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Loess-like and palaeosol sediments from Lanzarote (Canary Islands/Spain) — Indicators of palaeoenvironmental change during the Late Quaternary

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ABSTRACT

On Lanzarote (Canary Islands) Quaternary Saharan dust and weathered local volcanic material were trapped in Miocence to Pliocene valleys dammed by younger volcanic edifices. These sediments show sequences of alternating reddish/clayey and loess-like yellowish/silty material. In order to investigate if reddish/clayey layers contain material derived from local pedogenesis and if so, which pedogenetic processes were active, we performed sedimentological, micromorphological and environmental magnetic analyses. The analyses demonstrate that these layers contain material derived from local soils. These soils were characterised by clay formation, rubefication and the formation of superparamagnetic particles during periods of enhanced soil moisture. Thus, they can serve as natural archives in order to reconstruct the terrestrial palaeoclimatic history of Lanzarote. The distribution of soil material in the profiles shows that cold periods of the Late Quaternary were characterised by more humid conditions than today. Using palaeontological remains and a comparison with recent soils on Tenerife, we can roughly estimate maximal palaeoprecipitation values during more humid periods.

1. Introduction

Loess-palaeosol sequences are important terrestrial palaeoclimate archives for the past few million years as documented by numerous multiproxy-studies from both hemispheres (e.g. Bronger, 1976; Maher and Thompson, 1992; Dodonov and Baiguzina, 1995; Antoine et al., 2001; Schellenberger and Veit, 2006). In these sediments, palaeosol horizons are formed by various pedogenetic processes such as clay formation, rubefication or humus accumulation and indicate enhanced soil moisture compared to periods when unweathered loess was deposited. Enhanced soil moisture indicates a more positive landscape water budget and is therefore connected to more humid climate conditions (e.g. Bush et al., 2004; Carter-Stiglitz et al., 2006). Pedogenetic processes and thus the intensity of pedogenesis in such sequences can be traced back using variations of several proxies, e.g. clay content, clay mineral assemblages, carbonate contents, isotopic composition of organic matter and soil carbonates, micromorphological features or environmental magnetic parameters (e.g. Bronger and Heinkele, 1989; Heinkele, 1990; Junfeng et al., 1999; Hatté et al., 2001; Maher et al., 2002; Markovic et al., 2008).

Enviromagnetism, the magnetism of sediments and soils, describes the occurrence, abundance and properties of iron-bearing minerals in the environment. Magnetic grains, exclusively iron oxides/hydroxides and sulphides, occur virtually ubiquitously in Quaternary sediments, soils, dust and organisms, albeit often in minor or trace concentrations. After sedimentation and/or reworking, they undergo diagenesis and pedogenesis when, for example, more humid conditions predominate. This can result in their transformation, depletion, neo-formation or enhancement. Ferrimagnetic minerals in particular react several orders of magnitude more strongly in ambient laboratory magnetic fields than other iron-bearing minerals. These minerals control the magnetic properties of sediments or soils even when present in very small amounts. Since climate changes and human activity produce changes in sedimentary and soil-forming environments, magnetic properties from a wide range of marine and continental sedimentary archives reflect alternating warm/humid and cold/dry climates during the Quaternary (e.g. Walden et al., 1999; Hambach et al., 2008).

The properties of a magnetic assemblage depend not merely on the composition of the minerals, but largely on the grain size distribution of the particles. For a given mineral, initial magnetic susceptibility (κ) varies over orders of magnitude depending only on grain size. κ is largest for very fine superparamagnetic (SP) particles (roughly <30 nm), is reduced for single domain (SD) grains and increases again for multi domain grains (roughly >140 nm, valid for magnetite), although not reaching the values of superparamagnetic particles (e.g.

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Evans and Heller, 2003). Nowadays, essentially three models of the origin of ultrafine superparamagnetic minerals are discussed. (i) Firstly, large magnetic mineral grains may be decomposed or even "split" into smaller grains by weathering processes, producing large amounts of superparamagnetic particles when a relatively high concentration of magnetic minerals is present (Maher, 1998; van Velzen and Dekkers, 1999). (ii) Secondly, bacteria produce extracellular superparamagnetic Fe-minerals in different sedimentary or soil environments, a process obviously omnipresent in soils (Maher, 1998). Fassbinder et al. (1990) first demonstrated the occurrence of so-called magnetotactic bacteria in soils. These bacteria produce intracellular low susceptible, but highly magnetic particles in the single domain state as means of spatial orientation, thereby causing magnetic enhancement as observed in non-volcanic soils. (iii) Thirdly, recent works of Torrent et al. (2006) and Liu et al. (2008) demonstrate the importance of the ferrihydrite → hydromaghemite → hematite transformation. This transformation may constitute a major pathway accounting for the magnetic enhancement in many soils. The production of superparamagnetic hydromaghemite particles concurrently increases both the initial and frequency dependent magnetic susceptibility.

The Saharan desert is the largest source of dust in the world, contributing about 50% of all mobilised mineral aerools (Aléon et al., 2002). This dust accumulates in the circum-Saharan area and is called "warm" or "desert" loess, in contrast to lithologically similar deposits in boreal and temperate zones derived from material mobilised by periglacial processes (e.g. Yaalon and Bruins, 1977; Coudé-Gaussen, 1991; Wright, 2001; Dearing et al., 2001).

