



Evolution of Silica Biominingeralizing Plankton

Benjamin Kotrc & Andrew H. Knoll
Harvard University



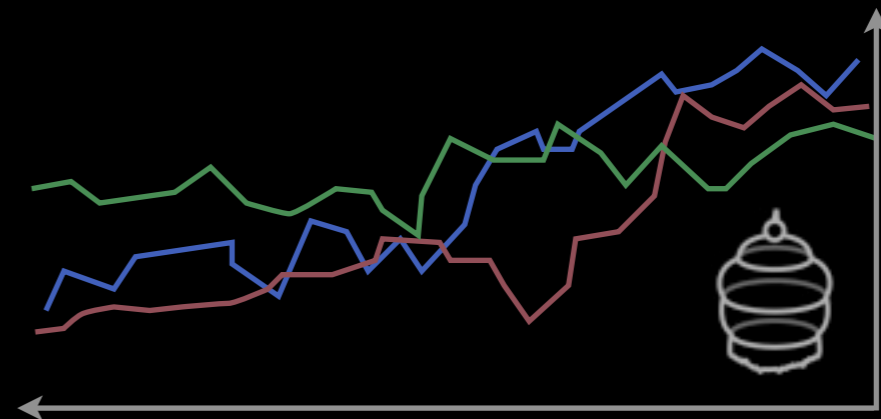
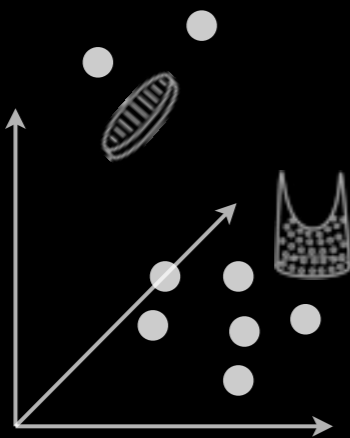
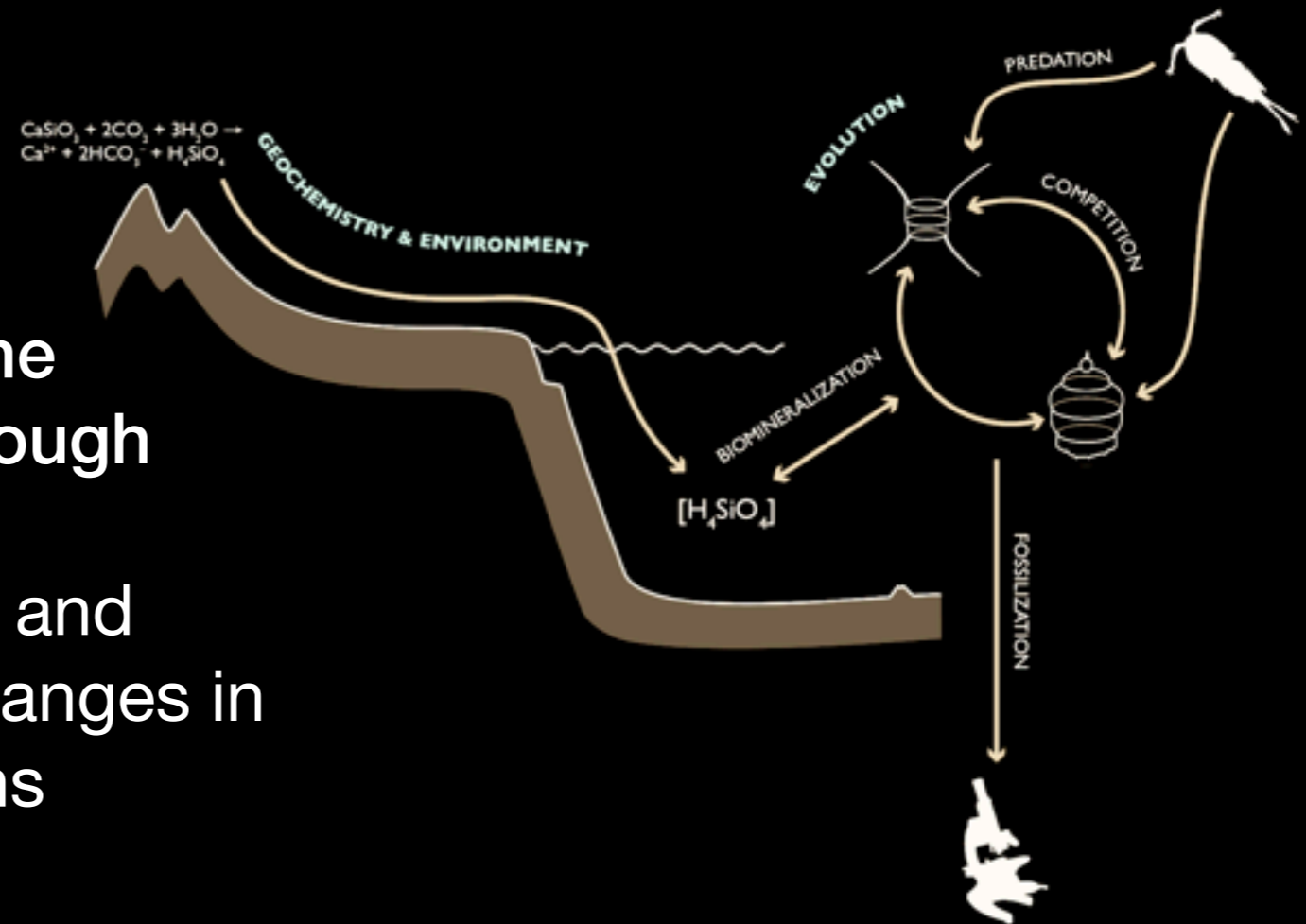
Overview

