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Heterotrophic Eukaryote Origination in an Anoxic Primitive Atmosphere

SCHOOL OF Freshwater Sciences

POWERFUL IDEAS | PROVEN RESULTS |

UNIVERSITY of WISCONSIN UWMILWAUKEE

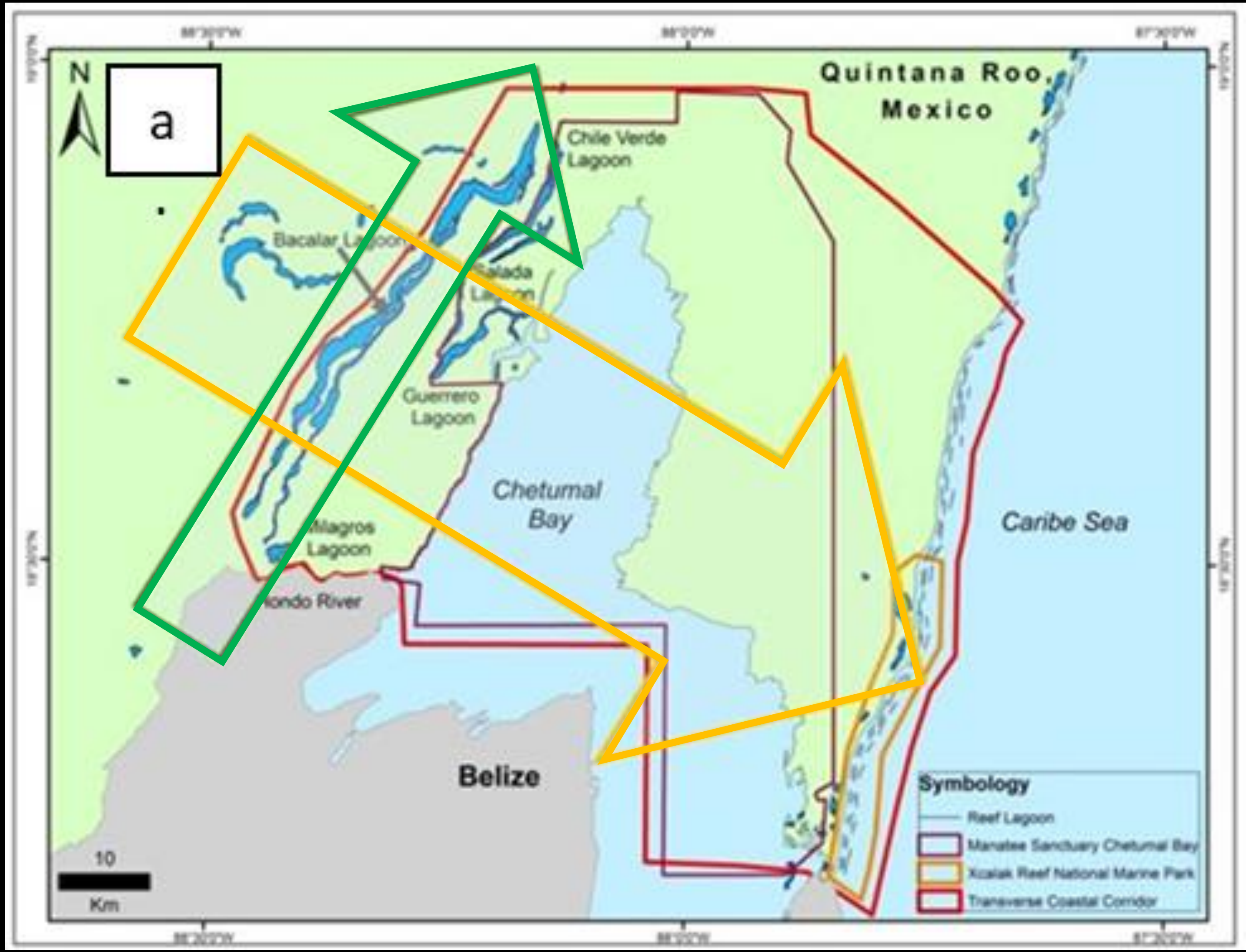
A little bit about Laguna Bacalar…

SFS scientists and students have engaged activities ranging from research to community outreach in the southern Yucatan Peninsula, at Bacalar, MX. The feature that draws us is Laguna Bacalar, that houses the largest living Stromatolites on Earth.

>Mexico's 2nd largest natural lake
>Perched on a massive karst platform
>Extensive carbonate precipitation
>Extensive Stromatolite growth
>Invasive *Mytilopsis sallei* is currently in an apparent ecological equilibrium
>Tourism is growing quickly
>Sewage treatment is inadequate

Biodiversity Hotspots


Google Earth
Laguna Bacalar
Chetumal
Bay

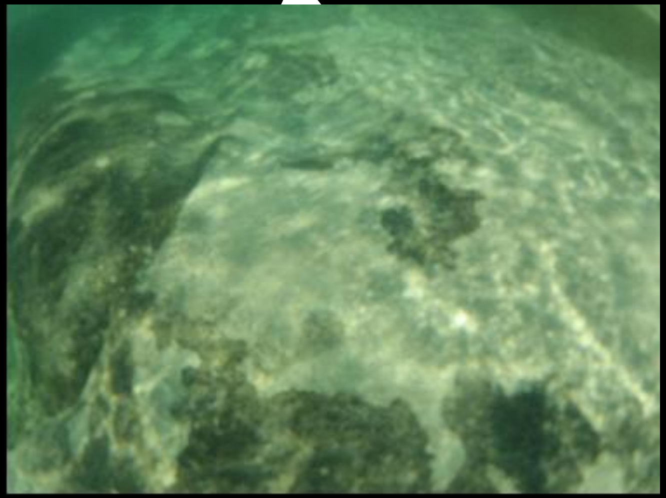


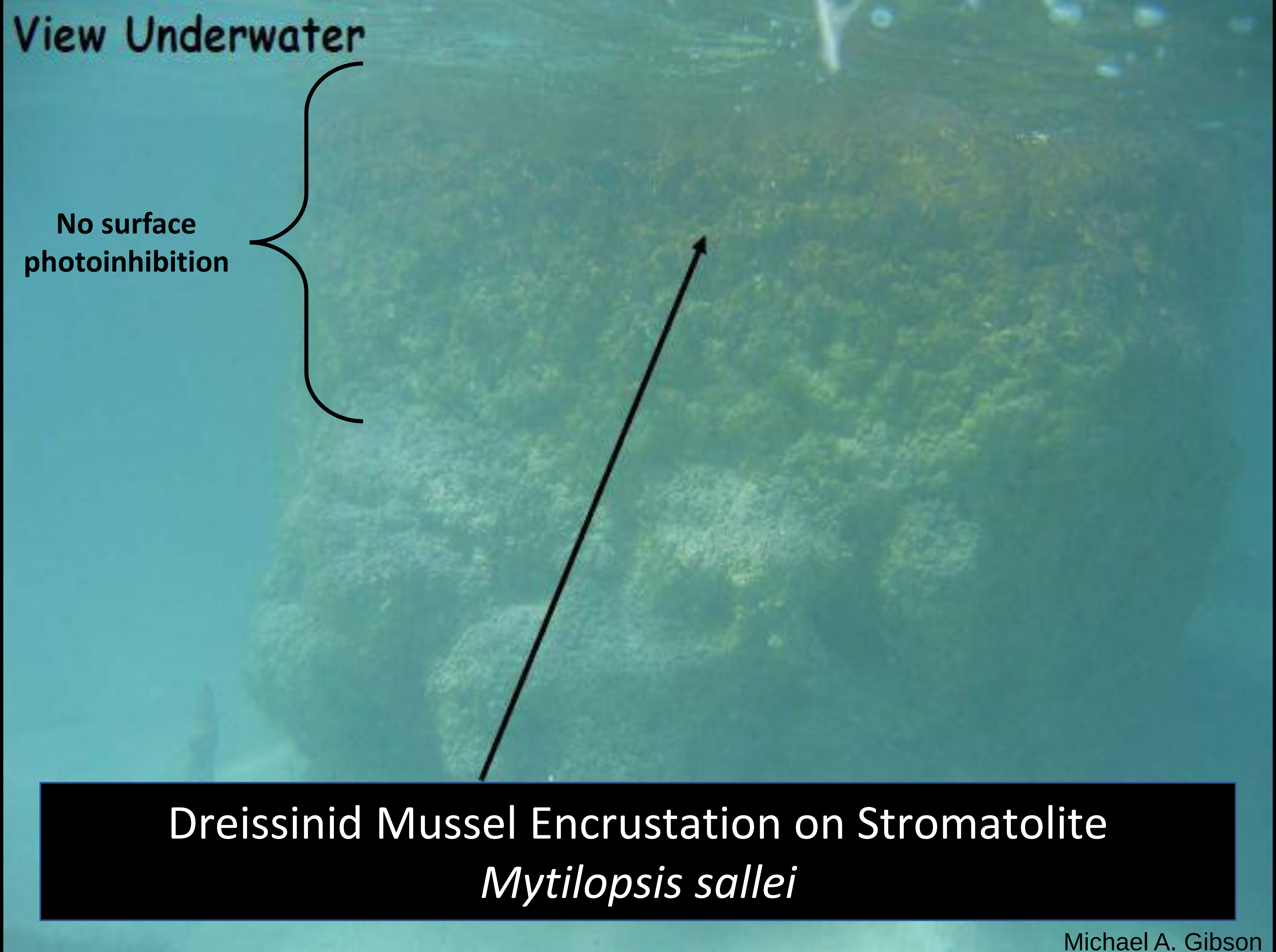
The horizontal ecological corridor...

The “carbonate beauty” of the Laguna Bacalar.

The perfect habitat to support the largest living Stromatolites on Earth.

Severe damage





Dreissinid Mussel Encrustation on Stromatolite
Mytilopsis sallei

Michael A. Gibson

Mytilopsis sallei *(Recluz 1849)*

A one mussel layer thickness

has a ~2mm-thick Cyanobacteria mat.

An adjacent area free of mussels has

a ~5mm-thick Cyanobacteria mat.

