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Late Glacial and Holocene Litho- and Biostratigraphy of Lake Biel, Western Switzerland

BY

BARBARA WOHLFARTH[1] and ANNE-MARIE SCHNEIDER[2]

Abstract.–WOHLFARTH B. and SCHNEIDER A.-M., 1991. Late Glacial and Holocene Litho- and Biostratigraphy of Lake Biel, Western Switzerland. *Bull. Soc. vaud. Sc. nat. 80.4*: 435-457.

Cores and outcrops from the southern shore of Lake Biel were studied to reconstruct the nearshore environment of the lake between c. 12,000 and 5,000 yrs BP. Core correlations were established by lithostratigraphical and pollen analytical correlations. From the Allerød to the Preboreal time quiet hydrodynamic conditions favoured the deposition of lake marl in the littoral zone and peat on the shore. Between ?the Preboreal and the Atlantic the littoral zone shows a higher hydrodynamic environment with allochthonous material, whereas peat and clay layers are recorded from the shore. From Younger Atlantic to Subboreal time the littoral zone displays quiet conditions again with sedimentation of lake marl.

On the basis of these results a lake level curve for Lake Biel is proposed: high lake level stands can be traced during the Allerød, Boreal, Older Atlantic and Younger Atlantic biozones; low lake level stands are found during the Allerød, Younger Dryas, Preboreal and Older Atlantic biozones.

Keywords.–Late Glacial, Holocene, lake sediments, palynology, lake level changes.

Résumé.–WOHLFARTH B. et SCHNEIDER A.-M., 1991. Lithostratigraphie et biostratigraphie du lac de Bienne (Suisse occidentale) pendant le Tardi- et le Postglaciaire. *Bull. Soc. vaud. Sc. nat. 80.4*: 435-457.

Une reconstitution de l'environnement du lac de Bienne pendant le Tardi- et le Postglaciaire a été effectuée à partir de carottages lacustres et de sondages terrestres.

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Les données lithostratigraphiques et palynologiques ont permis d'établir les corrélations de ces sondages. Les séquences obtenues peuvent être divisées en six unités lithologiques, elles-mêmes subdivisées en cinq cycles sédimentaires.
De l'Allerød au Préboréal, des conditions hydrodynamiques calmes favorisent le dépôt de craie lacustre en zone littorale et celui de tourbe sur le rivage. Entre le Préboréal et l'Atlantique, l'hydrodynamisme est plus agité en zone littorale: il y a apport de matériel allochtone, et, dans le même temps, dépôt de tourbe et d'argile sur le rivage. De l'Atlantique récent au Subboréal, la zone littorale offre à nouveau un hydrodynamisme plus calme, avec dépôt de craie lacustre.
Une courbe des fluctuations des niveaux du lac de Bienne est proposée: le niveau du lac était haut pendant l'Allerød, le Boréal, l'Atlantique ancien et l'Atlantique récent. Il était bas pendant l'Allerød, le Dryas récent, le Préboréal et l'Atlantique ancien.

1. INTRODUCTION

The near shore littoral environments of large lakes are characterised by evidence of multiple erosion and sedimentation. These processes depend largely on the hydrodynamics (waves, currents, water table) and morphology of the lake, river influx (sediment supply), bedrock, shore topography, catchment vegetation, and on climatic changes. All these factors interact and are interrelated. Thus the near shore sequences recorded today consist of primary sediments, together with reworked and redeposited sediments or of completely eroded layers which may change within a short distance.

To establish a litho-and palynostratigraphy requires 'complete' or at least continuous sequences, which are often lacking in near shore sediments. Therefore single drillings in these environments are not able to reflect the complete depositional history of the littoral zone. Only by comparing a large number of cores from the same area can an attempt be made to reconstruct the near shore sedimentary development.

Lake Biel is situated in Western Switzerland (Fig. 1) southeast of the Jura Mountains which consist of Jurassic and Cretaceous limestones. To the east, south and southwest are the Swiss Plateau with Tertiary Molasse hills (calcareous sandstones and marls) and overdeepened basins, filled with Quaternary deposits (Fig. 2); one of these overdeepened troughs contains Lake Biel and Lake Neuchâtel. A second basin lies to the east and includes Lake Murten and the alluvial plain of the River Aare. The area was covered by the most recent advance of the Rhone glacier, during the Upper Würmian (JÄCKLI 1970, WOHLFARTH-MEYER 1987).

The total surface area of the lake is 39,4 km^2 and its average water level is 429-430 m a.s.l. At its deepest point, west of Sutz, the water depth increases to 75 m (Fig. 1). The lake can be divided into the littoral zone, the slope and the basin. The littoral zone on the southwestern and southeastern shore extends up to 500 m into the lake and has an average water depth of 5 m.

The rivers Zihl and Schüss enter the lake, but the most important influx is the River Aare, which discharges into the lake through an artificial channel since 1878 (Fig. 1). An artificial lowering of the lake level by 2.2 m, and an

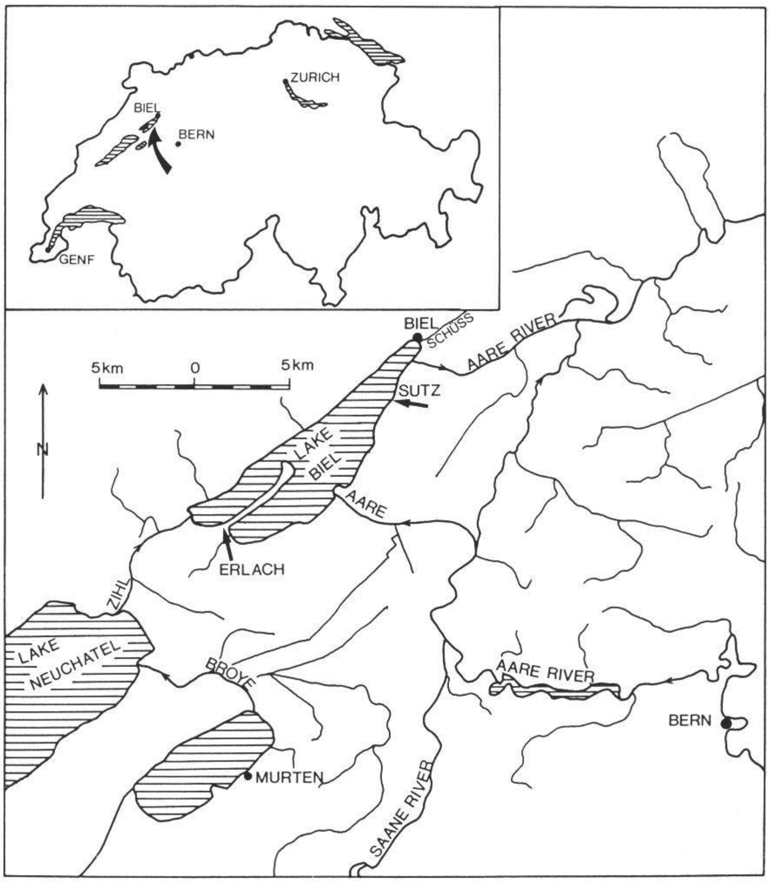

Figure 1.–Situation of Lake Biel in western Switzerland. The two localities studied are Sutz on the eastern shore and Erlach on the southern shore of the lake. The river Aare has been canalised into the lake since the year 1878.

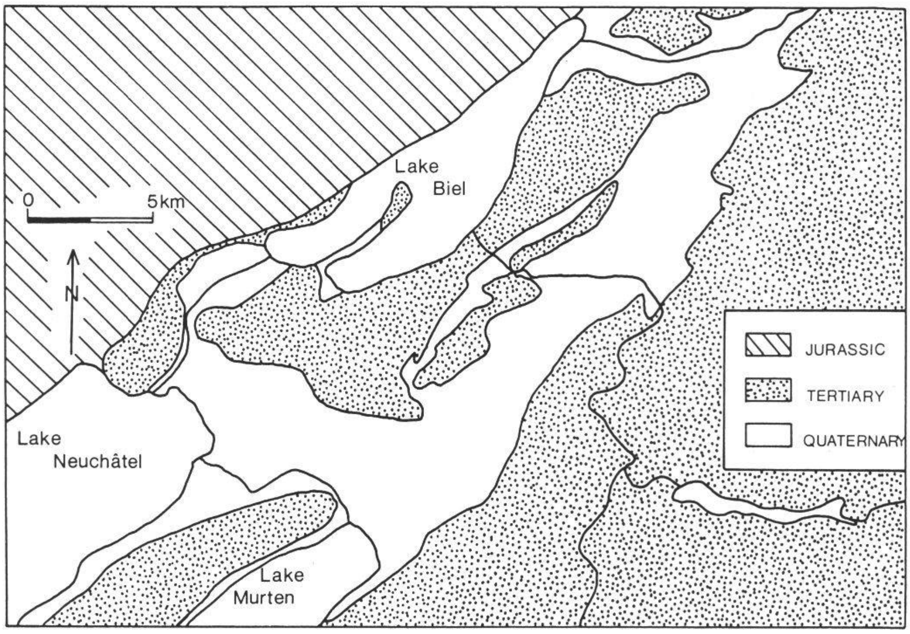

Figure 2.–Simplified geological map of the Lake Biel area. The lakes and the alluvial plain of the Aare river are situated in overdeepened troughs, filled with Quaternary sediments.

intensive drainage network constructed during the years 1868–1891 and 1962–1968 changed the hydrology of the basin to a great extent. The lowering of the lake level changed the original lake shore sedimentation and vegetation and might be considered responsible for the increased erosion of the present shore.

In order to determine the degree of erosional impact on Neolithic and Bronze age lake settlements, the Archaeological Survey of the Bern Canton, Switzerland undertook 1,300 drillings in the littoral zone of the lake.

In addition to the archaeological project it was possible to describe and sample most of the cores and to study several sections in construction pits beyond the shoreline. The purpose of this article is to discuss the geological and palynological investigations at two sites: Sutz and Erlach which are located on the eastern and southern shore of the lake (Fig. 1). Based on these results we propose a lake level curve for Lake Biel between the Allerød and the Atlantic.

2. METHODS

Drilling was carried out from a specially constructed raft (WINIGER 1989). A 3 m or 2 m long PVC tube 10 cm in diameter was hammered into the soft sediment and withdrawn using a handle. On land, the sediment was extruded using compressed air, the cores were cut into halves and cleaned. Because of the large number of drillings made (at Sutz IV and V 167 cores, each 3 m), the corings had to be completed within a limited time. All cores taken along the same line could be compared and recorded together, so that the extension of various layers and possible disturbances could be traced on site. At Sutz IV and V the cores were placed in lines perpendicular to the shore, 4 to 8 m apart; one transect parallel to the shore, with cores each 20 m apart was also drawn for archaeological purposes. Of 167 cores taken in Sutz IV and V, 10 cores were chosen for sedimentological analysis and 9 for palynological analysis (Fig. 3).

In Erlach, the outcrop was located in a large construction pit (20 x 30 m in size) beyond the present shoreline.

The sample preparation for pollen analysis followed procedures of FAEGRI and IVERSEN (1975). *Lycopodium* tablets were added in order to calculate concentrations (STOCKMARR 1971); these results will be presented in a later paper (thesis A.-M. SCHNEIDER *in prep*). The reference collections and photographs of the palynological labs in Berne and Lausanne were used, as well as the following keys: FAEGRI and IVERSEN (1975), MOORE and WEBB (1978), GAILLARD (1984), PUNT *et al.* (1976, 1980, 1981, 1984). The identification of conifer stomata is based on TRAUTMANN (1953). Calculation and plotting of the diagrams was partially undertaking using a computer programme by A. Tranquillini (University of Innsbruck) and partially by hand. Unless otherwise stated the basic pollen sum is AP + NAP = 100%, i.e. including *Cyperaceae*, excluding water plants and Pteridophytes.

