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Schwankungen des Seewasserspiegels bei Le Locle, Schweizer Jura, vom jüngeren Dryas bis zum mittleren Holozän: eine Aufzeichnung der Klima-Schwankungen während der letzten Enteisung mittels hoher Auflösung.

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Résumé de l'article

Grâce à la haute résolution (10 cm / 110 ans) de la séquence lacustre du Locle, dans le Jura suisse, il est possible d'établir une courbe détaillée des changements paléohydrologiques couvrant la dernière partie du Dryas récent et la première moitié de l'Holocène. La fin du Dryas récent est caractérisée par une ten- dance générale à la baisse du plan d'eau qui s'affirme au travers d'une grande instabilité. La première moitié de l'Holocène montre des fluctuations quasi-cycliques du niveau du lac. Deux baisses importantes surviennent vers 11 600- 10 200 étal. BP et 8 900-7 700 étal. BP. Chacune de ces périodes de déficit hydrique est interrompue par un court épisode de hausse et suivie par une phase prolongée de haut niveau qui se développe vers 10 200-8 900 étal. BP et 7 700- 6 600 étal. BP. Les périodes de haut niveau lacustre reconnues au Locle se révèlent correspondre avec des épisodes de refroidissement identifiés en Europe centrale et à l'est de l'Amérique du Nord ou encore avec des refroidissements et des changements de salinité dans la zone de l'Atlantique Nord. Elles coïncident aussi avec des maxima de $\Delta^{14}C$ résiduel. Ces données et la courbe GISP2 des variations de 18O établie pour le Tardiglaciaire conduisent à identifier trois cycles successifs de changements climatiques et environnementaux dont la structure interne montre de fortes similitudes. Ces trois cycles indiquent que du réchauffement du Bølling au milieu de l'Holocène, des oscillations du climat à large échelle pourraient avoir été associées à des changements dans la circulation thermohaline vraisemblablement induits euxmêmes par trois étapes dans la déglaciation. Finalement, une nouvelle mise en perspective du Dryas récent est tentée à partir des données holocènes présentées ici.

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LAKE-LEVEL FLUCTUATIONS AT LE LOCLE, SWISS JURA, FROM THE YOUNGER DRYAS TO THE MID-HOLOCENE: A HIGH-RESOLUTION RECORD OF CLIMATE OSCILLATIONS DURING THE FINAL DEGLACIATION

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RÉSUMÉ *Variations de niveau lacustre au Locle, Jura suisse, du Dryas récent au milieu de l'Holocène : un enregistrement à haute résolution des oscillations du climat pendant la fin de la déglaciation*. Grâce à la haute résolution (10 cm / 110 ans) de la séquence lacustre du Locle, dans le Jura suisse, il est possible d'établir une courbe détaillée des changements paléohydrologiques couvrant la dernière partie du Dryas récent et la première moitié de l'Holocène. La fin du Dryas récent est caractérisée par une tendance générale à la baisse du plan d'eau qui s'affirme au travers d'une grande instabilité. La première moitié de l'Holocène montre des fluctuations quasi-cycliques du niveau du lac. Deux baisses importantes surviennent vers 11 600-10 200 étal. BP et 8900-7700 étal. BP. Chacune de ces périodes de déficit hydrique est interrompue par un court épisode de hausse et suivie par une phase prolongée de haut niveau qui se développe vers 10 200-8900 étal. BP et 7700-6600 étal. BP. Les périodes de haut niveau lacustre reconnues au Locle se révèlent correspondre avec des épisodes de refroidissement identifiés en Europe centrale et à l'est de l'Amérique du Nord ou encore avec des refroidissements et des changements de salinité dans la zone de l'Atlantique Nord. Elles coïncident aussi avec des maxima de $\Delta^{14}C$ résiduel. Ces données et la courbe GISP2 des variations de ^{18}O établie pour le Tardiglaciaire conduisent à identifier trois cycles successifs de changements climatiques et environnementaux dont la structure interne montre de fortes similitudes. Ces trois cycles indiquent que du réchauffement du Bølling au milieu de l'Holocène, des oscillations du climat à large échelle pourraient avoir été associées à des changements dans la circulation thermohaline vraisemblablement induits eux-mêmes par trois étapes dans la déglaciation. Finalement, une nouvelle mise en perspective du Dryas récent est tentée à partir des données holocènes présentées ici.

ABSTRACT On the basis of a high-resolution (10 cm / 110 years) lacustrine sequence from Le Locle, Swiss Jura, a fine-scale pattern of palaeohydrological changes is reconstructed for the late Younger Dryas (YD) and the early to mid-Holocene period. The late YD is characterized by a general trend of a fall in lake level and a large climatic instability. The early to mid-Holocene period shows a quasi-cyclic pattern of lake-level fluctuations. Large drops in lake level occurred at *ca.* 11 600-10 200 cal. BP and *ca.* 8900-7700 cal. BP. Each was interrupted by a short-term rise in lake-level and followed by a longer phase of high lake level respectively at *ca.* 10200-8900 cal. BP and *ca.* 7700-6600 cal. BP. The high lake-level periods at le Locle appear to be in phase with cold spells reconstructed in central Europe, in eastern North America and in the Greenland ice-sheet, or with cooling events and salinity anomalies recorded in the North Atlantic zone. They also coincide with rising residual $\Delta^{14}C$ values. These data and the Lateglacial oxygen-isotope GISP2 record suggest three successive quasi-cycles of climatic and environmental changes showing strong similarities in their internal structure. These cycles suggest that large-scale climate oscillations developing from the Bølling warming to the mid-Holocene could have been associated with changes in ocean ventilation probably induced by three deglaciation steps. Finally, as a working hypothesis, a re-examination of the YD event is proposed from a Holocene point of view.

ZUSAMMENFASSUNG *Schwankungen des Seewasserspiegels bei Le Locle, Schweizer Jura, vom jüngeren Dryas bis zum mittleren Holozän : eine Aufzeichnung der Klima-Schwankungen während der letzten Enteisung mittels hoher Auflösung.* Mit Hilfe von hoher Auflösung (10 cm/110 Jahre) einer See-Sequenz von Le Locle, Schweizer Jura, wurde eine detaillierte Kurve der paläohydrologischen Veränderungen für die Zeit des späten jüngeren Dryas (YD) und des frühen bis mittleren Holozän rekonstruiert. Das späte YD zeichnet sich durch eine allgemeine Tendenz zur Senkung des Seespiegels und eine breite klimatische Instabilität aus. Die Zeit vom frühen bis mittleren Holozän weist ein quasi zyklisches Muster von Schwankungen des Seewasserspiegels auf. Zwei bedeutende Senkungen des Seewasserspiegels fanden um etwa 11 600 - 10 200 cal. v.u.Z. und etwa 8900 - 7700 cal. v.u.Z. statt. Jede wurde durch eine kurze Episode der Anhebung des Seespiegels unterbrochen, auf welche eine längere Phase mit hohem Seespiegel folgte und zwar um etwa 10 200 - 8900 cal. v.u.Z. und etwa 7700 - 6600 cal. v.u.Z. Die Phasen mit hohem Seespiegel bei Le Locle scheinen phasengleich mit in Zentraleuropa, im Osten Nordamerikas und in der Grönlandeisdecke festgestellten Abkühlungen zu sein oder auch mit Abkühlungen und Wechseln im Salzgehalt in der nordatlantischen Zone. Sie decken sich auch mit steigenden $\Delta^{14}C$-Verwitterungswerten. Diese Daten und der spätglaziale Sauerstoff-Isotopen GISP2-Beleg lassen drei aufeinanderfolgende zyklusartige Wechsel in Klima und Umwelt erkennen, deren Binnenstrukturen starke Ähnlichkeiten aufweisen. Diese Zyklen lassen vermuten, dass Klimaschwankungen auf breiter Basis, die sich von der Bølling-Erwärmung bis zum mittleren Holozän entwickelt haben, mit Veränderungen in der Ozean-Ventilation verbunden gewesen sein könnten, welche letztere womöglich durch drei Etappen in der Enteisung herbeigeführt worden sind. Schließlich wird als Arbeitshypothese vorgeschlagen vom Holozänstandpunkt aus das YD-Ereignis neu zu untersuchen.

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INTRODUCTION

Various proxy records from both oceanic and continental areas suggest that climatic instability was especially large during the last glacial-interglacial transition (Lowe, 1994; Andrews *et al.,* 1996). More recently, abrupt climatic changes have been shown to be associated with the early to mid-Holocene transition (Alley *et al.,* 1997; Stager and Mayewski, 1997). Recent investigations at Le Locle, Swiss Jura, highlighted a high-resolution sediment sequence and provided the opportunity to reconstruct a detailed continuous record of palaeohydrological changes covering the second part of the Younger Dryas (YD) and the early to mid-Holocene period (Magny *et al*., 1998).

This paper has two aims: 1) to present the high-resolution lake record of late YD and early Holocene palaeohydrological changes reconstructed at Le Locle; 2) to discuss the possible significance of this proxy record in relation to (i) others obtained from the North Atlantic ocean and adjacent continental areas and ii) the final steps of deglaciation.

Below, dating of records is indicated by uncalibrated radiocarbon dates: BP calendar dates (*i.e.* calibrated radiocarbon dates and dates obtained from annually laminated Greenland ice cores) are expressed: cal. BP.

