

Geochemical Cycles on the Early Earth

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▶ “solid Earth” cycling

▶ lithospheric fluids + volatile emissions

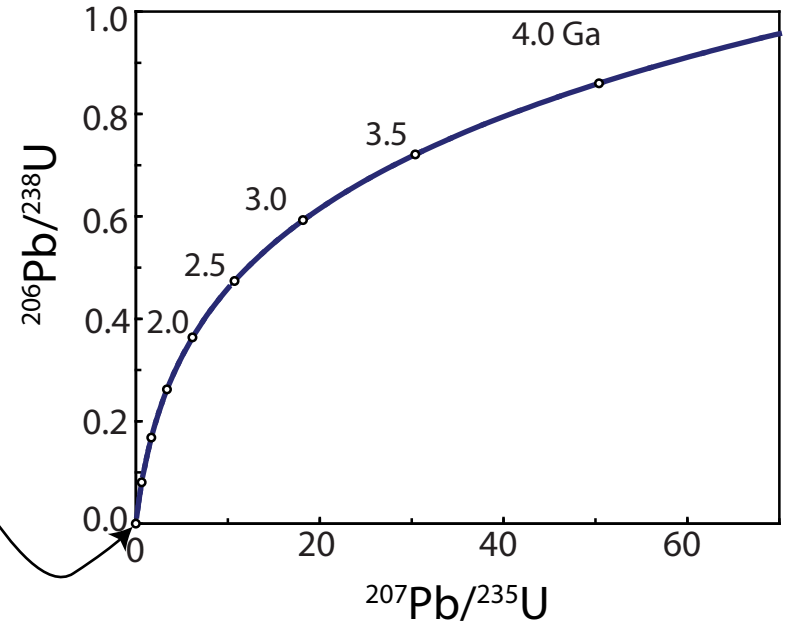
▶ Possible biosignatures

To talk about cycling, we need to know what types of reservoirs were being generated, and what their compositions were like.

We are material-limited.

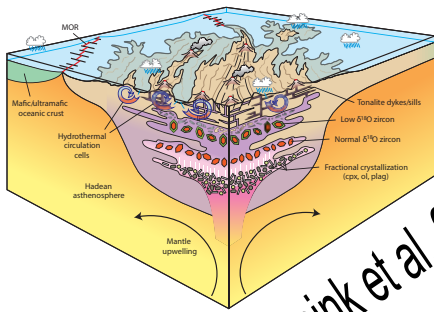


zircon forming today

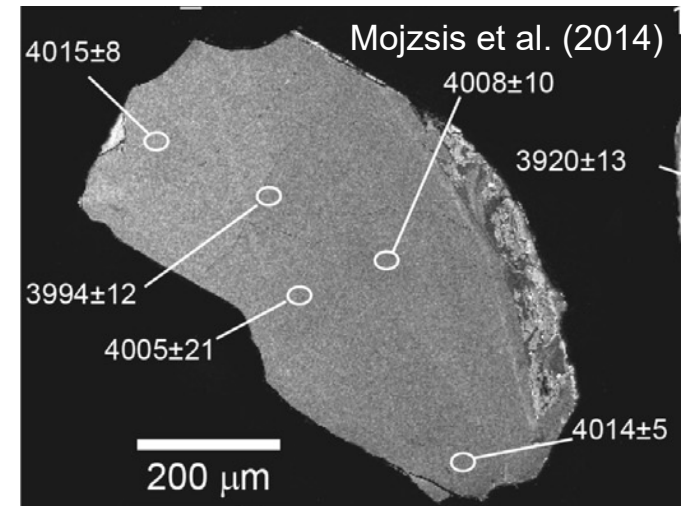


Uranium has two isotopes:
 ^{235}U \longrightarrow ^{207}Pb with a half-life of 704 million years
 ^{238}U \longrightarrow ^{206}Pb with a half-life of 4.47 billion years.

tonalite, plutonic (quartz plagioclase, alkali feldspar)



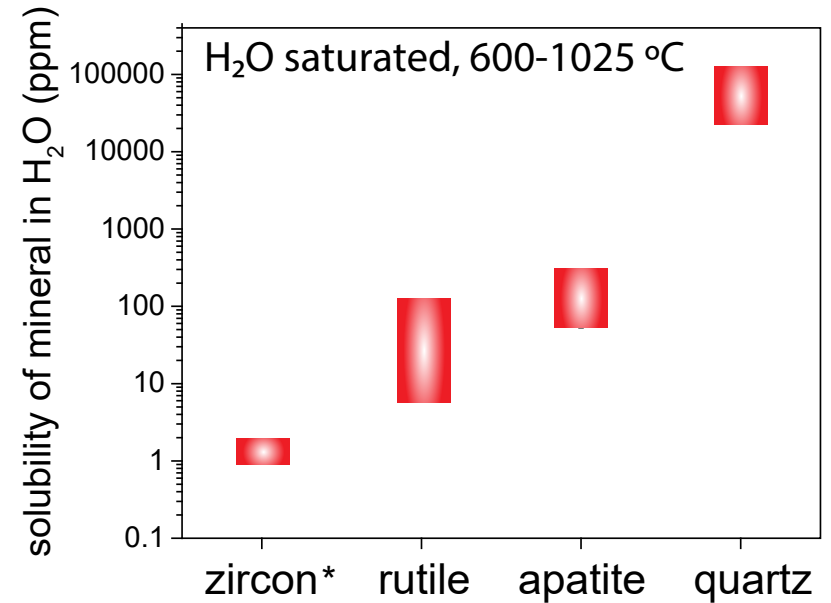
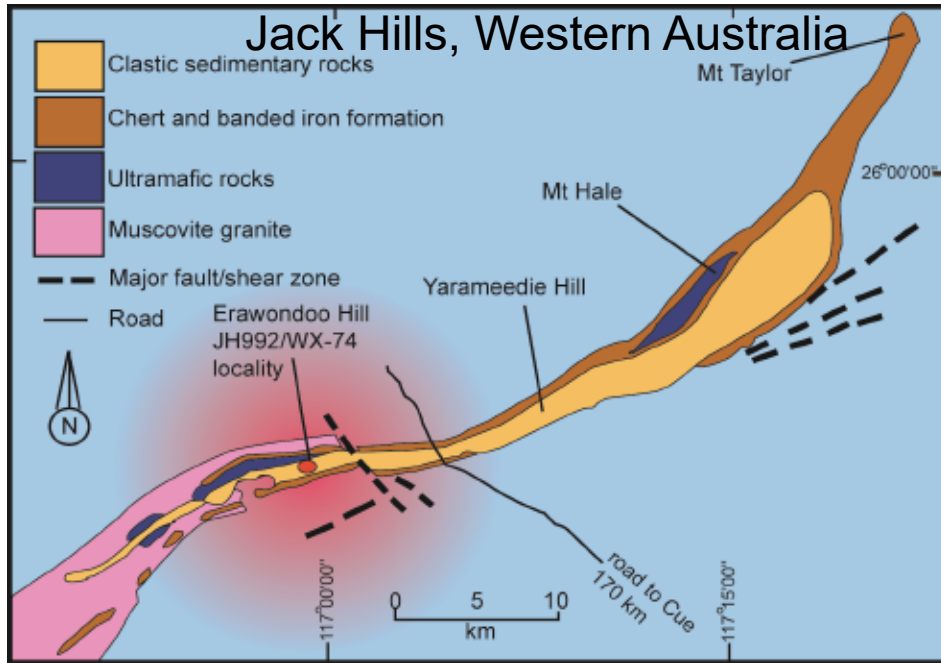
Reimink et al. 2014



What if we want to go back even further?

Why zircon? it survives because it is physically and chemically robust.

-It structurally accomodates trace impurities.



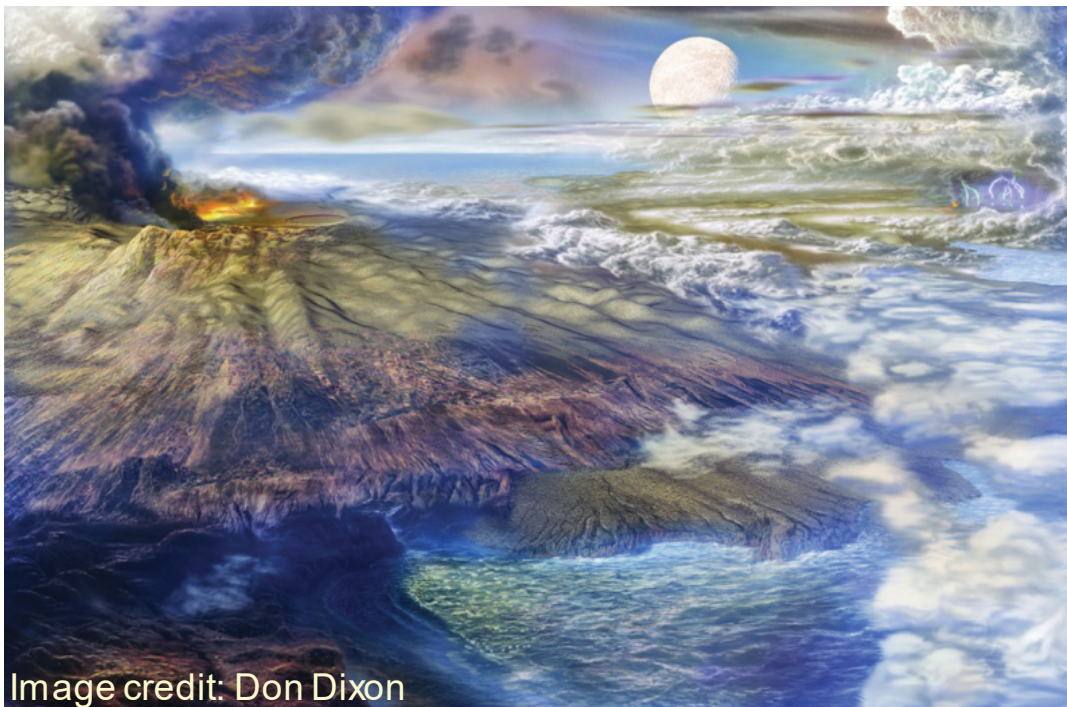
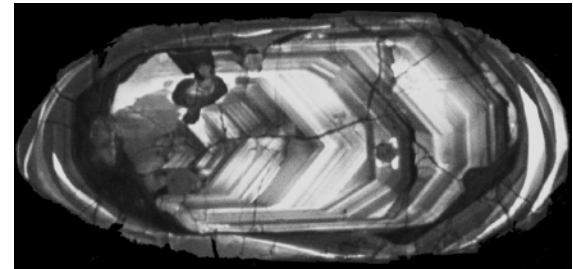
* with qtz present

