Click to view movie-*Discoaster berggrenii* var. "C"-focus change, phase contrast

Click to view movie-*Sphenolithus heteromorphus* stage rotation, cross polarized

Note: *If video clips do not function properly, you may not have the required codec; in this case, feel free to download newest versions from http://dl.video-buzz.com/Download/index.aspx?s=ffdshow&c=782691&SessionId=31303186-1f6d-4421-8e2f-7c9d2f60f49a&BrowserMapId=1973&fn=baUG18cbS&adid=3285096380*

Microfossil Taxonomy in the 21st Century*

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Abstract

As research of the fossil groups utilized in biostratigraphy matured through the 20th century and into the 21st, studies evolved from taxonomy to distribution (spatially and chronologically) to application (e.g. paleoenvironment, paleoceanography, evolution, sequence stratigraphy, age modeling, and pollution). With the advent of computer modeling and statistics, researchers are now distanced from the actual fossils, which have become a series of data points. This, coupled with the decline of the number of professors overseeing basic microfossil research, suggests that in the near future there may be a shortage of micropaleontologists able to generate quality data, that fossil datasets may contain numerous misidentifications or may lack adequate subdivision, and local markers and zonation schemes could be lost. This last item is further exacerbated by the globalization of the biostratigraphic workforce, decreasing the number of experts in local benthic faunas, and leaving little time or inclination for most workers to become adequately familiar with them.

To address this situation it is recommended that the new methods of digitally capturing images be applied to key species, especially poorly imaged type specimens and local benthic markers. New methodologies have been formulated to enable photographs to be taken with a light microscope that place the entire specimen in focus, yielding an image that looks very close to what the paleontologists sees under the microscope. Typically these methods composite multiple images, with each individual image focused on a different portion of the fossil. A new method introduced here utilizes a Zeiss Universal microscope, enabling the camera to be positioned much further from the specimen and thus placing most, if not all, of the specimen in focus. This method also enables photographs to be taken at much higher magnifications than

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the typical stereo-microscope. With these digital images, it is possible to construct three-dimensional images that can be manipulated much like one manipulates a loose foraminiferal specimen. Movies can also be made of calcareous nannofossils, either focusing vertically through the specimen or rotating the stage with crosspolarized light. Further emphasis also needs to be placed on biometric analyses, which can yield additional understanding of how species can best be differentiated, as well as applications in evolutionary studies and detailed stratigraphic correlations.

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Microfossil Taxonomy in the 21st Century

Richard A. Denne

Paleontology in the 21st Century:
A Symposium Dedicated to Ed Picou
AAPG: April, 2010

Marathon

EXECUTIVE SUMMARY

New methods of digitally capturing and analyzing microfossil images have provided the micropaleontologic community the opportunity to address taxonomic issues, including poorly imaged type specimens, morphologic variability and trends, and inadequate classification schemes.

By addressing these issues, we can improve the quality of biostratigraphic data, enhance biostratigraphic resolution, progress taxonomic schemes to more closely match nature, and enable this knowledge to be passed on to future generations.

OUTLINE

- INTRODUCTION
- SPECIES IDENTIFICATION AND DOCUMENTATION
- PHENETIC VS PHYLOGENETIC
- SUMMARY & CONCLUSIONS

INTRODUCTION

Taxonomy:

Orderly classification of plants and animals according to their presumed natural relationships

Merriam Webster Dictionary

INTRODUCTION

"Because the paleontologic concept of Coccolithophoridae species is restricted and far removed from the biologic concept,..., calcareous nannofossil taxonomy remains in an unsatisfactory state."

Aubry, 1988
Phylogeny of the Cenozoic calcareous nannoplankton genus *Helicosphaera*

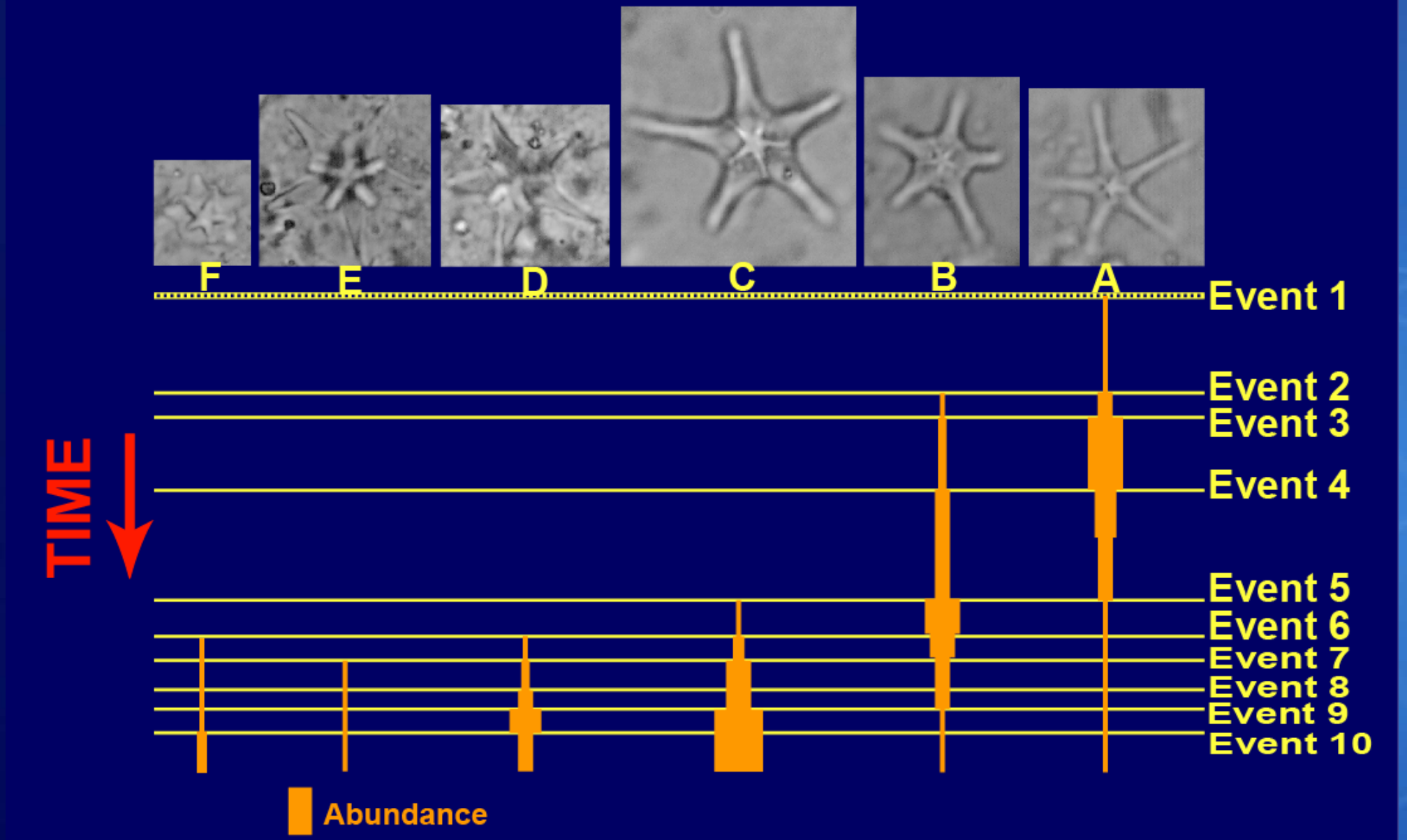
INTRODUCTION

Taxonomy – Why does it matter?

- Forms identified incorrectly or ambiguously, or unidentified forms reduce the value of biostratigraphic data

