Planktonic foraminifers

Modern and ancient oceans, SaltGiant Short Course 1

Salamanca November 25th – 29th 2019

Francesca Bulian

We will talk about . . .

Foraminifers:

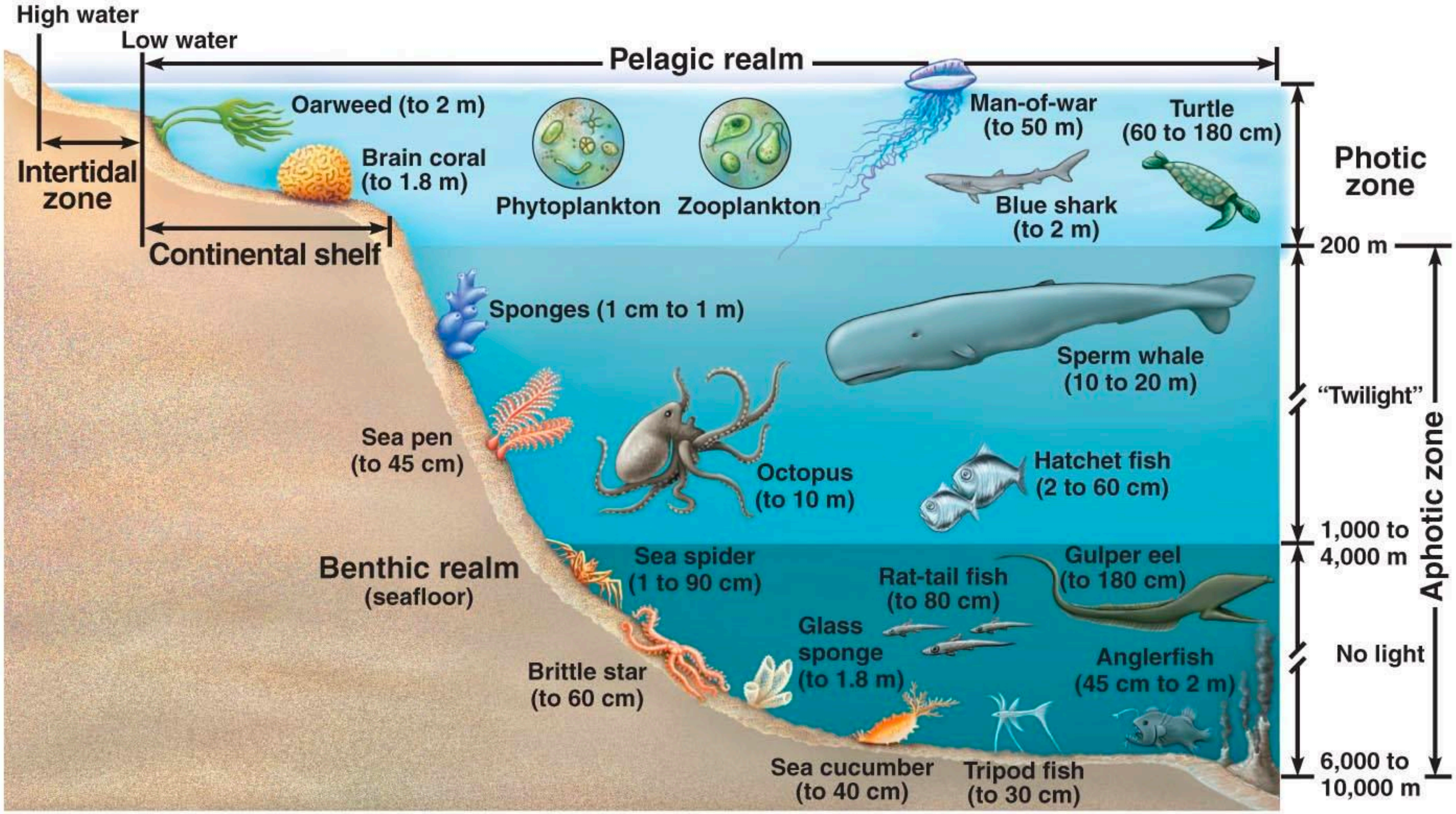
- What? Where? How?

What kind of ocean-climate information can be extracted from fossil foraminifera remains?

Where do we find foraminifera proxies and how do we get to them?

Available analytical methods?

Ocean division of marine life



Style of life

PLANKTON

Floating/suspended

NEKTON

Active swimmers

BENTHOS

The seafloor community

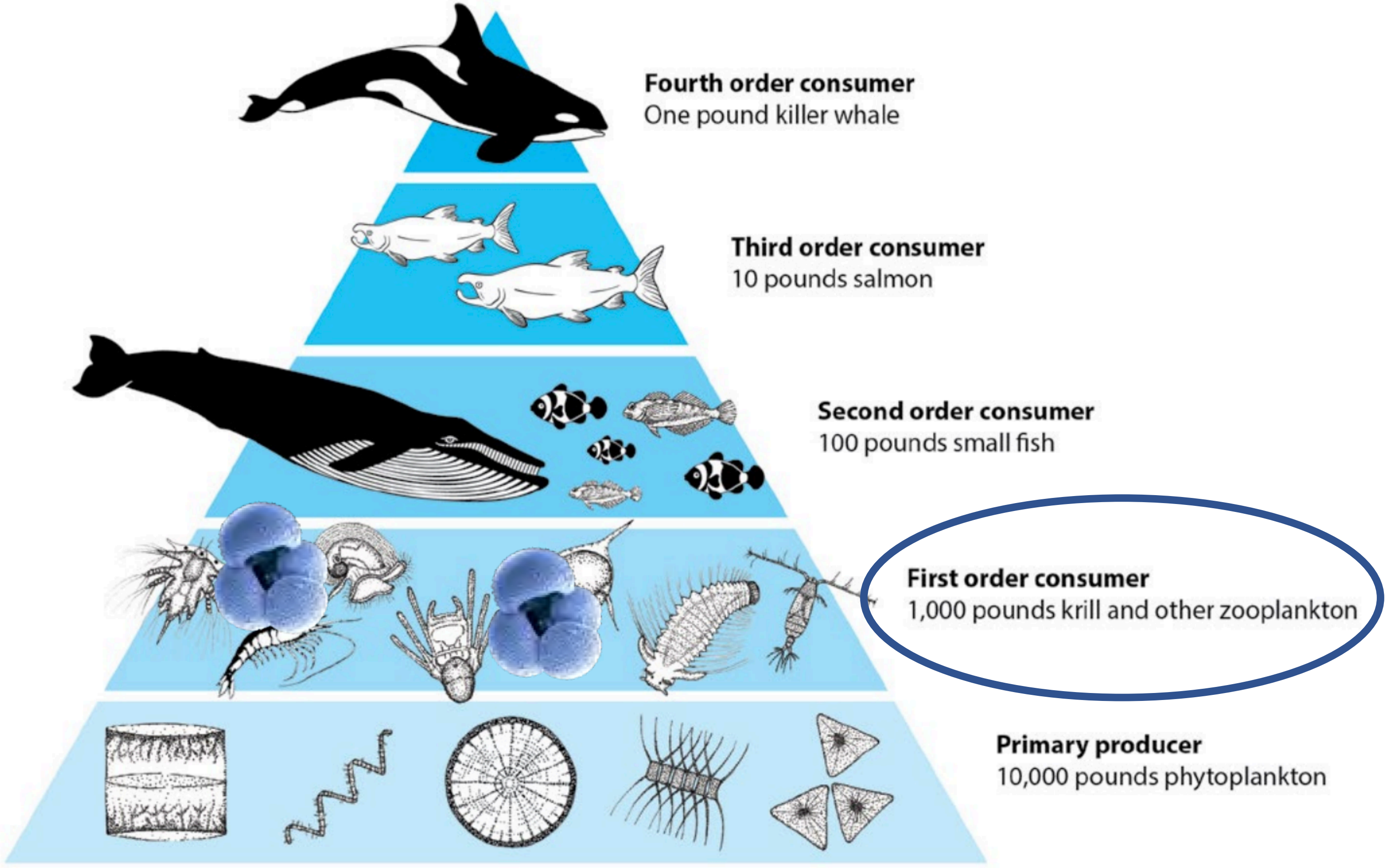
Plankton

Plankton has a crucial place at the base of aquatic food chains.

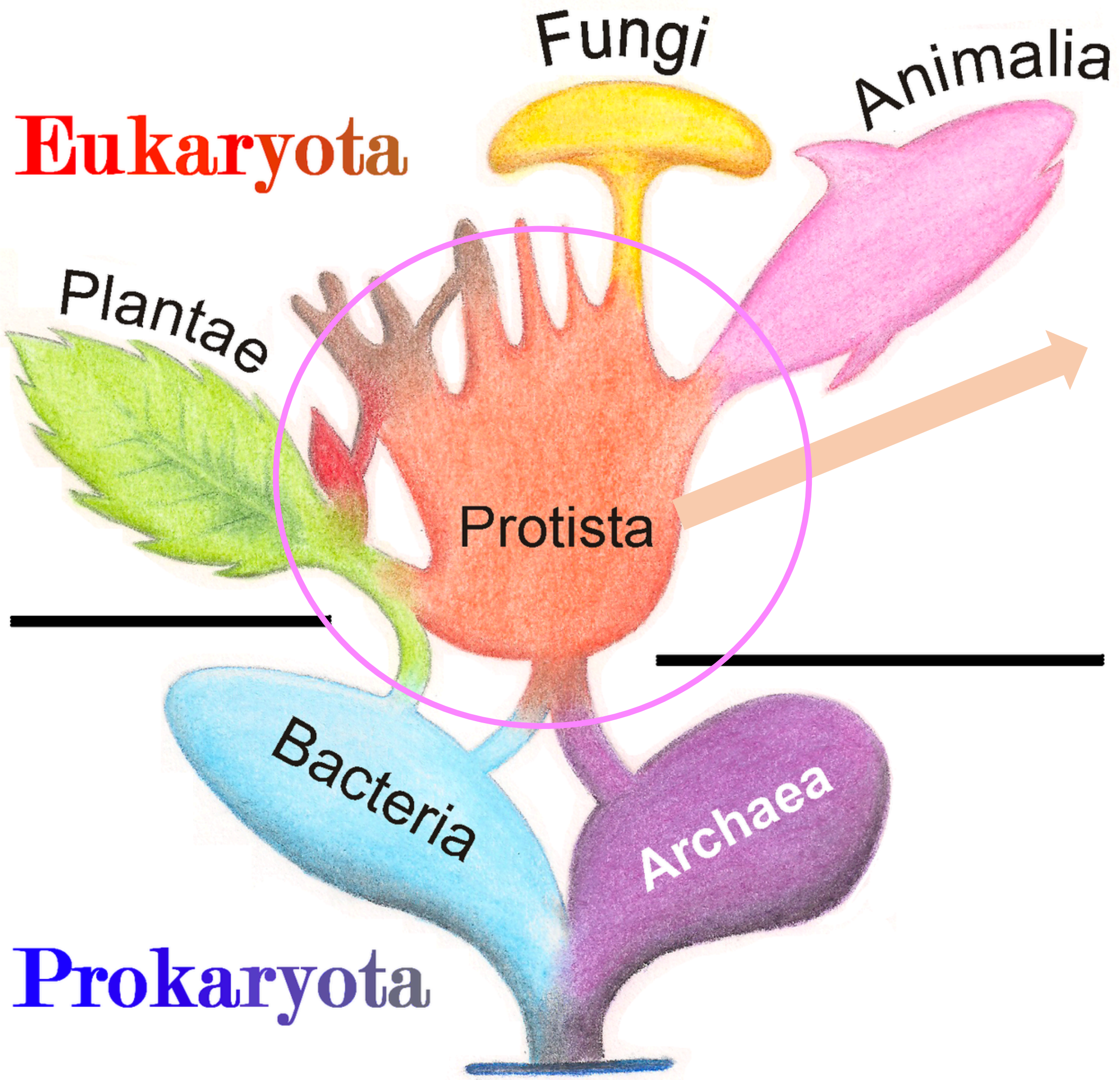
The types of plankton highly sensitive to environmental conditions.

Plankton size classes

Zooplankton	Mega- 20-200 cm Macro- 2-20 cm Meso- 0.2-20 mm Micro- 20-200 μm
Phytoplankton	Micro- 20-200 μm Nanno- 2-20 μm Pico- 0.2-2 μm Femto-0.02-0.2 μm



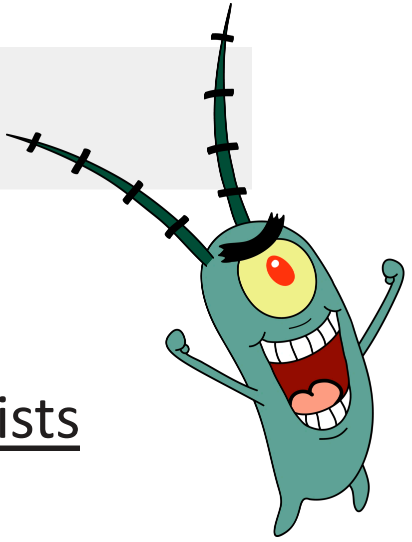
Foraminifera



Single-celled heterotrophic protists part of the eukaryotic domain.

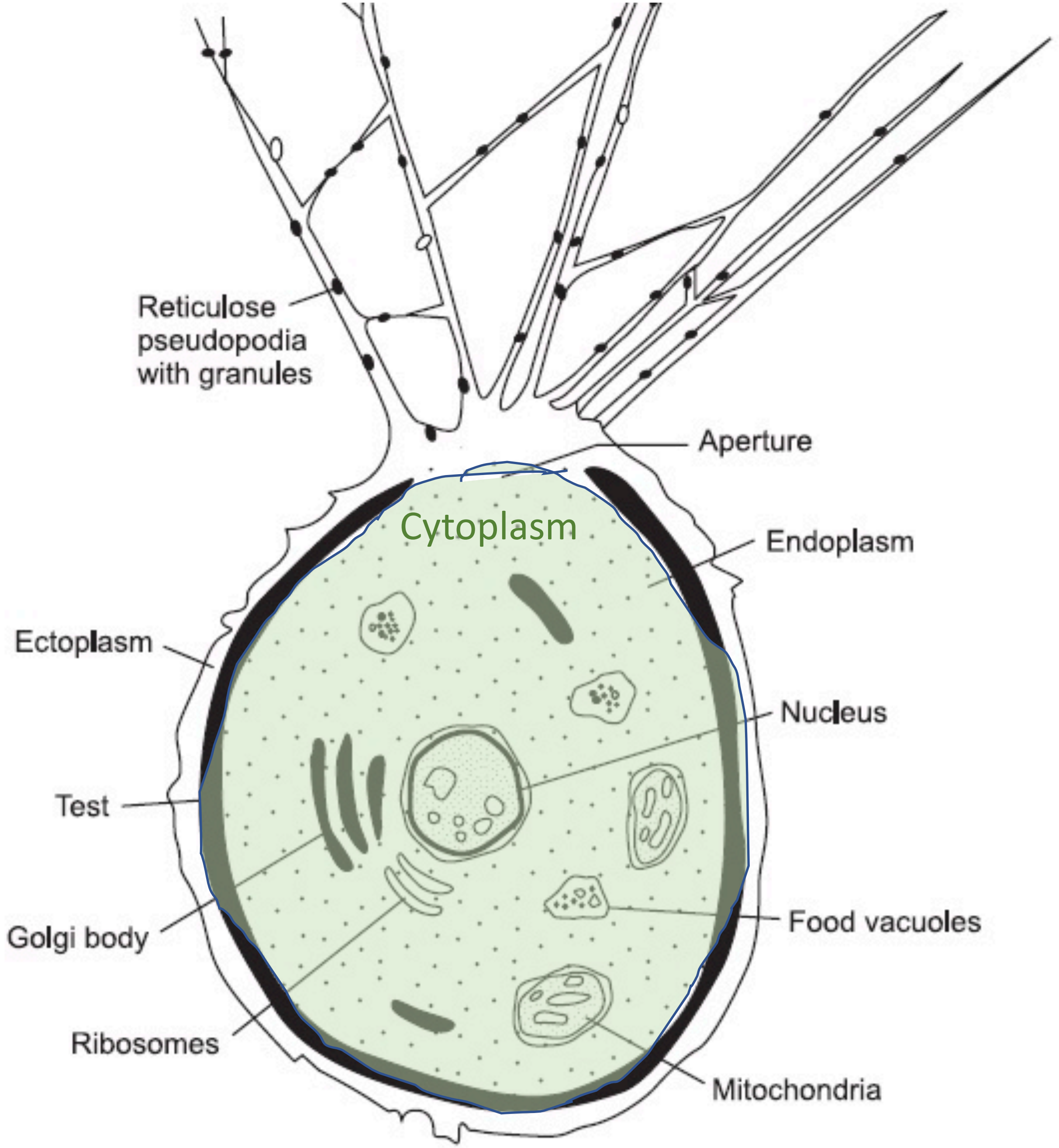
Tests are composed of secreted **calcium carbonate** ($CaCO3$).

They **eat** unicellular algae, especially diatoms, other protozoans and small metazoans (crustaceans such as copepods).

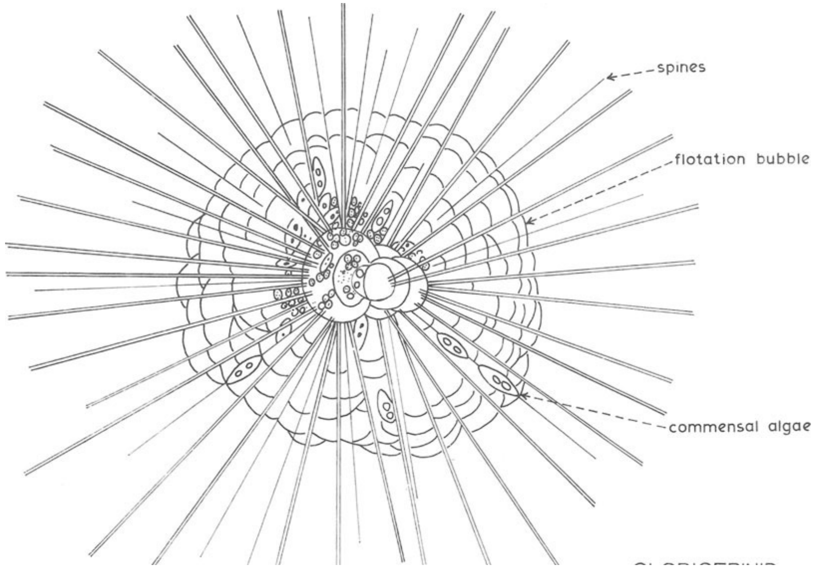


Living foraminifers

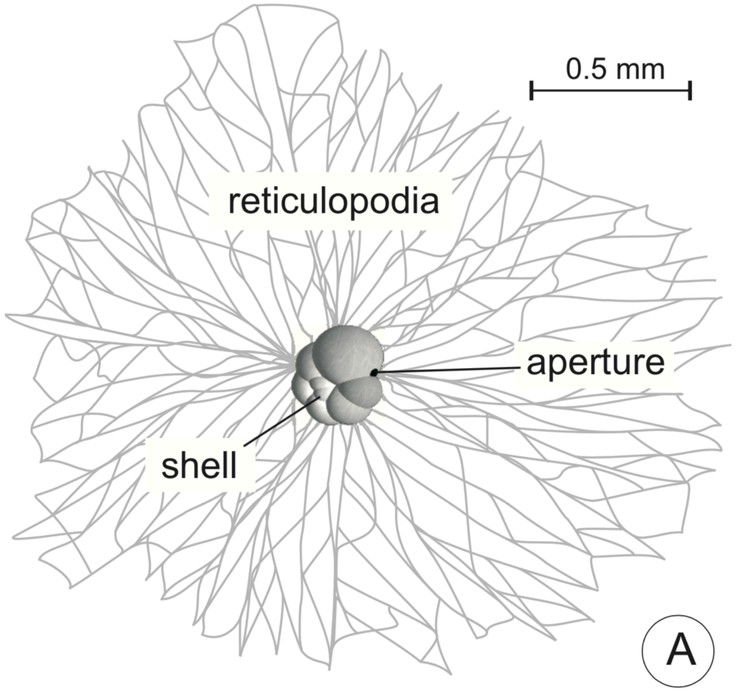
- Uni-cellular organism
- The cytoplasm contains typical eukaryotic cellular organelles: RIBOSOMES, FOOD VACUOLES, MITOCHONDRIA…
- Outside the cytoplasm in stretched into strands- RHIZOPODIA-are used to collect food particles and transport them to the APERTURE



