THE ORIGINS OF BIODIVERSITY

Did changing oxygen levels in the Proterozoic induce the rise of complex life?

Kaarel Mänd

COMPLEX LIFE LOVES OXYGEN

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Large bodies and complex behaviours need energy.

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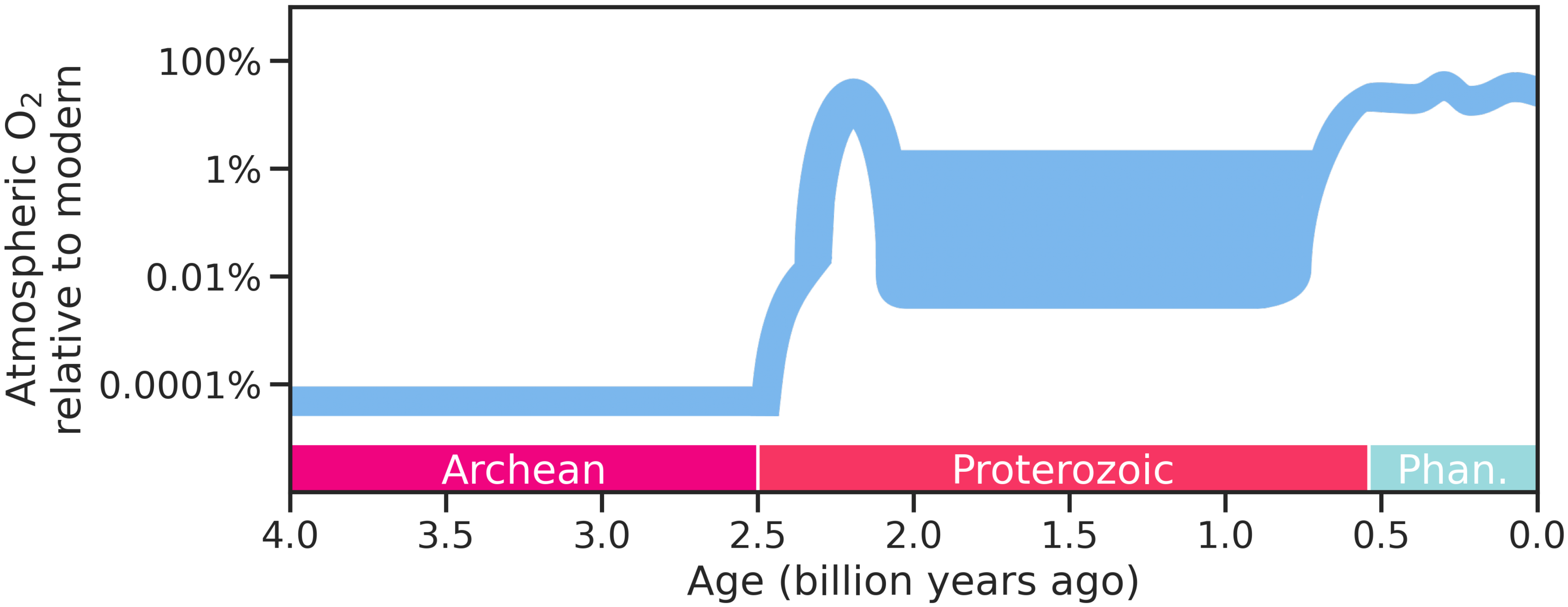
Oxygen metabolism is among the most energetic.

High oxygen levels allow high nutrient fluxes into the oceans.

COMPLEX LIFE LOVES OXYGEN



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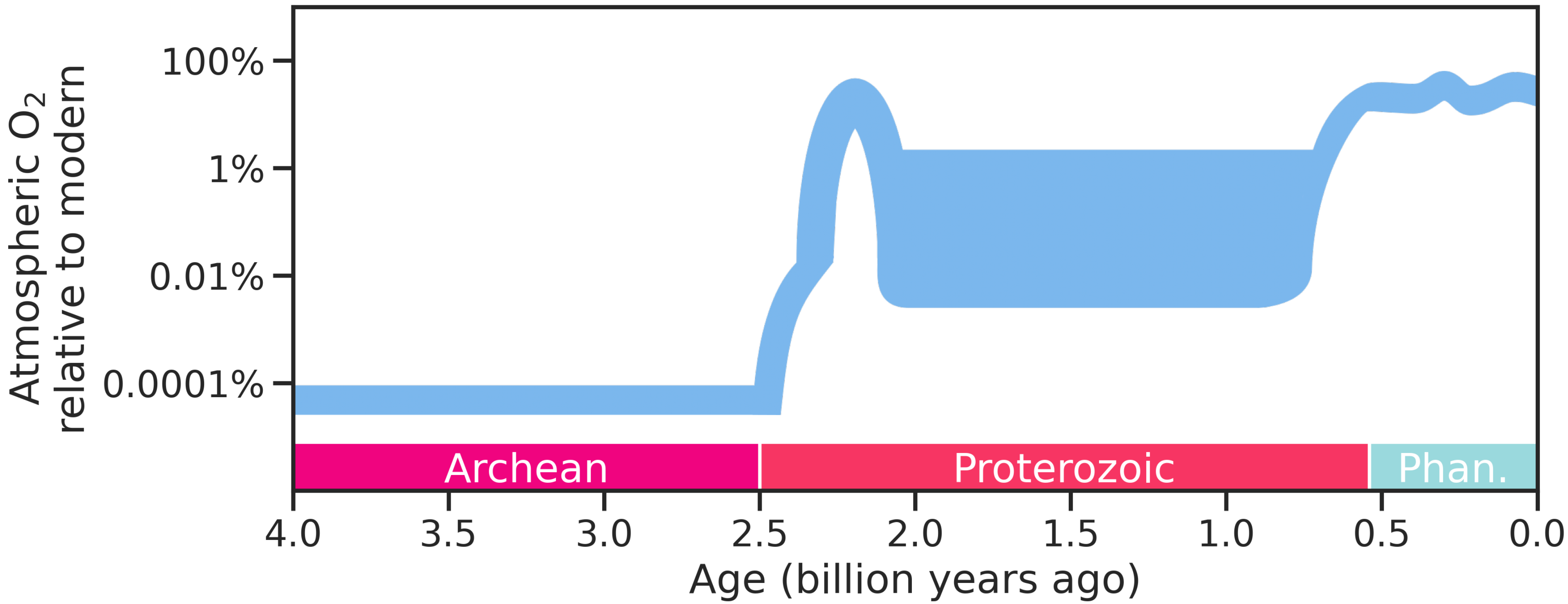
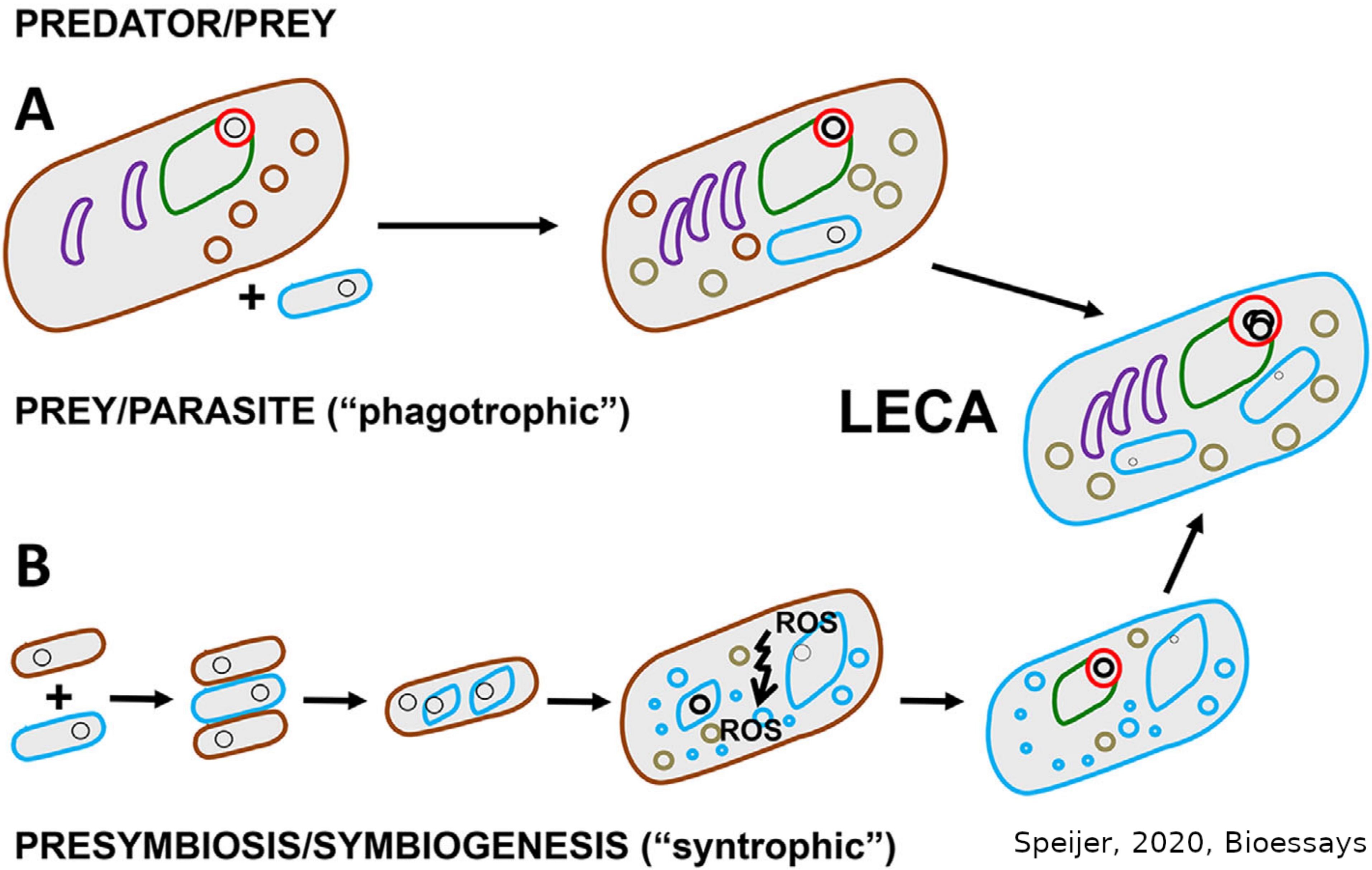


Was the rise of complex life controlled by oxygen availability?

EUKARYOTE EVOLUTION



Speijer, 2020, Bioessays

EUKARYOTES LOVE OXYGEN

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Ancestrally, the mitochondria was an oxygen-breathing organelle.

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Huge eukaryotic genomes and major genetic innovation require a lot of energy.

EUKARYOTES *TOLERATE* OXYGEN

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The mitochondria and nucleus were a way to reduce oxygen stress?

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Sexual reproduction was a way to repair genome damage from reactive oxygen?

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EUKARYOTES... *HATE* OXYGEN?

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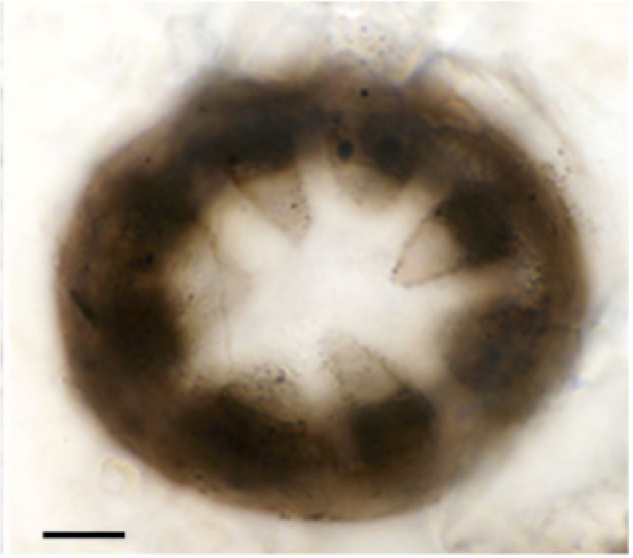
The last common eukaryotic ancestor had the full apparatus for anaerobic life.

