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A molecular isotope record of climate variability and vegetation response in southwestern North America during mid-Pleistocene glacial/interglacial cycles

Sergio Contreras [a,b,*], Josef P. Werne [a], Erik T. Brown [b], R. Scott Anderson [c], Peter J. Fawcett [d]

[a] Department of Geology and Environmental Science, University of Pittsburgh, Pittsburgh, PA 15260, USA
[b] Large Lakes Observatory and Department of Geological Sciences, University of Minnesota Duluth, Duluth, MN 55812, USA
[c] Environmental Programs, School of Earth Sciences and Environmental Sustainability, Northern Arizona University, Flagstaff, AZ 86011, USA
[d] Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA

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ABSTRACT

Climate variability during Pleistocene glacial/interglacial transitions is well documented in marine and ice-sheet isotopic records, but terrestrial records showing the continental response to these transitions are scarce, especially for earlier in the Pleistocene. Cyclic intervals of warm interglacial and cold glacial conditions preserved in terrestrial records such as lake sediments provide opportunities to probe the biosphere's response to climate change. In this study, we track climate and plant type changes, specifically the presence of C3 and C4 plants, using the abundance and δ^{13}C signatures of leaf waxes in paleolacustrine sediments from Valles Caldera in New Mexico. Through these changes, we assess the response of vegetation to climate variability in southwestern North America through two mid-Pleistocene glacial/interglacial transitions (Marine Isotope Stage [MIS] 14/13 and 12/11). Leaf wax data show that the C3 forest taxa were dominant through the entire record whereas C4 plants, better adapted to warm conditions and competitive under water stress, are favored during warming and extended arid periods during interglacials. The δ^{13}C signature in leaf wax *n*-alkanes suggests that C4 plants persisted in the watershed throughout the interglacials and that some summer rainfall (which is required to support C4 grasses) was maintained even during prolonged dry periods. The abundance and carbon isotope composition of leaf waxes together with new MBT/CBT (methylation index of branched tetraethers/cyclization index of branched tetraethers) temperature data confirm warmer and more arid conditions during MIS 13 than during MIS 11, in spite of relatively low greenhouse gas concentrations during MIS 13. This suggests that variations in incoming solar radiation have played a major role in regulating the surface temperature, regional hydrological systems and vegetation in southwestern North America, likely through changes in the North American Monsoon coupled with variations in the location of the mid-latitude westerlies.

1. Introduction

Southwestern North America has been identified as a hot spot of climate change due to the potential impacts of warming temperatures on the already limited water availability in the region (Giorgi, 2006; Diffenbaugh et al., 2008; Diffenbaugh and Giorgi, 2012). The main sources of moisture to the region are convective thunderstorms associated with the summer monsoon, and winter precipitation comprised of large-scale frontal systems that often involve snow accumulation at high elevations and locally account for half of the annual precipitation in the Jemez Mountains of New Mexico, the watershed of the former lake in the Valles Caldera (Reneau et al., 2007; Fawcett et al., 2007). Climate models consistently project declines in winter precipitation for the southwest, in response to warming due to rising concentrations of greenhouse gases (Seager et al., 2007; Seager and Vecchi, 2010; Cayan et al., 2010; Seager et al., 2013; Prudhomme et al., 2014). Under these conditions, the sub-tropical dry zones expand pole-ward where descending air suppresses precipitation by drying the lower atmosphere. Warming also shifts the rain-bearing mid-latitude winter storm tracks towards the poles (Yin, 2005).

Understanding long-term (centennial to glacial-interglacial timescales) natural climate variability of southwestern North America is crucial to disentangle forcing factors and project anthropogenic changes superimposed on natural climate variability. Fawcett et al. (2011) described a lacustrine sediment record (VC-3) from Valle Grande in Valles Caldera National Preserve (New Mexico) (Fig. 1), identifying

* Corresponding author at: Departamento de Química Ambiental & Centro de Investigación en Biodiversidad y Ambientes Sustentables (CIBAS), Universidad Católica de la Santísima Concepción, Casilla 297, Concepción, Chile.
E-mail addresses: scontreras@ucsc.cl, contrerasser@gmail.com (S. Contreras).

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megadroughts during the warmest phases of two mid-Pleistocene interglacials (MIS 13 and MIS 11). During these intervals the lake became hydrologically closed and evaporated to the extent that centimeter to decimeter-scale mud-cracks were identified. These dry climates were attributed to reduced winter and summer precipitation. Recently, hydrogen isotope (δD) analyses of leaf waxes were used to reconstruct precipitation changes in the same VC-3 core, which were interpreted as indicating greater summer monsoon strength and variability during interglacials than glacials (Cisneros-Dozal et al., 2014). This study identified a precessional signal in monsoon precipitation during the long MIS 11 interglacial (Cisneros-Dozal et al., 2014). An increase and subsequent decrease in both organic carbon concentration (%TOC) and carbon stable isotope values in bulk organic matter ($\delta^{13}C_{TOC}$) during the transitions to MIS 11 and MIS 13 were interpreted as an expansion and collapse of C4 plant communities in response to changes in summer precipitation (Fawcett et al., 2011). Enhanced summer precipitation due to warmer temperatures could trigger a rise in C4 plant communities. However, the apparent collapse of C4 plants and significant reduction in summer precipitation is not intuitive, and is inconsistent with climate models that predict a significant reduction in winter precipitation for southwestern North America over the next century. The interpretation of carbon isotopic source signals in bulk organic matter can become complicated in areas that receive contributions of organic matter from algae as well as terrestrial C3 and C4 plants, as is the case for Valles Caldera. Carbon isotope analysis of terrestrial leaf waxes (long-chain *n*-alkanes; C_{25} to C_{33}) provides a better approach to interpret such vegetation changes without the complication from multiple sources of organic matter (Eglinton and Calvin, 1967; Collister et al., 1994). Compound specific carbon isotope signatures are less influenced by diagenesis, differential preservation of compound classes, and changes in the sources of organic matter that can complicate interpretations of bulk $\delta^{13}C$ values (e.g., Pancost and Boot, 2004).

