Deciphering the tEmperature history of troPIcal oceanS: a cOccolith clumpeD isotopE approach

Berichterstattung

Projektinformationen

EPISODE

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Projektwebsite

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Periodic Reporting for period 1 - EPISODE (Deciphering the tEmperature history of troPIcal oceanS: a cOccolith clumpeD isotopE approach)

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Zusammenfassung vom Kontext und den Gesamtzielen des Projekts

Accurate predictions of climate's response to increasing CO2, and a timely implementation of mitigation strategies, depends on our ability to reconstruct past Earth's Climate Sensitivity (ECS) during conditions similar to those expected in the future, for which reliable absolute estimates of temperature and CO2 are required. Given the uncertainties of widely-used temperature proxies, this project evaluated the viability of clumped isotope (Δ47) thermometry applied to coccolith calcite, a mineral produced by photosynthetic organisms called coccolithophores, to reliably reconstruct absolute temperatures of surface oceans (SST). High uncertainties are associated to temperatures of warm, high CO2 worlds, as perhaps the currently best-trusted SST proxy (alkenone unsaturation index UK'37) becomes insensitive > 28 °C. Since warm waters covered larger parts of high CO2 worlds compared to today, a significant part of Earth's temperature history is unexplored. A further paleoclimate conundrum is the extreme polar amplification shown by widely-used temperature proxies for warm, high CO2 worlds. Climate modelers struggle to reproduce this small latitudinal temperature gradient, posing the question of whether it is models or the interpretation of proxies that should be improved.

To ensure a new proxy resolves a targeted parameter, in this case, temperature, further controls on the proxy must be ruled out or corrected for. The first goal was to determine if CO2 changes affect coccolith Δ47. For this, we proposed a mixed culture and core top-based study, considering a range of temperatures and CO2. The second main goal was to validate the coccolith Δ47 performance by comparing temperatures with those obtained by UK'37, which is based on lipids produced by coccolithophores. Finally, we proposed to apply the Δ47 proxy to tropical, well conserved, coccoliths throughout the Cenozoic, so as to produce the first absolute long-term tropical temperature record, and compare with high latitude temperatures to evaluate the latitudinal gradient in high CO2 worlds.

EPISODE project proved the invaluable potential of coccolith Δ47 to reconstruct mixed layer depth temperatures, where most coccolithophores' productivity occurs. We have found no evidence for vital effects. We also show that coccolith Δ47 may provide more reliable absolute temperatures than UK'37, especially in high latitudes. Coccolith Δ47 suggest a more modest polar amplification during the high mid-Miocene CO2 world compared to other temperature proxies.

Arbeit, die ab Beginn des Projekts bis zum Ende des durch den Bericht erfassten Berichtszeitraums geleistet wurde, und die wichtigsten bis dahin erzielten Ergebnisse

Successful carbonate Δ47 analyses requires low organic matter contents. Therefore, we developed a protocol for organic matter removal, and proved that this method successfully eliminates organic contaminants, and does not affect stable isotope or Δ47 estimates. The advantage of using coccolith calcite is that it ensures a surface signal. However, this requires a careful separation from other calcite sources. Further separation of discrete size fractions may be needed, if, for instance, a specific coccolith fraction is more affected by diagenesis, or if there are important changes in coccolith species through time. Therefore, a key success of this project was the development of a coccolith size separation method, which combines centrifugation, settling and semi-automated microfiltering

techniques, and produces enough calcite for Δ47 analysis. The centrifugation part was submitted to Biogesciences, and the implementation of the whole method produced 90-98% pure coccolith fractions.

We applied Δ47 thermometry to 85 coccolith fractions, i.e. to 21 additional ones than those planned. One of the key results is the Δ47 temperature record from pure and well-preserved North Atlantic coccoliths of the last 15 Ma, which show similar cooling trends but significantly colder absolute temperatures compared to UK'37-derived SSTs from the same samples. We showed that at least for high latitudes, coccolith Δ47 may provide more reliable absolute temperatures compared to UK'37. These results are in review in Nature Geosciences. We have had complications with coccolithophore culturing until a couple of months ago. Therefore, since carbon limitation is expected to affect more large cells due to their lower capacity of CO2 diffusion, we decided to alternatively test if carbon limitation influences coccolith Δ47 by measuring Δ47 in three discrete, well-separated coccolith size fractions from the same North Atlantic sediments. These results, combined with vital effects of coccolith δ13C and δ18O, and carbon isotopic fractionation of alkenones (εp), are currently prepared to be submitted to EPSL.

