Cenozoic changes in the Si and C marine cycles from the point of view of diatoms

Johan Renaudie
Museum für Naturkunde

23.07.2019

Leibniz-Gemeinschaft

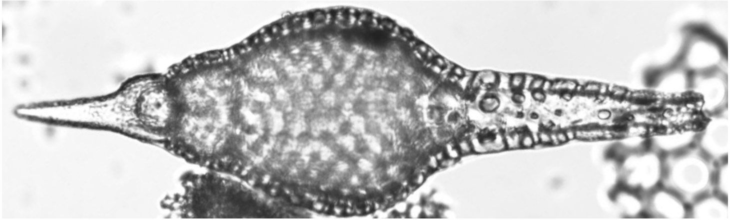
Neptune Sandbox Berlin

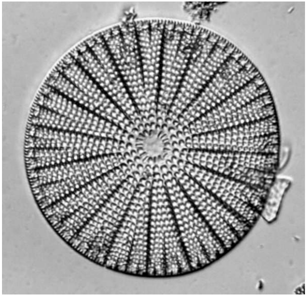
Museum für Naturkunde Berlin

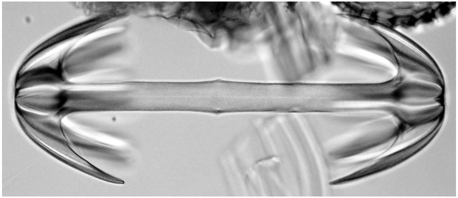
Outline

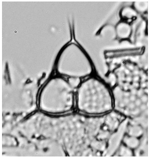
- Siliceous microfossils
- Big Data in Micropaleontology
- How climate affected diatom evolution
- Diatom development effect on the Carbon Cycle
- Link with the Silicon cycle
- Ongoing project on Late Eocene Southern Ocean diatom development

Siliceous microfossils and their fossil record

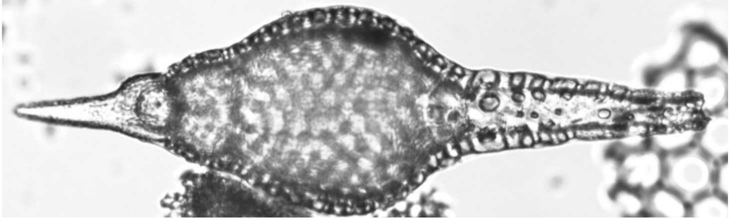








Siliceous microfossils and their fossil record



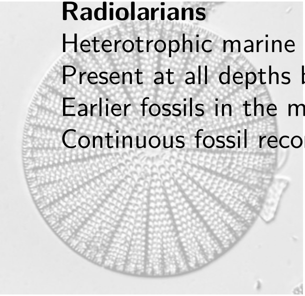
Radiolarians

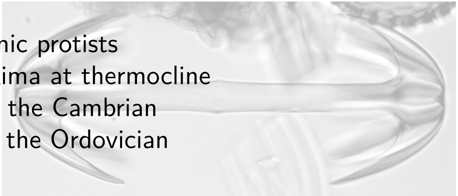
Heterotrophic marine planktonic protists

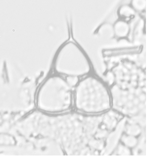
Present at all depths but maxima at thermocline

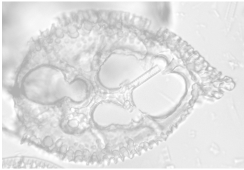
Earlier fossils in the middle of the Cambrian

Continuous fossil record since the Ordovician

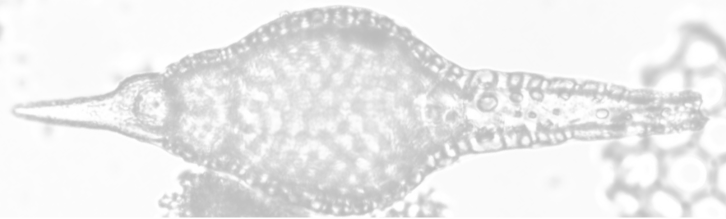


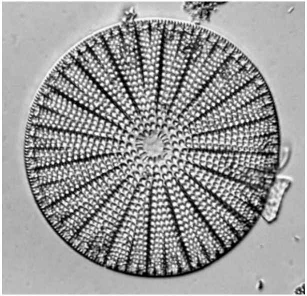


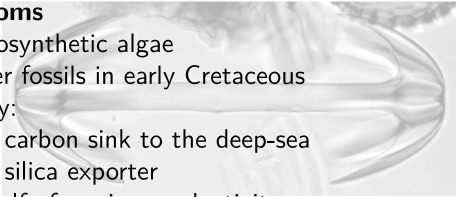




Siliceous microfossils and their fossil record







Diatoms

Photosynthetic algae

Earlier fossils in early Cretaceous

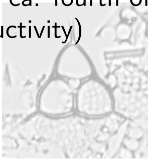
Today:

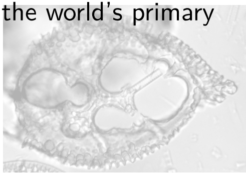
main carbon sink to the deep-sea

main silica exporter

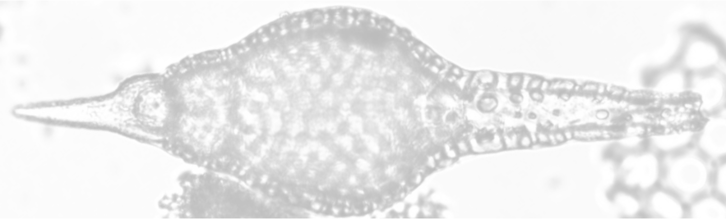
ca. half of marine productivity

(i. e. ca. fourth of the world's primary productivity)

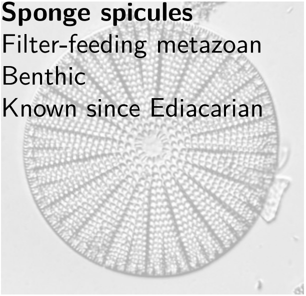


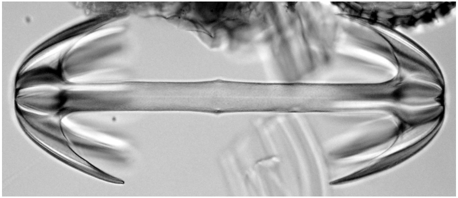


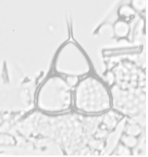
Siliceous microfossils and their fossil record

