Comment on some Ice Age Theories

by P. A. Mandich, Chicago, Illionois

The argument about the causes of the Pleistocene Glaciations took an especially sharp form at the end of 1967. In the Journal of Geology and in Science, Donn and Shaw[1] fiercely attacked Emiliani's[2] newest temperature curve for the surface water of the central Caribbean, reaching back for more than 400,000 years. Emiliani[3], in his response, regards the ice age theories of Donn and Ewing as absurd[4]. However, these researchers perhaps do not realize that their theses are workable only combined in as much as they can be brought to a synthesis easily by adding one missing link, i. e., the periodical flooding of the Arctic Ocean by continental melt water. This must have occurred regularly when a sufficiently high summer insolation increase on the northern hemisphere met an advanced continental glaciation.

The Milanković or so-called astronomical theory to which Emiliani's work relates is – besides being the most widely accepted theory among all pertaining concepts – still inconclusive as applied, not because of some inherent deficiency but rather because of its overstressing. Nevertheless, the astronomical climate-regulating effect is exercised, primarily, through the medium of the melting and refreezing ice cover of the Arctic Ocean. This as an amplifier modifies the radiation loss because of the changing albedo and the moving of the main Atlantic water cooling area from the Norwegian Sea into the Arctic Basin and back.

It goes without saying that Donn and Ewing's model of the climate changes cannot stand without the radiation theory either. All the phenomena listed by these authors for allegedly causing the freezing and melting of the Arctic Ocean's surface – significant in particular as they are – seem still inadequate to the whole task.

To start from Ewing and Donn's[5] concept that the present climate with periodically occuring general coolings and heavy glaciations on the northern continents is a consequence of shiftings of the earth's crust with the effect that the poles became thermally isolated will be permissible in as much as this part of their theory is quite well supported by the most recent geological research. A good summary is given

[1] W. L. Donn and D. M. Shaw, J. Geol. 75, 4 (1967); Science, 157, 722 (1967).
[2] C. Emiliani, Science, 154, 851 (1966).
[3] C. Emiliani, J. Geol. 75, 4 (1967); Science, 157, 723 (1967).
[4] W. L. Donn and M. Ewing, Science, 152, 1706 (1966).
[5] M. Ewing and W. L. Donn, ibid 123, 1061 (1956).

on that by Heirtzler et al[6]. It seems also understandable that the large quantities of precipitation available from an Arctic Ocean, probably ice-free at the beginning would have started glaciations by themselves on the northern continents when they shifted to surround the pole as now. Nevertheless, a coinciding summer radiation low on the northern hemisphere should have greatly facilitated such ice accumulation. Milder winters combined with cooler summers increase, in higher latitudes, the chances of snow and slow down its melting. Hot summers, on the other hand, with severe winters decrease in winter the snow fall and melt more of it during the summer. The whole mechanism at work for this varying condition as basic element of Milanković's theory is exhaustively explained in the pertinent literature, especially by Wundt[7].

It is also well understood how glaciation once started will perpetuate itself for a while by the feedback effect of increased albedo and other factors which later, however, all come to an equilibrium and stabilize the glacial mode of climate.

Nevertheless, from this point on the difficulties and contradictions in the interpretation start. Donn and Ewing[4] affirmed what was also recognized by other authors that „it seems easier to turn glaciers on than off," apparently with the latter a more complicated process may be at work than that for which the given explanations hold. Indeed, as long as the warm water of the Gulf Stream or the North Atlantic Current can circulate unhindered in the open Arctic basin, it is not likely for the polar sea to freeze over.

Donn and Shaw[8] presented a 2.63×10^{21} calories positive heat balance in their yearly budget for an assumed ice-free polar sea. At the time of fully developed continental glaciation, this should have been upset, according to Donn and Ewing[4], by an increasing turbulent heat exchange with the extended ice sheets on the continents and some other smaller cooling effects. A questionably high value of 5×10^{21} calories, used by Vowinckel and Taylor[9] in a different setting, was here mentioned by the authors as an „idea" of the cooling effect. This, if applicable, would leave a minus of 2.37×10^{21} calories in the budget. However, in spite of the obviously accurate finding that the present Atlantic-Arctic Ocean water interchange has little control on the arctic heat budget, for ice-free conditions the token 0.23×10^{21} calories estimate for the heat flux of the ocean current seems much too low. Any substantial water interchange with the Atlantic Ocean would outbalance those additional cooling effects whatever they may be.

