Holocene lake-level fluctuations in Lake Seedorf, southern Swiss Plateau

Autor(en): **Magny, Michel / Richoz, Isabelle**

Objekttyp: **Article**

Zeitschrift: **Eclogae Geologicae Helvetiae**

Band (Jahr): **91 (1998)**

Heft 3

PDF erstellt am: **15.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-168428

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

http://www.e-periodica.ch

0012-9402/98/030345-13 $1.50 + 0.20/0
Birkhäuser Verlag, Basel, 1998

Eclogae geol. Helv. 91 (1998) 345–357

Holocene lake-level fluctuations in Lake Seedorf, southern Swiss Plateau

MICHEL MAGNY[1] & ISABELLE RICHOZ[2]

Key words: Swiss Plateau, Holocene, palaeoclimates, lake-level fluctuations, palynology, sedimentology
Mots clefs: Plateau suisse, Holocene, paléoclimats, fluctuations du niveau des lacs, palynologie, sédimentologie

ABSTRACT

Holocene lake-level fluctuations in lake Seedorf are reconstructed using sediment and plant macrofossil analyses. A pattern of palaeohydrological changes from ca 10 000 to 2000 BP is established. Major increases in lake level occurred at ca 8800–8100, 6700–6200, 4800–4300 and 2700–2200 BP, and a major lake-level lowering developed at ca 6000 BP. The palaeohydrological Seedorf record presents strong similarities with other palaeoclimatic records from (1) central Europe based on lake-level fluctuations, variations in river discharge, glacier advances and tree-limit oscillations, and (2) Greenland based on GISP2 glaciochemical series. Thus, the palaeohydrological changes at Seedorf support both the concepts of a climatic complexity and of a coupled cryosphere-atmosphere system around the North Atlantic during the whole Holocene period.

RESUME

Les fluctuations holocènes du niveau du lac de Seedorf sont reconstituées sur la base de l'analyse de séquences sédimentaires et de macrorestes végétaux. L'évolution paléohydrologique régionale a pu être établie pour la période 10 000–2000 BP. Des hausses majeures du niveau du lac sont survenues vers 8800–8100, 6700–6200, 4800–4300 et 2700–2200 BP, et un abaissement prononcé du plan d'eau est centré sur 6000 BP. La courbe paléohydrologique du lac de Seedorf présente de fortes similitudes avec d'autres enregistrements paléoclimatiques obtenus (1) en Europe centrale à partir de l'étude des fluctuations des plans d'eau, des variations du débit des rivières, des avancées des glaciers et des oscillations de la limite forestière, ou encore (2) au Groenland à partir de l'analyse chimique des glaces du sondage GISP2. Ainsi, les changements paléohydrologiques reconstitués au lac de Seedorf confortent l'idée de l'existence d'un système couplé cryosphère-atmosphère dans la zone de l'Atlantique Nord et d'une certaine complexité du climat tout au long de l'Holocène.

1. Introduction

Various palaeoenvironmental approaches have been used to reconstruct Holocene climatic oscillations in central Europe, such as timberline fluctuations, glacier advances and retreats (Zoller 1977; Patzelt 1977; Burga & Perret 1997, Tinner et al. 1996), oxygen-isotope studies (Eicher 1979; Grafenstein et al. 1992), palaeohydrological oscillations inferred from variations in river discharge or lake-level fluctuations (Harrisson et al. 1993; Magny & Ruffaldi 1995; Starkel et al. 1996). Due to the controversial questions raised by the past environmental conditions of the neolithic and Bronze Age lake-shore settlements, and thanks to a large number of lacustrine basins, numerous lake-level studies using various reconstruction methods have been performed on the Swiss Plateau since the pionieer work of Lüdi in 1935. We here present the reconstruction of Holocene lake-level fluctuations at lake Seedorf inferred mainly from sedimentological records and we refined the palaeohydrological data from Seedorf previously reported by Richoz et al. (1994), Richoz (1998) and Haas et al. (1998).

2. Site and methods

Lake Seedorf (National Map 1185–569,62/182,81) is located on the southern Swiss Plateau at an altitude of 609 m (Fig. 1). Its catchment area covers circa 5 km^2 and is surrounded by hills varying between 650 and 750 m in altitude. The area is characterized by molassic hills, morainic ridges and till deposits. The present lake (ca, 14 ha) is the residual basin of a larger partly overgrown lacustrine basin. It has three inlets and one oulet. The remains of a Neolithic settlement of the "Cortaillod classic" culture (3900–3700 cal. BC) were found in the western part of the basin (Richoz, 1998).

Two cores (S22 and S23, see Fig. 1) from the profundal zone of the lake provided a detailed pollen record of Holocene vegetation development filling a geographical gap in the distribution of Holocene sites studied for palaeoecology on the Swiss Plateau (Richoz 1998 ; Richoz et al. 1994). The lake-level investigations were centred on the Neolithic site. The results were based on sediment (cores S11, A7, A9, A9 bis and A11) and plant macro-fossil (core S8) analyses of cores from two

---

[1] Chrono-Ecology Laboratory, UMR 6565 CNRS, Faculty of Sciences and Techniques, 16 route de Gray, F-25030 Besançon Cedex
[2] Botanical Museum, Avenue de Cour 14 bis, CH-1007 Lausanne

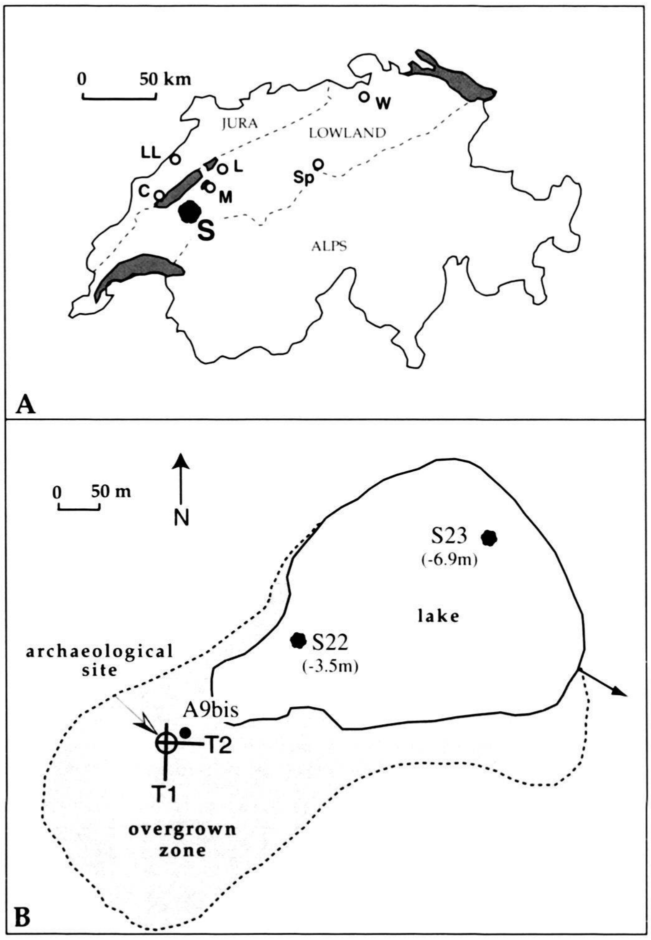

Fig. 1. A: geographical location of the lake Seedorf. S: Seedorf, W: Wallisellen-Langachermoos, L: Lobsigensee, Sp: Soppensee, M: Montilier.
B: location of core transects T1 and T2, and core stations S22 and S23 in the lake.

transects crossing on the central part of the archaeological site (Fig. 1). The sediment profiles presented in Figures 2 and 3 show that the Neolithic settlement was established on the extremity of a peninsula.

The reconstruction of past lake-levels from sediment analyses refers to the method developed by Magny in the carbonate-rich lacustrine infillings (Magny 1992a, b, in press). This method is based on a study of the present-day deposits settling in the Jura lakes. This study highlights two sediment characteristics varying from the shore to the profundal zone in relation to the increasing water depth:

- Lithology (lake marl, gyttja, peat...). Organic sediment mostly appears to characterize shallow water, late stage of filling up (shallow residual basin) or overgrowing phases. Lake marl corresponds to deeper water.

Tab. 1. Correlations of the local pollen assemblage zones (LPAZ) defined at Seedorf with the LPAZ defined at Lobsigensee (Ammann 1989), the regional pollen assemblage zones (RPAZ) defined on the Swiss Plateau (Ammann et al. 1995), the RPAZ defined by Lotter (in press) at Soppensee and the Firbas zones.

