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Fluvial tufa evidence of Late Pleistocene wet intervals from Santa Barbara, California, U.S.A.

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ABSTRACT

Past pluvials in the western United States provide valuable context for understanding regional hydroclimate variability. Here we report evidence of conditions substantially wetter than today from fluvial tufa deposits located near Zaca Lake, Santa Barbara County, California that have been dated by radiocarbon (^{14}C) and Infra-Red Stimulated Luminescence (IRSL). Two successions of tufa deposition occur within a small catchment that drains Miocene Monterey Formation bedrock: 1) a fluvial deposit (0–0.5 m thick, 200 m in extent) that formed along a narrow valley below a modern spring, and 2) a perched deposit ~10 m higher (2 m thick, 15 m in extent). IRSL and radiocarbon dating of the perched carbonates suggest at least two episodes of carbonate growth: one at 19.4 ± 2.4 (1σ) through 17.8 ± 2.8 (1σ) ka and another at 11.9 ± 1.5 (1σ) ka verified with a charcoal ^{14}C age of 10.95 ± 0.12 (2σ) cal ka BP. The relationship between the perched and fluvial spring deposits is inferred to represent a drop in the water table of more than 10 m associated with a transition from a wet climate in the late glacial to a dry Holocene today.

The wet period indicated by the perched tufa deposit between 19.4 and 17.8 ka is relatively consistent with other California climate records both north and south of Zaca Lake. However, tufa growth ca. 12 to 11 ka demonstrates wet conditions occurred as far south as Zaca Lake during the Younger Dryas event, in contrast to climate records farther south in Lake Elsinore that indicate a drying trend through this interval. A small shift north in the average position of the winter season storm track could explain wet winters at Zaca while at the same time generating dry winters at Lake Elsinore, ~275 km southwest of Zaca. If true, these data indicate that rather small latitudinal shifts in the average winter season storm track can produce large changes in regional hydroclimate.

1. Introduction

With concern over the projected aridification of the southwestern United States (Seager et al., 2007; Williams et al., 2013), there is heightened interest in characterizing past evidence for extended pluvial periods and droughts in California's pre-instrumental record to better understand the large scale controls on climate and how these may change in the future. The western United States (western US) experienced a wetter climate during the Last Glacial Maximum (LGM) (18–20 ka cf. Denton et al., 2010) relative to present as evidenced by palaeolakes Bonneville and Lahontan (Benson et al., 1990), as well as expanded palaeolakes Estancia and Mojave (Allen and Anderson, 2000; Anderson et al., 2002; Wells et al., 2003). Additional evidence for wetter conditions comes from elevated and expanded palaeolake shorelines in Owens Valley (Mensing, 2001), higher sand contribution to profundal sediments in Lake Elsinore (Kirby et al., 2013), isotopic evidence from speleothems in New Mexico and Arizona (Asmerom et al., 2010; Wagner et al., 2010), and evidence for vegetation change based on (1) plant leaf waxes from Lake Elsinore sediments (Kirby et al., 2013) and (2) pollen from Ocean Drilling Program (ODP) marine sediments in the Santa Barbara Basin (ODP site 893) (Heusser and Sirocko, 1997). Detailed analyses of those proxy records with high temporal resolution and improved dating precision have revealed that temperature and hydroclimate were spatially and temporally variable across the western US in the late glacial and across the deglacial (Lyle et al., 2012; Kirby et al., 2013). In particular, pollen records from marine sediments offshore southern and northern California (ODP site 893 and 1019, respectively) reveal variable timing of hydroclimatic change along the coast (Lyle et al., 2010, 2012). Adding records that concentrate on spatial and temporal hydroclimate patterns is key to resolve the history and causes of hydroclimatic variability for specific regions across the western US (e.g., coastal versus inland). Presently there are few terrestrial records from coastal southern California that address hydrological balance during the LGM and across the last deglacial (e.g., Heusser and Sirocko, 1997; Kirby et al., 2013).

