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A HIGH-RESOLUTION LATE-GLACIAL AND EARLY HOLOCENE ENVIRONMENTAL HISTORY OF ROTMEER, SOUTHERN BLACK FOREST (GERMANY)

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Abstract

The late-glacial and early Holocene environmental history of Rotmeer (960 m a.s.l.), a mire in the southern Black Forest (Germany) was investigated by analysing 96 contiguous 1 cm samples of lacustrine sediments. Pollen concentrations and geochemical erosion indicators (*e.g.* Al, Ti, K) suggest that the reforestation of the catchment by pine and birch occurred at the onset of the Allerød. Moreover, geochemistry and pollen indicate three phases of climatic deterioration, each characterized by the occurrence of allochthonous minerogenic sediment with increased values of NAP. The first fluctuation occurred shortly before the pine expansion and was correlated with the Aegelsee oscillation of the Alps. The second and major event was identified as the Younger Dryas. It resulted in a substantial lowering of the timberline in the Black Forest. The third oscillation occurred during the Preboreal and is very inconspicuous in the terrestrial pollen record, whereas the geochemical analysis shows a short increase in elements indicative of soil erosion.

The diatom assemblages of the Oldest Dryas and Bølling biozones are dominated by epiphytic alkaliphilous and circumneutral species. Progressing pedogenesis in the catchment connected with decreased inwash of basic cations into the former lake may then have favoured the expansion of acidophilous diatoms, mainly *Aulacoseira* species. The climatically induced changes evidenced in vegetation and in soil erosion are well reflected as changes in the pH spectra of the diatoms, indicating more neutral to basic pH conditions.

Introduction

The Black Forest was one of the first regions outside Scandinavia where vegetation history was investigated by means of pollen analysis (STARK 1912, 1924). By the early twentieth century the vegetation history had been outlined by palynological investigations of various mires in this region (*e.g.* BROCHE 1929; OBERDORFER 1931). However, it was only in the 1950s that the work of LANG (1952, 1954) revealed the detailed characteristic features of the late-glacial and Holocene vegetation history of the Black Forest region, which are still valid today. Using the tephra layer of the Laacher See volcano as a chronostratigraphical marker, LANG (1952, 1963, see also LANG *et al.* 1984) was able to prove the existence of Allerød sediments in the Black Forest.

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Moreover, he provided the first radiocarbon dates for this region (LANG 1955a) and reviewed the plant distribution from a plant-geographical point of view (LANG 1955b, 1967, 1971, 1992).

Inspired by LANG's (1975) proposal for a multidisciplinary palaeobotanical and palaeolimnological working program for the Black Forest, we started our investigations of late-glacial lacustrine deposits in 1986 (LOTTER & HÖLZER 1989). The initial idea behind these different investigations was to test whether the eruption of the Laacher See volcano with its subsequent tephra deposition had any significant effect on terrestrial and aquatic ecosystems (LOTTER & BIRKS 1993; BIRKS & LOTTER, in press) in an area that is sensitive to acidification by atmospheric pollutants (see, *e.g.*, ARZET *et al.* 1986; STEINBERG *et al.* 1987). Therefore, only short sequences of sediment around the Laacher See Tephra (LST) were analyzed. However, we have decided to present here the complete Rotmeer late-glacial sedimentary sequence, and would like to take this opportunity to dedicate this study to our teacher and mentor Gerhard Lang. The profile represents a high-resolution record of past environmental change. We feel that the combination of several methods such as geochemical, pollen and diatom analyses can provide different independent lines of evidence and may thus aid in obtaining a better interpretation of past environmental change.

Site

Rotmeer (8°6'30"E 47°52'N) is an ancient lake basin in the southern part of the Black Forest in southern Germany (Fig.1). It lies at an elevation of 962 m a.s.l. and is overgrown today by a mire. According to DIERSSEN & DIERSSEN (1984) the Rotmeer mire is not ombrotrophic. It is surrounded by spruce and fir forests (Bazzanio-Piceetum and Vaccinio-Abietum, PRINZ 1986). The raised bog (mainly a Pino mugo-Sphagnetum magellanici) comprises today about 19 ha, loosely covered by *Pinus mugo* ssp. *rotundata*. Parts of the mire were used as a refuse dump until the late 1970s and the influence of additional ions is seen in the soil water of neighbouring parts of the dump (BOGENRIEDER *et al.* 1989).

Geologically, the region investigated consists of acidic bedrock, mainly granites and paragneiss (METZ 1977). During the last glaciation, the region was covered by local glaciers. The present climate is characterized by a mean annual precipitation of *ca.* 1300 mm and a mean annual temperature of ca. 5°C (mean July ca. 14°C, mean January *ca.* -2°C).

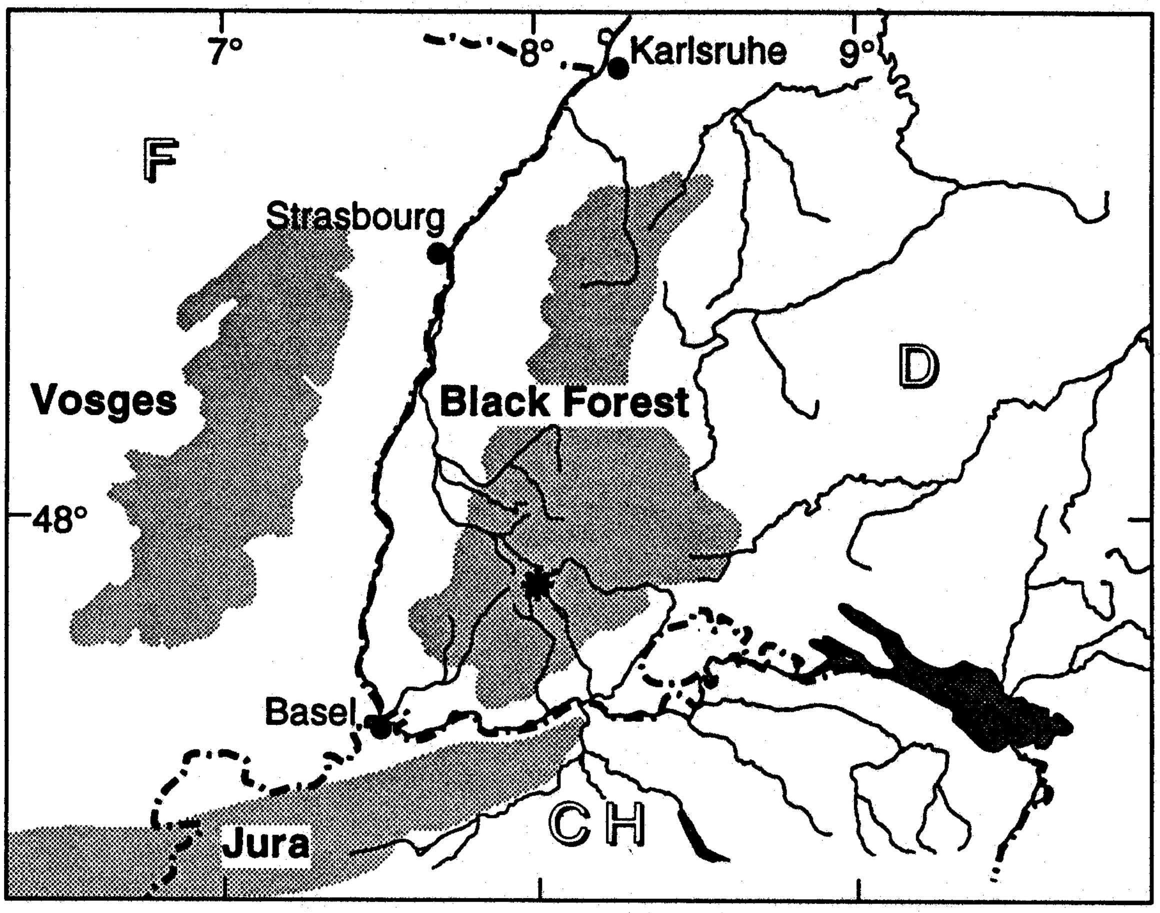


Figure 1. Map of Central Europe indicating the location of Rotmeer (★).

Material and methods

Rotmeer core RO-6 was taken in 1988 in the deepest, central part of the raised bog using a modified Livingstone piston corer (MERKT & STREIF 1971) with a diametre of 80 mm and a segment length of 100 cm. The core segments were extruded on the same day and the 1 m segment including the late-glacial sediments was subsequently cut into 1 cm slices. Contiguous 1 cm samples of 96 levels in depths of 1002-906 cm below the surface of the mire were used for this study. The 1 cm sediment slices were homogenized and analyzed for pollen, diatoms and geochemistry. The amount of organic matter was estimated as loss after ignition at 550° C for 2h.

Sample preparation for pollen and diatom analyses followed standard methods (see, *e.g.*, LOTTER 1988). Absolute pollen and diatom concentrations were estimated by adding *Lycopodium* tablets (STOCKMARR 1971) and microspheres (BATTARBEE & KNEEN 1982), respectively. A minimum of 400 valves and 600 pollen was counted for each level. The pollen sum (100%) is defined as ΣAP+NAP, with the percentages of aquatics and spores calculated outside this sum. Diatom identification followed KRAMMER & LANGE-BERTALOT (1986-1991) as well as CAMBURN *et al.* (1984-1986). Chrysophyte cysts were counted together with the diatoms and their abundance is expressed as a percentage of the sum of total diatoms and cysts. Pollen and diatom diagrams were numerically zoned using CONSLINK (BIRKS & GORDON 1985) and CONISS (GRIMM 1987). As there are no regional modern diatom-pH calibration data sets available for the Black Forest, the Index B method (RENBERG & HELLBERG 1982) was used to infer past lake pH.

For the geochemical analyses the samples were dried at 105°C, homogenized in a ball mill and then ashed at 550°C for 12 h. Titanium was determined by Tiron colorimetrically after fusion with potassium pyrosulphate. Another aliquot was fused with sodium hydroxide and silicon was determined by colorimetry using the molybdenum blue method. Amorphous silicon was determined by the same method after extraction with 0.5 N NaOH (BLACK 1965). Organic nitrogen was determined colorimetrically after KJELDAHL digestion by a modified indo-phenol blue method. The remaining elements were determined after digestion with HNO_3-H_2SO_4. The following methods were used: polarography and inverse voltametry (polarograph E626 with electrode E623 by METROHM) for Cu, Pb, Cd, Zn, Ni, Co, and Mo; flame-AAS (SP90 or SP9 by PHILIPS) for Na, K, Ca, Mg, Mn, Rb, and Fe; graphite tube-AAS (SP9 with PU9095 by PHILIPS) for Cr and Be; Hydridsystem ML 75 by BERGHOF for As; colorimetry for Al with Aluminon, and P and Si with ammonium molybdate. The samples for S, Cl, and Br were digested according to SCHÖNIGER (1961) and measured by ion chromatography (METROHM IC690).

