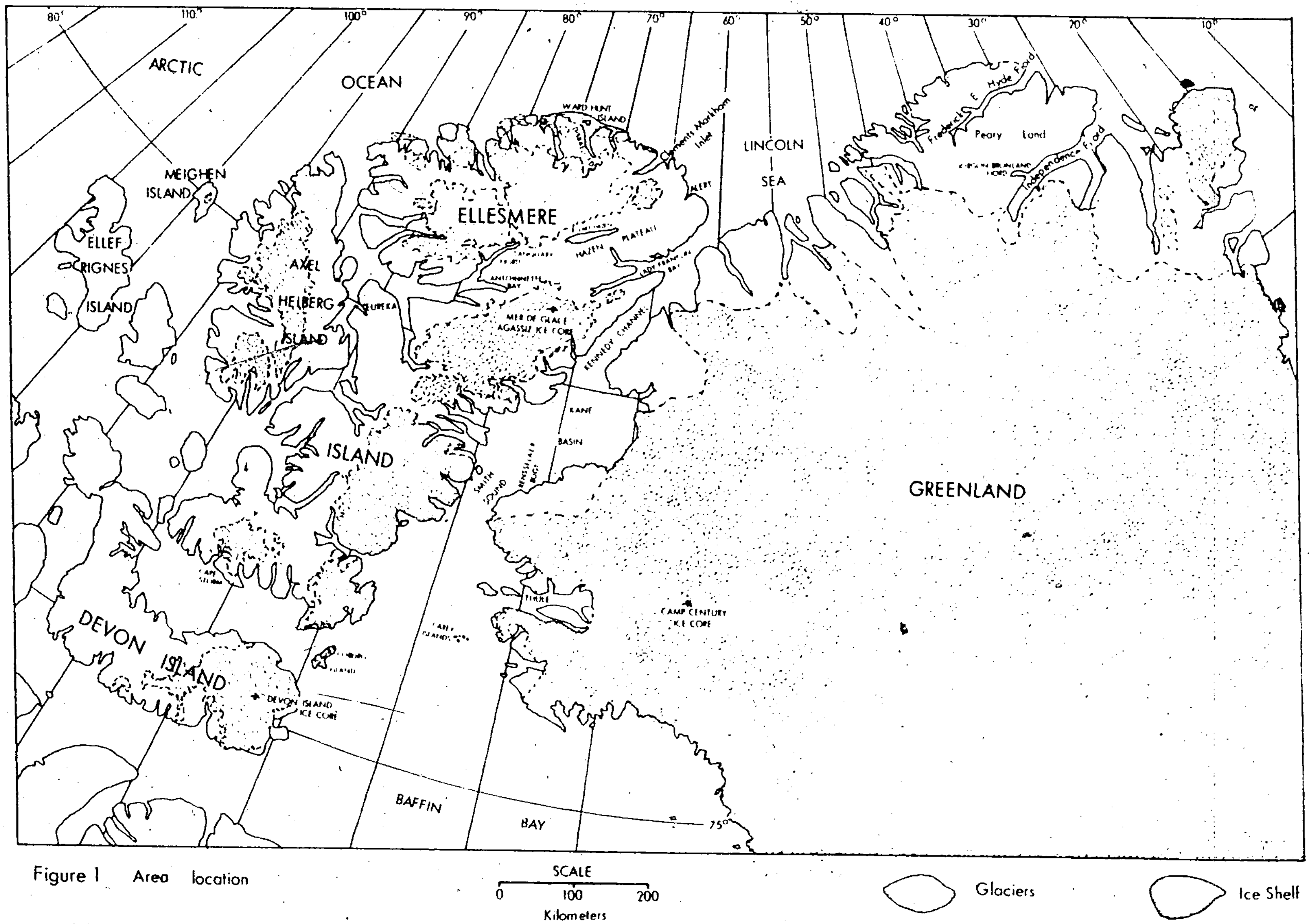

Figure 1 Area location

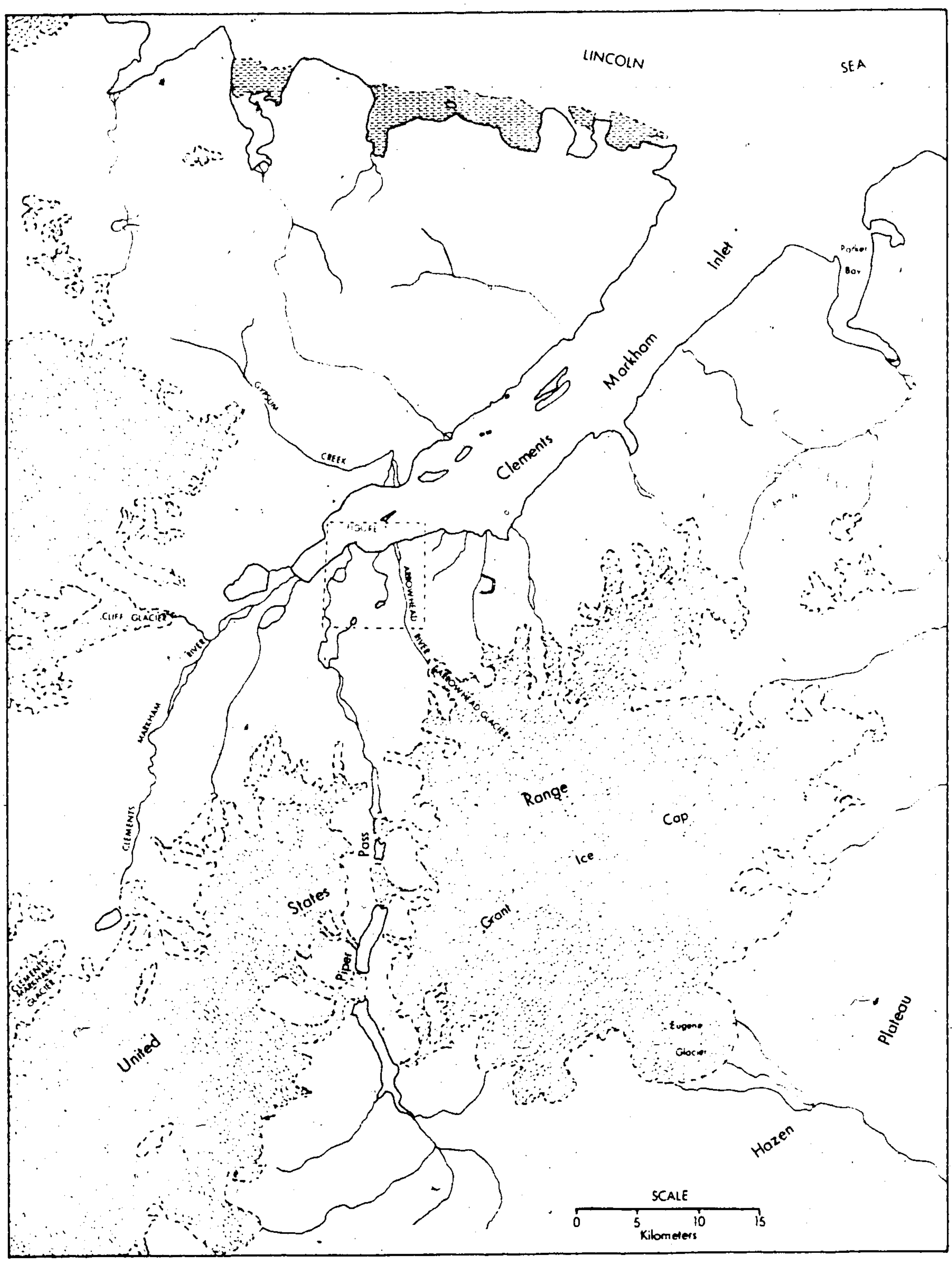

Figure 2 Clements Markham Inlet and vicinity

Glaciers

Ice Shelf

United States Range exceed 2000m asl and Mt. Barbeau, the highest peak in the range (*ca.* 2700m asl), is 200km to the southwest of the study area. Piper Pass at *ca.* 350m asl forms a major topographic depression through the United States Range leading south to the Hazen Plateau from the inlet head (Figure 2).

The mountains surrounding inner Clements Markham Inlet are covered by extensive icecaps and all the local rivers are in part glacier fed. Outlet glaciers from these icecaps often follow strike valleys or spill over bedrock sills to obstruct strike or fault block valleys. A fine example of this latter situation occurs in Piper Pass where two glaciers from the Grant Ice Cap and one from the United States Range icecap reach the valley floor creating three ice-dammed lakes (Figure 2).

1.2.1 Bedrock Geology

Northern Ellesmere Island lies within the Innuition Orogenic System which includes an older intrusive-metamorphic terrane to the north and several geosynclinal belts composed of sedimentary rocks of early Paleozoic to Tertiary age to the south (Fortier *et al.* 1954; Trettin 1972). All of the major orogenic units are important in the study area (Figure 3). The oldest unit is the intrusive-metamorphic terrane of late Proterozoic age which extends along the north coast of Ellesmere Island to the west of Clements Markham Inlet (Blackadar 1954; Christie

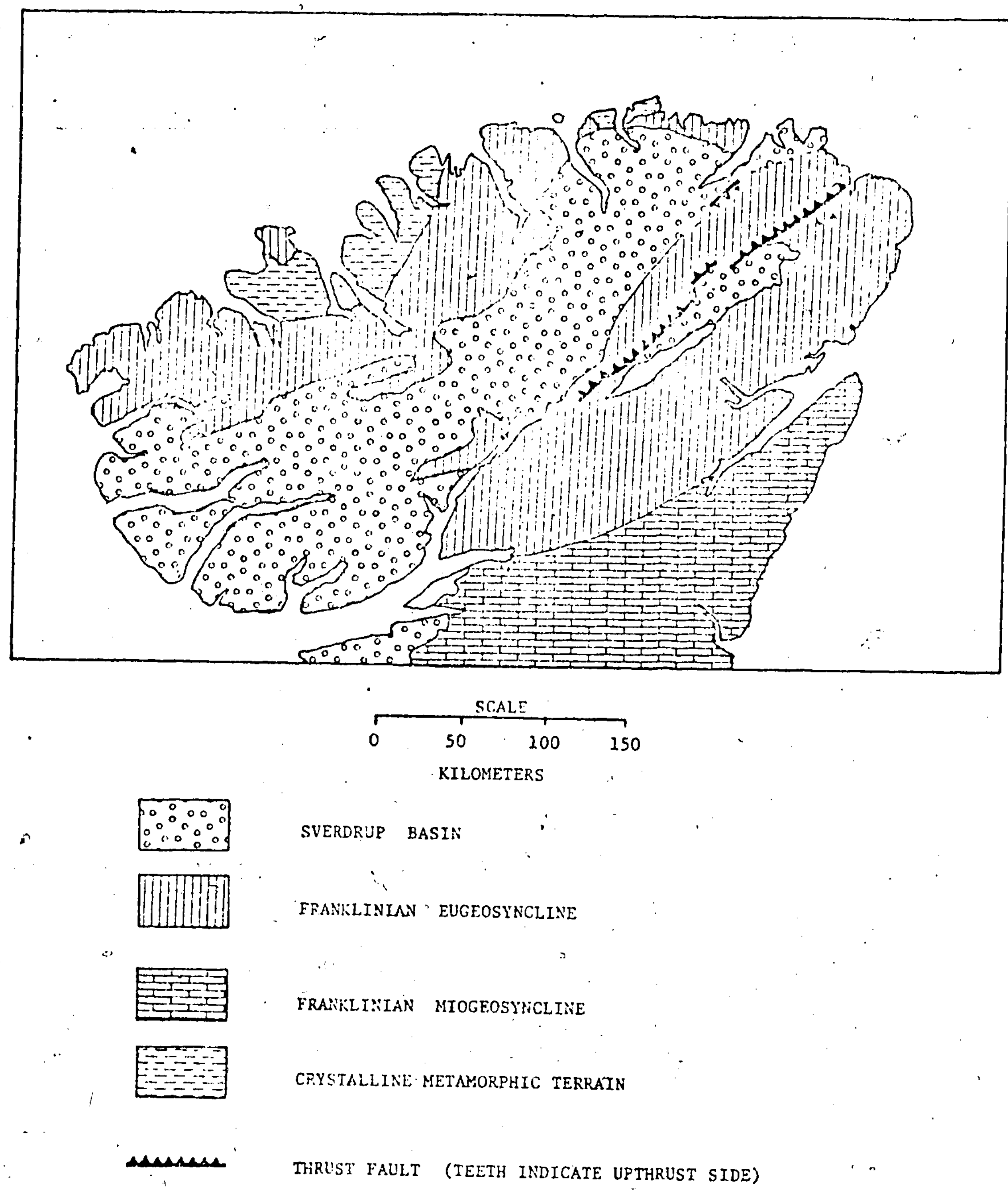

Figure 3. Major geologic units of northern Ellesmere Island (generalized from Thorsteinsson 1974).

1964; Frisch 1974). This complex, originally designated the Cape Columbia Group (Blackadar 1954) is composed of ultramafic intrusions, granitic and pegmatitic dikes and granitic gneisses and schists (Frisch 1974). These rocks once formed the Pearya Geanticline which provided many of the clastic sediments to the younger geosynclines to the south (Trettin 1971). It is also an important source for ice-rafted gneissic erratics at the head of Clements Markham Inlet. Ice-rafted materials of similar appearance may also originate from the Greenland Precambian Shield (see discussion below of former activity of the Greenland Ice Sheet).

The next youngest orogenic unit is the lower to mid-Paleozoic Franklinian Eugeosyncline which extends across to northwestern Greenland (Surlyk *et al.* 1980). The principal lithologies are sandstone, slate, graywacke, limestone and some conglomerate (Christie 1964). The mid-Paleozoic Ellesmerian Orogeny folded these Franklinian eugeosynclinal sediments into tight northeast trending anticlines and synclines which are exposed along the southern margin of the United States Range on the Hazen Plateau (Trettin 1971). South of the the Hazen Plateau, the clastic rocks give way to increasing carbonate rocks present in the miogeosyncline (Figure 3).

The next youngest unit is the Sverdrup Basin deposits of Carboniferous to early Tertiary age which were superimposed over the Franklin geosyncline in a narrow trough. At Clements Markham Inlet the Sverdrup Basin lithologies are chert pebble conglomerate, limestone, limestone breccia, sandstone, quartzite and gypsum (Christie 1964). In mid-Tertiary time the Eurekan Orogeny thrust the Cape Columbia Group, Franklinian Eugeosyncline and Sverdrup Basin deposits to the south. On northeastern Ellesmere Island the southern extent of this thrust is the Lake Hazen Thrust Zone which forms the abrupt southern margin of the United States Range (Trettin 1971). Sometime after this orogenic period block faulting also occurred to the north of this thrust zone (Trettin 1971). One such normal fault, the Porter Bay Fault Zone, now forms the approximate northern boundary of the United States Range and is subparallel to Clements Markham Inlet (Trettin 1971) which may also be a structurally controlled graben.

1.2.2 Climate

The nearest weather station to Clements Markham Inlet is Alert, 100km to the east on the shore of the Lincoln Sea (Figure 1). Climatic data for Alert (Meteorological Branch 1970) are shown in Figure 4. Alert's mean annual air temperature is -17.8°C with a mean annual precipitation of only 14.7cm. As a result of these low temperatures frozen ground is present below *ca.* 30cm (July) and periglacial features such as ice wedge polygons are widespread. The combination of low temperatures and rainfall, plus an annual water balance near zero, places northern Ellesmere Island in

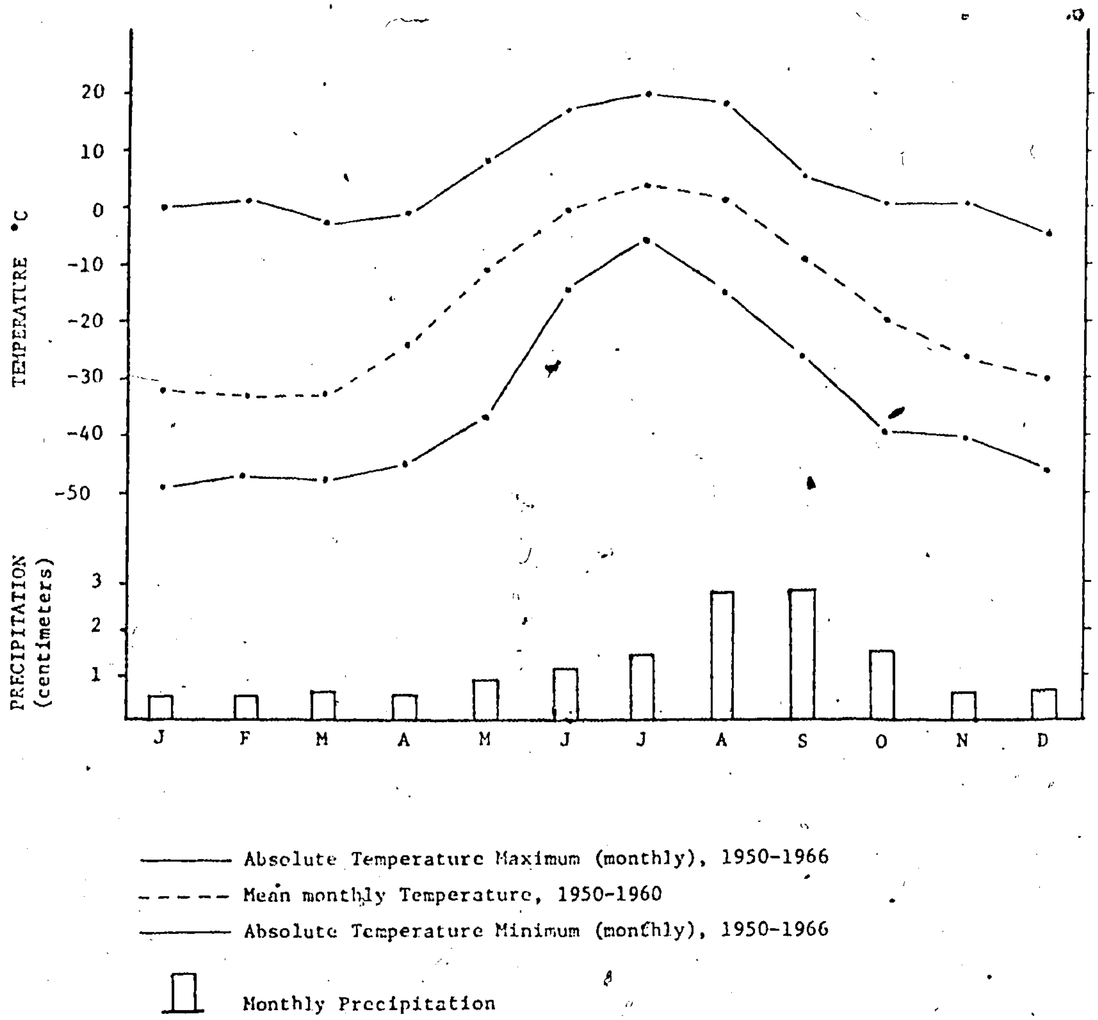

Figure 4. Climatic Data for Alert, Northwest Territories (from Meteorological Branch 1970).

the category of a true polar desert (Bovis and Barry 1974).

Although there is great year to year variability daily mean temperatures usually rise above 0°C in early to mid-June and remain above freezing until mid- or late August (Barry and Jackson 1969). During the 1979 field season in Clements Markham Inlet maximum daily temperatures were generally below 7°C between early June and early August. The frost free season in the region is usually 50-80 days (Corbet 1967; Barry and Jackson 1969; Jackson 1969; Corbet and Danks 1974). The actual growing season for plants, however, is greatly affected by site specific conditions such as snow cover and aspect. Mean annual snowfall is 1.2m at Alert (Meteorological Branch 1970) but snow depth is generally less than .5m except where wind drifted (Brassard 1971a, p. 240).

Because of the low overall precipitation and the tendency for snow to sublimate in the spring (Brassard 1971a) glacier melt is the major contributor to river runoff. During the 1979 field season the melting of the seasonal snowcover responsible for the nival flood (Church 1974) was essentially completed by 10 July. In the major rivers this nival flood produced only a small hydrograph rise and the major floods did not begin until early August when glacial melt reached its peak. In the smaller, non-ice fed gully systems which occur in extensive raised marine silts the nival period apparently produces the only major streamflow and it is only at this time that significant sediment transport occurs.

