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Stable strontium isotopes ($\delta^{88/86}$Sr) in cold-water corals — A new proxy for reconstruction of intermediate ocean water temperatures

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ABSTRACT

Zooxanthellate scleractinian corals are known as archives for temporal variations of climate variables, such as sea surface temperature, salinity or productivity. The use of azooxanthellate cold-water corals as potential archives for intermediate water mass properties and climate variability was tested recently. However, the correlation of established proxies such as δ^{18}O and δ^{13}C with temperature is difficult since there is no direct temperature equation applicable as in shallow-water corals. Other temperature proxies such as Sr/Ca, Mg/Ca and U/Ca are influenced by the complex microstructure of the aragonite skeleton, the rate of calcification, and other vital effects observed for coral species.

For the first time we show that the stable strontium isotope ratio $\delta^{88/86}$Sr incorporated in the skeletons of the cold-water coral species *Lophelia pertusa* portrays the ambient seawater temperature. The temperature sensitivity from live samples collected along the European continental margin covering a temperature range from 6° to 10 °C is 0.026 ± 0.003‰/°C (2σ standard error) which is a sensitivity similar to the tropical shallow-water coral record of *Pavona clavata*. This indicates a similar fractionation process of strontium for both, zooxanthellate and azooxanthellate corals. For coral aragonite the $\delta^{88/86}$Sr ratio may serve as a new paleo-temperature proxy and introduces new perspectives in paleoceanography with respect to intermediate water dynamics.

1. Introduction

Cold-water corals are known to be abundant in the world's oceans forming unique reef structures mainly built up by colonial azooxanthellate scleractinians *Lophelia pertusa* and *Madrepora oculata*. Focusing on the European continental margin, these cold-water coral reefs occur on moraine ridges off Norway to small coral topped mounds and huge coral banks in the Rockall Trough, the Porcupine Seabight, the Gulf of Cadiz, but only have a patchy occurrence in the Mediterranean Sea (Freiwald et al., 1999; De Mol et al., 2002; Kenyon et al. 2003; Álvarez-Pérez et al., 2005; Taviani et al., 2005). Their distribution and development is supposed to be related to climatic changes governing the local oceanographic regime where strong bottom currents control the sedimentation and food supply (Freiwald et al., 2004; Roberts et al., 2006; Rüggeberg et al., 2007; White, 2007).

Lophelia pertusa occurs in water depths as shallow as 40 m in some Norwegian fjords down to over 3000 m on the New England seamount chain (Freiwald et al., 2004). This species tolerates temperatures between 4° and 14 °C (Freiwald, 2002) and salinity values from as low as 32 psu in Scandinavian fjords to at least 38.8 psu in the Mediterranean (Strømgren, 1971; Taviani et al., 2005). The growth rate of *L. pertusa* varies between 5 and 25 mm/yr (Mikkelsen et al., 1982; Freiwald et al., 1997; Mortensen and Rapp, 1998; Spiro et al., 2000), which indicates that a branch of several coral polyps can represent an archive of several years to few decades.

Previous studies intend to use cold-water corals as a potential archive of intermediate water temperatures and salinity (Smith et al., 2000, 2002; Blamart et al., 2005; Lutringer et al., 2005; Shirai et al., 2005; Cohen et al., 2006). Smith et al. (2000) and later Lutringer et al. (2005) presented δ^{18}O-temperature relationships, corrected to seawater δ^{18}O, between the linear regression of δ^{18}O and δ^{13}C of aragonite and the δ^{13}C seawater DIC. These calculated temperatures have a precision of ±1.5 °C (Smith et al., 2000) and ±0.7 °C in higher resolution sampling (Lutringer et al., 2005). Nevertheless, the problem of this acquisition is the enormous sampling procedure and stable isotope analysis (>15 measurements) for one determined temperature value. However, it was found that stable isotopes (δ^{18}O, δ^{13}C) as well as elemental ratio analyses (Sr/Ca, Mg/Ca, U/Ca) exhibit strong vital effects (Smith et al., 2000, 2002; Shirai et al., 2005; Cohen et al., 2006) and that the aragonite skeleton of *L. pertusa* has not been precipitated in isotopic equilibrium with the ambient seawater. Latter observations challenge the application of these proxies for ambient seawater reconstructions in cold-water corals. In this study we further evaluate

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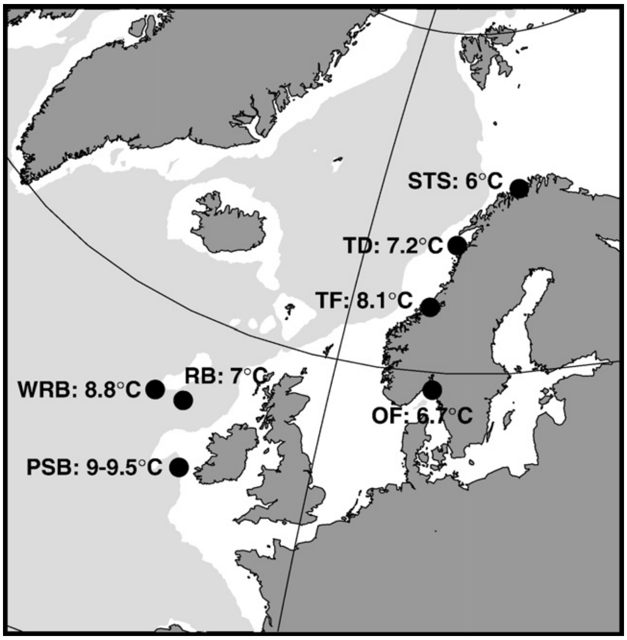

