Quaternary Science Reviews 76 (2013) 1–15

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Invited review

Latest Pleistocene to Holocene hydroclimates from Lake Elsinore, California

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ARTICLE INFO

Article history:
Received 1 October 2012
Received in revised form
19 May 2013
Accepted 22 May 2013
Available online 26 June 2013

Keywords:
Deglacial
Southwest United States
Dipping westerlies
Hydrogen isotope
Lake Elsinore

ABSTRACT

The hydroclimate of the southwestern United States (US) region changed abruptly during the latest Pleistocene as the continental ice sheets over North America retreated from their most southerly extent. To investigate the nature of this change, we present a new record from Lake Elsinore, located 36 km inland from the Pacific Ocean in Southern California and evaluate it in the context of records across the coastal and interior southwest United States, including northwest Mexico. The sediment core recovered from Lake Elsinore provides a continuous sequence with multi-decadal resolution spanning 19–9 ka BP. Sedimentological and geochemical analyses reveal hydrologic variability. In particular, sand and carbonate components indicate abrupt changes at the Oldest Dryas (OD), Bølling–Allerød (BA), and Younger Dryas (YD) transitions, consistent with the timing in Greenland. Hydrogen isotope analyses of the C_{28} *n*-alkanoic acids from plant leaf waxes (δD_{wax}) reveal a long term trend toward less negative values across 19–9 ka BP. δD_{wax} values during the OD suggest a North Pacific moisture source for precipitation, consistent with the dipping westerlies hypothesis. We find no isotopic evidence for the North American Monsoon reaching as far west as Lake Elsinore; therefore, we infer that wet/dry changes in the coastal southwest were expressed through winter-season precipitation, consistent with modern climatology. Comparing Lake Elsinore to other southwest records (notably Cave of Bells and Fort Stanton) we find coincident timing of the major transitions (OD to BA, BA to YD) and hydrologic responses during the OD and BA. The hydrologic response, however, varied during the YD consistent with a dipole between the coastal and interior southwest. The coherent pattern of hydrologic responses across the interior southwest US and northwest Mexico during the OD (wet), the BA (drier), and YD (wet) follows changes in the Atlantic Meridional Overturning Circulation, presumably via its combined influence on North Pacific winter storm tracks and the extent/magnitude of the North American Monsoon. In contrast, Lake Elsinore and the coastal southwest experiences a deglacial drying trend punctuated by abrupt change at the OD to BA and BA to YD transitions. This trend tracks rising greenhouse gases through the deglacial, with an apparent southward shift in westerly moisture sources adjusting to the retreating ice sheet.

1. Introduction

The rates and amplitude of climatic change associated with global warming over the next century are expected to extend beyond that recorded by instrumental records (IPCC, 2007). Abrupt climatic transitions that cause permanent shifts in regional mean climatic states are of particular concern (Overpeck, 1996). Climate model projections for the southwest United States predict a change in the frequency and magnitude of precipitation, perhaps with an overall drying (Beuhler, 2003; Seager et al., 2007; Dominguez et al., 2012). Any change to the region's hydroclimatology likely will have costly consequences for the highly populous, water-stressed region (e.g., Smith, 2011). Here we seek evidence for past hydroclimatic change and offer insights into spatial differences within the southwest that may be key for projecting how these systems respond in the future. For the water-stressed southwest, there is a particular urgency to understand the causes and spatial patterns of hydrologic change, particularly abrupt changes (Seager et al., 2005; Cook et al., 2011). The most recent glacial termination at the end of the Pleistocene and start of the Holocene (hereafter most recent deglacial) provides evidence for large amplitude variability

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http://dx.doi.org/10.1016/j.quascirev.2013.05.023

punctuated by rapid transitions between climatic states (e.g., Clark et al., 2012). Here, we explore the implications for the hydroclimates of the southwest United States and northwest Mexico during the most recent glacial termination.

Evaluation of terrestrial climate for the region was limited previously by the lack of a high resolution, complete deglacial sequence from the coastal southwest. In the absence of a coastal southwest terrestrial site, marine archives were used to infer terrestrial climate change during the most recent deglacial (Lyle et al., 2010, 2012). We present a new record from Lake Elsinore, California, which fills this geographic gap in the coastal southwest. We analyze climatic transitions across the region primarily through comparison to the interior southwest records from Cave of Bells, Arizona (Wagner et al., 2010) and Fort Stanton, New Mexico (Asmerom et al., 2010). Eight additional sites add to the millennial-scale evidence for hydroclimatic change across the region; although, their contributions are limited variously by lower temporal resolution of sampling and age control. The objective of the regional comparison is to identify the spatial patterns of hydrologic change across the study area during the most recent deglacial. We explore further the drivers of most recent deglacial through the principal "modes of deglacial variability" identified by Clark et al. (2012). Specifically we seek to test which of the two principal modes – radiative or Atlantic Meridional Overturning Circulation (AMOC) forcings (Clark et al., 2012) – dominate the response in the coastal (Lake Elsinore) and interior (Cave of Bells and Fort Stanton) southwest. Lastly we use insights from compound specific hydrogen isotopic measurements at Lake Elsinore to evaluate the 'dipping westerlies' hypothesis. This hypothesis states that during the most recent glacial the dominant westerly storm track that transported precipitation to the west coast of the United States, was redirected further south in response to the position of the North American ice sheets (Negrini, 2002; cf. Lyle et al., 2010, 2012).

