



Development and physical characteristics of the Irish shelf-edge Macnas Mounds, Porcupine Seabight, NE Atlantic

Erica Terese Krueger¹ · Vincent Mouchi^{1,2} · Xavier Monteys³ · Stephen McCarron⁴ · Aaron Lim^{5,6} · Quentin G. Crowley^{1,7}

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Abstract

Modern cold-water corals (CWCs) occur in a wide range of water depths, with *Desmophyllum pertusum* being one of the most common species. Pleistocene, Holocene, and modern coral mound formation by living CWC reefs have previously been described in the Porcupine Seabight from water depths greater than 700 m in the vicinity of the transitional zone between the Eastern North Atlantic Water and Mediterranean Outflow Water. Here we document occurrence of fossil corals retrieved from two cores at 370 m depth in the Macnas Mounds, a relatively shallow occurrence for mounds on the Irish shelf-edge. Both cores feature *D. pertusum* restricted to the upper two metres, immediately overlying an erosive surface and a coeval major down-core change in grain size from sand to mud. Radiocarbon dating of coral specimens indicates the CWC mounds initiated 7.82 Cal ky BP. Our study unequivocally documents the existence of Holocene shelf-edge coral mounds in the eastern Porcupine Seabight and highlights the possibility of other occurrences of CWCs in similar settings elsewhere in the northeast Atlantic. Given that no living CWCs were encountered in the study area, we suggest that the area previously experienced more favourable conditions for CWC mound initiation and development along the shelf-edge margin, possibly due to differing conditions in the European Slope Current which flows northward along the continental slope from south of the Porcupine Bank to the Faroe-Shetland Channel.

Keywords Cold-water coral · *Desmophyllum pertusum* · Radiocarbon dating · Porcupine Seabight · Macnas Mounds

Introduction

Cold-water corals (CWCs) occur globally at all latitudes except the high Arctic regions (Davies et al. 2008; Roberts et al. 2009). Cold-water corals are found in a range of seawater depths, from relatively shallow waters (e.g. 40 m water depth off the coast of Norway; Fosså et al. 2002) down to extremely deep waters (e.g. 4000 m in the Mediterranean; Tsounis et al. 2010); this range suggests that their distribution is controlled by a combination of factors that include water temperature, food availability, aragonite saturation state, and a strong hydrodynamic regime (Davies and Guinotte 2011; Gómez et al. 2018; Naumann et al. 2015). Some species such as the scleractinian CWC *Desmophyllum pertusum* (recently synonymized from *Lophelia pertusa*; Addamo et al. 2016) are capable of constructing aragonitic skeletons that form large coral reefs and mounds (De Mol et al. 2007; Foubert and Henriot 2009; Wheeler et al. 2005), creating biodiversity hotspots that serve as habitat structures for refuge and

✉ Erica Terese Krueger
kruegere@tcd.ie

¹ Department of Geology, School of Natural Sciences, Trinity College Dublin, Dublin D02 PN40, Ireland

² Present Address: Sorbonne Université, CNRS UMR 7144, AD2M, 29680 Roscoff, France

³ Geological Survey of Ireland, Beggar's Bush, Dublin D04 K7X4, Ireland

⁴ Department of Geography, Maynooth University, Maynooth W23 HW31, Ireland

⁵ Earth and Ocean Lab, Department of Geography, School of the Human Environment, University College Cork, Cork T12 YN60, Ireland

⁶ Environmental Research Institute, University College Cork, Cork T12 YN60, Ireland

⁷ Trinity Centre for the Environment, Trinity College Dublin, Dublin D02 PN40, Ireland

nurseries (Turley et al. 2007), as well as feeding grounds for fishes and other organisms (Biber et al. 2014; Costello et al. 2005; Dorschel et al. 2009; Henry and Roberts 2007, 2017; Söffker et al. 2011). The formation of coral mounds is highly dependent upon environmental conditions and satisfactory sediment supply that allow for steady growth and stabilisation of these framework-forming organisms (Matos et al. 2017; Wang et al. 2021; Wienberg and Titschack 2017). Lateral and vertical advection of phytoplankton and organic carbon along with near-bed currents that enhance food supply are important for the continued function and growth of coral communities (Davies et al. 2009; Maier et al. 2023). Furthermore, sediment input is important for mound development as deposition composes greater than 50% of coral mound material (Titschack et al. 2009). Sediments become baffled by the coral framework and are deposited between the skeletal remains, preventing bioerosion of coral skeletons and hence stabilising the biogenic construction (Huvenne et al. 2009; Titschack et al. 2009; Wienberg and Titschack 2017; Maier et al. 2023). Due to the nature of successive sediment deposition, coral mounds can be used as paleoenvironmental archives as they preserve the history of coral growth and decline through the stratigraphic record (Wienberg and Titschack 2017). Along with the importance of CWCs as paleoenvironmental archives and ecosystem engineers, the growing knowledge of shelf-edge corals in the northeast Atlantic lends these areas to be considered vulnerable marine ecosystems; management approaches used to protect CWCs include special areas of conservation (SAC) and marine protected areas (MPAs). The Porcupine Seabight (PSB) currently has a few offshore SACs, but stricter regulations need to be set in place to enhance protection of these vulnerable marine habitats (Appah et al. 2022).

The study area of the Macnas Mounds is located along the Irish shelf-edge margin on a west-facing slope between 300 and 500 m water depth, adjacent to the eastern border of the Belgica Mound Province (BMP; Wilson et al. 2007; Wienberg et al. 2010). Although the Macnas Mounds were previously surveyed using remotely operated vehicle (ROV) footage and gravity cores, they were described as small mound-like features of unknown origin composed of sand dunes with coral rubble that were thought to have been covered with live coral colonies at some point (Grehan et al. 2005; Wienberg et al. 2010; Wilson et al. 2007). The aim of this research is to present the first sedimentological description of the Macnas Mounds from two cores, and to temporally constrain coral occurrence within the area. A full description of two cores collected from the mound province is presented along with multibeam mapping and on- and off-mound imaging. Finally, a model of environmental conditions (i.e. shifts in water currents, anthropogenic impacts) that may have influenced the formation of the Macnas Mounds is proposed.

