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ENVIRONMENTAL CHANGE AND CULTURAL CHANGE IN THE EASTERN CANADIAN ARCTIC DURING THE LAST 5000 YEARS

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ABSTRACT

Archaeological research suggests that cultural changes in the Canadian Arctic are closely linked to environmental changes. Current knowledge of postglacial climate and marine conditions in the eastern Canadian Arctic—an area demonstrably sensitive to small fluctuations in these conditions—is reviewed in the context of the prehistoric cultural sequence. Most of the major cultural events since 4500 BP appear to correlate well with the paleoclimatic conditions inferred from environmental data, although specific causal mechanisms cannot be documented.

The expansions of Arctic Small Tool tradition (ASTt) and later of the Thule people seem to be related to warmer climatic conditions, whereas the evolution and decline of Dorset culture seems to show an inverse relation to temperature trends. More work is required on the dating of environmental and cultural changes and on the precise nature of possible interactions between environmental factors and cultural response.

INTRODUCTION

Research in arctic archaeology since the late 1960s has shown an increasing recognition of the importance of climatic conditions and their variability for cultural change and development. Several attempts have been made by arctic archaeologists to correlate inferred changes of climate and culture in the Canadian Arctic. Data from extensive archaeological excavations enabled Fitzhugh (1972) to infer environmental conditions in coastal Labrador, and McGhee (1972) combined his own fieldwork with a survey of archaeological data from the Canadian Arctic. Dekin (1969, 1972a, 1972b) summarized published archaeological findings against a background of paleoclimatic data to highlight the similar timing of cultural and climatic changes. The results of these three studies are presented in Table 1.

These studies can be furthered by drawing on several lines of evidence of arctic environmental conditions during prehistoric times and by taking into consideration other recent archaeological findings. In this paper we re-

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examine the hypothesis, most fully articulated by Dekin (1969), that the prehistoric cultural sequence in the eastern Canadian Arctic is closely linked to ecological changes induced by climatic change. Following a brief discussion of the possible significance of environmental factors to prehistoric arctic cultures, we review the evidence for major environmental and cultural changes and thereby attempt to evaluate this concept.

TABLE 1

A comparison of the climatic schemes presented by Dekin (1972a), Fitzhugh (1972), and McGhee (1972)

Fitzhugh (1972)		Dekin (1972a)			McGhee (1972)	
Period	Climate	Date (BC/AD)	Stage	Climate	Date (BP)	Climate
		1900				
				Cold	100	
	Little Ice Age					Cold
VIII		1500				
	Colder oscillations					
			VIII		500	
	Forest retreat					Continued warm
					800	
			VII	Much warmer		Warm
		1000				
	Second northern forest					
VII	maximum				1000	
	Continued warm					
	Forest moves north		VI	Slightly colder		
		500		wetter		Cooler
	Cool episode but not					
	cold				1600	
VI	Sharp warming trend					Warmer
	Dry	AD				
			V	Warmer		
					1900	
		-0-				
		BC				Cold
	Prolonged cold and					
	wet			Cold		
			IV			
		500			2500	
						Warm, stable
IV	Cooling continues					
	Wetter					
					2800	
			III	Warm		Warmer
	Gradual cooling					
	wet	1000				
III					3100	
	Cooling begins					Colder, unstable
						winters
	Widespread forest		II	Cold unstable		
	retreat					
		1500				
					3600	
	Maximum northern					
	extension of forest			Warm		Warmer in the
						North
			I			
		2000			4000	
II	Oscillations					
	Generally warm					
	Cooling					
	Warm and dry	2500				

ENVIRONMENTAL FACTORS OF SIGNIFICANCE TO CULTURAL DEVELOPMENT

Cultural change and development are limited by a variety of factors, among them technological shortcomings, social and ideological barriers, and environmental constraints. The limitations may be direct, as in the case of inadequate food or fuel resources, or indirect, as when climatic factors make travel and, therefore, cultural interaction more restricted. In the Arctic, changes in environmental factors have always had a significant impact on human populations. Alternative sources of food, fuel, and raw materials are limited because the ecosystem supplying these needs is a "simple" one and contains relatively few alternative energy paths. Thus, arctic populations must adapt to an ecosystem which is subject to strong control by the physical environment and vulnerable to the effects of environmental changes.

Archaeological research on the cultural significance of environmental factors and probable changes in their importance at different stages of cultural development is still in its infancy (Irwin-Williams and Haynes, 1970). Nevertheless, it seems likely that changes in two basic environmental factors — climate and the marine environment — were of paramount significance to prehistoric arctic people. These two factors are, of course, closely interrelated over short and long time scales. Thus, the seasonal extent and persistence of sea ice is greatly influenced by the energy budget regime at the ice-air interface and by the surface wind stress. Fluctuations in sea level over intervals of hundreds or thousands of years are partly eustatic, in response to changes in the global hydrological cycle, and partly isostatic, in response to the depression of the land masses under the weight of an ice cover. Climate is the ultimate cause of the eustatic and isostatic controls on sea level. Temperature changes in the atmosphere, however, may involve complex interactions between air and ocean and the causal mechanisms are often uncertain. For present purposes, therefore, it is useful to treat the marine and atmospheric environments separately.

In explaining prehistoric events, archaeologists use information concerning climate and the marine environment in two ways. First, information on present and past environments helps the archaeologist understand the cultural behavior associated with particular assemblages of artifactual data. Second, such information provides the archaeologist with insights regarding environmental processes which may have affected the artifactual data after deposition. This paper focuses on the first of these aspects by examining a number of recent findings concerning changes in both climate and the marine environment and by considering their relationship to the results of current archaeological research. Since the paleoenvironmental information most readily available is not necessarily that most needed by the archaeologist, an additional outcome of this discussion should be to identify the areas where further paleoenvironmental research is required.

As a general framework for this discussion, it will be helpful to view paleoenvironmental factors as operating at a variety of levels. Table 2 illustrates three orders of interaction between paleoenvironmental change and cultural change. Undoubtedly this scheme could be greatly elaborated but, in its present form, it is adequate as the basis for subsequent, more detailed evaluation of the information discussed below. In terms of the *direction* of a climatic change, we may note the statement of McGhee (1972: 55) that it seems "likely that negative responses (of a culture) to deteriorating conditions . . . would have occurred much more rapidly than positive response to ameliorating conditions." It is certainly true that negative cultural responses may be more readily detected in the archaeological record. Recent archaeological research indicates, however, that the simple relationships between negative cultural response and deteriorating climatic conditions, and their converse, do not hold for all areas (Arundale, 1976a, 1976b). In fact, more complex relationships may often be involved and this is illustrated below.

