Development of Mediterranean cold-water coral ecosystems since the late glacial

Hiske G. Fink[1], Claudia Wienberg[1], Ricardo De Pol-Holz[2] and Dierk Hebbeln[1]

1 MARUM - Center for Marine Environmental Sciences, University of Bremen, Leobener Strasse, 28359 Bremen, Germany. hfink@marum.de cwberg@marum.de, dhebbeln@marum.de

2 Departamento de Oceanografía and Center for Climate and Resilience Research (CR)2, Universidad de Concepción, Barrio Universitario s/n, Chile. ricdepol@udec.cl

Abstract: *Based on all available ages obtained on the dominant framework-building scleractinian cold-water coral species Lophelia pertusa and Madrepora oculata collected in the entire Mediterranean Sea (compiled from literature review and own studies), we discuss the basin-wide occurrences of these species emphasising their spatial and temporal development during the late glacial and Holocene. We show that these species became abundant since the deglacial (<14ka) and their Late Pleistocene and Holocene proliferation or demise significantly differed between the eastern and western Mediterranean Sea sub-basins, depending on regional (sub-basin-related) environmental conditions, like the availability of food or bottom water oxygenation. In combination with the corals' preference to settle in intermediate depths, a strong relationship between Mediterranean cold-water coral development and intermediate water mass circulation is suggested, though resulting regionally in different parameters influencing the corals' prosperity.*

Key words: *Cold-water corals, Mediterranean Sea, Holocene, Levantine Intermediate Water*

INTRODUCTION

Cold-water corals are common in the temperate Mediterranean Sea, where they currently thrive in intermediate water depth. Numerous cold-water coral carbonate structures on the seafloor indicate their prosperity in the past. Former studies dealing with the past development of cold-water corals in this marginal sea discussed their occurrences in a rather generalised manner for the entire basin (e.g. McCulloch et al., 2010) or trace their appearance trough time on a locally restricted setting (e.g. Malinverno et al., 2010, Fink et al., 2012, 2013).

As the Mediterranean sub-basins were affected by basically different events since the last glacial (e.g. anoxic formation of sapropel S1 in the east; variability of the inflow of Atlantic surface waters in the west), which resulted in different paleo-environmental conditions, this study outlines for the first time the prosperity of cold-water coral ecosystems on a regional sub-basin scale.

DATA AND RESULTS

Eighty-one cold-water coral ages obtained on the reef-forming scleractinian coral species *Lophelia pertusa* and *Madrepora oculata* collected in the entire Mediterranean Sea were compiled from literature (references see caption of Fig. 1), and complemented by nineteen new radiocarbon ages of coral specimens sampled in the Alboran Sea and in the Strait of Sicily (Fig. 1). Becoming abundant in the deglacial (after ~14ka), cold-water corals seem to have thrived throughout the entire Holocene. However, by grouping the coral dates according to their sampling area (Alboran Sea, Strait of Sicily, Eastern and Western Mediterranean Sea) distinct age cluster and regional differences appear.

DISCUSSION

Whereas in the western Mediterranean Sea the initial deglacial cold-water coral growth was forced by increased primary production and well ventilated intermediate water masses prevailing during the formation of the so-called organic rich layer 1 (ORL1, ~14.5 to 8.2ka), favourable conditions for cold-water corals in the eastern basin were established only during the Younger Dryas (YD, 12.9 to 11.7ka). However, in the Alboran Sea, as the westernmost part of the Mediterranean Sea, the YD is characterised by an absence of cold-water corals probably induced by enhanced inflow of Atlantic waters during this cold event, which led to environmental instabilities.

During the deposition of sapropel S1 in the deep eastern Mediterranean Sea, dysoxic conditions prevailing in intermediate water depths caused a temporal coral demise in the eastern basin (~11.5 to 5.9ka). Moreover, the impaired formation of both, Levantine Intermediate Water (LIW) in the east (during S1 deposition) and Winter Intermediate Water in the west (after ORL1 deposition), had a negative impact on the prosperity of western Mediterranean coral ecosystems during the Mid Holocene (8.2- ~6ka).

Along with the onset of LIW formation (~ 6ka) cold-water corals re-colonised the entire Mediterranean Sea and thrived there throughout the Late Holocene until today.

CONCLUSIONS

This detailed comparative study between the western and eastern Mediterranean sub-basins indicates that the development of cold-water corals during the late glacial and Holocene relies on a rather complex pattern, precluding any generalised basin-wide approach to describe their occurrence trough time. Their proliferation or demise rather depends on different regional (sub-basin-related) environmental conditions, mainly driven by the intensity of the intermediate water circulation, which is linked to climatic conditions.

ACKNOWLEDGEMENTS

This study was supported by the EU Seventh Framework Programme (FP7/2007-2013) under the HERMIONE project, grant agreement no. 226354.

REFERENCES

Angeletti, L. and Taviani, M., 2011. Entrapment, preservation and incipient fossilization of benthic predatory molluscs within deep-water coral frames in the Mediterranean Sea. Geobios 44(6), 543-548.

Fink, H.G., Wienberg, C., De Pol-Holz, R., Wintersteller, P. and Hebbeln, D., 2013. Cold-water coral growth in the Alboran Sea related to high productivity during the Late Pleistocene and Holocene. Marine Geology 339, 71-82.

