Quaternary International 376 (2015) 134–145

Contents lists available at ScienceDirect

Quaternary International

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

Pedogenetic processes and pedostratigraphy of the Quaternary on the Balearic Islands and in the Granada Basin, Spain

Stephen Wagner [a, *], Eileen Eckmeier [b], Armin Skowronek [a], Norbert Günster [c]

[a] Institute of Crop Science and Resource Conservation – Soil Science, University of Bonn, Nußallee 13, D-53115 Bonn, Germany
[b] RWTH Aachen University, Department of Geography, Templergraben 55, 52056 Aachen, Germany
[c] Bergstraße 26, D-51503 Rösrath, Germany

ARTICLE INFO

Article history:
Available online 20 February 2015

Keywords:
Palaeopedology
Pedostratigraphy
Loess
Aeolianite
Redness
Western Mediterranean

ABSTRACT

Sediment-soil-sequences are suitable geoarchives and may contribute to resolving palaeoclimate conditions and reconstructing the according stratigraphy. We highlight the characteristics of Holocene soils, Pleistocene palaeosols, aeolianites, loess, slope debris and calcretes on the Balearic Islands at 17 new locations on Mallorca, Ibiza, and Menorca. Their stratigraphy is correlated with sedimentary and pedogenetic processes, and compared to sequences in the Granada Basin (Southern Spain).

On the Balearic Islands, surface soils are mainly brunified and loamy, while underlying palaeosols have different features due to clay illuviation, iron weathering and intense reddening, as emphasized by higher iron indices [Fe_{Index} = (% Fe_d – % Fe_o)/(% Fe_t/% clay)] and their close correlation to redness. Intermediate sediments appear as aeolianites, silty loess, calcretes and silt–clay dominated slope debris, and may reflect rather dry-cool climates and scarce vegetation. The increase of palaeosol redness with depth underlines a successive development in respect of polygenesis. While the palaeoclimate is humid Mediterranean, the declined pedogenetic intensity refers to gradual transition to less pronounced humidity and lower temperatures.

The palaeosols of the Granada Basin are comparatively less developed. Surface soils are brunified and loamy, and underlying palaeosols show features connected to clay-illuviation and reddening, while a distinctly smaller Fe_{Index} is evidence of less intense weathering. Soil properties indicate declined pedogenetic intensity upon time. Soil formation is influenced by distinct sea level oscillations and a seasonal humid climate. Close correlations between Fe_{Index} and RR_{visual} ($R^2 = 0.89$) highlight hematite formation as particularly intense in the Early Pleistocene. It followed a more arid Late Pliocene with intense erosion and sedimentation, as underlined by distinctly lower values of both Fe_{Index} and RR_{visual} during this time. Quaternary processes of pedogenesis and sedimentation therefore not only substantiate a distinct climatic cyclicity in the Western Mediterranean, but also reflect advanced development of palaeosols with depth and thus with time.

1. Introduction

Numerous studies have been carried out to resolve Quaternary climate changes in the Western Mediterranean (e.g. Butzer, 1964; Hillaire-Marcel et al., 1996; Rose and Meng, 1999; Rose et al., 1999; Vesica et al., 2000; Tuccimei et al., 2006; Hodge et al., 2008; Bardají et al., 2009; Ginés et al., 2012; Zazo et al., 2013; Wagner et al., 2014). The resolution of palaeoclimate conditions and the geochronology haven been improved by sedimentary and palaeopedological studies (e.g. Butzer, 1962, 1975; Brunnacker and Lozek, 1969; Rohdenburg and Sabelberg, 1973; Brunnacker, 1974; Günster, 1999; Günster and Skowronek, 1999, 2001; Günster et al., 2001; Ortiz et al., 2002; Füllner et al., 2005; Suchodoletz et al., 2009a, 2009b; Muhs et al., 2010; Wagner et al., 2011a, 2011b, 2014). A specific focus on calcrete genesis was set by Nash and Smith (1998), Candy and Black (2009), and Candy et al. (2012). Local and distant sources of aeolianites and loess were studied by Henningsen et al. (1981), Coudé-Gaussen (1990), Henningsen (1990), and Fornós et al. (2012).