AMS radiocarbon dates at Seedorf	LPAZ at Seedorf (Richoz, 1998)	LPAZ at Lobsigensee (Ammann, 1989)	RPAZ on the Swiss Plateau (Ammann et al., 1995)		LPAZ at Soppensee (Lotter, in press)	Age BP	Firbas zones	
					CHb-9	0		
	SD-13	L-30	CHb-9	CHb-9	CHb-8b		X	SUBATLANTIC
	SD-12	L-29						
	SD-11	L-28						
	SD-10	L-27 L-26	CHb-8	CHb-8b CHb-8a	CHb-8a	1000		
	SD-9	L-25 L-24	CHb-7	CHb-7b	CHb-7b		IX	
	SD-8	L-23						
	SD-7	L-22		CHb-7a	CHb-7a3	2000		
	SD-6	L-21					VIII	SUBBOREAL
	SD-5d	L-20				3000		
4170 ±75 BP	SD-5c				CHb-7a2	4000		
	SD-5b							
	SD-5a2	L-19						
5085 ±75 BP	SD-5a1	L-18				5000	VII	YOUNG. ATL.
	SD-4b							
	SD-4a	L-17			CHb-7a1			
	SD-3b	L-16	CHb-6	CHb-6b		6000	VI	OLDER ATLANTIC
	SD-3a	L-15 L-14		CHb-6a	CHb-6b CHb-6a	7000		
	SD-2	L-13 L-12	CHb-5	CHb-5b CHb-5a	CHb-5b CHb-5a	8000 9000	V	BOREAL
9500 ±95BP	SD-1	L-11	CHb-4	CHb-4c	CHb-4c	10 000	IV	PREB.

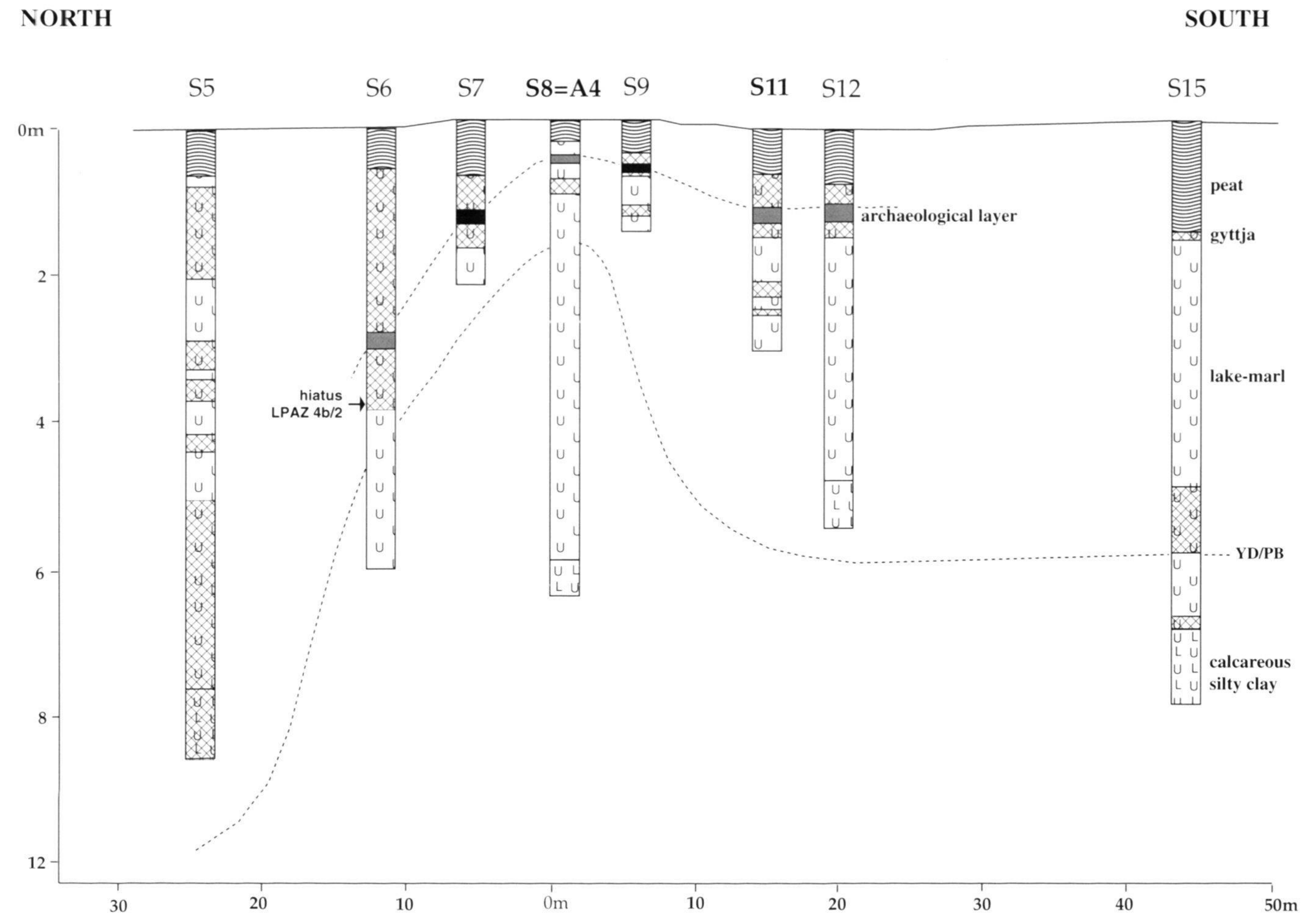

Fig. 2. Core transect T1. Transects T1 and T2 cross at S8 = A4. Broken lines indicate the archaeological layer (anthropogenic remains dated at 3900–3700 BC by tree-ring) and the Younger Dryas (YD)/Preboreal (PB) transition.

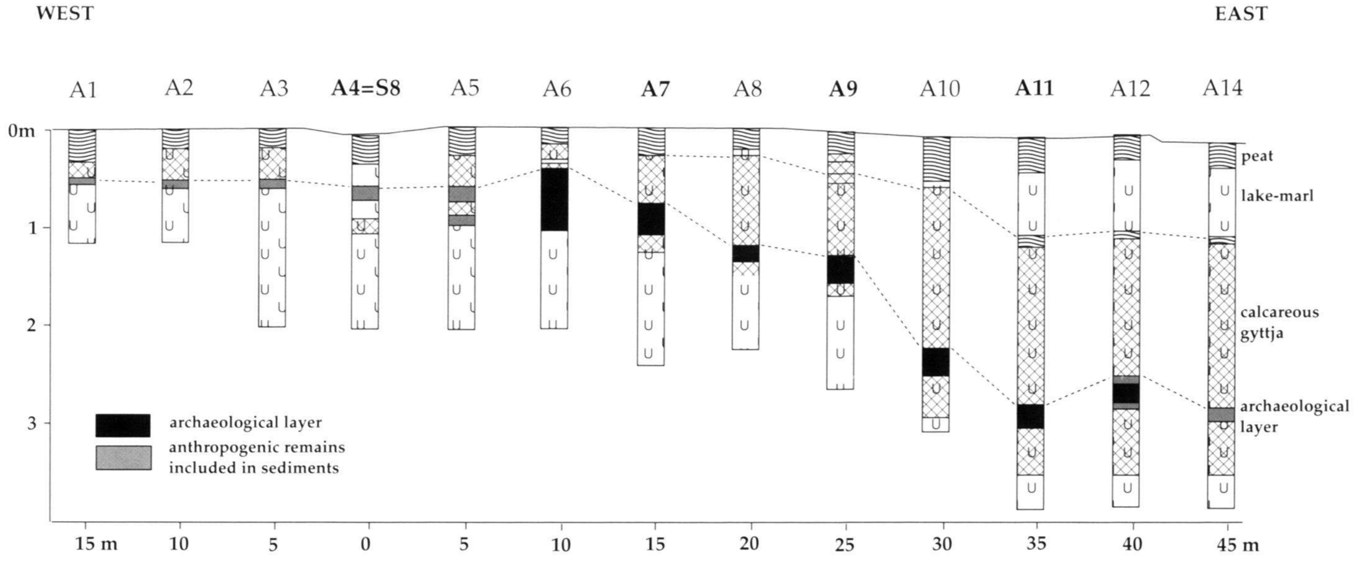

Fig. 3. Core transect T2. Transects T1 and T2 cross at S8 = A4. Bold characters indicate the analysed cores.

