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Devils Hole, Nevada, $\delta^{18}O$ record extended to the mid-Holocene

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Abstract

The mid-to-late Pleistocene Devils Hole $\delta^{18}O$ record has been extended from 60,000 to 4500 yr ago. The new $\delta^{18}O$ time series, in conjunction with the one previously published, is shown to be a proxy of Pacific Ocean sea surface temperature (SST) off the coast of California. During marine oxygen isotope stages (MIS) 2 and 6, the Devil Hole and SST time series exhibit a steady warming that began 5000 to >10,000 yr prior to the last and penultimate deglaciations. Several possible proximate causes for this early warming are evaluated. The magnitude of the peak $\delta^{18}O$ or SST during the last interglacial (LIG) is significantly greater (1 per mill and 2 to 3°C, respectively) than the peak value of these parameters for the Holocene; in contrast, benthic $\delta^{18}O$ records of ice volume show only a few tenths per mill difference in the peak value for these interglacials. Statistical analysis provides an estimate of the large shared information (variation) between the Devils Hole and Eastern Pacific SST time series from ~41 to ~2°N and enforces the concept of a common forcing among all of these records. The extended Devils Hole record adds to evidence of the importance of uplands bordering the eastern Pacific as a source of archives for reconstructing Pacific climate variability.

Keywords: Late Pleistocene; Holocene; Southwestern U.S.; Nevada; Devils Hole; Paleoclimate; SST; Eastern Pacific; Tropical Pacific; Atmospheric teleconnection

Introduction

In earlier studies (Winograd et al., 1992; Ludwig et al., 1992), we presented a continuous 500,000-yr time series of Pleistocene climate recorded in vein calcite from Devils Hole cave in southern Nevada (Fig. 1). Those reports initiated a decade-long discussion regarding the validity of the Milankovitch hypothesis of the Pleistocene ice ages (Broecker, 1992; Imbrie et al., 1993; Kerr, 1997; Karner and Muller, 2000; Henderson and Slowey, 2000). They also spurred renewed interest in cave carbonate deposits as archives of Quaternary paleoclimate (McDermott, 2004).

Herein, we present new data that bring the Devils Hole oxygen-18 ($\delta^{18}O$) time series forward from 60,000 to 4500 yr ago, extending our original record (which covered the period 568,000 to 60,000 yr ago) into the mid-Holocene. Having this new mid-Wisconsin to mid-Holocene record enables us to compare the Devils Hole record with marine and continental records during times when dating uncertainties of the various climate proxies are relatively minor, thereby enhancing recognition of similarities and differences in their phases. For example, we can determine if the much discussed phase offset between the Devils Hole $\delta^{18}O$ time series and the penultimate deglaciation – as recorded by foraminiferal $\delta^{18}O$ – was a unique event, or if it also occurred during the last deglaciation. Additionally, we address to what extent the Devils Hole $\delta^{18}O$ time series is a proxy of temperature versus a mixture of several variables (i.e., ocean water $\delta^{18}O$, moisture source, seasonality of recharge, etc.). We also examine the question whether the Devils Hole $\delta^{18}O$ time series is predominantly a local paleoclimate record (Imbrie, 1992; Imbrie et al., 1993), a regional record (Herbert et al., 2001), or a proxy of interhemispheric relevance (Landwehr and Winograd, 2001). Finally, the ^{230}Th uranium-series dating of the Devils Hole calcite (Ludwig et al., 1992) was replicated in 1997 using both ^{230}Th and ^{231}Pa

