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Petrographic and isotopic evidence for Holocene long-term climate change and shorter-term environmental shifts from a stalagmite from the Serra do Courel of northwestern Spain, and implications for climatic history across Europe and the Mediterranean

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ABSTRACT

A small stalagmite from Cova da Arcoia in the Serra do Courel of northwestern Spain provides a record both of general climate change across the Holocene and of shorter-term shifts between wetter and drier conditions. Nineteen U-series dates from 9.3 ka to the present provide a chronology of the stalagmite with uncertainties of commonly only decades and at the most only 200 years. These dates constrain the age of 18 petrographic surfaces that are of two types, one (Type E) inferred to result from dissolution during enhanced flow of water and the other (Type L) inferred to result from lesser flow. Aragonite is more abundant in the earlier parts of the stalagmite and calcite is more abundant in the later part. Values of $\delta^{13}C$ range from −5.6 to −1.3‰ relative to VPDB but are greatest beneath Type L surfaces. Values of $\delta^{18}O$ range from −5.4 to −4.4‰ relative to VPDB and have a weak but statistically significant correlation with $\delta^{13}C$.

Greater abundance of aragonite, greater values of $\delta^{13}C$, and lesser frequency of Type E surfaces early in the stalagmite suggest a drier and perhaps warmer early to middle Holocene, whereas greater abundance of calcite and frequent Type E surfaces higher in the stalagmite suggest wetter conditions later in the Holocene. $\delta^{18}O$ data are most compatible with this general conclusion. However, a prominent Type E surface records the 8.2 ka event as an isolated wetter episode in the otherwise-dry early Holocene.

Much of the stalagmite's aragonite and calcite suggests normal stalagmite growth in moderate climatic conditions. However, the near or complete cessation of growth at Type L surfaces and greater $\delta^{13}C$, greater $\delta^{18}O$, and lesser fluorescence of aragonite beneath those surfaces combine to suggest at least six century-scale episodes of strikingly dry conditions. On the other hand, evidence of dissolutional erosion at Type E surfaces suggests at least ten distinct episodes of much wetter conditions. These combine to suggest highly variable climate across the Holocene at the scale of decades to a few centuries.

The record from this stalagmite is similar to records from Greenland ice cores and from pollen and/or stalagmite records from France, northernmost Spain, and more broadly from northern or Atlantic-facing Europe. In contrast, it suggests trends nearly opposite those in records from eastern and southern Spain, suggesting that the Serra do Courel is north of, but perhaps not far from, the boundary between Atlantic and Mediterranean regions of Holocene climate trends in the Iberian Peninsula. That general antiphasal relationship between northwestern Spain and regions to the south and east extends to the specific observation that four of the most pronounced wetter events in the stalagmite's record coincide with periods of widespread drought and/or cultural collapse in the Mediterranean and Middle East.

1. Introduction

At the broadest scale, the Holocene is considered a period of relative climate stability, in contrast to the variability in climate from

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interglacial to glacial maximum in the 100,000 years that preceded the Holocene. However, significant climate change has occurred in the Holocene (Roberts, 1998; Oldfield, 2003), and recent work has documented significant temporal and geographic variation of major climatic intervals within the Holocene (e.g., Davis et al., 2003; Fisher and Koerner, 2003; Mayewski et al., 2004). Furthermore, work of the last few decades has documented that some climate change has been remarkably abrupt (e.g., Berger and Labeyrie, 1987; National Research Council, 2002).

As a contribution to the emerging picture of climate change in the Holocene, this paper reports on a stalagmite from northwestern Spain that spans the last ten thousand years. Stalagmites have many characteristics from which palaeoclimate can be inferred (Gascoyne, 1992). These include radiometric age (Harmon et al., 1975; Edwards et al., 1987; Lauritzen, 2003), variation of C and O stable isotopes (McDermott, 2004), trace element chemistry (Verheyden, 2004; Fairchild and Treble, 2009), UV-stimulated fluorescence (Shopov et al., 1994; Baker et al., 1998), pollen content (McGarry and Caseldine, 2004), varying detrital content (Railsback et al., 1999; Webster et al., 2007), petrographic relationships (Railsback, 2000; Turgeon and Lundberg, 2001; Frisia et al., 2002) and, perhaps most fundamentally, changing mineralogy (González and Lohmann, 1988; Railsback et al., 1994; Frisia et al., 2002). With regard to the two principal $CaCO_3$ minerals, aragonite and calcite, many studies have linked precipitation of aragonite to more extensive evaporation (Murray, 1954; Pobeguin, 1965; Siegel, 1965; Siegel and Dort, 1966; Thrailkill, 1971; Cabrol and Coudray, 1982) and to higher temperature (Burton and Walter, 1987; Morse et al., 1997) than the conditions in which calcite forms. The stalagmite described herein contains both calcite and aragonite in layers bounded by critical petrographic surfaces and characterized by abrupt shifts in C isotope composition. These characteristics, combined with 19 radiometric ages, provide a record of both long-term trends and shorter shifts in climate in the Atlantic-facing highlands of northwestern Spain during the Holocene.

