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Periods of rapid environmental change around 12500 and 10000 years B.P., as recorded in Swiss lake deposits*

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Abstract

In the sediment of three Swiss lakes at a range of altitude from 514 to 2017 m, the Bölling and the Preboreal are recognized as two periods of rapid biotic changes. The main reason is rapid climatic change that triggered shifts in different groups of aquatic and terrestrial organisms. Although these groups would be expected to have very different response times, e.g., to increasing summer temperature, their assemblages responded with surprizing synchroneity. For extracting climatic signals from stratigraphies, the quickly responsive indicators like oxygen isotopes or beetles are useful. For understanding ecological dynamics under a changing climate, the comparison of biota with various response time are important.

Introduction

Over 50 years ago, in describing and interpreting vegetation history, Oberdorfer (1937: 526–527) had already expressed what is still striking in late-glacial pollen diagrams from central Europe, i.e., two steps of very rapid changes, first the reforestation and then the transition to the Holocene: 'Die Klimaäanderung, die von der arktischen Zeit in die subarktische überleitete, muss sehr plötzlich und ruckartig vor sich gegangen sein und war vielleicht von ähnlicher Bedeutung und ähnlichem relativem Ausmass, wie jene zweite Klimabesserung, die zur endgültigen borealen Wärmezeit führte'. And later, he said: 'Explosionsartige Ausbreitung der Birken- und Kieferngehölze...' and 'Zweite unvermittelt einsetzende Klimamilderung, die zum vollen Einbruch der wärmeliebenden Gehölze führte'.

In reviewing Swiss material recently published in Lang (1985), we can now ask: how are these two steps recorded in biostratigraphies other than pollen? How synchronous or metachronous were changes in terrestrial and lalcustrine ecosystems? And, how good a time scale do we have for distinguishing between synchronism and metachronism?

Out of the 13 sites presented in Lang (1985) I will concentrate here on only three, all from the main transect, viz. Hobschensee, Amsoldingersee and Lobsingensee (Fig. 1).

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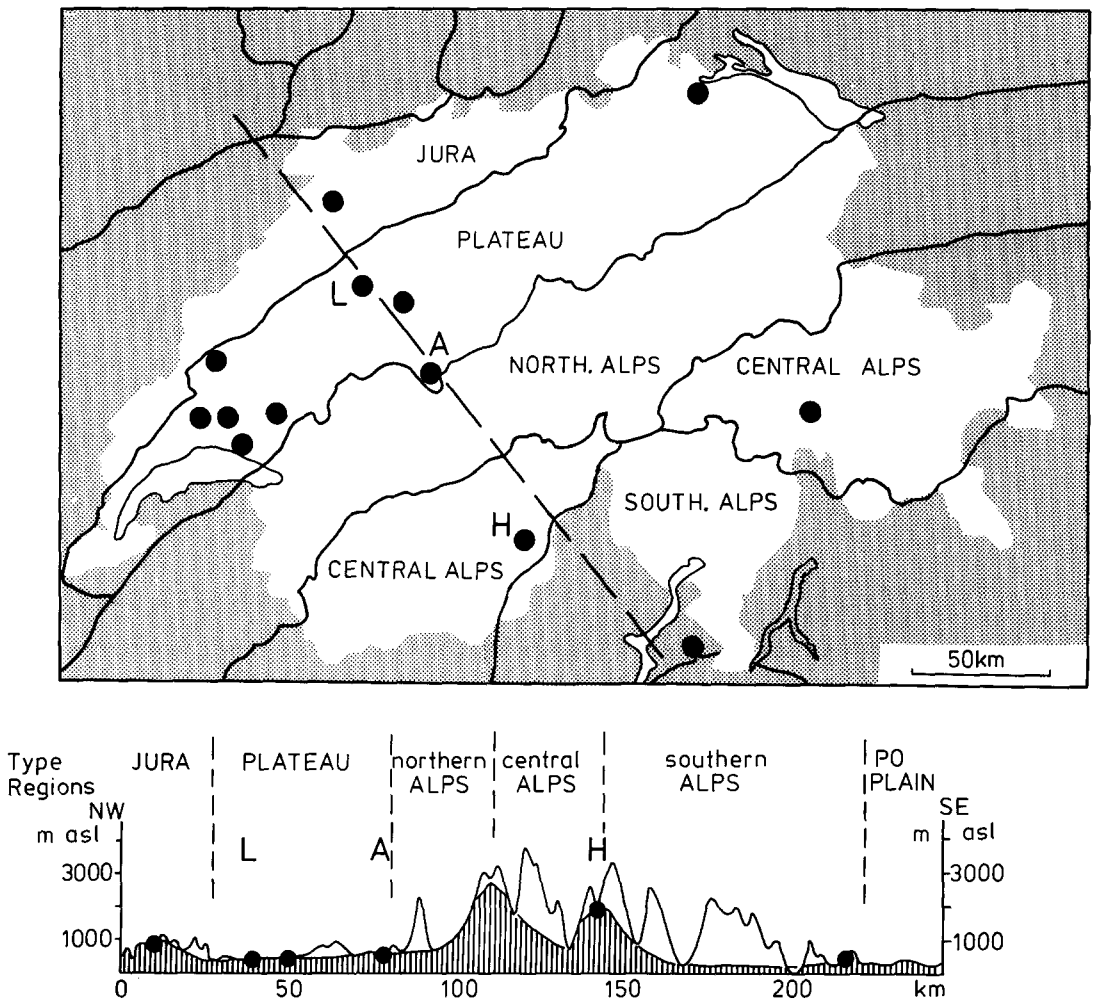