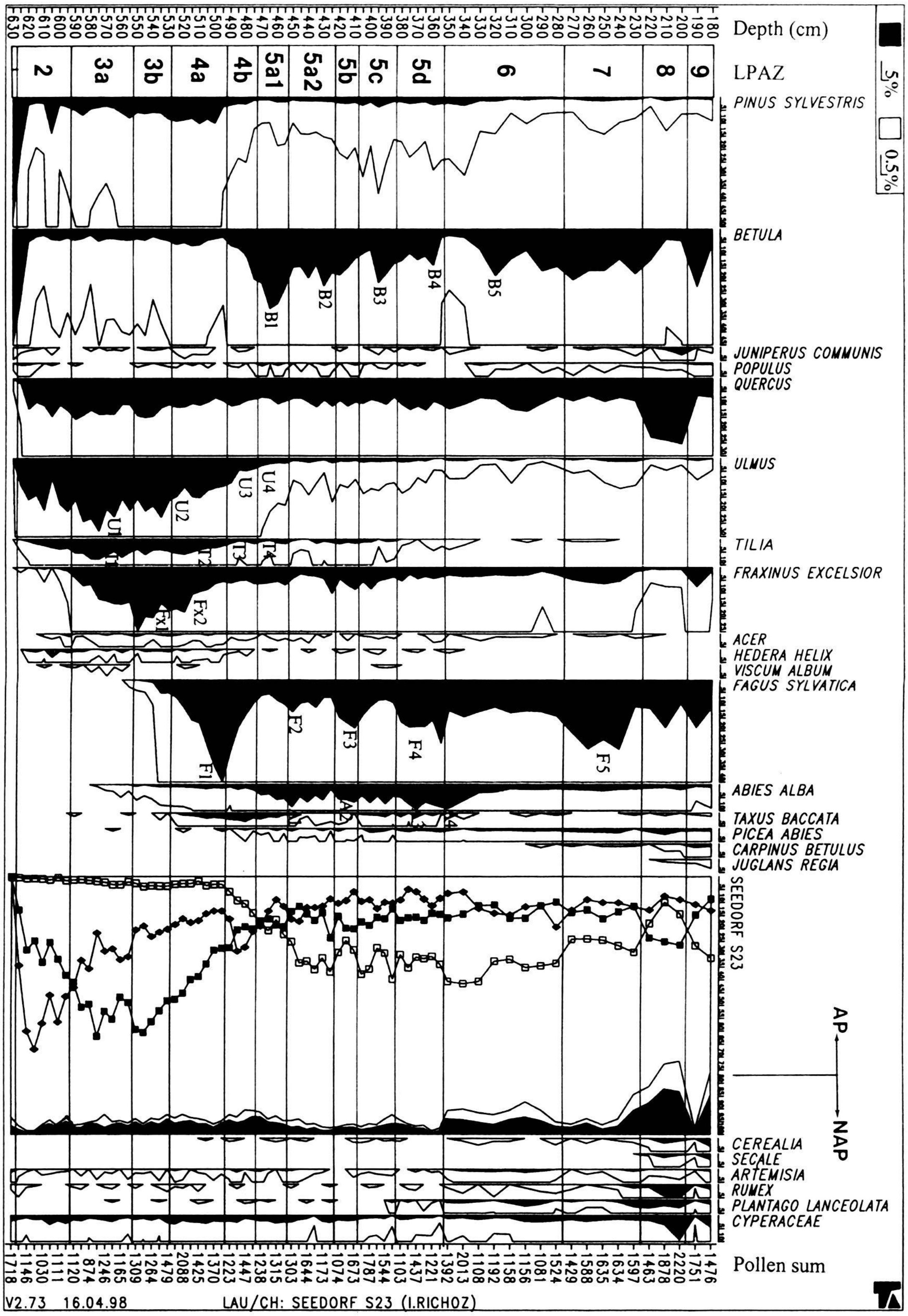

Fig. 4. Simplified pollen diagram from core S23. Peaks of *Betula, Fagus sylvatica* and *Abies alba*, and minimums of *Ulmus, Tilia* and *Fraxinus excelsior* are marked respectively B1, F1, A1, U1, T1 and F1. Pollen of *Cyperaceae,* aquatics and spores of Pteridophytes are excluded from the calculation sum. Black diamonds: *Corylus;* black squares: Quercetum mixtum; open squares: *Alnus.*

- Macroscopic components of lake marl. The coarser fractions (larger than 0,2 mm) of lacustrine chalk are mainly composed of carbonate concretions of biochemical origin (Magny 1992b), plant remains and mollusc tests. The carbonate concretions divide into several morphotypes each showing a specific spatial distribution from the shore to the profundal zone: oncolites characterize nearshore areas, cauliflower-like forms dominate the littoral platform, plate-like and tube-like forms chiefly develop on the platform slope (deeper water). The reconstruction of changes in water depth is never based on the predominance of a single morphotype, but on temporal sequences showing changes in the relative development of all morphotypes. Vegetal components include plant macrofossils orginating from the lake (aquatic plants) or from the shore (terrestrial plants). Their frequency and that of the mollusc remains increase in the nearshore areas (Magny 1992 b). In the sediment analysis, the mollusc remains are considered not as biological descriptors but as sedimentological markers.

The plant macrofossil analysis refers to the method developed by Digerfeldt (1986).

The chronology is based on a combination from :

1. AMS radiocarbon dates. Unfortunately, only four dates among the 17 attempted AMS datings provided coherent results (Richoz 1998) (Tab. 1).
2. Correlation with tree-ring dates. The available tree-ring dates obtained from near lake-shore archaeological sites place the so-called "Cortaillod classic" culture at ca. 3900–3700 cal. BC (Voruz 1995) which corresponds to palynostratigraphical features.
3. Pollen stratigraphical correlation with other sites on the Swiss Plateau. Figure 4 presents the reference pollen diagram obtained from core 23 and the local pollen assemblage zones (LPAZ) distinguished at Seedorf. Richoz (1998) discussed in detail the correlations of these LPAZ with those defined by several authors on the Swiss Plateau (Ammann 1989; Ammann et al. 1995; Lotter in press) (Tab. 1). The pollen diagrams which permitted the pollen zonation of the sediment diagrams are presented in Richoz (1998). The age of the Firbas zone boundaries follows the proposal of Ammann (1989) except for the limit VII–VIII. The Holocene vegetation history can be summarized as follows.

- Preboreal: 10 000–9500 BP (LPAZ 1). This period is characterized by an open *Betula-Pinus* forest with birch dominant. Heliophilous taxa such as *Populus, Juniperus* and *Artemisia* are well developed. Mesophilous taxa such as *Corylus, Quercus, Ulmus* and *Alnus* start to invade the area (empirical limits).
- Boreal: 9500–8000 BP (LPAZ 2). The development of the mesophilous forest, where *Corylus* is dominant, occurs to the detriment of the pioneering *Betula-Pinus* forest. *Corylus, Quercus, Ulmus* (rational limits) and Tilia (empirical limits) expand in the first part of the period while *Fraxinus* and *Acer* (empirical limits) in the second part. Simultaneously the thermophilous taxa *Hedera* and *Viscum* expand.
- Older Atlantic: 8000-6000 BP (LPAZ 3a–3b). With the development of *Fraxinus principally, Tilia* and *Acer,* the Quercetum mixtum forest (mixed oak forest) shows its maximum expansion and supersedes *Corylus.* The empirical limits of *Abies* and *Fagus* occur in the subzone 3a. *Viscum* presents its maximum percentages in subzone 3a. In subzone 3b *Fagus* presents its rational limit while *Abies* still shows low values.
- Younger Atlantic: 6000–5000 BP (LPAZ 4a–4b and 5a1). During this period a major change in the landscape occurs, the Quercetum mixtum is replaced by a beech-fir forest. Subzone 4a is characterized by the expansion of *Fagus* (F1) and a decrease in *Ulmus* (U2), *Tilia* (T2) and *Fraxinus* (FX2). The rational limit of *Taxus* (shade-tolerant species) occurs at the beginning of this period whereas the values of *Hedera* (light-demanding species) decrease. Subzone 4b shows a sharp regression of *Fagus,* a decline in *Ulmus* (U3) and *Tilia* (T3) while *Corylus* and *Betula* increase. At this time, the first pollen of Cerealia appear in all the Seedorf pollen diagrams. The sudden expansion of *Alnus* seems to be metachronous and dependent on the local development of the littoral vegetation (Bennett & Birks 1990). *Fraxinus* remains well represented because it participates in the riparial forest (Alno-Padion). Subzone 5a1 is defined by the development of *Betula* (B1) followed by the expansion of *Fagus* and *Abies* (rational limit). Abies has certainly reached the valley of Seedorf at this time. *Ulmus* (U4) and *Tilia* (T4) are still declining.
- Subboreal: 5000–2500 BP (LPAZ 5a2–5d and 6). The picture of the landscape is a beech-fir forest where *Quercus* is still well represented. Peaks of *Fagus* (F2–F4) and *Abies* (A1–A4) alternate with peaks of *Betula* (B3–B5) which seem linked to deforestation cycles. At the transition to zone 6, *Abies* and *Taxus* decrease abruptly whereas NAP increase, specifically the anthropogenic taxa.
- Older Subatlantic: 2500–1000 BP (LPAZ 7–9). The first phase (LPAZ 7) is defined by a significant peak in *Fagus* (F5) which is interpreted as a forest recolonization. The second phase (LPAZ 8) shows a sudden increase in *Quercus, Juniperus, Secale* and NAP, a decrease in *Alnus* and *Fraxinus,* and the first occurrence of *Juglans.* The third phase is characterized by an abrupt decrease in *Quercus, Juniperus* and NAP, and an increase in *Betula, Alnus* and *Fraxinus.* The features of these three phases can be recognized in other pollen diagrams of the Swiss Plateau (e.g. Hadorn 1987; Ammann 1989; Richoz & Gaillard 1989) and correlated with the Iron Age (LPAZ 7), the Roman colonization (LPAZ 8) and the Migration period (LPAZ 9) respectively.