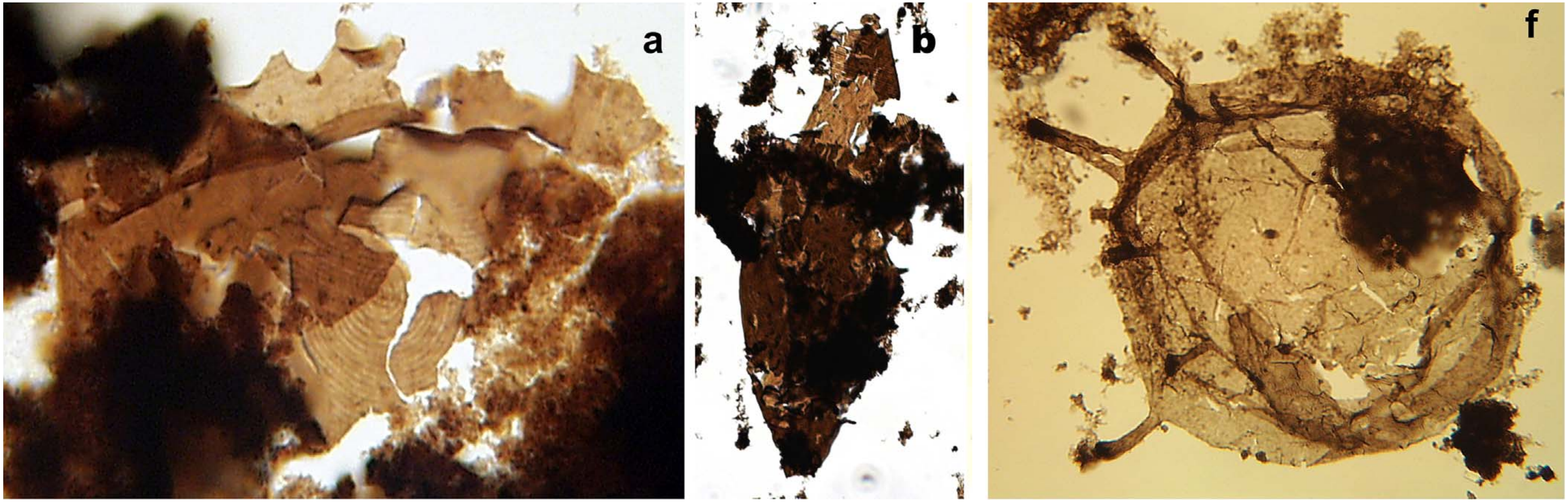
FIRST SIGNS OF EUKARYOTES

Bangimorpha pubescens, ~1.1 b.y.a.

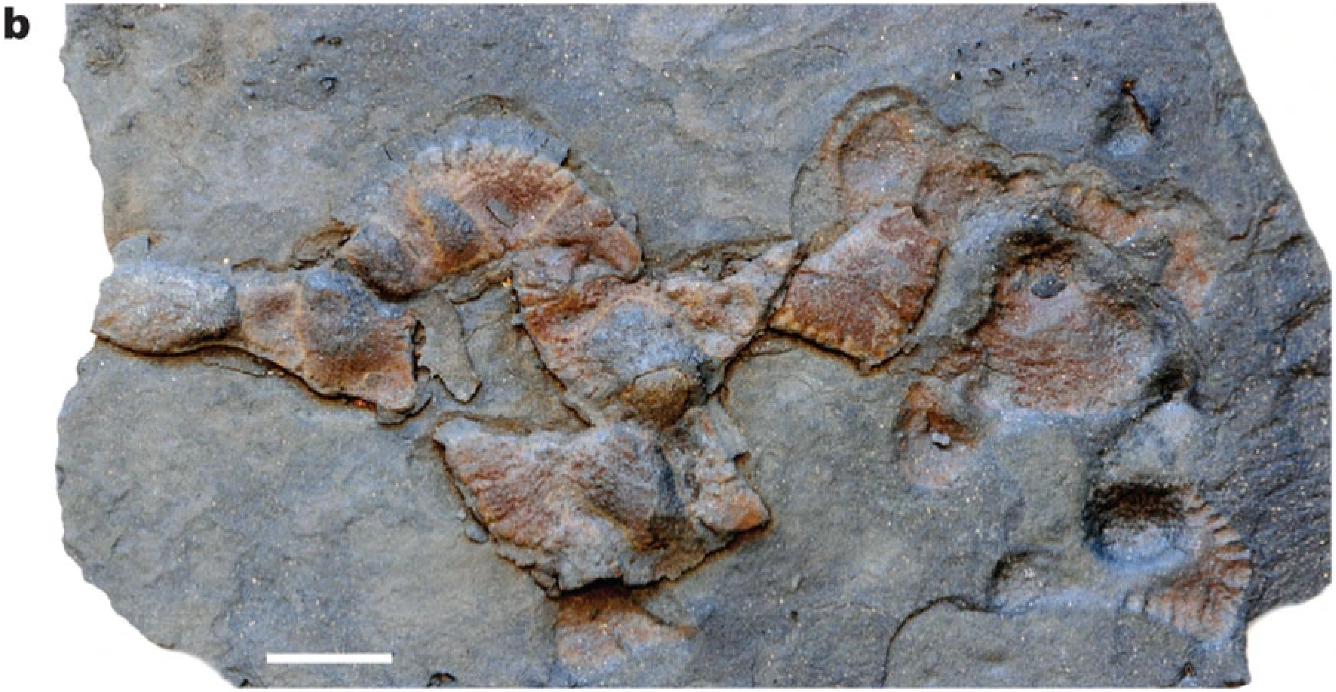

FIRST SIGNS OF EUKARYOTES

Valeria and *Tappania*, ~1.6 b.y.a.



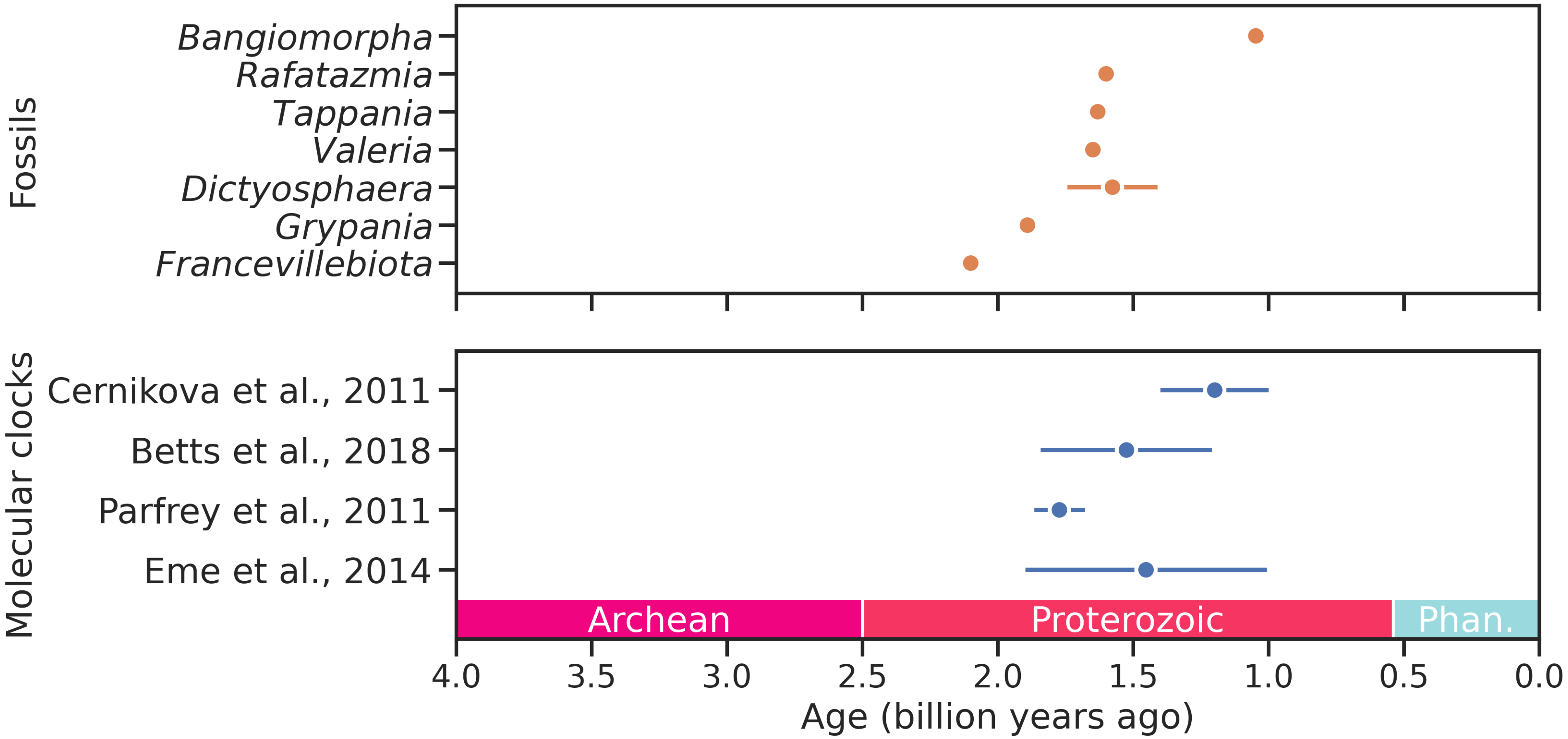
FIRST SIGNS OF EUKARYOTES

Grypania, ~1.8 b.y.a., and Franceville biota, ~2.1 b.y.a.



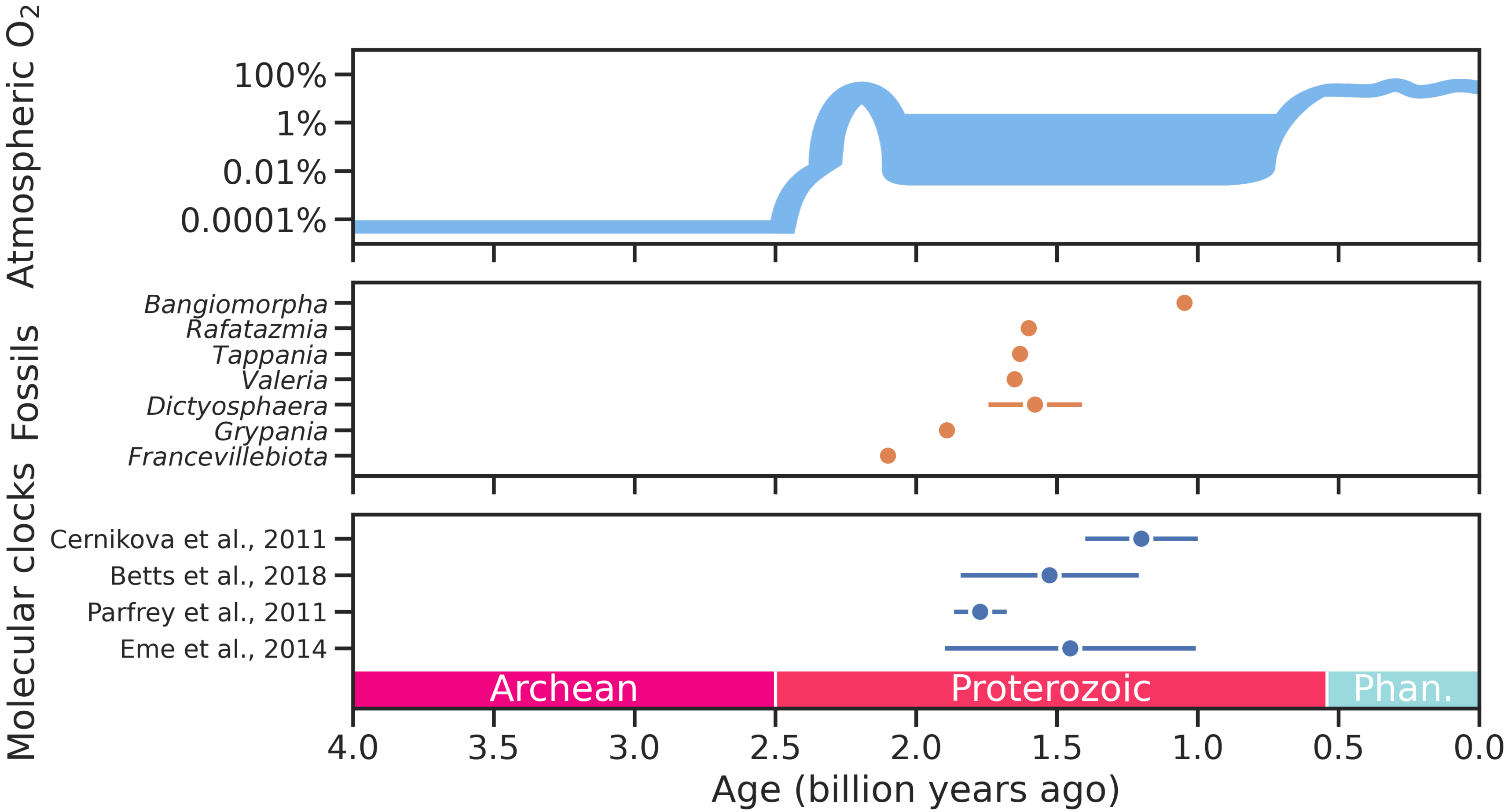
FIRST SIGNS OF EUKARYOTES

Evidence for eukaryotes converges at ~1.6 b.y.a.