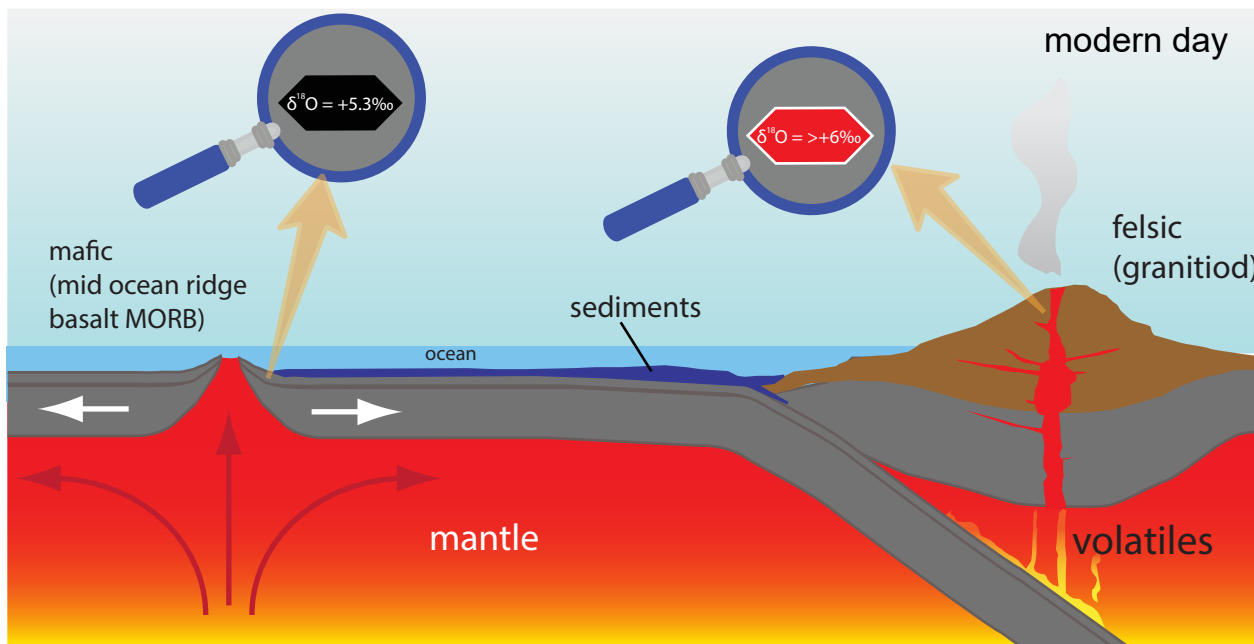
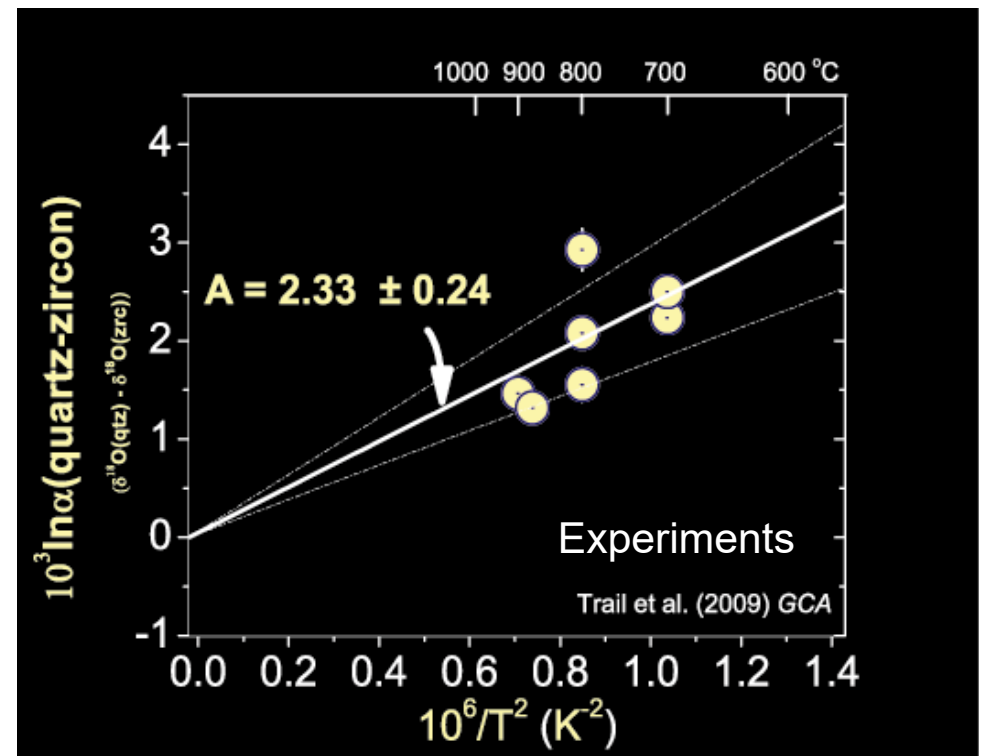
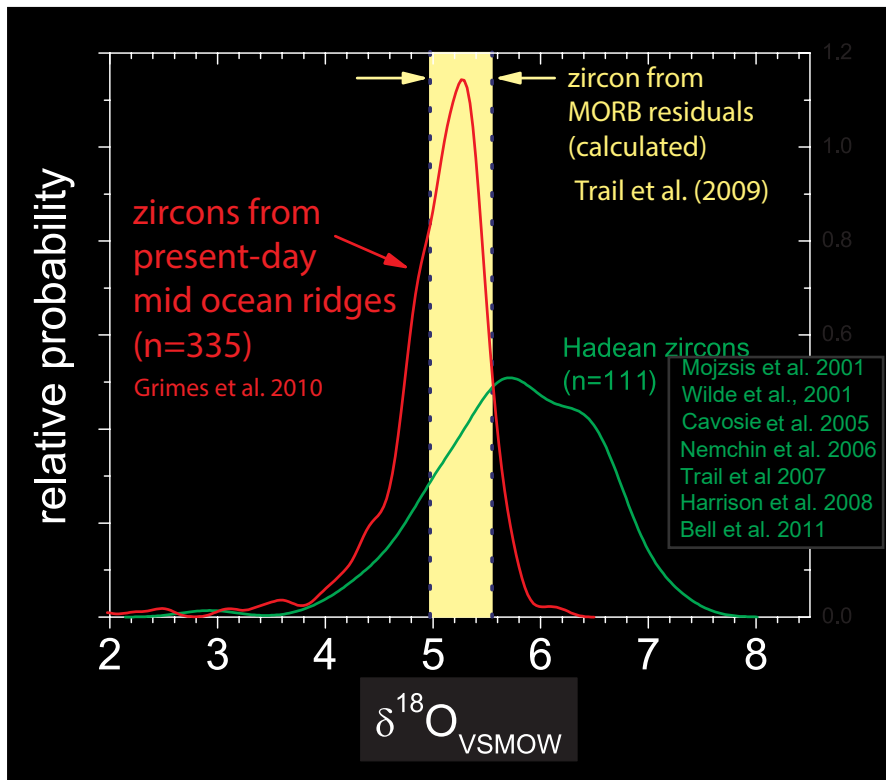
...but the mere presence of the mineral itself is not diagnostic of any particular rock type or tectonic environment.

HUGE selection bias (other minerals are not as robust).



While zircons do not directly record low-temperature weathering processes, they can inherit isotopic information upon recycling and remelting of water-altered rock or sediment.

