Geobiology & Astrobiology at PKU

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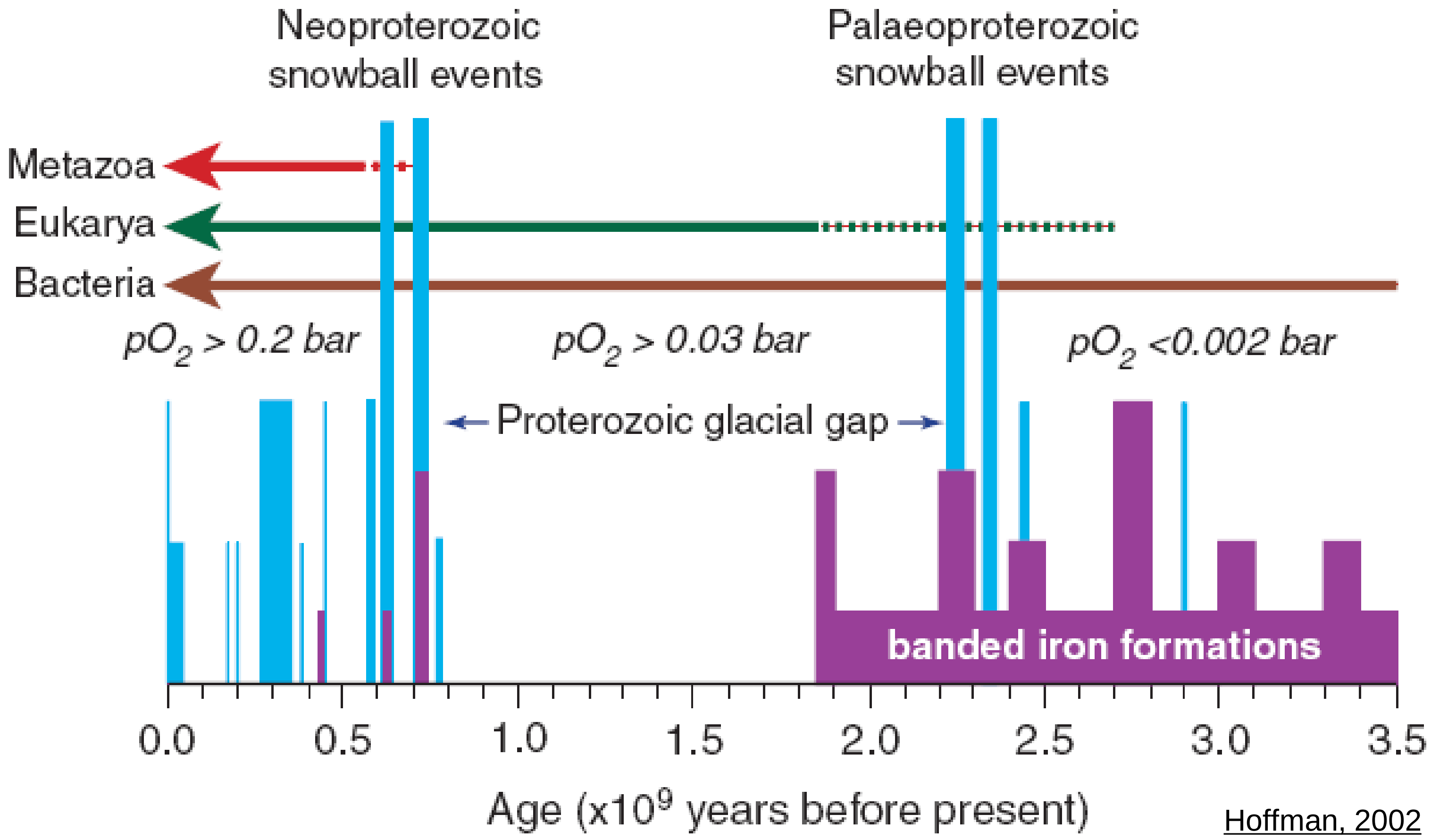
Contents

- Geobiology 1: The deep time ice-house climate
- Geobiology 2: The evolution of terrestrial system
- Astrobiology 1: The early evolution of Planetary Earth
- Astrobiology 2: The early evolution of metabolism

Glaciation records

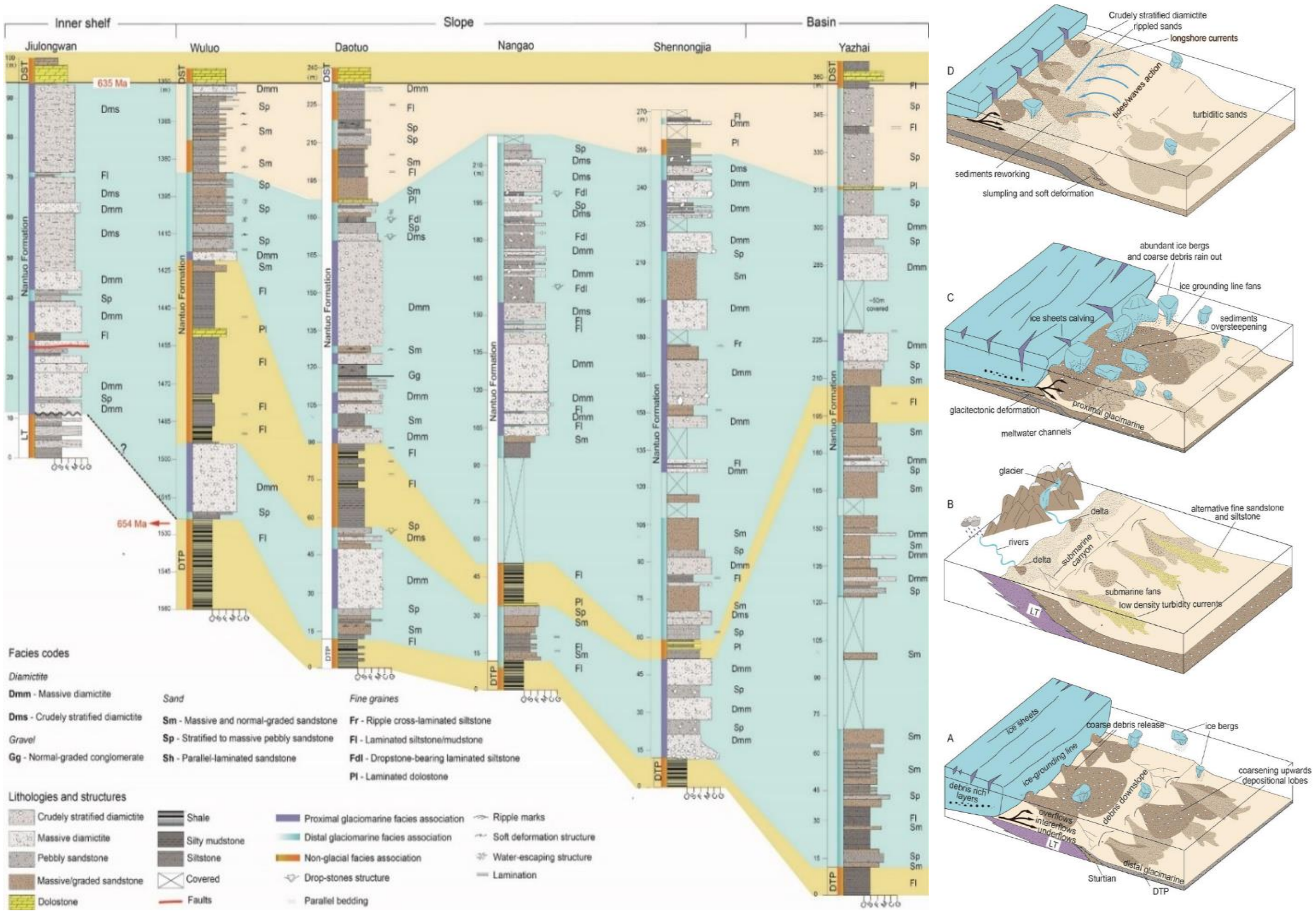


Hoffman, 2002

Cryogenian snowball Earth glaciation

Ediacaran glaciation

Challenging the snowball Earth model



- **Stage 4：** silt-fine sandstone: The meltdown of glaciation
- **Stage 3：** coursing upward into a suite of diamictite: The second glacial episode
- **Stage 2：** fine siliciclastic deposition with carbonate layers: Non-glacial interval
- **Stage 1：** transition from Datangpo shale to Nantuo diamictite: The first glacial episode

Lang, 2018, *PR*

- **Dynamic glaciers in the Snowball Earth?**

Key issues of snowball Earth glaciation

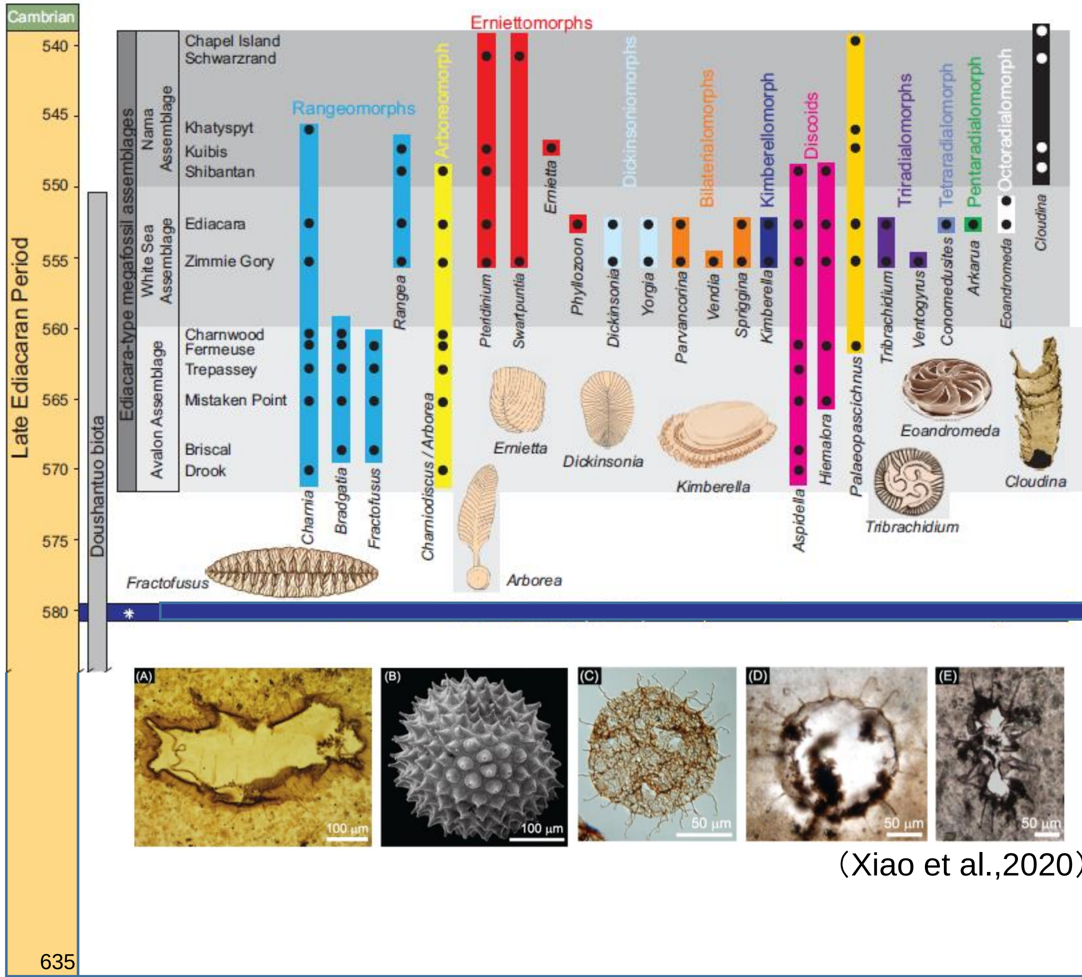
- **Onset:** Rodinia breakup → Continent-ocean configuration → Chemical weathering

- **Process:** Complete ice-coverage → Termination of atmosphere-ocean exchanges

- **Termination:** High atmospheric pCO_2 → Intense chemical weathering → Cap dolostone precipitation

Are there any biological processes involved in the Snowball Earth?

Ediacaran glaciations



Ediacaran-type megafossils

(Complex macroscopic life)

Shuram CIE

Gaskiers glaciation

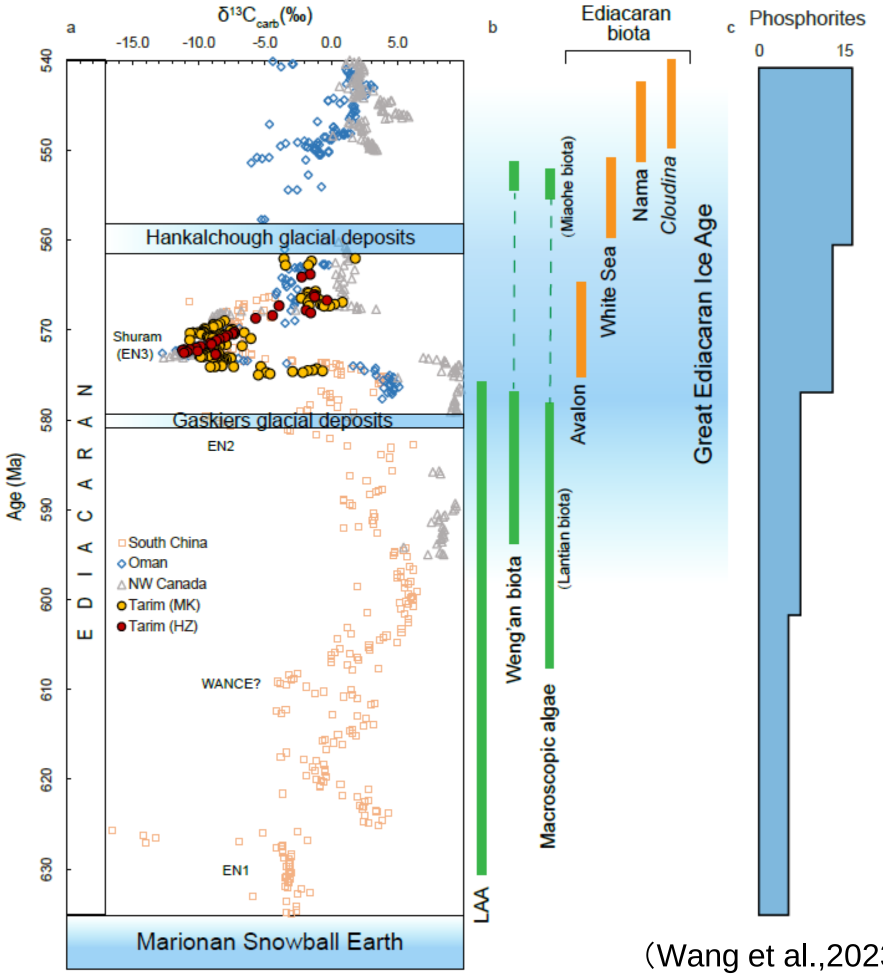
Microfossils (e.g., Acritarch)