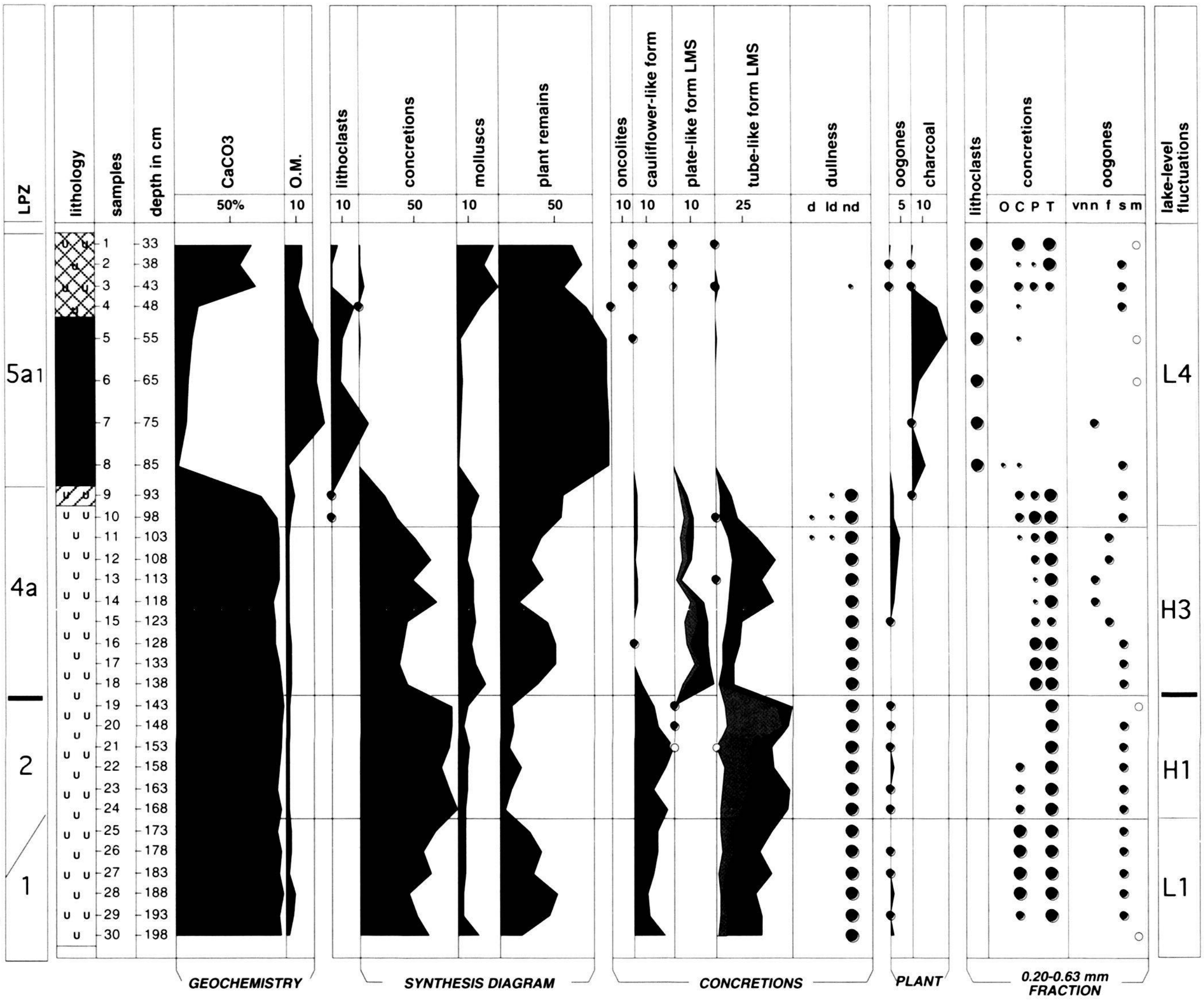

Fig. 5. Sediment diagram of core A7. O.M. : organic matter (loss by ignition from the whole sample); LMS: large (black), middle (grey) or small (white) size; d, ld, nd: dulled, less dulled, no dulled; O, C, P, T: oncolites, cauliflower-like, plate like and tube like concretions; vn, n, f, s, m: very numerous, numerous, frequent, scarce, missing. The representation of each component is expressed (1) as a percentage of the total macroscopic components (i.e. concretions + mollusc tests + plant remains) accounted in the fraction larger than 0,63 mm, and (2) with a circle corresponding in size to its frequency in the fraction 0,2–0,63 mm.

3. Results

The sediment and plant macrofossil diagrams presented in Figures 5 to 10 lead to a definition of 14 successive lake-level periods as follows.

- Phase L1 : relative low lake-level recorded in core A7 (Fig. 5) and placed in the Preboreal (LPAZ 1). The small and medium-size tube-like concretions are scarce.
- Phase H1 : high lake-level recorded in core A7 (Fig. 5) and placed in the Boreal (LPAZ 2). Two successive high lake-level events can be distinguished, the first one being of smaller magnitude than the second. The curve of the medium-size tube-like concretions shows a rather progressive increase suggesting a progressive rise in the lake-level. The lithofacies and the plant macrofossils in core S8 (Fig. 10) indicate that phase H1 ends at the LPAZ 2/3a transition.
- Phases L 2 (low lake-level) and H 2 (high lake-level). The Older Atlantic is not documented in the sedimentological diagrams except for some samples of core S 11 covering its final part. The plant macrofossil diagram of core S8 (Fig. 10) records it wholly although with a weak time resolution. The beginning of the period is characterized by an abrupt lowering that is well-marked by the sudden expansion of *Cladium mariscus* and a change in the lithology. The weaker time-resolution of the LPAZ 3a gives further support

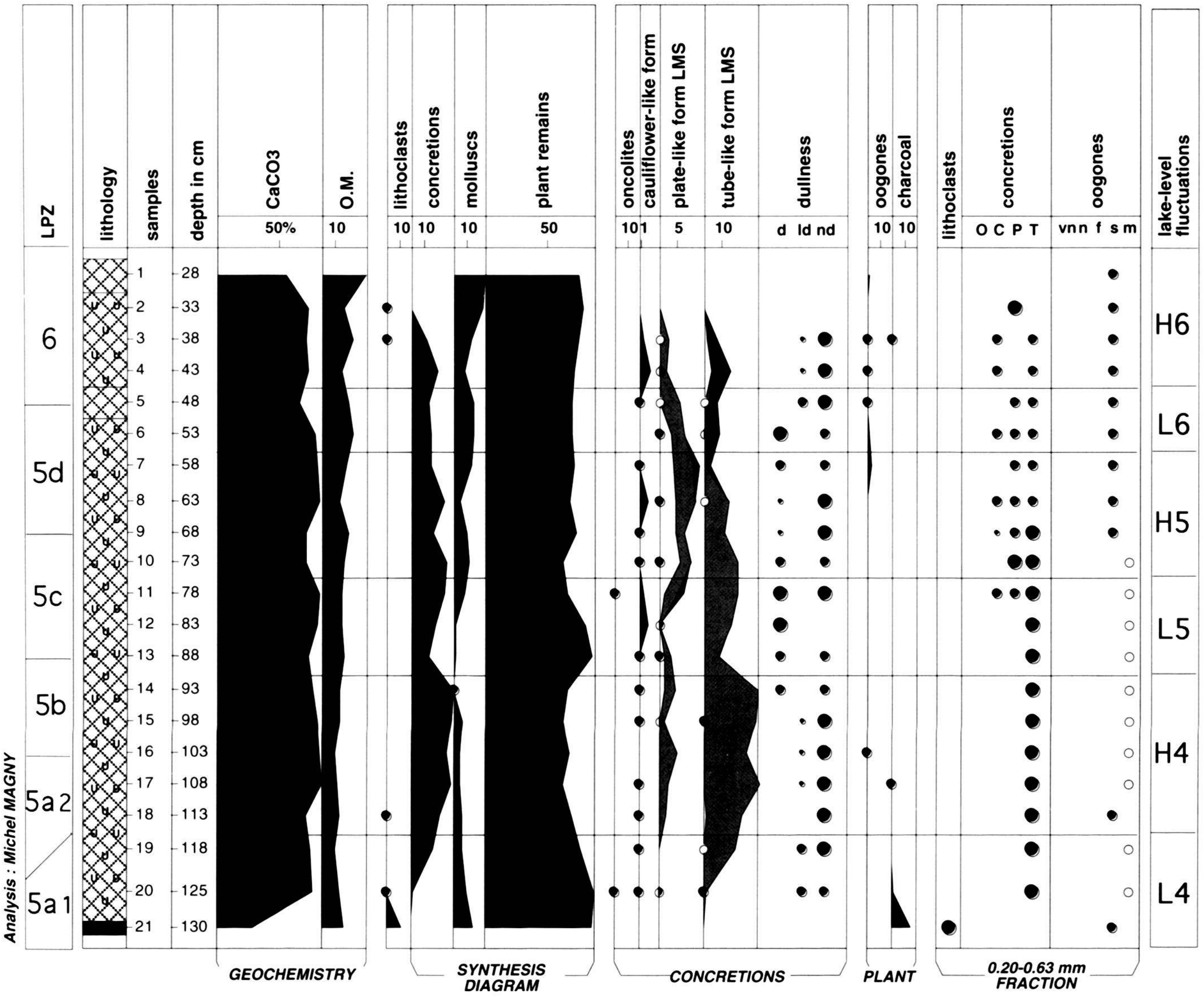

Fig. 6. Sediment diagram of core A9.

for a decrease in lake level. This lowering is followed by a progressive rise in the lake-level highlighted by the decline of *Cladium mariscus* and the expansion of *Najas marina* and *Schoenoplectus lacustris.* These results appear to be coherent with the information given by the lower part of the sedimentological diagram of core S11 (Fig. 9).

