

Paléoenvironnement tardiglaciaire et holocène des lacs de Pelléautier et Siguret (Hautes-Alpes, France). IV. Stable isotopes of oxygen and carbon in the carbonate sediments of lac de Siguret (Hautes-Alpes, France)

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**Résumé**

Grâce aux variations du  $\delta_{18}\text{O}$ , les Auteurs identifient l'amélioration climatique de l'interstade *Bølling-Allerød* ainsi que le refroidissement du Dryas récent ; par contre ni les variations au cours de l'Holocène, ni celles du  $\delta_{13}\text{C}$  ne peuvent être expliquées simplement en termes climatiques.

**Abstract**

Thanks to the  $\delta_{18}\text{O}$  variations, the Authors identify the *Bølling-Allerød* interstadial climatic amelioration as well as the younger Dryas cooling but neither the variations during the Holocene nor those of the  $<5 \text{ }^{13}\text{C}$  can be explained in climatic terms.

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**Paléoenvironnement tardiglaciaire et holocène des lacs de Pelléautier et Siguret ( Hautes-Alpes, France )**  
**IV. Stable isotopes of oxygen and carbon in the carbonate sediments of lac de Siguret ( Hautes-Alpes, France )**

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*RESUME - Grâce aux variations du  $\delta^{18}\text{O}$ , les Auteurs identifient l'amélioration climatique de l'interstade Bølling-Allerød ainsi que le refroidissement du Dryas récent; par contre ni les variations au cours de l'Holocène, ni celles du  $\delta^{13}\text{C}$  ne peuvent être expliquées simplement en termes climatiques.*

*SUMMARY - Thanks to the  $\delta^{18}\text{O}$  variations, the Authors identify the Bølling-Allerød interstadial climatic amelioration as well as the younger Dryas cooling but neither the variations during the Holocene nor those of the  $\delta^{13}\text{C}$  can be explained in climatic terms.*

*MOTS CLES : Environnement lacustre, isotopes stables, Tardiglaciaire, Holocène.*

INTRODUCTION

The application of stable isotopes in lake sediments for paleoclimatic studies is based on the observation that under favourable conditions, the isotope ratios  $^{18}\text{O}/^{16}\text{O}$  and  $^{13}\text{C}/^{12}\text{C}$  of carbonates precipitated in a lake contain climate-related information. In the following we shortly mention some causes of isotopic variations in lake marl; for a detailed discussion the reader is referred to Eicher et al. (1976, 1981, 1982).