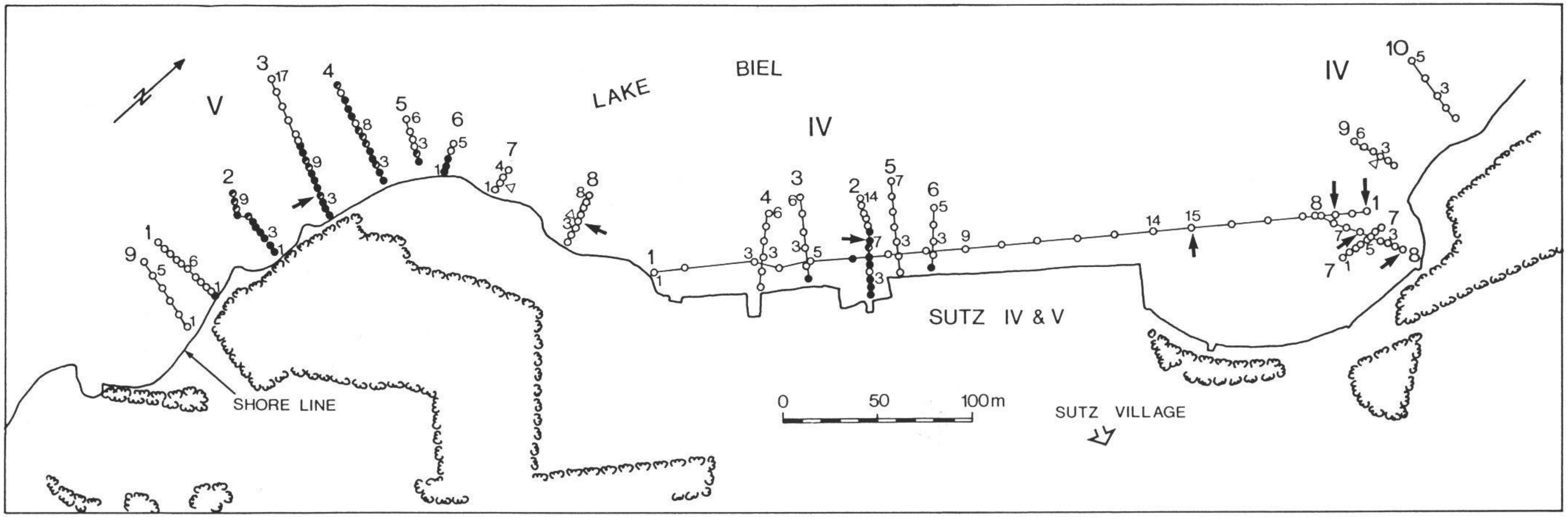

Figure 3.–Position of the cross sections in Sutz IV and V. The larger numbers refer to the cross section numbers, the smaller ones indicate the core number. Black circles show sections where cultural layers were found, white circles show cores without cultural layers and half black/half white circles indicate reworked antropogenic layers. Black arrows point to cores studied by pollen analysis, triangles to those where sediment samples were taken. In this paper the cross sections Sutz IV, 2 - 6 and 8 - 10 are discussed.

The sedimentological investigations include grain size analysis, determination of carbonate content and analysis of the sand fraction between 0.5–1.0 mm diameter. In this fraction the following components were differentiated: allochthonous mineral grains (quartz, alpine and Jurassic limestones, crystalline rock fragments), carbonate concretions (biogenically precipitated carbonate crusts, charophyte fructifications, oncoids (SCHÖTTLE and MÜLLER 1968, PERYT 1983, table 2), mollusc debris, gastropods, plant and wood fragments and charcoal fragments. In each sample 250–300 grains were counted and their percentage was plotted graphically.

In addition to the palynological and geological analysis two radiocarbon dates on peat and wood were obtained from Erlach.

3. LITHOLOGY AND LITHOSTRATIGRAPHY AT SUTZ

The sequence at Sutz IV and V can be divided into 6 local lithological units (A–F), which can be recognized in a large number of cores along the southern shore of the lake. These units are distinguished by colour, grain size, content of organic matter, carbonate concretions, detrital rock fragments and anthropogenic debris. Units comprising equivalent grain sizes were distinguished by the amount of mineralogical or biogenic components (Fig. 4, 5 and 6).

Within sediment units B and C five sedimentary “cycles” (1–5) were distinguished. The succession of these “cycles” was obtained by correlating the different layers of all sections along the same section line on the basis of lithological variations (grain size, thickness, colour, erosional features). The results were then compared with neighbouring cross sections (Fig. 4, 5). Each “cycle” was defined by a coarsening upward sequence including from the base upwards: clayey silt or lake marl, alternating layers of clayey silt and fine sand, fine sand, medium sand and coarse sand. Complete sequences are only developed in some cores reflecting the preservation potential in the near shore zone.

In general the following sediment types were distinguished:

a.–a stiff, overconsolidated greyish clayey silt with gravel (<1.5 mm diameter) and reworked reddish and pink Tertiary marl fragments (Fig. 5, cross section 8).

b.–rounded gravel (2-63 mm diameter) and coarse sand (0.63–2 mm diameter). The gravel consists of up to 70% of reworked Tertiary clasts (marls, crystalline rock fragments) and of up to 30% of alpine and Jurassic clasts (Fig. 6, section 8/6).

c.–a coarse sand (0.63–2 mm diameter), a medium sand (0.2–0.063 mm diameter) and a fine sand (0.063–0.02 mm diameter) which are either of greenish brown colour (unit B) or of grey colour (unit C) (Fig. 4, 5). Their components are made up of detrital quartz, limestone grains (alpine, Jurassic) and crystalline rock fragments which derive either from underlying glacial deposits or from reworked Tertiary sandstones. In addition carbonate

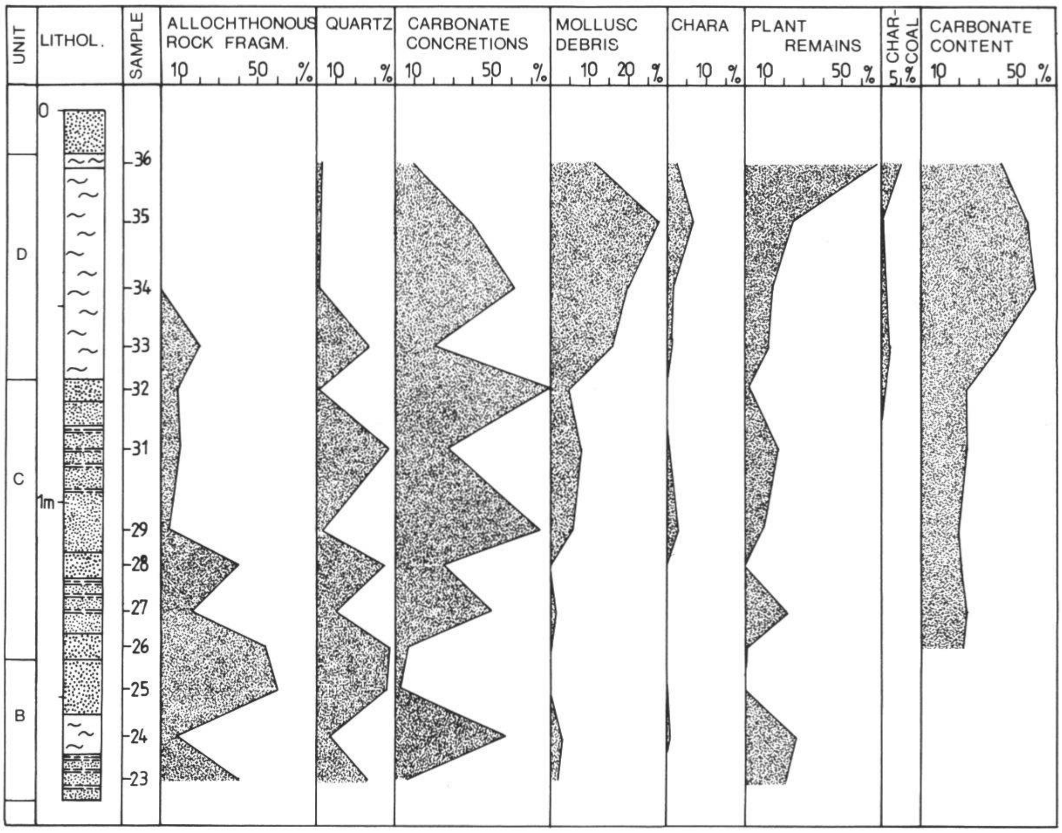

Figure 6.–Analysis of the 0.5 - 1.0 mm fraction and carbonate content of section 8/4 of Sutz V. Unit B is generally characterized by a high amount of allochthonous rock fragments, whereas unit C and D show an increase in carbonate concretions. See Fig. 3 for the location of the core and Fig. 8 for the sediment legend.

concretions, oncoids, gastropod and mollusc debris and plant fragments occur. The fraction 0.5–1 mm diameter shows an amount of 10 - 70% detrital grains, 5–70% carbonate concretions and 0–30% plant remains (Fig. 6). In general the detrital grains decrease in the grey sand, where more carbonate concretions, oncoids, mollusc and gastropod debris are present. The oncoids show commonly a shell or stone nucleus and range in size from 0.5–5 mm. The carbonate content of the grey sand lies between 20 -25% (Fig. 6).

d.–clayey silts (< 0.063 mm diameter) are intercalated as thin horizons in the sand or form thin layers up to 10 cm thick, both in unit B and C (Fig. 4, 5). Detrital clasts –mainly rounded quartz grains– predominate; plant remains are scarcely present, gastropod and mollusc fragments occur rarely (Fig. 6, 7).

e.–alternating sequences of clayey silt layers and fine to coarse sand are either of greenish brown (unit B) or grey colour (unit C) (Fig. 4). The thickness of the clayey silt layers and of the sand layers varies between 5–60 mm. Detrital clasts predominate in this sequence. The grey layers contain more organic material than the greenish brown layers (Fig. 6).

f.–lake marl/lake chalk is present as a typical light beige coloured sediment, with a high amount of carbonate concretions (50-80%), oncoids, molluscs and gastropod debris, some plant remains and scarce charcoal fragments (Fig. 6). The silt fraction (0.125–0.002 mm diameter) dominates in the grain size distribution (Fig. 7). The definition of lake marl and lake chalk

