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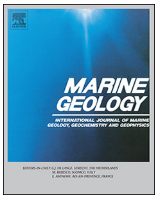

New insights on coral mound development from groundtruthed high-resolution ROV-mounted multibeam imaging

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ABSTRACT

Currents play a vital role in sustaining and developing deep water benthic habitats by mobilising food and nutrients to otherwise relatively barren parts of the seabed. Where sediment supply is significant, it can have a major influence on the development and morphology of these habitats. This study examines a segment of the Belgica Mound Province, NE Atlantic to better constrain the processes affecting a small-sized cold water coral (CWC) mound habitat and conversely, the hydrodynamic influence of CWC mounds on their own morphological development and surroundings. Here, we utilise ROV-mounted multibeam, ROV-video data, and sediment samples to investigate current processes, mound morphology, density and development. Detailed mapping shows that the area may have the highest density of coral mounds recorded so far, with three distinct mound types defined based on size, morphology and the presence and degree of distinct scour features. A residual current of 36–40 cm s^{-1} is estimated while large scour features suggest low-frequency, high-magnitude events. These 3 mound types are i) smaller mounds with no scour; ii) mounds with scour in one to two distinct directions and; iii) larger mounds with mound encircling scour. The differing mound types likely had a staggered initiation where younger mounds preferentially developed near clusters of pre-existing mounds. Given the high density of these small CWC mounds, we support the hypothesis that over time, this clustering may eventually lead to these mounds coalescing into larger coral mound features.

1. Introduction

Frame-building cold water corals (CWC) are sessile, filter-feeding organisms that can produce large three dimensional calcium carbonate skeletons and develop complex bioconstructions (Freiwald and Wilson, 1998; Zibrowius, 1980). Some species, such as *Lophelia pertusa* and *Madrepora oculata*, occur worldwide and have the ability to exist in a range of settings, from large submarine canyons to contourite drifts and from the Indian Ocean to the Canadian Arctic (e.g. Davies and Guinotte, 2011; Edinger et al., 2011; Freiwald et al., 2004; Hargrave et al., 2004; Huvenne et al., 2011; Roberts et al., 2009; van Rooij et al., 2003). Frame-building CWC are typically found where a supply of food is concentrated and transported to the corals via enhanced currents (Davies et al., 2009). The three dimensional framework developed by the coral skeleton creates frictional drag, slowing the current causing the deposition of suspended particles (Wheeler et al., 2005). Continued deposition of sediments coupled with growth of CWC generates positive topographic features on the seabed called CWC mounds (De Mol et al., 2007; Victorero et al., 2016; Wheeler et al., 2008).

CWC mounds can range in height above the surrounding seabed from 10 m to 350 m (Henriet et al., 2014; Huvenne et al., 2005). Although development of CWC mounds tends to be episodic, dating of sediment cores from CWC mounds shows that mound growth can be as high as 120 cm ka^{-1} offshore Scotland (Douarin et al., 2013), 220 cm ka^{-1} offshore Ireland and between 600 and 1500 cm ka^{-1} offshore Norway (Wienberg and Titschack, 2015 and references therein). The current interglacial, the Holocene, has been particularly well-studied in terms of periods of CWC mound development (Frank et al., 2009; Wienberg and Titschack, 2015). During this period, the morphology of coral mounds is a result of the processes (e.g. currents) that have influenced them through their development (Huvenne et al., 2009a; Thierens et al., 2010; Wheeler et al., 2007; Wheeler et al.,

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2005). Early research showed that currents were among the main drivers for faunal distribution across coral mounds (Messing et al., 1990). More recently, direct measurements from current meters show that currents vary in velocity and regime across a coral mound and are likely to be the main control on coral distribution and therefore mound growth (Dorschel et al., 2007). The influence of currents on mound development and morphology can also be seen across a number of small coral mounds where they elongate with prevailing current direction and become larger with increasing current velocity (Lim, 2017; Wheeler et al., 2008). Observations show that clusters of mounds develop an elongate pattern, corresponding to the direction of the highest currents speeds (Mienis et al., 2007). As such, CWCs are known to occur where currents are particularly high (Mohn et al., 2014). In support of this, long term measurements at coral mounds in the Rockall Trough, NE Atlantic show that low currents are one of the factors that limit coral growth on mound structures (Mienis et al., 2012).

More recently, Cyr et al. (2016) show that mound size has a direct influence on local hydrodynamics where larger mounds have a greater influence on hydrodynamics than smaller mounds. The same authors go on to show that CWC mounds create hydrodynamic turbulence, favourable for coral growth, and suggest that at a certain size flow can become blocked, detrimental to vertical growth of the mound.

Despite many studies carried out so far, the influence of environmental factors on mound density, morphology and size (and vice versa) is still poorly understood. This work focuses on the Moira Mounds region, a key study area characterised by densely-packed CWC mounds and well-defined, current-generated bedforms. It aims to better understand (1) the interactions between currents and CWC mound morphology and size and (2) the mechanisms that regulate coral mound development and coalescence.

