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Early Eocene greenhouse conditions: new insights from carbonate clumped isotope climate reconstruction on fossil corals.

Irene M. Waajen*[1], Inigo A. Müller[1], David Wallis[1], Rein Nijhof[1], Joost Frieling[1], Peter K. Bijl[1], Martin Ziegler[1] and Furu Mienis[2].
*i.m.waajen@students.uu.nl; [1]Department of Earth Sciences, Utrecht University, Utrecht, The Netherlands; [2]Royal Netherlands Institute for Sea Research (NIOZ), The Netherlands.

Introduction

The Early Eocene climate is often referred to as potential future climate analogue. Especially at higher latitudes close to the Polar circle climate reconstructions from multiple proxies reveal extreme warm and humid conditions (e.g. Bijl et al., 2009; Pross et al., 2012), while most paleoclimate studies only show minor temperature increase at equatorial latitudes. Climate models struggle to reproduce this smaller meridional temperature gradient (e.g. Bijl et al., 2009; Evans et al., 2018). This polar amplification needs further investigation from proxy reconstructions, as well as climate simulations, to better understand the past greenhouse conditions and to constrain the consequences for future climate scenarios. For this purpose, fossil corals and a gastropod (figure 1) from the Dilwyn location (Otway basin, Victoria, ca. 54.5 Ma, figure 2) have been analysed with clumped isotope paleothermometry.

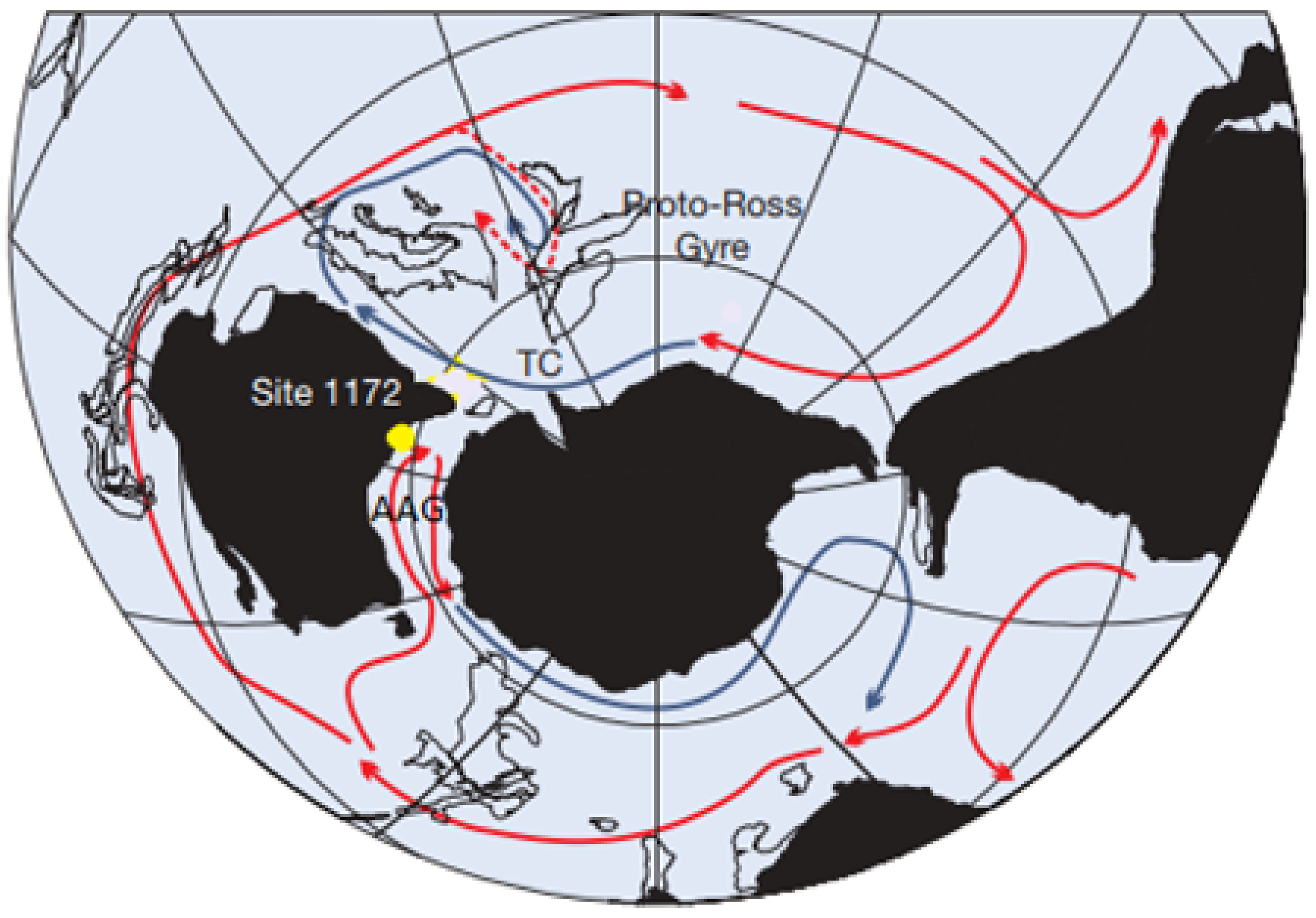
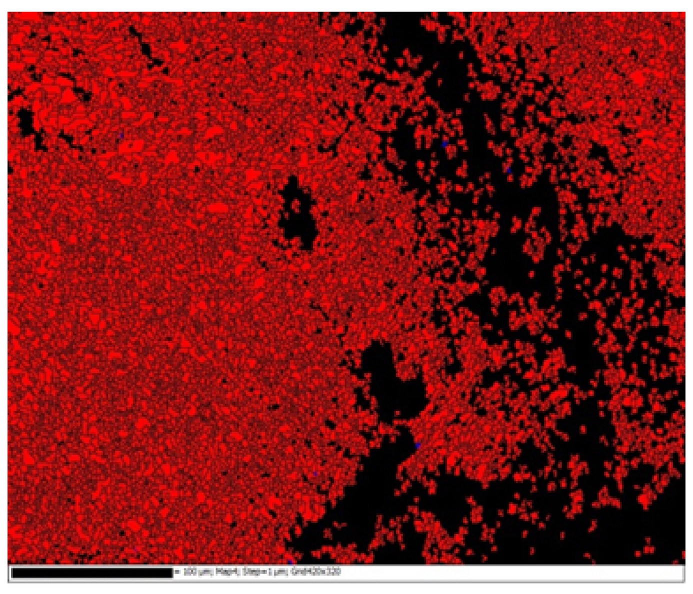


