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Environmental evolution in the Picos de Europa (Cantabrian Mountains, SW Europe) since the Last Glaciation

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ABSTRACT

The Western Massif of the Picos de Europa (latitude 43° N, longitude 4–5° W) includes some of the highest peaks in the Cantabrian Mountains. This massif was heavily glaciated during the Last Glaciation, though the post-glacial environmental evolution is still poorly understood. Using a complementary geomorphological and sedimentological approach, we have reconstructed the environmental events occurred in this massif since the last Pleistocene glaciation. The geomorphological distribution of glacial landforms suggests the occurrence of four main glacial stages: maximum glacial advance, glacial expansion after the maximum advance, Late Glacial and Little Ice Age. Moreover, a 5.4-m long sedimentary sequence was retrieved from the karstic depression of Belbín providing a continuous record of the paleoenvironmental conditions in this area since the Last Glaciation until nowadays. This section suggests that the maximum glacial expansion occurred at a minimum age of 37.2 ka cal BP, significantly prior to the global Last Glacial Maximum. Subsequently, periglacial processes prevailed in the mid lands of the massif until glaciers expanded between 22.5 and 18.7 ka cal BP. Following the melting of the glaciers, a shallow lake appeared in the Belbín depression. Lake sediments do not show evidence of a cold stage during the Late Glacial, when moraine systems formed at higher locations. The terrestrification of this lake started at 8 ka cal BP and the area turned into grassland. At 4.9 ka cal BP the existence of charcoal particles in the sediments of Belbín sequence reveals the onset of human occupation in the massif through the use of fire activity for grazing purposes. Finally, the presence of moraines inside the highest northern cirques shows evidence of the last glacial phase that occurred during the Little Ice Age cold event. Since then, the warming climate has led to the melting of these glaciers and periglacial processes prevail in the high lands of the massif.

1. Introduction

Research on Quaternary environmental dynamics in mountain ranges of the Iberian Peninsula has significantly increased in recent years. Most of the studies have focused on the absolute chronology of the Last Glaciation, but less research addressed the reconstruction of the postglacial environmental history. The widespread use of different dating systems has generated an intense scientific debate about the calendar of the maximum glacial advance in many high Iberian mountain massifs (Hughes et al., 2006; Hughes and Woodward, 2008; García-Ruiz et al., 2010). While datings based on ^{14}C and OSL techniques report chronologies predating the global Last Glacial Maximum (LGM) in many Iberian ranges (García-Ruiz et al., 2003, 2012; Lewis et al., 2009; Rodríguez-Rodríguez et al., 2011), the use of cosmogenic isotopes has approached the age of the maximum glacial expansion in the Pyrenees and Central Range mountains closer to the LGM timing (Pallàs et al., 2006; Palacios et al., 2011, 2012a, b; 2015; Domínguez-Villar et al., 2013). In Sanabria lake, the combination of different dating techniques (^{14}C, OSL and cosmogenic isotopes) suggested a local readvance of

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glaciers during the global LGM of similar extent to the Maximum Local Ice Extent (MLIE) reached at 33 ka BP (Rodríguez-Rodríguez et al., 2014b).

The evolution of the scientific knowledge of the Pleistocene last glacial cycle in the Cantabrian Mountains, northern Iberian Peninsula, has experienced a major breakthrough since the late 70's of the XX century. The Cantabrian Mountains are composed of several massifs, and Picos de Europa constitutes the massif including the highest elevations of the entire mountain range. In a first step, several studies focused their attention on the geographical reconstruction of the different glacial systems during the phase of maximum glacial advance in these mountains (Frochoso, 1980, 1990; Frochoso and Castañón, 1986; Castañón, 1989, 1990; García de Celis, 1997; González-Gutiérrez, 2002; Serrano and González-Trueba, 2002; Santos-González et al., 2013), the different recognizable glacial stages and the altitude of their fronts (Frochoso and Castañón, 1998; Flor and Bailón-Misioné, 1989; Gale and Hoare, 1997; González-Gutiérrez, 2002; González-Trueba, 2005, 2006, 2007; González-Trueba et al., 2008; González-Trueba and Serrano, 2010a, 2011; Santos-González, 2010; Ruiz-Fernández, 2015), in addition to the existence of possible glacial landforms and deposits in low-altitude mountain ranges (Martínez de Pisón and Arenillas, 1979).

