

Planktonic foraminifera –
Geochemical variability, eddies and
seasonality in the Mozambique Channel

Juliane Steinhardt

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VRIJE UNIVERSITEIT

Planktonic foraminifera –
Geochemical variability, eddies and
seasonality in the Mozambique Channel

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door

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geboren te Erfurt, Duitsland

promotoren: prof.dr. G.J.A. Brummer
 prof.dr. G.J. Reichart

"I have no special talents. I am only passionately curious."

Albert Einstein

Equipped with his five senses, man explores the universe around him and calls the adventure science.

Edwin Powell Hubble, *The Nature of Science*, 1954.



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Summary

Summary

Owing to their excellent fossil record, planktonic foraminifera play an important role as proxies for the reconstruction of oceanic conditions over geological time scales (e.g. Kucera et al., 2005). These proxies include the chemical composition of their shells that records the properties of the ambient seawater to which the planktonic foraminifer was exposed during biomineralization (e.g. Kucera and Schönfeld, 2007). The aim of this thesis is to investigate how planktonic foraminifera record seasonal change and ocean perturbations such as are commonly produced by large eddies passing through the Mozambique Channel.

In **chapter 2** seasonal and sub-seasonal patterns are investigated in a one-year time-series of species fluxes of planktonic foraminifera. In addition to the winter indicator species *Globigerinoides sacculifer*, I find that also *Globorotalia tumida*, *Globorotalia menardii* and *Globorotalia cultrata* exhibit clear winter maxima. *Candeina nitida* exhibits a minor late autumn 2008 and a more prominent summer bloom in 2009. Shell flux ratios of summer species *G. ruber* and winter species *G. trilobus* mimic the seasonal sea surface temperatures (SST) pattern, whereas flux ratios of *Neogloboquadrina dutertrei* and *Globorotalia scitula* correspond to winter mixed layer deepening. Superimposed on the seasonal trend, *Globigerinoides ruber* shows early flux maxima, with the onset of isotherm deepening during the passage of eddies. However eddy-correlated fluxes of *G. ruber* have a minor impact compared to seasonal forcing. On an annual basis, the flux-weighted species composition is very similar to that found in core top sediments taken across the channel. In general, the one-year seasonal flux intercepted by the sediment trap appears to be a relatively average year, while the time-averaged sediments appear to preserve both seasonal and eddy-generated fluxes. Based on previously published stable isotope and trace-metal data (Fallet et al., 2012; Birch et al., 2013; Steinhardt et al., 2014; 2015), annual flux based calculated isotope and trace metal-based proxies correspond well with values measured in sea floor sediments, albeit slightly elevated calculated potential annual flux-weighted Mg/Ca values for *G. ruber*. Recent warming in the southern Indian Ocean might explain the calculated offset between sediment and sea surface temperatures.

In **chapter 3** the element composition of four species of planktonic foraminifera, collected by sediment traps, are compared to in situ water column conditions in the Mozambique Channel. Single-chamber trace element composition of these foraminifera reveals a close coupling with hydrographic changes induced by anticyclonic eddies. Single-chamber Mg/Ca values for the surface dwelling *Globigerinoides ruber* as well as the thermocline dwelling *Neogloboquadrina dutertrei* follow temperature changes and reduced temperature stratification

during eddy conditions. At greater depth, *Globorotalia scitula* and *Pulleniatina obliquiloculata* record stable temperatures and thus respond to hydrographic changes with habitat deepening. During eddy conditions the thermal gradient between the surface water and the thermocline is reduced whereas the gradient between thermocline and deep water is larger. This is reflected in a reduced difference in the Mg/Ca based temperatures between *G. ruber* and *N. dutertrei* and a larger difference in Mg/Ca based temperatures between *N. dutertrei* and *G. scitula*. The temperature difference between the two species, *N. dutertrei* and *G. scitula*, is greater than Mg/Ca calibration-related uncertainties and hence likely to be a proxy suitable for down-core application. Furthermore, test Mn/Ca values indicate a relationship between water column oxygenation and Mn incorporation in these planktonic foraminiferal species. Coinciding with a water column O₂ minimum, *P. obliquiloculata* and *G. scitula* record higher Mn/Ca values in line with water column variability in dissolved Mn concentrations, whereas near-surface dwelling *G. ruber* and shallow thermocline dwelling *N. dutertrei*, inhabit well oxygenated surface waters and show lower Mn/Ca values in their tests.

Chapter 4 investigates the vertical migration of planktonic foraminifera through the water column during life, meeting a range of depth-related conditions as they grow and calcify. Single-chamber Mg/Ca is combined with single shell $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ of surface water *Globigerinoides ruber*, the thermocline-dwelling *Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata* and the deep dweller *Globorotalia scitula* from the Mozambique Channel. Species-specific Mg/Ca, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ data combined with a depth-resolved mass balance model confirm distinctive migration and calcification patterns for each species as a function of hydrography. Whereas single specimen $\delta^{18}\text{O}$ does not always reveal changes in depth habitat related to hydrography (e.g. temperature), measured Mg/Ca differences of the last chambers can only be explained by migration in response to changes in temperature stratification. Results show that the single chamber Mg/Ca and single test $\delta^{18}\text{O}$ are in agreement with each other and in line with the changes in hydrography induced by eddies. Whereas single chamber Mg/Ca values are most affected by eddy frequency, seasonality is reflected more clearly in single test $\delta^{18}\text{O}$.

In **chapter 5** I investigate the calcite veneer, crust or cortex that some planktonic foraminifera form at the end of their lifecycle. This additional calcite layer may vary in structure, composition and thickness, potentially accounting for most of their total shell mass and thereby dominating the element and isotope signature of the whole shell. In this chapter I apply laser ablation ICP-MS profiling to assess variability in thickness and Mg/Ca composition of shell walls of three encrusting species derived from sediment traps. Compositionally, Mg/Ca is significantly lower in the crusts of *Neogloboquadrina dutertrei* and *Globorotalia scitula*, as well as in the cortex of

Pulleniatina obliquiloculata, independent of the species-specific Mg/Ca of their lamellar calcite shell. Wall thickness increased by nearly half of the total thickness in both crustal species and nearly a third in cortical *P. obliquiloculata*, regardless of their initial shell wall thickness. Crust thickness and Mg/Ca decreases towards the younger chambers in *N. dutertrei* and to a lesser extent, also in *G. scitula*. In contrast, the cortex of *P. obliquiloculata* shows a nearly constant thickness and uniform Mg/Ca over the complete specimen. Patterns in the thickness and Mg/Ca of the crust indicate that temperature is not the dominant factor controlling crust formation. Instead, I present a depth-resolved model explaining compositional differences within individuals and between successive chambers as well as compositional heterogeneity of the crust and lamellar calcite in all three species studied here.

In **chapter 6** “Synthesisis and perspectives”, results of the different chapters in this thesis are combined to calculate the potential differences of the various species used throughout the studies of this thesis. The calculation of the potential geochemistry (Mg/Ca and $\delta^{18}\text{O}$) takes into consideration shell fluxes and takes the differing crust and lamellar calcite components of the foraminiferal shell. Furthermore, this chapter also discusses issues that could potentially complicate the proposed eddy proxy. Also, inter- and intra-species differences of foraminiferal calcite U/Ca are discussed and compared to previous findings. Also, an attempt is made to speculate about promising research directions for the future.

Samenvatting

Door hun uitstekende record zijn planktonische foraminiferen belangrijke proxy-dragers voor de reconstructie van verschillende parameters van de oceaan over geologische tijdschalen (e.g. Kucera et al., 2005). De chemische samenstelling van de kalk schelpjes gemaakt door deze foraminiferen registreert de eigenschappen van het omgevende zeewater tijdens de biomineralisatie (e.g. Kucera and Schönfeld, 2007). Het doel van dit proefschrift is om te onderzoeken hoe de schelpen van planktonische foraminiferen seizoensgebonden veranderingen vastleggen, en of het mogelijk is om oceaan verstoringen van zogenoemde eddies, die door de Straat van Mozambique passeren, te herkennen.

In **hoofdstuk 2** worden seizoensgebonden en sub-seizoensgebonden patronen in de fluxen van verschillende soorten planktonische foraminiferen gedurende een tijd-serie van een jaar onderzocht. Naast de typische winter indicatorsoorten *Globigerinoides sacculifer*, concludeer ik dat ook *Globorotalia tumida*, *Globorotalia menardii* en *Globorotalia cultrata* een duidelijke winter maxima vertonen. *C. nitida* vertoont een duidelijke maxima in het late najaar van 2008 en een meer prominente zomerbloei in 2009. Schelp flux verhoudingen van de zomersoort *Globigerinoides ruber* en wintersoort *G. trilobus* bootsen de seizoensgebonden SST patroon na, terwijl de verhouding tussen de flux van *Neogloboquadrina dutertrei* en *Globorotalia scitula* overeen komt met een verdieping van de gemengde laag in de winter. Bovenop de seizoensfluctuatie, toont *G. ruber* vroege flux maxima, met de start van verdieping van isotherm tijdens het passeren van eddies. Maar deze aan eddies-gecorrleerde flux van *G. ruber* hebben een geringe invloed in vergelijking met het seizoen-effect. Op jaarbasis is de flux-gewogen soortensamenstelling zeer vergelijkbaar met die gevonden in het bovenste sediment van het kanaal transect. Hieruit volgt, dat de eenjarige seizoengebonden flux verzameld door de sedimentval een gemiddeld jaar blijkt te zijn, terwijl het door de tijd gemiddelde sediment zowel seizoensgebonden en eddy-gegenereerde stromen bevat. Proxies gebaseerd op de isotopen en spoormetalen van de jaargemiddelde flux komen goed overeen met de waarden gemeten in zeebodem sedimenten, zij het licht verhoogde voor *G. ruber*. Recente opwarming in de zuidelijke Indische Oceaan zou dit verschil tussen sediment en zee oppervlakte temperaturen kunnen verklaren.

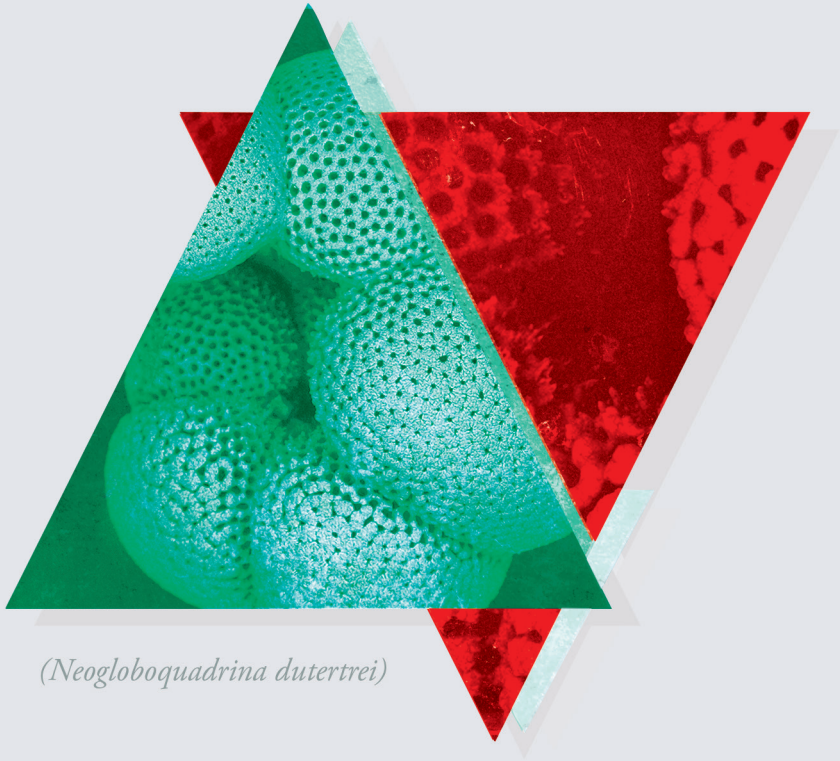
In **hoofdstuk 3**, worden de element samenstelling van vier soorten planktonische foraminiferen, verzameld door sedimentvallen, vergeleken met in situ waterkolom omstandigheden in de Straat van Mozambique. De analyses per kamer van deze foraminiferen onthult een nauwe koppeling tussen het voorkomen en de distributie van sporenelementen en hydrografische

veranderingen bij het passeren van anticyclonische eddies. Mg/Ca waarden van individuele kamers van (de aan het oppervlakte levende) *Globigerinoides ruber* en (de in de thermocline levende) *Neoglobobulimina dutertrei* volgen de temperatuursveranderingen en verminderde thermische stratificatie tijdens eddy condities. Op grotere diepte, registreren *Globorotalia scitula* en *Pulleniatina obliquiloculata* stabiele temperaturen en reageren daarmee op hydrografische veranderingen door hun habitat te verdiepen. Tijdens eddy omstandigheden wordt de thermische gradiënt tussen het oppervlaktewater en de thermocline verminderd, terwijl de gradiënt tussen thermocline en diepere water groter is. Dit blijkt uit een kleiner verschil in Mg/Ca gebaseerde temperaturen tussen *G. ruber* en *N. dutertrei*, en een grotere verschil in Mg/Ca gebaseerde temperaturen tussen *N. dutertrei* en *G. scitula*. Het temperatuurverschil tussen de twee species, *N. dutertrei* en *G. scitula* is groter dan de Mg/Ca-kalibratie gerelateerde onzekerheden en is daarom waarschijnlijk een geschikte proxy voor down-core-applicatie. Daarnaast duiden Mn/Ca waarden in schelpen van planktonische foraminiferen op een relatie tussen de waterkolom zuurstofvoorziening en inbouw van Mn. *P. obliquiloculata* en *G. scitula* bevatten hogere Mn/Ca waarden tijdens zuurstof minima in de waterkolom, wat overeen komt met de waterkolom variabiliteit van opgeloste Mn concentraties, terwijl de dicht aan de oppervlakte levende *G. ruber* en ondiepe thermocline levende *N. dutertrei*, in goed zuurstofrijke oppervlaktewater leven en daardoor lagere Mn/Ca-waarden in hun schelpjes tonen.

Hoofdstuk 4 onderzoekt de verticale migratie van planktonische foraminiferen tijdens hun leven door de waterkolom, waar zij een aantal diepte-gerelateerde condities tegen komen tijdens hun groei en calcificatie. Mg/Ca metingen aan individuele kamers worden gecombineerd met individuele schelp $\delta^{18}\text{O}$ en $\delta^{13}\text{C}$ van (de aan het oppervlakte levende) *Globigerinoides ruber*, (de in de thermocline levende) *Neoglobobulimina dutertrei* en *Pulleniatina obliquiloculata* en (de in dieper water levende) *Globorotalia scitula* van het Straat van Mozambique. De combinatie van soort specifieke Mg/Ca, $\delta^{13}\text{C}$ en $\delta^{18}\text{O}$ data met een diepte-resolutie massabalans model, bevestigen de verschillende migratie en calcificatie patronen voor elke soort als een functie van hydrografie. Individuele schelp $\delta^{18}\text{O}$ kunnen niet altijd veranderingen van de diepte van het habitat in relatie met hydrografie (b.v. temperatuur) onthullen, maar de verschillen in Mg/Ca van de laatste kamers kunnen alleen worden verklaard door migratie van de foraminifeer als een reactie op veranderingen in temperatuurstratificatie. Deze resultaten laten zien dat de individuele kamer Mg/Ca en schelp $\delta^{18}\text{O}$ metingen in overeenstemming zijn met elkaar en overeen komen met de veranderingen die eddies veroorzaken in de hydrografie. Waar individuele kamer Mg/Ca waarden het meest worden beïnvloed door eddy frequentie, weerspiegelen individuele schelp $\delta^{18}\text{O}$ metingen de seizoensnaliteit duidelijker.

In **hoofdstuk 5** onderzoek ik het calciëet fineer, korst of cortex die sommige planktonische foraminiferen aan het einde van hun levenscyclus vormen. Deze extra calciëet laag kan variëren in structuur, samenstelling en dikte, en dragen potentieel het grootste deel van hun totale schelp massa bij, waardoor deze laag de element en isotoop compositie van de hele schelp domineren. In dit hoofdstuk pas ik Laser-Ablatie-ICP-MS profilering toe, om de variabiliteit in Mg/Ca en dikte van de schelpwanden van drie korstvormende soorten uit van sedimentvallen te onderzoeken. Qua samenstelling is de Mg/Ca in de korst significant lager van *Neogloboquadrina dutertrei* en *Globorotalia scitula*, evenals de cortex van *Pulleniatina obliquiloculata*, ongeacht de species-specifieke Mg/Ca van de gelamelleerde calciëet schelp. Door korst/cortex-vorming neemt de dikte van de wand bijna de helft toen beide korst species en bijna een derde toe in de corticale *P. obliquiloculata*, ongeacht de initiële wanddikte van de schelp. Korstdikte en Mg/Ca neemt af naar de jongere kamers in *N. dutertrei* en in mindere mate ook in *G. scitula*. In tegenstelling, de cortex van *P. obliquiloculata* toont een vrijwel constante dikte en uniforme Mg/Ca compositie over het gehele specimen. Uit patronen in korstdikte en Mg/Ca blijkt dat temperatuur niet de dominante factor bij korstvorming is. In plaats daarvan, presenteer ik een diepte-resolutie model die de verschillen in samenstelling binnen individuen en tussen opeenvolgende kamers, evenals de heterogeniteit van de compositie van de korst en gelamelleerde calciëet, verklaard in alle drie de soorten die hier bestudeerd worden.

In **hoofdstuk 6** „Syntheses en perspectieven“, worden de resultaten van de verschillende hoofdstukken in dit proefschrift gecombineerd om de mogelijke verschillen tussen de diverse soorten, gebruikt in de studies van dit proefschrift, te berekenen. De berekening van de potentiële geochemie (Mg/Ca en $\delta^{18}\text{O}$) houden rekening met schelpen flux en omvat de verschillen in korst en gelamelleerde calciëet van de foraminiferen schelp. Verder beschrijft dit hoofdstuk ook onderwerpen die mogelijk de voorgestelde eddy proxy zou kunnen compliceren. Daarnaast worden inter- en intra-species U/Ca verschillen in het calciëet van foraminiferen besproken en vergeleken met eerdere bevindingen. Ook wordt een poging gedaan om te speculeren op veelbelovende onderzoek richtingen voor de toekomst.



(Neogloboquadrina dutertrei)

Chapter 1

A general introduction

Chapter 1

A general introduction

Juliane Steinhardt

1. Introduction

1.1. A general introduction

Anthropogenic inputs of carbon dioxide to the Earth's atmosphere increasingly affect global climate (IPPC, 2014). The extent to which our climate will change is, however, still subject of intense debate (Alley et al., 2003; European Marine Board, 2003). This largely depends on future socio-economic developments and to a lesser extent on the unknown equilibrium climate under much higher CO₂ conditions than today (e.g. Harley et al., 2006). On a regional scale the uncertainty of predictions increases dramatically and particular components such as cloud cover, precipitation and storm frequency are often very difficult to predict. In turn, such small-scale processes have potentially strong feedbacks on global climate, adding to the general uncertainty in climate change scenarios. To better constrain regional processes, and hence global change, methods have to be developed to better understand their behaviour and potential impact on the global ocean-climate system.

The oceans form an important component of the global climate system. They alter our climate by various mechanisms, such as heat transport by means of ocean circulation or the sequestration of atmospheric carbon. Most of the solar radiation received at the Earth's surface is captured by the ocean and warms its surface waters. As a result of its heat capacity and circulation, the ocean has the ability to both store and redistribute this heat before it is released to the atmosphere (much of it in form of latent heat, that is, water vapour). Additionally, the ocean participates in the biogeochemical cycles and exchanges gases with the atmosphere, thus influencing its greenhouse gas content.

Transport of highly saline waters from the Indo-Pacific into the South Atlantic via the Agulhas leakage forms an important component of the global oceanic circulation. The Agulhas leakage is involved in regulating the Atlantic meridional overturning in the global climate (Fig. 1.1) and evidence indicates that Agulhas leakage is increased by anthropogenic climate change (Beal et al., 2011). Interactions between the Agulhas system and the climate over longer periods appear from paleoceanographic evidence in sediment cores that uses the abundance of planktonic foraminiferal species associated with modern day Agulhas waters in the South Atlantic (Peeters et al., 2004, Caley et al., 2014) and the geochemical composition of their shells in the Agulhas leakage area (e.g. Simon et al., 2013, Dyez et al. 2014). Models geared towards simulating future Agulhas leakage need to be constrained by quantitative proxies

for understanding the underlying longer-term mechanisms in the source area upstream of the retroflexion area that includes eddy transports in the Mozambique Channel. However, past variability of Agulhas leakage from upstream source areas that prominently include the Mozambique Channel, remains poorly known.

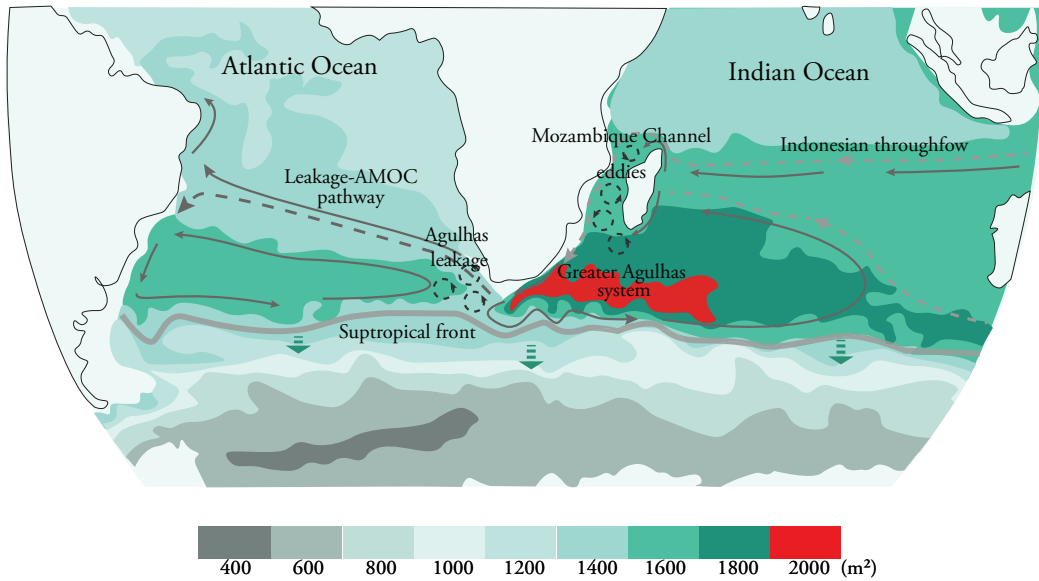


Fig. 1.1: Schematic of the greater Agulhas system within the Southern Hemisphere supergyre. Background colours show the mean subtropical gyre circulation, depicted by climatological dynamic height integrated between the surface and 2,000 dbar. The outline of the Southern Hemisphere supergyre is given by the grey dashed line, the subtropical front is given by the thick grey line (from: Beal et al., 2011).

1.2. The greater Agulhas system

1.2.1. Ocean circulation

The greater Agulhas system around southern Africa forms a key component of the global ocean circulation (Gordon et al., 1992; De Ruijter et al., 1999; Lutjeharms, 2006). Warm and saline water from the Indian Ocean is injected into the upper arm of the Atlantic meridional overturning circulation (AMOC) through the leakage via so-called Agulhas rings. These Agulhas rings are meso-scale eddies formed by occlusion at the Agulhas Retroflexion) from the Indian Ocean to the Atlantic off South Africa (Gordon et al., 1992; Donners and Drijfhout, 2004; Van Aken et al., 2004) (Fig. 1.1). Over geological time scales, its variability is associated with Southern Hemisphere westerly winds. These winds are related to the latitude

of the oceanic subtropical front (STF), separating the subtropical gyre from the Antarctic Circumpolar Current (Fig. 1.1). In short, if the westerlies shift southwards, in a warming climate, then the oceanic ‘gateway’ between the African continent and the STF expands and leakage from the Indian Ocean to the Atlantic increases (De Ruijter, 1982; Biastoch et al., 2009). As inferred from paleo-records, a northward shift such as during glacial periods, would reduce that leakage (Wefer et al, 1999; Bard and Rickaby, 2009; Rouault et al., 2009,).

Fluctuations in the strength of Agulhas leakage over the late-Pleistocene have been inferred from an assemblage of planktonic foraminifera representative of modern Agulhas waters in marine sediment records (Peeters et al., 2004). The reconstructions suggest that less Agulhas water was leaking into the South Atlantic during glacial periods, with the STF shifted several degrees northwards of its present-day position (Flores et al., 1999). The leakage started to increase during late-glacial conditions, preceding the disappearance of the full glacial ice volume (Berger and Wefer, 1996; Flores et al., 1999; Peeters et al., 2004). This leakage maximum, during glacial terminations, suggests that Agulhas leakage may have had a role in the rapid resumption of interglacial climate, presumably through its influence on the AMOC (Knorr and Lohmann, 2003; Peeters et al., 2004; Chiessi et al., 2008). The Agulhas Current is fed mainly by recirculating subtropical gyre waters, in addition to waters from the Red and Arabian seas, from the Indonesian Throughflow and from the equatorial Indian Ocean via Mozambique Channel eddies and the East Madagascar Current (EMC) (Song et al., 2004; Beal et al., 2006).

1.2.2. Water mass properties

The main water masses contributing to the upper layers in the Mozambique Channel are Tropical Surface Water (TSW), Subtropical Surface Water (STSW), and Indonesian Throughflow Water (ITFW) (Fig. 1.2). The TSW is a fresh but warm surface water mass, formed in the tropics by surface warming and excess precipitation, and is found within or north of the South Equatorial Current (SEC; New et al., 2007). Near the western margin the SEC bifurcates and continues poleward either east of Madagascar or through the Mozambique Channel (e.g. Swallow et al., 1988; Gründlingh et al., 1991). A subsurface salinity maximum (STSW) results from high salinity surface waters (Fig. 1.2), produced by excess evaporation, which subducts below the fresher TSW (Wyrski, 1973). The predominant water mass in the permanent thermocline is the South Indian Central Water (SICW). Intermediate waters in the southwest Indian Ocean are influenced foremost by salty Red Sea Water (RSW) from the north and fresh Antarctic Intermediate Water (AAIW) from the south. Identified by a strong salinity maximum and oxygen minimum, the RSW spreads over large parts of the Indian

Ocean, however mostly restricted to patches and lenses (Shapiro and Meschanov, 1991). The main tongue of RSW follows the African continent southward (Beal et al., 2000), diluting on its path as far south as the Agulhas Current (Beal and Bryden, 1999), where it potentially contributes to the Agulhas Rings (Lutjeharms and Gordon, 1987; Van Aken et al., 2003; Roman and Lutjeharms, 2007). Low salinity AAIW ($S < 34.5$), is transported northwards into

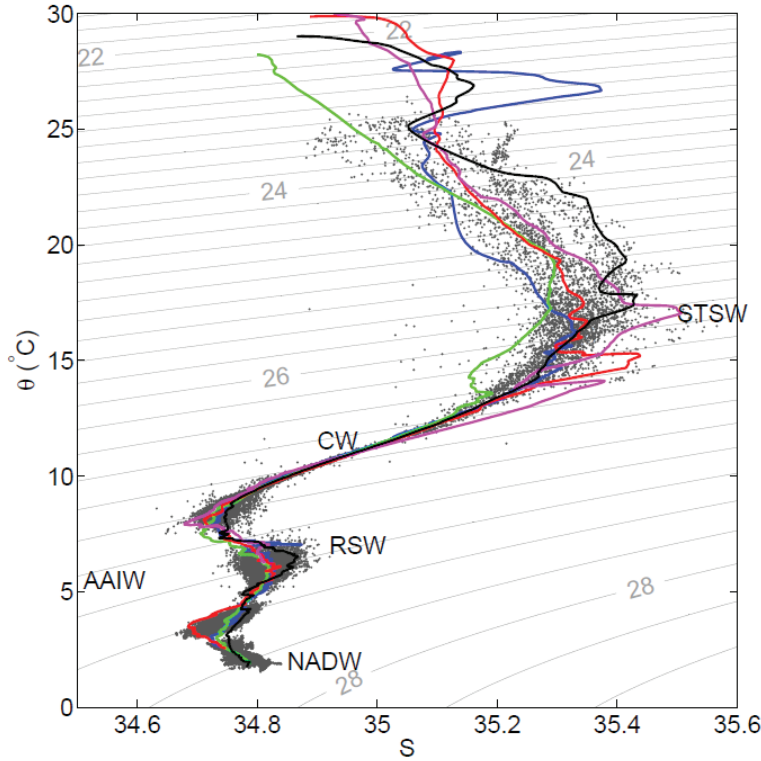


Fig. 1.2: Θ - S Diagram of the cross-section of the Mozambique Channel. Grey dots: daily average values from moored instruments. Lines: selected CTD profiles from the narrows transect, from 2003 (blue), 2005 (green), 2006 (red and pink), and 2009 (black). Main water masses are labelled: Sub-Tropical Surface Water (STSW), South Indian Central Water (SICW), Red-Sea Water (RSW), Antarctic Intermediate Water (AAIW), and North Atlantic Deepwater (NADW) (adapted from Ullgren et al., 2012).

the Mozambique Channel by the intermediate core of the Mozambique Undercurrent, which diminishes further north (de Ruijter et al., 2002). The northward transport of AAIW on one hand and eddy-transported RSW southward (Swart et al., 2010) on the other, results in a patchy distribution of low and high salinity intermediate waters that produce the varying zonal salinity patterns observed in the channel (e.g. de Ruijter et al., 2002; Donohue and

Toole, 2003).

1.2.3. Eddies

Ocean eddies and, more generally, mesoscale variability form a crucial component of the ocean circulation, including the large-scale and time-mean ocean circulation (Traon and Morrow, 2001). Eddies can be observed almost everywhere at mid and high latitudes, their energy generally exceeding the energy of the mean flow by an order of magnitude or more (e.g., Wyrski et al., 1976; Richardson, 1983; Schmitz and Luyten, 1991). In contrast to waves, they may transport mass and properties such as heat, salt, and chemical tracers including nutrients, salt and chemicals over long distances (Bakun, 2006; Xiu et al., 2011), thereby regulating marine species abundances and community composition (Owen, 1981; Sabarros et al., 2009; Huggett, 2014; Lamont et al., 2013). Anticyclones have a tendency for southward propagation and cyclones for northward propagation (e.g. Iseline and Fuglister, 1948; Fuglister, 1972; Morel and McWilliams, 1997; Morrow et al., 2004; Chaigneau et al., 2008). They can also

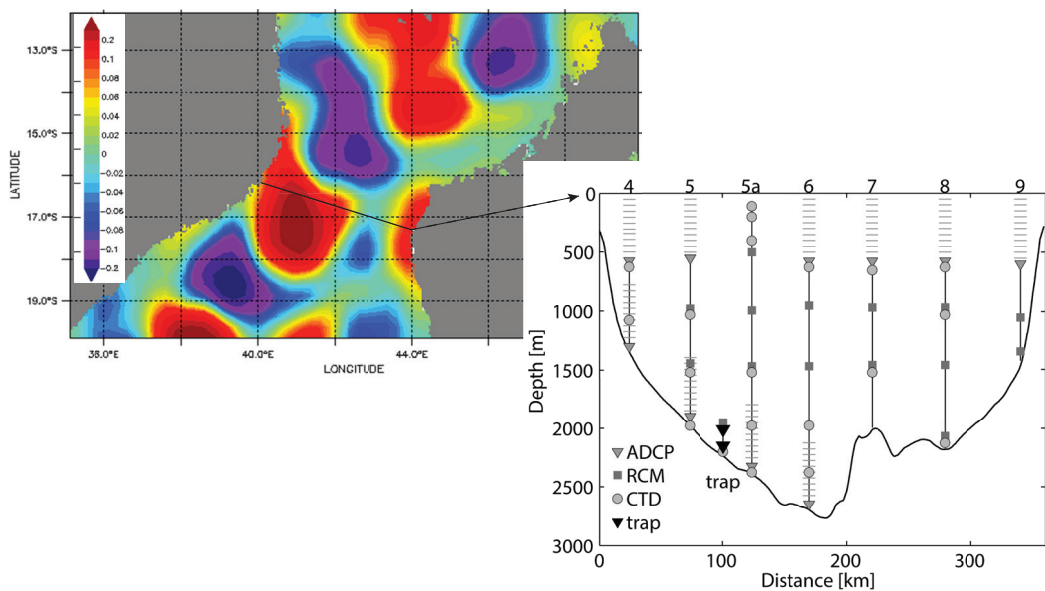


Fig. 1.3: Sea-level anomaly (SLA) map of the Mozambique Channel. Anti-cyclonic eddies passing through the Mozambique Channel are characterized by positive SLA (red). The black line indicate the mooring array, which is shown in detail on the right. The mooring array with current meters (squares), ADCPs (grey triangles); profiling range demonstrated by stripes), T–S sensors (circles), and sediment traps (black triangles).

feed energy back to the mean flow and drive deep circulation (Holland et al., 1982; Lozier, 1997) although their climate role in terms of heat and salt transport is still not well established.

Long-term moorings in the narrows of the Mozambique Channel show that on average five large anticyclonic eddies drift southwards through the channel per year, feeding the Agulhas Current (Fig. 1.3). These eddies can span a diameter of up to 350 km and can reach the seafloor, carrying a mean transport of 17 Sv (Ridderinkhof et al, 2010). Interannual variability is high (9 Sv), owing to upstream variations related to the phase of the Indian Ocean Dipole mode, an intrinsic mode of coupled climate variability in the tropical Indian Ocean (Ridderinkhof et al., 2010). Anti-cyclonic eddies in the MC account for up to 30 - 40% of the observed hydrographic variability (Ullgren et al., 2012). These eddies pass through the channel with a southward propagation speed of 3-6 km^d⁻¹ before joining the Agulhas Current. An eddy passage is associated with vertical movement of isopycnals, which can occasionally exceed 40 m per day in the upper layer (Ullgren et al., 2012). Eddy features such as temperature and altimetry data (e.g. sea level anomalies) can be used to identify the passing of an eddy over the sediment trap location. Ultimately, this allows coupling foraminiferal fluxes as well as foraminiferal shell geochemistry with hydrographic changes induced by anti-cyclonic eddies.

1.3. Planktonic foraminiferal proxies

The usefulness of planktonic foraminiferal shells as recorders of past-ocean and climate change was realized already by Murray (1897). Planktonic foraminifera are an ubiquitous group of protists that occupy an extraordinary position amongst the marine plankton as they are perhaps the most important producer of ocean carbonate, at an average of 3 Gt CaCO₃ globally per year (Schiebel, 2002). After planktonic foraminifera reproduce or die, their shells sink to the seafloor, where they accumulate in the sediment to form the so called “globigerina oozes” (Berger and Vincent, 1981). Since the early Cambrian, from approximately 541 million years (Ma) ago, calcifying foraminifera have inhabited the oceans (e.g. Pawslowski et al., 2003). Planktonic foraminifera, though, did not evolve until the Jurassic about 180 Ma ago (e.g. Cifelli, 1969). Our modern fauna originated more recently and can be traced back to an early Miocene adaptive radiation, from “globigerine” survivors of an extinct fauna at the Eocene/Oligocene boundary (Cifelli 1969; Kucera and Schönfeld, 2007; Aze et al. 2011).

Because of their excellent fossil record, the shells of planktonic foraminifera are widely applied in micropaleontological and oceanographic studies for reconstructing ocean surface properties during past climate change (e.g. Kucera & Schonfeld, 2007). Among the target properties are sea-surface temperature (e.g. Kucera et al., 2005), upwelling intensity (e.g. Conan and Brummer, 2000), and primary productivity (e.g. Ivanova et al., 2003). These properties are

reflected in the changing species composition of the shells, and their stable oxygen/carbon isotopes and element/calcium ratios. All provide powerful proxies for paleoceanographic reconstruction owing to the high productivity of shells and the high preservation potential in ocean sediments (e.g. Emiliani, 1955; Shackleton, 1974; Fischer and Wefer, 1999). However, for an accurate and reliable interpretation of species distributions, isotopic and elemental signatures from the fossil record, a detailed knowledge of the behaviour of modern species and associated environmental variables are needed to validate proxy application. This comprises the identification and quantification of the factors controlling the incorporation of stable isotopes and trace/minor element incorporation in a given species, considering its geographic and seasonal distribution as well as its calcification depth.

1.3.1. Stable isotopes

Following the pioneering works of Urey (1947) and Emiliani (1955), the calcite shells of foraminifera have been commonly used to reconstruct seawater temperatures from the stable oxygen isotope composition of their carbonate. However, next to temperature the oxygen isotope composition of foraminiferal calcite is also determined by another external factor, i.e. the oxygen isotope composition of the seawater itself that changes by evaporation and precipitation, and eventually to global ice volume on the time scales of climate change (Epstein et al., 1953; Shackleton et al., 1974; Bemis et al., 1998). In addition to external factors, isotope composition is affected by internal, physiological factors that introduce the so-called “vital effects” as offsets from the equilibrium calcification at a fixed temperature and isotope composition of the sea water (e.g. Urey et al., 1951; Shackleton et al., 1974; Lončarić et al., 2006; Conan, 2006). Vital effects are even stronger for the carbon stable isotopes in the same calcite shells, as incorporation is strongly impacted by symbiont activity (Spero and Williams, 1988, 1989; Spero, 1992; Spero and Lea, 1993). Later culturing experiments by Spero et al. (1997) also revealed strong effects related to the carbonate ion concentration of the seawater.

1.3.2. Element composition

In comparison to inorganic precipitates, foraminiferal calcite is two orders of magnitude lower in Mg^{2+} compared to Ca^{2+} (Bentov and Erez et al., 2006). The ratio of conservative elements (e.g. Mg, Sr, B, Li, U) to Ca is more or less constant in seawater given their long oceanic residence times. Any variations of these element/Ca ratios in foraminiferal shells found in modern samples must reflect physical and/or biological controls onto the calcification process. The compositional relationship between shell calcite and seawater is expressed by an empirical *partition coefficient* D , which is defined by:

$$\frac{[Te]}{[Ca]}_{(foram\ calcite)} = D \times \frac{[Te]}{[Ca^{2+}]_{seawater}}$$

where the bracket term indicates the ambient concentration ratios of the trace element (TE) to Ca in calcite and seawater (Morse and Bender, 1990; Mucci and Morse, 1990). If D is less than one, then the trace element is preferentially discriminated from the incorporation into the foraminiferal calcite, with a D greater than one, trace elements are preferentially concentrated in the foraminiferal calcite.

Several studies have demonstrated an increase in Mg/Ca in planktonic foraminiferal shells with increased temperature, and culturing experiments have confirmed that this temperature relationship is exponential (Nürnberg et al., 1996; Mashiotta et al., 1999; Lea et al., 1999, Hönisch et al., 2013) according to:

$$\text{Mg/Ca} = B \times e^{AT}$$

where T is the ambient temperature, B is a species-specific pre-exponential constant and A is the exponential constant, which reflects temperature sensitivity. Since these first innovative studies, many (including species-specific) calibrations have been proposed (e.g. Elderfield and Ganssen, 2000; Lea, 2000; Dekens et al., 2002; Anand et al., 2003; McKenna and Prell, 2004; McConnell and Thunell, 2005; Cléroutx et al., 2008; Chiessi et al., 2008; Regenberg et al., 2009; Fallet et al., 2010; Groeneveld and Chiessi, 2011).

1.3.3. Analytical approaches

There is particular interest in combining Mg/Ca temperatures with $\delta^{18}\text{O}$ measurements on the same shell material, in order to determine paleo-seawater $\delta^{18}\text{O}$, isolated from the temperature-dependent fractionation during shell precipitation (Mashiotta et al., 1999; Lea et al., 1999; Elderfield and Ganssen, 2000). In this way, paleo-salinity (and seawater density) can be estimated from relationships between seawater $\delta^{18}\text{O}$, temperature and salinity. For such purposes a detailed analysis of the compositional variation within a population of shells is necessary to understand which factors impact calcification of individual foraminifera (e.g. varying temperatures in different seasons and years). In recent years technical innovation, e.g. Laser Ablation Induced Coupled Plasma Mass Spectrometry (LA-ICP-MS), has further improved high-resolution analysis and allowed for very small amounts of calcite to be analysed (Reichart et al., 2003) for trace metal composition. With this technical improvement very small amounts of foraminiferal calcite can be analysed chamber-by-chamber for its trace metal composition. Recent approaches with this technique include intra-shell trace element distribution (e.g. Eggins et al., 2003, 2004; Hathorne et al. 2003, 2009; Sadekov et al., 2005), to identify diagenetic imprints (Pena et al., 2005, 2008; Van Raden et al., 2011; Bolton and Marr, 2013) and tracing of water masses (Marr et al., 2013).

Foraminifera are commonly measured in groups of specimens to ease instrumental performance (detection limit) and minimise specimen-to-specimen variability (seasonality). Pooling specimens yields climate conditions from the average composition of species populations in the sample. In the early 1980's instrumentation became available to analyse single shells for isotopes and constrain shell size related effects associated with different life-stages (Duplessy et al., 1981; Killingley et al., 1981). Besides the effects of ontogeny, depth habitat and symbionts on calcification (collectively termed vital effects, e.g., Berger et al., 1978; Oppo and Fairbanks, 1989; Wefer and Berger, 1991; Rohling and Cooke, 1999), single specimen analysis should resolve short-scale oceanographic variability that is related to seasonality or climate excursions such as El Niño events (Billups and Spero, 1996; Koutava et al., 2006; Leduc et al., 2009; Ganssen et al., 2011).

1.4. Biomineralization in planktonic foraminifera

According to multi-gene evidence, the phylum Foraminifera is part of the eukaryotic supergroup Rhizaria, which comprises amoeboid and skeleton-building protists. One of the most prominent and utilized feature of planktonic foraminifera is the construction of calcite (CaCO_3) shells around their cell. The multi-chambered shell consist of either a monolamellar or bilamellar wall of calcite, which is secreted onto a primary organic membrane (e.g. Hemleben et al., 1989). The shell wall contains integrated pores, calcitic spines and outgrowths like pustules. Throughout their ontogeny, planktonic foraminifera grow chamber by chamber accompanied by conspicuous morphological changes (Brummer et al. 1987) until they reach their adult size. The addition of chambers during their life cycle follows a tightly controlled calcification mechanism (Erez, 2003, De Nooijer et al., 2009, 2014). The process of calcification starts with the vacuolisation of seawater into the cell (Erez, 2003). In the cell's interior, $\text{Ca}^{2+}_{\text{seawater}}$ is concentrated in a Ca^{2+} pool, regulated via trans-membrane transport or ion-specific pumps (De Nooijer et al., 2009, 2014). Divalent cations, such as Mg^{2+} and Sr^{2+} , may be transported through the same mechanisms and thus be added to the Ca-pool (Fig. 1.4). Via internal regulation of the pH, inorganic carbon is concentrated. The elevation of pH values causes higher carbonate ion (CO_3^{2-}) concentration (De Nooijer et al., 2009; Glas et al., 2012). The concentration of Ca^{2+} and DIC from seawater produces a supersaturated solution at the calcification site, reducing crystal inhibitors such as Mg^{2+} or PO_4^{2-} , that occur naturally in seawater. Precipitation of CaCO_3 takes place when both these pools combine.

The nucleation of foraminiferal calcite involves organic templates, which are located in the so called Primary Organic Sheet (POS). With the onset of the formation of a new chamber, higher cytoplasmic activity is observed (Bé, 1979), leading to the formation of a dense pseudopodial network that transports vacuoles, mitochondria and organic particles to a defined zone, outlining the new chamber. Moreover, nucleation and the following crystal growth are also conditioned by the physio-chemical environment at the site of calcification. These conditions are sparsely known in benthic foraminifera (e.g. Erez, 2003; Bentov and Erez, 2005) and have yet only been modelled for planktonic foraminifera (Zeebe et al., 1999; Zeebe and Sanyal, 2002). Kunioka et al. (2006) measured elevated Mg^{2+} concentrations around the POS in *Pulleniatina obliquiloculata*. This might indicate that the calcifying fluid composition is different during the first stage of chamber formation, possibly linked to a different calcification rate or process of ion concentration (Mg^{2+} vs. Ca^{2+}). Proceeding from the initial crystal nucleation, calcification takes place on both sides of the POS. Layer by layer, $CaCO_3$ is precipitated on top of pre-existing calcite each time new chamber is added to the

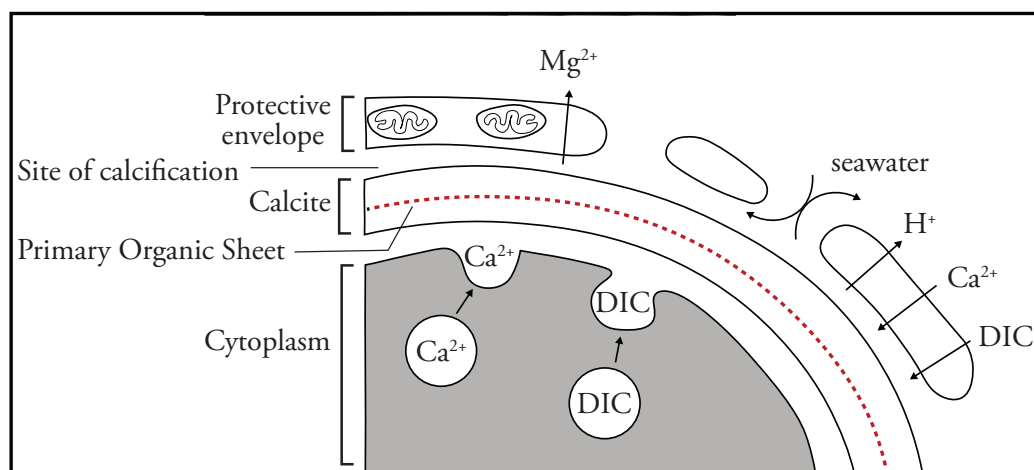


Fig. 1.4: Calcification mechanisms in foraminifera summarized in a schematic illustration. Shown are Ca^{2+} transport, active Mg^{2+} -removal and the contribution of potential internal reservoirs (figure adapted from: De Nooijer et al., 2014)

shell (Reiss, 1957, 1960; Bé and Hemleben, 1970; Erez, 2003). Hence, the term “lamellar” or ontogenetic calcite (Erez, 2003) is used to refer to the primary and secondary layers of calcite. Laboratory observations show that the first stages of calcification, producing a thin-walled chamber, occur within 1-3 hours (Spero, 1988), while the thickening of the chamber walls proceeds subsequently for the next 24 to 48 hours until a new chamber is formed. Whether the timing of the start of chamber formation and the thickening of previously formed chambers are coinciding, or whether chamber wall thickening is a continuous process, still remain

questions to be answered. After forming the primary wall, features such as spines and pustules develop as the chamber wall thickens by lamellar calcification (Hemleben et al., 1975). Lastly during ontogeny (Brummer et al., 1986, 1987), various species also form supplementary layers of calcite that cover the whole shell (crust, cortex or gametogenic calcite). Gametogenic and crust calcite are exclusive to planktonic foraminifera (De Nooijer et al., 2014) and added after the last chamber has formed, just prior to meiotic division and gametogenesis (e.g. Bé, 1980). Calcite crusts, and in some planktonic species a cortex, are also formed during the terminal stage of foraminiferal life (Bé and Ericson, 1963; Bé and Lott, 1964; Bé, 1965; Bé and Hemleben, 1970; Olsson, 1976). This crust calcite is markedly different from lamellar or gametogenic calcite. Not just morphologically, but also in its element and isotope composition, which has been linked to changes in depth habitat at different environmental conditions (e.g. temperature and/or salinity).

The shell may serve to protect the cell, but for the functioning of cellular processes, exchange with the environment is indispensable. Via openings such as the aperture, the cell can extrude its rhizopodia via the aperture to the outside of the shell and uptake of oxygen as well as food takes place (Schiebel and Hemleben, 2005). Macroperforate species (e.g. *N. dutertrei*, *P. obliquiloculata* and *G. scitula*) are observed to possess pore plates, continuous with the POS, and separates the cytoplasm from the outside medium (Hemleben et al., 1977) (Fig. 1.4). In symbiont-barren species, diffusion of gasses between cytoplasm and environment could be realized via enhancing permeability of the pore plates (De Nooijer et al., 2014). From a biomineralization perspective, the various forms of calcite that are precipitated by foraminifera suggest that multiple physiological processes are involved in shell calcification.

1.5. Ecology of planktonic foraminifera

Our ability to read the information stored in planktonic foraminiferal shells depends on understanding their ecology. Planktonic foraminifera are exclusively marine protists that occur abundantly in the world's oceans. Currently 46 species of planktonic foraminifera are recognised in three major groups (Parker, 1962), each characterised by a particular shell morphology (Hemleben et al., 1989), genetic fingerprint (Darling et al., 2006, 2009; Aurahs et al., 2011) and shell geochemistry (Anand et al., 2003). Despite specific differences in environmental requirements, modern species fall into five major assemblages (Fig. 1.5), i.e. polar, subpolar, transitional, subtropical and tropical (e.g. Bé and Tolderlund, 1971; Bé, 1977). These can be found in each ocean and appear to be related to overall temperature (Fig. 1.5; Kucera, 2007). Seasonal changes in shell production are extreme in the high latitude

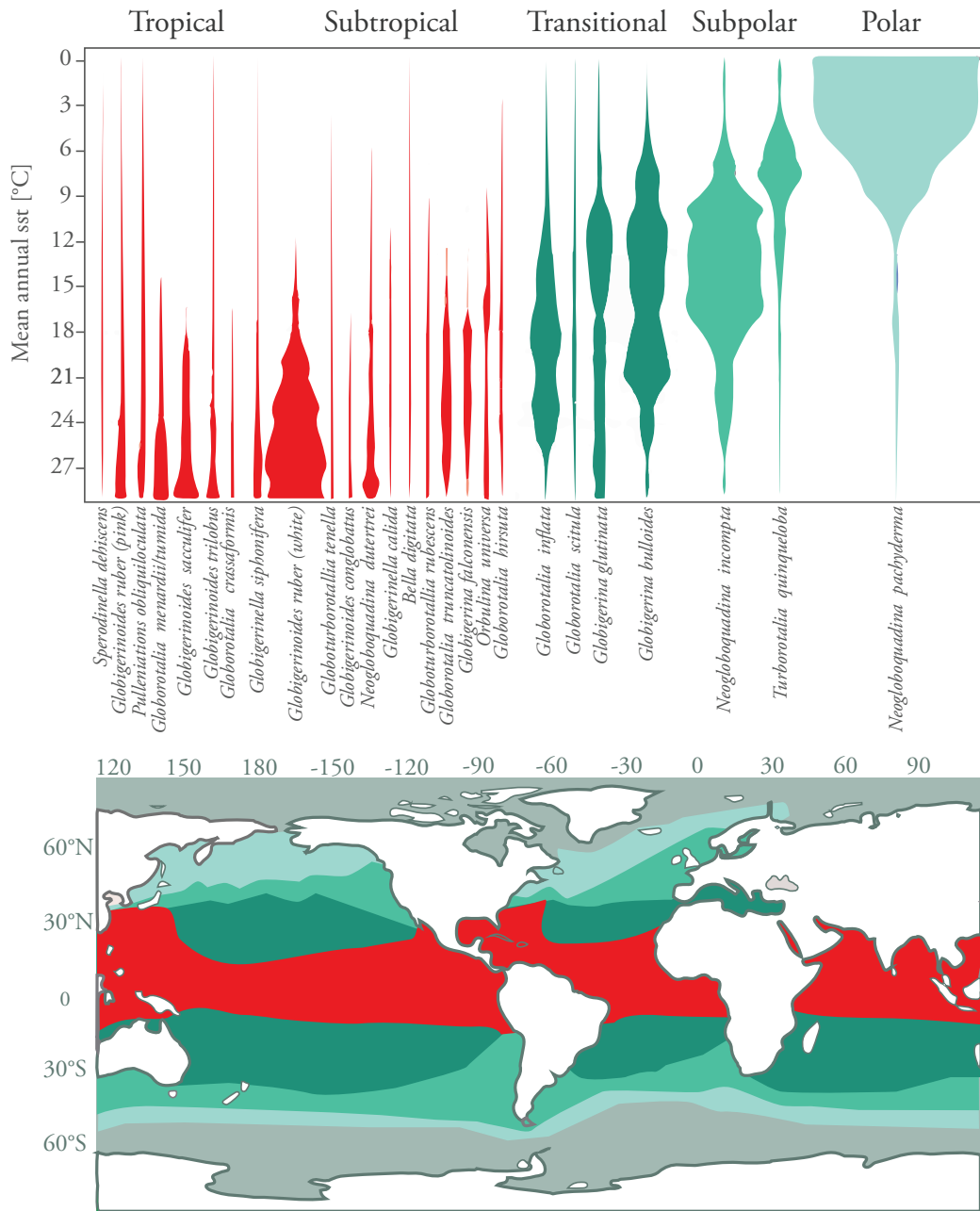


Fig. 1.5: Planktonic foraminiferal provinces in the modern ocean. The distribution of the provinces (Bé et al., 1977; Vincent & Berger, 1981) follows sea-surface temperature gradients, reflecting the strong relationship between SST and species abundances. The abundance plots are based on surface-sediment data from the Atlantic Ocean (Kucera et al., 2005), averaged at 1°C intervals (figure adapted from: Kucera, 2007)

species where productivity is restricted to a few weeks in the year (Bé and Wefer, 1990; Fischer and Wefer, 1999) or the summer only (Jonkers et al., 2014), as opposed to continuous production at lower latitudes. Despite the small seasonal changes in tropical temperatures and overall productivity, clear seasonal successions appear in summer and winter species (e.g. Tolderlund and Bé, 1971; Fairbanks and Wiebe, 1980; Reynolds and Thunell 1985; Sautter and Thunell, 1989; Ortiz and Mix, 1992; Mothadi et al., 1999; Chapman, 2010). Moreover, these species have different depth habitats, i.e. will calcify at different temperatures, and also be intermittently affected by vertical mixing and eddy transport.

1.5.1. Life cycle and feeding.

Planktonic foraminifera are characterized by a complex life cycle that includes vertical migration during their life span of several weeks to up to one year (e.g. Emiliani, 1971; Hemleben, 1985; Hemleben et al., 1989). However, little is known about the exact depth habitat, where juveniles first calcify or where shell growth terminates, or to what extent depth habitats change seasonally. Sparse field studies show that calcification does not exclusively occur at a single depth as often thought, but rather at various depths in the water column. Furthermore, foraminifera may modify their habitat depth in response to changing hydrographic conditions and food supply (e.g. Fairbanks et al., 1982; Field, 2004). The vertical range in calcification depth of many species is wide and may vary both regionally and seasonally.

Planktonic foraminifera follow various feeding strategies (herbivorous, carnivorous or omnivorous). Rhizopodia extrude to the outside of the shell, secrete adhesive substances holding captured prey, and transport tissue particles via rhizopodial streaming into the shell, where digestion takes place in vacuoles (Hemleben et al., 1989). This allows spinose planktonic foraminifera to prey on motile zooplankton larger than themselves (Caron et al. 2012). Although planktonic foraminifera appear generally heterotrophic, some species also host algal symbionts, providing energy from photosynthesis in exchange for metabolites and a stable microenvironment inside the calcite shell (e.g. Faber et al., 1988). If a species is associated with symbionts like *G. ruber*, its distribution in the water column is restricted to the euphotic zone during day time, since its symbionts depend on light. The abundance of symbiont-barren species changes strongly with depth, with the deepest and rarest ones living as deep as 1500-2000 m water depth (e.g. Ortiz et al., 1996; Hull et al., 2011). Understanding the vertical distribution patterns of different species and their ecological requirements allows for fingerprinting the vertical structure of the water column by using specific differences in geochemical proxies.

1.5.2 Seasonality

Besides a well-defined spatial distribution, planktonic foraminiferal species show a clear temporal (seasonal) phasing. Highest abundances occur during optimum conditions defined by specific temperature, feeding strategy, and light availability for species with autotrophic symbionts (e.g. Bé, 1960; Parker, 1960; Cifelli, 1962; Tolderlund and Bé, 1971; Fairbanks and Wiebe, 1980; Deuser and Ross, 1989; Field, 2004). Such optimum conditions may exist locally and for only a short period of the year, yet dominate annual shell productivity and export in a given hydrographic regime. Consequently, the shells which are found in time-averaged sediments are skewed towards the hydrographic and biological conditions during the most productive times of the year for a particular species. Using plankton nets, stratified tows and sediment trapping differences in the spatial and temporal distribution of foraminifera have been studied over the last decades (e.g. Schindler et al., 1969; Thunell et al., 1983; Wiebe et al., 1985; Deuser et al., 1987; Sautter and Thunell, 1991; Thunell and Sautter, 1992; Curry et al., 1992; Ravelo and Fairbanks, 1992; Schiebel et al., 1996; Peeters et al., 1999; Lončarić et al., 2006; Wejnert et al., 2010; Fallet et al., 2011, 2012; Salmon et al., 2015).

1.5.3. Species description

Globigerinoides ruber (d'Orbigny, 1939)

Globigerinus ruber is a shallow, surface mixed layer dwelling spinose species, which hosts dinoflagellate symbionts (Hemleben et al., 1989). Its shallow sub-surface habitat is confirmed by a series of stratified net samples (Deuser et al., 1981; Lončarić et al., 2006; Peeters and Brummer et al., 2002). Hence, it is often used to reconstruct past sea surface temperature (e.g. Hemleben et al., 1989; Fischer and Wefer, 1999). There are two moieties of this species, occurring as two differently coloured shells (white and pink), which also bear isotopically distinct signatures (Deuser and Ross, 1989; Robbins and Healy-Williams, 1991). However, in the Indo-Pacific regions only the white type occurs, since the extinction of the pink type during the late Pleistocene (~120kyr, Thompson et al., 1979). It has a wide temperature tolerance between 16 and 31°C, with peak occurrences at an optimum between 21 and 29°C (Bé and Tolderlund, 1971; Hemleben et al., 1989; Richey et al., 2012).

Neoglobobadrina dutertrei (d'Orbigny, 1939)

Neoglobobadrina dutertrei is a non-spinose species, which is spread across subtropical to tropical waters. It inhabits the mixed layer and has been found to prefer deep chlorophyll maxima, during parts of its ontogeny (Fairbanks and Wiebe, 1980; Fairbanks et al., 1980, 1982; Ravelo et al., 1990; Brock et al., 1992; Ravelo and Fairbanks, 1992). This species has also been described to occur in higher abundances at the continental margins associated

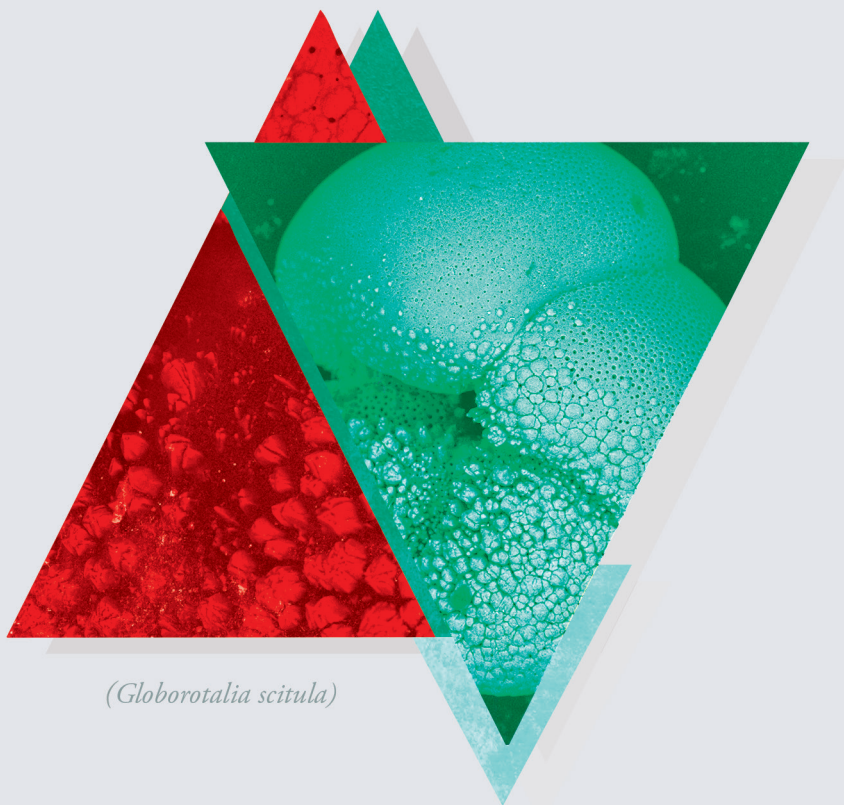
with upwelling (Imbrie and Kipp, 1971; Bé, 1977). *N. dutertrei* is found in waters with temperatures between 9 and 30°C. Highest abundances are found between 16 and 24°C (Bé and Tolderlund, 1971; Hilbrecht, 1997; Farmer et al., 2007). The habitat depth of *N. dutertrei* ranges between 0-150 m (e.g. Fairbanks et al., 1982; Peeters and Brummer, 2002; Kiefer et al., 2006; Farmer et al., 2007; Fallet et al., 2011)

***Pulleniatina obliquiloculata* (Parker and Jones, 1860)**

Pulleniatina obliquiloculata is a non-spinose and symbiont-barren planktonic foraminiferal species. The species is generally known to inhabit tropical to subtropical water masses during winter (Bé and Tolderlund, 1971; Deuser et al., 1981), and was also shown to depict the winter season in a study by Ganssen and Sarnthein (1983) off northwest Africa. These observations are confirmed by a study of Wilke et al. (2009), which showed a restricted seasonal distribution of *P. obliquiloculata*, linked to the winter bloom. A stratified net study of Wilke et al. (2009) found that the habitat of this species ranges from the surface down to approximately 180 m. The bulk shell geochemical composition *P. obliquiloculata* indicates calcification at the base of the upper thermocline, around 100 m depth (Cléroux et al., 2007; Farmer et al., 2007; Steph et al., 2009).

***Globorotalia scitula* (Brady, 1882)**

Globorotalia scitula is generally classified as a polar to sub-polar species (e.g. Thunell, 1978; Bé and Tolderlund, 1971). However, its wide geographical distribution in the North Atlantic, the Mediterranean Sea, the Panama Basin, the Indian Ocean, the central equatorial Pacific Ocean, the Sea of Okhotsk, and the Eastern Pacific Ocean (Baumfalk et al., 1987; Bé and Hutson, 1977; Belyaeva and Burmistrova, 1998; Hendy and Kennett, 2000; Marchant et al., 1998; Schiebel et al., 1995; Thunell and Reynolds, 1984; Watkins et al., 1996) suggests that *G. scitula* cannot be considered as an exclusively polar and sub-polar species. The habitat depth of *G. scitula*, which ranges between the surface and 1000 m (e.g. Bé, 1977; Schiebel et al., 1995; Ortiz et al., 1996), records environmental variables in the thermocline and intermediate water masses (Ortiz et al., 1996; Itou et al., 2001; Chiessi et al., 2007; Cléroux et al., 2007, 2008).



(Globorotalia scitula)

Chapter 2

*Seasonal and eddy imprints on planktonic foraminifera
in the Mozambique Channel*

Chapter 2

Seasonal and eddy imprints on planktonic foraminifera in the Mozambique Channel

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Abstract

The Mozambique Channel is a gateway in the western equatorial Indian Ocean, which is disrupted by large (>300 km diameter) eddies passing through. A one-year time series of planktonic foraminiferal fluxes from a sediment trap located in the Mozambique Channel is investigated for seasonal and sub-seasonal patterns. In addition to the winter indicator species *Globigerinoides sacculifer*, we find that also *Globorotalia tumida*, *Globorotalia menardii*, *Globorotalia cultrata* and *Sphaeroidinella dehiscens* exhibit clear winter maxima. *Candeina nitida* exhibits a minor late autumn 2008 and a more prominent summer maximum in 2009. Shell flux ratios of summer *Globigerinoides ruber* and winter *Globigerinoides sacculifer* mimic the seasonal sea surface temperature (SST) pattern, whereas flux ratios of *Neogloboquadrina dutertrei* and *Globorotalia scitula* correspond to winter mixed layer deepening. Superimposed on the seasonal trend, *G. ruber* shows early flux maxima with the onset of isotherm deepening during the passage of eddies. However, eddy impacts on *G. ruber* fluxes are minor compared to seasonal forcing. On an annual basis, the flux-weighted species composition is very similar to that found in core top sediments taken across the channel. In general, the one-year seasonal flux intercepted by the sediment trap appears to be a relatively average year, while the time-averaged sediments appear to preserve both seasonal and eddy-generated fluxes. Based on previously published stable isotope and trace-metal data (Fallet et al., 2012; Birch et al., 2013; Steinhardt et al., 2014; 2015, Chapter 3 & 4), annual flux based calculated isotope and trace metal-based proxies correspond well with values measured in sea floor sediments, albeit slightly elevated calculated potential annual flux-weighted Mg/Ca values for *G. ruber*. Recent warming in the southern Indian Ocean might explain the calculated offset between sediment and sea surface temperatures.

2.1. Introduction

Planktonic foraminiferal shell fluxes are governed by upper ocean conditions (e.g. Deuser, 1986, Hemleben et al., 1989, Eguchi et al., 1999, Lončarić et al., 2007, Jonkers et al., 2014). Changes in their relative abundance as well as the geochemistry of their shells in sedimentary records fundamentally contribute to our understanding of past oceanic and climatic conditions (Elderfield et al., 2002). Individual species of planktonic foraminifera are generally restricted to specific climatic-biogeographical zones, as well as vertically within the water column, according to their physiological, feeding and reproductive preferences (e.g. Bé and Hamlin, 1967; Tolderlund and Bé, 1971). Also temporally, foraminiferal species show

clear variability in abundance that are often seasonal but also at higher frequencies ranging from lunar reproductive cycling (Bijma et al., 1990, 1994; Erez et al., 1991; Lončarić et al., 2005; Jonkers et al., 2014) to eddy perturbation (Conan and Brummer, 2000; Fallet et al., 2011; Salmon et al., 2015) and storm events (Schiebel, 1995). These changes in foraminiferal abundances through the year are also coupled to their specific ecological requirements and life cycle (Jonkers et al., 2014). Various environmental factors may induce species-specific responses (Kuroyanagi and Kawahata, 2004), which model and field studies have shown to result in substantial seasonal differences in shell fluxes (Deuser et al., 1981; Jonkers et al., 2014). Such differences in fluxes also modify the species proportions of planktonic foraminifera in the sediment and can subsequently be translated in so-called proxy relations. Seasonality of foraminiferal production is an important factor to be accounted for in paleo-oceanographic applications (e.g. Deuser and Ross, 1989; Fischer and Wefer, 1999; Ganssen and Kroon, 2000). Since environmental factors controlling modern-day planktonic foraminiferal abundance vary from place to place, accurate interpretations of palaeo-records require regional understanding of the relation between environmental factors and foraminiferal flux.

Here we investigate a one year-time series of planktonic foraminiferal fluxes in the >250 μm size fraction from a sediment trap in the Mozambique Channel with the aim to unravel seasonal and shorter-term changes in species fluxes and relate these to the prevailing environmental conditions. Besides the three major species commonly used for geochemical analysis (*G. ruber*, *G. trilobus*, *N. dutertrei*) we also concentrate on minor species, and to what extent they are affected or introduced by eddies in the Mozambique channel. The results presented in this study offer the potential to develop foraminifera based proxies for seasonality and eddy frequency (Fallet et al., 2010, 2011). Furthermore, the data presented here, allow for better SST reconstructions based on annually averaged $\delta^{18}\text{O}$ (Deuser, 1987) and Mg/Ca (Elderfield and Ganssen, 2000; Oppo et al., 2009) such as found in the time-averaged sediment.

2.2. Oceanographic Setting

The Mozambique Channel forms part of the greater Agulhas Current system (Lutjeharms, 2006), which exchanges heat and salt between the Indian and Atlantic Ocean (Gordon, 1986; Weijer et al., 1999). Warm surface waters are transported poleward, either east of Madagascar via the East Madagascar Current, or through the Mozambique Channel (MC), after the South Equatorial Current (SEC) bifurcates close to the western margin at around 18°S (e.g. Chen and Wu, 2015; Gründlingh, 1995; Swallow et al., 1988). The Subtropical Surface Water is characterized by relatively high salinities and a subsurface maximum with salinities of 35.2–

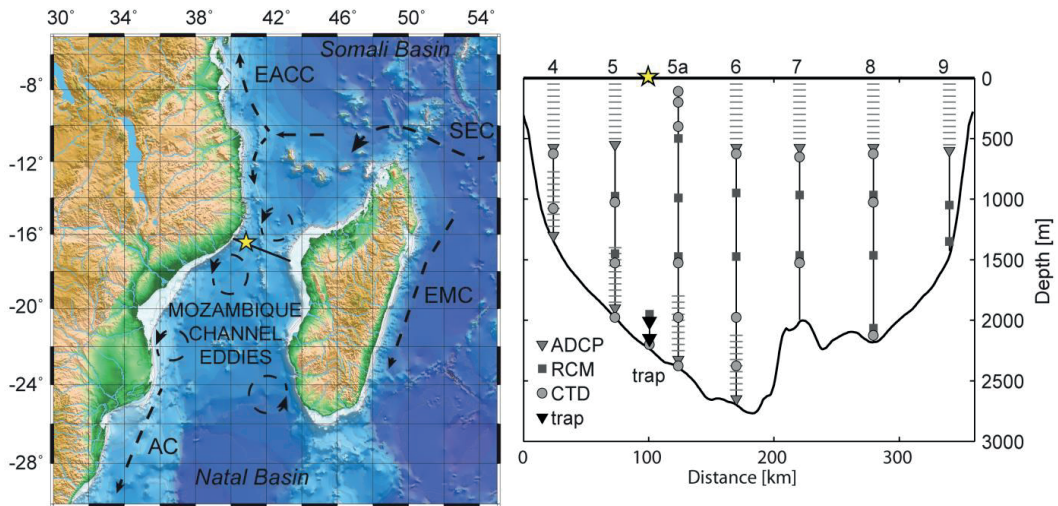


Fig. 2.1: Map of the southwestern Indian Ocean with location of the sediment traps (yellow star) in the array of moorings (line) deployed within the Long-term Ocean Climate Observation (LOCO) program detailed in the right panel. EACC: East African Coastal Current, SEC: South Equatorial Current, AC: Agulhas Current, EMC: East Madagascar Current (Figure: Steinhardt et al., 2014).

35.5, at approximately 200 m depth, where it subducts below the fresher Tropical Surface Water (Wyrki, 1973). Thermocline waters are characterized by South Indian Central Waters (SICW), showing a strong linear Θ -S relationship (Schott and McCreary, 2001). About four to seven anticyclonic meso-scale eddies with a diameter of >300 km pass southward through the MC per year, propagating at $3\text{--}6$ km d^{-1} , before joining the Agulhas Current (Fig. 2.1). An eddy passage is associated with vertical downward movement of isopycnals, which occasionally exceed 40 m day^{-1} in the upper layer (Ullgren et al., 2012). Within the Mozambique Channel, temperature differences of more than 8°C between non-eddy and eddy conditions have been measured (lmc5a) at 110 m (Ullgren et al., 2012). The passing of an eddy also coincides with a change in water masses, explaining up to 40% of the total hydrographic variability in the Channel. Backeberg and Reason (2010) suggested that formation of meso-scale eddies in the Mozambique Channel is linked to SEC transport variabilities (Fig. 2.1). SST in the MC vary seasonally and with eddy-induced transport (Fallet et al., 2011). The monsoon system strongly influences seasonal temperatures in this region due to the seasonal convergence of the Inter Tropical Convergence Zone (ITCZ) and the related trade wind system, causing SSTs to range between 25 to over 30°C at an annual mean of 27.6°C . Rainfall in the MC is regulated by the seasonal migration of the ITCZ and the South Indian Convergence Zone (SICZ, Cook, 2000), causing increased rainfall in austral summer, and sea surface salinities to decrease slightly from 35.2 in winter to 34.9 in summer (Fallet et al., 2010).

2.3. Material and Methods

2.3.1 Sediment trap sampling and mooring array

In order to trace seasonality and intermittency in abundance of planktonic foraminifera we monitored settling shell fluxes in a consecutive time series using deep-moored sediment

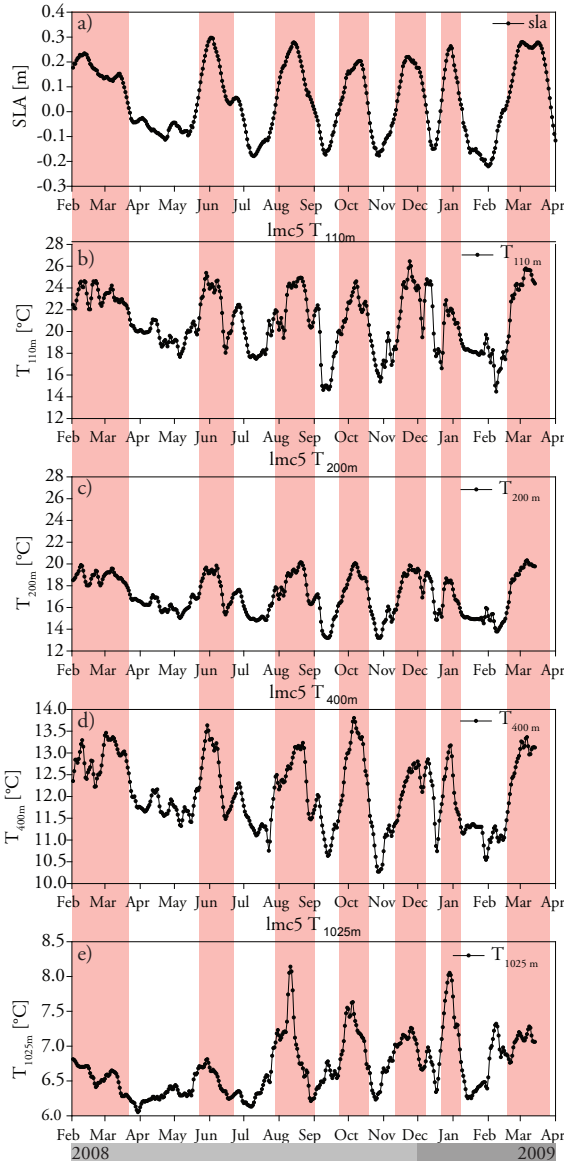


Fig. 2.2: Sea level anomalies (SLA) and mooring temperatures. (a) SLA altimetry data and measured temperatures at (b) 110 m, (c) 200 m, (d) 400 m and (e) 1025 m depth by sensors on mooring lmc5a. Note that temperature peaks correspond with peaks in SLA during the passing of an eddy.

traps deployed within the framework of the Long-term Ocean Climate Observation (LOCO) program (Ruijter et al., 2006; Ridderinkhof et al., 2010), upstream of the modern Agulhas Current in the central Mozambique Channel at 16.71°S and 40.85°E (Fig. 2.1). A Technicap PPS 5 sediment trap (collecting area of 1 m² with 1.5 cm honeycomb baffle; 24-cup automated sampling carousel) was positioned 250 m above the channel floor at a water depth of 2250 m. Sampling intervals are 17 days for each of the 24 collecting cups, starting on February 1, 2008 to March 15, 2009. Prior to deployment, sample cups were filled with an HgCl₂ poisoned and borax-buffered solution of seawater collected from the deployment depth (Lončarić et al., 2007). For this study, we used temperatures measured in situ at 110 m, 200 m, 400 m and 1025 m water depth by CTDs deployed on mooring lmc5a next to the trap site (16.8°S, 41.1°E, Figs. 2.1 and 2.2).

2.3.2 Planktonic Foraminifera

Sediment trap samples were wet-split using a binary Folsom splitter with a precision of >95% (Sell and Evans, 1982; Lončarić et al., 2007; Fallet et al., 2009). A minimum of approximately 300 foraminifera (when present) were enumerated to determine the species flux and relative abundance in the >250 μm fraction (Supplementary tab. 1 & 2). Additionally, pteropod shells were counted as a group in the same split as the planktonic foraminifera, without further taxonomic subdivision. Fluxes are given in shells $\text{m}^{-2} \text{d}^{-1}$ (Supplementary tab. 1). Annual flux was calculated by averaging the shell fluxes within one year, considering the overlapping time interval (43 days) during the start (first two cups, February 1th to March 5th, 2008) and end (last two cups, February 09th to March 14th, 2009) of the deployment period. Foraminifera shells were identified and counted in the >250 μm size fraction. Although for census counts often the >150 μm is used, the >250 μm size fraction more closely matches the size window commonly used in shell geochemistry studies (250-315 μm , e.g. Cl  roux et al., 2008; Sadekov et al., 2008; Fallet et al., 2010; Mohtadi et al., 2014; Steinhardt et al., 2014; Chapter 3).

We used the taxonomy of Parker (1962) and Hemleben et al. (1989) for species identification of planktonic foraminifera. In addition we distinguished between *Globorotalia menardii* (Parker, Jones and Brady, 1865; Parker, 1962) and *Globorotalia cultrata* (d'Orbigny, 1839), which both belong to the extant tropical Neogene menardiform globorotaliids, whose taxonomy was recently reviewed by Knappertsbusch (2007). These species are known to inhabit the seasonal thermocline (e.g. Lohmann and Schweitzer, 1990; Ravelo and Fairbanks, 1992; Schmuker and Schiebel, 2002; Farmer et al., 2007; Mohtadi et al., 2009). For *Globigerinoides sacculifer* we distinguished between morphotypes with a terminal sack-like chamber (as *G. sac.sac.*) and the "normalform" one (as *G. sac.tril.*; *G. trilobus* of authors). Although we initially separated *G. ruber* sensu stricto and *G. ruber* sensu lato, following Wang et al. (2000), we observed that fluxes of *G. ruber* s.str. were two orders of magnitude higher than those of *G. ruber* s.l. Since their flux patterns are very similar (Supplementary fig. 1), we treated all morphotypes as a single taxon, *G. ruber* (white).

2.3.3 Element and isotope ratios

Element/Ca ratios (e.g. Mg/Ca) of single chambers of *C. nitida* were determined by LA-ICP-MS (Steinhardt et al., 2015, chapter 5). In total, 65 single-chamber profiles were obtained, which average 3.8 ± 1.6 mmol/mol (SE: 0.2 mmol/mol). Profiles showing concentrations deviating more than twice the standard deviation from the average of the initial dataset were regarded outliers and therefore discarded from the dataset (2 out of 65 measurements). The sediment data we use to compare with our calculated flux weighted average oxygen isotope

and Mg/Ca values are derived from Fallet et al. (2012), which were measured in the 250-315 μm size fraction and Birch et al. (2013) in the different size fractions $>250 \mu\text{m}$.

2.3.4 Core top sediments

Coretop samples were taken along the LOCO mooring array (Ullgren et al., 2012, Fig. 2.1), in the channel narrows between $40.36^{\circ}\text{E} - 42.48^{\circ}\text{E}$ and $16.38^{\circ}\text{S} - 17.1^{\circ}\text{S}$ at water depths between 1700 and 2700 m (cruises PE304 and M75-1b, see appendices). The top 0-1 cm from 20 multi- and mono-cores was washed over a $63 \mu\text{m}$ sieve, dried and subsequently sieved over a $150 \mu\text{m}$ mesh and split into a sub-sample containing at least 300 specimens of planktonic foraminifera using an Otto-type micro-splitter. The relative abundance of each taxon is expressed as the percentage of the total census count (Appendix Tab.). Pteropods were counted and quantified relative to the number of planktonic foraminifera (Supplementary tab.3), which is an indication for the aragonite compensation depth (ACD). From the 20 core tops (Supplementary fig. 2), 11 core tops from the Mid-Channel area were selected, away from the slope area, to avoid cross-slope transport effects (Supplementary Tab. 3), to calculate an average sedimentary assemblage within the Mozambique Channel.

2.3.5 Satellite and altimetry data

For tracking eddies passing through, we used altimetry data (Fig. 2.2) available under <http://las.aviso.altimetry.fr/las/getUI.do> that are produced by Ssalto/Duacs and distributed by AVISO, with the support from Cnes (<http://avis.altimetry.fr/duacs>). The measured sea level anomaly (SLA) is excellently suited to track the passing of eddies. Monthly precipitation data (CPC Merged Analysis of Precipitation) was retrieved from KNMI Climate Explorer (<http://climexp.knmi.nl/>) for the deployment period. Additionally MODIS Aqua Level3 daily mapped 4 km chlorophyll-a data and sea surface temperatures were retrieved from the 4 km daytime MODIS/AQUA dataset around trap site ($16 - 17^{\circ}\text{S}$ and $40 - 41^{\circ}\text{E}$) for the duration of the deployment of the sediment trap (<http://podaac-tools.jpl.nasa.gov/las>). SeaWiFS and MODIS provide an absorption coefficient for seawater, phytoplankton, and the combined coefficient for dissolved and detrital particulate matter at 443 nm, which is calibrated to dissolved and detrital matter in sea water (IOCCG, 2006). Precipitation was retrieved from the KNMI Climate Explorer (CPC Merged Analysis of Precipitation).

2.3.6 Data analysis

Principal component analysis (PCA; SPSS Statistics 20) was conducted on the normalized foraminiferal fluxes to detect linear relationship between the foraminifera species during the

deployment period of sediment trap, To investigate the coherence of variability contained in our samples with sea level anomalies (SLA) generated by passing eddies, cross wavelets were calculated using foraminiferal fluxes and sub-sampled SLA data (every 17-days, Fig. 2.2), allowing identification of regions in time-frequency space where the time series show high common power, at the same time providing information on possible leads and lags (Grinsted et al., 2004).

2.4. Results

2.4.1 Total shell fluxes

For the integrated duration of the deployment foraminiferal shell fluxes average $300 \text{ shells m}^{-2} \text{ d}^{-1}$, with a total annual flux of $111908 \text{ shells m}^{-2} \text{ year}^{-1}$. Maximum shell fluxes of about $600 \text{ shells m}^{-2} \text{ d}^{-1}$ were recorded from late February to early March 2008, contrasting with lowest fluxes of about $100 \text{ shells m}^{-2} \text{ d}^{-1}$ in early October 2008 (Fig. 3e.). Pteropod shell flux averaged $80 \text{ shells m}^{-2} \text{ d}^{-1}$ for the entire deployment and a total annual flux of $30224 \text{ shells m}^{-2} \text{ year}^{-1}$. Highest pteropod fluxes of about $200 \text{ shells m}^{-2} \text{ d}^{-1}$ were recorded in April 2008 during austral winter, with a minimum of about $10 \text{ shells m}^{-2} \text{ d}^{-1}$ in late January 2009 during austral summer (Fig. 3e). During the deployment the ratio of pteropod fluxes to planktonic foraminifera Log(PF/P) ranges between 0.2 and 1.1, with an annual mean of 0.6 and lowest ratios during austral winter (Supplementary Tab. 1).

2.4.2 Species fluxes and composition

Highest average annual fluxes of $78 \text{ shells m}^{-2} \text{ d}^{-1}$ are found in *G. ruber*, with a maximum of $243 \text{ shells m}^{-2} \text{ d}^{-1}$ during austral summer and a minimum of $8 \text{ shells m}^{-2} \text{ d}^{-1}$ during austral winter (Figs. 2.3 and 2.4). Shell fluxes of *G. sacculifer* (combined morphotypes) are on average $75 \text{ shells m}^{-2} \text{ d}^{-1}$ and range from summer minima down to $9 \text{ shells m}^{-2} \text{ d}^{-1}$ to winter maxima up to $173 \text{ shells m}^{-2} \text{ d}^{-1}$. *Neogloboquadrina dutertrei* fluxes average $24 \text{ shells m}^{-2} \text{ d}^{-1}$ with a minimum of $4 \text{ shells m}^{-2} \text{ d}^{-1}$ and a maximum of $51 \text{ shells m}^{-2} \text{ d}^{-1}$ without a clear seasonal preference, while *G. scitula* averages $11 \text{ shells m}^{-2} \text{ d}^{-1}$ ranging from 1 to $47 \text{ shells m}^{-2} \text{ d}^{-1}$ with higher fluxes in summer.

Several species show a single abundance peak in winter, e.g. *P. obliquiloculata* (Fig. 2.4) with a clear maximum of $34 \text{ shells m}^{-2} \text{ d}^{-1}$ in winter and are nearly absent in summer, at an annual average of $6 \text{ shells m}^{-2} \text{ d}^{-1}$. Also *G. tumida*, *G. cultrata*, *G. menardii* and *S. debiscens* show a clear winter maximum with trace fluxes in other seasons (Supplementary tab. 1 and Fig. 2.5).

