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Late Pleistocene–Holocene palaeoenvironmental evolution of the Añamaza River valley (Iberian Range, NE Spain): Multidisciplinary approach on the study of carbonate fluvial systems

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ABSTRACT

The uppermost Pleistocene and Holocene palaeoenvironmental evolution of the Añamaza river valley (Iberian Range, NE Spain) is deduced using multidisciplinary approach including stratigraphical, mineralogical, palynological, geochemical, geophysical methods and drilling. Main changes were registered in distinct subenvironments of a carbonate fluvial system, including the channelled zone and wetlands in the floodplain.

Tufa barrages dominated although pools also existed. Geophysical survey and coring reveal tufa buildups and pool facies also in the subsoil. Lower water temperature and scarce evaporation are deduced for the Pleistocene fluvial system that progressively changed through the Holocene, with more hydrologically closed areas and higher evaporation influence. A general aggrading evolution during warm stages related with increasing base level and damming due to fast carbonate precipitation, characterised the Holocene. Detrital tufa indicates erosive high-energy floods or colder stages when water level would decrease favouring erosion. ^{14}C and ^{230}Th/^{234}U dating reveal high sedimentation rates and three main discontinuities related with cold episodes: Younger Dryas, middle part of the Holocene Climate Optimum and Iron Age Epoch. During the uppermost Pleistocene tufa growth would be enhanced during warmer episodes as the Bølling/Allerød. In the Younger Dryas scarce vegetation favoured erosion of both, slopes and tufa constructions. Subsequent warmer temperatures during the first part of the Holocene favoured vegetated slopes, enhanced tufa growing (although interrupted in the middle part of the Holocene Climate Optimum), and development of wetlands with riparian vegetation in the floodplain, where either siliciclastics or detrital tufa incoming alternated with low-energy waters stages and mud settling. Progressive decline in tufa is deduced for the upper Holocene but it is not possible to determine whether this, and other palaeoenvironmental changes were related either to climate or increasing human activities. During the Roman and Medieval Warm Periods more oxidizing conditions in the wetlands and increasing erosion prevailed, probably conditioned by human activities.

The pollen record shows for the Early Holocene development of Pinus forest with Betula, and expansion of deciduous Quercus, xerophilous and heliophilous grassland. Subsequent increasing moisture supported open forests with deciduous (Quercus, Ulmus, Corylus) and evergreen (Quercus ilex, Pistacia) species. From ca.4000 yrBP, a dominant deciduous Quercus forest with groves of Corylus, Ulmus, Acer, Fagus and Taxus expanded and human activities (grazing) occurred. From 1200 yrBP dry grassland expanded due to intensive land use (agropastoral activities). Almost completely deforested plateaus surround the site today with slopes covered by patchy grass with junipers groves and screeds with little soil.

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1. Introduction

Ancient fresh water carbonate fluvial systems have been profusely studied all around the world mainly by analysing their most common and best preserved deposits: fluvial tufa constructions. A common topic on fluvial tufa systems studies has been sedimentology, with the main aim to recognize and interpret lithofacies and lithofacies associations and to propose coherent sedimentological models (Ordóñez and García del Cura, 1983; Pedley, 1990, 2009; Ford and Pedley, 1996; Zamarreño et al., 1997; Martín Algarra et al., 2003; Ordóñez et al., 2005; Carthew et al., 2006; Vázquez Urbez et al., 2010; Arenas et al., 2014; García-García et al., 2014). In fluvial systems fitting with the barrage/pool model (Pedley, 1990, 2009; Ford and Pedley, 1996), other kind of deposits mostly generated in the fluvial floodplains (e.g. detrital tufa and mud) are rarely studied due to their scarce preservation potential: they are highly erodible facies intensely exposed to erosion during entrenchment stages (Ordóñez et al., 2005; Ortiz et al., 2009). Climate has been traditionally considered the main control factor on active tufa generation, which is favoured during warm and wet episodes (Pedley et al., 1996; Andreo et al., 1999; Horvatinčić et al., 2000; Zak et al., 2002; Martín Algarra et al., 2003; Pedley, 2009; Sancho et al., 2015). Nevertheless, tufas also develop in other climate regimes (Willing, 1985; Pedley, 2009). Moreover, water level fall stages associated fluvial downcutting or destructive floods, cause often erosion of previous sediments (Vaudour, 1986; Taylor et al., 1994; Carthew et al., 2003; Ordóñez et al., 2005) and for this reason identification of sedimentary hiatuses in the series can be of equal importance on the study of palaeoenvironmental changes.