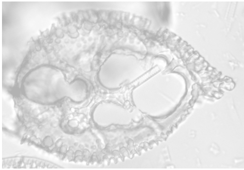


Sponge spicules
Filter-feeding metazoan
Benthic
Known since Ediacarian









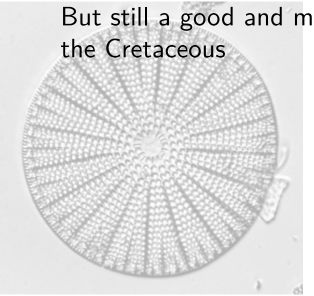
Siliceous microfossils and their fossil record

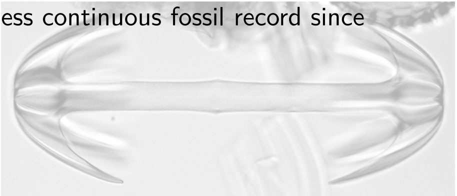
Plenty of other planktonic silicifying protists

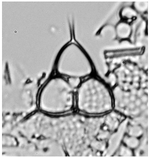
Most of them algal

Mostly rare and lower diversity

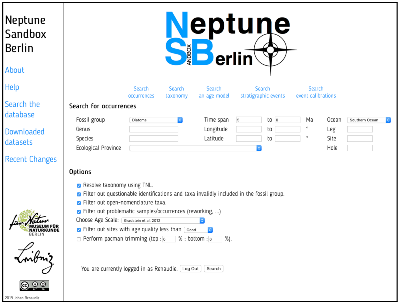
But still a good and more or less continuous fossil record since the Cretaceous







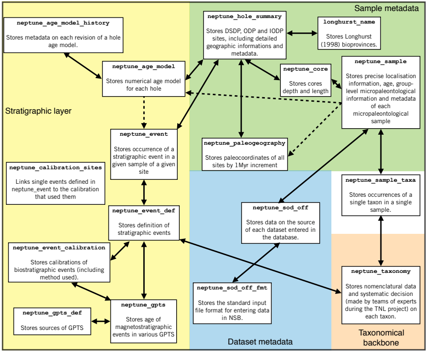
The Neptune (NSB) Database



Exists since 1994

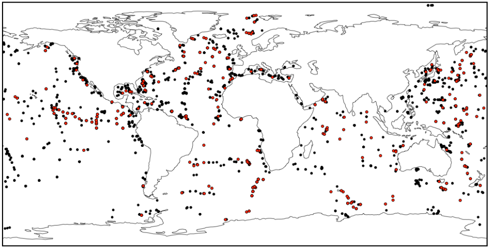
Modern implementation is NSB (`http://nsb-mfn-berlin.de`)

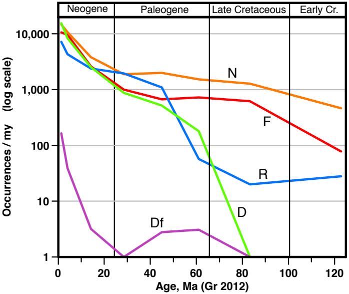
Micropaleontological occurrences in deep-sea drilling record with a complex stratigraphic layer allowing reliable and precise numerical age for most sample



The Neptune (NSB) Database

Good geographic coverage (in red vs all deep-sea drilling sites in black from DSDP, ODP and IODP programs)





ca. 800k occurrences for 4 taxonomic groups

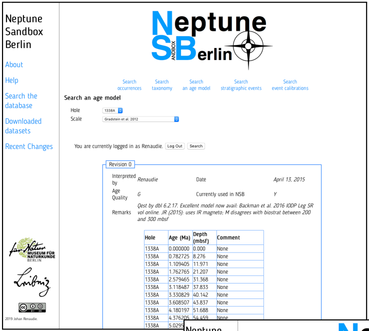
Excellent coverage of Cenozoic, but also good coverage of Cretaceous calcareous microfossils

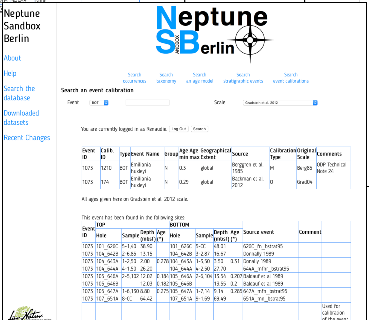
Taxonomy resolved thanks to IODP Paleo Coordination Group 'Taxonomical Name List' (TNL)

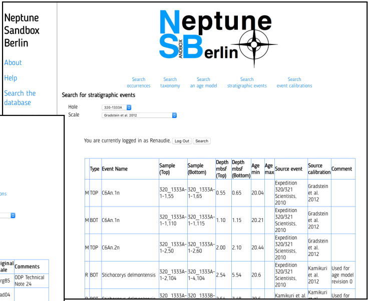
The Neptune (NSB) Database

Samples are given a numerical age thanks to a large library of age models

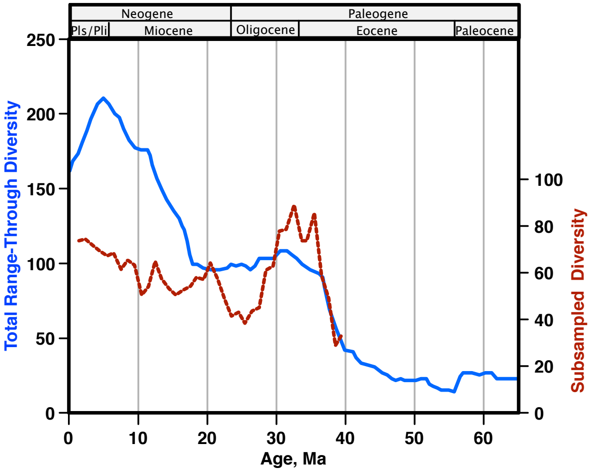
In addition, large library of calibrated stratigraphic events needed to produce and maintain age models







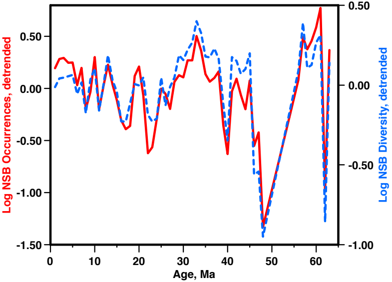
Cenozoic marine diatom diversity



Prior studies (Cervato, 1999 and Rabosky & Sorrhannus 2008) conflict

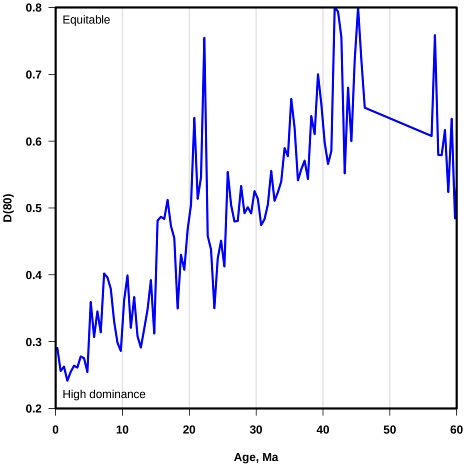
Both based on NSB, first is litteral reading of fossil record, second compensate for sampling biases and plenty of other untested biases.