Materials and methods

Cores

Two 11-cm diameter cores were recovered in May 2011 using a 6 m barrel Geo-Vibro Corer 3000 + 6000 on board the R.V. *Celtic Explorer* during cruise CE11017, under the Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR) programme (Monteys et al. 2011). Core C074 (51°26'05" N, 11°31'38" W; 556 cm core length) was recovered from 369 m water depth and core C075 (51°26'07" N, 11°31'45" W; 486 cm core length) was recovered from 372 m water depth (Fig. 1). Cores were stored at a refrigerated temperature of 4 °C during the cruise and in the laboratory, cut longitudinally with an electric saw into 1.5 m sections, split in two halves using a core splitter with a wire, and placed back in cold storage for further analysis.

Particle size analysis

Sediment samples were collected from core C074 ($n = 14$) and C075 ($n = 12$) for particle size analysis (PSA). The majority of sediment samples were collected from the upper core section containing abundant coral fragments, whereas additional sediment samples were collected from the lower section of the cores where there was a visual change in sediment matrix and a concomitant absence of coral fragments. Sediment samples were collected approximately every 15 cm from the top of the core. The sampling strategy is not intended to represent an equal temporal spread through the core, rather the regular sampling intervals capture a range of representative sediments over the selected time interval of deposition. Sediments were wet sieved using a 2 mm mesh to remove larger shell or coral fragments using standard processes, with a cover on top to prevent sample loss during agitation and a sieve pan underneath to collect fine fraction. Only biogenic shell and skeletal fragments were observed in > 2 mm fraction. Sieved sediments were subjected to PSA using a Malvern Mastersizer 2000 at the Institut des Sciences de la Terre de Paris (ISTeP) at Sorbonne Université (Paris, France) and a Malvern Mastersizer 3000 at Trinity College Dublin (Dublin, Ireland). Samples were chemically pretreated with HCl (10%, 15 °C overnight) and H₂O₂ (30%, 15 °C overnight) prior to analysis to remove calcium carbonate and organic matter (modified from Fentimen et al. 2020). Measured volume distributions were assigned to 100 logarithmically spaced classes ranging from 0.02 µm to 2 mm in diameter. The calculation of statistics was processed using GRADISTAT for logarithmic method of moments from Blott and Pye (2001).

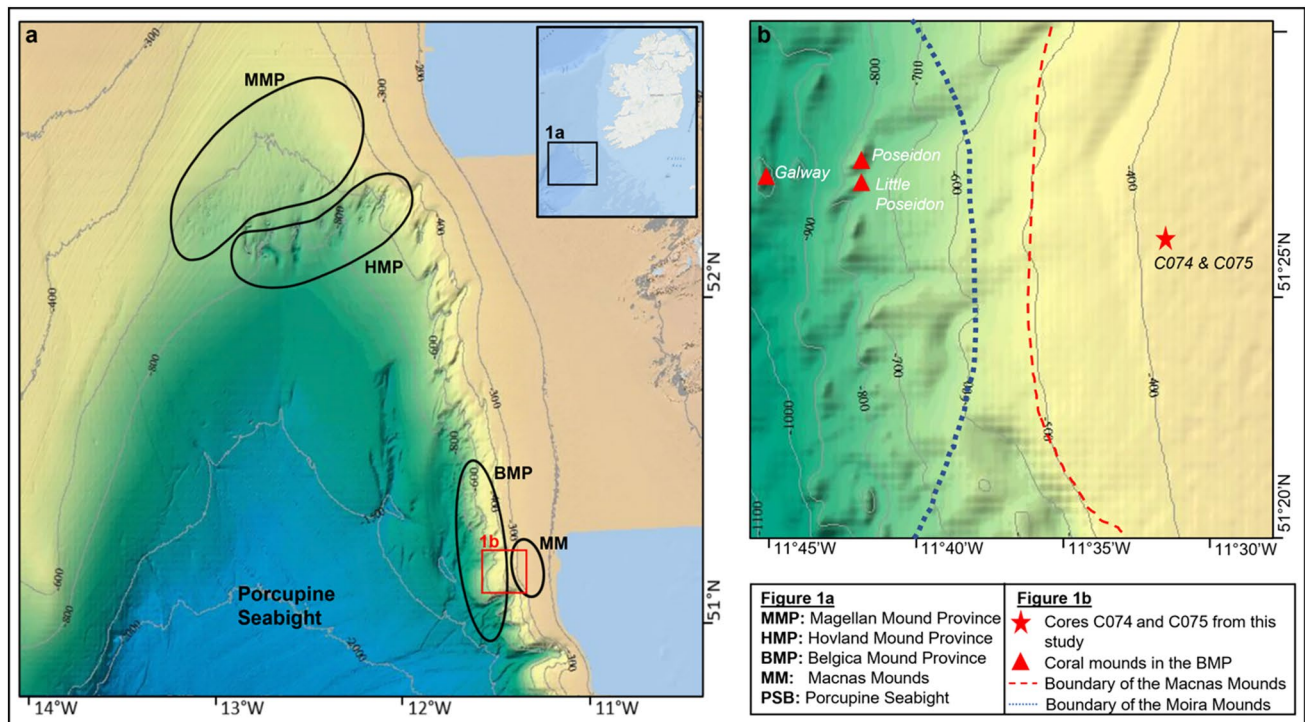


Fig. 1 **a** Overview map showing the locations of the Macnas Mounds area and the Magellan, Hovland, and Belgica Mound Provinces in the Porcupine Seabight, off the southwest coast of Ireland (inset). **b** Detailed map of cores C074 and C075 described in this study, along with locations of previously studied coral mounds in the Belgica

Mound Province and the eastern boundary of the Macnas Mounds. Map produced from INFOMAR Dynamic Bathymetric Viewer (<https://www.infomar.ie/maps/interactive-maps/dynamic-bathymetric-viewer>)

