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Planktonic Foraminifera: From production to preservation of the oceanographic signal

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2013

document version
Publisher's PDF, also known as Version of record

Link to publication in VU Research Portal

citation for published version (APA)
Metcalfe, B. (2013). *Planktonic Foraminifera: From production to preservation of the oceanographic signal*. [PhD-Thesis - Research and graduation internal, Vrije Universiteit Amsterdam].

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Download date: 04. Aug. 2024

Summary

For the past 150 years, since the Industrial Revolution, humanity has emitted a range of greenhouse gases through the combustion of fossil fuels, land-use change and deforestation. As of the 10th May 2013 atmospheric concentrations of the greenhouse gas Carbon dioxide reached 400 ppm for the first time in 3-5 Million years, at a rate unseen for the past 35 Million years. Carbon dioxide traps heat in the atmosphere leading to Global warming. There is, however, another CO_2 problem which lies within the ocean: without the ocean acting as a reservoir, the atmospheric concentrations of CO_2 would be ~25% higher. The consequence of this oceanic-mitigation however, is a change in the carbonate chemistry of the seawater and a shift toward lower pH levels, referred to as Ocean Acidification.

The oceans are an important resource. For 3 billion people fish accounts for ~16% of their annual consumption of protein whilst for about a billion others it is the primary source. By the turn of the next century atmospheric concentrations of CO_2 are predicted to exceed 1000 ppm and the global surface *p*H is expected to reduce by 0.14-0.35 units, dependent upon socio-economic factors. Measurements of ocean conditions prior to the instrumental record rely on so-called proxies. Predicting the future requires an understanding of the past through the use of so-called 'proxies'. The shells of calcifying plankton such as coccolithophores, pteropods and foraminifera, settle to the seafloor after death leaving a record of it preserved in the sediment, as the ocean floor is covered in the meter thick remains of this plankton. The geochemical ($\delta^{18}O$, $\delta^{11}B$, $\delta^{13}C$, Mg/Ca) and physiological (faunal abundance, shell weight) composition may be used to reconstruct hydrological characteristics that can no longer be measured directly.

Over the past 800,000 years the *p*H of seawater has oscillated between 8.3 during glaciations and 8.2 during interglacials, following a change in atmospheric pCO_2 of ~90-100 ppm. The shell weight of planktonic foraminifera tracks changes in the carbonate ion concentration ($[CO_3^{2-}]$), with a 40% reduction across the last glacial maximum (LGM). Given the modern emission of CO_2 and the change in seawater chemistry the modern shells of planktonic foraminifera from the Southern Ocean and the Arabian Sea are somewhat lighter by 25-35% than their pre-industrial revolution counterparts. Proxies are neither the unaltered, nor original,

signal and therefore their reliability is dependent upon the assumptions made. Seasonal temperature changes, depth migration, seafloor dissolution, the activity of the benthos may alter these proxies. It is imperative for modelling future scenarios that we understand the processes affecting proxies from production to preservation.

Laboratory monocultures have shown that there will be winners and losers from the impact of Ocean acidification, however these do not simulate the real world, nor do they attempt to. In order to relate culture results to real processes we can use the geological record as it represents a natural archive of *p*H and pCO_2 change. To get to this signal we must unpick various competing signals (i.e. seasonality, depth habitat, bioturbation, dissolution and methodological error). This thesis aims to test the features that may alter, affect or negate the impact of Ocean acidification in the geological record, using Planktonic foraminifera.

In *Chapter Two* **'Shell weight of planktonic foraminifera: Points and perspectives'** we discuss the Planktonic foraminifera shell weight proxy in detail, based upon the results of a series of experiments and discussions of the European Project on Ocean Acidification (EPOCA) shell weight experiment following the Joint EPOCA-BIOACID meeting in Bremerhaven (2011).

Then in *Chapter Three* **'*The effect of chemical pre-treatment of sediment upon foraminiferal based proxies*'** we focus upon the application of chemicals, such as sodium pyrophosphate and peroxide utilised in sediment laboratories to remove foraminifera from sediment cores. These chemicals may impact upon the geochemical and physiological characteristics of planktonic foraminifera which could induce potential bias or artefacts in proxy measurements between laboratories.

In *Chapter Four* **'Is size dependent isotopic variability in planktonic foraminifera constant over a Glacial - Interglacial cycle?'** we aim to resolve an outstanding question what sieve size should be used in reconstructions involving oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) stable isotopes. The literature provides contradictory answers using conventional isotope analysis [*Birch et al.,* 2013; *Elderfield et al.,* 2002; *Friedrich et al.,* 2012]. Isotopic differences between shells from different size fractions could reflect changes in metabolism during ontogeny or, alternatively, it could also reflect changes in the depth habitat of foraminifera. Ocean acidification is predicted to impact surface communities first and have a drastically more negative effect upon juvenile forms.

In *Chapter Five* ***'Are all sieve size fractions equally suited to obtain a shell mass proxy for past CO_2 variability?'*** we aim to test the robustness of the shell mass proxy by validating size-fractionated shell mass. Most shell weight studies prior to picking, weighing and measuring the size use sieving to concentrate foraminifera. The choice of sieve

size aims to help the researcher by concentrating the greatest abundance of easily identifiable foraminifera of a given species. A question remains does sieve size selection impact upon the shell weight record? With this in mind in this chapter we extend the shell weight record in the North Atlantic Ocean back to Termination III (~230kya) using the shallow dwelling *Globigerina bulloides* and deeper dwelling *Globorotalia inflata* and *Globorotalia truncatulinoides* (dextral) from four size fractions.

Then in *Chapter Six* ***'Quantifying sea surface temperature ranges of the Arabian Sea for the past 20,000 years'*** we attempt to reconstruct seasonality using two species with distinctly different seasonal preferences, *Globigerina bulloides* and *Globigerinoides ruber*, from the upwelling area off Somalia. *de Moel et al.* [2009] from a core located close to this location observed a decrease in shell weight of *G. ruber* following the Industrial revolution to the present. However, their conclusions were limited by the observation that shell weights of *G. ruber* during seasonal upwelling events were lighter than non-upwelling conditions. In order to strengthen this we attempt to reconstruct the seasonality at this core site.

Subsequently in *Chapter Seven* ***'A field experiment to quantify the effect of post depositional dissolution'*** using a depth transect in the North Atlantic we focus our attention upon the effect of dissolution on both shell weight and stable isotopes of planktonic foraminifera. A number of authors have attempted to qualify and quantify the extent of dissolution using scanning electron microscopy, yet with no reference to the original pre-mortem wall textures. Thus, we will describe the wall texture of *G. bulloides* and *G. inflata* from field collected plankton tows.

In *Chapter Eight* **'Deducing the echoes from the voices of the past: a closer look at oxygen isotope frequency distributions of fossil foraminifera'** we apply the single specimen oxygen isotope method to a North-South transect core top of *G. inflata*. Unlike *G. bulloides*, *G. inflata* shows no trend with latitude despite changes in both carbonate ion concentration, with higher latitudes having lower concentrations than lower latitudes, and changes in seasonality. We will elaborate upon the work of *Wit et al.* [2013] in this respect, to test whether lower latitude cores have a larger flux of individuals that have through bioturbation been brought to the surface.

Chapter Nine ***'Synthesis and Outlook: Senses and Sensitivity'*** provides a summary of the results presented in this thesis.