Cenozoic marine diatom diversity



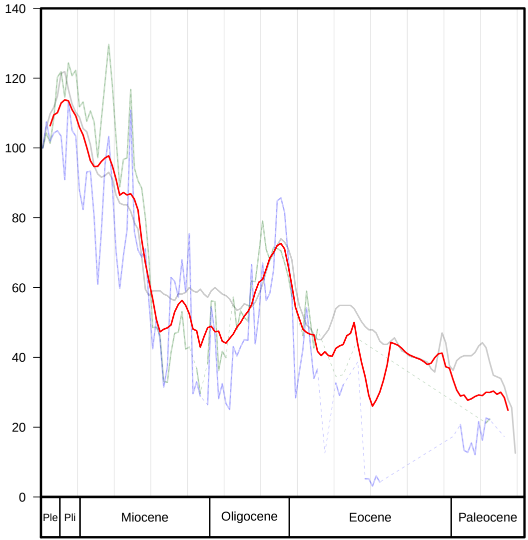
Need to account for sampling bias and evenness/ubiquity bias in Neptune database
2 independant methods:

- Alroy's 'Shareholder Quorum Subsampling' (SQS) + evenness correction (D80)
- Rarefaction + D80 + geographic correction (Tropical vs Polar)



From Lazarus *et al.* 2014 (PLoS ONE).

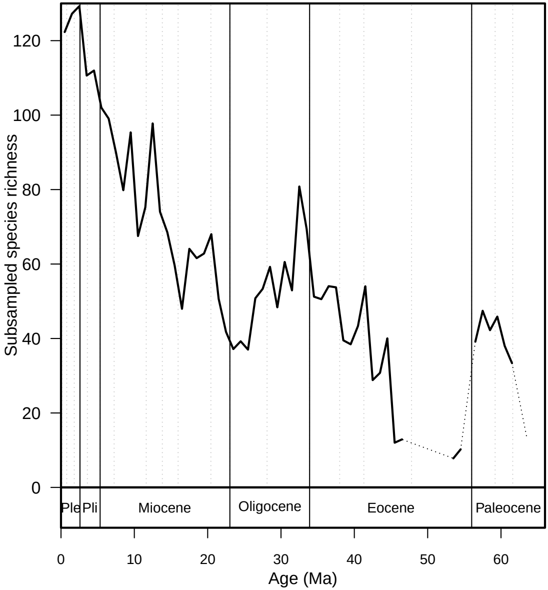
Cenozoic marine diatom diversity



Also include a third reconstruction based on an indenpendant catalog by John Barron, including a different (partly overlapping) set of sites.

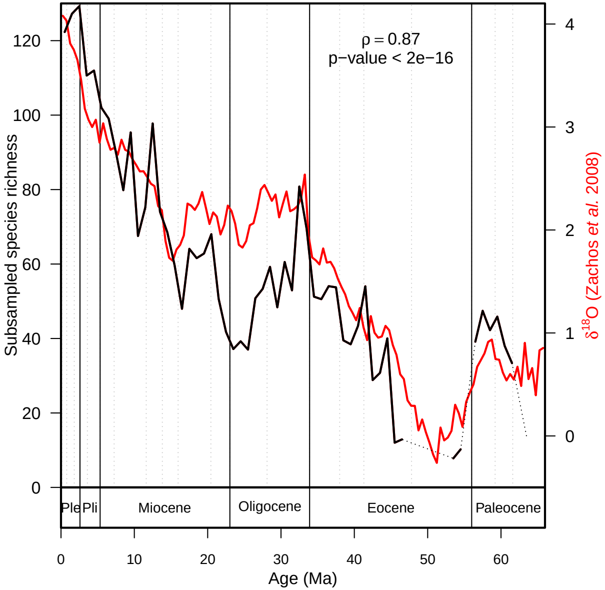
From Lazarus *et al.* 2014 (PLoS ONE).

Cenozoic marine diatom diversity



Modified from Renaudie *et al.* 2018 (Fossil Record).

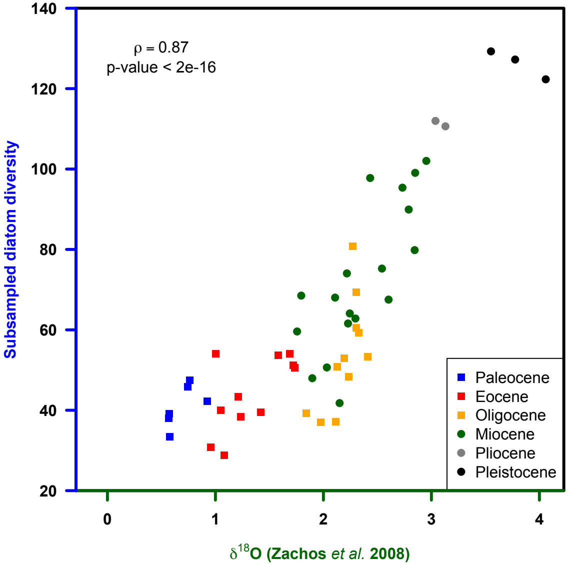
Cenozoic marine diatom diversity



Latest update, with newly collected data for the Paleocene-Early Eocene.

Modified from Renaudie *et al.* 2018 (Fossil Record).

