23. THE HOLOCENE BOUNDARY STRATOTYPE: LOCAL AND GLOBAL PROBLEMS

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INTRODUCTION

The late-glacial climatic warming began in the tropics around 14 000–13 500 years B.P. I attributed this (1961) to the rising solar radiation predicted by Milankovitch and also at the same time noted the inverse relationship that existed between ^{14}C flux and mean temperature (and eustatic sea level). The warm-up of the southern hemisphere, with its oceanic continuity, was extremely rapid. Not so the northern hemisphere with its high continentality and extensive ice sheets where in the ocean it was around 3 000 years later (Hays *et al.* 1977, Salinger 1981). Indeed, as one goes farther north, the Postglacial warm maximum is found to be younger and younger, until in the high Arctic it was as late as 6 000 years B.P. a classic "retardation" phenomenon (Fairbridge 1961), due largely to oceanic feed-back (Ruddiman and McIntyre 1981).

If one selects climatic proxies from different parts of the world it becomes all-too evident that one could select anything from 14 000 to 6 000 years B.P. as the most suitable time plane where a stratotype might be established (Fig. 23:1). In the early discussions, the Russian specialists tended to favour a early date, perhaps 12 000 to 12 500 years B.P. On the other hand, some of the Americans, with experience in Alaska, wanted the date closer to 6 000 years B.P.

In the deep-sea carbonate cores, the average date for the cool/warm transition (shown by foraminifers) was generally about 11 000 years B.P. (Broecker 1966). In many high-latitude terrestrial sections it was evident that 11 000 years B.P. heralded a short but sharp cooling event (the Younger Dryas pollen zone, the Loch Lomond advance of Scotland and the Valders advance in North America). Furthermore, it is clear that an 11 000 years date in deep-sea carbonates represents an averaging, where older layers are homogenized with the younger by bioturbation. The true date must be younger.

In the middle latitudes, the critical turning point for the general warming trend, shown by innumerable pollen series, was around 10 000 years B.P.,

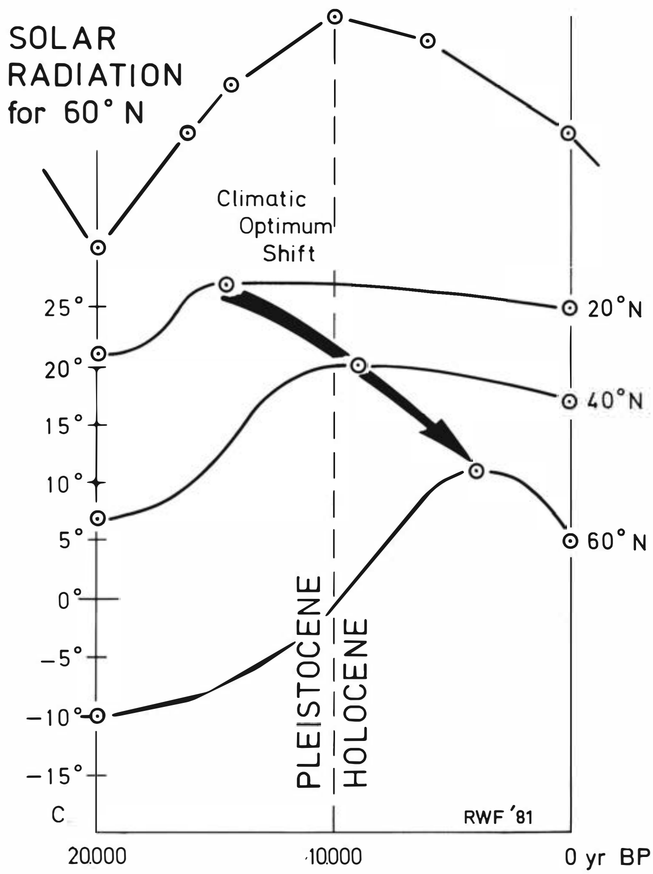

Fig. 23:1. Curves to show the diachronous nature of the late glacial and post-glacial warming in different latitudes. Estimated for the mean annual temperature at sea level on the basis of numerous climatic proxies. The first curve illustrates the early start of "post-glacial" trends at 20° (and lower) latitudes, but the low amplitude of the change. The curves for 40° and 60°N disclose progressively later warm-ups, but with increasing amplitudes (based on a figure in Fairbridge 1972, p. 297). Also indicated is the insolation curve of Milankovitch (for 65°N) which shows a peak at 10 000 years B.P., the subsequent warming being evidently reinforced by oceanic feed-back and other mechanisms.

and this seems a good average for the ocean too. Perhaps the most striking argument for the global significance of the 10 000 years B.P. turning point comes from Antarctica (Fig. 23:2). In the long ice cores this date (approximately) marks the time when the supply of world-wide dust (aerosol) fell by several orders of magnitude (Thompson and Mosley-Thompson 1981). This time marked the re-vegetation of enormous areas of Saharan desert/savannas, and of the loess-covered prairies and steppes of the higher latitudes.

