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Western Mediterranean environmental changes: Evidences from fluvial archives

Daniel Wolf*, Dominik Faust

Technical University of Dresden, Germany

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ABSTRACT

When dealing with current and past landscape evolution, a key issue addresses responses of geomorphic systems to the large number of influencing variables. Identifying morphodynamic phases and revealing interrelations with specific driving forces are demanding tasks for Quaternary research. In this paper, we present late Pleistocene and Holocene fluvial sedimentation patterns of three Western Mediterranean river catchments, namely Jarama River, Guadalete River and Guadalquivir River that extent along a climatic transect from semi-humid SW-Spain to semi-arid central Spain. These studies are based on extensive fieldwork conducted on 36 exposures and 13 drillings in floodplain positions. Field data is supported by geochemical analyses, while the chronological framework was obtained from the analyses of 70 radiocarbon samples. Results show distinct patterns of fluvial sedimentation as well as soil formation linked to floodplain stability for each river catchment. On regional or catchment scale, pollen stratigraphical correlation and comparison with lacustrine records show that fluvial dynamics have a strong reaction to climatic shifts, with phases of high fragility characterized by catchment erosion and floodplain sedimentation in response to climatic aridification events and phases of climate change in general. The comparison of the examined river systems reveals that periods of supra-regional floodplain sedimentation in several catchments occurred from 8.0 to 7.0, 5.0 to 3.8, 2.2 to 1.5, and around 1.0 as well as 0.4 ka cal. BP, while we found periods of supra-regional soil formation from 13.3 to 12.7, 7.0 to 5.1 (with a short interruption around 6.0 to 5.5 ka), 2.8 to 2.3 ka, 1.4 to 1.2 ka, and 0.8 to 0.5 ka cal. BP. Beside these consistencies we found deviating dynamic patterns that are apparently expressed in terms of differing onset and offset, differing durations, or even the lack of fluvial system response. The main reasons for this can be seen in different regional climate condition and impacts of further influencing factors, or in different levels of sensitivity of the river catchments that may be controlled by initial hydrological conditions, catchment size, or the degree of anthropogenic influence. A larger scale assessment shows that fluvial dynamic patterns are hardly comparable across entire Spain due to strong spatial heterogeneity of physiographic and climatic conditions on the Iberian Peninsula, in particular when areas are influenced by different circulation systems (e.g. regions influenced by the Atlantic Ocean vs. regions influenced by the Mediterranean Sea). However, the consideration of North Atlantic marine records reveals a certain coupling between North Atlantic coolings, atmospheric processes leading to arid climate over large parts of Spain, as well as increased landscape instability including strong fluvial sedimentation activity. Attendant atmospheric conditions are discussed.

1. Introduction

Archive investigation for the purpose of environmental and climate change is a highly acclaimed research field in the geosciences for several decades now. Given the variety of terrestrial records (see e.g. Magny, 2004; Mayewski et al., 2004; Wanner et al., 2008; Fletcher and Zielhofer, 2013; Moreno et al., 2014) that are used to investigate climatic shifts and their impact on the environment in the past, fluvial archives may play a specific role, since river systems respond to a multitude of environmental influences. Among the various kinds of fluvial archives, especially floodplain records that mainly consist of overbank fines are assumed to be sensitive towards catchment behavior (e.g. Lane and Richards, 1997; Blum and Törnqvist, 2000; Vandenberghe

* Corresponding author.
E-mail address: daniel_wolf@tu-dresden.de (D. Wolf).

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et al., 2010) as they inhere a wide range of fluvial processes that take place in a river catchment. For the build up of cohesive floodplain records generally two things are needed: (1) sediment delivery from the catchment that requires superficial soil erosion, and (2) a certain degree of transport capacity for shifting eroded material to floodplain positions. This concept is complicated by a series of non-linear dependencies (see e.g. Walling, 1983; de Vente et al., 2007) but describes the fundamental significance of floodplain records. A basic question is to what degree and in which manner fluvial dynamics are driven or at least influenced by climatic factors. Aggravatingly, potential effects of climate are overprinted by tectonics, base-level changes, anthropogenic impact or intrinsic forcing (Schumm, 1973; Pope and van Andel, 1984; Blum and Törnqvist, 2000; Vandenberghe and Maddy, 2001; Hoffmann et al., 2009; Vandenberghe et al., 2010; Cordier et al., 2014), preventing to deduce direct relationships between climate and fluvial dynamics. Considering the variety of parameters, the interpretation of fluvial archives is a difficult matter, particularly in view of problems like equifinality, divergence or multiplicity as already Schumm (1991) pointed out. However, the feasibility of climatic interpretation of fluvial records could be convincingly demonstrated (Törnqvist, 2007; Fletcher and Zielhofer, 2013; Wolf et al., 2013; von Suchodoletz et al., 2015), although a careful handling of non-climatic parameters is obviously needed. Apart from assessing the specific reaction of fluvial systems and landscapes on climate influences (e.g. dynamic patterns in relation to the gradient of climate change), outstanding issues relate to system connectivity and system response times, not only in a spatial context but likewise concerning interdependencies of climate, vegetation, soil and geomorphological systems. Another pending question belongs to the spatial variability of landscape dynamics, or more precisely, how reliable are local or regional findings when they are placed in a supra-regional context? The spectrum ranges from regionally specific dynamics proceeding on rather small spatial scales, to supra-regional dynamics that take place across long distances. In view of the regional heterogeneity of physiographic configurations on the Iberian Peninsula it is conceivable that even large-scale climatic impulses induce divergent system responses in different environmental conditions, which, for example, should appear in form of diverging fluvial dynamics in various river catchments.

