Mars Time and Martian Environments: Changing Habitability through Time and Prospects for Ancient Mars Biosignatures

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and thanks to the Mars-2020 Landing Site seminar (a multi-institution, paper-reading class)

16 May 2016 | Biosignature Preservation & Detection in Mars Analog Environments

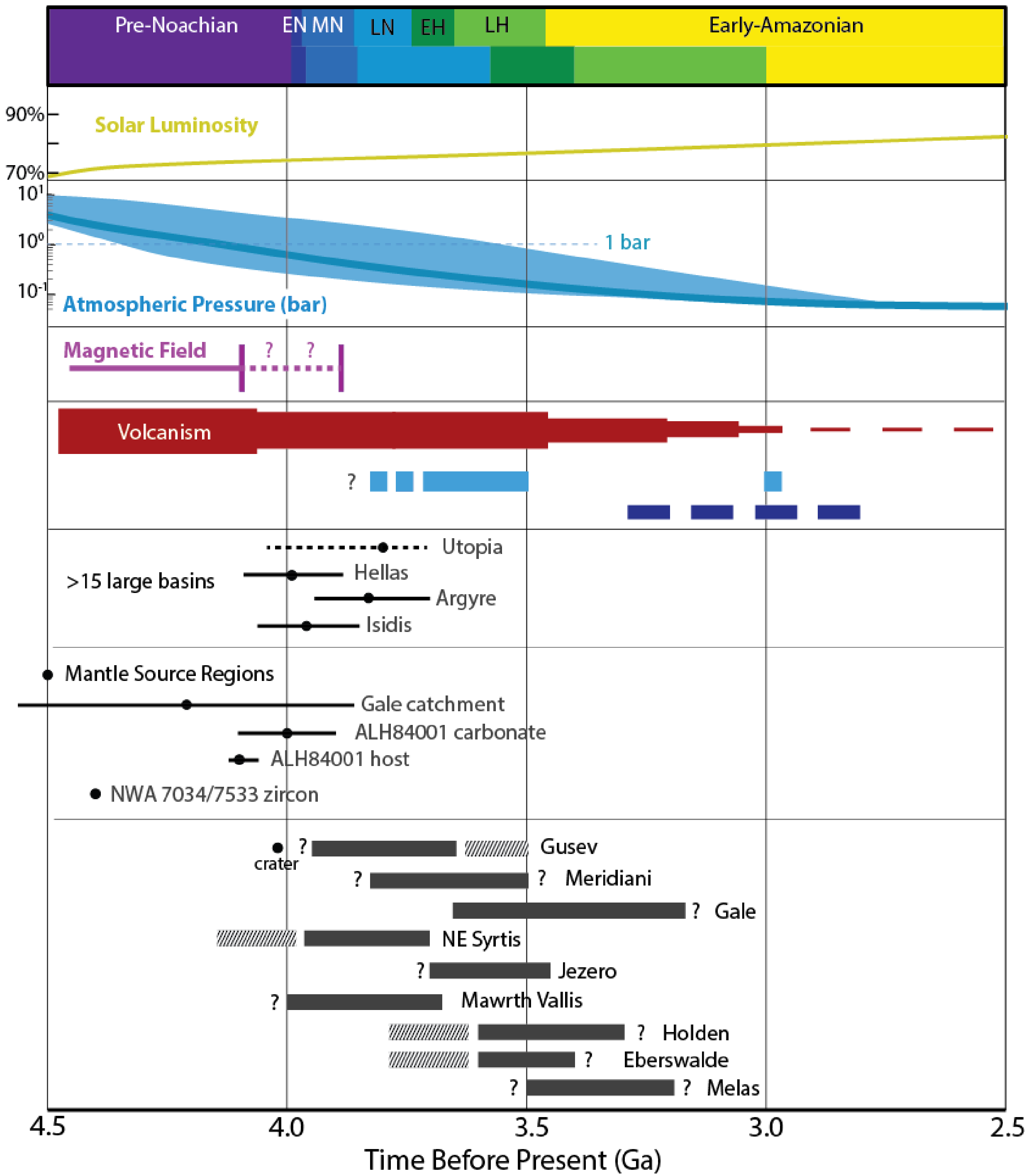
Food for thought

[While it is commonly assumed there was some period of time in Mars history when all conditions favorable to habitability] existed simultaneously (active magnetic field, valley formation, erosion and transport, aqueous alteration, etc.)….a variety of observations constraining the timing of these processes suggests that it may not be the most probable scenario.

-Fassett & Head, 2011, Icarus

This is **crucial** to think about for biosignature preservation because **preserving the signatures requires (a) that there be biomass** in the environment in question and (b) a geologic mechanism to preserve them

Martian Timeline



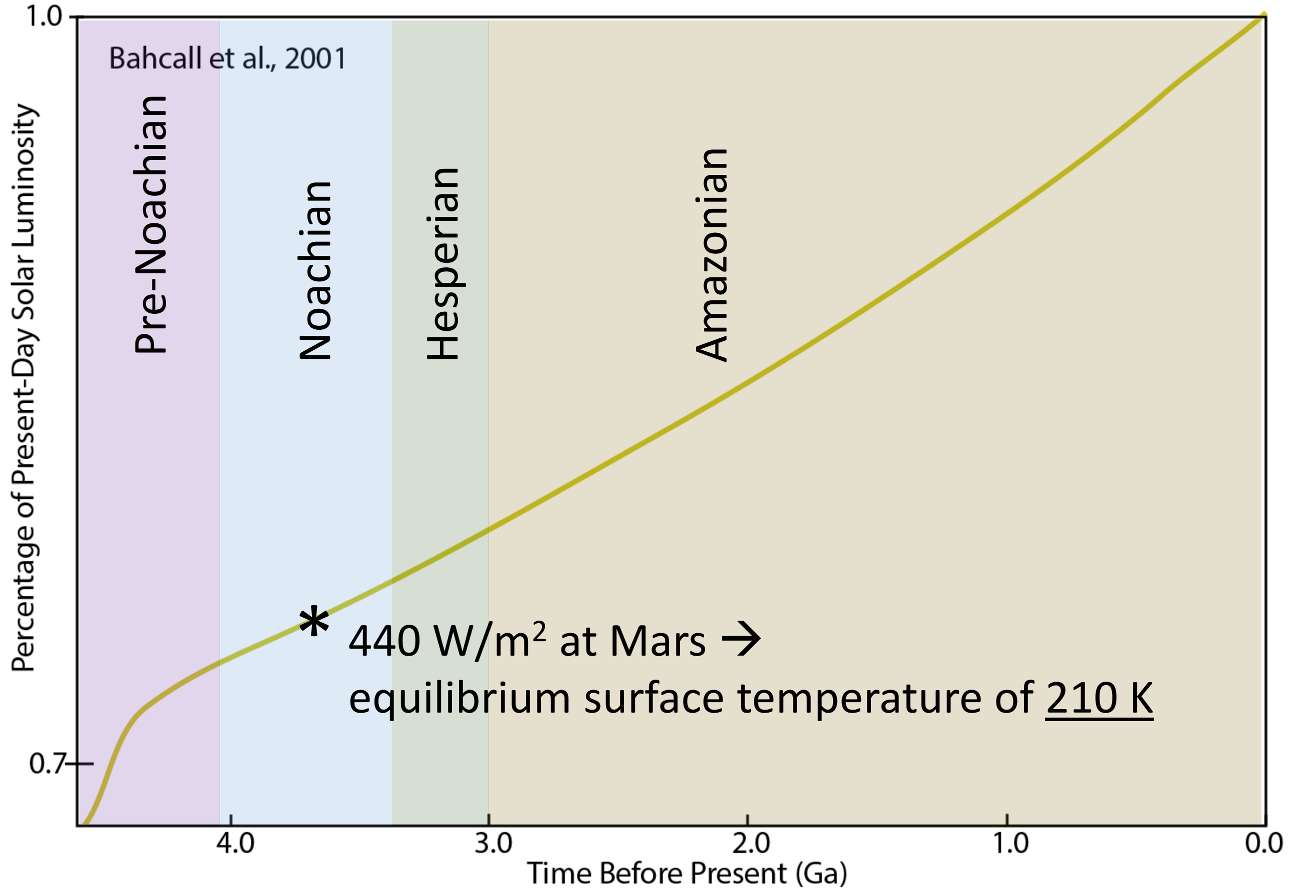
Ehlmann et al., in prep., JGR-Planets 25th anniv. issue

Key Physical Parameters for Habitability (a Pre-requisite for Biosignatures)

- Solar Luminosity
- Atmospheric Pressure
- Impacts
- Magnetic Field
- Volcanism

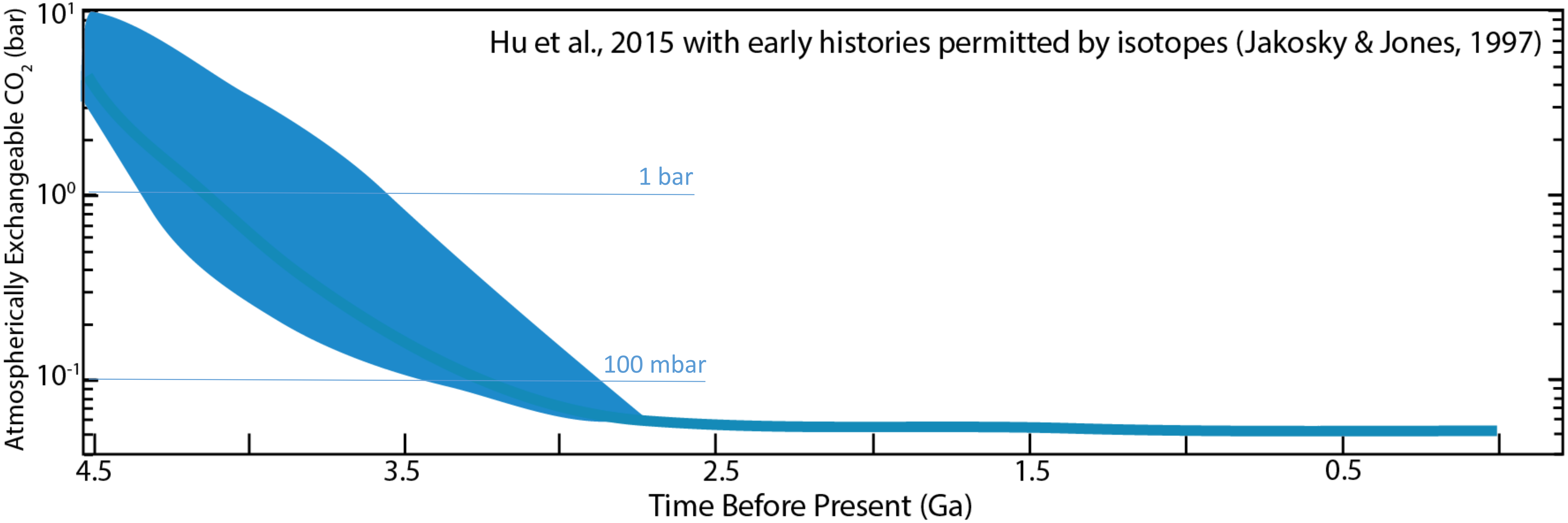
Faint Young Sun

- Solar insolation was 75% of the present value during the Noachian and Hesperian



An (Inferred) History of Atmospheric Pressure

- Multiple sources suggest multiple bars at late Noachian/early Hesperian is unlikely
  - Impact crater populations: **1.1-2.1 bar upper limit** (Kite et al., 2014, NatGeo)
  - Amount of carbonate sequestered since valley network formation: **<0.5 bar** (Edwards & Ehlmann, 2015, Geology)
  - Atmospheric loss models constrained by C isotopes: **0.5-2.1 bar upper limit** (Hu et al., 2015, NatComm)
  - Low pCO2's implied by non-detection of appreciable carbonate in YKB sediments (Bristow et al., submitted)
- However, >90% loss of atmosphere by the time of ALH84001 (e.g. see noble gas isotopes discussion in Jakosky & Jones, 1997, Rev. Geophysics)