FIRST REDOX REVOLUTION

2.4 b.y.a.: the first rise of O_2 in Earth's atmosphere.



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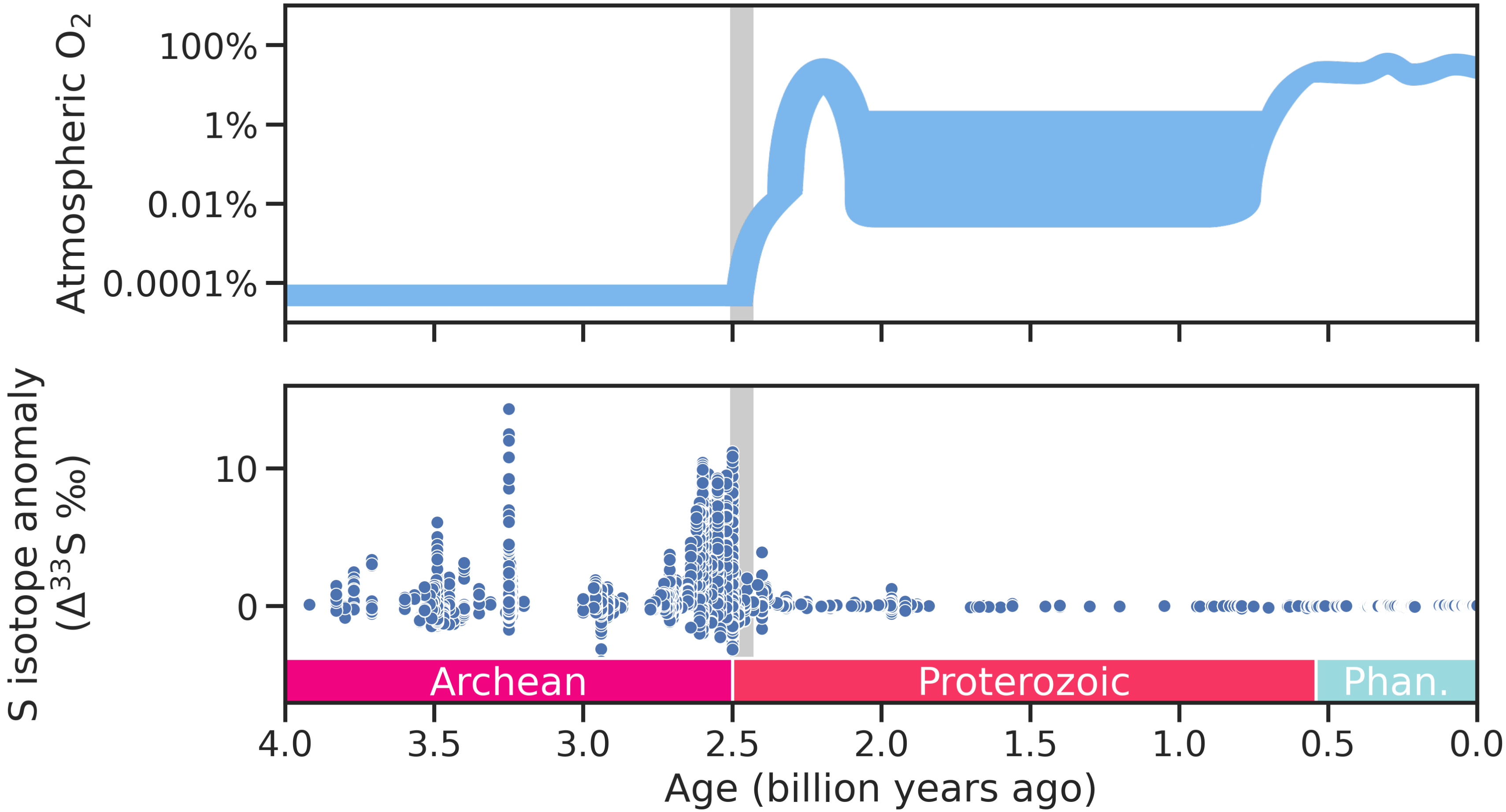
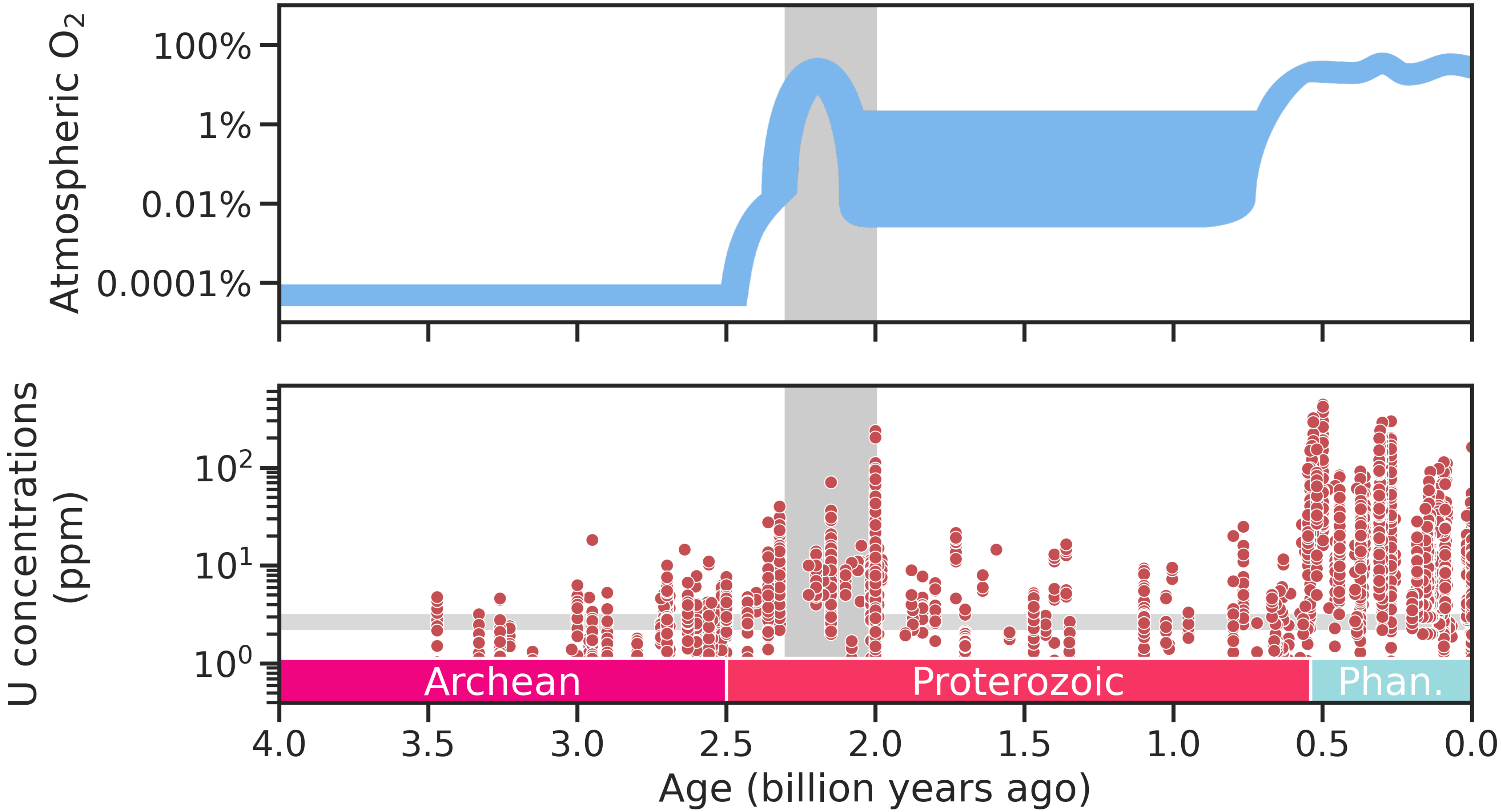


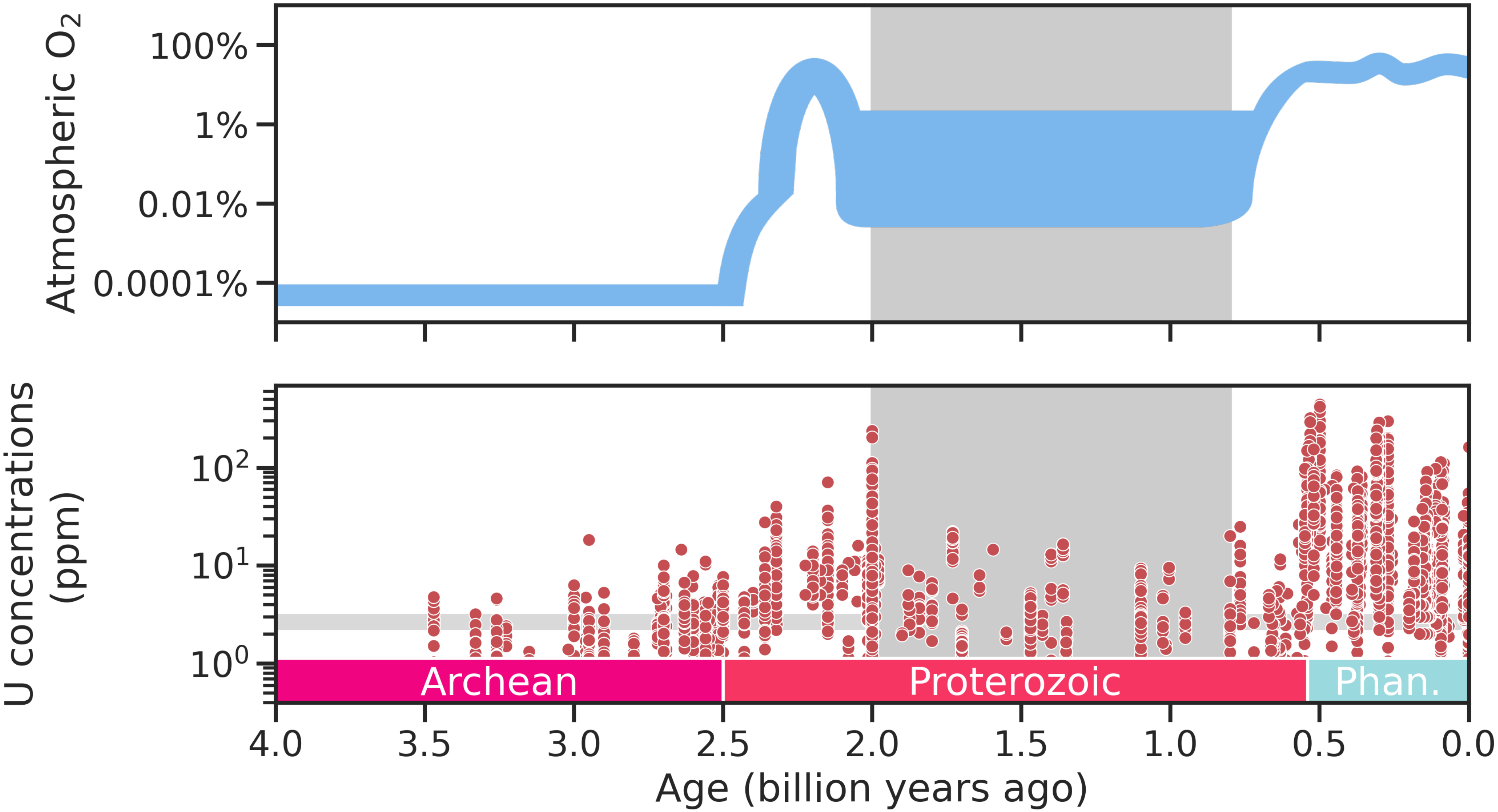
O_2 OVERSHOOT

2.3-2.1 b.y.a.: even higher O_2 levels.


