Catena 147 (2016) 372–385

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Late Quaternary pedogenesis of lacustrine terraces in Gallocanta Lake, NE Spain

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ARTICLE INFO

Article history:
Received 26 December 2015
Received in revised form 24 June 2016
Accepted 27 July 2016
Available online 30 July 2016

ABSTRACT

Transitional areas of lake margins are complex environments whose evolution is strongly controlled by flooding frequency and persistence. The edaphic development of lacustrine marginal environments can be reconstructed by combining detailed geomorphological analysis with a systematic edaphic study of toposequences. This approach has been applied to a set of recent lacustrine terraces in the downwind palustrine area of the Gallocanta saline lake, located in a semiarid area in NE Spain. Up to five terraces, from 1.6 to 4.5 m above the lake bottom, have been identified and mapped using stereo photointerpretation and airborne LiDAR data. Several cycles of water level fluctuations, as part of a general trend towards lake desiccation, have generated stepped terrace levels. The soils of these terraces have different morphological characteristics and provide evidences for the Gallocanta paleolake being larger than that of the present day. The soils have a sandy loam texture with variable clay content (1% to 46%) and a predominantly carbonate composition (mean = 26%). The soils are developed in a sequence of lacustrine carbonate-rich (mean = 37%) fine-grained gray layers overlaying detrital (mean = 51% gravels) and frequently erosive, carbonate-poor reddish layers. The pedogenesis of the downwind palustrine area is mainly characterized by poorly-developed carbonate accumulations and common redox mottles associated with water level fluctuations in the lake, which continuously rejuvenate or truncate the soils. Integrating pedological and geomorphological features provides insight into recent complex lacustrine and soil forming processes and facilitates management strategies and plans for this protected saline environment.

1. Introduction

Little is known about wetland soils developed in lake basins under semiarid climates. These soils frequently become seasonally or intermittently dry due to the limited precipitation and high evapotranspiration rates. Along the margins of arid wetlands, soil formation and properties are closely related to geomorphic position and fluctuations in lake, or playa-lake, water levels (Kolka and Thompson, 2007; Biggs et al., 2010; Farpoor et al., 2012; Shabanova et al., 2015). For this reason the study of wetland soils is always intimately linked to the study of wetland geomorphology and hydrology (Richardson et al., 2001).

Lake margins in semiarid climates are complex environments where sedimentation and soil formation are determined by the balance between detrital inputs during wet seasons and salt deposition during dry conditions (Boettinger and Richardson, 2001). In the wetting-drying margins of the lake, water action on soils strongly influences their characteristics such as texture, color, and types of horizons (Richardson et al., 2001). In this context, the study of soils provides evidence of recent and past water level fluctuations in the lake (Castañeda et al., 2015), and may be used for identifying regulatory boundaries (Lichvar et al., 2006). If high lake water periods are long enough, they favor the generation of a morphosedimentary marginal surface of mixed sedimentary-edaphic origin which can be abandoned and left perched once the lake level drops again (Romanovsky, 2002). This is the origin of stepped lacustrine terraces in lakes that experience a progressive desiccation trend (Gracia, 1995; Landmann and Reimer, 1996), as is the case of Gallocanta Lake. Water level fluctuations in lakes are common in the arid and semiarid Mediterranean region where most lakes are shallower (Beklioglu et al., 2007) and more sensitive to climate oscillations than in more humid areas. Lake water level fluctuations during the Late Quaternary have received much attention as proxies for identifying past environmental changes, usually based on sedimentology (Ghinassi et al., 2012; De Cort et al., 2013; McGlue et al., 2013) together with paleoecological evidence (e.g., pollen, ostracods, diatoms) (Shuman et al., 2001; Hoffmann et al., 2012).

Although classic geomorphological studies of lakes focus on the different lake morphologies in order to understand their origin and general evolution (Timms, 1992), few studies have investigated the geomorphology of lacustrine terraces in shallow lakes and most of these studies

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http://dx.doi.org/10.1016/j.catena.2016.07.046
0341-8162/

have looked at Pleistocene terraces related to major climatic oscillations (Bowman, 1971; Stine, 1990; Abu and Kempe, 2009; Ocakoglu et al., 2013). Only isolated contributions relate the distribution and elevation of Holocene lacustrine terraces to recent climate changes (Romanovsky, 2002; Gutiérrez et al., 2013). In fact, when compared to Pleistocene terraces, Holocene historical levels are usually close to present water levels and hence their study requires a very detailed high-resolution topographic analysis to distinguish different historical and recent terrace levels, not often affected by present flooding.

Recognition of such lacustrine terraces and associated past flooding events requires geomorphological and topographical techniques. Hence, lake terrace formation and the interaction between lacustrine and pedogenetic processes can be reconstructed by combining detailed geomorphological analysis and a systematic edaphic study of toposequences. This kind of quantitative analysis is feasible with modern topographic techniques like airborne LiDAR surveys and the digital terrain models derived from them, together with GIS software (Jones et al., 2008; Budja and Mlekuž, 2010). High-resolution LiDAR-derived digital elevation models have been widely applied in coastal areas (Kim et al., 2013; Matsu'ura, 2015) and fluvial systems with subtle topography (Jones et al., 2008).

The present study focuses on soil development in lacustrine terraces that are assumed to have been intermittently exposed during Late Quaternary-historical times, in the Gallocanta saline lake, NE Spain. The aim is to integrate pedological and geomorphological features to reconstruct the lacustrine terraces formation and understand recent lacustrine and soil formation processes associated with water level fluctuations.