Spring-associated carbonates generated from carbonate-rich, ambient temperature groundwater, referred to hereafter as 'tufa' sensu

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Pedley (1990), serve as potential archives of source waters and climate of their local region (Andrews, 2006). Notably, the presence of large tufa accumulations in arid and semi-arid regions is indicative of periods of accelerated groundwater recharge, as carbonate will only form when there is a net recharge to the groundwater aquifer (Pedley, 1990). Tufa deposits are therefore robust indicators of past pluvials (Szabo, 1990; Crombie et al., 1997; Auler and Smart, 2001; Viles et al., 2007), and may serve as proxy records of hydrological balance to complement other local proxy records of palaeoclimate (e.g., Garnett et al., 2004; Domínguez-Villar et al., 2011; Cremaschi et al., 2010; Stone et al., 2010).

A number of tufa deposits are found in the western US, including the well-known towers and pinnacles from lakes in Nevada and California (Scholl, 1960; Newton and Grossman, 1988; Benson, 1994; Li et al., 2008). Climate reconstructions from these lacustrine tufa deposits and related lake sediments have added support to the idea that the LGM in the Great Basin was wetter than today (e.g., Benson, 1978). However, records of *fluvial* tufa deposits are less well-known (e.g., Barnes, 1965) as they are perhaps less conspicuous compared to their *lacustrine* counterparts in the present semi-arid climate of southern California.

Here we present compelling terrestrial evidence of persistent wet conditions based on comparisons of fossil and recent fluvial tufa deposits from a coastal site near Zaca Lake, in Santa Barbara County, California (Fig. 1). Radiocarbon and Infra-Red Stimulated Luminescence (IRSL) dating allow us to constrain the age of these deposits. We combine geomorphic, textural, petrographic, and geochemical observations to evaluate the nature of the depositional environment during this wet interval. We compare these new findings to other terrestrial and marine records towards better understanding of the regional patterns and the magnitude, timing, and causes of pluvial conditions in coastal southern California.

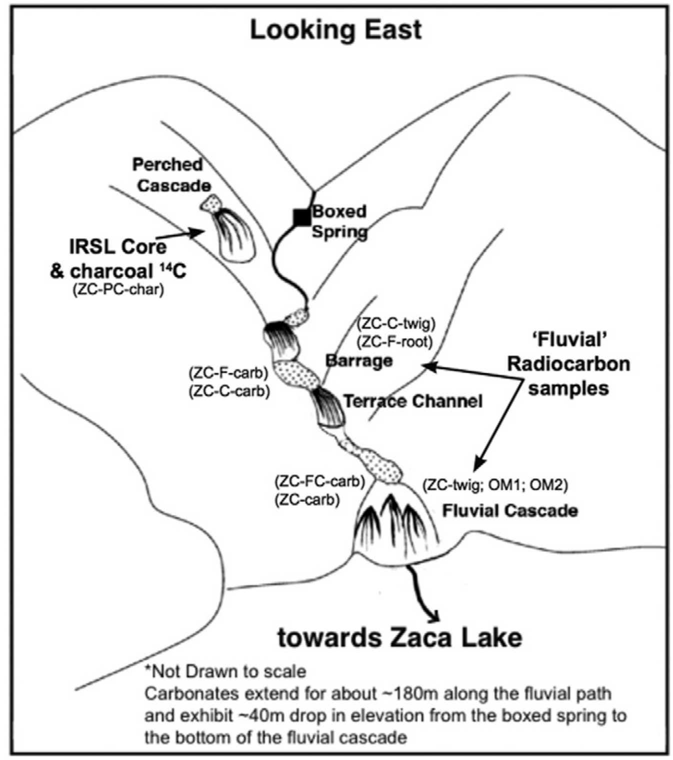

Fig. 2. Schematic of carbonate facies with corresponding sample labels. Modified from Viles et al. (2007) and Ibarra et al. (2014)

