

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

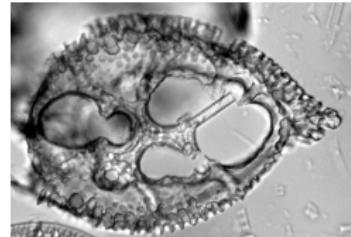
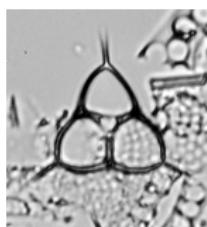
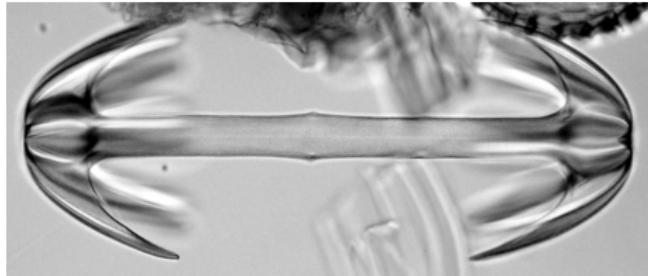
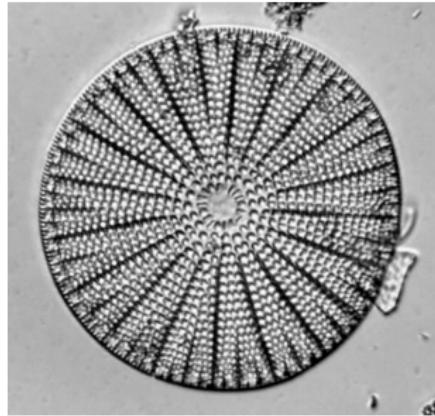
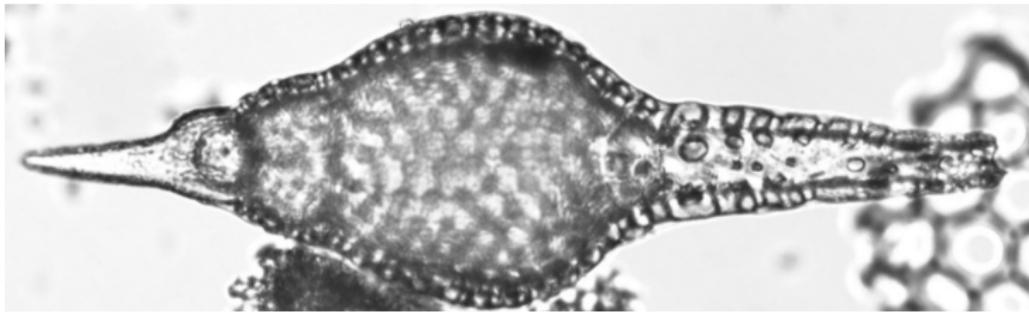
Johan Renaudie
Museum für Naturkunde
23.07.2019



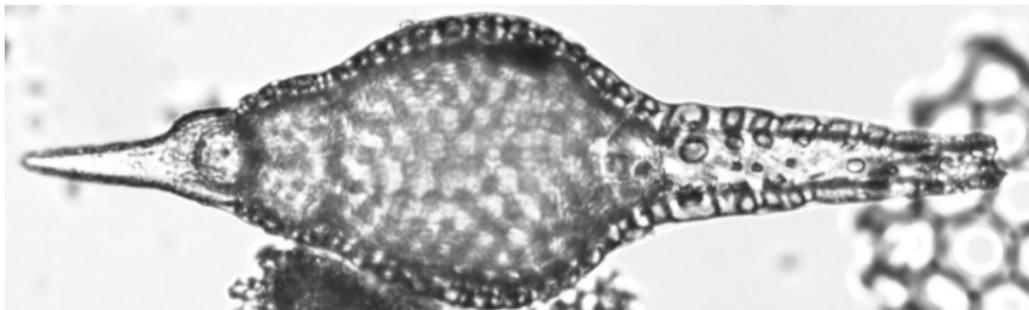
Outline

- 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



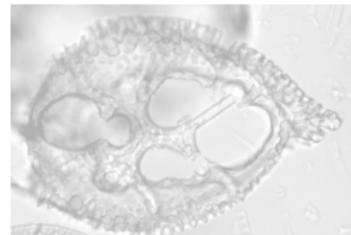
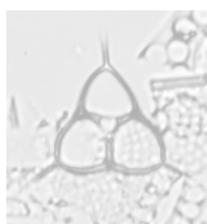
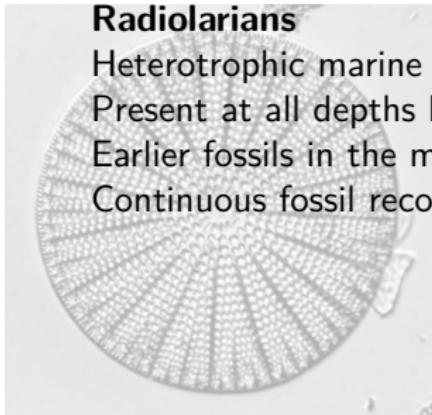
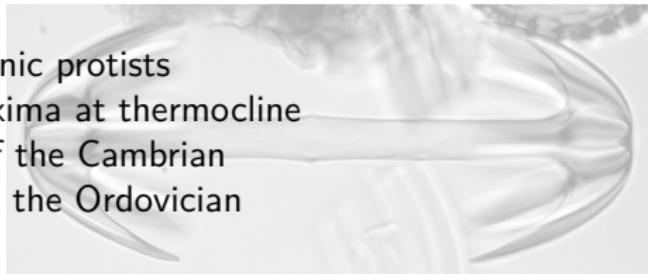
Radiolarians

Heterotrophic marine planktonic protists

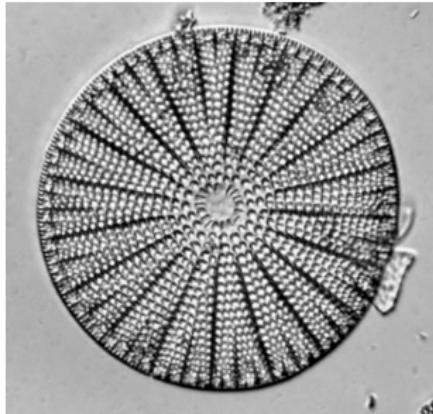
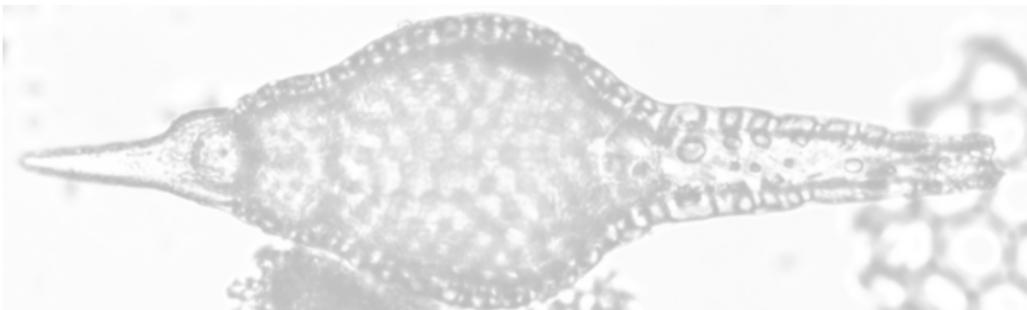
Present at all depths but maxima at thermocline

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

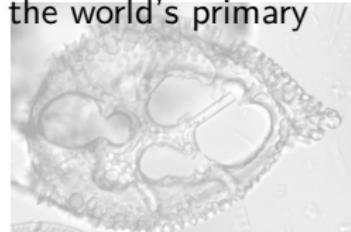
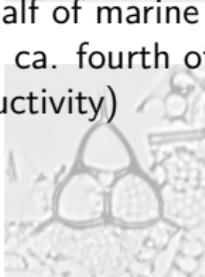
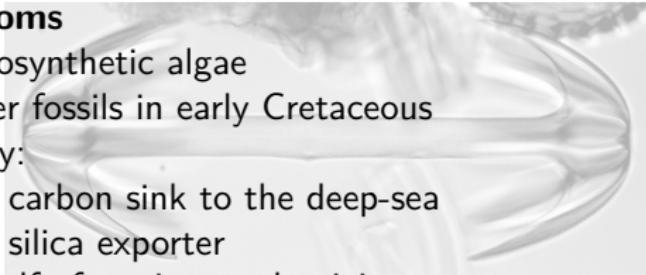
Today:

main carbon sink to the deep-sea

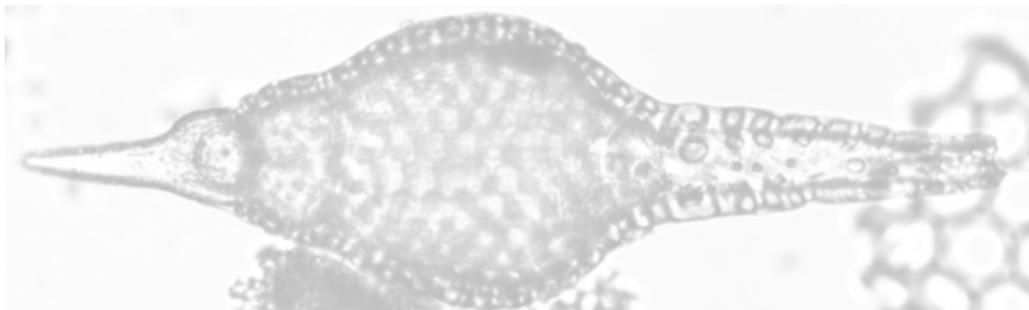
main silica exporter

ca. half of marine productivity

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



Siliceous microfossils and their fossil record

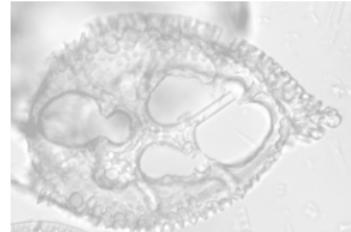
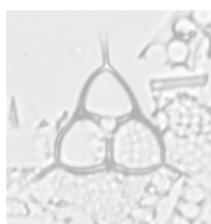
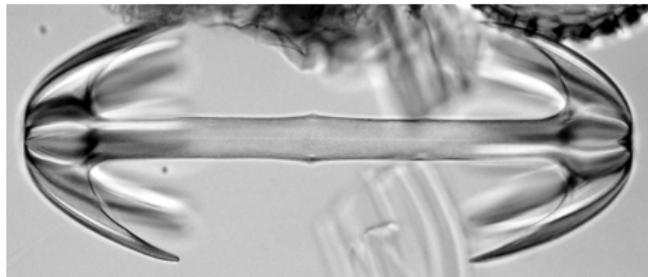
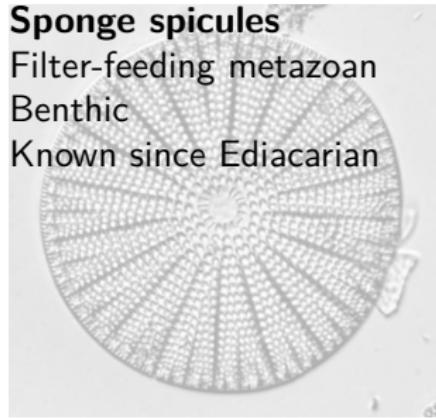


