



Drop Chapter

A Deglacial Cold-Water Coral Boom in the Alborán Sea: From Coral Mounds and Species Dominance

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Abstract

The two scleractinian cold-water corals *Lophelia pertusa* and *Madrepora oculata* are widely distributed in the Alborán Sea. They have been found (alive and fossil) on seamounts, volcanic ridges and mud volcanoes, and they formed coral mounds in the geological past. While the cold-water corals show a reduced occurrence during the last glacial period, they experienced a boom since the last deglaciation until the Early Holocene. The proliferation of cold-water corals during this time is expressed in very high vertical mound aggradation rates of >400 cm kyr⁻¹. Since the mid-Holocene coral mound aggradation significantly slowed-down, which is ascribed to the reduced occurrence of cold-water corals likely supplemented by a reduced sediment supply. During the Holocene, a shift in coral species dominance towards a *M. oculata*-dominated cold-water coral community becomes apparent. It is speculated that in comparison to *L. pertusa*, *M. oculata* has a higher tolerance against the increasing Holocene bottom water temperatures, but is not efficient in building-up mounds likely attributed to its thinly branching framework.

Keywords

Lophelia pertusa · *Madrepora oculata* · Deglaciation · Coral mound · Mound aggradation · Environmental tolerance · Alborán Sea

The Alborán Sea (AS) comprises the westernmost part of the Mediterranean Sea, which is bordered by the Spanish and Moroccan continental margins (Fig. 7.1a). The AS is a very narrow basin (180 × 330 km) and water depths are shallower

than 2000 m. It has a complex seafloor topography with three sub-basins separated by volcanic ridges and seamounts (Muñoz et al. 2008). The two prominent framework-forming scleractinian cold-water corals (CWC), *Lophelia pertusa* and *Madrepora oculata*, are widely distributed in the AS comprising living and fossil occurrences (Fig. 7.1a; see also Chimienti et al., this volume; Vertino et al., this volume). They are a common member of the faunal community colonising various seamounts and ridges (Palomino et al. 2015 and references therein; see Rueda et al., this volume; Lo Iacono et al., this volume). They are also associated to a rather exceptional habitat as they have been encountered on some of the mud volcanoes within a large mud diapir province in the western AS (Margreth et al. 2011; Palomino et al. 2018). However, *L. pertusa* and *M. oculata* do not just occur as single living colonies or as scattered small-sized accumulations of coral rubble and dead framework on topographic highs, both species also formed substantial accumulations on the seafloor, which over thousands of years developed to mound- or ridge-like seabed structures of tens of metres in height. Such coral mounds are composed of skeletal remnants of both species (and other benthic organisms) and sediments. Their formation depends on a well-balanced interplay between sustained coral growth, the development of a coral framework with a high sediment baffling capacity, and the continuous supply of sediments which stabilises the biogenic construction (Wienberg and Titschack 2017).

In the northern AS, up to 9-m-high mounds grouped into provinces have been reported from southeast of Málaga and north of the Chella bank in water depths between 150 and 250 m (Muñoz et al. 2008). Potential mound structures are also reported from some seamounts (e.g., Herradura, Chella) and from the Alborán ridge (Fig. 7.1a; Lo Iacono et al. 2008; Palomino et al. 2011; Lo Iacono et al., this volume). However, all these reports are mainly based on acoustic data and a definite evidence that these structures are formed by CWC is still lacking. For mounds discovered in the southern AS, it is

