EVIDENCE FOR HOLOCENE ABRUPT CHANGES IN A STALAGMITE RECORD FROM EL PINDAL CAVE (ASTURIAS, N SPAIN)

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ABSTRACT

Climate reconstruction during the Holocene requires paleoclimate archives with constrained chronologies and sensitive proxies able to respond to relatively small climate perturbations. Here we present a new Holocene record from a stalagmite obtained in El Pindal cave (Asturias, Spain) where both gradual and abrupt climate changes are observed. Short and rapid dry events appear as a response to reductions in deep water formation in the North Atlantic.

RESUMEN

La reconstrucción del clima durante el Holoceno requiere archivos paleoclimáticos de cronologías precisas y el uso de indicadores suficientemente sensibles para detectar los cambios climáticos relativamente pequeños de este periodo. Presentamos aquí un nuevo registro Holoceno obtenido de una estalagmita de la cueva El Pindal (Asturias, España) donde se observan tanto los cambios climáticos graduales como rápidos. Varios eventos cortos caracterizados por un clima seco aparecen como una respuesta al debilitamiento de la formación del agua profunda en el Atlántico Norte.

INTRODUCTION

The Holocene in southern Europe and in the Mediterranean region was habitually considered a stable period characterized by wetter conditions during the early Holocene and a progressive aridification after 5.5–4.5 ka BP (JALUT *et al.*, 2000), coincident with the end of the African Humid Period (AHP) (DEMENOCAL *et al.*, 2000). Recently, rapid oscillations in both temperature and precipitation were detected in marine (BOND, 1997) and continental records (MAGNY *et al.*, 2003) and were even modelled (RENSSEN et al., 2007). Latest paleoclimate studies in the Iberia Peninsula have found similar abrupt climate changes (FRIGOLA et al., 2007; MORELLÓN et al., 2008) that correlate, within dating uncertainties, with the Rapid Climate Changes (RCC) defined by *MAYEWSKI et al.*, (2004) after compiling records all over the world. However, although it is clear now that the Northern Iberian Peninsula responded to the North Atlantic rapid climatic changes during the Holocene, the forcing mechanisms that transfer the signal and how marine and terrestrial systems responded remain unknown. To address those questions, we studied a stalagmite record obtained at El Pindal cave in Asturias (N Spain) covering the time period since the beginning of the Holocene to 4 ka BP. The stable isotope profiles ($\delta^{18}O$, $\delta^{13}C$) together with trace metal ratios (Mg/Ca, Ba/Ca, Sr/Ca) allow reconstruction of climate variability and abrupt changes in the northern Iberian Peninsula and to compare them with other paleoclimate records from the area.

CLIMATIC CHARACTERIZATION

The study area is characterized today by Atlantic climate, i.e., high annual precipitation (about 1000mm) due to the proximity to the ocean, occurring mainly in winter. Winters are mild and summers are cool with a very small annual temperature range (ca. 13°C). Rainfall is mainly associated with mid-latitude storms from the Atlantic Ocean. Much of the present day climate variability in this region on a decadal timescale has been linked to a natural mode of atmospheric pressure variation, the North Atlantic Oscillation (NAO; TRIGO *et al.*, 2004)). The measurement of chemical and isotopic composition of both dripwater in the cave and rainfall has allowed us to confirm the influence of the NAO in the precipitation. The high correlation (r^2=0.83) between positive NAO index and less negative oxygen isotopes of rainfall samples was confirmed (MORENO *et al.*, in press). Correlation between NAO index and amount of precipitation is much lower (0.3).

Pindal Cave (4°30'W, 43°23'N) is located in the eastern of Asturias (NW Spain). The cave is 590m long (314m open to guided tours), trends east-west and opens in a large entrance 24 m above sea level a short distance (<10m) back from the modern sea cliff. The cave is developed in a karstic massif composed of Carboniferous Limestone of the Barcaliente Formation. Speleothem deposition in the cave dates from at least 166 kyr BP, the age of the oldest flowstone in the main cave gallery (JIMÉNEZ-SÁNCHEZ *et al.*, 2006).

RESULTS

Chronology. Although sixteen U-Th dates were obtained for MAR, only nine are used for the age model, discarding seven dates from the lowermost 4cm since some inversions were detected probably related to high ^{232}Th content or to alterations of the closed system behaviour (Table 1). The age model was constructed by linear interpolation between the available U/Th data (Figure 1). The presented record of MAR (4 to 47cm) grew continuously with growth rates ranging from 19 to 68 mm/year from 11.6 to 4.5 ka BP.

