Marine Geology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margo

Good neighbours shaped by vigorous currents: Cold-water coral mounds and contourites in the North Atlantic

Dierk Hebbeln [a,*], David Van Rooij [b], Claudia Wienberg [a]

[a] MARUM — Center for Marine Environmental Sciences, University of Bremen, Leobener Strasse, 28359 Bremen, Germany
[b] Ghent University, Dept. of Geology, Krijgslaan 281 S8, B-9000 Ghent, Belgium

ARTICLE INFO

Article history:
Received 18 June 2015
Received in revised form 21 December 2015
Accepted 29 January 2016
Available online xxxx

Keywords:
Cold-water coral mounds
Contourites
Bottom currents
Sediment supply
Continental margins
Palaeo-archives

ABSTRACT

Over the recent years, two research fields addressing continental slope sedimentary systems have gained significant momentum: contourites and cold-water coral mounds. Being both related to intense bottom currents and being both dependent on sediment supply, they share some commonalities resulting in their widespread co-occurrence. However, as cold-water coral mounds predominantly occur in shallow to intermediate water depths, this co-occurrence is restricted to these depth levels. For both systems, the available knowledge is derived basically from North Atlantic Ocean settings, indicating the potential to discover such systems hidden in the other ocean basins (as well as still hidden in the Atlantic). Contourites and cold-water coral mounds have the capability of providing high-resolution palaeo-environmental records, although with often differing temporal ranges and/or temporal resolutions. Applying the concept of a joint exploitation of sedimentary records obtained from mounds and contourites offers the unique possibility of analysing contourite and mound development as well as the related palaeo-environmental settings much more comprehensively than done when only considering one of these archives. Thus, after two decades of intense research, providing significant knowledge about contourites and cold-water coral mounds from the North Atlantic, new ideas and concepts may arise from a close collaboration of scientists working in these two fields.

1. Introduction

The capability of bottom currents to shape the seafloor in areas well below the wave base was first documented by Heezen and Hollister (1964) who showed the presence of ripples at the sea floor in ~4000 m of water depth by using photographs (Fig. 1). Later on, they termed the related deposits 'contourites' (Hollister and Heezen, 1972), which are defined as sediments deposited or substantially reworked by the persistent action of along-slope bottom currents (see Rebesco et al., 2014). As any bottom current impact results in selective deposition, e.g., the non-deposition of the finer fractions, almost all deep-sea sediments can be termed contourites if the above mentioned definition is used in a strict sense. However, a noticeable impact of bottom currents on the sediment facies in terms of selective deposition occurs when the flow goes faster than 10 cm s^{-1} (Stow et al., 2009; Rebesco et al., 2014). Much stronger bottom currents finally may even cause erosion, however, without contributing any longer to the formation of a contourite facies. The most prominent drivers of contourite deposition are thermohaline processes affecting surface, intermediate and bottom water masses worldwide (Hernández-Molina et al., 2011; Rebesco et al., 2014). Overall, contourites can develop from the upper slope down to the deep-sea, but they may also occur in shelf settings where they are termed 'shallow-water contourites' (Stow et al., 2002), however, most likely limited to places where the influence of geostrophic currents outweighs that of storm- and wind-induced currents (Viana et al., 2007).

Continuing contourite deposition results in the formation of 'drift bodies' (Faugères et al., 1999; Rebesco et al., 2014). Whereas contourite drifts are formed under persistent bottom current activity, sediment drifts comprise the gradient from strong to weak bottom current influence resulting in a transition from contourites to (hemi-)pelagites (Stow and Piper, 1984). Such contourite depositional systems can be quite extensive reaching hundreds of kilometres in length and thicknesses of up to 2 km (Rebesco et al., 2014). Sediment drifts are frequently related to obstacle-induced gradients of bottom current strength that might result in the formation of typical features ranging from moats (resulting from erosion due to most enhanced current speed) to contourites (formed by enhanced current speed causing selective deposition) to (hemi-)pelagites (related to comparably low current speeds) as it is nicely illustrated for the Pontevedra obstacle along the Galician margin (Hanebuth et al., 2015), and around diapiric ridges and mud volcanoes along the Moroccan Atlantic margin (Vandorpe et al., in this issue).