Atmospheric O_2
100%
1%
0.01%
0.0001%
U concentrations (ppm)
10^2
10^1
10^0
Archean
Proterozoic
Phan.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Age (billion years ago)

O_2 CRASH

O_2 levels drop and stay low between ~2.0–0.8 b.y.a.



Atmospheric O2
100%
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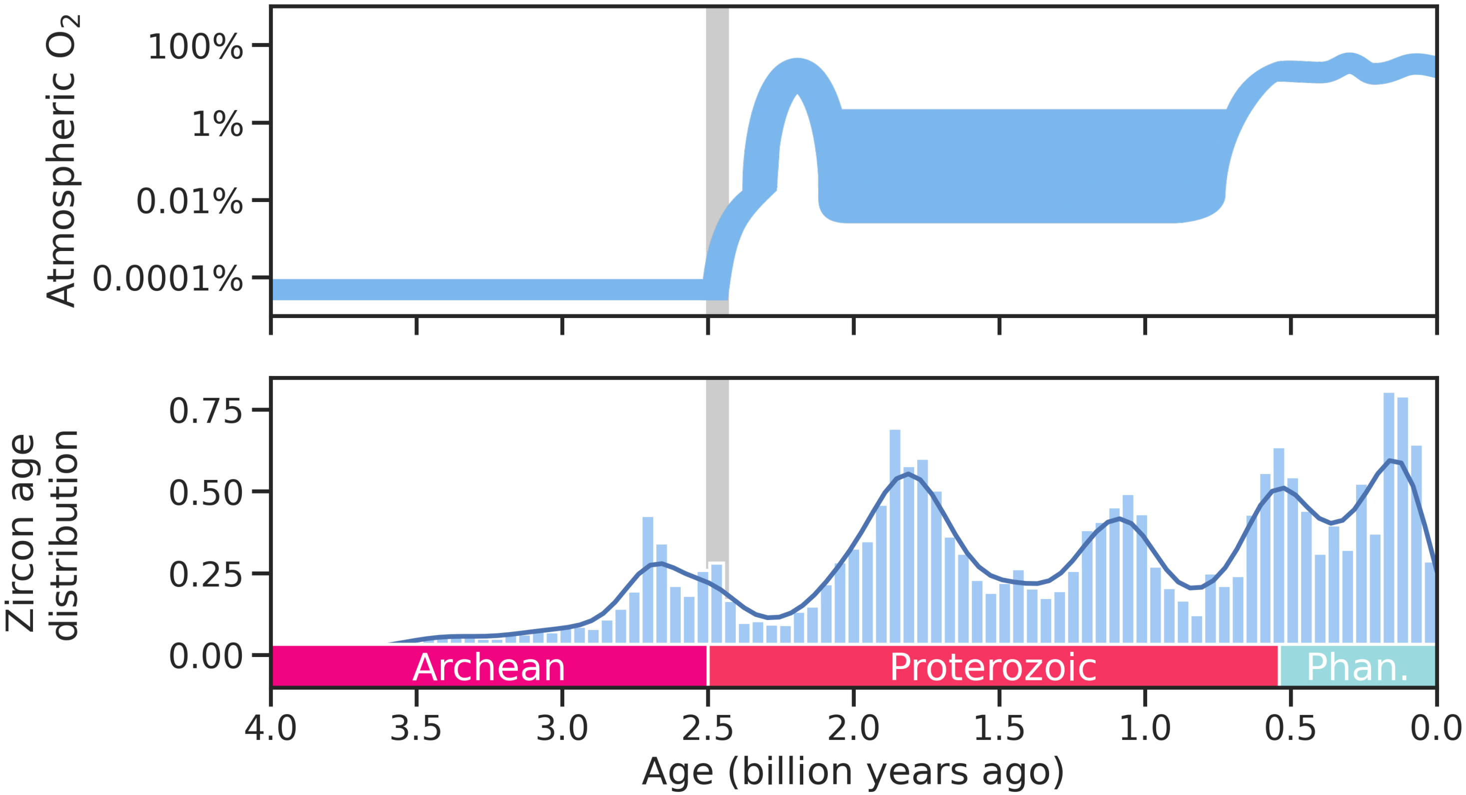
Proterozoic
Phan.
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Age (billion years ago)

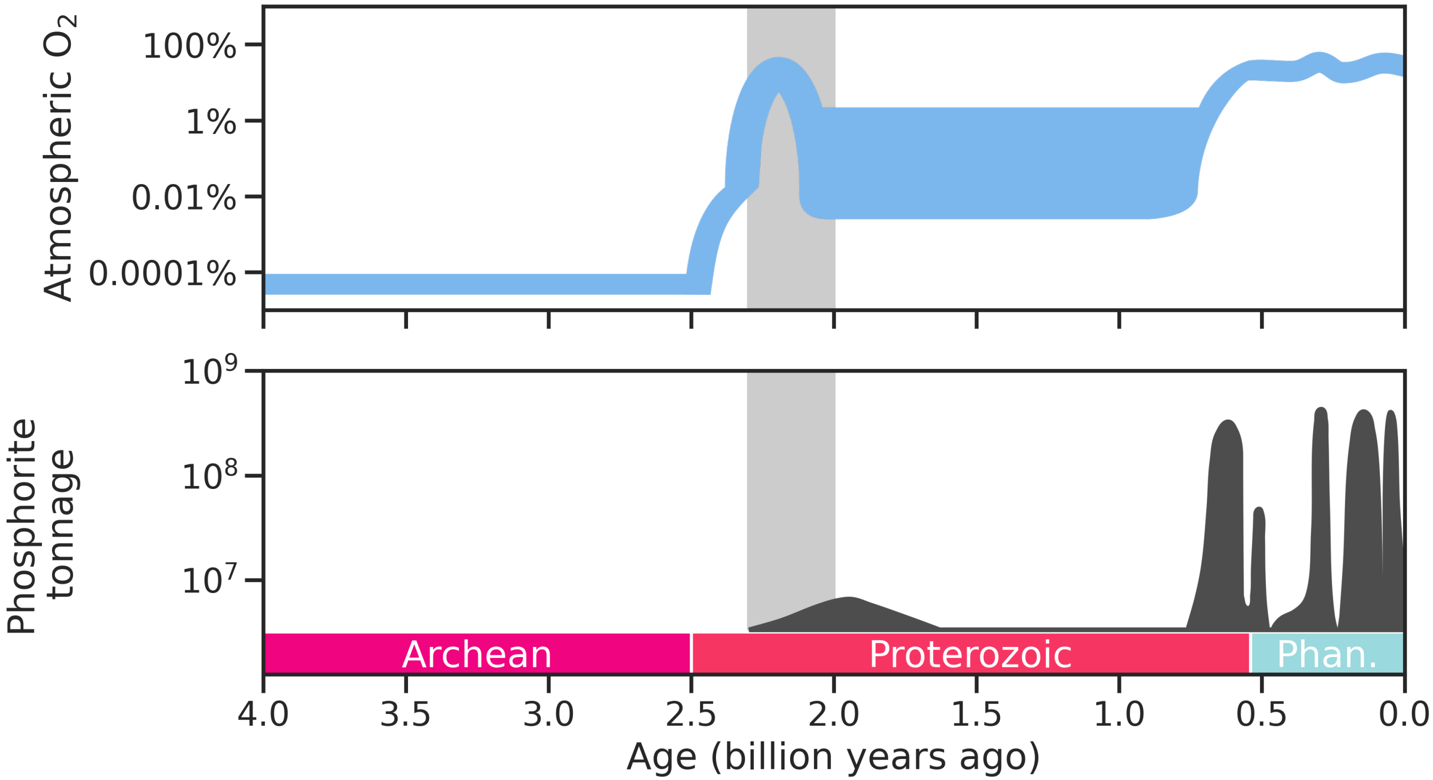
REASONS FOR O_2 SHIFTS

Change in volcanic gases or niches for cyanobacteria affected oxygen accumulation.



REASONS FOR O_2 SHIFTS

Nutrient-rich minerals reacted with O_2, leading to higher bioproduction.



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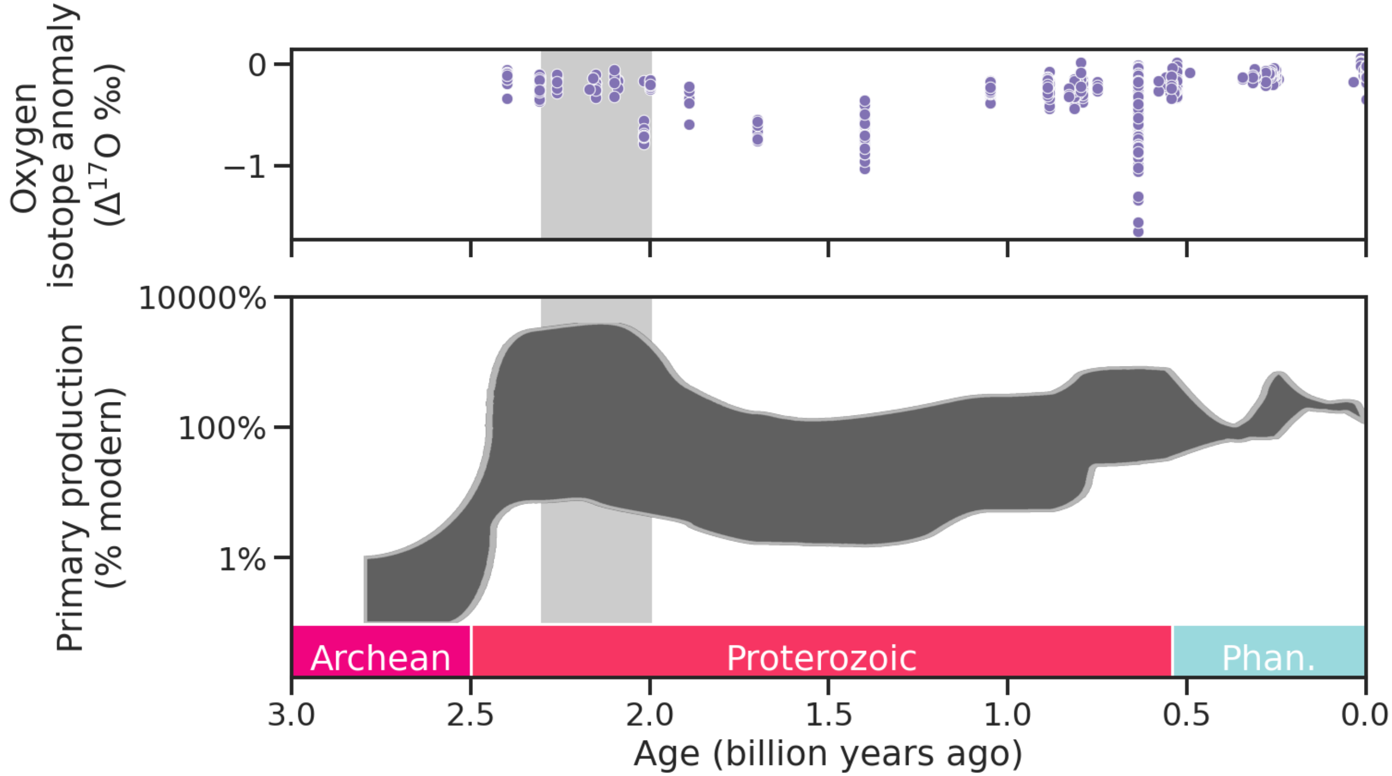
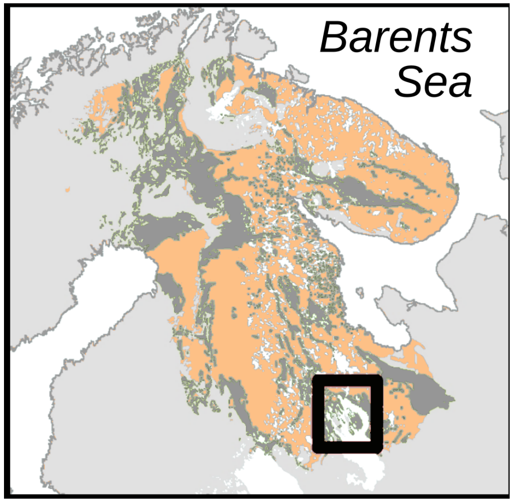
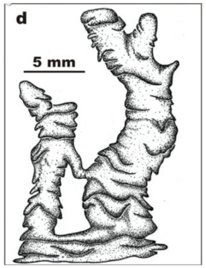
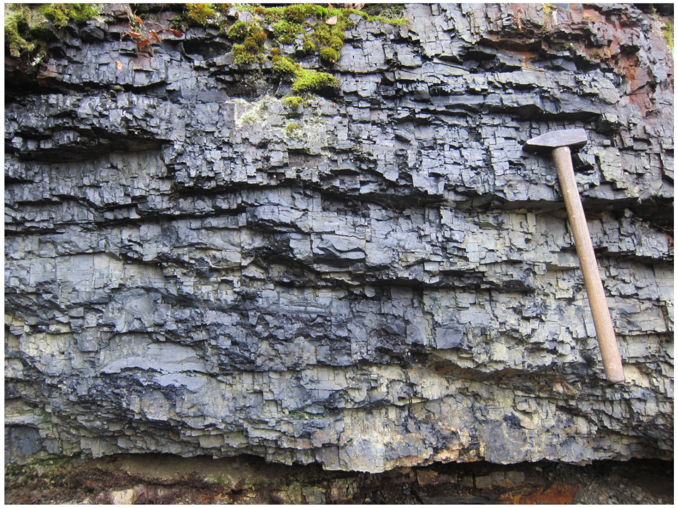