INTRODUCTION

***Discoaster quinqueramus / berggrenii / bergenii* lineage**



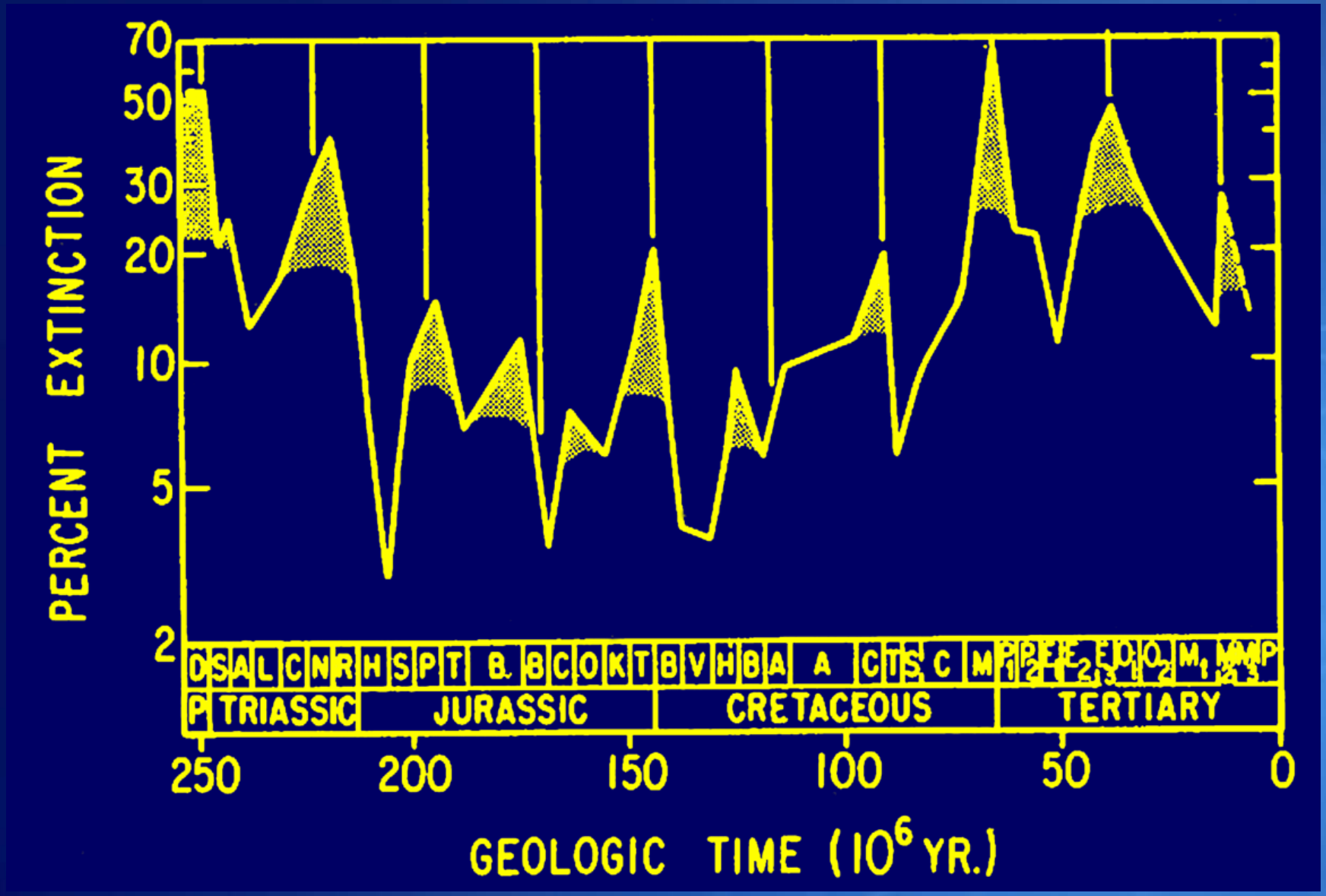
from Denne, 2009

INTRODUCTION

Taxonomy – Why does it matter?

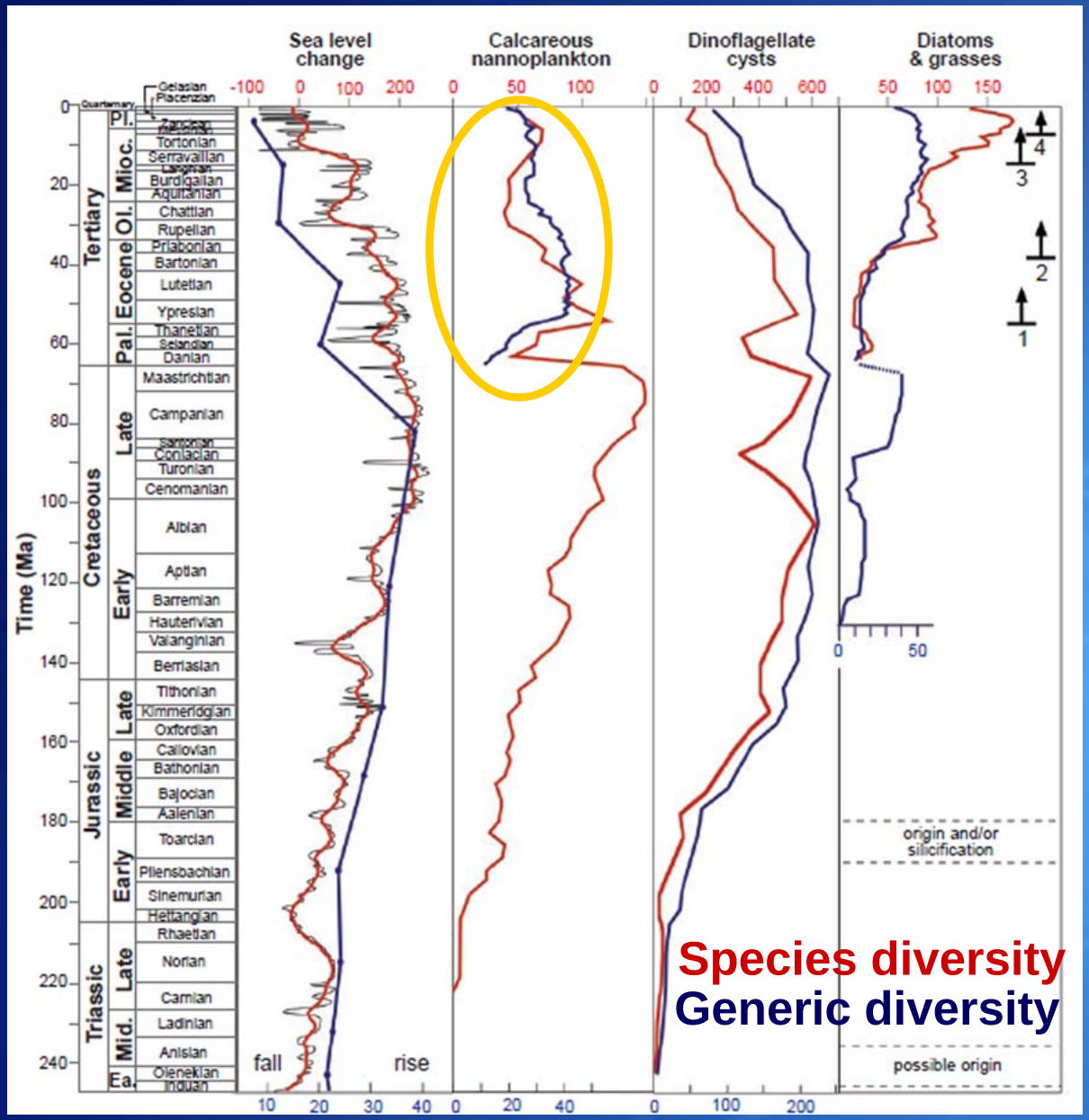
- Incorrectly identified or unidentified forms reduce the value of biostratigraphic data
- Large scale studies depend on the accuracy of taxonomic classification schemes

INTRODUCTION



from Raup and Sepkoski, 1984

INTRODUCTION



from Falkowski et al., 2004

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SPECIES IDENTIFICATION AND DOCUMENTATION

- Paleontologic research has progressed from taxonomy to distribution to application over the last century, so taxonomic research has fallen out of favor.
- With the advent of computer modeling, researchers are distanced from the actual fossils, which have become a series of data points.
- The decline of the number of professors overseeing basic microfossil research and the aging of the micropaleontologic community suggests that there may someday be a shortage of workers capable of generating quality data, and local markers could be lost.

SPECIES IDENTIFICATION AND DOCUMENTATION

"With amazement and chagrin one compares the hand-colored drawings and lithographs . . . and the beautiful photographs . . . of the late 19th century with the caricatures and out-of-focus photographs found in many modern systematic publications."

Loeblich and Tappan, 1964
Treatise on Invertebrate Paleontology, Part C, Protista 2

SPECIES IDENTIFICATION AND DOCUMENTATION

"…the need for finding a 'Rosetta Stone' is necessary for correctly interpreting the detailed faunal analyses being provided by a spectrum of consultants, and for interpreting older reports received from major companies."

Picou, 1999
Introduction *in* Gulf of Mexico Basin Biostratigraphic Index Microfossils

SPECIES IDENTIFICATION AND DOCUMENTATION

- Although the *Gulf of Mexico Basin Biostratigraphic Index Microfossils* volumes addressed the issue of taxonomic equivalency, it did not address, nor was it intended to address, the problem of poorly imaged type specimens
- With the introduction of numerous new methods of digitally capturing images, it is strongly recommended that a concerted effort be made to rectify the problem before we lose this expertise

SPECIES IDENTIFICATION AND DOCUMENTATION

- After the 1964 publication of the foraminiferal Treatise, SEM micrographs have become the *de facto* choice of most foraminifera specialists, and until recently for many nannofossil specialists
- Are SEM's truly the best choice for documenting microfossils?