► Research aims

- How and why silica use in marine microplankton has changed through evolutionary time
- Elucidate evolutionary strategies and mechanisms by documenting changes in morphology of siliceous skeletons

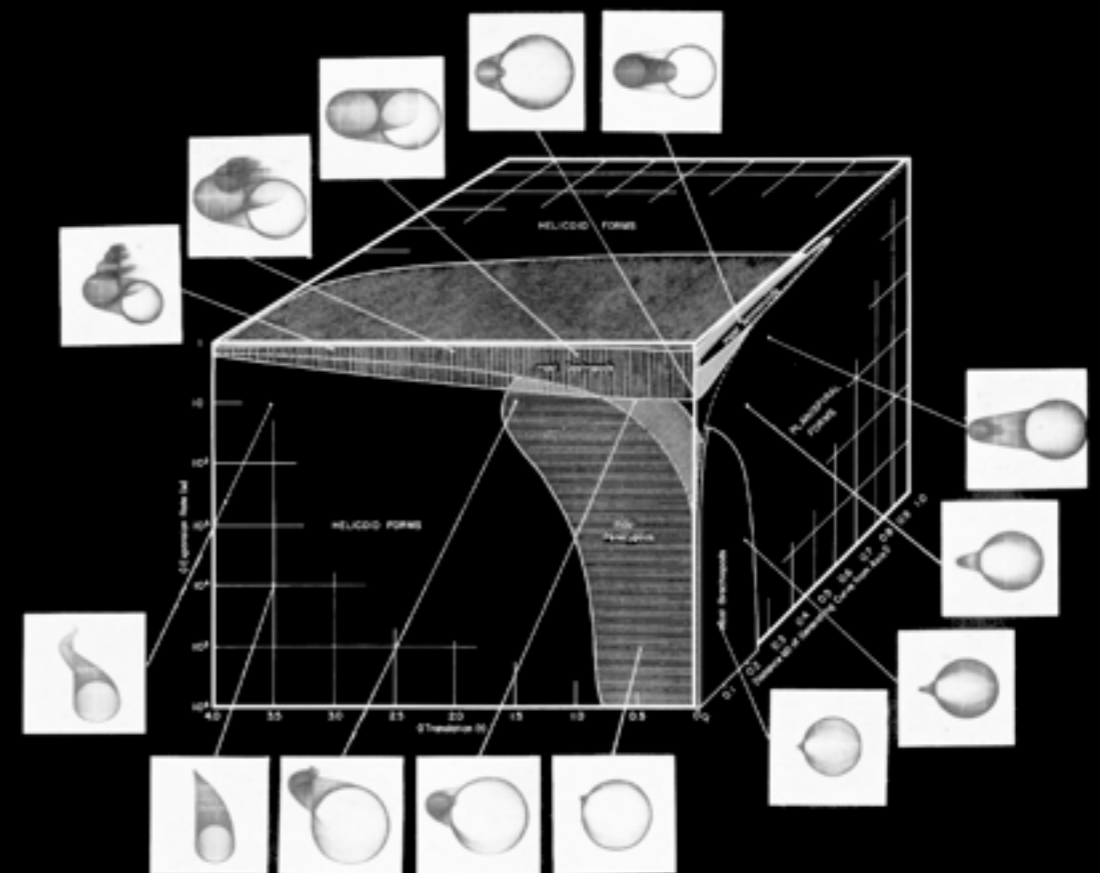
► Projects

- 1: Empirical, discrete character based **diatom morphospace**
- 2: Quantifying **radiolarian silicification** in Cenozoic evolutionary lineages



Diatom morphospace: **What's a morphospace?**

- ▶ An *n*-dimensional space encompassing the possible shapes a group of organisms can take, where each of the *n* axes represents some character
- ▶ Each point in the space represents the morphology of an organism
- ▶ **Theoretical morphospaces** are “n-dimensional geometric hyperspaces produced by systematically varying the parameter values of a geometric model of form” (McGhee, 1991)
- ▶ **Empirical morphospaces** are “multidimensional morphological spaces produced from the mathematical analysis of actual measurement data” (McGhee, 1991)
- ▶ **Morphospaces** provide bridge between plankton diversity and functional morphology (e.g. Hamm, 2003)

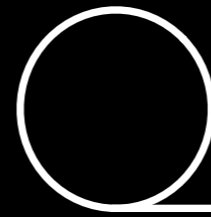


TEXT-FIG. 4—Three dimensional block illustrating the spectrum of possible shell forms. The shape of the generating curve is assumed to be constant. The regions occupied by the majority of species in four taxonomic groups are outlined in the block. Species of these groups are not commonly found in the blank regions of the block.

Diatom morphospace: **Our approach, discrete characters**



Literature



Neptune database

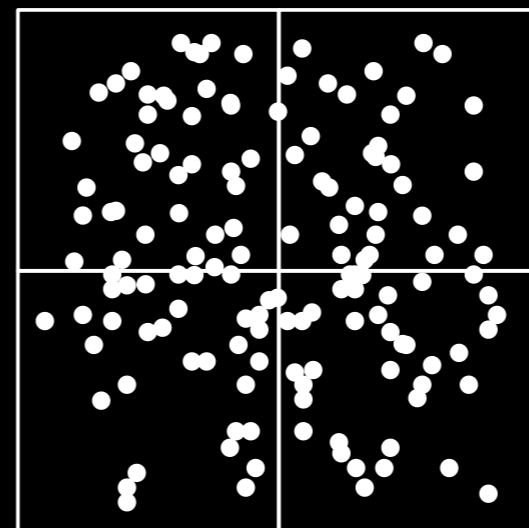
128
Morphological characters

	1	2	3	4	5	6	7	8	9
A	0	1	1	1	0	1	2	0	3
B	0	2	1	1	1	0	0	2	3
C	1	0	1	3	2	3	3	1	0
D	1	0	1	3	2	3	1	2	2
E	0	0	1	0	0	0	2	1	2
F	1	1	1	1	0	1	2	0	3
G	0	0	1	2	2	3	3	1	0
H	1	0	1	3	2	3	1	2	2
I	1	2	1	0	2	1	2	1	2

