

A Quaternary soil chronosequence study on the terraces of the Alcanadre River (semiarid Ebro Basin, NE Spain)

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ABSTRACT

A sequence of dated alluvial terraces can provide an excellent geomorphological framework for studying soil evolution over time. The aim of this study is to establish a soil chronosequence over the last million years on the calcareous fluvial deposits of the Alcanadre River in the semiarid Ebro Basin (NE Spain). Moreover, two methods for determining total CaCO_3 content are compared: by calcimetry, in the lab, and by a portable XRF analyzer, in the field. Pedogenic CaCO_3 accumulation is the most characteristic age-related pedofeature in the studied semiarid conditions. This accumulation directly affects soil classification: the soils evolved from an initial Calcaric Fluvisol into Haplic Calcisol and later into Petric Calcisol; as well as some management properties, e.g., reducing water holding capacity from 170 to 14 mm/profile. The young Holocene soils that developed on the lower terraces maintain their original fluvic and calcaric properties, but calcic horizon can be found (as pendants) on soils from the Early Holocene to Late Pleistocene (from 10 ± 1 ka). On Middle Pleistocene (from 176 ± 14 ka) terraces, petrocalcic horizon is found, whose thickness is greatest on the soil evolved on oldest Early Pleistocene surface. This net retention of carbonates over time suggests the predominance of dry periods over wet ones during soil evolution. The measure of total carbonates by XRF in the field and those on fine earth by calcimetry in the laboratory shows a highly significant linear regression ($R^2 = 0.91$), which highlights the efficiency of in situ approach for measuring them.

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1. Introduction

The study of soil chronosequences is a powerful tool to elucidate the degree and direction of soil evolution (Hugget, 1998), which can also be used for dating or correlating Quaternary landscape sequences (Birkeland, 1999). Some surfaces used for this purpose are those generated by rivers, called strath terraces or cut-in-bedrock terraces. First, the river erodes a nearly flat planation surface, or “strath,” on bedrock and deposits a thin veneer of coarse gravel across the valley; subsequent erosional events related to climate changes create a set of strath terraces that occur at different altitudinal levels (Fuller et al., 2009). Although some chronosequences have been documented for a variety of climates, geomorphic units and parent rocks (e.g., Harden, 1982; Bockheim et al., 1996; Dan et al., 1981), there are few long-term studies on soil evolution in semiarid Mediterranean regions because of the scarcity of dated geomorphic surfaces (Lewis et al., 2009) and the difficulties of finding soils that are not eroded below a low plant cover (Zielhofer et al., 2009). The Ebro river Basin, the northernmost semiarid region in Europe, is an area where various tributaries with stepped alluvial terraces provide an excellent morphostratigraphic framework for evaluating time-

dependent soil-forming factors. This is the case for the Alcanadre River, whose terraces have recently been dated (Calle et al., 2013) with the youngest soils at the lowest altitude (Holocene), intermediate soils in the middle (Late and Middle Pleistocene), and the oldest soils in the highest terraces (Early Pleistocene).

In arid and semi-arid climates, soils with a secondary accumulation of carbonates are common (Nettleton et al., 1991) and represent over half of Spain's surface (Gómez-Miguel, 2005; Porta et al., 1989), along with a large store of inorganic carbon (EU, 2006). This carbonate enrichment in the subsoil, resulting in calcic or petrocalcic horizons (Calcisol), and its thickness, depth and coexistence with other processes can provide information about the time of formation and climate changes (Dan et al., 1981; Machette, 1985; Retallack, 2005; Brock and Buck, 2009; Monger et al., 2009; Sheldon and Tabor, 2009).

The measurement of the soil's total carbonate content can be established in the lab by traditional methods (Nelson, 1982) that are more or less modified (Fonnesbeck et al., 2013), although a field method has also been recently proposed (Gillot, 2014). Also, some pedogenic carbonate accumulations, which occur as carbonate coatings on the bottom of gravels (pendants or rinds), have been measured (Amoroso, 2006; Pustovoytov, 2003; Badía et al., 2009a).

The objectives of this study are to 1) establish a chronosequence of soils that developed in dated Holocene–Pleistocene deposits in the

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semiarid Ebro Basin; 2) determine the main morphological, physical and chemical properties and major elements of these soils to demonstrate that carbonation is a process sustained over time; and 3) compare the measurements of total CaCO_3 by calcimetry in the lab and by a portable XRF analyzer in the field.