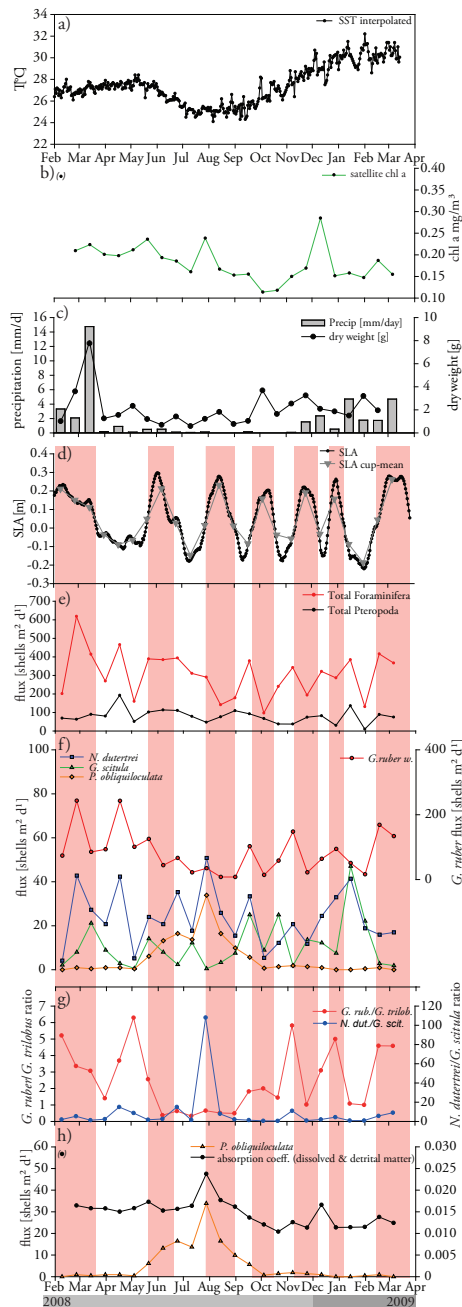


Fig. 2.3: Overview graph of (a) satellite-derived sea surface temperature (SST), (b) chlorophyll-a and (c) precipitation at the sediment trap location. Sediment trap dry weights in correspondence to precipitation (c) indicates terrestrial inputs during the rainy seasons. (d) Daily SLA and 17-days mean SLA are given to show the corresponding eddies passing over the sediment trap. (e) Total foraminifera and total pteropod flux, as well as fluxes of *G. ruber*, *N. dutertrei*, *G. scitula* and *P. obliquiloculata* (f) are given in correspondence to eddy events (red rectangles). (g) Ratios of *G. ruber* and *G. trilobus* follow SST; ratios of *N. dutertrei* and *G. scitula* show a peak during austral winter. (h) The flux of *P. obliquiloculata* corresponds to satellite-derived absorption coefficient.

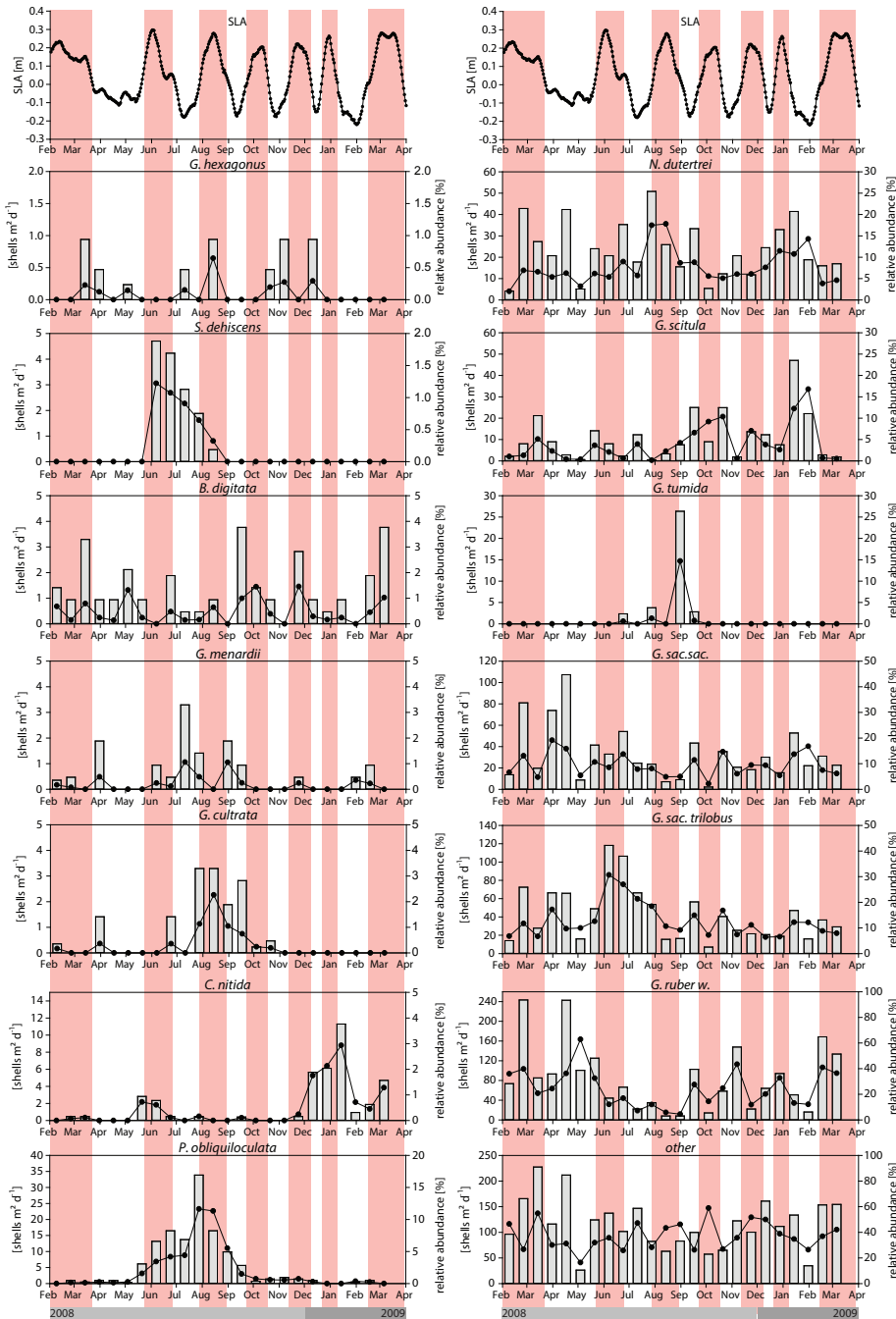


Fig.2.4: Sea level anomalies (top) with fluxes (grey bars) and relative abundances (dotted line) of planktonic foraminifera during sediment trap deployment MOZ4.

By contrast, shell fluxes of *C. nitida* are bi-annual with two distinct peaks in late autumn and summer of up to $12 \text{ shells m}^{-2} \text{ d}^{-1}$, while virtually absent during winter.

With an annual average contribution of 25%, *G. ruber* is the most abundant planktonic foraminifer in the Mozambique Channel, accounting for 4% to 63% (May 2008) of the total shell flux during the deployment period. Second is *G. sacculifer* (22%) which varies between 9% and 41%, followed by *N. dutertrei* (8%) varying between 2 and 18%. On average *G. scitula* contributes 4% to the annual shell flux with peaks up to 17% while mostly close to being absent. Relative abundance in *P. obliquiloculata* varies between 0 and 12%, being on average 2%.

2.4.4 Satellite and altimetry data

Surface water chlorophyll *a* concentrations during the deployment period are generally low and varied between 0.40 mg m⁻³ and 0.10 mg m⁻³ (Fig. 2.3). Altimetry data (SLA) and mooring temperatures show corresponding peaks over the deployment period (Figs. 2.2 and 2.3), which is coherent with warmer temperatures in the centre of an eddy.

Whereas through the year the absorption coefficient (Fig. 2.3) is affected by both input of terrestrial material from rivers and sea water biological productivity, the maximum during August rather seems to be linked exclusively to local marine productivity. Since August precipitation was low, this suggests that river outflow and hence terrestrial input must have been low.

2.4.5 Principle component analysis (PCA)

Normalised species fluxes of foraminifera were analysed using a principle component analysis in order to distinguish common linear behaviour to environmental forcing (Tab. 2.1 ,Fig. 2.5).

Tab. 2.1: Results of the principle component analysis on the normalised species fluxes of planktonic foraminifera with Eigenvalues for the first six principal components.

Component	Total Variance Explained		
	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	3.27	25.11	25.11
2	2.67	20.56	45.67
3	1.6	12.33	58
4	1.28	9.88	67.88
5	1.17	9.03	76.91
6	1.02	7.84	84.75

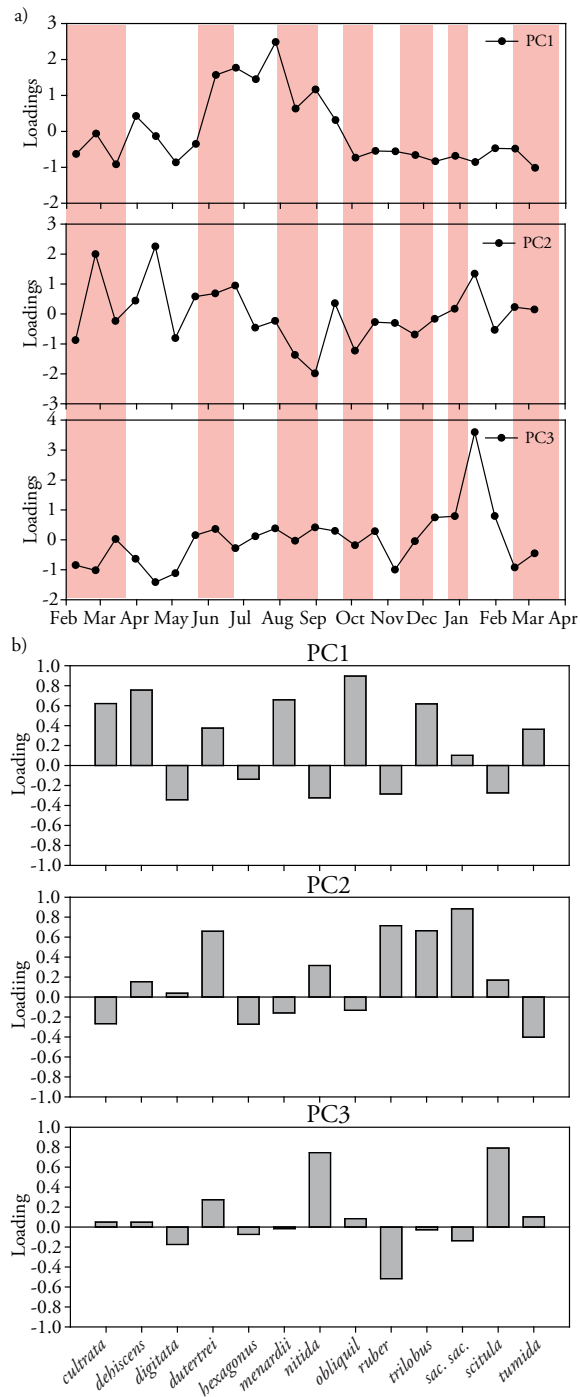


Fig. 2.5: Results of the principle component analysis on the normalised species fluxes of planktonic foraminifera. a) Loadings of the first three principal components (PC 1-3) that do not correlate with eddy intervals (in red). b) Loadings of the foraminiferal species.

The first three Principle components (PC) explain together 58% of the total variance. For PC-1 (25.1%) highest component loadings are observed for the winter species *P. obliquiloculata* (0.90), *S. dehiscens* (0.76), *G. menardii* (0.66), *G. cultrata* (0.62) and *G. sac.tril* (0.62). The strongest negative loading is observed for *C. nitida* (-0.34). For PC-2 (20.6%) the strongest positive loading is observed for *G. sac.sac.* (0.88), followed by *G. ruber* (0.72), *G. sac.tril.* (0.67) and *N. dutertrei* (0.66). Strongest negative loading in PC-2 is observed for *G. tumida* (-0.40). Two species with high positive loadings dominate PC-3 (12.3%), i.e. *G. scitula* (0.79) and *C. nitida* (0.75), while the only major negative loading regards *G. ruber* (-0.52).

2.4.6 Sedimentary assemblages

In core tops across the MC, the average assemblage (>150 μm) is dominated by *G. ruber* ($32.2 \pm 3.4\%$), followed by *G. sacculifer* ($13 \pm 0.7\%$), *G. siphonifera* ($10.1 \pm 0.4\%$), *G. glutinata* ($9.3 \pm 3.6\%$), *N. dutertrei* ($8.7 \pm 1.2\%$) (Supplementary fig. 2). Relative abundances between 2% and 5% are observed for *G. bulloides* ($2.7 \pm 0.9\%$), *T. quinqueloba* ($2.5 \pm 1.5\%$), *O. universa* ($2.2 \pm 0.2\%$) and *P. obliquiloculata* ($2.0 \pm 0.9\%$) (Supplementary tab. 3). Core tops were studied across the entire width of the Mozambique Channel, showing a gradual change in species from the slopes to the central part of the channel (Supplementary fig. 2). The log(PF/P) varies between 1.4 and 3.2 with a mean of 2.4.

2.5. Discussion

2.5.1 Foraminiferal fluxes

Total foraminiferal shell fluxes do not show a particular seasonal pattern during the deployment, although minimum and maximum values change by a factor of about six. In contrast, individual species fluxes and relative abundances do show a clear seasonality. This is in agreement to earlier studies on four species in this area (Fallet et al., 2010, 2011, 2012) showing strongly seasonal shell fluxes in surface-dwelling *G. ruber* peaking in late austral summer (March) and *G. trilobus* in early austral winter (July). Also on a shorter sub-seasonal time scales individual species show strong variation in fluxes and consistent patterns in relative abundance. For subsurface-dwelling *N. dutertrei* and deep-dwelling *G. scitula*, Fallet et al. (2011) observed large, sub-seasonal variability in shell fluxes suggesting a pronounced influence of quick, high-frequency changes in sub-surface water mass characteristics associated with eddies. We also find that *N. dutertrei* and *G. scitula* show higher frequency flux variations, but were not able to directly link these fluctuations to the eddy frequency.

Tab. 2.2: Correlation table of foraminiferal fluxes with p-values sigma (1-tailed) shaded in grey. Correlations significant on the 0.05 level are indicated in bold.

correlation matrix													
	<i>cul</i>	<i>dehis</i>	<i>digi</i>	<i>dut</i>	<i>hexa</i>	<i>men</i>	<i>nit</i>	<i>obli</i>	<i>rub</i>	<i>tril</i>	<i>sac.sac</i>	<i>scit</i>	<i>tum</i>
<i>cul</i>		0.26	0.45	0.06	0.39	0.1	0.08	0	0.06	0.38	0.34	0.27	0.04
<i>dehis</i>	0.14		0.16	0.20	0.28	0.03	0.32	0	0.10	0	0.42	0.18	0.46
<i>digi</i>	0.03	-0.22		0.30	0.39	0.13	0.46	0.11	0.22	0.30	0.41	0.36	0.17
<i>dut</i>	0.33	0.18	-0.11		0.33	0.48	0.08	0.02	0.06	0.01	0.00	0.22	0.44
<i>hexa</i>	0.06	-0.12	-0.06	-0.10		0.34	0.28	0.44	0.3	0.13	0.19	0.49	0.21
<i>men</i>	0.27	0.40	-0.24	-0.01	-0.09		0.08	0.02	0.11	0.06	0.45	0.34	0.04
<i>nit</i>	-0.30	-0.10	-0.02	0.29	-0.13	-0.29		0.14	0.48	0.44	0.41	0.01	0.24
<i>obli</i>	0.70	0.64	-0.26	0.41	-0.03	0.44	-0.23		0.04	0.03	0.29	0.10	0.12
<i>rub</i>	-0.33	-0.27	0.16	0.33	-0.11	-0.27	-0.01	-0.37		0.14	0	0.13	0.11
<i>tril</i>	0.07	0.76	-0.11	0.47	-0.24	0.33	-0.03	0.39	0.23		0.00	0.48	0.29
<i>sac.sac</i>	-0.09	0.05	-0.05	0.58	-0.19	0.03	0.05	-0.12	0.67	0.62		0.29	0.19
<i>scit</i>	-0.13	-0.20	0.08	0.16	-0.00	-0.09	0.51	-0.28	-0.24	-0.01	0.12		0.36
<i>tum</i>	0.37	-0.02	-0.21	-0.04	-0.18	0.38	-0.15	0.25	-0.26	-0.12	-0.19	-0.08	

Seasonality is expressed in PC-1 (Fig. 2.5a) with positive loadings for *P. obliquiloculata*, *S. dehis*, *G. menardii*, *G. cultrata*, *G. trilobus* and *G. tumida* (Fig. 2.5b) and show significant positive correlations (Tab. 2.2). All these species have flux maxima during austral winter, with considerable offsets in time that suggest they occur in a winter succession. The first species to peak is *S. dehis*, which only occurs during austral winter, with a maximum flux of 5 shells $\text{m}^{-2} \text{d}^{-1}$ in June and gradually decreasing until mid-August, followed by *Globorotalia cultrata* and *G. menardii*. Although the highest flux of *P. obliquiloculata* occurs later, its fluxes already start increasing before *S. dehis* peaks, while *G. tumida* shows the last and sharpest single peak of all winter species. Their productivity maximum is associated with mixed layer deepening and nutrient entrainment during austral winter in the Mozambique Channel, which results in a deep chlorophyll maximum (Fallet et al., 2010; Ridderinkhof et al., 2010). Interestingly, high fluxes of *P. obliquiloculata* closely match a localised august maximum in satellite derived absorption, linked exclusively to marine productivity rather than being supported by riverine inputs.

Seasonality also contributes to the negative loadings on PC-1 for *G. digitata*, *C. nitida*, *G. ruber* and *G. scitula*, which mainly occur outside the winter months. They contribute either as a summer species (*G. ruber*), in a spring and autumn maximum (*C. nitida*) or in multiple maxima also in summer (*G. scitula*), or in low highly scattered fluxes throughout the year (*G. digitata*). Enhanced shell fluxes of *N. dutertrei* are partly coinciding with these winter species,

but also occur at other times of the year.

The observed single flux maximum of *G. tumida* suggests an annual life cycle. This is in agreement with previous findings of Žarić et al. (2005) and Jonkers et al. (2014) for globorotalid family-members. Moreover the thick crust made by *G. tumida* is in line with previous suggested causal relationships for crust formation and foraminiferal life cycles (Steinhardt et al., 2015, chapter 5). Patterns in crust and cortex thickness as well as composition suggest that these terminal shell features may have formed over a prolonged time period and may reflect a deep resting stage. Resting stages might be a common feature in the life cycle of planktonic foraminifera in species that only show a single, sharp peak in abundance during the year. This includes mostly deeper dwelling, encrusting species such as *P. obliquiloculata*, *G. truncatulinoides*, *N. pachyderma* (e.g. Deuser, 1986; Hemleben et al., 1989; Schiebel and Hemleben, 2005; Mothadi et al., 2009; Salmon et al., 2015)

Also PC-2 accounts for significant variability in the data set (20.6%) and is dominated by *G. sacculifer* (including *G. sac.sac.* and *G. trilobus*), *G. ruber* and *N. dutertrei*. PC-2 shows a more gradual change throughout the year than either PC-1 or PC-3, with maximum scores during austral summer towards autumn (Fig. 2.5a). Hence PC-2 shows a gradual shift, related to the time of the year rather than a single bloom event such as PC-1. The fact that *G. sac.tril.* is both related to PC-1 and has a strong positive loading on PC-2 shows that this morphotype exhibits a seasonal cycle (PC-2) as well as having a superimposed maximum related to the winter productivity (PC-1).

Although only minor variability is accounted for by PC-3 (12.3%), it shows a single maximum related to the flux maxima of *G. scitula* and *C. nitida* (Fig. 2.5b) which both have strong positive loadings on PC-3. This maximum seems to be linked to an odd chlorophyll maximum in January (Fig. 2.3). Interestingly the two, more or less symmetrical maxima in *C. nitida* are linked to different PC-axes and hence possibly not related causally. Whereas the first maximum during June coincides with the early winter bloom, the second maximum appears in PC-3. The process underlying PC-axis 3 is not clear from our studies and might not be part of the annual changes in the Mozambique Channel. Still, understanding the relatively rare species *C. nitida* could shed some light on the underlying mechanism producing this PC-axis.

The shell flux ratios of *G. ruber* to *G. trilobus* and of *N. dutertrei* to *G. scitula* show strong seasonality (Figs. 2.3 and 2.4). The *G. ruber* and *G. trilobus* ratio reflects the seasonal pattern of SST, with higher ratios during austral summer (Fig. 2.3), in agreement with previous findings

of Fallet et al. (2010, 2011). Shell flux ratios of *N. dutertrei* and *G. scitula* show a pronounced single peak in austral winter (August), which coincides with flux maxima of *P. obliquiloculata*. This is in line with observations of Ravelo et al. (1990) and Itou and Noriki (2002), who both found that shell fluxes of *N. dutertrei* are concurrent with surface water stratification, with higher *N. dutertrei* fluxes corresponding to well stratified conditions. In addition, Itou et

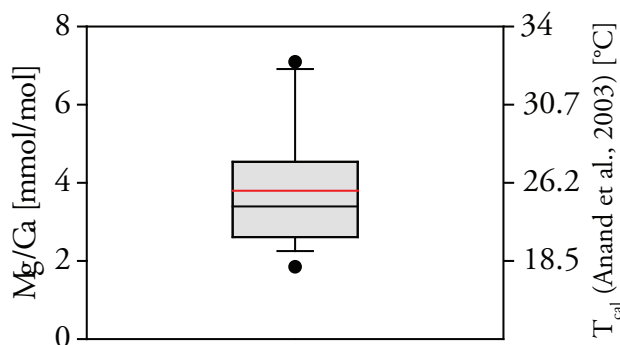


Fig. 2.6: Mg/Ca ratios for *C. nitida* shells. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. In addition, the graph shows the mean (red line) whereas the open circles indicate the 5th and 95th percentiles. The standard percentile method uses linear interpolation to determine the percentile values. The 50th percentile (median) is indicated with the black lines within the boxes. Calcification temperatures are calculated using the general Anand et al., 2003 equation $Mg/Ca = 0.38 \cdot \exp(0.09 \cdot T)$.

al. (2001, 2002) suggest that increasing shell fluxes of *G. scitula* are in response to increased downward transport of fine suspended organic matter, due to winter surface water turnover. Hence elevated shell flux ratio of *N. dutertrei* and *G. scitula* is likely to reflect deepening of the winter-mixed layer.

One of the least known species among larger planktonic foraminifera is the thin-walled micro-perforate *C. nitida*. It is unusually common in our material and the only species with high fluxes after the summer months with SST still being relatively high. This is in line with its Mg/Ca values (3.8 mmol/mol, Fig. 2.6) that translate into a calcification temperature of $24.8 \pm 4.2^\circ\text{C}$ (SE: 0.5°C , Fig. 2.6) according to the general Mg/Ca calibration of Anand et al. (2003). These temperatures are found in the upper 160 m of the water column. In the seasonal succession *C. nitida* succeeds the major summer species and precedes the major winter species,

without a clear relation to specific environmental variables.

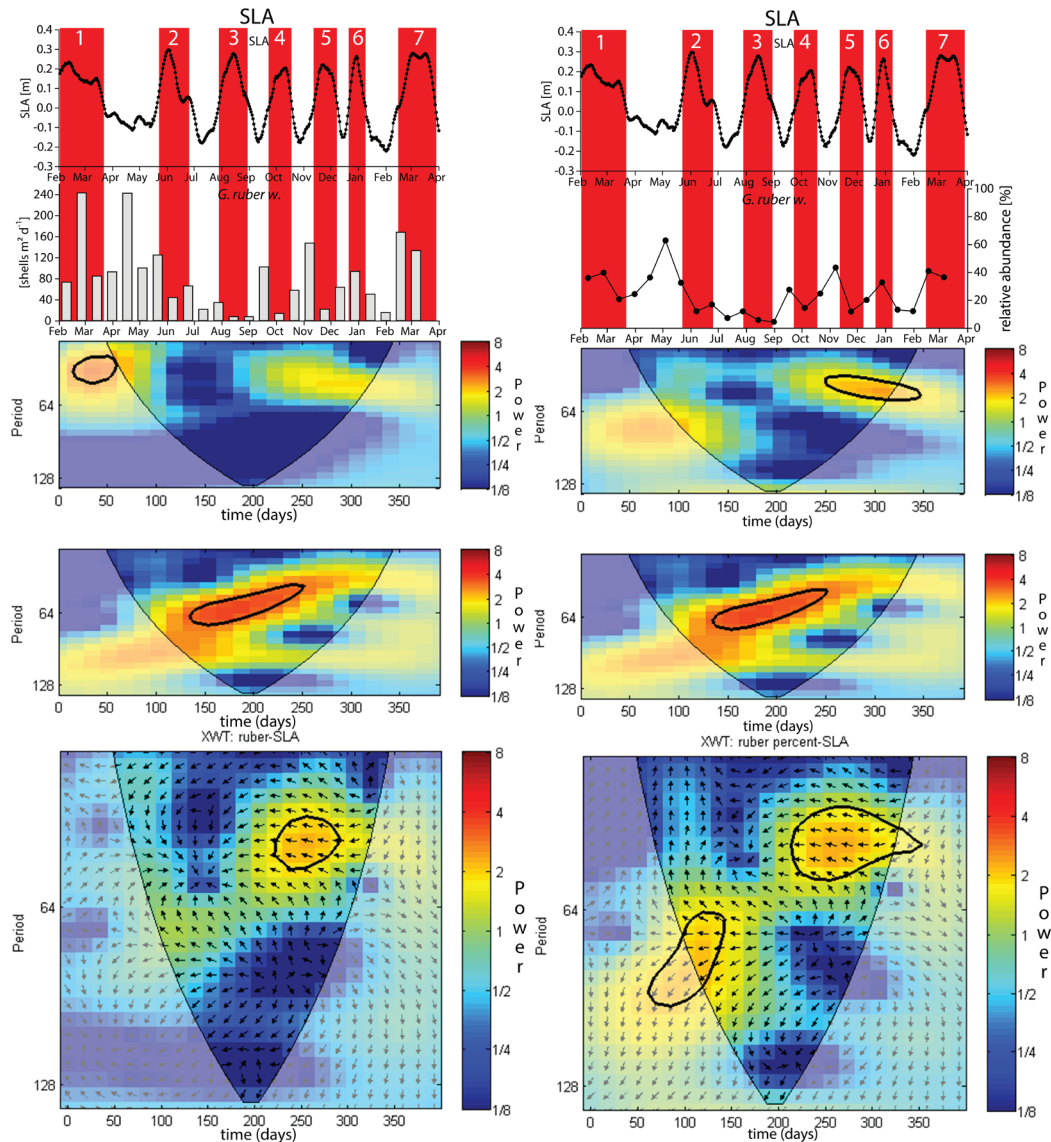


Fig. 2.7: Continuous wavelet (cwt) and cross wavelet analysis (xtw) of *G. ruber* fluxes and relative abundance compared to SLA during the sediment trap deployment. The cwt expands the time series into time frequency space, whereas the xwt finds regions in time frequency space where the time series show highest common power. The 5% significance level against the red noise is shown in thick contours. The cone of influence (COI) where edge effects make the analyses unreliable are marked by areas shaded white. The colour coding shows the power (blue=low to red=high). During the deployment period seven eddy events are identified. Phase arrows indicate the relative phase relationship between the series. The arrows pointing to the left indicate an anti-phase of *G. ruber* and SLA. High fluxes and relative abundance of *G. ruber* seem to be an early response to the onset of the deepening of the isotherms with the passing of an eddy.

2.5.2 Higher frequency variability and eddies

To separate the effect of seasonal changes and higher frequency variability such as the passing of eddies we performed wavelet analyses of both SLA and shell fluxes of all species. Frequency analysis of SLA, using a morlet wavelet clearly shows a gradual changing power maximum, from below 60 days to about 30 days at the end of the deployment. This is in line with the seven eddies passing through Mozambique Channel, that that year showed a decrease in wavelength from almost two months during eddy number 2 (Fig. 2.7), to less than a month during eddy number 6 (Fig. 2.7). Although no straightforward correlation is observed between any of the PC axes and the SLA, wavelet analysis shows that the flux of *G. ruber*, in addition to their seasonal variability, also have variability in line with the SLA. A clear maximum power is visible at 30-50 days amplitude, albeit only during the second half of the deployment. Looking subsequently in detail at the actual flux maxima of *G. ruber*, they occur slightly earlier than maxima in SLA (Fig. 2.7). Such an early response of *G. ruber* flux implies that *G. ruber* is at its maximum at the rim rather than the centre of the eddy, which is in line with the very oligotrophic conditions in the centre. However, in view of the relatively fast rotation of the eddy (days to about a week) a second maximum would be expected after SLA maximum. This second maximum is either not very well expressed or missed due to the limited sampling resolution. Irrespective, the cumulative annual flux is only weakly affected by changes in the number or the intensity of these eddies, as the seasonal contrast in fluxes is an order of magnitude higher than eddy contrasts. Extrapolating to down core records, changes in abundance of *G. ruber* would be dominantly driven by changes in seasonality rather than in eddy frequency and/or intensity. Variability on a seasonal or potentially inter annual time scale is much larger than the differences in flux observed here to co-vary with eddies. Down core reconstruction of eddy transports using *G. ruber* fluxes is therefore not possible in the Mozambique Channel. In view of the short time scale associated with these eddies such approaches might be based by inter and/or intra shell differences in foraminiferal shell geochemistry (Steinhardt et al., 2014, Chapter 3).

2.5.3 Comparison with core top sediments

Expressing the sediment trap-based fluxes in annual averages allows comparing relative abundances to the sedimentary record. In our Mozambique Channel record, the annual cumulative sediment trap assemblage (>250 μm) is dominated by *G. ruber* (24.8%), followed by *G. sacculifer* (23.9%), *N. dutertrei* (7.6%), *G. scitula* (3.7%) and *P. obliquiloculata* (1.8%) (Fig. 2.8). In core tops across the MC, the average assemblage (>150 μm) is dominated by *G. ruber* ($32.2 \pm 3.4\%$), followed by *G. sacculifer* ($13 \pm 0.7\%$), *G. siphonifera* ($10.1 \pm 0.4\%$), *G. glutinata* ($9.3 \pm 3.6\%$), *N. dutertrei* ($8.7 \pm 1.2\%$). Relative abundances between 2% and 5% are

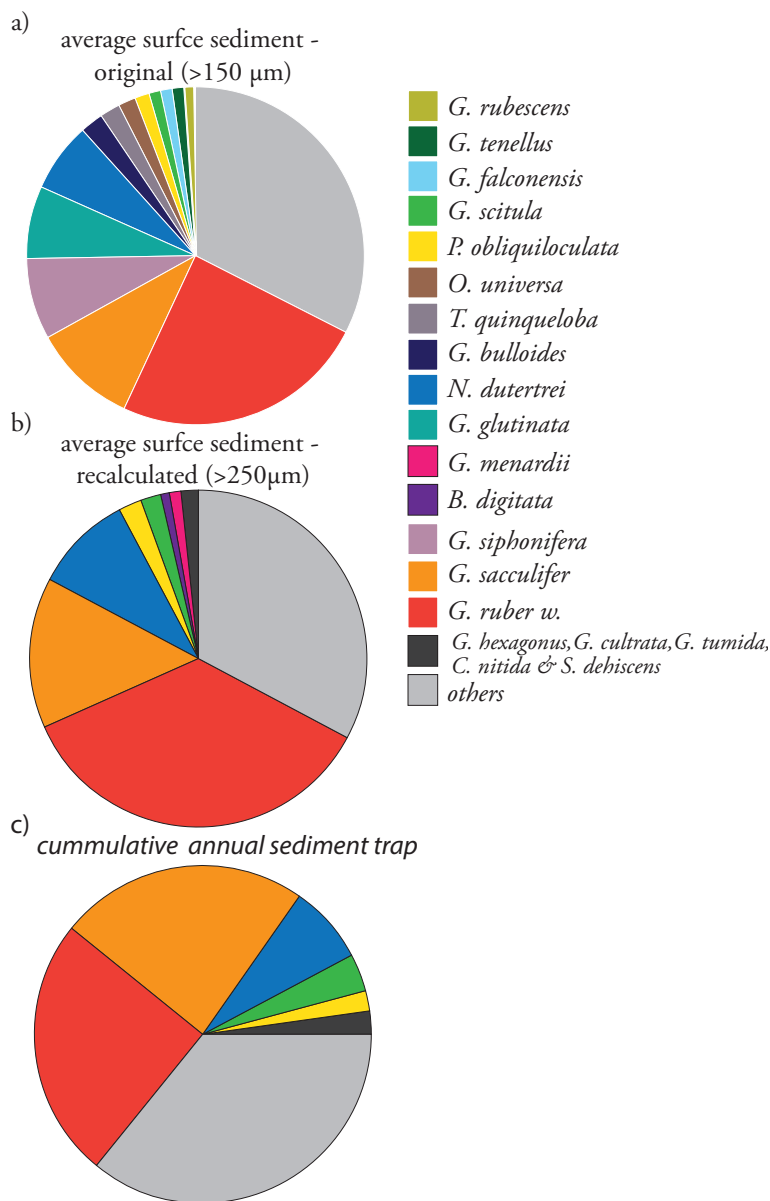


Fig 2.8: a) Average core top species composition >150 µm, b) species composition based on averaged recalculated core top sediments from the Mozambique Channel and c) based on the annual shell flux from a one year sediment trap time series (bottom; >250 µm).

observed for *G. bulloides* ($2.7 \pm 0.9\%$), *T. quinqueloba* ($2.5 \pm 1.5\%$), *O. universa* ($2.2 \pm 0.2\%$) and *P. obliquiloculata* ($2.0 \pm 0.9\%$). Considering the different size fractions used, the cumulative annual assemblage is thus in reasonable agreement with relative abundances of the same species in the surface sediment. Because of the different size fractions used, however, we recalculated the average composition omitting species generally smaller than 250 µm. Moreover, as we did not

specify *O. universa* and *G. siphonifera* for the sediment trap, they were lumped in the “others” bin for the core tops as well to facilitate direct comparisons. The recalculated composition of the sedimentary fauna more closely corresponds to annual flux weighted averages based on the sediment data (Fig. 2.8). The recalculated sediment composition (Fig. 2.8b) is again dominated by *G. ruber* (35.6%), followed by *G. sacculifer* (14.3%), *N. dutertrei* (9.6%), *P. obliquiloculata* (2.2%) and *G. scitula* (1.8%). In this case, the higher relative abundance of *G. ruber* is probably due to size fraction effects as *G. ruber* tends to be more prominent in the fine size fraction as opposed to the other species (Peeters et al., 1999). Relative abundances for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* are very similar to the annual sediment trap flux weighted average. Overall, the clear correspondence between the annual flux weighted averages and the sediment faunal composition, representing the average of at least the last few decades, implies that the single seasonal flux captured here is similar to the average year. A divergent seasonal pattern in the year sampled would change relative abundances of the summer species (e.g. *G. ruber*) and winter species (*G. menardii*, *G. cultrata*, *G. tumida*, *P. obliquiloculata*), whereas that might be true to some extent, overall fluxes and sediment composition agree.

To assess to what extent the change in planktonic foraminiferal flux during the year affects geochemical proxies in the time-averaged sediment, we calculated species specific flux-weighted annual potential $\delta^{18}\text{O}$ and Mg/Ca values, based on in situ temperatures and existing calibrations (Fallet et al., 2012; Birch et al., 2013). Using the species-specific calibration developed by Anand et al. (2003) and the 17-day averaged temperatures at 110 m (lmc5a) flux-weighted annual Mg/Ca values for *N. dutertrei* should be about 2.2 mmol/mol (Fig. 2.9). This calculated flux-weighted annual Mg/Ca value is in good agreement with Mg/Ca values between 2.0 and 2.2 mmol/mol in *N. dutertrei* from mid-channel sediments (Fallet et al., 2012). For *G. ruber*, using the species specific calibration developed by Fallet et al. (2010) and 17-day average SST, we calculate Mg/Ca values of 5.1 mmol/mol (Fig. 2.9). In contrast, Fallet et al. (2012) find lower Mg/Ca values of 4.1 mmol/mol in sediment *G. ruber*. Such an offset for *G. ruber* could either imply inter-annual variability in the seasonal flux with respect to the year captured in the sediment trap, skewing the flux weighted average towards the dominant season in the time-averaged sediment (Berger and Wefer, 1990; Curry et al., 1992; Deuser et al., 1981), or an overall warming at the sea surface. Since the *G. ruber* flux is in close correspondence to its relative abundance in the sediment, recent warming could explain the observed offset between calculated potential Mg/Ca and values measured on the sub-fossil assemblage.

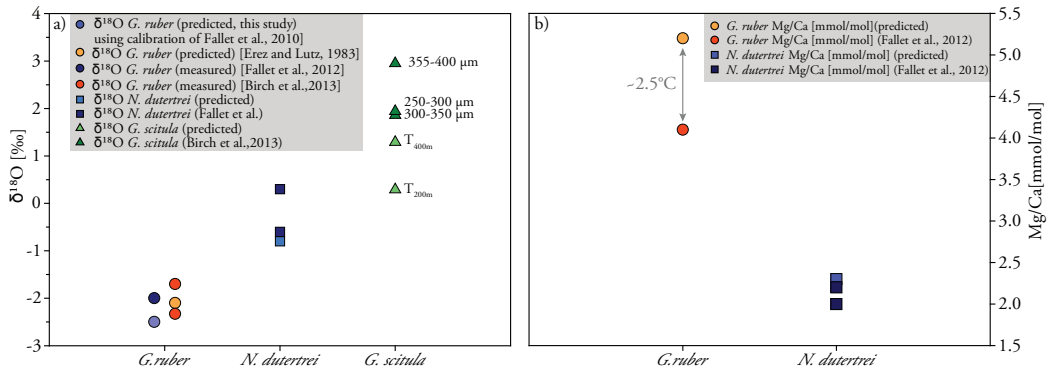


Fig. 2.9: Result summary of predicted (this study) and measured surface sediment (a) Mg/Ca (Fallet et al., 2012) and (b) $\delta^{18}\text{O}$ (Fallet et al., 2012; Birch et al., 2013) values.

In a way similar to Mg/Ca we can assess the $\delta^{18}\text{O}$ as measured by Fallet et al. (2012), using the species-specific equation for *G. ruber* developed by Fallet et al. (2010) and for *N. dutertrei* the general calibration from Epstein et al. (1953). We calculate a potential flux weighted average for $\delta^{18}\text{O}$ of -2.5‰ for *G. ruber* and -0.8‰ for *N. dutertrei*. Fallet et al. (2012) measured slightly more positive $\delta^{18}\text{O}$ values of -2.0‰ for *G. ruber* and between -0.6 to 0.3‰ for *N. dutertrei* from the sediment (Fig. 2.9). Furthermore, we compare potential $\delta^{18}\text{O}$ values of *G. ruber* and *G. scitula* to surface sediment specimen measured by Birch et al. (2013), using the general equation of Erez and Luz (1983). For *G. ruber* our calculated potential $\delta^{18}\text{O}$ using SST of -2.1‰ is within the range of -1.7 to -2.3‰ measured by Birch et al. (2013) for the size fraction between 250 to 400 μm . Using 17-day mean temperatures at 200 m water depth, based on the proposed deeper calcification depth for this species (Ortiz et al., 1996, Fallet et al., 2011), we calculate that *G. scitula* has a potential flux weighted $\delta^{18}\text{O}$ value of 0.3‰ . This is considerably lower than found by Birch et al. (2013), with values ranging between 1.87 and 3‰ in the 250 - 400 μm size fraction (Fig. 2.10). As *G. scitula* is known to inhabit water depths below 200 m (Ortiz et al., 1996), we also calculated the flux weighted mean $\delta^{18}\text{O}$ value using 17-day mean temperatures at 400 m, which yield a $\delta^{18}\text{O}$ value of 1.3‰ . This value is considerably lower than the values measured by Birch et al. (2013). Nevertheless, the annual flux-weighted $\delta^{18}\text{O}$ -based temperatures for *G. scitula* of 16.6°C at 200 m and 12°C at 400 m, are higher than the calcification temperature of about 9.5°C in the 250 - 300 μm size fraction estimated of Birch et al. (2013). Hence, this suggests that *G. scitula*, in the Mozambique Channel, might calcify at greater water depths below 400 m.

Whereas the flux weighted mean values calculated for oxygen isotopes and Mg/Ca are quite close, albeit somewhat warmer to the actual values measured in the sediment, these values

are offset from those reported by Fallet et al., (2012) for the trap. This implies that another, unknown, factor must have affected the isotope values. The somewhat warmer conditions based on our calculated proxy values suggest that the sea surface temperatures today are higher ($\sim 2.5^{\circ}\text{C}$) than the average found at the sediment surface (Fig. 2.9). Since the sediment surface probably represents about the last 1000 years (Fallet et al., 2012) a recent warming would explain this offset. Recent observations and model comparisons suggest unusually strong anthropogenic warming in the Indian Ocean (e.g. Barnett et al., 2005; Alory et al., 2007; McClanahan et al., 2009; Nakamura et al., 2009; Zinke et al., 2014), which is in line with our observations. Basin-mean SST of the tropical Indian Ocean have amounted to 0.5°C by the end of the 20th century, since steadily increasing from the 1950's (Du and Xie, 2008). A more recent study of Roxy et al., 2014 found that the western basin of the Indian Ocean experienced a more pronounced warming (1.2°C) over the last century. Although we cannot fully account for the temperature difference between predicted and measured temperatures based on foraminiferal geochemistry, the recent SST increase supports our hypothesis.

2.6. Conclusions

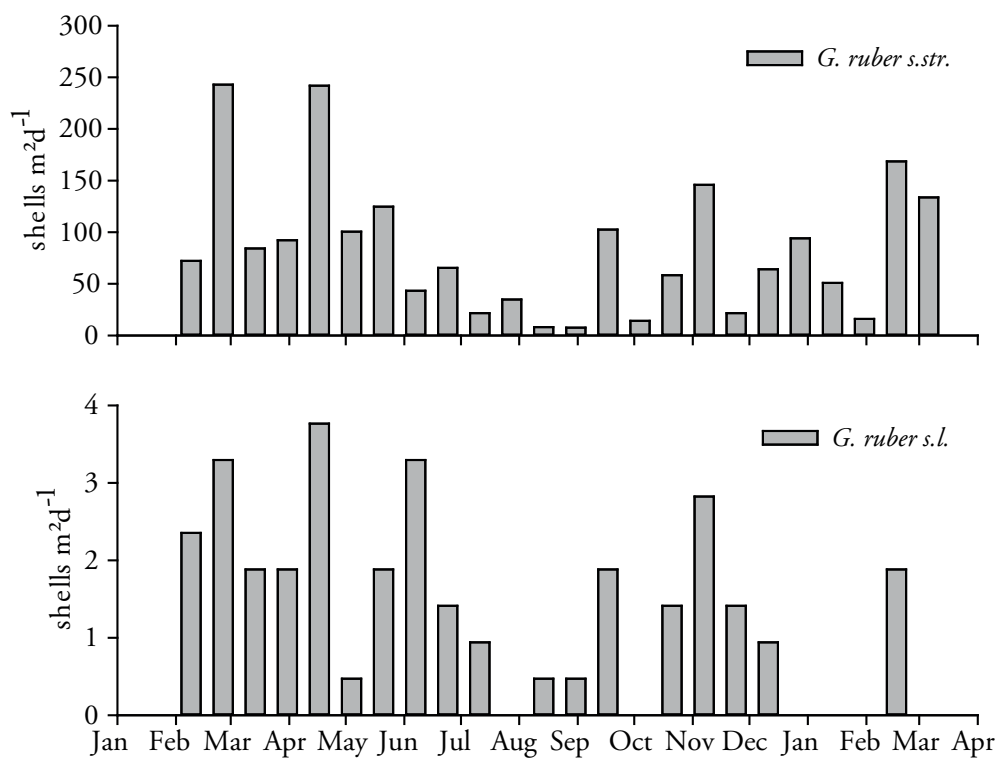
Species fluxes of planktonic foraminifera show clear seasonality in the Mozambique Channel, some in a clear single maximum. Within this bloom a clear succession of species is observed. Seasonality and productivity bloom together explain nearly 50% of the observed variability. Although several species show sub-seasonal variability, maxima in *G. ruber* fluxes are related to eddies and show an early response to the onset of eddy-related thermocline deepening. On an annual basis, the flux-weighted species composition is very similar to that found in core top sediments across the channel narrows. Downcore reconstructions will have to rely on geochemical shell chemistry constraints rather than foraminiferal census data if the aim of the reconstruction is to track eddy variability.

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Supplements

Supplement



Supplementary fig. 1: Fluxes of *G. ruber sensu stricto* and *G. ruber sensu lato* during the deployment of MOZ4.



Supplementary Tab. 1: Foraminiferal fluxes during the deployment of MOZ4.

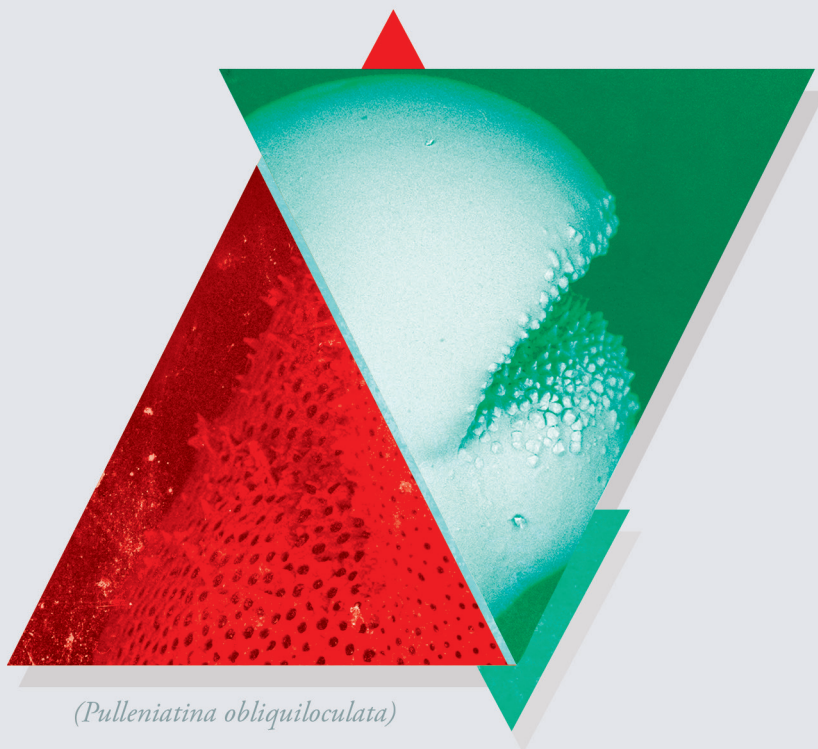
date	<i>G. cult</i>	<i>S. debis</i>	<i>B. digi</i>	<i>N. dut</i>	<i>G. hexa</i>	<i>G. men</i>	<i>C. nit</i>	<i>P. obli</i>	<i>G. rub u.</i>	<i>G. tril</i>	<i>G. sac. sac.</i>	<i>G. sac</i>	<i>G. scit</i>	<i>G. tum</i>	others	total foram	Pteropoda	<i>G. rub s.str.</i>	<i>G. rub s.l.</i>	PF/P	LOG (PF/P)
2/9/2008	0	0	1	4	0	0	0	0	0	14	14	28	2	0	96	202	70	72	2	3	0.5
2/26/2008	0	0	1	43	0	0	0	1	243	72	81	153	8	0	166	619	64	243	3	10	1
3/14/2008	0	0	3	27	1	0	0	0	85	28	20	48	21	0	227	415	90	84	2	5	0.7
3/31/2008	1	0	1	21	0	2	0	1	93	66	74	140	9	0	116	270	81	92	2	3	0.5
4/17/2008	0	0	1	42	0	0	0	1	243	66	107	173	3	0	212	466	193	242	4	2	0.4
5/4/2008	0	0	2	5	0	0	0	0	101	16	9	25	1	0	26	160	52	100	0	3	0.5
5/21/2008	0	0	1	24	0	0	3	6	125	49	41	90	14	0	124	389	103	125	2	4	0.6
6/7/2008	0	5	0	21	0	1	2	13	44	118	33	151	8	0	137	385	114	43	3	3	0.5
6/24/2008	1	4	2	35	0	0	0	16	66	106	54	160	2	2	102	394	111	65	1	4	0.5
7/11/2008	0	3	0	18	0	3	0	14	22	66	24	91	12	0	147	311	79	22	1	4	0.6
7/28/2008	3	2	0	51	0	1	0	34	35	54	24	77	0	4	82	291	48	35	0	6	0.8
8/14/2008	3	0	1	26	1	0	0	16	8	16	7	23	3	0	63	142	77	8	0	2	0.3
8/31/2008	2	0	0	16	0	2	0	10	8	16	9	25	8	26	83	179	110	8	0	2	0.2
9/17/2008	3	0	4	33	0	1	0	6	103	56	43	100	25	3	100	379	93	103	2	4	0.6
10/4/2008	0	0	1	5	0	0	0	1	14	7	2	9	9	0	57	97	68	14	0	1	0.2
10/21/2008	0	0	1	12	0	0	0	1	58	40	35	76	25	0	65	241	38	58	1	6	0.8
11/7/2008	0	0	0	21	1	0	0	2	148	25	21	46	2	0	122	343	38	146	3	9	1
11/24/2008	0	0	3	12	0	0	0	1	22	22	18	40	14	0	100	194	75	22	1	3	0.4
12/11/2008	0	0	1	24	1	0	6	1	64	21	30	51	12	0	161	322	83	64	1	4	0.6
12/28/2008	0	0	0	33	0	0	6	0	94	19	16	34	8	0	112	287	31	94	0	9	1
1/14/2009	0	0	1	41	0	0	11	0	51	47	53	100	47	0	134	385	136	51	0	3	0.5
1/31/2009	0	0	0	19	0	0	1	0	16	16	22	38	22	0	35	132	10	16	0	13	1.1
2/17/2009	0	0	2	16	0	1	2	1	168	37	31	68	3	0	153	416	89	168	2	5	0.7
3/6/2009	0	0	4	17	0	0	5	0	134	29	23	52	2	0	154	367	75	134	0	5	0.7

Supplementary Tab. 2: Relative abundances of planktonic foraminifera during the deployment of MOZ4

date	<i>G. cult</i>	<i>S. dehis</i>	<i>B. dǔgi</i>	<i>N. dut</i>	<i>G. hexa</i>	<i>G. men</i>	<i>C. nit</i>	<i>P. obli</i>	<i>G. rub u.</i>	<i>G. tril</i>	<i>G. sac. sac.</i>	<i>G. sac</i>	<i>G. scit</i>	<i>G. tum</i>	<i>others</i>	<i>G. rub s.str.</i>	<i>G. rub s.l.</i>
2/9/2008	0.17	0	0.68	2.02	0	0.17	0	0	35.99	6.82	6.59	13.41	1.02	0	46.53	34.86	1.14
2/26/2008	0	0	0.15	6.92	0	0.08	0.08	0.15	39.77	11.71	13.08	24.79	1.29	0	26.77	39.24	0.53
3/14/2008	0	0	0.79	6.58	0.23	0	0.11	0.11	20.77	6.7	4.77	11.46	5.11	0	54.82	20.32	0.45
3/31/2008	0.37	0	0.24	5.37	0.12	0.49	0	0.24	24.39	17.2	19.15	36.34	2.32	0	30.12	23.9	0.49
4/17/2008	0	0	0.14	6.25	0	0	0	0.14	36.25	9.72	15.83	25.56	0.42	0	31.25	35.69	0.56
5/4/2008	0	0	1.32	3.19	0.15	0	0	0.26	62.89	9.97	5.43	15.4	0.37	0	16.43	62.6	0.29
5/21/2008	0	0	0.24	6.17	0	0	0.73	1.57	32.53	12.58	10.64	23.22	3.63	0	31.92	32.04	0.48
6/7/2008	0	1.22	0	5.38	0	0.24	0.61	3.42	12.1	30.68	8.56	39.24	2.08	0	35.7	11.25	0.86
6/24/2008	0.36	1.08	0.48	8.96	0	0.12	0.12	4.18	16.97	27	13.74	40.74	0.6	0.6	25.81	16.61	0.36
7/11/2008	0	0.91	0.15	5.71	0.15	1.06	0	4.41	7.26	21.34	7.87	29.2	3.93	0	47.21	6.96	0.3
7/28/2008	1.13	0.65	0.16	17.48	0	0.49	0.16	11.65	11.97	18.45	8.09	26.54	0.16	1.29	28.32	11.97	0
8/14/2008	2.27	0.32	0.65	17.8	0.65	0	0	11.33	5.83	10.68	4.85	15.53	2.27	0	43.37	5.5	0.32
8/31/2008	1.05	0	0	8.66	0	1.05	0	5.51	4.46	9.19	4.99	14.17	4.2	14.7	46.19	4.2	0.26
9/17/2008	0.75	0	0.99	8.81	0	0.25	0.11	1.49	27.58	14.91	11.43	26.34	6.6	0.75	26.34	27.08	0.5
10/4/2008	0.24	0	1.45	5.56	0	0	0	0.72	14.49	7.25	2.17	9.42	9.18	0	58.94	14.49	0
10/21/2008	0.2	0	0.39	5.08	0.2	0	0	0.59	24.8	16.8	14.65	31.45	10.35	0	26.95	24.22	0.59
11/7/2008	0	0	0	6.04	0.27	0	0	0.55	43.41	7.42	6.04	13.46	0.55	0	35.71	42.58	0.82
11/24/2008	0	0	1.46	6.07	0	0.24	0.24	0.73	11.89	11.17	9.47	20.63	7.04	0	51.7	11.17	0.73
12/11/2008	0	0	0.29	7.6	0.29	0	1.75	0.29	20.18	6.43	9.36	15.79	3.8	0	50	19.88	0.29
12/28/2008	0	0	0.16	11.48	0	0	2.13	0	32.79	6.56	5.41	11.97	2.62	0	38.85	32.79	0
1/14/2009	0	0	0.24	10.76	0	0	2.93	0	13.2	12.22	13.69	25.92	12.22	0	34.72	13.2	0
1/31/2009	0	0	0	14.29	0	0.36	0.71	0.36	12.14	12.14	16.79	28.93	16.79	0	26.43	12.14	0
2/17/2009	0	0	0.45	3.85	0	0.23	0.45	0.23	40.95	8.82	7.47	16.29	0.68	0	36.88	40.5	0.45
3/6/2009	0	0	1.03	4.62	0	0	1.28	0	36.41	7.95	6.15	14.1	0.51	0	42.05	36.41	0

Supplementary Tab. 3: Recalculated relative abundances of planktonic foraminifera in the surface sediment of 11 core tops across the MC.

species	PE304 MC56	PE304 MC63	M75-1b Mono64	M75-1b Mono67	M75-1b Mono69	M75-1b Mono70	M75-1b Mono71	M75-1b Mono74	M75-1b Mono75	M75-1b Mono76	M75-1b Mono77	cummulative average
<i>G. cultrata</i>	1.06	0.4	0.3	0.87	0.7	0.15	0.48	0.39	1.23	0.11	0.18	0.53
<i>S. debiscens</i>	0.19	0	0.6	0	0	0	0	0.1	0.18	0	0	0.1
<i>B. digitata</i>	1	0.94	0.6	0.87	0.35	1.64	0.95	0.39	1.23	1.17	1.47	0.97
<i>N. dutertrei</i>	9.26	9.41	8.16	10.17	9.58	9.42	8.73	8.97	11.93	10.73	9.71	9.64
<i>G. hexagonus</i>	0.5	0.27	0	1.3	0.58	0.75	0.95	0.49	1.05	0.85	0.55	0.66
<i>G. menardii</i>	0.69	0.54	0.6	0.65	0.7	1.05	0.32	4.54	0.35	0.74	0.37	0.96
<i>C. nitida</i>	0	0.4	0.3	0	0.12	0.3	0	0.1	0	0	0.18	0.13
<i>P. obliquiloculata</i>	3.56	1.08	2.42	2.81	1.4	1.64	0.95	2.17	2.63	2.66	2.38	2.16
<i>G. ruber w.</i>	30.58	40.86	38.67	37.66	32.13	33.33	35.71	33.43	35.61	38.26	35.9	35.65
<i>G. sacculifer</i>	14.7	14.92	12.69	11.9	14.49	13.9	12.7	13.41	16.67	15.2	17.03	14.33
<i>G. scitula</i>	2.06	2.28	0.91	2.81	1.52	2.09	0.79	0.59	2.28	1.7	2.38	1.77
<i>G. tumida</i>	0.38	0.13	0	0.22	0.12	0.3	0.32	0.2	0	0.32	0	0.18
others	36.02	28.76	34.74	30.74	38.32	35.43	38.1	35.21	26.84	28.27	29.85	32.93
<i>Log10(PF/P)</i>	3.24	1.91	1.39	2.25	1.96	2.87	1.73	3.03	2.77	2.71	2.14	2.36



(Pulleniatina obliquiloculata)

Chapter 3

Anti-cyclonic eddy imprint on calcite geochemistry of several planktonic foraminiferal species in the Mozambique Channel

Chapter 3

Anticyclonic eddy imprint on calcite geochemistry of several planktonic foraminiferal species in the Mozambique Channel

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Abstract

Hydrographic conditions in the Mozambique Channel are dominated by the passing of large anticyclonic eddies, propagating poleward into the upstream Agulhas area. Further south, these eddies have been found to control the shedding of Agulhas rings into the Atlantic ocean, thereby playing a key role in Indo-Atlantic Ocean exchange. The element composition of several planktonic foraminifera species collected from sediment trap samples, was compared to in situ water column data from the Mozambique Channel. Single-chamber trace element composition of these foraminifera reveals a close coupling with hydrographic changes induced by anticyclonic eddies. Obtained Mg/Ca values for the surface dwelling *Globigerinoides ruber* as well as the thermocline dwelling *Neogloboquadrina dutertrei* follow temperature changes and reduced temperature stratification during eddy conditions. At greater depth, *Globorotalia scitula* and *Pulleniatina obliquiloculata* record stable temperatures and thus respond to hydrographic changes with a deepening in habitat depth. Furthermore, test Mn/Ca values indicate a close relationship between water column oxygenation and Mn incorporation in these planktonic foraminiferal species.

3.1. Introduction

Mesoscale eddies play a crucial role in transporting water (e.g. Schouten et al., 2002a,b) and heat (Bryan, 1986; Sallée et al., 2008) over long distances, thereby promoting large-scale mixing of the ocean (Lutjeharms et al., 1989; Ballegooyen et al., 1994; De Ruijter et al., 1999). In addition to the well-studied eddies within the Gulf Stream and Kuroshio Current (Cronin and Watts, 1996; Mensa et al., 2013), eddies are ubiquitous and found in many regions (e.g. McGillicuddy et al., 1998; Martin and Richards, 2001; Mackas et al., 2005; Kolasinski et al., 2012). Eddies also transport nutrients, salt and other chemicals (Bakun, 2006; Xiu et al., 2011), thereby regulating marine species abundances and community composition (Owen, 1981; Sabarros et al., 2009; Huggett, 2013; Lamont et al., 2013). Cyclonic eddies rotate clockwise in the Southern Hemisphere and carry a cold water core, corresponding to a reduced sea surface height. Anticyclonic (anti-clockwise) eddies are characterized by a warm water core and associated with elevated sea surface height. The impact of eddy activity is not confined to the sea surface but affects deeper and in some cases, bottom water conditions. Oceanographers in the 1960s placed drifters and floats at depth providing evidence of mesoscale eddy features (Cook, 1966; Send et al., 1999). Since then satellite images of SST, ocean colour and altimetry have been applied to detect and study eddies (e.g. Fu et al.,

2010). Considering their ubiquitousness, it is expected that eddies affect the circulation in large parts of the global ocean system. Eddies being shed from the Agulhas Current into the Atlantic Ocean, so called “Agulhas leakage”, is among the better described examples of the impact of eddies on climate. Global warming, as observed currently, is likely to cause a further increase in Agulhas leakage (Biaostoch and Böning, 2013), thereby affecting ocean mixing and biogeochemical dynamics, which in turn might influence climate. This relation implies an unexplored feedback mechanism potentially affecting the global climate system.

The Agulhas Current, one of the major western boundary currents, plays a crucial role in the global ocean conveyor circulation (Gordon et al., 1992; Weijer et al., 2002). By shedding rings, eddies and filaments into the South Atlantic, Agulhas leakage supplies warm and saline water from the Indian Ocean into the Atlantic (Gordon, 1986; Gordon et al., 1992; De Ruijter et al., 1999; Beal et al., 2011) thereby influencing Atlantic meridional overturning circulation (AMOC) (Biaostoch et al., 2008). Records of past changes in Agulhas leakage based on planktonic foraminiferal assemblages (Peeters et al., 2004) showed a link to glacial–interglacial cycles. The salt export into the Atlantic basin by Agulhas eddies is hypothesized to provide the negative overall buoyancy needed for deep-water formation in the North Atlantic (Weijer et al., 2001; 2002).

Up-stream of the Agulhas Current, eddies in the Mozambique Channel propagate poleward into the Agulhas Retroflexion where they have been shown to occasionally trigger shedding of Agulhas Rings (Schouten et al., 2002a,b). There are extensive records from satellite sensors, in situ observations and numerical models, which can be used collectively to study and interpret eddy-induced environmental impacts (e.g. Byrne et al., 1995; Biaostoch and Krauss, 1999; De Ruijter et al., 2002; Backeberg et al., 2012). A recent model study (Backeberg et al., 2012) suggested an increase in eddy kinetic energy between 1993 and 2009, resulting in a doubling of the pole ward propagation of anticyclones. Flow from the Mozambique Channel and the southern extension of the East Madagascar Current (EMC) are both considered to be important sources for the Agulhas Current (Schouten et al., 2002a,b; De Ruijter et al., 2004). This implies that intensification of the mean flow and its mesoscale variability may have downstream implications for the Agulhas Current and could thereby influence leakage into the South Atlantic Ocean. To study the interplay between eddy activity and large-scale climate variability, reconstructing past eddy activity could provide valuable information. Here we propose a novel approach based on the chemical composition of planktonic foraminiferal calcite tests to develop such a proxy. We selected specimens from sediment trap times series in the Mozambique Channel where eddies are frequent and long-term oceanographic observations

available (Ullgren et al., 2012). Long-term moorings in the center of the Mozambique Channel show that five to seven large anticyclonic eddies with a diameter of >300 km pass southwards every year (Schouten et al., 2002a,b; Harlander et al., 2009). These eddies can extend down to depths of 1.5 km (De Ruijter et al., 2002; Ullgren et al., 2012) and account for up to 30 - 40% of the observed hydrographic variability.

Here we present single-chamber trace element compositions from specimens with contrasting calcification depths, the surface-dweller *Globigerinoides ruber* (d'Orbigny, 1839), thermocline-dwelling species *Neoglobobquadrina dutertrei* (d'Orbigny, 1839) and *Pulleniatina obliquiloculata* (Parker et al., 1865) and the deep dweller *Globorotalia scitula* (Brady, 1882). Specimens were collected from sediment trap samples and analyzed using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Obtained element/Ca ratios will allow calibrating incorporation of e.g. magnesium and manganese in planktonic foraminifera in function of in situ hydrographic conditions, both during eddy and non-eddy conditions and compare incorporation of these elements in the surface versus sub-surface water column.

3.2. Materials and methods

3.2.1. Oceanographic setting

The Mozambique Channel (MC) is an oligotrophic region with concentrations of chlorophyll *a* in surface waters between 0.3 mg/m³ in summer and 0.25 mg/m³ in winter. Seawater temperatures (SST) in the MC vary seasonally and with eddy-induced transport (Fallet et al., 2011). The seasonal temperature forcing is associated with the monsoon system and is reflected by sea surface temperatures (SST) ranging from 25°C to more than 30°C with an annual mean of 27.6°C. With the onset of austral summer, rainfall increase caused by the seasonal migration of the ITCZ, sea surface salinities decrease slightly from 35.2 in winter to 34.9 in summer (Fallet et al., 2010). The main water masses of the upper layer in the MC include the Tropical Surface Water (TSW), Subtropical Surface Water (STSW) and Indonesian Throughflow Water (ITFW). The warm, fresh surface water (TSW) forms in the tropics and is transported westward within or north of the South Equatorial Current (SEC, New et al., 2007). Close to the western margin, where the SEC bifurcates, warm surface waters are transported poleward, either east of Madagascar, or through the Mozambique Channel (e.g. Gründlingh, 1995; Swallow et al., 1988). The STSW is characterized by relatively high salinities and a subsurface maximum, with salinities of 35.2 – 35.5, at approximately 200 meters below sea surface, at which depth the surface water subducts below the fresher TSW (Wyrski, 1973). Southward migration of anticyclonic meso-scale eddies, originating at 10°S north off the Comoros Islands,

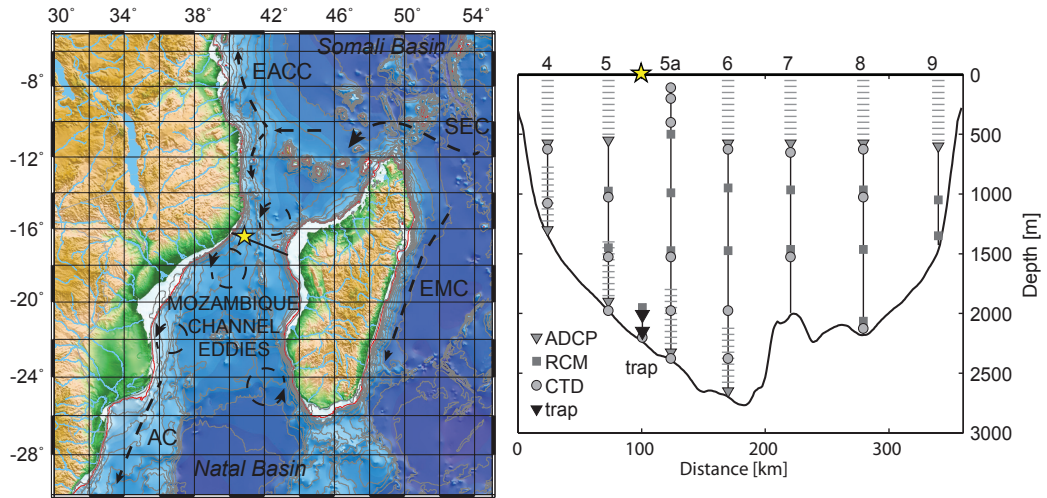


Fig. 3.1: Overview map of southwestern Indian Ocean and location of the sediment trap (indicated by yellow star) and the line of mooring deployments. The mooring array is shown in detail on the right. The yellow star indicates the location of the trap within the mooring array. EACC: East African Coastal Current, SEC: South Equatorial Current, AC: Agulhas Current, EMC: East Madagascar Current, star: sediment trap location

affects the Mozambique Channel hydrography (Fig. 3.1). Mozambique Channel eddies have high rotational velocities, often above 1.5 m/s (Schouten et al., 2003; Ullgren et al., 2012). These eddies pass through the channel at a mean frequency of about four to seven per year (at a southward propagation speed of 3-6 km.d⁻¹) before joining the Agulhas Current. An eddy passage is associated with vertical movement of isopycnals, which can occasionally exceed 40 m per day in the upper layer (Ullgren et al., 2012). Backeberg and Reason (2010) suggested that formation of meso-scale eddies in the Mozambique Channel is related to variability in SEC transport (Fig. 3.1).

3.2.2. Sediment trap and mooring array

Ongoing observations started in November 2003, as part of the Long-term Ocean Climate Observations (LOCO) program, with an array of eight moorings across the narrowest part of the channel, providing continuous current velocities, temperature and salinity measurements at fixed depths. Over the period 2003 to 2009, the average volume transport was estimated at -17 Sv (1 Sv = 10⁶ m³ s⁻¹; negative poleward), daily values ranging between -65 and 45 Sv (Ullgren et al., 2012). Below the poleward mean flow, a deep undercurrent is flowing in the opposite direction along the continental slope (De Ruijter et al., 2002; Harlander et al., 2009; Ridderinkhof et al., 2010). For this study, we used temperatures recorded at 110 meters; 200 meters and 400 meters water depth by a CTD deployed on mooring lmc5a (16.8°S, 41.1°E,

Fig. 3.1), which is closest to the trap site. Additionally, we obtained averaged daily SST from the 4 km daytime MODIS/AQUA dataset for the area 16 - 17°S and 40 - 41°E (trap site) for the period of the selected sediment trap intervals (<http://poet.jpl.nasa.gov/>).

Technicap PPS 5 sediment traps were deployed at 16.8°S and 40.8°E in the central MC (Fig. 3.1). Equipped with a 24-cup automated sampling carousel and a baffled collecting area of 1 m², the trap was positioned 250 meters above the channel floor at 2250 meters water depth. In total four sediment trap deployments took place between November 2003 and February 2009, each programmed to a 17, 21 or 23 days sampling interval. Prior to deployments, sample cups were filled with an HgCl₂-poisoned and borax-buffered solution of seawater collected from the deployments depth (Lončarić et al., 2007). Time-series sediment trap samples were wet-split, sieved and foraminiferal shells were cleaned as previously described (Fallet et al., 2009; 2010).

3.2.3. Eddy/ non-eddy detections & sample selection

The passing of an anticyclonic eddy through the narrows of the Channel is marked by high temperature and salinity, as well as high dynamic height in the satellite altimetry record. At the leading (southern) edge of the eddy with a diameter of up to 300 km (De Ruijter et al., 2002), current velocities are expected to have a predominant eastward component, whereas a zonal section across the center of the eddy would show a strong southward flow on the western side and a northward component on the eastern side, and the trailing (northern) edge of the eddy should show a westward component. An eddy core passing through the LOCO mooring section thus coincides with a peak in the difference between meridional current velocity on the eastern and western side of the mooring array. The meridional current velocity averaged over the upper 500 m at mooring lmc5 on the western side of the array was subtracted from the similarly averaged meridional velocity at lmc8 on the eastern side to give a measure of the lateral current shear across the Channel, which was used as a proxy for eddy presence at the mooring section. The lateral current shear from in situ measurements was combined with dynamic heights from satellite altimetry in order to define periods when eddies were present at the section. An eddy core was considered to be at the mooring section when there was a local maximum in dynamic height at 41.3°E greater than 10 cm above surrounding values, coinciding with a maximum in absolute lateral current shear within 10 days. This measure corresponded well with the hydrographic eddy signatures in temperature and salinity; for example maxima in subsurface temperature measured by the moorings correlate well with the peaks in dynamic height or velocity shear.

We are not only concerned with the timing of eddy cores at the section, but rather with accounting for the full period in which an eddy passes the sediment traps location. For this reason we defined “eddy segments” as a period between two dynamic height minima which contains one well-defined combined maximum of dynamic height and lateral velocity shear, following the criteria outlined above. We selected the sediment trap intervals during which the whole sediment cup collection took place under either full eddy or full non-eddy conditions. The following three intervals were appointed as representing non-eddy conditions: MOZ1 A07 (28. March - 17. April 2004), MOZ2 A11 (25. October -16. November 2005), and MOZ4 A01 (1. - 17. February 2008). The three intervals representing eddy conditions were MOZ1 A08 (18. April - 08. May 2004), MOZ2 A12 (17. November - 9. December 2005), and MOZ4 A06 (26. April - 12. May 2008). Eddy variability in the upper and intermediate waters is dominated by the effect of temperature, whereas salinity only has a minor effect (Ullgren et al., 2012). For the chosen sediment trap intervals, temperature observations from the mooring (lmc5a), are compiled and daily means were used to calculate eddy and non-eddy temperature profiles (Fig. 3.2). Mean conditions during the selected eddy and non-eddy

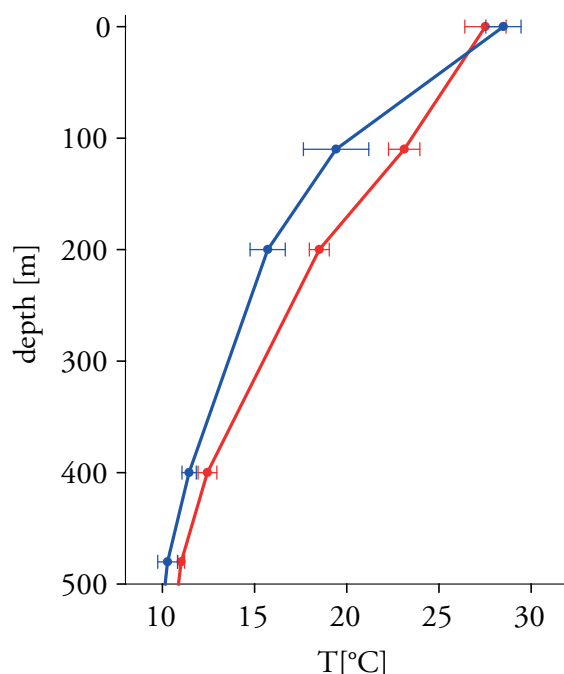
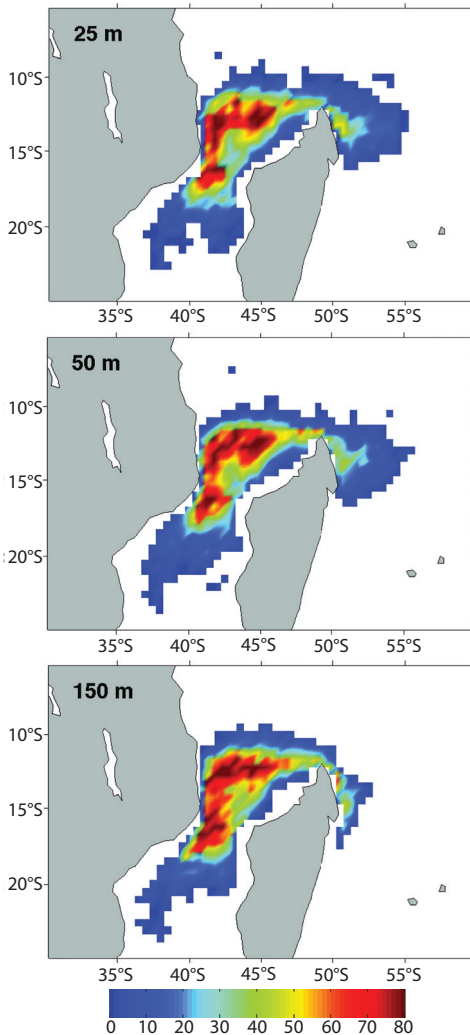


Fig. 3.2: Temperature profiles for the water column in the Mozambique Channel. Indicated in red for eddy and in blue for non-eddy conditions, derived from averaging the observed T [°C] profiles during 3 individual eddy intervals and 3 non-eddy intervals. Data is plotted for the upper 500 m only.

intervals show that eddy conditions are associated with warmer upper water columns.

To ensure that the planktonic foraminifera are not derived from long-distance transport, but rather formed and settled locally within the Mozambique Channel, we simulated the provenance of virtual particles within the high-resolution INALT01 model (Durgadoo et al., 2013). INALT01 has been shown to represent the intricacies of the greater Agulhas Current system faithfully (Durgadoo et al., 2013). For these calculations, ~10,000 particles, representing planktonic foraminifera, were released within a hind-cast experiment at the location and depth of the sediment trap. Back trajectories were calculated

in two steps: first (representing the last phase of transport of shells to the trap) relatively fast sinking occurs after the foraminifera die, second (occurring earlier) followed by back



tracking living foraminifera and confinement to a specific depth interval. This way we calculated the likelihood for particular locations being the origin of the trapped foraminifera. Assuming an average sinking speed of ~ 1 cm/s after death (Takahashi and Bé, 1984), foraminiferal shells reached the depth of the sediment trap within approximately 3 days. Prior to this sinking stage foraminiferal tests were assumed to have travelled at 25, 50 and 150 m water depth respectively, and were thus back-tracked for 6 weeks (assuming this as an average lifespan for the planktonic foraminiferal species used here (Hemleben et al., 1986; Lončarić et al., 2006).

Fig. 3.3: Lagrangian back trajectory results. For the experiment 10,000 particles are released at 40.85°E; 16.71°S and from 2100 m water depth. Assuming 1 cm/s sinking speed, particles placed back at 25 meters, 50 meters and 150 meters. The particles reach the surface after ~ 3 days. Graph shows the distribution of particles per $0.5 \times 0.5^\circ$ box after 6 weeks of advection (assuming an average lifespan approximation of foraminifera) after they surfaced at their respective depths. Warmer colors can be interpreted as a more probable location of foraminifera 6 weeks before they started to sink. Sediment trap location is indicated with a black cross.

The back-trajectory model-results show that the majority of the foraminifera captured by our sediment trap originated from the MC and hence are suitable to trace hydrographic changes within the MC (Fig. 3.3).

3.2.4. Species selection and chamber analysis used for proxy development

We selected four planktonic foraminiferal species, suggested to dwell at different depth intervals in the water column for element analyses of their carbonate tests. *Globigerinoides ruber* white is a shallow dwelling species (0 - 50 m), often used to reconstruct SST (Hemleben et al., 1989). The subsurface-dwellers *Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata*

have been associated with a calcification depth of 0 - 100 m and 60 - 150 m in the upper and middle thermocline, respectively (Erez and Honjo, 1981; Fairbanks et al., 1982; Ravelo and Fairbanks, 1992; Pflaumann and Jian, 1999; Spero et al., 2003; Field, 2004; Kuroyanagi and Kawahata, 2004; Cl  roux et al., 2007; Huang et al., 2008). We also included the deep-dwelling species *Globorotalia scitula* to analyse deep water conditions (B  , 1969; Ortiz et al., 1996; Itou et al., 2001; Fallet et al., 2011). This set of foraminiferal species should therefore cover the vertical extend of the upper water column and thereby the most pronounced changes associated with eddy variability.

Specimens were selected from the 250 - 315 μm size fraction as much as possible. In case sufficient specimens from the designated trap samples were not available within this size range for replicate LA-ICP-MS analyses larger specimens were also used, which is indicated in table S1 (Supplementary material). For *G. ruber* we ablated the penultimate- and pre-penultimate chamber (F-1 or F-2 chambers) and results for both chambers were combined to calculate relevant averages, since no significant differences for Mg/Ca between chambers were observed (see result section 3.1). For *N. dutertrei*, *P. obliquiloculata* and *G. scitula* we ablated the final three to four chambers. Previously a size effect was suggested for *G. ruber* whole test Mg/Ca values (Friedrich et al., 2012). Still, Friedrich et al. (2012) observed almost no change between the 250 - 300 μm and 300 - 350 μm size fractions and hence, in view of the rather narrow size interval used here (250-315 μm), Mg/Ca differences related to size are likely to be negligible. This is also in line with Ni et al., (2007), who showed that variability of Mg/Ca ratio with test size is largely negligible. Also when using laser ablation ICP-MS limiting the size range is a good way to exclude a major ontogenetic effect on single-specimen Mg/Ca-derived temperatures (Wit et al., 2010).

3.2.5. LA-ICP-MS

Element/Ca ratios (e.g., Mg/Ca) of single chambers were determined by LA-ICP-MS at Utrecht University (Reichert et al., 2003). A GeoLas 200 Q Excimer 193 nm deep ultra violet laser (Lambda Physik) was used to ablate circular craters of 60 or 80 μm in diameter depending on the surface area of the chambers. Energy density at the sample surface was approximately 1 J cm^{-2} and all samples were ablated with a repetition rate of 7 Hz in a He atmosphere. The sector field mass spectrometer (Element 2, Thermo Scientific) was run in low-resolution mode and masses monitored included ^{23}Na , ^{24}Mg , ^{26}Mg , ^{27}Al , ^{43}Ca , ^{44}Ca , ^{55}Mn , ^{88}Sr , ^{114}Cd , ^{138}Ba and ^{238}U . Calibration was performed against SRM NIST610 glass standard (using values from Jochum et al., 2011), with ^{43}Ca as an internal standard, which was ablated at higher energy density (5 J cm^{-2}) 3 times between every 10 - 12 foraminiferal samples. A matrix

matched, homogenous calcite crystal (Icelandspar) with known Mg/Ca was ablated to check for matrix dependent fractionation caused by the different energy densities when switching between glass and calcium carbonate (Dueñas-Bohórquez et al., 2011). Concentrations of Mg in the foraminiferal shell were calculated using count rates for ^{24}Mg . Concentrations of Mg and confidence intervals for each individual measurement were calculated using the Glitter

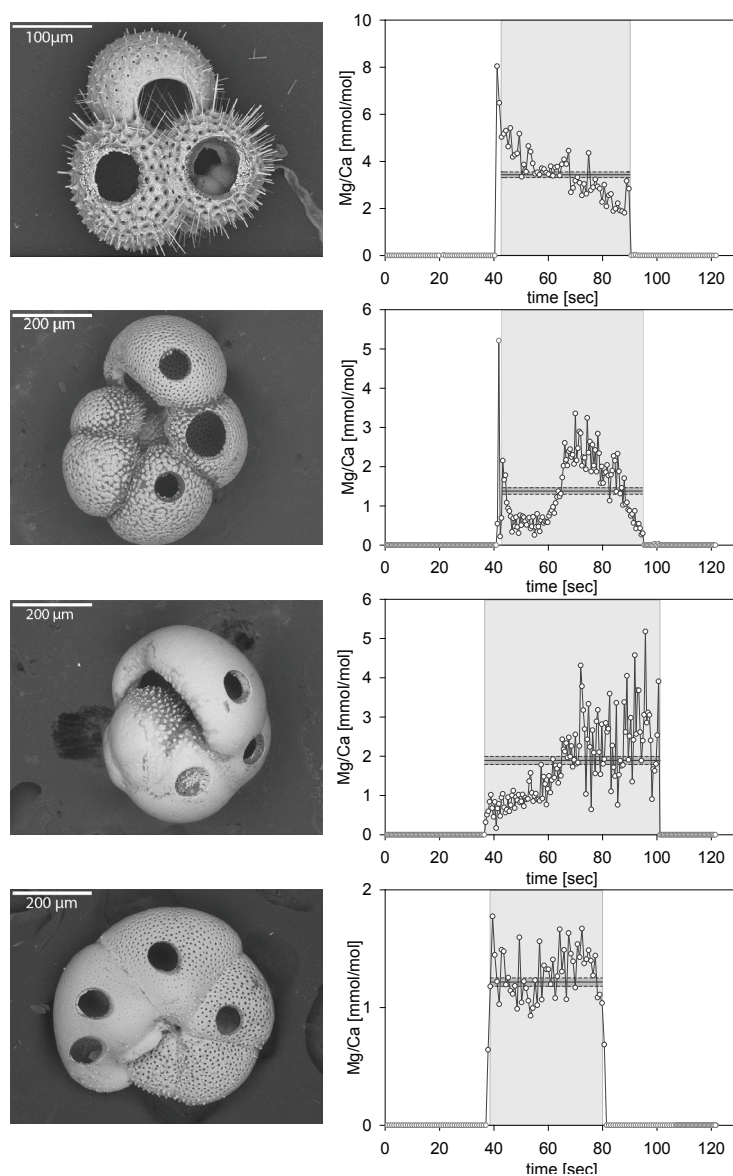


Fig. 3.4: Scanning electron microscope (SEM) pictures of *G. ruber*, *N. dutertrei*, *P. obliquiloculata* and *G. scitula*, showing the laser ablation craters created during the trace metal analyses. On the right panel, typical LA-ICP-MS Mg/Ca profiles are shown. Circles within grey area are used for integration of Me/Ca concentration calculations.

software (Glitter, Maquarie Research Limited, 1999 - 2000). The matrix matched in-house standard showed average relative standard deviations (SD) of 3.7% for Mg/Ca and 3.2% for Mn/Ca. Measurements were performed on intact specimens and always proceeded from the outside towards the inside (Fig. 3.4). In total, 536 single-chamber Me/Ca values were obtained. We do not consider variability (and outliers) within the profiles. Values deviating more than twice the standard deviation from the initial dataset were regarded as outliers and discarded from the initial dataset. In total we discarded 19 Mg/Ca values based on an outlier analysis.

3.2.6. Mg/Ca calibrations

Mg incorporation into foraminiferal calcite is related to temperature and likely affected by a combination of thermodynamic controls and foraminiferal physiology (Bentov and Erez, 2006; Rosenthal et al., 1997). For many planktonic species it was shown that calcitic Mg/Ca varies exponentially with calcification temperature (Nürnberg et al., 1996; Lea et al., 1999; Rosenthal et al., 2000; Anand et al., 2003; Cléroux et al., 2008) in the form:

$$\text{Mg/Ca [mmol mol}^{-1}] = B * e^{AT}.$$

The exponential constant (A) reflects temperature sensitivity. For many species, it is reported to be between 0.09 and 0.10 (e.g. Anand et al., 2003). The pre-exponential constant (B) is species-specific and may also vary with differences in size fraction used, cleaning protocols and dissolution effects (Anand et al., 2003; Fallet et al., 2010).

We used the following equations to translate measured Mg/Ca ratios into calcification temperatures:

- a) *G. ruber*: $\text{Mg/Ca} = [\text{SST} - 15.71] / 2.32$ (Fallet et al., 2010)
- b) *N. dutertrei*: $\text{Mg/Ca} = 0.342 * \exp(0.09 * T)$ (Anand et al., 2003)
- c) *P. obliquiloculata*: $\text{Mg/Ca} = 0.328 * \exp(0.09 * T)$ (Anand et al., 2003)
- d) *G. scitula*: $\text{Mg/Ca} = 0.409 * \exp(0.09 * T)$ (Anand et al., 2003)

These calibrations are all based on whole multiple test analyses from sediment trap samples. Previous studies showed that both single-chamber and multiple-shells Mg/Ca data are similarly correlated to temperature (Hathorne et al., 2003; Reichert et al., 2003). Recent culture studies (e.g. Dueñas-Bohórquez et al., 2009) also found that data from multiple individual chambers are consistent with previously derived whole-foraminiferal test calibrations.

