Marine Geology 378 (2016) 114–126

Contents lists available at ScienceDirect

Marine Geology

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

Bottom currents and their influence on the sedimentation pattern in the El Arraiche mud volcano province, southern Gulf of Cadiz

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ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 26 October 2015
Accepted 29 November 2015
Available online 30 November 2015

Keywords:
Bottom currents
Internal tides
Contourite drifts
El Arraiche mud volcano province
Gulf of Cadiz

ABSTRACT

The completion of IODP expedition 339 within the Cadiz contourite depositional system, along the southern Iberian margin (which was created and maintained by the Mediterranean Outflow Water) has brought increased amounts of attention to this natural contourite laboratory. In contrast, a lot less attention is given to the southern Gulf of Cadiz despite the ubiquitous presence of tectonic ridges, small contourite deposits, mud volcanoes and cold-water coral mounds. The El Arraiche mud volcano province (EAMVP) is located in the southern Gulf of Cadiz and is characterized by an extensional regime, creating two tectonic ridges named Renard and Vernadsky. Also, nine mud volcanoes and numerous cold-water coral mounds are present in this area.

The northward flowing bottom currents are deflected by the topographic obstacles and flow in a westward direction at the foot of the NW–SE-oriented Renard Ridge. Calculations indicate that this bottom current is capable of turning around the tip of the Renard Ridge and continues its path along its northern edge. The locations of the contourite deposits at the foot of the Renard Ridge are controlled by the steepness of the ridge: slopes of more than 12° are associated to contourite deposits, while less steep ones merely show hemipelagic deposits. The moats around the mud volcanoes originate due to a combination of subsidence and the action of bottom currents, as the seismic data show separated mounded drift deposits perpendicular to the moats as well as subsidence rims. Some mud volcanoes have a less incised northern and a deeper southern moat, which indicates eastward flowing bottom currents. This orientation is consistent with the shoreward component of the internal tides, which flow vigorously in this area with peaks of speed over 30 cm/s. The integration of geophysical and hydrographic datasets in the EAMVP sheds new light on the dynamic nature of the interaction of bottom currents and topographic features.

1. Introduction

Ever since contourites have been first recognized (Heezen et al., 1966), an increasing amount of different types of contourites have been described, e.g. plastered drifts, separated mounded drifts and channel drifts (Faugères and Stow, 1993; Faugères et al., 1999; Stow et al., 2002; Rebesco et al., 2005; Rebesco et al., 2014). Over the years, the definition of contourites has been broadened and they are now considered to be sediments deposited or significantly affected by the action of bottom currents (Rebesco et al., 2014). Bottom currents can occur in a wide range of geological settings: from the abyssal depths (Faugères et al., 1999; Uenzelmann-Neben and Gohl, 2012) to the continental shelves (Roque et al., 2012; Preu et al., 2013) and even in lakes (Gilli et al., 2004; Heirman et al., 2012). Any bottom current strong enough to pick up sediment at one place and deposit it somewhere else may thus in theory create a contourite deposit. Whether a current is capable of affecting the sediment depends on the strength of the current and the nature of the sediment. In muddy and silty environments, sediments can be displaced by bottom currents of 5–10 cm/s (Stow et al., 2009), while for sands higher flow intensities are required (more than 30 cm/s). In some areas, topographic obstacles (e.g. mud volcanoes, salt diapirs, tectonic ridges) are known to alter the current pattern and increase the flow speed (Faugères et al., 1999; Somoza et al., 2003; Palomino et al., 2011; Hanebuth et al., 2015).

Contourites occur in a wide variety of settings, the northern Gulf of Cadiz for instance houses many contourite deposits, such as the Faro, Albufeira and Quadalquivir drifts (Llave et al., 2001; Hernández-Molina et al., 2006b; Stow et al., 2013). Several of these drifts are not aligned along-slope, but grouped together in the Cadiz contourite depositional system. Tectonic ridges and salt diapirs alter the pathway of the Mediterranean Outflow Water in this region and create separated mounded drift deposits perpendicular to the slope (García et al., 2009). On the Galicia Bank (northwestern tip of Spain), contourite

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http://dx.doi.org/10.1016/j.margeo.2015.11.012
0025-3227/

deposits are associated to cold-water coral mounds (Van Rooij et al., 2003; Somoza et al., 2014). Some areas have bottom currents which are not strong enough to create contourite deposits, but flow enhancement by deflection against obstacles can lead to the creation of contourite deposits. This is observed in the Le Danois area (Van Rooij et al., 2010), the Galicia bank (Hanebuth et al., 2015) and the South China Sea (Chen et al., 2014).

The El Arraiche mud volcano province (EAMVP, Fig. 1) consists of two NW–SE-oriented tectonic ridges (Vernadsky in the north and Renard in the south), nine mud volcanoes (with Al Idrissi and Gemini being the biggest) and hundreds small to medium-sized cold-water coral mounds (Van Rensbergen et al., 2005a,b; Foubert et al., 2008; De Mol et al., 2011; Van Rooij et al., 2011). As such, the area is ideal for investigating the role of topographic obstacles on bottom currents. South of the Pen Duick Escarpment (Figs. 1 & 2) and the Gemini mud volcano, a separated mounded drift has been discovered (Vandorpe et al., 2014). This Quaternary drift system originated due to the deflection of bottom currents against the Gemini mud volcano and the Pen Duick Escarpment and is affected by the mud outflow from the volcano, the uplift of the escarpment and the presence of coral mounds at the foot of the escarpment. Therefore, it may be reckoned as a clear example of an obstacle-related contourite drift.

