RIVER-RESPONSE AND TERRACE AGRADATION IN THE MEDITERRANEAN IBERIAN PENINSULA DURING HISTORICAL TIMES

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ABSTRACT

Mediterranean fluvial environments have responded sensitively to past changes in climate, physiographic conditions and human activity. Chronosequences of river terraces and alluvial deposits were established using morphologic, sedimentological and pedologic criteria, ^{14}C- and ^{210}Pb-dating techniques, historical data and pottery fragments. The objective of this study addresses the fluvial dynamic of several river systems focusing on the Vera basin and the lower Penedes basin over the last 1600 years. The correlation between 13 catchments of Southwest, Southeast and Northeast Spain, studied by this research and by various authors, shows that fluvial activity increased during the cooler Holocene climate events such as the Early Medieval Ice Advance (6th – 10th century) and the Little Ice Age (15th – 19th century). In contrast, fluvial dynamics during the Medieval Climate Optimum were insignificant.

1 INTRODUCTION

Paleofloods and their related morphological processes are the result of climate variability and specific geo-ecological conditions and changes in the past. The natural records of these processes, including fluvial terraces, floodplains, colluvia, paludal and slope deposits and paleosols, can be assessed by geomorphological, sedimentological, pedological and chronostratigraphical methods. The objective of this study addresses the fluvial environments of several Mediterranean river systems focusing on the Vera basin in Southeast Spain and the lower Penedes basin in Northeast Spain. A crucial question is whether the river dynamics during historical times have been sensitive to centennial and decennial climate variability or whether they have been conditioned by the influence of human land-use. A large number of local studies of individual river systems exist for the Mediterranean Basin. However, systematic regional assessment of Holocene river dynamics or supra-regional overviews is rare. Regional studies undertaken by *Brückner* (1986) in Italy and *Van Andel et al.* (1990) in Greece show that regional and local river dynamics are much more complex than the stratigraphical subdivision of valley floors in “older” and “younger fill” deposits, proposed by the pioneer studies of *Vita-Finzi* (1969). The present study aims to integrate the data obtained on paleo-fluvial environments from the Vera and Penedes basin with other case studies, and to establish a fluvial chronostratigraphy of the Mediterranean Iberian Peninsula over the last 1600 years.

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2 MATERIALS AND METHODS

Holocene fluvial landforms of the Vera and the Penedes basin were mapped by aerial photograph survey and fieldwork. Sedimentological descriptions were carried out for fluvial and paludal sediments. Samples and artifacts were collected from several geological sections and their magnetic susceptibility was measured. Soil description and geochemical and micromorphological analysis were carried out to assess the Holocene and late Quaternary soil development. The chronology of the river terrace sequences was determined from ^{14}C and U/Th-dating as well as from artifacts. In addition, ^{210}Pb-dating, undertaken in floodplain deposits, was calculated following the Constant Initial Concentration model (CIC).

3 SITE DESCRIPTION

The Vera basin is located at the eastern margin of the Betic ranges in Southeast Spain, the driest region in Europe. The semi-desert characterised by sparse vegetation cover, records today between 200 to 250 mm/yr total annual precipitation. Three mayor river systems cross the Vera basin from the west to the Mediterranean Sea in the east: the Almanzora river in the north, the Antas river in the middle and the Aguas river in the south. The northern study site, the lower Penedes basin, is located at the western end of the Catalan Coastal Range. The research focuses on the ephemeral catchments of the Riera de la Bisbal, Torrent del Lluc and Torrent de la Gralhera. Annual precipitation at 500 mm/yr is higher than in the Vera basin. Nevertheless, the Neogene marls, limestones and sandstones contribute to edaphic aridity. According to archaeological data, human settlement and land-use are recorded in the Vera and Penedes basins since the Neolithic period.

4 RESULTS

A Holocene chronosequence of 4 and 5 river terraces was established for the Antas (terraces H1, H2, H3a and H3b) and Aguas valleys (terrace H1, H2, H3, H4a, H4b), respectively. Unlike the late Pleistocene stage 2 deposits, the Holocene terraces are composed of well-stratified point bar deposits and form row terrace textures (*Schulte*, 2002b).

