ARTICLE IN PRESS
PALAEO-08337; No of Pages 12
Palaeogeography, Palaeoclimatology, Palaeoecology xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Palaeogeography, Palaeoclimatology, Palaeoecology
journal homepage: www.elsevier.com/locate/palaeo

# Multiple generations of buried cold-water coral mounds since the Early-Middle Pleistocene Transition in the Atlantic Moroccan Coral Province, southern Gulf of Cádiz

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ARTICLE INFO

*Article history:*
Received 4 November 2016
Received in revised form 8 June 2017
Accepted 15 June 2017
Available online xxxx

*Keywords:*
Glacial
Sediment input
Bottom currents
Early-Middle Pleistocene transition

ABSTRACT

Cold-water coral mounds are common seabed features in the North Atlantic Ocean, where they are mainly restricted to water depths between 200 m and 1000 m. Coral mounds consist of coral fragments and hemipelagic sediments, reflecting an often complex history of mound aggradation and erosion linked to coral vitality. In the southern Gulf of Cádiz along the Moroccan margin, a large field (extension: 1800 km$^2$) of 781 comparatively small buried and exposed mounds (average height: about 20 m) has recently been discovered. The mounds in the so-called Atlantic Moroccan Coral Province (AMCP) initiated on at least ten different horizons, all of them most likely related to glacial periods since the Early-Middle Pleistocene Transition. A strong link between the intensification of bottom currents and the number of coral mounds rooting on each of the identified horizons is assumed. Also a shift of the average water depth at which coral mounds initiated towards deeper regions and an accompanied increase in mound height is observed between MIS 14 and MIS 12. Finally, reduced or low sediment input is regarded as one of the main factors causing the rather small size of coral mounds in the AMCP in comparison to other Atlantic mound provinces.



## 1. Introduction

During the last 15 years, cold-water coral (CWC) research experienced a boost resulting in a steadily increasing knowledge regarding their environmental requirements and preferences, their ecology and physiology, their recent spatial distribution and their temporal occurrence (Freiwald, 2002; Freiwald and Roberts, 2005; Hebbeln et al., 2016; Roberts et al., 2006). Of particular interest are framework-forming scleractinian CWC, such as *Lophelia pertusa* and *Madrepora oculata*, as they have the capability to form small to large reefs (Roberts et al., 2006), possibly leading to the development of huge CWC mounds (hereafter called coral mounds; de Haas et al., 2009; Mienis et al., 2006; van Weering et al., 2003). The temporal development of coral mounds often is discontinuous with recurring periods of CWC colonization and mound aggradation alternating with periods of coral demise and possible mound erosion (Roberts et al., 2006; Wienberg and Titschack, 2017). Coral mounds are the result of an interplay between sustained phases of CWC growth and concurrent sediment input, with the sediments being entrapped within the coral framework (known as baffling effect; Huvenne et al., 2009; Titschack et al., 2009) and thus stabilizing the biogenic construction. Over time, this can result in mound aggradation rates of up to 1500 cm kyr$^{-1}$ as calculated for Norwegian coral mounds (Titschack et al., 2015). During periods of coral demise, the mounds might by covered solely by (hemi) pelagic sediments, which later on may act as a weak layer and could induce slumping, widening the mound at the base (Eisele et al., 2008).

Coral mounds are widely distributed in the North Atlantic Ocean, where they occur on the shelf and along the continental margin mainly being confined to water depths of 200 to 1000 m (Roberts, 2009; Wienberg and Titschack, 2017). They can become rather high (tens to hundreds of meters), as for example in the Porcupine Seabight and the Rockall Trough (De Mol et al., 2002; Eisele et al., 2008; Huvenne et al., 2003; Mienis et al., 2006) or remain rather small (several to tens of meters high) as seen for the Moira mounds in the Porcupine Seabight (Wheeler et al., 2007) and along the Moroccan margin (Foubert et al., 2008; Wienberg et al., 2009). Due to their highly heterogeneous composition, the internal structure of coral mounds appears as acoustically transparent on seismic profiles (Hebbeln et al., 2016; Huvenne et al.,

