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Upper Pleistocene interstratal piping-cave speleogenesis: The Seso Cave System (Central Pyrenees, Northern Spain)

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ABSTRACT

The Seso Cave System (SCS, South Central Pyrenees, Northeastern Spain) develops in poorly soluble marly interstratum between limestone beds of Eocene age. We propose an innovative and singular pseudokarstic speleogenetic model under vadose conditions based on cave morphological evidence, physicochemical and mineralogical characteristics of the Eocene marly host rock, U–Th dating of cave deposits, and local geological and geomorphological information. Eocene marls are shown to be sensitive to dispersion processes supported by their high clay content and the high concentration of sodium and low electrical conductivity in the seepage water. Runoff inside the cave results from water that infiltrates through joints and seepage water in cave walls. Thereby piping processes become very active, triggering mechanical scouring and outwashing mechanisms. The hydraulic gradient required to develop piping activity is determined by regional fluvial incision. The base level controlling water discharge during opening of the SCS coincides with a terrace of the Ara River dated at 65 ka BP. Considering this age, as well as the U–Th age of the oldest speleothems dated in the cave at 38 ka BP, the timing of the SCS interstratal piping-cave speleogenesis is constrained to the Upper Pleistocene; very likely at the end of Marine Isotope Stage 4 during a period characterized by high water availability following glacial retreat in northern Iberian mountains.

1. Introduction

Pseudokarst refers to karst-like landforms, such as caves and dolines, primarily produced by a process other than dissolution (Halliday, 2007). Different types of pseudokarst involving coastal/marine, volcanic, glacial, periglacial, aeolian, mass movement, soil piping, weathering and anthropogenic geomorphic domains have been differentiated (Eberhard and Sharples, 2013). Nevertheless, it remains problematic to associate some karst-like morphologies to a pseudokarst origin (Eberhard and Sharples, 2013).

Piping pseudokarst has usually been recognized in poorly consolidated materials outcropping in drylands, boglands and volcanic landscapes (Halliday, 2007). Piping or tunnel erosion is defined as the hydraulic removal of subsurface soil causing the formation of underground channels in natural landscapes (Boucher, 1990). A similar definition is proposed by Parker and Higgins (1990). Piping literature is extensive and deals with the role of piping processes developing badland landscapes as well as affecting civil structures (earthen dams, embankments, etc.). Piping erosional processes result from the interaction of different factors, including climate (strong seasonal contrasts and water availability), flow hydraulics (hydraulic gradient and topography) and properties of eroded material (swelling clay mineralogy, exchangeable sodium content and plasticity index) (Jones, 1981; Bryan and Yair, 1982; Gutiérrez et al., 1997; Faulkner, 2013; among others).

In piping pseudokarstic landscapes, some noticeable, but scarce, piping caves have been documented worldwide. In general, they are unique cases that require special attention. Officer's cave (Eastern Oregon, USA) (Parker and Higgins, 1990) and Anvil Points Claystone Cave (Western Colorado, USA) (Davis, 2001), among others, are mud caves excavated exclusively by piping processes. Su Niarzu Cave (North Sardinia, Italy) formed through weathering of tufaceous rock and subsequent piping phenomena (De Waele et al., 2008). Other cases such as McClung's Cave (West Virginia, USA) (Ford, 1965) and Bohemia Cave (South New Zealand) (Tásler, 2001) share piping processes

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and groundwater entrenchment on poorly soluble materials underlying mechanically stronger carbonate rocks as speleogenetic mechanisms.

In this work we present the speleogenesis of the Seso Cave System (SCS hereafter), a singular and exceptional case study of pseudokarstic cave in the Central Pyrenees (northern Spain). A new type of pseudokarstic cave developed by interstratal subsurface piping affecting dispersive marl lithologies is proposed. Erosive and depositional features of the cave as well as mineralogical and physicochemical properties of the hosting rock supporting the pseudokarstic origin of this non-dissolutional cave are provided. In addition, a chronological framework of the formation and evolution of SCS as well as a palaeoenvironmental scenario is proposed.

2. Regional setting

SCS is located in the lower Ara River valley near Boltaña village, a sub-humid mountainous area in the southern central Pyrenees (Huesca Province, N Spain) (Fig. 1). The studied cave is formed in the eastern flank of the Boltaña Anticline that constitutes the structural limit between the Jaca Basin and the South Pyrenean Central Unit (Soto and Casas, 2001). Eocene marls and limestones with microfossils (Boltaña Formation) (Barnolas et al., 1991) outcrop in this area. The stratigraphic sequence is arranged in a monoclinal structure dipping to the East.