Haynes, 1981



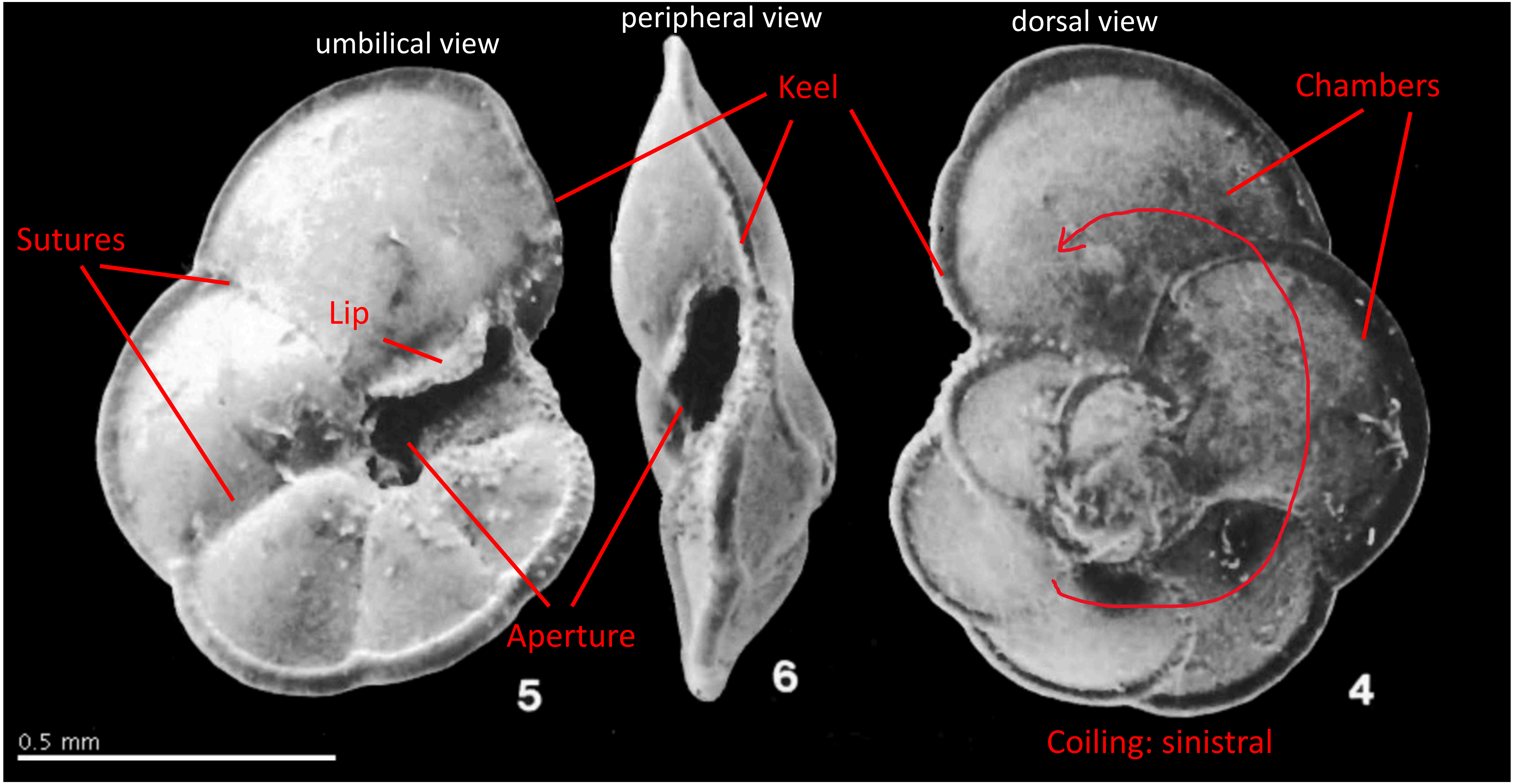
Haynes, 1981



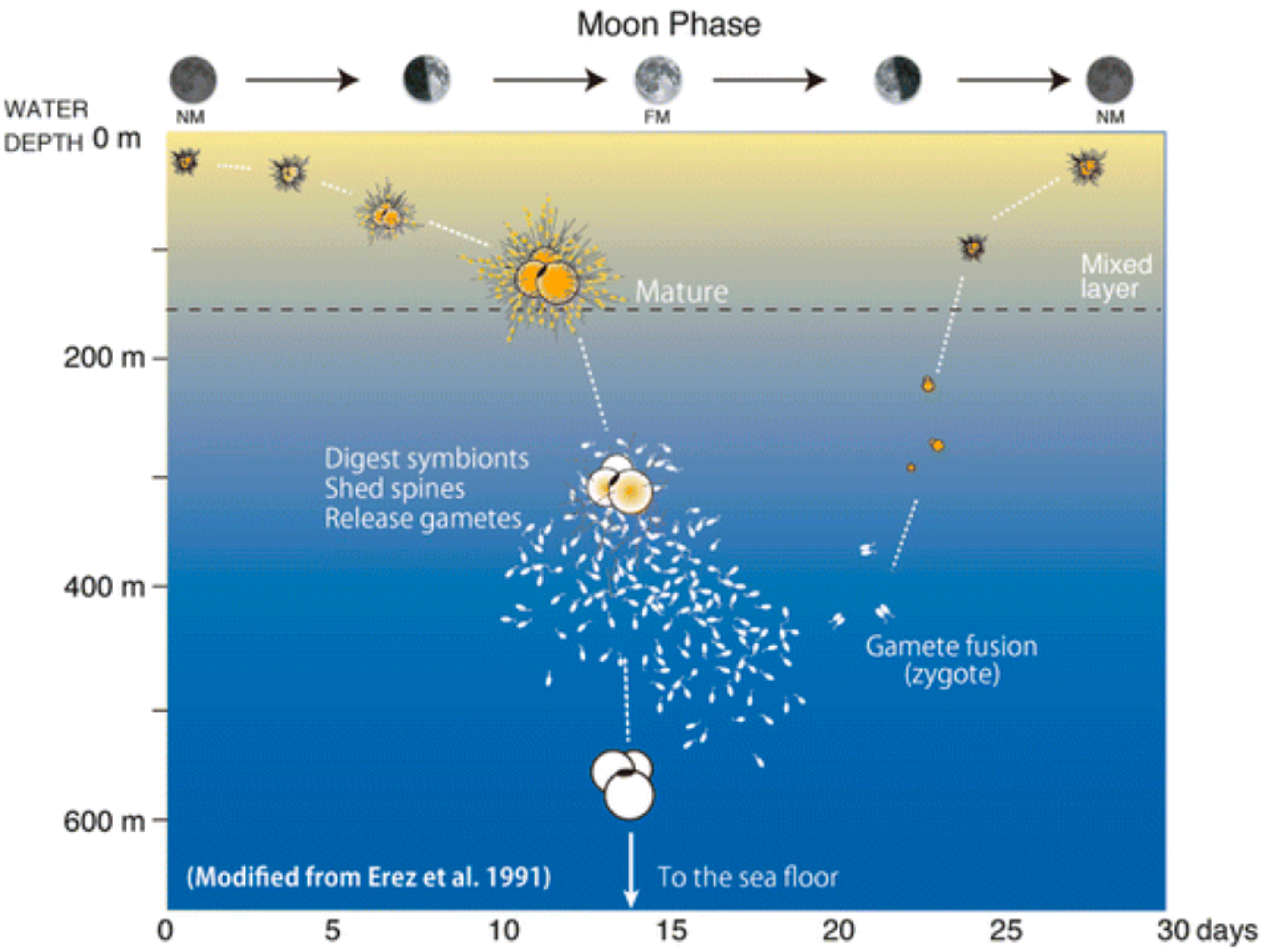
Komosinski et al., 2016

Basic soft part morphology

Foraminifera test



Reproduction



Kucera, 2007; Kimoto, 2015

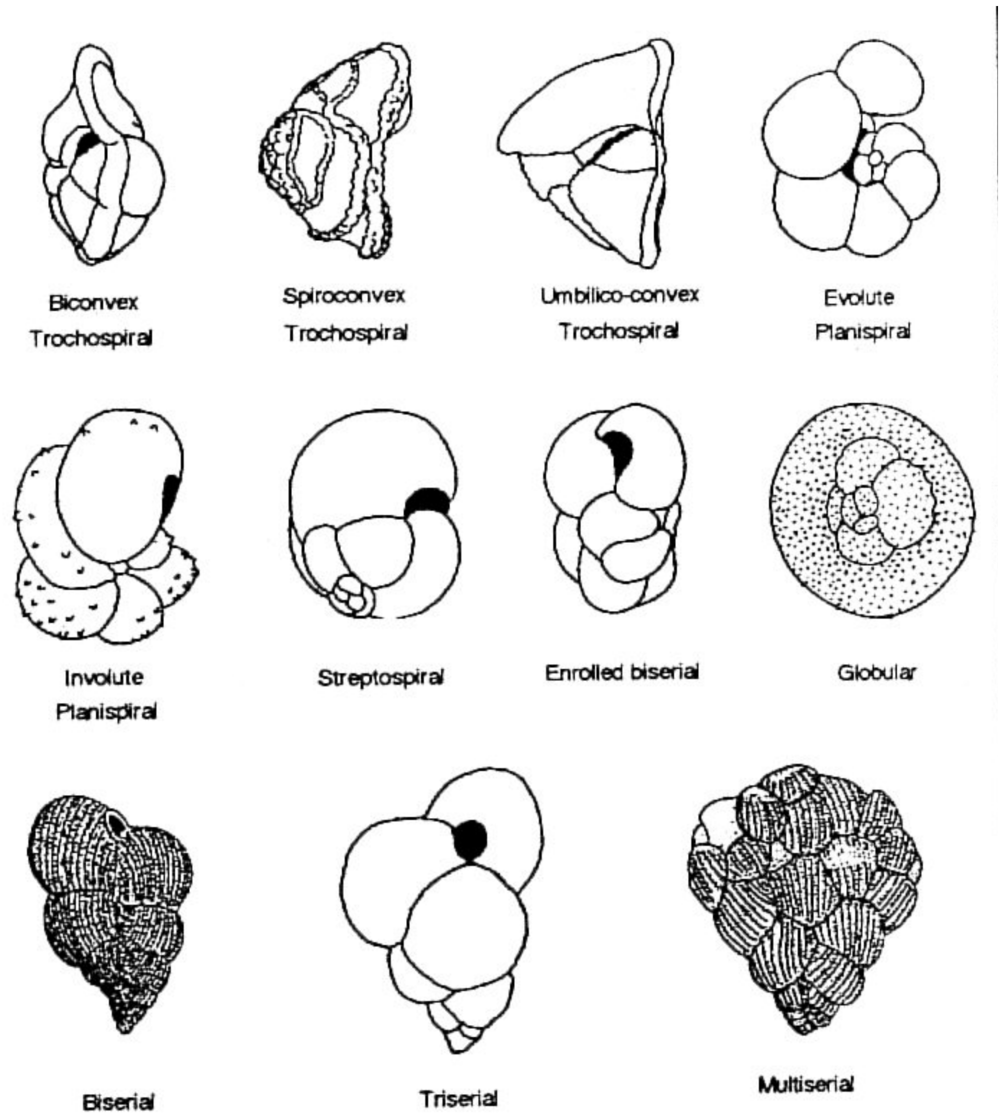
Sexual reproduction

1. The cytoplasm is divided into hundreds of thousands of biflagellate isogametes;
2. To maximize the chances of the gametes from different individuals to find each other, the reproduction is synchronized in space and time;
3. Most shallow water species appear to reproduce in pace with the lunar cycle or half cycle;
4. Following gamete fusion, shell growth is facilitated by the sequential addition of chambers, gradually increasing the dimensions of the shell.

Molphology-based classification

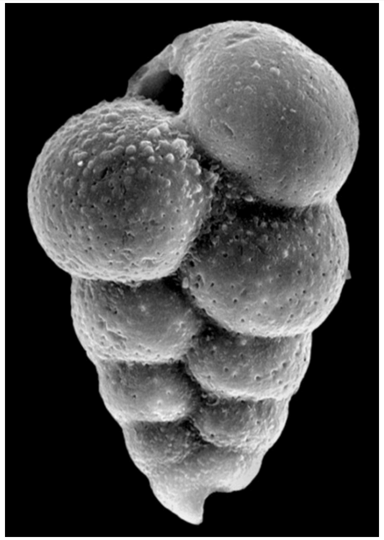
- Trochospiral
- Planispiral
- Streptospiral
- Biserial
- Globular
- Triserial
- Multiserial

TYPE OF CHAMBER ARRANGMENT

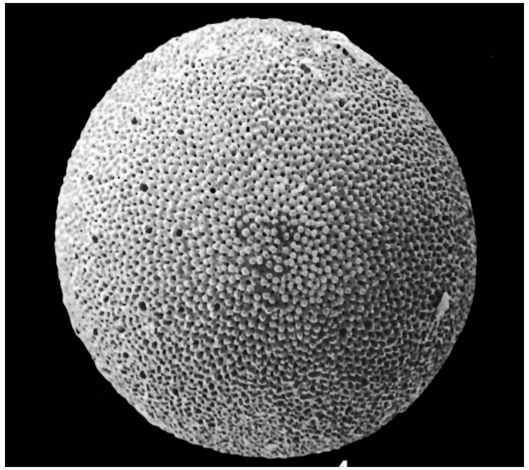


Loeblic and Tappan, 1964

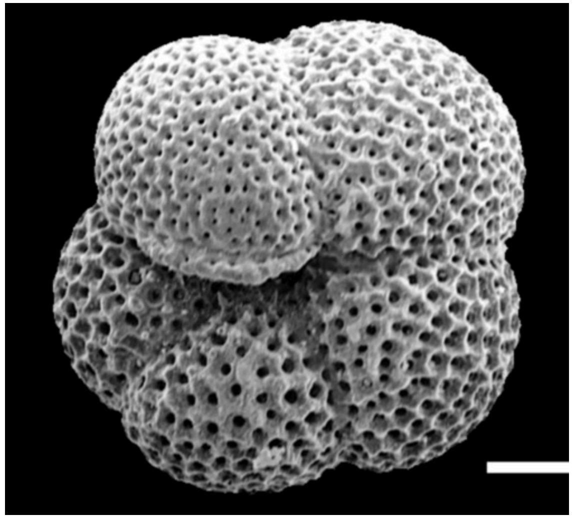
Chambers

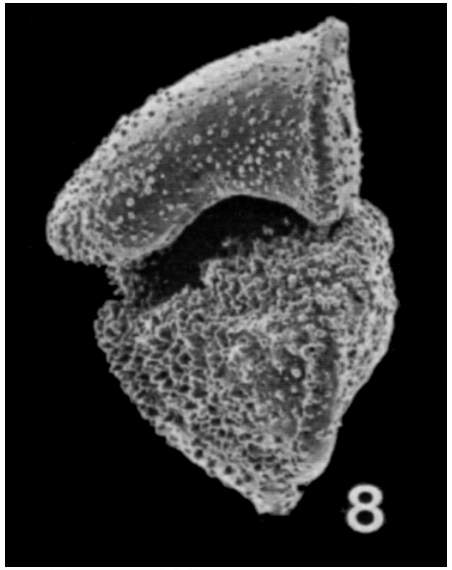


Biserial

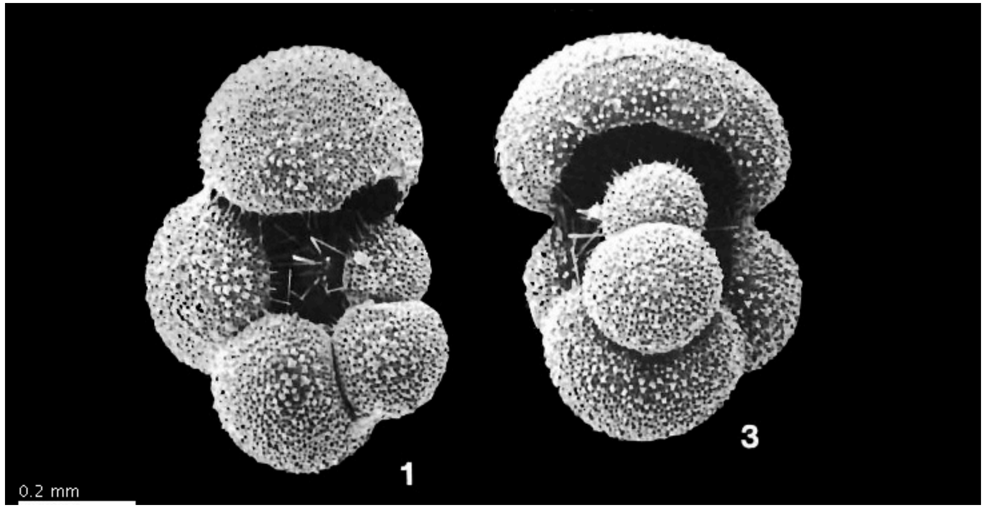


Globular

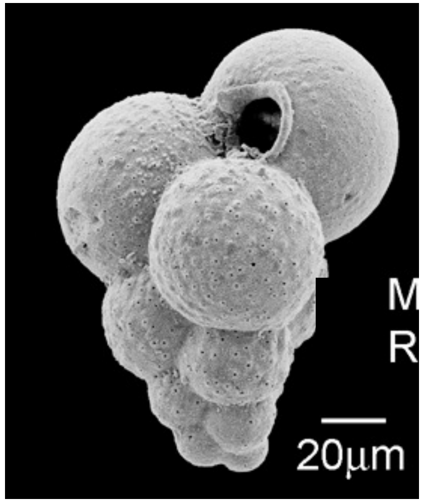




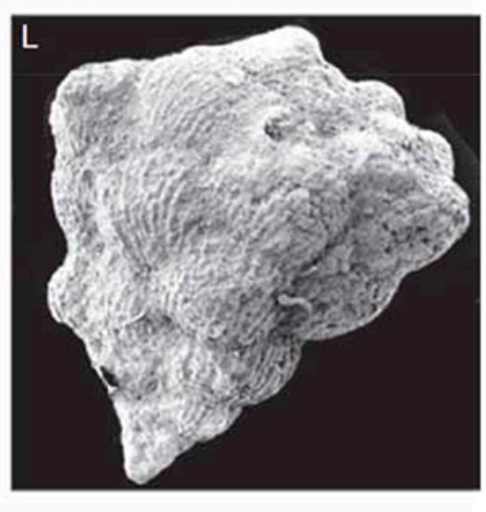
Trochospiral



Planispiral



Triserial

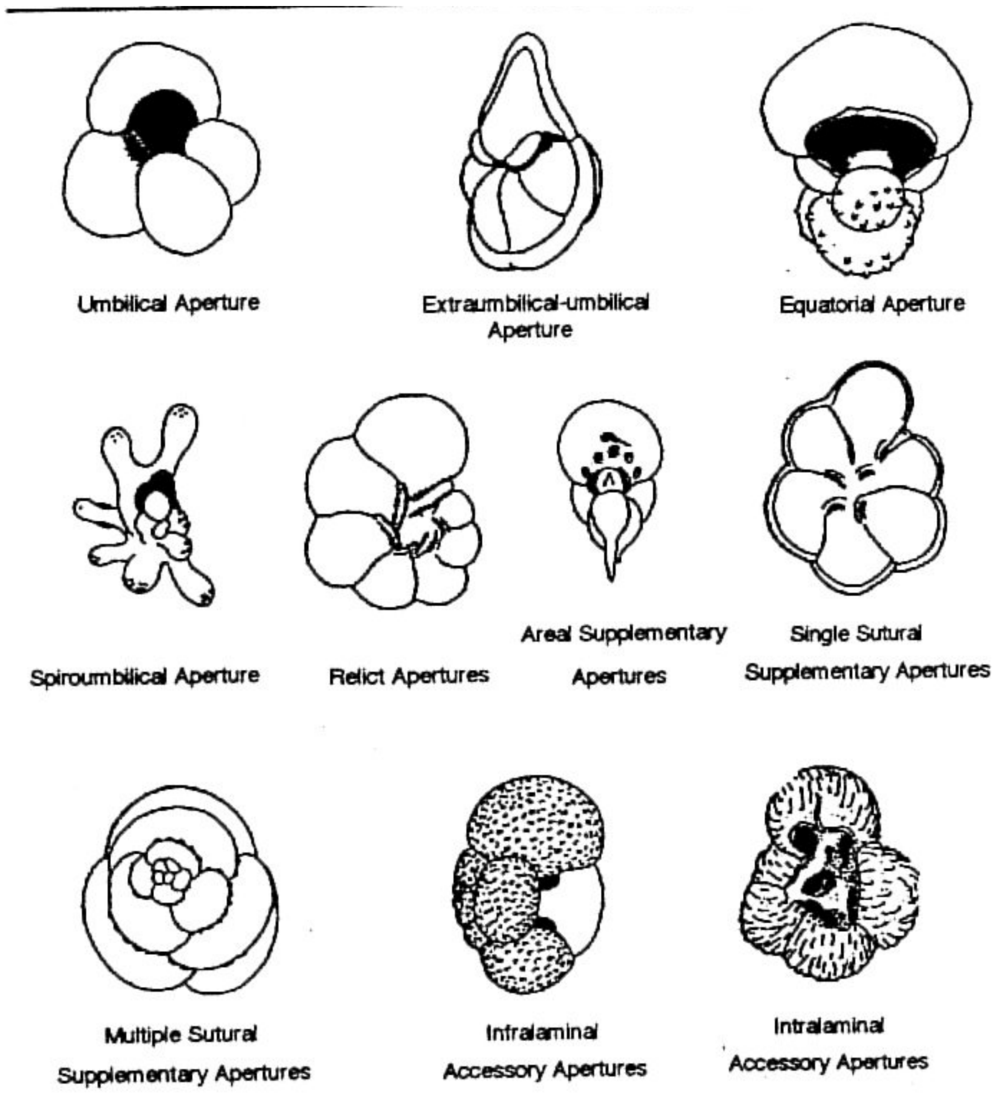


Multispiral

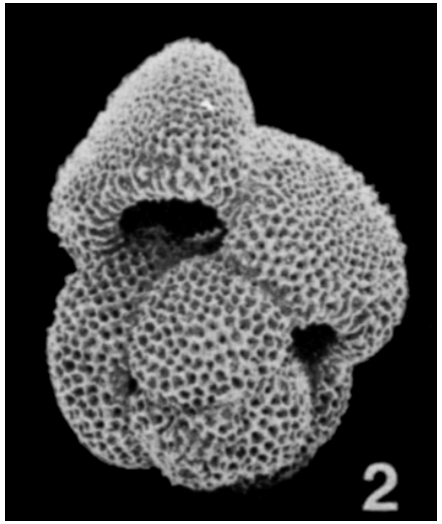
Molphology-based classification

- Umbelical
- Extraumbelical
- Equatorial
- Spiroumbelical
- Dorsal apertures
- Intralaminal
- Relict apertures
- With phialine lip
- With umbelical teeth
- With umbelical bulla