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http://dx.doi.org/10.1016/j.palaeo.2017.06.021

2007; Pirlet et al., 2010). The dimensions of the coral mounds depend on environmental controls and sediment input. Environmental control for mound aggradation first and foremost depends on a complex set of suitable environmental conditions that allow the CWC themselves to settle, grow and develop into large thriving reefs. Important are distinct ranges for seawater temperature (−1.8 °C to 14.9 °C), salinity (31.7–38.8) and dissolved oxygen concentration (3–7.2 ml $l^{-1}$) as well as a high net primary production (Davies and Guinotte, 2011; Davies et al., 2008). Additionally, several other chemical and biological parameters such as the pH, the aragonite saturation state and concentrations of dissolved and particulate organic matter were indicated to play an important role in the occurrence of CWC (Davies and Guinotte, 2011; Davies et al., 2008). Given that the physical setting fits the CWC requirements, the availability of sufficient food particles and distinct hydrodynamic processes (geostrophic currents, local bottom currents, internal waves and tides) to deliver the food particles to the corals or enrich food around them (nepheloid layers) are the most important parameters (Hebbeln et al., 2016; Mienis et al., 2007; Mienis et al., 2012). Even under erosive conditions for the surrounding areas, coral mounds can still aggrade (Thierens et al., 2013) as sediments delivered by vigorous bottom currents are entrapped or baffled within the coral framework (Hebbeln et al., 2016; Huvenne et al., 2009; Titschack et al., 2009).

The current knowledge obtained for coral mounds largely originates from examples which have today an exposed position at the seabed surface. However, also buried coral mounds have been discovered along the Moroccan, Mauritanian and Irish margins and in the western Mediterranean Sea (Colman et al., 2005; Foubert et al., 2008; Huvenne et al., 2009; Lo Iacono et al., 2014; Vandorpe et al., 2016). There seem to be some apparent differences between the above mentioned areas regarding the initiation and development of these mounds. For example, the Irish buried mounds of the Magellan mound province, Porcupine Seabight, nearly all root on one single horizon (Huvenne et al., 2007), while hundreds of small coral mounds were identified to have originated at multiple horizons along the Moroccan margin (Foubert et al., 2008; Hebbeln et al., 2015). However, the existing knowledge on buried mounds along the Moroccan margin was so far restricted to a rather small area within and south of the El Arraiche mud volcano province (Fig. 1). As the number of discovered exposed coral mounds along the Moroccan margin increased steadily with every new mapping survey (by now comprising a very large area bordered by the El Arraiche mud volcano province in the north and the SWIM 2 fault in the south; henceforth be called the Atlantic Moroccan Coral Province, AMCP), it is to be expected that also many more buried mounds are present in the area then assumed so far.

The recent knowledge about the temporal development of the Moroccan coral mounds is based on datings of CWC fragments, obtained from gravity cores of exposed coral mounds developed on top of the Pen Duick escarpment and Renard Ridge (Fig. 1), which indicated that mound aggradation was largely restricted to glacial periods during the last 500 kyr (Frank et al., 2011; Wienberg et al., 2009; Wienberg et al., 2010). So far, nothing is known about the timing of the formation of the buried coral mounds in the AMCP. However, the buried mounds are present at several depth levels in the vicinity of sediment drift systems, these provide an initial chronostratigraphic framework (Vandorpe et al., 2016), which allow an appraisal of the temporal evolution of the buried coral mounds possibly going back further in time than the past 500 kyr and indicating when mound formation initiated in this region. Additionally, a thorough evaluation of the number of buried mounds being present in the AMCP as well as of their spatial distribution and dimensions (height, volume) is still lacking. These quantitative data might shed new insights on the spatial occurrence pattern of coral

