Prolonged wet period in the southwestern United States through the Younger Dryas

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ABSTRACT

The Younger Dryas was one of the more dramatic climatic transitions ever recorded. How these types of climatic shifts are expressed in continental interiors is of primary scientific interest and of vital societal concern. Here we present a speleothem-based absolutely dated record (using uranium-series data) of climate change for the southwestern United States from growth chronology of multiple speleothems. The stalagmite growth represents the onset of wetter climate (12,500 yr B.P.) soon after the start of the Younger Dryas; the wetter climate persisted a millennium beyond the termination of the Younger Dryas. This wet cycle is likely related to a more southern positioning of the polar jet stream in response to cooler Northern Hemisphere climate. The end of the wet period coincides with the peak of the Holocene summer insolation maximum ca. 10,500 yr B.P. The Ållerød (prior to the Younger Dryas), which corresponds to Clovis occupation in the southwestern United States, was drier in comparison and seems in line with a climatic contribution to megafauna extinction.

Keywords: Carlsbad Caverns, stalagmite, paleoclimate, U-series, Younger Dryas.

INTRODUCTION

The Younger Dryas climatic event represents the last episode in which North Atlantic climate returned to near-glacial conditions. This event occurred between 13,000 and 11,200 yr B.P. (Bennett et al., 2000); ice cores have more distinctly defined the Younger Dryas to have occurred from 12,940 to 11,640 yr B.P., with return to normal conditions with unprecedented rapidity in less than a decade (Alley et al., 1993). Understanding climate conditions in continents around the Younger Dryas chronozone is important because it provides insight into the response of continental interiors to such dramatic climate change. How rapidly climate deteriorates and recovers is of vital societal importance. Current understanding of climate change in continental interiors during the time of the Younger Dryas is unclear, in part because of the lack of well-dated proxies. Here we present a well-dated speleothem climate proxy from around the time of the Younger Dryas for a continental interior.

In arid regions such as the southwestern United States, speleothem growth is moisture limited (Polyak and Asmerom, 2001). Thus, in decorated but inactive cave interiors, the dry speleothems usually represent past periods of wetter-than-present conditions. High-precision uranium-series (U-series) dating of six small stalagmites from three caves in the Guadalupe Mountains, southeastern New Mexico (Fig. 1), shows a record of stalagmite growth from ca. 30,000 to 10,500 yr B.P. Most of the ages are robust (low error) determinations. Some ages have large errors due primarily to samples with low U and high ^{232}Th (detrital); such samples require significant initial ^{230}Th/^{232}Th ratio corrections based on ^{230}Th/^{232}Th versus ^{234}Th/^{232}U isochrons. The U-series dates are cited as calendar years before present (yr B.P.; present is A.D. 2002). Images of samples and tabulated U-series data are available.[1]

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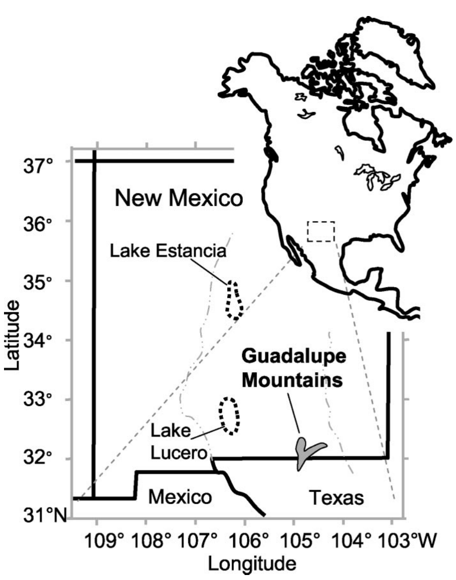

Figure 1. Location of study area.

