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Morphological characteristics and superficial structure of submarine mounds in the lower slope of the Canary continental margin (W of Canary Islands)

Características morfológicas y estructura superficial de montículos submarinos del talud inferior del margen continental canario (O de las Islas Canarias)

O. Sánchez Guillamón (1), J.T. Vázquez (1), L. Somoza (3), D. Palomino (1), L.M. Fernández-Salas (2), T. Medialdea (3), R. León (3), N. López-González (1) & F.J. González (3)

(1) Instituto Español de Oceanografía, CO de Málaga, C/Puerto Pesquero S/N, 29640 Fuengirola. E-mail: olga.sanchez@ma.ieo.es
(2) Instituto Español de Oceanografía, CO de Cádiz. Muelle Pesquero S/N, 11006 Cádiz.
(3) Instituto Geológico y Minero de España, C/Ríos Rosas 23, 28003 Madrid.

Abstract: Extrusive edifices and structural reliefs, catalogued as mounds and located on the seafloor to the west of Canary Islands were analyzed by acoustic data obtained with multibeam and parametric echosounders during several oceanographic expeditions. They were carried out at deep waters, from 4800 to 5200 m, and they have allowed characterizing 41 newly discovered submarine structures which occur either as isolated edifices or clustered mounds. These features have circular to elongated shapes with diameters of 2-24 km and relief heights of 10 to 250 m, showing different flank slopes of 2-50°. They generally display mounded forms and show morphological elements as ridges, near-circular rock outcrops, depressions and fault scarps together with mass flow and slide deposits located at the vicinity of the edifices. Two types of extrusive features are evidenced by the morphological and seismic data analyses, the first one probably corresponds to high velocity extrusions that reach the seafloor surface and the second one is probably formed by the combination of faulted structures and low velocity extrusions that produce singular domes in the shallower sedimentary records. Based on both analyses, extrusive phenomena represent the dominant mechanism for mound field evolution in the Canary lower slope region.

Keywords: *geomorphology, mounds, Canary Slope, neotectonic, fluid extrusion*

1. INTRODUCTION

Seafloor mounds are positive surface meso-scale structures constituted by small build-up edifices, generally below 500 m high, and are commonly formed by the expulsion of fluids or coral reef development (IHO, 2013). They have been observed and investigated worldwide at active and passive margins.

The geomorphological characteristics of the structures that occur in the continental margin can reflect the evolution of the ocean seafloor. This work is focused on the western Canary lower continental slope where 41 newly discovered submarine structures have been revealed. Their geomorphological features have been described by geoacustic data to understand the main processes involved in the formation of these structures.

The morphology of the features developed in the sea bottom associated to the submarine mounds in this region provides valuable information regarding the recent evolution of the Canary Basin and may help us to establish the role of geological processes. The main types of submarine mounds in this setting can be associated to fluid venting and volcanic processes due to the vicinity of the Canary Islands Volcanic Province (Van den Bogaard, 2013) and the presence of oceanic fracture zones with associated basement depressions and structural highs (Ranero *et al.*, 1997). In these conditions, serpentinization processes related to hydrothermal activity may be recorded in the basement rocks.

2. MATERIAL AND METHODS

Data set were compiled during several oceanographic cruises (GAROE2010, GAIRE2011, AMULEY2012 and SUBVENT0913) onboard the Spanish research vessels BIO Hespérides and Sarmiento de Gamboa. Bathymetric data from multibeam echosounder (Kongsberg-Simrad EM-120 and Atlas Hydrosweep-DS) were acquired and processed with CARIS HIPS &

SIPS yielding bathymetric maps with a resolution ranging from 25 m to 50 m to interpret the seabed morphology. Very-high resolution seismic profiles (HRSP) (TOPAS PS18 and Parasound 35) were imported to HS Kingdom Suite software for interpretation.

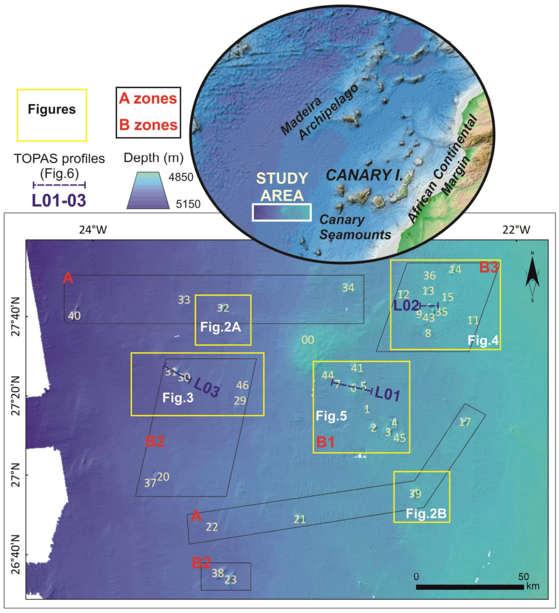

Fig. 1. Bathymetric map of the study area showing the 41 newly described mounds (M00 to M46). Figures 2-5 location and the isolated (A) and clustered mounds area (B) are also shown.