The calibration for *G. ruber* from Fallet et al. (2010) was recently derived using the same sediment trap material as used here. Over the temperature range considered here the calibrations of Fallet et al. (2010) and the calibration for *G. ruber* of Anand et al. (2003) ($Mg/Ca = 0.449 * \exp(0.09 * T)$) are very similar. Still, since the calibration of Fallet et al. (2010) is based on the local seasonal temperature cycle, this calibration is probably best suited for our purposes. For *N. dutertrei* and *P. obliquiloculata* we applied species-specific calibrations from the sediment trap time-series from the North Atlantic Ocean (Anand et al., 2003). Because no species specific calibration is available for *G. scitula* we applied a calibration based on *G. hirsuta* (Anand et al., 2003). This seems reasonable since both species are Globorotalids, having similar depth habitats and Mg/Ca values within the same range (1 - 2 mmol/mol). Importantly, since here we focus on differences between eddy and non-eddy conditions, the calibrations used as such are less important as this mainly affects absolute temperatures.

3.3. Results

3.3.1. Mean Me/Ca ratios

3.3.1.1. Mg/Ca

Average Mg/Ca values of *G. ruber* are highest, followed by those of *N. dutertrei*, *P. obliquiloculata* and lowest values are observed in *G. scitula* tests (Fig. 3.5). Average Mg/Ca values for *N. dutertrei* (2.6 mmol/mol, standard error: (SE): 0.06 mmol/mol, N=228) correspond to lower temperature (22.5°C) compared to those based on Mg/Ca *G. ruber* (Mg/Ca= 5.32 mmol/mol, SE: 0.09 mmol/mol, N=176, 28.1°C). Mg/Ca values of *N. dutertrei* and *P. obliquiloculata* (2.29 mmol/mol, SE: 0.1 mmol/mol, N=47, 21.6°C) are similar, Mg/Ca values for *G. scitula* are the lowest (1.5 mmol/mol, SE: 0.07 mmol/mol, N=100) (Fig. 3.4), corresponding to temperatures of 14.4°C. The inter-test variability is highest in *G. ruber* (standard deviation (SD): ± 1.2 mmol/mol), followed by *N. dutertrei* (SD: ± 1.0 mmol/mol), *P. obliquiloculata* (SD: ± 0.6 mmol/mol), with lowest spread in *G. scitula* (SD: ± 0.4 mmol/mol).

Average Mg/Ca of the different chamber positions (F; F-1; F-2, Supplement 1) were compared for each species. No significant intra-test Mg/Ca variability was detected in *G. ruber*, *P. obliquiloculata* and *G. scitula*. Only *N. dutertrei* shows increasing Mg/Ca values towards the final chamber (Fig. 3.6). An analysis of variance on ranks (Kruskal-Wallis One Way analysis) showed that the differences are significant at the level of $p < 0.001$. A pairwise Multiple Comparison Procedure was used to show that all chambers in *N. dutertrei* differ in Mg/Ca (Dunn's Method, $p < 0.05$).

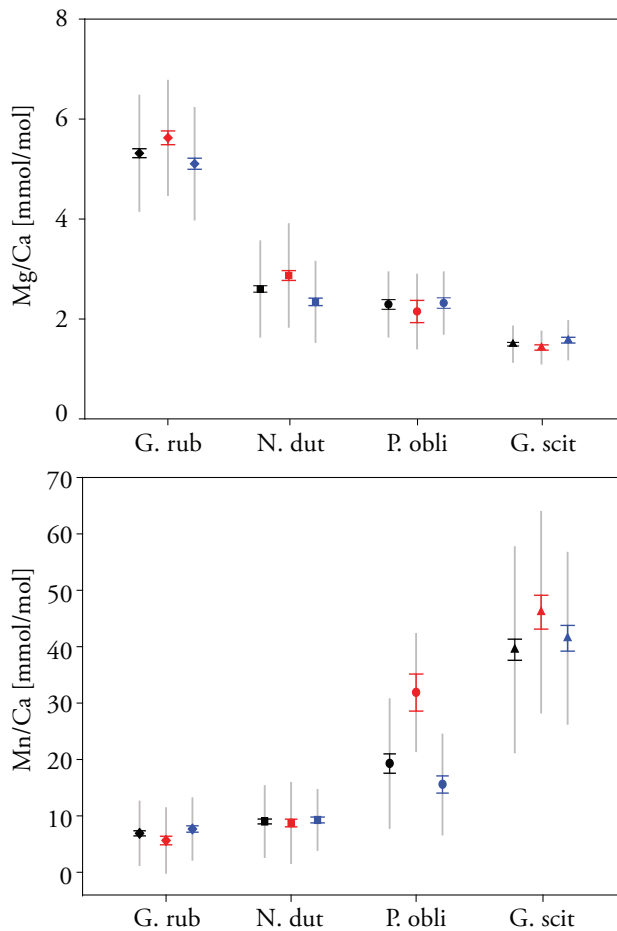


Fig. 3.5: Averaged Mg/Ca (a) and Mn/Ca (b) values (black), based on all specimen analyzed, excluding outliers based on two times standard deviation (SD) of the entire population. In red data for eddy conditions. Blue symbols correspond to non-eddy conditions. Error bars indicate standard error, extended gray lines show SD.

3.3.1.2. Mn/Ca

Average test values of Mn/Ca in *G. ruber* ($< 8 \mu\text{mol/mol}$) and *N. dutertrei* are low ($< 10 \mu\text{mol/mol}$) compared to the values recorded for *P. obliquiloculata* ($19.3 \mu\text{mol/mol}$, SE: $1.7 \mu\text{mol/mol}$, SD: $\pm 11 \mu\text{mol/mol}$) and *G. scitula* ($40 \mu\text{mol/mol}$, SE: $1.9 \mu\text{mol/mol}$, SD: $\pm 18 \mu\text{mol/mol}$). Hence observed concentrations for all species are well above the detection limit for single chamber Mn/Ca analyses ($0.42 \mu\text{mol/mol}$). The maximum offset in average Mn/Ca values observed between species (*G. ruber* versus *G. scitula*) is approximately $33 \mu\text{mol/mol}$.

There is no significant intra-test variability in Mn/Ca observed in *N. dutertrei* or *P. obliquiloculata* for the analysed chambers (Fig. 3.6). We detect, however, significant intra-test variability in Mn/Ca values between successive chambers of *G. scitula*. The average Mn/Ca of its final chamber (F) (19 ± 10 $\mu\text{mol/mol}$) is almost 50% lower than observed for F-1 and F-2 (both chambers do not significantly differ from each other). We also observed a significant difference in Mn/Ca for *G. ruber* between test chambers ($p = < 0.001$) Lower Mn/Ca (4 $\mu\text{mol/mol}$, SD: ± 4 $\mu\text{mol/mol}$) are recorded by F-1 compared to F-2 (11 $\mu\text{mol/mol}$, SD: ± 8 $\mu\text{mol/mol}$). For further comparison of Mg/Ca and Mn/Ca values, contrasting eddy and non-eddy conditions we excluded the final chamber (F-0) for all species.

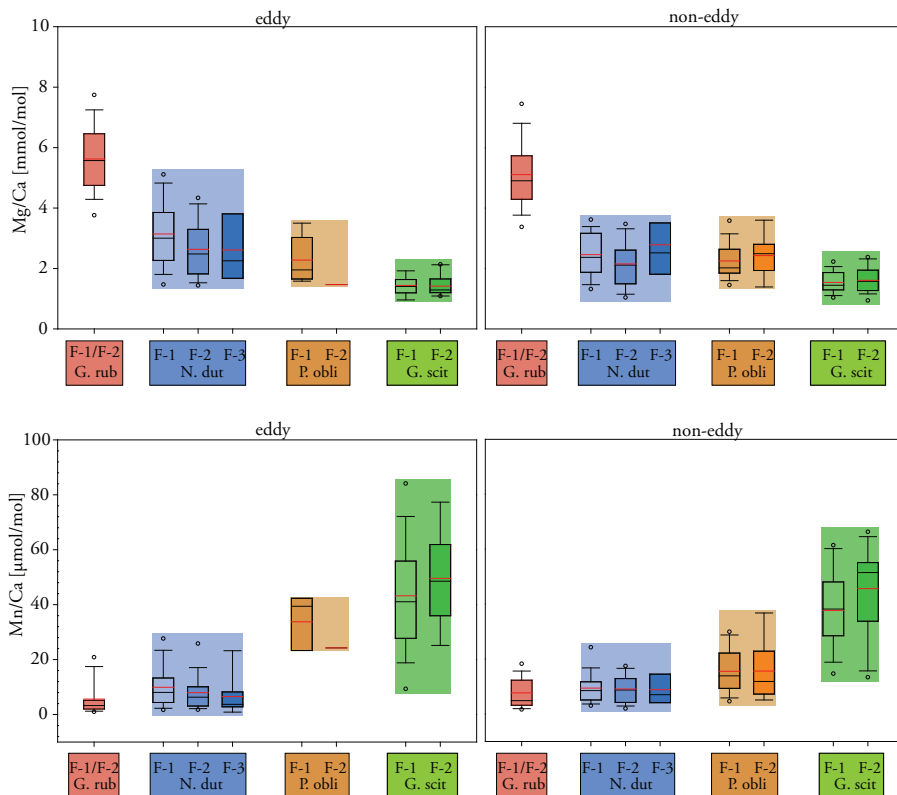


Fig. 3.6: Intra-species Mn/Ca and Mg/Ca during eddy and non-eddy for *G. ruber*, *N. dutertrei*, *P. obliquiloculata* and *G. scitula*, summarized in a box plot. Older chambers are indicated with darker colors. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. In addition, the graph shows mean (red line) whereas the open circles indicate the 5th and 95th percentile. The Standard percentile method uses linear interpolation to determine the percentile values. The 50th percentile (median) is indicated with the black lines within the boxes. The bounding boxes are used to graphically show overall differences between species.

3.3.2. Differences in Me/Ca between eddy and non-eddy intervals

3.3.2.1. Mg/Ca

Both *G. ruber* ($N_{\text{eddy}} = 70$; $N_{\text{non-eddy}} = 106$) and *N. dutertrei* ($N_{\text{eddy}} = 114$; $N_{\text{non-eddy}} = 152$) have significantly higher Mg/Ca values during eddy compared to non-eddy periods (Fig. 3.5) (*G. ruber*: $p = 0.004$, *N. dutertrei*: $p = <0.001$). Although differences in average values are modest, plotting the individual test data in a histogram clearly shows a shift in the relative distribution (Fig. 3.7). We observe a slightly more positive skewness of Mg/Ca distributions for *G. ruber*, *N. dutertrei* and *G. scitula* for eddy conditions compared to non-eddy conditions. However a randomization test showed that none of the three species showed a significant difference in skewness ($p = 0.38$, $p = 0.36$, and $p = 0.09$, respectively).

Mg/Ca values for *G. ruber* are lower during non-eddy conditions ($p = 0.002$). Average Mg/Ca values for *N. dutertrei* in the F-1 and F-2 chambers are significantly lower ($p = 0.002$ and $p = 0.011$, respectively) during non-eddy conditions (Fig. 3.5). Additional data on F-3 shows no significant difference in Mg/Ca between eddy and non-eddy conditions. Generally, there is less Mg/Ca variability between chambers during non-eddy conditions compared to eddy conditions. *P. obliquiloculata* and *G. scitula* do not show significant differences in Mg/Ca between chambers (one way ANOVA) between eddy and non-eddy conditions.

3.3.2.2. Mn/Ca

Both *G. ruber* and *N. dutertrei* record slightly lower Mn/Ca during eddy conditions compared to non-eddy conditions (Fig. 3.5). However these differences are not significant (Kruskal-Wallis One Way Analysis of Variance on Ranks: *G. ruber*, $p = 0.439$; *N. dutertrei*,

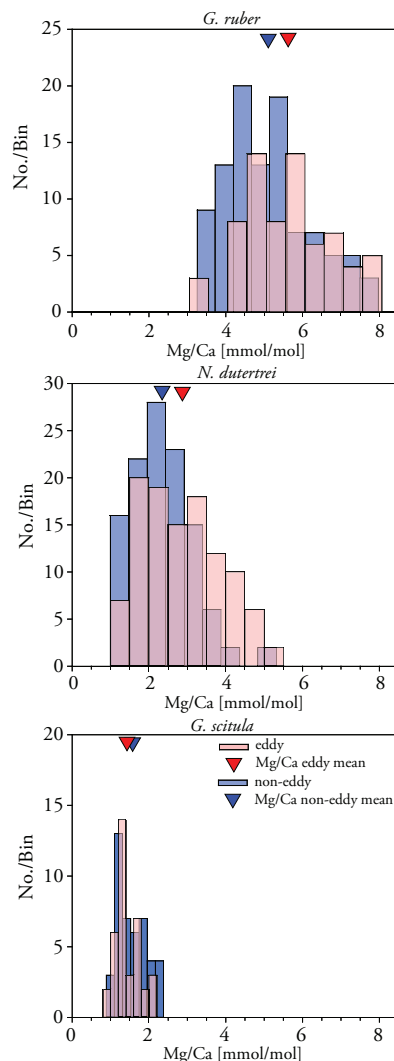


Fig. 3.7: Mg/Ca histograms for *G. ruber*, *N. dutertrei*, and *G. scitula*. Histograms indicate variability, distribution and skewness of modern distribution of Mg/Ca in the planktonic foraminifera studied here under eddy and non-eddy condition. Blue histograms represent distributions during non-eddy condition, red histograms eddy conditions. Blue down-sided triangle indicates mean Mg/Ca value for non-eddy, red down-sided triangle indicates mean Mg/Ca value for eddy condition.

$p = 0.044$) (Fig. 3.5). In contrast we observe on average higher Mn/Ca for *P. obliquiloculata* during eddy conditions (Kruskal-Wallis one way analysis of variance on ranks, $p < 0.001$). *G. scitula* shows no difference in Mn/Ca ratios between eddy and non-eddy conditions. There are no significant differences in intra-test trends observed between eddy and non-eddy conditions for any species studied here (Fig. 3.6).

3.4. Discussion

3.4.1. Environmental controls on Mg- and Mn-incorporation

3.4.1.1. Mg/Ca

Single chamber Mg/Ca results show that ratios in *G. ruber* and *N. dutertrei* are higher during eddy conditions (Figs. 3.5 and 3.6), reflecting observed warming at the depths where these species calcify. To test whether differences in temperature stratification between eddy and non-eddy intervals can be reconstructed, we compare inferred calcification depths from multiple species Mg/Ca temperatures with in situ mooring data.

We have selected four common species with contrasting depth habitats based on existing literature. Previous studies suggested that *G. ruber* dwells at or close to the sea surface (e.g. Anand et al., 2003; Field, 2004; Fallet et al., 2010), calcifying in the top 50 m (e.g. Dekens et al., 2002; Mohtadi et al., 2006; Farmer et al., 2007; Fallet et al., 2010; Birch et al., 2013).

N. dutertrei is an intermediate deep dwelling species living preferentially in the seasonal thermocline (e.g. Fairbanks et al., 1982; Curry et al., 1983; Eguchi et al., 2003; Farmer et al., 2007), where maximum abundances may coincide with a deep chlorophyll maximum (Fairbanks et al., 1980; Ravelo et al., 1990). Overall living depth is likely within the upper 200 m (Kroon and Darling, 1995; Farmer et al., 2007). Analyzing inter-chamber Mg/Ca variability within single specimen test walls of *N. dutertrei* from the Timor Sea Eggins et al. (2003) showed that this species recorded temperatures between 12 and 23°C, implying migration through the entire thermocline. However, the majority of calcification may be limited to a more restricted depth interval. This is suggested by oxygen isotope analyses of *N. dutertrei* in the Indian Ocean (Kiefer et al., 2006), showing a much narrower range within the upper thermocline (40 - 150 m). Paired Mg/Ca - $\delta^{18}\text{O}$ analyses of sediment trap samples from the Mozambique Channel suggest that *N. dutertrei* also calcifies at depths of approximately 80 m at this location (Fallet et al., 2011).

The species *P. obliquiloculata* is known to inhabit tropical to subtropical water masses (e.g. Tolderlund and Bé, 1971; Wilke et al., 2006, 2009). It was also shown by Ganssen and Sarnthein (1983) that this species thrives in winter periods off NW Africa, when upwelling conditions are prevailing. Its habitat depth has been suggested to be between 0 and 100 m (Erez and Honjo, 1981; Ravelo and Fairbanks, 1992; Watkins et al., 1996; Cléroux et al., 2008). Other field studies reported somewhat deeper calcification for this species at 120 - 180 m, based on plankton tows, sediment traps and coretops off NW Africa (Wilke et al., 2009).

The deep dweller *G. scitula* is non-symbiont bearing and has been shown to inhabit the deeper part of the water column between 0 and 700 m (Bé et al., 1977; Ortiz et al., 1996; Schiebel and Hemleben, 2000; Itou et al., 2001; Hathorne et al., 2009). A recent study used Mg/Ca to suggest a calcification depth of 200 - 300 m (Fallet et al., 2011).

Culture studies revealed that chamber formation occurs relatively fast and is concentrated in short time intervals (5 - 6 hrs, Bé et al., 1979; every 1-3 days, Bé et al., 1977; Caron et al., 1987; Spero and Lea, 1993; Lea et al., 1999). When chambers are added, a layer of calcite precipitates over pre-existing carbonate, resulting in so-called bilamellar chamber walls (Reiss, 1957). This is reflected by an increase in the thickness of chamber walls and in the length of the ablation profiles towards the older chambers.

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used to quantify intra-specimen variability in Mg/Ca in planktonic foraminifera. Part of the observed intra-specimen variability was attributed to seasonal variability in sea surface temperatures. Other factors contributing to intra-specimen variability are, e.g., changes in symbiont activity, carbonate chemistry and ontogenetic effects. These ontogenetic effects may influence Mg/Ca in two ways: first, formation of a final layer of calcite with relatively low Mg/Ca enveloping the whole test at the end of the life cycle potentially results in a trend in trace element incorporation with test size (Marr et al., 2011). And secondly, decreasing Mg/Ca values towards the younger chambers of *G. sacculifer* tests are in line with a decreasing contribution of gametogenic calcite to the total calcite with increasing test size (Sadekov et al., 2008; Wit et al., 2010; Marr et al., 2011; Jonkers et al., 2012). Our Mg/Ca results for *G. ruber*, however, indicate that combining Mg/Ca values of F-1 and F-2 chambers does not bias the results. The F-0 chambers do show somewhat deviating values and were, therefore, excluded from further analyses. Since the F-0 chambers also have the thinnest test wall and thus shortest ablation profiles, excluding measurements on the F-0 chamber from the calculations also lowers the observed intra-test variability. Wit et al. (2010) also showed that mean Mg/Ca values for *G. ruber* between the

final three chambers differ, but only the offset between the final chamber and the others is significant. In line with the results presented here there was no significant difference in Mg/Ca values between F-1 and F-2.

Mg/Ca results obtained for all species are in line with previously published data and consistent

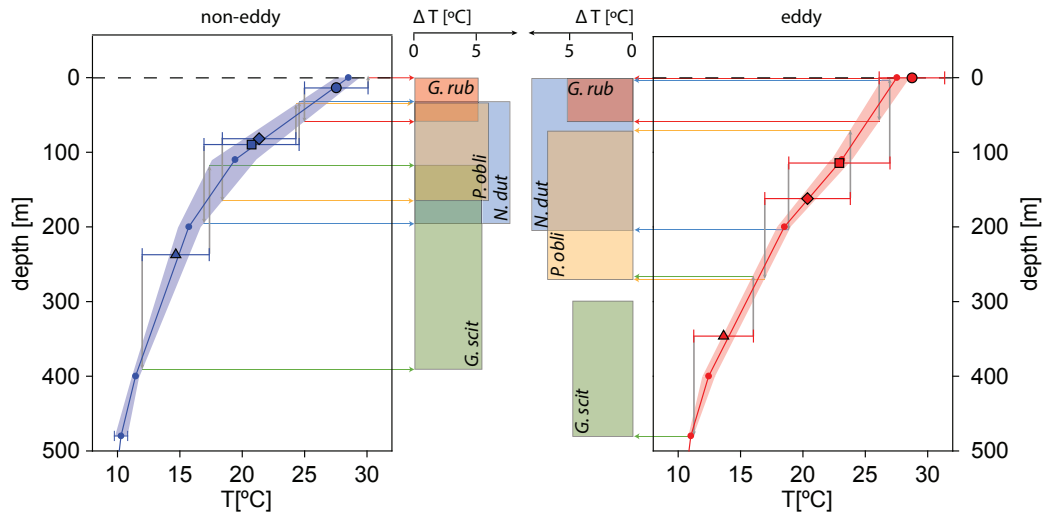


Fig. 3.8: Mg/Ca temperature ranges for the individual species. Depth ranges are based on cross correlating species-specific temperature ranges and temperature depth profiles. Horizontal scale in middle indicates extend of temperature range (difference between observed maximum and minimum calcification temperatures) of the individual species.

with inferred depth habitats of these species (Figs. 3.2 and 3.8). The average Mg/Ca value for *G. ruber*, for example, is 5.3 mmol/mol, which corresponds to a seawater temperature of 28°C, which is in agreement with reconstructed average flux-weighted Mg/Ca SSTs of 28°C for *G. ruber* (Fallet et al., 2010) for the same trap location. For the other species, inferred calcification temperatures are 22.5°C (*N. dutertrei*, SD: $\pm 4^\circ\text{C}$), 21.2°C (*P. obliquiloculata*, SD: $\pm 3.1^\circ\text{C}$) and 14.4°C (*G. scitula*, SD: $\pm 2.5^\circ\text{C}$). Both Mg/Ca inferred temperatures for *N. dutertrei* and *G. scitula* compare well with flux-weighted Mg/Ca temperatures of 23.1°C and 15.1°C, respectively (Fallet et al., 2011). Additionally, our LA-ICP-MS Mg/Ca values (2.6 mmol/mol, SD: ± 1 mmol/mol) of specimens of *N. dutertrei* match LA-ICP-MS measurements from the same species in the SW Indian Ocean (Jonkers et al., 2012), showing consistency of the data.

The error in Mg/Ca-based reconstructed seawater temperature encompasses analytical uncertainty, the error due to inter-individual variability in Mg/Ca (Fig. 3.6) and the uncertainty in calibrating Mg/Ca to temperature. The main uncertainty in absolute temperature is related to the calibration error, since both analytical uncertainty and inter specimen variability are

largely canceled out by using a large number of individuals (De Nooijer et al., 2014). For a number of planktonic species, including the foraminiferal species used here, uncertainties in the Mg/Ca-temperature calibration are ~ 0.02 for the pre-exponential constant and ~ 0.003 for the exponential one (Anand et al., 2003). At a temperature of about 20°C this results for both the pre-exponential and exponential constants to a 6% change in Mg/Ca, which translates to a 1°C temperature uncertainty. Still, since we are looking at differences between species rather than absolute temperatures the error related to the uncertainty in the calibration does not affect our results. Uncertainties in the calculated offsets between species will hence be mainly due to true inter-individual variability. For down-core applications, when enough specimens are available, using even larger sample sizes and pooling specimens for analyses, could further reduce the error (see section 4.4.2.3.).

Decreasing Mg/Ca values when comparing species calcifying from the surface to the thermocline [*G. ruber* > *N. dutertrei* $\geq$ *P. obliquiloculata* > *G. scitula*], are in line with the hypothesis that the selected species inhabit different depth intervals with increasingly cooler temperatures at depth. Hence, single specimen- or single chamber Mg/Ca values record short-term temperature variations at the average depth of calcification. Comparing different planktonic species from sediment trap samples thus potentially allows quantification of the impact of meso-scale scale eddies and the associated changes in the seawater temperature profiles on foraminiferal test chemistry.

3.4.1.2. Mn/Ca

Both *G. ruber* and *N. dutertrei* record lower Mn concentrations in their calcite ($<10\text{ }\mu\text{mol/mol Ca}$) compared to *P. obliquiloculata* ($19\text{ }\mu\text{mol/mol}$, SD: $\pm 11\text{ }\mu\text{mol/mol}$) and *G. scitula* ($40\text{ }\mu\text{mol/mol}$, SD: $\pm 18\text{ }\mu\text{mol/mol}$). Mn/Ca for these last two species varies considerably between specimens.

So far, Mn/Ca in foraminifera has been used as an indicator for contamination (Boyle, 1983; Lea et al., 2005; Pena et al., 2008). Mn coatings are precipitated after deposition the seafloor due to Mn cycling close to the sediment water interface and are thus absent in specimens derived from sediment trap samples. Also clay minerals can provide a major source for natural contamination for Mn- and Mg/Ca analyses of foraminiferal calcite (Barker et al., 2003), but are often absent in sediment trap samples. Still, as some Mn cycling might have occurred even on these short time scales within the sediment trap cups (although poisoned), we rejected Mn/Ca ratios higher than 0.1 mmol/mol from further analyses (total $n=537$, rejected = 3; see also Barker et al., 2003 for procedure used). Previously Klinkhammer et al. (2009) showed that the

Mn/Ca ratio in *G. ruber* and *N. dutertrei* could be used to reconstruct changes in terrestrial input and oxidation/reduction reactions in the water column during the last 30 kyrs. Our study shows that differences in Mn/Ca between species can be linked to differences in seawater Mn concentrations in the water column in combination with the different inferred depth habitat preferences of the individual species.

Incorporation of Mn^{2+} from seawater into inorganic calcite scales linearly with dissolved Mn^{2+} concentration (Franklin and Morse, 1983). Manganese is a redox-sensitive trace metal that is more soluble in its reduced (Mn^{2+}) than oxidized (Mn^{4+}) form. Mn/Ca records derived from biogenic carbonate could potentially provide a proxy for dissolved Mn^{2+} concentrations (Munsel et al., 2010) and thereby reflect redox processes controlling the concentration of this element in seawater. Studies on bivalve shells suggest that intra-shell Mn/Ca most likely reflects seasonal variation of seawater Mn^{2+} concentrations (Freitas et al., 2006; Bougeois et al., 2014). The Mozambique Channel however, is an oligotrophic area in which Mn concentrations are thus unlikely regulated by changes in redox conditions due to phytoplankton activity. Mn belongs to the scavenged type of trace metals, with highest concentrations at the surface and a relatively uniform distribution in deeper waters. Data on seawater Mn concentrations in the Indian Ocean are sparse but measurements from outside the oxygen minimum zone, generally indicate a surface maximum rapidly decreasing below 100 meters (Morley et al., 1993; Thi Dieu Vu and Sohrin, 2013).

The distribution of Mn in the water column is often closely coupled to oxygen concentration (Mangini et al., 1990). Mn profiles in the western Indian Ocean show various Mn maxima at depth (Saager et al., 1989) that can be linked to hydrographic features such as Intermediate water originating from the Red Sea which exhibits a strong Mn maximum (4.6 - 6.5 nM) coinciding with a deep O_2 minimum. Oxygen profiles from the water column in the Mozambique Channel show a distinct O_2 minimum at about 200 m below the sea surface (Fig. 3.9). Below this minimum, oxygen concentrations gradually increase until a depth of about 500 meters where a secondary maximum occurs, after which oxygen concentration decreases towards the sea floor. This oxygen minimum at 200 m appears to be accompanied by maximum Mn concentrations (Saager et al., 1989) (Fig. 3.9). We hypothesize that the oxygen depleted conditions at this depth recycle Mn^{2+} back into solution, supporting incorporation of Mn into biogenic calcite of species calcifying within this depth range. This is consistent with higher Mn/Ca incorporation by *P. obliquiloculata* and especially in *G. scitula*, whereas surface and upper thermocline dwellers *G. ruber* and *N. dutertrei*, thriving in the well oxygenated surface waters, incorporate lower Mn/Ca. Comparing seawater Mn with Mn/Ca ratios of the

carbonate tests shows that they all fall close to a $D_{Mn}=1$ line, except for *G. ruber*. At the sea surface, where *G. ruber* thrives seawater Mn concentrations are higher than expected based on the Mn incorporated. This might be due to the relatively lower concentration of Mn available for being incorporated into test carbonate due to the complex speciation of trace metals has a major effect on their biological availability (Bruland et al., 1991). Potentially, multiple species Mn/Ca values can hence be used to infer paleo-water column oxygenation.

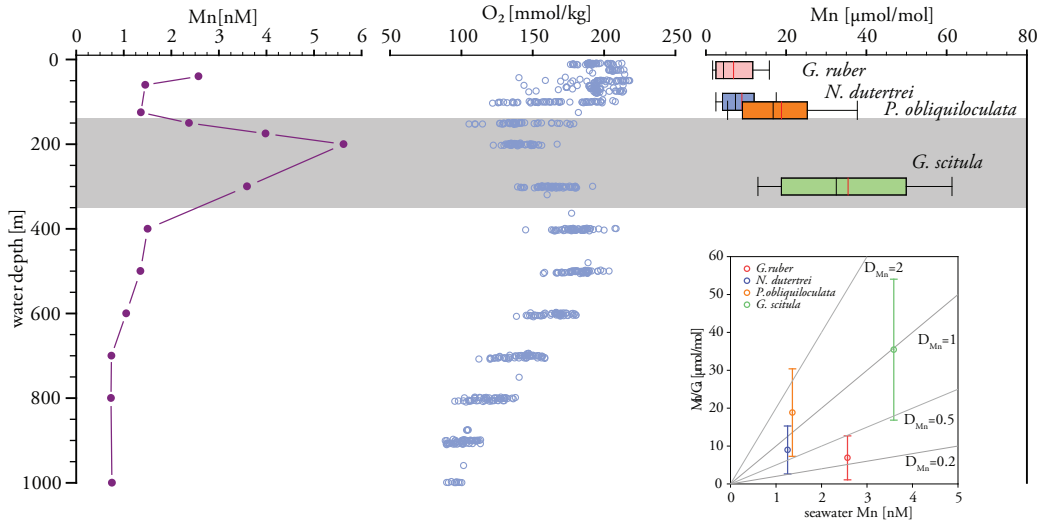


Fig. 3.9: On the right of the panel, seawater Mn concentration depth profile at 14°N and 67°E (Saager et al., 1989) is indicated in purple (dot and line). In the middle of the panel, indicated by blue circles are oxygen depth profiles retrieved during the CD153b Charles Darwin Cruise (2003), D289b Discovery (2005), D301b RRS Discovery (2006) and the M75b Meteor cruises during the LOCO program. The oxygen data covers summer and winter seasons. On the right of the panel inter-species Mn/Ca differences are shown as vertical whisker plots of *G. ruber* (red), *N. dutertrei* (blue), *P. obliquiloculata* (orange) and *G. scitula* (green). Species specific Mn/Ca is plotted at depth as suggested habitat depth based on literature and inferred calcification depth (Bé, 1969; Cléroux et al., 2007; Erez and Honjo, 1981; Fairbanks et al., 1982; Fallet et al., 2011; Hemleben et al., 1989; Huang et al., 2008; Itou et al., 2001; Kuroyanagi and Kawahata, 2004; Ortiz et al., 1996; Pflaumann and Jian, 1999; Ravelo and Fairbanks, 1992; Spero et al., 2003) for the species studied here. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. In addition, the graph shows mean (red line) whereas the open circles indicate the 5th and 95th percentile. The Standard percentile method uses linear interpolation to determine the percentile values. The 50th percentile (median) is indicated with the black lines within the boxes. Additionally, average foraminiferal test Mn/Ca ratios versus seawater Mn concentrations at species specific calcification depth are plotted. Extended line indicate SD of foraminiferal test Mn/Ca. Grey lines indicate a range of Mn partition coefficients (D_{Mn}). Light grey horizontal bar indicates zone of oxygen minimum zone.

3.4.2. Inter-species Mg- and Mn/Ca as a proxy for eddies

3.4.2.1. Mn/Ca in eddy/non eddy intervals

Although Mn/Ca values of *G. ruber* and *N. dutertrei* are relatively low, during eddy conditions these values become even lower. In contrast, Mn/Ca values for *P. obliquiloculata* are significantly higher during eddy conditions (Kruskal-Wallis one way analysis of variance on ranks, $p < 0.001$). Mn/Ca in *G. scitula* is not significantly different between eddy and non-eddy conditions. The slightly lower Mn/Ca concentrations recorded by *G. ruber* and *N. dutertrei* during eddy conditions, fits the expectation of more oligotrophic conditions during these events (Huggett, 2013). Because of its slightly deeper habitat *P. obliquiloculata* apparently records an increase in dissolved Mn concentration in seawater during the passing of the eddy. Previous observations in the MC (Swart et al., 2010), showed a deepening of the nutricline and the O₂ minimum zone, in an anticyclonic eddy compared to a non-eddy condition. This is also evident in the mean oxygen anomaly, showing a positive anomaly in the upper 150 m (up to 20 μM) and then a sudden decrease to a negative anomaly between 150 and 500 m (Figs. 3.2 and 3.8). This implies that the Mn peak (at ~200 m, Saager et al., 1989), coinciding with the primary O₂ minimum, within the water column would also shift and apparently coincide with the calcification depth of *P. obliquiloculata*. *G. scitula* does not show a significant shift as it is calcifying already within the zone of high Mn²⁺ and continues to do so during eddy conditions. Hence foraminiferal trace metal incorporation might simultaneously record isotherm and nutricline movements associated with the passing of an eddy.

3.4.2.2. Comparison recorded in-situ temperatures with foraminiferal Mg/Ca

Changes in the water column temperature profile in response to a passing eddy in the MC potentially affect differences in Mg/Ca between different species of planktonic foraminifera. Since eddies mainly affect temperatures at the upper thermocline, comparing Mg/Ca-based temperatures of thermocline dwellers, such as *N. dutertrei* and *P. obliquiloculata*, with those of either a surface dwelling species such as *G. ruber*, or a deep dwelling species such as *G. scitula* potentially should reflect eddy conditions. Still, such a proxy requires no or limited changes in depth habitat related to hydrographic changes caused by passage of an eddy. For *P. obliquiloculata* we observed a change in depth habitat (constant Mg/Ca) between eddy and non-eddy conditions, making it unsuitable for reconstructing changes in thermocline temperatures (Fig. 3.8). Mg/Ca values for *P. obliquiloculata* remain relatively constant between eddy and non-eddy conditions, suggesting a change in calcification depth. Comparing the temperature profiles from the moorings with the measured Mg/Ca values for *P. obliquiloculata* suggests that the mean calcification depth shifts from 80 m, during non-eddy conditions, to a depth of about 160 m during eddy conditions. This suggests that this species might be bound

to a specific temperature range for optimal living conditions. In contrast, *N. dutertrei* records significantly warmer temperatures when an eddy passes the MC, compared to periods without an eddy (one way analysis of variance, $p < 0.001$).

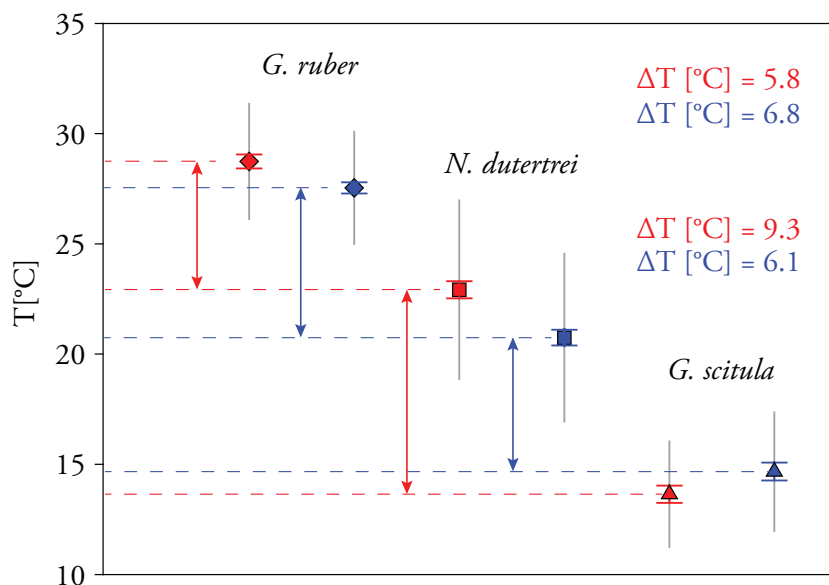


Fig. 3.10: Inter-species comparison of calculated Mg/Ca-based temperatures during eddy and non-eddy intervals for *G. ruber*, *N. dutertrei* and *G. scitula*. Blue symbols correspond to non-eddy conditions. Error bars indicate standard error, extended gray lines show SD (1 sigma).

The temperature difference between *G. ruber* and *N. dutertrei* is 5.8°C during eddy conditions (Fig. 3.10), corresponding to an observed temperature difference between 0 and 115 m. During non-eddy conditions, the difference in Mg/Ca-based temperatures between *G. ruber* and *N. dutertrei* is larger (6.8°C), although less than expected when assuming a constant calcification depth for these two species. This suggests a slightly shallower calcification depth for *N. dutertrei* (from ~115 to 90 m) during non-eddy conditions. Moreover, the temperature recorded by *G. ruber* is also somewhat higher during eddy conditions (one-way analysis of variance, $p = 0.002$). Despite these small changes in calcification depths, overall habitat preferences for *G. ruber* and *N. dutertrei* are relatively constant. The restricted, shallow habitat depth of *G. ruber* is likely related to its associated symbionts (Gastrich, 1987), whereas the living depth of *N. dutertrei* is related to the deep chlorophyll maximum (Fairbanks et al., 1980; Ortiz et al., 1996, Cl  roux et al. 2013). Potentially, food availability may restrict foraminiferal species to a certain calcification depth (e.g. Ortiz et al., 1996; Mortyn and Charles, 2003; Cl  roux et al., 2009). Irrespective of the underlying mechanism, the recorded Mg/Ca-based temperatures coincide

with a deepening in isotherms during the passing of an eddy. Still, temperature differences based on Mg/Ca of *G. ruber* and *N. dutertrei* from eddy and non-eddy conditions are relatively small and a two-way ANOVA test showed this difference to be not significant ($p = 0.166$).

Alternatively, changes in upper thermocline temperature (i.e. recorded by Mg/Ca of *N. dutertrei*) could be contrasted with that of a species dwelling below the thermocline to develop a proxy for eddy activity. The deep dwelling species *G. scitula* has similar Mg/Ca values during eddy and non-eddy conditions (Fig. 3.8). Facultative and non-symbiotic species, such as *P. obliquiloculata* and *G. scitula*, generally are less restricted to light availability and are thus capable of more extensive vertical migration through the water column (Hemleben, 1989). For *G. scitula*, the lack of an Mg/Ca response to eddy versus non-eddy conditions actually implies a change in calcification depth. Based on the observed similar Mg/Ca values this species changes its calcification depth from 215 m during non-eddy conditions to 325 m during eddy conditions. Still, the temperature gradient at the depth *G. scitula* calcifies is small, hence translating into large depth changes. The similar Mg/Ca values for *G. scitula*, comparable to *P. obliquiloculata*, suggest that these planktonic foraminifera are passively dragged downward with the isopycnal movement, induced by the passing of an eddy. Comparing the temperature difference between *N. dutertrei* and *G. scitula*, we see a larger offset under eddy conditions (ΔT : 9.3°C) compared to non-eddy conditions (ΔT : 6.1°C). This difference in Mg/Ca between eddy and non-eddy conditions for *N. dutertrei* and *G. scitula* is significant (two-way ANOVA test, $p = 0.0015$). The inferred difference in temperature offset between the two species during eddy conditions (3.2°C) matches well with the observed difference at 110 m of about 3.7°C. Moreover, using the difference in temperature offset between a thermocline and a deep dweller limits the effects of seasonality, which becomes less with depth (annual difference: ΔT_{0m} : $\pm 5^\circ\text{C}$; ΔT_{200m} : 2.3°C ; ΔT_{400m} : 0.6°C).

The difference in calcification temperature, based on Mg/Ca, between thermocline and sub-thermocline foraminiferal species provides a promising proxy for reconstructing eddies. The temperature contrast between the upper part of the thermocline and sub-thermocline during eddy and non-eddy conditions is more than 3°C, comparable to changes in temperature gradients related to eddy occurrences. Potentially, this allows the reconstruction of changes in eddy-intensity over geological time in the proximity of the MC.

3.4.2.3. Paleo-application

Eddies are expressed on a sub-seasonal time scale (Fallet et al., 2011) lasting approximately 6 weeks (Ullgren et al., 2012). On average 5 - 7 eddies pass the MC every year (for the past ~10 years; Schouten et al., 2002; Ullgren et al., 2012). Without a clear seasonal pattern in

eddy occurrences and no impact of eddy presence on foraminiferal shell fluxes (Fallet et al., 2010; 2011), this implies that approximately 69% of all planktonic foraminifera arriving at the seafloor in the MC are produced under eddy-induced conditions. Different conditions prevailing in the past may have resulted in a different frequency of eddies. Even if this resulted in only 1 extra or 1 less eddy per year compared to the current-day frequency, the portion of foraminiferal specimens affected by eddy conditions increases from 69% to 81% (or decreases to 58%). Although average inter-specific offsets in some cases (as for example between *G. ruber* and *N. dutertrei*) might be limited, determining single specimen Mg/Ca also results in significant shifts in the distribution of single specimen Mg/Ca-based temperatures. Histograms of the modern day single specimen Mg/Ca distributions comparing eddy and non-eddy conditions already clearly illustrate the shift in distribution of Mg/Ca values for *N. dutertrei* (Fig. 3.7). Since eddy frequency and changes in seasonality both affect average Mg/Ca values, these histograms might be used to deconvolve the underlying processes. In view of the observed offset, the difference in Mg/Ca values between *G. scitula* and *N. dutertrei*, both impacted much less by seasonality, may well provide a robust proxy for eddy frequency. Moreover, in combination with Mn/Ca, this proxy might add further constraints for the reconstruction of past water column conditions in the context of eddy frequency.

3.5. Conclusions

LA-ICP-MS Me/Ca analyses of four species of planktonic foraminifera show that *G. ruber* and especially *N. dutertrei* Mg/Ca-based temperatures record eddy-induced changes in upper water column stratification. During eddy conditions the thermal gradient between the surface water and the thermocline is reduced whereas the gradient between thermocline and deep water is larger. This is reflected in a reduced difference in the Mg/Ca based temperatures between *G. ruber* and *N. dutertrei* and a larger difference in Mg/Ca based temperatures between *N. dutertrei* and *G. scitula*. Whereas the difference between *G. ruber* and *N. dutertrei* is not statistically significant, the difference between *N. dutertrei* and *G. scitula* is significant. The temperature difference between the two species is larger than Mg/Ca calibration-related uncertainties and hence likely to be a proxy suitable for down-core application. Whereas seasonal temperature changes might bias the relatively smaller temperature difference between *G. ruber* and *N. dutertrei*, the difference between *N. dutertrei* and *G. scitula* is more robust. Whereas *G. ruber* and *N. dutertrei* inhabit relatively stable calcification depths, *P. obliquiloculata* and *G. scitula* record similar temperatures during eddy and non-eddy conditions, implying passive or active transport with isopycnal movements induced by passing of an eddy. Additionally, we found that near-surface dwelling *G. ruber* and shallow thermocline dwelling *N. dutertrei*, inhabit well

oxygenated surface waters and show lower Mn/Ca values in their tests than the deeper dwelling species. Coinciding with a water column O₂ minimum, *P. obliquiloculata* and *G. scitula* record higher Mn/Ca values in line with water column variability in dissolved Mn concentrations. Potentially, combining the analyses of Mg/Ca and Mn/Ca from multiple species may be used to infer past eddy conditions in the Mozambique Channel.

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(Globorotalia scitula)

Chapter 4

*Reconciling single chamber Mg/Ca with whole shell $\delta^{18}\text{O}$ in
surface to deep dwelling planktonic foraminifera from the
Mozambique Channel*

Chapter 4

Reconciling single chamber Mg/Ca with whole shell $\delta^{18}\text{O}$ in surface to deep dwelling planktonic foraminifera from the Mozambique Channel

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Abstract

Most planktonic foraminifera migrate vertically through the water column during life, meeting a range of depth-related conditions as they grow and calcify. For reconstructing past ocean conditions from geochemical signals recorded in their shells it is therefore necessary to know vertical habitat preferences. Species with a shallow habitat and limited vertical migration will reflect conditions of the surface mixed layer and short- and meso-scale (i.e. seasonal) perturbations therein. Species spanning a wider range of depth habitats, however, will contain a more heterogeneous, intra-specimen variability (e.g. Mg/Ca and $\delta^{18}\text{O}$), which is less for species calcifying below the thermocline. Obtained single-chamber Mg/Ca are combined with single specimen $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ of the surface water inhabitant *Globigerinoides ruber*, the thermocline-dwelling *Neoglobobulimina dutertrei* and *Pulleniatina obliquiloculata* and the deep dweller *Globorotalia scitula* from the Mozambique Channel. Species-specific Mg/Ca, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ data combined with a depth-resolved mass balance model confirm distinctive migration and calcification patterns for each species as a function of hydrography. Whereas single specimen $\delta^{18}\text{O}$ rarely reflect changes in depth habitat related to hydrography (e.g. temperature), measured Mg/Ca of the last chambers can only be explained by active migration in response to changes in temperature stratification. Foraminiferal geochemistry and modeled depth habitats shows that the single chamber Mg/Ca and single shell $\delta^{18}\text{O}$ are in agreement with each other and in line with the changes in hydrography induced by eddies.

4.1. Introduction

Most planktonic foraminifera inhabit the upper 200 m of the water column, with exceptions of some species living as deep as 1000 m (e.g. Hemleben, 1989). The average depth habitat of individual species and the range of water depths at which they are found reflect their ecology (e.g. feeding behavior), ontogeny and seasonal preferences. Stable oxygen isotope values ($\delta^{18}\text{O}$) and Mg/Ca ratios (Shackleton et al., 1974; Fairbanks et al., 1980; Ortiz et al., 1996; Elderfield and Ganssen, 2000) have been used to reconstruct upper water column conditions using species with a known depth range (e.g. Ravelo et al., 1992; Patrick and Thunell, 1997; Faul et al., 2000; Cl  roux et al., 2013). For many species, however, application of Mg/Ca as a seawater temperature proxy is complicated by depth migration as a function of ontogeny. Previous studies revealed major Mg/Ca heterogeneity within foraminiferal shells (e.g. Eggins et al., 2003; Hathorne et al., 2009; Kunioka et al., 2006; Jonkers et al., 2012), which were attributed to a combination of vertical migration during their life and vital effects. Nevertheless, species-specific patterns of vertical migration and hence depth of calcification

determine what part of the water column can be reconstructed.

Field observations show that most foraminiferal species do not occupy a single depth, but rather calcify at a range of depths. Many species migrate vertically as they grow and, therefore, the chemical composition (e.g. Mg/Ca and $\delta^{18}\text{O}$) of their shells changes with age. Fairbanks et al. (1982) and Field (2004) suggested that foraminifera may modify their habitat depth depending on hydrographic condition and food supply. However, little is known about the exact controls on depth habitat, termination of shell growth and controls on shell features (e.g. formation of crusts). A better understanding of the vertical calcification pattern of different species is needed to reconstruct past changes in vertical structure of the water column by using geochemical proxies, e.g. for temperature ($\delta^{18}\text{O}$ and Mg/Ca). Using geochemical signals of species with different and well-constrained calcification depths (Emiliani, 1954; Mulitza et al., 1997) changes in water column conditions can be resolved.

Using core top samples from the Indian Ocean, Birch et al. (2013) report $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ measurements made on several species of planktonic foraminifera across a range of tightly constrained size windows. From size controlled $\delta^{18}\text{O}$ calcite trajectories they inferred depth habitats, using modern vertical temperature profiles. However, by using multiple core-top specimens this data set encompasses not only vertical changes in the water column structure, but also inter- and intra-annual changes therein, which are both known to vary substantially in this region (e.g. McClanahan, 1988; Damassa et al., 2006; Hastenrath et al., 1993). In this study we use sediment trap samples, allowing analyses of specimens that lived during a confined time interval and link in situ hydrographic changes (i.e. temperature) more directly to their shell chemistry.

Single-chamber Mg/Ca compositions from specimens with contrasting calcification depths (the surface-dweller *Globigerinoides ruber* (d' Orbigny, 1839), the thermocline-dwelling species *Neoglobobulimina dutertrei* (d' Orbigny, 1839) and *Pulleniatina obliquiloculata* (Parker et al., 1865) and the deep dweller *Globorotalia scitula* (Brady, 1882) reflect temperatures throughout the upper 500 m and were shown to reliably reflect short-term hydrographic changes (Steinhardt et al., 2014). Meso-scale eddies such as observed in the Mozambique Channel (MC) induce variations in temperature and salinity. Anticyclonic (anti-clockwise) eddies in the MC are characterized by a warm water core and are associated with elevated sea surface heights and large vertical isopycnal excursions. Foraminifera living in the mixed layer of the MC are affected by eddy-induced changes, which is reflected by the geochemistry of *G. ruber* and *N. dutertrei* (Steinhardt et al., 2014), resulting in higher Mg/Ca ratios and

more depleted $\delta^{18}\text{O}_{\text{cc}}$ values. These short-term changes in vertical water column temperature and $\delta^{18}\text{O}_{\text{sw}}$ distribution should influence shell $\delta^{18}\text{O}$ and Mg/Ca throughout the different ontogenetic stages for any species migrating during its life. Alternatively, foraminifera may respond to altered hydrographic conditions by changing their calcification depth. Here we present combined single-specimen $\delta^{18}\text{O}$ and single-chamber Mg/Ca measurements for different species, providing a composite of thermocline and sub-thermocline conditions. Since single chamber Mg/Ca values cannot be compared one-on-one with whole shell $\delta^{18}\text{O}$ -values we evaluate our results using a mass balance model for depth related carbonate addition of four species of planktonic foraminifera.

4.2. Oceanographic setting

In the oligotrophic Mozambique Channel (MC) (Fig. 4.1) sea surface temperatures (SST) vary seasonally and with eddy-induced transport (Fallet et al., 2011) we examine material collected from a deep-moored sediment trap in the Mozambique Channel (SW Indian Ocean). The SSTs range from 25°C to over 30°C with an annual mean of 27.6°C, the seasonal change in temperatures is associated with the monsoon system. With the onset of Austral summer rainfall increases, caused by the seasonal migration of the ITCZ and sea surface salinities decrease slightly from 35.2 in winter to 34.9 in summer (Fallet et al., 2010). The calcite compensation depth in the Western Indian Ocean is below 3000 m and hence does not result in dissolution of foraminiferal calcite at the depth of the trap's location (2225 m).

Southward migration of anticyclonic meso-scale eddies, originating at 10°S north off the Comoros Islands, affects the hydrography in the MC (Fig. 4.1). Eddies pass through the MC at a mean frequency of about four to seven per year (at a southward propagation speed of 3-6 km.d⁻¹) before joining the Agulhas Current. An eddy passage is associated with vertical movement of isopycnals, which can occasionally exceed 40 m per day in the upper layer (Ullgren et al., 2012). The formation of meso-scale eddies in the Mozambique Channel is related to variability in the South Equatorial Current (SEC) transport (Backeberg and Reason, 2010; Fig. 1). The main water masses contributing to the upper part of the MC include the Tropical Surface Water (TSW), Subtropical Surface Water (STSW) and Indonesian Throughflow Water (ITFW). The warm, fresh surface water (TSW) forms at equatorial latitudes and is transported westward within or north of the SEC (New et al., 2007). In the proximity of the western margin, where the SEC bifurcates, warm surface waters are transported poleward, either east of Madagascar, or through the MC (e.g. Gründlingh, 1995; Swallow et al., 1988). The STSW is characterized by relatively high salinities and a subsurface maximum, with salinities of 35.2

– 35.5, at approximately 200 m below sea surface, at which depth the surface water subducts below the fresher TSW (Wyrski, 1973).

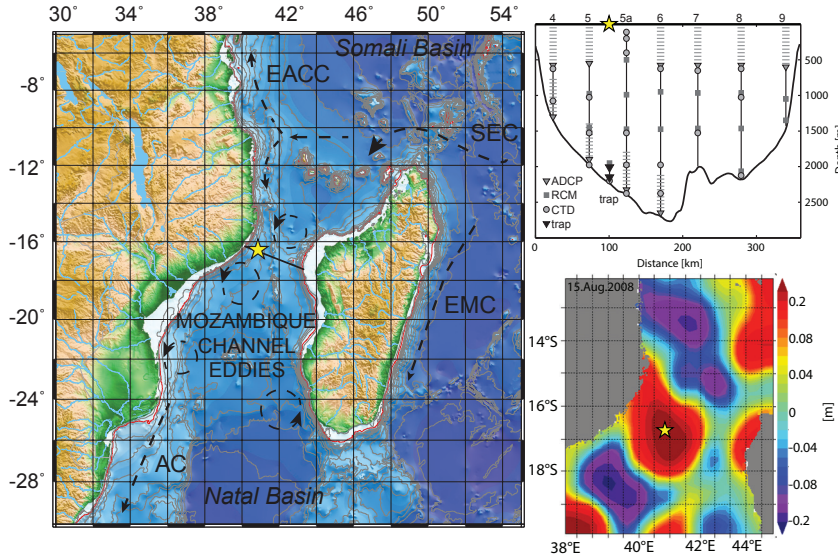


Fig. 4.1: Hydrography of southwestern Indian Ocean and location of the sediment trap (star) within the mooring array (right top). On the right bottom a map of sea level anomaly shows the passing of an anti-cyclonic eddy over the trap location (star). AVISO sea level anomaly map was produced using the AVISO live access server (<http://las.aviso.altimetry.fr/las/getUI.do>). EACC: East African Coastal Current, SEC: South Equatorial Current, AC: Agulhas Current.

4.3. Material & Methods

4.3.1. Sediment trap and mooring array

Within the Long-term Ocean Climate Observations (LOCO) program, an array of eight moorings across the narrowest part of the Mozambique Channel, provides continuous measurements of current velocities, temperatures and salinities at fixed depths since November 2003 (Ullgren et al., 2012). Sediment traps of the type Technicap PPS 5 were deployed at 16.8°S and 40.8°E in the central MC (Fig. 4.1), equipped with an automated sampling carousel of 24 cups and a baffled collecting area of 1.0 m². The trap was positioned 250 m above the channel floor at 2250 m water depth. Between November 2003 and February 2009, a total of four sediment trap deployments took place, each programmed to a 17, 21 or 23 days sampling interval. Prior to deployments, sample cups were filled with an HgCl₂-poisoned and borax-buffered solution of seawater collected from the deployments depth (Lončarić et al., 2007). Sediment trap samples were wet-split, sieved and foraminiferal shells were cleaned

according to the protocol of Barker et al. (2003), modified by Fallet et al. (2009) (see also Fallet et al., 2010; Chapter 3 for detailed description of the procedure here).

Using sediment trap material allows linking the chemistry of the shells to recorded *in situ* conditions from the moorings and from real-time satellite derived observations. Therefore we are able to link short-term changes in hydrography (i.e. eddies) to the differences in shell chemistry. Calculated back trajectories, based on a high-resolution INALT01 model (Durgadoo et al., 2013), show that specimens ending up in the sediment trap all originate from the area under influence of the eddy-variability (Steinhardt et al., 2014; Chapter 3). We selected the sediment trap intervals during which the complete sediment cup collection took place under either full eddy or full non-eddy conditions (for full description see chapter 3; supplement). For the selected collecting intervals, temperature and salinity observations from the mooring (lmc5a) are compiled and daily means were used to calculate eddy and non-eddy depth-resolved temperature profiles.

4.3.2. Temperature and Salinity data

For this study, we used temperatures recorded at 110 m; 200 m and 400 m water depth by a CTD deployed on mooring lmc5a (16.8°S, 41.1°E, Fig. 4.1), which is closest to the sediment trap site. Moored salinity and temperature data, collected during the selected intervals of eddy and non-eddy conditions (Supplementary tab. S4.1), was spline fitted in Analyseries 1.1.6 68K to achieve meter-wise data resolution. Sea surface temperatures were retrieved from the 4 km daytime MODIS/AQUA dataset around trap site (16 – 17°S and 40 – 41°E) for the period of the selected collecting intervals (<http://poet.jpl.nasa.gov/>). Surface salinity data is not available for the complete deployment period and therefore, CTD-based salinity-depth profiles taken during the deployment/recovery cruises were used instead (Ullgren et al., 2012). Based on the trend observed in the moored salinity data at 110 m water depth (Ullgren et al., 2012; less saline during eddy condition) we used CTD minimum surface salinities to represent eddy surface salinities and maximum surface salinities to represent non-eddy conditions. Since salinity mooring data were not available for depths between 400 and 1525 m, we have chosen two more “anchor points” at 700 and 1000 m water depth from the CTD depth profiles in order to better capture the Red Sea Water (RSW) advection at these depths and to achieve a more accurate salinity fitting curve for the upper 1000 m.

4.3.3. Planktonic foraminiferal species and ontogeny

We selected four species from the sediment trap samples according to differences in depth habitats as reported in previous studies. *Globigerinoides ruber* (white) is a shallow, surface

mixed layer dwelling species, occupying the upper 50 m of the water column and is commonly used to reconstruct SST (Hemleben et al., 1989). To minimize a potential biases in $\delta^{18}\text{O}$ and Mg/Ca associated when combining different morphotypes (Steinke et al., 2005), we used only *G. ruber* sensu stricto that was by far the most abundant in these samples (Fallet et al., 2010). The subsurface-dwellers *Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata* have been associated with a calcification depth of 0 - 100 m and 60 - 150 m in the upper and middle thermocline, respectively (Erez and Honjo, 1981; Fairbanks et al., 1982; Ravelo and Fairbanks, 1992; Spero et al., 2003; Field, 2004; Kuroyanagi and Kawahata, 2004; Huang et al., 2008). The deep-dwelling species *Globorotalia scitula* was used as a representative for deep water conditions (Bé, 1969; Ortiz et al., 1996; Itou et al., 2001; Fallet et al., 2011). Measurements on *G. ruber* were usually performed on specimens in the 250 - 315 μm size fraction. In a limited number of samples, abundances of this species were low in this size fraction, and geochemical analyses were therefore performed on specimens from a larger size fraction (315 - 400 μm). Analyses on *N. dutertrei*, *P. obliquiloculata* and *G. scitula* were generally done on the size range >315 μm , with additional measurements on the 250 - 315 μm size fraction depending on the specimen's abundance within a sample. All specimens show excellent preservation and do not show any signs of diagenesis (based on SEM microscopy). Recently, Fallet et al. (2012) showed that shell size normalized weights of three species of planktonic foraminifera from the same sediment trap location do not differ from those of the surface sediment samples below this trap. Absence of dissolution is also reported by Birch et al. (2013) describing planktonic foraminifera from surface sediments at ~ 3000 m water depth, in the northern part of the Mozambique Channel, as being glassy and preserved excellently.

4.3.4. Mg/Ca and stable isotope analyses

The Mg/Ca ratios of single chambers used in this study were previously published (Steinhardt et al., 2014) and were determined by Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) at Utrecht University (Reichart et al., 2003) trace element concentrations were accurately measured without the elaborate cleaning required in standard methods. Contaminated coatings are easily excluded during spatially resolved analysis. Application of this new technique allowed us to calibrate the trace elements incorporated in single tests of living (when sampled (for summary of the results see Tab. 4.1). Subsequently, specimens were analyzed for whole shell $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ after removal from the laser ablation stub with ethanol and inspection for possible contaminations. Measurements were performed at the Universitat Autònoma de Barcelona on a Thermo Finnigan MAT253 mass spectrometer coupled to a Kiel IV device for CO_2 sample gas preparation. External reproducibility (1σ) of $\delta^{13}\text{C}$ standards NBS19 and IAEA-CO was 0.04‰ and for $\delta^{18}\text{O}$ 0.08‰.

Tab. 4.1: Average Mg/Ca ratios (Steinhardt et al., 2014, chapter 3), $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ with standard errors (SE) and corresponding standard deviations (SD). Mg/Ca-based temperature are based on species specific temperature equations. The equation developed by Fallet et al. (2010) was applied for *G. ruber*. The equations developed by Anand et al. (2003) were applied to *N. dutertrei*, *P. obliquiloculata*. For *G. scitula* Anand's equation for *G. hirsuta* was applied following the example of Fallet et al. (2011). Calculate $\delta^{18}\text{O}$ -based temperatures are based on the equation of Kim and O'Neil (1997).

species	Mg/Ca $\pm$ SE [mmol/mol]	Mg/Ca SD [mmol/mol]	Mg/Ca-based temperatures [°C]	$\delta^{18}\text{O}\pm$ SE [‰]	$\delta^{18}\text{O}$ SD [‰]	$\delta^{18}\text{O}$ -based temperatures [°C]	$\delta^{13}\text{C}\pm$ SE [‰]	$\delta^{13}\text{C}$ SD [‰]
<i>G. ruber</i>	5.3 $\pm$ 0.09	$\pm$ 1.2	28.1 $\pm$ 2.8	-2.57 $\pm$ 0.04	$\pm$ 0.35	29.4 $\pm$ 1.3	0.51 $\pm$ 0.03	$\pm$ 0.47
<i>N. dutertrei</i>	2.6 $\pm$ 0.06	$\pm$ 1.0	22.5 $\pm$ 3.7	-1.53 $\pm$ 0.03	$\pm$ 0.48	24.3 $\pm$ 2.0	0.53 $\pm$ 0.04	$\pm$ 0.44
<i>P. obliquiloculata</i>	2.3 $\pm$ 0.1	$\pm$ 0.6	21.6 $\pm$ 3.1	-1.13 $\pm$ 0.04	$\pm$ 0.24	22.3 $\pm$ 1.1	0.04 $\pm$ 0.04	$\pm$ 0.21
<i>G. scitula</i>	1.5 $\pm$ 0.07	$\pm$ 0.4	14.4 $\pm$ 3.4	1.47 $\pm$ 0.14	$\pm$ 0.87	10.4 $\pm$ 3.9	0.27 $\pm$ 0.04	$\pm$ 0.22

*Mg/Ca data from Steinhardt et al. 2014

Single shells from part of the sample set were analyzed using a Thermo Finnigan Delta Plus mass spectrometer equipped with a Gas Bench II preparation device at the VU University Amsterdam. Single specimens were loaded into round-bottom vials, which were subsequently flushed with He. The samples then reacted with phosphoric acid (H_3PO_4) injected into the vial producing CO_2 gas, which is transported in a helium stream to the mass spectrometer. Traps are used to remove residual H_2O from the sample gas and the CO_2 is separated from other possible contaminant gases on a poraplot Q GC column. Reproducibility (1σ) of $\delta^{13}\text{C}$ standards NBS19 and was 0.07‰ and 0.12‰ for $\delta^{18}\text{O}$. Values measured on the Kiel IV and the GASBENCH-II are comparable and species-specific $\delta^{18}\text{O}_{\text{CC}}$ are in good agreement (Tab. 4.2). Measurements with the GASBENCH-II have a somewhat wider standard deviation inherent to continuous flow mass spectrometry.

Tab. 4.2: Average measurements of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ with standard errors (SE) and corresponding standard deviations (SD) performed at the Universitat Autònoma de Barcelona on a Thermo Finnigan MAT253 mass spectrometer coupled to a Kiel IV device for CO_2 sample gas preparation (BCN) and the Thermo Finnigan Delta Plus mass spectrometer equipped with a Gas Bench II preparation device at the VU University Amsterdam (VU). Measurements of *N. dutertrei*, *P. obliquiloculata* and *G. scitula* are comparable and species-specific values are in good agreement.

Species	$\delta^{13}\text{C}$ [‰]		$\delta^{13}\text{C}$ SD [‰]		^{18}O [‰]		^{18}O SD [‰]	
	VU	BCN	VU	BCN	VU	BCN	VU	BCN
<i>G. ruber</i>	-	0.51 $\pm$ 0.03	-	$\pm$ 0.47	-	-2.57 $\pm$ 0.04	-	0.35
<i>N. dutertrei</i>	0.41 $\pm$ 0.12	0.54 $\pm$ 0.01	0.41	0.45	-1.37 $\pm$ 0.09	-1.58 $\pm$ 0.03	0.59	0.46
<i>P. obliquiloculata</i>	-0.07 $\pm$ 0.13	0.05 $\pm$ 0.01	0.29	0.2	-1.46 $\pm$ 0.09	-1.10 $\pm$ 0.02	0.37	0.21
<i>G. scitula</i>	0.13 $\pm$ 0.14	0.3 $\pm$ 0.02	0.24	0.21	1.55 $\pm$ 0.11	1.45 $\pm$ 0.04	0.69	0.92

In total, 391 single shell stable isotope values were obtained. Values deviating more than twice the standard deviation from the average of the total dataset were regarded as outliers (n=23) and removed from the dataset (Appendix chapter 4).

The $\delta^{18}\text{O}_{\text{sw}}$, expressed on the SMOW scale is converted to Pee Dee Belemnite (PDB) scale by subtracting 0.27‰ (Hut, 1987). Various $\delta^{18}\text{O}$ -temperature equations have been proposed and discussed in detail in other studies (Bemis et al., 1998; Regenberg et al., 2009), without clear consensus on the most appropriate equation. Here, we integrated calcification depth for each species calculated by matching the foraminiferal calcite $\delta^{18}\text{O}_{\text{CC}}$ with the calculated calcite $\delta^{18}\text{O}_{\text{calc}}$ following equation (1) from Kim and O'Neil (1997) for the temperature dependent fractionation of calcite by inorganic precipitation (assuming calcification in equilibrium with the ambient seawater).

$$(1) \quad \delta^{18}\text{O} = 25.778 - 3.333 * \sqrt{43.704 + T} + (\delta^{18}\text{O}_{\text{sw}} - 0.27)$$

We extracted $\delta^{18}\text{O}_{\text{sw}}$ values from the South Indian Ocean for the upper 2000 m (4.5 - 120.2°E; 0 - 32.9°S, N=154) from the Global Seawater Oxygen-18 Database (see supplementary tab., <http://data.giss.nasa.gov/o18data/>). Additionally we included in situ $\delta^{18}\text{O}_{\text{sw}}$ measurements from the MC, near the sediment trap location (41.08°E; 16.74°S) in order to determine the regional relationship between $\delta^{18}\text{O}_{\text{sw}}$ and salinity (Eq. 2)

$$(2) \quad S = 0.463 * \delta^{18}\text{O}_{\text{sw}} - 15.9, r^2 = 0.87$$

This linear relationship (3) is subsequently used to estimate $\delta^{18}\text{O}_{\text{sw}}$ values based on salinities measured in the proximity of the trap by moored T-S sensors during eddy and non-eddy conditions for depths ranging from 0 to 1000 m.

Seawater temperature and estimated $\delta^{18}\text{O}_{\text{sw}}$ profiles for eddy or non-eddy conditions are used to compare the $\delta^{18}\text{O}$ data depending on the time interval sampled by the sediment trap. We used averaged $\delta^{18}\text{O}_{\text{sw}}$ from the depth range suggested by previously measured single chamber Mg/Ca analyses (Steinhardt et al., 2014), to calculate the $\delta^{18}\text{O}$ -derived calcification temperature for all species, following the temperature equation of Kim and O'Neil (1997):

$$(3) \quad T = 16.1 - 4.64 * (\delta^{18}\text{O}_{\text{CC}} - (\delta^{18}\text{O}_{\text{sw}} - 0.27)) + 0.09 * (\delta^{18}\text{O}_{\text{CC}} - (\delta^{18}\text{O}_{\text{sw}} - 0.27))^2$$

The temperature equation of Kim and O'Neil (1997) is the most general calibration, which allows comparing inter specific differences that are automatically accounted for when using

species-specific calibrations.

4.4. Results

4.4.1. Oxygen isotopes

Single specimen values of $\delta^{18}\text{O}_{\text{CC}}$ range from -3.50‰ to 2.65‰ . Although the values measured on individual specimens clearly overlap, each species has a different average $\delta^{18}\text{O}_{\text{CC}}$ and $\delta^{13}\text{C}_{\text{CC}}$ (Fig. 4.2 and 4.3).

The $\delta^{18}\text{O}_{\text{CC}}$ values are most depleted for *G. ruber*, somewhat more enriched in comparison to *G. ruber* for *P. obliquiloculata* and *N. dutertrei*, with most enriched values in *G. scitula* (Tab. 4.1, Fig. 4.2 and 4.3). The relationship between temperature and $\delta^{18}\text{O}_{\text{CC}}$ is generally described with more depleted $\delta^{18}\text{O}_{\text{CC}}$ values indicating higher temperatures and thereby

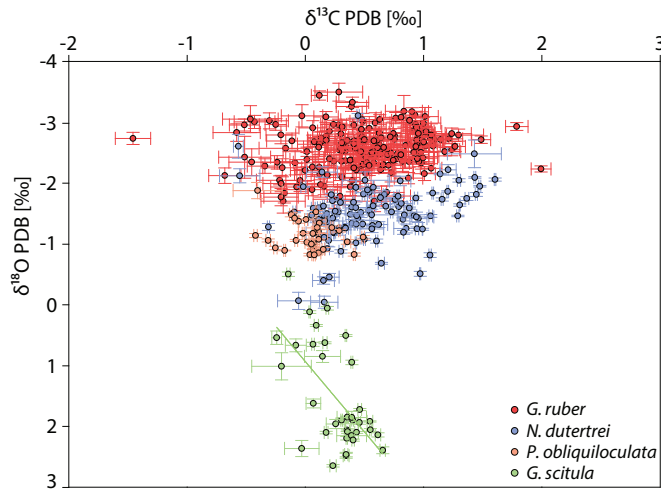


Fig. 4.2: Scatter plot of single shell $\delta^{13}\text{C}$ versus $\delta^{18}\text{O}$ with analytical error. Note the linear relation in *G. scitula* ($r^2=0.388$, $p<0.001$).

shallower calcification depths. Thus, each species has a distinct whole shell- $\delta^{18}\text{O}$ signature, reflecting their different mean calcification depth. *G. ruber* ($-2.57 \pm 0.04\text{‰}$, SD: $\pm 0.24\text{‰}$), *N. dutertrei* and *P. obliquiloculata* record negative $\delta^{18}\text{O}_{\text{CC}}$ values between $-1.53 \pm 0.03\text{‰}$ (standard deviation (SD): $\pm 0.42\text{‰}$) and $-1.13 \pm 0.04\text{‰}$ (SD: $\pm 0.24\text{‰}$), more noticeable positive values are found for *G. scitula* with $1.47 \pm 0.14\text{‰}$ (SD: $\pm 0.87\text{‰}$) (Fig. 4.3). No significant trend between size fractions and stable isotopes was observed for any of the analyzed species over the size range we used, as confirmed by ANOVA tests (Kruskal-Wallis one way analysis of variance on ranks) of $\delta^{18}\text{O}_{\text{CC}}$ between the size fractions (*G. ruber*: $p=0.774$, *N. dutertrei*: $p=0.500$, *G. scitula*: $p=0.373$).

No significant differences in $\delta^{18}\text{O}$ values for *G. ruber* and *N. dutertrei* were found between eddy and non-eddy conditions. In the deeper dwelling species *P. obliquiloculata* ($U=54$, $P=0.04$) and *G. scitula* ($U=80$, $P=0.021$), most depleted $\delta^{18}\text{O}$ values were found during eddy

conditions and non-eddy conditions, respectively (Tab. 4.3; Fig. 4.3).

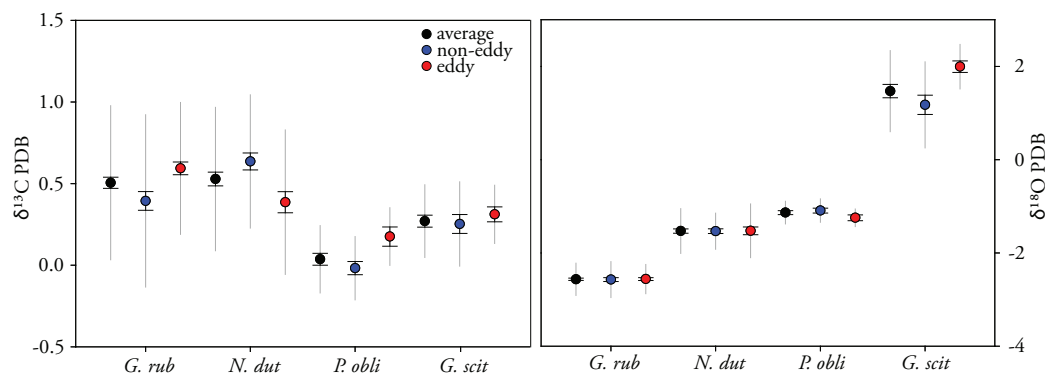


Fig. 4.3: Eddy (red circles), non-eddy (blue circles) comparison of $\delta^{13}\text{C}$ PDB and $\delta^{18}\text{O}$ PDB for the analyzed species. Grey lines indicate standard deviation (SD), black capped lines are indicative of standard error (SE).

4.4.2. Carbon isotopes

Values for $\delta^{13}\text{C}$ range from -1.5‰ to 2.0‰ . Most enriched $\delta^{13}\text{C}$ values are found in *N. dutertrei* ($\delta^{13}\text{C} = 0.53 \pm 0.042\text{‰}$, SD: $\pm 0.44\text{‰}$), whereas values for *P. obliquiloculata* are most depleted ($\delta^{13}\text{C} = 0.04 \pm 0.04\text{‰}$, SD: $\pm 0.21\text{‰}$). Individuals of *G. ruber* reflect a relatively large range in $\delta^{13}\text{C}_{\text{cc}}$ values ($0.51 \pm 0.04\text{‰}$, SD: $\pm 0.47\text{‰}$), whereas *G. scitula* ($0.27 \pm 0.04\text{‰}$, SD: $\pm 0.22\text{‰}$) displays a much more limited variability in $\delta^{13}\text{C}_{\text{cc}}$ (Tab. 4.1, Fig. 4.3). Species specific $\delta^{13}\text{C}$ - $\delta^{18}\text{O}$ relationships (Fig. 4.2) differ and only *G. scitula* showed a positive correlation between single specimen carbon and oxygen isotope ratios (Fig. 4.2, $r^2 = 0.388$, $p < 0.001$). Moreover, values for *G. scitula* differ from those of other species, with relatively depleted $\delta^{13}\text{C}$ (0.27‰ , SD: $\pm 0.22\text{‰}$) and relatively enriched $\delta^{18}\text{O}$ values (1.47‰ , SD: $\pm 0.87\text{‰}$).

Tab. 4.3: Results for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ with standard errors (SE) and corresponding standard deviations (SD) under eddy and non-eddy conditions for *G. ruber*, *N. dutertrei*, *P. obliquiloculata* and *G. scitula*.

Species	$\delta^{18}\text{O} \pm \text{SE}$ [‰]		$\delta^{18}\text{O}$ SD [‰]		T [°C], (Kim&O'Neil, 1997)		$\delta^{13}\text{C} \pm \text{SE}$ [‰]		$\delta^{13}\text{C}$ SD [‰]	
	Eddy	Non-Eddy	Eddy	Non-Eddy	Eddy	Non-Eddy	Eddy	Non-Eddy	Eddy	Non-Eddy
<i>G. rub</i>	-2.56 ± 0.03	-2.57 ± 0.04	0.31	0.39	29.8	29.2	0.59 ± 0.04	0.39 ± 0.06	0.4	0.53
<i>N. dut</i>	-1.53 ± 0.08	-1.53 ± 0.05	0.58	0.39	24.6	24	0.39 ± 0.06	0.64 ± 0.04	0.44	0.41
<i>P. obli</i>	-1.25 ± 0.06	-1.09 ± 0.05	0.19	0.25	23.3	21.9	0.18 ± 0.06	-0.02 ± 0.04	0.18	0.19
<i>G. scit</i>	1.99 ± 0.1	1.18 ± 0.2	0.48	0.92	8.2	11.5	0.31 ± 0.05	0.25 ± 0.06	0.18	0.26

From the four investigated species, only *G. scitula* (N: 37) did not show a significant difference in $\delta^{13}\text{C}$ between eddy and non-eddy conditions. *G. ruber* (N: 200; Mann-Whitney rank sum

test $U = 3373$, $p = 0.002$), and *P. obliquiloculata* ($N: 33$; $U = 52$, $p = 0.032$) showed significantly more positive $\delta^{13}\text{C}$ values during non-eddy conditions. During non-eddy condition however, *N. dutertrei* ($N: 118$; $U = 939.5$, $p = 0.002$) recorded more negative $\delta^{13}\text{C}$ values (Fig. 4.3).

4.4.3. Calcification temperatures

The calculated multi-specimen $\delta^{18}\text{O}$ -based temperature from eq. (3) and the single chamber Mg/Ca are positively, exponentially correlated (Fig. 4.4). Variability in this relationship is highest at higher ($> 25^\circ\text{C}$) temperatures. Mg/Ca -derived calcification temperatures, for *G. ruber* are on average $28.1 \pm 2.8^\circ\text{C}$, based on the calibration of Fallet et al. (2010) for this species in this region. Calcification temperatures for *N. dutertrei* and *P. obliquiloculata* are $22.5 \pm 3.7^\circ\text{C}$

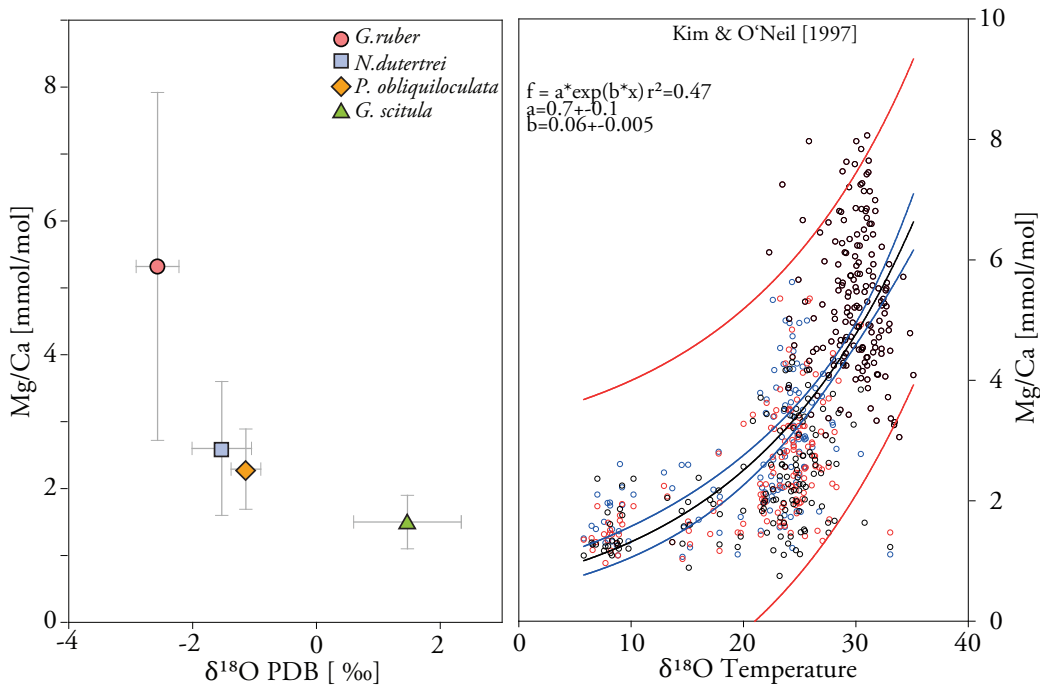


Fig. 4.4: Scatter plot of Mg/Ca versus $\delta^{18}\text{O}_{\text{occ}}$ (left panel). Right panel: single chamber Mg/Ca exponential relationship with $\delta^{18}\text{O}$ -derived Temperatures calculated using Kim & O'Neil (1997). Regression: $f = a \cdot \exp(b \cdot x)$, with $a = -0.7$, $b = 0.06$, $r^2 = 0.47$ using F-1/2 Mg/Ca from *G. ruber*, F-0 for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* (black circles). F-1 for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* (red circles) and F-2 for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* (blue circles). Mg/Ca data from Steinhardt et al. (2014). Note that the correlation coefficient also indicates that approximately 60% of the observed variability is not due to temperature alone.

and $21.6 \pm 3.1^\circ\text{C}$, respectively, both based on species-specific calibrations from Anand et al. (2003). Mg/Ca ratios of *G. scitula* were transformed into temperatures using the equation for *G. hirsuta* (Anand et al., 2003) resulting in an average temperature of $14.4 \pm 3.4^\circ\text{C}$ (Fig. 4.5).

Calcification temperatures based on $\delta^{18}\text{O}$ result in markedly different values, ranging from $29.4 \pm 1.3^\circ\text{C}$ for *G. ruber* to $24.4 \pm 2^\circ\text{C}$ for *N. dutertrei*, $22.5 \pm 1.1^\circ\text{C}$, for *P. obliquiloculata* and $10.4 \pm 3.9^\circ\text{C}$ for *G. scitula* (Tab. 4.1). Since *P. obliquiloculata* and *G. scitula* showed significant differences for $\delta^{18}\text{O}_{\text{CC}}$ between eddy and non-eddy conditions, we separately calculated temperatures for eddy and non-eddy condition. Mean $\delta^{18}\text{O}$ from Eq. (3) for eddy intervals yield $22.8 \pm 0.9^\circ\text{C}$ for *P. obliquiloculata* and $7.9 \pm 2.1^\circ\text{C}$ for *G. scitula*. For non-eddy intervals calcification temperatures are $22.5 \pm 1.2^\circ\text{C}$ for *P. obliquiloculata* and $11.8 \pm 4.1^\circ\text{C}$ for *G. scitula* (Fig. 4.5).

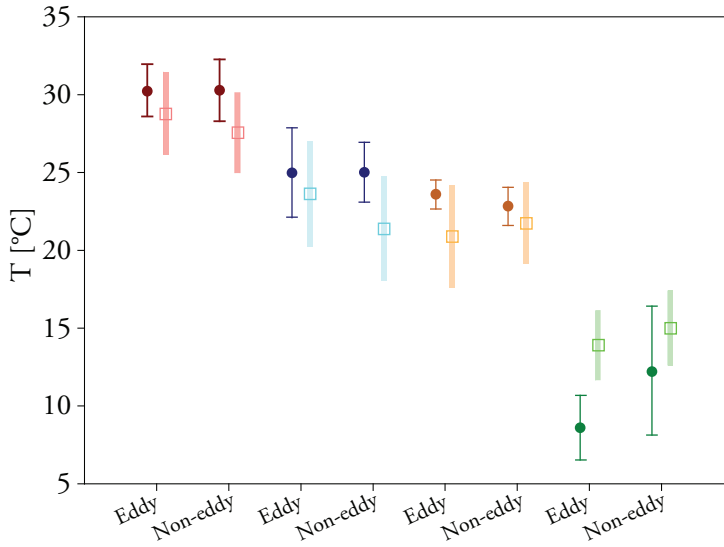


Fig. 4.5: Inter-species $\delta^{18}\text{O}$ - and Mg/Ca-derived temperature for eddy and non-eddy intervals. Circles: $\delta^{18}\text{O}$ -based temperatures using the equation of Kim and O'Neil (1997), Squares represent Mg/Ca-based temperatures using the species specific equations of Anand et al. (2003) for *N. dutertrei*, *P. obliquiloculata* and *G. scitula*. For *G. ruber*, the equation of Fallet et al. (2011) was used. Vertical error bars (SD) for $\delta^{18}\text{O}$ derived temperatures, horizontal error bars (SD) for Mg/Ca derived temperatures. Red colors: *G. ruber*, blue: *N. dutertrei*, orange: *P. obliquiloculata*, green: *G. scitula*.

4.5. Discussion

4.5.1. Single specimen isotope temperatures

The average, single-specimen $\delta^{18}\text{O}_{\text{CC}}$ of *G. ruber* reflect SSTs of $27.0 \pm 2.2^\circ\text{C}$ - $28.4 \pm 2.1^\circ\text{C}$ (based on sediment-trap calibrations from Fallet et al., 2010 and Wilke et al., 2009, respectively),

which is close to the satellite-derived annual mean SST of 27.6°C (Fallet et al., 2010). When applying the equation of Kim and O'Neil (1997) for conversion of $\delta^{18}\text{O}_{\text{CC}}$ into temperature SST is considerably higher ($29.4 \pm 1.3^\circ\text{C}$). This discrepancy, may be caused by the fact that the calcite-water calibration of Kim and O'Neil (1997) is based on inorganic precipitation experiments, free of vital effects and therefore may be offset compared to the temperature- $\delta^{18}\text{O}_{\text{CC}}$ relationship of biogenic carbonates. Nevertheless this temperature estimate based on Kim and O'Neil (1997) is in good agreement with the average temperature of $28 \pm 1.1^\circ\text{C}$ during the investigated intervals. The intertest variability of this species can be explained by the high temperature variability at the sea surface, as well as differences in symbiont activity. The shallow depth habitat of *G. ruber* in the MC is in line with previous studies showing that this species is confined to the photic zone (e.g. Deuser et al., 1981; Lončarić et al., 2006; Peeters and Brummer, 2002), because of the light requirement of its symbionts. Based on its relatively narrow preferred depth habitat, this species is a suitable tracer for (sub)tropical surface-water (0 - 100 m, mixed layer) conditions (e.g. Deuser, 1987; Anand et al., 2003; Field, 2004; Fallet et al., 2010). Birch et al. (2013) show that shell size of specimens of *G. ruber* is not correlated to $\delta^{18}\text{O}_{\text{CC}}$, confirming that this species occupies a narrow calcification depth during its life. In addition to its shallow living depth, *G. ruber* is known to occur in some areas relatively equally throughout the year (e.g. Deuser, 1987; Mohtadi et al., 2006; Tedesco et al., 2007), whereas in other areas, including the MC, they occur at highest densities during summer months (e.g. Tolderlund and Bé, 1971; Duplessy et al., 1981; Ganssen and Sarnthein, 1983; Deuser and Ross, 1989; Eguchi et al., 2003; Lončarić et al., 2006; Fallet et al., 2010). This seasonal preference results in SSTs that are slightly biased towards summer conditions when using fossil specimens of this species.

