El Médano megarhizoliths field, Tenerife: Origin and paleoenvironmental significance

El campo de megarrizolitos de El Médano, Tenerife: origen y significado paleoambiental

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ABSTRACT

The vertical cylindrical structures that occur in El Médano (Tenerife) have had varied interpretations. The structures are about a few decimeters in diameter and may reach near 1 m high. In this paper we provide data that support their interpretation as megarhizoliths formed by roots and associated microorganisms within eolian deposits. The common association with smaller roots and insect traces, as well as the fine carbonate laminae indicate their formation in vegetated soils during relatively wetter periods. The micritic-microesparitic coatings, the peloids, ooids and the alveolar septal structures confirm the biogenic origin of these structures.

Key-words: *Tenerife, eolian deposits, megarhizoliths, roots, microbes.*

RESUMEN

Las estructuras cilíndricas verticales que aparecen en el área de El Médano (Tenerife) han sido interpretadas de formas muy diversas. Estas estructuras tienen diámetros de varios decímetros y alturas que pueden llegar a medir cerca de 1 m. En este trabajo aportamos datos claros que permiten interpretarlas como megarrizolitos formados en depósitos eólicos por la actividad de raíces y microorganismos asociados. La frecuente asociación de los megarrizolitos con trazas menores e inequívocas de raíces (rizolitos) y de insectos, así como las finas láminas de carbonato indican su formación en suelos colonizados por vegetación en los periodos relativamente más húmedos. Rasgos característicos como las cubiertas micritícas-microesparíticas, los peloides, los ooides y las estructuras alveolares confirman el papel de los microorganismos y por tanto el carácter biogénico de estas estructuras.

Palabras clave: *Tenerife, depósitos eólicos, megarrizolitos, raíces, microbios.*

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Introduction

The dune field of El Médano in the southeast of Tenerife Island (Fig. 1) has become a location of geological interest with significant discussion on the origin of the cylindrical structures occurring within ancient sand dunes. The structures have been interpreted as: a) the result of scape of gases by sudden vaporization of the interstitial sand water due to the warming by pyroclastic flows (Carracedo and Day, 2002; Martin and Nemeth, 2004); b) paleoliquefaction features related to seismic activity (González de Vallejo *et al.*, 2003; González de Vallejo *et al.*, 2005), and c) more recently as trace fossils or rhizocretions (Kröchert *et al.*, 2008; Buchner and Kröchert, 2009). The cylindrical structures are similar in size and morphology to those described in the Pleistocene dune field of Tufía in Gran Canary Island (Alonso-Zarza *et al.*, 2008a, b), interpreted as megarhizoliths. The correct interpretation of these structures is critical as they may indicate specific paleoenvironmental conditions in the archipielago. In this paper we describe the macro and micromorphology of these structures with the aim of understanding the processes involved in their formation and their significance.

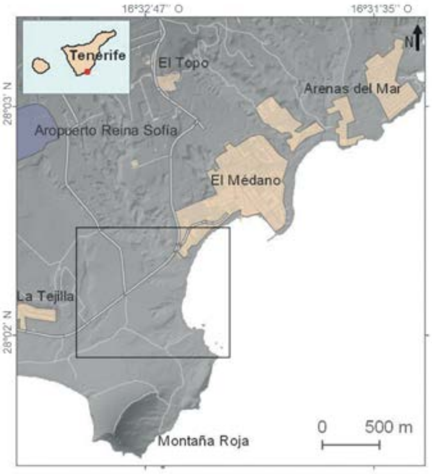

Fig. 1.- Location of the study area. See color figure in the web.

Fig. 1.- Situación del área de estudio. Ver figura en color en la web.

Geological Setting

Tenerife Island has an overall pyramidal shape, being the Teide volcano the highest altitude. The volcano is situated in the intersection between three structural axes (rifts or dorsals) that conform the edges of the pyramid. The southern rift is defined by varied

