Catena 117 (2014) 133–144

Contents lists available at ScienceDirect

Catena

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

Dust deposits on La Graciosa Island (Canary Islands, Spain): Texture, mineralogy and a case study of recent dust plume transport

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ARTICLE INFO

Keywords:
Canary Islands
Saharan airborne dust
Dust deposit
Wind transport
Giant quartz
SEM

ABSTRACT

La Graciosa volcanic island evolved in the late Pleistocene–Holocene. It is situated along the northeast of the Canarian Archipelago, with a subaerial surface of 27 km^2. This island is located close to the Western Sahara, being 80 km from the north-western African continental shelf and 145 km from the coast. The island supports a very small permanent population. The climate is coastal-arid (116 mm precipitation per annum). Regular occurrences of Saharan dust plumes (about 30% of the year), with a dust accumulation rate of 20 g^{-2} year^{-1}, produce sedimentation of dust on the island of ca. 540 t year^{-1}. Wind-blown sediments cover a large area (more than 52%) of the otherwise volcanic island, forming sandy beaches, sand sheets, nebkhas and other aeolian deposits. Re-distributed dust deposits often occur on the leeward sides of inter-volcano areas, inter-dune areas and in endorheic sediment traps. Many of these deposits are edaphized and carbonatized. Textural analysis of the dust deposit samples shows a variable proportion of silt (80–20%), clay (19–9%), and fine to very fine sand (71–4%). The general mineralogical composition of these sediments as measured by XRD and SEM-EDS is calcite (26%), illite (26%), quartz (11%), augite (10%), aragonite (6%), anorthite (8%), kaolinite (5%) and montmorillonite (3%). The mineralogy in different size fractions is very consistent; for example, quartz content decreases from 15% in the coarse silt fraction to 5% in the fine sand. A mineral and grain-size comparison with airborne dust collected on Gran Canaria Island was undertaken; close similarities were found in the two sample sets. Such closely-matched characteristics point to a similar origin for both airborne dust and dust deposits, in line with the Saharan plume dust that regularly traverses this archipelago. It is unusual to find so much quartz in the fine sand fraction of these aeolian dust deposits. Individual quartz grains with an intermediate axial length of ~160 μm were identified by SEM-EDS. Previous investigators have found similar "giant" particles in long-range transported aeolian dust (Middleton et al., 2001), in contrast to the classic model for gravity settling of airborne dust particles. The debate on this subject remains open for discussion. We present evidence of long-range, wind-transported large mineral particles and a 2004 case study of uplift wind velocity vs. plume dust generation, as well as a transport efficiency model that can explain the existence of fine sand in the dust deposits on La Graciosa Island and in the airborne samplers on Gran Canaria Island. Recent Saharan dust shows that about 10% of similar coarse-grained particulate matter is also present.

1. Introduction

Geogenic dust occurrence is common in every environment. Studies of dust deposits on a global scale include the Asian region (Arimoto et al., 2005; Engelbrecht et al., 2009a,b; Hojati et al., 2012; Nilson and Lehmkuhl, 2001; Wang et al., 2005), the margins of the Sahara Desert (Breuning-Madsen and Awadzi, 2005; Fiol et al., 2005; Guieu et al., 2002; Kandler et al., 2007; McTainsh et al., 1997; Rodriguez et al., 2011; von Suchodoletz et al., 2009) and South Western North America (Reheis et al., 2009; Reynolds et al., 2006). Well-developed deposits have also been described in humid, glacial and periglacial environments, including the Northern margins of the Tibetan Plateau (Derbyshire et al., 1998), the German Alps (Küffmann, 2003), Patagonia (Zárate and Blasi, 1993) and New Zealand (Marx and McGowan, 2005).

The sources of geogenic dust are fairly well established (Chen et al., 2002; Jickells et al., 2005; Prospero et al., 2000; Pye, 1987; Rodriguez et al., 2011), thanks to operational meteorological models, including consistent airborne plume dust and back trajectory models. There is a certain degree of agreement concerning mineralogical characterization used to define the distinctive dust mineralogy, with quartz as tracer (Cattle et al., 2002; Hojati et al., 2012; Mizota and

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http://dx.doi.org/10.1016/j.catena.2013.05.007