Based on an average $\delta^{18}\text{O}_{\text{CC}}$ -derived temperature of $24.3 \pm 2^\circ\text{C}$ (Tab. 4.2), following the equation of Kim and O'Neil (1997), calcification depths of *N. dutertrei* are in the range of 20 - 130 m (Fig. 4.6) with an average of 58 m. For eddy conditions, the average calcification depth is approximately 80 m, for non-eddy condition it is approximately 37 m. Average Mg/Ca-based temperature of $22.5 \pm 4^\circ\text{C}$ is in relatively good agreement with the average $\delta^{18}\text{O}_{\text{CC}}$ -derived temperature (Tab. 4.2). The difference between Mg/Ca- and $\delta^{18}\text{O}$ -based temperatures are smaller than the 1.2°C uncertainty associated with the Mg/Ca calibration (Anand et al., 2003). Previous studies using *N. dutertrei* from Indian Ocean core top samples and Mozambique Channel sediment traps have reported similar depth ranges between 40 - 150 m (Kiefer et al., 2006) and similar average depths of 80 m (Fallet et al., 2011), respectively. Both of these studies used pooled specimen for their stable isotope analysis and hence provided the population's average calcification depth. Moreover, pooling of specimens from sediment core

samples (Kiefer et al., 2006) does not allow for resolving short-term variability in calcification temperatures as do single specimens (e.g. seasonality). The inferred calcification depth for *N. dutertrei* is in line with its characterization as an intermediate deep dwelling species, living preferentially in the seasonal thermocline (e.g. Fairbanks et al., 1982; Curry et al., 1983; Eguchi et al., 2003; Farmer et al., 2007), coinciding with a deep chlorophyll maximum (Fairbanks et al., 1980; Ravelo et al., 1990). Overall living depth of this species is confined to the upper 200 m (Farmer et al., 2007; Kroon and Darling, 1995). Variability in Mg/Ca within single specimen shell walls of *N. dutertrei* from the Timor Sea suggested temperatures between 12 and 23°C, implying migration through the entire thermocline (Eggins et al., 2003). However, most calcification seems limited to a much smaller depth interval and the extremes in Mg/Ca might reflect upper and lower depth limits occupied by this species. Moreover, banding of Mg/Ca in shell calcite has been viewed in terms of discrete calcification events (Elderfield et al., 1996; Erez et al., 2003). Plankton tow studies (Fairbanks et al., 1980) showed oxygen isotope equilibrium calcification for *N. dutertrei* and *P. obliquiloculata*.

The $\delta^{18}\text{O}_{\text{cc}}$ -based calcification depths for *P. obliquiloculata* reported here (48-125 m, with an average of 74 m, Fig. 4.6) are in close agreement with those reported previously (e.g. between 60 and 80 m; Mohtadi et al., 2009). Indeed, in plankton tows from the central equatorial Pacific the largest abundance of adult *P. obliquiloculata* with a terminal cortex was found below 60 m (Watkins et al., 1996). All specimens used in this study had the distinctive smooth outer cortex that envelops the final whorl in the adult as well as an arched aperture (Watkins et al., 1996). Non-corticated *P. obliquiloculata* (“juveniles”) are confined mostly to the mixed layer (Watkins et al., 1996), indicating migration to greater depths at the time of cortex formation during the terminal stage of its life cycle (Erez and Honjo, 1981; Hemleben et al., 1989; Ravelo and Fairbanks, 1992).

The average $\delta^{18}\text{O}_{\text{cc}}$ for *G. scitula* yields a calcification temperature of $10.4 \pm 3.9^\circ\text{C}$, suggesting that this species calcifies between 290 and 1100 m (Fig. 4.6) with an average of approximately 500 m. This overlaps with the depth range indicated by the Mg/Ca temperatures of $14.4 \pm 3.4^\circ\text{C}$ derived from the last few chambers added, suggesting that these shells formed at a depth between about 250 and 350 meter for non-eddy and eddy conditions respectively. The $\delta^{18}\text{O}_{\text{cc}}$ based estimates, however, do not consider possible vital effects that were previously suggested for this species (e.g. Kahn and Williams, 1981). If taken into account, this would lower the temperature and depth habitat estimates by some 4°C and 500 m, respectively.

Birch et al. (2013) support previous findings of a distinct positive correlation between $\delta^{18}\text{O}$

and size in *G. scitula* (e.g. Friedrich et al., 2012), which is linked to a substantial ontogenetic vertical migration through the water column. Largest individuals have been inferred to live below the thermocline, consistent with the supposed absence of symbionts in this species. This

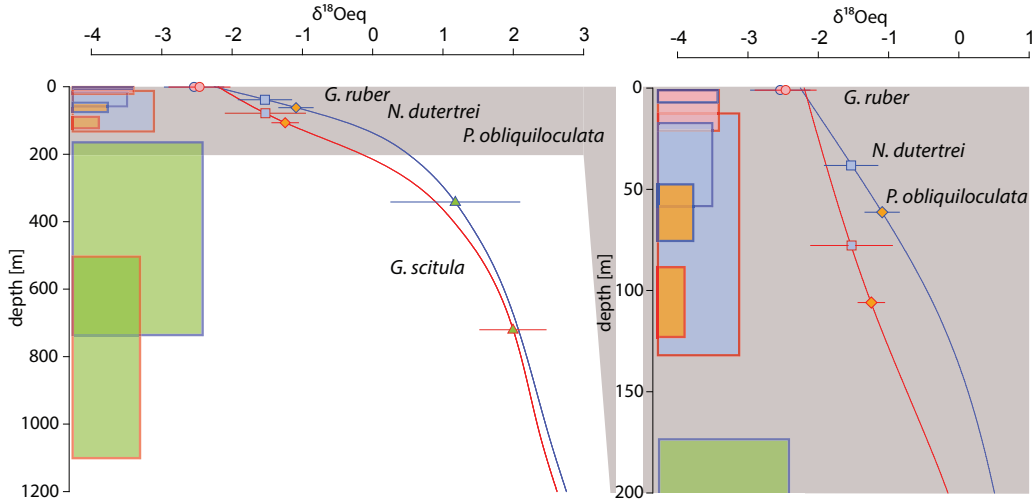


Fig. 4.6: Apparent calcification depths of species are generally shallower during non-eddy conditions. Apparent calcification depths for eddy (red) and non-eddy conditions (blue) calculated from single specimen $\delta^{18}\text{O}_{\text{CC}}$ using in situ temperature and $\delta^{18}\text{O}_{\text{sw}}$. Calcification depth was determined by matching the measured foraminiferal $\delta^{18}\text{O}_{\text{CC}}$ with the $\delta^{18}\text{O}_{\text{eq}}$, using the equation of Kim and O'Neil (1997). We used $\delta^{18}\text{O}_{\text{sw}}$ from the species calcification depth. The grey box indicates the zone of the close-up on the right (upper 200 m).

is in line with our observations, showing higher inter-specimen variability in $\delta^{18}\text{O}_{\text{CC}}$ for *G. scitula*, than in the other species.

4.5.2 Habitat depth versus calcification depth

Planktonic foraminifera collected by sediment traps might record $\delta^{18}\text{O}_{\text{cc}}$ signals comprising calcification at various depths and thus document an *apparent* average calcification depth by integrating the entire calcification history of the specimen. Given changes in seawater temperature with water depth, even minor changes in the upper or lower range of the depth at which planktonic species calcify, can have a profound effect on the average $\delta^{18}\text{O}_{\text{cc}}$ and reconstructed temperature. Since evidence is accumulating that some species have a flexible calcification range (e.g. due to seasonality or local hydrography; Lončarić et al., 2006; Wilke et al., 2009), interpretation of down core stable isotope data in terms of thermal structure may be challenging. Therefore, it is crucial to accurately quantify the impact of environmental factors on depth preferences of planktonic foraminifera. Contrasting eddy and non-eddy conditions,

a short-term feature, allow us to disentangle seasonal and other short-term local hydrography changes and their effect on foraminiferal calcification depth.

While Mg/Ca-based temperatures of *G. ruber* and *N. dutertrei* record eddy induced changes in upper water column stratification (Steinhardt et al., 2014), $\delta^{18}\text{O}$ -based temperatures are relatively similar for both species (Fig. 4.6). Using the paleo-temperature equation (equation (1); Kim and O'Neil, 1997) and fitting $\delta^{18}\text{O}_{\text{calc}}$ with $\delta^{18}\text{O}_{\text{cc}}$, we find that *G. ruber* calcifies on average at the sea surface (down to 7 m during non-eddy conditions and down to 18 m under eddy conditions) (Fig. 4.6). *N. dutertrei* calcifies on average between 12 and 120 m during eddy conditions (average calcification depth 81 m) and between 17 and 58 m under non-eddy conditions (average 37 m). During eddy conditions, *P. obliquiloculata* calcifies between 89 and 124 m (average 107 m), whereas it calcifies at shallower depth, between 20 and 77 m (average calcification depth 60 m) during non-eddy condition. Largest changes in calcification depth in this study are inferred from *G. scitula*. From a calcification range between 500 to 1100 m and an average calcification around 716 m during eddy condition it shifts to a calcification range from 168 to 745 m and an average calcification depth of 343 m (Fig. 4.6).

Conversely, $\delta^{18}\text{O}$ -based temperatures are significantly different for *P. obliquiloculata* and *G. scitula*, while the Mg/Ca-based temperature of the last formed chambers of *P. obliquiloculata* indicate similar calcification temperature (Tab. 4.1). Mg/Ca inferred calcification temperatures, representing the depth occupied at the later stages of the foraminifer's life, were similar between eddy and non-eddy conditions. Nonetheless, temperature mooring data show a steep temperature gradient, coinciding with the habitat depth of *G. scitula*, and thereby revealing a wide range of calcification depths for this species, changing significantly with deepening of the thermocline during eddy passage.

Inferred higher variability in calcification temperature for *G. ruber* presented in this study compared to observed satellite SST likely results from the spatial resolution employed here. Inter-individual differences in depth migration add to the variability in isotopes and element/Ca ratios when measuring single specimens. Potential effects of ontogeny on stable isotope composition are minimized by using narrow size fractions, as confirmed by the lack of ontogenetic trends with shell size in our measurements. Russell and Spero (2000) concluded that natural variability in oxygen isotopes is species specific. Measuring single specimen $\delta^{18}\text{O}_{\text{cc}}$ of *G. ruber* shells from sediment traps in the eastern equatorial Pacific, they show that over a 1.5 – 3 day period, the standard deviation of $\delta^{18}\text{O}$ results in a temperature variability of $\pm 0.87^\circ\text{C}$. Such a variability could explain between 12 and 38% of the variability in $\delta^{18}\text{O}$ -

based temperatures in our samples. Another cause of natural variability might be differences in depth at which an individual calcifies. In laboratory cultures, the addition rate of new chambers in *G. sacculifer* ranges from 1.6 to 6.2 days (Bé, 1981), while chamber formation in *G. hirsuta* and *G. truncatulinoides* takes about 5 to 6 hours (Bé, 1979). Considering that our sample duration ranges between 17 and 21 days, $\delta^{18}\text{O}$ variability is likely to be affected by other parameters (e.g. temperature). Therefore, the observed variability in $\delta^{18}\text{O}$ -based temperatures caused by species specific natural variability in $\delta^{18}\text{O}_{\text{cc}}$ (e.g. Russell and Spero, 2000) during the time it takes to add new chambers, which might be calcified under different conditions or water depth.

4.5.3. Reconciling $\delta^{18}\text{O}$ and Mg/Ca-derived calcification depths

Mg/Ca-derived temperatures indicate that calcification depths of *N. dutertrei* range between 42-169 m (average depth: 81 m) under non-eddy conditions and between 13 and 196 m (average depth: 98 m) during eddy conditions (Steinhardt et al., 2014). Thus, the shoaling in average calcification depth from 98 m during eddy conditions to 81 m during non-eddy conditions, indicated by the whole shell $\delta^{18}\text{O}_{\text{cc}}$ is less as than inferred from Mg/Ca, derived from the calcification of the last chambers. A more pronounced trend is present in Mg/Ca of *P. obliquiloculata*, shifting between 70 and 90 m (average 75 m) during non-eddy conditions, to depths between 147 and 244 m (average 150 m) during eddy conditions (Steinhardt et al., 2014). The Mg/Ca-derived shift is hence larger than the shift inferred from $\delta^{18}\text{O}_{\text{cc}}$ (eddy: 107 m and non-eddy: 60 m). Mg/Ca-derived calcification temperatures for *N. dutertrei* and *P. obliquiloculata* are hence cooler and indicative of deeper calcification of the final chambers compared to that of the whole shell (based on $\delta^{18}\text{O}_{\text{cc}}$). Calcification temperatures derived from Mg/Ca for *G. scitula* (Fig. 4.5), indicate an opposite trend, shifting between approximately 200 and 460 m (average 330 m) during eddy conditions to shallower depths between approximately 120 and 420 m (average 270 m) during non-eddy conditions (Steinhardt et al., 2014). Although the $\delta^{18}\text{O}_{\text{cc}}$ suggests calcification somewhat deeper than the Mg/Ca data, both Mg/Ca and $\delta^{18}\text{O}$ -derived calcification depth indicate a shoaling for this species during non-eddy conditions. Furthermore, the average $\delta^{18}\text{O}$ -derived calcification temperature of $10.4 \pm 3.9^\circ\text{C}$ is in good agreement with previously published results for this species (Fallet et al. 2011; Birch et al. 2013). We refrain from correcting for a vital effect, as this would lower $\delta^{18}\text{O}$ -derived calcification temperature to values unrealistically lower than the Mg/Ca-derived calcification temperatures for the last chambers. The observed remaining offset between single-specimen $\delta^{18}\text{O}$ and single chamber Mg/Ca in *G. scitula* suggest that either 1) there is a vital effect resulting in more enriched (i.e. positive) $\delta^{18}\text{O}$ values than when this species would precipitate its shell in isotopic equilibrium with seawater, 2) a more shallow calcification depth

during formation of the final chamber, 3) that crust carbonate adds significantly to the total shell mass, or, 4) the Mg/Ca calibration for *G. hirsuta* (Anand et al., 2003) might be different from that of *G. scitula*. Following the vital effect correction of Williams and Kahn (1981), calcification temperature is $6.4^{\circ}\text{C} \pm 3.9^{\circ}\text{C}$, which is equivalent to an average calcification depth for *G. scitula* between 600 and deeper than 1100 m. This is in agreement with a suggested depth habitat within the upper 1000 m for this species (Schiebel et al., 1995; Ortiz et al., 1996; Itou et al., 2001). In our opinion the last two explanations are most likely, however, irrespective of the underlying mechanism it is clear that the majority of the test carbonate precipitated at a depth greater or comparable to that of the ontogenetic carbonate of the final chambers.

The range of uncertainties related to a species' average calcification depth results from the relatively large natural inter-specimen variability in Mg/Ca. Since we focus on relative differences within species between hydrographic conditions, the uncertainty in calcification temperature resulting from errors in the applied Mg/Ca-temperature calibration does not affect the absolute temperature differences between the eddy- and non-eddy conditions. Instead, uncertainties in the calculated difference in calcification depths between species will be caused by the inter-specimen variability in Mg/Ca.

4.5.3.1. Cumulative calcification model

We used a conceptual oxygen isotope mass balance model (Wilke, 2006; 2009), applying the temperature fractionation from inorganic calcite precipitation of Kim and O'Neil (1997) to our measured $\delta^{18}\text{O}_{\text{CC}}$. The model equation describing foraminiferal migration as a function of depth used here is known as the cumulative form of the Weibull function (Weibull, 1939). It is a continuous probability function (Eq. 4), relating the shell mass 'M' to depth (z) using two constants (α and β) determining the shape of this relationship:

$$(4) \ M(z) = 1 - \exp(-1 * (z/\beta)^{\alpha})$$

Since shell size of planktonic foraminifera is thought to increase with water depth (Hemleben and Bijma, 1994; Peeters and Brummer, 2002) shell mass must also increase with depth. The isotopic composition of a single shell thus represents the weighted sum of equilibrium calcite precipitated over a depth range of the productive zone (i.e. where primary calcite formation takes place).

Based on equation (5), the expected stable isotope composition of a specimen for a discrete

water depth interval can be calculated as follows:

$$(5) \quad \delta^{18}O = \sum_i^n \frac{(M_i - M_{i-1}) + \delta^{18}O_{eq,i}}{M_i}$$

Given the $\delta^{18}O_{eq}$ profile in the water column and the measured $\delta^{18}O_{cc}$ of the planktonic foraminifera it is possible to model the mass development (growth pattern) by using the determined Mg/Ca calcification depth of the last chambers, indicating the base of the calcite production zone. The Mg/Ca-based temperature of the F-1 chamber was used to delimit 95% of the calcite production. In equation (5), $\delta^{18}O_{eq,i}$ denotes the interval averaged $\delta^{18}O$ of equilibrium calcite for the specified depth interval. For convenience, shell mass at the sea surface was taken as zero and modelled $\delta^{18}O_{cc}$ was done by adapting the variables ‘ α ’ and ‘ β ’ in equation (5).

Increasing the value of ‘ α ’ results in a growth curve with a narrow calcification range. Higher values for ‘ β ’ result in a deepening of the growth curve, thereby determining the position of the base of the productive zone. In contrast to Wilke’s (Wilke et al., 2006; 2009) approach, we have determined the calcification temperatures of the last three to four chambers, which were used to constrain the base of the calcification range and hence constrained values for ‘ β ’.

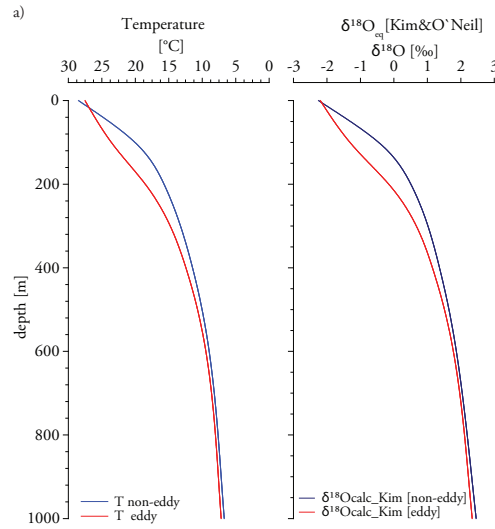


Fig 4.7

In this model, it is assumed that shell growth always follows the same function, which is continuous and does not differ between species. Offsets between $\delta^{18}O_{CC}$ and $\delta^{18}O_{sw}$ from expected equilibrium (‘the vital effect’), is assumed to be constant over the temperature range in which the species calcifies. We have adapted $\delta^{18}O_{sw}$ in meter steps as calculated from *in situ* salinity measurements, which were interpolated for the upper 2000 meters. We have used expected $\delta^{18}O_{eq}$ values of eddy and non-eddy condition to compare depth distributions for all four species of planktonic foraminifera.

Calcification depths inferred from the cumulative $\delta^{18}O$ model (Fig. 4.7) match previously published calcification depths and associated temperatures for each of the species relatively

well (e.g. Cl  roux et al., 2008; 2013; Wilke et al., 2009; Fallet et., 2010; 2011; Birch et al., 2013). In three species, measured $\delta^{18}\text{O}_{\text{CC}}$ values reflect shallower calcification depths than do single-chamber Mg/Ca-based calcification depths, which is consistent with the general model of migration to greater depth during growth. In case of the deep dwelling *G. scitula*, however, $\delta^{18}\text{O}$ -based calcification depth is below that of the final chambers as derived from Mg/Ca-temperatures. Without applying a temperature correction for $\delta^{18}\text{O}$ -based calcification temperatures of *G. scitula*, calcification depth based on $\delta^{18}\text{O}_{\text{CC}}$ can deviate up to 300 m from the Mg/Ca based depths. This would suggest that the majority of the previously formed calcite was precipitated deeper in the water column. The model shows that species modulate their

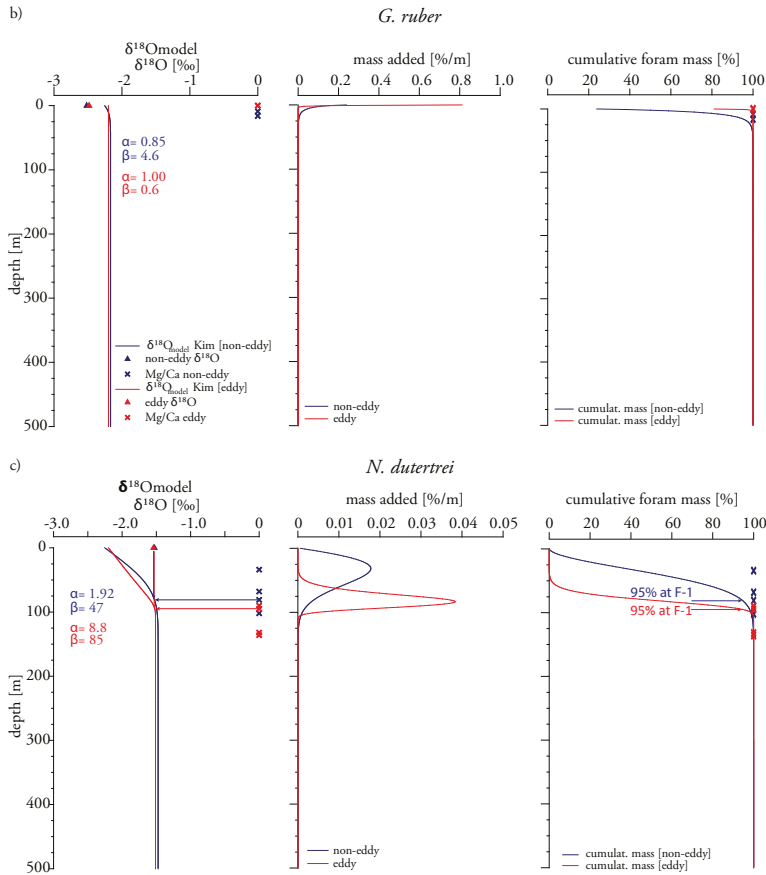


Fig. 4.7

calcification pattern depending on the hydrographical conditions they live in (e.g. eddy, non-eddy condition). For *G. ruber*, our results show that this species seems to be an exclusive surface dweller and hence an application of the cumulative calcification model only confirms that the majority of the calcite is formed at the sea surface.

For the thermocline dwelling species *N. dutertrei* we find that this species calcifies most of its

calcite in a narrow depth range. Our model indicates that calcification during eddy conditions is more intense in the deeper part of the thermocline ($\alpha = 8.8$; $\beta = 85$), whereas calcification during non-eddy condition is more equally distributed over the entire thermocline ($\alpha = 1.9$; $\beta = 47$). It is noteworthy that *N. dutertrei* appears to intensify its calcification efforts during eddy conditions deeper in the thermocline, matching well with the deepening of the isopycnals and hence a narrower range of optimal calcification conditions (Steinhardt et al., 2014). This calcification response is also reflected in more enriched $\delta^{13}\text{C}$ values during eddy conditions. For *P. obliquiloculata* modelled α and β values are relatively high, particularly during eddy conditions ($\alpha = 5.25$; $\beta = 133$, compared to $\alpha = 3.1$; $\beta = 63$ for non-eddy conditions). This

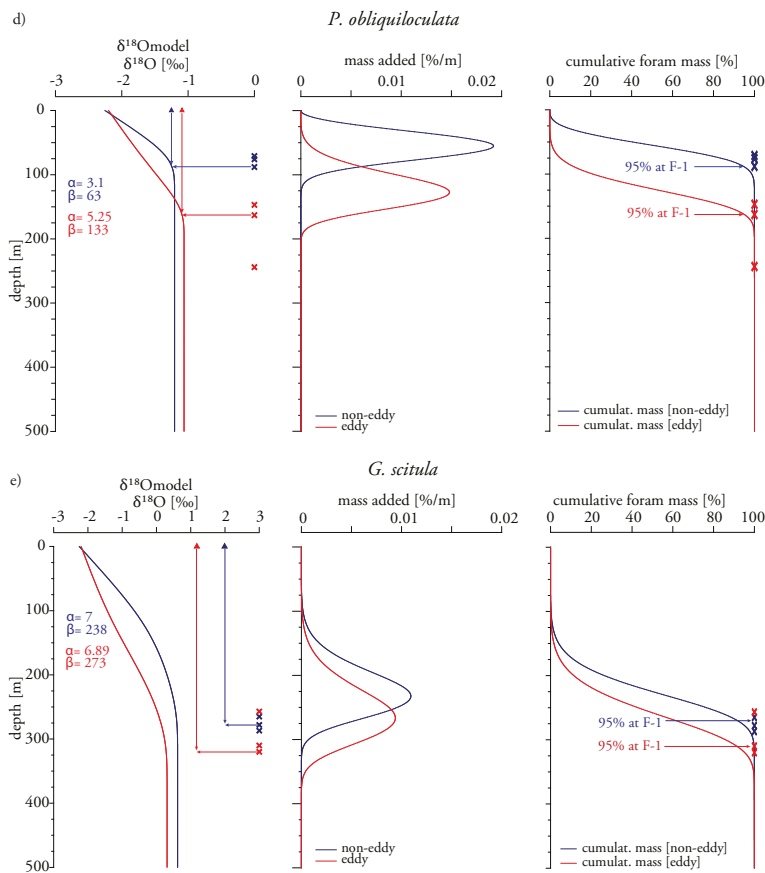


Fig. 4.7: (a) Temperature profiles as well as $\delta^{18}\text{O}_{\text{equilibrium}}$ ($\delta^{18}\text{O}_{\text{eq}}$) for the upper 1000 m for eddy (red) and non-eddy (blue) conditions. (b–e) $\delta^{18}\text{O}_{\text{cumulative}}$ ($\delta^{18}\text{O}_{\text{model}}$), mass development/growth pattern and cumulative mass of the foraminifera (foram mass) are plotted for the upper 500 m. Bulk $\delta^{18}\text{O}_{\text{foram}}$ (triangles) Mg/Ca-derived single-chamber calcification depths (crosses) are indicated in the relevant plots for *G. ruber* (b), *N. dutertrei* (c), *P. obliquiloculata* (d) and *G. scitula* (e).

indicates that most of the calcification in *P. obliquiloculata* takes place at a water depth around

125 m during eddy conditions, and around 50 m during non-eddy conditions. The range at which *G. scitula* calcifies is well below the seasonal thermocline, reflected by high values for α and β (Fig. 4.7) and does not vary considerably during eddy and non-eddy conditions.

In general, we conclude that temperature changes within the thermocline induced by eddies affect non-symbiotic species mostly. Also, changes in cumulative calcite addition with depth seem to be species-specific. We modified the model by including Mg/Ca-based temperatures (following the species specific equations of Anand et al., 2003) of the F-1 chamber to constrain the 95% calcification level. This allows to predict expected $\delta^{18}\text{O}_{\text{eq}}$ for different species and shell sizes (Spero et al., 1997; Bijma et al., 1999; Itou et al., 2001; Peeters et al., 2002). The extended version of the model does not distinguish between calcite deposited during chamber formation (primary calcite) and calcite added as a result of wall thickening due to gametogenic calcite or the precipitation of crust (secondary calcite, Bé, 1980; Duplessy et al., 1981; Lohmann, 1995; Jonkers et al., 2012). Secondary calcification might play an important role for deeper dwelling species such as *G. scitula*, which could explain the offset (about 1‰) between $\delta^{18}\text{O}_{\text{model}}$ and $\delta^{18}\text{O}_{\text{CC}}$. This suggests that relatively more calcite is formed deeper in the water column, or secondary calcite is precipitated with a fundamentally different calcification mechanism.

4.5.3.2 Carbon isotopes – testing the calcification model

The $\delta^{13}\text{C}$ values found in planktonic foraminifera is primarily a function of the carbon isotope composition of the dissolved inorganic carbon (DIC) in seawater (e.g. Urey, 1947; Epstein et al., 1953; McCorkle et al., 1990), which changes with water depth (e.g. Fairbanks et al., 1980, Curry and Crowley, 1987). Therefore, we can use the cumulative mass balance model output of the mass added per meter to calculate $\delta^{13}\text{C}_{\text{expect}}$ as the weighted sum of the $\delta^{13}\text{C}_{\text{DIC}}$ (Wilke et al., 2006). Depth-resolved carbon isotope composition ($\delta^{13}\text{C}_{\text{DIC}}$), available from locations closest to our study site (locations between 37-43 °E and 24.7 °S, World Ocean Database 2009) were used to calculate the expected $\delta^{13}\text{C}$ of each species of foraminifera ($\delta^{13}\text{C}_{\text{expect}}$). Since there is no relation between size and stable carbon isotopes in our specimens, the employed size fractions contained only mature (adult) specimens (Brummer et al., 1986, 1987). Comparing water column $\delta^{13}\text{C}_{\text{DIC}}$ data (Supplementary, Fig. 1) from several stations near the MC reveals that absolute values and depth range over which values decrease is similar at the different sites. To verify the depth related calcification model we compare measured $\delta^{13}\text{C}_{\text{CC}}$ with model-based $\delta^{13}\text{C}_{\text{expect}}$ values (Fig. 4.8).

Carbon isotope values become more negative from surface dwelling *G. ruber* towards deeper dwelling *P. obliquiloculata* near the upper thermocline. Conversely, the $\delta^{13}\text{C}$ of *Globorotalia*

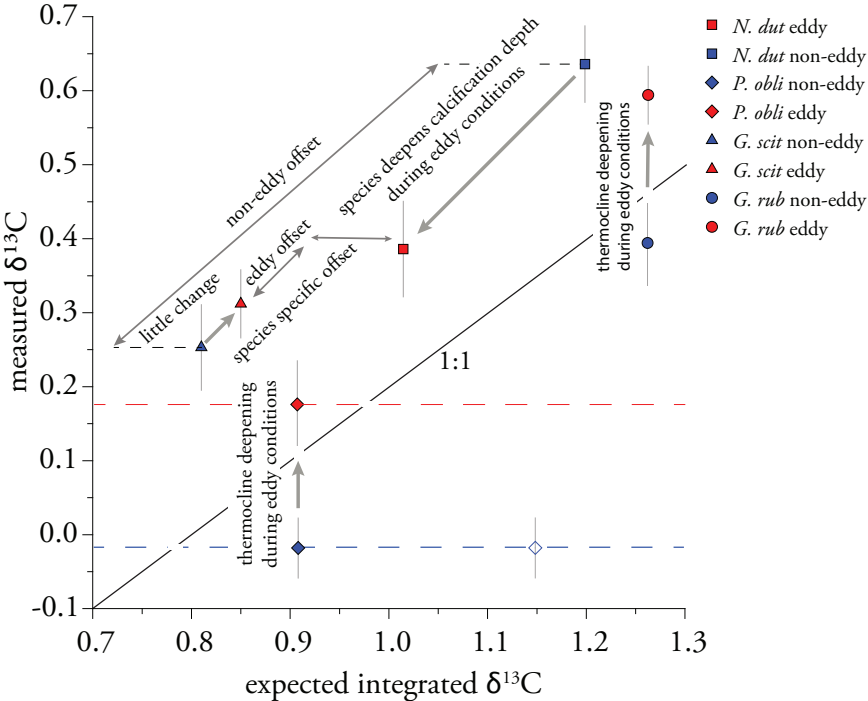


Fig. 4.8: Inter-species differences between expected $\delta^{13}\text{C}$ values, based on the cumulative mass balance model, and measured $\delta^{13}\text{C}$ values of *G. ruber*, *N. dutertrei*, *P. obliquiloculata* and *G. scitula*. Dashed line indicates the 1:1 line of measured and expected $\delta^{13}\text{C}$. Red symbols represent values for eddy conditions, blue symbols represent values for non-eddy condition. Thick grey arrows indicate intra-species trends between non-eddy and eddy conditions, thin arrows indicate inter-specific trends. *P. obliquiloculata* does not calcify in isotopic equilibrium with dissolved ΣCO_2 , but the deviation from isotopic equilibrium is a linear function of temperature (Mulitza et al., 1999), hence there is no projected $\delta^{13}\text{C}_{\text{exect}}$, this is indicated by the dotted lines. Open diamond indicates $\delta^{13}\text{C}_{\text{exect}}$ for *P. obliquiloculata* non-eddy conditions.

scitula increases with depth. Low temperatures and reduced food availability have been suggested to result in relatively low metabolic rates in deep dwelling species, so that their $\delta^{13}\text{C}$ likely approaches $\delta^{13}\text{C}_{\text{DIC}}$ values (Birch et al., 2013). This suggests the involvement of biological controls on the $\delta^{13}\text{C}$ of the different genera (*Globigerinoides*, *Neogloboquadrina*, *Pulleniatina* and *Globorotalia*). All $\delta^{13}\text{C}_{\text{expect}}$ are higher than the measured $\delta^{13}\text{C}_{\text{CC}}$.

Our cumulative mass balance shows that the majority of the carbonate of *G. ruber* is formed in surface waters (Fig. 4.7). Equal $\delta^{13}\text{C}_{\text{expect}}$ values for eddy and non-eddy conditions are the result of similarly enriched $\delta^{13}\text{C}_{\text{DIC}}$ in the mixed layer. The measured differences in $\delta^{13}\text{C}_{\text{CC}}$ (Fig. 4.8) are likely a consequence of the deepening thermocline during passage of an eddy, carrying nutrient-depleted waters (Kolasinski et al., 2013). Anticyclonic eddies are characterized by

accumulation of warm, nutrient-poor and chlorophyll-depleted water in the center, which implies that also $\delta^{13}\text{C}_{\text{DIC}}$ is more isotopically enriched. Still, local nutrient enrichment potentially occurs at the outer edge as a result of high turbulence along the isopycnal slope (e.g. Falkowski et al., 1991; Lévy, 2003). The strong response of the Mg/Ca and $\delta^{18}\text{O}$ of *N. dutertrei* during eddy conditions (deeper calcification) is also reflected by more depleted $\delta^{13}\text{C}_{\text{CC}}$ values. Remineralization of organic matter at greater depth cause enrichment of $\delta^{13}\text{C}_{\text{DIC}}$, resulting in the incorporation of lighter carbon isotopes into the shell of *N. dutertrei* during eddy conditions. Based on samples from a sediment trap in Cape basin, Wilke et al. (2009) showed that the species *N. dutertrei* is an accurate recorder of the $\delta^{13}\text{C}_{\text{DIC}}$. This is in agreement with previous findings (Mulitza et al., 1999), showing that the carbon isotopic composition of *N. dutertrei* exhibits a constant and temperature-independent off-set from $\delta^{13}\text{C}_{\text{DIC}}$ of $\sim 0.5\text{‰}$ over a wide temperature range. This difference is in line with the offset in our dataset between $\delta^{13}\text{C}_{\text{expect}}$ and $\delta^{13}\text{C}_{\text{CC}}$ of *N. dutertrei* (0.6‰).

The $\delta^{13}\text{C}$ of the symbiont-barren *G. scitula* significantly deviates from those of the shallower dwelling species as a result of a decrease in $\delta^{13}\text{C}_{\text{DIC}}$ with water depth (see supplementary information, Fig. A4.1 and A4.2). The more depleted $\delta^{13}\text{C}_{\text{CC}}$ of *G. scitula* may also be a consequence of a lower metabolism of this species (Vergnaud-Grazzini, 1976; Kahn, 1977, 1979; Berger et al, 1978; Erez, 1978) compared to that of *G. ruber* and *N. dutertrei*. At high metabolic activity, more isotopically lighter carbon is incorporated and since lower temperatures usually reduce metabolic rates, species inhabiting deeper water depths may incorporate relatively heavier carbon isotopes. Minor changes in $\delta^{13}\text{C}_{\text{CC}}$ for *G. scitula* during eddy versus non-eddy conditions are in line with the minor response in calcification depth for this species. Similar to previous conclusions, this suggests that Mg/Ca inferred temperature differences between *N. dutertrei* and *G. scitula* are good indicators for eddies passing (Steinhardt et al., 2014). In addition, the $\delta^{13}\text{C}_{\text{CC}}$ differences between these species might very well help to reconstruct eddy frequency in this area. The depth integrated difference between $\delta^{13}\text{C}$ of *N. dutertrei* and *G. scitula* changes from 0.25 to 0.05 ‰.

Comparing $\delta^{13}\text{C}_{\text{expect}}$ and $\delta^{13}\text{C}_{\text{CC}}$ for *P. obliquiloculata* there is a discrepancy between eddy and non-eddy conditions (Fig. 4.8). Similar to *N. dutertrei*, this species is mostly associated with the thermocline (Anand et al., 2003; Cléroux et al., 2008; Sadekov et al., 2009). Our cumulative calcification model showed a slightly deeper calcification depth for *N. dutertrei* and a minor eddy response in calcification range (Fig. 4.7). However, $\delta^{13}\text{C}$ values indicate a significant difference between eddy and non-eddy conditions. Mulitza et al. (1999) showed that *P. obliquiloculata* does not calcify in isotopic equilibrium with dissolved ΣCO_2 , but the

deviation from isotopic equilibrium is a linear function of temperature (Fig. 4.8). While the mean of the $\delta^{13}\text{C}$ cannot be used to infer the actual calcification depth, they argue that the spread and skewness of the individual $\delta^{13}\text{C}$ measurements should still be representative of the range of calcification depths and habitat preferences within the thermocline. Also changes in the carbonate ion concentration with depth potentially play an important role in the observed differences between species and between eddy and non-eddy conditions (Supplementary figs. 1 and 2). Since the carbonate ion profile is expected to change in accordance with thermocline deepening when an eddy passes we refrained from correcting for this. The observed offsets between species, however, suggest that carbonate ion does play a role there. The deeper living species show an increasing offset with respect to the 1:1 line (Fig. 4.8). The exception is *P. obliquiloculata* which responds to temperature rather than $\delta^{13}\text{C}_{\text{DIC}}$ carbonate ion changes (Mulitza et al., 1999).

Overall the here observed relations indicate that interpretation of the foraminifera vertical distribution in the upper water column can be unraveled by coupling various geochemical methods in order to retrieve calcification temperature at different stages in a foraminifera's life cycle. This in turn can be used to develop new proxies for the thermal and nutrient structure of the upper part of the water column.

4.6. Conclusion

Documenting changes in upper ocean stratification is essential for understanding past climatic conditions from sediment cores and is commonly estimated by determining the difference in $\delta^{18}\text{O}$ between thermocline and surface-dwelling planktonic foraminifera (Spero et al., 2003; Cléroux et al., 2007; Farmer et al., 2007; Lin and Hsieh, 2007; Steph et al., 2009). We conducted stable isotope measurements on four species of planktonic foraminifera (*G. ruber*, *N. dutertrei*, *P. obliquiloculata* and *G. scitula*) from selected sediment trap samples, representing eddy and non-eddy conditions in the MC.

Using single shell $\delta^{18}\text{O}_{\text{CC}}$ paired to single-chamber LA-ICP-MS Mg/Ca measurements we applied a cumulative mass balance model in order to compare growth patterns of the various planktonic species during eddy and non-eddy conditions. The results indicate that most of the species have somewhat different calcification patterns during eddy and non-eddy conditions. Only Mg/Ca values of *G. scitula* suggest higher calcification temperatures than inferred from $\delta^{18}\text{O}$. Furthermore, the results of the $\delta^{18}\text{O}$ cumulative mass balance model agree with previous findings that thermocline dwelling *N. dutertrei* and deep dwelling *G. scitula* are suitable

recorders of eddy induced hydrographic changes (Steinhardt et al., 2014). The combination of various proxies (e.g. Mg/Ca, $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) can thus provide a useful set of geochemical proxies to reconstruct the thermal and nutrient structure of the upper part of the water column.

All species analyzed have unique offsets from ambient seawater $\delta^{13}\text{C}$. However, comparison of species specific isotopic trajectories with water column $\delta^{13}\text{C}$ reveals that ambient $\delta^{13}\text{C}_{\text{DIC}}$ may be recorded by the species used in this study. The $\delta^{13}\text{C}$ of *N. dutertrei* and *G. scitula* show eddy related changes in their offsets and can potentially aid to unravel eddy related changes in the nutrient structure.

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Supplements

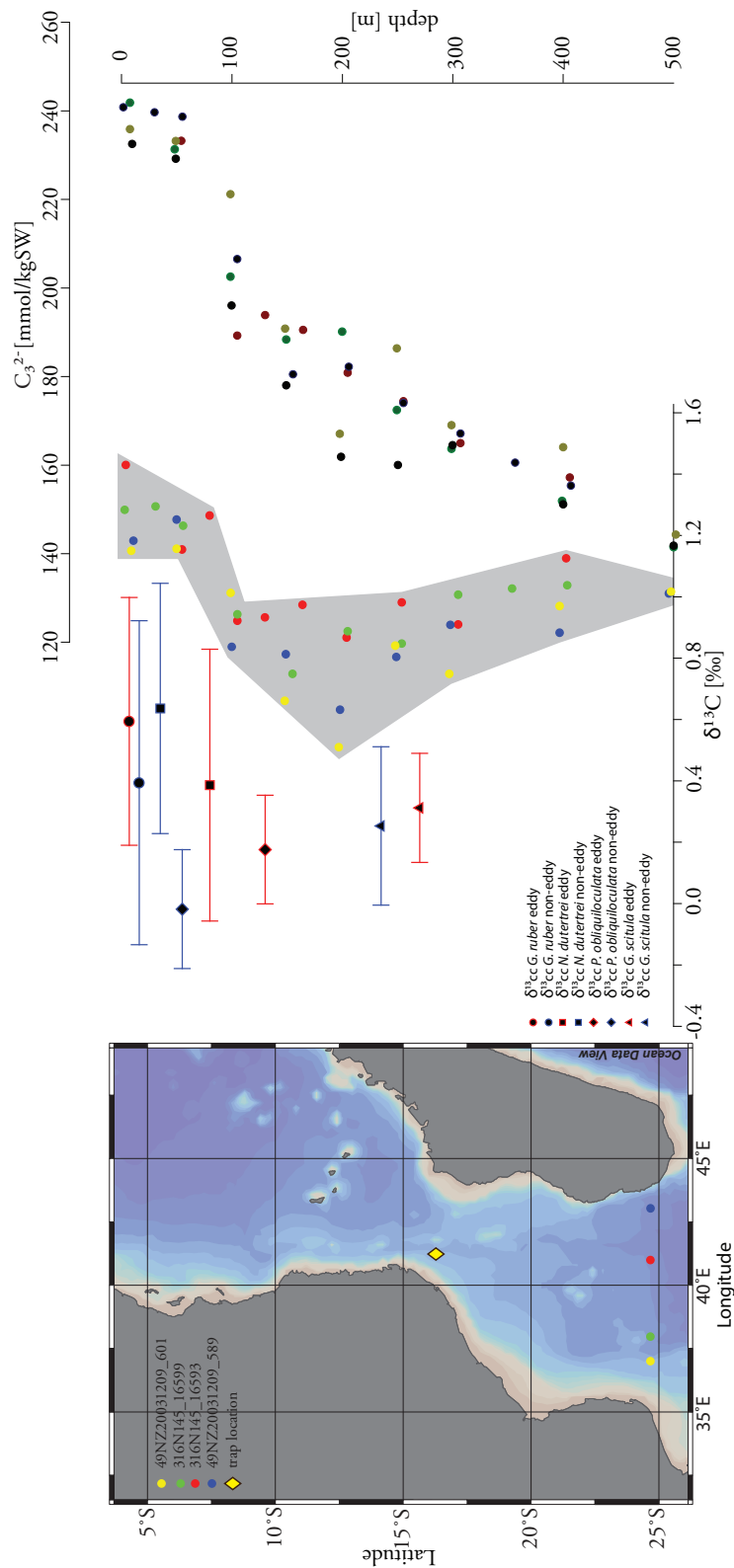


fig. S1: Map of sediment trap location (diamond) and locations of the C_{3-2} and $\delta^{13}C_{DIC}$ data extracted from the World Ocean Database 2009. For comparison, means values of $\delta^{13}C_{CC}$ for *G. ruber*, *N. duerrei*, *P. obliquilocutata* and *G. scitula* for eddy (red) and non-eddy(blue) are plotted. Horizontal scale in middle indicates standard deviation. Data is plotted for the upper 500 m only.

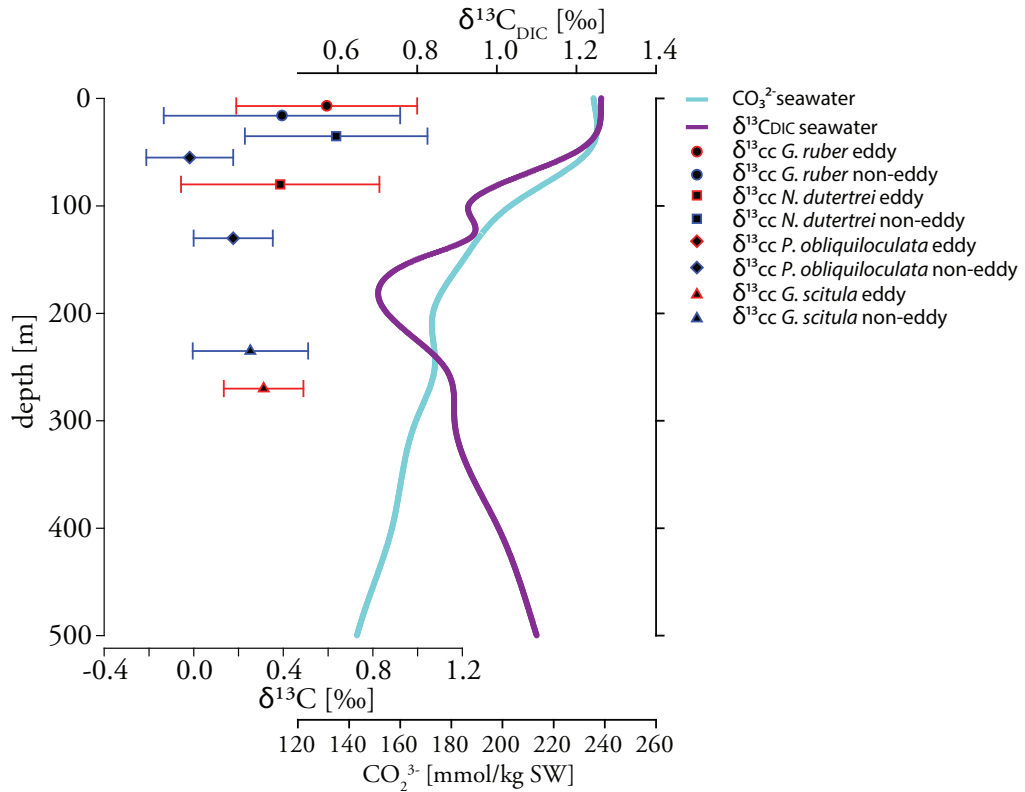


fig. S2: Spline interpolated seawater $\delta^{13}\text{C}_{\text{DIC}}$ (purple line) and CO_3^{2-} (light blue line) for the Mozambique Channel. For comparison, means values of $\delta^{13}\text{C}_{\text{CC}}$ for *G. ruber*, *N. dutertrei*, *P. obliquilocuata* and *G. scitula* for eddy (red) and non-eddy (blue) are plotted. Horizontal scale in middle indicates standard deviation. Data is plotted for the upper 500 m only.



(Neogloboquadrina dutertrei)

Chapter 5

Profiling planktonic foraminiferal crust formation

Chapter 5

Profiling planktonic foraminiferal crust formation

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Abstract

Planktonic foraminifera migrate vertically through the water column during their life, thereby growing and calcifying over a range of depth-associated conditions. Some species form a calcite veneer, crust or cortex at the end of their lifecycle. This additional calcite layer may vary in structure, composition and thickness, potentially accounting for most of their total shell mass and thereby dominating the element and isotope signature of the whole shell. Here we apply laser ablation ICP-MS depth profiling to assess variability in thickness and Mg/Ca composition of shell walls of three encrusting species derived from sediment traps. Compositionally, Mg/Ca is significantly lower in the crusts of *Neogloboquadrina dutertrei* and *Globorotalia scitula*, as well as in the cortex of *Pulleniatina obliquiloculata*, independent of the species-specific Mg/Ca of their lamellar calcite shell. Wall thickness accounts for nearly half of the total thickness in both crustal species and nearly a third in cortical *P. obliquiloculata*, regardless of their initial shell wall thickness. Crust thickness and crustal Mg/Ca decreases towards the younger chambers in *N. dutertrei* and to a lesser extent, also in *G. scitula*. In contrast, the cortex of *P. obliquiloculata* shows a nearly constant thickness and uniform Mg/Ca through the complete chamber wall. Patterns in thickness and Mg/Ca of the crust indicate that temperature is not the dominant factor controlling crust formation. Instead, we present a depth-resolved model explaining compositional differences within individuals and between successive chambers as well as compositional heterogeneity of the crust and lamellar calcite in all three species studied here.

5.1. Introduction

Planktonic foraminifera form calcite shells, which they extend step-wise by adding new chambers. Construction of these chambers follows a logarithmic spire in a tightly controlled building plan. Layers of primary and secondary calcite, together called the “lamellar” or “ontogenetic” calcite (Reiss, 1957; 1960; Erez et al., 2003) are formed with each chamber added. The secondary calcite, moreover, covers all preceding chambers of the last whorl during addition of every new chamber (e.g. Reiss 1957, 1960; Takayanagi et al., 1968). In various species, a final calcite layer with a markedly different morphology and thickness covers this lamellar calcite. Crusts, for example formed by blocky euhedral crystals, thicken the shell, reduce its porosity and give the surface of the chambers a rough appearance. Gametogenic calcite, in contrast, precipitates as a relatively thin veneer, giving spinose species in life a non-spinose appearance in the sediment (Bé, 1980; Hemleben et al., 1985). Some foraminiferal

species develop a thick final cortex of smooth glossy calcite (e.g. Burt and Scott, 1975; Erez and Honjo, 1981; Kunioka et al., 2006). All are shell features that typically occur last in ontogeny, defined by Brummer et al. (1987) as the terminal stage of shell development associated with the reproductive process. However, unlike gametogenic calcite, there are no direct observations confirming the relation between reproduction and the construction of a crust or cortex.

Fossil tests of calcifying foraminifera are popular tools used to reconstruct marine environmental conditions and past climate change. Elemental and isotopic compositions of foraminiferal calcite depend on various environmental parameters such as temperature, salinity, pH and ion concentration (McCrea, 1950; Epstein et al., 1951; Boyle, 1981; Nürnberg et al., 1996; Lea et al., 1999; Russell, 2004; Dissard et al. 2010; De Nooijer et al., 2014). However, minor and trace elements are known to be distributed heterogeneously within foraminiferal tests (Eggins et al., 2003; Hathorne et al., 2003; Allison and Austin, 2003; Sadekov et al., 2005; Kunioka et al., 2006; Jonkers et al., 2012). This is mainly caused by physiological (i.e. biomineralization) controls on chamber formation (Bé et al., 1960; Hemleben et al., 1989; Fairbanks et al., 1980; Erez et al., 2003; De Nooijer et al., 2009; Vetter et al., 2014; Steinhardt et al., 2014; Chapter 3), although the absolute values may be modified by depth migration during their life cycle. Diurnal rhythms in symbiont activity potentially cause the alternating bands of high- and low- Mg/Ca ratios found in some species (Bemis et al., 2000; Eggins et al., 2004; Spero et al., 2015). Also calcification features such as crust and cortex calcite introduce potential sources of within- and between-specimen variability in calcite chemistry of many planktonic foraminifera. Not only differences in chemical composition, but also relative contributions from the different calcite layers (Takayanagi et al., 1968) may affect average whole shell composition on which temperature calibrations are currently based (e.g. Dekens et al., 2002; Anand et al., 2003; Cléroux et al., 2008; Regenberg et al., 2009).

Here we investigate the thickness and composition of crust calcite, whether it differs chemically and morphologically from a cortex and assess how their formation is linked to the foraminiferal life cycle. For this purpose, we selected specimens from three planktonic foraminiferal species with contrasting life cycles, all known to form crusts or a cortex. *Neoglobobulimina dutertrei* is a mixed layer dweller, *Pulleniatina obliquiloculata* has a similar albeit somewhat deeper assumed habitat, and *Globobulimina scitula* is a sub-surface to deep dwelling species (e.g. Bé and Hutson, 1977; Fairbanks et al., 1982; Watkins et al., 1996; Ortiz et al., 1996; Mücke and Oberhänsli, 1999; Chapter 3). We compare structural differences between lamellar, crust and cortex calcite using SEM imaging in combination with laser ablation (LA) ICP-MS depth profiling of shell walls to investigate compositional differences within and between species and

to quantify their contribution to the overall calcite composition. Quantifying the impact of environmental parameters on the incorporation of elements and isotopic fractionation allows improving proxies for downcore reconstructions (e.g. Wefer and Fischer, 1999; Henderson, 2002; Zeebe et al., 2008; Katz et al., 2010). Hence, understanding the fundamental processes underlying crust and cortex formation sets the stage for further refinement of foraminiferal shell chemistry-based proxies.

5.2. Material and Methods

5.2.1. Species selection and chambers analysed

In this study we used material collected with a Technicap PPS 5 sediment trap (Supplementary tab. 1) that was deployed at 16.8°S and 40.8°E in the central Mozambique Channel (MC). The trap was positioned 250 meters above the channel floor, at water depth of 2250 m. Sea surface temperatures (SST) in the MC vary seasonally (ranging from 25°C to over 30°C with an annual mean of 27.6°C). Sea surface salinities decrease slightly from 35.2 in winter to 34.9 in summer (Fallet et al., 2010).

Processing of the time-series sediment trap samples is described in Fallet et al. (2009; 2010). We selected three planktonic foraminiferal species, known to add either crust calcite or form a cortex layer. These species dwell at different times and at different depth intervals in the water column (e.g. Erez and Honjo, 1981; Wilke et al., 2006; Jonkers et al., 2012; chapter 3). Subsurface-dwellers *Neogloboquadrina dutertrei* and *Pulleniatina obliquiloculata* have been suggested to calcify between 0 and 100 m depth and between 60 and 150 m, i.e. in the upper and middle seasonal thermocline, respectively (Cléroux et al., 2007; Erez and Honjo, 1981; Fairbanks et al., 1982; Field, 2004; Huang et al., 2008; Kuroyanagi and Kawahata, 2004; Pflaumann and Jian, 1999; Ravelo and Fairbanks, 1992; Spero et al., 2003). We also selected specimens of the deep-dwelling *Globorotalia scitula* to analyse the impact of deeper, colder waters on the thickness and composition of crusts (Bé, 1969; Ortiz et al., 1996; Fallet et al., 2011; Itou et al., 2001). A depth habitat within the upper 1000 m has been suggested for this species (Schiebel et al., 1995; Ortiz et al., 1996; Itou et al., 2001). Together, these three foraminiferal species cover a major part of the upper water column at a single location and hence encompass a major temperature range.

Specimens were selected from the >315 µm size fraction as much as possible to ensure the selection of mature specimens. In case insufficient specimens from the designated trap samples

(Supplementary tab. 1) were available within this size range for replicate LA-ICP-MS analyses, specimens in the 250 – 315 μm were added to the pool of analyzed specimens (Appendix table 2). We measured thickness and elemental composition of the final three to four chambers as these are positioned in the final whorl in all three species studied.

5.2.2. LA-ICP-MS

The Mg/Ca ratios of single chambers used in this study were previously published (Chapter 3) and were determined by Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) at Utrecht University (Reichert et al., 2003). The matrix matched in-house standard showed an average relative standard deviation (SD) for Mg/Ca of 3.7%. Measurements were performed on intact specimens and always proceeded from the outside towards the inside of the chambers.

In addition to these laser ablation analyses we added high resolution profiles by ablating 12 specimens per species with a NWR193UC (New Wave Research) using an ArF Excimer laser (193nm) with short pulse ($< 4\text{ns}$) and a dual volume TruLine cell with fast ($< 1\text{s}$) wash out time. Ablation was performed at a repetition rate of 4 Hz with an energy density of 1 J cm^{-2} using an 80 μm , circular diameter spot size. The aerosol was transported out of the cell with a helium flow rate of 0.8 L/min of cell gas and 0.3 L/min of cup gas to a quadrupole ICP-MS (Thermo Scientific iCAP-Q). Foraminiferal shells were typically ablated from the outside towards the inside of the chambers. A signal-smoothing device between the cell and the ICP-MS was used to improve ratio stability (e.g. Tunheng and Hirata, 2004; Evans and Müller, 2013). To optimize sensitivity and minimize ThO^+/Th^+ , 0.3 mL/min Ar gas was admixed to the He flow before being introduced into the plasma. To minimize cycle time between masses and hence improve depth resolution, only 4 masses were measured: ^{24}Mg , ^{27}Al , ^{43}Ca , and ^{238}U . ThO^+/Th^+ ratios were maintained at levels between 0.1 - 0.7%. Concentrations of Mg and confidence intervals for each individual ablation profile were calculated using Thermo Qtegra software (version 2.2.1465.44) and ablation of an SRM NIST610 standard every 10 samples. The matrix matched in-house standard showed an average relative standard deviation (RSD) for Mg/Ca of 2.7%. In total, 629 single-chamber profiles were obtained (Appendix tab. chapter 5). Crust and cortex Mg concentrations are based on the low Mg/Ca part at the beginning of the ablation profiles, whereas lamellar calcite is based on the integration over the higher Mg/Ca part of the ablation profile. The boundary between the crust (or cortex) and lamellar calcite is not always marked by an instantaneous change in Mg/Ca and therefore, the precise location of the boundary between crust and lamellar calcite can be placed within error limits. However, ablation profiles in this study are generally relatively long and shifting the

boundary by a few seconds does therefore not have a noticeable impact on the average crust/cortex and lamellar Mg/Ca ratios. Regardless of the spatial resolution, profiles measured both with the LA-Sector Field-ICP-MS and that measured with the LA-Quadrupole-ICP-MS show similar thickness of low- and high Mg parts of crust or cortex and lamellar calcite. Previously measured LA-Sector Field-ICP-MS profiles (Fig. 5.4 in chapter 3) are as representative as LA-Quadrupole-ICP-MS ablation profiles. Profiles showing concentrations deviating more than twice the standard deviation from the average of the initial dataset were regarded outliers and therefore discarded from the dataset (28 from the 629).

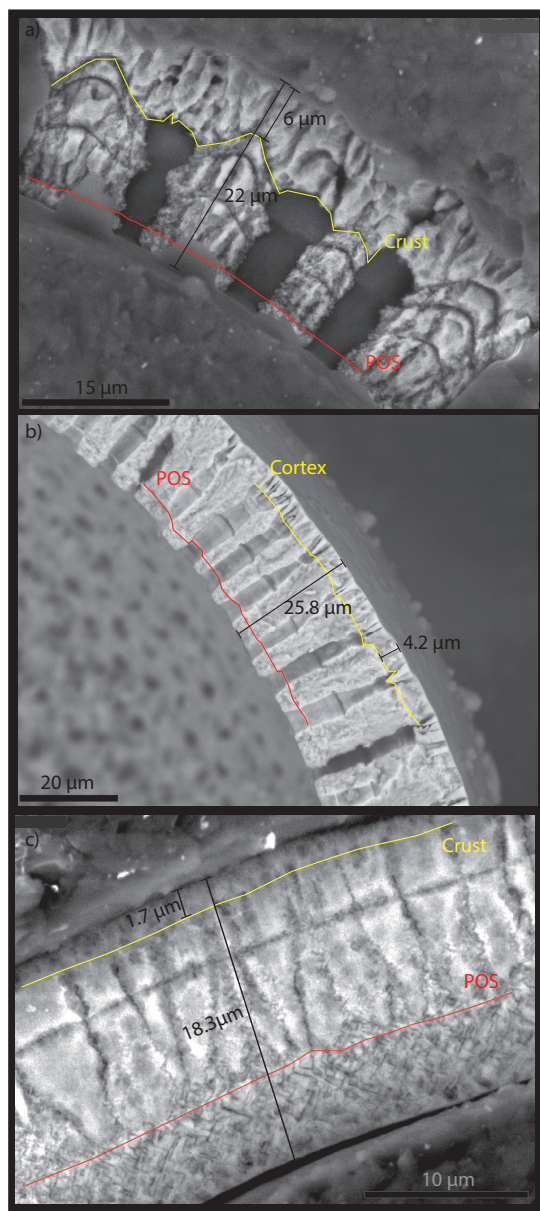


Fig. 5.1: SEM image of chamber wall cross-section of different species of planktonic foraminifera. Red line indicates the location of the POS, yellow line, cortex/crust, and black line indicates chamber wall thickness and crust/cortex thickness. a) Cross-section image of an F-2 chamber wall of *N. dutertrei* b) Cross-section image of an F-1 chamber wall of *P. obliquiloculata*. Note how the cortex is covering the pore space c) Cross-section image of an F-1 chamber wall of *G. scitula*.

5.2.3. Embedding, Etching and Scanning Electron Microscopy (SEM)

A minimum of twelve specimens of each species were dissected after laser ablation by breaking off the ablated chambers individually with a fine needle. All SEM pictures were taken with a Hitachi High-Tech TM3000 tabletop microscope, allowing measurement of the wall thickness of the ablated specimens. Each chamber wall was vertically positioned on a carbon stub, so that the chamber cross-section was positioned perpendicularly to the SEM's electron beam. Using the machine's software, thicknesses of the crust, lamellar calcite and the complete chamber wall were determined (Fig. 5.1).

5.2.4. Electron Microprobe

To cross-validate element profiles obtained by LA-ICP-MS to determine thickness of crust and lamellar calcite, element maps were made using electron microprobe. We embedded 9 specimens of each species in resin (Araldite 20/20). After 24 hours, after the resin was fully hardened, a thin layer of the resin's surface was removed by sanding paper to expose a cross-section of the foraminiferal specimens. The samples were rinsed thoroughly with distilled water and subsequently polished with increasingly finer sanding. After rinsing again with distilled water and drying, the surface was etched with 0.5% hydrochloric acid for approximately 5 seconds. The etched surface was rinsed again with distilled water and left to dry at 50°C. These etched samples allow for detection of the position of the primary organic template and measurement of the thickness of the crust versus that of the lamellar calcite using electron microprobe mapping. A number of polished cross-sectioned *P. obliquiloculata* specimens were not etched but carbon coated and placed in the electron microprobe (JEOL JXA-8530F Field emission Electron Probe Micro Analyzer) for mapping Mg and Ca at 15kV. Mapping of the entire specimen was carried out in lower spatial resolution, using a dwell time of 500 ms, a spot diameter of 2 μm and a step size of 2 μm (image: 320x320 points). Subsequently, on the same specimen, selected sections of the F-0 and F-2 chamber walls were mapped at higher resolution (images: 200x200 points) using a dwell time of 1000 ms, a spot diameter of 1 μm and a 0.5 μm step size. Counts (current strength) were converted to elemental ratios by combining the maps by using forsterite as standard for Mg and diopside for Ca concentrations.

5.3. Results:

5.3.1 Crust and cortex distribution

Crust and cortex are visually clearly distinct in SEM images of cross-sectioned walls (Figure 5.1). Also the embedded shells, upon etching, show a clear separation between lamellar and crust and/or cortex calcites (Fig. 5.2). These images hence allow measuring thicknesses of the lamellar and crust calcites. Wall thickness (in μm) and number of laser pulses needed to ablate through the test wall are positively correlated ($r^2=0.59$; Fig. 5.3) at approximately 40 nm per pulse (Fig. 5.3). This rate is, considering the energy density used (1 Jcm^{-2}), in line with earlier reported rates of 150 nm/pulse at 5 Jcm^{-2} (Eggins et al., 2003) and 200-300 nm/pulse at 10 Jcm^{-2} (Reichart et al., 2003). Moreover, Mg/Ca ablation profiles fitted the visual properties of crust/cortex and lamellar calcite (Figs. 5.2a-c). The smooth cortex of *P. obliquiloculata* can be clearly differentiated from the crust in e.g. *N. dutertrei*, as it does not show larger-sized euhedral crystals on its surface, and lacks pustule-like structures except around its aperture

(Figs 5.4a-d).

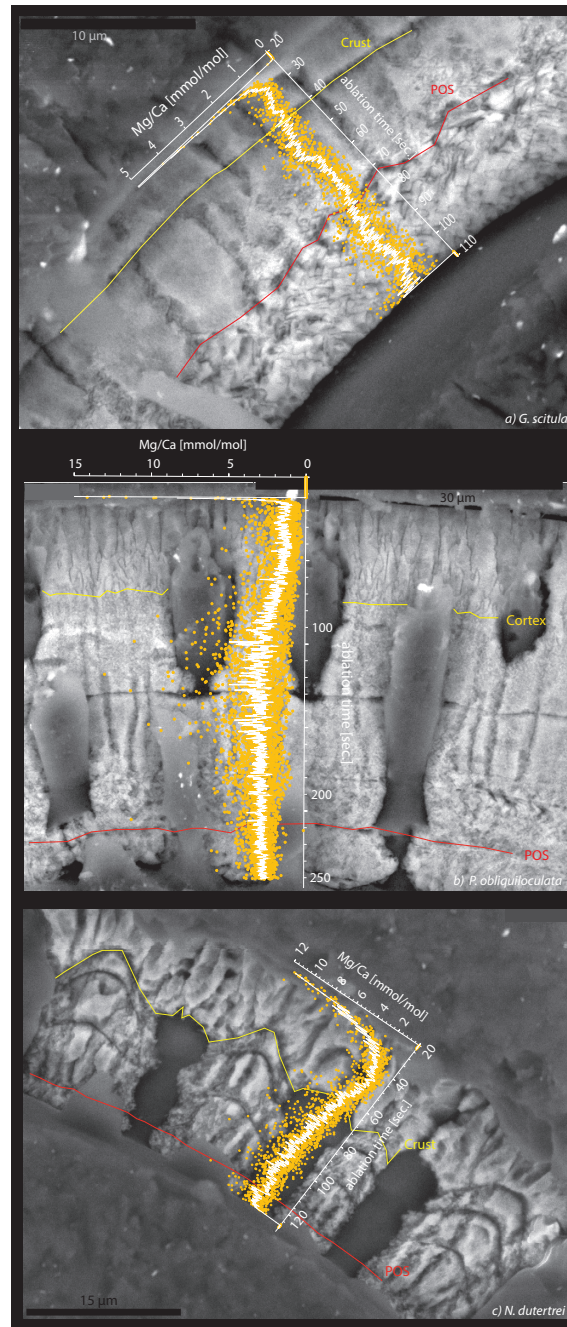


Fig. 5.2: SEM images of an embedded polished and etched specimen of a) *G. scitula*, b) *P. obliquiloculata* and c) *N. dutertrei*. The chamber cross-section images are overlaid with the matching LA-ICP-MS Mg/Ca profiles from the same chamber.

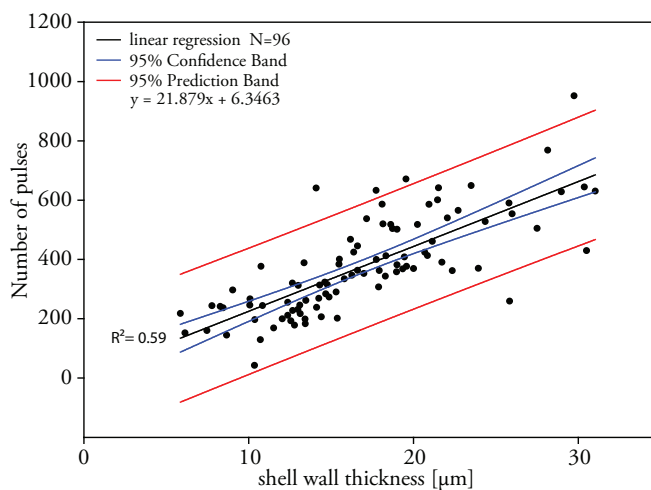


Fig. 5.3: Ablation length (in pulses) and wall thickness (in μm) are positively correlated in the 41 number of specimens analysed of *N. dutertrei*, *P. obliquiloculata* and *G. scitula*.

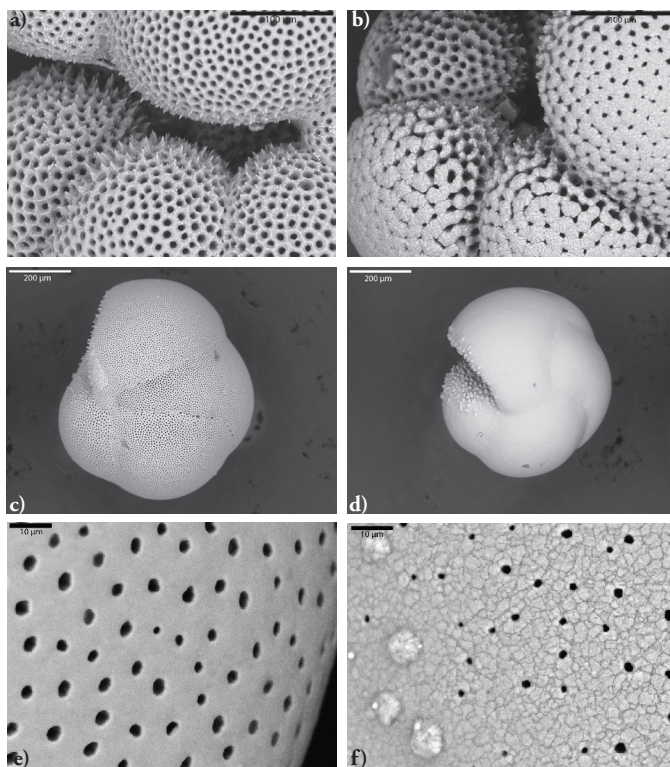


Fig. 5.4: SEM images of encrusted (left) and non-encrusted (right) planktonic foraminifera. a) non-encrusted shell surface of *N. dutertrei* b) encrusted *N. dutertrei* c) *P. obliquiloculata* with early cortex, d) cortex covered *P. obliquiloculata*, e) non-encrusted shell surface of *G. scitula*, f) encrusted shell surface of *G. scitula*.

Based on the geochemistry of the ablation profiles and SEM shell thickness measurements, the crust contributes approximately half ($7.6 \pm 0.5 \mu\text{m}$ or $\pm 47\%$) to the total thickness of chamber walls of *N. dutertrei* ($16.2 \pm 4.2 \mu\text{m}$). There is a significant difference in crust thickness between chambers within specimens of *N. dutertrei* (Figure 5.5a). To compare the different shell chambers we labeled successive chambers from the chamber added last (F-0) towards earlier formed chambers using the preceding position with respect to this first chamber, with n counting back along the whorl (F-n). Also lamellar calcite increases significantly in thickness between F-0 and F-2 (Jonckheere-Terpstra test, $p = 0.002$) and between F-0 and F-3 (Jonckheere-Terpstra test, $p < 0.0001$), as well as the F-1 and F-3 (Jonckheere-Terpstra test, $p = 0.018$). In *P. obliquiloculata*, cortex ($7.1 \pm 0.3 \mu\text{m}$) contributes on average 32% to the total wall thickness ($24.0 \pm 5.3 \mu\text{m}$) and is remarkably similar in successive chambers (Figure 5.5b) as is the thickness of its lamellar calcite (Tab. 5.1). Lamellar calcite in *G. scitula* shows a gradual, but significant, increase in thickness from the youngest towards the older chambers (Fig. 5.5c). In *G. scitula* the crust ($7.2 \pm 0.4 \mu\text{m}$) contributes on average 45.6% to the total wall thickness ($15.8 \pm 3.2 \mu\text{m}$) and, albeit with some variability, does not change significantly between successive chambers (Figure 5.5c).

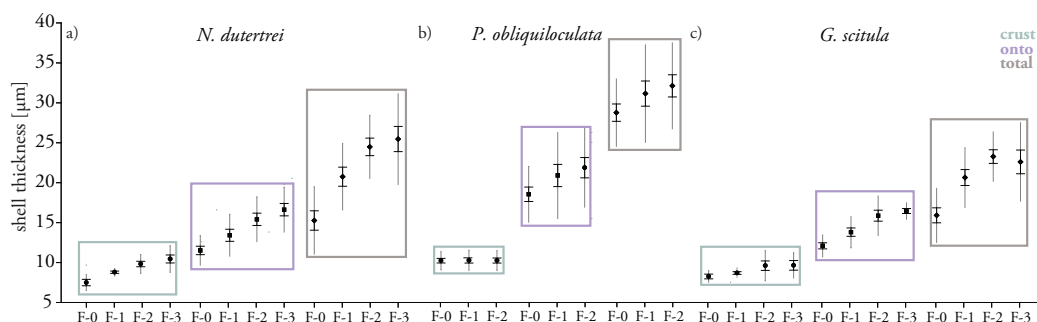


Fig. 5.5: Wall thickness of several chambers of a) *N. dutertrei*, b) *P. obliquiloculata* and c) *G. scitula*. Average shell thickness of crust, lamellar and total shell calcite are indicated by circles. Error bars indicate standard error, extended grey lines show standard deviations (D, 1 sigma).

5.3.2 Crust, cortex and lamellar Mg/Ca

Combined analysis on the same specimen show that low Mg/Ca ratios from LA-ICP-MS analyses correlate well with visually identified crust for *N. dutertrei* and *G. scitula* and cortex for *P. obliquiloculata* morphology in all three species (Figs. 5.6a-f). This correlation is confirmed by Electron Microprobe element maps of cross sectioned shells (Fig. 5.7) clearly showing lower Mg/Ca ratios in that part of the outer wall corresponding to the cortex. The difference in Mg/Ca between the outer crust/cortex and the inner lamellar calcite hence allows

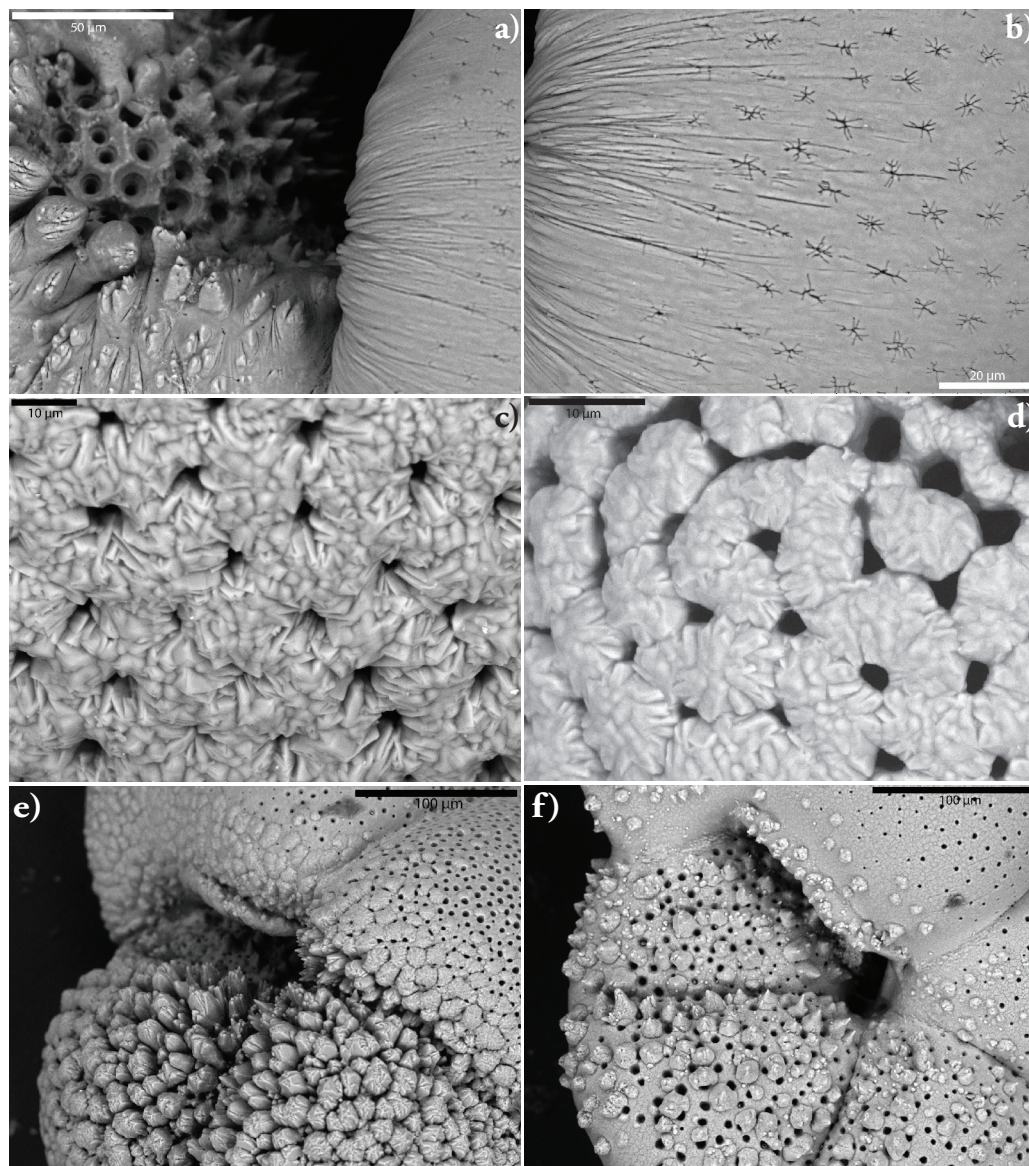


Fig. 5.6: Crustal features of a-b) *P. obliquiloculata*, SEM image showing details of the aperture. Visible stream marks (striae), emerging from the aperture, imprinted on the cortex. Markedly smaller pore openings (fissure-like) due to cortex cover. c-d) *N. dutertrei* with euhedral crystals. e-f) *G. scitula* crust crystals and pustules, which are isolated ornamentations on otherwise relatively smooth lamellar calcite.

determining absence/presence of crusts and/or cortex and when present, its thickness (Figs. 5.7a-c). Accordingly, we identified low Mg/Ca crusts in 60% (N= 164) of the chambers in the final whorl of *G. scitula*, 70% (N= 335) in those of *N. dutertrei* and up to 93% (N= 109) in the cortex of *P. obliquiloculata* chambers. On average, the Mg/Ca of the lamellar calcite

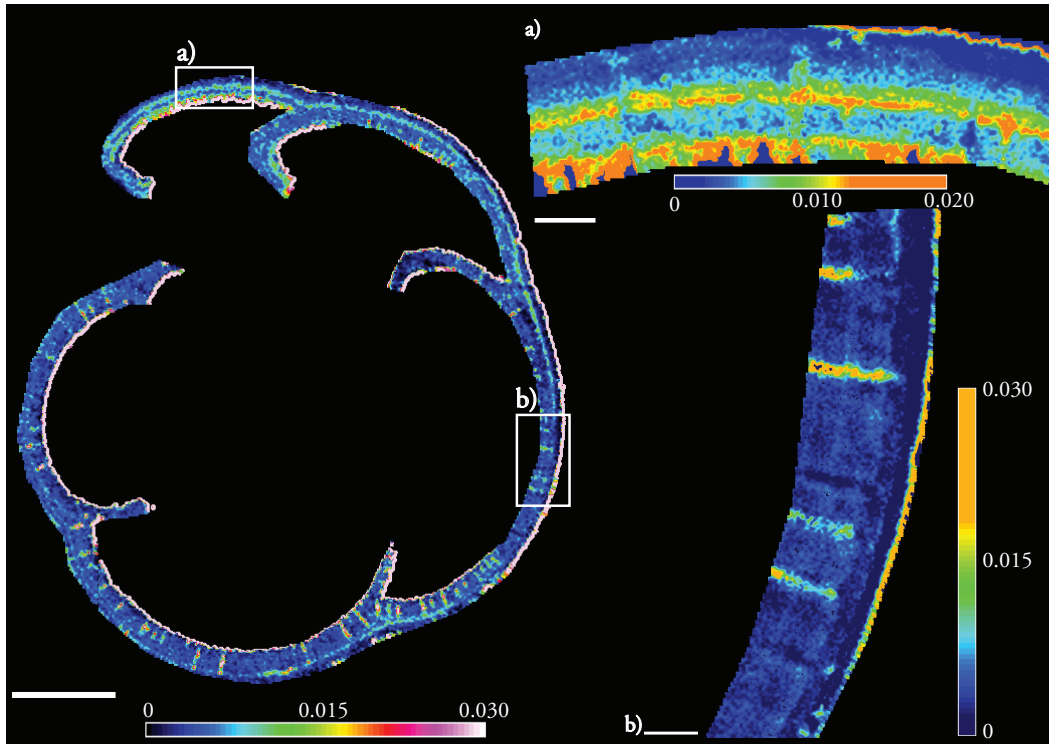


Fig. 5.7: Mg/Ca (count ratios) distributions for a selected specimen of an encrusted *P. obliquiloculata* specimen. a) Mg/Ca distribution map close-up of the F-0 chamber in high resolution (see 2.4 for method description) b) Mg/Ca distribution map close-up of the F-2 chamber in high resolution (see 2.4 for method description). High Mg/Ca values at the edges and near pores are caused by irregularities at the shell-resin interface, the so called edge effect (Sadekov et al., 2005, Pena, 2005, and Fehrenbacher and Martin 2010, 2014)

was similar between specimens with and without a crust (Figs. 5.8a). However, the Mg/Ca of the crusts is considerably lower than that of the lamellar calcite for all three species (Figure 5.8b). In *N. dutertrei*, average crust Mg/Ca was 1.83 ± 0.79 mmol/mol ($N = 223$, SE: ± 0.05 mmol/mol), which was significantly lower (Mann–Whitney test, $p < 0.001$) than Mg/Ca for the lamellar calcite (3.22 ± 0.99 mmol/mol; $N = 344$, SE: ± 0.06 mmol/mol) (Figure 5.8b). For *P. obliquiloculata* cortex Mg/Ca values are on average 1.17 ± 0.41 mmol/mol ($N = 107$, SE: ± 0.04 mmol/mol), compared to 2.86 ± 0.81 mmol/mol for the lamellar calcite ($N = 113$, SE: ± 0.08 mmol/mol), a significant difference according to the Mann-Whitney test ($p < 0.001$). The Mann-Whitney test is a nonparametric test of the null hypothesis that compares two unpaired groups from the same population, with a particular population tending to have larger values than the other (e.g. Mann and Whitney, 1947; Ramsey, 2000). Crust Mg/Ca values for *G. scitula* are on average 0.93 ± 0.35 mmol/mol ($N = 97$, SE: ± 0.04 mmol/mol), which is significantly lower (Mann-Whitney test, $p = 0.006$) than in the lamellar calcite (1.60 ± 0.45 mmol/mol, $N = 164$, SE: ± 0.04 mmol/mol).

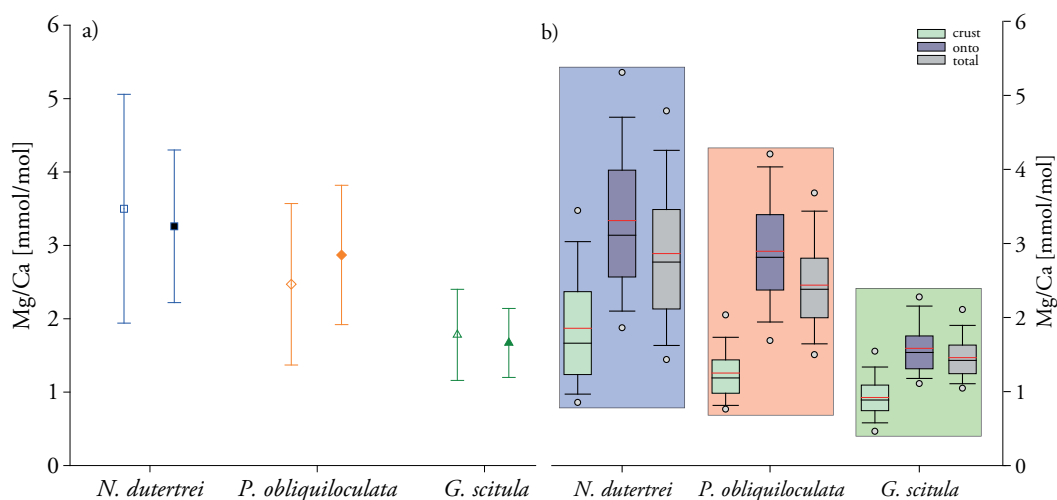


Fig. 5.8: a) Comparison of lamellar calcite of encrusted and non-encrusted specimens of *N. dutertrei*, *P. obliquiloculata* and *G. scitula*. Open symbols indicate non-encrusted specimens, filled symbols encrusted specimens. b) box-plot of average crust, lamellar and whole shell wall Mg/Ca for *G. scitula*, *P. obliquiloculata* and *N. dutertrei*. In addition, the graph shows mean (red line) whereas the open circles indicate the 5th and 95th percentile. The Standard percentile method uses linear interpolation to determine the percentile values. The 50th percentile (median) is indicated with the black lines within the boxes. The open boxes are used to graphically show overall differences between species.

