

The Arctic Shelf in the Late Pleistocene and Certain Problems of Paleoglaciology¹

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ABSTRACT

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By analysing Arctic glaciation dynamics the author concludes that the Polar seas under went glacioeustatic regression that was much lower in amplitude than is commonly hypothesized, and that the maximum regression occurred at the beginning of the Holocene.

ADDITIONAL INDEX WORDS: *Arctic glaciation, glacioeustatic regression, sea-level change.*



INTRODUCTION

As is known, in the late Pleistocene sea level oscillations were reflecting principal events in the northern hemisphere's glacial history; regression (36,000-17,000 years ago) being related to the growth of the ice sheet, and transgression (17,000 years ago) accompanying deglaciation. The chronological events identified in the analysis of ice sheet dynamics appear to be in good agreement with marine geology and paleoceanology data (ALTWATER *et al.*, 1977; EMERY *et al.*, 1967, 1971; GROSVOLD *et al.*, 1977). Some discrepancies in the dating of the phases mainly involve minor details, and do not alter the overall pattern. The maximum amplitude of sea level oscillations, according to most of the estimates, did not exceed 130-140 m. Since the Arctic Ocean and the world ocean were connected throughout the Pleistocene, it is universally recognized that there was a regressive-transgressive cycle, of a similar amplitude, in the Arctic basin as well (BADYUKOV and KAPLIN, 1979; LASTOCHKIN and FEODOROV, 1978). Another interpretation appears highly unlikely; unless, of course, we do not accept the basic concept of a continuous

connection between the western part of the Arctic Ocean and the world ocean. However, with certain paleogeographic conditions, this is quite possible. Evidence of glaciation in the Arctic basin and on the shelf shows a different regime of world ocean and Arctic Ocean sea level oscillations during the glacioeustatic regressive-transgressive cycle.

Contrary to DONN and EWING (1966), it is a proven fact that during cold intervals ice thickness in the Arctic Ocean was increasing. According to CHIZHON (1970), during the late Pleistocene cold maximum, when the average annual temperature in high latitudes dropped to 14°C, an approximately 20 m thick stationary marine ice sheet formed over the surface of the Arctic basin. A change in atmosphere and hydrospheric circulation, caused by the onset of the world-wide fall in temperature, could have diverted the Gulf Stream from the Polar basin. This would result in glaciation earlier in the Arctic Ocean than on the continents (LILJEQUIST, 1956). Thermodynamic calculations for this hypothesis indicate a significant freezing of the Polar basin water to a depth of 400-600 m (CRARY, 1960). The latest data confirms the absence of the Gulf Stream in the Arctic Ocean during the glacial maximum (BARASH and OS'KINA, 1979) and, consequently, indicates development of an even greater thickness of marine ice in comparison to calculations that do not include the negative effect of warm Gulf Stream water.

¹[Editorial Note: We are pleased to publish the English version of papers presented at the 1982 INQUA Symposium (Shorelines Commission) held in Moscow. Russian versions were previously published in collection by "Nauka" and Moscow State University publishers but this is the sixth installment in a series of reports that will appear in subsequent issues of the journal.] Received 15 January 1984

CAUSES OF ARCTIC GLACIATIONS

The main Pleistocene events associated with climatic changes were determined by insolation fluctuations. The fluctuations in insolation calculated by MILANKOVICH (1939), and subsequently updated, are in good agreement with the changes in paleotemperatures and glacioeustatic fluctuations in world-wide sea level; thus being accepted widely as the causative factor of glaciations (BROECKER and VAN DONC, 1974; CHAPPEL, 1973). However, ASEEV (1974) indicates that insolation cooling could not be sufficient for the development of ice sheet glaciation in the northern hemisphere. The correlation between the insolation regime and glaciation dynamics, on the one hand, and an insufficient drop in temperature due to insolation for the onset of glaciation, on the other, point to the fact that an intensification of initial temperature descent was due to some process in the geosphere.

