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Sedimentary sources of the mud-breccia and mud volcanic activity in the Western Alboran Basin

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ABSTRACT

During the TTR-17 Leg 1 cruise in the West Alboran Basin, gravity cores were acquired from three mud volcanoes (MVs): Dhaka, Carmen and the recently discovered Maya. This paper presents micropaleontological and radiocarbon dating results from the three mud volcanoes, using cores containing mud breccias overlain by and interbedded with hemipelagic sediments. At Dhaka MV, the mud-breccia matrix contains very rare Holocene planktonic foraminifera associated with abundant reworked specimens of mixed Late Cretaceous to Mio-Pliocene age. At Carmen MV, the reworked assemblage is dominated by Miocene to Pliocene foraminifera occurring together with rare Late Cretaceous species while at Maya MV the mud-breccia matrix is characterized by the dominance of Santonian–Maastrichtian forms, with subordinate Tertiary species. Shallow-water benthic foraminifera such as *Ammonia* spp. and *Elphidium* spp. are generally rare and randomly distributed, but present at all studied sites. Based on these results, we suggest that the main sediment source of the mud-breccia extruded at Dhaka, Carmen and Maya MVs is possibly the lowermost overpressured olistostromic Unit VI (Aquitanian?–Burdigalian). Differences in the micropaleontological composition of the mud-breccia matrix at different sites are most likely due to differences in the main source layer and in the plumbing systems underneath the MVs. Radiocarbon dating of hemipelagic sediments associated to the mud-breccia allowed to define the age of the latest extrusion activities (>0.27 ka to >15.6 ka BP), which seem to be episodic, short-lived and recurrent over thousands of years.

1. Introduction

Mud volcanism and diapirism include both subaerial and subaqueous manifestations (Chapman, 1974) and are a widespread phenomenon in many areas of the world's oceans such as the Mediterranean Sea, the Gulf of Cadiz, the Black Sea, Barbados, Makran, Aleutians, and the Caspian Sea. They occur on both active and passive margins, but are more abundant in convergent tectonic settings (reviews in Dimitrov, 2002; Kopf, 2002).

Mud volcanoes (MVs) are prominent surface or seafloor features resulting from the upward migration of hydrocarbon-rich fluids and solids generated by pore-fluid overpressures in clay-rich formations at depth (e.g., Dimitrov, 2002; Kopf, 2002; Praeg et al., 2009). Their surface expression is the result of the progressive accumulation of extruded mud-breccia, a semi-liquid, clayey matrix containing various amounts of heterogenic rock fragments and clasts, derived from the geological section through which the mud ascends, which are eventually incorporated into the matrix (Cita et al., 1981; Staffini et al., 1993; Dimitrov, 2002; Kopf, 2002).

Mud volcanoes can root in sedimentary deposits that are several kilometers below the seafloor (Higgins and Saunders, 1974; Fowler et al., 2000; Aslan et al., 2001) and can thus be considered as 'windows' into the sedimentary basins that reveal the composition of deep sediments. However, fluids rising through deep-rooted feeding channels may be also stored at intermediate to shallow-depth mud chambers and be remobilized via sub-surface interconnected plumbing systems (Deville et al., 2003, 2010; Praeg et al., 2003, 2009; Mazzini et al., 2009).

In the Eastern Mediterranean, mud volcanoes (MVs) were first discovered west of Crete (Cita et al., 1981) on the Mediterranean Ridge, an accretionary prism with double vergence developed in a subduction zone (e.g., Camerlenghi et al., 1995; Premoli Silva et al., 1996). Since then, intensive investigation mostly carried out in the framework of the Training Through Research Program (TTR) has resulted in the discovery of numerous new MVs on the crest of the Mediterranean Ridge (Limonov et al., 1996). Drilling during ODP Leg

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160 proved that mud volcanoes in the northern margin of the Mediterranean Ridge were active since at least 1 Ma (Robertson and Ocean Drilling Program Leg 160 Scientific Party, 1996). Mud volcanoes active over the last 3 Ma were recently discovered along the off-shore Calabrian Arc, at the tip of the Apenninic–Maghrebide accretionary system (Praeg et al., 2009). Occurrence of mud volcanism and diapirism in the Eastern Mediterranean is also recorded in an extensional setting: the Nile Deep Sea Fan (e.g., Loncke et al., 2004; Dupré et al., 2007)

Mud volcanoes are well known west of the Gibraltar Strait, in the Gulf of Cadiz, along the Atlantic counterpart of the Alboran Basin in the Gibraltar Arc System (GAS; e.g., Pinheiro et al., 2003; Somoza et al., 2003; Fernández-Puga et al., 2007) where the related phenomena such as cold seepage, pockmarks, hydrocarbon venting, methane-derived authigenic carbonates and gas hydrates have been investigated since 1996 (Baraza and Ercilla, 1996; Baraza et al., 1999; Ivanov et al., 2000, 2001; Kenyon et al., 2000; Somoza et al., 2000, 2003; Gardner, 2001; Mazurenko et al., 2002; Pinheiro et al., 2003, 2006; Magalhães et al., 2012). Their origin is associated with recent compressive tectonics on shale and salt deposits of the olistostrome/accretionary complex units, emplaced as an allochthonous unit in the Late Miocene as a result of Africa– Eurasia convergence (Maldonado et al., 1999; Somoza et al., 2003).