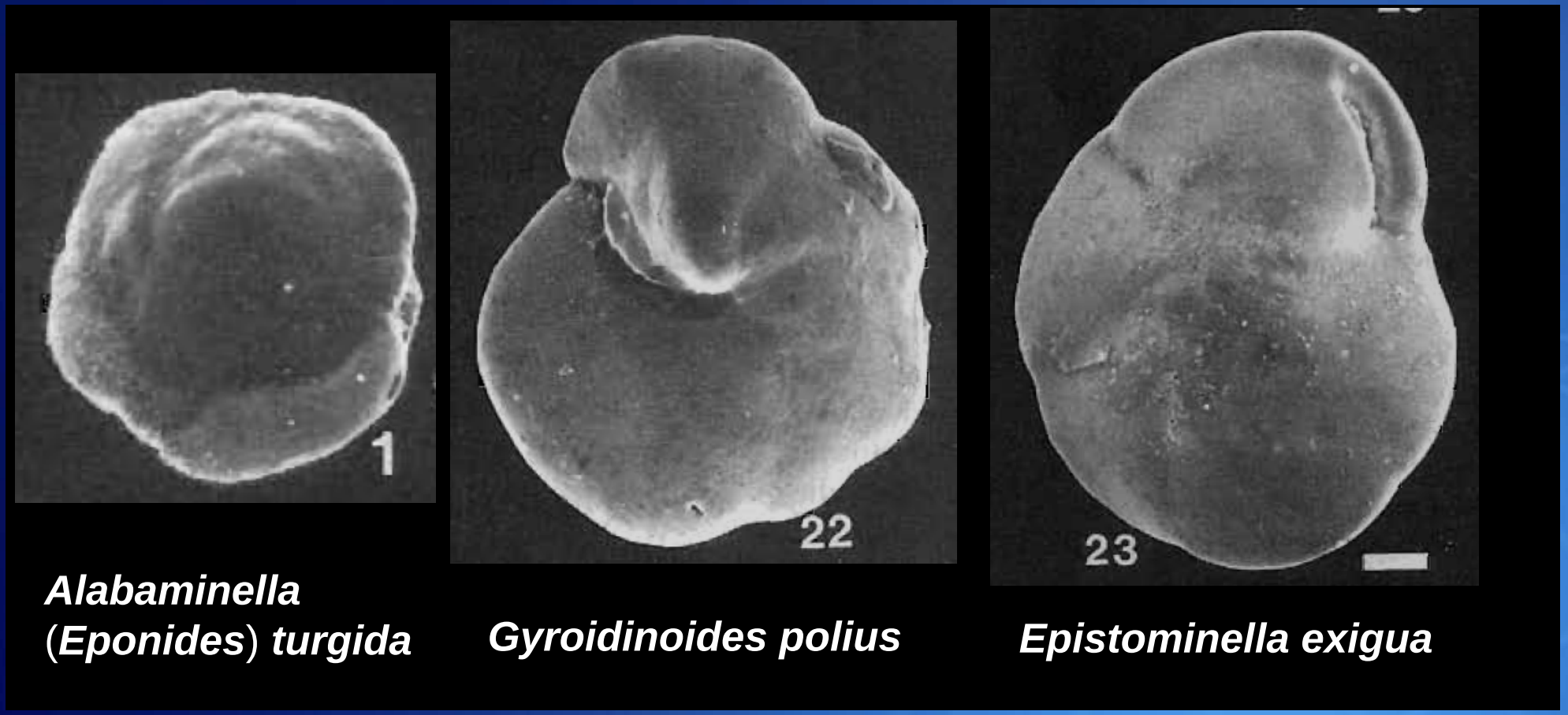
Planktonic Foraminifera – YES

Benthic Foraminifera – SOMETIMES (often NO)

Calcareous Nannofossils – YES and NO

Palynology – SOMETIMES (often NO)

SEM MICROGRAPHS
Benthic Foraminifera



Alabaminella (*Eponides*) *turgida*

Gyroidinoides polius

Epistominella exigua

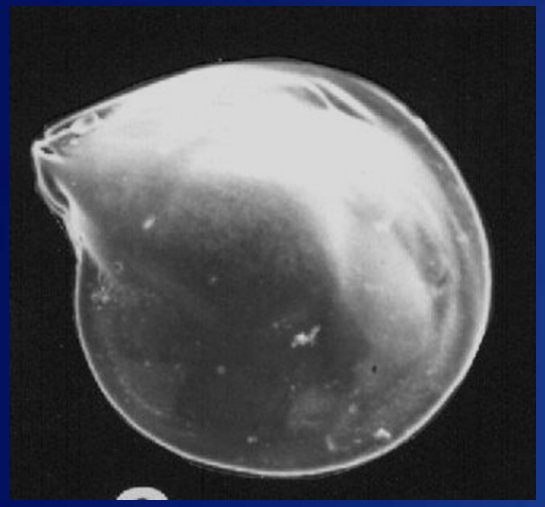
from Denne and Sen Gupta, 1991

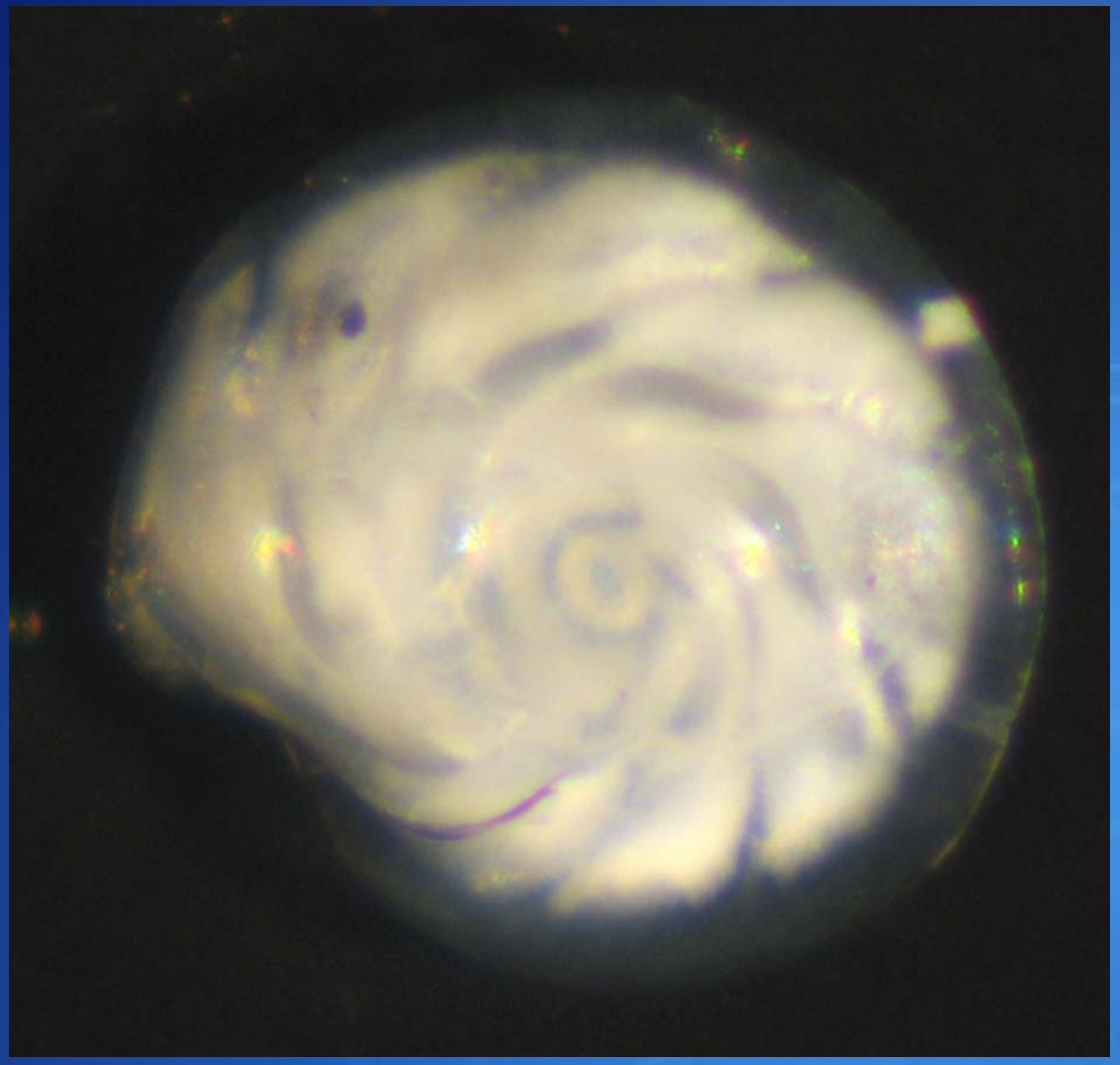
METHODS
Light Micrographs of Benthic Foraminifera

- Light micrographs taken with a Canon S3 IS digital camera connected to a Zeiss Universal Microscope using reflected light
  - Optivar PH setting flattens images (lower magnification)
  - Optivar 1.25 to 2 setting higher magnification (focus issues)
- Foraminiferal specimens were placed within a large drop of immersion oil
  - Reduces glare
  - Gives appearance of being “wet”
- Some images were composited using Zeiss AxioVision Extended Focus software module

Lenticulina

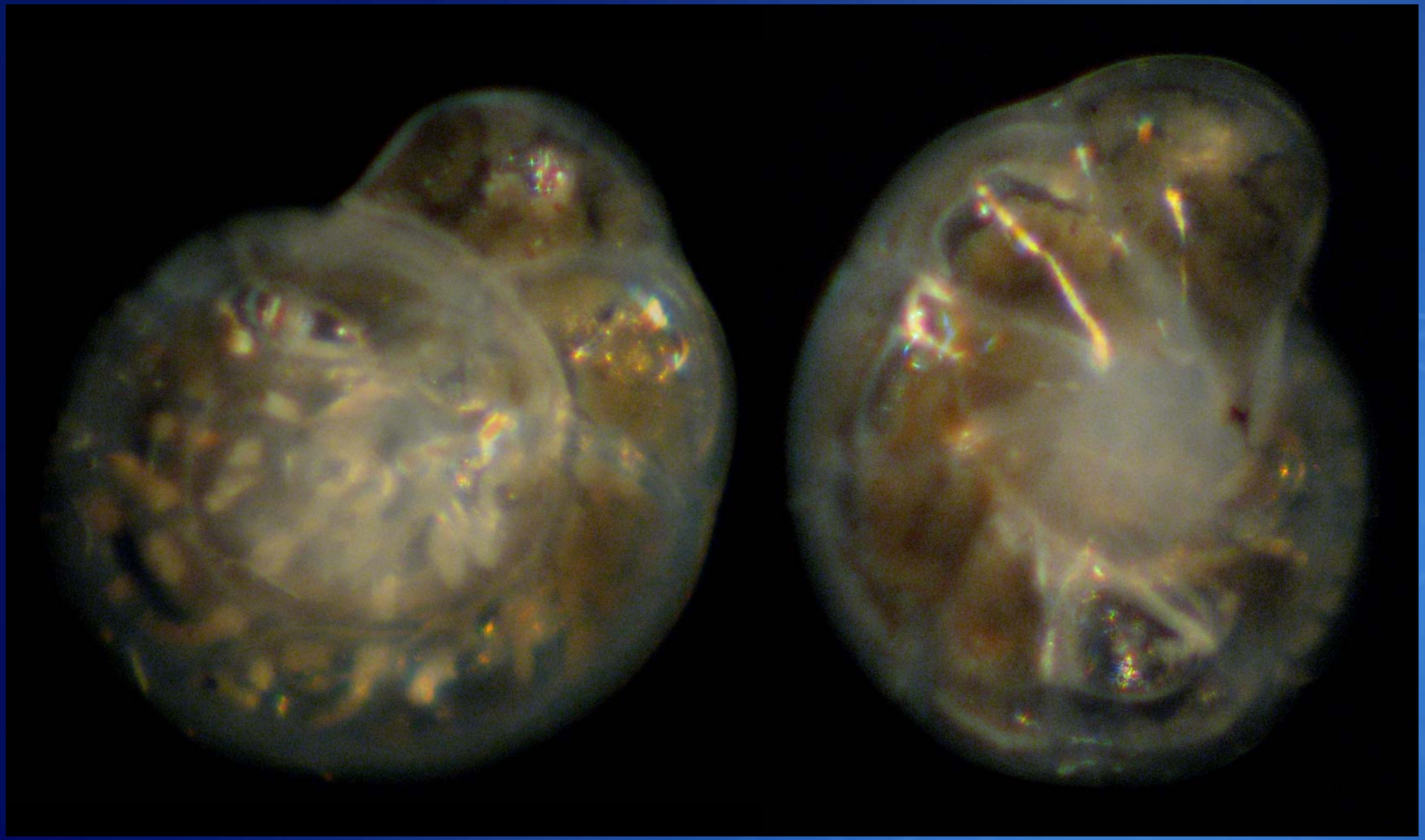
Advantage of light photography: Ability to see within the foraminiferal test