- Phase L 3: low lake-level recorded in cores A7, A9 bis and S11 (Fig. 5, 7 and 9) by a sediment hiatus in the nearshore areas (cores A7 and A9 bis) and by changes in the lithology and in the macroscopic components in the deeper water areas (core S11). Abrupt changes in pollen percentages recorded in core S22 could also be associated with this event (Richoz 1998). The sediment diagram of core S11 indicates that this lowering overlapped the transition from LPAZ 3b to LPAZ 4 a.
- Phase H3 : high lake-level. This phase is best recorded in core A9 bis (Fig. 7). There, it appears to be divided into four events, the first still belonging to LPAZ 4 a and the last preceding immediately the Cortaillod classic settlement. The weak time-resolution of LPAZ 4 in core S8 (Fig. 10) suggests that this increase in lake level had a rather limited magnitude.
- Phase L 4 : low lake level recorded in cores A7, A9 bis, and S11 (Fig. 5, 7 and 9). This phase included the Neolithic sett-

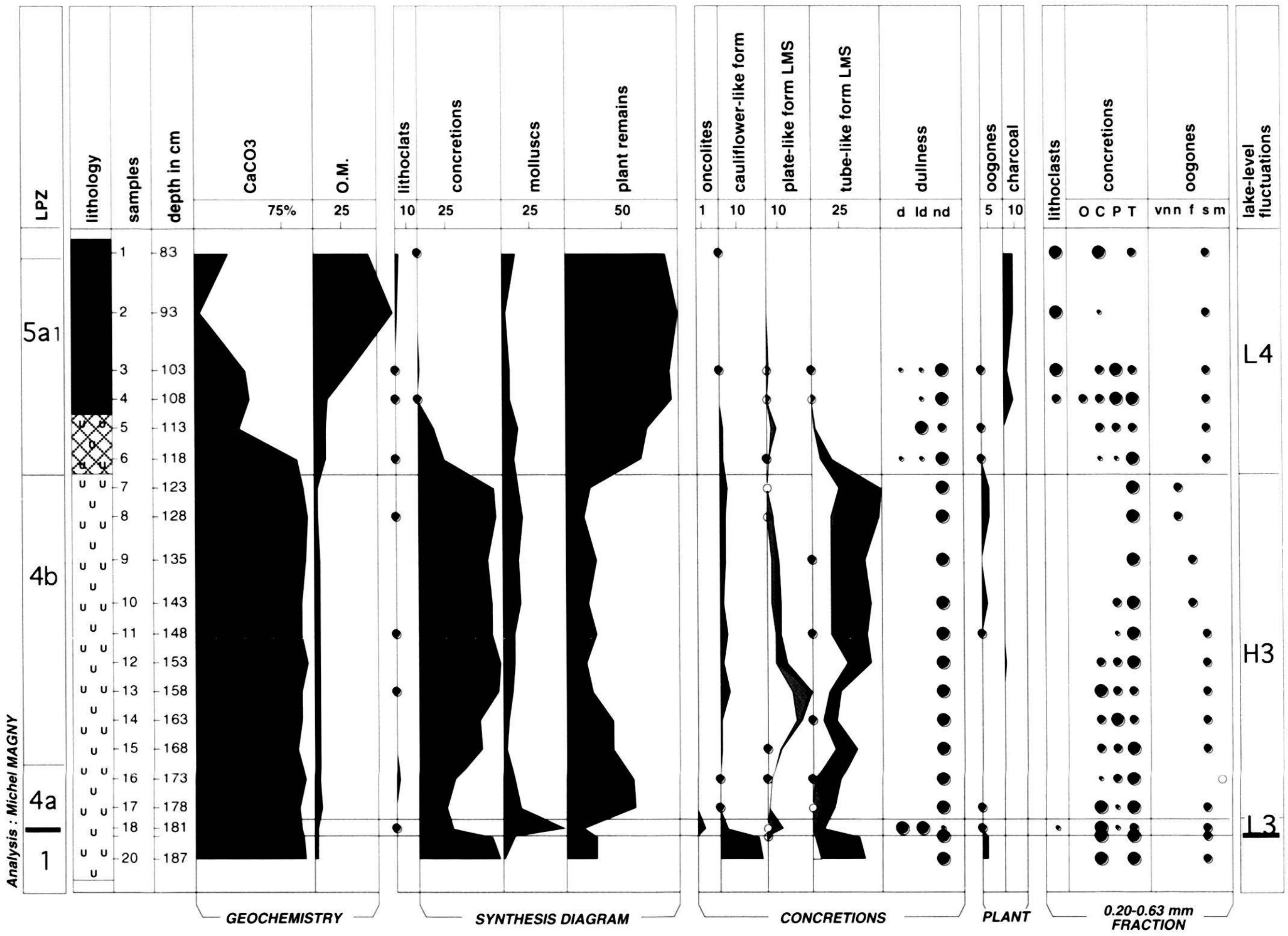

Fig. 7. Sediment diagram of core A9bis.

lement placed at ca. 3900–3700 cal. BC from indirect tree-ring dates, or at ca. 5980–5650 cal. BP from an AMS radiocarbon date (5085 ± 75 BP). The upper part of the archaeological layer is radiocarbon dated at ca. 4590 ± 75 BP (i.e. 5560–4990 cal. BP) in core A6. The first part of the calibration time-window appears to be the closest to the reality by reference to the archaeological artefacts and their usual tree-ring date (Voruz 1995). In core S8 (Fig. 10), phase L 4 is indicated by an increase in *Typha*, a decrease of *Najas marina* (LPAZ 5a1), and the replacement of *Nymphea, Typha* and *Schoenoplectus lacustris* by *Carex* (LPAZ 5a2) synchronous with the establishment of the Cortaillod site (presence of Cerealia).

- Phase H 4 : high lake-level recorded in cores A9 and S11. The sedimentological diagram of core S11 highlights two successive high lake-level events (Fig. 9). In core A9 (Fig. 6) this H 4 phase overlapps the final part of LPAZ 5 a 2 and LPAZ 5 b.
- Phase L 5: low lake-level recorded in cores A9 (Fig. 6).
- Phase H 5: high lake-level recorded in core A9 (Fig. 6). Its beginning overlapped the final part of LPAZ 5 c and it is also dated at ca. 4170 ± 75 BP, i.e. 4860-4440 cal BP (Tab. 1). It covers the two first thirds of the LPAZ 5 d. The continuous presence of dulled concretions suggests a rather limited increase in lake level.
- Phase L 6: Low lake level recorded in cores A9 and A11 (Fig. 6 and 8). The lowering is well marked in cores A11, A12 and A14 (Fig. 2) by an overgrowing peat layer.
- Phase H 6: major high lake-level well recorded in core A11 (Fig. 8). The rise of the water level began before the LPAZ 6/LPAZ 7 transition and led to the overlaying of the overgrowing peat (phase L 6) by lake-marl. A synchronous erosion could also explain the disappearance of this overgrowing peat in cores A8, A9 and A10 (Fig. 2 and 6). The sedimentological diagram of the core A11 clearly highlights two successive high lake-level events, the first being of larger magnitude than the second.