Despite the pronounced aridity of the region the climatic severity of northern Ellesmere Island is well reflected in its glaciation levels. On the outer coast, bordering the Arctic Ocean, Miller *et al.* (1975) report glaciation levels down to 400m asl and equilibrium line altitudes (ELA's) down to 200m asl while numerous glaciers descend to sea level. Additionally, during some years snow may even accumulate at sea level on the ice shelves (Marshall 1955). The Arctic Ocean is obviously an important contributor to this low glaciation level since extensive sea ice and low water temperatures, combined with frequent stratus clouds and fog, reduce summer tempertures and ablation. Paterson (1969) considered that the high frequency of coastal fog and low cloud generated by the Arctic Ocean was a partial cause of reduced summer ablation on the Meighen Ice Cap (Figure 1). Alt (1979) showed that virtually the only positive mass balance years on the Meighen Ice Cap were associated with 'Polar Ocean Flow.' This northerly air flow resulted in riming of the ice cap surface by fog and it also decreased the surface albedo because of trace snowfalls. Similarly, low ablation caused by abundant fog and low temperatures along the Arctic Ocean coast of northern Ellesmere Island also contributes to the existence of the various ice shelves which are unique in the northern hemisphere (e.g. the Ward Hunt Ice Shelf, Hattersley-Smith and Serson 1970). Towards the interior of Clements Markham

Inlet, however, the Polar Ocean influence decreases and continentality increases resulting in rising glaciation levels and ELA's (*ca.* 1050m and 850m, respectively) (Miller *et al.*1975; Alt 1979; Koerner 1979).

A process which likely contributes to the general continentality of these fiord interiors and therefore this inland rise of glaciation level, is the generation of local chinook winds in the fiordheads. Barry and Jackson (1969) found that the head of Tanquary Fiord (Figure 1) had higher mean summer temperatures than Eureka, west-central Ellesmere Island, which is the warmest of all the High Arctic weather stations (Bradley and England 1979). Inspection of combined wind and temperature data revealed that Tanquary Fiord's warm summer temperatures were principally due to intermittent high temperatures produced during conditions of descending air or chinooks (Barry and Jackson 1969). Similar conditions of local summer warming caused by chinooks have also been reported from north-central Devon Island where a 'thermal oasis' occurs in the Truelove Lowlands (Courtin and Labine 1977). This more continental climate and chinook effect in the interior of fiords is also widely recognized in Greenland (Trans 1955; Funder 1978).

In Clements Markham Inlet a marked chinook was experienced by our field party on 30 July 1979 when strong (>30km/hr), warm southerly winds were channelled out of Piper Pass for several hours clearly producing strong ablation on the numerous outlet glaciers in the area.

Additionally, large amounts of windblown silt were deposited on these glaciers with resultant decreases in their albedoes and increased melt (cf. Hattersley-Smith 1961a). Although the frequency of these winds is presently unknown the concentration of aeolian landforms in this vicinity suggests considerable persistence through time. For example, on a bedrock ridge (175m asl) between Piper Pass and lower Clements Markham Inlet, many rocks form highly polished ventifacts with pronounced sand shadows on their lee (northern) sides. Raised marine silt benches (40m asl) to the north of this same ridge also contain several wind-eroded yardangs with similar orientations to the aforementioned sandshadows and Piper Pass. These yardangs are prominent features, long enough to be visible on aerial photographs (1:60000 scale) and some are over 3m in relief.

1.2.3 Vegetation

The vegetation of northern Ellesmere Island is characterized by sparse plant cover and great species diversity (Brassard 1971a, 1976). Water and nutrient availibility in particular, plus the length of the growing season in general, are the primary limiting factors to both vascular plant and bryophyte growth (Bruggeman and Calder 1953; Schuster *et al.* 1959; Powell 1961; Corbet 1969; Brassard 1971a). In spring, plant growth is first initiated on those sites which first become snowfree even though air temperatures may not yet be above 0°C. For example, *Saxifraga oppositifolia*, which is noted for its early growth, was already in bloom on snowfree sites when we arrived in the field on 15 June 1979 when temperatures were -2.0°C. In lower Clements Markham Inlet the greatest plant cover was observed in the continuously moist to wet habitats of lake margins. Here plant cover may reach 100% although these are very localized and rare sites. Another habitat favoring plant growth is earth hummocks and other sites where a silty sand matrix apparently provides adequate water holding capacity. On such sites plants may comprise 10-40% of the surface cover. Elsewhere plants tend to grow in specialized habitats adjacent to snow patches (water source) or on bird perches (nitrogen source). In lower Clements Markham Inlet there are extensive raised marine silts which are extremely xeric habitats and these rarely support plant life except where there has been an incorporation of sand particles due to wave action during land emergence.

Contrasting this very limited plant biomass on northern Ellesmere Island is the considerable diversity of the flora which includes 166 species of bryophytes and 125 species of vascular plants (Brassard 1971a, 1971b, 1976). Brassard (1976) suggests that any area with a suitable variety of habitats on northern Ellesmere Island should support a bryophyte flora of approximately 100-125 species. Such a population represents greater floristic diversity than has been reported from northern Greenland (Peary Land) and many other High Arctic areas to the south (Holmen 1957, 1960; Muc and Bliss 1977). On the basis of this evidence together with the presence of a variety of disjunct and endemic High Arctic bryphytes, Brassard (1971a) suggests that a late Wisconsin refugia persisted somewhere on northern Ellesmere Island and possibly on its previously exposed continental shelf. Leech (1966) has also discussed evidence for refugia on northern Ellesmere Island based on entomological data from the Lake Hazen area.

1.3 Northern Ellesmere Island Glacial Record

Northern Ellesmere Island exhibits widespread geomorphic evidence of extensive former glaciations. To account for the deeply eroded fiords on the northwestern side of the island, Taylor (1955) suggested that much of northern Ellesmere Island was overridden by the Greenland Ice Sheet. However, this concept was rejected by Smith (1961) and Christie (1967) in favor of an independent outflow of ice from the United States Range. This former outflow is marked by high elevation moraines, erratics and meltwater channels together with glacially abraded terrain occasionally overlain by ice-transported shells (Nares 1878; Smith 1961; Christie 1967; England 1978). However, the history of this maximum glacierization is unknown. Christie (1967) also showed that the advance of the Greenland Ice Sheet onto Ellesmere Island was of much more limited extent than Taylor (1955) originally hypothesized (see below).

On the basis of field work in Tanquary Fiord Hattersley-Smith (1969) reported evidence of extensive glacierization but he also suggested that this was followed by glacier advances of lesser magnitude. That these advances were of different ages was suggested by the more advanced weathering of the uppermost glacial deposits together with their greater redistribution by mass movement. The date of deglaciation at the head of Tanquary Fiord is unknown but it must be older than marine shells dated at 6820±140 BP (GSC-373).

On northeastern Ellesmere Island Christie (1967) provided numerous observations on former ice flow directions, the distribution of erratics, the occurrence of marine shells in postglacial deposits, and an initial interpretation of the deglaciation of the area. Although he concluded that most of the glacial features in the area were the product of local ice from the United States Range he also recognized that granite and gneiss erratics on Judge Daly Promontory and the northeastern Hazen Plateau recorded a limited advance of the Greenland Ice Sheet onto Ellesmere Island. He also recognized that many of these granite and gneiss erratics, below the local marine limits, had been sea ice-rafted into the area. In several localities Christie (1967) recorded the highest elevations of marine silts and shells thereby providing preliminary data on the profile of the Holocene marine limits. These observations followed upon the initial, speculative map of marine limit elevations constructed for northern Ellesmere Island and Greenland by Farrand and Gajda (1962). Finally, several of Christie's (1967) observations in Clements Markham Inlet provided the impetus for the present investigation and these are discussed below where appropriate.

Subsequent fieldwork on northeastern Ellesmere Island by England (1974, 1976a, 1976b, 1978) and England and Bradley (1978) has greatly expanded the available data on Quaternary stratigraphy, chronology and glacio-isostasy. This work collectively shows that the advance of the Greenland Ice Sheet onto northeastern Ellesmere Island is of great antiquity. This is based on the advanced weathering of its surficial deposits together with a tentative amino acid age estimate of >80,000 BP on an associated shelly till. This zone of maximum Greenland ice cover was subsequently cross-cut by the outermost advance of the Ellesmere Island ice which has been dated by both radiocarbon and amino acid methods at >28,000 BP and >35,000 BP, respectively (England and Bradley 1978).

During the last glaciation a restricted ice advance out of the upland icefields deposited the Hazen Moraines which form a discontinuous boundary extending only to the fiordheads of inner Archer Fiord-Lady Franklin Bay and generally well inland of the present coastline elsewhere in this area (England 1978). In one locality these moraines are associated with a marine limit of *ca.* 105m asl that is radiocarbon dated at *ca.* 8200 BP which is very similar (±200 years) to other dates on initial emergence beyond this ice margin (England 1978; England and Bradley 1978). Note that this limited, last or 'late Wisconsin' glaciation extended well into Holocene time and that it left considerable portions of northeastern Ellesmere Island ice-free. Similarly, unglaciated areas also existed above the earlier and outermost Ellesmere Island and northwest Greenland ice advances (see England and Bradley 1978, their Figure 2). As yet no evidence has been found to demonstrate that the Greenland Ice Sheet reached the northeast Ellesmere Island coast during the last glaciation (Davies 1972; Weideck 1972, 1976) and hence it is presently concluded that an ice-free corridor existed along much of Robeson and Kennedy Channels at this time (England and Bradley 1978). This is also indicated by the initial synchronous emergence (*ca.* 8200 BP) in the proposed ice-free zone which suggests the unloading of an ice-margninal depression (cf. Walcott 1970; England 1978). At present no evidence has been reported on glacial events intermediate in age between the Hazen Moraines (*ca.* 8200 BP) and the outermost Ellesmere Island ice advance (>35,000 BP, England and Bradley 1978).

1.4 The Holocene Paleoenvironment of Clements Markham Inlet

The study of Holocene paleoenvironments employs a wide range of techniques determined by the types of information sought and perhaps more often by the types of evidence that can be found in the field. In the high latitudes of North

America and Greenland paleoenvironmental data has been provided by palynology and lake sediment cores (Hegg 1963; Colinvaux 1967; Fredskild 1967, 1973; Hyvarinen 1972; Funder 1978); archeological reconstruction (Knuth 1967; McGhee 1972; Barry *et al.* 1977; Schledermann 1980); marine faunal migrations (Andrews 1972; Hjort and Funder 1974; Weideck 1976; Street 1977); snowfield and ice core stratigraphy (Hattersley-Smith 1960a, 1960b, 1963b; Koerner and Paterson 1974; Koerner 1977, 1979); isotopic studies (Dansgaard *et al.* 1969, 1971; Andrews 1973; Paterson *et al.* 1977; Koerner and Russell 1979); ice shelf stratigraphy (Marshall 1955; Crary 1960; Lyons *et al.* 1971); and driftwood penetration into the interisland channels of the Queen Elizabeth Islands (Blake 1972, 1975). The present study deals with three specific types of data from inner Clements Markham Inlet. These include a fossil plant deposit, the postglacial marine molluscan fauna, and variations in driftwood abundance on emerged Holocene shorelines.

Of particular interest to the paleoenvironmental history of this area are deposits at the head of Clements Markham Inlet which Christie (1967, p. 20) describes as "cyclically deposited beds of silt, sand and plant remains...exposed in a region of thick marine silts." He adds that "the relation of the plant bearing deposits to the marine silts is unknown." Although Christie (1967) describes a similar deposit in lacustrine sediments south of Piper Pass (Figure 1) such extensive plant remains are comparitively rare and may therefore provide a unique view of the paleovegetation of northern Ellesmere Island.

The present study of these deposits includes an interpretation of their depostional environment and the identification and radiocarbon dating of their fossil plant assemblage. Since these deposits occur among extensive marine silts the general stratigraphy of the area was also investigated. Chapter 2 discusses the nature of these sediments and the enclosed plant material.

Marine pelecypods and gastropods are also common in the marine sediments of inner Clements Markham Inlet. On eastern Baffin Island and eastern Greenland Andrews (1972), Hjort and Funder (1974) and Street (1977) have all demonstrated the northward expansion of subarctic marine molluscs during a postglacial 'climatic optimum' specific to each area. Collections of marine molluscs in Clements Markham Inlet were therefore made to determine their faunal affinities and also to determine if there had been any alteration in the species composition of this fauna during the Holocene. These data are discussed in Chapter 4.

Another major aspect of the present study is the elevational distribution and abundance of driftwood on emerged Holocene shorelines in Clements Markham Inlet. On southern Ellesmere island similar observations have been used as a relative index of summer sea ice severity during the Holocene. Elevational zones of abundant driftwood are interpreted as times of reduced summer sea ice due to an ameliorated summer climate (Blake 1972). Blake (1972, 1975) dated the initial postglacial driftwood penetration into the interisland channels of the Queen Elizabeth Islands at *ca.* 8500 BP with the most abundant driftwood accumulating between *ca.* 6500 BP and 4500 BP. This was followed by a decline in driftwood abundance until *ca.* 500 BP after which driftwood again increased.

The time-elevational distribution of driftwood Clements Markham Inlet provides an important index of summer sea ice severity and inferred summer climate in this region of northernmost North America (cf. Knuth 1967; Blake 1972). Such observations on sea ice history are of particular interest on northern Ellesmere Island as this area presently supports the only (sea ice) ice shelves in the northern hemisphere. These ice shelves begin immediately to the west of Clements Markham Inlet and the most noteable and best studied ice shelf (the Ward Hunt Ice Shelf) surrounds Ward Hunt Island and blocks Disraeli Fiord *ca.* 80km west of Clements Markham Inlet (Figure 1). Crary (1960) originally concluded that the initiation of the Ward Hunt Ice Shelf postdated the deposition of low elevation driftwood found within Disraeli Fiord which dated *ca.* 3000 BP. The local record of driftwood penetration in Clements Markham Inlet, therefore, presents additional data on landfast sea ice stability bordering the Arctic Ocean and is also pertinent to determining the similarities of sea ice history between northern and southern Ellesmere Island (cf. Blake 1972).

This data can also provide a framework for comparison with other paleoclimatic models in this region (e.g. the developing ice core record). Additionally, the high latitude position of northern Ellesmere Island within the Arctic Basin means that data from this locality may be applicable to interpreting Holocene variations in the sea ice cover of the Arctic Ocean proper. A discussion of Holocene driftwood variations in Clements Markham Inlet and its paleoenvironmental significance is presented in Chapter 3.

2. STRATIGRAPHY AND FOSSIL PLANTS

2.1 Introduction

This chapter discusses the fossil plant deposits from Inner Clements Markham Inlet originally described by Hattersley-Smith (1960b) and Christie (1967). This discussion includes their depositional environment, floral composition, radiometric age and paleoenvironmental significance. These topics are preceded by a general account of the Quaternary stratigraphy of the area including the deltaic complex in which the plant fossils are found.

2.2 General Stratigraphy

The lower portion of Clements Markham Inlet receives drainage from four river systems plus several tributaries (Figure 2). Glaciers terminate in these major river valleys within 7-25km of present sea level and their contemporary sandurs grade to a depositional plain of approximately 200km² at the inlet head. Reconnaissance of this latter area by Christie (1967), the author and J. Bednarski (personal communication 1980) shows a wide variety of glacial, fluvial and marine deposits. These include till, kames, moraines, kettled sandurs, aeolian deposits, marine deltas and raised marine silts. Talus, rock glaciers and rock-glacierized moraines (cf. England 1978) are also common on the valley sides. The presence of till-covered bedrock, a kettled sandur and two well developed kames, all contacting glacio-marine deltas of Holocene age indicate that glaciers reached the inlet head during the last glaciation. However, there are no well developed glacial features beyond the constriction in the inner inlet (Figure 2) which also coincides with the abrupt termination of the massive raised marine silts in the area. This locality, therefore, may mark the maximum extent of the last or late Wisconsin glaciation though work on the Quaternary glaciations and glacio-isostatic adjustments is still in progress (J. Bednarski, personal communication 1980).

A provisional composite diagram of the early Holocene stratigraphy in lower Clements Markham Inlet is shown in Figure 5. It represents only the depositional environment during the establishment of the local marine limit (i.e. the uppermost elevation of the late-glacial marine transgression, Andrews 1970). This sequence begins with till deposited over bedrock during the last glaciation. During deglaciation there was a marine transgression across the glacio-isostatically depressed landscape and deposition of rhythmically bedded silts over this till. Christie (1967, p. 32) recognized that "The extensive, uniform deposits of marine silt presumably represent a large volume of silt-laden water such as would derive from a retreating ice sheet...." and "that the silt carrying flood occurred either just before or just after marine submergence reached its maximum." At all sites examined (J. Bednarski, personal communication 1980) the lowest silts, stratigraphically,

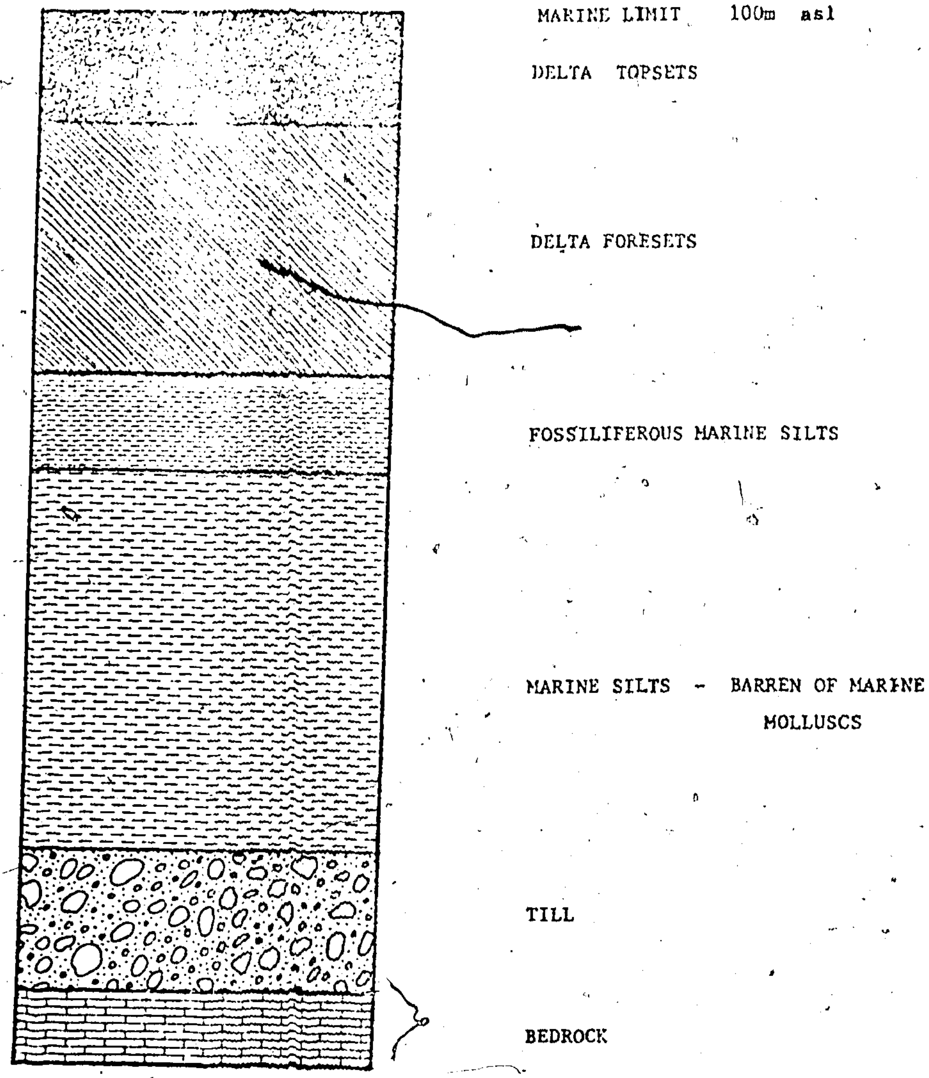

Figure 5. Generalized composite geologic column for inner Clements Markham Inlet during establishment of the marine limit.

were barren of marine macrofauna (pelecypods and gastropods). This suggests that these silts were deposited either before such fauna had time to migrate into this area or that the fauna was present locally but could not occupy this zone because the initial postglacial environment was unfavorable due to high sedimentation rates and low salinity (cf. Ocklemann 1958). The barren marine silts grade up into similar rhythimically bedded marine silts which do contain a marine fauna. These marine shells are likely slightly younger than the establishment of the marine limit deltas at *ca.* 100m asl (provisional marine limit for the inlet head determined by J. Bednarski, personal communication 1980).