Quaternary fluvial incision of the Ara River in this geological setting produces a local landscape dominated by cuestas (Fig. 1). Some scarps and large gentle back-slopes tilting around 20°–25° to the east developed in competent layers are easily recognized in the landscape. In addition, two strath terraces related to the Ara River incision are also preserved, as indicated in Fig. 1. These terraces appear about 62 m and 5 m above the active channel, and are located very near to the confluence of the Ara River into the Cinca River (Fig. 1). Consequently it is possible to correlate the upper terrace of the Ara River to one of the Cinca River staircase terrace sequence by using topographic location, geomorphological features and soil development degree. Thus, the upper terrace of the Ara River is correlated to the Qt7 level of the Cinca River that has a weighted age of 61 ± 4 ka based both on OSL and soil stratigraphy ages (Lewis et al., 2009). The typical soil profile formed on this terrace has a thick (around 130–200 cm) and well developed Bt horizon. Furthermore these soils have moderately developed Btk and Ck horizons with carbonate enrichment ranging between 21–41% wt/wt and with stage II carbonate morphology (Sancho et al., 2004). This Qt7 terrace constitutes an important geomorphic marker throughout the Cinca River basin (Sancho et al., 2003).

The present-day climate in the SCS area is temperate with dry and hot summers under the influence of Mediterranean–Atlantic climatic transition (López et al., 2007). Mean annual rainfall is higher than 1000 mm and mean annual temperature is around 13 °C. Geomorphic substratum supports a Cambic Calcisol more developed on weathered marls. This soil

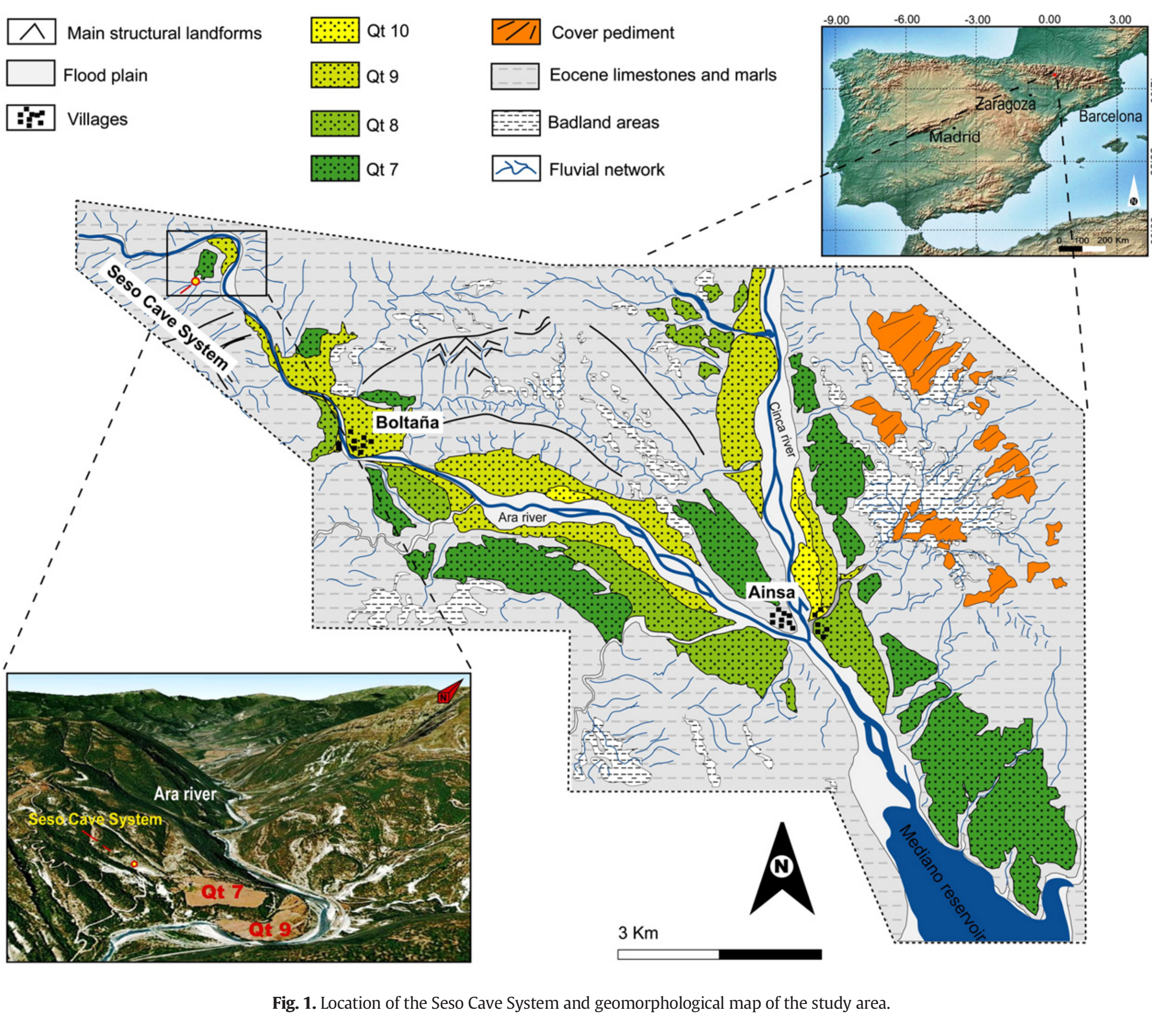

Fig. 1. Location of the Seso Cave System and geomorphological map of the study area.