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VARIABLE CALCITE DEPOSITION RATES AS PROXY FOR PALEO-PRECIPITATION DETERMINATION AS DERIVED FROM SPELEOTHEMS IN CENTRAL FLORIDA, U.S.A.

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Abstract: Deposition rates derived from speleothems have been shown to be a useful paleoclimatic proxy. Past studies have shown that the most common climatic parameter measured by variable deposition rates is precipitation, where increased precipitation leads to increased calcite deposition. This was the premise of our study, where three Floridian stalagmites' deposition rates were measured and compared to paleohydrologic indicators taken from the sample or from other regional records. Deposition rates were measured by determining the volume of calcite precipitated between TIMS U-series dates ($mm^3\ yr^{-1}$), thereby accounting for morphological changes on the stalagmite over its depositional history. Most prior research relied on a simple linear interpolation between known ages to calculate rate ($mm\ yr^{-1}$). Results show three distinct periods of increased deposition for our stalagmites centered on 2.0, 1.25 and 0.5 ka BP. A comparison with Mg/Ca and Sr/Ca ratios and calcite deposition tentatively shows elevated elemental ratios during the three aforementioned periods. Elevated trace element ratios have been shown to be correlated with increased residence time of percolation waters in the overlying bedrock above caves and consequently decreased rainfall. To corroborate this finding, paleo-precipitation records from Little Salt Spring, Florida and Lake Miragoane, Haiti, were examined for coeval arid periods with our stalagmites. Both records do possess similar dry periods and provide added support that the region experienced periods of abrupt aridity over the last two millennia. The combined effect of a change in the mean position of the Intertropical Convergence Zone and the easterly winds associated with the North Atlantic High appear to be the major causes for these times of aridity.

INTRODUCTION

The deposition rates of speleothems can provide information about paleoclimatic variations, including precipitation, temperature, and soil activity, above a cave (Kaufmann and Dreybrodt, 2004; White, 2004). The rate of speleothem deposition is determined by soil carbon dioxide concentration, drip rate, and temperature, all of which are climate related and can affect the rate and shape of deposition (Dreybrodt, 1999). Hiatuses in a speleothem can indicate periods of climate change that include glacial periods, droughts, and changes in the hydrologic pattern of water flow. Faster deposition rates can be indicative of a warmer, wetter climate in the area, whereas slower deposition rates can result from cooler, drier conditions above the cave (Hennig et al., 1983; Musgrove et al., 2001; van Beynen et al., 2004).

The deposition rate of speleothems is a function of supersaturation (P_{CO_2}) of percolation waters and drip rate (rainfall amount) (Baker et al., 1998). The deposition rate of stalagmites can then be used as a paleo-environmental proxy for surface precipitation (Baker et al., 1993; Genty and Quinif, 1996; Holmgren et al., 1999; Qin et al., 1999). The determination of speleothem deposition rates has evolved to a high level of accuracy due to radiogenic dating methods, such as U-series TIMS mass spectrometry (Li et al., 1989; Dorale et al., 1992; Gascoyne, 1992; Musgrove et al., 2001). Through the use of accurate U/Th dates combined with speleothem lengths, deposition rates can be calculated with high precision, also providing evidence of hiatuses and deposition rate variability (Dreybrodt, 1999).

The purpose of this study is to develop and improve the understanding of the paleoclimate of Florida, with emphasis on whether speleothems can record hydrologic responses to changing atmospheric circulation patterns that affect the Florida Peninsula. The approach taken in this study was to measure shifts in speleothem deposition rate and determine the paleoclimatic significance of those shifts. Hence, we tested the following hypothesis: Increased deposition rates derived from speleothems are indicative of wetter conditions above the cave.

To test such a hypothesis requires an accurate chronology of these changes in calcite precipitation rate. Uranium-series disequilibria dating is the method used here to achieve this goal. Many studies have demonstrated that the speleothems provide reliable chronologies using the U-

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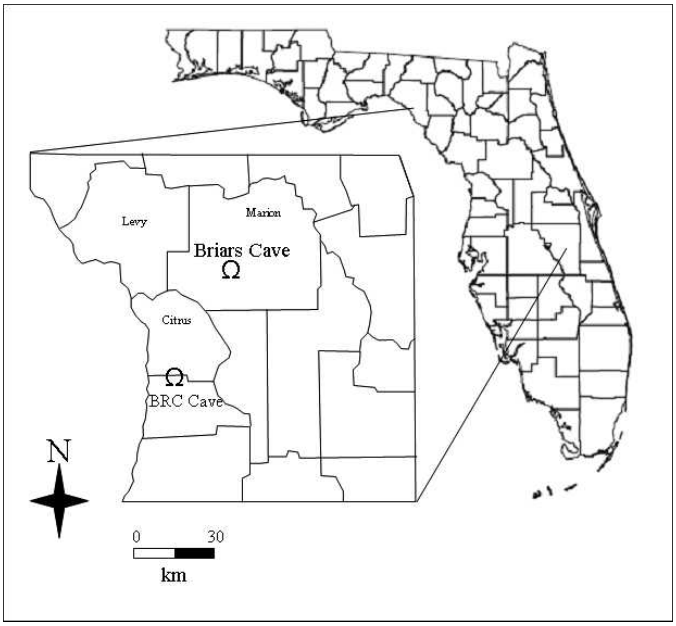

Figure 1. Location of study sites, Briars Cave and Brown Rat Cave, in relation to one another.