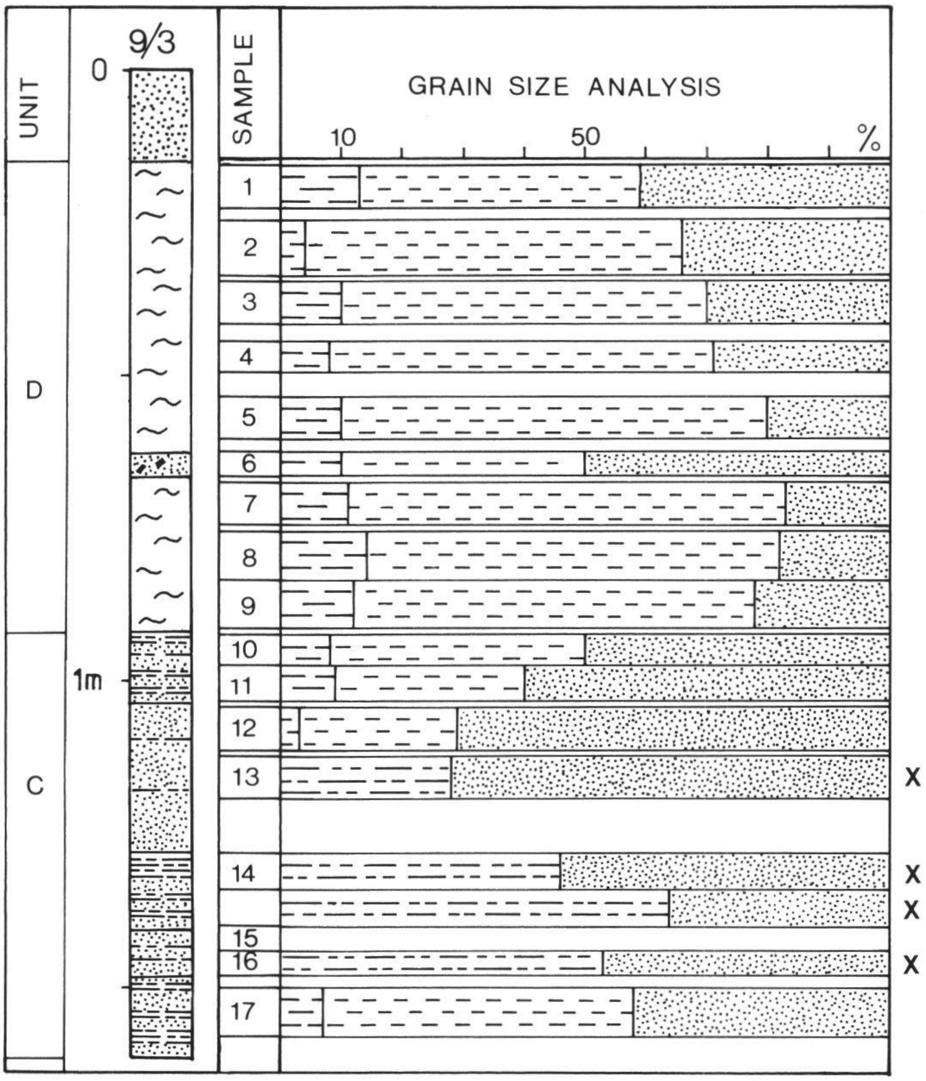

Figure 7.–Grain size analysis on section 9/3 of Sutz IV. The crosses indicate samples which flocculated during sieving, so that the silt and clay fraction could not be differenciated. See Fig. 3 for the location of the core and Fig. 8 for the legend.

varies to a great extent according to different authors (see SCHROEDER 1982 for discussion). In general lake marl is defined by a carbonate content of 40-60% and lake chalk by a carbonate content of >60%. The carbonate content in these sediments rarely exeeds 60% and often falls to 40% at the upper and lower boundary (Fig. 6). The present sediments are therefore termed here "lake marl".

4. BIOSTRATIGRAPHY AT SUTZ

The pollen record of the sites studied is controlled by two major factors: a) the drillings were made in the littoral zone of a large lake and, b) they are situated in the immediate vicinity of lacustrine dwellings. Apart from the regional

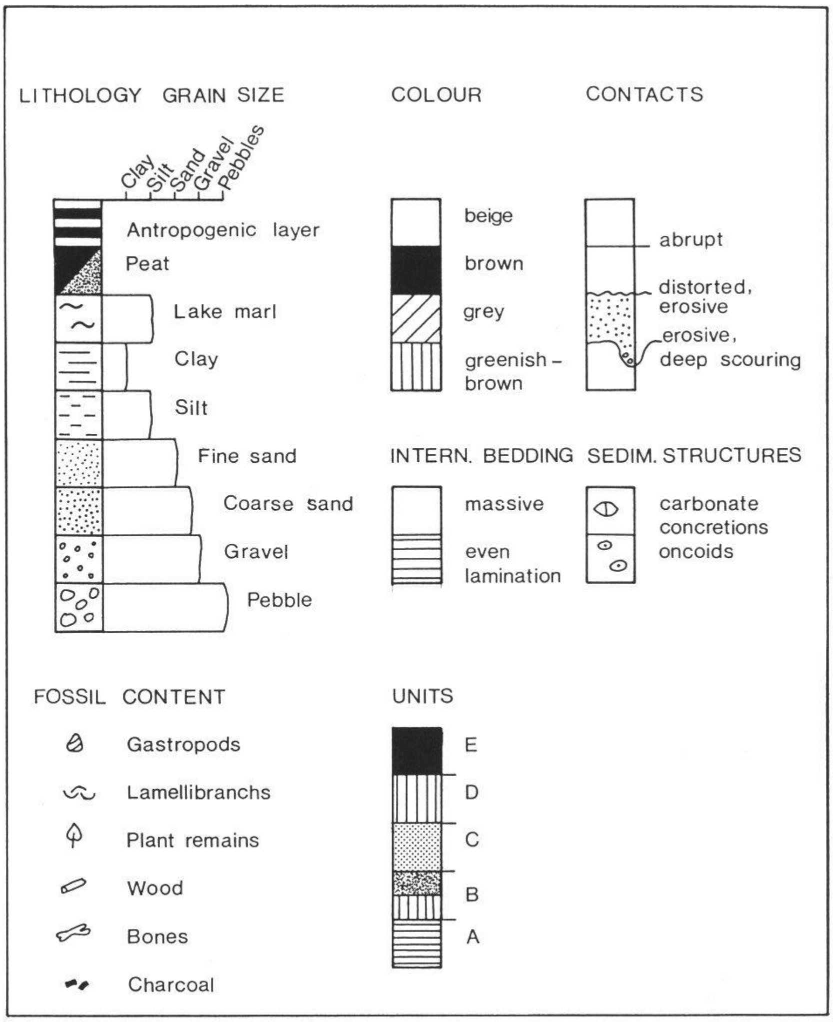

Figure 8.– Legend to symbols used in the figures.

pollen rain, the pollen will have had three different origins: atmospheric, fluvial and human inputs (PENNINGTON 1979, EDWARDS 1982, PRENTICE 1985, BEHRE and KUCAN 1986). Therefore several difficulties must be considered:

1.–The pollen curves may be subject to strong local influences, such as over-representation from the riparian forest taxa, from the aquatic plants or from coniferous taxa.

2.–In the littoral zone of a large lake, effects of stratigraphic condensation (i.e. the association of pollen of different ages in thin stratigraphic intervals) and/or recycling of pollen from older sediments may be a common phenomena (MCANDREWS and POWER 1973).

3.–In addition local variations of pollen content related to local river sources should also be considered (MC ANDREWS and POWER 1973, PECK 1973).

Littoral sequences do not provide either standard pollen assemblages nor a regional picture of the vegetation due, for example, to hiatuses and/or recycling of pollen spectra. For this work the standard diagrams were used from Lobsigensee to compare our LPAZ (Local Pollen Assemblage Zones) with the regional pollen zones proposed by AMMANN (1989). Lobsigensee is a small lake adjacent to Lake Biel (13 km to the east). In the Late Glacial, the Early Holocene and the earlier Middle Holocene, the pollen assemblage zones at Sutz and Lobsigensee are very similar (see also AMMANN 1989). However following the immigration of *Abies*, *Picea* and *Fagus* they begin to differ strongly. This may result from the different geographical situation of the two lakes –the northern shore of Lake Biel faces directly the wooded slopes of the Jura Mountains– which may influence the representation of *Abies* and *Picea*, principally. On the other hand, Lobsigensee is a small closed basin (AMMANN 1989), whereas Lake Biel is a large lake with an extensive catchment area. Therefore the Middle and Late Holocene sites situated nearer to or in the Jura Mountains were used for comparative sequences (MATTHEY 1958, 1971, WEGMÜLLER 1966, 1986).

In this paper the LPAZ of one core, Sutz IV, 2/7 are presented in a summarized form. A detailed description of the local pollen assemblage zones (LPAZ) are in preparation by A.-M. Schneider.

Figures 9, 10 and 11 show simplified pollen diagrams for the Late Glacial, and Early to Late Holocene time periods. The correlation of the LPAZ with regional PAZ, proposed by AMMANN (1989) for the Swiss Plateau and their assignment to the Firbas zones is given in Table 1.

4. 1. LATE GLACIAL AND EARLY HOLOCENE:
Allerød–Younger Dryas–Preboreal (Fig. 9 and Table 1)

The pollen spectra of the littoral zone in Lake Biel often render a differentiation of the Allerød–Younger Dryas–Preboreal complex difficult (AMMANN-MOSER 1975, LIESE-KLEIBER 1977, 1982 AMMANN 1980, 1982). The criteria commonly used to recognize these three zones as regional pollen zones for this area are not appropriate to pollen spectra from littoral sediments of large lakes. The younger part of the Allerød (LPAZ 1a and 1b) is usually characterised by a dominance of *Pinus* over *Betula*, associated with minima values of NAP (Fig. 9). However, the variety of the NAP taxa in LPAZ 1a, and the presence of a few heliophilous genera, such as *Artemisia* or *Thalictrum* at quite high frequencies are more unusual features. Two hypothesis may explain this phenomenon:

a.– the local presence of these taxa in the immediate vicinity.

b.–older layers (possibly from the Oldest Dryas) have been eroded, suspended and redeposited together with Allerød sediment.

A more or less pronounced increase of herbaceous plants and of shrubs usually characterises the Younger Dryas (LPAZ 1c), but *Pinus* remains dominant over *Betula*. The slight increase of the NAP percentages and the increasing diversity of these taxa make an attribution of these spectra to the Younger Dryas plausible (LPAZ 10 at Lobsigensee, AMMANN *et al.* 1985, AMMANN 1989). These changes are however, not very marked in our diagrams. The high values of *Pinus*, possibly due to accumulation of their vesiculate grains in the littoral zone (HOPKINS 1950), certainly suppress the values of the NAP.

The Preboreal (LPAZ 2) is usually characterised by a certain increase in *Betula* and by the appearance of thermophilous taxa (Fig. 9). However, *Pinus* remains dominant over *Betula*. The over-representation of *Pinus* in the littoral zone does not always allow the separation of these three zones with certainty. Over-representation of *Pinus* can easily overwhelm the signals usually correlated with the Younger Dryas and Preboreal. Pollen spectra resemble then the Allerød spectra of our area. When the *Pinus-Betula*-PAZ are not followed by unequivocal spectra of the Younger Dryas and of the Preboreal, they are attributed to the complex "Allerød–Younger Dryas–Preboreal".

4. 2. EARLY TO LATE HOLOCENE:
Boreal–Atlantic–Subboreal (Fig. 10, 11 and Table 1)

The rapid extension of *Corylus* and of the mixed oak forests, associated with the presence of *Hedera* and *Viscum* are characteristic of the Boreal in Switzerland (LPAZ 3, Fig. 10). The high values of these taxa together with the presence of *Fraxinus* and *Acer* are typical features of the younger part of this biozone, for example LPAZ 13 at Lobsigensee (AMMANN *et al.* 1985; AMMANN 1989). The high percentages of *Pinus* are attributed to flotation of their vesiculate grains into the littoral shore (HOPKINS 1950).

The decline of the three main constituents of the mixed oak forests (LPAZ 4a) occurs as at Lobsigensee, shortly after their maximum values and we attribute it to the older part of the Older Atlantic (Fig. 10).

The decrease of the mixed oak forest percentages results from an increase of *Corylus* (LPAZ 4b). Peaks of *Corylus* are also quite common in the Older Atlantic of this region (LPAZ 15 at Lobsigensee, AMMANN *et al.* 1985, AMMANN 1989). In LPAZ 4c the mixed oak forests are once again dominant over *Corylus*; we attribute this LPAZ to the middle part of the Older Atlantic (Fig. 10). The *Cerealia* type, appearing in the last sample (LPAZ 5), are possibly due to reworked sediments (sands). LPAZ 5 represents the upper part of the Older Atlantic (Fig. 10). The drastic changes in the pollen assemblages, the little peak of *Abies* and the position of the *Cerealia* type in layers dated of the Older Atlantic may point to a hiatus.