Fig. 1. Map of Switzerland (white area) indicating type regions and 13 sites of the Bernese research program (Lang, 1985). H = Hobschensee, A = Amsoldingersee, L = Lobsigensee.

Hobschensee at Simplon Pass – results and interpretations

Simplon Pass (2005 m asl) connects the central alpine (longitudinal) part of the Rhone Valley (Valais) with the southern alpine (transverse) valley of the Toce River (Italy). Crystalline bedrock types including gneisses and schists dominate. During the Würm Glaciation, confluence of local glaciers from mountains around the pass with the Rhone ice in the north and with the Ticino ice in the south, resulted in at least 200 m depth of ice over the pass (Müller, 1984). Hobschensee (Fig. 1), at 2017 m altitude is at today's timber line, and therefore at a sensitive elevation. This sensitivity is one reason why several scientists have chosen it for investigation (Keller, 1935; Küttel, 1979; Welten, 1982; Lang & Tobolski, 1985). Two findings are striking: (1) the site became ice-free as early as during the Bölling (i.e. after 13000 BP), in spite of the lake's situation in the Central Alps at 2000 m altitude (Welten, 1982); and (2) the reforestation occurred very rapidly and as early as at the transition from Younger Dryas to Preboreal (i.e., at the beginning of the Holocene at ca. 10000 yr B.P.). This was demonstrated by Küttel (1979) and Welten (1982) who identified stomata of *Juniperus, Larix* and

Pinus, and by Tobolski in Lang & Tobolski (1985) who recorded a large variety of macrofossils of *Juniperus, Larix, Betula 'alba'* and *Pinus cembra* (Fig. 2). Time control is not yet good as the only two late-glacial radiocarbon dates (B-529 and B-608) in Welten's diagram considered of Alleröd age are 12580 ± 200 yr B.P. and 10430 ± 250 yr B.P., older and younger, respectively, than expected. Palaeolimnological studies are in progress (Cladocera by M. Boucherle; diatoms by B. Marciniak).