Rapidos, 2019

Byssal Hilo (utilizado para la conexión)
(Byssal Threads)

Extant Stromatolites Around the World

Shark Bay, Australia

Pavilion Lake, BC, Canada

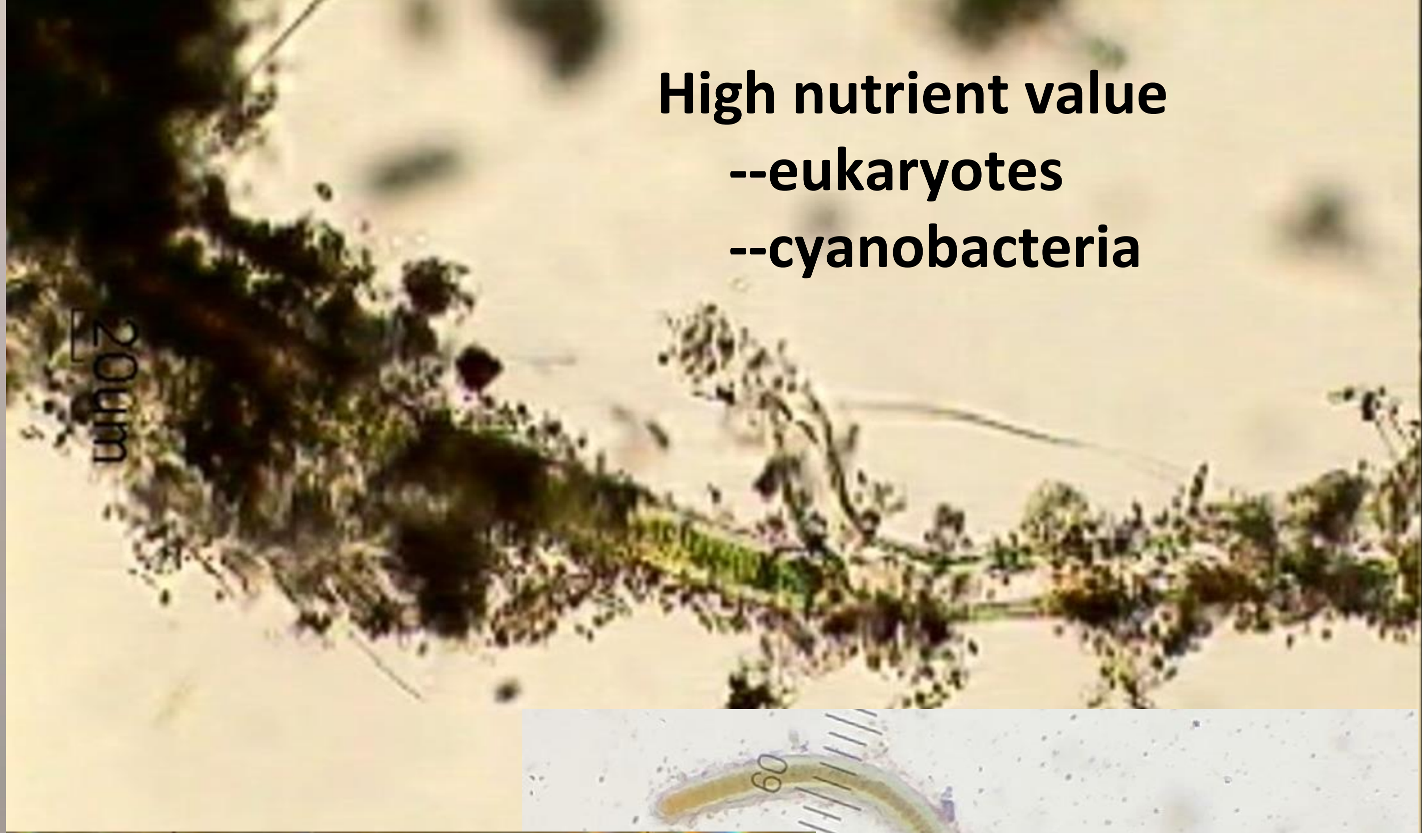
Exuma Sound, Bahamas

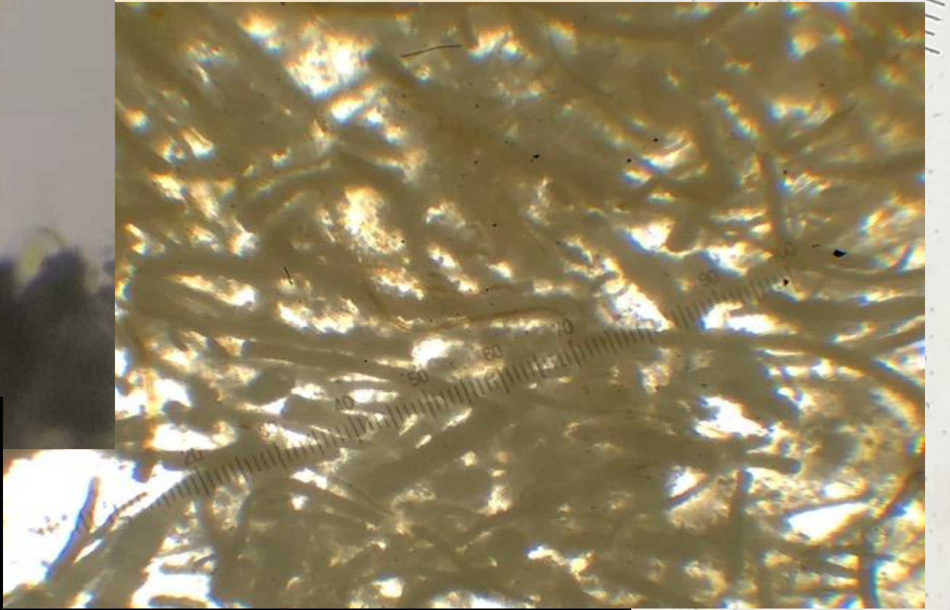
Stromatolite builders: Cyanobacteria are collectors of particles (from Laguna Bacalar)

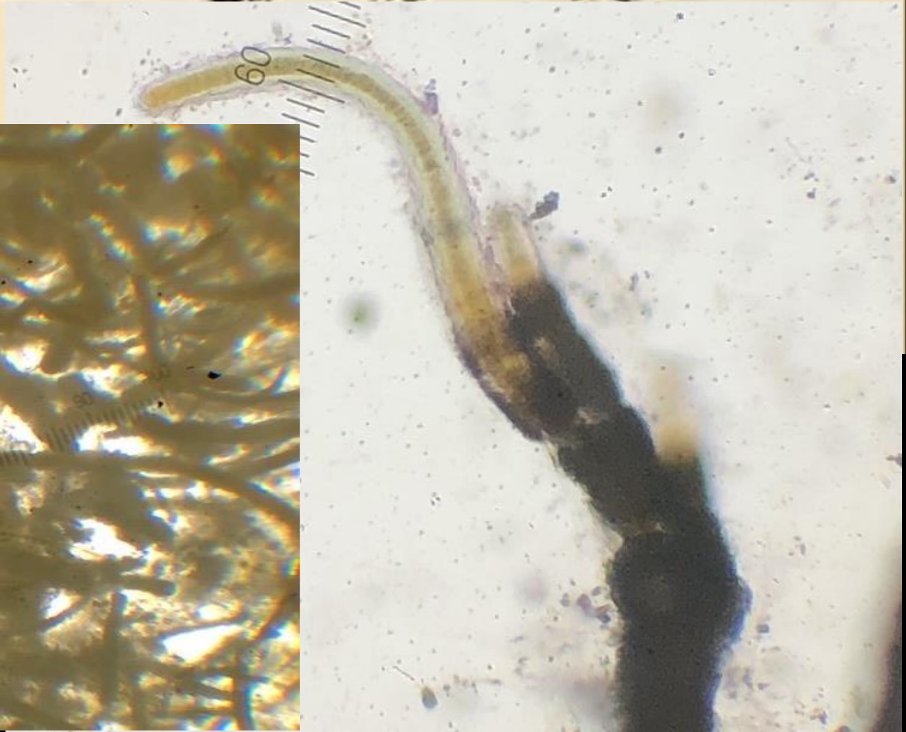
High nutrient value

--eukaryotes

--cyanobacteria







Why do they move?