New seismic data from the R/V Belgica "COMIC" cruise in 2013 indicate the presence of several other bottom current controlled features in the area. Moreover, the acquisition of oceanographic data allows us to characterize the local water column in great detail. The goal of this paper is to examine these features, identify which water masses are involved, interpret the role of the different obstacles and find out how they affect sedimentation and bottom currents. A morpho-sedimentary map is constructed and the occurrence of the contourite drifts is compared to the present-day oceanographic and topographic setting.

2. Regional setting

2.1. Geological setting

The Gulf of Cadiz experienced several phases of rifting, extension and compression since the Triassic (Maldonado et al., 1999). The ongoing European–African convergence and the accompanied westward migration of the Gibraltar Arc resulted in the emplacement of large allochtonous wedges within the Gulf of Cadiz during the late Miocene (Maldonado et al., 1999; Medialdea et al., 2004). The Neogene and Quaternary cover on top of this allochtonous unit is pierced by several mud volcanoes, salt diapirs, diapiric and tectonic ridges and pockmarks (Somoza et al., 2003; Medialdea et al., 2009). In the northern Gulf of Cadiz, these topographic obstacles interact with the pathway of the Mediterranean Outflow Water (García et al., 2009) and create a complex contourite depositional system.

The El Arraiche mud volcano province (EAMVP, Fig. 1) is situated on the continental slope between 35°10′N to 35°30′N and 6°30′E to 7°E and contains two tectonic ridges (Renard and Vernadsky), 9 mud volcanoes and many surfacing small cold-water coral mounds. The Renard and Vernasky ridges were created due to a local extensional regime creating rotated blocks bound by lystric faults (Flinch, 1993). This is in

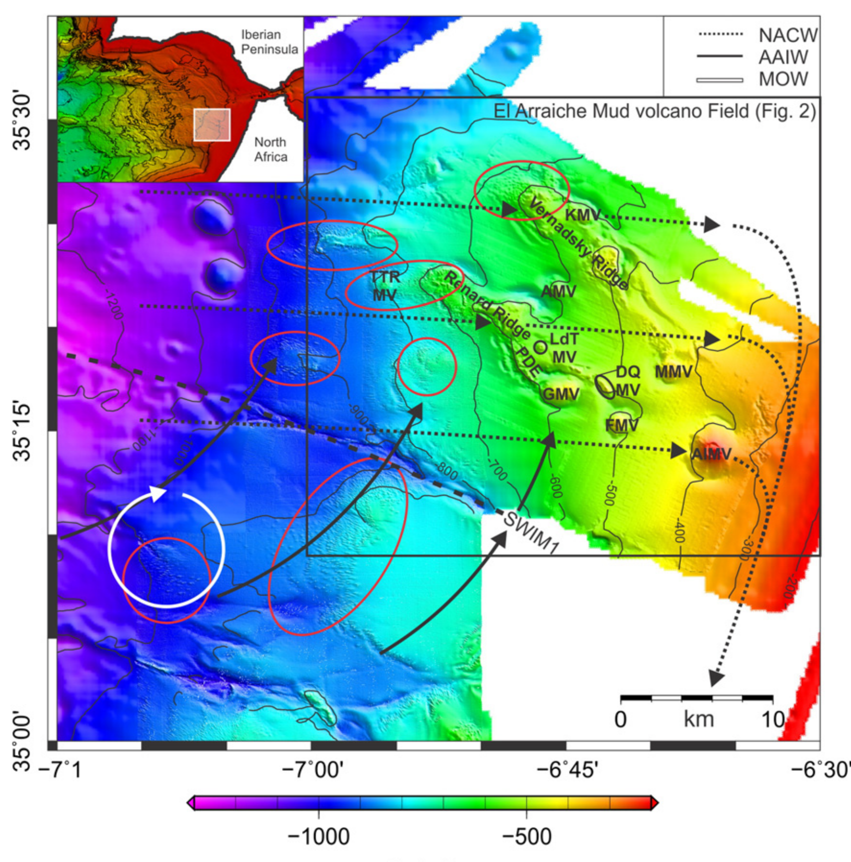

Fig. 1. Multibeam map of the broader research area in the southern Gulf of Cadiz with contour lines every 100 m. All of the topographic obstacles are named on the map: the Vernadsky and Renard tectonic ridges and all of the mud volcanoes. Cold-water coral fields are indicated by the red ovals. The general direction of the currents and their water masses has been indicated based on (Criado-Aldeanueva et al., 2006; Machín et al., 2006a,b; Ambar et al., 2008; Louarn and Morin, 2011). The black box indicates the area characterized in Fig. 4. NACW = North Atlantic Central Water, AAIW = Antarctic Intermediate Water, MOW = Mediterranean Outflow Water, AIMV = Al Idrissi mud volcano, AMV = Adamastor mud volcano, DQMV = Don Quijote mud volcano, FMV = Fiúza mud volcano, GMV = Gemini mud volcano, KMV = Kidd mud volcano, LdTMV = Lazarillo de Tormes mud volcano. The SWIM compilation dataset (Zitellini et al., 2009) has been used as a background.