Amsoldingersee at the boundary Plateau/ Prealps – results and interpretations

Where the rivers (the glaciers, during the Ice Ages) leave the limestone Prealps and enter the lowland of the Tertiary Molasse-Plateau, a fringe of large piedmont lakes (such as Zürichsee and Thunersee) and of small kettle hole lakes (e.g., Amsoldingersee, Fig. 1) occur. Littoral cores from Amsoldingersee (641 m asl) were analysed for pollen, chemistry, stable isotopes, fossil pigments and Cladocera (Lotter & Boucherle, 1984; Lotter, 1985) (Fig. 3). A disturbance or hiatus in the sediment from the Younger Dryas prevents detailed studies of the transition to the Holocene, but it offers an interesting example of an early lake-level lowering in the European context (Gaillard, 1985). The transition from the Oldest Dryas to the Bölling, on the other hand, is very sharp for several parameters, and, like at Gerzensee, 12 km away, the $\delta^{18}O$ measured on precipitated carbonates (lake marl) rose rapidly with reforestation. This rapid rise can be interpreted as indicating a rise in summer temperature (Eicher & Siegenthaler, 1976; Eicher, 1987). Cladocera and fossil pigments mainly reflect changes in trophic state of the lake. Cladocera also show changes in relative sizes of the littoral and limnetic (pelagial) zones, also reflecting lake level changes. Such developments may or may not be triggered by climatic changes. The cladoceran fauna of Amsoldingersee shifts distinctly at the beginning of the Bölling. This can be

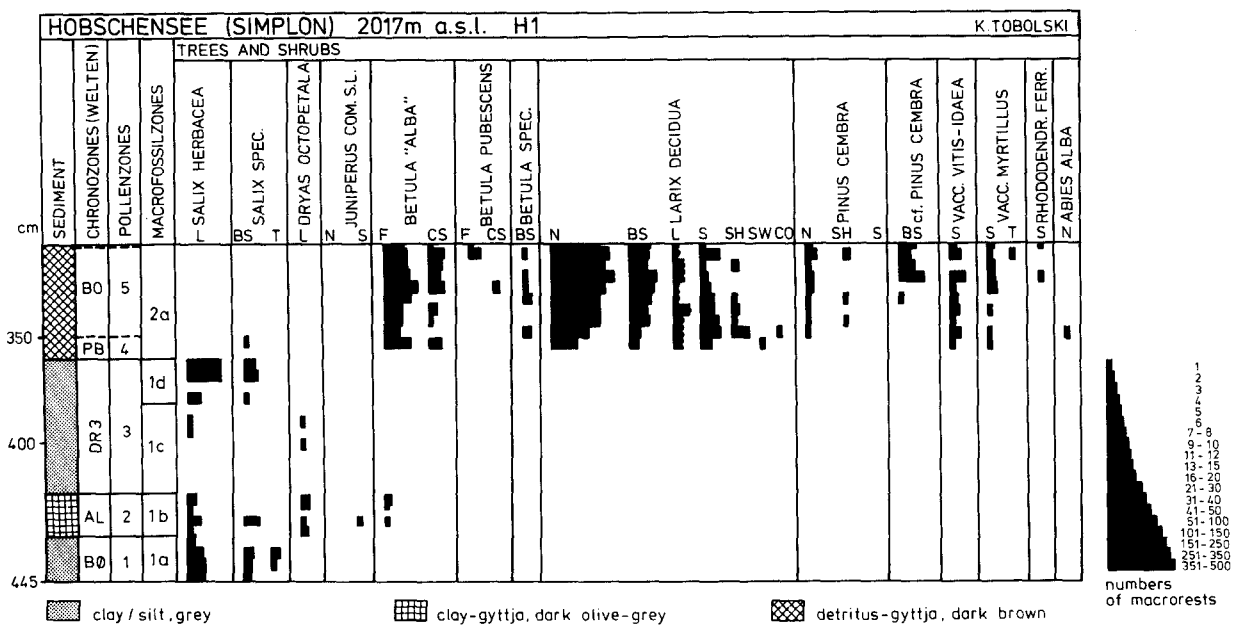

Fig. 2. Simplified macrofossil diagram from Hobschensee (after Lang & Tobolski, 1985), including selected taxa from the late-glacial and early Holocene, and showing the reforestation at the beginning of the Holocene. The scale on the right gives the number of macrorests recorded. BS = bud scale, CO = cone, CS = catkin scale, F = fruit, L = leaf, N = needle, S = seed, SH = short shoot, SW = seed wing, T = twig. BØ = Bölling, AL = Alleröd, DR3 = Younger Dryas, PB = Preboreal, BO = Boreal.