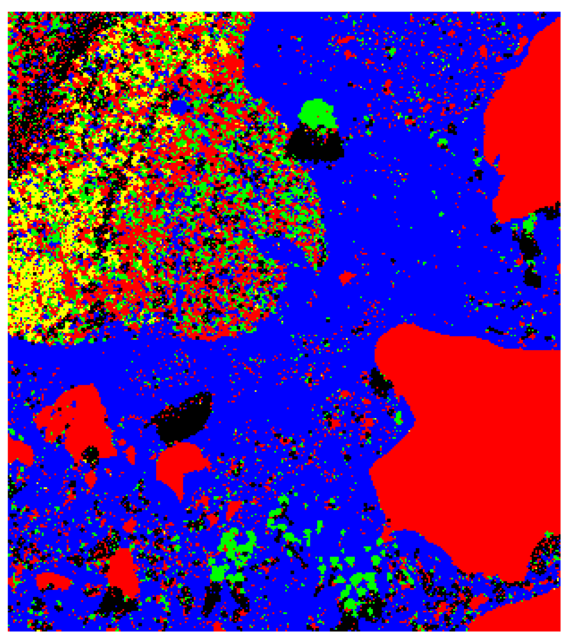
Figure 2 - Location of the samples in the Otway basin, Australia (paleolatitude of 60°S).