It is evident that sea-ice conditions can also be viewed as operating at the second and third order levels of interaction with cultural factors. The significance of smooth coastal fast ice, with respect to the distribution of ringed seals in winter and the consequent effect on the location of coastal settlements, was first noted in the 1880s by Franz Boas (Boas,

TABLE 2

Examples of climate-culture relationships

Order of interaction	Climatic factors	Cultural significance
1st	Minimum temperature, wind speed, heat losses (from the body), relative humidity	Physiological limitations on survival
2nd	Temperature, wind speed, snow cover, net radiation	Limitations on the availability of resources (food, fuel, building and clothing materials)
3rd	Temperature, wind speed, snow cover	Effect of travel or resource limitations, etc., on susceptibility to disease, on technological innovation, etc.

1964: 9 and 52). More recently, research by McLaren (1958a, 1958b) has shown that the overall area and stability of the local fast ice is positively correlated both with the size of the local ringed seal population and with the average size of the animals within that population. Thus, changes in sea-ice conditions may have affected the availability of food, fuel, and travel routes and thereby brought about cultural changes at the second and third levels of interaction. Sea-level changes, a second example, may also have brought about (long term) second- or third-order effects since they affected the availability of material resources, travel routes and settlement sites in newly uplifted coastal areas. It is worth pointing out that the 10^2-to-10^3-year time scale involved in changes of sea level has also facilitated the use of uplift data from raised marine beaches as a basis for relative dating of prehistoric sites (Meldgaard, 1962; Taylor, 1968; Andrews *et al.*, 1971).

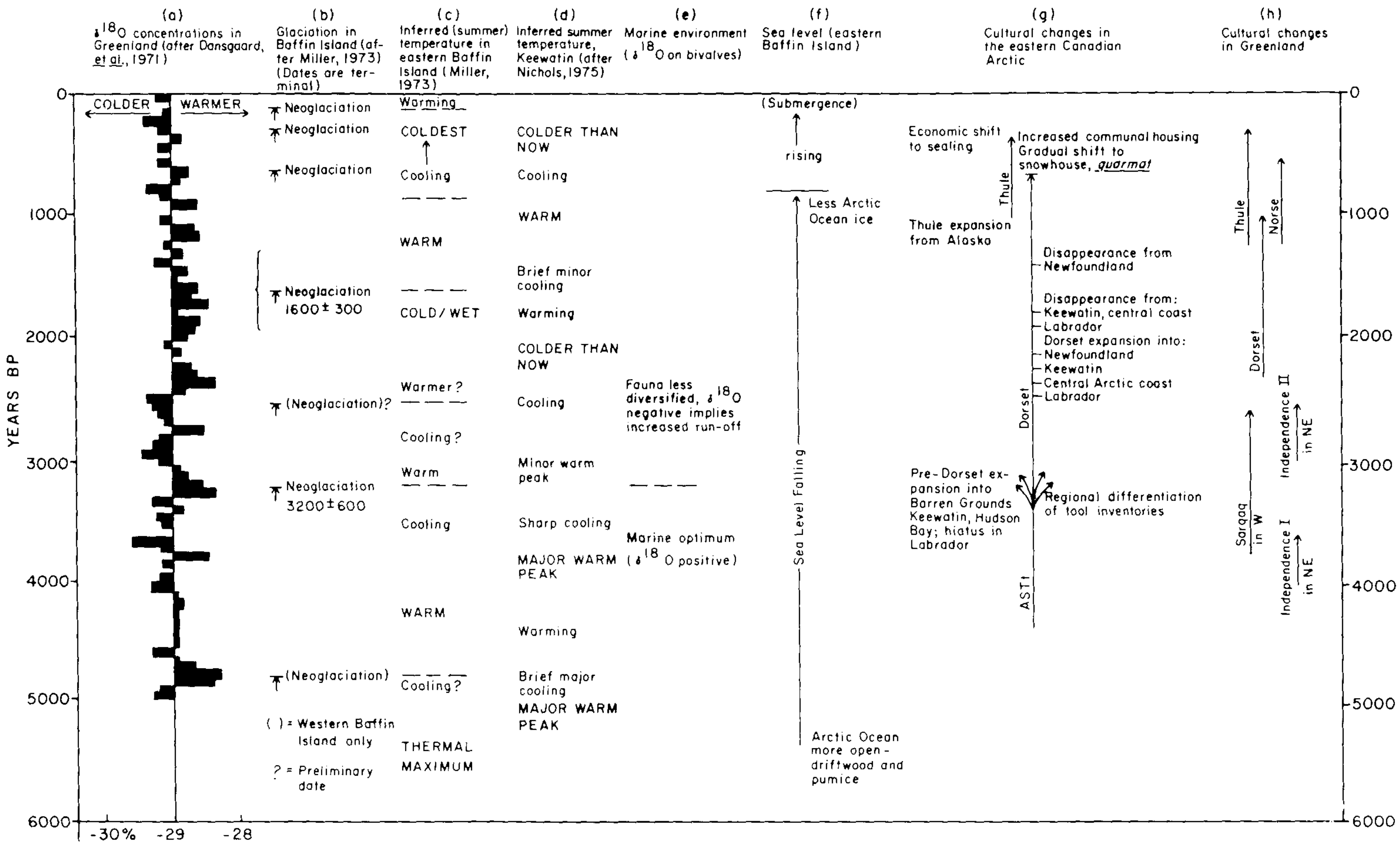
EVIDENCE OF LATE GLACIAL AND POSTGLACIAL ENVIRONMENTAL CHANGES

The three sources presented in Table 1 summarize much of the significant paleoenvironmental and archaeological data available prior to 1971. This paper will focus on more recent paleoenvironmental investigations and on some new perspectives regarding their possible relationship to arctic prehistory. Table 3 summarizes the principal results of these newer sources. The inferred summer climatic conditions in column (c) refer to eastern Baffin Island where temperature is the major control of snowline altitude and therefore ice extent. Miller (1973) postulates that peat accumulates during the intervals between Neoglacial advances in response to relatively warm moist conditions. Organic deposition appears to cease under cold dry conditions (Nichols, 1975: 64). Column (d) summarizes, for comparison, Nichols's (1975) composite reconstruction for summer temperatures in Keewatin-Mackenzie. It is worth noting that the warm interval III shown by Dekin in Table 1 is a minor interruption to a long interval of substantial cooling. The intervals when the Canadian Arctic was colder than now were just prior to 2000 BP and around 300 to 400 BP. Only the major cultural events are indicated in columns (g) and (h) of Table 3.