（Xiao et al.,2020）

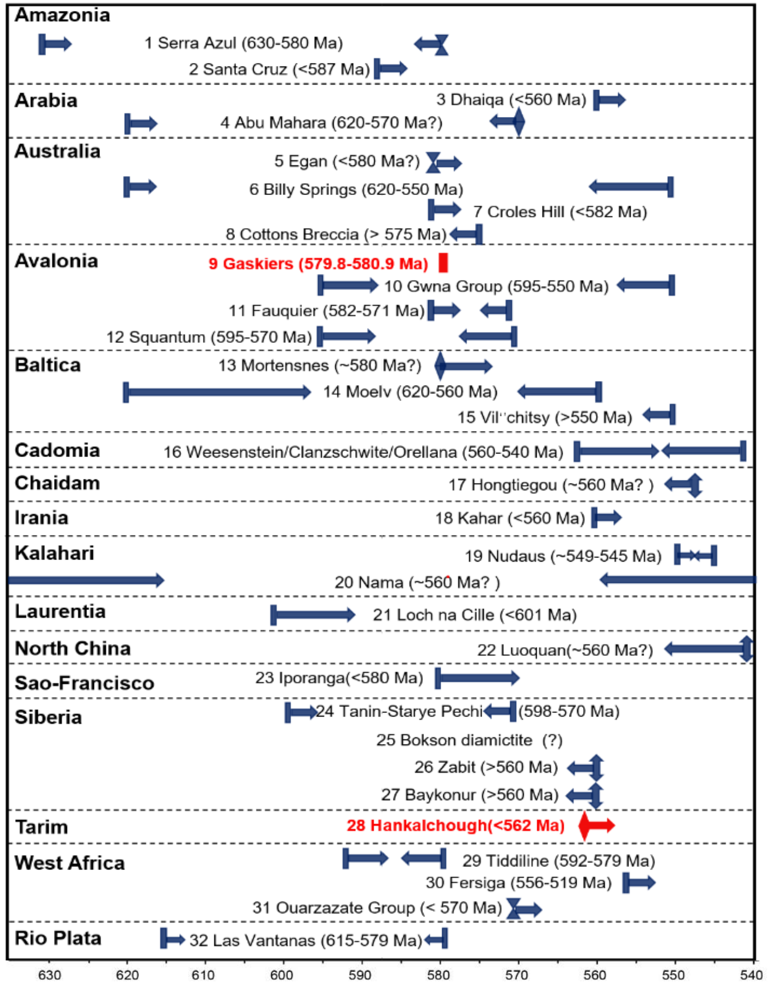
Cryogenian Snowball Earth

- ➢ A possible glacial fuse for the evolution of animals

Dilemma: Poor age constraints

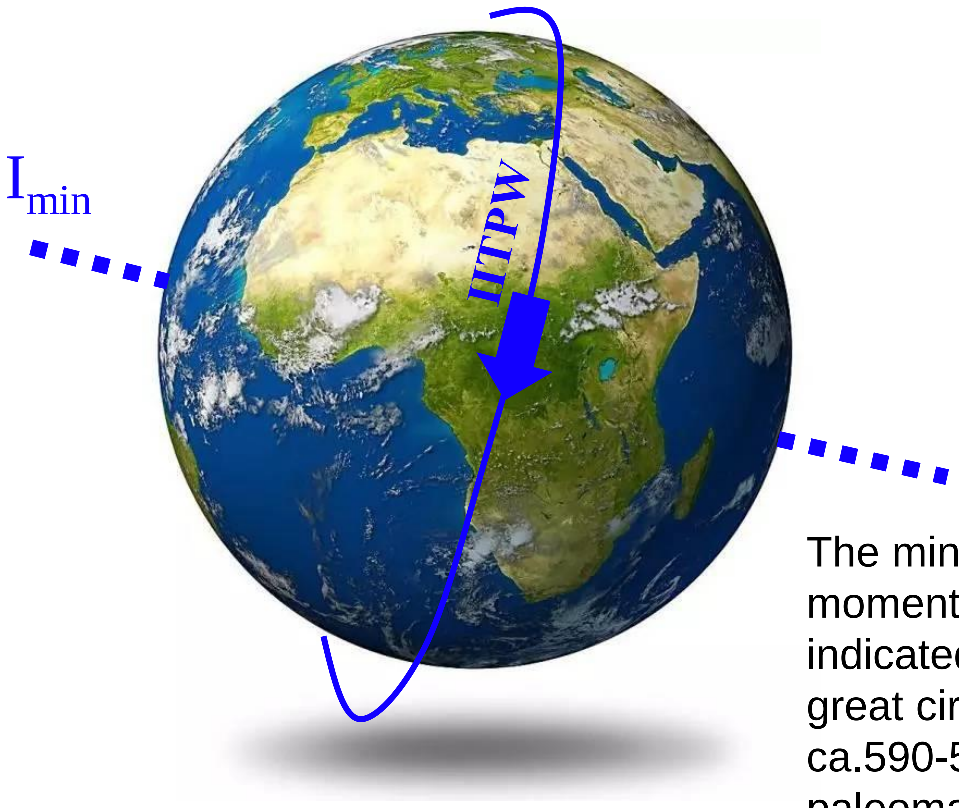


(Wang et al.,2023)

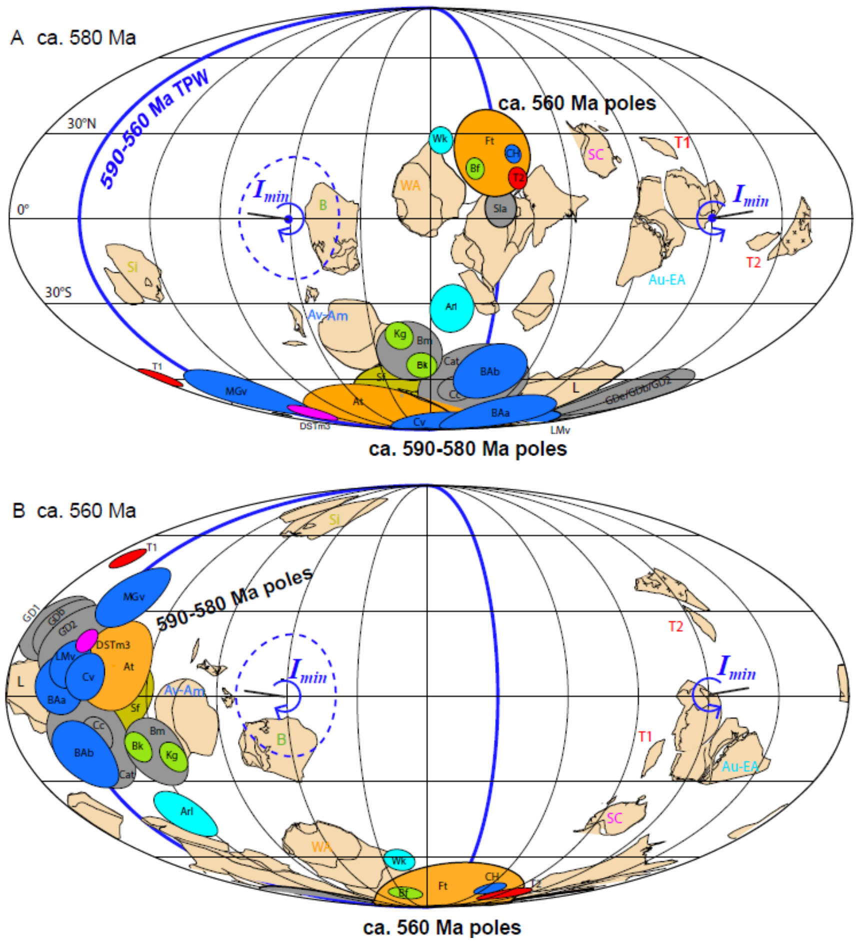


- ➢ Two episodes? multiple episodes? continuous?
- ➢ The ages and durations of other Ediacaran glaciations need to be further constrained.

True Polar Wander (~580 Ma-560 Ma)

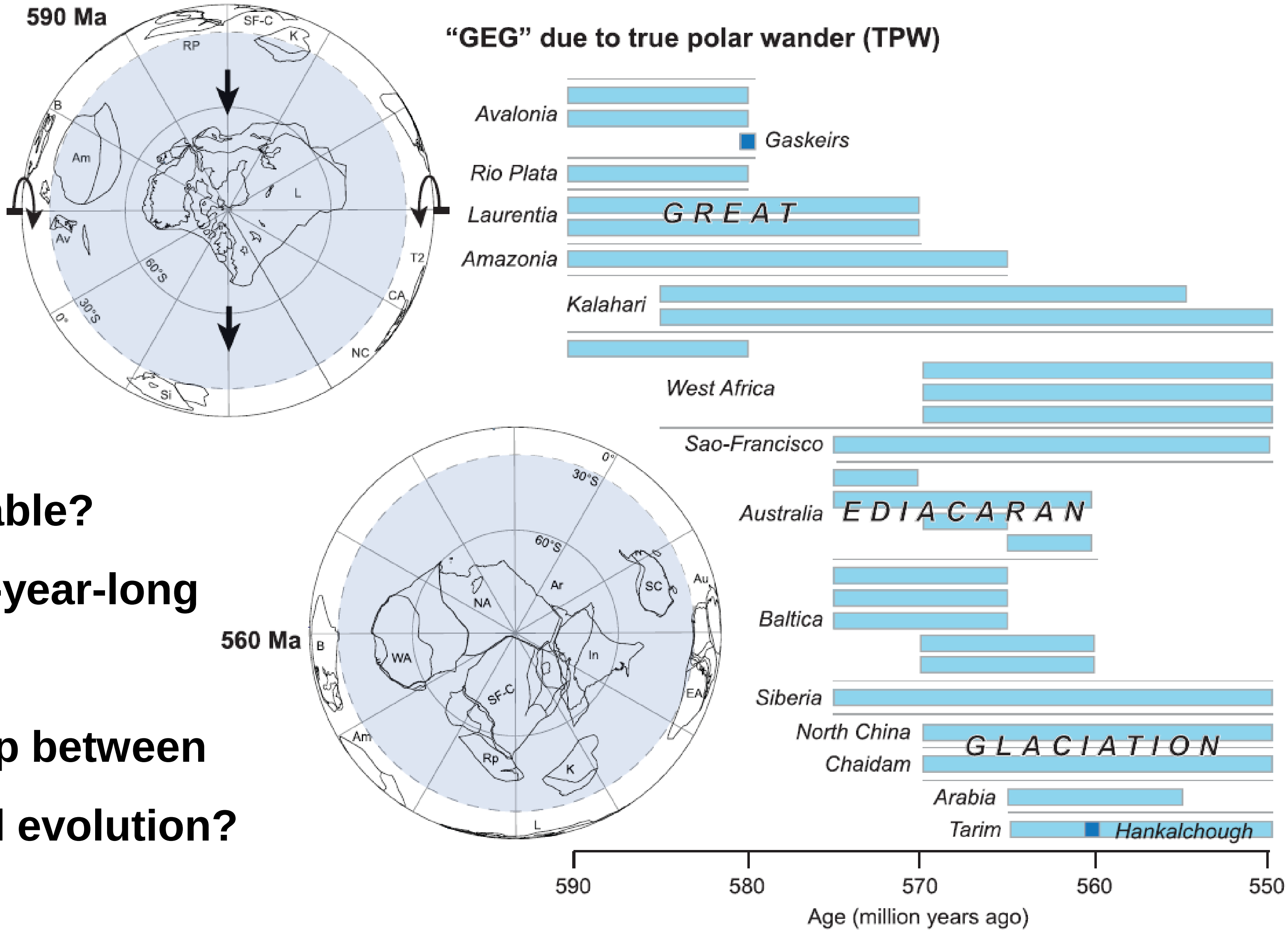


The minimum-inertial moment axis (I_{min}) is indicated as the pole to the great circle by fitting the ca.590-560 Ma paleomagnetic poles



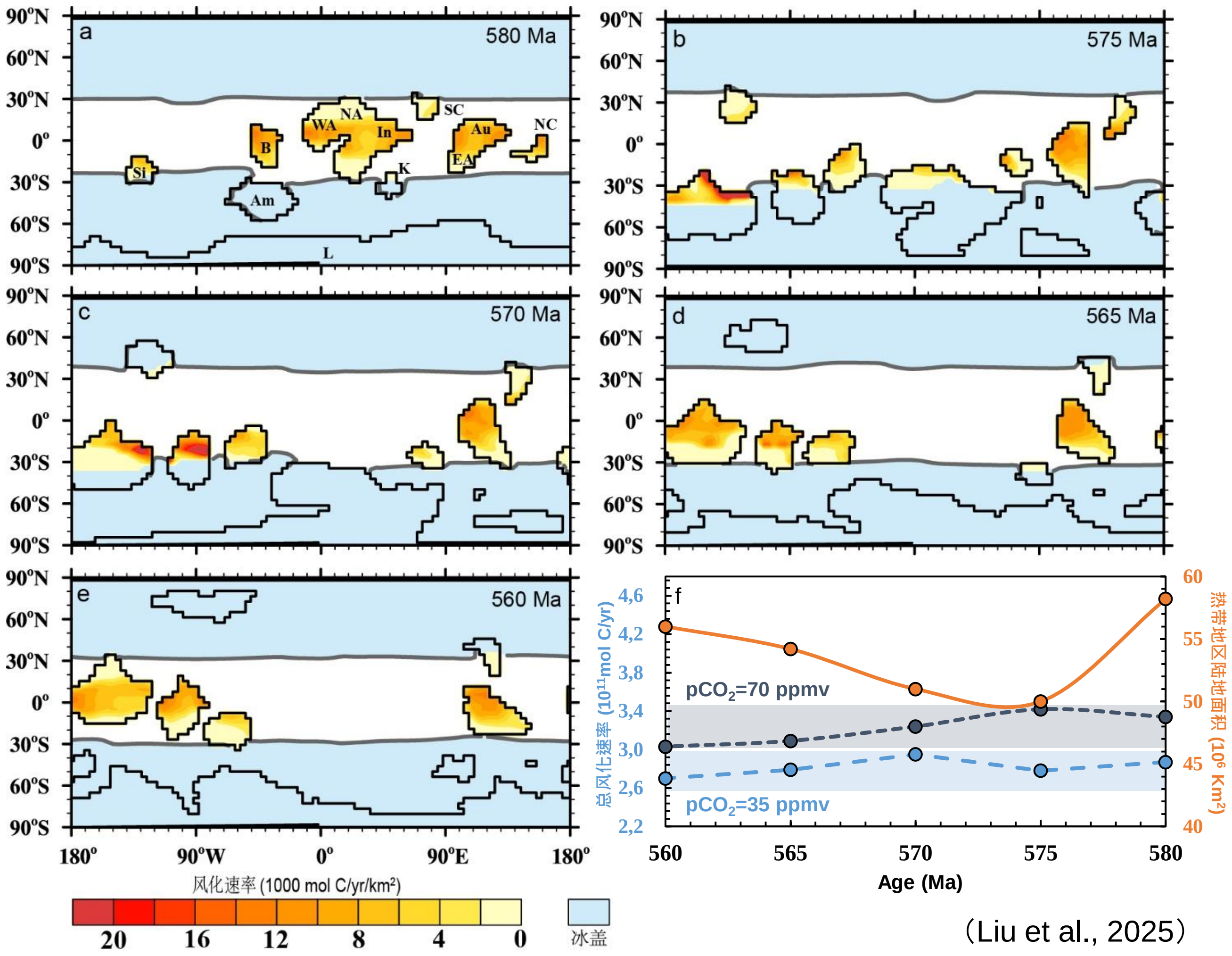
- Many blocks were moving much faster than them in theory of “plate drift”
- **IITPW**, i.e., the entire crust and mantle rotated ~90◦ about the liquid outer core to align Earth’s maximum moment of inertial (Imax) with the spin axis

A Great late Ediacaran ice age (GEG)



- **Is this climate state stable?**
- **How did the 20 million-year-long ice age persist?**
- **What is the relationship between ice ages and biological evolution?**

Maintenance of the great late Ediacaran ice age

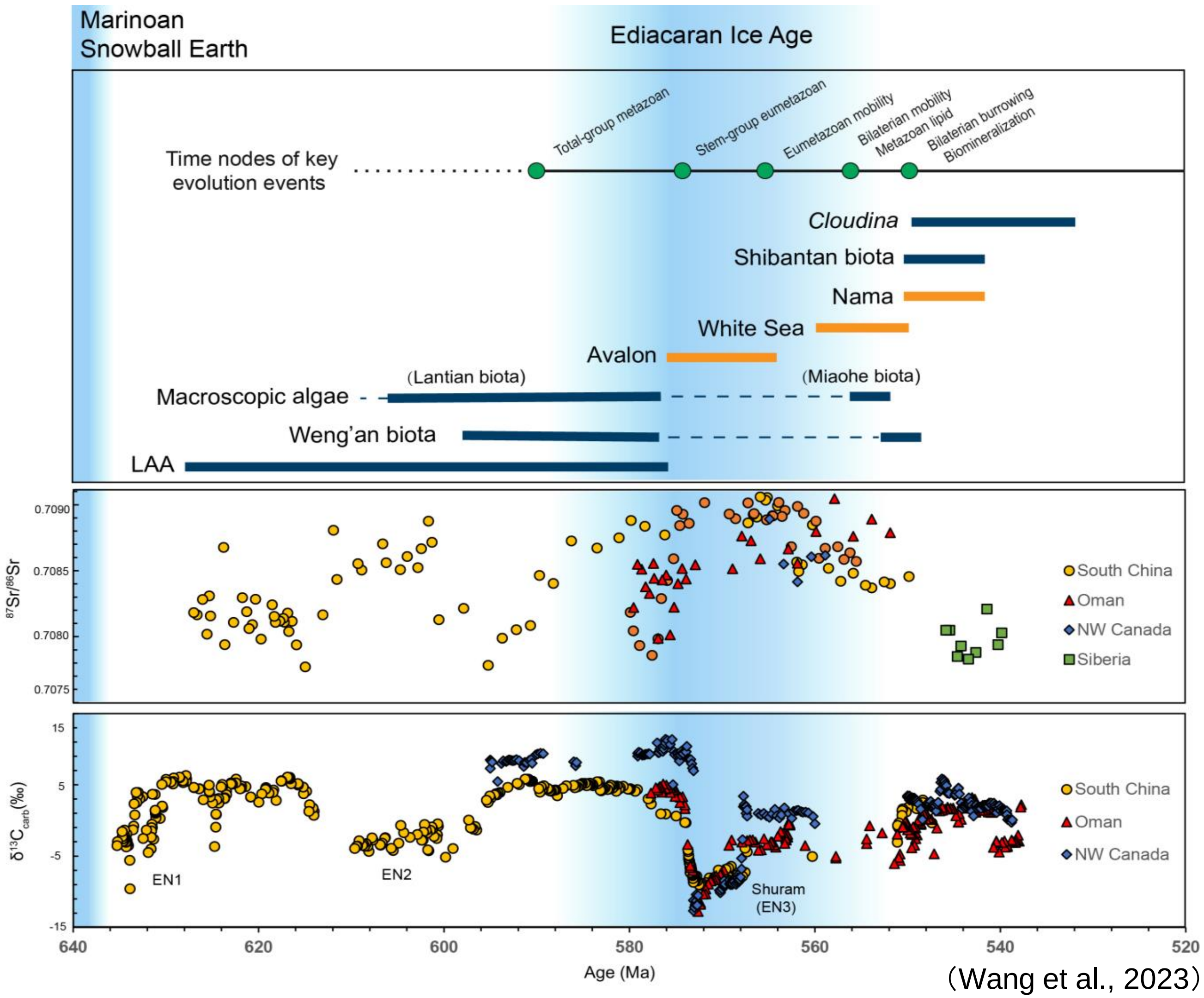


(Liu et al., 2025)