2. Geologic and environmental setting

Two successions of spring-associated carbonate deposits have been described from the Zaca Lake catchment ~3 km east of Zaca Lake in Santa Barbara County, California (Fig. 2; Ibarra et al., 2014). One succession occurs along a narrow valley (referred to hereafter as 'fluvial' carbonates) and extends discontinuously for approximately 200 m with an overall drop in elevation of ~40 m. The other succession occurs perched upon the slope of the north ridge (referred to here as 'perched cascade' carbonates) ~10 m above the fluvial carbonates (Fig. 2). The carbonates formed within a relatively small catchment, and drape over Miocene Monterey Formation bedrock (Fig. 1A). In 1911 the spring was boxed and piped for human consumption (Norris and Norris, 1994) which continues to the present day, such that carbonate deposition downstream is likely not active along the entirety of the fluvial path (Ibarra et al., 2014). The residence time of water in the catchment seems to be relatively short as fluctuations in the water table on the order of years to decades have been observed in historical documents (Norris and Norris, 1994), and they are associated with known fluctuations in recorded precipitation for the region (SBB Water Works, 2013). The sensitivity of the spring to decadal scale climatic fluctuations

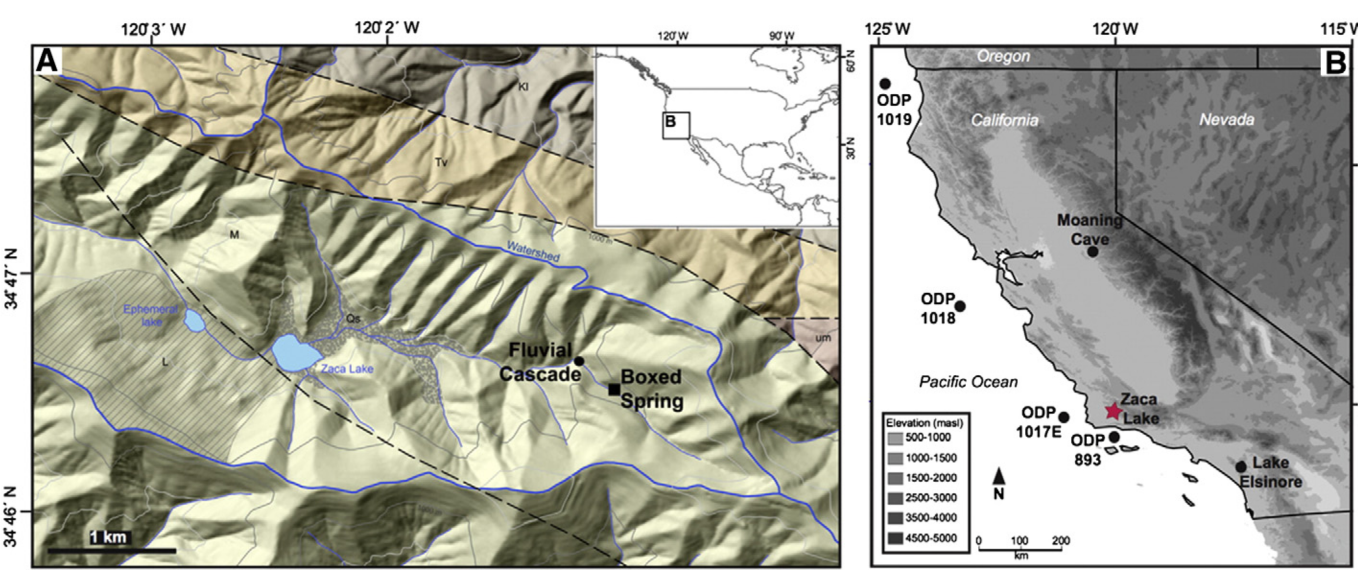

Fig. 1. Study site. (A) Geologic map of the study area. Abbreviations: M = Monterey; Qs = surface Quaternary; L = landslide; Tv = Tertiary volcanics. Dashed lines denote fault lines. Contours are at 200 m intervals; modified from Ibarra et al. (2014). (B) Regional map denoting locations mentioned in the text.