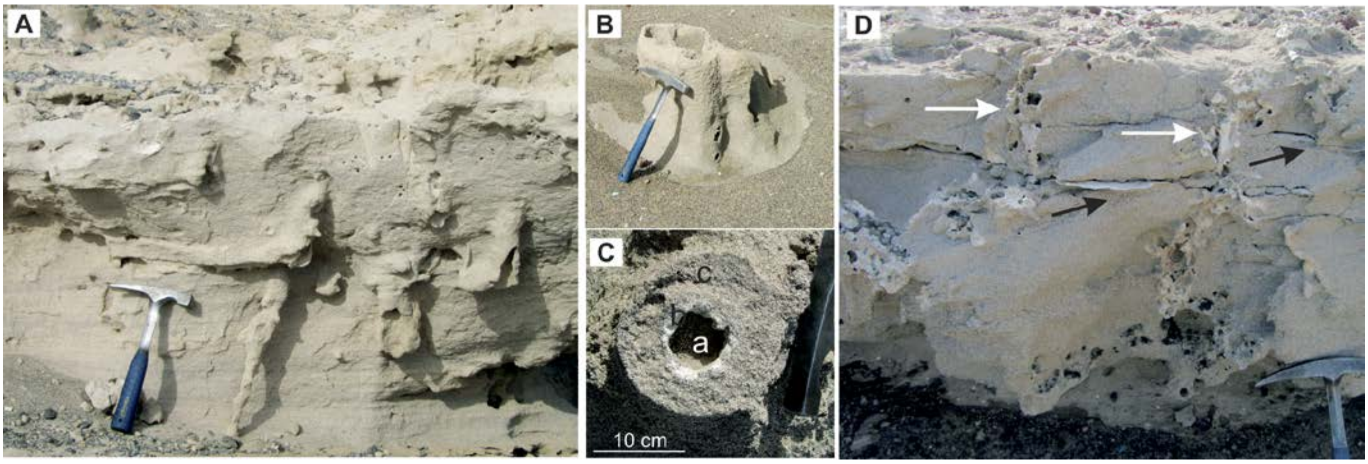

Fig. 2.- A) Field image showing the bedded sand with prominent megarhizolits. B) Megarhizoliths appears also as free standing cylindrical bodies. C) Detail view of a megarhizoliths showing: a) inner cavity, b) carbonate layer, c) indurated sands. D) Irregular and branching rhizoliths (white arrows) with trace fossils and thin carbonate laminae (black arrow). See color figure in the web.

Fig. 2.- A) Imagen de las arenas bien estratificadas con megarrizolitos. B) Los megarrizolitos son estructuras cilíndricas verticales. C) Vista detallada de un megarrizolito mostrando: a) cavidad central, b) lámina carbonática, c) arenas endurecidas. D) Rizolitos irregulares y ramificados (flechas blancas) con trazas fósiles y finas láminas carbonáticas (flecha negra). Ver figura en color en la web.

pyroclastic cones and subsequent flows and some tuff rings. The basaltic activity of this rift started 1 million years ago (Kröcher and Buchner, 2008) with the last eruption forming the pyroclastic cone of the Buzonada 95 000 years ago. The study area is located between the Montaña Roja eroded pyroclastic cone and the locality of El Médano (Fig. 1). The Montaña Roja cone has an age of 948 ± 15 ka (Kröcher and Buchner, 2008). Pyroclastic flows, pumite deposits, alluvial deposits, eolian sands and paleosols occur over the pyroclastic cone of Montaña Roja.

The eolian sands appear in several main levels with high angle planar and through cross bedding. Some sets of cross-bedded sands are capped by horizontal planar sand dm-thick beds, which are usually redder and contain rhizoliths and trace fossils (paleosols). Overall thickness of the sands deposits is 1-4 m. The base of the sand deposit lies on a pyroclastic bed that shows neat pedogenic features such as corrosion of the clasts and thin carbonate laminae (calcrete) that amalgamate towards the top. The sand is included between two ignimbrites of 169 and 668 ka respectively (Ancochea *et al.,* 1990; Brown *et al.,* 2003).

Sand macrofeatures

The sand deposits show at outcrop scale the following distinctive features:

1.- Megarhizoliths are large vertical cylindrical structures of about 10-30 cm in diameter and up 1 m high. They occur either at the tops of the sand beds or as standing bodies preserved from erosion after the blowing of the surrounding sands by wind action (Figs. 2A, B). These structures are very similar to those described in the Tufía dune field in Gran Canaria (Alonso-Zarza *et al.,* 2008a, b). They commonly show a central cavity surrounded by a thin white carbonate rich layer (< 2 cm) followed by indurated sands (Fig. 2C). Some megarhizoliths have a thin white vertical carbonate cylinder in the center of the cavity. The dimensions of the pore with relation to the outer indurated area (cortex) is highly variable. In some cases, the cortex is only of a few cm whereas in other structures the central pore is small and the cortex is thicker. The outer area is irregular and in many cases have some cylindrical structures of about a few cm in diameter. Some megarhizoliths coalesce, in other cases are connected or aligned with thin carbonate layers.