Recent paleoclimatic inferences come from four main sources: (1) on-going glaciological, geological, and climatological studies of Baffin Island and the eastern Canadian Arctic (Andrews and Ives, 1972; Andrews *et al.*, 1972; Blake, 1972; Bradley and Miller, 1972; Lamb, 1972; Barry, 1973; Bradley, 1973; Miller, 1973; Andrews *et al.*, 1974), (2) isotopic analyses of the first Greenland ice core (Dansgaard *et al.*, 1971; Johnsen *et al.*, 1972), (3) Holocene palynological data from extensive areas of the eastern Canadian Arctic and Subarctic and Greenland (Fredskild, 1972; Nichols, 1972, 1974, 1975; Jordan, 1975; Short and Nichols, 1977), and (4) paleosol studies on tree-line displacement (Sorenson *et al.*, 1971; Sorenson and Knox, 1974). The cli-

TABLE 3

Environmental and cultural changes in the eastern Canadian Arctic and Greenland



mate inferences drawn by arctic archaeologists, from their own work and that of other arctic specialists, are amplified by these studies with resulting better understanding of some of the local variations in the overall pattern.

Past Climate

Between 11,500 and 8000 BP much of the glacier ice which formerly covered most of the Canadian High Arctic disappeared (Blake, 1970, 1972) and prior to 5000 BP the final remnants of the Laurentide ice sheet were gone from Keewatin and Labrador-Ungava (Bryson *et al.*, 1969). In eastern Baffin Island the climatic amelioration culminated in a thermal maximum which is dated about 6000 to 5000 BP (Andrews and Ives, 1972; Miller, 1973). Evidence of abundant driftwood in the northern parts of the Canadian Arctic Archipelago between 6500 and 4500 BP indicates the likelihood of more open water in the inter-island channels and in the Arctic Ocean about the same time (Blake, 1972). Other driftwood evidence from northeastern Greenland suggests a second warm peak between 4500 and 3000 BP, with strong support from palynological data (Fredskild, 1969).

The first major event in the eastern arctic archaeological record is the dramatic eastward expansion of the Arctic Small Tool tradition (ASTt) (Irving, 1953) across the North American Arctic to Baffin Island, Labrador, and northeastern Greenland. McGhee (1972) considers that sea mammals and caribou were major sources of food and fuel for people of the expanding ASTt, although in the Arctic islands the musk-ox was also important. Until recently, this expansion was thought to have occurred about 4500 BP, but recent reanalysis of the radiocarbon dates for many eastern arctic sites indicates that a date just prior to 4000 BP is more probable (Dekin, 1975; McGhee and Tuck, 1976) (Note 1). None of the three existing models for explaining the nature of this expansion (McGhee, 1974, 1976; Dekin, 1975, 1976; Maxwell, 1976a) involves significant climatic change.

Though it appears from the data of Dansgaard *et al.* (1971) that the thermal maximum was already past, other evidence points to a second major warming episode within the period 4600 to 3600 BP (Nichols, 1967, 1972, 1974, 1975; Fredskild, 1969, 1973). This coincides with the period of increasing size, growth rate, and diversity of marine molluscs reported by Andrews (1972), suggesting warmer conditions until 3500 BP, although the effects of salinities 1 to 2% greater than in the present waters were also involved (Andrews, 1973). Initial palynological data from northern Labrador-Ungava (Short and Nichols, 1977) indicate that forest migration was greatly delayed relative to western Canada and reached its most northerly extent from 6000 to 3000 BP. However, the climatic controls on this sequence are not yet established. The paleoenvironmental data, while not conclusive, therefore, nevertheless show some major changes similar in timing to those in the cultural sequence.

Following the ASTt expansion, the first significant climatic event on record was the onset of a marked cooling trend, dated about 3600 to 3400 BP across the entire central and western Canadian Arctic (Nichols, 1975), with the formation of Neoglacial moraines on Baffin Island, immediately prior to 3200 ± 600 BP (Miller, 1973). The disappearance of Independence I culture from its range in the High Arctic and the expansion of the ASTt into the Barren Grounds are well-known cultural concomitants of this event. Recent evidence has also revealed a hiatus in the ASTt occupation of Labrador about 3500 BP (Tuck, 1976). These cultural changes and the concurrent regional differentiation in artifacts are attributed by Dekin (1975) to the break-up of the ASTt into five regional phases: the so-called Canadian Tundra-Taiga tradition (Noble, 1971; Gordon, 1975); Sarqaq (Mathiesson, 1958); Independence II (Knuth, 1967); a Pre-Dorset assemblage from Port Refuge, Devon Island (McGhee, 1973, 1976); and the Pre-Dorset found elsewhere in the eastern Arctic. A change in climate is the basic causal factor in Dekin's explanatory model of this pattern of regionalization. However, this viewpoint is highly controversial (see Note 2).

This cooler episode was followed by a warmer and perhaps drier interval between approximately 3200 and 2800 BP (Table 3) during which the rapid development of Dorset culture from Pre-Dorset was originally thought to have occurred. However, the analysis of radiocarbon dates on wood charcoal, noted earlier, has shown that the develop-

ment of Dorset may have taken place somewhat later, in a subsequent period of marked cooling beginning about 3000 BP in Mackenzie-Keewatin (Nichols, 1975) and in Labrador (Short and Nichols, 1977), and intensifying by 2500 BP. Maxwell (1976b: 5) notes that current hypotheses of Dorset development "deal mainly with marked climatic cooling and a consequent effect on critical fauna. This in turn could lead to shifts in economic emphasis such as increased activity in sea-ice hunting; demographic contraction toward centers of greater food reliability resulting in cultural compaction; and a complex of factors imbalancing the earlier system." This period of cooling caused further southward retreat of the northern forest limit throughout subarctic Canada (Nichols, 1967, 1974, 1975; Short and Nichols, 1977) and may also have brought about the disappearance of the Independence II culture from the High Arctic. Such cooling perhaps initiated a readvance of the Barnes Ice Cap (Andrews, 1970), although the preliminary dating of this at 2300 ± 650 BP was based on an early lichen study (Andrews and Webber, 1964). The true age was probably older. Moraines dating from this interval have not been identified in eastern Baffin Island (Carrara and Andrews, 1972; Miller, 1973). Evidence for cooling may be recorded in the pollen sequence at Maktak Fiord, where peat growth was initiated at 2500 BP, possibly resulting from changing levels of the permafrost (Boulton *et al.*, 1976). This would seem to parallel palynological evidence for cooling at 2500 BP and more clearly at 2300 BP in west Greenland (Fredskild, 1967). At present, the evidence of environmental conditions for this period is not yet definitive enough to resolve apparent ambiguities in the timing and/or spatial pattern of events.