No significant variation in average Mg/Ca between successive chambers is detected in the cortex of *P. obliquiloculata* and crust of *G. scitula* (Fig. 5.9), nor in the lamellar calcite of *G. scitula*. However, Mg/Ca of the lamellar calcite of *P. obliquiloculata* does show significant differences between chambers (One way Anova, $p=0.018$), i.e. between the final (F-0) and penultimate (F-1) chamber (pairwise multiple comparison Holm-Sidak method following the one way ANOVA, $p=0.047$) and also between F-0 and the pre-penultimate (F-2) chamber ($p=0.033$). Similarly, in *N. dutertrei* we observed a significant difference between the Mg/Ca of the crust in F-0 (Mg/Ca: 2.48 ± 0.79 mmol/mol, SE: ± 0.12 mmol/mol) and F-1 (Mg/Ca: 1.87 ± 0.76 mmol/mol, SE: ± 0.08 mmol/mol) (Fig. 5.9; Mann-Whitney test, $p < 0.001$) and also between crust calcite in F-1 and F-2 (Mg/Ca: 1.51 ± 0.62 mmol/mol, SE: ± 0.07 mmol/mol) (Mann-Whitney test, $p=0.009$). Differences between crust Mg/Ca values in F-2 and F-3 (1.54 ± 0.63 mmol/mol, SE: ± 0.15 mmol/mol) are not significant. Furthermore, lamellar Mg/Ca for *N. dutertrei* significantly differs between F-0 (Mg/Ca: 3.61 ± 1.10 mmol/mol, SE: ± 0.12 mmol/mol) and F-1 (Mg/Ca: 3.12 ± 0.91 mmol/mol, SE: ± 0.08 mmol/mol) and between the F-0 and F-2 chambers (Mann-Whitney test, $p < 0.001$).

5.4. Discussion

5.4.1. Constraints on crust and cortex formation based on Mg/Ca

In all species studied here, the element composition of crust and cortex calcite differs from that of the lamellar calcite, coinciding with morphological differences between the two types of calcite. In general, crust and cortex Mg/Ca are relatively low with minor variability within species, but varies significantly between species (One way ANOVA, $p < 0.001$). There are no significant changes in crust/cortex Mg/Ca between eddy and non-eddy intervals. Changes in crust/cortex and lamellar Mg/Ca are minor between eddy and non-eddy intervals and are negligible compared to differences in Mg/Ca between crust/cortex and lamellar calcite.

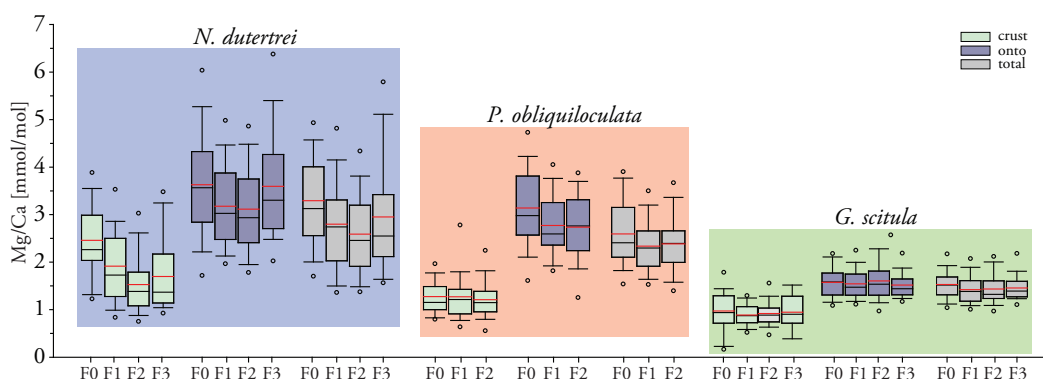


Fig. 5.9: Box-plot of intra-test variability of crust, lamellar and total shell wall Mg/Ca for *G. scitula*, *P. obliquiloculata* and *N. dutertrei*. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. In addition, the graph shows mean (red line) whereas the open circles indicate the 5th and 95th percentile. The Standard percentile method uses linear interpolation to determine the percentile values. The 50th percentile (median) is indicated with the black lines within the boxes. The open boxes are used to graphically show overall differences between species

The offset between crust and lamellar calcite Mg/Ca (Figs 5.2c and 5.8b) is in line with earlier studies showing lower values in crusts of *G. truncatulinoides* (Duckworth, 1977), *G. inflata* (Van Raden et al., 2011) and *N. dutertrei* (Eggins et al., 2003; Jonkers et al., 2012). These earlier studies related the low crust Mg/Ca primarily to terminal calcification in deeper and hence colder waters. Irrespectively, the observed strong partitioning against seawater Mg indicates that crust and cortex calcification is even more strongly biologically controlled than that of the lamellar calcite. This contrasts with the markedly higher Mg/Ca values of diagenetic calcite precipitated after burial in the sediment (Pena, 2005). Since the foraminiferal shells studied here are retrieved from sediment traps, no diagenetic crust is expected, nor did inorganic calcite precipitate on the shells while settling through the water column.

A pairwise multiple comparison using the Dunn's Method, testing for stochastic dominance and reports the results among multiple pairwise comparisons after a Kruskal-Wallis test for stochastic dominance among different groups (Kruskal and Wallis, 1952), showed that all three species differ significantly in crust/cortex Mg/Ca from each other. Of all species studied here, the crust of *N. dutertrei* has highest Mg/Ca values, whereas crust Mg/Ca values for *P. obliquiloculata* and *G. scitula* are relatively low. Higher crustal Mg/Ca values for *N. dutertrei* are in line with its overall shallower habitat compared to that of the other species investigated in this study. However, similar Mg/Ca values of the crust in *G. scitula* and cortex in *P. obliquiloculata* conflicts with their contrasting temperature-derived depth habitats (chapter 3). This difference in Mg/Ca despite precipitation at similar temperatures or depths, suggests that biological fractionation is overprinting the effect of depth-induced temperature decrease on crust/cortex chemistry. This implies that the difference in Mg/Ca between lamellar and crust/cortex calcite not solely depends on depth habitat-related temperature changes.

The largest difference in average Mg/Ca between crust and lamellar calcite is found in *P. obliquiloculata* ($\Delta\text{Mg/Ca} = 1.74 \pm 0.08$ mmol/mol), slightly less in *N. dutertrei* ($\Delta\text{Mg/Ca} = 1.64 \pm 0.08$ mmol/mol) and smallest in *G. scitula* ($\Delta\text{Mg/Ca} = 0.71 \pm 0.05$ mmol/mol). Translated into temperatures using species-specific calibrations (Anand et al., 2003), average lamellar calcite Mg/Ca values of *N. dutertrei* correspond to a temperature of 24.9°C, whereas its crust would reflect a temperature of 18.6°C. Likewise, *P. obliquiloculata*'s average lamellar Mg/Ca suggest a calcification temperature of 24.1°C, whereas its crustal Mg/Ca (Figure 5.8b) yields a temperature of 14.1°C, corresponding to depths around 60 m and 310 m in the Mozambique Channel, respectively. The integrated, average wall Mg/Ca (2.4 mmol/mol) translates into a temperature of 22°C, found at a depth of approximately 100 m. Average lamellar calcite Mg/Ca values of *G. scitula* correspond to a temperature of 15.2°C, whereas average crust Mg/Ca reflect a temperature of 9.1°C, indicating calcification at 250 and 620 m, respectively. Average wall Mg/Ca (1.48 mmol/mol) translates into a temperature of 14.3°C, at approximately 290 m depth. For all these species, Mg/Ca-temperature reconstructions suggests a substantial deepening in habitat between lamellar calcite and crust/cortex formation. However, this assumes that calibrations based on multiple, whole shells (Anand et al., 2003) can be applied to individual layers within the shell wall, which is highly unlikely given the observed offset between lamellar and crust/cortex Mg/Ca. There are (at least) two processes responsible for the Mg/Ca difference within and between species: a biomineralization control and a habitat-related component that modifies the overall Mg/Ca (and possibly, its within-shell heterogeneity).

Interestingly we observe a gradient in crust Mg/Ca values of successive chambers in *N. dutertrei* (Fig. 5.9), which is in line with earlier observations of Jonkers et al. (2012). This implies that

when crust formation is indeed triggered by temperature, as suggested earlier by Hemleben & Spindler (1983), crust formation continued when temperatures decreased further. A change in metabolic rate, related to temperature could also cause an overall shift in the mode of calcification and result in a different partitioning for Mg (Supplementary fig. 1). The Mg/Ca-derived temperature difference of the lamellar calcite between chamber F-0 and F-1 is 1.6°C, while Mg/Ca differences in their crust correspond to a temperature of 3.1°C. An integrated shell wall Mg/Ca average of 2.8 mmol/mol translates to a temperature of 23.3°C and a calcification depth of 75 m (Supplementary fig. 1). Increased Mg/Ca in the crust of *N. dutertrei* could either indicate an increasingly warmer habitat during crust formation or a larger relative contribution of a high-magnesium phase. For gametogenic calcite, a thin terminal veneer precipitated immediately prior to gametogenesis in spinose planktonic foraminifers, Nürnberg et al. (1996) showed significantly enhanced Mg/Ca with respect to the lamellar calcite of *G. sacculifer* growing in culture. Since culture temperature was kept constant (Nürnberg et al. 1996), Mg/Ca partitioning in gametogenic calcite must be related to something other than temperature. Similar to our findings for *N. dutertrei*, Jonkers et al. (2012) also show increasing crust Mg/Ca ratios towards the younger chambers, which is not in line with gradual habitat deepening alone. An increasing relative contribution of gametogenic calcite to the crust calcite could result in higher average Mg/Ca since the higher Mg concentrations in the gametogenic calcite increasingly affects the thinner crust towards the last chambers in *N. dutertrei*. However, gametogenic calcification only occurs last during ontogeny and ends the terminal stage, while crust formation in *N. dutertrei* appears a more prolonged process. Furthermore, as parent individuals do not survive gametogenesis (as observed in culture), crust/cortex cannot have formed after gametogenesis. Independent of the underlying mechanism, the observed gradient in crust Mg/Ca suggests that crust was sequentially added to the chambers during growth in *N. dutertrei*. This is in contrast to the two deeper dwelling species, which show similar Mg/Ca values for crust/cortex calcite in all chambers. Although this suggests similar depths for the entire crust/cortex of these two species, the relatively small temperature differences at larger depths might also obscure changes in depth habitat.

Inferred temperatures and calcification depths are only valid if Mg incorporation into crust/cortex and lamellar calcite follows the same temperature dependence within a species. However, microenvironmental controls related to foraminiferal physiology might result in disequilibrium fractionation (De Nooijer et al., 2014). Reduced metabolic activity could hence impact partitioning during the terminal (reproductive) stage as opposed to the adult (growth) stage of the planktonic foraminiferal life cycle. The biological controls on element incorporation and isotope fractionation causing offsets between species are often summarized

as ‘the vital effect’ (Urey et al., 1951; Weiner and Dove, 2003). These vital effects comprise 1) chemical alterations of the foraminiferal microenvironment by physiological processes, 2) cellular controls on the composition of the fluid from which calcite is precipitated and 3) biological controls on crystal growth (e.g. via organic templates). Since these ‘vital effects’ cause substantial species-specific offsets in Mg/Ca values (Anand et al., 2003; Bentov and Erez, 2006; Wit et al., 2012), they likely also produce a different, ontogenetic partitioning between lamellar and crust/cortex calcite, e.g. as observed for the gametogenic calcite of *G. sacculifer* in temperature controlled cultures (Nürnberg et al. 1996). Nevertheless, calcification depths derived from Mg/Ca-based temperatures yield reasonable habitat depths for *N. dutertrei* crust values compared to observations of *N. dutertrei* in stratified tows (e.g. Bouvier-Soumagnac and Duplessy, 1985; Sautter and Thunell, 1991; Ravelo and Fairbanks, 1992; Weijnert et al., 2013), potentially indicating similar Mg partitioning into the lamellar and crust calcite for this species. For *G. scitula* and *P. obliquiloculata* this is not clear when considering Mg/Ca only.

5.4.2. Constrains on crust and cortex formation from observed wall thickness

Foraminiferal chamber walls generally increase in thickness by continued addition of calcite on all chambers exposed in the last whorl each time a new chamber forms. Foraminiferal chamber construction starts by formation of a thin organic layer (primary organic sheet (POS); Banner et al., 1973; Hemleben et al., 1977; Hansen, 1999), followed by deposition of calcite on both sides of the POS of both the newly formed chamber and on the outer surface of all preceding chambers of the last whorl. This successively enveloping of existing chambers results in the lamellar microstructure of test walls also seen in the chambers of the last whorl of all three species studied here. Increasing wall thickness towards the older chambers is clearest and statistically most significant in *N. dutertrei* and accompanied by a thickening of added crust calcite. This suggests that terminal crust formation is an ongoing process with most calcite added to the “oldest” chambers exposed in the final whorl. This is in line with the gradient in crustal Mg/Ca of successive chambers in *N. dutertrei*.

Although successive chambers of *P. obliquiloculata* show a trend in wall thickness, this trend is not significant, or at least not enough to statistically resolve (see Tab. 5.1 for statistical results). Cortex thickness in *P. obliquiloculata* is surprisingly uniform on all chambers of its final whorl (Fig. 5.5b and 5.10, approximately $7.7 \pm 0.3 \mu\text{m}$), suggesting it is evenly added after the last chamber had formed. The simultaneous addition of cortex calcite over the entire shell is in line with its homogeneous Mg/Ca composition.

In line with its clear lamellar structure, *G. scitula* shows a statistically significant increase in wall thickness towards the older chambers in the final whorl (i.e. formed earlier). The crust calcite, although showing somewhat of a trend, is statistically uniform in thickness over the entire last whorl. As for *G. scitula* this is in line with the Mg/Ca data for the crust calcite of the different successive chambers. Not only thickness of the crust and/or cortex provides information on its formation, also differences in appearance and surface structure may reflect processes involved.

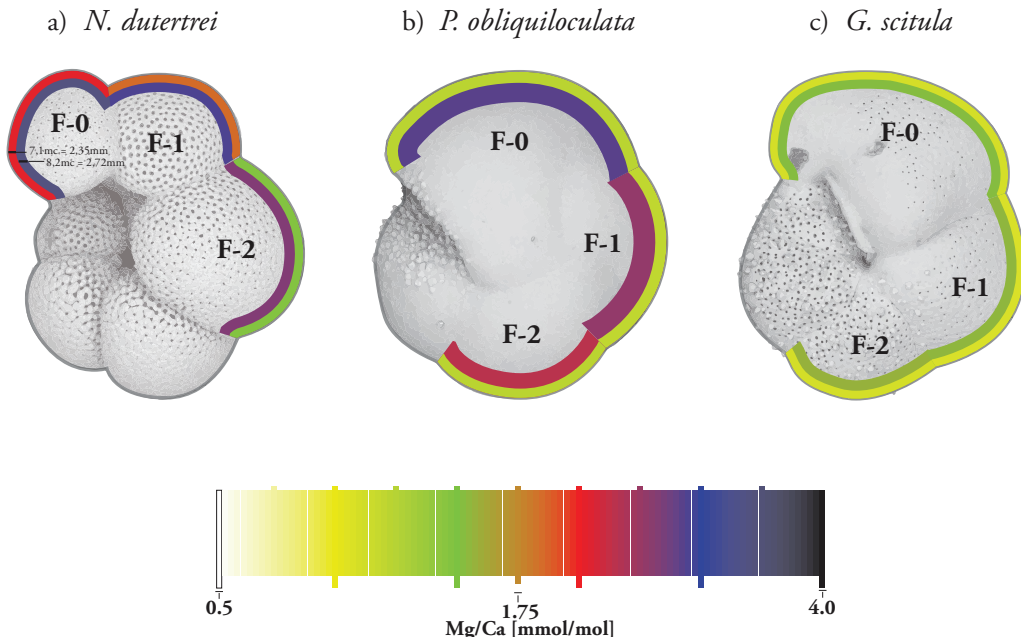


Fig. 5.10: Schematic illustration for intra- and inter-species crust and lamellar Mg/Ca values, as represented by color scale. Shell thickness, crust and lamellar calcite are shown in scale for a) *N. dutertrei*, b) *P. obliquiloculata* and c) *G. scitula*.

5.4.3 Constraints from morphology

Typical terminal features include crust and/or cortex formation (as here in *G. scitula*, *N. dutertrei* and *P. obliquiloculata*), gametogenic calcification, as well as the formation of a final diminutive (i.e. “kummerform”) chamber (or two of such chambers as observed here for *N. dutertrei*: Figs 5.10 and 5.11a) and/or a chamber of diagnostic shape (e.g. bulla, sphere, sack and ampulla). The addition of a terminal cortex drastically changes the appearance of adult specimens of *P. obliquiloculata*. Whereas adult specimens have a thin, perforate shell with a hispid appearance, cortex formation thickens its walls, obliterates its pores and smoothens the outer shell completely (Fig. 5.11b). Such drastic changes typically occur during late ontogeny of planktonic foraminifera, i.e. when adult shell growth stops and individuals enter the

Tab. 5.1: A Jonckheere-Terpstra test is a non-parametric test of analysis of variance performed in SPSS (Version 20.0 for Windows, SPSS Inc., Chicago) to test for significant trends in Mg/Ca and shell wall thickness (Lunneborg, 2005). Results of this test for intra-species trends in Mg/Ca and shell wall thicknesses reveal significant correlations at the 0.005 level (2-tailed) and significant correlations at the 0.001 level (2-tailed), indicated by a ‘*’ and ‘**’, respectively.

species	Mg/Ca		
	crust/cortex	onto	average
<i>N. dutertrei</i>	p (2-tailed): 0.000, r (Pearson): -0.423**	p (2-tailed): 0.001, r (Pearson): -0.188**	p (2-tailed): 0.000, r (Pearson): -0.262**
<i>P. obliquiloculata</i>	p (2-tailed): 0.462	p (2-tailed): 0.013, r (Pearson): -0.221*	p (2-tailed): 0.137
<i>G. scitula</i>	p (2-tailed): 0.971	p (2-tailed): 0.745	p (2-tailed): 0.122
shell wall thickness			
	crust/cortex	onto	average
<i>N. dutertrei</i>	p (2-tailed): 0.003, r (Pearson): 0.475**	p (2-tailed): 0.000, r (Pearson): 0.543**	p (2-tailed): 0.000, r (Pearson): 0.726**
<i>P. obliquiloculata</i>	p (2-tailed): 0.692	p (2-tailed): 0.054, r (Pearson): 0.278	p (2-tailed): 0.650
<i>G. scitula</i>	p (2-tailed): 0.042, r (Pearson): 0.300*	p (2-tailed): 0.000, r (Pearson): 0.453**	p (2-tailed): 0.000, r (Pearson): 0.587**

Jonckheere-Terpstra test

* correlation is significant at the 0.005 level (2-tailed)

** correlation is significant at the 0.001 level (2-tailed)

terminal stage of ontogeny in preparation for reproduction (Brummer et al., 1986, 1987; Hemleben et al., 1989). The terminal stage is the last in a succession of five such ontogenetic stages that are recognized in planktonic foraminifera. All stages are marked by sudden transitions in shell morphology linked to changes in Svital behaviour, such as the change-over from an herbivorous to carnivorous diet in spinose species (Brummer et al., 1987). Terminal stages mark the transition from growth to reproduction, including the deposition of an additional layer of gametogenic calcite immediately prior to gametogenesis in various spinose species (Hemleben et al., 1989). Burt and Scott (1975) describe an ontogenetic change in *P. obliquiloculata* from a globigerine (juvenile) architecture during early ontogeny to a pulleniatine (adult) architecture later in ontogeny. Changes in shell morphological appearance thus define important transitions in life cycle.

Exemplary, *N. dutertrei* analyzed here have six chambers in its final whorl (Fig. 5.11a), four of which typically result from adult growth (F-5 to F-2), i.e. are “normalform” chambers that increase exponentially in size. By contrast, the final two chambers are both diminutive

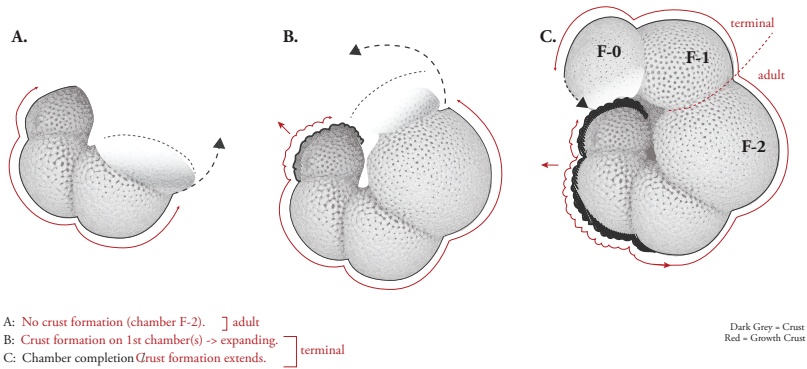
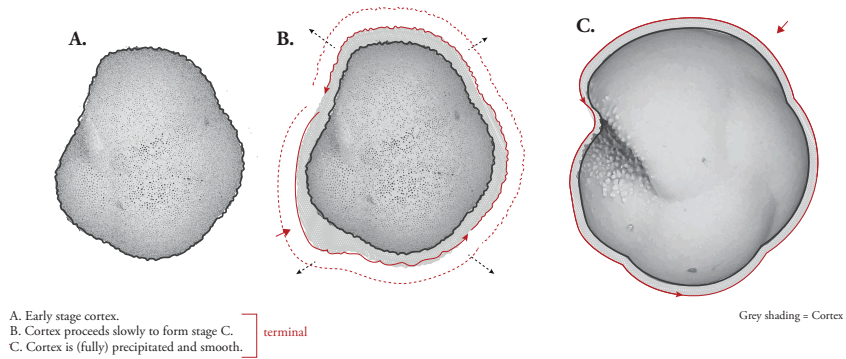
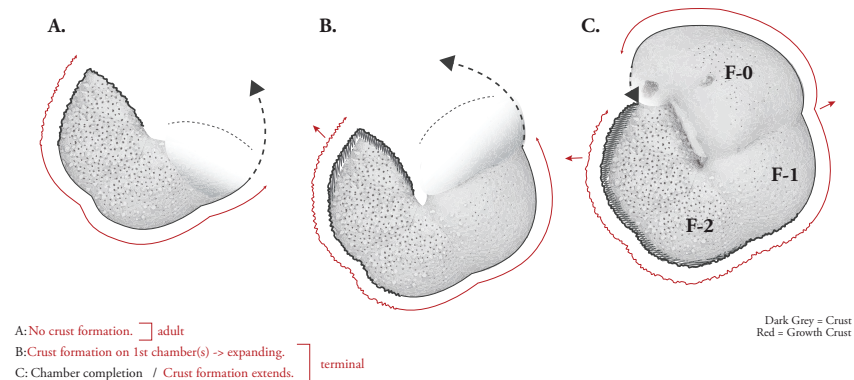
a) *N. dutertrei*b) *P. obliquiloculata*c) *G. scitula*

Fig. 5.11: Schematic illustration of formation processes of crust in *N. dutertrei* (a), cortex in *P. obliquiloculata* (b) and crust in *G. scitula* (c). In *N. dutertrei*, crust starts to form in the terminal stage with the onset of chamber F-1 calcification. Crust formation in *G. scitula* takes place during or after the formation of the final chamber (F-0).

(“kummerform”), i.e. are smaller than adult logarithmic shell growth predicts. The last two chambers probably result from terminal stage calcification that also produced the crust. Based on the gradual thinning of the crust after the F-1 chamber this observation is in line with crust formation starting after adult F-2, i.e. together with the calcification of the first kummerform chamber. Since there are clear differences in crust Mg/Ca between the subsequent chambers (Fig. 5.9), the earliest crustal layer on e.g. F-5 may well be deposited during calcification of the first kummerform chamber (F-1, with its aperture on F-5). Subsequently, the first crust on F-4 is deposited when the second kummerform chamber was produced (F-0) and also covered the preceding chambers, similar to lamellar calcification, and thus produced the gradients we observe in both Mg/Ca and wall thickness towards the final chamber. Potentially crust formation may have continued much longer without addition of any additional new chamber, until gametogenesis concludes the life of the parent *N. dutertrei*.

Crust thickness in *N. dutertrei* appears to decrease towards the aperture and the sutures between chambers (Fig. 5.4a-b), i.e. where the cytoplasm exits the shell. Hence, the micro-environment around the cytoplasm, which is influenced by active and passive element transport (Bentov and Erez, 2006; De Nooijer et al., 2014) may play a role in precipitation of crust and its distribution. Similarly, in various specimens of *P. obliquiloculata* we found incisions into the cortex that diverge from the aperture (Figure 5.6a-b), which reflect the presence of pseudopodia during cortex formation, indicating that the specimen is alive and active while the cortex is precipitated, consistent with both its Mg/Ca value and its cortex thickness. As observed for *P. obliquiloculata* (Fig. 5.11) the final whorl consists of 5 chambers, all of which are normal-form pulleniatine (i.e. adult-terminal streptospiral coiling); both specimens in Fig. 5.11 are terminal stages given their cortex (early stage in Fig. 5.11a, fully developed in Fig. 5.11b). Apparently a cortex also differs from a crust in being precipitated equally over the entire outer shell instead of being concentrated on the earlier chambers and away from the aperture and sutures. Also, the cortex appears rather smooth over the entire shell in *P. obliquiloculata* (as in the spinose taxon *Sphaeroidinella dehiscens*) while the crust of *N. dutertrei* and *G. scitula* becomes increasingly more coarse crystalline towards the earliest chamber in the final whorl, suggesting that crusts on the “oldest” chamber form over a longer time span.

Pore diameters in *P. obliquiloculata* are drastically reduced by the formation of a cortex, changing their wide circular profile to narrow radiating fissures (Burt et al., 1971) (Fig. 5.6b). Decreased porosity typically results from crust formation as well, as observed for both *G. scitula* and, to a lesser degree, *N. dutertrei*. Although the actual function of pores yet remains to be clarified, pores are characteristically abundant in living adult stages (Be, 1976), suggesting

that a terminal reduction in porosity marks a change-over to a lower metabolic level that may have changed Mg/Ca partitioning during crust and cortex formation. Such a lower metabolic level may be caused by lower temperatures at greater depth. Hemleben et al. (1985) observed that crusts started form when freshly collected specimens of *G. truncatulinoides* were exposed to culture temperatures below 14 - 8°C.

For *G. scitula* as in Fig. 5.11, we observed just over four chambers in its final whorl, which all seem normal-form adult-terminal. Being of similar thickness over the entire shell, crust formation would have started together with, or after the calcification of F-0 and may have continued/extended to other chambers later, potentially in wait for reproduction. This suggests that the crust or cortex might be somehow involved in protection, as calcite shells are generally thought to have originated as protective armors against predation that evolved during the Cambrian radiation (Brenckston, 1994). While no larger organisms are known that prey specifically on planktonic foraminifera, calcified shells do protect against viral or bacterial infections. Similarly, reduced pore diameters would help to safeguard the organism. Analogous to coccolithophorids this potentially might play a major role in governing mortality in populations of planktonic foraminifera. Emiliani (1993) named viral infections as one of the possible causes for foraminiferal extinctions.

In four specimens of *N. dutertrei*, we observed patches of crust inside the chamber wall (Fig. 5.12). The fact that crust calcite also forms on the inside of the shell and seems to start precipitating around the pores makes a biological control likely. Albeit resulting in much thinner and patchier coverage, crust formation on the shell inside is in line with an internalized mode of crust and cortex formation that is consistent with the bilamellar biomineralization of planktonic foraminifera. Investigating the internal variability in chemistry within foraminiferal shell walls Eggins et al. (2003) showed that the internal layering is symmetrical with respect to the POS. The layers formed towards the outside from the POS are, however, much thicker than the layers on the inside. Apparently this pattern is not restricted to the lamellar calcification only, but continues also during crust formation.

5.4.4. Interspecific differences in cortex and crust formation

5.4.4.1 *N. dutertrei*

The Mg/Ca data from crust and lamellar calcite, the decreasing crust thickness towards the final chamber and the overall appearance with larger crystals being deposited towards the aperture, suggest that crust formation in *N. dutertrei* proceeds sequentially. This would result in a gradual formation of the crust, starting before the last “kummerform” chambers are formed

(Fig. 5.11a). This hypothesis explains the thicker crust on earlier chambers, as these chambers are the exposed longest to accretion of crust calcite. Continued sequential addition of crust calcite also explains the observed gradients in crust Mg/Ca as these layers not necessarily formed at the same time. Differences in either temperature or related to vital effects therefore would cause offsets between the crust calcite added to the different chambers. The observed difference in crust Mg/Ca could hence potentially be related to the migration pattern of this foraminifera during the last phases of its life cycle.

5.4.4.2 *P. obliquiloculata*

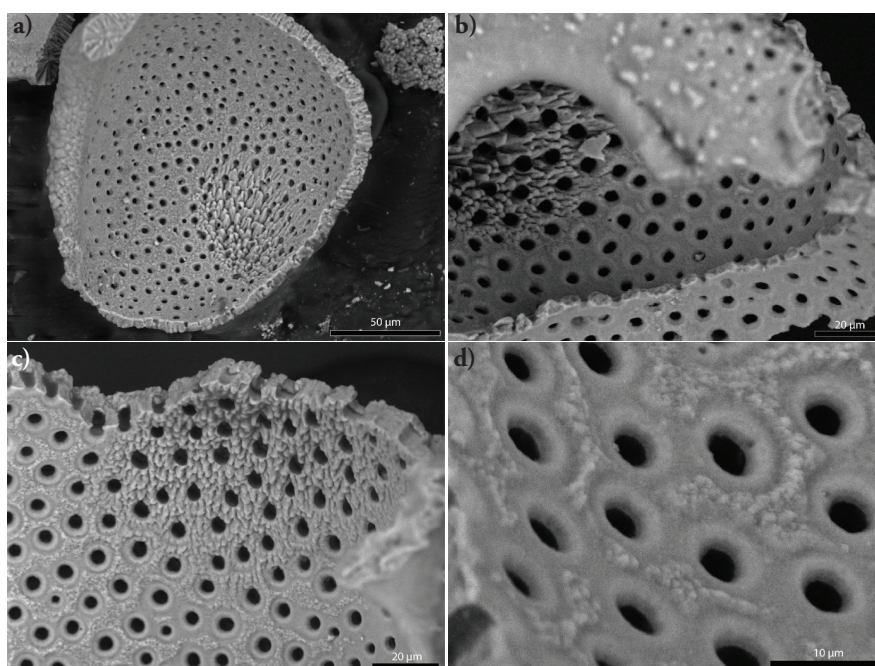


Fig. 5.12: SEM images of *N. dutertrei*, exemplifying patchy crust-like features on the inner surface of the chamber wall as observed in four different specimens. Note that these crust-like features clearly are elevated above the surrounding shell surface (particularly panels C and D), whereas dissolution features would result in depressions of the shell surface.

In contrast to *N. dutertrei* and *G. scitula*, *P. obliquiloculata* shows no size-related trend in cortex Mg/Ca or in cortex thickness (see Tab. 5.1 for statistical results). It is therefore likely that the cortex formed under similar conditions and within a similar time frame. Since the last chamber is also covered by the cortex, it must have formed after the last chamber was added, via biologically controlled precipitation (Fig. 5.11b) judging from the cytoplasmatic striae on its outer surface near the aperture (Fig. 5.6a-b). The low Mg/Ca ratios of the cortex could

reflect both lower temperatures during its formation and/or enhanced partitioning against Mg during the terminal stage. A slower metabolic rate during the late stages of a foraminiferal life cycle (Hemleben, 1989) might reduce active Ca-ion transport into the cell, which would also lower leakage of ions such as Mg (Nehrke et al., 2013). This would thereby result in slow growth of the cortex and a low Mg/Ca. In some cases we observe small variations in Mg/Ca within the cortex (Fig. 5.13), which may thus indicate a modest depth migration of the species during the formation of the cortex or slight changes in metabolic activity. Either way such internal variability suggests that cortex formation is a prolonged process rather than an instantaneous event, which is in line with the observed imprints of a (locally dense) pseudopodial network.

Pulleniatina obliquiloculata has been suggested to have an annual production cycle (e.g. Jonkers et al., 2014; Salmon et al., 2015), with a terminal cortex possibly forming over months and reflecting a deep inactive (diapausing) stage between reproductive peaks. For example, Hemleben et al. (1985) showed crust formation for *G. truncatulinoides* in a culture study and although no exact timing was indicated this involved a few weeks at most. The limited time involved with crust formation implies that alternatively a terminal crust or cortex could have formed relatively fast (days to weeks) at the beginning of a resting stage. Resting stages have been reported for phytoplankton (i.g. dinoflagellates) and zooplankton taxa such as rotifers, tintinids, cnidarians and copepods (Paranjape, 1980; Dale, 1983; Snell et al., 1983; Boero et al., 1992; Marcus, 1996). Entering a dormant stage has been associated with countering adverse/unfavorable environmental conditions (e.g. Marcus, 1980, 1984; Elgmork et al., 1990), may occur seasonally (hibernation), and protect from predation (e.g. Hairston and Olds, 1984). Here we hypothesize that some planktonic foraminiferal species may also have a dormant stage, which in the case of *P. obliquiloculata* is reflected by the cortex layer.

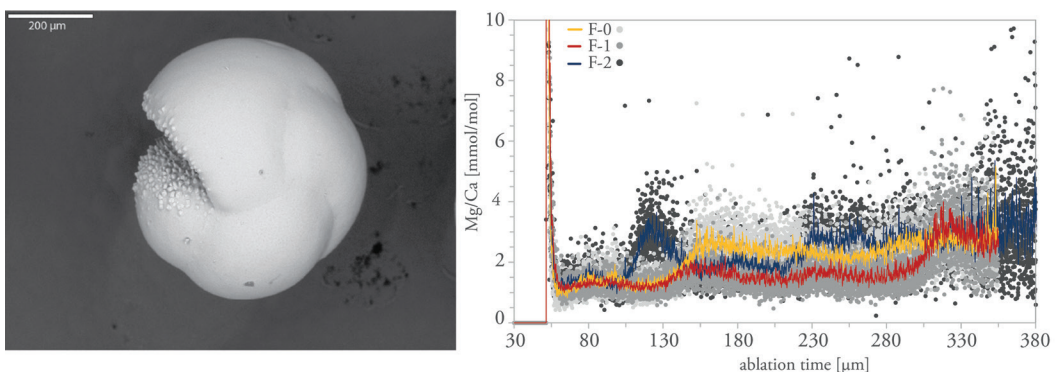


Fig. 5.13: Scanning electron microscope (SEM) images of *P. obliquiloculata*. On the right the LA-ICP-MS raw (greyish points) and 9-point running average (colored dots) Mg/Ca profiles of several chambers from the same specimens. Note the Mg/Ca variability within the low Mg/Ca part of the cortex.

5.4.4.3 *G. scitula*

Crust thickness decreases slightly towards the younger chambers in *G. scitula* (Jonckheere-Terpstra test, $p=0.04$), similar to but less so than in *N. dutertrei*. In line with *P. obliquiloculata* the lack of differences in Mg/Ca and minor change in crust thickness suggest a more or less synchronous crust deposition over the entire shell. Still, in contrast to *P. obliquiloculata* we recognize pustule-like structures near the aperture (Fig. 5.6d). Crust formation in *G. scitula* therefore seems to be related to that of both *N. dutertrei* and *P. obliquiloculata* (Fig. 5.11c). Given the deep habitat of *G. scitula*, changes in calcification depth during crust formation would only cause little temperature-induced variability in crust Mg/Ca. Alternatively, depth migration by *G. scitula* may have been limited during its late ontogenetic stage. In fact the only differences observed in Mg/Ca of *G. scitula* are between crust and lamellar calcite in all four chambers. Consequently, the only depth migration that may have occurred, should have occurred right between the end of lamellar calcification and the start of crust formation in order to explain the contrast in crust and lamellar Mg/Ca. In our opinion it is highly unlikely that there would have been a kind of pausing during which no shell growth nor encrustation occurs, while the specimen settles down a few hundred meters, and subsequently resuming with encrustation.

5.4.5 Implications- Effects of crust on paleo-reconstructions

Patterns in crust and cortex thickness as well as composition suggest that these test features may have formed over a prolonged time period and, at least for *P. obliquiloculata*, may reflect a deep resting stage. Resting stages might be a common feature in the life cycle of planktonic foraminifera in species that only show a single, sharp peak in abundance during the year. Such species include *P. obliquiloculata*, *G. scitula*, *G. truncatulinoides*, *G. hirsuta* and *G. tumida* (e.g. Deuser, 1986; Mohtadi et al., 2009; Salmon et al., 2015) which are typically encrusted and only bloom in winter when surface temperatures are relatively low and the water column is deeply mixed. In between two annual peaks, a very small population persists judging from observed trace shell fluxes (Wilke et al., 2009), and it is such a persistent population that will reproductively generate peak fluxes the next year. In high latitude settings, the trace fluxes in winter regard survivors from the previous summer maximum, given their stable isotope signature (Jonkers et al. 2010). Virtually no living planktonic foraminifera are found below 1000 m (Vincent & Berger, 1981) and there are no confirmed reports of living (or resting) planktonic foraminifera on the sea floor (Kucera, 2007). Although some benthic species exhibit a complex life cycle including an array of reproductive strategies (e.g. Alve et al., 2003; Goldstein, 2003), planktonic species are only known to reproduce sexually (see Hemleben et al., 1989). To increase reproduction chances, gamete release by different specimens from the

same species may be synchronized in space and time. Wilke et al. (2009) used plankton net and sediment traps to show that *P. obliquiloculata* abounds in the surface mixed layer during winter, while absent or in trace abundances in or below the surface mixed layer during other seasons. For *G. truncatulinoides*, Lončarić et al. (2006) found a similar winter maximum throughout the upper 150 m, contrasting with low summer concentrations below the surface mixed layer. Whether sharp peaks in abundance during winter represent an annual reproduction cycle or a short period of rapid overturning in multiple generations yet remains to be determined (Lončarić et al., 2006). Still, the specimens releasing gametes ultimately growing into the next generation have to be present throughout the year. A resting stage of *P. obliquiloculata* would mechanistically link life cycle and a single annual reproductive pulse.

The difference in composition of crust and lamellar calcite also potentially affects the application of Mg/Ca as temperature proxy, if applied on whole single shells. In specimens of *N. dutertrei*, crust Mg/Ca can be 10–20% lower than that of the lamellar calcite. In *P. obliquiloculata* and *G. scitula*, Mg/Ca of the crust is approximately 13–18% and 3–11% lower, respectively. Due to variability in crust thickness, the contribution of the crust to the total specimen's Mg/Ca is also variable between species and to a lesser extent, within species. In *N. dutertrei* we find a gradual decrease of crust Mg/Ca contribution onto the average Mg/Ca composition, while the crust contributes on average 46% to its total wall thickness. In *P. obliquiloculata* we find that the average Mg/Ca composition of the F-2 chamber is slightly less affected (13.1%) than the F-1 and F-0 chamber (17.2 and 17.8%, respectively), while its cortex makes up an average 32% of the total wall thickness. Interestingly, the average Mg/Ca composition of the F-2 chamber in *G. scitula* is most affected by its crust (11.4% lower than lamellar calcite) and lowest for F-3 (2.9%). On average, the crust in *G. scitula* contributes 47% to the total wall thickness. Mg/Ca-temperatures can be biased by varying thicknesses of low Mg/Ca crust and/or cortex contributions to the whole shell Mg/Ca. Applying a simple mass balance, with changing crust contributions we can assess changes to the total shell composition and its implications on Mg/Ca temperature reconstructions.

Previous studies have shown that shell thickness can vary on glacial/interglacial time scales and between ocean basins (e.g. Barker and Elderfield, 2002; De Moel et al., 2009). Assuming a crust contribution of 50% to the total wall thickness in *N. dutertrei*, average crustal Mg/Ca (Fig. 5.8b) temperatures are estimated to be 22.2°C. If the crust makes up 75% of the wall, Mg/Ca-based temperature would decrease by about 3.5°C; if the crust however only contributes 25%, Mg/Ca-based temperatures would increase by 1°C. In *P. obliquiloculata*, a cortex contribution of just 25% to the total wall thickness affects Mg/Ca-based temperatures more so than in *N.*

dutertrei, as a 25% cortex contribution would result in a 2.1°C higher temperature estimate compared to a 50% cortex contribution (20.2°C). A 75% cortex contribution has an equally strong effect, decreasing Mg/Ca-temperature by approximately 2.6°C. In *G. scitula*, low Mg/Ca crust affects average wall Mg/Ca less than in *P. obliquiloculata*. Temperature estimates decrease by about 1.3°C for every 25% of crust calcite added. Hence, varying contributions of crust and/or cortex calcite may introduce significant scatter on whole wall Mg/Ca based temperature reconstructions of single specimens.

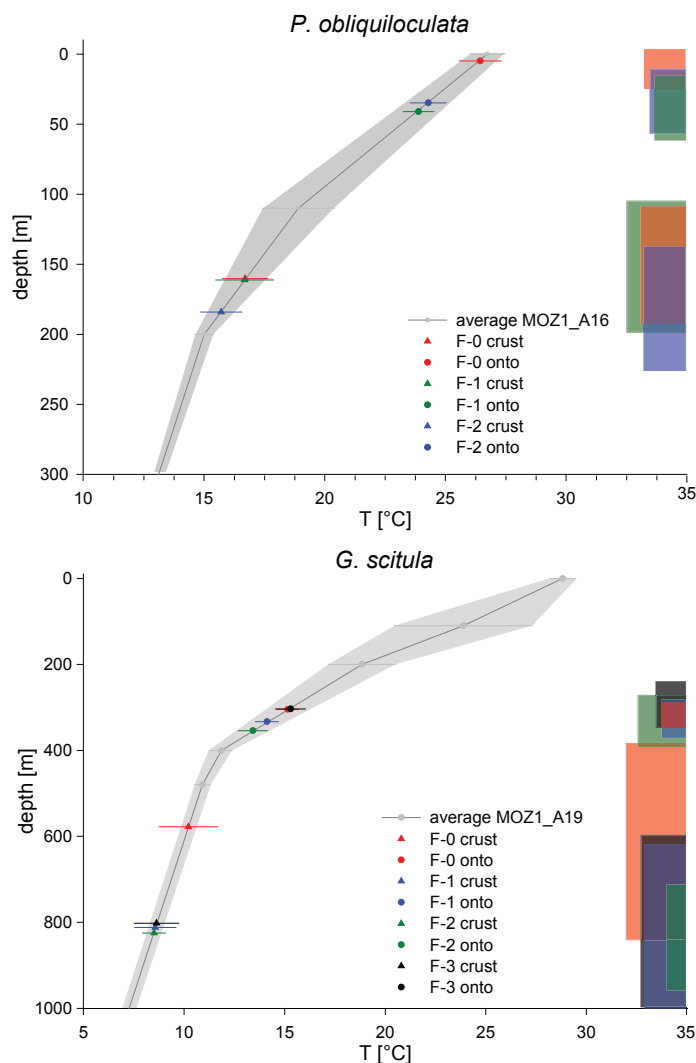
5.5. Conclusion

We analyzed crust/cortex Mg/Ca with LA-ICP-MS and measured crust/cortex as well as total wall thicknesses on three species of planktonic foraminifera (*N. dutertrei*, *P. obliquiloculata* and *G. scitula*) from sediment trap samples. All species analyzed have a lower crust/cortex Mg/Ca than their lamellar calcite. Additionally, crust/cortex Mg/Ca differs between species. Only *N. dutertrei* shows increasing crust Mg/Ca values towards its last chambers. Using crust/cortex Mg/Ca and wall thicknesses, we constructed a conceptual model for all three species to reconstruct growth pattern and crust/cortex formation. The results suggest different processes for crust and cortex formation. *N. dutertrei* and to a lesser degree potentially also *G. scitula*, seem to precipitate crust gradually while still adding chambers, leading to a thinning of the crust towards the younger chambers. The trend in crust Mg/Ca, found in *N. dutertrei* is likely caused by migration during the later stages of its life. For *P. obliquiloculata*, slow precipitation of cortex after the last chamber has been formed is more likely.

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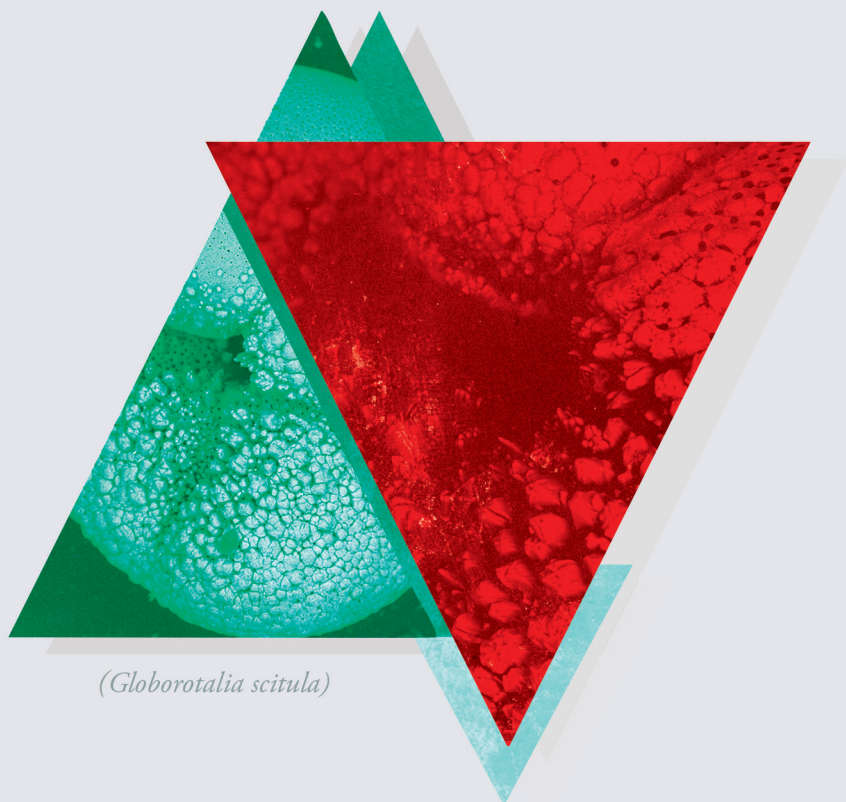
Supplements



Supplementary fig. 1: Calculated calcification depth for *P. obliquiloculata* and *G. scitula*, using crust, ontogenetic and average shell Mg/Ca concentrations from one specific sediment interval, MOZ4 A16 and MOZ4 A19 respectively. Species specific calibrations from Anand et al., 2003 were used to calculate calcification temperatures [*P. obliquiloculata*: $\text{Mg/Ca} = 0.328 \cdot \exp^{(0.09 \cdot T)}$; *G. scitula* using the calibration for *G. hirsuta*: $\text{Mg/Ca} = 0.409 \cdot \exp^{(0.09 \cdot T)}$]. Squares indicate calculated calcification depth, based on average crust, onto and total Mg/Ca for the different chambers.

Supplementary tab.1. Sediment trap samples and number of specimens collected for analyses.

sediment trap cup	condition	time interval	<i>N. duertrei</i> specimen	<i>P. obliquiloculata</i> specimen	<i>G. scitula</i> specimen
MOZ1_A07	non-eddy	28.March - 17.April.2004	25	N.A.	7
MOZ1_A08	eddy	18.April – 08.May.2004	3	N.A.	7
MOZ2_A11	eddy	25.October.- 16.November.2005	27	11	10
MOZ2_A12	non-eddy	17.November - 9.December.2005	20	6	4
MOZ1_A16	non-eddy	3. - 23. October.2004	15	12	14
MOZ1_A19	non-eddy	5. - 25.December.2004	N.A.	N.A.	2
MOZ3_A20	eddy	12.June - 4.July.2007	3	3	3
MOZ4_A01	eddy	1.-17.February.2008	21	N.A.	4
MOZ4_A06	non-eddy	26.April-12.May.2008	21	7	17



(Globorotalia scitula)

Chapter 6

Synthese and perspectives

Chapter 6

Synthesis and perspectives

Juliane Steinhardt

6. Synthesis and perspectives

Ocean circulation is generally considered as one of the main players in the climate system. How certain ocean current systems have varied over time has a profound impact on climate and also the future climate is expected to be strongly affected by changes in ocean circulation. Specific parts of the global ocean circulation have been suggested to play a key role for global climate and the Agulhas current is one of those. The Agulhas current is fuelled, amongst others, by eddies originating from the Mozambique Channel. Within this thesis, several attempts are made to develop and calibrate potential proxies for the occurrence and intensity of eddies passing through Mozambique Channel. These eddy proxies are based on differences in the geochemical composition of foraminiferal shells from sediment traps, for which the link to eddy occurrence is known in real-time. As shown in chapter 2, other processes, such as seasonality, also impact the fluxes of different foraminiferal species during the year and hence the environmental conditions recorded in the chemistry of their shells. The reliability of the proxies suggested here, critically depends on the relative impact of the different processes on the annually integrated proxy signal and hence on the relative distribution of the different species throughout the year.

6.1. Robustness of the proxy signal

6.1.1. Potential Mg/Ca differences based on flux weighted averages

In order to test the potential application of the Mg/Ca eddy proxy (Chapter 3), annual shell flux data (Chapter 2) was combined with the mooring sea water temperatures and SST during MOZ4 of sediment trap samples that were centered on eddy and non-eddy intervals. In this way the average flux-weighted temperatures could be calculated for different species, taking into account their supposed depth migration (Fig. 6.1). By comparing the offset between the annual flux-weighted average to the flux-weighted averages for eddy and non-eddy periods, the robustness of the proxy signal can be assessed. This shows appreciable differences between the surface dwelling species *G. ruber* and the thermocline dwelling species *N. dutertrei* of 8.5°C during non-eddy conditions, compared to a reduced temperature offset of only 5.8° under eddy conditions. The temperature difference ($\Delta\Delta T$) between eddy and non-eddy conditions thus is estimated to be about 3.6°C (Fig. 6.1a). Furthermore, the potential ΔT during eddy conditions between *N. dutertrei* and the sub-surface dweller *G. scitula*, based on temperatures at 400 m, is 7.6°C under non-eddy condition and becomes greater under eddy condition (10.3°C). This results into an effective $\Delta\Delta T$ of 2.7°C (Fig. 6.1). Both these offsets are well within

the analytical resolution of Mg/Ca and $\delta^{18}\text{O}$ -based temperature reconstructions. The slightly larger offset between *G. ruber* and *N. dutertrei* and the smaller offset between *N. dutertrei* and *G. scitula* is likely to be caused by the temperatures at the assumed depth habitats. The

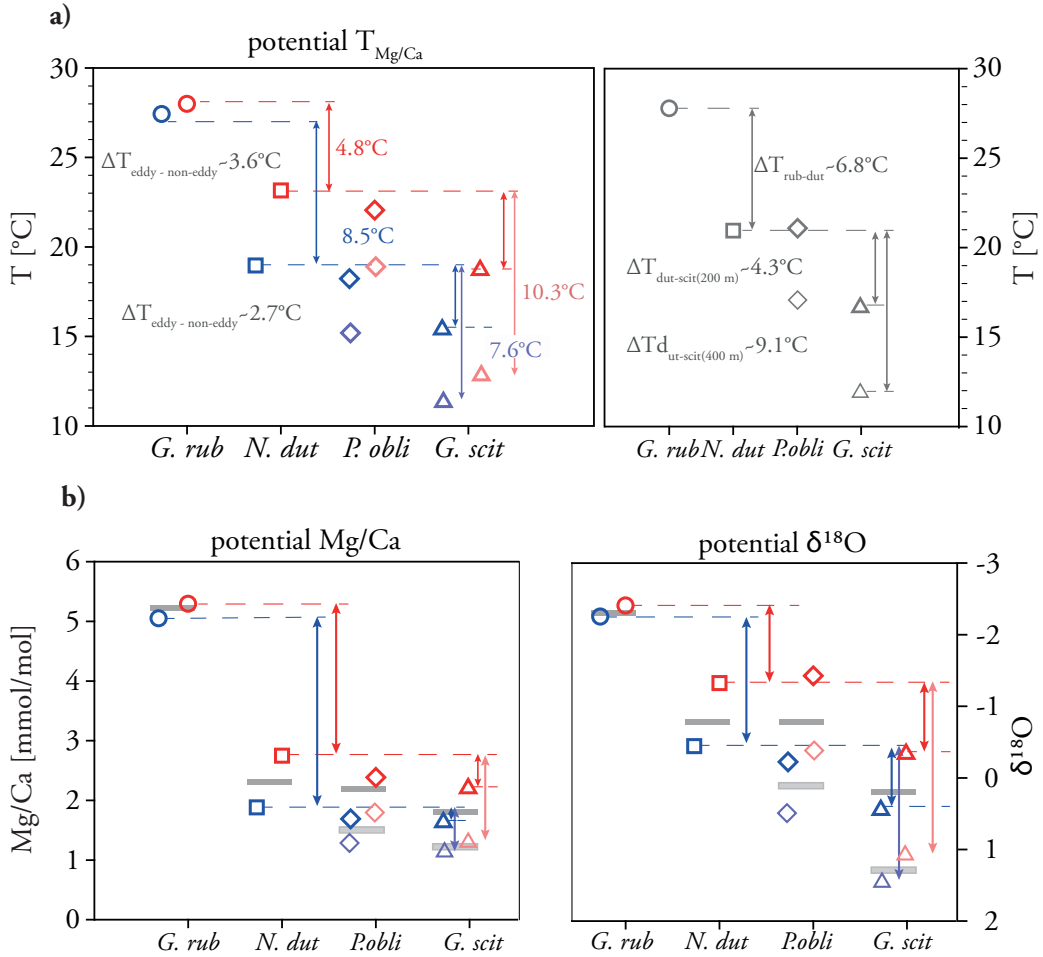


Fig. 6.1: a) Potential calcification temperatures of surface dwelling species *G. ruber*, thermocline dwelling *N. dutertrei* and deep dwelling species *G. scitula* are calculated. Mg/Ca based temperature are calculated applying species specific calibrations. For *G. ruber* and *N. dutertrei*, satellite sst and temperatures at 110 m were used for calculations. For *P. obliquiloculata* and *G. scitula*, temperatures at two depth were applied, for *P. obliquiloculata* 110 m (red) and at 200 m (light red), for *G. scitula* temperatures at 200 m (red) and 400 m (light red) were utilized. *G. ruber*, temperatures were calculated using the calibration developed by Fallet et al. (2011). Calcification temperatures for *N. dutertrei*, we applied the calibration developed by Anand et al. (2003). For *G. scitula* we calculated calcification temperatures using the calibration developed by Anand et al. (2003) for *G. hirsuta*. For calculations of potential $\delta^{18}\text{O}$, the general equation of Epstein et al. (1953) was applied. Potential annual flux-weighted b) Mg/Ca and c) $\delta^{18}\text{O}$ are calculated for eddy (red) and non-eddy (blue) conditions. Grey vertical bars indicate annual averaged Mg/Ca and $\delta^{18}\text{O}$.

calculated depth habitat of 110 m, based on cross calibrating Mg/Ca data and the temperature profile from the mooring deployments, is probably deeper than the true habitat depth of *N. dutertrei*, which is likely to be around 80 m (Fallet et al., 2011 and chapter 4 of this thesis).

Calculated temperature differences are subsequently translated into flux-weighted potential Mg/Ca and $\delta^{18}\text{O}$ signals for the different species (Fig. 6.1b). This shows that the offsets should be easily detectable. Hence, combined changes in shell flux and water column eddy characteristics (e.g. the extent of the deepening of the isotherms) should theoretically be preserved in the sediment and analytically possible to differentiate, as long as the eddy occurrence and/or intensity has an offset of at least 10% from its current value.

6.1.2. Impact of ontogeny

Low Mg/Ca ratios in crust and cortex covering some species of planktonic foraminifera (e.g. Kunioka et al., 2006; Van Raden et al., 2011; Jonkers et al., 2012; Chapter 5) will reduce Mg/Ca of the whole shell. In chapter 5, I used potential annual flux weighted-Mg/Ca from eddy and non-eddy conditions during the sediment trap deployment (Chapter 2) and measured crust Mg/Ca composition (Chapter 5) and its contribution to overall shell wall thickness (Chapter 5) to calculate potential lamellar calcite Mg/Ca ratios using a simple mass-balance-equation:

$$A \cdot X + B \cdot Y = C / (A + B)$$

where A is crust contribution to total shell thickness, X is the Mg/Ca ratio of the crust, B is the contribution of the lamellar calcite, Y is the Mg/Ca ratio of the lamellar calcite and C is the total Mg/Ca ratio of the shell.

Using the measured average crust composition of 1.8 mmol/mol (Chapter 5), *N. dutertrei* should have a lamellar calcite Mg/Ca ratio of 3.8 mmol/mol during eddy and 1.9 mmol/mol during non-eddy conditions. This would translate in Mg/Ca-based calcification temperatures (Anand et al., 2003) of 26.6°C and 19.3°C for eddy and non-eddy conditions, respectively. This is a different temperature range compared to using flux-weighted, whole specimen values (23.3°C and 19°C for eddy and non-eddy conditions, respectively). Still, it remains questionable whether these values can be translated to different depth ranges as until now calibrations are based on whole shell analyses. The more pronounced offset using lamellar calcite Mg/Ca ratios

rather than whole shell Mg/Ca ratios, is promising and invites future research to develop new calibrations using parts of the shell wall only. Similarly, using the measured average Mg/Ca crust composition of 0.93 mmol/mol, for *G. scitula* (Chapter 5), potential lamellar calcite Mg/Ca should be 1.6 mmol/mol for eddy conditions and 1.3 mmol/mol for non-eddy conditions. Following the example of Fallet et al. (2010) we applied the Mg/Ca-temperature calibration of Anand et al. (2003) for *G. hirsuta*, to translate Mg/Ca ratios for *G. scitula* into calcification temperatures of 17°C and 11.8°C for eddy and non-eddy conditions, respectively. Also here the offset differs from the whole shell values, but the difference is smaller, as expected given the lower temperature gradient at the depth this species would calcify.

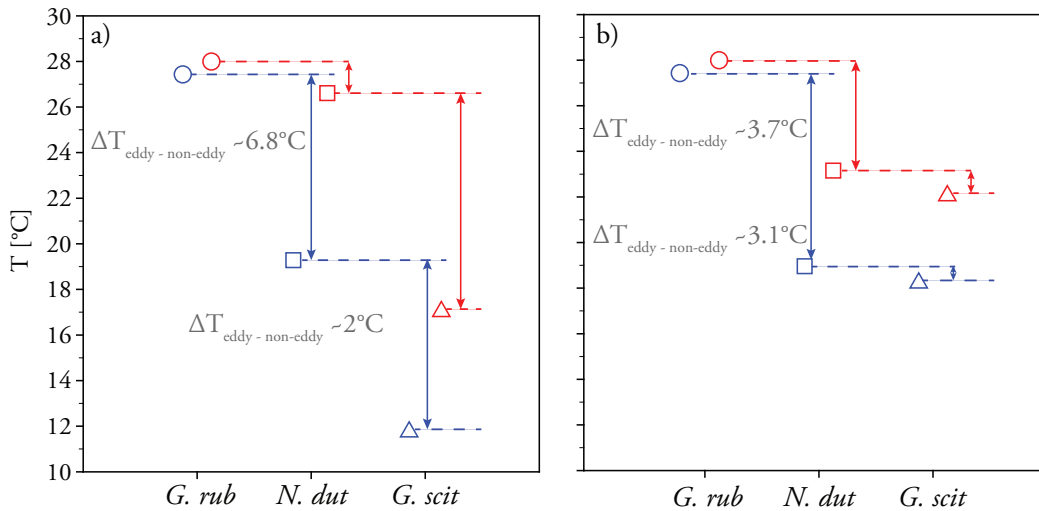


Fig. 6.2: To test potential crust related biases, annual flux-weighted Mg/Ca based potential calcification temperatures of surface dwelling species *G. ruber* (using satellite sst), thermocline dwelling *N. dutertrei* (using temperatures at 110 m) and deep dwelling species *G. scitula* (using temperatures at 400 m) are calculated. Mg/Ca based temperatures are calculated applying species specific calibrations. For *G. ruber*, temperatures were calculated using the calibration developed by Fallet et al. (2011). Calcification temperatures for *N. dutertrei*, we applied the calibration developed by Anand et al. (2003). For *G. scitula* we calculated calcification temperatures using the calibration developed by Anand et al. (2003) for *G. hirsuta* a) Mg/Ca based temperatures based on constant crust values based chapter 5 (crust Mg/Ca *N. dutertrei*: 1.83 mmol/mol, crust Mg/Ca *G. scitula*: 0.93 mmol/mol) b) Mg/Ca based temperatures based on recalculated crust values, using the known Mg/Ca gradient between crust and ontogenetic Mg/Ca.

When combined the theoretical temperature difference between lamellar calcite in *N. dutertrei* and *G. scitula* is 2°C between eddy and non-eddy conditions (Fig. 6.2a). The smaller theoretical offset based on lamellar Mg/Ca ratios between *N. dutertrei* and *G. scitula* compared to whole shell Mg/Ca ratios, is due to the assumed restricted depth intervals of lamellar calcification of

the last chambers. However, in chapter 5 crust calcite Mg/Ca values reported for *N. dutertrei* are significantly different between the final chamber (F-0) and penultimate chamber (F-1), as well as between F-1 and pre-penultimate chamber (F-2). Furthermore, the same species shows significantly different lamellar calcite Mg/Ca between the F-0 chamber and chamber F-1 and F-2. Hence, the smaller theoretical offset between *N. dutertrei* and *G. scitula* implies that we somehow underestimate the differences in their depth habitat. Using single chamber analysis, it is thus possible to capture a larger offset between these two species, which is attributed to the species specific migration pattern (Chapter 4).

Because crust calcite is formed deeper in the water column it could theoretically provide a better estimate for the base of the thermocline and hence be useful in reconstructing eddies. This implies that a separate calibration is needed for crust calcite. To test the potential of this approach we can calculate the potential values for crust carbonate using a mass balance approach, similar to the lamellar calcite above. Assuming that crust Mg/Ca is a function of the whole shell chemistry, depending on the specimen's calcification depth and the condition (i.e. temperature) it encounters, crust Mg/Ca values can be calculated from whole specimen Mg/Ca values. Because the actual thickness of the crust is known from the Mg/Ca and U/Ca profiles, a mass-balance equation can be used to calculate changes in potential crust Mg/Ca and potential annual flux-weighted Mg/Ca to calculate Mg/Ca ratios of the lamellar calcite. Assuming that crust Mg/Ca is ~35% lower than the average shell Mg/Ca, the recalculated crust Mg/Ca values for *N. dutertrei* are 1.8 mmol/mol and 1.2 mmol/mol for eddy and non-eddy conditions respectively. Recalculated crust Mg/Ca values for *G. scitula*, assuming that crust Mg/Ca is ~37% lower than the average shell Mg/Ca, are 0.8 and 0.7 mmol/mol for eddy and non-eddy conditions respectively. Using the recalculated crust Mg/Ca values for *N. dutertrei*, the potential lamellar Mg/Ca value during eddy conditions would be 3.6 mmol/mol Mg/Ca (translating into a calcification temperature of 26.2°C) and 2.5 mmol/mol (translating into a calcification temperature of 22°C) during non-eddy conditions. Using the recalculated crust Mg/Ca values for *G. scitula*, the potential lamellar Mg/Ca value during eddy conditions is 1.7 mmol/mol Mg/Ca (translating into a calcification temperature of 12.2°C) and 1.5 mmol/mol (translating into a calcification temperature of 11°C) during non-eddy conditions. Ultimately, the potential temperature difference between *N. dutertrei* and *G. scitula* is 3.1°C (Fig. 6.2b) and larger than assuming a constant crust value. In contrast, the potential temperature difference of 3.7°C between *G. ruber* and *N. dutertrei* (Fig. 6.2b) between eddy and non-eddy conditions, is only half the value produced by assuming a constant crust Mg/Ca. These theoretical calculations underline the importance to further investigate Mg/Ca distribution between crust and ontogenetic calcite in order to improve proxy application and show the

potential for developing proxies that are considering the geochemistry of both, crust/cortex and lamellar calcite.

6.1.3. The potential imprint of inter annual variability

Besides a strong seasonal climatic contrast, there are also inter-annual modulations of Indian Ocean climate. The down-core application of the eddy proxy, suggested in this thesis (Chapter 3), might be biased by climate phenomena such as e.g. El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and the Pacific Decadal Oscillation (PDO), events depending on the associated temperature anomaly. ENSO (McPhadden et al., 2006) and IOD (Saji et al., 1999) are two prominent features of the inter-annual variability influencing the Indian Ocean. ENSO is characterized by periodic warming (La Niña) and cooling (El Niño) of the eastern equatorial Pacific, arising from changes in the Walker circulation (McPhadden et al., 1996). During positive ENSO events (La Niña) there is a corresponding warming of the Indian Ocean, which peaks during boreal spring (March – May). The associated temperature impact is between 0.5 and 1 degree at the sea surface (Manyilizu et al., 2014), but might also impact thermal stratification. Sometimes coinciding, the IOD, develops in June and peaks in October (Saji et al., 1999). The IOD has an impact similar to ENSO, but is centered on another time of the year. The IOD impacts also the thermocline as associated strong monsoon winds occasionally result in shoaling of the eastern equatorial thermocline, opposite to the effect of the warm-core eddies. On a much lower frequency, one cycle being between 50-70 years, also the PDO might impact the western Indian Ocean, with SSTs rising during a positive PDO phase. The amplitude on SST of the PDO is not exactly known, but estimated to be exceeding the impact of ENSO (Krishnan et al., 2003). There also seems to be a link between these phenomena, whereby they might reinforce each other. The strongest inter-annual signal in the Indian Ocean is related to ENSO, modulated by inter-decadal climate variability of the PDO (Cole et al., 2000; Crueger et al., 2009) and negative IOD are often connected with a La Niña event. The associated combined temperature changes in the Mozambique Channel are hence probably up to 2°C inter-annually. Although this is lower than the temperature difference associated with eddies, it could still suppress signals integrated over multiple years, when somehow mechanistically linked.

6.1.4. Glacial/interglacial cycle

On a geological time scale, our present day climate varies between glacials and interglacials. During glacial periods, SSTs were lower (~2.5°C during the LGM in the Indian Ocean), but more importantly for reconstructing eddies, the overall temperature gradient within the

upper water column might have been reduced. When the temperature difference in the upper thermocline becomes too small, the reconstruction of past eddy intensity might be hampered. Moreover, a shift in seasonality and a possible moving of the biogeographic zonation could result in a general change in foraminiferal assemblages. The application of species specific offsets to reconstruct eddy intensity over glacial-interglacial transitions therefore will need a multi-proxy context to assess reliability. Also including other species and different size fractions could help to improve the proxies proposed in this thesis to more non-analogous conditions.

6.1.5. Diagenesis

Diagenesis could potentially interfere with the proxies proposed here in several ways. For instance the Mg/Ca of foraminifera shells is susceptible to dissolution (Hecht et al., 1975; Lorens et al., 1977). Rosenthal and Boyle (1993) demonstrated the relationship between Mg/Ca and $\delta^{18}\text{O}$ and related decreasing Mg/Ca with increasing water depth. Furthermore, studies indicate that Mg-rich lamellar calcite is preferentially dissolved compared to Mg/Ca-low calcite related to the keel or crust (Brown and Elderfield, 1996; Johnstone et al., 2010). Also overgrowth of non-biogenic high Mg calcite could interfere with the proxies proposed here, especially the one based on crust chemistry. Analyzing test wall profiles using laser ablation ICP-MS seems therefore crucial for the robust application, even when used only as a regular check.

6.1.6. Is it important how many eddies go through the MC?

The number of eddies might be important, if the total number and duration of eddies is too few to be transferred, by foraminifera fluxes of species recording eddy signals, into the sedimentary record. This would mean that eddy frequency will be overprinted by seasonal or annual frequencies. Looking at the flux data for *G. ruber* it seems that the difference between winter-summer and eddy-non-eddy is quite comparable. Using the flux difference between the annual mean and the seasonal contrast (summer/winter) we can estimate the seasonal flux imprint to be about $235 \text{ shells m}^{-2} \text{ d}^{-1}$ using:

$$\text{Seasonal effect} = \Delta_{\text{season-annual}} \text{flux}_{\text{min}} - \text{flux}_{\text{max}}$$

Based on the seasonal effect, the eddy/non-eddy effect can be estimated by:

$$\text{Eddy/non-eddy effect} = \Delta_{\text{eddy/noneddy-season}} \text{flux}_{\text{min}} - \text{flux}_{\text{max}}$$

For *G. ruber* this results in an eddy estimate of $\sim 190 \text{ shells m}^{-2} \text{ d}^{-1}$ and for non-eddy conditions

of ~ 250 shells $\text{m}^{-2} \text{d}^{-1}$. This implies that the seasonal and eddy related impacts on *G. ruber* flux are comparable.

6.2. The potential use of intra shell differences in $\delta^{13}\text{C}$ for calcification depth reconstruction

Single shell $\delta^{13}\text{C}$ of planktonic foraminifera living at different depths, seem to record ambient $\delta^{13}\text{C}_{\text{DIC}}$ and can be used to reconstruct seawater carbonate chemistry carbon uptake but also vital effects during the calcification process (Rollion-Bard and Erez, 2010). Single shell differences of $\delta^{13}\text{C}$ in *N. dutertrei* and *G. scitula* seem to record eddy induced changes in the deepening of the nutricline (Chapter 4). Still, these data are based on whole shell analyses and do not allow resolving intra-shell differences expected to result from a gradual shift in depth habitat as found in Mg/Ca.

Recently, Vetter et al. (2013) showed that $\delta^{18}\text{O}_{\text{calcite}}$ and elemental tracers seem to be precipitated synchronously within the test wall, with no measurable spatial offsets. We have profiled foraminiferal shell walls and distinguished crust, cortex and lamellar calcite using LA-ICP-MS (Chapter 5). Analysing intra-shell $\delta^{18}\text{O}_{\text{calcite}}$ using Nano-SIMS, could help to better unravel the growth history of the foraminiferal shell. Moreover, NanoSIMS would also allow studying intra-shell carbon isotopes. The proposed calcification model based on single chamber Mg/Ca and single shell $\delta^{18}\text{O}$ (Chapter 3) might ultimately be refined by high-resolution $\delta^{13}\text{C}$ NanoSIMS measurements on single chambers using a planktonic foraminifera species with a wide ontogenetic depth migration (e.g. *G. truncatulinoides*, *N. dutertrei*), crossing a $\delta^{13}\text{C}$ DIC gradient that can be analytically resolved.

6.3. What can U/Ca tell us?

U/Ca in planktonic foraminiferal shells has been suggested to show a strong temperature effect (Yu et al., 1998). Controlled growth experiments, however, showed U/Ca records carbonate chemistry without an appreciable temperature effect (Russel et al., 2003). Also more recent studies primarily linked U/Ca in foraminiferal shell carbonate to the seawater carbonate system (Raitzsch et al., 2011; Russel et al., 2004; Keul et al., 2013). Comparing the results from the Mozambique Channel sediment trap to the culture results of Keul et al. (2013), no inverse relationship between U/Ca incorporation and $[\text{CO}_3^{2-}]$ ($\text{Log}D_{\text{U}} = 2.3 - 0.0027 * [\text{CO}_3^{2-}]$) is observed, using in situ CO_3^{2-} values (locations between 37–43°E and 24.7°S, World Ocean

Database 2009). Incorporation of U in planktonic foraminifera hence appears not solely controlled by $[\text{CO}_3^{2-}]$.

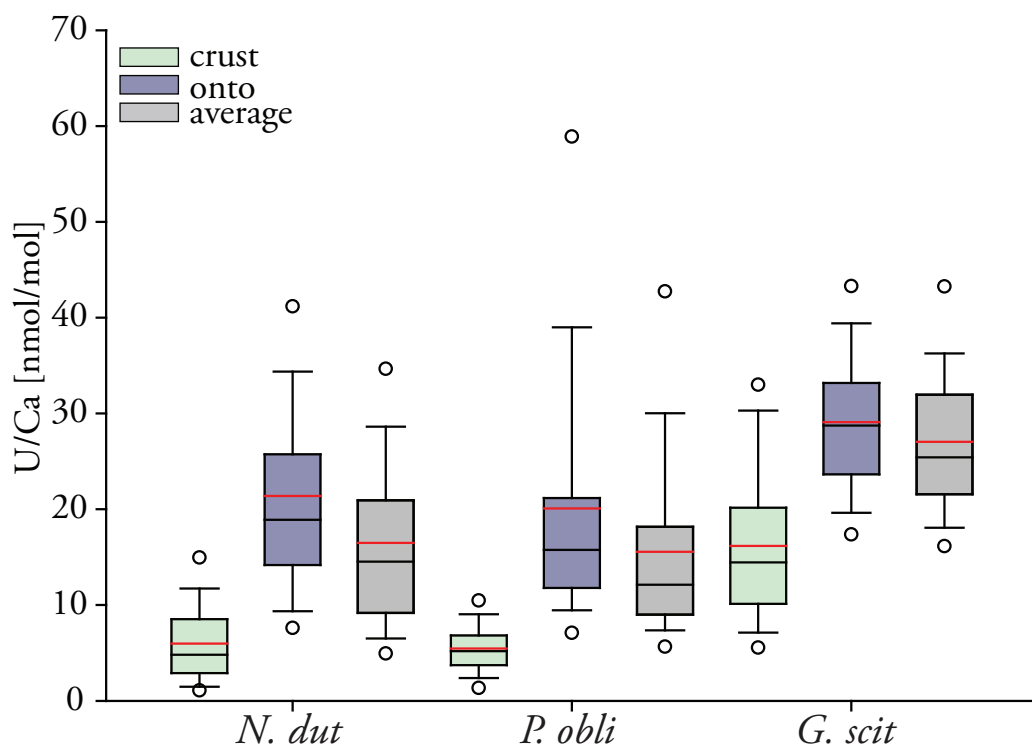


Fig. 6.3: Box plot of average crust, ontogenetic and whole shell wall U/Ca for *N. dutertrei*, *P. obliquiloculata* and *G. scitula*. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. In addition, the graph shows mean (red line) whereas the open circles indicate the 5th and 95th percentile. The Standard percentile method uses linear interpolation to determine the percentile values. The 50th percentile (median) is indicated with the black lines within the boxes. The bounding boxes are used to graphically show overall differences between species

Single chamber LA-ICP-MS, shows that U/Ca calcite concentrations are species specific and, of the species studied here, have the lowest values in *N. dutertrei* (10 nmol/mol) and the highest values in the deep dwelling species *G. scitula* (27 nmol/mol) (Fig. 6.3). Overall U/Ca results are comparable with previous studies, reporting U/Ca values of 10 nmol/mol for mixed species (Delaney and Boyle, 1983) and species-specifically between 3 and 15 nmol/mol for cultured and coretop specimens (Russel et al., 1994; Yu et al., 2008). Using an average seawater U/Ca ratio of 1305 nmol/mol, the U/Ca values I measured correspond to the empirical partition

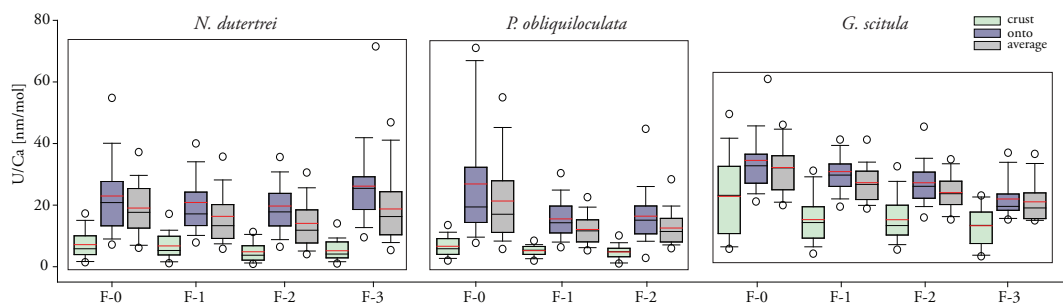


Fig. 6.4: Box plot of average crust, ontogenetic and whole shell wall U/Ca for *N. dutertrei*, *P. obliquiloculata* and *G. scitula* for the last three to four chambers. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. In addition, the graph shows mean (red line) whereas the open circles indicate the 5th and 95th percentile. The Standard percentile method uses linear interpolation to determine the percentile values. The 50th percentile (median) is indicated with the black lines within the boxes. The bounding boxes are used to graphically show overall differences between species.

coefficients $D_{U/Ca}$ [$D_{U/Ca} = (U/Ca)_{\text{calcite}} / (U/Ca)_{\text{sw}}$] of 0.012 to 0.021. These partition coefficients are generally lower than partition coefficients determined for inorganic calcite precipitated from seawater of $0.04 < D < 0.26$ (Kitano and Oomori, 1971) and $0.046 < D < 0.2$ (Meece and Benninger, 1993), suggesting a firm biological control over the incorporation of U into foraminiferal calcite.

LA-ICP-MS profiling shows that crust U/Ca is generally lower than lamellar calcite. In *N. dutertrei* U/Ca values in crust calcite are about 6 nmol/mol compared to higher U/Ca values of 21 nmol/mol in lamellar calcite (Fig. 6.3). Average cortex calcite of *P. obliquiloculata* has a U/Ca value of 6 nmol/mol compared to the 20 nmol/mol in lamellar calcite. Also *G. scitula* shows lower crust U/Ca ratios of 16 nmol/mol, compared to lamellar calcite with a U/Ca ratio of 29 nmol/mol (Fig. 6.3). Empirical partition coefficients $D_{U/Ca}$ for crust calcite show lower values, between 0.004 and 0.012, compared to partition coefficients of lamellar calcite, which are between 0.015 and 0.022. This implies, that biological discrimination against U appears to be even higher in crust calcite compared to lamellar calcite, similar to what is observed for Mg. This is in agreement with my findings in chapter 5, where I showed that Mg/Ca ratios in crust calcite are generally lower than in lamellar calcite. Such differences may be caused by differences in calcification rate between lamellar and crust calcite (Chapter 5). Irrespectively, the fact that a strong difference is observed between ontogenetic and crust calcite for both Mg and U is in line with a strong biological control for both elements.

For *G. scitula* only crust U/Ca ratios between F-0 and F-1 are significantly different (t-test, $p = 0.047$). The U/Ca ratios in lamellar calcite of *G. scitula* seems to suggest an increasing U/Ca trend from the earlier (F-3) towards the younger chambers. Lamellar U/Ca ratios between F-2 and F-3 show no significant difference, however U/Ca in F-0 is significantly different from lamellar U/Ca ratios in F-2 and F-3 ($p < 0.001$). Also, lamellar U/Ca ratios in F-1 are significantly different compared to U/Ca values in F-3. For the total calcite U/Ca in *G. scitula*, I find that total U/Ca between all chambers are significantly different from one another, except total calcite U/Ca ratios between chambers F-1 and F-2, as well as between chambers F-2 and F-3. Generally I find that lamellar U/Ca ratios in all three species are higher in the last and the youngest chamber of the final whorl. This is also true for the crust U/Ca values in *N. dutertrei* and *G. scitula*. Only *P. obliquiloculata* shows no differences in cortex U/Ca ratios between chambers. Comparing these differences in U/Ca with the observed differences in Mg/Ca between the different growth stages suggests that U/Ca and Mg/Ca incorporation are tightly linked. This is likely an effect of species-specific vital-effects and environmental variations within the species depth habitat (vertical migration), however we cannot exclude effects of co-precipitation.

In conclusion, it seems that also U/Ca partitioning is strongly biologically controlled in lamellar but also crust and cortex calcite. This is in agreement with observations of Mg/Ca (Chapter 5). Slower precipitation rates during the terminal stages of foraminiferal calcification can potentially explain higher U/Ca incorporation.

6.4. Towards understanding crust and cortex formation

Many of the here proposed proxies and life cycle changes are based primarily inversely on using inter- and intra-shell differences in chemistry. To tie these observations to reality, stratified plankton tows are needed. At the same time these tows could improve understanding crust and cortex formation, both in time and space. The precise depth where the foraminifera are captured holds valuable information. Detailed investigations could decipher the depth distribution of specimens with and without crust/cortex and constrain the here presumed formation depth. Additionally, measurements of hydrographic parameters (temperature, salinity, trace metal concentrations and seawater chemistry) could be used to understand the mechanisms triggering crust and cortex formation and allow the calibration of the individual parts of the shell, i.e. lamellar versus crust calcite.



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me first. I owe you everything. Grandma, thank you so much for being there and supporting me. I love you both.



Juliane Steinhardt was born on the 9th of March 1985 in Erfurt, Germany. Inspired by her travels with her mother, she became interested early on in history, art and all things they could find on the ground - from the beach shores to the mountains. After a while of considering which subject she should choose to concentrate on, Juliane decided to pursue a study in Geosciences after graduating in 2004. Her love for the marine realm soon led her to specialize in Marine Micropaleontology. On the very day she received her diploma in 2010, she immediately packed her car and rode off to the Netherlands, where she started her Ph.D. in the Marine Geology and Chemical Oceanography (GCO) group at the Royal Netherlands Institute for Sea Research (NIOZ) on Texel. After a little more than four years, her work has accumulated in this thesis and an unforgettable period in her life. She left Texel in May 2015 to start a postdoc position within the ARAMACC project, investigating the commercial potential of sclerochronology in environmental monitoring.