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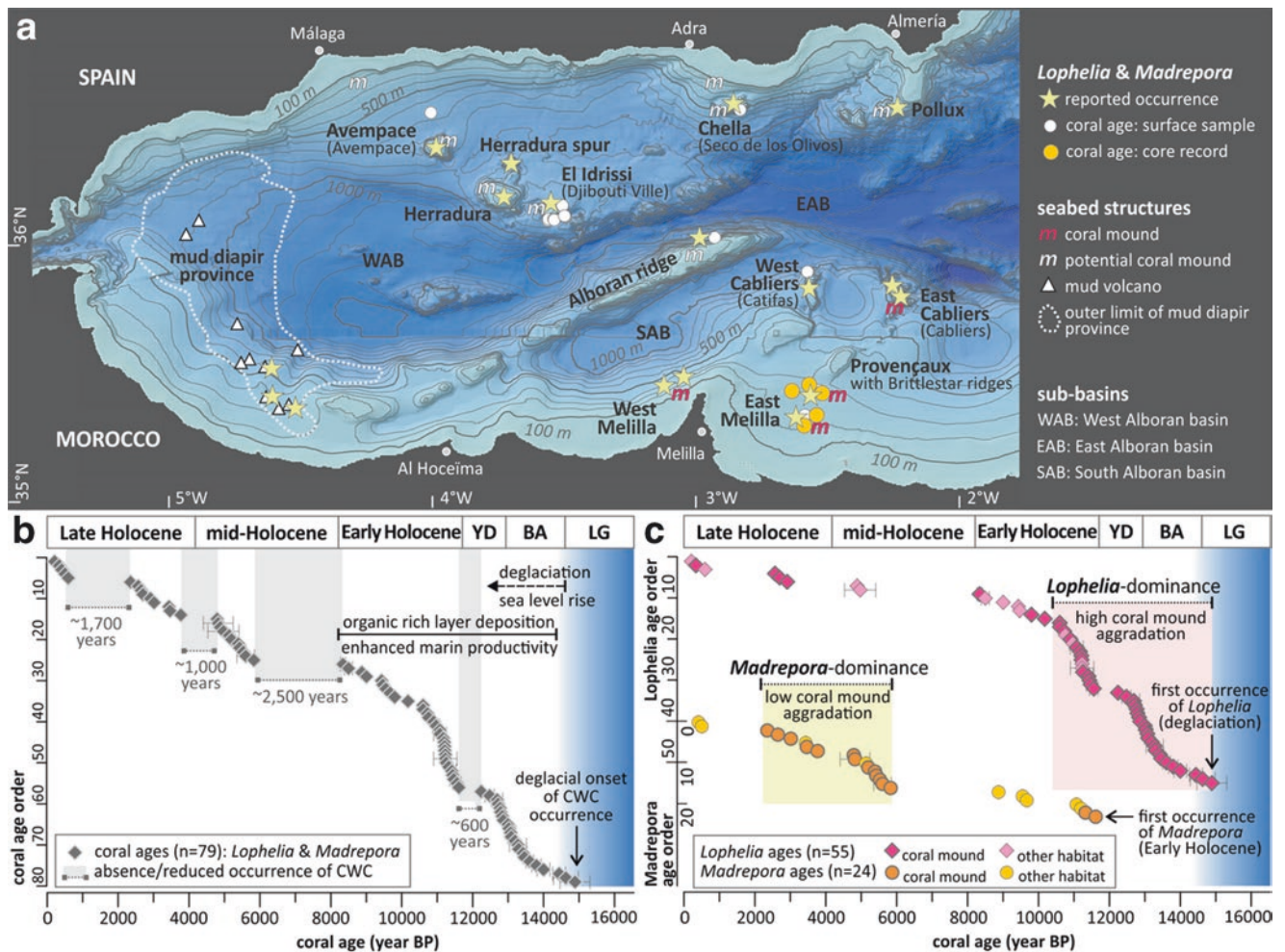


Fig. 7.1 (a) Bathymetric map of the Alborán Sea (data source: <http://www.emodnet-hydrography.eu>) showing its volcanic ridges, seamounts/banks (alternative names found in literature are given in brackets), and mud volcanoes. Displayed are reported live/fossil occurrences of *Lophelia pertusa* and *Madrepora oculata*, coral mounds formed by both species, and sites from which coral ages are available (note: core records from the East Cabliers bank and the West Melilla province are indicated but not considered for the coral age plots shown in b and c as

they are not published yet). (b) Complete coral age dataset obtained for *L. pertusa* and *M. oculata* collected in the Alborán Sea (note: two recently published glacial ages of 28,560 and 43,040 years BP obtained for *L. pertusa* are not displayed, see Dubois-Dauphin et al. 2016). (c) Separation between *L. pertusa* (pink) and *M. oculata* (orange) ages. Ages that derived from coral mounds and from other habitats are indicated. See legend for symbol code; see text for references. YD Younger Dryas, BA Bølling-Allerød, LG late glacial period