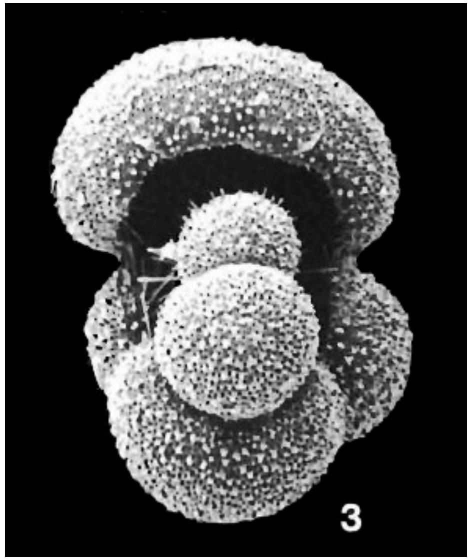
APERTURE



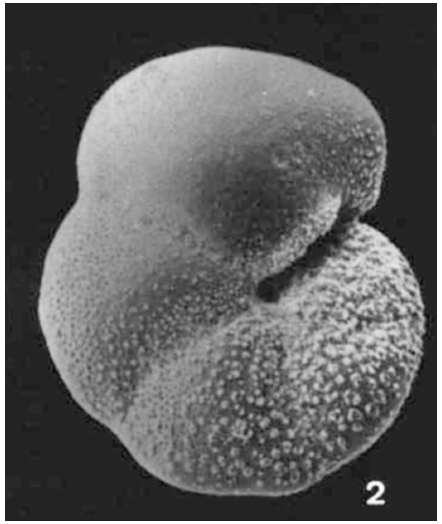
Loeblic and Tappan, 1964



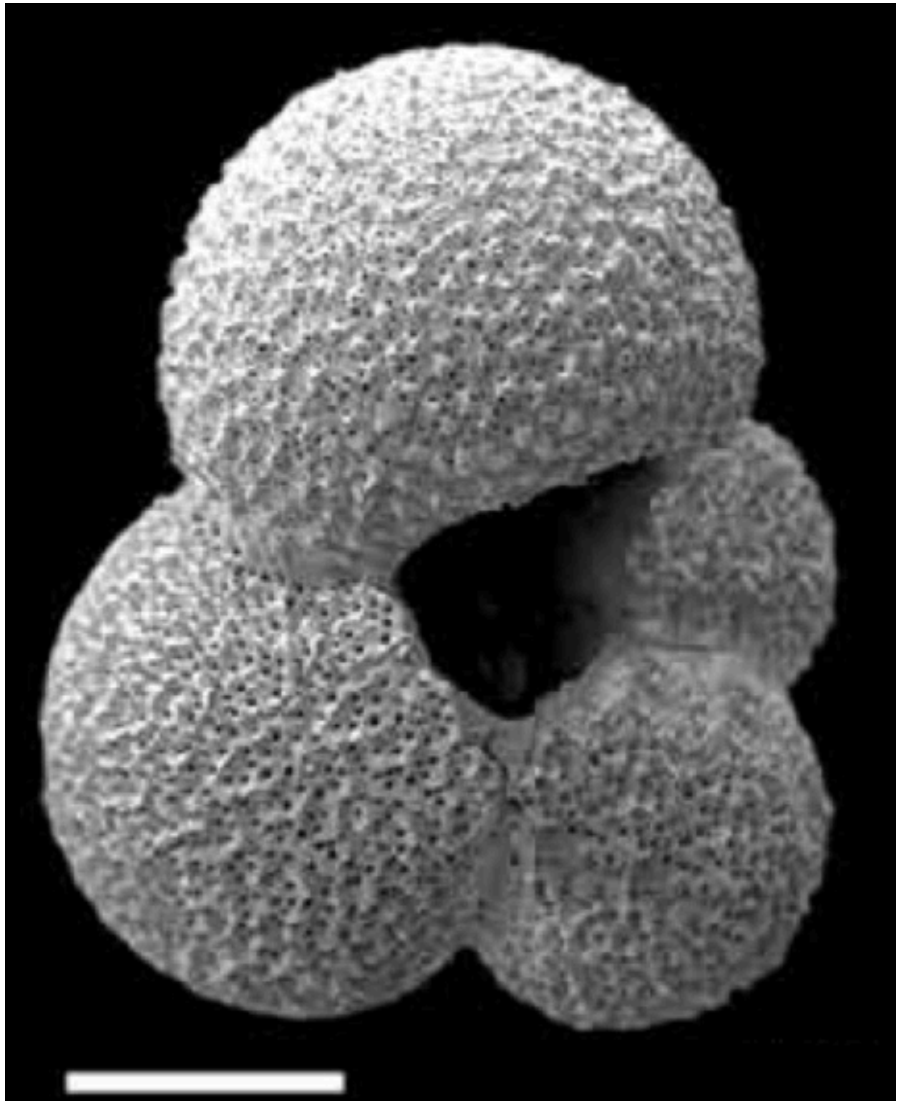
Dorsal apertures



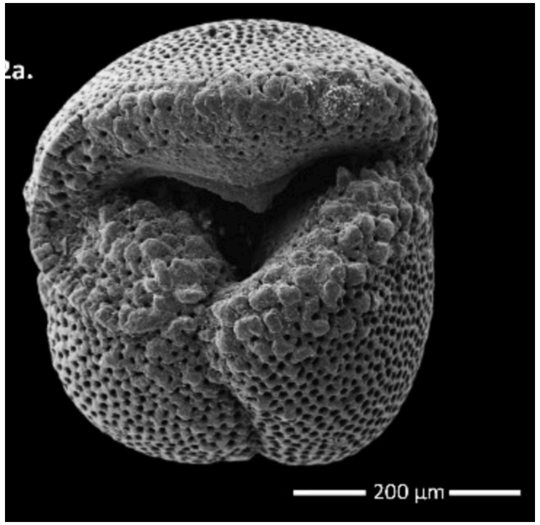
Equatorial



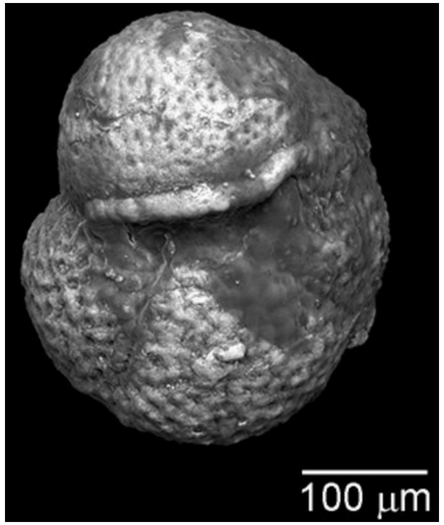
Extraumbelical



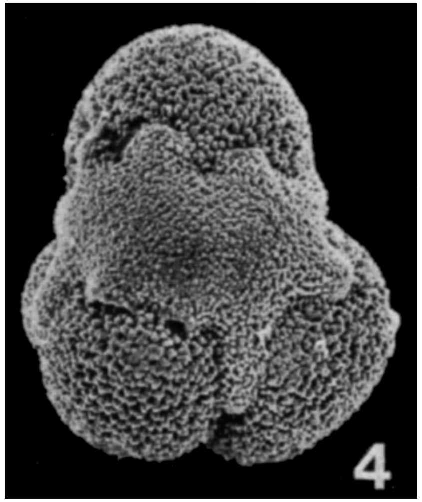
Umbelical



With umbelical teeth



With phialine lip

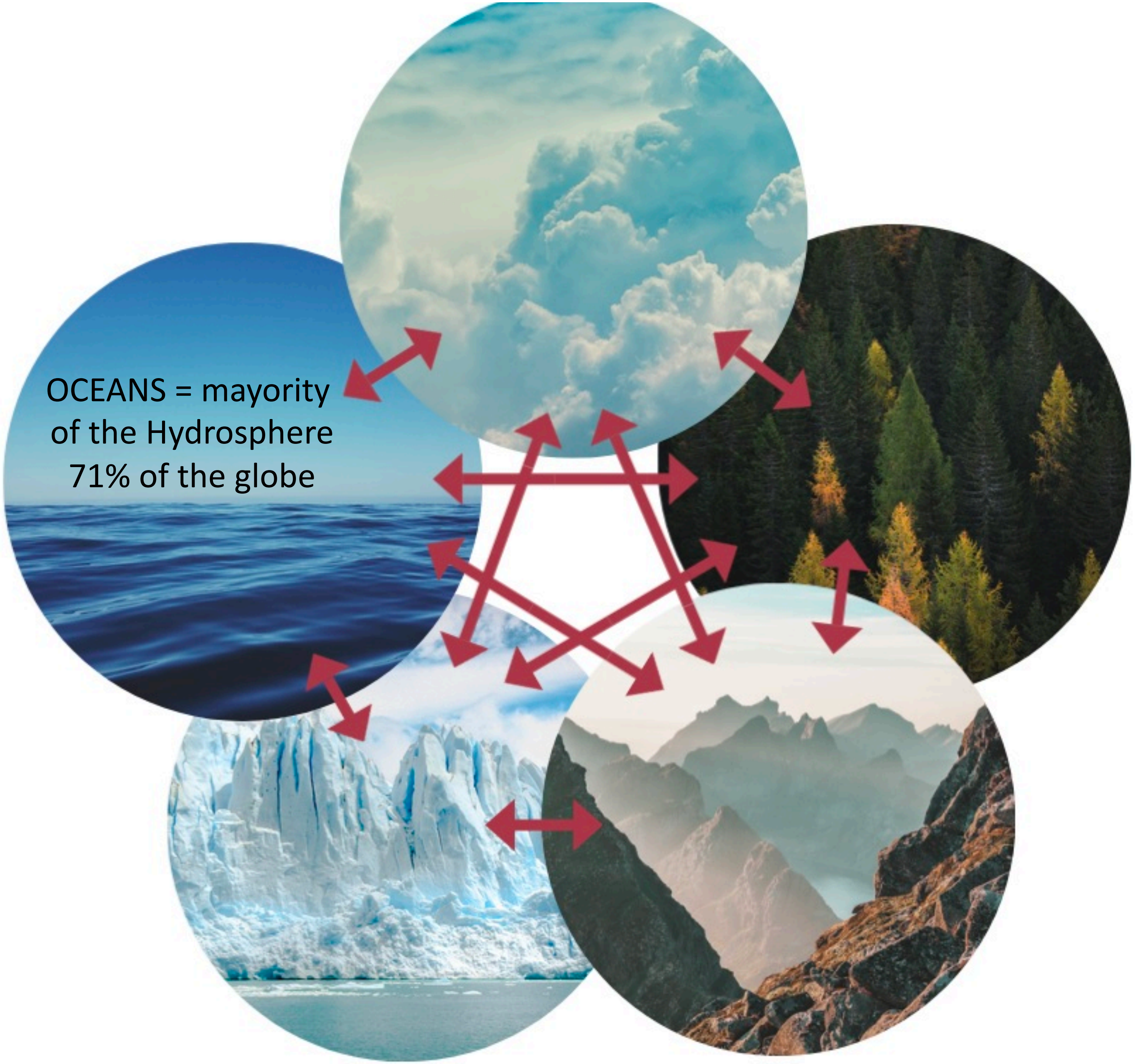


With umbelical bulla

Apertures

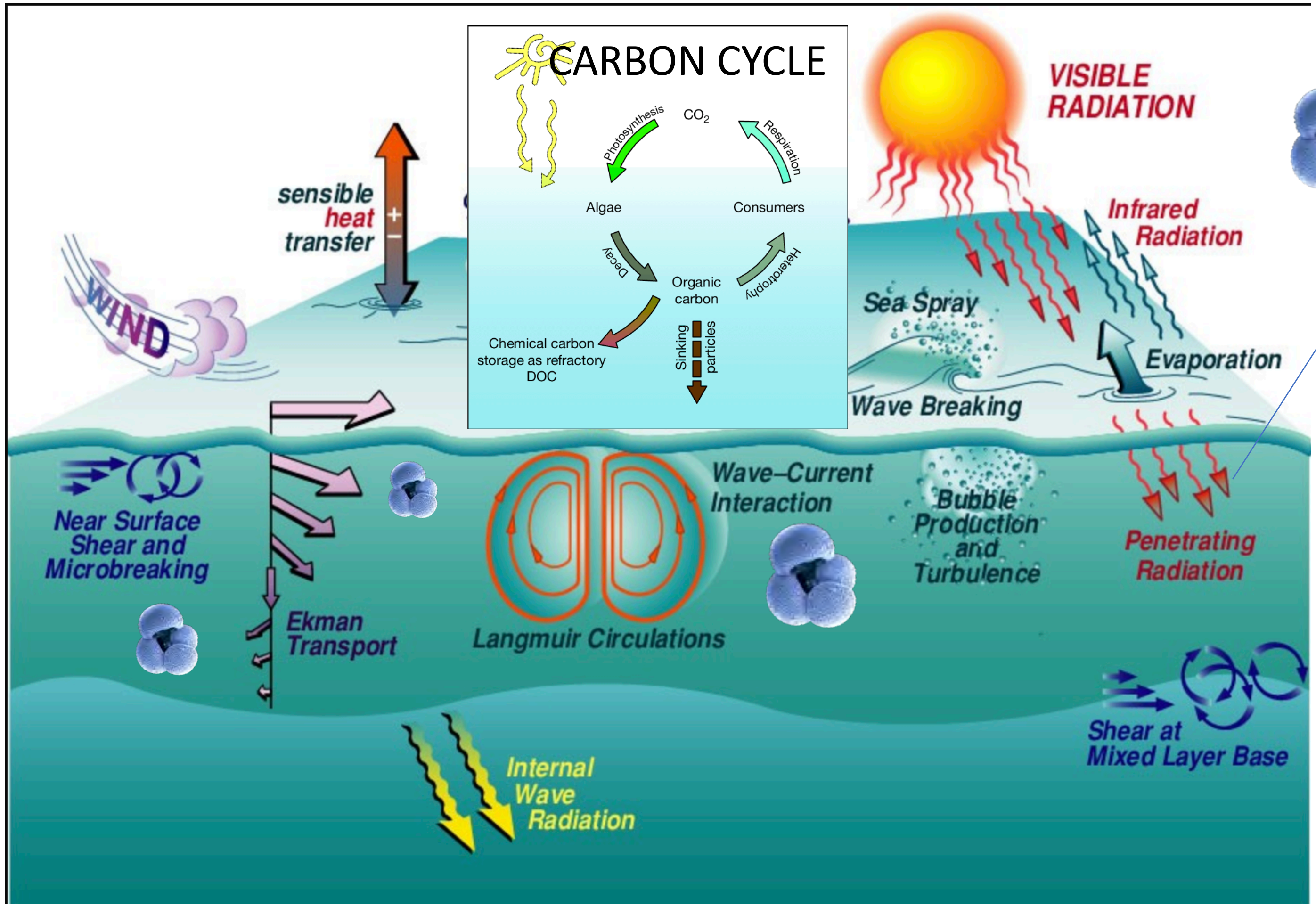
Foraminifers as proxies

- 5 main components of the climate system and they all interact with each other on different time scales;
- <u>OCEANS</u>: <u>largest reservoir</u> of heat derived from solar insolation
  - Surface ocean in direct contact with the Sun's energy is of particular importance for understanding the climate system.



Planktonic foraminifers as proxies

The mineralized shells of foraminifera preserve a record of the ocean's chemical and physical properties that can be utilized for evolutionary, paleobiological, and geochemical analyses of global environmental change.



https://www.whoi.edu/science/AOPE/dept/CBLASTmain.html

UPPER OCEAN

High preservation in the deep-sea sedimentary record.

Carbonate sediments rich in the calcitic shells of foraminifera are abundant in both space and time, which allows their use in different time scales.

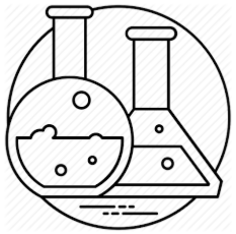
Sigman & Hain, 2012

Application of planktonic forams as proxies

Assemblage-based

1. Paleotemperature
2. Paleoproductivity
4. Physical properties
5. Biostratigraphy

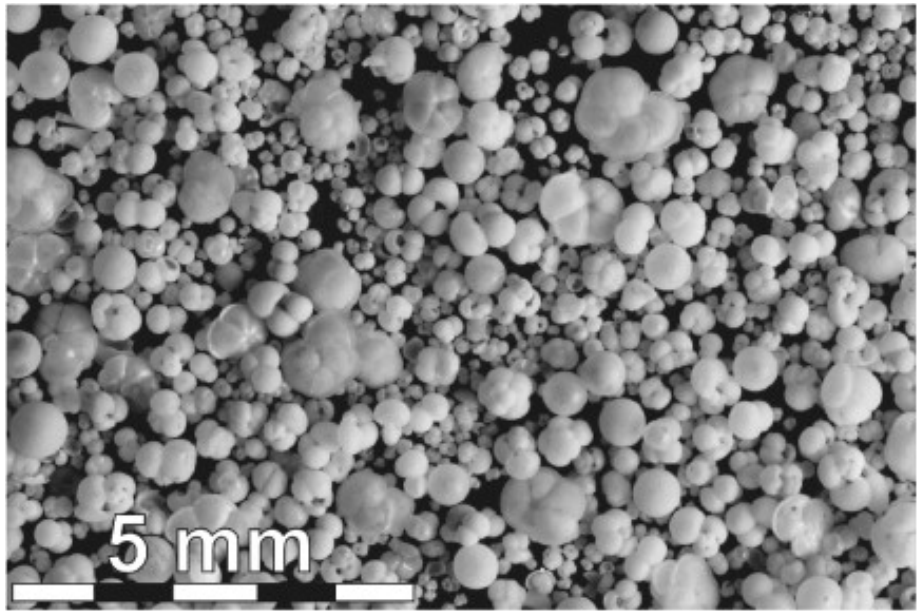
Geochemical-based



1. Oxygen isotopic composition (δ18O)
2. Nutrient availability: Carbon isotopic composition (δ 13C)
3. Continental weathering and oceanic circulation: Nd isotopic composition (εNd)
4. Paleotemperature: Mg/Ca ratio
5. Meltwater: Ba/Ca ratio
6. Paleoproductivity: Cd/Ca
7. pH: boron isotopic composition (δ11B)

Census data (assemblages)

Census	Counts of taxa, ecological or functional types
	Presence/absence
	Semi-quantitative abundance estimates
	Absolute abundances
	Relative abundances

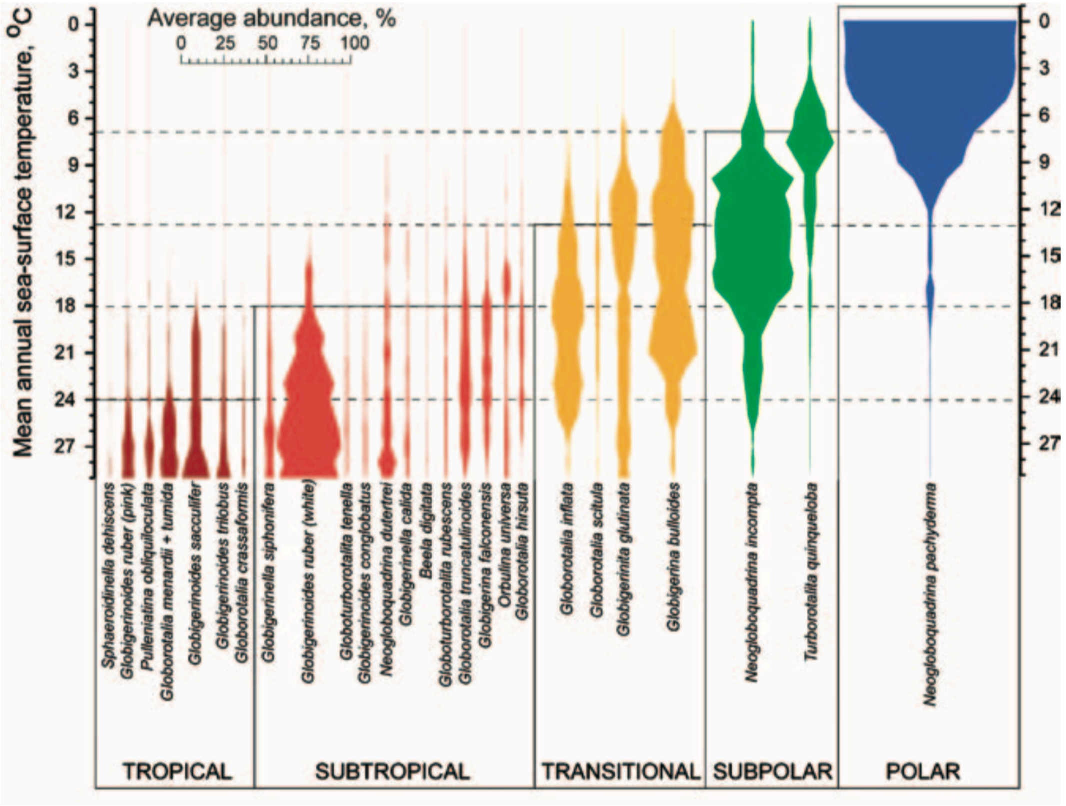


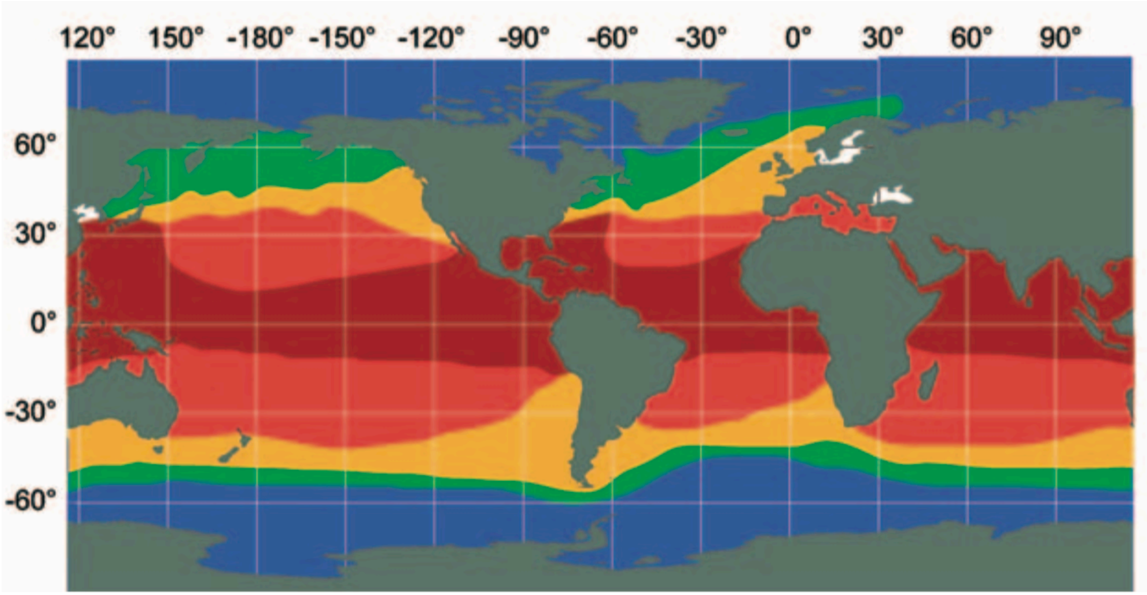
Determination foraminiferal assemblage:

- Counting of 300-500 specimen in random sub samples of >0.150 mm fraction
- It relies on correct identification of the counted taxonomical units

Temperature estimates

Five main assemblages of Planktonic foraminifera





Temperature reconstruction

1. Proportion between warm- and cold- water species could be used to track thermal history of the ocean's surface on geological time scales.

2. Transfer fuctions: absolute value estimate

proportion of the species i

optimal temperatura for species i

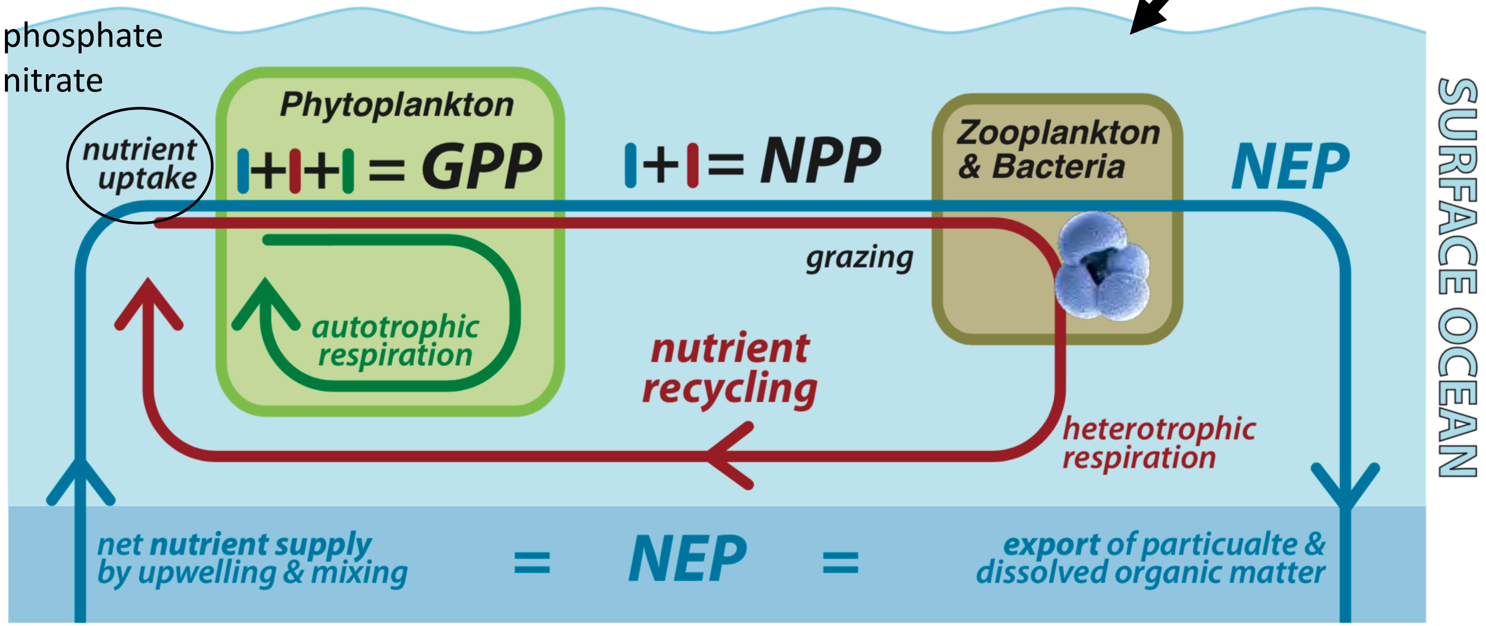
$$T_{\mathrm{est}} = \frac{\sum (p_{\mathrm{i}} \cdot t_{\mathrm{i}})}{\sum p_{\mathrm{i}}}$$

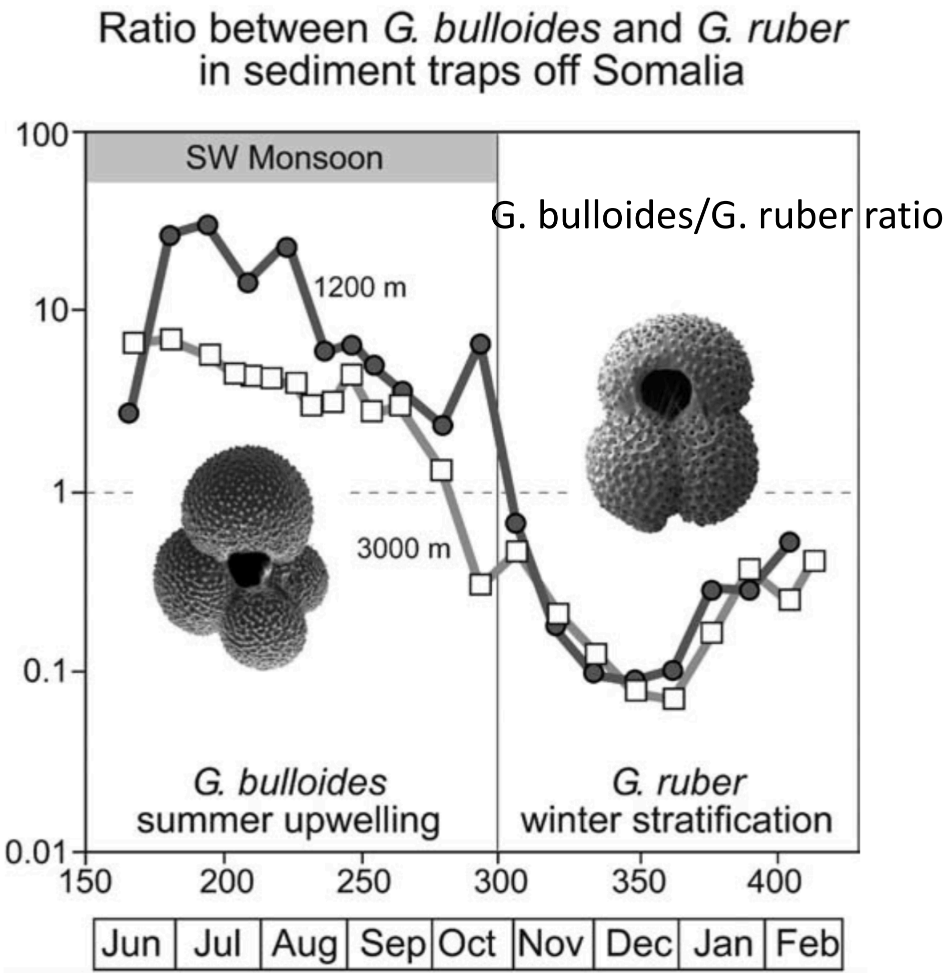
Kucera, 2007

Productivity in the Surface ocean

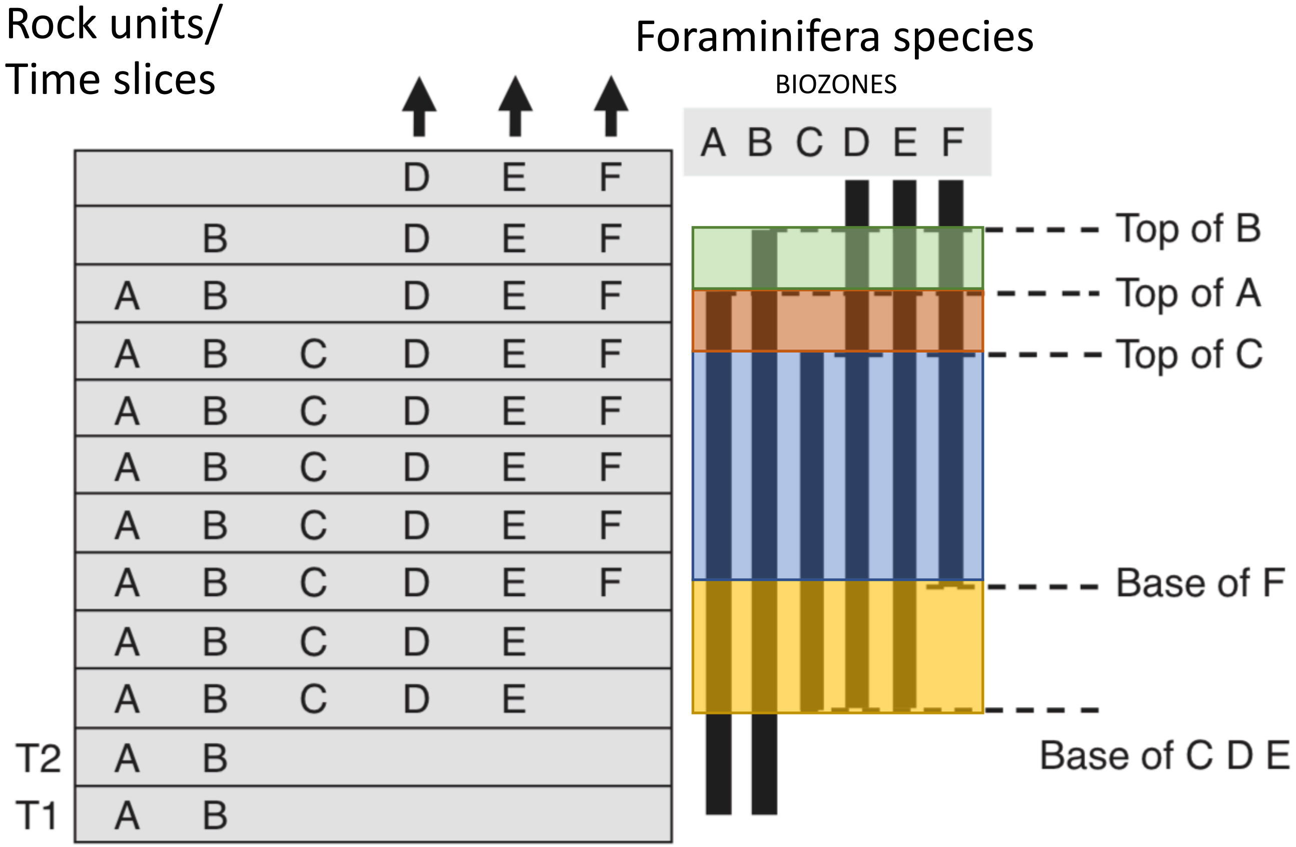
The production of organic matter by phytoplankton: **photoautotrophs** - harvesting light to convert inorganic to organic carbon, and they supply this organic carbon to diverse **heterotrophs**, organisms that obtain their energy solely from the respiration of organic matter (oxidation of organic carbon back to carbon dioxide).