Sponge spicules

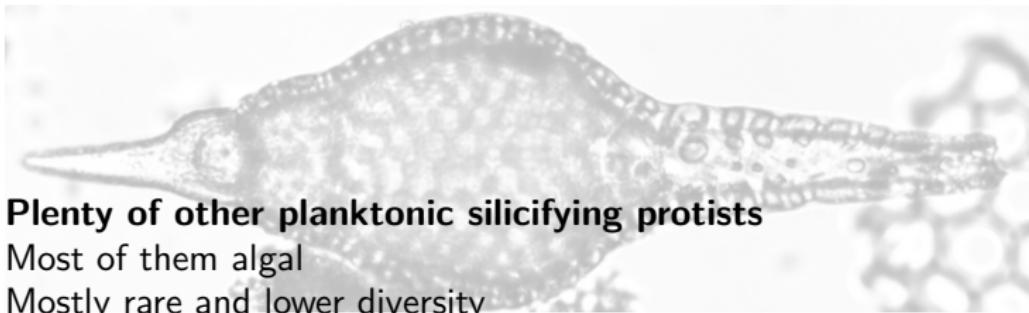
Filter-feeding metazoan

Benthic

Known since Ediacaran



Siliceous microfossils and their fossil record

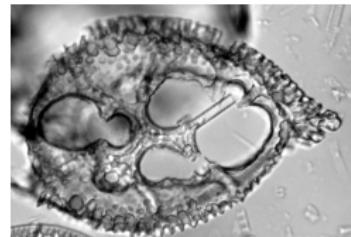
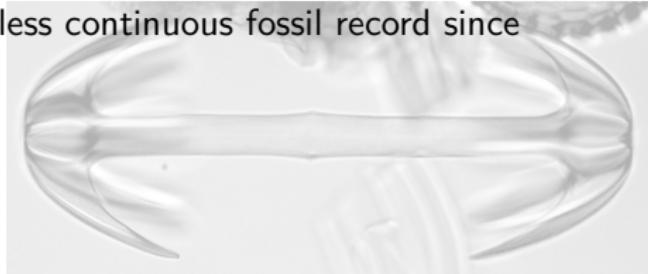
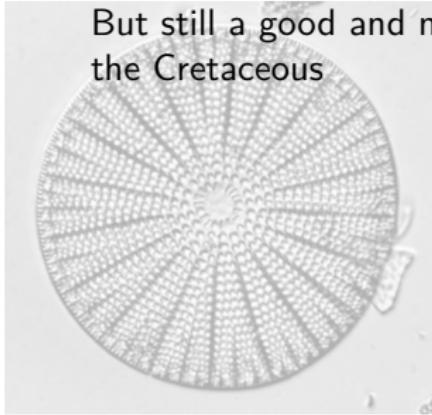


Plenty of other planktonic silicifying protists

Most of them algal

Mostly rare and lower diversity

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

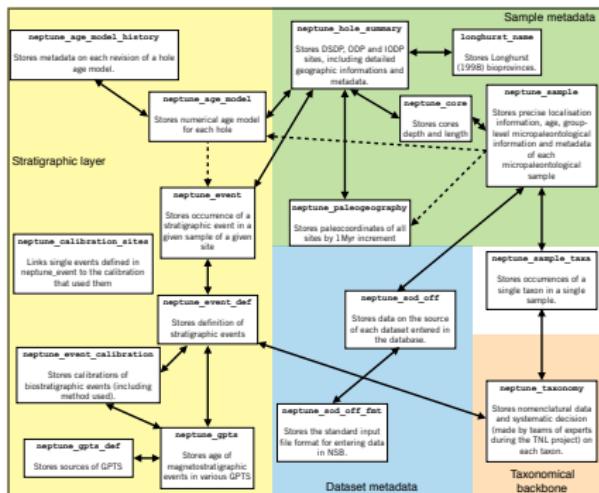


The Neptune (NSB) Database

The screenshot shows the Neptune SB Berlin database homepage. On the left, there's a sidebar with links: Neptune Sandbox Berlin, About, Help, Search the database, Downloaded datasets, and Recent Changes. Below these are logos for the Leibniz Institute for Natural Resource Sciences and the German Research Foundation (DFG). The main area has a search bar with fields for Fossil group (Dolines), Time span (start and end dates), Ma (Age), Ocean (Northern or Southern Ocean), and Log (Site ID). There are also dropdowns for Genus, Species, and Ecological Province. Below the search bar are several checkboxes for filtering results based on taxonomy, questionable identifications, open-temperament taxa, problematic samples, age scale, and quality loss. At the bottom, it says "You are currently logged in as Renaudie. Log Out | Search".

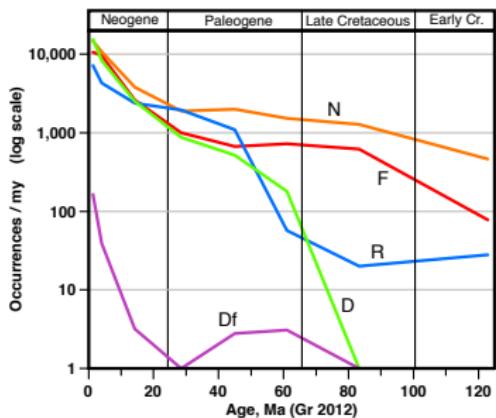
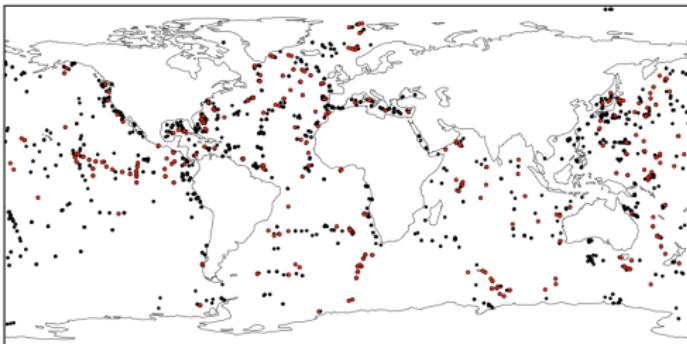
Micropaleontological occurrences in deep-sea drilling record with a complex stratigraphic layer allowing reliable and precise numerical age for most sample

Exists since 1994
Modern implementation is NSB
(<http://nsb-mfn-berlin.de>)



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

Neptune Sandbox Berlin

About Help Search the database Downloaded datasets Recent Changes

Neptune SB Berlin

Search an age model

Age model ID: 11189 Scale: Gruber et al. 2012

You are currently logged in as Renselius. Log Out | Search.

Revision 0

Interpreted by: Renselius Date: April 13, 2013

Age Quality: G Currently used in NSB Y

Remarks: Best fit dL 2.17. Excellent model since 2012. Backman et al. 2014 (ODP leg 35R vol 1c, 197-201 m) uses R magnetic. M disagrees with backfit between 200 and 300 mrefl.

Hole	Age (Ma)	Depth (mrefl)	Comment
1338A	0.000000	0.000	None
1338A	0.000000	1.25	None
1338A	1.185197	1.917	None
1338A	1.763765	21.207	None
1338A	2.574965	31.568	None
1338A	3.19487	37.853	None
1338A	3.530305	40.968	None
1338A	3.669907	43.837	None
1338A	4.180197	51.688	None
1338A	4.539495	54.455	None
1338A	5.024		

Librarius

2013 Inter-Results

Neptune Sandbox Berlin

About Help Search the database Downloaded datasets Recent Changes

Neptune SB Berlin

Search an event calibration

Event ID: 1073 Calibration ID: 900 Scale: Gruber et al. 2012

You are currently logged in as Renselius. Log Out | Search.

Event ID	Calib. ID	Type	Event Name	Group	Age	Geographical location	Source	Calibration	Original Scale	Comments
1073	101	8262	Benthic forams	N	0.3	global	Sergien et al. 2012	M	Renggli	ODP Technical Note 2a
1073	174	900	Benthic forams	N	0.29	global	Backman et al. 2012	G	Gratiotis	

All ages given here are Gratiotis et al. 2012 scale.

This event has been found in the following sites:

Event ID	Hole	Sample ID	Depth (mrefl)	Age	Geographical location	Source event	Comment			
1073	101	8262	5-14.0	38.90	"	101_8262	5-14.0	48.07	"	RBCF_fe_benthos
1073	104	8428	2-4.05	13.15	"	104_8428	2-4.05	16.07	"	Density 1989
1073	106	8444	1-1.5	1.58	"	106_8444	1-1.5	1.58	"	GRATIOTIS 2012
1073	106	8444	1-1.50	28.20	"	106_8444	1-1.50	27.70	"	GRATIOTIS 2012
1073	105	8444	2-5.02	12.02	0.016	105_8444	2-5.02	12.02	0.016	GRATIOTIS 2012
1073	105	8444	2-5.02	12.03	0.016	105_8444	2-5.02	12.03	0.016	GRATIOTIS 2012
1073	105	8444	2-5.02	12.03	0.016	105_8444	2-5.02	12.03	0.016	GRATIOTIS 2012
1073	102	8514	8-17	1.17	"	102_8514	8-17	1.17	"	GRATIOTIS 2012
1073	102	8514	8-17	84.42	"	102_8514	8-17	84.42	"	GRATIOTIS 2012

Used for calibration of hole 101

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

Neptune Sandbox Berlin

About Help Search the database

Neptune SB Berlin

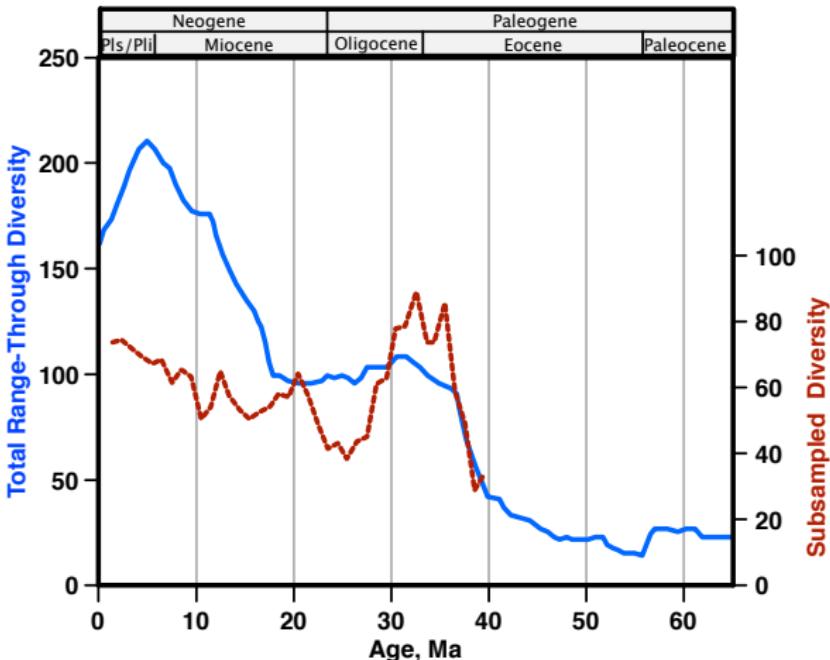
Search for stratigraphic events

Hole: 101 Scale: Gruber et al. 2012

You are currently logged in as Renselius. Log Out | Search.