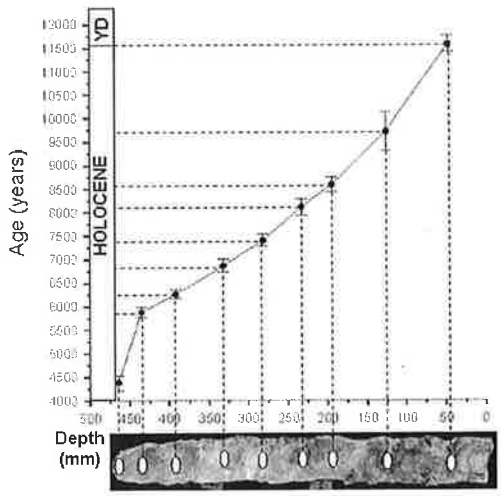

Figure 1. Plot of depth (mm) versus age (years BP) for stalagmite MAR. Error bars indicate 2σ error in the dates. The scanned image of CAN is shown with the position of the U-Th drilled samples.

Table 1. The chronology of MAR stalagmite from El Pindal cave was obtained by U-Th following the procedures described in (EDWARDS *et al.*, 1987) using a Finnigan ELEMENT ICP-MS at the University of Minnesota.

Sample ID	^{238}U ppb	$\delta^{234}U$	$[^{230}Th/^{238}U]$ activity	$[^{230}Th/^{232}Th]$ ppm	Age uncorrected	Age corrected	$\delta^{234}U_{initial}$ corrected	Depth mm
MAR-C2	117 ±	228. ±	0.1245 ±	1520.9 ± 43	11,61 ± 170	11,5 ±	235. ±	47
MAR-A3	139 ±	182. ±	0.1020 ±	488.8 ± 21	9,805 ± 414	9,72 ±	187. ±	126
MAR-A4	213 ±	146. ±	0.0873 ±	1493.9 ± 47	8,615 ± 165	8,59 ±	150. ±	195
MAR-C3	117 ±	143. ±	0.0827 ±	626.8 ± 17	8,173 ± 167	8,11 ±	147. ±	233
MAR-B3	215 ±	124. ±	0.0740 ±	11635. ±	7,413 ± 126	7,41 ±	127. ±	282
MAR-A5	264 ±	128. ±	0.0693 ±	995.8 ± 25	6,902 ± 130	6,87 ±	130. ±	332
MAR-B4	286 ±	120. ±	0.0627 ±	5043.9 ± 277	6,269 ± 86	6,26 ± 86	122. ±	392
MAR-C4	171 ±	122. ±	0.0593 ±	1039.8 ± 38	5,915 ± 113	5,89 ±	124. ±	435
MAR-t	171 ±	102. ±	0.0445 ±	168.3 ± 6	4,496 ± 153	4,38 ±	103. ±	464

Stable isotopes. A high variability in the isotopic values is observed considering that we are investigating the "stable" Holocene interval (7‰ in $\delta^{13}C$; 2.5‰ in $\delta^{18}O$) and both isotopic profiles appear very similar (Figure 2). Previous interpretation of stable isotopes in this cave (MORENO *et al.*, in press) allows correlating higher values to dry and/or cold climate. The Early Holocene is characterized by a trend towards lower values that remain constant from 9 to 6 ka and increase afterwards, coeval with the end of the AHP. Superimposed to this gradual variation, several abrupt changes are detected as higher isotopic values at 5, 7.4, 8.2, 9.2, 10, 10.5 and 11.2 ka BP pointing to drier and/or colder climate.

Trace metals. Since Pindal is right on current coast, mass balance for Pindal drips suggests that currently about 80% of Mg could be from seasalt aerosols. The increase in Mg/Ca starting at 8 ka BP is thus potentially attributable to sea level rise. On the other hand, Sr/Ca and Ba/Ca ratios show maximum values at 7500-6000 ka, coinciding with the most recent humid period in North Africa (DEMENOCAL *et al.*, 2000). Sr and Ba are associated with greater vegetation (eg mobilization of Ba by organic chelates), and faster driprate (increasing Sr). Although not so evident as the isotopic profiles, trace elements, particularly Sr, also show higher values at 5, 8.2, 9.2, 10 and 11.2 ka BP.

