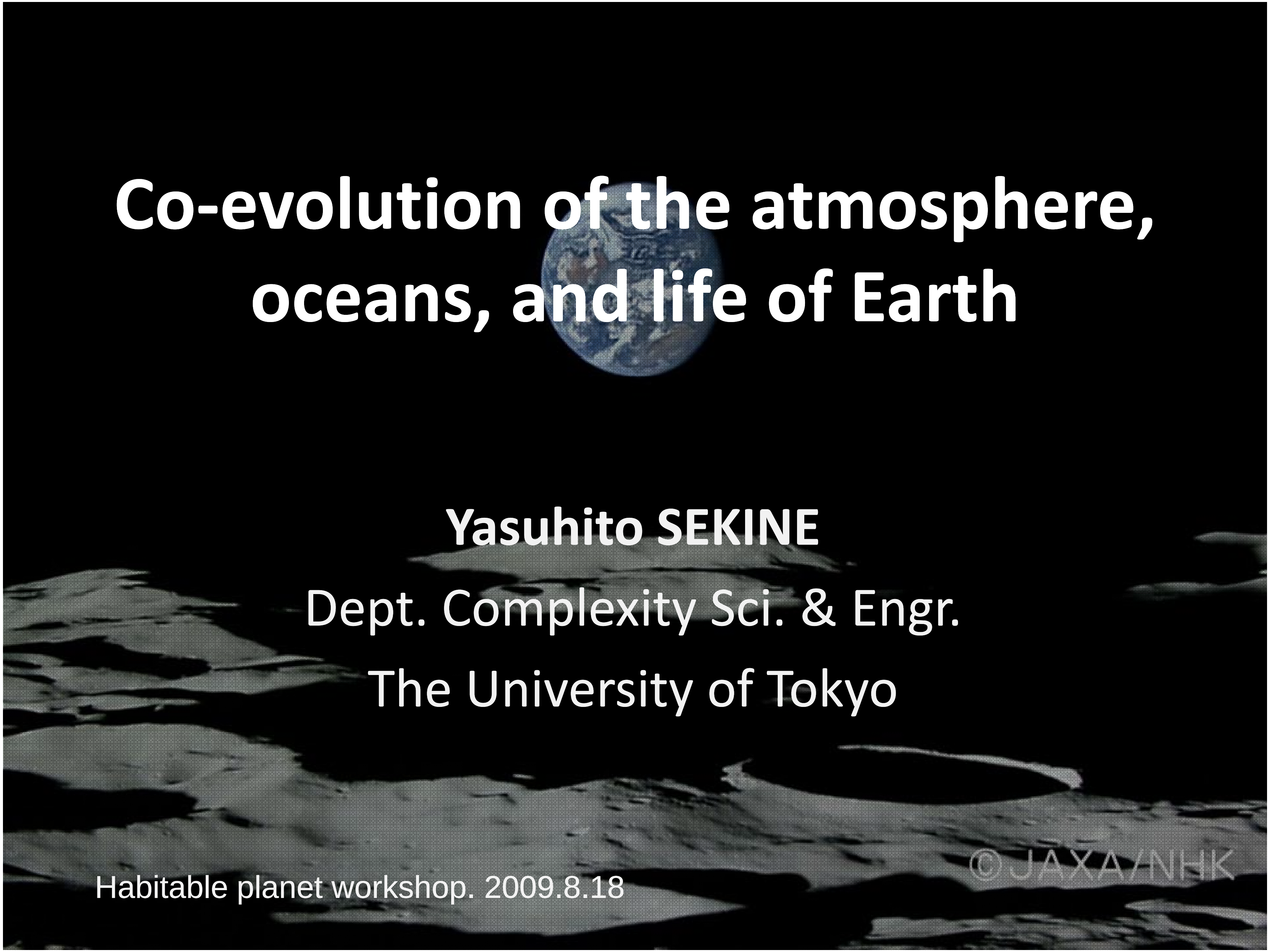


Co-evolution of the atmosphere, oceans, and life of Earth

Yasuhito SEKINE

Dept. Complexity Sci. & Engr.

The University of Tokyo

Habitable planet workshop. 2009.8.18

Today's topic: co-evolution of Earth & life

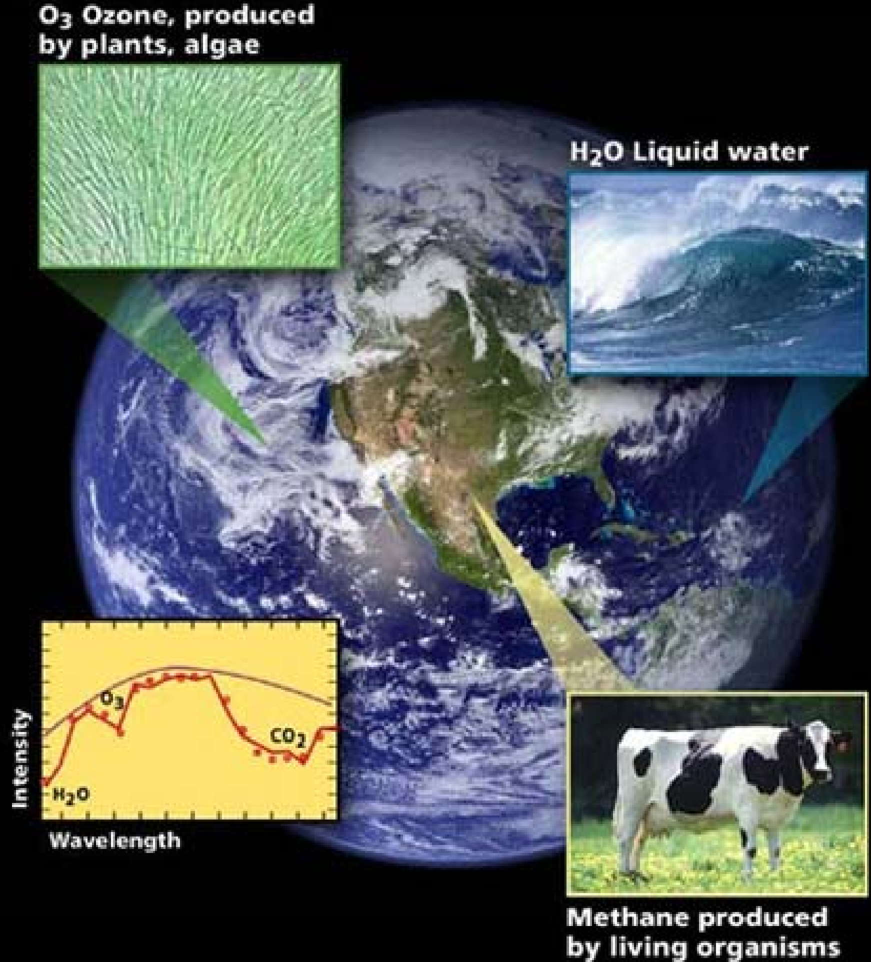
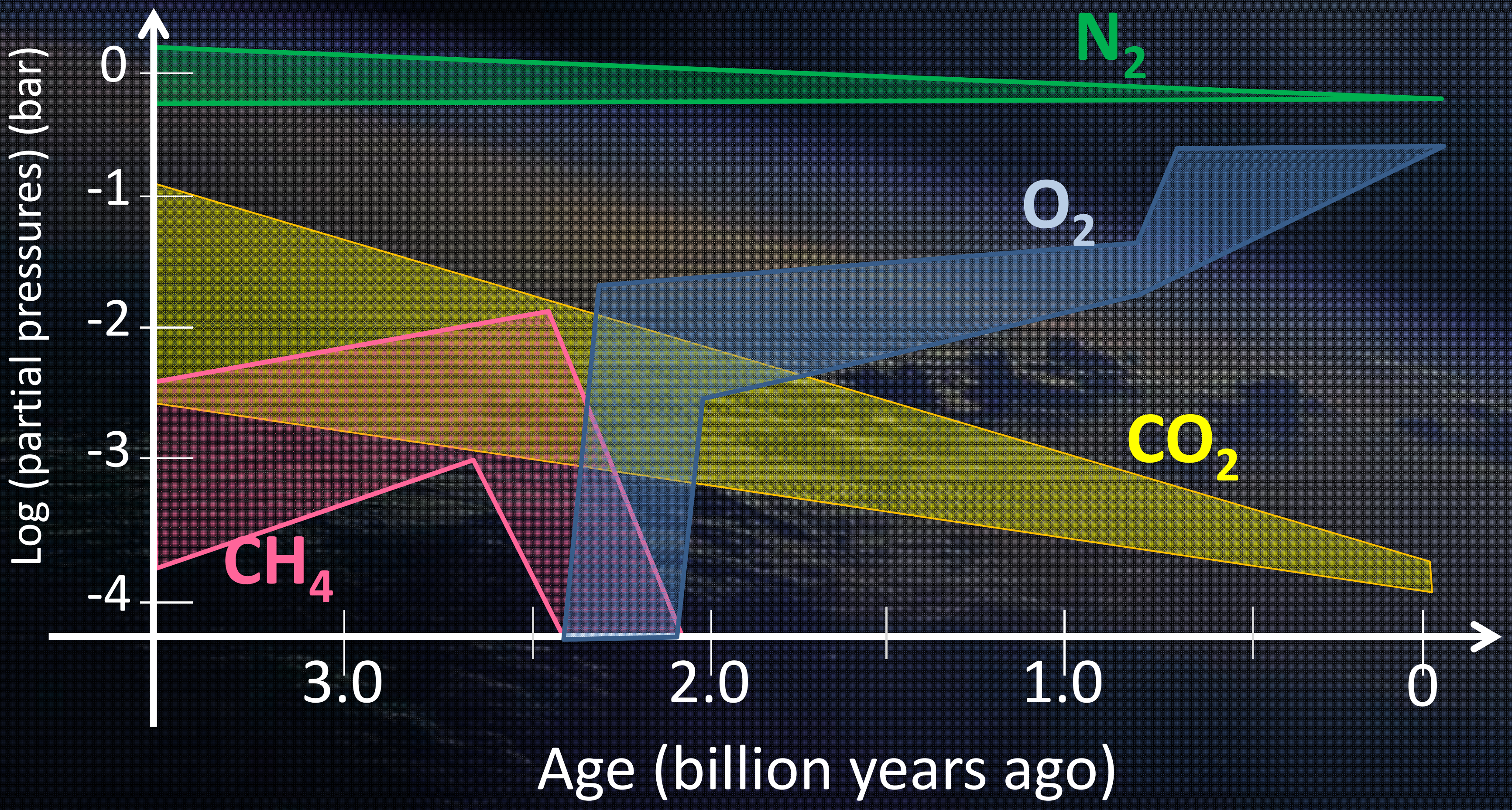


