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## Palaeogeographical reconstruction of the Sierra de Atapuerca Pleistocene sites (Burgos, Spain)

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## ABSTRACT

The Sierra de Atapuerca is an anticlinal ridge of Mesozoic carbonate rocks on the NW edge of the Iberian Chain (Northern Spain, Burgos), surrounded by subhorizontal continental sediments of the NE Duero Cenozoic Basin under endorheic conditions. The shift to exorheic conditions in the Duero Basin lead to the onset of an episodic downcutting phase and the development of the Atapuerca multilevel cave system, containing several sites from the Early and Middle Pleistocene. In this work, we have reconstructed the Pleistocene palaeogeographical evolution of the SW flank of the Sierra de Atapuerca, where these archaeological sites are located. The study is based on a detailed geomorphological and geological analysis, combined with Global Navigation Satellite System (GNSS) and 3D LiDAR data, and GIS modeling. These techniques have been applied to analyse the small valleys and the interfluvium on the SW flank of the SW Sierra de Atapuerca. The results were combined with the regional base levels recorded by fluvial terraces and the chronostratigraphic sequences of the Sierra de Atapuerca sites. These reconstructions have allowed us to model the palaeogeographical evolution in the nearby area of the cave sites during the Early–Middle Pleistocene, coupling the main formation phases of the sites with the local physical landscape changes that occurred outside the caves. Surface processes are defined by incision phases entailing mitigate knickpoint recession and slope retreatment, and local aggradational phases associated with caves opened and captured by fluvial incision. This reconstruction provides the local physical palaeogeographical habitats developed during the Pleistocene hominid occupation of the Sierra de Atapuerca.

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## 1. Introduction

Palaeogeographical studies are essential to understand the settlement and mobility of human groups since they provide valuable information about site formation processes and past physical landscapes (Mirazón, 2010; Schattner, 2010; Lambeck et al., 2011). Palaeogeographical models can be based on the sedimentological interpretation of stratigraphic records (Stanistreet, 2012), the analysis of relict landforms (Bonnet et al., 2001; Leverington et al., 2002; Benito-Calvo et al., 2008), or the modeling of processes (Kooi and Beaumont, 1994; García-Castellanos et al., 2003).

In this paper we carried out the palaeogeographical reconstruction of the SW flank of the Sierra de Atapuerca through landform correlation and modeling, in order to understand the physical palaeohabitats and the landscape processes characterizing this area during the formation of Early–Middle Pleistocene archaeological sites. These sites contain Early to Middle Pleistocene sequences with several human-bearing layers (Parés and Pérez-González, 1999; Carbonell et al., 2008; Arsuaga et al., 2014; Bermúdez de Castro and Martínón-Torres, 2014; Ortega et al., 2014), which are preserved in allochthonous facies (Pérez-González et al., 1999, 2001; Campaña et al., 2015). The latter are associated with cavity entrances belonging to a Pleistocene multi-level endokarst system related to phreatic levels controlled by fluvial incision (Ortega et al., 2013). The regional base levels were modeled in preliminary investigations (Benito-Calvo et al., 2008).

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In the current work we deal with the palaeogeographical reconstruction of the nearby area of the archaeological sites.

The SW flank of the Sierra de Atapuerca is characterized by small valleys and hillslopes in the intervening interfluvies, where the entrances to the cavities containing the sites are located. These landforms have been studied using a Geographical Information Systems (GIS), high resolution spatial datasets (LiDAR, aerial photographs), and Global Navigation Satellite System (GNSS) surveying. During this work, characteristics of knickpoints and convex shapes identified in longitudinal profiles and hillslopes, were interpreted as non-steady states related to past processes (Loget and Van Den Driessche, 2009; Wegmann et al., 2011; Castillo et al., 2012; Tsou et al., 2014). Through this study we reconstruct the palaeogeographical evolution of the area and the physical landscape inhabited by hominins found in the Sierra de Atapuerca sites.

## 2. Physical landscape framework

### 2.1. Geological context

The Sierra de Atapuerca (N42°21'05.29"; W3°30'39.20"; WGS84) is situated in the north-east area of the Duero Depression (north-central Iberian Peninsula), and belongs to the NW part of the Iberian Chain (Fig. 1). In this area, the Sierra de Atapuerca is a gentle anticlinal ridge (1085 m a.s.l.) surrounded by Cenozoic continental sediments. This anticlinal ridge occurs in the SE part of the Bureba Corridor, which is an intermountain depression

connecting the Ebro and Duero basins and bounded by the Cantabrian and the Iberian ranges, to the north and south respectively (Fig. 1).