Common beneficiaries of enhanced bottom current activity are cold-water corals that depend as sessile suspension-feeders on catching food

* Corresponding author.
E-mail address: dhebbeln@marum.de (D. Hebbeln).

http://dx.doi.org/10.1016/j.margeo.2016.01.014

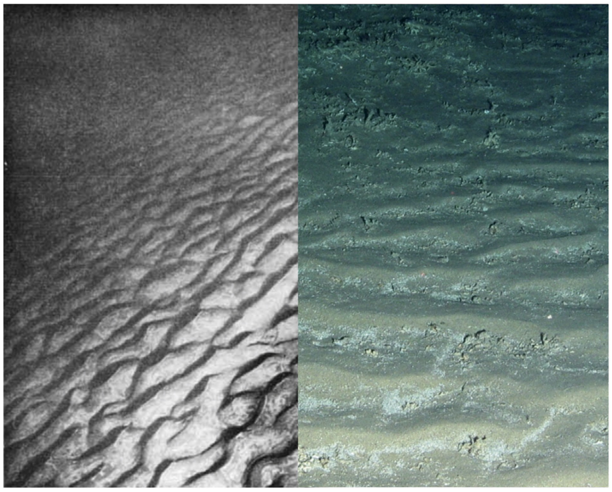

Fig. 1. Evidence for the action of bottom currents on the seafloor. Left picture: Sediment ripples in 4000 m water depth in the Scotia Sea have been the first evidence for current-induced sedimentation in the deep sea (from Heezen and Hollister, 1964; no scale information available). Right picture: Sediment ripples and cold-water coral fragments close to a cold-water coral mound at the Irish margin (from Hebbeln and Samankassou, 2015). The width of the picture represents approximately 40 cm.
Image copyright MARUM, Bremen.

particles delivered to them by vigorous bottom currents (e.g., White et al., 2005). Despite their discovery in the 18th century, cold-water coral research only experienced a boost in the 1990s due to the availability of modern deep-sea technology and due to their occurrence being tentatively linked to hydrocarbon seepage (Hovland et al., 1994). However, after 20 years of intense research, convincing evidence for a predominantly environmental control has been gathered encompassing various biotic and abiotic factors including distinct chemical and physical properties of the surrounding water masses, the availability of sufficient food, and the local hydrodynamic regime (e.g., Duineveld et al., 2004; White et al., 2005; Davies and Guinotte, 2011; Flögel et al., 2014). In particular, framework-forming scleractinian cold-water corals act as ecosystem engineers creating biodiversity hotspots in the bathyal zone showing a biodiversity enriched by at least a factor of three compared to the surrounding sea floor (Henry and Roberts, 2007).

On geological timescales, some framework-forming scleractinian cold-water corals have even the capability to form yet another kind of impressive seabed structures: 'cold-water coral mounds'. In the NE Atlantic *Lophelia pertusa* is the dominant mound-forming cold-water coral species, but in other regions species such as *Madrepora oculata* (Remia and Taviani, 2005), *Enallopsammia profunda* (Hebbeln et al., 2014), *Solenosmilia variabilis* (Mangini et al., 2010), *Oculina varicosa* (Reed, 2002) and *Goniocorella dumosa* (Squires, 1965) can also dominate mound coral assemblages, however, with basically having the same principal 'depositional effect' on mound formation (see below). Cold-water coral mounds are composed of a mixture of coral fragments, other subordinate bioclasts (e.g., mollusks) and hemipelagic sediments (Dorschel et al., 2005), and reach heights of a few metres to even several hundreds of metres. For instance, the giant cold-water coral mounds off Ireland arose to >300 m above the surrounding seafloor (De Mol et al., 2002; Mienis et al., 2007) over a period of ~2.4–2.6 Ma (Kano et al., 2007; Huvenne et al., 2009; Foubert and Henriet, 2009; Thierens et al., 2010, 2013; Raddatz et al., 2011). Internally, such mounds often display several recurring periods of cold-water coral colonisation, coral decline and renewed colonisation (e.g., Dorschel et al., 2005; Kano et al., 2007; Frank et al., 2009; Wienberg et al., 2010; Thierens et al., 2013). Although an individual mound structure only reaches an expansion of hundreds of metres to a few kilometres in diameter, the clustering of such mounds to large mound provinces eventually can cover several 10s of square kilometres (e.g., Mortensen et al., 2001; De Mol et al., 2002; Hebbeln et al., 2014; Glogowski et al., 2015). Overall, cold-water coral mounds are reported from shelf environments (off Norway, Sweden, Scotland, and Florida: Reed, 2002; Fosså et al., 2005; Lavaleye et al., 2009; Douarin et al., 2014) and (even more abundantly) from the upper to mid-slopes of the continental margins (e.g., Mullins et al., 1981; Kenyon et al., 2003; Colman et al., 2005; Taviani et al., 2005; Reed et al., 2006; Foubert et al., 2008; Freiwald et al., 2009; White and Dorschel, 2010; Fink et al., 2013; Hebbeln et al., 2014; Glogowski et al., 2015). It is still an open question, why the occurrence of cold-water coral mounds apparently seems to be limited to shallow to intermediate water depths ranging from 50 m down to ~1000 m, although framework-forming cold-water corals being the architects of these mounds show a much more extended depth distribution as they may occur even down to water depths of >3000 m (Zibrowius, 1980).