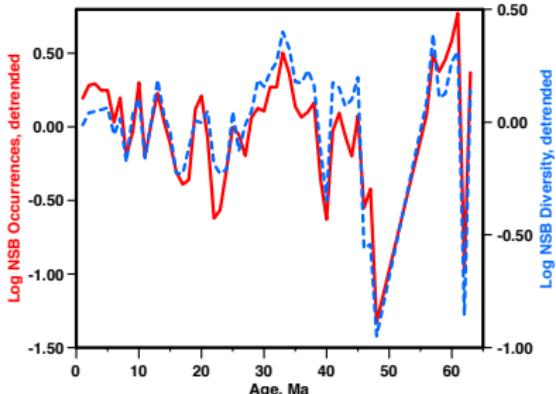
Type	Event Name	Sample (Top)	Sample (Bottom)	Depth ref (Top)	Depth ref (Bottom)	Age max	Age min	Source event	Source calibration	Comments
M10P	SLAn_1n	S26_1335a	S20_1335a	>1.25	>1.25	0.55	0.65	20.04	Expedition 320/321	Gratiotis et al. 2012
M10P	SLAn_1n	S26_1335a	S1-118	>1.115	>1.115	1.10	1.15	20.21	Expedition 320/321	Gratiotis et al. 2012
M10P	SLAn_2n	S26_1335a	S20_1335a	>2.50	>2.50	2.00	2.18	20.44	Expedition 320/321	Gratiotis et al. 2012
M10T	Stichotaxis dentimensis	S26_1335a	S2-1704	>1-2.104	>1-2.104	3.54	5.54	20.8	Expedition 320/321	Gratiotis et al. 2012
M10T	Stichotaxis dentimensis	S26_1335a	S20_1335a	>1-2.104	>1-2.104	3.54	5.54	20.8	Expedition 320/321	Gratiotis et al. 2012
		S26_1335a	S20_1335a						Kaminski et al.	Used for age model revision 0

Cenozoic marine diatom diversity



Prior studies
(Cervato, 1999 and
Rabosky &
Sorhannus 2008)
conflict
Both based on NSB,
first is litteral reading
of fossil record,
second compensate
for sampling biases
and plenty of other
untested biases.

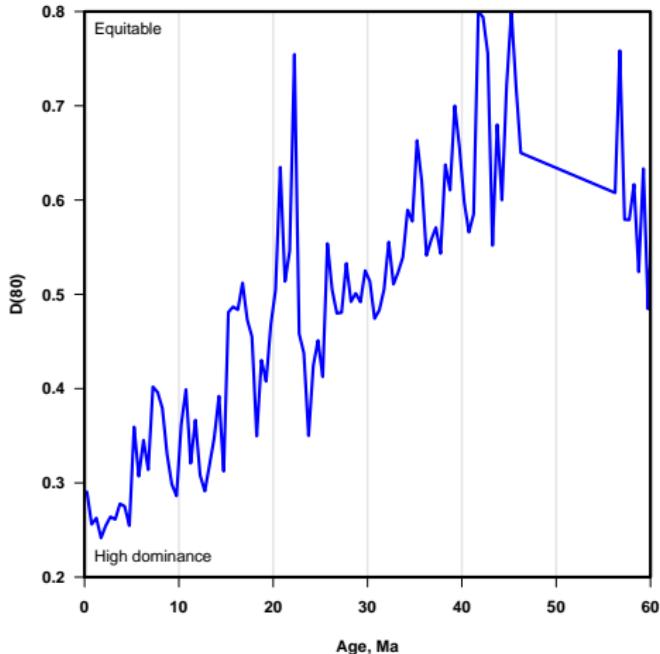
Cenozoic marine diatom diversity



Need to account for sampling bias and evenness/ubiquity bias in Neptune database

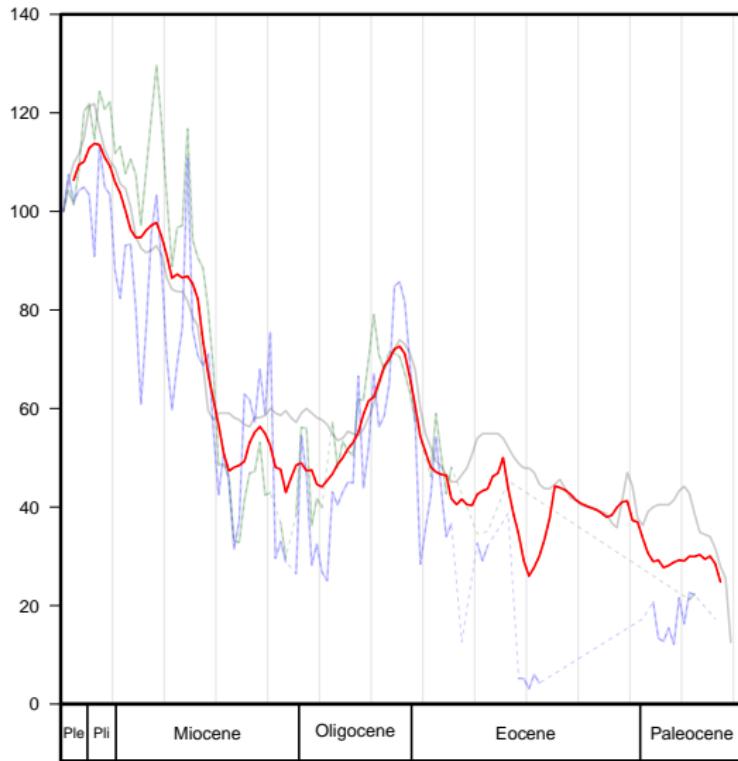
2 independant methods:

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



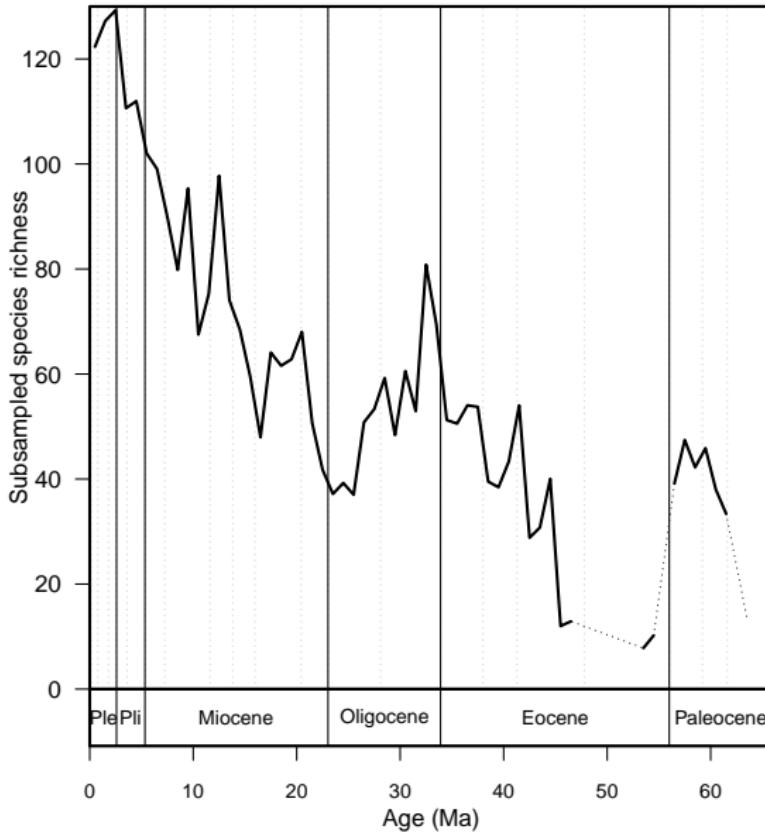
From Lazarus et al. 2014 (PLoS ONE).

Cenozoic marine diatom diversity



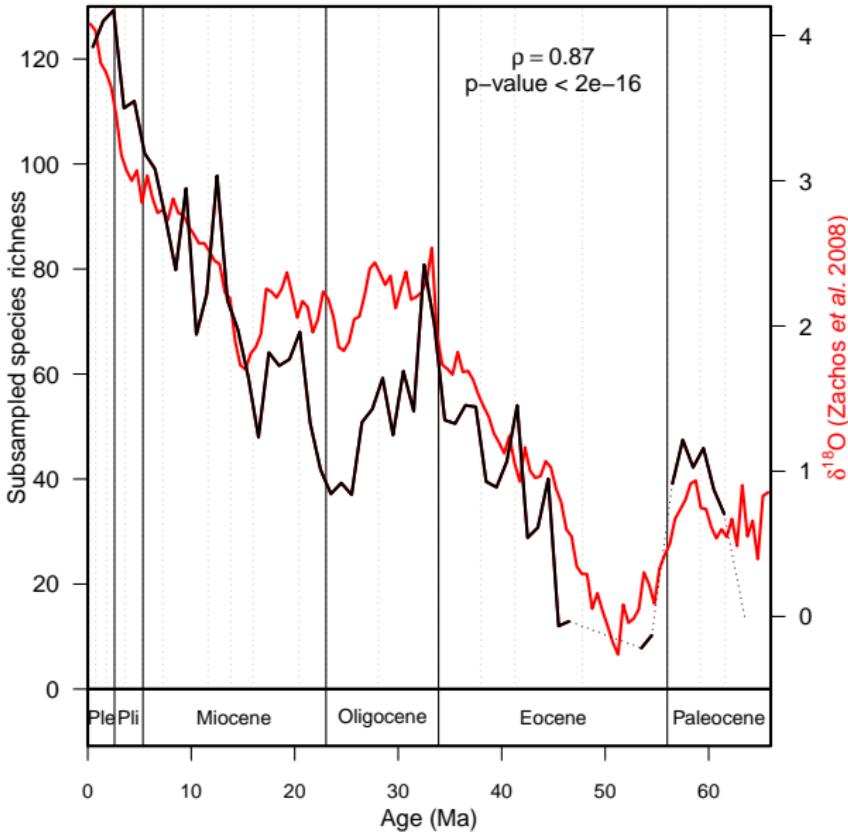
Also include a third reconstruction based on an independent catalog by John Barron, including a different (partly overlapping) set of sites.