Pronounced cooling continued at least through 2100 BP in Greenland (Fredskild, 1972) and widely in northern Canada, possibly with minimum summer temperatures about 2200 to 2100 BP (Nichols, 1970). On eastern Baffin Island, lichen colonization of moraines from about 1600 BP (Miller, 1973) may indicate a lag in glacier response to the subsequent temperature recovery, although the dating precision is only ±300 years, but Bartley and Matthews (1969) also date major peat growth at Sugluk, Labrador, from 1600 BP. This warming is not recognized in all areas, although in southern Baffin Island its onset about 1900 BP is believed to have brought about unfavorable conditions for caribou, such as winter icing of feeding grounds due to freezing rain (Fitzhugh, 1972: 171), and for ringed seal as a result of early break-up of shorefast ice, which resulted in changes in the local pattern of settlements by 1800 BP (Arundale, 1976a, 1976b).

Previously, Dekin (1969: 7) hypothesized that Dorset culture underwent a decline during the colder period prior to 1900 BP and then expanded in the subsequent warmer period. However, three new sources of data indicate a need for a reassessment of this view. First, the reexamination of radiocarbon dates (Dekin, 1975; McGhee and Tuck, 1976) raises questions as to the dates of occupation of some of the sites from these periods. Second, as more Dorset sites become known, evidence shows that Dorset culture had already spread to such "marginal" areas as the central Arctic Coast, Keewatin, Labrador, and Newfoundland prior to 2100 BP. With the exception of Newfoundland, all of these marginal areas were abandoned prior to 1900 BP or shortly thereafter. Third, better ecological data indicate that warming conditions were unfavorable for key faunal resources in some areas (Arundale, 1976a, 1976b; Schledermann, 1976a). Thus, previous views of these changes in the Dorset culture no longer appear to be tenable.

It is appropriate to note that in some recent discussions of the expansion and contraction of Paleoeskimo[3] culture, the eastern Canadian Arctic has been viewed as consisting of a core area of cultural and resource continuity surrounded by marginal areas which have undergone repeated periods of occupation followed by abandonment. A simple pulsation model of climatically induced expansion and withdrawal has been proposed to explain the relationship of the core area and its surroundings (Fitzhugh, 1974). According to this model, favorable climatic conditions permitted populations to expand into marginal areas, while deteriorating climatic trends forced withdrawal to the core. Although climatic change is clearly involved in these population movements, two factors which contradict the predictions of the model have become clear. First, these population movements into

and out of marginal areas are not synchronous. Second, instead of contraction, catastrophic decline and extinction were more often the fate of marginal settlements (McGhee, 1976). Thus, explanation of these population movements awaits clearer identification of crucial ecological factors and a more complex model of the processes involved.

The recent warm interval, which included the period 1100 to 800 BP, referred to as the "Medieval Warm Epoch" (Lamb, 1965), witnessed the well-known Norse settlement of southern coastal Greenland and the rapid eastward expansion of Thule culture from northern Alaska (McGhee, 1970). A key feature of the Thule culture was their hunting of baleen whale from boats, indicating open sea conditions (McGhee, 1972: 47). Nichols (1975) estimates that mean summer temperatures in southern Keewatin and Mackenzie were about 1°C above modern values, compared with a +3 to +4°C anomaly in the preceding warm intervals about 3800 and 5000 BP. For some time it has generally been thought that Dorset culture ceased abruptly following the Thule arrival. On the contrary, newer data seem to indicate that a wide variety of processes of culture change were in operation. Instead of totally succumbing, traditional Dorset culture persisted in parts of eastern Hudson Bay for nearly five centuries after Thule migration into the eastern Arctic (Maxwell, 1976b).

The period from 800 to 400 BP, which was characterized by a return to colder conditions (Nichols, 1974), witnessed the maximum expansion of Thule culture. The great use of whalebone in Thule villages in the Cumberland Peninsula testifies to the continued importance of the whale in their economy. However, the continued shift to a culture characterized by the snow house and the seal, and the exploitation of areas where a whale-based economy was not possible, suggest more reliance on winter and spring hunting. Schledermann (1976b) believes that the snow house and possibly the *quarmat*[4] (as an autumn house) were introduced to the Thule culture by Dorset traditions. By the end of this period, permanent sod/stone and whalebone winter houses gave way to use of the snow house and the *quarmat* in many areas. The shift to a pattern of winter hunting of ringed seal began first, and developed most fully in the northern areas that were affected earliest by more extensive and persistent fast ice.

The period of colder summers, culminating in the Little Ice Age, about 400 to 100 BP, saw the pattern of winter hunting of ringed seal become more widespread (McGhee, 1970) and the *quarmat* increasingly used as an alternative form of winter housing in Labrador (Schledermann, 1976a). A growing tendency toward communal housing can also be seen in the archaeological record from Labrador and elsewhere (Schledermann, 1976a, 1976b), but whether this was directly related to environmental stress is unclear. This cold episode eliminated the Norse population in Greenland and forced the abandonment of the High Arctic by Thule people, although perhaps not until 400 BP (Fredskild, 1972: 304). The evidence of lichen trimlines peripheral to present snowbanks in Baffin Island led Ives (1962) to suggest that "during a period culminating between 200 and 350 years ago, extensive tracts of North Central Baffin Island (more than 70%) were buried beneath permanent ice and snow." Miller (1973) shows from lichenometric studies of late Neoglacial moraines in eastern Baffin Island that glacial advances occurred, to limits more extensive than at any time since the maximum of the late Wisconsin glaciation and that retreat has characterized only the last 60 to 70 years. Based on the inferred snowline in Baffin Island during the Little Ice Age, Williams (in press) has calculated that a summer cooling of about 1.5°C, compared with present, must have occurred. This cooling is widely marked in arctic pollen diagrams and peat sections (Nichols, 1974), by the cessation of sediment accumulation, due to cold dry summers (Nichols, 1975), as well as by reduced exotic tree pollen influx into Baffin Island (Nichols and Andrews, 1977).