Radiocarbon dating of samples

Radiocarbon (^{14}C) dating of coral skeleton samples from cores C074 ($n=9$) and C075 ($n=9$) was performed by both Beta Analytic Radiocarbon Dating Laboratory (Miami, FL, USA) and the ^{14}C CHRONO Centre at Queen's University Belfast (Belfast, Northern Ireland). Acid etch pretreatment protocols from both laboratories were used for ^{14}C dating (Beta Analytic: <https://www.radiocarbon.com/pretreatment-carbon-dating.htm>; ^{14}C CHRONO: <http://14chronology.org/radiocarbon-dating/pre-treatment-analysis/>; Burr et al. 1992). Benthic foraminifera were extracted for ^{14}C dating from the bottom sections of cores C074 and C075 where no coral fragments were present. Foraminifera from core C074 ($n=1$) was extracted from around 5.5 m core depth, several meters below the first occurrence of *D. pertusum*, whereas those from core C075 ($n=2$) were extracted from 215 and 220 cm core depth, corresponding to an important change in particle size and immediately below to the first occurrence of the CWC mound. Accelerator mass spectrometry (AMS) ^{14}C age determination was performed, and mass fractionation was corrected by measurements of $\delta^{13}\text{C}$ (relative to PDB standard) by isotope

ratio mass spectrometry. All ^{14}C dates were calibrated for the Reservoir (R) value using the marine20 dataset (Heaton et al. 2020) for the 10 nearest available modern data points from the sample location ($\Delta R = -185$, error = 45) and the CALIB 8.2 programme (<http://calib.org/calib/calib.html>; Stuiver et al. 2021). Scanning electron microscopy, X-ray diffraction, and cathodoluminescence results are presented in Mouchi et al. 2014 and Supplementary Information.

Multibeam Echosounder data

Multibeam Echosounder (MBES) data were acquired using a Kongsberg EM302 mounted on the R.V. *Celtic Explorer* during cruise CE20011 (Lim et al. 2020a). The EM302 was operated at 30 kHz, surveying at a speed of 6 knots. Multibeam Echosounder data were stored as *.all files and imported to QPS Qimera where they were corrected for tide and anomalous soundings. The data were exported as a 10 m geotiff. The cleaned bathymetric data were saved as *.gsf and processed using the geocoder algorithm in QPS FMGT to obtain a correct value of backscatter strength.

Seafloor imaging

A series of images were retrieved from the Macnas Mounds during ROV operations on cruise CE20011. During acquisition, the ROV maintained a height of approximately 2 m above the seabed to achieve a consistent field of view. A series of lights ranging from 250 to 400 watts were attached to the ROV at a fixed angle in order to maintain consistent illumination within the field of view. Remotely operated vehicle positioning data were recorded using a Sonardyne Ranger 2 Ultra Short Baseline (USBL) beacon with an accuracy of 0.2% of the slant range (Lim et al. 2020a).

Results

Core descriptions

In core C074, muddy sediments were observed from the bottom of the core up to 250 cm. Above this, there is a transition to sandy sediments and the presence of *D. pertusum* from 212 cm to the top of the core. Core C075 also documents a clear transition of muddy sediments from the bottom of the core up to roughly 220 cm, topped by sandy sediments and the presence of *D. pertusum*. In both cores (Fig. 2), *D. pertusum* appears above the transition from muddy to sandy parts and prevails throughout the sandy sections of the cores. It should be noted that the transition from muddy to sandy sediments in core C075 is less pronounced when compared to core C074. Based on multiple visible characteristics (e.g. grain size, Munsell colour index, presence/absence of bioclasts, continuity of sediment layers), there was no evidence of reworking in either core from the vibrocoring process. A full description of both cores, along with MSCL data and core images are available in Supplementary Information.

Particle size analysis

Mean results from PSA for each sediment sample are presented in Table 1 and Fig. 3 for cores C074 and C075. In core C074, two groups of samples are well defined as described above; these groups correspond to the lower muddy section below the coral rubble (mean particle size of 4.32 to 39.52 μm) and the upper sandy sections which correspond to the portion of the cores containing the abundance of coral rubble (mean particle size of 71.45 to 176.2 μm). Core C074 is composed of silt from bottom of core to 310 cm, transitioning to a small section of very fine sand from 250 to 220 cm. Above that is fine sand from 201 cm to the top of the core, with one area of very fine sand at 110 cm. Core C075 is composed of silt from the bottom of the core up to 270 cm. The core transitions to very fine sand from 200 to 55 cm, with fine sand at 40 cm.

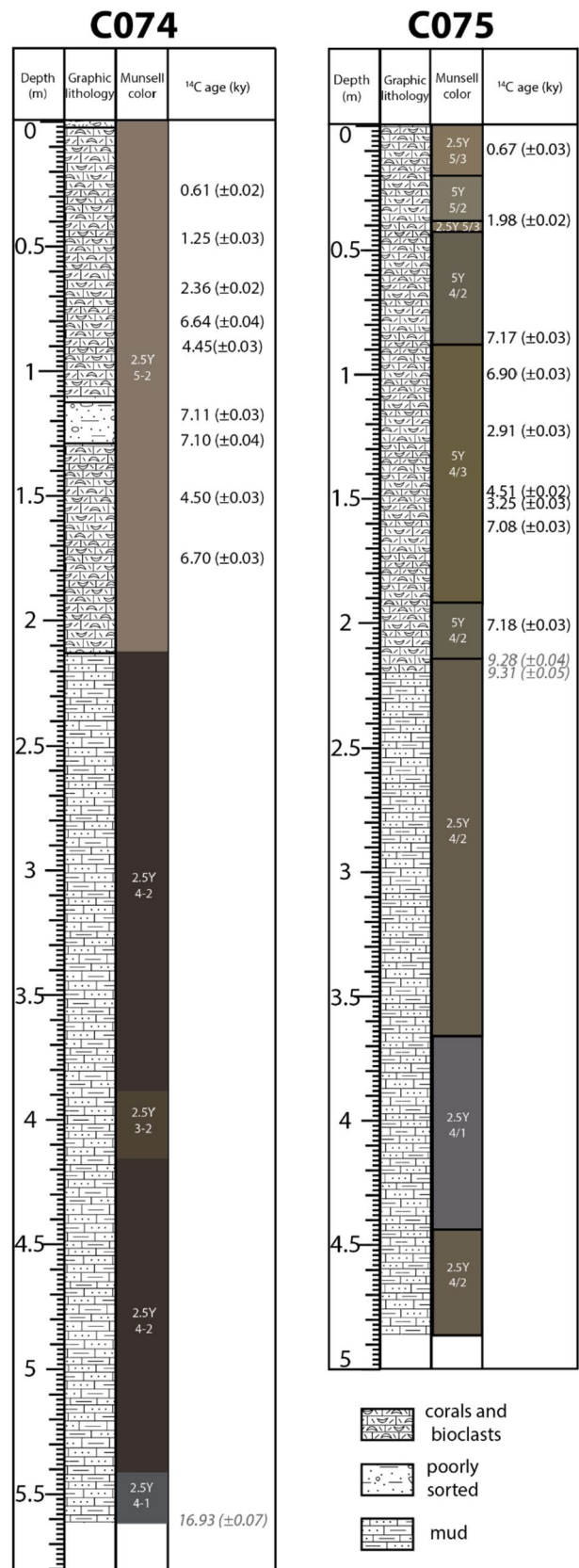


Fig. 2 Core descriptions for C074 and C075. Measured radiocarbon ages are indicated for coral fragments (black text) and benthic foraminifera (italicised in grey text)