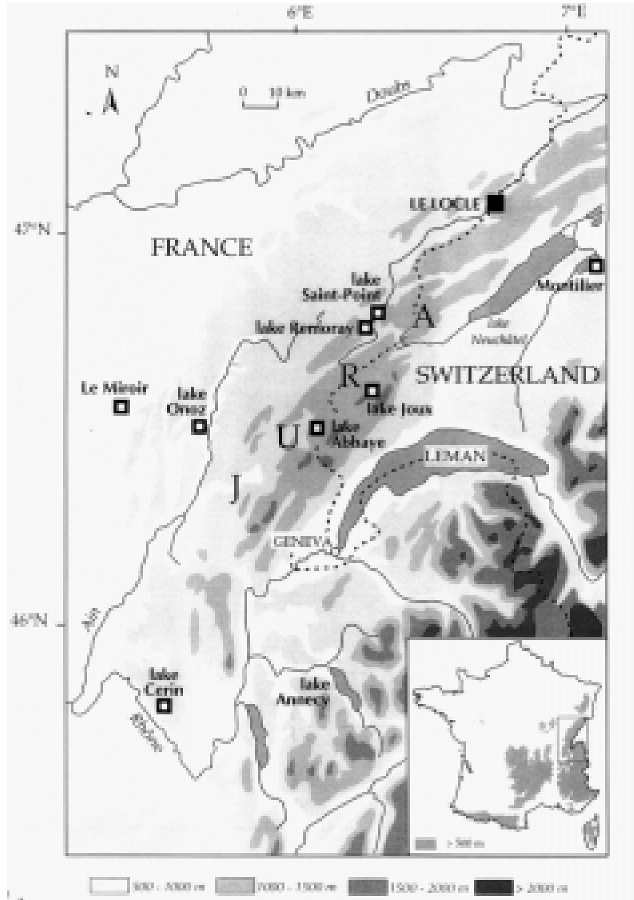


FIGURE 1. Geographical location of the palaeolake Le Locle.
Situation géographique du paléolac du Locle.

PALAEOHYDROLOGICAL CHANGES AT LE LOCLE FROM *CA.* 12 200 TO *CA.* 6500 CAL. BP

The site of Le Locle (47°03'N, 6°43'E) is located at 915 m in the summit zone of the Swiss Jura (Fig. 1). The complete overgrowth of the basin resulted from an anthropogenic drying out in the early 19th. century; hence, the initial lake was replaced by a mire. The area of the initial lake was 67 ha and its catchment area covered 26 km^2. The sediment stratigraphy (Fig. 2) shows a typical infilling sequence with late Pleniglacial silts at the base, authigenic lake-marl in the middle part (Lateglacial and early to mid-Holocene) and organic sediments (peat and gyttja) at the top. A core was taken with a Russian corer to reconstruct vegetation history (Schoellammer, 1997) and lake-level changes since the Jura deglaciation (Magny *et al*., 1998).

This paper presents lake-level fluctuations reconstructed from the middle unit of core 1 in the deepest part of the basin

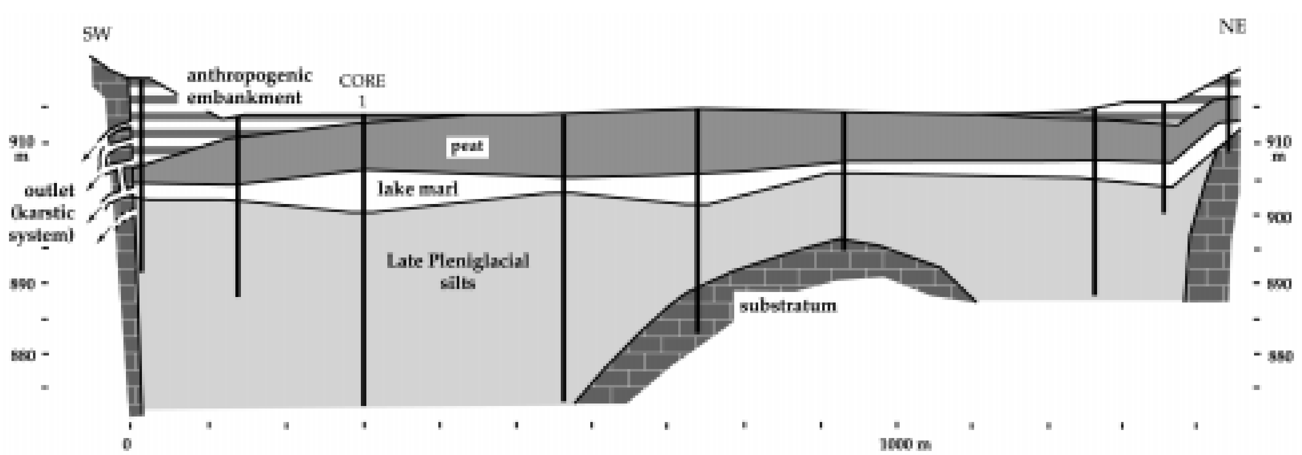


FIGURE 2. Schematic sediment stratigraphy of the Late Pleniglacial to Holocene infillings of the lacustrine basin of Le Locle.

Stratigraphie schématique des remplissages tardi-würmiens et holocènes de la cuvette du Locle.

where the early Holocene carbonate sequence shows the highest resolution. The late Pleniglacial silts are directly overlain by late YD deposits (hiatus). The palaeohydrological changes were reconstructed using multiple lines of evidence, *i.e.* changes in the sediment texture, the lithology and the frequency of various carbonate concretions included in the lake-marl. The coarser fractions (larger than 0.2 mm) of lacustrine chalk are mainly composed of carbonate concretions of biochemical origin (Magny, 1992a). They divide into several morphotypes each showing a specific spatial distribution from the shore to the profundal zone: oncolithes characterize nearshore areas, cauliflower-like forms dominate the littoral platform, plate-like and tube-like forms develop on the platform slope (deeper water). Vegetal components include organic remains from aquatic plants and littoral terrestrial vegetation (lignosous remains); their frequency and that of the molluscs increase in the nearshore areas. Modern analogues show that deposits where oncolithe peaks are associated with maximums of Characeae oogones (similar to deposits of phases L3 and L4; see Fig. 4) reflect a reworking of sediments by the waves in the shallow water of the nearshore areas (Magny, 1987). In the sediment analysis, the mollusc remains are not considered to be biological descriptors, but sedimentological markers.(Magny, 1992a, b, in press).

The chronology is based on the pollen stratigraphy (Fig. 3) and AMS radiocarbon dates from terrestrial plant macrofossils (Table I). The Preboreal-Boreal boundary (crossing between the *Pinus* and *Corylus* curves) was placed by reference to the overlapping of the calibrated time windows given by (1) the radiocarbon dates obtained at 1136-39 cm (9425 ± 70 BP, *i.e.* 10 858-10 213 cal. BP) and 1130-35 cm (9355 ± 60 BP, *i.e.* 10 776-10 143 cal. BP) of the Le Locle sequence (Fig. 4) and (2) the radiocarbon date of 9050 ± 120 BP (*i.e.* 10 296-9859 cal. BP) obtained at the lake Abbaye (870 m, French Jura) for a similar event, *i.e.* the crossing between *Pinus* and *Corylus* curves (Ruffaldi, 1993).The YD-Holocene transition was placed at 11 650 ± 250 cal. BP by reference to the Greenland GISP2 core (Taylor *et al.*, 1993). Moreover, the lake-level lowering at the older-younger Atlantic transition was placed at 5800 ± 45 BP (*i.e.* 6731-6482 cal. BP) by reference to the radiocarbon date obtained at Montilier, lake Morat (Swiss plateau, Fig. 1) for a similar event recorded at the older-younger Atlantic transition (Magny and Richoz, 1998).

The time-depth curve presented in Figure 5 is based only on tree-ring calibrated radiocarbon dates and the age of the YD-Holocene transition at the GISP2 core. It shows a rather regular and stable sediment accumulation rate of *ca.* 10 cm/110 yr. A detailed subsampling (every 5 cm and sometimes less) led to the identification of short-lived palaeohydrological fluctuations. Seventeen phases of lake-level changes can be reconstructed from the sediment diagram and the lithology (Figs. 3 and 4) as presented in the Table II. The age of these palaeohydrological events is based on the radiocarbon dates and the assumption of linear sedimentation rates between dated intervals as supported by the time-depth curve in Figure 5.

The lake-level curve presented in Figure 5 shows a general trend towards a rise in lake-level probably reflecting the progressive obstruction of the karstic system, which forms the outlet of the lake (Fig. 2), due to the progressive infilling of the basin by sediment. Moreover, the curve shows higher-frequency lake-level changes superimposed on this general trend. The YD appears to be characterized by a trend towards a lake-level lowering and by an especially large instability. Figure 5 depicts a quasi-cyclic pattern of palaeohydrological changes during the early Holocene. Large drops in lake level developed during the Preboreal chronozone and the first half of the Older Atlantic chronozone. Each was interrupted by a short-term rise in lake-level (respectively at *ca.* 11 100-10 600 cal. BP and at *ca.* 8400-8300 cal. BP) and followed by a long-lived phase of high lake-level, respectively at *ca.* 10 200-8900 cal. BP (Boreal chronozone) and *ca.* 7700-6600 cal. BP (second half of the Older Atlantic chronozone). The Older-Younger Atlantic transition was characterized by a lake-level lowering. The largest falls in lake-level occurred at the beginning of the Preboreal and the Older Atlantic chronozones and at the Older-Younger Atlantic transition.