THE MARINE ENVIRONMENT

Geological knowledge of the marine environment is relatively scanty and comes primarily from two sources: marine fauna and sea-level changes. The recent work of Blake (1972) on the temporal pattern of driftwood dispersal adds a third important dimension. Raised marine deposits, isolated by isostatically rising coasts, contain faunas that can be dated, identified taxonomically, and chemi-

cally analyzed. For the Arctic, an early attempt to undertake a statement of changing postglacial marine conditions is the work of Laursen (1946: 52) on the collections of the Fifth Thule Expedition, in which he recognized a threefold temporal division of the fauna, with a subarctic element present in his study area at elevations between 30 and 50 m.

Andrews (1972) has examined changes in growth rate, shell size, and faunal composition of postglacial marine shells from Arctic Canada.[5] He suggests that the inshore, relatively shallow water marine faunas indicate a threefold division of the Holocene with optimum conditions for growth peaking about 3500 BP, followed by a decrease in growth rate and the migration of certain shell species to the south of their most extended Holocene range. Since that report, the $\delta^{18}O$ and $\delta^{13}C$ contents of marine shells from Hudson Bay and eastern Baffin Island have been obtained for certain collections, and it appears that the marine "optimum" of 3500 BP was related to salinity conditions, rather than to temperature (Andrews, 1973).

No one has studied raised marine sequences with sufficient detail to evaluate the changes of the last 5000 years, especially the suggestion of more open water conditions about 800 BP (McGhee, 1972) and of more favorable conditions for marine fauna and for the use of boats during other warm periods.

There have been significant changes of sea level along the coasts of the Canadian Arctic during the last 5000 years. Maximum isostatic recovery over this interval has been approximately 70 m at some arctic sites, with the most rapid uplift occurring over and around the shores of Hudson Bay north of Southampton Island. Along the inner fiords of eastern Baffin Island, maximum uplift during the same period has been ≤ 30 m (Dyke, 1974), and in certain areas along these coasts submergence of about 1 m has occurred over the last 1000 years. Active destruction of Thule and Dorset sites is occurring in sections of northern Cumberland Peninsula either by the physical encroachment of the sea over a site or by wave erosion. Sea levels at various periods have been presented previously by Andrews *et al.* (1971) and Walcott (1972a).

For the last 5000 years eustatic sea-level fluctuations have been superimposed on the general isostatic recovery of the Arctic, but the magnitude of these fluctuations was probably too small to be environmentally significant. Although there is considerable debate as to the exact course, level, and interpretation of sea-level changes over the last 5000 years (c.f. Bloom, 1967; Mörner, 1969; Walcott, 1972b), these changes have been less than ± 1 m and are therefore unlikely to be of significance to the arctic archaeologist.

SHORT-TERM ENVIRONMENTAL CHANGES

The characteristics of recent fluctuations in climate and sea-ice conditions are summarized briefly in this section. It is important to anticipate such variability during past epochs, but these data have additional significance as will be discussed below.

SECULAR CLIMATIC FLUCTUATIONS

For the latitude belts 67°30′N to 72°30′N and 72°30′N to 88°30′N, Treshnikov and Borisenkov (1971) cite increases in mean annual temperature of 0.88°C and 1.11°C, respectively, between 1891-1921 and 1921-1960. Such generalizations must be treated with caution since climatic records exceeding 1 to 2 years' duration from the Canadian Arctic only rarely predate 1930 and in the Queen Elizabeth Islands the records only began about 1950. For Greenland, however, there are records for the last 100 years.

The Greenland temperature records are of considerable interest (Figures 1 and 2). Winter (September through May) temperatures rose intermittently from about 1890 to 1930-1940 resulting in an overall increase of 4 to 5°C. The warming was especially pronounced in the 1920s. Some cooling has occurred since 1930-1940 although temperatures in the 1960s are still approximately 3°C above those of the 1880s. Summer (June through August) temperatures show similar trends to those in the winter months. Again there was marked warming between 1918 and 1928 and this has been reported in many other parts of the Arctic—Eurasia (Petrov, 1959), Iceland (Stefánsson, 1969), Baffin Island (Bradley, 1973), Ellesmere Island (Hattersley-Smith, 1963), and in some records from Alaska

(Hamilton, 1965). The dominant circulation regime over the Northern Hemisphere changed from meridional (north/south) to zonal (west/east) about 1917 (Dzerdzeevski and Sergin, 1972), giving rise to the observed warming trends, and this mode continued until the early 1950s when a reversal took place.

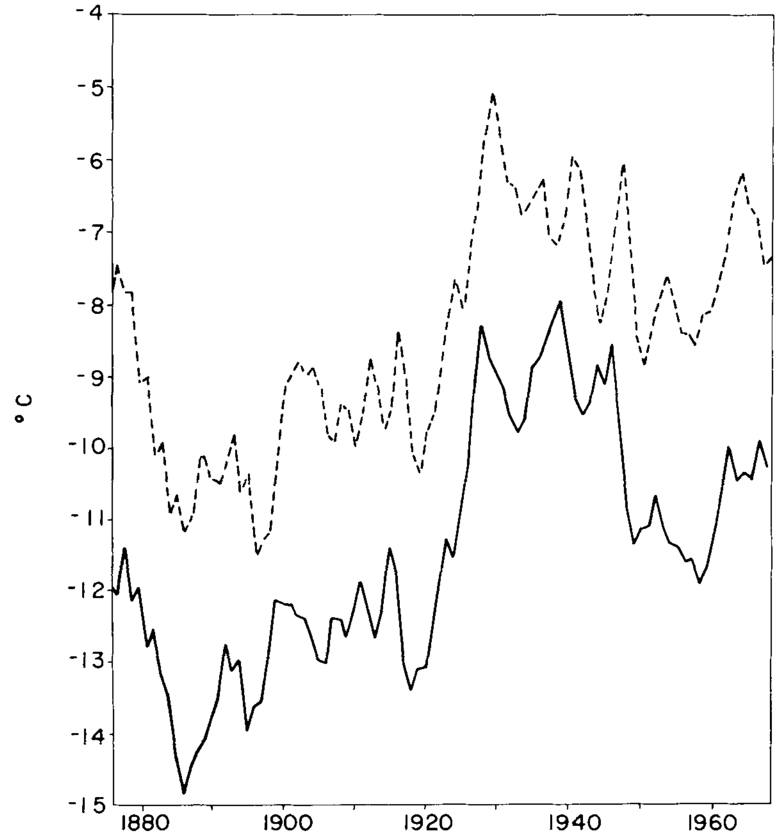


FIGURE 1. Winter (September-May) mean temperatures in West Greenland shown as 5-yr weighted running means. Dashed line: Jakobshavn (1873-1971) 69°13′N, 51°03′W. Solid line: Upernavik (1874-1970) 72°47′N, 56°10′W.