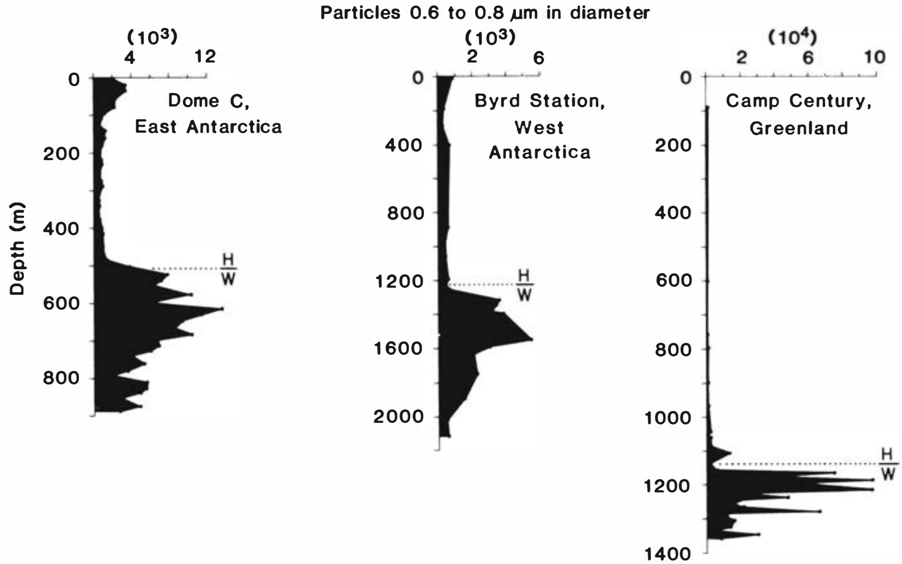

Fig. 23:2. Curves of air-borne dust (aerosol) preserved in Antarctic ice cores (diagram courtesy of L.G. Thompson and E. Mosley-Thompson 1981, p. 814), showing the close approximation to around 10 000 years B.P. It is concluded that this abrupt interruption is eolian dust – supply reflects a world-wide spread of grasses, shrubs and trees across the loess landscapes (prairies and stepps in North America, Eurasia, Patagonia, and New Zealand) as well as across the tropical and subtropical deserts of Africa (Sahara, Kalahari), India and Australia (which became largely savannas until around 3 000 years B.P.).

THE CHOSEN STRATOTYPE AREA

The selection of the Swedish West Coast for the stratotype area was not a causal decision. The writer, as president of the INQUA Shorelines Commission, had for several decades been reviewing possible sites in many parts of the world. To conform with the Code's requirements, the site had to be a, relatively stable tectonically, b, in a continuous marine sequence, c, well-studied with adequate radiocarbon dates and palaeontological information, and d, in an easily accessible area.

Now, most of the Holocene boundary areas in stable areas are today beneath sea level on the continental shelf, which has limited accessibility. This severely limits the choice of localities. Uplift areas are required, and these are found either in the vicinity of plate boundaries, as in Japan or New Zealand, or in regions of glacio-isostatic emergence, which includes such places as eastern Canada, north-western USA (Puget Sound), Scotland, southern Norway, and western Sweden. It was the large number of detailed studies that persuaded our Commission that the Swedish option, in

Göteborg area, should receive closest attention, specifically at a level dated around 10 000±250 years B.P. The writer formally presented this motion at the Paris INQUA in 1969.

Through the imaginative and energetical initiative of N.A. Mörner, the first selection was core B-873 that was put down in the Göteborg Botanical Garden (Mörner 1976, Fairbridge 1976). A joint field meeting of the INQUA Commissions for Shorelines and for Holocene met in Göteborg in 1973, but a number of speakers felt that a critical part of the cool/warm transition was marred by the presence of a narrow layer of freshwater origin, and that a better section could be established. Accordingly a group led by E. Olausson, I. Cato and C. Fredén carried out numerous further borings in western Sweden, particularly in the area north of Göteborg (Olausson 1980). The undisturbed samples obtained by the Foil Piston Corer were studied by an extensive panel of experts, and the results presented at a specially convened meeting, May 5–8, 1981, at the Aspenäsgården Conference Center, near Göteborg.