The lake-level fluctuations reconstructed at Le Locle from the late YD to the mid-Holocene appear to be in agreement with the regional pattern of palaeohydrological changes established in the Jura from previous investigations as illustrated by Figure 6 (Magny, 1992b; Magny and Ruffaldi, 1995). At Le Locle, the YD shows a progressive fall in water level as was the case at Onoz and the short-term rise event at *ca.* 11 700 cal. BP, *i.e.* just at the YD termination, has its equivalent in the Onoz 3 phase. The long-lived and major high lake-level events developing at *ca.* 10 200-8900 cal. BP and *ca.* 7700-6600 cal. BP correspond to the Joux and Cerin phases. Recent investigations in lake Annecy have also identified both these phases; there, AMS radiocarbon dates suggest that the Joux phase begun at 8885 ± 85 BP and the Cerin phase occurred a little later 7480 ± 100 BP (Magny *et al.*, in preparation). The short-term rise in lake-level occurring at *ca.* 11 100-10 600 cal. BP coincides with the Remoray phase placed at *ca.* 11 100-10 700 cal. BP using the sedimentation rate at lake Remoray (Magny, 1995). It also appears to have been synchronous with a cooling event noted from a pollen record at Le Miroir and AMS radiocarbon dated at 9845 ± 75 BP, *i.e.* 11320-10940 cal. BP (Richard, 1996). Furthermore, the high-resolution record from Le Locle revealed a short-lived but well-marked event dated at *ca.* 8400-8300 cal. BP from the sedimentation rate and called the “Le Locle phase” in the following discussion. It can also be noted from Figures 3 and 5 that major changes in vegetation at the transitions between YD and Holocene, Preboreal and Boreal, or Boreal and older Atlantic, coincide with significant changes in lake-level.

CORRELATION WITH CLIMATIC CHANGES IN EUROPE AND EASTERN NORTH AMERICA

The radiocarbon plateaux identified at 10 000-9900 BP, *i.e.* at the YD-Preboreal transition, and at 9600-9500 BP, *i.e.* in the Preboreal, (Ammann and Lotter, 1989; Lotter *et al.*, 1992), prevent precise dating and inter-regional correlations. Hence, as recommanded by Wohlfarth (1996), the following correla-

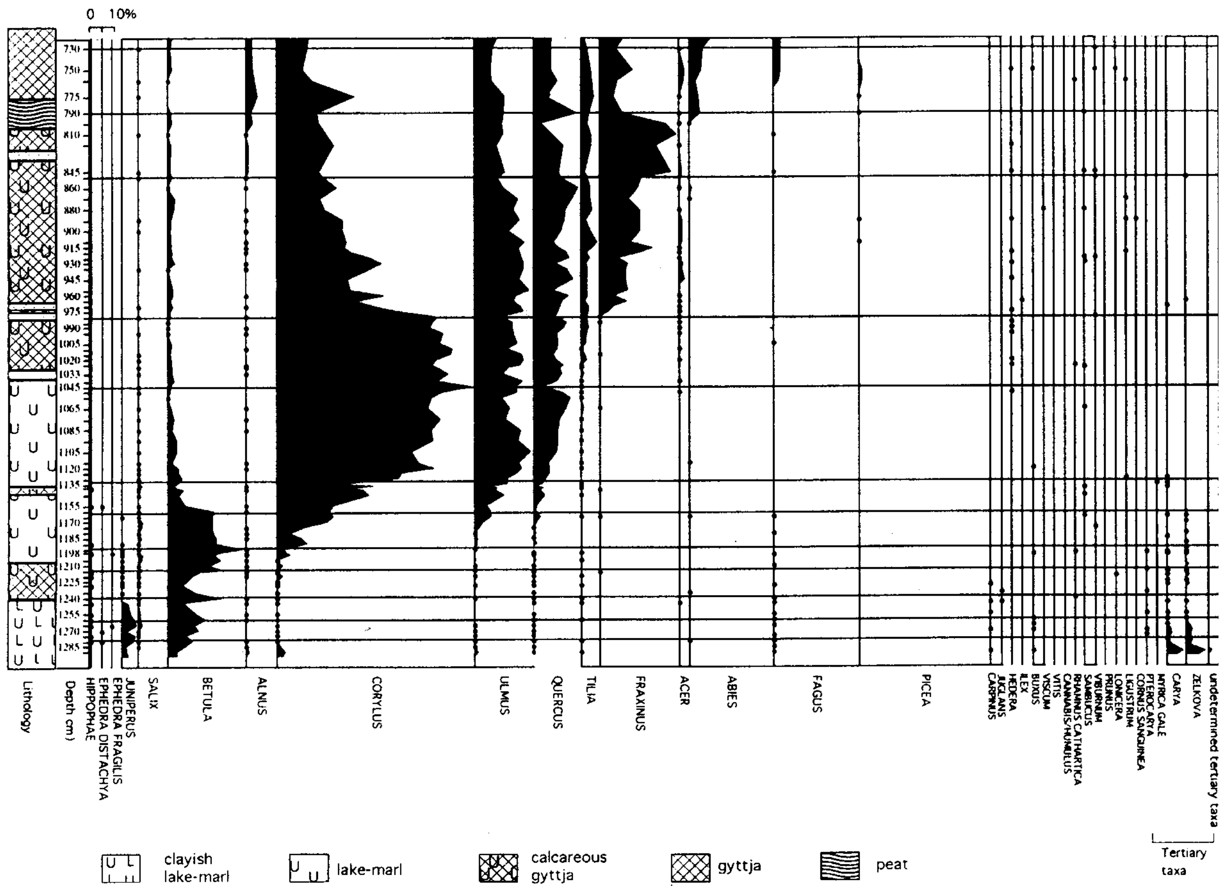


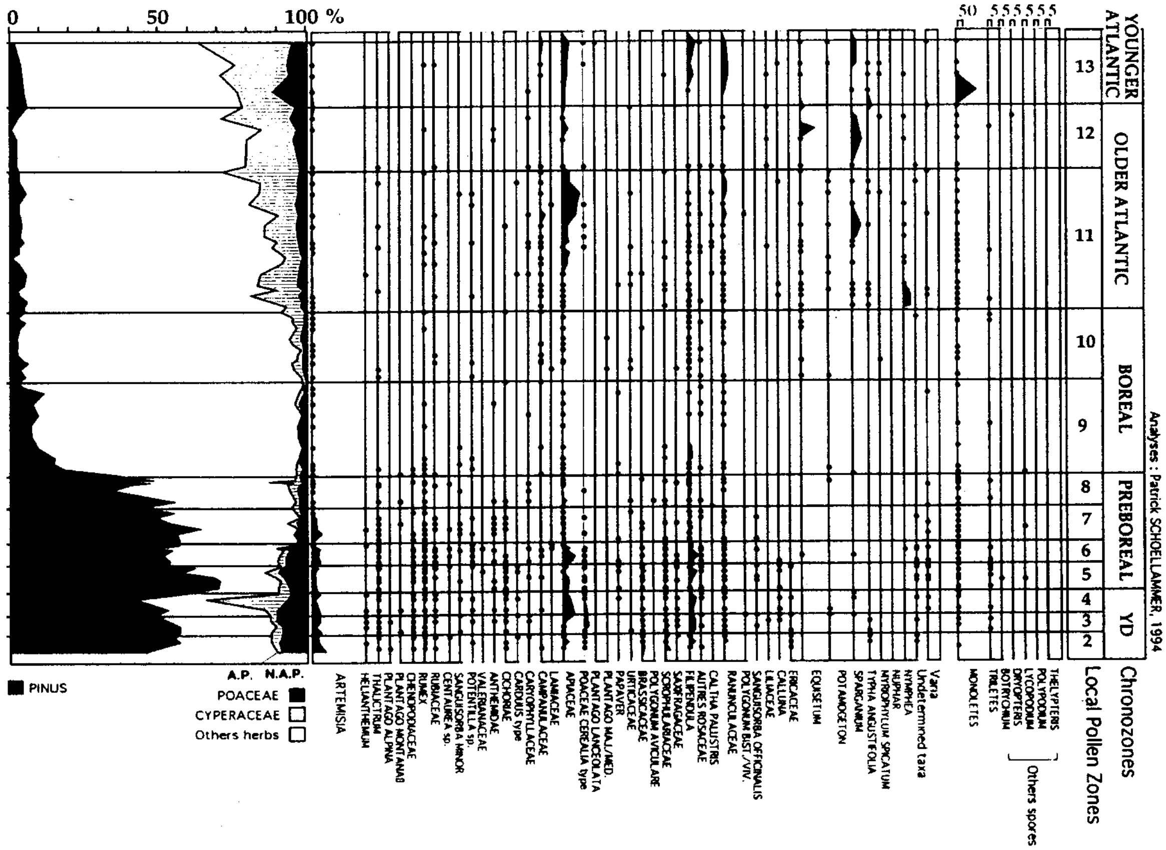
FIGURE 3. Pollen diagram from the median unit of core 1.

Diagramme pollinique de l'ensemble moyen du sondage 1.

tions and discussion are based on marked climatic events such as the YD and the Preboreal oscillation recorded by miscellaneous records from different areas and linked to atmospheric circulation changes (Björck *et al.*, 1997).

The palaeohydrological pattern reconstructed from Le Locle is in good agreement with other palaeoclimatic records established in the Alps and Europe for the same periods. The deficit in water balance during the YD has also been reported by Gaillard and Moulin (1989) in lake Neuchâtel, Lotter *et al.* (1992) in the Swiss lakes, Markgraf (1969), Kerschner (1980) and David (1993) in the Alps, and Guiot and Pons (1986) using pollen time series in France and eastern Spain. The higher climatic instability during the YD at Le Locle could be correlated with the three YD glacier advances established in the Austrian/ Swiss Alps by Patzelt (1977) and Maisch (1992), with the multiple YD glacier advances reconstructed by Couteaux (1983) at La Muzelle in the French Alps, and with the several YD Fennoscandian end moraines (Andersen, 1981). The GISP2 $\delta^{18}O$ record also shows a relative YD variability (Stuiver *et al.*, 1995). From marine cores off northwest Scottland, Austin and Kroon (1996) also concluded that the YD stadial is marked by climate instability.

