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The giant Mauritanian cold-water coral mound province: Oxygen control on coral mound formation

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ABSTRACT

The largest coherent cold-water coral (CWC) mound province in the Atlantic Ocean exists along the Mauritanian margin, where up to 100 m high mounds extend over a distance of ~400 km, arranged in two slope-parallel chains in 400–550 m water depth. Additionally, CWCs are present in the numerous submarine canyons with isolated coral mounds being developed on some canyon flanks. Seventy-seven Uranium-series coral ages were assessed to elucidate the timing of CWC colonisation and coral mound development along the Mauritanian margin for the last ~120,000 years. Our results show that CWCs were present on the mounds during the Last Interglacial, though in low numbers corresponding to coral mound aggradation rates of 16 cm kyr^{-1}. Most prolific periods for CWC growth are identified for the last glacial and deglaciation, resulting in enhanced mound aggradation (>1000 cm kyr^{-1}), before mound formation stagnated along the entire margin with the onset of the Holocene. Until today, the Mauritanian mounds are in a dormant state with only scarce CWC growth. In the canyons, live CWCs are abundant since the Late Holocene at least. Thus, the canyons may serve as a refuge to CWCs potentially enabling the observed modest re-colonisation pulse on the mounds along the open slope. The timing and rate of the pre-Holocene coral mound aggradation, and the cessation of mound formation varied between the individual mounds, which was likely the consequence of vertical/lateral changes in water mass structure that placed the mounds near or out of oxygen-depleted waters, respectively.

1. Introduction

Cold-water coral (CWC) mounds formed by framework-building scleractinian CWCs (mainly *Lophelia pertusa*) are widely distributed along the continental margins of the Atlantic Ocean (Hebbeln and Samankassou, 2015; Roberts et al., 2009). They occur from shelf environments down to the upper and middle slopes (<1000 m water depth) and are mostly arranged in large provinces that comprise hundreds of individual mounds and cover extensive areas of several tens of square kilometres (e.g., Fosså et al., 2005; Glogowski et al., 2015; Grasmueck et al., 2006; Hebbeln et al., 2014; Paull et al., 2010; Vandorpe et al., 2017; Wheeler et al., 2007). Coral mounds are the result of a complex interplay between CWC growth and sediment input. In particular, the capability of the coral framework to baffle current-transported sediments plays a crucial role as the entrapped sediments stabilize the biogenic construction, and hence, favour mound aggradation (Huvenne et al., 2009; Thierens et al., 2013; Titschack et al., 2015, 2016). Consequently, coral mounds can develop into impressive seabed structures up to 300 m high and several kilometres in

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diameter that are deposited over many thousands to even millions of years (Kano et al., 2007; Roberts et al., 2006). Hence, coral mounds offer important records to reconstruct (i) the population history of CWCs with recurring periods of CWC growth and decline, and (ii) the temporal variability in vertical mound aggradation, alternating between active and dormant mound stages (Wienberg and Titschack, 2017). Moreover, the widespread occurrence and large dimension of coral mounds highlight their crucial role in continental margin architecture (De Mol et al., 2009; Hebbeln et al., 2016) and their relevance as important carbonate factories forming significant sinks for inorganic carbon (Lindberg and Mienert, 2005; Titschack et al., 2016). Due to their age and enhanced aggradation, they also provide unique archives of environmental and climate change, even preserving stratigraphic records lacking in the neighbouring sedimentary succession where simultaneously erosion or non-deposition prevailed (e.g., Frank et al., 2011; Hebbeln et al., 2016; Thierens et al., 2013; Titschack et al., 2009).

Much progress has been made in recent years to decipher the temporal development of Atlantic coral mounds across major climate changes, such as those induced by glacial-interglacial variability (Frank et al., 2009; Kano et al., 2007; López Correa et al., 2012; Raddatz et al., 2014; van der Land et al., 2014; Wienberg et al., 2010). For the Northeast Atlantic, it was demonstrated that areas offering optimal conditions for sustained coral mound formation have shifted latitudinally in pace with major climate changes (Frank et al., 2011). The opposing settings are characterized by coral mound provinces along the NW European margin, whose most recent formation period occurred during the Holocene associated with very high vertical mound aggradation rates (ARs) of 200–1500 cm kyr^{-1} (Dorschel et al., 2005; Douarin et al., 2013; López Correa et al., 2012; Titschack et al., 2015; Victorero et al., 2016). In contrast, mound formation was active along the NW African margin during the last glacial (and former glacial periods), ceased with the onset of the Holocene, and remained in a dormant state until today (Eisele et al., 2011; Wienberg et al., 2009, 2010). First studies of coral mound provinces in the Northwest Atlantic revealed a predominantly interglacial mound formation along the US margin (Cape Lookout) and in the southern Gulf of Mexico (Campeche Bank) (Matos et al., 2015, 2017).