O_2 RECORD AT LAKE ONEGA

NW-Russia hosts extensive ~2.0 b.y. old sedimentary rocks.







O_2 RECORD AT LAKE ONEGA

Surprisingy high O_2 levels have been inferred from geochemical proxies in these rocks.

ARTICLES
https://doi.org/10.1038/s41561-020-0558-5
nature geoscience

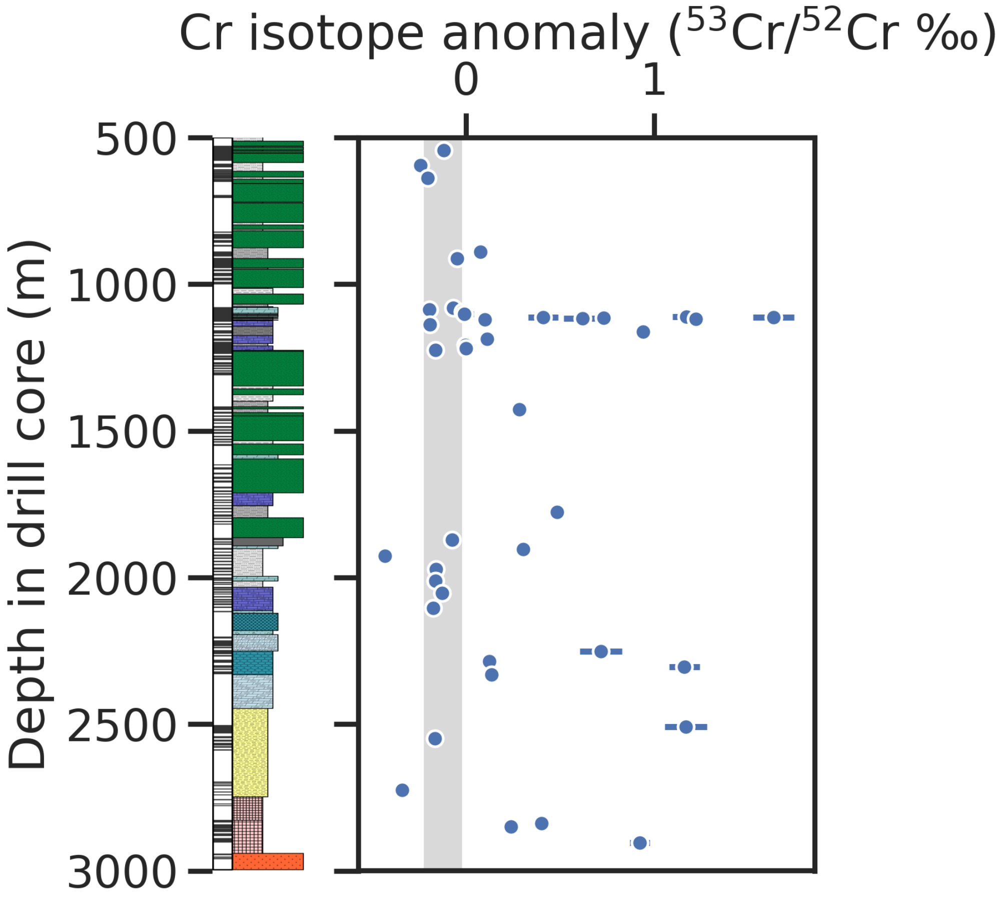
Check for updates

Palaeoproterozoic oxygenated oceans following the Lomagundi–Jatuli Event

Kaarel Mänd[1,2] ✉, Stefan V. Lalonde[3], Leslie J. Robbins[4], Marie Thoby[3], Kärt Paiste[2,5], Timmu Kreitsmann[2], Päärn Paiste[2], Christopher T. Reinhard[6,7], Alexandr E. Romashkin[8], Noah J. Planavsky[4,7], Kalle Kirsimäe[2], Aivo Lepland[2,5,9,10] and Kurt O. Konhauser[1]

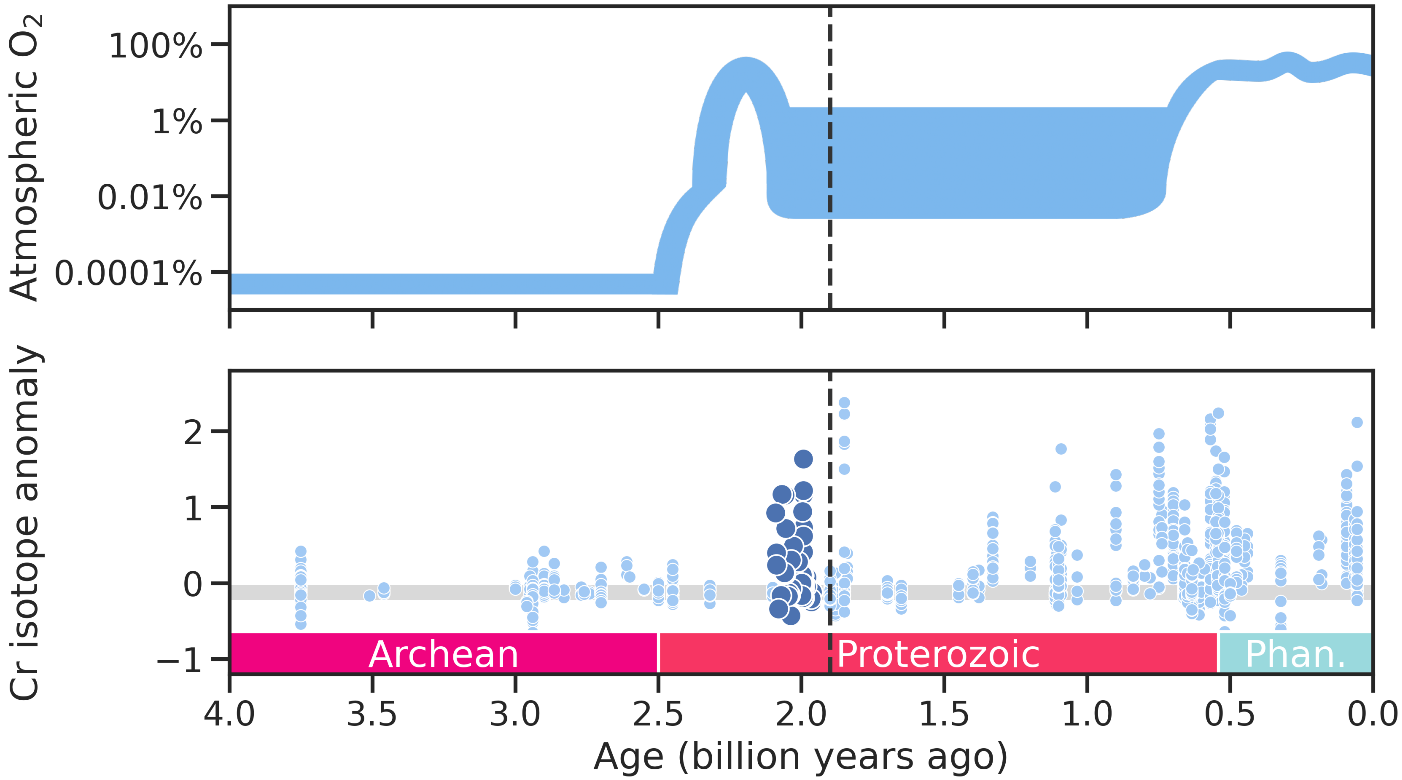
CHROMIUM IN ONEGA ROCKS

Stable, high atmospheric O_2 throughout 100 m. years.



