with a maximum accumulation of 1 m of water equivalent (two to three times the present amounts) and a snow line lowered to 300 m from its present elevation of 800 m or more over the plateaus of Baffin Island. In future experiments a function will be incorporated into the model to increase basal ice temperatures in response to geothermal heat flux as the ice sheet thickens and modifies the thermal gradient. Under these circumstances, the ice sheet would tend to spread more rapidly. Preliminary results in the present simulation experiment indicate that after 4000 years of buildup the ice sheet had a volume of 0.3×10^6 km^3 and covered Baffin Island, with smaller ice caps in Labrador-Ungava. However, the volume in the ice sheet at this stage was equivalent to a rate of sea level lowering of only $\simeq 0.25$ m per 1000 years. After 10,000 years, ice sheets covered most of Baffin Island and north central Labrador-Ungava (Fig. 2) with an area of 1.78×10^6 km^2 and a volume of 3×10^6 km^3. This volume figure represents a world sea level lowering of 7.5 m; this figure is an order of magnitude smaller than the total amount suggested from the Barbados work (*26, 27*), but in the last 2000 years of the model experiment the equivalent rate of lowering of sea level is 3 to 5 m per 1000 years. The increase in the volume of the ice sheet is strongly nonlinear and consists of an initial 3000 to 5000 years of slow buildup followed by an accelerating phase of growth. Although some of these data add a measure of support to the dramatic events centered around 115,000 years B.P., nevertheless there still appear to be severe physical constraints on such rapid sea level lowering based on considerations of atmospheric circulation conditions and the global energy balance. It is hard to visualize appropriate circulation regimes to provide the necessary input of snow accumulation (*31*) recurring over thousands of years. Even more critical, the rates proposed for the uptake of water into the ice sheets match the fastest rates of return of water into the ocean system during deglaciation, despite the fact that the energy requirements of the processes determining ice sheet accumulation (evaporation, freezing, and precipitation) are approximately seven times greater than for the melting process. In the present study we have not attempted to deal with this more fundamental problem.

In summary, a study of recent climatic fluctuations and Little Ice Age conditions in the eastern Canadian Arctic illustrates the climatic sensitivity of the area and provides significant clues on the likely mechanism and location of the growth of continental ice in North America during the last glaciation. The immediate mechanism is in all probability the widespread and rapid lowering of the snow line over the upland plateaus of Baffin Island and north central Labrador-Ungava. Little Ice Age conditions appear to provide a useful analog of glacial inception. Lichen-free areas demarcating permanent snowfields in Baffin Island during the Little Ice Age have been mapped from ERTS imagery, and a snow line lowering of 200 to 600 m has been determined from these maps.

Geological evidence suggests a rapid sea level lowering of 5 m per 1000 years during the early ice sheet buildup that bottomed out about 115,000 years B.P. Simulations with an ice flow model give results within the correct order of magnitude after 10,000 years of growth, with a snow line lowering of about 500 m and two to three times the present-day precipitation, but these simulations are orders of magnitude too small for the first 4000 years. Further study of physical processes in the atmosphere-ocean-cryosphere system is required to resolve these apparent discrepancies.

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Storm Wave Climates at Cape Hatteras, North Carolina: Recent Secular Variations

Abstract. *Mid-Atlantic coastal wave climates have undergone significant change within the last three decades. The duration and frequency of storms generating high waves and the length of the winter storm wave season have increased. These changes may, in part, account for the observed trend in shoreline erosion along the east coast of the United States.*

The U.S. Army Corps of Engineers has assigned more than 86 percent of the shoreline along the Atlantic coast of the United States to the categories of erosion or critical erosion (*1*). Numerous engineering measures have been implemented along the mid-Atlantic to check the continuing recession of the shoreline. This erosional trend has been attributed to a variety of factors including (i) the current sea level rise; (ii) the reduced supply of new sands from inland sources; (iii) human activites that alter the coastal geomorphology; and (iv) a lower average central pressure of damaging storms (*2*). Previously unrecognized secular variations in storm wave climates are reported here as yet another important factor contributing to the coastal erosion.