Postglacial emergence has subsequently resulted in the dissection of these marine limit sediments producing several inset deltas graded to progressively lower and younger sea levels. These telescoping deltas result in the prograding of coarse, shallow water deltaic sediments over fine grained, deeper water sediments. Figure 6 is a generalized lithofacies diagram of this sequence which shows, from left to right, a progressive decrease in time and sea level elevation as younger deltaic sediments and marine silts are prograded over the previously transgressive barren marine silts (see discussion of emergence curve, Chapter 3). The barren marine silts attain their greatest thickness and height in close proximity to the marine limit deltas and are therefore shown decreasing in thickness away from the inlet head.

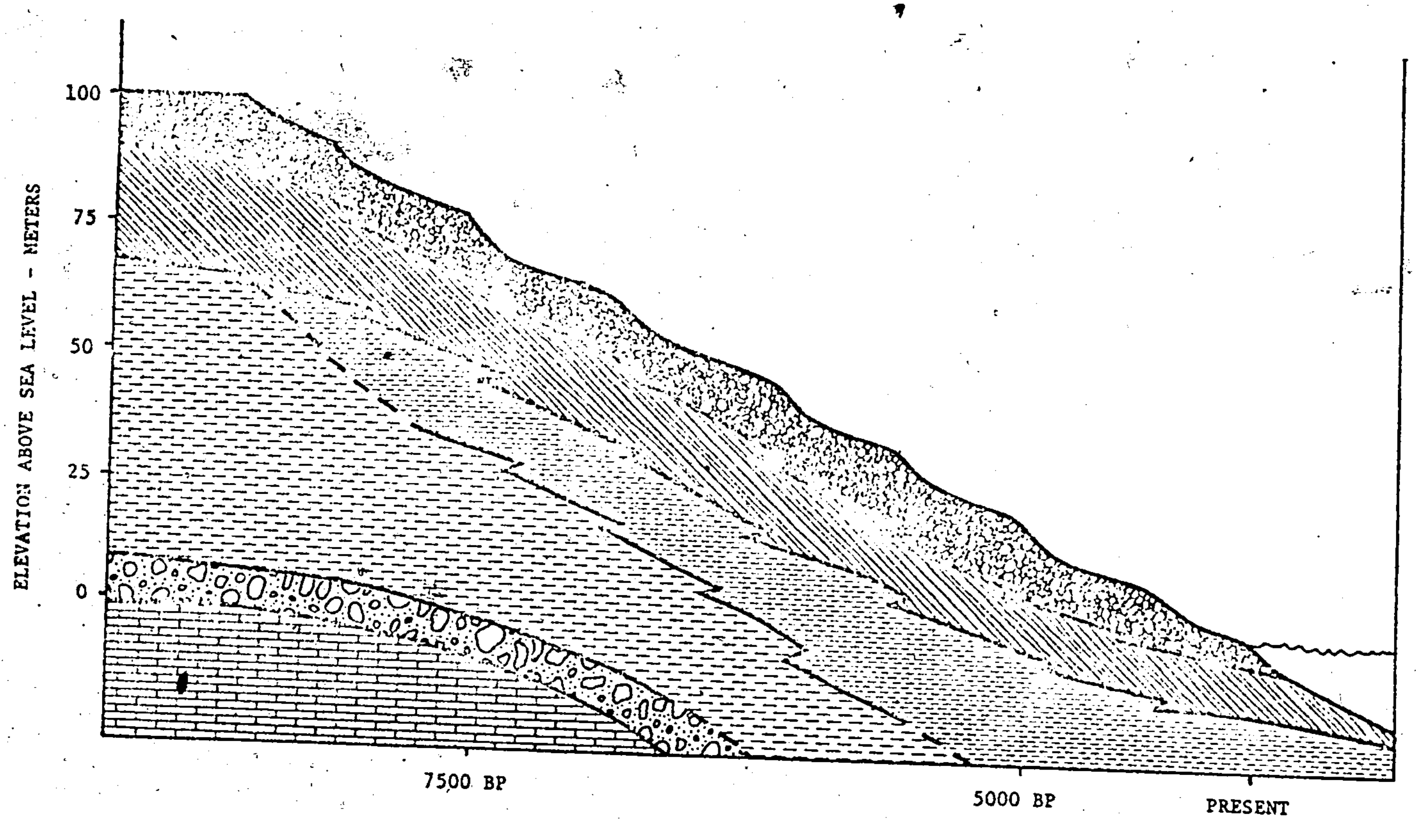

Figure 6. Lithofacies diagram of inner Clements Markham Inlet showing progradation during postglacial emergence. Units same as Figure 5.

2.3 Generalized Surficial Geology of Delta Complex #2

The plant-bearing beds originally described by Hattersley-Smith (1960b) and Christie (1967) are exposed in several gullies incised into Delta Complex #2 along the south shore of inner Clements Markham Inlet (Sites 1 and 2, Figure 7 and 8). This delta complex is related to distributary ice from Piper Pass (area of kettled sandur on Figure 7). The predominance of rounded cobbles and coarse gravels with four well developed kettle lakes on this tributary valley surface suggest that the retreating ice stagnated here and was then covered by glacial outwash. Presently, the main drainage from the kettled sandur is a lake-fed stream which is depositing an alluvial fan into the inlet head.

A marine limit delta is developed here at *ca.* 95m asl (J. Bednarski, personal communication 1980) and later delta surfaces grading to *ca.* 72m, 69m, and 43m asl were observed downvalley from the kettled sandur (Figures 7 and 8). There is also a delta surface which has been truncated by later stream erosion; its lowest point is presently at *ca.* 33m asl and it likely relates to an unknown relative sea level slightly lower than this elevation. Since the barren marine silts reach an altitude of *ca.* 70m asl it is apparent that the lower delta surfaces have been inset within them. There are also two distinct delta surfaces on the east side of the Arrowhead River as shown in Figure 7. The first is a delta graded to a former sea level at 7m asl (see Chapter 3,

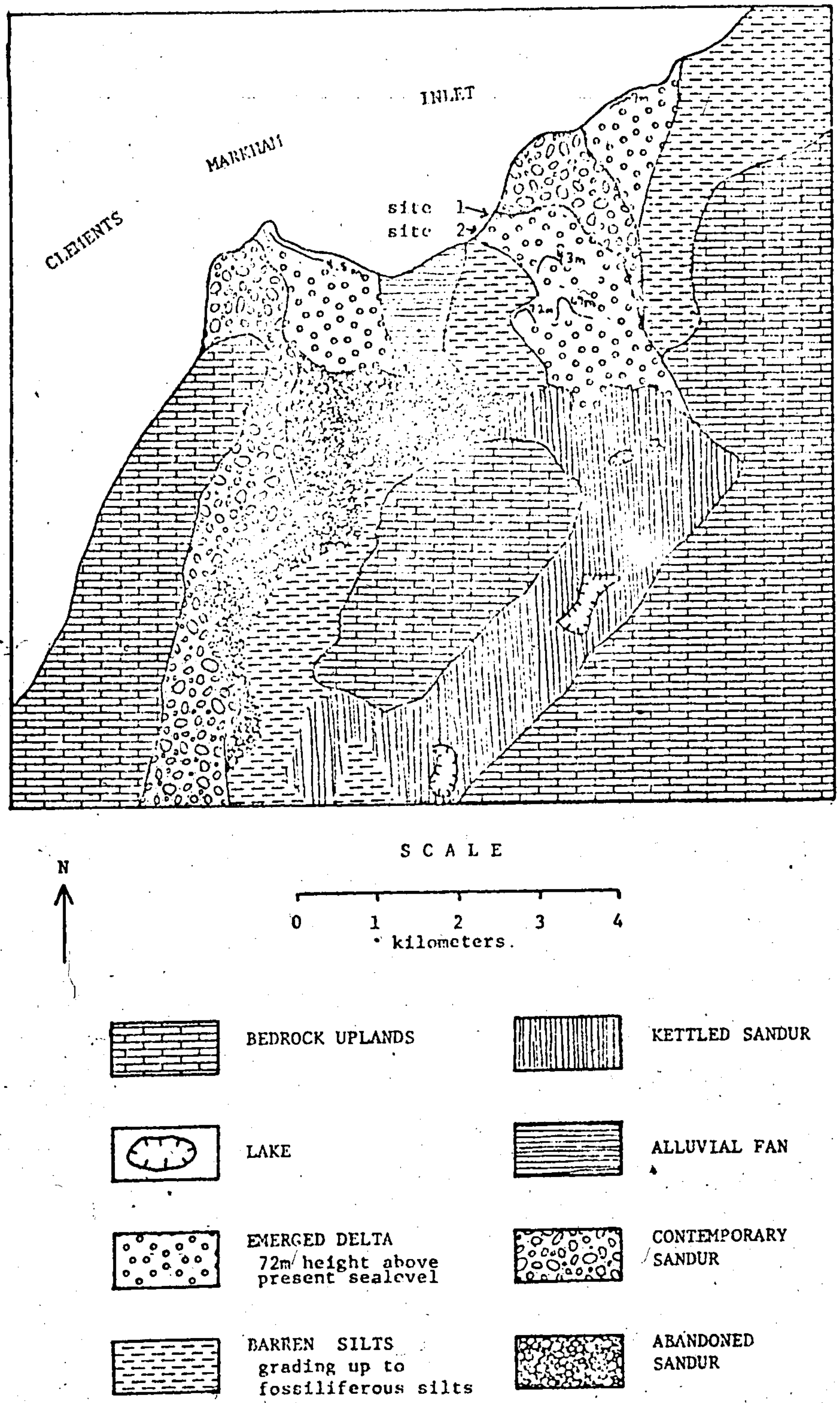

Figure 7. Generalized Surficial Geology of Delta Complex #2.

Figure 8. Overview of Delta Complex #2. Horizontal arrow indicates prominent 43m delta lip. Vertical arrows show location of site 1 and 2, left to right, respectively. Contemporary sandur of Arrowhead River at left and foreground. View is to the southeast.

discussion of radiocarbon date GSC-3031, 2180±60 BP). Between this former shoreline and the higher raised deltas to the west is the contemporary sandur-fan delta of the Arrowhead River. Erosion along its western boundary has created a 1.5km long exposure through the distal portion of the emerged delta systems.

2.4 Fossil Plant Beds

Sites 1 and 2, Figure 7, both contain allochthonous plant remains and because of their proximity and similar elevations (*ca.* 8-25m asl) these deposits are interpreted as being laterally equivalent and therefore synchronous. Although both sites contain recognizeable plant remains they are much more abundant at Site 1 which is likely the one described by Hattersley-Smith (1960b) and Christie (1967). Figures 9, 10 and 11 show details of the stratigraphy of Site 1 (Figure 7) which forms a section *ca.* 80m long and *ca.* 10m high at the gully mouth. This section consists of rhythmically bedded sands and silts which dip *ca.* 3° seaward (Figure 9). Pebbles are rare and individual beds are generally continuous along the exposure. Some sedimentary structures are present, the most common being ripple formsets with draped laminations overlying them. Small scale load casts and convoluted bedding (amplitude *ca.* 0.5m, see Figure 10) are common. Marine pelecypods and gastropods are present but not common. In this exposure the plant remains are generally within the sandy basal portion of a couplet or

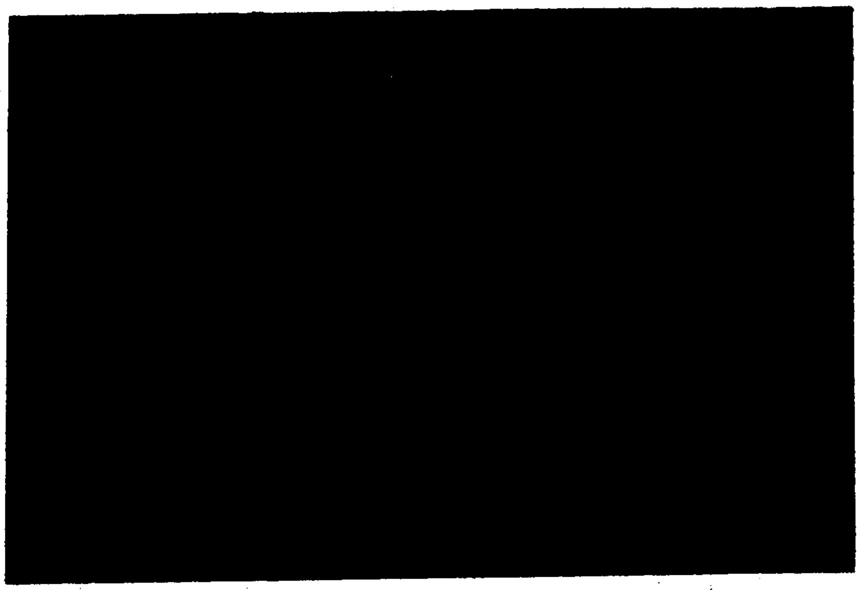

Figure 9. Site 1, Delta Complex #2. Note rhythmic sedimentation plus overturning of beds at right center.

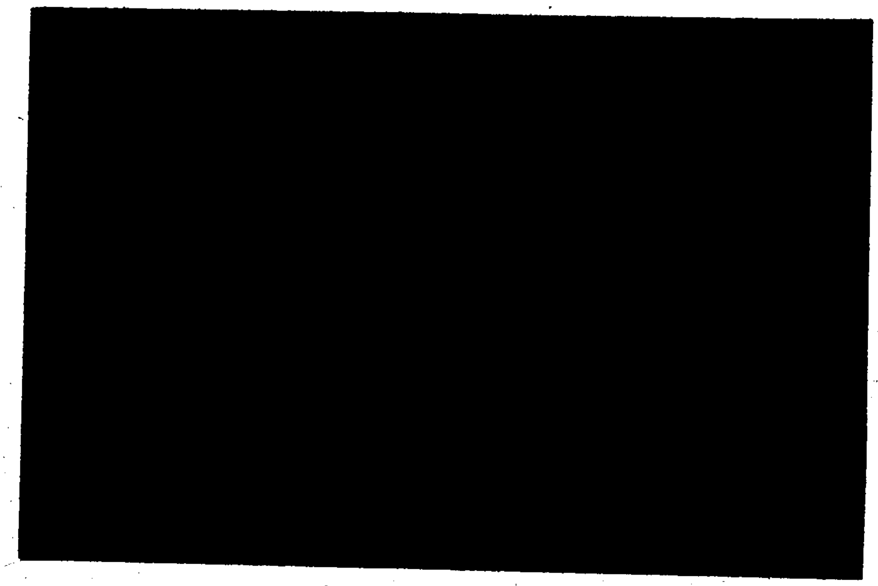

Figure 10. Convoluted bedding, site 1, Delta Complex #2. Shovel is .7m; divisions on rule are 1 inch.

series of sandy laminae (Figure 11). The plants are both abundant and well preserved. Within an individual layer entire handfuls of plants may be removed at one time. Intact vascular plant specimens (roots, stems, leaves) are common and easily recognizeable. Bryophyte specimens are equally well preserved and are more abundant than the vascular plants. Specimens from this exposure, collected at *ca.* 16-17m asl, were identified and radiocarbon dated (see discussion below).

Site 2, Figure 7, is approximately 200m to the west of Site 1. At the base of this section is a dense, massive, silty clay overlain by about 6-7m of rhythmically bedded, sands and silts similar to those at Site 1. Marine pelecypods and gastropods are fairly common in both units. The lower, massive silty clay contains the disjunct (?) pelecypod *Limatula (Lima) subauriculata* which is discussed in Chapter 4. The rhythmically bedded sands and silts also contain recognizeable vascular plant and bryophyte remains though they are far less abundant than at Site 1. Also in contrast to Site 1 the plant remains in the rhythmically bedded unit are often sandwiched between the sand layers and the overlying silt layers. At this site the beds can be traced to the edge of the 43m delta lip shown in Figures 7 and 8. The contact between foresets of the 43m delta and these bedded deposits was not observed but their relationship can be inferred from radiometric evidence (see following discussion).

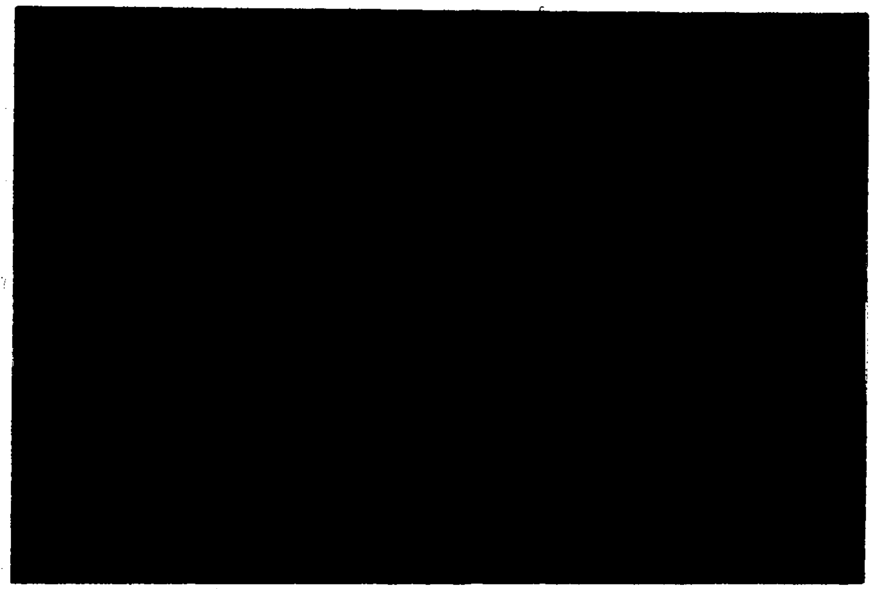

Figure 11. Detail of bedding, site 1, Delta Complex #2. Note layer of plants at top.

2.4.1 Depositional Environment of the Fossil Plants

Fossil plants collected from Site 1 (Figures 7 and 8) were radiocarbon dated at 6400±60 BP (SI-4314). In addition, driftwood collected from the fiordhead at an elevation of 43m dated 6445±65 BP (SI-4315) and this provides a maximum date for the 43m shoreline since some downslope movement of this sample cannot be discounted. Due to the similarity in the radiometric ages on the fossil plants and the 43m driftwood it is concluded that the plants were deposited into a similar former sea level and consequently they are contemporaneous with the construction or alteration of the nearby 43m delta surface beneath which the plant beds appear to extend. Since these plants were collected at 16-17m asl it is apparent that they were deposited at a depth of at least 26m below sea level. The presence of coarse to fine grained sands imply proximity to a sediment source whereas the silts imply periods of sedimentation from suspension under more quiescent conditions. The ripples on the other hand indicate sand transportation by tractive currents and the rapidly alternating depositional sequence also indicates pulsating inputs of sediment . The depositional environment of the fossil plants is therefore interpreted as a marine, proximal bottomset facies.

2.4.2 Fossil Plants-Paleoenvironmental Inferences

Table 1 is a species list of plants identified from Site 1. Bryophytes were identified by J. Janssens

TABLE I: FOSSIL BRYOPHYTES AND VASCULAR PLANTS COLLECTED FROM SITE 1, DELTA COMPLEX #2, CLEMENTS MARKHAM INLET.