Cenozoic marine diatom diversity



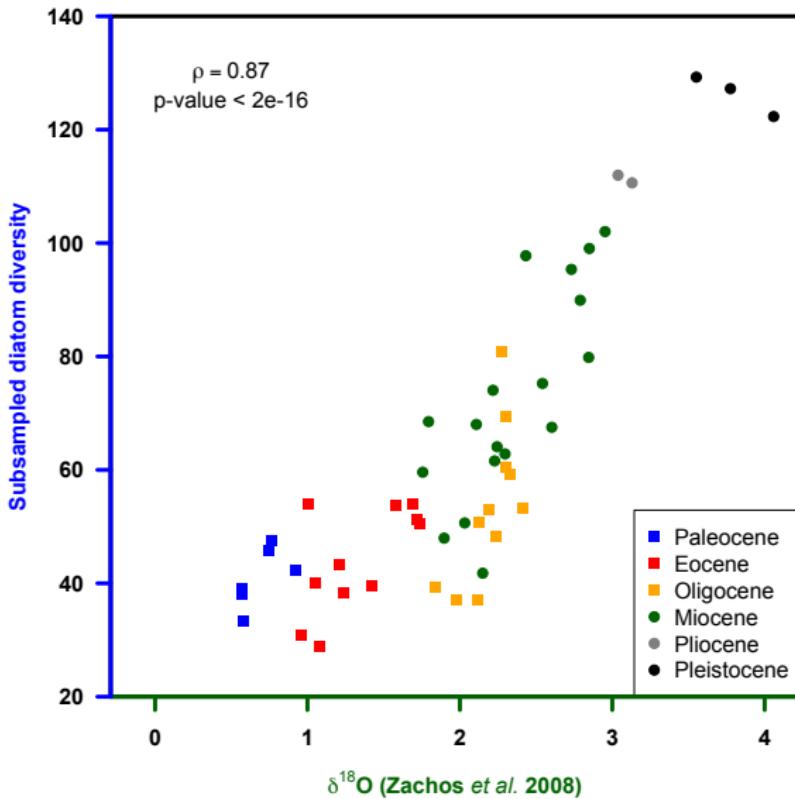
Modified from Renaudie et al.
2018 (Fossil Record).

Cenozoic marine diatom diversity



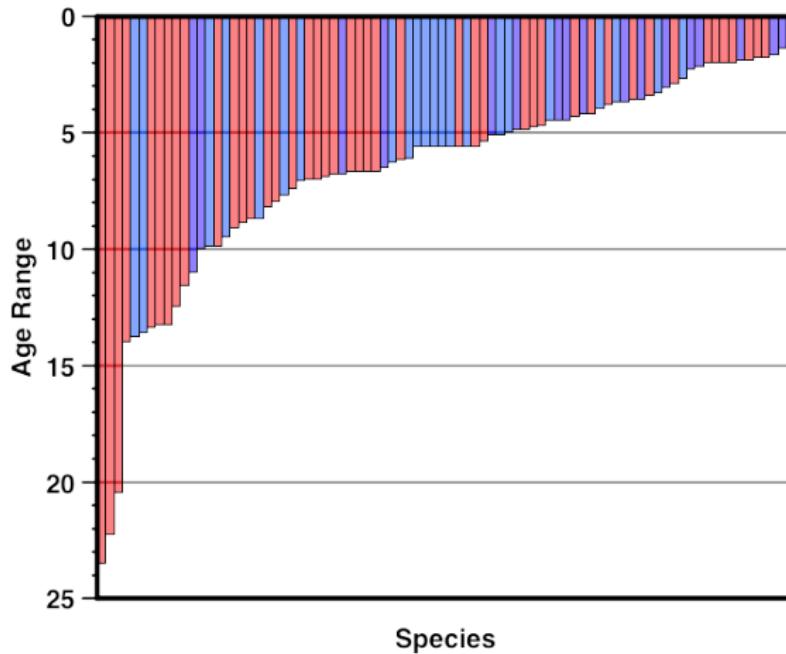
Latest update, with
newly collected data
for the
Paleocene-Early
Eocene.

Cenozoic marine diatom diversity



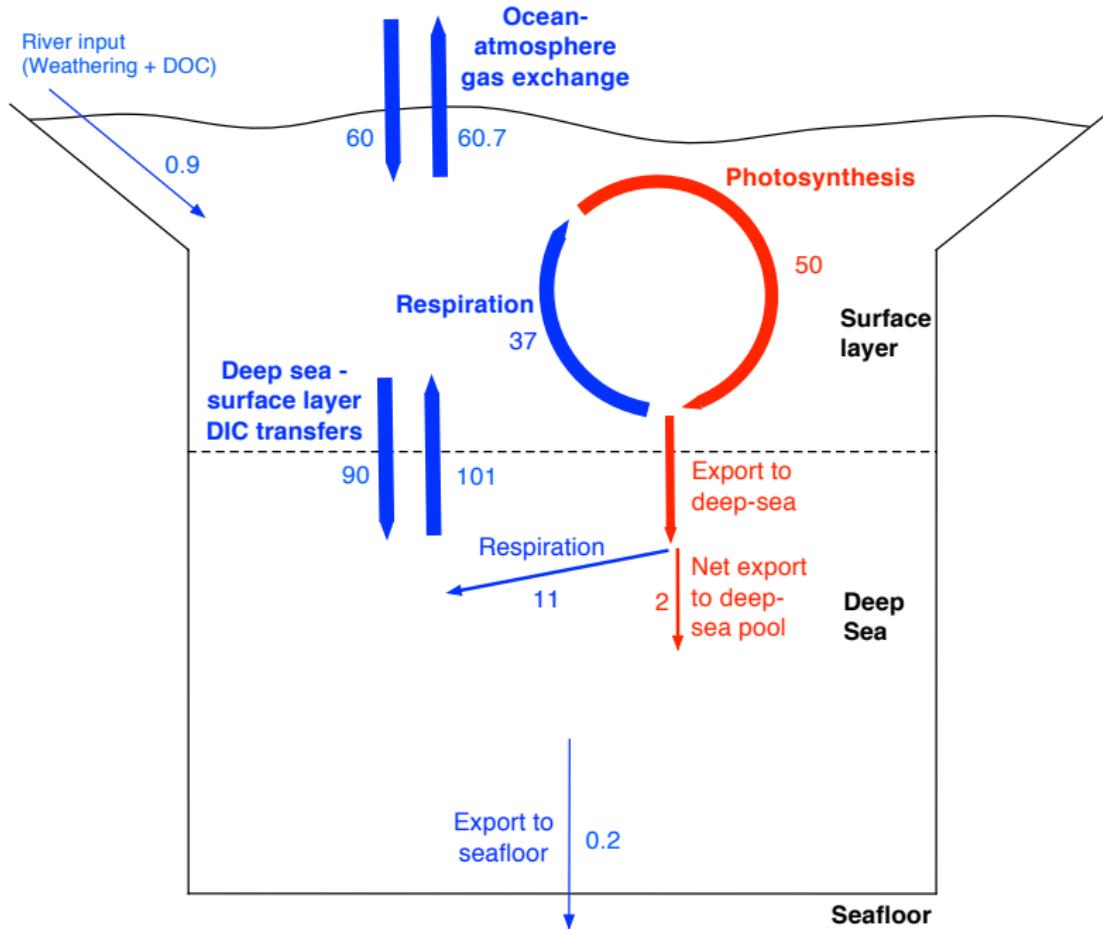
Very strong correlation with climate state:
Cold climate = Very diverse marine diatom
Warm climate = Low diversity

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

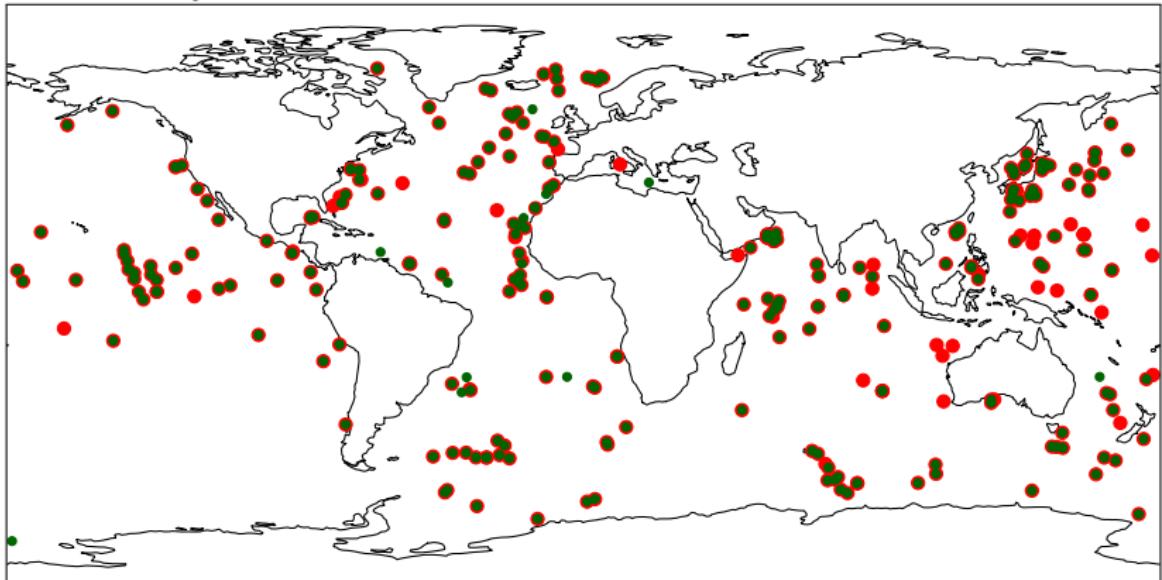
Diatoms in the Marine Carbon Cycle



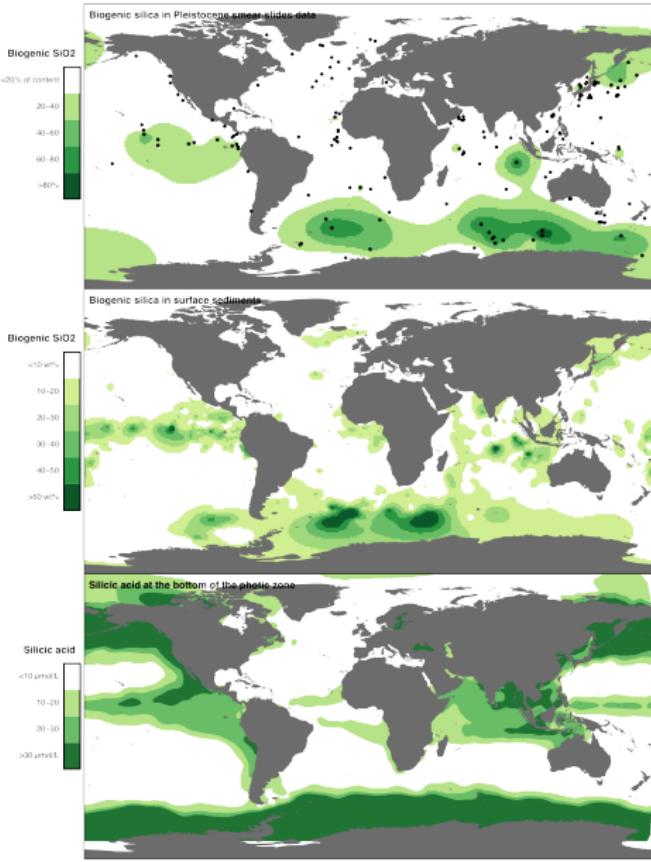
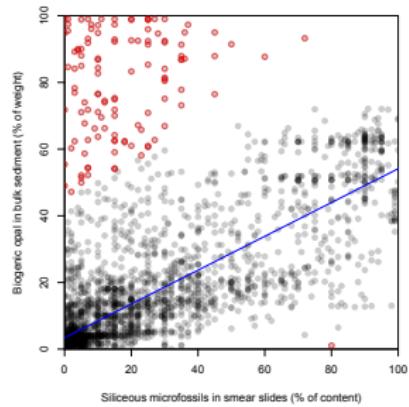
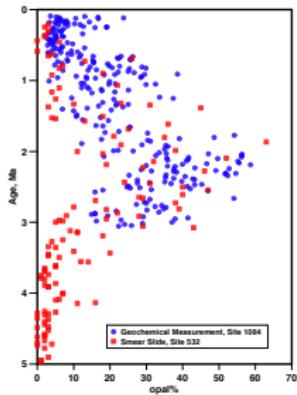
Cenozoic changes in diatom abundance in sediments