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Appendix

Appendix table chapter 3

species	ID	sample	weight [µg]	chamber	Mg/Ca [mmol/mol]	Mn/Ca [µmol/mol]
<i>N. dutertrei</i>	1	MOZ4_A01 >315	35.0	F-0	4.11	5.93
<i>N. dutertrei</i>	1	MOZ4_A01 >315	35.0	F-1	3.63	5.70
<i>N. dutertrei</i>	1	MOZ4_A01 >315	35.0	F-2	3.52	3.39
<i>N. dutertrei</i>	2	MOZ4_A01 >315	10.0	F-0	4.04	5.32
<i>N. dutertrei</i>	2	MOZ4_A01 >315	10.0	F-1	3.70	10.67
<i>N. dutertrei</i>	2	MOZ4_A01 >315	10.0	F-2	2.63	12.74
<i>N. dutertrei</i>	3	MOZ4_A01 >315	11.0	F-0	6.98	24.72
<i>N. dutertrei</i>	3	MOZ4_A01 >315	11.0	F-1	10.20	21.04
<i>N. dutertrei</i>	3	MOZ4_A01 >315	11.0	F-2	3.26	9.23
<i>N. dutertrei</i>	4	MOZ4_A01 >315	27.0	F-1	4.10	13.63
<i>N. dutertrei</i>	4	MOZ4_A01 >315	27.0	F-2	3.09	7.72
<i>N. dutertrei</i>	4	MOZ4_A01 >315	27.0	F-3	4.00	6.48
<i>N. dutertrei</i>	5	MOZ2_A12; >315	14.0	F-1	1.79	17.27
<i>N. dutertrei</i>	5	MOZ2_A12; >315	14.0	F-2	1.99	33.58
<i>N. dutertrei</i>	5	MOZ2_A12; >315	14.0	F-3	1.56	16.96
<i>N. dutertrei</i>	6	MOZ2_A12; >315	29.0	F-0	3.79	9.19
<i>N. dutertrei</i>	6	MOZ2_A12; >315	29.0	F-1	2.28	5.19
<i>N. dutertrei</i>	7	MOZ2_A12; >315	22.0	F-0	3.13	17.57
<i>N. dutertrei</i>	7	MOZ2_A12; >315	22.0	F-1	3.49	11.47
<i>N. dutertrei</i>	7	MOZ2_A12; >315	22.0	F-2	2.69	12.61
<i>N. dutertrei</i>	8	MOZ2_A12; >315	24.0	F-0	2.84	10.41
<i>N. dutertrei</i>	8	MOZ2_A12; >315	24.0	F-1	2.68	11.54
<i>N. dutertrei</i>	8	MOZ2_A12; >315	24.0	F-2	2.75	17.00
<i>N. dutertrei</i>	9	MOZ2_A12; >315	20.0	F-0	3.51	4.97
<i>N. dutertrei</i>	9	MOZ2_A12; >315	20.0	F-1	3.24	3.39
<i>N. dutertrei</i>	9	MOZ2_A12; >315	20.0	F-2	2.27	3.80
<i>N. dutertrei</i>	10	MOZ2_A11,>315	25.0	F-0	4.66	7.44
<i>N. dutertrei</i>	10	MOZ2_A11,>315	25.0	F-1	2.17	6.21
<i>N. dutertrei</i>	10	MOZ2_A11,>315	25.0	F-2	2.22	3.28
<i>N. dutertrei</i>	11	MOZ4_A01 >315	27.0	F-0	2.52	1.86
<i>N. dutertrei</i>	11	MOZ4_A01 >315	27.0	F-1	1.43	2.60
<i>N. dutertrei</i>	11	MOZ4_A01 >315	27.0	F-2	2.80	2.24
<i>N. dutertrei</i>	12	MOZ4_A01 >315	34.0	F-0	2.31	9.76
<i>N. dutertrei</i>	12	MOZ4_A01 >315	34.0	F-1	2.26	10.65
<i>N. dutertrei</i>	12	MOZ4_A01 >315	34.0	F-2	2.56	8.19
<i>N. dutertrei</i>	13	MOZ4_A01 >315	16.0	F-0	2.89	20.59
<i>N. dutertrei</i>	13	MOZ4_A01 >315	16.0	F-1	2.94	19.90
<i>N. dutertrei</i>	13	MOZ4_A01 >315	16.0	F-2	3.19	13.76

<i>N. dutertrei</i>	14	MOZ4_A01 >315	21.0	F-0	1.11	1.84
<i>N. dutertrei</i>	14	MOZ4_A01 >315	21.0	F-1	1.47	2.31
<i>N. dutertrei</i>	14	MOZ4_A01 >315	21.0	F-2	1.23	3.49
<i>N. dutertrei</i>	15	MOZ4_A01 >315	22.0	F-0	1.73	2.17
<i>N. dutertrei</i>	15	MOZ4_A01 >315	22.0	F-1	1.46	3.08
<i>N. dutertrei</i>	15	MOZ4_A01 >315	22.0	F-2	1.40	1.87
<i>N. dutertrei</i>	16	MOZ4_A01 >315	33.0	F-0	3.03	3.02
<i>N. dutertrei</i>	16	MOZ4_A01 >315	33.0	F-1	2.55	5.08
<i>N. dutertrei</i>	16	MOZ4_A01 >315	33.0	F-2	2.23	2.75
<i>N. dutertrei</i>	17	MOZ4_A01 >315	34.0	F-0	2.77	9.03
<i>N. dutertrei</i>	17	MOZ4_A01 >315	34.0	F-1	4.92	14.85
<i>N. dutertrei</i>	17	MOZ4_A01 >315	34.0	F-2	3.84	17.67
<i>N. dutertrei</i>	18	MOZ4_A01 >315	16.0	F-0	1.60	5.93
<i>N. dutertrei</i>	18	MOZ4_A01 >315	16.0	F-1	1.76	2.37
<i>N. dutertrei</i>	18	MOZ4_A01 >315	16.0	F-2	1.81	2.22
<i>N. dutertrei</i>	19	MOZ4_A01 >315	30.0	F-1	3.15	4.57
<i>N. dutertrei</i>	19	MOZ4_A01 >315	30.0	F-2	2.46	4.08
<i>N. dutertrei</i>	19	MOZ4_A01 >315	30.0	F-3	2.32	3.15
<i>N. dutertrei</i>	20	MOZ4_A01 >315	8.0	F-1	2.79	6.88
<i>N. dutertrei</i>	20	MOZ4_A01 >315	8.0	F-2	3.52	7.26
<i>N. dutertrei</i>	21	MOZ2_A12; >315	24.0	F-0	3.76	9.10
<i>N. dutertrei</i>	21	MOZ2_A12; >315	24.0	F-1	3.15	5.28
<i>N. dutertrei</i>	21	MOZ2_A12; >315	24.0	F-2	3.55	8.74
<i>N. dutertrei</i>	22	MOZ2_A12; >315	37.0	F-0	3.49	9.68
<i>N. dutertrei</i>	22	MOZ2_A12; >315	37.0	F-1	1.94	6.43
<i>N. dutertrei</i>	22	MOZ2_A12; >315	37.0	F-2	1.63	4.22
<i>N. dutertrei</i>	23	MOZ2_A12; >315	31.0	F-0	2.56	27.83
<i>N. dutertrei</i>	23	MOZ2_A12; >315	31.0	F-1	2.24	27.19
<i>N. dutertrei</i>	23	MOZ2_A12; >315	31.0	F-2	2.16	17.53
<i>N. dutertrei</i>	24	MOZ2_A12; >315	28.0	F-0	4.23	10.03
<i>N. dutertrei</i>	24	MOZ2_A12; >315	28.0	F-1	2.03	3.42
<i>N. dutertrei</i>	24	MOZ2_A12; >315	28.0	F-2	3.31	3.42
<i>N. dutertrei</i>	25	MOZ2_A12; >315	38.0	F-0	4.27	3.37
<i>N. dutertrei</i>	25	MOZ2_A12; >315	38.0	F-1	3.21	9.26
<i>N. dutertrei</i>	25	MOZ2_A12; >315	38.0	F-2	1.96	1.87
<i>N. dutertrei</i>	26	MOZ2_A12; >315	26.0	F-0	4.17	3.40
<i>N. dutertrei</i>	26	MOZ2_A12; >315	26.0	F-1	3.40	11.27
<i>N. dutertrei</i>	27	MOZ2_A12; >315	19.0	F-0	3.05	5.75
<i>N. dutertrei</i>	27	MOZ2_A12; >315	19.0	F-2	2.75	14.51

<i>N. dutertrei</i>	28	MOZ2_A12; >315	23.0	F-0	3.72	6.52
<i>N. dutertrei</i>	28	MOZ2_A12; >315	23.0	F-1	2.53	13.20
<i>N. dutertrei</i>	28	MOZ2_A12; >315	23.0	F-2	2.21	11.12
<i>N. dutertrei</i>	29	MOZ2_A12; >315	30.0	F-0	3.84	12.43
<i>N. dutertrei</i>	29	MOZ2_A12; >315	30.0	F-1	1.93	5.13
<i>N. dutertrei</i>	29	MOZ2_A12; >315	30.0	F-2	2.70	2.02
<i>N. dutertrei</i>	30	MOZ2_A12; >315	15.0	F-0	2.87	17.02
<i>N. dutertrei</i>	30	MOZ2_A12; >315	15.0	F-1	3.20	4.17
<i>N. dutertrei</i>	30	MOZ2_A12; >315	15.0	F-4	1.41	4.33
<i>N. dutertrei</i>	31	MOZ2_A12; >315	23.0	F-0	6.35	8.12
<i>N. dutertrei</i>	31	MOZ2_A12; >315	23.0	F-1	2.15	6.64
<i>N. dutertrei</i>	31	MOZ2_A12; >315	23.0	F-2	5.12	4.20
<i>N. dutertrei</i>	32	MOZ2_A12; >315	33.0	F-0	6.13	43.10
<i>N. dutertrei</i>	32	MOZ2_A12; >315	33.0	F-3	5.32	12.09
<i>N. dutertrei</i>	33	MOZ2_A12; >315	32.0	F-1	3.28	9.01
<i>N. dutertrei</i>	33	MOZ2_A12; >315	32.0	F-2	2.56	7.48
<i>N. dutertrei</i>	33	MOZ2_A12; >315	32.0	F-3	2.91	4.04
<i>N. dutertrei</i>	34	MOZ2_A12; >315	24.0	F-0	2.51	7.23
<i>N. dutertrei</i>	34	MOZ2_A12; >315	24.0	F-1	1.87	4.17
<i>N. dutertrei</i>	34	MOZ2_A12; >315	24.0	F-2	1.38	3.19
<i>N. dutertrei</i>	35	MOZ2_A12; >315	22.0	F-0	2.49	5.11
<i>N. dutertrei</i>	35	MOZ2_A12; >315	22.0	F-1	2.70	5.57
<i>N. dutertrei</i>	35	MOZ2_A12; >315	22.0	F-2	1.54	
<i>N. dutertrei</i>	36	MOZ2_A11; >315	19.0	F-0	4.99	39.10
<i>N. dutertrei</i>	36	MOZ2_A11; >315	19.0	F-1	4.28	48.40
<i>N. dutertrei</i>	36	MOZ2_A11; >315	19.0	F-2	4.16	26.52
<i>N. dutertrei</i>	37	MOZ2_A11; >315	20.0	F-0	2.56	14.22
<i>N. dutertrei</i>	37	MOZ2_A11; >315	20.0	F-1	2.37	19.75
<i>N. dutertrei</i>	37	MOZ2_A11; >315	20.0	F-2	1.52	5.13
<i>N. dutertrei</i>	38	MOZ2_A11; >315	26.0	F-0	3.58	7.72
<i>N. dutertrei</i>	38	MOZ2_A11; >315	26.0	F-1	2.56	11.45
<i>N. dutertrei</i>	38	MOZ2_A11; >315	26.0	F-2	1.84	3.11
<i>N. dutertrei</i>	39	MOZ2_A11; >315	32.0	F-0	4.95	29.11
<i>N. dutertrei</i>	39	MOZ2_A11; >315	32.0	F-1	3.52	60.30
<i>N. dutertrei</i>	39	MOZ2_A11; >315	32.0	F-2	4.19	32.65
<i>N. dutertrei</i>	40	MOZ2_A11; >315	37.0	F-0	2.60	3.44
<i>N. dutertrei</i>	40	MOZ2_A11; >315	37.0	F-1	2.11	6.43
<i>N. dutertrei</i>	40	MOZ2_A11; >315	37.0	F-2	1.96	8.50
<i>N. dutertrei</i>	41	MOZ2_A11; >315	40.0	F-0	5.63	7.90

<i>N. dutertrei</i>	41	MOZ2_A11; >315	40.0	F-1	4.84	7.68
<i>N. dutertrei</i>	41	MOZ2_A11; >315	40.0	F-2	4.29	6.32
<i>N. dutertrei</i>	42	MOZ2_A11; >315	30.0	F-0	4.53	6.59
<i>N. dutertrei</i>	42	MOZ2_A11; >315	30.0	F-1	3.85	10.32
<i>N. dutertrei</i>	42	MOZ2_A11; >315	30.0	F-2	3.16	6.43
<i>N. dutertrei</i>	43	MOZ2_A11; >315	34.0	F-0	3.52	0.95
<i>N. dutertrei</i>	43	MOZ2_A11; >315	34.0	F-1	3.85	18.77
<i>N. dutertrei</i>	43	MOZ2_A11; >315	34.0	F-2	3.24	10.10
<i>N. dutertrei</i>	44	MOZ2_A11; >315	23.0	F-0	2.66	6.84
<i>N. dutertrei</i>	44	MOZ2_A11; >315	23.0	F-1	2.27	13.20
<i>N. dutertrei</i>	44	MOZ2_A11; >315	23.0	F-2	2.11	7.06
<i>N. dutertrei</i>	45	MOZ2_A11; >315	36.0	F-3	3.25	10.03
<i>N. dutertrei</i>	45	MOZ2_A11; >315	36.0	F-2	3.20	9.39
<i>N. dutertrei</i>	45	MOZ2_A11; >315	36.0	F-1	2.41	8.59
<i>N. dutertrei</i>	45	MOZ2_A11; >315	36.0	F-0	4.48	5.26
<i>N. dutertrei</i>	46	MOZ2_A11; >315	28.0	F-1	2.46	2.08
<i>N. dutertrei</i>	46	MOZ2_A11; >315	28.0	F-2	1.83	7.28
<i>N. dutertrei</i>	46	MOZ2_A11; >315	28.0	F-3	1.89	3.70
<i>N. dutertrei</i>	47	MOZ2_A11; >315	30.0	F-1	5.35	3.84
<i>N. dutertrei</i>	47	MOZ2_A11; >315	30.0	F-2	2.80	12.00
<i>N. dutertrei</i>	47	MOZ2_A11; >315	30.0	F-3	6.63	23.24
<i>N. dutertrei</i>	48	MOZ2_A11; >315	28.0	F-1	3.23	5.08
<i>N. dutertrei</i>	48	MOZ2_A11; >315	28.0	F-2	3.39	6.06
<i>N. dutertrei</i>	48	MOZ2_A11; >315	28.0	F-6	1.91	3.37
<i>N. dutertrei</i>	49	MOZ2_A11; >315	25.0	F-1	4.78	
<i>N. dutertrei</i>	49	MOZ2_A11; >315	25.0	F-2	7.02	3.37
<i>N. dutertrei</i>	49	MOZ2_A11; >315	25.0	F-1	4.95	5.02
<i>N. dutertrei</i>	50	MOZ2_A11; >315	20.0	F-0	10.29	11.21
<i>N. dutertrei</i>	50	MOZ2_A11; >315	20.0	F-1	5.79	9.59
<i>N. dutertrei</i>	50	MOZ2_A11; >315	20.0	F-2	6.72	13.11
<i>N. dutertrei</i>	51	MOZ2_A11; >315	21.0	F-1	4.51	8.59
<i>N. dutertrei</i>	51	MOZ2_A11; >315	21.0	F-2	3.92	7.95
<i>N. dutertrei</i>	51	MOZ2_A11; >315	21.0	F-3	4.13	5.72
<i>N. dutertrei</i>	52	MOZ2_A11; >315	26.0	F-1	2.90	3.06
<i>N. dutertrei</i>	52	MOZ2_A11; >315	26.0	F-2	2.18	4.46
<i>N. dutertrei</i>	52	MOZ2_A11; >315	26.0	F-3	2.19	2.75
<i>N. dutertrei</i>	53	MOZ2_A11; >315	24.0	F-0	2.36	2.31
<i>N. dutertrei</i>	53	MOZ2_A11; >315	24.0	F-1	2.09	8.92
<i>N. dutertrei</i>	53	MOZ2_A11; >315	24.0	F-2	1.94	5.19

<i>N. dutertrei</i>	54	MOZ2_A11; >315	21.0	F-0	3.79	7.35
<i>N. dutertrei</i>	54	MOZ2_A11; >315	21.0	F-1	3.24	2.28
<i>N. dutertrei</i>	54	MOZ2_A11; >315	21.0	F-2	3.41	17.37
<i>N. dutertrei</i>	55	MOZ2_A11; >315	32.0	F-0	3.09	2.20
<i>N. dutertrei</i>	55	MOZ2_A11; >315	32.0	F-1	3.06	4.68
<i>N. dutertrei</i>	55	MOZ2_A11; >315	32.0	F-2	2.39	3.09
<i>N. dutertrei</i>	56	MOZ2_A11; >315	35.0	F-0	1.81	N.A.
<i>N. dutertrei</i>	56	MOZ2_A11; >315	35.0	F-1	1.97	4.88
<i>N. dutertrei</i>	56	MOZ2_A11; >315	35.0	F-2	1.48	2.88
<i>N. dutertrei</i>	57	MOZ2_A11; >315	23.0	F-0	2.22	2.77
<i>N. dutertrei</i>	57	MOZ2_A11; >315	23.0	F-1	1.58	1.46
<i>N. dutertrei</i>	57	MOZ2_A11; >315	23.0	F-2	1.62	2.13
<i>N. dutertrei</i>	58	MOZ2_A11; >315	25.0	F-1	3.11	13.01
<i>N. dutertrei</i>	58	MOZ2_A11; >315	25.0	F-2	1.60	3.13
<i>N. dutertrei</i>	58	MOZ2_A11; >315	25.0	F-3	1.60	2.84
<i>N. dutertrei</i>	59	MOZ2_A11; >315	31.0	F-0	4.28	1.26
<i>N. dutertrei</i>	59	MOZ2_A11; >315	31.0	F-1	3.68	1.80
<i>N. dutertrei</i>	59	MOZ2_A11; >315	31.0	F-2	2.51	2.53
<i>N. dutertrei</i>	60	MOZ2_A11; >315	38.0	F-0	4.73	40.46
<i>N. dutertrei</i>	60	MOZ2_A11; >315	38.0	F-1	4.39	28.67
<i>N. dutertrei</i>	60	MOZ2_A11; >315	38.0	F-2	4.38	25.32
<i>N. dutertrei</i>	61	MOZ2_A11; >315	32.0	F-0	2.97	N.A.
<i>N. dutertrei</i>	61	MOZ2_A11; >315	32.0	F-1	2.84	1.33
<i>N. dutertrei</i>	61	MOZ2_A11; >315	32.0	F-2	1.94	1.58
<i>N. dutertrei</i>	62	MOZ2_A11; >315	25.0	F-0	3.75	3.37
<i>N. dutertrei</i>	62	MOZ2_A11; >315	25.0	F-1	3.07	12.43
<i>N. dutertrei</i>	62	MOZ2_A11; >315	25.0	F-2	2.34	8.01
<i>N. dutertrei</i>	63	MOZ1_A07, >315	32.0	F-1	1.28	6.73
<i>N. dutertrei</i>	63	MOZ1_A07, >315	32.0	F-2	1.05	10.99
<i>N. dutertrei</i>	63	MOZ1_A07, >315	32.0	F-0	3.70	13.12
<i>N. dutertrei</i>	64	MOZ1_A07, >315	22.0	F-1	3.01	64.25
<i>N. dutertrei</i>	64	MOZ1_A07, >315	22.0	F-2	2.01	19.22
<i>N. dutertrei</i>	64	MOZ1_A07, >315	22.0	F-0	3.41	45.29
<i>N. dutertrei</i>	65	MOZ1_A07, >315	18.0	F-1	3.11	14.89
<i>N. dutertrei</i>	65	MOZ1_A07, >315	18.0	F-2	3.10	14.58
<i>N. dutertrei</i>	65	MOZ1_A07, >315	18.0	F-0	3.02	12.43
<i>N. dutertrei</i>	66	MOZ1_A07, >315	27.0	F-1	2.27	11.05
<i>N. dutertrei</i>	66	MOZ1_A07, >315	27.0	F-2	2.11	11.78
<i>N. dutertrei</i>	66	MOZ1_A07, >315	27.0	F-0	3.46	18.04

<i>N. dutertrei</i>	67	MOZ1_A07, >315	35.0	F-1	1.44	9.70
<i>N. dutertrei</i>	67	MOZ1_A07, >315	35.0	F-2	1.36	16.75
<i>N. dutertrei</i>	67	MOZ1_A07, >315	35.0	F-0	2.83	18.48
<i>N. dutertrei</i>	68	MOZ1_A07, >315	24.0	F-1	1.88	15.64
<i>N. dutertrei</i>	68	MOZ1_A07, >315	24.0	F-2	1.48	15.49
<i>N. dutertrei</i>	69	MOZ1_A07, >315	25.0	F-1	1.73	9.37
<i>N. dutertrei</i>	69	MOZ1_A07, >315	25.0	F-2	2.22	13.54
<i>N. dutertrei</i>	70	MOZ1_A07, >315	28.0	F-1	2.02	20.33
<i>N. dutertrei</i>	70	MOZ1_A07, >315	28.0	F-2	1.18	10.83
<i>N. dutertrei</i>	71	MOZ1_A07, >315	33.0	F-1	2.13	10.43
<i>N. dutertrei</i>	71	MOZ4_A06 > 315	25.0	F-0	3.12	5.33
<i>N. dutertrei</i>	71	MOZ4_A06 > 315	25.0	F-1	1.67	1.67
<i>N. dutertrei</i>	71	MOZ4_A06 > 315	25.0	F-2	1.69	2.77
<i>N. dutertrei</i>	72	MOZ1_A07, >315	27.0	F-1	1.69	9.56
<i>N. dutertrei</i>	72	MOZ4_A06 > 315	18.0	F-0	2.86	25.77
<i>N. dutertrei</i>	72	MOZ4_A06 > 315	18.0	F-1	2.23	12.63
<i>N. dutertrei</i>	72	MOZ4_A06 > 315	18.0	F-2	2.61	12.69
<i>N. dutertrei</i>	73	MOZ1_A07, >315	26.0	F-2	1.31	6.39
<i>N. dutertrei</i>	73	MOZ4_A06 > 315	25.0	F-0	4.12	13.91
<i>N. dutertrei</i>	73	MOZ4_A06 > 315	25.0	F-1	3.24	5.11
<i>N. dutertrei</i>	73	MOZ4_A06 > 315	25.0	F-2	2.29	3.79
<i>N. dutertrei</i>	74	MOZ1_A07, >315	35.0	F-1	1.33	13.45
<i>N. dutertrei</i>	74	MOZ4_A06 > 315	21.0	F-0	4.32	6.01
<i>N. dutertrei</i>	74	MOZ4_A06 > 315	21.0	F-1	3.99	10.58
<i>N. dutertrei</i>	74	MOZ4_A06 > 315	21.0	F-2	3.45	5.99
<i>N. dutertrei</i>	75	MOZ1_A07, >315	36.0	F-2	1.63	11.14
<i>N. dutertrei</i>	75	MOZ4_A06 > 315	33.0	F-0	4.18	4.24
<i>N. dutertrei</i>	75	MOZ4_A06 > 315	33.0	F-1	2.82	4.40
<i>N. dutertrei</i>	75	MOZ4_A06 > 315	33.0	F-2	2.40	4.11
<i>N. dutertrei</i>	76	MOZ1_A07, >315	35.0	F-1	1.50	7.06
<i>N. dutertrei</i>	76	MOZ4_A06 > 315	30.0	F-0	3.16	2.55
<i>N. dutertrei</i>	76	MOZ4_A06 > 315	30.0	F-1	2.46	4.62
<i>N. dutertrei</i>	76	MOZ4_A06 > 315	30.0	F-2	2.59	N.A.
<i>N. dutertrei</i>	77	MOZ1_A07, >315	25.0	F-1	1.23	10.27
<i>N. dutertrei</i>	77	MOZ4_A06 > 315	39.0	F-0	2.55	33.98
<i>N. dutertrei</i>	77	MOZ4_A06 > 315	39.0	F-1	2.57	22.99
<i>N. dutertrei</i>	77	MOZ4_A06 > 315	39.0	F-2	2.32	15.31
<i>N. dutertrei</i>	78	MOZ1_A07, >315	32.0	F-2	1.29	10.63
<i>N. dutertrei</i>	78	MOZ4_A06 > 315	47.0	F-0	3.73	45.58

<i>N. dutertrei</i>	78	MOZ4_A06 > 315	47.0	F-1	2.52	11.76
<i>N. dutertrei</i>	78	MOZ4_A06 > 315	47.0	F-2	1.90	5.84
<i>N. dutertrei</i>	79	MOZ1_A07, >315	34.0	F-1	2.17	8.57
<i>N. dutertrei</i>	79	MOZ4_A06 > 315	31.0	F-0	3.02	5.92
<i>N. dutertrei</i>	79	MOZ4_A06 > 315	31.0	F-1	3.24	13.09
<i>N. dutertrei</i>	79	MOZ4_A06 > 315	31.0	F-2	3.40	14.33
<i>N. dutertrei</i>	80	MOZ1_A07, >315	26.0	F-2	1.11	11.83
<i>N. dutertrei</i>	80	MOZ4_A06 > 315	39.0	F-0	3.87	3.31
<i>N. dutertrei</i>	80	MOZ4_A06 > 315	39.0	F-1	2.53	4.31
<i>N. dutertrei</i>	80	MOZ4_A06 > 315	39.0	F-2	2.02	3.09
<i>N. dutertrei</i>	81	MOZ1_A07, >315	23.0	F-1	1.56	7.15
<i>N. dutertrei</i>	81	MOZ4_A06 > 315	35.0	F-0	6.43	41.23
<i>N. dutertrei</i>	81	MOZ4_A06 > 315	35.0	F-1	3.43	7.17
<i>N. dutertrei</i>	81	MOZ4_A06 > 315	35.0	F-2	3.32	7.81
<i>N. dutertrei</i>	82	MOZ1_A07, >315	30.0	F-2	2.02	11.74
<i>N. dutertrei</i>	82	MOZ4_A06 > 315	37.0	F-0	3.63	7.86
<i>N. dutertrei</i>	82	MOZ4_A06 > 315	37.0	F-1	2.97	4.42
<i>N. dutertrei</i>	82	MOZ4_A06 > 315	37.0	F-2	2.75	5.19
<i>N. dutertrei</i>	83	MOZ1_A07, >315	26.0	F-2	1.93	10.99
<i>N. dutertrei</i>	83	MOZ4_A06 > 315	29.0	F-0	4.95	12.00
<i>N. dutertrei</i>	83	MOZ4_A06 > 315	29.0	F-1	3.37	13.32
<i>N. dutertrei</i>	83	MOZ4_A06 > 315	29.0	F-2	2.27	7.72
<i>N. dutertrei</i>	84	MOZ1_A07, >315	27.0	F-2	0.99	8.72
<i>N. dutertrei</i>	84	MOZ4_A06 > 315	28.0	F-0	1.76	7.97
<i>N. dutertrei</i>	84	MOZ4_A06 > 315	28.0	F-1	2.23	4.00
<i>N. dutertrei</i>	84	MOZ4_A06 > 315	28.0	F-2	1.83	5.52
<i>N. dutertrei</i>	85	MOZ1_A07, >315	32.0	F-2	1.43	9.30
<i>N. dutertrei</i>	85	MOZ4_A06 > 315	29.0	F-0	5.33	53.19
<i>N. dutertrei</i>	85	MOZ4_A06 > 315	29.0	F-1	2.73	26.63
<i>N. dutertrei</i>	85	MOZ4_A06 > 315	29.0	F-2	2.19	13.56
<i>N. dutertrei</i>	86	MOZ1_A07, >315	35.0	F-2	1.40	17.40
<i>N. dutertrei</i>	86	MOZ4_A06 > 315	25.0	F-0	2.83	11.01
<i>N. dutertrei</i>	86	MOZ4_A06 > 315	25.0	F-1	1.64	2.38
<i>N. dutertrei</i>	86	MOZ4_A06 > 315	25.0	F-2	1.10	1.91
<i>N. dutertrei</i>	87	MOZ1_A08, >315	38.0	F-1	3.14	23.66
<i>N. dutertrei</i>	87	MOZ1_A08, >315	38.0	F-2	1.67	15.51
<i>N. dutertrei</i>	87	MOZ4_A06 > 315	27.0	F-0	3.07	16.44
<i>N. dutertrei</i>	87	MOZ4_A06 > 315	27.0	F-1	1.41	N.A.
<i>N. dutertrei</i>	87	MOZ4_A06 > 315	27.0	F-2	1.49	N.A.

<i>N. dutertrei</i>	88	MOZ1_A08, >315	32.0	F-1	2.56	26.14
<i>N. dutertrei</i>	88	MOZ1_A08, >315	32.0	F-2	1.47	16.00
<i>N. dutertrei</i>	88	MOZ4_A06 > 315	49.0	F-1	2.25	7.26
<i>N. dutertrei</i>	88	MOZ4_A06 > 315	49.0	F-2	1.96	5.06
<i>N. dutertrei</i>	89	MOZ1_A08, >315	30.0	F-1	2.74	28.25
<i>N. dutertrei</i>	89	MOZ1_A08, >315	30.0	F-2	2.68	27.85
<i>N. dutertrei</i>	89	MOZ4_A06 > 315	46.0	F-1	2.74	7.41
<i>N. dutertrei</i>	89	MOZ4_A06 > 315	46.0	F-2	2.45	2.88
<i>N. dutertrei</i>	89	MOZ4_A06 > 315	46.0	F-3	2.18	4.19
<i>N. dutertrei</i>	90	MOZ4_A06 > 315	33.0	F-1	4.12	8.48
<i>N. dutertrei</i>	90	MOZ4_A06 > 315	33.0	F-2	2.74	N.A.
<i>N. dutertrei</i>	90	MOZ4_A06 > 315	33.0	F-3	2.86	1.64
<i>N. dutertrei</i>	91	MOZ4_A06 > 315	36.0	F-1	3.21	3.49
<i>N. dutertrei</i>	91	MOZ4_A06 > 315	36.0	F-2	2.60	8.15
<i>N. dutertrei</i>	91	MOZ4_A06 > 315	36.0	F-3	1.89	7.03
<i>N. dutertrei</i>	92	MOZ4_A01, 250-315	15.0	F-0	2.68	5.11
<i>N. dutertrei</i>	92	MOZ4_A01, 250-315	15.0	F-1	2.19	3.75
<i>N. dutertrei</i>	92	MOZ4_A01, 250-315	15.0	F-2	1.62	0.96
<i>N. dutertrei</i>	93	MOZ4_A01, 250-315	22.0	F-0	2.81	5.02
<i>N. dutertrei</i>	93	MOZ4_A01, 250-315	22.0	F-1	2.78	4.84
<i>N. dutertrei</i>	93	MOZ4_A01, 250-315	22.0	F-2	2.17	2.73
<i>N. dutertrei</i>	94	MOZ4_A01, 250-315	10.0	F-0	3.06	6.72
<i>N. dutertrei</i>	94	MOZ4_A01, 250-315	10.0	F-1	4.35	8.43
<i>N. dutertrei</i>	95	MOZ4_A01, 250-315	13.0	F-0	3.26	11.32
<i>N. dutertrei</i>	95	MOZ4_A01, 250-315	13.0	F-1	4.45	15.54
<i>N. dutertrei</i>	95	MOZ4_A01, 250-315	13.0	F-2	3.77	9.96
<i>N. dutertrei</i>	96	MOZ4_A01, 250-315	15.0	F-0	4.12	17.71
<i>N. dutertrei</i>	96	MOZ4_A01, 250-315	15.0	F-1	5.46	27.14
<i>N. dutertrei</i>	96	MOZ4_A01, 250-315	15.0	F-2	4.68	15.29
<i>N. dutertrei</i>	97	MOZ4_A01, 250-315	25.0	F-0	1.50	1.73
<i>N. dutertrei</i>	97	MOZ4_A01, 250-315	25.0	F-2	1.64	2.99
<i>N. dutertrei</i>	97	MOZ4_A01, 250-315	25.0	F-3	1.53	0.89
<i>N. dutertrei</i>	98	MOZ4_A01, 250-315	24.0	F-0	3.85	4.20
<i>N. dutertrei</i>	98	MOZ4_A01, 250-315	24.0	F-1	3.01	5.61
<i>N. dutertrei</i>	98	MOZ4_A01, 250-315	24.0	F-2	3.06	2.04
<i>N. dutertrei</i>	99	MOZ4_A01, 250-315	13.0	F-0	2.06	10.74
<i>N. dutertrei</i>	99	MOZ4_A01, 250-315	13.0	F-1	1.96	9.52
<i>N. dutertrei</i>	99	MOZ4_A01, 250-315	13.0	F-2	1.78	4.79

species	ID	sample	weight [µg]	chamber	Mg/Ca [mmol/mol]	Mn/Ca [µmol/mol]
<i>P. obliquiloculata</i>	1	MOZ2_A11; >315	-	F-0	3.88	19.09
<i>P. obliquiloculata</i>	1	MOZ2_A11; >315	-	F-1	3.50	15.80
<i>P. obliquiloculata</i>	2	MOZ2_A11; >315	38.0	F-0	2.80	12.71
<i>P. obliquiloculata</i>	2	MOZ2_A12; >315	27.0	F-0	1.97	16.98
<i>P. obliquiloculata</i>	2	MOZ2_A12; >315	27.0	F-1	2.02	11.30
<i>P. obliquiloculata</i>	3	MOZ2_A11; >315	49.0	F-0	1.56	18.78
<i>P. obliquiloculata</i>	3	MOZ2_A11; >315	49.0	F-1	1.65	22.79
<i>P. obliquiloculata</i>	3	MOZ2_A11; >315	49.0	F-2	0.75	23.79
<i>P. obliquiloculata</i>	4	MOZ2_A11; >315	38.0	F-0	2.00	31.74
<i>P. obliquiloculata</i>	4	MOZ2_A11; >315	38.0	F-1	1.66	42.76
<i>P. obliquiloculata</i>	4	MOZ2_A11; >315	38.0	F-2	1.47	24.74
<i>P. obliquiloculata</i>	5	MOZ2_A11; >315	29.0	F-0	2.42	21.70
<i>P. obliquiloculata</i>	5	MOZ2_A11; >315	29.0	F-1	1.96	38.59
<i>P. obliquiloculata</i>	6	MOZ2_A11; >315	36.0	F-0	2.21	34.42
<i>P. obliquiloculata</i>	6	MOZ2_A11; >315	36.0	F-1	1.89	41.08
<i>P. obliquiloculata</i>	7	MOZ2_A11; >315	47.0	F-0	3.63	18.80
<i>P. obliquiloculata</i>	7	MOZ2_A11; >315	47.0	F-1	3.50	44.05
<i>P. obliquiloculata</i>	8	MOZ2_A11; >315	36.0	F-0	2.25	46.32
<i>P. obliquiloculata</i>	8	MOZ2_A11; >315	36.0	F-1	2.55	40.21
<i>P. obliquiloculata</i>	9	MOZ2_A11; >315	67.0	F-0	1.21	16.02
<i>P. obliquiloculata</i>	9	MOZ2_A11; >315	67.0	F-1	2.23	24.85
<i>P. obliquiloculata</i>	10	MOZ2_A11; >315	43.0	F-0	1.56	35.95
<i>P. obliquiloculata</i>	10	MOZ2_A11; >315	43.0	F-1	1.58	57.85
<i>P. obliquiloculata</i>	10	MOZ2_A12; >315	33.0	F-0	1.84	4.61
<i>P. obliquiloculata</i>	11	MOZ2_A11; >315	32.0	F-0	4.51	25.28
<i>P. obliquiloculata</i>	11	MOZ2_A11; >315	32.0	F-1	5.28	59.56
<i>P. obliquiloculata</i>	11	MOZ2_A12; >315	26.0	F-0	2.41	16.00
<i>P. obliquiloculata</i>	12	MOZ2_A12; >315	26.0	F-0	2.07	4.82
<i>P. obliquiloculata</i>	12	MOZ2_A12; >315	26.0	F-1	1.69	6.95
<i>P. obliquiloculata</i>	12	MOZ2_A12; >315	26.0	F-2	2.01	7.08
<i>P. obliquiloculata</i>	13	MOZ2_A12; >315	27.0	F-0	3.06	9.10
<i>P. obliquiloculata</i>	13	MOZ2_A12; >315	27.0	F-1	2.72	22.13
<i>P. obliquiloculata</i>	13	MOZ2_A12; >315	27.0	F-2	2.60	14.34
<i>P. obliquiloculata</i>	14	MOZ2_A12; >315	29.0	F-0	2.40	13.47
<i>P. obliquiloculata</i>	14	MOZ2_A12; >315	29.0	F-1	2.00	16.84
<i>P. obliquiloculata</i>	15	MOZ2_A12; >315	27.0	F-0	2.18	11.69
<i>P. obliquiloculata</i>	15	MOZ2_A12; >315	27.0	F-1	1.80	13.76
<i>P. obliquiloculata</i>	16	MOZ2_A12; >315	26.0	F-0	3.39	22.28

<i>P. obliquiloculata</i>	16	MOZ2_A12; >315	26.0	F-1	4.42	29.11
<i>P. obliquiloculata</i>	16	MOZ2_A12; >315	26.0	F-2	3.71	18.77
<i>P. obliquiloculata</i>	17	MOZ2_A12; >315	26.0	F-0	2.16	5.11
<i>P. obliquiloculata</i>	17	MOZ2_A12; >315	26.0	F-1	2.46	5.37
<i>P. obliquiloculata</i>	17	MOZ2_A12; >315	26.0	F-2	1.17	N.A.
<i>P. obliquiloculata</i>	18	MOZ2_A12; >315	26.0	F-1	2.10	22.35
<i>P. obliquiloculata</i>	18	MOZ2_A12; >315	27.0	F-0	3.68	6.15
<i>P. obliquiloculata</i>	18	MOZ2_A12; >315	27.0	F-1	3.62	8.35
<i>P. obliquiloculata</i>	18	MOZ2_A12; >315	27.0	F-2	3.44	9.10
<i>P. obliquiloculata</i>	19	MOZ2_A12; >315	40.0	F-0	1.82	6.64
<i>P. obliquiloculata</i>	19	MOZ2_A12; >315	40.0	F-1	1.97	28.00
<i>P. obliquiloculata</i>	20	MOZ2_A12; >315	31.0	F-0	1.96	9.87
<i>P. obliquiloculata</i>	20	MOZ2_A12; >315	31.0	F-1	1.79	4.48
<i>P. obliquiloculata</i>	20	MOZ2_A12; >315	31.0	F-2	1.87	7.75
<i>P. obliquiloculata</i>	21	MOZ2_A12; >315	43.0	F-0	1.50	5.41
<i>P. obliquiloculata</i>	21	MOZ2_A12; >315	43.0	F-1	1.44	9.54
<i>P. obliquiloculata</i>	22	MOZ2_A12; >315	14.0	F-0	1.82	41.90
<i>P. obliquiloculata</i>	22	MOZ2_A12; >315	14.0	F-1	2.55	18.07
<i>P. obliquiloculata</i>	23	MOZ2_A12; >315	35.0	F-0	2.34	27.07
<i>P. obliquiloculata</i>	23	MOZ2_A12; >315	35.0	F-1	2.25	24.03
<i>P. obliquiloculata</i>	23	MOZ2_A12; >315	35.0	F-2	2.41	24.25
<i>P. obliquiloculata</i>	24	MOZ2_A12; >315	32.0	F-0	4.00	17.58
<i>P. obliquiloculata</i>	24	MOZ2_A12; >315	32.0	F-1	3.19	16.76
<i>P. obliquiloculata</i>	25	MOZ2_A12; >315	16.0	F-1	2.28	12.05
<i>P. obliquiloculata</i>	25	MOZ2_A12; >315	16.0	F-0	3.30	37.44
<i>P. obliquiloculata</i>	25	MOZ2_A12; >315	16.0	F-2	3.00	37.75
<i>P. obliquiloculata</i>	26	MOZ4_A06 >315	91.0	F-0	2.22	47.93
<i>P. obliquiloculata</i>	26	MOZ4_A06 >315	91.0	F-1	1.58	30.07
<i>P. obliquiloculata</i>	26	MOZ4_A06 >315	91.0	F-2	1.72	34.48
<i>P. obliquiloculata</i>	27	MOZ4_A06 >315	67.0	F-0	2.73	7.37
<i>P. obliquiloculata</i>	27	MOZ4_A06 >315	67.0	F-1	2.98	12.07
<i>P. obliquiloculata</i>	27	MOZ4_A06 >315	67.0	F-2	2.57	11.54
<i>P. obliquiloculata</i>	28	MOZ4_A06 >315	55.0	F-0	2.14	8.32
<i>P. obliquiloculata</i>	28	MOZ4_A06 >315	55.0	F-1	1.97	8.70
<i>P. obliquiloculata</i>	28	MOZ4_A06 >315	55.0	F-2	2.00	5.15
<i>P. obliquiloculata</i>	29	MOZ4_A06 >315	44.0	F-0	2.75	8.08
<i>P. obliquiloculata</i>	29	MOZ4_A06 >315	44.0	F-0	2.65	6.15
<i>P. obliquiloculata</i>	29	MOZ4_A06 >315	44.0	F-2	2.49	5.10
<i>P. obliquiloculata</i>	30	MOZ4_A06 >315	42.0	F-0	2.38	33.18

<i>P. obliquiloculata</i>	30	MOZ4_A06 >315	42.0	F-1	1.89	17.64
<i>P. obliquiloculata</i>	31	MOZ4_A06 >315	50.0	F-0	3.24	10.21
<i>P. obliquiloculata</i>	31	MOZ4_A06 >315	50.0	F-1	2.92	10.19
<i>P. obliquiloculata</i>	32	MOZ4_A06 >315	35.0	F-0	2.22	29.96
<i>P. obliquiloculata</i>	32	MOZ4_A06 >315	35.0	F-1	2.02	14.03
<i>P. obliquiloculata</i>	32	MOZ4_A06 >315	35.0	F-2	2.60	12.16

species	ID	sample	weight [µg]	chamber	Mg/Ca [mmol/mol]	Mn/Ca [µmol/mol]
<i>G. ruber</i>	1	MOZ2_A12; 250-315	7.0	F-1	6.28	6.59
<i>G. ruber</i>	2	MOZ2_A12; 250-315	9.0	F-1	4.18	5.55
<i>G. ruber</i>	3	MOZ2_A12; 250-315	9.0	F-1	3.43	3.00
<i>G. ruber</i>	4	MOZ2_A12; 250-315	8.0	F-1	4.67	4.68
<i>G. ruber</i>	5	MOZ2_A12; 250-315	9.0	F-1	6.30	3.91
<i>G. ruber</i>	6	MOZ2_A12; 250-315	8.0	F-1	4.34	3.91
<i>G. ruber</i>	7	MOZ2_A12; 250-315	8.0	F-1	4.54	4.95
<i>G. ruber</i>	8	MOZ2_A12; 250-315	10.0	F-1	4.80	4.70
<i>G. ruber</i>	9	MOZ2_A12; 250-315	11.0	F-1	6.24	4.22
<i>G. ruber</i>	10	MOZ2_A12; 250-315	9.0	F-1	4.32	2.49
<i>G. ruber</i>	11	MOZ2_A12; 250-315	10.0	F-1	4.39	3.86
<i>G. ruber</i>	12	MOZ2_A12; 250-315	9.0	F-1	4.52	5.90
<i>G. ruber</i>	13	MOZ2_A12; 250-315	11.0	F-1	4.72	4.22
<i>G. ruber</i>	14	MOZ2_A12; 250-315	6.0	F-1	3.37	4.19
<i>G. ruber</i>	15	MOZ2_A12; 250-315	7.0	F-1	4.47	4.42
<i>G. ruber</i>	16	MOZ2_A12; 250-315	10.0	F-1	4.07	5.32
<i>G. ruber</i>	17	MOZ2_A12; 250-315	11.0	F-1	5.57	4.44
<i>G. ruber</i>	18	MOZ2_A12; 250-315	7.0	F-1	5.13	3.08
<i>G. ruber</i>	19	MOZ2_A12; 250-315	9.0	F-1	6.45	2.44
<i>G. ruber</i>	20	MOZ2_A12; 250-315	18.0	F-1	5.93	2.84
<i>G. ruber</i>	21	MOZ4_A01 >315	14.0	F-1	8.07	4.15
<i>G. ruber</i>	22	MOZ4_A01 >315	8.0	F-1	6.84	2.35
<i>G. ruber</i>	23	MOZ4_A01 >315	18.0	F-1	7.65	2.51
<i>G. ruber</i>	24	MOZ4_A01 >315	26.0	F-1	6.50	2.33
<i>G. ruber</i>	25	MOZ4_A01 >315	14.0	F-1	6.86	2.37
<i>G. ruber</i>	26	MOZ4_A01 >315	17.0	F-1	6.99	3.04
<i>G. ruber</i>	27	MOZ4_A01 >315	18.0	F-1	5.82	1.58
<i>G. ruber</i>	28	MOZ4_A01 >315	15.0	F-1	8.56	1.02
<i>G. ruber</i>	29	MOZ4_A01 >315	16.0	F-1	6.06	2.95
<i>G. ruber</i>	30	MOZ4_A01 >315	22.0	F-1	6.12	1.40
<i>G. ruber</i>	31	MOZ4_A01 >315	9.0	F-1	6.62	7.50

<i>G. ruber</i>	32	MOZ4_A01 >315	15.0	F-1	6.34	2.06
<i>G. ruber</i>	33	MOZ4_A01 >315	22.0	F-1	6.42	2.11
<i>G. ruber</i>	34	MOZ4_A01 >315	25.0	F-1	4.71	2.13
<i>G. ruber</i>	35	MOZ4_A01 >315	17.0	F-1	7.86	3.77
<i>G. ruber</i>	36	MOZ4_A01 >315	18.0	F-1	5.95	4.59
<i>G. ruber</i>	37	MOZ4_A01 >315	22.0	F-1	5.30	4.84
<i>G. ruber</i>	38	MOZ4_A01 >315	14.0	F-1	6.11	2.29
<i>G. ruber</i>	39	MOZ4_A01 >315	19.0	F-1	7.25	N.A
<i>G. ruber</i>	40	MOZ4_A01 >315	21.0	F-1	5.46	5.64
<i>G. ruber</i>	41	MOZ4_A01 >315	14.0	F-1	7.21	2.42
<i>G. ruber</i>	42	MOZ4_A01 >315	17.0	F-1	7.27	3.29
<i>G. ruber</i>	43	MOZ4_A01 >315	20.0	F-1	7.84	1.64
<i>G. ruber</i>	44	MOZ4_A01 >315	16.0	F-1	6.69	1.84
<i>G. ruber</i>	45	MOZ2_A11; 250-315	8.0	F-1	5.73	4.73
<i>G. ruber</i>	46	MOZ2_A11; 250-315	11.0	F-1	5.62	32.69
<i>G. ruber</i>	47	MOZ2_A11; 250-315	7.0	F-1	5.03	3.26
<i>G. ruber</i>	48	MOZ2_A11; 250-315	6.0	F-1	4.45	4.79
<i>G. ruber</i>	49	MOZ2_A11; 250-315	10.0	F-1	5.15	3.62
<i>G. ruber</i>	50	MOZ2_A11; 250-315	8.0	F-1	5.26	5.19
<i>G. ruber</i>	51	MOZ2_A11; 250-315	10.0	F-1	4.10	11.61
<i>G. ruber</i>	52	MOZ2_A11; 250-315	6.0	F-1	3.09	4.71
<i>G. ruber</i>	53	MOZ2_A11; >315	17.0	F-1	4.24	1.75
<i>G. ruber</i>	54	MOZ2_A11; >315	12.0	F-1	6.36	0.60
<i>G. ruber</i>	55	MOZ2_A11; >315	15.0	F-1	3.43	0.97
<i>G. ruber</i>	56	MOZ2_A11; >315	11.0	F-1	7.63	1.15
<i>G. ruber</i>	57	MOZ2_A11; >315	10.0	F-1	5.39	2.68
<i>G. ruber</i>	58	MOZ2_A11; >315	13.0	F-1	5.62	1.77
<i>G. ruber</i>	59	MOZ2_A11; >315	14.0	F-1	5.77	4.22
<i>G. ruber</i>	60	MOZ2_A11; >315	16.0	F-1	4.57	1.69
<i>G. ruber</i>	61	MOZ2_A11; >315	9.0	F-1	5.97	N.A
<i>G. ruber</i>	62	MOZ2_A11; >315	15.0	F-1	5.56	3.44
<i>G. ruber</i>	63	MOZ2_A11; >315	14.0	F-1	4.64	3.51
<i>G. ruber</i>	64	MOZ2_A11; >315	6.0	F-1	5.92	0.67
<i>G. ruber</i>	65	MOZ2_A11; >315	10.0	F-1	5.65	2.80
<i>G. ruber</i>	66	MOZ2_A11; >315	19.0	F-1	4.78	4.04
<i>G. ruber</i>	67	MOZ2_A11; >315	21.0	F-1	4.58	1.51
<i>G. ruber</i>	68	MOZ2_A11; >315	14.0	F-1	4.29	1.87
<i>G. ruber</i>	69	MOZ2_A11; >315	13.0	F-1	5.07	1.07
<i>G. ruber</i>	70	MOZ2_A11; >315	15.0	F-1	4.24	2.35

<i>G. ruber</i>	71	MOZ2_A11; >315	19.0	F-1	6.66	4.51
<i>G. ruber</i>	72	MOZ2_A11; >315	21.0	F-1	5.02	5.19
<i>G. ruber</i>	73	MOZ2_A11; >315	17.0	F-1	4.72	2.82
<i>G. ruber</i>	74	MOZ2_A11; >315	17.0	F-1	4.97	4.75
<i>G. ruber</i>	75	MOZ1_A07, >315	15.0	F-2	4.44	10.47
<i>G. ruber</i>	76	MOZ1_A07, >315	17.0	F-2	3.36	14.63
<i>G. ruber</i>	77	MOZ1_A07, >315	13.0	F-2	5.28	6.92
<i>G. ruber</i>	78	MOZ1_A07, >315	15.0	F-2	5.11	11.30
<i>G. ruber</i>	79	MOZ1_A07, >315	16.0	F-2	5.52	22.04
<i>G. ruber</i>	80	MOZ1_A07, >315	20.0	F-2	6.81	18.60
<i>G. ruber</i>	81	MOZ1_A07, >315	16.0	F-2	4.85	11.72
<i>G. ruber</i>	82	MOZ1_A07, >315	18.0	F-2	3.53	14.82
<i>G. ruber</i>	83	MOZ1_A07, >315	14.0	F-2	4.15	15.60
<i>G. ruber</i>	84	MOZ1_A07, >315	12.0	F-2	4.54	15.65
<i>G. ruber</i>	85	MOZ1_A07, >315	15.0	F-2	4.09	18.38
<i>G. ruber</i>	86	MOZ1_A07, >315	11.0	F-2	3.33	14.94
<i>G. ruber</i>	87	MOZ1_A07, >315	10.0	F-2	5.35	14.25
<i>G. ruber</i>	88	MOZ1_A07, >315	17.0	F-2	4.63	15.33
<i>G. ruber</i>	89	MOZ1_A07, >315	21.0	F-2	4.24	14.65
<i>G. ruber</i>	90	MOZ1_A07, >315	8.0	F-2	4.80	20.19
<i>G. ruber</i>	91	MOZ1_A07, >315	19.0	F-2	3.87	12.83
<i>G. ruber</i>	92	MOZ1_A07, >315	11.0	F-2	3.30	13.98
<i>G. ruber</i>	93	MOZ1_A07, >315	13.0	F-2	3.25	8.57
<i>G. ruber</i>	94	MOZ1_A07, >315	13.0	F-2	3.72	9.10
<i>G. ruber</i>	95	MOZ1_A07, 250-315	11.0	F-2	4.01	22.39
<i>G. ruber</i>	96	MOZ1_A07, 250-315	11.0	F-2	5.23	12.98
<i>G. ruber</i>	97	MOZ1_A07, 250-315	10.0	F-2	4.09	13.78
<i>G. ruber</i>	98	MOZ1_A07, 250-315	11.0	F-2	4.01	13.67
<i>G. ruber</i>	99	MOZ1_A07, 250-315	13.0	F-2	4.82	30.07
<i>G. ruber</i>	100	MOZ1_A07, 250-315	14.0	F-2	4.71	12.51
<i>G. ruber</i>	101	MOZ1_A07, 250-315	7.0	F-2	4.29	15.71
<i>G. ruber</i>	102	MOZ1_A07, 250-315	13.0	F-2	5.31	18.99
<i>G. ruber</i>	103	MOZ1_A07, 250-315	9.0	F-2	4.96	12.25
<i>G. ruber</i>	104	MOZ1_A07, 250-315	11.0	F-2	4.38	14.02
<i>G. ruber</i>	105	MOZ1_A07, 250-315	12.0	F-2	4.49	9.43
<i>G. ruber</i>	106	MOZ1_A07, 250-315	12.0	F-2	4.06	10.58
<i>G. ruber</i>	107	MOZ1_A07, 250-315	8.0	F-2	5.13	14.45
<i>G. ruber</i>	108	MOZ1_A07, 250-315	11.0	F-2	6.09	11.83
<i>G. ruber</i>	109	MOZ1_A07, 250-315	9.0	F-2	4.21	11.41

<i>G. ruber</i>	110	MOZ1_A07, 250-315	8.0	F-2	4.89	12.01
<i>G. ruber</i>	111	MOZ1_A07, 250-315	10.0	F-2	4.08	12.09
<i>G. ruber</i>	112	MOZ1_A07, 250-315	11.0	F-2	4.55	16.91
<i>G. ruber</i>	113	MOZ1_A07, 250-315	14.0	F-2	4.03	12.01
<i>G. ruber</i>	114	MOZ1_A07, 250-315	10.0	F-2	5.52	11.96
<i>G. ruber</i>	115	MOZ1_A07, 250-315	11.0	F-2	4.08	17.53
<i>G. ruber</i>	116	MOZ1_A08, 250-315	10.0	F-2	4.83	23.01
<i>G. ruber</i>	117	MOZ1_A08, 250-315	7.0	F-2	4.53	10.83
<i>G. ruber</i>	118	MOZ1_A08, 250-315	10.0	F-2	4.94	23.70
<i>G. ruber</i>	119	MOZ1_A08, 250-315	14.0	F-2	7.14	21.35
<i>G. ruber</i>	120	MOZ1_A08, 250-315	10.0	F-2	3.05	15.91
<i>G. ruber</i>	121	MOZ1_A08, 250-315	10.0	F-2	5.57	18.17
<i>G. ruber</i>	122	MOZ1_A08, 250-315	18.0	F-2	4.52	21.01
<i>G. ruber</i>	123	MOZ1_A08, 250-315	12.0	F-2	5.93	44.91
<i>G. ruber</i>	124	MOZ1_A08, 250-315	14.0	F-2	4.92	16.02
<i>G. ruber</i>	125	MOZ1_A08, 250-315	14.0	F-2	6.81	15.34
<i>G. ruber</i>	126	MOZ1_A08, 250-315	11.0	F-2	4.99	20.00
<i>G. ruber</i>	127	MOZ1_A08, 250-315	12.0	F-2	5.47	21.46
<i>G. ruber</i>	128	MOZ1_A08, 250-315	12.0	F-2	4.67	18.09
<i>G. ruber</i>	129	MOZ1_A08, 250-315	10.0	F-2	5.72	27.41
<i>G. ruber</i>	130	MOZ1_A08, 250-315	12.0	F-2	5.23	11.58
<i>G. ruber</i>	131	MOZ1_A08, 250-315	14.0	F-2	4.38	29.00
<i>G. ruber</i>	132	MOZ4_A06 > 315	10.0	F-2	4.90	4.48
<i>G. ruber</i>	133	MOZ4_A06 > 315	11.0	F-2	5.49	1.97
<i>G. ruber</i>	134	MOZ4_A06 > 315	18.0	F-2	4.51	1.69
<i>G. ruber</i>	135	MOZ4_A06 > 315	11.0	F-2	5.74	3.79
<i>G. ruber</i>	136	MOZ4_A06 > 315	15.0	F-2	5.56	2.20
<i>G. ruber</i>	137	MOZ4_A06 > 315	18.0	F-2	4.89	3.42
<i>G. ruber</i>	138	MOZ4_A06 > 315	10.0	F-2	3.51	1.73
<i>G. ruber</i>	139	MOZ4_A06 > 315	17.0	F-2	4.46	1.60
<i>G. ruber</i>	140	MOZ4_A06 > 315	19.0	F-2	7.97	4.53
<i>G. ruber</i>	141	MOZ4_A06 > 315	20.0	F-2	5.33	4.99
<i>G. ruber</i>	142	MOZ4_A06 > 315	18.0	F-2	5.54	4.28
<i>G. ruber</i>	143	MOZ4_A06 > 315	17.0	F-2	5.21	6.32
<i>G. ruber</i>	144	MOZ4_A06 > 315	21.0	F-2	5.67	3.17
<i>G. ruber</i>	145	MOZ4_A06 > 315	15.0	F-2	5.24	5.01
<i>G. ruber</i>	146	MOZ4_A06 > 315	12.0	F-2	8.30	1.87
<i>G. ruber</i>	147	MOZ4_A06 > 315	7.0	F-2	7.45	17.31
<i>G. ruber</i>	148	MOZ4_A06 > 315	10.0	F-2	5.46	2.66

<i>G. ruber</i>	149	MOZ4_A06 > 315	20.0	F-2	5.39	5.52
<i>G. ruber</i>	150	MOZ4_A06 > 315	10.0	F-2	5.90	6.64
<i>G. ruber</i>	151	MOZ4_A06 > 315	15.0	F-2	6.21	3.09
<i>G. ruber</i>	152	MOZ4_A06 250-315	11.0	F-2	7.59	4.35
<i>G. ruber</i>	153	MOZ4_A06 250-315	14.0	F-2	6.60	4.13
<i>G. ruber</i>	154	MOZ4_A06 250-315	10.0	F-2	5.28	4.79
<i>G. ruber</i>	155	MOZ4_A06 250-315	16.0	F-2	4.31	1.91
<i>G. ruber</i>	156	MOZ4_A06 250-315	11.0	F-2	5.20	2.37
<i>G. ruber</i>	157	MOZ4_A06 250-315	10.0	F-2	6.85	N.A
<i>G. ruber</i>	158	MOZ4_A06 250-315	14.0	F-2	4.30	3.57
<i>G. ruber</i>	159	MOZ4_A06 250-315	13.0	F-2	7.42	4.73
<i>G. ruber</i>	160	MOZ4_A06 250-315	11.0	F-2	3.74	5.26
<i>G. ruber</i>	161	MOZ4_A06 250-315	14.0	F-2	11.22	3.53
<i>G. ruber</i>	162	MOZ4_A06 250-315	11.0	F-2	6.80	N.A
<i>G. ruber</i>	163	MOZ4_A06 250-315	9.0	F-2	6.23	1.07
<i>G. ruber</i>	164	MOZ4_A06 250-315	11.0	F-2	8.39	3.80
<i>G. ruber</i>	165	MOZ4_A06 250-315	11.0	F-2	8.31	3.19
<i>G. ruber</i>	166	MOZ4_A06 250-315	12.0	F-2	5.20	1.53
<i>G. ruber</i>	167	MOZ4_A06 250-315	6.0	F-2	5.90	0.91
<i>G. ruber</i>	168	MOZ4_A06 250-315	16.0	F-2	6.56	2.06
<i>G. ruber</i>	169	MOZ4_A06 250-315	13.0	F-2	7.35	2.77
<i>G. ruber</i>	170	MOZ4_A06 250-315	9.0	F-2	7.47	1.71
<i>G. ruber</i>	171	MOZ4_A06 250-315	12.0	F-2	5.49	3.66
<i>G. ruber</i>	172	MOZ4_A06 250-315	14.0	F-2	7.14	3.53
<i>G. ruber</i>	173	MOZ4_A06 250-315	13.0	F-2	5.72	2.48
<i>G. ruber</i>	174	MOZ4_A06 250-315	9.0	F-2	7.61	1.53
<i>G. ruber</i>	175	MOZ4_A06 250-315	12.0	F-2	8.20	3.00
<i>G. ruber</i>	176	MOZ4_A06 250-315	6.0	F-2	5.76	3.66

species	ID	sample	weight [µg]	chamber	Mg/Ca [mmol/mol]	Mn/Ca [µmol/mol]
<i>G. scitula</i>	1	MOZ1_A07, >315	51.0	F-0	2.18	46.56
<i>G. scitula</i>	1	MOZ1_A07, >315	51.0	F-1	1.83	32.51
<i>G. scitula</i>	1	MOZ1_A07, >315	51.0	F-2	1.95	13.32
<i>G. scitula</i>	2	MOZ1_A07, >315	36.0	F-0	1.68	49.07
<i>G. scitula</i>	2	MOZ1_A07, >315	36.0	F-1	2.51	59.83
<i>G. scitula</i>	2	MOZ1_A07, >315	36.0	F-2	2.38	64.35
<i>G. scitula</i>	3	MOZ1_A07, >315	38.0	F-0	1.09	11.96
<i>G. scitula</i>	3	MOZ1_A07, >315	38.0	F-1	1.09	48.07
<i>G. scitula</i>	3	MOZ1_A07, >315	38.0	F-2	1.26	54.61

<i>G. scitula</i>	4	MOZ1_A07, >315	31.0	F-0	1.55	29.58
<i>G. scitula</i>	4	MOZ1_A07, >315	31.0	F-2	1.57	38.75
<i>G. scitula</i>	5	MOZ1_A07, >315	34.0	F-0	1.22	17.98
<i>G. scitula</i>	5	MOZ1_A07, >315	34.0	F-1	1.28	61.65
<i>G. scitula</i>	5	MOZ1_A07, >315	34.0	F-2	1.60	86.28
<i>G. scitula</i>	6	MOZ1_A07, >315	29.0	F-0	0.68	1.93
<i>G. scitula</i>	6	MOZ1_A07, >315	29.0	F-1	2.07	20.15
<i>G. scitula</i>	6	MOZ1_A07, >315	29.0	F-2	2.05	30.94
<i>G. scitula</i>	7	MOZ1_A07, >315	33.0	F-1	1.45	40.05
<i>G. scitula</i>	7	MOZ1_A07, >315	33.0	F-2	2.01	103.92
<i>G. scitula</i>	8	MOZ1_A08, >315	26.0	F-0	1.32	22.35
<i>G. scitula</i>	8	MOZ1_A08, >315	26.0	F-2	1.09	63.58
<i>G. scitula</i>	9	MOZ1_A08, >315	25.0	F-0	2.17	25.87
<i>G. scitula</i>	9	MOZ1_A08, >315	25.0	F-1	1.62	72.12
<i>G. scitula</i>	9	MOZ1_A08, >315	25.0	F-2	1.23	125.18
<i>G. scitula</i>	10	MOZ1_A08, >315	23.0	F-0	1.00	12.78
<i>G. scitula</i>	10	MOZ1_A08, >315	23.0	F-1	1.20	67.06
<i>G. scitula</i>	10	MOZ1_A08, >315	23.0	F-2	1.29	65.77
<i>G. scitula</i>	11	MOZ1_A08, >315	28.0	F-0	1.30	21.52
<i>G. scitula</i>	11	MOZ1_A08, >315	28.0	F-1	0.96	41.06
<i>G. scitula</i>	11	MOZ1_A08, >315	28.0	F-2	1.24	56.75
<i>G. scitula</i>	12	MOZ1_A08, >315	34.0	F-0	1.49	21.35
<i>G. scitula</i>	12	MOZ1_A08, >315	34.0	F-1	1.44	30.45
<i>G. scitula</i>	12	MOZ1_A08, >315	34.0	F-2	1.21	38.88
<i>G. scitula</i>	13	MOZ1_A08, >315	33.0	F-0	1.32	10.76
<i>G. scitula</i>	13	MOZ1_A08, >315	33.0	F-2	1.20	35.00
<i>G. scitula</i>	14	MOZ1_A08, >315	33.0	F-1	1.67	24.06
<i>G. scitula</i>	14	MOZ1_A08, >315	33.0	F-2	1.33	25.52
<i>G. scitula</i>	15	MOZ2_A11; >315	35.0	F-0	1.28	13.05
<i>G. scitula</i>	15	MOZ2_A11; >315	35.0	F-1	1.18	40.97
<i>G. scitula</i>	15	MOZ2_A11; >315	35.0	F-2	1.27	90.28
<i>G. scitula</i>	16	MOZ2_A11; >315	29.0	F-0	1.93	48.51
<i>G. scitula</i>	16	MOZ2_A11; >315	29.0	F-1	1.61	37.93
<i>G. scitula</i>	16	MOZ2_A11; >315	29.0	F-2	1.76	33.66
<i>G. scitula</i>	17	MOZ2_A11; >315	24.0	F-0	1.11	12.71
<i>G. scitula</i>	17	MOZ2_A11; >315	24.0	F-1	0.94	38.63
<i>G. scitula</i>	18	MOZ2_A11; >315	32.0	F-0	1.58	11.96
<i>G. scitula</i>	18	MOZ2_A11; >315	32.0	F-1	1.38	9.32
<i>G. scitula</i>	18	MOZ2_A11; >315	32.0	F-2	1.30	47.98

<i>G. scitula</i>	19	MOZ2_A11; >315	28.0	F-0	2.61	12.98
<i>G. scitula</i>	19	MOZ2_A11; >315	28.0	F-1	1.76	24.19
<i>G. scitula</i>	19	MOZ2_A11; >315	28.0	F-2	1.86	46.87
<i>G. scitula</i>	20	MOZ2_A11; >315	30.0	F-0	1.37	21.92
<i>G. scitula</i>	20	MOZ2_A11; >315	30.0	F-1	1.35	43.10
<i>G. scitula</i>	20	MOZ2_A11; >315	30.0	F-2	1.09	51.82
<i>G. scitula</i>	21	MOZ2_A11; >315	23.0	F-0	1.51	18.04
<i>G. scitula</i>	21	MOZ2_A11; >315	23.0	F-1	2.15	84.09
<i>G. scitula</i>	21	MOZ2_A11; >315	23.0	F-2	2.12	78.93
<i>G. scitula</i>	22	MOZ2_A11; >315	24.0	F-0	1.31	8.23
<i>G. scitula</i>	22	MOZ2_A11; >315	24.0	F-1	1.35	18.82
<i>G. scitula</i>	22	MOZ2_A11; >315	24.0	F-2	1.10	46.31
<i>G. scitula</i>	23	MOZ2_A11; >315	30.0	F-0	1.25	6.81
<i>G. scitula</i>	23	MOZ2_A11; >315	30.0	F-1	1.29	50.60
<i>G. scitula</i>	23	MOZ2_A11; >315	30.0	F-2	1.30	117.68
<i>G. scitula</i>	24	MOZ2_A11; >315	31.0	F-1	1.17	55.86
<i>G. scitula</i>	24	MOZ2_A11; >315	31.0	F-2	1.13	51.68
<i>G. scitula</i>	25	MOZ2_A12; >315	26.0	F-0	1.07	15.62
<i>G. scitula</i>	25	MOZ2_A12; >315	26.0	F-1	1.03	38.50
<i>G. scitula</i>	25	MOZ2_A12; >315	26.0	F-2	1.29	50.22
<i>G. scitula</i>	26	MOZ2_A12; >315	23.0	F-0	1.29	14.78
<i>G. scitula</i>	26	MOZ2_A12; >315	23.0	F-1	1.16	38.19
<i>G. scitula</i>	26	MOZ2_A12; >315	23.0	F-2	1.16	51.49
<i>G. scitula</i>	27	MOZ2_A12; >315	18.0	F-0	2.59	15.51
<i>G. scitula</i>	27	MOZ2_A12; >315	18.0	F-1	2.71	57.70
<i>G. scitula</i>	27	MOZ2_A12; >315	18.0	F-2	1.83	55.64
<i>G. scitula</i>	28	MOZ2_A12; >315	26.0	F-1	1.61	31.18
<i>G. scitula</i>	28	MOZ2_A12; >315	26.0	F-2	1.83	28.18
<i>G. scitula</i>	29	MOZ4_A01 >315	37.0	F-0	1.92	27.12
<i>G. scitula</i>	29	MOZ4_A01 >315	37.0	F-1	1.51	48.91
<i>G. scitula</i>	29	MOZ4_A01 >315	37.0	F-2	1.61	76.65
<i>G. scitula</i>	30	MOZ4_A01 >315	24.0	F-0	1.72	16.89
<i>G. scitula</i>	30	MOZ4_A01 >315	24.0	F-1	1.90	27.74
<i>G. scitula</i>	30	MOZ4_A01 >315	24.0	F-2	2.13	24.30
<i>G. scitula</i>	31	MOZ4_A01 >315	40.0	F-0	1.97	31.74
<i>G. scitula</i>	31	MOZ4_A01 >315	40.0	F-1	1.46	56.68
<i>G. scitula</i>	31	MOZ4_A01 >315	40.0	F-2	1.25	85.71
<i>G. scitula</i>	32	MOZ4_A01 >315	30.0	F-1	2.60	49.75
<i>G. scitula</i>	32	MOZ4_A01 >315	30.0	F-2	1.65	49.11

<i>G. scitula</i>	33	MOZ4_A06 > 315	30.0	F-0	1.53	15.05
<i>G. scitula</i>	33	MOZ4_A06 > 315	30.0	F-1	1.31	37.55
<i>G. scitula</i>	33	MOZ4_A06 > 315	30.0	F-2	1.27	52.08
<i>G. scitula</i>	34	MOZ4_A06 > 315	35.0	F-0	1.47	11.27
<i>G. scitula</i>	34	MOZ4_A06 > 315	35.0	F-1	1.17	21.82
<i>G. scitula</i>	34	MOZ4_A06 > 315	35.0	F-2	1.27	23.26
<i>G. scitula</i>	35	MOZ4_A06 > 315	27.0	F-0	1.34	18.68
<i>G. scitula</i>	35	MOZ4_A06 > 315	27.0	F-1	1.63	39.34
<i>G. scitula</i>	35	MOZ4_A06 > 315	27.0	F-2	1.24	36.60
<i>G. scitula</i>	36	MOZ4_A06 > 315	31.0	F-0	1.52	29.89
<i>G. scitula</i>	36	MOZ4_A06 > 315	31.0	F-1	1.44	60.45
<i>G. scitula</i>	36	MOZ4_A06 > 315	31.0	F-2	1.34	66.47
<i>G. scitula</i>	37	MOZ4_A06 > 315	38.0	F-0	1.65	17.97
<i>G. scitula</i>	37	MOZ4_A06 > 315	38.0	F-1	1.44	13.82
<i>G. scitula</i>	37	MOZ4_A06 > 315	38.0	F-2	1.17	13.80
<i>G. scitula</i>	38	MOZ4_A06 > 315	38.0	F-0	1.60	14.49
<i>G. scitula</i>	38	MOZ4_A06 > 315	38.0	F-1	1.50	18.02
<i>G. scitula</i>	38	MOZ4_A06 > 315	38.0	F-2	0.89	51.69
<i>G. scitula</i>	39	MOZ4_A06 >315	8.0	F-0	2.47	19.68
<i>G. scitula</i>	39	MOZ4_A06 >315	8.0	F-1	2.24	42.45
<i>G. scitula</i>	39	MOZ4_A06 >315	8.0	F-2	2.65	85.51
<i>G. scitula</i>	40	MOZ4_A06 >315	23.0	F-0	1.88	15.04
<i>G. scitula</i>	40	MOZ4_A06 >315	23.0	F-1	1.52	31.33
<i>G. scitula</i>	40	MOZ4_A06 >315	23.0	F-2	1.61	53.04
<i>G. scitula</i>	41	MOZ4_A06 >315	21.0	F-0	1.96	20.97
<i>G. scitula</i>	41	MOZ4_A06 >315	21.0	F-1	1.34	40.88
<i>G. scitula</i>	41	MOZ4_A06 >315	21.0	F-2	1.80	61.34
<i>G. scitula</i>	42	MOZ4_A06 >315	24.0	F-0	1.77	5.95
<i>G. scitula</i>	42	MOZ4_A06 >315	24.0	F-1	2.05	26.23
<i>G. scitula</i>	42	MOZ4_A06 >315	24.0	F-2	1.58	45.54
<i>G. scitula</i>	43	MOZ4_A06 >315	22.0	F-0	2.22	23.77
<i>G. scitula</i>	43	MOZ4_A06 >315	22.0	F-1	1.94	48.75
<i>G. scitula</i>	43	MOZ4_A06 >315	22.0	F-2	2.25	53.04
<i>G. scitula</i>	44	MOZ4_A06 >315	15.0	F-0	2.21	21.41
<i>G. scitula</i>	44	MOZ4_A06 >315	15.0	F-1	1.31	30.02
<i>G. scitula</i>	44	MOZ4_A06 >315	15.0	F-2	1.31	64.60
<i>G. scitula</i>	45	MOZ4_A06 >315	19.0	F-0	2.10	16.15
<i>G. scitula</i>	45	MOZ4_A06 >315	19.0	F-1	1.91	28.47
<i>G. scitula</i>	45	MOZ4_A06 >315	19.0	F-2	2.36	49.93

Appendix table chapter 4

deployment	cond.	sp.	weight	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$ SD	$\delta^{18}\text{O}$	$\delta^{18}\text{O}$ SD	Cham.	Mg/Ca	Cham.	Mg/Ca	Cham.	Mg/Ca
MOZ1_A08, 250-315	Eddy	G. rub	18	0.933	0.107	-2.960	0.130					F-2	4.52
MOZ1_A08, 250-315	Eddy	G. rub	14	0.480	0.113	-2.760	0.102					F-2	7.14
MOZ1_A08, 250-315	Eddy	G. rub	14	0.135	0.116	-2.739	0.105					F-2	4.92
MOZ1_A08, 250-315	Eddy	G. rub	14	0.496	0.203	-2.688	0.145					F-2	6.81
MOZ1_A08, 250-315	Eddy	G. rub	14	0.606	0.119	-2.705	0.070					F-2	4.38
MOZ1_A08, 250-315	Eddy	G. rub	12	0.175	0.103	-3.088	0.089					F-2	5.93
MOZ1_A08, 250-315	Eddy	G. rub	12	0.313	0.148	-2.533	0.065					F-2	5.47
MOZ1_A08, 250-315	Eddy	G. rub	12	0.119	0.123	-2.258	0.082					F-2	4.67
MOZ1_A08, 250-315	Eddy	G. rub	12	0.629	0.186	-3.044	0.082					F-2	5.23
MOZ1_A08, 250-315	Eddy	G. rub	11	0.312	0.170	-2.924	0.109					F-2	4.99
MOZ1_A08, 250-315	Eddy	G. rub	10	0.810	0.169	-3.083	0.091					F-2	4.83
MOZ1_A08, 250-315	Eddy	G. rub	10	1.013	0.111	-3.094	0.151					F-2	4.94
MOZ1_A08, 250-315	Eddy	G. rub	10	0.390	0.128	-3.260	0.080					F-2	3.05
MOZ1_A08, 250-315	Eddy	G. rub	10	0.302	0.142	-2.808	0.176					F-2	5.57
MOZ1_A08, 250-315	Eddy	G. rub	10	0.399	0.137	-3.328	0.086					F-2	5.72
MOZ1_A08, 250-315	Eddy	G. rub	7	0.120	0.187	-2.639	0.202					F-2	4.53
MOZ2_A11; >315	Eddy	G. rub	17	0.973	0.157	-2.436	0.092			F-1	4.72		
MOZ2_A11; >315	Eddy	G. rub	17	-0.239	0.137	-2.341	0.110			F-1	4.97		
MOZ2_A11; >315	Eddy	G. rub	17	0.661	0.096	-2.303	0.077			F-1	4.24		
MOZ2_A11; >315	Eddy	G. rub	16	0.638	0.141	-2.481	0.096			F-1	4.57		
MOZ2_A11; >315	Eddy	G. rub	16	0.557	0.108	-2.470	0.055						
MOZ2_A11; >315	Eddy	G. rub	15	0.206	0.097	-2.398	0.105			F-1	3.43		
MOZ2_A11; >315	Eddy	G. rub	15	-0.113	0.216	-2.694	0.129			F-1	5.56		
MOZ2_A11; >315	Eddy	G. rub	15	0.877	0.168	-2.354	0.091			F-1	4.24		
MOZ2_A11; >315	Eddy	G. rub	14	1.238	0.067	-2.549	0.099			F-1	5.77		
MOZ2_A11; >315	Eddy	G. rub	14	0.310	0.151	-2.094	0.148			F-1	4.64		
MOZ2_A11; >315	Eddy	G. rub	14	0.489	0.125	-2.302	0.091			F-1	4.29		
MOZ2_A11; >315	Eddy	G. rub	13	0.703	0.122	-2.292	0.117			F-1	5.62		
MOZ2_A11; >315	Eddy	G. rub	13	0.513	0.109	-2.418	0.212			F-1	5.07		

MOZ2_A11; >315	Eddy	G. rub	12	0.412	0.107	-2.695	0.100	F-1	6.36
MOZ2_A11; >315	Eddy	G. rub	11	0.822	0.089	-2.356	0.163	F-1	7.63
MOZ2_A11; >315	Eddy	G. rub	10	0.386	0.162	-2.382	0.137	F-1	5.39
MOZ2_A11; >315	Eddy	G. rub	10	-0.001	0.125	-2.210	0.177	F-1	5.65
MOZ2_A11; >315	Eddy	G. rub	9	0.129	0.335	-1.973	0.204	F-1	5.97
MOZ2_A11; >315	Eddy	G. rub	6	0.431	0.131	-2.214	0.190	F-1	5.92
MOZ2_A11; >315	Eddy	G. rub	21	0.119	0.016	-1.435	0.023	F-1	4.58
MOZ2_A11; >315	Eddy	G. rub	21	1.069	0.008	-1.342	0.022	F-1	5.02
MOZ2_A11; >315	Eddy	G. rub	19	0.571	0.015	-0.799	0.021	F-1	4.78
MOZ2_A11; >315	Eddy	G. rub	19	0.270	0.013	-1.587	0.038	F-1	6.66
MOZ2_A11; 250-315	Eddy	G. rub	11	-0.466	0.235	-3.052	0.221	F-1	5.62
MOZ2_A11; 250-315	Eddy	G. rub	10	N.A.	N.A.	N.A.	N.A.	F-1	5.15
MOZ2_A11; 250-315	Eddy	G. rub	10	0.475	0.168	-2.883	0.131	F-1	4.10
MOZ2_A11; 250-315	Eddy	G. rub	8	-0.514	0.219	-2.426	0.345	F-1	5.73
MOZ2_A11; 250-315	Eddy	G. rub	8	-0.072	0.222	-1.936	0.389	F-1	5.26
MOZ2_A11; 250-315	Eddy	G. rub	7	0.294	0.107	-1.783	0.142	F-1	5.03
MOZ2_A11; 250-315	Eddy	G. rub	6	-0.454	0.192	-2.345	0.221	F-1	4.45
MOZ2_A11; 250-315	Eddy	G. rub	6	-0.205	0.155	-1.994	0.135	F-1	3.09
MOZ2_ A11;>315	Eddy	G. rub	21	1.063	0.091	-2.243	0.077	F-1	4.58
MOZ2_ A11;>315	Eddy	G. rub	21	1.007	0.092	-2.156	0.113	F-1	5.02
MOZ2_ A11;>315	Eddy	G. rub	19	0.119	0.068	-3.441	0.076	F-1	4.78
MOZ2_ A11;>315	Eddy	G. rub	19	0.493	0.069	-2.312	0.091	F-1	6.66
MOZ4_A01 >315	Eddy	G. rub	22	0.981	0.100	-2.328	0.097	F-1	6.12
MOZ4_A01 >315	Eddy	G. rub	22	1.239	0.165	-2.814	0.092	F-1	6.42
MOZ4_A01 >315	Eddy	G. rub	22	1.487	0.080	-2.716	0.061	F-1	5.30
MOZ4_A01 >315	Eddy	G. rub	22	1.092	0.075	-2.708	0.079		
MOZ4_A01 >315	Eddy	G. rub	21	0.763	0.142	-2.393	0.079	F-1	5.46
MOZ4_A01 >315	Eddy	G. rub	20	1.020	0.122	-2.612	0.097	F-1	7.84
MOZ4_A01 >315	Eddy	G. rub	19	1.266	0.087	-2.603	0.083	F-1	7.25
MOZ4_A01 >315	Eddy	G. rub	19	1.070	0.093	-2.706	0.076		

MOZ4_A01 >315	Eddy	G. rub	18	0.641	0.094	-2.742	0.133	F-1	7.65
MOZ4_A01 >315	Eddy	G. rub	18	1.056	0.130	-2.744	0.084	F-1	5.82
MOZ4_A01 >315	Eddy	G. rub	18	0.424	0.128	-2.570	0.085	F-1	5.95
MOZ4_A01 >315	Eddy	G. rub	17	0.945	0.100	-2.629	0.083	F-1	7.27
MOZ4_A01 >315	Eddy	G. rub	17	0.744	0.123	-2.816	0.189		
MOZ4_A01 >315	Eddy	G. rub	17	0.975	0.113	-2.851	0.086	F-1	6.99
MOZ4_A01 >315	Eddy	G. rub	17	N.A.	N.A.	N.A.	N.A.	F-1	7.86
MOZ4_A01 >315	Eddy	G. rub	16	0.977	0.138	-2.506	0.092	F-1	6.06
MOZ4_A01 >315	Eddy	G. rub	16	0.984	0.113	-2.709	0.110	F-1	6.69
MOZ4_A01 >315	Eddy	G. rub	16	0.411	0.121	-2.645	0.055		
MOZ4_A01 >315	Eddy	G. rub	16	0.695	0.160	-2.469	0.082		
MOZ4_A01 >315	Eddy	G. rub	16	1.034	0.147	-2.815	0.066		
MOZ4_A01 >315	Eddy	G. rub	15	0.995	0.123	-2.413	0.108	F-1	6.34
MOZ4_A01 >315	Eddy	G. rub	15	0.519	0.132	-2.339	0.126	F-1	
MOZ4_A01 >315	Eddy	G. rub	14	0.499	0.094	-2.714	0.115	F-1	8.07
MOZ4_A01 >315	Eddy	G. rub	14	1.179	0.136	-2.517	0.070	F-1	6.86
MOZ4_A01 >315	Eddy	G. rub	14	0.961	0.124	-2.351	0.080	F-1	6.11
MOZ4_A01 >315	Eddy	G. rub	14	0.947	0.145	-2.403	0.093	F-1	7.21
MOZ4_A01 >315	Eddy	G. rub	13	1.021	0.132	-2.847	0.083		
MOZ4_A01 >315	Eddy	G. rub	12	0.999	0.146	-2.988	0.095		
MOZ4_A01 >315	Eddy	G. rub	18	0.939	0.045	-2.914	0.088		
MOZ4_A01 >315	Eddy	G. rub	9	0.397	0.158	-2.042	0.184	F-1	6.62
MOZ4_A01 >315	Eddy	G. rub	8	0.846	0.103	-2.618	0.377	F-1	6.84
MOZ4_A01 >315	Eddy	G. rub	26	1.368	0.006	-2.659	0.024	F-1	6.50
MOZ4_A01 >315	Eddy	G. rub	28	1.918	0.020	-2.507	0.022		
MOZ4_A01 >315	Eddy	G. rub	22	0.098	0.005	-0.980	0.032	F-1	6.12
MOZ4_A01 >315	Eddy	G. rub	22	0.865	0.010	-2.540	0.033	F-1	6.42
MOZ4_A01 >315	Eddy	G. rub	22	1.037	0.008	-1.628	0.031	F-1	5.30
MOZ4_A01 >315	Eddy	G. rub	22	-0.762	0.048	-2.359	0.198		
MOZ4_A01 >315	Eddy	G. rub	21	-0.433	0.023	-0.930	0.034	F-1	5.46

MOZ4_A01 >315	Eddy	G. rub	20	0.295	0.023	3.115	0.056	F-1	7.84	
MOZ4_A01 >315	Eddy	G. rub	19	0.043	0.008	-1.221	0.029	F-1	7.25	
MOZ4_A01 >315	Eddy	G. rub	19	0.668	0.019	-1.130	0.036			
MOZ4_A01 250-315	Eddy	G. rub	11	0.917	0.125	-2.503	0.080		F-2	7.59
MOZ4_A01 250-315	Eddy	G. rub	11	0.610	0.163	-2.579	0.042		F-2	5.20
MOZ4_A01 250-315	Eddy	G. rub	11	0.688	0.146	-1.848	0.106		F-2	3.74
MOZ4_A01 250-315	Eddy	G. rub	11	0.060	0.130	-2.264	0.152		F-2	6.80
MOZ4_A01 250-315	Eddy	G. rub	11	0.727	0.128	-2.491	0.101		F-2	
MOZ4_A01 250-315	Eddy	G. rub	11	0.935	0.115	-2.599	0.124		F-2	
MOZ4_A01 250-315	Eddy	G. rub	11	0.356	0.088	-2.699	0.109			
MOZ4_A01 250-315	Eddy	G. rub	11	0.563	0.157	-2.500	0.099			
MOZ4_A01 250-315	Eddy	G. rub	10	N.A.	N.A.	N.A.	N.A.		F-2	5.28
MOZ4_A01 250-315	Eddy	G. rub	10	0.178	0.154	-2.705	0.086		F-2	6.85
MOZ4_A01 250-315	Eddy	G. rub	10	0.309	0.130	-2.662	0.077			
MOZ4_A01 250-315	Eddy	G. rub	9	0.663	0.206	-2.587	0.138		F-2	6.23
MOZ4_A01 250-315	Eddy	G. rub	9	0.539	0.198	-2.290	0.164		F-2	7.47
MOZ4_A01 250-315	Eddy	G. rub	9	0.808	0.236	-2.466	0.225			
MOZ4_A01 250-315	Eddy	G. rub	9	0.410	0.212	-2.248	0.224			
MOZ4_A01 250-315	Eddy	G. rub	9	0.380	0.200	-1.938	0.143			
MOZ4_A01 250-315	Eddy	G. rub	7	0.580	0.291	-2.694	0.175			
MOZ4_A01 250-315	Eddy	G. rub	6	0.186	0.137	-2.134	0.116			
MOZ4_A01 250-315	Eddy	G. rub	6	0.114	0.129	-2.591	0.117		F-2	5.76
MOZ4_A01 250-315	Eddy	G. rub	6	0.744	0.098	-2.374	0.261			
MOZ4_A01 250-315	Eddy	G. rub	6	0.872	0.121	-2.082	0.093			
MOZ1_A07, >315	Non- Eddy	G. rub	21	1.147	0.095	-2.715	0.058		F-2	4.24
MOZ1_A07, >315	Non- Eddy	G. rub	20	1.993	0.084	-2.233	0.051		F-2	6.81
MOZ1_A07, >315	Non- Eddy	G. rub	19	1.214	0.117	-2.728	0.072		F-2	3.87
MOZ1_A07, >315	Non- Eddy	G. rub	18	0.755	0.097	-2.776	0.120		F-2	3.53
MOZ1_A07, >315	Non- Eddy	G. rub	17	0.927	0.081	-3.119	0.049		F-2	3.36
MOZ1_A07, >315	Non- Eddy	G. rub	17	0.624	0.084	-2.832	0.092		F-2	4.63