The Remoray phase in the early Holocene can be synchronized with the widespread "Youngest Dryas" event described by Behre (1978) from European palaeoclimatic records and thereafter supported by various proxy records in Europe (Lowe, 1994; Magny and Ruffaldi, 1995; Björck *et al.*, 1997). It corresponds notably (1) to the P oscillation identified by Lotter *et al.* (1992) from Swiss lakes and AMS radiocarbon-dated to ca 9500 BP, and (2) to the Palü glacier advance in the Alps (Patzelt, 1977; Burga, 1988) centered at *ca.* 9500 BP. The Joux and Cerin phases coincide with the glacier advances or tree-limit declines of Schams-Venediger and Misox-Frosnitz in the Swiss-Austrian Alps (Zoller, 1977; Patzelt, 1977; Magny, 1995), and with the central European cool phases CE-2 and CE-4 defined by Haas *et al.* (1998) in the Swiss Alps. Phases CE2 and CE4 have been AMS radiocarbon dated respectively to 8600-8200 BP and 6600-6200 BP. At the Pian di Signano mire, Swiss Alps, the tree-limit decline and the detrital layer corresponding to the Misox phase are preceded by another similar cold spell marked by a timberline decline and a detritic input placed just before 6850 ± 120 BP, *i.e.* 7904-7439 cal. BP (Zoller, 1960); this short-lived event could correspond to the Le Locle phase,



the central European cool phase CE-3 placed by Haas *et al.* (1998) at *ca.* 7500-7000 BP, or the “8200 yr event” described by Alley *et al.* (1997).

The early to mid-Holocene palaeohydrological pattern from Le Locle also has an equivalent in Poland. The Upper Vistula shows larger discharges at *ca.* 8700-7700 BP and *ca.* 7000-6000 BP (Starkel, 1991). In lake Gosciaz, high lake-levels were dated at *ca.* 9700 BP, 8700-8200 BP, and 6500 BP from a combination of varve counting and radiocarbon measurements (Pazdur *et al.*, 1995; Starkel *et al.*, 1996). In Burgundy, France, Rousseau *et al.* (1993) reconstructed a two-step early Holocene warming from mollusc assemblages with warming phases at *ca.* 10 000-9200 BP and *ca.* 8000 BP and a cold episode developing between *ca.* 9200-8200 BP; radiocarbon dates from peat layers and organic matter from valley sediment profiles were used to date these events. In the southern French Alps, Miramont (1998) reconstructed three phases of increasing river discharge during the early Holocene: the first and the second, respectively AMS radiocarbon dated at *ca.* 10 250-9950 cal. BP and 9500-9150 cal. BP, appear to be synchronous with the Joux phase in the Jura; the third AMS radiocarbon dated at 8500-8150 cal. BP coincides with the Le Locle phase.

In North America, pollen investigations in Gaspé and Newfoundland led to distinguishing cooling phases at *ca.* 9500 BP (Andersen and Macpherson, 1994) and *ca.* 9200-8000 BP (Richard *et al.*, 1997). In the Labradorean sector, the Holocene start corresponds to a large retreat of the Laurentide Ice Sheet (LIS). However, on southeastern Baffin island, Miller and Kaufman (1991) identified a readvance at *ca.* 8600 BP. This so-called Cockburn readvance appears to be broadly synchronous with the Cochrane tills dated at *ca.* 8500-8000 BP and the Sakami moraines dated at *ca.* 8000 BP on the southern flank of the LIS. Furthermore, in eastern Canada between the YD St Narcisse moraines and the Sakami moraines, another moraine, *i.e.* the Lac Daigle-Manitou-Matamek moraine, developed near 9600 BP (Hillaire-Marcel *et al.*, 1981). Beget (1983) pointed out that these moraine systems have been interpreted in different ways, and Bruneau and Gray (1997) recently questioned the existence of the Cockburn/Noble Inlet readvance in the Hudson Strait region.

In Greenland, most of the $\delta^{18}O$ records show that the early to mid-Holocene warming was interrupted by two well-marked cold episodes, the first at *ca.* 11 350 cal. BP and the second at *ca.* 8200 cal. BP (Fisher *et al.*, 1994). Keeping in

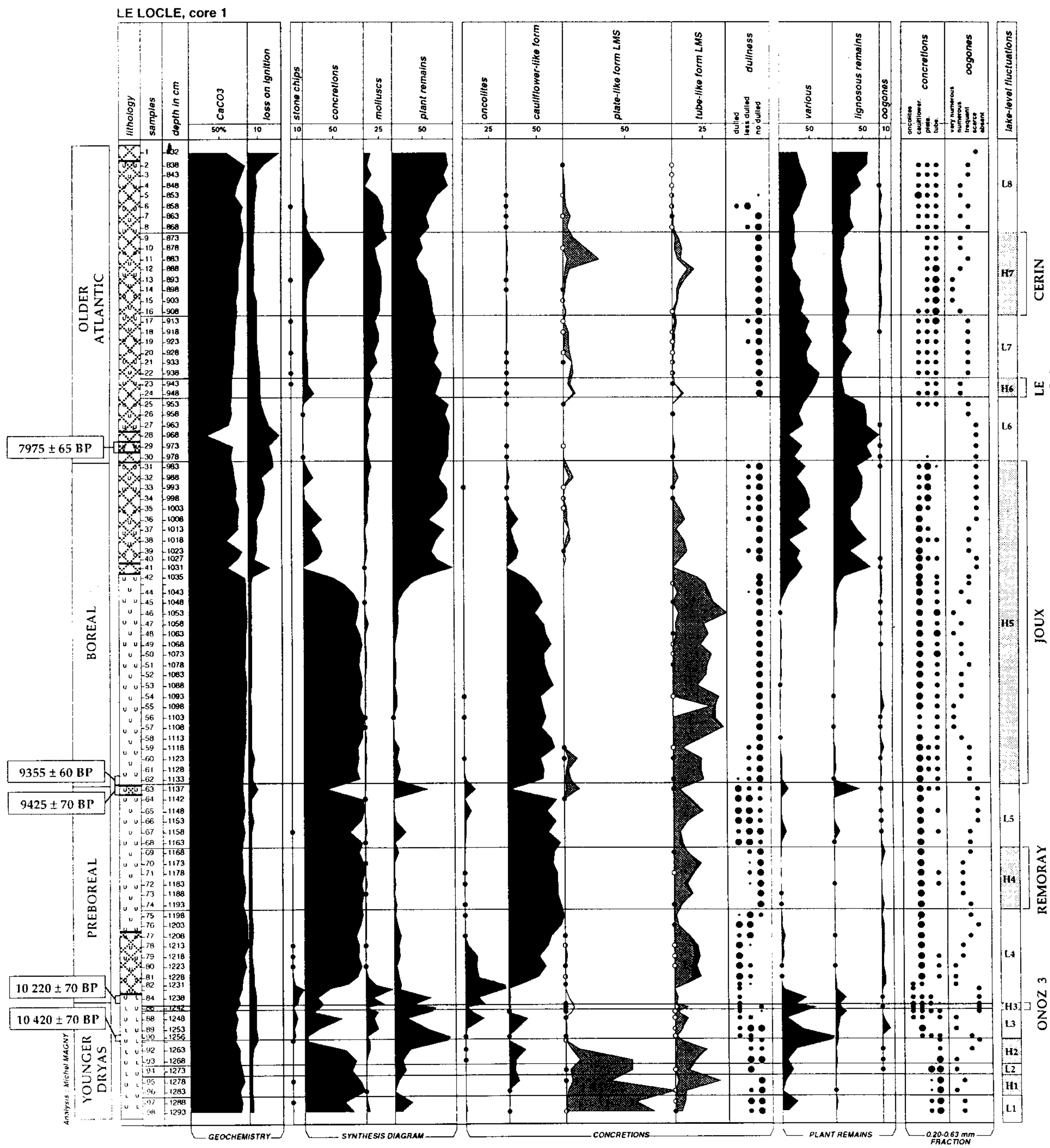


FIGURE 4. Sediment diagram from the median unit of core 1. LMS: Large (black), Medium (grey) or Small (white) size.

Diagramme sédimentologique de l'ensemble moyen du sondage 1. LMS : taille grosse (noir), moyenne (gris) ou petite (blanc).

mind the error of the depth-age scale (Alley *et al.*, 1993), these events could be synchronized respectively with the Remoray and Le Locle phases (Fig. 2).

CORRELATION WITH CLIMATIC CHANGES IN THE NORTH ATLANTIC ZONE

Previous studies have already shown that the Preboreal cold oscillation (*i.e.* the Remoray phase) reconstructed from European and Greenland proxy records coincided with major changes in the temperature and circulation of the North Atlantic ocean (Karpuz and Jansen, 1992; Lehman and Keigwin, 1992; Magny, 1995; Hughen *et al.*, 1996; Björck *et al.*, 1996).