Results

Lithology

The lithology of the mire has been determined by a NE to SW transect of 13 cores through Rotmeer (Fig.2, see also RAISCH in V.D. GOLZ *et al.* 1976). The lowermost deposits consist of a silty clay layer. Subsequently, the organic content slowly increases, with the sediment changing gradually into a clay gyttja and then into a diatom-rich fine-detritus gyttja. Within this fine-detritus gyttja the volcanic ash of the Laacher See Tephra (LST) can be found as a conspicuous ca. 1 cm thick layer originating from the Eifel mountains. A few centimetres above the LST the sediment changes abruptly into a clay gyttja. After this minerogenic sediment layer of up to 50 cm, the organic content increases again rapidly and the sediment eventually becomes a homogenous, diatom-rich fine-detritus gyttja for up to 6 m. Above these limnic deposits, a *Sphagnum* peat of up to 5 m in thickness has accumulated up to the modern mire surface (Fig.2). In the central part of Rotmeer, this overgrowing began to take place shortly after the expansion of *Abies* (V.D. GOLZ *et al.* 1976), *i.e.* approx. 6000-5000 radiocarbon years ago (see, *e.g.*, RÖSCH 1989).

Table 1. Lithological description of Rotmeer core RO-6

Depth	description after TROELS-SMITH (1955)	sediment type
900 - 926 cm	Ld 3, Lso 1, homogenous, dark brown	diatomaceous fine-detritus gyttja
926 - 966 cm	Ld 2, As 2, homogenous, olive-grey	clay gyttja with bryophyte remains
966 - 968 cm	Ld 3, Lso 1, homogenous, dark brown	diatomaceous fine-detritus gyttja
968 - 969 cm	Ga 4, grainy, brown-grey	Laacher See Tephra
969 - 974 cm	Ld 3, Lso 1, homogenous, dark brown, lower limit gradual	diatomaceous fine-detritus gyttja
974 - 979 cm	Ld 2, As 2, homogenous, grey-brown, lower limit gradual	clay gyttja
979 - 1005 cm	As 4, homogenous, olive to blue-grey	silty clay

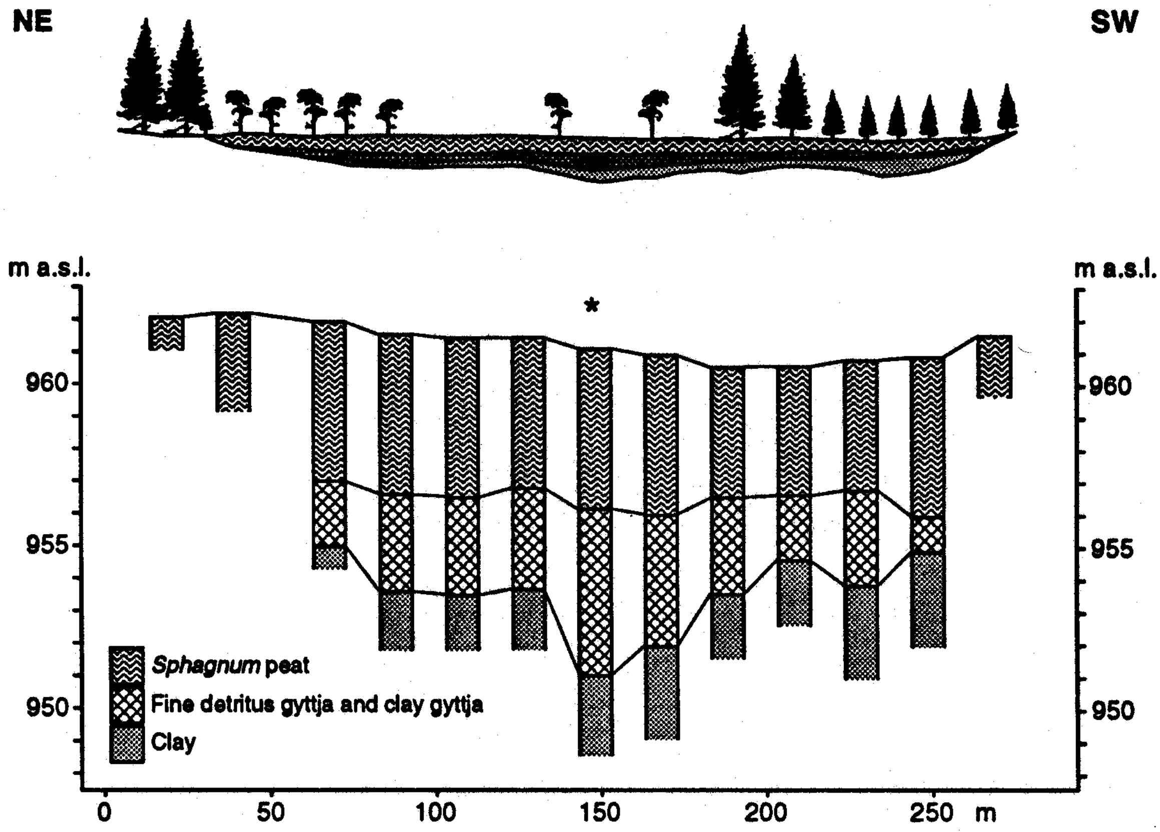


Figure 2. Stratigraphical transect through Rotmeer (modified after ZÖTTL 1979). Core RO-6 was taken in the vicinity of the marked core (*).

Pollen zonation

The pollen stratigraphy of core RO-6 has been subdivided into five local PAZ (pollen assemblage zones) and the pollen taxa have been grouped as trees and shrubs, terrestrial herbs, spores and aquatics (Fig.3).

The lowermost zone RP-1 (Gramineae-*Artemisia* PAZ) is characterized by the highest values of NAP, mainly grasses and heliophilous herbs (*e.g. Artemisia, Helianthemum, Saxifraga oppositifolia*-type, Caryophyllaceae). The onset of PAZ RP-2 (*Juniperus*-Gramineae PAZ) is marked by increasing values of *Juniperus* and *Salix*. The values of *Hippophaë, Salix* and *Juniperus* reach their optima during this PAZ whereas the NAP (mainly Gramineae) values gradually decrease. During PAZ RP-3 (*Betula*-Gramineae-*Juniperus* PAZ) the *Betula* curve reaches its rational limit while *Juniperus* decreases steadily. A short regressive phase characterized by a birch decrease and a NAP increase (consisting mainly of Gramineae) occurs in the middle of this PAZ (979-982 cm). Zone RP-4 (*Pinus* PAZ) is characterized by high pine values. It can be subdivided into three subzones. The onset of sub-PAZ RP-4a (*Pinus-Betula* sub-PAZ) is characterized by the rational limit of the pine curve and the sub-zone has high values of *Betula* and *Pinus*. Sub-PAZ RP-4b (*Pinus*-Gramineae-*Artemisia* sub-PAZ) represents a second regressive phase characterized by an increase in grasses and heliophilous taxa (*e.g. Artemisia, Helianthemum, Plantago,* Caryophyllaceae, and *Juniperus*), whereas the values of pine and mainly birch decrease. The decrease in the NAP values and the increase in *Pinus* values mark the onset of sub-PAZ RP-4c (*Pinus-Betula-Corylus* sub-PAZ). *Pinus* reaches the highest values in the core and the *Corylus* curve has its empirical limit. PAZ RP-5 (*Corylus-Pinus* PAZ) is characterized by the rational limit of hazel and subsequently by high *Corylus* and decreasing *Pinus* values.

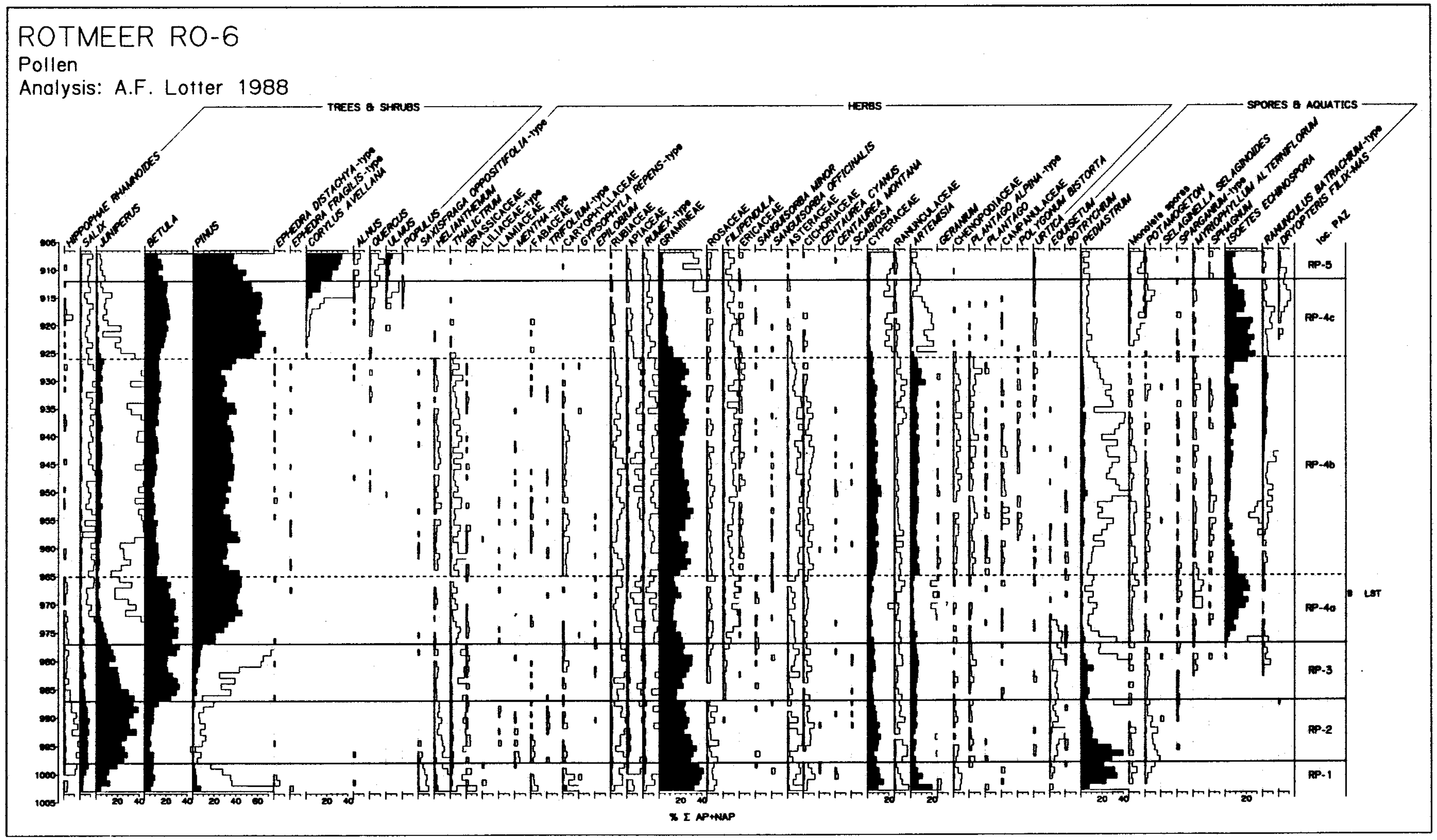


Figure 3. Pollen percentage diagram of Rotmeer core RO-6. Only the most prominent taxa are shown.