Using the Bretschneider method, I have hindcasted the number of occurrences and the duration of storm waves at Cape Hatteras, North Carolina, for each of seven deep-water significant wave-height categories: 5.1 to 8.0 feet (1.6 to 2.4 m); 8.1 to 11.0 feet (2.5 to 3.4 m); 11.1 to 14.0 feet (3.4 to 4.3 m); 14.1 to 17.0 feet (4.3 to 5.2 m); 17.1 to 20.0 feet (5.2 to 6.1 m); 20.1 to 23.0 feet (6.1 to 7.0 m); and 23.1 to 32 feet (7.0 to 9.8 m) (*3*). I chose 5.1 feet as the lowest limit because smaller waves do not erode the barrier-island dune face along the coast of North Carolina.

Fetch length was estimated from U.S. Weather Bureau 12- and 24-hour synoptic weather charts. I obtained wind speed over the fetch area from records of the Cape Hatteras Weather Station, from published logs of ships at sea, or by estimating wind speed from isobaric spacings. There were 1009 extratropical storms from July 1942 through June 1974 which generated deep-water waves in excess of 5 feet.

Figure 1 summarizes the monthly occurrence over the last 30 years of storms generating deep-water significant wave heights equal to or greater than 5 feet. From 1943 to 1960, there was a winter maximum for storm occurrences in March. In the first half of the 1960's this maximum shifted from March to February and in the latter half of the 1960's to January; concurrently, from 1965 to 1970, there was a spring maximum in April.

During the 1940's there was a secondary maximum in January which shifted to December for the first half of the 1950's and to November for the second half of the 1950's. By the second half of the 1960's and into the 1970–1974 period, this secondary maximum is clearly evident in October even though it is not evident during the first half of the 1960's. This early season maximum is followed by a seasonal storm frequency minimum in the following month. These data show a general lengthening of the storm season over the last three decades, with the greatest changes occurring in the 1960's. The storm season increased by 4 months from 1942 to 1973, with duration defined as the time between the first and the last seasonal maxima.

In addition to a lengthening of the storm season, an increase in the frequency or duration of high waves also results in the dominance of erosion over deposition. Dolan and Vincent (*4*) found that 80 percent of the variance in the position of the Cape Hatteras shoreline from 1945 to 1969 was

Table 1. Variations in storm wave frequency and magnitude since 1942; I, mean annual number of storms with waves greater than 5 feet; II, mean annual number of storms with waves greater than 11 feet; and III, yearly mean number of hours of waves greater than 11 feet.

Period	I	II	III
1942–1945	30.7	3.3	64.0
1945–1950	35.5	4.0	57.4
1950–1955	33.0	3.2	42.6
1955–1960	38.4	3.8	49.6
1960–1965	33.2	4.0	40.6
1965–1970	32.2	7.0	117.2
1970–1974	26.0	6.8	122.5

caused by deep-water waves in excess of 11 feet. In 1972 and 1973, during field studies at Cape Hatteras, I found that oceanic overwash was initiated only by deep-water waves of 11 feet or more. Accordingly, I have summarized the frequencies of wave events of 5 feet and greater and the frequencies and durations of wave events of 11 feet and greater for the 1942–1974 period (Table 1).

During the 1942–1965 period, 10.7 percent of the storm wave events recorded reached the 11-foot deep-water wave magnitude. From 1965 through 1974, 26.0 percent reached this same magnitude, a 2.43-fold increase. The probability of an 11-foot wave event increased 1.86 times during recent years (1965–1974) by comparison with the 1942–1965 period. In addition to the increased frequency of 11-foot storm wave events and a greater proportion of storms reaching this magnitude, the average annual duration of such storm waves increased over the same period. From 1942 to 1965 the average annual duration of 11-foot waves was 50.8 hours. Since 1965 an average annual duration of 119.9 hours has been recorded. This difference amounts to a 136 percent increase in the total annual duration.