SPECIES	PRESENT OCCURRENCE ON NORTHERN ELLESMERE ISLAND[1]
BRYOPHYTES	
Aulacomnium turgidum	Restricted - generally abundant
Catascopium nigritum	Rare - very restricted
Distichium capillaceum	Widespread
Ditrichum flexicaule	Widespread
Drepanocladus uncinatus	Widespread - only locally abundant
Encalpyta alpina	Widespread
Grimmia alpicola	Rare - abundant specific sites on N. coast
Hygrohypnum luridum	Rare
Hypnum bambergeri	Widespread - abundant on N. coast
Hypnum revolutum	Widespread - very common
Meesia uliginosa	Rare - nowhere abundant
Mnium hymenophylloides	Widespread
Mnium orthorrhynchum	Widespread - common all localities
Orthothecium chryseum var. *cochlearifolium*	Widespread - among most ubiquitous plants
Philonotis fontana var. *pumila*	Widespread - abundant on north coast
Poganatum dentatum	Restricted
Polytrichum juniperinum	Restricted - not abundant anywhere
Timmia austriaca	Widespread
Tomenthypnum nitens	Widespread
Tortella arctica	Rare - abundant specific sites on N. coast
Bryum cf. *pseudotriquetrum*	
Encalypta cf. *procera*	
Orthotrichum cf. *speciosum*	
Pohlia species	
cf. *Tortula mucronifolia*	

VASCULAR PLANTS	DISTRIBUTION[2]
Salix arctica	Circumpolar, arctic-alpine
Saxafraga oppositifolia	Circumpolar, wide ranging arctic-alpine
Dryas integrifolia	N. America, wide ranging, arctic

1 - Based on Brassard 1971a 1971b, 1976

2 - Based on Porsild 1957

(Bryological Report 401a and subsequent reports in this series, on file Boreal Institute for Northern Studies, University of Alberta). The vascular plants were identified by the author. All species are presently extant on northern Ellesmere Island and their habitat preferences and relative abundance in the present vegetation are indicated in Table 1. For the bryophyte species three generalized habitats are indicated: rich fen (bog), dry tundra and riverine (J. Janssens, personal communication 1980). The vascular plants grow in a variety of habitats but these are all generally xeric. For the bryophytes there are a minimum of 21 genera and 25 species contained in the sample which is a higher species diversity than most fossil samples (J. Janssens, personal communication 1980). This diversity plus the extremely well preserved condition of the specimens suggests they were not transported any great distance and they must have originated near the 43m delta surface.

It is proposed that the plants originated from an environment quite similar to that found on the contemporary kettled sandur (Figure 7). Former lakes or ponded areas would have allowed growth of a rich fen (bog) community whereas the majority of the sandur surface was likely covered with *Dryas integrifolia-Salix arctica-Saxifraga oppositifolia* and other plants and bryophytes typical of dry tundra communities occupying well drained gravelly and sandy-silty deposits or ice wedge depressions. The remaining riverine bryophytes probably grew in smaller feeder channels draining into the lakes as its unlikely they would grow along the larger, swifter moving rivers. Stream channel migration could well have cut across these sandur deposits and into such lake margins or ponded depressions. Consequently, streams could have entrained plants from these two habitats plus bryophytes growing in the adjacent smaller stream channels transporting them to the delta front where they settled from suspension into the bottomset deposits.

The cause and paleoclimatic significance of this fen growth, however, is more problematical. Miller (1973) and Nichols (1975) suggest that in arctic areas the initiation and cessation of peat growth represents amelioration and deterioration (warming and cooling), respectively. Based on pollen evidence from northern Greenland, Fredskild (1969, 1973) considers intensified plant growth to represent not only warmer summer temperatures but also "higher plant productivity and precipitation during (the) summers, (which is) a result of the open fjords in Peary Land and more open water in the Arctic Ocean" (Fredskild 1969, p. 581). In Clements Markham Inlet warmer summers after *ca.* 6500 BP are also suggested by the presence of abundant driftwood in this time-elevational zone (see Chapter 3). On southern Ellesmere Island Blake (1972, 1975) also provides driftwood evidence for this period of warmer summers with reduced sea ice. It is possible therefore that the 6400±60 BP date on the fossil plants in Clements Markham Inlet corresponds to the beginning of higher plant productivity and initiation of fen growth which in turn may reflect a climatic amelioration characterized by less extensive summer sea ice and greater summer humidity. Regionally two other radiocarbon dates on basal peat also suggest initiation of greater plant growth in this same general period. The first, from Tanquary Fiord (Figure 1), dated 6480±200 BP (SI-468, Hattersley-Smith and Long 1967). The second from the Carey Islands, northwest Greenland (Figure 1) dated 6280±80 BP (GSC-2368, Brassard and Blake 1978). These two sites are, respectively, 200 km to the southwest and 625 km to the south of Clements Markham Inlet.

If these peat deposits do in fact reflect summer amelioration then peat accumulation at these sites should have ceased *ca.* 4500 BP since after this date driftwood accumulation on southern Ellesmere Island (Blake 1972, 1975) and in Clements Markham Inlet (see Chapter 3) become less abundant. This driftwood reduction implies the retention of landfast sea ice during the summers (post 4500 BP) and therefore lower ablation season temperatures. On the Carey Islands peat growth did terminate at 4360±140 BP (GSC-2415, Brassard and Blake 1978). The interpretation that late lying snowpatches on this northwest-facing site (therefore implying lower summer temperatures) prevented bog growth prior to 6500 BP and after 4500 BP is reasonable.

That bog growth need not be controlled by such large scale ameliorations, however, is shown by a basal peat date of 8930±90 BP (GSC-2440) from an interior site on the Carey

Islands (Brassard and Blake 1978). This indicates that bog growth and peat accumulation was occurring there much earlier than the climatic amelioration at 6500 BP. Another example is Nichol's (1969) report of a radiocarbon date of 7800±200 BP (L109A) on bryophytes from foreset beds in a raised marine delta at Rensselaer Bugt on northwest Greenland (Figure 1). Though the species are not listed, these bryophytes were also interpreted as having grown in "wet places on land" (Nichols 1969, p. 28) and might be interpreted as evidence of climatic amelioration. In the arid to semi-arid environment of the High Arctic, however, it is likely that fen growth and related peat accumulation can be as dependent on local site conditions as on macroclimatic changes. Boulton *et al.* (1976), for example, report the initiation of peat growth at a site on Baffin Island during a climatic deterioration which they relate to ponding resulting from a rising permafrost table. Fen growth could therefore be controlled by localized moisture availibility provided by lakes or ponded depressions. In this regard it should be noted that there is fen growth on the contemporary kettled sandur in Clements Markham Inlet and also on portions of northeastern Ellesmere Island (Radforth 1965).

Whether this contemporary fen growth in Clements Markham Inlet relates only to local site conditions or large scale amelioration, however, is difficult to interpret. Brassard and Blake (1978), for example, found only very thin layers of peat growth above their uppermost dated samples implying that growth was only recently renewed. Fredskild (1973), on the other hand, provides radiocarbon dates from Peary Land, north Greenland which may indicate essentially continuous peat growth since *ca*. 1500 BP. Since peat sections on northern Ellesmere Island have not been dated in detail the present fen growth there may indicate either a climatic amelioration or simply favorable site specific conditions. With such a small number of available radiocarbon dated samples from northern Ellesmere Island and the High Arctic in general it is stressed that local site conditions may have been very significant for past fen and peat occurrences and caution should be exercised in drawing strictly paleoclimatic conclusions from these dated samples.

Given the above considerations two alternative interpretations of the 6400±60 BP date (SI-4314) on the fossil plants in Clements Markham Inlet are warranted. First, primary plant productivity prior to 6400 BP was restricted by shorter growing seasons and greater aridity resulting from a combination of cooler summers, lower ablation, and the retention of sea ice during summers. Climatic amelioration post 6400 BP would have moderated these conditions causing increased plant production and the beginning of fen growth. This interpretation gains added support in that the plants are, on the local emergence curve (Chapter 3), contemporaneous with the nearby 43m delta and therefore do not represent older peat incorporated into these deposits. Alternatively, the second explanation would assert that fen growth had been occuring throughout postglacial time in localized habitats. The bryophytes found in the proximal bottomset beds of the 43m delta could then represent stream channel migration which by chance intercepted one of these fen microhabitats thereby providing a random incorporation of localized plant life at *ca.* 6400 BP. Barring the presence of any locally extinct species this would be of no specific paleoclimatic importance though it would indicate that these plants were present at this time . Because of the independent evidence suggesting amelioration beginning at 6500 BP in Clements Markham Inlet (see Chapters 3 and 4 on driftwood penetration and the disjunct (?) pelecypod *Limatula subauriculata*, respectively); the synchroneity of the plants and the 43m delta; plus evidence for synchronous amelioration elsewhere in the Canadian High Arctic (Blake 1972, 1975; Brassard and Blake 1978), the first explanation is provisionally accepted. Furthur field data, however, is required to test this preliminary paleoclimatic model.

The fossil diversity in this deposit may indicate that the high species diversity of the contemporary northern Ellesmere Island bryophyte flora (Brassard 1971a,b, 1976; Muc and Bliss 1977) was already established at *ca.* 6400 BP. Whether these plant deposits relate to a possible glacial refugium on northern Ellesmere Island, however, (cf. Brassard 1971a) is uncertain. Deglaciation on northeastern

Ellesmere Island, as indicated by the majority of dates on initial postglacial emergence, was likely in the 8000 to 8500 BP range (England and Bradley 1978). The high species diversity present in this fossil deposit, *ca.* 2000 years after deglaciation, plus the presence of a well defined fen communitiy similar to present day analogues, may well indicate a long period of plant establishment dating back to full glacial time in some nearby areas. Conversely, it is also plausible that 2000 years was sufficient time for bryophytes to migrate from unglaciated or already deglaciated areas to the south (e.g., the Carey Islands, 8930±90 BP, GSC-2440, Brassard and Blake 1978).

Although the present geomorphic evidence suggests the possiblity that outer Clements Markham Inlet was unglaciated during the last glaciation (J. Bednarski, personal communication, 1980) the present fossil botanical evidence from this area does not permit a definitive statement on the existence of a late Wisconsin refugium on northern Ellesmere Island. Additional ice-free areas during the last glaciation have been discussed on the south side of the United States Range and could also have served as botanical refugia (cf. England 1978; England and Bradley 1978). If such a refugium did exist then eventually organic deposits should be found which are older that initial postglacial emergence and consequently older than initial deglaciation.

In summary, the fossil plants originally described by Hattersley-Smith (1960b) and Christie (1967) occur in marine proximal bottomset beds related to the formation or alteration of the 43m delta in Delta Complex #2. The plants dated 6400±60 BP (SI-4314) and are contemporaneous with the 43m relative sea level. They do not represent older peat deposits transported to this site. The fossil plants have an especially diverse bryophyte component representing three generalized habitats: rich fen (bog), dry tundra and riverine. Independent evidence demonstrates climatic amelioration and less abundant summer sea ice beginning *ca.* 6500 BP. The fossil plants are therefore provisionally accepted as representing the commencement of greater plant productivity in response to longer growing seasons and greater moisture availibility in this arid polar environment.

3. HOLOCENE DRIFTWOOD VARIATIONS

3.1 Introduction

This chapter examines the variations in Holocene driftwood abundance on raised marine deposits in Clements Markham Inlet and considers both its local and regional implications. The time-elevational distribution of this driftwood shows distinct periods of varying driftwood abundance which are, in turn, related to the landfast sea ice conditions along the north coast of Ellesmere Island. The present data shows that the chronology of these variations is similar to those described by Blake (1972) who reported initial driftwood penetration into the Queen Elizabeth Islands *ca.* 8500 BP; followed by abundant driftwood between *ca.* 6500-4500 BP; and greatly reduced driftwood between *ca.* 4500-500 BP with an increase thereafter. An attempt is also made to evaluate driftwood variations in the last 4500 years, during which the overall driftwood data and high latitude ice core records indicate a general cooling with more severe summer sea ice conditions (Paterson *et al.* 1977; Koerner 1977b). This, however, does not preclude intervals of amelioration during this period such as the apparent warming *ca.* 3500 BP and *ca.* 1000 BP when, respectively, Independence I and Thule paleoeskimos expanded into the High Arctic (McGhee 1972, 1976; Barry *et al.* 1977).

The documentation of these driftwood-sea ice variations is relevant to both the timing of Holocene ice shelf initiation on northern Ellesmere Island (Crary 1960; Lyons and Mielke 1973) and to evaluation of the timing of late Holocene glacial advances in the region. Observations in Clements Markham Inlet indicate that most glaciers in this locality are at, or in retreat from, their most advanced positions since deglaciation and similar conditions have been noted by several investigators in this region (Hattersley-Smith 1969; Blake 1975; England 1978). The driftwood variations discussed in this chapter are also relevant to investigations of climatic-oceanographic changes within the Arctic Basin immediately to the north. There extremely low sedimentation rates throughout the late Cenozoic (*ca.* 2mm/1000 years) reduce the paleoclimatic resolution provided by deep sea core studies such that only the most dramatic changes can be discerned (cf. Hermann and Hopkins 1980). The present study demonstrates, however, that the examination of driftwood variations on emerged shorelines has a much finer resolution for the study of Holocene sea ice variations. Indeed, evidence of the warmer interval from 6500-4500 BP, which must have been characterized by reduced summer sea ice within the Arctic Ocean, has never been observed in the existing ocean core research.

3.2 Arctic Ocean Characteristics

The Arctic Ocean's most striking feature is its seasonally fluctuating ice cover. Although there is wide spatial and temporal variability breakup usually occurs between May and August with freezeup commencing from September to November and lasting until the following spring (Billelo 1961, 1980a, 1980b; Barry *et al.* 1978, 1979; Weeks 1978; Jacobs and Newell 1979). Breakup and freezeup are primarily temperature related and can be reasonably well modeled by considering accumulated thawing degree days and frost days, respectively (usually taking a base of 0°C, Billelo 1961, 1980a, 1980b; Barry *et al.* 1978). Consequently, they are affected by the overall energy balance and advection of warm or cold air (Maykut and Untersteiner 1969; Budyko 1966; Barry *et al.* 1978; Crane 1978, 1979; Billelo 1980a, 1980b). Local winds can also be important to the distribution of sea ice since the ice cover may completely breakup yet winds may cause the fragmented ice to concentrate so that an essentially continuous cover remains. Conversely, winds can expedite early breakup by exporting ice from one area to another (Winchester and Bates 1958; Markham 1975; Sanderson 1975; Rogers 1978; Jacobs and Newell 1979; Barry *et al.* 1979).

At the end of winter in the northern hemisphere sea ice covers *ca.* 14.1 x 10^6 km^2 with a reduction to *ca.* 7 x 10^6 km^2 at the end of summer (Walsh and Johnson 1979). During winter there are areas of open water (both temporary leads and polynyas) where there is divergent ice movement or advection of warmer water but these generally amount to less than 2% of the total surface area within the Arctic Basin proper (Koerner 1973; Parkinson and Washington 1979).

The Arctic Ocean sea ice cover consists of many recognizeable ice types and subtypes but only the following are pertinent here: first year ice, multi-year ice, landfast or fast ice, and ice shelves (all following definitions from World Meteorlogical Organization (1970) unless otherwise indicated). First year ice is ice of not more than one winter's growth and usually has a thickness of .3-2m. Multi-year ice is ice which has survived at least two summer's melt attaining a thickness of 2-3m or more. Multi-year ice, also referred to as pack ice, is a principal component of the central Arctic Ocean sea ice. Fast ice is coastal ice which remains attached to the land. Because its landward portion is often grounded it is relatively stable and unridged compared to the continuously moving pack ice of the adjacent 'open' ocean (cf. Reimnitz *et al.* 1978; Barry *et al.* 1979). Fast ice can be more than one year old in which case it is prefixed with an appropriate age category. Many bays and fiords on northern Ellesmere Island are presently blocked by multi-year fast ice (Hattersley-Smith 1962, bay ice in his terminology) as were many bays described by Greely (1885) along western Kennedy Channel in August 1881. When landfast sea ice grows to attain a relief of 2-50m above sea level (i.e. 2-50m of freeboard) it is considered an ice shelf. In the literature on northern Ellesmere Island (e.g. Lyons *et al.* 1971) floating ice shelves are differentiated from grounded ice shelves. These grounded portions are referred to as ice rises (freeboard *ca.* 30m) though by strict definition they are synonymous with their floating counterparts.

The major surface currents in the Arctic Ocean are shown in Figure 12. The original investigation of these currents and Arctic oceanography resulted from occupation of a variety of 'drifting stations' in the Arctic Basin. Initial scientific inquiry began in the late 1800's with the drift of the vessel *Fram* across the Arctic Basin (see below). This was followed in the early 1900's by the Russian investigation of the northeast passage (Gordienko 1961) and in the 1930's by Russian research conducted on floating pack ice (Sater 1969). North American work began in the 1950's after the discovery and occupation of the 'ice islands' which have broken off the ice shelves of northern Ellesmere Island (Koenig *et al.* 1952; Sater 1968). Investigations have become increasingly sophisticated with the use of nuclear submarines, remote sensing and unmanned telemetric stations (Sater 1969; Pritchard 1980).

Within the Arctic Basin, the most important currents in terms of driftwood origin are the Beaufort Sea Gyre, the currents along the coast of Siberia and the Transpolar Drift (Figure 12). The Beaufort Gyre and Transpolar Drift converge on northern Ellesmere Island and Greenland, respectively, so

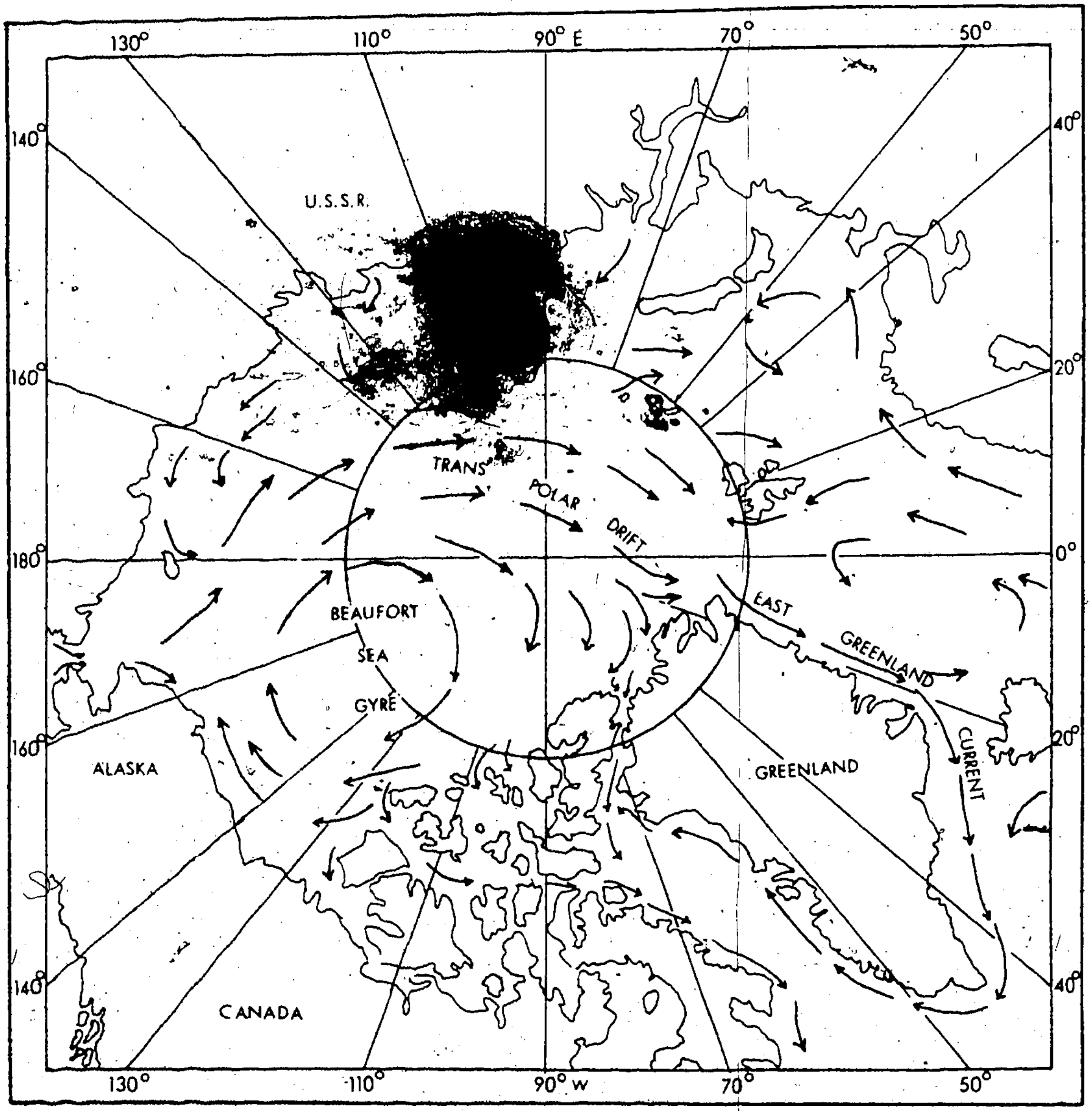

Figure 12 Surface currents of the Arctic Ocean (after Gordienko 1958, Ostenso 1966)

that driftwood deposited along these coastlines may be Eurasian or North American in origin (Blake 1972, 1975). Sea ice, as well as driftwood, is transported by these currents so this is also a region where such ice convergence on these coastlines results in substantial compression, deformation and erosion (Weeks 1978). Evidence of this compression is shown by the intensity of sea ice ridging along northern Ellesmere Island and Greenland which attains *ca.* 600-900 ridges/30 nautical miles, even at the end of the summer season, with the highest area of compression occurring where the Transpolar Drift contacts northeast Greenland (Wittman and Schule 1966).