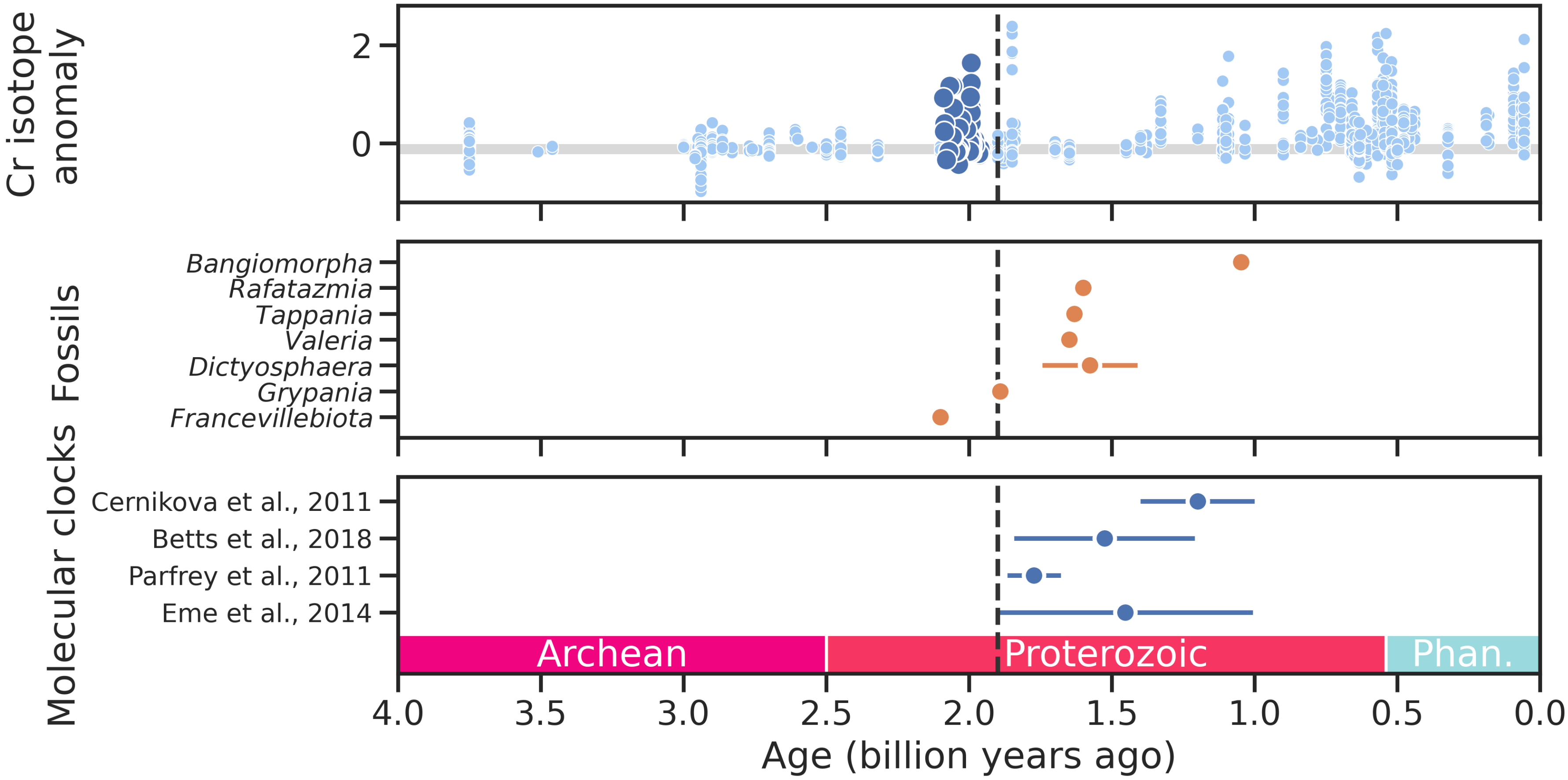
EUKARYOTE–O_2 CONNECTION

Major shift in Cr cycling across the 1.9 b.y. boundary—high, stable O_2 replaced by low, unstable O_2.



EUKARYOTE–O_2 CONNECTION

High O_2 levels did not bring about the first eukaryotes.



WHAT TIMED THE EMERGENCE OF EUKARYOTES?

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Environments with unstable O_2 levels? Endosymbioses are common chemically unstable environments.

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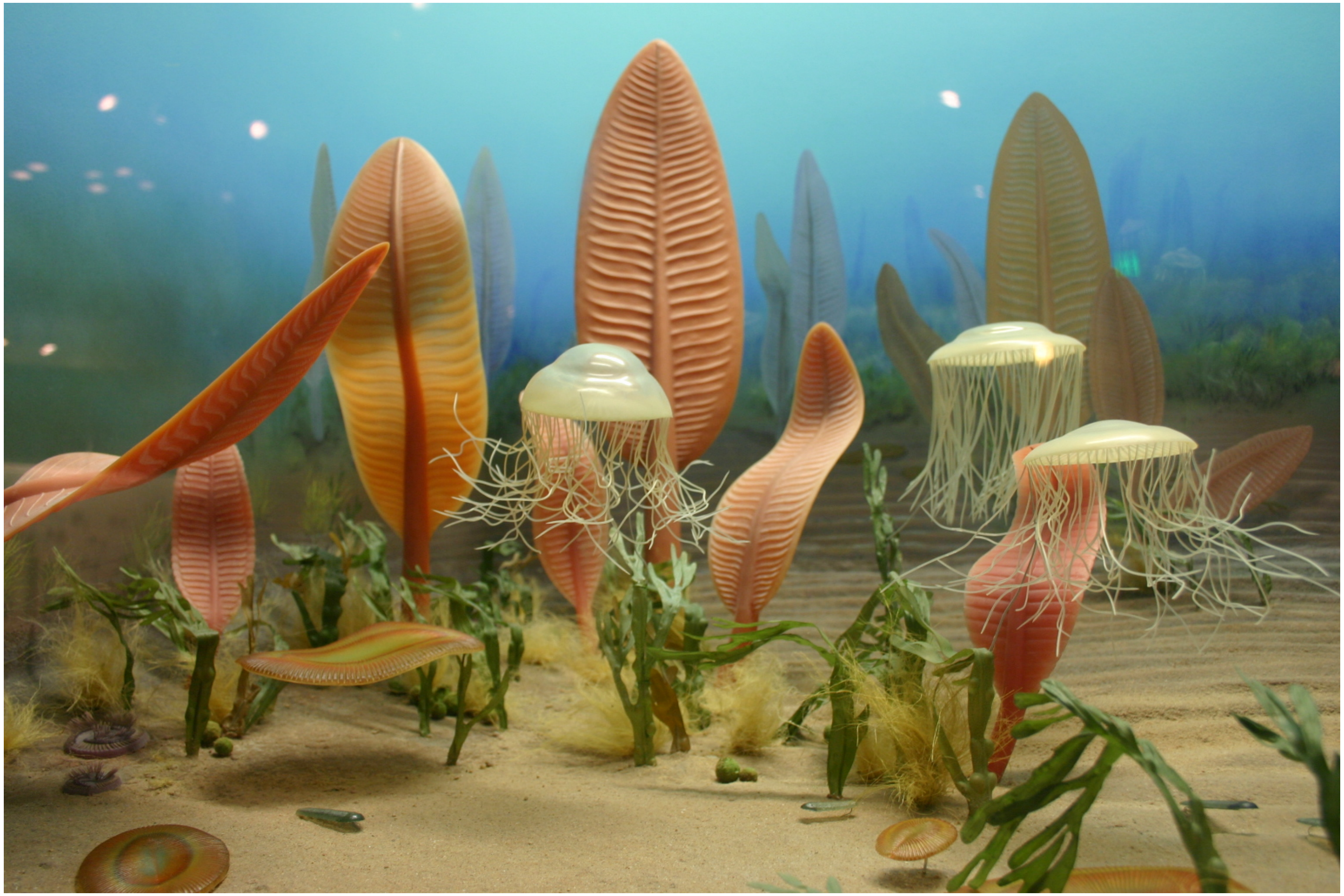
Timing not related to environmental backdrop. Evolution takes its own sweet time.

ANIMAL EMERGENCE

The next major leap in biological compexity.

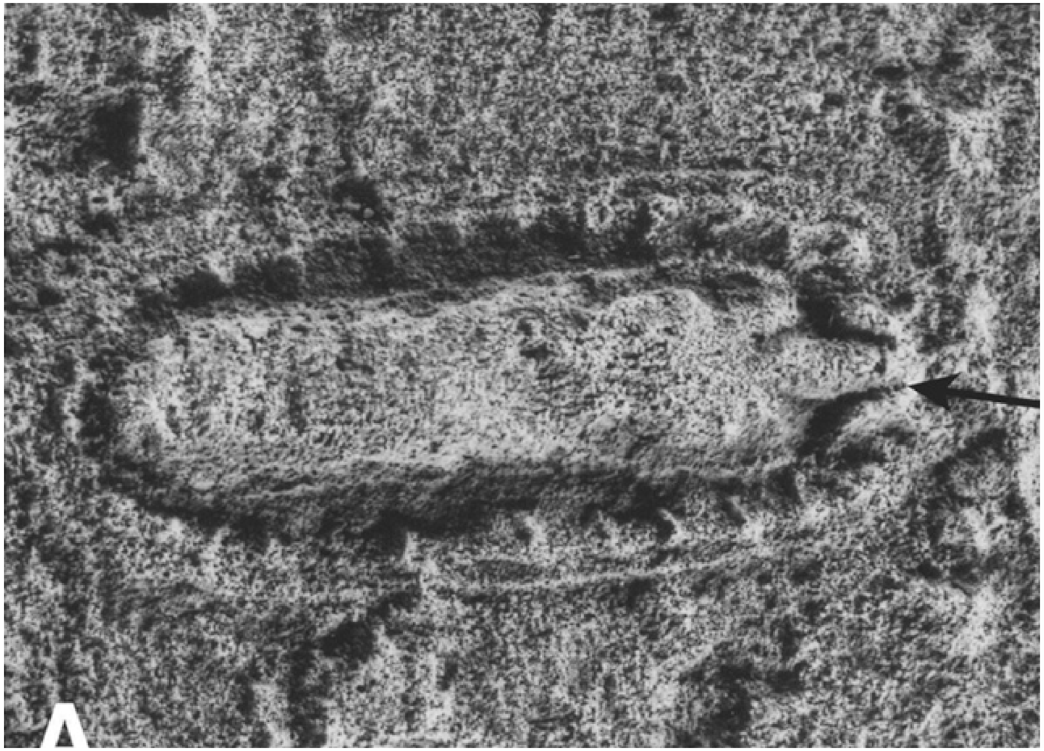


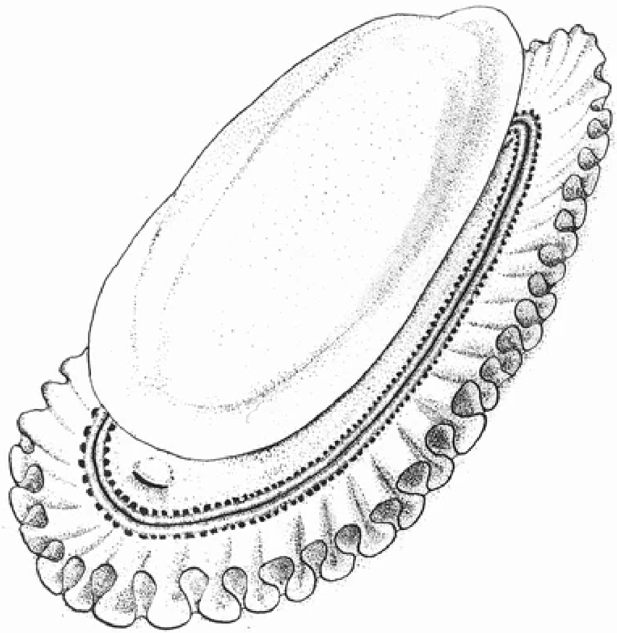
FIRST ANIMALS

Dickinsonia tenuis, ~560 m.y.a.

