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Understanding a bimineralic bryozoan: Skeletal structure and carbonate mineralogy of *Odontionella cyclops* (Foveolariidae: Cheilostomata: Bryozoa) in New Zealand

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ABSTRACT

Skeletal carbonate mineralogy of the bryozoan *Odontionella cyclops* (Busk, 1854) (family Foveolariidae) is extremely variable, with calcite:aragonite ratio ranging from 27 to 100 wt.% calcite (mean = 57 wt.% calcite, SD = 15, n = 118), and Mg content in calcite varying from 3.6 to 8.8 wt.% $MgCO_3$ (mean = 6.2 wt.% $MgCO_3$, SD = 1.1, n = 118). This study examines the sources of this wide variability and the possible effects of ocean acidification on bimineral invertebrates. Variation in calcite:aragonite ratio in *O. cyclops* is neither environmental nor related to colonial growth form, but appears to be astogenetic. Primary calcification of the zooecial 'box' is all calcite, followed by progressive construction of a secondary aragonitic superstructure which includes avicularia. Consequently, young parts of the colony are dominated by calcite, with increasing amounts of aragonite with age. Very old parts of the colony may have the aragonite eroded or chipped away to become again entirely calcitic. In contrast with many other bryozoans that are entirely calcitic or mainly aragonitic, this bipartite structure may result in increased vulnerability to ocean acidification. Given the southern-temperate shelf-to-slope distribution of this species, *O. cyclops* (and others like it) will begin to be subjected to decreasing pH in only a few decades. The consequence could be a modern sediment assemblage similar to a diagenetically-altered fossil assemblage — missing aragonitic skeletal parts and species.

1. Introduction

As science increasingly attempts to come to grips with the potential impacts of CO_2-driven acidification of shallow marine waters, it is becoming clear that we know far too little about mineralisation in temperate marine invertebrates. Some groups of organisms usually produce skeletons that are fairly mineralogically consistent, and these calcifiers, such as corals and coralline algae, might be expected to struggle with a rapid decrease in pH and carbonate ions. But some invertebrates are quite variable biomineralisers, incorporating two or more minerals in a layered or otherwise organised skeleton. Analysis of such complex biomineral skeletons is necessary to enable a wider understanding of how such complex calcifying invertebrates might fare in the lower-pH seas of a high-CO_2 world (Raven et al., 2005; Orr et al., 2005; McNeil and Matear, 2008).

Odontionella cyclops (Busk, 1854) is a cheilostome bryozoan (family Foveolariidae) that forms encrusting and/or erect colonies, occurring across New Zealand from Three Kings (34°S) to the Auckland Islands (52°S) in water depths ranging from 8 to 800 m (Gordon, 1986, who at that time called it *Foveolaria (O.) cyclops*). In all its colonial growth forms, skeletal carbonate mineralogy is variable. Smith et al. (1998, 2006) reported on 15 specimens ranging from 34 to 63 wt.% calcite, with another 8 specimens showing almost 100% calcite (mean = 63.2 wt.% calcite, N = 23, SD = 23.8). In contrast, the Mg content in the calcite of these specimens was fairly consistent (ranging from 4.3 to 7.5 wt.% $MgCO_3$ in calcite, mean = 6.0, N = 23, SD = 0.7), particularly given the wide range found in cheilostome bryozoans generally (0 to 14 wt.% $MgCO_3$, see Smith et al., 2006).

What kind of mechanism allows for such a large degree of variation in calcite: aragonite ratio within a single species?

The standard explanation is that each zooid forms a box of calcite, subsequently adding a discrete secondary coating of aragonite, generally on the frontal wall (Ryland, 1970; Sandberg, 1983). Thus compositions of 30 to 60% calcite are related to how far along the zooid is in astogeny (possibly related to how old it is) and specimens with 100% calcite are either too young to have secondary calcification of aragonite, or much older, after the secondary aragonite has been abraded, chipped off, or dissolved (Ryland, 1970; Wejnert and Smith, 2008).

On the other hand, sometimes a high degree of variation is an environmental signal, as calcite: aragonite ratio in some bryozoans appears to vary with water temperature. Lowenstam (1954) found in *Schizoporella unicornis* a basic skeleton of calcite with aragonite forming the frontal wall. While the thickness of the frontal wall increased with age, it grew up to three times thicker in the tropics than in cold waters (Rucker and Carver, 1969). Another possibility is that we could be examining two or more cryptic species. Or indeed,

