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Geomorphological features in the southern Canary Island Volcanic Province: The importance of volcanic processes and massive slope instabilities associated with seamounts

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ABSTRACT

The margin of the continental slope of the Volcanic Province of Canary Islands is characterised by seamounts, submarine hills and large landslides. The seabed morphology including detailed morphology of the seamounts and hills was analysed using multibeam bathymetry and backscatter data, and very high resolution seismic profiles. Some of the elevation data are reported here for the first time. The shape and distribution of characteristics features such as volcanic cones, ridges, slides scars, gullies and channels indicate evolutionary differences. Special attention was paid to recent geological processes that influenced the seamounts. We defined various morpho-sedimentary units, which are mainly due to massive slope instability that disrupt the pelagic sedimentary cover. We also studied other processes such as the role of deep bottom currents in determining sediment distribution. The sediments are interpreted as the result of a complex mixture of material derived from a) slope failures on seamounts and submarine hills; and b) slides and slumps on the continental slope.

1. Introduction

Seamounts are first order morphological elements both in the deep sea and on continental margins. In recent years, the traditional term “seamount” has been reviewed (Staudigel et al., 2010). Kennett (1982) defined seamounts as isolated mountains or chains of successive highs that rise at least 1000 m above the seafloor. For shorter features, the use of terms “hill” or “knoll” has been suggested (Kennett, 1982; OHI, 2008). However, the term seamount has recently been widened to include a variety of features, from hills ascending only 100 m to great mountains that rise several kilometres, sometimes almost reaching the sea surface (Smith and Cann, 1990; Wessel et al., 2010). The term “guyots” was also defined as “an isolated seamount having a comparatively smooth flat top” (OHI, 2008).

Seamounts and hills are characterised by several sedimentary environments mainly developed on both the summits and slopes of these mountains. In this sense, morpho-sedimentary features at the summit are related to the interference of the highs with different water masses (Turnewitsch et al., 2013) and/or carbonate deposits associated with high productivity rates (Vecsei and Freiburg, 2000), while the flanks are dominated by erosive features such as gullies and landslides scars (Ercilla et al., 2011; Palomino et al., 2011). Moreover, flank dismantling processes, especially at the base of the structures, may interfere with the prevailing depositional systems on the continental margin (contouritic, hemipelagitic, gravitational or turbiditic), producing local inputs of mass transport deposits in these systems (Ercilla et al., 2011; Palomino et al., 2011).

The west-southwest region of the Canary Islands is characterised by the presence of several seamounts such as The Paps, Ico, Echo, Drago and Tropic included in the Canary Island Volcanic Province (CIVP), an area of outstanding gravitational processes. This province includes the Lars–Essaouira seamount to the north of Lanzarote (32.7°N, 13.2°W), to the Tropic seamount, at the southwest of the archipelago (23.8°N, 20.7°W). To date, only a few studies have been devoted to these southern highs (Schmincke and Graf, 2000; Vázquez et al., 2011; Van der Bogaard, 2013), whereas numerous studies have been carried out on the continental margin west of the Canary Islands, looking at the seafloor sedimentary processes (Embley, 1976; Jacobi, 1976; Embley and Jacobi, 1977, Jacobi and Hayes, 1982, 1984, 1992; Wynn et al., 2000a; Weaver et al., 2000; Hunt et al., 2013 and references therein). Massive slope instabilities found on the continental slope are known as the Canary Debris Flow (Masson et al., 1997, 2002) and the Saharan Debris Flow (Embley, 1976; Masson et al., 1993; Masson, 1994; Gee et al.,

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1999, 2001). These two main debris flow systems have been related to the development of giant collapses on the islands of La Palma and El Hierro (see Masson et al., 1997; Gee et al., 1999, 2001), where landslide scars and associated deposits are readily observed both onshore and offshore, and seem to be common features on the seafloor of the archipelago (Carracedo et al., 1999).

In these morpho-sedimentary deep water environments, seamounts significantly influence sedimentary facies distribution and morphological features (Wynn et al., 2000a). In the same way, Jacobi and Hayes (1992) observed that deep bottom currents accelerate around seamounts giving rise to different morpho-sedimentary types. Massive slope instabilities associated with seamounts play an important role in sediment transport to the deep ocean. Studying them is essential for understanding and predicting potential geohazards and consequent morphological changes (Lee et al., 2005; Masson et al., 2006). There are only a few studies that tentatively connect the sedimentary processes and mass wasting around the seamounts in the Canary Islands (Gee et al., 1999, 2001; Masson et al., 2002).

This study addresses the geological processes in the southern region of the CIVP based on the study of geomorphological features and particularly the role played by massive slope instabilities in shaping the seafloor around the seamounts. To achieve this, we carried out a detailed morphological study of the seamounts and recently discovered submarine hills where different morpho-sedimentary units have been defined. Special attention has been paid to mapping the widespread slope instability features around the seamounts as well as other sedimentary deposits derived from the interaction of the highs with deep water masses.

2. Geological and oceanographical setting

The continental slope of the CIVP is limited to the east by the shelf break at 100–200 m water depth (mwd) and to the west by the lower continental slope that gives way to the abyssal plain that is deeper westward, dropping down to 5400 mwd. The continental slope has a low angle, ranging from 6° on the upper slope, to 0.1° on the lower slope (Masson et al., 1992; Wynn et al., 2000a).