2. Area of study

The Alcanadre River rises in the Pre-Pyrenees (North East of Spain), a calcareous headwater area that was never glaciated, where it is initially embedded in fluvio-karstic canyons; later, the river arrives at the Tertiary deposits of the Ebro Basin (Millán, 2006), which are arranged horizontally and provide modeling in structural morphologies. In the central sector of the Ebro Basin, the Alcanadre River runs north–south for 60 km, with a path almost rectilinear. When the river meets the resistant limestone reliefs of the Sierra Alcubierre, it turns 90° to the east. At that site, crossing the village of Sariñena, it joins with the Flumen River (Fig. 1). This is the area of study, the middle basin of the Alcanadre River, where different cut-in-bedrock or strath terraces connected by scarps are well

developed in a homogeneous semiarid climate. The terraces consist of coarse and very coarse clasts, with ellipsoidal, rounded, and subrounded forms, embedded in a predominantly calcareous sandy matrix. The clasts are mainly limestones, with occasional sandstones and conglomerates, all of calcareous nature. The lithology of the clasts in the oldest terrace presents greater diversity, including quartzite. Among the layers of clasts, alternate layers of silt-sized floodplain sediments can be found. The soils that were studied are placed on terraces with mean slopes ranging from 4 to 8‰ and an altitude from 230 to 443 m above sea level and from 4 to 174 m above the present channel (Table 1).

An approximate age for the strath terraces of the Alcanadre River by combining optically stimulated luminescence (OSL) and paleomagnetic analysis has been recently obtained (Calle et al., 2013). Paleomagnetic analysis has shown that terrace Qt1 is related to the Jaramillo subchron (approximately 1000 ka); it is the highest surface (and, therefore, the oldest) and consists of former sedimentary records related to the initial stages of the configuration of the Ebro Basin's exorheic fluvial network (Meléndez et al., 2011). The terrace Qt3 belongs to the Matuyama–

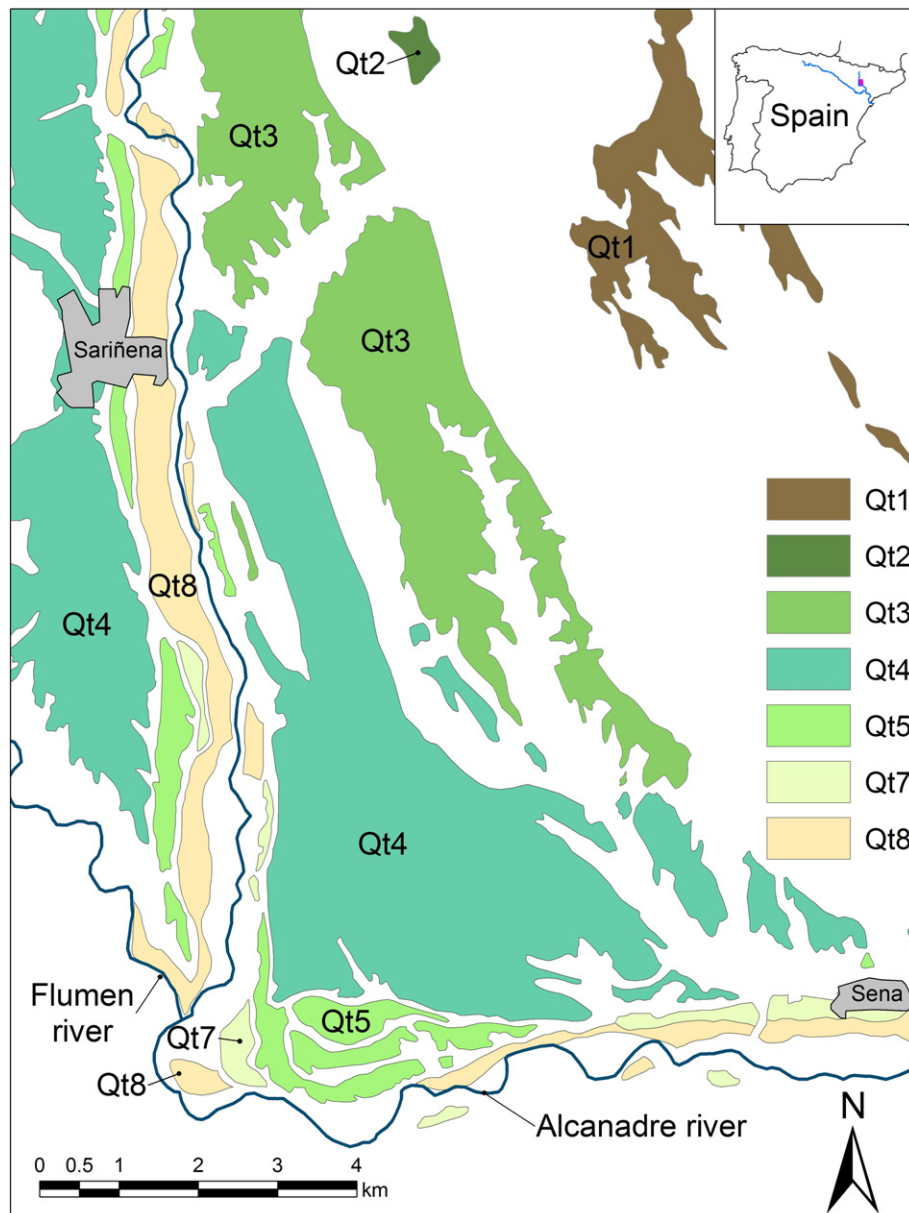


Fig. 1. Geomorphological map of the area of study.

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