Furthermore, the climate cooling periods marked by the Joux and Cerin phases appear to be synchronous with major changes in the North Atlantic ocean. Thus, the variations in

TABLE I

Accelerator mass spectrometer radiocarbon measurements from terrestrial macrofossils and calibrated calendar ages obtained from the middle unit of core 1 at le Locle

Depth (cm)	Radiocarbon age	Tree-ring corrected calender age (2 sigmas)	Lab. number (Tucson, Arizona, U.S.A.)	Material
970-975	7975 ± 65 BP	8991-8554 cal. BP	AA-222 62	wood fragments
1130-1135	9355 ± 60 BP	10 776-10 143 cal. BP	AA-222 66	wood fragments
1136-1139	9425 ± 70 BP	10 858-10 213 cal. BP	AA-222 61	wood fragments
1235-1240	10 220 ± 70 BP		AA-222 60	wood fragments
1255-1257	10 420 ± 70 BP		AA-222 59	wood fragments

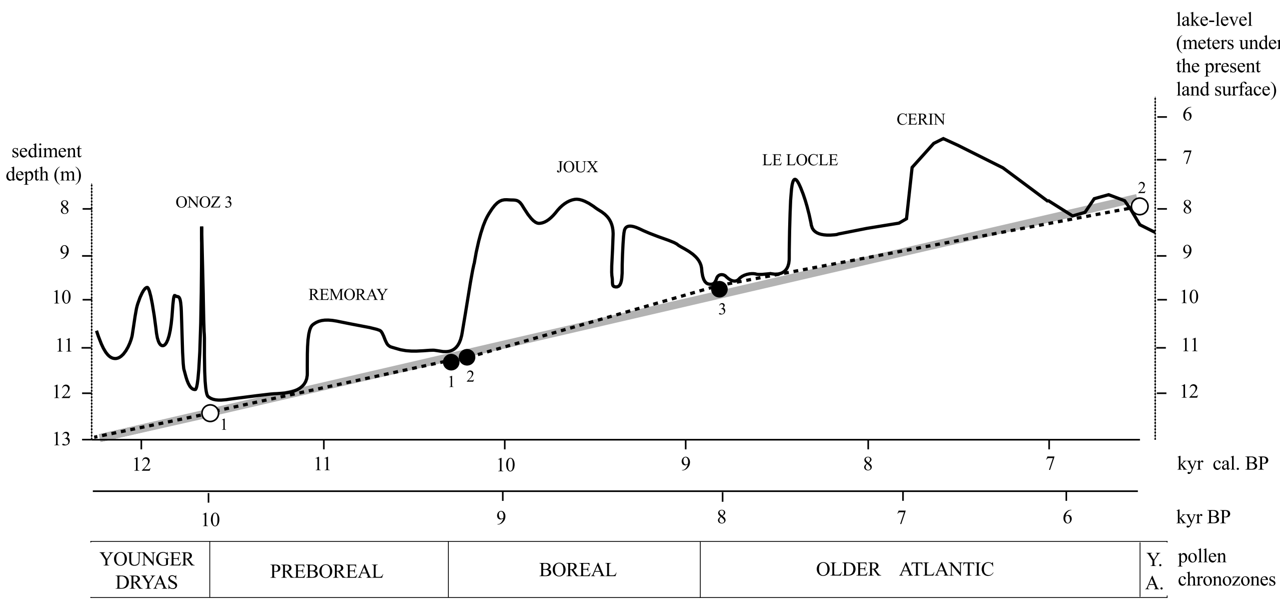


FIGURE 5. Tentative reconstruction of the lake-level fluctuations at Le Locle from the late Younger Dryas to the mid-Holocene. The names of the major high lake-level phases are indicated in italics. The AMS radiocarbon dates are indicated with black dots, 1) 9425 ± 70 BP (*i.e.* 10 858-10 213 cal BP), 2) 9355 ± 60 BP (*i.e.* 10 776-10 143 cal BP) and 3) 7975 ± 65 BP (*i.e.* 8991-8554 cal BP). The Younger Dryas-Holocene transition is placed at 11 650 ± 250 cal BP (open dot *1*) by referring to the Greenland GISP2 core (Taylor *et al.*, 1993). The lake-level lowering at the older-younger Atlantic transition is placed at 5800 ± 45 BP, *i.e.* 6731-6482 cal BP (open dot 2) by referring to the date obtained at Montilier, lake Morat (Swiss plateau) for a similar event recorded at the older-younger Atlantic transition (Magny and Richoz, in preparation). The time-depth curve (dotted line: actual curve, grey line: general trend curve) is based on tree-ring calibrated radiocarbon dates (black dots 1. 2 and 3, and open dot *2*) and on the age of the Younger Dryas-Holocene transition at the GISP2 core (open dot *1*). YA: Younger Atlantic.

Essai de reconstitution des fluctuations du niveau du paléolac du Locle de la fin du Dryas récent au milieu de l'Holocène. Le nom des principales phases de haut niveau est indiqué en italiques. Les dates radiocarbone SMA sont indiquées par des points noirs, 1) 9425 ± 70 BP (c'est-à-dire 10 858-10 213 étal. BP), 2) 9355 ± 60 BP (c'est-à-dire 10 776-10 143 étal. BP) et 3) 7975 ± 65 BP (c'est-à-dire 8991-8554 étal. BP). La transition Dryas récent-Holocène est placée à 11 650 ± 250 étal. BP par référence au sondage GISP2 du Groenland (Taylor et al.*, 1993). La baisse du plan d'eau à la transition Atlantique ancien-Atlantique récent est datée par référence à la date au radiocarbone 5800 ± 45 BP, c'est-à-dire 6731-6482 étal. BP (point blanc 2) obtenue sur le site de Montilier (lac de Morat, Plateau suisse) pour un événement similaire survenu à la transition Atlantique ancien - Atlantique récent (Magny et Richoz, en préparation). La courbe temps-profondeur (en pointillés : réelle ; en gris : tendance générale) est basée sur les dates au radiocarbone bénéficiant d'une calibration par la dendrochronologie (points noirs 1. 2 et 3, et point blanc 2) et sur la date de la transition Dryas récent-Holocène livrée par le sondage GISP2 (point blanc 1). YA : Atlantique récent.*

the sea-surface salinity reconstructed by Duplessy *et al.* (1992) from a core off Portugal show a significant decrease in salinity during the 9th and the 7th millennium BP. From marine cores off the western margin of Spitsbergen, Lloyd *et al.* (1996) identified a cool period dominated by a polar water regime between *ca.* 9000 and 8000 BP. A foraminiferan record from the northern Norwegian Sea documents two successive surface-ocean cooling episodes centered at *ca.* 9000-8500 BP and *ca.* 6500 BP (Hald and Aspeli, 1997). Diatom assemblages in a core from the southeast Norwegian Sea led Karpuz and Jansen (1992) to reconstruct a sea-surface cooling at *ca.* 9000-8000 BP. At the same time, a cooling phase appears to be documented for more southern areas in the North Atlantic at the DSDP site 609 (Koç *et al.*, 1996). Relatively low water temperature conditions were also recorded from diatoms assemblages between 8600 and 7700 BP in the Skagerrak-Kattegat, northeastern Atlantic margin (Jiang *et al.*, 1997).

TABLE II

Younger Dryas and early Holocene lake-level changes at Le Locle

Phases	Sedimentological and lithologic markers	Pollen zones
L9	Peat deposits interbedded between calcareous gyttja deposits (Fig. 2).	**Younger Atlantic**
H8	Return to calcareous gyttja deposits.	
L8	Increase in molluscs and plant remains, more dulled and rapidly disappearing concretions.progressive decrease in the Characeae oogones. The maximum of the lake-level lowering in the last part of phase L8 is marked by the deposition of a gyttja layer.	
H7	Development of concretions (tube-like and plate-like forms) and maximum in the Characeae oogones (= Cerin phase, *ca* 7700-6600 cal BP).	**Older Atlantic**
L7	The quasi-disappearance of the tube-like concretions, and decrease in the Characeae oogones.	
H6	Abrupt increase in concretions (plate-like and tube-like forms) and higher frequency of the Characeae oogones (= Le Locle phase, *ca* 8400-8300 cal BP).	
L6	Two gyttja layers, maximum loss on ignition, and quasi-disappearance of the carbonate concretion.	
H5	Development of the tube-like concretions and lower dullness. This long phase was interrupted by a short-term lowering well recorded by a gyttja layer.The last part of the H5 phase is characterised by a lower water depth indicated (1) by a decrease in the frequency of the concretions, the tube-like concretions and the Characeae oogones, and (2) an increase in plant remains, plate-like concretions and concretion dullness, beginning of the calcareous gyttja deposition (= Joux phase, *ca* 10 200-8900 cal BP).	**Boreal**
L5	Higher frequency of molluscs, plant remains, oncolithes, and more dulled concretions.	
H4	Decrease in the concretion dullness and higher frequency of the Characeae oogones.(= Remoray phase, *ca* 11 100-10 600 cal BP).	**Preboreal**
L4	Higher frequency of plant remains, oncolithes, and more dulled concretions.	
H3	Abrupt and short increase in plate-like and tube-like concretions, and decrease in concretion dullness (= Onoz 3 phase, *ca* 11 650 cal BP).	
L3	Higher frequency of molluscs, plant remains, oncolithes, and higher concretion dullness.	
H2	Successive increases in plate-like and tube-like concretions and weaker concretion dullness (*ca* 11 800 cal BP).	**Younger Dryas**
L2	Increase in plant remains and decrease in frequency of the tube-like concretions.	
H1	Higher frequency of concretions (plate-like and tube-like forms) and weaker concretion dullness (*ca* 12 050-11 950 cal BP).	
L1	Increase in plant remains and decrease in frequency of the plate-like concretions.	

The high-resolution PL 07-56PC record of climate changes established by Hughen *et al.* (1996) from the Cariaco basin documents two oscillations developing just before 9670 BP (possibly equivalent to the Preboreal oscillation) and 7180 BP (assumed to be the “8200 yr event”), but also a third well-marked oscillation centered at *ca.* 8450 BP which could correspond to the Joux phase.

Moreover, it can be noted that the cool Joux period appears to be synchronous with the pause in the deglaciation between the second (at 10 000-9000 BP) and the third (after 8000 BP) steps reconstructed by Mix and Ruddiman (1985). A similar stop in deglaciation at *ca.* 9000-8000 BP is also suggested by curves of a deglacial sea-level rise reconstructed from the Central Great Barrier Reef, Australia (Larcombe *et al.*, 1995), the Caribbean-Atlantic region where Blanchon and Shaw (1995) distinguished two catastrophic rise events (CRE) during the early to-mid Holocene at *ca.* 11 500 cal. BP and *ca.* 7600 cal. BP, and the European coasts in Sweden (Mörner, 1984), England (Tooley, 1974) and France (Morzadec-Kerfourn, 1974). Expressed in ^{230}Th age (presumably equivalent to calendar years) by Edwards *et al.* (1993), the Barbados curve of glacial meltwater discharge displays reduced melting after the meltwater pulse-1B at the Holocene start and a third minor additional meltwater pulse centered at *ca.* 9100 cal. BP (and called “meltwater pulse-1C” in the following discussion).

