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Evidence for humid conditions during the last glacial from leaf wax patterns in the loess–paleosol sequence El Paraíso, Central Spain

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ABSTRACT

The Mediterranean region is affected by the first consequences of anthropogenic climate change and suffers from aridization and drought periods. Reconstructing past climate and environmental changes might help to put those consequences into context, identify underlying mechanisms and improve predictions. Here we present leaf wax analyses for the loess–paleosol sequence (LPS) from El Paraíso, located in Central Spain and a selection of plants growing there today. The long-chain *n*-alkanes in almost the whole LPS are characterized by the dominance of C_{29}, C_{31} and C_{33}, indicating the presence of grasses and drought-adapted tree species, such as *Juniperus* and *Olea*. However, samples correlated with marine isotope stage (MIS) 2 (~29–14 ka) have higher abundances of C_{25}, C_{27} and C_{29}, which may signal the presence of less drought-adapted deciduous trees and more humid conditions. *n*-Alkanoic acid patterns can tentatively be interpreted to confirm these results, but are less robust, because more plant species are needed for comparison. Our findings and interpretation are in line with climate modelling studies that suggest a southward shift of the westerlies and storm tracks during MIS 2, with fluvial and lacustrine records, and with glacial refugia for temperate trees in southern Europe. Compound-specific isotope analyses will hopefully soon provide additional information about paleoclimatic and -hydrologic changes and help establish a more precise and robust age control.

1. Introduction

Today's climate change is of great importance. Hardly a day goes by without reports about extreme weather phenomena like hurricanes, droughts and floods in some regions of the earth. To better understand the mechanisms and environmental consequences of recent anthropogenic climate change, it is indispensable to reconstruct past climate and environmental changes, especially in regions that already suffer today. More and more attention is being paid, for example, to the Mediterranean region, which is prone to droughts and affected by aridization (Giorgi and Lionello, 2008; Seager et al., 2014). Paleoclimatically, the Iberian Peninsula is a very interesting location, because its climate is influenced by the polar front, the storm tracks from the North Atlantic, the Mediterranean Sea, and by its proximity to Africa and Africa's monsoons (Bout-Roumazeilles et al., 2007; Lewis et al., 2009; Beghin et al., 2015).

Information from Iberia about past climate and environmental changes is sparse and contended. One controversy arose from findings that glaciers in some parts of Iberia may have already reached the maximum extent before the global Last Glacial Maximum (LGM: ~25–19 ka, Clark et al., 2009; e.g. Pallàs et al., 2006 and references therein; Lewis et al., 2009). Another long-standing controversy concerns the hydrological conditions during the LGM. Pollen records are traditionally interpreted as indicating more arid conditions, whereas lacustrine and fluvial records, as well as climate models, all suggest more precipitation (Prentice et al., 1992; recent reviews of Moreno et al., 2012; Moreno et al., 2014; Beghin et al., 2015 and references therein).

Increasingly, new and interesting insights may soon come from biomarker analysis in LPS. Compared to pollen records, which are mostly established from lake sediments and peat bogs (i.e. from specific topographical and microclimatological settings), biomarker records can provide valuable complementary paleoenvironmental information. This is because LPS occur on plateaus and in protected slope positions. Although pollen is often not preserved in LPS, some biomarkers are (Zhang et al., 2006; Zech

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et al., 2011). Loess is often interpreted as documenting glacial, cold and arid conditions, and paleosols as documenting more humid conditions during interglacials and interstadials (Garcia Giménez et al., 2012; Zech et al., 2013). However, variable dust accumulation rates need to be taken into account, which is why proxies independent of dust accumulation rate, such as biomarkers, are particularly valuable.

Long chain *n*-alkanes and *n*-alkanoic acids are essential constituents of epicuticula leaf waxes that are produced by all types of plants to protect them from water stress and microbial attack (Eglinton and Hamilton, 1967; Gülz, 1994; Eglinton and Eglinton, 2008). Because of this protective function, leaf waxes can be highly inert; hence, they can be preserved in soils and sediments over geological timescales and serve as biomarkers. Numerous studies have investigated the chemotaxonomic potential of leaf waxes (Cranwell, 1973; Ficken et al., 1998; Maffei et al., 2004; Rommerskirchen et al., 2006; Zech et al., 2009; Zocatelli et al., 2012Schäfer et al., submitted for publicationSchäfer et al. submitted for publication). Higher abundances of the *n*-C_{27} and *n*-C_{29} alkanes have been found to be characteristic for deciduous trees and shrubs, while the longer alkane homologues *n*-C_{31} and *n*-C_{33} are more abundant in grasses and herbs. We recently conducted a transect study in Central Europe and were able to confirm this pattern (Schäfer et al., submitted for publicationSchäfer et al., submitted for publication). Moreover, we found the *n*-C_{24} alkanoic acid to be particularly abundant under coniferous trees, the *n*-C_{28} alkanoic acid under deciduous trees, and grasslands to have relatively high amounts of *n*-C_{32} and *n*-C_{34} (Schäfer et al., submitted for publication). Leaf wax production and homologue patterns can be highly variable, even within plants belonging to the same vegetation type (Diefendorf et al., 2011; Bush and McInerney, 2013; Schäfer et al., submitted for publication). Therefore, vegetation reconstructions (i) should be evaluated against leaf wax patterns at a regional scale, and (ii) might be biased or even flawed due to specific species. Climate conditions, such as changes in temperature, precipitation and relative humidity, may influence the homologue patterns (e.g. Poynter, 1989; Sachse et al., 2006; Tipple and Pagani, 2013; Bush and McInerney, 2015). Nevertheless, leaf waxes have been successfully applied in many paleostudies (e.g. Brincat et al., 2000; Schwark et al., 2002; Zhang et al., 2006; Zech et al., 2010; Tarasov et al., 2013).