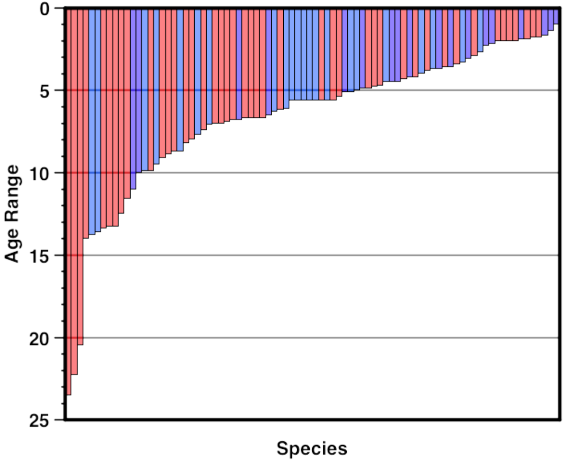
Cenozoic marine diatom diversity



Very strong correlation with climate state:
Cold climate = Very diverse marine diatom
Warm climate = Low diversity

Modified from Renaudie *et al.* 2018 (Fossil Record).

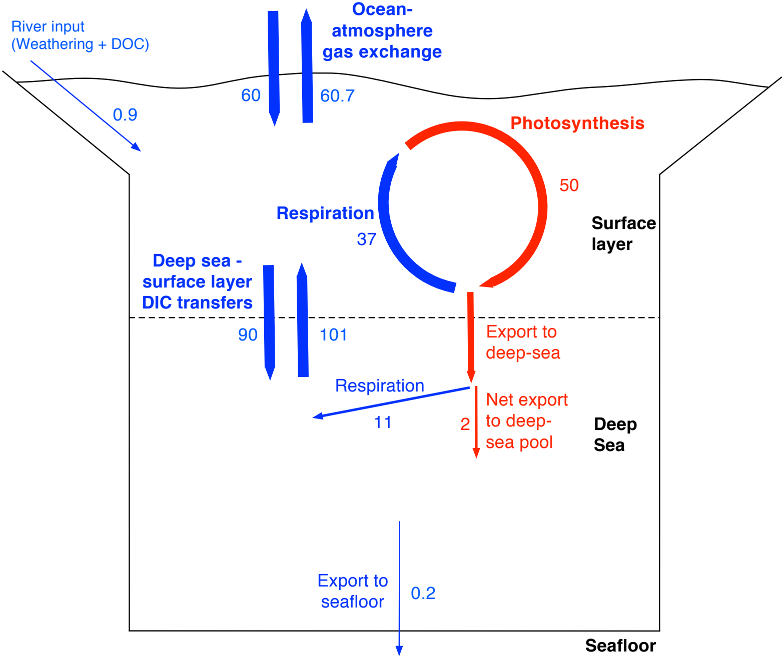
Cenozoic marine diatom diversity



ca. 80% of living species appeared since 15 Ma i. e. after the last warm event (Middle Miocene Climatic Optimum) including large proportion of polar species

From Lazarus *et al.* 2014 (PLoS ONE).

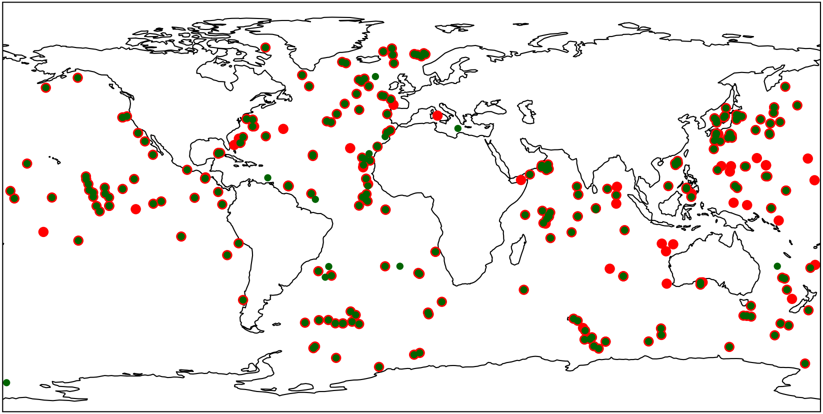
Diatoms in the Marine Carbon Cycle



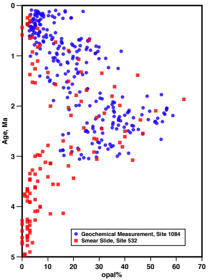
Cenozoic changes in diatom abundance in sediments

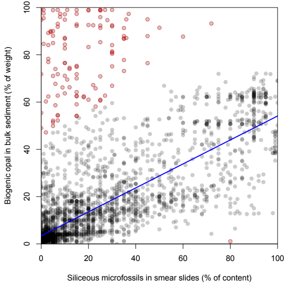
Dataset: smear slides content descriptions for all DSDP and most ODP Sites

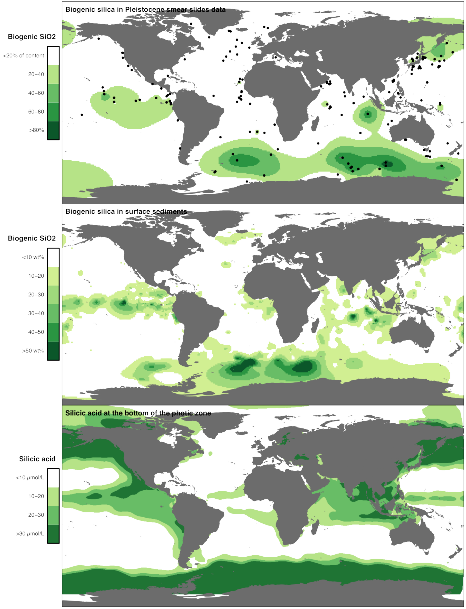
32k samples could be dated with reasonable accuracy using NSB age model library



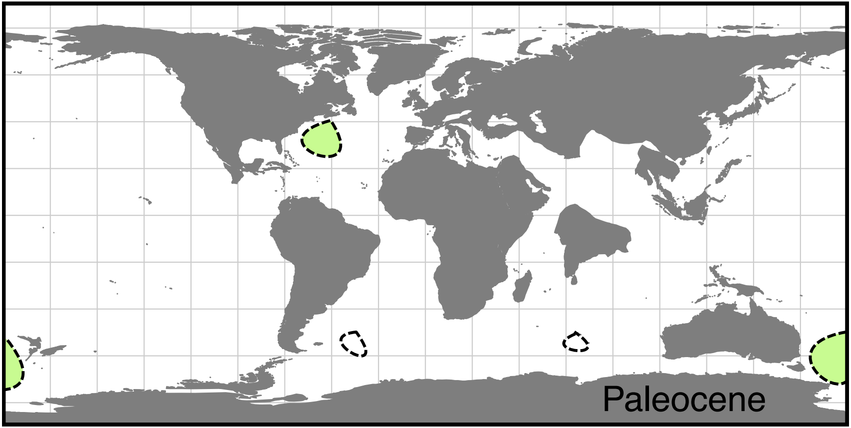
Cenozoic changes in diatom abundance in sediments