Figure after TPF HP

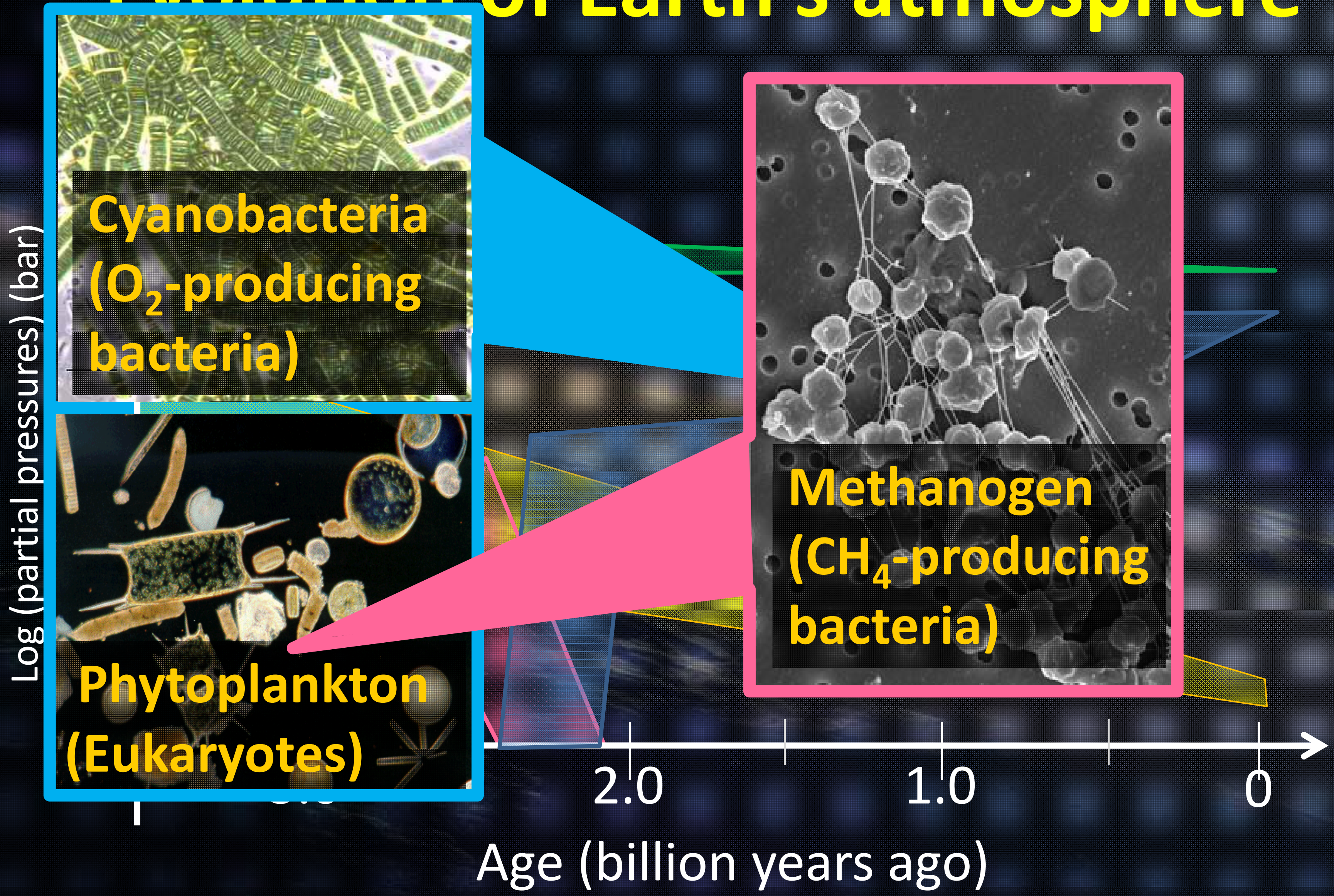
- Earth is the only known aqua planet so far.
- We need to know how the ocean, atmosphere, and life have evolved and interacted over Earth's history.

Evolution of Earth's atmosphere



(Holland, 1984; Tajika & Matsui, 1992; Kasting, 1993;
Rye & Holland, 1998; Farquhar et al., 2000; Pavlov et al., 2001; Hoffman & Schrag, 2000; Zahnle et al., 2006)

Evolution of Earth's atmosphere

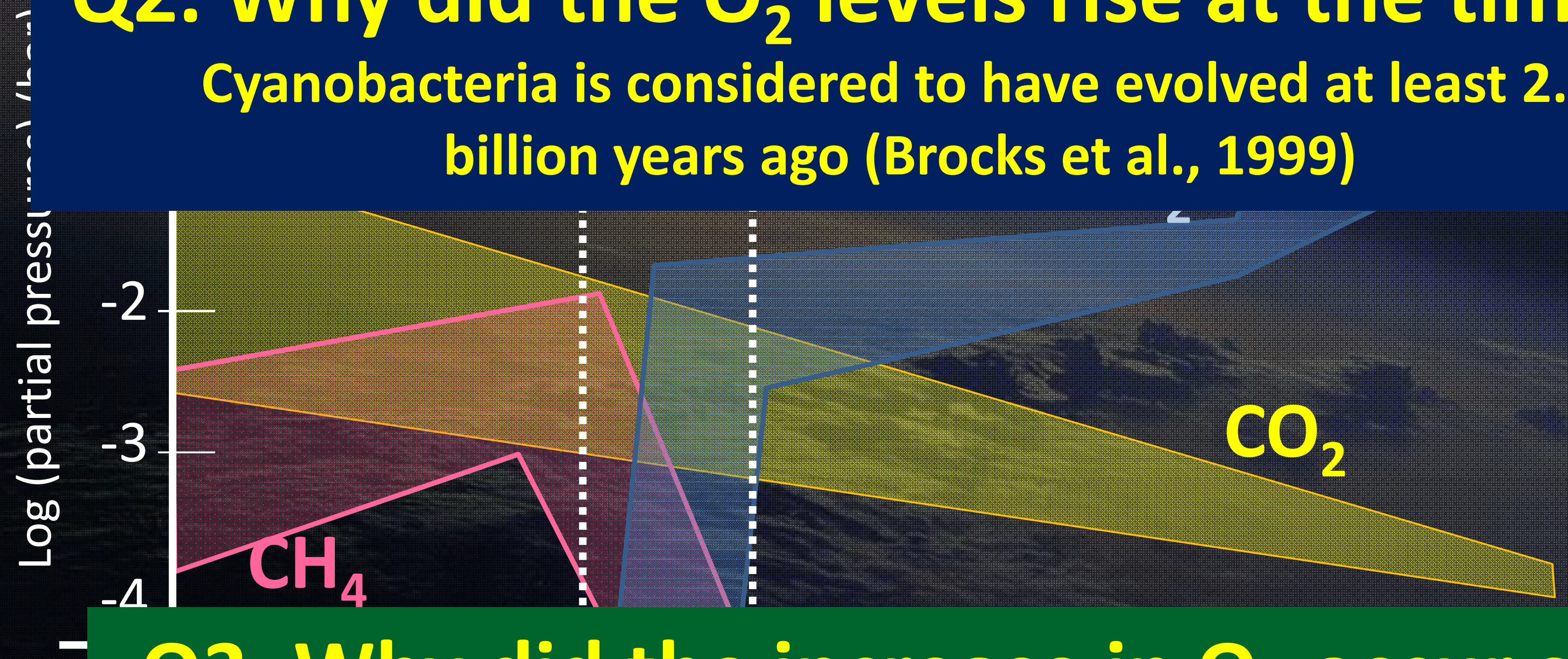


(Holland, 1984; Tajika & Matsui, 1992; Kasting, 1993;
Rye & Holland, 1998; Farquhar et al., 2000; Pavlov et al., 2001; Hoffman & Schrag, 2000; Zahnle et al., 2006)

Q1. How had the early Earth been seen from space?

Q2. Why did the O_2 levels rise at the time?

Cyanobacteria is considered to have evolved at least 2.7 billion years ago (Brocks et al., 1999)

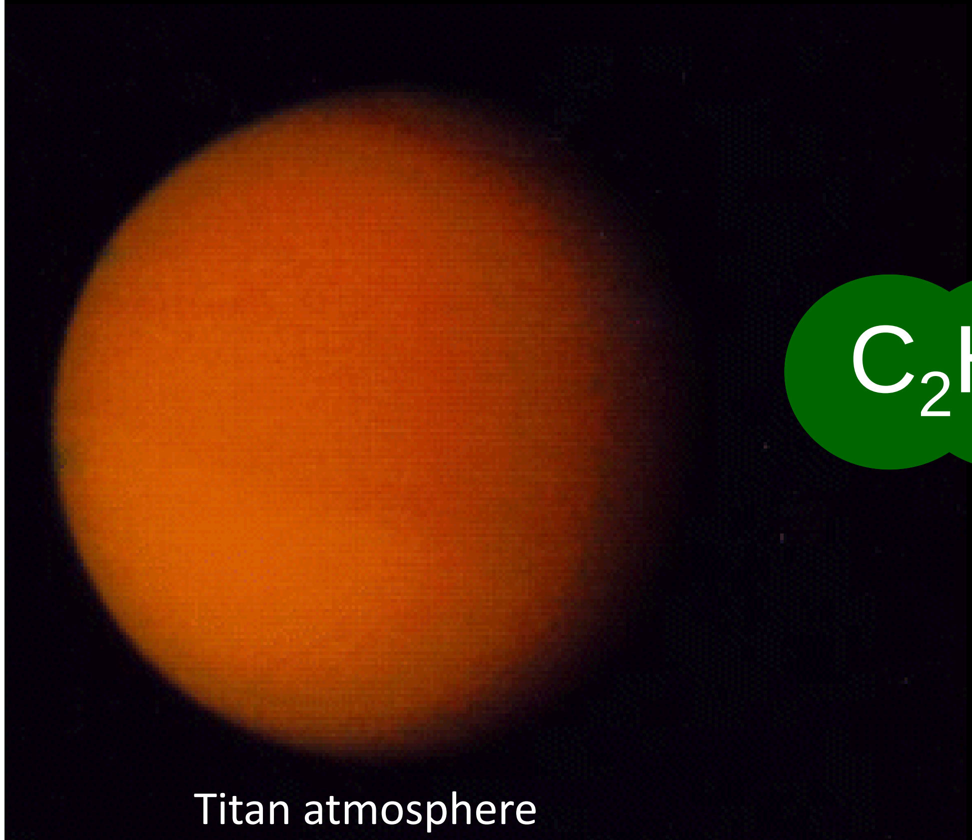


Q3. Why did the increase in O_2 occur so rapidly in geological timescale?