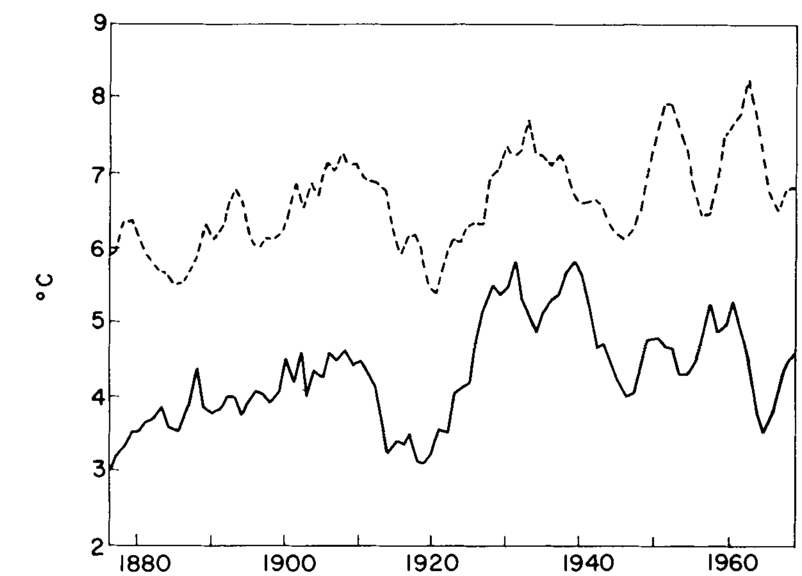


FIGURE 2. Summer (June-August) mean temperatures in West Greenland shown as 5-yr weighted running means. Dashed line: Jakobshavn (1873-1971) 69°13′N, 51°03′W. Solid line: Upernavik (1874-1970) 72°47′N, 56°10′W.

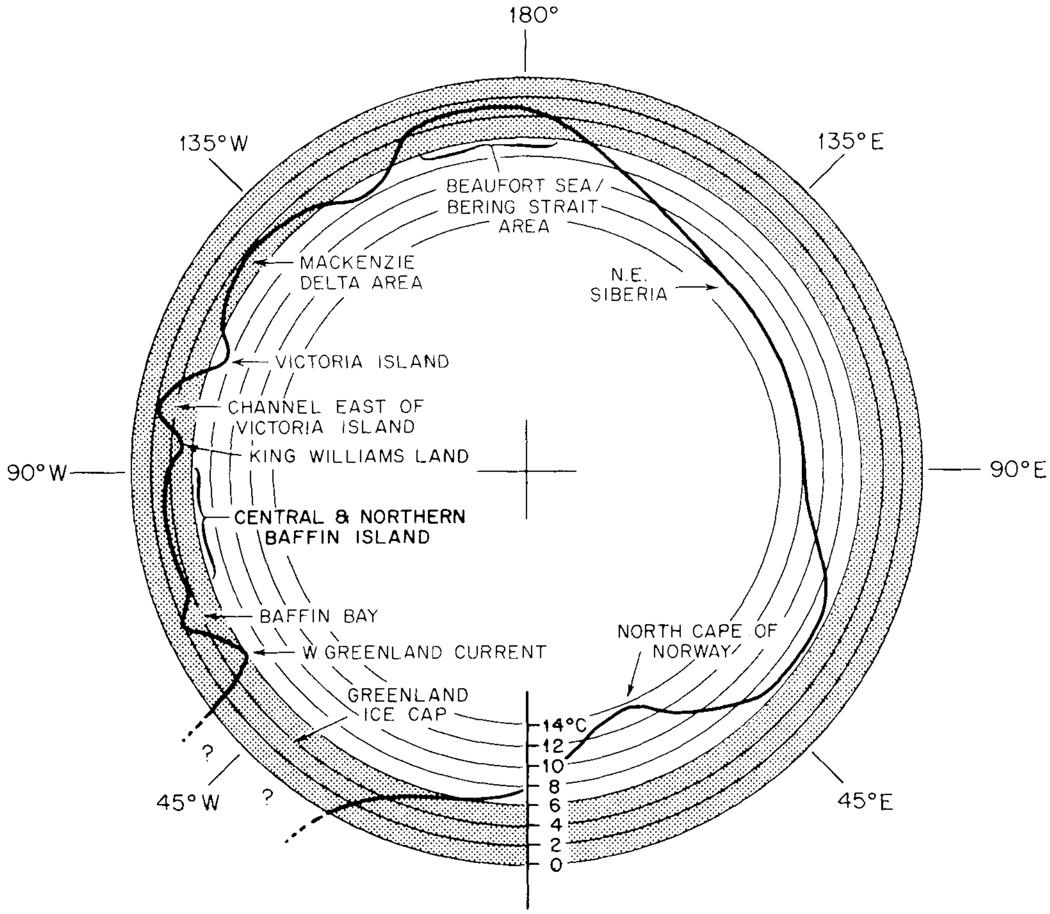


FIGURE 3. Mean July temperature around the Northern Hemisphere at 70°N (after Prik, 1959).

Compared to other land areas at a similar latitude, Baffin Island experiences very cool summers, with mean temperatures barely reaching 4°C in its northern half (Figure 3). Accordingly, conditions there are highly sensitive to small climatic fluctuations (Bradley and Miller, 1972). Cooling over the eastern Arctic in the summers of the 1960s was pronounced (Table 4), leading to lower temperatures than for 30 to 40 years in Baffin Island. Winter temperatures in the eastern Arctic showed a similar pattern, except on Baffin Island where an increase in the 1960s was accompanied by more snowfall. Such minor climatic fluctuations can significantly affect snow and ice cover. For example, in the early 1970s there was evidence that snowbanks, identifiable on aerial photographs of the Cumberland Peninsula, Baffin Island, taken in 1959, had become much more extensive as a result of increased winter snowfall and re-

TABLE 4

Change in seasonal mean temperatures, 1951-1960 to 1961-1970 (°C)

	Summer (June-August)	Winter (September-May)
Clyde	-0.56	+0.46
Coral Harbour	-0.44	-0.77
Frobisher Bay	-0.53	-0.19
Nottingham Island	-0.52	-0.43
Resolute[a]	-1.1	-0.19
Spence Bay[b]	-0.63	-0.58