Andrews *et al.* (1997) observed along the East Greenland margin that the interval of iceberg rafted debris (IRD) accumulation *ca.* 13 000-12 000 cal. BP (*i.e.* during the YD) was followed by a brief return to IRD conditions centered at 9000 cal. BP. In the same way, along the Labrador margin and in the Hudson Strait, Andrews *et al.* (1995a) identified one detrital carbonate event (DC) that is younger than a YD Heinrich-like event (HO) and dated to *ca.* 8400 BP. Other investigations by Andrews *et al.* (1995b) in the Hudson Strait showed a low magnetic susceptibility (LMS) dated to *ca.* 8000 BP.

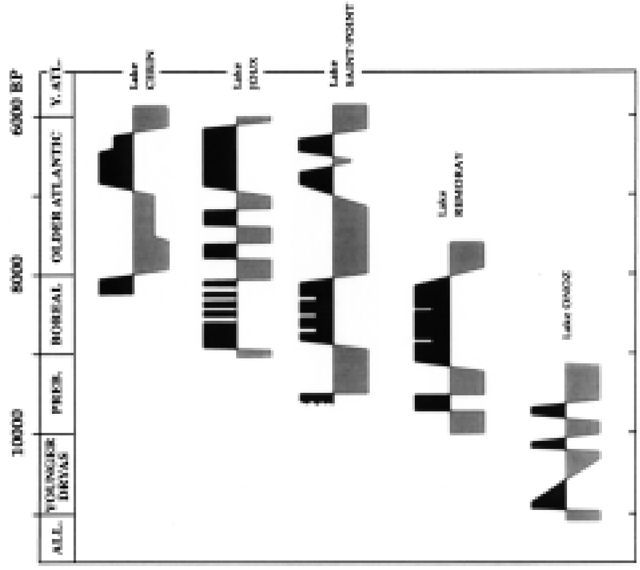


FIGURE 6. Palaeohydrological changes recorded in Jura lakes between 11 500 and 6000 BP (from Magny 1992a; Magny and Ruffaldi 1995). The timing of lake-level fluctuations is mainly inferred from pollen-stratigraphic cross-correlation with ^{14}C dated pollen sequences from peat bogs in Jura.

Changements paléohydrologiques enregistrés dans des lacs du Jura entre 11 500 et 6000 BP (d'après Magny 1992a ; Magny et Ruffaldi 1995). La chronologie des fluctuations des plans d'eau repose principalement sur des corrélations basées sur la palynostratigraphie et les dates au radiocarbone obtenues pour des séquences polliniques en tourbières dans le Jura.

CORRELATION WITH THE ATMOSPHERIC RESIDUAL $\Delta^{14}C$ RECORD

The palaeohydrological record from Le Locle can also be correlated with the atmospheric residual $\Delta^{14}C$ record extended back to 11 400 cal. BP from tree-ring series (Stuiver and Reimer, 1993). Figure 7 shows that the lake-level fluctuations match the ^{14}C variations: the cold climate periods marked by higher lake-levels (at 11 100-10 600, 10 200-8900, 8400-8300 and 7700-6600 cal. BP) coincide with $\Delta^{14}C$ maxima (respectively at 11 050-10 800, 10 100-8850, 8450-8300 and 7600-6650 cal. BP). Moreover, the trend towards a lake-level lowering during the YD parallels a fall in ^{14}C values before 11 700 cal. BP. This ^{14}C drop has been recently supported by the reconstructions of Hughen *et al.* (1998) and Kitagawa and Van Der Pflicht (1998). Taken as a whole, the ^{14}C record and the lake-level fluctuations at Le Locle display variations having a similar rhythm. More detailed correlations are suggested by Figure 7. Thus, the bipartition of the Cerin phase with a first major event followed by a minor event has an equivalent in the major ^{14}C peak at 7300 cal. BP and the following minor ^{14}C peak at 6750 cal. BP. The Joux phase appears to be tripartite as the ^{14}C peak between 10 100 and 8850 cal. BP. The lake-level lowering, less marked after 8300 cal BP than before 8400 cal. BP, could be correlated with the progressive decrease in ^{14}C values from 8300 to 7600 cal. BP.

Stuiver and Braziunas (1993) suggested that the $\Delta^{14}C$ variations reflect a dominant oceanic forcing between 11 400 and 8000 cal. BP and identified a dampened 512 yr oscillation which could represent the last phase of the deglaciation. Stuiver (1994) indicated that ^{14}C maxima could result from changes in the thermohaline circulation: a reduced upwelling of ^{14}C-deficient water increases surface ocean and atmospheric $\Delta^{14}C$ levels. The calculations developed by Goslar *et al.* (1995) from the lake Gosciaz record support this ocean hypothesis. Thus, the periods of lake-level lowering in Jura could coincide with strengthened thermohaline circulation.

A further examination of the early to mid-Holocene residual $\Delta^{14}C$ record shows two quasi-cycles with noticeable similarities in shape and internal structure (Fig. 7 and 8). The first developed between 11 550 and 8850 cal. BP (*i.e.* a duration of 2700 years) and the second between 8850 and 6650 cal. BP (*i.e.* a duration of 2200 years). Both these early Holocene $\Delta^{14}C$ cycles have an asymmetrical shape. Each displays the same successive oscillations, *i.e.* (1) an abrupt decrease in ^{14}C values at the beginning of the cycle, (2) a relatively short ^{14}C minimum around 200 years, (3) a progressive increase in the ^{14}C values punctuated by two short-term ^{14}C maxima (marked II1-II2 and III1-III2 in Fig. 4), and (4) a final prolonged ^{14}C maximum (marked II3 and III3 in Fig. 4). The II3 and III3 periods have a respective duration of 1100 and 900 years.

The magnitude of the change in ^{14}C between the minimal values at the beginning of the cycle and the maximal values at the end reaches respectively *ca.* 50 ‰ and 35 ‰. Although showing decreasing magnitudes and durations, both the cycles present a similar internal time structure. The prolonged $\Delta^{14}C$ maximum characterizing the last part of each cycle corresponds to *ca.* 41 % of the whole cycle duration; the ratio between the duration of the first part ($\Delta^{14}C$ minima) and that of the last part ($\Delta^{14}C$ maxima) of each early Holocene ^{14}C cycle attains *ca.* 0.69 (Fig. 8).

There is no other similar ^{14}C cycle in the ^{14}C curve after 6650 cal. BP. However, Figure 8 shows that an identical cycle with a similar shape and structure can be found in the Lateglacial GISP2 $\delta^{18}O$ climate record (Stuiver *et al.*, 1995). This Lateglacial cycle has a duration of *ca.* 3000 calendar years, from the Bølling start at 14 670 cal. BP to the Holocene start at 11 650 cal. BP. It successively displays (1) an abrupt warming, (2) a relatively short climate optimum, *i.e.* the Bølling optimum (less than 300 years), (3) a progressive cooling punctuated by two short-term cold events, *i.e.* the Older Dryas (OD = I1) and the Intra-Allerød cold period (IACP = I2), and (4) a final prolonged cold period, *i.e.* the YD (= I3) between 12 890 and 11 650 cal. BP from the ice layer count. Thus, the ratio between the duration of the YD stadial and that of the Bølling-Allerød interstadial can be evaluated at 0.69 and the YD duration represents *ca.* 41 % of the whole Lateglacial cycle duration (Magny, 1997). Both the OD and the IACP are also well documented in the Atlantic ocean (Hughen *et al.*, 1996) and the Norwegian Sea (Lehman and Keigwin, 1992) as well as in Europe (Lowe, 1994) and North America (Levesque *et al.*, 1993). Furthermore, studies by Zbinden *et al.* (1989), in Swiss lakes, Goslar *et al.* (1995) in Lake Gosciaz, Poland, and Gulliksen *et al.* (1994) at

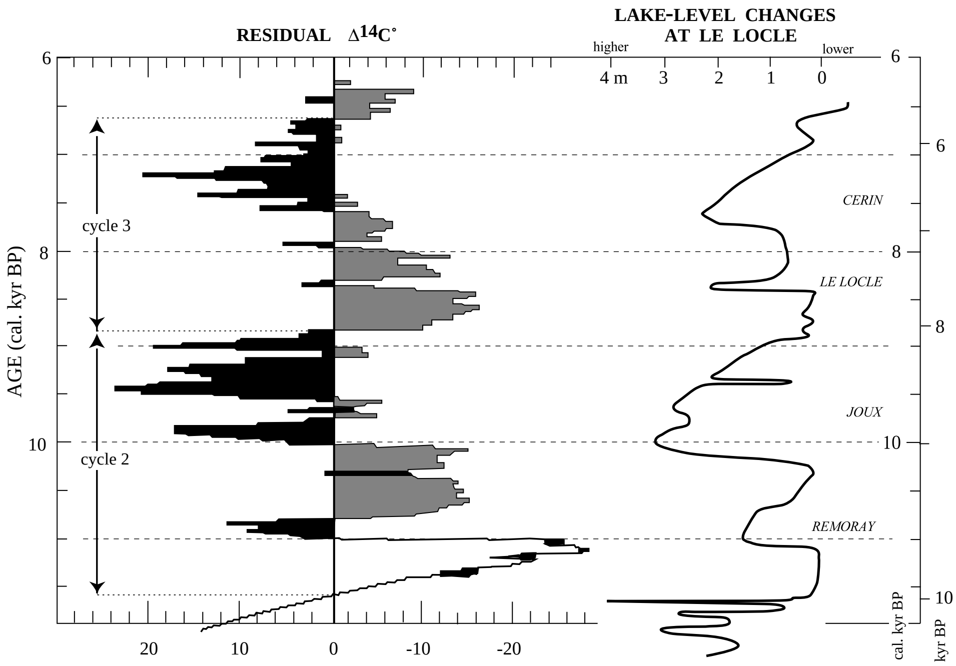


FIGURE 7. Tentative correlations between the variations of the residual $\Delta^{14}C$ (top, from Stuiver and Braziunas, 1993) and the lake-level fluctuations at Le Locle from the late YD to the mid-Holocene (bottom). The lake level curve is obtained from Figure 2 after subtracting of the effects induced by the obturation of the karstic oulet (see text). Cycles 2 and 3 indicated by double arrows refer to those described in Figure 4. High lake-levels are broadly synchronous with periods of $\Delta^{14}C$ maxima.