The study area is situated on the continental slope between 300 and 500 km south of the CIVP (Fig. 1), between 23.5°N and 26.5°N latitude and 19°W and 22°W longitude. This sector of the continental slope is around 3100–4700 mwd and has a gentle slope (0.1°–3°) although the summit of the shallowest seamount, Echo, is at 300 mwd, and the flanks can reach slope angles of about 45° (Fig. 2).

The continental slope has a complex submarine topography due to the numerous volcanic islands and seamounts, the development of debris avalanches coming from the islands, and the presence of canyons and channels that determine and modify the geological processes on the continental margin (Masson et al., 1992; Wynn et al., 2000a). The Canary and Sahara submarine debris flow systems that extend to the west and northwest, running distances of hundreds of kilometres (Embley, 1976; Embley and Jacobi, 1977), play an important role in sediment distribution along the continental margin. Both systems have sedimentary inputs from the Canary Islands avalanches. The first is basically fed from the islands of La Palma and El Hierro, while the second receives input from El Hierro (Carracedo et al., 1999). However, both systems also collect sediment from avalanches occurring to the north and south, respectively, on the other eastern islands (Masson et al., 2006; Hunt et al., 2013).

There are many theories about the origin of the Canary Islands and seamount volcanism in the region that includes the volcanic belt from the Lars–Essaouira seamount to the Tropic seamount. This has been suggested to be the result of both a propagating fracture model and a hotspot trace (Anguita and Hernán, 1975, 2000), due to mantle heating at the boundary between continental and oceanic lithosphere (Schmincke, 1982), or to a blob-model hotspot (Hoernle and Schmincke, 1993). Van der Bogaard (2013) attributed the origin of the seamounts to shallow mantle upwelling beneath the Atlantic Ocean off the NW African continental lithosphere flanks that produces recurrent melting anomalies and therefore the seamounts. The Paps and Tropic seamounts have been dated to 91.1 ± 0.2 and 119 Ma, respectively (Van der Bogaard, 2013).

Surface waters in the south CIVP occupy the upper 100 m of the water column. The central waters comprise the North Atlantic Central Water (NACW) and South Atlantic Central Water (SACW), of different origins, that reach 700 mwd (Pastor et al., 2015). Intermediate water masses, from 700 to 1000 mwd, are characterised by the Antarctic Intermediate Water (AAIW) to the north, and from 1000 to 1500 mwd by the Mediterranean Water (MW) and the Arctic Intermediate Water (AIW) to the south (Knoll et al., 2002). Deep-water bottom currents are divided into two major water masses (Sarnthein et al., 1982): the North Atlantic Deep Water (NADW) flowing southwards at 1500 to 3800 mwd, and the Antarctic Bottom Water (AABW) which fills the

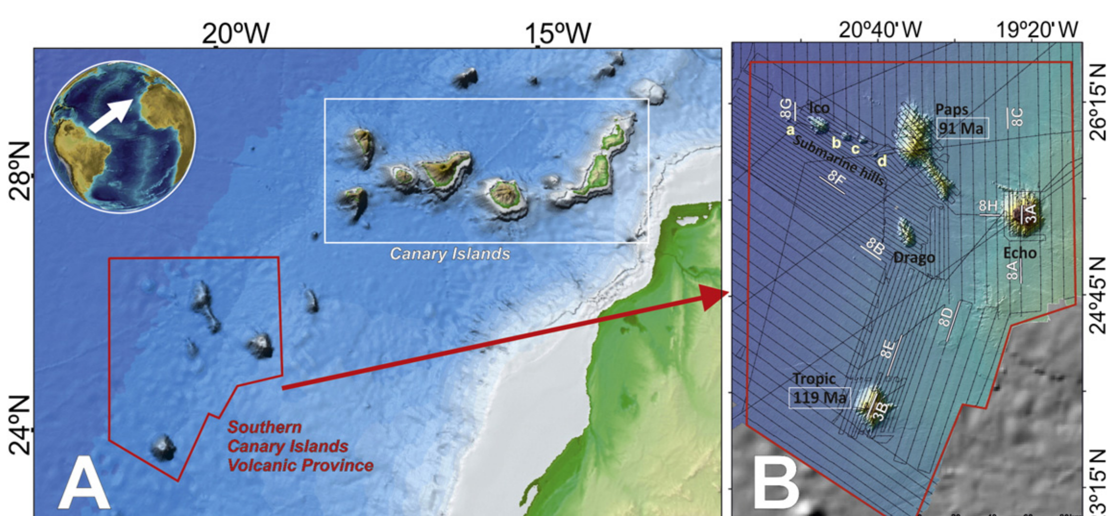

Fig. 1. General situation of the study area. A) Location of the study area in the southern Canary Islands Volcanic Province (red polygon). The bathymetric map was extracted from GEBCO (General Bathymetry Chart of the Oceans). B) Detailed bathymetric map showing the ship track lines of TOPAS seismic profiles and multibeam echosounder for the different surveys (black solid lines) and the location of the seismic profiles in Figs. 3 and 7 (white lines). Lowercase letters (a, b, c and d) correspond to the newly discovered submarine hills: a) Infinito, b) Pelicar, c) Malpaso and d) Tortuga. The age of The Paps and Tropic seamounts are also given (black numbers) based on Van der Bogaard (2013).