GPP-gross primary production
NPP-net primary production
NEP-net ecosystem production

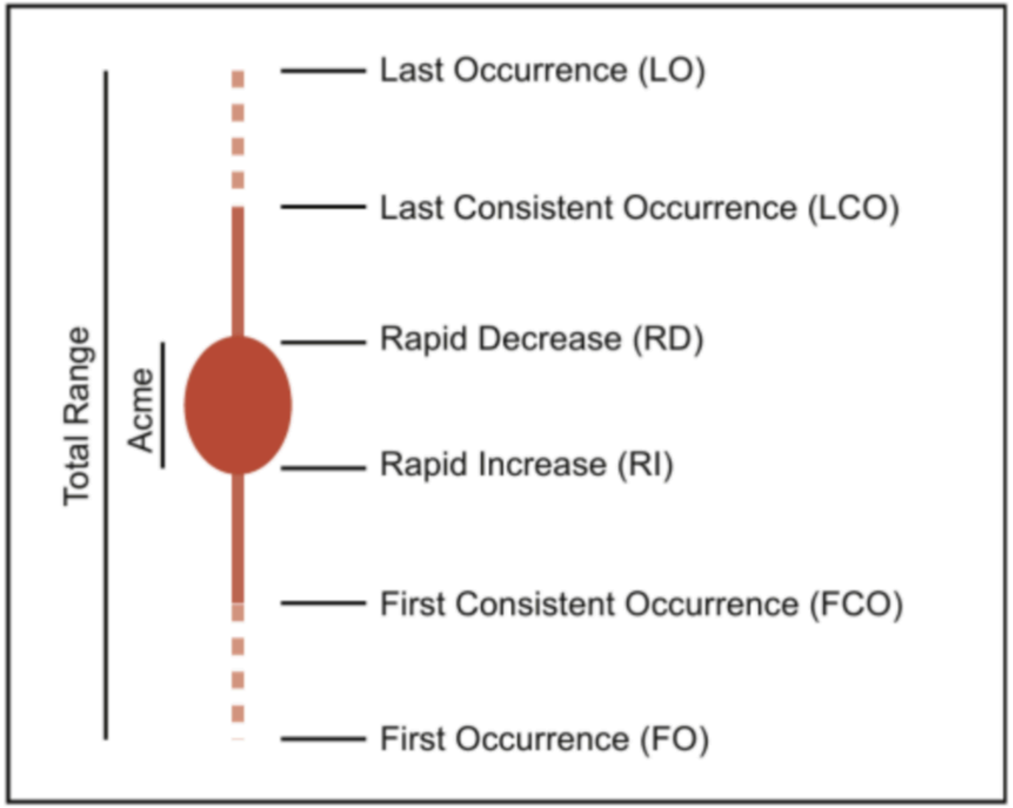




Sigman and Hain, 2012 Conan et al., 2002

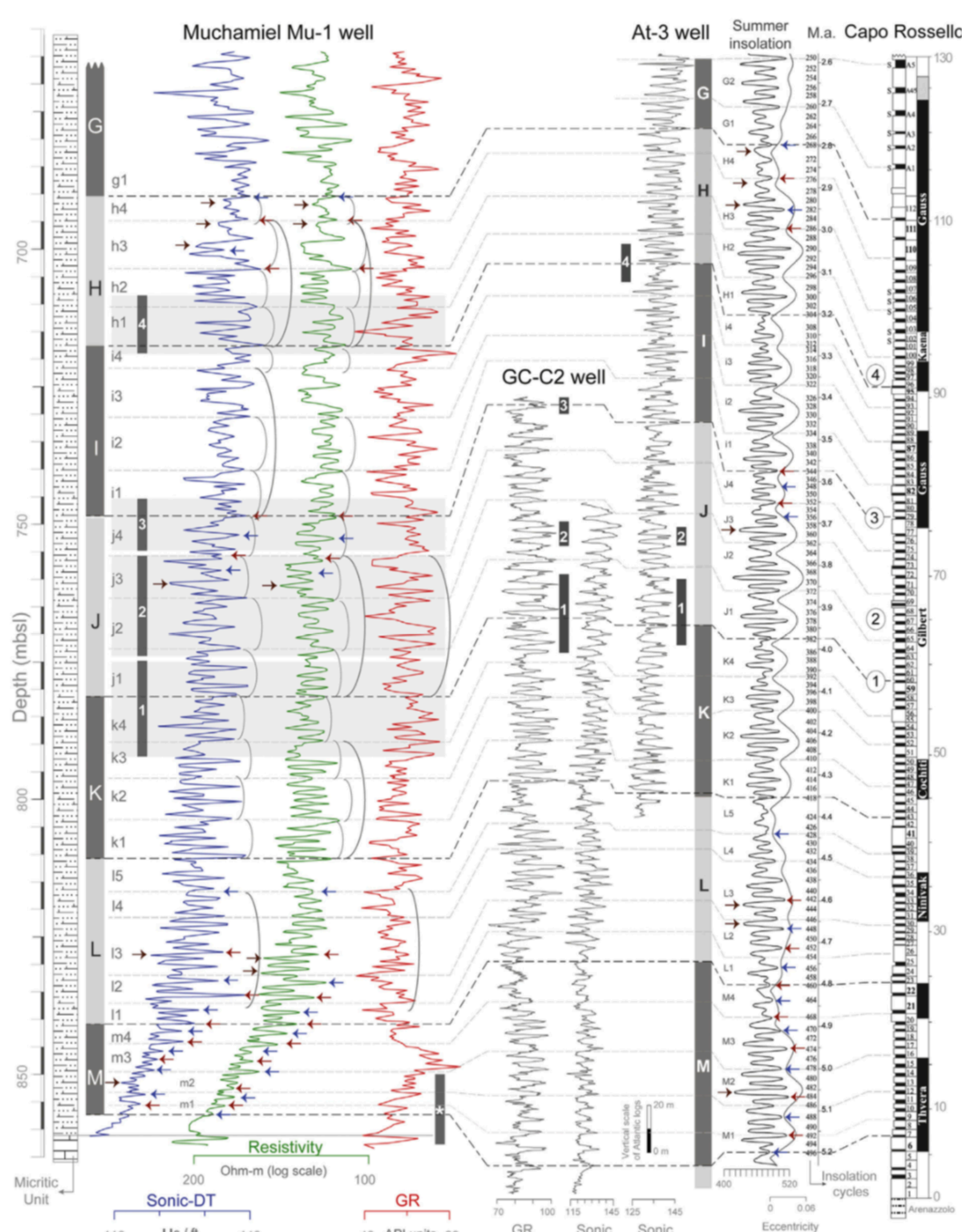


Jones, 2014



Gradstain, 2012

Biostratigraphy



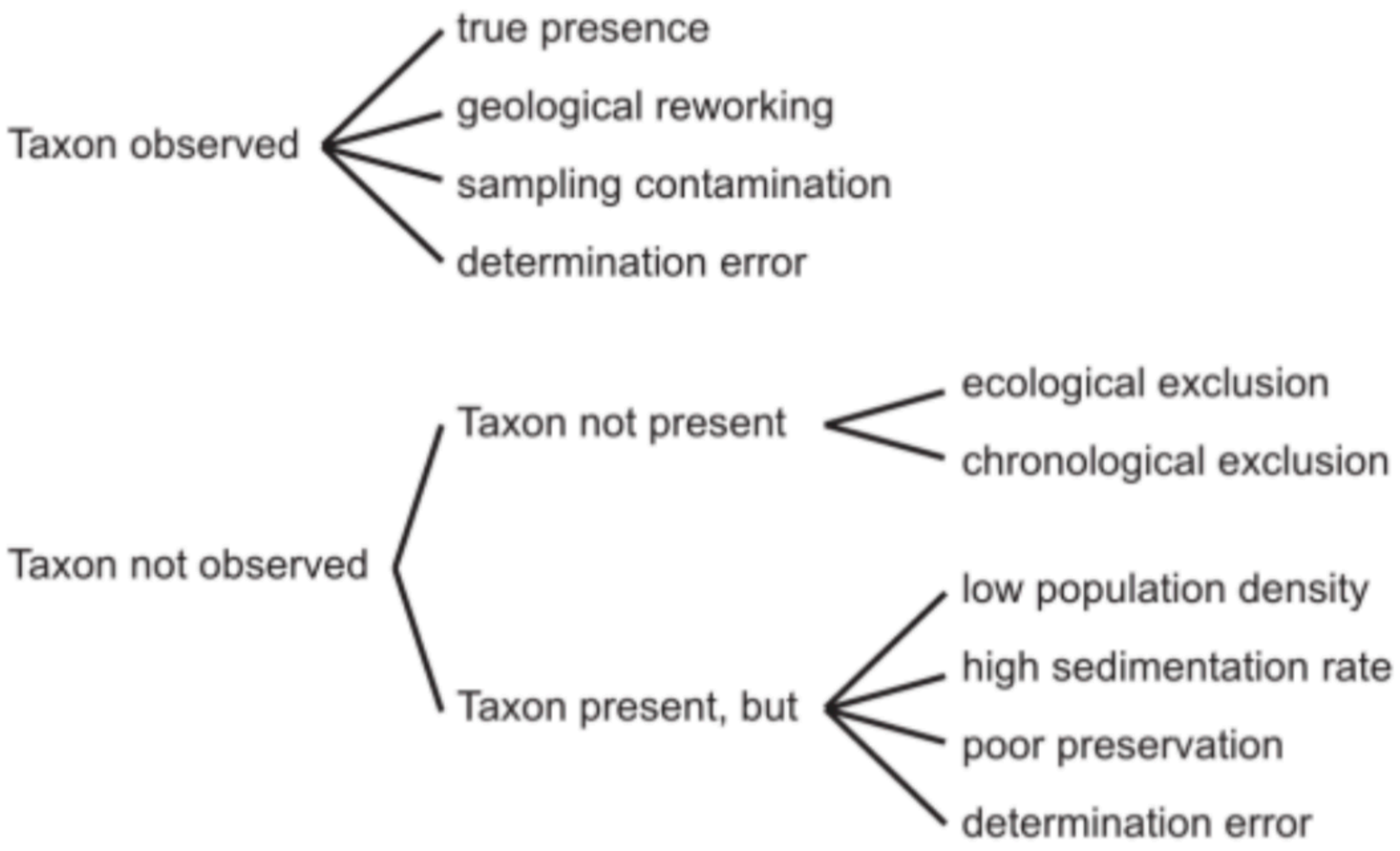
How do we know the age of a foraminiferal event?

- Previously established age on other sections:

1. Chemiostratigraphy: isotope geochemistry of marine carbonates (Foraminifers);
2. Cyclostratigraphy: search other cyclical patterns (Gamma ray, Sonic Log, Resistivity)
3. Event Stratigraphy: anoxic events, ice ages, large vulcanic events (tefra leyers) are additional tie points;
4. Radioisotopic dating: U-Pb, 40Ar/39Ar;
5. Magnetostratigraphy: sequence of geomagnetic field polarity;

Ochoa et al., 2018

Reasons of uncertanty in Biostratigraphy



Gradstain, 2012

Phisical properties

All organisms are affected during growth by the state of their physical environment.

Biometry	**Measurements made on individual specimens**
	Morphology — size, shape Shell ultrastructure Colour and weight
Modification	**Changes to fossils incurred after deposition**
	Preservation indices Fragmentation

Kucera, 2007

Phisical properties

All organism ... state of their physical environmen...

Biometry ... on individual specimens

...e, shape

Modifica... ...urred after deposition

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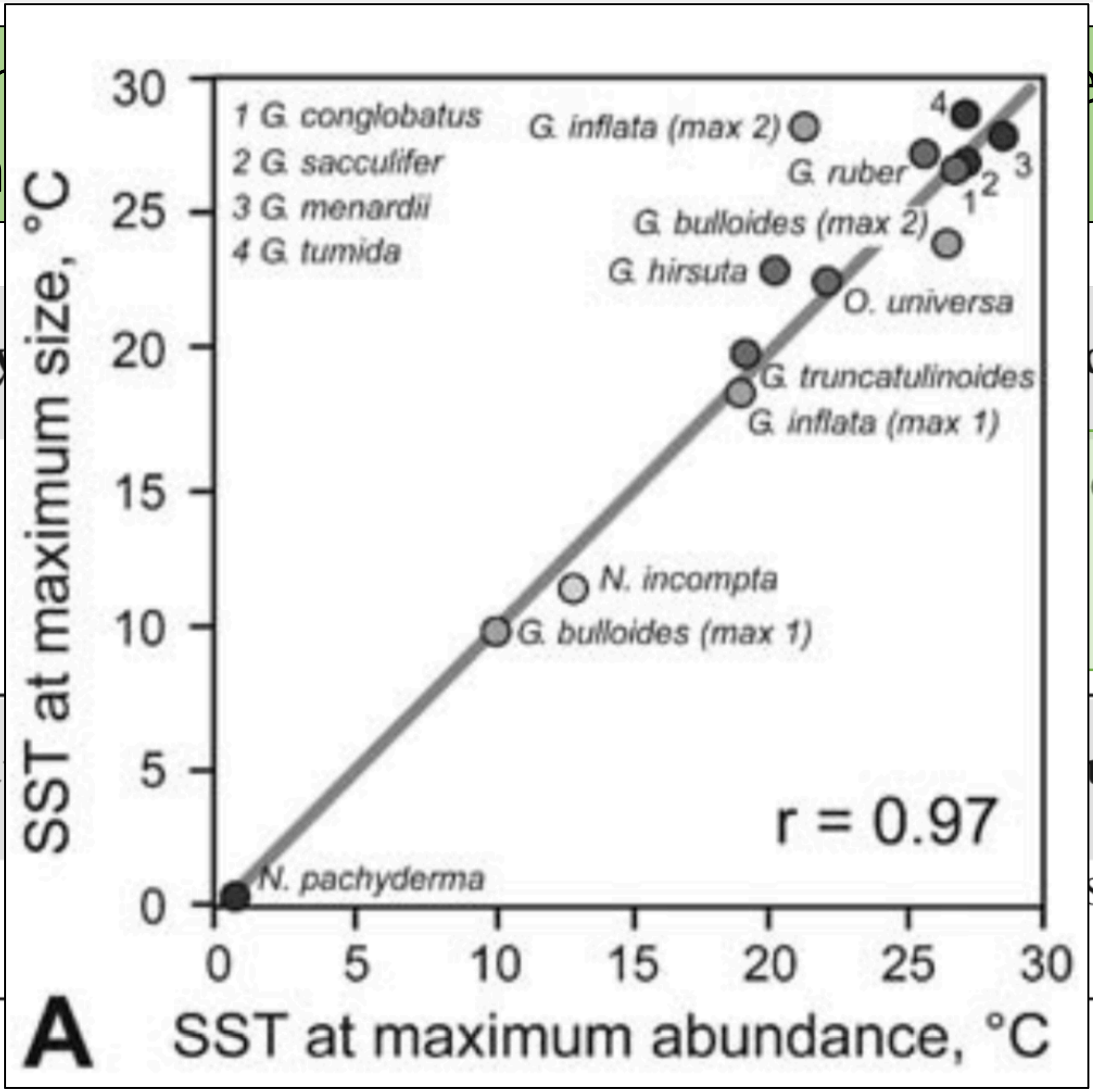
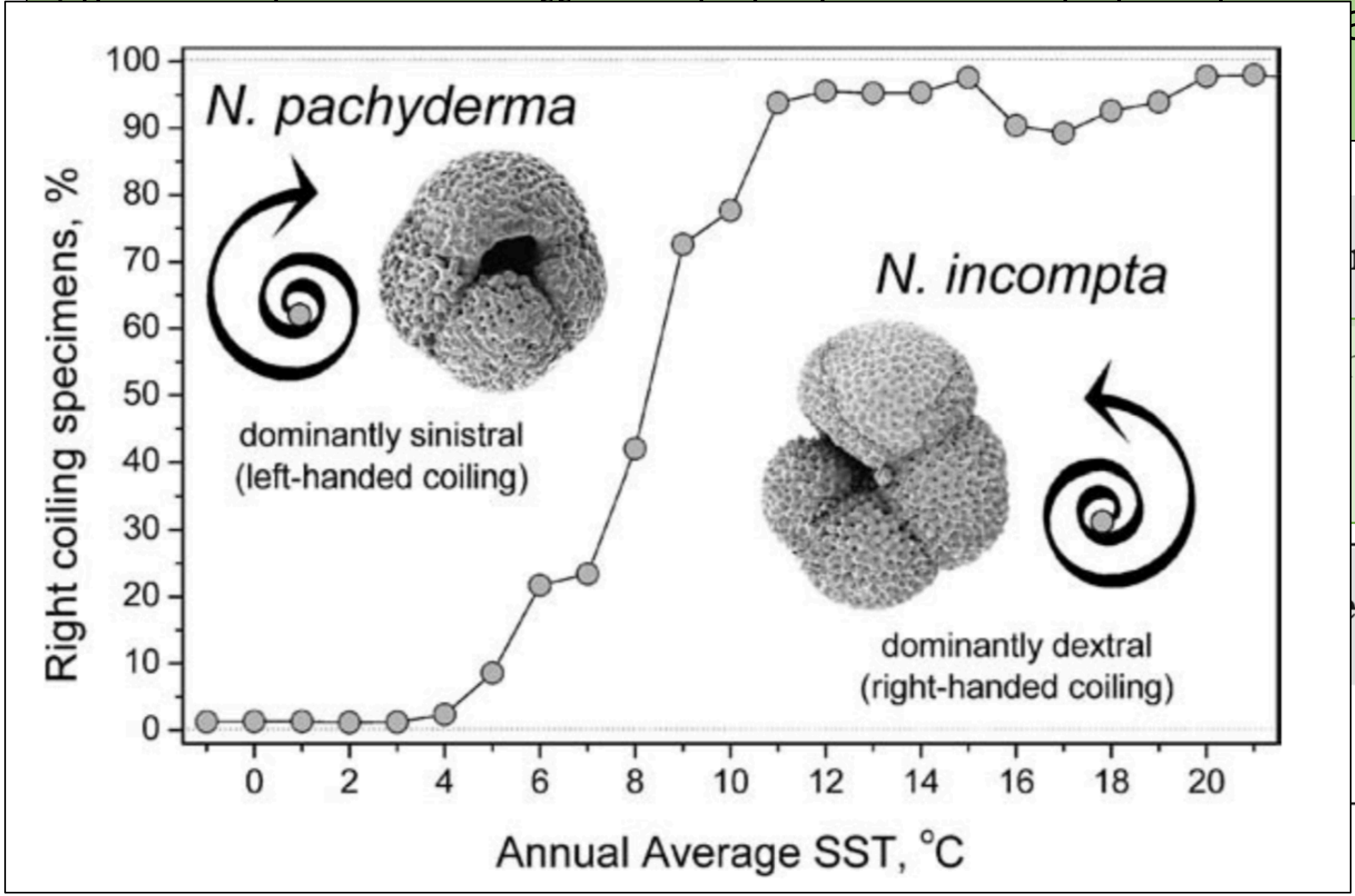


Kennett (1976) and Hecht (1976)

Kucera, 2007

Phisical properties

ate of their physical



Darling et al., 2006

ndividual specimens

nape

ed after deposition

Kucera, 2007

Phisical properties

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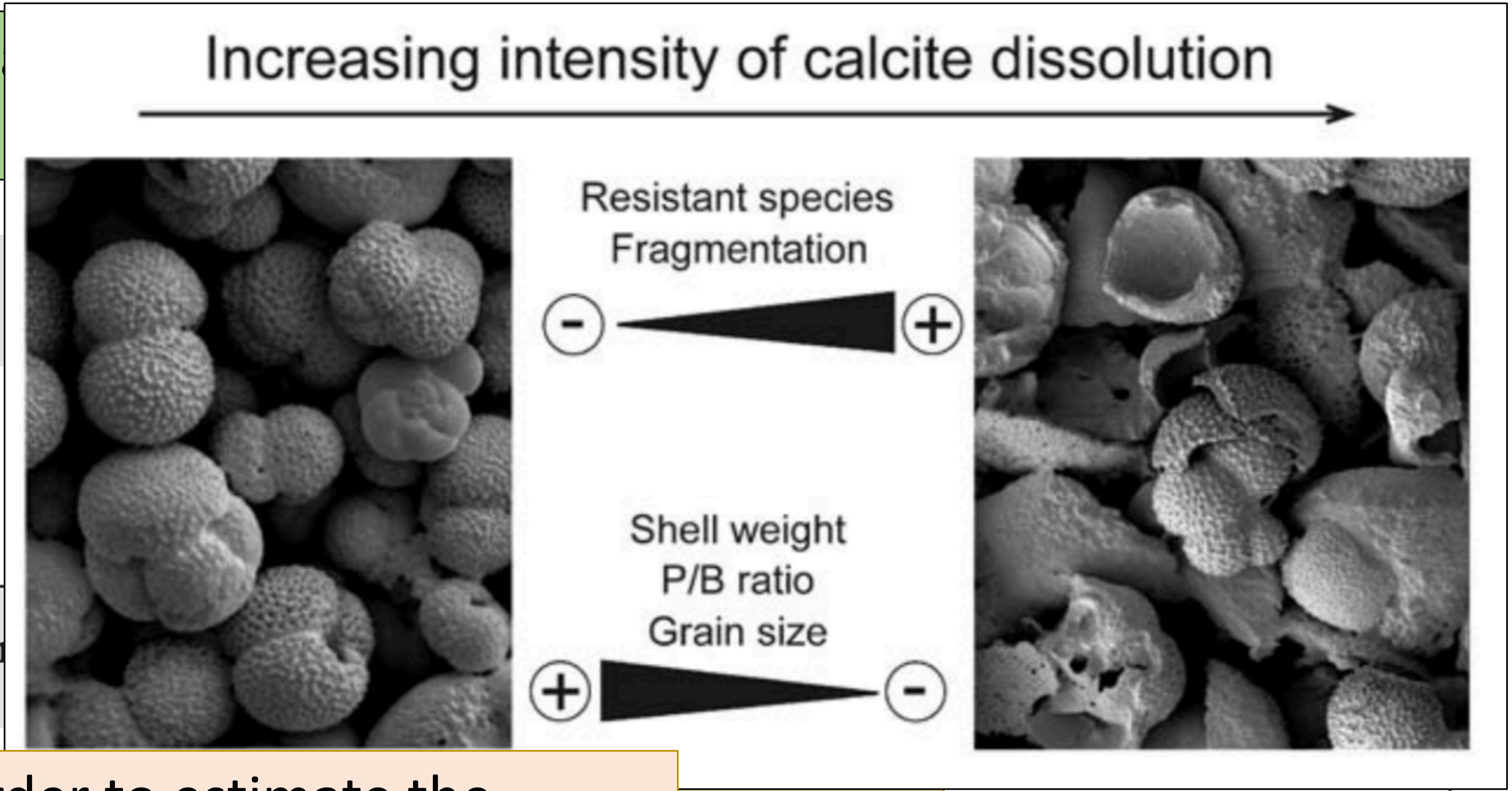
Kucera, 2007

Phisical properties

All organisms
environment.

Biometry

Modificatio



tion

Important in order to estimate the Calcite dissolution, when using geochemical proxies from shells.

Kucera, 2007

Mg/Ca and Sr/Ca ratios in planktonic foraminifera: Proxies for upper water column temperature reconstruction

Caroline Cléroux,[1] Elsa Cortijo,[1] Pallavi Anand,[2] Laurent Labeyrie,[1] Franck Bassinot,[1] Nicolas Caillon,[1] and Jean-Claude Duplessy[1]

Received 29 May 2007; revised 10 April 2008; accepted 20 May 2008; published 27 August 2008.