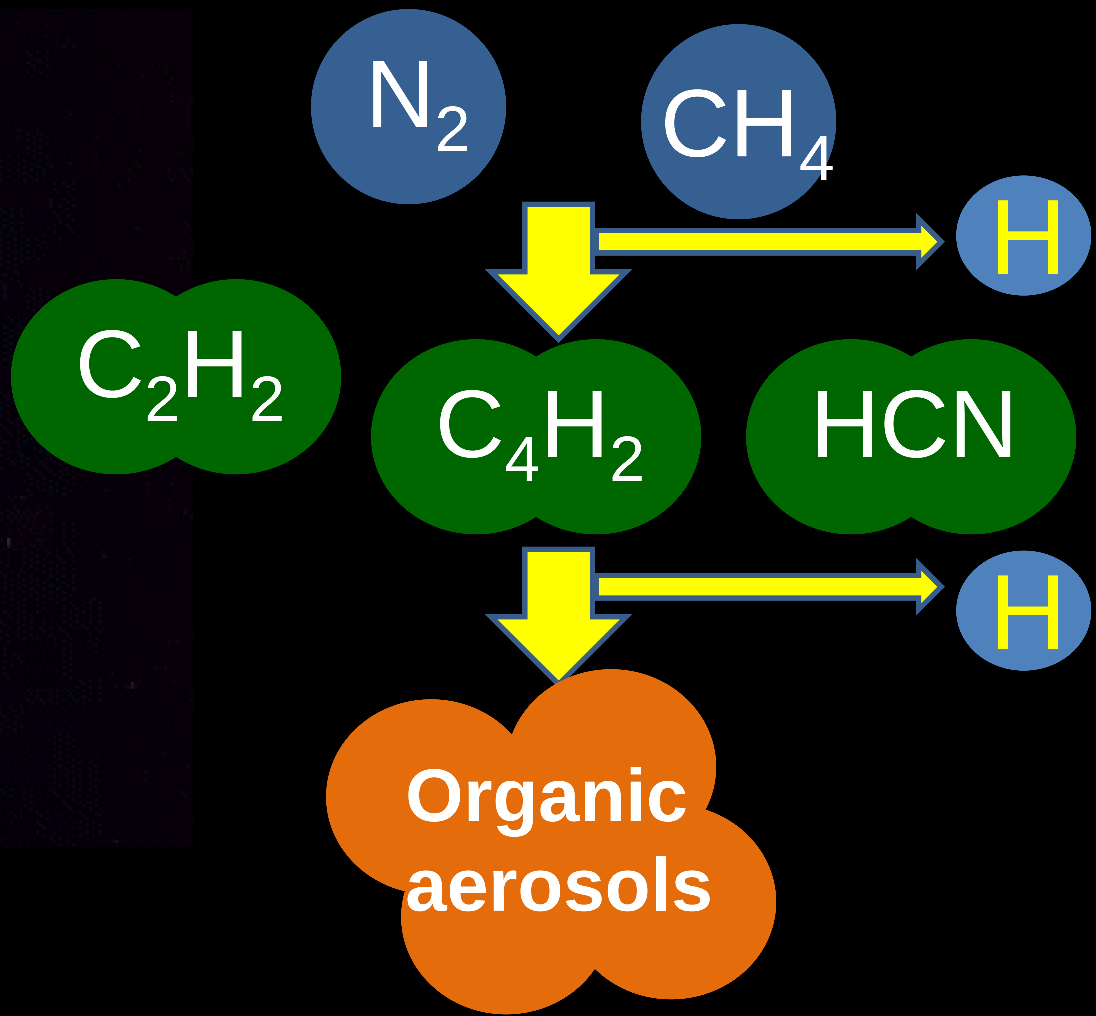
(Holland, 1984; Tajika & Matsui, 1992; Kasting, 1993;
Rye & Holland, 1998; Farquhar et al., 2000; Pavlov et al., 2001; Hoffman & Schrag, 2000; Zahnle et al., 2006)

Q1. How had the early Earth been seen from space?

Key: Titan (Organic chemistry in CH_4-rich atmosphere)



Titan atmosphere
N_2: 95–98%, CH_4: 2–5%



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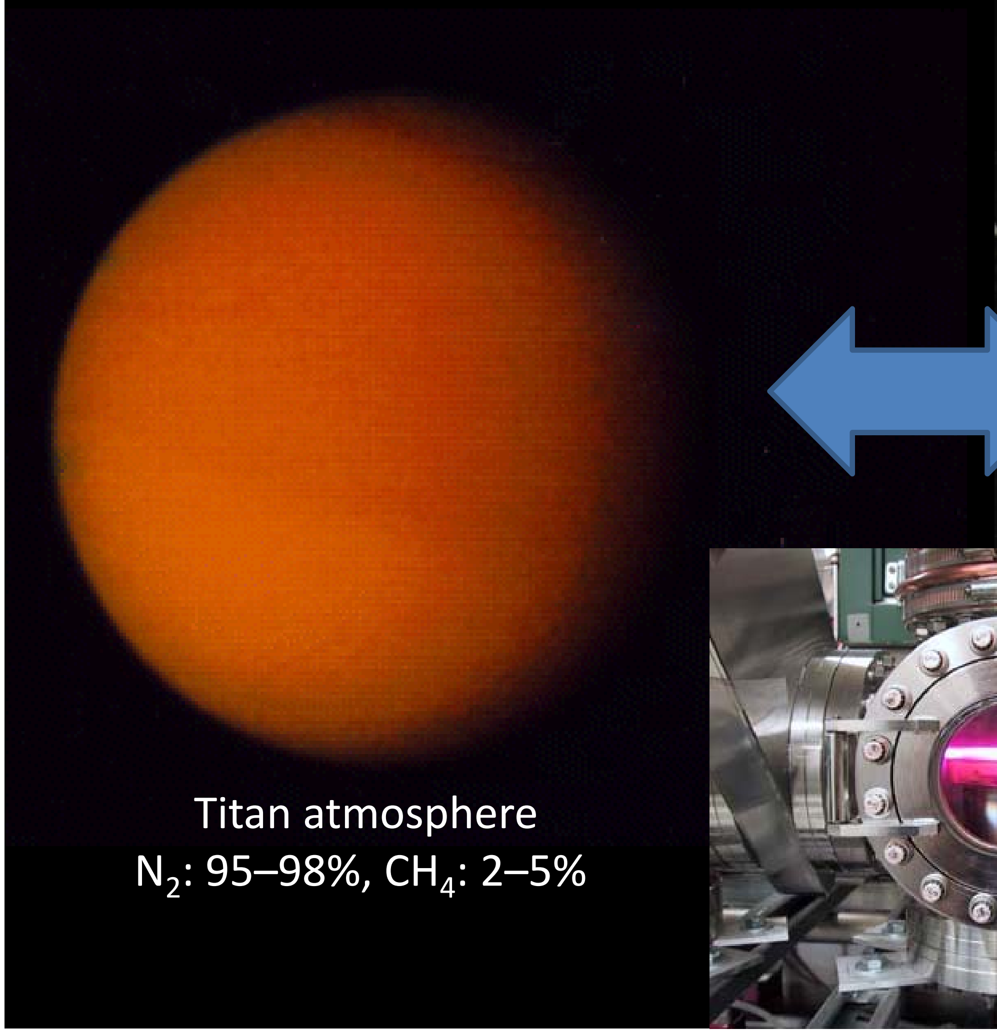

