Quaternary Science Reviews 81 (2013) 29–34

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

# In-life pteropod shell dissolution as an indicator of past ocean carbonate saturation

Deborah Wall-Palmer*, Christopher W. Smart, Malcolm B. Hart

*School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth PL4 8AA, UK*

ARTICLE INFO

*Article history:*
Received 19 April 2013
Received in revised form
20 September 2013
Accepted 24 September 2013
Available online 17 October 2013

*Keywords:*
Pteropoda
Ocean acidification
Late Pleistocene
Caribbean Sea
Indian Ocean

ABSTRACT

Recent concern over the effects of ocean acidification upon calcifying organisms has highlighted the aragonitic shelled thecosomatous pteropods as being at a high risk. Both in-situ and laboratory studies have shown that an increased dissolved $CO_2$ concentration, leading to decreased water pH and low carbonate concentration, causes reduced calcification rates and enhanced dissolution in the shells of living pteropods. In fossil records unaffected by post-depositional dissolution, this in-life shell dissolution can be detected. Here we present the first evidence of variations of in-life pteropod shell dissolution due to variations in surface water carbonate concentration during the Late Pleistocene by analysing the surface layer of pteropod shells in marine sediment cores from the Caribbean Sea and Indian Ocean. In-life shell dissolution was determined by applying the *Limacina* Dissolution Index (LDX) to the subtropical pteropod *Limacina inflata*. Average shell size information shows that high in-life dissolution is accompanied by smaller shell sizes in *L. inflata*, which may indicate a reduction in calcification rate. Comparison of the LDX profile to Late Pleistocene Vostok atmospheric $CO_2$ concentrations, shows that in-life pteropod dissolution is closely associated to variations in past ocean carbonate saturation. This study confirms the findings of laboratory studies, showing enhanced shell dissolution and reduced calcification in living pteropods when surface ocean carbonate concentrations were lower. Results also demonstrate that oceanic pH levels that were less acidic and changing less rapidly than those predicted for the 21st Century, negatively affected pteropods during the Late Pleistocene.



## 1. Introduction

The thecosomatous (fully shelled) pteropods are a common component of the zooplankton in our oceans and the major planktonic producers of aragonite (Orr et al., 2005). Pteropods have a global distribution, but are most abundant in polar and sub-polar waters where they can reach densities of 1000–10,000 individuals per cubic metre, replacing krill as the dominant zooplankton group in some areas (Royal Society, 2005; Fabry et al., 2008). In such regions, pteropods are an important food source for large cetaceans and commercially important fish, such as North Pacific salmon, mackerel, herring and cod (LeBrasseur, 1966; Takeuchi, 1972). However, recent concern over the effects of anthropogenic ocean acidification upon calcifying organisms has highlighted the thecosomatous pteropods as being at a high risk (Orr et al., 2005; Fabry et al., 2008; Comeau et al., 2009, 2010a, 2010b, 2012; Lischka et al., 2011; Bednaršek et al., 2012a, 2012b). Their increased susceptibility to ocean acidification is due to a combination of living in the most affected habitat, the surface ocean, and having a shell structure that is prone to dissolution. Pteropods construct their shells from aragonite, a form of calcium carbonate ($CaCO_3$), which is 50% more soluble in seawater than calcite (Fabry et al., 2008). It has been found that, although pteropods can calcify in waters undersaturated with respect to aragonite, the rate of calcification is reduced and enhanced dissolution corrodes the surface layer of their shells (Comeau et al., 2012). This results in the production of smaller, weaker shells with damaged outer layers of aragonite (Bednaršek et al., 2012b).

As an important part of the food web, especially in the Arctic and Southern oceans, understanding the potential demise of thecosomatous pteropods is of great importance. However, so far, research into the effects of decreased ocean $CaCO_3$ saturation on pteropods is based on the laboratory studies of only three of the 34 species of pteropod: *Cavolinia inflexa*, *Clio pyramidata* and *Limacina helicina* (Feely et al., 2004; Orr et al., 2005; Fabry et al., 2008; Comeau et al., 2009, 2010a, 2010b, 2012; Lischka et al., 2011; Bednaršek et al., 2012a). The response of *L. helicina antarctica* has also been observed in the natural environment, by analysing the

* Corresponding author.
*E-mail address:* deborah.wall-palmer@plymouth.ac.uk (D. Wall-Palmer).

0277-3791/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.quascirev.2013.09.019

shell structure of live specimens from the Southern Ocean (Bednaršek et al., 2012b). In this study, a different approach has been taken by using a simple methodology to assess the fossil record of the sub-tropical cosmopolitan species, *Limacina inflata*, for variations of in-life shell surface dissolution and average shell size.