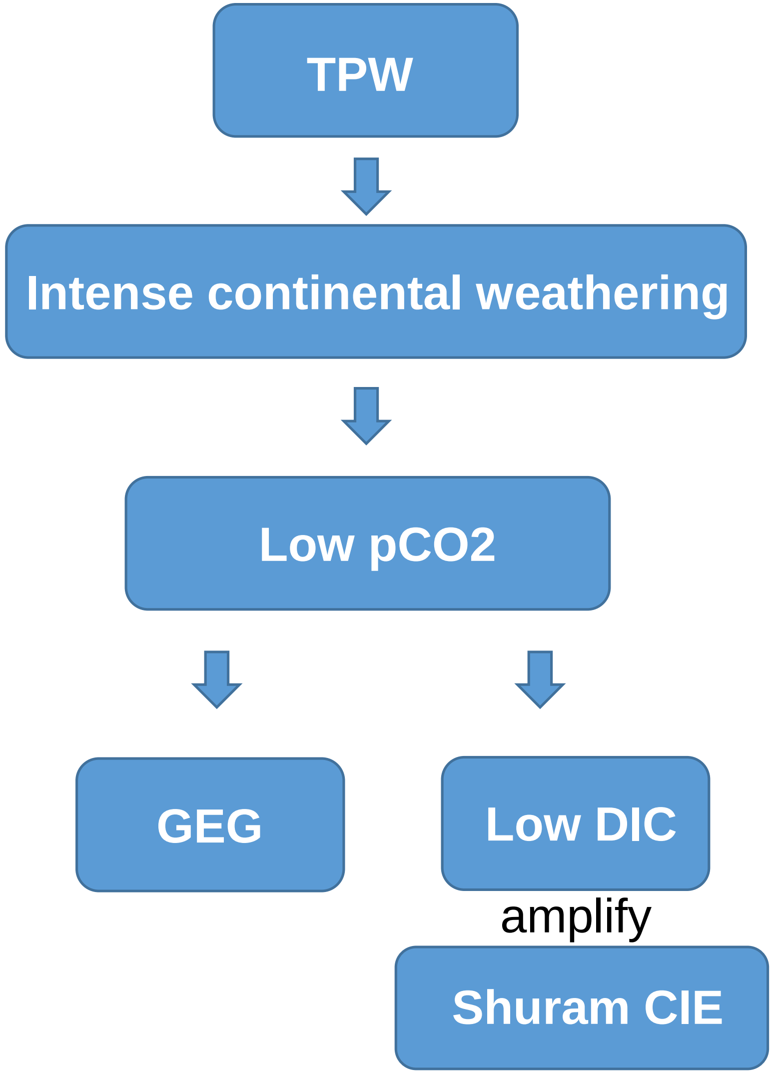
- Intensity of continental silicate weathering could be **enhanced** by exposing more chemically reactive rocks from higher glaciated latitudes

- the newly exposed regions with **high weatherability** could increase weathering rate to maintain uninterrupted late Ediacaran ice age, especially during 575–565Ma。

Maintenance of the great late Ediacaran ice age



(Wang et al., 2023)



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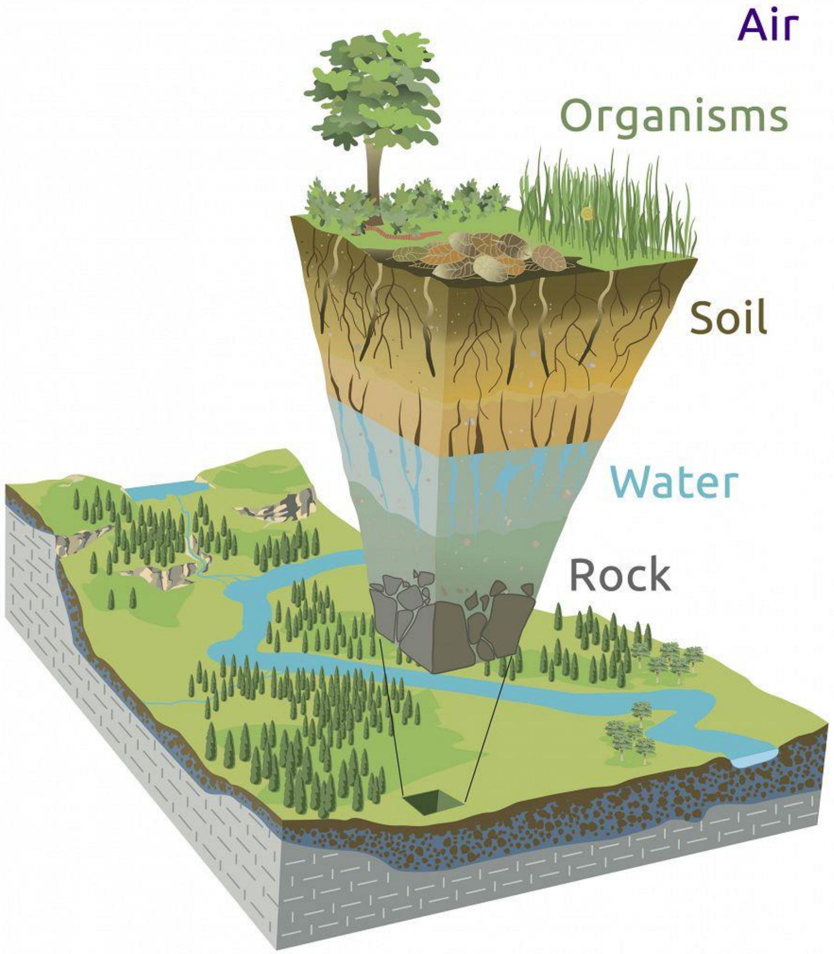
Mid-Paleozoic terrestralization

- ✓ Land plant is the **key component** in the Earth system, and the colonization of continents and **formation of terrestrial ecosystem** were the consequence of long term evolution of Earth system
- ✓ The origin and diversification of vascular land plant in late Paleozoic was the **milestone** of Earth system evolution
- ✓ Directly caused the dramatic changes in environments (e.g. glaciation and oxygenation) and associated with the accumulations of resources (e.g., coal, bauxite)



Chorover et al., 2007; Richardson, 2017

Objectives

- Based on the fossil records of the South China and North China blocks to reveal the spatial-temporal distribution and evolutionary pattern of early land plants

  → **Vegetation characters of different stages in plant terrestrialization**

- To restore the land-sea sedimentary systems through Silurian to Carboniferous

  → **The relationship between paleogeography and vegetation evolution**

- The element and mass transportations in different vegetation condition

  → **Earth System model of different vegetation stages**

- Devonian-Carboniferous coals, bauxites, and coal-related metals

  → **Mechanism of plant evolution driving ore formation**

The history of terrestralization

✓ **Six vegetation stages**

1) The prologue of radiation of vascular plants in Silurian;

2) The origination and radiation of extant clades in Early Devonian;

3) The first appearance of forests in Middle Devonian;

4) The origination of seed plants in Late Devonian;

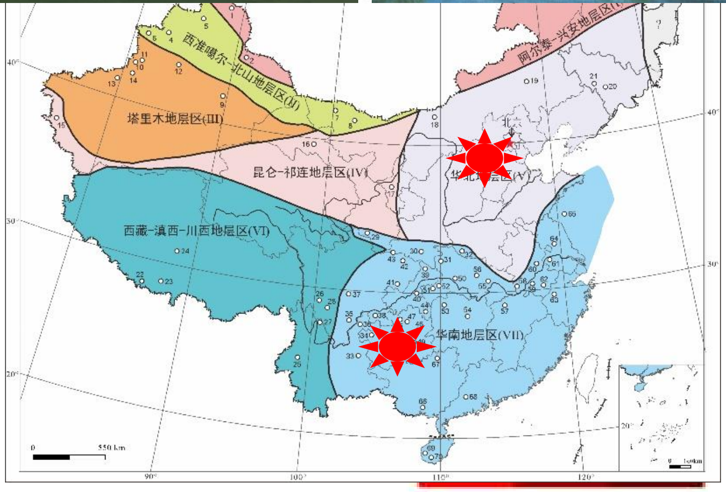
5) The development of proto-Cathaysian flora in Early Carboniferous;

6) The development of Cathaysian flora in Late Carboniferous and Permian

✓ Plants; paleosols; coals; and bauxites

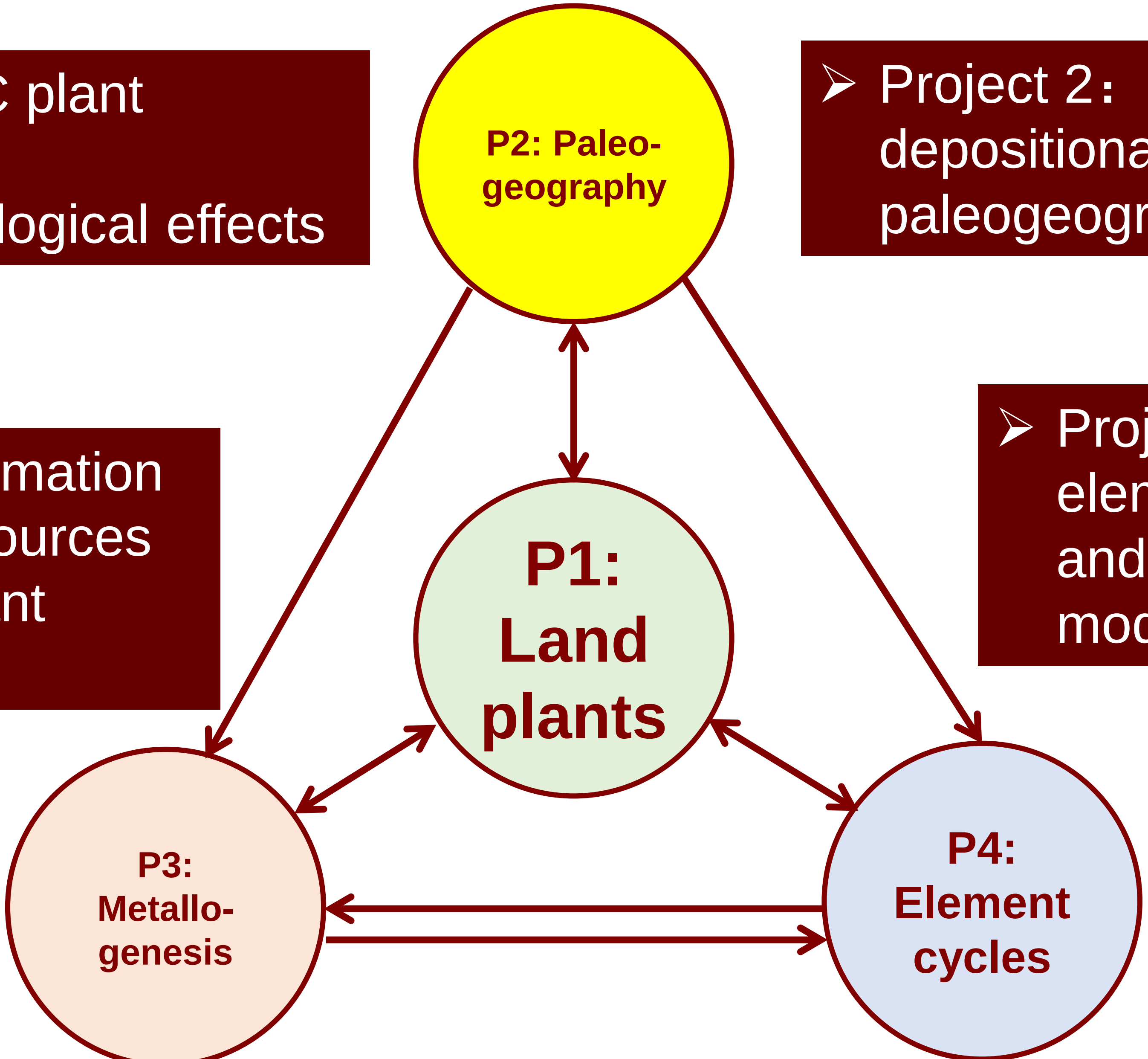
石炭纪	宾夕法尼亚亚纪	格舍尔期
		卡西莫夫期
		莫斯科期
		巴什基尔期
	密西西比亚纪	谢尔普霍夫期
		维宪期
		杜内期
泥盆纪		晚泥盆世
		中泥盆世
		早泥盆世
志留纪		普里道利世
		罗德洛世
		温洛克世
		兰多维列世

华夏植物群发育期
前华夏植物群发育期
种子植物首现期
森林首现期
支系爆发期
维管植物辐射序幕期



Projects

- Project 1： S-C plant evolution and biogeomorphological effects
- Project 2： Land-sea depositional systems and paleogeographic evolution
- Project 3： Formation of multiple resources induced by plant evolution
- Project 4： Mass and element transportation and Earth System modelling



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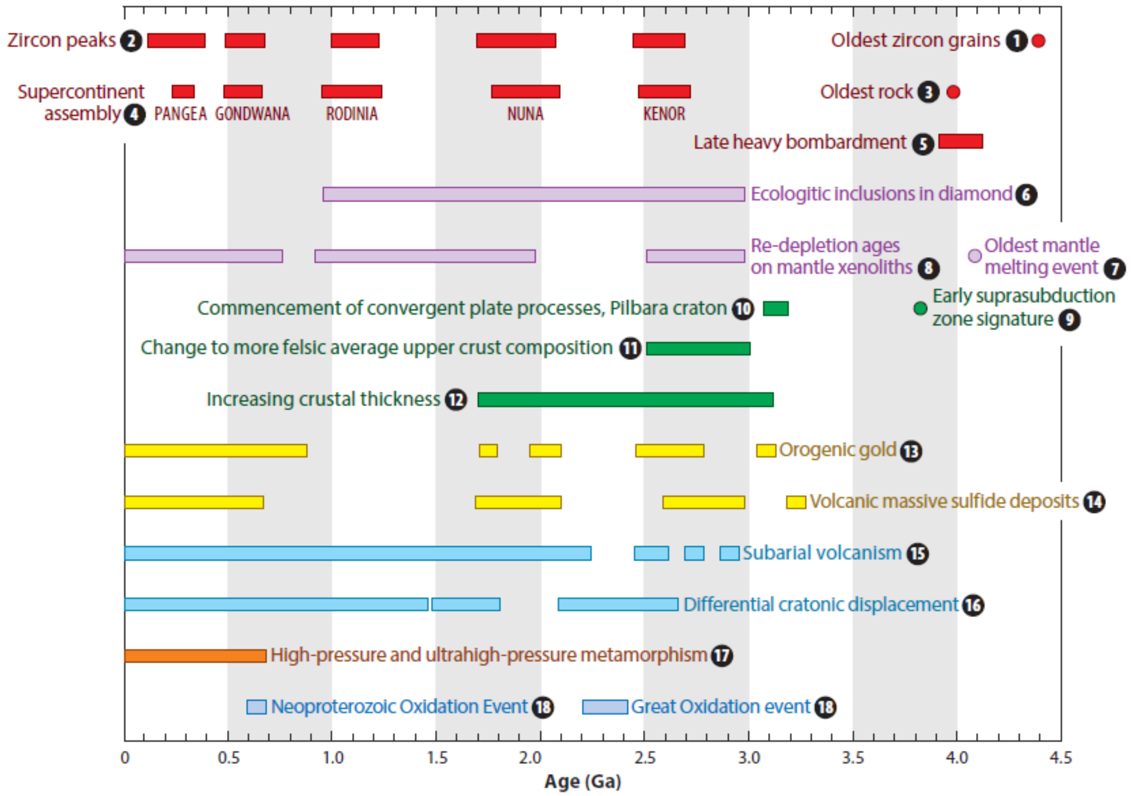
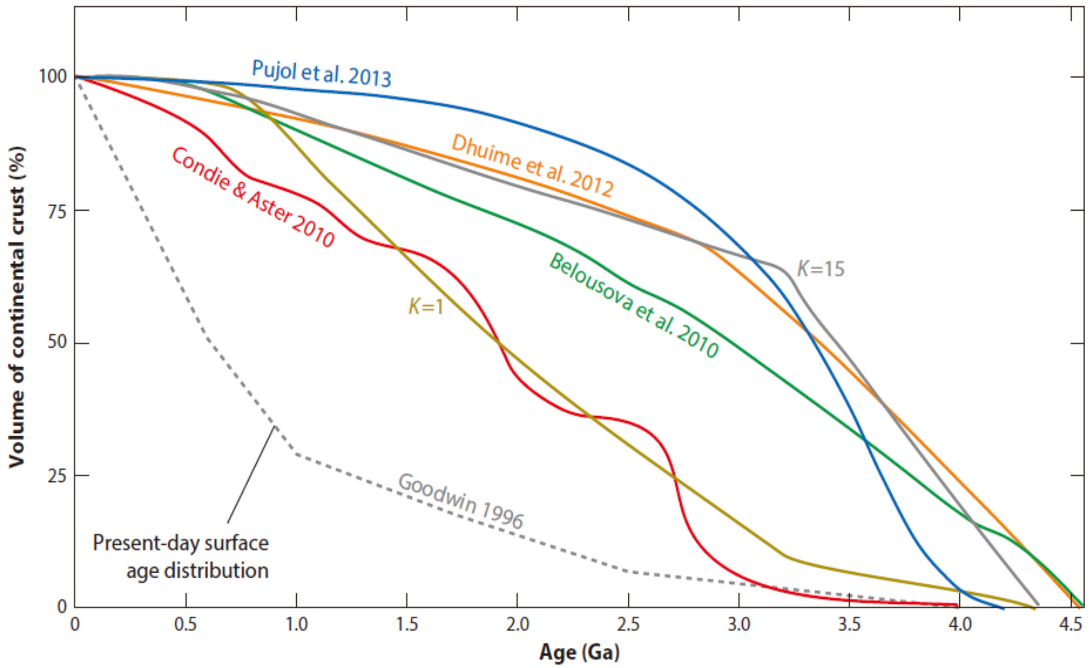
When did the first continental crust form?