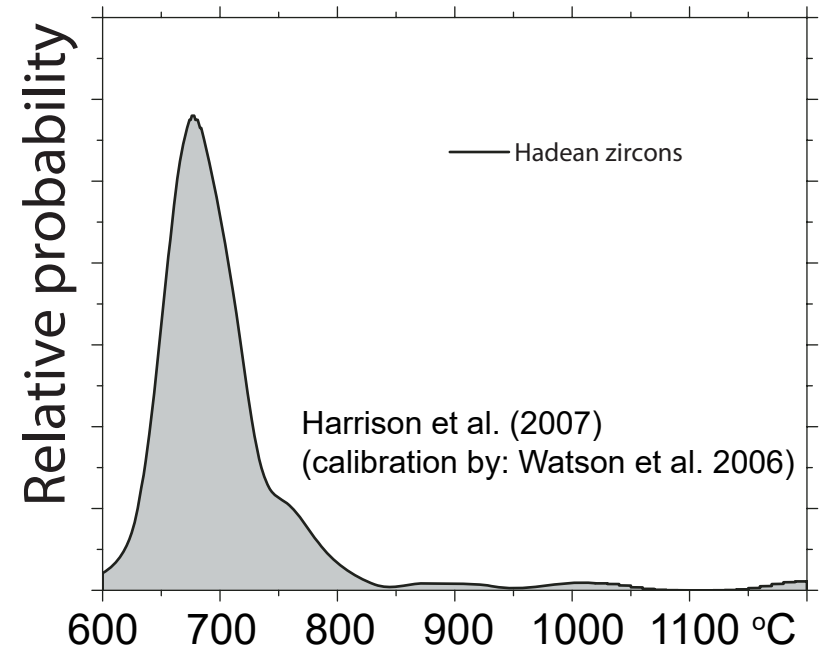
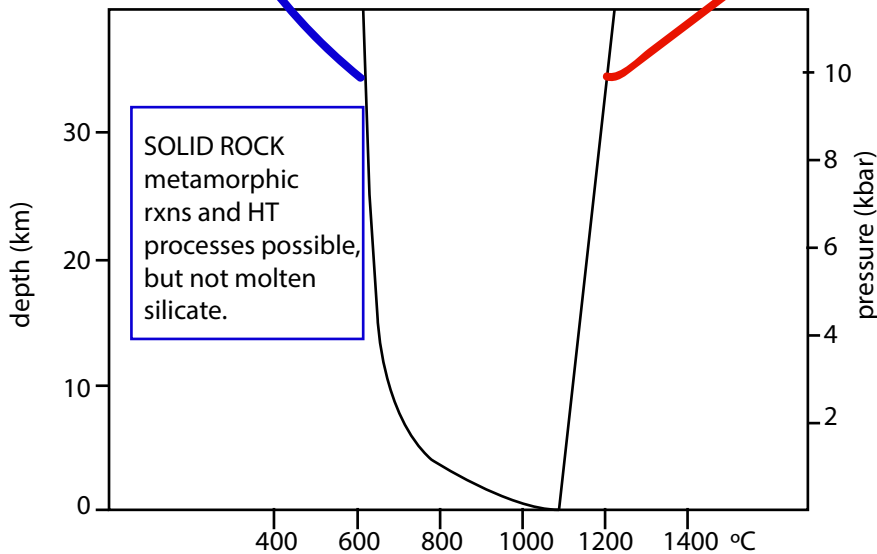




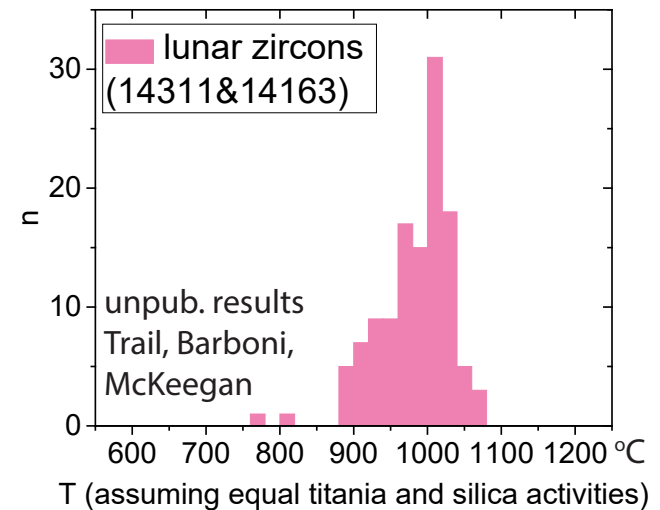
Implies liquid water was stable on Earth's surface at least by 4.2 to 4.3 Ga.

H₂O saturated solids

H₂O dissolves in silicate melts. if no H₂O, magma solidifies here

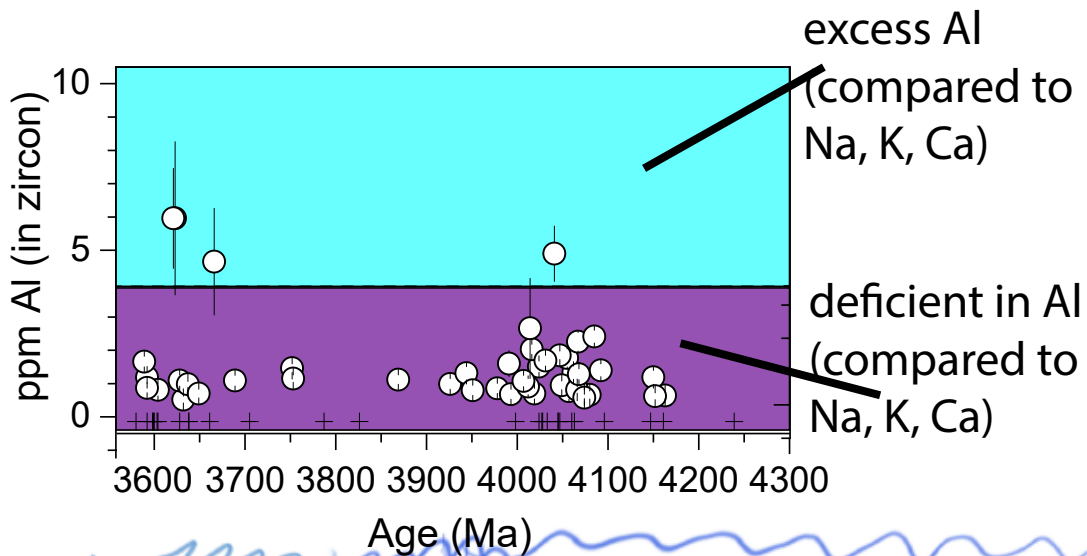


Conclusion: these early Earth magmas had water (volatiles) dissolved in them.



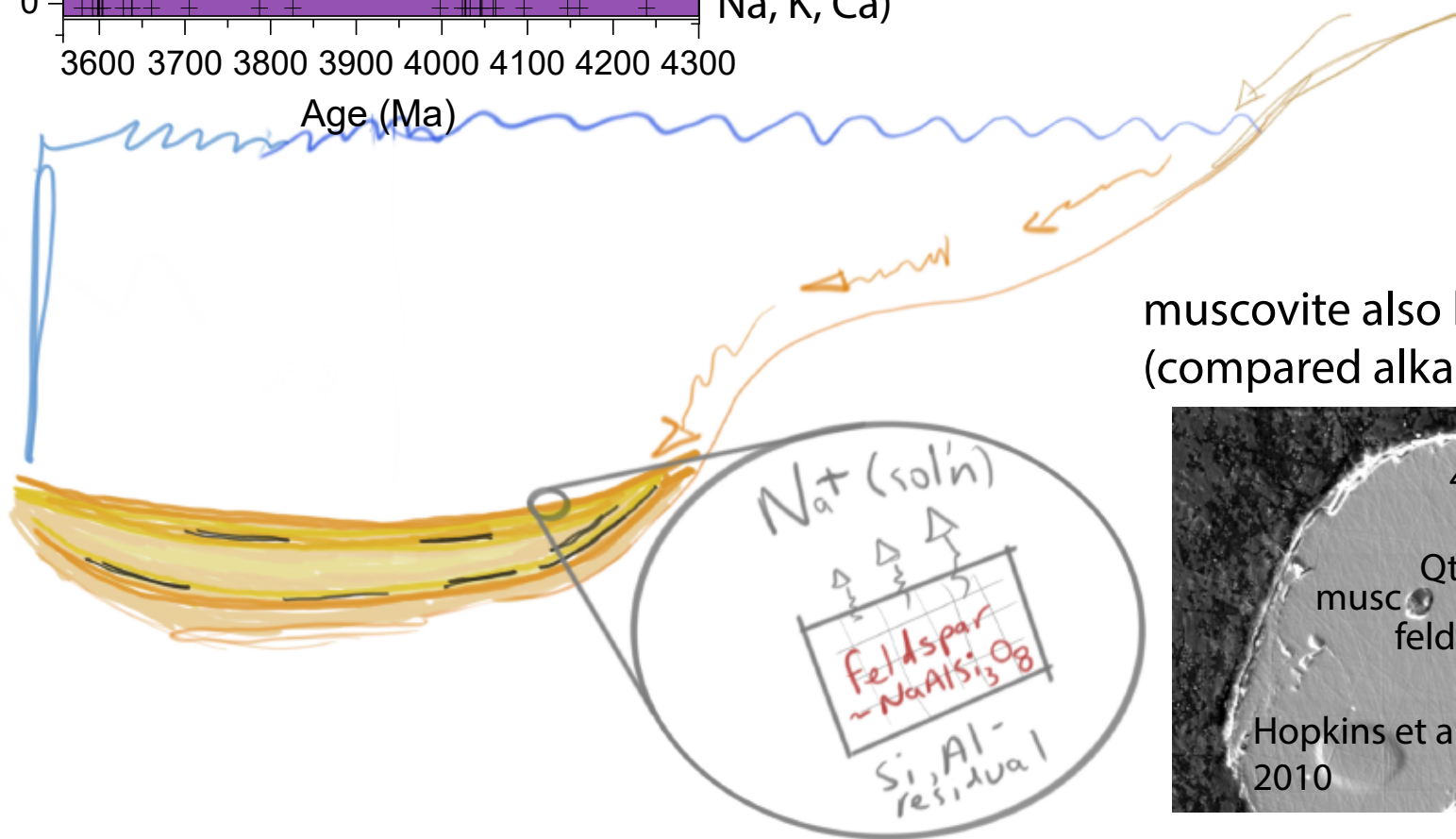
Hadean and Eoarchean surface-processed crust