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

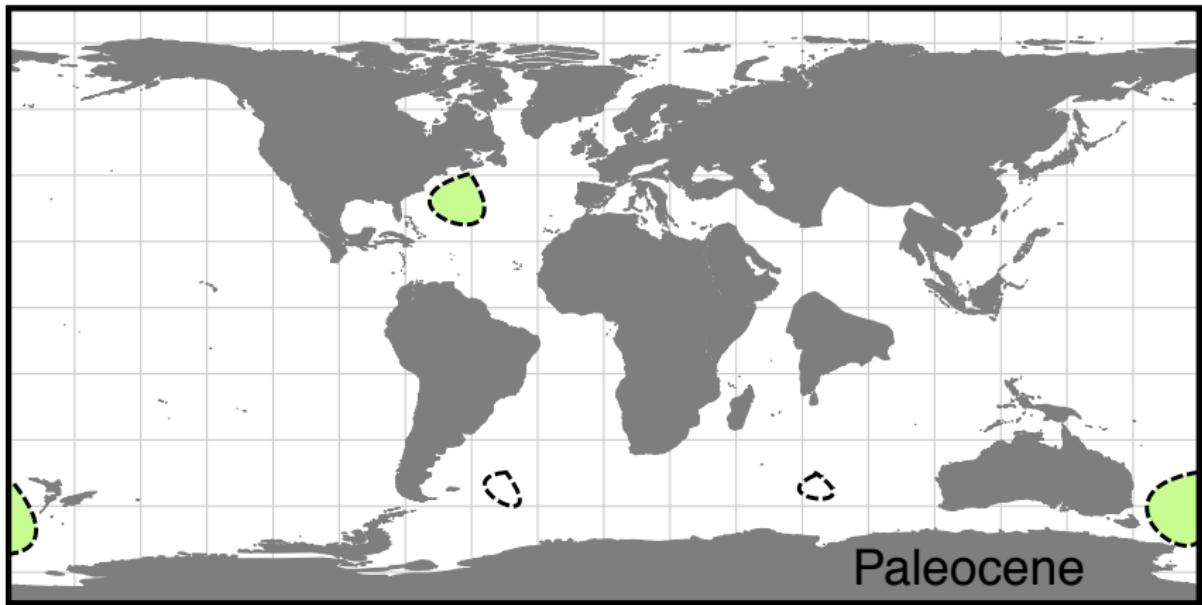
32k samples could be dated with reasonable accuracy using NSB age model library