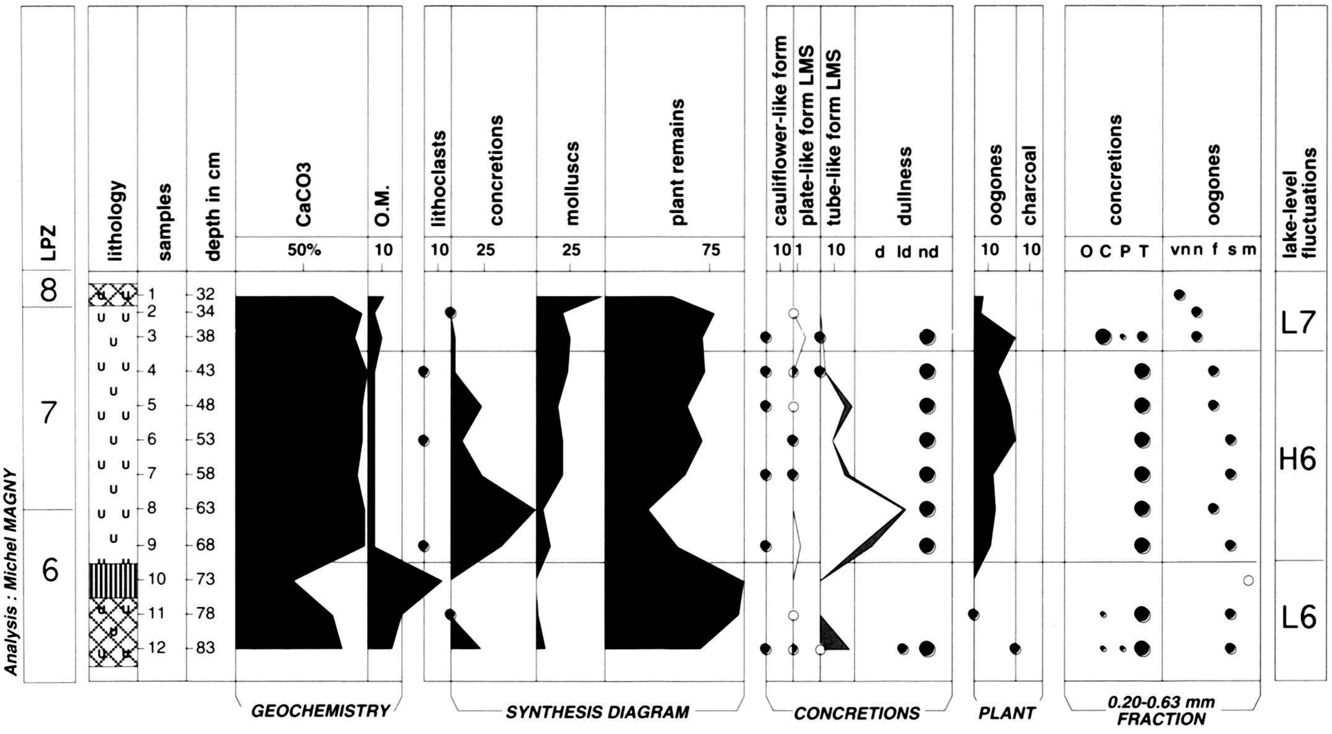

Fig. 8. Sediment diagram of core A11.

- Phase L 7: low lake-level recorded in core A11 (Fig. 8). This lowering developed as soon as the final part of LPAZ 7 and it overlapped the beginning of LPAZ 8.

The curve of Figure 11 presents a synthesis of the results. Major rises in the water level developed at ca 8800–8100, 6700–6200, 4800–4300 and 2700–2200 BP. A major lowering occurred at ca. 6000 BP. Thus, keeping in the mind that the two last millennia are not documented by the analysed cores, the Holocene period appears to be punctuated by an alternation of centennial to millennial-scale palaeohydrological variations. The sediment profiles led to the reconstruction of low frequency lake-level fluctuations due to a weaker time-resolution for the first half of Holocene. However, a higher time resolution for the period after 6000 BP provides a more detailed picture of the past lake-level fluctuations.

4. Discussion

As illustrated in Figures 11 and 12, the palaeohydrological phases reconstructed at lake Seedorf appears to be in agreement with that established in the Jura using the same method (Magny & Ruffaldi 1995). It also fits in with the palaeoclimatic oscillations inferred from glaciers advances and tree-limit high lake-level declines by Zoller (1977) and Burga & Perret (1997) in the Swiss Alps and Patzelt (1977) in the Austrian Alps. Thus, the high lake-level phases of Seedorf H1, H2, H3, H4, H5 and H6 correspond respectively to the cooling phases of Oberhalbstein/Schams/Venediger, Misox/Frosnitz, Piora 1/Rotmoos 1, Piora 2/Rotmoos 2, Löbben, and Göschenen 1. They also coincide with the climatic coolings recently defined by Haas et al. (1998) in central Europe, i.e. the phases termed CE 2, CE 4, CE 5, CE 6, CE 7 and CE 8. The phase H1 (=CE 2) also corresponds to (1) a high lake level identified from the sediment profils of Erlach, lake Bielersee (Wohlfarth & Schneider 1991), (2) a high lake-level reconstructed by Haas at Wallisellen (Haas et al. 1998), and (3) a ca –1‰ $\delta^{18}O$ anomaly at lake Gerzensee (Eicher 1979). The phases CE 1 (probably an equivalent of the Preboreal oscillation) and CE 3 (probably an equivalent of the 8200 yr event) do not appear to be recorded in the cores analysed at Seedorf whereas they were clearly distinguishable at the palaeolake Le Locle, Swiss Jura (Magny et al. 1998). Possible explanations for this can be found in (1) the rather short duration of these events and (2) the weak time-resolution of the sediment profiles studied for these periods. On the contrary, the core A9bis provides a detailed record of the time span between 6000 and 5000 BP, i.e. the Younger Atlantic (Firbas zone VII). The short but large increase in lake level occurring during the final part of phase H3 has an equivalent in sediment profiles from Concise, lake Neuchâtel where it developed between 5020±40 BP, i.e. 5905–5655 cal BP, and 4870±65 BP, i.e. 5715–5450 cal BP, from Montilier, lake Morat, where it took place just before 3800 BC (Magny and Richoz, unpublished data), and from lake Chalain, Jura, where it oc-

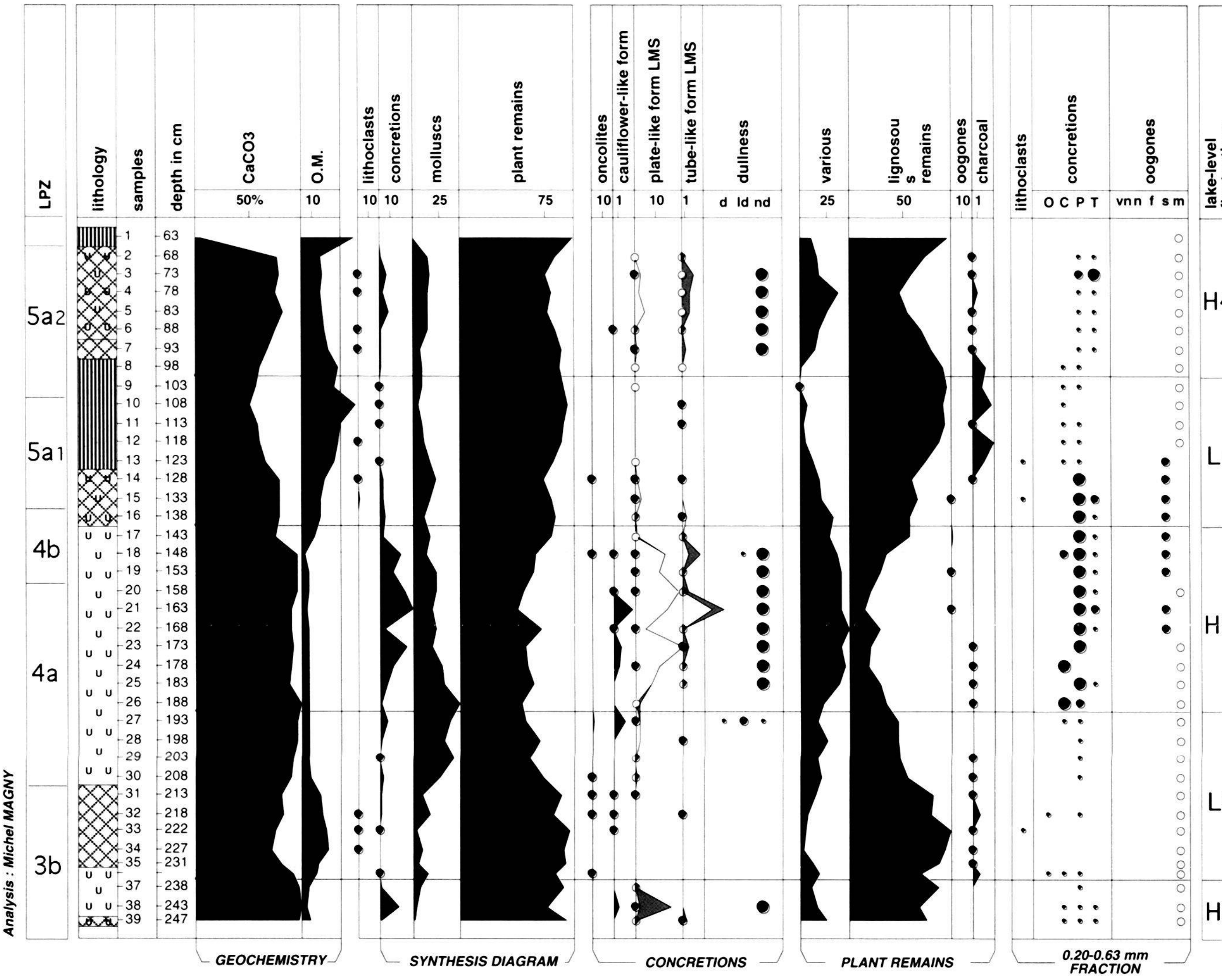

Fig. 9. Sediment diagram of core S11.

curred immediately before the Younger Atlantic-Subboreal transition (Magny 1997).