METHODS

Numerous U-series dates were acquired, and we found that construction of (^{230}Th/^{232}Th) versus (^{234}Th/^{232}U) (activity ratios) three-point isochrons was necessary to determine the initial ^{230}Th/^{232}Th ratio because of intermittently higher initial ^{230}Th/^{232}Th ratios or excess detrital Th combined with low U concentrations in some subsamples. Significant amounts of detrital ^{230}Th in the calcite result in anomalously older U-series ages. A correction is needed in young (<20 ka), low-uranium samples. The U-series dates constrain the period of stalagmite growth around the Younger Dryas and encompass the Pleistocene-Holocene transition in calendar years before A.D. 2002. Reversed (uncorrected) ages in the lower section of stalagmite BC2 were found to be due to higher initial ^{230}Th/^{232}Th ratios. A ^{230}Th/^{232}Th versus ^{234}Th/^{232}Th three-point isochron indicated an average initial ^{230}Th/^{232}Th $= 6 \times 10^{-5} = 60$ ppm, significantly greater than bulk silicate

[1]GSA Data Repository item 2004001, tabulated U-series data and photographs of samples, is available online at www.geosociety.org/pubs/ft2004.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, USA.

earth value of 4.4 ppm calculated from a bulk silicate earth ^{232}Th/^{238}U ratio of 3.8 (Asmerom and Jacobsen, 1993). On the basis of this isochron-determined age, the other three dates in this section were adjusted to the stalagmite's annual banding, an approach that showed that their initial ^{230}Th/^{232}Th ratios were ~20 ppm. Such big shifts in the ratios over short periods of time were, in this case, related to multicomponent contributions to the initial ^{230}Th/^{232}Th ratios. This problem and possible causes are discussed by Dorale et al. (2004). Several isochrons were constructed and indicate that most initial ^{230}Th/^{232}Th ratios were between 5 and 60 ppm. The near-global values (5 ppm) corresponded to calcite samples with higher ^{232}Th concentrations. The much higher initial ^{230}Th/^{232}Th ratios were observed in the cleaner calcite samples. These differences were fairly consistent, such that a correlation could be made that was applied to all dates. The correlation was based on the ^{230}Th/^{232}Th initial ratio versus the ^{232}Th concentration and expressed as $Y = 0.00091X^{-0.49713}$, where Y = initial ^{230}Th/^{232}Th and X = ^{232}Th concentration. A value of $Y \pm 50\%$ was used to correct all dates. The dependence of the initial ^{230}Th/^{232}Th on ^{232}Th content likely reflects contributions from a low ^{230}Th/^{232}Th ratio silicate end member and a high ^{230}Th/^{232}Th ratio carbonate end member.

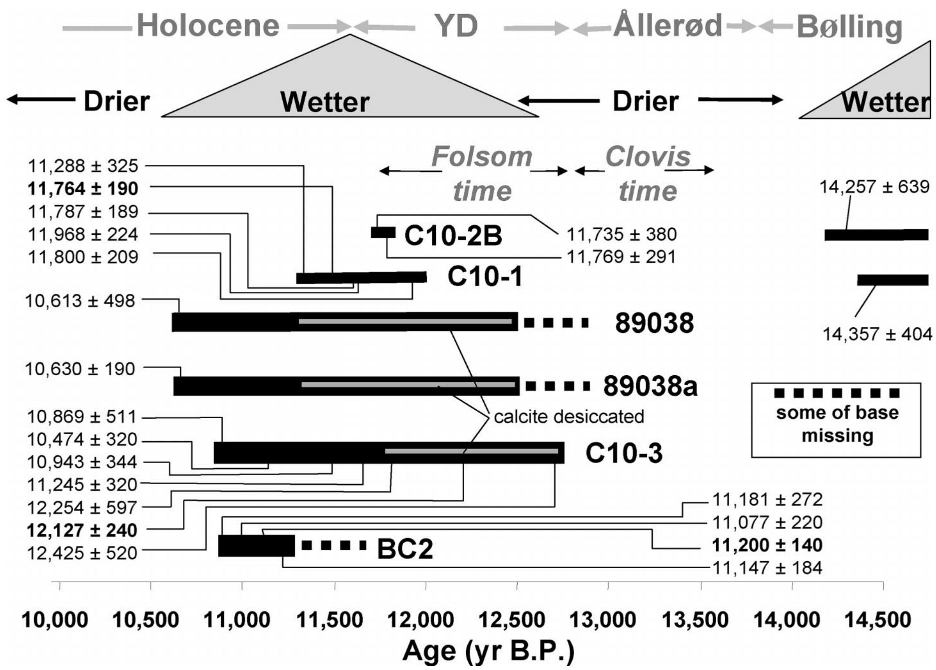

Figure 2. Graph shows period of stalagmite growth defined by six stalagmites. Note that wet period—represented by stalagmite growth that began soon after beginning of Younger Dryas (YD)—extended 1000 yr beyond termination of YD. Dates in bold are result of isochrons. Thicker growth bars represent stalagmites with growth rates of 100 ± 30 μm/yr. Thinner bars represent stalagmites with growth rates of 40 ± 20 μm/yr. Ages are calendar years before present. Some ill-defined growth is seen by two speleothems (89038 and 89038a); growth rates of these two samples are difficult to determine in lower half of speleothems because of desiccated calcite (gray bars).