The rapid initial increase of *Fagus*, the important rise of *Alnus* and the decline of *Ulmus* are typical features of the earliest part of the Younger Atlantic (LPAZ 6a, Fig. 10). In fact, all the components of the mixed oak forests have strongly diminished, including *Fraxinus*, in the first sample of this LPAZ. It does not seem possible to correlate these fluctuations with those observed at Lobsigensee. This might be due to a big change in the sedimentation rates or/and to condensation phenomena of the sequence (AMMANN 1989).

During LPAZ 6b (Fig. 10 and 11) *Fagus* diminishes, *Ulmus* and *Tilia* continue to decrease. The *Cerealia* type and a few apophytes are still present. There are no significant features to attribute these spectra either to the Younger Atlantic or the Subboreal (Table 1). This transition is generally fixed at the end of the elm decline, associated at Lobsigensee with the lime decline (AMMANN 1989).

The increase of the NAP in LPAZ 7 is attributed to an archeological layer, *in situ* or redeposited. Such an occupation is not known from Lake Biel (Winiger, oral communication 1989). The high values of the NAP (local effect) suppress the values of the AP; the curves of the AP taxa do not reflect the general trends of the vegetational history. The correlation with the sequence from Lobsigensee is not possible. It is unlikely that this LPAZ can be attributed to a well-defined period, such as the Younger Atlantic or Subboreal.

The difficulties in drawing an exact limit between the Younger Atlantic and the Subboreal have been discussed by various authors (WELTEN 1944, 1979, 1982, MATTHEY 1958, 1971, 1988, WEGMÜLLER 1966, 1986, LIESE-KLEIBER 1977, 1982, 1985, 1988, RÖSCH 1983, GAILLARD 1984, AMMANN *et al.* 1985, HADORN 1987, LOTTER 1988, AMMANN 1988, 1989, RICHOZ and GAILLARD 1989). We recognize similar problems in Lake Biel: there are no significant features that allow a definite attribution of the spectra either to the Late Atlantic or to the Subboreal (Fig. 10, 11 and Table 1).

The strong local human influence diminishes in LPAZ 8a-8c (Fig. 11), but is still present. High values of *Abies*, *Picea*, *Fagus* and low values of *Ulmus*, *Tilia* and *Hedera* are characteristic features of the Subboreal in this region (MATTHEY 1958, 1971, 1988, WEGMÜLLER 1966, 1986, AMMANN-MOSER 1975, AMMANN *et al.* 1985, AMMANN 1989). In LPAZ 9 the human influence is more and more scattered. *Abies* and *Picea* decrease, but *Fagus* maintains itself. *Corylus*, the mixed oak forests and *Alnus* are particularly well-represented. During LPAZ 10 the mixed oak forests reach their lowest values, whilst *Betula* is at its highest: it rejoins *Alnus* and *Corylus*. LPAZ 11 shows a strong decrease of *Fagus* and a recovering of the mixed oak forest taxa. *Alnus* increases and remains dominant until the end. The LPAZ 8a–8c, 9, 10 and 11 are correlated with the Subboreal without any further subdivision (Fig. 11 and Table 1).

5. THE STRATIGRAPHY AT ERLACH

This section, exposed in the large construction pit, beyond the modern shoreline shows the following sequence (426.80 m–429.50 m a.s.l.) from the top to the base (Fig. 12):

0–50cm	yellow coloured medium sand with reworked peat fragments (10 cm diameter; gravel and pebbles deposited in the cavities of the eroded peat surface)
50–125cm	dark brown peat including a 25 cm thick erosion zone
125–140cm	dark grey clay with wood fragments
140–170cm	dark brown peat

170–182cm	light grey clay with organic debris
182–222cm	dark brown peat
222–225cm	light brown clay with organic debris
225–226cm	dark brown peat
226–236cm	light brown clay with organic debris and gastropods concentrated at the base
236–246cm	light brown silty clay with reworked peat fragments, wood and an irregular surface
246–266cm	dark brown peat with erosional surface
266–286cm	light grey clay with organic debris at the base

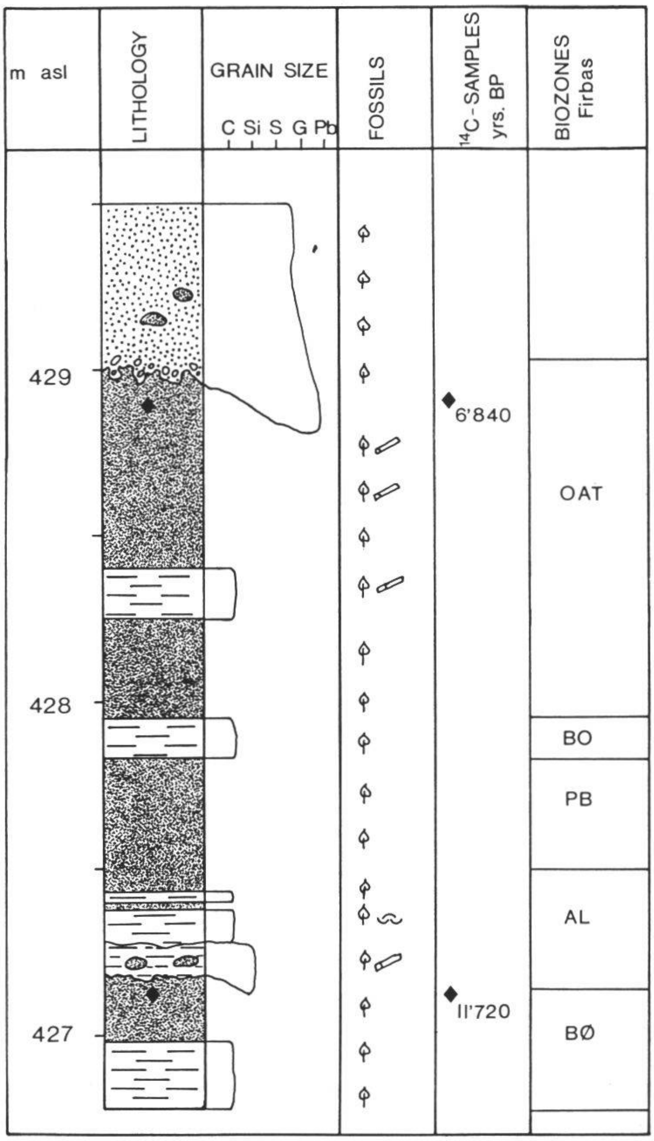

Figure 12.–Section beyond the actual lake shore in Erlach; during the Older Atlantic severe erosion took place, eroding the upper part of the peat. See Fig. 1 for the location of the section and Fig. 8 for the legend.

Two radiocarbon dates were obtained from peat samples from the lowermost peat and from the upper peat (Fig. 12) which gave ages of 11,720 ± 50 yrs BP (B-4895) and 6,840 ± 60 yrs BP (B-4894). The pollen zones are illustrated in Fig. 12; they will be presented in detail in a later paper (thesis A.-M. SCHNEIDER *in prep.*)

6. BASIS FOR LAKE LEVEL RECONSTRUCTION IN LAKE BIEL

Any attempt to reconstruct ancient lake level changes from a large lake must consider several problems:

In general, a rising and a lowering of a lake level may be recorded by similar deposits on the littoral bank (for example coarse sediments indicating the shoreline at a certain time) and both can be accompanied by erosional features (DIGERFELDT 1988, AMMANN 1989). To separate these two events long offshore –onshore transects are needed, in which 'complete' sequences are preserved and which show the time– transgressive evolution of the sediments (DIGERFELDT 1986, 1988). Therefore an attempt was made to establish a 'complete' sequence at Sutz with 5 sedimentary "cycles" by comparing all 167 cores from the same bay. Furthermore, it was possible to study sections beyond the present shoreline at Erlach, on the southern shore of the lake.

The nearshore area of a large lake can be compared to some extent with the marine nearshore environment where, for example, waves, currents, meteorology and water level phenomena contribute to the dynamic nature of the nearshore zone (SLY 1978, DAVIS 1985). Many of these variables also play an important role in the nearshore zone of lacustrine environments, yet in most lake systems, high current velocities may only occur locally (SLY 1978). In Lake Biel high current velocities can be observed especially along the southern shore of the lake during severe autumn and winter storms. They result in erosion and redeposition of the archaeological layers; on gravelly shores, ridges of up to 1 m in height may be formed during one night. Interpretation of the sedimentary sequence at Sutz in terms of lake level or environmental changes, requires the consideration, that similar short term events must have also occured in the nearshore zone during the periods studied. DEARING and FOSTER (1986) pointed out that normal dating methods –^{14}C and pollen analysis– bias interpretation towards apparently long-term changes. This is certainly true in some cases, where a sandy layer can be misinterpreted as recording a long-term lake level lowering or rise, although the layer was deposited during one short event. According to DIGERFELDT (1988, 178) "*the risk of such misinterpretation may be substantial in studies based on single cores from marginal sediments*". However, in Sutz the general sedimentary development can be followed in most of the 167 cores and can thus be regarded as reflecting a certain environmental pattern of the littoral zone during a longer time.

During the Bølling biozone limnic clay was deposited at Erlach (Fig. 12); it is overlain by peat which indicates a lowering of the lake level (Fig. 15).

At Sutz the Allerød biozone is characterized by low hydrodynamic activity (lower part of "cycle" 5, Fig. 13 and Table 2), followed by increased wave energy with deposition of sand and erosion of older layers ("reworked Allerød", upper part of "cycle" 5 in Fig. 13). The sedimentation of lake marl began during the Allerød and continued until the Preboreal ("cycle" 4, Fig. 13 and Table 2). Allerød lake chalk has also been reported from the southermost part of Lake Biel (WEISS 1977, AMMANN-MOSER 1975), which suggests that similar environmental conditions also existed in the littoral zone during Allerød. During the Younger Dryas increased clastic input is visible in the lake cores (Fig. 13 and Table 2) corresponding to silty sands and "sediments similar to lake chalk" described by WEISS (1977) from the southwestern part of the lake.This might indicate either changing hydrological conditions or increased run-off from nearby slopes.

At Erlach the peat development (Allerød–Preboreal) was interrupted by deposition of silty clay (Allerød) which eroded the surface of the lower peat layer (fig. 12).

The lower part of "cycle" 5 is correlated to the lower peat at Erlach, indicating a low lake level (fig. 14 and 15). Erosion of the peat surface and deposition of silty clay are regarded as synchronous with the increased hydrodynamic activity of the littoral zone at Sutz and are interpreted in terms of a high lake level (fig. 14 and 15). The upper part of the Allerød peat (fig. 12) and the Allerød lake marl (fig. 13) indicate a lowering of the lake level (Fig. 14 and 15). This low lake level persisted until the Preboreal biozone with continous deposition of lake marl/peat (Fig. 14 and 15), although slightly changing conditions during Younger Dryas are visible.

At Sutz the upper part of "cycle" 4 already displays increased hydrodynamic conditions with deposition of alternating sand and clayey silt layers offshore, and coarse sand onshore. "Cycle" 3 comprises an incomplete coarsening upward sequence which points to increasing wave energy (Table 2). These high hydrodynamic conditions are also reflected by the erosion of older layers (parts of "cycle" 5, 4 and 3 are eroded in many cores). The attribution of these sediments to either the Preboreal or Boreal biozones remains uncertain, since the Boreal is only recorded in the lowermost part of "cycle" 2 (Fig. 13).

During the Boreal biozone clay was deposited at Erlach (fig. 12). Compared to the sequence at Sutz this period might, as a working hypothesis, correspond to the uppermost part of "cycle" 4, to "cycle" 3 and to the lowermost part of "cycle" 2 (Table 2). If the deposits from Sutz can be linked with the Boreal clay at Erlach a lake level rise presumably occured during that period (Fig. 14, 15).

