New results on the Late-Glacial history and environment of the Lake of Neuchâtel (Switzerland) : sedimentological and palynological investigations at the Paleolithic site of Hauterive-Champréveyres

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Objekttyp: **Article**

Zeitschrift: **Eclogae Geologicae Helvetiae**

Band (Jahr): **82 (1989)**

Heft 1

PDF erstellt am: **24.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-166373

Eclogae geol. Helv. 82/1: 203–218 (1989)

0012-9402/89/010203-16 $ 1.50 + 0.20/0

New results on the Late-Glacial history and environment of the Lake of Neuchâtel (Switzerland). Sedimentological and palynological investigations at the Palaeolithic site of Hauterive-Champréveyres

By MARIE-JOSÉ GAILLARD[1]) and BERNARD MOULIN[2])

ABSTRACT

The results of sedimentological and palynological investigations at the Palaeolithic site of Hauterive-Champréveyres (Lake of Neuchâtel, Switzerland) are presented.

The sedimentological investigation provides evidence of a low water level (425–426 m a.s.l.) at the Lake of Neuchâtel during the Oldest Dryas Ia (*sensu* FIRBAS, older than 12,600 B.P.), and a slight rise occurring at the end of this period, after occupation of the site by Magdalenian Man (*c.* 12,700 B.P.). There is no indication of a high water level subsequent to the retreat of the Rhône glacier (*c.* 15,000 B.P.) until the beginning of the Bølling Ib (*sensu* FIRBAS, *c.* 12,600 B.P.); the first marked rise in lake level is correlated to the *Juniperus-Hippophae* local pollen zone. The second part of the Bølling Ib (*Betula* local pollen zone) is characterized by a series of minor water level fluctuations including three instances of low water level. One of these low stands corresponds to the Azilian layer (*c.* 12,300 B.P.). Another marked lake-level lowering (to 426–426.5 m a.s.l.) began during the Allerød chronozone (*c.* 11,500 B.P.) and continued during the Younger Dryas chronozone (11,000–10,000 B.P.). The early Holocene period (Preboreal, younger than 10,000 B.P.) was characterized by a rise in water level. Both climate and geomorphology probably affected the water level at the Lake of Neuchâtel.

The pollen diagrams reveal, for the first time, complete Late-Glacial vegetational sequences from the Lake of Neuchâtel. Pollen analysis provides temporal resolution for sedimentological and archaeological events for which ^{14}C dates were ambiguous. One of the Magdalenian occupations is correlated to the *Artemisia-Salix* local pollen zone (Oldest Dryas Ia *sensu* FIRBAS) and is ^{14}C-dated by AMS (accelerator mass spectrometry) to *c.* 12,700 B.P. (Bølling chronozone *sensu* MANGERUD et al.). The Azilian layer was ^{14}C-dated by AMS to *c.* 12,300 B.P. and is concurrent with the middle of the *Betula* local pollen zone (Bølling Ib *sensu* FIRBAS). The occurrence of particular Apiaceae species during the *Betula* local pollen zone (Bølling) just after the Azilian occupation, may indicate drier climatic conditions.

RÉSUMÉ

Le présent article donne un compte-rendu des principaux résultats des études sédimentologiques et palynologiques effectuées sur le site paléolithique de Hauterive-Champréveyres (Lac de Neuchâtel, Suisse).

Les études sédimentologiques mettent en évidence un bas niveau du lac de Neuchâtel (425–426 m a.s.l.) pendant le «Dryas ancien inférieur» Ia (*sensu* FIRBAS, plus vieux que 12 600 B.P.) et une légère hausse du niveau à la fin de cette période, après l'occupation du site par les Magdaléniens (env. 12 700 B.P.). Rien n'indique un haut niveau du lac suite au retrait du glacier du Rhône (env. 15 000 B.P.) avant le début du Bølling Ib (*sensu* FIRBAS, env. 12 600 B.P.); la première hausse importante du lac est contemporaine de la zone pollinique locale à *Juniperus* et *Hippophae*.

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La seconde partie du Bølling Ib (zone pollinique locale à *Betula*) est marquée par une série de fluctuations lacustres mineures comprenant trois bas niveaux; l'un d'entre eux correspond à la couche azilienne (env. 12 300 B.P.). Une importante baisse du niveau du lac (à 426–426,5 m a.s.l.) s'amorce à la fin de l'Allerød et se poursuit au Dryas récent (11 000–10 000 B.P.). Le début de l'Holocène (Préboréal, après 10 000 B.P.) se caractérise par une hausse du niveau lacustre. Des facteurs climatiques et géomorphologiques sont probablement à l'origine des fluctuations du niveau du lac de Neuchâtel.

L'analyse pollinique met en évidence pour la première fois la séquence complète de l'histoire tardiglaciaire de la végétation au Lac de Neuchâtel. De plus, elle permet de situer les différents niveaux archéologiques et phases sédimentologiques dans un cadre chronologique plus précis que celui offert par les datations ^{14}C. Une des occupations magdaléniennes est corrélée à la zone pollinique locale à *Artemisia* et *Salix* («Dryas ancien inférieur» Ia *sensu* Firbas) et datée au ^{14}C par spectrométrie de masse (AMS) de env. 12 700 B.P. (chronozone Bølling *sensu* Mangerud et al.). La couche azilienne a été datée au ^{14}C par AMS de env. 12 300 B.P. et se situe au milieu de la zone pollinique locale à *Betula* (Bølling Ib *sensu* Firbas). La présence d'espèces particulières d'Apiaceae dans la zone pollinique à *Betula* (Bølling), immédiatement après l'occupation azilienne, peut être attribuée à des conditions climatiques relativement sèches.

1. Introduction

In this paper we present vegetational and palaeohydrological reconstructions based on results of sedimentological and palynological investigations at the Palaeolithic site of Hauterive-Champréveyres (Fig. 1A), and we discuss their palaeoclimatic and palaeoecological implications. In addition, we demonstrate how pollen-analysis may resolve the dating of Late-Glacial sediment sequences and Palaeolithic occupation layers.