Although the major currents that converge on the northern Ellesmere Island coastline move off to the west-southwest there is also a probable eastward current flowing at least intermittently along this coast as evidenced by the eastward drift of an ice island (W-5) which broke off the Ward Hunt Ice Shelf in 1961 and by spits at Alert and Cape Aldrich (Hattersley-Smith 1963a). Additional support for this is suggested by the possibly wind-induced east-west ponds on the ice shelves (Hattersley-Smith 1957) together with the contemporary wind-drifted winter snow on the north coast which is strongly sastrugied from the west. The ice rafted erratics in Clements Markham Inlet which come from the Cape Columbia Group to the northwest indicate that similar currents or wind directions also existed during the Holocene.

3.3 Arctic Ocean Driftwood

Driftwood is a common feature in the Arctic Basin and it has long been of interest to Arctic habitation, exploration and scientific enquiry. Most driftwood is transported to the Arctic Basin from the large rivers of Siberia and North America. That massive amounts of driftwood can be transported by these rivers is shown by Mecking's (1928, p. 131) photographs of driftwood piled along the shores of the Kolyma and Mackenzie Rivers (Siberia and Canada, respectively; see also Kindle 1921). Lesser amounts of driftwood originate from northwestern Europe and from the Gulf Stream (Giddings 1943; Eurola 1971). Arctic Ocean currents distribute this driftwood throughout the Arctic Basin where it is deposited on the surrounding coastlines.

In some regions of the Arctic Basin driftwood is quite abundant and one of the earliest European explorers, William Barents, when shipwrecked on northern Novaya Zemlya (Siberia) in 1596/97, was able to spend the winter in a cabin built of, and heated by, driftwood (Eurola 1971; Mountfield 1974, p.38). Paleoeskimos on northern Greenland also used driftwood for fires (Knuth 1967) and on northern Ellesmere Island explorers and scientists naturally continued the tradition (Nares 1878; Greely 1885; Hattersley-Smith *et al.* 1955).

Driftwood also provided some of the impetus for the initial scientific inquiries in Arctic oceanography. The first attempts to reach the North Pole were by ship and several expeditions were halted when the ships were destroyed by sea ice. For example, in the summer of 1881 the vessel *Jeannette* was sunk by ice near Wrangell Island (northeast Siberia) and three years later articles from her were found on the southwest shore of Greenland, *ca.* 6500Km away (Mecking 1928). This and other driftwood found on southwest Greenland, including a throwing stick originating from northwest Alaska (Mecking 1928), convinced Fridtjof Nansen of the existence of a trans-Arctic Ocean current. This led to the building of the vessel *Fram* which was deliberately frozen into the ice north of the Laptev Sea on 25 September 1893. It successfully drifted across the Arctic Ocean and emerged north of Spitsbergen on 13 June 1896, a travel time of 35 months, and thus established the existence of the Transpolar Drift (Figure 12).

More recently driftwood has been used for the radiocarbon dating of raised marine shorelines upon which it has been stranded (Blake 1961, 1975; Ollson and Blake 1961; Pewe and Church 1962; Washburn and Stuiver 1962; Hume 1965; Fredskild 1969; Andrews 1970; Barnett 1972; England 1976a; McLaren and Barnett 1979), for providing paleoclimatic information on sea ice features (Crary 1960; Blake 1970, 1972, 1975; Hattersley-Smith 1973; Lyons and Mielke 1973), and for documenting the extensiveness of storm surges (Hopkins *et al.* 1979; Reimnitz and Maurer 1979). For an excellent review of Arctic Ocean driftwood investigations and particularly references to the early and non-English literature see Eurola (1971).

3.4 Driftwood Variations: Methodology

This investigation assumes that driftwood floating in Clements Markham Inlet during the Holocene became stranded on its contemporary shoreline as postglacial emergence progressed (cf. Andrews 1970). Blake (1975) has documented this process by showing the consistent relationship between increasing age and sample elevation at Cape Storm, southern Ellesmere Island, where 26 driftwood dates are plotted on the emergence curve together with corroborative radiocarbon dates on whale bones and marine pelecypods. However, the use of stranded driftwood, both to date isostatically-raised shorelines or to make paleoclimatic assessments, does involve some uncertainties. Since it takes driftwood some time to travel from its place of origin to its place of deposition, any particular piece of wood will only provide a maximum date on that shoreline, i.e., the shoreline cannot be older than the driftwood (Blake 1961). Judging from the present rates of ice movement and drift studies (Mecking 1928), the residence time for driftwood in the Arctic Ocean is estimated to be in the order of 3-50 years. Since this is less than the average standard error on Holocene radiocarbon age determinations and since radiocarbon dates on driftwood at present sea level are often modern (see, for example, dates B-433, GSC-1352, GSC-1378 in Table II) the youngest driftwood on a specific shoreline is considered to give a reasonable age estimate for it.

There are examples of young driftwood moved to higher elevations, perhaps by humans or animals, and there is also a single example of contemporary driftwood found on the ocean bottom (see GSC-2437 and GSC-2097, respectively, in Lowden and Blake 1979). The most common problem, however, is the downslope movement of driftwood after land emergence and if this occurs then the shoreline is much younger than the radiocarbon date on it (cf. England 1974). To help eliminate this problem, Blake (1970, 1972, 1975) only uses driftwood which is well imbedded in the gravel of a raised beach. In Clements Markham Inlet this approach was not possible since much of the driftwood was draped over previously deposited marine silts by a regressing sea and therefore it is rarely found on easily recognizeable strandlines. Most driftwood used in the present study, however, was at least partially imbedded in the marine silts and often on low angle slopes. Since in many cases some downslope movement of both marine silts and driftwood could not be discounted, a special effort was made to find driftwood >.7m in length which, because of its size, was less likely to have moved downslope. Driftwood in gullies was ignored unless it occurred at elevations where driftwood was rare (e.g. very high driftwood, >55m), or in a few instances where its original elevation could be reasonably inferred (e.g. near the upper limit of such gullied silts). The primary area examined was between the Arrowhead and Clements Markham

Rivers (Figure 2) and here it is likely that nearly 100% of the driftwood present was found. Some observations were made outside these limits but the northern shore of the inlet was not examined.

Most driftwood elevations were determined with a Paulin micro-altimeter with at least two and up to five independent readings. These readings were corrected for both temperature and pressure and comparisons with data obtained by levelling indicate an accuracy of ±2m above *ca.* 10m asl (at lower elevations accuracy was *ca.* ±1m). Elevations of some driftwood below 7m were determined by hand levelling (i.e. Abney level) together with the altimetry. Driftwood which was obviously part of the present beach is considered contemporary and plotted at 0m. Four pieces of driftwood from this study were radiocarbon dated and together with one previously published date (Crary 1960) are used to construct a provisional emergence curve for inner Clements Markham Inlet. The altimetered elevations of 36 pieces of driftwood that occur above the contemporary beach were then superimposed on this emergence curve in order to determine their time-elevational distribution and these provide the data base for the following discussion.

3.5 Emergence Curve and Driftwood Zonation

Figure 13 shows the provisional emergence curve for the head of Clements Markham Inlet. Elevations have not been corrected for eustatic changes (cf. Blake 1975) so the

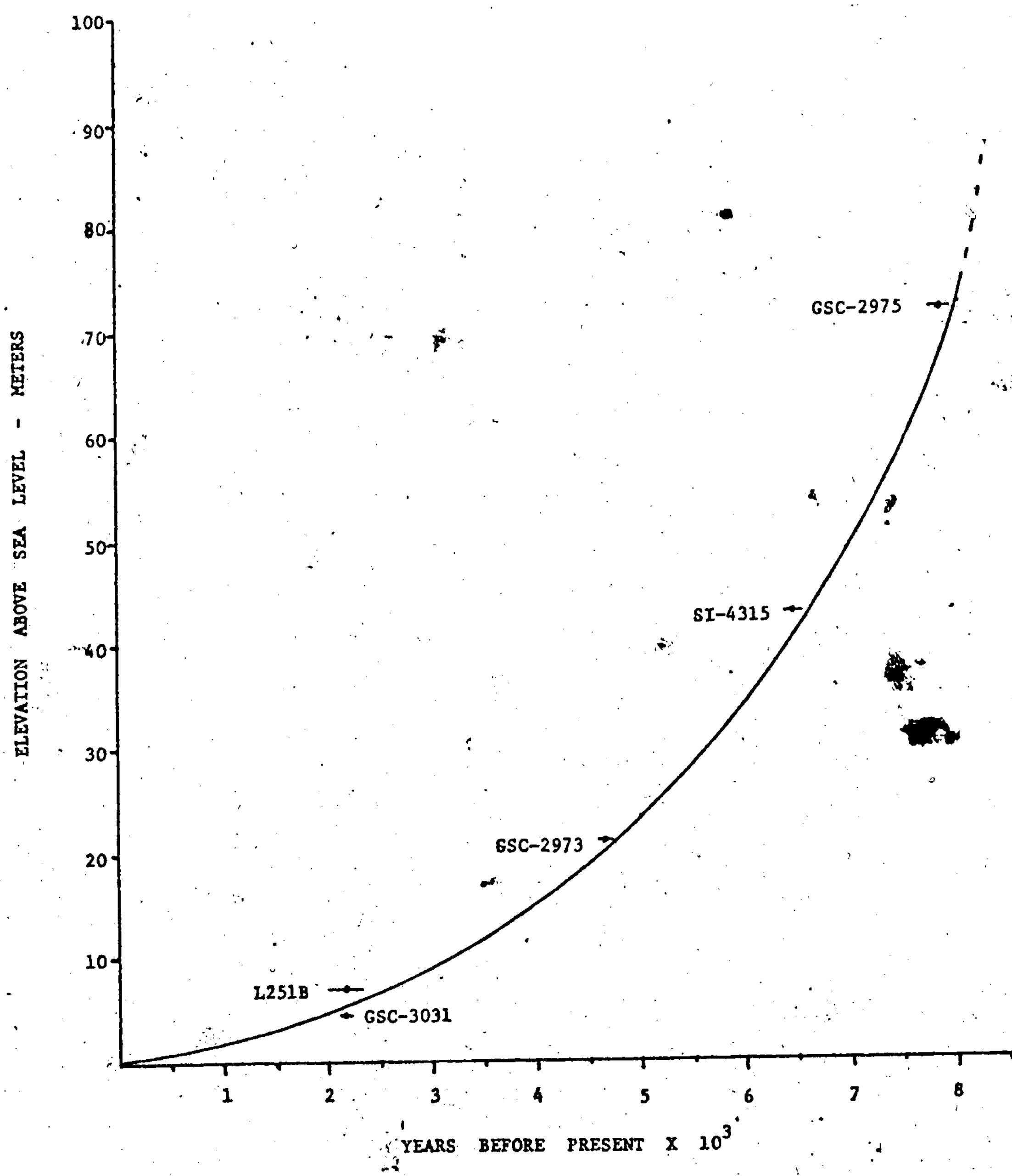

Figure 13. Emergence curve for inner Clements Markham Inlet.

relative sea level corresponding to each radiocarbon date is plotted immediately below the field elevation of that driftwood sample. The highest driftwood sample observed was collected at 72m asl and this provides a date for initial Holocene driftwood penetration into Clements Markham Inlet. This sample was found lying in a gully eroded into marine silts which are draped against the bedrock valley wall and these silts extend *ca.* 10m higher than the driftwood sample. The amount of downslope movement that has occurred, however, cannot yet be determined because there are no other available radiocarbon dates which relate to this relative sea level. This sample dated 7830±80 BP (GSC-2975). The next dated sample was collected at 43m asl in a broad, silt covered pass. The highest point in the pass is only *ca.* 45m asl and this should be the maximum relative sea level for this driftwood . This sample dated 6445±65 BP (SI-4315).

Three large driftwood logs were also found on a prominent raised beach at *ca.* 21m asl (Figure 14). These samples were located in a small valley on the south side of the Clements Markham River about 5km from the inlet head. Judging from local drainage divide elevations this valley formed a small marine embayment when relative sea levels were between *ca.* 30-12m above present. One of these logs was radiocarbon dated at 4680±60 BP (GSC-2973) and this likely provides a good age estimate on the 21m shoreline. Another driftwood log was found buried in marine silts at *ca.* 4.5m asl. This was immediately downslope from a gravelly

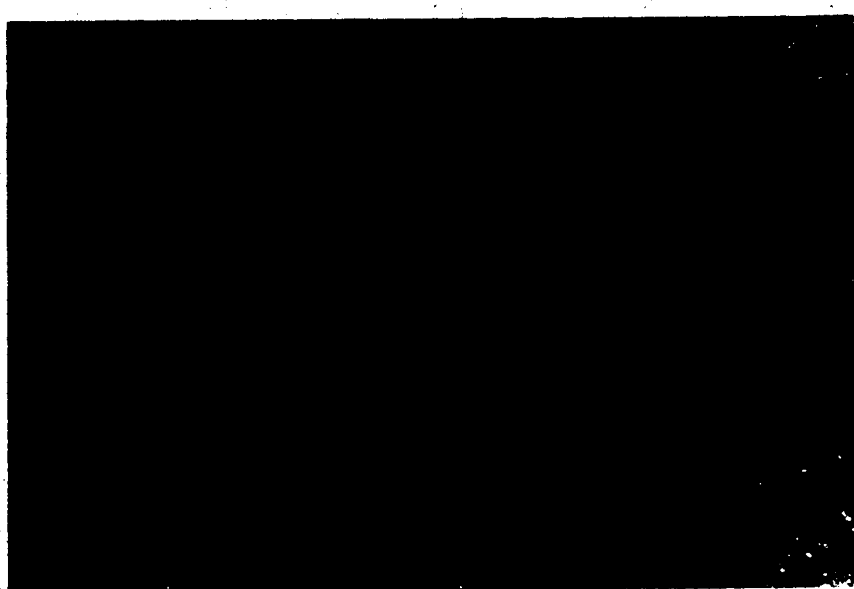

Figure 14. Driftwood logs on 21m shoreline which dated 4660±60 BP (GSC-2973).

ice-pushed ridge developed on an extensive 7m delta surface east of the Arrowhead River (unofficial name) where it drains into lower Clements Markham Inlet (7m shoreline in Figure 7). Because of its burial in the silts and its location just below the ice-pushed ridge it was interpreted as having been ground into the silts by overriding sea ice which formed the ice pushed ridge. This sample dated 2180±60 BP (GSC-3031) and the interpretation that it relates to the 7m relative sea level is reinforced by its close correspondance to a previously collected sample, also at 7m asl in this same area, which dated 2190±150 BP (L251B, Crary 1960).

When all of the elevations of the observed driftwood samples are plotted on the provisional emergence curve four time-elevational zones of driftwood abundance or sparcity become apparent (Figure 15). Zone 1 extends from the initial driftwood penetration at 7830±80 BP (GSC-2975) until *ca.* 6500 BP. Although driftwood is present in this zone it it not abundant (6 pieces in a total of 36). Zone 2 extends from *ca.* 6500 BP until *ca.* 4500 BP and during this interval driftwood becomes notably more abundant (25 pieces). Zone 3 extends from *ca.* 4500 BP to *ca.* 500 BP (?) and driftwood in this zone is noticeably depauperate (5 pieces). Finally, zone 4 is the contemporary shoreline which contains virtually as much driftwood as the rest of the higher elevations combined (>30 pieces). The time break between zones 3 and 4 depends on the age of the abundant driftwood

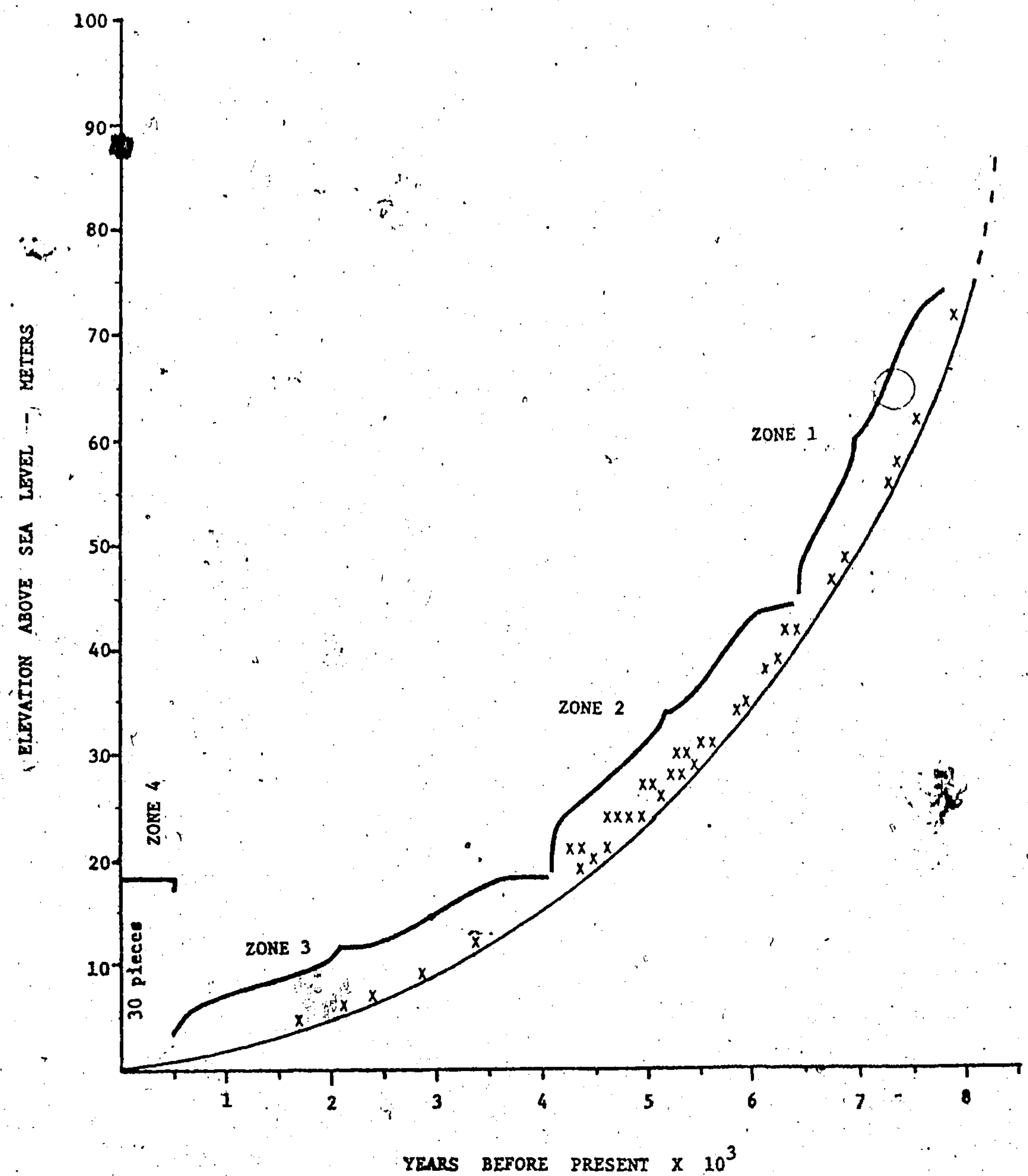

Figure 15. Driftwood abundance zones for inner Clements Markham Inlet.
X = driftwood sample.

bordering the contemporary shoreline and this is considered in more detail in section 3.6.1. These zones of driftwood abundance and scarcity during the postglacial period compare closely with those presented by Blake (1972, 1975) on southern Ellesmere Island implying similar variations on a regional scale.

