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Orbital-scale environmental and climatic changes recorded in a new ~200,000-year-long multiproxy sedimentary record from Padul, southern Iberian Peninsula

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A B S T R A C T

Padul is one of the few wetland sites in southern Europe and the Mediterranean region that exhibits an unusually large temporal span (>100 kyr) and continuous Quaternary sedimentary record. Previous core-based studies from Padul yielded paleoecological datasets (i.e., pollen and organic geochemistry), but with a poor age control that resulted in rather arbitrary climate inferences. Therefore, precise age control and a multidisciplinary approach is necessary to understand long-term regional environmental and climate change and the associated local response of the Padul wetland environment. Here we present a new long sediment record (Padul-15-05) from this wetland in the southern Iberian Peninsula with the aim of improving the age control of the sedimentary sequence and carrying out up-to-date high-resolution multiproxy analyses. In this study the age control is based on 61 AMS radiocarbon dates for the last ca. 50 kyr BP and on the extent of amino acid racemization (AAR) in mollusc shells extending back ~118 kyr BP. No numerical ages are available for the bottom part of the core but the sediment accumulation rates (SAR) and the cyclostratigraphic analysis of the multiproxy data suggest that the core preserves a continuous record of the last ~197 kyr (from late MIS 7 to present) with millennial-scale time resolution. Sedimentological (lithology, magnetic susceptibility, XRD, color), geochemical (XRF, TOC, C/N, % carbonate content) and paleontological (pollen, charophytes, gastropods) data show co-varying cyclical paleoenvironmental changes linked to orbital-scale climatic variability. Silicon, magnetic susceptibility (MS) and total organic carbon (TOC) data show periodicities between ~26.2–19.6 kyr linked to insolation, which is strongly dominated by precession cycles at this latitude. High values of Si and MS data have been related to high siliciclastic/detrital input from Sierra Nevada range during minima in insolation due to enhanced soil weathering/erosion during regional aridity and lower forest cover recorded by the arboreal pollen, which could also be favored by a minor biogenic productivity. In addition, warm climate conditions during maxima in insolation mostly resulted in negative precipitation/evapotranspiration balance and low lake levels, while cold glacial and stadial periods were mainly characterized by positive precipitation/evapotranspiration balance, and therefore, high lake levels. The improved chronology of the Padul sedimentary sequence along with a multiproxy study permitted us to better relate

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environmental and vegetation changes to climatic events and to demonstrate how both local (i.e., lake level, sedimentation) and regional (i.e., vegetation) environments responded to orbital-scale climate changes.

1. Introduction

Climate during the Quaternary has oscillated between glacial and interglacial conditions in response to Earth's orbital cycles. Long paleoenvironmental records are necessary to investigate recurrent climatic or paleoenvironmental changes occurring with a certain periodicity (e.g., glacial-interglacial cycles). Over the last few decades, a significant effort has been made to understand climate and environmental variability during the Quaternary in southern Europe and the Mediterranean region. A handful of continuous long terrestrial sedimentary sequences recording more than 100 kyr have been studied in the Mediterranean region, including well-known sites such as Lago Grande di Monticchio (Italy; Watts et al., 1996; Allen et al., 1999, 2000), Ioannina lake (Greece; Tzedakis et al., 2002, 2003a), Tenaghi Philippon (Greece; Wijmstra, 1969; Tzedakis et al., 2003b, 2006; Pross et al., 2015), Lake Ohrid (Macedonia/Albania; Wagner et al., 2014, 2017; Francke et al., 2016), Lake Van (Turkey; Litt et al., 2014) and Yammoûneh (Lebanon; Develle et al., 2011). These studies, together with other high-resolution multiproxy studies in long marine sedimentary cores from the nearby Alboran Sea (Combourieu-Nebout et al., 2002; Martrat et al., 2004; Fletcher and Sánchez-Goñi, 2008), reveal the high sensitivity of this region for recording orbital and millennial-scale climate variability. These multiproxy studies offer a plethora of paleoclimate and paleoenvironmental data to assess ocean-atmosphere linkages and examine local, regional and global climate patterns. However, in the Iberian Peninsula a limited number of long (>100 kyr) and continuous terrestrial sedimentary records have been described, including Villarquemado (González-Sampériz et al., 2013; García-Prieto, 2015), Carihuela Cave (Fernández et al., 2007), Fuentillejo maar lake (Ortiz et al., 2013) and Padul (Florschütz et al., 1971; Nestares and Torres, 1998).