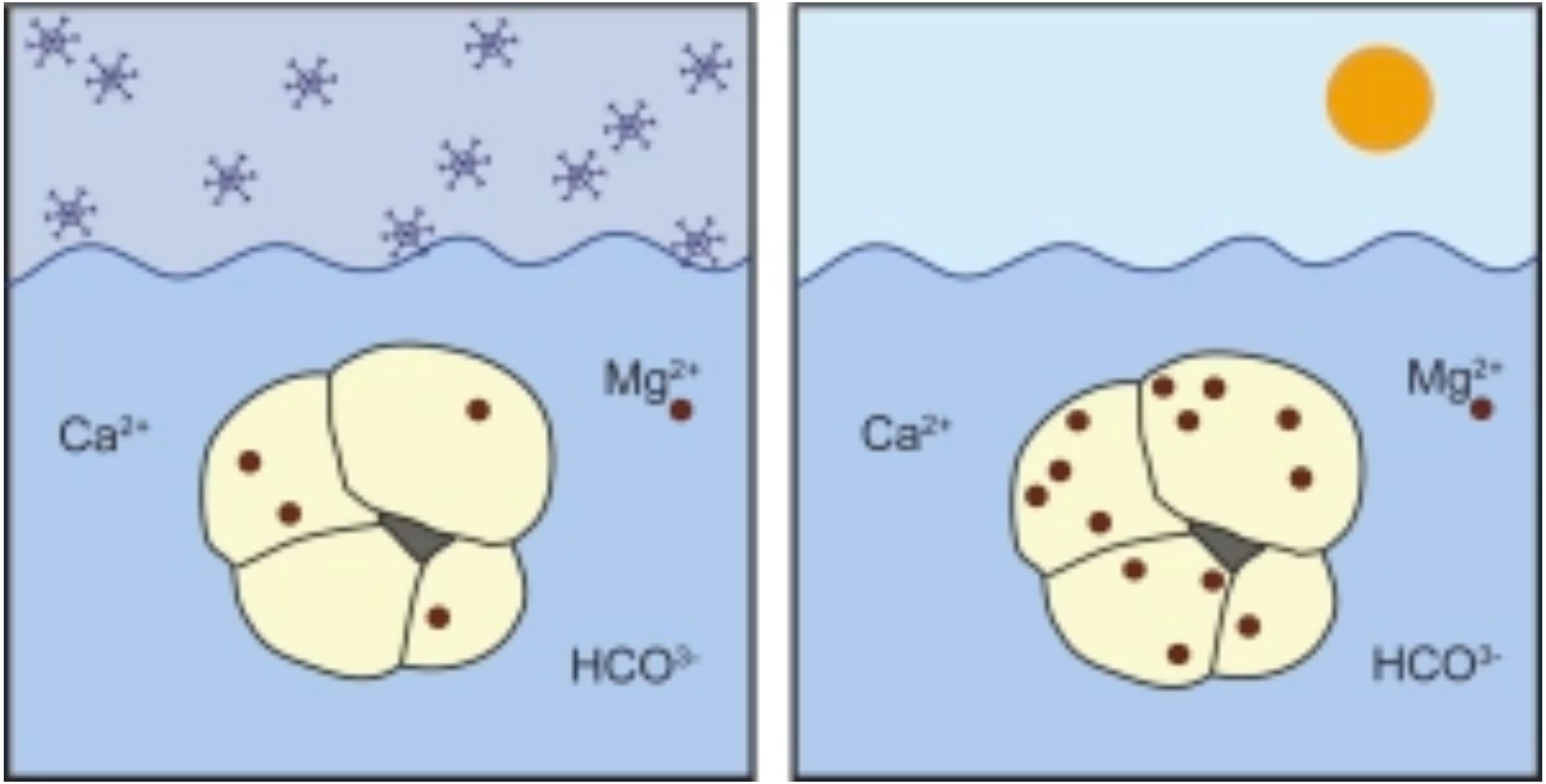
The effects of temperature, salinity, and the carbonate system on Mg/Ca in *Globigerinoides ruber* (white): A global sediment trap calibration

William R. Gray[a,*,1], Syee Weldeab[a], David W. Lea[a], Yair Rosenthal[b], Nicolas Gruber[c], Barbara Donner[d], Gerhard Fischer[d]

Nonthermal Influences on Mg/Ca in Planktonic Foraminifera: A Review of Culture Studies and Application to the Last Glacial Maximum

William R. Gray[1,2] and David Evans[3]

Mg/Ca ratio - Paleotemperature



https://foramsetal.wordpress.com/research/mgca-paleothermometry/

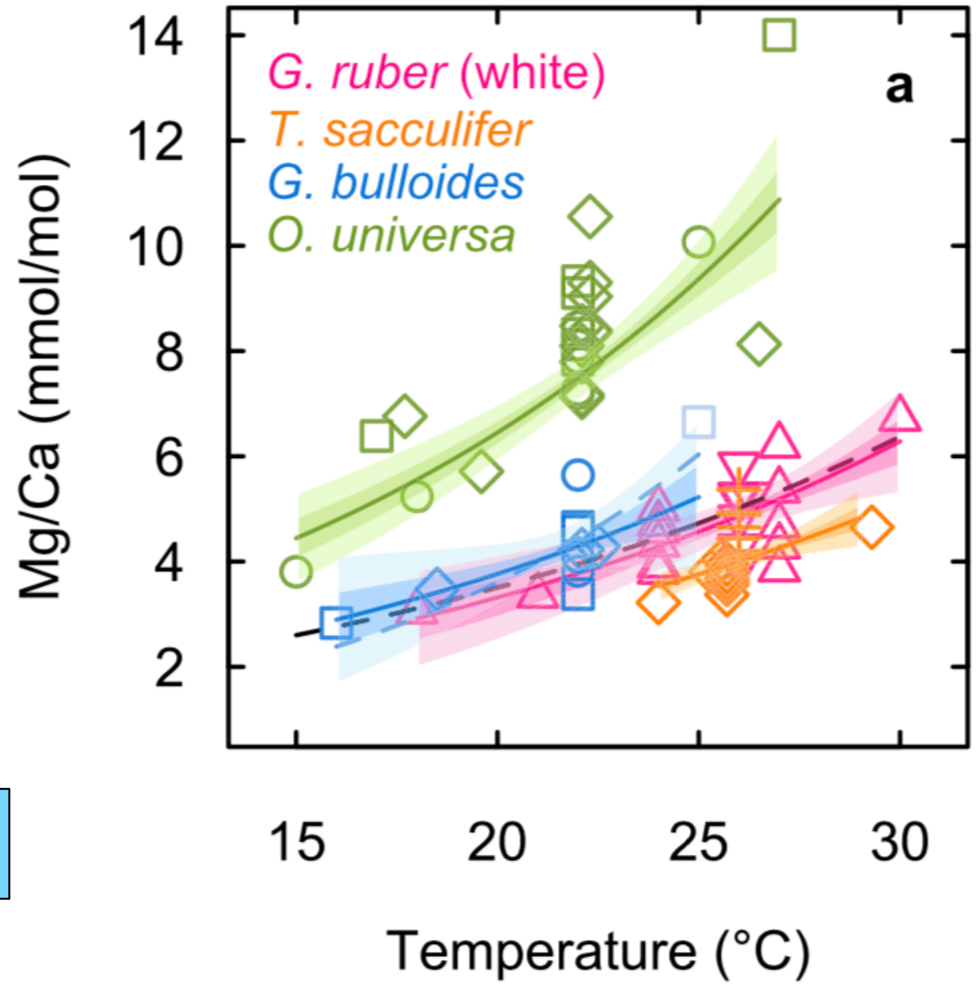
Mg/Ca ratio - Paleotemperature

- Fundamental to robust SST reconstruction is accurate knowledge of the relationship between foraminiferal Mg/Ca and temperature.
- Use of regression equation to calculate foraminifera Mg/Ca ratio dependency on calcification temperature:

$$Mg/Ca = B \exp (A \times T)$$

Cleroux et al., 2008

LABORATORY CULTURE



Gray and Evans, 2019

Barium in sediments off northwest Africa: A tracer for paleoproductivity or meltwater events?

K. Plewa,[1] H. Meggers,[1] and S. Kasten[2]

Received 20 January 20

Ba/Ca in *Neogloboquadrina pachyderma* as an indicator of deglacial meltwater discharge into the western Arctic Ocean

Jenney M. Hall

USA

SA

USA

arch 2004.

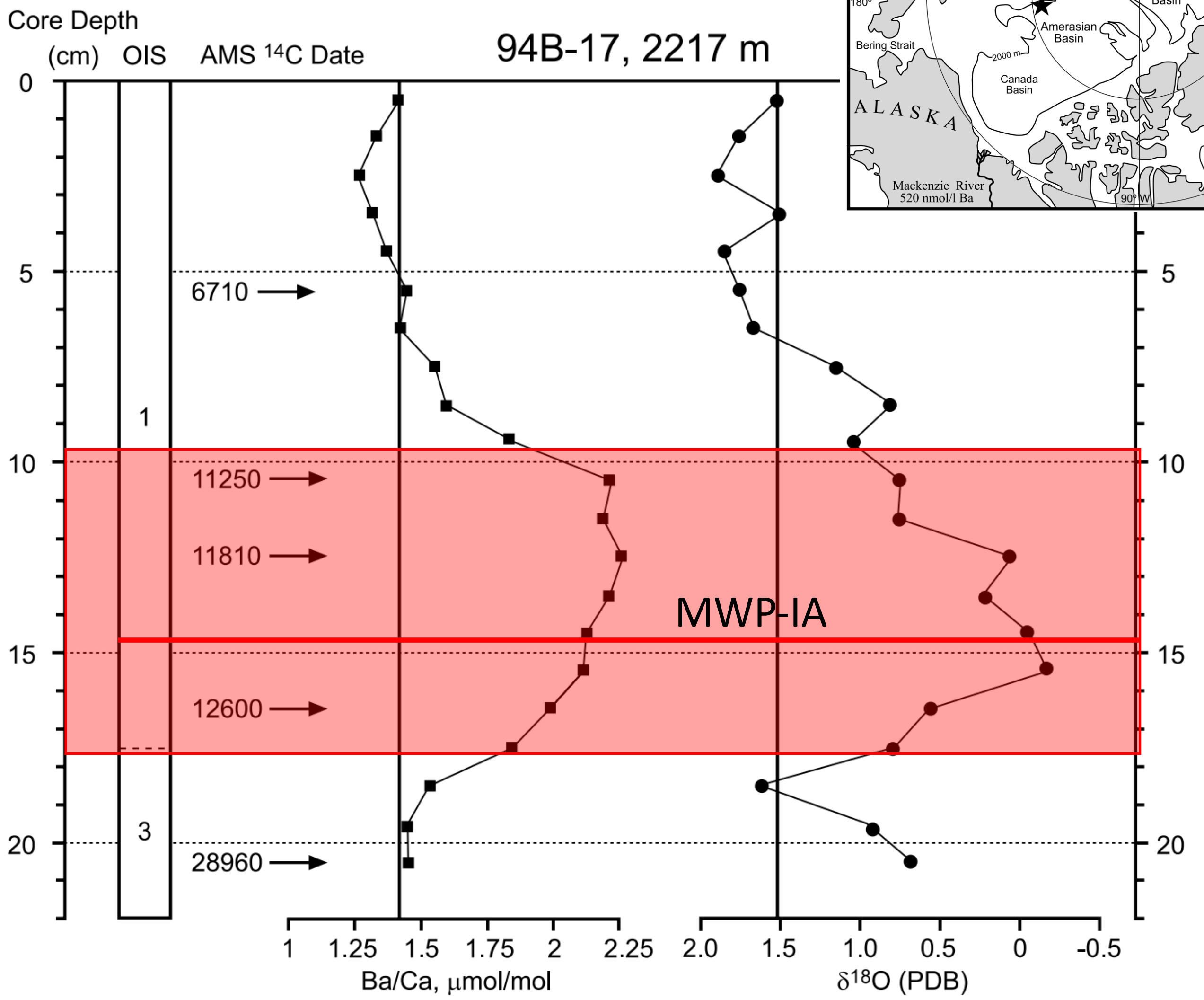
Comparison of water mass changes in the deep tropical Atlantic derived from Cd/Ca and carbon isotope records: Implications for changing Ba composition of deep Atlantic water masses

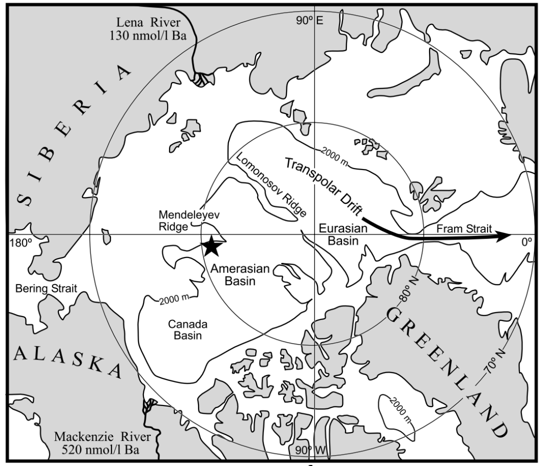
Pamela A. Martin and David W. Lea

Department of Geological Sciences and Marine Science Institute, University of California, Santa Barbara

Ba/Ca ratio - Meltwater discharge

- The main source of Barium to the ocean are **rivers, bedrock weathering in drainage basins**.
- Ba incorporation into foraminifera tests occurs in direct proportion to seawater concentration.
- A combination of Ba/Ca and d^{18}O in the planktonic foraminifer *N. pachyderma* sin. can be used as a proxy for continental meltwater discharge.





Hall and Chan, 2004

Planktonic foraminiferal Cd/Ca: Paleonutrients or Paleotemperature?

R. E. M. Rickaby and H. Elderfield

Department of Earth Sciences, University of Cambridge, Cambridge, England, United Kingdom

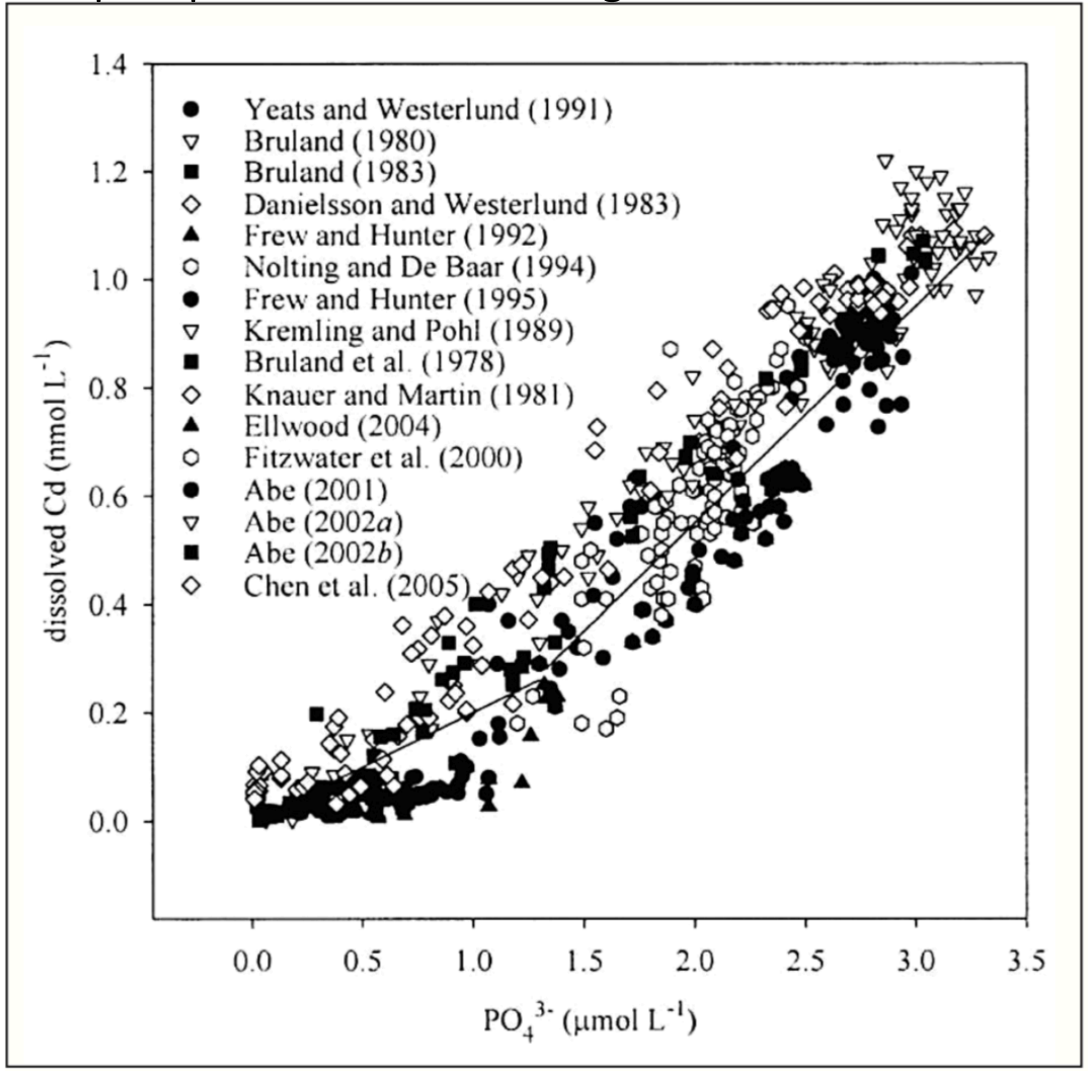
On the nonlinear relationship between dissolved cadmium and phosphate in the modern global ocean: Could chronic iron limitation of phytoplankton growth cause the kink?

Jay T. Cullen[1]

University of Victoria, School of Earth and Ocean Sciences, P.O. Box 3055 STN CSC, Victoria, British Columbia V8W 3P6, Canada

Cd/Ca ratio - Paleoproductivity

Nonlinear relationship between dissolved cadmium and phosphate in the modern global ocean.



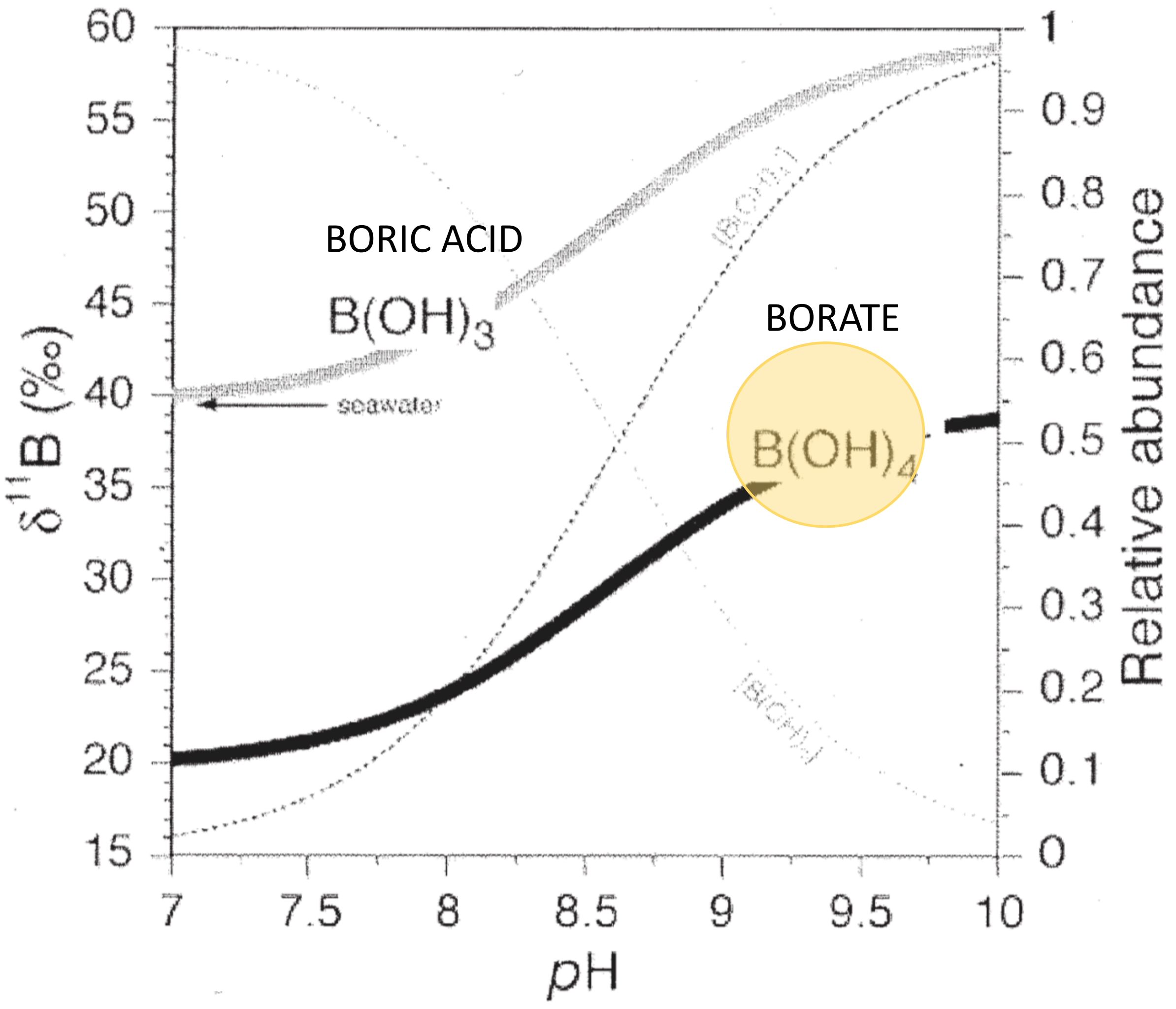
- Cd is a micronutrient.

- Cd is partitioned into planktonic foraminiferal calcite in direct proportion to the Cd concentration of surface water
    - then planktonic Cd/Ca offers great potential as an alternative tracer of surface water paleoproductivity.

