Geomorphology 313 (2018) 27–47

Contents lists available at ScienceDirect

Geomorphology

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

Morphology and shallow structure of seafloor mounds in the Canary Basin (Eastern Central Atlantic Ocean)

Sanchez-Guillamón O.[a,*], Vázquez J.T.[a], Palomino D.[a], Medialdea T.[b], Fernández-Salas L.M.[c], León R.[b], Somoza L.[b]

[a] Spanish Institute of Oceanography (IEO), Oceanographic Center of Málaga, Puerto Pesquero, S/N, 29640 Málaga, Spain
[b] Geological Survey of Spain (IGME), Ríos Rosas 23, 28003 Madrid, Spain
[c] Spanish Institute of Oceanography (IEO), Oceanographic Center of Cádiz, Muelle de Levante, S/N, 11006 Cádiz, Spain

A R T I C L E I N F O

Article history:
Received 5 June 2017
Received in revised form 10 April 2018
Accepted 13 April 2018
Available online 20 April 2018

Keywords:
Mounds
Morphology
Extrusive systems
Canary Basin

A B S T R A C T

The increasing volume of high-resolution multibeam bathymetry data collected along continental margins and adjacent deep seafloor regions is providing further opportunities to study new morphological seafloor features in deep water environments. In this paper, seafloor mounds have been imaged in detail with multibeam echosounders and parametric sub-bottom profilers in the deep central area of the Canary Basin (~350–550 km west off El Hierro Island) between 4800 and 5200 mbsl. These features have circular to elongated shapes with heights of 10 to 250 m, diameters of 2–24 km and with flank slopes of 2–50°. Based on their morphological features and the subsurface structures these mounds have been classified into five different types of mounds that follow a linear correlation between height and slope but not between height and size. The first, second (Subgroup A), and third mound-types show heights lower than 80 m and maximum slopes of 35° with extension ranging from 2 to 400 km^2 and correspond to domes formed at the surface created by intrusions located at depth that have not outcropped yet. The second (Subgroup B), fourth, and fifth mound-types show higher heights up to 250 m high, maximum slopes of 47° and sizes between 10 and 20 km^2 and are related to the expulsion of hot and hydrothermal fluids and/or volcanics from extrusive deep-seated systems. Based on the constraints on their morphological and structural analyses, we suggest that morphostructural types of mounds are intimately linked to a specific origin that leaves its footprint in the morphology of the mounds. We propose a growth model for the five morphostructural types of mounds where different intrusive and extrusive phenomena represent the dominant mechanisms for mound growth evolution. These structures are also affected by tectonics (bulge-like structures clearly deformed by faulting) and mass movements (slide scars and mass transport deposits). In this work, we report how intrusive and extrusive processes may affect the seafloor morphology, identifying a new type of geomorphological feature as 'intrusive' domes that have, to date, only been reported in fossil environments but might extend to other oceanic areas.

1. Introduction

Seafloor-venting fluids produced by volcanism and related structures are of major interest worldwide. This geological phenomenon has widespread implications in global climate change and the understanding of basin-scale processes. Research into geological phenomena that control fluid migration from deep layers to the seabed, under various geodynamic settings and lithospheric contexts (i.e., cold seeps, hot and hydrothermal vents, and volcanism) is ongoing (Hovland and Judd, 1988; Fisher et al., 2003; Jamtveit et al., 2004; Planke et al., 2005; Plaza-Faverola et al., 2010a; Webber et al., 2015). Fluids available to flow through the seabed can be derived from microbiological and geological processes, such as diagenesis, water flows, volcanism and magmatic intrusions and hydrothermal circulation systems (Judd and Hovland, 2007). These processes have different drivers, including the over-pressuring of formations at depth and tectonic structures, such as over-riding thrust sheets or diapirs (e.g., Courtillot et al., 2003; Magee et al., 2013). An interesting process has been recorded by Alt et al. (2007) at the Mid-Atlantic Ridge where hydrothermal activity is related to serpentinization processes in the oceanic basement. These processes could be an important source of fluids in deep oceanic areas. A wide variety of morphological fluid venting-related features are manifested throughout the subsurface including doming, cratering, pockmarks, mud volcanoes, hydrothermal and volcanic mounds, and seamounts, to name a few.