On the littoral bank, unit C ("cycles" 2 and 1) corresponds to the Older and Younger Atlantic biozones. Both "cycles" show coarsening upward sequences, from alternating layers of fine sand and clayey silt to coarse sand. During the deposition of "cycle" 2 (Early Atlantic) severe erosion took place that eroded many of the older layers down to the glacial sediments (Fig. 14).

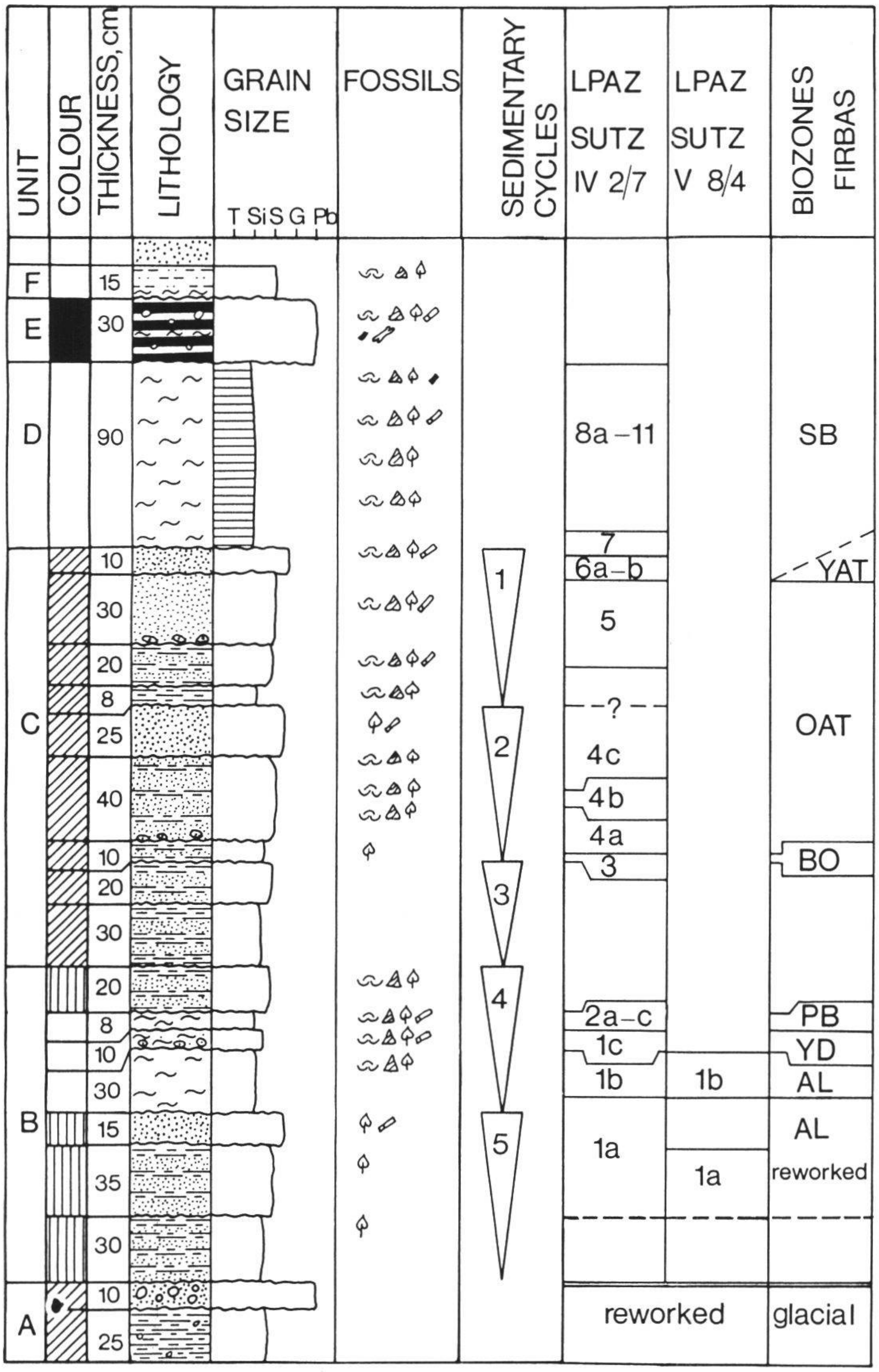

Figure 13.–Idealized section of Sutz, showing the lithological units A–F and the five sedimentary "cycles" (1–5) and their correlation with the local pollen assemblage zones (LPAZ) and the Firbas zones. The difficulties in correlating the different units, "cycles" and layers distinguished by geology with the local pollen zones may be connected with the strong hydrodynamic environment of the littoral zone. Unit E and F are only small remnants of layers that are eroded by the contemporary erosion of the shore. See Fig. 8 for the legend.

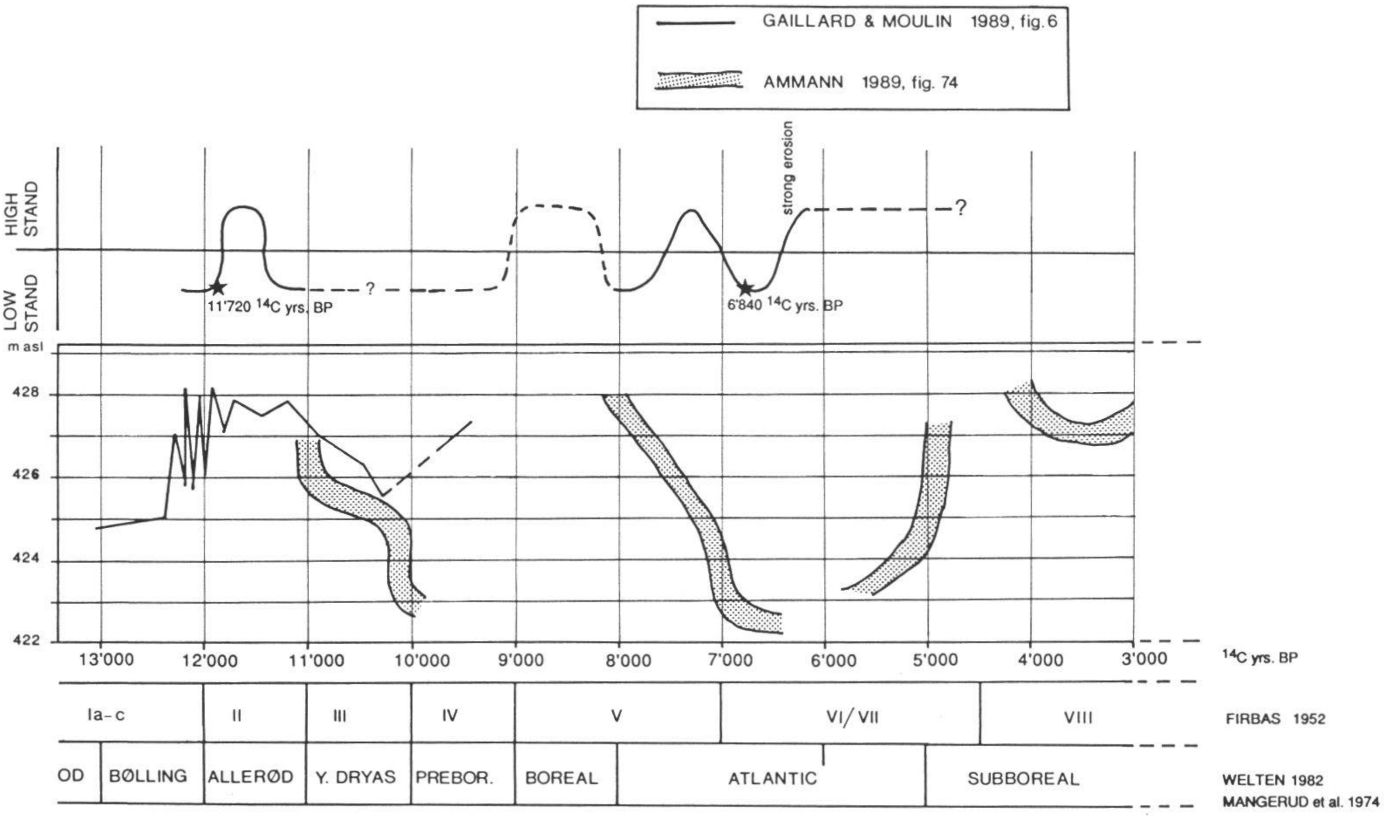

Figure 15.–Comparison of lake level changes in Lake Biel with data obtained by AMMANN (1989) for Lake Biel and GAILLARD and MOULIN (1989) for Lake Neuchâtel. The erosional episodes during the Older Atlantic might be responsible for the hiatus found by AMMANN (1989) between the Allerød and the Boreal biozones.

In cores from the southermost part of the lake, sediments from the Atlantic period are not found; here the Subboreal follows immediately on top of the Boreal (WEISS 1977). This hiatus may include parts of the Allerød in the nearshore sections, or the Younger Dryas, Preboreal and Boreal in offshore cores (AMMANN-MOSER 1975). The Early Holocene in the littoral zone can be characterized by an high energy environment starting already during the end of unit B. Phases of low wave activity can be traced at the base of "cycle" 2 and 1; in general these periods display high hydrodynamic conditions with deposition of predominantly coarse allochthonous sediments (Table 2 and Fig. 13). This change in sedimentation, in comparison to unit B, may reflect a change in the catchment area of the lake. Increased sediment supply, increased river discharge and dynamics (WOHLFARTH and AMMANN 1991) may have influenced the sedimentation in Lake Biel.

During the Older Atlantic peat developed at Erlach, but was interrupted by clay deposition and a severe erosional episode after 6,840 yrs BP during which gravel and sand were deposited in the eroded peat cavities (Fig. 12).

The clay deposits within the peat may represent either a short event (spill over, deposition of suspended fines) or as deposited during a higher lake level event. The second explanation is favoured here because of the considerable thickness of the clay layers (between 10 and 20 cm) and their record in the whole construction pit. The deposition of sand and gravel is interpreted as a second rise in lake level during the Older Atlantic.

One is tempted to correlate the severe erosion observed at Sutz during the deposition of "cycle" 2 with the erosion at Erlach after 6,840 yrs BP. However this correlation seems less possible. It is more convincing to correlate the lower part of "cycle" 2 with the Atlantic peat at Erlach and the upper part of "cycle" 2 with the clay layer (at Erlach). Then the lower part of "cycle" 1 would correspond to the upper peat and the upper part of "cycle" 1 could be correlated with the erosion of the peat surface. Based on these correlations we propose two lake level rises during the Atlantic biozone, which are at Sutz connected with coarsening upward sequences (Fig. 13, 14, 15 and Table 2).

The Younger Atlantic/Subboreal biozones are not recorded at Erlach, but can be observed in the lake marl layers at Sutz. Lake marl layers of that time period are not only recorded in Sutz, but are found all along the southern shore of the lake (AMMANN-MOSER 1975, WEISS 1977). Therefore the bay of Sutz does not display an isolated situation, but reflects the evolution of the littoral zone during the Subboreal. The littoral cores from Sutz give no indications on lower or higher lake levels, but indicate the rather quiet, protected environmental conditions of the lake shore during both Younger Atlantic and Subboreal. The following picture may be drawn with some caution: erosion ceased completely and quiet and temperate conditions predominated, which favoured an expanding vegetation in the littoral zone. A possible increase in temperature and higher plant productivity led to eutrophication of the lake which again accelerated macrophyte and microphyte production.

