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Calcite raft geochemistry as a hydrological proxy for Holocene aquifer conditions in Hoyo Negro and Ich Balam (Sac Actun Cave System), Quintana Roo, Mexico

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ABSTRACT

Two cores from calcite rafts deposits located in Cenote Ich Balam and Hoyo Negro were dated and analyzed for $^{87}Sr/^{86}Sr$, $\delta^{18}O$, $\delta^{13}C$, Sr/Ca and Cl/Ca. The geochemical records show changing aquifer salinity spanning the last ~ 8.5 cal kyrs BP and interrelationships with Holocene climate trends (wet and dry periods). During the wet mid-Holocene, the salinity of the meteoric Water Mass (WM; at 7.8–8.3 cal kyrs BP) was relatively high at 1.5–2.7 ppt and then became less saline (1.0–1.5 ppt) during the last ~ 7000 yrs as climate became progressively drier. High salinity of the meteoric WM during the wet mid-Holocene is attributed to increased turbulent mixing between the meteoric and underlying marine WM. Increased precipitation, in terms of amount, frequency, and intensity (e.g. hurricanes) causes higher flow of meteoric water towards the coast and mixing at the halocline, a phenomenon recorded with recent instrumental monitoring of the aquifer. Conversely, during dry periods reduced precipitation and flow in the meteoric WM would result in lower salinity. Karst properties and Holocene sea-level rise also seem to have an effect on the aquifer. When the regionally extensive network of shallow cave passages (~ 10–12 m water depth) are flooded at ~ 8000 cal yrs BP, there is a rapid shift in salinity. This study demonstrates that calcite raft deposits can be used as paleo-environmental recorders documenting the effects of sea level and climate change on aquifer condition.

1. Introduction

Human skeletal fossils from phreatic coastal karst systems on the eastern margin of the Yucatán Peninsula show early Pre-Ceramic migration and settlement in the Yucatán at the end of the Pleistocene (González et al., 2008, 2013, 2016). Recently, a well-preserved, age-constrained Late Pleistocene (13-12 cal kyrs BP) female skeleton [*Homo sapiens*] was found in the Hoyo Negro (HN) pit cave (*Naia*; HN-5/48; Chatters et al., 2014). Her cranial and dental features share morphometric similarities with other early Paleoamericans, but she has (mt)DNA of Native Americans (Chatters et al., 2014, 2017). HN represents the first and only example of a human skeleton found in direct association with now-extinct Pleistocene megafauna in the Americas (Chatters et al., 2014; Collins et al., 2015). The study of the fossil record in HN is still ongoing, but there are many questions on how early Paleoamerican migrants adapted and subsisted on the Yucatán landscape. The prevailing view is that *Naia* and the animals entering the cave were in search of water, although there is no geological information on the condition of the aquifer during the Pleistocene/Holocene to substantiate this claim.

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Calcite raft deposits which have extensive distributions throughout Yucatán caves could possibly provide insights into how the potability (i.e. salinity) of the aquifer has changed with Holocene climate and sea-level. Calcite rafts have many advantages as they form abiotically at the air/water interface documenting the upper aquifer, preserve well in the stratigraphic record, and they accumulate on the bottom in large stratified piles. However, despite these advantages, they have never been used before in paleoenvironmental studies.

1.1. Hydrological setting

The Yucatán Peninsula is the aerially emergent portion of the greater Yucatán Platform, a vast limestone platform with a surface area of 300 000 km^2 (Bauer-Gottwein et al., 2011). The Peninsula itself encompasses over 165 000 km^2 of the total surface area, separating the Caribbean Sea from the Gulf of Mexico, and consists of Cenozoic Era biogenic limestone (Fig. 1; Ward et al., 1985).

The climate is tropical with distinct wet and dry seasons (Kottek et al., 2006). Monthly average temperatures range between 23 and 29 °C, with an average annual temperature of 26 °C. The hot/wet season is from May to November, whereas the relatively cooler dry season is from December to April (Hodell et al., 2007). Seasonal precipitation is determined by the movement of the ITCZ, which is controlled by the strength and movement of the Bermuda High and the easterly trade winds (Fig. 1; Hastenrath, 2012). Neuman and Rahbek (2007) document a significant east-west precipitation gradient across the Peninsula, with most of the precipitation (80%) falling on the Caribbean coast (>1500 mm/yr) during the summer wet season (González-Herrera et al., 2002). Quintana Roo surface soil coverage is sparse and thin, hosting a tropical arid forest comprised of palms (i.e. rain trees), broad-leafed trees and succulents (Bautista et al., 2011).