AMSOLDINGERSEE
Late-glacial and Early Holocene
after LOTTER & BOUCHERLE (1984)

conventional ^{14}C-ages: regional (extrapolated) terrestrial plants (AMS)	conventional ^{14}C-ages: locally measured whole sediment (decay)	Regional pollenzones FIRBAS 1949/1954 WELTEN 1982	Local PAZ	Vegetational history	Climate (temperature) $\delta^{18}O$	Sediment-type	Lake history (Cladocera, pigments)
		V Boreal	A-8	Corylus, Ulmus + Quercus	temperature rising	lake marl	oligotrophic
10 000		IV Preboreal	A-7	Pinus-Betula forests + Corylus			
	10 280±120	III Younger Dryas	A-6	clearance of Pinus forests	cold	fine detritus gyttja	uninterpretable
10 800							
LST		II Allerød	A-5	Pinus-Betula forests	warm	chalk gyttja, LST	meso-eutrophic
12 000	13 020±170	Ib Bølling (s.l.)	A-4	open Betula forests		chalk gyttja with fine detritus gyttja layers	oscillating between more or less eutrophic
			A-3	Juniperus-Hippophaë shrubs			
12 500	13 490±170	Ia Oldest Dryas	A-2	Betula+Salix dwarf shrubs	cold	chalk gyttja	oscillating cond.*
16 000?			A-1	Steppe-Tundra		glacial clay	cold/ice conditions
		Würm-glacial					covered by the Aare glacier

*between oligotrophic and mesotrophic

Fig. 3. Palaeoecology at Amsoldingersee (641 m) during the late-glacial and the early Holocene, according to Lotter & Boucherle (1984). All dates are given in conventional radiocarbon ages *sensu* Stuiver & Polach 1977, without calibration. The regional time scale follows a new dating series for the central Swiss Plateau worked out on terrestrial plant macrofossils (therefore without hard-water error). The locally measured samples of whole sediment have a hard water error. LST = Laachersee tephra.

interpreted as a shift from conditions oscillating between oligotrophic and mesotrophic to more or less eutrophic conditions, a change consistent with rising summer temperature (Boucherle, in Lotter (1985)). Time control is not easy to directly establish at Amsoldingersee because the three late-glacial ^{14}C–dates from the main core are affected by a hard water error (Fig. 3).

Lobsigensee on the central Swiss Plateau

During at least part of the Würm Glaciation the area northwest of Berne was covered by Rhone ice. Lobsigensee (Fig. 1), at 514 m in that area, is a small kettle hole lake presently with a surface of 2 ha and a maximum depth of 2.7 m. It has no surface inflow and only a small, sporadic overflow functional mainly during the period of snow melt. Multidisciplinary studies were carried out on littoral and profundal cores that were correlated by palynology (Ammann *et al.*, 1983; Ammann *et al.*, 1985).

Lobsigensee results

A transition from shrub tundra in the Oldest Dryas to forest in the Bölling is concluded not only from the pollen diagrams but also from size statistics on *Betula* pollen (Gaillard, 1983) and from *Betula* macrofossils (Tobolski, in Ammann & Tobolski (1983)). During the Oldest Dryas *Betula nana* was the dominant birch species. Since the initial juniper peak of the Bölling tree birches prevailed (Fig. 4). In the coleopteran and trichopteran faunas, important shifts from boreal and boreo-montane to temperate assemblages are recorded in the early Bölling. By using today's biogeographic ranges an increase in mean July temperature from 10–12 °C to 14–16 °C can be inferred from theses faunistic shifts (Elias & Wilkinson, 1983, 1985). Unfortunately the lowermost part of the Bölling (i.e., the juniper peak) did not contain any plant-independent beetles or caddisflies. In the chironomid and ceratopogonid faunas, Hofmann (1983, 1985a) found a major change coinciding with the beginning of the Bölling, i.e., the extinction of the cold-stenothermic fauna for the whole lake (littoral as well