If only one fourth – about 20 million m^3/sec. – of the present more than 80 million m^3/sec. Atlantic water, which is carried in the northern section of the Gulf Stream, would have entered the ice-free open polar basin at the average temperature of 2° C, it should have counted for $1{,}26 \times 10^{21}$ calories in Donn and Shaw's yearly budget which was set

[6] I. R. Heirtzler, G. O. Dickson, E. M. Herran, W. C. Pitman III and X. Le Pichon, Journal of Geophysical Research, 73, 6, (1968).

[7] W. Wundt, Geol. Rundschau, 34, 713 (1944); Quartär, 15-16, p. 27 (1964).

[8] W. L. Donn and D. M. Shaw, J. Geophys. Res. 71, 1087 (1966).

[9] E. Vowinckel and B. Taylor, Arch. Met. Geoph. Bioc. B. (1965).

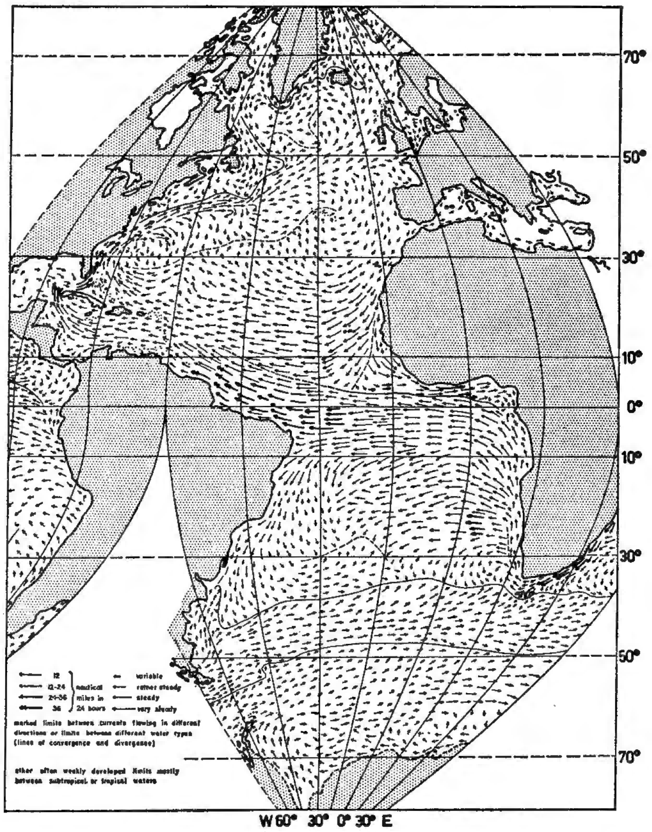

Fig. 1. Present time Atlantic Ocean surface currents in winter. (After A. Defant, Physical Oceanography, Pergamin Press, Oxford, England 1961)

up for a polar sea temperature of 0° C. But with freely circulating Atlantic water in the Arctic Ocean, freezing could only occur at a water temperature below −2° C considering the increased salinity calculated, according to the lowered sea level, as about 37 ‰ [10]. Moreover, a vigorous Atlantic-Arctic Ocean water interchange would have carried considerably warmer Atlantic water in the higher latitudes. Therefore, the heat delivery by Atlantic Ocean currents at the critical time before freezing can safely be expected to offset the 2.37×10^{21} calories yearly deficit mentioned above.

As I see it, freezing of the Arctic Ocean was mainly a consequence of fresh water floods from melting continental snow and ice. A floating layer of water of less than 24.7 ‰ salinity not only would shield the interlying warm Atlantic water from an atmospheric heat exchange; but after such dilution, sea water approaches the well known, favorable freezing characteristics of fresh water bodies when its maximum density will be attained at temperatures above the applying freezing point.

[10] J. Charlesworth, The Quarternary Era, 1, 1039 Arnold, London (1957).