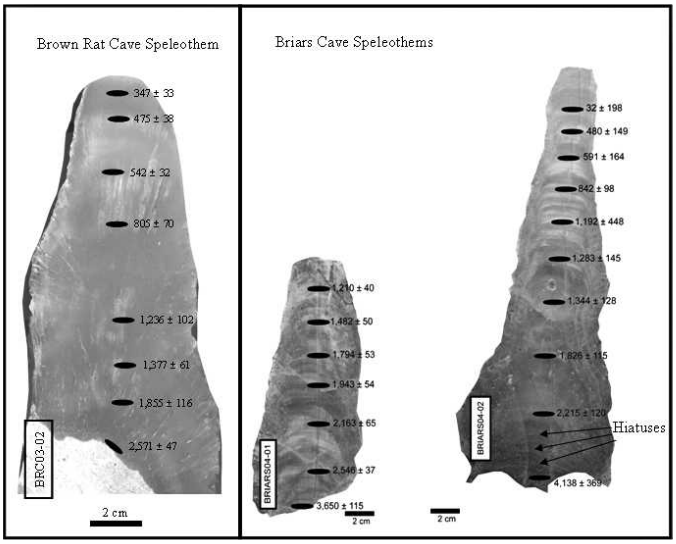

Figure 2. Photographs of the three speleothems used in this study.

series method (Harmon et al., 1978; Dorale et al., 1992; Gascoyne, 1992; Frumkin and Stein, 2004; Lachneit et al., 2004; Polyak et al., 2004). To fully address the hypothesis, the volume of calcite precipitated between these dates for multiple stalagmites will determine the variable deposition rate for each speleothem.

STUDY AREA

The study area consists of two caves, Brown Rat Cave (BRC), in Hernando County, and Briars Cave in Marion County, both in Florida (Fig. 1). They are located in the Brooksville Ridge section of the Ocala Arch that contains sinkholes, dry karst valleys, and interfluvial hills (Reeder and Brinkmann, 1998). The geology in the region is dominated by a series of carbonates that include the Eocene Ocala (location of both caves) and Oligocene Suwannee Limestones, which are unconformably overlain by the Hawthorn Group characterized by carbonates interspersed with siliclastics and phosphorite redeposition forming admixtures with dolomite, quartz sand, and Mg-rich clays (Scott, 1997). Approximately two meters of Pleistocene-aged quartz sands overlie these units in most parts of the region, although they drain rapidly.

With a length of ~1 km, BRC in Brooksville Ridge is one of the longest dry caves in Florida, and has a single, man-made entrance. Consequently, relative humidity levels in the cave would have been at ~100% until the entrance was created. The cave developed within the Ocala Limestone, and the vegetation above the cave is characterized as hardwood hammocks populated by oak, hickory and maples (Armstrong et al., 2003). The average temperature of the Brooksville Ridge area is 21.3 °C, and the average total precipitation is 1356 mm per year (Southeast Regional Climate Center). The stalagmite BRC03-02 was collected from this cave, which does not flood during hurricanes (as in Hurricanes Jeanne and Frances of 2004) or thunderstorms.

Briars Cave is located on the southern outskirts of Ocala. The cave underlies a low hill between two sinkholes. Briars Cave trends NE-SW and consists of a dry upper level and a partially flooded lower passage (Florea et al., 2003). The cave is approximately 1 km long, making it one of the longest caves in the state of Florida, with only one small tight entrance. The vegetation in the vicinity of the cave is characterized by hardwood species, including oak. The average temperature of Marion County is 22 °C, and the average annual precipitation is 1330 mm (Southeast Regional Climate Center). Two stalagmite samples, BRIARS04-01 and BRIARS04-02, were collected from the same area of the cave. A Hendy test (Hendy, 1971), undertaken for the latter of the two speleothems to determine whether the isotopes were deposited in equilibrium with the ambient waters, showed relative humidity levels in the cave would have remained close to ~100%.

METHODS

SAMPLE COLLECTION

Upon collection, the three stalagmites were cut vertically along their depositional axes, and polished to clarify the positioning of the lamina. Calcite samples of 250 mg were collected for U-series dating from all speleothems using a dental-bit equipped Dremel® tool. Samples were drilled at approximately 20–30 mm intervals along the growth axis of the stalagmite (Fig. 2). Exactly equal increments could not be attained in instances where the potential sampling area possessed a small void, or a dramatic color change or possible dirty calcite. We tried to sample from clear, homogenous calcite, which could not be achieved at a predetermined distance from the stalagmite base.

U-SERIES DATING

Successful dating of speleothems by U/Th methods depends on satisfying three criteria: 1) the specimen must contain a measurable amount of uranium (>0.02 ppm) and thorium; 2) the specimen must contain negligible initial ^{230}Th. This can be measured through the presence of the isotope ^{232}Th because it will be present in any thorium-bearing minerals that may occur in the insoluble detritus, but is not part of the decay chain; and 3) the specimen must not have undergone dissolution and re-crystallization that would alter the initial U/Th isotopic composition (Latham and Schwarcz, 1992; White, 2004).