Fig. 1. Locations of live-sampled cold-water coral *Lophelia pertusa* from the Norwegian shelf, the Skagerrak, the Rockall Trough, and the Porcupine Seabight. Mean water temperature of coral depths is increasing from ~6 °C in the north to ~10 °C in the south (see also Table 1). STS = Stjernsund, TD = Trænadjupet, TF = Trondheimsfjord, OF = Oslofjord, RB = Rockall Bank, WRB = West Rockall Bank, PSB = Porcupine Seabight.

cold-water corals as an archive for intermediate seawater variability. In particular, we follow recent findings of Fietzke and Eisenhauer (2006) who found that the stable strontium isotope ratios in tropical corals are temperature dependent and may serve as a reliable temperature proxy for cold-water corals. Furthermore, we used the stable strontium isotope method on the same coral species from different environmental and therefore temperature settings to determine the variability of this isotope ratio and to establish the method as tool for paleoceanographic questions.

2. Material and method

Sampling locations of living specimens of *L. pertusa* are the Norwegian shelf, the Skagerrak, the Rockall Bank, and the Porcupine Seabight (Fig. 1, Table 1). The corals were collected from water depths between 100 m and 1 000 m using box corers, the remotely operating vehicle ROV QUEST of MARUM (University of Bremen), and the manned submersible JAGO of IFM-GEOMAR (Kiel). All samples were immediately dried at 50 °C and then stored away. Water temperatures and salinities were collected from CTD measurements of same sample position during same cruises.

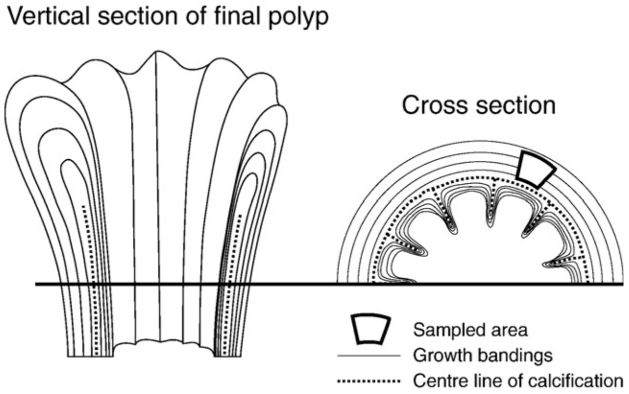

Fig. 2. Schematic illustration of vertical and cross sections of a final polyp of *Lophelia pertusa*. The full and dotted lines indicate main growth bands, centre line of calcification and sampled area between two main septa.

2.1. Sample preparation

For bulk analyses of $\delta^{88/86}$Sr in cold-water coral *L. pertusa*, the final polyp corresponding to the youngest one was embedded in epoxy resin and cut perpendicularly to the growth direction using a diamond saw. A minimum of 0.5 mg of skeleton powder was drilled from the cut surface using a dental drill (Fig. 2). Attention was paid to avoid centers lines of calcification during sampling, since these show a different fractionation behavior at least for oxygen and carbon isotopes (Smith et al., 2000; Blamart et al., 2005) and some element ratios (Shirai et al., 2005; Cohen et al., 2006).

Drilled skeleton powder was weighted in a Teflon beaker and dissolved using 4 N HNO_3. After careful dissolution, samples were evaporated to dryness, redissolved in 1 ml 4 N HNO_3 and finally loaded onto a column with 300 µl Eichrom SrSpec resin (Fietzke and Eisenhauer, 2006). The sample matrix was separated by washing the column with 4 ml 4 N HNO_3. Strontium was eluted with 3 ml ultrapure water (18.2 MΩ). Solutions (50 ppb Sr) were prepared using nitric acid (5%) for MC-ICP-MS measurements. In order to prevent isotope fractionation due to a chromatographic effect on the corals the columns have been tested for a complete strontium recovery.

Table 1
Coral samples and locations along the European continental margin

Lab code	Sample code	Location	Latitude	Longitude	Date of collection	Sampling	
						Depth (m)	Temperature (°C)
812-05	POS325-433	Stjernsund	70°16.04′ N	22°27.37′ E	27.07.2005	365	5.90
813-05	POS325-433	Stjernsund	70°16.04′ N	22°27.37′ E	27.07.2005	365	5.90
811-05	POS325-356/1	Traenadjupet	66°58.40′ N	11°06.53′ E	17.07.2005	300	7.24
634-05	# 3	Trondheimsfjord	63°28.61′ N	09°59.72′ E	21.10.2004	240	8.10
635-05	# 3	Trondheimsfjord	63°28.61′ N	09°59.72′ E	21.10.2004	240	8.10
802-06	AL275-422	Oslo Fjord	59°05.65′ N	10°47.94′ E	27.03.2006	91	6.70
636-05	M61/1-218	PSB	51°26.51′ N	11°45.43′ W	24.04.2004	881	8.96
637-05	M61/1-218	PSB	51°26.51′ N	11°45.43′ W	24.04.2004	881	8.96
638-05	M61/3-551	PSB	51°26.94′ N	11°45.16′ W	05.06.2004	837	9.54
803-06	M61/3-614	SW RB	56°29.80′ N	17°18.60′ W	12.06.2004	680	8.80
804-06	M61/1-218	PSB	51°26.51′ N	11°45.43′ W	24.04.2004	881	8.96
805-06	M61/1-218, Q1	PSB	51°26.51′ N	11°45.43′ W	24.04.2004	881	8.96

PSB = Porcupine Sea Bight, SW RB = South West Rockall Bank.