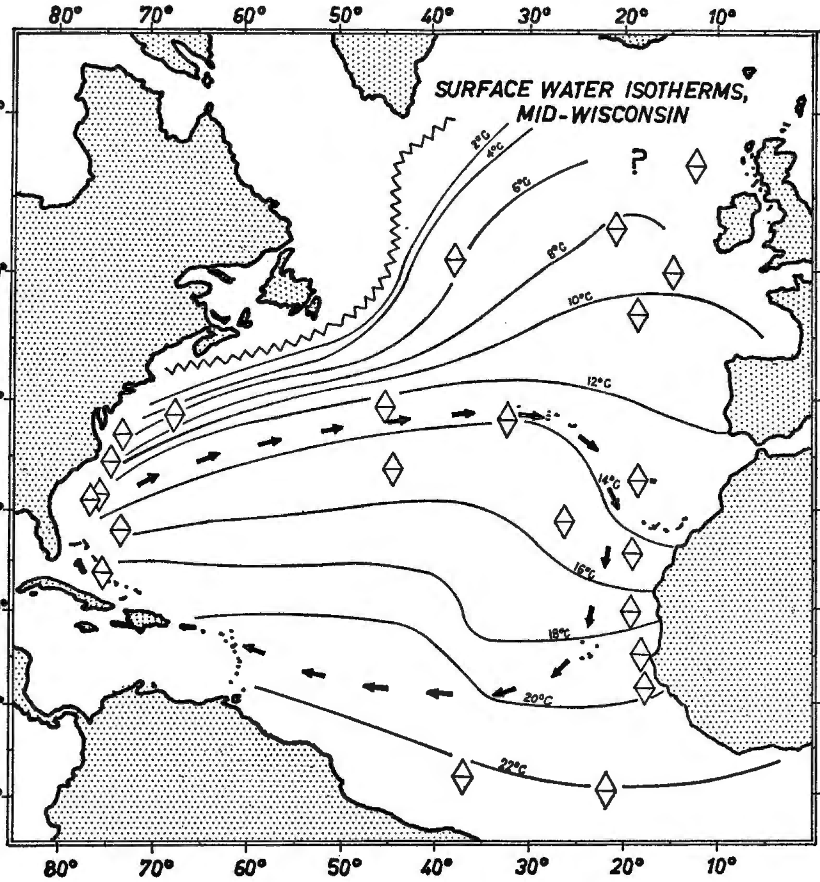

Fig. 2. Paleoisotherm map of the mid-Wisconsin North Atlantic, erected with the use of coccolithophorid temperature data. The dark arrows indicate presumed position of the subtropical gyral. (After McIntyre, see Ref.[13]).

Ample geomorphological evidence supports such inundations. The immensely widened beds of the great central European rivers, the so-called glacier spillways, are evidence of occasional flash floods which carried several times their present high water loads. Thome[11] considers for the Rhine watershed, during glacial time, an 80–85% run off, perhaps even more, resulting from the small water holding capacity of the frozen ground. That would increase the yearly water delivery of that river from the present 68 km^3 to more than 200 km^3. Moreover, the activity was compressed to a short 4–6 months melting season so that instead of today's 12,000 m^3/sec. an average flow of 30,000 to 40,000 m^3/sec. might have occurred fairly frequently. Similarly, high water

[11] K. N. Thome, Die Begegnung des Nördlichen Inlandeises mit dem Rhein, Geol. Jb. 76, Hannover (1958).

transports of those rivers were confirmed by comparative morphometric gravel analysis[12].

Not only the northward bound rivers would contribute to the fresh water inundation of the Arctic basin but also the combined flood waters of the rivers discharging into the Mediterranean, the Black Sea, and at times during the Caspian overflow even the waters of the Volga system. Possibly these waters were all drawn to the north after pouring into the Atlantic at Gibraltar. Ewing and Donn[5] have sketched the changed atmospheric ciculation for glacial times. A counterclockwise air movement of a polar low and the North Atlantic low displaced southward can be assumed accordingly. That the latter had extended the North Atlantic oceanic circulation southward seems documented by

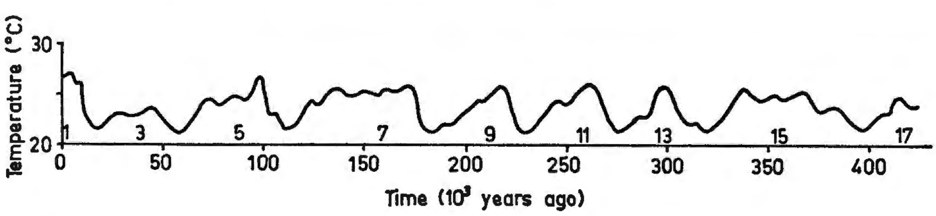

Fig. 3. Generalized temperature curve for the surface water of the central Caribbean. (After Emiliani, see Ref.[2]).

McIntyre's[13] recent report where he indicated a southward shift of the subtropical gyral for mid-Wisconsin time (Fig. 1 and 2).

The Arctic Ocean has at the present, relative to its total area, a 35 cm yearly positive balance of water exchange with the adjacent seas. This results from 24 cm precipitation plus 23 cm continental run-off minus 12 cm evaporation[14]. It is difficult to make a valid estimation of precipitation and evaporation for ice free glacial conditions but, with regard to all that was said for continental melt water flow, a 100 cm layer of fresh water gain or more, during a summer season, on the peak of an inland ice melting period would be reasonable to expect.

