Earth-Science Reviews 174 (2017) 53–83

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Interpreting drivers of change in fluvial archives of the Western Mediterranean - A critical view

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ARTICLE INFO

Keywords:
Fluvial behavior
Palaeoenvironmental reconstruction
Climate forcing
Human impact
Terrestrial archives
Spain
Tunisia

ABSTRACT

Fluvial archives, in particular, late glacial to Holocene floodplain records may provide valuable information regarding past environmental conditions and stages of landscape evolution. In view of the high significance of floodplain dynamics for the development of entire landscapes, the number of studies that have been performed on floodplain sediments remains comparatively low, especially regarding the Western Mediterranean region. However, one of the reasons could be seen in the high complexity and diversity of processes and factors that control and influence fluvial activity that often hampers a straightforward interpretation of floodplain dynamics. Therefore, a basic demand on fluvial archive research is to address the complexity of the factors that control the characteristics of fluvial sequences in order to provide a robust basis for their interpretation.

As a starting-point for discussion this paper aims to give an overview of fluvial dynamic patterns in the Western Mediterranean for the last 15 ka in order to examine their relevance for palaeoenvironmental reconstructions. The basis for this is provided by previous investigations on four different river systems in Spain and northern Africa the results of which are herein synthesized in order to propose a regional Late Pleistocene and Holocene fluvial history for the Western Mediterranean realm. Basic results are related to alluvial floodplain deposits and visible features within them such as alluvial soils, incision marks and aggradation phenomena. Since fluvial systems are open systems, we discuss our findings against the background of different influencing factors that could modify fluvial architecture and may restrict palaeoenvironmental reconstructions. A more comprehensive interpretation focuses on signals that are common to each of the studied river systems. In this respect, we critically discuss the customary nature of cumulative probability functions for the identification of regional flooding episodes and point out the benefits of a stratigraphy-supported approach for characterizing regional floodplain dynamics. Finally, three alluvial soil formation periods were found in all settings: a first phase after 15 ka, ending with the Younger-Dryas Event; a second one from 7 to 5 ka with a break between 6.5 and 5.5 ka, and a third phase between 3 and 2 ka. These soil formation periods were interrupted and framed by fluvial dynamic phases accompanied by channel aggradation, floodplain deposition, floodplain erosion and/or river incision. In particular, after 5 ka, around 1.6 and at 1 ka, and during the Little Ice Age (LIA) floodplain aggradation affected river systems in Iberia and northern Africa as well. A cautious assessment of these results and extensive comparisons with secondary archive information prompts us to relate the aggradation periods with climate forcing by means of a supra-regional aridification that effected large areas of the Western Mediterranean. In contrast, the three mentioned soil formation periods can be linked with landscape stability, most probably triggered by favorable climate conditions in the Western Mediterranean.

Apart from these large-scale patterns we discuss the reliability of information emerging from floodplain records against the background of individualistic river behavior and self-organization. Regarding future work we want to emphasize the great potential of yet rarely applied system-oriented approaches that also attach importance to sub-catchment dynamics as a link between catchment slopes and the main river floodplain.

1. Introduction

In 1991, Stanley A. Schumm published a book, in which he pointed to pitfalls in the way that we interpret the earth. In particular, if we deal with open systems such as fluvial systems, all of which have unique configurations of geo-parameters in their catchments and different catchment sizes, the interpretation of fluvial archives in terms of palaeoenvironmental reconstruction may increase the risk of misleading

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http://dx.doi.org/10.1016/j.earscirev.2017.09.011
Received 19 April 2016; Received in revised form 6 September 2017; Accepted 14 September 2017
Available online 28 September 2017
0012-8252/

conclusions. In this respect, key issues for the robust interpretation of fluvial archives are the problems of scale and place, the problems of cause and process, and the problems of system response and complexity (see Brunsden, 2001; Harvey, 2002; Schumm, 1991; Thomas, 2001). Following these concepts, we need to discuss phenomena of different catchment sizes, problems of singular occurrences, or phenomena of convergence and divergence (e.g. Phillips, 2014). On the one hand convergence means that we see identical features in all river deposits (e.g. incision in all river systems) that may have several causes and on the other hand divergence means that we observe different results (e.g. flooding in one and incision in the other river system) that could be related to the same causes. This awareness makes analogies almost impossible (see Phillips, 2007). A key prerequisite to approach these problems and to attain the basis for any deeper interpretation is to create an appropriate and reliable data base of fluvial response by characterizing fluvial architectural patterns based on a large number of individual profile sections over long distances. This enables single phenomena (aggradation phases, incision phases etc.) to be placed in the context of the overall stratigraphy of the catchment and, consequently, to develop a secured and representative standard stratigraphy (Dusar et al., 2012). As a simple rule of thumb, the more profiles that are taken, the better the resolution and the more robust the interpretation will be. Beyond a suitable data base, a reasonable interpretation is perhaps the most challenging part when working with fluvial archives, considering the multitude of factors and their multifaceted interrelationships.