The samples were analyzed at the Radiogenic Laboratory at the University of New Mexico. U and Th are measured on a Micromass Sector 54 thermal ionization mass spectrometer with a high-abundance sensitivity filter (Lachniet et al., 2004). All isotopes of interest were measured on an ion-counting Daly multiplier with abundance sensitivity in the range of 20 ppb at one mass unit in the mass range of U and Th, requiring very little background correction, even for samples with large ^{232}Th content. U isotopic standards, such as NBL-112, were measured along with samples. Typical analytical uncertainties are in the range of 0.2% for U isotope composition, similar or somewhat lower precision for Th, depending on the age and size of the sample measured. A detailed account of the technique can be found in Polyak and Asmerom (2001).

DEPOSITION RATES

When calculating deposition rates, it is important to consider that the speleothem morphology is not a constant linear relation (Franke, 1965; Curl, 1973; Gams, 1981; Baldini, 2001). Because the shape of the stalagmite can vary significantly over its depositional history, we calculated the deposition rates as a volume and not simply linear distance of calcite deposition between known ages. This approach of measuring speleothem deposition rate is similar one taken by Baldini (2001). Half of the stalagmite was photocopied to have a one-dimensional picture of the sample. Deposition lines were draw onto the copy to mark the different visible layers between the speleothem. Because the stalagmites were already dated, each known date was marked on the photocopy. With the dates and the exact location of them on the speleothem, a quantitative approach was applied. We used the formula of the frustum of a cone

$$V = \frac{1}{3}\pi h(r^2 + rR + R^2) \tag{1}$$

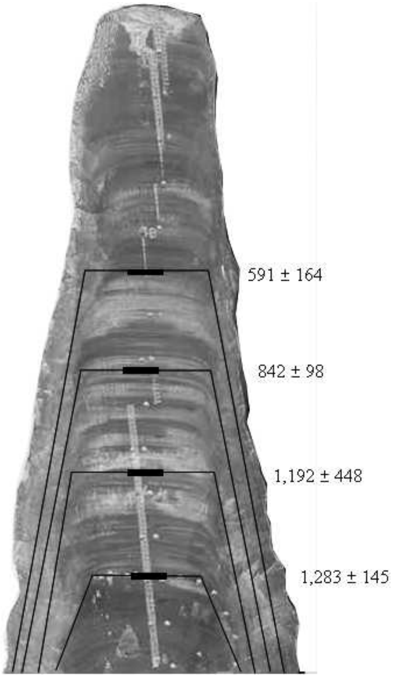

Figure 3. Diagram showing how the frustum of a cone is fitted to the growth layers for part the upper portion of BRIARS04-02.

to calculate the volume (mm^3) of calcite deposited between dated horizons. Figure 3 shows how the cross-section of the frustum of a cone is fitted to a portion of BRIARS04-02 between known dates. On occasion, to replicate the deposition between two dates, several different sized frustums had to be used. To calculate the deposition rate (calcite deposition), the volume of calcite was divided by the time of deposition (mm^3 yr^{-1}).

RESULTS

U-SERIES DATING

The entire suite of TIMS U-series dates for all three speleothems used in this study is presented in Table 1. All ages are reported as years before present. The speleothems meet all three criteria mentioned above. The uranium and thorium levels are sufficient for dating. All Th/U ages are in correct stratigraphic order (Fig. 4). This result suggests that all the speleothems remained closed systems (i.e., no dissolution or recrystallization) for their entire depositional histories; hence, no uranium migration occurred within any speleothem. The ^{230}Th/^{232}Th ratios (Table 1) are indicative of very little detrital Th being present in any of the samples. Clean calcite ^{230}Th/^{232}Th ratios are generally greater than 50, and the values for BRC and BC samples are well above that threshold value, some values approaching 1,136.

Depositional trends for each speleothem show a linear relationship for the majority of the growth period (Fig. 4). Only during the first 30 mm did each speleothem deviate

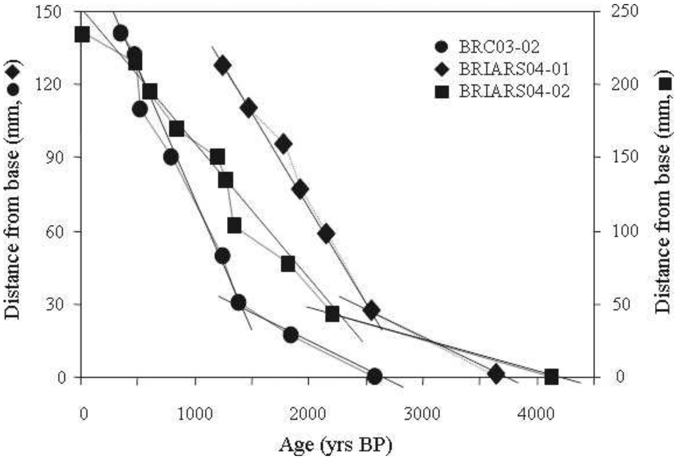

Figure 4. Age vs. depth plot for the Floridian speleothems. Solid lines show the linear trend for each speleothem.

from this linearity. Such deviation represents a slower deposition rate, which may be caused by the available calcite being spread over a larger area. For the carrot type stalagmites used in this study, such an initial slower deposition rate is common.