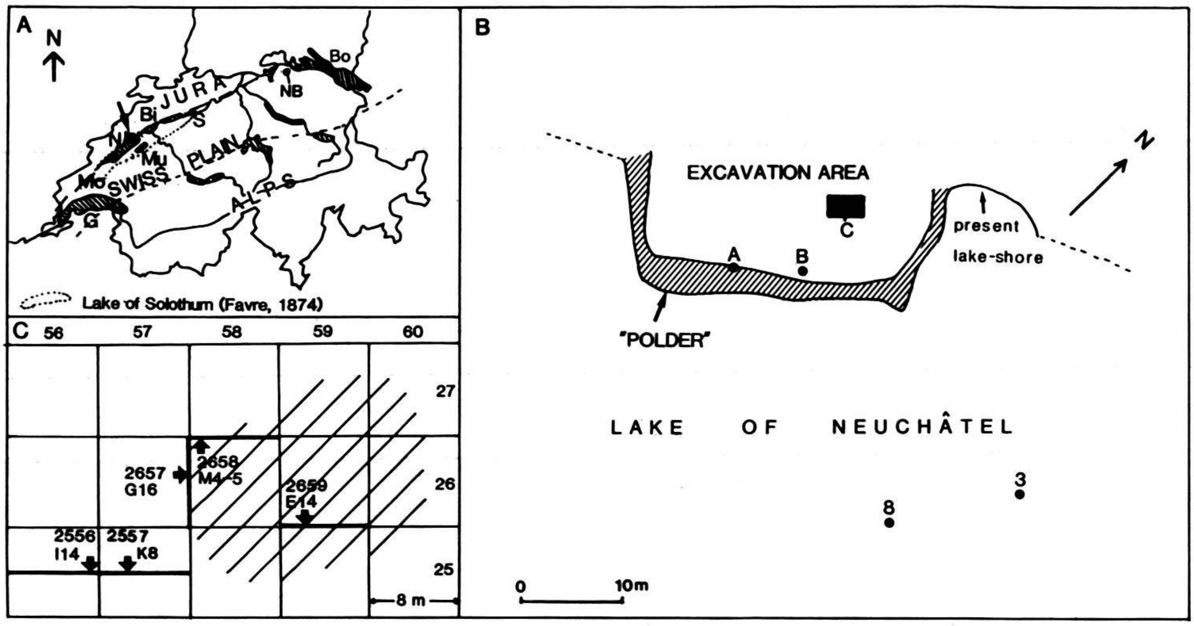

Fig. 1A. location of the investigated site. G = Lake of Geneva; Mo = Mormont; N = Lake of Neuchâtel; Mu = Murtensee; Bi = Bielersee; S = Solothurn; NB = Nussbaumerseen; Bo = Lake of Constance (Bodensee). The arrow shows the location of the archaeological "polder".

B. Excavation area (primarily Neolithic and Bronze Age strata) and location of the Palaeolithic excavation zone (C). The locations of cores A, B, 3 and 8 is indicated (see also Fig. 2).

C. Location of profiles in the Palaeolithic excavation area analysed for fossil pollen. The zone with firehearths is shown by oblique lines.

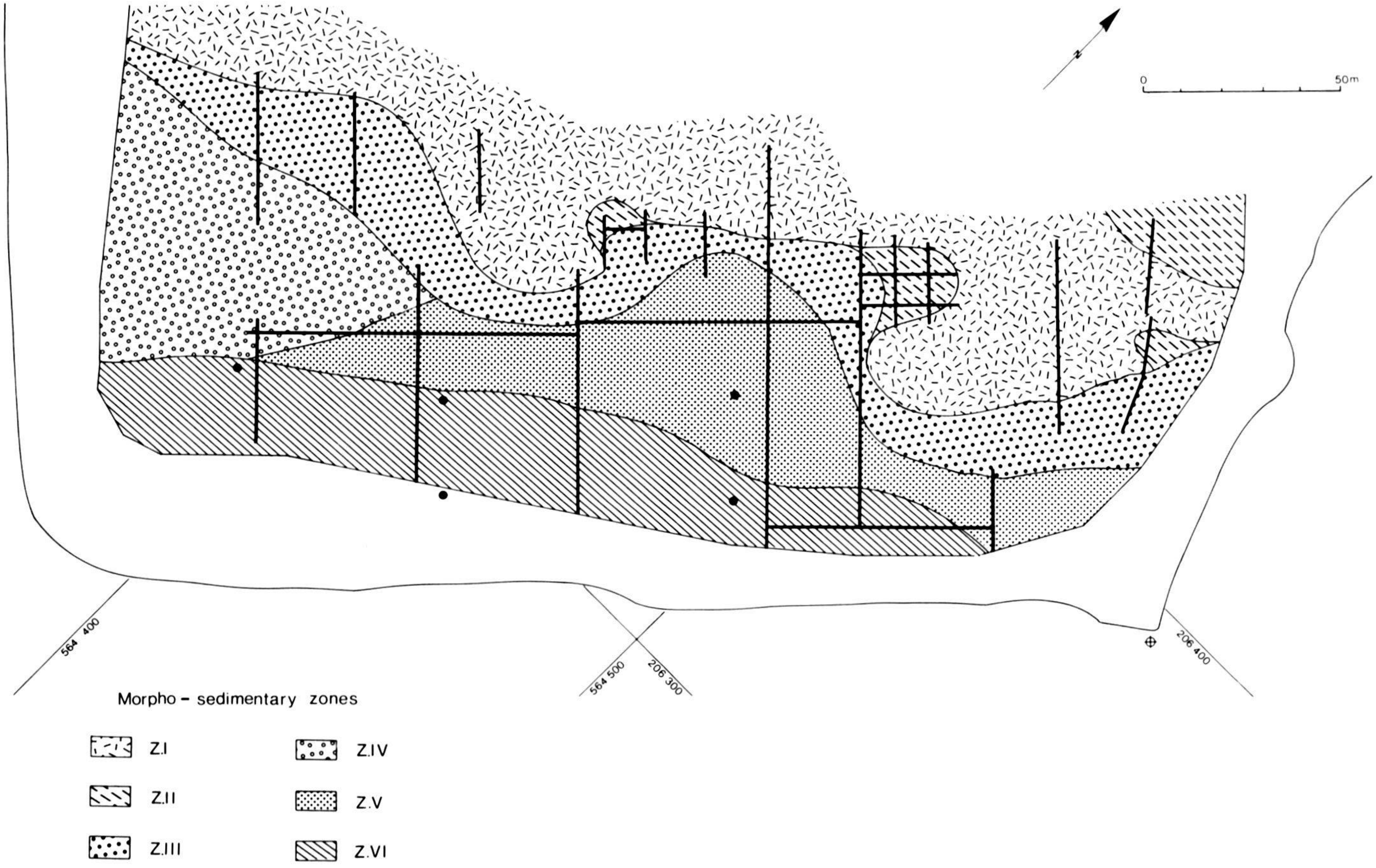

Fig. 2. The excavation area at Hauterive-Champréveyres with the six morpho-sedimentary zones described in the text (section 2.1), and location of the long sections and some of the cores.

A large archaeological excavation carried out by the Archaeological Survey of Neuchâtel (1982–1986) made it possible to perform sedimentological and palynological investigations of littoral sediment-sequences at Hauterive-Champréveyres, which lies on the northern shore of the Lake of Neuchâtel (GAILLARD, manuscript; MOULIN, in press; BROCHIER & MOULIN, manuscript) (Fig. 1).

Six long parallel sections through lake sediments and terrigenous deposits, combined with several corings (Figs. 1B and 2), made it possible to choose the best sediment sequences for palynological and sedimentological investigations, and to study the lithology and geometry of the deposits between 422 and 430 m a.s.l. This research was carried out as part of a large project including archaeological excavations LEESCH et al. in prep.), several palaeoecological analyses (CHALINE et al. in prep.), and ^{14}C dating (conventional and by accelerator mass spectrometry AMS) (LEESCH & MOULIN in prep.)[3]).

