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Evolution of multilevel caves in the Sierra de Atapuerca (Burgos, Spain) and its relation to human occupation

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ABSTRACT

The evolution of the Torcas cave system (Sierra de Atapuerca) is analysed in order to shed light on the formation of the Atapuerca archaeological sites and human occupation in the area, critical for identifying the paths of the first human dispersal into Europe. The geomorphological analysis of the endokarst system and the regional base levels has revealed a multilevel cave system, with drainage directions from south to north, where old karst springs fed the Pico River. Using morphological and topographic evidence we have correlated the fluvial terraces situated at relative heights of +84–80 m and +78–70 m above the Arlanzón River (main course), with the first and second cave levels, respectively, both of Early Pleistocene age. The fluvial levels T4 (+60–67 m) and T5 (+50–54 m) are linked with the third level (Early–Middle Pleistocene), which contains fluvial deposits probably related to terrace T6 (+44–46 m). Progressive fluvial incision allowed humans to gain access to the cave system through several entrances from ~1.22 Myr until the end of the Middle Pleistocene, when these cave entrances became filled, forming the most interesting hominid-bearing deposits in Europe.

1. Introduction

The present study is focused on the speleogenetic analysis of the sub-horizontal multilevel cave system of the Sierra de Atapuerca, which was occupied by hominids from the Early Pleistocene, and its relation with the geomorphological evolution of the area (Arsuaga et al., 1993; Bermúdez de Castro et al., 1997; Carbonell et al., 2001, 2008; Bermúdez de Castro et al., 2011). The formation of horizontal cave levels is thought to be the result of the circulation of groundwater during a relatively long period of stability of the phreatic level (water table) (Ford and Ewers, 1978; Bögli, 1980; Palmer, 1987; White, 1988). A series of horizontal caves at different elevations generally provides evidence for episodic downcutting of local base levels (Ford and Williams, 1989; Gillieson, 1998; Bakalowicz, 2005; Audra et al., 2006). Palaeo-water tables can be identified by cave features indicating the transition from phreatic to vadose conditions. The vadose entrenchments are normally formed after the drop in base level, as a result of river downcutting and/or the uplift of the limestone massif. It is widely accepted that the height of the passages in multilevel systems can be used to study the long-term evolution of caves and to infer the evolution of the landscape in limestone areas (Ford et al., 1981; Palmer, 1987, 1991; Granger et al., 1997, 2001; Anthony and Granger, 2004; Despain and Stock, 2005; Stock et al., 2005, 2006; Audra et al., 2006; Mocochain et al., 2006; Strasser et al., 2009; Kafri and Yechieli, 2010; Westaway et al., 2010; Frumkin et al., 2011; Yang et al., 2011). Consequently, caves are good markers to link past hydrogeological conditions with landscape evolution, since their development is often closely tied to the position of the local base level.

In the Sierra de Atapuerca, previous works reported on the relationships between regional landforms and speleogenetic processes. Benito-Calvo and Pérez-González (2007) described karst corrosion processes associated with the development of Miocene and Pliocene planation surfaces. These surfaces are related to base levels in the endorheic Duero Cenozoic Basin, before its capture by the external drainage network and change to exorheic conditions. This study reveals that the main phases of cave development took place in the Pleistocene, with the establishment of the drainage network in the Duero River Basin. The development of the new exorheic drainage network involved new flow directions and produced significant changes in the landscape like the formation of the Arlanzón River valley (Pineda, 1997; Benito-Calvo and Pérez-González, 2007). This paper

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analyses the relationships between the multilevel horizontal caves of the Sierra de Atapuerca and the evolution of the Arlanzón River along its middle reach (Benito, 2004; Benito-Calvo et al., 2008; Ortega, 2009). It thus sheds light on the development of the landscape occupied by hominids during their migratory routes across the interior of the Iberian Peninsula in the Lower and Middle Pleistocene.