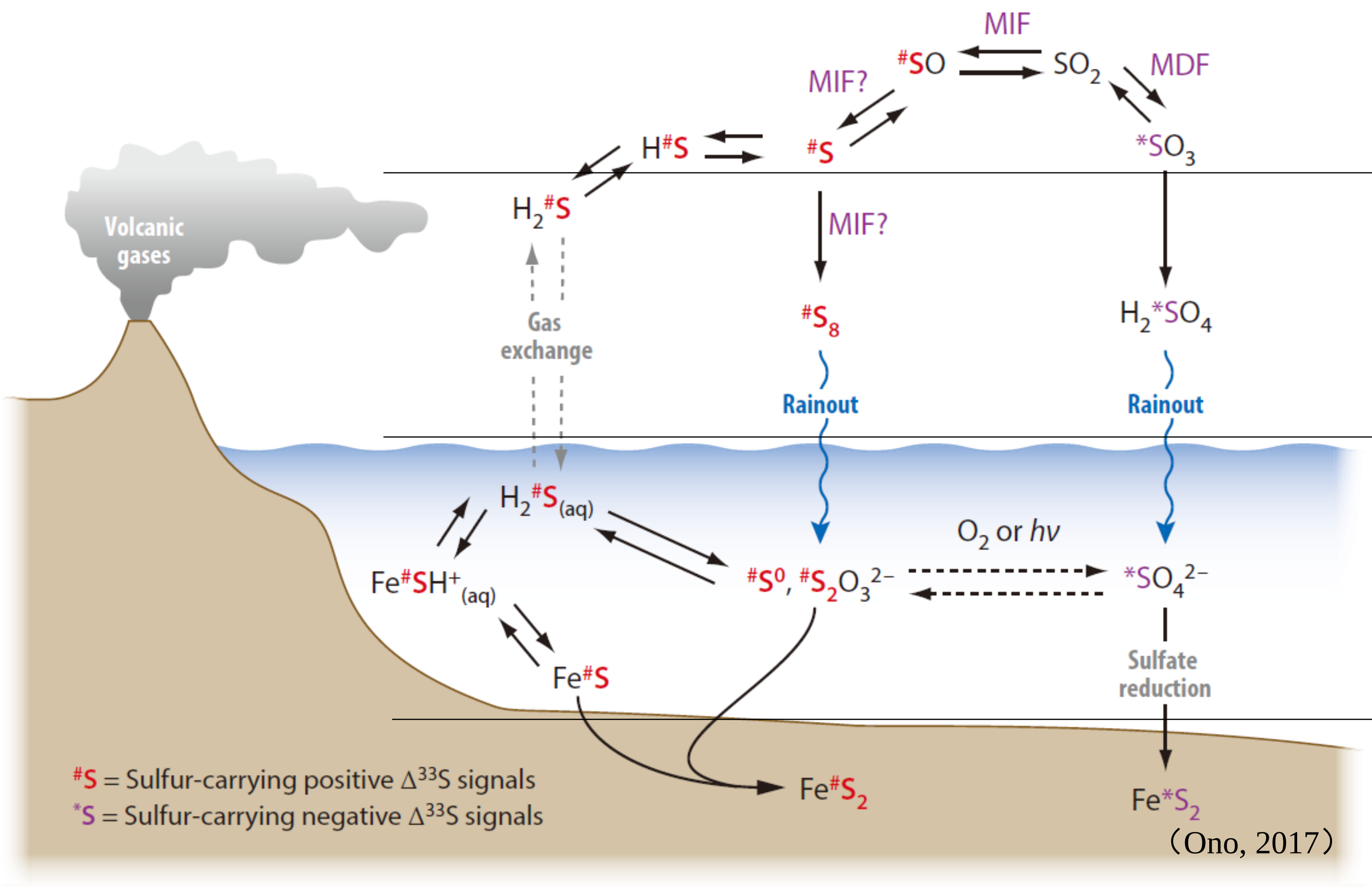




（Hawkesworth et al., 2017）

- **The direct evidence for subaerial volcanism can only be traced back no earlier than ~3.0 Ga**

What can S-MIF signals tell us?



(Ono, 2017)

✓ **S-MIF generation:**

Unknown, +15 ‰?

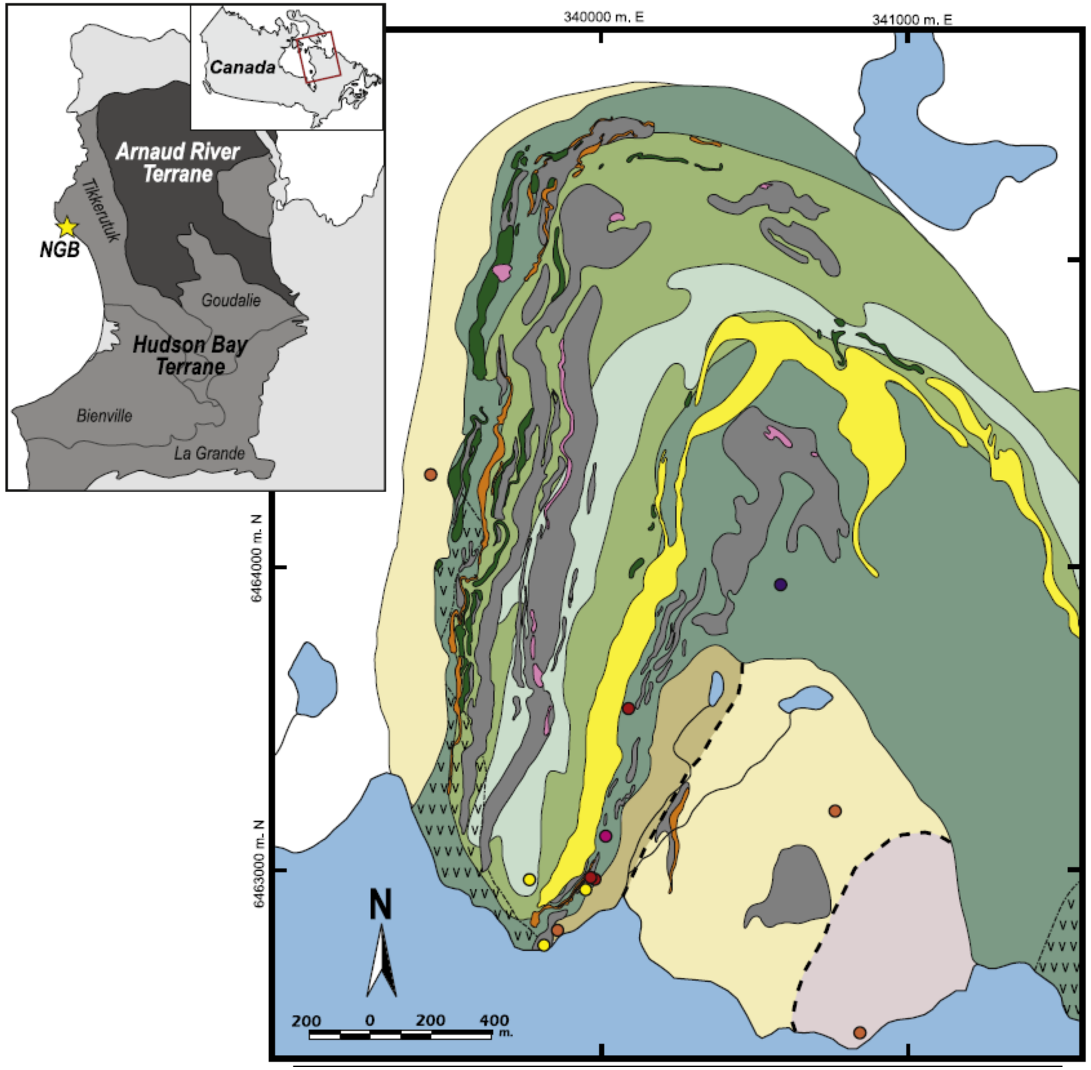
✓ **Transfer in atmosphere**

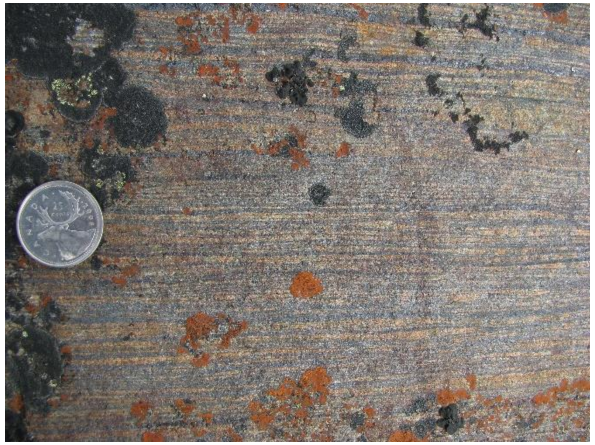
CH_4、SO_2/H_2S

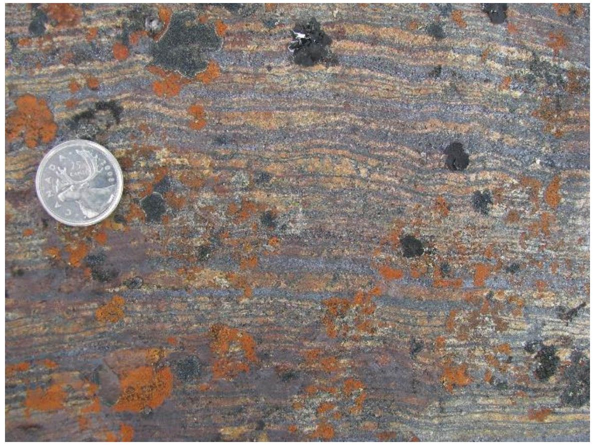
✓ **Preservation in ocean**

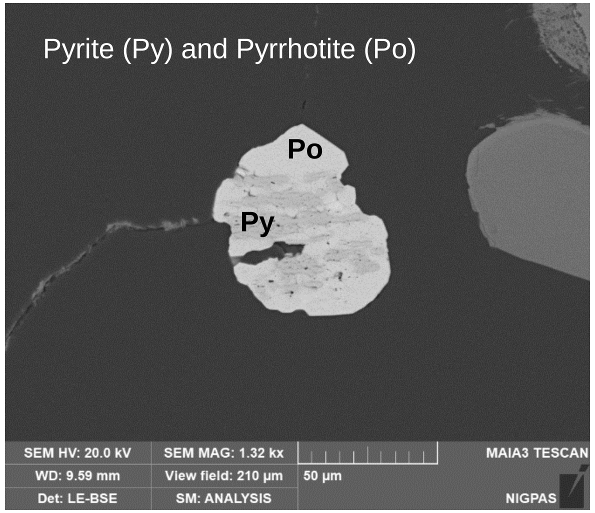
Mixing with MDF H_2S or SO_4^{2-}

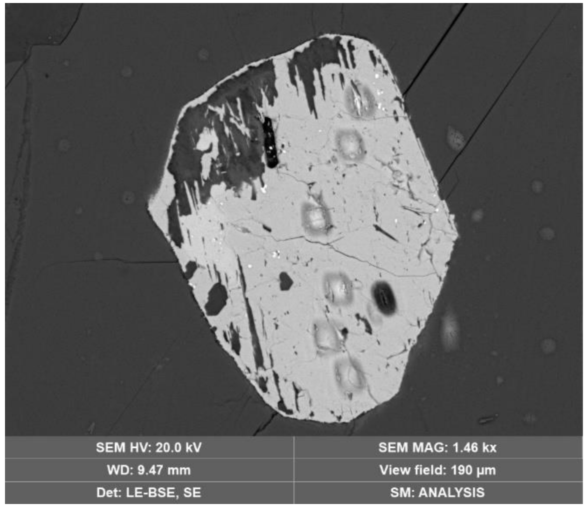
The oldest rock: BIF in NSB



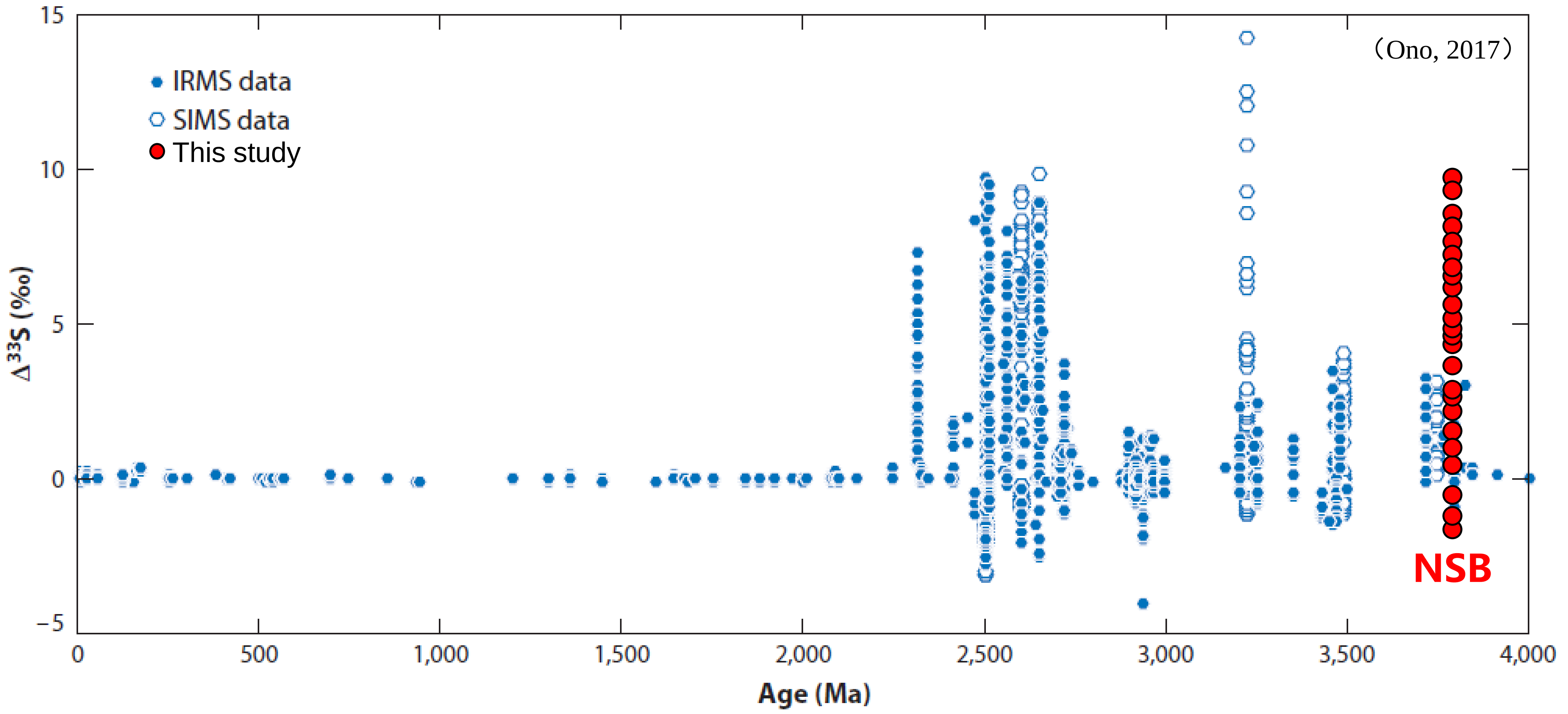








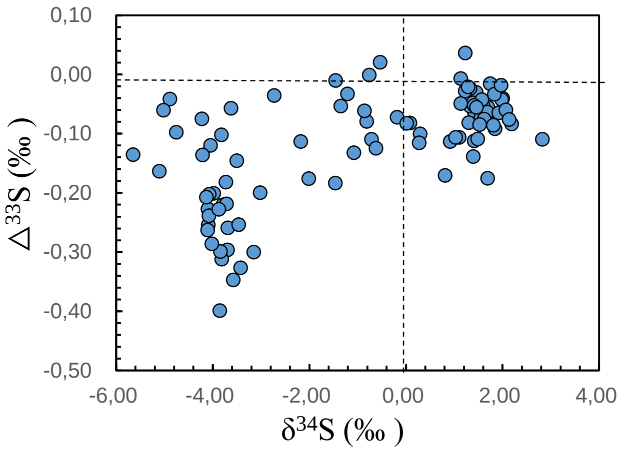
Large Magnitude S-MIF Signals in NSB

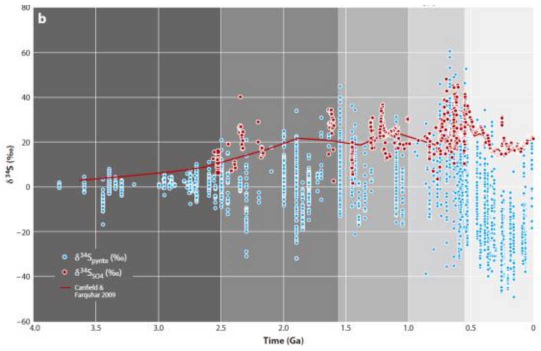


- The large magnitude S-MIF signal only occur in late Neoarchean to early Palaeoproterozoic (2.8-2.4 Ga) and sporadically in Mesoarchean (at ~3.4 Ga)

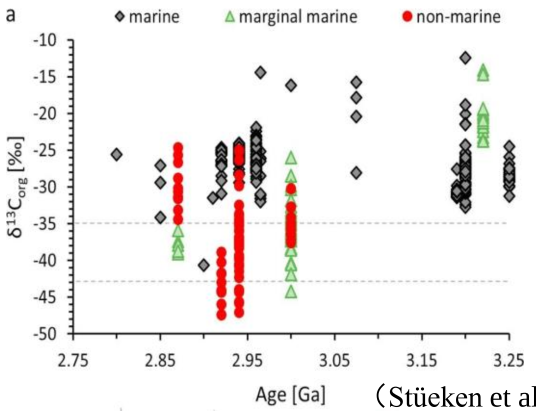
What can S-MIF signals tell us?

