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Stratigraphic architecture of alluvial–aeolian systems developed on active karst terrains: An Early Pleistocene example from the Ebro Basin (NE Spain)

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ABSTRACT

During the Early Pleistocene, fluvial, alluvial and aeolian depositional systems interacted in the central Ebro Basin, Spain, constructing wide alluvial plains over a Neogene evaporite substratum. Fluvial sediments, mainly longitudinal gravel bars and channels, are interdigitated with gravel mass flow and distal mudflat deposits. Aeolian sedimentation is registered as aeolian dunes and sand sheets. Episodes of fluvial deposition alternated with periods of alluvial fan progradation and aeolian deposition. These changes are related to climate-driven water availability. Stratigraphic units and deformation structures show synsedimentary karstification of the evaporite substratum that, although karst was not restricted to any particular climate scenario, was probably favoured during periods of high water availability. Karstification conditioned the development of local sedimentary depocentres which, in turn, influenced the distribution of sedimentary subenvironments as well as the accumulation and preservation of aeolian dunes and lacustrine–palustrine deposits. Stratigraphic architecture shows that thickening of the series due to karst subsidence did not occur homogeneously, but was controlled by diachronous subsidence resulting in numerous angular unconformities. In subsiding karst areas transport capacity was reduced and sediment preservation increased.

1. Introduction

Karst effects are widely considered in hydrogeology, environmental geology and geotechnical studies (Williams, 1972; Wright, 1988; Ford and Williams, 1989; Cooper, 1995; Milanovic, 2003). The development and intensity of karst processes are conditioned by factors such as rock type, water chemistry, hydraulic gradient and bedrock fracture patterns (Jassim et al., 1997; Plan, 2005; Closson et al., 2007; Mylroie and Mylroie, 2007). As the factors involved are very diverse, the study of karst requires multidisciplinary approaches.

Palaeokarst forms, such as palaeodolines or palaeokarstic surfaces, are common in the geological record (Yilmaz and Altiner, 2006; Soriano et al., 2012). Moreover, karst features and sediments that may be preserved in karstic depressions provide valuable palaeoclimatic and palaeoenvironmental data (Evans and Reed, 2007; White, 2007), as well as information related to karst evolution through time (Juhász et al., 1995; Molina et al., 1999; Rodríguez-Aranda et al., 2002; Calaforra and Pulido-Bosch, 2003).

Karst in the central Ebro Basin (NE Spain) is characterised by high dissolution rates as it develops on evaporites, primarily gypsum and halite, with solubility of ≈2.4 g/l and 360 g/l, respectively (Ford and Williams, 1989). This area has been extensively studied over the past decades. Various techniques have been used in order to discriminate potential hazard areas and to avoid risks associated with dolines in Zaragoza city and its metropolitan area (approximately 700,000 inhabitants). Studies have involved geomorphological mapping, geographic information systems, remote sensing, hydrogeological, geomechanical and geophysical surveys (e.g., Soriano et al., 1994; Simón-Gómez et al., 1998; Soriano and Simón, 2002; Lamelas et al., 2008; Castañeda et al., 2009; Galve et al., 2009; Pueyo et al., 2010, and references therein). Karst in this area is not a recent phenomenon. A high number of palaeodolines can be observed in Pleistocene terraces and pediments of the Ebro River and its main tributaries (Simón and Soriano, 1985; Soriano, 1992; Guerrero et al., 2004; Gutiérrez-Santolalla et al., 2008; Simón et al., 2008). Moreover, several authors have described local thickening in Quaternary terraces that has been attributed to synsedimentary karst subsidence (Benito et al., 1998; Guerrero et al., 2008; Pueyo et al., 2013). If time span is considered, the Upper terraces of the Ebro River are the oldest Quaternary levels affected by karst in the region. Although previous studies propose an Early Pleistocene age for these terraces (Colomer et al., 2006), reliable datings have not yet been performed,

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and correlation is made with the Upper terraces of the Gállego River (tributary of the Ebro River) that are Early Pleistocene in age (Benito et al., 1998).

Recently, multidisciplinary studies have been carried out especially focused on the sedimentary record associated with Quaternary palaeodolines. Results include identification of palaeokarst forms, facies analysis, structural analysis and geophysical characterization (Luzón et al., 2008, 2012; Pueyo et al., 2009; Pérez et al., 2011; Gil et al., 2012; Soriano et al., 2012). The main objectives of these works are centred on knowing the genetic mechanisms and the most favourable geological conditions for the development of karst, as well as on establishing different stages of karst evolution and changes in subsidence rates. In this paper, the results obtained from a multidisciplinary study of the uppermost Ebro River terrace level (Soriano, 1990) in the central Ebro Basin are shown. The main aim of the work is to demonstrate that karst determined the particular stratigraphic architecture of contemporary deposits. Karst influence was registered in two ways: 1) karst controlled configuration of sedimentary environments through the development of different depocentres, which permitted preservation of very erodible sediments, such as aeolian facies, between a gravel-dominated fluvial series; and 2) thickening of the terrace levels did not occur in a homogeneous way, but was controlled by the diachronous development of subsiding areas, resulting in numerous large-scale angular unconformities. Moreover our study documents the common interaction between fluvial and aeolian sedimentation in the central Ebro Basin. Palaeomagnetic surveys prove that karst activity has been developing since the Early Pleistocene. The reconstruction of Pleistocene subsidence is critical in understanding the genesis and evolution of the present doline fields in alluvial deposits, which constitute a major geohazard.