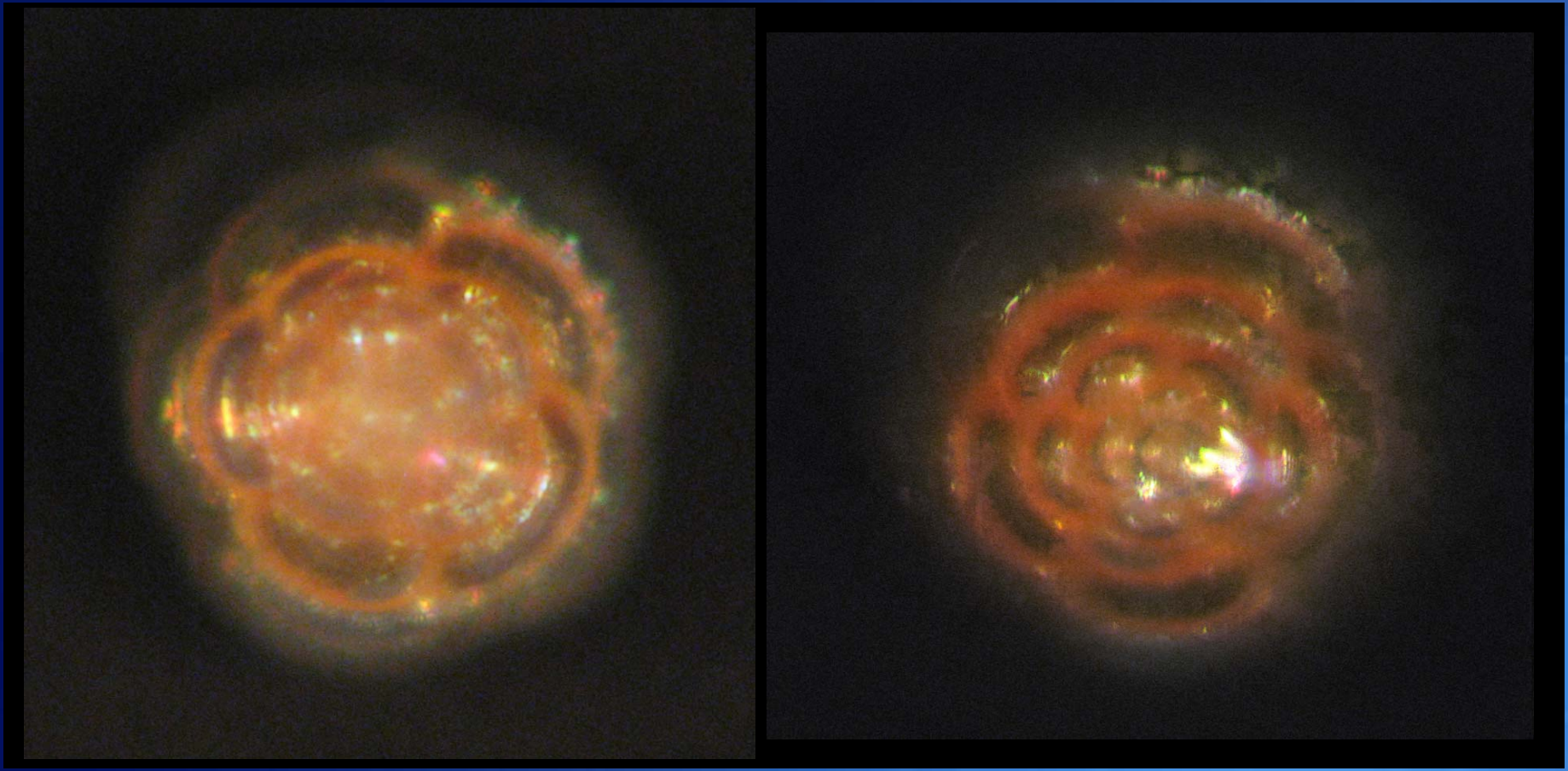
Optivar set at PH

Hoeglundina elegans



Optivar set at PH

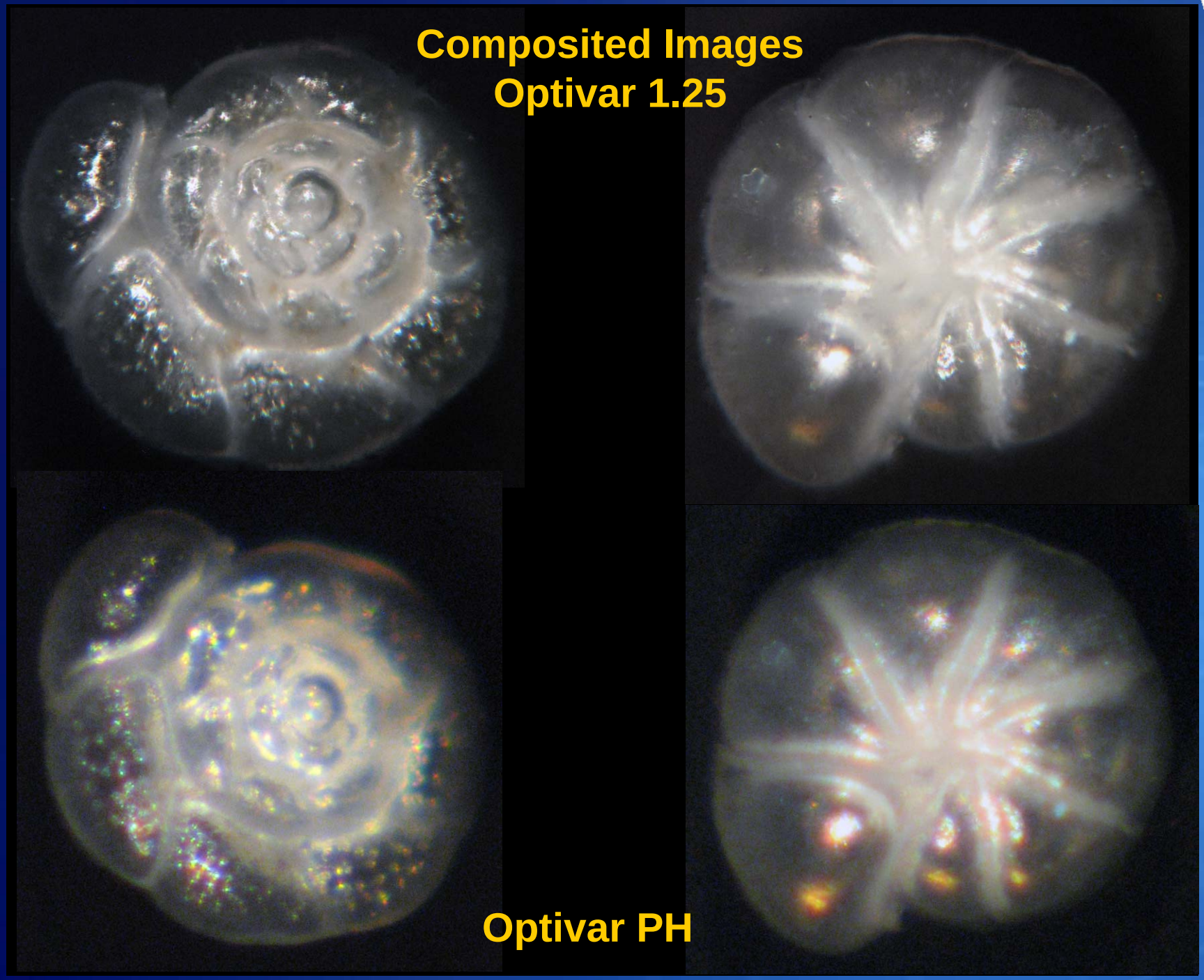
Ioanella (Eponides) tumidulum



Optivar set at PH

Optivar set at 2x
Composited image

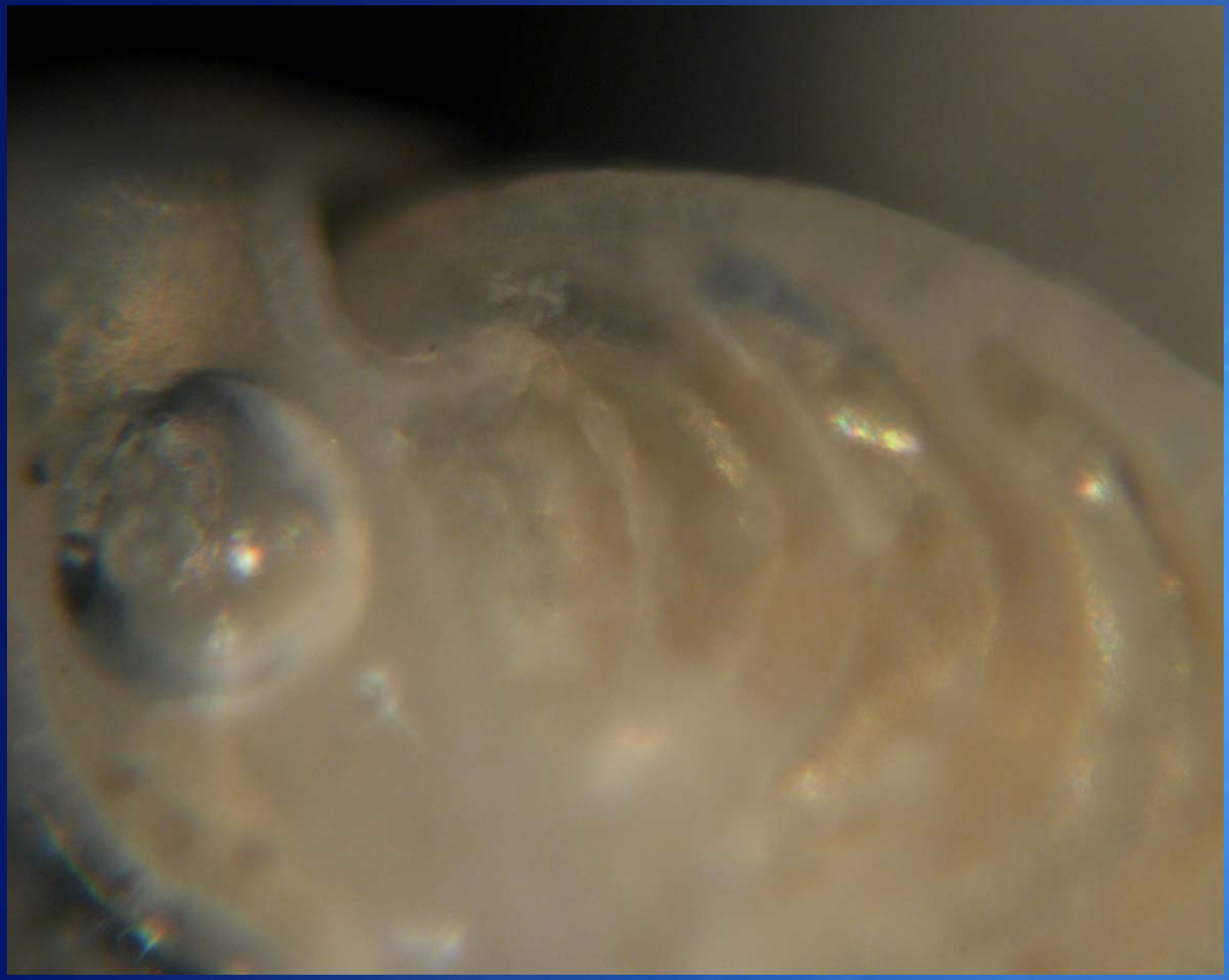
Cibicidoides bradyi



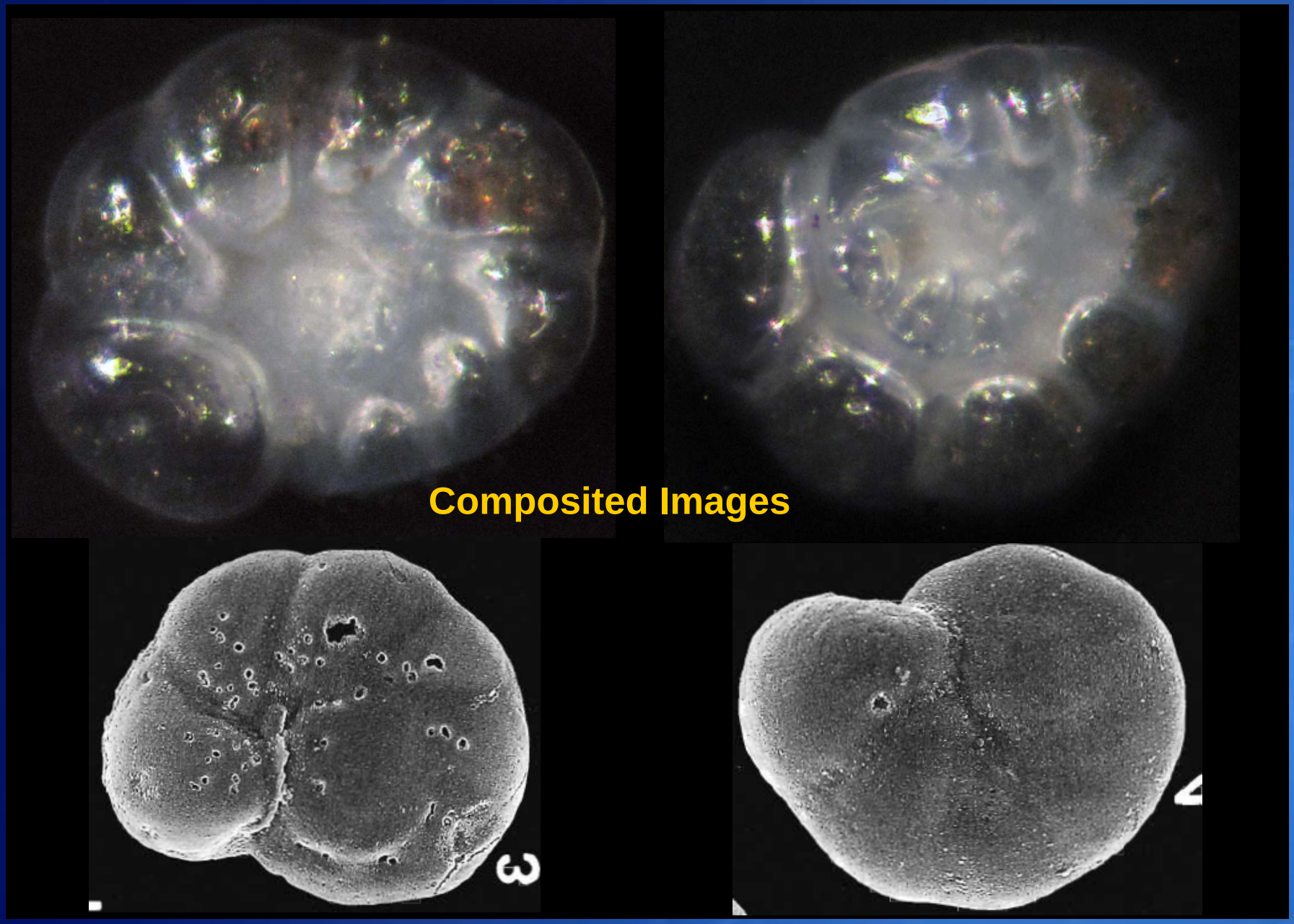
Uvigerina dirupta

Composited Image

Cibicides rugosus
Close-up of aperture



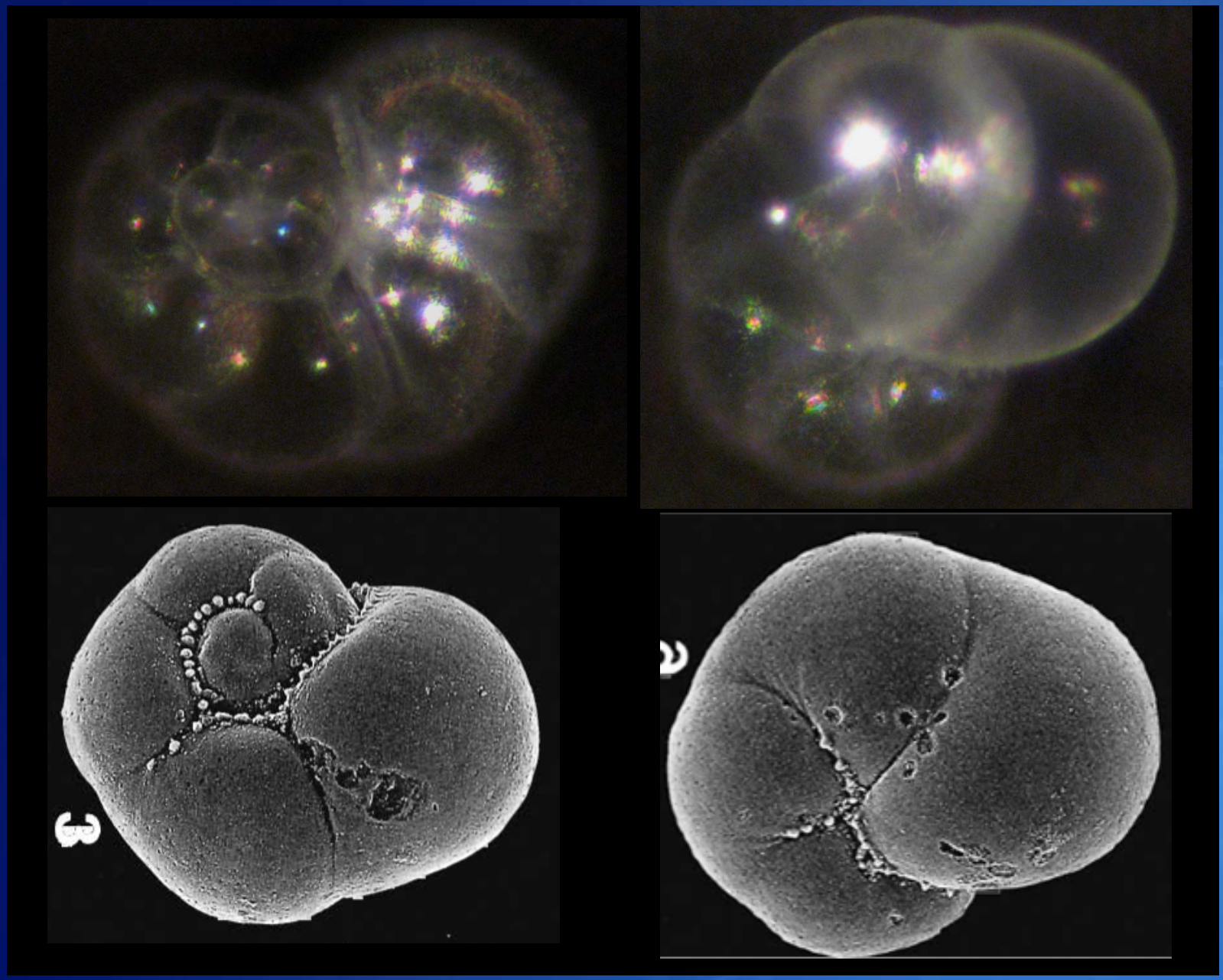
Louisianina pflumi



Composited Images

SEM micrographs from Denne and Sen Gupta, 1996

Grossmanella leroyi



SEM micrographs from Denne and Sen Gupta, 1996

SPECIES IDENTIFICATION AND DOCUMENTATION Calcareous Nannofossils