1. Mixing?

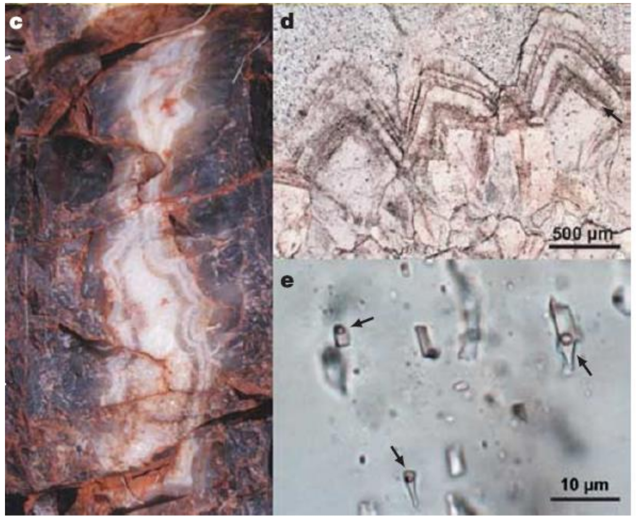




（Fike et al., 2015）



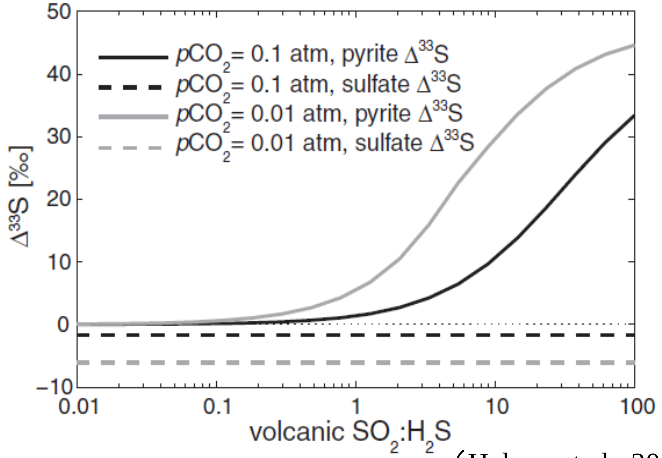
（Stüeken et al., 2006）



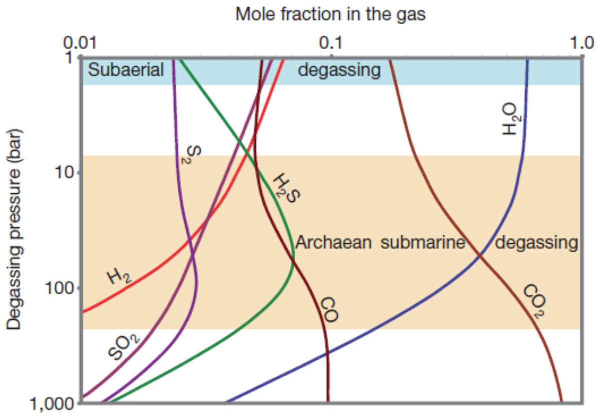
（Ueno et al., 2006）

2. Methane? (~3.5 Ga)

3. SO_2/H_2S ratios?

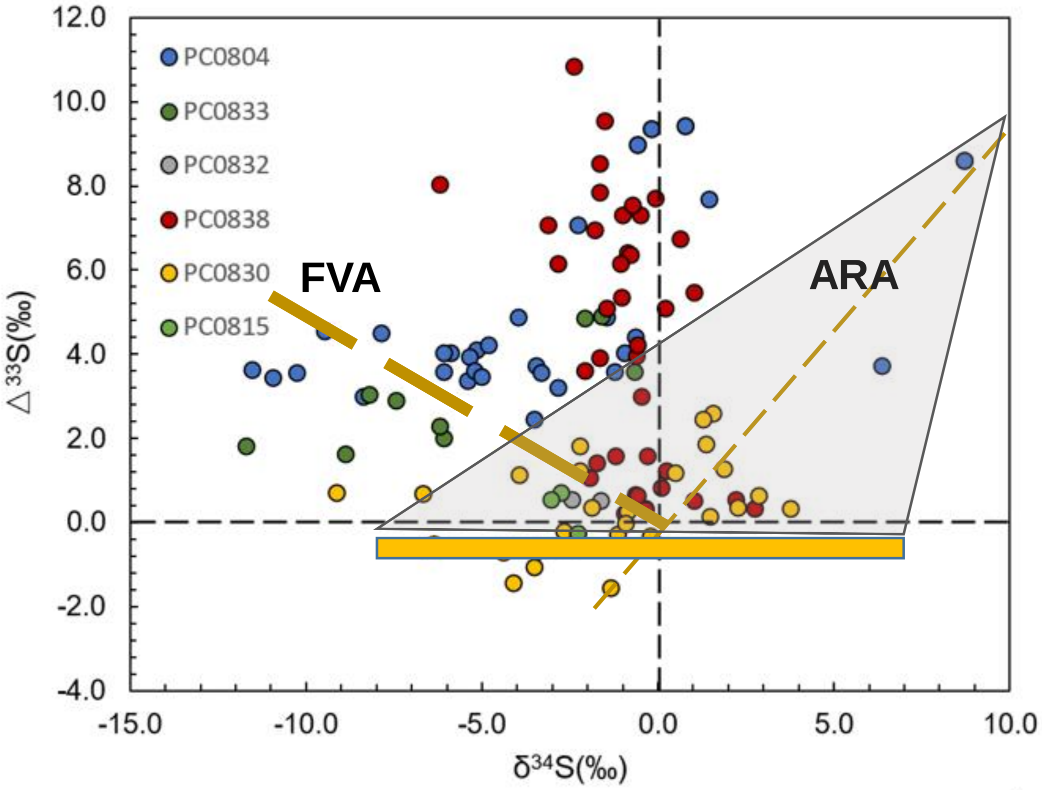


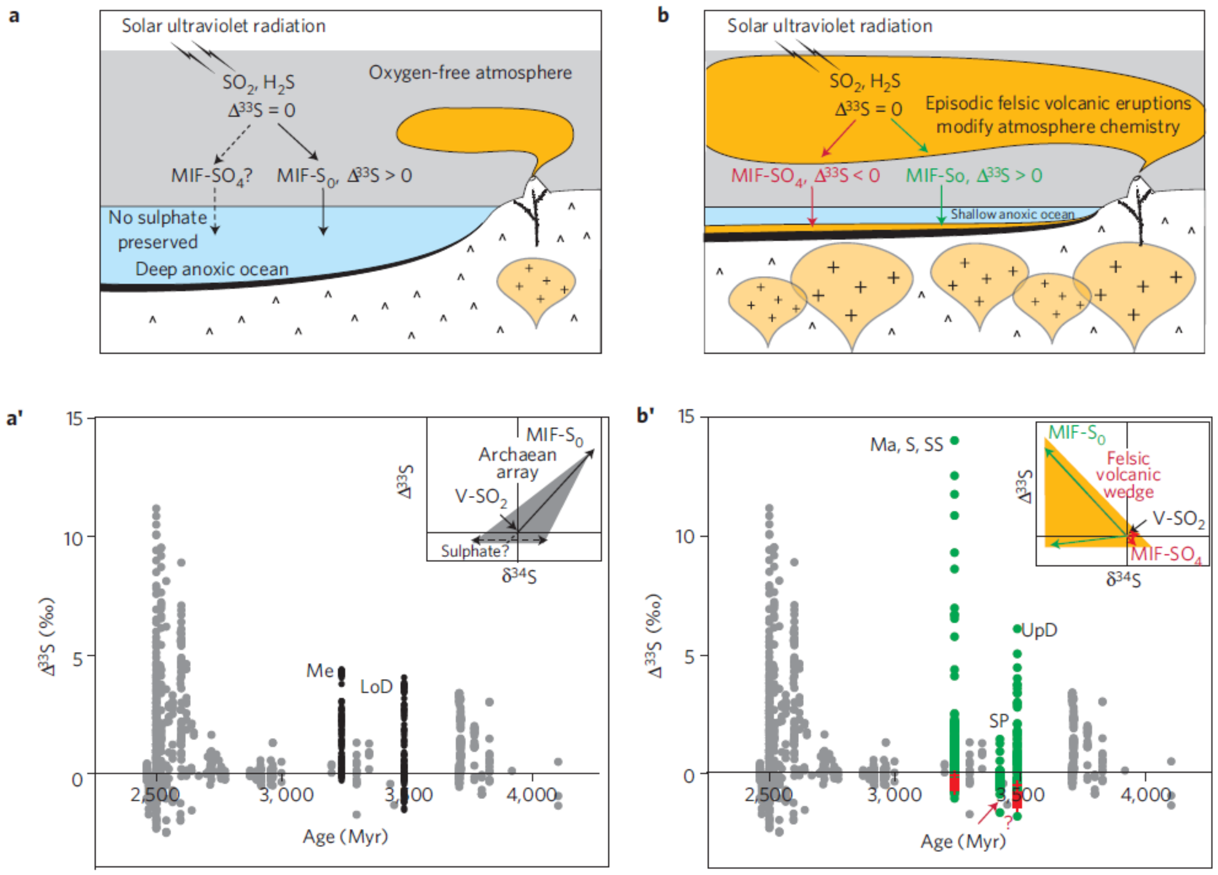
（Halevy et al., 2010）



（Gaillard et al., 2011）

Felsic Volcanisms Eruptions？





- ARA: Archean Reference Array
- FVA: Felsic volcanic array

（Philippot et al., 2012）

The early evolution of Planetary Earth

- We find Large magnitude S-MIF signals (~10‰) in >3.7 Ga BIFs;
- Volcanic degassing with high SO_2/H_2S ratios would provide one solution

  → the appearance of thick continental crust or subaerial volcanic activity in the early Earth



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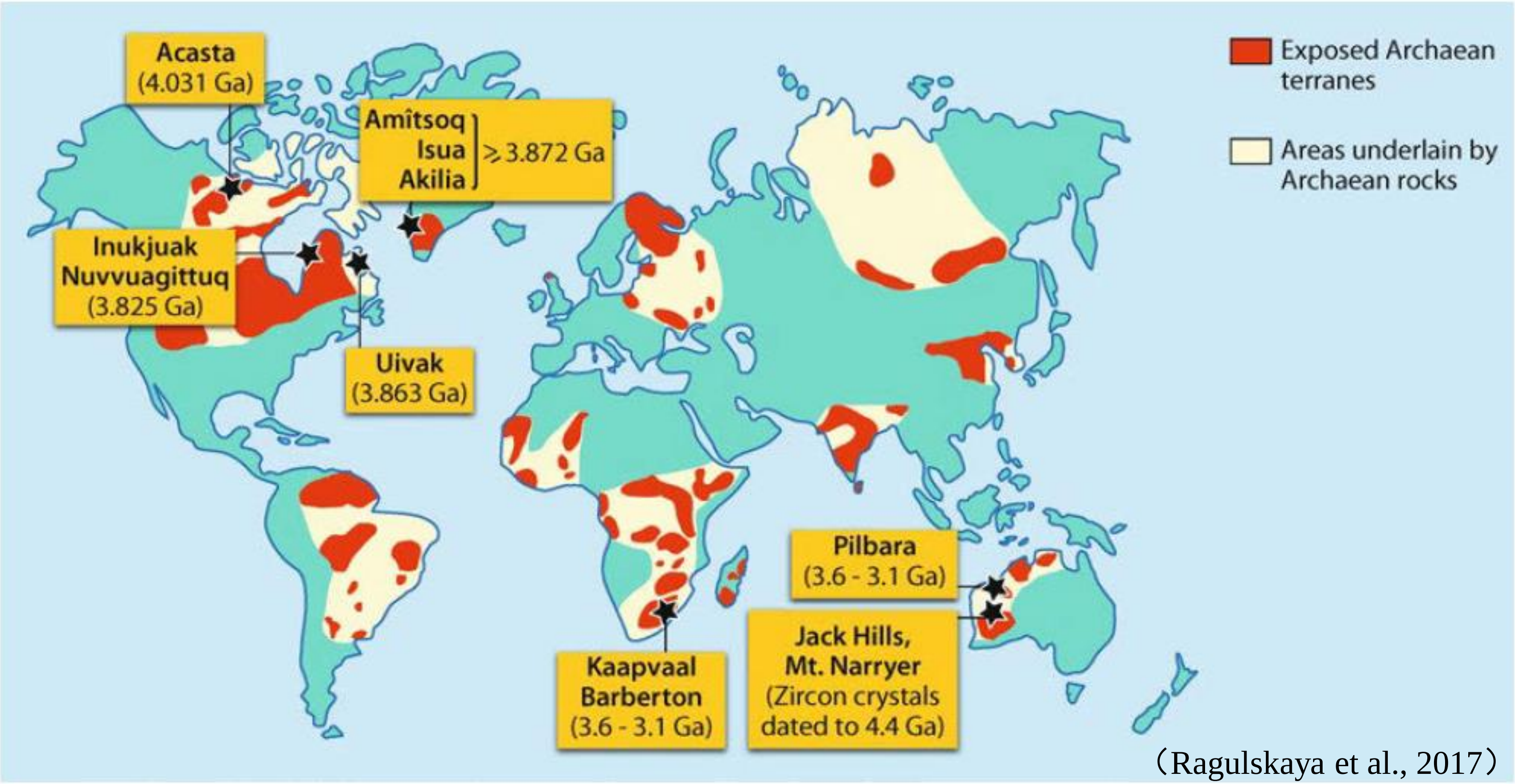
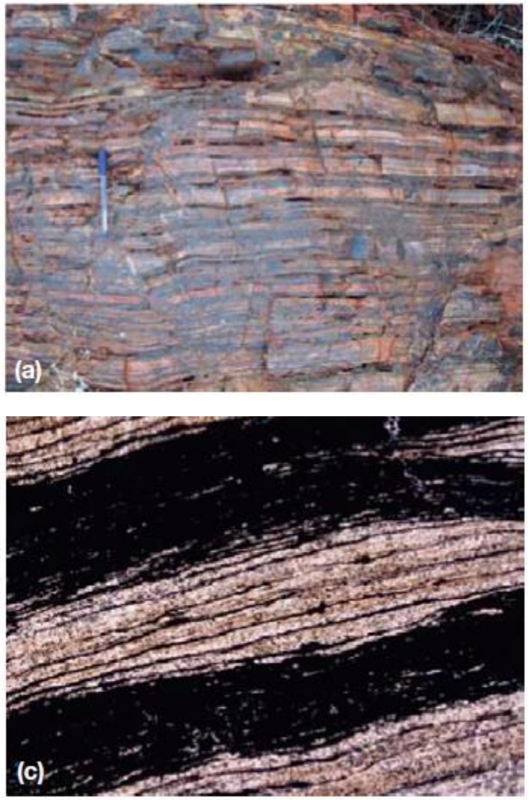
The oldest sedimentary rocks：Banded Iron Formation