Do Impacts Sterilize/Destroy? No. In fact, maybe good

Earth and Planetary Science Letters 442 (2016) 108–120

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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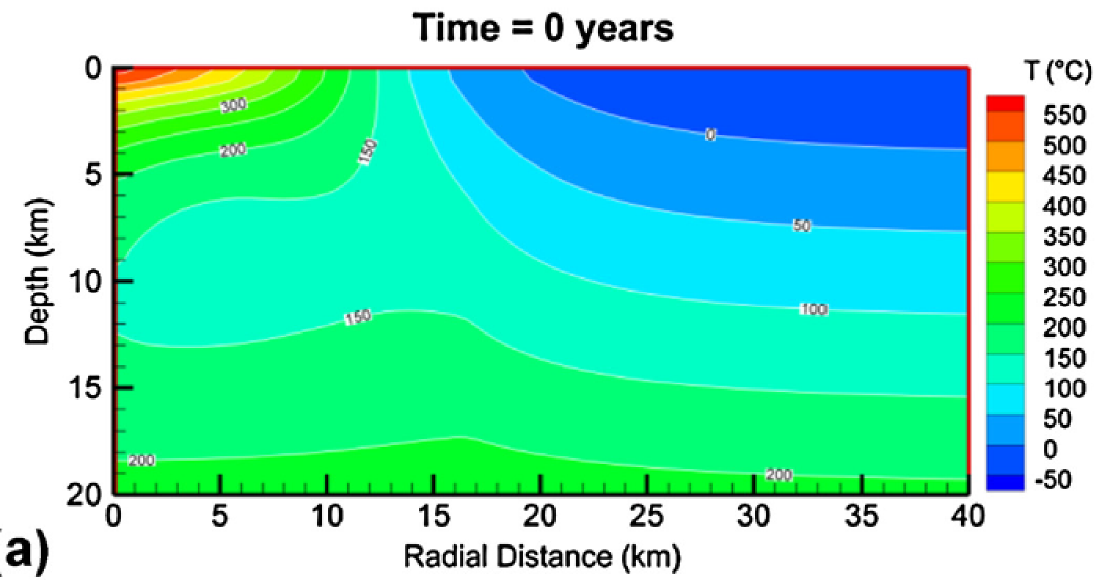
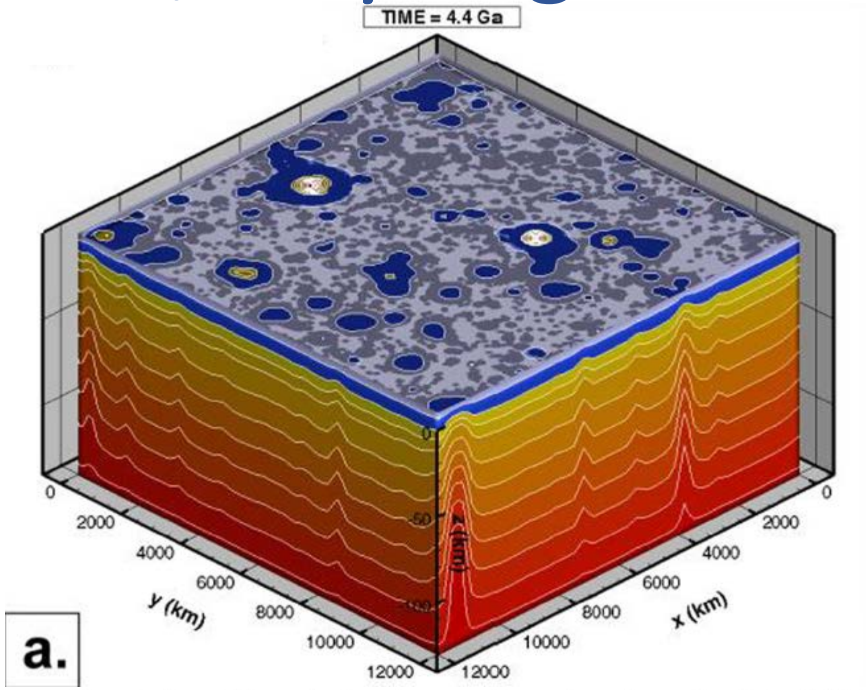
Frontiers paper

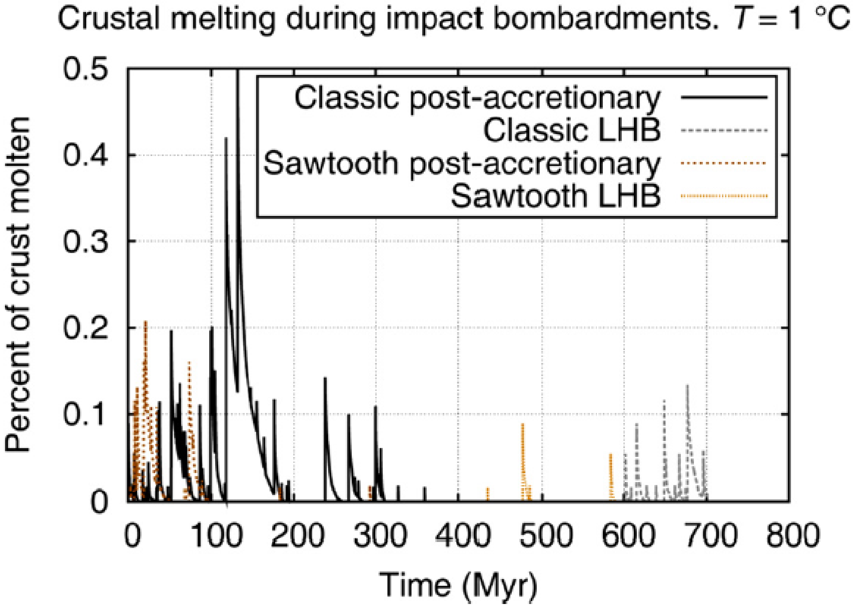
Thermal effects of impact bombardments on Noachian Mars

Oleg Abramov [a], Stephen J. Mojzsis [b,c,*]



(a)

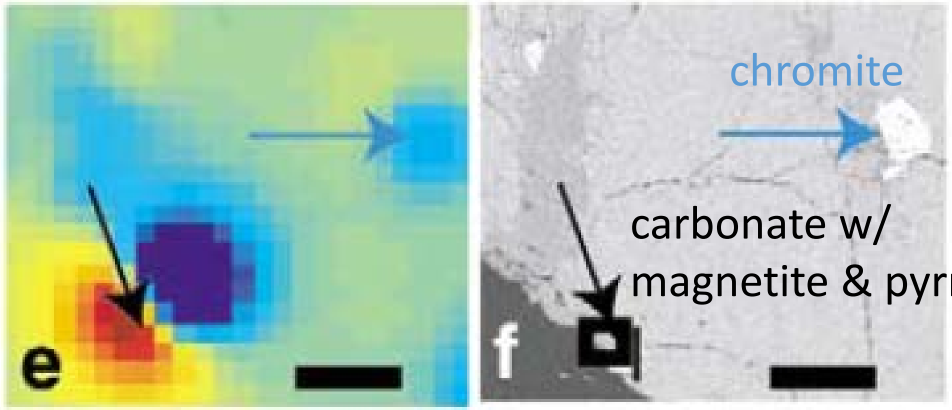




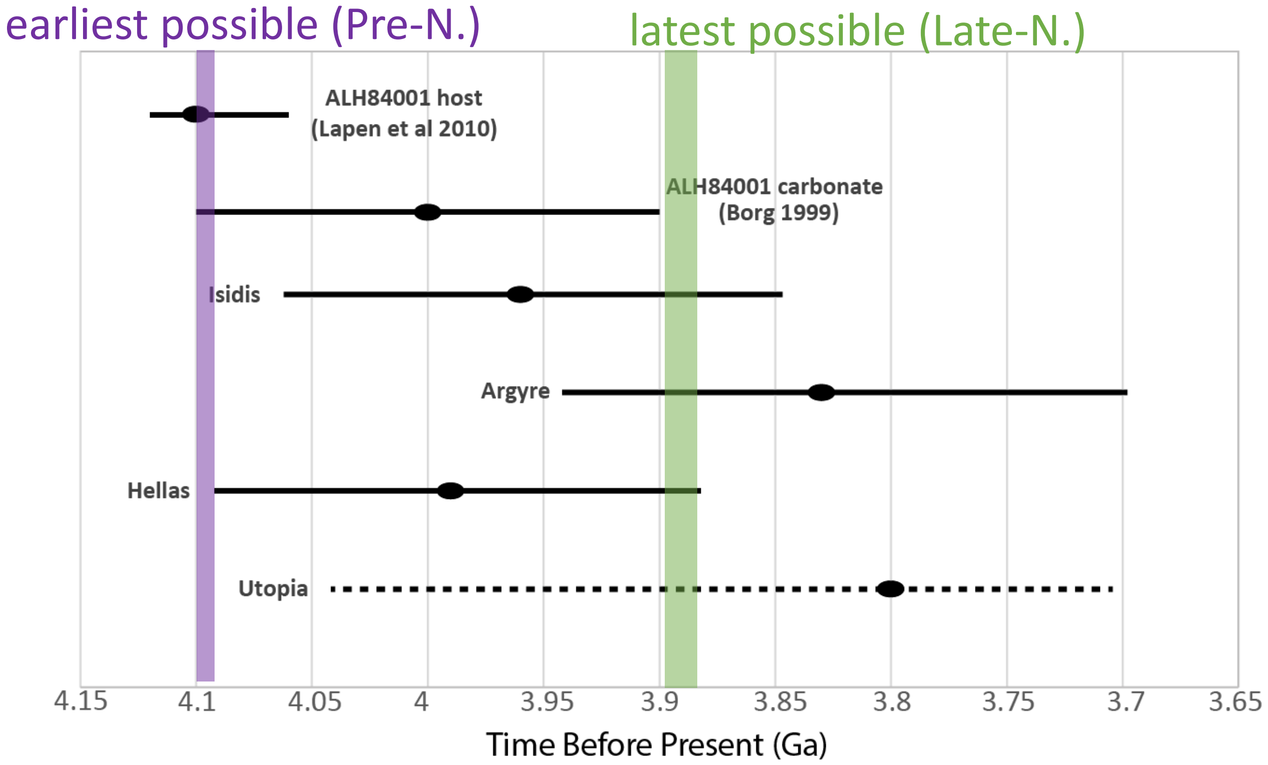
Timing of the Magnetic Field

- Remnant magnetism in ALH84001 carbonates (Weiss et al., 2002, EPSL)
- No magnetic signatures associated with the the largest impact basins (Acuna et al 1999, Science)