The landscape has low-lying topography that has been extensively karstified by the interaction of glacioeustacy, littoral processes and mixing-zone hydrology (Smart et al., 2006). Consequently, precipitation rapidly infiltrates through the limestone to a shallow, density stratified, unconfined coastal aquifer (Perry et al., 2003; Beddows et al., 2007). Hydrogeology of the aquifer is influenced by the porous nature of the limestone, which features structural heterogeneities (fissures and fractures), high matrix porosity, and karstic conduits (Kambesis and Coke, 2013). There is little surface drainage with no rivers and only a few lakes (Perry et al., 2003).

In anchialine settings, which characterize many karst coastlines, a meteoric Water Mass (WM) rests on a marine WM intruding from the coast that is separated by a halocline transition zone. In HN, the meteoric WM has a salinity of 1.1 ppt vs 35.1 ppt in the marine WM, and the current position of the halocline is at −18.5 m (all depths are relative to local water level unless otherwise stated; Fig. 3). The salinity of the meteoric WM varies spatially with areas closer to the coast having higher salinity than inland areas (Kovacs et al., 2017a). The interaction between the meteoric and marine WM is poorly understood in space and time, with few available paleo-environmental records to understand how meteroric WM salinity may have been affected by climate and sea-level change (Kovacs et al., 2017a). Consequently, we do not know whether the groundwater was potable at the end of the Pleistocene or the early Holocene, when the climate was dry and when early Paleoamericans arrived to the Yucatán (Chatters et al., 2014; Haug et al., 2001). Groundwater may have been quite important to early migrants who did not construct cisterns to store rainwater (i.e. Maya) and there were few lakes to rely upon for freshwater (Metcalfe et al., 2000). Therefore, groundwater from caves and cenotes may have provided a year-round water supply for early Paleoamericans, but with low sea level and thus groundwater during the early Holocene, only deep caves and pits would have provided access. The spatial extent of these deep access points may have influenced settlement and restricted movement on the landscape for early Paleoamericans.

1.2. Hoyo Negro and Ich Balam

HN is located on eastern coast of the Yucatán Peninsula (Quintana Roo) within the Outland Cave System, which is a distributary branch of the larger Sac Actun Cave system that has > 257 km of mapped passage (Figs. 1 and 2; Quintana Roo Speleological Survey,

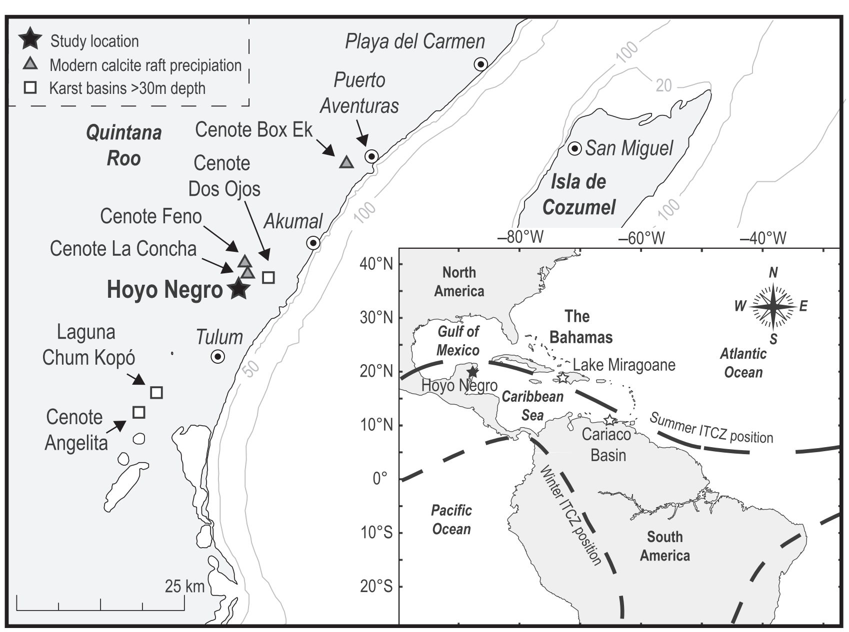

Fig. 1. Map showing the geographical position of HN and other cenotes used in this study. Bathymetric contours are represented in meters. Inset shows location of Cariaco Basin (Venezuela) and the summer/winter position of the Atlantic Intertropical Convergence Zone (ITCZ).