The main geological structure of the Sierra de Atapuerca is described as a NNW–SSE overturned anticline (Pineda and Arce, 1997), faulted and breached in its NW part, where Jurassic and Early Cretaceous rocks crop out (Fig. 2A; Benito-Calvo and Pérez-González, 2015). These rocks are overlain by Late Cretaceous carbonates, mainly consisting of Turonian–Lower Santonian limestones and dolostones (Fig. 2A). Mesozoic formations were folded during the Alpine orogeny, forming the overturned anticline. In the SW limb of this anticline, Late Cretaceous limestones and dolostones show a mean strike of N120°E and dips of 18–20°SW. The main deformation phase occurred during the Oligocene–Lower Miocene, coinciding with the sedimentation of syn-orogenic conglomerates, sandstones and mudstones. During the Neogene, sedimentation of alluvial and lacustrine deposits in Duero Basin took place, represented by several subhorizontal units separated by discontinuities (Armenteros et al., 2002; Alonso-Gavilán et al., 2004). The sequence commences with evaporitic and lacustrine Early Miocene deposits, which are overlain by Middle Miocene alluvial facies topped by a limestone layer (including flint nodules) or a relict palaeosol. These sediments are overlain by lacustrine sediments of Middle–Late Miocene age, whose carbonates at the top (Lower Páramo limestones) records an phase of major lacustrine expansion. These limestones forms the current top of the Neogene sequence around the Sierra de Atapuerca, although

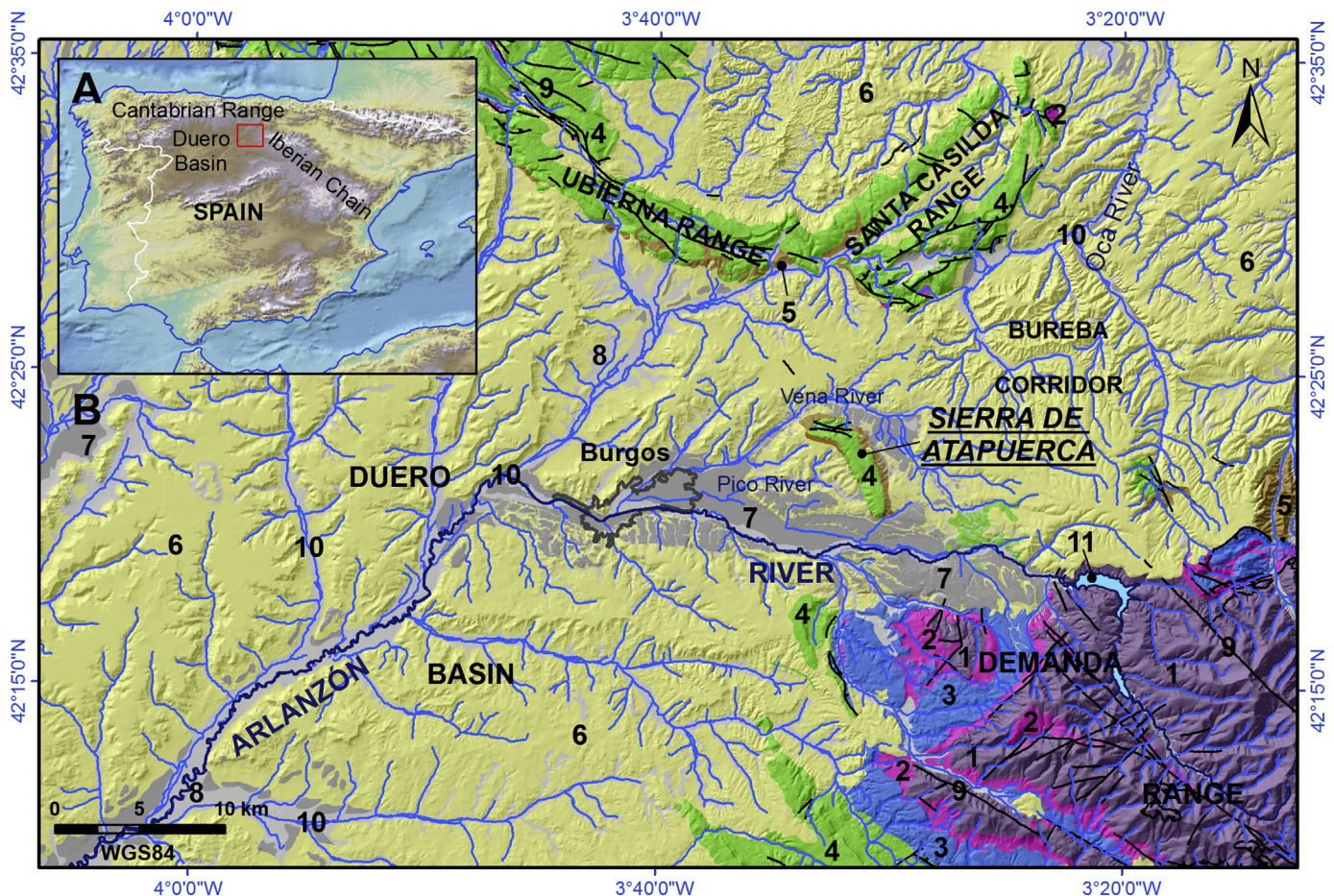


Fig. 1. Study area framework. A) Situation of the NE Duero Basin in the Iberian Peninsula. B) Location of the Sierra de Atapuerca in the NE Duero Basin. Legend: 1, Palaeozoic; 2, Triassic; 3, Jurassic; 4, Cretaceous; 5, Oligocene–Early Miocene; 6, Miocene; 7, Pleistocene; 8, Holocene; 9, Faults; 10, Drainage network; 11, Reservoir.

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