Magnetic carriers in ALH84001



Weiss et al., 2002, EPSL

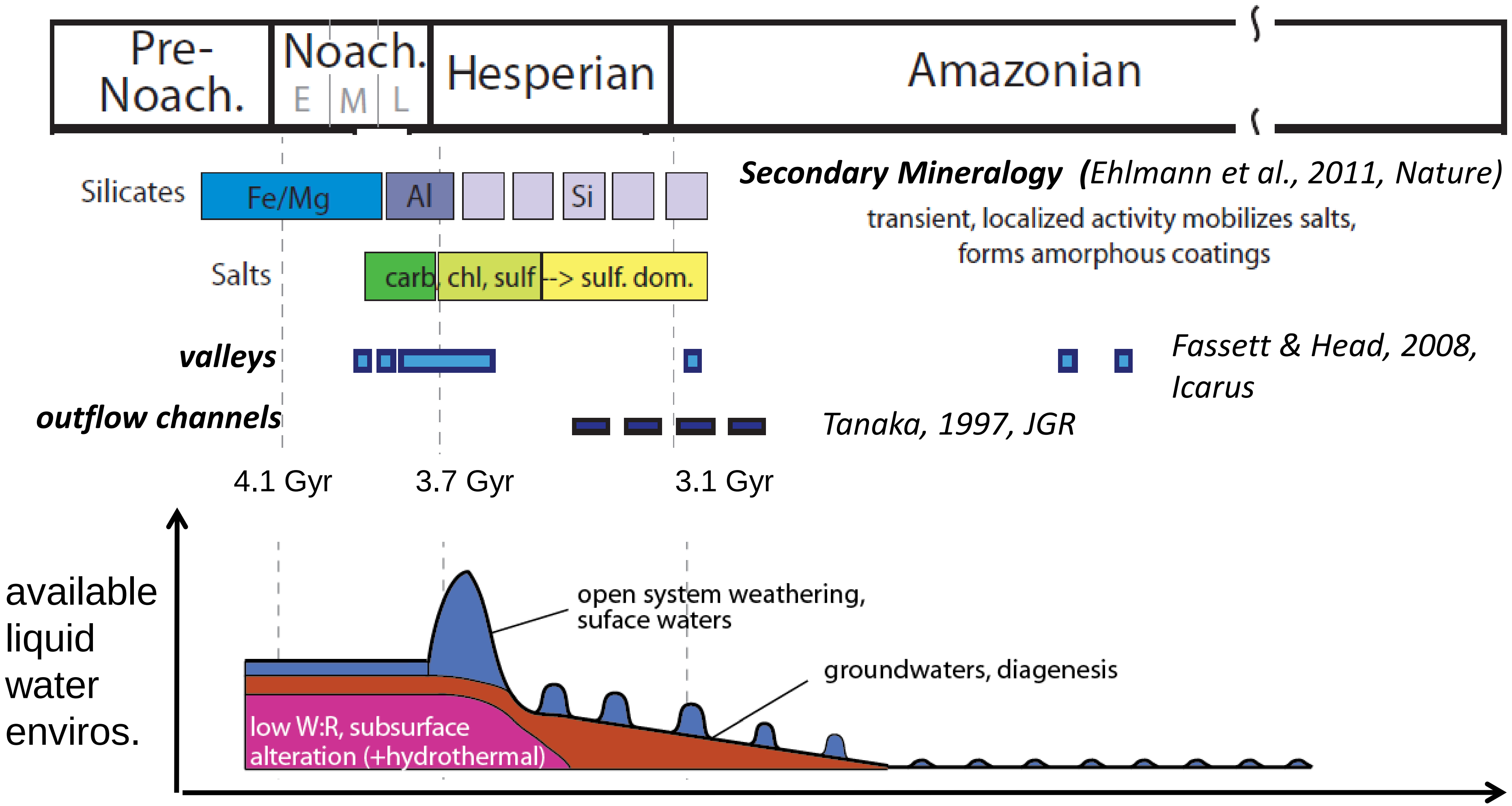


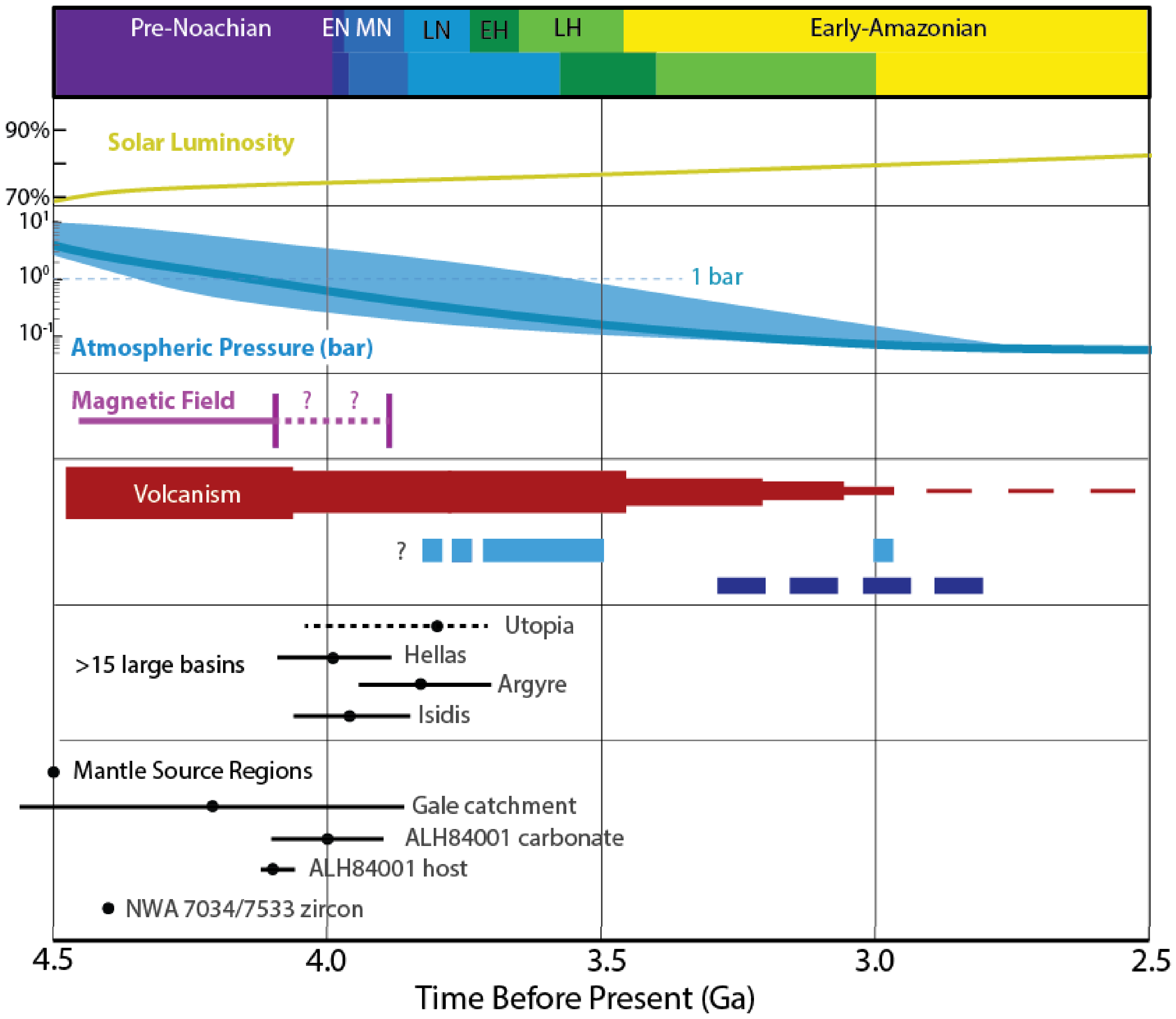
Impact Basin Ages

Name	Age in Ga	Chronology uncertainty
Argyre	3.83 ± 0.01	3.94 3.70
Hellas	3.99 ± 0.01	4.09 3.88
Isidis	3.96 ± 0.01	4.06 3.85
Acidalia[a]	(~3.7)	–
Utopia[a]	(~3.8)	–

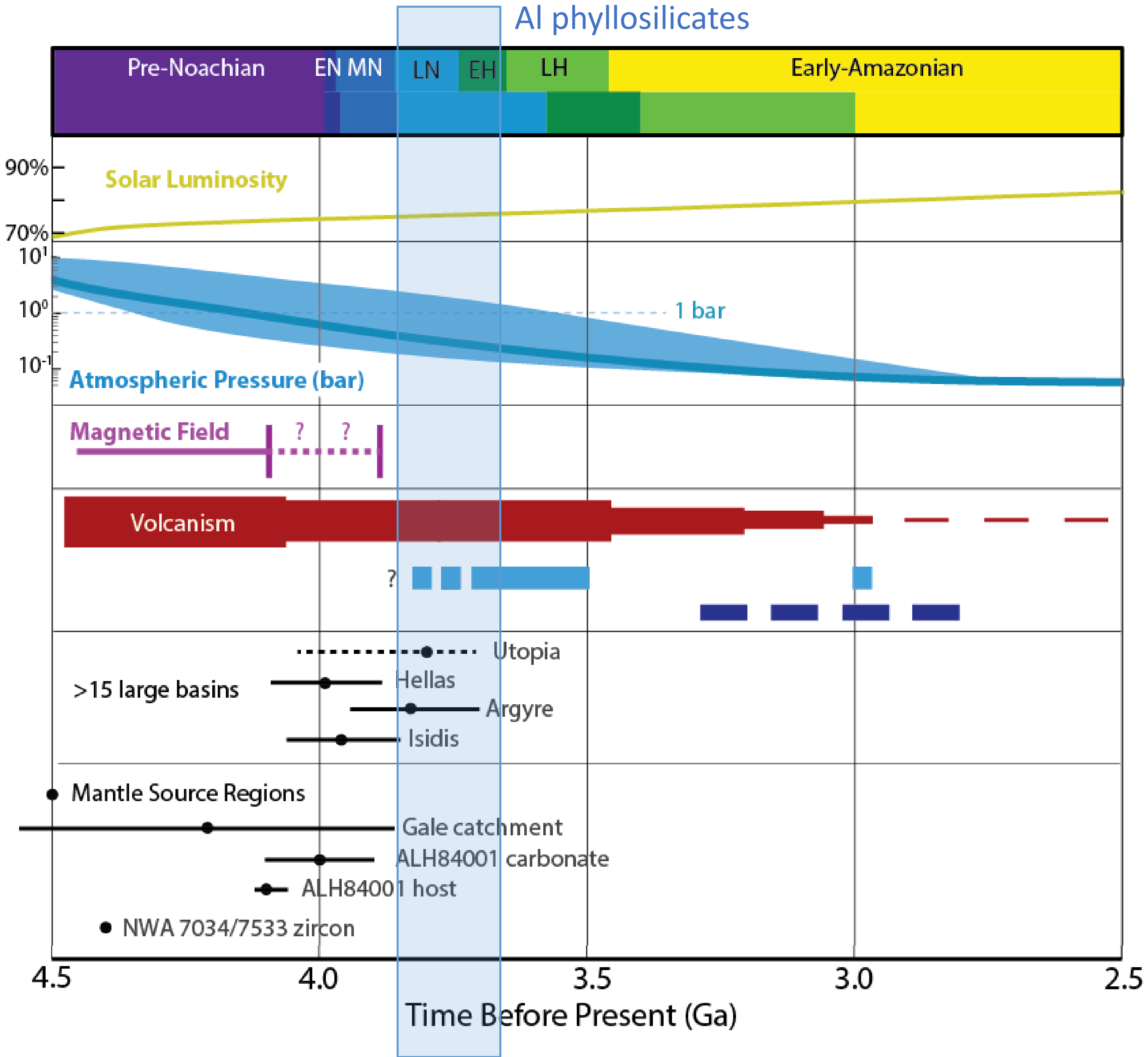
Werner, 2008, Icarus

Timing of Surface Waters and Aqueous Alteration





Ehlmann et al., in prep., JGR-Planets 25th anniv. issue



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-Fassett & Head, 2011, Icarus

Corollary:
Cold, arid conditions with only transient surface water may have characterized Mars's surface for over 4 billion years, since the early-Noachian period, and the longest-duration aqueous, potentially habitable environments may have been in the subsurface.

-Ehlmann et al., 2011, Nature

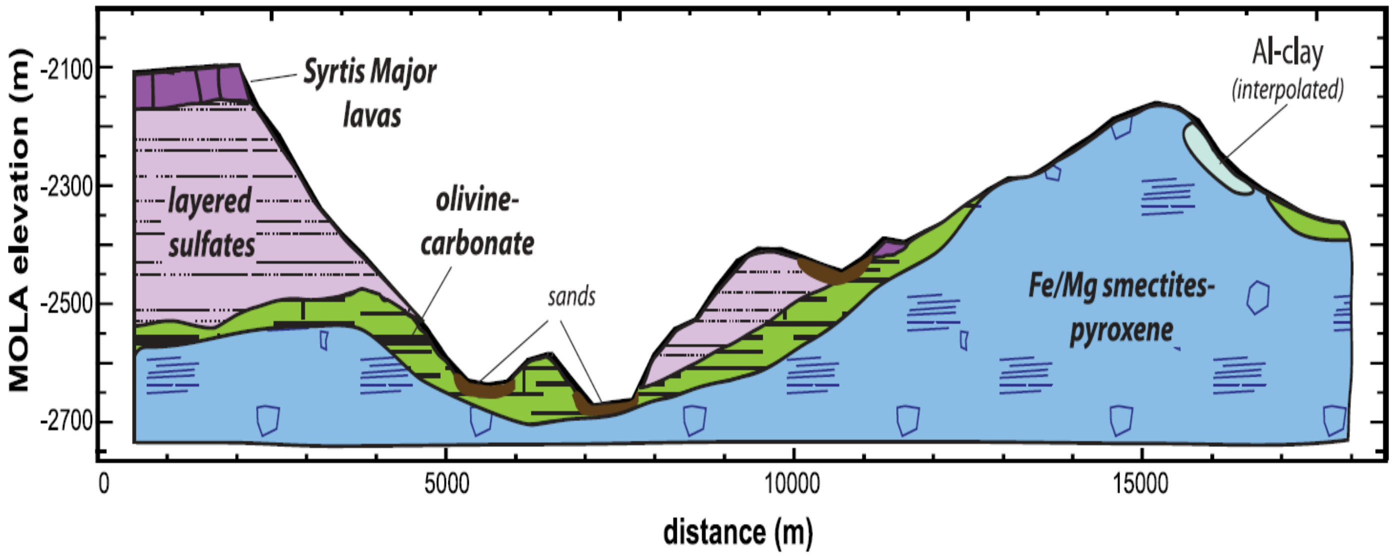
Time Periods Accessible at Each Candidate Site