fields defined by zircons from 'modern' rocks

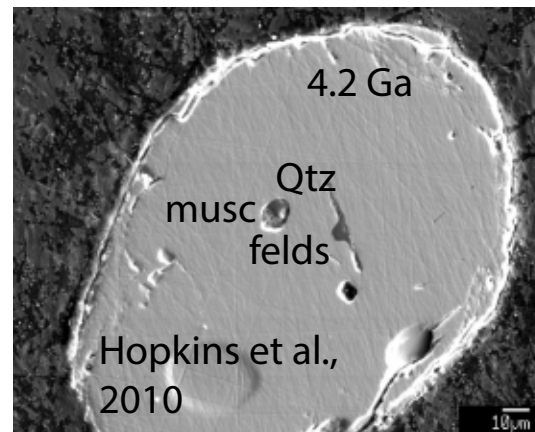


Si+O isotopes are consistent with the hydration (serpentinization) of crust

Li isotopes consistent with melt contamination by highly weathered rock.



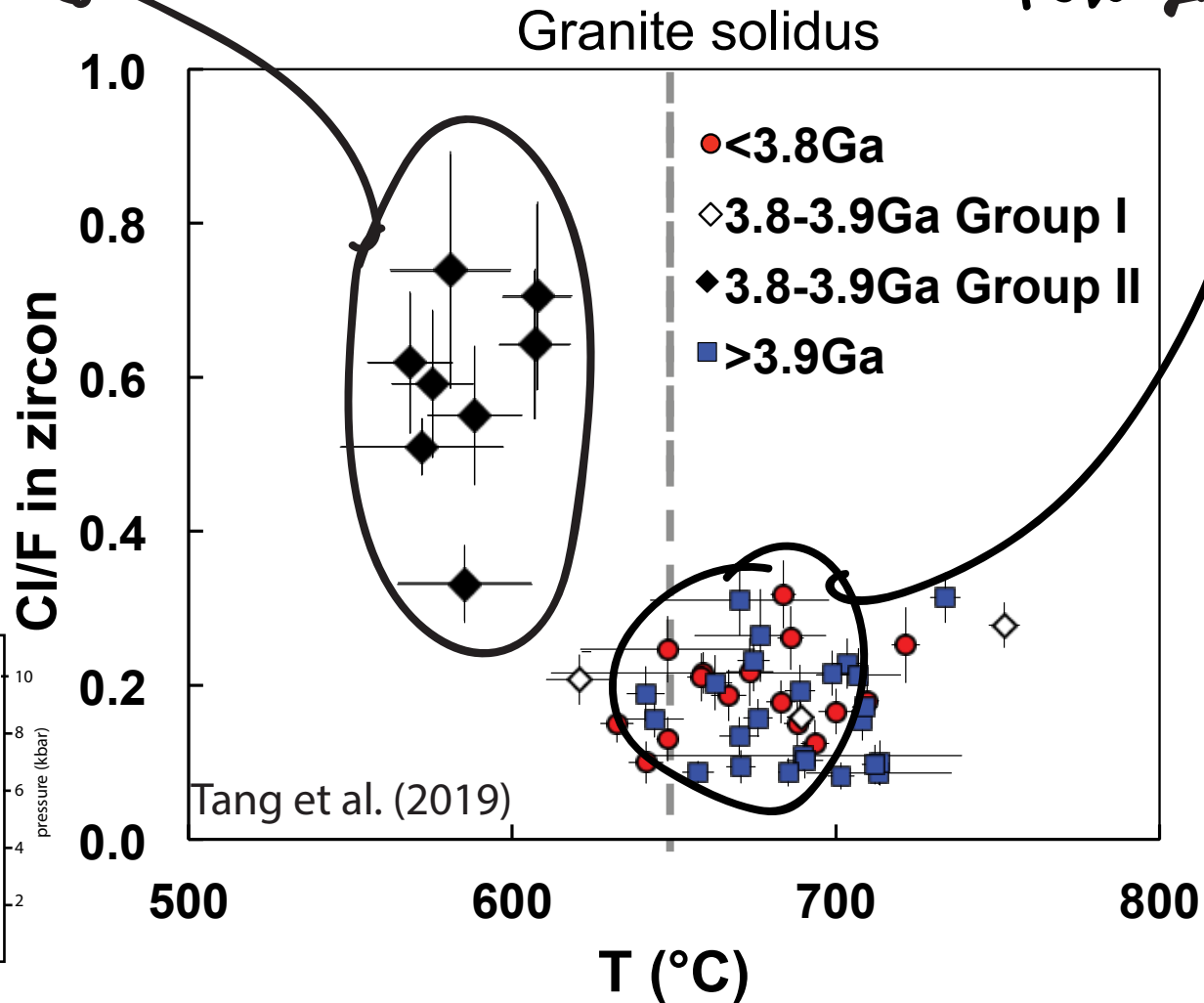
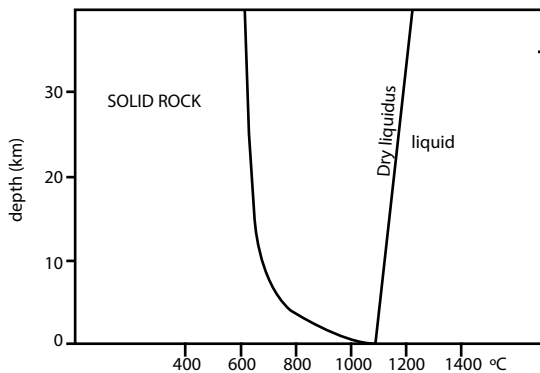
muscovite also has excess Al (compared alkalis)



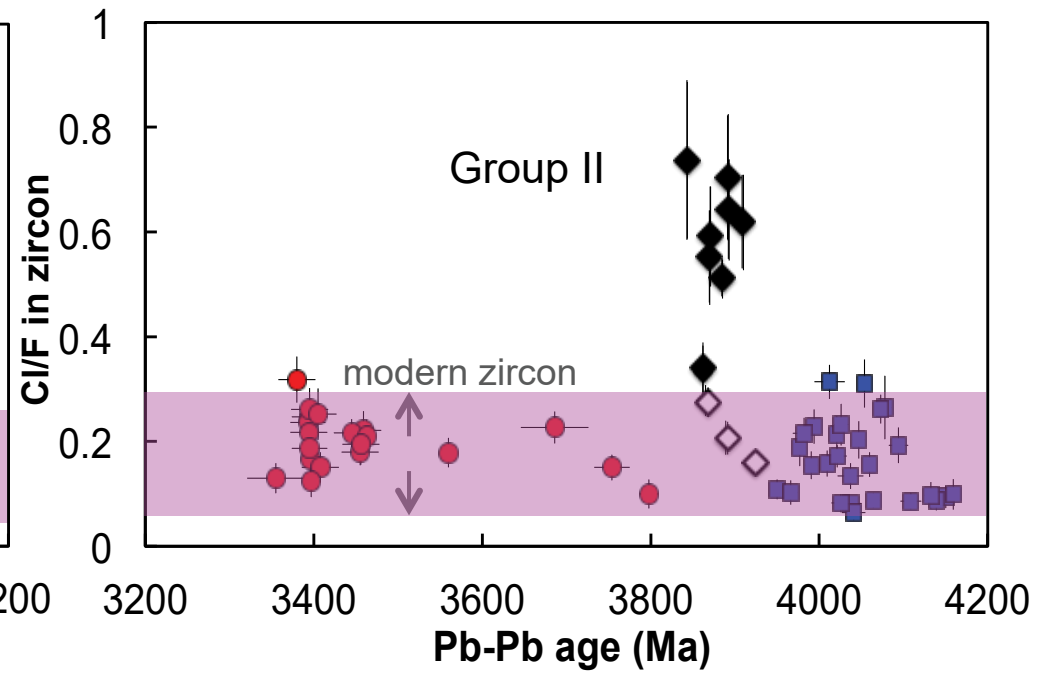
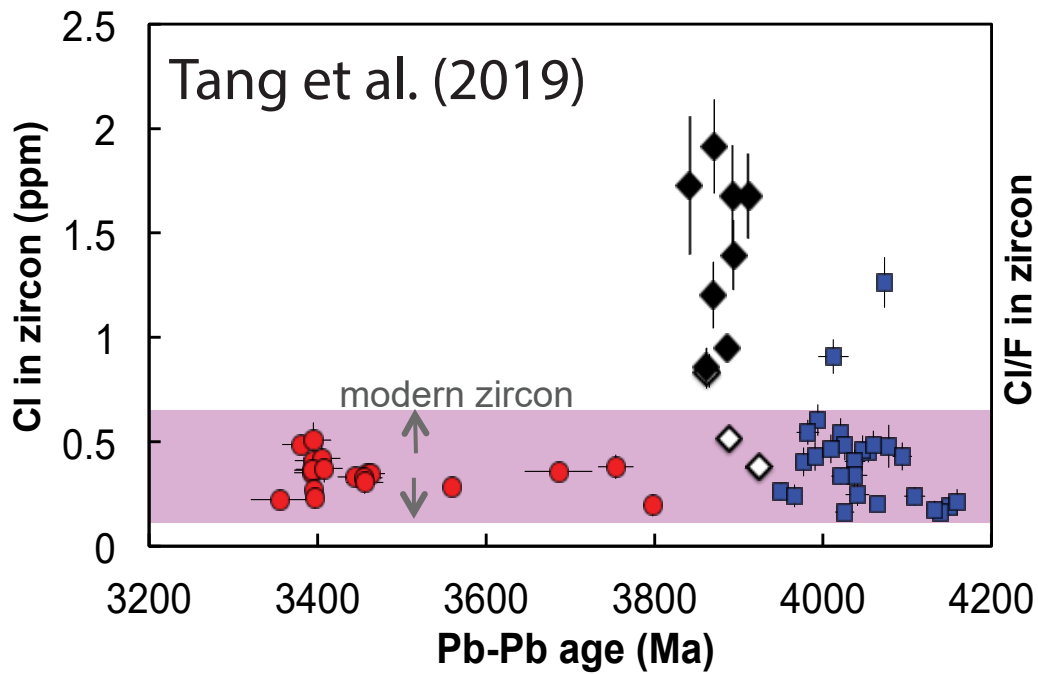
Eoarchean fluids in the lithosphere. Cl and F in pre-3.8 Ga zircon.