The discovery of archaeological layers of Magdalenian and Azilian age at an altitude of 427–428 m a.s.l. (JENNY et al., in press), 2 m below the present level of the lake, once again raised the question of water-level fluctuations at the Lake of Neuchâtel, and their climatic implications. Using geomorphological arguments, FAVRE (1983) was the first to propose the occurrence of a large "postwürmian" lake, the "Lake of Solothurn", extending from Solothurn to the Mormont (Fig. 1A). RUMEAU (1954) suggested a Late-Glacial lake-level at an altitude of 480 m a.s.l. and a Holocene lake-level at 450 m a.s.l. Therefore, archaeologists had no hope of finding cultural remains from Upper Palaeolithic time below those altitudes (SCHWAB 1973). However, LÜDI (1935) had already proposed the first reference curve for water level fluctuations of the Lake of Neuchâtel. According to him, the lake level lowered gradually between the time of deglaciation and the onset of reforestation (Bølling Ib *sensu* FIRBAS 1949/52), when it reached 428.50 m a.s.l. Then, damming of the outlet by mountain scree from Jensberg caused a sudden rise in the water level to 433 m a.s.l. or more at the beginning of the Bølling Ib. This was followed by a new gradual lowering until the Boreal period (*sensu* FIRBAS 1949/52).

2. Sedimentological results

The geological investigation includes a study of the lithology and geometry of sediments deposited between 422 and 430 m a.s.l. in the excavation area (Figs. 2 and 3). In addition to the stratigraphical record, the analytical methods include measurement of calcium carbonate content, analysis of grain-size, and determination of the composition of the sandy fraction. The chronology of lithostratigraphical events was established by absolute ^{14}C datings and pollen stratigraphy (section 3.1).

2.1 Morpho-sedimentary zones

Six morpho-sedimentary zones were identified in the excavation area (Figs. 2 and 3). They are described as follows:

- Zone I is characterized by a very compressed Late-Glacial and Holocene sequence of pebbles, gravel and sand overlying till deposits.

[3]) Conventional ^{14}C dating was performed by Mrs. T. RIESEN at the ^{14}C-Laboratory of the Physical Institute in Bern, Switzerland. Dating by accelerator mass spectrometry (AMS) was done at the Eidgenössische Technische Hochschule in Zürich, using the method developed by ANDRÉE et al. (1984).

- Zone II consists of fluvial material that was deposited by channel infilling during the Oldest Dryas Ia (*sensu* FIRBAS 1949/52) and the Bølling–Allerød chronozones (*sensu* WELTEN 1982).
- Zone III contains a series of pebble beach-deposits from Oldest Dryas Ia to the Younger Dryas chronozones (*sensu* MANGERUD et al. 1974).
- Zone IV is an alluvial-fan deposit occurring in the western part of the excavation and consisting of gravel overlying the silt and lacustrine chalk of the Bølling and the Allerød (*sensu* WELTEN 1982).
- Zone V consists of lake deposits, 1.5 m to 2.5 m thick. It often includes a hiatus between the silty-marly deposits of the Bølling Ib (*sensu* FIRBAS 1949/52) and the sandy, silty deposits of the Holocene.
- Zone VI is a well developed Late-Glacial and Holocene sequence (5–8 m thick) that comprises silty-clayey marl and sandy-silty deposits.

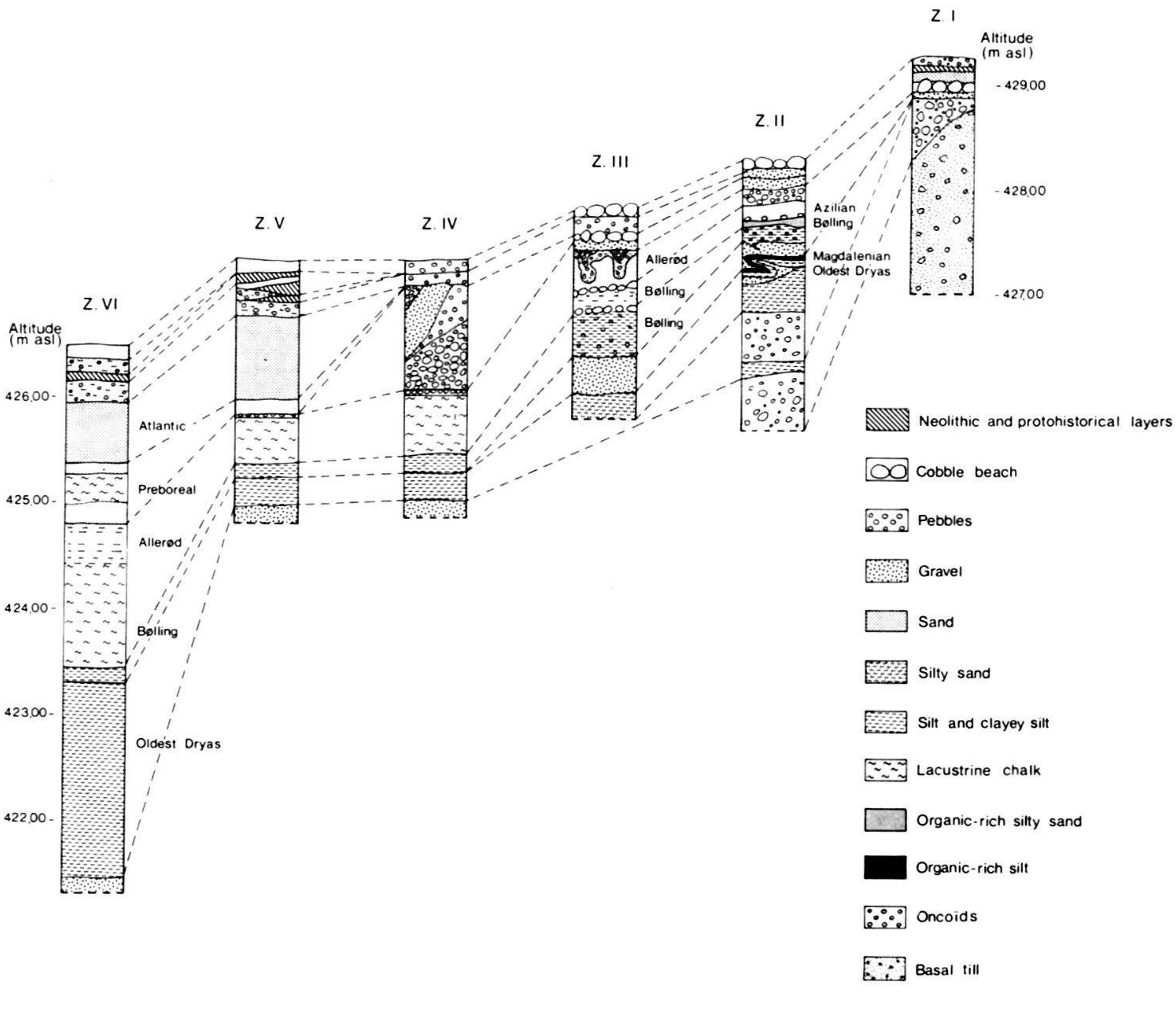

Fig. 3. Representative stratigraphic sequence of each morphosedimentary zone (described in the text, section 2.1).