2. Setting

The stalagmite described here, which was designated Stalagmite ESP03 in the Sedimentary Geochemistry Laboratory of the University of Georgia (U.S.A.), comes from Cova da Arcoia in the Serra do Courel in the westernmost Cordillera Cantabrica (Fig. 1). Cova da Arcoia is at 42° 36′ 44.39″ N latitude and 7° 05′ 06.32″ W longitude, near the village of Céramo in the province of Lugo, in the easternmost portion of the autonomous community of Galicia, in northwestern Spain. Cova da Arcoia sits at 1240 masl, whereas the summits upslope from the cave have elevations of 1500 to 1600 m, and the valley floors below are at 900 to 1100 m. The cave is on a north-facing slope.

Mean annual precipitation in the region around Cova da Arcoia is about 2500 mm (Leira and Santos, 2002), with most precipitation in the cooler months (Walter and Lieth, 1960). The native vegetation represents a transition from Eurosiberian to Mediterranean (Izco Sevillano et al., 1982, cited in Leira and Santos, 2002), although the present landscape is largely scrubland and pasture (Leira and Santos, 2002).

The whole zone has been affected during the Pleistocene by the Quaternary glaciations, developing the main karstic systems under the ice accumulations and helped by the subglacial melt waters. The fauna that occupied the territory during the Upper Pleistocene to Holocene, including the human species, is known in detail. The Holocene fossil record in Arcoia and surrounding caves includes

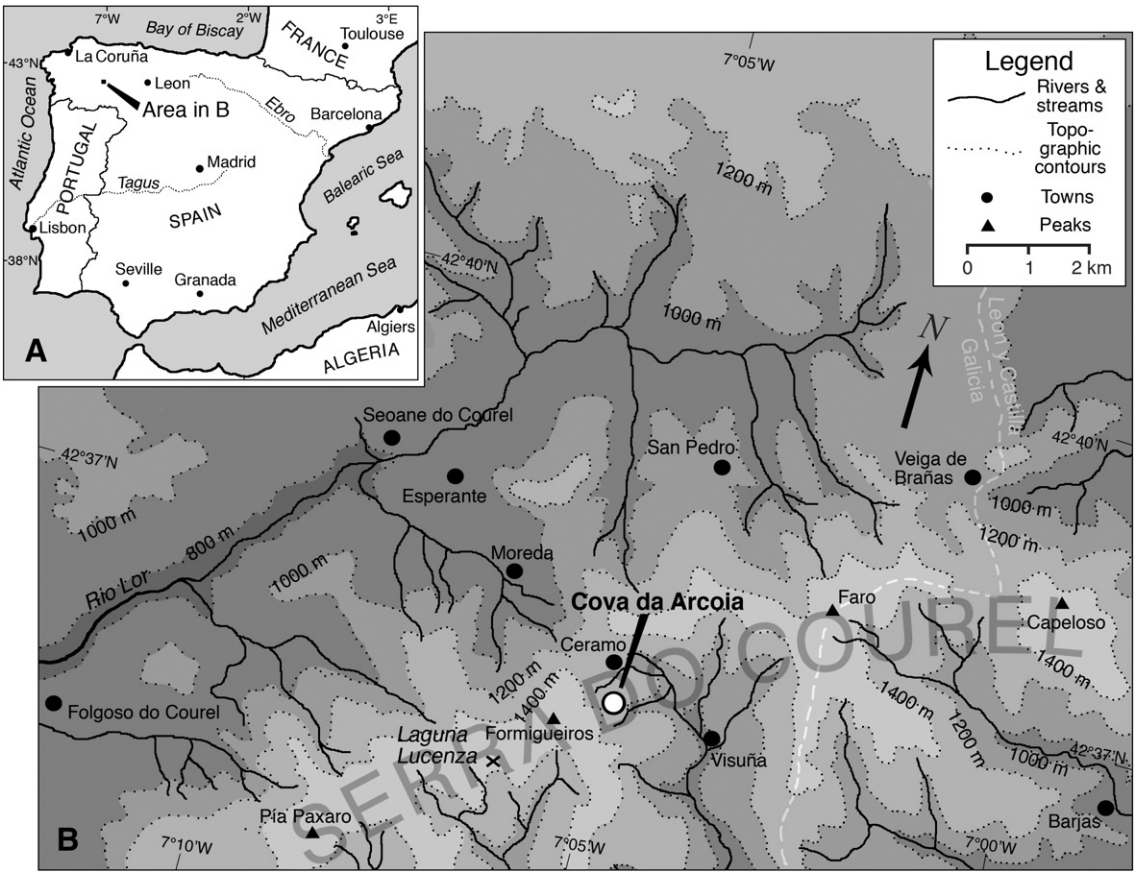

Fig. 1. A. Map of the Iberian Peninsula showing two major rivers mentioned in text and location of area in Part B. B. Map of the area around Cova da Arcoia, the cave from which Stalagmite ESP03 was taken.