The broad zones of driftwood abundance just defined also parallel interpretations of isotopic variations within ice cores from the High Arctic. The most complete record published for the Holocene is that of Dansgaard *et al.* (1971) from the Camp Century core near Thule, Greenland (Figure 1). This record indicates a postglacial climatic optimum between 8000 and 4000 BP corresponding to the initial penetration and maximum abundance of driftwood in Clements Markham Inlet (Zones 1 and 2, respectively, Figure 4) and the Queen Elizabeth Islands (Blake 1972). A variable cooling trend is indicated by Dansgaard *et al.* (1971) after *ca.* 4000 BP which parallels the decline in driftwood noted in zone 3. The Devon Island ice core (Figure 1) also indicates a cooling trend after *ca.* 5000±800 BP (Paterson *et al.* 1977). The Mer de Glace Agassiz ice core (Figure 1) has not yet been fully analyzed but preliminary data suggest a postglacial warming trend extending from *ca.* 10,000 BP to a maximum at *ca.* 5500 BP followed by a general cooling towards the present (W.S.B. Paterson, personal communication to J. England, 1979).

Another means of evaluating these Holocene climatic trends is by considering the published radiocarbon dates on all dated driftwood samples presently available from the High Arctic. Figure 16 is a histogram of such dates from Axel Hieberg, Ellesmere, northern Devon and Ellef Rignes islands plus additional data from northern Greenland. This histogram is plotted using 100 year intervals with the occurrence of a driftwood sample in any specific interval dependent upon its radiometric age (see list of radiocarbon dates in Table 2). These radiocarbon dates (96 in total) probably do not represent a true random sample as many pieces of driftwood have been collected and dated from single horizons (such as archeological sites) and represent a specific bias in sampling (e.g. Knuth 1967). Nonetheless this histogram does show certain patterns which suggest variations in the summer sea ice cover of the Canadian and Greenlandic High Arctic. Specifically, in Figure 16, the three older zones (1-3) discussed above are again evident. Driftwood in the High Arctic was present but not particularly abundant from *ca.* 8500-6500 BP (zone 1); it was abundant from *ca.* 6500-4500 BP (zone 2) followed by a decline in frequency thereafter (zone 3). Some important variations post 4500 BP are evident and these are discussed below.

So far in this discussion driftwood abundance during the postglacial period has been analyzed without any consideration of the conditions under which driftwood is admitted or excluded from Clements Markham Inlet. Today in

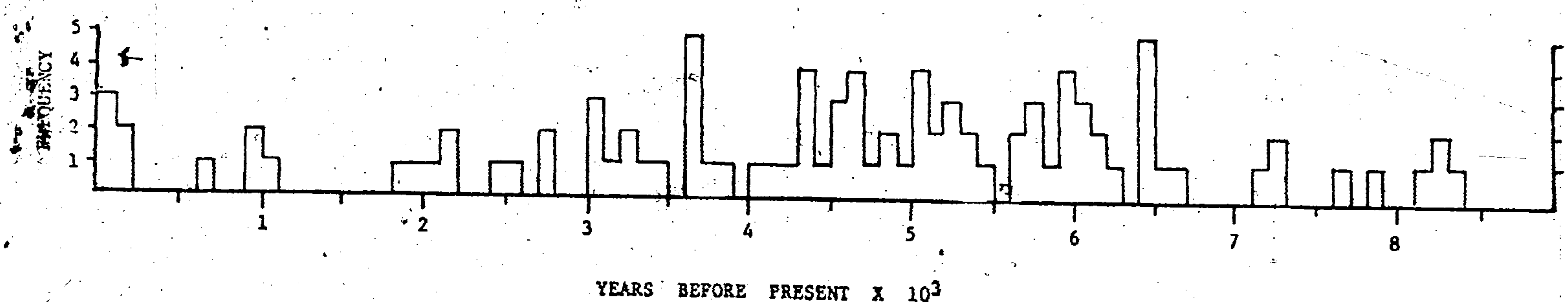

Figure 16. *Histogram of driftwood radiocarbon dates from the Canadian and Greenlandic High Arctic.* See Table II.

TABLE II. LIST OF DRIFTWOOD RADIOCARBON DATES FROM NORTHERN DEVON, ELLESMERE, AXEL HEIBERG, COBURG AND ELLEF RIGNES ISLANDS AND NORTHERN GREENLAND.

DATE	LAB #	ELEVATION (M)	LATITUDE/LONGITUDE	LOCATION	COMMENTS	REFERENCE
				ELLESMERE ISLAND		
8160±140	GSC-1534	76?	82°02'N, 81°57'W	YELVERTON INLET		BLAKE 1972
6410±250	GSC-1603	53?	82°08'N, 81°57'W	"		"
6280±140	SI-568	?	83°00'N, 74°13'W	DISRAELI FIORD		"
6120±150	L254C	?	"	"		CRARY 1960
5740±200	L254B	?	"	"		"
3400±150	L254A	3	"	"		"
3000±200	L254D	?	"	"		"
7830±80	GSC-2975	72	82°36'N, 68°25'W	CLEMENTS MARKHAM INLET		THIS STUDY
6445±65	SI-4315	43	82°35'N, 68°37'W	"		"
4660±60	GSC-2973	21	82°34'N, 68°43'W	"		"
2190±150	L261B	7	82°39'N, 67°30'W	"		CRARY 1960
2180±60	GSC-3031	4.5	82°39'N, 67°46'W	"		THIS STUDY
6050±200	L261C	30	82°28'N, 61°35'W	ALERT		CRARY 1960
3650^{+30}_{-70}	DIC-552	10	82°30'N, 62°55'W	"		BRADLEY & ENGLAND 1977
1830±200	St 4339	5		"		ENGLAND 1976a
1070±270	GSC-1770	11.5	82°30'N, 63°07'W	"		HATTERSLEY-Smith 1973b
985±180	St 4341	2		"		ENGLAND 1976a
980±100	L261A	6	82°~~3?'~~N, 63°01'W	"		CRARY 1960
6430±150	GSC-1614	82	81°05'N, 70°17'W	LADY FRANKLIN BAY		ENGLAND 1978
6000±150	GSC-1755	81	81°04'N, 70°02'W	"		"
5950±140	GSC-1610	55	81°11'N, 70°17'W	"		"
4390±80	GSC-2576	22	79°00'N, ~~76°00'~~W	THORVALD PENNINSULA	CHARRED DRIFTWOOD IN HEARTH	SCHLEDERMANN 1978
6100±90	GSC-1817	32.7	77°~~17'~~N, 81°23'W	MAKINSON INLET		LOWDEN & BLAKE 1978
2060±50	GSC-1836	4	77°19'N, 83°52'W	"		"
630±50	GSC-1791	20	77°18'N, 81°28'W	SWINNERTON PENNINSULA	MOVED BY MAN?	"

8200±80	GSC-1443	62.5	76°30'N, 85°00'W	SOUTH C[illegible]ORD		
7170±80	GSC-1225	42	"	"		BLAKE 1975
6670±70	GSC-1080	31	"	"		"
5220±80	GSC-1912	21	"	"		"
4670±60	GSC-1047	17	"	"		LOWDEN *et al.* 1977
4340±60	GSC-1078	16	"	"		BLAKE 1975
3630±60	GSC-1148	12.5	"	"		"
2730±60	GSC-1320	7	"	"		"
5740±140	GSC-823	19	76°21.5', 85°43'W	BASEMENT COVE		"
8280±70	GSC-845	71	76°26'N, 88°00'W	CAPE STORM		BLAKE 1970
7640±80	GSC-873	50.5	"	"		BLAKE 1975
7210±100	GSC-1709	45	"	"		"
7200±70	GSC-835	43.5	"	"		"
6510±260	GSC-1545	38	"	"		"
6450±70	GSC-833	33.5	"	"		"
6410±80	GSC-1591	33.5	"	"		"
6060±150	GSC-1007	31.5	"	"		"
5980±70	GSC-1713	30.5	"	"		"
5700±80	GSC-1463	29	"	"		"
5680±60	GSC-928	27.5	"	"		"
5350±60	GSC-1547	25.5	"	"		"
5170±70	GSC-986	24	"	"		"
5140±60	GSC-1714	23	"	"		"
5040±50	GSC-826	22.5	"	"		"
5010±60	GSC-1410	22	"	"		"
4750±60	GSC-1512	21.5	"	"		"
4600±60	GSC-921	20.5	"	"		"
4580±60	GSC-1537	19	"	"		"
4370±60	GSC-2165	22	"	"		"
4360±60	GSC-839	17.5	"	"	DRIFTWOOD CHARCOAL IN HEARTH	SCHLEDERMANN 1978 BLAKE 1975

TABLE II. (CONTINU[illegible]

DATE	LAB	ELEVATION (M)	LATITUDE/LONGITUDE	LOCATION	COMMENTS	REFERENCE
3630+130	GSC-114[illegible]	12.5	76°26'N, 88°00'W	ELLESMERE ISLAND (CON.) CAPE STORM (CON.)		BLAKE 1975
3270+80	GSC-1441	10?	"	"		"
2410+60	GSC-1419	7	"	"		"
160+60	GSC-1550	1	"	"		"
140+60	GSC-1352	1.5	"	"		"
10+40	GSC-1378	1	"	"		"
0+50	GSC-179[illegible]			NANSON SOUND	FROM SURFACE OF MULTI-YEAR SEA ICE	LOWDEN & BLAKE 1978
5970+130	GSC-2064	2	76°00'N, 79°00'W	COBURG ISLAND		BLAKE 1975
[illegible]880+100	S-431	11	75°50'N, 84°00'W	DEVON ISLAND		"
5250+130	GSC-1072	26.5	75°58.5', 89°58'	"		BLAKE 1972, 1973
5020+140	GSC-1704	25	76°13.5', 89°19'	"		LOWDEN & BLAKE 1973
4500+130	GSC-1606	24	75°58.5', 89°58'	"		"
4410+150	GSC-1699	36.5	76°15.5', 93°38'	"		"
5920+100	B-432	20	79°23.7', 90°43'	AXEL HEIBERG ISLAND		BLAKE 1972
5690+140	GSC-1138	95	79°23'N, 90°43'W	"		"
5480+100	B-431	20-22	79°24'N, 90°37'W	"		"
5325+270	GX-0144	95	79°25.5', 90°37'	"		"
0+100	B-433	0	"	"		"
8320+140	GSC-999	25+5	77°52'N, 99°37'W	ELLEF RIGNES ISLAND		"

				NORTHERN GREENLAND		
4815±115	I-5593	19	$83^{o}15'N$, $33^{o}00'W$	FREDERICK E. HYDE FIORD		WEIDECK 1972
4615±115	I-5592	15	"	"		"
1935±90	I-5591	4	"	"		"
2580±150	I-307	7.5	$82^{o}53'N$, $24^{o}05'W$	KAP WYCKOFF		"
5870±100	Y-19	65?	$82^{o}08'N$, $32^{o}00'W$	JORGON BRONLAND FIORD		"
5050±130	OX-2	11	$82^{o}10'N$, $29^{o}50'W$	INDEPENDENCE FIORD		"
4970±260	W-1073	"	"	"	SAME SAMPLE AS OX-2	"
4540±120	K-754	21	$82^{o}08'N$, $32^{o}00'W$	JORGON BRONLAND FIORD	CHARRED DRIFTWOOD IN HEARTH	KNUTH 1967
4140±120	K-755	14	"	"	"	"
3850±120	K-756	15?	"	"	"	"
3700±120	K-564	11.5	"	"	"	"
3610±120	K-563	12	"	"	"	"
3290±130	K-150	12.5	$82^{o}10'N$, $31^{o}14'W$	"		WEIDECK 1972
3180±110	K-933	7	$82^{o}08'N$, $32^{o}00'W$	"	CHARRED DRIFTWOOD IN HEARTH	KNUTH 1967
3030±130	K-142	6	"	"	"	"
3000±120	K-565	6	"	"	"	"
2760±120	K-934	7	"	"	"	"
4975±150	I-312	38	$80^{o}55'N$, $23^{o}30'W$	DANMARK FIORD (KAP VIBORG)		WEIDECK 1972
4860±150	I-306	27	$80^{o}45'N$, $23^{o}45'W$	" KAP TREND		"
4200±320	W-1066	6	$81^{o}36'N$, $16^{o}41'W$	STATION NORD		"
4040±170	K-138	12	$81^{o}35'N$, $16^{o}26'W$	PRINCESSE INGEBORG HALVO		"
3680±120	K-753	11.5	$80^{o}54'N$, $23^{o}45'W$	DANMARK FIORD (KAP VIBORG)		"
3375±150	I-313	7.5	$80^{o}31'N$, $23^{o}30'W$	DANMARK FIORD		"

many localities on northern Ellesmere Island driftwood from the Arctic Ocean is prevented from penetrating the fiord systems because of the persistance of local ice shelves and multi-year fast ice (Hattersley-Smith 1962) and not necessarily because the Arctic Ocean proper is more or less frozen during any particular season. Even in late winter, when the sea ice is most severe, the Arctic Ocean ice cover remains in constant motion and in the Beaufort Sea Gyre drifts averaging 1-3km/day, with maximum short term drifts of up to 50km/day, have been reported (Reimnitz *et al.* 1978; Barry *et al.* 1979). Therefore, it is likely that driftwood within the Arctic Ocean is continually in transit and hence always available for penetration into the fiords of northern Ellesmere Island. Consequently, it is likely that ice shelves or fast ice in these fiords is the controlling factor in regard to driftwood penetration from the Arctic Ocean. Driftwood penetration into Clements Markham Inlet, therefore, is interpreted to principally represent the seasonal breakup of the fast ice cover caused by warmer summer temperatures. By extension, prolonged periods of summer amelioration and resultant ~~driftwood~~ penetration indicate conditions unfavorable for the maintenance of local ice shelves such as those found along the north coast of Ellesmere Island today. The present driftwood data would therefore suggest that these ice shelves did not form until after *ca.* 4500 BP (see below). Because of the constant ice drift mentioned above the Arctic Ocean need not necessarily have been more open than at present to provide driftwood for these fiords. However, it is most probable that extended periods of climatic amelioration such as that inferred between 6500-4500 BP would also result in more extended open water conditions and greater sea ice mobility within the Arctic Ocean during summers and autumns (cf. Parkinson and Kellogg 1979). Conversely, periods of driftwood exclusion imply increased stability of sea ice and reduced open water conditions during the ablation season, specifically for Clements Markham Inlet and, more generally, for the adjacent Arctic Basin.

3.6 Climatic Variations since 4500 BP

The climatic deterioration since 4500 BP in Clements Markham Inlet is documented by the decrease in driftwood abundance within this time-elevational zone (i.e. zone 3, Figure 15). Additionally, the driftwood data of Blake (1972, 1975), the termination of peat growth in the Carey Islands (Brassard and Blake 1978), the ice core data discussed above, and the histogram of radiocarbon dates on High Arctic driftwood (Figure 16) all indicate this is an event of regional significance. Nonetheless, the data in Figure 16 do show several significant variations within the last 4500 years.

Within this period the major peak in this histogram of driftwood dates occurs between *ca.* 3000-4000 BP. The magnitude of this peak is somewhat artificial as seven radiocarbon dates within this range are from driftwood charcoal in hearths of Independence I and II sites and these were specifically collected to date these cultural occupations. Radiocarbon dates from Independence Fiord, northern Greenland, however, are also on hearth charcoal from locally derived *Salix* sp. as well as driftwood and they demonstrate the synchroneity of Independence I cultural occupation and driftwood presence (Knuth 1967). From this Knuth (1967) was able to deduce that from at least *ca.* 3600 to 4000 BP paleoeskimos in this area were collecting and burning driftwood which was floating ashore on the contemporary beach. This indicates that summers were warm enough for Independence Fiord to become clear of sea ice unlike the present situation when the fiord is frozen year round (Knuth 1967). Fredskild (1969) also concluded that this reduction in summer sea ice locally favored more humid summers and greater vegetative production based on pollen evidence from Jorgen Brønlund Fiord, north Greenland.

At Tanquary Fiord, Ellesmere Island, Independence I occupation has also been dated at *ca.* 3700-4000 BP (Tauber 1968). No driftwood has been dated from these hearths so sea ice conditions are more difficult to deduce. Bradley and England (1977), however, do report a driftwood date of 3650 BP (DIC-552) from Alert and note a relative abundance of driftwood in the same elevational range (6-10m asl). This "implies relatively open water during summer months at this time" (Bradley and England 1977, p. 142) and it is probable that similar conditions existed in this interval in Tanquary Fiord which is noted for its relatively warm summer climate (Barry and Jackson 1969). The synchroneity of Independence II occupation (*ca.* 3000 BP ?) and driftwood presence is less well documented (cf. Knuth 1967) but the number of radiocarbon dates between 3000-3600 BP (Figure 16) shows that driftwood was penetrating into the region at this time. The Camp Century isotopic record also suggests an amelioration at *ca.* 3000-3300 BP (Dansgaard *et al.* 1971). Overall, these combined data suggest a probable climatic amelioration of regional extent between 3000-4000 BP. The present data, however, do not have sufficient resolution to substantiate or reject the mid-3000 BP climatic deterioration suggested by Knuth (1967) to account for the time break between Independence I and II occupations.

In relation to the ice shelves along northern Ellesmere Island, Crary (1960) originally suggested that the initiation of the Ward Hunt ice shelf (Figure 1) postdated the youngest radiocarbon dates on driftwood found behind the ice shelf in Disraeli Fiord (3400±150 and 3000±200 BP, L254A and L254D, respectively). Lyons and Mielke (1973), however, suggested that ice shelf initiation corresponded to the climatic deterioration at *ca.* 4100 BP based indirectly on the isotopic evidence from the Camp Century ice core (cf. Dansgaard *et al.* 1971). They also suggested that a short term amelioration (*ca.* 3000 BP) could have allowed moat formation along the ice shelf's landward margin thus permitting the entrance of Crary's dated driftwood samples into Disraeli Fiord. The Clements Markham Inlet driftwood data (Figure 15) provide indirect but complementary evidence that ice shelf initiation could well have begun at *ca.* [illegible]00 BP as this likely dates the beginning of semi-permanent, landfast sea ice at least around the mouth of the inlet. As just discussed, however, the histogram of driftwood dates (Figure 16) does indicate a second major warm peak at *ca.* 3000-4000 BP and ice shelf growth may not have begun until after this period. Additional data from fiords presently blocked by ice shelves along northern Ellesmere Island is needed before this problem of ice shelf initiation can be resolved.

After *ca.* 3000 BP Figure 16 shows a decline in dated driftwood frequency which generally parallels the progressive climatic deterioration shown in this time range by the Devon Island ice core (Paterson *et al.* 1977). The relatively limited amount of driftwood after 3000 BP (Figure 16) most likely represents localized or short term sea ice reductions in the midst of a general interval of sea ice severity. Some correspondence between dates, however, is shown at certain localities. For example, three dates at *ca.* 2000 BP from northern Ellesmere Island (GSC-3031 and L261B from Clements Markham Inlet; St-4939 from Alert, Table 2) may indicate a brief climatic amelioration at that time but additional data from other sources is clearly needed to substantiate this event. Also, two driftwood radiocarbon dates at *ca.* 900 BP from Alert (St-4341, L261A, Table 2) coincide with the Viking occupation of North America and Greenland and the expansion of Thule paleoeskimos into the Canadian Arctic (cf. McGhee 1972, 1976; Barry *et al.* 1977; Schledermann 1978, 1980). Hattersley-Smith (1973) also reported a date of 1070± 270 BP (GSC-1770) from charred driftwood in a hearth west of Alert, and numerous Thule sites have been found in the Archer Fiord-Lady Franklin Bay area (Maxwell 1960; J. England, personal communication ...). In addition, during the 1980 field season a ...skimo tent ring was located at 5m on the north side of ... Clements Markham Inlet (J. England, personal communication, 1980) and it likely represents Thule paleoeskimo presence in this area. Thus it appears that a climatic amelioration corresponding to this cultural occupation did occur on northern Ellesmere Island. It should be pointed out, however, that the driftwood abundance at this time in Clements Markham Inlet (Figure 15) does not show these events. Therefore the possibility that these events are obscured by paleoeskimo collection of driftwood must be considered.

3.6.1 Driftwood on Modern Beaches

This examination of Holocene driftwood variation can be concluded with an evaluation of driftwood on the modern beaches of northern Ellesmere Island. In Clements Markham Inlet, as previously mentioned, driftwood is most common along the contemporary shoreline and similar observations have been made by Maxwell (1960) and Hattersley-Smith (1973) for two small bays in Lady Franklin Bay and Disraeli Fiord, respectively. Blake (1972) also noted more abundant driftwood on the modern beaches of southern Ellesmere Island than on the immediately higher raised shorelines.