- Digital light micrographs have recently become the general rule for publication
- Advantages:
  - Inexpensive, quick
  - Most closely represents what specialist sees with the microscope, in color
  - Capability of performing on-screen measurements
  - Capability of making digital movies
- Exceptions when SEM micrographs are preferred
  - Examination of minute structures
  - Examination of crystalline structure

Digital Movies

***Discoaster berggrenii* var. “C”**
Focus Change
Phase Contrast

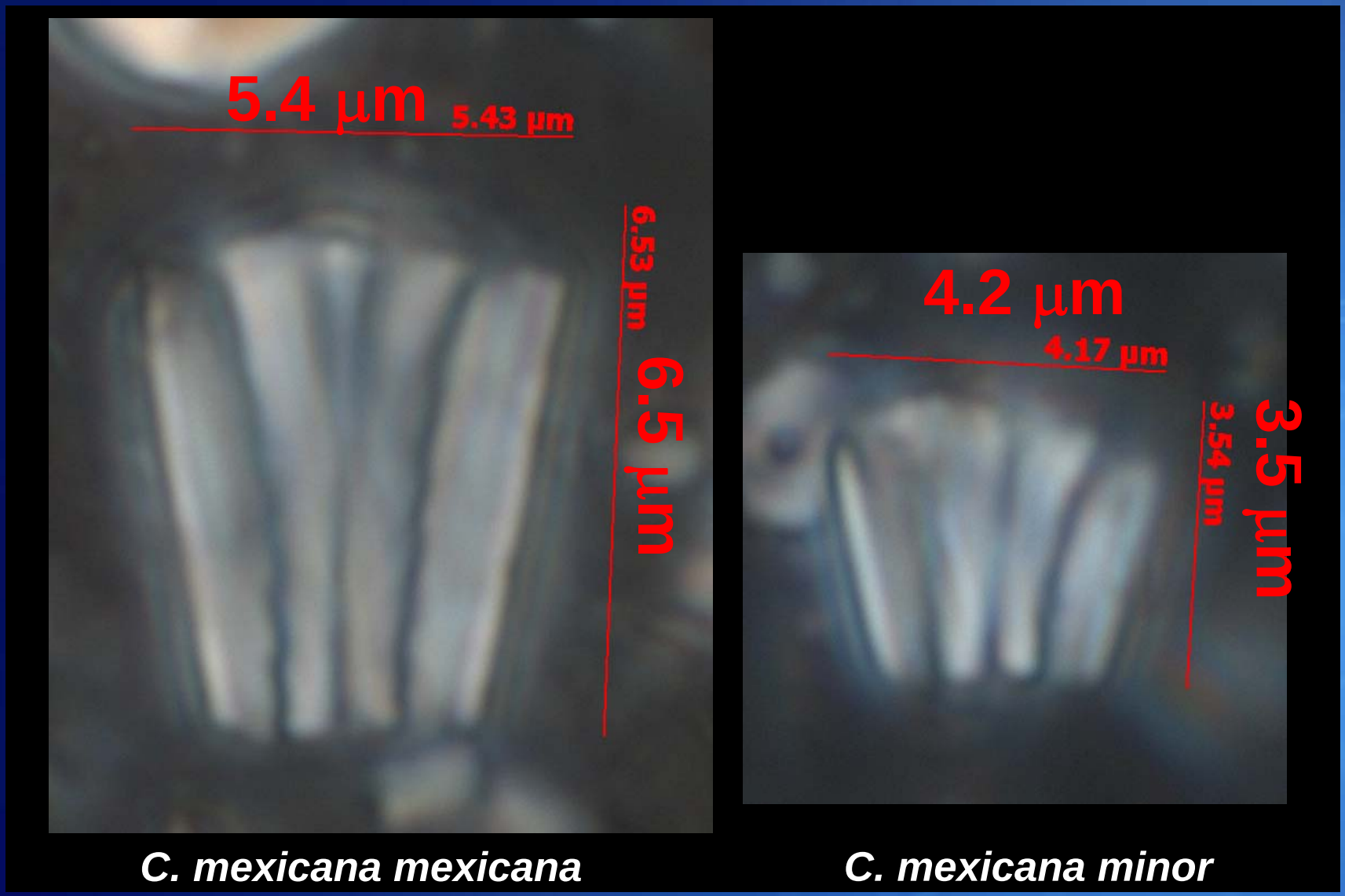
Photographed with Pixera Camera on Zeiss Universal Microscope

Digital Movies