1.1. Regional setting

The Belgica Mound Province (BMP) is located on the eastern margin of the Porcupine Seabight: a large north-south embayment on the Irish continental margin, NE Atlantic (see Fig. 1) (Beyer et al., 2003; van Rooij et al., 2003). Part of the BMP exists within a Special Area of Conservation (SAC) designated under the EU Habitats Directive (https://www.npws.ie/). The main modern-day Porcupine Seabight water mass, which affects coral mound growth, is the Mediterranean Outflow Water (MOW) (De Mol et al., 2005; Rice et al., 1991; White et al., 2005) characterised by a salinity maximum between 600 m and 1100 m water depth. At this depth, temperatures are approximately 10 °C with relatively high residual current speeds (White and Dorschel, 2010).

The BMP is known for its abundance of coral mounds (Wheeler et al., 2005). Large coral mounds occur in 2 distinct chains oriented parallel to the continental shelf (Fig. 1); the eastern chain is largely moribund (with a mainly dead coral cover; Foubert et al., 2005) while the western chain is mostly active with a profusion of live coral (De Mol et al., 2007; Dorschel et al., 2007; Eisele et al., 2008). These large coral mound morphologies range from conical to elongate, ridge-like forms and are typically 1 km across and 100 m tall (Beyer et al., 2003; Wheeler et al., 2005). Contourite drifts have accumulated between the giant (~100 m in height) carbonate mounds and buried their upslope flanks (van Rooij et al., 2003). Smaller CWC reefs, typically 30 m across and 10 m tall, are found throughout the BMP and are referred to as the "Moira Mounds" (Foubert et al., 2005; Kozachenko, 2005; Wheeler et al., 2005; Wheeler et al., 2011). These are divided into 4 zones (Fig. 1) based on their geographic distribution: upslope area, downslope area, mid-slope area and northern area (see Wheeler et al., 2011). The Moira Mounds in the northern and upslope areas are dormant (Wheeler et al., 2011) while the Moira Mounds in the mid-slope area have been described as "sediment stressed", where they are being smothered by sediments (Foubert et al., 2011). A blind channel, referred to as "Arwen Channel" (Fig. 1) (Murphy and Wheeler, 2017; Van Rooij, 2004), formerly connected to the shelf break, runs through the province and now contains the westernmost Moira Mounds studied here (referred from here on as downslope Moira Mounds).

Wheeler et al. (2011) hypothesise that the Moira Mounds may represent an early-stage "start-up" phase of the nearby, large Belgica coral mounds, noting that the "footprints" of clusters of Moira Mounds have a comparable size to the base of the giant cold-water coral mounds which, as such, may have formed through a coalescing of smaller coral mounds at early stages of their development (see also De Mol et al., 2005; Huvenne et al., 2005).

2. Materials and methods

2.1. ROV-mounted high-resolution multibeam echosounder

ROV-mounted multibeam echosounder (MBES) data were collected over the downslope Moira Mounds area during the QuERCi survey (2015) on board RV Celtic Explorer with the Holland 1 ROV (cruise number CE15009: Wheeler et al. (2015)). A high-resolution, dual-head Kongsberg EM2040 MBES was integrated with a sound velocity probe and mounted on the front-bottom of the ROV. Data were acquired at a frequency of 300 kHz while the ROV maintained a height of approx. 150 m above the seabed with a survey speed of approximately 2 knots. This achieved a swath width of approx. 400 m. Positioning and attitude were obtained using a Kongsberg HAINS inertial navigation system, ultra-short baseline (USBL) system (Sonardyne Ranger 2) and doppler velocity log (DVL). Data acquisition was carried out using SIS software, where calibration values, sensor offsets, real-time sound velocity, navigation and attitude values were incorporated. Seven lines ranging from 850 m to 4.2 km long were collected over the downslope Moira Mound study site. It is worth noting that, although rare, the DVL mis-triggered during data acquisition, affecting limited stretches of the raw navigation data. The MBES data were stored as *.all and *.wcd files and were processed using CARIS HIPS and SIPS v9.0.14 to apply tidal corrections and clean anomalous data spikes. The cleaned data were saved as a single *.xyz and gridded to a 0.5 m ArcView GRID.

The 0.5 m MBES grid was imported into ArcMap 10.4 and projected in UTM Zone 29 N. Slope (degrees) and aspect were derived from the bathymetry using the Arc Toolbox Spatial Analyst tools.

The raw multibeam backscatter data were processed using the Geocoder algorithm in IVS Fledermaus. This algorithm removes all the gains used during acquisition and applies a series of radiometric and geometrical corrections to the original acoustic observations in order to obtain a correct value of backscatter strength (Fonseca et al., 2009). The processed file was saved as a geotiff. Throughout this manuscript, references to backscatter refer to relative backscatter strength.

2.2. Seabed morphometric analyses and mound density

To characterise the study area, distinguish between mound types and associated bedforms, morphometric analyses were carried out. Bathymetric grids, backscatter and slope of study area were plotted in ArcMap 10.4. Using a combination of these datasets, three main geomorphological features were identified: positive mound features, negative scour features and positive ridge-form features. Each individual feature was delineated manually within ArcMap and saved as a polygon *.shp files. The mound and scour polygons were used to extract the pixel values from the bathymetric (depth), backscatter (backscatter strength) and slope (slope angle) rasters. Individual mound height and scour depth were calculated by subtracting the minimum bathymetric value from the maximum bathymetric value within each of these mound and scour polygons using the Extract by Attributes tool. Similarly, mound and scour polygon area, average backscatter, minimum slope, maximum slope and average slope were calculated using the same tool and added to the polygon attribute table.

Mound volumes were calculated by: