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3-D modelling of a fossil tufa outcrop. The example of La Peña del Manto (Soria, Spain)

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ABSTRACT

Classical studies of tufas lack quantitative outcrop descriptions and facies models, and normally do not integrate data from subsurface in the stratigraphic and evolutive analysis. This paper describes the methodology followed to construct one of the first digital outcrop models of fossil tufas. This model incorporates 3-D lines and surfaces obtained from a terrestrial laser scanner, electric resistivity tomography (ERT) profiles, and stratigraphic and sedimentologic data from 18 measured sections. This study has identified seven sedimentary units (from SU-1 to SU-7) which are composed of tufa carbonates (SU-1; 3; 5; 6) and clastics (SU-2; 4; 7). Facies identified occur in different proportions: phytoherm limestones of bryophytes represent 43% of tufa volume, bioclastic limestones 20%, phytoherm limestones of stems 12%, oncolitic limestones 8%, and clastics 15%. Three main architectural elements have been identified: 1) Steeply dipping strata dominated by phytoherm limestones of bryophytes; 2) gently dipping strata dominated by phytoherm limestones of stems; and 3) horizontal strata dominated by bioclastic and oncoid limestones. The alternation of tufa growth and clastic input stages is interpreted as the result of climatic changes during Mid–Late Pleistocene.

1. Introduction

Tufas have been widely studied from different points of view, hydrological, biological, geomorphological, sedimentological and mainly climatic (Andrews et al., 2000; Peña et al., 2000; Matsuoka et al., 2001; Garnett et al., 2004). A great number of papers have described the sedimentary model of tufas and their evolution (Pedley, 1990; Ford and Pedley, 1996; Pedley, 2009; Vázquez-Urbez et al., 2012; Arenas et al., 2014), but in many cases there is a lack of subsurface information. Pedley et al. (2000) studied and modelled the 3-D structure of a barrage tufa in the Lathkill Valley (U.K.) with ground-penetrating radar (GPR). This, the first paper to study tufa deposits with GPR, constructed 2-D isobath and isopach maps for the main truncation surfaces. The importance of this kind of study is their contribution of a subsurface view of tufas and characterization of potential analog for water-constructed landforms on Mars (Pellicer et al., 2014). The integration of sedimentary logs, detailed facies mapping, electrical resistivity tomography (ERT), GPS, and terrestrial laser scanner data using new software developed recently for the oil industry improves correlations between outcrops (Jennette and Bellian, 2003; Bellian et al., 2005; Verwer et al., 2007; Kenter et al., 2008; Verwer et al., 2009a; Verwer et al., 2009b; Fabuel-Pérez et al., 2010; Merino-Tomé et al., 2012). Software such as PETREL helps develop facies modelling based on deterministic and stochastic methods from log and facies maps, thus providing the opportunity to extract quantitative information relevant to the understanding of the spatial distribution of sedimentary facies and their physical properties. Similar integrated studies have been developed recently to characterize carbonate and siliciclastic marine and non-marine sedimentary systems (Adams et al., 2004; Falivene et al., 2007; Verwer et al., 2009a; Verwer et al., 2009b; Fabuel-Pérez et al., 2010; Cabello et al., 2011; Amour et al., 2012; Merino-Tomé et al., 2012; Amour et al., 2013).

The objective of this paper is to put together data from subsurface, sedimentological analysis and geomorphology acquired with classical and new techniques (i.e. terrestrial laser scanner) from an excellent outcrop of a recent tufa system to create a 3-D digital outcrop model (DOM) wherein the main characteristics of the tufa can be described, measured and quantified.

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2. Geological and geomorphological setting

The Peña del Manto is a Quaternary fossil tufa developed on the left margin of the Henar valley, close to Deza village (Soria, Spain) (Fig. 1). Its deposits unconformably overlie Paleogene conglomerates, sandstones and mudstones that form the infill of the Cenozoic Almazán basin, which is dissected by the modern fluvial drainage network (Huerta, 2007; Huerta et al., 2010; Huerta et al., 2011; Valero et al., 2015).

This tufa and older, related Oligocene tufas forming part of the Almazán basin infill occur along the Aragonian branch of the Iberian Chain, which forms the NE margin and substrate of the Cenozoic Almazán basin (Fig. 1). In the Deza area, Paleozoic metamorphic rocks and Mesozoic sandstones and limestones are exposed and affected by several northward verging thrusts.