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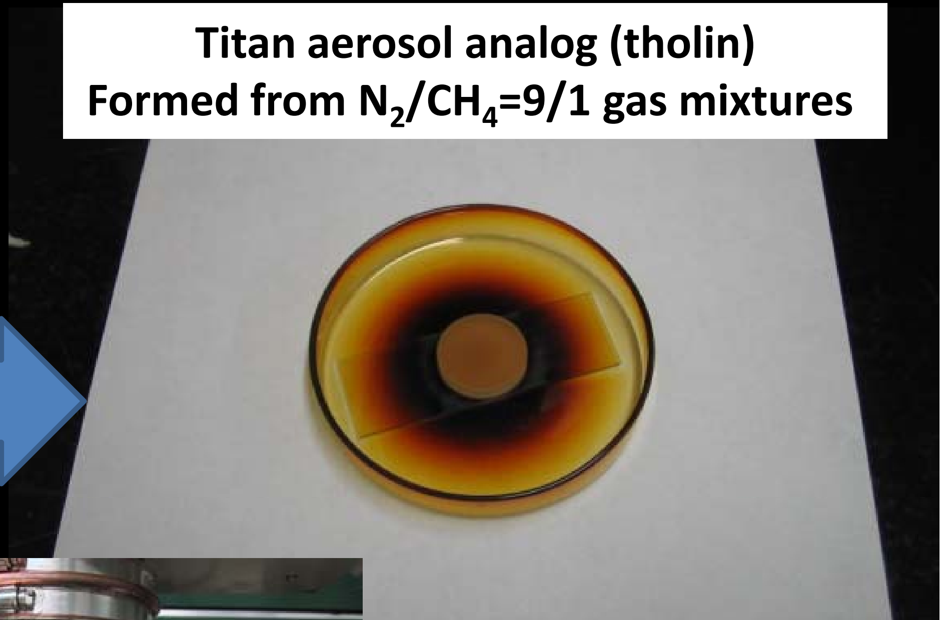
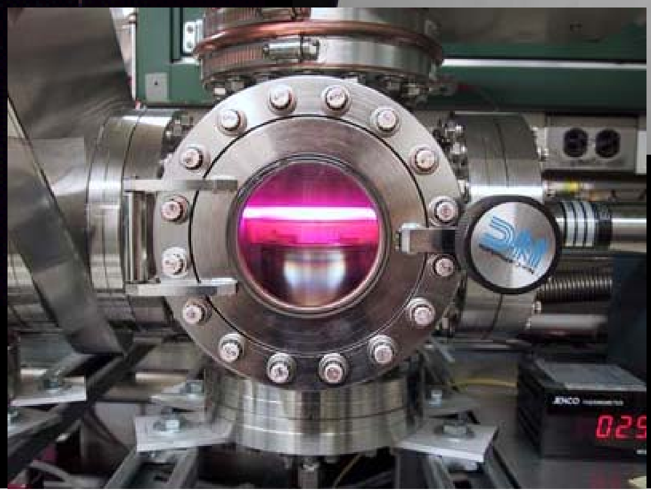
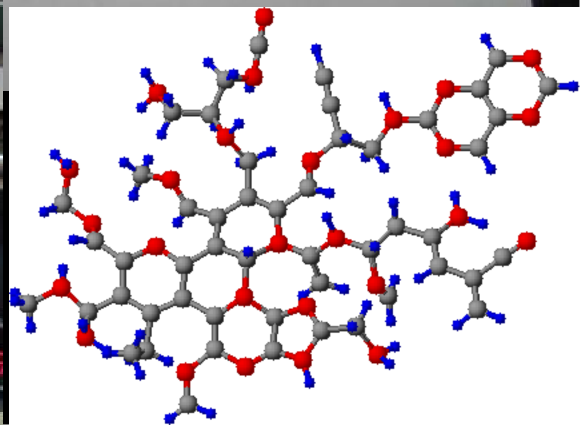
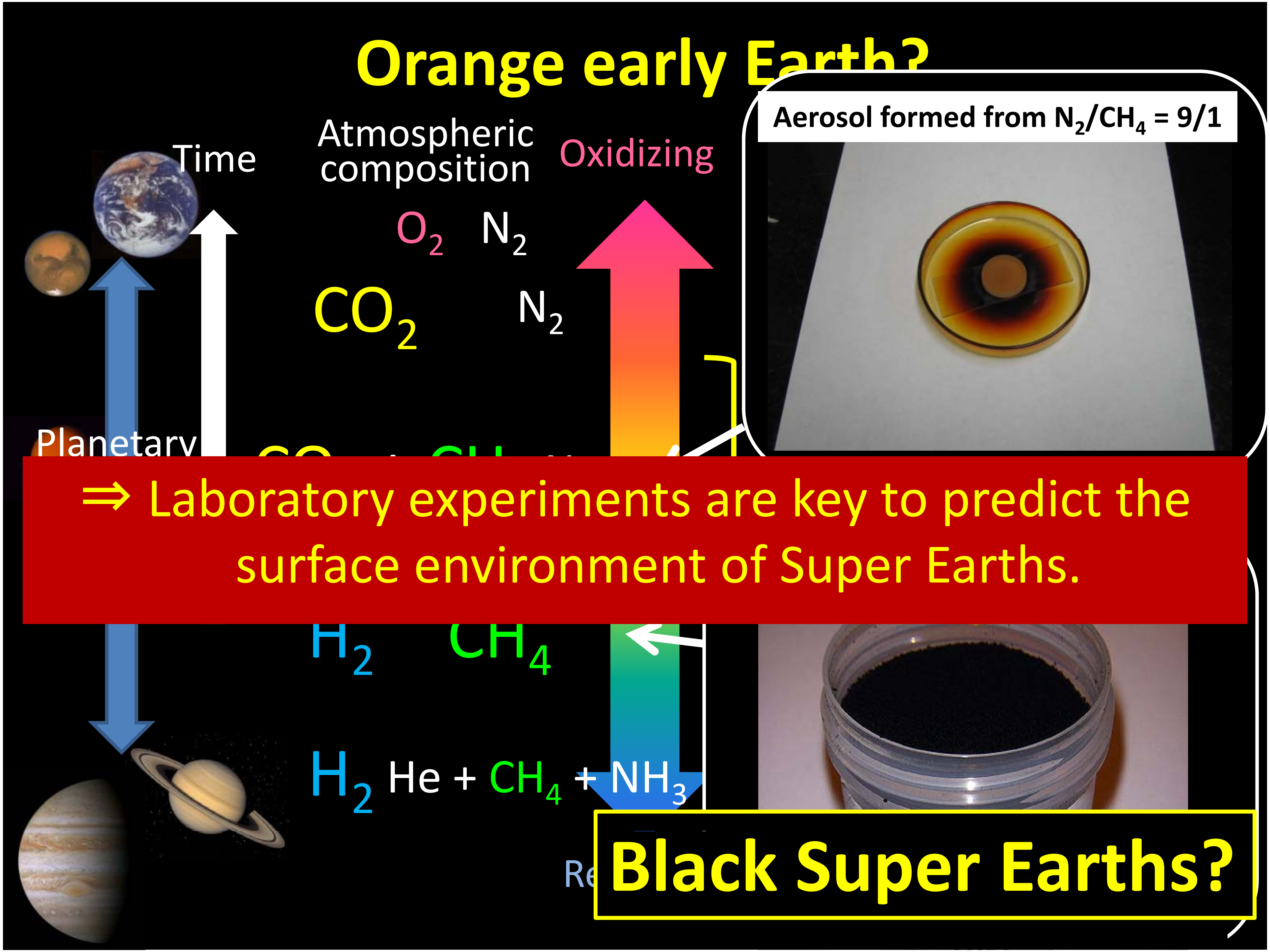


Titan aerosol analog (tholin)
Formed from N_2/CH_4=9/1 gas mixtures



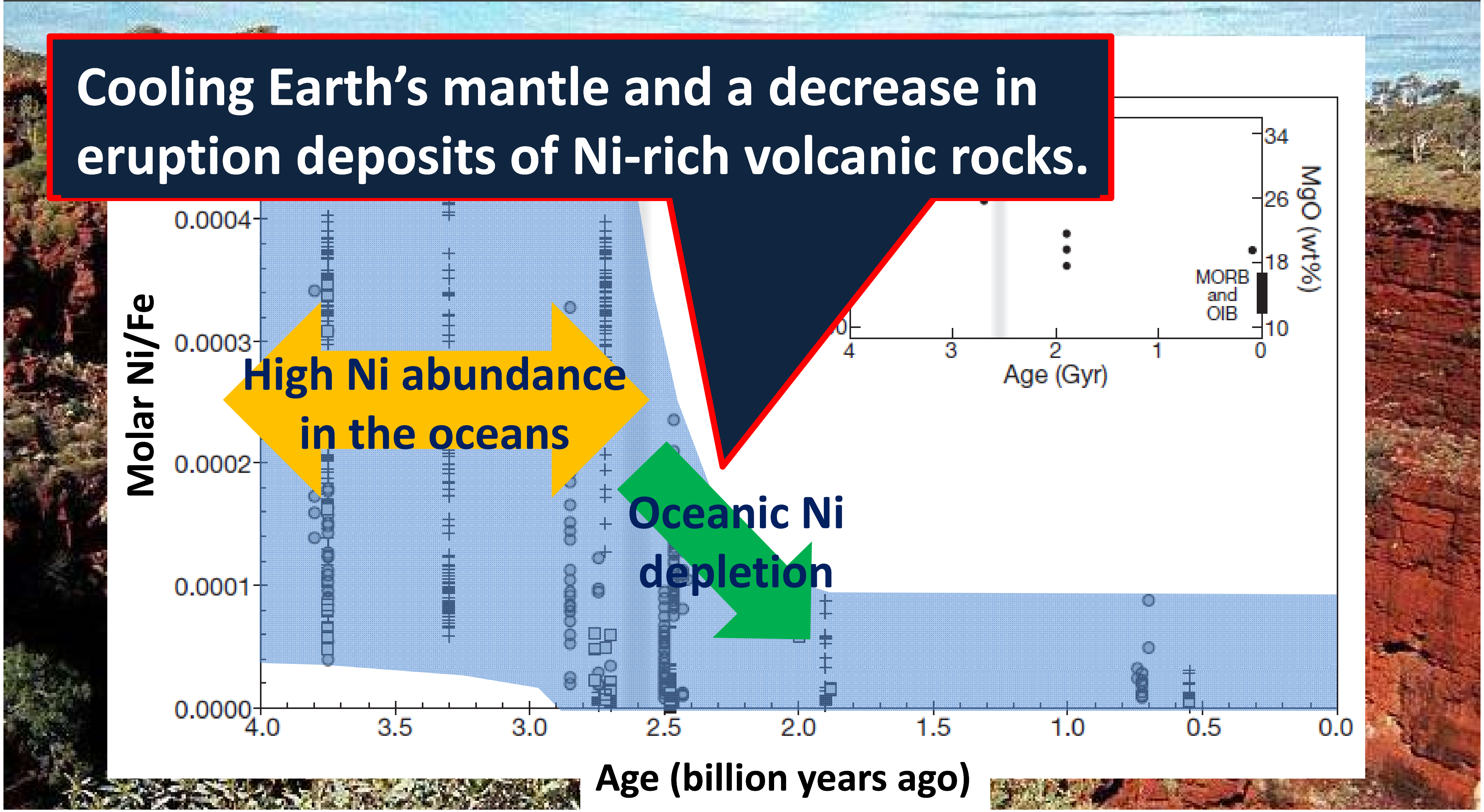




Orange early Earth?
Aerosol formed from N_2/CH_4 = 9/1
Time
Atmospheric composition
Oxidizing
O_2 N_2
CO_2 N_2
Planetary
⇒ Laboratory experiments are key to predict the surface environment of Super Earths.
H_2 CH_4
H_2 He + CH_4 + NH_3
Black Super Earths?

Q2. Why 2.5–2.2 billion years ago?

Key: Ocean composition (A decline in Ni abundance in the oceans from 2.5 billion years ago) (Konhauser et al., 2009)



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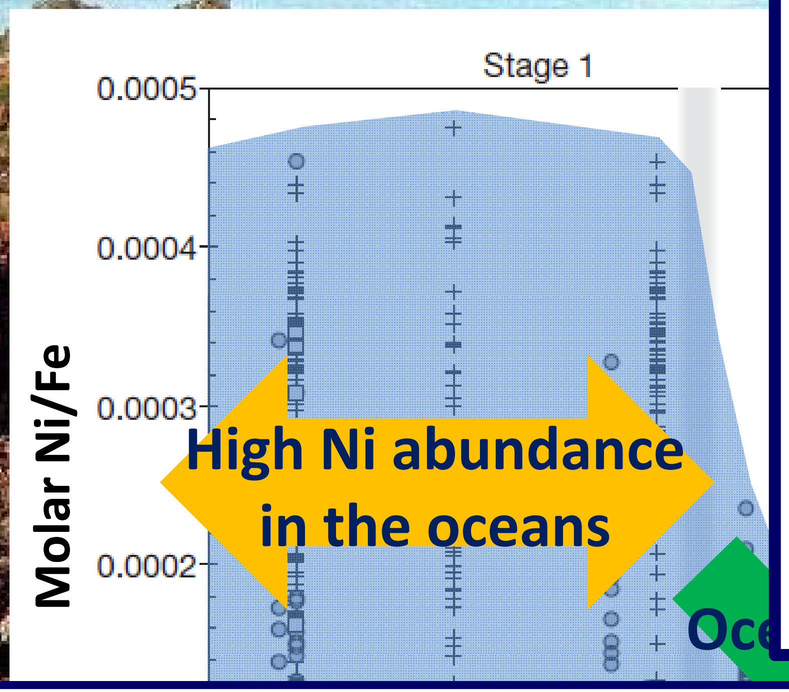
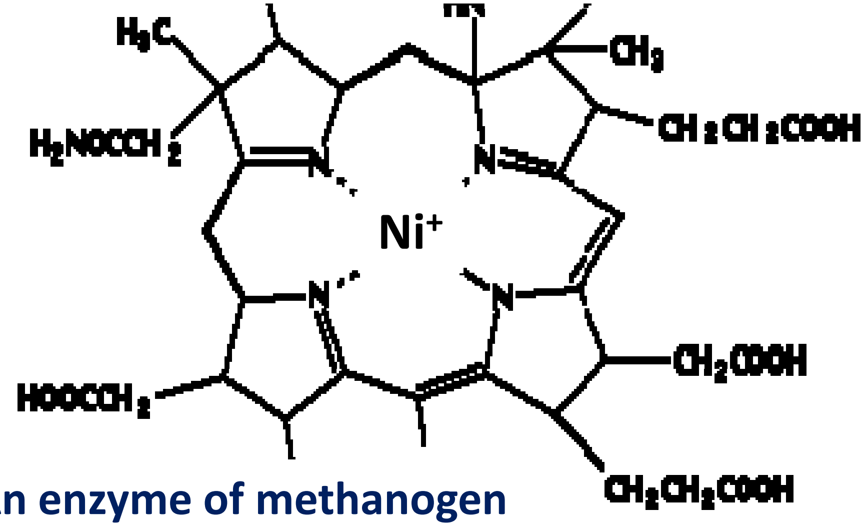


