

# Biogeochemistry and the Geologic Record

## **Chemical signatures for identifying life in the geological record**

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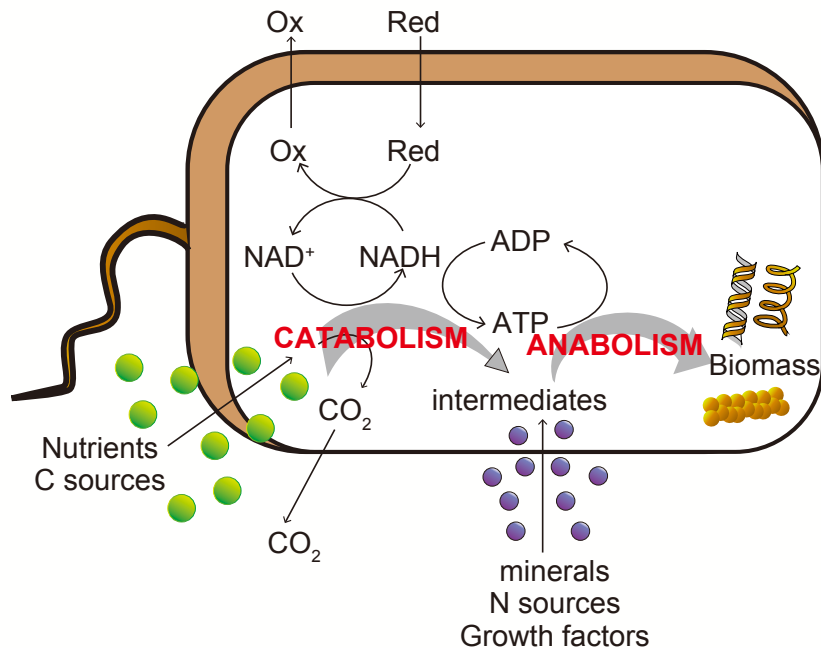




# Biogeochemistry

The study of ...

- How chemical elements flow through living systems and their physical environments.
- Investigate the factors that influence cycles of key elements such as bioelements (C, H, N, O, S...).



modified "Linares-Pastén, Javier (2018): A simplified view of the cellular metabolism. figshare."

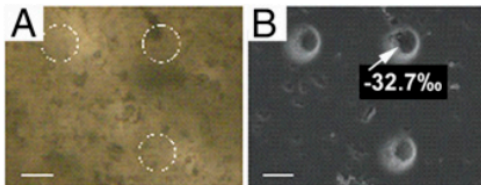


# Fingerprints of life

- DNA information cannot be preserved over geologic time scale (thousands ~ million years for eukaryotes' DNA)
- Chemical and morphological signatures are utilized
  - Fossils, molecular fossils
  - Mineral compositions
  - **Isotopic signatures**



Banded Iron Formation (BIF)



▲ Figure of microfossils and its C isotope ratio (Schopf et al., 2017)