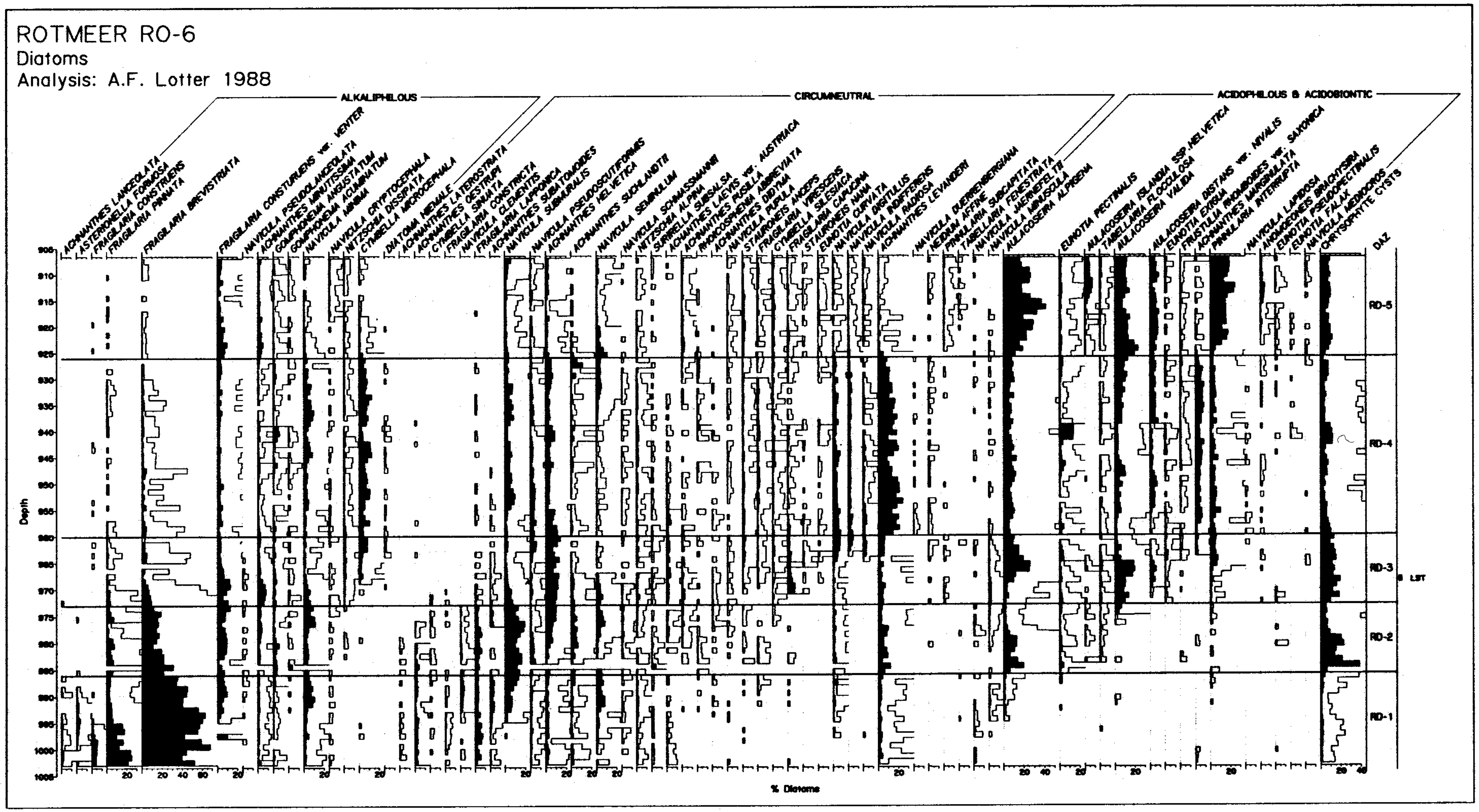


Figure 4. Diatom percentage diagram of Rotmeer core RO-6. Only the most prominent taxa are shown.

Diatom zonation

The diatom stratigraphy was subdivided into 5 diatom assemblage zones (DAZ). The diatoms were grouped according to their pH preferences (Fig.4) into alkaliphilous, circumneutral, acidophilous, and acidobiontic diatoms (see, *e.g.*, HUSTEDT 1937-39; SALDEN 1978). The assignment of some diatoms to a pH category may often, however, not be consistent between different authors (see, *e.g.*, LOWE 1974). In Fig.6 the taxa have also been grouped according to their life-form into planktonic and periphytic species, and the *Fragilaria* species have been grouped separately.

RD-1 (*Fragilaria brevistriata* DAZ) is dominated by alkaliphilous taxa, mainly *Fragilaria* species (*F. brevistriata, F. pinnata*). *Asterionella formosa* with its low abundance is the only planktonic diatom occurring in this zone. RD-2 (*F. brevistriata -Navicula submuralis* DAZ) is characterized by the dominance of circumneutral and alkaliphilous diatoms, but the first acidophilous taxa already begin to occur (*e.g. Aulacoseira alpigena*). During RD-3 (*Aulacoseira valida - A. alpigena* DAZ) the alkaliphilous taxa (mainly *F. brevistriata*) decrease, whereas the acidophilous and acidobiontic *Aulacoseira* species increase. RD-4 (*Achnanthes levanderi* DAZ) is dominated mainly by circumneutral (*e.g. A. levanderi, A. helvetica, Navicula digitulus, N. submuralis*) and alkaliphilous diatoms (*Cymbella microcephala, Navicula minima*). In RD-5 (*Aulacoseira alpigena - A. valida - Pinnularia interrupta* DAZ) acidophilous and acidobiontic diatoms (*Aulacoseira* spp., *Pinnularia interrupta*) increase again and dominate the diatom pH spectra.

Geochemistry

As the pollen zonation agrees well with the geochemical zonation, the geochemistry diagram has been subdivided according to the FIRBAS (1949, 1952) pollen zonation (see below). We have tried to arrange the elements (Fig.7) according to their potential as indicators for past lacustrine and catchment conditions. However, as the time of deposition in the sediment portion analyzed includes some millennia with changing conditions in and around the lake, it is difficult to characterize single elements as unequivocal indicators. Similar difficulties have been stated by JONES *et al.* (1993). Considering these issues, the following elements are considered as erosion indicators: Ti, K, Al, Mg, and Na. The best example is Ti as it is neither mobile, nor does it occur in plants. Si should actually also be grouped with these elements. A substantial part may have been washed into the basin as insoluble quartz. Yet, as the amount of amorphous Si is quite high the actual conditions are obscured.

Indicators for organic production are N, P, Ca, amorphous Si, and to a limited extent also S and Br. N represents the best of these indicators and the N curve shows a contrary behaviour to the Ti curve.

The main tephra indicators are Na and Cl. In addition, P, Ca, and Mn reach high values in the proximity of the LST. This might possibly be due to co-precipitation with fine tephra particles.

The rest of the elements have been arranged according to the similarity of their concentrations.

Discussion

Chronology and vegetation history

Owing to the relatively low amount of organic matter and the scarcity of plant macrofossils in the sediment it was not possible to obtain reasonable radiocarbon dates for the Rotmeer sedimentary record. Preliminary AMS ^{14}C-datings of bulk sediment just below and above the LST yielded ages far too young (Hajdas, unpublished data). However, the distinct LST layer forms an excellent time marker for the 11,000 B.P. level in the late-glacial deposits. Furthermore, the local PAZ of Rotmeer are comparable to the well-dated regional late-glacial PAZ defined for the Swiss Plateau (AMMANN & LOTTER 1989; LOTTER *et al.* 1992). All ages mentioned in this study refer to conventional radiocarbon years B.P. (before present, *i.e.* before 1950, see STUIVER & POLACH 1977).

Based on similarities in the features of some pollen curves (*e.g. Juniperus*, NAP, *Artemisia*, see Fig.3), we suggest that the boundary between local PAZ RP-1 and RP-2 corresponds to the onset of the *Juniperus-Hippophaë* PAZ (CHb-2) of the Swiss Plateau, dated to ca. 12,700 B.P. (see AMMANN & LOTTER 1989). PAZ RP-1 would, therefore, correspond to the Oldest Dryas biozone (Ia) *sensu* FIRBAS (1949, 1954). The vegetation during this zone was treeless, consisting of a mosaic of grasses and sedges, as well as heliophilous herbs such as, *e.g.*, *Saxifraga oppositifolia, Helianthemum* and *Artemisia* (Fig.3). According to plant macroremains found at nearby Schluchsee (OBERDORFER 1931) or Horbacher Moor (LANG 1954) dwarf shrubs such as *Betula nana* and *Salix herbacea, S. myrtilloides,* and *S. retusa* must also have formed an important part of the vegetation in the southern Black Forest. The pollen concentrations in this zone are very low (Fig.5) due to a high sediment accumulation rate and low vegetation cover.

The following PAZ RP-2 and RP-3 consequently correspond to the Bølling biozone (Ib/c), consisting of a first, juniper dominated (RP-2) and a second, birch dominated (RP-3) part. This assignment is supported by several features in the pollen curves, such as the coincidence of peaks in the *Juniperus*, *Hippophaë*, and *Salix* curves. These features compare well to results of other investigations from the Black Forest as well as from the Swiss Plateau. Considering the relatively high percentage values of NAP, and the low concentrations of AP in relation to NAP, it is likely that the vegetation consisted of scattered shrubs of juniper and willow within a landscape dominated by herbs. The onset of the second part of the Bølling biozone (RP-3) is characterized by the rational limit of the *Betula* curve. On the basis of the pollen concentrations (Fig.5) it cannot be decided whether the increase in *Betula* pollen is the result of long-distance transport or the presence of birch trees locally. Sediment lithology (silty clay) as well as the increased amounts of elements indicative of erosion (*e.g.* Ti, Al, K: see Fig.7) suggest an open, treeless vegetation in the Rotmeer catchment area. However, *Betula* macroremains found in contemporaneous lacustrine deposits nearby (*e.g.* LANG 1971) indicate that sparse stands of this tree may have occurred at this time.