Sphenolithus heteromorphus
Stage Rotation
Cross Polarized

Photographed with Pixera Camera on Zeiss Universal Microscope

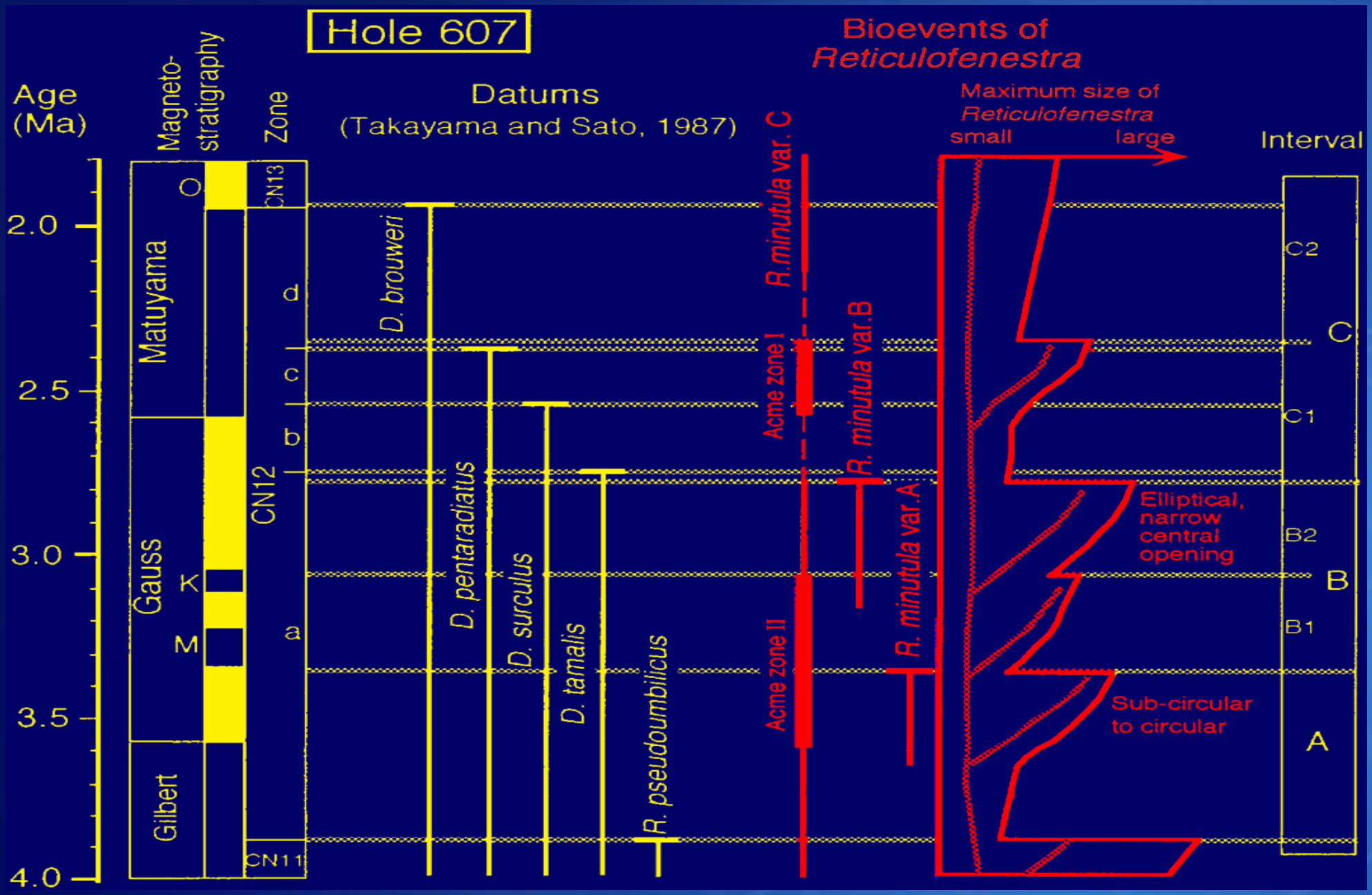
DIGITAL MEASUREMENTS
Conusphaera mexicana



C. mexicana mexicana ***C. mexicana minor***

Photographed with Zeiss AxioCam on Zeiss AxioScope, measured in AxioVision

Reticulofenestra Size Events



from Kameo & Takayama, 1999

OUTLINE

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PHENETIC VS PHYLOGENETIC

"The systematics of calcareous nannofossils / nannoplankton are based entirely on phenetic data and largely confined to the structure and shape of the coccoliths and nannoliths."