Loess is a terrestrial record of interglacial–glacial cycles providing a rich archive for reconstructing Quaternary climate change, and its time of sedimentation can be dated by

* Corresponding author.
E-mail address: stephen.wagner@uni-bonn.de (S. Wagner).

http://dx.doi.org/10.1016/j.quaint.2015.01.036
1040-6182/

luminescence (e.g. Frechen et al., 2003 and references therein; Roberts, 2008). Loess is a silt-dominated, highly erodible sediment, transported and redeposited by wind (Pye, 1987, 1995). Makeev (2009; cited by Smalley et al., 2011) refers to loess as gradually sedimented material altered by pedogenesis. In contrast, aeolianites are "lithified eolian deposits most commonly preserved in the form of eolian limestones" forming under constant winds and warm weather conditions (Fornós et al., 2012). Dust transport through the atmosphere thus helps to reconstruct climate history and dust production (Jickells et al., 2005). Dust transport from the Sahara Desert across the Atlantic Ocean accumulates 200 million t per year, and across the Mediterranean Sea 100 million t per year, highlighting dust as an important source of soil formation in the Mediterranean (Yaalon, 1997). Saharan dust is present in sediments of Lanzarote/Canary Islands (e.g. Suchodeletz et al., 2009a, 2009b). Muhs et al. (2010) identified the origin of dust deposits on Mallorca through satellite images. They distinguished fluvial and playa deposits in Algeria and Tunisia, south of the Atlas Mountains, as the most common source areas.

A pedostratigraphical system was established by describing pedogenetic and sedimentary processes in cliff profiles of two alluvial fans on Mallorca by Wagner et al. (2014). The current paper highlights results of these two sites and of 15 new locations on Mallorca, Menorca and Ibiza, including fossil soils and sediment-(palaeo)soil-series in (coastal) alluvial fans and relic soils. We discuss major pedogenetic and sedimentary processes during the Quaternary, and relate them to results of earlier studies on sediment-soil-sequences in alluvial fans and slope and loess deposits of the Granada Basin/Spain (Günster, 1999; Günster and Skowronek, 2001; Günster et al., 2001).

Our goals are (1) to reconstruct major pedogenetic and sedimentary processes on the Balearic Islands; (2) to compare these processes with processes in sediment-soil-sequences in alluvial fans and slope deposits (here: exemplified by the Granada Basin); and, based on results of these sediment-palaeosol series, (3) to determine the major climatic conditions in the Western Mediterranean during the Quaternary.

2. Regional setting of sediment-soil sequences

The archipelago of the Balearic Islands in the western Mediterranean Sea comprises Mallorca, Menorca, Ibiza (Eivissa) and Formentera and 147 smaller islands, with a total area of 4992 km^2. All information in this paragraph is based on Jenkyns et al. (1990). The predominantly marine sediments comprise Jurassic and Cretaceous carbonates, dolomites and marls. Menorca is separated from the other islands by major faults, and covered by shallow-water limestone and dolomites. Pliocene facies mainly comprise calcarenites, marls and conglomerates. The Pleistocene records distinguish a variety of periglacial elements with descending talus, deposits of braided-river gravels, deep valley incisions and descending beach dunes. At least six glacio-eustatic littoral–sedimentary cycles are recognized. Carbonate-rich waters contribute to current calcrete formation cementing valley deposits (Jenkyns et al., 1990).

While the geomorphological imprint on the georelief of the Balearic Islands is based on relief and rainfall intensity, current downwash and ephemeral gully erosion are mainly human-made processes. Karst forms and deeply incised V-shaped valleys with torrential water flow developed in the Early Pleistocene (Jenkyns et al., 1990).

