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Soil evolution indices in fluvial terrace chronosequences from central Spain (Tagus and Duero fluvial basins)

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ABSTRACT

Soil development in central Spain was studied through analysis of soil chronosequences from Tagus and Duero river valley terrace systems, evolved under similar Mediterranean climatic conditions throughout the Pleistocene. The most complete soil–terrace sequence, representative for our study, developed in the Tagus valley (Aranjuez–Toledo–Talavera sector). We present soil textural data for argillic horizons developed in Late to Early Pleistocene soils from five valleys. We derive soil development indices from clay and silt content and thickness of argillic horizons. Global clay content (GCC), clay content (CC) and clay/silt ratio (C/Si ratio), numerical indices related to clay illuviation, reflect soil evolution, explored by multiple regression of soil–terrace height and soil–age. Relative terrace heights above present river thalwegs (i.e. +100 m) were transformed to ages with a "height–age transfer function" on the basis of preliminary statistical geochronological analyses for central Spain. The height–age transfer function, a 3rd order polynomial ($R^2 = 0.90$), based on 60 published numerical ages and paleomagnetic data for terrace sequences:describes the overall trend of valley downcutting for the last c. 2 Ma in central Spain. It assigns numerical ages to terrace levels at different relative elevations; and gives an estimate of standardized ages for the related soils. The explored age–soil relationships, logarithmic functions ($R^2 > 0.80$), are sensitive to parent material clay content (corresponding to geology of river catchments) for most soil indices. Only the clay/silt ratio minimizes this sensitivity, and can thus be used for regional approaches (Tagus and Duero basins; central Spain) whereas the CC index is applicable only to individual river valleys or different river valleys with similar catchment geology (i.e. Tagus Basin). The C/Si ratio illustrates the logarithmic trend of weathering of soil particles into clay over time, the generation of soil textural balances sustaining illuviation processes, and therefore provides an estimate of "soil ageing", for the implementation of soil chronofunctions for regional analysis of river valleys evolving in similar climatic conditions and with similar base-level history.

1. Introduction

Soil-chronosequences in Mediterranean climates have been widely studied (e.g. Sauer, 2010). Numerous studies have focused on the characterization of soil age–property relationships by means of morphological or analytical indices (Bockheim, 1980; Harden, 1982; Busacca, 1987; Roquero et al., 1997; Birkeland, 1999) that quantify soil properties most closely related to soil age (i.e. soil thickness, clay illuviation, rubification). Most of these studies converted a variety of soil field property classes (Soil Survey Staff, 1951) to numerical data to calculate profile development (PDI), morphological horizon (MHI), or redness (RI) indices, introduced by Harden (1982), with later modifications (e.g. Harden and Taylor, 1983; Torrent et al., 1983). Other authors used similar reclassification of soil analytical physical and chemical properties to establish thickness (Dorronsoro and Alonso, 1994; Alonso et al., 2004), carbonate accumulation indices (Badía et al., 2009), and even non-linear textural measures (Calero et al., 2008). As in recent reviews of Mediterranean soils (Sauer, 2010), most studies from the Mediterranean region reclassified generic age morphometric

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trends with correlation regression coefficients (R^2) below 0.80–0.75, or even lower. Many of these studies, within the European Mediterranean zone, are soil chronosequences studies on river terraces in the Iberian Peninsula. Morphometric studies of other zones with Mediterranean climate outside Europe offer better correlation coefficients (R^2), up to 0.85–0.90, specially in chronosequences on river terraces (Sauer, 2010). This apparent misfit between European and non-European age correlation of soil-chronosequences, is probably related to the quality of numerical age data analysed in the Iberian river systems. Numerical ages reported in most of these studies were rough estimates from generic chronostratigraphic studies, not truly based on dating of fluvial sequences. Consequently, the numerical indices obtained are poor reflections of the role of progressing soil-forming processes. Only the thickness index proposed by Dorronsoro and Alonso (1994) provides a good morphometric fit when applied to different fluvial chronosequences in other zones of the world, but correlates poorly ($R^2 < 0.50$) when applied to other Iberian river systems (Sauer, 2010), evidence of the poor quality of the generic age estimates.