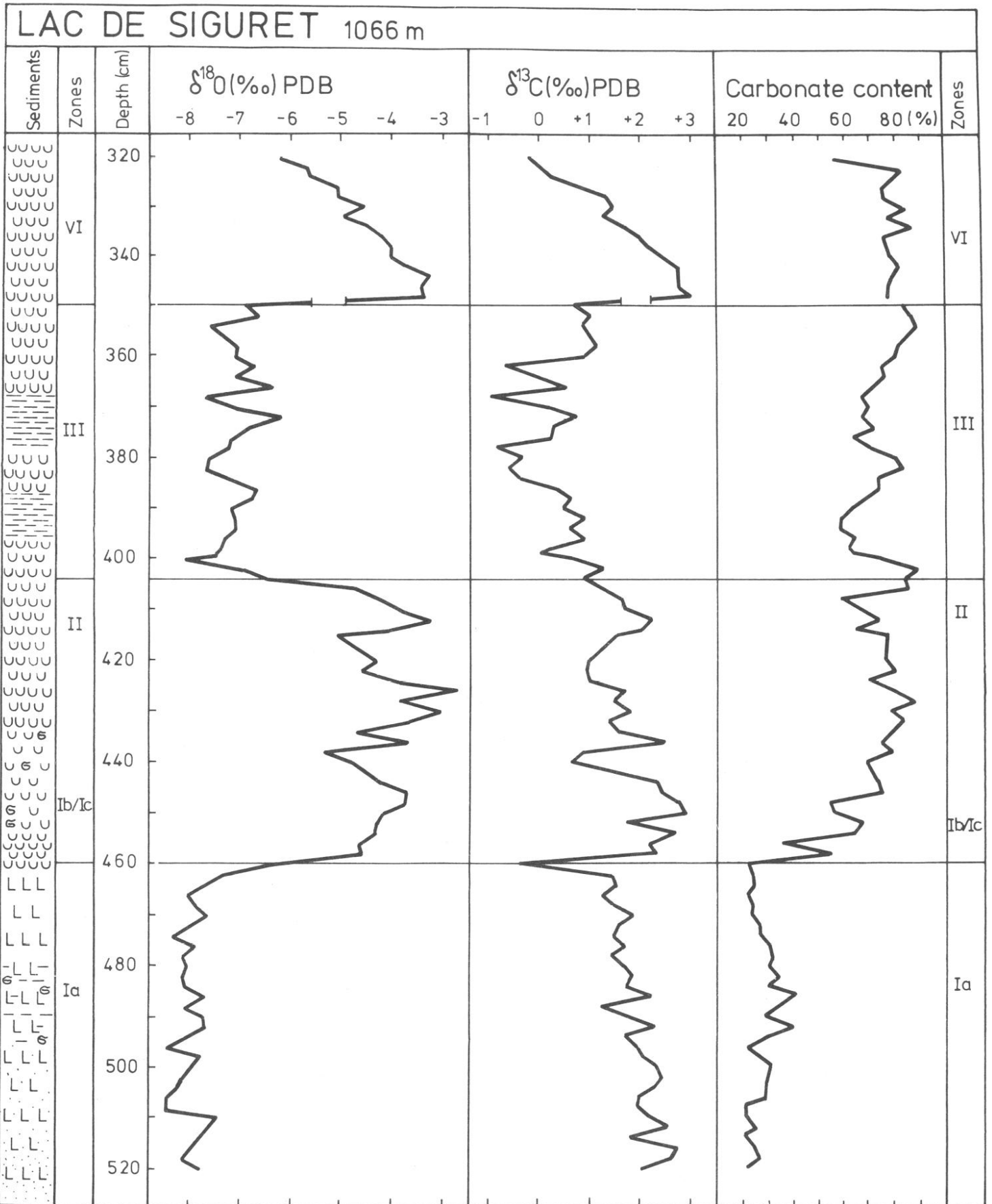
Lake marl is a carbonate sediment precipitated in the lake, in general by the action of plants which withdraw  $\text{CO}_2$  from the water for photosynthesis by which the carbonate equilibria in the water are shifted such that there is a supersaturation with respect to calcite. The formation of lake marl is therefore tied to the biological productivity, and the carbonate content of a lake sediment is partly a measure for this productivity.

Stable isotope ratios are indicated as relative deviations from the isotope ratio of a standard, as  $\delta^{18}\text{O}$  or  $\delta^{13}\text{C}$  in permil. For carbonates, the generally used scale refers to the standard PDB (CRAIG, 1957).

$\delta^{18}\text{O}$  in lake marl reflects the  $^{18}\text{O}$  concentration of the water from which it was precipitated, and at the same time it is influenced by the temperature of the water. It is found that the isotopic composition of the lake water, which in turn is governed by the composition of meteoric precipitation, is the main factor of influence.  $\delta^{18}\text{O}$  of precipitation water varies parallel to air temperature, so that finally, the oxygen isotope ratio in lake carbonate reflects variations of temperature, higher temperature leading to higher  $\delta^{18}\text{O}$ . In addition there are, however, several processes which influence the composition of lake water and of carbonate, for instance evaporation (more precisely, the ratio of evaporation to discharge of the inlet streams) and the season when carbonate precipitation occurs, and it has not been possible to interpret the observed variations in terms of climate in a quantitative way.