2.2 Sediments predating the Oldest Dryas

Glacial deposits from the last Weichselian (Würm) advance of the Rhône glacier were identified in the most littoral zone of the site.

After the retreat of the Rhône glacier (*c.* 15,000 B.P.), before or at the beginning of the Oldest Dryas Ia (*sensu* Firbas, 1949/52), an erosion phase formed three large channels in which archaeological layers were buried. This period of channel cutting was concurrent with low lake-levels at the Lake of Neuchâtel, estimated to *c.* 425 m a.s.l., more than 4 m below its present level (429.30 m a.s.l.).

2.3 The Oldest Dryas sediment sequence

The Oldest Dryas period (Ia *sensu* Firbas 1949/52) is represented by both lake- and terrigenous (channel-infilling) deposits. Lake deposits between 422 and 424 m consist of clayey silts (with 45–50% calcium carbonate) (Fig. 3, Z. VI). Channel-infilling deposits consisting of gravels and pebbles in a sandy or sandy-silty matrix, and sandy silts with gravels occur between 426.50 and 428 m (Fig. 3, Z. II). These deposits correspond to periods of colluvium formation. Two archaeological layers of Magdalenian age were found in the upper part of this sequence (Fig. 4, Z. II–III). The Magdalenian layer 2 is covered by organic-rich silt correlated to the *Artemisia-Salix* local pollen-assemblage zone (HCh 1 PAZ).

These data indicate a low lake-level (around 425 m a.s.l.) during the Oldest Dryas Ia and a water-level rise to an altitude of ca. 427 m at the end of the Oldest Dryas Ia, subsequent to the Magdalenian occupation.

2.4 The Bølling sediment sequence

Above the layer of organic-rich silt (*Artemisia-Salix* local PAZ, see section 2.3 above), the channel deposits include gravels in a sandy to sandy-silty matrix indicating low lake-levels (at *c.* 426 m a.s.l.) at the beginning of the Bølling Ib (*sensu* Firbas 1949/52) (Fig. 4, Z. II–III). This sediment is overlain by lacustrine silts with pebbles correlated to the *Juniperus-Hippophae* local PAZ. These sediments, which indicate a rise in lake-level to *c.* 428 m a.s.l., are affected by the first phase of plastic deformation (slumping), which occurred between 12,670 ± 140 and 12,330 ± 100 B.P. (conventional ^{14}C dating). The channel-infilling deposits are the only deposits showing evidence of slumping, which include many sedimentary structures described in the literature: multilayer folds, asymmetric folds, recumbent folds, and nappe-like and hook-like structures (Kziazkiewicz 1958, Potter & Pettijohn 1963, Dzulynski 1963, Pettijohn & Potter 1964).

In several profiles, a layer of beach pebbles and cobbles indicating a water level lowering occurs at 426.50 m at the transition between the *Juniperus-Hippophae* local PAZ and the *Betula* local PAZ (Fig. 3, Z. III). The first material deposited during the *Betula* local PAZ is a transgressive organic-rich silty sand (Fig. 3, Z. II; Fig. 4). This deposit is ^{14}C-dated (conventional method) to 12,330 ± 100 B.P. The occurrence of both an Azilian occupation horizon above those organic-rich sands at an altitude of 427.50 m a.s.l. (Fig. 3, Z. II), and a second layer of beach pebbles between 426.50 and 427 m a.s.l. (Fig. 3, Z. III), indicates another water-level lowering.

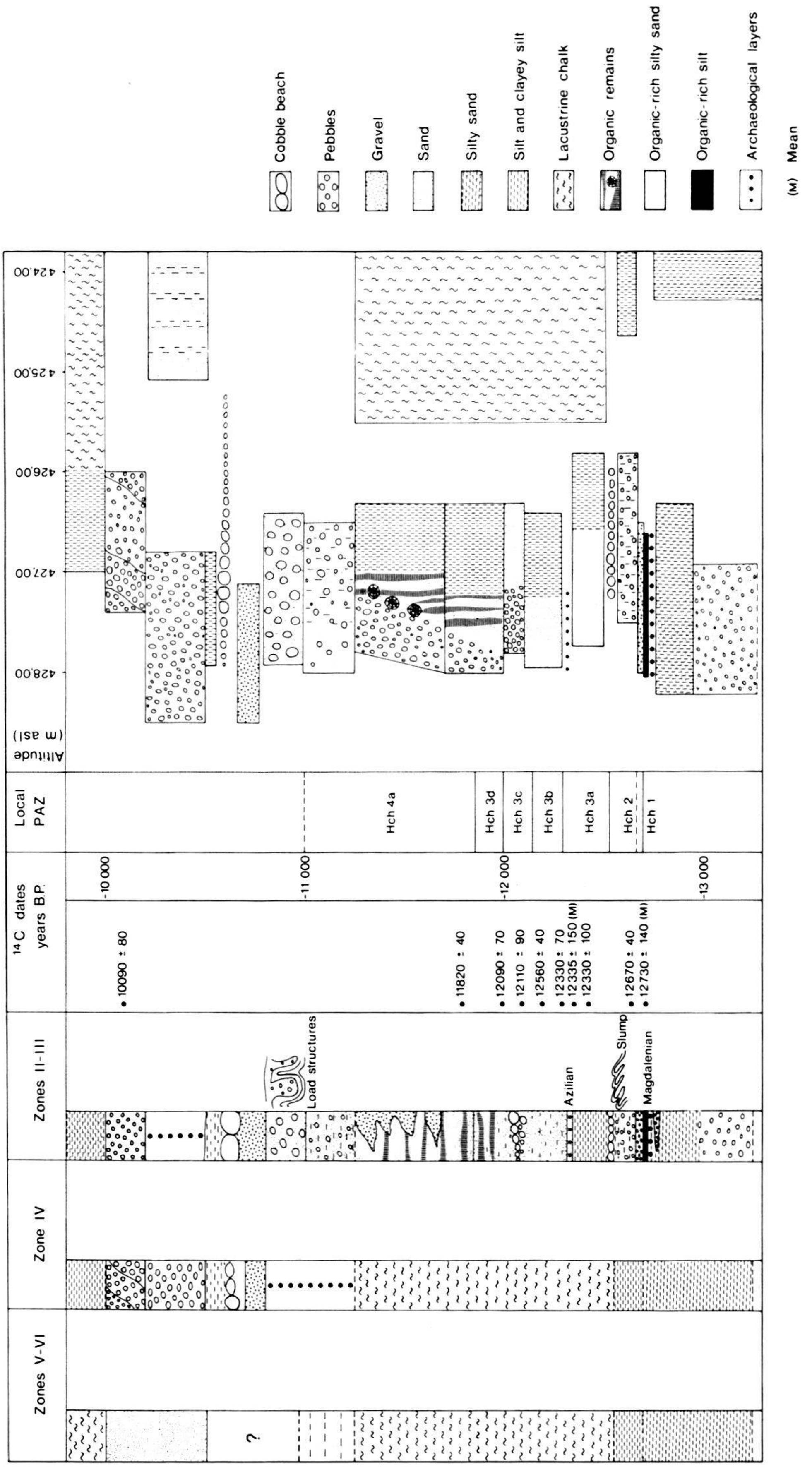

Fig. 4. Schematic presentation of the three main types of Late-Glacial sediment sequences with their ages. The altitudinal range of the different layers is shown on the right.