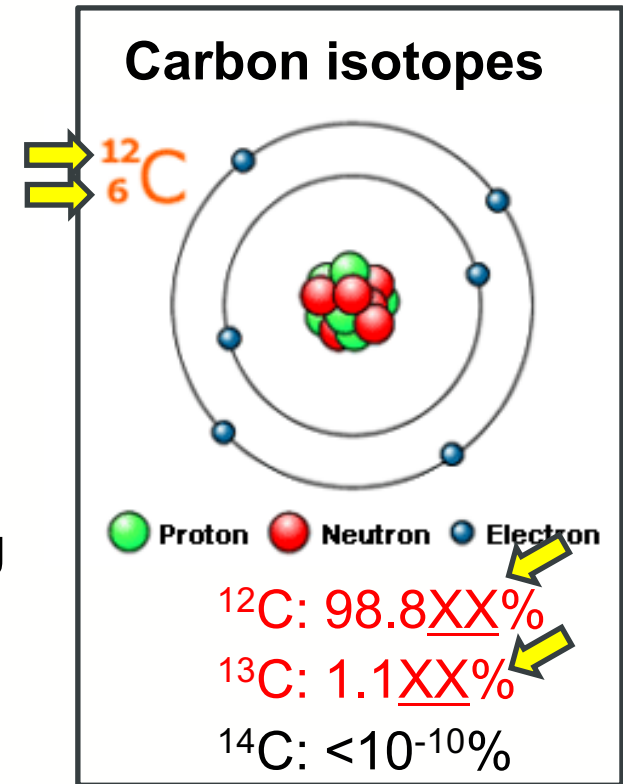


▲ Rock collections with fossils at Tokyo Tech



# Isotopic signatures

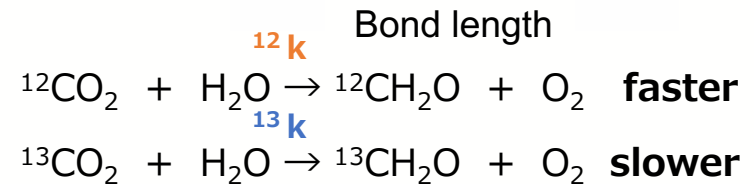
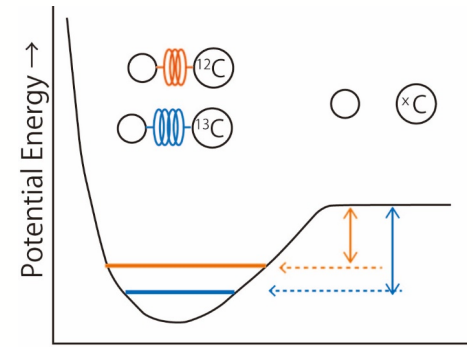
- **Isotope**  
variants of a particular chemical element which differ in neutron number
- **Radioactive isotope**  
one having an unstable nucleus and which emits characteristic radiation during its decay to a stable form.  
Ex :  $^3\text{H}$ ,  $^{14}\text{C}$ ...
- **Stable isotope**  
Stable. do not decay into other elements.  
Behavior is slightly different by **the mass**, useful for understanding material cycle.



# Isotopic signatures

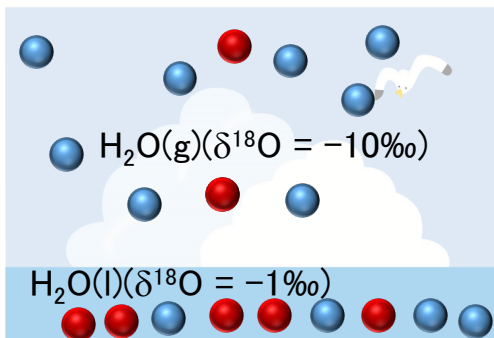
- Kinetic isotopic effect

Isotope ratio is changed by kinetic reactions  
e.g.) the isotopic ratios are changed between **substrates** and **products** reflecting the metabolic processes



- Equilibrium isotopic effect

Isotope ratio is changed by equilibrium reactions.  
e.g.) Temperature effect, phase (gas, liquid, solid)



$^{18}\text{O}$  ( $^{16}\text{O}$ ) is..  
more (less) enriched  
in liquid than gas  
phase



# Isotopic signatures

## Environmental conditions

- Temperature, pH, ORP, light intensity
- Chemical and Mineral Concentration

## Field & Lab Researches



## Chemical signatures

### ● Isotopic composition of bioelements

- Sources
- Production and Consumption

## Players

- Microbial diversity (Molecular biology)
- Bacteria, Archaea, Virus?, ...etc.