3. GEOLOGICAL AND PHYSIOGRAPHIC SETTINGS

The Canary Islands Volcanic Province constitutes one of the highest Atlantic Ocean volcanic domains due to the derivated volcanic volume and to the volcanism length. They have been related to a broad and diffuse mantle upwelling under a slow spreading plate. These mantle anomalies resulted in spatially and temporally diffuse volcanic activity, characterized by a large number of long-lived and simultaneous active volcanoes, distributed over a wide region (600 km) off the Canary Archipelago (Schmincke *et al.*, 1982). The central area of the western Canary Lower Continental Slope is characterized by the presence of 41 structures, located from 4800 to 5200 m water depth, catalogued as mounds based on their sizes (Fig. 1).

4. RESULTS

Small mounds can occur either as isolated edifices (A), or as clustered mounds along subparallel small chains (B1), in pairs (B2) or crowdy clustered (B3). Most of these features have irregular sub-circular to elongated shapes. The basal dimension range from 2 km^2 to 40 km^2, and up to 0.60 km^3 of volume (except M00, also called Garoe (Somoza *et al.*, 2010) whose dimension exceeds 400 km^2 and 11.5 km^3). These mounds can reach 10 to 250 m high from the seafloor and show slope values ranging from 2° to 50° along their flanks.

4.1 Isolated mounds

These mounds (A) are spatially individual but displayed in E-W and NE-SW alignments, and are mainly found at the northwest and southeast of the study area (Fig.1, zones A). They usually show steep and wide flanks from 16° to 40°. Overall scarps are facing to the east, excepting for M39 where the escarpment is found in the opposite direction (Fig.2B).

Most of the isolated mounds are elongated ridge mounds (5 of 8, 63 %) with sloping sides, about 140-195 m high and up to 9 km long. In contrast sub-circular mounds (3 of 8, 37 %) present medium to large slope, height values of 40-70m, except for the M32 which presents higher height value around 150 m and 30° of slope flank in its summit characterized by small abrupt terraces (Fig. 2A).

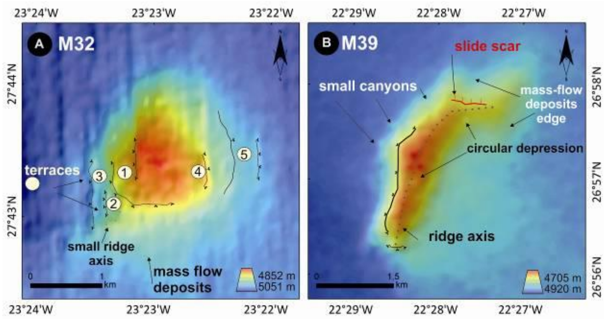

Fig. 2. Isolated mounds examples M32 and M39 located at the NW and SE of the study area showing the main morphological features.

4.2 Clustered mounds

Clustered mounds (Fig. 1, zones B) can be presented in pairs (8 of 32), displayed as crowdy gathered (14 of 32) or along small subparallel chains (10 of 32). These mounds have usually circular to irregular subcircular shapes (25 of 32) whereas elongated shapes are less dominant (7 of 32), showing high angle small scarps.

4.2.1 Mounds in pairs

Due to their varied morphology we may highlight two groups of mounds in pairs at the northern B2 zone (Fig. 3): M30-M31 and M29-M46, which have irregular elongate shapes and steep slope values (15° to 35°) with NE-SW trends regardless of their size and height reliefs.

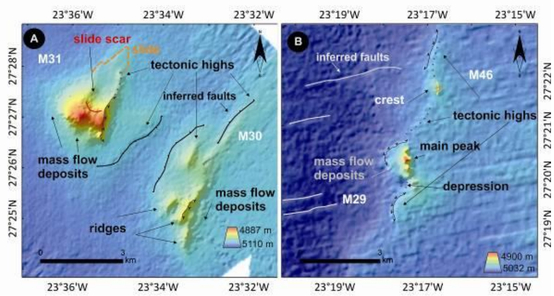

Fig. 3. Examples of mounds grouped in pairs. A) M30-31 and B) M46-29, both located at the western part of the study area with indication of their morphological characteristics.