Ni is an bioessential element for methanogen



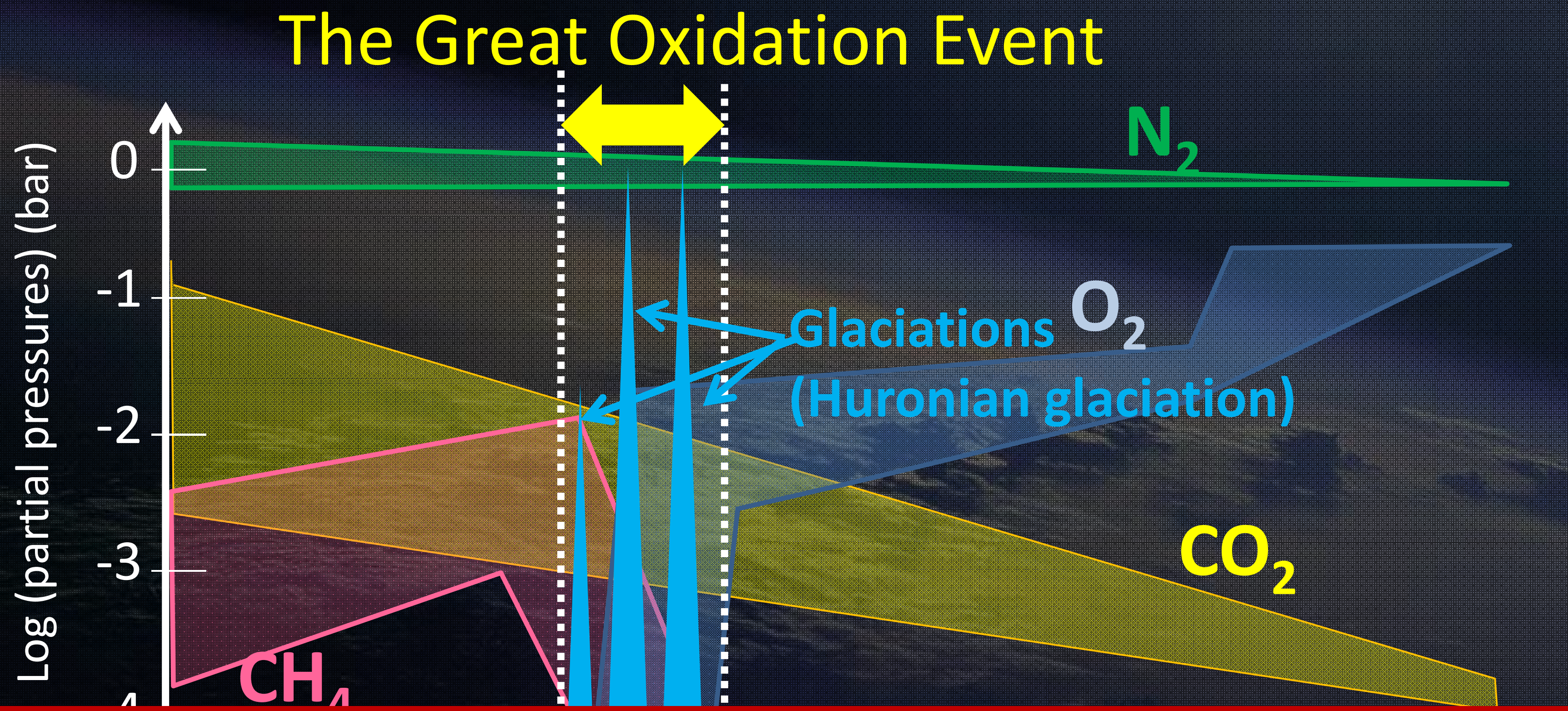
An enzyme of methanogen

Thermal evolution & a decline in Ni in the oceans

⇒ a methanogen famine & an increase in O_2.

Q3. Why did O_2 increase so rapidly?

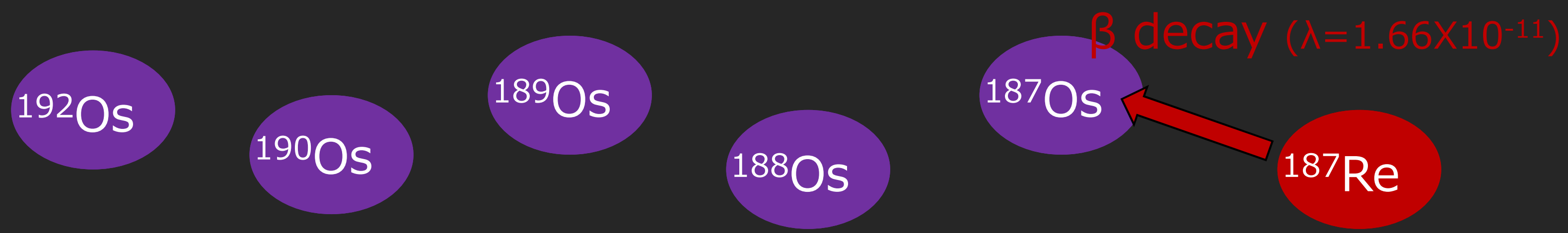
Key: Climate change (A decline in CH_4 ⇒ severe ice age)



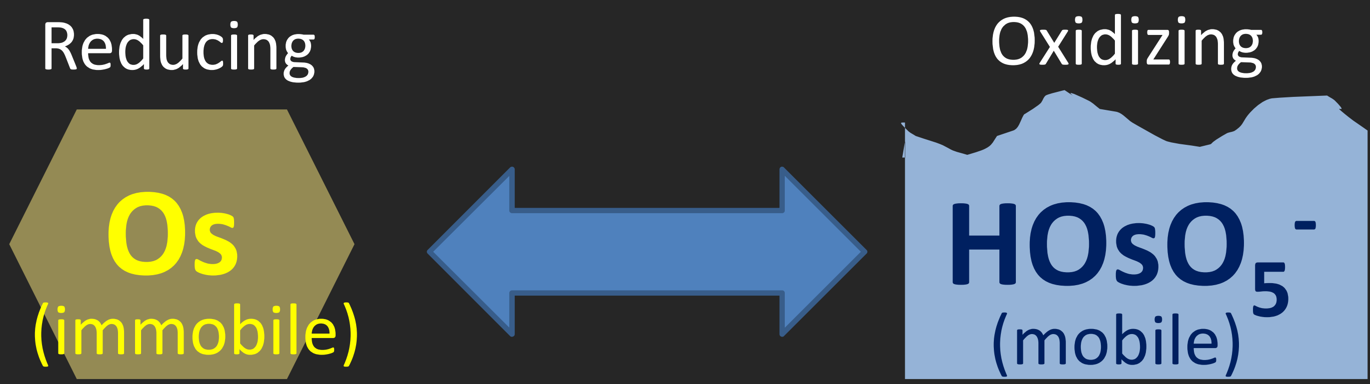
How were the severe glaciations related with the increase in O_2 levels? ⇒ *Timing is everything!*

Osmium (Os) isotopic compositions in ancient oceans (Sekine et al., under review)

- **Point 1**: Continental crusts have high concentrations of ^{187}Os decayed from ^{187}Re contained in continents.



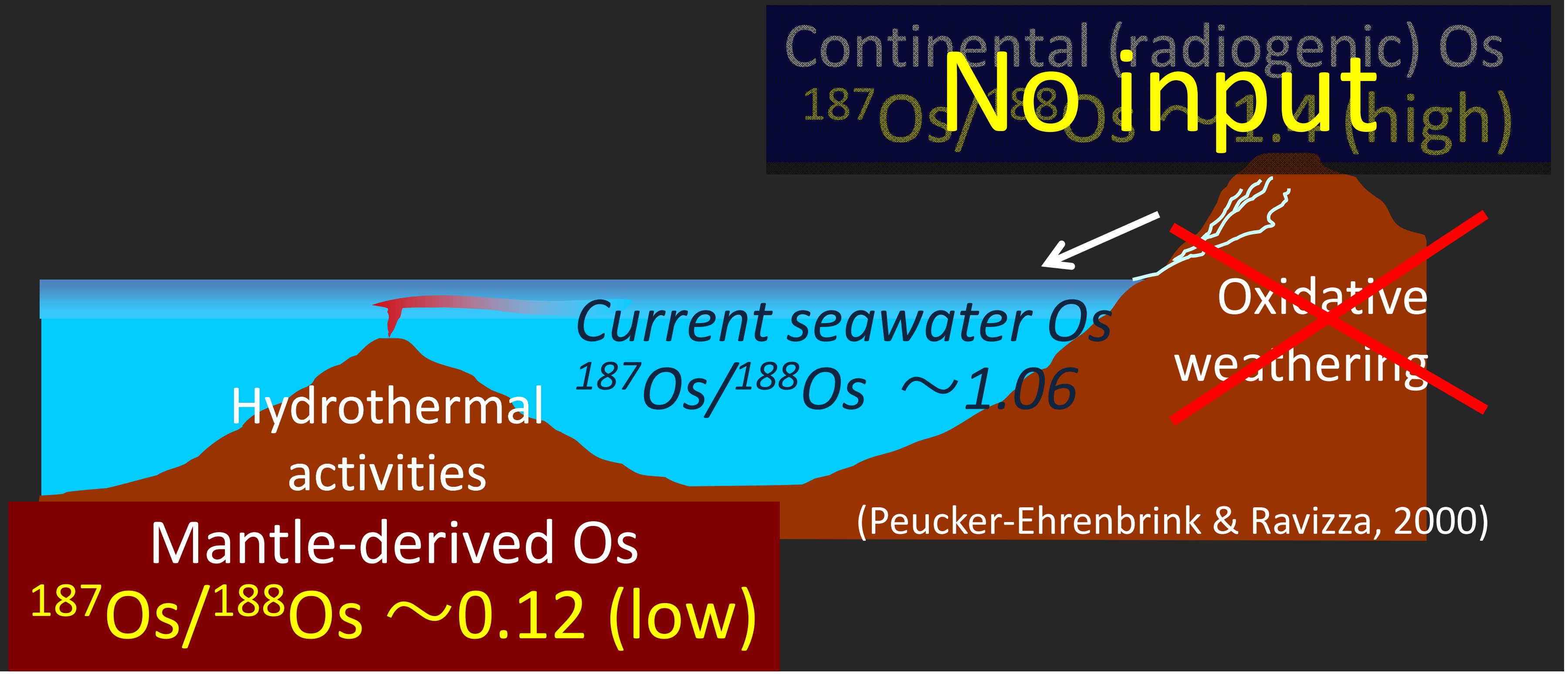
- **Point 2**: Os is a redox-sensitive element, soluble and mobile in hydrological cycle only under oxidizing atmospheres