The Padul wetland in southern Iberian Peninsula (Fig. 1) is an indispensable site for understanding past glacial/interglacial climate variability in the Mediterranean region due to its sensitive location between temperate and humid climate to the north and the subtropical and arid climate to the south. The Padul wetland has one of the longest and most continuous sediment records of southern Europe, with more than 100 m of peat and lacustrine sediments deposited over the last ~1 Ma (Ortiz et al., 2004a, 2010). Previous palynological studies from the Padul wetland (Menéndez-Amor and Florschütz, 1962, 1964; Florschütz et al., 1971; Pons and Reille, 1988) revealed a climatically induced regional vegetation changes during the late Quaternary, although noticeable discrepancies in the interpretation of the pollen data due to age control uncertainties demands further investigation. Florschütz et al. (1971), based on pollen data, suggested that sediment from the Eemian interglacial (MIS 5e, ~115–130 kyr BP) was reached at 24 m depth and that sequence extended back to the Holsteinian interglacial (MIS 11, ~350–400 kyr BP) at the base of their core at 70 m depth. On the contrary, Pons and Reille (1988), with very similar pollen data, interpreted the base of their core at 24 m depth as representing the first Prewürm interstadial (i.e., MIS 5c), not showing any other interglacial period apart from the Holocene for the upper 24 m. These different correlations of the vegetation changes to climatic events are mostly a consequence of the poor chronologic control of the different sediment cores. In particular, Florschütz et al. (1971) used the age control of a nearby sediment core from Menéndez-Amor and Florschütz (1964) that was based on only 14 radiocarbon dates (with a maximum age of 54 kyr BP), assuming the same sediment accumulation rates for both cores. Using age information based only on radiocarbon dating, they tried to reconstruct the vegetation of the last ~400 kyr. With respect to the study from Pons and Reille (1988), the vegetation results and interpretation of the last ~ 100 kyr is based only on 17 radiocarbon dates with a maximum age of 29,300 ± 600 years BP. A more recent core retrieving a 100 m-long sedimentary sequence was taken in Padul in 1997 (Nestares and Torres, 1998), from which Ortiz et al. (2004a, 2010) studied the organic geochemistry and lithology. In this core, the age control for the upper part of the core was based only on 9 radiocarbon dates with a maximum age of 17,300 ± 500 years BP. The older part of the core was dated using a combination of AAR, U/Th and paleomagnetic information. However, the AAR dating was based on the D/L ratios of several amino acids from different locations of southern Spain and not from the specific Padul wetland Ortiz et al. (2004a, b). Moreover, the U/Th results used for the older ages have to be taken carefully due to the problematic behavior of the U-series in open peatland and lake systems as recently outlined by Sierralta et al. (2017). Finally, Ortiz et al. (2004a, b) did not provide the paleomagnetic results from the Padul record, so the boundary between the Matuyama and Brunhes magnetozones is difficult to identify. In addition, their results were interpreted as local paleoenvironmental and paleohydrological changes at moderate to low temporal resolution, and the lack of additional multiproxy data limited their interpretation and linkages to global climate changes.

Therefore, improving the age control using higher resolution (61 radiocarbon dates) updated dating methodologies (AMS radiocarbon dating, including compound-specific radiocarbon dating, and AAR dating based on gastropods from Padul) and increasing the resolution of multiproxy analyses (i.e., lithology/facies, mineralogy, inorganic/organic geochemistry, magnetic susceptibility, palynological analysis) from the Padul sedimentary sequence were necessary to solve previous inconsistencies, facilitating the investigation of the response of the environment to rapid events and allowing more accurate correlations between millennial-scale paleoenvironmental changes with orbital- and suborbital-scale climate variability. In addition, a principal component analysis involving different multiproxy datasets (i.e., inorganic and organic geochemistry and magnetic susceptibility) under a well-constrained chronology was still imperative in order to obtain more accurate lake level estimations.

In this study we present a high-resolution multiproxy record from a new ~43 m-long core, Padul-15-05, taken from the Padul wetland. This study complements a previously published high-resolution paleoenvironmental and paleoclimatic record of the uppermost 3.67 m Holocene section of the Padul-15-05 core (Ramos-Román et al., 2018a; b). This new core was studied with the goals of (1) generating a highly resolved and robust age control and (2) obtaining new paleoenvironmental information at higher sampling resolution, integrating up-to-date geological, biological and geochemical proxies that were lacking from previous studies.