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Tufa buildups, landscape evolution and human impact during the Holocene in the Upper Ebro Basin

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ABSTRACT

The presence of tufas is of outstanding significance due to their inter-relationship with human occupation and landscape changes. The impacts induced by human occupation in the tufa systems during the Holocene would influence the balance of their construction and destruction and the genesis of tufaceous sequences. In the studied area, a Mediterranean-transitional low mountain environment in North Iberian Peninsula, there is numerous tufa buildups scattered by bottom valleys and slopes. In this paper, a first diachronic synthesis of landscape changes during the Holocene is carried out based on construction and erosion of tufas, evolution of settlement and known environmental changes by pollen studies, to establish a landscape sequence in which assess the importance of the natural dynamics or human activity in shaping the landscape. The main components of the landscape in the Holocene, tufas, vegetation, and human intervention are analyzed from published references and our work on tufa. Reconstruction of landscape evolution is based on tufa morphosequence evolution and geomorphology, archeological, dating, and palynological data. Nineteen dated tufa buildups, ten archaeological sites of environmental interest, and two peat bogs are available.

The evolution of the landscape involves human and natural changes during the Holocene. Nine different landscape stages have been differentiated from the Upper Pleistocene to historical times. The natural changes determine the landscape between 14 and 8.1 ka, after which the human occupation started to impact the natural environment. Approximately between 4.2 ka and 3.2 ka, the Millennium of Change occurred, when agriculture was consolidated, the population expanded, feeding habits and customs changed, the tufa system eroded, and intense landscape repercussions resulted. From 2 to 1.9 ka, a new constructive phase of tufas was generated that has also lasted to the present day. This new tufa construction stage is interpreted as the response to the re-balancing of the geosystem, now in balance with human use. This was the last phase of the anthropic-climate sequence that began 5.5 ka, determining the landscape evolution. The human intervention on the territory and consequent changes in the geomorphological processes on slopes and valley bottoms, altering tufa construction and generating intense erosion processes, soil loss and vegetation cover modification, permits us define the geomorphological and landscape Holocene evolution as a human-climate sequence.

1. Introduction

The relationship between the environmental conditions –climatic and hydrological- the evolution of vegetation cover and of local population growth with the genesis and destruction of the tufa buildups makes possible a first approximation to the evolution of the relief, environmental changes and, thus, changes in the landscapes of the Upper Ebro. The presence of tufas is of outstanding significance due to their inter-relationship with human occupation. Tufas are generated under warm conditions with water availability, without any sedimentary load or aggressive solutes (Vaudour, 1986; Weisrock, 1986; Pedley, 1990; Pentecost and Viles, 1994; Pentecost, 2005). For this reason, they are extremely fragile and respond quickly to dynamic changes, whether these be natural or human-induced. As a result, tufas are key elements for understanding our landscapes and the importance of natural or human-induced changes. Vaudour (1986) demonstrated the relationship between human occupation and the