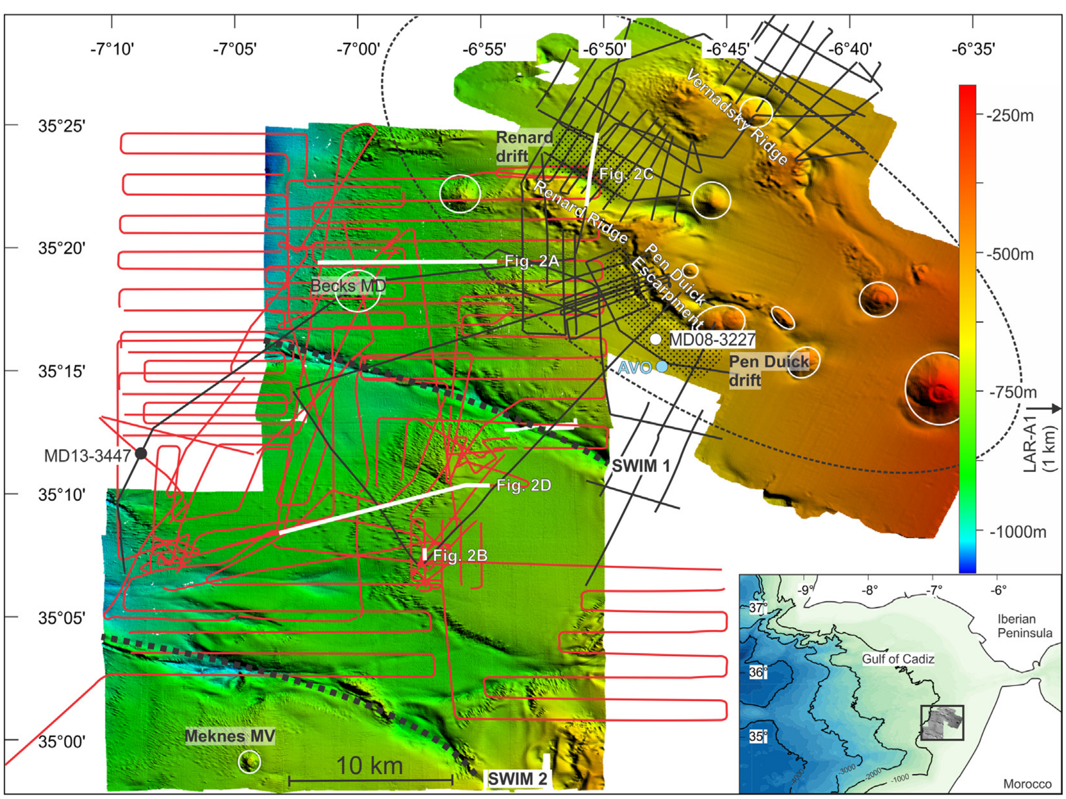


**Fig. 1.** Multibeam bathymetric map of the study area along the Atlantic Moroccan margin (see overview map in the lower right inset). The PARASOUND profiles are indicated in red and the single channel sparker reflection seismic profiles in black. The Pen Duick and Renard drifts are indicated by the dotted areas. The extent of the El Arraiche mud volcano province (Vandorpe et al., 2016) is indicated by the thin black dashed oval. The location of the amplitude versus offset (AVO) experiment is indicated by the light blue dot, while the core locations of the Marion Dufresne cores are indicated in white/black. The white bold lines indicate the position of seismic profiles displayed in Fig. 2. MD: mud diapir, MV: mud volcano, SWIM: Southwestern Iberian Margin faults. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Please cite this article as: Vandorpe, T., et al., Multiple generations of buried cold-water coral mounds since the Early-Middle Pleistocene Transition in the Atlantic Moroccan Cora..., Palaeogeogr. Palaeoclimatol. Palaeoecol. (2016), http://dx.doi.org/10.1016/j.palaeo.2017.06.021