Essai de corrélation entre la courbe du $\Delta^{14}C$ résiduel (d'après Stuiver et Braziunas, 1993), et les fluctuations du niveau du paléolac du Locle. La courbe des variations du plan d'eau est celle obtenue à partir de la figure 2 après soustraction des effets induits par le comblement du système karstique qui constitue l'exutoire du bassin (voir texte). Les cycles 2 et 3 indiqués par une double flèche renvoient à ceux décrits dans la figure 4. Les hauts niveaux lacustres se révèlent être globalement synchrones avec des maxima du ^{14}C.

Kråkenes in Norway suggest an abrupt fall in ^{14}C values at the beginning of the Bølling (radiocarbon plateau), a progressive increase in ^{14}C values during the Allerød period and a ^{14}C maximum during the YD cold period. This Lateglacial ^{14}C pattern has been recently supported by the ^{14}C records reconstructed from the Cariaco basin (Hughen *et al.*, 1998) and lake Suigetsu, Japan (Kitagawa and Van Der Plicht, 1998). It is noteworthy that the Suigetsu record shows an increase in the ^{14}C values during the Older Dryas as forecast by Magny (1995) and proposed by Björck *et al.* (1996). Thus, the Lateglacial ^{14}C pattern, broadly outlined by Zbinden *et al*. (1989) and more detailed by the Cariaco and Suigetsu records, matches the general outline described for the early Holocene ^{14}C cycles.

It can be noted that the Lateglacial $\delta^{18}O$ cycle and both the early Holocene ^{14}C cycles present strong similarities with the shape of the 15 Dansgaard-Oeschger climatic cycles indicated by Rasmussen *et al.* (1996) from a marine core at the Faeroe margin. Each cycle appears to be subdivided into three intervals with (1) a short warm interstadial, (2) a relatively long period marked by a gradual cooling, and (3) a stadial interval (including the Heinrich events) marked by LMS, high concentrations of IRD, depletions of $\delta^{18}O$ and more frequent *Neogloboquadrina pachyderma* (5). These three successive intervals were shown by Rasmussen *et al.* to be associated with three different modes of oceanic circulation.

DISCUSSION

The correlations previously noted between (1) the two quasi-cycles of palaeohydrological changes recorded at Le Locle, (2) continental proxy data from western and central Europe and North America, and (3) oceanic proxy data from the North Atlantic zone support the hypothesis that oceanic and atmospheric general circulation formed a dynamic-coupled system during the early to mid-Holocene period. Moreover, the correlations highlighted between the Le Locle record and the residual $\Delta^{14}C$ record point to possible changes in ocean circulation associated with these climate changes during the first part of the Holocene. This hypothesis is also supported by the synchroneity of the changes in sea surface salinity off Portugal (Duplessy *et al.,* 1992) and the palaeohydrological phases reconstructed at Le Locle.

Furthermore, the climate cooling synchronous with the Joux phase (at approximately 9000-8000 BP) appears to be in phase (1) with a slight pause in the deglaciation which is well-recorded by curves of a deglacial sea-level rise from the European coasts, Caribbean-Atlantic and Australian regions, and (2) with IRD-DC-LMS events in the Hudson Strait and along the East Greenland margin. These proxy data give further relief and interest to the third deglaciation step (Termination IC) tentatively described by Mix and Ruddiman (1985) and placed at *ca.* 8000-6000 BP, just after a pause between 9000 and 8000 BP. Thus, during the early to mid-Holocene period, the climate oscillations recorded in both the North Atlantic ocean and adjacent continental areas could show a coherent pattern and rhythm with two final deglaciation steps.

It is more difficult to assess the impact of the two successive meltwater pulses (MWP) -1B and -1C on the oceanic circulation. The first main handicap arises from the discordance in the sea-level curves and chronologies which vary from one site to another, and from the uncertainties due to the dating methods. The second handicap consists in the questionable existence of the second and third MWPs: the MWP-1C was distinguished from a junction between various data sets (Blanchon and Shaw, 1995). A record recently reconstructed at Tahiti suggests that MWP-1B, if real, was smaller than previously thought and that there is no detectable third MWP (Bard *et al*., 1996). Nevertheless, various records of a deglacial sea-level rise show an abrupt early Holocene rise interrupted by a pause or even a regression during the interval 9000-8000 BP (see for example Morzadec-Kerfourn, 1974; Tooley, 1974; Mörner, 1984; Larcombe *et al*., 1995).

Keeping in mind these questions, it can be noted that Bard *et al.* (1996) placed the MWP-1A shortly before the first major cooling event after the Bølling optimum (*i.e.* the OD) evidenced in the GISP2 and GRIP cores (see Fig. 8). They also placed a MWP-1B just after the Holocene start optimum and just before the Preboreal oscillation recorded in the GRIP ice core. Stuiver and Braziunas (1993) correlated the Preboreal oscillation (equivalent to the Remoray phase) described by Karpuz and Jansen (1992) from the Southeast Norwegian Sea with the $\Delta^{14}C$ maximum at 10 900 cal. BP (Fig. 7 and 8) and explained it as a consequence of the second MWP. In Northwestern Europe, on the basis of lacustrine sequences from Jura (Magny, 1995) and Sweden (Björck *et al*., 1996), the Preboreal oscillation was synchronized with rising residual $\Delta^{14}C$ values and ocean ventilation changes. Following these reconstructions, a further coherent succession appears between a possible minor MWP-1C occurring at *ca.* 8000 BP (as evidenced by curves of deglacial sea-level rise from Europe and Australia) and the climate cooling marked by the Le Locle phase synchronous with the $\Delta^{14}C$ maximum at *ca.* 8300 cal. BP and probably with the "8200 yr event" recorded in the Greenland ice cores.

Both the available information on the Lateglacial changes in the residual $\Delta^{14}C$ (Zbinden *et al.,* 1989; Gulliksen *et al.,* 1994; Goslar *et al.,* 1995) and the strong similarities in shape and structure evidenced by the three successive cycles identified from the early to mid-Holocene $\Delta^{14}C$ record and the Lateglacial GISP2 $\delta^{18}O$ record (Fig. 8) support the hypothesis that changes in thermohaline circulation could have been associated with three successive deglacial steps and that they could have acted as a main trigger for the climate changes during the final deglaciation. Moreover, these similarities point to vigorous and constant structures in ocean organization and call for model experiments which could reconstruct this type of internal cyclic structure over three successive deglaciation steps. Thus, the decrease in the duration and magnitude of the residual ^{14}C cycles could reflect the shorter time needed for salinity restoration after more and more smaller meltwater discharges. Without ruling out the possible impact of singular events in the YD origin (Björck *et al*., 1996), the strong similarities in the internal structure presented by the three successive $\delta^{18}O$ and $\Delta^{14}C$ cycles (Fig. 8) would suggest that the ocean-circulation organization played a prominent part in the origin of the YD as in that of the Joux and Cerin phases.

Finally, the preceding discussion would suggest the need for a reexamination of the Younger Dryas from a Holocene point of view. Broecker (1992) asked why the second MWP failed to cause a second Younger Dryas. As a working hypothesis, this paper suggests that the climate cooling periods synchronous with the Joux and Cerin phases in Jura constituted a type of "minor Younger Dryas events" each following a further deglaciation step, *i.e.* the Termination IB and the Termination IC; each was also preceded by a short-lived cooling event, *i.e.* the Preboreal oscillation and the 8200 yr event as the YD was preceded by the Older Dryas. Proxy data clearly show that the climate cooling had a smaller magnitude during the Joux and Cerin phases than during the YD. For example, the sea surface cooling off Norway reached *ca.* 2.5 °C in winter and less than 2 °C in summer at *ca.* 8500 BP against respectively 5 and 6 °C during the YD (Karpuz and Jansen, 1992). The oxygen-isotope record from lake Gerzensee, Switzerland, shows a *ca.* - 1 ‰ ^{18}O anomaly during the Boreal chronozone against - 2.5 % during the YD (Eicher, 1979). The climate cooling during the second part of the Older Atlantic chronozone could correspond to a mean annual temperature decrease of *ca.* 1°C as calculated from an oxygen-isotope record in southern Germany (Grafenstein *et al.,* 1992) or a mean summer temperature decrease of *ca.* 1.5 °C as reconstructed from tree-limit variations in the Austrian Alps (Bortenschlager, 1977).

When compared with the YD, the environmental changes associated with the two early Holocene deglacial cycles also show a dampened pattern. Thus, the ^{14}C curve reconstructed by Zbinden *et al.* (1989) shows a large increase of *ca.* 100 ‰ from the Bølling minimum to the YD maximum. The lake Gosciaz record confirms the large increase in $\Delta^{14}C$ at the onset of the YD by 40-70 ‰ (Goslar *et al*., 1995). The first and the second early Holocene $\Delta^{14}C$ cycles present respectively a magnitude of *ca.* 50 ‰ and 35 ‰ (Fig. 3 and 4). This dampened ^{14}C pattern suggests a decrease in the magnitude of changes in ocean ventilation associated with the successive deglacial steps. Figure 8 also highlights the decrease in cycle duration from the Lateglacial to the mid-Holocene, *i.e.* successively 3000, 2700 and 2200 years. In the same way, the salinity anomalies reconstructed off Portugal by Duplessy *et al.* (1992) present decreasing values from 13 000 to 6000 BP.