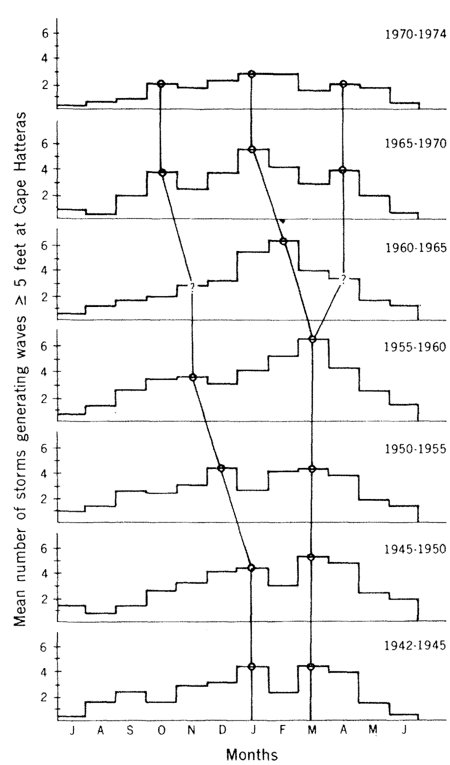

Fig. 1. Monthly mean frequencies of storm wave events greater than 5 feet at Cape Hatteras, North Carolina, since 1942. Vertical lines connect months of frequency maxima.

The most recent period studied (July 1970 through June 1974) is the stormiest on record for Cape Hatteras in spite of the exceptionally calm year from July 1973 to June 1974. Excluding this unusually calm year, the mean annual duration of waves over 11 feet totals 149 hours, nearly three times that observed for the years before 1965. So far during the 1970's, fewer storms than before have generated waves greater than 5 feet; however, a large percentage of those storms that have occurred have had waves higher than 11 feet and were of long duration.

The secular changes in the length of the storm season, the frequency of large storm waves, and the durations of high waves are consistent with the observed trends in shoreline erosion. Since beach sands are transported from the beach to offshore areas during the winter and from offshore to the beaches in the summer, the observed lengthening of the winter storm season is consistent with a deficit in the annual budget of beach sand. The recent higher frequencies and longer durations of high waves would also cause an increase in the net transport of sands from the beaches since waves of larger magnitude are the principal agents in the offshore transport of beach sands.

Whether or not the observed secular changes in the storm wave climate of Cape Hatteras are the result of general worldwide climatic changes recently reported (*5*) remains unresolved for the present. However, these documented changes at Cape Hatteras have raised important questions regarding the impact of climatic changes in general and specifically about their impact on shoreline stability.

Important questions are also raised concerning associated changes in the circumpolar vortex of the atmosphere and the positioning of ridge-and-trough systems in the North American sector. Similar studies for the west coast of the United States would contribute to the resolution of these questions.

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"Half" Membrane Enrichment: Verification by Electron Microscopy

Abstract. *Membranes of intact erythrocytes bound to polylysine-treated glass fracture nonrandomly when covered with thin copper and frozen. Electron microscopic examination of the glass side reveals extensive areas of outer "half" membrane (B face) and of the copper side, inner "half" membrane (A face). This technique allows the ultrastructural examination of square-centimeter areas of fractured membrane and the chemical analysis of these membrane "halves."*

During freeze-fracture the erythrocyte membrane is split along an interior plane (*1*) producing two fracture faces that are structurally asymmetric. The A face, cytoplasmic side, contains many particles, whereas the B face, extracellular side, contains fewer particles (*2*). At the chemical level, it is currently thought that the erythrocyte membrane is highly asymmetric in the transmembrane distribution of its phospholipids (*3, 4*) and major polypeptides (*4, 5*). This concept is derived from numerous chemical and physical experiments designed to examine membrane structure, often by utilizing permeant or nonpenetrating reagents or enzymatic degradation of intact or lysed cells (*3–5*). Another conceptually and experimentally different approach to answer questions of membrane structure would be to exploit the property of membrane splitting during freeze-fracture and isolate portions of the membrane "halves" in quantities suitable for bulk analysis (*6, 7*). In such an approach one of the most important aspects is the verification and quantitation of half membrane enrichment. The purpose of this report is first to describe a method for the preparation of square-centimeter areas substantially enriched in outer half membrane (complementary to areas substantially depleted in outer half membrane) and second to provide electron microscopic evidence for this enrichment and depletion.