[a]Moved 1960 (1′S,6′W)
[b]1952-60 to 1961-68

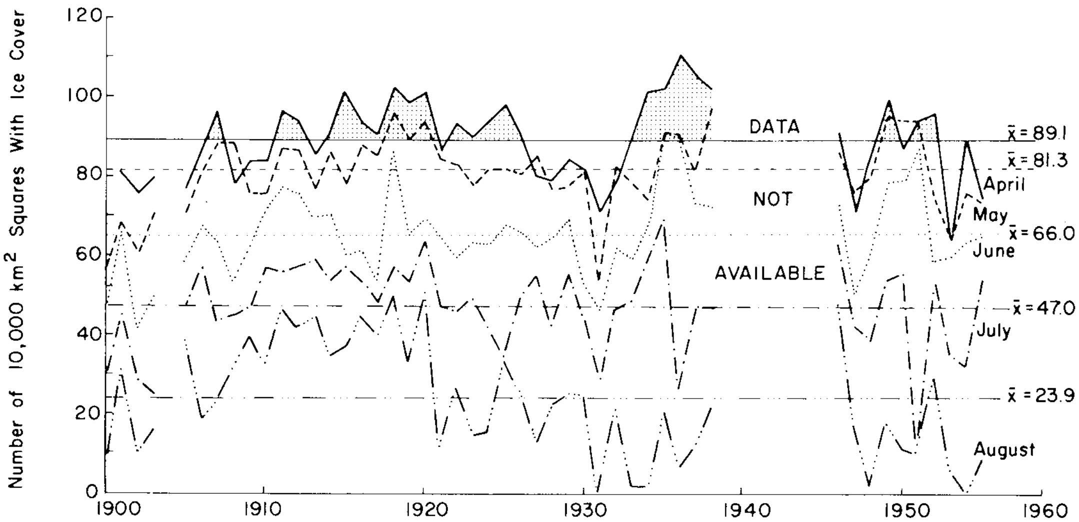


FIGURE 4. Ice cover over the sector 55°-70°N, 40°W to the east coast of Labrador and Baffin Island, April through August 1900 to 1955. Extent in 10,000-km² units (after Vladimirov, 1964).

duced summer snowmelt. Although such growth may easily be reversed by a single warm summer, the pattern is suggestive of what may happen more persistently during a prolonged phase of climatic deterioration. The cooling observed over Baffin Island during the 1960s and early 1970s appears to be closely related to shifts in the standing waves in the hemispheric westerly circulation reported by Namias (1969, 1970). Arundale (1976a, 1976b) has used a model based on shifts in the mean position of the standing waves to assess the effects of climatic change between 2500 and 1500 BP on the southern coast of Baffin Island. In this approach, circulation characteristics, summarized as synoptic types by Barry (1974) and analyzed by Bradley (1973), are used to provide information on possible seasonal differences in temperature and precipitation patterns. Such information provides a more detailed basis for assessing interaction between climatic change and cultural change. Extension of this approach to other areas offers the archaeologist the possibility for greater use of climatic data.

SECULAR VARIATIONS IN SEA ICE

Aerial reconnaissance of Arctic sea ice began only in the 1950s but observations by whalers in Baffin Bay and Davis Strait provide an indication of longer term variations in sea-ice cover. Vladimirov (1964) has calculated the number of 10,000-km² squares with ice cover between 55 and 70°N, 40°W and the east coast of Baffin Island and Labrador, in the months of April to August (Figure 4). The results show an increase in area from 1900 to 1920 followed by a decrease in 1930-31 and than a further rise in the mid-1930s. He suggests that the 1900 to 1930 "cycle" may have been repeated subsequently but the absence of data during the Second World War does not allow this to be substantiated.

Air reconnaissance data for the last two decades shows that between about 1963 and 1972 there was a significant increase in the severity of ice conditions for July through September in Baffin Bay (Dunbar, 1972). This apparently matches without any lag the cooling (up to 1972) in the eastern Canadian Arctic noted by Bradley and Miller (1972).

Since the Greenland temperature records span the last century it is of interest to examine the correlation between July mean temperature at Upernavik and the area of sea ice estimated by Vladimirov (1964) for Davis Strait. An inverse relationship is demonstrated ($r = -0.46$, significant at the 0.1% level for 48 cases) indicating less sea-ice cover during warm summers. Although the explained variance is only 21%, the relationship may provide some basis for extrapolating from interpretations of the land record to the summer sea ice conditions. The existence of this inverse relationship represents the effect of summer melt and does not conflict with

Dunbar's (1954) model of greater winter ice cover during warm periods in response to an increase in velocity and volume transport of both the West Greenland and the Canadian currents.

The primary significance of these environmental data for the last century or so is that they can serve as an analog for earlier protracted periods of cold or sea ice severity which are thought to have been related to cultural change. The possible impact of colder conditions is illustrated by Jacobs's (1975) calculations of accumulated temperatures and modern heating requirements at Broughton Island, near Baffin Island, and by his demonstration of the negligible catch of harp seal in the icy summer of 1972 due to the very limited open water. The research of Arundale (1976b) on the Lake Harbour area and the discussion by Fitzhugh (1976) of Hudson Bay settlement make it increasingly clear that research on secular changes in sea ice conditions can make important contributions to understanding the ecological processes which mediate the second and third order interactions noted in Table 2.[6] Furthermore, if methods of using secular climatic data to gain a more detailed picture of past climatic patterns can be enhanced by an improved understanding of the correlations between secular climatic changes and secular sea ice changes, the archaeologist will have a much richer environmental context in which to view the events of the archaeological record.

CONCLUSIONS

The primary points to emerge from this comparative review of paleoenvironmental and archaeological data are as follows:

(1) The eastern Canadian Arctic is highly sensitive to small climatic fluctuations (Andrews *et al.*, 1972; Bradley and Miller, 1972). Dunbar (1954) considered that the ocean in Baffin Bay buffered the area against recent climatic changes, but it would appear that the buffering role operates principally as a lag mechanism, rather than as a modulator of amplitude. Accordingly, the eastern Canadian Arctic should be a prime region for examining climate-cultural interactions.