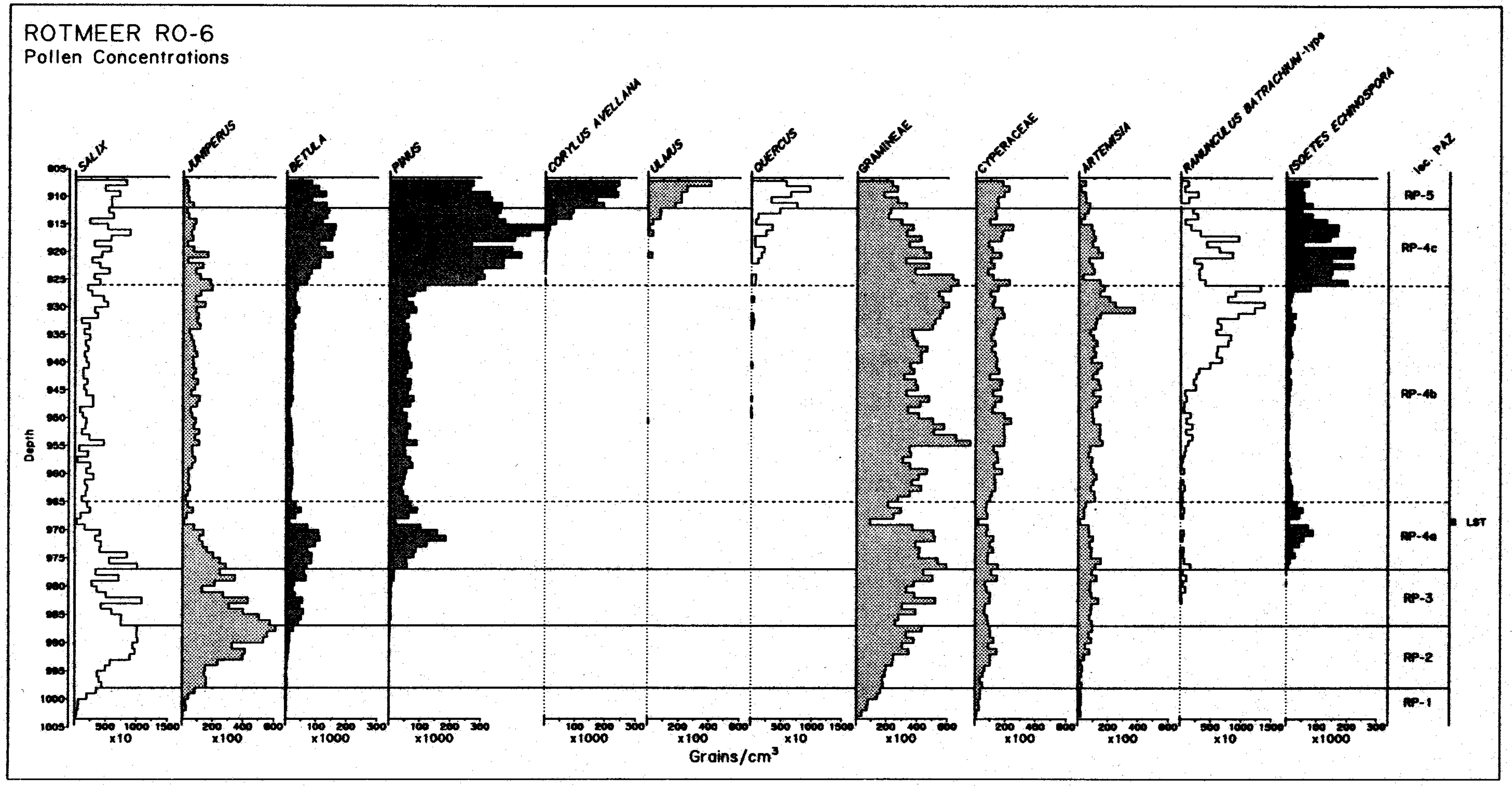


Figure 5. Pollen concentration diagram for Rotmeer core RO-6. Only selected taxa are shown. Note the scale difference for the pollen concentration values for each curve.

On the basis of its palynostratigraphical position just before the rational pine limit, the regressive phase during the second part of RP-3 at ca. 979-982 cm is presumably synchronous with the Aegelsee oscillation (LOTTER *et al.* 1992). This brief climatic fluctuation took place shortly before 12,000 B.P. and can also be detected in the lithology by a decrease in organic matter (Fig.6). Provided sampling resolution is sufficiently high, this feature can be found at many sites in Central Europe and might be synchronous with the Older Dryas pollen zone of Scandinavia (see, *e.g.*, BJÖRCK & MÖLLER 1987). At Rotmeer this phase is characterized by a decrease in AP percentages and concentrations, mainly caused by decreasing birch values (Figs.3 and 5). The increasing NAP percentages (mainly Gramineae and *Artemisia*) as well as the stable NAP concentrations suggest a lowering of the tree line. This is supported by an increase in minerogenic sediment as well as in erosion indicators, such as K, Al, Mg (Fig.7).

The onset of the Allerød biozone (II) is given by the rational limit of the *Pinus* curve. During this zone (RP-4a), the percentages of heliophilous plants (*e.g. Juniperus, Artemisia*), as well as the sum of NAP, decrease steadily. Macroremains of *Betula 'alba'* (*i.e. B. pendula* and *B. pubescens*) and *Pinus* (*sylvestris* and *P. mugo*, OBERDORFER 1931; LANG 1954, 1971) as well as *Pinus* stomata found at neighbouring sites (*e.g.* LANG 1952; LOTTER & HÖLZER 1989) suggest the presence of these trees in the Black Forest during the Allerød. However, based on the high amount of NAP (percentages and concentrations), the forest cover cannot have been very dense. According to the gradual change in lithology at ca. 974 cm and the increasing pollen concentrations, *Pinus* may have been locally present from that stratigraphic level onwards. LANG (1971) infers a timberline at an altitude of at least 950-1000 m a.s.l. for the Allerød biozone on the basis of macrofossils as well as on the occurrence of organic sediments with a low content of minerogenic matter. Moreover, needles of *Pinus mugo* have been found in Allerød deposits at Hornisgrinde in the Northern Black Forest at an altitude of 1000 m a.s.l. (HÖLZER & HÖLZER 1987). Since needles can only be transported a few metres by wind, the timberline has to be assumed to have been at this altitude or even higher.

The occurrence of the LST (968-969 cm) towards the end of this zone (RP-4a) is a good time-horizon for dating the 11,000 B.P level. Multivariate analyses of the pollen sequence indicate that this volcanic event had no statistically significant effect on the pollen assemblages in the Black Forest, despite an increase in NAP percentages (mainly Gramineae and Cyperaceae) after the deposition of the LST (LOTTER & BIRKS 1993; BIRKS & LOTTER, in press).

Local PAZ RP-4b represents a second regressive phase and is attributed to the Younger Dryas biozone (III). The onset of the Younger Dryas biozone has been dated to ca 10,700 B.P. and its end is situated in a phase of constant radiocarbon age centred at 10,000 B.P. (see, *e.g.*, AMMANN & LOTTER 1989). In core RO-6 the increased values (percentages and concentrations) of grasses as well as heliophilous herbs indicate a substantial lowering of the timberline. AP concentrations show that the amount of *Betula* and *Pinus* had decreased significantly during this zone, whereas NAP concentrations remained constant. If we assume a higher sediment accumulation rate during the Younger Dryas biozone due to increased minerogenic sediment input, these higher NAP concentrations would signify a larger extent of open, meadow-like, herbaceous vegetation. LANG (1971) has proposed a timberline at an altitude of 700-800 m during the Younger Dryas. Nevertheless, *Pinus* stomata as well as *Betula 'alba'* fruits have been found in sediments of the first part of Younger Dryas from Black Forest sites at altitudes above 850 m a.s.l. (LANG 1952, 1954). Sediment lithology as well as the increased amount of erosion indicators (Ti, K, Al, Mg, Fig.7), however, suggest a treeless, open vegetation at Rotmeer.

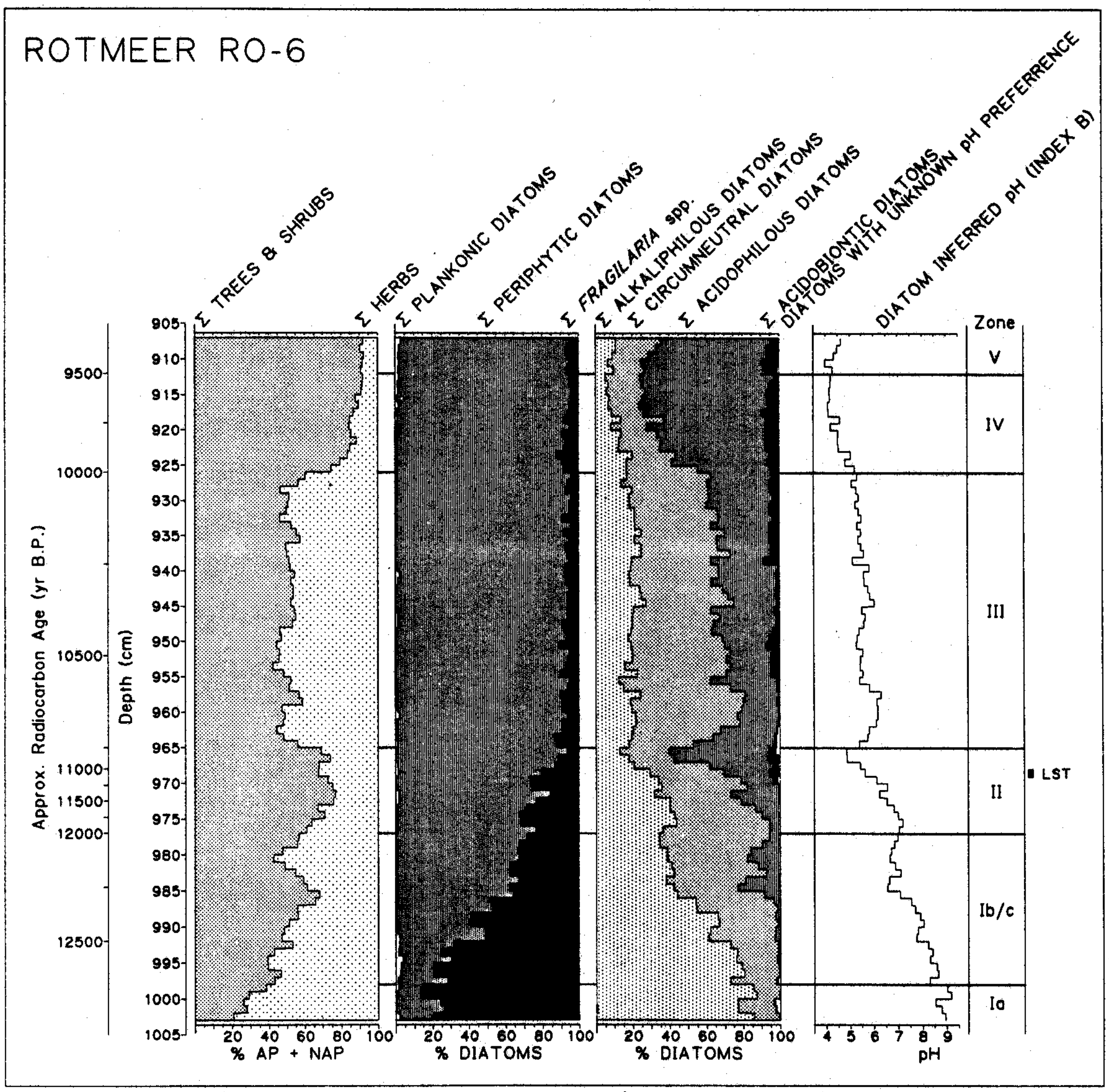


Figure 6. Summary percentage diagrams for Rotmeer core RO-6 pollen and diatom stratigraphies. The diatom-inferred pH reconstruction is based on Index B (RENBERG & HELLBERG 1982).

The last subzone (RP-4c) of the local pine zone is characterized by an increase in AP (principally *Pinus* and *Betula*) combined with a decrease in NAP percentages. This local PAZ compares well with the palynological features known from other investigations in the Black Forest (*e.g.* LANG 1952, 1954, 1971; RÖSCH 1989) and from the Swiss Plateau. It can, therefore, be attributed to the Preboreal biozone (IV), situated between two phases of constant radiocarbon age at 10,000 and at 9500 B.P. (see, *e.g.*, LOTTER 1991; KROMER & BECKER 1992). During this zone, the AP concentrations, especially those of pine and birch, increase considerably, whereas the NAP concentrations decrease (*e.g.* Gramineae) or remain constant. On the one hand the overall increase in pollen concentration is certainly the effect of a sediment accumulation rate that was lower than during the Younger Dryas biozone (III). On the other hand, however, the high pollen concentrations, especially AP, indicate more favourable climatic conditions that led to a rapid upward movement of the tree-limit. Based on the low pollen concentrations of heliophilous taxa (*e.g. Juniperus, Helianthemum, Artemisia*) the pine-birch woodland in the Rotmeer catchment area must have been denser during the Preboreal than during the Allerød biozone (II).