7. REGIONAL CORRELATION OF PAST LAKE LEVEL FLUCTUATION

Fig. 15 compares results obtained here with those from AMMANN (1989) and GAILLARD and MOULIN (1989). The lake level changes are given in terms of low and high stands and not in terms of absolute heights. In general our curve corresponds with trends from the other curves for the Late Glacial and the early Holocene: high lake levels during the Allerød and the Boreal; low lake levels during the Allerød, the Younger Dryas and the Preboreal. Lake level lowerings during Younger Dryas and the early Preboreal are in accordance with other investigations on the Swiss Plateau (GAILLARD 1984, 1985a, MEYER-WOHLFARTH 1987, AMMANN 1989, GAILLARD and MOULIN 1989, WOHLFARTH and AMMANN 1991). From the Atlantic onwards the curves diverge: instead of a distinct lake level lowering during the Older Atlantic and a lake level rise during the Younger Atlantic (AMMANN 1982, 1989, WOHLFARTH and AMMANN 1991), two lake level rises and one lake level lowering can be interpreted from Sutz and Erlach during the Older Atlantic

(Fig. 15). The lake level during the Younger Atlantic remains uncertain at Sutz, as well as the lake levels during the Subboreal. Our results indicate severe erosion episodes during the Older Atlantic; this erosion was in concert with a rise in the lake level, and may have been responsible for the hiatus described by AMMANN-MOSER (1975), AMMANN (1982, 1989) and WOHLFARTH and AMMANN (1991).

8. SPECULATION ON THE CLIMATIC SIGNIFICANCE OF PAST LAKE LEVEL CHANGES IN WESTERN SWITZERLAND

As discussed by AMMANN (1982) water level changes in Lake Biel and Lake Neuchâtel, as rather large lakes, may not primary be connected with climatic changes. However, as no detailed evidence is available for lake level fluctuations in Lake Biel caused by changing river courses or blocking of the outflow by rockfalls (AMMANN 1982), we assume that some of the environmental patterns inferred from the stratigraphic evidence reflect certain climatic influences. Following DIGERFELDT's statement (1988, 180) that, "*as climatic evidence, a fluctuation in lake level indicates a change in humidity, caused by a change in temperature and precipitation, or a combination of both*", here some speculations on the climatic significance of the recorded lake level changes are offered:

The rather quiet, protected and temperate environment of the littoral zone during the Allerød could correspond to an increase in vegetation on the lake shore and to a more favourable climate indicated by pollen and insect studies on the Swiss Plateau (GAILLARD 1984, 1985a, AMMANN *et al.*, 1985). The lowering of the lake level during the Younger Dryas is synchronous with the formation of dunes on the northeastern shore of Lake Neuchâtel (MEYER-WOHLFARTH 1987) and might point to drier conditions resulting from a more continental climate caused by the southward displacement of the polar front (RUDDIMAN and MCINTYRE 1981). Increased run off during the Younger Dryas might be correlated with increased soil erosion due to severe permafrost conditions in the Alpine regions (HÄBERLI 1983, Wohlfarth in prep.).

The Preboreal low lake level shows similar trends as registered in several lakes in Switzerland by GAILLARD (1985a) and AMMANN (1989), as well as in Scandinavia and in Central Europe (GAILLARD 1985b, DIGERFELDT 1988). This regional pattern might reflect a temperature increase and a decrease in the average humidity (GAILLARD 1985b) at the beginning of the Holocene. The Boreal high lake level at Lake Biel might concievably be connected with a period of increased humidity indicated from lakes in southern Sweden (DIGERFELDT 1988). The lake level fluctuations and the severe erosional episodes in Lake Biel during the Atlantic biozones seem to correspond broadly with records from Southern Sweden, where the established lake level fluctuations reflect a fluctuating climate with periods of increased dryness alternating with more humid periods (DIGERFELDT 1988). The possible correlations with Scandinavia suggest that the major lake level changes in Lake Biel might reflect climatic changes on an almost continental scale.

The compilation and interpretation of palaeohydrological records at a European continental scale as presented by HARRISON (1987) will hopefully provide more information on Holocene climatic changes. However, all factors and their feedback mechanisms, that contribute to environmental and climatic changes during Postglacial times must be carefully considered and ruled out before any clear climatic pictures can be obtained from large lacustrine environments.

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Annexe II

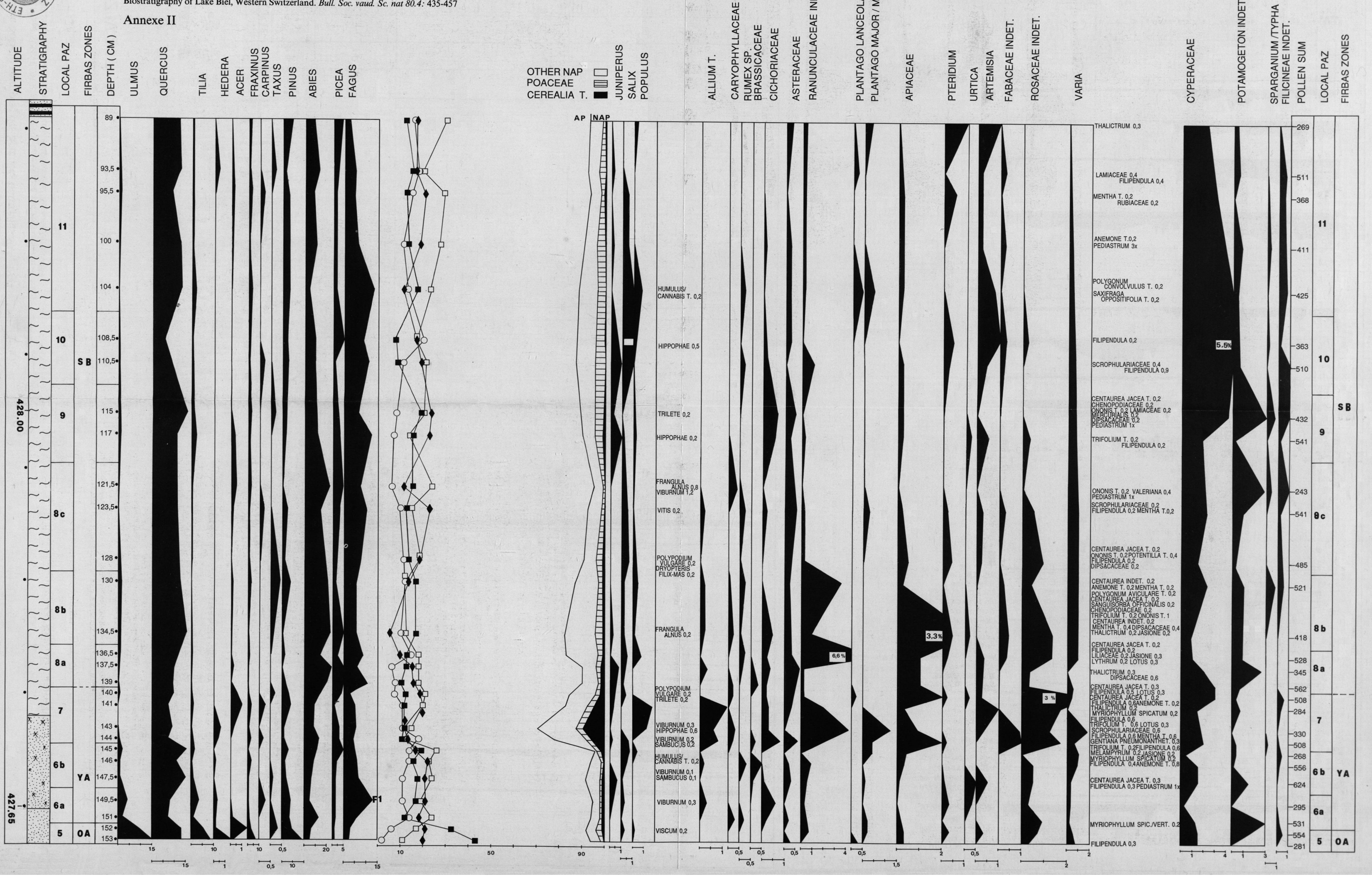

Figure 11. – Sutz IV, core 2/7, simplified pollen diagram of the Middle and Late Holocene. See Fig. 3 for the location of the core and Fig. 8 for the legend.

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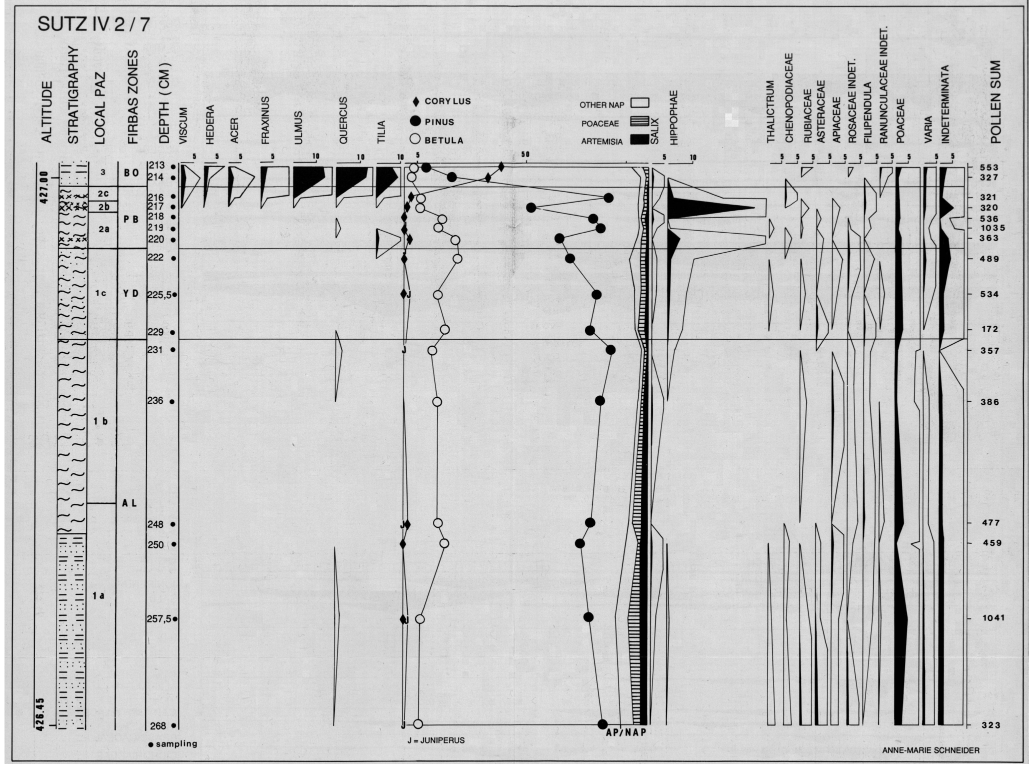

Figure 9. – Sutz IV, core 2/7, simplified pollen diagram for the Late Glacial and Early Holocene. See Fig. 3 for the location of the core and Fig. 8 for the legend.