Nowadays, active tufa deposits form in relation with springs located at the contact between Upper Cretaceous limestones and Paleogene clastic–carbonate succession of the Almazán basin (Huerta, 2007). In these springs, water temperature and salinity increase towards the southeast along the Aragonian Range (Yélamos and Sanz Pérez, 1998). Bicarbonate content of present-day waters exceeds 300 mg/l in Deza

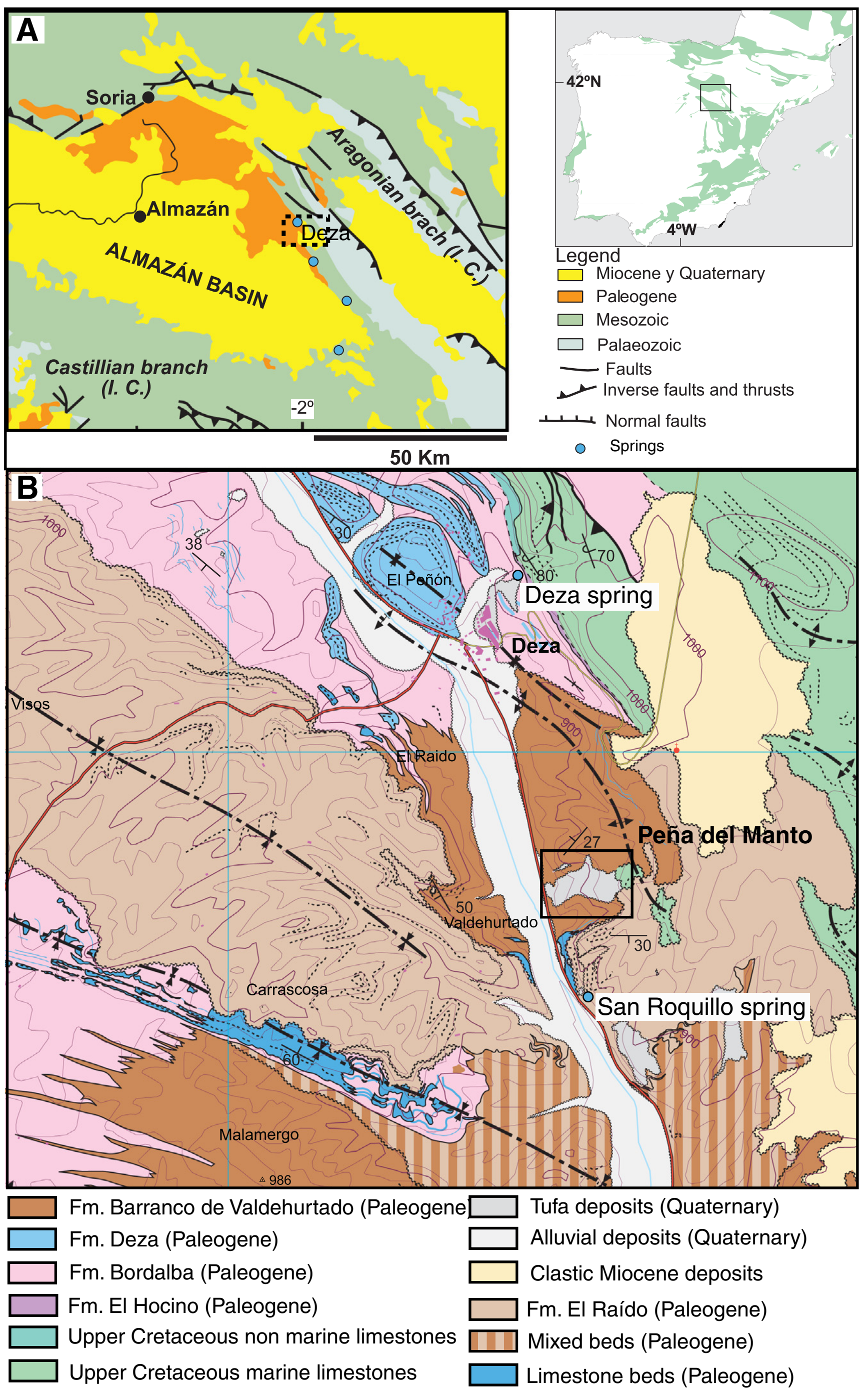

Fig. 1. Geological setting of the Peña del Manto tufa. A) Regional setting indicating the position of the Deza locality (close to the Peña del Manto), the Almazán basin and the Aragonian branch of the Iberian Chain (I.C.). Blue dots mark the location of springs with warm waters. B) Geological map of the Deza area marking the position of the Peña del Manto and other Quaternary tufa deposits. (For interpretation of the reference to colour in this figure legend, the reader is referred to the web version of this article.)
Huerta (2007)