4.2.2 Crowdy clustered mounds

At the northeast of the study area (B3 zone) there is a clustered group of mounds constituted by 14 elevations.

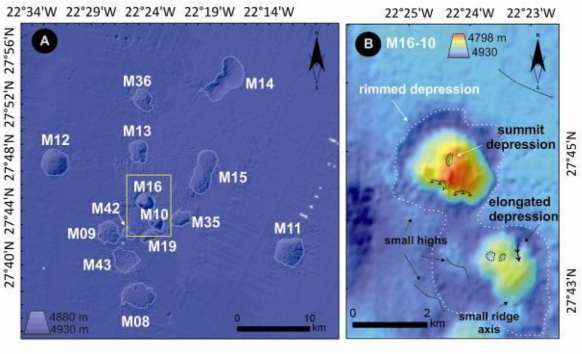

Fig. 4. A) Clustered mounds examples located at the NE of the study area. B) M16 and M10 bathymetry map is enhanced showing its main morphological features.

Globular-like clustered mounds have circular (8 to 14, 79%) to elongated shapes (4 to 14, 14%) whose moderate scarps (1° to 6°) and height (10 to 50 m) were not significant excepting for M16, which stands out from the rest (about 100 m) and presents the steepest flank (>23°, Fig.4B) in the zone. This mound is located at the middle of the cluster, showing rounded shape with NE-SW orientation, which differs from the other towards NE-SW. It shows an irregular profile due to possible sediment deposits from summit mass movement instabilities and it is surrounded by a pronounced rimmed depression (Fig.6A).

4.2.3 Small chained mounds

The most relevant mounds are located in the central area (B1 zone). They are characterized by high angle scarps (20° to 50°) and the greatest average height. They are grouped in small chains of three mounds that were preliminary called Tenores (M02-M03-M04) and Baritonos (M05-M06-M07) together with a central edifice M01, called Baritono Sur (Fig 5D, 5B and 5C, respectively) and several small reliefs around. Mounds are oriented from west to east (M02-M03) whereas M01, M04, M05 and M06 do not present a clear orientation.

Oriental Baritono (M05) presents a three-point star-like shape with distinct orientation between their flanks, predominantly NW-NE trends and different length and height. It is surrounded by a rimmed depression that rises 50 m high. It shows a conical shape and a crater-like circular depression of 30 m depth at the summit (Fig. 5B). Its southern flank is the most significant with 8° slope.

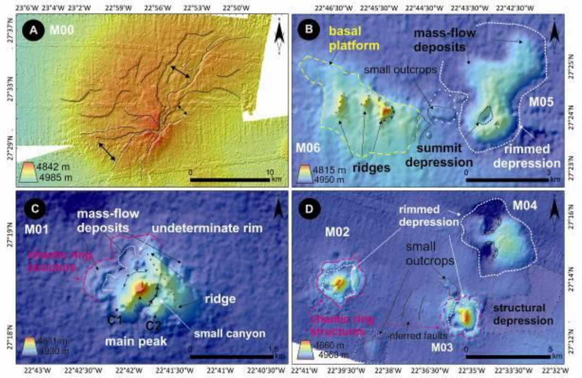

Fig. 5. Examples of small chained mounds located at the middle of the study area: A) Garoé dome , B) Barítonos, C) Baritono Sur and D) Tenores. Bathymetric maps and the main morphological features of the mounds are shown.

Central Baritono (M06) is an irregular triple-peaked mound with NW-SE trend in its major crest and NE-SW in the minor ones. It rises 70 m over a roughly structural platform that is 30 m high and has 3.5 Km lenght and whose slope range is 12° to 27°. The base of the mound is characterized by normal faults.

Downwards to the east, M01 is located. It is rising 120 m high and showing an irregular triangular shape without any dominant orientation. This mound is dominated at the east by a ridge of 1200 m long and 40 m high with a NW-SE trend, which presents scarps and mass-flow deposits in its SE end. Westwards, it is characterized by a main single-peaked edifice which presents a sharp sloping side (>40°) in its NW flank that is linked with other two minor cones. Between the main peak and the C2 an elongate, narrow and steep depression of 800 m length is observed (Fig. 5C). The three Tenores (M02-M03-M04) are the highest mounds on the study area, reaching from 230 m (M03) to 250 m (M02) high, with the sharpest scarps in their flanks. Their subcircular base show near-circular chaotic features affected by rimmed depressions, with the exception of M04 that presents an irregular shape with two abrupt depressions in its western flank within a circular rimmed depression (Fig. 5D).