The oldest Holocene terraces H1 of the Aguas and Antas river date from the Atlantic Period. In the Aguas valley Chalcolithic sites (5000 – 4200 yr cal B.P.) were found on the H1 terrace surface. Radiocarbon dating on microcarbon, yields an age of 1040 ± 40 yr B.P. for the channel deposits of terrace H2. From the +2 m Holocene terrace of the Rambla Ancha, *French & Passmore* (1998) obtained a radiocarbon age of 1340 ± 50 yr B.P. During the Little Ice Age, the H3 terrace of the Aguas river and the H2 terrace of the Antas river were deposited. The H3, dated 430 ± 50 yr B.P. by radiocarbon, belongs to the beginning of the Little Ice Age (Figures 1 and 2). The youngest fluvial terraces of the two river systems (H4a and H4b in the Aguas catchment, H3a and H3b of the Antas river) were deposited during the 20th century as recent artifacts indicate. ^{210}Pb dating and artifacts point to a relatively high accumulation rate of flood deposits (1902 ± 4 A.D. at 85 cm depth) in the lower Aguas valley. Between the 1930's and the 1950's, the sedimentation rate amounts to 2.9 cm/yr compared to an average of 0.89 cm/yr between 1902 and 1998. These flood events correlate with the years with maximum annual precipitation of the 20th c. (1946, 1948, 1949, 1951 A.D.) recorded by the 128 year-precipitation series of Murcia, 80 km northwest of the study area. Precipitation data prior to 1953 from the Vera basin are not available.

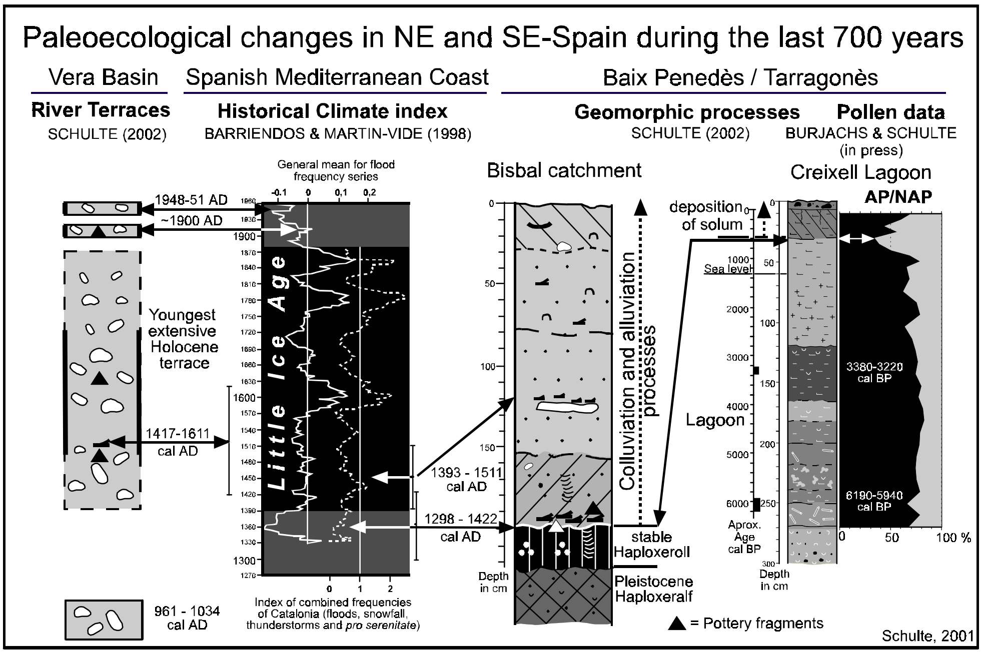

Figure 1. Synoptical paleoecological and morphological changes in the Vera and Penedes basins during the Little Ice Age. Chronology in calendar ages.

