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# An extended and higher-resolution record of climate and land use from stalagmite MC01 from Macal Chasm, Belize, revealing connections between major dry events, overall climate variability, and Maya sociopolitical changes

Pete D. Akers [a,*], George A. Brook [a], L. Bruce Railsback [b], Fuyuan Liang [c], Gyles Iannone [d], James W. Webster [e], Philip P. Reeder [f], Hai Cheng [g,h], R. Lawrence Edwards [h]

[a] Department of Geography, University of Georgia, Athens, GA 30602, USA
[b] Department of Geology, University of Georgia, Athens, GA 30602, USA
[c] Department of Geography, Western Illinois University, Macomb, IL 61455, USA
[d] Department of Anthropology, Trent University, Peterborough, ON, K9L 0G2, Canada
[e] United States Environmental Protection Agency [1], Atlanta, GA 30303, USA
[f] Bayer School of Natural and Environmental Sciences, Duquesne University, Pittsburgh, PA 15282, USA
[g] College of Global Environmental Change, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, PR China
[h] Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, USA

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ABSTRACT

The stalagmite MC01 was recovered from Macal Chasm cave on the Vaca Plateau of Belize in 1995, and an initial paleoclimate interpretation was published in 2007. Additional uranium-thorium ages have extended the paleoenvironmental record back from 3250 to 5250 cal yr BP, and the stable isotope ($\delta^{18}O$ and $\delta^{13}C$) record is dramatically improved by 660 new values. A series of major dry events (MDEs) evident in stable isotopes, ultraviolet-stimulated luminescence, and petrography began ~3100 cal yr BP, and the initiation of these events coincides with an increase in El Niño dominance and southern shift in the Intertropical Convergence Zone. Three MDEs, centered at 1750 cal yr BP (200 CE), 1100 cal yr BP (850 CE), and 850 cal yr BP (1100 CE) and found in other regional climate records, coincide with Maya sociopolitical changes. Residuals from regression of $\delta^{13}C$ versus $\delta^{18}O$ are interpreted as a proxy for maize cultivation and land clearing, with residual values gradually increasing at the start of Preclassic Period settlement (3950 cal yr BP/2000 BCE), peaking after 2250 cal yr BP (300 BCE) during major Maya development in the Late Preclassic and Classic Periods, and dropping to pre-Preclassic values after regional land abandonment (~850 cal yr BP/1100 CE). Regional Maya population growth and cultural expansion may have been aided by abnormally low precipitation variability, as stable isotope variability suggests the Late Preclassic through the Late Classic was the most stable precipitation regime of the past 4000 years. This additional research on MC01 complements other regional paleoenvironmental records that suggest that MDEs coincided with disruptions in Maya society from the Preclassic through the Postclassic Periods. Although it is clear that not all significant sociopolitical changes can be attributed to the MDEs, these events likely played an antagonistic role in social stability.

## 1. Introduction

A growing body of paleoenvironmental research has consistently provided evidence of a drying climate coincident with the Maya Late and Terminal Classic Periods (Table 1) and associated collapse of many Classic Maya polities between 1050 and 1200 cal yr BP (750–900 CE). This research ranges from initial findings in Yucatán lake sediment studies (Hodell and Curtis, 1995; Curtis et al., 1996; Hodell et al., 2005) to more recent evidence from other proxies including Mexican tree rings (Stahle et al., 2011), charcoal and human

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* Corresponding author at: Department of Geography, 210 Field St., Athens, GA 30602, United States.
*E-mail address:* pakers@uga.edu (P.D. Akers).

[1] Webster's views do not necessarily represent those of the United States Government or the U.S. Environmental Protection Agency, and this work is not a product of the U.S. Government or the EPA.

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**Table 1**
Mesoamerican chronological periods for the Vaca Plateau as referenced in this paper. The ages listed here are based upon sociopolitical changes observed in Vaca Plateau polities and centers (Iannone et al., 2014a; Schwake and Iannone, 2016). 'Present' in cal yr BP is defined as 1950 CE in this paper.

| Mesoamerican Period | Years (cal yr BP) | Years (CE/BCE) |
|---|---|---|
| Archaic | >3950 | >2000 BCE |
| Early Preclassic | 2850–3950 | 2000–900 BCE |
| Middle Preclassic | 2250–2850 | 900–300 BCE |
| Late Preclassic | 1700–2250 | 300 BCE–250 CE |
| Early Classic | 1400–1700 | 250–550 CE |
| Middle Classic | 1275–1400 | 550–675 CE |
| Late Classic | 1140–1275 | 675–810 CE |
| Terminal Classic | 1050–1140 | 810–900 CE |
| Early Postclassic | 750–1050 | 900–1200 CE |
| Late Postclassic | 350–750 | 1200–1600 CE |
| Modern | 350–present | 1600 CE–present |

remains in Belize (Hoggarth et al., 2014; Walsh et al., 2014), and speleothems across the Maya region in both Belize and Mexico (Webster et al., 2007; Medina-Elizalde et al., 2010; Kennett et al., 2012; Medina-Elizalde et al., 2016).

The nature of the Classic Maya political collapse and population center abandonment was complex and diverse, with different sites and regions experiencing effects at different times and intensities (Aimers, 2007; Kennett and Beach, 2013; Iannone, 2014). Variable human reactions to the sociopolitical changes during the Late and Terminal Classic Periods are a likely cause of many of these spatial and temporal differences, although local variations in climate may have also played a role (Aimers and Iannone, 2014). In addition to the Late to Terminal Classic decline, droughts have been suggested as causal agents for other Maya social and demographic changes, such as the 'Preclassic Abandonment' and the 'Middle Classic Hiatus' (Gill, 2000). This theory, which attributes all Maya sociopolitical changes to drought, has been challenged by many as being overly simplistic, deterministic, and ignorant of Maya resilience and adaptive strategies (Hansen et al., 2002; Aimers and Iannone, 2014; Dunning et al., 2014).