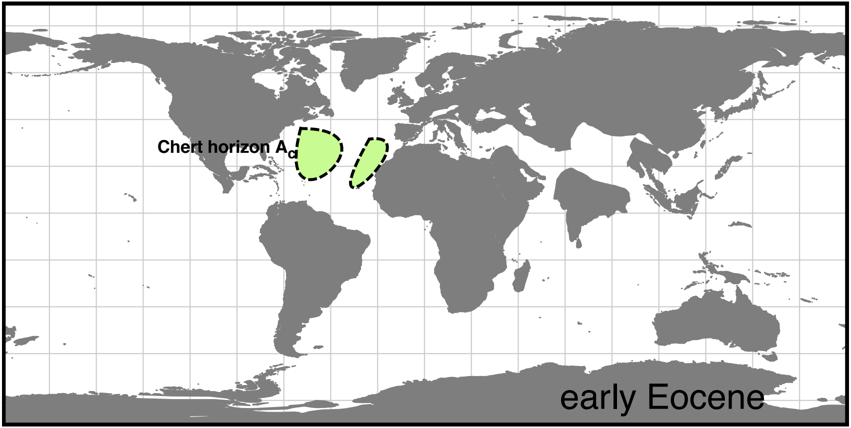


Cenozoic changes in diatom abundance in sediments



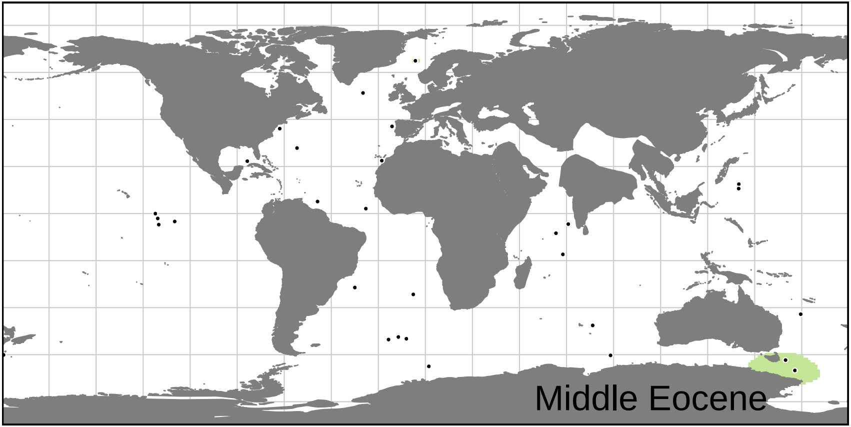
based on Renaudie *et al.* 2018

Cenozoic changes in diatom abundance in sediments



based on Muttoni & Kent 2008

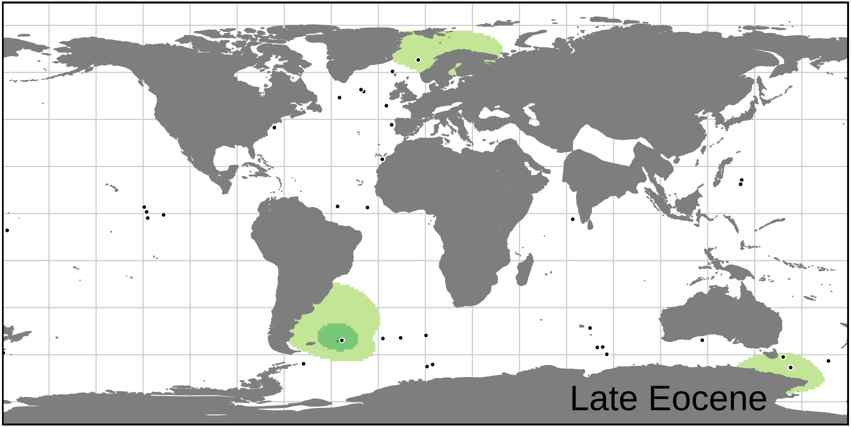
Cenozoic changes in diatom abundance in sediments



Start using smear slide analysis from that point on.
Ordinary Kriging based on logistic distance model.

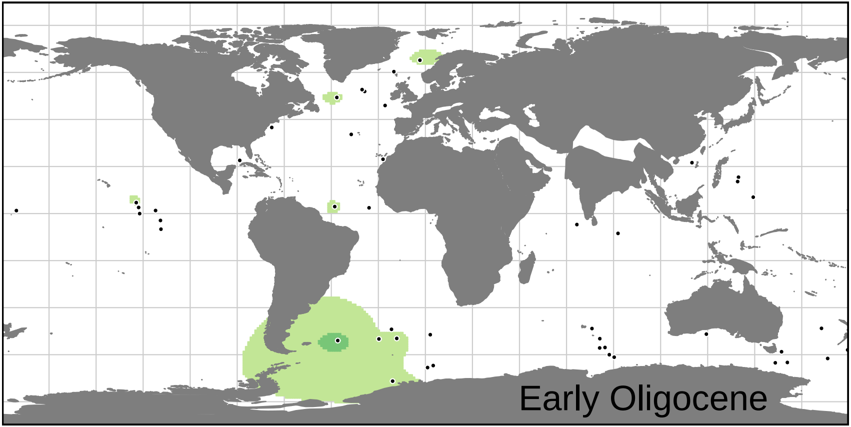
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



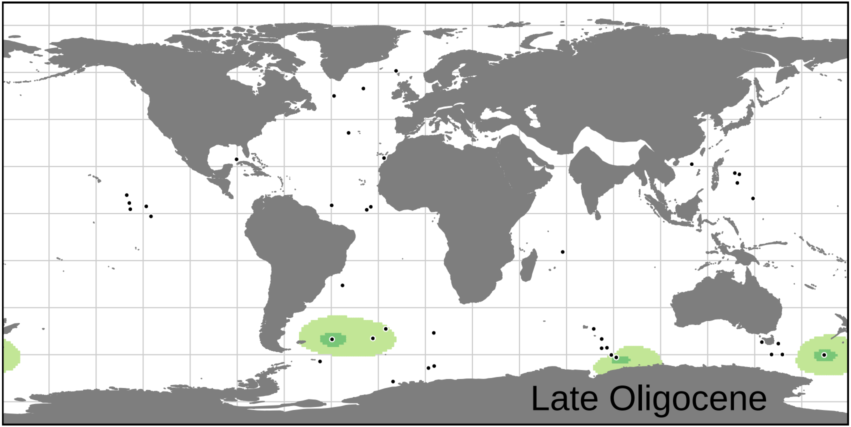
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