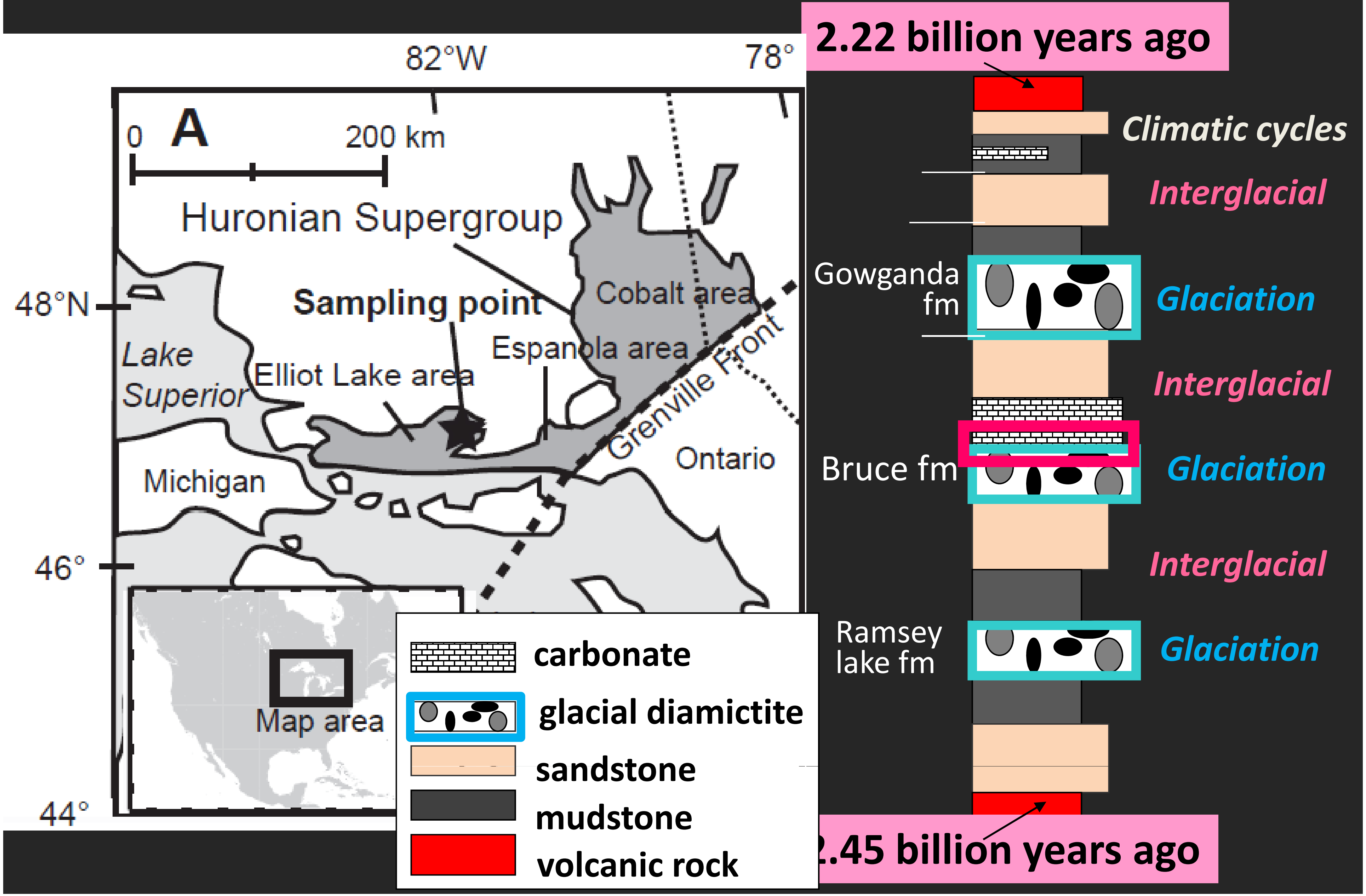
Osmium (Os) isotopic compositions in ancient oceans (Sekine et al., under review)

Oxidizing atmospheres ⇒ seawater $^{187}Os/^{188}Os > 0.12$

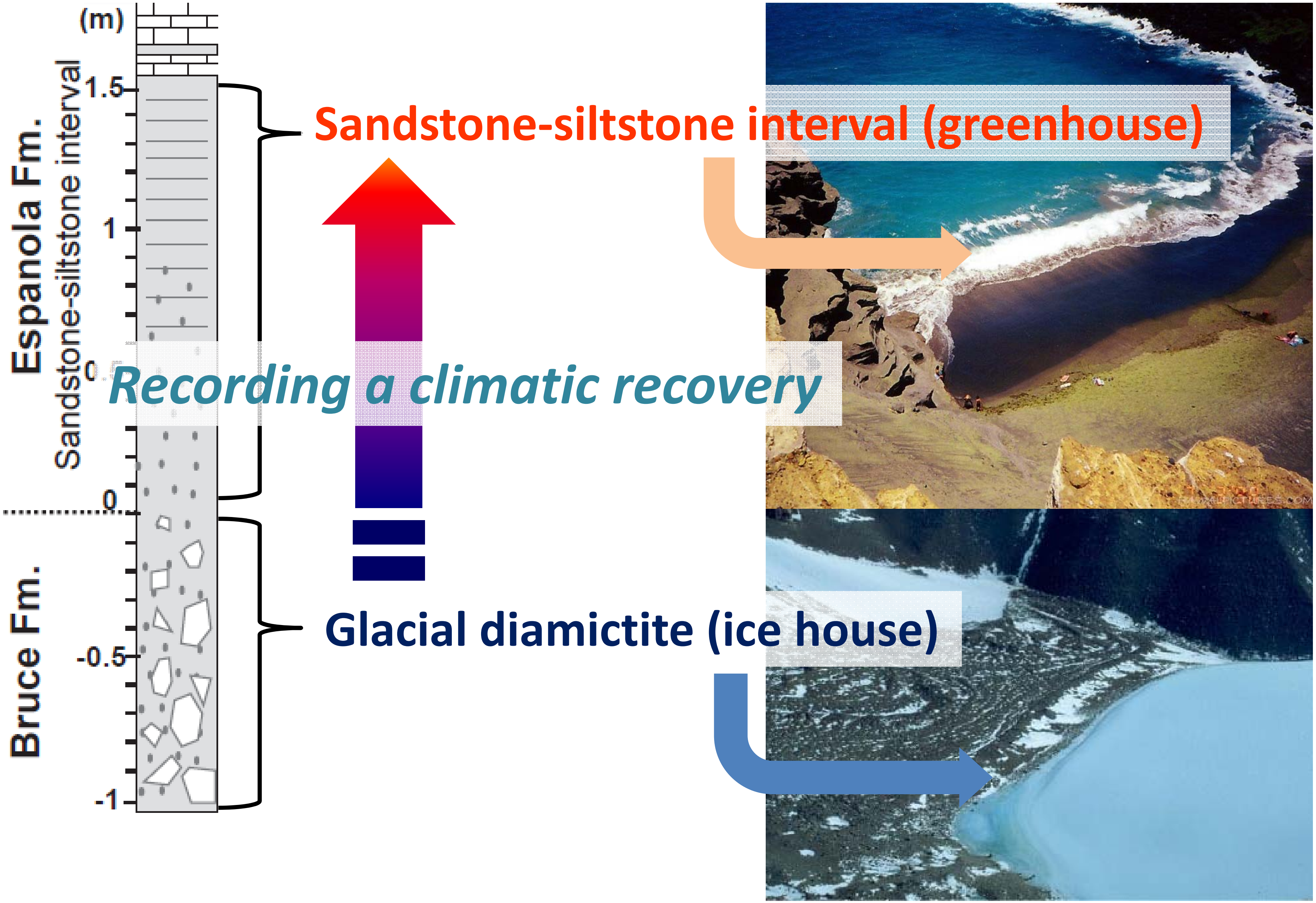
Reducing atmospheres ⇒ seawater $^{187}Os/^{188}Os \sim 0.12$



Huronian Supergroup (Canada)



Variation in initial $^{187}Os/^{188}Os$ (age =2.3±0.2 Ga)