Below solidification
point of
silicic
melts

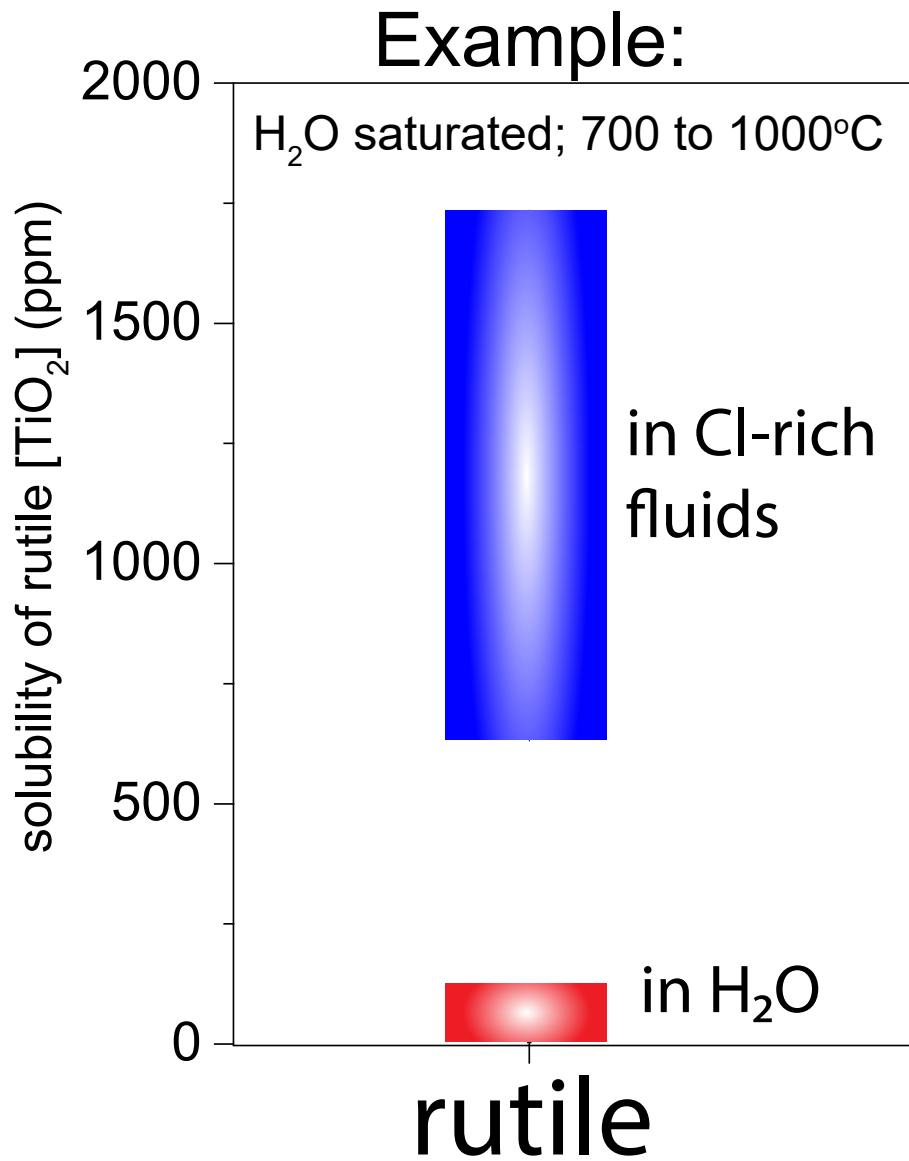
Need H₂O
in magma
for temps this
low



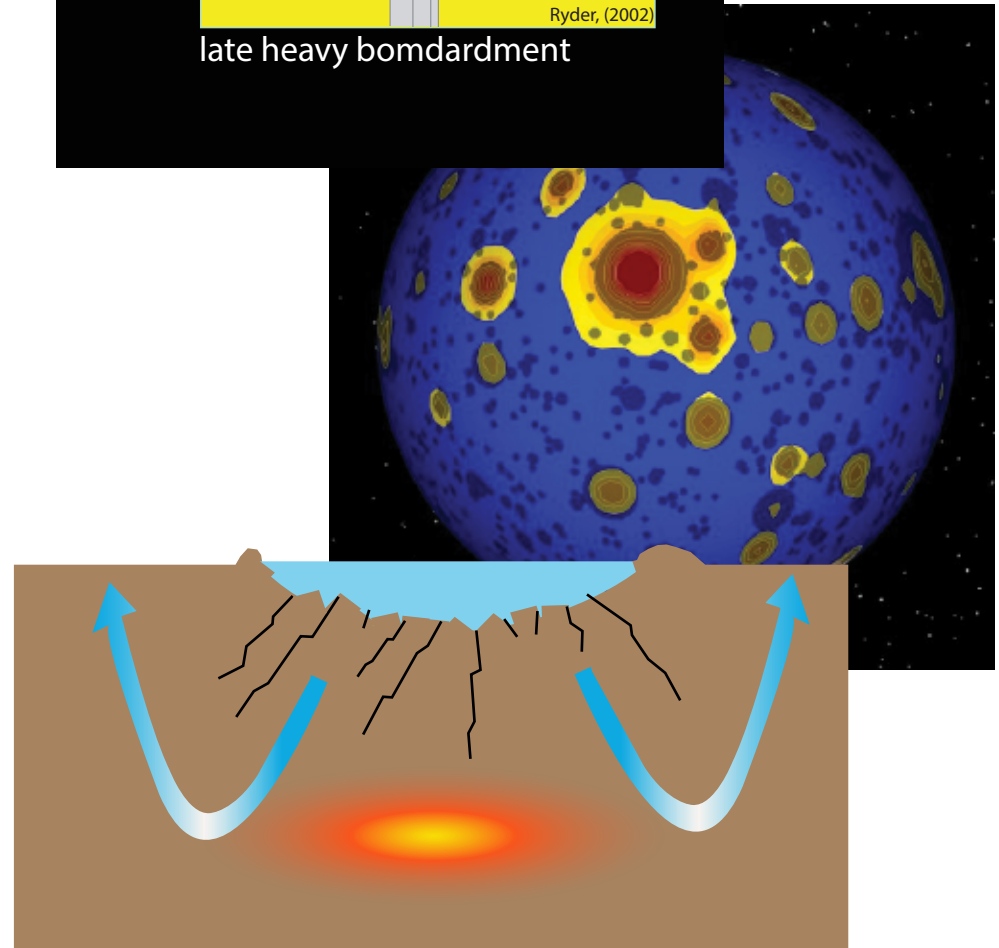
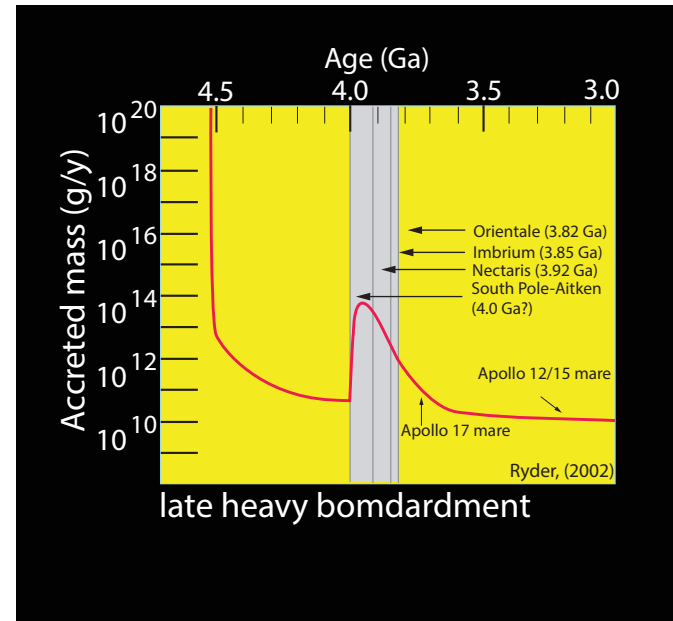
Eoarchean fluids in the lithosphere.