Soil chronosequences from fluvial or marine terraces are particularly suitable for soil–age development studies since soil properties in fluvial (Jongmans et al., 1991; McFadden and Weldon, 1987; Alonso et al., 1994; Roquero et al., 1997) or marine (Merritts et al., 1991; Scarciglia et al., 2006; Sauer et al., 2010) terrace sequences can be related with clear time-trends. In particular, fluvial chronosequences offer repeated, stable and low-slope surfaces (terrace surfaces) in inland settings subject to similar sedimentary/erosion, suitable for studying soil development through time (Stevens and Walker, 1970). In the Iberian Peninsula, the relative age of these surfaces has been established by analysing geomorphic, cartographic, palaeontological, palaeomagnetic and archaeological data (Roquero et al., 1997; Bridgland et al., 2006). At present the amount of available numerical dating (OSL, TL, ESR, AAR, Th/U, ^{14}C) for fluvial terraces is growing, especially for river basins from the central Iberian Peninsula (Cunha et al., 2008; Moreno et al., 2012; Pérez-González et al., 2013; Silva et al., 2013a). With this geochronological dataset, preliminary terrace altimetry relationships with numerical age have been proposed for central Spain (Silva et al., 2013b), to be used as standard chronofunctions to convert terrace height to numerical ages.

This work is focused on the development of age–soil evolution indices from textural analytical data based on the preliminary studies of Roquero et al. (1997) developed for the Tagus river basin in central Spain, now extended to other river systems of the Tagus and Duero basins draining towards the Atlantic Ocean (Fig. 1). As numerical age data are available only for particular valley segments and/or fluvial terraces (commonly ≤ +50 m), in this study we used age–terrace height transfer functions based on geochronological numerical models for terrace development in Central Spain (Silva et al., 2013b).

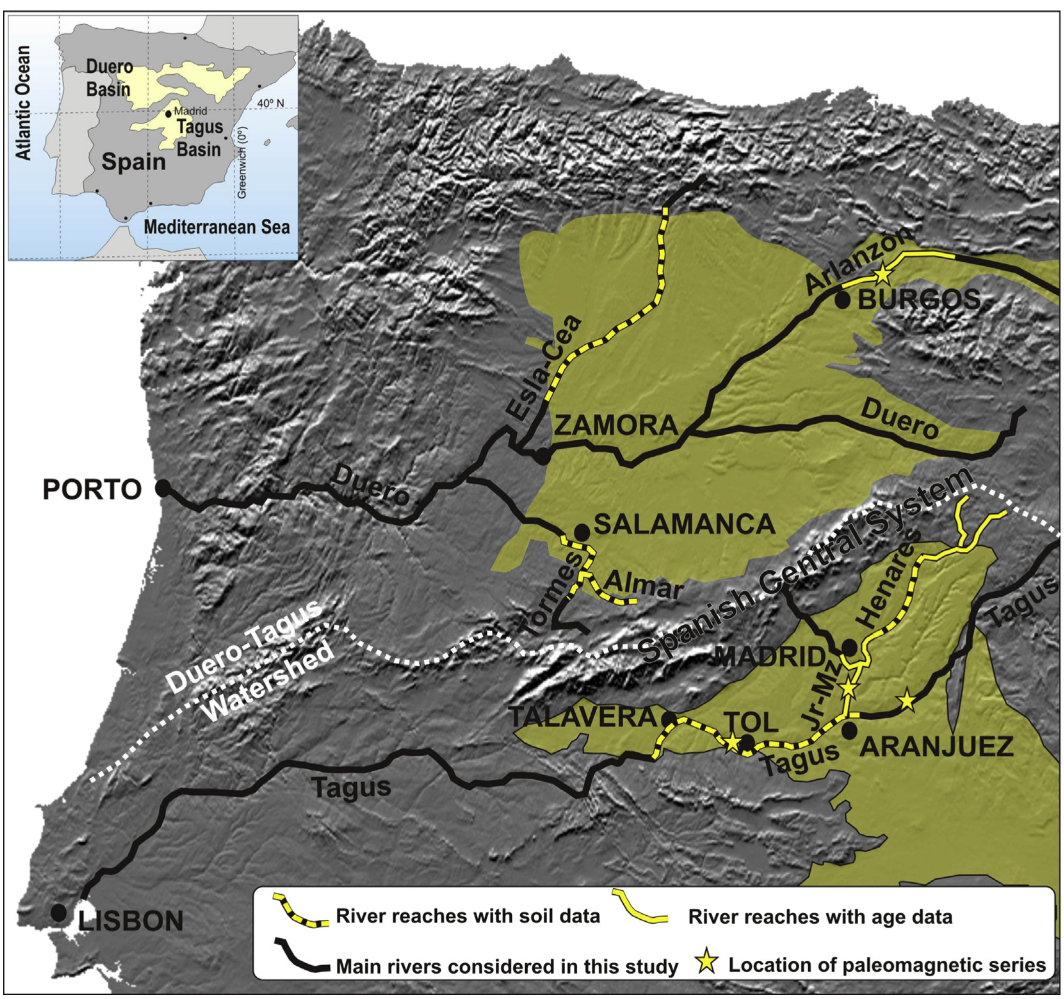

Fig. 1. Location of fluvial catchments studied, dissecting Neogene basins in Central Spain, showing river valley segments with soil data and valley segments with available geochronological fluvial terrace data (see inset legend).