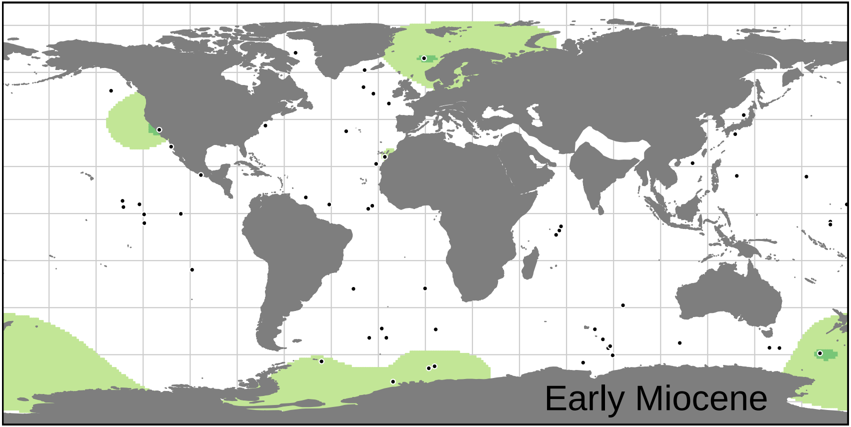
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



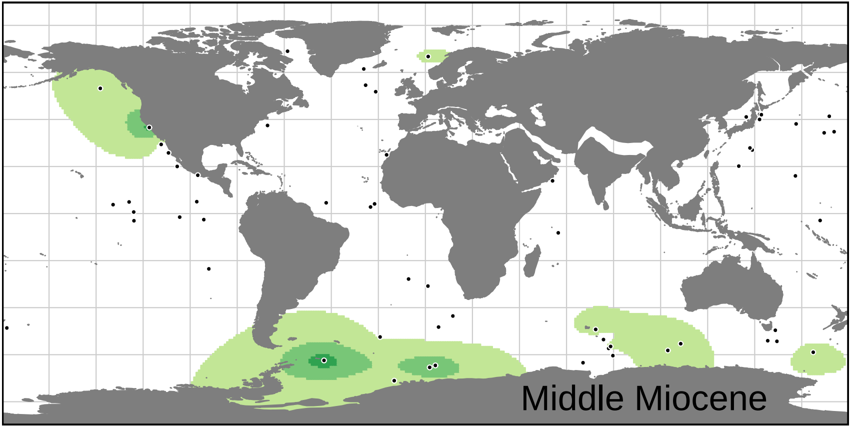
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



modified after Renaudie 2016

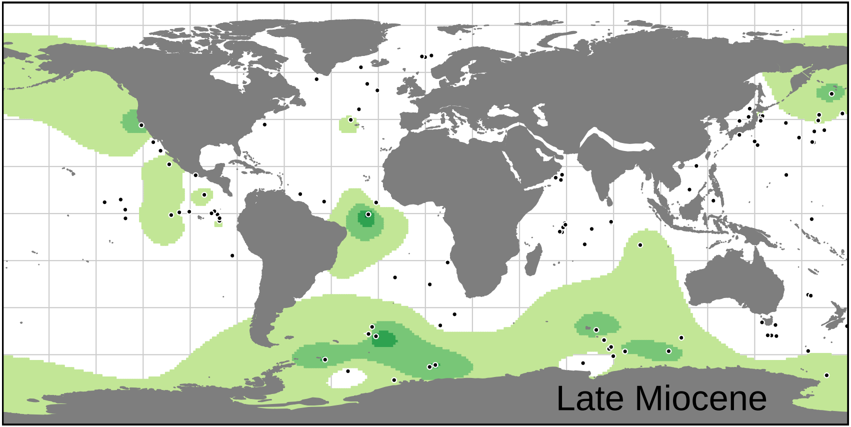
Cenozoic changes in diatom abundance in sediments



Onset of the “Silica Switch” (Keller & Barron 1983)

modified after Renaudie 2016

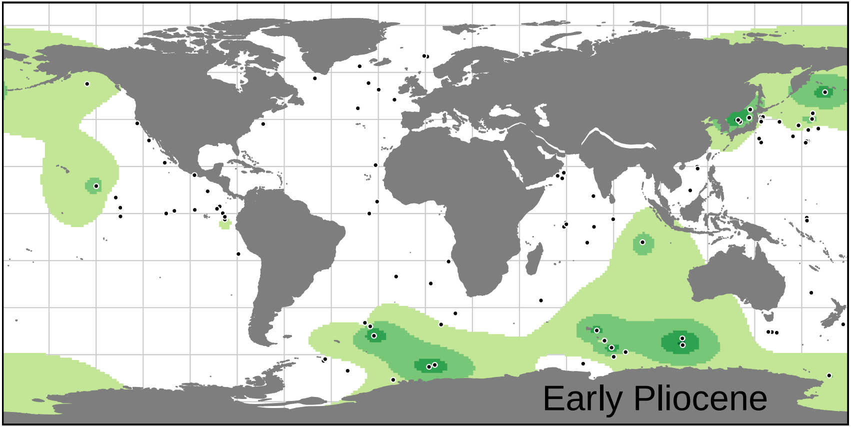
Cenozoic changes in diatom abundance in sediments



Onset of mid-latitude upwelling zones from Late Miocene onwards.