Climatic oscillations during the Preboreal biozone (IV) have been discussed by various authors (*e.g.* BEHRE 1966, 1978; SCHNEIDER 1985; INGOLFSSON 1991). The pollen percentage diagram from Rotmeer hardly indicates a regressive phase in vegetation development during the Preboreal biozone, except maybe an increase in NAP percentages between 917-921 cm (Fig.3). The fluctuations in the *Pinus* percentages from 918-921 cm might represent the normal variation of this curve, and the drop in *Isoëtes echinospora* at 918-919 cm could be an outlier due to a preparation artefact. The overall pollen concentrations, however, show a major decrease centred at 918-919 cm that coincides with a decrease in organic matter (Fig.6) and a short increase in erosion indicators (Ti, K, Al, Mg, Fig.7). The higher sediment accumulation associated with increased erosional minerogenic input has certainly lowered the total pollen concentration (Fig.8). However, it is mainly the decreased AP concentrations that are responsible for this concentration minimum. The NAP concentrations do not decrease substantially, thus indicating primarily a regression in trees. From the chronostratigraphic point of view this event took place around ca. 9500 B.P. Because of its extreme shortness it can only be detected by high resolution studies. It might be correlated with a Preboreal oscillation detected in different oxygen isotope records from the Alps and from Greenland (LOTTER *et al.* 1992), and could be synchronous with a Deuterium minimum measured in tree rings from southern Germany, dated to 9350 B.P. (BECKER *et al.* 1991).

The rational limit of *Corylus* marks the transition to local PAZ RP-5, which is synchronous with the beginning of the Boreal biozone (V). This zone is characterized by the occurrence of pollen of thermophilous trees such as *Quercus* and *Ulmus*. In core RO-6 only the lowermost part of this biozone has been analyzed. According to both pollen percentages and concentrations, the pollen of these taxa must have undergone long-distance transport during this part of the Boreal biozone. During the later part of the Boreal, however, macrofossils of *Corylus* (see LANG 1971: 336) indicate the presence of hazel in the Black Forest.

Percentages of *Betula* and mainly *Pinus* in Rotmeer core RO-6 are on the average 10% lower than in other investigations from this altitude in the Black Forest. This could be due to local effects, such as the topographic situation of the former lake, or to the location of the core in the centre of the former lake, where the pollen of certain taxa may be underestimated (see, *e.g.*, DAVIS *et al.* 1971; AMMANN 1994).

Palaeolimnology

The palaeolimnology of the ancient Rotmeer lake may be reconstructed by means of biological remains such as algae (Figs.3 and 4) and aquatic plants (Fig.3), as well as by the geochemistry (Fig.7). Moreover, the lithology of the deposits can also give valuable information on the development of the lake.

The lowermost sediments in Rotmeer include the highest values (percentages and concentrations) of *Pediastrum*. The occurrence of *Pediastrum* as well as of *Potamogeton* spp. is closely linked to the occurrence of silty clay (see Tab.1 and Fig.3), suggesting that the abundance of these two taxa may be controlled by turbidity and/or transparency of the lake water. It is mainly during the treeless biozones of Oldest Dryas (Ia) and Bølling (Ib/c) as well as during the Younger Dryas (III) that both taxa seem to have their optimal development. The diatom flora of the Oldest Dryas (Ia) and Bølling (Ib/c) is dominated by alkaliphilous and circumneutral species. It is a common phenomenon that many early late-glacial diatom assemblages are dominated by periphytic, alkaliphilous species, mainly *Fragilaria*, even in areas of acidic bedrock (see, *e.g.*, EVANS 1970; HAWORTH 1976, 1985; MARCINIAK 1979, 1988; RAWLENCE 1988) such as the Black Forest region. SMOL (1983) implies a competitive advantage of these species during cooler periods. From pollen and stable isotope studies (see, *e.g.*, LOTTER *et al.* 1992) it is known, however, that a rapid warming took place at the transition from biozone Ia to Ib/c. It is, therefore, more likely that the occurrence of such alkaliphilous, benthic *Fragilaria* assemblages is linked to the availability of nutrients in the water column and to the leaching of base cations from the recently deglaciated catchment area (see, *e.g.*, SMOL 1988), as well as to specific habitat availability.

During the biozones of Oldest Dryas (Ia) and Bølling (Ib/c), the open vegetation favoured extensive erosion of the morainic raw-soils in the Rotmeer catchment area. This is not only evidenced by the sediment lithology, but can also be seen by the increased amount of chemical elements indicative of erosion (Fig.7). With the immigration and expansion of *Pinus*, the soils stabilized and the amount of these elements consequently decreased markedly after the onset of the Allerød (II) biozone. Concurrent with this change in sediment type is the expansion of *Isoëtes echinospora* (= *I. tenella*). The same timing and pattern of late-glacial expansion has been observed in other Black Forest sites as well as on the Swiss Plateau (LANG 1955; WELTEN 1967). Together with the presence of *Myriophyllum alterniflorum*, these aquatics suggest carbonate-poor, oligotrophic conditions. This is also reflected in the diatom flora, where the alkaliphilous taxa decline, mainly in favour of the acidophilous *Aulacoseira alpigena* and *A. valida* (Figs.4 and 6). The deposition of the LST seems to have triggered the expansion of *Aulacoseira* species, especially the heavily silicified *A. valida*. This might be the result of a tephra-induced increased input of SiO_2 and/or other nutrients. According to V.D. BOGAARD & SCHMINCKE (1985), the LST consists of 62% SiO_2. Several studies in connection with tephra depositions in lakes have shown a substantial increase in absolute diatom abundance (*e.g.* KURENKOV 1966; BARSDATE & DUGDALE 1971; HARPER *et al.* 1986), or a fast eutrophication (EICHER & ROUNSEFELL 1957; WARD *et al.* 1983). In RO-6, however, no eutrophication can be evidenced by the diatom assemblages. Moreover, it is only the concentrations of acidophilous and acidobiontic taxa that have increased somewhat after the LST deposition, whereas the other pH-groups, as well as the total diatom concentrations, do not show any significant increase (Fig.8). KILHAM *et al.* (1986) have suggested that higher Si:P ratios lead to changes in diatom assemblages and that *Aulacoseira* species are largely limited by Si and by light. Constrained ordination associated with Monte Carlo permutation tests of the RO-6 diatom assemblages indicate that the deposition of LST and accompanying changes in lithology had statistically significant effects, when the effects of time and climatic change are allowed for. However, due to interactions between LST and lithology it has not been possible to decide whether the observed diatom changes were directly due to tephra deposition or indirectly due to lithological changes (for details see LOTTER & BIRKS 1993; BIRKS & LOTTER in press).

In the geochemical record, the LST layer is well defined by marked peaks in Na, Cl, Ca, and Mn. The decrease in most of the other elements is the result of dilution by the LST. In a similar investigation of Hirschenmoor, a site only some kilometres away from Rotmeer, we suggested that the stratigraphical position of the LST may not correspond to the time of its deposition (LOTTER & HÖLZER 1989). This hypothesis was based on a comparison with the stratigraphical position of the tephra (towards the end of the Allerød biozone) at many other sites as well as on biochemical features (a small Na peak before the transition to the Younger Dryas biozone). The Allerød sediment of RO-6 has a lower content of organic sedimentary matter (Fig.6) than Hirschenmoor. Its sediment thus has a higher specific gravity. This may prevent the heavy glass particles of the LST penetrating far into the uppermost unconsolidated sediment due to large density differences. Such a mechanism has been observed in Washington lakes after the Mt. St. Helens eruption (EDMONDSON 1984; ANDERSON *et al.* 1984). The peaks associated with the LST include three consecutive centimetres, but slightly increased values can be observed in the samples above and below. This could be either the consequence of bioturbation, a graded sinking of the tephra into the surficial organic sediment, or a combination of both. The presence of slightly higher values of, *e.g.*, Ni, Cr, and Mo 2-3 cm below the stratigraphical position of the LST (marked by the Na peak, Fig.7) would favour such a hypothesis of graded sinking of heavier elements into the organic sediment.

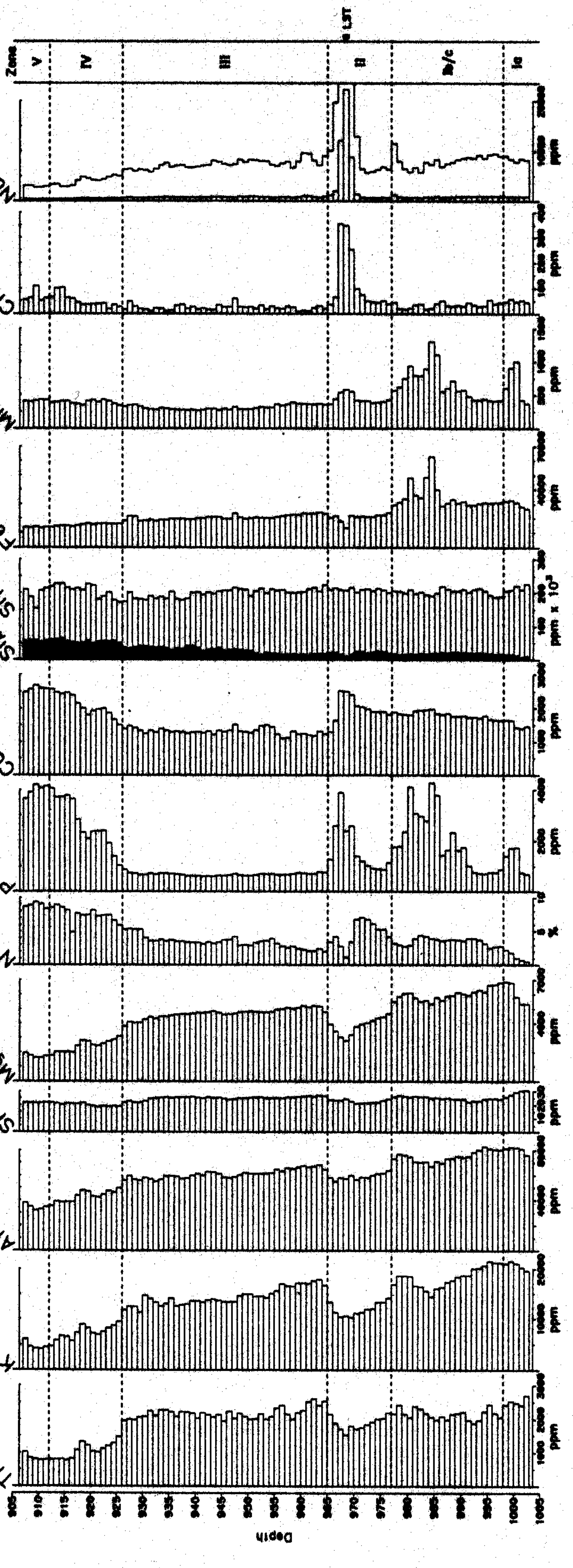
During the Younger Dryas biozone (III), the lithology reflects the lowering of the timberline. The sediment consists mainly of minerogenic matter which originates from soil erosion due to a sparse vegetation cover. The increased occurrence of elements such as Ti, K, Al, and Mg (Fig.7) is a good indicator for this erosional input from the catchment area. Decreasing abundance of *Isoëtes echinospora* (Figs.3 and 5) may indicate unfavourable conditions caused by a cooler climate and/or more turbid water. The diatom assemblages change from a flora dominated mainly by *Aulacoseira* spp. to assemblages characterized by *Achnanthes levanderi, A. marginulata, Cymbella microcephala, Navicula digitulus,* and *N. indifferens*. This mixture of alkaliphilous, circumneutral, and acidophilous periphytic diatoms illustrates the changing limnic conditions and available habitats. During the Younger Dryas biozone (III), the overall diatom concentrations reach values that are higher than those reached during the zones before and after. Considering the higher sediment accumulation rates prevailing during this biozone the diatoms must have produced their maximum biomass during a period of apparently unfavourable climate.