--positioning for light/O_2 utilization

--clear mucous sheath of debris

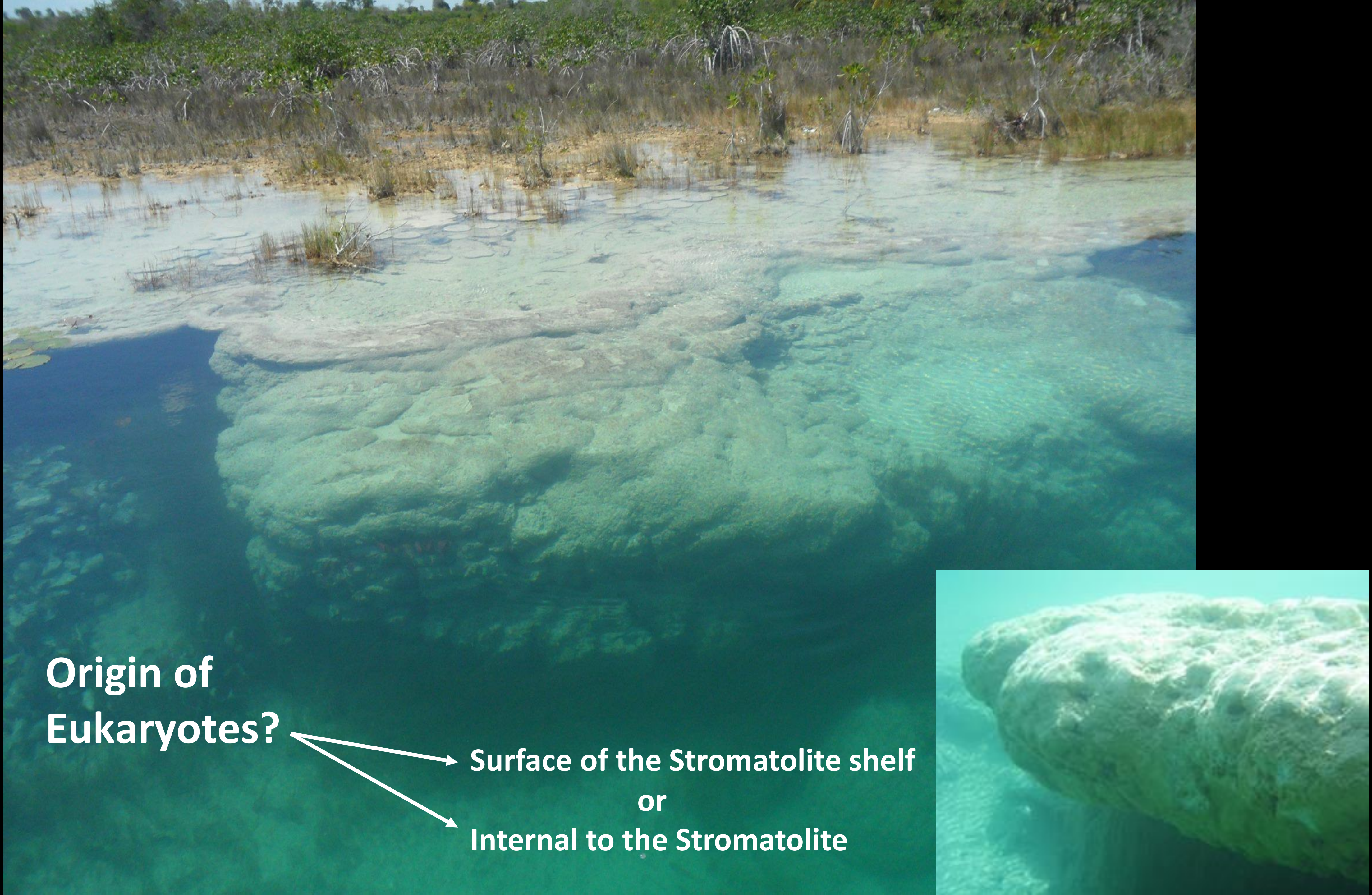
Laguna Bacalar Stromatolites

Extensive Microbialite/Carbonate Growth Platform for Mangroves

Rio Rapidos

"The only people who go into mangrove swamps are scientists and escaped convicts."
--E. O. Wilson


Rio Rapidos
Laguna Bacalar


Origin of Eukaryotes?
Surface of the Stromatolite shelf
or
Internal to the Stromatolite

Symecosis: The de novo origin and evolution of one community totally internal to another community. -Kaster

Stromatolite Symecosis hypothesis:

--early heterotrophic eukaryote communities originated de novo internally within a Stromatolite oxygen oasis, ultimately facilitating luxury oxygen production.

Of interest are the extant thrombolitic microbialites found in Laguna Bacalar, Q.R. Mexico.

Symecosis perhaps exemplifies the earliest example of a functional heterotrophic ecosystem in an oxygen deficient atmosphere of Archean/Proterozoic Earth (4000Ma-2500Ma/2500-540Ma).

Current: Ocean shelf Hypothesis

The ancient shallow ocean shelf served as an oxygen oasis that spawned early Stromatolite surface mats and origin of the eukaryotes.

Riding 2014, Gomes 2018

"Our findings support the view that during the Archean significant oxygen levels first developed in protected nutrient-rich shallow marine habitats. …these environments were spatially restricted, transient, and promoted limestone precipitation. Substantial amounts of molecular oxygen might have accumulated locally in protected shallow-water environments that favored cyanobacterial productivity (MacGregor 1927, Cloud 1965, Kasting 1992) and were sufficiently isolated so that the oxygen was not all immediately scavenged (Hayes 1983) [by anoxic open ocean waters]. With a low rate of atmospheric exchange, O_2 levels in these 'oxygen oases' (Fischer 1965) could have approached [8%] PAL, even under an anoxic atmosphere (Kasting 1992, Kasting 1992, Pavlov and Kasting 2002, Olson et al. 2013)" (Riding et al. 2014).

Problem:

Against the backdrop of an adjacent turbulent, anoxic atmosphere and turbulent anoxic oceans, time-stable oxygenated shallow isolated shelves seem unlikely.

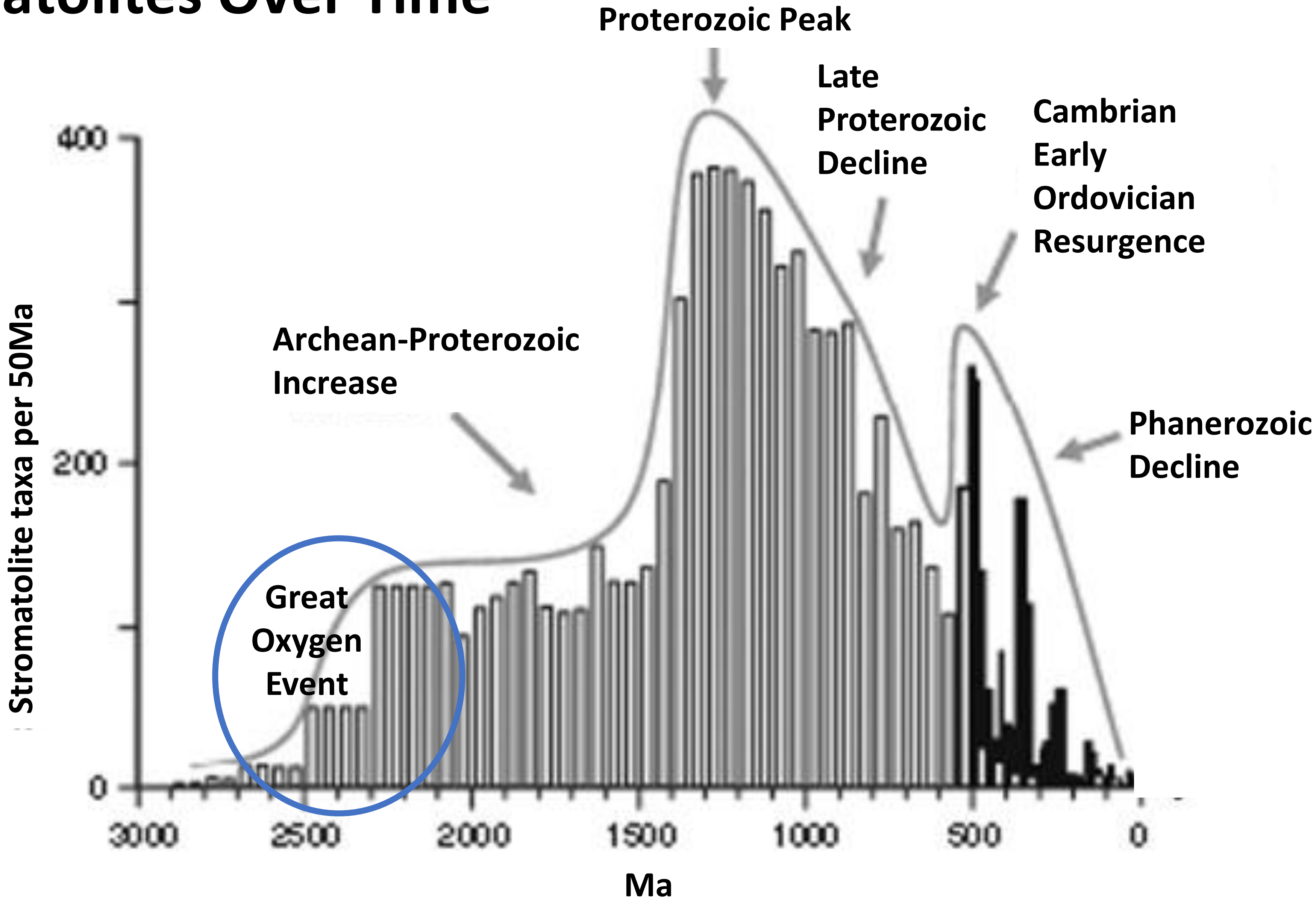
Other possible oxygen oases: shallow waters, terrestrial lakes, geothermal vents.

Shallow waters - Transient; not isolated
Terrestrial lakes - Transient
Geothermal vents – Aphotic & anoxic

What can the internal, symecosis oasis provide eukaryotes?

1) Moderating environment against backdrop of an inhospitable primitive atmosphere (e.g., lethal UV-radiation, anoxia)
2) Evolutionarily stable, long-term growth platform >3.0Ga)
3) Complex growth substrates
   Life loves a substrate (habitat)
4) Photosynthetic growth-accreting carbonaceous environment
5) Eco-homeostatic environment in support of a phototrophic / heterotrophic community
6) Provided complex boundaries
   Life loves a boundary (interfaces)
7) Photosynthesis oxygen production (P/R>1); heterotroph O_2 removal
8) High C and nutrient source for aerobic respiration, including K
9) Launch pad to quickly populate outside the microbialites as ambient conditions became hospitable
10) Proximity to ancestral prokaryotes in a local environment (e.g., endosymbiosis, endocytosis)

Stromatolites Over Time



Riding, 2006;
modified by Kaster

O^2 build-up in the Earth's atmosphere.

Stage 1: (3.85–2.45 Ga): Practically no O_2 in the atmosphere. The oceans were largely anoxic with the *possible* exception of O_2 oases.

Stage 2: (2.45–1.85 Ga): O_2 produced, rising but immediately absorbed in oceans and seabed rock. End of banded iron formation.

Stage 3: (1.85–0.85 Ga): O_2 starts to de-gas from the oceans, but is absorbed by land surfaces. No significant change in terms of oxygen level.

Stage 4: (0.85 Ga–present): Other O_2 reservoirs filled; gas accumulates in atmosphere.

Kick-starting early eukaryote evolution at the Earth's surface

Symecosis "Eukaryote Explosion" at Earth's surface:

Stromatolites were the ultimate "oxygen oasis" with early eukaryotes originating internally, protected from an ambient anoxic atmosphere, an anoxic ocean, and severe UV-radiation.

From this origin, heterotrophs quickly colonized the ocean shelf surface mats as they formed, leading to rapid ecesis and diversification of Earth's surface.