The most apparent characteristics of the generalized water temperature curve (Fig. 3) drawn by Emiliani[2] are the repeated steep, full-scale temperature rises around 11,000, 100,000, 172,000, 220,000, 270,000 years ago, and also some earlier. They coincide with the closing times of the major glaciations fairly well, known from terrestrial evidence.

It is feasible to match Broecker's[15] various treatments of the Milanković insolation curve for 65°N latitude (Fig. 4) with Emiliani's water temperature curve. Especially those for x = 1.2 and 2.5 (dotted and dashed). The general requirement that all transitions from glacial to interglacial climate be introduced by an insolation high is well satisfied in this way. Peculiar, however, is that the transitions from interglacial to

[12] K. W. Butzer, Environment and Archaeology, 298, Aldine, Chicago (1964).
[13] A. McIntyre, Science, 158, 1314 (1967).
[14] M. N. Hill, The Sea, v. 1 p. 137 (1963).
[15] W. S. Broecker, Science, 151, 299 (1966).

glacial climate have also been immediately preceded (at least since 300,000 years ago) by insolation highs and not, as the usual interpretations ask for, by insolation lows. This is by itself an important proof for my argument that the astronomical causes are effective climate modifiers, principally by extending or reducing the ice cover of the Arctic Ocean and the adjacent seas. A high summer insolation before a transition to a glacial stage seems necessary to clear enough ice from the Arctic basin and to establish that way a sufficient water interchange with the Atlantic. This results in a precipitation increase and glacial growth on the northern continents, but also in a global ocean water cooling.

The extremely long interglacial – from about 172,000 to 123,000 years ago (Ohe?) –

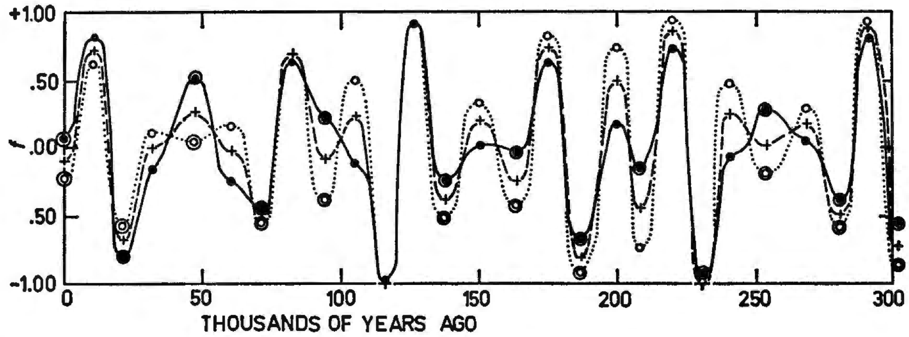

Fig. 4. Insolation curves constructed for various weighting factors (x) of tilt effect versus precession effect; (solid curve) $x = 5$; (dashed curve) $x = 2.5$; (dotted curve) $x = 1.2$ (After Broecker, see Ref. [15]).

illustrates best what I said about interglacial-glacial transitions. In spite of the two prominent insolation lows – 164,000 and 139,000 – the ocean water temperature remained at that time very high but cooled to the bottom of the range after the most pronounced insolation peak of the succession 125,000 years ago. Yet, the other cycles conform also to the rule.

The fresh water flooding and freezing of the Arctic Ocean before a glaciation ends is introduced by the same summer insolation high which reduces the continental ice sheets. In fact, the first is a consequence of the latter. Thus it might be debatable which one is decisive for ending a glaciation. But if it is true that an insolation high must also occur to start a glacial phase, this hardly could be explained but for the, in this paper, assumed reason of reducing the polar sea ice cover. On the other hand, the snow and ice growth of a summer insolation low actually hinders the start of a glaciation in as much as all ice accumulating effects of an insolation low will work, in the first place, to increase the polar sea ice. However, as long as that ice cover exists, there will never be enough precipitation to start a glaciation on the continents.