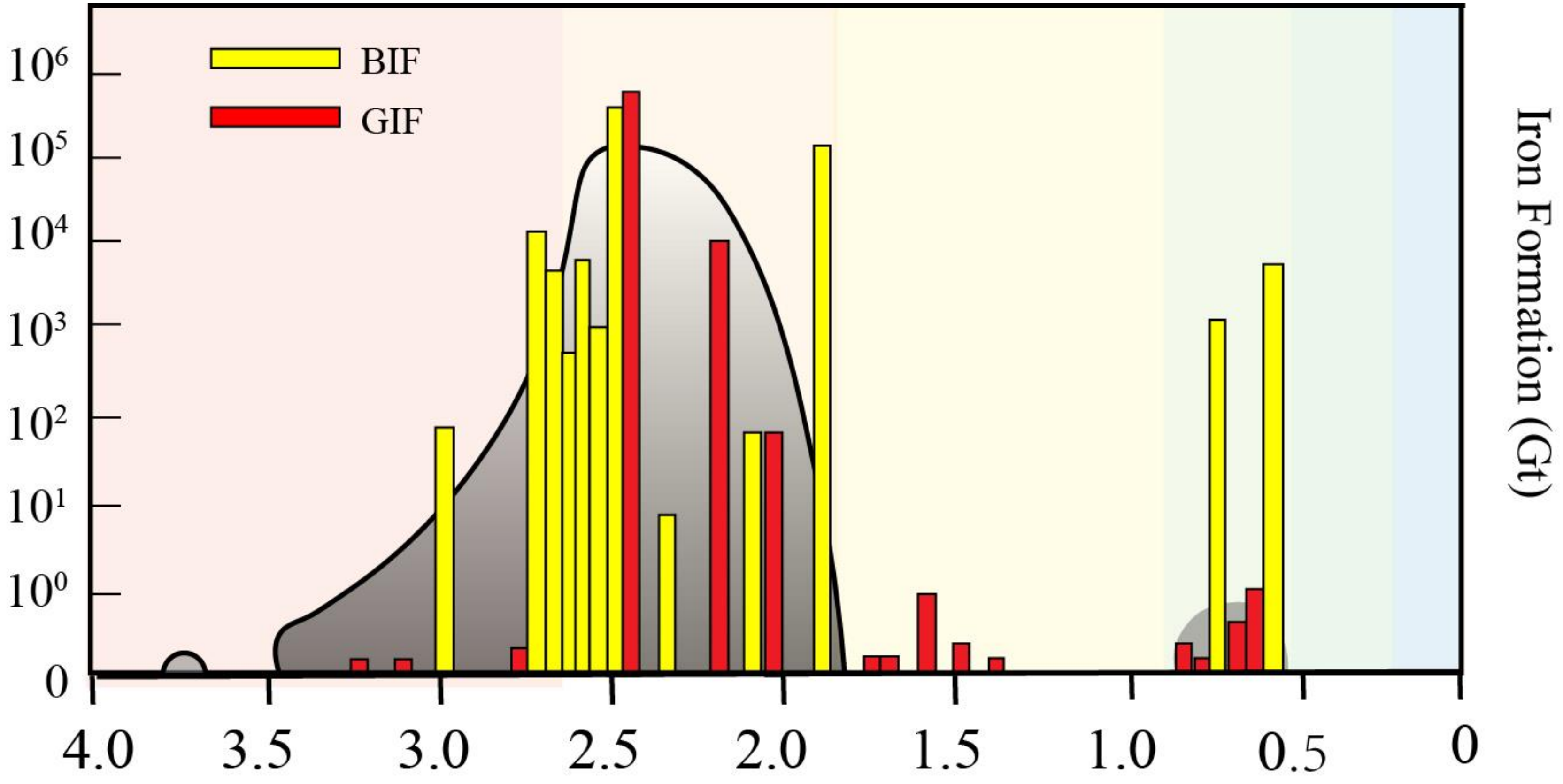
（Ragulskaya et al., 2017）



(Bekker et al., 2017)

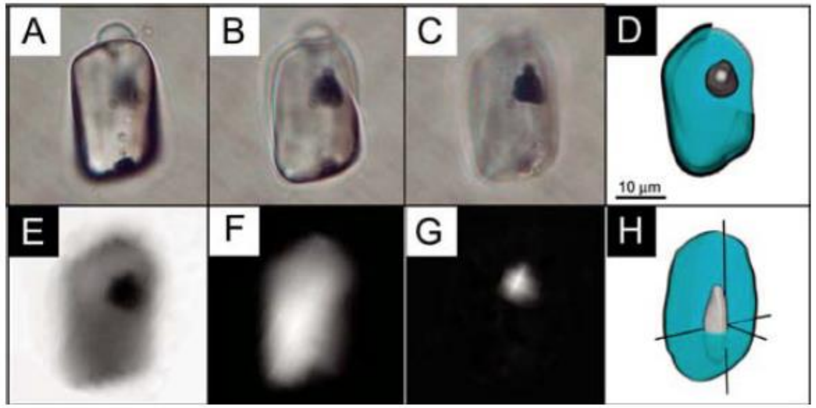
- **Banded iron formations (BIFs), consisting of rhythmic Fe-rich and Si-rich mm- to cm-thick laminae, are the Archean and Paleoproterozoic landmarks**

Secular Distribution of Banded Iron Formation

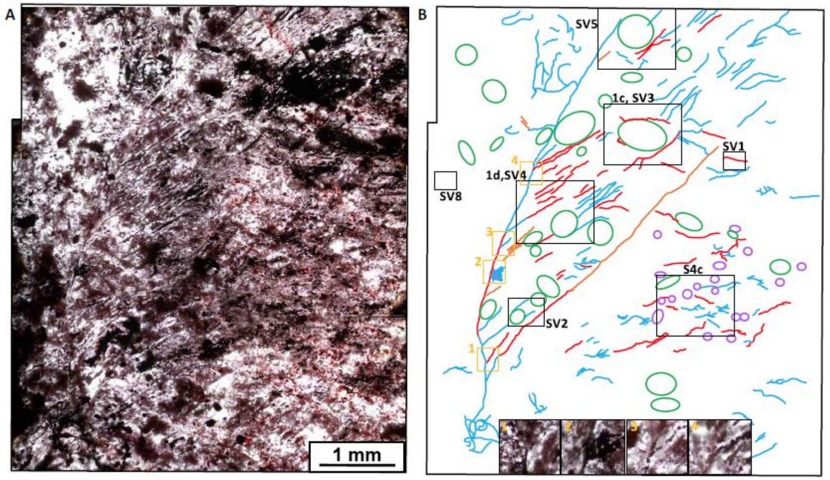


- BIF first occurred in 3.8 billion years ago (Ga), reached the maximum at about 2.5 Ga, and disappeared from the rock record since 1.8 Ga, except a brief window during the Neoproterozoic Snowball Earth (0.72-0.63 Ga).

Origin of rhythmic laminae in BIFs (Biosignature)？

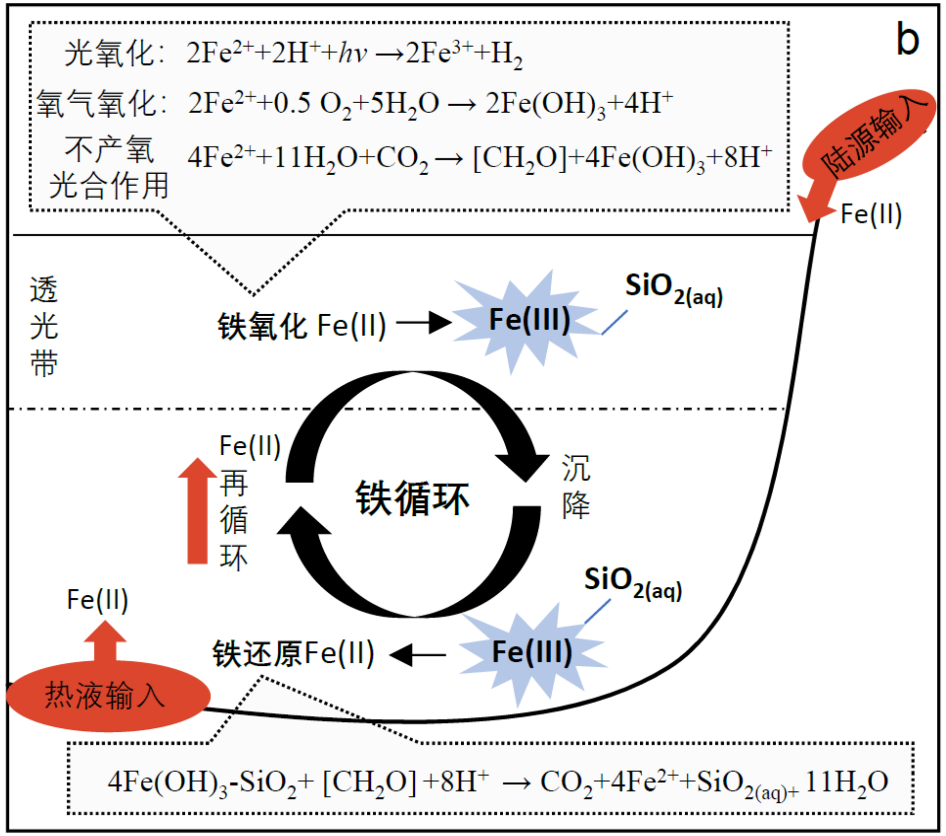


(Mckeegan et al., 2007)



(Dominic., et al., 2021)

Records of the early microorganisms

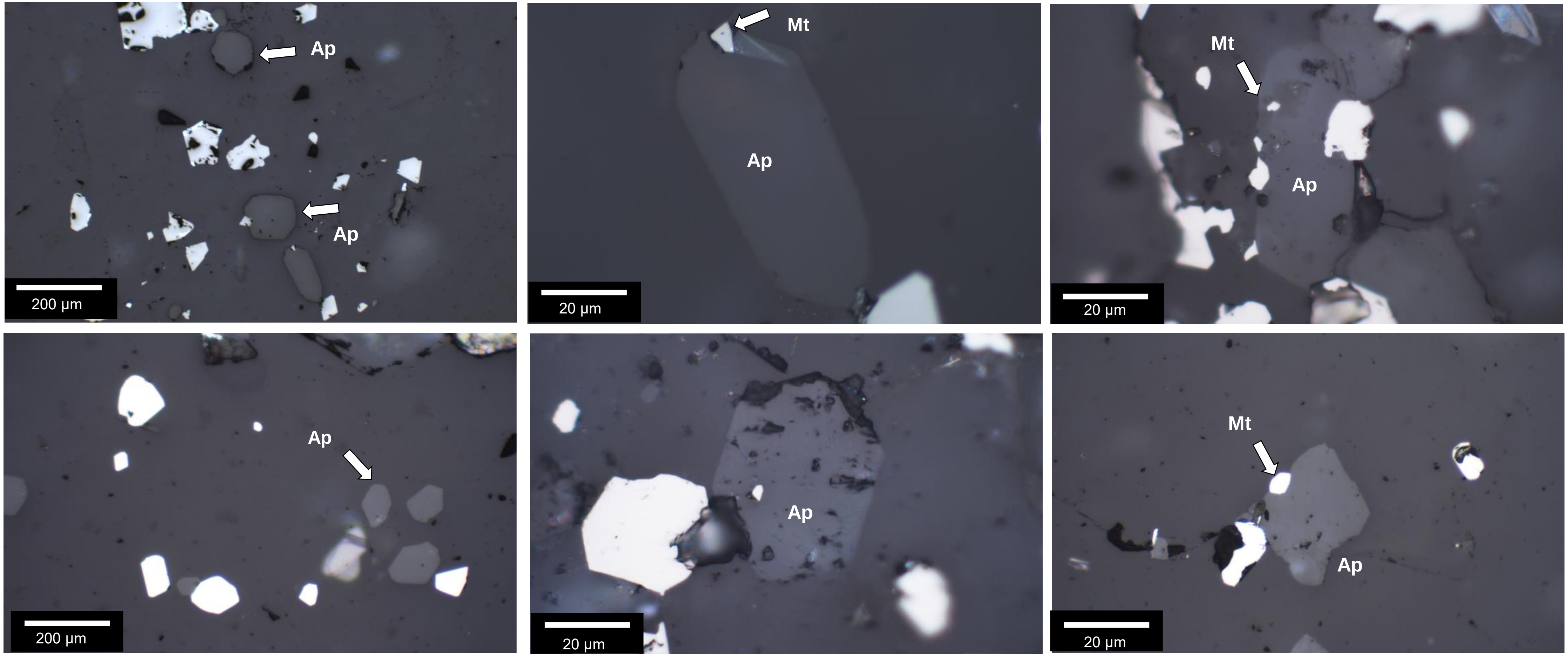


(Wang., et al., 2023)

What role do microorganisms play ?

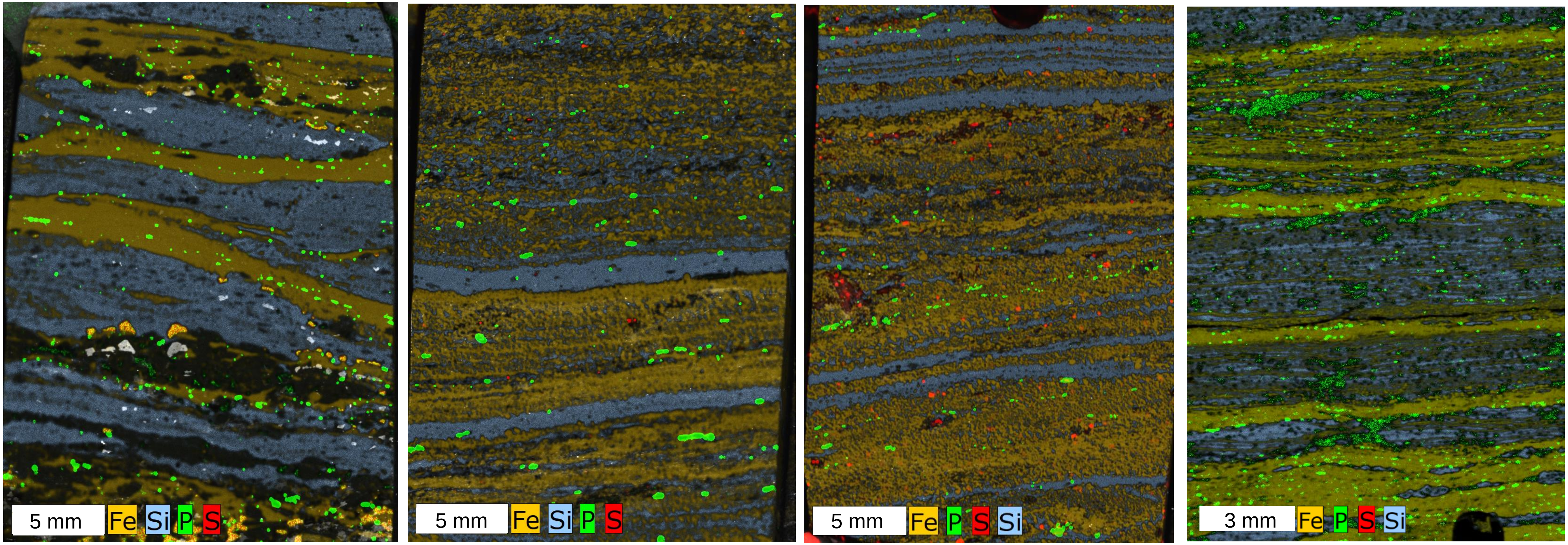
→ Microbial iron oxidation and iron reduction

Raman Microscopy: Iron Minerals and Apatite



- **Apatite and magnetite normally have a compromise boundary and apatite may contain magnetite inclusions**