(2) The mid-Holocene thermal maximum appears to have had a peak between 6000 and 5000 BP with widespread evidence of an episode of subsidiary or equal warmth between 4500 and 3500 BP (Nichols, 1974). At present, the Baffin Island record for the latter interval is incomplete, at least in terms of the duration of the climate deterioration that culminated in the 3200 ±600 BP Neoglaciation (Table 3). In the High Arctic and Greenland this phase may have been warmer than between 6000 and 5000 BP (Fredskild, 1969, 1972). If so, the correlation with the ASTt expansion is close in time. However, as emphasized by McGhee (1976: 38), the later Pre-Dorset (Paleoeskimo) expansion into "fringe areas" does not fit readily into our present paleoenvironmental data for this period about 3400 to 3000 BP.

(3) The evolution, expansion and eventual disappearance of the Dorset culture appear to be particularly complex in terms of possible environmental interactions although there is growing evidence that climatic change is implicated. The development phase appears to relate to a marked cooling phase (about 2500 to 2100 BP) while in some areas a decline of the culture appears to be synchronous with a warming (about 1800 to 1600 BP) that was somehow unfavorable to the key fauna. However, the timing of disappearance in Newfoundland may not fit this scheme.

(4) In contrast, the Thule expansion into, and subsequent abandonment of, the High Arctic appear to coincide with a slightly warmer phase about 1100 to 800 BP and the succeeding episode of severe cold and sea-ice expansion.

A more general point concerns the problems of dating the onset and termination of a climatic change and of relating such a change to an identifiable cultural response. Radiocarbon dates on shells, peat, wood, and sea mammal material do not give the same age even if all of the organisms coinhabited a small area within a small time interval (see also Note 1). In addition, there is a laboratory uncertainty of ±100 years (one standard deviation) for ^{14}C dates and a larger uncertainty (ca. ±20%) for lichen dates. In view of these errors, we cannot be sure, for example, whether the warm event dated about 1600 BP in eastern Baffin Island (Miller, 1973; Dyke, 1977) and northern Quebec (Bartley and

Matthews, 1969) is synchronous with warming in Keewatin about 1900 BP (Nichols, 1975). The discrepancy may be due to a real time lag or to a different response to the cause of the change, or it may be a result of dating imprecision.

The precise nature of the climatic influence, where it seems to have been critical in effecting cultural change, is hard to assess. Tuck (1976) notes the likelihood of regional extinctions of populations in coastal Labrador due to severe short-term weather conditions, which, in contrast to gradual climatic changes, do not allow time for human adjustments to develop. However, this idea is not at variance with recent views on the rapidity of significant major climatic changes and on the likelihood of greater short-term variability during colder intervals (Bryson, 1974). Such rapid shifts are only just beginning to be identified in the paleoenvironmental data due, at least in part, to imprecision and homogenization of the fossil sedimentary record.

Archaeologists are beginning to focus their concerns on the more complex aspects of the relationship between climatic change and cultural change. Returning to Table 2, it is clear that the instances of first order interaction between climatic change and cultural change have long been the best known and the most obvious. The abandonment of the High Arctic during a colder interval by the Independence I culture and the elimination of the Norse from Greenland are prime examples. However, instances of other levels of interaction are only gradually emerging from current research. An example of second order interactions is the settlement pattern change which Arundale (1976a, 1976b) has shown occurred in the Lake Harbour area shortly after 1900 BP. Schledermann's (1976a, 1976b) evidence of changes in Thule housing styles may be another example of second order interaction. The change in social scale which Dekin (1975) has suggested was a major factor in the regionalization of the ASTt characteristics may be an instance of third order interaction.

This review demonstrates that earlier attempts at synthesis, principally by Dekin, Fitzhugh, and McGhee, were significant steps in the continuing development of our understanding of the cultural implications of climatic change. There seems to be increasing evidence for synchrony of most of the major climatic changes and cultural response in the eastern Canadian Arctic, as proposed by Dekin (1972a). However, the characteristics of these relationships, and the actual mechanisms and processes involved differ from some of his interpretations. Continued investigation of the nature of these interactions is required. Even in the physical environment, the complex relationships between climatic factors and sea ice, for example, are not fully understood. Moreover, as better dating of climatic and cultural phases becomes available, the reality of some of the proposed associations will be open to reinterpretation.

The question of intrinsic variability within animal populations or social changes occurring independently of climatic factors also requires careful consideration. The roles of nonclimatic sources of environmental variability (for example, human social change, plus cyclical variation in the size of some resource animal populations) are still poorly appreciated. A better understanding of these factors would prevent both paleoenvironmental and archaeological researchers from mistaking such variability for the effects of environmental change.

As arctic archaeologists acquire more data, employ more sophisticated explanatory models in their research, and find available a growing body of information on environmental change, additional examples of second and third order interactions should become evident, and our understanding of relationship between climatic change and cultural change in the Arctic should become more refined. But the ecological processes which link these climatic and cultural changes are complex and only beginning to be understood. A better understanding of both these ecological processes and the environmental and cultural events to which they may relate offers many exciting challenges in paleoenvironmental and archaeological research.

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NOTES

[1]This reanalysis is based on (1) a consideration of possible corrections (a 10% reduction or a constant reduction of 400 yr) to the radiocarbon dates obtained from sea mammal material, and (2) elimination of all dates using sea mammal material and use only of those from terrestrial material (McGhee and Tuck, 1976).

[2]It is important to note that Dekin's interpretation of these events is not shared by all arctic archaeologists. In a recent analysis of the archaeological data pertaining to pre-Thule occupations of the central and high Arctic, McGhee (1976: 39) concludes that "a theoretical framework of historical particularism would seem to be a more trustworthy guide than one of systematic causation" in the interpretation of these data. This difference in theoretical perspective leads McGhee to some different conclusions regarding the events of this period, and in particular regarding the Pre-Dorset material from Port Refuge, Devon Island (Dekin's "Refuge Tradition").

[3]The term Paleoeskimo as used here follows the new usage of Maxwell (1976b: 4) and denotes all temporal and spatial variants of prehistoric culture in the Eastern Arctic which precede Thule and modern Inuit.

[4]The *quarmat* is a skin-roofed sod/stone, snow, or ice-block structure originally used as an intermediate autumn dwelling (Schledermann, 1976b: 42).

[5]Two large marine mammal species, the walrus (*Odobenus rosmarus*) and the bearded seal (*Erignathus barbatus*) depend very heavily on bivalves for food. Both also served as important food species for prehistoric Arctic peoples.

[6]Schledermann (1976b: 40) suggests that cold periods had a marked limiting effect on sea mammals, due to greater ice extent and persistence, but were generally advantageous to land mammals as a result of less snow. The former would be true mainly for colder summers, the latter for colder winters.

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