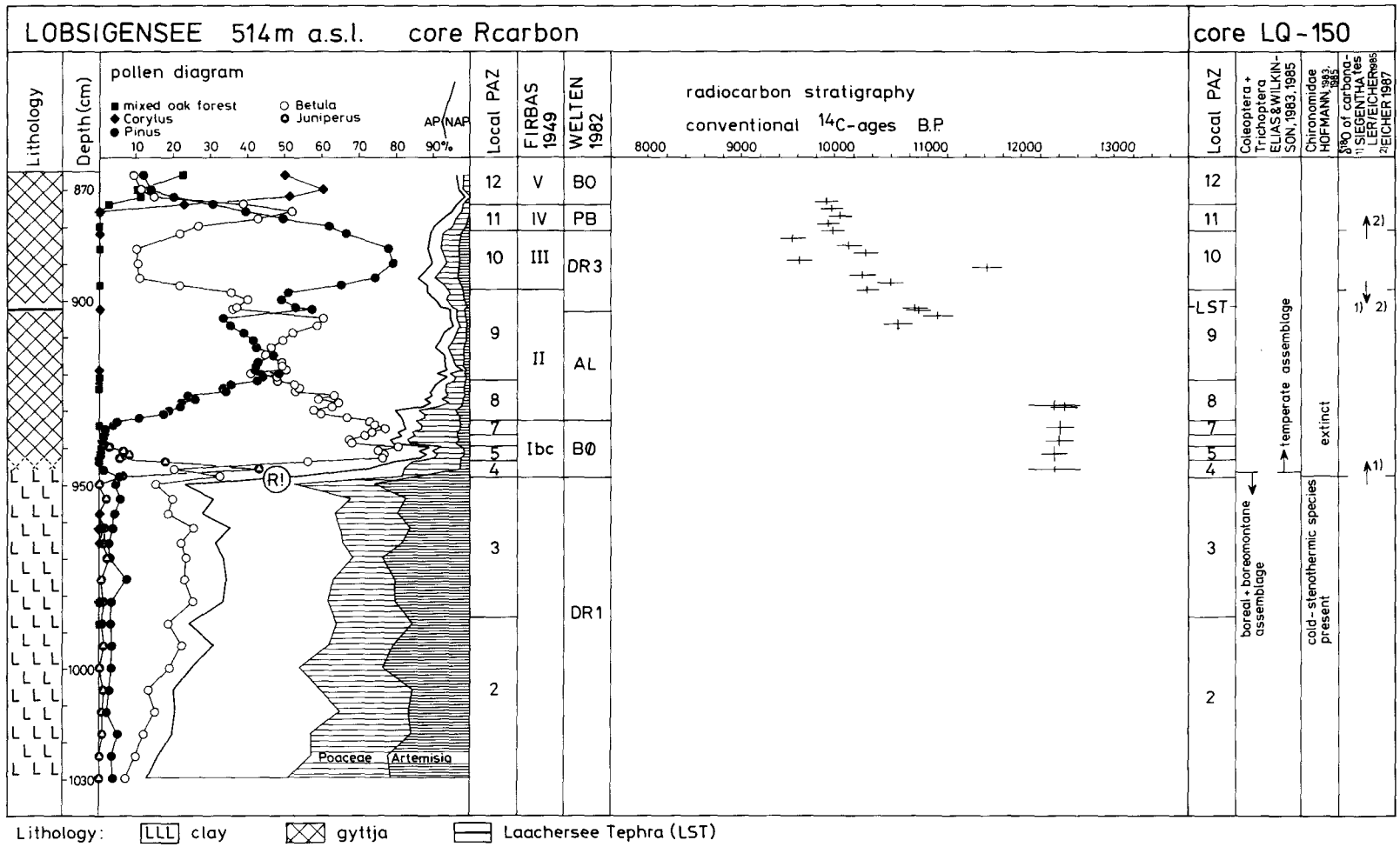

Fig. 4. Palaeoecological changes at Lobsigensee compared with the high-resolution radiocarbon-stratigraphy based on AMS datings of terrestrial plant macrofossils (Oeschger *et al.*, 1985; Andree *et al.*, 1986). Dates are presented in conventional, i.e. not calibrated radiocarbon years (Stuiver & Polach, 1977). The greatest environmental changes coincide with plateaus of constant age in the ^{14}C-stratigraphy. R! = reforestation.

as profundal). Among the Cladocera an abrupt faunal change was observed during the early part of the Bölling (during the juniper peak), namely the disappearance of subarctic species (Hofmann, 1985b). The Ostracoda developed a high species diversity during the Oldest Dryas but disappeared with the advent of the Bölling and didn't reappear until the late part of the Boreal, shifts that Löffler (1986) compared with results from lakes in Carinthia and interpreted to reflect the onset of meromixis at the beginning of the Bölling and of holomixis since the late Boreal. The Mollusca show a maximum number of individuals at the beginning of the Bölling and a somewhat gradual shift in species before this period (*Pisidium* spp. decrease; *Valvata piscinalis* increases (Chaix, 1983, 1985)). The stratigraphy of fossil algal and bacterial pigments displays a step change towards higher diversity and indicates more anoxic conditions at the beginning of the Bölling (Züllig, 1985, 1986). The stable isotopes $\delta^{18}O$ and $\delta^{13}C$ increase rapidly at the corresponding level (Siegenthaler & Eicher, 1985) (Fig. 4).

The transition from the Younger Dryas to the Preboreal is very sharp in the pollen diagrams (Ammann, 1985), and in the $\delta^{18}O$ stratigraphy (Eicher, 1987) (Fig. 4). Unfortunately the biostratigraphies of Coleoptera, Trichoptera and Mollusca could not be extended to this transition because in the littoral core used for these groups the transition is located in peat. In profundal cores (as the one presented in Fig. 4), Cladocera and fossil pigments were sampled at intervals that were too large, and Ostracoda were missing in this core section.

