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Granulometrical, mineralogical and geochemical characterization of loess deposits in the Tajo Basin

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ABSTRACT

Loess research has the merit of enabling reconstructions of Pleistocene sedimentation dynamics in many parts of the world. However, there is still very few information regarding the occurrence of loess deposits in the Mediterranean area, even though such records may provide a unique opportunity to investigate landscape evolution for a period for which terrestrial archives are very rare in this region. This paper presents the first results of investigations on a loess sequence in the middle Tajo Valley in central Spain. Findings from detailed granulometrical, mineralogical, geochemical, and grain morphological analyses help to give a first overview on character and composition of these deposits. Very high levels of carbonates (~60%), but also of gypsum, both to large extents of primary origin, indicate the incorporation of material derived from marls and limestone. Furthermore, we found evidence that allows deduction of possible loess proveniences more precisely. Dolomite contents of up to 20% indicate that the Iberian Range might have been an important source area of loess sediments. The fact that these uplands are located to the east seems to be opposed to the common assumption of prevailing west winds for glacial periods. The studied sequence (Paraiso profile) is one of seven sections that have been investigated as part of a programme to reconstruct Upper Pleistocene landscape dynamics in central Spain. In this context, the detailed characterisation of sediment properties is crucial for discussing loess proveniences and sedimentary environments.

1. Introduction

Loess covers 10% of the land surface (Pecsi, 1990). In almost all regions of Earth, loess shows a wide variation of different characteristics. Variations exist, such as mineralogy that reflects the geological nature of the source area, or granulometry, as the modal grain size is about 30 μm, but it can vary e.g. between 10 and 20 μm in China (Derbyshire, 1983) and 50–65 μm in Nebraska, USA (Winspear and Pye, 1995). Furthermore, thickness and colour, as well as geochemical composition and geotechnical characteristics may vary (Derbyshire, 1983; Bettis et al., 2003; Muhs and Bettis, 2003).

Initially, the origin of silt particles that make up the largest proportion of the loess was related to glacial formation processes ("glacial loess", Smalley, 1966). Further studies recognized that the dust could likewise be produced in desert areas (Yaalon and Ganor, 1973) which led to the term "peridesertic loess" (Smalley and Vita-Finzi, 1968; Yaalon, 1987) or "lower latitude Loess" (Zöller and Faust, 2009). Subsequently, numerous authors have attempted to explain the origin of silt particles that is essential to the question under which conditions loess has been formed (Smalley, 1966; Smalley and Krinsley, 1978; Coude-Gaussen, 1987; Yaalon, 1987; Pye, 1995; Iriondo, 1999; Wright, 2001; Smalley et al., 2005; Iriondo and Krohling, 2007). It is repeatedly emphasized that there are other important types of loess rather than simply those of glacial origin.

Analyses of loess deposits have been approached from different points of view with a particular focus on granulometrical characterisation, mineralogical and geochemical composition, and paleoenvironmental interpretation, as shown by an extensive bibliography (e.g. Velichko, 1990; Krohling and Orfeo, 2002; Sun, 2002; Sun et al., 2007; Muhs et al., 2008; Antoine et al., 2009). In the Western and Central part of Europe, loess has been abundantly investigated in the course of comprehensive characterizations of

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loess-paleosol sequences (e.g. Antoine et al., 2009). In contrast, loess deposits in the Mediterranean area were not identified before the middle of the twentieth century (Brunnacker, 1969, 1980; Coude-Gaussen, 1987; Coude-Gaussen, 1990; Cremaschi et al., 1990; Haase et al., 2007). An important step towards the recognition of loess in Spain was the celebration of the V International Congress of INQUA in 1957 in Madrid and Barcelona, which initiated the study of Quaternary stratigraphic sequences in different areas on the Iberian Peninsula (Garcia Gimenez and Gonzalez Martın, 2006). In Spain, aeolian deposits were first described in the 1960s (Benayas and Riba, 1961; Torras and Riba, 1968; .Brunnacker and Lozek, 1969; Coude-Gaussen, 1990; Garcia-Gimenez et al., 2010, 2012) followed by studies that were initially based on the analysis of single samples (Gonzalez et al., 1983; Garcia-Gimenez et al., 2010). Later, more detailed studies with a focus on whole profile sections were conducted (Garcia-Gimenez et al., 2012; Boixadera et al., 2015). Loess or loess-like deposits in Spain have been documented for the following geographical areas: the Ebro Basin (Torras and Riba, 1968; Iriondo and Krohling, 2004; Boixadera et al., 2015), the middle reach of the Tajo Valley (Gimenez Garcia and Gonzalez, 2006; Garcia-Gimenez et al., 2010, 2012), areas within the Granada Basin (Günster et al., 2001), areas along the Mediterranean coast (Alicante) (Cuenca and Walter, 1974, 1976), as well as certain mountainous areas (Garcia-Ruiz and Arbella, 1981). Finally, a study conducted by Eriksson (1979) in the Mediterranean Sea between Spain and Algeria discovered a series of sediments in deep sea cores which "could be considered as loessic in character".

