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Middle–late Holocene Caribbean aridity inferred from foraminifera and elemental data in sediment cores from two Cuban lagoons

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ABSTRACT

Coastal lagoons are rarely used as paleoclimate archives because of their complex geomorphic histories, which can be affected by both climate and sea-level change. Combined foraminiferal and XRF element analysis of sediment cores from Punta de Cartas and Playa Bailen, Cuba, isolated the effects of climate change (wet vs dry) on the lagoon environments. Foraminiferal assemblages from both Punta de Cartas and Playa Bailen show increasing diversity over the past 4000 yr BP, with a prominent increase at ~1400–1100 yr BP. Assemblages were initially dominated by *Ammonia* spp. (e.g., *Ammonia tepida*) and *Elphidium* spp. (e.g., *Elphidium excavatum*), indicating brackish conditions, but increased miliolid species (e.g., *Triloculina* spp. *Quinqueloculina* spp.), indicate a shift to more marine conditions up-core. Correspondingly, terrigenous input to the lagoon (Fe, Ti, Ti/Ca and K) declined over the past 4000 yr BP with a flexion at ~1200–1100 yr BP that is likely a consequence of decreasing precipitation. Fe, Ti and K have been used as proxies for detrital erosion and transport rates in tropical and sub-tropical basins, with greater input during wet periods, but have rarely been applied to shallow lagoon systems. Coincident changes in the XRF and foraminiferal data indicate decreased freshwater input to the lagoon and support an inference for the onset of drier climate conditions. Similar temporal patterns in the foraminifera and XRF records from the two lagoons, which are ~10 km apart, suggest a regional climate influence, with increasingly arid conditions developing since the middle-Holocene (4 kyr BP). A pronounced drying over the last ~1200 years agrees with other climate records from the Caribbean.

1. Introduction

The Caribbean supplies moisture for much of North America. Subtle changes in sea surface temperature and atmospheric circulation in the circum-Caribbean influences the climate of the surrounding region (Haug et al., 2001; Wang et al., 2006). Reconstructions of Caribbean climate during the Holocene are a basis for understanding these teleconnections, and better predicting future global climate. Previous paleoclimate studies in the Caribbean focused on archives in the Dominican Republic (Donnelly and Woodruff, 2007; Woodruff et al., 2008; Lane et al., 2011, 2014), Belize (Gischler and Storz, 2009; McCloskey and Keller, 2009; Wooller et al., 2009), Jamaica (Holmes et al., 1995), Haiti (Hodell et al, 1991; Higuera-Gundy et al., 1999), Venezuela (Haug et al., 2001, 2003; Wurtzel et al., 2013), Puerto Rico (Lane et al., 2013), St Martin (Malaizé et al., 2011), Grenada (Fritz et al., 2011) and the Yucatan Peninsula (Medina-Elizalde et al., 2010; Frappier et al., 2014). Paleoclimate information from Cuba, however, is limited to speleothem $\delta^{18}O$ records (Fensterer et al., 2013) and palynological, microfossil and isotope work from a lagoon sediment core (Peros et al., 2007a,b). More temporal and spatial data are needed to constrain Caribbean climate change, but there are few lakes that provide suitable archives. Although speleothem records are an excellent data source, a breadth of proxies are needed to provide a comprehensive understanding of climate forcing, and are vital for testing climate models and examining the importance of climate feedbacks (Sloan and Barron, 1992; Masson-Delmotte et al., 2005; Braconnot et al., 2012). A recent analysis by the Paleoclimate Modeling Intercomparison Project showed relatively poor agreement between modeled and observed tropical sea surface temperatures, emphasizing the importance of climate feedbacks in tropical regions, and requiring further investigation using proxy data (Braconnot et al., 2012).