MOZ1_A07, >315	Non-Eddy	G. rub	16	0.063	0.117	-2.908	0.118	F-2	5.52
MOZ1_A07, >315	Non-Eddy	G. rub	16	0.910	0.100	-2.855	0.113	F-2	6.81
MOZ1_A07, >315	Non-Eddy	G. rub	15	0.486	0.110	-3.013	0.135	F-2	5.11
MOZ1_A07, >315	Non-Eddy	G. rub	15	0.282	0.117	-2.959	0.093	F-2	4.44
MOZ1_A07, >315	Non-Eddy	G. rub	15	0.283	0.201	-3.497	0.147	F-2	4.09
MOZ1_A07, >315	Non-Eddy	G. rub	14	0.870	0.126	-2.636	0.109	F-2	4.15
MOZ1_A07, >315	Non-Eddy	G. rub	13	-0.430	0.172	-3.007	0.108	F-2	5.28
MOZ1_A07, >315	Non-Eddy	G. rub	13	0.903	0.139	-3.172	0.067	F-2	3.25
MOZ1_A07, >315	Non-Eddy	G. rub	13	0.764	0.166	-3.069	0.092	F-2	3.72
MOZ1_A07, >315	Non-Eddy	G. rub	12	0.205	0.101	-2.853	0.121	F-2	4.54
MOZ1_A07, >315	Non-Eddy	G. rub	11	0.924	0.066	-2.875	0.076	F-2	3.33
MOZ1_A07, >315	Non-Eddy	G. rub	11	0.833	0.157	-3.182	0.260	F-2	3.30
MOZ1_A07, >315	Non-Eddy	G. rub	10	0.591	0.125	-2.988	0.169	F-2	5.35
MOZ1_A07, >315	Non-Eddy	G. rub	8	1.296	0.211	-2.790	0.099	F-2	4.80
MOZ1_A07, >315	Non-Eddy	G. rub	21	0.553	0.007	-2.138	0.045	F-2	4.24
MOZ1_A07, >315	Non-Eddy	G. rub	20	0.313	0.015	-0.645	0.017	F-2	6.81
MOZ1_A07, >315	Non-Eddy	G. rub	19	0.692	0.021	-1.327	0.047	F-2	3.87
MOZ1_A07, 250-315	Non-Eddy	G. rub	14	0.948	0.115	-2.915	0.103	F-2	4.71
MOZ1_A07, 250-315	Non-Eddy	G. rub	14	1.081	0.077	-2.610	0.096	F-2	4.03
MOZ1_A07, 250-315	Non-Eddy	G. rub	13	-0.516	0.126	-2.956	0.100	F-2	4.82
MOZ1_A07, 250-315	Non-Eddy	G. rub	13	0.410	0.107	-2.953	0.113	F-2	5.31
MOZ1_A07, 250-315	Non-Eddy	G. rub	12	-0.028	0.176	-3.107	0.182	F-2	4.49
MOZ1_A07, 250-315	Non-Eddy	G. rub	12	-0.305	0.162	-3.024	0.132	F-2	4.06
MOZ1_A07, 250-315	Non-Eddy	G. rub	11	0.946	0.137	-2.517	0.135	F-2	4.01
MOZ1_A07, 250-315	Non-Eddy	G. rub	11	0.701	0.144	-2.536	0.104	F-2	5.23
MOZ1_A07, 250-315	Non-Eddy	G. rub	11	0.754	0.113	-2.719	0.113	F-2	4.01
MOZ1_A07, 250-315	Non-Eddy	G. rub	11	0.453	0.122	-2.717	0.075	F-2	4.38
MOZ1_A07, 250-315	Non-Eddy	G. rub	11	-0.219	0.195	-2.047	0.074	F-2	4.08
MOZ1_A07, 250-315	Non-Eddy	G. rub	11	-0.207	0.126	-2.792	0.145	F-2	6.09
MOZ1_A07, 250-315	Non-Eddy	G. rub	11	0.624	0.124	-2.635	0.114	F-2	4.55

MOZ1_A07, 250-315	Non- Eddy	G. rub	10	0.540	0.143	-2.900	0.193		F-2	4.09
MOZ1_A07, 250-315	Non- Eddy	G. rub	10	0.481	0.181	-3.041	0.224		F-2	5.52
MOZ1_A07, 250-315	Non- Eddy	G. rub	9	0.459	0.376	-2.467	0.186		F-2	4.96
MOZ1_A07, 250-315	Non- Eddy	G. rub	9	0.456	0.269	-2.560	0.155		F-2	4.21
MOZ1_A07, 250-315	Non- Eddy	G. rub	8	0.341	0.123	-2.365	0.110		F-2	5.13
MOZ1_A07, 250-315	Non- Eddy	G. rub	8	0.580	0.201	-2.543	0.156		F-2	4.89
MOZ1_A07, 250-315	Non- Eddy	G. rub	7	-0.582	0.200	-2.832	0.144		F-2	4.29
MOZ2_A12; 250-315	Non- Eddy	G. rub	11	0.287	0.115	-2.545	0.129		F-1	6.24
MOZ2_A12; 250-315	Non- Eddy	G. rub	11	0.475	0.157	-2.282	0.102		F-1	5.57
MOZ2_A12; 250-315	Non- Eddy	G. rub	11	0.306	0.145	-2.357	0.120		F-1	4.72
MOZ2_A12; 250-315	Non- Eddy	G. rub	10	0.725	0.185	-2.171	0.151		F-1	4.80
MOZ2_A12; 250-315	Non- Eddy	G. rub	10	0.509	0.170	-2.316	0.159		F-1	4.39
MOZ2_A12; 250-315	Non- Eddy	G. rub	10	N.A.	N.A.	N.A.	N.A.		F-1	4.07
MOZ2_A12; 250-315	Non- Eddy	G. rub	9	-0.188	0.187	-1.703	0.195		F-1	4.18
MOZ2_A12; 250-315	Non- Eddy	G. rub	9	0.511	0.254	-2.161	0.166		F-1	6.30
MOZ2_A12; 250-315	Non- Eddy	G. rub	9	0.585	0.247	-1.703	0.173		F-1	4.32
MOZ2_A12; 250-315	Non- Eddy	G. rub	9	0.244	0.178	-1.736	0.150		F-1	3.43
MOZ2_A12; 250-315	Non- Eddy	G. rub	9	0.645	0.245	-1.788	0.164			
MOZ2_A12; 250-315	Non- Eddy	G. rub	9	-0.178	0.204	-1.832	0.159		F-1	4.52
MOZ2_A12; 250-315	Non- Eddy	G. rub	9	0.057	0.215	-1.894	0.102		F-1	6.45
MOZ2_A12; 250-315	Non- Eddy	G. rub	8	-0.086	0.175	-2.334	0.198		F-1	4.67
MOZ2_A12; 250-315	Non- Eddy	G. rub	8	-0.682	0.136	-2.123	0.128		F-1	4.34
MOZ2_A12; 250-315	Non- Eddy	G. rub	8	0.160	0.144	-1.945	0.136		F-1	4.54
MOZ2_A12; 250-315	Non- Eddy	G. rub	7	-0.206	0.146	-1.771	0.142		F-1	4.47
MOZ2_A12; 250-315	Non- Eddy	G. rub	7	-0.342	0.150	-2.281	0.119		F-1	6.28
MOZ2_A12; 250-315	Non- Eddy	G. rub	7	0.123	0.213	-2.144	0.089		F-1	5.13
MOZ2_A12; 250-315	Non- Eddy	G. rub	6	-0.045	0.121	-2.042	0.181		F-1	3.37
MOZ2_A12; 250-315	NON- Eddy	G. rub	18	0.980	0.115	-2.821	0.051		F-1	5.93
MOZ4_A06 > 315	Non- Eddy	G. rub	21	0.779	0.076	-2.481	0.069		F-2	5.67
MOZ4_A06 > 315	Non- Eddy	G. rub	21	1.008	0.080	-2.624	0.095			

MOZ4_A06 > 315	Non-Eddy	G. rub	20	0.338	0.074	-2.620	0.085	F-2	4.51
MOZ4_A06 > 315	Non-Eddy	G. rub	20	1.787	0.095	-2.931	0.064		
MOZ4_A06 > 315	Non-Eddy	G. rub	19	0.461	0.158	-2.528	0.112	F-2	7.97
MOZ4_A06 > 315	Non-Eddy	G. rub	18	0.571	0.117	-2.573	0.104	F-2	4.51
MOZ4_A06 > 315	Non-Eddy	G. rub	18	-0.167	0.225	-2.573	0.221	F-2	4.89
MOZ4_A06 > 315	Non-Eddy	G. rub	18	0.014	0.203	-2.516	0.076	F-2	5.54
MOZ4_A06 > 315	Non-Eddy	G. rub	17	0.626	0.115	-2.818	0.072	F-2	4.46
MOZ4_A06 > 315	Non-Eddy	G. rub	17	0.147	0.105	-2.695	0.075		
MOZ4_A06 > 315	Non-Eddy	G. rub	17	0.300	0.132	-2.562	0.323		
MOZ4_A06 > 315	Non-Eddy	G. rub	17	0.595	0.119	-2.497	0.071	F-2	5.21
MOZ4_A06 > 315	Non-Eddy	G. rub	16	0.013	0.144	-2.386	0.118		
MOZ4_A06 > 315	Non-Eddy	G. rub	15	N. A.	N. A.	N. A.	N. A.	F-2	5.56
MOZ4_A06 > 315	Non-Eddy	G. rub	15	-0.251	0.090	-2.965	0.095	F-2	5.24
MOZ4_A06 > 315	Non-Eddy	G. rub	15	0.238	0.108	-2.964	0.068	F-2	6.21
MOZ4_A06 > 315	Non-Eddy	G. rub	15	0.338	0.097	-2.522	0.365		
MOZ4_A06 > 315	Non-Eddy	G. rub	14	0.614	0.108	-2.537	0.082		
MOZ4_A06 > 315	Non-Eddy	G. rub	13	0.578	0.092	-2.334	0.095		
MOZ4_A06 > 315	Non-Eddy	G. rub	12	N. A.	N. A.	N. A.	N. A.		
MOZ4_A06 > 315	Non-Eddy	G. rub	11	0.638	0.113	-2.217	0.052	F-2	5.49
MOZ4_A06 > 315	Non-Eddy	G. rub	11	0.584	0.136	-2.434	0.098	F-2	5.74
MOZ4_A06 > 315	Non-Eddy	G. rub	10	0.176	0.115	-2.769	0.092	F-2	4.90
MOZ4_A06 > 315	Non-Eddy	G. rub	10	-0.196	0.165	-2.252	0.149	F-2	3.51
MOZ4_A06 > 315	Non-Eddy	G. rub	10	0.483	0.096	-2.671	0.214	F-2	5.46
MOZ4_A06 > 315	Non-Eddy	G. rub	10	0.583	0.142	-2.529	0.134	F-2	5.90
MOZ4_A06 > 315	Non-Eddy	G. rub	9	0.242	0.179	-2.357	0.091		
MOZ4_A06 > 315	Non-Eddy	G. rub	7	-1.458	0.149	-2.735	0.099	F-2	7.45
MOZ4_A06 > 315	Non-Eddy	G. rub	21	0.130	0.014	-1.511	0.034	F-2	5.67
MOZ4_A06 > 315	Non-Eddy	G. rub	21	0.331	0.023	2.105	0.018		
MOZ4_A06 > 315	Non-Eddy	G. rub	20	0.016	0.026	0.859	0.028	F-2	5.33
MOZ4_A06 > 315	Non-Eddy	G. rub	20	0.010	0.015	-1.415	0.013		

MOZ4_A06 > 315	Non-Eddy	G. rub	19	0.368	0.570	-1.698	0.653					F-2	7.97
MOZ4_A06 250-315	Non-Eddy	G. rub	16	0.719	0.165	-2.758	0.131					F-2	6.60
MOZ4_A06 250-315	Non-Eddy	G. rub	16	N. A.	N. A.	N. A.	N. A.					F-2	6.56
MOZ4_A06 250-315	Non-Eddy	G. rub	14	1.065	0.129	-2.788	0.188					F-2	6.60
MOZ4_A06 250-315	Non-Eddy	G. rub	14	1.001	0.111	-2.674	0.097					F-2	4.30
MOZ4_A06 250-315	Non-Eddy	G. rub	14	0.470	0.156	-2.518	0.124					F-2	
MOZ4_A06 250-315	Non-Eddy	G. rub	14	0.325	0.131	-2.659	0.097					F-2	7.14
MOZ4_A06 250-315	Non-Eddy	G. rub	13	0.943	0.140	-2.707	0.134					F-2	7.42
MOZ4_A06 250-315	Non-Eddy	G. rub	13	0.076	0.058	-2.676	0.072					F-2	
MOZ4_A06 250-315	Non-Eddy	G. rub	13	0.957	0.139	-2.815	0.136					F-2	5.72
MOZ4_A06 250-315	Non-Eddy	G. rub	12	0.379	0.119	-2.375	0.106					F-2	5.20
MOZ4_A06 250-315	Non-Eddy	G. rub	12	0.882	0.153	-3.030	0.153					F-2	5.49
MOZ4_A06 250-315	Non-Eddy	G. rub	12	N. A.	N. A.	N. A.	N. A.					F-2	
MOZ1_A08, >315	Eddy	N. dut	30	0.669	0.011	-1.807	0.066			F-1	2.74	F-2	2.68
MOZ1_A08, >315	Eddy	N. dut	32	1.299	0.014	-2.045	0.028			F-1	2.56	F-2	1.47
MOZ1_A08, >315	Eddy	N. dut	38	1.140	0.003	-2.150	0.012			F-1	3.14	F-2	1.67
MOZ2_A11	Eddy	N. dut	30.00	0.112	0.105	-1.181	0.058			F-1	5.35	F-2	2.80
MOZ2_A11	Eddy	N. dut	21.00	0.394	0.077	-1.338	0.064			F-1	4.51	F-2	3.92
MOZ2_A11	Eddy	N. dut	21.00	0.469	0.101	-1.517	0.082	F-0	3.79	F-1	3.24	F-2	3.41
MOZ2_A11	Eddy	N. dut	20.00	0.284	0.101	-1.260	0.117	F-0		F-1		F-2	
MOZ2_A11	Eddy	N. dut	20.00	0.790	0.069	-1.610	0.073	F-0	2.56	F-1	2.37	F-2	1.52
MOZ2_A11	Eddy	N. dut	19.00	0.812	0.095	-1.663	0.033	F-0	4.99	F-1	4.28	F-2	4.16
MOZ2_A11, >315	Eddy	N. dut	28	0.278	0.013	-1.523	0.026			F-1	2.46	F-2	1.83
MOZ2_A11; >315	Eddy	N. dut	31	0.380	0.015	-1.485	0.008	F-0	4.28	F-1	3.68	F-2	2.51
MOZ2_A11; >315	Eddy	N. dut	30	0.230	0.004	-1.712	0.025			F-1	5.35	F-2	2.80
MOZ2_A11; >315	Eddy	N. dut	26	0.333	0.017	-1.272	0.038	F-0	3.58	F-1	2.56	F-2	1.84
MOZ2_A11; >315	Eddy	N. dut	26	0.230	0.007	-1.426	0.024			F-1	2.90	F-2	2.18
MOZ2_A11; >315	Eddy	N. dut	26	0.221	0.012	-1.808	0.026						
MOZ2_A11; >315	Eddy	N. dut	36	0.444	0.004	-1.421	0.025	F-0	4.48	F-1	2.41	F-2	3.20
MOZ2_A11; >315	Eddy	N. dut	35	0.538	0.010	-1.551	0.022	F-0	1.81	F-1	1.97	F-2	1.48
MOZ2_A11; >315	Eddy	N. dut	30	0.244	0.005	-1.180	0.033	F-0	4.53	F-1	3.85	F-2	3.16

MOZ2_A11; >315	Eddy	N. dut	28	0.161	0.011	-1.436	0.029			F-1	3.23	F-2	3.39
MOZ2_A11; >315	Eddy	N. dut	32	1.657	0.008	-1.350	0.025	F-0	4.95	F-1	3.52	F-2	4.19
MOZ2_A11; >315	Eddy	N. dut	37	0.301	0.016	-0.877	0.028	F-0	2.60	F-1	2.11	F-2	1.96
MOZ2_A11; >315	Eddy	N. dut	32	0.182	0.016	-1.497	0.033	F-0	3.09	F-1	3.06	F-2	2.39
MOZ2_A11; >315	Eddy	N. dut	32	0.232	0.011	-1.423	0.040	F-0	2.97	F-1	2.84	F-2	1.94
MOZ2_A11; >315	Eddy	N. dut	40	0.162	0.005	-1.395	0.015	F-0	5.63	F-1	4.84	F-2	4.29
MOZ2_A11; >315	Eddy	N. dut	38	0.825	0.008	-1.405	0.025	F-0	4.73	F-1	4.39	F-2	4.38
MOZ2_A11; >315	Eddy	N. dut	21	0.298	0.021	-1.682	0.033			F-1	2.90	F-2	3.92
MOZ2_A11; >315	Eddy	N. dut	21	0.183	0.015	-1.362	0.049	F-0	3.79	F-1	3.24	F-2	3.41
MOZ2_A11; >315	Eddy	N. dut	20	0.237	0.013	N.A.	N.A.	F-0	2.56	F-1	2.37	F-2	1.52
MOZ2_A11; >315	Eddy	N. dut	20	0.285	0.015	N.A.	N.A.	F-0	2.56	F-1	2.37	F-2	1.52
MOZ2_A11; >315	Eddy	N. dut	19	-0.313	0.009	-1.279	0.056	F-0	4.99	F-1	4.28	F-2	4.16
MOZ4_A01 >315	Eddy	N. dut	27	N.A.	N.A.	N.A.	N.A.						
MOZ4_A01 >315	Eddy	N. dut	27	0.492	0.011	-1.817	0.026			F-1	4.10	F-2	3.09
MOZ4_A01 >315	Eddy	N. dut	35	1.475	0.009	-1.948	0.012	F-0	4.11	F-1	3.63	F-2	3.52
MOZ4_A01 >315	Eddy	N. dut	30	1.682	0.009	-1.913	0.013			F-1	3.15	F-2	2.46
MOZ4_A01 >315	Eddy	N. dut	34	0.054	0.007	-1.471	0.022	F-0	2.31	F-1	2.26	F-2	3.52
MOZ4_A01 >315	Eddy	N. dut	33	1.306	0.004	-1.640	0.019	F-0	3.03	F-1	2.55	F-2	2.23
MOZ4_A01 >315	Eddy	N. dut	34	-0.567	0.042	-2.606	0.195	F-0	2.77	F-1	4.92	F-2	3.84
MOZ4_A01 >315	Eddy	N. dut	22	0.092	0.028	-1.371	0.022	F-0	1.73	F-1	1.46	F-2	1.40
MOZ4_A01 >315	Eddy	N. dut	21	0.446	0.010	-3.107	0.039	F-0	1.11	F-1	1.47	F-2	1.23
MOZ4_A01, 250-315	Eddy	N. dut	22	-0.093	0.013	-1.523	0.009	F-0	2.81	F-1	2.78	F-2	2.17
MOZ4_A01; >315	Eddy	N. dut	22.00	0.203	0.082	-0.455	0.060	F-0	1.73	F-1	1.46	F-2	1.40
MOZ4_A01; >315	Eddy	N. dut	21.00	0.154	0.093	-0.399	0.062	F-0	1.11	F-1	1.47	F-2	1.23
MOZ4_A01; >315	Eddy	N. dut	16.00	0.637	0.111	-1.760	0.081	F-0	2.89	F-1	2.94	F-2	3.19
MOZ4_A01; >315	Eddy	N. dut	16.00	N.A.	N.A.	N.A.	N.A.	F-0	1.60	F-1	1.76	F-2	1.81
MOZ4_A01; >315	Eddy	N. dut	14.00	0.852	0.104	-1.254	0.073			F-1	2.79	F-2	3.52
MOZ4_A01; >315	Eddy	N. dut	11.00	1.429	0.228	-2.481	0.227	F-0		F-1		F-2	3.26
MOZ4_A01; >315	Eddy	N. dut	10.00	0.505	0.194	-2.046	0.138	F-0	4.04	F-1	3.70	F-2	2.63
MOZ4_A01; >315	Eddy	N. dut	8.00	2.504	0.916	-2.516	1.968						

MOZ4_A01; 250-315	Eddy	N. dut	22.00	0.160	0.115	-0.043	0.099	F-0	2.81	F-1	2.78	F-2	2.17
MOZ4_A01; 250-315	Eddy	N. dut	15.00	0.197	0.143	-1.055	0.103	F-0	2.68	F-1	2.19	F-2	1.62
MOZ4_A01; 250-315	Eddy	N. dut	15.00	N.A.	N.A.	N.A.	N.A.	F-0	4.12	F-1	5.46	F-2	
MOZ4_A01; 250-315	Eddy	N. dut	13.00	-0.556	0.170	-2.120	0.115	F-0	3.26	F-1	4.45	F-2	3.77
MOZ4_A01; 250-315	Eddy	N. dut	13.00	-0.057	0.178	-0.064	0.142	F-0	2.06	F-1	1.96	F-2	1.78
MOZ4_A01; 250-315	Eddy	N. dut	10.00	N.A.	N.A.	N.A.	N.A.	F-0	3.06	F-1	4.35		
MOZ1_A07, >315	Non- Eddy	N. dut	18.00	-0.629	0.199	-1.517	0.114	F-0	3.02	F-1	3.11	F-2	3.10
MOZ1_A07, >315	Non- Eddy	N. dut	32	0.431	0.010	-1.325	0.013					F-2	1.29
MOZ1_A07, >315	Non- Eddy	N. dut	27	0.185	0.019	-0.921	0.042	F-0	3.46	F-1	2.27	F-2	2.11
MOZ1_A07, >315	Non- Eddy	N. dut	27	1.604	0.007	-2.059	0.025			F-1	1.69		
MOZ1_A07, >315	Non- Eddy	N. dut	26	0.253	0.014	-1.537	0.026					F-2	1.11
MOZ1_A07, >315	Non- Eddy	N. dut	36	-0.649	0.039	-2.671	0.171					F-2	1.63
MOZ1_A07, >315	Non- Eddy	N. dut	35	-0.337	0.021	-3.453	0.134	F-0	2.83	F-1	1.44	F-2	1.36
MOZ1_A07, >315	Non- Eddy	N. dut	35	-0.017	0.021	-1.940	0.007			F-1	1.33		
MOZ1_A07, >315	Non- Eddy	N. dut	35	0.830	0.001	-1.191	0.033					F-2	1.40
MOZ1_A07, >315	Non- Eddy	N. dut	30	0.160	0.024	-1.106	0.023					F-2	2.02
MOZ1_A07, >315	Non- Eddy	N. dut	28	0.435	0.013	-1.464	0.003			F-1	2.02	F-2	1.18
MOZ1_A07, >315	Non- Eddy	N. dut	33	0.393	0.007	-1.606	0.029			F-1	2.13		
MOZ1_A07, >315	Non- Eddy	N. dut	35	0.541	0.017	-1.849	0.024			F-1	1.50		
MOZ1_A07, >315	Non- Eddy	N. dut	34	1.060	0.015	-1.461	0.022			F-1	2.17		
MOZ1_A07, >315	Non- Eddy	N. dut	22	0.375	0.029	2.705	0.028	F-0	3.41	F-1	3.01	F-2	2.01
MOZ1_A07; >315	Non- Eddy	N. dut	36.00	0.803	0.090	-2.036	0.079					F-2	1.63
MOZ1_A07; >315	Non- Eddy	N. dut	22.00	0.113	0.090	-1.400	0.089	F-0	3.41	F-1	3.01	F-2	2.01
MOZ2_A12; >315	Non- Eddy	N. dut	20.00	0.486	0.074	-1.326	0.065	F-0	3.51	F-1	3.24	F-2	2.27
MOZ2_A12; >315	Non- Eddy	N. dut	19.00	0.426	0.090	-1.596	0.093	F-0	3.05			F-2	2.75
MOZ2_A12; >315	Non- Eddy	N. dut	15.00	N.A.	N.A.	N.A.	N.A.	F-0	2.87	F-1	3.20		
MOZ2_A12; >315	Non- Eddy	N. dut	14.00	0.560	0.217	-1.478	0.093			F-1	1.79	F-2	1.99
MOZ2_A12; >315	Non- Eddy	N. dut	32	0.971	0.005	-0.509	0.040			F-1	3.28	F-2	2.56
MOZ2_A12; >315	Non- Eddy	N. dut	31	0.165	0.009	-1.379	0.031	F-0	2.56	F-1	2.24	F-2	2.16
MOZ2_A12; >315	Non- Eddy	N. dut	28	0.067	0.016	-1.585	0.039	F-0	4.23	F-1	2.03	F-2	3.31

MOZ2_A12; >315	Non-Eddy	N. dut	26	0.500	0.008	-1.074	0.018	F-0	4.17	F-1	3.40		
MOZ2_A12; >315	Non-Eddy	N. dut	30	1.289	0.010	-1.461	0.012	F-0	3.84	F-1	1.93	F-2	2.70
MOZ2_A12; >315	Non-Eddy	N. dut	29	1.055	0.010	-0.817	0.039	F-0	3.79	F-1	2.28		
MOZ2_A12; >315	Non-Eddy	N. dut	33	0.409	0.008	-1.683	0.031			F-3	5.32	F-8	3.69
MOZ2_A12; >315	Non-Eddy	N. dut	37	0.944	0.014	-1.248	0.033	F-0	3.49	F-1	1.94	F-2	1.63
MOZ2_A12; >315	Non-Eddy	N. dut	38	0.991	0.002	-1.242	0.017	F-0	4.27	F-1	3.21	F-2	1.96
MOZ2_A12; >315	Non-Eddy	N. dut	20	0.115	0.012	-1.592	0.029	F-0	3.51	F-1	3.24	F-2	2.27
MOZ2_A12; >315	Non-Eddy	N. dut	19	0.271	0.030	1.740	0.022	F-0	3.05			F-2	2.75
MOZ4_A06 > 315	Non-Eddy	N. dut	31	0.681	0.008	-1.619	0.030	F-0	3.02	F-1	3.24	F-2	3.40
MOZ4_A06 > 315	Non-Eddy	N. dut	27	0.423	0.004	1.584	0.026						
MOZ4_A06 > 315	Non-Eddy	N. dut	27	0.574	0.023	-1.627	0.012	F-0	3.07	F-1	1.41	F-2	1.49
MOZ4_A06 > 315	Non-Eddy	N. dut	26	0.237	0.019	-1.196	0.034						
MOZ4_A06 > 315	Non-Eddy	N. dut	36	0.428	0.006	-1.016	0.014			F-1	3.21	F-2	2.60
MOZ4_A06 > 315	Non-Eddy	N. dut	35	0.643	0.026	-0.682	0.016	F-0		F-1	3.43	F-2	3.32
MOZ4_A06 > 315	Non-Eddy	N. dut	30	0.621	0.075	-1.319	0.048						
MOZ4_A06 > 315	Non-Eddy	N. dut	30	0.921	0.021	-1.464	0.010	F-0	3.16	F-1	2.46	F-2	2.59
MOZ4_A06 > 315	Non-Eddy	N. dut	29	0.730	0.011	-1.526	0.022	F-0	4.95	F-1	3.37	F-2	2.27
MOZ4_A06 > 315	Non-Eddy	N. dut	29	0.603	0.010	-1.047	0.034	F-0	5.33	F-1	2.73	F-2	2.19
MOZ4_A06 > 315	Non-Eddy	N. dut	28	0.340	0.025	-1.258	0.027	F-0	1.76	F-1	2.23		
MOZ4_A06 > 315	Non-Eddy	N. dut	32	0.760	0.007	-1.731	0.014						
MOZ4_A06 > 315	Non-Eddy	N. dut	37	0.936	0.014	-1.752	0.037	F-0	3.63	F-1	2.97	F-2	2.75
MOZ4_A06 > 315	Non-Eddy	N. dut	33	0.879	0.012	-1.589	0.017			F-1	4.12	F-2	2.74
MOZ4_A06 > 315	Non-Eddy	N. dut	54	0.575	0.002	-1.930	0.013						
MOZ4_A06 > 315	Non-Eddy	N. dut	53	1.433	0.008	-2.093	0.013						
MOZ4_A06 > 315	Non-Eddy	N. dut	49	1.366	0.016	-1.747	0.032			F-1	2.25	F-2	1.96
MOZ4_A06 > 315	Non-Eddy	N. dut	47	0.428	0.005	-1.928	0.028	F-0	3.73	F-1	2.52	F-2	1.90
MOZ4_A06 > 315	Non-Eddy	N. dut	46	0.784	0.010	-1.785	0.021			F-1	2.74	F-2	2.45
MOZ4_A06 > 315	Non-Eddy	N. dut	45	1.157	0.009	-1.732	0.026						
MOZ4_A06 > 315	Non-Eddy	N. dut	43	0.526	0.008	-1.887	0.031						
MOZ4_A06 > 315	Non-Eddy	N. dut	43	1.077	0.007	-1.835	0.012						

MOZ4_A06 > 315	Non- Eddy	N. dut	39	1.446	0.009	-1.814	0.031	F-0	3.87	F-1	2.57	F-2	2.59
MOZ4_A06 > 315	Non- Eddy	N. dut	39	0.154	0.008	-1.623	0.017	F-0	2.55	F-1	2.53	F-2	2.02
MOZ4_A06 > 315	Non- Eddy	N. dut	38	0.837	0.005	-1.476	0.029						
MOZ4_A06 > 315	Non- Eddy	N. dut	21	0.218	0.021	1.760	0.025	F-0	4.32	F-1	3.99	F-2	3.45
MOZ4_A06 > 315	Non- Eddy	N. dut	33	0.568	0.011	-1.303	0.020	F-0	4.18	F-1	2.82	F-2	2.40
MOZ4_A06 > 315	Non- Eddy	N. dut	20	1.204	0.007	-1.863	0.012						
MOZ4_A06 > 315	Non- Eddy	N. dut	33.00	0.956	0.072	-1.417	0.063	F-0	4.18				
MOZ4_A06 > 315	Non- Eddy	N. dut	25.00	0.563	0.100	-1.247	0.058	F-0	2.83	F-1	1.64	F-2	1.10
MOZ4_A06 > 315	Non- Eddy	N. dut	21.00	1.207	0.068	-2.219	0.085	F-0	4.32	F-1	3.99	F-2	3.45
MOZ4_A06 > 315	Non- Eddy	N. dut	20.00	0.939	0.148	-1.444	0.078						
MOZ4_A06 > 315	Non- Eddy	N. dut	18.00	0.141	0.131	-2.182	0.086	F-0	2.86	F-1	2.23	F-2	2.61
MOZ2_A11	Eddy	P. obli	22.00	0.119	0.054	-1.342	0.053	F-0	3.88	F-1	3.50		
MOZ2_A11, >315	Eddy	Pobli	36	0.288	0.007	-1.218	0.022	F-0	2.21	F-1	1.89	F-2	2.60
MOZ2_A11, >315	Eddy	Pobli	36	0.355	0.029	-1.034	0.039	F-0	2.25	F-1	2.55		
MOZ2_A11, >315	Eddy	Pobli	29	0.091	0.007	-1.525	0.026	F-0	2.42	F-1	1.96		
MOZ2_A11, >315	Eddy	Pobli	67	0.006	0.012	-1.401	0.008	F-0	1.21	F-1	2.23		
MOZ2_A11, >315	Eddy	Pobli	47	-0.057	0.003	-1.374	0.033	F-0	3.63	F-1	3.50		
MOZ2_A11, >315	Eddy	Pobli	43	0.225	0.009	-1.267	0.030	F-0	1.56	F-1	1.58		
MOZ2_A11, >315	Eddy	Pobli	38	0.067	0.021	-0.940	0.017	F-0	2.00	F-1	1.66	F-2	1.47
MOZ2_A11; >-315	Eddy	P. obli	22	0.489	0.011	-1.110	0.029	F-0	3.88	F-1	3.50		
MOZ2_A12; >315	Non- Eddy	Pobli	16.00	-0.529	0.193	-2.111	0.165	F-0	3.30	F-1	2.28	F-2	3.00
MOZ2_A12; >315	Non- Eddy	Pobli	14.00	-0.404	0.208	-1.878	0.133	F-0	1.82	F-1	2.55		
MOZ2_A12; >315	Non- Eddy	P. obli	24.00	0.064	0.123	-1.171	0.094	F-0	1.56	F-1	1.65	F-2	0.75
MOZ2_A12; >315	Non- Eddy	Pobli	31	0.067	0.008	-0.882	0.026	F-0	1.96	F-1	1.79	F-2	1.87
MOZ2_A12; >315	Non- Eddy	Pobli	27	-0.176	0.008	-0.894	0.006	F-0	1.97	F-1	2.02		
MOZ2_A12; >315	Non- Eddy	Pobli	27	0.111	0.011	-1.210	0.025	F-0	3.06	F-1	2.72	F-2	2.60
MOZ2_A12; >315	Non- Eddy	Pobli	27	-0.422	0.015	-1.138	0.033	F-0	2.18	F-1	1.80		
MOZ2_A12; >315	Non- Eddy	Pobli	27	-0.254	0.014	-0.934	0.029	F-0	3.68	F-1	3.62	F-2	3.44
MOZ2_A12; >315	Non- Eddy	Pobli	26	0.069	0.018	-1.017	0.027	F-0	2.41				
MOZ2_A12; >315	Non- Eddy	Pobli	26	0.014	0.017	-1.027	0.014	F-0	2.07				

MOZ2_A12; >315	Non-Eddy	Pobli	26	-0.315	0.019	-1.058	0.024	F-0	3.39	F-1		F-2	2.01
MOZ2_A12; >315	Non-Eddy	Pobli	26	0.039	0.016	-0.825	0.020			F-1	2.10	F-2	3.71
MOZ2_A12; >315	Non-Eddy	Pobli	26	-0.077	0.012	-1.058	0.017	F-0	2.16	F-1	2.46	F-2	1.17
MOZ2_A12; >315	Non-Eddy	Pobli	35	-0.018	0.008	-1.174	0.027	F-0	2.34	F-1	2.25	F-2	2.41
MOZ2_A12; >315	Non-Eddy	Pobli	33	0.052	0.011	-0.996	0.016	F-0	1.84				
MOZ2_A12; >315	Non-Eddy	Pobli	32	0.114	0.008	-1.074	0.013	F-0		F-1	3.19		
MOZ2_A12; >315	Non-Eddy	Pobli	43	0.414	0.009	-0.826	0.025	F-0	1.50	F-1	1.44		
MOZ2_A12; >315	Non-Eddy	Pobli	40	-0.119	0.014	-1.481	0.034	F-0	1.82	F-1	1.97		
MOZ4_A06>315	Non-Eddy	P. obli	35	0.112	0.019	-0.852	0.017	F-0	2.22	F-1	2.02	F-2	1.83
MOZ4_A06>315	Non-Eddy	P. obli	80	0.076	0.009	-1.184	0.008	F-0	2.22	F-1	1.58	F-2	1.72
MOZ4_A06>315	Non-Eddy	P. obli	67	0.101	0.019	-1.268	0.023	F-0	2.73	F-1	2.98	F-2	2.57
MOZ4_A06>315	Non-Eddy	P. obli	55	0.153	0.012	-0.908	0.035	F-0	2.14	F-1	1.97	F-2	2.00
MOZ4_A06>315	Non-Eddy	P. obli	50	-0.090	0.012	-1.423	0.034	F-0	3.24	F-1	2.92		
MOZ4_A06>315	Non-Eddy	P. obli	44	-1.153	0.037	-3.181	0.121	F-0	2.75	F-0	2.65	F-2	2.49
MOZ4_A06>315	Non-Eddy	P. obli	42	0.076	0.008	-0.821	0.015	F-0	2.38	F-1	1.89		
MOZ1_A08, >315	Eddy	G. scit	26	0.354	0.025	2.060	0.023	F-0	1.32			F-2	1.09
MOZ1_A08, >315	Eddy	G. scit	28	0.351	0.006	2.194	0.029	F-0	1.30	F-1	0.96	F-2	1.24
MOZ1_A08, >315	Eddy	G. scit	34	0.546	0.024	1.918	0.010	F-0	1.49	F-1	1.44	F-2	1.20
MOZ1_A08, >315	Eddy	G. scit	33	0.460	0.016	1.722	0.017	F-0	1.32			F-2	1.20
MOZ1_A08, >315	Eddy	G. scit	33	0.307	0.007	1.899	0.037			F-1	1.67	F-2	1.33
MOZ2_A11; >315	Eddy	G. scit	30.00	0.257	0.081	1.960	0.075	F-0	1.25	F-1	1.29	F-2	1.30
MOZ2_A11; >315	Eddy	G. scit	32	0.345	0.025	2.482	0.040	F-0	1.58	F-1	1.38	F-2	1.30
MOZ2_A11; >315	Eddy	G. scit	31	0.358	0.015	2.086	0.028			F-1	1.17	F-2	1.13
MOZ2_A11; >315	Eddy	G. scit	30	0.234	0.027	2.648	0.020	F-0	1.37	F-1	1.35	F-2	1.09
MOZ2_A11; >315	Eddy	G. scit	29	0.356	0.008	1.848	0.018	F-0	1.93	F-1	1.61	F-2	1.76
MOZ2_A11; >315	Eddy	G. scit	28	0.400	0.008	1.896	0.022	F-0	2.61	F-1	1.76	F-2	1.86
MOZ2_A11; >315	Eddy	G. scit	35	0.346	0.014	2.463	0.036	F-0	1.28	F-1	1.18	F-2	1.27
MOZ4_A01 >315	Eddy	G. scit	30	-0.243	0.041	0.541	0.110	F-1	2.60	F-2	1.65	F-5	1.98
MOZ4_A01 >315	Eddy	G. scit	37	0.433	0.015	2.098	0.015	F-0	1.92	F-1	1.51	F-2	1.61
MOZ4_A01 >315	Eddy	G. scit	40	0.176	0.016	2.101	0.021	F-0	1.97	F-1	1.46		

MOZ1_A07, >315	Non-Eddy	G. scit	31	0.166	0.018	0.624	0.016	F-0	1.55			F-2	1.57
MOZ1_A07, >315	Non-Eddy	G. scit	36	0.093	0.018	0.339	0.016	F-0	1.68	F-1		F-2	2.38
MOZ1_A07, >315	Non-Eddy	G. scit	29	0.393	0.008	0.947	0.036	F-0		F-1	2.07	F-2	2.05
MOZ1_A07, >315	Non-Eddy	G. scit	34	0.343	0.007	0.505	0.016	F-0	1.22	F-1	1.28	F-2	1.60
MOZ1_A07, >315	Non-Eddy	G. scit	33	0.037	0.006	0.119	0.023			F-1	1.45	F-2	2.01
MOZ1_A07, >315	Non-Eddy	G. scit	51	0.186	0.011	0.057	0.030	F-0	2.18	F-1	1.83	F-2	1.95
MOZ1_A07, >315	Non-Eddy	G. scit	38	0.457	0.010	1.937	0.027	F-0	1.09	F-1	1.09	F-2	1.26
MOZ2_A12; >315	Non-Eddy	G. scit	18.00	-0.081	0.089	0.666	0.106	F-0	2.59	F-1		F-2	1.83
MOZ2_A12; >315	Non-Eddy	G. scit	26	0.065	0.011	0.650	0.033	F-0	1.07	F-1	1.03	F-2	1.29
MOZ2_A12; >315	Non-Eddy	G. scit	26	-0.143	0.014	-0.503	0.037			F-1	1.61	F-2	1.83
MOZ4_A06	Non-Eddy	G. scit	22.00	0.393	0.125	1.854	0.102	F-0	2.22	F-1	1.94	F-2	2.25
MOZ4_A06	Non-Eddy	G. scit	21.00	0.391	0.126	2.152	0.057	F-0	1.96	F-1	1.34	F-2	1.80
MOZ4_A06	Non-Eddy	G. scit	19.00	-0.030	0.147	2.364	0.132	F-0	2.10	F-1	1.91	F-2	2.36
MOZ4_A06 > 315	Non-Eddy	G. scit	31	0.550	0.007	2.057	0.023	F-0	1.52	F-1	1.44	F-2	1.34
MOZ4_A06 > 315	Non-Eddy	G. scit	27	0.614	0.023	2.139	0.035	F-0	1.34	F-1	1.63	F-2	1.24
MOZ4_A06 > 315	Non-Eddy	G. scit	35	N.A.	N.A.	-0.058	0.144	F-0	1.47	F-1	1.17	F-2	1.27
MOZ4_A06 > 315	Non-Eddy	G. scit	30	0.654	0.023	2.392	0.056	F-0	1.53	F-1	1.31	F-2	1.27
MOZ4_A06 > 315	Non-Eddy	G. scit	38	0.404	0.011	2.225	0.017	F-0	1.65	F-1	1.44	F-2	1.17
MOZ4_A06 > 315	Non-Eddy	G. scit	38	N.A.	N.A.	0.528	0.096	F-0	1.60	F-1	1.50	F-2	0.89
MOZ4_A06, 250-315	Non-Eddy	G. scit	15.00	0.145	0.152	0.850	0.098	F-0	2.21	F-1	1.31	F-2	1.31
MOZ4_A06, 250-315	Non-Eddy	G. scit	8.00	-0.202	0.252	1.012	0.224	F-0	2.47	F-1	2.24	F-2	
MOZ4_A06, 250-315	Non-Eddy	G. scit	22	0.515	0.006	N.A.	N.A.	F-0	2.22	F-1	1.94	F-2	2.36
MOZ4_A06, 250-315	Non-Eddy	G. scit	21	0.298	0.006	N.A.	N.A.	F-0	1.96	F-1	1.34	F-2	1.80
MOZ4_A06, 250-315	Non-Eddy	G. scit	19	0.068	0.062	1.622	0.073	F-0	2.10	F-1	1.91	F-2	2.36

Appendix table chapter 5

code	crust	sp.	sample	interval	weight [µg]	cham.	crust	Mg/Ca [mmol/mol]	Mn/Ca [µmol/mol]	Sr/Ca [mmol/mol]	U/Ca [µmol/mol]	onto.	Mg/Ca	Mn/Ca	Sr/Ca	U/Ca	total	Mg/Ca	Mn/Ca	Sr/Ca	U/Ca
130125	yes	N.dut	dut_46b-054	MOZ1_A07,>315	35	F-0		1.80	15.11	1.68	N.A.	3.94	23.66	1.68	N.A.	N.A.	2.83	18.48	1.67	N.A.	N.A.
130125	yes	N.dut	dut_45b-055	MOZ1_A07,>315	27	F-0		2.66	10.90	1.64	N.A.	4.30	23.99	1.78	N.A.	N.A.	3.46	18.04	1.69	N.A.	N.A.
130125	no	N.dut	dut_44b-056	MOZ1_A07,>315	18	F-0		N.A.	N.A.	N.A.	N.A.	3.03	12.00	1.53	N.A.	N.A.	3.02	12.43	1.54	N.A.	N.A.
130125	yes	N.dut	dut_43b-057	MOZ1_A07,>315	22	F-0		2.24	N.A.	1.58	N.A.	3.80	82.07	1.77	N.A.	N.A.	3.41	45.29	1.76	N.A.	N.A.
130125	yes	N.dut	dut_42b-058	MOZ1_A07,>315	32	F-0		1.99	11.07	1.38	N.A.	4.69	13.71	1.86	N.A.	N.A.	3.70	13.12	1.69	N.A.	N.A.
130701	no	N.dut	dut_sub1_025-033	MOZ2_A11,>315	19	F-0		N.A.	N.A.	N.A.	N.A.	4.92	38.61	1.45	0.02	0.02	4.99	39.10	1.47	0.02	0.02
130701	no	N.dut	dut_sub1_026-041	MOZ2_A11,>315	20	F-0		N.A.	N.A.	N.A.	N.A.	2.60	14.65	1.34	0.02	0.02	2.56	14.22	1.29	0.02	0.02
130701	yes	N.dut	dut_sub1_027-044	MOZ2_A11,>315	26	F-0		2.99	7.68	1.98	N.A.	3.26	8.26	1.54	0.03	0.03	3.58	7.72	1.75	0.03	0.03
130701	no	N.dut	dut_sub1_028-047	MOZ2_A11,>315	32	F-0		N.A.	N.A.	N.A.	N.A.	4.49	26.48	1.41	0.02	0.02	4.95	29.11	1.55	0.02	0.02
130701	no	N.dut	dut_sub1_029-055	MOZ2_A11,>315	37	F-0		N.A.	N.A.	N.A.	N.A.	2.43	3.22	1.43	0.03	0.03	2.60	3.44	1.53	0.03	0.03
130701	no	N.dut	dut_sub1_030-058	MOZ2_A11,>315	40	F-0		N.A.	N.A.	N.A.	N.A.	5.44	7.66	1.45	0.04	0.04	5.63	7.90	1.50	0.04	0.04
130701	no	N.dut	dut_sub1_031-061	MOZ2_A11,>315	30	F-0		N.A.	N.A.	N.A.	N.A.	4.57	6.66	1.73	0.03	0.03	4.53	6.59	1.72	0.03	0.03
130701	no	N.dut	dut_sub1_032-064	MOZ2_A11,>315	34	F-0		N.A.	N.A.	N.A.	N.A.	4.16	*	1.31	0.03	0.03	3.52	0.95	1.42	0.01	0.01
130701	yes	N.dut	dut_sub1_033-072	MOZ2_A11,>315	23	F-0		1.42	5.01	1.28	0.00	3.30	7.19	1.54	0.04	0.04	2.66	6.84	1.45	0.03	0.03
130701	yes	N.dut	dut_sub1_034c-078	MOZ2_A11,>315	36	F-0		N.A.	8.01	1.27	N.A.	4.07	4.88	1.51	0.04	0.04	4.48	5.26	1.57	0.04	0.04
130701	no	N.dut	dut_sub1_039-095	MOZ2_A11,>315	20	F-0		N.A.	N.A.	N.A.	N.A.	9.35	10.21	1.44	0.02	0.02	10.29	11.21	1.59	0.02	0.02
130701	yes	N.dut	dut_sub1_044	MOZ2_A11,>315	24	F-0		2.14	2.09	1.40	0.02	2.14	2.09	1.40	0.02	0.02	2.36	2.31	1.55	0.02	0.02
130701	no	N.dut	dut_sub1_045	MOZ2_A11,>315	21	F-0		N.A.	N.A.	N.A.	N.A.	3.63	7.06	1.42	0.02	0.02	3.79	7.35	1.48	0.02	0.02
130701	no	N.dut	dut_sub1_046	MOZ2_A11,>315	32	F-0		N.A.	N.A.	N.A.	N.A.	2.97	2.11	1.45	0.02	0.02	3.09	2.20	1.51	0.02	0.02
130701	yes	N.dut	dut_sub1_047	MOZ2_A11,>315	35	F-0		1.62	*	1.16	0.01	1.62	*	1.16	0.01	0.01	1.81	N.A.	1.38	0.01	0.01
130701	no	N.dut	dut_sub1_048	MOZ2_A11,>315	23	F-0		N.A.	N.A.	N.A.	N.A.	2.84	11.89	1.31	0.01	0.01	2.22	2.77	1.48	0.01	0.01
130701	yes	N.dut	dut_sub1_050	MOZ2_A11,>315	31	F-0		3.34	*	1.19	0.01	4.27	1.87	1.35	0.02	0.02	4.28	1.26	1.41	0.02	0.02
130701	no	N.dut	dut_sub1_051	MOZ2_A11,>315	38	F-0		N.A.	N.A.	N.A.	N.A.	4.58	39.19	1.53	0.02	0.02	4.73	40.46	1.58	0.02	0.02
130701	yes	N.dut	dut_sub1_052	MOZ2_A11,>315	32	F-0		2.78	*	1.25	0.01	2.78	*	1.25	0.01	0.01	2.97	N.A.	1.34	0.01	0.01
130701	no	N.dut	dut_sub1_054	MOZ2_A11,>315	25	F-0		N.A.	N.A.	N.A.	N.A.	3.34	3.15	1.41	0.02	0.02	3.75	3.37	1.53	0.03	0.03

130703	no	N_dut	dur_sub2_8-9	MOZZ_A12:>315	24	F-0	N.A.	N.A.	N.A.	3.74	9.43	1.45	0.01	3.76	9.10	1.46	0.01
130703	no	N_dut	dur_sub2_9-92	MOZZ_A12:>315	37	F-0	N.A.	N.A.	N.A.	3.48	9.68	1.20	0.02	3.49	9.68	1.20	0.02
130703	yes	N_dut	dur_sub2_10-100	MOZZ_A12:>315	31	F-0	N.A.	N.A.	1.43	3.99	34.75	1.39	0.02	2.56	27.83	1.44	0.01
130703	no	N_dut	dur_sub2_11-103	MOZZ_A12:>315	28	F-0	N.A.	N.A.	N.A.	3.61	12.60	1.61	0.02	4.23	10.03	1.55	0.03
130703	yes	N_dut	dur_sub2_12-106	MOZZ_A12:>315	38	F-0	3.74	3.84	1.24	4.79	5.37	1.37	0.01	4.27	3.37	1.33	0.01
130703	yes	N_dut	dur_sub2_13-109	MOZZ_A12:>315	26	F-0	2.94	4.44	1.58	5.45	2.22	1.49	0.01	4.17	3.40	1.50	0.02
130703H1	yes	N_dut	dur_sub2_15-6	MOZZ_A12:>315	23	F-0	2.31	6.79	1.37	4.70	6.77	1.53	0.01	3.72	6.52	1.48	0.01
130703H1	no	N_dut	dur_sub2_16-9	MOZZ_A12:>315	30	F-0	N.A.	N.A.	N.A.	3.83	12.40	1.37	0.02	3.84	12.43	1.37	0.02
130703H1	no	N_dut	dur_sub2_17-12	MOZZ_A12:>315	15	F-0	N.A.	N.A.	N.A.	2.87	16.98	1.25	0.03	2.87	17.02	1.25	0.03
130703H1	no	N_dut	dur_sub2_18-15	MOZZ_A12:>315	23	F-0	N.A.	N.A.	N.A.	6.26	7.85	1.46	0.02	6.35	8.12	1.49	0.02
130703H1	yes	N_dut	dur_sub2_19-23	MOZZ_A12:>315	33	F-0	N.A.	N.A.	1.21	6.16	42.54	1.39	0.02	6.13	43.10	1.32	0.02
130703H1	no	N_dut	dur_sub2_21-29	MOZZ_A12:>315	24	F-0	N.A.	N.A.	N.A.	2.51	7.23	1.31	0.01	2.51	7.23	1.31	0.01
130703H1	yes	N_dut	dur_sub2_22-32	MOZZ_A12:>315	22	F-0	1.58	3.77	1.22	3.56	7.17	1.57	0.02	2.49	5.11	1.40	0.01
130704	yes	N_dut	dur_sub2_24-9	MOZZ_A12:>315	29	F-0	4.14	19.00	1.20	5.26	9.39	1.45	0.02	3.79	9.19	1.41	0.02
130704	no	N_dut	dur_sub2_25-12	MOZZ_A12:>315	22	F-0	N.A.	N.A.	N.A.	3.13	17.57	1.56	0.03	3.13	17.57	1.56	0.03
130704	no	N_dut	dur_sub2_26-15	MOZZ_A12:>315	24	F-0	N.A.	N.A.	N.A.	3.36	12.32	1.91	0.02	2.84	10.41	1.91	0.02
130704	yes	N_dut	dur_sub2_27-23	MOZZ_A12:>315	20	F-0	2.98	1.60	1.38	4.12	9.03	1.44	0.02	3.51	4.97	1.41	0.02
130704	yes	N_dut	dur_sub2_29-29	MOZZ_A11:>315	25	F-0	3.42	6.19	1.20	5.13	7.88	1.33	0.03	4.66	7.44	1.26	0.02
130704	yes	N_dut	dur_sub2_85-96	MOZA_A01>315	27	F-0	1.85	0.75	1.35	3.64	4.62	1.55	0.02	2.52	1.86	1.50	0.01
130704	yes	N_dut	dur_sub2_86-99	MOZA_A01>315	34	F-0	2.22	9.48	1.12	2.22	9.48	1.12	0.01	2.31	9.76	1.21	0.01
130704	no	N_dut	dur_sub2_87-107	MOZA_A01>315	16	F-0	N.A.	N.A.	N.A.	2.89	20.59	1.53	0.03	2.89	20.59	1.53	0.03
130704	yes	N_dut	dur_sub2_88-110	MOZA_A01>315	21	F-0	1.01	1.82	1.26	1.24	3.17	1.27	0.02	1.11	1.84	1.27	0.01
130704	yes	N_dut	dur_sub2_89-113	MOZA_A01>315	22	F-0	1.21	1.62	1.24	2.71	4.50	1.30	0.04	1.73	2.17	1.26	0.01
130704	no	N_dut	dur_sub2_90-116	MOZA_A01>315	33	F-0	N.A.	N.A.	N.A.	3.04	3.55	1.47	0.02	3.03	3.02	1.47	0.02
130704	no	N_dut	dur_sub2_91-125	MOZA_A01>315	34	F-0	N.A.	N.A.	N.A.	2.79	9.85	1.20	0.01	2.77	9.03	1.18	0.01
130704	yes	N_dut	dur_sub2_92-128	MOZA_A01>315	16	F-0	1.25	4.82	1.36	3.06	6.57	1.14	0.01	1.60	5.93	1.34	0.01

130705	yes	N.dut	dut_sub2_96-6	MOZA_A01>315	35	F=0	3.96	3.26	1.30	0.01	3.95	7.61	1.29	0.03	4.11	5.93	1.29	0.02
130705	no	N.dut	dut_sub2_97-9	MOZA_A01>315	10	F=0	N.A.	N.A.	N.A.	N.A.	4.04	5.32	1.37	0.05	4.04	5.32	1.37	0.05
130705	no	N.dut	dut_sub2_98-12	MOZA_A01>315	11	F=0	N.A.	N.A.	N.A.	N.A.	6.98	24.72	1.37	0.05	6.98	24.72	1.37	0.05
130718	yes	N.dut	Ndut_sub3_38-62	MOZA_A06> 315	25	F=0	2.14	2.38	1.15	0.01	4.12	8.86	1.44	0.06	3.12	5.33	1.28	0.03
130718	no	N.dut	Ndut_sub3_39-70	MOZA_A06> 315	18	F=0	N.A.	N.A.	N.A.	N.A.	2.86	25.79	1.49	0.03	2.86	25.77	1.48	0.03
130718	yes	N.dut	Ndut_sub3_40-73	MOZA_A06> 315	25	F=0	2.27	4.48	1.22	0.01	6.09	24.92	1.57	0.06	4.12	13.91	1.39	0.03
130718	no	N.dut	Ndut_sub3_41-76	MOZA_A06> 315	21	F=0	N.A.	N.A.	N.A.	N.A.	4.32	6.01	1.39	0.02	4.32	6.01	1.39	0.02
130718	yes	N.dut	Ndut_sub3_42-79	MOZA_A06> 315	33	F=0	3.11	4.82	1.16	0.01	4.60	4.48	1.40	0.02	4.18	4.24	1.28	0.01
130718	no	N.dut	N.dut_54	MOZA_A06> 315	30	F=0	N.A.	N.A.	N.A.	N.A.	3.10	2.58	1.17	0.01	3.16	2.55	1.18	0.01
130718	yes	N.dut	N.dut_55	MOZA_A06> 315	39	F=0	2.11	N.A.	1.11	0.01	2.84	35.46	1.40	0.02	2.55	33.98	1.29	0.01
130718	yes	N.dut	N.dut_56	MOZA_A06> 315	47	F=0	3.66	N.A.	1.11	0.01	4.34	64.44	1.42	0.03	3.73	45.58	1.32	0.03
130718	yes	N.dut	N.dut_57	MOZA_A06> 315	31	F=0	2.87	4.93	1.24	0.00	3.04	12.92	1.28	0.02	3.02	5.92	1.24	0.01
130718	yes	N.dut	Ndut_sub3_58-104	MOZA_A06> 315	39	F=0	2.62	3.42	1.44	0.02	5.94	2.68	1.52	0.04	3.87	3.31	1.44	0.02
130718	no	N.dut	Ndut_sub3_59-107	MOZA_A06> 315	35	F=0	N.A.	N.A.	N.A.	N.A.	6.23	42.74	1.43	0.05	6.43	41.23	1.41	0.05
130718	yes	N.dut	Ndut_sub3_62-120	MOZA_A06> 315	37	F=0	2.25	12.47	1.38	N.A.	4.16	7.23	1.42	0.03	3.63	7.86	1.37	0.03
130718	yes	N.dut	Ndut_sub3_64-126	MOZA_A06> 315	29	F=0	3.50	15.04	1.15	0.00	6.34	8.65	1.41	0.02	4.95	12.00	1.26	0.01
130718	yes	N.dut	Ndut_sub3_66-137	MOZA_A06> 315	28	F=0	1.26	3.44	1.23	0.00	2.29	12.47	1.39	0.04	1.76	7.97	1.31	0.02
130718	yes	N.dut	Ndut_sub3_67-140	MOZA_A06> 315	29	F=0	3.08	N.A.	1.26	0.01	6.19	56.54	1.44	0.04	5.33	53.19	1.39	0.03
130718	yes	N.dut	Ndut_sub3_68-143	MOZA_A06> 315	25	F=0	2.24	7.55	1.32	0.01	3.55	15.78	1.26	0.01	2.83	11.01	1.28	0.01
130718	no	N.dut	Ndut_sub3_69-146	MOZA_A06> 315	27	F=0	N.A.	N.A.	N.A.	N.A.	3.07	16.47	1.43	0.01	3.07	16.44	1.43	0.01
130719	yes	N.dut	dut_sub4_2-25	MOZA_A01, 250-315	15	F=0	1.34	1.60	1.39	0.00	3.42	4.00	1.19	0.01	2.68	5.11	1.43	0.01
130719	yes	N.dut	dut_sub4_3-28	MOZA_A01, 250-315	22	F=0	2.25	5.02	1.32	0.00	3.61	4.39	1.26	0.02	2.81	5.02	1.29	0.01
130719	yes	N.dut	dut_sub4_4-31	MOZA_A01, 250-315	10	F=0	2.97	6.77	1.35	N.A.	3.58	15.49	1.28	0.02	3.06	6.72	1.33	0.03
130719	no	N.dut	dut_sub4_5-38	MOZA_A01, 250-315	13	F=0	N.A.	N.A.	N.A.	N.A.	3.01	10.45	1.20	0.02	3.26	11.32	1.24	0.02

130719	no	N. dur	dur_sub4_6-41	MOZL_A01_250-315	15	F-0	N.A.	N.A.	3.57	17.95	1.50	0.06	4.12	17.71	1.52	0.06
130719	no	N. dur	dur_sub4_7-44	MOZL_A01_250-315	25	F-0	N.A.	N.A.	1.50	1.73	1.26	0.01	1.50	1.73	1.26	0.01
130719	yes	N. dur	dur_sub4_8-47	MOZL_A01_250-315	24	F-0	2.94	2.00	4.24	5.13	1.28	0.02	3.85	4.20	1.27	0.01
130719	no	N. dur	dur_sub4_9-55	MOZL_A01_250-315	13	F-0	N.A.	N.A.	2.06	10.74	1.26	0.00	2.06	10.74	1.26	0.00
201408	yes	N. dur	dur2	MOZL_A20>315	34	F-0	2.23	N.A.	2.56	N.A.	N.A.	N.A.	2.54	N.A.	N.A.	N.A.
201408	yes	N. dur	dur3	MOZL_A20>315	33	F-0	2.42	N.A.	2.31	N.A.	N.A.	N.A.	2.53	N.A.	N.A.	N.A.
2014_05	yes	N. dur	dur_11a	MOZL_A16>315	23	F-0	2.19	N.A.	4.42	N.A.	N.A.	N.A.	4.00	N.A.	N.A.	N.A.
2014_05	no	N. dur	dur_12a	MOZL_A16>315	28	F-0	N.A.	N.A.	2.25	N.A.	N.A.	N.A.	2.27	N.A.	N.A.	N.A.
2014_05	no	N. dur	dur_13a	MOZL_A16>315	29	F-0	N.A.	N.A.	1.69	N.A.	N.A.	N.A.	2.13	N.A.	N.A.	N.A.
2014_05	no	N. dur	dur_14a	MOZL_A16>315	18	F-0	N.A.	N.A.	3.26	N.A.	N.A.	N.A.	3.33	N.A.	N.A.	N.A.
2014_05	yes	N. dur	dur_15a	MOZL_A16>315	27	F-0	3.45	N.A.	5.31	N.A.	N.A.	N.A.	4.94	N.A.	N.A.	N.A.
130124	yes	N. dur	dur-62-055	MOZL_A07,>315	32	F-1	0.75	5.08	2.81	15.40	1.61	N.A.	1.28	6.73	1.21	
130124	yes	N. dur	dur-63-056	MOZL_A07,>315	22	F-1	2.12	N.A.	4.08	98.73	1.70	N.A.	3.01	64.25	1.30	
130124	yes	N. dur	dur-64-057	MOZL_A07,>315	18	F-1	3.47	12.29	4.35	26.38	1.48	N.A.	3.11	14.89	1.19	
130124	yes	N. dur	dur-65-058	MOZL_A07,>315	27	F-1	1.94	7.77	4.02	21.55	1.62	N.A.	2.27	11.05	1.24	
130124	yes	N. dur	dur-66-059	MOZL_A07,>315	35	F-1	1.25	9.76	3.12	20.17	1.67	N.A.	1.44	9.70	1.26	
130124	yes	N. dur	dur-67-060	MOZL_A07,>315	24	F-1	2.25	17.73	2.60	26.36	1.75	N.A.	1.88	15.64	1.28	
130124	yes	N. dur	dur-68-061	MOZL_A07,>315	25	F-1	1.38	8.19	2.58	15.56	1.51	N.A.	1.73	9.37	1.18	
130124	yes	N. dur	dur-69-062	MOZL_A07,>315	28	F-1	2.20	15.16	2.98	31.47	1.48	N.A.	2.02	20.33	1.13	
130124	yes	N. dur	dur-50-063	MOZL_A07,>315	33	F-1	N.A.	9.17	2.65	12.30	1.66	N.A.	2.13	10.43	1.33	
130124	no	N. dur	dur-51-064	MOZL_A07,>315	27	F-1	N.A.	N.A.	2.19	11.80	1.62	N.A.	1.69	9.56	1.24	
130124	yes	N. dur	dur-52-068	MOZL_A07,>315	26	F-1	1.00	5.95	2.09	10.12	1.47	N.A.	1.31	0.64	1.19	
130124	no	N. dur	dur-53-069	MOZL_A07,>315	35	F-1	N.A.	N.A.	1.62	15.82	1.52	N.A.	1.33	13.45	1.16	
130124	no	N. dur	dur-54-070	MOZL_A07,>315	36	F-1	N.A.	N.A.	2.17	14.80	1.54	N.A.	1.63	1.11	1.15	
130124	yes	N. dur	dur-55-071	MOZL_A07,>315	35	F-1	1.66	6.50	1.94	10.30	1.56	N.A.	1.50	7.06	1.17	

130124	yes	N.dut	dur-56-072	MOZ1_A07,>315	25	F-1	1.28	6.84	1.66	N.A.	1.86	18.00	1.66	N.A.	1.23	10.27	1.29
130124	yes	N.dut	dur-57-073	MOZ1_A07,>315	32	F-1	0.62	5.90	1.57	N.A.	3.29	23.46	1.54	N.A.	1.29	1.06	1.22
130124	no	N.dut	dur-58-074	MOZ1_A07,>315	34	F-1	N.A.	N.A.	N.A.	N.A.	2.87	10.39	1.61	N.A.	2.17	8.57	1.25
130124	yes	N.dut	dur-59-075	MOZ1_A07,>315	26	F-1	0.84	10.30	1.55	N.A.	2.13	23.61	1.56	N.A.	1.11	1.18	1.23
130124	yes	N.dut	dur-60-076	MOZ1_A07,>315	23	F-1	1.74	4.15	1.56	N.A.	2.13	14.23	1.65	N.A.	1.56	7.15	1.26
130124	yes	N.dut	dur-61-077	MOZ1_A07,>315	30	F-1	1.46	10.47	1.52	N.A.	5.37	25.72	1.83	N.A.	2.02	1.17	1.22
130124	yes	N.dut	dur-62-078	MOZ1_A07,>315	26	F-1	1.46	6.83	1.48	N.A.	3.24	19.26	1.60	N.A.	1.93	1.10	1.23
130124	yes	N.dut	dur-63-082	MOZ1_A07,>315	27	F-1	1.26	11.09	N.A.	N.A.	1.26	11.09	1.72	N.A.	0.99	0.87	1.35
130124	yes	N.dut	dur-64-083	MOZ1_A07,>315	32	F-1	1.23	8.45	1.55	N.A.	2.32	13.76	1.58	N.A.	1.43	0.93	1.28
130125	no	N.dut	dur-82-014	MOZ1_A08,>315	38	F-1	N.A.	N.A.	N.A.	N.A.	4.12	28.07	1.61	N.A.	3.14	23.66	1.54
130125	yes	N.dut	dur-83-015	MOZ1_A08,>315	32	F-1	2.62	N.A.	1.32	N.A.	2.54	28.74	1.70	N.A.	2.56	26.14	1.63
130125	yes	N.dut	dur-84-016	MOZ1_A08,>315	30	F-1	2.57	14.73	1.62	N.A.	2.93	33.20	1.67	N.A.	2.74	28.25	1.64
130701	no	N.dut	dur_sub1_025a-034	MOZZ_A11,>315	19	F-1	N.A.	N.A.	N.A.	N.A.	3.88	45.36	1.36	0.02	4.28	48.40	1.40
130701	yes	N.dut	dur_sub1_026a-042	MOZZ_A11,>315	20	F-1	2.18	7.59	1.43	0.01	2.87	32.75	1.30	0.01	2.37	19.75	1.37
130701	yes	N.dut	dur_sub1_027a-045	MOZZ_A11,>315	26	F-1	1.42	5.66	1.17	0.00	2.43	12.27	1.41	0.01	2.56	11.45	1.36
130701	no	N.dut	dur_sub1_028a-048	MOZZ_A11,>315	32	F-1	N.A.	N.A.	N.A.	N.A.	3.39	58.14	1.22	0.02	3.52	60.30	1.27
130701	no	N.dut	dur_sub1_029a-056	MOZZ_A11,>315	37	F-1	N.A.	N.A.	N.A.	N.A.	1.99	6.06	1.24	0.02	2.11	6.43	1.31
130701	no	N.dut	dur_sub1_030a-059	MOZZ_A11,>315	40	F-1	N.A.	N.A.	N.A.	N.A.	4.85	7.72	1.43	0.03	4.84	7.68	1.43
130701	yes	N.dut	dur_sub1_031a-062	MOZZ_A11,>315	30	F-1	2.54	5.32	1.28	0.01	4.18	11.78	1.45	0.02	3.85	10.32	1.44
130701	yes	N.dut	dur_sub1_032a-065	MOZZ_A11,>315	34	F-1	3.44	13.36	1.13	0.01	4.72	24.01	1.43	0.02	3.85	18.77	1.46
130701	yes	N.dut	dur_sub1_033a-073	MOZZ_A11,>315	23	F-1	1.61	8.34	1.29	0.00	2.47	14.38	1.42	0.03	2.27	13.20	1.40
130701	yes	N.dut	dur_sub1_034b-077	MOZZ_A11,>315	36	F-1	2.25	1.51	1.18	0.00	2.34	8.68	1.36	0.02	2.41	8.59	1.32
130701	yes	N.dut	dur_sub1_035-079	MOZZ_A11,>315	28	F-1	1.40	0.71	1.13	0.00	2.72	4.11	1.49	0.02	2.46	2.08	1.42
130701	no	N.dut	dur_sub1_036-082	MOZZ_A11,>315	30	F-1	N.A.	N.A.	N.A.	N.A.	5.19	3.73	1.59	0.03	5.35	3.84	1.64
130701	yes	N.dut	dur_sub1_037-090	MOZZ_A11,>315	28	F-1	2.19	3.35	1.32	0.01	2.19	3.35	1.32	0.01	3.23	5.08	1.31
130701	yes	N.dut	dur_sub1_038-092	MOZZ_A11,>315	25	F-1	3.85	*	1.17	0.01	3.85	*	1.17	0.01	4.78	N.A.	1.21

130701	yes	N. dur	dur_sub1_038b-094	MOZZ_A11:>315	25	F-1	3.73	3.60	1.02	0.00	4.99	5.37	1.08	0.01	4.95	5.02	1.20	0.01
130701	no	N. dur	dur_sub1_039a-096	MOZZ_A11:>315	20	F-1	N.A.	N.A.	N.A.	N.A.	5.48	9.10	1.35	0.01	5.79	9.59	1.43	0.01
130701	no	N. dur	dur_sub1_040-098	MOZZ_A11:>315	21	F-1	N.A.	N.A.	N.A.	N.A.	4.21	8.03	1.32	0.02	4.51	8.59	1.41	0.02
130701	no	N. dur	dur_sub1_044	MOZZ_A11:>315	26	F-1	N.A.	N.A.	N.A.	N.A.	2.87	2.99	1.30	0.02	2.90	3.06	1.32	0.02
130701	yes	N. dur	dur_sub1_045a	MOZZ_A11:>315	24	F-1	1.43	1.35	1.34	0.00	2.28	13.03	1.28	0.01	2.09	8.92	1.37	0.01
130701	no	N. dur	dur_sub1_046a	MOZZ_A11:>315	21	F-1	N.A.	N.A.	N.A.	N.A.	3.02	2.13	1.42	0.01	3.24	2.28	1.52	0.02
130701	yes	N. dur	dur_sub1_047a	MOZZ_A11:>315	32	F-1	2.54	5.70	1.19	0.01	3.51	3.00	1.43	0.02	3.06	4.68	1.34	0.01
130701	yes	N. dur	dur_sub1_048a	MOZZ_A11:>315	35	F-1	1.30	2.95	1.31	0.00	2.14	5.59	1.26	0.02	1.97	4.88	1.32	0.01
130701	no	N. dur	dur_sub1_049	MOZZ_A11:>315	23	F-1	N.A.	N.A.	N.A.	N.A.	2.03	3.04	1.38	0.01	1.58	1.46	1.51	0.00
130701	yes	N. dur	dur_sub1_050a	MOZZ_A11:>315	25	F-1	1.25	1.64	1.44	0.00	1.91	6.35	1.17	0.01	3.11	13.01	1.36	0.01
130701	yes	N. dur	dur_sub1_051a	MOZZ_A11:>315	31	F-1	2.84	*	1.21	0.01	3.96	3.28	1.36	0.02	3.68	1.80	1.38	0.01
130701	yes	N. dur	dur_sub1_052a	MOZZ_A11:>315	38	F-1	3.89	19.15	1.15	0.01	4.14	29.45	1.33	0.02	4.39	28.67	1.37	0.02
130701	yes	N. dur	dur_sub1_054a	MOZZ_A11:>315	32	F-1	2.32	1.27	1.18	0.00	2.82	1.86	1.26	0.01	2.84	1.33	1.34	0.01
130701	no	N. dur	dur_sub1_053a-147	MOZZ_A11:>315	25	F-1	N.A.	N.A.	N.A.	N.A.	2.84	11.07	1.29	0.02	3.07	12.43	1.42	0.01
130703	no	N. dur	dur_sub2_8a-90	MOZZ_A12:>315	24	F-1	N.A.	N.A.	N.A.	N.A.	3.15	5.26	1.22	0.00	3.15	5.28	1.23	0.00
130703	yes	N. dur	dur_sub2_9a-93	MOZZ_A12:>315	37	F-1	1.50	3.62	1.31	0.01	2.01	6.52	1.30	0.01	1.94	6.43	1.32	0.01
130703	yes	N. dur	dur_sub2_10a-101	MOZZ_A12:>315	31	F-1	1.67	18.18	1.31	0.01	2.61	34.02	1.23	0.01	2.24	27.19	1.27	0.01
130703	yes	N. dur	dur_sub2_11a-104	MOZZ_A12:>315	28	F-1	1.07	1.84	1.41	0.00	2.60	8.06	1.35	0.01	2.03	3.42	1.34	0.01
130703	no	N. dur	dur_sub2_12a-107	MOZZ_A12:>315	38	F-1	N.A.	N.A.	N.A.	N.A.	3.03	11.25	1.29	0.00	3.21	9.26	1.24	0.00
130703	no	N. dur	dur_sub2_13a-110	MOZZ_A12:>315	26	F-1	N.A.	N.A.	N.A.	N.A.	2.95	9.68	1.55	0.02	3.40	11.27	1.51	0.02
130703H	yes	N. dur	dur_sub2_15a-7	MOZZ_A12:>315	23	F-1	1.77	14.74	1.31	0.00	3.26	10.78	1.95	0.02	2.53	13.20	1.66	0.01
130703H	yes	N. dur	dur_sub2_16a-10	MOZZ_A12:>315	30	F-1	0.84	2.37	1.35	0.01	2.83	7.34	1.37	0.01	1.93	5.13	1.37	0.01
130703H	yes	N. dur	dur_sub2_17a-13	MOZZ_A12:>315	15	F-1	2.07	4.91	1.37	0.02	3.99	4.33	1.46	0.02	3.20	4.17	1.42	0.02
130703H	no	N. dur	dur_sub2_18a-16	MOZZ_A12:>315	23	F-1	N.A.	N.A.	N.A.	N.A.	2.15	6.63	1.39	0.01	2.15	6.64	1.39	0.01
130703H	no	N. dur	dur_sub2_20-26	MOZZ_A12:>315	32	F-1	N.A.	N.A.	N.A.	N.A.	3.27	8.99	1.32	0.02	3.28	9.01	1.33	0.02
130703H	yes	N. dur	dur_sub2_21a-30	MOZZ_A12:>315	24	F-1	1.24	2.99	1.32	0.00	2.22	4.90	1.31	0.01	1.87	4.17	1.32	0.01

130703H	yes	N	dur	dur_sub2_22a-33	MOZ2_A12>315	22	F-1	1.69	2.73	1.25	0.01	3.10	7.68	1.33	0.02	2.70	5.57	1.30	0.01
130704	no	N	dur	dur_sub2_23-6	MOZ2_A12>315	14	F-1	N.A.	N.A.	N.A.	N.A.	1.83	20.13	1.41	0.02	1.79	17.27	1.32	0.01
130704	yes	N	dur	dur_sub2_24a-10	MOZ2_A12>315	29	F-1	1.28	3.53	1.25	0.01	3.29	6.17	1.24	0.01	2.28	5.19	1.21	0.01
130704	yes	N	dur	dur_sub2_25a-13	MOZ2_A12>315	22	F-1	3.44	12.45	1.60	0.02	3.44	12.45	1.60	0.02	3.49	11.47	1.63	0.02
130704	yes	N	dur	dur_sub2_26a-16	MOZ2_A12>315	24	F-1	2.49	10.65	1.95	0.02	2.49	10.65	1.95	0.02	2.68	11.54	1.95	0.02
130704	yes	N	dur	dur_sub2_27a-24	MOZ2_A12>315	20	F-1	2.53	2.22	1.31	0.01	4.09	6.13	1.36	0.02	3.24	3.39	1.33	0.01
130704	yes	N	dur	dur_sub2_29a-30	MOZ2_A11>315	25	F-1	1.26	2.38	1.25	0.00	3.16	9.19	1.22	0.01	2.17	6.21	1.25	0.01
130704	yes	N	dur	dur_sub2_35a-97	MOZA_A01>315	27	F-1	0.98	3.02	1.33	0.00	2.33	2.53	1.29	0.01	1.43	2.60	1.34	0.01
130704	yes	N	dur	dur_sub2_36a-100	MOZA_A01>315	34	F-1	1.04	5.57	1.41	*	2.70	11.52	1.33	0.02	2.26	10.65	1.35	0.01
130704	yes	N	dur	dur_sub2_37a-108	MOZA_A01>315	16	F-1	2.31	19.15	1.28	N.A.	3.52	16.71	1.28	0.03	2.94	19.90	1.27	0.02
130704	yes	N	dur	dur_sub2_38a-111	MOZA_A01>315	21	F-1	0.84	1.51	1.37	0.00	2.78	4.64	1.22	0.04	1.47	2.31	1.34	0.01
130704	yes	N	dur	dur_sub2_39a-114	MOZA_A01>315	22	F-1	1.00	2.04	1.23	0.01	2.51	5.84	1.23	0.03	1.46	3.08	1.22	0.01
130704	yes	N	dur	dur_sub2_39a-117	MOZA_A01>315	33	F-1	1.74	4.10	1.28	0.01	2.80	6.10	1.28	0.01	2.55	5.08	1.29	0.01
130704	yes	N	dur	dur_sub2_91a-126	MOZA_A01>315	34	F-1	2.82	10.27	1.11	0.01	5.96	15.82	1.36	0.02	4.92	14.85	1.29	0.02
130704	yes	N	dur	dur_sub2_92a-129	MOZA_A01>315	16	F-1	0.97	1.16	1.27	0.00	3.31	5.08	1.24	0.01	1.76	2.37	1.27	0.01
130704	no	N	dur	dur_sub2_93-131	MOZA_A01>315	30	F-1	N.A.	N.A.	N.A.	N.A.	3.33	5.68	1.47	0.02	3.15	4.57	1.49	0.02
130704	no	N	dur	dur_sub2_95-134	MOZA_A01>315	8	F-1	N.A.	N.A.	N.A.	N.A.	2.75	6.75	1.35	0.03	2.79	6.88	1.34	0.03
130705	yes	N	dur	dur_sub2_96a-7	MOZA_A01>315	35	F-1	N.A.	4.24	1.24	N.A.	3.41	5.92	1.33	0.01	3.63	5.70	1.31	0.01
130705	no	N	dur	dur_sub2_97a-10	MOZA_A01>315	10	F-1	N.A.	N.A.	N.A.	N.A.	3.70	10.67	1.34	0.06	3.70	10.67	1.34	0.06
130705	no	N	dur	dur_sub2_98a-13	MOZA_A01>315	11	F-1	N.A.	N.A.	N.A.	N.A.	10.20	21.04	1.32	0.12	10.20	21.04	1.32	0.12
130705	yes	N	dur	dur_sub2_99-15	MOZA_A01>315	27	F-1	2.88	11.92	1.19	0.01	4.28	13.11	1.27	0.04	4.10	13.63	1.25	0.02
130718	yes	N	dur	Ndur_sub3_38a-63	MOZA_A06>315	25	F-1	0.83	1.13	1.42	0.00	2.60	4.64	1.33	0.01	1.67	1.67	1.40	0.01
130718	no	N	dur	Ndur_sub3_39a-71	MOZA_A06>315	18	F-1	N.A.	N.A.	N.A.	N.A.	2.23	12.63	1.26	0.02	2.23	12.63	1.26	0.02
130718	yes	N	dur	Ndur_sub3_40a-74	MOZA_A06>315	25	F-1	1.42	2.38	1.20	0.00	5.24	7.66	1.43	0.03	3.24	5.11	1.31	0.02
130718	no	N	dur	Ndur_sub3_41a-77	MOZA_A06>315	21	F-1	N.A.	N.A.	N.A.	N.A.	3.99	10.58	1.32	0.02	3.99	10.58	1.31	0.02
130718	yes	N	dur	Ndur_sub3_42a-80	MOZA_A06>315	33	F-1	2.55	1.95	1.22	0.01	2.91	6.21	1.27	0.02	2.82	4.40	1.26	0.02

130718	no	N. dut	N. dut_54a	MOZA_A06> 315	30	F-1	N.A.	N.A.	N.A.	2.46	4.62	1.26	0.01	2.46	4.62	1.26	0.01
130718	yes	N. dut	N. dut_55a	MOZA_A06> 315	39	F-1	1.55	N.A.	1.04	2.74	19.08	1.26	0.02	2.57	22.99	1.22	0.01
130718	yes	N. dut	N. dut_56a	MOZA_A06> 315	47	F-1	1.90	6.63	1.27	2.66	13.29	1.35	0.03	2.52	11.76	1.30	0.02
130718	yes	N. dut	N. dut_57a	MOZA_A06> 315	31	F-1	2.52	5.99	1.20	3.17	15.62	1.24	0.02	3.24	13.09	1.24	0.02
130718	no	N. dut	N.dut_sub3_58a-105	MOZA_A06> 315	39	F-1	N.A.	4.31	1.36	2.53	4.31	1.36	0.02	2.53	4.31	1.35	0.02
130718	yes	N. dut	N.dut_sub3_59a-108	MOZA_A06> 315	35	F-1	2.94	7.86	1.24	3.20	4.37	1.43	0.03	3.43	7.17	1.28	0.02
130718	yes	N. dut	N.dut_sub3_60-110	MOZA_A06> 315	49	F-1	1.72	3.13	1.25	2.38	13.60	1.22	0.02	2.25	7.26	1.23	0.01
130718	yes	N. dut	N.dut_sub3_61-112	MOZA_A06> 315	46	F-1	2.31	7.46	1.23	3.24	8.39	1.45	0.02	2.74	7.41	1.31	0.01
130718	yes	N. dut	N.dut_sub3_62a-121	MOZA_A06> 315	37	F-1	2.60	5.75	1.17	3.04	4.17	1.32	0.01	2.97	4.42	1.29	0.01
130718	yes	N. dut	N.dut_sub3_63-123	MOZA_A06> 315	36	F-1	2.46	*	1.29	3.98	7.59	1.44	0.14	3.21	3.49	1.35	0.07
130718	yes	N. dut	N.dut_sub3_64a-127	MOZA_A06> 315	29	F-1	1.69	13.00	1.21	4.98	12.23	1.32	0.02	3.37	13.32	1.26	0.01
130718	no	N. dut	N.dut_sub3_65-	MOZA_A06> 315	33	F-1	N.A.	N.A.	N.A.	3.62	9.39	1.41	0.03	4.12	8.48	1.38	0.03
130718	yes	N. dut	N.dut_sub3_66a-138	MOZA_A06> 315	28	F-1	1.21	*	1.36	2.94	6.63	1.47	0.02	2.23	4.00	1.41	0.01
130718	yes	N. dut	N.dut_sub3_67a-141	MOZA_A06> 315	29	F-1	1.26	10.30	1.22	3.41	34.13	1.27	0.01	2.73	26.63	1.25	0.01
130718	yes	N. dut	N.dut_sub3_68a-144	MOZA_A06> 315	25	F-1	1.01	2.09	1.47	2.46	*	1.33	0.02	1.64	2.38	1.41	0.01
130718	yes	N. dut	N.dut_sub3_69a-147	MOZA_A06> 315	27	F-1	1.30	*	1.48	2.07	15.78	1.31	0.02	1.41	N.A.	1.46	N.A.
130719	yes	N. dut	dut_sub4_2a-26	MOZA_A01, 250-315	15	F-1	1.48	2.93	1.19	3.38	5.19	1.21	0.02	2.19	3.75	1.18	0.01
130719	yes	N. dut	dut_sub4_3a-29	MOZA_A01, 250-315	22	F-1	2.15	4.42	1.20	3.56	5.79	1.22	0.02	2.78	4.84	1.22	0.01
130719	no	N. dut	dut_sub4_4a-32	MOZA_A01, 250-315	10	F-1	N.A.	N.A.	N.A.	4.15	7.57	1.25	0.04	4.35	8.43	1.26	0.04
130719	no	N. dut	dut_sub4_5a-39	MOZA_A01, 250-315	13	F-1	N.A.	N.A.	N.A.	4.45	15.54	1.28	0.02	4.45	15.54	1.28	0.02
130719	no	N. dut	dut_sub4_6a-42	MOZA_A01, 250-315	15	F-1	N.A.	N.A.	N.A.	5.46	27.14	1.56	0.05	5.46	27.14	1.56	0.05
130719	yes	N. dut	dut_sub4_8a-48	MOZA_A01, 250-315	24	F-1	2.13	2.64	1.28	3.15	6.32	1.24	0.01	3.01	5.61	1.25	0.01

