Sensing Seasonality by Planktonic Foraminifera

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Summary

Planktonic foraminifera are unicellular zooplankton that form a shell of calcium carbonate and inhabit the upper layers of the world oceans. These organisms have no active means of propulsion and the approximately 48 modern species are characterized by being either spinose or non-spinose, symbiotic or non-symbiotic and being micro-, meso- or macroperforate. Many species of planktonic foraminifera have specific habitats, most with a regional restriction and living only within certain climate zones, others with a clear depth preference calcifying either only within surface waters or down to 1000 meters water depth. Hence, the stable isotope signal recorded within their calcite shell can hold very explicit information on seasonal hydrological and temperature conditions of the world oceans.

The stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope composition of planktonic foraminiferal tests has been used for palaeoclimate and palaeoceanographic reconstructions ever since the mid-1950s. Foremost, the $\delta^{18}O$ of foraminifera has proven to be a good indicator of the (mean) temperature and isotopic composition of the water in which the test was precipitated. Several factors can bias the planktonic foraminiferal stable isotope record, i.e. pre-depositional (e.g. the vital effect) and post-depositional (e.g. bioturbation), and need to be accounted for when interpreting data from sediment cores.

Large scale climate variability, e.g. glacial-interglacial cycles, has been the subject of palaeoceanographic studies since the 1960's. Subsequently, with advances in sampling methodology and measuring techniques, the resolution and quality of data records greatly improved. This progress led to studies unraveling short scale climate fluctuations, e.g. Dansgaard-Oeschger events (DO-events) and Heinrich Events (HE) since the 1980's. Where many studies of stable (oxygen) isotopes of planktonic foraminifera aimed at the highest possible resolution in time we are now able to investigate the stable isotope ranges within a sample by measuring individual shells and therefore gain insight into past (seasonal) variability. Within this thesis I aim to reconstruct seasonal variability in a sample by means of single shell analysis (SSA) of planktonic foraminifera covering the afore mentioned large and small scale climate fluctuations. This information will strengthen our knowledge on past climate perturbations and facilitate better predictions of future climate.

Chapter 2 '*The effect of chemical pre-treatment of sediment upon foraminiferal based proxies*' focusses on the use of chemical additives like sodium pyrophosphate and hydrogen peroxide to sediment samples to ease the recovery of foraminifera. These chemicals potentially change the geochemical composition and the robustness of the shells of planktonic foraminifera, which may introduce a bias to proxy measurements. Such biases could lead to unforeseen, artificial offsets when comparing inter-laboratory studies. Our results show, however, that the use of these additives have no significant impact on the geochemistry and physical appearance of planktonic foraminifera from the sediment.

Subsequently, in **Chapter 3** '*Do stable isotope values of planktonic foraminifera depend on measurement strategy?*' a methodological study is performed to identify the potential biases due to different measuring strategies. Researchers employ either pooled, crushed or whole, specimen analysis or single shell analysis (SSA) but as there is no agreement on what method to use when, where and why inter laboratory comparisons of stable isotope data could suffer from unanticipated artifacts. Results for *Globigerina bulloides*, *Globigerinoides ruber* and *Neogloboquadrina dutertrei* show that the crushing of shells can have a significant impact on the stable isotope results. Furthermore, this study gives an indication of the number of specimens one would need to measure to acquire an acceptable standard error on the mean and suggests making a core stratigraphy with a species that has the least variability. This would require a short preliminary investigation on material from an envisaged core to assess the range on different species. Within our study we found that *N. dutertrei* has the least isotopic variability making this species well suited for isotope stratigraphy in cores from the Arabian Sea and Timor Sea used in this study.

In **Chapter 4** '*Sensing seasonality in the Arabian Sea: a coupled δ^{18}O-Mg/Ca approach*' two much used geochemical temperature proxies, δ^{18}O and the Mg/Ca ratio, were measured on the same individual tests of planktonic foraminifera. Measurements were performed on *G. bulloides*, *G. ruber* and *N. dutertrei* from the western Arabian Sea, off Somalia, and the eastern Arabian Sea, off Pakistan. The results showed no significant change in SW-monsoon strength between Interstadial 8 (IS8) and Heinrich event 4 (HE4) but do show increased seasonality during HE4 in the eastern Arabian Sea due to stronger winds, and, therefore increased mixing of the water column. Furthermore, this study reveals no correlation between both proxies. It is speculated that this is caused by isotopically lighter waters as a result of increased runoff or precipitation affecting the δ^{18}O of the foraminiferal shells and not the Mg incorporation.