DEPOSITION RATES

The deposition rates calculated using the U-series dates are presented in Table 2. Eight dates in stratigraphic order were used to develop deposition rates for sample BRC03-02 (Fig. 5a). This stalagmite grew from around 2.6 to 0.35 ka BP. The average deposition rate (calcite deposition) for this sample was 375 mm^3 yr^{-1}. In the early stage of accumulation, the deposition rate was 63 mm^3 yr^{-1}, a very low calcite accumulation for the speleothem. A significant change occurred from 1.8 to 1.3 ka BP when the rate increased with a deposition rate of 337 mm^3 yr^{-1}. A continued increase in deposition rate occurred from 1.3 to 1.2 ka BP, when calcite accumulated at 326 mm^3 yr^{-1} (Fig. 5a). At around 0.5 ka BP, the deposition rate increased considerably, being close to 1164 mm^3 yr^{-1}, the highest rate measured in any speleothem in this study.

Speleothems collected from Briars Cave were also analyzed for deposition rates. For BRIARS04-01 seven dates in stratigraphic order establish that the speleothem grew from 3.6 to 1.2 ka BP (Table 2). The average rate of deposition for the speleothem was 224 mm^3 yr^{-1} (Fig. 5a). The lowest rate was from ~3.6 to 2.5 ka BP, attaining a value of 40 mm^3 yr^{-1}. The stalagmite deposition from 2.1 to 1.9 ka BP increased considerably, averaging ~385 mm^3 yr^{-1}, the highest rate for this speleothem, although it was followed by another rapid period of calcite deposition from 1.9 to 1.8 ka BP, with a rate of 366 mm^3 yr^{-1}. A decrease in deposition rate occurred after 1.8 to 1.2 ka BP where the values diminished to nearly half of the previous ones.

Stalagmite BRIARS04-02 has ten dates in stratigraphic order showing that it has grown continuously from 4.5 ka BP until the present (Table 2). However, the youngest date of 32 years ±198 has such a high error compared to the actual date (Fig. 5a) that it will not be included in any further analysis. The average rate of deposition for this sample was 542 mm^3 yr^{-1}, the highest of all the speleothems. A slow deposition rate of 51 mm^3 yr^{-1} was recorded at the base of the stalagmite from 4.1 to 2.2 ka BP. However, with only two dates delineating this 2,000 year period, it is not possible to identify any periods of more rapid calcite deposition that may have occurred during speleothem growth. BRIARS04-02 contains a few possible hiatuses during this period, which would account for the low deposition rates. Three distinct horizons are present within this zone that are not found in any other intervals for this or the other speleothems. Only with more frequent dating could the timing of these potential hiatuses be resolved. At approximately 2.2 to 1.8 ka BP, a significant increase in deposition rate was recorded; this is consistent with an increased deposition rate recorded at the same time for BRIARS04-01. The rate was the highest from 1.35 to 1.3 ka BP, attaining a value of 972 mm^3 yr^{-1}. Another major change was recorded from 0.6 to 0.5 ka BP, with a deposition rate of 915 mm^3 yr^{-1}: this increase in deposition rate was also recorded in the speleothem BRC03-02.

As aforementioned, most speleothem studies examining deposition rates calculate the rate in mm yr^{-1}, as in the number of mm calcite deposited between each date. To show how this technique may give an unrealistic impression of how quickly a speleothem was deposited, Figure 5b allows a comparison between the volumetric (mm^3 yr^{-1}) and linear (mm yr^{-1}) methods. It is readily apparent that the linear method tends to exaggerate deposition rate as seen in BRC03-02 at ~0.5 ka BP and for BRIARS04-02 at ~1.3 ka BP. The volumetric technique accentuates episodes of augmented deposition but also periods that are not apparent in the linear method. For example, BRC03-02 has a noticeable increase at ~1.3 ka BP that cannot be seen in Figure 5a.

DISCUSSION

Our initial hypothesis stated that increased deposition rates were indicative of wetter conditions above the cave. This hypothesis is derived from previous paleoclimate studies using speleothems that showed the rate of deposition is controlled by the amount of precipitation falling above the cave, such that an increase in precipitation leads to more speleothem growth (Hennig et al., 1983; Lauritzen and Lundberg, 1999). However, not all studies support this conclusion, with some showing that drier conditions can lead or have led to an increase in deposition rate (Denniston et al., 1999; Fairchild et al., 2000). While our hypothesis proposes the first scenario, we tested it by correlating the deposition rates outlined above with trace

Table 1. U-series dates for Floridian speleothems. All ages assuming a $^{230}Th/^{232}Th$ initial ratio of 10 ± 2 ppm.