Hattersley-Smith (1962) surveyed the ice conditions off the north coast of Ellesmere Island in 1961 and compared them with aerial photographs taken between 1947-1952 and also with the sea ice descriptions of early explorers in the area. He concluded that there had been no major changes in the existing blockage of the fiords and bays in this area thus implying that the driftwood on modern beaches must have been deposited prior to the Little Ice Age, perhaps earlier that the 17th century. In Clements Markham Inlet, however, remnants of a ship wreckage (or dock planking ?) containing spikes were found on the modern beach. Similarly, Maxwell (1960), also reports ship wreckage, fence pickets, telegraph poles and other cultural debris on the modern beach in Lady Franklin Bay. The spikes contained in the Clements Markham Inlet debris are difficult to date precisely but they are machine wrought and are apparently not older than mid-19th century and more likely late 19th or early 20th century (Robert McGhee, written communication, 1980). The likelihood of driftwood penetration during this period is reinforced by ablation evidence on the Ward Hunt Ice Shelf (Hattersley-Smith and Serson 1970) and firn studies on the

Gilman Glacier (Hattersley-Smith 1963b) which show high melt and consequently warm summer temperatures after 1910 and 1925, respectively.

This strong ablation period was preceded by a cold period in the 17th, 18th and 19th centuries (i.e. the Little Ice Age) when sea ice in the archipelago was probably more severe than at present (cf. Koerner 1977). From an examination of climatic events and their influence on animal populations Vibe (1967) likewise infers a colder period with more severe sea ice on the Arctic Ocean around northeast Greenland from 1810 to 1860. Thus it is likely that the above mentioned ship wreckage or dock planking postdates the Little Ice Age and was transported to this site in the early 20th century. If the sea ice blocking Clements Markham Inlet did not break up between 1947-1961 (Hattersley-Smith 1962) then the inlet must have been open, perhaps numerous times, between 1910 and 1947 or after 1961 (less likely given the age of the wreckage cited). However, it is also likely that some of the driftwood on or adjacent to the modern beaches in Clements Markham Inlet originated before the 17th century. Additionally, occasional catastrophic breakups of the landfast sea ice thought to be blocking Clements Markham Inlet during the Little Ice Age cannot be discounted (cf. Hattersley-Smith 1963a; Holdsworth 1971). Therefore, the dividing date between the scarse to abundant driftwood zones (zone 3 and 4, Figure 15) is tentatively placed at *ca.* 500 BP. Addition radiocarbon dating of samples from this zone of very abundant, low elevation driftwood will aid in clarifying this transition point.

3.6.2 Post 4500 BP Climatic Deterioration and Glacial Expansion

Another necessary consideration of the post 4500 BP climatic deterioration is its obvious importance to the expansive glacierization which occurs on northern Ellesmere Island today (cf. Hattersley-Smith 1960b). Not only do glaciation levels and ELA's decline to near sea level along the north coast, partially because of the Arctic Ocean influence (cf. Miller *et al.* 1975; Hattersley-Smith and Serson 1970; Alt 1979; Koerner 197[illegible]) but numerous investigators have also noted that many contemporary glaciers are at, or retreating from, their maximum postglacial positions. Glaciers have been observed overriding Holocene raised beaches (Hattersley-Smith *et al.* 1955; Blake 1975) and well vegetated and lichen encrusted surfaces (Hattersley-Smith 1969; England 197[illegible]). Maxwell (1960) noted a glacier within 1.7km of paleoeskimo tent rings and concluded that the glacier was at or near its maximum position of the last 400 years. England (1978) also describes an outlet glacier in Lady Franklin Bay overriding glaciofluvial terraces within 5km of marine deposits dated 6595±250 BP (St 4098) . In addition, radio echo sounding of ice caps in this area has revealed subglacial ridges near the snouts of some glaciers and these may represent moraines overridden by recent glacial advances (Hattersley-Smith *et al.* 1969). Although many glaciers are at their maximum postglacial positions Hattersley-Smith (1969) also described numerous glaciers which were receding from moraines marking their maximum postglacial extent. Smith (1961) also concluded that a drained lake along the margin of the Henrietta Nesmith Glacier (near Lake Hazen) was due to very recent glacier thinning.

Observations made in Clements Markham Inlet indicate similar late Holocene glacier activity at this locality. Christie (1967) and Hattersley-Smith (1969) both note that the Clements Markham Glacier (Figure 2) was advancing into glacio-fluvial gullies. Christie (1967) also reported a glacier overriding glacial ice which was covered by [illegible] of coarse gravels and sands. These sediments form a series of two to three, very well vegetated, terrace levels at the glacier snout. Christie (1967, p. 9) stated that "The buried ice is exposed by meltwater streams and in the walls of a moulin that has been partially destroyed by melting....The moulin...is about 300 feet from the existing cliff-like snout...." When examined on 27 June 1979 this moulin was *ca.* 10-15m from the glacier snout indicating an advance of perhaps 80m during the 21 years since it was first observed (25 May 1958, R. L. Christie, personal communication, 1979). Striking evidence that this glacier is indeed advancing and overriding these terrace gravels and glacial ice is shown in Figure 17. It is also clear from this photograph that the

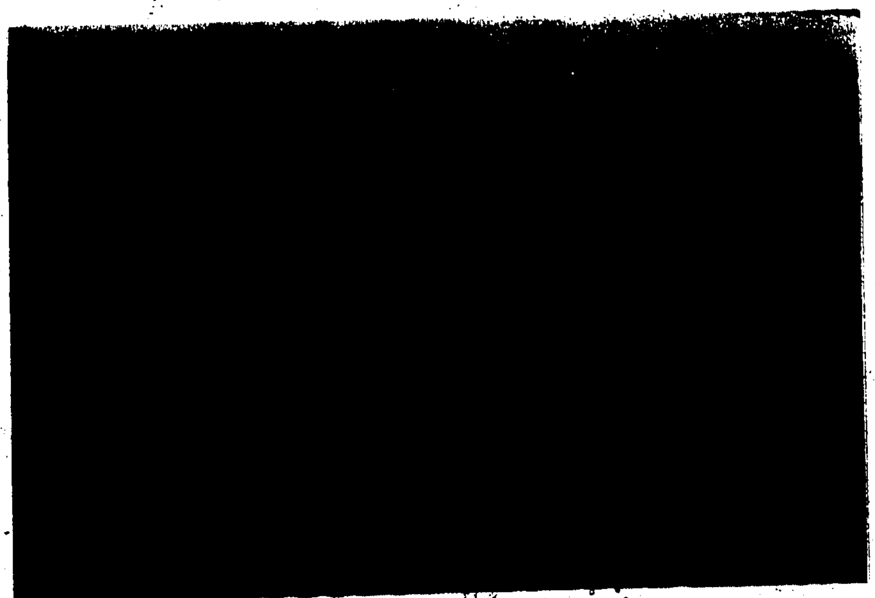

Figure 17. Cliff Glacier snout overriding and thrusting well vegetated sandur. View is to the north. Figure 18 taken from breached vegetation mat to right of center.

two apparent terraces were previously level and that the advancing glacier is in the process of thrusting a portion of this terrace remnant over itself. Formation of the resultant decollement has disrupted the vegetative mat and the exposed gravels are now spilling onto the lower surface (Figure 17 and 18). As noted by Christie (1967) the age of the underlying glacial ice is unknown and it could be a remnant of late Wisconsin ice or a later Holocene advance.

At the Arrowhead Glacier (unofficial name, headwaters of the Arrowhead River, Figure 7) well developed vegetation is found right up to the glacier snout. No moraines were observed downvalley from this glacier and it is likely at its maximum postglacial position. Several other glaciers in the lower inlet, however, are retreating from moraines which seem to mark their maximum postglacial extent (e.g. Figure 19).

This very recent retreat of many glaciers is considered a response to the post 1910-1925 climatic amelioration in this area (cf. Hattersley-Smith 1960b) which is characterized by relative summer warmth (Bradley and England 1978). As Hattersley-Smith notes, it is predominantly the smaller glaciers which are presently retreating while the glaciers which drain much larger reserviors of upland ice are stable or advancing. It is also probable that many of the advancing glaciers are "*still* responding to the Little Ice Age climatic deterioration" (England 1978, p. 612). Considering the low activity indices for Arctic glaciers

Figure 18. Disrupted vegetation mat, Cliff Glacier snout. Figure 17 taken from small remnant of sandur at upper center. This remnant is also well vegetated.

Figure 19. Glacier flowing from United States Range ice cap into west central Piper Pass. Note withdrawal from prominent trimline and moraine which likely mark its maximum postglacial extent. Vertical relief in photograph approximately 300m. View is slightly west of south.

(Andrews 1975; Sugden and John 1976) the period of the Little Ice Age alone seems too short a time to account for the extremely advanced glacier positions on Ellesmere Island. These postglacial maximum positions, therefore, likely imply an already expanding regime at the beginning of the Little Ice Age which was in turn superimposed on the preceding period of rejuvenation.

A possible maximum date on the initiation of these postglacial advances on Ellesmere Island is given by Blake (1975) who reports glaciers overriding raised beaches formed more recently than 5000 BP. Dyck and Fyles (1963) similarly report a radiocarbon date of 4190±130 BP (GSC-105) on peat collected within a few hundred feet of a piedmont glacier (8[illegible] N, 82°17′ W) which therefore advanced to its present position sometime after 4000 BP. Also, a radiocarbon date of 3000 BP on bicarbonate from sea water now trapped within Lake Tuborg implies a glacial advance cutting off the inner fiord of Antoinette Bay (Figure 1) at about this time (Long 1967). On the Hazen Plateau recent retreat of the Gilman Glacier has exposed vegetation dated 965±75 BP (I-428, Trautman 1963) indicating a glacial advance reaching this point sometime after the vegetation was established. Collectively, this limited dating implies that the present glacier positions are the result of a general expansion due to the post 4500 BP climatic deterioration with only limited interruptions due to periods of climatic amelioration.

3.7 High Arctic Driftwood and the Study of Arctic Ocean Sea Ice Variations

Most previous investigations that have dealt with Arctic Ocean sea ice variations have utilized deep ocean sediment cores (e.g. Clarke 1970, 1971; Hermann 1974). These cores provide a long record extending back to the Pliocene (Hermann and Hopkins 1980) but their usefulness is hampered by extremely low sedimentation rates which significantly reduce their paleoclimatic resolution. Most Holocene sedimentation rates, for example, are on the order of 2-8mm/1000 years (Hunkins and Kutschale 1967; Hunkins *et al.* 1971; Cambell and Clarke 1977) and similar rates are suggested for the entire sedimentary record (Ku and Broecker 1967; Clarke 1970). This poor resolution has so far precluded recognition of any but the major, long-term climatic-oceanographic events in the Arctic Basin and even these are controversial (Clarke 1971, 1977; Herman and Hopkins 1980; Margolis and Herman 1980). Though some investigators recognize long term variations of Arctic Ocean sea ice (10^6 years; Herman 1974; Herman and Hopkins 1980) others suggest extremely long periods of ice cover similar to or worse than the present (Clark 1971, 1977; Hunkins *et al.* 1971) and no sea ice variations during the Holocene have ever been documented by these investigations.

The data presented here and in Blake (1972), however, show that at least during the Holocene there have been substantial variations of landfast sea ice cover along northern and southern Ellesmere Island and that many of these variations likely reflect climatic changes of regional significance. In particular, the zone of maximum driftwood abundance, *ca.* 6500-4500 BP, represents a prolonged period of climatic amelioration at high latitudes in the Canadian Arctic Archipelago and northern Greenland. Although at present we can only conjecture as to the magnitude of this amelioration within the central Arctic Basin we can justifiably infer that it must have had some effect on sea ice thickness, mobility and open water conditions during the summer seasons (cf. Parkinson and Kellogg 1979; Parkinson and Washington 1979).

Holocene variations in Arctic Ocean driftwood penetration and, consequently, sea ice stability, are especially pertinent to climatic (Fletcher 1966; Maykut and Untersteiner 1969; Herman and Johnson 1978), glacio-climatic (Alt 1978, 1979; Bradley and England 1978, 1979; Koerner 1979), biological (McClaren 1958; Vibe 1967; Sergeant and Hoek 1974; Stirling *et al.* 1977; Stirling 1980) and archeological studies (McGhee 1972, 1976; Barry *et al.* 1977; Schlederman 1978, 1980). The unique position of the Canadian High Arctic and northern Greenland at the outflow of the Arctic Ocean, plus their high latitude projection into the Arctic Basin, provide an excellent field laboratory for the study of Holocene driftwood variations and their implications for Arctic Ocean sea ice history. The importance of this high resolution driftwood record is heightened by the much poorer resolution of the available Arctic Ocean cores and by the significant environmental role of sea ice within the Arctic Basin and its peripheral landmasses.

4. MARINE MOLLUSCS

4.1 Introduction

This chapter discusses the fossil pelecypods and gastropods collected from the raised marine deposits in Clements Markham Inlet. The collections discussed were most often made in conjunction with other observations rather than as a specific and systematic effort to provide facies-community correlations. Despite this generalized approach to sampling two basic community types can be recognized. One type represents bottom communities relatively uninfluenced by freshwater influx and the other represents deltaic zones influenced by lowered salinities, higher oxygination and high sedimentation rates.

Though marine shells have been used extensively for dating former relative sea levels on northeastern Ellesmere Island (e.g. England 1976a) few species lists from this region have been published (Christie 1967; Lyons and Mielke 1973). Such information on Holocene marine species diversity is particularly important considering the well documented range expansions of some subarctic molluscs in the Canadian Arctic Archipelago and along the coasts of Greenland during the postglacial period (Andrews 1972; Street 1977). The fossil faunas collected in Clements Markham Inlet presently indicate that arctic marine conditions have prevailed there throughout the Holocene. However, the fossil occurrence of the subarctic pelecypod *Limatula (Lima) subauriculata* may indicate ameliorated marine conditions along the north coast of Ellesmere Island at 6400 BP or earlier.

4.2 The Arctic Marine Environment

The contemporary distribution of arctic marine molluscs is predominantly controlled by specific water masses reflecting faunal responses to their attendant salinity, temperature and nutrient characteristics. Hence species migration in the past likely reflect changes in the characteristics or distribution of these water bodies and these variations are of obvious paleoenvironmental importance.

On the basis of temperature and salinity three water masses can be distinquished with depth in the Arctic Ocean. The surface layer is known as the Arctic Water and it extends to depths of *ca.* 200m (Coachman and Aagaard 1974). On northern Ellesmere Island Holocene raised marine deposits are generally less than 120m asl (England 1978) and hence their associated fauna likely originate exclusively from this zone (cf. Andrews 1972). Because of its salinity the Arctic Water does not freeze until -1.0° to -2.0°C (Pounder 1965). Salinities are generally 33.0 to 34.5 ppt (parts per thousand) and may be 27.0 to 30.0 ppt or lower in areas of freshwater mixing. Near surface salinities in Nares Strait (Figure 1) have been measured at *ca.* 31.0 ppt and increase to 34.0 ppt at 200m (Sadler 1976). In more enclosed basins sea ice may remain intact well into the ablation season so that terrestrial runoff and sea ice meltwater can produce a freshwater layer several meters in thickness beneath the sea ice (cf. Thorson 1933). Keys (1977) found fresh water to depths of 44m in Disraeli Fiord behind the Ward Hunt ice shelf (Figure 1) and there is evidence that such discharge is sufficient to generate estuarine circulation in fiords (Ford and Hattersley-Smith 1965; Lake and Walker 1976).

Below the Arctic Water is the Atlantic Layer which extends from *ca.* 200 to 900m in depth. Depending on the locality temperatures rise to a maximum of about +1.0°C between 250-500m and then decline to near 0°C at *ca.* 900m. Salinities are uniform and range from 34.92 to 34.99 ppt (Coachman and Aagaard 1974). Below *ca.* 900m is the Bottom Water with temperatures everywhere less than 0°C, and usually between -0.4 and -0.9°C. Salinities here are also uniformly between 34.92 and 34.99 ppt (Coachman and Aagaard 1974). The depth boundaries between these three water masses vary in different parts of the Arctic Basin being shallower in the European portions and deepest in the Ellesmere Island-Greenland area (Coachman and Aagaard 1974).

Arctic Ocean surface currents are shown in Figure 12 (Chapter 3). In general, these include outflow of Arctic Water through the interisland channels of the Canadian Arctic Archipelago and also along the east Greenland coast as the East Greenland Current. Warmer, more saline Atlantic water from the North Atlantic Drift enters the Arctic Basin from the northeast Atlantic Ocean, principally through the

Norwegian Sea, and it subsequently submerges beneath the Arctic Water. These Atlantic waters also arch southward along the southeast coast of Greenland where they mix with the East Greenland Current. These mixed, but still ameliorated, waters then flow northward along the west coast of Greenland where they meet outflowing Arctic Water from Nares Strait and are again deflected south (Tooma 1978). Areally, then, colder, less saline Arctic water predominates in the interisland channels of the Canadian Arctic Archipelago, as well as along eastern Baffin Island and eastern Greenland, whereas warmer, more saline Subarctic waters influence the southern and west coasts of Greenland. Therefore, west to east across Baffin Bay-Davis Strait shallow water (less than 200m) marine faunas change from Arctic to Subarctic affinities in response to changes in water masses.

Though contemporary subarctic molluscs do not reach past Thule, Greenland (Figure 1) Atlantic water copepods can be traced as far north as Smith Sound (Tidmarsh 1972). Their distribution here closely coincides with the recurring polynya in northern Baffin Bay-Smith Sound known as the North Water (Nutt 1969; Dunbar and Dunbar 1972; Tidmarsh 1972). In this area the subarctic molluscs *Mytilus edulis* and *Chlamys (Pecten) islandicus* have also been collected in pre-Holocene deposits from, respectively, northwestern Baffin Bay (Blake 1973) and northeastern Smith Sound (Weideck 1976).

Another constraint on the marine fauna, independent of water mass characteristics, is sea ice which, because of its scouring and grinding action along the coastline, creates unfavorable conditions for most marine molluscs. Though *Hiatella arctica* and *M. edulis* are sometimes found almost to high tide level (Vibe 1950; Petersen 1977) true littoral faunal communities are rare in the High Arctic (Ellis 1960; Ellis and Wilce 1961) and marine macrofauna become prominent only at depths below 3 to 5m (Thorson 1933; Ocklemann 1958).

4.3 Marine Community Types in Clements Markham Inlet

4.3.1 Bottom Communities

A prominent feature of the raised marine deposits in Clements Markham Inlet are the sloping silt benches which occur at a variety of elevations below the local marine limit. Though these silts have been dissected by badland gullying (Christie 1967), and are modified by mass wasting, many of these benches appear to be remnants of original depositional surfaces, i.e. former sea beds (cf. Donner and Jungner 1975). These benches appear to have formed in small embayments or other localities not directly associated with deltaic sedimentation. The majority of collections interpreted as bottom communities were made from these surfaces whose fine-grained sediments imply environments of slow sedimentation and minimal freshwater input. Occasionally infaunal (burrowing) species such as *Mya truncata* were in obvious growth position although specimens had often been transported downslope. In many collections this redeposition probably did not amount to more than a few meters as numerous shells still occurred as whole bivalves with the periostrachum unworn and with siphons still attached.

These sites and their contained species appear to be similar to contemporary surfaces called clay bottom or level bottom communities by Thorson (1933, 1934, 1957), Ocklemann (1958) and Ellis (1960) in the fiords of east and west Greenland and the Canadian Arctic Archipelago. The community most widely recognized by these authors is the *Macoma calcarea* community at depths of *ca.* 5 to 45m. Although *Macoma calcarea* is not known to occur on northern Ellesmere Island (Lubinsky 1972) the large number of *Astarte warhami* found in Clements Markham Inlet does suggest similarities to the upper *Astarte* zone of the *Macoma* community (cf. Thorson 1933, 1934; Ellis 1960).

The following species seem most representative of these bottom communities based upon their observed occurrence in Clements Markham Inlet and from literature records: *Mya truncata*, *Astarte warhami*, *Bathyarca glacialis*, *Limatula (Lima) subauriculata*, *Thyasira equalis*, *Hiatella arctica*, *Colus togatus*, and *Trichotropis borealis* (Ocklemann 1958; Lubinsky 1972; Wagner 1977). In Clements Markham Inlet these shell specimens were generally concentrated in small patches, several square meters in extent, interspersed within much larger areas which appeared barren of fauna.

