Calcification patterns of the coccolithophore
*Coccolithus braarudii* (Haptophyta), from the late Quaternary to present in the Southern Ocean

by

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Declaration of Originality

I declare that the material presented in this thesis is original, except where due acknowledgement is given, and has not been accepted for award of any other degree or diploma

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Dedication

To my beautiful man Philip (Felipe), for his love, patience and kindness…

To our gorgeous son Gabriel and the strength he has already given me…

To my dear family: my dad, Mariano, my mum, Pola, my sisters Paula and Pamela, and my beautiful nephews Benjamin and Emilio…
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Abstract

Ocean acidification, caused by a decrease in pH due to elevated anthropogenic CO₂ input from the atmosphere into the ocean, is the focus of intense current research with regard to biological impacts. Allegedly, the most affected species will be those that produce hard calcite and aragonite shells. In the present study, we assessed calcification and morphometry of the large-sized, heavily calcified coccolithophore genus *Coccolithus*, in the Southern Ocean, south of Tasmania.

Firstly, we characterised the species, past and present, in the Southern Ocean using the following source materials: fossil core-top material from Core GC07 (South Tasman Rise); recent sediment trap samples collected during Sept 2003 - Feb 2004 from the Subantarctic Zone (SAZ) south of the subtropical front (STF); and two newly isolated culture strains from coastal Tasmania. Results showed that only a single taxon, designated *Coccolithus braarudii* [(Gaarder, 1962) Baumann et al., 2003] sensu Geisen et al. (2002) and Young et al., (2003), was consistently present in the Southern Ocean, with coccolith length ranging from 10-16 µm and consistent presence of a central bar across the central area. Core-top sediments showed its presence for at least the past ~1000 years, and recent sediment trap samples demonstrated a well-established population from Sept 2003 to Feb 2004 (coccolith and coccosphere fluxes of ~ 6.87 x 10³ and ~ 2.11 x 10² counts/m²/day, respectively in September to over ~ 6.41 x 10⁶ and 1.23 x 10⁴ counts/m²/day in January 2004, respectively). Tasmanian culture material proved that this species was equally present both north and south of the STF (~ 46°S).

To evaluate calcification patterns, a method to estimate coccolith weight was newly adapted in order to suit this large, heavily calcified species. This method is based on the intensity of birefringence of individual coccoliths under cross-polarised light, measured in grey levels, which is converted into relative weight (picograms per pixels) through a calibrated transfer function. In its original approach, the birefringence technique is unsuitable for partially non-birefringent coccoliths in standard orientation, such as those of the family Coccolithaceae. However, we
here consider only the birefringent parts of the coccoliths, the proximal shield (PS) and central area (CA) to determine intra-specific coccolith weight variation. Since only part of the coccolith is measured, this constitutes a relative weight measurement, here called weight index (WI). In contrast to other methods that exclusively rely on coccolith length to estimate calcification, the advantage of this approach is that it decouples coccolith weight from length, to provide separate estimates of how each morphological feature of coccoliths responds to environmental changes. Furthermore, we advocate for a combined approach of WI and morphometry, to depict allometric relationships within coccoliths, i.e. how coccolith shape varies with size.

Sediment trap samples from the Subantarctic Zone (SAZ) were analysed for seasonal variations in the morphology of *C. braarudii*. Distal shield length (DSL), WI, and various other parameters of individual coccoliths were measured ($N = \sim 3000$), as well as coccolith and coccosphere concentrations estimated. Results showed an increase in WI, DSL and cell concentration from spring to summer, correlated with the seasonal increase in phytoplankton chlorophyll $a$. No correlation was found between WI and environmental parameters (Atmospheric CO$_2$, [CO$_3^{2-}$], DIC, sea surface temperature (SST) and nutrients), which appears to confirm earlier observations that this species is insensitive to chemical variations. However there was a positive correlation between DSL and SST. We also recorded the occurrence of a lighter, slightly smaller phenotype during early spring - which could be the remnant of a winter population - and a larger, heavier phenotype in mid-summer. Although this might indicate a constant allometric relationship between size and weight at a seasonal scale, the appearance of healthier populations in summer may suggest certain seasonal plasticity of *C. braarudii* coccoliths.

In order to analyse changes in WI and morphological parameters at a geological time scale, fossil material from sediment Core MD972106 was investigated from the Last Glacial Maximum (LGM, $\sim 20$ ka) through to the late Holocene ($\sim 4.2$ ka), and compared with recent sediment trap samples. Additionally, we incorporated a novel estimator for intra-specific variations in the degree of calcification, combining WI and DSL, resulting in a calcification index (CI). Coccolith weight (WI) in *C. braarudii* in the Southern Ocean has significantly increased (not decreased) from the
late Quaternary to the present, further confirming that this genus could be insensitive to changes in ocean chemistry composition.

Lighter, larger coccoliths during the LGM could imply degrees of calcification would be lower as a trade-off for larger coccolith under glacial conditions. Holocene material contained a smaller, heavier phenotype, while a larger, heavier phenotype was present in contemporary oceans. While variations in DSL were correlated with environmental parameters such as SST, atmospheric CO₂ (ppmv) and CO₃²⁻ concentrations ([CO₃²⁻]), WI was not related to any of these variables. Our results showed that the scaling between size and weight (allometry) of coccoliths was not constant over geological time, indicating subtle but significant changes in the mean shape of _C. braarudii_, and that the allometric relationships at a seasonal scale may represent short term adaptation processes. CI exhibited a clear response to environmental parameters, especially SST, implying that variable allometry between size and weight underpins phenotypic plasticity in this species, which is assumed to be an adaptive response to changing environmental conditions.