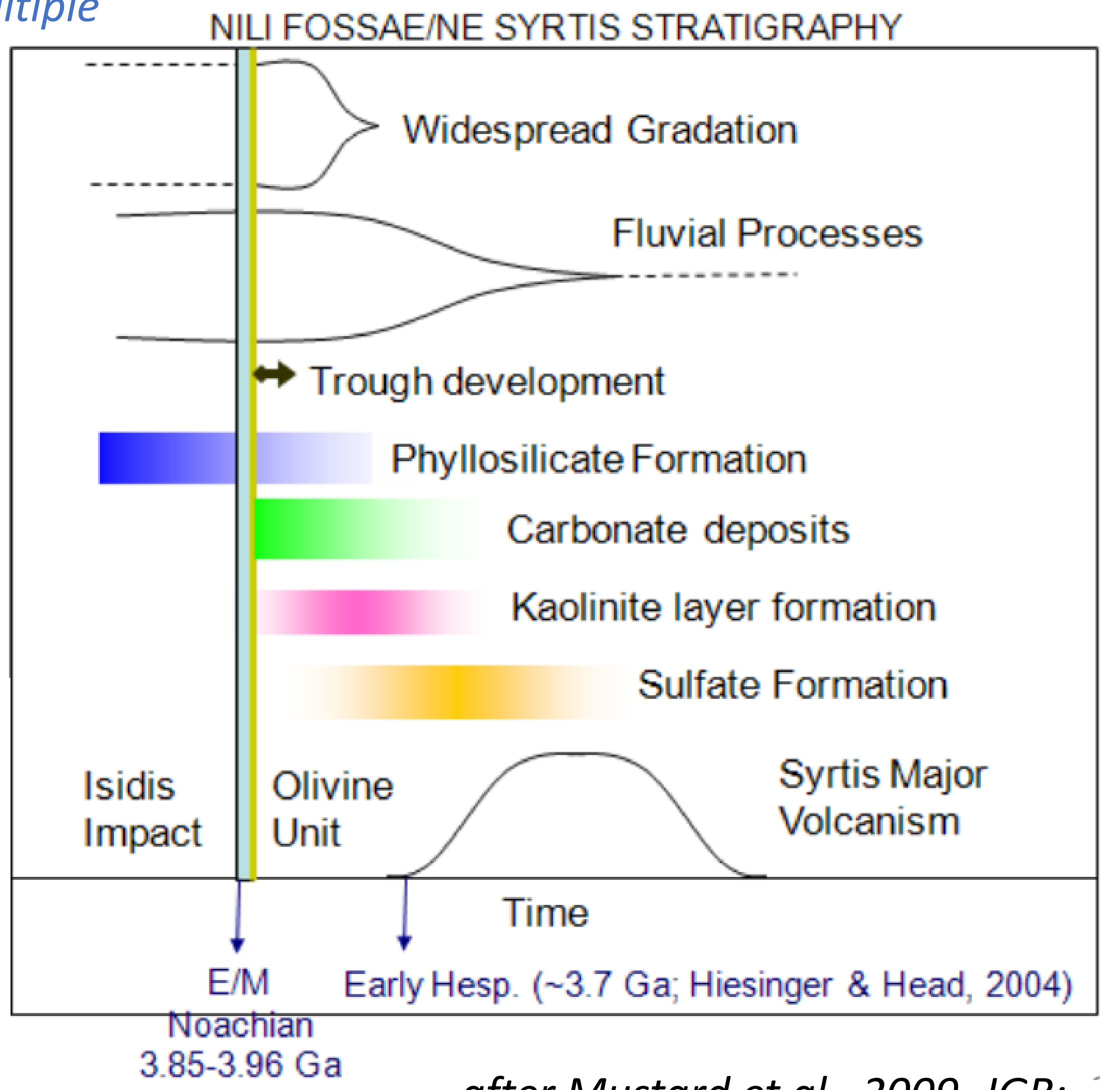
- Assumptions when making orbit-based age determinations
  - Cross cutting relationships trump crater counts
  - Crater counts are useful in a relative sense for a surface age, but can be overprinted (use with caution)
  - Desire is for a time-constrained stratigraphy of units (not just soils)
    - Assume every site has some access to Amazonian processes but these will not be counted unless there is a stratigraphic unit
  - Megabreccia of sufficient size to ensure capturing a stratigraphy (>10m) should be noted

Timing: Nili Fossae & NE Syrtis

Ancient stratigraphies preserving multiple geologic units with multiple clays, (carbonates, sulfates at NE Syrtis), lavas, impact products

- Firm stratigraphic constraints provided by crater counts and cross-cutting relationships
  - Early to Middle Noachian Isidis impact (3.96 Ga; Werner, 2008)
  - Early Hesperian Syrtis Major flows (~3.7; Hiesinger & Head, 2004)



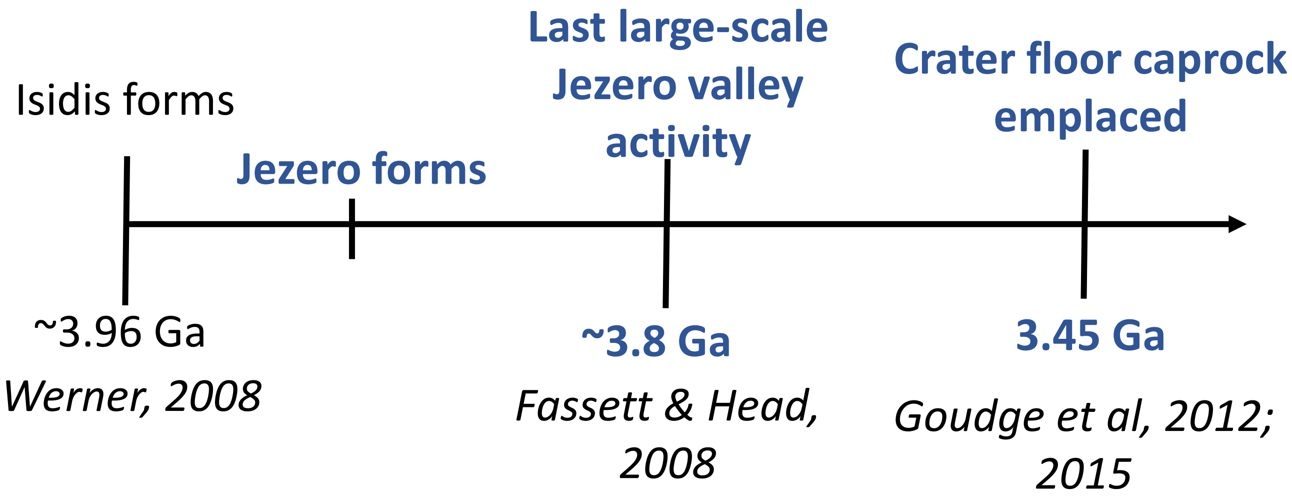


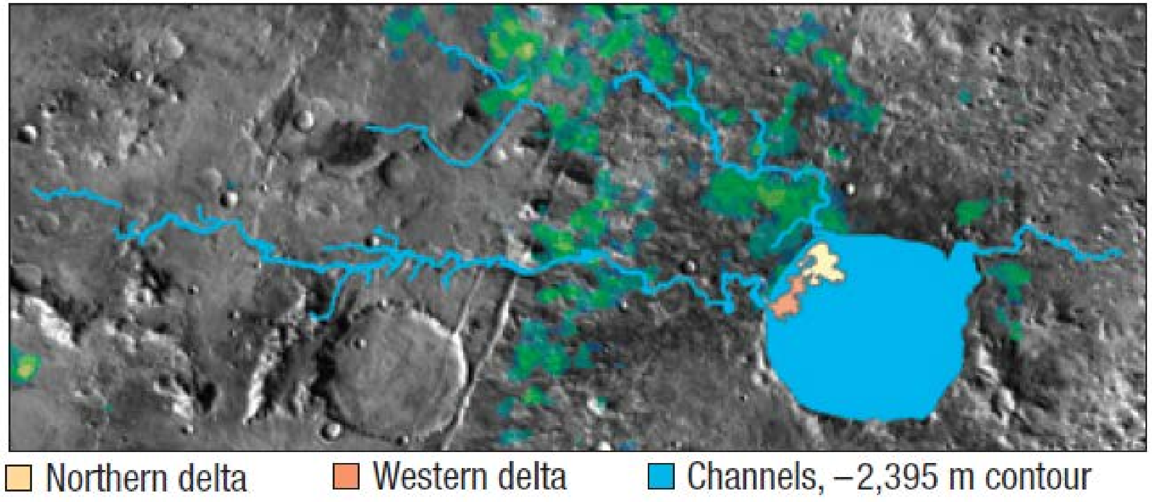
after Mustard et al., 2009, JGR; Ehlmann & Mustard, 2012, GRL

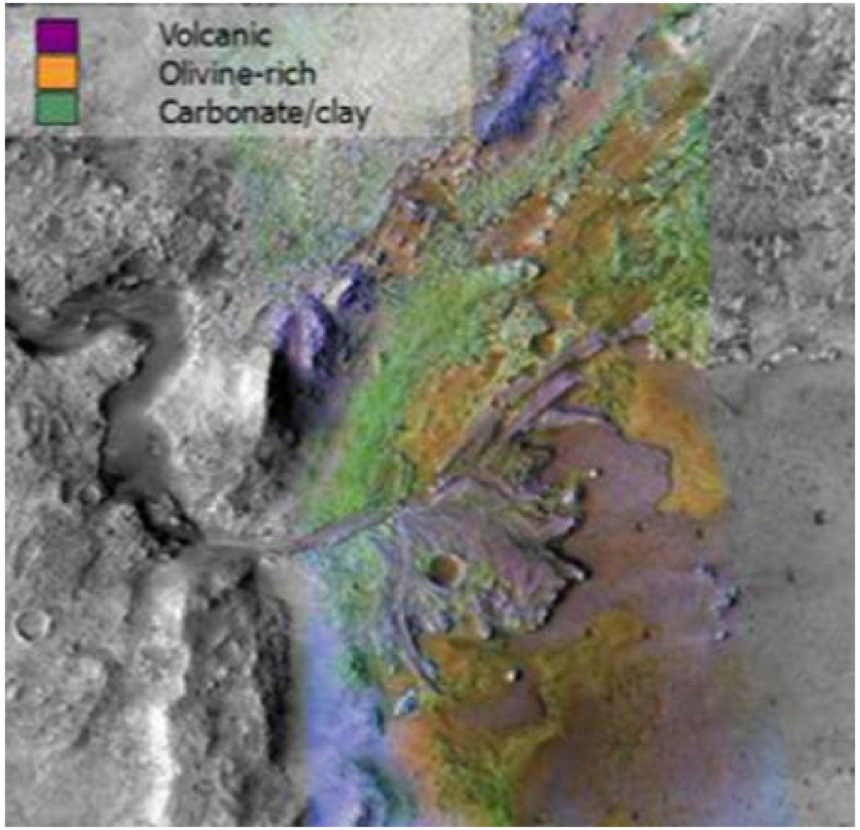
Timing: Jezero Delta

Clay & carbonate-bearing deltaic sediments, drains Nili Fossae/NE Syrtis catchment

- Constrained to post-Isidis (~3.96 Ga) and prior to emplacement of a capping unit (3.45 Ga)
- Last large scale feeder valley network activity ~3.8 Ga from buffered crater counts



