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# A 27cal ka biomarker-based record of ecosystem changes from lacustrine sediments of the Chihuahua Desert of Mexico

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ABSTRACT

Hydroclimate variation of the northwest Mexico during the late Pleistocene and Holocene is an active area of debate, with uncertainty in the nature and sources of precipitation. Previous research has inferred the influences of winter storms, summer monsoonal rain and autumn tropical cyclones. The impacts on regional and local ecosystems, however, are not well constrained. Here, we investigate the response of lacustrine and terrestrial habitats of the Santiaguillo Basin in the Chihuahua Desert (Mexico) to hydrological changes occurring since the late last glacial. Biomarkers from the sediments reflect variable input of organic matter (OM) from algal and bacterial biomass, aquatic microfauna and surrounding vegetation, revealing distinct stages of ecosystem adaption over the last 27 cal ka. Based on previously published and new data, we show that a perennial productive lake was present during the late glacial and it persisted until 17.5 cal ka BP. Coinciding with Heinrich event 1, OM supply from deteriorating wetland soils may have been caused by early dry conditions. Further phases of increasing aridity and a shrinking water body drove changing OM quality and biomarker composition during the early and mid-Holocene. A pronounced shift in biomarker distributions at 4 cal ka BP suggests that the supply of plant litter from resinous trees and grasses increased, likely reflecting the establishment of modern vegetation. Our results illustrate the potential of biomarker applications in the area, adding to the evidence of hydroclimate variability and enabling reconstructions of local ecosystem dynamics.

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## 1. Introduction

The Chihuahua Desert is located between 22 and 32° N and 100-109° W and is the largest desert in North America. Its area of ~450,000 km$^2$ extends through the northern Mexican states of Chihuahua, Durango, Zacatecas, Nuevo Leon and San Luis Potosi and the southern USA states of New Mexico, Texas and Arizona (Palacios-Fest et al., 2002). Reconstructions of past climate variations in this desert have received significant attention over the last few decades, particularly with respect to the North American Monsoon (NAM) during the Late Quaternary. Previous records include lacustrine sediments, aeolian deposits, packrat middens and speleothems, producing proxy data through the distributions of pollen, diatoms and ostracods, inorganic geochemistry (X ray fluorescence, X ray diffraction, magnetic susceptibility) and stable isotopes (e.g. Lozano-García et al., 2002; Metcalfe et al., 2002; Roy et al., 2012, 2013; 2016; Chávez-Lara et al., 2015; Quiroz-Jimenez et al., 2017). These records have provided insight into past climatic change but the carbon cycling and vegetation responses to those changes are still poorly understood (Metcalfe et al., 2015).

Recent publications have presented different hypotheses with regard to the role of the NAM, winter storms and tropical cyclones in regional precipitation patterns during the last glacial maximum (LGM). Oster et al. (2015) argued that the location and strength of the contemporary pressure system were responsible for a higher contribution of winter precipitation from the Pacific Ocean to the southwestern USA during the LGM. In Northwest Mexico, however, the NAM was weaker during the LGM due to high latitude cooling that shifted the westerlies south, causing changes in the main wind direction and cold and dry conditions in the region (Bhattacharya et al., 2017). Furthermore, Roy et al. (2015) observed humid conditions in the Santiaguillo Basin in central northern Mexico during the LGM but concluded that, although the NAM was inactive or weaker, the frequent formation of tropical cyclones in the eastern North Pacific brought more albeit regionally restricted autumn rainfall. By contrast, based on speleothem record from tropical

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Southwest Mexico, Lachniet et al. (2013) argued that the NAM was active and attributed this to an active but shallow Atlantic Meridional Overturning Circulation and the proximity of their study site to the northern limits of the Intertropical Convergence Zone (ITCZ). Although the exact causes of climatic change in the Chihuahua Desert thus remain uncertain, it is still useful to explore how those changes impacted local ecosystems. The development of the vegetation, for example, can also reflect changes in the seasonality of rainfall and, hence, may provide clues towards changes in the moisture source since the LGM. For the late glacial, pollen records indicate the presence of cold climate species, in contrast to the current dominance of desert shrublands in the southwestern USA (Van Devender, 1990; McAuliffe and Van Devender, 1998; Holmgren et al., 2003, 2006). Similarly, close to the Mexican border, packrat middens indicate the presence of summer-flowering annuals and the absence or minimal proportions of desert shrublands (Holmgren et al., 2007). During the early Holocene, the belt of greater winter precipitation shifted north. Associated with this was a migration of cold weather vegetation to higher latitudes and elevations over 2000 m a.s.l., being replaced by shrub and desert species during the establishment of the North American deserts (Van Devender, 1990; Holmgren et al., 2003). For the mid to late Holocene, as the conditions became drier in northwestern Mexico, paleovegetation records become scarce due to fossil pollen being poorly preserved and sediments becoming organic lean, leaving unclear much of the overall biome development from the last glacial to today (e.g. Lozano-García et al., 2002; Metcalfe et al., 2002).