For this study we analysed *n*-alkanes and *n*-alkanoic acids in the LPS El Paraíso, as well as in some plants growing at and near that site. The objectives of our study were (i) to test whether or not leaf wax patterns of local common plants are in line with homologue patterns typical for vegetation types in Central Europe; and (ii) to use the leaf wax patterns in the LPS El Paraíso to infer changes in paleoenvironmental conditions during the Late Quaternary in Central Spain.

2. Regional setting, climate and vegetation

2.1. Regional setting

The LPS El Paraíso (560 m a.s.l., N 40° 01.855′ W 03° 28.031′) is located east of Aranjuez (Fig 1a) on north facing slopes that mediate between the Mesa de Ocaña and the incised river valley s of the Tagus River. The Tagus is the longest river of the Iberian Peninsula and it has the third largest catchment area (Benito et al., 2003). The Tagus Basin evolved during the Tertiary with thick successions of alluvial fan material and lacustrine deposits (Calvo et al., 1996). These sediments consist of evaporites that are assigned to the Miocene Lower Unit and the Miocene Intermediate Unit. The sediments of the Miocene Upper Unit are transformed into conglomerates and lacustrine limestones (Garcia Giménez et al., 2012 and references therein). After intense dissection of these basin deposits, Pleistocene and Holocene deposits have accumulated above the Miocene marls (Roquero et al., 2015; Wolf and Faust, 2015). Today, these Quaternary sediments are mainly exposed along the valley floor and the remains of river terraces where also the main loess outcrops occur (Fig. 1b; Garcia Giménez et al., 2012).

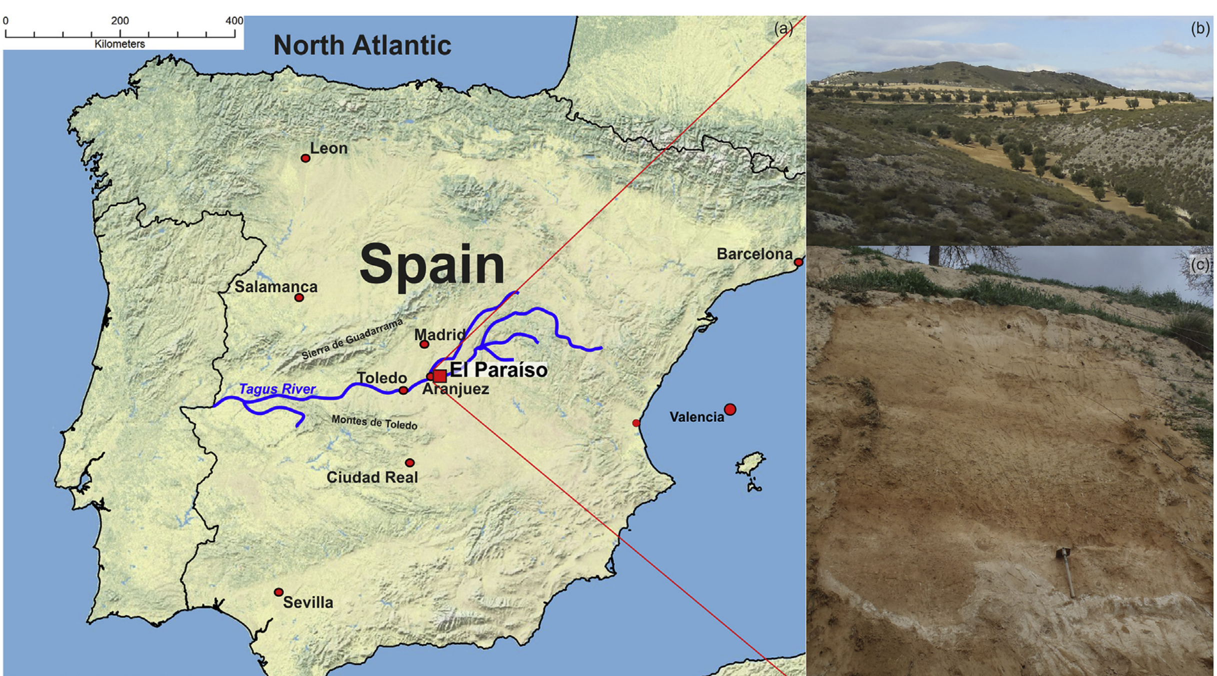

Fig. 1. (a) Map of the sample location, (b) photograph of the research area and (c) the LPS El Paraíso.