During the second part of the Younger Dryas biozone, aquatics of the *Ranunculus Batrachium* section become more important in the lake. The increase in *Isoëtes echinospora* just one sample before the lithological and palynological end of the Younger Dryas might be an example of the fast reaction to climatic warming exhibited by aquatic vegetation compared to the time-lag exhibited by terrestrial vegetation (see, *e.g.*, IVERSEN 1964).

With the onset of the Preboreal biozone (IV), the erosive minerogenic input decreased rapidly (Fig.7), whereas elements such as N and P reflect the increased biological productivity in the lake. Relative and absolute abundances of alkaliphilous and circumneutral diatoms decrease and the assemblages are again dominated by *Aulacoseira* spp. In the aquatic system, the short regressive phase in terrestrial vegetation development is marked mainly by a decrease in concentrations of *Isoëtes echinospora* at 918-919 cm, whereas the diatoms react by a decrease in percentages and concentrations of acidophilous taxa (mainly *Aulacoseira alpigena*, Figs.4 and 9).

The history of the hydrogen ion concentration at Rotmeer can be traced through the reconstruction of diatom-inferred pH (RENBERG & HELLBERG 1982). Considering the problems in assigning some diatoms to a specific pH category, the inferred pH values may be considered as a preliminary estimate. Nevertheless, we think that the inferred trend of pH decrease through time reflects the changing hydrogen ion concentration in Rotmeer.

ROTMEER RO-6
Geochemistry
Analysis: A. Hölzer 1989



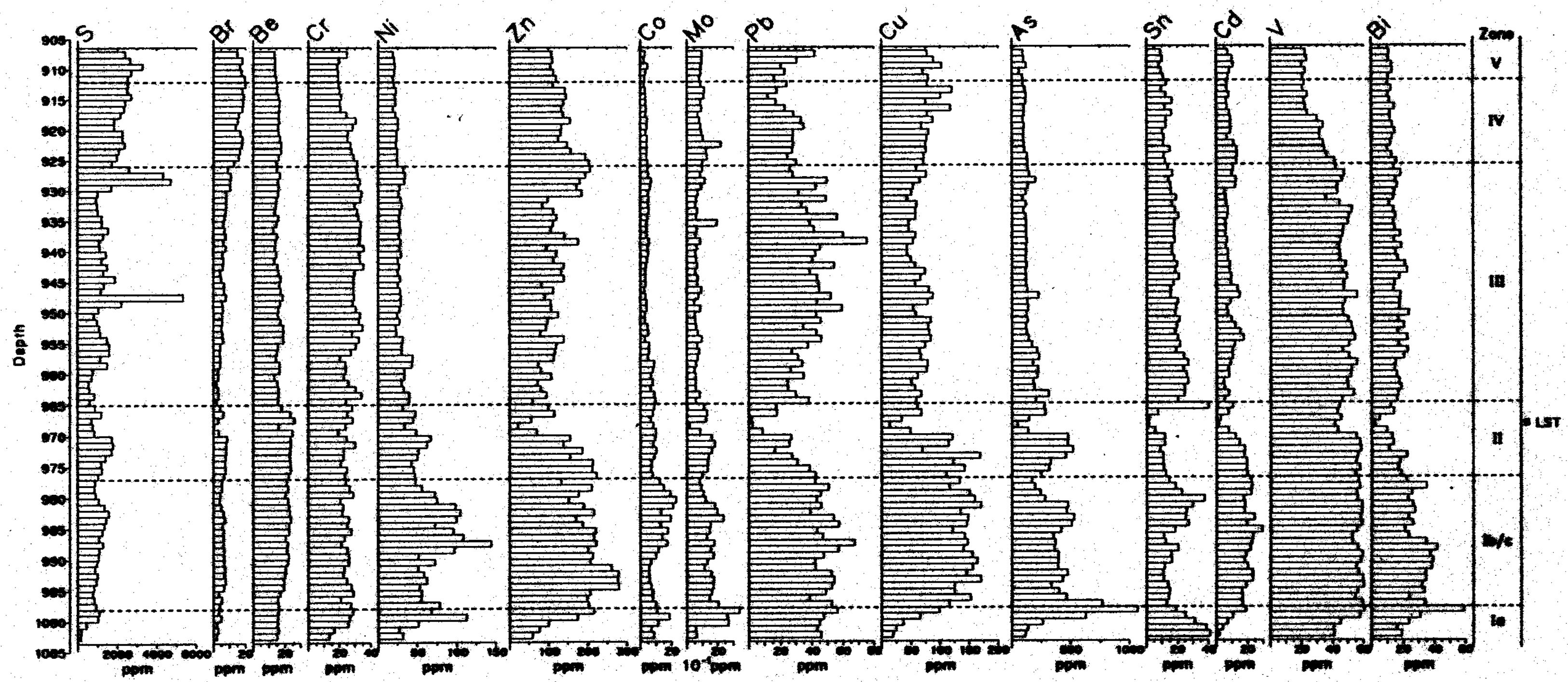


Figure 7. Geochemistry diagrams of Rotmeer core RO-6. Note the scale difference for the different elements.

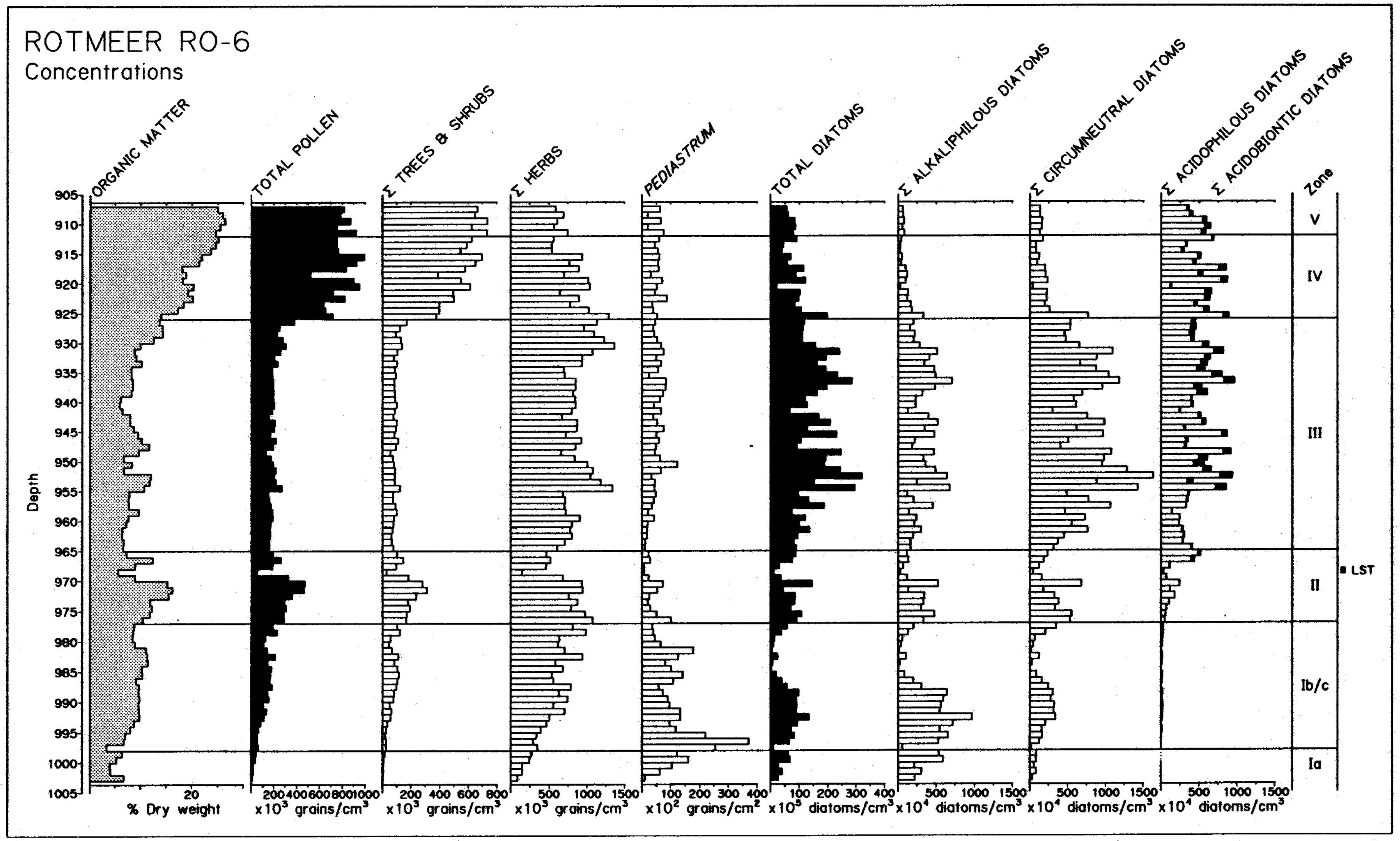


Figure 8. Summary concentration diagrams for Rotmeer core RO-6 pollen and diatom stratigraphies. The amount of organic matter was estimated by loss-on-ignition. Note the scale difference for the concentration values for each curve.

During the Oldest Dryas biozone (Ia), the inferred pH values lie between 8 and 9 (Fig.6). Since the Index B method was originally calibrated for acidic to neutral waters, the pH values may be somewhat overestimated. During the Bølling biozone (Ib/c), however, with decreasing erosional input (Figs.7 and 9) the values begin to drop slightly. Generally, the reconstructed pH values are stable during phases of erosion, but decrease during phases of vegetation development and pedogenesis. Erosional phases may provide some basic cations that would buffer the water. A comparable process of leaching of bases and nutrients, caused however by prehistoric agriculture, has been described lately (RENBERG *et al.* 1993a, b). During phases of favourable climate with vegetation development and pedogenesis, more acidic input into the lake could result from an increased supply of humic acids, produced, *e.g.*, by pine needles.

Geochemistry and site history

The geochemical composition of the sedimentary record reflects well the geochemical nature of the Rotmeer catchment area. Stable environmental conditions are reflected by low changes in the content of elements indicative of soil erosion. Immobile elements are particularly indicative of erosion. Ti is among the most immobile elements. In soils it is mainly present in the form of oxides, and its minerals are almost insoluble. The solubility of Al after weathering is also very low and the its weathering products are among the most stable minerals (URE & BERROW 1982).

The Kjeldahl-N is one of the major productivity indicators. It displays an anticyclic behaviour in relation to the immobile parameters (Fig.9). The nitrogen content rises steadily during phases of climate favourable for plant development (*i.e.* pollen zones Ib/c, II, and IV). The major decrease in the N curve is caused by dilution by the LST. The other decreases in N may, however, be caused by reduced organic production in the lake as a consequence of an unfavourable climate (Aegelsee oscillation, Younger Dryas biozone, Preboreal oscillation). The curve of amorphous Si behaves in a similar way (Fig.9). This element is derived mainly from diatoms, but can also originate from higher plants such as, *e.g.*, *Equisetum* or Cyperaceae. Br displays the same tendencies (Fig.9), maybe by Br-absorption on organic matter. S is mainly bound in organic matter. The S peaks between 925-930 cm and 945-950 cm (Fig.7) are concurrent with higher values of Fe, Mn, Ni, Co, Mo, and As. These elements are likely to have precipitated as sulphides.