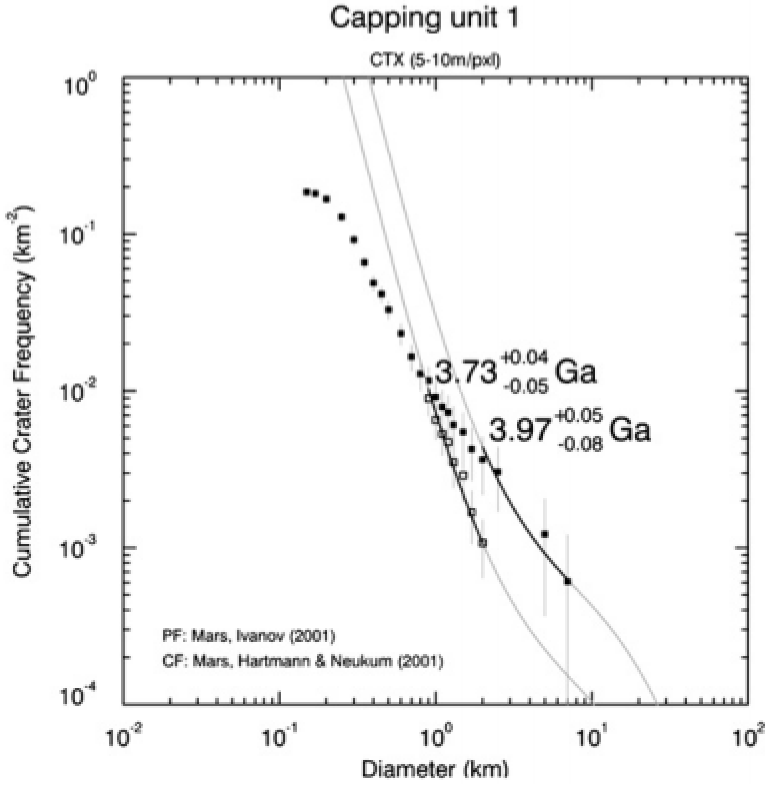


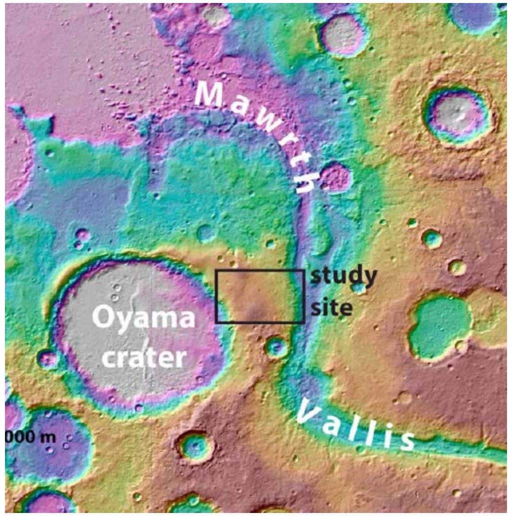


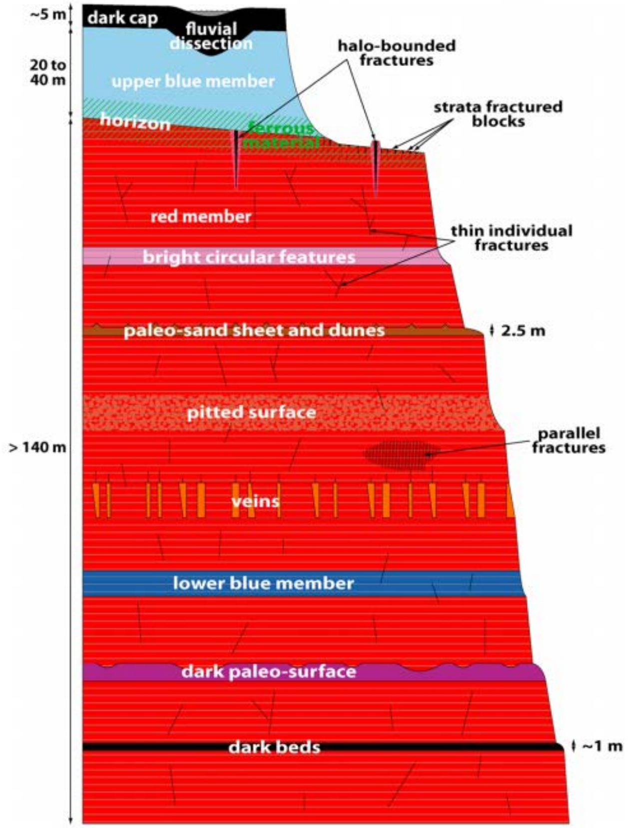
Timing: Mawrth Vallis

Ancient stratigraphy preserving multiple geologic units with multiple clays, sulfates

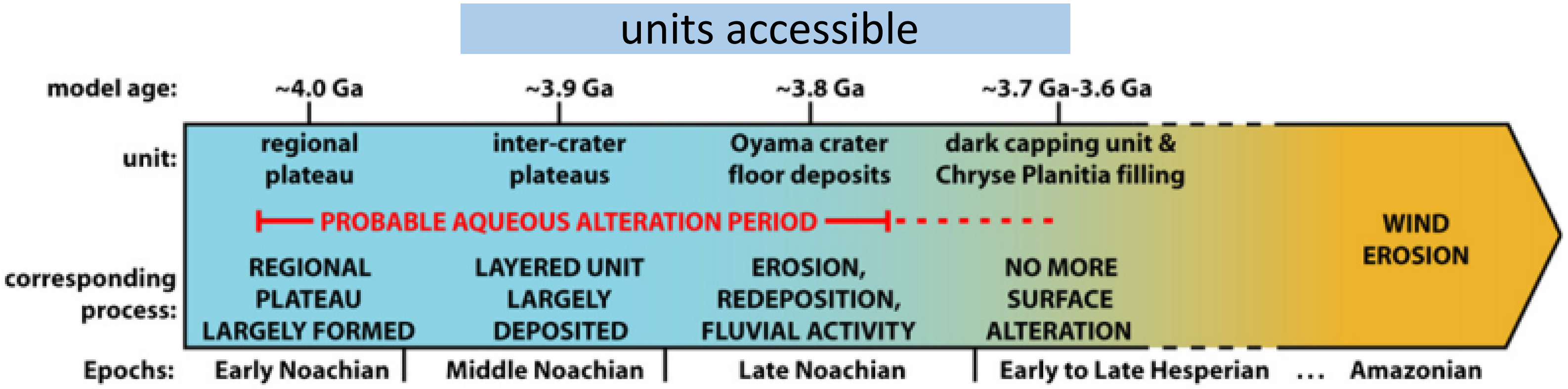
- Approximate stratigraphic age for plateau formation, underlying the phyllosilicates (~4.0 Ga)
- Dark cap unit age (~3.7 Ga)







Loizeau et al, 2012, PSS; 2015, Icarus



Timing: Gusev Crater

Ancient central peak hills (?) deposits, with draped ashes, altered by volcanic activity to carbonate and clay, spring or hydrothermal leaching silica mineralization

- Gusev crater formed ~4.0 Ga
- Volcanic plains unit ~3.65 Ga embays the Columbia Hills
- However, age of some key Spirit rover deposits uncertain because they drape the hills

Gusev forms

Columbia Hills form, draped by tephras

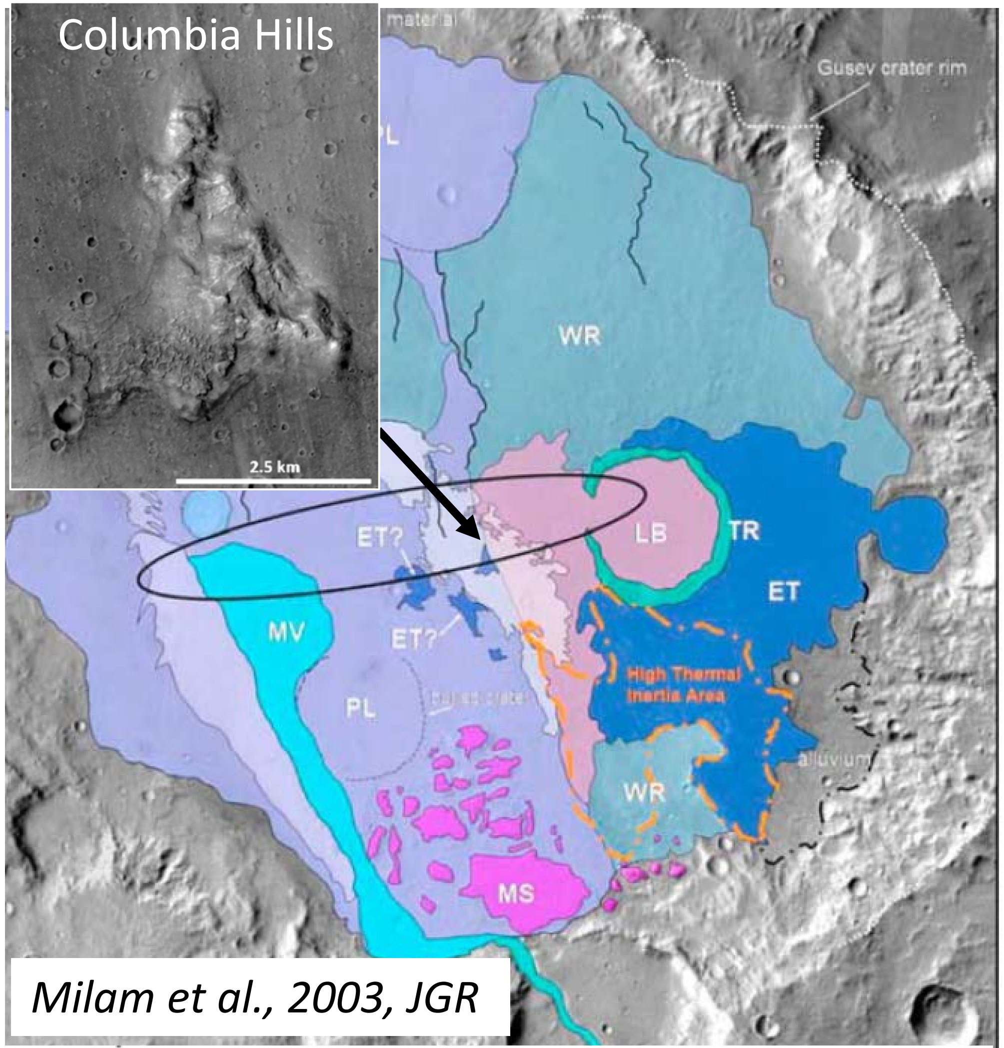
Crater floor volcanic plains emplaced

a Gusev lake? (no obv. sed.)

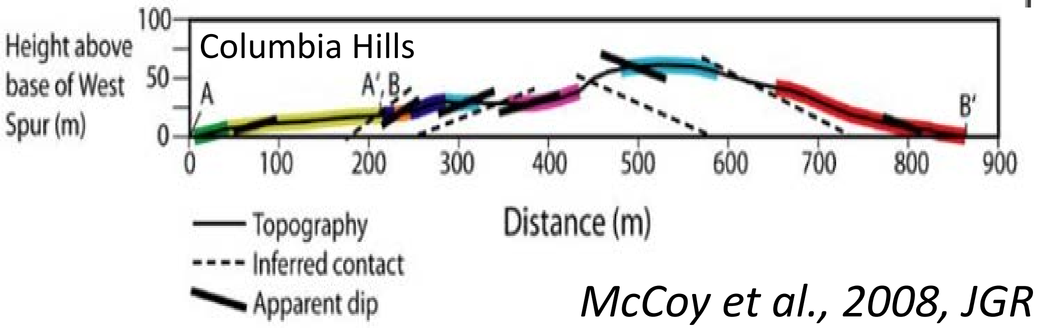
~3.9-4.1 Ga
Werner, 2008

3.65 Ga
Greeley et al., 2005

Home Plate silica?