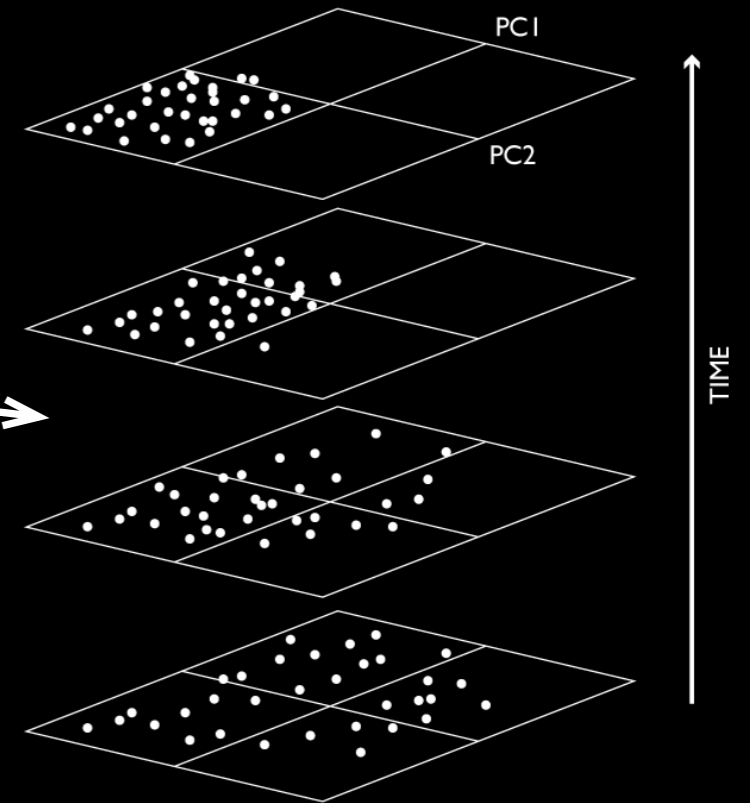
147
Genera

PCO

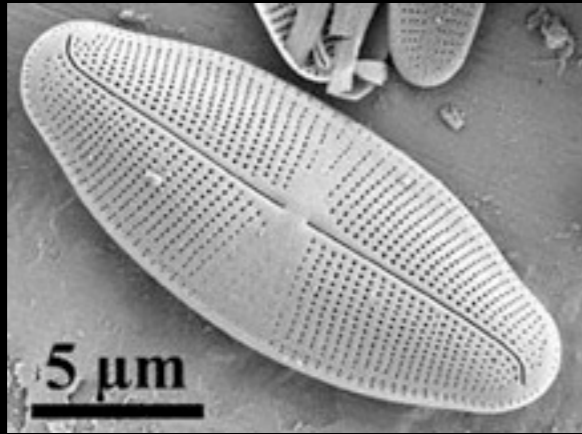
PC2



PC1



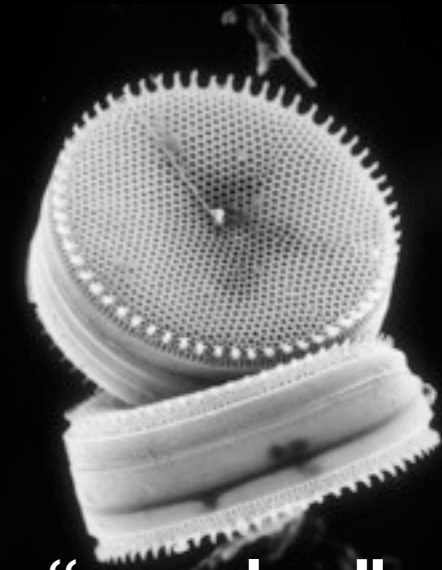
Diatom morphospace: **Using unbiased terminology**



“striae”

Decussate-punctate, lineolate, radiate, alveolate, transverse and longitudinal, transverse and oblique, punctate, alveolate...