Sample	Distance from base (mm)	U (ppm) Error × 10^{-3}	Th (ppm) ×10^{-3} Error × 10^{-5}	$^{230}Th/^{232}Th$	$^{234}U/^{238}U$ Error × 10^{-3}	$^{230}Th/^{238}U$ Error × 10^{-3}	Uncorrected Age (yr B.P.)	Corrected Age (yr B.P.)
Briars04-01	130	1.031 ± 0.6	8.4 ± 0.1	233.8 ± 3.9	1.008 ± 0.5	0.012 ± 0.1	1,263 ± 38	1,210 ± 40
	110	1.249 ± 1.0	2.5 ± 0.2	1136.1 ± 102.2	1.010 ± 0.5	0.014 ± 0.1	1,495 ± 50	1,482 ± 50
	95	1.201 ± 0.7	5.5 ± 0.2	601.5 ± 21.4	1.012 ± 0.3	0.017 ± 0.1	1,824 ± 53	1,794 ± 53
	77	1.353 ± 1.0	9.1 ± 0.2	446.1 ± 8.3	1.013 ± 0.4	0.018 ± 0.1	1,987 ± 49	1,943 ± 54
	58	1.030 ± 0.6	3.4 ± 0.2	989.2 ± 45.1	1.012 ± 0.3	0.020 ± 0.1	2,185 ± 65	2,163 ± 65
	27	0.953 ± 0.7	6.0 ± 0.2	622.3 ± 18.3	1.017 ± 0.7	0.024 ± 0.1	2,587 ± 36	2,546 ± 37
	0	1.193 ± 0.6	43.9 ± 0.5	158.7 ± 2.0	1.018 ± 0.2	0.036 ± 0.1	3,891 ± 105	3,650 ± 115
Briars04-02	235	0.474 ± 0.2	15.3 ± 0.3	11.5 ± 0.2	1.004 ± 0.4	0.002 ± 0.2	246 ± 167	32 ± 198
	215	0.399 ± 0.2	16.1 ± 0.2	27.9 ± 0.3	1.004 ± 0.4	0.007 ± 0.1	748 ± 65	480 ± 149
	195	0.399 ± 0.2	13.6 ± 0.2	36.1 ± 0.6	1.008 ± 0.5	0.008 ± 0.1	817 ± 120	591 ± 164
	170	0.381 ± 0.2	9.5 ± 0.1	60.3 ± 0.9	1.002 ± 0.4	0.009 ± 0.1	1,009 ± 51	842 ± 98
	150	0.403 ± 0.2	10.2 ± 0.2	81.2 ± 1.9	1.015 ± 0.4	0.013 ± 0.4	1,359 ± 441	1,192 ± 448
	135	0.418 ± 0.3	9.9 ± 0.2	90.6 ± 1.7	1.002 ± 0.6	0.013 ± 0.1	1,441 ± 122	1,283 ± 145
	103	0.349 ± 0.2	10.6 ± 0.2	75.9 ± 1.1	1.004 ± 0.4	0.014 ± 0.1	1,546 ± 78	1,344 ± 128
	78	0.285 ± 0.2	4.2 ± 0.2	193.4 ± 7.1	1.002 ± 0.6	0.017 ± 0.1	1,925 ± 104	1,826 ± 115
	43	0.346 ± 0.2	6.8 ± 0.2	178.6 ± 5.1	1.004 ± 0.4	0.021 ± 0.1	2,345 ± 100	2,215 ± 120
	0	0.607 ± 0.3	36.1 ± 0.3	112.6 ± 1.1	1.006 ± 0.4	0.041 ± 0.3	4,553 ± 313	4,138 ± 369
BRC03-02	141	0.897 ± 0.3	2.9 ± 0.2	184.4 ± 34.1	1.068 ± 0.3	0.004 ± 0.1	367 ± 32	347 ± 33
	132	0.972 ± 0.4	3.9 ± 0.3	202.4 ± 17.0	1.075 ± 0.3	0.005 ± 0.1	500 ± 36	475 ± 38
	110	1.102 ± 0.5	4.6 ± 0.3	211.8 ± 12.5	1.069 ± 0.6	0.005 ± 0.1	550 ± 29	524 ± 32
	90	1.111 ± 0.5	8.3 ± 0.3	182.9 ± 54.0	1.071 ± 0.6	0.008 ± 0.1	851 ± 66	805 ± 70
	50	0.928 ± 0.2	17.0 ± 0.3	118.1 ± 2.1	1.073 ± 0.7	0.013 ± 0.1	1,350 ± 85	1,236 ± 102
	31	0.825 ± 0.1	6.3 ± 0.2	299.6 ± 9.6	1.076 ± 0.4	0.014 ± 0.1	1,424 ± 56	1,377 ± 61
	17	0.839 ± 0.6	20.7 ± 0.3	130.2 ± 1.9	1.075 ± 0.4	0.020 ± 0.1	2,007 ± 88	1,855 ± 116
	0	1.033 ± 0.5	5.1 ± 0.1	849.9 ± 19.0	1.080 ± 0.3	0.026 ± 0.1	2,601 ± 45	2,571 ± 47

Table 2. Deposition rates for Floridian speleothems. * Date of 32 years ±198 has been deleted from the dataset due to unacceptable error relative to age.

Time Intervals (years)	Time of Deposition (years)	Volume of Calcite (mm^3)	Calcite Deposition (mm^3/yr)
BRC03-02 (2571-1855)	716	44829	63
BRC03-02 (1855-1377)	478	160898	337
BRC03-02 (1377-1236)	141	45900	326
BRC03-02 (1236-805)	431	67057	156
BRC03-02 (805-524)	281	65220	232
BRC03-02 (524-475)	49	57022	1164
BRC03-02 (475-347)	128	65313	510
BRC03-02 (347-0)	347	73788	213
BRIARS04-01 (3650-2546)	1104	43649	40
BRIARS04-01 (2546-2163)	383	76308	199
BRIARS04-01 (2163-1929)	220	84738	385
BRIARS04-01 (1929-1794)	149	54585	366
BRIARS04-01 (1794-1482)	312	54333	174
BRIARS04-01 (1482-1210)	272	49388	182
BRIARS04-02 (4138-2215)	1923	98059	51
BRIARS04-02 (2215-1826)	389	309237	795
BRIARS04-02 (1826-1344)	482	106266	220
BRIARS04-02 (1344-1283)	61	59322	972
BRIARS04-02 (1283-1192)	91	79194	870
BRIARS04-02 (1192-842)	350	93840	268
BRIARS04-02 (842-591)	251	115830	461
BRIARS04-02 (591-480)	111	101601	915
BRIARS04-02 (480-0)*	480	52969	110

elements extracted from one of the speleothems and with other paleo-precipitation proxy data from the region.