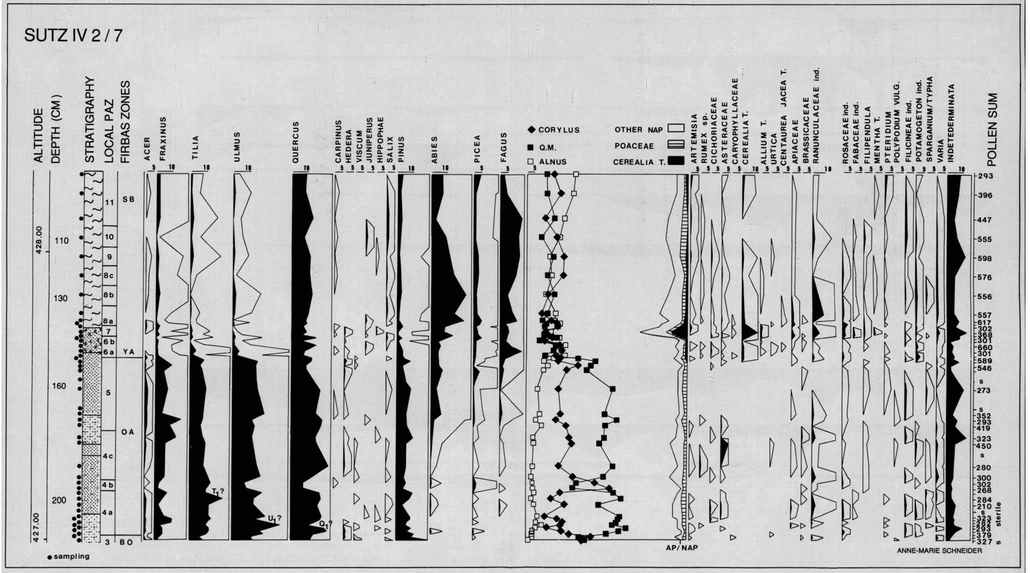

Figure 10. – Sutz IV, core 2/7, simplified pollen diagram of the Early Holocene. See Fig. 3 for the location of the core and Fig. 8 for the legend.

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Annexe I

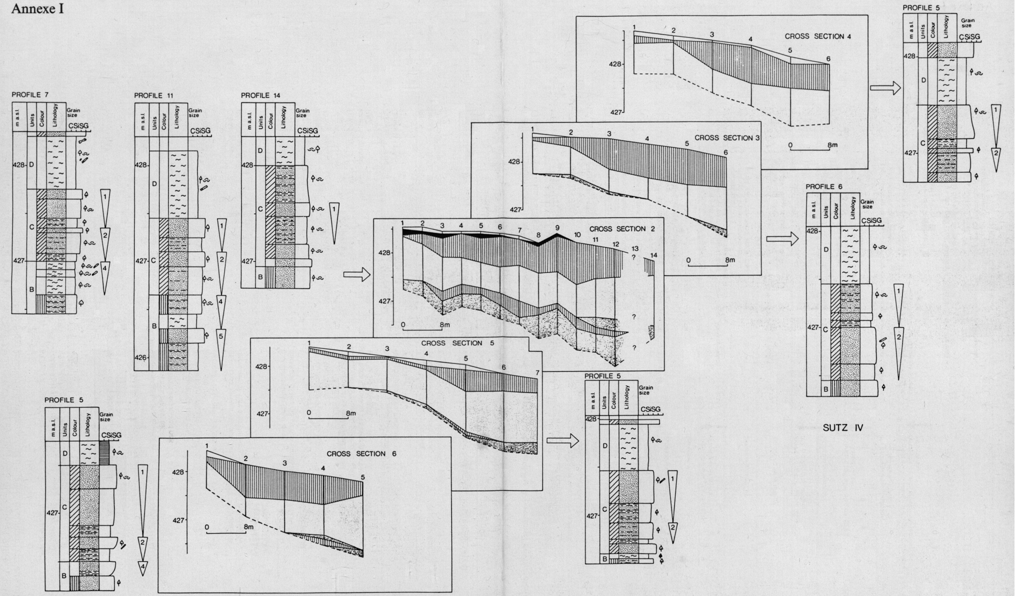

Figure 4. – Sutz IV, cross sections 2 - 6. The sequences in Sutz can be divided into different units (A - F) according to colour, grain size differences and the amount of organic material; here units B, C, and D are present. By comparing all layers within one cross section to the neighboring cross section it was possible to establish five sedimentary "cycles", each displaying a coarsening upward sequence. See Fig. 3 for the location of the cross sections and Fig. 8 for the legend.

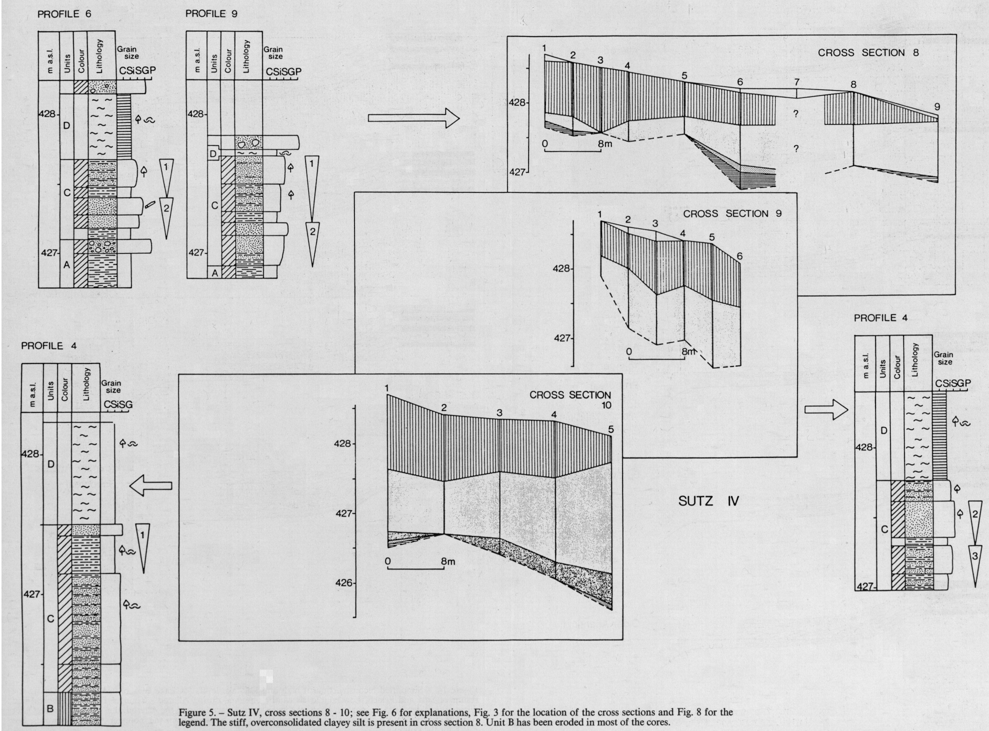

Figure 5. – Sutz IV, cross sections 8 - 10; see Fig. 6 for explanations, Fig. 3 for the location of the cross sections and Fig. 8 for the legend. The stiff, overconsolidated clayey silt is present in cross section 8. Unit B has been eroded in most of the cores.

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Annexe I

Table 1. – Correlation of the Local Pollen Assemblage Zones (LPAZ) in Lake Biel with the Regional Pollen Assemblage Zones proposed by AMMANN (1989) for the Swiss Plateau; the vegetational development is described in comparison with other studies in the surroundings.

LOCAL POLLEN ASSEMBLAGE ZONES LAKE BIEL (LPAZ)		REGIONAL POLLEN ASSEMBLAGE ZONES PROPOSED FOR THE SWISS PLATEAU (AMMANN 1989, table 17 and and 19)	VEGETATION DEVELOPMENT (AMMANN 1989, MATTHEY 1958, 1971, 1988, WEGMUELLER 1966, 1986)	FIRBAS ZONES (BIOZONES)	TIMESCALE ^{14}C yrs BP.
Alnus - PAZ	11		wide spread alder forests, recovering of the mixed oak forest taxa		
Alnus - Corylus - Betula - PAZ	10		lowest values of mixed oak forest taxa		
Corylus - mixed oak forest - Alnus - PAZ	9	FAGUS - (ABIES) -	wide spread fir and spruce in the Jura mountains; alder, hazel, birch and mixed oak	SUBBOREAL	
Abies - PAZ	8c 8b 8a	ALNUS - PAZ	forests fluctuate and are important. During LPAZ 9 fir looses ground. decrease of human influence		
Cerealia Type - Apophytes - PAZ	7		mixed oak forests still subdominant, decrease of Tilia and Ulmus archaeological layers present?	YOUNGER ATLANTIC/ SUBBOREAL TRANSITION	
Alnus - Corylus -	6b				5 000
Fagus - PAZ	6a		first Cerealia in Lake Biel decrease of the mixed oak forest taxa	YOUNGER ATLANTIC	6 000
Mixed oak forest - Abies - Alnus - PAZ	5	QUERCETUM MIXTUM -	expansion of alder, spruce, fir, birch, mixed oak forests are still important	OLDER	
Mixed oak forest - Corylus - PAZ	4c 4b 4a	CORYLUS - PAZ	hazel decreases and mixed oak forests increase. Spruce, fir and birch immigrate to the Jura mountains and to the Prealps	ATLANTIC	8 000
Corylus - Ulmus Quercus - PAZ	3	CORYLUS - QUERCETUM MIXTUM - PAZ	hazel woods, mixed oak forests, ivy and misteltoe are frequent, ash and maple immigrate	BOREAL	9 000
Pinus - Betula - Thermophilous - PAZ	2c 2b 2a	PINUS - BETULA - CORYLUS - PAZ	dense birch and pine forests, local presence of buckthorne, immigration of hazel, alder, oak, elm and lime	PREBOREAL	10 000
Pinus -	1c	PINUS - GRAMINEAE - NAP - PAZ	wide spread and dense pine forests	YOUNGER DRYAS	11 000
Betula - PAZ	1b 1a	PINUS - BETULA - PAZ	dense forests of birch and pine	ALLERØD	

Table 2. – Description of the different units and "cycles", the pollen significance and the depositional environment during the Late Glacial and Holocene at Sutz.

UNIT		SEDIMENT DESCRIPTION (see Fig. 4, 5 and 13)	POLLEN SIGNIFICANCE (see Fig. 9, 10, 11)		DEPOSITIONAL ENVIRONMENT HYDRODYNAMIC CONDITIONS	BIOZONES (Firbas)
E		dark brown clayey silt with abundant plant remains (seeds, nuts, twigs, leaves), charcoal, bone and ceramic fragments			erosion by contemporary erosion and reworking of the archaeological sediments	SUBBOREAL
D		laminated light grey lake marl with abundant plant and mollusc remains, charcoal fragments on top	high values of Abies, Picea, Fagus; low values of Ulmus, Tilia and Hedera		quiet, protected bays, low wave energy	
C	cycle 1	- coarse sand with plants & molluscs	fall of mixed oak taxa, rise of Alnus, first peak of Fagus	↑	high wave energy	SUBBOREAL/ YOUNGER ATLANTIC TRANSITION
		- fine sand with oncoids, plants & molluscs	Abies present; increasing values of Fagus and Picea		increasing wave energy	
		- alternating layers of fine sand and clayey silt				
		- clayey silt			low wave energy	OLDER ATLANTIC
	cycle 2	- fine sand/coarse sand to gravel with plants and molluscs		↑	high wave energy and erosion of many older layers	
		- alternating layers of fine sand (4cm thick) and clayey silt (2cm thick), plants and molluscs	no Fagus, Abies or Picea			
		- alternating fine sand and clayey silt layers (each 2cm thick), plants, molluscs			low wave energy	BOREAL
	cycle 3	- alternating layers of thick fine sand (5cm) and thin clayey silt layers (2cm)	no pollen samples analysed			
		- alternating layers of fine sand and clayey silt layers (each 5cm thick)			increasing wave energy	??BOREAL/PREBOREAL
B	cycle 4	- fine sand alternating with clayey silt (offshore) and coarse sand (onshore)		↑	increased hydrodynamic conditions and erosion of older layers	
		- light coloured lake marl with plants and wood fragments	decrease of NAP spectra, Corylus and other thermophilous taxa appear		low hydrodynamic conditions, protected environment	PREBOREAL
		- light coloured lake marl with organic debris, carbonate concretions & detrital clasts (Sutz IV, 2/7) and alternating fine sand and clayey silt (Sutz V, 3/4)	increase of NAP percentages	↑	increased hydrodynamic conditions/ increased run off	YOUNGER DRYAS
		- light coloured lake marl with scarce plant remains and mollusc debris	dominance of Pinus over Betula		low hydrodynamic conditions, protected environment	ALLEROED
	cycle 5	- coarse sand with plant and wood remains	variety of NAP taxa and presence of few helipohilous plants together with Allerõd spectra	↑	increased wave energy and high hydrodynamic conditions causing erosion and redepostion of older layers	REWORKED ALLEROED
		- thick fine sand layers (5cm) alternating with thin clayey silt layers (2cm)				
		- thin fine sand layers (2cm) alternating with thin clayey silt layers (2cm)	no pollen samples analysed		low wave energy	
A		- coarse sand and gravel - stiff greyish clayey silt with small rounded stones of gravel size	reworked pollen spectra			GLACIAL