Fine lacustrine sand covers the occupation layer, and is laterally correlated to organic, sandy, and calcareous silts (Fig. 3). At the end of the Bølling chronozone, another pebble beach was deposited (Fig. 4, Z. II–III) and is ^{14}C-dated to 12,110 ± 90 B.P. (conventional method on organic macro-remains). It is covered by fine organic-rich sand. In the lowest part of the excavation, (423–425.50 m a.s.l.), the youngest part of the Bølling is represented by the deposition of lacustrine chalk (Fig. 3, Z. IV, V et VI).

2.5 The Allerød and Younger Dryas sediment sequence

The sediments of Allerød age (*sensu* Welten 1982) occurring in zone II (Figs. 3, 4) consist of sands with organic remains (i.e. trunks, branches and cones of *Pinus sylvestris*) and gravel bars. The organic remains are ^{14}C-dated (conventional method) to 11,820 ± 40 B.P., thus to the beginning of the Allerød chronozone. During that period, lacustrine chalk continued to be deposited in the lowest part of the site (Fig. 3, Z. IV–VI).

The sands with organic remains are overlain by a sandy, silty deposit with gravel, that, in turn, is covered by yellow sand with gravel and pebbles. Thereafter there is evidence of a second phase of plastic deformation affecting a 10 m-large and more than 100 m-long littoral band (Fig. 4, Z. II–III). These deformations, which are of Allerød age, are different from those occurring during the Bølling. They are load structures of several types, including ball-and-pillow, pouche, and diapir (Pettijohn & Potter 1964), as well as drop structures (Brodzikowski et al. 1984). They are truncated between 426.50 and 427.50 m a.s.l. by a sandy, gravelly layer succeeded by a deposit of large pebbles and cobbles, indicating a marked lowering of lake level (Fig. 4). The ^{14}C dates obtained on sediments covering this beach (10,350 ±110, 10,160 ± 100, 10,090 ± 80 B.P.) suggest that it was formed during the Younger Dryas chronozone (*sensu* Mangerud et al. 1974).

A silty layer covers the beach and an alluvial-fan formed in the western part of the site (Fig. 3 and 4, Z. IV). The material of the fan was sorted in a series of gravel bars between 426 and 427 m a.s.l., suggesting that the water level of the lake was at about 426 m a.s.l. when the bars were formed.

2.6 The Holocene sediment sequence

The beach- and alluvial-fan deposits are covered by transgressive sandy silts and fine sands (Fig. 4). Pollen analysis of these sediments revealed a typical Early Holocene sequence with the *Pinus* local PAZ (Preboreal), the *Corylus* local PAZ (Boreal) and the *Quercetum mixtum* local PAZ (Atlantic), pollen zones IV, V and VI of Firbas (1949/52), respectively.

3. Palynological results

The primary purpose of palynological studies at the Palaeolithic site of Champréveyres was to provide a chronological and vegetational context in which to place the Magdalenian and Azilian occupation layers.

Approximately 40 conventional and AMS ^{14}C dates were obtained from charcoal of Magdalenian and Azilian hearths and from remains of terrestrial plants recovered from the sediments.

All dates from sediment sequences including or contemporaneous with archaeological layers vary between 12,000–13,000 B.P., which corresponds to the Bølling chronozone (MANGERUD et al. 1974). Continuous series of AMS ^{14}C dates from lake sediments of the Swiss Plain (Fig. 1A) have revealed sequences of nearly constant ages for parts of the Late-Glacial period, the Bølling Ib and Younger Dryas III pollen zones (FIRBAS 1949/52) in particular (ANDRÉE et al. 1986; AMMANN & LOTTER, manuscript; LOTTER & ZBINDEN 1989). This implies that temporal resolution of events occurring during those periods is extremely difficult. Because the Bølling Ib and Allerød II pollen zones are characterized by rapid vegetational changes, pollen analysis provides a valuable method to distinguish between different sedimentological or archaeological events for which ^{14}C dates were ambiguous.

3.1 Chronology of Late-Glacial sediments at Hauterive-Champréveyres inferred from pollen stratigraphy

Several sediment profiles were analysed for fossil pollen (Fig. 1B and C). The deposits including archaeological remains often lacked pollen, probably because of oxydation during periods of low water level. The profile 2659 E14 (Fig. 1C and 5) is the only one that includes two layers of Magdalenian age. The position of the Azilian layer in the palynological sequence (profile 2658 M4-5) had to be inferred from stratigraphical correlations.

The complete Late-Glacial vegetational sequence was obtained by correlation and combination of all pollen diagrams to be published in GAILLARD (manuscript). The summary diagram (Fig. 5) gives a simplified synthesis of the results. The classical Late-Glacial vegetation sequence (open tundra-like vegetation, *Juniperus* shrubland, *Betula* parkland, and *Pinus* woodland) of the Swiss Plain (AMMANN 1985, GAILLARD 1985a) is recorded at Hauterive-Champréveyres.

The oldest sediments analysed for pollen (profile 2659 E14) are dominated by herbs (primarily *Artemisia*, Cyperaceae and Gramineae) and have high percentages of *Salix* pollen (60% of the total pollen sum); high concentrations of *Salix* cf. *retusa* charcoals were also found in the Magdalenian hearths (SCHOCH pers. comm.). This first local pollen-assemblage zone (HCh 1 PAZ) is tentatively correlated to the *Artemisia-Betula nana* regional PAZ (GAILLARD 1985a, AMMANN 1985) and dated to the end of the Oldest Dryas Ia (*sensu* FIRBAS 1949/52). The *Artemisia-Betula nana* regional PAZ was ^{14}C-dated by AMS to *c.* 13,300 to 12,600 B.P. in several profiles on the Swiss Plain (AMMANN & LOTTER, manuscript); it thus covers both the end of the Oldest Dryas and the beginning of the Bølling chronozones *sensu* MANGERUD et al. (1974). Ten dates obtained from charcoal of the Magdalenian layer 2 (Fig. 5) range between 13,050 and 12,510 B.P., the first part of the Bølling chronozone *sensu* MANGERUD et al. (1974).