Coastal environments, such as estuaries and lagoons, are not often used for reconstructing paleoclimate trends because of uncertainties regarding their geomorphic evolution (e.g., barrier formation, sea-level change, etc.,). Foraminifera and ostracods have been used extensively for reconstructing paleoenvironmental evolution of estuaries and lagoons, as the organisms respond predictably to salinity change. Within a given lagoon or estuary, salinity is a function of sea-level, barrier configuration and freshwater input, the latter a consequence of changing

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precipitation and evaporation rates. The multiple variables influencing salinity can make identification of the primary cause of salinity shifts difficult (Brewster-Wingard and Ishman, 1999; Cann et al., 2000; Cann and Cronin, 2004; Peros et al., 2007a; Gabriel et al., 2008; van Hengstum et al., 2010; Cheng et al., 2012).

Trace element analysis of sediments has become more common with the development of high-resolution X-ray fluorescence (XRF) core scanning in the early 2000s, which enables rapid measurement of trace element composition in sediment (Haug et al., 2001; Lamy et al., 2001; Rothwell, 2006). The trace element composition reflects a combination of deposited mineral material, solutes in the water scavenged by organic flocculants and clays, and biotic and abiotic precipitates from the water column (e.g., calcareous and siliceous shells and tests), all of which can be affected by early diagenesis in the uppermost sediment (Engstrom and Wright, 1984; Battistion et al., 2003). Different mineral combinations have been used to identify a wide range of factors that affect depositional processes specific to environments or basins (Rothwell et al., 2006; Thanachit et al., 2006; Thomson et al., 2006). Fe, Ti, Ti/Ca and K have been used to indicate erosion and transport of continental rocks and alluvium within drainage basins (Haug et al., 2001; Thanachit et al., 2006). Increased precipitation can intensify transport of terrigenous elements towards the basin depocenter via runoff (e.g., Haug et al., 2001; Lamy et al., 2001). The relationship between precipitation and terrigenous sediment input has been established in many environments, including deep ocean basins (Yarincik et al., 2000; Haug et al., 2001; Mora and Martinez, 2005; Yao et al., 2012), continental shelves and slopes (Arz et al., 1998; Lamy et al., 2001; Zabel et al., 2001; Bertrand et al., 2007; Mahiques et al., 2009) and lakes (Haberzettl et al., 2008; Sáez et al., 2009; Warrier and Shankar, 2009; Löwemark et al., 2011). Similar relationships should apply to lagoons if they are closed or semi-closed relative to the larger basin, but this has not been investigated.

Here we present high-resolution XRF and foraminiferal data from sediment cores taken in two Cuban lagoons, Punta de Cartas and Playa Bailen. The foraminiferal data document salinity shifts over the past ~4000 years, whereas the trace elements (Fe, Ti, Ti/Ca and K) reflect changes in the magnitude of erosion, which is influenced by rainfall. Comparison of the two datasets from two separate lagoons enabled isolation of precipitation and its influence on salinity, indicating a regional climate response.

2. Study area

We analyzed sediment cores from two lagoons on the southwest coast of Cuba (Fig. 1). Punta de Cartas is an elliptical, restricted lagoon on the north shore of the Bahia de Cortez. Punta de Cartas is the seaward segment of a larger wetland system that is composed of dense red mangrove forests (*Rhizophora mangle*) and shallow ponds (Fig. 1C). A ~100-m barrier of developing mangrove, beach grasses and sand separates the lagoon from the ocean. Presently, a 200-m-long, 5-m-wide channel intersects this barrier, connecting the lagoon to the ocean.