The Maya significantly altered the landscape to suit their needs and were aware of the sociopolitical needs and benefits of controlling scarce water resources. The growth and sustainment of high populations for centuries in the often water-stressed Maya lowlands suggests a highly climate-resilient society (Scarborough, 1998; Kennett and Beach, 2013; Beach et al., 2015); thus, any argument indicating climate as a causal agent in the Late to Terminal Classic decline requires well-dated and highly-detailed paleoclimate data for comparison with the timing of Maya sociopolitical changes (Kennett et al., 2012; Iannone et al., 2014b). Speleothems offer an excellent opportunity for paleoenvironmental work in the region due to their accurate and precise uranium-thorium (U-Th) dating (Cheng et al., 2000; Shen et al., 2002), multiple climate and environmental proxies (e.g., stable isotopes, petrography) (McDermott, 2004; Fairchild and McMillan, 2007; Railsback et al., 2013), and the relative abundance of caves in much of the Maya region (Reeder et al., 1996).

This paper reports on new data generated by more detailed and extensive sampling of stalagmite MC01 from the Vaca Plateau in Belize to further our understanding of the relationship between Maya sociopolitical changes and regional climate variations. Previous work by Webster et al. (2007) provided a paleoclimate record from MC01 covering the past 3300 years based largely on a high-resolution ultraviolet-stimulated luminescence (UVL) record that was buttressed by only 89 $\delta^{18}O$ and $\delta^{13}C$ values and constrained by 13 U-Th ages. The record presented here, designated MC01-E because it is a more extensive paleoclimate record, comes from the same stalagmite but covers the last 5300 years, adds eight new U-Th ages to the chronological model, and includes 660 new $\delta^{18}O$ and $\delta^{13}C$ values. This new higher-resolution and longer MC01-E record offers a more complete paleoenvironmental record for the Vaca Plateau that is comparable in stable isotope resolution to recently published Mesoamerican speleothem records (e.g., Kennett et al., 2012; Medina-Elizalde et al., 2010), provides a detailed look at climate changes during periods of Maya occupation, and places these climate changes in a longer Holocene context.

## 2. Regional setting and paleoclimate proxy controls

### 2.1. Study area

### 2.1.1. MC01 and Macal Chasm

The stalagmite MC01 (Fig. 1) was originally collected in 1995 CE from Macal Chasm, Cayo District, Belize (16.883°N, 89.108°W), by James W. Webster. MC01 measures 93.6 cm in height and was actively growing when collected. Macal Chasm has a 40 m deep vertical shaft entrance opening into a large (62 × 45 m) chamber, and MC01 was located in this chamber approximately 8 m southwest of the entrance shaft. Chamber temperatures recorded in three consecutive March visits averaged 21 °C with relative humidity ranging from 93 to 94% (Webster et al., 2007). Although MC01 likely experienced a wider range of environmental changes at its position near the entrance shaft than locations deeper within the cave, these varying conditions generally serve to amplify climate proxy variations regarding wet versus dry conditions. Additionally, proximity to the entrance shaft allowed for preservation of outside airborne dust settling on MC01, which was previously used as a dryness proxy in Webster et al. (2007). Since a quantitative precipitation isotope reconstruction was not the goal of this research, potential isotopic disequilibrium and kinetic fractionation due to entrance proximity was not judged to be a significant deterrent to research. However, the possible impact of kinetic fractionation is considered in the interpretation of stalagmite stable isotope values and addressed in Section 2.3.4.

Macal Chasm is located on the Vaca Plateau, a karst region of uplifted Campur Formation limestone (Reeder et al., 1996) in west-central Belize (Fig. 2). The plateau ranges in elevation from 450 to 600 m and has little to no running surface water (Chase et al., 2011). Although the region is heavily forested, the karst terrain exacerbates dry season water stress and many plant species experience leaf drop in the dry season (Penn et al., 2004). Crops grown by the Maya on the karst slopes would have been rain-dependent (Chase et al., 2014; Dahlin and Chase, 2014) and also would have very likely suffered enhanced drought stress during drier times similar to modern vegetation.

### 2.1.2. Vaca Plateau climate

Satellite rainfall estimates from the National Aeronautics and Space Administration (NASA) Goddard Earth Sciences Data and Information Services Center (GES DISC) Giovanni online data system and Tropical Rainfall Measuring Mission (TRMM) satellite data (Kummerow et al., 1998; Acker and Leptoukh, 2007; Huffman et al., 2007) indicate high annual rainfall (mean: 2095 mm) with significant interannual variability over the period from 1998 to 2014 (Fig. 3). The rainfall is strongly seasonal: the height of the wet season (June–October) averages >250 mm rainfall per month while the height of the dry season (February–April) averages <65 mm rainfall per month. A midsummer dry spell, common in Central America and the Caribbean, manifests as a reduction in wet season precipitation after an early season peak, but the exact timing, magnitude, and duration of this dry spell varies from year to year. Although precipitation generally recovers for a secondary peak in the late wet season, the midsummer dry spell can pose a significant threat to crop production (Magaña et al., 1999). Beyond this temporal variability of precipitation, the Vaca Plateau also has great spatial variability in precipitation, with many rain events localized to individual valleys and generally exhibiting an unpredictable climate (Penn et al., 2004).

Modern droughts in the Maya region are commonly associated with the El Niño phase of the El Niño-Southern Oscillation (ENSO) (Giannini et al., 2000; Haug et al., 2001; Wang, 2007). El Niño decreases regional