The phosphorus curve cannot be explained in a straightforward way. P mineralization in the sediment is dependent, among other things, on redox conditions. Under anoxic conditions at the sediment-water interface, dissolution and remobilization of sediment P can occur (see, *e.g.*, VOLLENWEIDER 1976). Taken in conjunction with the curves of Fe and Mn, the P-curve suggests that there has been co-precipitation of these three elements under oxic conditions (see, *e.g.*, WEHRLI *et al.* 1992) during the late-glacial period. There are no linear relationships between P and the erosion indicators (Fig.9).

The difficulties in interpreting the indicator potential of some elements is exemplified by the relationships existing between N and a series of other elements (Fig.9). Within the Oldest Dryas (Ia) and the Bølling (Ib/c), the trend of the N curve is more or less comparable to the trends of the curves of S, Zn, Cu, Cd, Bi, As, *etc.* This may indicate a bonding of these elements onto the organic matter. However, the Sn curve displays an almost converse behaviour. During the Allerød (II), a similarity in the behaviour of N, S, Ni, Mo, As, *etc.* can be observed. Further up in the sediment the concurrence between these elements is very weak.

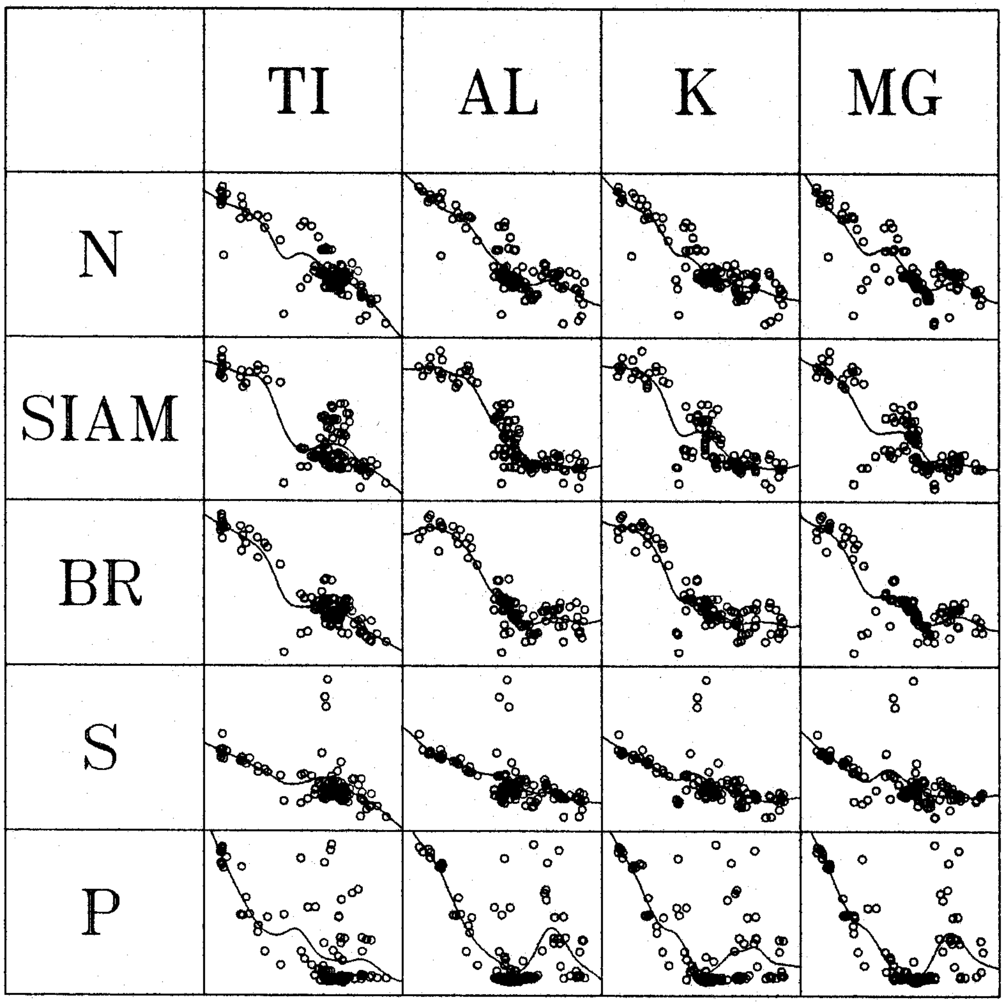


Figure 9. Relationship between erosion indicators (Ti, Al, K, Mg) and productivity indicators (N, amorphous Si, Br, S, P).

The late-glacial fluctuations in the content of heavy metals are not anthropogenically influenced. This is important for any interpretation of heavy metal loads in modern sediments, where shifts of the same order of magnitude are often explained by human impact. In the late-glacial Rotmeer sediments, the As content is extremely high, with maximum values of up to 7000 ppm. In Hirschenmoor (LOTTER & HÖLZER 1989) the As concentrations reached only 30 ppm.

Decreasing pH values accelerate the dissolution of Ca, Mn, Al, Pb, Zn and related elements (see, *e.g.*, TOLONEN & JAAKOLA 1983). The critical values for Zn and Cd seem to be at pH 5.5, for Al and Ca below pH 5, and for Pb below pH 4. TOLONEN & JAAKOLA (1983) have proposed the use of influx values for geochemical parameters. However, this is not possible for the Rotmeer sediments on the basis of the available chronology: the sediment accumulation rates change within very short sediment portions, as can be seen from the variability in the concentration of the erosion indicators Ti, Al, Mg, and K.

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References

AMMANN, B. 1994. Differential flotation of saccate pollen - a nuisance and a chance. *Dissertationes Botanicæ* 234, 101-110.

AMMANN, B. & LOTTER, A.F. 1989. Late-glacial radiocarbon- and palynostratigraphy on the Swiss Plateau. *Boreas* 18, 109-126.

ANDERSEN, R.Y., NUHFER, E.B. & DEAN, W.E. 1984. Sinking of volcanic ash in uncompacted sediment in Williams Lake, Washington. *Science* 225, 505-508.

ARZET, K., KRAUSE-DELLIN, D. & STEINBERG, C. 1986. Acidification of four lakes in the Federal Republic of Germany as reflected by diatom assemblages, cladoceran remains and sediment chemistry. In: SMOL, J.P., BATTARBEE, R.W., DAVIS, R.B., & MERILÄINEN, J. (eds.), *Diatoms and Lake Acidity*. Junk, Dordrecht. 227-250.

BARSDATE, R.J. & DUGDALE, R.C. 1972. Effects of volcanic ashfalls on chemical and sediment characteristics on two Alaskan lakes. *Journal of Fisheries Research Board of Canada* 29, 229-236.

BATTARBEE, R.W. & KNEEN, M.J. 1982. The use of electronically counted microspheres in absolute diatom analysis. *Limnology and Oceanography* 27, 184-188.

BECKER, B., KROMER, B. & TRIMBORN, P. 1991. A stable-isotope tree-ring timescale of the Late-Glacial/Holocene transition. *Nature* 353, 647-649.

BEHRE, K.-E. 1966. Untersuchungen zur spätglazialen und frühpostglazialen Vegetationsgeschichte Ostfrieslands. *Eiszeitalter und Gegenwart* 17, 69-84.

BEHRE, K.-E. 1978. Die Klimaschwankungen im europäischen Präboreal. *Petermanns Geographische Mitteilungen* 1/1978, 97-102.

BIRKS, H.J.B. & GORDON, A..D. 1985. *Numerical Methods in Quaternary Pollen Analysis*. Academic Press, London. 1-317.

BIRKS, H.J.B. & LOTTER, A.F. The impact of the Laacher See volcano (11,000 yr B.P.) on terrestrial vegetation and diatoms. *Journal of Paleolimnology*, in press.

BJÖRCK, S. & MÖLLER, P. 1987. Late Weichselian environmental history in southeastern Sweden during the deglaciation of the Scandinavian Ice Sheet. *Quaternary Research* 28, 1-37.

BLACK, C.A. (ed.) 1965. *Methods of Soil Analysis*. Part 1. Physical and Mineralogical Properties, including Statistics of Measurements and Sampling. Madison. 770 pp.

BOGAARD, P., V.D. & SCHMINCKE, H.-U. 1985. Laacher See Tephra: a widespread isochronous late Quaternary tephra layer in central and northern Europe. *Bulletin of the Geological Society of America* 96, 1554-1571.

BOGENRIEDER, A., PRINZ, J. & RÖCK, M. 1989. Eine Hausmülldeponie im Moor. Auswirkungen einer Altlast - Ein Beispiel aus dem südlichen Schwarzwald. *TELMA* 19, 171-186.

BROCHE, W. 1929. Pollenanalytische Untersuchungen an Mooren des südlichen Schwarzwaldes und der Baar. *Berichte Naturforschende Gesellschaft zu Freiburg i.Br.* 29, 1-243.

CAMBURN, K.E., KINGSTON, J.C. & CHARLES, D.F. (eds.) 1984-1986. PIRLA Diatom Iconograph. *PIRLA unpublished Report Series* 3.

DAVIS, M.B., BRUBAKER, L.B. & BEISWENGER, J.M. 1971. Pollen grains in lake sediments: pollen percentages in surface sediments from southern Michigan. *Quaternary Research* 1, 450-467.

DIERSSEN, B. & DIERSSEN, K. 1984. Vegetation und Flora der Schwarzwaldmoore. *Beihefte Veröffentlichungen Naturschutz und Landschaftspflege Baden-Württembergs* 39, 1-512.

EDMONDSON, W.T. 1984. Volcanic ashes in lakes. *Northwest Environmental Journal* 1, 139-150.

EICHER, G. & ROUNSEFELL, G. 1957. Effects of lake fertilization by volcanic activity on abundance of salmon. *Limnology and Oceanography* 2, 70-76.

EVANS, G.H. 1970. Pollen and diatom analyses of the late-Quaternary deposits in the Blelham basin, north Lancashire. *New Phytologist* 69, 821-874.

FIRBAS, F. 1949. *Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nördlich der Alpen.* Erster Band: Allgemeine Waldgeschichte. Fischer, Jena. 1-480.

FIRBAS, F. 1954. Die Synchronisierung der mitteleuropäischen Pollendiagramme. *Danmarks Geologiske Undersøgelse* II, 80, 12-21.

GOLZ, H. V.D., MÜLLER, G., RAISCH, W. & WIPF, J. 1976. *Die Bodengesellschaften im oberen Haslachtal bei Neuglashütten (Hochschwarzwald).* Diplomarbeit Universität Freiburg im Breisgau, 249 pp.

GRIMM, E.C. 1987. CONISS: A FORTRAN 77 program for stratigraphically constrained cluster analysis by the methods of incremental sum of squares. *Computers and Geosciences* 13, 13-35.

INGOLFSSON, O. 1991. A review of the late Weichselian and early Holocene glacial and environmental history of Iceland. In: MAIZELS, J.K. & CASELDINE, C. (eds.), *Environmental Change in Iceland: Past and Present.* Kluwer, Dordrecht. 13-29.

HARPER, M.A., HOWORTH, R. & MCLEOD, M. 1986. Late Holocene diatoms in Lake Poukawa: effects of airfall tephra and changes in depth. *New Zealand Journal of Marine and Freshwater Research* 20, 107-118.