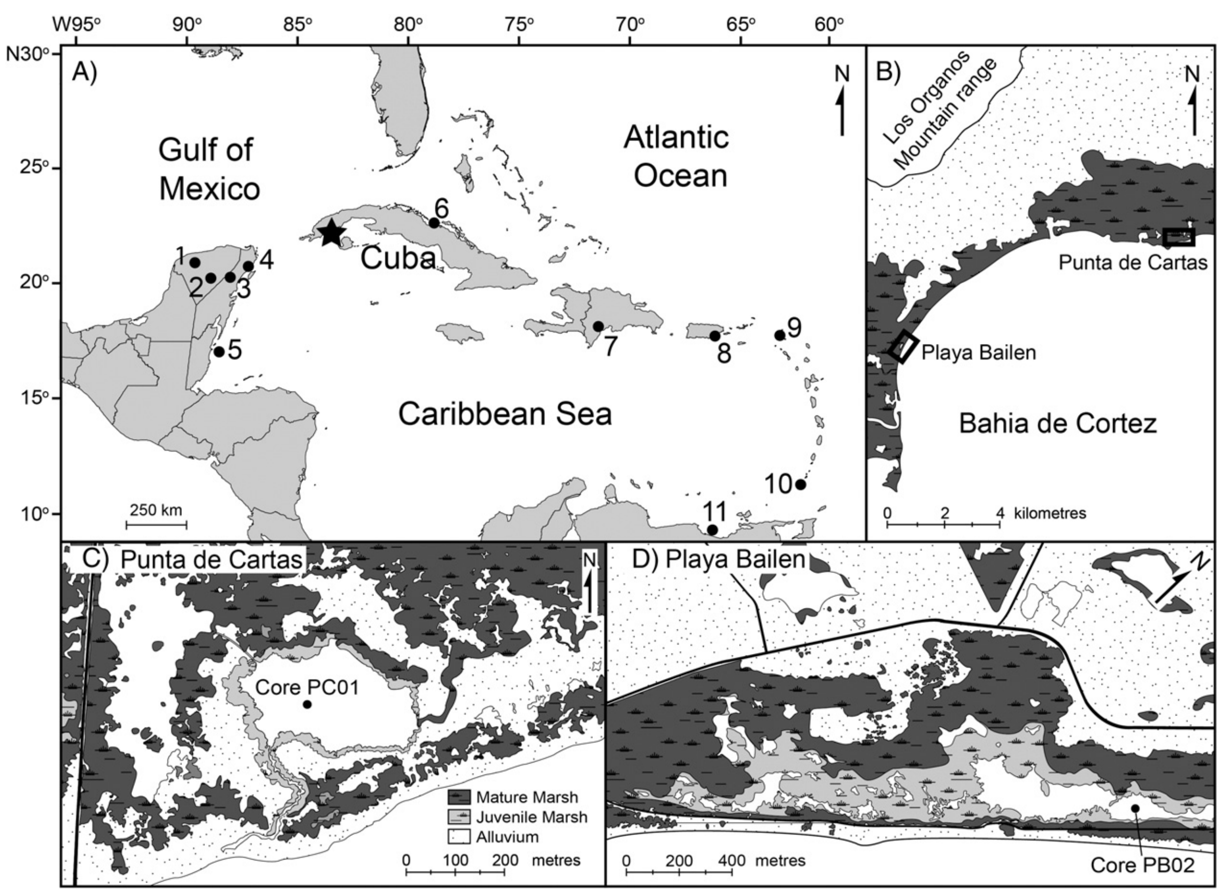

Fig. 1. Map of the study area. (1A) The location of the study areas, demarcated by the black star, and other climate records from the circum-Caribbean. Other locations include (1) Aquada X'caamal, Mexico (Hodell et al., 2005); (2) Lake Chichancanab, Mexico (Hodell et al., 1995); (3) Lake Punta Laguna, Mexico (Curtis et al., 1996); (4) Puerto Morelos, Mexico (Islebe and Sanchez, 2002); (5) Turneffe Atoll, Belize (Wooller et al., 2009); (6) Laguna de la Leche, Cuba (Peros et al., 2007a,b); (7) Laguna Castilla, Dominican Republic (Lane et al., 2009, 2014); (8) Laguna Playa Grande, Puerto Rico (Donnelly and Woodruff, 2007; Woodruff et al., 2008); (9) Grand Case Pond, St Martin (Malaizé et al., 2011); (10) Lake Antoine, Grenada (Fritz et al., 2011); and (11) the Cariaco Basin, Venezuela (Haug et al., 2001). (1B) Aerial view of the area surrounding Punta de Cartas and Playa Bailen showing their relation to the Los Organos mountain range to the north, and the Bahia de Cortez to the south. (1C) The first of two study sites, Punta de Cartas, and the location of core PC01 (black circle). (1D) Playa Bailen, the second study site, with the location of core PB02 (black circle).