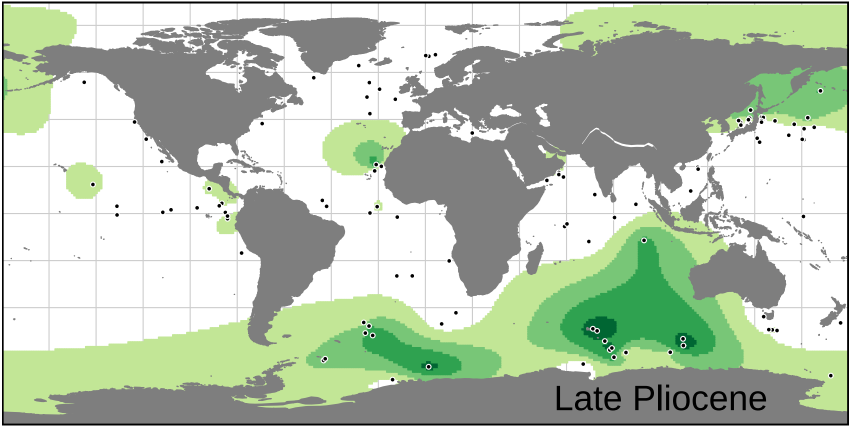
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



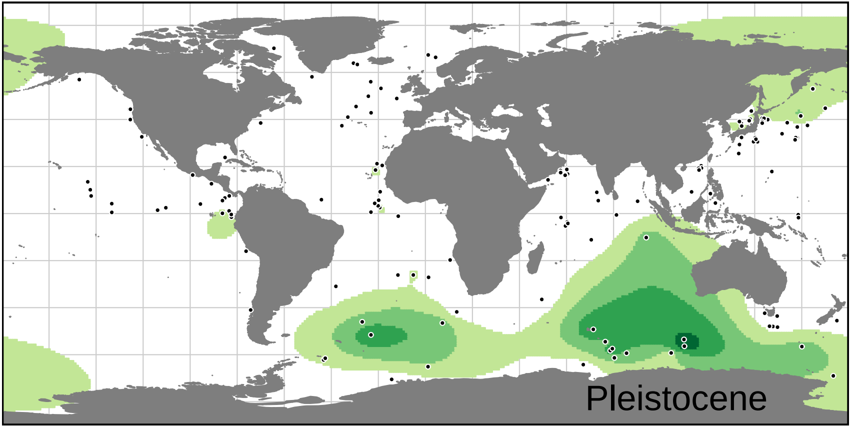
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



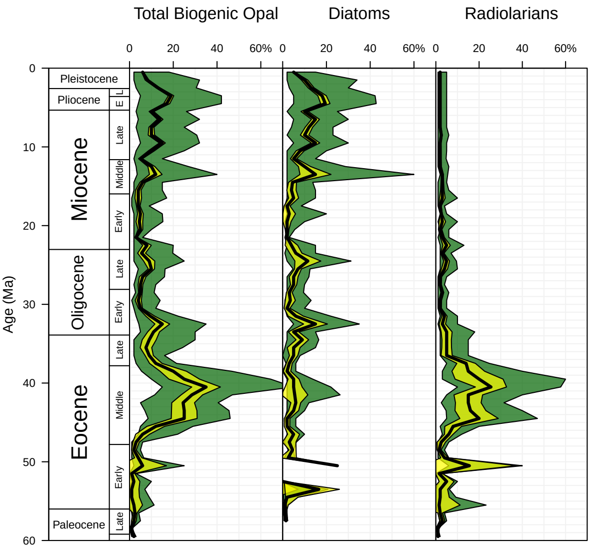
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments

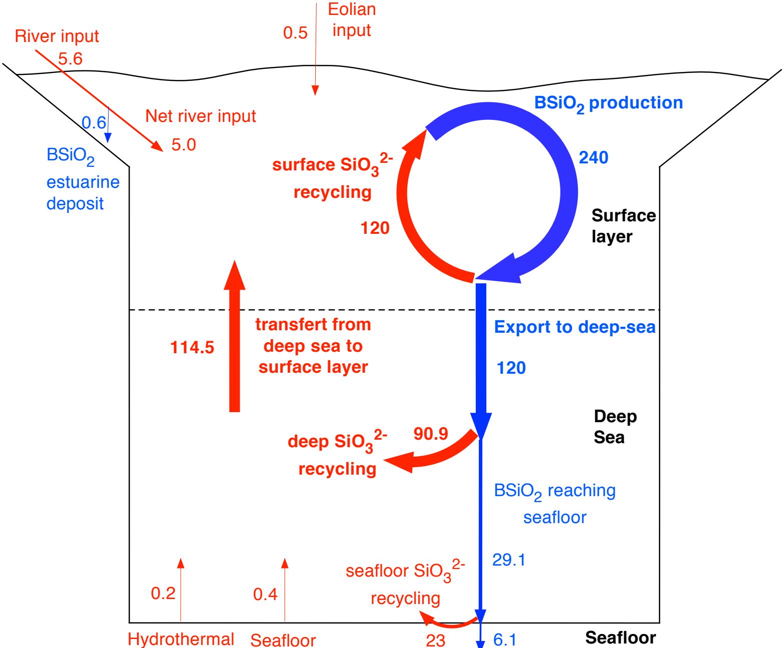


Switch from radiolarian-based to diatom-based silica deposition at the end of the Eocene.

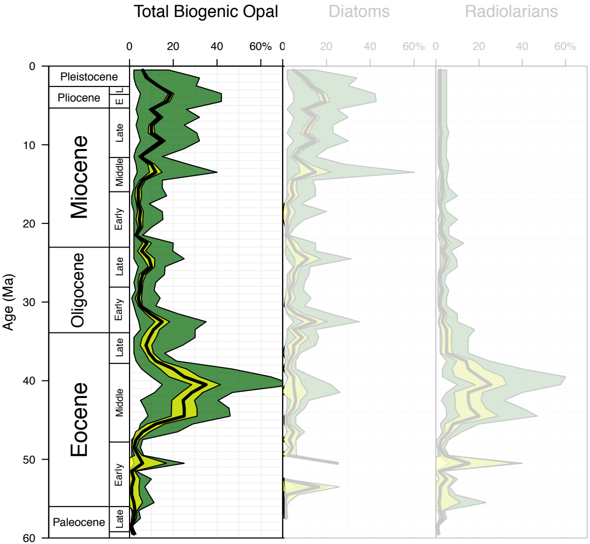
Radiolarian/Diatom competition for silicon availability (Harper & Knoll 1975; Lazarus *et al.* 2009)

From Renaudie 2016.