About 30–50% of the dust originating from the Saharan desert is transported to the Atlantic Ocean (Goudie and Middleton, 2001; Prospero and Lamb, 2003). The Canary Islands are located at the northern fringe of this Atlantic Saharan dust plume, and aerosol deposition is well documented since the Middle Pleistocene (Moreno et al., 2001; Bozzano et al., 2002). On Lanzarote, Saharan dust and volcanic material are trapped in valleys which have developed in Miocene to Pliocene volcanic massifs and were at least partly dammed by younger volcanic material during the Early to Middle Pleistocene (Instituto Tecnológico y Geominero de España, 2005; Zöller et al., 2006). The trapped sediments show alternating distinct beds of reddish/clayey and loess-like yellowish/silty material. Previous soil studies in Lanzarote mainly focussed on slope sediments (Jahn, 1988; Schüle et al., 1989; Zarei, 1989), whereas the sequences developed in valley positions and exposed in profiles up to 7 m thickness (Zöller et al., 2003) have not yet been the focus of pedostratigraphical investigations. Recent geomorphological investigations revealed that a part of these valley sediments were directly deposited as aeolian fallout, whereas the larger part was colluvially reworked from the slopes. Both types of sediment alternate frequently (high frequency/low magnitude) and are partly mixed by vertic peloturbation processes, thus appearing as homogenous layers today (von Suchodoletz et al., 2009). The fact that erosion occurred with high frequency and low magnitude is demonstrated by a recent (and as demonstrated in this paper, past-) precipitation regime causing high landscape instability (cf. Langbein and Schumm, 1958). It is further demonstrated by the largely continuous sedimentation rate found in the valley base. This is revealed by luminescence datings, yielding sediment ages ranging from Holocene to Mid-Pleistocene (>180 ka)(Zöller et al., 2003; von Suchodoletz et al., 2008).

We propose that the alternation of loess-like yellowish/silty and reddish/clayey layers reflects differing periods of weathering on the

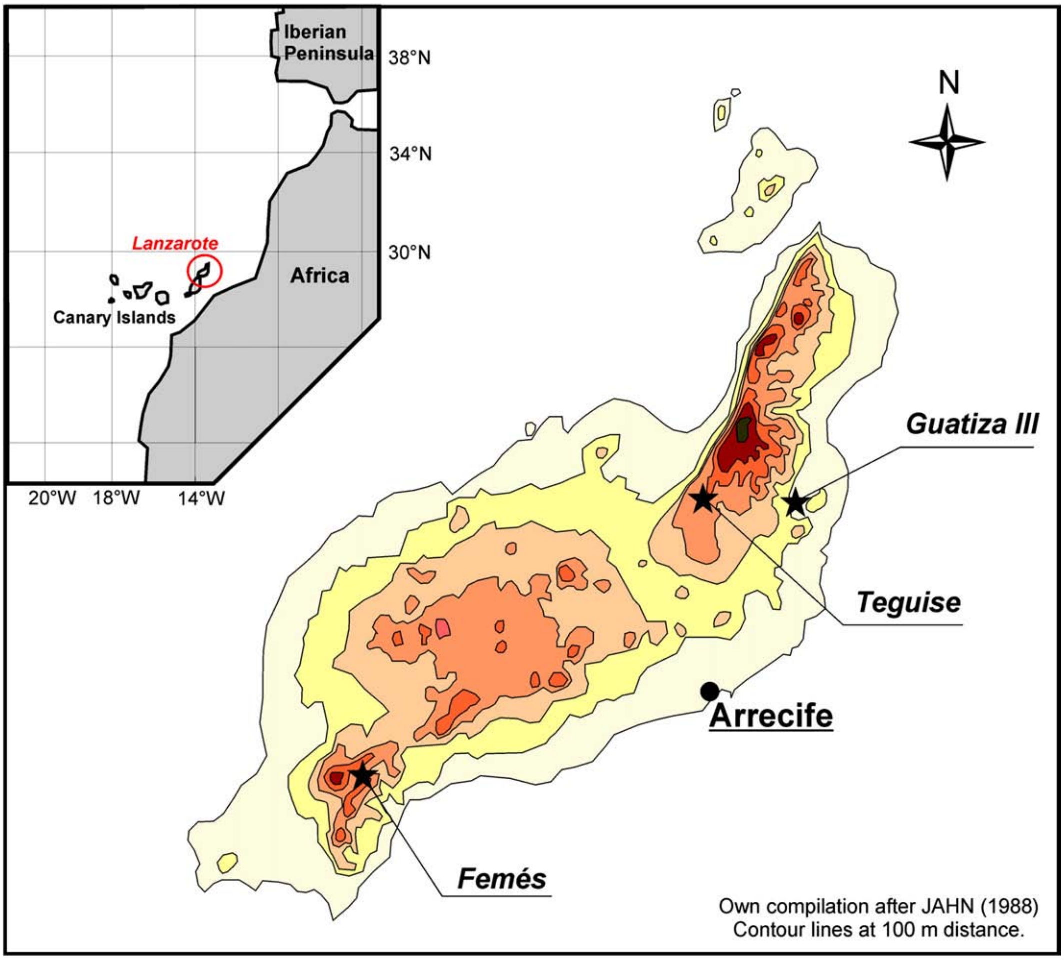

Fig. 1. Location of Lanzarote and studied sites.