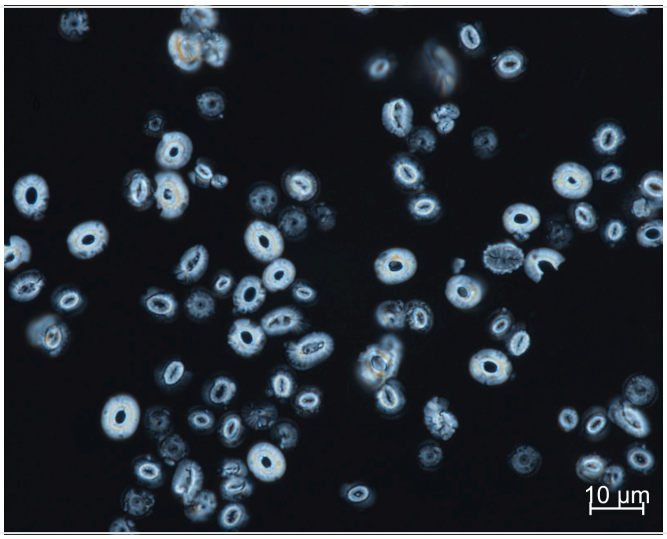
We obtained Δ47 temperatures from coretop coccolith separations from diverse oceanographic settings with varying SSTs, CO2, seasonalities, and depths of production. UK'37 SSTs measured in the same samples show differences compared to Δ47 temperatures. We also obtained εp estimates, which, combined with ratios of alkenones C37:C38, can provide information on factors affecting the alkenone CO2 proxy. This study is being prepared for submission to EPSL. Finally, we have measured Δ47 from coccolith separations of low latitudes in the Equatorial Pacific over the last 60 Ma. This tropical absolute temperature record is expected to provide the first long-term mixed layer depth absolute temperature estimates of tropical oceans, in latitudes where the alkenone proxy is insensitive. Results are being prepared for submission, likely to a high impact journal like Nature.

Results have been presented in international conferences, including Goldschmidt 2018, 2019, EGU 2020, ICP 2019 and SGM 2018. Outreach activities include a talk and a video directed to the public and politicians in Colombia, the organization and participation in a Doctoral Geological excursion to Colombia, and an interview on my experience as a Marie Curie fellow to EURAXESS LAC. Manuscripts are in review (Nature Geosciences, Biogeoscienes) or in preparation for submission and a field guide to the excursion was published.

Fortschritte, die über den aktuellen Stand der Technik hinausgehen und voraussichtliche potenzielle Auswirkungen (einschließlich der bis dato erzielten sozioökonomischen Auswirkungen und weiter gefassten gesellschaftlichen Auswirkungen des Projekts)

Our new Δ47 temperatures from North Atlantic coccoliths suggest that polar amplification in warmer CO2 worlds may not have been as extreme as other proxies have suggested, and argues for a more optimistic response of high latitudes to CO2 forcing. Unexpectedly, we show that the best-trusted

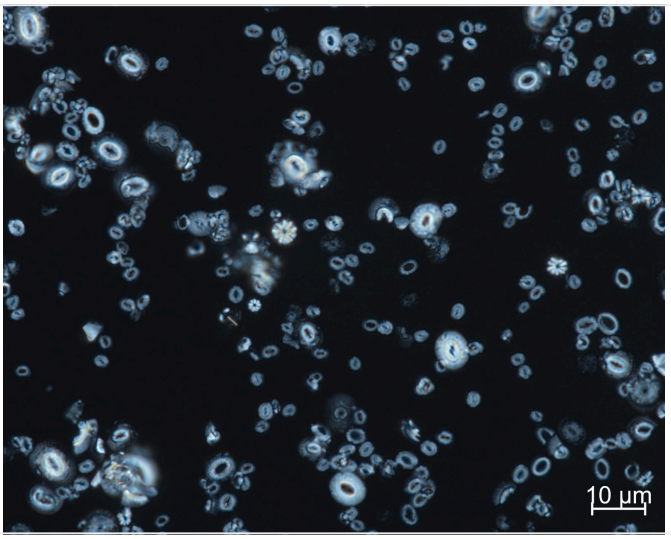
UK’37 SST proxy may be significantly influenced by non-thermal effects, potentially biasing absolute estimates, and calls the attention of the paleo-community to better understand empirical proxies, as physiological and ecological mechanisms may affect them in ways not previously considered. These results, now in review in Nature Geosciences, already inspired ideas for a new project within the Climate Geology group, to study non-thermal effects of the UK’37 proxy. Moreover, the Δ47 and stable isotope vital effect study on discrete coccolith size fractions and alkenone δ13C will improve our interpretation of both the coccolith Δ47 temperature proxy and the alkenone CO2 proxy. Finally, our coccolith Δ47-based long-term mixed layer depth absolute temperature estimates of tropical oceans will serve as input for climate models, to better understand ECS during warm, high CO2 worlds, under conditions similar the ones we are expecting in our future.



Coccolith size fraction separation (5-8 microns 100% coccoliths)

Outreach talk to the general public, including politicians in Pereira, Colombia

Group of ETH PhDs and Postdocs at Nevado del Ruiz National Park, Colombia



Mixed coccolith size fraction (2-10 microns 98% coccoliths)

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