Siliceous microfossils in the Marine Silicon Cycle



Cenozoic changes in diatom abundance in sediments



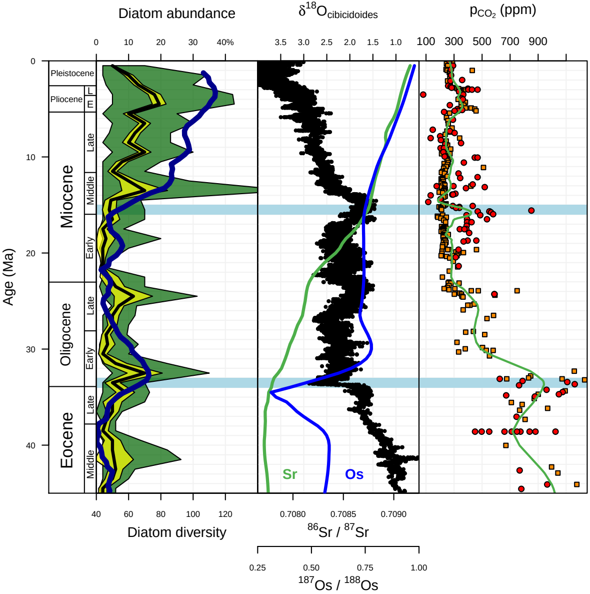
Switch from radiolarian-based to diatom-based silica deposition at the end of the Eocene.

Radiolarian/Diatom competition for silicon availability (Harper & Knoll 1975; Lazarus *et al.* 2009)

Global biogenic silica abundance curve should fluctuate in sync with changes in amount of weathered Si.

From Renaudie 2016.

Cenozoic changes in diatom abundance in sediments



Middle Miocene event, concordant with Himalayan erosion.

Late Eocene-early Oligocene event, concordant with East Antarctic ice-sheet formation.

From Renaudie 2016; with data from Zachos *et al.* 2008; Beerling & Royer 2008; Ravizza & Zachos 2003

Polar Oceans, Plankton and Oceanic Carbon Sequestration in a warm high p_{CO_2} world (DAAD MOPGA-GRI)

Tectonic drives changes in ocean circulation & increases in weathering
$\rightarrow$ increased polar ocean areal extent & nutrients
$\rightarrow$ polar diatom diversify & increase in abundance
$\rightarrow$ increases in global plankton export productivity
$\rightarrow$ drawdown of p_{CO_2}.

Questions:

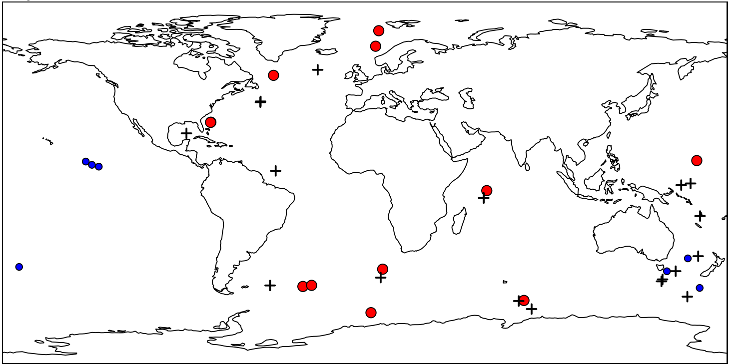
1. How much did the Southern Ocean increase in areal extent between the Eocene and Oligocene?
2. How did ocean export productivity change between the Eocene and Oligocene?
3. What effect did these changes in polar ocean environments have on the evolution of species of siliceous plankton?

DAAD

MAKE OUR PLANET GREAT AGAIN

Polar Oceans, Plankton and Oceanic Carbon Sequestration in a warm high p_{CO_2} world (DAAD MOPGA-GRI)

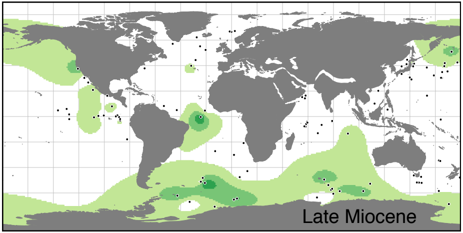
- Focus on 40-25 Ma interval to get the before and after picture as well as the events themselves.
- Radiolarian biogeography to identify areal extent of the Southern Ocean biota.
- Geochemical proxy measurements (δ^{18}O and δ^{13}C on planktic and benthic forams, P accumulation rates, BFAR, etc.) as temperature and productivity control points



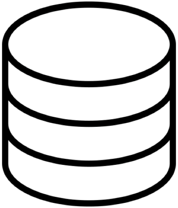
Polar Oceans, Plankton and Oceanic Carbon Sequestration in a warm high p_{CO_2} world (DAAD MOPGA-GRI)

- Focus on 40-25 Ma interval to get the before and after picture as well as the events themselves.
- Radiolarian biogeography to identify areal extent of the Southern Ocean biota.
- Geochemical proxy measurements ($\delta^{18}O$ and $\delta^{13}C$ on planktic and benthic forams, P accumulation rates, BFAR, etc.) as temperature and productivity control points
- Diatom accumulation rate and diatom diversity based on full diatom floral data (also $\delta^{30}Si$ on diat/rads?)
- Literature-based, global compilation of $BSiO_2$ and $CaCO_3$ accumulation rates (using NSB age model library).
- All of that integrated in or compared with climate/ocean modeling results (cooperation with Georg Feulner at PIK).

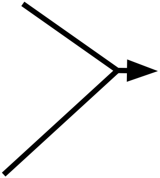
Next step for quantification of diatom abundance



Geographical pattern of diatom abundance as "model" and regional %Diatom vs sum of siliceous fossils



Database of published MAR $BSiO_2$ measurements



Gridded maps of Diatom MAR per Myr

Conclusions

- Diatom diversity history tightly tied to climate history, with a significant proportion of modern species appearing since last cooling event, in the polar biome.
- Diatom abundance peaks correlates with changes in silicate weathering regime and drops in atmospheric CO2:
  - strong control of silica input on diatom abundance;
  - diatom-led biological pump affects atmospheric pCO2 on a geological timescale.
- Diatom took over marine silica cycle at Eocene/Oligocene boundary.
- Current research is focussed on testing quantitatively the "tectonically-enhanced weathering rate $\rightarrow$ enhanced diatom abundance $\rightarrow$ p_{CO_2} drop" model during the late Eocene-early Oligocene events.

Thanks for listening.

And thanks to my collaborators:

David Lazarus, Gayane Asatryan, Volkan Özen, Gabriella Rodrigues de Faria & Sylvia Salzmann, Museum für Naturkunde, Berlin
Robert Wiese, Freie Universität, Berlin
Patrick Diver, Divdat consulting, US
John Barron, United States Geological Survey
Andreas Türke, University of Bremen
Effi-Laura Drews & Simon Böhne, University of Bonn

Access to the Neptune Database website:
`http://nsb-mfn-berlin.de`
Username: guest
Password: arm_aber_sexy