already proven by video observations and long sediment cores that substantial parts of these structures have been build up by *L. pertusa* and *M. oculata*. The East Melilla province comprises coral mounds with different morphologies (Hebbeln, [this volume](#)). In the north, steep and elongated ridges (Brittlestar ridges I to III) are attached to the southern edge of the Provençaux bank (Fig. 7.1a). They have heights of 50–150 m and rise to water depths of 250–450 m (Fink et al. 2013). Their morphology and orientation might point to a tectonic-related origin, but a recent drilling campaign revealed that at least the upper 70 m of these ridges are made up of coral-sediment-deposits (Hebbeln et al. 2015). *Lophelia pertusa* and *M. oculata* still colonise these ridges today though in low numbers and as small and scattered colonies. To the south at water depths below 300 m, a field with oval

to curved coral mounds (height: > 20 m) occurs, followed by a cluster with elongated mounds (height: < 20 m) with some of them being partly buried by sediments (Hebbeln, [this volume](#)). The West Melilla province, situated 50 km westward of the East Melilla province (Fig. 7.1a), comprises >100 mounds, which are organised in two clusters, occur in water depths of 300–590 m, and have heights of 10–45 m. The mounds have an asymmetrical to circular shape and some of them are completely buried by sediments (Lo Iacono et al. 2014). No living CWC are found today on these mounds (Lo Iacono et al. 2016). A third coral mound site exists to the north of the Melilla provinces on the East Cabliers bank (Fig. 7.1a), which is a 25-km-long N-S oriented structurally controlled volcanic ridge. Substantial coral accumulations have been deposited on the crest of this structure, which rises

today to water depths of 250–710 m. In the northern portion, living occurrences of *L. pertusa* and *M. oculata* were observed (Lo Iacono et al. 2016).

Many efforts have been conducted to gain information about the past occurrence of *L. pertusa* and *M. oculata* in the AS. Until the present day, ~80 datings have been published for both species (Fig. 7.1b). This dataset contains datings obtained from CWC fragments collected from the seabed surface ($n = 35$), which mainly originate from seamounts (see compilation by Fink et al. 2015 and references therein), while the majority of ages ($n = 47$) derive from core records retrieved from coral mounds along the Moroccan margin (Fink et al. 2013; Stalder et al. 2015; Dubois-Dauphin et al. 2016; unpubl. Data Wienberg). Overall, sediment cores collected from coral mounds are crucial to reconstruct recurring periods of sustained coral colonisation on these mounds (see Angeletti et al., [this volume](#)), and thus, to identify periods of enhanced vertical mound aggradation under suitable environmental conditions (Wienberg and Titschack 2017). The number of CWC ages obtained for the AS is still rather low but will potentially significantly increase in the near future with respect to ongoing studies for which more than 100 new datings are expected for the East and West Melilla provinces, and the East Cabliers bank (Krengel et al. 2015; Lo Iacono et al. 2016; Wang et al. 2016). However, the available dataset already reveals a distinct pattern regarding the past occurrence of *L. pertusa* and *M. oculata*.

During the last glacial period, a reduced occurrence of both species in the AS is assumed as only two glacial ages have been obtained so far (see Dubois-Dauphin et al. 2016), which comprise just 2% of all available ages. However, the low number of glacial coral ages could also be ascribed to the lack of appropriate core material covering longer timescales. Yet, preliminary dating results obtained from 70-m-long drill cores collected from the East Melilla province (Hebbeln et al. 2015) revealed that there was indeed no sustained occurrence of *L. pertusa* and *M. oculata* lasting since ~100,000 years BP until the last deglaciation, thus a time span covering the last glacial, and part of the preceding interglacial (Krengel et al. 2015). There is a conspicuous common start-up phase for their occurrence coinciding with the onset of the Bølling-Allerød (BA) warm interval at ~14,600 years BP (Fig. 7.1b), which marked the onset of the last deglaciation with a post-glacially rising sea level (Fink et al. 2013; Stalder et al. 2015; Lo Iacono et al. 2016; see Vertino et al., [this volume](#) and references therein). The first post-glacial period of pronounced coral occurrence lasted until the mid-Younger Dryas (~12,200 years BP) and is followed by a second boost roughly covering the entire Early Holocene (11,600–8,300 years BP; Fig. 7.1b). Both periods of pronounced coral occurrence coincided with intensified intermediate water mass circulation and enhanced productivity in the surface ocean increasing the availability of food for CWC (Cacho et al. 2002; Fink et al. 2013, 2015;