The formation of coral mounds directly depends on the proliferation of the framework-forming scleractinian cold-water corals, thus mound formation likely requires similar environmental conditions than identified for coral growth (e.g., Duineveld et al., 2004; Mienis et al., 2007; Davies and Guinotte, 2011; Thresher et al., 2011; Flögel et al., 2014; Wienberg and Titschack, accepted for publication). However, in addition, a contemporaneous input of sediments from vertically as well as laterally advected sediments triggered by distinct hydrodynamic processes is necessary to stabilize the biogenic construction, whereby the capacity of the coral framework to entrap (baffle) bypassing suspended sediments is a crucial factor (e.g., Dorschel et al., 2005; Mienis et al., 2009). This circumstance might explain why cold-water corals in general show a widespread distribution in the North Atlantic (Roberts et al., 2006) occurring in a wide variety of habitats extending from the shelf down to the deep sea (including remote areas such as the Mid-Atlantic Ridge; e.g., Mortensen et al., 2008), while the occurrence of coral mounds is restricted to regions where large amounts of sediment are available (e.g., Mullins et al., 1981; Paull et al., 2000; De Mol et al., 2002; Kenyon et al., 2003; Foubert and Henriet, 2009; Correa et al., 2012; see also the compilation of cold-water coral mound occurrences around the Atlantic Ocean presented by Hebbeln and Samankassou, 2015).

Triggered by an active bottom current regime and being strongly related to sediment supply, contourites and cold-water coral mounds both are often found side-by-side. However, this co-occurrence appears to be largely limited to the depth range of approximately 200 m to 1000 m, where the "mound range" (~50 m to ~1000 m) overlaps with the "contourite range" (mainly >200 m; i.e. below the zone commonly dominated by storm- and wind-induced currents; cf. Viana et al., 2007). Being part of a morphodynamic system, cold-water coral mounds form three-dimensional obstacles on the seafloor that have the potential to affect bottom water flow and, thus, the ambient bottom current field, which in turn controls contourite deposition. This review aims to (i) depict the linkage between these two very important continental margin sedimentary systems, thereby focusing on the North Atlantic as most of the recent knowledge on contourites and cold-water coral mounds providing several examples of their co-occurrence originates from this basin, and to (ii) assess the potential of combining the sedimentary archives provided by both systems for a comprehensive evaluation of the environmental setting controlling the depositional processes.

2. Environmental controls — a matter of hydro- and sediment dynamics

The proliferation of scleractinian cold-water corals is controlled by a wide range of physico-chemical parameters including temperature, dissolved oxygen concentrations, aragonite saturation state, density gradients etc. (e.g., Davies and Guinotte, 2011; Dullo et al., 2008; Thresher et al., 2011; Flögel et al., 2014). Nevertheless, even in regions offering the required physico-chemical setting, the cold-water corals rely as sessile suspension-feeders on a steady or periodic delivery of food particles to their tentacles (Duineveld et al., 2007). Obviously, the

Please cite this article as: Hebbeln, D., et al., Good neighbours shaped by vigorous currents: Cold-water coral mounds and contourites in the North Atlantic, Marine Geology (2016), http://dx.doi.org/10.1016/j.margeo.2016.01.014