2.- Rhizoliths are irregular and elongated structures of few cm in diameter and variable lengths from a few cm to 50 cm. They occur with different orientations. Rhizoliths occurring at the top of some beds are mostly vertical but relatively irregular (contorted), although some are straight (Fig. 2D). Irregular horizontal rhizoliths are also very common and connect each other and also with the megarhizoliths (Fig. 2A). Downwards and horizontal bifurcations are common. Rhizoliths may have a central cavity surrounded by a thin carbonate coating enveloped by a cortex of indurated sands or may lack the central cavity. In the latter cases the central area has less grains and it is whitish. Ovoidal trace fossils similar to those recognized in Lanzarote and Fuerteventura and assigned to *Rebuffoichnus guanche* (Genise *et al.,* 2013) and attributed to coleopterans are commonly associated with the rhizoliths (Fig. 2D).

3.- Thin (mm-cm) irregular carbonate laminae occur horizontally within the sand beds but also irregularly distributed and connecting rhizoliths and trace fossils. They are also common in vertical and oblique discontinuities (cracks) within the sands. In cases these laminae amalgamate and form thin laminar horizontal calcretes several cm thick and appear interlayered within the sands (Fig. 2D).

4.- Indurated sands associated with vertical cracks. The cracks constitute a relatively regular system which follows the main N-S to NW-SE and E-W to WNW-ESE trends. The indurated sands are vertical to oblique sheets of a few cm thick symmetrically arranged with respect to the cracks. In cases the fracture is partially occupied by the irregular carbonate laminae and rhizoliths. Some cracks are irregular or sinuous.

Petrology

The sands are of fine to medium grain sized and are composed of volcanic fragments, bioclasts (equinods, red algae, molluscs, foraminifera, etc.), feldspars-plagioclase and quartz grains. They are well-sorted and subrounded to subangular. These sands constitute the framework of the macrofeatures described above. Under the microscope the main characteristics of the sands are:

1. Sandy micrite occurs as a white and porous mass in the innermost part of the rhizoliths. It fills most of the porosity between the grain frameworks and contains dark micritic filaments and irregular denser masses of mi-