With this in mind and based on the suggestions of Schumm (1991) we once again critically considered the detailed findings on the fluvial history of three different river systems in the Western Mediterranean, namely the Jarama River in central Spain (Wolf et al., 2013; Wolf and Faust, 2015; Wolf and Faust, 2016), the Guadalete River in southwestern Spain (Wolf et al., 2014; Wolf and Faust, 2015), and the Medjerda River in northern Tunisia (Faust and Zielhofer, 2002; Faust et al., 2004; Moldenhauer et al., 2008; Zielhofer et al., 2002; Zielhofer et al., 2004; Zielhofer and Faust, 2008; Zielhofer et al., 2008; Zielhofer et al., 2009). These results were completed by isolated findings from the Guadiana River in central southern Spain, the Guadalquivir River in Andalusia (Wolf and Faust, 2015), as well as findings from the Oued Moulouya in northern Morocco (Zielhofer et al., 2010, see Fig. 1). Our objective was to characterise fluvial dynamic features such as channel incision, river bank erosion, channel aggradation, floodplain sedimentation, and soil formation in all the studied river systems in order to relate these features to possible influencing factors. Stratigraphic findings were supported by detailed geochemical and granulometric analyses, clay mineral detection, provenience analyses of the river deposits, heavy metal detection in order to trace the onset of human activity, and thin section analyses to detect soil formation features, biospoors and rootmarks. The chronological frame was confirmed by > 200 radiocarbon datings and supported by palaeomagnetics for the last 3 ka.

The overall aim of this study is to interpret our findings against the background of theoretical concepts and problems in order to present a general and robust history of Holocene fluvial dynamics in Western Mediterranean river catchments. In the pursuit of this objective, we are focusing on three key issues that we consider essential for the work on fluvial sedimentary archives.

(1) a representative reflection of the stratigraphic sequence, together with an appropriate temporal assessment of sedimentation dynamics, paying particular attention to kind, quality, and uncertainties of the datings, as well as dating positions in a stratigraphic context;
(2) information must be extracted from the archive that are suitable for an interregional comparison with other archives. This requires a careful assessment, whether such a comparison is even permissible, for example, whether compared phases and processes might be assigned to similar causations, and whether they are strongly scale dependant;
(3) the awareness of fluvial systems to be highly complex and non-linear systems and the associated difficulties in assessing the system's response on specific influences of certain factors.

Beyond these considerations issues, the treatment of age data seems to be a crucial point in fluvial archive research. River deposits in general contain a variety of information that can be interpreted from different perspectives and in different ways. Already type and arrangement may provide valuable information regarding sedimentary environments (e.g. Collinson, 1996; Miall, 1985; Reineck and Singh, 1980), given that the results are placed in an adequate spatial context (Houben, 2007). However, the interpretation of fluvial features against the background of climate and environmental changes, the comparison with independent archive information, or even the comparison of different data sets in order to derive more complex and large-scale interdependencies heavily depend on a responsible handling of the age data. In this context, it is becoming increasingly common to make use of meta- analyses on radiocarbon dates from fluvial archives in order to develop time series of flooding activity, and to transfer them in a vast regional context. We will demonstrate that there are a number of challenges to these approaches that are mainly based on the facts that meta-analyses (e.g. cumulative probability functions) are often accompanied by the release of the age data from their original (stratigraphic) context, and that the data is often unreflectedly used and correlated across a variety of scales.

In summary, this paper aims to review regional fluvial archive research with a particular focus on our own studies in Western Mediterranean river catchments. Here, we will indicate some difficulties in data collection, handling, and interpretation, and we will discuss our stratigraphy-supported approach to derive fluvial sedimentation phases as well as a step-wise up-scaling approach to synthesize several fluvial archives against the background of meta-analyses approaches.

2. Geographical frame

The main research work was conducted in three different river catchments, all of them situated in the Western Mediterranean (Fig. 1), and all of them characterized by different geo-parameters that make them unique. However, each chosen catchment has an adequate size to address the above mentioned issues and all rivers are meandering rivers in each examined location. Here we follow the principle that climate driven dynamics can better be separated from human induced geomorphodynamics if the chosen scale is big enough to “filter” the human signal (Faust et al., 2004). This indicates that relatively small areas are more susceptible to the effect of human activities, or irregular individual events in general, whether natural or man-made, compared to larger areas (Fig. 2). Thus, single events may have a greater significance for fluvial records of small catchments compared to large catchments, where at least several events are required in order to generate corresponding sedimentation patterns. This is a first principle that is sometimes ignored in case studies dealing with fluvial dynamics (e.g. Faust et al., 2000) or in comparative studies (e.g. Benito et al., 2015).

The Jarama catchment in central Spain has an extension of about 11.500 km^2 reaching up to the high mountain chain of the Sierra de Guadarrama (2100 m). It is a tectonically active area where fluvial dynamics are partly influenced by halokinetic movements (events) originating from the underlying Tertiary marls (Wolf and Faust, 2016). The present-day average annual precipitation in the Madrid Basin is about 450 mm. This means, that under present-day semi-arid climate conditions, regardless of the distinct human influence, the landscape is particularly vulnerable to periods of higher aridity and increased precipitation variability that could initiate intense surface erosion, runoff, and sediment shifting. By contrast, in the semi-humid Guadalete catchment (see below) in Western Andalucía the mean annual precipitation is actually about 750 mm that leads to a more stable and less