The two layers of Magdalenian age are covered by a deposit of silt and gravel, which is characterized by very high percentages (75%) of *Juniperus* (profile 2659 E14, HCh 2 local PAZ, Fig. 5). This pollen assemblage is found in two other profiles, 2658 M4-5 and 2657 G16 (Fig. 5), and is typical at the onset of reforestation on the Swiss

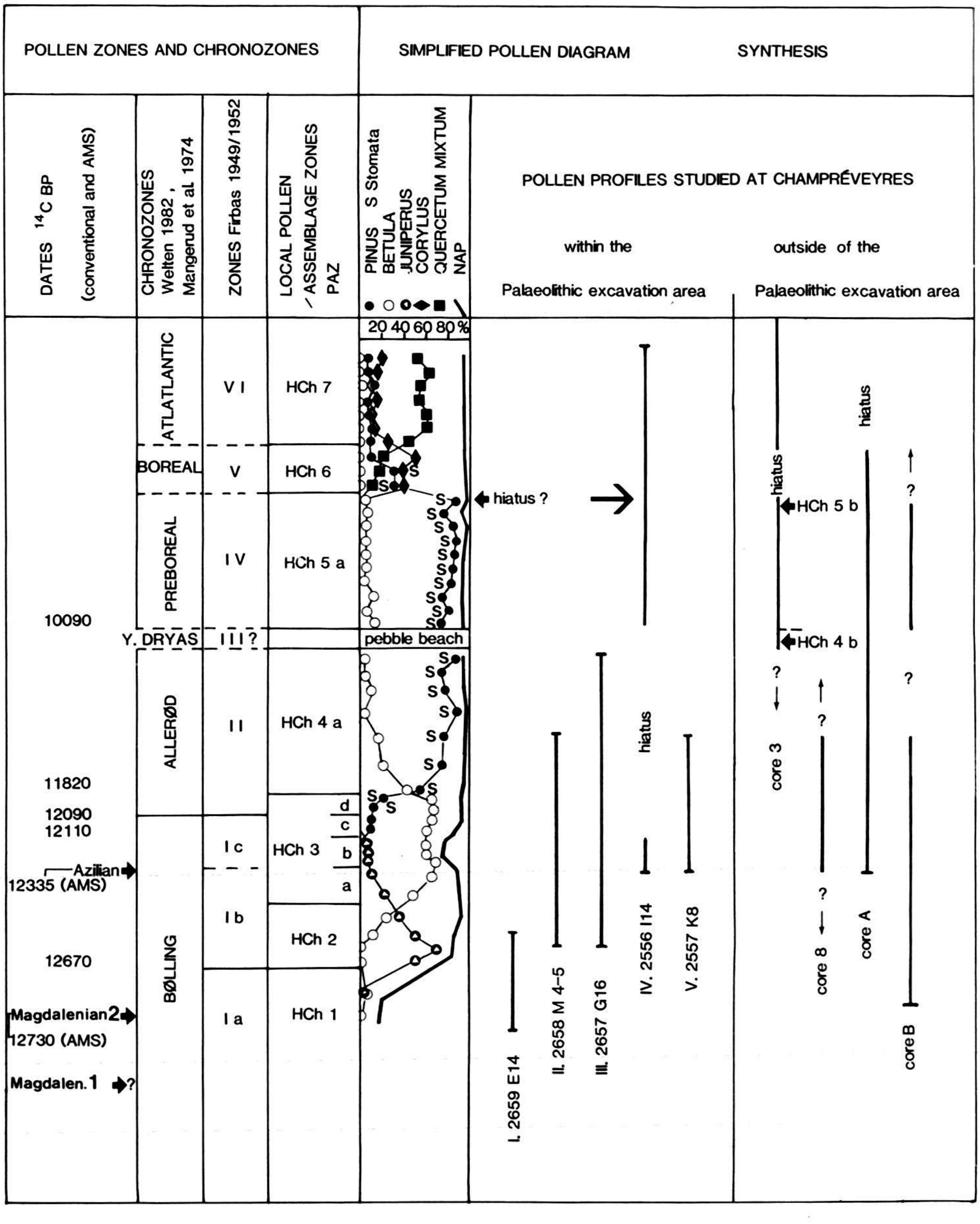

Fig. 5. Simplified pollen diagram giving a synthesis of the results obtained from all investigated profiles in the Palaeolithic excavation area. Some of the results obtained outside the Palaeolithic zone (cores A, B, 3 and 8) are presented as well. The biostratigraphic positions of the profiles analyzed for fossil pollen are shown on the right. ^{14}C dates (conventional or by accelerator mass spectrometry, AMS), chronozones according to Mangerud et al. (1974) and Welten (1982), and local pollen assemblage zones (PAZ) at Hauterive-Champréveyres are presented on the left. The local PAZ HCh 4b and HCh 5b were described from cores 3 and A only. They are, therefore, not included in the simplified pollen diagram. NAP: non arboreal pollen (herbs).

Plain (*Juniperus-Hippophae* PAZ, GAILLARD 1985a). This phase has been ^{14}C-dated by AMS to *c.* 12,600 to 12,300 B.P. in several sites on the Swiss Plain (AMMANN & LOTTER, manuscript). A date of 12,670 ± 40 B.P. was obtained at Champréveyres for the beginning of this pollen zone.

The *Juniperus* phase is followed by the expansion of *Betula* (HCh 3 local PAZ). This period is characterized by a succession of events (Table 1 and Fig. 5), including a gradual decrease in *Juniperus* pollen percentages (HCh 3a), a short phase with higher percentages of herbs (*Artemisia*, Gramineae, Apiaceae, *Thalictrum, Helianthemum;* HCh 3b), a slight increase in *Pinus* pollen percentages (HCh 3c) and, finally, a definitive increase in *Pinus* (over 10%, HCh 3d) together with the first occurrence of *Pinus* stomata (specialized cells of the leaves' epidermis). The local PAZ HCh 3a–3c are dated to the Bølling *sensu* WELTEN (1982). The transition HCh 3c/HCh 3d marks the beginning of the Allerød *sensu* WELTEN, which is dated to *c.* 12,000 B.P. on the Swiss Plain (ANDRÉE et al. 1986, AMMANN & LOTTER, manuscript). According to lithostratigraphical correlations at Hauterive-Champréveyres, the Azilian layer occurs in the middle of the *Betula* local PAZ, just at the base of the subzone HCh 3b (Fig. 5). The ^{14}C ages obtained from the Azilian layer, 12,120 and 12,550 B.P., belong to the Bølling chronozone, and thus support the lithostratigraphical correlation.

Dominance of *Pinus* occurs in several profiles (2658 M4-5, 2657 G16, 2557 K8), and represents the first part of the Allerød chronozone *sensu* WELTEN (1982). In profile 2556 I14, sediments of this period are truncated by a layer of beach pebbles, which is, in turn, overlain by sediments of Preboreal age (younger than 10,000 B.P.). The beach deposit is, therefore, assigned tentatively to the Younger Dryas chronozone (11,000–10,000 B.P.). Lake sediments dated by pollen analysis to the Younger Dryas chronozone were found in two long cores recovered from deep water (cores A and 3, Fig. 1C and 5).

3.2 Vegetation history and palaeoecology

Table 1 presents the different local pollen-assemblage zones and their vegetational interpretation. Pollen analysis of the Late-Glacial sediments at Champréveyres reveals a sequence of events comparable to that demonstrated by pollen diagrams from the Swiss Plain. Nevertheless, we note some differences that may result from local conditions.