130719	yes	N. dur	dur_ausb1_9a-56	MOZLA001_250<315	13	F-1	1.16	9.61	1.19	0.00	3.02	8.88	1.37	0.02	1.96	9.52	1.30	0.01
201408	yes	N. dur	dur2	MOZ2_A20>315	34	F-1	2.45	N.A.	N.A.	N.A.	3.61	N.A.	N.A.	N.A.	3.46	N.A.	N.A.	N.A.
201408	yes	N. dur	dur3	MOZ2_A20>315	33	F-1	2.38	N.A.	N.A.	N.A.	2.35	N.A.	N.A.	N.A.	3.40	N.A.	N.A.	N.A.
2014_05	yes	N. dur	dur_11b	MOZ1_A16>315	23	F-1	1.62	N.A.	N.A.	N.A.	4.17	N.A.	N.A.	N.A.	3.15	N.A.	N.A.	N.A.
2014_05	yes	N. dur	dur_12b	MOZ1_A16>315	28	F-1	2.06	N.A.	N.A.	N.A.	5.32	N.A.	N.A.	N.A.	4.26	N.A.	N.A.	N.A.
2014_05	yes	N. dur	dur_13b	MOZ1_A16>315	29	F-1	1.71	N.A.	N.A.	N.A.	2.07	N.A.	N.A.	N.A.	1.75	N.A.	N.A.	N.A.
2014_05	yes	N. dur	dur_14b	MOZ1_A16>315	18	F-1	2.03	N.A.	N.A.	N.A.	3.90	N.A.	N.A.	N.A.	3.18	N.A.	N.A.	N.A.
2014_05	yes	N. dur	dur_15b	MOZ1_A16>315	27	F-1	1.81	N.A.	N.A.	N.A.	2.95	N.A.	N.A.	N.A.	2.78	N.A.	N.A.	N.A.
130125	yes	N. dur	dur_82a-043	MOZ1_A08,>315	38	F-2	1.40	5.90	1.52	N.A.	1.96	28.34	1.63	N.A.	1.67	15.51	1.59	N.A.
130125	yes	N. dur	dur_83a-044	MOZ1_A08,>315	32	F-2	1.15	9.17	1.46	N.A.	1.78	21.57	1.60	N.A.	1.47	16.00	1.55	N.A.
130125	no	N. dur	dur_84a-045	MOZ1_A08,>315	30	F-2	N.A.	N.A.	N.A.	N.A.	2.65	28.18	1.56	N.A.	2.68	27.85	1.55	N.A.
130125	yes	N. dur	dur_42a-046	MOZ1_A07,>315	32	F-2	0.53	8.77	1.63	N.A.	1.39	12.47	1.40	N.A.	1.05	10.99	1.52	N.A.
130125	yes	N. dur	dur_43a-047	MOZ1_A07,>315	22	F-2	1.06	13.42	1.65	N.A.	2.67	45.82	1.45	N.A.	2.01	19.22	1.53	N.A.
130125	yes	N. dur	dur_44a-051	MOZ1_A07,>315	18	F-2	2.06	9.85	1.55	N.A.	5.21	23.90	1.64	N.A.	3.10	14.58	1.60	N.A.
130125	yes	N. dur	dur_45a-052	MOZ1_A07,>315	27	F-2	1.44	9.61	1.60	N.A.	2.83	13.47	1.25	N.A.	2.11	11.78	1.43	N.A.
130125	yes	N. dur	dur_46a-053	MOZ1_A07,>315	35	F-2	0.86	10.78	1.66	N.A.	1.93	22.68	1.59	N.A.	1.36	16.75	1.62	N.A.
130125	yes	N. dur	dur_47a-059	MOZ1_A07,>315	24	F-2	1.11	10.67	1.59	N.A.	2.55	27.94	1.56	N.A.	1.48	15.49	1.56	N.A.
130125	yes	N. dur	dur_48b-060	MOZ1_A07,>315	25	F-2	0.99	13.52	1.44	N.A.	2.37	13.25	1.48	N.A.	2.22	13.54	1.49	N.A.
130125	no	N. dur	dur_49a-061	MOZ1_A07,>315	28	F-2	N.A.	N.A.	N.A.	N.A.	1.16	10.83	1.48	N.A.	1.18	10.83	1.48	N.A.
130701	no	N. dur	dur_ausb1_025b-035	MOZ2_A11,>315	19	F-2	N.A.	N.A.	N.A.	N.A.	4.04	25.81	1.23	0.02	4.16	26.52	1.26	0.02
130701	no	N. dur	dur_ausb1_026b-043	MOZ2_A11,>315	20	F-2	N.A.	N.A.	N.A.	N.A.	1.48	4.99	1.37	0.00	1.52	5.13	1.40	0.00
130701	yes	N. dur	dur_ausb1_027b-046	MOZ2_A11,>315	26	F-2	0.79	*	1.24	0.00	2.25	4.24	1.41	0.02	1.84	3.11	1.40	0.01
130701	yes	N. dur	dur_ausb1_028b-049	MOZ2_A11,>315	32	F-2	1.28	9.28	1.24	0.00	5.36	43.63	1.32	0.02	4.19	32.65	1.35	0.02
130701	no	N. dur	dur_ausb1_029b-057	MOZ2_A11,>315	37	F-2	N.A.	N.A.	N.A.	N.A.	1.94	8.45	1.25	0.02	1.96	8.50	1.26	0.02
130701	yes	N. dur	dur_ausb1_030b-060	MOZ2_A11,>315	40	F-2	2.96	4.24	1.30	0.00	4.23	6.41	1.28	0.02	4.29	6.32	1.39	0.02
130701	yes	N. dur	dur_ausb1_031b-063	MOZ2_A11,>315	30	F-2	1.57	2.86	1.31	0.00	4.02	8.94	1.31	0.02	3.16	6.43	1.35	0.01

130701	yes	N. dur	dur_sub1_032b-066	MOZZ_A11:>315	34	F-2	2.36	4.40	1.45	0.01	3.80	14.63	1.30	0.01	3.24	10.10	1.43	0.01
130701	yes	N. dur	dur_sub1_033b-074	MOZZ_A11:>315	23	F-2	0.73	2.93	1.44	0.00	2.85	8.94	1.23	0.03	2.11	7.06	1.44	0.02
130701	yes	N. dur	dur_sub1_034a-076	MOZZ_A11:>315	36	F-2	2.63	6.35	1.07	0.01	3.01	9.10	1.36	0.03	3.20	9.39	1.36	0.03
130701	yes	N. dur	dur_sub1_035a-080	MOZZ_A11:>315	28	F-2	1.48	5.62	1.12	0.00	2.06	9.85	1.27	0.02	1.83	7.28	1.23	0.01
130701	no	N. dur	dur_sub1_036a-083	MOZZ_A11:>315	30	F-2	N.A.	N.A.	N.A.	N.A.	2.83	12.51	1.37	0.02	2.80	12.00	1.39	0.02
130701	no	N. dur	dur_sub1_037a-091	MOZZ_A11:>315	28	F-2	N.A.	N.A.	N.A.	N.A.	3.33	5.99	1.41	0.04	3.39	6.06	1.43	0.04
130701	no	N. dur	dur_sub1_038a-093	MOZZ_A11:>315	25	F-2	N.A.	N.A.	N.A.	N.A.	6.55	3.15	1.37	0.03	7.02	3.37	1.47	0.03
130701	yes	N. dur	dur_sub1_039b-097	MOZZ_A11:>315	20	F-2	N.A.	5.64	1.58	0.00	6.47	15.02	1.24	0.01	6.72	13.11	1.41	0.01
130701	yes	N. dur	dur_sub1_040a-099	MOZZ_A11:>315	21	F-2	3.04	3.11	1.38	0.01	3.82	8.50	1.35	0.02	3.92	7.95	1.45	0.02
130701	yes	N. dur	dur_sub1_044a	MOZZ_A11:>315	26	F-2	1.52	1.87	1.30	0.00	2.94	5.73	1.24	0.01	2.18	4.46	1.36	0.01
130701	yes	N. dur	dur_sub1_045b	MOZZ_A11:>315	24	F-2	1.00	*	1.34	0.00	2.61	9.48	1.33	0.01	1.94	5.19	1.42	0.01
130701	yes	N. dur	dur_sub1_046b	MOZZ_A11:>315	21	F-2	1.96	7.26	1.16	0.01	3.81	22.13	1.49	0.02	3.41	17.37	1.44	0.02
130701	yes	N. dur	dur_sub1_047b	MOZZ_A11:>315	32	F-2	1.76	0.91	1.30	0.01	2.47	3.80	1.32	0.02	2.39	3.09	1.37	0.01
130701	yes	N. dur	dur_sub1_048b	MOZZ_A11:>315	35	F-2	0.94	1.55	1.30	0.00	2.23	4.71	1.28	0.02	1.48	2.88	1.36	0.01
130701	yes	N. dur	dur_sub1_049a	MOZZ_A11:>315	23	F-2	1.49	1.37	1.42	0.00	2.65	6.28	1.28	0.01	1.62	2.13	1.43	0.00
130701	yes	N. dur	dur_sub1_050b	MOZZ_A11:>315	25	F-2	1.17	*	1.33	0.00	2.21	8.06	1.31	0.01	1.60	3.13	1.49	0.00
130701	yes	N. dur	dur_sub1_051b	MOZZ_A11:>315	31	F-2	1.77	1.53	1.32	0.00	2.85	2.44	1.27	0.01	2.51	2.53	1.39	0.00
130701	yes	N. dur	dur_sub1_052b	MOZZ_A11:>315	38	F-2	3.02	10.65	1.16	0.01	4.26	28.83	1.18	0.02	4.38	25.32	1.29	0.02
130701	yes	N. dur	dur_sub1_054b	MOZZ_A11:>315	32	F-2	1.39	0.98	1.33	0.00	1.97	1.66	1.24	0.01	1.94	1.58	1.37	0.01
130701	yes	N. dur	dur_sub1_053b-148	MOZZ_A11:>315	25	F-2	1.62	1.04	1.32	0.00	2.38	11.54	1.23	0.02	2.34	8.01	1.38	0.01
130703	no	N. dur	dur_sub2_8b-91	MOZZ_A12:>315	24	F-2	N.A.	N.A.	N.A.	N.A.	3.55	8.72	1.21	0.02	3.55	8.74	1.21	0.02
130703	yes	N. dur	dur_sub2_9b-94	MOZZ_A12:>315	37	F-2	1.30	5.30	1.32	0.00	1.78	3.99	1.11	0.01	1.63	4.22	1.19	0.01
130703	yes	N. dur	dur_sub2_10b-102	MOZZ_A12:>315	31	F-2	1.23	10.81	1.25	0.01	2.52	20.06	1.38	0.02	2.16	17.53	1.33	0.01
130703	yes	N. dur	dur_sub2_11b-105	MOZZ_A12:>315	28	F-2	1.23	2.31	1.35	0.00	4.15	5.50	1.42	0.02	3.31	3.42	1.39	0.02
130703	yes	N. dur	dur_sub2_12b-108	MOZZ_A12:>315	38	F-2	1.59	1.49	1.44	*	2.18	1.58	1.18	0.01	1.96	1.87	1.32	0.00
130703	no	N. dur	dur_sub2_14-117	MOZZ_A12:>315	19	F-2	N.A.	N.A.	N.A.	N.A.	3.04	5.73	2.00	0.02	3.05	5.75	2.00	0.02

130703H1	yes	N	dur	dur_sub2_14b-5	MOZ2_A12:>315	19	F-2	3.06	18.09	1.27	0.01	2.52	13.58	1.42	0.02	2.75	14.51	1.39	0.02
130703H1	yes	N	dur	dur_sub2_15b-8	MOZ2_A12:>315	23	F-2	1.24	6.90	1.42	0.00	2.65	12.98	1.47	0.01	2.21	11.12	1.45	0.01
130703H1	yes	N	dur	dur_sub2_16b-11	MOZ2_A12:>315	30	F-2	1.33	*	1.31	0.01	3.57	3.44	1.28	0.02	2.70	2.02	1.28	0.02
130703H1	no	N	dur	dur_sub2_18b-17	MOZ2_A12:>315	23	F-2	N.A.	N.A.	N.A.	N.A.	7.84	3.49	1.36	0.01	5.12	4.20	1.35	0.01
130703H1	yes	N	dur	dur_sub2_20b-27	MOZ2_A12:>315	32	F-2	1.78	2.24	1.26	0.00	3.32	11.83	1.24	0.04	2.56	7.48	1.26	0.02
130703H1	yes	N	dur	dur_sub2_21b-31	MOZ2_A12:>315	24	F-2	0.93	2.78	1.49	0.00	2.02	3.99	1.32	0.01	1.38	3.19	1.46	0.00
130703H1	yes	N	dur	dur_sub2_22b-34	MOZ2_A12:>315	22	F-2	0.91	*	1.42	0.00	2.41	3.19	1.23	0.02	1.54	N.A.	1.39	0.00
130704	no	N	dur	dur_sub2_23a-7	MOZ2_A12:>315	14	F-2	N.A.	N.A.	N.A.	N.A.	1.79	22.66	1.84	0.02	1.99	33.58	1.65	0.02
130704	yes	N	dur	dur_sub2_25b-14	MOZ2_A12:>315	22	F-2	1.95	8.35	1.42	N.A.	3.15	15.44	1.39	0.01	2.69	12.61	1.40	0.02
130704	no	N	dur	dur_sub2_26b-17	MOZ2_A12:>315	24	F-2	N.A.	N.A.	N.A.	N.A.	2.77	16.89	1.84	0.03	2.75	17.00	1.85	0.02
130704	yes	N	dur	dur_sub2_27b-25	MOZ2_A12:>315	20	F-2	1.40	1.18	1.27	0.00	3.17	8.14	1.31	0.01	2.27	3.80	1.30	0.01
130704	yes	N	dur	dur_sub2_29b-31	MOZ2_A11:>315	25	F-2	1.35	1.22	1.32	0.00	3.24	6.06	1.24	0.02	2.22	3.28	1.28	0.01
130704	yes	N	dur	dur_sub2_28b-98	MOZA_A01>315	27	F-2	1.18	0.93	1.25	0.00	4.35	3.29	1.22	0.02	2.80	2.24	1.24	0.01
130704	yes	N	dur	dur_sub2_36b-101	MOZA_A01>315	34	F-2	1.26	4.86	1.26	0.01	3.02	8.83	1.28	0.01	2.56	8.19	1.28	0.01
130704	yes	N	dur	dur_sub2_37b-109	MOZA_A01>315	16	F-2	2.04	4.46	1.16	0.01	3.66	16.49	1.29	0.02	3.19	13.76	1.25	0.02
130704	yes	N	dur	dur_sub2_38b-112	MOZA_A01>315	21	F-2	0.59	1.93	1.41	0.00	2.80	7.92	1.20	0.03	1.23	3.49	1.32	0.01
130704	yes	N	dur	dur_sub2_39b-115	MOZA_A01>315	22	F-2	0.85	1.24	1.21	0.00	3.47	3.90	1.25	0.03	1.40	1.87	1.21	0.01
130704	yes	N	dur	dur_sub2_39b-118	MOZA_A01>315	33	F-2	1.15	0.98	1.27	0.00	2.72	3.57	1.33	0.02	2.23	2.75	1.31	0.01
130704	yes	N	dur	dur_sub2_91b-127	MOZA_A01>315	34	F-2	2.76	11.43	1.21	0.01	4.53	22.59	1.40	0.02	3.84	17.67	1.34	0.01
130704	yes	N	dur	dur_sub2_92b-130	MOZA_A01>315	16	F-2	0.93	2.22	1.29	0.00	4.14	4.37	1.28	0.03	1.81	2.22	1.29	0.01
130704	yes	N	dur	dur_sub2_93a-132	MOZA_A01>315	30	F-2	1.82	*	1.23	0.00	2.66	4.71	1.48	0.01	2.46	4.08	1.44	0.01
130704	no	N	dur	dur_sub2_95a-135	MOZA_A01>315	8	F-2	N.A.	N.A.	N.A.	N.A.	3.63	8.37	1.28	0.03	3.52	7.26	1.30	0.03
130705	yes	N	dur	dur_sub2_96b-8	MOZA_A01>315	35	F-2	2.02	1.09	1.48	*	3.92	4.77	1.30	0.01	3.52	3.39	1.36	0.00
130705	no	N	dur	dur_sub2_97b-11	MOZA_A01>315	10	F-2	N.A.	N.A.	N.A.	N.A.	2.63	12.74	1.36	0.03	2.63	12.74	1.36	0.03
130705	no	N	dur	dur_sub2_98b-14	MOZA_A01>315	11	F-2	N.A.	N.A.	N.A.	N.A.	3.26	9.23	1.31	0.04	3.26	9.23	1.31	0.04
130705	no	N	dur	dur_sub2_99a-16	MOZA_A01>315	27	F-2	N.A.	N.A.	N.A.	N.A.	3.05	7.94	1.16	0.01	3.09	7.72	1.17	0.01

130718	yes	N. dut	N.dut_sub3_38b-64	MOZA_A06> 315	25	F-2	0.75	2.44	1.44	*	2.40	5.75	1.26	0.01	1.69	2.77	1.38	0.01
130718	yes	N. dut	N.dut_sub3_39b-72	MOZA_A06> 315	18	F-2	2.36	11.70	1.13	0.02	2.88	12.54	1.24	0.03	2.61	12.69	1.21	0.03
130718	yes	N. dut	N.dut_sub3_40b-75	MOZA_A06> 315	25	F-2	0.99	2.22	1.32	*	3.56	5.02	1.29	0.02	2.29	3.79	1.31	0.01
130718	yes	N. dut	N.dut_sub3_41b-78	MOZA_A06> 315	21	F-2	2.26	*	1.38	0.01	3.85	7.50	1.30	0.02	3.45	5.99	1.30	0.02
130718	yes	N. dut	N.dut_sub3_42b-81	MOZA_A06> 315	33	F-2	1.38	3.97	1.14	0.01	2.81	5.04	1.17	0.02	2.40	4.11	1.15	0.01
130718	yes	N. dut	N. dut_54b	MOZA_A06> 315	30	F-2	1.49	*	1.27	0.00	2.41	*	1.17	0.01	2.59	N.A.	1.26	0.01
130718	yes	N. dut	N. dut_55b	MOZA_A06> 315	39	F-2	1.29	10.72	1.37	0.00	2.90	18.60	1.38	0.02	2.32	15.31	1.33	0.01
130718	yes	N. dut	N. dut_56b	MOZA_A06> 315	47	F-2	1.09	3.95	1.26	0.01	2.39	6.15	1.17	0.03	1.90	5.84	1.20	0.02
130718	yes	N. dut	N. dut_57b	MOZA_A06> 315	31	F-2	2.75	12.20	1.27	0.01	3.75	13.98	1.29	0.02	3.40	14.33	1.28	0.01
130718	no	N. dut	N.dut_sub3_58b-106	MOZA_A06> 315	39	F-2	N.A.	N.A.	N.A.	N.A.	1.92	4.50	1.19	0.02	2.02	3.09	1.19	0.01
130718	no	N. dut	N.dut_sub3_59b-109	MOZA_A06> 315	35	F-2	N.A.	N.A.	N.A.	N.A.	3.29	7.70	1.30	0.02	3.32	7.81	1.30	0.02
130718	yes	N. dut	N.dut_sub3_60a-111	MOZA_A06> 315	49	F-2	1.60	2.62	1.13	*	2.01	5.59	1.20	0.01	1.96	5.06	1.18	0.01
130718	yes	N. dut	N.dut_sub3_61a-113	MOZA_A06> 315	46	F-2	1.91	*	1.11	0.01	2.69	5.15	1.41	0.02	2.45	2.88	1.24	0.01
130718	yes	N. dut	N.dut_sub3_62b-122	MOZA_A06> 315	37	F-2	3.10	6.37	1.10	0.01	2.57	4.13	1.22	0.02	2.75	5.19	1.20	0.01
130718	yes	N. dut	N.dut_sub3_63a-124	MOZA_A06> 315	36	F-2	1.70	3.70	1.27	0.00	3.14	13.40	1.42	0.04	2.60	8.15	1.35	0.02
130718	yes	N. dut	N.dut_sub3_64b-128	MOZA_A06> 315	29	F-2	1.05	5.66	1.25	0.00	3.30	9.36	1.22	0.02	2.27	7.72	1.24	0.01
130718	yes	N. dut	N.dut_sub3_65a-130	MOZA_A06> 315	33	F-2	2.13	*	1.21	0.01	2.76	*	1.18	0.02	2.74	N.A.	1.22	0.01
130718	yes	N. dut	N.dut_sub3_66b-139	MOZA_A06> 315	28	F-2	0.95	1.73	1.33	*	2.44	7.75	1.33	0.02	1.83	5.52	1.32	0.01
130718	yes	N. dut	N.dut_sub3_67b-142	MOZA_A06> 315	29	F-2	1.11	10.54	1.20	0.00	2.94	19.46	1.15	0.01	2.19	13.56	1.18	0.01
130718	yes	N. dut	N.dut_sub3_68b-145	MOZA_A06> 315	25	F-2	0.75	1.95	1.44	0.00	1.83	2.91	1.26	0.00	1.10	1.91	1.41	0.00
130718	no	N. dut	N.dut_sub3_69b-148	MOZA_A06> 315	27	F-2	N.A.	N.A.	N.A.	N.A.	1.39	*	1.42	0.01	1.49	N.A.	1.43	0.01
130719	yes	N. dut	dut_sub4_2b-27	MOZA_A01, 250-315	15	F-2	0.93	1.11	1.28	0.01	2.73	1.09	1.15	0.01	1.62	0.96	1.24	0.01
130719	yes	N. dut	dut_sub4_3b-30	MOZA_A01, 250-315	22	F-2	1.42	1.58	1.29	0.00	3.04	4.35	1.21	0.01	2.17	2.73	1.24	0.01

130719	no	N_dut	dat_sub4_5b-40	MOZA_A01, 250<315	13	F-2	N.A.	N.A.	3.75	10.03	1.26	0.02	3.77	9.96	1.26	0.02
130719	no	N_dut	dat_sub4_6b-43	MOZA_A01, 250<315	15	F-2	N.A.	N.A.	4.68	15.29	1.25	0.03	4.68	15.29	1.25	0.03
130719	yes	N_dut	dat_sub4_7a-45	MOZA_A01, 250<315	25	F-2	1.26	1.89	2.23	4.22	1.13	0.02	1.64	2.99	1.24	0.01
130719	yes	N_dut	dat_sub4_8b-49	MOZA_A01, 250<315	24	F-2	0.96	0.82	3.68	2.57	1.19	0.01	3.06	2.04	1.22	0.01
130719	yes	N_dut	dat_sub4_9b-57	MOZA_A01, 250<315	13	F-2	0.91	4.22	4.66	10.50	1.44	0.03	1.78	4.79	1.26	0.01
201408	yes	N_dut	dat1	MOZA_A20>315	28	F-2	1.32	N.A.	1.96	N.A.	N.A.	N.A.	1.79	N.A.	N.A.	N.A.
201408	yes	N_dut	dat2	MOZA_A20>315	34	F-2	1.28	N.A.	4.09	N.A.	N.A.	N.A.	2.78	N.A.	N.A.	N.A.
201408	yes	N_dut	dat3	MOZA_A20>315	33	F-2	1.57	N.A.	2.95	N.A.	N.A.	N.A.	2.52	N.A.	N.A.	N.A.
2014_05	yes	N_dut	dat_11c	MOZ1_A16>315	23	F-2	1.71	N.A.	6.14	N.A.	N.A.	N.A.	3.58	N.A.	N.A.	N.A.
2014_05	yes	N_dut	dat_12c	MOZ1_A16>315	28	F-2	1.22	N.A.	3.48	N.A.	N.A.	N.A.	2.51	N.A.	N.A.	N.A.
2014_05	yes	N_dut	dat_13c	MOZ1_A16>315	29	F-2	1.16	N.A.	2.95	N.A.	N.A.	N.A.	2.08	N.A.	N.A.	N.A.
2014_05	yes	N_dut	dat_14c	MOZ1_A16>315	18	F-2	1.55	N.A.	4.42	N.A.	N.A.	N.A.	3.00	N.A.	N.A.	N.A.
2014_05	yes	N_dut	dat_15c	MOZ1_A16>315	27	F-2	2.49	N.A.	4.03	N.A.	N.A.	N.A.	3.76	N.A.	N.A.	N.A.
130701	yes, thin	N_dut	dat_sub1_034-075	MOZZ_A11:>315	36	F-3	2.39	4.37	3.11	10.72	1.30	0.03	3.25	10.03	1.35	0.03
130701	yes	N_dut	dat_sub1_035b-081	MOZZ_A11:>315	28	F-3	1.06	1.82	2.64	5.55	1.25	0.02	1.89	3.70	1.34	0.01
130701	no	N_dut	dat_sub1_036b-084	MOZZ_A11:>315	30	F-3	N.A.	N.A.	5.61	19.71	1.29	0.02	6.63	23.24	1.53	0.02
130701	yes	N_dut	dat_sub1_040b-100	MOZZ_A11:>315	21	F-3	2.22	0.78	4.38	6.66	1.28	0.03	4.13	5.72	1.44	0.02
130701	yes	N_dut	dat_sub1_044b	MOZZ_A11:>315	26	F-3	1.55	1.15	2.50	3.71	1.18	0.03	2.19	2.75	1.34	0.02
130701	yes	N_dut	dat_sub1_049b	MOZZ_A11:>315	25	F-3	1.17	1.13	2.54	4.93	1.26	0.01	1.60	2.84	1.38	0.00
130703H	yes	N_dut	dat_sub2_19a-24	MOZZ_A12:>315	33	F-3	3.28	9.16	6.00	20.50	1.35	0.03	5.32	12.09	1.36	0.01
130703H	yes	N_dut	dat_sub2_20b-28	MOZZ_A12:>315	32	F-3	1.56	1.78	4.28	7.19	1.24	0.03	2.91	4.04	1.28	0.02
130704	no	N_dut	dat_sub2_23b-8	MOZZ_A12:>315	14	F-3	N.A.	N.A.	1.64	18.58	1.68	0.03	1.56	16.96	1.71	0.02
130704	yes	N_dut	dat_sub2_29b-133	MOZA_A01>315	30	F-3	1.15	1.13	2.84	4.20	1.41	0.01	2.32	3.15	1.39	0.01
130705	no	N_dut	dat_sub2_29b-17	MOZA_A01>315	27	F-3	N.A.	N.A.	4.00	6.48	1.19	0.02	4.00	6.48	1.19	0.02
130718	yes	N_dut	N_dut_sub3_61b-114	MOZA_A06> 315	46	F-3	1.21	2.35	3.00	5.64	1.26	0.03	2.18	4.19	1.21	0.02

130718	yes	N. dut	N.dut_sub3_6b-125	MOZ4_A06 > 315	36	F-3	0.87	*	1.31	0.00	3.00	14.63	1.42	0.02	1.89	7.03	1.35	0.01			
130718	yes	N. dut	N.dut_sub3_6b-131	MOZ4_A06 > 315	33	F-3	1.98	*	1.21	0.01	3.06	2.66	1.17	0.03	2.86	1.64	1.24	0.01			
130719	yes	N. dut	dut_sub4_7b-46	MOZ4_A01_250>315	25	F-3	1.05	*	1.29	0.00	2.34	2.18	0.99	0.02	1.53	0.89	1.17	0.01			
201408	yes	N. dut	dut1	MOZ3_A20>315	28	F-3	2.15	N.A.	N.A.	N.A.	2.48	N.A.	N.A.	N.A.	2.52	N.A.	N.A.	N.A.			
201408	yes	N. dut	dut2	MOZ3_A20>315	34	F-3	1.43	N.A.	N.A.	N.A.	4.26	N.A.	N.A.	N.A.	3.01	N.A.	N.A.	N.A.			
201408	yes	N. dut	dut3	MOZ3_A20>315	33	F-3	1.04	N.A.	N.A.	N.A.	2.56	N.A.	N.A.	N.A.	1.89	N.A.	N.A.	N.A.			
2014_05	yes	N. dut	dut_12d	MOZ1_A16>315	28	F-3	1.20	N.A.	N.A.	N.A.	3.27	N.A.	N.A.	N.A.	2.78	N.A.	N.A.	N.A.			
2014_05	yes	N. dut	dut_13d	MOZ1_A16>315	29	F-3	1.15	N.A.	N.A.	N.A.	3.46	N.A.	N.A.	N.A.	2.06	N.A.	N.A.	N.A.			
2014_05	yes	N. dut	dut_14d	MOZ1_A16>315	18	F-3	1.29	N.A.	N.A.	N.A.	3.79	N.A.	N.A.	N.A.	2.55	N.A.	N.A.	N.A.			
2014_05	no	N. dut	dut_15d	MOZ1_A16>315	27	F-3		N.A.	N.A.	N.A.	5.37	N.A.	N.A.	N.A.	5.49	N.A.	N.A.	N.A.			
code	crust	species	sample	interval	weight [µg]	chamb.	crust	Mg/Ca [mmol/mol]	Mn/Ca [µmol/mol]	Sr/Ca [mmol/mol]	U/Ca [µmol/mol]	onto.	Mg/Ca	Mn/Ca	Sr/Ca	U/Ca	total	Mg/Ca	Mn/Ca	Sr/Ca	U/Ca
130125	yes	P. obli	obli-94-029	MOZ2_A11,>315	38.0	F-0	1.78	7.72	1.60	N.A.	N.A.	3.40	17.729	1.86	N.A.	N.A.	2.802	12.705	1.744	N.A.	N.A.
130125	yes	P. obli	obli-85a-031	MOZ2_A11,>315	49.0	F-0	0.76	10.34	1.70	N.A.	N.A.	2.53	31.727	1.83	N.A.	N.A.	1.556	18.785	1.764	N.A.	N.A.
130125	yes	P. obli	obli-86a-032	MOZ2_A11,>315	38.0	F-0	0.97	13.92	1.69	N.A.	N.A.	2.35	39.171	2.04	N.A.	N.A.	1.996	31.745	1.942	N.A.	N.A.
130125	yes	P. obli	obli-87a-036	MOZ2_A11,>315	29.0	F-0	1.15	15.54	1.59	N.A.	N.A.	3.06	26.612	1.74	N.A.	N.A.	2.423	21.697	1.701	N.A.	N.A.
130125	yes	P. obli	obli-88a-037	MOZ2_A11,>315	36.0	F-0	1.05	16.20	1.48	N.A.	N.A.	3.84	78.234	1.74	N.A.	N.A.	2.212	34.421	1.567	N.A.	N.A.
130125	yes	P. obli	obli-89a-038	MOZ2_A11,>315	47.0	F-0	1.90	8.41	1.52	N.A.	N.A.	4.21	22.971	1.85	N.A.	N.A.	3.632	18.803	1.773	N.A.	N.A.
130125	yes	P. obli	obli-90a-039	MOZ2_A11,>315	36.0	F-0	0.80	12.69	1.43	N.A.	N.A.	2.76	50.493	1.70	N.A.	N.A.	2.246	46.325	1.640	N.A.	N.A.
130125	yes	P. obli	obli-91a-040	MOZ2_A11,>315	67.0	F-0	1.04	15.49	1.56	N.A.	N.A.	2.89	22.735	1.63	N.A.	N.A.	1.214	16.018	1.599	N.A.	N.A.
130125	yes	P. obli	obli-92a-041	MOZ2_A11,>315	43.0	F-0	1.22	32.16	1.60	N.A.	N.A.	2.01	38.971	1.89	N.A.	N.A.	1.564	35.950	1.741	N.A.	N.A.
130125	yes	P. obli	obli-93a-042	MOZ2_A11,>315	32.0	F-0	1.18	18.18	1.80	N.A.	N.A.	5.44	27.740	1.83	N.A.	N.A.	4.506	25.283	1.829	N.A.	N.A.
130702	yes	P. obli	obli_sub1_73-56	MOZ2_A11,>315	N.A.	F-0	1.11	10.39	1.33	0.002	0.002	4.62	21.53	1.39	0.024	0.024	3.878	19.094	1.380	0.018	0.018
130703	yes	P. obli	obli_sub1_92-23	MOZ2_A12,>315	33.0	F-0	1.00	2.38	1.32	0.009	0.009	2.24	5.59	1.46	0.01	0.01	1.836	4.605	1.423	0.011	0.011
130703	yes	P. obli	obli_sub1_93-26	MOZ2_A12,>315	26.0	F-0	1.25	13.87	1.33	0.004	0.004	4.08	14.16	1.60	0.02	0.02	2.407	16.000	1.455	0.010	0.010

130703	yes	P. obli	obl_sub1_94-27	MOZ2_A12:>315	27.0	F-0	1.21	19.64	1.18	0.003	2.40	18.02	1.29	0.01	1.972	16.983	1.228	0.006
130703	yes	P. obli	obl_sub1_95-35	MOZ2_A12:>315	26.0	F-0	1.14	1.77	1.32	0.007	2.98	8.72	1.41	0.02	2.070	4.824	1.356	0.013
130703	yes	P. obli	obl_sub1_96-38	MOZ2_A12:>315	27.0	F-0	1.40	8.23	1.38	0.005	3.50	12.47	1.49	0.02	3.056	9.101	1.374	0.012
130703	yes	P. obli	obl_sub1_98-41	MOZ2_A12:>315	29.0	F-0	0.82	5.52	1.33	0.008	3.31	25.19	1.53	0.02	2.398	13.470	1.466	0.017
130703	yes	P. obli	obl_sub1_99-43	MOZ2_A12:>315	27.0	F-0	0.90	15.54	1.27	0.009	2.71	10.28	1.44	0.02	2.178	11.686	1.408	0.018
130703	yes	P. obli	obl_sub1_100-51	MOZ2_A12:>315	26.0	F-0	1.22	8.90	1.47	0.009	1.22	8.90	1.47	0.01	3.393	22.280	1.628	0.018
130703	yes	P. obli	obl_sub1_102-57	MOZ2_A12:>315	26.0	F-0	0.98	2.91	1.41	0.003	2.92	6.61	1.36	0.01	2.155	5.115	1.388	0.005
130703	yes	P. obli	obl_sub2_1-60	MOZ2_A12:>315	27.0	F-0	2.83	1.60	1.29	0.004	4.32	11.29	1.46	0.01	3.681	6.152	1.397	0.010
130703	yes	P. obli	obl_sub2_2-68	MOZ2_A12:>315	40.0	F-0	1.15	4.95	1.39	0.004	1.97	7.55	1.47	0.01	1.825	6.644	1.464	0.010
130703	yes	P. obli	obl_sub2_3-70	MOZ2_A12:>315	31.0	F-0	1.00	6.90	1.41	0.008	2.53	13.72	1.34	0.01	1.962	9.866	1.372	0.008
130703	yes	P. obli	obl_sub2_4-73	MOZ2_A12:>315	43.0	F-0	0.87	5.66	1.42	0.003	1.78	5.37	1.37	0.01	1.499	5.406	1.390	0.011
130703	yes	P. obli	obl_sub2_5-76	MOZ2_A12:>315	14.0	F-0	1.32	52.75	1.22	0.005	2.61	24.86	1.54	0.01	1.820	41.902	1.343	0.008
130703	yes	P. obli	obl_sub2_6-83	MOZ2_A12:>315	35.0	F-0	1.01	7.86	1.24	0.014	1.22	8.57	1.22	0.02	2.337	27.067	1.434	0.023
130703	yes	P. obli	obl_sub2_7-86	MOZ2_A12:>315	32.0	F-0	1.72	3.42	1.34	0.009	4.98	22.79	1.48	0.03	4.000	17.583	1.434	0.020
130704	no	P. obli	obl_sub2_28-26	MOZ2_A12:>315	16.0	F-0	N.A.	N.A.	N.A.	N.A.	3.74	42.32	1.44	0.023	3.298	37.442	1.407	0.022
130719	yes	P. obli	obl_sub4_10-58	MOZ4_A06>315	91.0	F-0	0.93	9.28	1.31	0.010	2.64	63.25	1.59	0.015	2.22	47.93	1.52	0.013
130719	yes	P. obli	obl_sub4_11-61	MOZ4_A06>315	67.0	F-0	1.44	4.13	1.31	0.006	4.11	11.19	1.57	0.018	2.73	7.37	1.46	0.011
130719	yes	P. obli	obl_sub4_12-64	MOZ4_A06>315	55.0	F-0	0.91	3.84	1.39	0.002	2.42	11.70	1.42	0.021	2.14	8.32	1.43	0.017
130719	yes	P. obli	obl_sub4_16-72	MOZ4_A06>315	44.0	F-0	1.61	7.10	1.34	0.010	3.01	8.05	1.44	0.019	2.75	8.08	1.42	0.017
130719	yes	P. obli	obl_sub4_16a-73	MOZ4_A06>315	44.0	F-0	1.49	11.09	1.26	0.003	2.93	5.06	1.35	0.014	2.65	6.15	1.33	0.012
130719	yes	P. obli	obl_sub4_14_75	MOZ4_A06>315	42.0	F-0	0.79	11.90	1.40	0.003	3.23	51.06	1.47	0.018	2.38	33.18	1.44	0.013
130719	yes	P. obli	obl_sub4_15-78	MOZ4_A06>315	50.0	F-0	1.31	9.06	1.25	0.006	4.03	10.98	1.38	0.017	3.24	10.21	1.34	0.014
130719	yes	P. obli	obl_sub4_16-81	MOZ4_A06>315	35.0	F-0	1.19	6.12	1.34	0.003	2.83	52.60	1.46	0.015	2.22	29.96	1.41	0.011
130125	yes	P. obli	obl(1)	MOZ3_A20>315	101	F-0	1.46	N.A.	N.A.	N.A.	2.81	N.A.	N.A.	N.A.	2.41	N.A.	N.A.	N.A.
130125	yes	P. obli	obl(2)	MOZ3_A20>315	65	F-0	1.39	N.A.	N.A.	N.A.	3.50	N.A.	N.A.	N.A.	2.83	N.A.	N.A.	N.A.
130125	yes	P. obli	obl(3)	MOZ3_A20>315	71	F-0	N.A.	N.A.	N.A.	N.A.	4.05	N.A.	N.A.	N.A.	3.96	N.A.	N.A.	N.A.

130125	yes	P. obli	obli_21a	MOZ1_A16>315	50	F-0	1.15	N.A.	N.A.	2.33	N.A.	N.A.	N.A.	2.02	N.A.	N.A.	N.A.
130125	yes	P. obli	obli_22a	MOZ1_A16>315	55	F-0	1.02	N.A.	N.A.	3.16	N.A.	N.A.	N.A.	2.58	N.A.	N.A.	N.A.
130125	yes	P. obli	obli_23a	MOZ1_A16>315	61	F-0	1.06	N.A.	N.A.	4.04	N.A.	N.A.	N.A.	3.46	N.A.	N.A.	N.A.
130125	yes	P. obli	obli_24a	MOZ1_A16>315	45	F-0	0.89	N.A.	N.A.	2.90	N.A.	N.A.	N.A.	2.40	N.A.	N.A.	N.A.
130125	yes	P. obli	obli_25a	MOZ1_A16>315	40	F-0	1.81	N.A.	N.A.	5.19	N.A.	N.A.	N.A.	4.13	N.A.	N.A.	N.A.
130702	yes	P. obli	obli_86-021	MOZ2_A11,>315	38.0	F-1	0.76	33.36	1.58	1.94	45.069	1.77	N.A.	1.658	42.757	1.704	
130703	yes	P. obli	obli_88-023	MOZ2_A11,>315	36.0	F-1	0.83	41.68	1.54	2.57	43.886	1.51	N.A.	1.891	41.083	1.524	
130703	yes	P. obli	obli_89-024	MOZ2_A11,>315	47.0	F-1	2.09	28.98	1.29	4.04	49.201	1.61	N.A.	3.499	44.050	1.522	
130703	yes	P. obli	obli_90-025	MOZ2_A11,>315	36.0	F-1	0.91	27.85	1.48	3.03	46.252	1.54	N.A.	2.554	40.209	1.504	
130703	yes	P. obli	obli_91-026	MOZ2_A11,>315	67.0	F-1	1.20	25.03	1.45	2.82	23.445	1.65	N.A.	2.226	24.846	1.581	
130703	yes	P. obli	obli_92-027	MOZ2_A11,>315	43.0	F-1	1.06	58.94	1.52	1.90	60.668	1.62	N.A.	1.583	57.847	1.593	
130703	yes	P. obli	obli_93-028	MOZ2_A11,>315	32.0	F-1	1.18	30.87	1.79	5.45	62.489	1.73	N.A.	5.281	59.558	1.711	
130703	yes	P. obli	obli_85-030	MOZ2_A11,>315	49.0	F-1	0.86	23.35	1.59	2.60	24.864	1.77	N.A.	1.645	22.789	1.656	
130703	yes	P. obli	obli_sub1_73a-57	MOZ2_A11,>315	-	F-1	1.10	16.89	1.23	4.02	15.49	1.39	0.021	3.501	15.800	1.359	0.019
130703	yes	P. obli	obli_sub1_94a-28	MOZ2_A12,>315	27.0	F-1	1.28	14.98	1.29	2.37	10.98	1.45	0.02	2.016	11.304	1.399	0.012
130703	yes	P. obli	obli_sub1_95a-36	MOZ2_A12,>315	26.0	F-1	1.00	7.64	1.24	2.72	11.09	1.34	0.02	1.686	6.953	1.285	0.009
130703	yes	P. obli	obli_sub1_96a-39	MOZ2_A12,>315	27.0	F-1	1.21	14.98	1.37	3.20	28.16	1.25	0.01	2.723	22.134	1.269	0.006
130703	yes	P. obli	obli_sub1_98a-42	MOZ2_A12,>315	29.0	F-1	0.55	19.28	1.19	2.58	15.22	1.29	0.02	1.997	16.837	1.264	0.014
130703	no	P. obli	obli_sub1_99a-44	MOZ2_A12,>315	27.0	F-1	1.14	15.73	1.28	2.21	12.81	1.35	0.01	1.802	13.761	1.319	0.008
130703	yes	P. obli	obli_sub1_100a-52	MOZ2_A12,>315	26.0	F-1	1.34	23.70	1.26	1.34	23.70	1.26	0.01	4.421	29.106	1.470	0.016
130703	yes	P. obli	obli_sub1_101a-54	MOZ2_A12,>315	26.0	F-1	1.22	25.54	1.25	2.35	15.51	1.39	0.01	2.101	22.352	1.348	0.006
130704	no	P. obli	obli_sub1_102a-58	MOZ2_A12,>315	26.0	F-1	1.05	2.38	1.33	3.66	6.97	1.37	0.01	2.460	5.370	1.363	0.007
130719	yes	P. obli	obli_sub2_1a-61	MOZ2_A12,>315	27.0	F-1	3.07	4.37	1.35	4.06	11.67	1.41	0.01	3.623	8.355	1.398	0.008
130719	yes	P. obli	obli_sub2_2a-69	MOZ2_A12,>315	40.0	F-1	1.27	35.26	1.44	2.46	20.39	1.48	0.01	1.972	27.995	1.464	0.008
130719	yes	P. obli	obli_sub2_3a-71	MOZ2_A12,>315	31.0	F-1	1.21	2.69	1.29	3.27	10.38	1.68	0.02	1.788	4.478	1.403	0.008
130719	yes	P. obli	obli_sub2_4a-74	MOZ2_A12,>315	43.0	F-1	0.70	13.98	1.32	1.78	7.28	1.35	0.01	1.437	9.538	1.340	0.006

130719	yes	P. obli	obl_sub2_5a-77	MOZ2_A12:>315	14.0	F-1	N.A.	N.A.	N.A.	2.55	18.04	1.35	0.01	2.551	18.075	1.351	0.010
130719	yes	P. obli	obl_sub2_6a-84	MOZ2_A12:>315	35.0	F-1	1.21	16.13	1.43	1.21	16.13	1.43	0.01	2.252	24.027	1.336	0.011
130125	yes	P. obli	obl_sub2_7a-87	MOZ2_A12:>315	32.0	F-1	1.52	8.39	1.37	3.73	19.17	1.34	0.02	3.191	16.764	1.355	0.017
130125	no	P. obli	obl_sub2_28a-27	MOZ2_A12:>315	16.0	F-1	N.A.	N.A.	N.A.	2.28	12.05	1.33	0.014	2.282	12.050	1.331	0.014
130125	yes	P. obli	obl_sub4_10a-59	MOZA_A06>315	91.0	F-1	0.87	26.90	1.24	1.94	35.04	1.31	0.006	1.58	30.07	1.29	0.004
130703	yes	P. obli	obl_sub4_11a-62	MOZA_A06>315	67.0	F-1	1.55	12.98	1.28	4.52	11.21	1.46	0.017	2.98	12.07	1.37	0.012
130703	yes	P. obli	obl_sub4_12a-65	MOZA_A06>315	55.0	F-1	0.91	6.28	1.39	2.30	9.37	1.35	0.012	1.97	8.70	1.36	0.010
130703	yes	P. obli	obl_sub4_14a-76	MOZA_A06>315	42.0	F-1	0.78	32.11	1.26	2.56	17.95	1.24	0.012	1.89	17.64	1.27	0.009
130703	yes	P. obli	obl_sub4_15a-79	MOZA_A06>315	50.0	F-1	1.26	8.79	1.24	3.51	10.83	1.32	0.014	2.92	10.19	1.30	0.012
130703	yes	P. obli	obl_sub4_16a-82	MOZA_A06>315	35.0	F-1	1.33	5.72	1.17	2.59	27.89	1.28	0.012	2.02	14.03	1.26	0.008
130703	yes	P. obli	obl(1)	MOZ3_A20>315	101	F-1	1.07	N.A.	N.A.	2.75	N.A.	N.A.	N.A.	2.40	N.A.	N.A.	N.A.
130703	yes	P. obli	obl(2)	MOZ3_A20>315	65	F-1	1.12	N.A.	N.A.	3.39	N.A.	N.A.	N.A.	3.06	N.A.	N.A.	N.A.
130704	no	P. obli	obl(3)	MOZ3_A20>315	71	F-1	1.46	N.A.	N.A.	3.08	N.A.	N.A.	N.A.	2.88	N.A.	N.A.	N.A.
130719	yes	P. obli	obl_21b	MOZ1_A16>315	50	F-1	1.16	N.A.	N.A.	1.86	N.A.	N.A.	N.A.	1.49	N.A.	N.A.	N.A.
130719	yes	P. obli	obl_22b	MOZ1_A16>315	55	F-1	1.22	N.A.	N.A.	2.54	N.A.	N.A.	N.A.	2.35	N.A.	N.A.	N.A.
130719	yes	P. obli	obl_23b	MOZ1_A16>315	61	F-1	1.45	N.A.	N.A.	2.56	N.A.	N.A.	N.A.	2.33	N.A.	N.A.	N.A.
130719	yes	P. obli	obl_24b	MOZ1_A16>315	45	F-1	0.60	N.A.	N.A.	2.54	N.A.	N.A.	N.A.	2.09	N.A.	N.A.	N.A.
130719	yes	P. obli	obl_25b	MOZ1_A16>315	40	F-1	1.28	N.A.	N.A.	3.29	N.A.	N.A.	N.A.	2.68	N.A.	N.A.	N.A.
130703	yes	P. obli	obl_87-022	MOZ2_A11:>315	29.0	F-2	1.17	37.115	1.63	N.A.	35.458	1.63	N.A.	1.955	38.589	1.610	
130703	yes	P. obli	obl_85b-062	MOZ2_A11:>315	49.0	F-2	N.A.	N.A.	N.A.	0.75	23.790	1.47	N.A.	0.751	23.790	1.474	
130703	yes	P. obli	obl_86b-066	MOZ2_A11:>315	38.0	F-2	1.04	20.368	1.52	N.A.	26.612	1.63	N.A.	1.468	24.737	1.564	
130703	yes	P. obli	obl_sub1_95b-37	MOZ2_A12:>315	26.0	F-2	0.98	4.20	1.35	3.41	10.76	1.27	0.01	2.008	7.081	1.299	0.008
130703	yes	P. obli	obl_sub1_96b-40	MOZ2_A12:>315	27.0	F-2	0.87	6.37	1.42	3.29	20.59	1.26	0.01	2.600	14.343	1.324	0.007
130703	yes	P. obli	obl_sub1_100b-53	MOZ2_A12:>315	26.0	F-2	0.98	13.80	1.30	0.98	13.80	1.30	0.00	3.710	18.767	1.343	0.013
130703	yes	P. obli	obl_sub1_102b-59	MOZ2_A12:>315	26.0	F-2	0.88	4.24	1.28	1.35	*	1.36	0.01	1.175	N.A.	1.331	0.005
130702	yes	P. obli	obl_sub2_1b-62	MOZ2_A12:>315	27.0	F-2	2.68	4.97	1.24	3.83	11.29	1.36	0.01	3.437	9.101	1.308	0.011

130703	yes	P. obli	obl_sub2_3b-72	MOZ2_A12;>315	31.0	F-2	1.32	6.84	1.29	0.004	2.76	9.59	1.39	0.02	1.867	7.754	1.342	0.010
130719	yes	P. obli	obl_sub2_6b-85	MOZ2_A12;>315	35.0	F-2	1.13	13.82	1.40	0.006	2.79	27.56	1.44	0.02	2.405	24.246	1.410	0.018
130719	yes	P. obli	obl_sub2_28b-28	MOZ2_A12;>315	16.0	F-2	N.A.	N.A.	N.A.	N.A.	3.02	38.61	1.50	0.030	3.002	37.752	1.519	0.031
201408	yes	P. obli	obl_sub4_10b-60	MOZ4_A06>315	91.0	F-2	0.58	48.22	1.24	0.001	2.23	30.31	1.27	0.009	1.72	34.48	1.27	0.007
201408	yes	P. obli	obl_sub4_11b-63	MOZ4_A06>315	67.0	F-2	1.38	8.68	1.23	0.004	4.02	15.16	1.44	0.016	2.57	11.54	1.32	0.009
201408	no	P. obli	obl_sub4_12b-66	MOZ4_A06>315	55.0	F-2	0.77	5.42	1.49	0.001	2.49	4.99	1.32	0.011	2.00	5.15	1.37	0.008
201408	yes	P. obli	obl_sub4_16b-74	MOZ4_A06>315	44.0	F-2	1.35	6.44	1.24	0.003	2.70	5.02	1.27	0.012	2.49	5.10	1.26	0.010
201408	yes	P. obli	obl_sub4_16b-83	MOZ4_A06>315	35.0	F-2	1.17	3.15	1.25	0.003	3.04	15.34	1.35	0.010	2.60	12.16	1.33	0.009
201408	no	P. obli	obl(1)	MOZ3_A20>315	101	F-2	0.85	N.A.	N.A.	N.A.	2.40	N.A.	N.A.	N.A.	1.98	N.A.	N.A.	N.A.
201408	yes	P. obli	obl(2)	MOZ3_A20>315	65	F-2	1.06	N.A.	N.A.	N.A.	3.65	N.A.	N.A.	N.A.	3.00	N.A.	N.A.	N.A.
201408	yes	P. obli	obl(3)	MOZ3_A20>315	71	F-2	N.A.	N.A.	N.A.	N.A.	3.66	N.A.	N.A.	N.A.	3.55	N.A.	N.A.	N.A.
201408	no	P. obli	obl_21c	MOZ1_A16>315	50	F-2	1.19	N.A.	N.A.	N.A.	2.27	N.A.	N.A.	N.A.	2.17	N.A.	N.A.	N.A.
2014_05	yes	P. obli	obl_22c	MOZ1_A16>315	55	F-2	1.13	N.A.	N.A.	N.A.	2.25	N.A.	N.A.	N.A.	2.02	N.A.	N.A.	N.A.
2014_06	yes	P. obli	obl_23c	MOZ1_A16>315	61	F-2	0.95	N.A.	N.A.	N.A.	2.34	N.A.	N.A.	N.A.	2.01	N.A.	N.A.	N.A.
2014_07	yes	P. obli	obl_24c	MOZ1_A16>315	45	F-2	0.51	N.A.	N.A.	N.A.	2.14	N.A.	N.A.	N.A.	1.61	N.A.	N.A.	N.A.
2014_08	yes	P. obli	obl_25c	MOZ1_A16>315	40	F-2	1.43	N.A.	N.A.	N.A.	3.57	N.A.	N.A.	N.A.	2.81	N.A.	N.A.	N.A.
2014_09	yes	P. obli	obl_sub1_29b-45	MOZ2_A12;>315	27.0	F-3	1.23	5.75	1.30	0.004	2.94	12.51	1.29	0.01	2.441	10.630	1.287	0.012
2014_10	yes	P. obli	obl_sub1_101a-55	MOZ2_A12;>315	26.0	F-3	1.18	6.19	1.34	0.001	2.19	5.88	1.33	0.01	1.792	8.974	1.334	0.010
2014_11	yes	P. obli	obl_sub2_4b-75	MOZ2_A12;>315	43.0	F-3	0.77	6.19	1.52	0.002	1.69	7.59	1.29	0.01	1.320	6.262	1.371	0.009

code	crust	species	sample	interval	weight [µg]	chamb.	crust	Mg/Ca [mmol/mol]	Mn/Ca [µmol/mol]	Sr/Ca [mmol/mol]	U/Ca [µmol/mol]	onto.	Mg/Ca	Mn/Ca	Sr/Ca	U/Ca	total	Mg/Ca	Mn/Ca	Sr/Ca	U/Ca
130705	no	G. scit	scit_rub2_101-26	MOZA_A01>315	37	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.89	27.90	1.57	0.02	1.92	27.12	1.57	0.02	0.02	
130705	yes	G. scit	scit_rub2_102-29	MOZA_A01>315	24	F-0	0.83	1.12	20.50	1.12	0.01	2.14	14.51	1.47	0.02	1.72	16.89	1.34	0.02	0.02	
130718	no	G. scit	scit_rub3_1-6	MOZA_A01>315	40	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.83	32.11	1.55	0.06	1.97	31.74	1.55	0.06	0.06	
130718	no	G. scit	scit_rub3_32-39	MOZA_A06>315	30	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.53	15.07	1.48	0.03	1.53	15.05	1.48	0.03	0.03	
130718	no	G. scit	scit_rub3_33-42	MOZA_A06>315	35	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.47	11.27	1.70	0.02	1.47	11.27	1.70	0.02	0.02	
130718	no	G. scit	scit_rub3_34-45	MOZA_A06>315	27	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.34	18.68	1.69	0.03	1.34	18.68	1.69	0.03	0.03	
130718	yes	G. scit	scit_rub3_35-53	MOZA_A06>315	31	F-0	1.22	1.41	12.27	1.41	0.03	1.59	32.20	1.55	0.02	1.52	29.89	1.50	0.02	0.02	
130718	no	G. scit	scit_rub3_36-56	MOZA_A06>315	38	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.54	17.37	1.71	0.04	1.65	17.97	1.69	0.04	0.04	
130718	yes	G. scit	scit_rub3_37-59	MOZA_A06>315	38	F-0	1.78	5.81	N.A.	1.69	0.03	2.11	25.70	1.63	0.06	1.60	14.49	1.62	0.04	0.04	
130719	no	G. scit	scit_rub4_17-89	MOZA_A06>315	8	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	2.47	19.68	1.40	0.02	2.47	19.68	1.40	0.02	0.02	
130719	no	G. scit	scit_rub4_18-92	MOZA_A06>315	23	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.83	14.80	1.53	0.04	1.88	15.04	1.53	0.05	0.05	
130719	no	G. scit	scit_rub4_19-95	MOZA_A06>315	21	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.93	20.59	1.42	0.02	1.96	20.97	1.42	0.02	0.02	
130719	no	G. scit	scit_rub4_20-98	MOZA_A06>315	24	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.73	5.73	1.50	0.03	1.77	5.95	1.50	0.03	0.03	
130719	no	G. scit	scit_rub4_27-106	MOZA_A06>315	22	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	2.17	23.19	1.64	0.05	2.22	23.77	1.63	0.04	0.04	
130719	yes	G. scit	scit_rub4_28-109	MOZA_A06>315	15	F-0	1.04	9.74	1.45	1.45	0.02	4.72	41.61	1.70	0.09	2.21	21.41	1.57	0.04	0.04	
130719	no	G. scit	scit_rub4_27-112	MOZA_A06>315	19	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	2.10	17.44	1.53	0.03	2.10	16.15	1.52	0.03	0.03	
130705	no	G. scit	scit_rub1_055-149	MOZ2_A11>315	30	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.19	0.01	1.72	0.04	1.25	6.81	1.81	0.04	0.04	
130705	no	G. scit	scit_rub1_056-6	MOZ2_A11>315	35	F-0	1.08	6.97	N.A.	1.39	0.03	1.29	14.14	1.38	0.03	1.28	13.05	1.38	0.03	0.03	
130705	yes	G. scit	scit_rub1_057b-11	MOZ2_A11>315	29	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.93	48.51	1.33	0.02	1.93	48.51	1.33	0.02	0.02	
130718	yes	G. scit	scit_rub1_059-15	MOZ2_A11>315	24	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.11	12.71	1.52	0.03	1.11	12.71	1.52	0.03	0.03	
130718	no	G. scit	scit_rub1_060-23	MOZ2_A11>315	32	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.58	11.96	1.57	0.04	1.58	11.96	1.57	0.04	0.04	
130718	no	G. scit	scit_rub1_061-26	MOZ2_A11>315	28	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	2.61	12.98	1.72	0.05	2.61	12.98	1.72	0.05	0.05	
130718	yes	G. scit	scit_rub1_062-29	MOZ2_A11>315	30	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.37	21.92	1.55	0.04	1.37	21.92	1.55	0.04	0.04	
130718	yes	G. scit	scit_rub1_063-32	MOZ2_A11>315	23	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.51	18.04	1.61	0.05	1.51	18.04	1.61	0.05	0.05	
130718	no	G. scit	scit_rub1_064-40	MOZ2_A11>315	24	F-0	N.A.	N.A.	N.A.	N.A.	N.A.	1.31	8.23	1.53	0.03	1.31	8.23	1.53	0.03	0.03	

130718	yes	G. scit	scit_rub1_74b-61	MOZL_A07 >315	51	F-0	1.35	70.46	1.32	0.05	2.23	44.63	1.37	0.03	2.18	46.56	1.35	0.03
130719	no	G. scit	scit_rub1_75-62	MOZL_A07 >315	36	F-0	N.A.	N.A.	N.A.	N.A.	1.67	50.13	1.54	0.04	1.68	49.07	1.54	0.04
130719	no	G. scit	scit_rub1_76-70	MOZL_A07 >315	38	F-0	0.85	7.72	1.60	0.02	1.26	16.62	1.76	0.03	1.09	11.96	1.70	0.02
130719	no	G. scit	scit_rub1_77-73	MOZL_A07 >315	31	F-0	0.48	9.85	1.19	0.01	1.84	35.29	1.50	0.03	1.55	29.58	1.42	0.03
130719	no	G. scit	scit_rub1_83a-97	MOZL_A08 >315	23	F-0	0.84	13.49	2.05	0.02	1.11	16.86	1.90	0.04	1.00	12.78	1.88	0.03
130719	no	G. scit	scit_rub1_84-104	MOZL_A08 >315	28	F-0	N.A.	N.A.	N.A.	N.A.	1.30	21.52	1.81	0.03	1.30	21.52	1.80	0.03
130719	yes	G. scit	scit_rub1_85-107	MOZL_A08 >315	34	F-0	N.A.	N.A.	N.A.	N.A.	1.47	20.86	1.64	0.03	1.49	21.35	1.65	0.04
130719	no	G. scit	scit_rub1_86-110	MOZL_A08 >315	33	F-0	N.A.	N.A.	N.A.	N.A.	1.32	10.76	1.76	0.03	1.32	10.76	1.75	0.03
130705	no	G. scit	scit_rub1_88-6	MOZL_A12 >315	26	F-0	N.A.	N.A.	N.A.	N.A.	1.06	16.07	1.43	0.02	1.07	15.62	1.43	0.02
130705	no	G. scit	scit_rub1_90-12	MOZL_A12 >315	23	F-0	N.A.	N.A.	N.A.	N.A.	1.29	14.78	1.58	0.02	1.29	14.78	1.58	0.02
130705	yes	G. scit	scit_rub1_91-15	MOZL_A12 >315	18	F-0	N.A.	N.A.	N.A.	N.A.	2.59	15.51	1.27	0.02	2.59	15.51	1.27	0.02
130718	yes	G. scit	G. scit1	MOZL_A20 >315	30	F-0	0.16	N.A.	N.A.	N.A.	1.77	N.A.	N.A.	N.A.	1.74	N.A.	N.A.	N.A.
130718	no	G. scit	G. scit2	MOZL_A20 >315	19	F-0	0.23	N.A.	N.A.	N.A.	1.22	N.A.	N.A.	N.A.	1.20	N.A.	N.A.	N.A.
130718	yes	G. scit	G. scit3	MOZL_A20 >315	27	F-0	N.A.	N.A.	N.A.	N.A.	1.29	N.A.	N.A.	N.A.	1.26	N.A.	N.A.	N.A.
130718	yes	G. scit	scit_35a	MOZL_A16 >315	32	F-0	N.A.	N.A.	N.A.	N.A.	0.97	N.A.	N.A.	N.A.	0.96	N.A.	N.A.	N.A.
130718	yes	G. scit	scit_36a	MOZL_A16 >315	22	F-0	1.21	N.A.	N.A.	N.A.	1.59	N.A.	N.A.	N.A.	1.47	N.A.	N.A.	N.A.
130718	no	G. scit	scit_37a	MOZL_A16 >315	33	F-0	0.72	N.A.	N.A.	N.A.	1.59	N.A.	N.A.	N.A.	1.46	N.A.	N.A.	N.A.
130718	yes	G. scit	scit_40a	MOZL_A19 >315	34	F-0	N.A.	N.A.	N.A.	N.A.	1.52	N.A.	N.A.	N.A.	1.48	N.A.	N.A.	N.A.
130719	no	G. scit	scit_41a	MOZL_A19 >315	30	F-0	1.36	N.A.	N.A.	N.A.	1.69	N.A.	N.A.	N.A.	1.63	N.A.	N.A.	N.A.
130719	no	G. scit	scit_rub2_100-23	MOZL_A01 >315	30	F-1	N.A.	N.A.	N.A.	N.A.	2.60	49.75	1.25	0.03	2.60	49.75	1.25	0.03
130719	yes	G. scit	scit_rub2_101a-27	MOZL_A01 >315	37	F-1	N.A.	N.A.	N.A.	N.A.	1.51	48.91	1.42	0.03	1.51	48.91	1.42	0.03
130719	yes	G. scit	scit_rub2_102a-30	MOZL_A01 >315	24	F-1	0.64	17.38	1.13	0.01	2.44	27.79	1.39	0.04	1.90	27.74	1.30	0.03
130719	no	G. scit	scit_rub3_1a-7	MOZL_A01 >315	40	F-1	0.80	114.58	1.10	0.01	0.80	114.58	1.10	0.01	1.46	56.68	1.47	0.03
130719	yes	G. scit	scit_rub3_32a-40	MOZL_A06 >315	30	F-1	N.A.	N.A.	N.A.	N.A.	1.31	37.57	1.34	0.03	1.31	37.55	1.34	0.03
130719	no	G. scit	scit_rub3_33a-43	MOZL_A06 >315	35	F-1	N.A.	N.A.	N.A.	N.A.	1.17	21.82	1.55	0.02	1.17	21.82	1.55	0.02
130705	yes	G. scit	scit_rub3_34a-46	MOZL_A06 >315	27	F-1	0.88	74.32	1.13	0.01	1.98	15.38	1.60	0.03	1.63	39.34	1.41	0.02

130701	no	G, scit	scit_rub3_35a-54	MOZL_A06 > 315	31	F-1	0.82	110.62	1.16	0.01	1.84	27.12	1.53	0.02	1.44	60.45	1.40	0.02
130702	yes	G, scit	scit_rub3_36a-57	MOZL_A06 > 315	38	F-1	N.A.	N.A.	N.A.	N.A.	1.44	13.83	1.44	0.04	1.44	13.82	1.44	0.04
130702	no	G, scit	scit_rub3_37a-60	MOZL_A06 > 315	38	F-1	1.09	18.22	1.44	0.02	2.21	19.73	1.85	0.04	1.50	18.02	1.63	0.03
130702	no	G, scit	scit_rub4_17a-90	MOZL_A06 > 315	8	F-1	N.A.	N.A.	N.A.	N.A.	2.24	42.59	1.30	0.02	2.24	42.45	1.30	0.02
130702	no	G, scit	scit_rub4_18a-93	MOZL_A06 > 315	23	F-1	N.A.	N.A.	N.A.	N.A.	1.46	30.82	1.35	0.03	1.52	31.33	1.35	0.03
130702	no	G, scit	scit_rub4_19a-96	MOZL_A06 > 315	21	F-1	N.A.	N.A.	N.A.	N.A.	1.32	40.23	1.39	0.02	1.34	40.88	1.40	0.02
130702	no	G, scit	scit_rub4_20a-99	MOZL_A06 > 315	24	F-1	N.A.	N.A.	N.A.	N.A.	2.17	14.54	1.60	0.04	2.05	26.23	1.47	0.03
130702	no	G, scit	scit_rub4_27a-107	MOZL_A06 > 315	22	F-1	N.A.	N.A.	N.A.	N.A.	1.94	48.75	1.62	0.04	1.94	48.75	1.62	0.04
130702	no	G, scit	scit_rub4_28a-110	MOZL_A06 > 315	15	F-1	0.83	43.69	1.12	0.02	1.42	22.52	1.73	0.03	1.31	30.02	1.53	0.03
130702	yes	G, scit	scit_rub4_27a-113	MOZL_A06 > 315	19	F-1	N.A.	N.A.	N.A.	N.A.	1.89	28.23	1.41	0.03	1.91	28.47	1.42	0.03
130702	no	G, scit	scit_rub1_78a-76	MOZL_A07 > 315	34	F-1	N.A.	N.A.	N.A.	N.A.	1.22	17.98	2.04	0.03	1.22	17.98	2.04	0.03
130702	yes	G, scit	scit_rub1_055a-150	MOZL_A11 > 315	30	F-1	0.89	0.08	1.10	0.02	1.32	0.02	1.50	0.03	1.29	50.60	1.51	0.03
130702	yes	G, scit	scit_rub1_056a-7	MOZL_A11 > 315	35	F-1	0.90	60.16	1.19	0.01	1.54	36.77	1.40	0.03	1.18	40.97	1.34	0.02
130702	no	G, scit	scit_rub1_057a-10	MOZL_A11 > 315	29	F-1	1.12	63.49	1.04	0.01	1.89	21.93	1.39	0.02	1.61	37.93	1.27	0.02
130702	no	G, scit	scit_rub1_058-12	MOZL_A11 > 315	31	F-1	0.77	86.15	1.06	0.02	1.71	12.69	1.57	0.03	1.17	55.86	1.27	0.02
130702	no	G, scit	scit_rub1_059a-16	MOZL_A11 > 315	24	F-1	0.60	50.49	1.07	0.00	1.11	32.44	1.30	0.03	0.94	38.63	1.22	0.02
130702	no	G, scit	scit_rub1_060a-24	MOZL_A11 > 315	32	F-1	N.A.	N.A.	N.A.	N.A.	1.38	9.32	1.47	0.03	1.38	9.32	1.47	0.03
130702	yes	G, scit	scit_rub1_061a-27	MOZL_A11 > 315	28	F-1	N.A.	N.A.	N.A.	N.A.	1.76	24.19	1.38	0.03	1.76	24.19	1.38	0.03
130702	no	G, scit	scit_rub1_062a-30	MOZL_A11 > 315	30	F-1	N.A.	N.A.	N.A.	N.A.	1.35	43.10	1.42	0.03	1.35	43.10	1.42	0.03
130702	no	G, scit	scit_rub1_063a-33	MOZL_A11 > 315	23	F-1	1.11	202.46	1.08	0.02	2.62	25.85	1.47	0.04	2.15	84.09	1.35	0.03
130702	no	G, scit	scit_rub1_064a-41	MOZL_A11 > 315	24	F-1	0.75	30.51	1.14	0.01	1.42	18.57	1.41	0.02	1.35	18.82	1.39	0.02
130703	no	G, scit	scit_rub1_74a-60	MOZL_A07 > 315	51	F-1	1.58	36.81	1.32	0.03	1.94	30.51	1.54	0.04	1.83	32.51	1.46	0.03
130703	no	G, scit	scit_rub1_75a-63	MOZL_A07 > 315	36	F-1	1.59	109.83	1.32	0.03	2.97	21.79	1.69	0.04	2.51	59.83	1.54	0.03
130703	no	G, scit	scit_rub1_76a-71	MOZL_A07 > 315	38	F-1	0.62	106.67	1.18	0.01	1.28	25.52	1.57	0.03	1.09	48.07	1.48	0.02
130701	yes, thin	G, scit	scit_rub1_78a-77	MOZL_A07 > 315	34	F-1	0.76	64.98	1.15	0.03	1.32	60.27	1.61	0.03	1.28	61.65	1.56	0.03

130702	yes	G, scit	scit_rub1_79a-80	MOZL_A07 > 315	29	F-1	1.09	43.32	1.20	0.01	2.33	13.87	1.68	0.03	2.07	20.15	1.56	0.02
130702	yes	G, scit	scit_rub1_80-87	MOZL_A07 > 315	33	F-1	1.24	53.64	1.38	0.03	1.54	27.29	1.60	0.04	1.45	40.05	1.53	0.04
130702	yes	G, scit	scit_rub1_82a-94	MOZL_A08 > 315	25	F-1	1.26	192.07	1.25	0.02	1.74	32.95	1.80	0.04	1.62	72.12	1.66	0.03
130702	yes	G, scit	scit_rub1_85-96	MOZL_A08 > 315	23	F-1	0.74	180.40	1.09	0.02	1.41	31.85	1.51	0.04	1.20	67.06	1.41	0.03
130702	no	G, scit	scit_rub1_84a-105	MOZL_A08 > 315	28	F-1	0.52	80.58	1.13	0.01	1.15	25.01	1.72	0.03	0.96	41.06	1.57	0.02
130702	no	G, scit	scit_rub1_85a-108	MOZL_A08 > 315	34	F-1	1.06	47.62	1.21	0.01	1.69	19.42	1.60	0.03	1.44	30.45	1.45	0.02
130702	no	G, scit	scit_rub1_87-113	MOZL_A08 > 315	33	F-1	0.87	49.64	1.13	0.02	1.75	22.90	1.61	0.03	1.67	24.06	1.53	0.03
130702	yes	G, scit	scit_rub1_88a-7	MOZL_A12 > 315	26	F-1	0.70	59.67	1.19	0.02	1.21	28.85	1.45	0.03	1.03	38.50	1.32	0.02
130702	yes	G, scit	scit_rub1_89-9	MOZL_A12 > 315	26	F-1	N.A.	N.A.	N.A.	N.A.	1.66	36.97	1.51	0.03	1.61	31.18	1.52	0.03
130702	yes	G, scit	scit_rub1_90a-13	MOZL_A12 > 316	23	F-1	0.64	35.22	1.12	0.01	1.52	34.13	1.46	0.03	1.16	38.19	1.36	0.02
130702	yes	G, scit	scit_rub1_91a-16	MOZL_A12 > 315	18	F-1	N.A.	N.A.	N.A.	N.A.	2.56	63.23	1.34	0.03	2.71	57.70	1.40	0.03
130702	yes	G, scit	G, scit1	MOZL_A20 > 315	30	F-1	0.91	N.A.	N.A.	N.A.	1.75	N.A.	N.A.	N.A.	1.70	N.A.	N.A.	N.A.
130702	yes	G, scit	G, scit2	MOZL_A20 > 315	19	F-1	0.82	N.A.	N.A.	N.A.	1.23	N.A.	N.A.	N.A.	1.16	N.A.	N.A.	N.A.
130702	yes	G, scit	G, scit3	MOZL_A20 > 315	27	F-1	0.89	N.A.	N.A.	N.A.	1.18	N.A.	N.A.	N.A.	1.16	N.A.	N.A.	N.A.
130702	yes	G, scit	scit_35b	MOZL_A16 > 315	32	F-1	0.58	N.A.	N.A.	N.A.	1.11	N.A.	N.A.	N.A.	1.01	N.A.	N.A.	N.A.
130702	yes	G, scit	scit_36b	MOZL_A16 > 315	22	F-1	0.89	N.A.	N.A.	N.A.	1.34	N.A.	N.A.	N.A.	1.26	N.A.	N.A.	N.A.
130702	yes	G, scit	scit_37b	MOZL_A16 > 315	33	F-1	0.55	N.A.	N.A.	N.A.	1.38	N.A.	N.A.	N.A.	1.13	N.A.	N.A.	N.A.
130702	yes	G, scit	scit_40b	MOZL_A19 > 315	34	F-1	1.13	N.A.	N.A.	N.A.	1.55	N.A.	N.A.	N.A.	1.50	N.A.	N.A.	N.A.
130702	yes	G, scit	scit_41b	MOZL_A19 > 315	30	F-1	1.22	N.A.	N.A.	N.A.	1.44	N.A.	N.A.	N.A.	1.42	N.A.	N.A.	N.A.
130702	yes	G, scit	scit_rub2_100a-24	MOZL_A01 > 315	30	F-2	N.A.	N.A.	N.A.	N.A.	1.65	49.11	1.30	0.03	1.65	49.11	1.30	0.03
130703	yes	G, scit	scit_rub2_101b-28	MOZL_A01 > 315	37	F-2	N.A.	N.A.	N.A.	N.A.	1.61	76.65	1.16	0.04	1.61	76.65	1.16	0.04
130703	no	G, scit	scit_rub2_102b-31	MOZL_A01 > 315	24	F-2	0.67	7.48	1.04	0.00	2.58	28.07	1.33	0.03	2.13	24.30	1.26	0.02
130703	yes	G, scit	scit_rub3_11b-8	MOZL_A01 > 315	40	F-2	0.89	163.33	1.11	0.02	0.89	163.33	1.11	0.02	1.25	85.71	1.35	0.02
130703	no	G, scit	scit_rub3_32b-41	MOZL_A06 > 315	30	F-2	N.A.	N.A.	N.A.	N.A.	1.27	52.10	1.22	0.02	1.27	52.08	1.22	0.02
130701	yes	G, scit	scit_rub3_33b-44	MOZL_A06 > 315	35	F-2	1.27	23.26	1.26	0.02	1.27	23.26	1.26	0.02	1.27	23.26	1.26	0.02
130702	yes	G, scit	scit_rub3_34b-47	MOZL_A06 > 315	27	F-2	0.84	63.84	1.13	0.01	1.44	25.90	1.41	0.02	1.24	36.60	1.32	0.01

130702	no	G. scit	scit_rub3_35b-55	MOZL_A06 > 315	31	F-2	0.76	90.36	1.00	0.01	1.47	52.55	1.30	0.02	1.34	66.47	1.21	0.02
130702	yes	G. scit	scit_rub3_36b-58	MOZL_A06 > 315	38	F-2	N.A.	N.A.	N.A.	N.A.	1.14	13.29	1.44	0.03	1.17	13.80	1.46	0.03
130702	no	G. scit	scit_rub3_37b-61	MOZL_A06 > 315	38	F-2	0.71	52.66	1.28	0.02	1.55	32.38	1.52	0.04	0.89	51.69	1.37	0.03
130702	yes	G. scit	scit_rub4_17b-91	MOZL_A06 > 315	8	F-2	N.A.	N.A.	N.A.	N.A.	2.65	85.51	1.34	0.02	2.65	85.51	1.34	0.02
130702	no	G. scit	scit_rub4_18b-94	MOZL_A06 > 315	23	F-2	N.A.	N.A.	N.A.	N.A.	1.61	53.04	1.27	0.02	1.61	53.04	1.27	0.02
130702	yes	G. scit	scit_rub4_19b-97	MOZL_A06 > 315	21	F-2	0.91	81.20	1.21	0.01	2.68	38.48	1.94	0.05	1.80	61.34	1.55	0.03
130702	yes	G. scit	scit_rub4_20b-100	MOZL_A06 > 315	24	F-2	1.30	54.26	1.13	0.02	1.93	32.02	1.39	0.03	1.58	45.54	1.26	0.02
130702	yes	G. scit	scit_rub4_27b-108	MOZL_A06 > 315	22	F-2	N.A.	N.A.	N.A.	N.A.	2.28	60.91	1.30	0.04	2.25	53.04	1.32	0.04
130702	yes	G. scit	scit_rub4_28b-111	MOZL_A06 > 315	15	F-2	0.97	116.06	1.07	0.01	1.47	49.44	1.52	0.03	1.31	64.60	1.37	0.02
130702	yes	G. scit	scit_rub4_27b-114	MOZL_A06 > 315	19	F-2	N.A.	N.A.	N.A.	N.A.	2.03	49.77	1.22	0.03	2.36	49.93	1.21	0.03
130702	yes	G. scit	scit_rub1_79b-79	MOZL_A07 > 315	29	F-2	N.A.	N.A.	N.A.	N.A.	0.68	1.93	1.32	0.01	0.68	1.93	1.32	0.01
130702	yes	G. scit	scit_rub1_055b-151	MOZL_A11 > 315	30	F-2	0.72	0.16	1.17	0.01	1.59	0.06	1.38	0.03	1.30	117.68	1.39	0.02
130702	yes	G. scit	scit_rub1_056b-8	MOZL_A11 > 315	35	F-2	0.95	117.81	1.14	0.02	2.50	52.00	1.54	0.06	1.27	90.28	1.28	0.03
130702	yes	G. scit	scit_rub1_057-9	MOZL_A11 > 315	29	F-2	N.A.	N.A.	N.A.	N.A.	1.76	33.66	1.39	0.03	1.76	33.66	1.39	0.03
130702	yes	G. scit	scit_rub1_058a-13	MOZL_A11 > 315	31	F-2	0.77	91.78	1.08	0.01	1.36	19.08	1.40	0.02	1.13	51.68	1.28	0.02
130702	yes	G. scit	scit_rub1_060b-25	MOZL_A11 > 315	32	F-2	N.A.	N.A.	N.A.	N.A.	1.30	47.98	1.27	0.03	1.30	47.98	1.27	0.03
130702	yes	G. scit	scit_rub1_061b-28	MOZL_A11 > 315	28	F-2	1.56	62.96	1.12	0.02	2.20	28.47	1.57	0.04	1.86	46.87	1.33	0.03
130702	yes	G. scit	scit_rub1_062b-31	MOZL_A11 > 315	30	F-2	N.A.	N.A.	N.A.	N.A.	1.09	51.82	1.20	0.02	1.09	51.82	1.20	0.02
130702	yes	G. scit	scit_rub1_063b-34	MOZL_A11 > 315	23	F-2	1.23	250.48	1.09	0.02	2.32	49.33	1.21	0.03	2.12	78.93	1.20	0.03
130702	yes	G. scit	scit_rub1_064b-42	MOZL_A11 > 315	24	F-2	0.71	21.08	1.10	0.02	1.16	48.18	1.26	0.03	1.10	46.31	1.24	0.03
130702	yes	G. scit	scit_rub1_74-59	MOZL_A07 > 315	51	F-2	1.15	16.35	1.26	0.03	2.22	17.77	1.70	0.03	1.95	13.32	1.66	0.03
130703	yes	G. scit	scit_rub1_75b-64	MOZL_A07 > 315	36	F-2	2.37	137.61	1.14	0.04	2.34	64.47	1.47	0.04	2.38	64.35	1.41	0.04
130703	yes	G. scit	scit_rub1_76b-72	MOZL_A07 > 315	38	F-2	0.74	77.40	1.15	0.01	1.44	44.29	1.36	0.02	1.26	54.61	1.29	0.02
130703	yes	G. scit	scit_rub1_77a-74	MOZL_A07 > 315	31	F-2	0.74	11.12	1.30	0.01	1.83	47.56	1.46	0.03	1.57	38.75	1.43	0.02
130703	yes	G. scit	scit_rub1_78b-78	MOZL_A07 > 315	34	F-2	0.43	17.78	1.29	0.01	1.82	94.29	1.47	0.03	1.60	86.28	1.44	0.03
130702	yes	G. scit	scit_rub1_79b-81	MOZL_A07 > 315	29	F-2	0.72	17.44	1.24	0.01	2.62	33.89	1.54	0.03	2.05	30.94	1.43	0.02

130702	yes	G. scit	scit_rub1_80a-88	MOZL_A07>315	33	F-2	1.68	172.76	1.43	0.03	2.28	38.68	1.64	0.03	2.01	103.92	1.54	0.03
130702	no	G. scit	scit_rub1_81a-91	MOZL_A08>315	26	F-2	0.57	100.22	1.02	0.01	1.22	55.23	1.28	0.02	1.09	63.58	1.23	0.02
130702	yes	G. scit	scit_rub1_82b-95	MOZL_A08>315	25	F-2	1.26	176.98	1.13	0.02	1.22	114.24	1.36	0.03	1.23	125.18	1.32	0.02
130702	no	G. scit	scit_rub1_83b-98	MOZL_A08>315	23	F-2	0.84	157.03	1.07	0.01	1.46	34.46	1.53	0.03	1.29	65.77	1.40	0.03
130702	yes	G. scit	scit_rub1_84b-106	MOZL_A08>315	28	F-2	0.99	111.94	1.15	0.03	1.38	40.05	1.50	0.03	1.24	56.75	1.36	0.02
130703	yes	G. scit	scit_rub1_85b-109	MOZL_A08>315	34	F-2	1.06	41.19	1.12	0.01	1.31	36.22	1.37	0.02	1.21	38.88	1.25	0.02
130702	no	G. scit	scit_rub1_86a-111	MOZL_A08>315	33	F-2	0.67	59.18	1.18	0.01	1.31	30.76	1.65	0.02	1.20	35.00	1.56	0.02
201408	yes	G. scit	scit_rub1_87a-114	MOZL_A08>315	33	F-2	1.11	37.75	1.04	0.01	1.78	18.66	1.53	0.03	1.33	25.52	1.24	0.02
201408	yes	G. scit	scit_rub1_88b-8	MOZL_A12>315	26	F-2	0.86	49.47	1.17	0.02	1.69	44.67	1.38	0.03	1.29	50.22	1.29	0.02
201408	no	G. scit	scit_rub1_89a-10	MOZL_A12>315	26	F-2	1.56	35.22	1.36	0.02	1.97	32.87	1.48	0.03	1.83	28.18	1.45	0.02
201408	yes	G. scit	scit_rub1_90b-14	MOZL_A12>317	23	F-2	0.41	6.43	1.09	0.01	1.60	71.35	1.40	0.03	1.16	51.49	1.29	0.02
201408	yes	G. scit	scit_rub1_91b-17	MOZL_A12>315	18	F-2	0.94	17.93	1.01	0.03	2.13	62.80	1.52	0.03	1.83	55.64	1.35	0.03
201408	yes	G. scit	G. scit1	MOZL_A20>315	30	F-2	0.94	N.A.	N.A.	N.A.	1.55	N.A.	N.A.	N.A.	1.52	N.A.	N.A.	N.A.
201408	yes	G. scit	G. scit2	MOZL_A20>315	19	F-2	1.00	N.A.	N.A.	N.A.	1.55	N.A.	N.A.	N.A.	1.47	N.A.	N.A.	N.A.
201408	yes	G. scit	G. scit3	MOZL_A20>315	27	F-2	0.58	N.A.	N.A.	N.A.	1.30	N.A.	N.A.	N.A.	1.16	N.A.	N.A.	N.A.
201408	yes	G. scit	scit_35c	MOZL_A16>315	32	F-2	0.74	N.A.	N.A.	N.A.	1.20	N.A.	N.A.	N.A.	1.11	N.A.	N.A.	N.A.
201408	yes	G. scit	scit_36c	MOZL_A16>315	22	F-2	N.A.	N.A.	N.A.	N.A.	1.59	N.A.	N.A.	N.A.	1.58	N.A.	N.A.	N.A.
201408	yes	G. scit	scit_37c	MOZL_A16>315	33	F-2	N.A.	N.A.	N.A.	N.A.	0.96	N.A.	N.A.	N.A.	0.95	N.A.	N.A.	N.A.
201408	yes	G. scit	scit_40c	MOZL_A19>315	34	F-2	0.93	N.A.	N.A.	N.A.	1.40	N.A.	N.A.	N.A.	1.32	N.A.	N.A.	N.A.
2014_05	yes	G. scit	scit_41c	MOZL_A19>315	30	F-2	0.97	N.A.	N.A.	N.A.	1.40	N.A.	N.A.	N.A.	1.36	N.A.	N.A.	N.A.
2014_06	no	G. scit	scit_rub1_81-90	MOZL_A08>315	26	F-3	N.A.	N.A.	N.A.	N.A.	1.31	22.17	1.90	0.04	1.32	22.35	1.87	0.04
2014_07	yes	G. scit	scit_rub1_058b-14	MOZL_A11>315	31	F-3	0.90	108.65	1.13	0.02	1.41	38.24	1.22	0.02	1.28	55.13	1.18	0.02
2014_08	yes	G. scit	scit_rub1_77b-75	MOZL_A07>315	31	F-3	1.63	26.17	1.69	0.02	1.57	15.00	1.89	0.03	1.60	18.82	1.82	0.03
2014_09	no	G. scit	scit_rub1_80b-89	MOZL_A07>315	33	F-3	N.A.	N.A.	N.A.	N.A.	2.57	104.37	1.48	0.03	2.63	111.33	1.48	0.03
2014_10	yes	G. scit	scit_rub1_81b-92	MOZL_A08>315	26	F-3	0.46	51.88	0.86	0.01	1.15	64.04	1.14	0.02	1.07	64.27	1.12	0.02
2014_11	no	G. scit	scit_rub1_86b-112	MOZL_A08>315	33	F-3	N.A.	N.A.	N.A.	N.A.	1.27	67.28	1.34	0.02	1.29	68.06	1.34	0.02

2014_12	yes	G. scit	set_rubbl_87b-115	MOZ1_A08 >315	33	F-3	1.02	46.38	1.04	0.01	1.23	30.09	1.21	0.02	1.23	30.11	1.20	0.02
2014_13	yes	G. scit	set_rubbl_89b-11	MOZ2_A12 >315	26	F-3	2.39	56.63	1.32	0.03	3.56	29.36	1.42	0.04	2.58	71.06	1.26	0.04
2014_14	yes	G. scit	G. scit1	MOZ3_A20 >315	30	F-3	1.38	N.A.	N.A.	N.A.	1.74	N.A.	N.A.	N.A.	1.73	N.A.	N.A.	N.A.
2014_15	yes	G. scit	G. scit2	MOZ3_A20 >315	19	F-3	0.10	N.A.	N.A.	N.A.	1.55	N.A.	N.A.	N.A.	1.52	N.A.	N.A.	N.A.
2014_16	yes	G. scit	G. scit3	MOZ3_A20 >315	27	F-3	0.60	N.A.	N.A.	N.A.	1.35	N.A.	N.A.	N.A.	1.30	N.A.	N.A.	N.A.
2014_17	yes	G. scit	sci_35d	MOZ4_A16 >315	32	F-3	0.90	N.A.	N.A.	N.A.	1.38	N.A.	N.A.	N.A.	1.24	N.A.	N.A.	N.A.
2014_18	yes	G. scit	sci_36d	MOZ4_A16 >315	22	F-3	0.94	N.A.	N.A.	N.A.	1.65	N.A.	N.A.	N.A.	1.60	N.A.	N.A.	N.A.
2014_19	no	G. scit	sci_37d	MOZ4_A16 >315	33	F-3	N.A.	N.A.	N.A.	N.A.	1.38	N.A.	N.A.	N.A.	1.37	N.A.	N.A.	N.A.
2014_20	yes	G. scit	sci_40d	MOZ4_A19 >315	34	F-3	1.49	N.A.	N.A.	N.A.	1.56	N.A.	N.A.	N.A.	1.54	N.A.	N.A.	N.A.
2014_21	yes	G. scit	sci_41d	MOZ4_A19 >315	30	F-3	1.21	N.A.	N.A.	N.A.	1.59	N.A.	N.A.	N.A.	1.49	N.A.	N.A.	N.A.