2. Regional setting and geomorphological evolution

The Sierra de Atapuerca is located in the northeast sector of the Cenozoic Duero Basin, north-central Iberian Peninsula, which connects in its eastern sector with the Ebro Basin through the Bureba Corridor (Fig. 1A). The northeastern sector of the Duero Basin is bounded by the Cantabrian Mountains and Iberian Chain to the north and south, respectively (Fig. 1). The Sierra de Atapuerca constitutes an inlier of Mesozoic formations within the Duero Cenozoic Basin. This ridge is controlled by a NNW–SSE trending and NE-verging overturned anticline faulted on its northern end (Pineda, 1997; Benito, 2004). In the south of the Sierra de Atapuerca, Late Cretaceous marine limestones and dolostones crop out, in which the analysed endokarst system has been developed (Martín et al., 1981; Ortega, 2009). The Upper Cretaceous carbonates are unconformably overlain by continental Cenozoic sediments deposited in the Duero Basin under endorheic conditions (Fig. 1B) and associated with the development of planation surfaces in the Sierra de Atapuerca (Benito-Calvo and Pérez-González, 2007). The Cenozoic deposits include syntectonic conglomerates and clays (Oligocene to Lower Miocene), and a post-orogenic Neogene sequence (Armenteros et al., 2002). In the study area, the latter comprises alluvial and lacustrine sediments, Lower Miocene (Orleanian) to the Upper Miocene (Vallesian) in age, in which three units separated by discontinuities can be distinguished (Benito-Calvo and Pérez-González, 2007). At the end of the Neogene (Upper Miocene to Pliocene), once the Duero Basin was opened to the Atlantic Ocean, a new exorheic fluvial network started to develop and dissect the basin fill. In the study area this drainage network is represented by the Arlanzón River and its main tributaries, the Vena and Pico rivers (Fig. 1B). The Quaternary evolution of these valleys is characterised by alternating incision and aggradation stages recorded by a sequence of 14 fluvial terraces and the current floodplain (Benito, 2004).