The first approach is to try to reject the hypothesis by comparing trace elements with deposition rates for the same speleothem. Fairchild et al. (2000) demonstrated a link between Mg/Ca and Sr/Ca ratios in the dripwaters in two caves and the residence time of water in the bedrock above the cave. Longer residence times will lead to enhanced dolomite dissolution of the bedrock, thereby augmenting Mg and Sr levels. The Hawthorn Group, which lies above Briars Cave, has Mg rich clays and Sr bearing siliciclastics and dolomite interspersed within the carbonates (Scott, 1997). Decreased rainfall above the cave promotes longer residence times of percolating waters. Taking these findings and applying them to our study, Mg/Ca and Sr/Ca ratios and deposition rates were compared for BRIARS04-02 (Fig. 6) as this is currently the only speleothem examined in this study with a trace element record. While we do not have the same high resolution of the trace elements for the deposition rates, it is apparent that periods of increased calcite deposition coincide with higher Mg/Ca and Sr/Ca ratios, especially during periods centered on 2.0 and 1.25 ka BP. This result then suggests that the deposition rate is negatively related to rainfall, causing us to reject our initial hypothesis.

The reason for an increase in deposition rate during drier periods is probably due to the increase in the calcite saturation state of the seepage waters. A slower flow of water through the bedrock would allow more time for dissolution of the bedrock. Within the cave, a decrease in drip rate would lead to a thinner film of water on the speleothem and more degassing. Both situations would increase the deposition rate for the speleothem. This agrees with Fairchild et al. (2000), who found that increased calcite precipitation in the cave occurred during the winter when the recharge to the cave was reduced due to the frozen ground. Baldini (2001) provides a different explanation whereby a decrease in the drip rate during drier periods allows more CO_2 degassing on the stalactite above the stalagmite, thereby increasing deposition rates on the stalactite and decreasing deposition on the paired stalagmite. Determining which of these explanations applies to the central Floridian stalagmites requires comparison of deposition rate with regional paleo-precipitation records.

Little Salt Spring (LSS) is located within 100 km of our study sites and Alvarez Zarikian et al. (2005) interpreted variations in the stable oxygen isotope ratio ($\delta^{18}O$ values) of *Cytheridella ilosvayi* (an ostracod species) as measures of changing precipitation. More negative $\delta^{18}O$ values corresponded to drier periods and conversely, more positive values indicated wetter conditions. Figure 7 shows a comparison between their $\delta^{18}O$ record and our deposition rates from BRIARS04-02. It is readily apparent that during more negative phases in the $\delta^{18}O$ (dry periods), deposition