Mineralogy

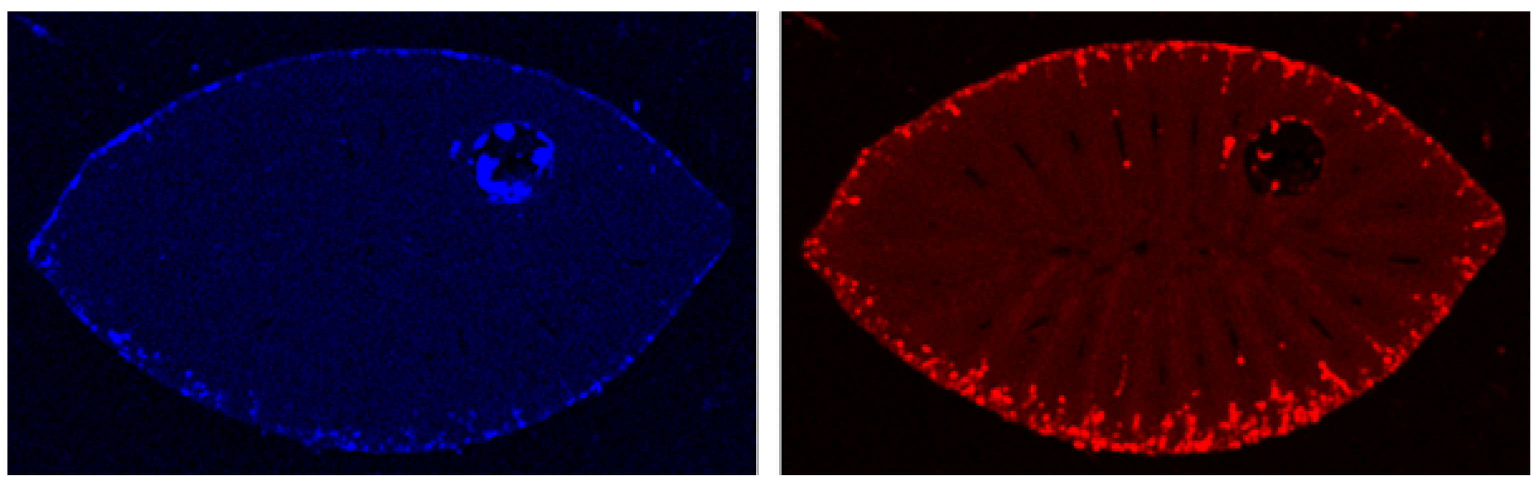
Prior to preforming clumped isotope analysis on fossils, the mineralogy of the fossils need to be studied. Fossil corals should consist only of primary aragonite, as altering the phase, often to calcite, can change the oxygen isotope composition (Eiler, 2011). In order to find the primary phase of the fossil corals and gastropod, a combination of three geochemical methods were applied: XRD, µXRF and EBSD.



EBSD phase map. Red = aragonite, blue = calcite, black = unidentified.



EBSD phase map. Blue = calcite, red = quartz, yellow = aragonite, green = pyrite.



µXRF results indicating the presence of Bromine (left, blue) and sulphur (right, red) on the edges and within some part of the corallite. These elements could indicate organic matter within the fossil, which could falsify results.