Cenozoic changes in diatom abundance in sediments

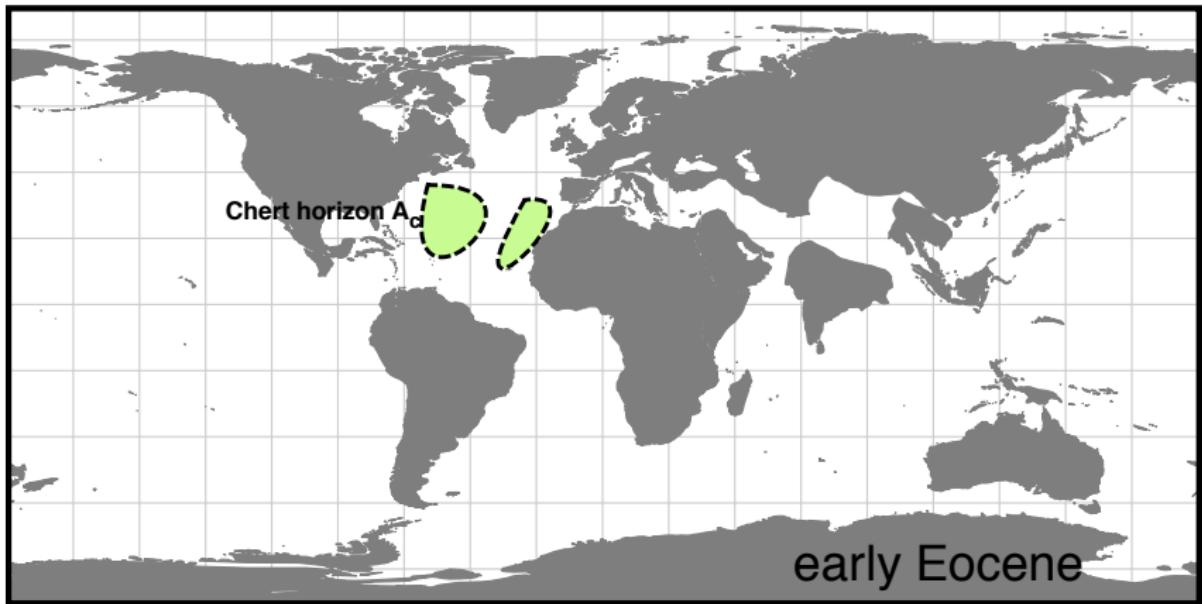


Cenozoic changes in diatom abundance in sediments



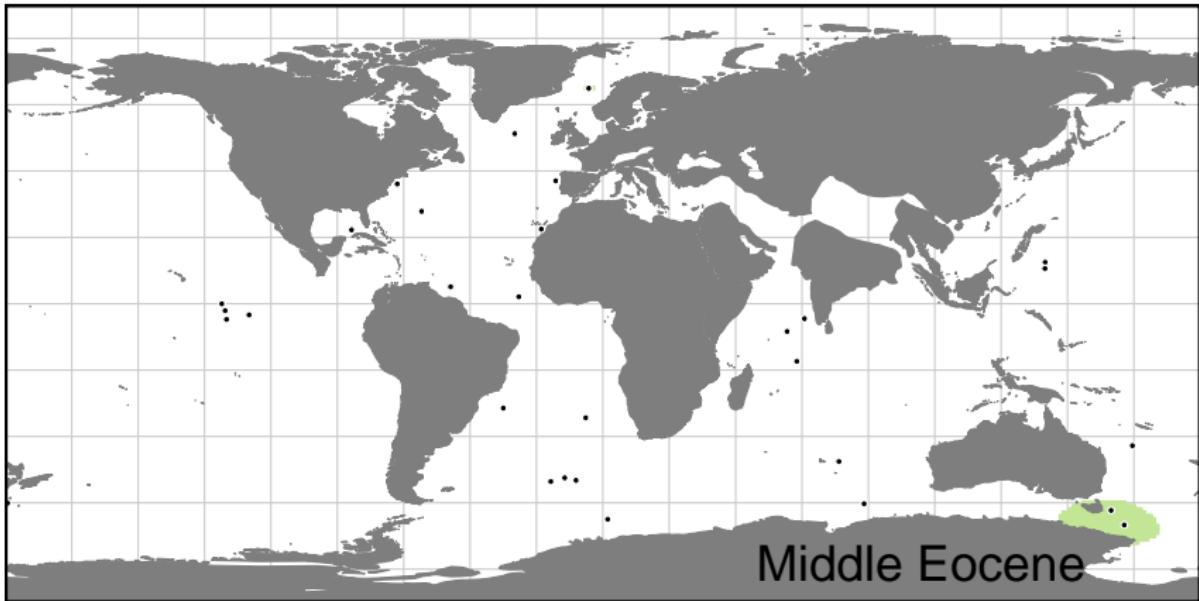
based on Renaudie *et al.* 2018

Cenozoic changes in diatom abundance in sediments



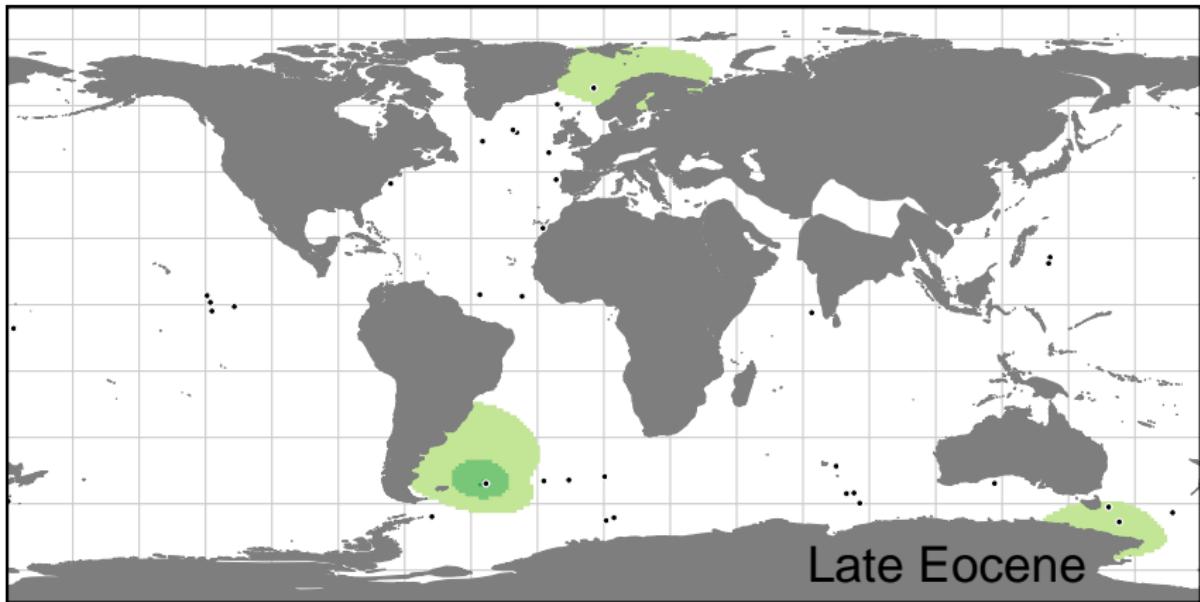
based on Muttoni & Kent 2008

Cenozoic changes in diatom abundance in sediments



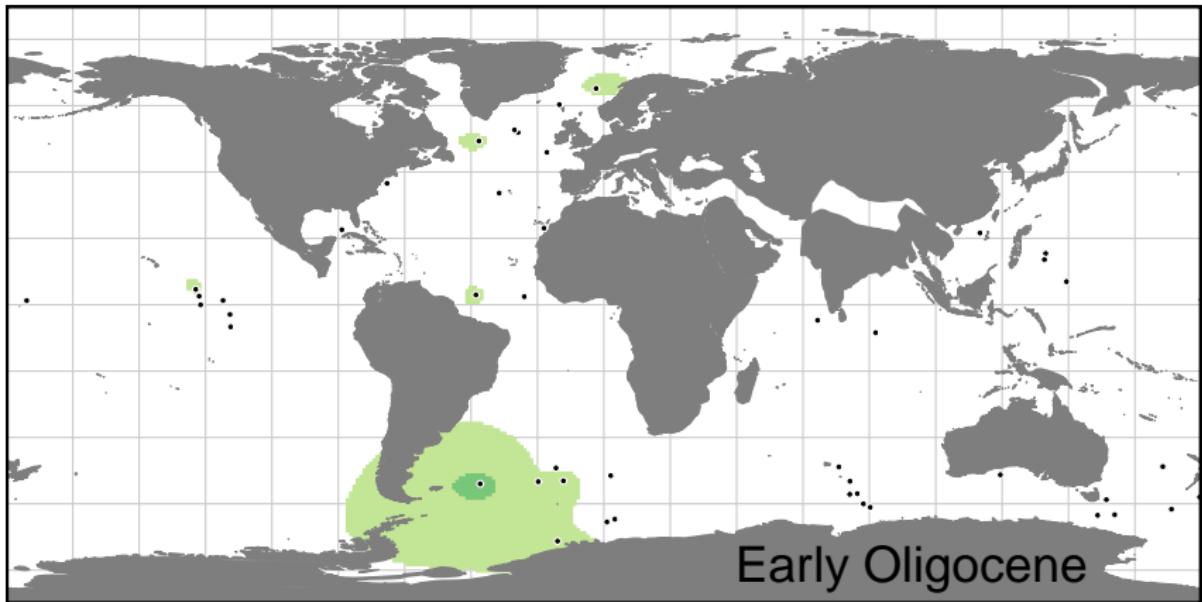
Start using smear slide analysis from that point on.
Ordinary Kriging based on logistic distance model.

Cenozoic changes in diatom abundance in sediments



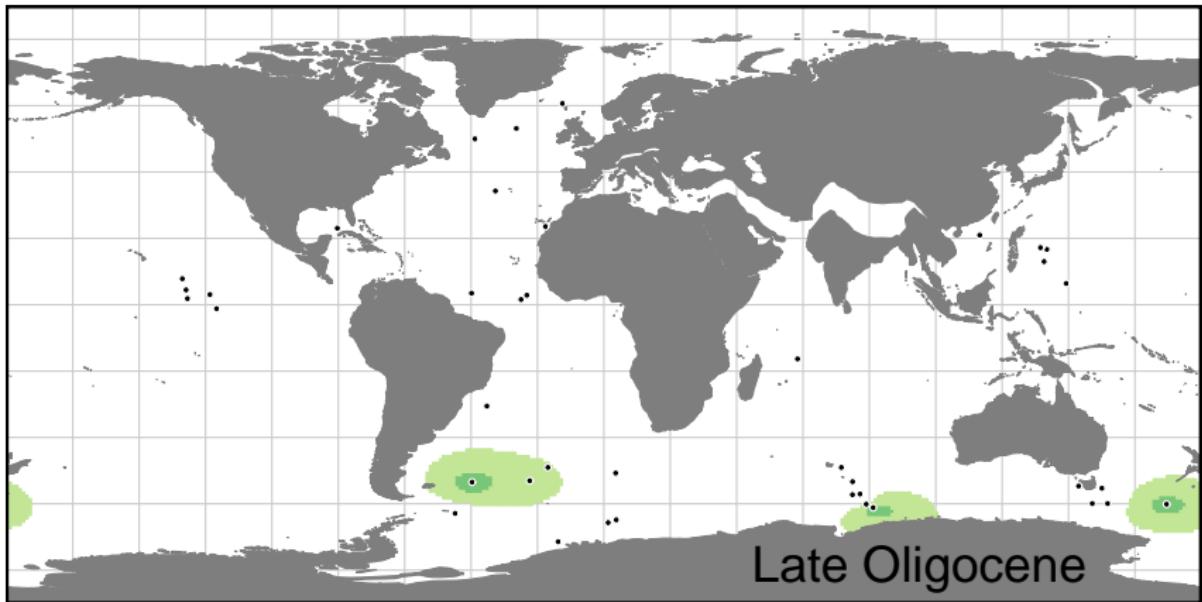
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



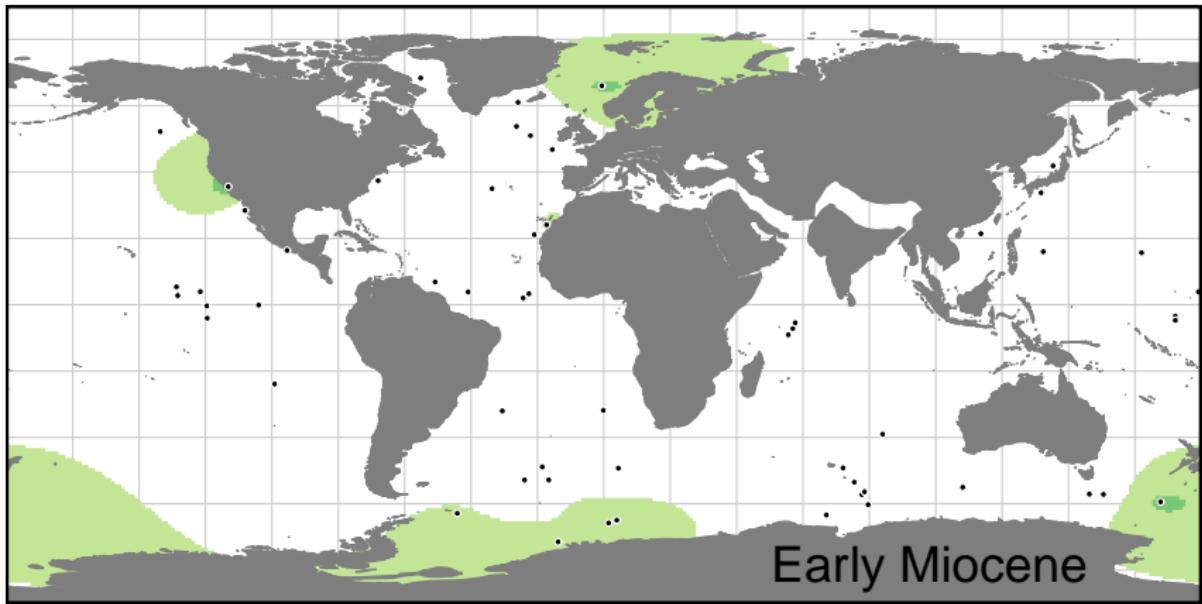
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



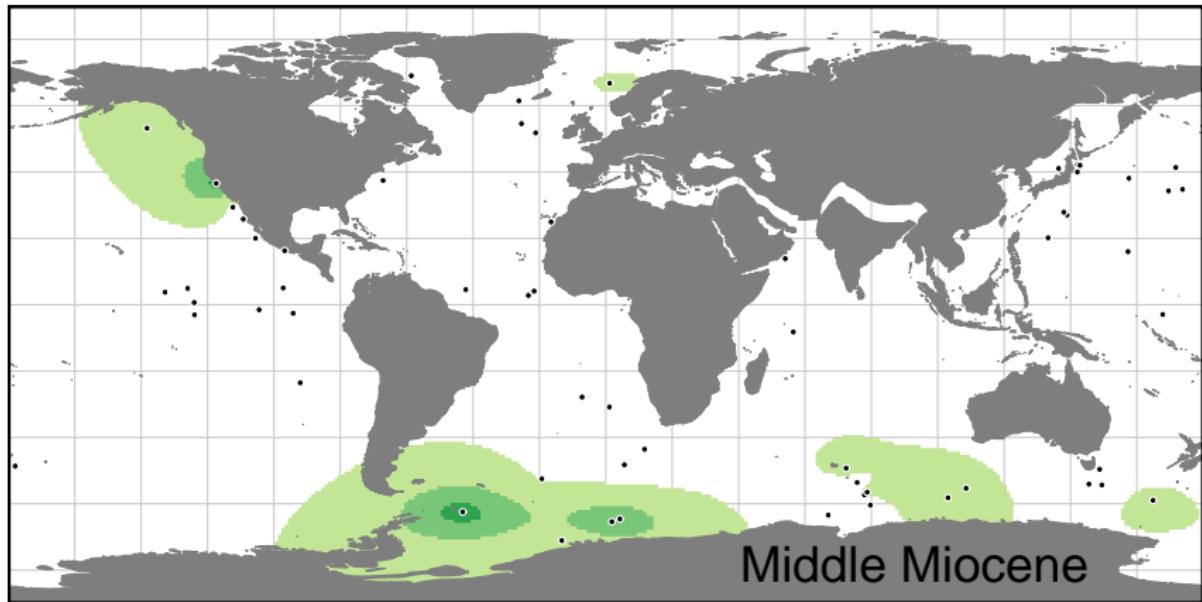
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



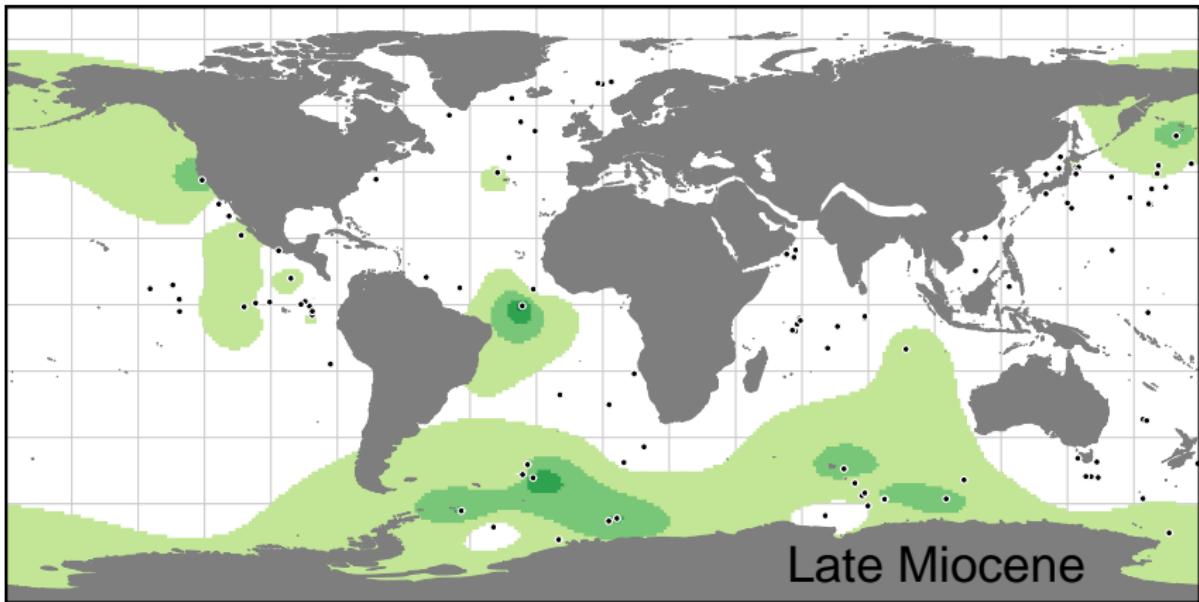
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