Stromatolites provided a persistent,
stable heterotroph growth platform for 3.8 billion years

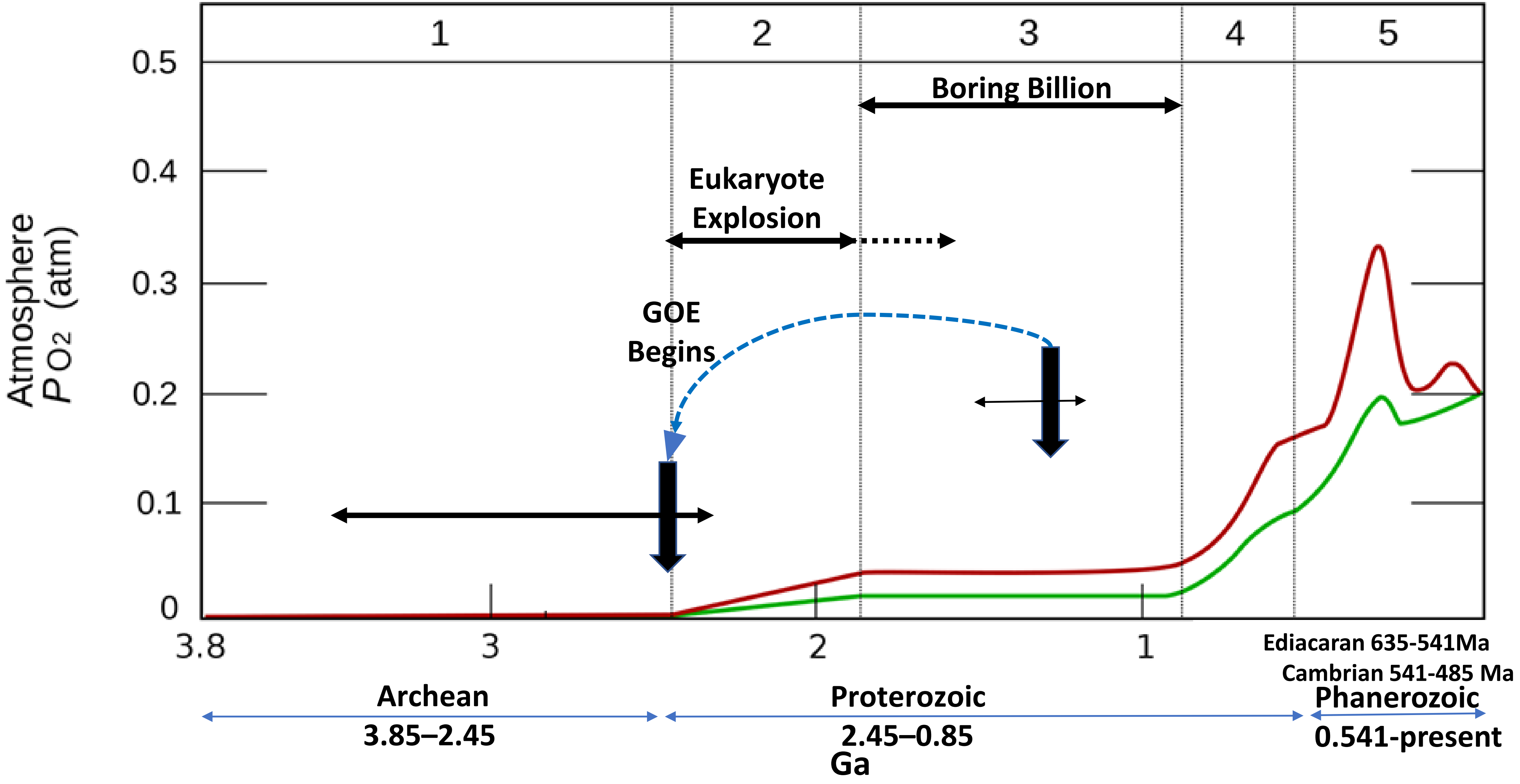
Early Evolution….

<u>The eukaryote explosion</u>

“Phylogenomic reconstructions show that the characteristic eukaryotic complexity arose almost 'ready made', without any intermediate grades seen between the prokaryotic and eukaryotic levels of organization.

Explaining this apparent leap in complexity at the origin of eukaryotes is one of the principal challenges of evolutionary biology.”

Eugene Koonin, 2010. Genome Biology (and citations 9, 28, 29, 30)



Red and green lines: range of the estimates.

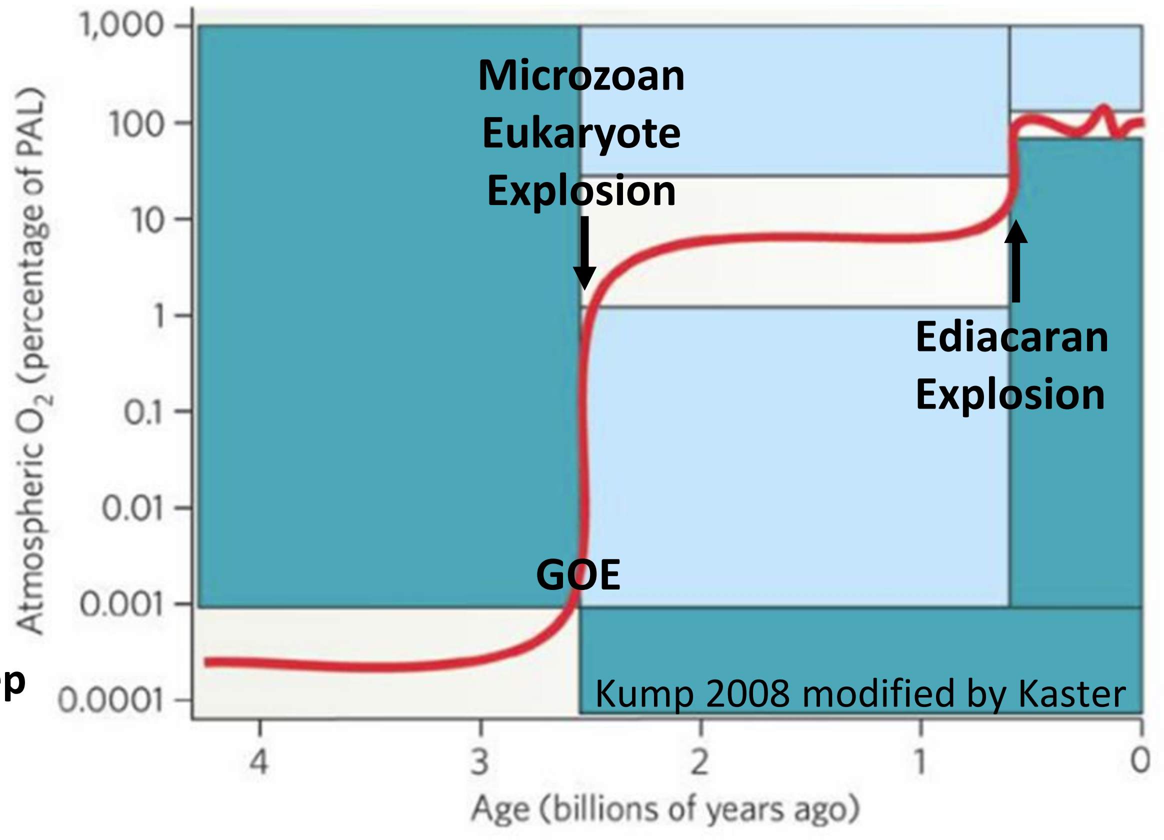
Holland 2006 modified by Kaster

Eco-homeostasis: Ramping-up Oxygen Productivity

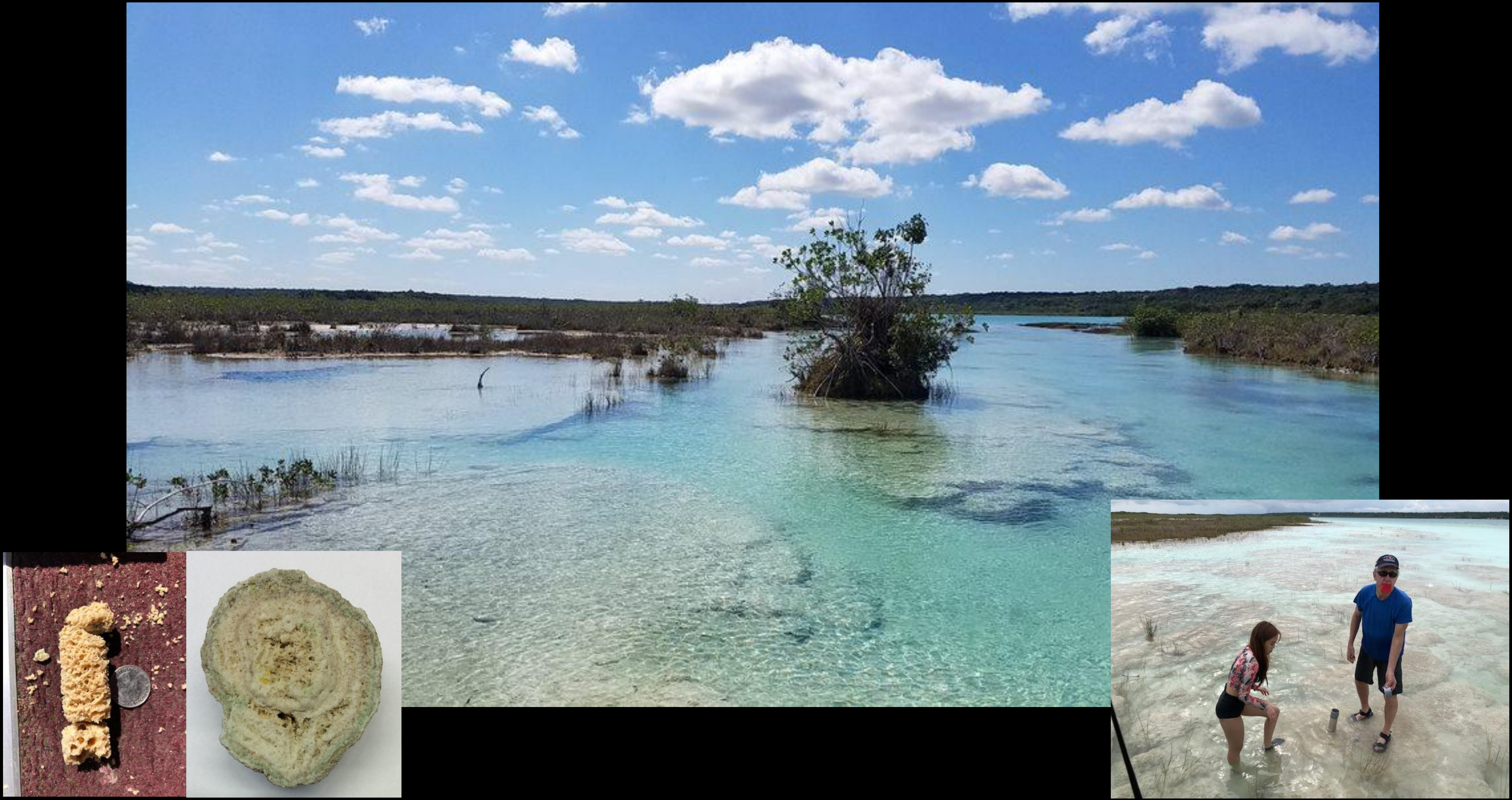
1) Luxury oxygen production (P\R>>1) was a result of a Stromatolite/heterotroph eco-homeostasis.