In any case, carbonate fluvial systems dynamics is not only climate-dependent and it is widely known that can be controlled by other factors, both natural or antrophic (Bell and Walker, 1992; Pentecost and Viles, 2007; Goudie et al., 1993; Viles and Pentecost, 2007; Capezzuoli et al., 2014), which can strongly complicate the knowledgement of the system and avoid correct palaeoenvironmental interpretations to be attained. For these reasons, during the last years, new research fields highlight the great importance of fluvial carbonates not only on the study of climate (Andrews et al., 1997, 2000; Kano et al., 2004; Andrews and Brasier, 2005; Capezzuoli et al., 2010; Luzón et al., 2011) but also of hydrological changes (Golubić, 1969; Kano et al., 2007; Auqué et al., 2013), tectonic setting (Sbeinati et al., 2010; Pazzaglia et al., 2013; Ascione et al., 2014; Henchiri, 2014; Camuera et al., 2015) or anthropogenic influence (Goudie et al., 1993; Limondin-Lozouet et al., 2010) in the area where this kind of facies have developed. For the moment, most of the studied fluvial tufas are Quaternary in age as, commonly, only fragmentary erosional remnants of the fluvial system preserve (Pedley, 2009; Capezzuoli et al., 2014). In this sense, the study of fluvial carbonate systems has benefited greatly during the last years of the use of coring methods (Pedley et al., 1996, 2000; Ordóñez et al., 2005; Sbeinati et al., 2010) or shallow geophysical techniques that allow to better define internal geometries and not outcropping sectors to be studied (Pedley et al., 2000; Pedley and Hill, 2003; Pérez et al., 2012).

The present work is focused on the study of non-outcropping deposits belonging to a carbonate fluvial system developed during the Late Pleistocene–Holocene in the central Iberian Range (Spain), and the interpretation of the main palaeoenvironmental changes occurred in the area. Tufas in the channelled area have been considered, but also detrital tufas and mud deposits in the floodplain. The innovative aspect is that a multidisciplinary approach including stratigraphical, palynological, geophysical, geochemical and mineralogical studies all together has been followed on the study of different parts of the system, which difficult, but reinforce, palaeoenvironmental interpretations as they fit with all the considered proxies and have been registered in different parts of the system.

2. Geological setting

The Añamaza River valley is located in the central area of the Iberian Range (Fig. 1). The geological succession in the region is mainly Mesozoic (Middle Jurassic-Lower Cretaceous) and Tertiary in age. The Mesozoic is represented by the carbonate Chelva Formation (Middle Jurassic), the terrigenous Tera Group (Jurassic–Cretaceous transition) and the carbonate Oncala Group (Cretaceous). Conglomerates, lutites and limestones integrate the Tertiary series, which lies subhorizontal and unconformably on the Mesozoic rocks. Winter temperatures in the region are low (December and January mean temperatures below 4 °C) and summers relatively warm (August mean temperature 19.9 °C). The average annual rainfall is about 600 mm although there is significant inter-annual variability. During the summer months, the subtropical Azores anticyclone blocks moisture transport from the west. The vegetation dominant species in the heights are *Quercus ilex* and *Quercus rotundifolia* as well as *Quercus faginea* and *Quercus canariensis*, whereas at lower altitude *Erica spp*, *Juniperus spp, Poaceae* and *Thero-Brachypodietea* predominate.

The studied fluvial deposits form part of a Late Pleistocene–Holocene complex sedimentary system (Luzón et al., 2011) integrated by alluvial fans, passing downstream to a shallow lake (Añavieja Lake). Lacustrine deposits are represented by black and brown muds related to settling and carbonate precipitation. Both, alluvial fans and lake were located upstream the area where this study is focused. Downstream the lake, several stepped tufa barrages separated small lakes or natural pools, or slow flowing areas (Sáenz and Sanz, 1989; Coloma et al., 1996; Pérez et al., 2010; Luzón et al., 2011; Arenas et al., 2014). The sedimentary system had a catchment area of about 140 km^2 and water supplies included superficial discharges, but mainly groundwater (Coloma et al., 1996). Groundwater supplies to the Añamaza River come from the Jurassic aquifer; in fact, conductivity values (600–900 µS/cm) and bicarbonate-sulphate calcium composition of this aquifer show clear similarity with the Añamaza River water. On the contrary, groundwater in the Quaternary aquifer has a predominantly sulphate calcium composition and higher conductivity values (1000–1400 µS/cm). Springs mainly concentrate in two zones: i) close to Añavieja village, at 960 m.a.s.l (Fig. 1). supplying a flow of 160 l/s, and ii) close Dévanos village, at 950 m.a.s.l., with 40 l/s (Coloma et al., 1996). Tufa deposits in the area are considered to have formed discontinuously from the Miocene to the Holocene. Arenas et al. (2014) proposed a detailed lithofacies classification for the Pleistocene and Holocene tufas and two different fluvial models related respectively to moderate and high slope reaches of the valley. The moderate-slope model that these authors consider representative for the Holocene, included extensive standing-water areas dammed by barrage-cascades; the high-slope model, consisted of small slow flowing areas between cascades and barrage-cascades. The Holocene tufas are located slightly higher than the present course of the river (Luzón et al., 2011; Auqué et al., 2013; Arenas et al., 2014).

3. Methodology

Different methods have been used for the study of the Añamaza fluvial carbonate deposits, in order to test and compare the potential of distinct sediments as palaeoenvironmental registers. As previously indicated, sedimentary facies analysis was the focus of previous works by Luzón et al. (2011) and Arenas et al. (2014); the

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