Table 1 Particle size analysis of sediment samples from cores C074 ($n=14$) and C075 ($n=12$). The grain size (D_{50}) is presented in both μm and logarithmic, with the mean grain size corresponding to the calculated mean fraction using logarithmic method of moments in GRADISTAT (Blott and Pye 2001)

Sample	Sample core depth (cm)	D_{50} (μm)	D_{50} (ϕ)	Mean grain size (ϕ)	Wentworth size classification
C074_040	40	139.8	2.839	3.175	Fine sand
C074_080	80	135.9	2.880	3.260	Fine sand
C074_110	110	109.4	3.193	3.916	Very fine sand
C074_140	140	176.2	2.505	2.572	Fine sand
C074_160	160	161.6	2.630	3.065	Fine sand
C074_190	190	139.3	2.844	3.170	Fine sand
C074_210	210	131.1	2.932	3.287	Fine sand
C074_220	220	125.5	2.994	3.576	Very fine sand
C074_250	250	71.45	3.807	4.570	Very fine sand
C074_310	310	18.73	5.739	6.231	Fine silt
C074_350	350	39.52	4.661	5.338	Coarse silt
C074_390	390	12.32	6.343	6.615	Fine silt
C074_460	460	4.32	7.857	7.867	Very fine silt
C074_520	520	8.55	6.869	7.151	Fine silt
C075-040	40	142.3	2.813	3.025	Fine sand
C075-055	55	88.93	3.491	4.076	Very fine sand
C075-090	90	95.56	3.387	4.069	Very fine sand
C075-115	115	104.1	3.264	3.869	Very fine sand
C075-140	140	114.0	3.133	3.696	Very fine sand
C075-175	175	88.15	3.504	4.169	Very fine sand
C075-200	200	94.65	3.401	3.814	Very fine sand
C075-270	270	6.013	7.378	7.122	Very fine silt
C075-320	320	7.638	7.033	6.689	Very fine silt
C075-350	350	14.72	6.086	6.110	Fine silt
C075-390	390	9.519	6.715	6.466	Fine silt
C075-480	480	24.95	5.325	5.665	Medium silt

Radiocarbon Dating

In total, 21 ^{14}C ages were performed on cores C074 ($n=10$) and C075 ($n=11$), presented in Table 2 and Fig. 4. Coral ages range from 7.74 to 0.47 Cal ky BP in C074 and 7.82 to 0.47 Cal ky BP in C075. Foraminifera ages range from 20.07 Cal ky BP at the base of core C074 to approximately 10.40 Cal ky BP mid-core of C075 immediately above the shift in grain size from muddy to sandy sections. From Table 2, we see that ^{14}C dates do not follow a consistent downcore progression.

Bathymetry and seafloor imaging

Multibeam Echosounder data show that the furthest western extent of the Macnas Mounds is at the shelf edge, which is delineated by a northeast to southwest orientated blind

channel. A total of 338 km^2 was mapped by MBES (Fig. 5) from the eastern slope of the PSB. The continental shelf exists at 244 m water depth and slopes at approximately 3 degrees down the eastern slope of the PSB to a depth of 1160 m in the central PSB. To the west, the larger Belgica Mounds exist ranging in length from 850 to 2000 m along their long axis. Along the edge of the continental shelf, approximately 50 of the Macnas Mounds are imaged (Fig. 5B). Although their diameter ranges from 50 to 200 m, they are typically 6 m in height. Likewise, their slope varies from 2 to 10 degrees which is reflected in their morphology where some of the mounds are elongate, while others are conical. Their spatial density is highest near the edge of the continental slope, progressively decreasing with distance towards the continental shelf. Conversely, the mounds with the largest diameter (200 m) occur along the shelf while those with the smallest diameter (50 m) occur closest to the shelf edge.

Seafloor images were retrieved on- and off-mound of the Macnas Mounds (Fig. 6). The surface of the seafloor on a Macnas Mound (348 m depth— $51^\circ 28' 22.774''$ N, $11^\circ 30' 32.277''$ W) is displayed in Fig. 6A; there was no live coral on top of the mound, mainly coral rubble. An image of the adjacent area off-mound of a Macnas Mound (351 m depth— $51^\circ 28' 20.749''$ N, $11^\circ 30' 33.712''$ W) is displayed in Fig. 6B; only a few scattered coral fragments were observed from this area (Lim et al. 2020a).

Discussion

Although shelf-edge mounds in the eastern Atlantic are observed off Norway (Titschack et al. 2015), Scotland (Douarin et al. 2013), and Namibia (Tamborrino et al. 2019), the Macnas Mounds are less frequently observed on the Irish shelf-edge margin. The previous studies have concluded that coral mounds (i.e. BMP and MMP, Huvenne et al. 2003; Huvenne et al. 2007; Hebbeln et al. 2020a; Pen Duick drift, Vandorpe et al. 2014) developed where strong bottom currents precluded sediment deposition around the mounds, creating moat features between established coral mounds (i.e. off-mound areas). It is possible that as current velocity reduced, the parameters needed to sustain these mounds (i.e. nutrient and sediment input) were no longer available. Most data on the Irish Shelf where coral mound provinces are located indicate a dominant current direction towards the north (Lim et al. 2018, 2020b; Summers et al. 2022; White 2007), including the lower Mediterranean Outflow Water (MOW) that flows counterclockwise in the PSB, and continues northward along the continental shelf (De Mol et al. 2005; Van Rooij et al. 2010; Wienberg et al. 2020). It is also noteworthy that the majority of coral mounds off Ireland are located between 500 to 1000 m depth (e.g. White 2007;