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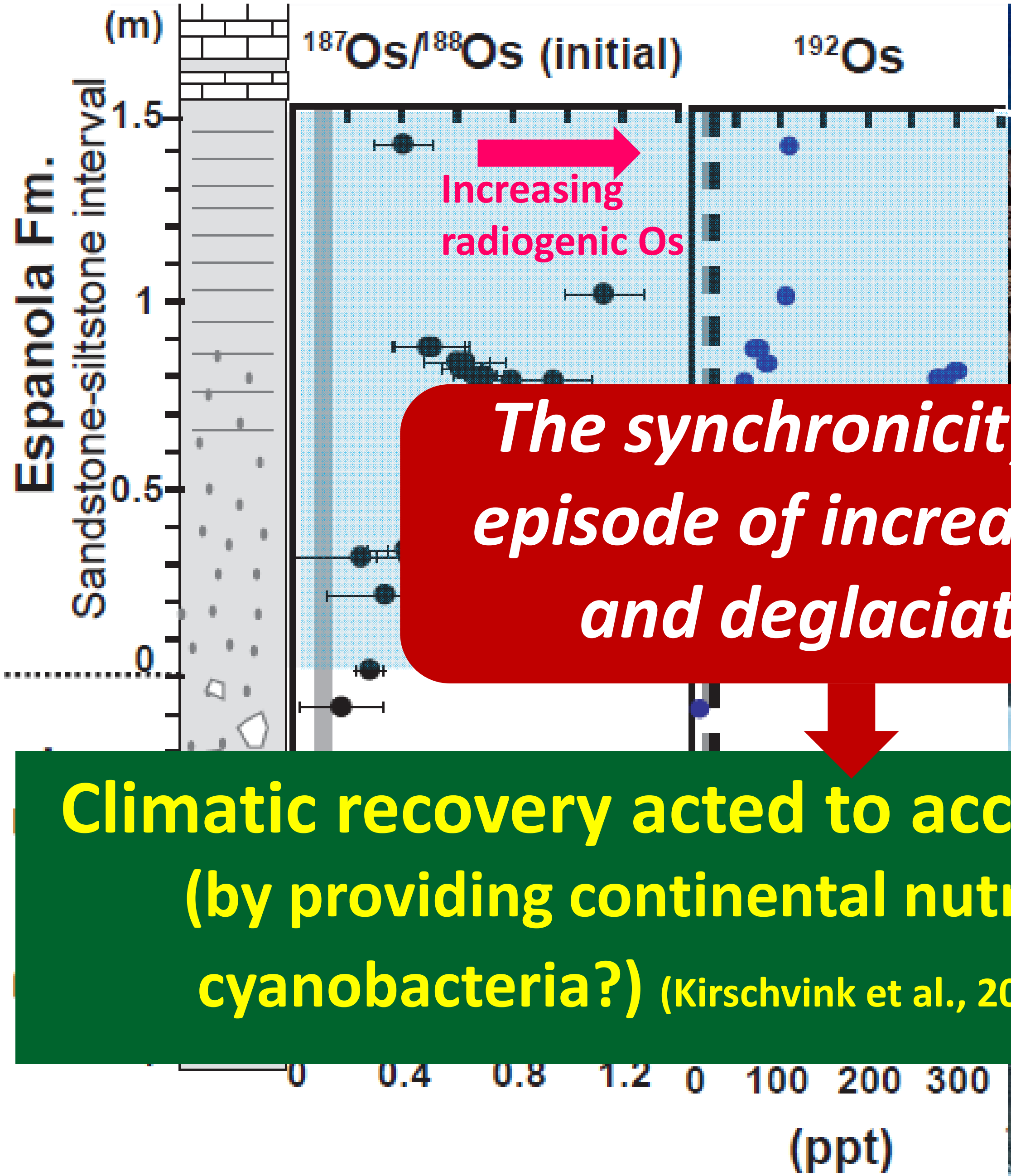
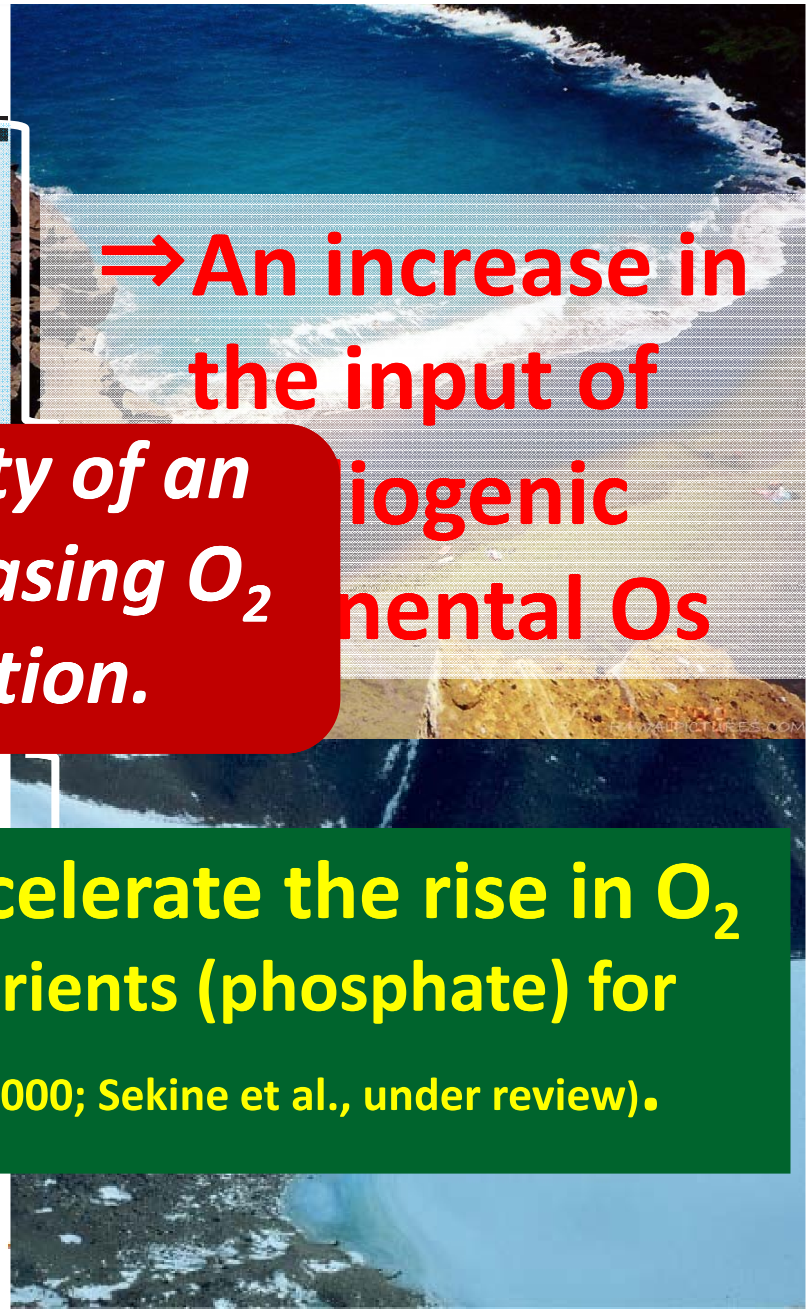


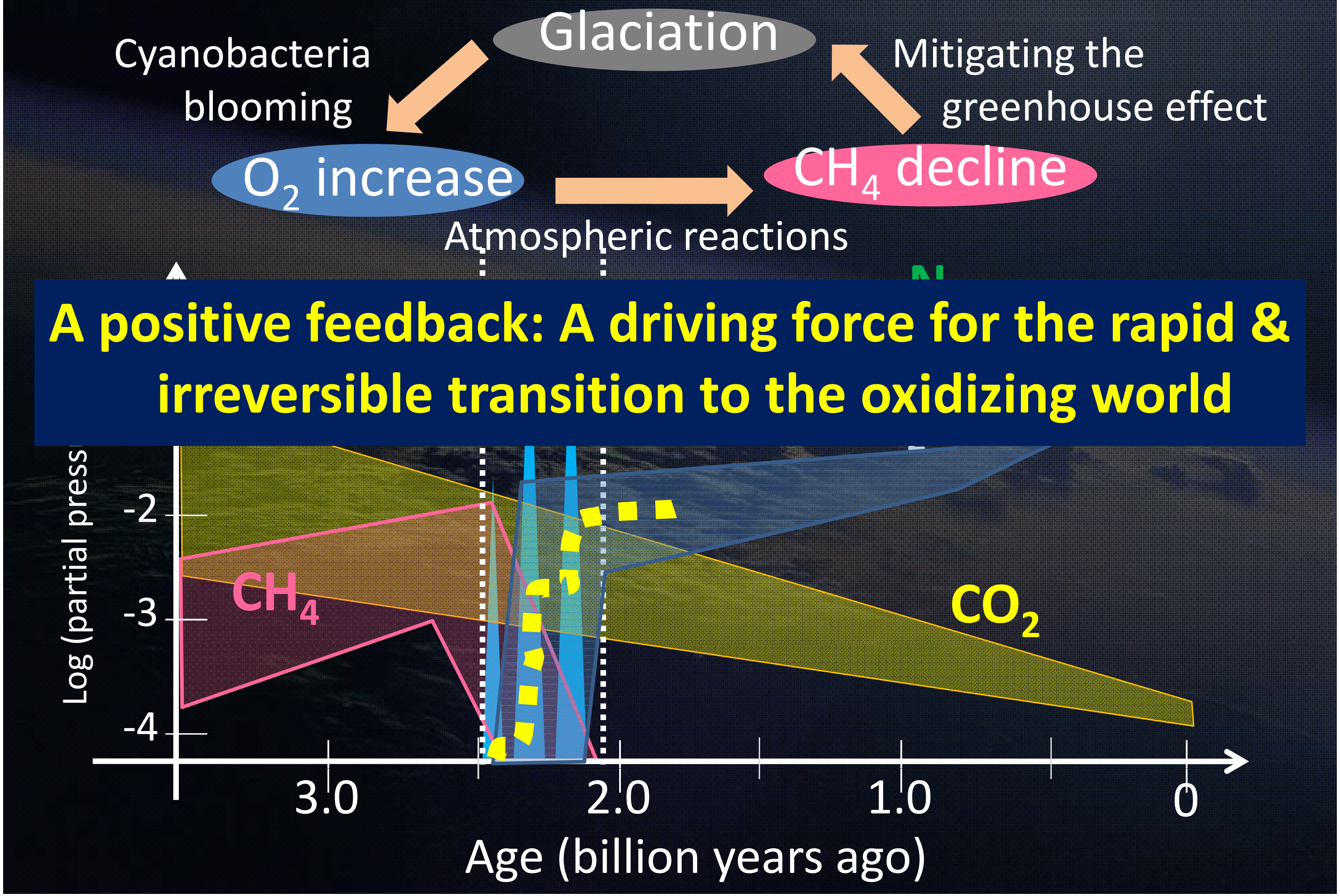


⇒An increase in the input of radiogenic continental Os

The synchronicity of an episode of increasing O_2 and deglaciation.

Climatic recovery acted to accelerate the rise in O_2 (by providing continental nutrients (phosphate) for cyanobacteria?) (Kirschvink et al., 2000; Sekine et al., under review).