PENNINGTON (1986) discusses the role of soils for vegetation development and the onset of reforestation during the Early Late-Glacial in Great Britain. Our results also suggest that the soils surrounding the archaeological site at Champréveyres probably were a critical factor in the local vegetational development at the beginning of the Late-Glacial period. The local environment of Palaeolithic Man consisted primarily of the lake shore and the slopes of the neighbouring Jura Mountain. Sandy, clayey, or stony soils were probably prevailing in the area. These local characteristics may explain the abundance of *Salix* (mainly *S. retusa*) instead of *Betula nana* at the end of the Oldest Dryas Ia (HCh 1 local PAZ), the high percentages of *Juniperus* pollen at the beginning of the Bølling Ib (HCh 2 local PAZ), and the high values of *Hippophae* during the birch period (HCh 3 local PAZ); these shrubs probably expanded easily on the poorly developed soils at the beginning of the Bølling chronozone.

CHRONOZONES (MANGERUD ET AL.1974; WELTEN 1982)	LOCAL PAZ		INTERPRETATION IN TERMS OF VEGETATION
ATLANT.	HCh 7 QUERCETUM MIXTUM		OAK (QUERCUS), ELM (ULMUS), LIME (TILIA) AND ASH (FRAXINUS) WOODLAND DOMINANT.
BOREAL	HCh 6 CORYLUS		HAZEL (CORYLUS) WOODLAND DOMINANT. SUCCESSIVE EXPANSION OF HAZEL, OAK, ELM AND LIME.
PREBOREAL	HCh 5 PINUS 2	b.- CORYLUS	PINE (PINUS) WOODLAND DOMINANT. POSSIBLE ARRIVAL OF HAZEL AT THE SITE (?)
		a.- FILIPENDULA	PINE WOODLAND DOMINANT. WET MEADOWS PLANTS SUCH AS FILIPENDULA ARE COMMON.
YOUNGER DRYAS	HCh 4 PINUS 1	b.- BETULA - GRAMINEAE - ARTEMISIA	PINE WOODLAND DOMINANT. SOME TREE BIRCHES (BETULA ALBA). SLIGHT OPENING OF THE FOREST AND DEVELOPMENT OF SHRUBS (SALIX, HIPPOPHAE) AND MEADOWS (GRAMINEAE, ARTEMISIA,ETC..)
ALLERØD		a.- BETULA	PINE WOODLAND DOMINANT. SOME TREE BIRCHES.
	HCh 3 BETULA	d. - PINUS 2	PINE IS EXPANDING GRADUALLY IN THE OPEN WOODLAND OF TREE BIRCHES.
BØLLING		c. - PINUS 1	TREE BIRCHES WOODLAND DOMINANT. PINE DOES NOT OCCUR CLOSE TO THE SITE. BUCKTHORN (HIPPOPHAE) IS STILL COMMON AT THE SITE.
		b. - SALIX - ARTEMISIA	OPEN WOODLAND OF TREE BIRCHES AND DRY MEADOWS (ARTEMISIA, HELIANTHEMUM, APIACEAE, SANGUISORBA MINOR). SALIX SP. IS COMMON.
		a. - JUNIPERUS	JUNIPER (JUNIPERUS) AND BUCKTHORN ARE STILL COMMON, BUT TREE BIRCHES ARE EXPANDING ON THE MOST MATURE SOILS.
	HCh 2 JUNIPERUS - HIPPOPHAE		SHRUBLAND WITH JUNIPER AND BUCKTHORN, SMALL STANDS OF TREE BIRCHES, AND MEADOWS (GRAMINEAE, CYPERACEAE, ARTEMISIA, CHENOPODIACEAE, LIGULIFLORAE, ANTHEMIS T., RUBIACEAE, THALICTRUM, RUMEX/OXYRIA).
	HCh 1 SALIX - ARTEMISIA		OPEN VEGETATION WITH ALPINE - LIKE MEADOWS (GRAMINEAE, HELIANTHEMUM, THALICTRUM, SELAGINELLA SELAGINOIDES), PLANT COMMUNITIES ON WET STONY SOILS (SAXIFRAGA OPPOSITIFOLIA, GYPSOPHILA REPENS, CRUCIFERAE), SMALL STANDS OF BUSHES (BETULA NANA; JUNIPERUS, SALIX SP.). SALIX cf. S. REPENS IS VERY COMMON AT THE SITE. POSSIBLY SOME ISOLATED TREE BIRCHES.

Table 1: Late-Glacial and Holocene pollen-assemblage zones from the littoral zone of the Lake of Neuchâtel at Hauterive-Champréveyres, and their vegetational interpretation. The chronozones according to Mangerud et al. (1974) and Welten (1982) are indicated on the left.

During Magdalenian time (*c.* 12,700 B.P.), Man inhabited an open landscape of alpine meadows and dwarf shrubs. At Champréveyres, the lake shore probably was partly covered with dwarf willow *(Salix retusa)* and herbs such as those found today along gravelly mountain streams (*Gypsophila repens,* species of Liguliflorae and Brassicaceae). During Azilian time (*c.* 12,350 B.P.), the landscape was characterized by open birch-forests with shrubs and dry meadows. Shrubs including sea buckthorn *(Hippophae rhamnoides)* apparently were dominant features of the vegetation at the site.

Recent palaeoecological investigations of Late-Glacial sediments (Gaillard 1985a; Ammann et al. 1983, 1985) showed that pollen analysis was not the best tool for climatic reconstructions of the Early Late-Glacial period. Oxygen isotope-, mollusc- and insect-analyses provided better evidence for climatic changes. At Hauterive-Champréveyres, plant macrofossil-, insect- and mollusc analyses were performed in addition to pollen analysis. A synthesis of the results will be presented in Chaline et al. (in prep.). Those studies show that the Bølling was characterized by a temperate climate (mean July temperatures of 14–16 °C) (Coope pers. comm.). There is no indication of a colder period that would correspond to the Older Dryas Ic (*sensu* Firbas 1949/52). Moreover, pollen analysis revealed an abundance of species characteristic of dry soils, primarily from the family Apiaceae *(i.e. Bupleurum falcatum, Eryngium campestre, Falcaria vulgaris, Meum athamanticum)*, a fact which further supports the hypothesis of Ammann & Tobolski (1983). This period of drier conditions is recorded in sediments directly overlying the Azilian layer (local PAZ HCh 3b).