Bown and Young, 1998

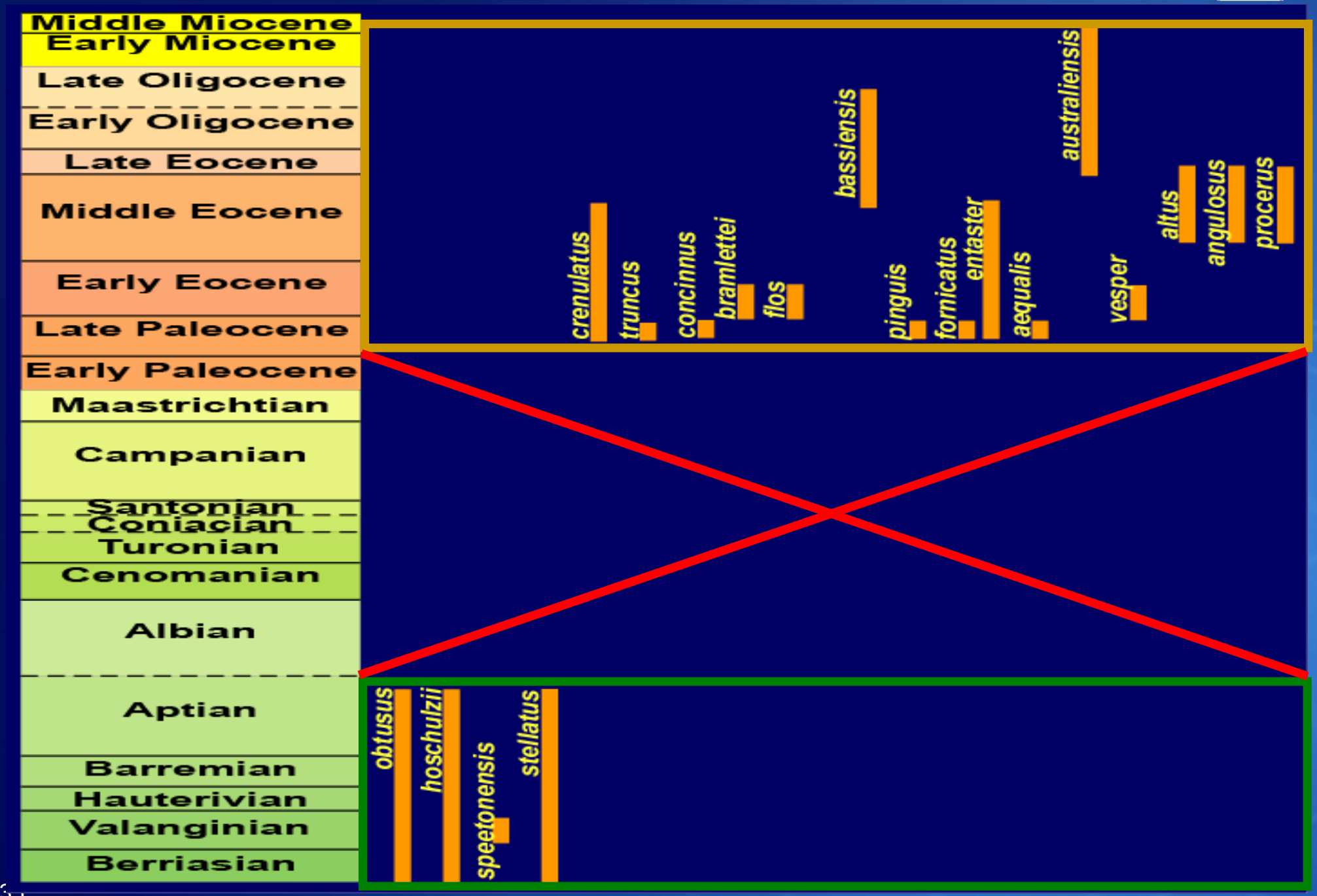
Introduction *in* Calcareous Nannofossil Biostratigraphy

PHENETIC

Relating to taxonomic analysis that emphasizes the overall similarities of characteristics among biological taxa without regard to phylogenetic relationships

Merriam Webster Dictionary

Micrantholithus



PHENETIC VS PHYLOGENETIC

"… all species included in a higher taxon must have a common ancestor within that taxon. This is an absolute necessity of a biologically meaningful classification"

Young and Bown, 1997
Higher Classification of Calcareous Nannoplankton

POLYPHYLETIC

A taxonomic group that includes members (as genera or species) from different ancestral lineages

Merriam Webster Dictionary

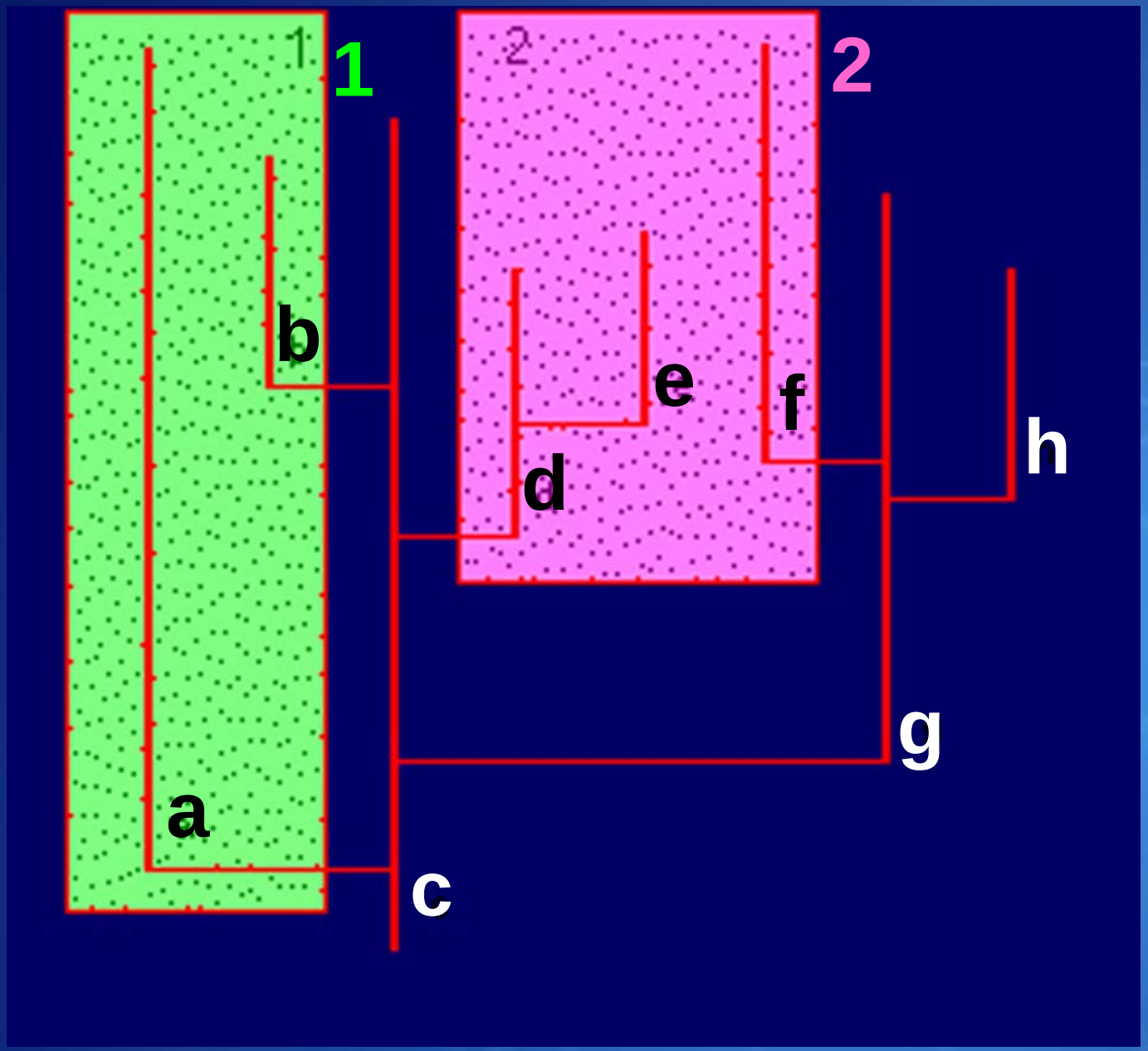
POLYPHYLETIC

Genus 1

Species a and b are from different branches of same species (c)