The general picture given by the magnitude of the lake-level fluctuations at Seedorf (Fig. 11) appears to be coherent with that of (1) the lake-level fluctuations in the Jura (Magny in press) and (2) the variations in tree-limit in the Swiss Alps such as reconstructed by Burga & Perret (1997). Thus, major cooling events marked by more durable and higher lake-levels at lake Seedorf, or longer and lower tree-limits in the Swiss Alps culminated at circa 8500, 6500, 4700/4500 and 2700/2500 BP. Moreover, the major lowering of lake Seedorf at 6000 BP has several equivalents in other lakes of the Swiss Plateau (Ammann 1989 ; Wohlfarth & Ammann 1991 ; Wohlfarth 1993) and the Jura (Magny et al. 1998). This event often marked by sedimentation hiatuses in the nearshore areas was also recognized at Montilier, Murtensee, where it is dated at ca 5800±45 BP (Magny and Richoz, unpublished data). Well marked (hiatuses) lake-level lowerings were also identified on the Swiss Plateau at the beginning of the Holocene (ca 10 000 BP), during the first half of the middle Atlantic (ca 8000–7000 BP) and in the middle part of the Subboreal (ca 3500 BP) (Ammann 1975 ; Wohlfarth & Schneider 1991; Wohlfarth et al. 1993).

Furthermore, glacial advances dated at ca 4500 and 2500 BP on Spitzbergen (Svendsen & Mangerud 1997) and at ca 4600 BP on James Ross Island, Antarctic Peninsula (Hjort et al. 1997) suggest a more global significance of the palaeoclimatic Seedorf record. It is also noteworthy that the major high lake-level culminating at ca 8500, 6500, 4700–4500 and 2700–2500 BP at lake Seedorf coincides with phases of reinforced Polar Circulation Index over the Greenland area evidenced by Mayewski et al. (1997) from the GISP2 glaciochemical series

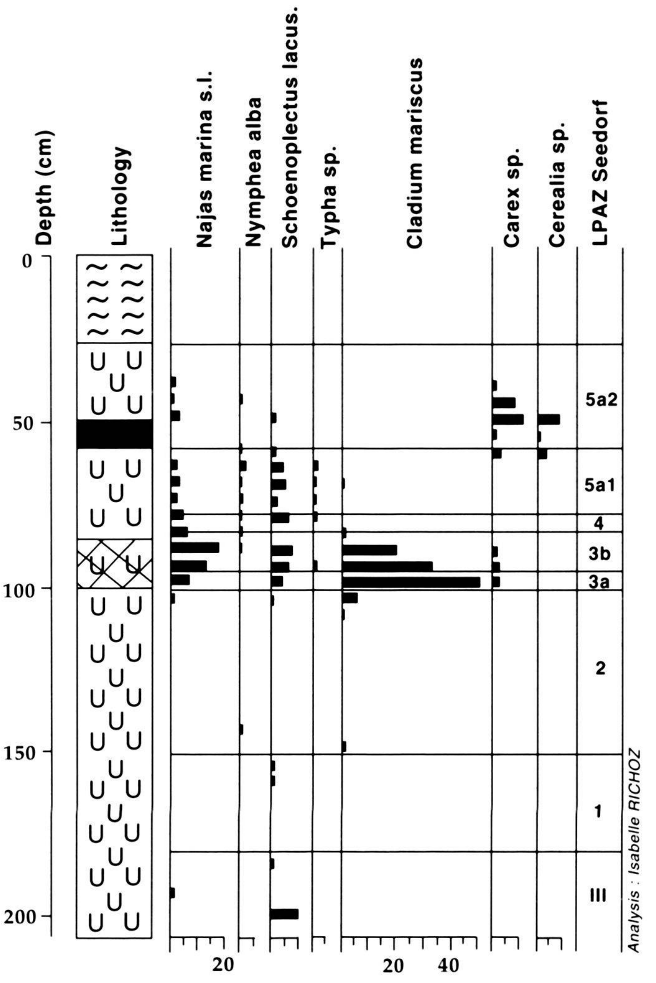

Fig. 10. Plant macrofossil diagram of core S8 (= A4). The frequency is indicated in seed number per 100 cm^3.

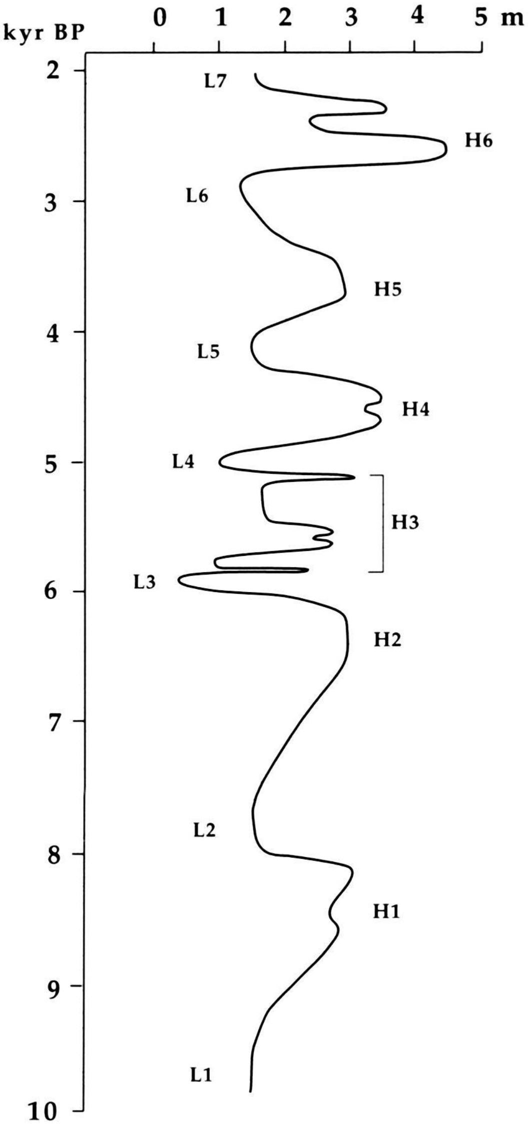

Fig. 11. Lake-level fluctuations at Seedorf from ca 10 000 to 2000 BP.

and dated at ca 10 500–9000 cal. BP (i.e. ca 9500–8150 BP), 8000–7000 cal. BP (i.e. ca 7200–6100 BP), 5000–4500 cal. BP (i.e. ca 4500–4000 BP) and 3200–2500 cal. BP (i.e. ca 3000–2500 BP). This coincidence during the Holocene between cooling phases over Northern high latitudes and the major phases of cooler and wetter climate over European mid-latitudes supports the general circulation pattern discussed by Magny (1993).

Thus, by comparison with other continental records, the palaeoclimatic pattern reconstructed at Seedorf testifies that the whole Holocene was punctuated by successive century to millennial-scale cooling events and that the Little Ice Age was only the last one (Zoller 1977; Patzelt 1977; Burga & Perret 1997; Haas et al. 1998). It also helps to identify the palaeohydrological pattern associated with this alternation of warming and cooling phases in the European mid-latitudes.

Acknowledgments

These investigations were supported by the French C.N.R.S. and the Swiss F.N.R.S (grant n° 31–9125.87/3). The authors express their sincere thanks to Dr Marilyn Gill (Besançon) for her help with the English translation of the manuscript.

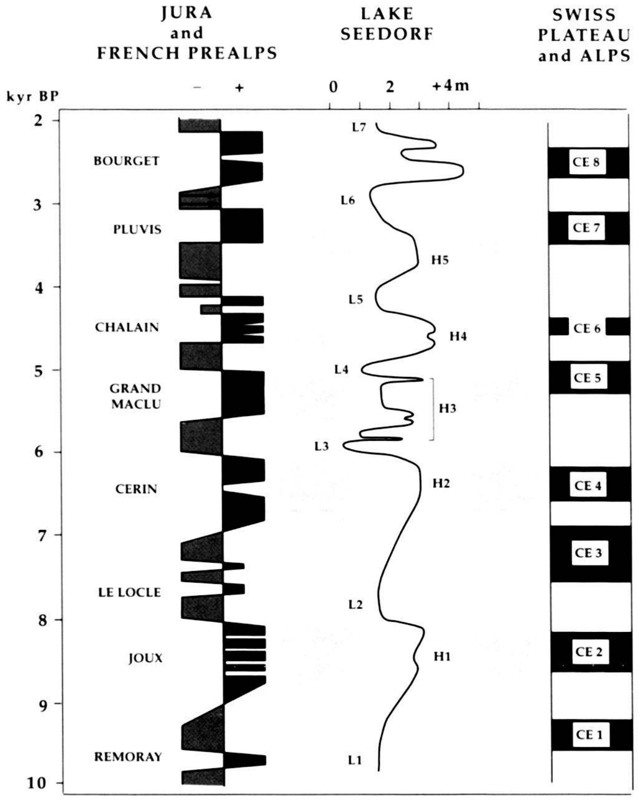

Fig. 12. Comparison between lake-level fluctuations at Seedorf (see Figure 11) and (1) lake-level fluctuations reconstructed by Magny and Ruffaldi (1995) in Jura and French Alps and (2) cold humid periods defined by Haas et al. (1998) in the Alps and on the Swiss Plateau. Phases Remoray and Le Locle, and phases CE1 and CE3 do not appear to be recorded in the cores analysed at Seedorf. Moreover, phase H5 at Seedorf appears to have begun earlier than phases Pluvis and CE7.