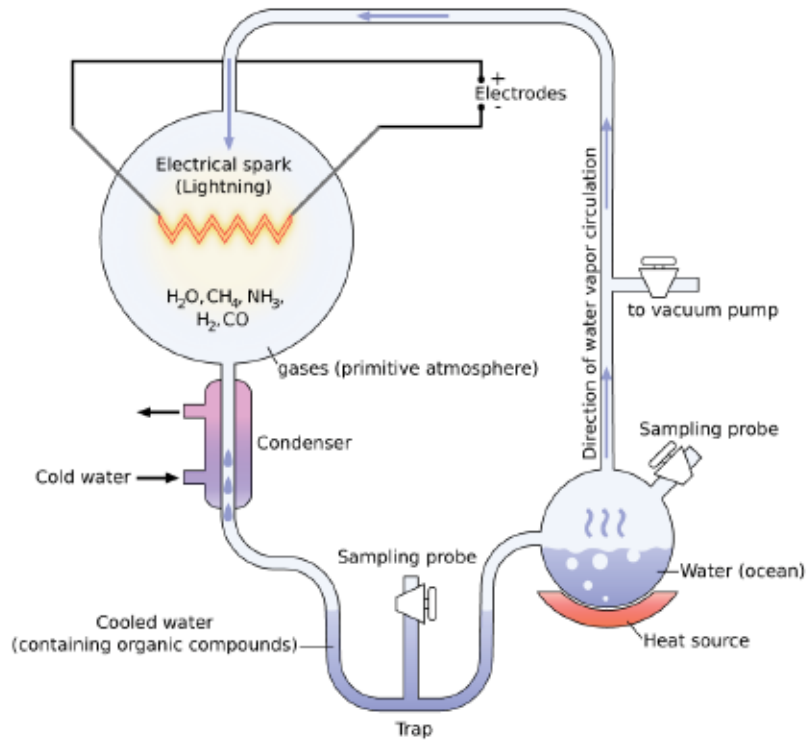
Metal cycling and transport is enhanced in the presence of Cl



Other metal-bearing minerals exhibit similar behavior



Earth's early atmosphere



How are complex molecules made in the environment of a primitive planet?

First breakthrough in this research effort was the Miller Urey experiment.

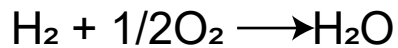
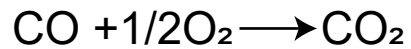
Reducing gases subjected to simulated lightning; in the mix of products were many of amino acids which are major components of the modern cells. The building blocks were made easily.

Elemental components
of gas species:

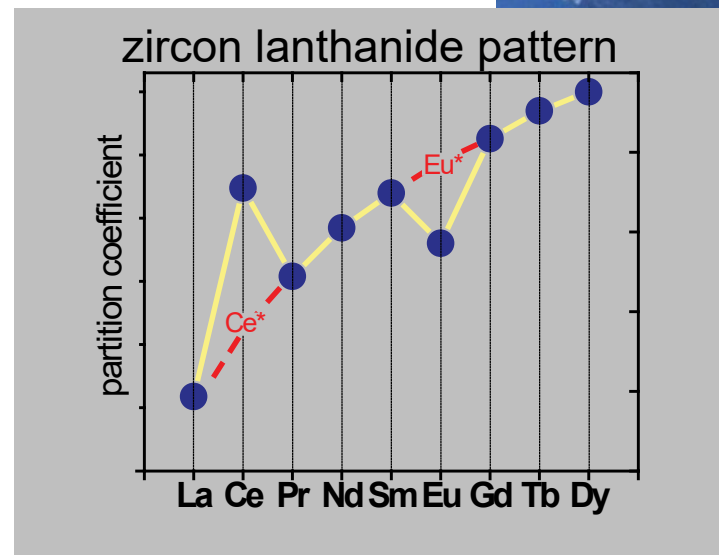
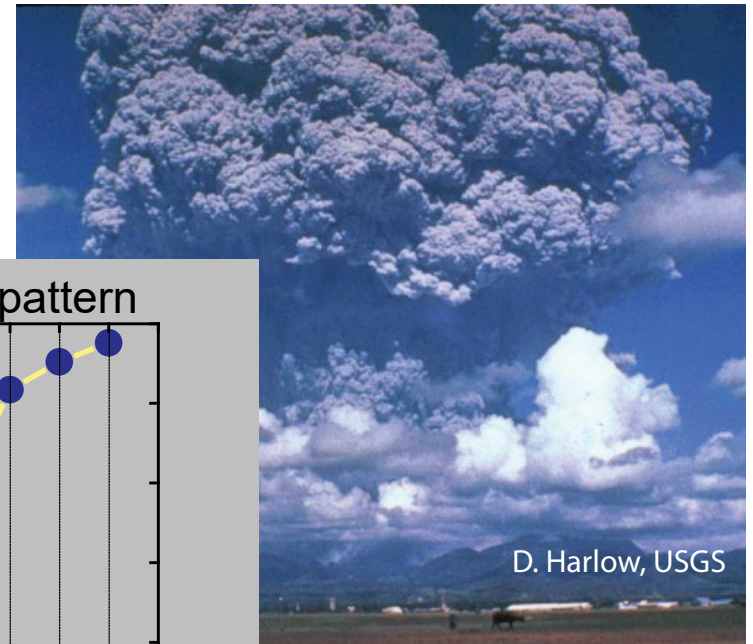
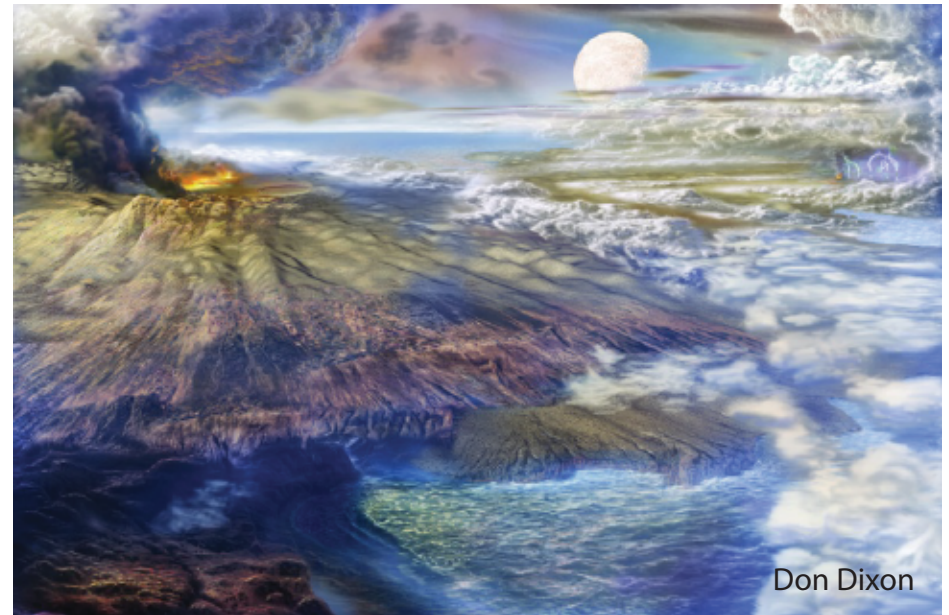
H,C,N,O,S