CHRONOLOGY AND STALAGMITE GROWTH

Our speleothem data show that, after an overall dry episode that started at the Bølling-Allerød transition (ca. 14,000 yr B.P., lack of stalagmite growth), wetter conditions were established by ca. 12,500 yr B.P. (Fig. 2), soon after the start of the Younger Dryas. The base of C10-3 at 12,500 yr B.P. marks the onset of the wet episode (Fig. 2). This wet period (= stalagmite growth) lasted for ~2000 yr. The termination of this wet period is best defined near the base of stalagmite BC2 (Carlsbad Caverns) by an 8000 yr growth hiatus that separates late Holocene stalagmite growth (=wet period, Polyak and Asmerom, 2001; Polyak et al., 2001) from the early Holocene to late Pleistocene stalagmite growth. The early Holocene calcite below the hiatus yields U-series dates that are robust even with sizably high initial ratios of ^{230}Th/^{232}Th. The BC2 hiatus (distinct black layer possibly formed by thousands of years of organic debris settling onto the stalagmites from bat flights), established by U-series dates and annual bands, occurred at 10,900 yr B.P., 300 yr (determined from annual bands) after an isochron-determined date of 11,200 ± 140 yr B.P. Termination of early Holocene stalagmite growth is also well defined by the top of stalagmite 89038a (Hidden Cave), where aragonite layers become more abundant. This hiatus is at 10,500 yr B.P., ~130 yr following a date of 10,630 ± 190 yr B.P. (determined from band-thickness growth rate). The other four stalagmites all have tops with ages near 11,000 yr B.P. The period of Younger Dryas to early Holocene growth is defined by the cave number 10 (C10) stalagmites (Fig. 2). Stalagmite C10-1 is probably most typical of the growth period, because it exhibits important hiatuses between 30 and 11 ka. Growth of this stalagmite terminated near 20 ka; then minor growth occurred at 14 ka, and a final episode of growth occurred from 12 to 11 ka, possibly indicating the timing of the core of the Younger Dryas to early Holocene growth period. The C10-3 stalagmite grew from ca. 12.5 to ca. 10.6 ka. Overall, the timing of Younger Dryas–early Holocene growth appears to have been from ca. 12.5 to ca. 10.5 ka; most growth occurred between 12 and 11 ka (Fig. 2).

The C10 stalagmites show hiatuses or slowing of growth during the Allerød and early Younger Dryas chronozones and reestablishment of growth by the early to middle Younger Dryas. These stalagmites do not exhibit growth after 10,500 yr B.P., suggesting that the conditions controlling growth of these stalagmites were more pronounced prior to that time than during the entire Holocene. Stalagmites 89038 and 89038a also do not exhibit continued middle or late Holocene growth, although late Holocene stalagmites from this same cave and Carlsbad Caverns have been reported (Polyak and Asmerom, 2001). Termination of growth of all six stalagmites by 10,500 yr B.P. equates to the onset of distinctly drier conditions.

DISCUSSION AND CONCLUSIONS

Cessation of growth of these stalagmites by ca. 11,000 and no later than 10,500 yr B.P. was coeval with the termination of the last highstand of regional lakes, such as Lake Lucero (Longford, 2003; <100 km north of our study area) and Lake Estancia (Anderson et al., 2002; <300 km north of the Guadalupe Mountains). It also coincides with a change from cooler wetter to warmer drier climate, evidenced in lake sediments in central and northern Arizona (Weng and Jackson, 1999) and increased moisture in much of the Great Basin, indicated by the prevalence of black mats (Quade et al., 1998). Globally, climate proxies with high-resolution chronologies from the Atlantic margin settings, both in coastal regions (e.g., Cariaco Basin; Hughen et al., 2000) and continental interiors (e.g., Great Lakes area; Yu and Eicher, 1998), show strong synchronicity with the Young Dryas chronozone. Strong synchronicity has also been reported from high-altitude tropical ice cores, such as those from Peru (Thompson et al., 1995) and Bolivia (Thompson et al., 1998). Reported near-synchronicity from continental interiors away from the North Atlantic region, such as Owens Valley (Benson et al., 1997), has somewhat less definition with respect to the onset and termination of the Younger Dryas event, compared to the previously mentioned cases. Lack of synchronicity is widely reported from a number of regions outside the Atlantic Basin, including New Zealand (Singer et al., 1998; Turney et al., 2003), Chile (Bennett et al., 2000), and Japan (Nakagawa et al., 2003), among others.