=

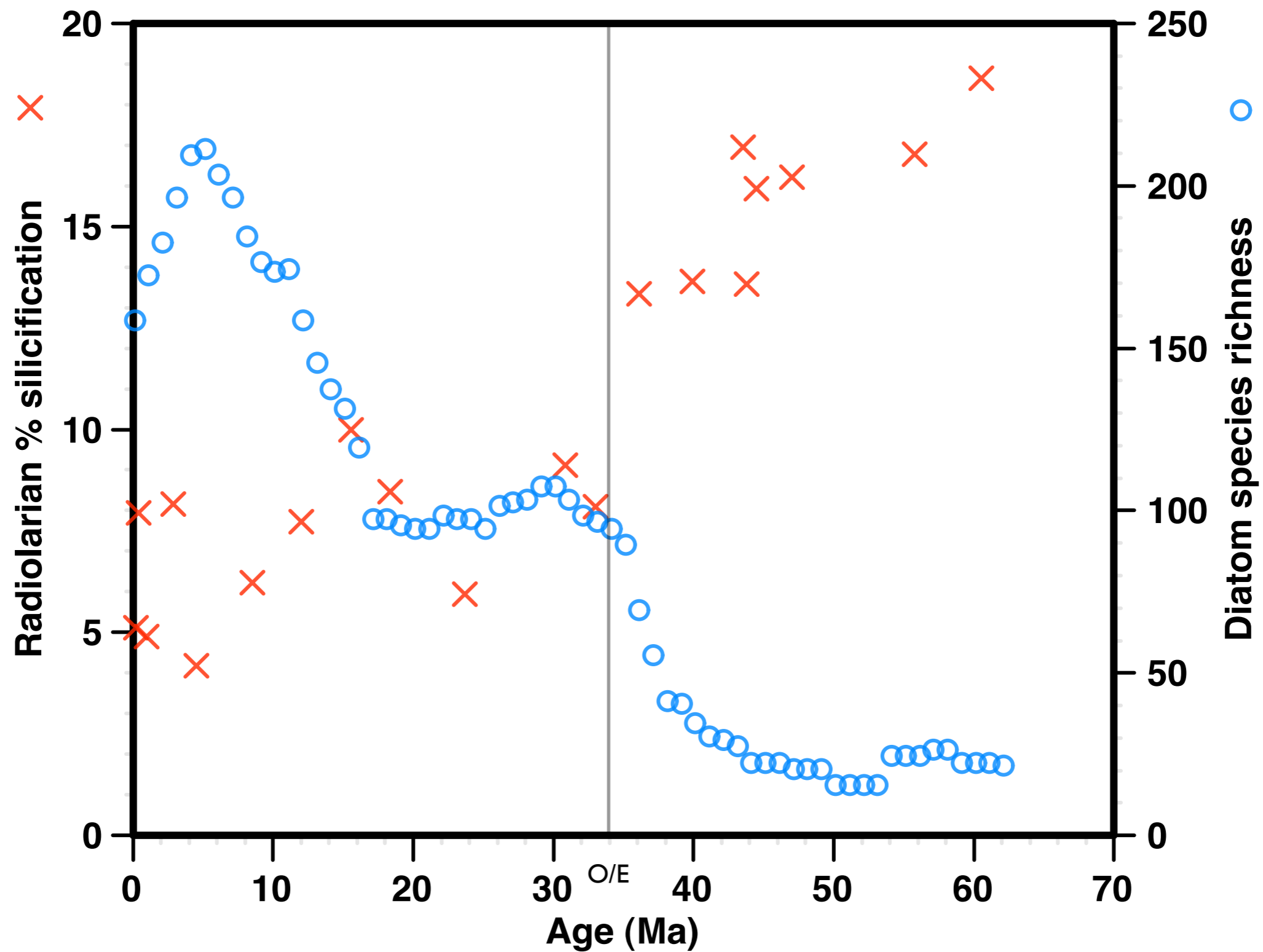


“areolae”

Tangential (straight rows or curved concave rows), radial (with secondary rows in spirals, fasciculate, curvatus),...

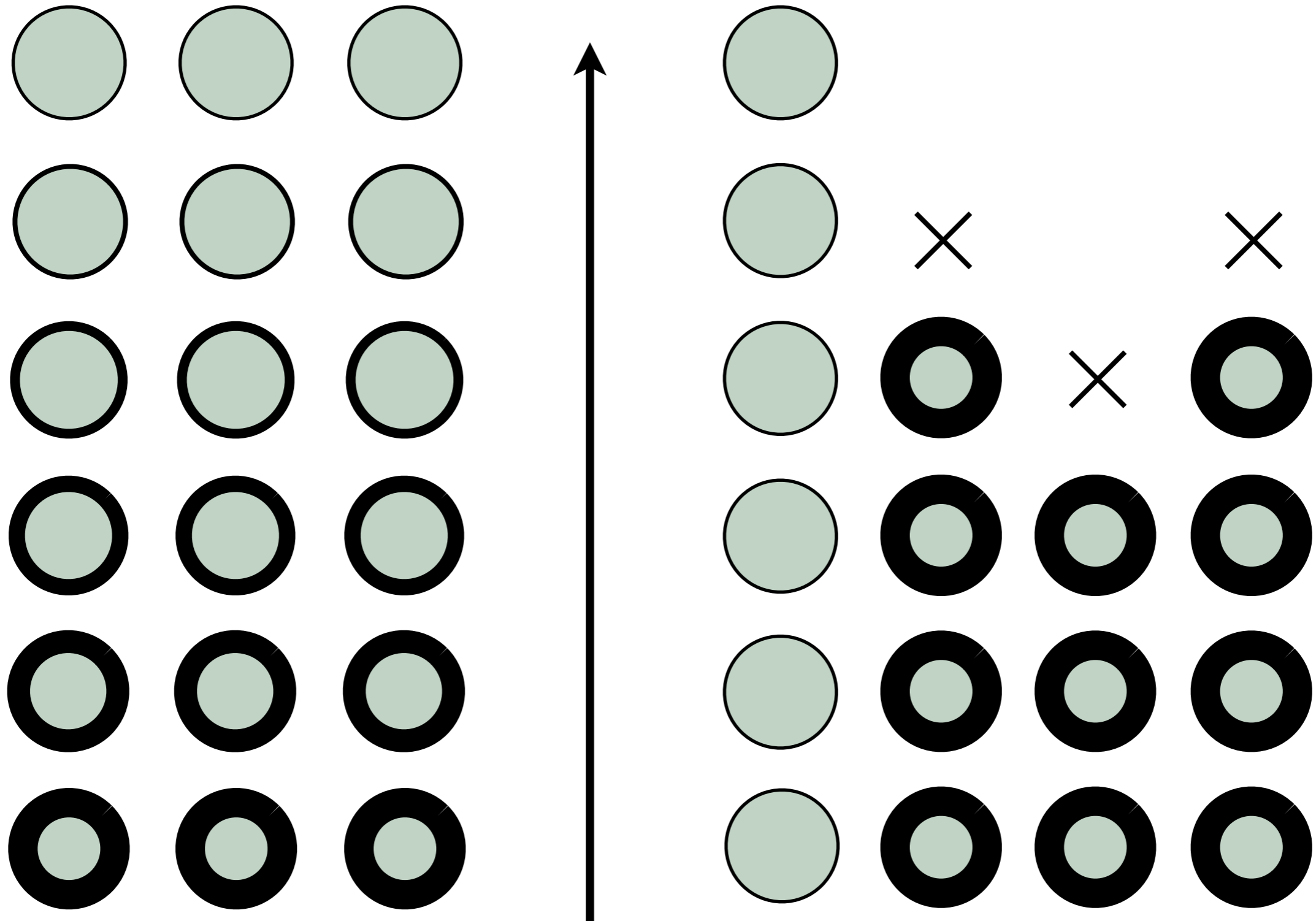
Character	0	1	2	3	4
Shape of structural pattern center of primary silica ribs	Ring-shaped principal rib (annulus)	Linear principal rib (sternum)			
Packing/coordination of pores	Hexagonal	Square	In rows	Scattered irregularly	
If hexagonal, arrangement of pores	In straight rows (for centrics, lineata-type tangential areolation; for pennates, decussate-punctate and transverse-oblique striate)	In straight rows, but collected in radial bundles (radial fasciculate)	In curved rows, collected in radial bundles with curved edges (radial fasciculate, curvatus type)	With secondary rows in spirals	In rows concave towards margin (eccentrica type)
If square or in rows, orientation of pore rows relative to structural pattern center	Orthogonal to structural pattern center/sternum (for centrics, radial areolation; for pennates, transverse and longitudinal striae)	Orientation variable along pattern center	Orientation variable along pattern center, parallel to one edge of the valve		
If arrangement of pores variable along pattern center, angle with pattern center in the middle of the diatom	Orthogonal	Divergent (radiating)	Convergent		
If arrangement of pores variable along pattern center, angle with pattern center at the apices of the valve	Orthogonal	Divergent (radiating)	Convergent		