Cullen et al., 2006

pH: boron isotopic composition ($\delta^{11}B$)

Dissolved boron in seawater



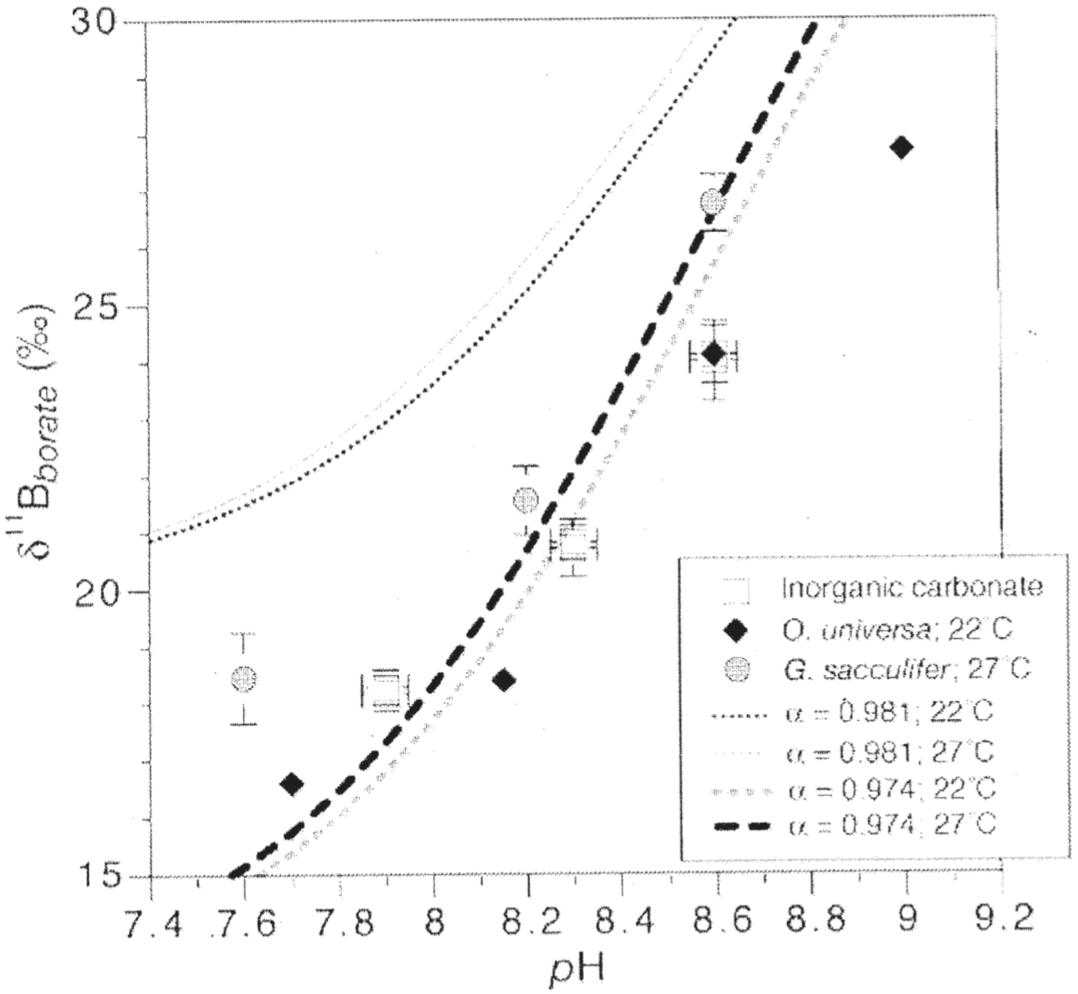
Pagani et al., 2004

- Carbonates forming in marine environments incorporate trace amounts of boron into their structures during growth through incorporation of the charged borate $B(OH)_4^-$.
- Theoretical model of carbonate $\delta^{11}B$ assumes that measurement of the isotopic composition of boron trapped in ancient carbonate shells, give the boron isotopic composition of only borate, could conceivably be used to estimate the pH of ancient seawater.

$$\delta 11B_{carb} = \delta 11B_{borate}$$

Mortyn and Martinez-Botí, 2007

pH: boron isotopic composition ($\delta^{11}B$)



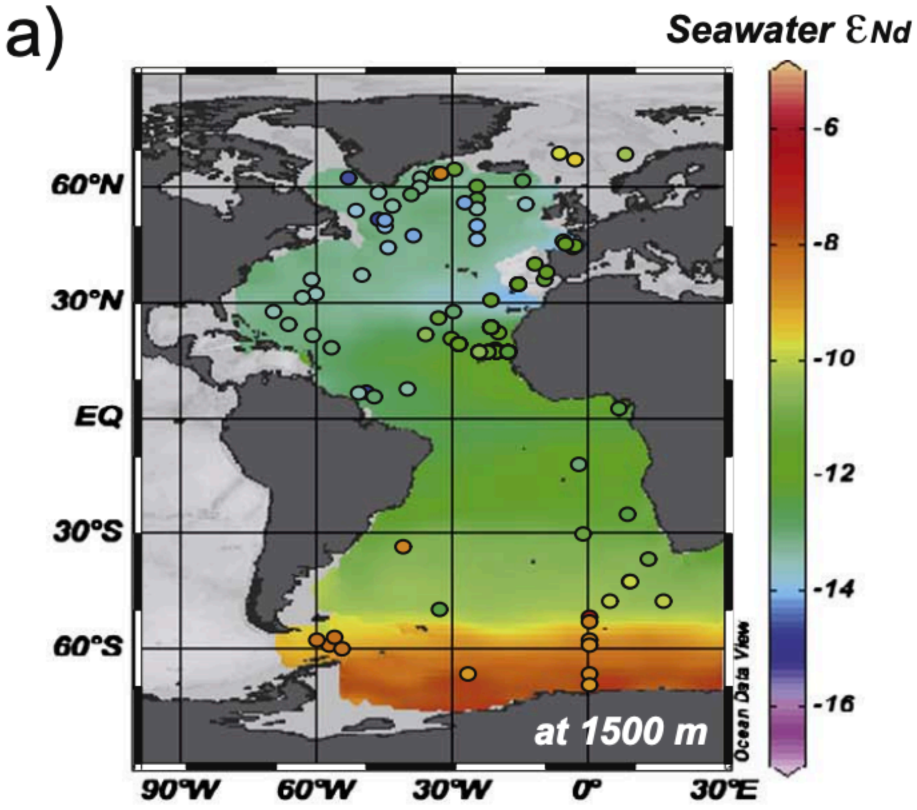
Pagani et al., 2004

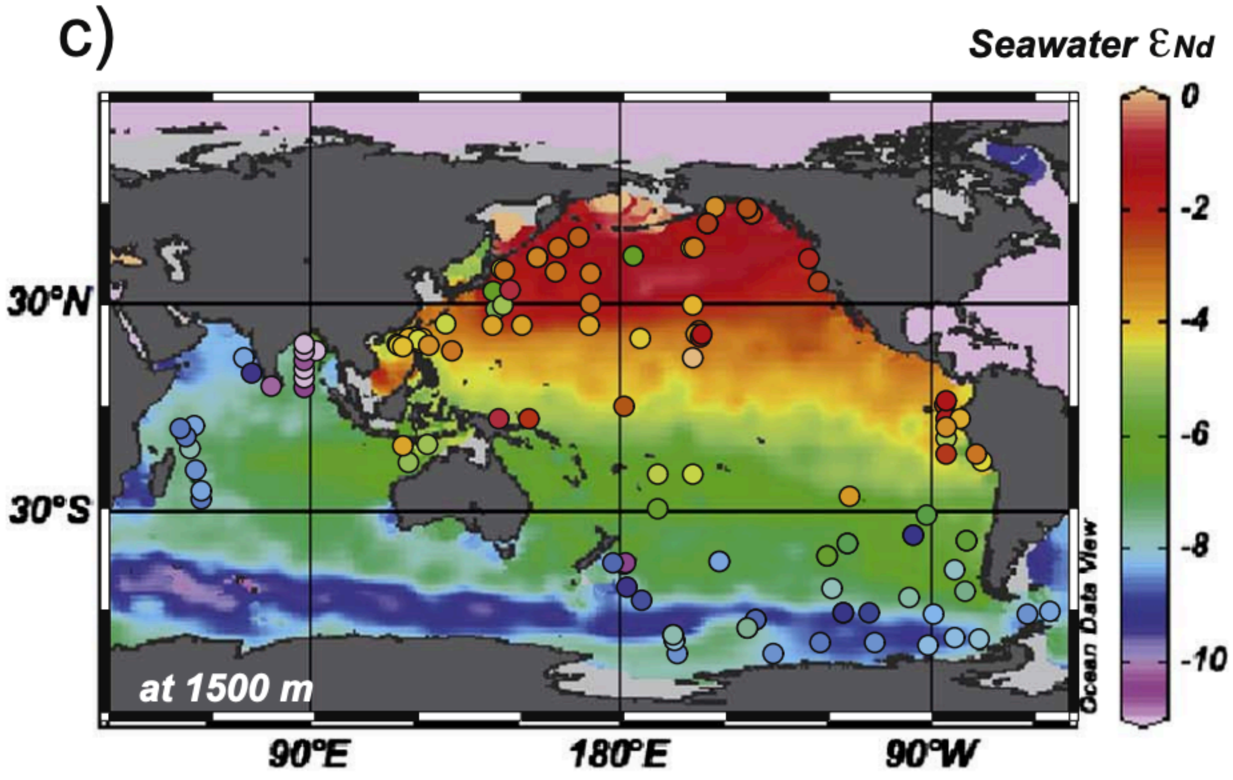
Since the pH of seawater is directly related to atmospheric pCO_2

$\delta^{11}B$ measured in foraminiferal tests have been used to derive pH values and consequently pCO2

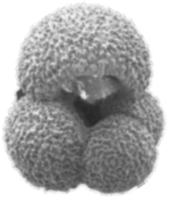
Mortyn and Martinez-Botí, 2007

Nd isotopic composition (εNd)





foraminifera Fe-Mn-oxide coatings



- The variability of εNd can be used to infer past changes in both continental weathering processes and oceanic circulation.

Tachikawa et al., 2017

ForCenS coretop database

SCIENTIFIC DATA

OPEN

Data Descriptor: ForCenS, a curated database of planktonic foraminifera census counts in marine surface sediment samples

Received: 31 March 2017
Accepted: 20 June 2017
Published: 22 August 2017

Michael Siccha & Michal Kucera

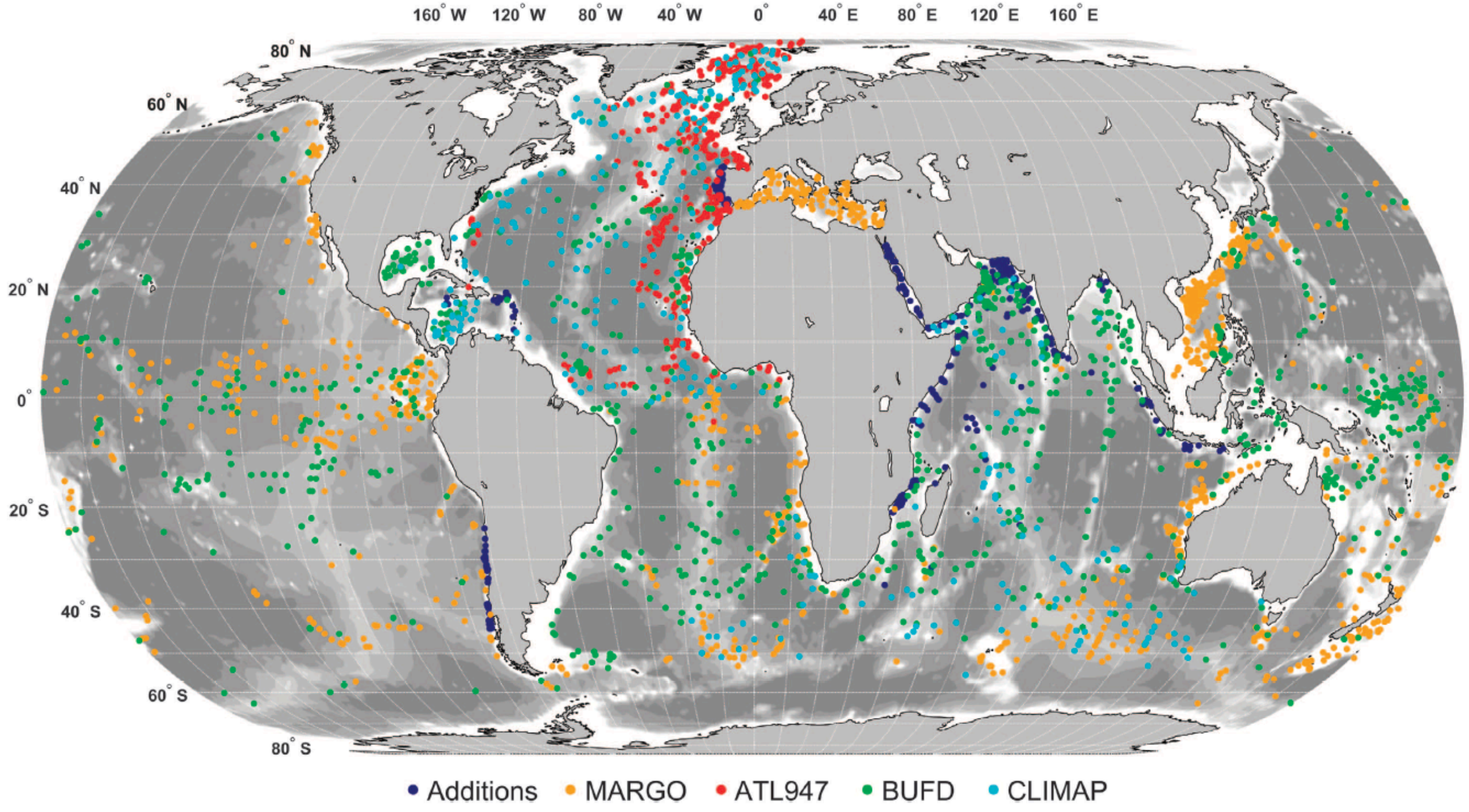


Figure 1. Location of all census counts retained in the ForCenS compilation. Colours denote the sample source, the first occurrence of a sample in a compilation taking precedence over reuse in later compilations.

SP.	MAX.	MIN.
Globigerinoides_ruber	80.9 %	0.4 %
Neogloboquadrina_incompta	71.6 %	0.0 %
Globoconella_inflata	54.2 %	0.0 %
Globigerina_bulloides	53.9 %	1.7 %
Globorotalia_truncatulinoides	36.3 %	0.0 %
Orbulina_universa	19.8 %	0.0 %
Neogloboquadrina_dutertrei	18.7 %	0.0 %
Trilobatus_Saculifer	17.2 %	0.0 %
Globigerinella_calida	13.5 %	0.0 %
Globigerinita_glutinata	12.4 %	0.0 %
Globigerina_falconensis	11.1 %	0.0 %
Globigerinella_siphonifera	11.1 %	0.0 %
Turborotalita_quinqueloba	9.1 %	0.0 %
Globoturborotalita_rubescens	8.8 %	0.0 %
Globorotalia_scitula	6.0 %	0.0 %
Globigerinoides_tenellus	4.0 %	0.0 %
Beella_digitata	4.0 %	0.0 %
Neogloboquadrina_pachyderma	1.4 %	0.0 %

SP.	MAX.	MIN.
Globigerinoides_ruber	80.9 %	0.4 %
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Globoconella_inflata	54.2 %	0.0 %
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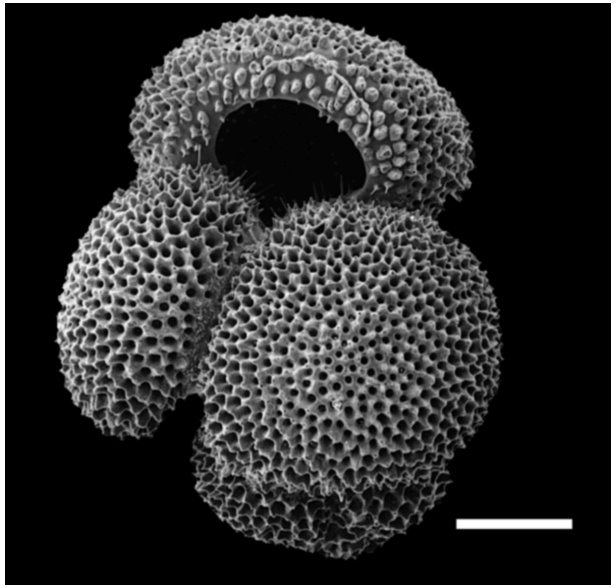
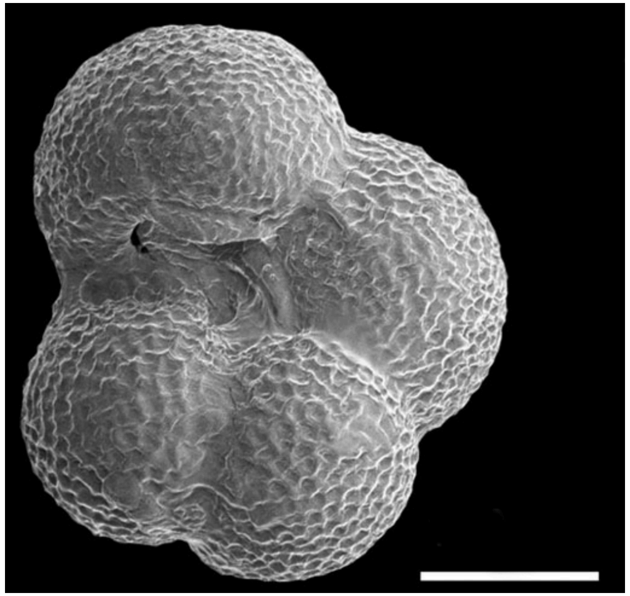
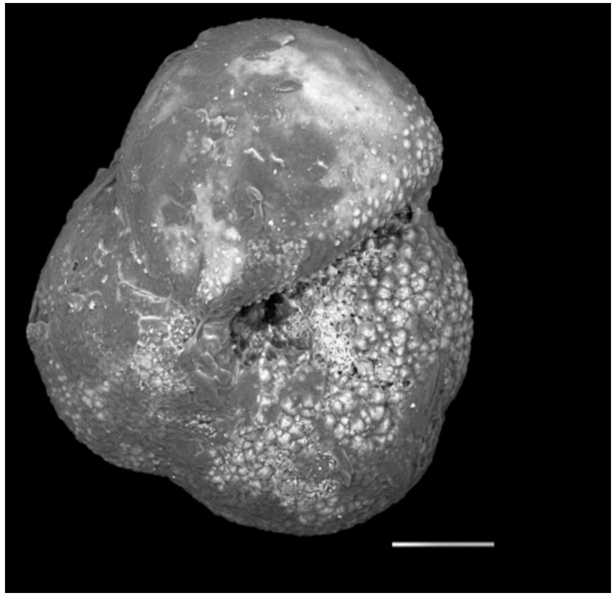
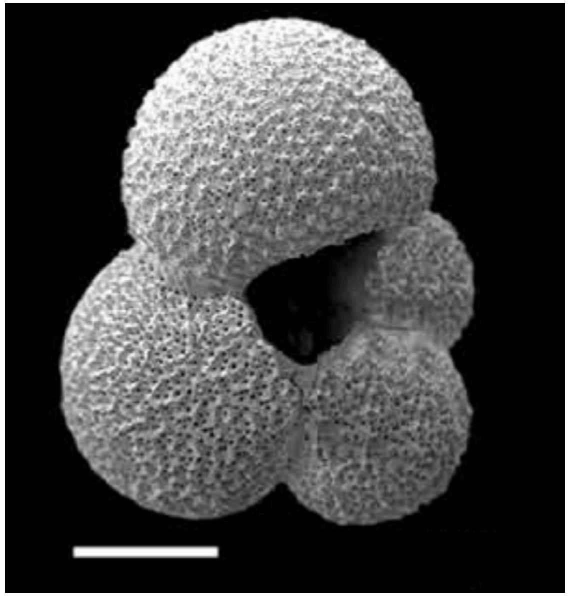
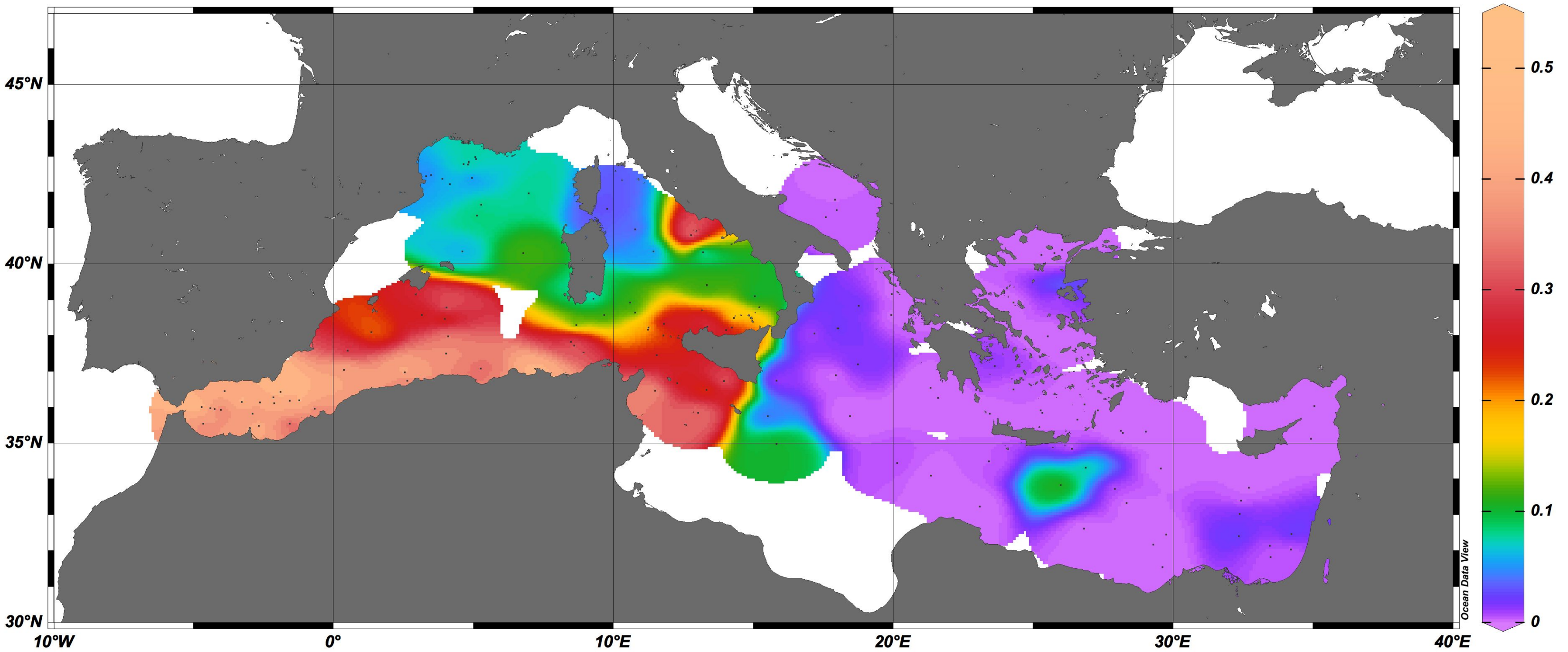
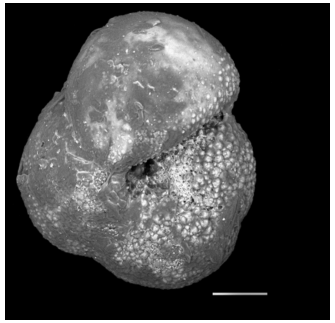