FIRST ANIMALS

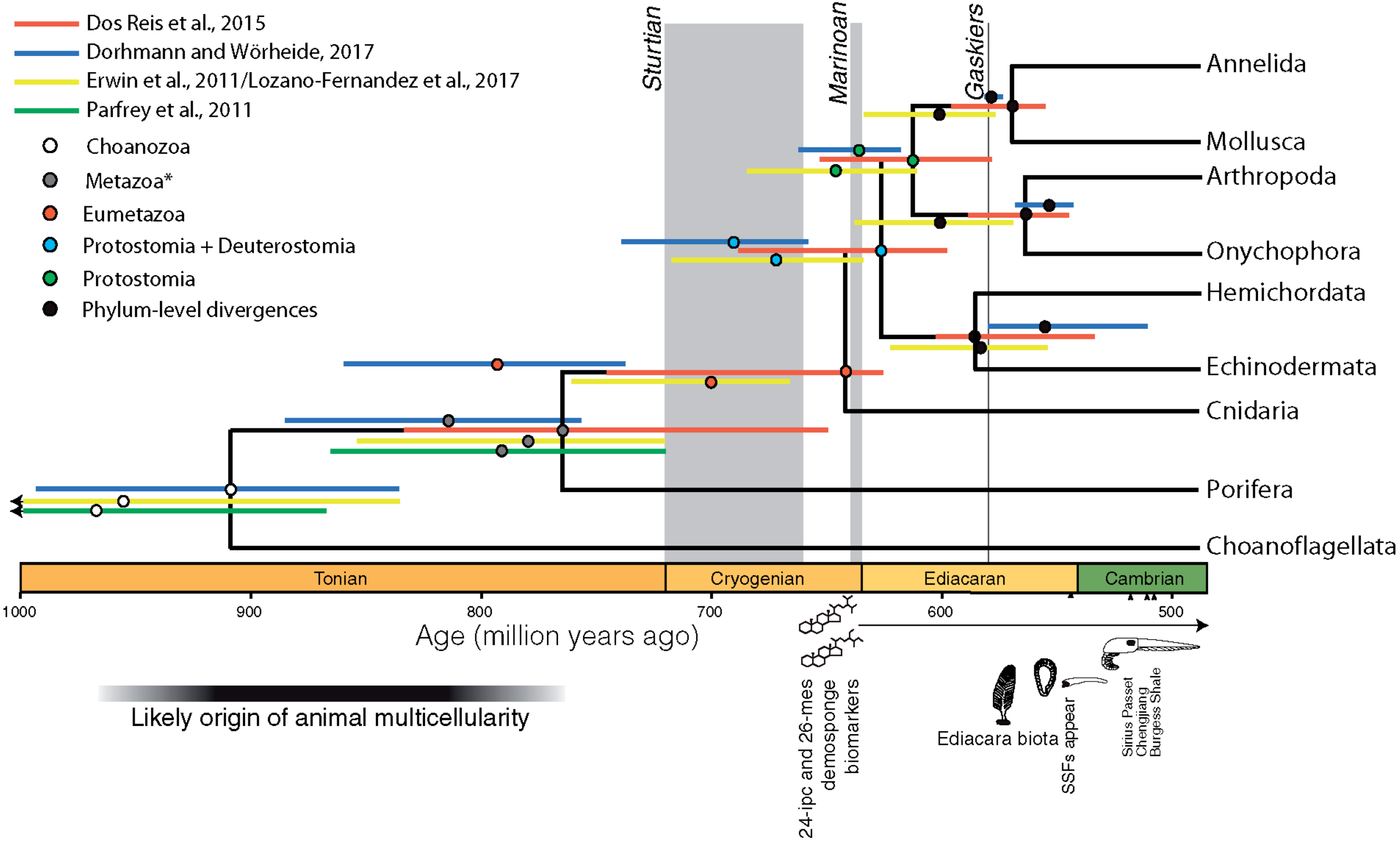
Kimberella, >555 m.y.a.





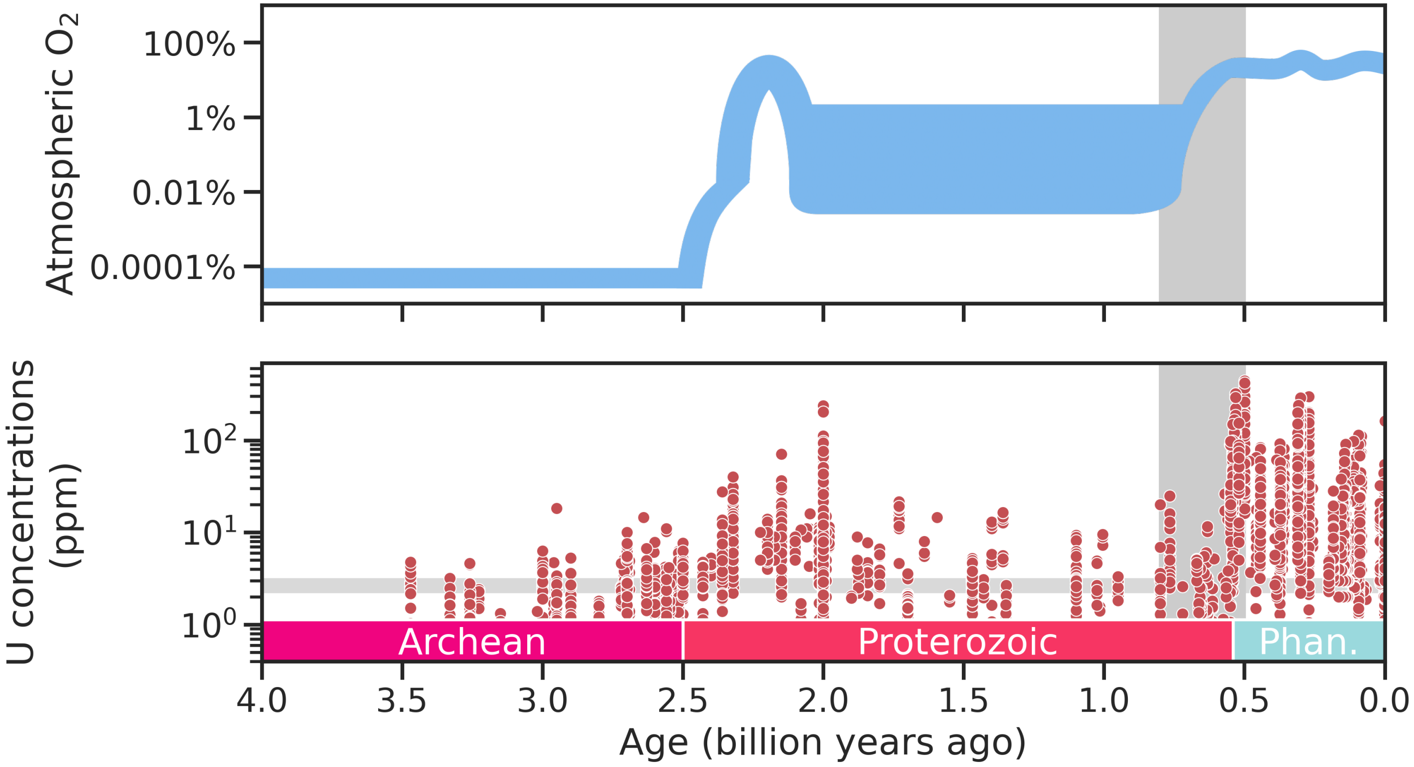
FIRST ANIMALS

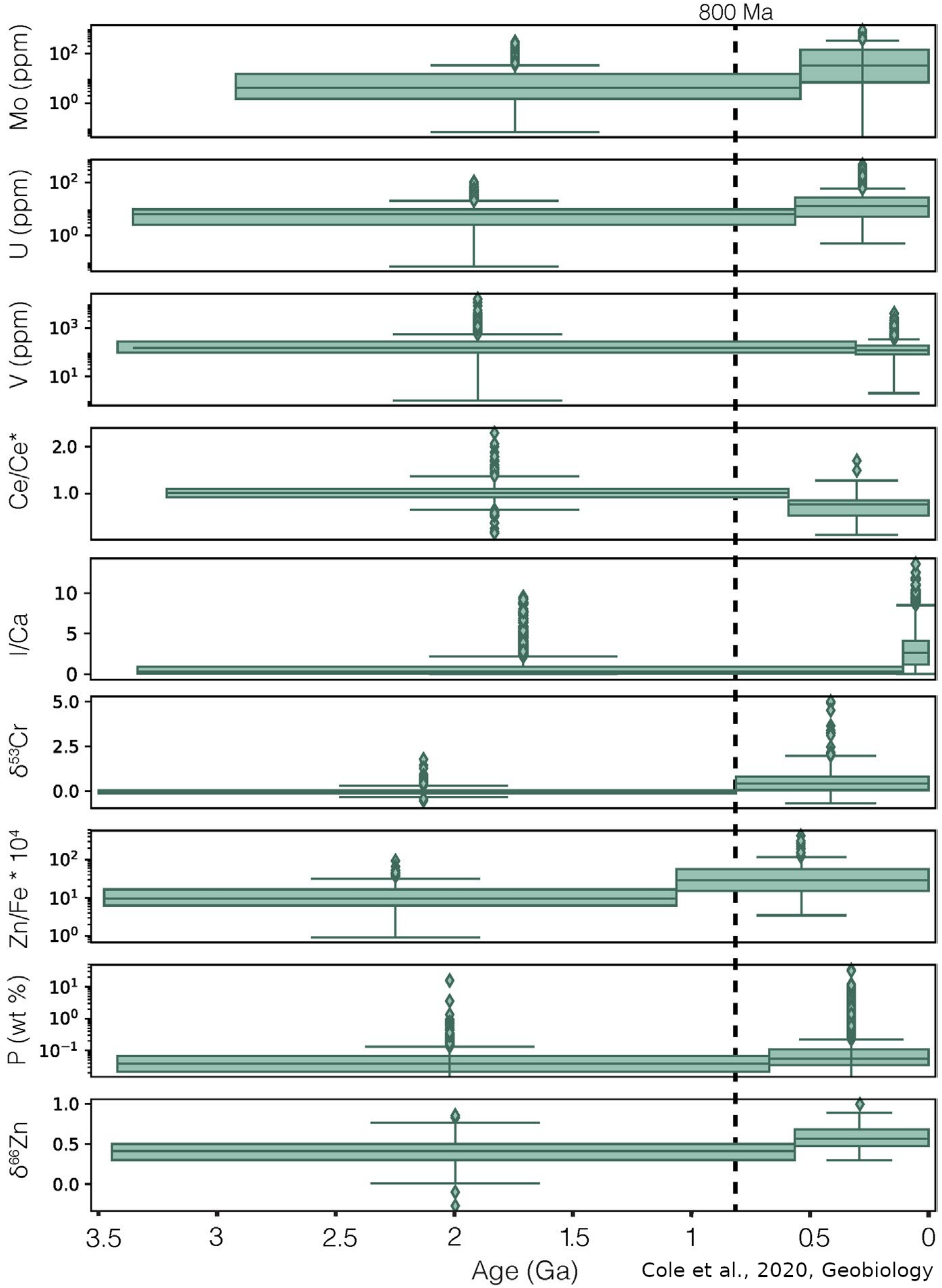
Molecular clocks suggest ~800 m.y.a. divergence.



NEOPROTEROZOIC OXYGENATION EVENT

Another rise in oxygen 800–500 m.y.a.





Cole et al., 2020, Geobiology

ANIMALS WERE O_2-DEPENDENT

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O_2 increase corresponds well with animal emergence.

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All animals need O_2 during their life cycle.

ANIMALS DID FINE WITH LOW O_2

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Many animals can survive anoxic conditions.