Beside the assessment of the temporal development of coral mounds and of any large-scale pattern or basin-wide relation between the different provinces in the Atlantic, the understanding of the environmental and oceanographic factors controlling mound formation today and in the past is of main interest. This knowledge is essential to assess the response of these important deep-sea ecosystems to future ocean circulation changes, increasing water temperatures, and ocean acidification (Guinotte et al., 2006; Orr et al., 2005; Turley et al., 2007). The formation of coral mounds foremost depends on sustained CWC growth, which is in turn controlled by specific environmental boundary conditions. These encompass (i) physical and chemical properties of the surrounding bottom water masses (e.g., temperature, dissolved oxygen concentration (DOC), aragonitic saturation state, pH); (ii) the availability of sufficient food steered by enhanced surface ocean productivity; and (iii) the local hydrodynamic regime providing a constant to periodic delivery of suspended food particles to the sessile suspension-feeding CWCs (e.g., Büscher et al., 2017; Davies et al., 2009; Davies and Guinotte, 2011; Duineveld et al., 2012; Flögel et al., 2014; Mienis et al., 2007; Thresher et al., 2011; White et al., 2005). However, even if environmental conditions are within the constraints for CWC growth, coral mounds do not necessarily develop or turn from a dormant into an active state assuming that environmental controls on mound formation are far more complex and restrictive (Wienberg and Titschack, 2017). Nevertheless, regional studies indicate that mound formation depends on a dynamic bottom current regime (e.g., increased bottom current strength controlling food supply; Dorschel et al., 2005; Eisele et al., 2008; Matos et al., 2015) and enhanced palaeoproductivity (Eisele et al., 2011; Wienberg et al., 2010), while low bottom water oxygenation might present a major stressor (Fink et al., 2012). Overall, the regional environmental conditions stimulating or suppressing coral mound formation are strongly linked to the water column structure and water mass circulation at intermediate water depths (Fink et al., 2015; Henry et al., 2014; Matos et al., 2017). However, although our knowledge on coral mound formation steadily increased with every new coral mound province being discovered, it is still fragmentary.

In this study, the temporal development of the present-day world's largest coherent coral mound province along the Mauritanian margin is described and assessed. The Mauritanian coral mound province consists of up to 100-m-high coral mounds, which are arranged in two slope-parallel chains distributed over ~400 km (Figs. 1 and 2; Ramos et al., 2017). Today, the Mauritanian mounds are in a dormant state, deduced by the current scarcity of living CWCs. However, live CWCs are more frequently described from the numerous submarine canyons in the region (Westphal et al., 2012). The knowledge about the timing of CWC colonisation and coral mound development off Mauritania as well as of any

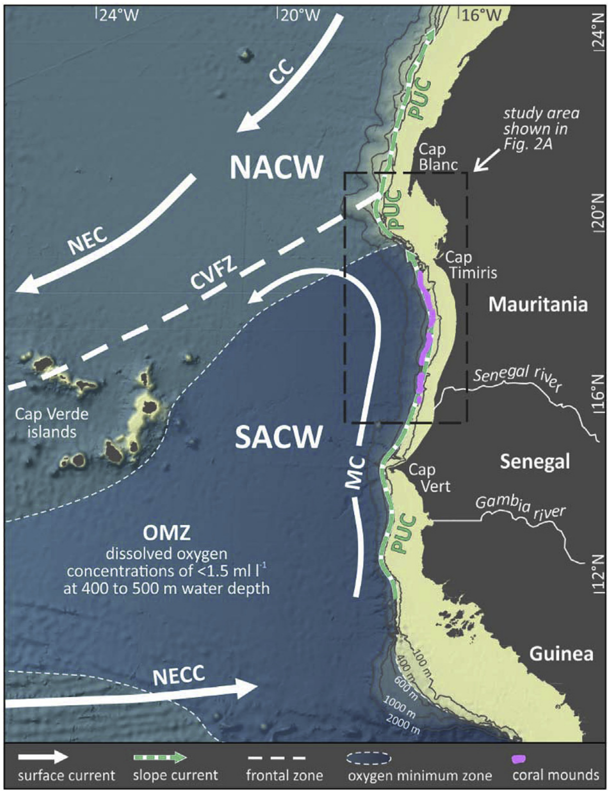

Fig. 1. Map showing the schematic oceanic circulation pattern along the NW African margin (source of bathymetry data: www.gebco.net). Shown are the main surface (white arrow; CC: Canary Current, NEC: North Equatorial Current, MC: Mauritanian Current, NECC: North Equatorial Countercurrent) and slope currents (green dashed arrow; PUC: Poleward Undercurrent), and the position of the Cap Verde frontal zone (CVFZ; bold dashed white line) separating the North and South Atlantic Central Waters (NACW, SACW). The extension of the oxygen minimum zone (OMZ) with DOCs of <1.5 ml l^{-1} at 400–500 m water depth is indicated (blue colour with white dashed edging; modified after Arístegui et al., 2009; Peña→Izquierdo et al., 2012, 2015). The Mauritanian cold-water coral mound province is marked by pink stripes (according to Ramos et al., 2017; for details see Fig. 2). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)