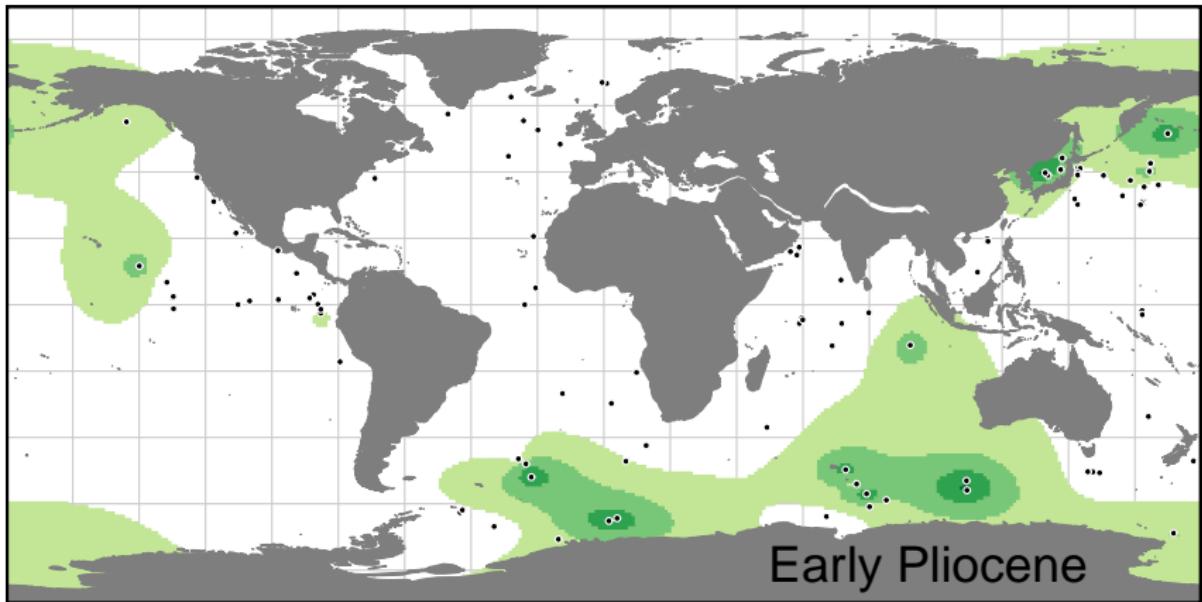
Onset of the “Silica Switch” (Keller & Barron 1983)

Cenozoic changes in diatom abundance in sediments



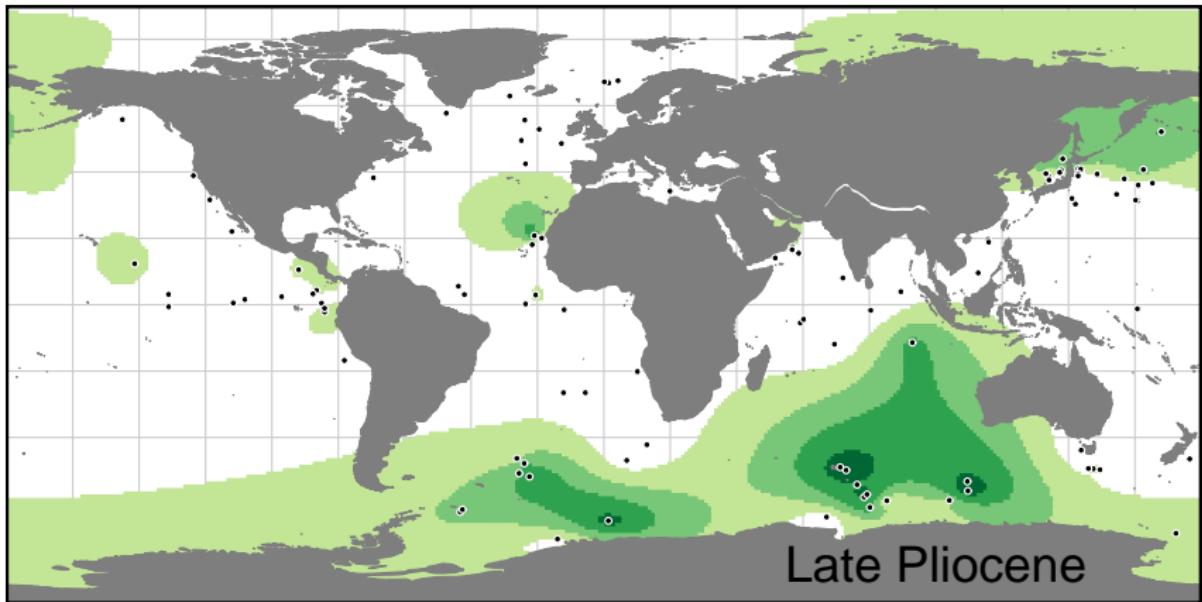
Onset of mid-latitude upwelling zones from Late Miocene onwards.

Cenozoic changes in diatom abundance in sediments



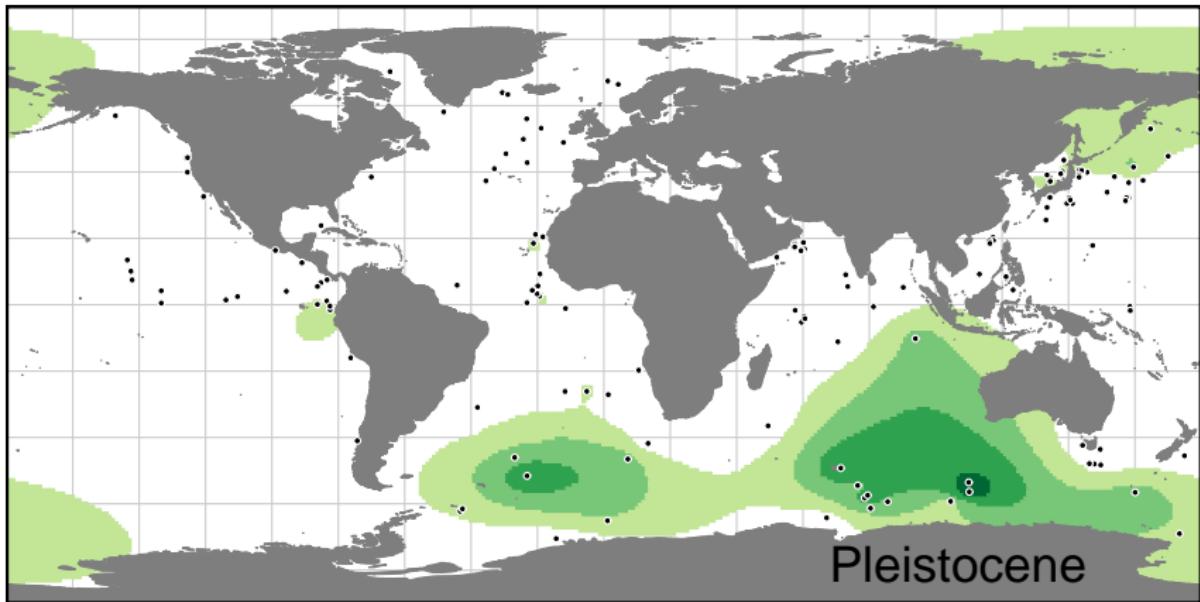
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