Widespread alluvial fan sediments and gravel fields reflect increased surface runoff and distinct fluvial activity in plains (Rose and Meng, 1999; Rose et al., 1999). A scarce vegetation cover generally relates to arid climate conditions (Hodge et al., 2008) enhancing aeolian transport. This is evident by dune fields along torrents (Rose et al., 1999), coastal dunes and widespread aeolianites derived from shelf material and exposed during subsequent regression phases. While the relative age of such aeolianites correlates with Pleistocene deflation phases according to distribution, colour, thickness and consolidation, their exact stratigraphy requires absolute dating (Henningsen et al., 1981; Henningsen, 1990). The partial presence of loess is mainly of supraregional origin and deposited by rainfalls (Rose et al., 1999). For the Late Pleistocene, Hillaire-Marcel et al. (1996) and Vesica et al. (2000) identified two sea level maxima during the Eemian (MIS 5e) around the Balearic Islands.

The most common Quaternary pedogenetic and sedimentary processes on the Balearic Islands can be summarized in an idealized "model of climatic cycling of pedogenesis and sedimentation", with one sedimentary cycle comprising six subcycles (detailed descriptions in Günster and Skowronek, 1999; Wagner et al., 2014): 1) Humid climate with geomorphodynamic stability allowing pedogenesis; 2) Drier climate with geomorphodynamic activity, erosion and sedimentation; 3) Pronounced aridity, induration of eolianites, soils covered by sediments; 4) Cool-arid climate with sediment deflation and loess deposition; 5) More humid climate with loess and sediment redistribution; 6) Warm-humid climate with vegetation cover allowing pedogenesis. This sequence of processes is modified by erosional gaps or abrupt climate changes and in case of incomplete pedogenesis.

The pedology of the Balearic Islands is mainly characterized by weathered relict soils and by fossil soils and soil complexes in coastal alluvial fans (Rohdenburg and Sabelberg, 1973). Detailed investigations were conducted at the sites of El Toro (SW Mallorca) and Colonia de Sant Pere (NE Mallorca) (Wagner et al., 2014). The mighty sediment-palaeosol series of El Toro is of Late Pliocene to Early Quaternary age (Solé Sabaris, 1962), while in Colonia de Sant Pere, sediments of the Lower Sand Complex formed in the Early Glacial (Rohdenburg and Sabelberg, 1973). Both sites contain series of up to 30 fossil soils and palaeosol complexes representing geomorphological stability, alternating with interlayered sediments representing geomorphological activity (i.e. slope erosion, runoff).

The locations of all 17 profiles are presented in Fig. 1. Whereas the two sites of El Toro and Colonia de Sant Pere are located in coastal alluvial fans, the other sediment-palaeosol- sequences are

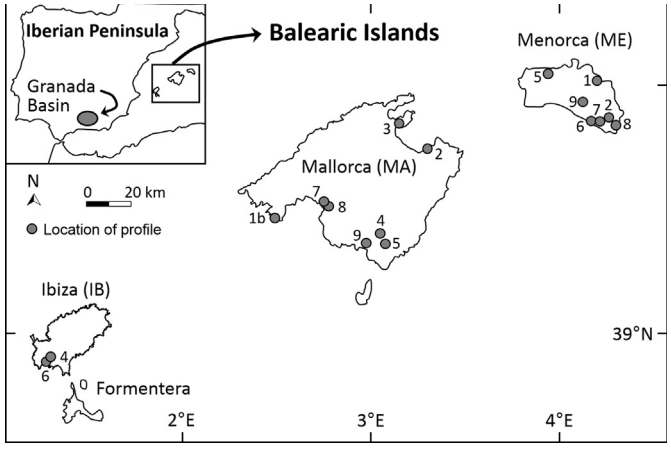

Fig. 1. Locations of the investigated sediment-palaeosol-sequences on the Balearic Islands and the Granada Basin. MA1b = El Toro II, MA2 = Colonia de Sant Pere, MA3 = Port d'Alcudia, MA4 = Campos I, MA5 = Campos II, MA7 = El Pilarí, MA8 = Ses Cadenes, MA9 = Sa Rapita, IB4 = San Josep, IB6 = Vista Alegre, ME1 = Na Macarét, ME2 = San Luis, ME5 = Biniancolla, ME6 = Binidalí, ME7 = Binisafú, ME8 = Punta Prima, ME9 = Son Bou.