REFERENCES

AMMANN, B. 1975: Vegetationskundliche und pollenanalytische Untersuchungen auf dem Heidenweg im Bielersee. Beitr. Geobot. Landesaufn. der Schweiz 56, 76 p.

– 1989: Late-Quaternary palynology at Lobsigensee. Regional vegetation history and local lake development. Dissertationes Botanicae 137, 1–157.

AMMANN, B, GAILLARD, M.J. & LOTTER, A.F. 1995: Switzerland. In : BERGLUND, B.E., BIRKS, H.J.B., RALSKA-JASIEWICZOWA, M. & WRIGHT, H.E. (eds), Palaeoecological events during the last 15 000 years. Regional syntheses of palaeoecological studies of lakes and mires in Europe, John Wiley and Sons, Chichester, 647–666.

BENNETT, L. & BIRKS, H.J.B., 1990: Postglacial history of alder (Alnus glutinosa (L.) Gaertn.) in the British Isles. J. Quatern. Sci. 5, 123–133.

BURGA, C.A. & PERRET, R. 1997: Vegetation und Klima der Schweiz seit dem jüngeren Eiszeitalter. Ott Verlag Thun, 806 p.

DIGERFELDT, G. 1986 : Studies on past lake-level fluctuations. In : Berglund, B.E. (ed.): Handbook of Holocene Palaeoecology and Palaeohydrology, Wiley, Chichester, 127–143.

EICHER, U. 1979: Pollen- und Sauerstoffisotopenanalysen an spätglazialen Profilen von Gerzensee, Faulenseemoos und vom Regenmoos ob Boltigen. Mitt. natf Ges. Bern 37, 65–80.

GRAFENSTEIN (VON), U., ERLENKEUSER, H., MÜLLER, J., & KLEIMANN-EISENMANN, A. 1992: Oxygen isotope records of benthic ostracods in Bavarian lake sediments. Naturwissenschaften 79, 145–152.

HAAS, J.N., RICHOZ, I., TINNER, W. & WICK, L., in press. Sybchronous Holocene climatic oscillations recorded on the Swiss Plateau and at the timberline in the Alps. The Holocene.

HADORN, PH., 1987: Pollenanalytische Untersuchungen über die jüngere nacheiszeitliche Vegetations- und Siedlungsgeschichte am Murtensee. In: Chronique archéologique 1984, Fribourg, Editions universitaires, 107–127.

HARRISON, S.P., PRENTICE, I.C. & GUIOT, J. 1993: Climatic controls on Holocene lake-level changes in Europe. Climate Dynamics 8, 189–200.

HJORT, C., INGOLFSSON, O., MÖLLER, P. & LIRIO, J.M. 1997: Holocene glacial history and sea-level changes on James Ross Island, Antarctic. J. Quatern. Sci. 12, 259-273.

LOTTER, A.F., in press: Late-glacial and Holocene vegetation history and dynamics at Soppensee (Central Switzerland), as evidence by pollen and plant macrofossil analyses. J. Paleolimn.

MAGNY, M. 1992a: Holocene lake-level fluctuations in Jura and the northern subalpine ranges, France : regional pattern and climatic implications. Boreas 21, 319–334.

– 1992b : Sédimentation et dynamique de comblement dans les lacs du Jura au cours des 15 derniers millénaires. Rev. Archéométrie 16, 27–49.

– 1993: Holocene fluctuations of lake levels in the French Jura and Subalpine ranges, and their implications for past general circulation pattern. The Holocene 3, 306–313.

– 1997: Chalain de 6000 à 4500 BP. L'histoire du lac, du climat et du soleil. In : Pétrequin, P. (ed.) : Les sites littoraux néolithiques de Clairvaux-les-lacs et de Chalain (Jura). III. Chalain station 3, 3200-2900 av. J.-C. 2vol. Ed Maison des Sciences de l'Homme, Paris, 65–86.

– in press : Reconstruction of Holocene lake-level changes in the Jura (France) : methods and results. In : Guiot J. & Harrison S.P. (eds) : Palaeohydrology as reflected in lake level changes as climatic evidence for Holocene times. Paläoklimaforschung, Acad. Sci. d Lit. Mainz.

MAGNY, M. & RUFFALDI, P. 1995: Younger Dryas and early Holocene lake-level fluctuations in Jura, France. Boreas 24, 155–172.

MAGNY, M., SCHOELLAMMER, P., RICHARD, H. & BOSSUET, G. 1998: A high-resolution record of late Younger Dryas to mid-Holocene palaeohydrological changes from the palaeolake Le Locle, Swiss Jura. Comptes Rendus Acad. Sci. Paris 326, 787-793.

MAYEWSKI, P.A., MEEKER, L. D., TWICKLER, M. S., WHITLOW, S., YANG, Q. & PRENTICE, M. 1997: Major features and forcing of high latitude northern hemispheric atmospheric circulation using a 110 000 year long glaciochemical series. J. Geophysi. Res. 102, 26345–26366.

PATZELT, G. 1977: Der zeitliche Ablauf und das Ausmass postglazialer Klimaschwankungen in den Alpen. In: FRENZEL, B. (ed.), Dendrochronologie und postglaziale Klimaschwankungen in Europa, Wiesbaden, 248–259.

RICHOZ, I. 1998 : Etude paléoécologique du lac de Seedorf (Fribourg, Suisse). Histoire de la végétaion et du milieu durant l'Holocène: le rôle de l'homme et du climat. Dissertationes Botanicae 293: 177 pp.

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. Sci. nat. 79/4: 355–377.

RICHOZ, I., GAILLARD, M.J. & MAGNY, M. 1994: The influence of human activities and climate on the development of vegetation at Seedorf, southern Swiss Plateau during the Holocene: a case study. Dissertationes Botanicae 234, 423-446.

STARKEL, L., PAZDUR, A., PAZDUR, M.F., WICIK, B. & WIECKOWSKI, K., 1996: Lake-level and groundwater-level changes in the lake Gosciaz area, Poland : palaeoclimatic implications. The Holocene 6/2, 213–224.

SVENDSEN, J. I. & MANGERUD, J., 1997: Holocene glacial and climatic variations on Spitsbergen, Svalbard. The Holocene 7, 45–57.

TINNER, W., AMMANN, B. & GERMANN, P. 1996: Treeline fluctuations recorded for 12500 years by soil profiles, pollen and plant macrofossils in the Central Swiss Alps. Arctic and Alpine Res. 28, 131-147.

VORUZ, J.-L. (ed.), 1995: Chronologies néolithiques. De 6000 à 2000 avant notre ère dans le bassin rhodanien. Ed. Soci. Préhist. Rhodanienne, Ambérieu-en-Bugey, 422 p.

WOHLFARTH, B. 1993: Landschaftsentwicklung im Spätglazial des Oberen Würm und im frühen Holozän der Schweiz. In: SCHWEIZERISCHE GESELLSCHAFT FÜR UR- UND FRÜHGESCHICHTE (ed.), Die Schweiz von Paläolithikum bis zum frühen Mittelalter Verlag Schweizerische Gesellschaft für Ur- und Frühgeschichte, Basel, I, 57–65.

WOHLFARHT, B. & AMMANN, B. 1991: The history of the Aar river and the Forealpine lakes in Western Switzerland. In: GREGORY, L.K., THORNES, J.B. & STARKEL, L. (eds), Fluvial processes in the temperate zone in the last 15000 years, New York, 301–318.

WOHLFARHT, B. & SCHNEIDER, A.M. 1991: Late Glacial and Holocene lake level fluctuations in lake Biel, Western Switzerland. J. Quatern. Sci. 6, 4, 293–302.

WOHLFARHT, B., SCHWALB, A. & SCHNEIDER, A.M. 1993: Seen- und Flussgeschichte im westschweizerischen Seeland zwischen 5000 und 12000 Jahre vor heute. Mitt. natf Ges. Bern, NF 50, 45–59.

ZOLLER, H. 1977 : Alter und Ausmass postglazialer Klimaschwankungen in den Schweizer Alpen. In: B. FRENZEL, (ed.), Dendrochronologie und Klimaschwankungen in Europa Steiner Verlag, Wiesbaden, 271–281.

Manuscript received July 7, 1998
Revision accepted October 9, 1998