The function of an intensifier was presumably performed by the Arctic Ocean, whose ice cover accurately responds to temperature oscillations by changes in thickness and areal extent. Under climatic cooling of the Arctic this would cause an additional temperature decline due to a higher albedo. Formation of the Arctic ice sheet occurs with a temperature descent of 4-5°C; and this leads in turn, due to feedback relationships, to climatic cooling on an order of twice that (BUDYKO, 1974). Thus, though a decline in insolation level causes glaciation, it requires an intensified primary impulse generated by an increase in the total albedo in the northern polar region.

For a further analysis, it is unimportant whether the divergence of the Gulf Stream preceded the freezing of the Arctic basin, or whether it was squeezed out by the growth of the ice sheet volume. What is important is that the freezing of the Polar basin, and preservation on its surface of stationary marine ice throughout the year, was an essential condition for the development of ice sheet glaciation in the northern hemisphere.

Even though a stationary ice sheet developed in the Arctic basin before the main stage of continental glaciation, the world ocean sea level was still relatively high. According to the MILLIMAN and EMERY (1968) glacioeustatic curve, it was at least 30 m lower than present day sea level. Consequently, in the time span of 35,000 to 21,000 years ago, only that portion of the shelf less than -30 meters deep could have been substantially exposed. Yet, even these figures seem excessive.

In fact, an emerged ice sheet 20 m thick would have further increased in thickness, given the 4 cm or more of atmospheric precipitation occurring in regions of ice sheet glaciation today. It is worth noting that according to LAMB and WOODROFFE (1969), the amount of precipitation in high latitudes is estimated to be 10-15 times as large. However, even for the minimal value of 4 cm/yr we find that: (1) the growth rate of ice sheet thickness is significantly greater, by an order of magnitude, than the beginning sea level regression rate of 0.2 cm/yr, and (2) the ice mass would be emerging and building up at the southern periphery of the shelf. Under conditions of sharp reductions in summer temperatures, this appears to be unavoidable. Calculations show that ablation would not significantly affect the process, because the 4 cm/yr of precipitation used in our estimates is so much lower than the actual rates that it can be considered to have included precipitation minus ablation. Thus, by the end of the first regression stage there must have been a layer of ice about 400-600 m thick on the inner shelf (Table 1).

DISCUSSION

The ice sheet in the Polar basin area would have reached a similar thickness; due solely to buildup of the ice from above, without the effect of freezing the water in depth. Upon reaching the sea floor it stopped sinking, with the subaerial portion contributing to the glacial relief of the inner shelf zone.

During the second regression stage, while there was a rapid buildup of ice mass on the continents at a rate of 10,000 km³/yr, the recession rate of world-wide sea level increased by an order to reach 2 cm/yr. Consequently, the rate of ice sheet buildup exceeded that of the glacioeustatic regression.

Let us now consider for a moment variations in humidity, namely the latitudinal shifting of planetary fronts according to the level of the earth's energy balance as determined by the insolation regime. At the insolation minimum the two planetary fronts, Arctic and Polar, were displaced southward. As a result, the high latitude regions, where the thermal prerequisites for glaciation were optimal, experienced a deficit in precipitation. This was manifested by an extremely slow buildup of ice mass (600 km³/yr). Following the energy minimum 21,000 years ago, the paths of cyclones associated with planetary fronts shifted to higher latitudes. For 4,000 years this engendered the two conditions

Table 1. Marine glaciation and level of the Polar Basin in late Pleistocene time.

Indices	Regression		Transgression		
	I	II	I	II	
A	-0.2	-0.2	1.1	1.7	0.1
B	600	10,000	-4000	-6000	-1250
C	400	700	1,000	0	0
D	-350	-600	-850	25	0
E	-30	-130	-50	-25	0

A = Rate and sign of World ocean level variability, cm/yr.

B = Build-up (thawing) rate of sheet mass ice, Km^3/yr .

C = Ice cover thickness (m) in the Arctic basin.

D = Hypsometric position of the lower surface of marine ice (m) with respect to synchronous World ocean level.