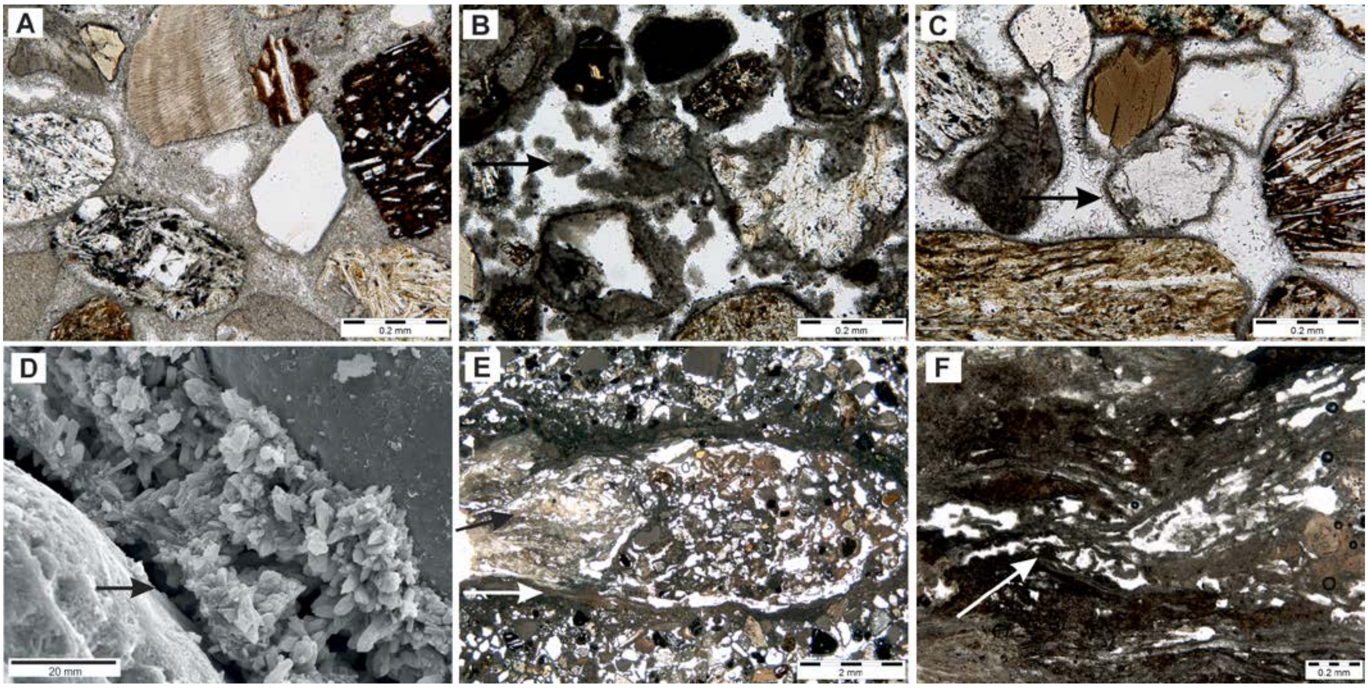

Fig. 3.- A) Micrite occupies much of the porosity between the sand grains in the inner part of the rhizoliths. B) Irregular micritic coatings and peloids (arrowed). C) Micrite and cement coatings (arrowed), some coatings are detached from the grains. D) SEM view of the coatings formed by both micrite and fine crystalline cements. E) Fine root trace outlined by laminated micrite (white arrow) and constituted by coated grains and alveolar septal structures (black arrow). F) Detailed view of the alveolar septal structures of E. The arrow point to micritic filaments. See color figure in the web.

Fig. 3.- A) Micrita ocupando gran parte de la porosidad de la arena en la zona central de los rizolitos. B) Cubiertas micríticas irregulares y peloides (flecha). C) Cubiertas micritícas y de cemento calcítico (flecha), algunas cubiertas están separadas de los granos. D) Imagen de SEM de las cubiertas formadas por cristales tamaño micrita y microesparita. E) Traza de raíz marcada por micrita laminada (flecha blanca) y formada por granos con cubiertas y estructuras alveolares (flecha negra). F) Vista detallada de las estructuras alveolares, la flecha señala los filamentos micríticos. Ver figura en color en la web.

crite about 0.1 mm across (Fig. 3A). The grains in the contact with the micrite have a fine dark envelope, either of finer crystalline micrite or as a weathered (oxidized) surface.

2. Micritic/microsparitic grain coatings are about 10-50 µm thick. They commonly coat all the grains and in cases can be followed form one grain to their nearby grain (Fig. 3B). They tend to maintain the thickness but thickened irregular coatings are common. The coatings are in part grain destructive as the micrite penetrate and corrode bioclasts and siliciclastic grains. Aligned micrite/microsparite (filaments) crystals outgoing from the coatings are common. Some of the coatings are slightly detached from the grains. The coatings consist of fine trigonal calcite crystals (up to 10 µm across) with some intercalated elongated (up to 10 µm) crystals suggesting the presence of aragonite.

3. Calcite cements are are common in the outer areas of the mega- and rhizoliths and are lacking in the carbonate laminae. They commonly occur on the micritic/microsparitic coatings and in cases directly over the grains forming relatively continuous, but irregular, thin envelopes (up to 50 µm across) of trigonal calcite transparent crystals (Figs. 3C, D).

4. Peloids occur in the spaces between the grain frameworks either connected or disconnected to the micrite coatings. They are micritic and rounded and up to 50 µm in diameter (Fig. 3B). They occur sparsely in all the fabrics but are especially common in the inner areas of the rhizoliths and in the carbonate laminae. Very commonly they are surrounded by the calcite cements that show radial arrangements on the peloids. In the carbonate laminae the peloids lack the cements and are distributed between the ooids. Some of the peloids are connected by micritic filaments.

5. Laminated micrite appears as thin (mm to cm) irregular mostly horizontal, but also oblique laminae within the sands and also in the first inner layer of the megarhizoliths (Fig. 2C). It consists of an alternation of irregular dark and lighter brown micrite containing some detrital grains. In the horizontal calcretes some of the laminae contain relatively large ooids (see description below).