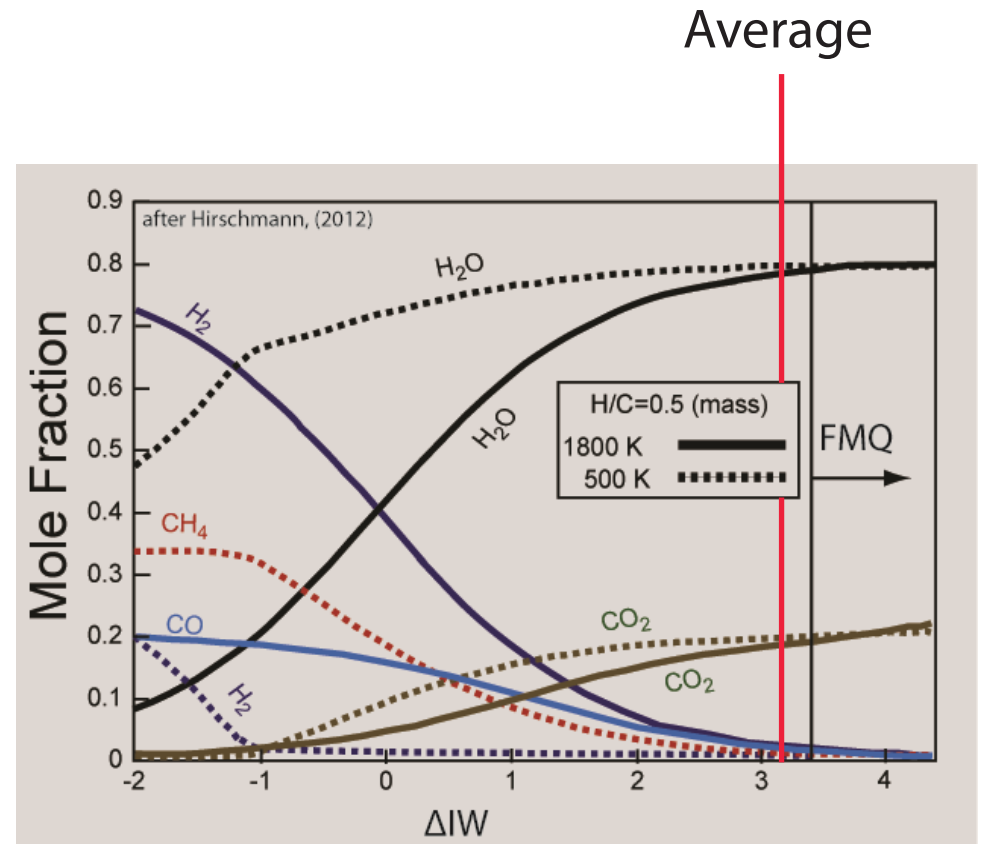
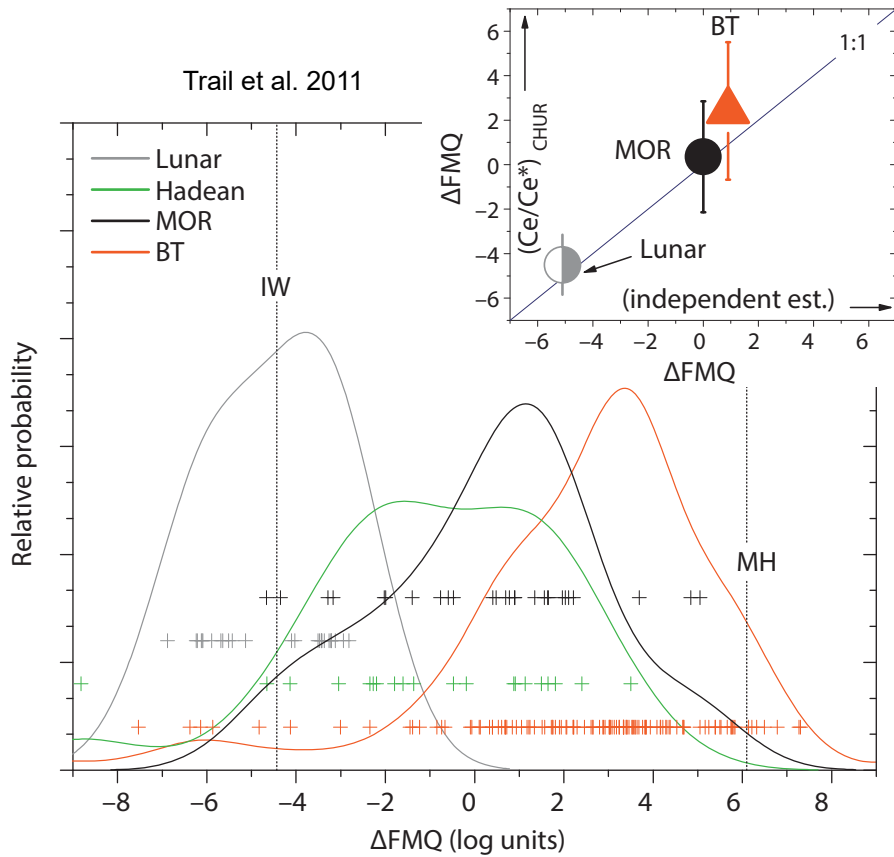
What might the speciation of volatiles
exsolved from magmas in the Hadean
have been? (e.g. H_2O , CO_2 , SO_2 vs.
 CH_4 , H_2 , CO)

**recall that zircon crystallization Ts tell us that
Hadean magmas contain volatiles...



High O_2 “pressure” drives these
reactions to the right.





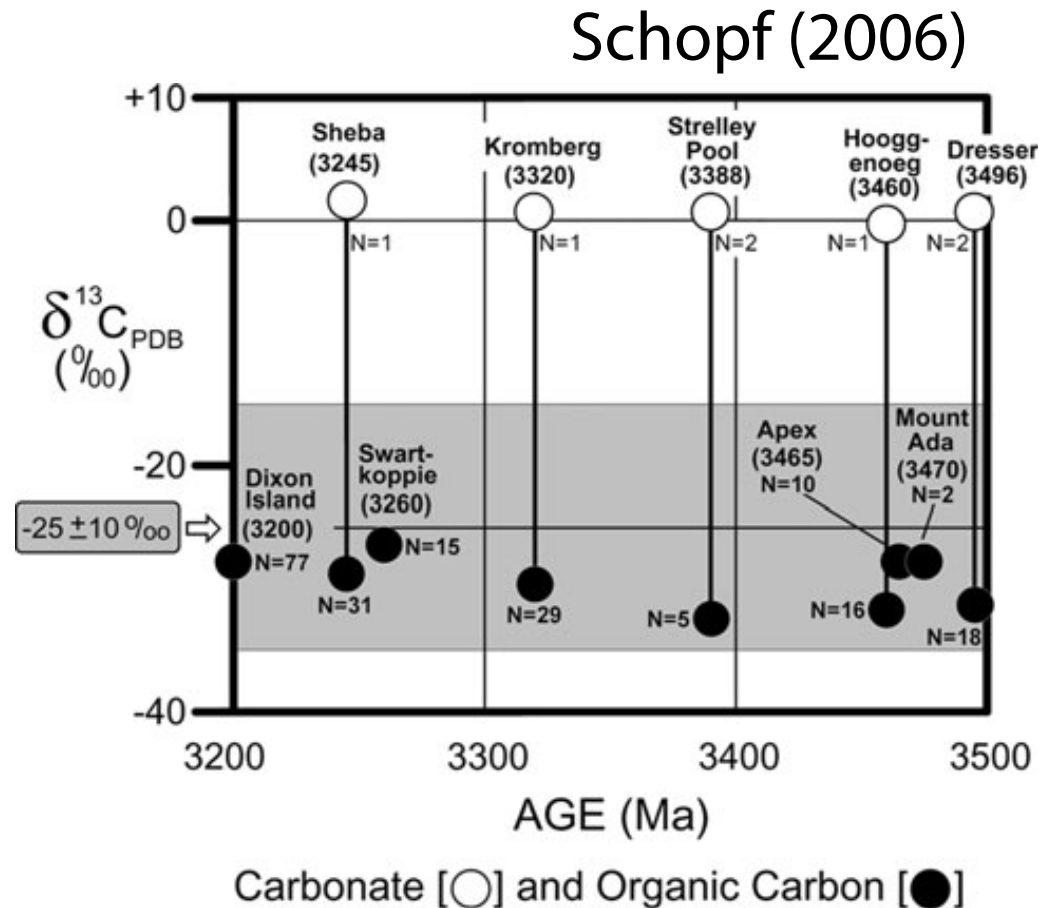
major gas components:
CO₂, H₂O, N₂

minor:
CO, CH₄

What are some likely biosignatures on the (early >3.8 Ga) Earth?

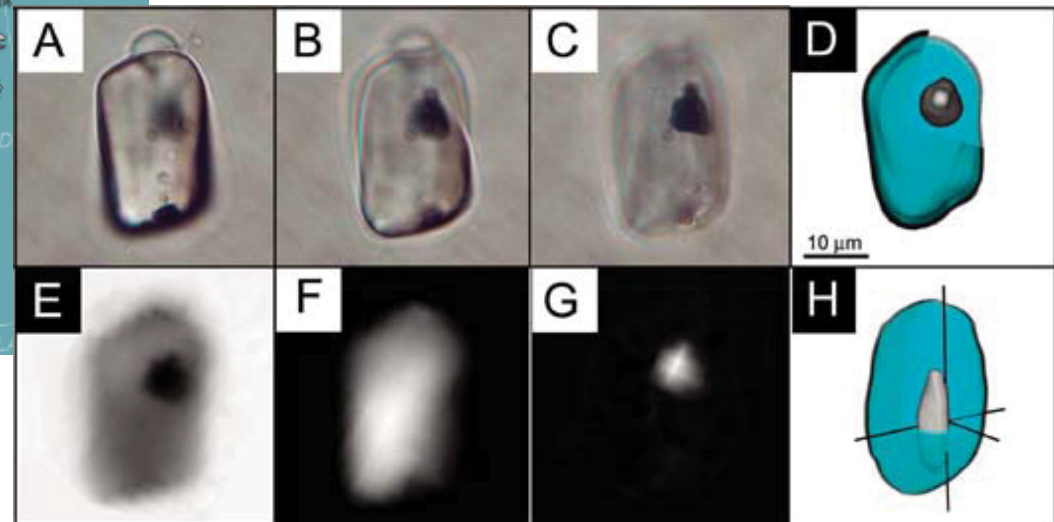


Since 540 Ma: identify dateable strata containing morphological fossils



from 0.54 to ~3.5 Ga (micro)paleontology still possible. Carbon isotopic values for carbonate and organic kerogen measured in bulk samples of microfossiliferous units.