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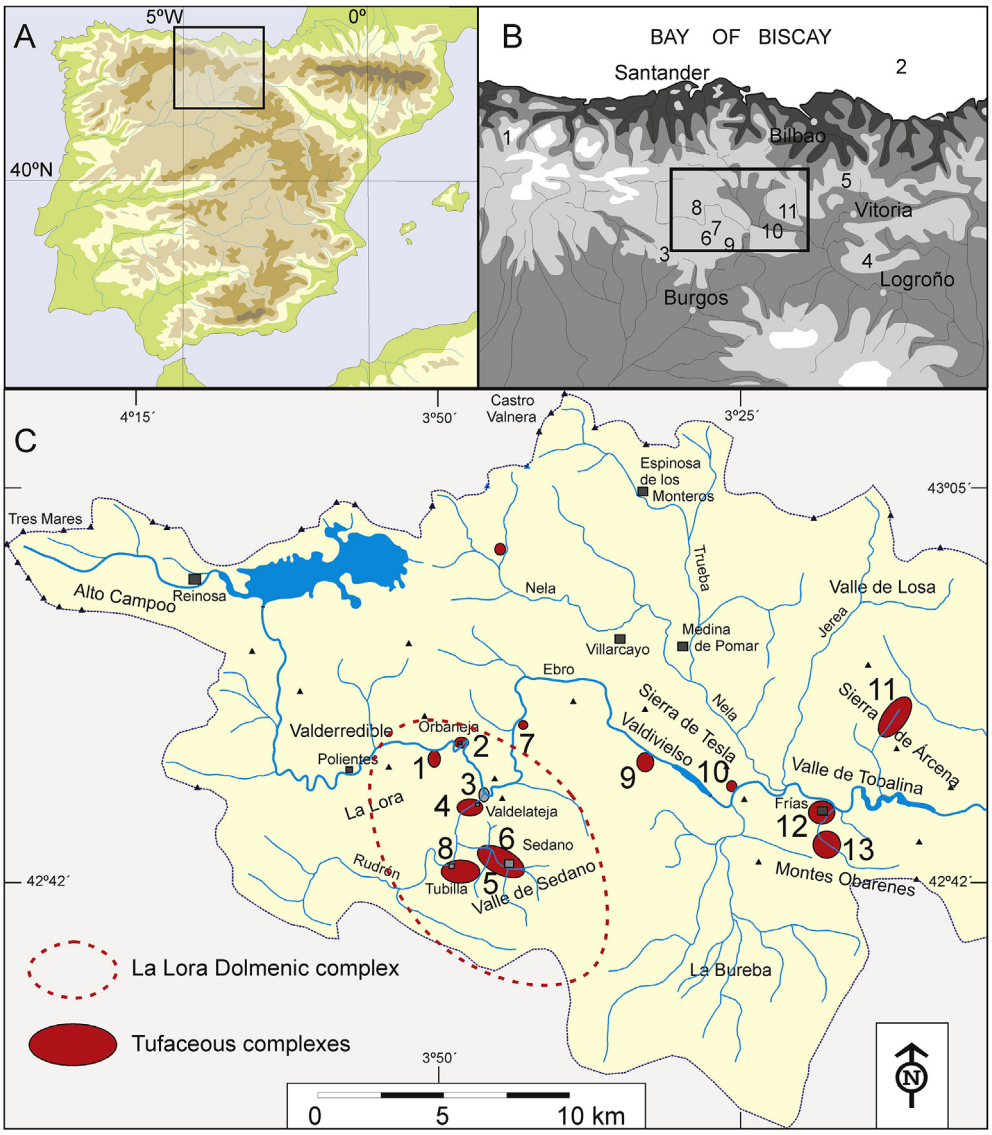

Fig. 1. Location of the study area in the Upper Ebro Basin. A, Area represented in map B. B, Numbers refer to location of places where there are works on tufa, archaeology or pollens used in the text. 1, Enol lake. 2, Bay of Biscay core. 3, La Piedra lake. 4, Los Husos site. 5, Saldropo site. 6, Tubilla del Agua. 7, Sedano. 8, Orbaneja del Castillo. 9, La Lora dolmenic complex. 10, Molinar valley. 11, Purón valley. C. Upper Ebro basin. Numbers refer to tufa buildups. 1, El Tobazo, 2, Orbaneja, 3, Rudrón. 4, Valdelateja. 5, Sedano. 6, La Tobaza. 7, El Tobazo. 8, Tubilla del Agua. 9, Toba. 10, La Horadada, 11, Purón. 12, Frías. 13, Molinar.

dynamics of tufas, though postures soon arose in favour and against the interpretation of the influence of environmental changes, either of human or natural factors. Whatever the case, a fall in tufa activity is observed in Europe during the recent Holocene, which is associated with human land use (Vaudour, 1986, 1994; Goudie et al., 1993; Ambert, 1997; González Martín and Rubio, 2000; Guendon et al., 2003). In the Mediterranean area, the concept of climate-anthropic sequences was established, considered as the succession of processes and forms induced by the climatic and human inter-relationship as opposed to those that respond exclusively to climatic variations and changes (Vaudour, 1994; Guendon et al., 2003). For Olivier et al. (2008), the combination of intra-Holocene climatic variability, the intensity of human occupation and the sensitivity of the environment make 'anthropization' more or less effective, and therefore, in the presence of tufas the impacts induced by human occupation during the Neolithic and the Bronze and Iron ages would influence the balance of their construction and destruction and the genesis of tufaceous sequences. The location of tufaceous buildups at sites with easy access to water and in environments of phytostabilization made them places favourable to human occupation, and this explains why archaeological sites and settlements are repeatedly found on tufas in the study area, and why there are even historical-artistic monuments on tufaceous build-ups (Orbaneja del Castillo and Frías). Nowadays, the sensitivity of tufas and changes in the landscape have gained interest in relation to the establishment of the Anthropocene, either as a recent fact related to the industrial revolution and CO_2 and CH_4 emissions capable of altering the atmospheric composition (Ruddiman, 2005; Steffen et al., 2011), or as a prior process from the Holocene (Ruddiman, 2003). There are now many archaeological, cultural, historical and geological tests pointing to previous anthropogenic environmental changes related to pastoralism and deforestation, incipient agriculture and irrigation, also capable of altering the level of CO_2 in the atmosphere (Ruddiman, 2003,