The lack of important tectonic uplift in the Penedes basin led to the erosion of low angle pediments at the basin margins and to the accumulation of Pleistocene fluvial terraces in the middle reaches, whereas flood plains formed near the coastline. The mapping of Holocene fluvial terraces under this specific morphological configuration is difficult. Therefore, pedological and sedimentological studies focused on several sections of Holocene floodplain deposits. The excellent exposures, which in some locations exceed 100 m width and the clear correlation between the profiles, make the synoptical stratigraphy shown in Figure 1 possible. The Pleistocene-Holocene boundary separates the early-middle Holocene Haploxerolls (organic soils) from the underlying late Pleistocene Haploxeralfs (reddish Mediterranean soils). Absolute dating of this youngest Haploxeralf was not possible. Its chronostratigraphy is based on the correlation with radiometric dated late Quaternary soil chronosequences of the Mediterranean Iberian coast (*Schulte & Julià*, 2001). In contrast, the Haploxerolls were formed predominantly during the more humid climate conditions at the beginning of the Holocene, shown by several pollen records (*Burjachs et al*., 1997). Iberian, Phoenician and Roman pottery fragments in the upper part of the Haploxerolls (Figure 1) indicate land-use during historical time. However, a radiocarbon age of 585 ± 50 yr B.P. of *in situ* charcoals extracted from the top of the fossil Haploxeroll shows that its surfaces were relatively stable until the 14th century (*Schulte*, 2002c). After 585 ± 50 yr B.P. the soil was covered by colluvial and alluvial sediments. The fast accumulation (0.85 cm/yr), particularly during the 15th c. can be related to maximum clearance of woodland that has been shown by pollen records from a nearby coastal lagoon (Figure 1; *Burjachs & Schulte*, in press). According to the obtained ^{14}C-datings (5300 ± 40 yr B.P. at 255 cm depth and 3090 ± 40 yr B.P. at 135 cm depth), the formation and subsequent paludal sedimentation of the lagoon commenced at the end of the Versilian transgression. At the beginning of the 15th c., the sedimentation pattern switched from the paludal deposition to an accumulation of reddish *solum* as a consequence of soil erosion on the surrounding hill slopes.

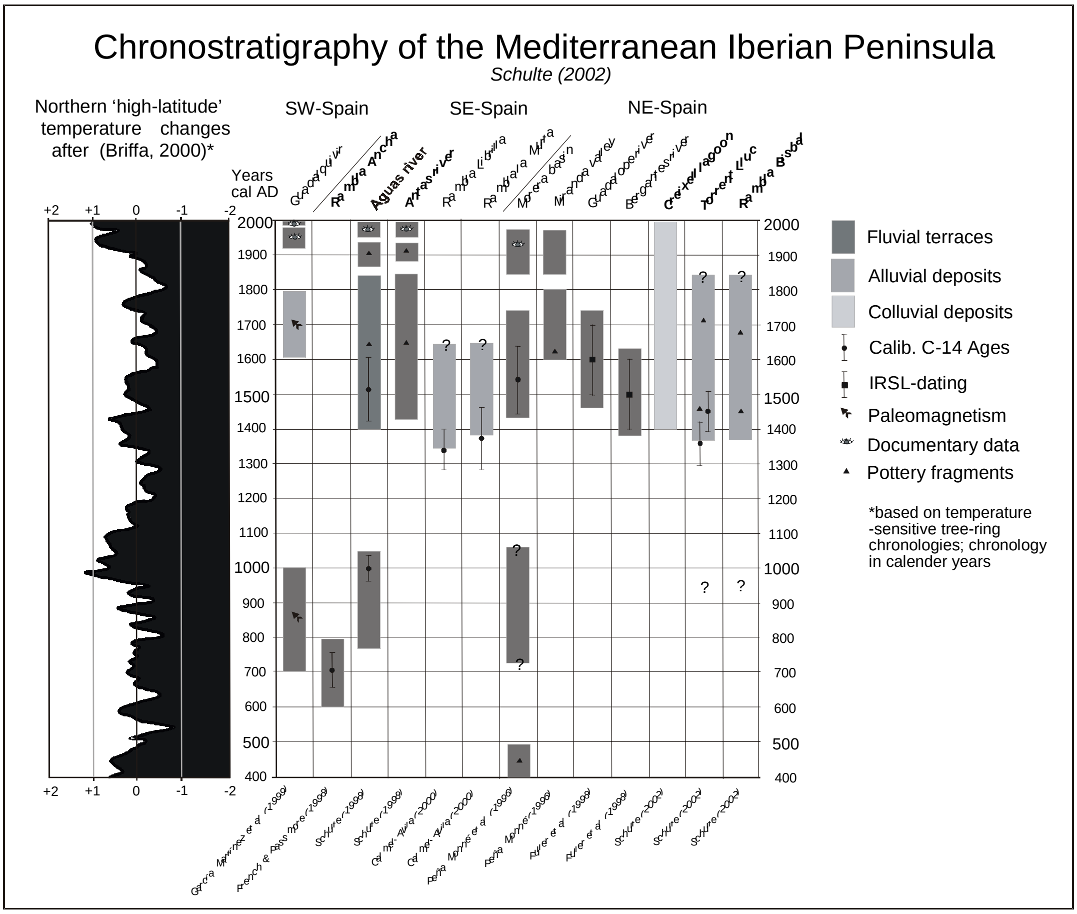

Figure 2. A 1600-year stratigraphy of fluvial terraces, alluvial and colluvial deposits of the Mediterranean Iberian peninsula.