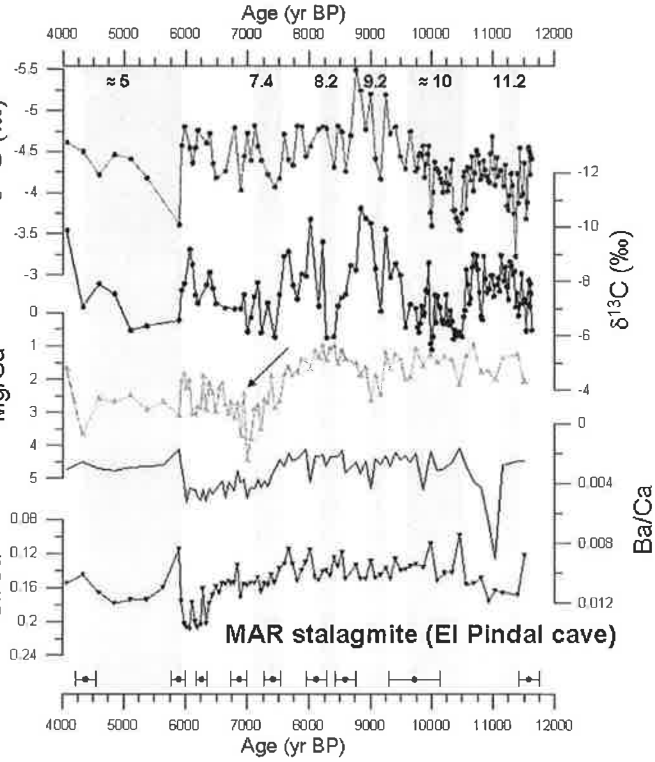

Figure 2. Plot versus age of the main data from MAR stalagmite. Note that all records are plotted with reversed y-axis, thus vertical grey bands mark higher values.

HOLOCENE RAPID CLIMATE VARIABILITY

For the interval between the Younger Dryas to 8 ka ago, there are several cold events defined in Greenland ice cores (Figure 3). Some of them are clearly observed in Dongge Cave (China) (DYKOSKI *et al.*, 2005) and interpreted as weak monsoon events related to the occurrence of outburst floods (TELLER *et al.*, 2002), affecting the salinity of the North Atlantic, heat transport into the North Atlantic region, and the monsoon, through atmospheric teleconnections. In the MAR record those events correspond with more positive values of $\delta^{18}O$ and $\delta^{13}C$ pointing to dry and cold climate.

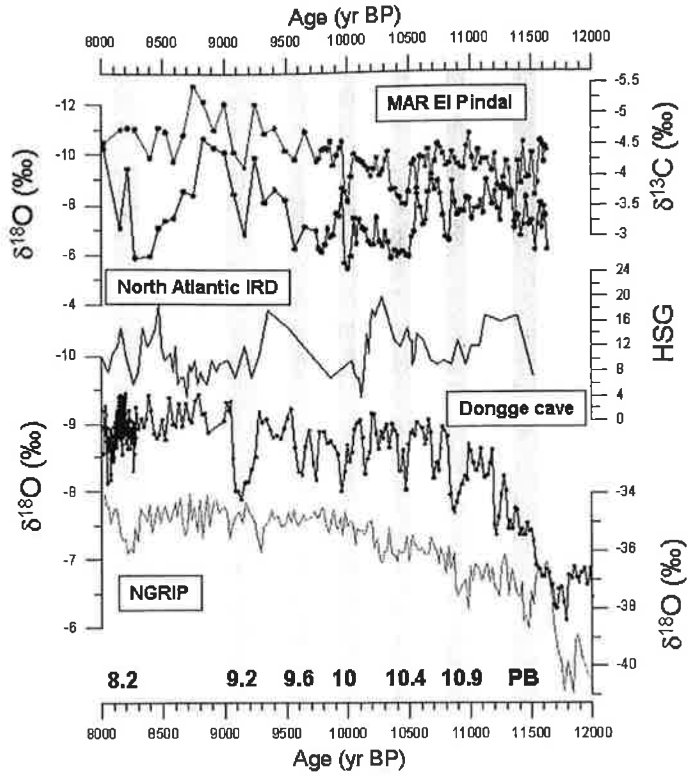

Figure 3. Comparison of isotopic records from MAR sample (El Pindal cave, Asturias, Spain) with the percentage of hematite-stained grains (HSG) as indicators of North Atlantic ice-rafted debris (BOND et al., 1997), the $\delta^{18}O$ profile from Dongge Cave in China (DYKOSKI et al., 2005) as a proxy for the Asian monsoon and the $\delta^{18}O$ variability measured in NGRIP Greenland ice core (RASMUSSEN et al., 2007). Grey vertical bands mark the Greenland events, including the Preboreal Oscillation (PB).

The inferred climatic signal from the studied Northern Iberian speleothem supports the interpretation of North Atlantic Deep Water reduction events during the Holocene with the consequent decrease in the heat transport to Europe and, particularly, to our study area in Northern Iberian Peninsula.

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