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LETTER TO THE EDITOR

Defining the Boundaries of the Late-Glacial Isotope Episodes

Deciphering the details of the climatic record for the interval 15,000 to 9000 ^{14}C yr B.P. has assumed great importance in the quest to understand glacial cycles (Broecker and Denton, 1989). The reason is that evidence for abrupt changes has emerged. In the northern Atlantic basin, two abrupt warmings (one at about 12,700 and the other at about 10,000 ^{14}C yr B.P.) and one abrupt cooling (at about 10,800 ^{14}C yr B.P.) are recorded in the oxygen isotope and dust record from Greenland ice (Dansgaard and Oeschger, 1989), in the oxygen isotope and foraminifera record from northern Atlantic sediment (Ruddiman and McIntyre, 1981; Duplessy *et al.*, 1981; Bard *et al.*, 1987; Broecker *et al.*, 1988), and in the oxygen isotope (Siegenthaler *et al.*, 1984), beetle (Atkinson *et al.*, 1987), and pollen (Welten, 1982; Ammann and Lotter, 1989) records from European lakes and bogs. The second of these warmings has recently been found in the hydrogen isotope record for European pine trees (Becker *et al.*, 1991). Fairbanks (1989) has accumulated evidence from Barbados corals for abrupt rises in sea level several hundred years after each of these two warmings. While the strongest imprints of these changes are found in records from the northern Atlantic basin, evidence for lesser impacts appears in records from distant points on the planet (Lorius *et al.*, 1979; Chinzei *et al.*, 1987; Keigwin and Jones, 1990; Kudrass *et al.*, 1991). The task of the next decade or so will be to establish detailed records for this time interval at many places on the globe.

The point of this note is to suggest a remedy for what I consider to be a confusing situation with regard to nomenclature applied to one part of this time interval, i.e., that between the first of the northern Atlantic basin's abrupt warmings (i.e., at ca. 12,700 ^{14}C yr ago) and the cooling event marking the onset of the Younger Dryas event (ca. 10,800 ^{14}C yr B.P.). For historical palynological reasons (Hartz, 1902; Iversen, 1942, 1954; Firbas, 1949, 1952; Van der Hammen, 1951), this interval commonly has been divided into three subintervals: the Bølling (warm), the Older Dryas (cold), and the Allerød (warm). However, evidence for the Older Dryas is absent (or not identified) in most records, leaving only a single warm episode (the Bølling and Allerød). A pollen record from Swiss Lake Rotsee reveals a transition from birch (during Bølling) to pine (during Allerød), while the oxygen isotope record shows no clear break separating these two warm episodes (Fig. 1).

In accord with earlier suggestions by Pennington and Bonny (1970), Birks (1973, p. 382–384), Pennington (1977), Coope and Pennington (1977), Gray and Lowe (1977), and Berglund (1979), I propose that in isotope records this interval be treated as a single entity, the Bølling–Allerød (BOA), and that the boundaries marking the onset and ending of the BOA interval be defined by the midpoints of the stable isotope (oxygen or deuterium) shifts marking the abrupt warming at about 12,700 ^{14}C yr B.P. and the abrupt cooling at about 10,800 ^{14}C yr B.P. (Fig. 1). Similarly, I would define the Younger Dryas (YD) interval as extending from the midpoint of the stable isotope cooling that marks its onset to the midpoint of the isotope warming that marks its termination. I opt for the isotopic record because isotopes constitute the only signal common to the Greenland ice core, north-