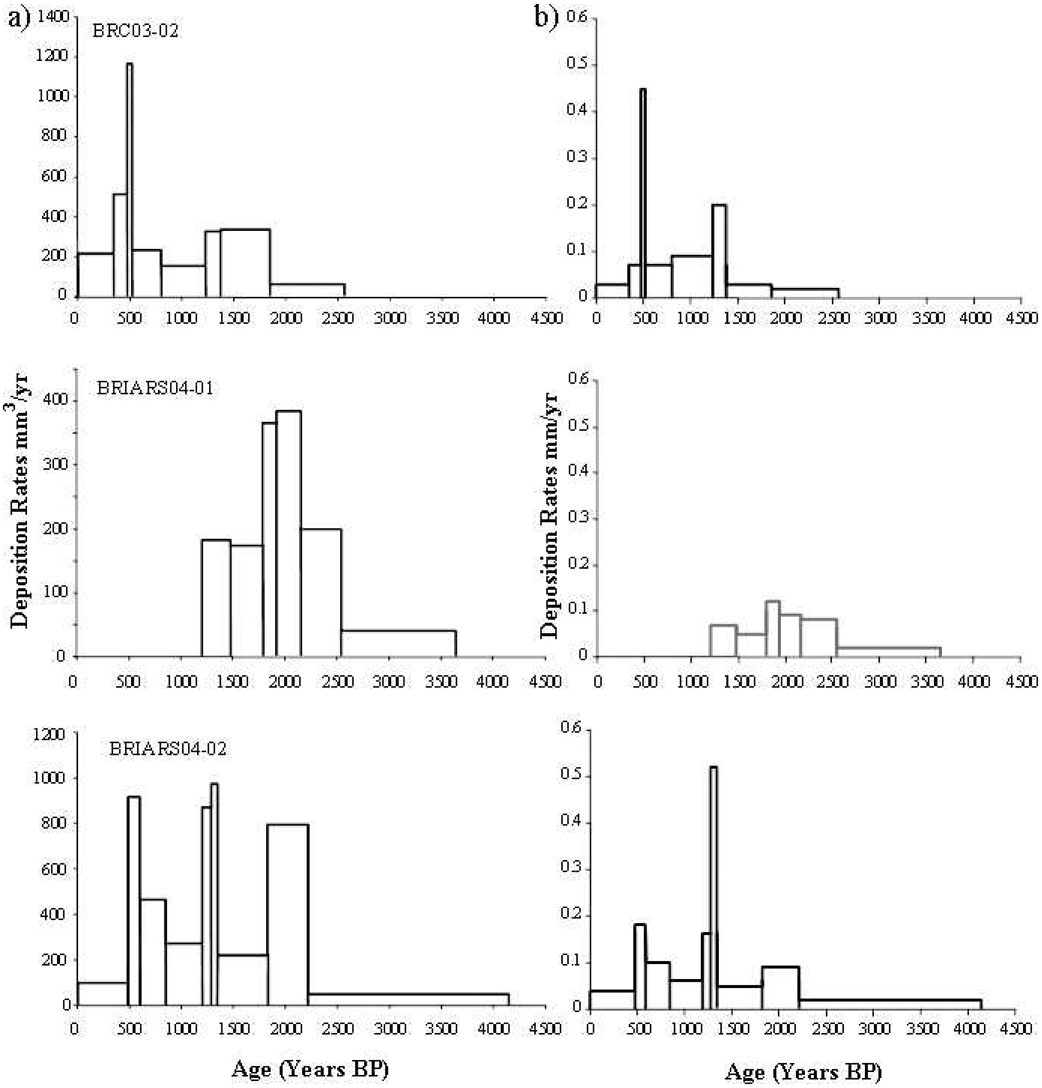

Figure 5. a) Variable deposition rates (mm^3 yr^{-1}) for each stalagmite. Note the different timescales on the y-axes. b) Extension rates (mm yr^{-1}) for each speleothem using the traditional linear method.

rates for BRIARS04-02 increased and during more positive δ^{18}O intervals, calcite precipitation decreased. LSS attained maximum aridity for the late Holocene between 2.6–2.0 ka BP (Alvarez Zarikian et al., 2005), corresponding with the first major dry period in the BRIARS04-02 speleothem record. In all, the three phases of aridity in LSS during the last 3.0 ka coincide with increased calcite deposition. This provides more evidence for refuting our initial hypothesis and suggests that for this particular study, decreased precipitation leads to an increase in speleothem deposition rate. It should be noted that our resolution of dating from 2.5 to 4.2 ka BP precludes any detailed comparison of trends, although the other low deposition rates do appear to coincide with more positive δ^{18}O values in LSS.

Another regional comparison of paleo-precipitation can be made with Lake Miragoane, Haiti (Hodell et al., 1991). δ^{18}O values from ostracodes found in the sediments reflect changes in precipitation/evaporation (P/E) ratios. More negative δ^{18}O values show a P/E increase indicating higher lake levels. Figure 5 shows that Lake Miragoane recorded the same arid period centered on 2.0 ka as the speleothem and LSS records. The wet periods before 2.0 ka and later at ~1.0 ka as measured in the other records are also found in Haiti. From these two paleo-records, it appears that the Fairchild et al. (2000) explanation holds for our Floridian speleothems. However, we cannot irrefutably discount a potential contribution of the Baldini (2001) degassing mechanism.

Paleoclimatic Interpretation

With the number of dates we have for each speleothem, the best resolution attained is ~100 years. Consequently we cannot discuss decadal-scale climate influence, only

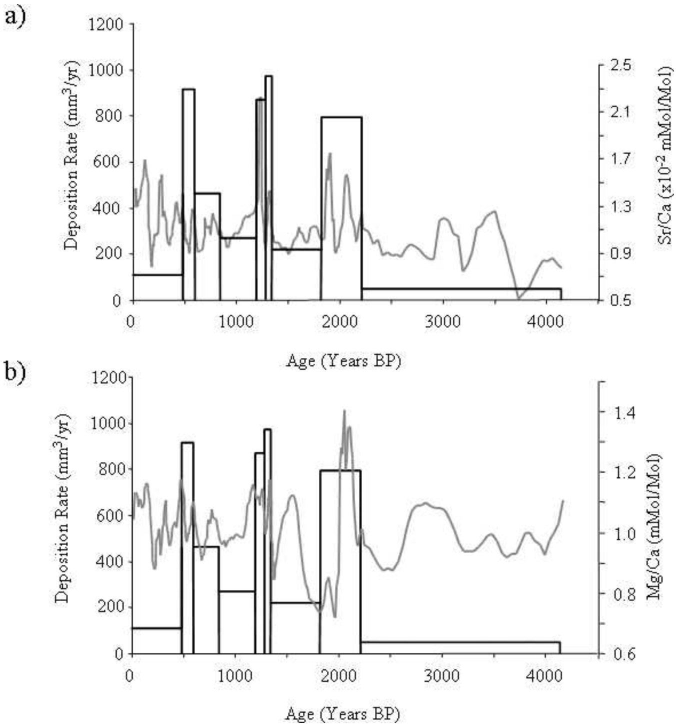

Figure 6. Comparison between the trace elements and deposition rates for BRIARS04-02. a) Five point running mean applied to the Sr/Ca ratios, b) Five point running mean applied to the Mg/Ca ratios.

those in the centennial timeframe. This excludes the Atlantic Multidecadal Oscillation (AMO - Enfield et al., 2001). During the cold phase of the AMO, Central Florida experiences drier conditions, with a period of 60–80 years. However, this is of shorter duration than can be resolved by our records. Another factor that produces drought in the region is the western extension of the North Atlantic High (NAH), which directs subsiding air into Florida leading to reduced rainfall. However, at other times the NAH is positioned further to the east, and can also direct warm moist Caribbean air into the peninsula, increasing rainfall.