Similar observations have been made in contemporary dredge studies (Ellis 1960) and Spjeldnaes (1978) also noted similar faunal patchiness in emerged fiord deposits in Norway. These spatial variations may be related to small changes in the original compactness of the sediment (Spjeldnes 1978) or to other little understood environmental differences (Carey and Ruff 1977). In Clements Markham Inlet another reason for this variability may simply be that many of the infaunal (burrowing) species are still buried and therefore are not yet visible at the surface (cf. Funder 1978).

4.3.2 Deltaic Zones

Specimens collected in deltaic zones were obtained from facies identified as deltaic foreset beds and proximal bottomset beds (e.g. Sites 1 and 2, Figure 7). These are areas where rapid sedimentation and varying influxes of fresh water put extreme environmental stress on the marine fauna (Thorson 1933, 1934; Ocklemann 1958). The greatest number of species were collected from this zone, almost exclusively in proximal bottomset beds. However, the increased species diversity in this zone is most likely due to the increased sampling which was done in conjunction with the fossil plant studies.

Species common in this zone are *Portlandia arctica portlandia*, *Thracia myopsis*, *Yoldiella frigida*, *Delectopecten groenlandicus*, *Thyasira dunbari*, *Hiatella* *arctica* and *Siphonodentalium lobatum*. Especially well known from this environment are *P. arctica portlandia*, *T. dunbari* and *D. groenlandicus* and this association has been widely recognized as the *Portlandia arctica* community (Thorson 1933, 1934; Ocklemann 1958). *P. arctica portlandia* (cf. Lubinsky 1972) is also known as an early migrator into this zone and is therefore often the only species found in marine limit deltas (J. England, personal communication 1980).

Hiatella arctica is generally reported as being a byssally attached member of the epifauna (Ocklemann 1958; Sneli and Steinnes 1975). Its common occurrence in coarse, deltaic foreset beds may indicate that in this environment it is also a sediment burrower. Though Strauch (1968) mentions that *H. arctica* can live in relatively unconsolidated sediment its occurrence in such foreset sections may simply reflect deltaic progradation and burial rather than burrowing. More detailed observations are necessary before the mode of attachment in this habitat can be determined.

4.4 Marine Molluscs from Clements Markham Inlet

The marine macrofauna collected from the raised marine deposits in Clements Markham Inlet are listed in Table 3 (pelecypods and gastropods identified by Dr. Irene Lubinsky and Elizabeth Macpherson, respectively). A total of 21 marine molluscs were identified including 15 pelecypods (9 families), 5 gastropods (3 families) and 1 scaphopod (1

TABLE III. MARINE MOLLUSCS COLLECTED FROM RAISED MARINE DEPOSITS, CLEMENTS MARKHAM INLET, ELLESMERE ISLAND.

SPECIES \ DISTRIBUTION	HIGH ARCTIC (1,2)	PREDOMINANTLY PANARCTIC (i.e. CIRCUMARCTIC) (1)	PANARCTIC-BOREAL (1)	WIDE DISTRIBUTION AND TYPICAL IN HIGH ARCTIC SEAS (1)	WIDE DISTRIBUTION LACKING FROM TYPICAL HIGH ARCTIC SEAS (1)	COSMOPOLITAN IN ARCTIC CANADA (2)
PELYCEPODA[5]						
NUCULIDAE						
Nuculana pernula (Muller 1779)	X[3]					
Yoldiella frigida (Torell 1859)	X					
Portlandia arctica portlandica (Gray 1824)	?[1]					
ARCIDAE						
Bathyarca glacialis (Gray 1824)		X				
PECTINIDAE						
Delectopecten (Propeamussium) groenlandicus (Sowerby 1845)		X				
LIMIDAE						
Limatula (Lima) subauriculata (Montagu 1808)					X	
ASTARTIDAE						
Astarte crenata (Gray 1824)		X				
Astarte warhami Hancock 1846	X[3]					
THYASIRIDAE						
Axinopsida orbiculata (G.O. Sars 1878)		X				
Thyasira dunbari Lubinsky	X[3,4]					
Thyasira gouldi (Philippi 1845)		X				
Thyasira equalis		X				
MYIDAE						
Mya truncata uddevalensis Forbes 1846			X			
HIATELLIDAE						
Hiatella arctica (Linne 1767)				X		

THRACIIDAE			
Thracia devexa G.O. Sars 1873	X		
Thracia myopsis (Beck) Moller 1842		X	
GASTROPODA[6]			
TRICHOTROPIDAE			
Trichotropus borealis Broderip and Sowerby			X
BUCCINIDAE			
Colus togatus (Morch)	X		
TURRIDAE			
Oenopota novajasemliensis (Leche)	X		
Oenopota reticulata (Brown)		o	X
Oenopota turricula (Montagu)			X
SCAPHOPODA[6]			
SIPHONODENTALIIDAE			
Siphonodentalium lobatum (Sowerby)			X

1 - Based on Ockelman (1958: 169-171)

2 - Based on Macpherson (1971: 131-132)

3 - Based on Lubinsky (1972)

4 - Based on Lubinsky (1976)

5 - Identified by Dr. Irene Lubinsky

6 - Identified by Elizabeth Macpherson

family). As shown in Table III these species are predominantly high arctic to panarctic (i.e. circumpolar) in distribution with *Mya truncata* and *Hiatella arctica* extending to more southerly seas. Species such as *Bathyarca glacialis* and *Thyasira equalis* are also found in the Atlantic Ocean although there they occur in the deeper abyssal zones rather than on the continental shelves or in coastal environments (Ocklemann 1958). Although radiocarbon dates are not available for the existing Clements Markham Inlet collection (Table III) these samples can be inferred to represent most of postglacial time since they were obtained from raised marine deposits covering a wide elevational range. This implies that Clements Markham Inlet has remained a high arctic to arctic marine enviroment since deglaciation. The presence of the possibly disjunct pelecypod *Limatula (Lima) subauriculata* in deposits dated *ca.* 6400 BP, however, may indicate amelioration at that time and this is discussed below.

Also of interest in these collections is the presence of *Thyasira dunbari* a species endemic to the Canadian and Greenlandic High Arctic (Lubinsky 1972, 1976). This species was first described in 1972 and since it can be mistaken for other members of the genus or for *Axinopsida orbiculata* it is not surprising that this is its first reported fossil occurrence. It was found within Delta Complex #2 (Site 1, Figure 7, Chapter 2) in deposits which also contained the fossil plants dated 6400±60 BP (SI-4314). In the northwestern Archipelago and northern Ellesmere Island *Thyasira dunbari* "was collected in fiords and bays at a depth of 10 to 70m, on muddy bottoms, often close to the outwash fan of rivers" (Lubinsky 1976, p. 1668). This environmental information reinforces the interpretation that the deposits at Site 1 are proximal bottomsets to the 43m delta (see Chapter 2).

Two other samples containing *T. dunbari* were collected from Delta Complex #2 (Site 2, Figure 7). The deposits at this site are interpreted as being laterally equivalent to the deposits at Site 1 as previously discussed (see Chapter 2). At this site *T. dunbari* occurs immediately above a muddy horizon containing *Limatula (Lima) subauriculata*. It is interesting that the first reported fossil occurrence of *T. dunbari*, a high arctic endemic, is juxtaposed with the second reported high arctic fossil occurrence of *L. subauriculata*, a probable subarctic-Atlantic disjunct.

4.4.1 *Limatula (Lima) subauriculata*

Limatula (Lima) subauriculata is a small (3.5 x 5.5 x 3mm, length x height x breadth of shell) epifaunal pelecypod which usually inhabits muddy substrates and is considered to have a subarctic-boreal, Mediterranean-Atlantic range (Ocklemann 1958; Abbot 1974). Its present range is reported to extend to 72°47′N in the warmer, subarctic waters of west Greenland whereas it does not extend beyond the southernmost portion of the island on the colder east coast (*ca.* 60°N, Ocklemann 1958). To date, only one specimen has been collected in the waters of the Canadian Arctic Archipelago, this being immediately southwest of Devon Island (Figure 1) during the 19th century (Reeve 1855). However, it was not found in any of the extensive contemporary collections from the Canadian Arctic Archipelago examined by Lubinsky (1972). One specimen has also been collected from Jan Mayen Island, north of Iceland (71°N 8°W, Sneli and Steinnes 1975). The fauna there is predominantly arctic but the abundance of the subarctic species *Chlamys (Pecten) islandicus* and the lack of typical arctic forms such as *Astarte warhami* also indicates subarctic affinities at this site (Sneli and Steinnes 1975). The occurrence of *L. subauriculata* southwest of Devon Island and at Jan Mayen Island may represent relict populations from range extentions which occurred during previous climatic ameliorations. A similar interpretation has been made of isolated populations of *C. islandicus* which occur north of their normal range in east Greenland (Ocklemann 1958; Hjort and Funder 1974; Street 1977; Funder 1978). This has also been suggested for similar disjunct populations of *M. edulis* on Baffin Island (Andrews 1972).

L. subauriculata has been found as a fossil in west Greenland by Laursen (1944, 1950) and Kelly (1973). Laursen (1950) reports *L. subauriculata* from 17 sites but all are south of 72°N and all contain such 'warm' water molluscs as *C. islandicus* or *Mytilus edulis*. Laursen (1950) considered all these assembleges to be subarctic in his stratigraphic nomenclature ('arctic' by his original terminology). Kelly (1973) reports *L. subauriculata* in two fossil samples from west Greenland at 68°N which dated 7550±130 BP and 7320±130 BP (K-1557 and K-1551 respectively). Both of these samples contained *C. islandicus* and one also contained *M. edulis*. The presence of *M. edulis* and *C. islandicus* at 9070±160 BP and 9090±140 BP (K-1337 and K-1549 respectively, Kelly 1973) indicates the early establishment of subarctic marine conditions on west Greenland. This implies that in all Holocene fossil occurrences in this area *L. subauriculata* inhabited a subarctic marine environment (cf. Laursen 1950). From the above citations it is evident that both the contemporary and fossil range of *L. subauriculata* is almost exclusively subarctic to boreal, though it borders on Arctic areas.

In more northern sites *L. subauriculata* has been collected solely as a fossil and at only two localities. The first is from northwest Greenland at 82°50′N, 43°30′W (Laursen 1954) and the second is from Clements Markham Inlet (this study). Lyons and Mielke (1973) also report the genus *Limatula* from Ward Hunt Island but they only list it as a footnote to their Table 1 and no other information is provided. Since *Limatula hyperborea* is a high arctic species which occurs in this region no conclusions can be drawn from their report of the genus. In northwest Greenland *L. subauriculata* was collected from raised marine deposits along with 18 other arctic species of pelecypods and gastropods, however, no radiocarbon dates are available for this deposit (Laursen 1954). Laursen felt the presence of *L. subauriculata* indicated that the postglacial warm period had affected the coast of northern Greenland but because of the lack of distributional information on this species he concluded that it would be "premature to draw a final conclusion from a single finding of *Lima subauriculata* (Mont.)" (Laursen 1954, p. 23).

In Clements Markham Inlet *L. subauriculata* was collected from raised marine deposits at *ca*. 10m asl (Site 2, Figure 7) where it occurred in a dense mud overlain by rhythmically-bedded sands and silts. This upper layer is considered to be contemporaneous with the proximal bottomset beds at Site 1 (Figure 7) which contained the fossil plants dated 6400±60 BP (SI-4314). At this site *L. subauriculata* also occurs in association with such arctic species as *Portlandia arctica portlandia*, *Astarte warhami*, and *Thyasira dunbari* (cf. Laursen 1954).

This presence of *L. subauriculata* in Clements Markham Inlet occurs during a time interval which several lines of independent evidence indicate to be a period of climate amelioration (i.e warmer summer temperatures or a more northerly extent of subarctic marine waters). Such evidence includes: abundant driftwood penetration on southern and northern Ellesmere Island (Blake 1972 and Chapter 3, respectively); greater plant productivity in Clements Markham Inlet at 6400±60 BP (SI-4314, Chapter 2) and initiation of peat accumulation at Tanquary Fiord at 6480±200 BP (Hattersley-Smith 1969) and on the Carey Islands at 6280±80 BP (GSC-2368, Brassard and Blake 1978); an expanded range of subarctic marine molluscs in the Canadian Archipelago and Greenland (Andrews 1972, 1973; Hjort and Funder 1974; Donner and Jungner 1975; Street 1977; Funder 1978); and finally an increase in ^{18}O in the Camp Century and Devon Island ice cores (Dansgaard *et al.* 1971; Paterson *et al.* 1977).

The fossil presence of *L. subauriculata* in Clements Markham Inlet is therefore provisionally accepted as a range extension due to ameliorated marine conditions at or preceeding 6400 BP. Ameliorated conditions in the marine environment may be due to temperature or salinity changes (cf. Andrews 1972, 1973) or increased nutrient availibility because of increased fiord circulation due in turn to more open water conditions and increased input from glacier melt (cf. Sparck 1933). Assuming the occurrence of a regional amelioration in the arctic it seems likely that all these factors would be interacting to produce favorable environmental changes. Previous studies of subarctic marine mollusc range extensions have dealt with *C. islandicus*, *M. edulis* and *Macoma balthica* (Andrews 1972, 1973; Hjort and Funder 1974; Street 1977). The disjunct fossil presence of *L. subauriculata* on northwest Greenland (Laursen 1954) and in Clements Markham Inlet indicates that this species may also be useful for interpreting former Holocene marine conditions in the High Arctic. A more detailed knowledge of its present range and ecologic requirements, however, will be required in order to determine how useful this species may be in this regard. Also, Bernard (1979) suggests that the species designations within this genus may require revision.

5. CONCLUSIONS

5.1 Introduction

The previous chapters in this thesis outline environmental change in Clements Markham Inlet during the postglacial period. The following briefly summarizes these findings and also discusses needed improvements in the data base.

5.2 Review

The last or late-Wisconsin glaciation occupied inner Clements Markham Inlet and portions of the north and northeast coasts of Ellesmere Island may have remained unglaciated (cf. England 1978; J. Bednarski, personal communication, 1980). The time of deglaciation at the inlet head is presently undated but it must be older than the driftwood radiocarbon date of 7830±80 BP (GSC-2975) and it could be as young as *ca.* 8000-8500 BP based upon initial emergence on northeastern Ellesmere Island (cf. England and Bradley 1978). During deglaciation marine deltas were established and large quantities of marine silts were deposited within the inner inlet. This massive sedimentation and associated freshwater influx prohibited marine molluscs from occupying the inlet head for some unknown period following deglaciation. Postglacial emergence to *ca.* 100m asl caused stream incision into these raised marine deposits resulting in the formation of inset deltas graded to progressively lower and younger sea levels.

Subsequent to deglaciation the variability of driftwood penetration into Clements Markham Inlet is considered to represent sea ice changes at the inlet mouth. Thus during cold summers, when landfast sea ice did not breakup, the outer inlet was blocked and driftwood was excluded. However, during warm summers, when the landfast sea ice did breakup, available driftwood entered into the lower inlet and became stranded on the contemporary shoreline (cf. Blake 1972). By *ca.* 7800 BP driftwood began entering Clements Markham Inlet and sporadic driftwood penetration continued until *ca.* 6500 BP indicating at least occasional breakup of the landfast sea ice cover during this interval (zone 1, Figure 14). Driftwood abundance reached its maximum between *ca.* 6500 and 4500 BP (zone 2, Figure 14) and though fast ice breakup may be catastrophic (cf. Hattersley-Smith 1963a; Holdsworth 1971) prolonged periods of driftwood penetration such as this likely imply frequent fast ice deterioration due to increased summer temperatures.

In Clements Markham Inlet the fossil presence of the apparent subarctic disjunct *Limatula (Lima) subauriculata* also suggests amelioration of marine conditions at or earlier than 6400 BP. In addition, the abundant plant remains and diverse bryophyte flora found in Delta Complex #2 (Site 1, Figure 7) suggests higher plant productivity at 6400±60 BP (SI-4314) as well. Higher plant productivity in the arid High Arctic is likely a response to increased moisture availability due to more open water in the local fiords and the adjacent Arctic Ocean (cf. Fredskild 1969). Collectively, therefore, the driftwood zonation, fossil vegetation and marine mollusc evidence suggest that warmer summers and more open water conditions began at *ca.* 6500 BP.

The existing driftwood model provisionally suggests that the period of abundant driftwood penetration (warmer summers) lasted until *ca.* 4660±60 BP (GSC-2973) when driftwood abruptly declined indicating the beginning of a period of colder summers with more stable landfast sea ice (zone 3, Figure 14) The driftwood data from Clements Markham Inlet indicates this colder and likely drier period lasted until driftwood again became abundant at *ca.* 500 BP (zone 4, Figure 14) However, a review of driftwood radiocarbon dates from the High Arctic also suggests that other periods of warming and reduced summer sea ice occurred between 3000-4000 BP, at *ca.* 2000 BP and 1000 BP. This regional variability is beyond the resolution of the present Clements Markham Inlet data base, hence the existence of these short term ameliorations cannot be discounted in the author's field area. Also, the occurrence of Thule culture hearths in Archer Fiord-Lady Franklin Bay and in the Alert area indicates that the Thule culture expansion into the High Arctic at *ca.* 1000-900 BP (McGhee 1972, 1976; Barry *et al.* 1977) extended all the way to northernmost Ellesmere Island. Collectively, this Holocene paleoenvironmental model compares well with the existing isotopic record from high latitude ice cores (Dansgaard *et al*.1971; Paterson *et al*.1977).

An important aspect of the contemporary environment in Clements Markham Inlet is the advanced position of many outlet glaciers. Similar observations have also been made by several investigators on Ellesmer Island (Hattersley-Smith 1969; Blake 1975; England 1978). This expansion is interpreted to be a response to the climatic deterioration which has occurred since 4500 BP. The recent and minor retreat of these glaciers on the other hand is most likely a response to the post 1910-1925 climatic warming in this region (cf. Hattersley-Smith 1960b, 1963c) which was characterized by generally warmer summer temperatures until *ca*. 1963 (Bradley and England 1978). This is also the period when ship wreckage (or dock planking) with attached spikes floated into Clements Markham Inlet indicating that this short term amelioration was sufficient to cause deterioration of the landfast sea ice cover which may have blocked the inlet at least between 1947 and 1961 (cf. Hattersley-Smith 1962).

5.3 Suggestions for Furthur Research

In terms of the present postglacial model for environmental change in Clements Markham Inlet there is room for refinement and expansion of the data base. Perhaps the most obvious opportunity is to test the various zones by continued location and levelling of driftwood plus additional radiometric control. Particularly, a more detailed survey of the inlet in the post 4500 BP range (less than 21m asl) may help evaluate the extent of the climatic ameliorations indicated within this period by other workers (cf. Figure 16; Knuth 1967; Fredskild 1969; McGhee 1972; Barry *et al.* 1977). Additionally, the dating of the apparent Thule culture hearth found on the north side of inner Clements Markham Inlet would help to clarify the relationship between this cultural occupation and driftwood abundance. Evidence of Independence I and II paleoeskimo occupation in this area would likewise refine the climatic-cultural-driftwood relationship in the post 4500 BP zone (cf. Knuth 1967).

Continuing examination of the bryophytes in the fossil plant deposits is still yielding additional species (J. Janssens, personal communication, 1980) and disjunct or locally extinct species may yet be encountered. Also, the identification and dating of plant remains reported in lacustrine sediments immediately south of Piper Pass (Christie 1967) would provide an important comparison with the fossil plants from Clements Markham Inlet. In addition, pollen analysis of lake sediments or peats in this area would be an excellent means of establishing vegetation variations through time and would allow a better paleoenvironmental integration of the macrofossil materials and driftwood data.

With regard to the marine fauna a more detailed examination of the fossil diversity in this region may well provide an important and comparable paleoenvironmental record over a larger area (cf. Andrews 1972; Street 1977). Particularly, more detailed taxonomic, ecologic and distributional (fossil and contemporary) information on *Limatula (Lima) subauriculata* would enhance our understanding of its disjunct character and its potential as a paleoenvironmental indicator.

As more refined contemporary and paleoenvironmental data become available an improved model of Holocene climatic change in the Canadian High Arctic should emerge. Particularly useful would be the integration of ongoing research in synoptic climatology, glacier mass balance and isotopic variations (cf. Jackson 1960; Markham 1975; Alt 1978, 1979; Bradley and England 1978, 1979; Crane 1978, 1979; Koerner 1979; Moritz 1979) with the Holocene paleoenvironmental data base.

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