Our results for the southwestern United States—showing a dry Ållerød–Younger Dryas transition followed by a wetter Younger Dryas–Holocene transition and the termination of the wetter phase a millennium after the end of the Younger Dryas (Fig. 2)—suggest that the link with North Atlantic climate variability is complex. The onset of the wet cycle at the start of the Younger Dryas likely reflects a southward shift and strengthening of the jet stream due to cooling of the Northern Hemisphere associated with the Younger Dryas. Southward shift of the split jet stream during the Last Glacial Maximum (Kutzbach and Wright, 1985) was associated with pronounced increase in effective moisture in this part of the southwestern United States during the Last Glacial Maximum (Allen and Anderson, 1993). The persistence of this wet cycle a millennium beyond the termination of the Younger Dryas was likely related to a complex set of factors, including retardation of northward retreat of the jet stream, possibly by expanded Cordilleran-Laurentide ice sheets. Although it is not clear whether there was expansion of Laurentide ice sheets during the Younger Dryas, it is thought that the Cordilleran-Laurentide ice sheet was still present in northwestern North America (Dyke and Prest, 1987). Atmospheric conditions that control the near-surface ocean along the California coast (Emery and Hamilton, 1985), including the California Current, also influence the climate over much of the southwestern United States (Ely et al., 1994). Periods in which the California Current is disrupted, such as during El Niño, are also periods of higher precipitation in the southwestern United States. There is evidence that the northern California Current had collapsed prior to the last glacial maxima and its recovery was gradual, lasting well into the Holocene, ca. 10 ka (Herbert et al., 2001). The termination of the wet period occurred near the peak of the Holocene summer insolation maximum (Berger and Loutre, 1991), initiating a long dry spell in the southwestern United States that lasted until the late Holocene.

This Younger Dryas to early Holocene wet period was coeval with the earliest well-documented cases of human colonization of North America (Clovis and Folsom cultures) and pronounced changes in the megafauna (Haynes, 1991; Haynes et al., 1999). In this regard, our data have direct relevance to the paleo-Indian cultures and changes in megafauna in the southwestern United States. For the nearby Southern High Plains, the periods of Clovis and Folsom occupation are reported from at least 11,200–10,900 ^{14}C yr B.P. and 10,900–10,200 ^{14}C yr B.P. (13,200–12,750 calibrated yr B.P. and 12,750–11,800 yr B.P.), respectively (Holliday, 2000), and Clovis occupation is documented as far back as 13,500 yr B.P. (Haynes et al., 1999). There is a lack of agreement as to the climate during the Clovis and Folsom occupations; evidence supports both a drier Clovis period relative to Folsom (Haynes et al., 1999) and a Folsom drought (Holliday, 2000). The middle Ållerød to early Younger Dryas, which best corresponds to Clovis occupation in the southwestern United States, was overall drier by our interpretation and therefore consistent with the presence of prehistoric Clovis wells at 13,500 yr B.P. (Haynes et al., 1999). Drier climate also compliments an explanation that climate change played a role in the extinction of some megafauna, such as the mammoth, in the southwestern United States (Haynes et al., 1999). Recent models predict human-driven megafaunal mass extinction for this period without invoking climate change (Alroy, 2001). However, an apparent warming and drying trend after the Last Glacial Maximum in the study area resulted in important faunal and floral changes (Harris, 1997) prior to human colonization. These changes likely stressed the Pleistocene megafaunal populations. An overkill explanation for megafaunal mass extinction is more realistic during an arid interval. The beginning of the Folsom culture coincides with drier conditions by our interpretation (relative to 20 ka, 14 ka, and 12.5–10.5 ka), which may explain evidence for the Folsom drought (Holliday, 2000), but we interpret an increasingly wetter Folsom time from beginning to end for the southwestern United States.

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