The present study reconstructs broad-scale plant type changes in the VC-3 lacustrine sedimentary record using the abundance and carbon isotope composition of the long chain *n*-alkanes (C_{27}, C_{29}, C_{31}), which are unambiguous indicators of terrestrial vegetation. The molecular isotopic data presented reveal details of the response of southwestern North American vegetation to climate change during Pleistocene glacial/interglacial transitions (MIS 14/13 and MIS 12/11). We focus on changes in terrestrial higher plant inputs as well as the $\delta^{13}C$ signature of the leaf waxes, which can be attributed to terrestrial vegetation changes (i.e. C3 and C4 plants), through glacial/interglacial transitions where abrupt decreases in %TOC and $\delta^{13}C_{TOC}$ were interpreted as C4 vegetation decline by Fawcett et al. (2011). In addition, we increased the resolution of the temperature reconstruction based on MBT/CBT from VC-3 to evaluate differences between MIS 13 and MIS 11 in more detail than was possible by Fawcett et al. (2011). Such high-resolution temperature reconstructions are needed to understand the natural response of the Earth to climate change, and the VC-3 record is one of a few continental sedimentary records that span MIS 11 and 13.

2. Regional setting

2.1. Study site

The Valles Caldera complex formed as a result of a large shallow magma chamber eruption 1.23 million years ago (Ma) (Goff and Gardner, 1994). Post-caldera ring-fracture eruptive domes blocked drainages out of the caldera complex, forming several lakes after 0.8 Ma (Reneau et al., 2007). A lake formed in the Valle Grande (35°

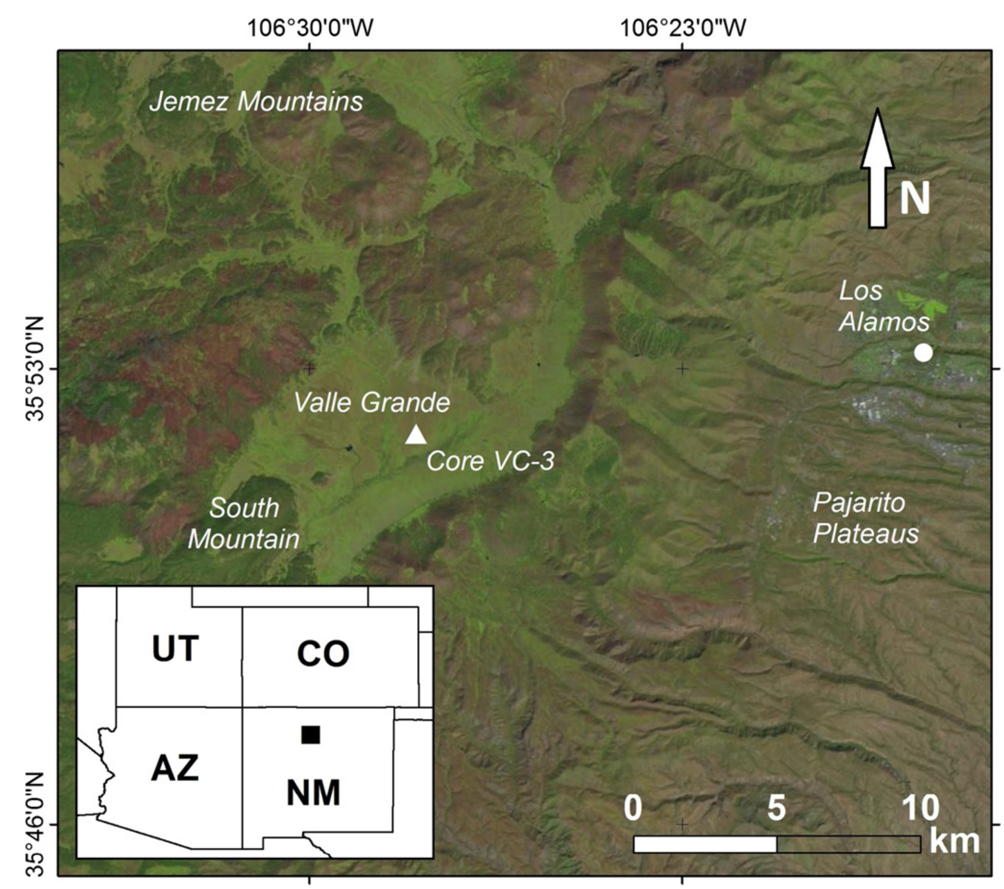

Fig. 1. Map of Valles Caldera in New Mexico showing location of drilling in Valle Grande (VC-3: 35° 52′ N, 106° 28′ W, 2553 m asl).