$\delta^{13}\text{C}$  is determined by other factors than  $\delta^{18}\text{O}$  and reflects climatic variations only indirectly.  $\delta^{13}\text{C}$  of bicarbonate in the water from the drainage basin is determined

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Sediment types

- L L L Sandy clay
- L L L Clay
- UUUU Marl
- e e e Molluscs
- Cyperaceae peat

Figure 1

essentially by soil composition and probably remains relatively constant for long times in a given region. Typical values for groundwater are -10 to -14 ‰. In a lake,  $\delta^{13}\text{C}$  can be modified by different processes. By photosynthetic activity of submerged aquatic plants, the light isotope  $^{12}\text{C}$  is preferentially withdrawn from the water, so that the remaining bicarbonate is enriched in  $^{13}\text{C}$ . The degree of this enrichment depends on the biological productivity (STILLER and HUTCHINSON, 1980). Another process important for  $\delta^{13}\text{C}$  is exchange between the dissolved bicarbonate and atmospheric  $\text{CO}_2$ . If the water stays long enough in the lake, it will finally reach isotopic equilibrium with the atmosphere; the corresponding value of  $\delta^{13}\text{C}$  in the water is about + 2 ‰, depending somewhat on temperature and on pH. Besides,  $\delta^{13}\text{C}$  is influenced by other, generally local processes, for instance lake stratification (STILLER and HUTCHINSON, 1980), and it is often difficult, if not impossible, to interpret the observed variations in a reliable way.

### RESULTS FOR $\delta^{18}\text{O}$

In the profile of Lac de Siguret we analysed the isotope ratios between 520 cm and 320 cm depth (Figure 1). A general description of the site and the profile is given by BEAULIEU (1977) and BEAULIEU and REILLE (1983). Between 520 cm (deepest sample) and 466 cm,  $\delta^{18}\text{O}$  is relatively low and is nearly constant. The clayey sediment still has a low carbonate content (Figure 1) which reflects a rather low level of biological productivity. Presumably a cold, oligotrophic lake was formed in this late stage of Ice Age. Since marine-derived carbonates generally have  $\delta^{18}\text{O}$  near 0‰, there was probably little allochthonous carbonate in the sediment already in this period. Between 466 cm and 458 cm,  $\delta^{18}\text{O}$  increases from -8.0 to -4.7‰. This strong increase must have been caused by a dramatic climatic change. The warming is also indicated by a subsequent rise of the carbonate content of the sediment. The isotopic increase starts slightly before the ascent of pollen percentages of *Juniperus* and *Hippophaë*, and  $\delta^{18}\text{O}$  reaches a maximum at the same time as the pollen percentage of *Betula*.

From 458 cm to 406 cm,  $\delta^{18}\text{O}$  is relatively high, with a mean value of -4.1 ‰, indicating elevated temperatures. This section corresponds to the last Late-Glacial interstadial (Bølling-Allerød). The values fluctuate, which may be due to a not very constant climate during that phase. Thus, the maximum is -2.8 ‰ (at 426 cm), the minimum -5.5 ‰ (at 438 cm).

A rapid decrease is observed between 412 cm and 400 cm depth. Above that level a section with constantly low  $\delta^{18}\text{O}$  follows, with a mean value of -7.1 ‰, only a little higher (0,8 ‰) than in the oldest part of the profile (below 462 cm). This section can be identified with the final cold phase of the Late Glacial, the Younger Dryas period.

There is an abrupt jump in  $\delta^{18}\text{O}$  and in  $\delta^{13}\text{C}$  from 350 cm to 348 cm. Pollen profile and  $^{14}\text{C}$  dates (BEAULIEU et REILLE, 1983) indicate that there is a hiatus at this depth, so that sediments from the Early Atlantic period (zone VI) directly follow after those of the Younger Dryas period (zone III).