To the understanding of this entanglement I took into account first theoretically the working of an Arctic Ocean ice cover separate from the astronomic changes. This is so much easier that, at present, the summer insolation of the northern hemisphere is around its median. In the articles discussed here, several mathematical computations and in situ observations are cited which supply reliable climatological data for more than one hundred years. According to these, a sensitive water-air heat balance prevails in the Arctic basin. Still the mean thickness and areal extent of the polar sea pack-ice

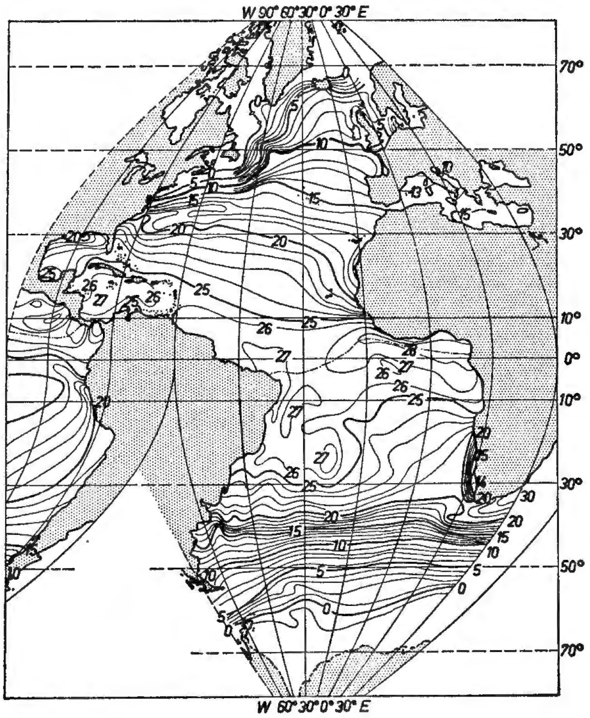

Fig. 5. Maximum extend of pack-ice. Border runs along (heavily drawn) 10° C February isotherm, as proposed by Emiliani and Geiss[18]. (Map after A. Defant, Physical Oceanography, Pergamin Press, Oxford, England 1961).

has shrunk for the last half century. Precipitation increased in the arctic and subarctic regions also in these years[16]. A slight global temperature decrease of the ocean water, even if not yet measured, can be expected to come after any ice retreat in the Arctic Ocean. At present the Norwegian sea and the adjacent waters are the major radiational heat sinks on earth[17]. However any northward shift of that sensitive part of the circulation intensifies the water cooling. But global cooling of water and atmosphere will reverse the ice retreat until a consequently following new ocean water temperature increase will complete the cycle.

[16] R. F. Flint, Glacial and Pleistocene Geology, 482, Wiley, New York (1957).
[17] E. Vowinckel and S. Orvig, Arch. Met. Geoph. Biokl. B. Bd. 13 H. 4, 451 (1964).

This dynamic equilibrium cannot be overthrown by a decreasing summer insolation on the northern hemisphere. That will just bring the polar sea ice somewhat nearer to the more intensive warm water circulation which will stop its further southward advance. But not so when a northern summer insolation rise clears great areas from polar pack-ice. The Gulf Stream steps into the breeches, disposes of most of the polar sea ice and flushes out the arctic water of low salinity before a general cooling of the ocean water, which anyway takes a hundred years or more in order to be effective, would establish the equilibrium as with a low summer insolation.

A remarkable testimony of the last glacial cycle are the three latest cold relapses, the Dryas succession from about 14,000 to 10,000 years ago. At their onset the northern summer insolation was at its climax and more than half of the continental ice sheets had already melted. Still severe and dry as they were, these cold waves had not extended south in proportion. They were most pronounced in northern Europe. I see no other explanation for that peculiarity and their chronological order except the cooling effect of the regained Arctic Ocean ice cover.

It seems that the freezing ocurred in three stages, the first corresponding to the Oldest Dryas. A great part of the Arctic Ocean could have frozen over then, increased albedo causing the cold relapse. Melt waters ceased to flow. However, the North Atlantic Ocean water temperature rose because polar sea ice limited the northward extension of the Atlantic oceanic circulation. The warming Atlantic water together with the high summer insolation would melt again the polar sea's ice on large areas and carry out the residual low salinity surface water. Refreezing during the winters was retarded. Decreased albedo brought the Bölling warm episode, and the melt waters regained their strength. That caused further freezing of the polar sea with a cold relapse following (Older Dryas). Once more the ice retreated resulting in the Alleröd warming after which the final overfreezing ocurred. During the following and most severe cold return (Younger Dryas) the pack-ice border might have been where Emiliani and Geiss [18] had sugggested - around the present 10°C February surface water isotherm (Fig. 5) in the Northern Atlantic Ocean – locking out the Gulf Stream altogether from the Arctic basin.

The Atlantic Ocean water temperature increased, according to Emiliani's curve, sharply during the whole Dryas time span. But the longer Alleröd warming still shows up in the little break on the high part of the curve.

[18] C. Emiliani and Geiss, Geol. Rundschau, 46, 592 (1959).