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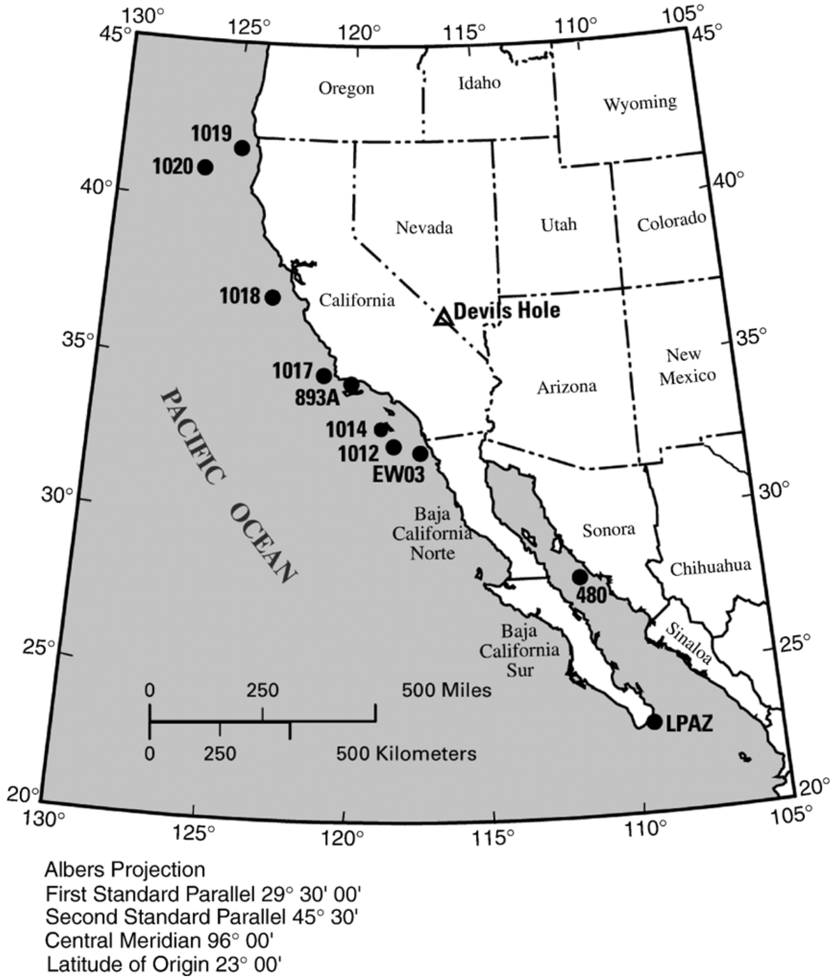

Figure 1. Western United States and adjacent northeastern Pacific Ocean showing the location of Devils Hole and marine cores discussed in text.

(Edwards et al., 1997) and is now unquestioned. However, the correction that must be added to the ages to account for groundwater transit/travel time through the aquifer tributary to Devils Hole was not resolved in our earlier work. We now can say that the correction is <2000 yr.

Extending the Devils Hole record to the mid-Holocene

Devils Hole core DH-11, which yielded our 500,000-yr record, was recovered from a depth of ~30 m below the water table (~45 m beneath the ground surface). Cessation of vein calcite growth ~60,000 yr ago was perplexing, given the absence of any hiatuses in the growth of this fracture coating during the preceding ~500,000 yr (Winograd et al., 1992) and the likelihood that the groundwater from which the calcite was precipitated has always been slightly supersaturated with respect to calcite (Riggs et al., 1994). We speculated that at ~60,000 yr ago the fissure that comprises Devils Hole opened to the surface. Thereafter, calcite precipitation ceased due to land surface inputs of organic and mineral matter and subaquatic growth that poisoned calcite precipitation from the slightly supersaturated groundwater (saturation index, SI = 0.2; Plummer et al., 2000).

This line of reasoning suggested that portions of the cavern up the hydraulic gradient (i.e., upstream in the aquifer) from the near-surface DH-11 core site might yield calcite that grew uninhibited by contaminants. Several divers, including two of the authors (ACR and PTK), searched Devils Hole Cave no. 2, a similar cave ~200 m north of Devils Hole, for recently precipitated calcite coatings. The first dives in 1994 retrieved several samples one of which, DHC2–3, was precipitated from 80,000 to 19,000 yr ago, thus providing 41,000 yr of new record plus a 20,000-yr overlap with core DH-11 (Winograd et al., 1996). Additional dives in 1996 yielded sample DHC2–8, which grew between 30,000 and ~4500 yr ago, and which overlaps DHC2–3 by 11,000 yr.

Thin-section petrography – to check for hiatuses in calcite growth, and for calcite recrystallization or dissolution – preceded sampling of the calcite for stable isotopic analyses and uranium-series dating. No such events were noted. Starting at the free (i.e., outer or wetted) face of each sample, and proceeding inward at right angles to the growth laminae, we micro-milled 209 samples, each 0.25 mm thick, for $\delta^{18}O$ analyses. The stable isotope data were plotted against their distance inward from the free face of the samples, and the resulting curves were used to select intervals for uranium-series