This 1981 meeting concluded that of the various cores studied in detail, the Solberga core would be the best selection, at a depth of 18–20 m, the precise details to be submitted later in the year. Most illuminating impressions at this meeting emerged from the reviews by invited experts that generated a regional palaeogeographical picture of western Sweden in late Pleistocene (Younger Dryas)/early Holocene (Preboreal) transition period. This region was then a complex archipelago of skerries (low, rocky islands) and channels receiving floods of fresh meltwater from the ice sheet margin that then lay 120 km north-east of Göteborg. These waters were probably seasonally variable in strength, spreading out over the cold water that was coming in from the west, in the manner of a gigantic estuarine salt-water wedge. The environment was evidently changing rapidly due to several other variables: the position of the ice front, the glacio-isostatic crustal uplift, and the eustatic and geoidal fluctuations.

CHRONOLOGY OF THE HOLOCENE BOUNDARY

At the 1981 meeting, the writer presented some of the evidence for constructing a new basis for a Holocene chronology that can be checked against varve chronologies, dendrochronology, isotopic time series, ice core data, geomagnetics, and other standards. It is based on astronomical periodicities, and therefore it is absolutely essential for this work for dates to be expressed in sidereal years. It greatly simplifies calculations if we adhere to the usual geological datum year, that is AD 1950, and all ages are thus expressed as B.P. (before present) or A.P. (after present). Radiocarbon years are often distinguished as "bp" (and preferably with "^{14}C" to make it perfectly clear). Too many articles and tables confuse the two systems of dating for want of a single word of explanation. It should also be recalled that in precise chronology, when it is required to convert B.C. to B.P. dates and *vice versa,* one should add or subtract 1949 (not 1950, because there was no zero year AD or B.C.). Warnings need to be repeated constantly against the use of precise radiocarbon dates, where a spurious accuracy is implied. First, there are variations in the isotopic flux rate that, for example, in the 7th millenium B.P. cause radiocarbon dates to be up to 1 000 years too young. Then there is the old carbon effect, which is particularly notable in shell dates near the ice margins where old water (melted ice) and old limestone (dissolved) can give dates that are 300 to 600 years too old (Mangerud and Gulliksen 1975). Shells that are too old for radiocarbon dating, such as those of 125–85K, from the last interglacial, frequently give "live dates" of 25 000–35 000 years B.P.; this is because they absorb modern CO_2 while sitting on the lab shelf waiting their turn to be dated (Olsson 1979). And not least there is charcoal, which is very reliable because it is difficult to contaminate, but the oak tree that furnished the charcoal may have been 300–400 years old (Suess 1979).

All this points up the great need for year-by-year chronologies such as provided by lake varves, tree rings and ice cores. The marine varves from the Santa Barbara basin (Psias 1978) may well lead the way towards a revolutionary new approach to climate studies, because they record surface-water temperatures (by $^{18}O/^{16}O$ studies of foraminifers) that appear to reflect pulses of the North Pacific gyre. On the Japan coast, Taira (1980) has shown that the warm pulses can be matched by high sea levels and reef-building corals. The cold interruptions are marked by volcanism, and Taira (op.cit.) suggests plate tectonic control. It is important to appreciate that while volcanic explosions may modify the stratospheric aerosol screen and cause a few years' cooling, the timing of the eruptions often *follows* the initiation of a cool cycle by more than 10 years (Rampino, Self and Fairbridge 1979). In other words the volcanism is not the cause of the cooling, but one of its related effects.

CONCLUSIONS

1. The purpose of stratigraphical nomenclature and stratotypes is *user-convenience.* Clarity of meaning and availability both demand and require site selection and accurate description.
2. From global studies extending over some decades, the western Swedish area was selected for the Holocene boundary stratotype, its anticipated age being 10 000±250 ^{14}C years B.P., this being the boundary between the (cold) Younger Dryas and the (warmer) Preboreal as indicated by terrestrial pollen on the nearby land.
3. Site selection from numerous cores in the region north of Göteborg seems to indicate that Solberga at the 18–20 m depth interval contains the most diagnostic evidence, to be reported by the separate specialists.

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