When cells are frozen in bulk, the fracture meanders randomly. Nonrandom splitting of the membrane on one side of the cell is relatively rare. However, if the cell is bound, flattened, to a smooth substrate and the other side is free and thus of irregular shape, the fracture preferentially follows the flattened side, especially if this geometry is reinforced by large numbers of contiguous cells similarly bound over a large area. I have tested a variety of materials and techniques following this principle. The most reproducible procedure is described here.

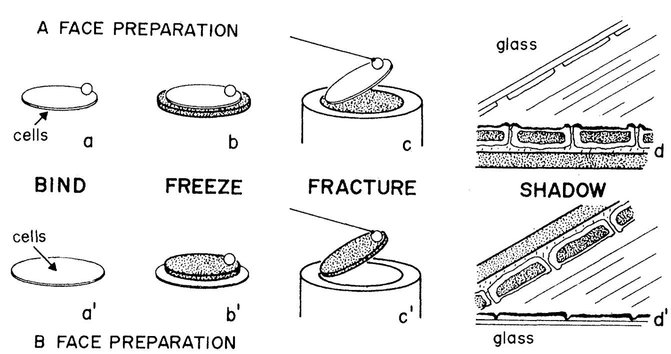

Fig. 1. Four steps—binding, freezing, fracturing, and shadowing—are common to the preparations of inner half membrane (a to d) and outer half membrane (a′ to d′). Replicas of A faces are prepared by binding erythrocytes to the lower side of a positively charged glass disk with a pull ring (a), applying the disk to a larger copper disk and freezing (b), transferring the frozen sandwich to a stage that holds the copper disk while the glass is pulled free in vacuo (c), and shadowing the copper side (d). Replicas of B faces are prepared by binding erythrocytes to the upper side of the glass disk (a′), applying a smaller copper disk (b′), transferring them to a cold stage that retains the glass disk while the copper is pulled free (c′), and shadowing the glass side (d′).

Because the outer surface of the erythrocyte possesses a net negative charge at physiological *p*H (*8*), it will bind strongly to a surface that possesses a net positive charge. Adsorption of polycationic polylysine (*9, 10*) to clean, optically smooth cover glass provides such a surface (*11*). Disks of Corning No. 1 cover glass (9 mm in diameter for A face preparations, 12 mm for B face) are cleaned with acid, rinsed in distilled water, and dried with filtered compressed air or dry N_2. Ten microliters of 5 m*M* poly-L-lysine, molecular weight 2000 (Sigma Chemical Company), is applied for 30 seconds at 22°C to one side of the cleaned cover glass, which is then washed with distilled water and dried with compressed air. After the cleaning and polylysine application the surface of the glass must remain totally hydrophilic.

Human erythrocytes from freshly drawn blood are washed three times with 0.155*M* NaCl, followed by three washes with phosphate-buffered saline (PBS). Twenty microliters containing 1.4×10^8 erythrocytes in PBS are applied to the positively charged glass disk and unbound cells are washed off with PBS. The use of fresh blood and its thorough washing and proper dilution are essential for the reproducible generation of a homogeneous closely packed monolayer of cells.

For A face preparations, erythrocytes are applied to the polylysine-treated side of a glass disk 9 mm in diameter (Fig. 1a). Unbound cells are removed by washing, and the cell side, wet with about 10 μl of residual buffer, is placed against a dry copper disk (Fig. 1b). For B face preparations erythrocytes are applied to a glass disk 12 mm in diameter and unbound cells are washed free by immersing the disk in buffer at 4°C and agitating for 60 seconds. The untreated side is then wiped dry quickly. Drying ensures close contact to the stage and quickness prevents lysis due to buffer evaporation from the cell side. A copper disk with pull ring is gently placed against the cell side (Fig. 1b′). For both A face and B face preparations the copper had been flattened, ground smooth, and made hydrophilic by dipping in nitric acid, rinsing in distilled water, and drying with compressed air. A platinum pull ring had been attached with low-temperature epoxy to the 9-mm glass disks.

The copper-erythrocyte-glass sandwich is immediately frozen in liquid Freon 22 at −150°C. Interference colors are occasionally seen, suggesting that substantial fracturing occurs during freezing, a probable result of thermal expansion differences be-