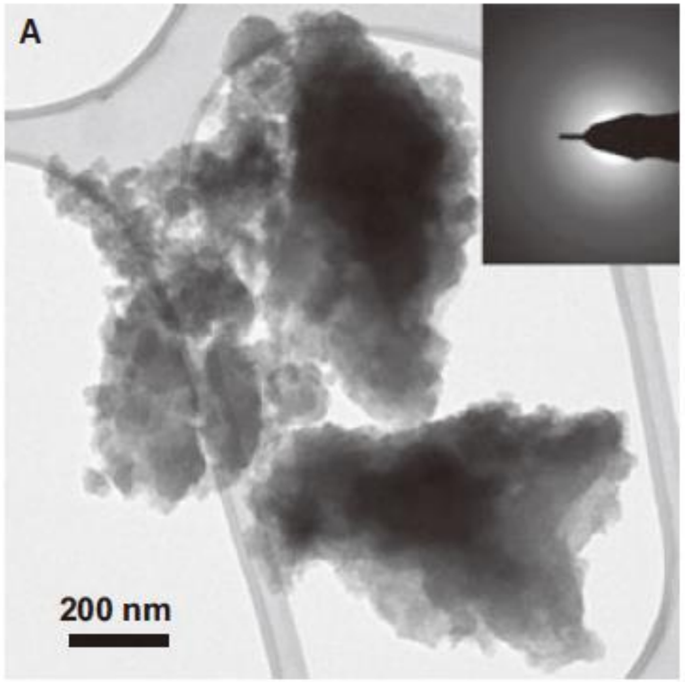
XRF mapping: Iron Minerals and Apatite



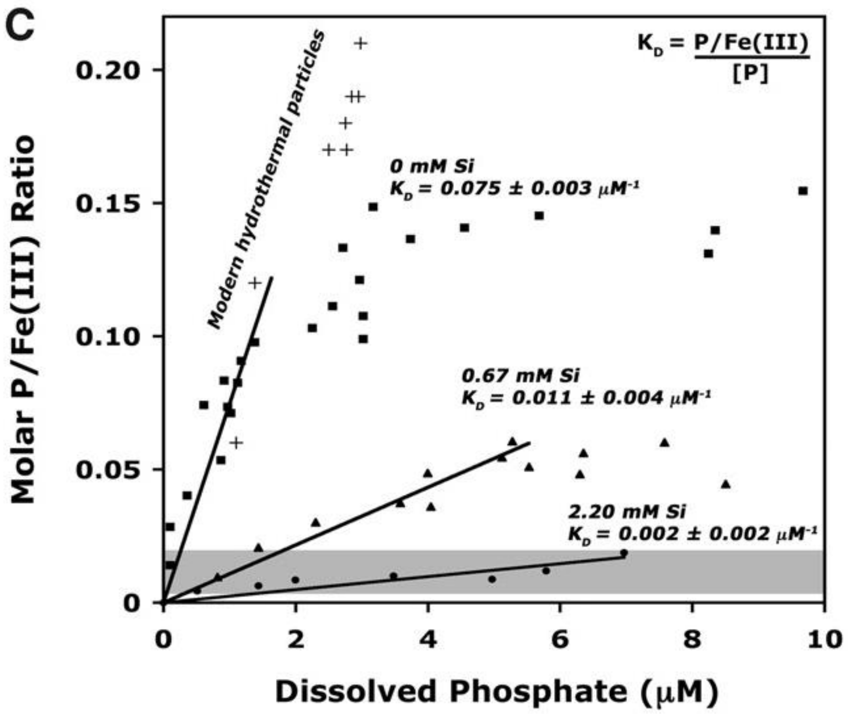
(~2.5 Ga BIFs in North China)

- **Apatite is common and randomly dispersed (i.e., not associate with hydrothermal veins), but more enriches in Fe-rich laminae**

The coupled Si-Fe-P precipitations



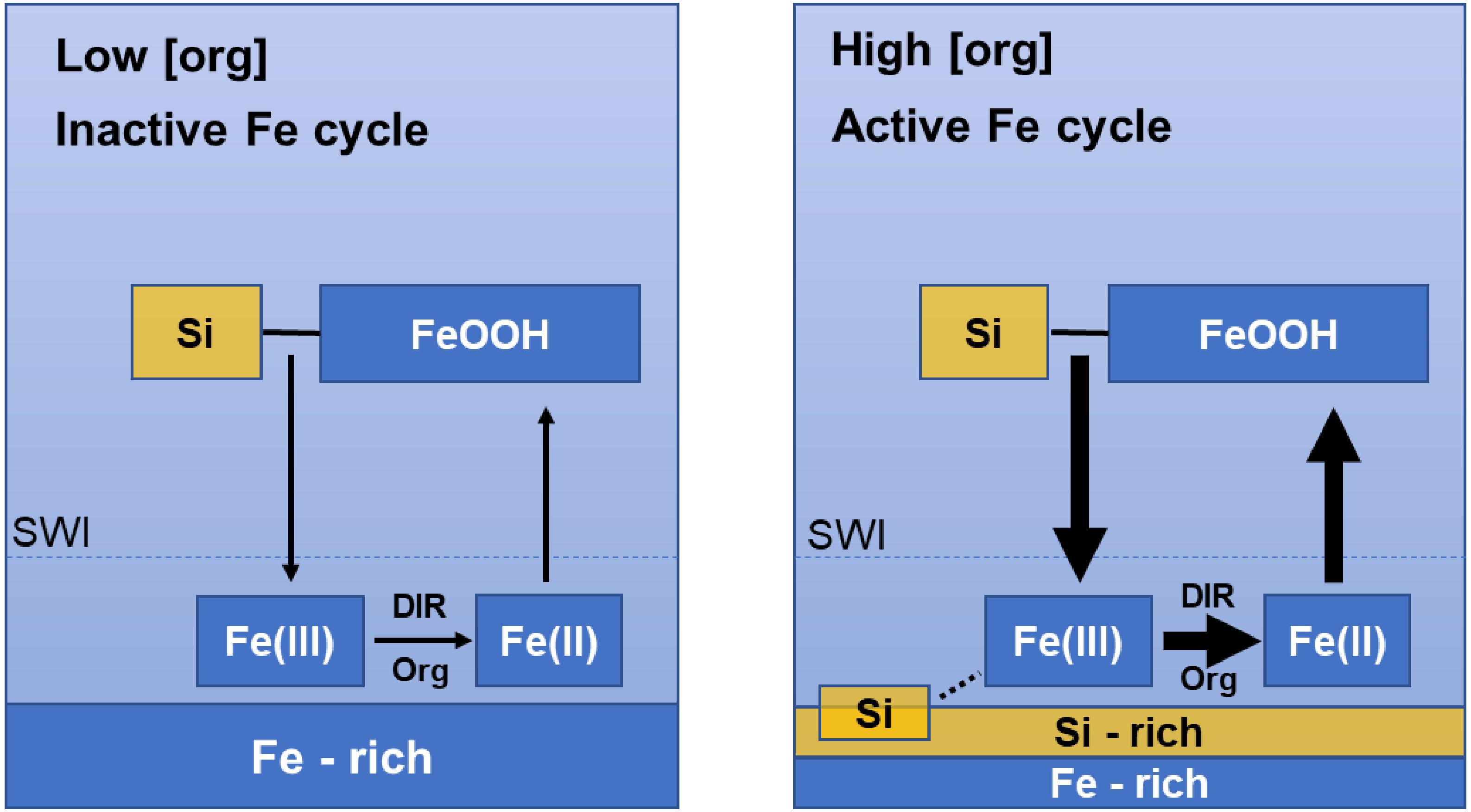
(Percak-Dennett et al., 2011)



(Konhauser et al.,2007)

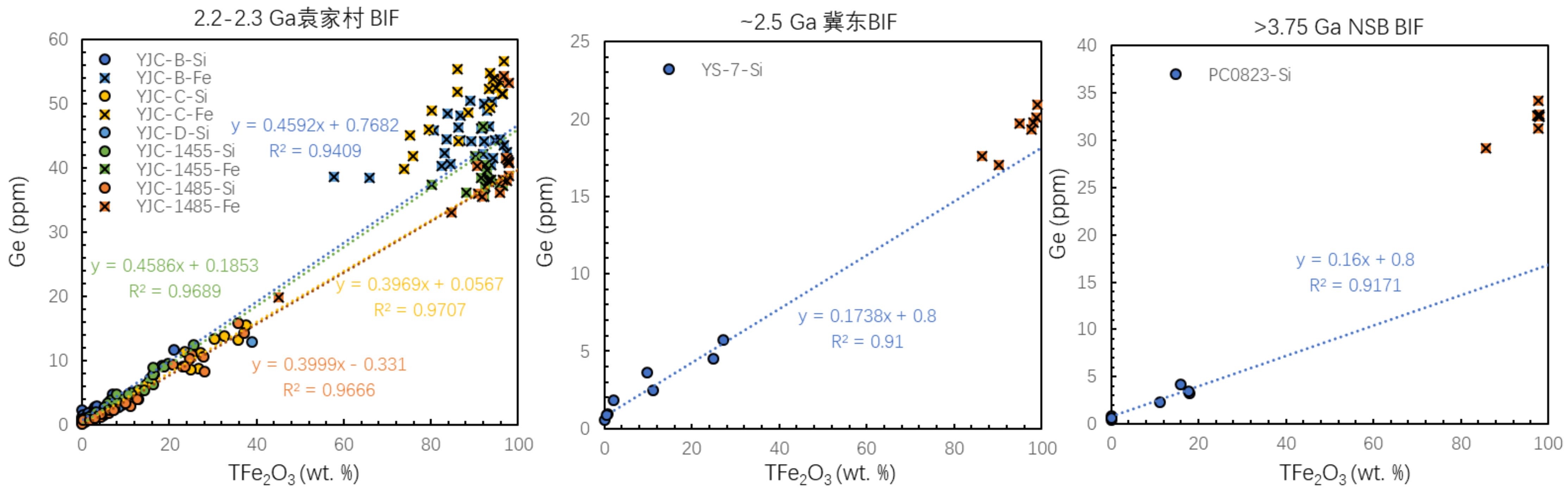
- Laboratory experiments have confirmed the process of co-precipitation of Fe-Si-P
- **The petrographic observations indicate that the Fe-Si-P co-precipitation process is widely present during the formation of BIF.**

Models for BIFs Lamination Formation



- Organic matter → Fluctuations of Fe redox cycle→ BIFs lamination
- Low organic matter→Inactive DIR→Inactive iron shuttle→Fe-rich layers
- High organic matter→Active DIR→Active iron shuttle→Si-rich layers

Geochemical Test：Ge content in iron minerals



- The Ge content of iron minerals in the rich-silicon layer is lower than that of iron minerals in the rich-iron layer.
- The change of Input or output (Ge)?

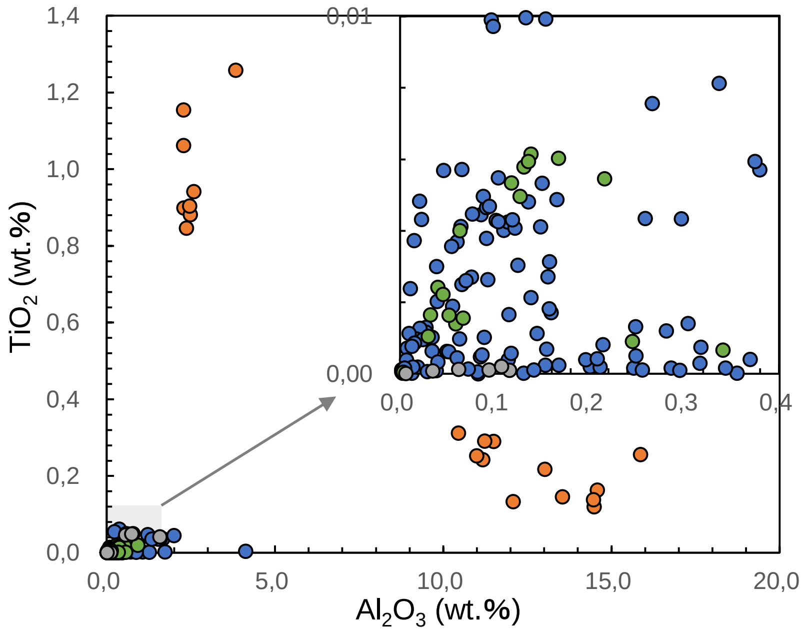
Geochemical Test：Ge content in iron minerals

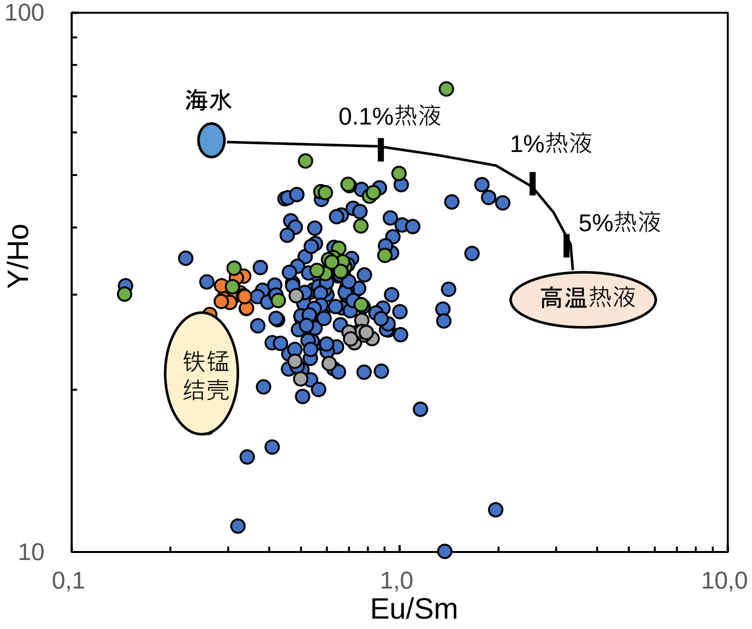
- **Si-rich layer: Low $[Ge]_{sw}$**
- **Fe-rich layer: High $[Ge]_{sw}$**

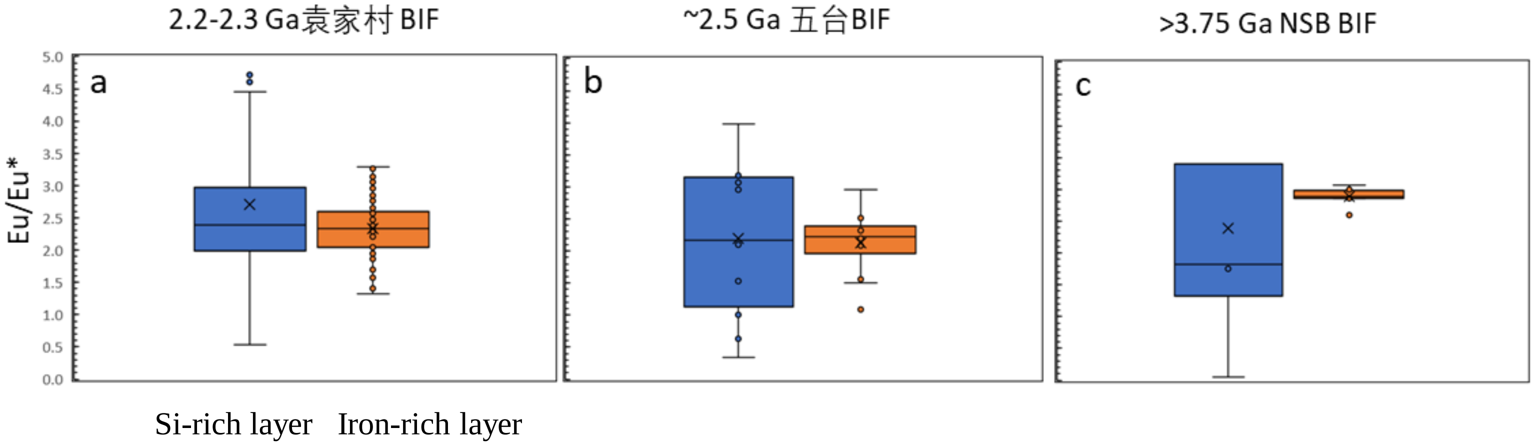
X input：Hydrothermal flux

√Output：Iron redox cycle

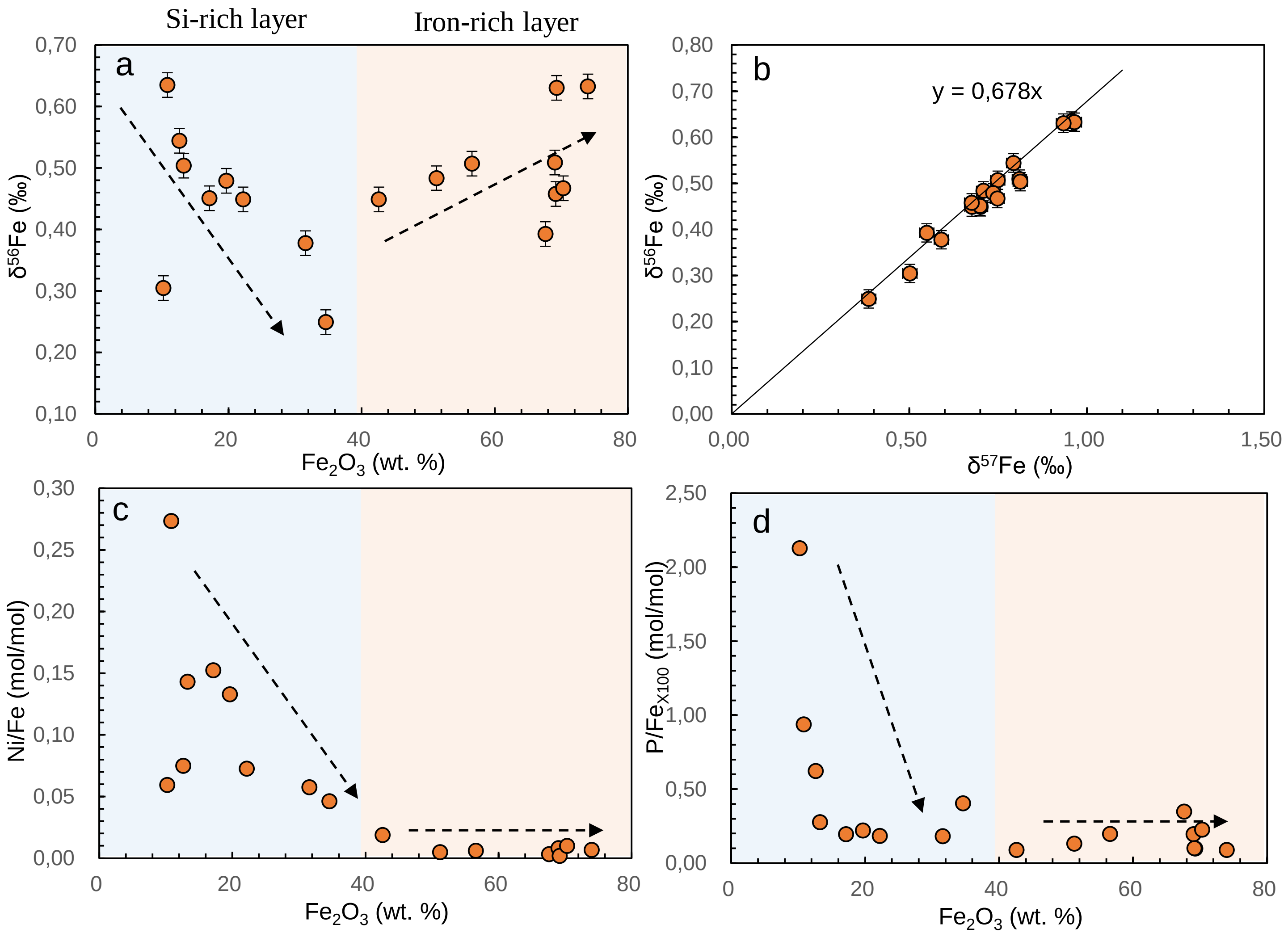
- **Si-rich layer： Active Iron redox cycle**
- **Fe-rich layer: Inactive Iron redox cycle**