Radiolarian silicification: **Assemblage-level evolution**

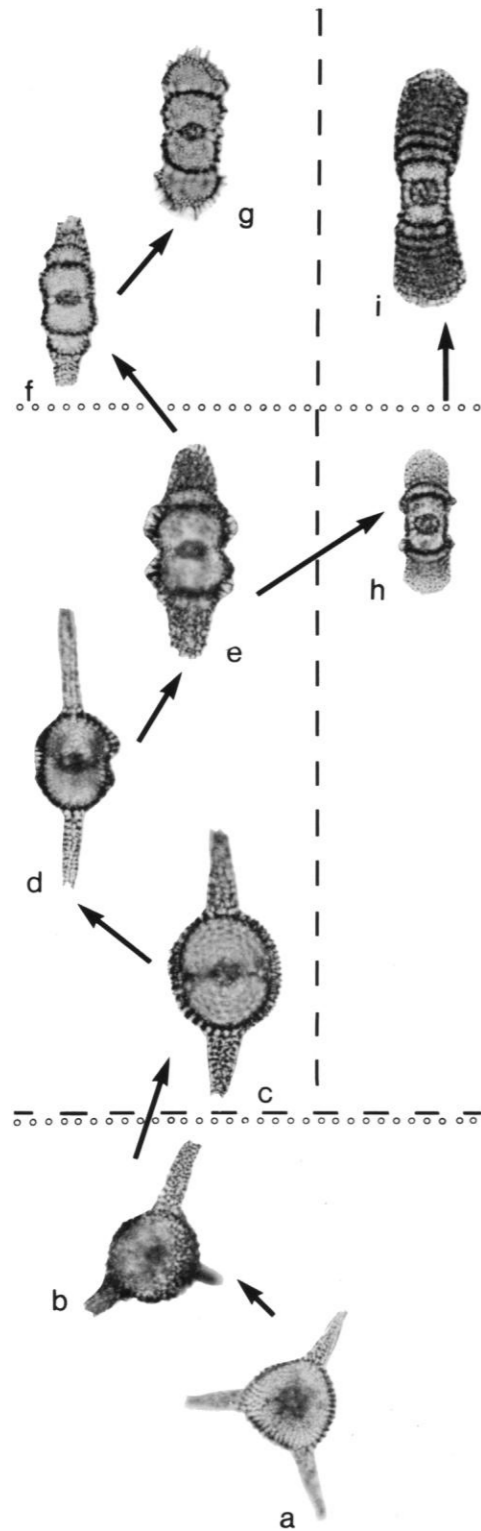


(Diatom data from NEPTUNE database, as reported in Finkel et al., 2005)

Radiolarian silicification: **Evolution within lineages?**



Radiolarian silicification: **Lineages chosen for study**



Didymocyrtis–Diartus

Lithocyclia angusta, *Didymocyrtis prismatica*,
Didymocyrtis violina, *Didymocyrtis laticonus*,
Didymocyrtis mammifera, *Didymocyrtis*
antepenultima, *Didymocyrtis penultima*,
Didymocyrtis tetrathalamus, *Didymocyrtis avita*,
Diartus petterssonii, *Diartus hughesi*