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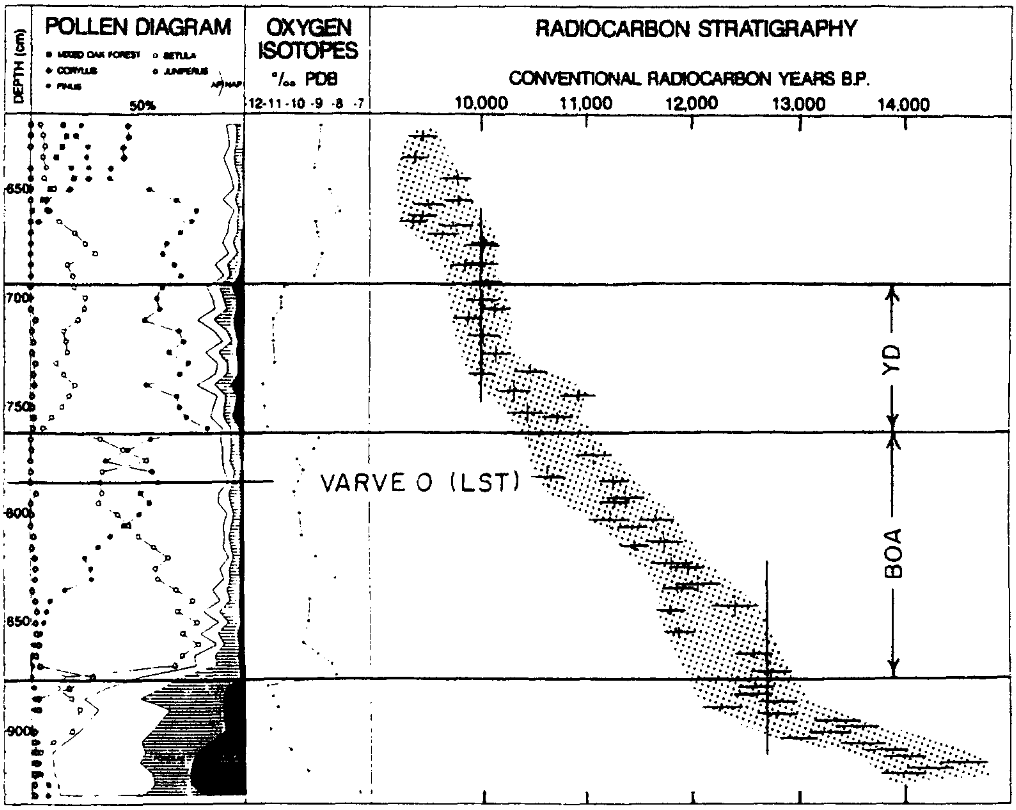

FIG. 1. Radiocarbon-dated (by AMS on terrestrial macrofossils) sediment record for Rotsee near Lucerne, Switzerland (Lotter, 1991). Added to this diagram are the boundaries proposed for the Bølling–Allerød (BOA) and Younger Dryas (YD) intervals. Note that the Laacher See Tephra (LST) is located in the upper portion of the Bølling–Allerød zone. The vertical lines at 10,000 and 12,800 yr show the location of the radiocarbon age plateau.

ern Atlantic sediment, and European lake records, and because the isotope signal is likely to have been synchronous over the northern Atlantic basin. While several reviewers of this paper suggested that the beginning or end of the isotope change be used rather than the midpoint, I feel strongly that less ambiguity will arise in the identification of the midpoints than the endpoints. I hasten to admit that the assumption of synchronous isotopic shifts across the northern Atlantic basin has not been proven. However, the rapidity of these transitions (several decades), the similarity in the shapes of the Greenland Dye 3 and Gerzensee, Switzerland oxygen isotopic records, and the similarity in the radiocarbon dates for the faunal and floral equivalents to these transitions certainly suggest regional synchrony.

A combination of fossil evidence and radiocarbon dating will serve as a means of extending these boundaries to deposits in the northern Atlantic basic for which stable isotope records are not available. However, both the abrupt warming at about 12,700 yr B.P. and that at about 10,000 yr B.P. unfortunately occur during radiocarbon age plateau (Fig. 1), making radiocarbon-based correlations somewhat ambiguous.

The divergence between the ^{230}Th and ^{14}C age scales found for Barbados coral (Bard *et al.*, 1990) provides a strong incentive to tighten up the definition of these boundaries. Several groups are currently

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attempting to make accurate counts of annual layers in lake sediments covering the period of deglaciation (Pazdur *et al.*, 1987; Zolitschka, 1989; Lotter, 1991). These groups are also obtaining radiocarbon ages for terrestrial macrofossils contained in the sediment. Similar checks may be possible from radiocarbon dating (of CO_2) and couplet counting in the new Greenland ice cores (GISP II and GRIP). These studies will be more meaningful if the annual layer counts can be referenced to one or more of the boundaries defined here. Rumor has it that an acidity peak equivalent to the Laacher See Tephra (^{14}C age ca. 11,000 yr B.P.) has been found by the Danes in the Greenland ice cores (Sigfuss Johnson, personal communication, 1990). If this correlation is verified, then the LST horizon will prove ideal as the zero year reference in annual layer counting.

Finally following Watson and Wright (1980) and Birks (1982), I suggest that use of chronozones for this interval (Mangerud *et al.*, 1974) be eliminated. While at the time of their introduction they served a useful purpose, currently they add more confusion than light.

In making these suggestions, I realize that I am treading on ground considered sacred by many stratigraphers. Fortunately, I have not proposed new terminology nor have I designated new boundaries. Rather, I am proposing that we formalize definitions most people have already been using.

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WALLACE S. BROECKER
Lamont-Doherty Geological Observatory of Columbia University Palisades, New York 10964

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