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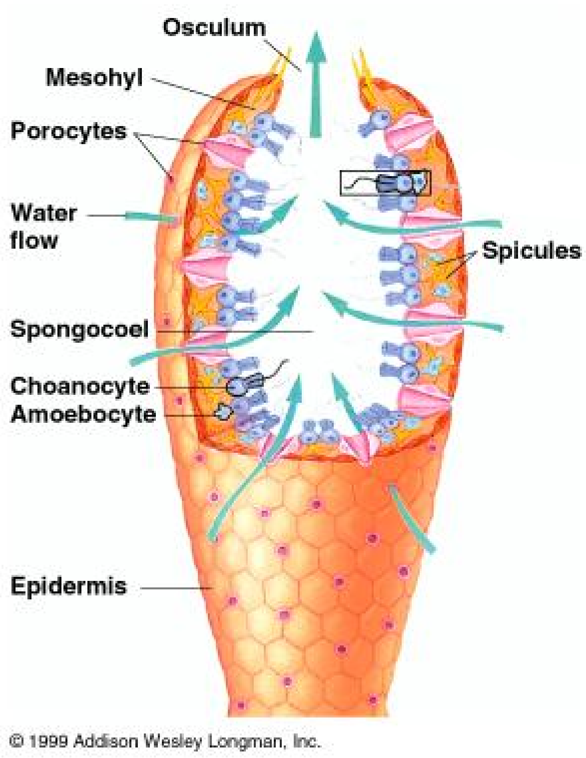
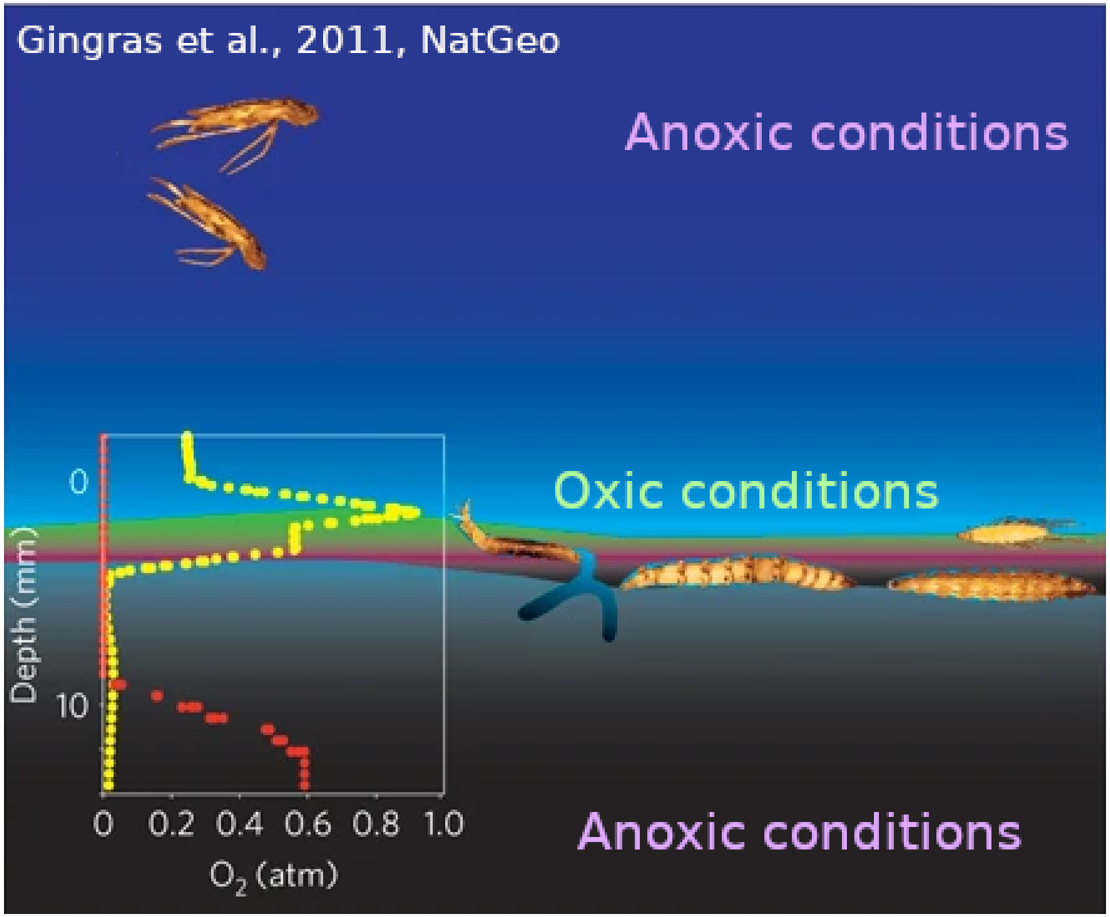
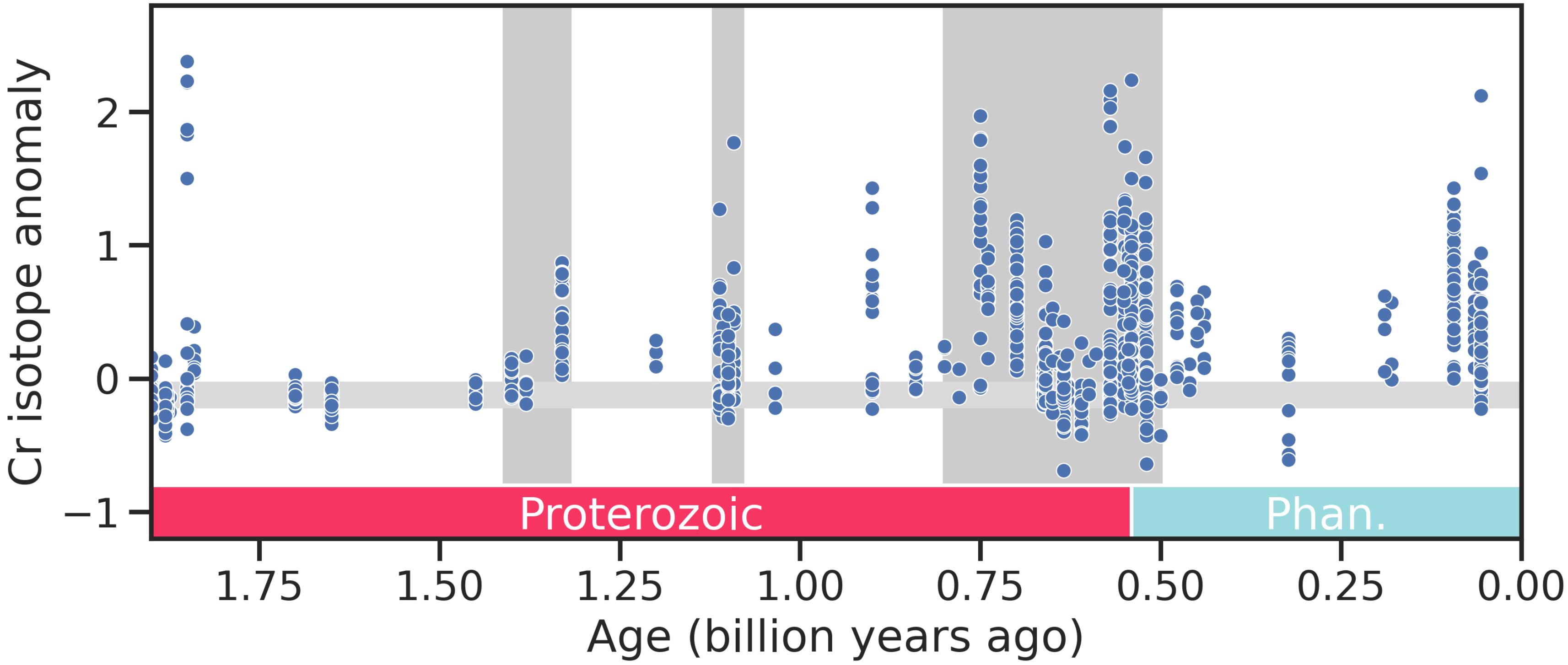


MOTILITY AS A LOW-O_2 ADAPTATION



WERE MIDDLE PROTEROZOIC O_2 LEVELS EVEN THAT LOW?



DID COMPLEX LIFE INDUCE THE FINAL O_2 RISE?

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Filter feeders scavenge suspended organic matter, and lead to O_2-rich waters.

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Fecal pellets lead to more efficient carbon burial and decreased O_2 consumption.

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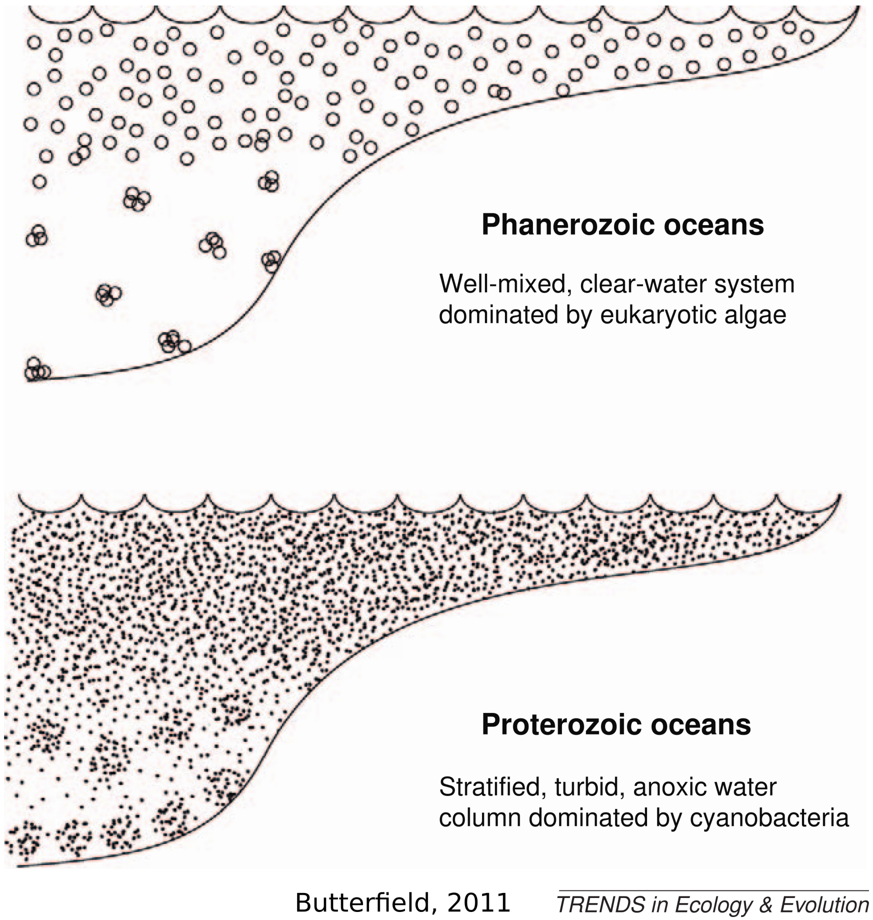
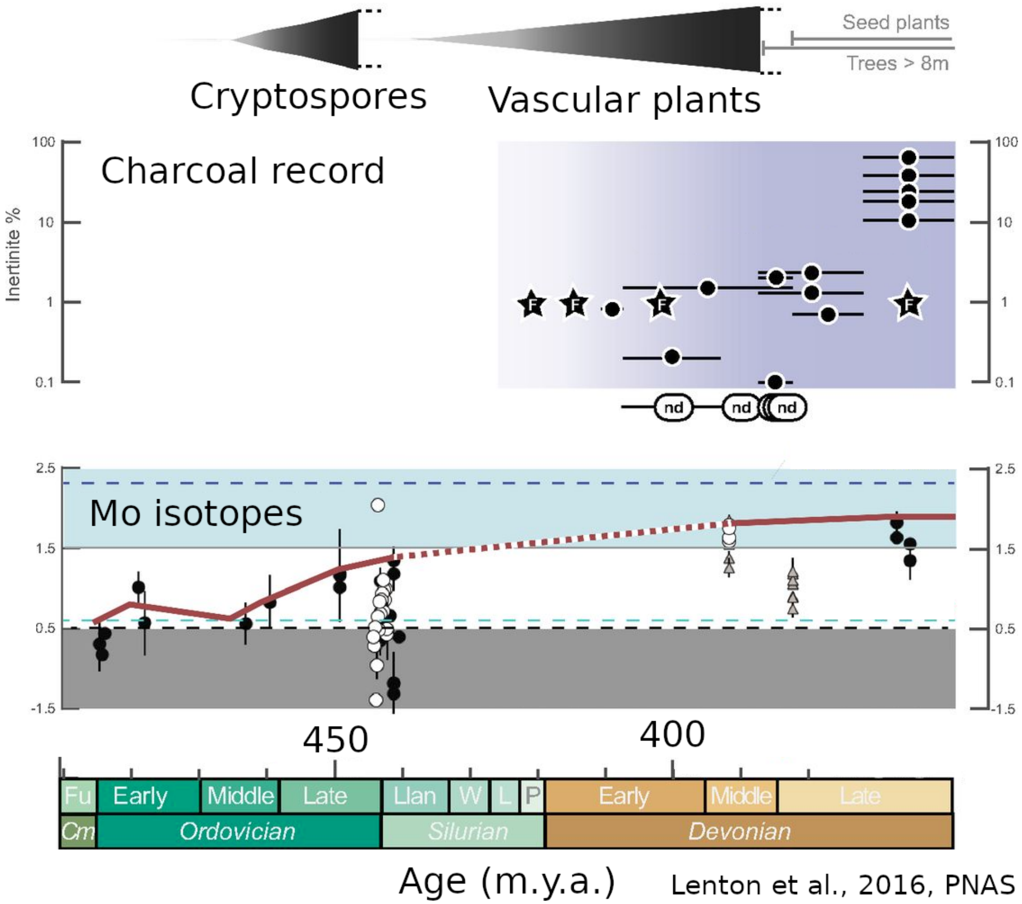


Butterfield, 2011

DID COMPLEX LIFE INDUCE THE FINAL O_2 RISE?



Lenton et al., 2016, PNAS

CONCLUSIONS

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Animal emergence and oxygen rise are closely spaced.

The role of oxygen in initiating biological complexity remains largely unclear.