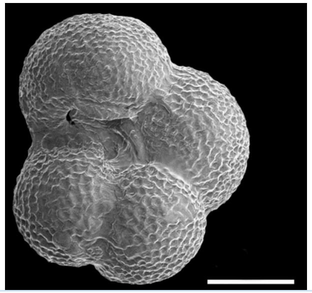




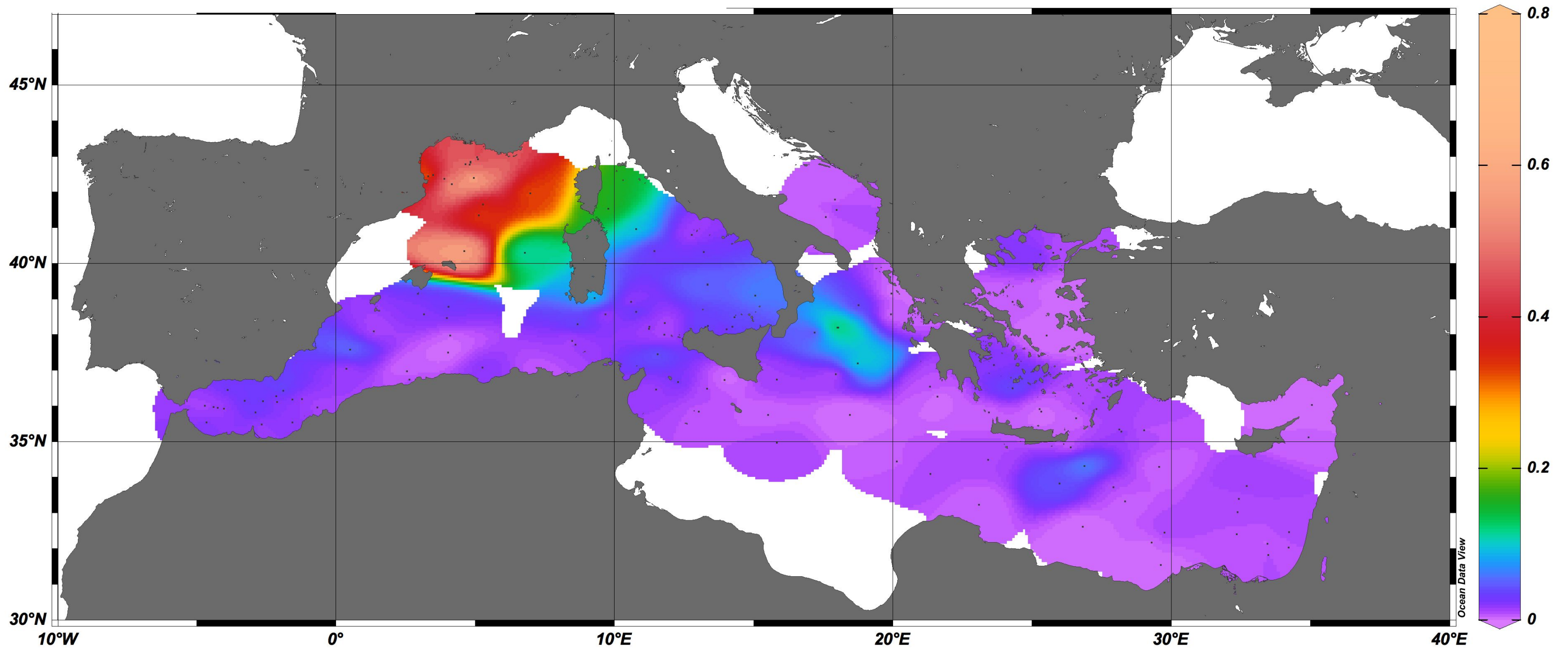


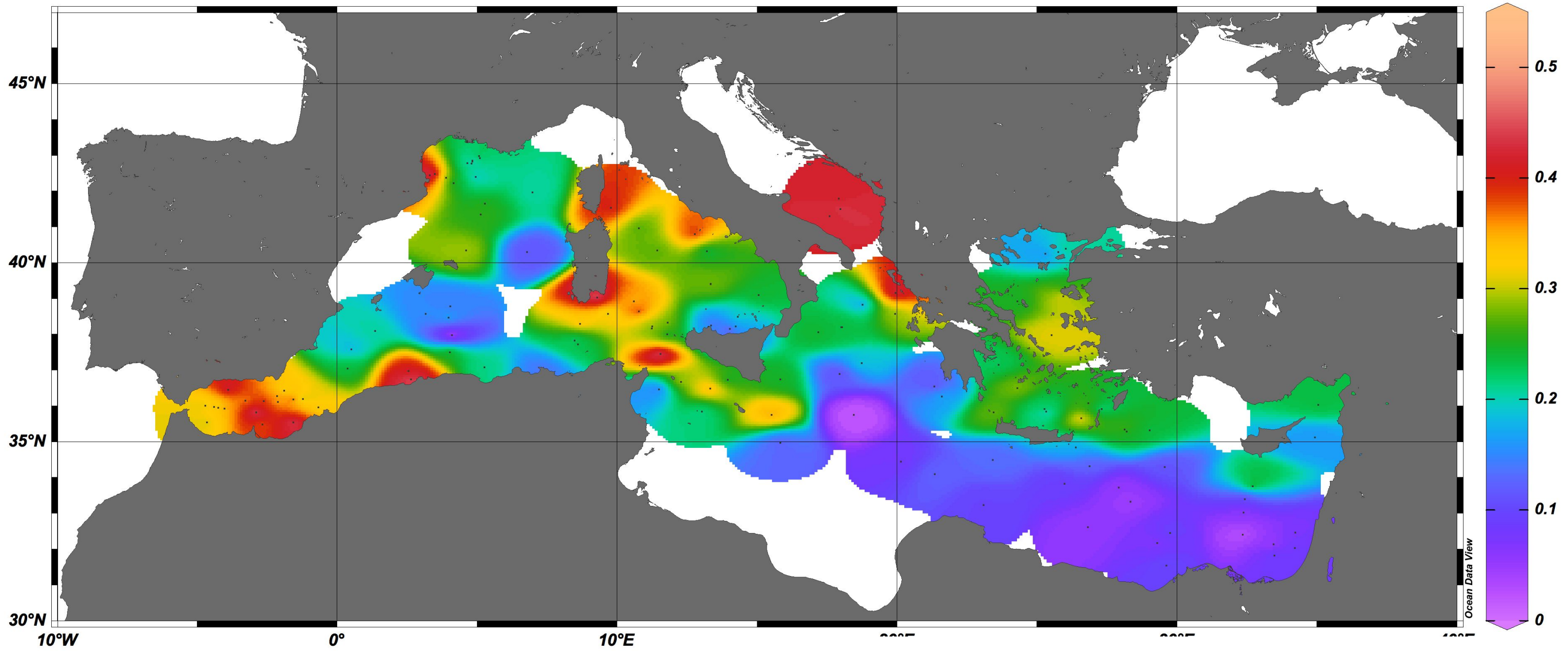


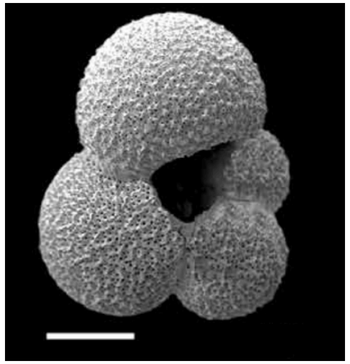
Globoconella inflata



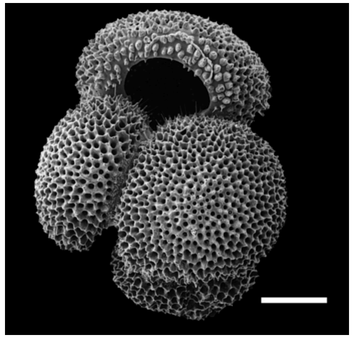
Neogloboquadrina_incompta



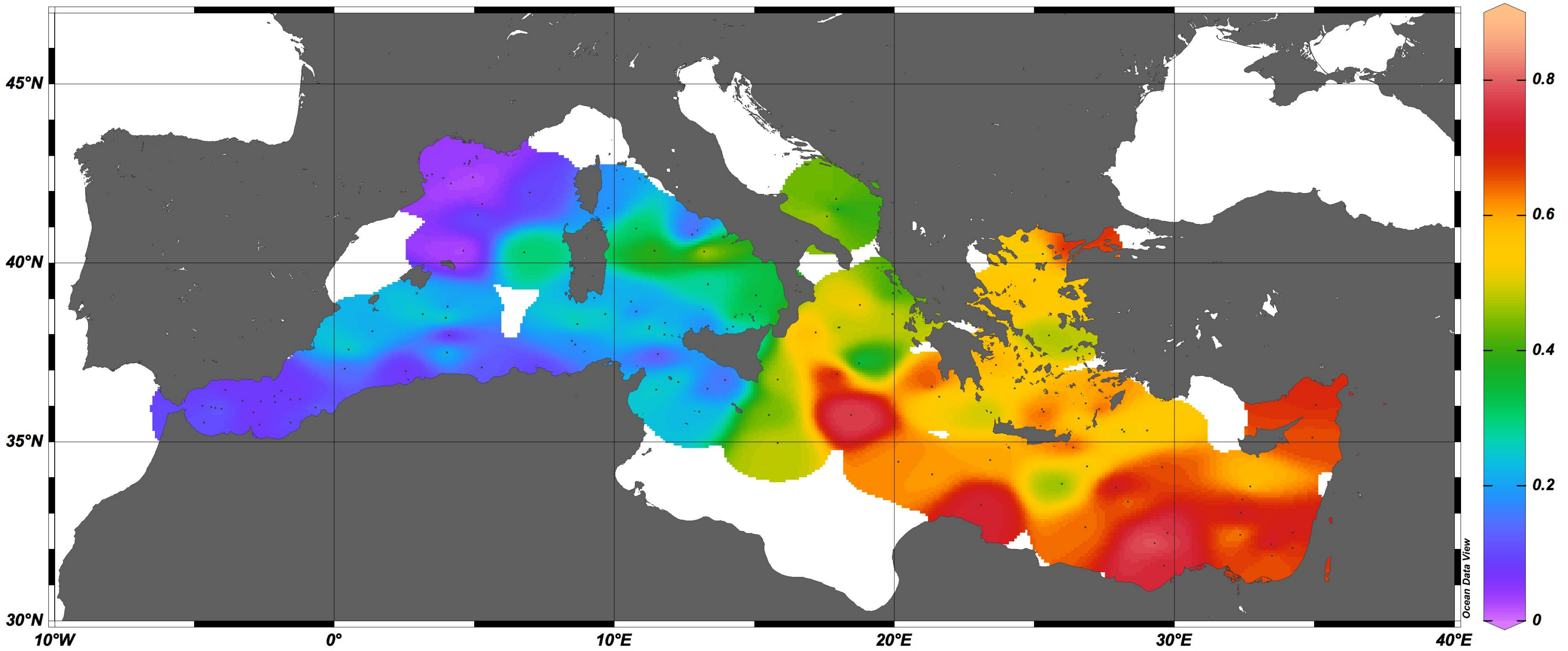




Globigerina bulloides



Globigerinoides_ruber



WHY?

WOA 1998
SST

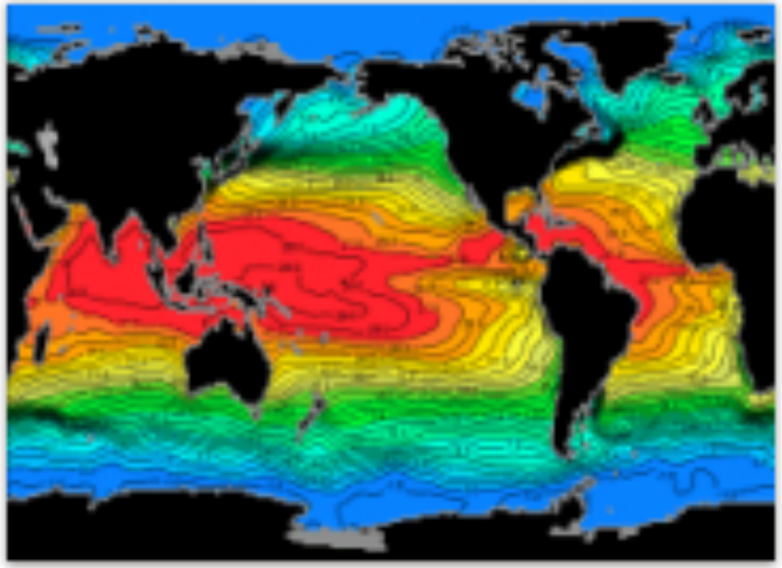
World Ocean Atlas 1998 Figures (WOA98F)

Temperature, Salinity, Oxygen, Nutrients, Chlorophyll

Objectively Analyzed Fields and Statistics

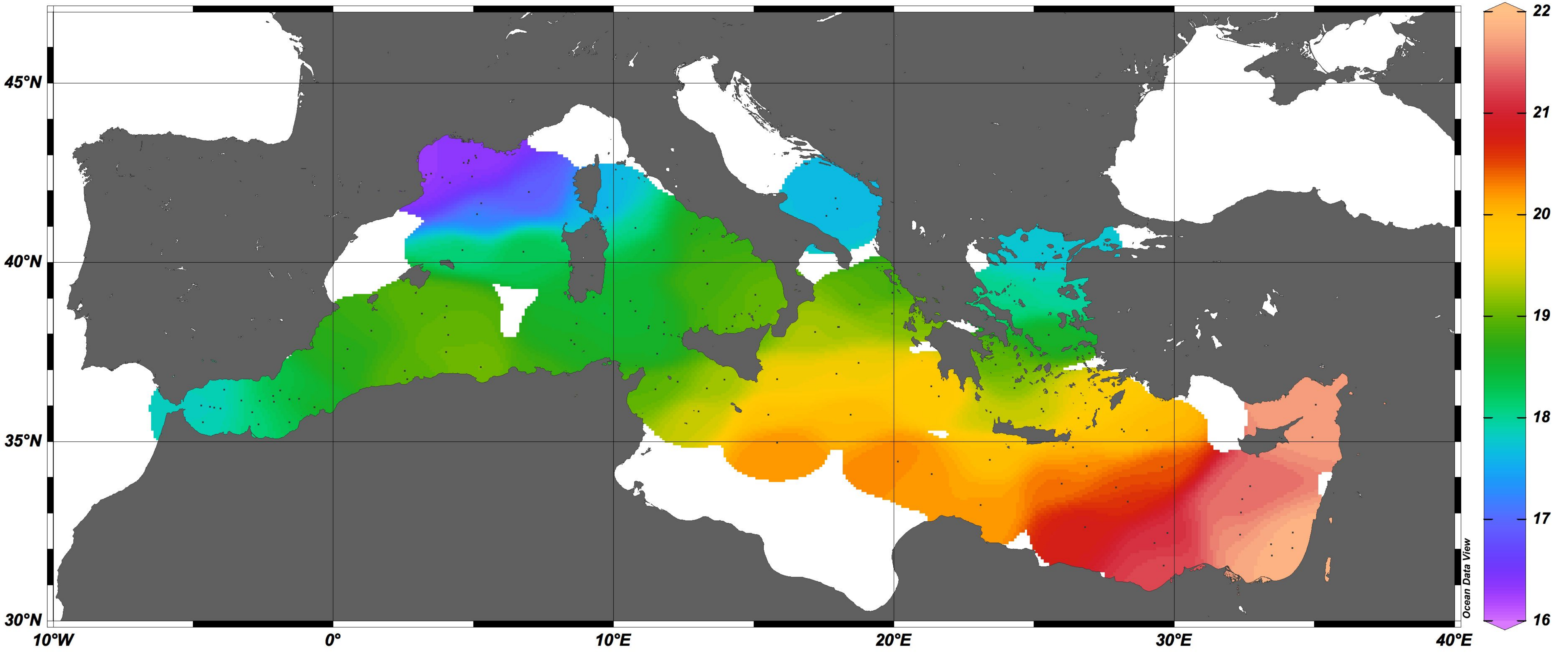
Ocean Climate Laboratory

National Oceanographic Data Center

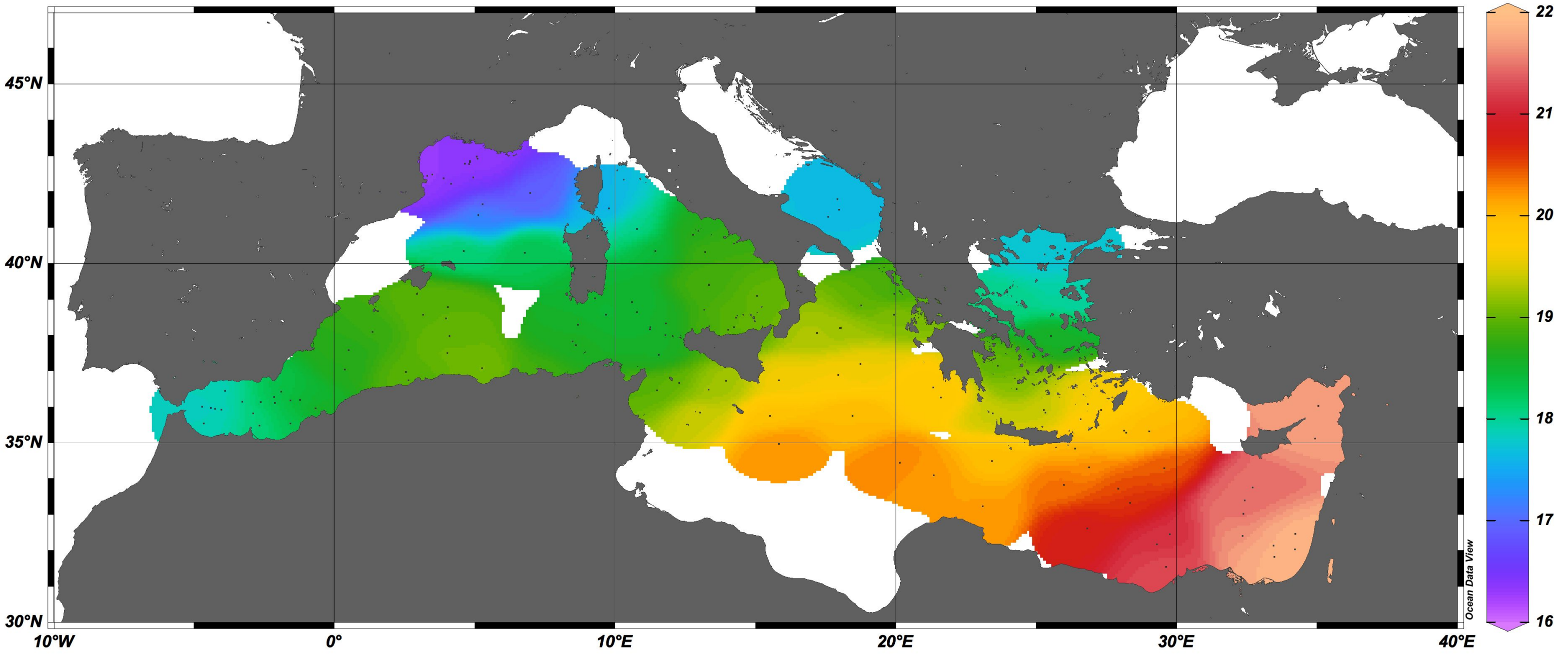


Version 1.0
April, 1999

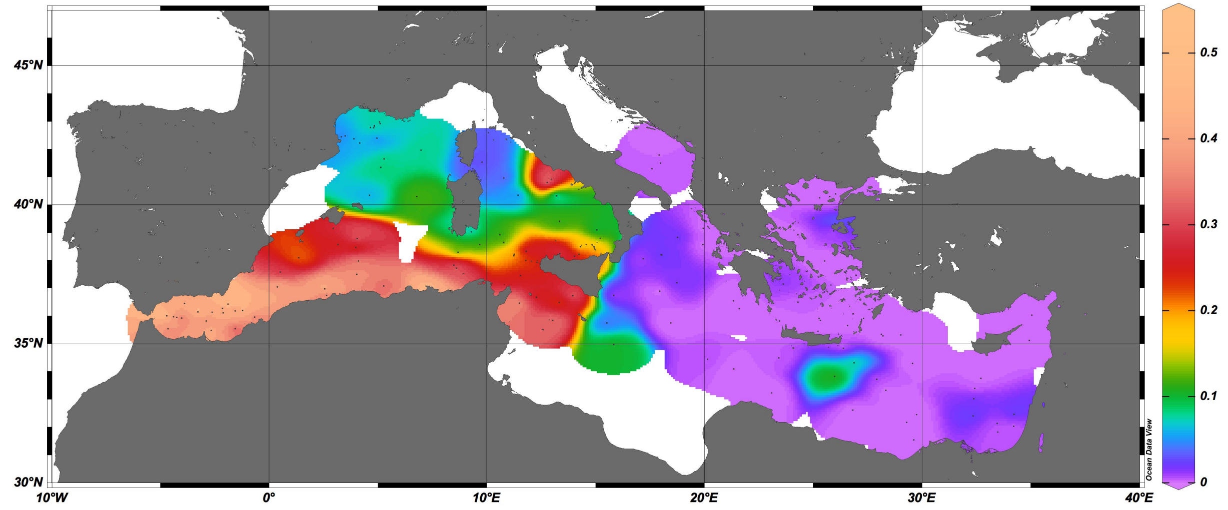
ANUAL MEAN SEA SURFACE TEMPERATURE (SST)



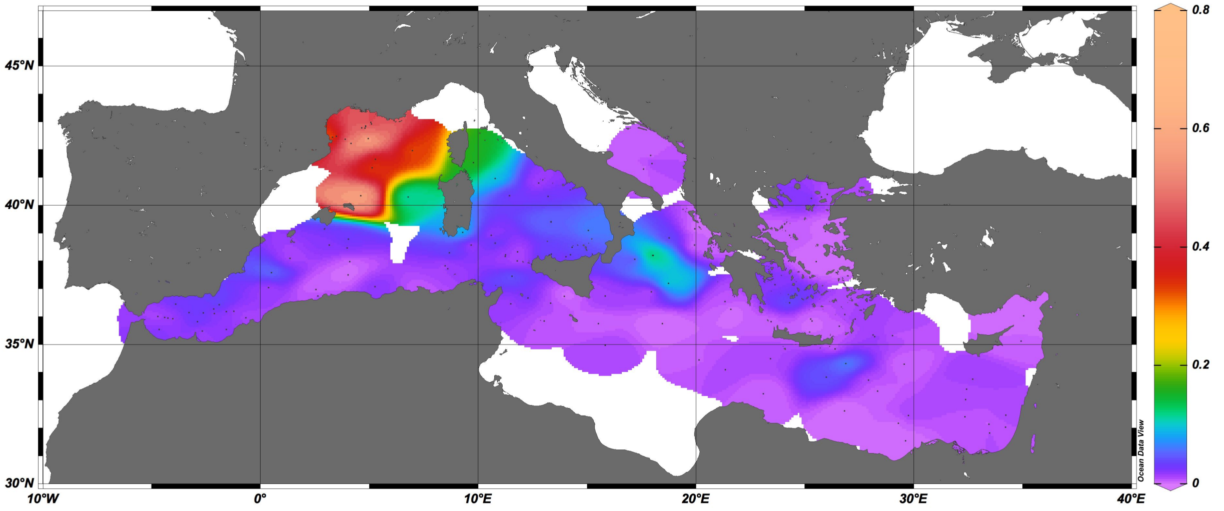
ANUAL MEAN SEA SURFACE TEMPERATURE (SST)



Globoconella_inflata



Neogloboquadrina_incompta



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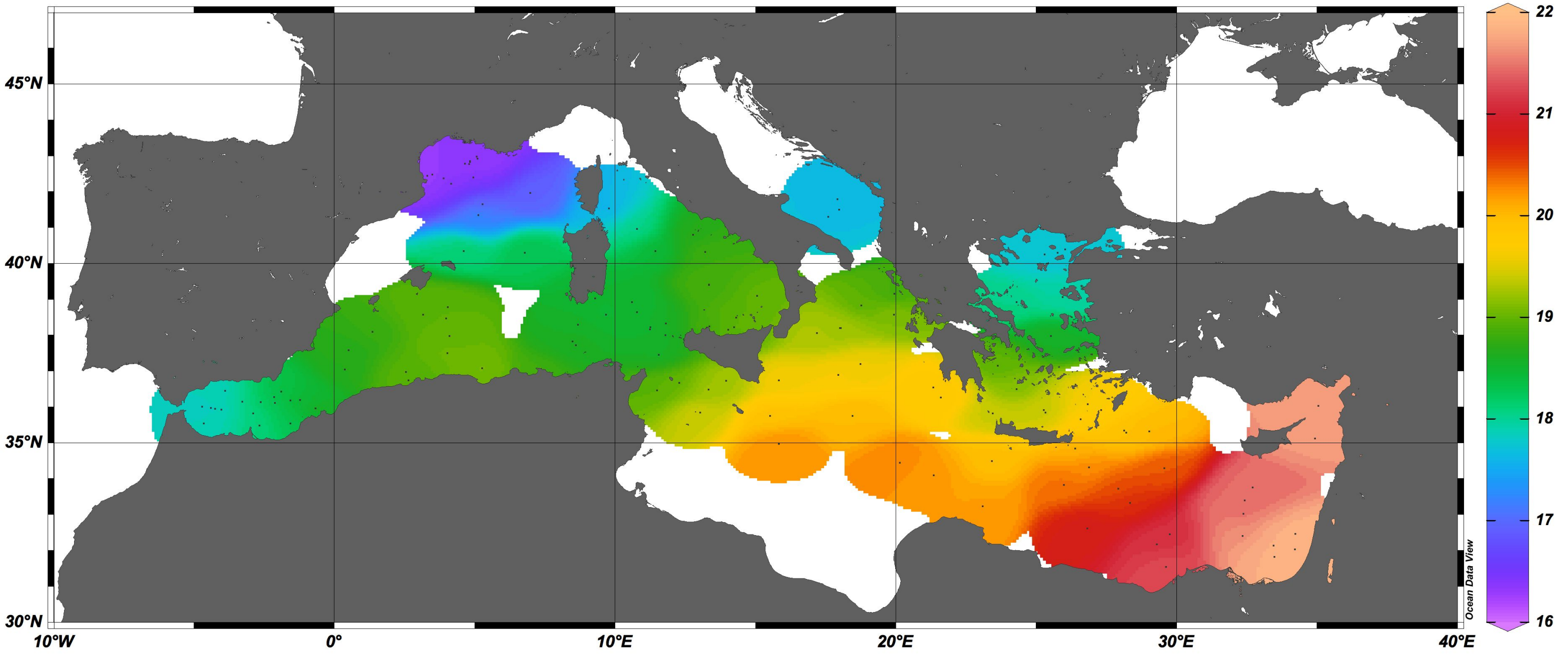
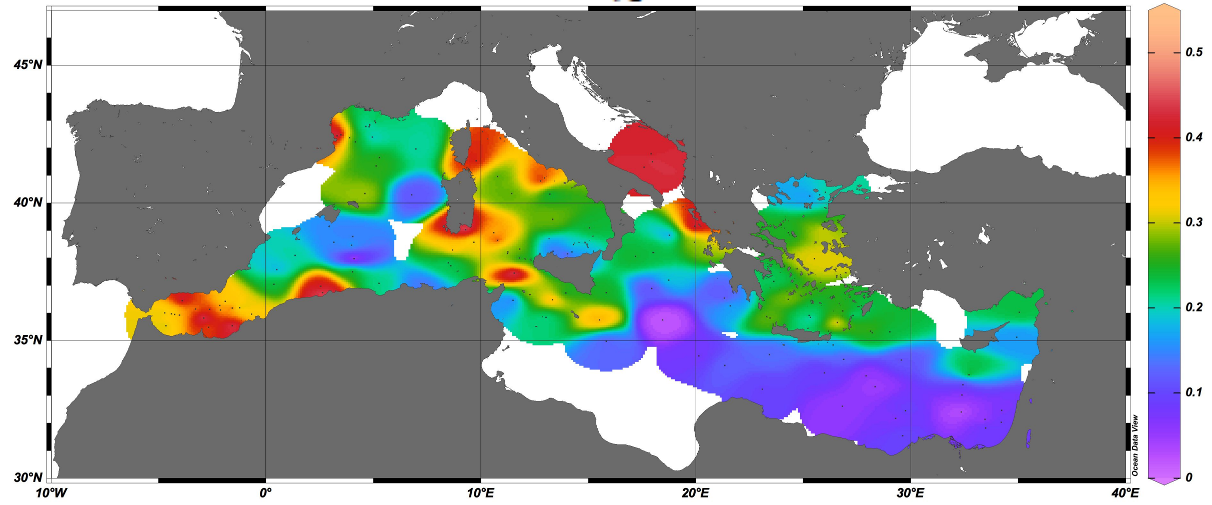
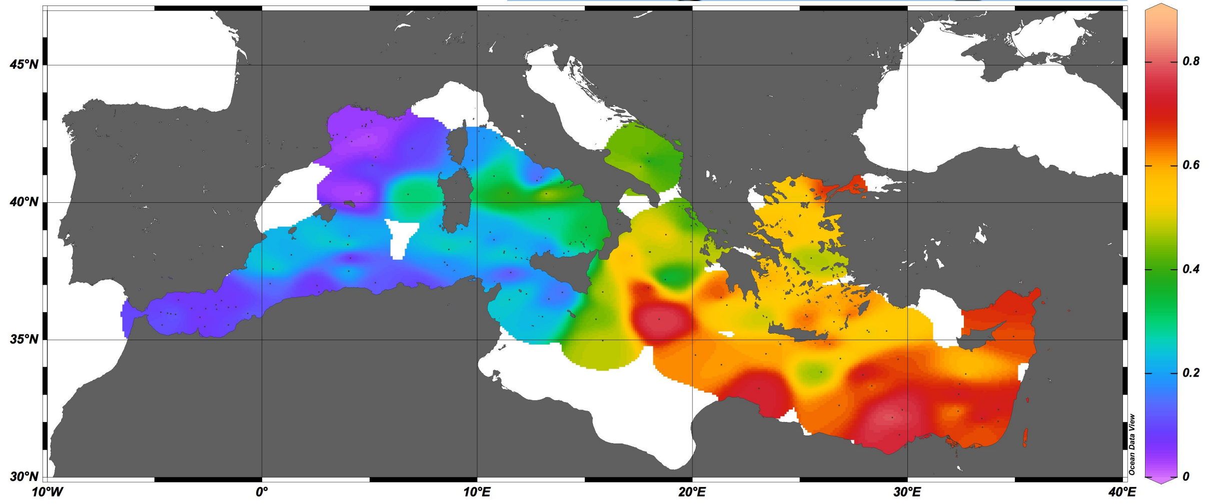
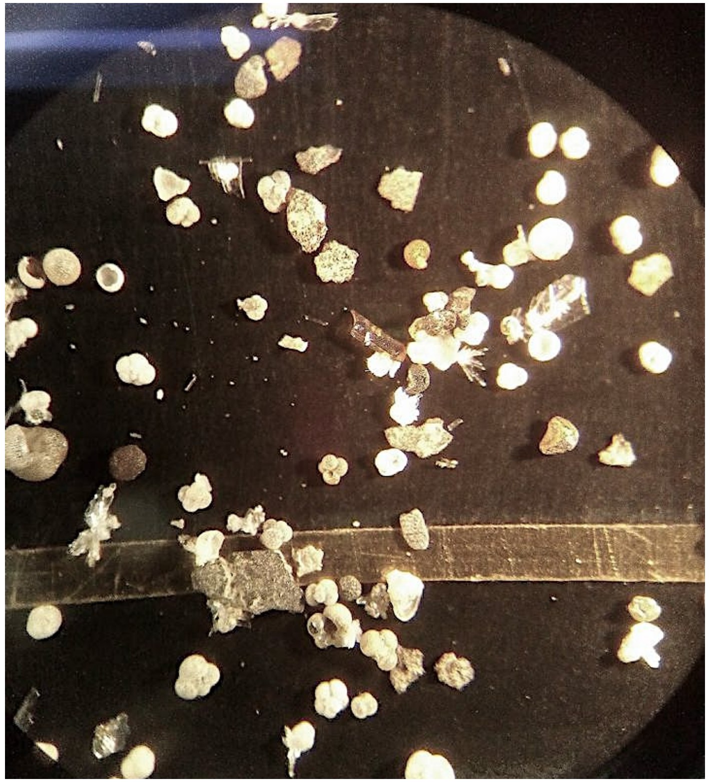