Seamounts, ridges, and guyots are the main geomorphological features in ocean basins found between continental margins and mid-

* Corresponding author.
E-mail address: olga.sanchez@ma.ieo.es. (O. Sanchez-Guillamón).

https://doi.org/10.1016/j.geomorph.2018.04.007

ocean ridges (e.g., Harris et al., 2014). Seamounts are defined as “a discrete (or group of) large isolated elevation(s), greater than 1000 m in relief above the seafloor, characteristically of conical form” (International Hydrographic Organization (IHO, 2008). These high “conical peaks” (length/width ratio < 2) (Mitchell, 2001) can be distinguished from both ridges (length/width ratio > 2) and flat-topped guyots. For shorter features, the use of terms “hill”, “knoll” and “mound” has been suggested (IHO, 2008).

Mounds comprise a wide range of genetically distinct geological elevations, and examples exist from all over the world mostly in shallow waters. They usually appear as minor topographic highs with diameters ranging from 10 to 1000 m (Hovland and Judd, 1988). The hydrographic definition of seafloor mounds is “A distinct elevation with a rounded profile generally less than 500 m above the surrounding relief as measured from the deepest isobath that surrounds most of the feature, commonly formed by the expulsion of fluids or by coral reef development, sedimentation and (bio)erosion” (IHO, 2013). However, modern classifications of seamounts have widened from features further than 100 m high (i.e., Casalbore, 2018), thus mounds would be the smaller type of seamounts. In the literature mounds have been also defined including those related to intrusion and extrusion structures associated with igneous vents (e.g., Davies et al., 2002) or hydrothermal processes (Head et al., 1996; White et al., 2002).

In recent decades, there has been a growing interest in the study of seafloor mounds. These have been observed in the Porcupine, Faroe Shetland, Niger Delta, and Gulf of Mexico basins along the Atlantic margins (Henriet et al., 2011; Macelloni et al., 2013; Benjamin and Huuse, 2017); the Great Australian Bight and Natal Valley within the Indian Ocean (Jackson, 2012; Wiles et al., 2014), related to oceanic spreading centers and transform faults (Tivey, 2007); and the Okinawa Trough and on the northern of the Japan Trench (Hirano et al., 2001, 2008; Yeats et al., 2016) in the Pacific Ocean. However, mounds have not been described in detail for intraplate oceanic domains due to the low resolution of the digital elevation models at greater depths, making it difficult to discern structures <500 m high with a 10 km^2 basal area. The geodiversity of mounds means they are unique features that help increase our understanding of basin-scale processes, including sediment diagenesis, bacterial activity, faunal distribution and vent activity (i.e., Svensen et al., 2004; Henriet et al., 2014). These are driven by bioerosion, the colonization of scleractinian cold water corals and hemipelagic sedimentation (Dorschel et al., 2005), mud eruption and gas flow (Lee and Chough, 2002), volcanic and/or hydrothermal activity (Barreyre et al., 2012) and often faulting (Roberts and Carney, 1997; Hannington et al., 2005; Lowell, 2017). The detailed characterisation and study of seafloor mounds and their sub-surface structures is needed to improve our knowledge of their activity, and understand why and how they are formed, and what factors control their evolution.

This work focuses on the central area of the Canary Basin, Eastern Central Atlantic Ocean (Fig. 1A), where 40 mesoscale submarine structures (<500 m high) have been discovered at water depths of between 4800 and 5200 mbsl (meters below sea level) (Fig. 1B). Here, the term “mound” is used loosely to refer to all submarine edifices regardless of their basal shape and tentative origin. The genesis of these features was first reported and characterised by Medialdea et al. (2017), and has been associated with buried intrusive complexes accompanying volcanic and hydrothermal activity. Nevertheless, at that time no detailed morphological analysis of these features was undertaken. The aim of this study is to provide the first detailed morphological characterisation of these seafloor mounds and their shallow structure, using data from both high-resolution multibeam echosounders and sub-bottom profilers. The morphological analysis in conjunction with sub-bottom characteristics contributes valuable information on the recent evolution of the west Canary region. Formational mechanisms for the seafloor and shallow sub-surface features are proposed to assess their possible associations and facilitate discussion about the different morphostructural types of mound in the study area.