5 DISCUSSION

The morphological, sedimentologic and pedological studies of the valley bottoms of the Vera and Penedes basins show important changes regarding the Holocene fluvial environments. The river terraces, alluvial and colluvial deposits result from different periods of fluvial erosion and accumulation. The origin of the fluvial terrace H1 in the Vera basin is climatically induced, although the Versilian transgression may have played an important role. Soil and travertine formation (9.300 ± 70 yr B.P.; U/Th) can be ascribed to more humid climate conditions during the early Holocene (*Schulte & Julià*, 2001). Historical terrace deposition in the Vera basin occurred during the early Middle Ages, the Little Ice Age and in the 20th century. The erosion of a terrace generation and the accumulation of the next unit represent important morphodynamic changes, particularly an increase in flood magnitude and frequency. The deposition of the point bar deposits point to a meandering river system. Periods of sparse or moderate floods are characterised by stability or minor migration of the main channels.

The installation of the early Middle Ages terraces might be attributed to climatic factors. It can be concluded from the archaeological and historical data that this terrace formation was not caused by human impact. During the late Visigothic and early Arabian

Periods, population density was low and agriculture was based on subsistence production. Pollen profiles from the Almería and Alicante Provinces indicate a maximum aridity at the beginning of the Middle Ages (*Burjachs et al*., 1997). In contrast, human interference in the landscape related to land-use changes during the Christian conquest and the expulsion of the Muslims of the 16th c. may have played a certain role in river dynamics (terraces H3 in the Aguas, terrace H2 in the Antas river). The correlation between the river terrace accumulation in the Vera basin and the flood frequency series of the Spanish Mediterranean coast (*Barriendos* & *Martin-Vide*, 1998), illustrated in Figure 1, indicates that the accumulation of the terrace unit started at the beginning of the Little Ice Age and not during the major peaks of flood frequency around 1600, 1780 and 1850 A.D. However, the youngest small-size terraces of the 20th c. can be correlated with the secondary peaks around 1900 AD and the end of the 40's (Figure 1).

In the small-size catchments studied in Northeast Spain, human impact has led to increased surface run-off causing drastic alluviation and colluviation in the valley bottoms since the end of the 14th c., particularly during periods of maximum woodland clearance of the 15th c. Iberian, Phoenician and Roman pottery fragments in the upper part of the organic soil also demonstrate land-use during historical time, although no alluvial or colluvial deposits related to these periods were found. During the Roman Period intensive land-use (viniculture, olive groves, and wheat) were restricted to the lowlands of the Penedes basin. In contrast, the modern age woodland clearance affected the slopes of the surrounding mountains and led probably in this way to increased surface runoff and soil erosion. Similar to the findings of the Vera basin, the morphological processes correlate with the beginning of the Little Ice Age (Figure 1).

To find out the influence of climate or human control on fluvial processes in both study areas it is necessary to establish correlations with other Mediterranean rivers. Figure 2 shows a 1600-year stratigraphy of 13 fluvial catchments of Southwest, Southeast and Northeast Spain, studied by this research and by various authors (*García Martinez et al.*, 1999; *French & Passmore*, 1998; *Calmel-Avila*, 2000; *Peña Monné et al.*, 1996; *Fuller et al.*, 1998; *French & Passmore*, 1998). According to the stratigraphy, fluvial terraces were accumulated in some catchments during the Early Medieval Ice Advance (6th - 10th century), whereas fluvial activity during the Medieval Optimum was insignificant. However, in nearly all river systems sedimentation of fluvial deposits occurred during the Little Ice Age. The aggradation processes mostly started at the onset of this global climate period. The increased flood-events can be related to the southward shift of the Northern Hemisphere westerlies during the Little Ice Age.