Interpretation of Lobsigensee results

The beginning of the Bölling biozone (*sensu* Welten, 1982; 12500 yr B.P., as determined without hard water error, Andrée *et al.*, 1986), and the beginning of the Holocene (10000 yr B.P.) are very distinct; each has synchronous shifts for several bio- and isotope stratigraphies. This is true for both: (1) the biota of terrestrial environments (pollen of terrestrial plants, terrestrial Coleoptera), and (2) the biota of lacustrine environments (pollen of aquatic plants, lacustrine Coleoptera, Trichoptera, Chironomidae, Ceratopogonidae, Ostracoda, Mollusca, algae and photosynthetic bacteria). This synchronism is higher than expected if we consider the predominantly individualistic behaviour of species (Iversen, 1954; Birks, 1981, 1986). Like Oberdorfer (1937), I interpret the rapidity of ecological change and the synchronism at the two major transitions to indicate external forcing, viz. rapid climatic warming (Atkinson *et al.*, 1987). No time-lag in the response of oxygen isotopes to the rise of summer temperature is expected. Some migrational lags of various lengths are recorded in the biostratigraphies. However, many biotic changes occur at the same stratigraphic levels. As an exemple: reforestation at the beginning of the Bölling could be interpreted to indicate the reaching and passing of a mean July temperature of 10 °C, although local differences in temperatures at timberlines add uncertainty to this interpretation (Friedel, 1967; Tranquillini, 1967; Hustich, 1983). The Coleoptera and Trichoptera point to a mean July temperature of 14–16 °C since the early Bölling. This would be warm enough for broadleaved deciduous trees like *Quercus* and *Corylus*, but these taxa do not arrive until 3000 years later. Thus, while response times may be very different for isotopes, plants and insects (Wright, 1984), if a climatic change is rapid enough and of great enough amplitude it may provoke a major stratigraphic synchronism (by 'telescoping together' different developments), e.g., as at the beginning of the Bölling.

