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Coral mound development at the Campeche cold-water coral province, southern Gulf of Mexico: Implications of Antarctic Intermediate Water increased influence during interglacials

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ABSTRACT

Coral mounds formed by framework-forming scleractinian cold-water corals (CWC; mainly *Lophelia pertusa*) are a common seabed feature along the Atlantic continental margins. While coral mound areas in the NE Atlantic reveal a climate-dependent temporal pattern of CWC occurrence and mound aggradation that is related to distinct environmental conditions (e.g., productivity, water mass properties, hydrodynamics), the long-term development of CWC and coral mounds at the western side of the Atlantic is less well documented and understood. Here, we present a 260-kyr coral record from the recently described Campeche CWC province in the southern Gulf of Mexico, combined with a reconstruction of the paleo-environmental conditions for the last 140 kyr. Uranium-series dating of 26 coral samples reveals that CWC growth predominantly coincided with interglacial periods. Highest vertical mound aggradation rates of 34 to 40 cm kyr^{-1} occurred during the Holocene. The reduced occurrence of CWC and the concurrent almost complete stagnation in mound aggradation during glacial periods could be linked to a diminished presence of Antarctic Intermediate Water at those intermediate depths in which the coral mounds occur. Such setting would have caused a less dynamic bottom current regime resulting in a reduced food supply to the CWC along the Campeche Bank.

1. Introduction

The framework-forming scleractinian cold-water corals (CWC) *Lophelia pertusa* and *Madrepora oculata* are known to have the capability of forming large three-dimensional seabed structures, called coral mounds (e.g., De Mol et al., 2002; Freiwald and Roberts, 2005; Hebbeln and Samankassou, 2015; Mortensen et al., 2001; Paull et al., 2000; Roberts et al., 2009; Wienberg and Titschack in press). Coral mounds form when the environmental conditions, such as food availability, distinct physico-chemical water mass properties and a vigorous bottom current regime (see Davies and Guinotte, 2011) allow steady CWC growth and sufficient sediment is supplied and deposited to secure the stabilization of the biogenic framework (e.g., de Haas et al., 2009; Hebbeln and Samankassou, 2015; Huvenne et al., 2009; Wienberg and Titschack in press). Whereas strong hydrodynamics and a persistent sediment supply form important boundary conditions for the development of coral mounds, these factors also control the development of contourite drift deposits (e.g., Rebesco et al., 2014). Consequently, coral mounds and contourites often co-occur given that they are dependent of similar environmental conditions (Hebbeln et al., 2016).

Coral mounds can form impressive paleo-archives preserving the history of CWC development for > 2 million years (e.g., Kano et al., 2007). So far, numerous coral mounds have been described mainly from the North Atlantic Ocean, where they are often arranged in clusters or provinces covering extended areas along the shelf and continental margins of NW Europe, NW Africa and the eastern US margin (e.g., Colman et al., 2005; Correa et al., 2012; De Mol et al., 2002; Fosså et al., 2005; Glogowski et al., 2015; Paull et al., 2000). Several studies

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from the extensively studied NE Atlantic have reconstructed the temporal occurrence of *Lophelia pertusa* and *Madrepora oculata* as well as the past development of coral mounds formed by these species during the past thousands to millions of years (e.g., Kano et al., 2007), thereby revealing a climate-dependent pattern (e.g., Frank et al., 2011). In the northern NE Atlantic (> 50°N; mainly comprising the Norwegian shelf and the Irish slope), CWC occurrence and coral mound aggradation are documented mainly for interglacial periods (Dorschel et al., 2005; Eisele et al., 2008; Frank et al., 2009; López Correa et al., 2012; Raddatz et al., 2014; Van der Land et al., 2014). Contrarily, the formation of coral mounds in the southern NE Atlantic (< 37°N), namely along the Moroccan and Mauritanian margins, was largely restricted to glacial periods (Eisele et al., 2011; Taviani et al., 1991; Wienberg et al., 2010, 2009).

Previous studies dealing with the temporal occurrence of CWC in the NW Atlantic and using them for palaeo-oceanographic and ecological studies mainly focused on solitary corals such as *Desmophyllum dianthus* collected from various seamounts (New England seamounts; Robinson et al., 2007; Thiagarajan et al., 2013). However, the long-term development of NW Atlantic coral mounds formed by *L. pertusa*, comprising CWC areas along the eastern US slope, the Florida Straits, and the Gulf of Mexico (GoM), are less well documented. Besides the three *L. pertusa* datings obtained from the northern and eastern GoM (Viosca Knoll and West Florida Slope), presenting ages from the last glacial period (~25–31 calibrated (cal) ka BP; Newton et al., 1987; Sulak, 2008), only one stratigraphic study based on sediment cores is available. The single long-term record regarding coral mound development along the NW Atlantic margin comes from the Cape Lookout CWC area (off North Carolina, USA; Matos et al., 2015). Here, coral mounds are mainly formed by *L. pertusa* and the sustained occurrence of this species and concurrent mound aggradation seem to have been restricted to interglacial periods, displayed by coral ages spanning from 123 to 128 ka and the last 6.8 kyr (Matos et al., 2015).