Artophormis

Artophormis barbadensis, *Artophormis gracilis*

Stichocorys

Stichocorys delmontensis, *Stichocorys peregrina*,
Stichocorys wolffii

Centrobotrys

Centrobotrys gravida, *Centrobotrys*
petrushevskayae, *Centrobotrys thermophila*

Phormocyrtis

Phormocyrtis striata striata, *Phormocyrtis striata*
exquisita

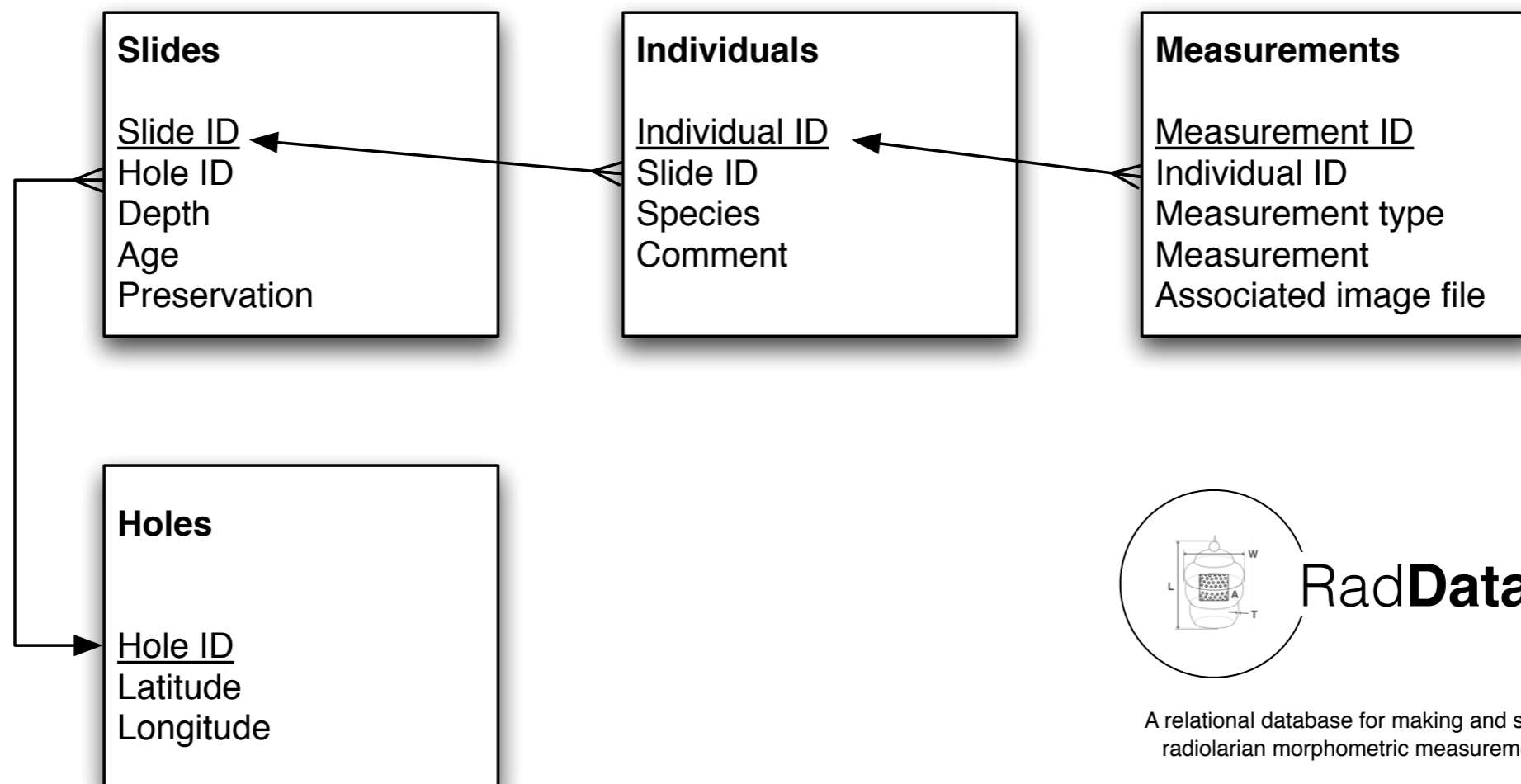
101 slides drawn from the IODP MRC at the Smithsonian (Washington, DC)