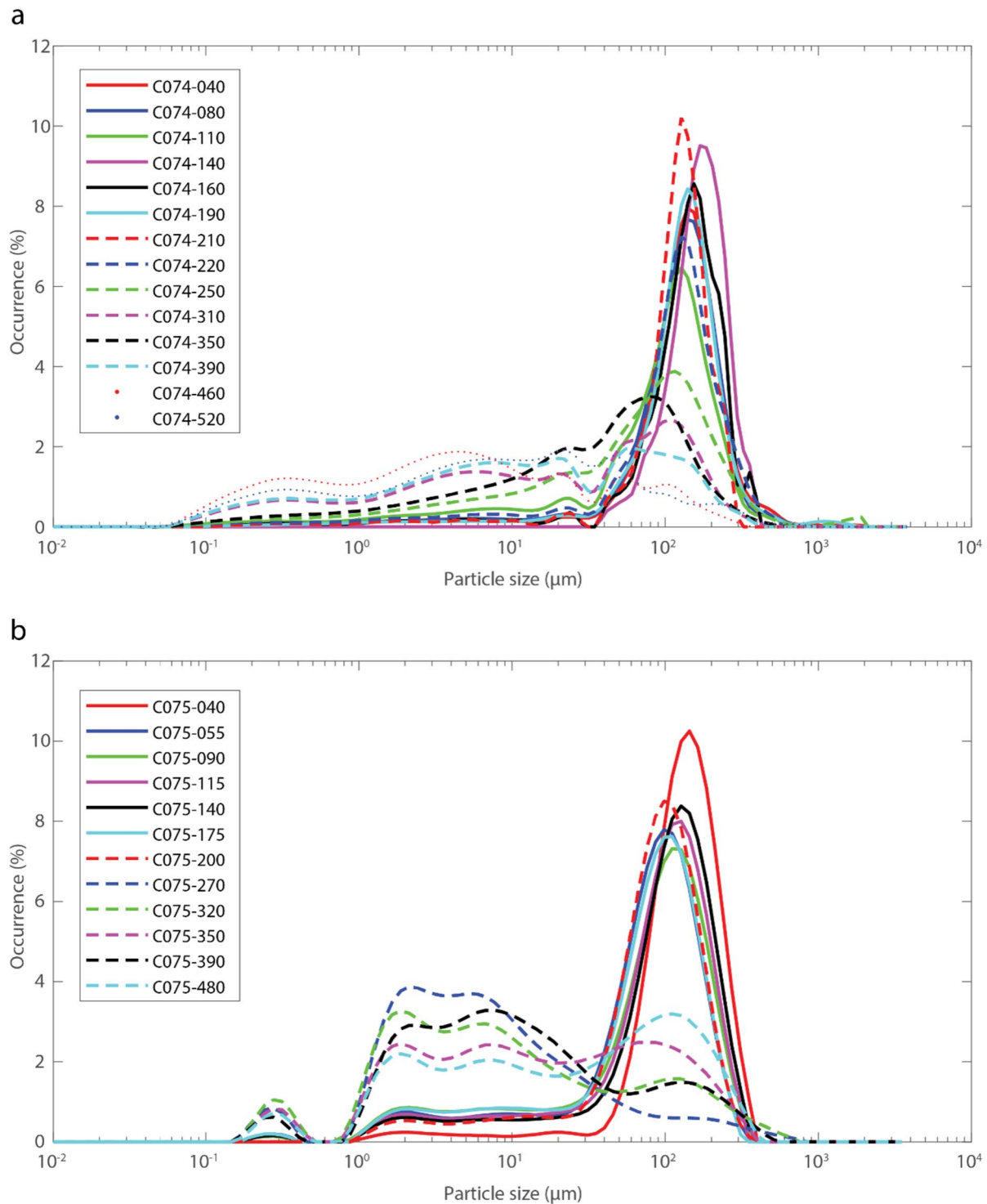


Fig. 3 Particle size distributions of sediment samples from cores **a** C074 ($n = 14$) and **b** C075 ($n = 12$) in the Macnas Mounds

White and Dorschel 2010). Although CWCs along Ireland's shelf-edge are relatively rare, there are documented occurrences in various locations within the eastern boundary of the northeast Atlantic, i.e. Angolan and Namibian continental margins (Gori et al. 2023; Hebbeln et al. 2017, 2020b;

Tamborrino et al. 2019); Bay of Biscay (De Mol et al. 2011); Norwegian continental shelf (Mortensen and Lepland 2007; Titschack et al. 2015); and Mingulay Reef Complex off western Scotland (Douarin et al. 2013). Although the MOW is important for coral mound formation in the BMP (Wienberg

Table 2 Accelerator mass spectrometry radiocarbon (^{14}C) dates obtained from *Desmophyllum pertusum* samples extracted from cores C074 and C075 in the Macnas Mounds. Benthic foraminifera samples are italicised and denoted with an asterisk (*). The Reservoir (R) value was corrected using the 10 nearest available modern data points from the sample's location ($\Delta\text{R} = -185$, error = 45) and applied to the marine20 calibration curve (Heaton et al. 2020). Conventional ^{14}C ages were corrected for ^{13}C and calibrated using the CALIB 8.20 software (Stuiver et al. 2021)

Sample	Sample core depth (cm)	Conventional ^{14}C age (ky BP)	2σ (95%) Cal ky BP	Median probability age (cal ky BP)
C074_027	27	0.61 (± 0.02)	0.14–0.47	0.31
C074_047	47	1.25 (± 0.03)	0.66–0.97	0.82
C074_067	67	2.36 (± 0.02)	1.84–2.25	2.03
C074_080	80	6.64 (± 0.04)	6.94–7.32	7.14
C074_090	90	4.45 (± 0.03)	4.45–4.84	4.67
C074_117	117	7.11 (± 0.03)	7.42–7.74	7.58
C074_127	127	7.10 (± 0.04)	7.41–7.74	7.57
C074_151	151	4.50 (± 0.03)	4.53–4.92	4.74
C074_174	174	6.70 (± 0.03)	7.01–7.37	7.20
<i>C074_560*</i>	560	<i>16.93 (± 0.07)</i>	<i>19.46–20.07</i>	<i>19.75</i>
C075_010	10	0.67 (± 0.03)	0.15–0.47	0.33
C075_038	38	1.98 (± 0.02)	1.40–1.74	1.57
C075_085	85	7.17 (± 0.03)	7.48–7.81	7.64
C075_100	100	6.90 (± 0.03)	7.24–7.55	7.39
C075_123	123	2.91 (± 0.03)	2.51–2.89	2.72
C075_148	148	4.51 (± 0.02)	4.53–4.93	4.74
C075_150	150	3.25 (± 0.03)	2.94–3.34	3.13
C075_162	162	7.08 (± 0.03)	7.40–7.71	7.55
C075_200	200	7.18 (± 0.03)	7.49–7.82	7.65
<i>C075_215*</i>	215	<i>9.28 (± 0.04)</i>	<i>9.90–10.36</i>	<i>10.15</i>
<i>C075_220*</i>	220	<i>9.31 (± 0.05)</i>	<i>9.93–10.40</i>	<i>10.17</i>