Milam et al., 2003, JGR

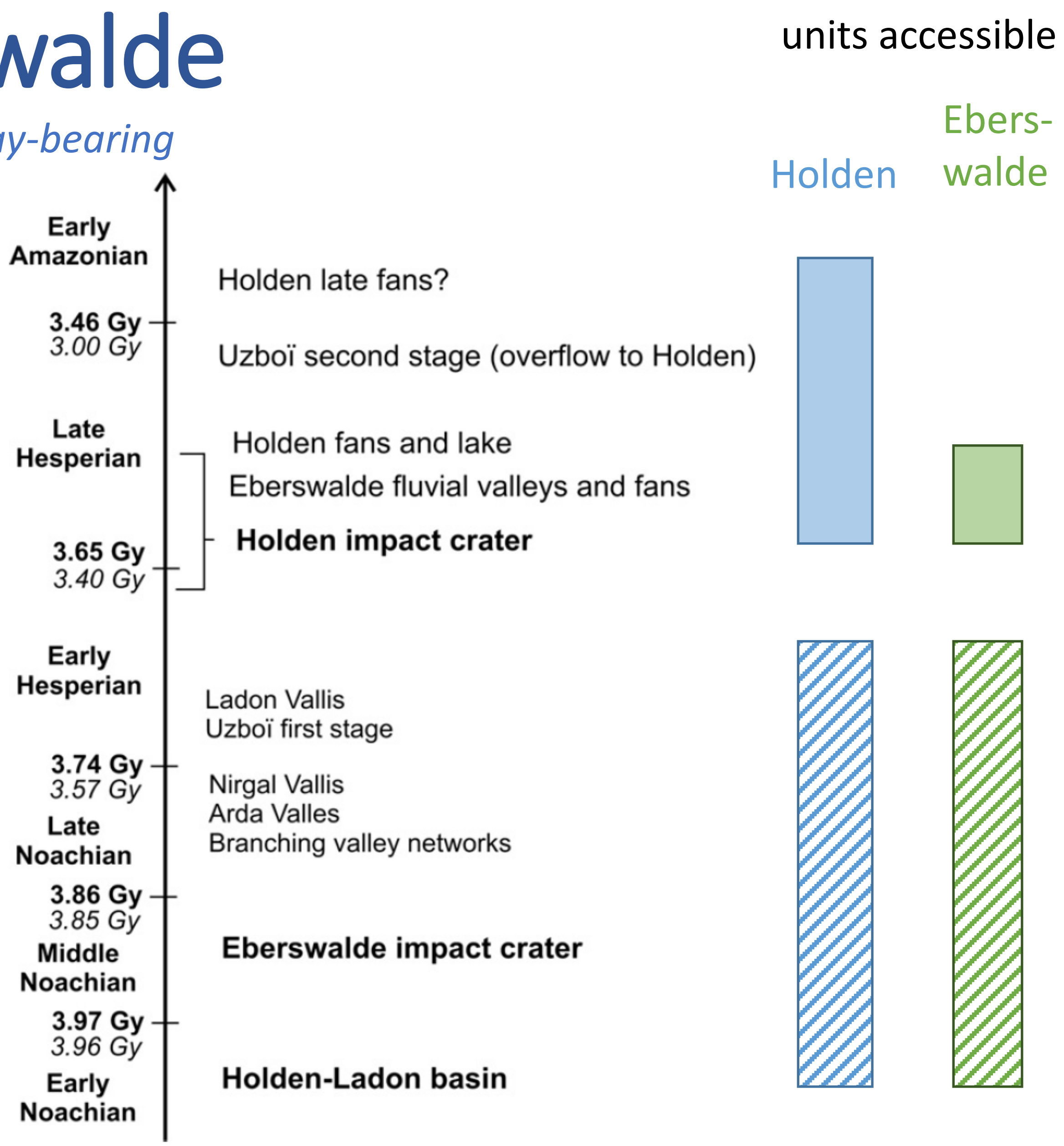


McCoy et al., 2008, JGR

Timing: Holden & Eberswalde

Series of lacustrine, (outflow channel at Holden), and clay-bearing fluvial deposits, possible access to megabreccia

- Holden crater formed (3.65-3.4 Ga; Late Hesperian)
- Its ejecta underlie Eberswalde delta deposits
- Latest sedimentary unit age not well constrained, possibly early Amazonian
- Megabreccia at both Holden and Eberswalde may access the earlier period of Holden-Ladon basin activity

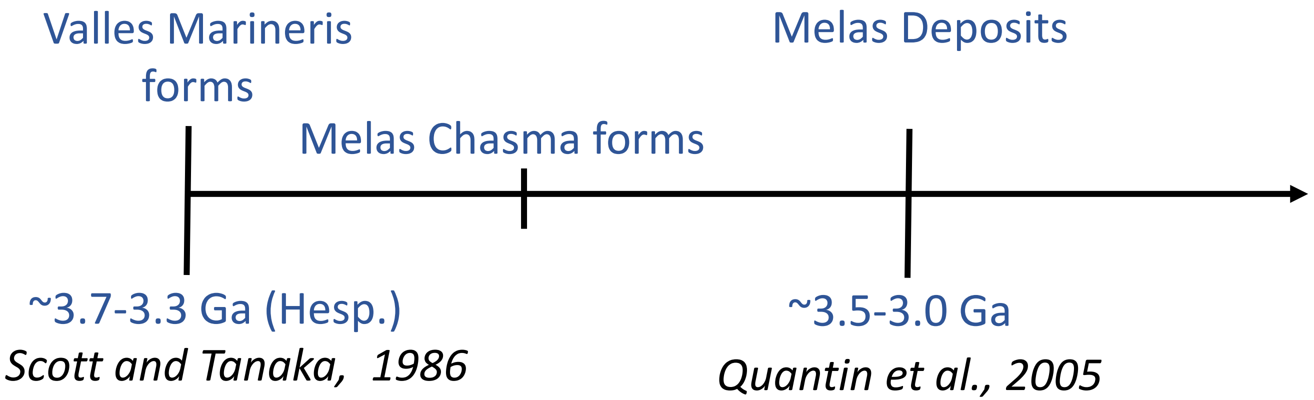


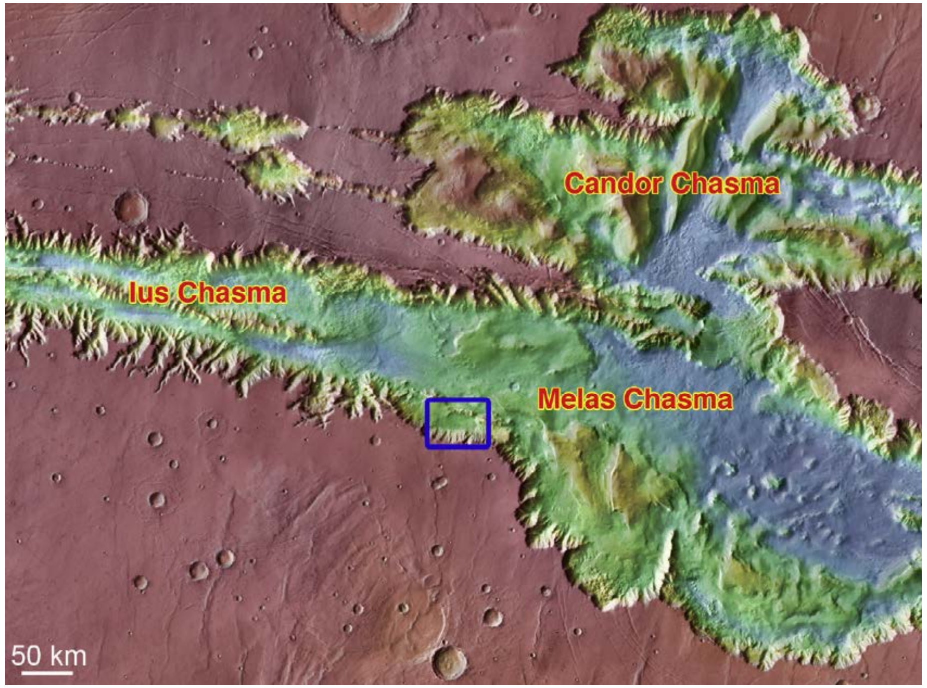
Mangold et al., 2012, Icarus; see also Rice et al., 2013, Mars J.

Timing: Melas Chasma

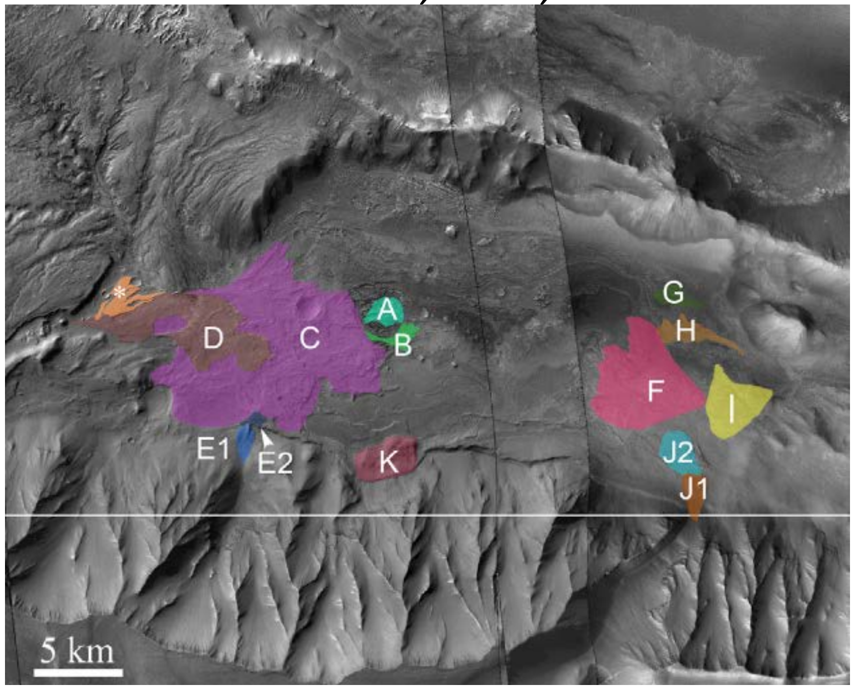
Series of lacustrine and fluvial deposits mineralized to silica and jarosite in select locales

- Valles Marineris formed in the Hesperian
- Melas Chasma formed later
- Melas sedimentary deposits are hard to date but appear to be from ~3.0-3.5 Ga (late Hesperian, early Amazonian)