## 2. Methodology

### 2.1. Site locations

Pteropods were analysed from three sites situated above the Aragonite Lysocline (ALy) and appear to be un-affected by post-depositional dissolution. Two cores from sites situated close together off-shore Montserrat in the Caribbean Sea (CAR-MON 2 and JR123-35-V, Fig. 1, Table 1) were analysed to test the reproducibility of data at a single location. The sea around Montserrat is relatively shallow and super-saturated with respect to aragonite. Water chemistry around the Lesser Antilles Island Arc is complicated by influences of several water masses flowing between the islands and through a number of deeper passages into the Caribbean Sea. Gerhardt and Henrich (2001) found that the influence of Antarctic Intermediate Water (AAIW), towards the south of the island arc, caused moderate to very poor preservation of pteropods (below 700 m water depth). However, towards the north of the island arc, where Montserrat is situated, the influence of AAIW is minor (maximum 10% of water composition) due to a large volume of Upper North Atlantic Deep Water (UNADW), which flows through the nearby Anegada Passage. This area consequently records very good preservation of pteropods. Gerhardt and Henrich (2001) place the ALy at 2000 m and the Aragonite Compensation Depth (ACD) at 3800 m water depth in this area. CAR-MON 2 and JR123-35-V were collected in 1102 m and 765 m water depth respectively, which is well above the present day ALy and ACD thus discounting any effects that this may cause. Core collection, sampling techniques and oxygen isotope stratigraphy have been previously published for cores CAR-MON 2 and JR123-35-V (Le Friant et al., 2008; Trofimovs et al., 2010).

An additional core from the Chagos-Laccadive Ridge, within the Maldives Islands in the Indian Ocean (ODP Hole 716B, Fig. 2, Table 1), was analysed to test the reproducibility of data across different locations. The water masses in this area (Fig. 2) are composed of Indian Equatorial Water (IEW), which lies between 0 and 500 m, the Red Sea-Persian Gulf Intermediate Water (RSPGIW), which lies between 500 and 1500 m and the Circumpolar Deep Water (CDW), which lies between 1500 m and the sea floor (Emery, 2001). Climate and oceanography in the Indian Ocean is strongly influenced by the monsoonal wind system, which affects the cycling and upwelling of nutrients in the ocean. Strong monsoonal winds cause an increase of nutrients in surface waters, which ultimately lead to increased surface water productivity. This, in turn, creates a mid-water Oxygen Minimum Zone (OMZ, Fig. 2) by increasing the input and decay of organic matter in sub-surface waters. The increasing concentration of dissolved inorganic carbon then causes a lowering of the pH, shoaling the ALy (Klöcker and Henrich, 2006). In the Indian Ocean, the calcite saturation depth ranges from 2900 to 3900 m, with the deepest saturation situated in the central Indian Ocean (Sabine et al., 2002). The ALy is extremely shallow in comparison to the Caribbean Sea, between 200 and 1400 m, with the deepest saturation levels occurring to the south-west (Sabine et al., 2002). At ODP Site 716, the ALy is positioned at 600 m, less than 100 m below the coring site (Sabine et al., 2002). However, pteropod remains have been found previously from this area (Gischler, 2006) and have also been noted for their abundance within ODP Hole 716B (Cullen and Droxler, 1990; Sarkar and Gupta, 2009). Core collection, sampling techniques and oxygen

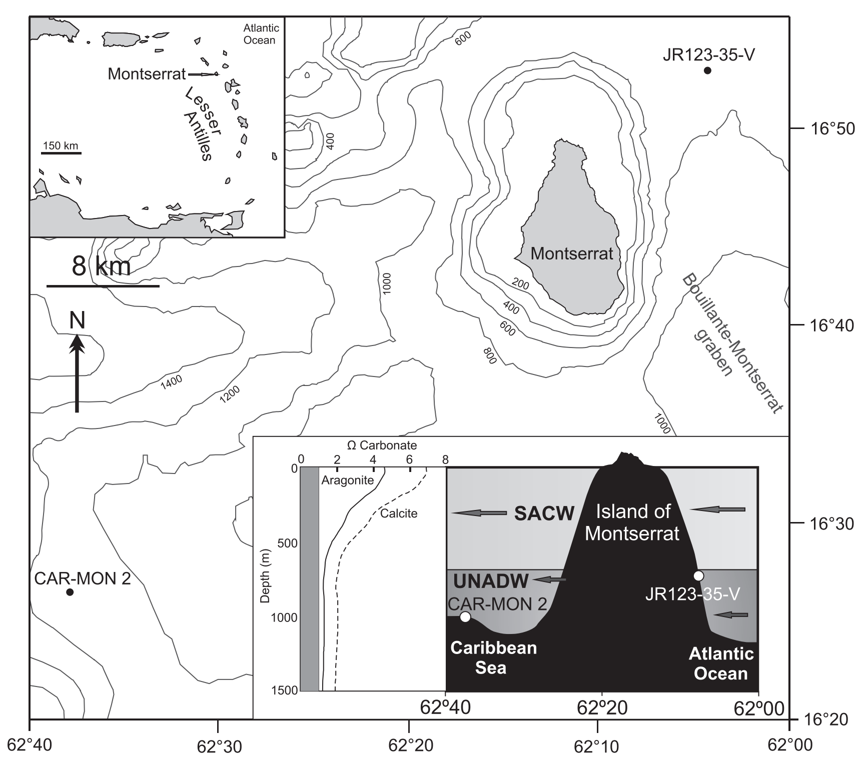


**Fig. 1.** Location of Caribbean sites CAR-MON 2 and JR123-35-V around the island of Montserrat. Inset carbonate saturation profile of the Caribbean Sea from GLODAP site 17.03N, 66′W (Key et al., 2004). Inset modern water masses around the island of Montserrat, with the relative position of study sites. South Atlantic Central Water (SACW), Upper North Atlantic Deep Water (UNADW). UNADW contains a maximum of 10% Antarctic Intermediate Water. Information from Gerhardt and Henrich (2001).