Globigerina_bulloides



Globigerinoides_ruber





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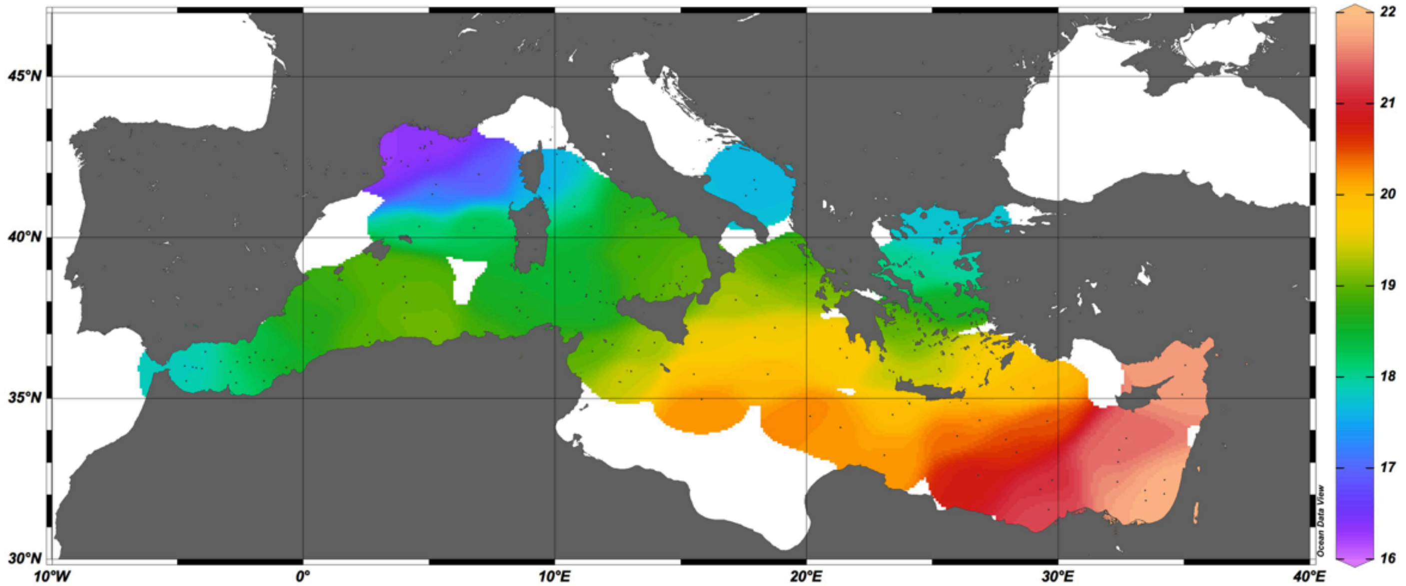
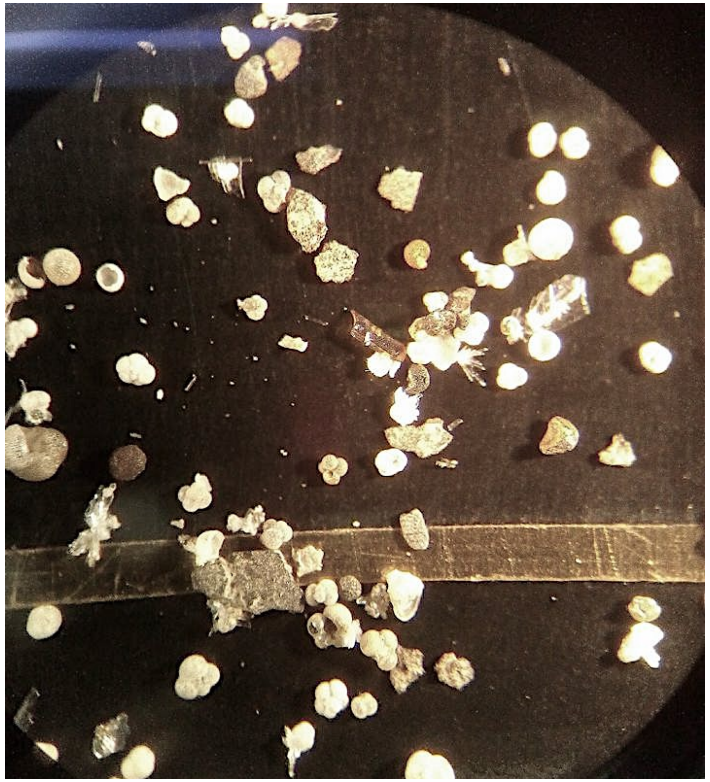
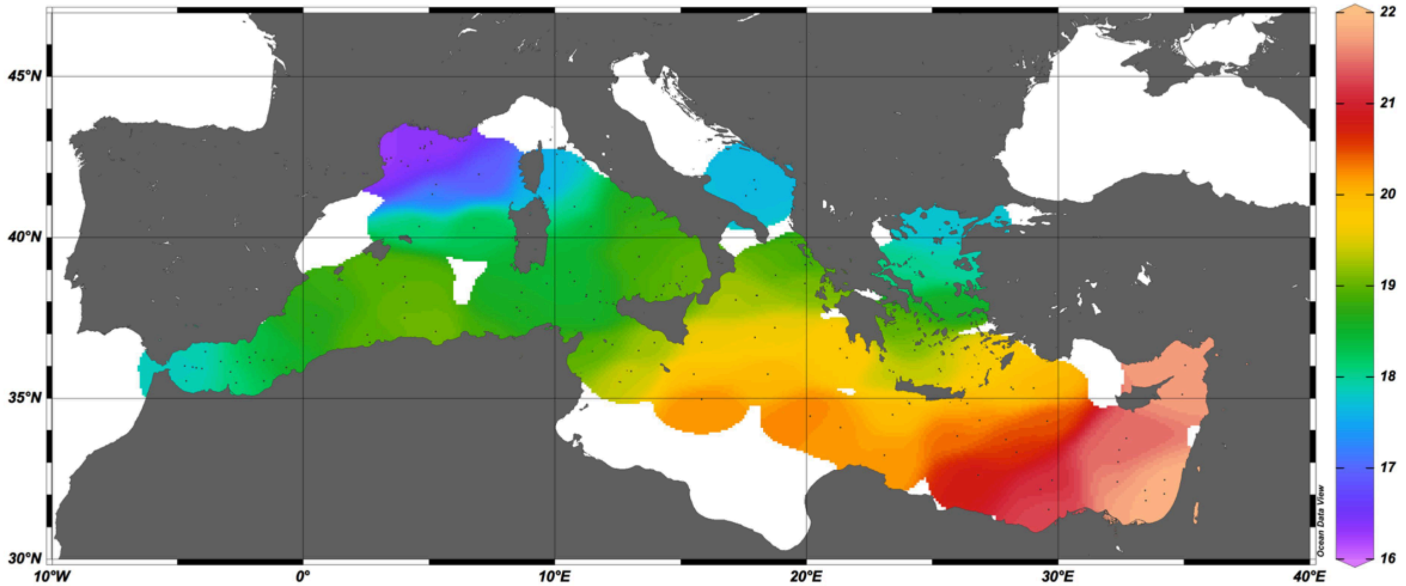


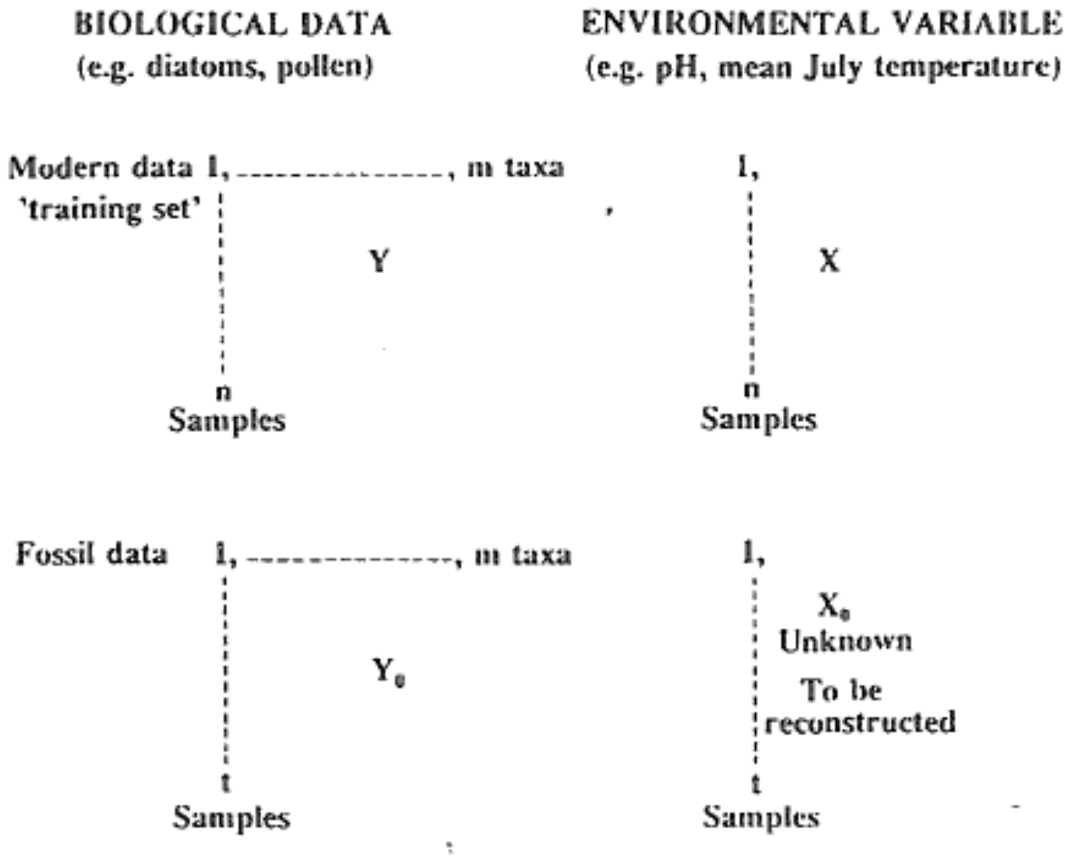


ANUAL MEAN SEA SURFACE TEMPERATURE (SST)



?

BASIC IDEA OF QUANTITATIVE ENVIRONMENTAL RECONSTRUCTION



The modern relationships between Y and X are modelled statically and the resulting function is the used as a transfer function to transform the fossil data Y_0 into quantitative estimates of the past environmental variable X_0.

-MAT / RAM
-WA
-ARTIFICIAL NEURAL NETWORKS

ELSEVIER

Quaternary Science Reviews 24 (2005) 951–998

QSR

Reconstruction of sea-surface temperatures from assemblages of planktonic foraminifera: multi-technique approach based on geographically constrained calibration data sets and its application to glacial Atlantic and Pacific Oceans

Michal Kucera[a,*], Mara Weinelt[b], Thorsten Kiefer[c], Uwe Pflaumann[b], Angela Hayes[a,d], Martin Weinelt[e], Min-Te Chen[f], Alan C. Mix[g], Timothy T. Barrows[h], Elsa Cortijo[i], Josette Duprat[j], Steve Juggins[k], Claire Waelbroeck[i]

Table 2
Overview of the MARGO planktonic foraminifer data sets with prediction errors for individual regions

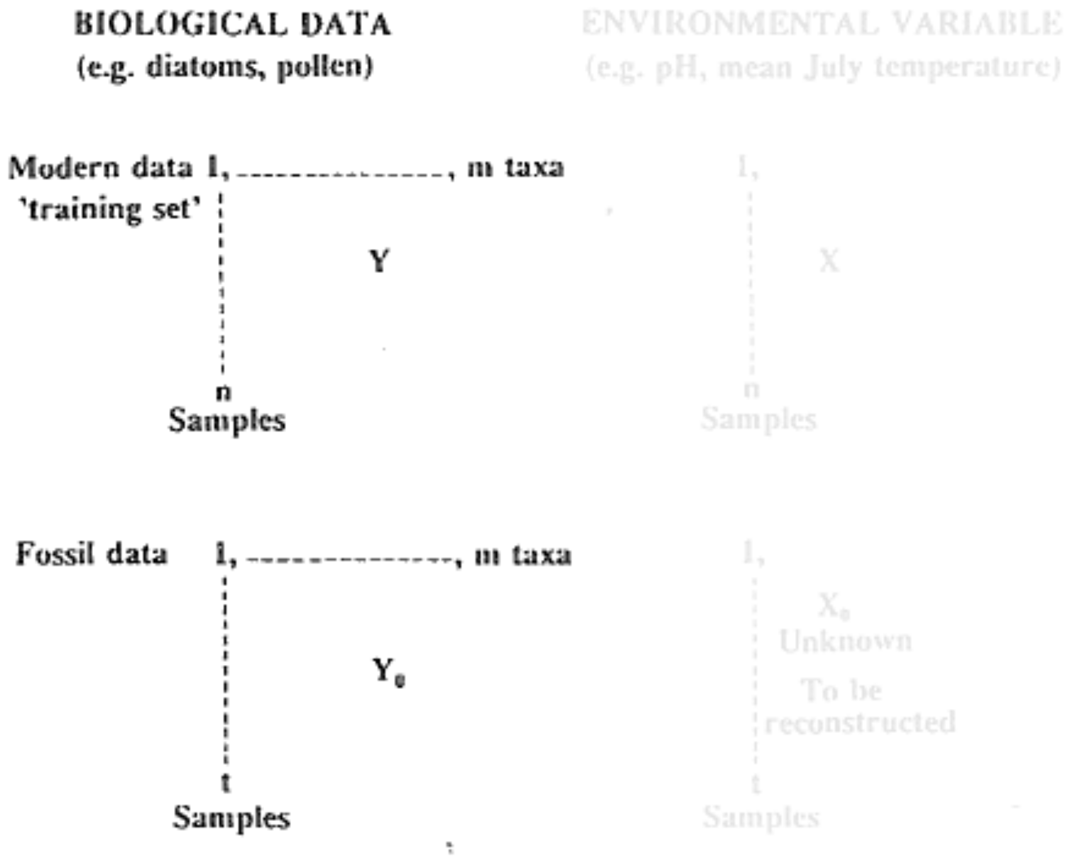
Calibration data set				Root Mean Square Error of Prediction (°C)					LGM data set	
Region	Source	Samples	Remarks	SST	ANN	RAM	SIMMAX	MAT	Cores	Samples
North Atlantic	1	862		Summer	1.14	1.09	0.91	1.42	102	550
				Winter	0.96	0.79	0.86	1.32		
				Annual	0.96	0.85	0.81	1.26		
South Atlantic	1	321	83 tropical samples in common	Summer	0.81	0.76	0.98	1.36	69	198
			with North Atlantic	Winter	0.95	0.96	0.98	1.47		
				Annual	0.83	0.62	0.93	1.36		
Pacific	1	1111	Some core tops common to	Summer	1.19	0.78	1.00	1.63	82	265
			IndoPacific data set 13 LGM cores	Winter	1.64	1.17	1.27	1.88		
			common to IndoPacific data set	Annual	1.35	0.93	1.10	1.67		
Mediterranean	2	274	Includes 129 samples from North	Summer	1.14	0.74			37	273
			Atlantic	Winter	0.79	0.47				
				Annual	0.91	0.54				
Indian Ocean and	3	1344	Some core tops common to Pacific	Summer	0.93	0.91		0.89	170	301
Australia			data set 13 LGM cores common to	Winter	1.01	0.98		0.98		
(IndoPacific)			Pacific data set	Annual	0.86	0.86		0.84		
Total									460	1574

(1) This paper; (2) Hayes et al. (2004); (3) Barrows and Juggins (2004).The error rates have been determined by cross validation of the calibration data sets using ten independent partitions (ANN and MAT and RAM for Indian Ocean and Australia) and the leaving-one-out method (SIMMAX, RAM, MAT). MAT values for North and South Atlantic and Pacific data sets refer to error rates for SIMMAX without distance weighting. Note that the leaving-one-out procedure in RAM02 software, used for all regions except the Indian Ocean and Australia, underestimates the error rate as the samples are ‘‘left out’’ after the two-dimensional interpolation procedure.

Messinian SST?

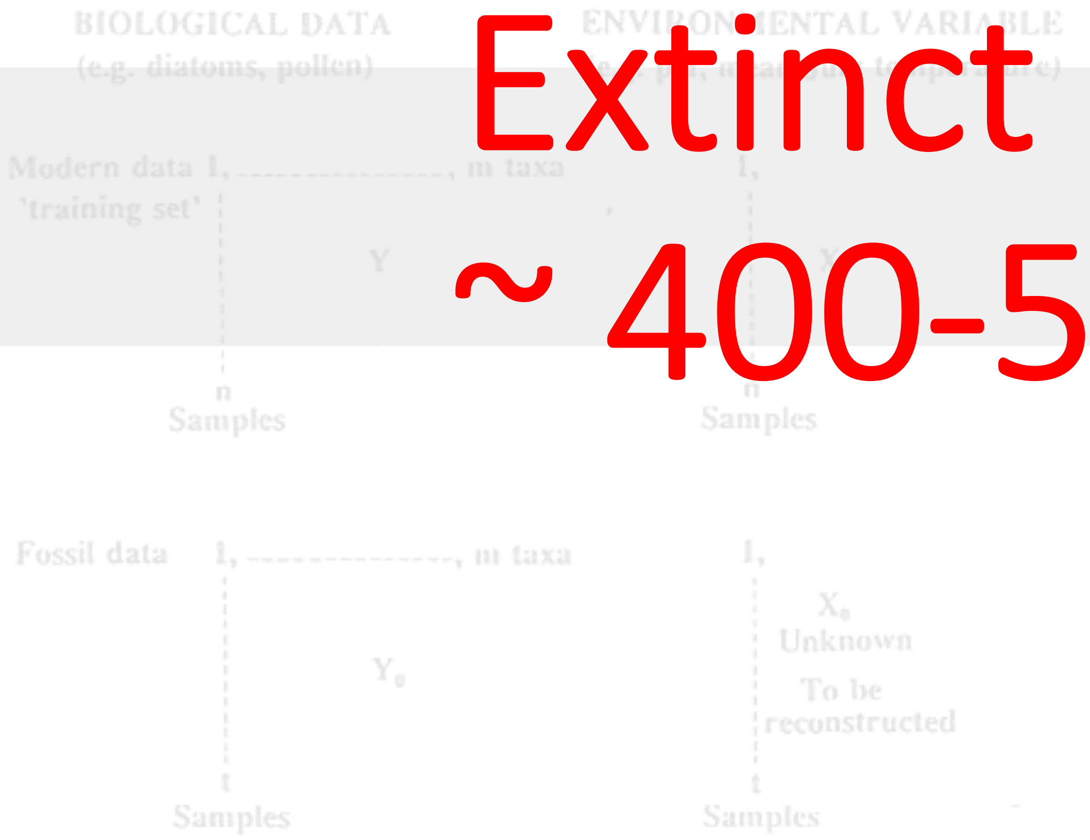

Messinian SST?

BASIC IDEA OF QUANTITATIVE ENVIRONMENTAL RECONSTRUCTION



The modern relationships between Y and X are modelled statically and the resulting function is the used as a transfer function to transform the fossil data Y_0 into quantitative estimates of the past environmental variable X_0.

BASIC IDEA OF QUANTITATIVE ENVIRONMENTAL RECONSTRUCTION



The modern relationships between Y and X are modelled statically and the resulting function is the used as a transfer function to transform the fossil data Y_0 into quantitative estimates of the past environmental variable X_0.

Extinct spp.?

~ 400-500 ky

Qualitative reconstruction based on assemblages: Tropical / Subtropical / Transitional / Subpolar / Polar

Just SST?

Monthly SST

66.86 % variability of PF assemblages

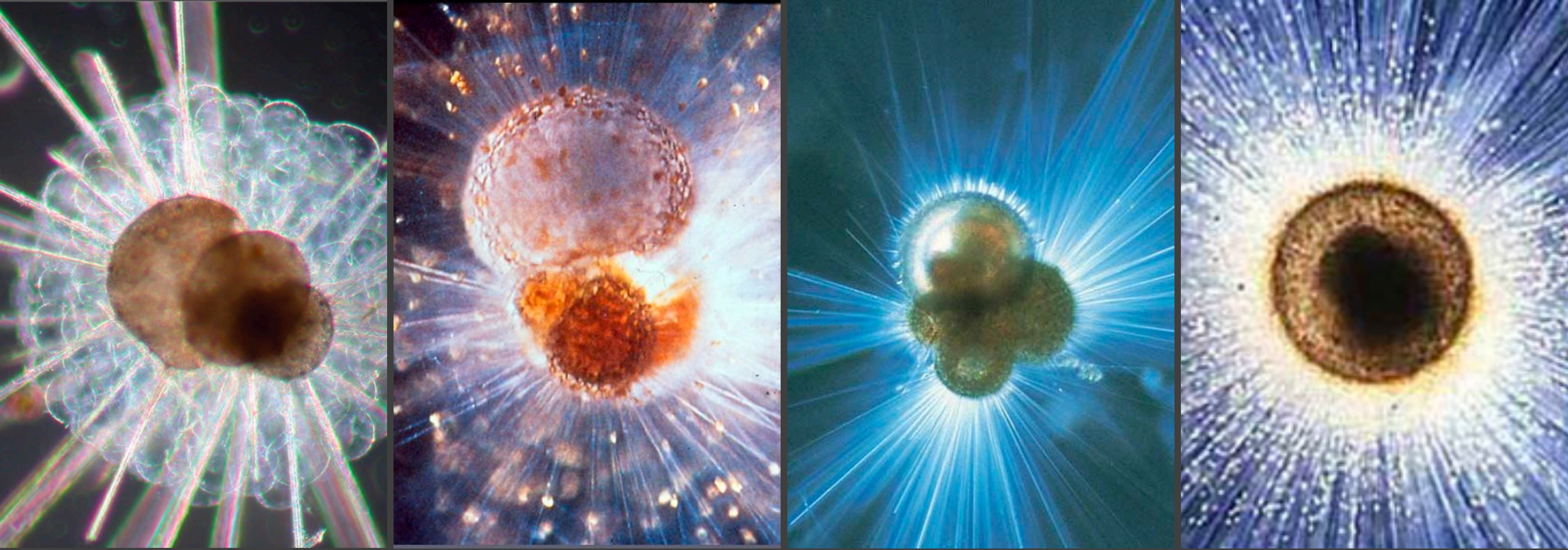
Monthly SST

66.86 % variability of PF assemblages

Monthly SST/[Chl]/TG

81.02 %

(14.16 %)



Thank you for the attention!