HAWORTH, E.Y. 1976. Two Late-Glacial (Late Devensian) diatom assemblages from northern Scotland. *New Phytologist* 77, 227-256.

HAWORTH, E.Y. 1985. The highly nervous system of the English lakes: aquatic ecosystem sensitivity to external changes, as demonstrated by diatoms. *FBA Annual Report* 53, 60-79.

HÖLZER, A. & HÖLZER, A. 1987. Paläoökologische Moor-Untersuchungen an der Hornisgrinde im Nordschwarzwald. *Carolinea* 45, 43-50.

HUSTEDT, F. 1937-1939. Systematische und ökologische Untersuchungen über die Diatomeenflora von Java, Bali und Sumatra. *Archiv für Hydrobiologie Supplement* 15 & 16.

IVERSEN, J. 1964. Plant indicators of climate, soil, and other factors during the Quaternary. *INQUA Report Warsaw* 1961, 2, 421-428.

JONES, V.C., FLOWER, R.J., APPLEBY, P.G., NATANSKI, N., RICHARDSON, N., RIPPEY, B., STEVENSON, A.C. & BATTARBEE, R.W. 1993. Palaeolimnological evidence for the acidification and atmospheric contamination of lochs in the Cairngorm and Lochnagar areas of Scotland. *Journal of Ecology* 81, 3-24.

KILHAM, P., KILHAM, S.S. & HECKY, R.E. 1986. Hypothesized resource relationship among African planktonic diatoms. *Limnology and Oceanography* 31, 1169-1181.

KRAMMER, K. & LANGE-BERTALOT, H. 1986-1991. Bacillariophyceae. In: ETTL, H., GERLOFF, J., HEYNIG, H. & MOLLENHAUER, D. (eds.), *Süsswasserflora Mitteleuropas.* Band 2/1-4. G. Fischer, Stuttgart.

KROMER, B. & BECKER, B. 1992. Tree-ring ^{14}C calibration at 10,000 BP. In: BARD, E. & BROECKER, W.S. (eds.), The Last Deglaciation. *NATO ASI Series* I 2, 3-11.

KURENKOV, I.I. 1966. The influence of volcanic ashfall on biological processes in a lake. *Limnology and Oceanography* 11, 426-429.

LANG, G. 1952. Zur späteiszeitlichen Vegetations- und Florengeschichte Südwestdeutschlands. *Flora* 139, 243-294.

LANG, G. 1954. Neue Untersuchungen über die spät- und nacheiszeitliche Vegetationsgeschichte des Schwarzwaldes. I. Der Hotzenwald im Südschwarzwald. *Beiträge zur naturkundlichen Forschung in Südwestdeutschland* 13, 3-42.

LANG, G. 1955a. Neue Untersuchungen über die spät- und nacheiszeitliche Vegetationsgeschichte des Schwarzwaldes. II. Das absolute Alter der Tannenzeit im Südschwarzwald. *Beiträge zur naturkundlichen Forschung in Südwestdeutschland* 14, 24-31.

LANG, G. 1955b. Über spätquartäre Funde von *Isoëtes* und *Najas flexilis* im Schwarzwald. *Bericht deutsche botanische Gesellschaft* 68, 24-27.

LANG, G. 1963. Chronologische Probleme der späteiszeitlichen Vegetationsentwicklung in Südwestdeutschland und im französichen Zentralmassiv. *Pollen et Spores* 5, 129-142.

LANG, G. 1967. Über die Geschichte von Pflanzengesellschaften auf Grund quartärbotanischer Untersuchungen. In: TÜXEN, R. (ed.), *Pflanzensoziologie und Palynologie*. Junk, Den Haag. 24-37.

LANG, G. 1971. Die Vegetationsgeschichte der Wutachschlucht und ihrer Umgebung. *Die Wutach.* 323-349.

LANG, G. 1975. Palynologische, grossrestanalytische und paläolimnologische Untersuchungen im Schwarzwald - ein Arbeitsprogramm. *Beiträge naturkundliche Forschung in Südwestdeutschland* 34, 201-208.

LANG, G. 1992. Some aspects of European late- and post-glacial flora history. *Acta Botanica Fennica* 144, 1-17.

LANG, G., MERKT, J. & STREIF, H. 1984. Spätglazialer Gletscherrückzug und See- und Moorentwicklung im Südschwarzwald, Südwestdeutschland. In: LANG, G. (ed.), Festschrift Max Welten. *Dissertationes Botanicæ* 72, 213-234.

LOTTER, A. 1988. Paläoökologische und paläolimnologische Studie des Rotsees bei Luzern. *Dissertationes Botanicæ* 124, 1-187.

LOTTER, A.F. 1991. Absolute dating of the late-glacial period in Switzerland using annually laminated sediments. *Quaternary Research* 35, 321-330.

LOTTER, A.F. & HÖLZER, A. 1989. Spätglaziale Umweltverhältnisse im Südschwarzwald: Erste Ergebnisse paläolimnologischer und paläoökologischer Untersuchungen an Seesedimenten des Hirschenmoores. *Carolinea* 47, 7-14.

LOTTER, A.F., EICHER, U., BIRKS, H.J.B. & SIEGENTHALER, U. 1992. Late-glacial climatic oscillations as recorded in Swiss lake sediments. *Journal of Quaternary Science* 7, 187-204.

LOTTER, A.F. & BIRKS, H.J.B. 1993. The impact of the Laacher See Tephra on terrestrial and aquatic ecosystems in the Black Forest (Southern Germany). *Journal of Quaternary Science* 8, 263-276.

LOWE, R.L. 1974. Environmental requirements and pollution tolerance of freshwater diatoms. *EPA Report* 670/4-74-005. 332 pp.

MARCINIAK, B. 1979. Dominant diatoms from Late Glacial and Holocene lacustrine sediments in northern Poland. *Nova Hedwigia Beihefte* 64, 411-426.

MARCINIAK, B. 1988. Diatoms in bottom sediments of Lake Hobschen, Simplon, Switzerland. Preliminary report. In: LANG, G. & SCHLÜCHTER, C. (eds.), *Lake and mire environments during the last 15000 years*. Balkema, Rotterdam. 31-39.

MERKT, J. & STREIF, H.J. 1970. Stechrohr-Bohrgeräte für limnische und marine Lockersedimente. *Geologisches Jahrbuch* 88, 137-148.

METZ, R. 1977. *Mineralogisch-landeskundliche Wanderungen im Nordschwarzwald.* Schauenburg Verlag, Lahr. 1-632.

OBERDORFER, E. 1931. Klima- und Vegetationsgeschichte des Schluchsees (Schwarzwald). *Berichte Naturforschende Gesellschaft zu Freiburg i.Br.* 31, 1-85.

PENNINGTON, W., HAWORTH, E.Y., BONNY, A.P. & LISHMAN, J.P. 1972. Lake sediments in northern Scotland. *Philosophical Transactions of the Royal Society London* B 264, 191-294.

PRINZ, J. 1986. *Vegetationskundliche und standörtliche Untersuchungen im Rotmeer (Gemeinde Feldberg, Bärental).* Diplomarbeit Universität Freiburg im Breisgau. 102 pp.

RAWLENCE, D.J. 1988. The post-glacial diatom history of Splan Lake, New Brunswick. *Journal of Paleolimnology* 1, 51-60.

RENBERG, I. & HELLBERG, T. 1982. The pH history of lakes in south-western Sweden, as calculated from the subfossil diatom flora of the sediments. *Ambio* 11, 30-33.

RENBERG, I., KORSMAN, T. & BIRKS, H.J.B. 1993a. Prehistoric increase in the pH of acid-sensitive Swedish lakes caused by land-use changes. *Nature* 362, 824-826.

RENBERG, I., KORSMAN, T. & ANDERSON, N.J. 1993b. A temporal perspective of lake acidification in Sweden. *Ambio* 22, 264-271.

RÖSCH, M. 1989. Pollenprofil Breitnau-Neuhof: Zum zeitlichen Verlauf der holozänen Vegetationsentwicklung im südlichen Schwarzwald. *Carolinea* 47, 15-24.

SALDEN, N. 1978. Beiträge zur Ökologie der Diatomeen (Bacillariophyceae) des Süsswassers. *Dechenia Beihefte* 22, 1-238.

SCHNEIDER, R. 1985. Lago di Ganna - Late-Glacial and Holocene environments of a lake in the southern Alps. In: LANG, G. (ed.), Swiss Lake and Mire Environments during the last 15000 years. *Dissertationes Botanicæ* 87, 229-271.

SCHÖNIGER, W. 1961. Die Kolbenmethode in der organischen Mikroelementanalyse. *Zeitschrift für Analytische Chemie* 181, 28-39.

SMOL, J.P. 1983. Paleophycology of a high arctic lake near Cape Herschel, Ellesmere Island. *Canadian Journal of Botany* 61, 2195-2204.

SMOL, J.P. 1988. Paleoclimate proxy data from freshwater arctic diatoms. *Verhandlungen Internationale Vereinigung für Limnologie* 23, 837-844.

STARK, P. 1912. Beiträge zur Kenntnis der eiszeitlichen Flora und Fauna Badens. *Berichte Naturforschende Gesellschaft zu Freiburg i.Br.* 19, 1-120.

STARK, P. 1924. Pollenanalytische Untersuchungen an zwei Schwarzwaldhochmooren. *Zeitschrift für Botanik* 16, 593-618.

STEINBERG, C., ARZET, K., KRAUSE-DELLIN, D., SANIDES, S. & FRENZEL, B. 1987. Long core study of natural and anthropogenic acidification of Huzenbachersee, Black Forest, Federal Republic of Germany. *Global Biogeochemical Cycles* 1, 89-95.

STOCKMARR, J. 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores* 13, 612-615.

STUIVER, M. & POLACH, H.A. 1977. Discussion: reporting of ^{14}C-data. *Radiocarbon* 19, 355-363.

TOLONEN, K. & JAAKOLA, T. 1983. History of lake acidification and air pollution studied on sediments in South Finland. *Annales Botanici Fennici* 20, 57-78.

TROELS-SMITH, J. 1955. Characterization of unconsolidated sediments. *Danmarks Geologiska Undersøgelse* IV, 3/10.

URE, A.M. & BERROW, M.L. 1982. The elemental constituents of soils. In: BOWEN, H.J.M. (ed.), *Environmental chemistry*, Vol. 2. 286 pp.

VOLLENWEIDER, R.A. 1976. Rotsee, a source, not a sink for phosphorus? *Schweizerische Zeitschrift für Hydrologie* 38, 29-34.

WARD, A.K., BAROSS, J.A., DAHM, C.N, LILLEY, M.D. & SEDELL, J.R. 1983. Qualitative and quantitative observations on aquatic algal communities and recolonization within the blast zone of Mt. St. Helens, 1980 and 1981. *Journal of Phycology* 19, 238-247.

WEHRLI, B., VENTLING, A. & MÜLLER, R. 1992. Biogeochemische Prozesse an der Sedimentoberfläche. *EAWAG-Mitteilungen* 34, 19-22.

WELTEN, M. 1967. Ein Brachsenkraut, *Isoëtes setacea* Lam., fossil im schweizerischen Molasseland. *Botanisches Jahrbuch* 86, 527-536.

ZÖTTL, H.W. (ed.) 1979. Exkursionführer zur Jahrestagung 1979 in Freiburg i.Br. *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft* 28, 1-398.