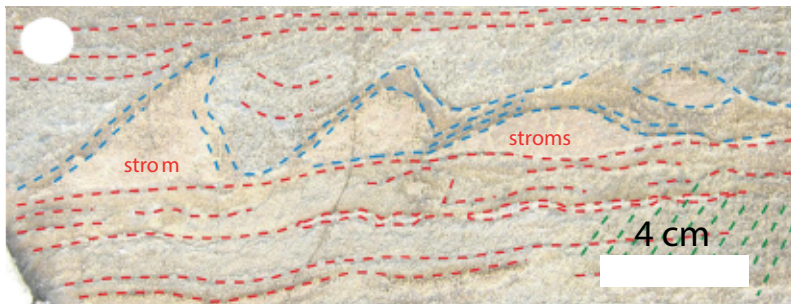
>3.5 to 3.7 Ga fossils and kerogens destroyed by high temperature and high pressure metamorphism* but some C isotope ratio biosignatures remain.



McKeegan et al., 2007

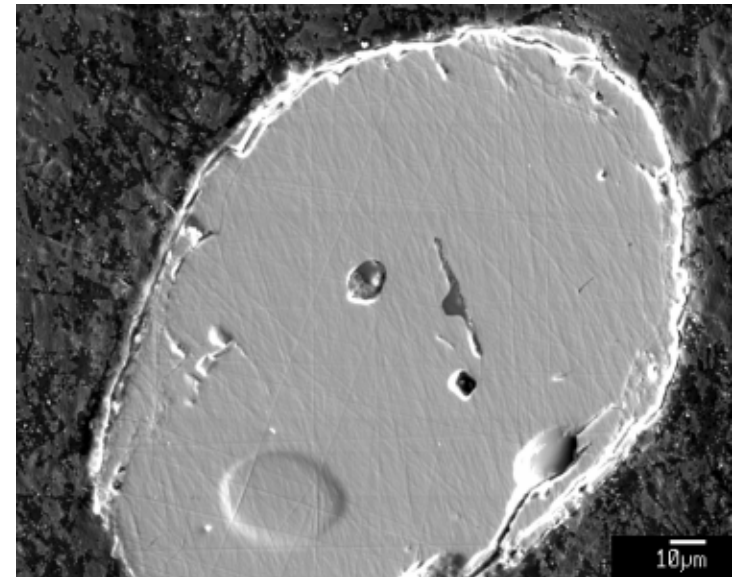
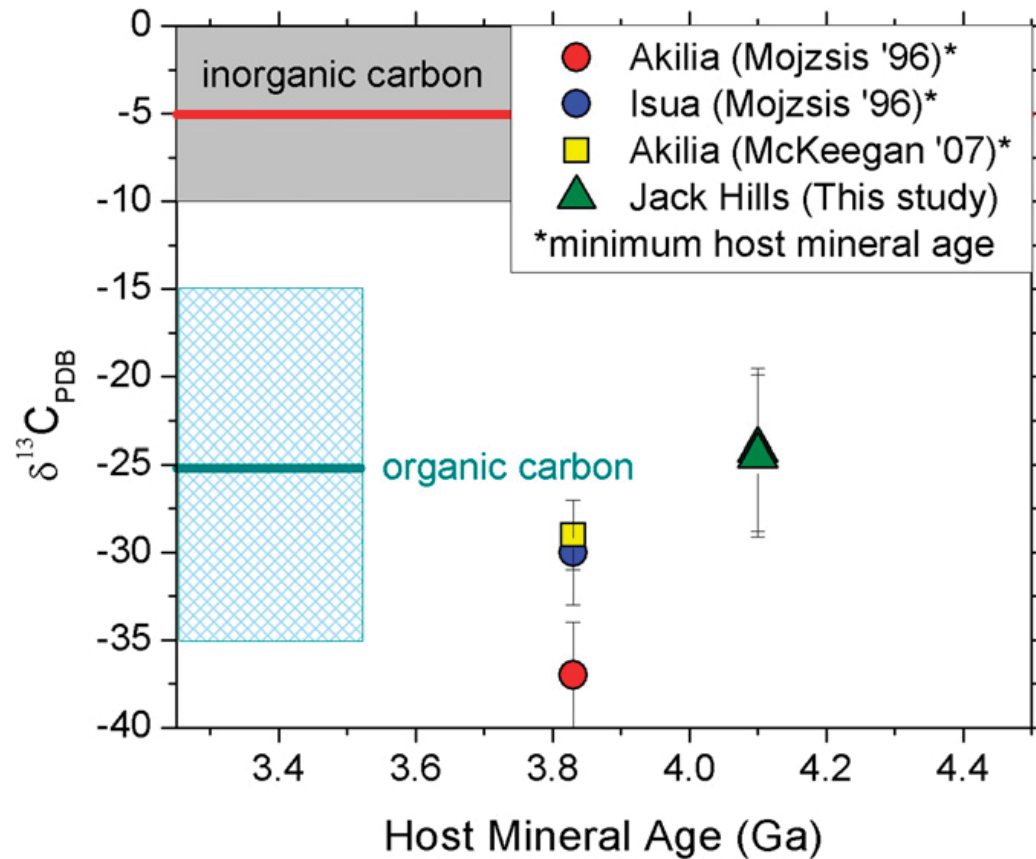
*

Nutman et al. (2016)

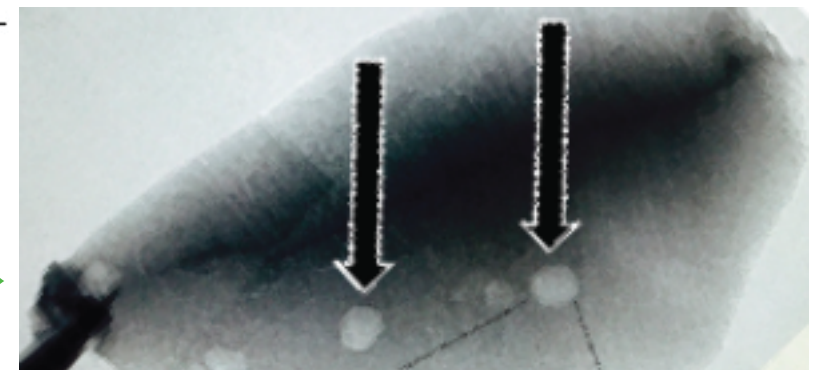


Potentially biogenic carbon preserved in a 4.1 billion-year-old zircon

Elizabeth A. Bell^{a,1}, Patrick Boehnke^a, T. Mark Harrison^{a,1}, and Wendy L. Mao^b



Transmission X-ray image of disordered graphite inclusions within a 4.1 Ga zircon crystal. (Image modified from Bell et al. 2015). The inclusions are described as primary.



~30 microns

Key Points

Crust was being weathered, buried, and recycled by 4.3 to 4.2 Ga and possibly earlier.

Hadean magma contained volatiles (zircons have low crystallization temperatures)

Evidence for sub-solidus Eoarchean crustal fluids (<600°C) that contain Cl. The presence of Cl is interesting because it can enhance the mobility metals, potentially making them 'available'

Volcanic emanations were broadly neutral.

Likely biosignatures are limited to isotope ratio measurements. Oldest record is a "graphite" inclusion (enriched in ^{12}C) contained within a 4.1 Ga zircon.

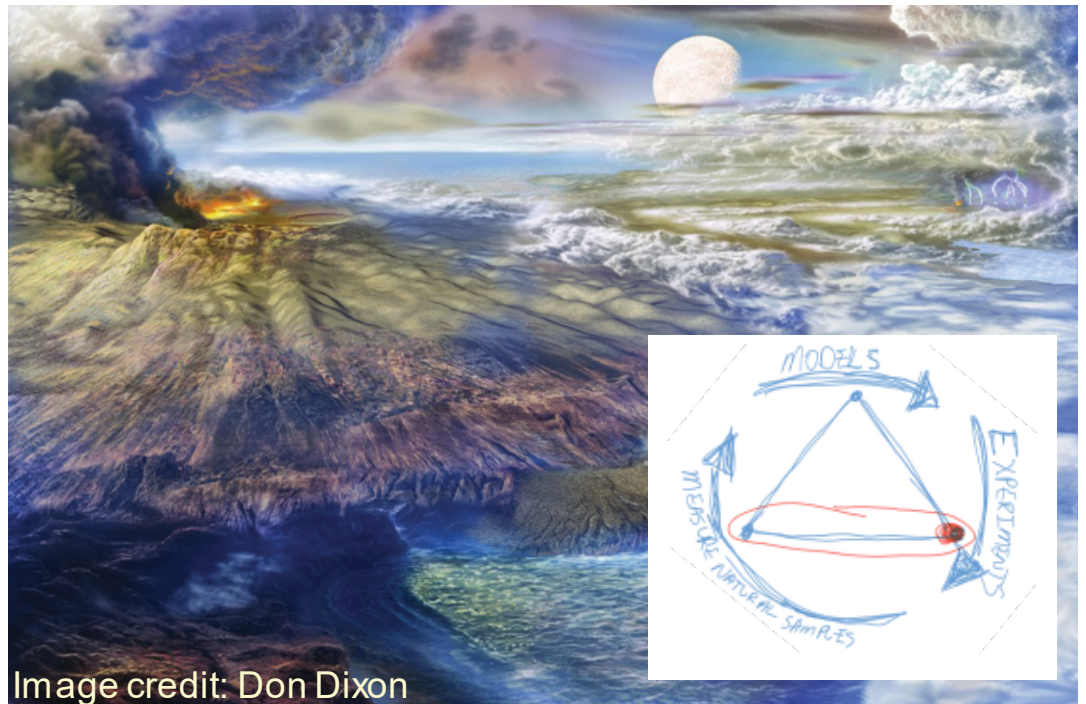


Image credit: Don Dixon