4. Late-Glacial history of the Lake of Neuchâtel and its contribution to the understanding of the regional palaeoenvironment and palaeoclimate

The sedimentological and palynological investigations at the Palaeolithic site of Hauterive-Champréveyres provide a detailed reconstruction of the Late-Glacial history of sediment accumulation in the littoral zone of the Lake of Neuchâtel. This study

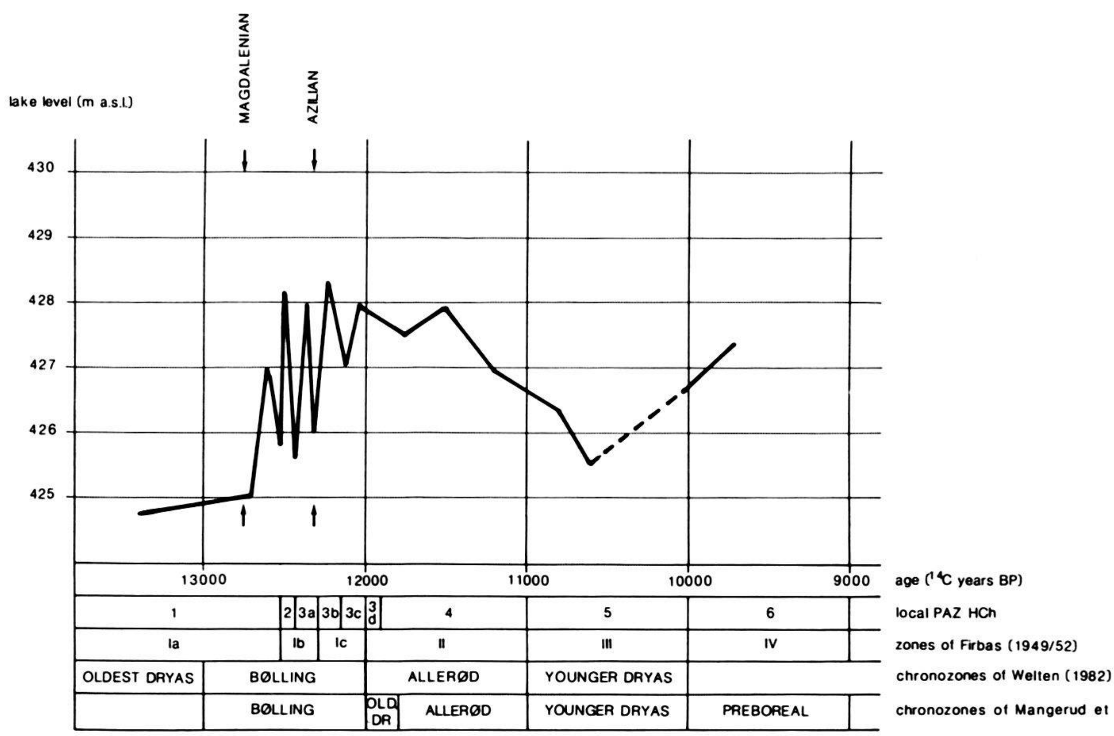

Fig. 6. Late-Glacial lake-level fluctuations at Hauterive-Champréveyres (Lake of Neuchâtel) inferred from litho-stratigraphical and sedimentological studies. The chronology is based on correlation of pollen stratigraphies and ^{14}C dates (see text sections 2 and 3 for further explanations). The local pollen-assemblage zones (PAZ), the zones of Firbas (1949/52) and the chronozones of Welten (1982) and Mangerud et al. (1974) are shown for comparison.

also contributes to a better understanding of the local palaeoenvironmental conditions including vegetation, soils, and geomorphology of the site during that period. The most important insights gained for the regional palaeoenvironment involve the reconstruction of lake-level fluctuations (Fig. 6).

As previously discussed by several authors (AMMANN 1982, JOOS 1982, GAILLARD 1985b), lake-level fluctuations have numerous possible causes, which are often difficult to resolve on the basis of a single study. During the Late-Glacial period both climate and geomorphology may have influenced lake-levels.

Our investigation indicates a low lake-level (425–426 m a.s.l.) during Oldest Dryas Ia (*sensu* FIRBAS 1949/52) and a slight rise in water level occurring at the end of this period, after the occupation by Magdalenian Man (thus after *c.* 12,700 B.P.). There is no indication of high water-levels after the retreat of the Rhône glacier and, therefore, no confirmation of the existence of a large "Lake of Solothurn" at that time (FAVRE 1883, LÜDI 1935, MÜLLER 1973). The low water-level of the Lake of Neuchâtel during the Oldest Dryas Ia may have resulted from the continental, cold and dry climate that probably prevailed at that time (FRENZEL 1983), or from the absence of an adequate inlet. The situation was different for the Lake of Geneva, where recent results confirm that the terrasse situated 30 m above the present lake-level is of Oldest Dryas age (GABUS et al. 1987).

The first marked rise in lake level (+3 m), which occurs at the beginning of the Bølling Ib (*sensu* WELTEN 1982), may be explained by increased inflow of melt water from the Alps via the river Aare. It is likely that increased melting resulted from the sudden rise in temperatures demonstrated by the oxygen-isotope record of several Swiss lakes (EICHER & SIEGENTHALER 1983).

The second part of the Bølling (*Betula* local PAZ), is characterized by a series of water-level fluctuations indicated by three different beach formations, each of which suggests lake levels at 426–427 m a.s.l. Low lake-levels during the Bølling period were proposed earlier from studies of littoral sediments at the Lake of Geneva (VILLARET & BURRI 1965, GAILLARD et al. 1981, REYNAUD 1982). Investigations at the Bielersee AMMANN (1975) also suggest that lake-levels were lower during Bølling time than during Allerød time. However, until more comparative data from the three northwestern Swiss lakes are available, we cannot determine the regional significance of palaeohydrological events recorded at Champréveyres. Nevertheless, the relatively low lake-levels during that period may have been associated with drier climate, as suggested by pollen spectra (cf. section 3.2, HCh 3b local PAZ). Moreover, the pollen stratigraphy provides no indication of a colder episode until the Younger Dryas, which corroborates other results obtained on the Swiss Plateau (AMMANN & TOBOLSKI 1983, GAILLARD 1985a), as well as the conclusions of palaeoecological investigations carried out at Champréveyres (CHALINE et al. in prep.).

The marked lake-level lowering (to 426–426.50 m a.s.l.) starting at the end of the Allerød chronozone and continuing during the Younger Dryas chronozone may be correlated to a similar event recorded at the Bielersee (Fig. 1A) (AMMANN 1975). However, AMMANN (1982) revised her interpretation and proposed dating the lake-level lowering to the end of Boreal time instead; this would contradict results at Champréveyres that show a rise in water-level already during the Preboreal. On the basis of a detailed stratigraphical investigation of the Nussbaumerseen (Fig. 1B), RÖSCH (1983) presented a tentative curve of lake-level fluctuations. His reconstruction includes a lowering during the Younger Dryas and a rise at the end of the Preboreal, which is consistent with the reconstruction presented here for Champréveyres. At the Lake of Geneva, the Younger Dryas period is characterized by the formation of a lower terrasse ^{14}C-dated to 10,520 ±140 B.P., 10 m above the present lake level (Gabus et al. 1987). A water level lowering at the Lake of Neuchâtel during the Younger Dryas may be related to a readvance of glaciers during the Egesen stadial (Biéler 1976, Kerschner 1980, Burri 1986), and the consequent retention of water in alpine glaciers. It could also be explained by a change in the course of the river Aare, from a southward to a northward flow.

Acknowledgments

We are very grateful to Professor Michel Egloff (Head of the Cantonal Department of Archaeology) and to his assistant Béat Arnold for the opportunity and financial support to perform this research at Champréveyres. We thank all our colleagues at Neuchâtel, including Denise Leesch, in particular, for support and thoughtful discussions. We also are much indebted to Heather Jacobson and Dr. George Jacobson Jr. (University of Maine) for revising the English manuscript and for making helpful suggestions.

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Manuscript received 18 April 1988
Revision accepted 16 November 1988