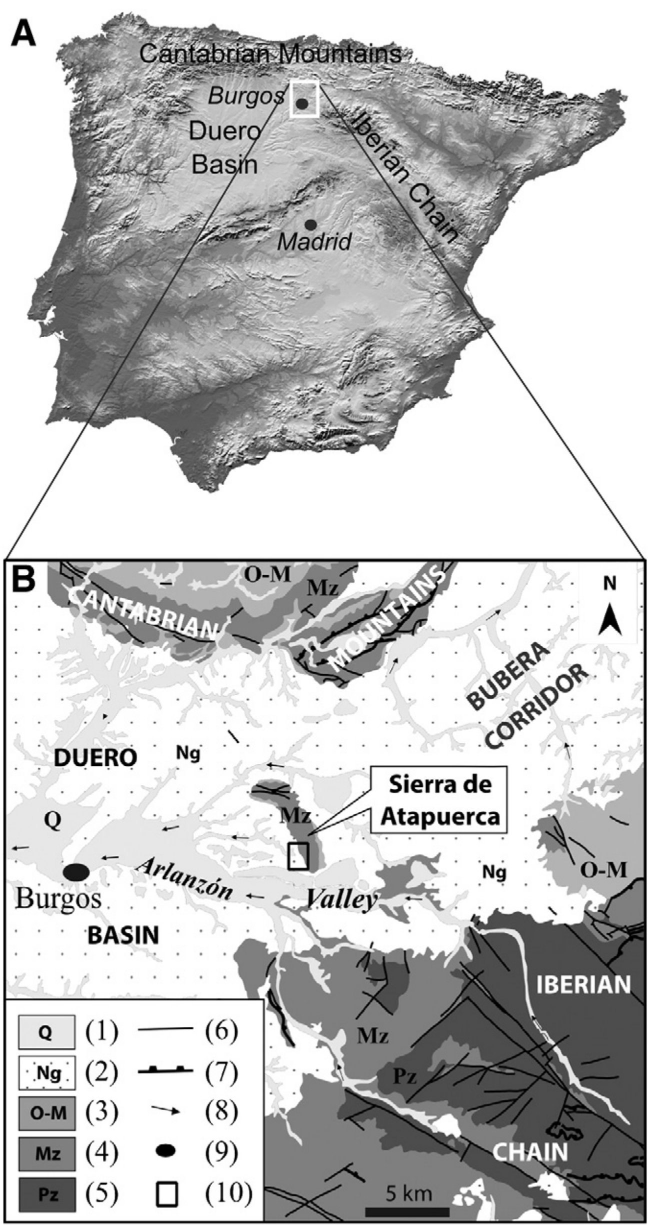

Fig. 1. A) General location of the study area in the Iberian Peninsula. B) Geological map of the NE sector of the Duero Basin. Legend: (1) Quaternary; (2) Neogene; (3) Oligocene–Lower Miocene; (4) Mesozoic; (5) Palaeozoic; (6) fault; (7) thrust; (8) drainage direction; (9) city; (10) study area (after Benito-Calvo et al., 2008).

The geomorphic evolution of the region is characterised by the development of planation surfaces related to erosion–sedimentation/uplift cycles during the Neogene, and by the predominance of fluvial incision of the valleys in Pleistocene and Holocene times (Benito, 2004; Benito-Calvo et al., 2008) (Fig. 2B). The oldest planation surface (SE1), situated at 1084–1060 m a.s.l. in the Sierra de Atapuerca, developed in Oligocene–Lower Miocene times, during the accumulation of synorogenic sediments in the basin (Zazo et al., 1983; Benito-Calvo and Pérez-González, 2007) (Fig. 2A, B). The second planation surface (SE2, 1065–1050 m a.s.l.) has been correlated with the alluvial deposits and the overlying limestone unit (Astaracian, Middle Miocene) that crop out in the NE sector of the Duero Basin. In the areas adjacent to the Sierra de Atapuerca these sedimentary units are tilted 2–7° (Figs. 2A and 3) and unconformably overlain by Upper Miocene horizontal deposits (Fig. 2A), indicating tectonic uplift of Middle Miocene age. A third planation surface (SE3, 1030–1035 m a.s.l.) lies at an elevation similar to that of Upper Miocene deposits designated as the Upper Páramo units (Benito-Calvo and Pérez-González, 2007). In nearby mountains, a fourth planation surface (SE4) can be distinguished at 950–1000 and 1025 m a.s.l., correlatable with Plio-Pleistocene alluvial fan gravels (Fig. 2A, B). Within the basin, this planation surface is developed mainly on Middle Miocene limestones (Lower Páramo limestones, Benito-Calvo and Pérez-González, 2007).

During the Quaternary, the fluvial network dissected the Neogene surfaces and generated a stepped sequence of terraces (Benito, 2004; Benito-Calvo et al., 2008). In the Arlanzón Valley 14 terrace levels and the present floodplain have been mapped (Fig. 2A, B). This sequence has also been identified in other valleys of the region like the Arlanza Valley, which includes two older terrace levels located at +107–114 m and +121–130 m above the river channel. So far, dating conducted on terrace deposits (Benito-Calvo et al., 2008) allows ascribing T14 (+2–3 m) to the Holocene (4827 ± 338 TL yr BP) and T11 (+12–13 m) to the Middle–Upper Pleistocene transition (Fig. 2B), since the equivalent terrace in the Arlanza Valley has yielded a TL age of 115.052 ± 11.934 yr BP, whereas preliminary magnetostratigraphic data for the Arlanzón terraces reveal normal and reverse polarity for T5 (+50–54 m) and T4 (+60–67 m), respectively, suggesting that the Matuyama–Brunhes reversal could be located between both terraces (Benito-Calvo et al., 2008).

The evolution of the base levels in the area during the Neogene and Pleistocene has controlled the onset and development of the Torcas cave system in the Sierra de Atapuerca (Ortega, 2009). These caves levels were hydrologically abandoned during the Lower Pleistocene (Parés and Pérez-González, 1995; Pérez-González et al., 2001; Parés et