**Record** **Decord**

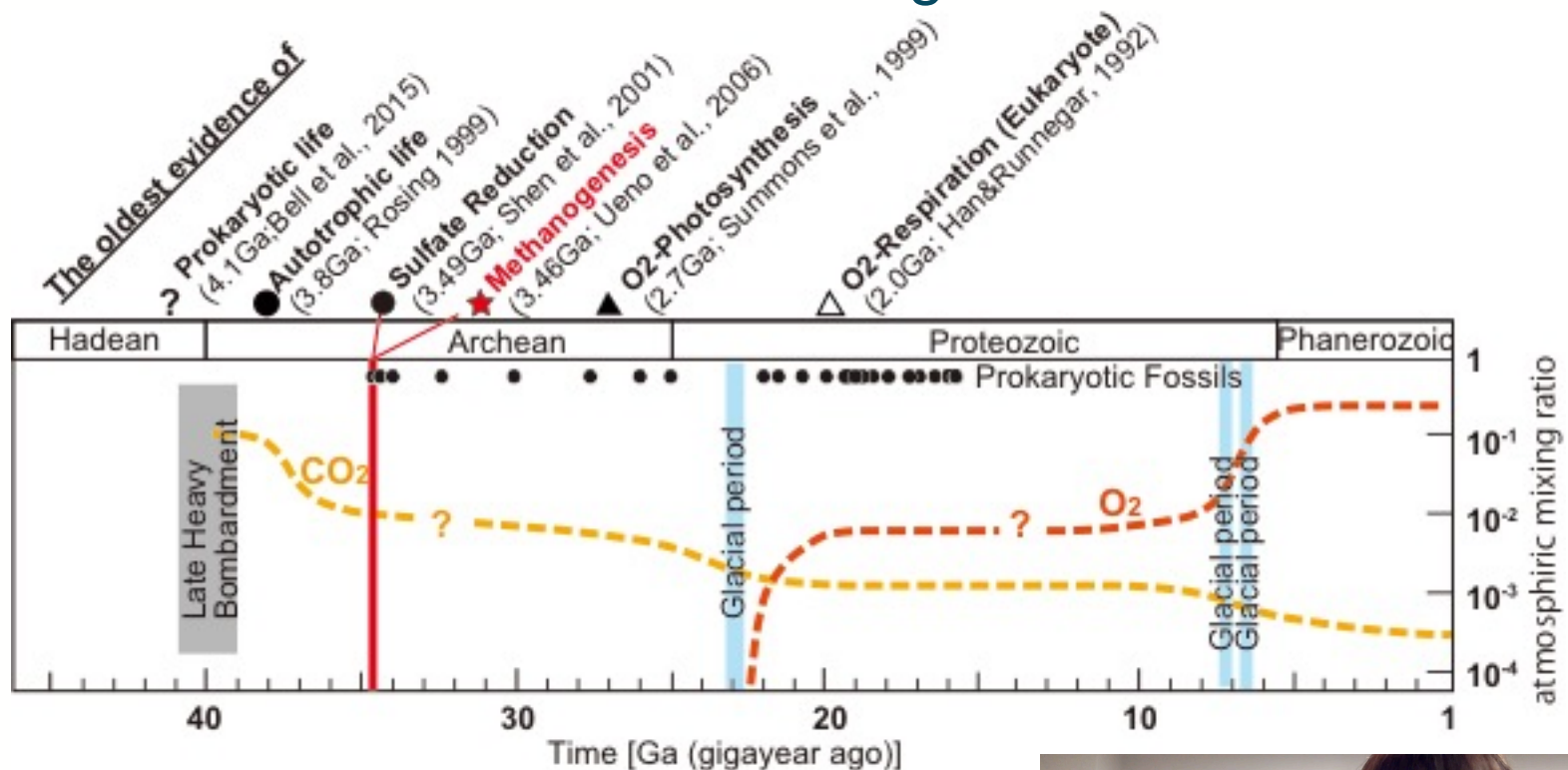
Geological records





# Earth's Early Environment

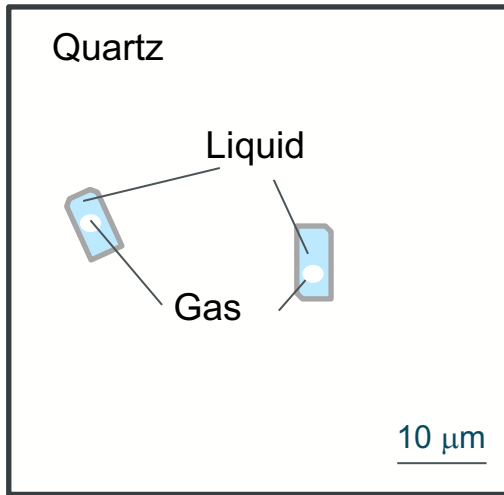
Earth environment interact with origin and evolution of life



- O<sub>2</sub> level is important for evolution of life  
→ the content of oxidized minerals and S isotope ratios are used for signatures of O<sub>2</sub> level
- Small C isotope ratio ( $\delta^{13}\text{C}$ ) of microfossils  
→ The difference of  $\delta^{13}\text{C}$  values between carbonate and organic carbon ( $< -30\text{‰}$ ) indicated the possibility of Acetyl-CoA pathway and/or Calvin cycle product.