et al. 2020), it is located from 700 m water depth, well below the area of the Macnas Mounds. It is unclear how the MOW may affect the initiation and development of the Macnas Mounds, and a more suitable current would be the European Slope Current (ESC), a northward flowing shelf current from the Bay of Biscay to the Faroe-Shetland Channel (McCarthy et al. 2023; Porter et al. 2018; Xu et al. 2015). Density distribution changes have an enhanced effect on the ESC and shelf-edge environment flowing through the Rockall Trough and being deflected onto the shelf (Marsh et al. 2017; Porter et al. 2018). Weakening and warming of the ESC has been documented in the last four decades (Clark et al. 2022). Over longer time periods, variability of the ESC and climatic changes following glacial periods could be linked to basin-scale events that caused the demise of the Macnas Mounds, noting that warmer periods can decrease CWC populations (Frank et al. 2009).

Along with the Macnas Mounds presented in this study, shelf-edge coral occurrences in the northeast Atlantic are early to mid-Holocene in age and located at 500 m water depth or above; *D. pertusum* started growing at the Manas Mounds around 7 ka BP. The age data presented here for corals from cores C074 and C075 are similar in Holocene age to a vibrant growth period documented in the Darwin Mounds (Victorero et al. 2016) that is dominated by the Continental Slope Current. A salinity maximum from 100 to 400 m water depth occurs across the eastern slope of the Porcupine

Seabight (Wienberg et al. 2020) where the Macnas Mounds are located; a combination of salinity shifts combined with the ESC could have been favourable for CWC occurrence due to the possibility of enhanced density changes at the boundaries.

Specifically for the two cores described in this study, age inversions could result from slumping, debris flows, or redistribution due to skeletal framework collapse; the smaller shelf-edge Macnas Mounds appear to be related to slumping on the continental slope, locally aligned to sediment slumps. It is noteworthy that neither process would show significant grain-size sorting effects, explaining why the reworking events are only evident from the ^{14}C dates. Similar age inversions are observed in other Holocene mounds in the northeast Atlantic (e.g. Rockall Bank, Frank et al. 2005; Rockall Trough, Victorero et al. 2016), suggesting skeletal framework collapse via bioerosion or redistribution of coral debris (Frank et al. 2005; Krueger et al. 2023; Victorero et al. 2016). We exclude the influence of the vibrocoring process in relation to the presence of the age reversals, as there is no visible evidence of downcore tracking of coral rubble, marginal clasts, or sediment disruption. We note the coarser siliciclastic grain-size distributions within the mound, compared to the underlying hemipelagic sediments. Such a contrast in grain size distribution within the cores may suggest effective baffling on-mound from reduced near-bottom

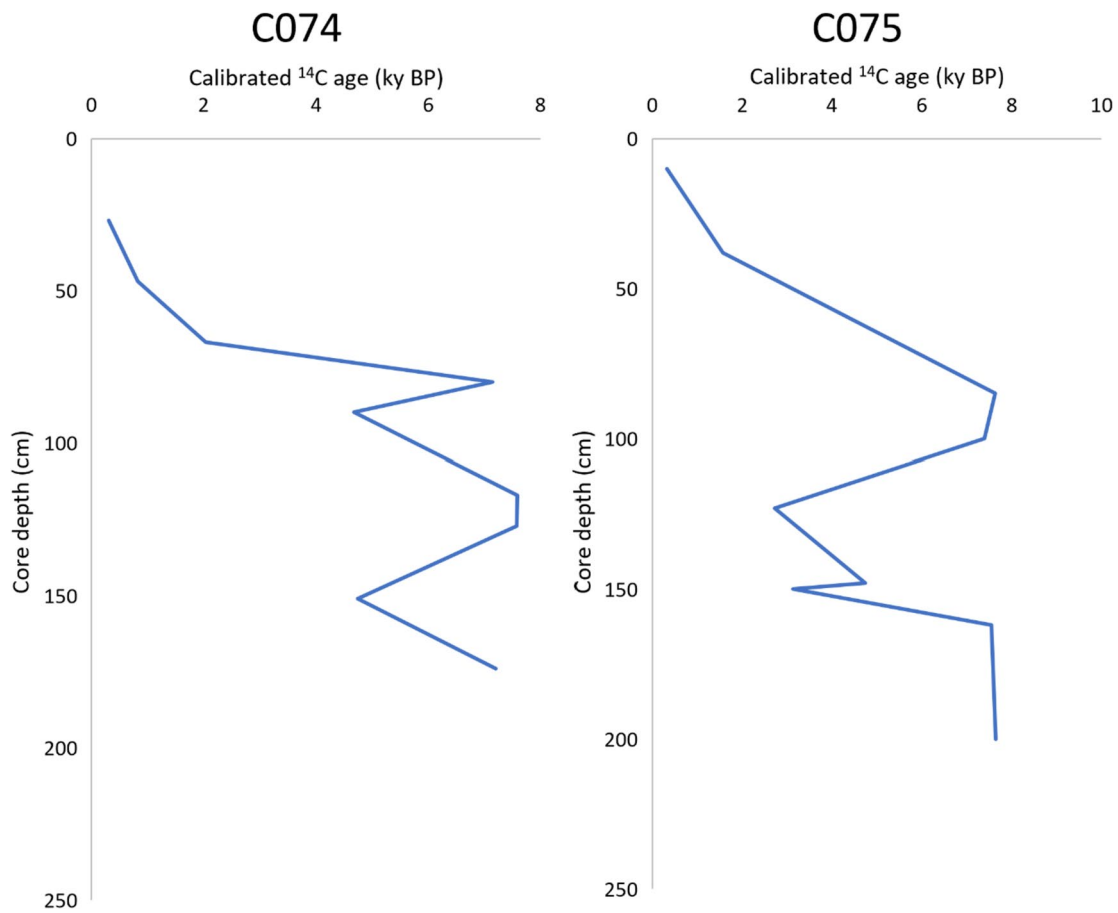


Fig. 4 The downcore records of calibrated radiocarbon (¹⁴C) age against core depth for cores C074 and C075 in the Macnas Mounds