It has been suggested that increased transport of Caribbean surface waters and moisture into the Gulf of Mexico associated with the northward migration of the average position of the ITCZ would influence precipitation in the region (Hodell et al., 1991; Poore et al., 2003). The more northerly position of the ITCZ would enhance easterly winds bringing precipitation to Haiti (Hodell et al., 1991) and the Gulf of Mexico (Poore et al., 2003). Consequently, a southward shift in the ITCZ mean position would produce periods of aridity. These shifts were proposed to have occurred over a millennial timescale. The similarities of the deposition rates from the Floridian speleothems and the LSS - Haiti paleoprecipitation interpretations (Fig. 7) appear to record this regional atmospheric-ocean influence suggested by Poore et al. (2003). The easterly winds discussed by these authors are generated by the NAH and consequently provide some insight into how this high pressure system has affected Florida's climate during the late Holocene.

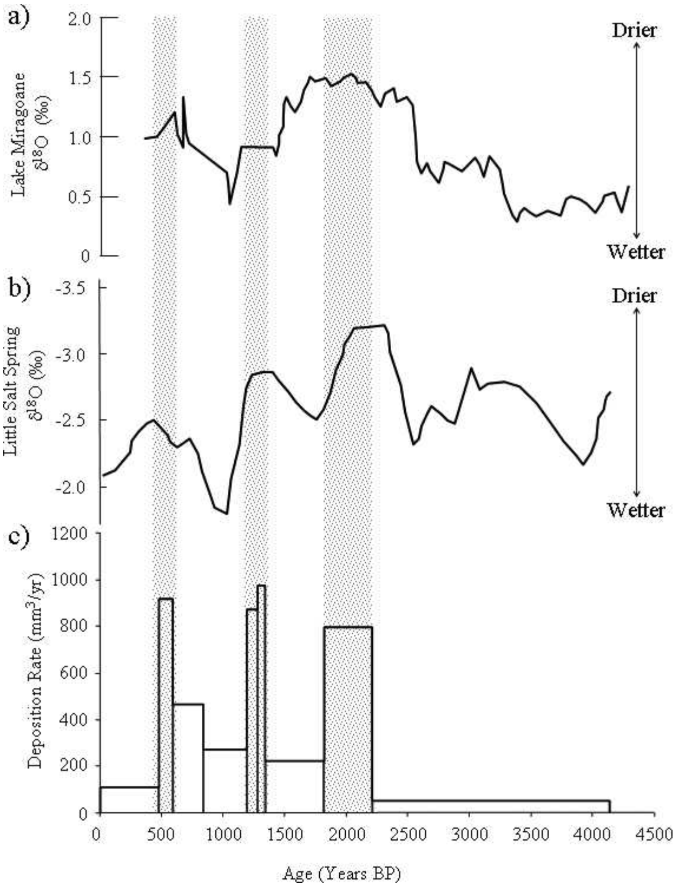

Figure 7. Regional paleoprecipitation comparison for a) δ^{18}O value Lake Miragoane record, Haiti (5 point running mean); b) δ^{18}O value record from Little Salt Spring, Florida; c) Deposition rates from BRIARS04-02. Shaded areas denote periods of aridity. Note that δ^{18}O values are plotted on an inverted axis.

CONCLUSIONS

By calculating the volume of calcite deposited between U-series dates, and dividing this by the years between those dates, a more realistic estimate of changing deposition rates can be achieved, as opposed to the method of merely measuring the millimeters of calcite deposited each year along the growth axis between known ages. This latter method does not recognize changes in the shape of the speleothem over time.

The results from our study suggest that for the speleothems examined, deposition rate is controlled by rainfall above the cave, but not in the accepted manner as suggested by Hennig et al. (1983), Gascoyne (1992) or Lauritzen and Lundberg (1999). They suggested wetter periods led to greater calcite precipitation. Our study appears to contradict that finding; periods of aridity increase the rate of speleothem growth. Such a result supports the research done by Fairchild et al. (2000). They found Mg/Ca and Sr/Ca ratios in cave calcite are negatively related to rainfall and our increased deposition rates correspond with periods of higher Mg/Ca and Sr/Ca ratios. A paleo-precipitation record from the region (Alvarez Zarikian et al., 2005) agrees with our periods of aridity in Central Florida. These periods of aridity are mostly caused by a southward shift in the mean position of the ITCZ and a weakening of the NAH easterly winds that direct warm water and moist air into the Northern Gulf of Mexico.

Future work will involve a calibration study of Briars Cave, measuring the Mg/Ca and Sr/Ca ratios in cave dripwaters and relating it to rainfall data above the cave to test if our explanation of the trace elements corresponds to that of Fairchild et al. (2000). Secondly, as more funds become available, we hope to improve the resolution of our deposition rate reconstruction with more U/Th dates.

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