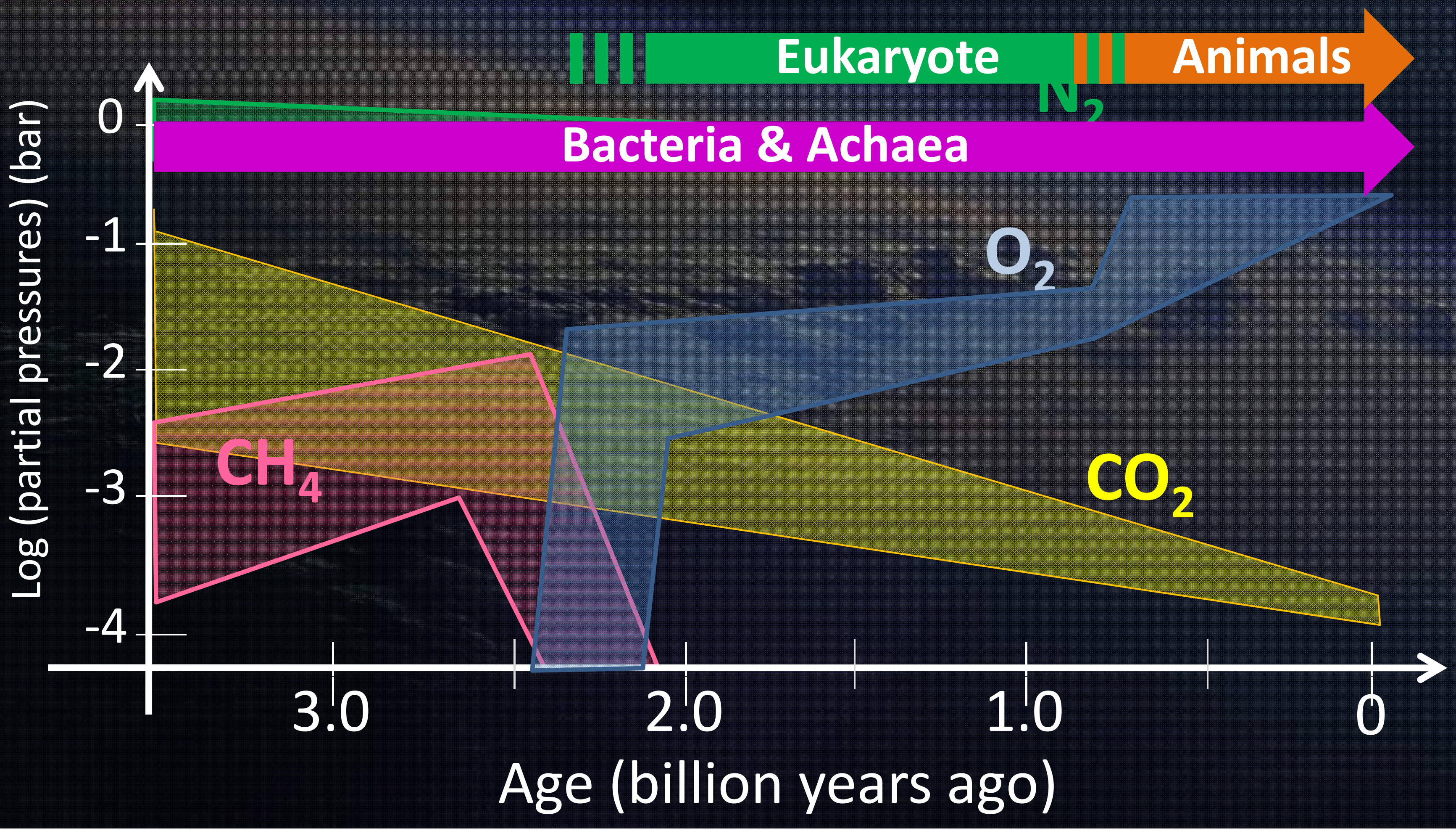
Relationship between climate & O_2



A positive feedback: A driving force for the rapid & irreversible transition to the oxidizing world

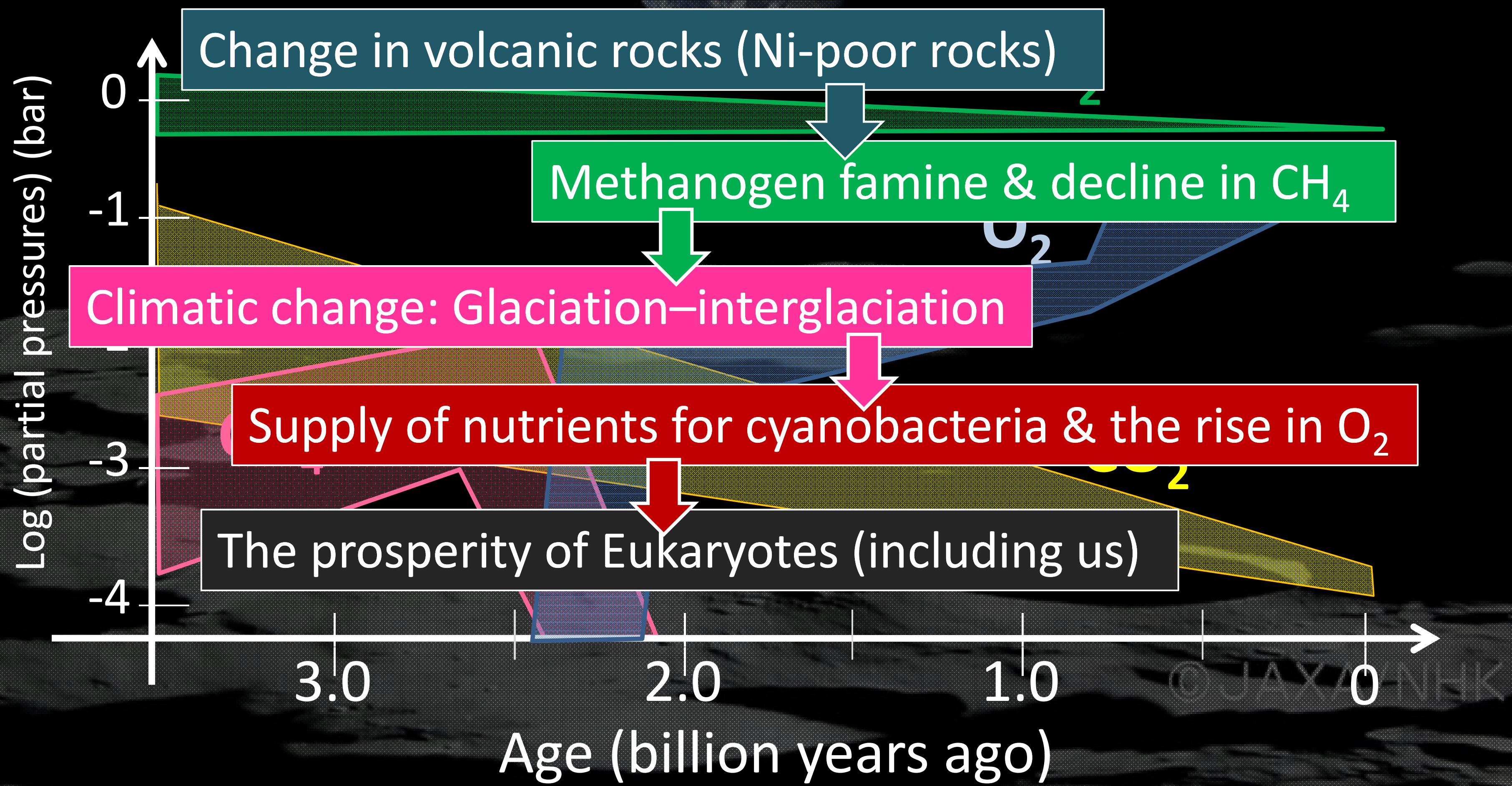
In the aftermath of the rise in O_2…

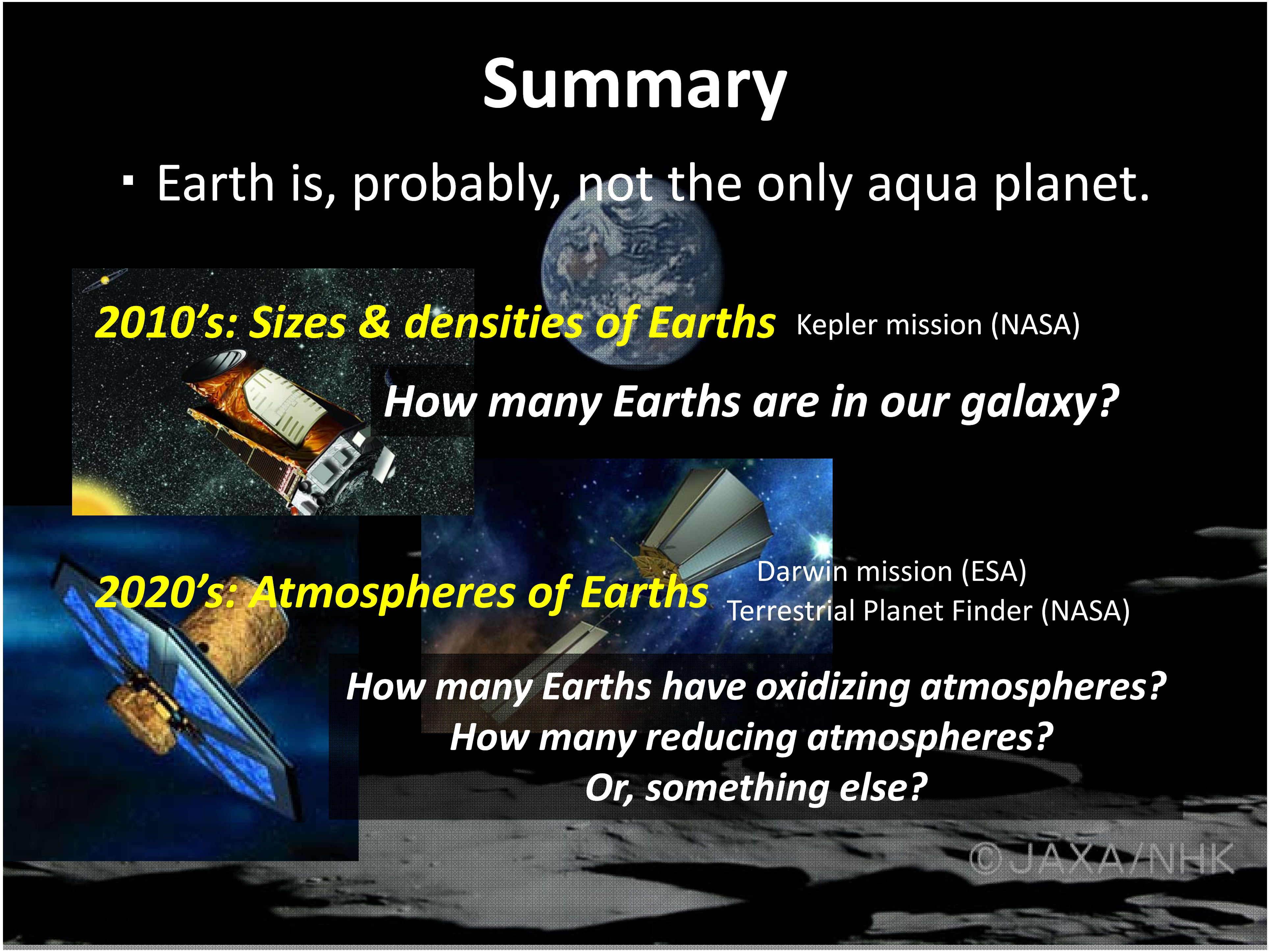
- Enhancements of other redox-sensitive metals Mo, Zn, & V in oceans, bioessential element for Eukaryotes (Anbar & Knoll, 2002; Knoll et al., 2006; Dupont et al., 2006) ⇒ *leading to prosperity of Eukaryotes*



Summary

- In Earth's history, the evolutions of the atmosphere, ocean, and climate have been closely related with that of life.




Summary
・ Earth is, probably, not the only aqua planet.
2010's: Sizes & densities of Earths
Kepler mission (NASA)
How many Earths are in our galaxy?
2020's: Atmospheres of Earths
Darwin mission (ESA)
Terrestrial Planet Finder (NASA)
How many Earths have oxidizing atmospheres?
How many reducing atmospheres?
Or, something else?
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