Remarkable progress has lately been made in establishing an absolute chronological framework for the Last Glaciation in the Cantabrian Mountains. Several studies have proposed a maximum glacial advance in these mountains prior to the global LGM, ranging in age between 45 and 36 ka BP (Jiménez and Farias, 2002; Moreno et al., 2010; Serrano et al., 2012, 2013, 2015; Jiménez et al., 2013; Pellitero, 2013; Rodríguez-Rodríguez et al., 2014a) and even earlier (Frochoso et al., 2013). A second stage of glacier advance has been inferred in some massifs between 23 and 19 ka BP, mostly contemporary to the global LGM (Rodríguez-Rodríguez et al., 2014a). However, few studies have analyzed the environmental dynamics in the Cantabrian Mountains since the onset of the last deglaciation (Moreno et al., 2010, 2011; Serrano et al., 2012; Nieuwendam et al., 2016). Moreover, as in other areas in the Iberian Peninsula and the Mediterranean region, the landscape in the high lands of the Cantabrian Mountain started to be modified by human activity during the Mid Holocene through the use of fire activity to extend grazing activities (Díez, 1995; González-Díez et al., 1999; González-Pellejero et al., 2014).

Taking into account the present status of knowledge about the geomorphological and geochronological evolution in the Cantabrian Mountains since the local LGM, there are still several uncertainties that need to be addressed, such as:

(a) What was the maximum extent of the Last Glaciation in the west-central area of the Cantabrian Mountains where the Western Massif of the Picos de Europa, study area of this research, is located?
(b) What were the spatial domain and approximate timing of the various recognizable glacial stages in the Cantabrian Mountains?
(c) What has been the postglacial environmental evolution in the regional area until present?

With the purpose of giving answer to these questions, the aim of this paper is to:

(a) Synthesize the succession and spatial extension of the different glacial phases inferred from a geomorphological analysis of the deposits and glacial erosive and accumulative landforms.
(b) Infer the environmental changes since the Last Glaciation based on a detailed multi-proxy analysis of a long sedimentary sequence collected next to a formerly glaciated area in this massif.
(c) Frame the postglacial landscape succession in the Western Massif of the Picos de Europa within the glacial and postglacial chronology in the Cantabrian Mountains and the Iberian Peninsula.

2. Regional setting

The Picos de Europa Mountains constitute the highest and most extensive massif in the Cantabrian Mountains (NW Iberian Peninsula). In addition to be one of the main limestone massifs in the world, the Picos de Europa is the high mountain range in SW Europe with larger influence of the Atlantic Ocean on climate. These mountains stretch from E to W at latitude 43° 7′ N – 43° 17′ N and longitude 4° 35′ W – 5° 3′ W. The massif is located in a forward position with respect to the dividing line of the Cantabrian waters. This rugged relief with steep slopes stands out at only 20 km away from the Cantabrian Sea, contrasting with the relatively smooth morphology of the surrounding mid- and low-mountains composed of Paleozoic rocks.

The Picos de Europa enclose three different massifs (the Western or Cornión, the Central or Urrieles, and the Eastern or Ándara) separated by deep gorges carved by the Dobra, Cares, Duje and Deva rivers (Fig. 1). They are essentially composed of Carboniferous limestones, which are organized in an approximately E-W oriented imbricate thrust faults system with strata inclined towards south (Marquínez, 1989). Accordingly, more gentle slopes are found facing northwards whereas steep fronts prevail in southern orientations. This morphostructural framework has been intensively incised by fluvial erosion (Ruiz-Fernández and Poblete, 2011), and karstic processes (Miotke, 1968; Smart, 1986; Ruiz-Fernández and Serrano, 2011), including the development of deep cave systems (Ballesteros et al., 2011, 2015; Ruiz-Fernández and Poblete, 2012). The relief of the Picos de Europa has been also strongly shaped by Quaternary glaciers (Frochoso and Castañón, 1998; González-Trueba, 2007; González-Trueba and Serrano, 2010a, 2011; Ruiz-Fernández et al., 2009; Moreno et al., 2010; Serrano et al., 2012, 2013; Jiménez et al., 2013) and past and present-day periglacial dynamics (Castañón and Frochoso, 1998; Serrano and González-Trueba, 2004; González-Trueba and Serrano, 2010b; Ruiz-Fernández et al., 2014).

Geographically, the study area corresponds to the Western Massif, the largest of the three units with 137 km^2 (Fig. 1). The highest elevations exceed 2450 m a.s.l., such as Peña Santa de Castilla (2596 m), Torre Santa María de Enol (2486 m) and Torres del Torco (2452 m). Precipitation in the highest areas is estimated around 2500 mm/year (Serrano et al., 2013). The altitudinal temperature gradient in the region is 0.56 °C/100 m, which suggests that the 0 °C annual isotherm is placed at 2400–2500 m (Muñoz, 1982). According to the Köppen classification, the high lands in the massif have a Dfsc climate type (Muñoz, 1982). Vegetation in the massif is characteristic of the Eurosiberian region, with continuous forest in the lowlands composed of deciduous species and a discontinuous forest belt, fragmented into small woods at higher elevations. In the highest lands of the massif soil formation is limited by the steep relief and the well-developed nival karst (Ruiz-Fernández, 2015).

The Western Massif of Picos de Europa was declared National Park in 1918, the first of its kind in Spain. In 1995 this degree of protection extended to all the three massifs encompassing the Picos de Europa. This area is also classified as a Biosphere Reserve since