# Isotopic signature for Methanogens



▲ Image of Fluid inclusion in the rock

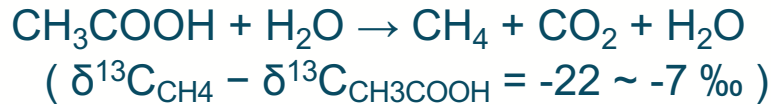
- The sample rocks (~3.5Ga); at the Dresser Formation at the North Pole area in Pilbara craton, Western Australia (Ueno et al., 2006)
- **Fluid inclusion**; Tiny bubble of liquid or gas trapped inside a solid mineral-phase
- Measure C isotope ratio ( $\delta^{13}\text{C}$ ) of  $\text{CO}_2$  and  $\text{CH}_4$  in fluid inclusion



# Isotopic signature for Methanogens

## Methane production processes (Biogenic)

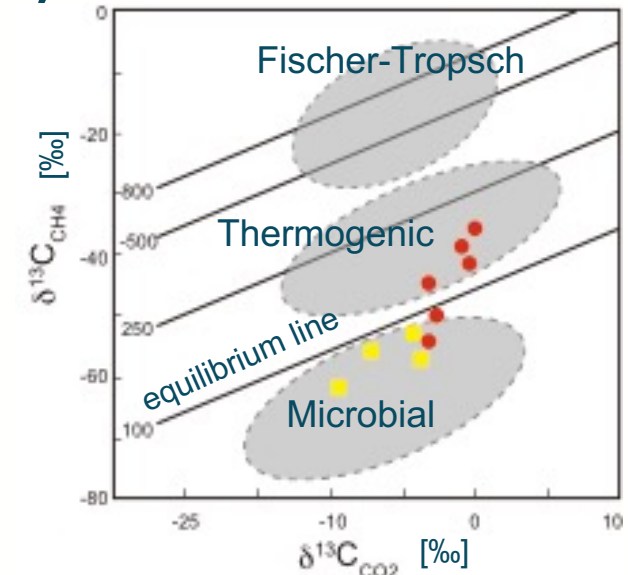
- Acetate Fermentation



- CO<sub>2</sub> reduction



Comparison with  
present-day hydrothermal system



▲ Measured fluid inclusions in rocks  
(Figure simplified from Ueno et al., 2006)

## Methane production processes (Abiotic)

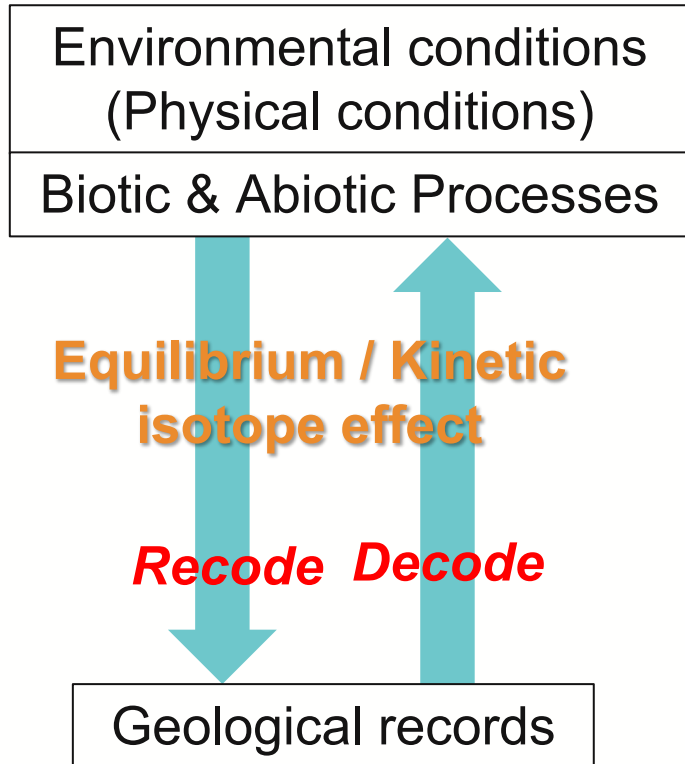
- Thermogenic decomposition,  
... -C-C-C-C-... → C + C-C + C-C-C + ...  
(kerogen)

- Fischer-Tropsch reaction





# Take-home message



## Signatures of life ...

- Chemical signatures, especially stable isotope information, are important tool for identifying the biogenic signatures preserved in geological records
- To understand how to record and decode the signatures, researches on modern earth material cycle and organisms are necessary.



# Suggested Reading

## Isotope geochemistry

Allègre, C. (2008). Stable isotope geochemistry. In C. Sutcliffe (Trans.), *Isotope Geology* (pp. 358-435). Cambridge: Cambridge University Press. doi:10.1017/CBO9780511809323.008

## OPEN EDUCATIONAL RESOURCES

Sharp, Zachary. "Principles of Stable Isotope Geochemistry, 2nd Edition." (2017). doi:10.5072/FK2GB24S9F

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