E = Synchronous World ocean level hypsometric difference between World ocean level and sub-ice Polar basin level (m).

that control the buildup of glacial ice: energy (temperature) and water (humidity). Therefore, in the period between 21,000 and 17,000 years ago the amount of precipitation was greater than in the previous period. Extrapolating from the quantitative relationship between the rate of buildup of glacial ice ($10,000 \text{ km}^3/\text{yr}$) and the glaciation area ($36,000,000 \text{ km}^2$) we obtain an average rate of precipitation of 30 cm/yr. Because during the glaciation epoch, as today, the humidity field was not uniform, it can be presumed that the western Arctic sector received more precipitation than the eastern sector, and that in higher latitudes the quantity of precipitation was greater than in lower latitudes. Precipitation rates were, of course, different. This enables us to adopt for higher latitudes a lower-than-average value and for lower latitudes a higher-than-average value. Utilizing minimum estimates, let us propose a precipitation rate of 7 cm/yr; twice as large as that of the preceding cold period, but lower than minimum of 10 cm/yr (the present precipitation rate for the Arctic as a whole being 26 cm/yr, the accepted rate differs, consequently, from the present one by nearly a factor of four). Extrapolating the adopted value through time we obtain by the end of the stage (17,000 years ago) an ice sheet thickness of 700 m in the central part of the basin, and a similar thickness of the shelf glacier. Thus, at the same time, despite the maximum rate of sea level recession, no regression was taking place in the Arctic basin.

Initiation of rapid glacial decay ($4,000 \text{ km}^3/\text{yr}$) generated a transgression with a very high rate (1.1 cm/yr) in the Arctic, where calculations show that the glacial mass had been building up for nearly 8,000 years, events were lagging behind. During that time (17,000-9,500 years ago) the ice was accumulating at the rapid rate of 9 cm/yr, so that by

the beginning of the Holocene the thickness of the ice sheet at the central part of the basin area was as much as 1 km. Glaciation in moderate latitudes had, by this time, almost completely ceased, and the southern boundary was across mid-Scandinavia and the lower reaches of the rivers in northern Europe (GROSVOLD *et al.*, 1977). Glaciation was then regional and waning, while the Arctic glacial mass, occupying the central part of the basin area, was in a state of hydrostatic equilibrium and could, therefore, have no effect on sea level or the progress of the transgression. However, the melting of the shelf glacial mass did accelerate the transgression to 1.7 cm/yr; a conclusion which appears to be in agreement with empirical data. For example, glacioeustatic curves (FAURE and ELLOURD, 1967; MARTIN, 1972) reflect this acceleration.

It remains unclear, however, as to what kind of energy or what mechanisms were basically responsible for such a rapid collapse of glaciation in the Arctic. To account for this phenomenon, a significant role must be attributed to the surge mechanism; and it is also assumed that the Gulf Stream became more prominent in warming the Arctic basin. In all probability, these processes did have some effect; but the details, in the initial phases, have not yet been convincingly explained.

Recession of glaciation in the Arctic was complete by 8,000 years ago, when world ocean level was at -25 m. It was then that the world ocean and the Arctic basin level became equal. Thus, regression in the Arctic took place for only 8,000 years; and was notable for a significantly lower amplitude of sea level change as compared to other shelf areas.

CONCLUSIONS

On the basis of the foregoing discussion we can draw a conclusion about the concept of a world ocean level being rather arbitrary. In the sense that this concept is used today (all basins which are connected having the same level), it is applicable only to interglacial epochs. During times of glaciation those portions of the world ocean that are covered with ice are singularly at a different hydrological level.

The sub-ice level in the Arctic basin at the glacial maximum differed from the ocean's level by hundreds of meters; and was even dissimilar in different parts of the basin area. Therefore, the Arctic shelf has no obvious parallels to the late Pleistocene levels that have been found on lower latitude shelves.

The relief of the Arctic shelf, similar to that of the adjoining land, is polygenetic and is composed of forms dating to different stages of geological development. Those forms which have been described in the literature may have different ages, and do not necessarily belong to the latest glacial epoch. These may be relict phases, reflecting events of the earlier stages of the Pleistocene or pre-Pleistocene history of the Arctic shelf.

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