The recent discovery of the large Campeche CWC province in the southern GoM, comprising numerous coral mounds presently covered by extensive living CWC (Hebbeln et al., 2014) that co-occur with a large contourite drift body (Hübscher et al., 2010), advocates for favorable conditions (at least) under the present-day setting. Nonetheless, nothing is known so far about the temporal occurrence of CWC and the development of the Campeche coral mounds in the past nor about the regional paleoenvironmental setting as it might be recorded in the nearby drift deposits.

Newly obtained sediment cores, collected from the Campeche CWC province, provide unique paleo-records, which allow to unravel periods of sustained CWC occurrence and mound formation in this area and to relate these to a distinct environmental setting. Regarding the still limited knowledge about the past occurrence of CWC and development of coral mounds in the NW Atlantic, this study provides an important contribution to (a) increase our understanding on the likely climate-dependent development of CWC sites at this side of the Atlantic and to (b) identify any potential linkage between CWC sites in the NW and NE Atlantic in relation to intermediate water mass circulation.

2. Regional setting

The Campeche CWC province is a coral mound area (> 40 km^2) at the northeastern rim of the Campeche Bank (Hebbeln et al., 2014), an extensive carbonate platform situated in the north of the Yucatán Peninsula in the southern GoM (Fig. 1). It is limited to the west by a 40-m-high escarpment that separates the coral mounds from the shallower Campeche Bank and to the east by a major sediment drift in water depths of > 600 m (Hebbeln et al., 2014; Hübscher et al., 2010). The Campeche coral mounds occur along a gently dipping slope between 480 m and 600 m water depth. They have an elongated shape with lengths varying from a few tens of meters to > 1000 m and heights between 20 and 40 m. Their surface is covered by a live coral framework composed of *L. pertusa* and *Enallopsammia profunda* (Hebbeln et al., 2014).

The local oceanography is mainly characterized by five water masses (Hebbeln et al., 2014; Merino, 1997; Rivas et al., 2005). The Caribbean Surface Water is confined to depths shallower than 80 m (salinity < 36.4; 26–27.5 °C). Below, we find the Subtropical Intermediate Water, whose core is characterized by a salinity maximum at 100–160 m water depth (salinity 36.8; 23 °C); followed by the Tropical Atlantic Central Water (TACW) presenting an oxygen minimum at depths ~500 m and thermohaline characteristics (salinity 35–36.1; 8–16 °C) and the Antarctic Intermediate Water (AAIW). The upper boundary of the AAIW is identified by the salinity minimum found at ~540 m water depth (salinity < 35; 7 °C). The North Atlantic Deep Water can be found at depths deeper than 1000 m, characterized by a salinity maximum (salinity 35; 4 °C). A strong density gradient is found at around 520–540 m (the upper range of observed living CWC) that is likely related to the boundary (pycnocline) between the TACW and the AAIW, where the occurrence of internal waves is suggested by the presence of undulating isotherms (Hebbeln et al., 2014).

The Campeche CWC province is dominated by SE-NW currents, influenced by the Yucatán and Loop currents (Fig. 1), which are strongest at the surface (< 130 m water depth; 74–83 cm s^{-1}) (Hebbeln et al., 2014). Between 500 and 600 m water depth (the depth interval in which the Campeche coral mounds occur), lower but still strong bottom currents with average velocities of ca. 30 cm s^{-1} are observed (Hebbeln et al., 2014).

3. Material and methods

All the sediment cores used in this study were acquired during the WACOM MSM 20-4 expedition (German R/V *Maria S. Merian*) in Spring 2012 (Hebbeln et al., 2012). Coral-bearing gravity cores collected from the coral mounds (on-mound cores) have been studied in order to investigate the pattern of temporal CWC occurrence in the Campeche CWC province. Three on-mound cores were collected at water depths ranging between 553 and 573 m having recoveries between 2.5 and 10.5 m (Table 1). The usage of three on-mound cores from three coral mounds (Fig. 1) allows the detection of potential spatial variability in coral mound development and increases the representativeness of the data. Prior to sampling in the lab, the cores were cut frozen with a diamond saw, in order to keep the internal sedimentary structure intact.

Additionally, a paleoceanographic record has been developed from a core barren of CWC fragments collected from the nearby sediment drift (off-mound core) in order to define the environmental factors controlling CWC mound development. The off-mound core was collected at 626 m water depth, slightly downslope of the Campeche CWC province, and had a total recovery of 4.4 m (Fig. 1, Table 1).

3.1. Uranium-series dating on cold-water corals

In order to identify periods of sustained CWC occurrence, 26 well-preserved fragments of *L. pertusa* (24 ×) and *E. profunda* (2 ×) were sampled from the three on-mound gravity cores and used for Uranium-series dating. Given that the cores were completely filled with relatively well preserved coral fragments and exhibit a moderately homogeneous appearance regarding sediment color and apparent grain size, the sampling strategy was mostly based on a fairly even-spaced sampling along the cores. Prior to the analyses, the coral samples were cleaned mechanically to remove small borings by organisms and remains of organic tissue and non-coral contaminants from the skeleton surfaces (e.g. epibionts, iron–manganese crusts, coatings). They were then prepared chemically using weak acid leaching and water rinsing procedures as described by Frank et al. (2004). The aragonite fragments were then weighed, dissolved and spiked as described in Matos et al. (2015). Thorium (Th) and Uranium (U) were extracted and purified from the sample solutions using the ion exchange resin U-TEVA according to