4.3 Garoé dome

In the central zone of study area, there is a single elevation (M00) called Garoé dome, that is characterized by the widest bulge observed in the area. It shows an elliptic shape that reaches a maximum height of 77 m from the seafloor westwards. Its major axis is NE-SW oriented along 23.75 km length and its summit appears clearly affected by normal faults generating three structural terraces (Fig. 5A).

5. DISCUSSION AND CONCLUSION

Based on seismic and morphological characteristics of the mounds, the main processes controlling the formation of these features are related to recent tectonic activity and fluid extrusion.

Recent tectonic processes generate these mounds are related to deeper structures as folding systems and normal faults. They have outcropped and deformed overlying sedimentary units and have generated seabottom scarps, respectively (Fig. 6C). For example, M07 is a smooth dome-like structure where sedimentary record is deformed and weakly fractured in its summit by faults. Otherwise, M00 (Fig. 5A) is a dome-like bulge that have been formed by extensional processes and fractured by recent normal faults. These faults have also developed three structural terraces. This type of mounds represents about 39% (17 of 41) and can be catalogued as structural reliefs being mainly concentrated at the B1 and B3 zones.

Extrusive processes can be distinguished based on the seismic characteristics. Mounds with shallow transparent internal facies are related to hourglass-like structures in the HRSP. This points out that most of these elevations are caused by extrusive processes (24 to 41, 61%; Fig. 6). Two types of extrusive mounds have been differentiated. The first type corresponds to vertical acoustic chimneys with an apex-down triangular shape where lateral pull-down reflectors are truncated by overlying seismic units (Fig 6A). They have been interpreted as result of rapid extrusive processes. These mounds usually present rimmed depressions in their base and extrusive chaotic ring structures surrounding the edifice (i.e. M16, M02-M03-M04 and M01). Their highest values of height and slope flanks and the irregular shapes are probably due to this extrusive behavior. M02 and M03 represent the most important extrusive structures within the whole study area. This type of extrusion was only observed in chained mounds and, exceptionally, in M16. There is no evidence of subbottom structures connected to these mounds, despite that alignments and small chains suggest the existence of faulting in the oceanic basement. The second type of extrusive mounds corresponds to upward deformed overlying sediments. They are controlled by the interplay between constructive processes, caused by not as faster extrusions, with previous tectonic deformation. In these cases fluid flow seeps through the pathways of previous surficial faults (Fig 6B, 6C). For instance, M30-M31, M29-M46 and M05-M06 show basal outcrop controlled by tectonic features as accommodation normal faults and inverse faults. Over these structures mass flow deposits are laying as result of slope instabilities processes within the constructive edifices. This type of extrusion is mostly observed in isolated and mounds in pairs.

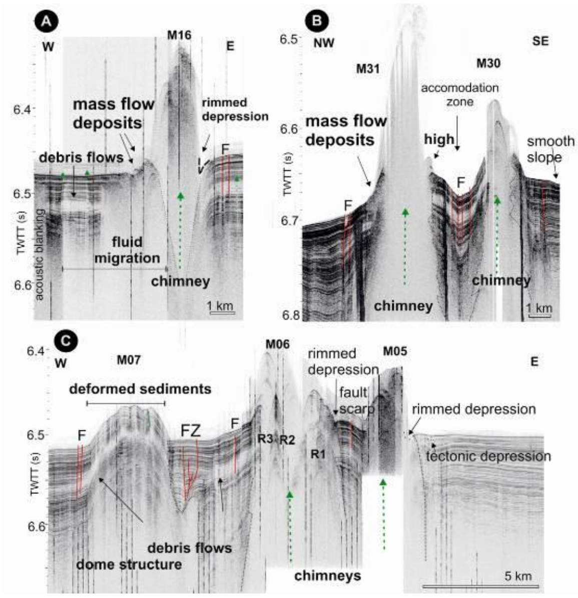

Fig. 6. High resolution seismic profiles of M16, M30-M31 and M05-06-07 showing their main features.

The types of mounds established in this study and the inter-relationships between seismic facies and morphological features within these mounds suggest that several extrusive phases can be differentiated. In the lower slope of the Canary continental margin, morphometric measurements of the mounds reveal that those above 100 m high and 20° slope flank are probably caused by extrusive processes meanwhile smaller mounds can be originated by both processes, tectonic deformation with related fluid extrusion, having a mixed origin.

Acknowledgements

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