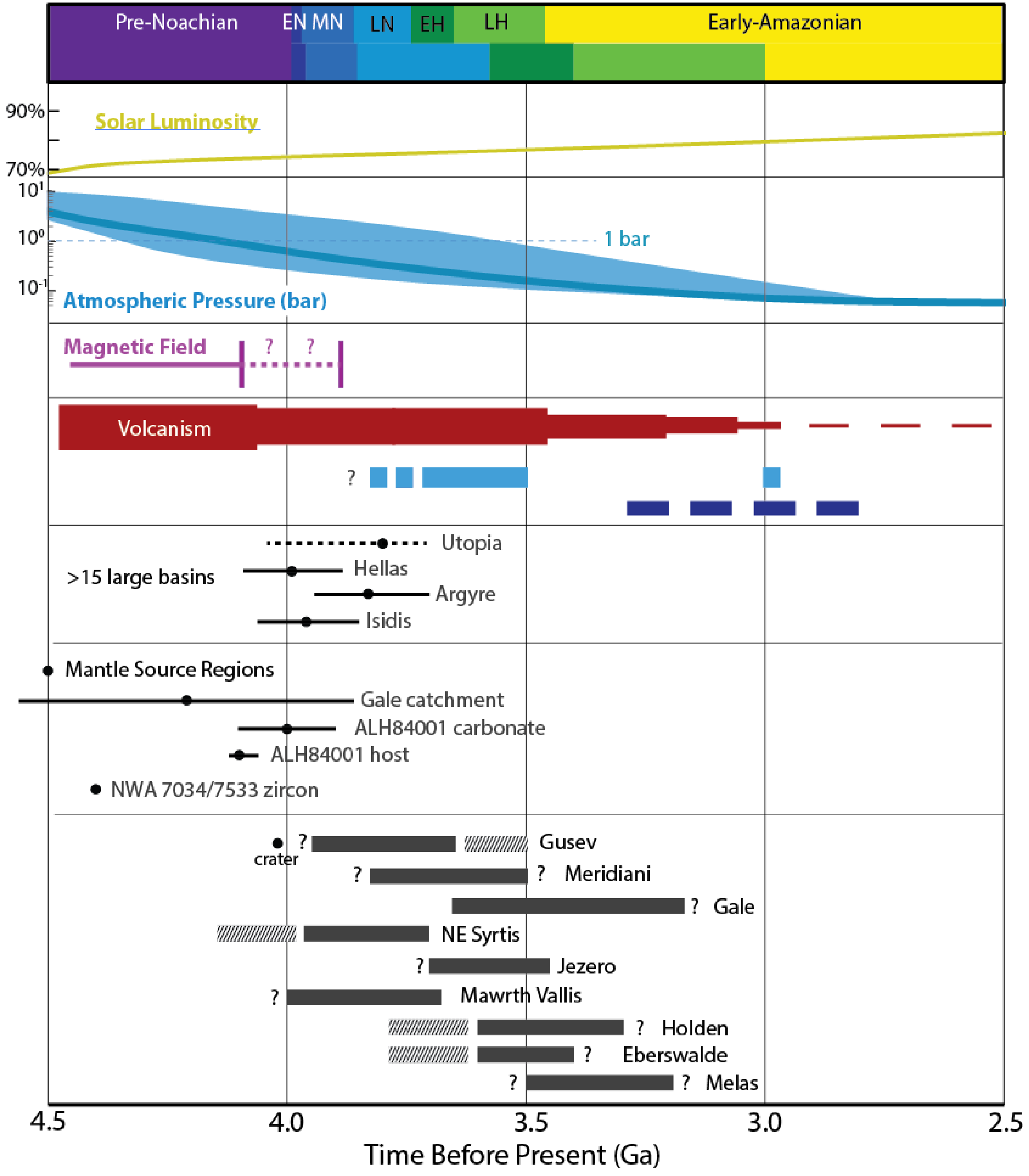




Williams et al, 2014, Icarus



Mars Timeline With Landing Site Strat. Units



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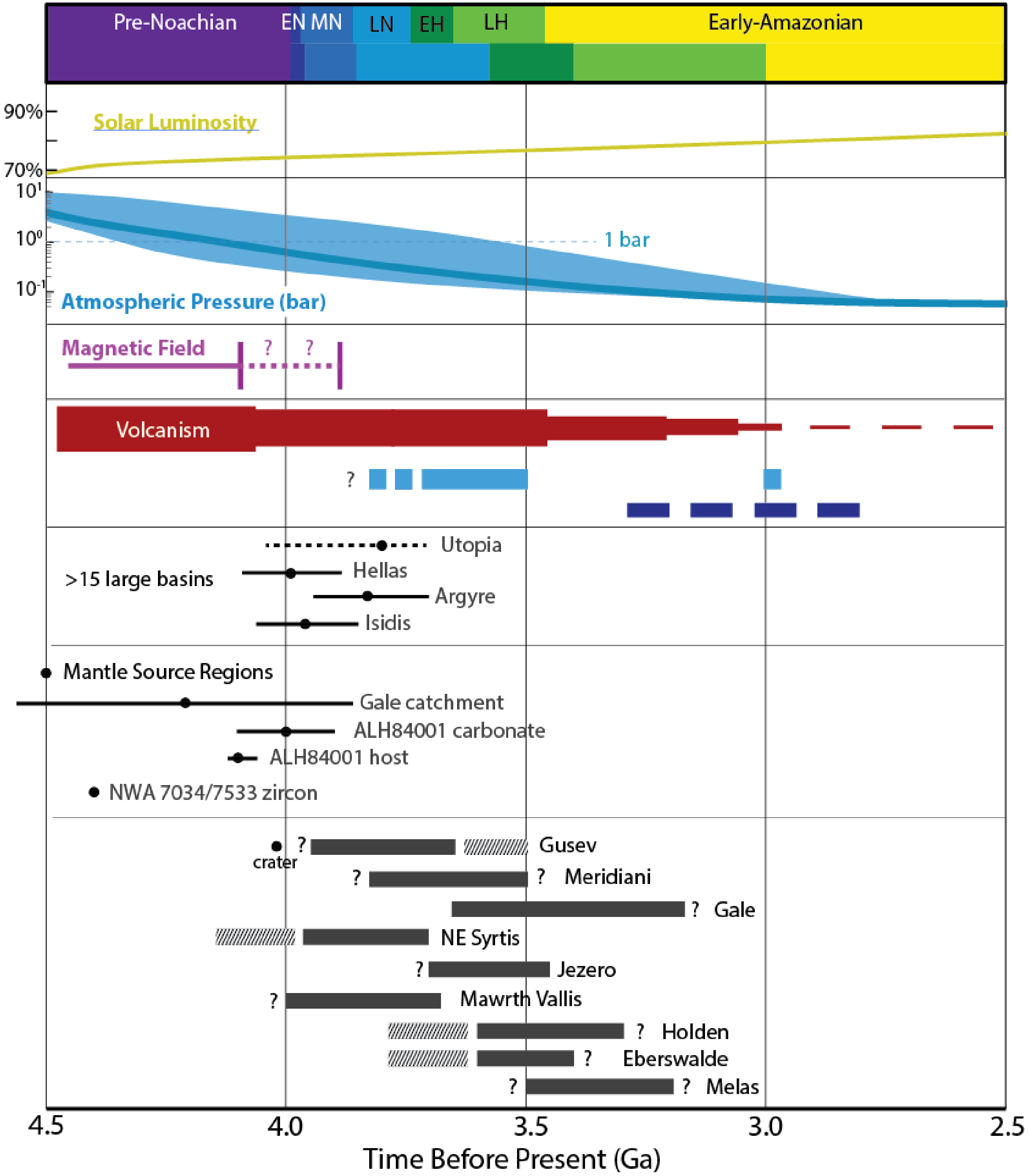

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Ancient Biosignature Preservation

- Subaqueous mineralization (silica, carbonate, phosphate)
  - Good enviro. See A. Allwood ppt – good summary
- Deltaic/fluvial
  - Summons & Hallman, 2014, *Treatise on Geochemistry 2nd Edition* : "Regions dominated by siliciclastic sedimentation are typically not prime localities in the search for Archean fossil life due to a very low level of in situ mineral formation and a generally poor preservation potential for biomass"
- Subsurface

If subsurface life, what might be the biosignatures ?

- **MORPHOLOGIC: Microtubules?**
- MINERALOGIC/ISOTOPIC: Carbonates, Sulfates, Phosphates, Fe oxides
- **CHEMICAL/ISOTOPIC: Trapped Gases**
- **ORGANIC: Trapped Organics**

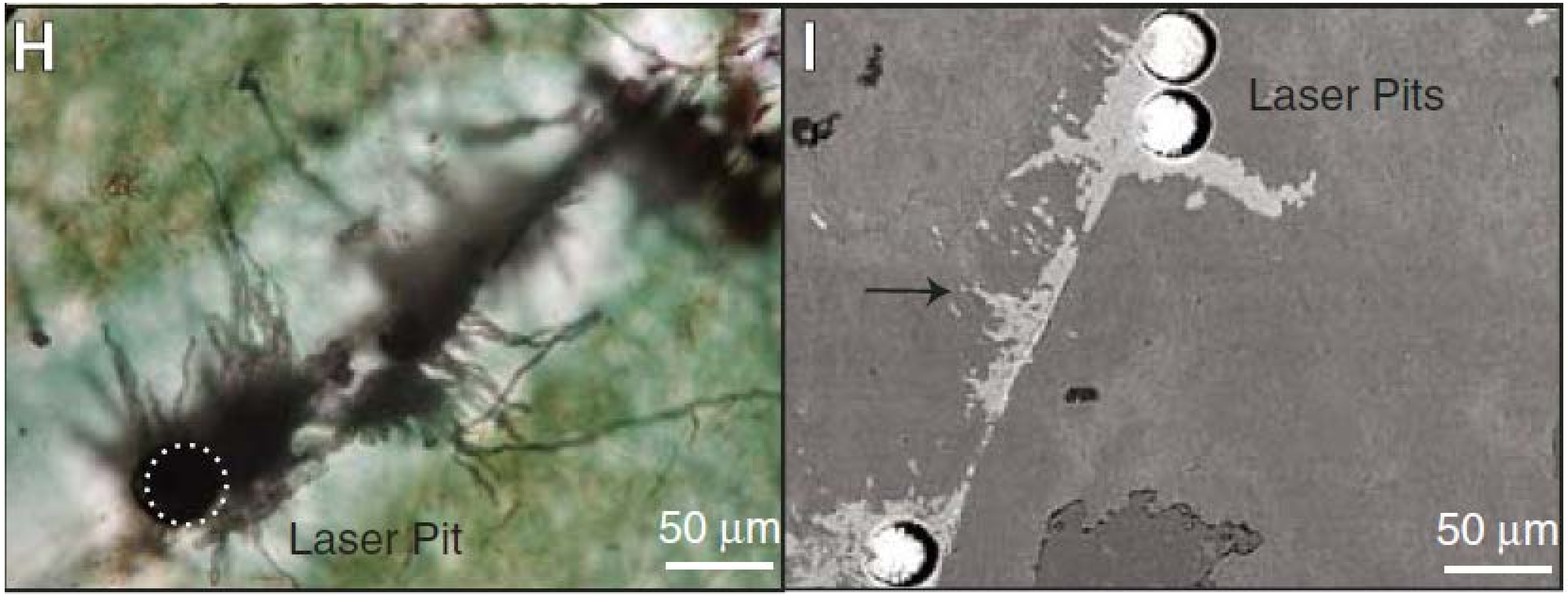
↓

Biological mediation usually forms isotopically light minerals. In context of knowledge of abiotic fractionation, this can be a great signature (vast literature, will not talk about here)

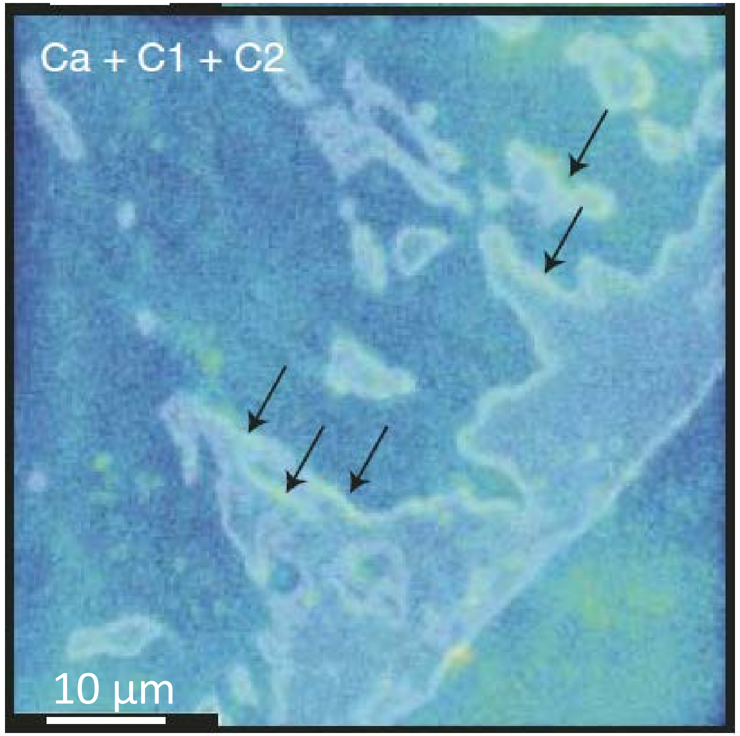
Microtubules: A biosignature or chemical process?

- “Microbial ichnofossils”: in Archaen basalts, micron-sized tubular structures mineralized by titanite ($CaTiSiO_4$) with residual organic carbon preserved along their margins
- Carbon-rich spheroidal assemblages encased in multiple layers of iddingsite found with microtubules in a Nakhlite (White et al., 2014, Astrobio.)