Directly after the hiatus, high  $\delta^{18}\text{O}$  is observed pointing to a warm climate. Then the values continuously decrease until the end of our profile at 320 cm. It is not clear whether this reflects a climatic development (for which no evidence can be found in the pollen spectra) or whether the reason for the decrease is rather some local effect, for instance disturbed sedimentation when the site of the profile got in a near-shore shallow water zone.

RESULTS FOR  $\delta^{13}\text{C}$ 

$\delta^{13}\text{C}$  results are also given in Fig. 1. In the lowest section, between 520 cm and 460 cm depth, the mean value is 1.9 ‰. This may reflect that exchange with atmospheric  $\text{CO}_2$  was important and the carbon isotope ratio in the lake was approximately equilibrated with that of air- $\text{CO}_2$ . Photosynthetic activity, which might have led to the relatively high  $\delta^{13}\text{C}$  values observed, was still restricted in this period.

Above 460 cm, the  $\delta^{13}\text{C}$  curve varies on the average more or less parallel to  $\delta^{18}\text{O}$ , although the abrupt changes occurring in  $\delta^{18}\text{O}$  are less marked for  $\delta^{13}\text{C}$ . A reasonable interpretation is that the variations of  $\delta^{13}\text{C}$  mainly reflect bioproductivity, more positive values corresponding to higher productivity and therefore to more favourable climatic conditions than more negative values. However, the relatively high  $\delta^{13}\text{C}$  values observed in the oldest cold period clearly indicate that  $\delta^{13}\text{C}$  is determined also by factors other than bioproductivity, for instance water hardness or residence time of the water in the lake, so that our interpretation is only tentative.

## CONCLUSIONS

From the isotopic results the profile can be divided into four sections. In the oldest section, corresponding to a cold phase (zone Ia, Oldest Dryas period) there was little biological productivity in the lake, judging from the low carbonate content of the sediment. The second section with relatively high  $\delta^{18}\text{O}$  and increasing carbonate content, corresponding to the Late Glacial interstadial Bølling-Allerød, is followed by a section with again low  $\delta^{18}\text{O}$  (Younger Dryas period). After a hiatus in the sediment,  $\delta^{18}\text{O}$  points towards a warm climate again, but the results in this youngest part cannot be interpreted in detail.

The  $\delta^{18}\text{O}$  pattern observed in the Late-Glacial sections of the profile of Lac de Siguret is similar in many respects to what we have found at other sites in regions north and west of the Alps (e.g. EICHER et al., 1976, 1981, 1982) : relatively low values in the early and in the last cold phases of the Late-Glacial, in between a period with relatively high  $\delta^{18}\text{O}$  values, isotopically more or less uniform but with some fluctuations. The transitions between the different isotopic zones occur within short distances in sediment, indicating rapid climatic changes. In several other lake marl profiles,  $\delta^{18}\text{O}$  exhibits a decreasing trend in the second, warm zone; this is not observed at Lac de Siguret (section from 458 cm to 406 cm). The fact that  $\delta^{18}\text{O}$  profiles of lake sediments exhibit the same major features at different sites in Central Europe indicates that these variations must reflect climatic changes of a continental scale, not local events. Their direct cause must have been large scale changes of  $\delta^{18}\text{O}$  in precipitation, due to major climatic variations. With high probability the abrupt changes between the different more or less uniform periods occurred simultaneously over a large region, since the major weather patterns are governed by the large scale atmospheric circulation. Therefore, in our opinion the rapid  $\delta^{18}\text{O}$  changes can be used for synchronizing profiles from different regions. The mechanism which led to the dramatic climatic variations in the Late Glacial can be traced, thanks to the results of CLIMAP, to changes in the direction of the North Atlantic drift which at present carries anomalously warm water to the coasts of north-western Europe, but which before 13,000 BP and from 11,000 to 10,000 BP flowed straight from east to west, while cold polar water advanced far to the south (RUDDIMAN and McINTYRE, 1981).

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