current velocity (Dorschel et al. 2007; Wang et al. 2021; Wheeler et al. 2011). There is a possibility that the grain-size distributions within the mound are comparable to the grain-size distributions off-mound before and after mound formation, which may indicate a shift in the bottom-water hydrodynamic regime. Strong currents coupled with a low baffling effect likely resulted in bypass of fine sediments during reef aggradation, and the deposition of only coarse sediments. Although we cannot exclude a change in sediment source, we note the observed grain-size distribution within the cores and the elongated geometry of the Macnas Mounds (Wienberg et al. 2010). This is compatible with a combination of sediment waves and subsequent coral mound formation, potentially equivalent to the cigar-shaped reefs of the Træna Deep on the Norwegian shelf (Mortensen and Lepland 2007), and similarly shaped Darwin Mounds in Rockall Trough (Victorero et al. 2016). Using the ¹⁴C ages and core depths, an average mound aggradation rate was calculated to approximately 29 cm ka⁻¹. Although this aggradation rate is low for mound formation in general, it falls within aggradation

rates observed in other shelf-edge coral provinces in the northeast Atlantic (e.g. 26 to 57 cm ka⁻¹ on Røst Reef, Titschack et al. 2015; 20 to 44 cm ka⁻¹ on Cabliers Coral Mound Province, Corbera et al. 2021).

Previous multibeam data collected by the Irish National Seabed Survey revealed multiple mound features from the area of Macnas Mounds in the eastern Porcupine Seabight (GOTECH 2002). GOTECH (2002) described the area of roughly 200 km² as a larger upper region that contained the majority of the mounds, separated from the lower region containing small mound patches by a definitive channel, similar to our findings (Fig. 5). GOTECH (2002) showed consistent coral rubble patterns in the upper region where the cores in this study were recovered from, suggesting that more than 8 km² of the Macnas Mounds were previously covered in live coral colonies. Between the mounds were rippled sediment and small dropstones. Although there were no visible live coral colonies, the area was observed to be scattered with small coral rubble on-mound with smooth sandy bottoms off-mound, the same as we present in this study in Fig. 6.

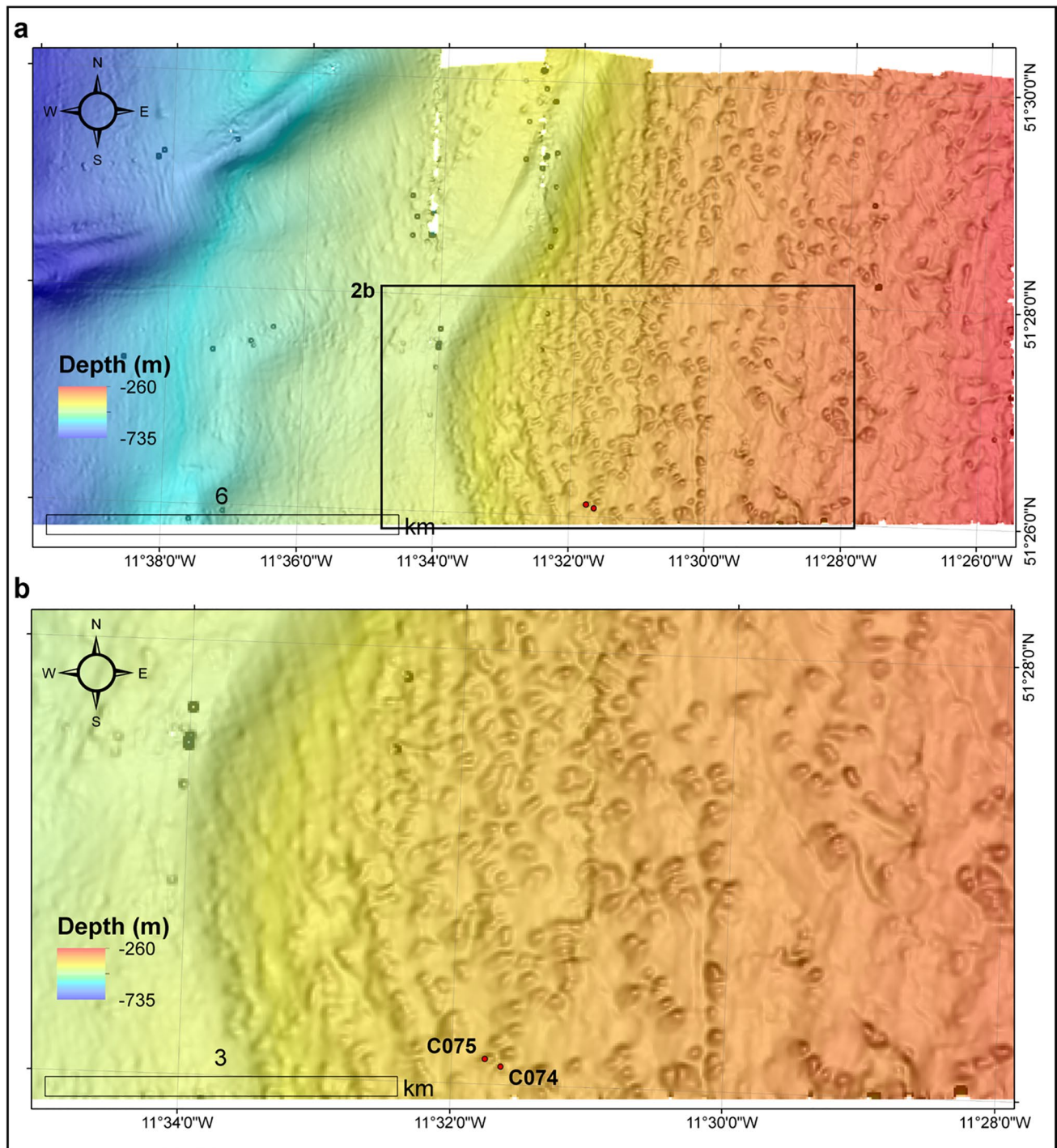


Fig. 5 Multibeam Echosounder bathymetric map of the Macnas Mounds showing **a** the extent of mounds in the region and **b** a detailed image of the mound locations for cores C074 and C075 described in this study, where you can visualise the long axes of the mounds