In the Western Mediterranean, MVs are relatively scarce features (e.g., Sautkin et al., 2003), and in particular, in the Alboran Sea, they are related to mud diapirs and active sediment and fluid flow in a back-arc basin setting (Talukder, 2003; Talukder et al., 2003; Comas et al., 2010). Their existence in this basin was first documented in 1999 during the TTR-9 Leg 2 along the Moroccan margin. Further surveys carried out from 2002 to 2008 (TTR-12, 14, 17) revealed the existence of several mud volcanoes, pockmarks and seepage-related structures on both the Spanish and the Moroccan margin of the West Alboran Basin. Among them, the mud volcano named Carmen, discovered in 2004 during TTR-14, was proved to be active (Fig. 1; Comas et al., 2000, 2003a, 2003b, 2006, 2010; Kenyon et al., 2000, 2003, 2006; Sautkin et al., 2003; Talukder et al., 2003; Blinova et al., 2011).

During the TTR-17 Leg 1 cruise, the mud volcano fields of the West Alboran Basin (Iberian and Moroccan margins) were revisited to core some of the MVs previously known and to explore the occurrence of new MVs and related features in the region (Fig. 1). As a result of this extensive survey, a new small mud volcano, named Maya, was discovered and cored for the first time (Blinova et al., 2011; Margreth et al., 2011).

Previous works on the Mud Diapiric Province focused on the MV structures and their relationship with shale diapirs (Sautkin et al., 2003; Talukder et al., 2003; Somoza et al., 2012), as well as on the identification of the source layer (Sautkin et al., 2003). Recently, the study of fluid discharged at different seep sites in the area proved that Carmen MV is presently active (Blinova et al., 2011).

In this research, we investigate the micropaleontology of three gravity cores retrieved from Dhaka, Carmen and Maya MVs during the TTR-17 cruise (Fig. 2). The cores contain mud breccias interbedded with or overlaid by hemipelagic sediments. Following previous studies on mud volcanoes (e.g., Staffini et al., 1993; Premoli Silva et al., 1996, Sautkin et al., 2003), this study focuses on the mud-breccia matrix, because it is considered as more representative of the whole breccia-framework, in which coarser clasts are often of difficult interpretation and attribution, due to the fact that they may correspond to remobilization of olistostromic allochthonous bodies. The aims of our study are:

1. To investigate the stratigraphic succession underlying the mud volcanoes;
2. To identify the source of the extruded mud-breccias;
3. To date recent extrusive episodes.

2. Geological setting

The Alboran Sea, located behind the Gibraltar Arc, is the westernmost basin of the Mediterranean Sea. Its northern boundary is the Betic Cordillera (Southern Spain) and its southern boundary is the

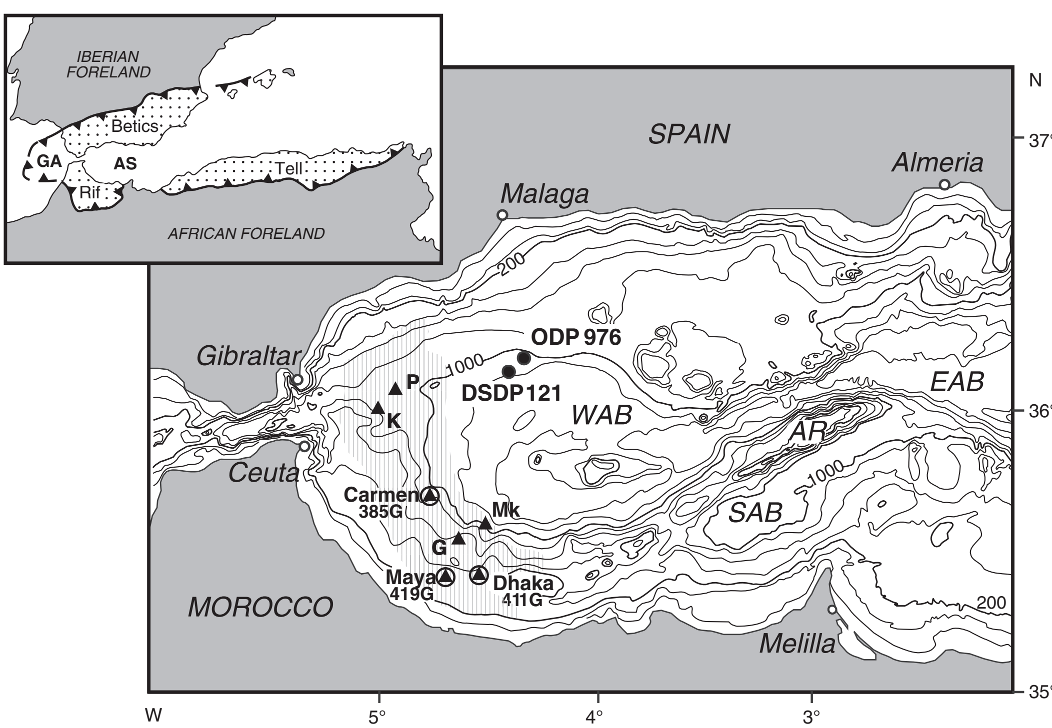

Fig. 1. Location map of the studied cores in the Alboran Sea (GA: Gibraltar Arc; AS: Alboran Sea; WAB, SAB, EAB: Western, Southern, Eastern Alboran Sea; AR: Alboran Ridge; Vertical shaded area: Mud Diapiric Province). Solid triangles show locations of mud volcanoes (P: Perejil; K: Kalinin, G: Granada; Mk: Marrakech). Empty circles indicate coring sites. Solid circles indicate location of DSDP Site 121 and ODP Site 976. (Modified from Comas et al., 1999).