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# Growth and demise of cold-water coral ecosystems on mud volcanoes in the West Alboran Sea: The messages from the planktonic and benthic foraminifera

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ABSTRACT

The Dhaka and Maya mud volcanoes (MVs), located in the Mud Diapir Province in the Western Alboran Basin along the Moroccan Coasts, were cored during the TTR-17, Leg 1 cruise. Cores were taken on the top of the volcanoes at a water depth of 370 m on the Dhaka MV (core TTR17-MS411G) and at 410 m water depth on the Maya MV (core TTR17-MS419G), respectively. On both mud volcanoes the extruded mud breccia provides the nucleation point for the colonization and development of cold-water corals and associated ecosystems. Two phases of cold-water coral growth are observed: (1) between slightly older than 4175 ± 62 years BP and around 2230 ± 59 years BP at Dhaka, and (2) between slightly older than 15583 ± 185 years BP and around 7613 ± 38 years BP at Maya MV. On the top of the Maya MV only a small patch reef and/or isolated corals proliferated, whereas a more extended patch reef colonized the top of the Dhaka MV. At both sites the cold-water coral development was triggered by the availability of a suitable substrate for initial coral settling, provided either as a firm ground or as single clasts. Subsequently coral growth was supported by enhanced nutrient flux possibly related to upwelling and/or strong currents. During the intervals of coral growth planktonic foraminiferal assemblages were dominated by *Neogloboquadrina incompta*. The decline of coral ecosystems on the mud volcanoes is accompanied at surface by a shift from the *N. incompta* dominated assemblage to a *Globorotalia inflata* dominated assemblage, possibly reflecting more oligotrophic conditions. This shift is coeval to the passage from wet to arid conditions at the end of the African Humid Period at Maya MV. It is interpreted as an effect of an early human impact on a fragile environment, which was already stressed by desiccation at the time of the development of complex human society along the Mediterranean coasts, at Dhaka MV.


## 1. Introduction

Mud volcanoes and mud diapirs are common features in the Alboran Sea in the Western Mediterranean (e.g., Sautkin et al., 2003) and along the Atlantic margin of the associated Gulf of Cadiz (e.g., Pinheiro et al., 2003; Somoza et al., 2003; Fernandez-Puga et al., 2007). Mud volcanism and associated phenomena such as cold seepage, hydrocarbon venting and gas hydrates in the Gulf of Cadiz have been investigated since 1996 (Baraza and Ercilla, 1996; Baraza et al., 1999; Ivanov et al., 2000, 2001; Somoza et al., 2000; Gardner, 2001; Kenyon et al., 2001; Mazurenko et al., 2002; Pinheiro et al., 2003). An exploratory cruise of *R/V Belgica* in 2002 on an accretionary setting in the Gulf of Cadiz (Gutscher et al., 2002) off Larache (Morocco), led to the discovery of a cluster of nine mud volcanoes: the El Arraiche mud volcanoes field (Van Rensbergen et al., 2005). These structures occur in close association to cold-water coral carbonate mounds, which are up to 60 m high and located in water depths of 500–600 m on the Pen Duik Escarpement (Van Rensbergen et al., 2005; Foubert et al., 2008; Wienberg et al., 2009).

The existence of mud volcanoes in the Alboran Sea was first documented in 1999 during the UNESCO-IOC Training Through Research Program (TTR-9) Leg 2 along the Moroccan margin. A further survey carried out in 2002 with the *R/V Logachev* during TTR-12 Leg 3 revealed the existence of mud volcanism along both Spanish (Northern Mud-Volcano Field) and Moroccan (Southern Mud-Volcano Field) margins of the West Alboran Basin. Additional mud volcanoes were discovered during the TTR-14 campaign between the northern and southern mud-volcano fields (Comas et al., 2000, 2003a,b; Sautkin et al., 2003; Talukder et al., 2003; Comas and Ivanov, 2006). In 2007, a cruise of the *R/V Hesperides* focusing on mud volcanoes in the Alboran Sea (Comas and Pinheiro, 2007) unveiled an outcropping mound province off

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Melilla, which displays striking affinities with the Cadiz cold-water coral carbonate mounds and with those discovered in the North Atlantic (e.g., Henriet et al., 1998). The Melilla field was cored for the first time in June 2008 during the TTR-17 cruise (Comas and the SAGAS08-TTR17, Leg 1-Scientific Party, unpublished). During the same cruise mud volcanoes from the southern part of the Alboran Sea were also cored. A few cores contained intervals characterized by cold-water coral fragments. Cold-water corals have been identified in the Mediterranean Sea since the 60s (see McCulloch et al., 2010 and reference therein). However, only recently their full extent and distribution has been mapped. McCulloch et al. (2010) have compiled a data set summarizing the occurrence of cold-water coral from the Eastern to the Western Mediterranean according to their age and paleoenvironment. In this study, the westernmost analyzed cores were in the Eastern Alboran Sea. Therefore, a few data are presently available for the Western Alboran.

This study aims to investigate the sedimentary sequence deposited on the top of Dhaka and Maya MVs in the Alboran Sea (Fig. 1), to reconstruct the paleoceanographic setting and to identify a possible causal link between cold-water coral growth and the mud volcanoes activity.

## 2. Regional setting

The Alboran Sea is a 400 km long and 200 km wide basin with a water depth not exceeding 2 km, located in the westernmost part of the Mediterranean Sea (e.g., Comas et al., 1999). Its complex seafloor morphology shows ridges, seamounts and troughs and it is divided in three sub-basins: the West Alboran, the East Alboran and the South Alboran Basins (Fig. 1). The West Alboran and the South Alboran Basins are separated by the Alboran Ridge, a prominent NE–SW linear relief, locally forming the small Alboran Island.