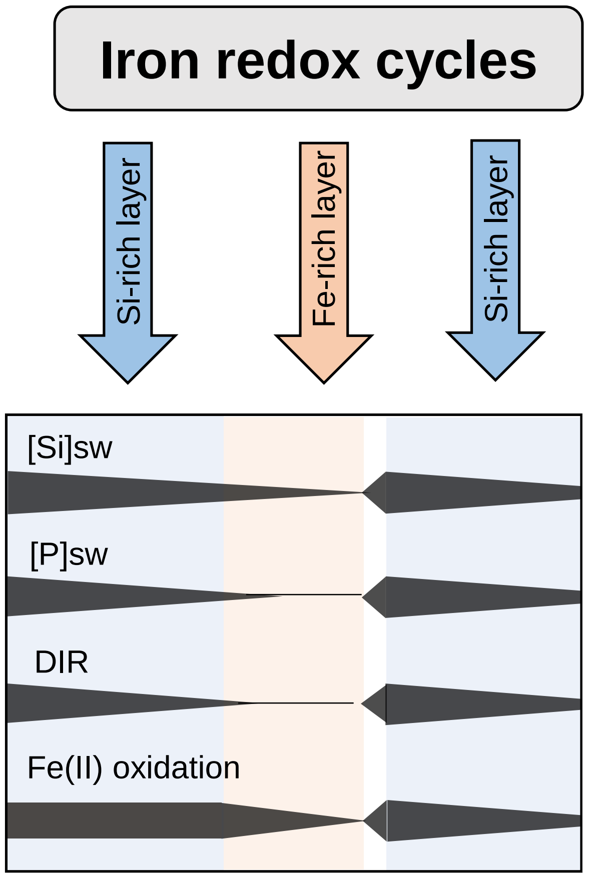




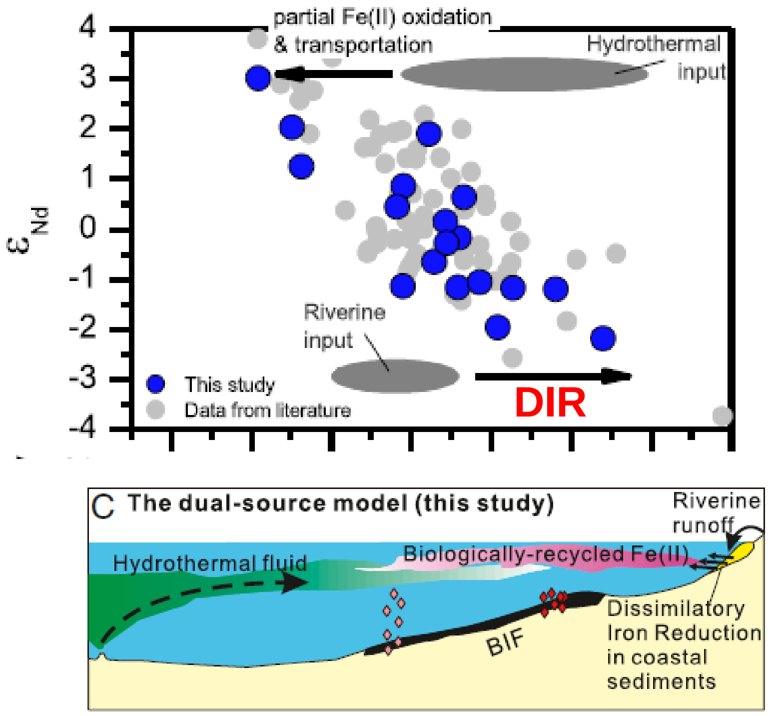
Geochemical Test : Fe isotopes



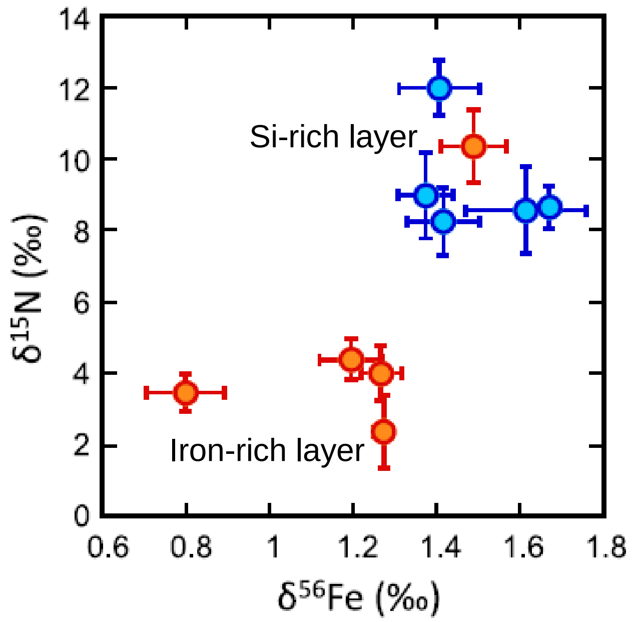
"Self-organized process"



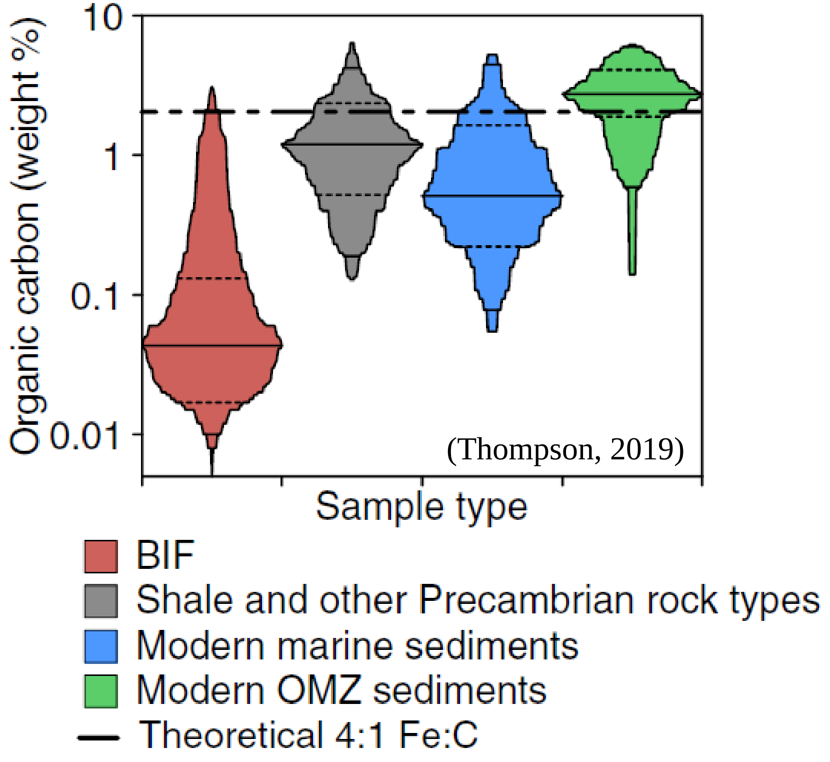
Geochemical Test



(Li et al., 2015)

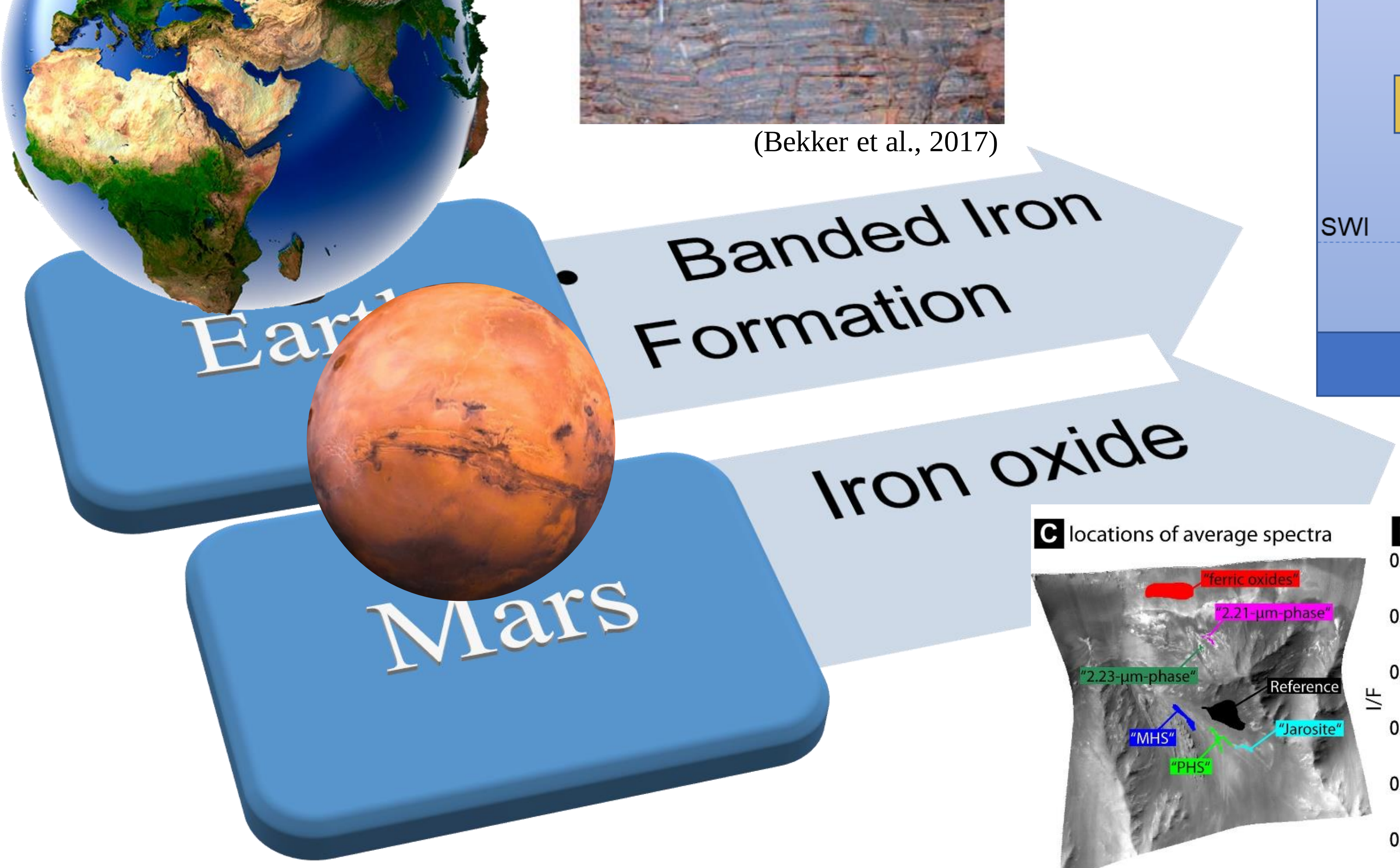


(Hashizume ,2016)

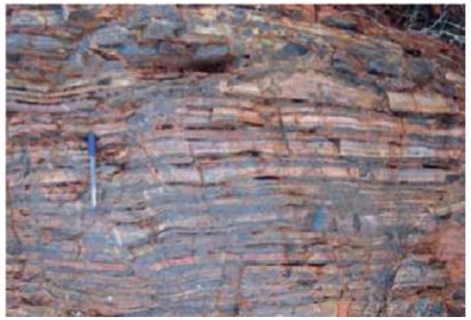


- **Iron isotopes**
- **Nitrogen isotopes**
- **Benthic flux/iron shuttle**
- **Low TOC content in BIF**

Explore the early evolution of metabolism

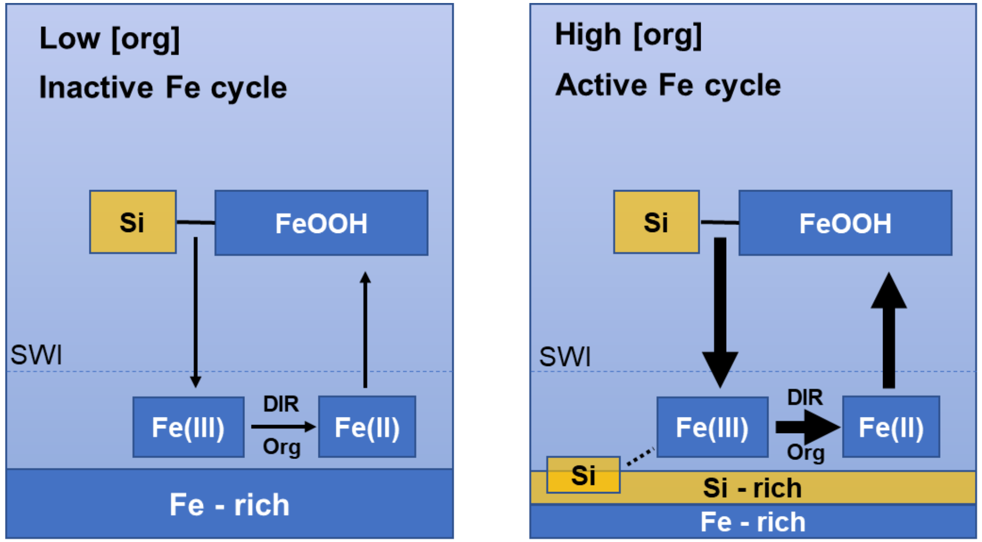


BIF in early Earth

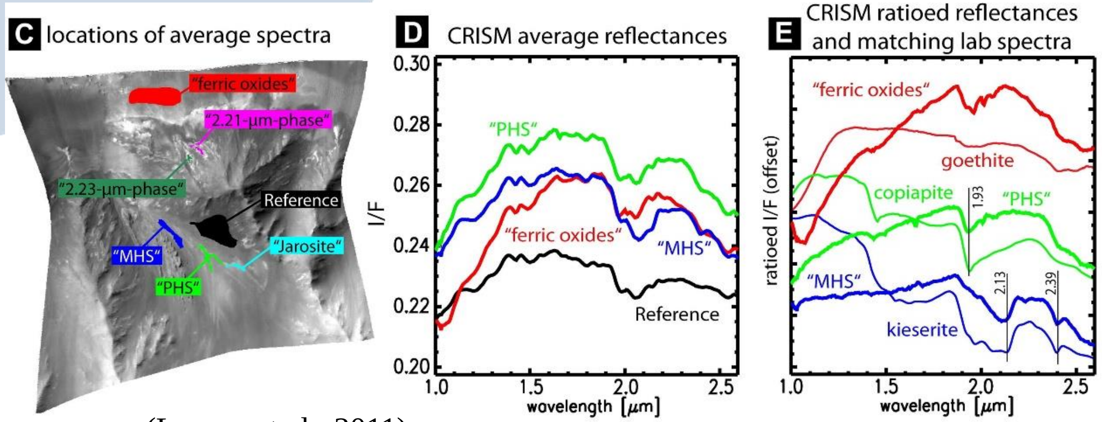


(Bekker et al., 2017)

Origin of rhythmic Fe-rich and Si-rich laminae in BIFs



Iron oxides in Ophir Chasma, Mars



(Lorenz et al., 2011)

Future collaborations

- **From the snowball Earth to Cambrian explosion → Based on the stratigraphy in Siberia**
- **Paleozoic evolution of terrestrial system and reservoir effects (coal, bauxite…)→ Low latitude vs. mid-to-high latitude flora**
- **The habitability of early Earth → Based on the Archean of Siberia and North China**

Thank you!

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