1.1. Regional climatology

Across the coastal and interior southwest US and northern Mexico (Fig. 1), the seasonality of precipitation varies between Mediterranean, desert, and monsoon regimes (Comrie and Glenn, 1998). Wet winters and dry summers characterize the Mediterranean precipitation regime. The desert precipitation regime is annually dry with small winter and late-summer precipitation contributions; whereas, the monsoon precipitation regime is dominated by late-summer to early fall precipitation maxima with a small winter contribution. Two meteorological sites (Ensenada, Mexico; and, Phoenix, Arizona) fall within the transitional precipitation regime; no sites fall within the Texas/Oklahoma regime (eastern edge of Fig. 1).

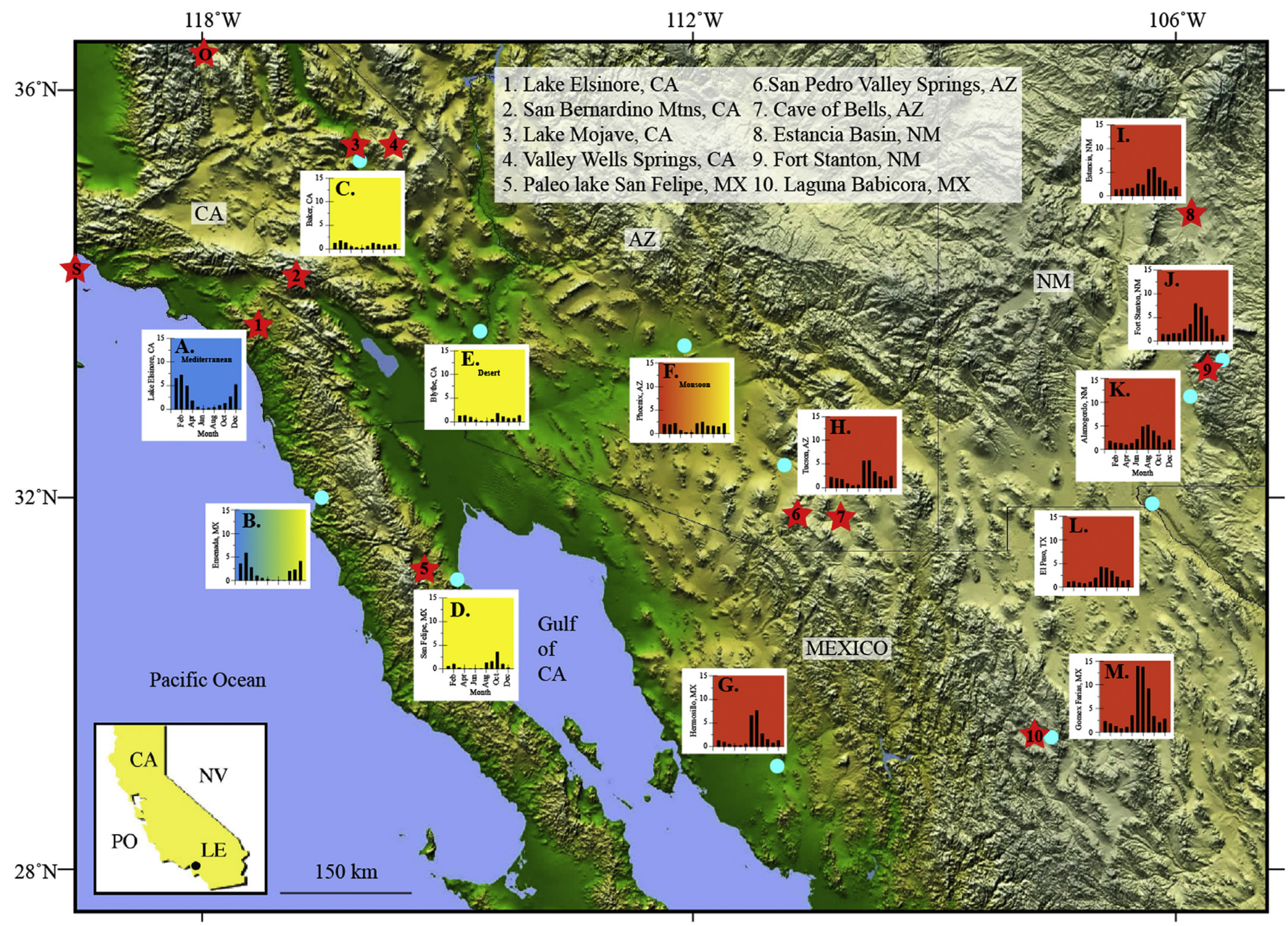

Fig. 1. Regional map with study sites and precipitation regimes. Blue = Mediterranean climate; Yellow = Desert climate; Orange = Monsoon climate. Red stars with numbers represent study site locations. Light blue dots represent precipitation sites. If the study site and the precipitation sites are the same (e.g., Lake Elsinore), the red star is only shown. S = Santa Barbara Basin. O = Owens Lake. Precipitation data from www.weatherbase.com and/or http://www.ncdc.noaa.gov.