Stalder et al. 2015). Concurrent with the onset of the mid-Holocene occurs a relevant gap in the age dataset (Fig. 7.1b). This ~2,500-years-lasting temporary reduced occurrence of CWC was likely related to a significant decrease in productivity after 9,000 years BP, which occurred concurrent to the termination of the organic rich layer deposition in the AS (Fink et al. 2015; Cacho et al. 2002). After ~5,800 years BP, CWC seem to be present in the AS until the present-day, except from two gaps at the transition from the mid- to Late Holocene and during the Late Holocene (Fig. 7.1b). Overall, all presently observed age gaps need to be considered with care as the lack of dating does not necessarily indicate the complete absence of CWC but clearly document phases of reduced CWC occurrence in the AS. Moreover, as the majority of coral ages derive from the East Melilla province, it cannot be excluded that the identified temporal pattern might slightly differ for other coral sites in the AS.

The identified temporal pattern in the general occurrence of CWC in the AS is even more clearly displayed in core records obtained from individual coral mounds, and is explicitly expressed in the varying vertical aggradation rates estimated for these mounds. Coral mounds of the East Melilla province show highest aggradation rates of >400 cm kyr⁻¹ for the last deglaciation and up to ~300 cm kyr⁻¹ for the Early Holocene (Fink et al. 2013; Stalder et al. 2015; Titschack et al. 2016). These values are in the upper range of aggradation rates obtained so far for other coral mound areas in the North Atlantic (see compilation by Wienberg and Titschack 2017), and preliminary results of mound records of the West Melilla province and the East Cabliers bank seem to display a very similar pattern (Lo Iacono et al. 2016; Wang et al. 2016). During the late Younger Dryas and the mid- to Late Holocene, mound aggradation rates decreased noticeably to values of ~30–50 cm kyr⁻¹ and < 20 cm kyr⁻¹, respectively. Thus, although CWC still colonised the East Melilla mounds during these time intervals, mound aggradation slowed-down or even stagnated. This reduction in mound aggradation can be explained by the environmental change to less favourable conditions for the corals themselves, but might also be the consequence of a reduced sediment supply.

A third species-related pattern comes up when considering ages obtained for *L. pertusa* and *M. oculata* separately (Fig. 7.1c). Periods of pronounced CWC occurrence associated with high coral mound aggradation rates during the last deglaciation and the Early Holocene relate to ages obtained for *L. pertusa*, while *M. oculata* seems to have been largely absent from the AS before the onset of the Holocene. On the contrary, since the mid-Holocene, *M. oculata* seems to dominate over *L. pertusa* (Fig. 7.1c). A similar pattern is also shown by faunal analyses based on mound records, which revealed that *M. oculata* becomes more abundant since the Early Holocene eventually culminating in a *M. oculata*-dominated coral community (Stalder et al. 2015; Lo

Iacono et al. 2016). Moreover, as the dominance of *M. oculata* coincides with periods of low mound aggradation rates (Fig. 7.1c), it can be speculated that this species is not as successful and efficient in building-up mounds as *L. pertusa*. This might be explained by the thinly branching framework formed by *M. oculata* which does not allow a sufficient baffling of sediment and therefore might inhibit enhanced vertical mound aggradation.

It is still not known which environmental change triggered the obvious shift in coral species dominance during the Holocene in the AS. It might be the consequence of the increasing bottom water temperatures to which *M. oculata* is likely to be more tolerant, as it occurs preferentially in warmer waters (8.5–10 °C), while *L. pertusa* seems to dominate in colder waters (6.5–8 °C; Wienberg and Titschack 2017). This assumption is further supported by experimental studies showing that both species have their specific thermal preferences and tolerances, with *M. oculata* showing acclimatisation capacity toward the presumed CWC upper thermal tolerance limit of 14 °C (Naumann et al. 2014). Overall, this highlights that a detailed knowledge of bio-ecological dynamics of the CWC species adopted for stratigraphic studies is of utmost importance when interpreting coral age datasets in a regional, climatological and palaeoceanographic context (see also Vertino et al., [this volume](#)).

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