2. Gallocanta Lake

2.1. General setting

Gallocanta Lake is the largest well-preserved saline lake in Western Europe and has been included in the Ramsar list since 1994 (Ramsar Convention Secretariat, 2010). The area comprises a 6477 ha natural reserve that is protected and managed by the local government in order to conserve endemism as well as habitats for the overwintering of migratory birds (Leránoz and González, 2009). The lake, formed at the bottom of a karst polje (Gracia et al., 2002), is located in a 543 km^2 endorheic basin at approximately 1000 m.a.s.l. in the Iberian Chain, NE Spain. The basin holds more than 20 lakes of karstic origin, Gallocanta Lake being the largest. The Gallocanta Quaternary basin is elongated in the dominant wind direction (NW-SE), parallel with the Valdelacasa mountain range, which runs along the NE side of the basin with peaks of up to 1400 m.a.s.l. (Fig. 1). This mountain range is composed of siliceous Ordovician rocks and flanks an extensive outcrop of deformed carbonate units from the Mesozoic (Gracia, 2014). The basin is excavated into Triassic clays and gypsum, as well as other more soluble salts (Gracia et al., 2009) which contribute to the soil and water salinity.

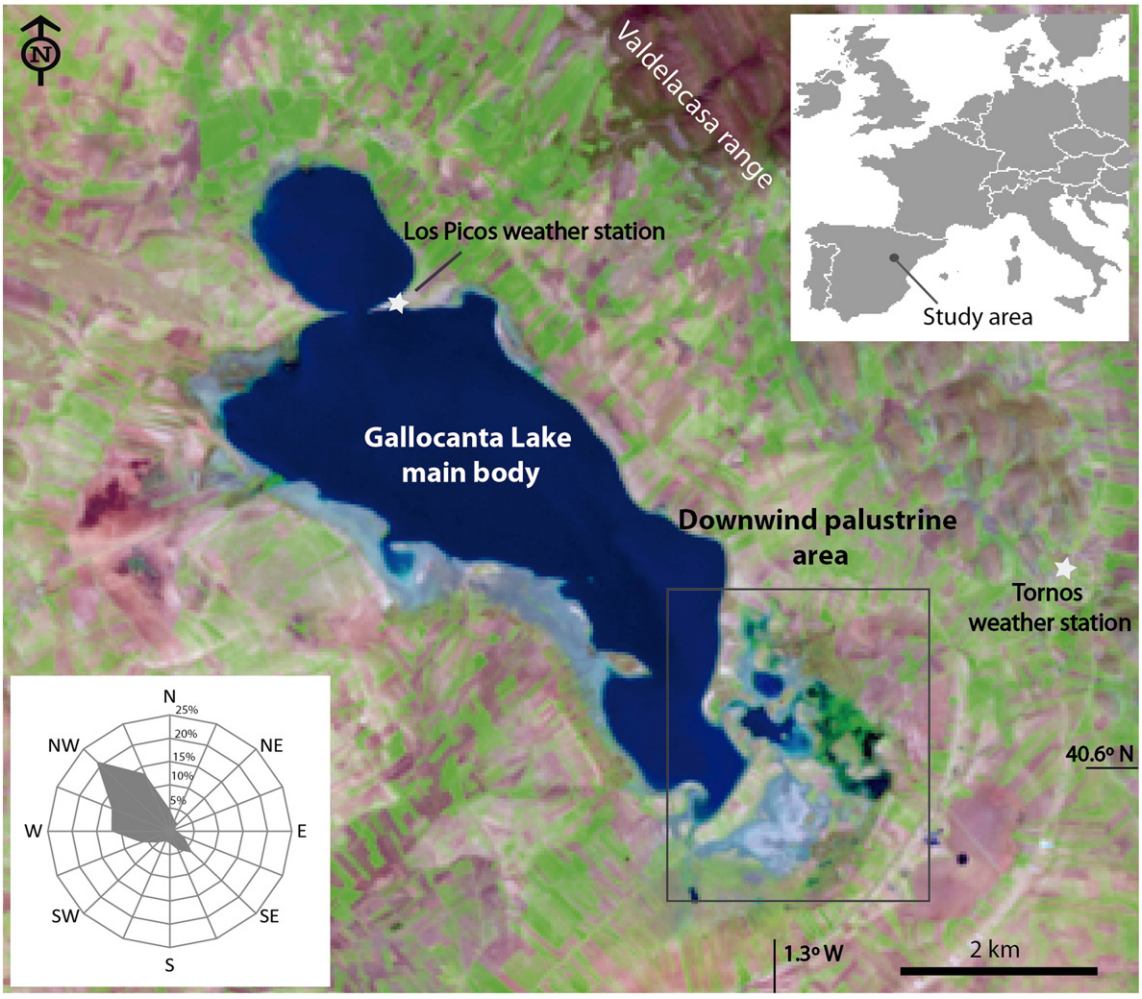

Fig. 1. False color composition (RGB 543) of a Landsat 5TM image (from the U.S. Geological Survey) acquired on 14/04/1987 showing Gallocanta Lake and its downwind palustrine area partially flooded. The nearest weather stations, Los Picos and Tornos, are marked. The wind rose shows the relative frequency and direction of the moderate (2.0 to 5.0 m s^{-1}) winter winds measured at a height of 2 m (modified from Martínez-Cob et al., 2010).