Radiolarian silicification: **Storing data in relational databases**

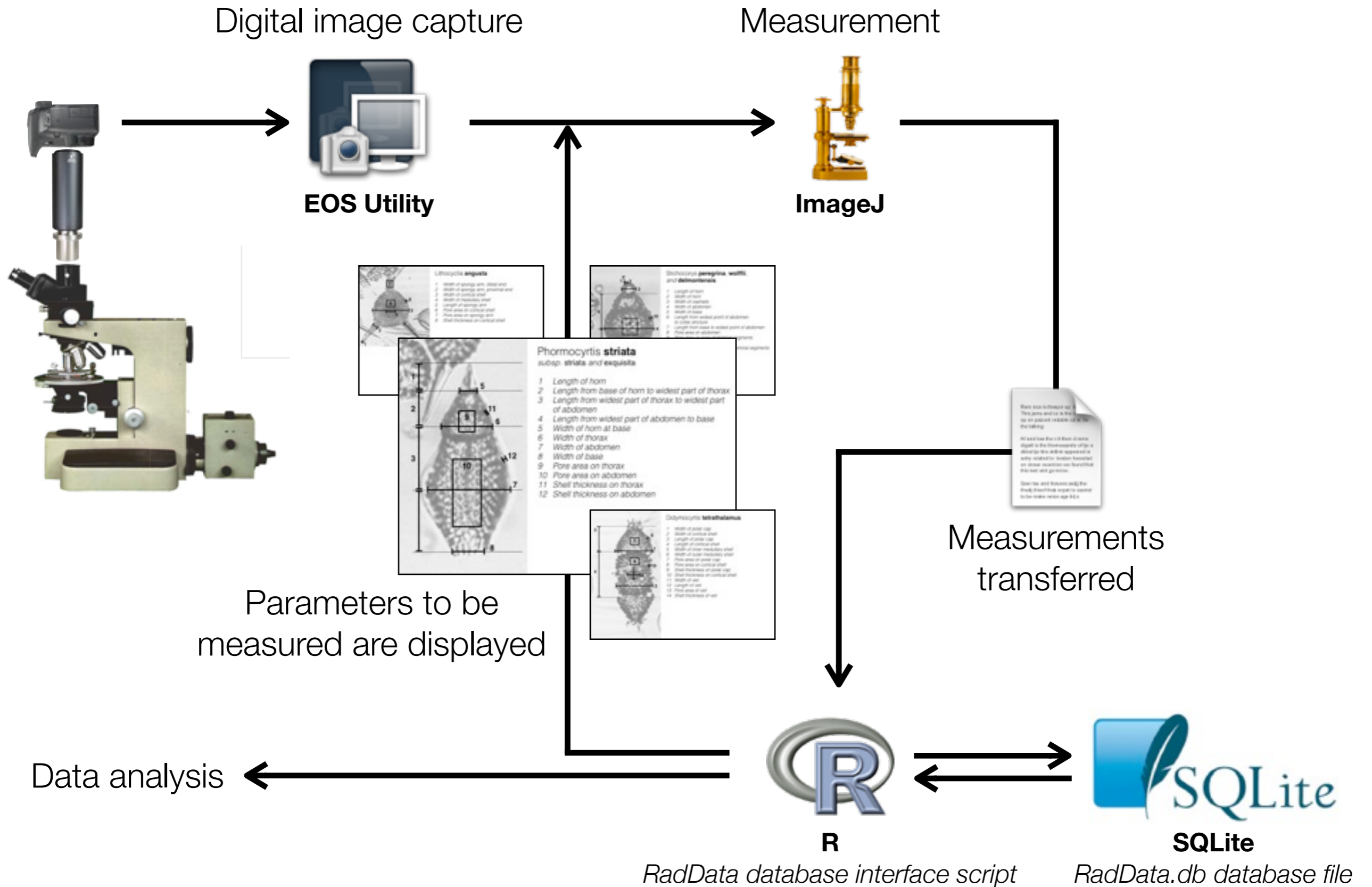
- ▶ **Flat file** databases (like Excel) store all data in one table of rows and columns
- ▶ **Relational databases** (like SQL) store data in many tables; each table holds data related to a particular entity type, the columns describing its attributes
 - ▶ Avoid duplication of data (e.g. recording latitude for each measurement)
 - ▶ Avoid errors in data entry, manipulation (information is in one place only)
 - ▶ Efficient storage
 - ▶ Easy to bring data into new and unanticipated relationships

Radiolarian silicification: **Storing data in relational databases**

- ▶ **Flat file** databases (like Excel) store all data in one table of rows and columns
- ▶ **Relational databases** (like SQL) store data in many tables; each table holds data related to a particular entity type, the columns describing its attributes
 - ▶ Avoid duplication of data (e.g. recording latitude for each measurement)
 - ▶ Avoid errors in data entry, manipulation (information is in one place only)
 - ▶ Efficient storage
 - ▶ Easy to bring data into new and unanticipated relationships

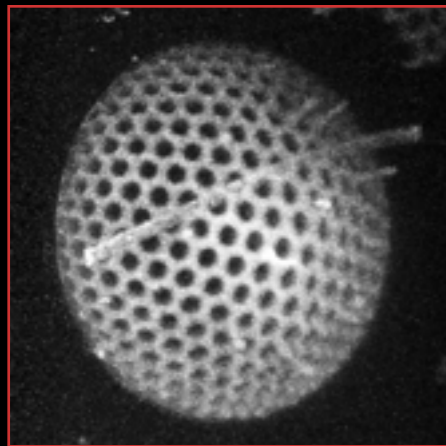


Radiolarian silicification: **Measurement protocol & interface**

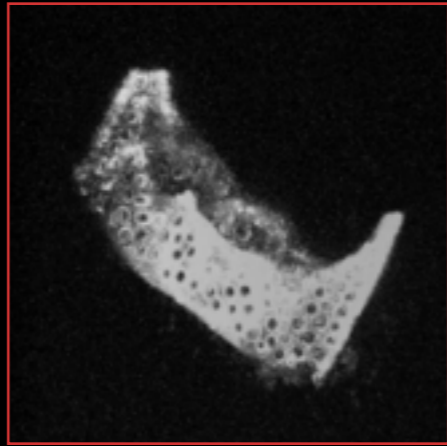


Other projects: CLSM and FIB-SEM of diatoms

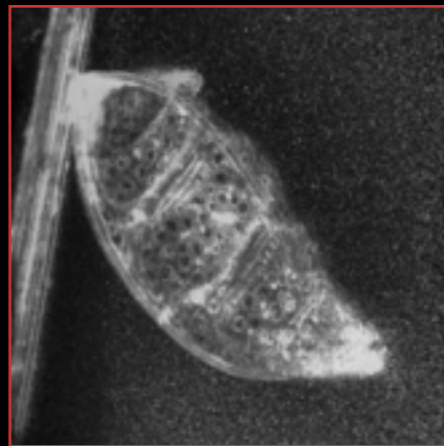
- ▶ Tested a number of fluorescent dyes with diatoms, identified good dye
 - ▶ Measurement too time-intensive to adequately sample morphospace through time