Research on loess is well advanced in many countries of the world. In recent decades, loess sequences received an increasing amount of attention, especially with respect to their significance as archives for Quaternary climate fluctuations and associated palaeoenvironmental conditions (Muhs and Bettis, 2003). Beside this environmental significance, loess deposits often possess a specific fingerprint according to their place of origin and thus, may furthermore serve as direct records of atmospheric circulation patterns and past wind directions. When dealing with the Mediterranean as a region of high sensitivity towards climate changes, palaeoenvironmental reconstructions have a high relevance within the research community. In this context, the emphasis is not just on the Holocene, but also on Late Pleistocene dynamics (e.g. Cacho et al., 1999; Sánchez-Goñi et al., 2002; Moreno et al., 2012). Hitherto, major efforts have been undertaken to link terrestrial archives of different nature (glacial, fluvial, aeolian, speleothems, lakes) with specific climatic and environmental conditions (e.g. Moreno et al., 2012; Fletcher and Zielhofer, 2013; Roquero et al., 2013; Wolf and Faust, 2015). However, since the investigation of loess sequences considerably advanced Quaternary research throughout the world, it is all the more surprising that so far loess sequences in Spain obtained little attention, although the presence of aeolian deposits in the Tajo Basin was already confirmed by the cartographic work of IGME (IGME, 1977, 1999a, 1999b) and studies done by González et al. (1983) and Gonzalez and Asensio (1983). Admittedly, more detailed and systematic work started at the beginning of the twenty-first century (Perez Gonzalez et al., 2004; Rodriguez de Tembleque et al., 2005; Garcia Gimenez and Gonzalez Martın, 2006; García Gimenez et al., 2010, 2012). However, research on these deposits is far from exhaustive and loess sequences have not been studied in the same comprehensive way as, for example, in loess areas of Germany, France, Hungary or China (e.g. Smalley and Leach, 1978; Antoine et al., 2009; Marković et al., 2015). Furthermore, most of the mentioned literature dealing with the Tajo Basin reveals that little, if any, palaeoenvironmental information has been extracted from loess deposits. Therefore, we consider that a more detailed investigation of these deposits is necessary, especially with respect to paleoenvironmental reconstructions, but also from the perspective of potential sources areas and transport pathways, as these loess deposits represent outstanding archives for the usually underrepresented period of the Late Pleistocene.

For this reason, the objectives of the study in hand are (1) to provide a comprehensive characterization of the loess deposits from the middle Tajo Valley with a detailed description of granulometric, mineralogical, geochemical and grain morphological features, and (2) to discuss and specify potential source areas and associated wind directions in the central Iberian Peninsula during the time of loess sedimentation.

This research is novel because it proposes a different methodology for the analyses of loess deposits compared to the studies carried out previously in this region. As a contrast to loess from other parts of the world, loess of the Tajo Basin contains large amounts of carbonates and soluble salts due to its specific provenance. The spectrum of applied methods should take this fact into account.

This article aims to serve as a starting point for a series of investigations about loess deposits in the Tajo Basin. Therefore it is intended to initially focus on granulometry, mineralogy, geochemistry, and grain morphology of one key profile and to postpone issues such as stratigraphic composition and environmental significance at the present moment as these aspects shall be treated in detail in the future.

2. Regional setting

The loess area is located in the Tajo Basin as part of the Sub-Meseta Sur, bounded in the north and west by the Central System (Gredos, Guadarrama, Somosierra), in the east by the Iberian System (Sierra de Altomira and Serrania de Cuenca), and in the south by the Montes de Toledo. The studied aeolian deposits are located in the eastern part of the middle valley of the Tajo River near the town of Aranjuez, Madrid (Fig. 1), between the mesas of Colmenar de Oreja-Chinchon in the north and the Mesa de Ocaña-Tarancón in the south. From a geological perspective, a wide variety of materials is observed within this part of the Tajo Valley. There are sediments formed during the Miocene and constituted by gypsum (lower and middle Miocene units) and lacustrine limestones and conglomerates (upper Miocene unit) (Ordoñez et al., 1977). Furthermore, apart from the accumulation of aeolian sediments, Quaternary fluvial formations (gravel and sand terraces, floodplain sediments) can be found (IGME, 1977, 1999a, 1999b; Vera, 2004; González Martın et al., 2007).

Geomorphologically, loess deposits occur with varying spatial extent but not exceeding 20–30 ha. The thickness can reach about 8 m. These deposits are generally situated on both sides of the Tajo River on surfaces that have been incised by the fluvial network and partly cover the tablelands in form of a thin layer. With a wider distribution, loess can be found on fluvial terraces of Pleistocene age. In the area of the dissected marls, loess deposits are nearly ubiquitous on east-facing slopes of small valleys ("arroyos") running to the Tajo river in a north-south (and vice versa) direction. Here, the loess deposits are apparently closely related to an asymmetric shape of these valleys. In general, loess deposits unconformably overlie geological strata that appear in the area.

3. Material and methods

Detailed mapping and preliminary field work revealed the locations of the most appropriate profiles to study loess deposits in the middle Tajo Valley. A number of sequences are located in the area, but in this paper we will focus on a thorough and detailed investigation of one of them, the so called "Paraiso Profile". This