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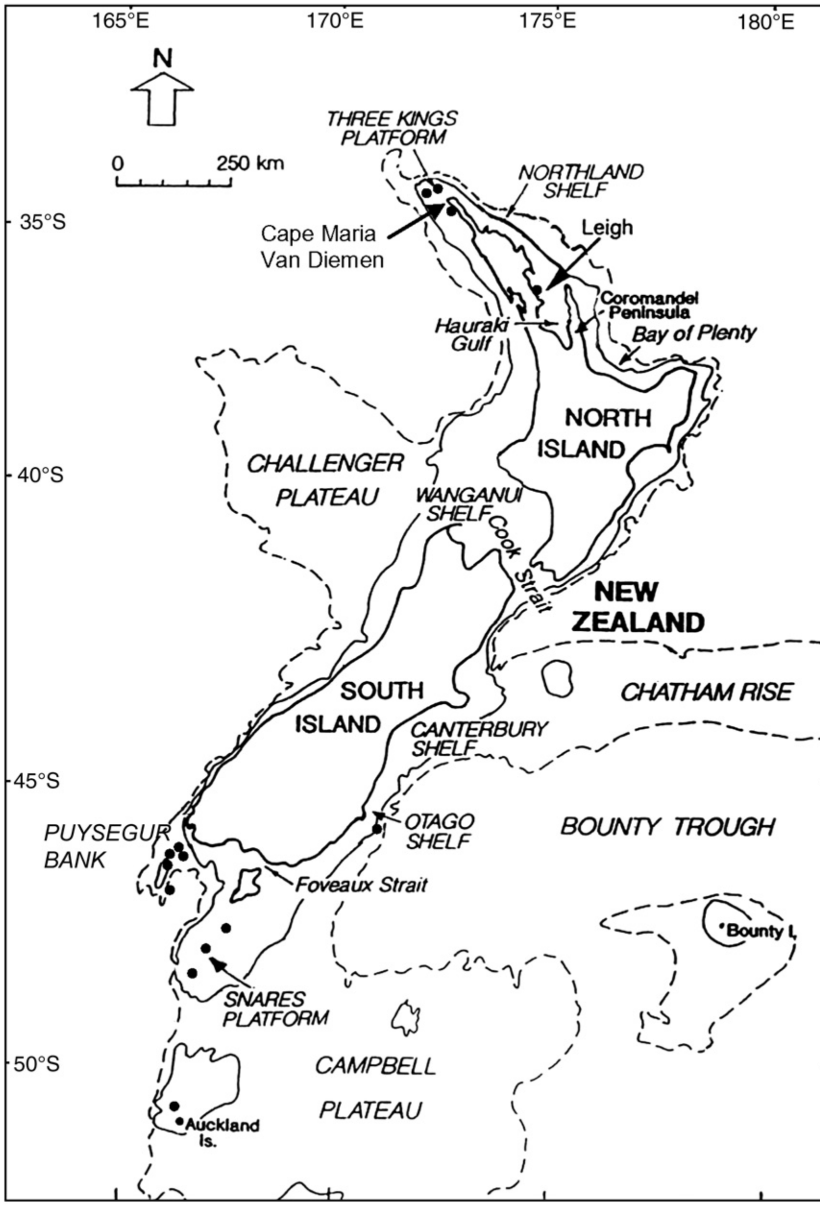

Fig. 1. Sample locations for *Odontionella cyclops* around New Zealand.

there could be a functional association between mineralogy and growth form (see, e.g., Bone and James, 1993).

Here we examine skeletal morphology and mineralogical variation in *Odontionella cyclops* from across New Zealand, with a view to understanding more about complex biomineralisation in temperate invertebrates.

2. Methods

Specimens of *Odontionella cyclops* were picked from carbonate sediment samples collected by grab and dredge from the New Zealand shelf (archived at Department of Marine Science, University of Otago, Dunedin, New Zealand). In the far north of New Zealand, samples were obtained from the Three Kings Platform, Cape Maria van Diemen, and Leigh (Fig. 1). There are few carbonate sediments to the east and west of New Zealand, but a concentration of bryozoans on the Otago Shelf to the southeast yielded some specimens. *O. cyclops* was common in dredged samples from Foveaux Strait, Snares Platform and Puysegur Bank, and was also found in sediments from near the Auckland Islands (Fig. 1; Table 1). One sample from near the Snares Islands (SN19) was particularly rich in *O. cyclops*, and provided specimens in four different growth forms (Fig. 2), following the classification of Nelson et al. (1988) and Smith et al. (2006): encrusting unilaminar (EN ul) and erect rigid

Table 1
Thirteen sample locations for *Odontionella cyclops* in New Zealand (see also Fig. 1).

Location	Latitude (°S)	Longitude (°E)	Water depth (m)
Three Kings	33.90	172.28	187
Cape Maria van Diemen	34.50	172.65	10
Leigh	36.27	174.80	20
Otago Shelf	45.50	170.52	86
Puysegur Bank 2	46.04	166.37	120
Puysegur Bank 3	46.05	166.28	145
Puysegur Bank 4	46.05	166.14	115
Puysegur Bank 6	46.13	165.97	208
Puysegur Bank 10	46.57	165.95	146
Snares 6	47.85	166.87	157
Snares 3	48.03	166.62	127
Snares 19	48.05	166.55	156
Auckland Islands	51.97	165.47	252