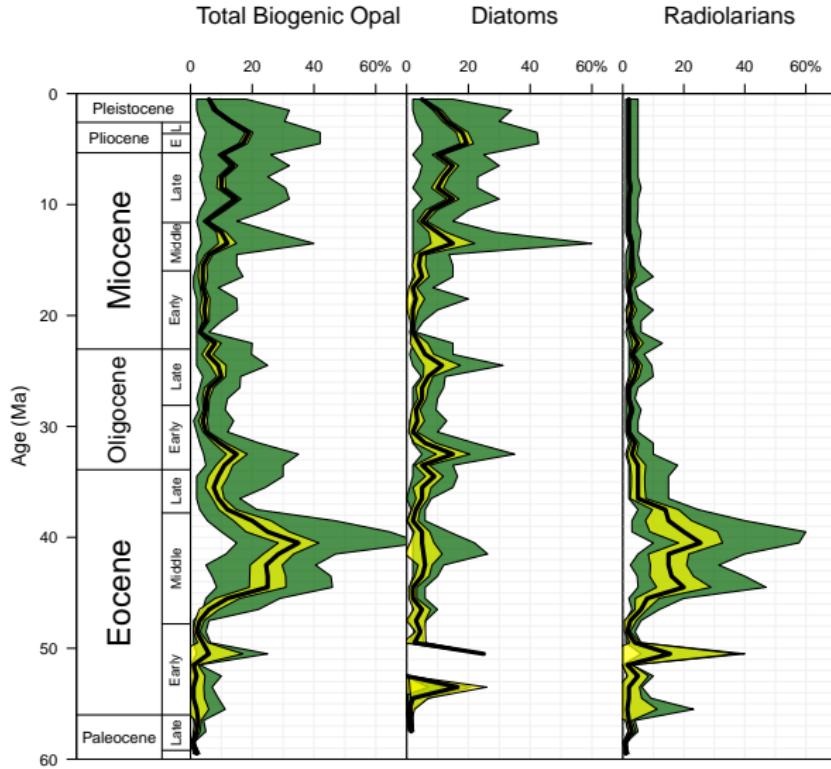
modified after Renaudie 2016

Cenozoic changes in diatom abundance in sediments



modified after Renaudie 2016

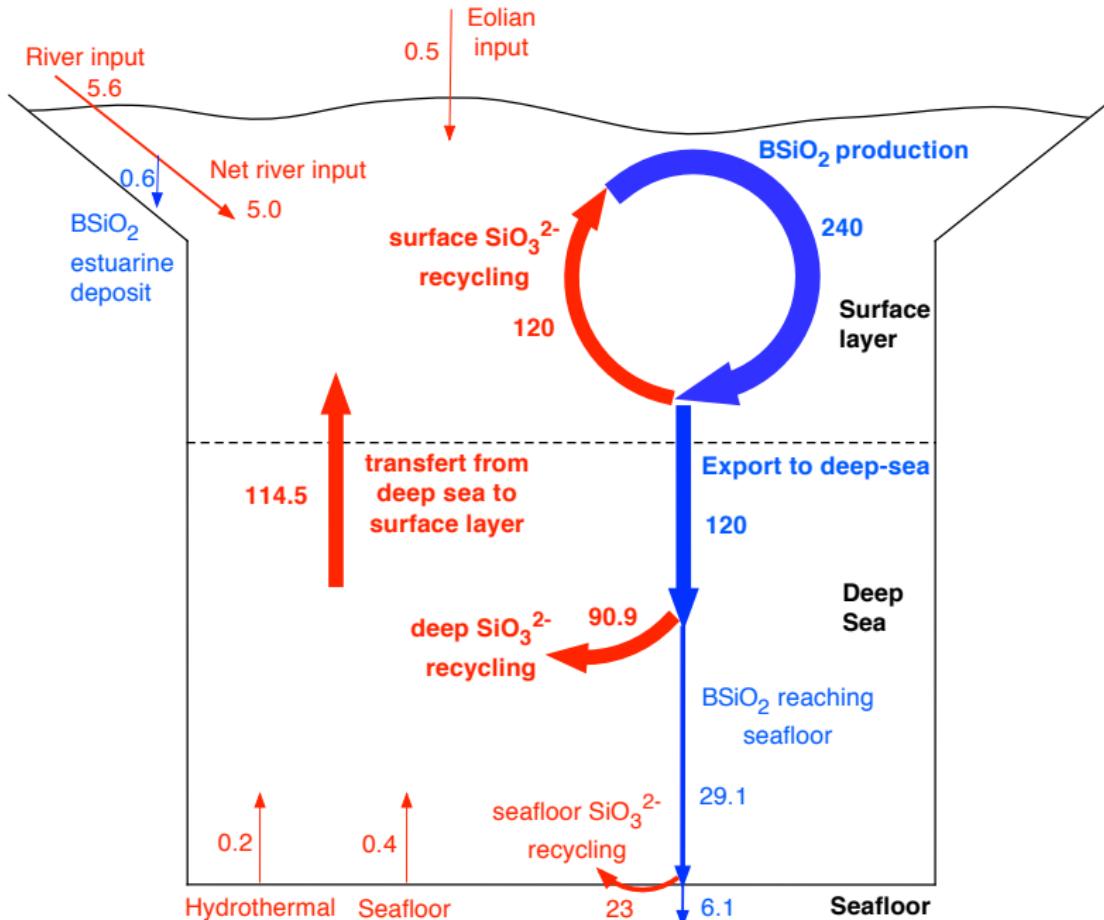
Cenozoic changes in diatom abundance in sediments



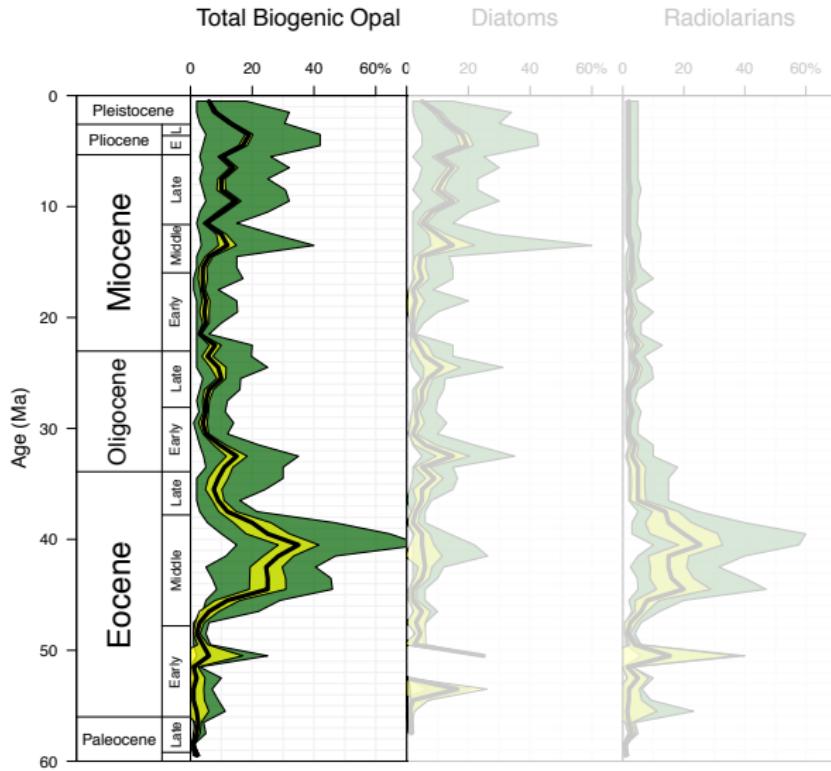
Switch from radiolarian-based to diatom-based silica deposition at the end of the Eocene.

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

Siliceous microfossils in the Marine Silicon Cycle



Cenozoic changes in diatom abundance in sediments

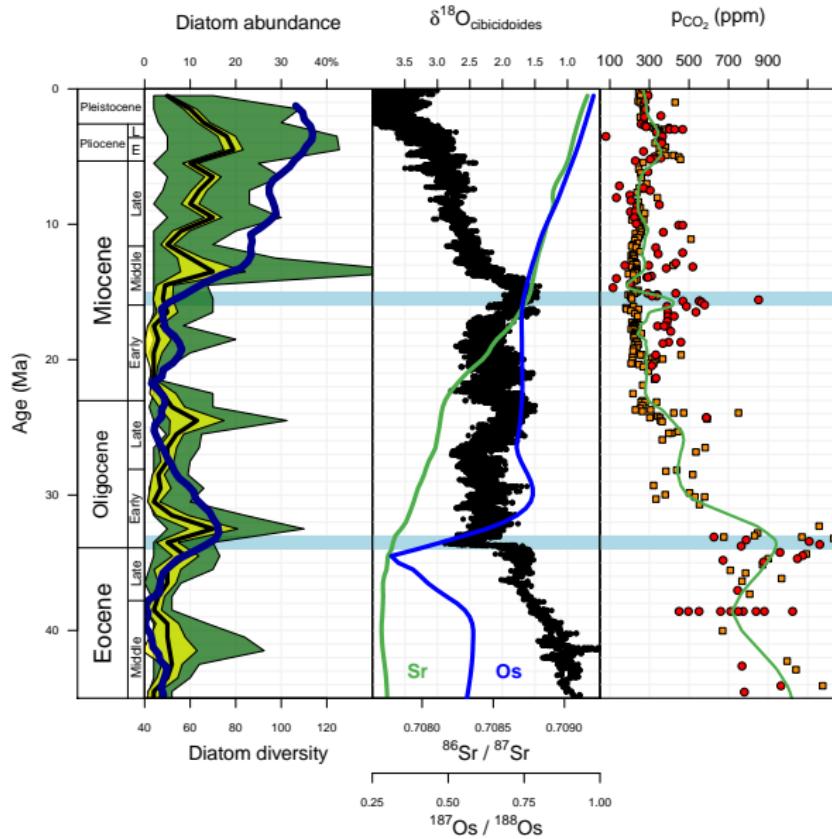


Switch from radiolarian-based to diatom-based silica deposition at the end of the Eocene.

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.

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.

Polar Oceans, Plankton and Oceanic Carbon Sequestration in a warm high $p\text{CO}_2$ world (DAAD MOPGA-GRI)

Tectonic drives changes in ocean circulation & increases in weathering
→ increased polar ocean areal extent & nutrients
→ polar diatom diversify & increase in abundance
→ increases in global plankton export productivity
→ drawdown of $p\text{CO}_2$.

Questions:

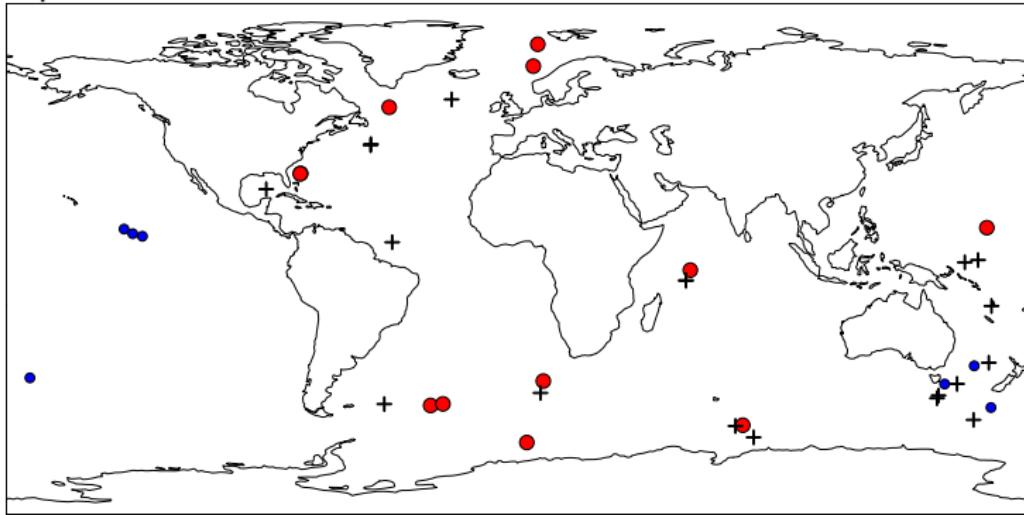
1. How much did the Southern Ocean increase in areal extent between the Eocene and Oligocene?
2. How did ocean export productivity change between the Eocene and Oligocene?
3. What effect did these changes in polar ocean environments have on the evolution of species of siliceous plankton?

DAAD

**MAKE OUR
PLANET
GREAT AGAIN**

Polar Oceans, Plankton and Oceanic Carbon Sequestration in a warm high pCO₂ world (DAAD MOPGA-GRI)

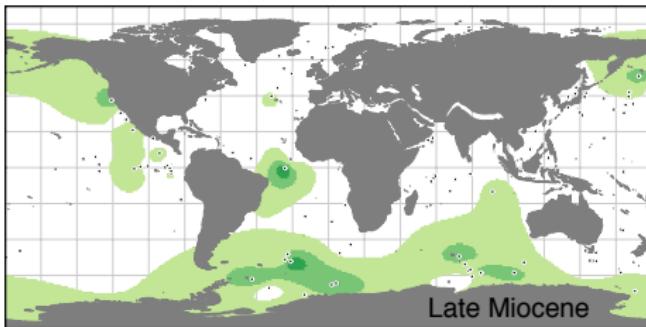
- Focus on 40-25 Ma interval to get the before and after picture as well as the events themselves.
- Radiolarian biogeography to identify areal extent of the Southern Ocean biota.
- Geochemical proxy measurements ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ on planktic and benthic forams, P accumulation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



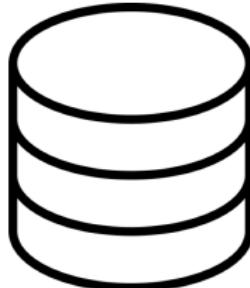
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- Diatom accumulation rate and diatom diversity based on full diatom floral data (also $\delta^{30}\text{Si}$ on diat/rads?)
- Literature-based, global compilation of BSiO₂ and CaCO₃ accumulation rates (using NSB age model library).
- All of that integrated in or compared with climate/ocean modeling results (cooperation with Georg Feulner at PIK).

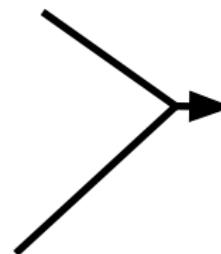
Next step for quantification of diatom abundance



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 → enhanced diatom abundance → pCO₂ 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