How good a time scale do we have for the distinction between synchronism and metachronism? At Lobsigensee the AMS ^{14}C dates on terrestrial plant macrofossils (Oeschger *et al.*, 1985; Andrée *et al.*, 1986) enable us to reduce the sample thickness and refine chronostratigraphic resolution. Furthermore, by dating only terrestrial vascular plant remains we avoid the hard water error that may derive from dating whole sediment containing remains of aquatic biota or error from reworked carbon or penetrating rootlets. Sedimentary changes like carbonate layers in the gyttja

(deposited since reforestation, see Fig. 4) would have introduced complications of changing sedimentation rates; we therefore chose two undisturbed one meter Livingstone core sections of pure fine detritus gyttja, linked them by the sharp isochronous volcanic ash layer from Laach (Boogard & Schmincke, 1984) and called this 'artificial core' Rcarbon. The striking feature in Fig. 4 is, that there are two plateaus of constant age, one around 12500 yr B.P. and the other around 10000 yr B.P. Thus during the two periods when the greatest environmental changes occur the high resolution radiocarbon dating does not help to establish a chronology for the assessment of rates of change.

A plateau of constant age could be the result of increased sedimentation rate, but here this can be excluded for two reasons: (1) throughout the core the sediment deposited since the reforestation is uniformly a fine detritus gyttja with very thin densely packed laminations (in the thin-section these laminations show a network of organic matter preventing the counting of possible annual layers), and (2) stratigraphically rapid changes like the reforestation or the expansion of *Corylus* would be even more rapid (which I consider unlikely) if I postulate increased sedimentation rate. Such considerations call for a reinvestigation in annually laminated sediment.

The geophysical reasons for a plateau of constant age can be, according to Andrée *et al.* (1986, p. 415): 'decreasing ^{14}C production rate or (by) dilution of the atmospheric ^{14}C with carbon of lower ^{14}C concentration. The drastic changes in the environmental system observed at this transition could, e.g., have accelerated ocean circulation, involving a reduction of the atmospheric ^{14}C level (e.g., Siegenthaler, Heimann & Oeschger 1980)'. For several reasons this explanation concerning the carbon cycle is favored by the geophysicists.

The palaeoecological consequences of plateaux of constant age are discussed in Ammann and Lotter (in prep.). There are several problems if these two plateaus prove to be real:

(1) high-resolution ^{14}C sampling will not improve chronological resolution,
(2) influx calculations or rates of change cannot be calculated if based on ^{14}C, and
(3) long distance correlations are strongly affected when based on radiocarbon dates around 12500 yr and 10000 yr B.P.

This last point raises the possibility that plateaus of constant age artificially sharpen transitions. We submit many samples for ^{14}C dating from sections with interesting stratigraphic changes and we therefore get many dates centered around these ages. But such plateaus function like traps for ^{14}C-ages and we possibly get more very similar dates than expected in calendar years. In the context of long distance correlation, this leads us to consider several events as synchronous which actually may be metachronous within the plateau.

Conclusion

There is a need for very detailed and multidisciplinary research concentrating on these rapid changes as recorded in varved lacustrine sediments and in ice cores (both to be correlated by $\delta^{18}O$ stratigraphy) to understand the leads and lags of these rapid climatic and environmental shifts. Such changes are obviously faster than (and superimposed on) the climatic changes resulting from orbital forcing. Of the following two key climatic parameters: atmorpheric CO_2 concentration and ocean circulation (deep water formation), the latter seems to be discernible in continental sediments and in tree rings (if $\Delta^{14}C$ is calculated), as well as in ocean cores. In addition, lake deposits offer a wide variety of biostratigraphies which may enable us to evaluate what future rapid climatic changes could possibly mean to ecosystems.

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