Conclusions

This is the first study to provide ^{14}C age determination and unequivocal evidence of past coral colonisation at the Macnas Mounds. The constrained radiocarbon age of 7.82 to 0.47 Cal ky BP is the first study to report a Holocene coral

mound east of the BMP in an area shallower than 500 m water depth. Occurrence of CWCs from 370 m water depth in the Macnas Mounds is above the Mediterranean Outflow Water in this region (Wienberg et al. 2020), suggesting a change in the European Slope Current over the course of its history. Both cores penetrated through the coral mounds

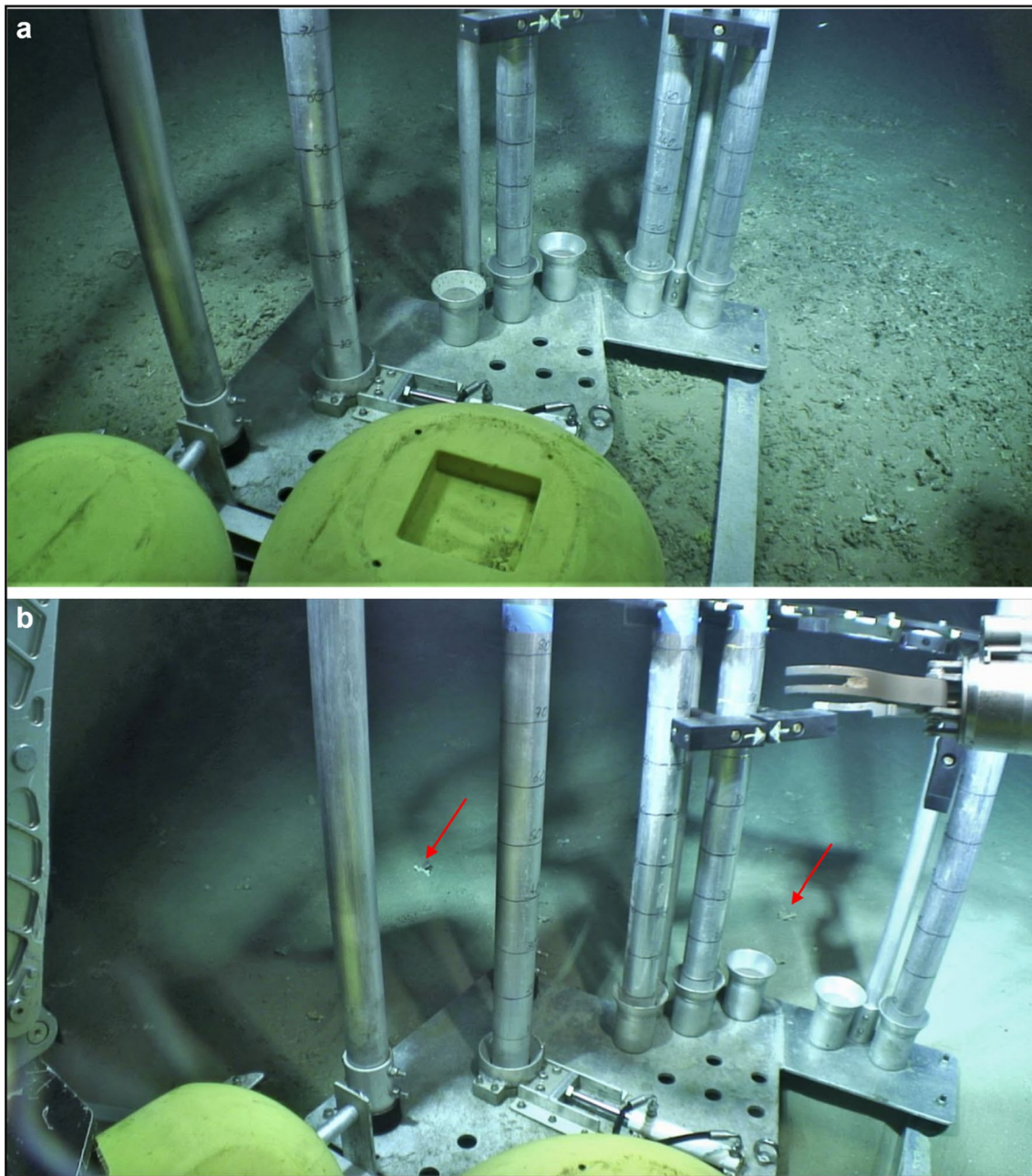


Fig. 6 Seafloor images collected at the **a** summit of a Macnas Mound with scattered coral rubble on the seafloor surface at 348 m water depth and **b** off-mound from a Macnas Mound site with very few coral rubble fragments (red arrows) at 351 m water depth

to the base, where triggering controls can be inferred. We suggest that the development of the Macnas Mounds is compatible with coral mound formation superimposed on pre-existing sediment waves similar to other Holocene coral provinces in the PSB. Although previous authors (e.g. Frank et al. 2011) have documented climate-driven latitudinal oscillations of the biogeographic limit of coral development, here we highlight that temporally restricted local or regional changes in bathymetric extent of CWCs may occur, and may be linked to both broader interglacial periods (e.g.

following the Little Ice Age) and regional or local climate-driven perturbations (e.g. dynamic shifts in the European Slope Current). Finally, the demise of the investigated corals is likely attributed to a shift in hydrodynamics and diminished nutrient supply that was unfavourable for continued coral growth. Further analysis is needed to determine the extent of environmental drivers that impacted past mound growth in the Macnas Mounds and if present environmental conditions are still favourable for CWC growth and

development, which would aid in sustainable management of the area as an SAC or MPA.

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Data availability The authors declare that the data supporting the findings of this study are available within the paper and its supplementary information files.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work submitted in this publication.

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