6. Ooids occur in the laminar calcretes. They have an inner nucleus, either a bioclast or a siliciclastic grain, coated by laminated micrite. The size varies between 0.1 to 1 mm in diameter, being the nucleus larger than the coatings, but some coatings can be relatively thick (0.2 mm). The envelopes are very rounded even if the nucleus is angular. The envelopes consist of an alternation of dark and light micrite, commonly brown with birefringence, and containing some filaments.

7. Fine root traces (cm-mm) are common in the laminated micrite and in some areas of the rhizoliths. Under the microscope they are seen as elongated ovoidal structures (Fig. 3E) that show an outer micrite area that surrounds: 1) a lower part of coated grains connected by micritic filaments and 2) an area with laminated micrite and alveolar septal structures (Fig. 3F). The alveolar septal structures are composed of a network of irregular micritic filaments leaving irregular porosity between them.

Interpretation and Discussion

Most of the carbonate microfabrics recognized in the sands suggests carbonate precipitation by direct biogenic influence. The thin micritic coatings are characteristic of vadose meteoric environments and are very common in eolian deposits (Calvet, 1982), in which the microbes are the responsible for the destructive and constructive envelopes (Calvet and Juliá, 1983). Similarly, ooids and peloids are commonly interpreted as biogenic products. Peloids are either fecal pellets, microbially induced precipitates or micritic fragments individualized within the soil (Zhou and Chafetz, 2009). Ooids are very similar to those commonly described in calcretes from Lanzarote and Fuerteventura (Genise *et al.,* 2013; Huerta *et al.,* 2015). Their formation seems to occur within a soil where microbial films and clays adhere to grains while these rolled by the activity of root hairs and soil microorganisms (Hay and Reeder, 1978). In the better preserved rhizoliths the inner sandy micrite containing filaments is another proof of the significance of microbes in the formation of these structures. The calcite cements are more common in areas with less biogenic influence, for example in the external areas of the rhizoliths or megarhizoliths. These cements are very probably vadose to phreatic cements formed under a higher water table. They only occupied previously consolidated sands as these were less permeable and the saturated waters could be retained for longer periods in the intragranular porosity.

The laminated micrite forming the irregular carbonate laminae is characteristic of thin and thick laminar calcretes and interpreted as calcification of root-mats by the activity of cyanobacteria, bacteria, fungi or lichens (Wright *et al.,* 1988; Alonso-Zarza, 1999; Alonso-Zarza, 2018). The presence of roots is clearly seen in the well preserved root traces (Figs. 3E, F).

The driving mechanism for the formation rhizoliths and megarhizoliths was the presence of a well stablished root network within the eolian deposit, similarly to that described in the Tufia eolianites from Gran Canaria (Alonso-Zarza *et al.,* 2008b). The evidences come from the presence of eolian sand bodies capped by thin soils containing laminar calcretes and traces fossils and the mega- and rhizoliths. Roots also occupied the fractures and induced their lithification (grain coatings). All these features suggest relatively more humid periods favoring the colonization of the eolian sands. The different preservation degree of the mega- and rhizoliths and their zonation respond to the interplay between microbial decomposition, induced microbial precipitation and decomposition, erosion and cementation around the rhizosphere (Calvet *et al.,* 1975; Klappa, 1980). In the inner areas microbes control the formation of micritic coatings and the micrite matrix of the sands as well as the laminated micrite. The induration of the most external areas with less biogenic influence is due to calcite-aragonite cements. In some mega- and rhizoliths the lack of cements and/or micritic coatings in specific areas together with eolian activity favors the loss of material and so these mega- rhizoliths have a central or intermediate cavity (Alonso-Zarza *et al.,* 2008b).

Our interpretation agrees with Kröcker *et al.* (2008) and offers clear arguments on the biogenic character of these structures, excluding some previous interpretations such as liquefaction or gas scape structures (Carracedo and Day, 2002; Martin and Nemeth, 2004; Gónzalez Vallejo *et al.,* 2005).

Conclusions

El Médano megarhizolith field constitutes an outstanding case study of incipient soil processes opperating in eolian sands. The mega- and rhizoliths structures, which have made this area a controversial geological site, should be interpreted taking into account not only their detailed microstructure, but also the widespread presence of thin laminar calcretes, and trace fossils along the area. All these features point to eolian landscapes colonized by vegetation in the relatively more humid periods. Root activity and the associated microorganisms were the responsible for the lithification of the sands and for the formation of the mega- and rhizoliths.

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