The formation of the Alboran Basin as part of the Gibraltar Arc started in the late Cretaceous as a consequence of crustal extension in a setting of overall convergence of the African and Eurasian plates that have had variable directions of relative motion since the late Cretaceous (e.g., Dewey et al., 1989). Seismic data show that present-day plate tectonics contribute to the actual deformation of the Alboran Basin (e.g., Fernández-Ibáñez et al., 2007 and references therein; Frizon de Lamotte et al., 2006). Early Miocene under-compacted shales and olistostromic sediments mobilized by fluid flows in a back-arc basin setting characterized by coeval extensional tectonics have been suggested as the source layer for the Mud Diapir Province in the Western Alboran Basin, which during the post-Messinian compressive tectonics developed piercing diapirs and subsequent mud volcanoes (Comas et al., 1992, 1999; Comas et al., 1992; Chalouan et al., 1997; Pérez-Belzuz et al., 1997; Sautkin et al., 2003; Talukder et al., 2003).

The Alboran Sea represents the transitional zone between Atlantic (AW, cold, low saline and nutrient-rich) and the Mediterranean (MW, warmer and with higher salinity) type water. Air–sea interaction processes modify the AW while it flows at the surface from west to east and give origin to the Modified Atlantic Water — MAW (Millot, 2009). Levantine Intermediate Water (LIW) generated in the Eastern Mediterranean Sea, flows in the opposite direction below the MAW. Western Mediterranean Deep Water (WMDW), fills the deepest part of the basin (e.g., Jimenez-Espejo et al., 2008 and references therein).

The hydrography is also controlled by local winds, which are a direct consequence of atmospheric pressure gradients between the Western Mediterranean and the Gulf of Cadiz (e.g., García Lafuente et al., 2002). Changes in the water flow through the Strait of Gibraltar are modulated by this wind forcing as suggested by García Lafuente et al. (2002). Wind forcing also regulates the formation of gyres within the Alboran Sea and the transportation of atmospheric dust and moisture (e.g., Bucca and Kinder, 1984; Rodriguez et al., 2001; Jimenez-Espejo, et al., 2008).

The recent Mediterranean Sea is overall oligotrophic (Cruzado, 1985). However, one of its highest productivity areas is in the Alboran Sea where it is associated to upwelling triggered by the hydrological structure of surface waters (Morel, 1991). The Atlantic inflow and the eolian and fluvial influxes are also responsible for nutrient transport into the Alboran Sea (Dafner et al., 2001).

### 2.1. Dhaka and Maya mud volcanoes

The Dhaka and Maya MVs are located in the Mud Diapir Province in the Western Alboran Basin (35°25.43′ N; 04°31.89′ W and 35°27.11′ N;

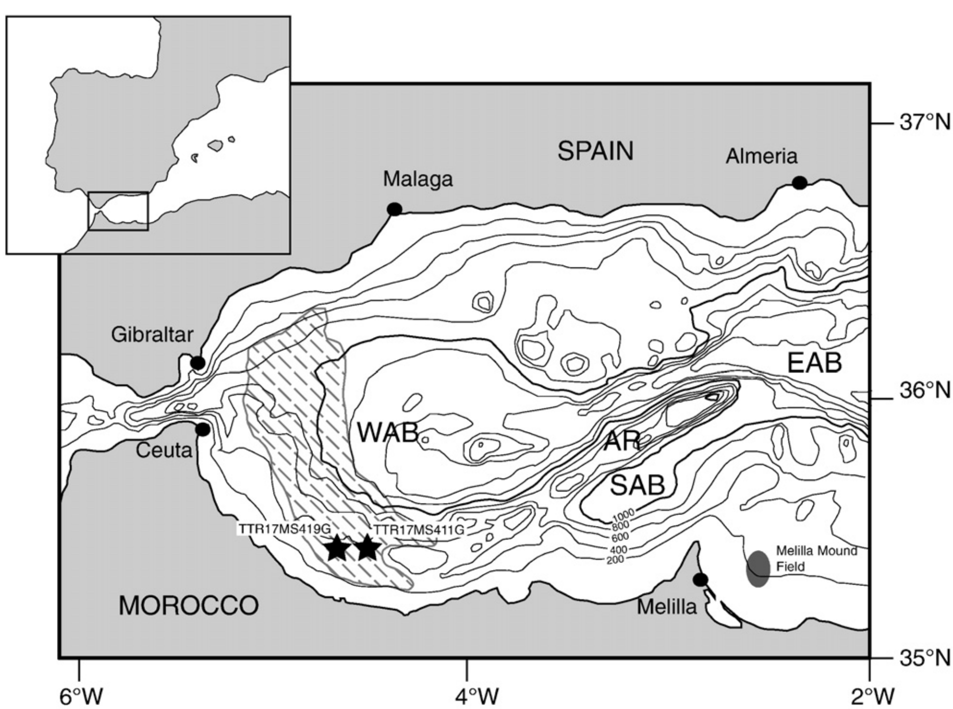


**Fig. 1.** Location map of the studied cores. Shaded area: Mud Diapir Province. WAB: West Alboran Basin; EAB: East Alboran Basin; SAB: South Alboran Basin; AR: Alboran Ridge. Modified from Comas et al. (1999) and Comas and the SAGAS08-TTR17, Leg 1-Scientific Party (unpublished).