Fink, H.G., Wienberg, C., Hebbeln, D., McGregor, H.V., Schmiedl, G., Taviani, M. and Freiwald, A., 2012. Oxygen control on Holocene cold-water coral development in the eastern Mediterranean Sea. Deep-Sea Research Part I: Oceanographic Research Papers 62, 89-96.

Frank, N., Freiwald, A., López Correa, M., Wienberg, C., Eisele, M., Hebbeln, D., Van Rooij, D., Henriet, J.-P., Colin, C., van Weering, T., de Haas, H., Buhl-Mortensen, P., Roberts, J.M., De Mol, B., Douville, E., Blamart, D. and Hatte, C., 2011. Northeastern Atlantic cold-water coral reefs and climate. Geology 39(8), 743-746.

Malinverno, E., Taviani, M., Rosso, A., Violanti, D., Villa, I., Savini, A., Vertino, A., Remia, A. and Corselli, C., 2010. Stratigraphic framework of the Apulian deep-water coral province, Ionian Sea. Deep Sea Research Part II: Topical Studies in Oceanography 57(5-6), 345-359.

McCulloch, M., Taviani, M., Montagna, P., López Correa, M., Remia, A. and Mortimer, G., 2010. Proliferation and demise of deep-sea corals in the Mediterranean during the Younger Dryas. Earth and Planetary Science Letters 298(1-2), 143-152.

Millot, C. and Taupier-Letage, I., 2005. Circulation in the Mediterranean Sea, The Mediterranean Sea. The Handbook of Environmental Chemistry. Springer Berlin, Heidelberg, pp. 323-334.

Schröder-Ritzrau, A., Freiwald, A. and Mangini, A., 2005. U/Th-dating of deep-water corals from the eastern North Atlantic and the western Mediterranean Sea. In: A. Freiwald and J.M. Roberts (Editors), Cold-Water Corals and Ecosystems. Springer, Berlin, Heidelberg, pp. 157-172.

Taviani, M., Vertino, A., López Correa, M., Savini, A., De Mol, B., Remia, A., Montagna, P., Angeletti, L., Zibrowius, H., Alves, T., Salomidi, M., Ritt, B. and Henry, P., 2011. Pleistocene to Recent scleractinian deep-water corals and coral facies in the Eastern Mediterranean. Facies 57(4), 579-603.

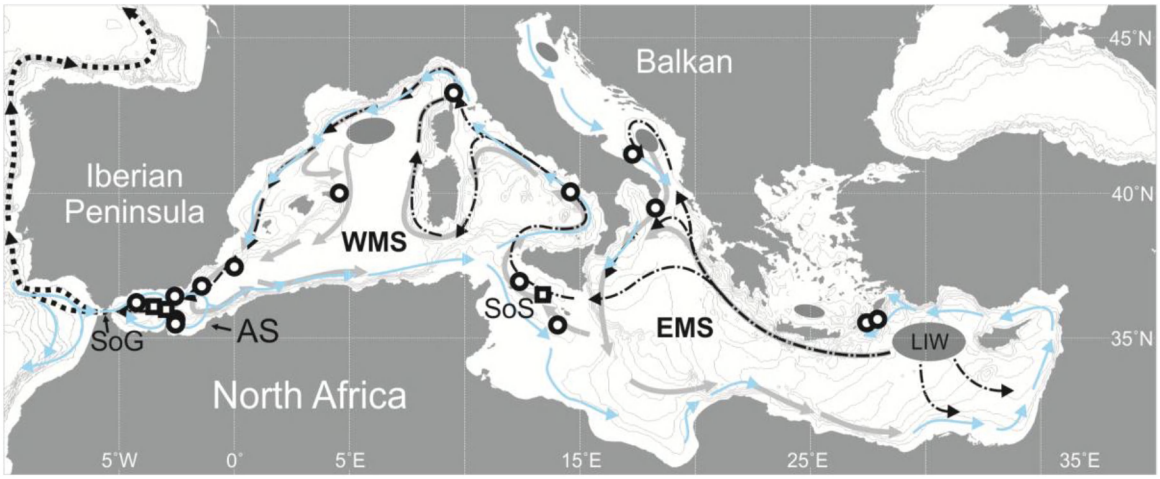

FIGURE 1: Overview map of the Mediterranean Sea. Displayed is the general ocean circulation pattern in the Mediterranean Sea (modified after Millot and Taupier-Letage, 2005). Blue arrows: Surface water circulation. Dashed-dotted black arrows: Intermediate water circulation. Thick grey arrows: Deep water circulation. Dotted black arrows: Mediterranean Outflow Water (MOW). Highlighted in grey are the areas of modern dense (deep- and intermediate) water formation. Displayed are the sampling sites of this study (squares) and reference locations (circles; data from Schröder-Ritzrau et al., 2005; Malinverno et al., 2010; McCulloch et al., 2010; Angeletti and Taviani, 2011; Frank et al., 2011; Taviani et al., 2011; Fink et al., 2012; 2013. Abbreviations: AS-Alboran Sea, EMS-Eastern Mediterranean Sea, WMS-Western Mediterranean Sea, SoS-Strait of Sicily, SoG Strait of Gibraltar.