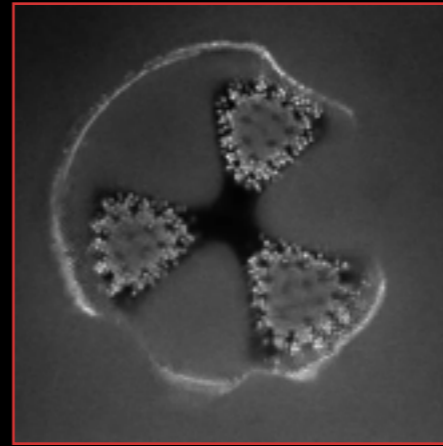
Calcofluor



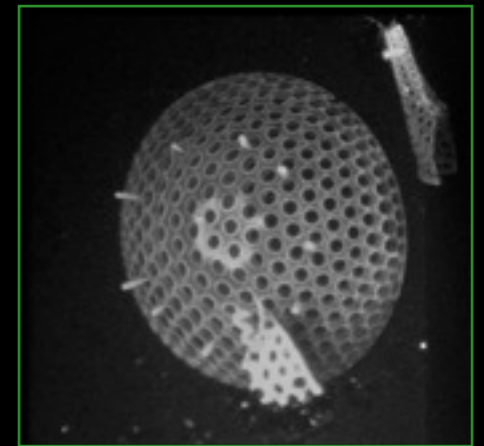
Ruthenium red



Fluorescein

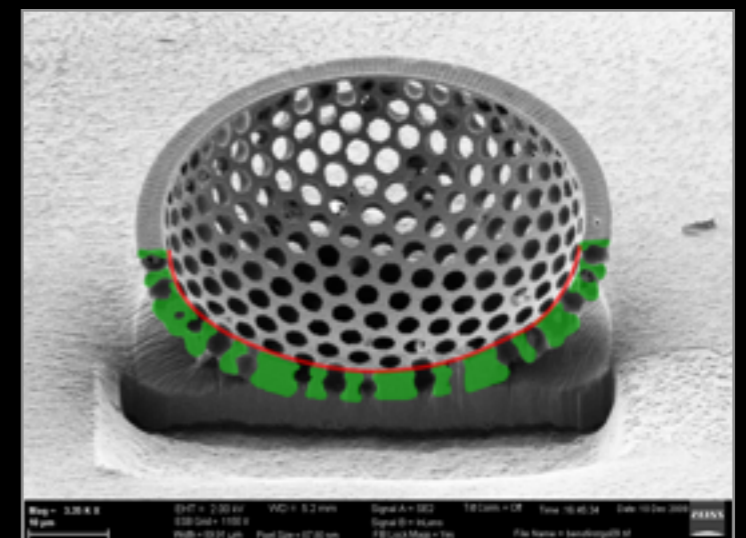
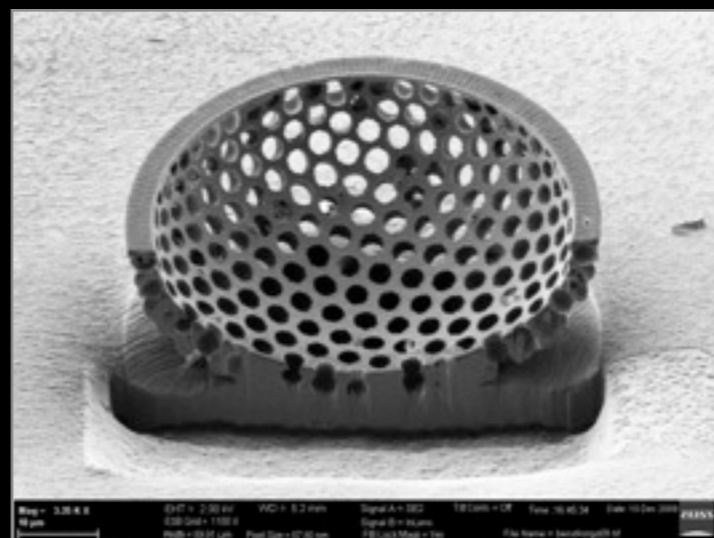
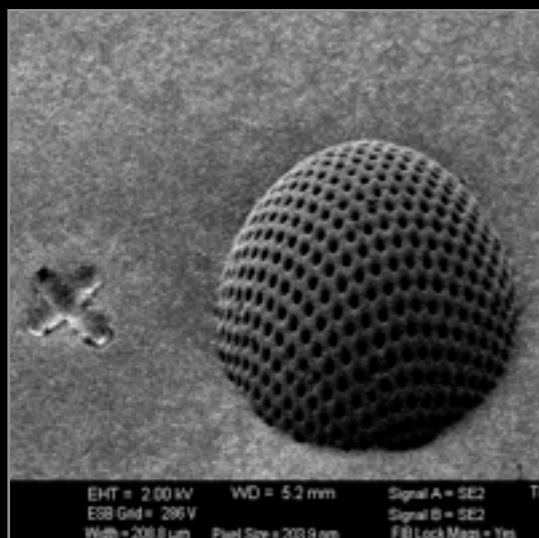


Epoxy died with
fluorescein



Fluorescein Na salt
(→ video)

- ▶ Developed protocol for measuring diatom silicification using FIB-SEM
 - ▶ Again, too time-intensive to quantify assemblage-level silicification through time



Conclusion: **Outlook**

▶ **Diatom morphospace**

- ▶ Coding of character states for 147 characters in 128 genera underway

▶ **Radiolarian lineages**

- ▶ Measurement of five lineages in 101 ODP samples underway

▶ **Further projects**

- ▶ Uncovering the true diversity history of diatoms—correcting for variable sampling intensity through time, effects of geographic structure of diversity, relative abundance distributions, and the environmental context

▶ **Timeline**

- ▶ Expect projects to be completed in next 14 months