2. Geological setting of the Canary Islands

The Canary Islands have been emplaced in an intraplate setting on Jurassic oceanic lithosphere. The formation and volcanic evolution of the Canary Islands is controversial. They are most commonly considered to originate from melting in an underlying mantle hotspot. The most cited formation hypotheses account for a broad and diffuse fixed mantle plume under a slow spreading plate (Carracedo, 1999; Geldmacher et al., 2001, 2005), whereas others are related to volcanic and tectonic stress regime as a clue in the temporal and spatial distribution of the volcanism (Hernán, 2004). This volcanic system is characterised by a large number of long-lived and simultaneous active volcanoes, which includes both the archipelago and surroundings seamounts (sm), growing from the Late Jurassic to Quaternary, designated as the Canary Island Volcanic Province (CIVP) (Fig. 1A). This makes the CIVP the oldest hotspot track in the Atlantic Ocean (van den Bogaard, 2013). The interpretation of seafloor spreading magnetic anomalies originally created at the Mid-Atlantic Ridge (Klitgord and Schouten, 1986) reveal a regional pattern of WNW-ESE oceanic fracture zones with associated depressions and highs at the basement (Roest et al., 1992; Ranero and Banda, 1997). According with these authors, the survey area is located over Cretaceous oceanic crust (120 Ma, magnetic anomaly M0).

3. Physiographical setting of the western Canary lower continental slope

The Canary Islands are located close to the continental margin offshore NW Africa (Fig. 1A), where there are various elevations, including seamounts and hills with slopes of up to 25° (Fig. 1C), which interrupt its smooth character (0.1°–6°) (Masson et al., 1992; Wynn et al., 2000; Palomino et al., 2016). At the foot of the Canary Islands, the western margin drops down over 1500 km (Masson et al., 1992) and reaches depths of >5000 mbsl (Fig. 1C). The lower slope is characterised by a heterogeneous distribution of various morphological seafloor features that allow us to divide it into three different areas (Fig. 1C): (1) the northern area, which is characterised by eleven trails of mounds and hills up to 600 m in height; (2) the central area, which is largely covered with complex clusters of mounds; and (3) the southern area, which has two mound trails rising a maximum of 230 m above the seafloor, the most easterly of which is practically contiguous with the trail of hills and seamounts studied by Palomino et al. (2016). The mound and hill trails in the northern and southern areas mainly trend WNW-ESE.

The northern area has a range of gradients, from of 0.2–0.55°, with scarps and crests that reach 1.2°. This area is characterised by a staircase morphology, comprising NNE-SSW to NE-SW trending structural terraces 12–64 km long with slopes of up to 2.5°, which are thought to be related to normal faults. Several deeply incised channels >500 km long and 2.5 km wide, mostly following a WNW-ESE trend, have been differentiated in this area (Somoza et al., 2010) and interpreted as the result of a mass flow system deriving from volcanoclastic avalanches in the Canary Islands (Masson et al., 1998, 2002; Hunt et al., 2013). The southern area has a mean slope value of 0.2°–0.6°, although certain topographic features have slopes of up to 5°. To the east and southeast, several seamounts and hills, namely The Paps, Ico, Echo, Drago, and Tropic, included in the southern CIVP, serve as the source for massive slope instabilities (Palomino et al., 2016). In addition a branch of the main debris flow system, known as the Saharan Debris Flow and coming from the upper slope, has been recognized in the easternmost part of this sector (Wynn et al., 2000).

4. Material and methods

The main datasets analysed in this work were compiled over four oceanographic cruises (GAROÉ-2010, GAIRE-2011, AMULEY-ZEEE-2012 and MAEC-SUBVENT-2013), taken between 2010 and 2013 in the lower and middle continental slope offshore the Canary Islands, aboard the Spanish R/V *Hespérides* and R/V *Sarmiento de Gamboa*.