Lipid biomarkers in lacustrine sediments can be used to fill this gap (Meyers, 2003). The organic matter (OM) of lacustrine sediments is derived from the particulate detritus of aquatic plants and algae as well as vegetation present in the surrounding lake catchment. It contains a range of biomarkers that represent input of OM from different sources and subsequent diagenetic alteration (Perry et al., 1979). Both of these characteristics can be used to reconstruct environmental changes in ancient ecosystems (Meyers and Benson, 1988). In this paper, we present the lipid biomarkers in organic-poor sediments (total organic carbon concentration/TOC: 0.2–1.2%) deposited over the last 27 cal ka in the Santiaguillo Basin of central-northern Mexico. This is the first biomarker-based investigation of late Quaternary lacustrine sediments from Mexico, and we use these data to identify changes in the sources of organic carbon to the lake system during the late Pleistocene and Holocene, with implications for carbon cycling, and to reconstruct the paleovegetation of the Chihuahua Desert of Mexico.

## 2. Regional setting

The Santiaguillo Basin is located in central-north Mexico (Fig. 1), in the rain shadow of the Sierra Madre Occidental hills. It has an area of 1964 $km^2$ within 24°30′ to 25°00′ N and from 104°40′ to 105°00′ W. Tectonic movements formed this basin during the Cenozoic, and its bedrock is composed of Cretaceous to Quaternary metamorphic, igneous, and sedimentary rocks (Nieto-Samaniego et al., 2012). The most recent deposits are lacustrine sediments and Quaternary alluvium (Nieto-Samaniego et al., 2012). A nearby meteorological station (Guatimape: 24°48′25” N, 104°55′19” W) provides mean monthly temperature and precipitation data from 1981 to 2010 AD (Source: Servicio Meteorologico Nacional, Mexico). The basin receives around 394 mm of its average annual precipitation of 445 mm between June and October and the rest of the year contribute around 51 mm of precipitation (Fig. 1).

## 3. Materials and methodology

Sediments were collected from a 3 m deep pit at the western

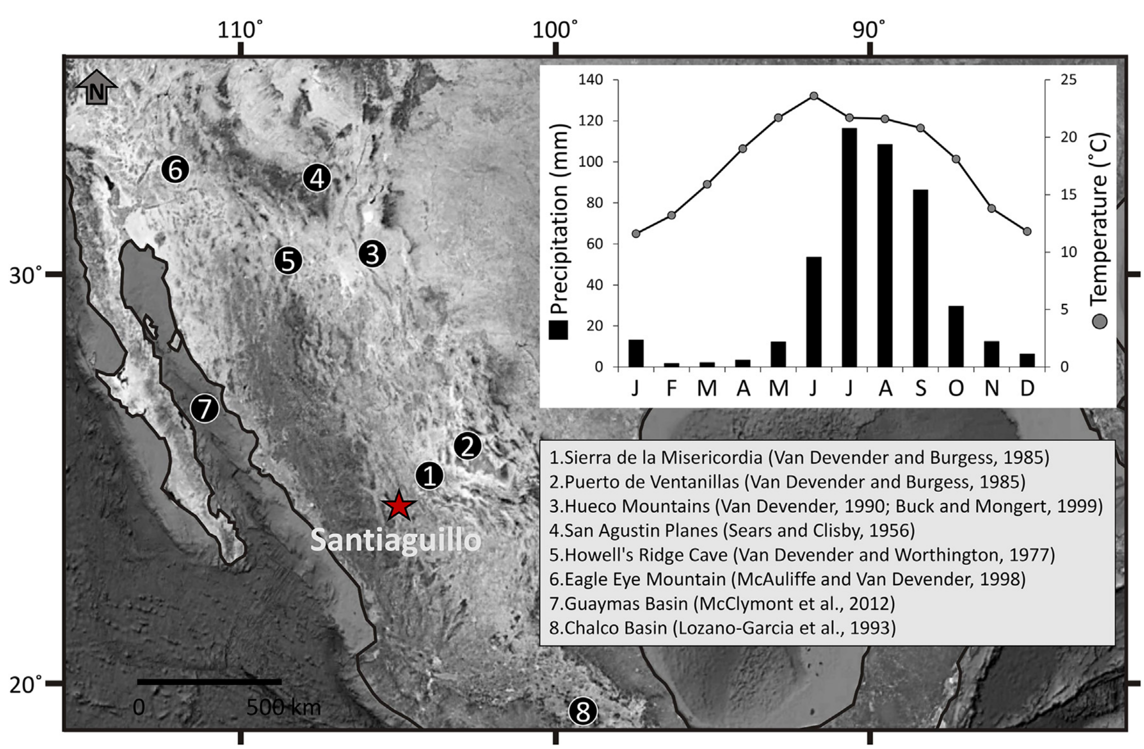


**Fig. 1.** The Santiaguillo Basin (red star) is located in the central-northern Mexico. Location of other records used here for comparison (circles). Mean monthly temperature and precipitation from 1981 to 2010 AD are calculated from data obtained from the nearest meteorological station at Guatimape. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

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