Within **Chapter 5** '*Deglaciation changes the North Atlantic seasonality*' we attempt to unravel the seasonal succession of ice cover and related planktonic foraminiferal assemblages dynamics of the northern North Atlantic over Termination I. Single shell analysis of *Neogloboquadrina pachyderma* and *G. bulloides* combined with sediment trap data from different locations in the northern North Atlantic enable the tracking of the movement of the polar front. A bimodal distribution is seen in *N. pachyderma* during Termination I and was interpreted as a shift from calcification during a single short season during the glacial without ice cover, towards a biannual calcification stage during the glacial-interglacial transition. Finally, the absence of sea ice at the core location (56°N) during the interglacial again leads to a unimodal distribution. As the location of the polar front is tied to the formation of North Atlantic Deep Water (NADW), one of the drivers for the global conveyor belt, this study contributes to our knowledge on the global climate variability during Termination I. Furthermore, SSA results for both *N. pachyderma* and *G. bulloides* from the full glacial indicate that the inferred fresh water pulse associated with the interval of enhanced ice rafted debris (IRD), is not picked up by these foraminifera due to a seasonal offset between the foraminiferal growing season and the period of fresh water influx.

Chapter 6 '*The faunal response of planktonic foraminifera to seasonal changes in the North Atlantic during Termination III*' is based on SSA of *G. bulloides*, *Globorotalia inflata*, *Globorotalia truncatulinoides*$_{\text{dextral}}$ and *N. pachyderma* and pooled analysis of *Globigerinita glutinata*, *Neogloboquadrina incompta* plus the benthic species *Cibicidoides wuellerstorfi*. These stable isotope data combined with other proxies, e.g. the ratio of *N. pachyderma*/*N. incompta* and IRD abundance, indicate that during the glacial Marine Isotope Stage (MIS)8 there was reduced seasonality. Subsequently, the data yield information on the seasonal shifts between the sub-stages of interglacial MIS7, with more seasonal variability during the warm MIS7e and less during cold MIS7d.

Chapter 7 '*Reconstructing the depth of the permanent thermocline through the morphology and geochemistry of the deep dwelling planktonic foraminifer* Globorotalia truncatulinoides' reveals additional SSA on *G. truncatulinoides*$_{\text{sinistral}}$ from a fine (212-250 µm) and coarse (355-400 µm) size fraction. The $\delta^{18}O$ and $\delta^{13}C$ of different size fractions of both coiling varieties combined with the knowledge from previous studies allow for a depth reconstruction of the permanent thermocline before, during and after Termination III. As small specimens of the sinistral variety sink down the water column faster than their dextrally coiling counterparts, the $\delta^{18}O$ is similar to that of the large individuals. The results show the permanent thermocline located deepest during MIS8 followed by a significant shoaling through Termination III. After the glacial termination, during MIS7, the permanent thermocline was located deeper again.

In **chapter 8** '*Size dependent isotopic variability in Planktonic Foraminifera*' we analyzed the size dependency on the $\delta^{18}O$ and $\delta^{13}C$ of *G. bulloides*, *G. inflata* and *G. truncatulinoides*$_{\text{dextral}}$ a surface, intermediate and deep dweller, respectively. The results show no size-isotope correlation for *G. bulloides* yet small (212-250 µm) *G. inflata* and *G. truncatulinoides* are lighter in both $\delta^{18}O$ and $\delta^{13}C$ than larger (>250 µm) specimens. The likely cause for this offset is calcification by larger specimens of these globorotalids at greater depth at which the temperature is lower thus precipitating calcite more enriched in both ^{18}O and ^{13}C.

Chapter 9 'Synthesis and perspectives' collates the findings of all the studies in this thesis and provides a more elaborate overview of the most interesting results. Furthermore, within this chapter some of the potential caveats or 'pitfalls' of using the foraminiferal geochemistry as proxy for past climate are discussed. Lastly it provides some ideas for further investigation and potentially fruitful new avenues to embark on sparked by the findings in this thesis.