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Isotopic composition of palaeo-precipitation from a British speleothem : the temporal slope of δ^{18}O *vs* mean annual temperature over a 100 ka timescale

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We present isotopic analyses of fluid inclusions from 6 flowstone layers deposited in Lancaster Hole, a cave in northwest England, during Marine Isotope Stages (MIS) 5 to 3. The layers represent short periods of 2 to 5 ka duration, with best age estimates of 131-125.5 ka, 103 ka, 85-83 ka, 59.5-57.5 ka, 52-49 ka and 38-36 ka. Fluid inclusions record directly the annual average δ^2H of local palaeo-precipitation.

Published results on British ground waters dated by ^{14}C show that palaeo-waters from the last cold stage lie close to the Meteoric Water Line. This fact justifies our reconstruction of δ^{18}O values for the fluid inclusion waters, using the relation δ^2H=8δ^{18}O+10, a step that makes it possible to compare fluid inclusion δ^{18}O with the contemporaneous ocean δ^{18}O determined from foraminifera. The fractionation between them is designated $\delta^{18}O_{CO}$, the $_{CO}$ indicating 'Contemporaneous Ocean'.

$\delta^{18}O_{CO}$ values range from –9.6 to –7.1 $^{o}/_{oo}$ and can be compared with interpolated values of –7.2 to –7.6 $^{o}/_{oo}$for modern precipitation close to Lancaster Hole. From 131 to *ca.*127 ka $\delta^{18}O_{CO}$ increased from *ca.*-9 $^{o}/_{oo}$ to values around –7.3 $^{o}/_{oo}$, reflecting climatic amelioration during Termination II. Light $\delta^{18}O_{CO}$ characterises MIS 5c or Chelford Interstadial for which beetle and pollen data indicate mean annual temperature was 4-5 ^{o}C cooler than today. Although the heaviest values for the layer deposited during MIS 5a are similar to the present day, lighter $\delta^{18}O_{CO}$ values occur at the base and in the upper part. Similarly, $\delta^{18}O_{CO}$ values between –8 and –9.2 $/_{oo}$ occur at *ca.* 59.5 ka, corresponding to the start of a period when speleothem deposition was widespread in Britain. Thus, the light values for $\delta^{18}O_{CO}$ appear to correspond with

periods of warming or cooling climate. In contrast, the layer deposited at 52-49 ka has $\delta^{18}O_{CO}$ similar to present-day. This may correspond to the warm Upton Warren Interstadial documented from beetle evidence, when the thermal climate in Britain was temperate for a few millenia. The youngest layer analysed, *ca.* 38-36 ka, has $\delta^{18}O_{CO}$ slightly lighter than present precipitation.

The British Quaternary record is too fragmentary and poorly dated for detailed comparisons between palaeo-temperatures and $\delta^{18}O_{CO}$ to be made easily. Instead, we have compared the Lancaster Hole record with reconstructed mean annual temperatures for the continuously deposited sediments at Grande Pile in northeast France. Reduced major axis regression of paired values provides a direct estimate of 0.2 $^{o}/_{oo}.^{o}C^{-1}$ for the temporal slope of the $\delta^{18}O$ *vs* temperature relationship over a timescale of $\sim$100 ka (r = 0.62, n=28). This is similar to the seasonal slope found between monthly mean temperatures and $\delta^{18}O$ in precipitation at meteorological stations in Ireland, Britain and Netherlands, and much lower than the widely-quoted spatial slope of 0.69 $^{o}/_{oo}.^{o}C^{-1}$ based on stations near the north Atlantic. Isotope-GCMs also suggest that values for temporal slopes may be much less than the modern spatial slope, although the modelled values vary considerably from place to place.

This study provides the first direct evidence of the isotope-temperature relationship in palaeo-precipitation from outside the limits of present-day ice sheets. More widely distributed data may in future provide important tests for the ability of isotope-GCMs to simulate circulation and vapour transport correctly.