2) Within a hard surface Stromatolite,
↑O_2 production & accumulation -- Cyanobacteria move lower;
↓O_2 production & accumulation -- Cyanobacteria moved higher;
resulting in an O_2 maintenance production of P/R≈1.
- - inadequate to fill an anoxic atmosphere.

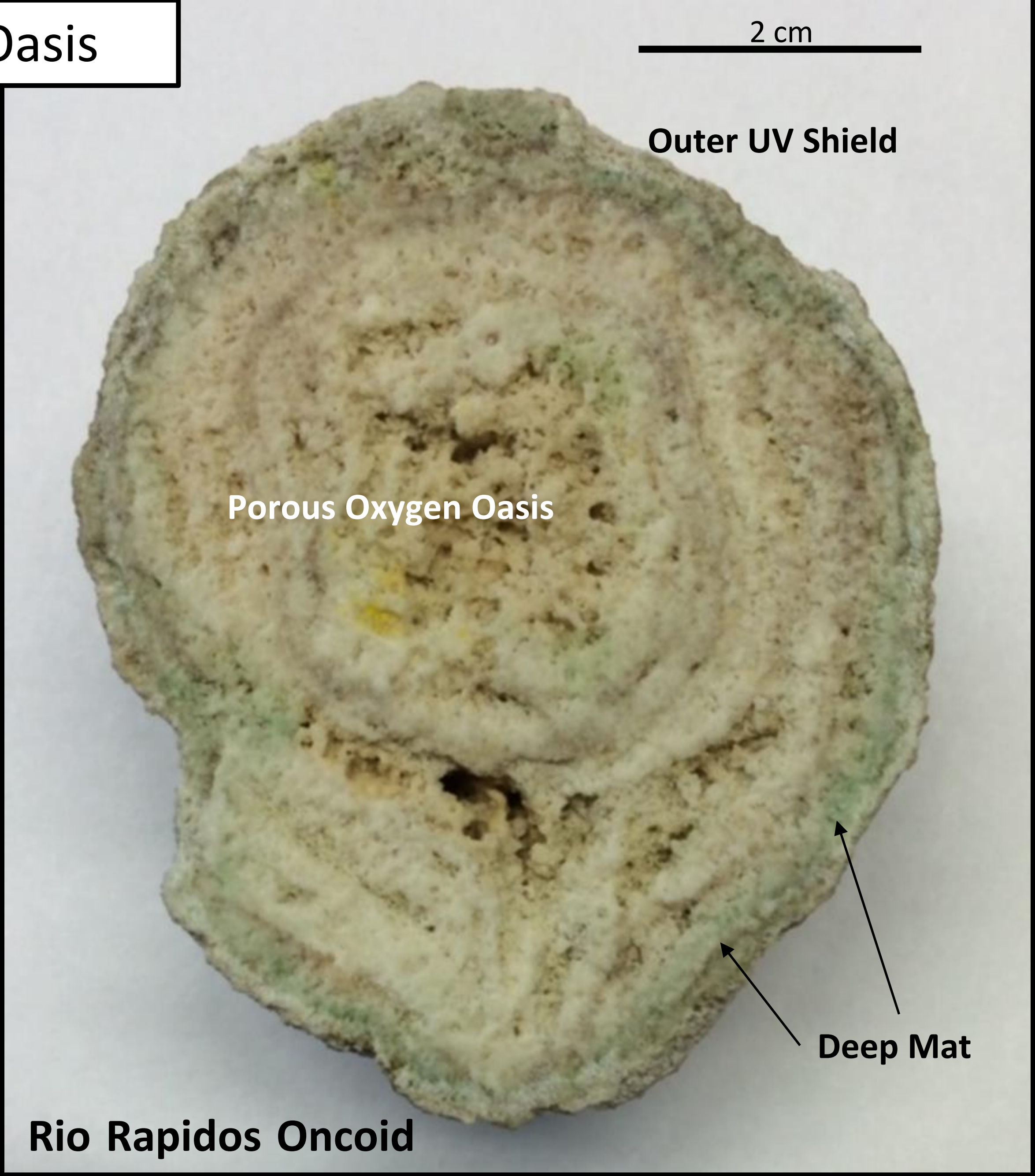
3) Very high, luxury O_2 production was supported by heterotroph respiration, allowing Cyanobacteria to live higher in the deep mat without oxygen toxicity.

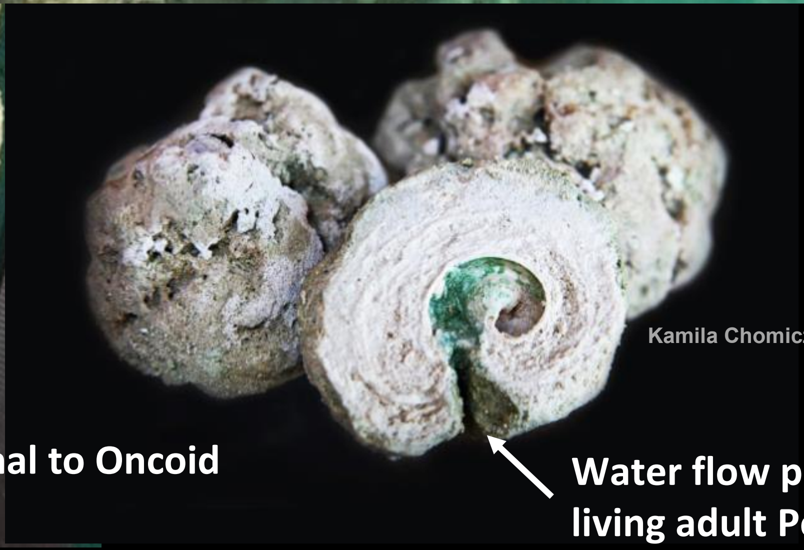


--Heterotrophs ramped-up Cyanobacteria O_2 production.



Oxygen Oasis





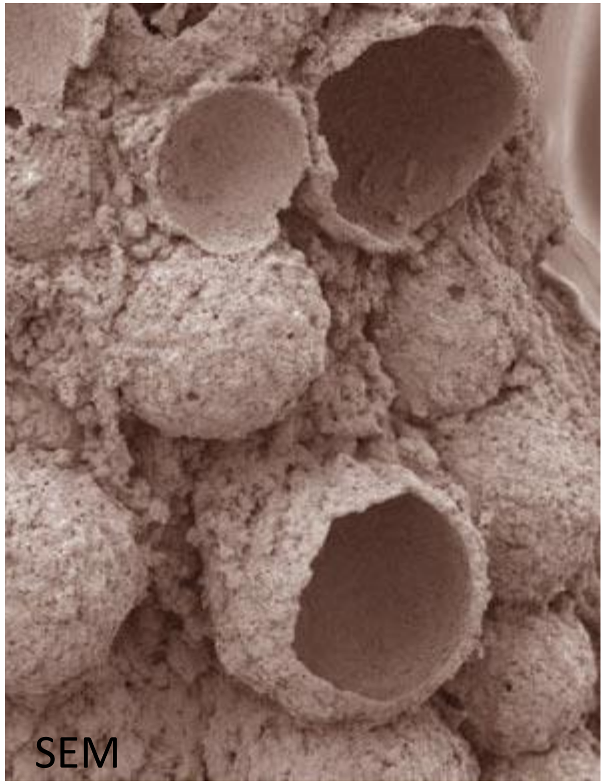
Water flow path indicating living adult Pomacea

Luxury Oxygen Production

1.6 Ga Oxygen Bubbles

Fossilized bubbles and cyanobacterial fabric from 1.6 billion-year-old phosphatized microbial mats of the Chitrakoot Formation. Image credit: Stefan Bengtson.

T. Sallstedt *et al*. 2018



Why wait? Early evolution of microzoans

Laguna Bacalar Stromatolites

Extant surface mats can be "hard biofilms" ① or "soft tufts" ②, both with deep mat ecosystems ③ ↗.

SIDE BAR

(poison gas)