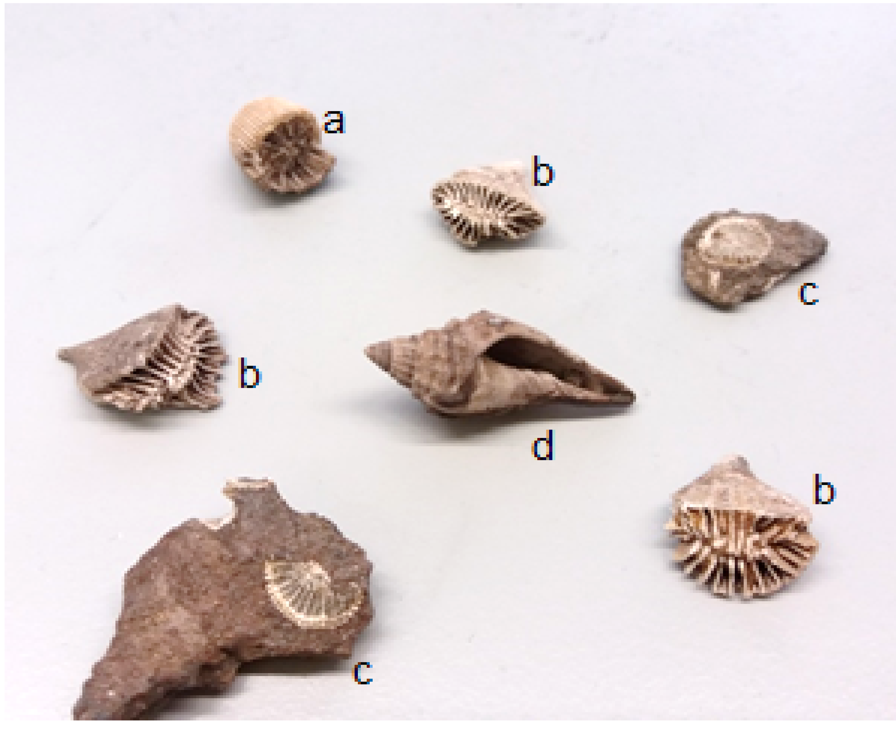


Figure 1 - The different coral genera and gastropod studied.
a - Cyathotrochus genus;
b - Flabellum genus;
c- Australocyathus genus (probably A. vincentius);
d - Gastropod Athleta wangerrip.

Results mineralogy

- XRD: indicates mineralogy present in powdered samples. Samples without calcite and pyrite could be selected.

- µXRF: indicates areas in the corallite that were altered by diagenetic fluids and areas with pure aragonite.

- EBSD: proved to be well applicable for carbonate research. It indicates the location and size of grains, and the mineral phases that are present, which provides a better understanding of the secondary calcite phase. It also indicated that the centres of calcification probably contain organic matter, which should be avoided for clumped isotope measurements.

Table 1: Results clumped isotope paleothermometry on multiple samples of the 2 sites PP380 and PP381. The gastropod was found at site PP381.

ID	#	$\delta^{13}C$ (‰)	$\delta^{18}O_{VPDB}$ (‰)	$\Delta_{47\ CDES\ 25\ °C}$ (‰)	T (°C)	$\delta_{VSMOW\ fluid}$ (‰)	T (°C) Cc cor
Site PP380							
PP380-01A	8	-1.13±0.02	-1.40±0.04	0.738±0.055	9±13	-3.5±3.0	13±14
PP380-01C	12	-0.22±0.00	-1.18±0.01	0.725±0.025	11±6	-2.6±1.4	16±7
PP380-01				**0.730±0.020**	**10±5**		
PP380-03A	18	-2.20±0.01	-1.97±0.02	0.723±0.014	11±4	-2.2±1.6	16±4
PP380-03B	20	-0.95±0.01	-1.37±0.02	0.727±0.014	10±4	-2.9±0.8	15±4
PP380-03C	9	-0.34±0.01	-1.22±0.01	0.708±0.034	16±9	-1.7±1.9	21±9
PP380-03				**0.722±0.010**	**12±2**		
Site PP381							
PP381-01A	13	-4.55±0.01	-2.80±0.03	0.736±0.013	8±3	-4.8±0.7	13±3
PP381-01B	12	-4.69±0.01	-2.76±0.03	0.723±0.014	11±4	-4.1±0.8	16±4
PP381-01				**0.730±0.009**	**9±2**		
Gastropod							
PP381-09	23	-1.48±0.01	-0.91±0.02	**0.689±0.024**	**21±7**	-0.2±1.4	27±7
Modern coral							
Ref M2005-63 MO	17	-3.21±0.01	1.22±0.02	0.760±0.013	2±3	-2.2±0.7	7±3

-all uncertainties are displayed at the 95% CL
-the Δ_{47} values are corrected for difference of acid fractionations between aragonite and calcite for 70 °C (+0.018 ‰ recalculated from Müller et al., 2017)
-T's calculated with ETH calcite calibration (Kele et al., 2015 recalculated in Bernasconi et al., 2018)

Conclusions and outlook

- Well preserved coral samples reveal Δ47-T estimates of around 10 °C and the gastropod around 21 °C, probably reflecting a strong seawater T gradient in the Otway Basin, southern Australia during the Early Eocene (~60° S).

- The coral growth temperature matches d18O T reconstructions of benthic foraminifera of U1172 reflecting intermediate water masses (Bijl et al., 2013) and align well with MWT/MAT estimates from the more southern site U1356 (70 °S; Pross et al., 2012),

- Whereas the T estimate of the gastropod matches MST estimates of U1356 and sea surface T estimates of U1172. Most probable the gastropod was transported to coral site after death.

- Aragonite specific clumped isotope acid fractionation correction needs further investigation with aragonitic samples from well constraint growth conditions.

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