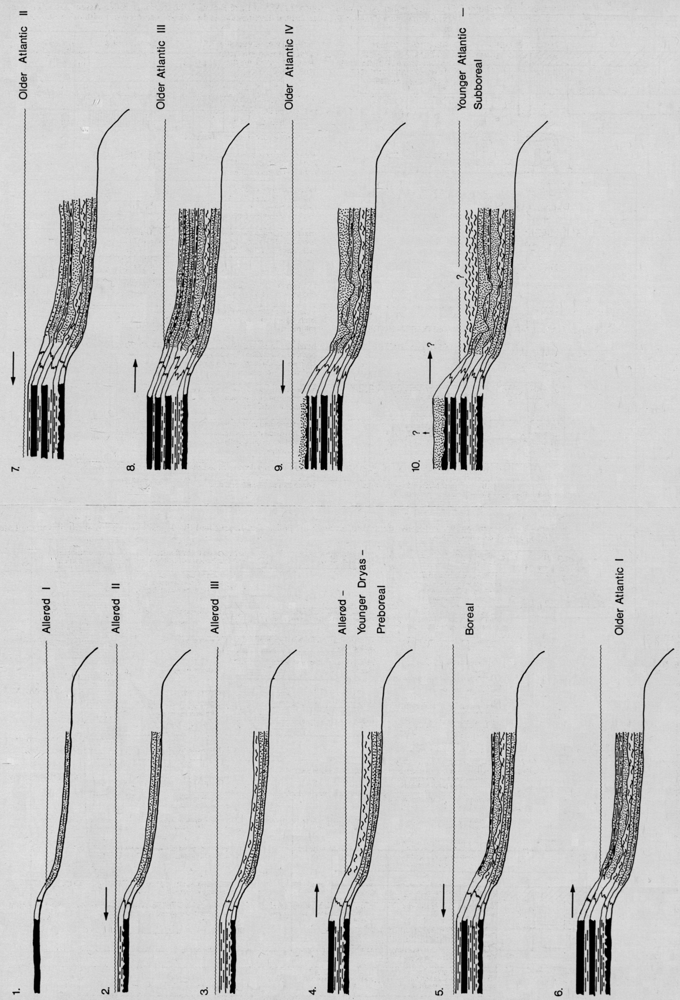
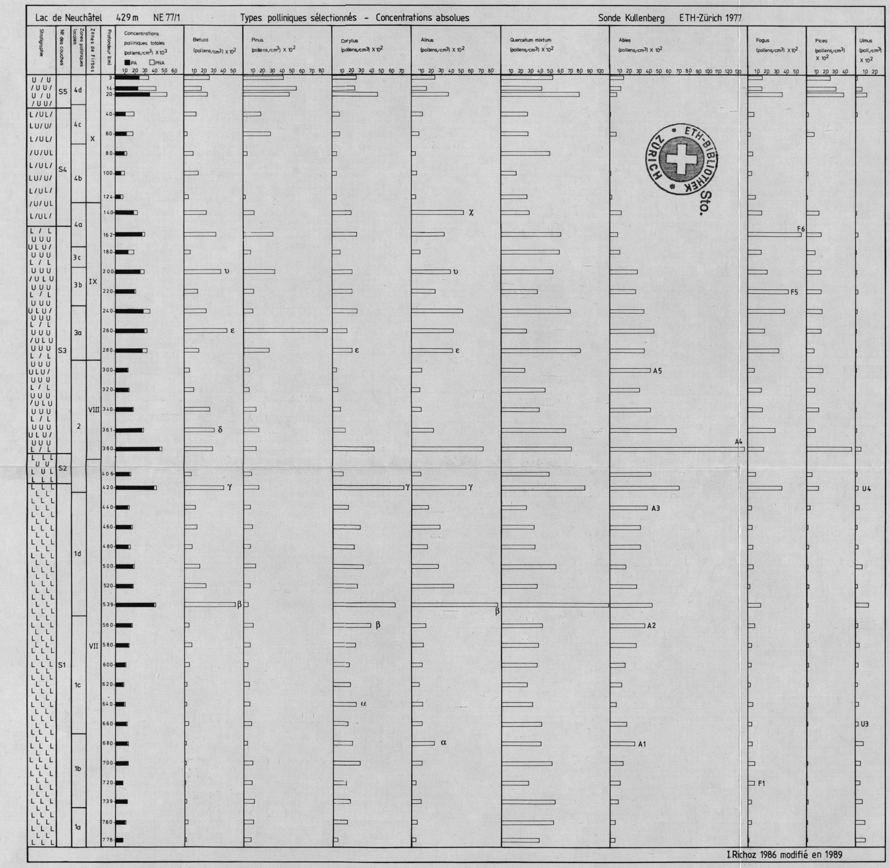


Figure 14. – Simplified reconstruction of high and low lake levels for Lake Biel, obtained by correlating the results of Sutz and Erlach. Low lake levels can be observed during Allerød - Younger Dryas - Preboreal and during the Older Atlantic biozone. High lake levels can be traced during the Allerød, the? Boreal and the Older Atlantic biozone. No indications for lake level stands can be given from the Younger Atlantic onwards. See Fig. 8 for the symbols.

Figure 4.-Diagramme des concentrations absolues



I.Richoz 1986 modifié en 1989

RICHOZ I., GAILLARD M.-J., 1989. Histoire de la végétation de la région neuchâteloise de l'époque néolithique à nos jours. Analyse pollinique d'une colonne sédimentaire prélevée dans le lac de Neuchâtel (Suisse). *Bull. Soc. vaud. Sc. nat. 79.4*: 355-377.

Figure 5.-Diagramme de l'influence humaine

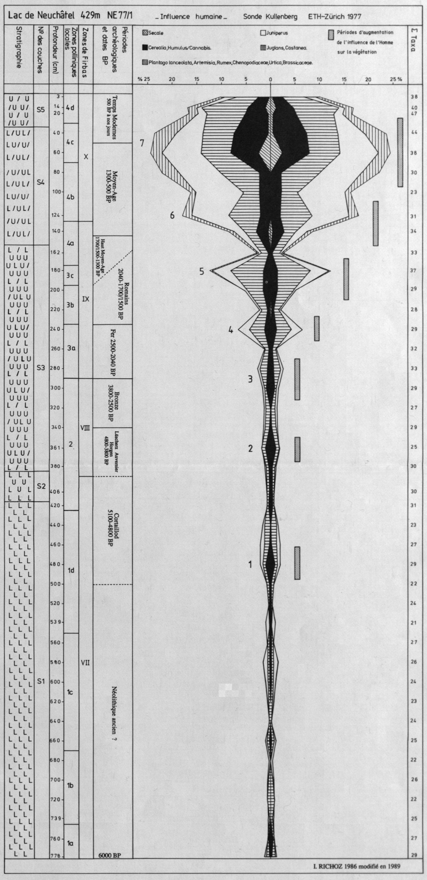


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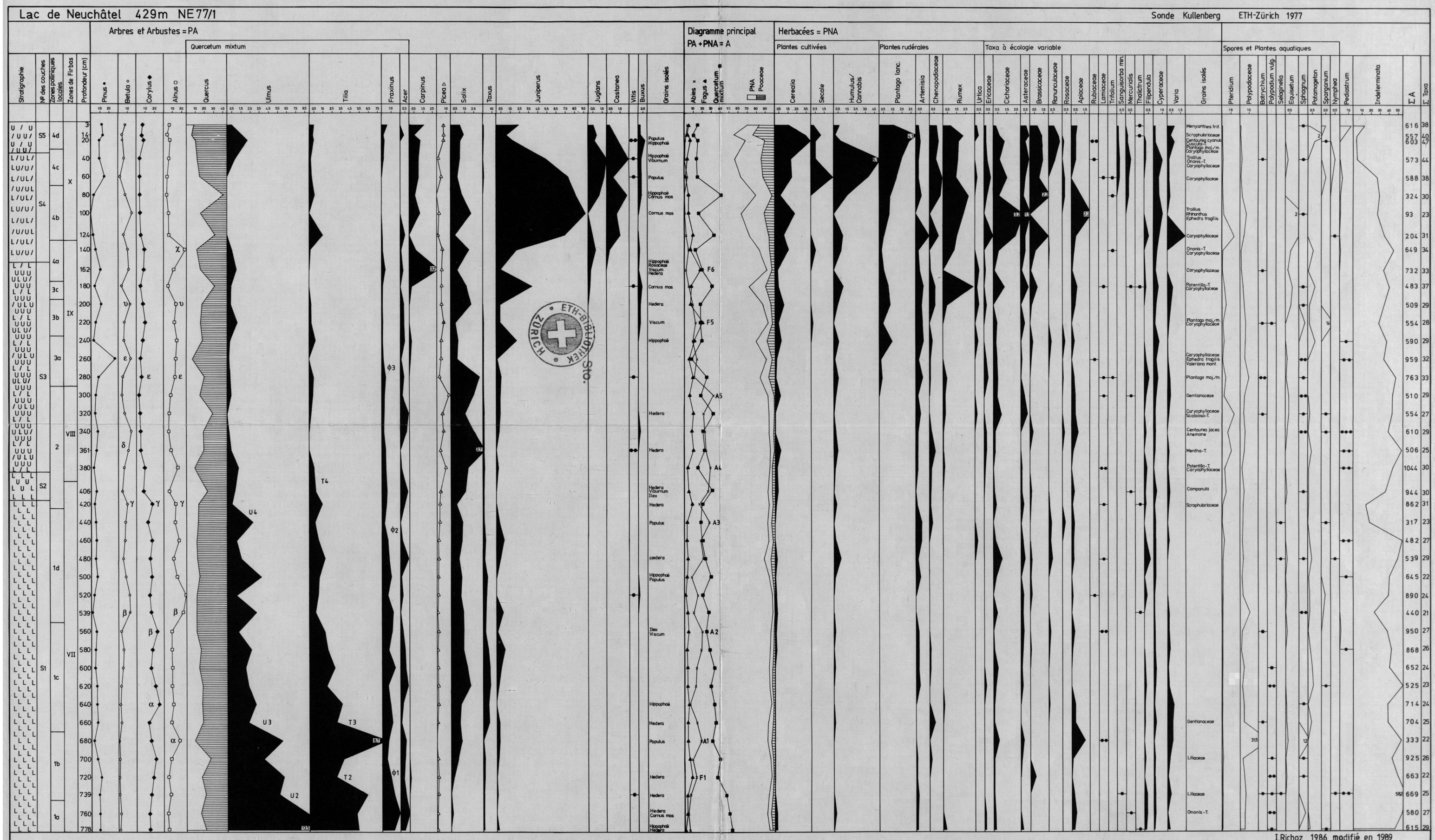
Figure3.-Diagramme des pourcentages relatifs



RICHOZ I., GAILLARD M.-J., 1989. Histoire de la végétation de la région neuchâteloise de l'époque néolithique à nos jours. Analyse pollinique d'une colonne sédimentaire prélevée dans le lac de Neuchâtel (Suisse). *Bull. Soc. vaud. Sc. nat. 79.4*: 355-377.