6 CONCLUSIONS

Despite the different physiographic frameworks and sedimentation patterns, the reconstruction of river environments and associated erosion-accumulation processes of the southeastern and northeastern Iberian study areas shows a certain synchronism of fluvial dynamics. The 1600 year stratigraphy of 13 fluvial systems of Southwest, Southeast and Northeast Spain provides evidence for increased fluvial activity, during periods of cooler Holocene climate such as the Early Medieval Ice Advance and the Little Ice Age (*Schulte*, 2002a, 2002b). Cycles of river activity are interpreted as periods characterised by increased flood magnitude and frequency. From the available data it can be concluded that the human impact on river dynamics in the Vera and Penedes basins may have been decisive in terms of magnitude of surface runoff and sedimentation yield, but is less important in triggering long-term Holocene river dynamics.

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REFERENCES

Barriendos Vallve, M., Martin Vide, J. Secular climatic oscilations as indicated by catastrophic floods in the Spanish Mediterranean coastal area (14^{th}-19^{th} centuries), *Climatic change*, 1998, 38, 473-49.

Brückner, H. Man's Impact on the Evolution of the Physical Environment in the Mediterranean Region in Historical Times, *GeoJournal*, 1986, 13 (1), 7-17.

Burjachs, F., Giralt, S., Roca, J.R., Seret, G., Julià, R. Palinología holocénica y desertización en el Mediterráneo occidental, ed. J.J. Ibáñez et al., *El paisaje mediterráneo a través del espacio y del tiempo*, Geoforma Ediciones, Logroño, 1997, pp. 379-394.

Burjachs, F. & Schulte, L. El paisatge vegetal del Penedès entre la Prehistoria i el Món Antic, ed. J. Gitart & J.M. Palet, *Simposi Internacional d'Arqueologia del Baix Penedès*, El Vendrell, in press.

Calmel-Avila, M. Géomorphogenèse Holocène dans le Bas-Guadalentín. Bassin du Segura, Province de Murcie, Espagne, Presses Universitaires du Septentrion, Villeneuve d'Ascq, 2000.

French, Ch., Passmore, D. Detailed geomorphological and micromorphological analysis of the Barranco de Gatas, the Rambla Ancha and Gatas settlement, ed. P.V. Castro et al., *Aguas Project*, European Commission, D.G.XII, Luxembourg, 1998, pp. 45-49.

Fuller, I.C., Macklin, M.G., Lewin, J., Passmore, D.G., Wintle, A.G. River response to high-frequency climate oscillations in southern Europe over the past 200 k.y., *Geology*, 1998, 26 (3), 275-278.

García Martínez, B., Guerrero, I., Baena Escudero, R. La dinámica de meandros durante el Cuaternario reciente en la conformación de la llanura aluvial del Bajo Guadalquivir aguas arriba de Sevilla, ed. L. Palli Buxó & C. Roqué Pau, *Avances en el estudio del Cuaternario español*, AEQUA, Girona, 1999, pp. 119-124.

Schulte, L. Evolución cuaternaria de la depresión de Vera y de Sorbas oriental (SE-Península Ibérica), Reconstrucción de las fluctuaciones paleoclimáticas a partir de estudios morfológicos y edafológicos, Servei de Publicacions de la Universitat de Barcelona, Barcelona, 2002a.

Schulte, L. Climatic and human influence on river systems and glacier fluctuations in southeast Spain, *Quaternary International*, 2002b, 93-94, 85-100.

Schulte, L. The influence of climate change and human dynamic on fluvial environments in southeast and northeast Spain over the last 1500 years, *Environmental Dynamics and History in Mediterranean areas*, Université Paris-Sorbonne, International Association of Geomorphologist, Working Group on Geoarchaeology, 2002c, p. 79.

Schulte, L. & Julià, R. A Quaternary soil chronostratigraphy of Southeastern Spain. *Zeitschrift für Geomorphologie*. N.F., 2001, 45 (2), 145-158.

Van Andel, T.H., Zangger, E., Demitrack, A. Lande Use and Soil Erosion in Prehistoric and Historical Greece, *Journal of Field Archaeology*, 1990, 17, 379-396.

Vita-Finzi, C. The Mediterranean Valleys: Geological Changes in Historical Times, Cambridge University Press, Cambridge, 1969.