Pre-eukaryote: Cyanobacteria metabolism limited to P/R≈1

thus, little O_2 build-up in atmosphere

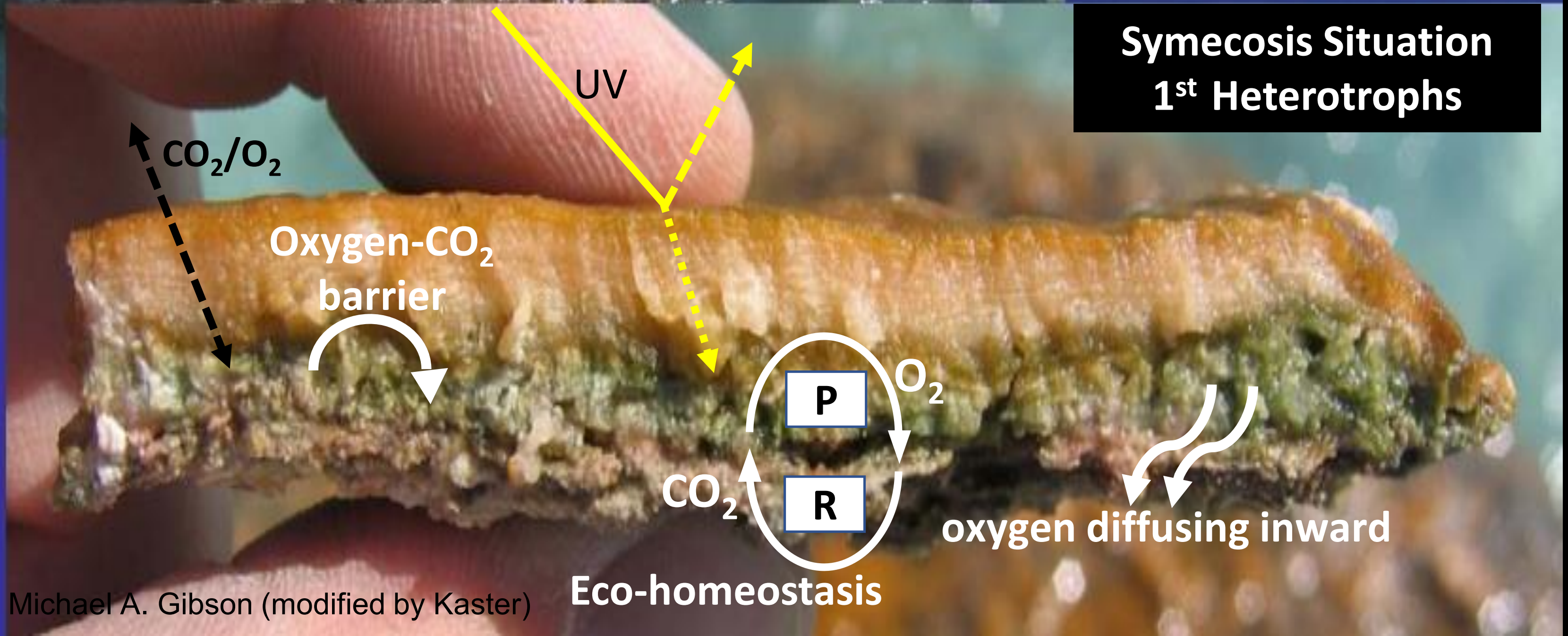
Heterotroph respiration releases metabolic potential of Cyanobacteria for luxury O_2 production, P/R >> 1

Laguna Bacalar: Cocolitos Cenote (Extant)

High UV/solar radiation, limited penetration (primitive atm Pre 2.45 Ga)

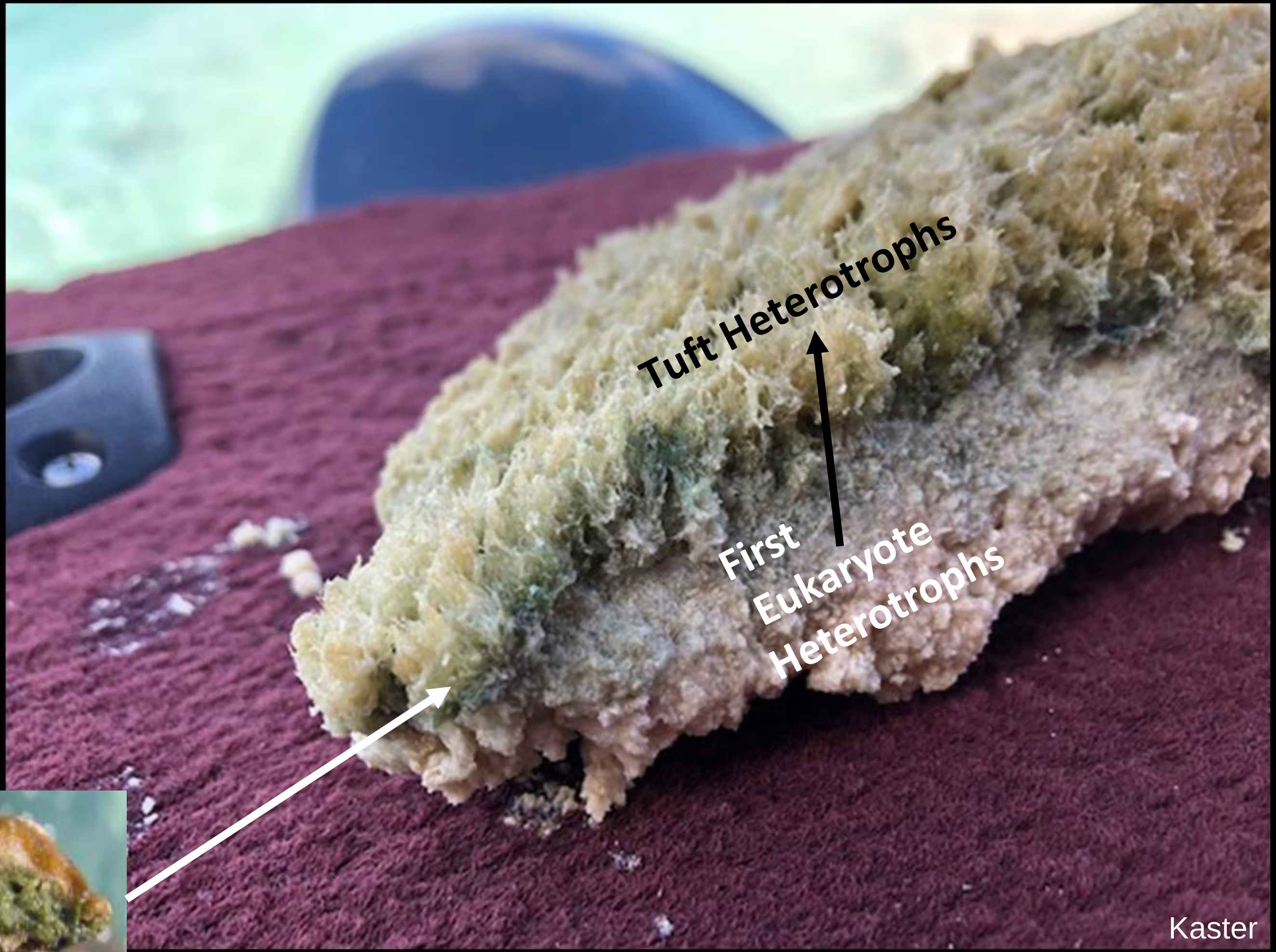
Symecosis Situation

1st Heterotrophs

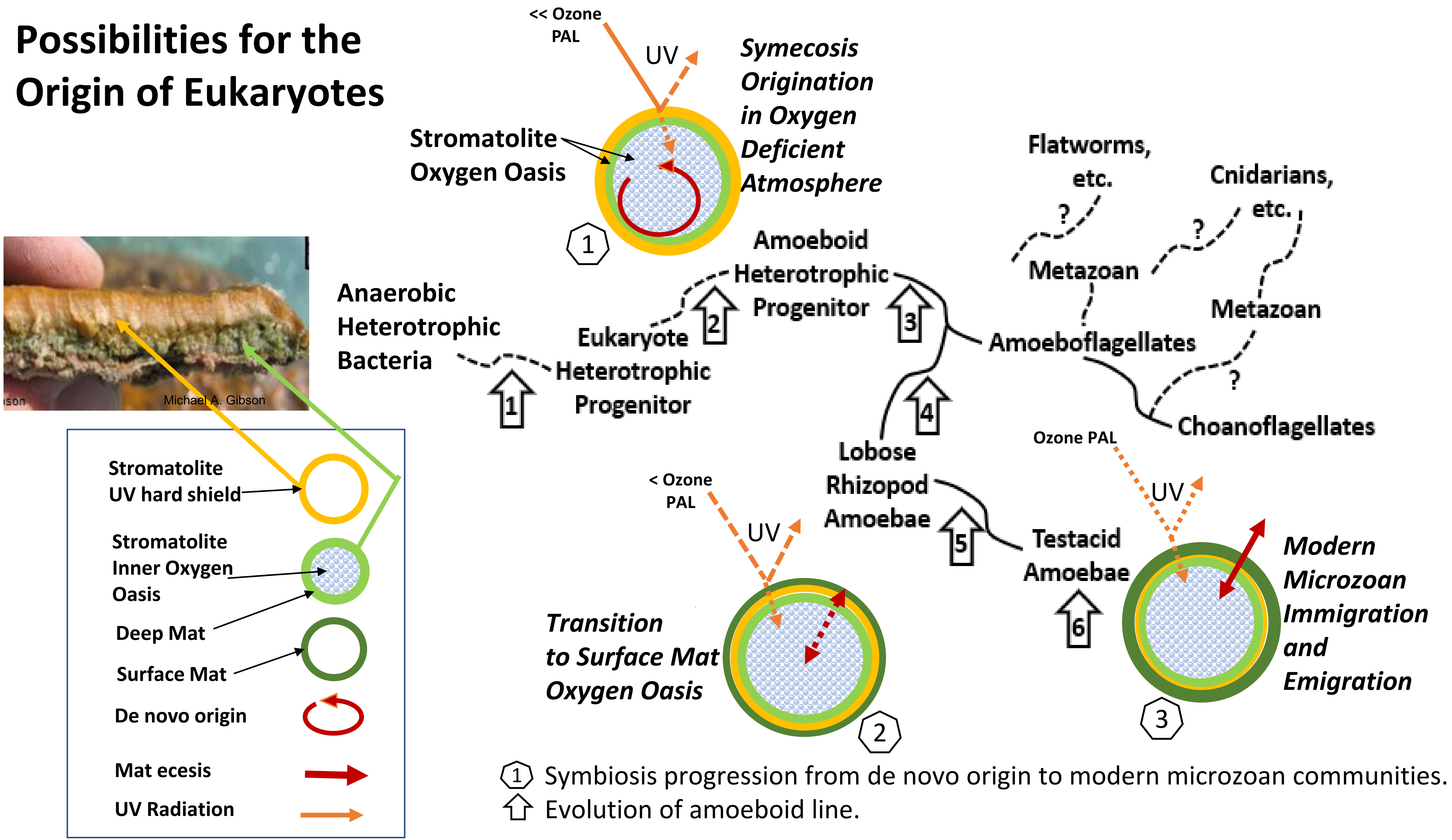


Laguna Bacalar:
Bird Island mat
(Extant)

“Low UV/solar radiation”
(low UV penetration;
oxygen atm;
post ~1.85 Ga)