Banerjee et al., 2007, Geology



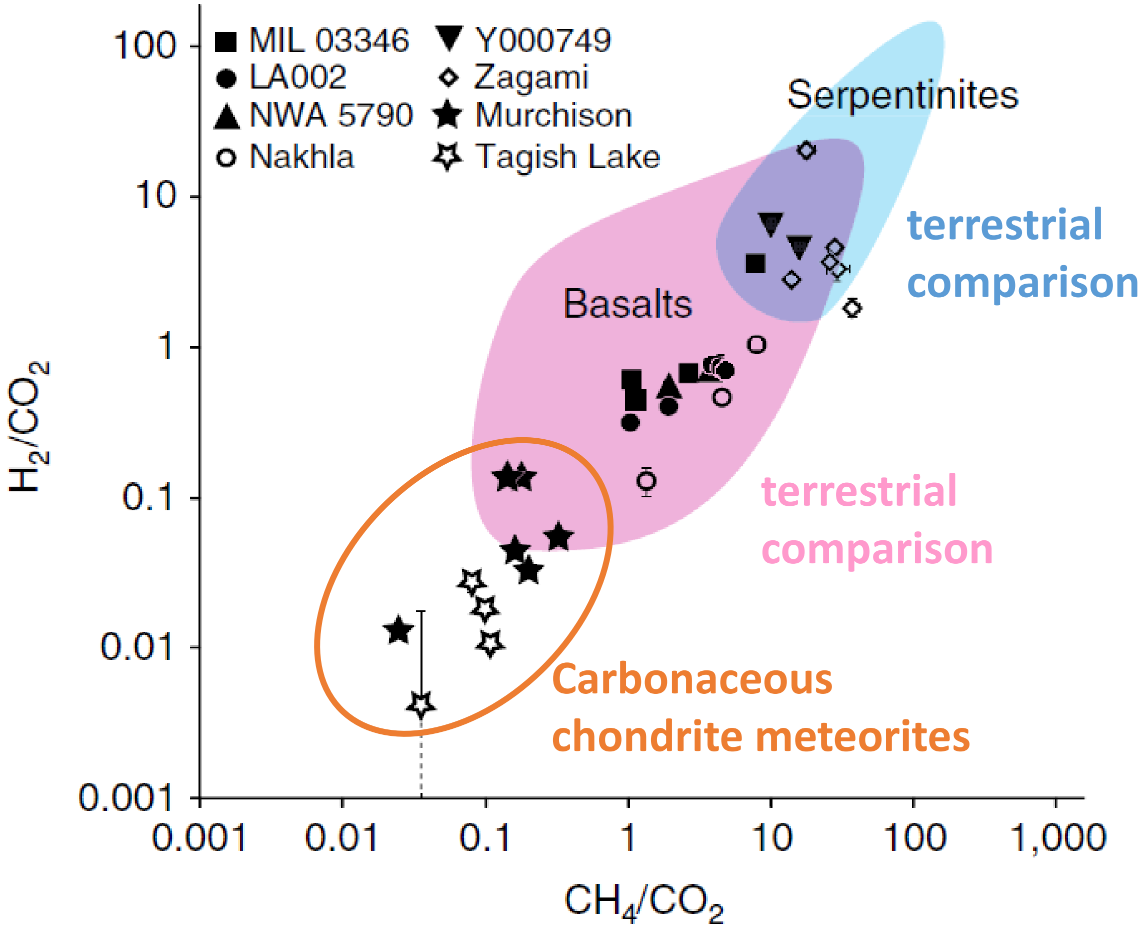
Carbon on tubule margins



Trapped Gases in Hydrothermally Altered Mafics

- Meteorites analyzed using the crush-fast scan technique with QMS (releases fluid inclusions and crystal boundaries)
- 3 to 23 CH_4/CO_2 ratio; , strongly suggesting a mechanism for methane generation in the Martian crust.
- A typical sample size of about 250 mg (one or two 3-mm grains) released 4–10 bursts of volatiles (up to ~2×10^{-11} mol)

Martian Meteorites Analysis

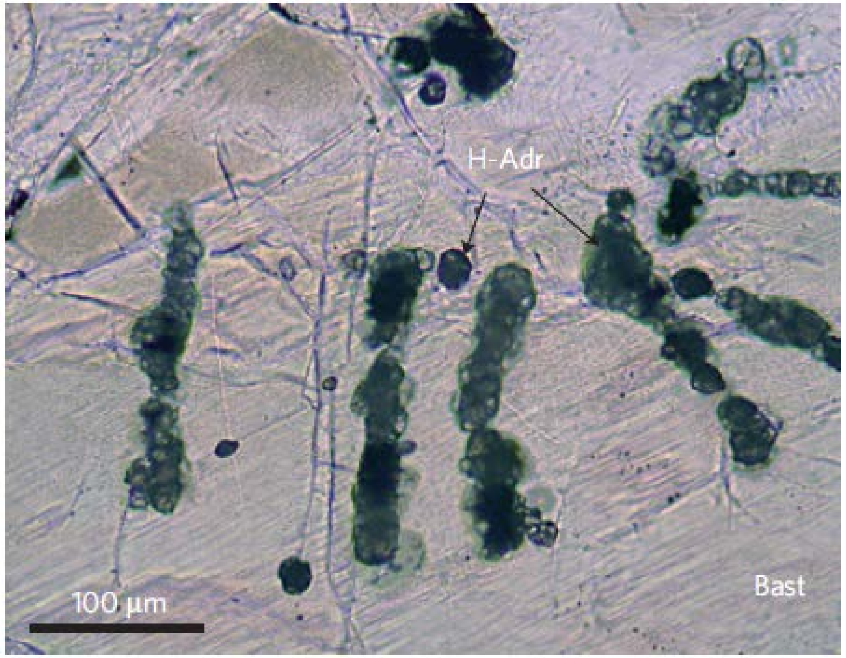


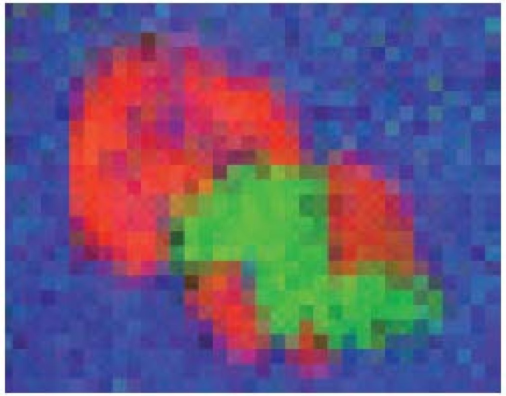
Blamey et al., 2014, Nat. Comm.

Trapped Organics

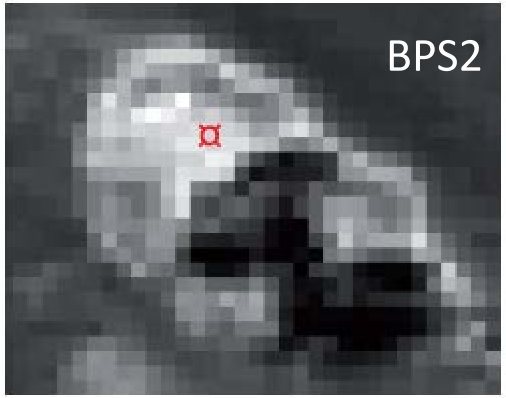
Menez et al., 2012, Nat Geosci.

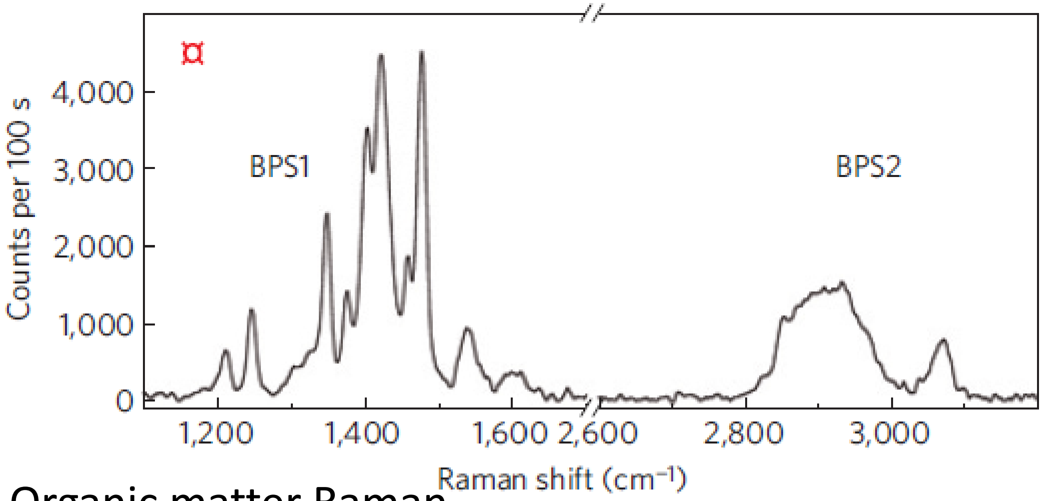
- High concentrations of organic matter, of two types, intimately associated with serpentine-hosted hydrogarnets
  - **a complex mixture of aliphatic and aromatic compounds and functional groups such as amides, usually associated with biopolymers** such as proteins, lipids and nucleic acids.
  - dense aggregates of **thermally evolved carbonaceous matter** with a weak structural organization, attributed to the **maturation of carbon compounds present in the organic matter described above**





hydroandraditic garnet
magnetite
serpentine





Organic matter Raman signatures

Trapped Organics

Menez et al., 2012, Nat Geosci.

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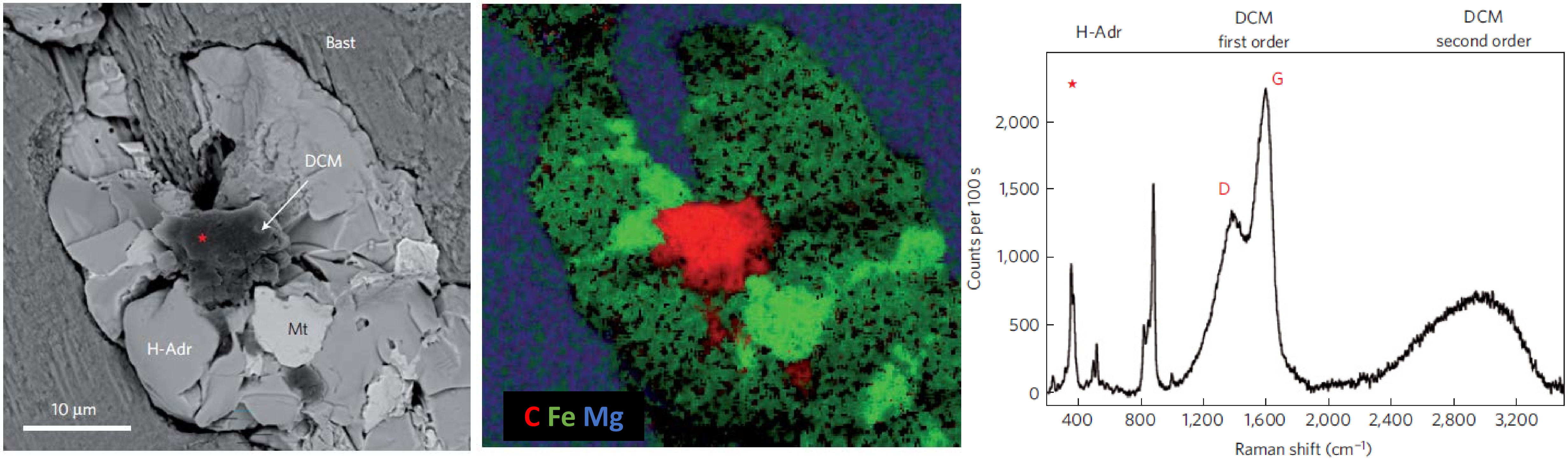
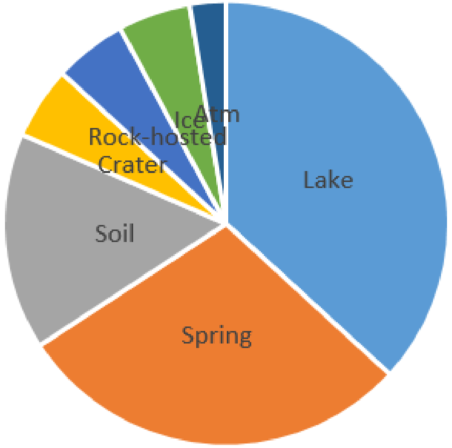


Our Understanding of the Subsurface Biosphere is Just Beginning



- 2 of 38 presentations at this workshop are on rock-hosted life
- Yet vigorous efforts to understand are underway…
  - NSF Center for the Study of the Deep Biosphere (C-DEBI)
  - NAI Life Underground (USC, J. Amend)
  - NAI Rock Powered Life (Colorado, A. Templeton)
  - Various international research groups, esp. in Canada, France, and Japan
- So expect more knowledge to inform our Mars data interpretation
- My firm scientific belief: This knowledge from Earth is fully necessary for understanding whether Mars ever hosted life because…

Food for thought

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-Fassett & Head, 2011, Icarus

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-Ehlmann et al., 2011, Nature

Final Thoughts on Biosignature Preservation

- Martian lakes – as geomorphically preserved – are unlikely to be analogous to terrestrial lakes with microbial/large scale biomass in the water to preserve
  - Thus the analog to terrestrial deltas is flawed. It requires a long term habitable surface environment that simply was not present
- The Early Earth Record shows groundwater springs (cold and warm – most likely cold at the Mars near surface)
  - Thus, these are good sites
  - Mineralized facture fills and streams on large carbonate, sulfate units on Mars indicate these groundwater→surface conduits for fluids
- The Pre-/Early Noachian record is hard – it is a stratigraphic section or megabreccia, affected by impact – nevertheless, this is likely the most habitable period for the Mars, there is order in the sections (and blocks), and it records the early biotic or prebiotic part of solar system history not well-accessible on Earth