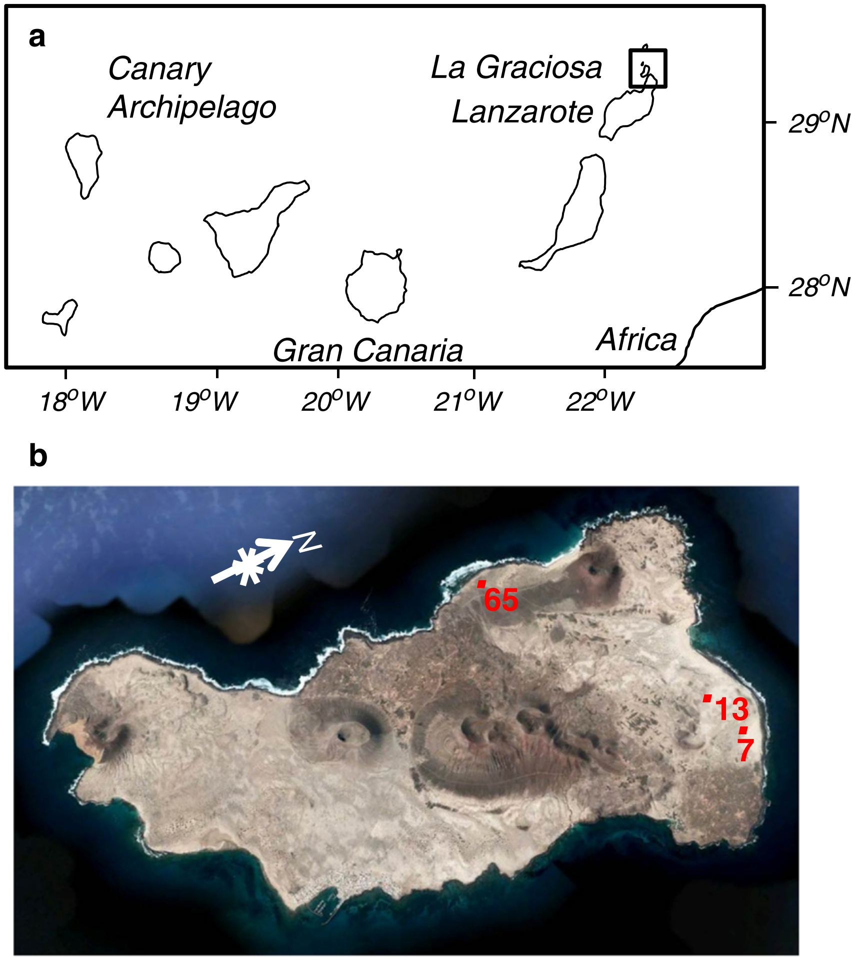

Fig. 1. a) Location of the study area; b) satellite image of La Graciosa Island with the plots selected for sampling (numbers 7, 13 and 65).

Matsuhisa, 1995; von Suchodoletz et al., 2012; von Suchodoletz et al., 2013), together with palygorskite and feldspars (Fiol et al., 2005), micas (Küffmann, 2003), magnetite (Reynolds et al., 2006) and other minerals depending on the geology of the source region (Engelbrecht et al., 2009b; Reheis et al., 2009; Reynolds et al., 2006), and even a distinctive geochemical pattern (Reheis et al., 2009).

However, many studies have focused on the mode of airborne dust sampling and the efficiency of the collectors (Goossens, 2007; Sow et al., 2006). It has been assumed that the coarser fractions occur in short-term suspension dust only (>20 μm, Breuning-Madsen and Awadzi, 2005; McTainsh et al., 1997), with a limit of 40–50 μm (Wang et al., 2005) or 50 μm (Singer et al., 2003) for longer-distance transport, the coarser fractions being negligible in the optical thickness and plume dust transport models (Nickovic et al., 2001; Tegen and Fung, 1995). Thus, the process and range of dust transport are far from being resolved. For instance, Houser and Nickling (2001) concluded that, in supply-limited environments, dust emission models should be directly related to the saltation transport rate and to the factors that control its ability to abrade the surface, rather than to the shear velocity. Moreover, preferential concentration of inertial particles and cluster formation has been observed in turbulent flow transport (Monchaux et al., 2012).

The goals of this study are to characterize the dust deposits found on La Graciosa Island (Canary Islands) and to compare it with airborne dust collected on Gran Canaria, demonstrating the presence in these deposits of aeolian fine sand from the Saharan Desert, and the implications of these fractions for the transport capacity of particles in plume dust. In order to reach these goals, we analyzed the grain-size and mineralogical similarities of both dust deposits and airborne samples. The transport of 'giant' airborne particles has been described a number of times in the scientific literature but, thus far, no case studies based on data from individual events have been published.

As a further contribution, the 2004 data-based case study of uplift was undertaken in order to show how such heavy dust particles can be lofted into the Saharan plume. For this reason, a numerical simulation, which offers reconstruction of the wind transport conditions in an actual and representative case study, was developed.

2. Study area

La Graciosa Island, with an area of 27.05 km^2, is located to the North of Lanzarote Island and is part of the Natural Park of the "Archipiélago Chinijo" (Fig. 1a). The island is sparsely populated, with just 652 inhabitants in 2011 (Instituto Nacional de Estadística, 2012). In recent decades, the economy of the island has changed from a model based on traditional farming and fishing to one based on tourism; as a Natural Park, La Graciosa is protected by Regional, National and European Legislation.

La Graciosa Island was built on a Quaternary shallow marine platform, where mafic volcanic materials (lava flows, pyroclasts and hyaloclastite) were erupted during the Upper Pleistocene and Holocene. This marine platform originated as a result of a giant Plio-Quaternary