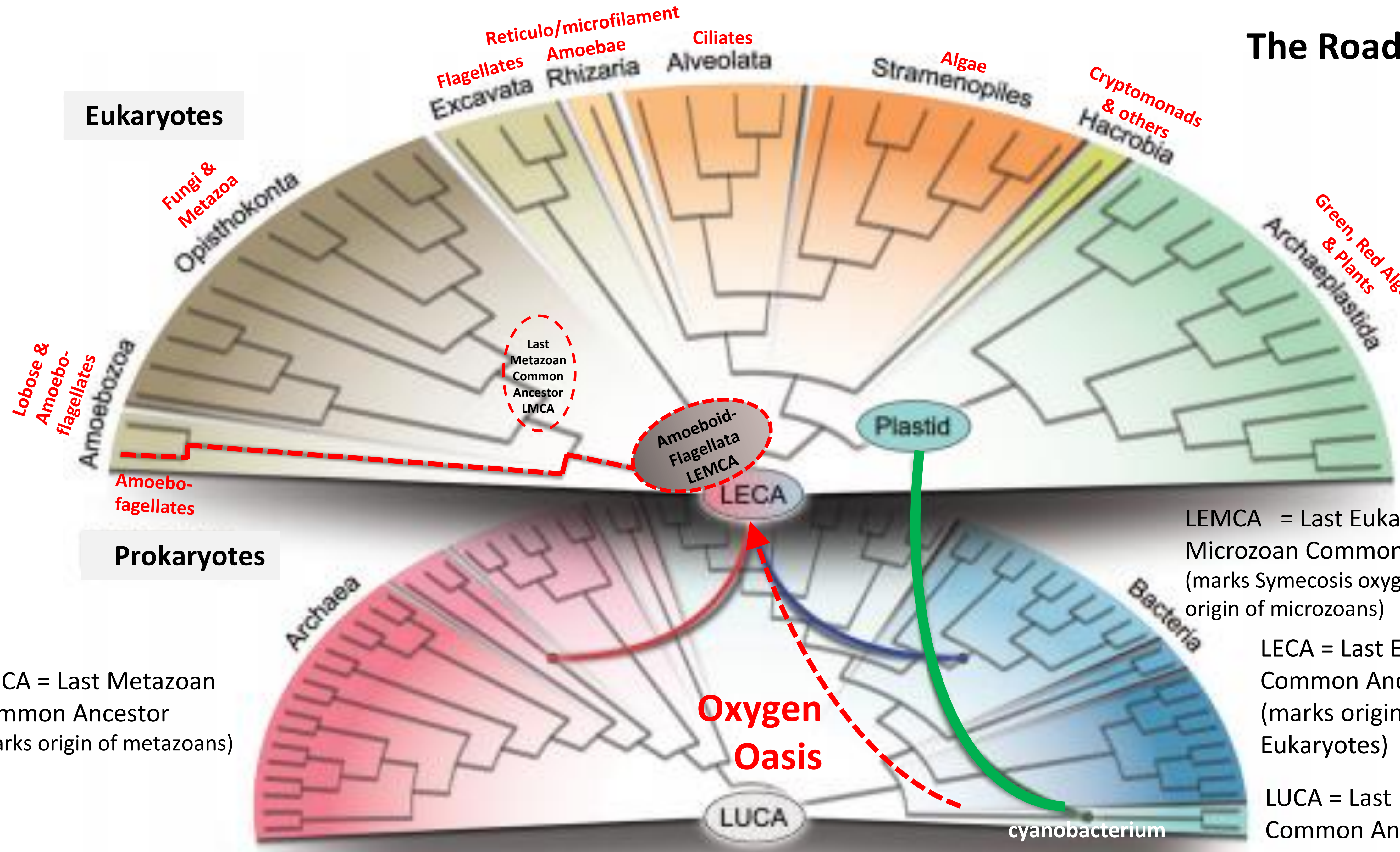
Possibilities for the Origin of Eukaryotes



1 Symbiosis progression from de novo origin to modern microzoan communities.

⇧ Evolution of amoeboid line.

The Road Map



LEMCA = Last Eukaryotic Microzoan Common Ancestor (marks Symecosis oxygen oasis origin of microzoans)

LECA = Last Eukaryotic Common Ancestor (marks origin of Eukaryotes)

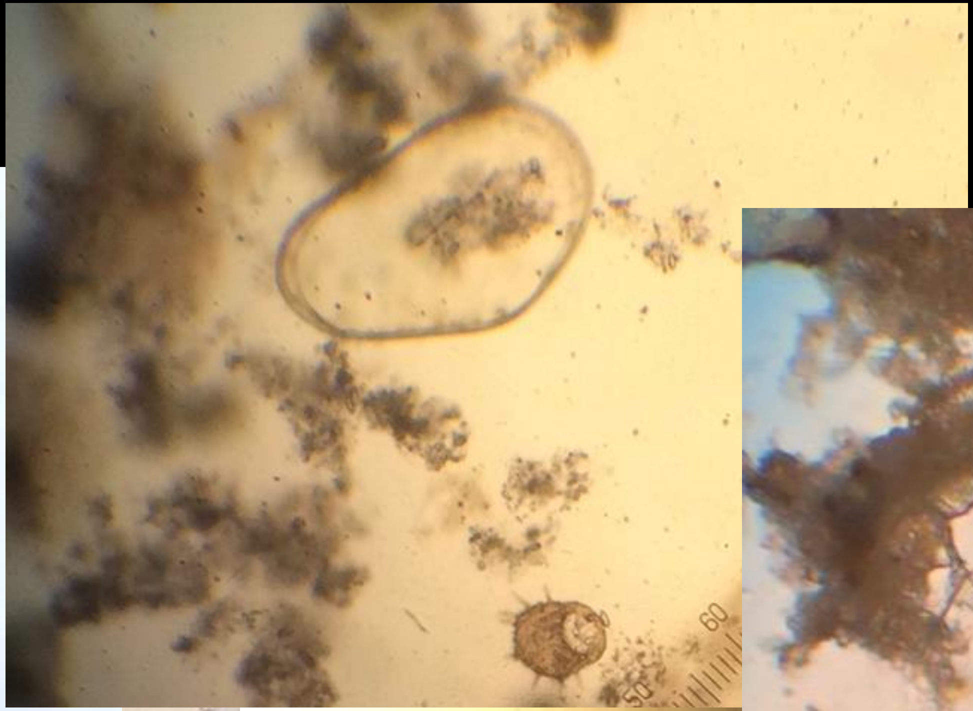
LUCA = Last Universal Common Ancestor (marks origin of life)

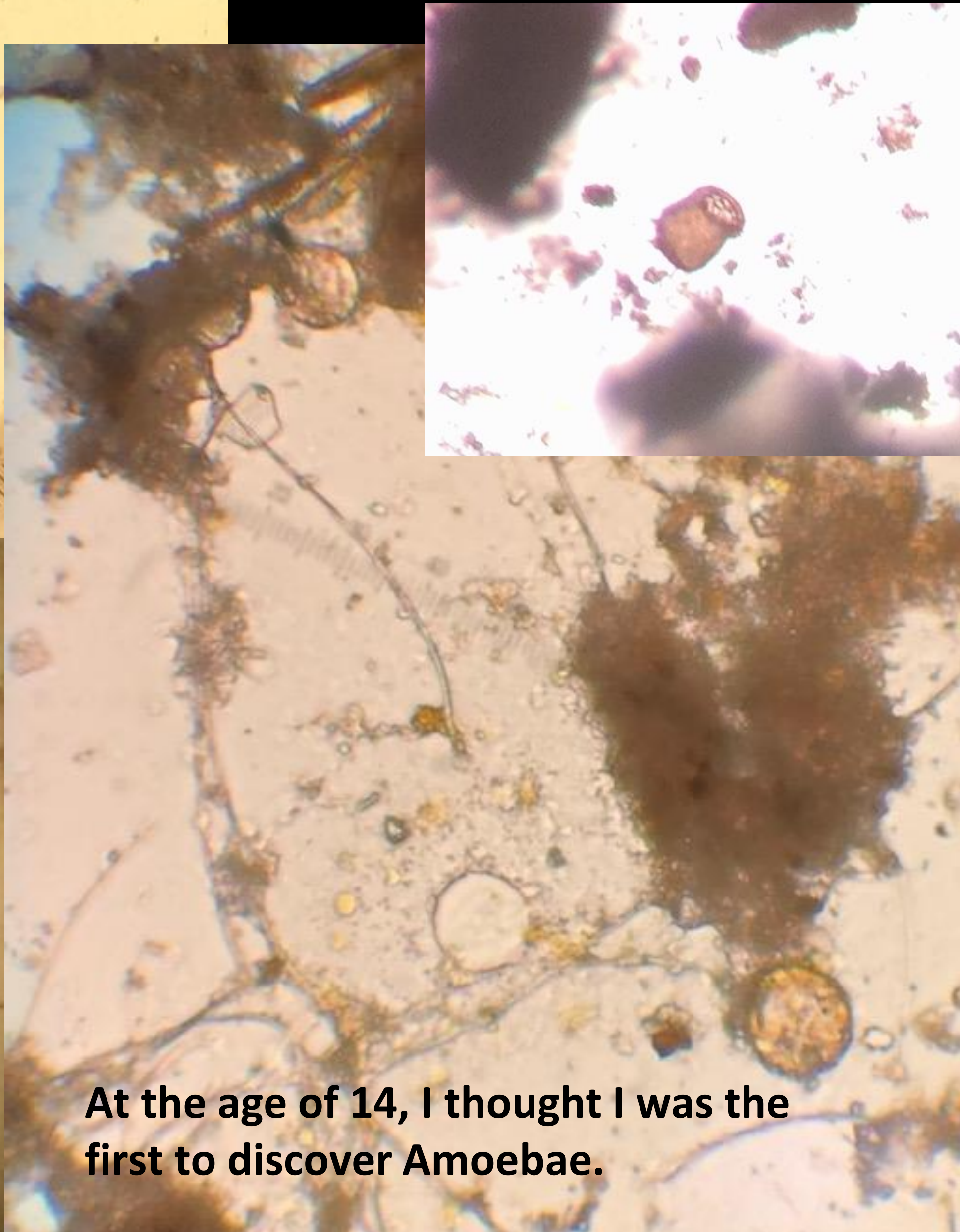
LMCA = Last Metazoan Common Ancestor (marks origin of metazoans)