This decreasing pattern could be explained by the decreasing volume of the three successive MWP drawn by Edwards *et al.* (1993). Furthermore, Bard *et al.* (1996) speculated that the MWP-1A could have been the largest one so far. An additional explanation could be in the origin of these meltwater influxes and their possible impact on the thermohaline circulation and the Nordic heat pump. By referring to the meltwater history reconstructed by Sakai and Peltier (1997), the MWP-1A originated chiefly from a North American influx and secondarily from a European influx, the MWP-

1B from North American and Antarctic influxes (each had approximately the same volume), and the MWP-1C from a dominant Antarctic influx. Furthermore, the model developed by Schäfer-Neth and Stattegger (1997) suggests that a MWP originating from both the western and eastern margins of the Greenland-Iceland-Norwegian (GIN) Seas could have had a larger impact on the ocean circulation than that of an MWP originating from only the western margins of the GIN Seas. This model experiment could explain the smaller magnitude of the cooling phases following MWP-1B and 1C.

Thus, on the one hand, the residual ^{14}C record and the salinity record off Portugal, and on the other, the climate records from the North Atlantic zone and adjacent continental European and North American areas, suggest that oceanic and atmospheric general circulation formed an oscillating system similar to that described by Björck *et al.* (1996) throughout the deglaciation from the Bølling warming to the mid-Holocene. This dynamic-coupled system shows progressively dampened deglacial oscillations until reaching a relative equilibrium-state at *ca.* 6000 BP. Like the internal structure of the Dansgaard-Oeschger events (Rasmussen *et al.*, 1996), the

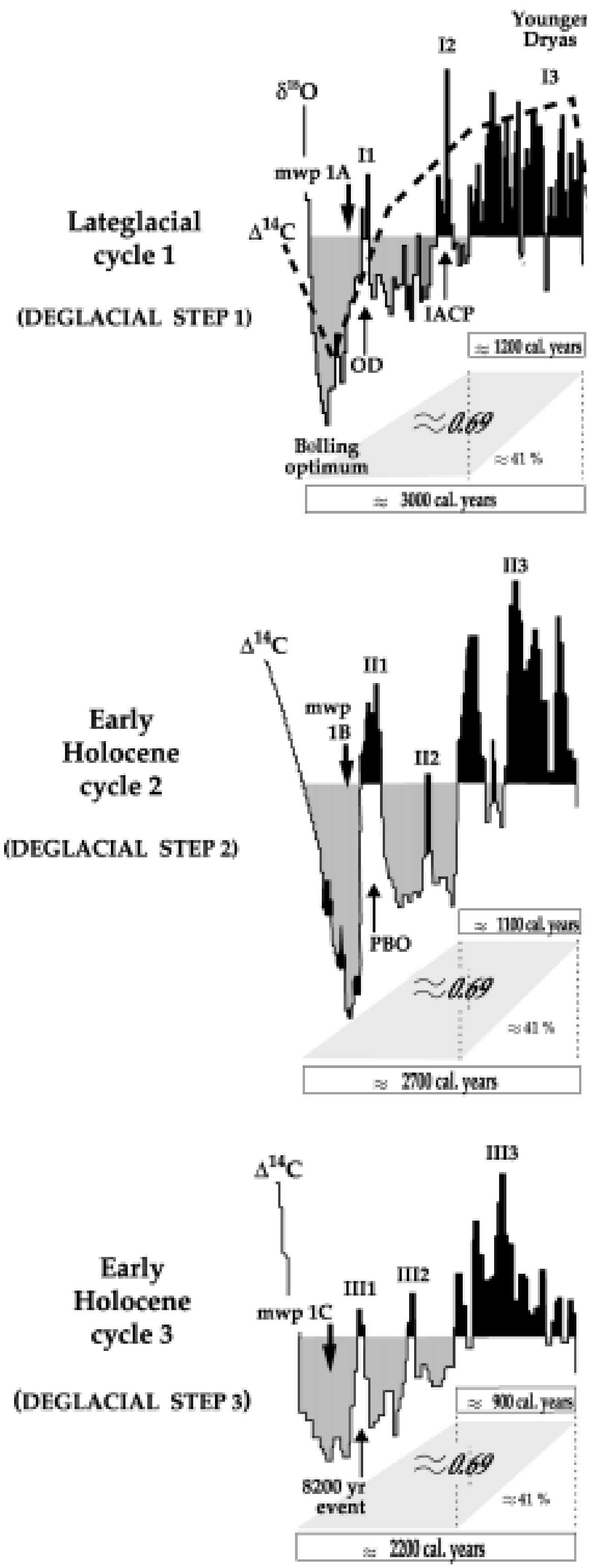


FIGURE 8. Duration, magnitude and internal structure of the three successive cycles evidenced from the GISP2 $\delta^{18}O$ record (Stuiver *et al.*, 1995), the Lateglacial Swiss $\Delta^{14}C$ record (Zbinden *et al.*, 1989) and the tree-ring $\Delta^{14}C$ record (Stuiver and Braziunas, 1993). Despite differences in duration and magnitude, the three cycles are similar in their internal structure. Each cycle has an asymmetrical shape. The prolonged $\Delta^{14}C$ maximum characterizing the last part of each early Holocene cycle corresponds to *ca.* 41 % of the whole cycle duration. Moreover, the ratio between the duration of the first part ($\Delta^{14}C$ minima) and that of the final part ($\Delta^{14}C$ maxima) of each early Holocene cycle reaches *ca.* 0.69. The Lateglacial cycle outlined from the GISP2 $\delta^{18}O$ record shows the same shape and structure as the early Holocene cycles. The $\Delta^{14}C$ broken line is that reconstructed by Zbinden *et al.* (1989). Note that the $\Delta^{14}C$ events marked II1-III1 and II2-III2 have their equivalents respectively in the OD, *i.e.* Older Dryas (I1) and IACP, *i.e.* Intra Allerod Period (I2) isotopic events of the Lateglacial cycle. Event II1 is synchronized with the cool Remoray phase, *i.e.* the Preboreal oscillation, event II3 with the cool Joux phase, event III1 with the cool Le Locle phase, *i.e.* the 8200 yr event, and event III3 with the cool Cerin phase.

Durée, amplitude et structure interne des trois cycles successifs identifiés à partir de la courbe isotopique du sondage GISP2 (Stuiver et al.*, 1995), de la courbe du $\Delta^{14}C$ établie à partir des lacs suisses (Zbinden* et al.*, 1989) et de celle retracée à partir de la dendrochronologie (Stuiver and Braziunas, 1993). Malgré leur durée et leur amplitude différentes, les trois cycles montrent de fortes similitudes dans leur structure interne. Chacun révèle une forme assymétrique. Le maximum prolongé de $\Delta^{14}C$ qui caractérise la dernière partie de chacun des deux cycles holocènes représente environ 41 % de la durée totale du cycle. De plus, le rapport entre la durée de la première partie de chaque cycle Holocène (minimums de $\Delta^{14}C$) et celle de la dernière partie (maximums de $\Delta^{14}C$) s'élève à O,69. Le cycle tardiglaciaire retracé à partir de la courbe isotopique du sondage GISP2 montre une forme et une structure identiques à celles des cycles holocènes. La courbe du $\Delta^{14}C$ (ligne brisée) indiquée pour ce cycle est celle reconstruite par Zbinden* et al. *(1989). Noter que les événements $\Delta^{14}C$ indiqués II1-III1 et II2-III2 ont leurs équivalents respectifs dans les événements marqués OD, c'est-à-dire Dryas moyen (I1) et IACP, c'est à dire oscillation froide intra-Allerød (I2) dans la courbe isotopique du cycle tardiglaciaire. L'événement II1 est corrélé avec la phase de refroidissement de Remoray, qui est l'équivalent de l'oscillation froide du Préboreal, l'événement II3 avec la phase de refroidissement de Joux, l'événement III1 avec la phase de refroidissement du Locle, qui est l'équivalent de l'événement 8200, et l'événement III3 avec la phase froide de Cerin.*

three successive cycles described in this paper (Fig. 4) show an asymmetrical shape with an abrupt reinforcement followed by a gradual then abrupt weakening of the ocean ventilation. This similarity suggests a commun oceanic factor (among others) acting in the climate changes during the growth as well as the collapse of ice sheets. However, contrary to the Bond cycles that display a succession of progressively cooler interstadials (Bond *et al*., 1993), the deglacial cycles show an inverse pattern with a decreasing magnitude resulting from the progressive achievement of the deglaciation in a context of summer insolation maximum (Berger, 1979).

Many difficulties in the recognition of the origins of major climate events such as the YD and the 8200 yr event arise from uncertain timing of the proxy records due to imprecise ^{14}C datings (standard deviation, evaluation of the marine reservoir effect...). Furthermore, any short-lived and moderate change in climate is unlikely to be detected in most marine records due to bioturbation (De Vernal *et al*., 1997). Additional climate records benefitting from a high-resolution due to a high sediment accumulation rate and/or multiple datings are needed to complete the puzzling proxy data from ice, oceanic and continental archives and to assemble these proxies in a coherent dynamic reconstruction. Meanwhile, the three successive cycles depicted in Figure 8 include the YD and the 8200 yr event in a continuous oscillating system covering a great part of the deglaciation period from the Bølling to the early Holocene. The internal structure of these three cycles could offer a possible useful framework to suggest and test further working hypotheses.

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