2. Geological Setting

The studied area is located in the central Ebro Basin (NE Spain), which is the foreland basin of the Pyrenees. The Catalonian Coastal Range to the east and the Iberian Range to the south also bound this basin (Fig. 1). Until the Late Eocene the Ebro Basin was connected with the Atlantic Ocean. Subsequently, it was an endorheic trough and alluvial systems developed, which spread from the basin margins and interfingered in central areas with carbonate or evaporite lacustrine systems (Muñoz et al., 2002). In the Middle–Late Miocene (García-Castellanos et al., 2003) the basin connected with the Mediterranean Sea and the current drainage network initiated.

Neogene evaporite rocks (Zaragoza Fm, by Quirantes, 1969) outcrop in the central part of the Ebro Basin. These rocks are mainly composed of gypsum and mudstone, deposited in a saline mudflat. They belong to the Ebro Basin tectonosedimentary Unit T5 (Pérez, 1989). Quaternary deposits in this area are mainly preserved in terraces belonging to the Ebro River and its major tributaries, and in pediment levels (Fig. 1). A disconformity separates the Neogene rocks from the overlying Quaternary deposits. These materials are affected by sets of fractures (van Zuidam, 1976; Simón and Soriano, 1985; Simón, 1989; Arlegui and Simón, 2000) that show wide dispersion, although N–S and WNW–ESE orientations dominate. Fractures affecting Neogene rocks conditioned the Quaternary drainage system and, consequently, landforms in the basin. These include infilled valleys (with preferred NE–SW and NW–SE direction), or the general NW–SE trend of the Ebro River and its terraces (Arlegui and Soriano, 1998, 2003). These terraces are best preserved on the right bank, where lower levels (T1 and T2 by Soriano, 1990) and middle levels (T3 and T4) are well represented. High terrace levels in the studied sector (T5 to T8) have been strongly eroded and only local hills, between 55 and 220 m above the present river, are preserved.

The studied deposits are located 30 km southeast Zaragoza in the T8 terrace level. In this zone T8 is located 210 m high above the river thalweg. Polygenic rounded gravels with horizontal stratification predominate, even though sands with planar cross bedding are common and massive mudstones are rare. In this sector T8 is bounded to the west, north and east by infilled valleys and to the south by the Mediana Lake depression, which is interpreted as a karstic depression (Soriano, 1990; Guerrero et al., 2012). Recent mantled dolines, large karst depressions (Soriano and Simón, 1995; Gutiérrez-Santolalla et al., 2005b; Galve et al., 2009) and Pleistocene dolines (Luzón et al., 2011; Soriano et al., 2012) are common in this zone.

3. Methodology

Our study has required a multifaceted approach and the application of several geological techniques in a selected quarry. Criteria for quarry selection include: high quality and thickness of outcrops, orthogonally oriented outcrops and wide variety of facies and deformation structures.

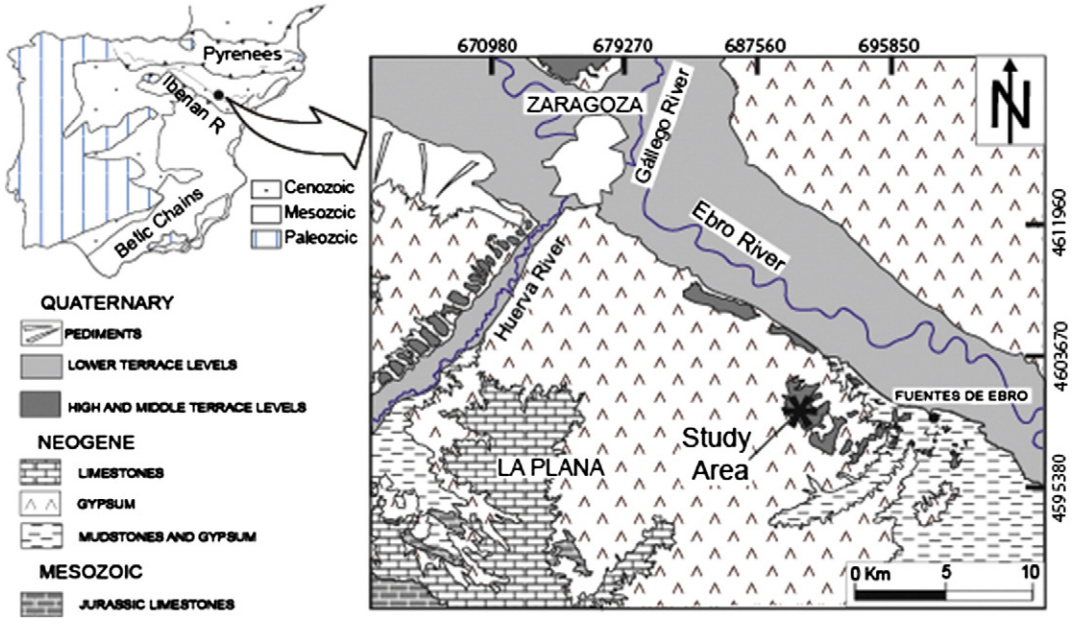

Fig. 1. Geographical and geological location of the surveyed area in the central Ebro Basin. The quarry under study has been marked with a black star.