Martin, et al. 2017 (The Physiology of Phagocytosis…) modified by Kaster

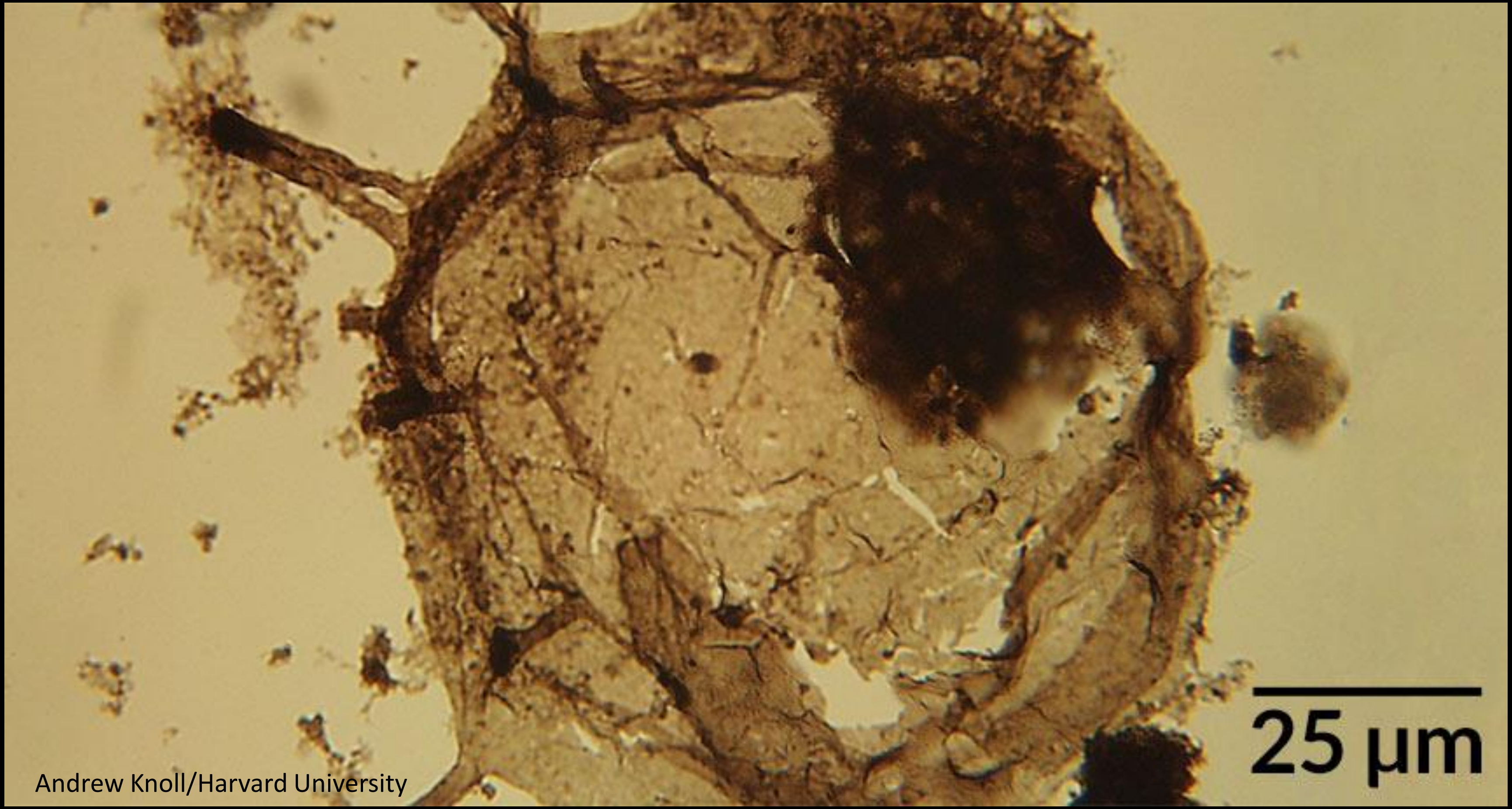
Testacid Amoebae, et al.

Three cohorts
(30 - 100 µm)





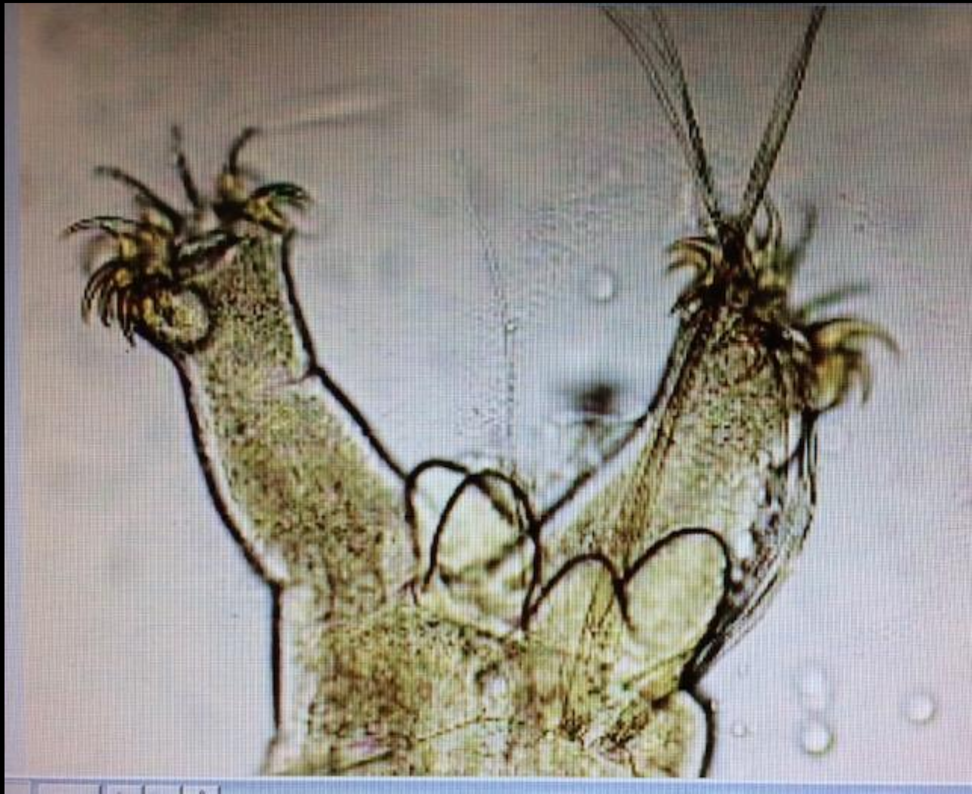
At the age of 14, I thought I was the first to discover Amoebae.



Oxygen was abundant enough for complex life-forms such as this 1.4-billion-year-old fossilized eukaryote. Polynamorph = organic walled microfossil.

Laguna Bacalar forms within oncoids

Chironominae Emerging from Oncoid



Conclusion

→ LUCA origin of life

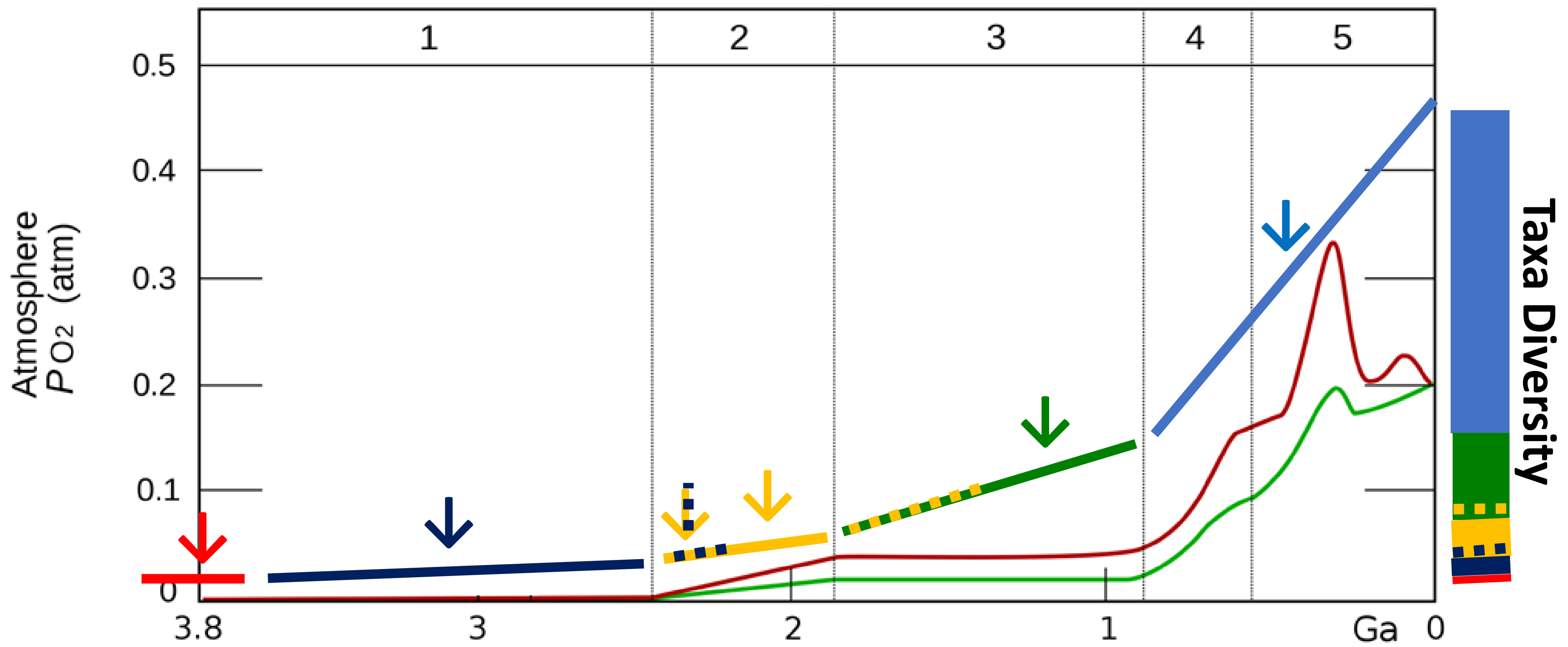
→ LECA origin of eukaryotes (hard mat symecosis)

→ LEMCA symecosis origin of metazoa

→ Shallow shelf tufted mat expansion

→ Continental shelf expansion

→ PAL/Metazoan expansion



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more…

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End