In order to examine floodplain records for the purpose of reconstructing palaeoenvironments and stages of landscape evolution, floodplain sediments of selected river catchments in Spain have been investigated (see also Wolf et al., 2013, 2014). Due to its fragility concerning climate changes and related earth shaping processes, the Western Mediterranean realm is particularly well suited for such research. The main objective was to obtain a solid fluvial stratigraphy for each river catchment based on a sufficiently large number of studied profile sections to minimize elements of randomness and singularity. Based on this, fluvial sedimentation histories supported by reliable chronological resolution should enable a direct comparison with other archives of environmental relevance in a regional context. In this way, it should be possible to assess the fluvial response on changes of external parameters, respectively to identify driving forces behind fluvial dynamics. Particularly challenging in this context is to shed some light on the constantly recurring question, whether flooding and floodplain aggradations take place in times of arid or rather in times of humid climate conditions (see review in Fletcher and Zielhofer, 2013). The examined river systems are recently situated in areas of different annual values of precipitation. A comparison of the different fluvial dynamic patterns should on the one hand allow to consider the geographic scope of fluvial dynamics and determining factors and, on the other hand, permit to assess the importance of initial precipitation regimes for kind and character of fluvial responses including response time and duration.

In this study, new results are presented that, together with findings already shown in Wolf et al. (2013, 2014), will be intensively discussed to address above-mentioned issues.

2. Study area

The studied catchments of the rivers Guadalete, Guadalquivir and Jarama are distributed along a transect reaching from the semi-humid southwestern part of Andalucía (SW-Spain) to the semi-arid area of the eastern Tajo Basin (Central Spain) (Lautensach, 1964) (Fig. 1A). All catchments are connected to Atlantic river basins and are therefore hydro-climatically influenced by Atlantic air masses that may provide intense rainfall during winter season, especially in case of negative North Atlantic Oscillation (NAO) modes (Trigo et al., 2004). The climate shows a significant gradient and becomes gradually more continental with annual temperature amplitudes of 13–16 °C in the Guadalete catchment and 19–21 °C in the Jarama catchment (Lautensach, 1964). Mean annual precipitation is very inhomogeneous on catchment-scale due to strong altitudinal contrasts but generally decreases further inland. In the Guadalete catchment close to the Atlantic Ocean, precipitation varies from 646 mm/a in Jerez de la Frontera (36°45′N/06°04′W) (Sträßer, 1998) nearby the coastline to more than 2000 mm/a in the Sierra de Grazalema (Hidalgo-Muñoz et al., 2011). In the Jarama catchment large parts of the Madrid Basin point to annual precipitation of 400–500 mm, with 456 mm in Madrid (40°25′N/03°41′W) (Sträßer, 1998) but in the upper part of the Sierra de Guadarrama precipitation rises to 1400 mm/a (Palacios et al., 2012). The Guadalquivir Basin with an area of about ~57,000 km^2 offers a wide range of climatic conditions and precipitation varies from 400 to 500 mm/a e.g. in the basins of Loja and Baza to more than 1400 mm/a in the Betic Range (Anderson et al., 2011).

2.1. Jarama River

The Jarama River drains a catchment area of ~11,500 km^2 that is located in central Spain (Fig. 1A). It originates in the Sierra de Guadarrama at 2120 m above mean sea level (MSL) and after a total flow length of some 180 km it converges with the Tajo River at 485 m MSL. The greater part of the catchment is taken up by the Madrid Basin, a tertiary depression between altitudes of 500–800 m (MSL) that was filled up with several hundred meters of Miocene sediments. With a concentrical arrangement these sediments consist of arkosic alluvial fan material in the outer parts, followed by calcareous marls, and finally evaporitic gypsum marls in the center (Calvo et al., 1996). Towards the northwest, the basin is bordering the Spanish Central System, where igneous and metamorphic rocks reach elevations up to ~2400 m MSL. Towards the northeast the catchment is framed by Mesozoic rocks of the Iberian Range. Since the middle Miocene the Madrid Basin is subject to severe tectonic activity linked to large-scale Betic compressions (Andeweg et al., 1999). Corresponding fault lines and flexures are generally orientated NE–SW and determine the pathways of the fluvial drainage network (e.g. Fig. 1C). Moreover, mapped fault lines across the river valley with associated knickpoints of the valley floor (Silva et al., 1988) give evidence for seismic activity during the Pleistocene (de Vicente et al., 2007) and on a moderate level until today (Tejero et al., 2006). Since the lower catchment is dominated by gypsum marls strongly vulnerable to bulging and solution processes, widespread indication of halokinetic deformation occur along the river valleys. Along its lower reach, the Jarama River actually incised up to a depth of 60–80 m into gypsum marls, leading to steep escarpments. Here,