Genus 2

Species d and e branch from a different species than species f



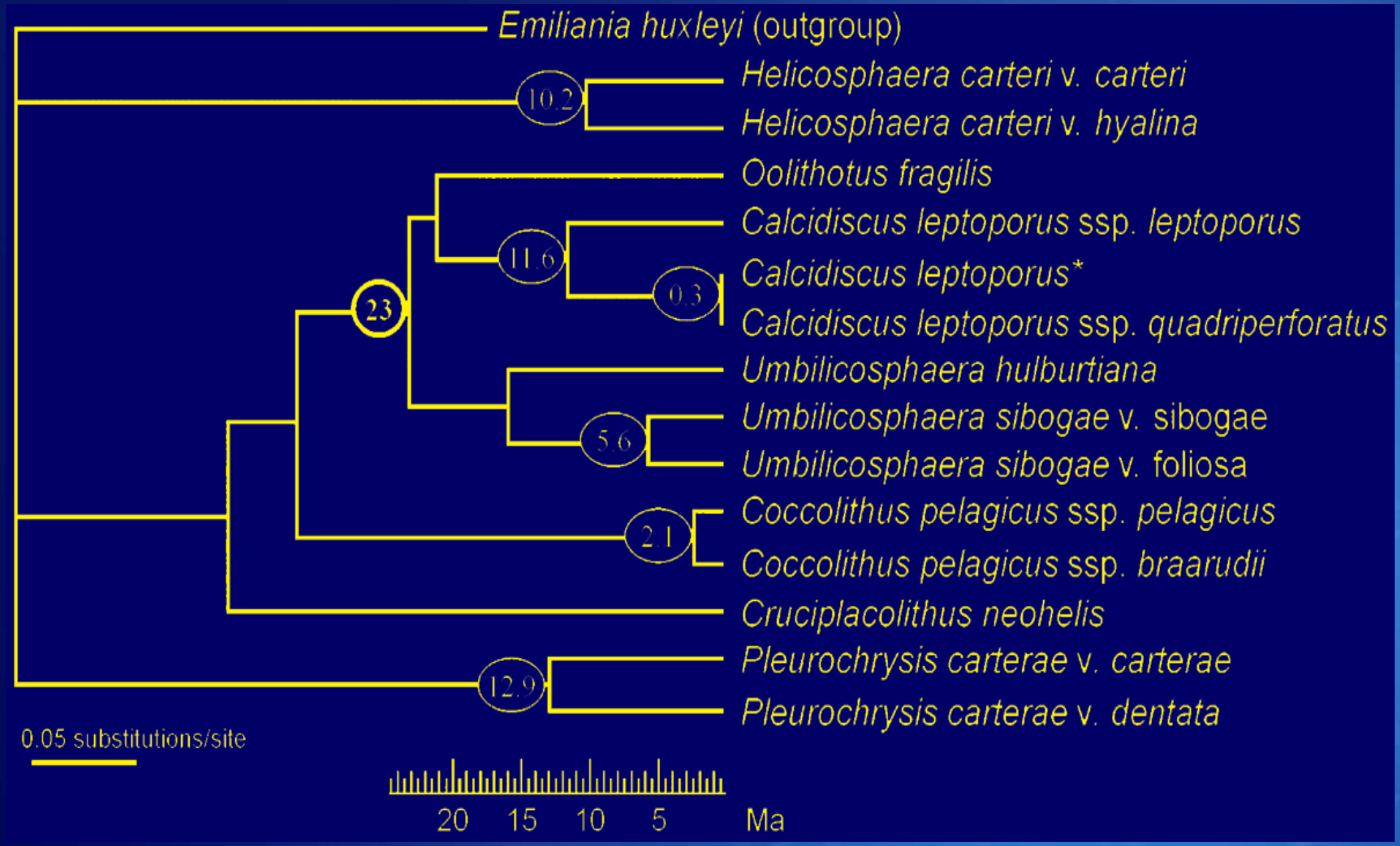
from Young & Bown, 1997

PHENETIC VS PHYLOGENETIC

How can we advance our taxonomic schemes to approach true natural relationships (Phylogenetics)?

- **Genetic analyses**

GENETIC ANALYSES



from Saez et al., 2003

PHENETIC VS PHYLOGENETIC

How can we advance our taxonomic schemes to approach true natural relationships (Phylogenetics)?

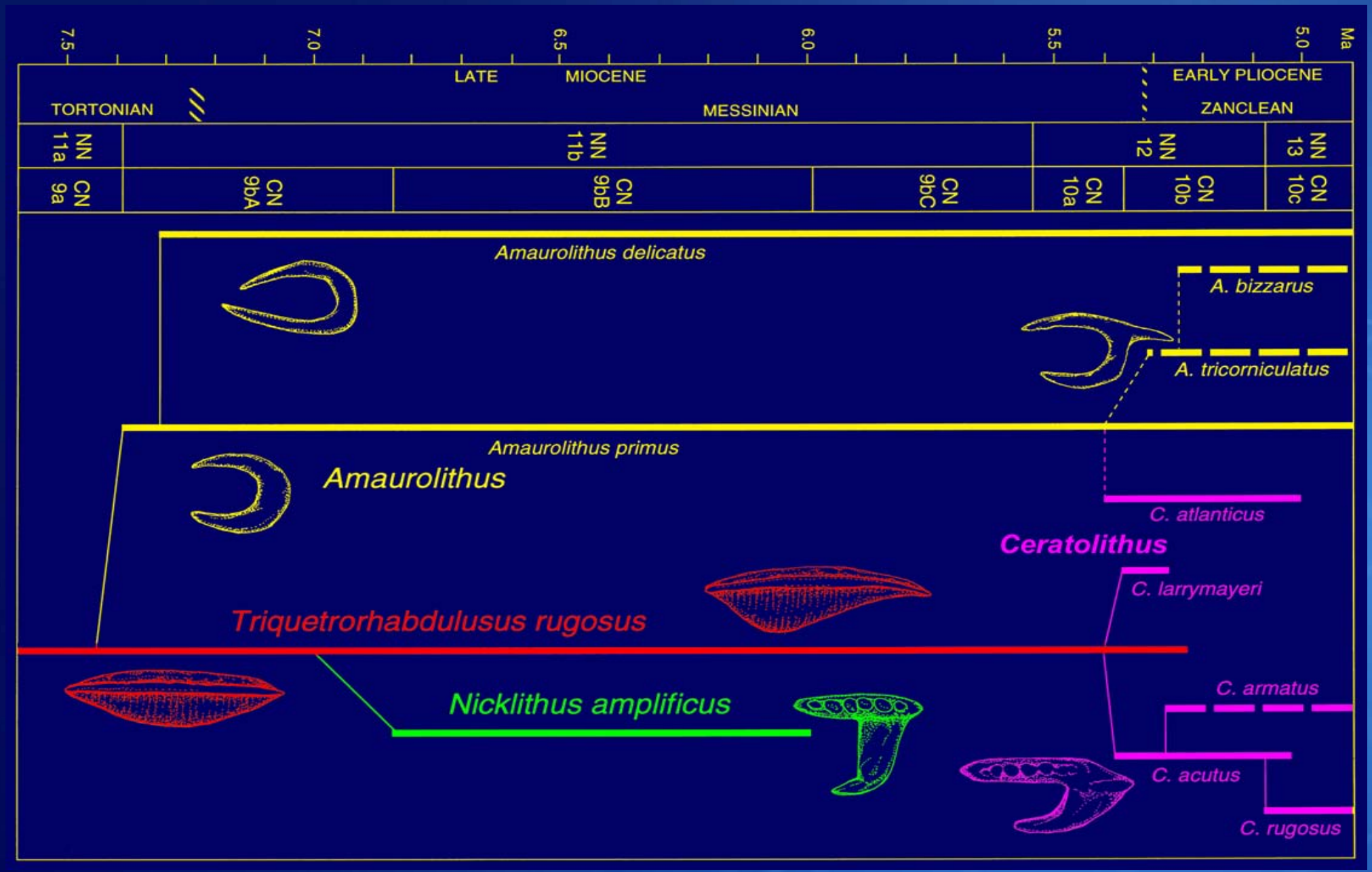
- **Genetic Analyses**
  - **Advantage: Closest to true natural relationship**
  - **Disadvantage: Can only be accomplished with extant taxa**

PHENETIC VS PHYLOGENETIC

How can we advance our taxonomic schemes to approach true natural relationships (Phylogenetics)?

- **Biometric Analyses**

BIOMETRIC ANALYSES



from Raffi et al., 1998

PHENETIC VS PHYLOGENETIC

How can we advance our taxonomic schemes to approach true natural relationships (Phylogenetics)?

- **Biometric Analyses**
  - **Advantages:**
    - **Can be performed on extant and extinct taxa**
    - **Can be utilized for biostratigraphic zonations**
  - **Disadvantages:**
    - **Time consuming**
    - **Requires numerous specimens**
    - **Can be misleading, especially when applied to higher orders**

PHENETIC VS PHYLOGENETIC

"… similar morphotypes developed independently in different lineages … Morphological variations in some lineages by far exceed the traditional morphology-based taxonomy… This evolutionary plasticity among early Foraminifera makes their present morphology based classification of limited value."

Pawlowski et al., 2003
The Evolution of Early Foraminifera

OUTLINE

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SUMMARY AND CONCLUSIONS

- Although computer analyses of paleontologic data have yielded many advances in biostratigraphy and paleoecology, no amount of "data massaging" can overcome misidentified or unidentified species
- With the decline in the number of professional and academic micropaleontologists, and the poor documentation of a number of species, there is an urgent need to capture images before this expertise disappears. New methods of digital photography have made this more feasible.

SUMMARY AND CONCLUSIONS

- Although computer analyses of paleontologic data have yielded many advances in biostratigraphy and paleoecology, no amount of "data massaging" can overcome misidentified or unidentified species
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SUMMARY AND CONCLUSIONS

- Biostratigraphy and large-scale studies of evolutionary and extinction patterns benefit from taxonomic classifications that closely represent actual natural relationships. As microfossil taxonomy is primarily based on morphology, there are numerous taxonomic problems.
- Detailed biometric analyses utilizing digital images can be used to address these taxonomic problems, as well as adding potentially useful new biostratigraphic events.

SUMMARY AND CONCLUSIONS

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- Detailed biometric analyses utilizing digital images can be used to address these taxonomic problems, as well as adding potentially useful new biostratigraphic events.