NOTE ADDED BY JPL WEBMASTER: This content has not been approved or adopted by NASA, JPL, or the California Institute of Technology. This document is being made available for information purposes only, and any views and opinions expressed herein do not necessarily state or reflect those of NASA, JPL, or the California Institute of Technology.

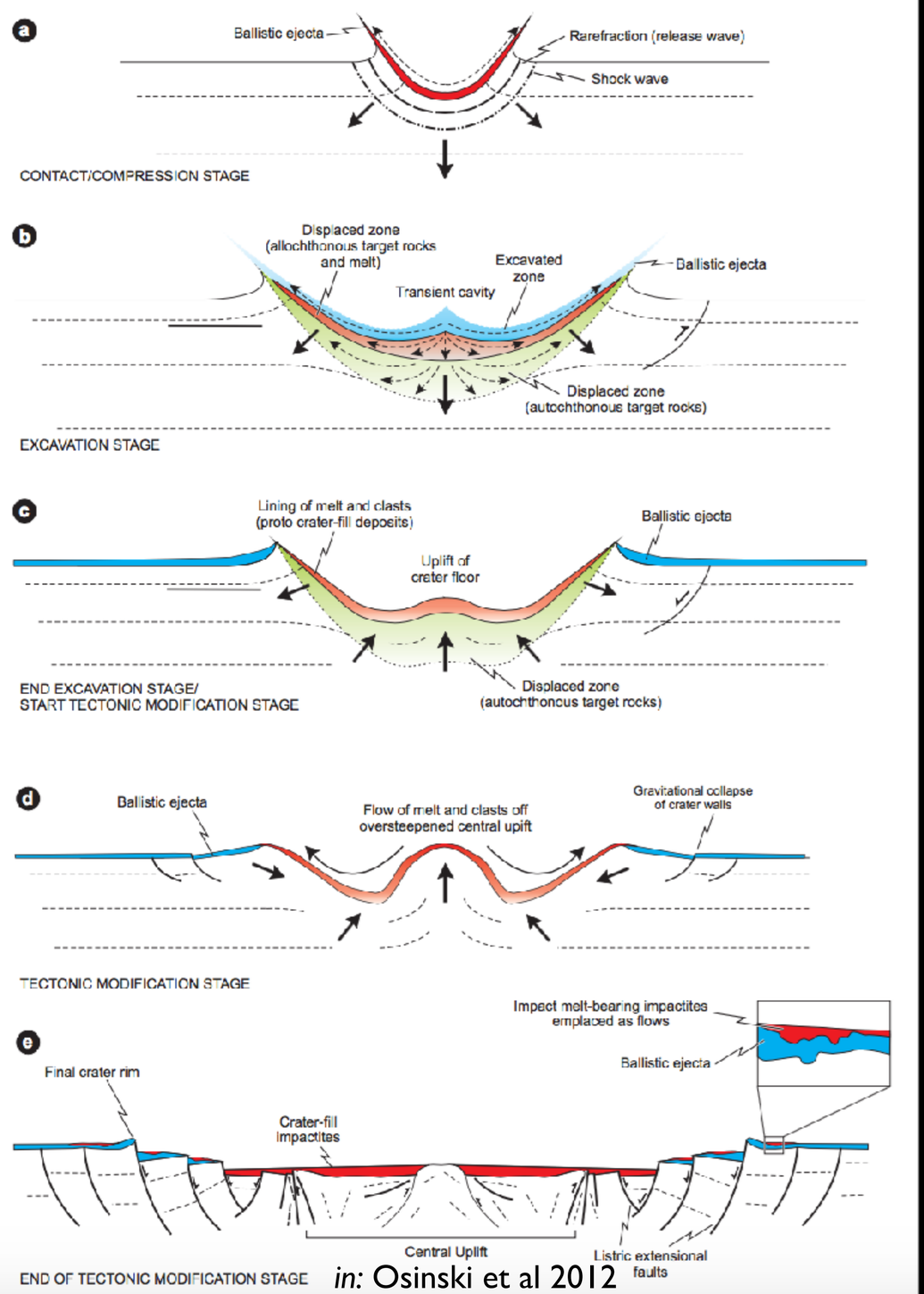
Science value and biogenetic potential of impact lithologies: relevance to Mars 2020 landing sites

4th Landing site Workshop for the Mars 2020 rover mission
Oct 16-18, 2018

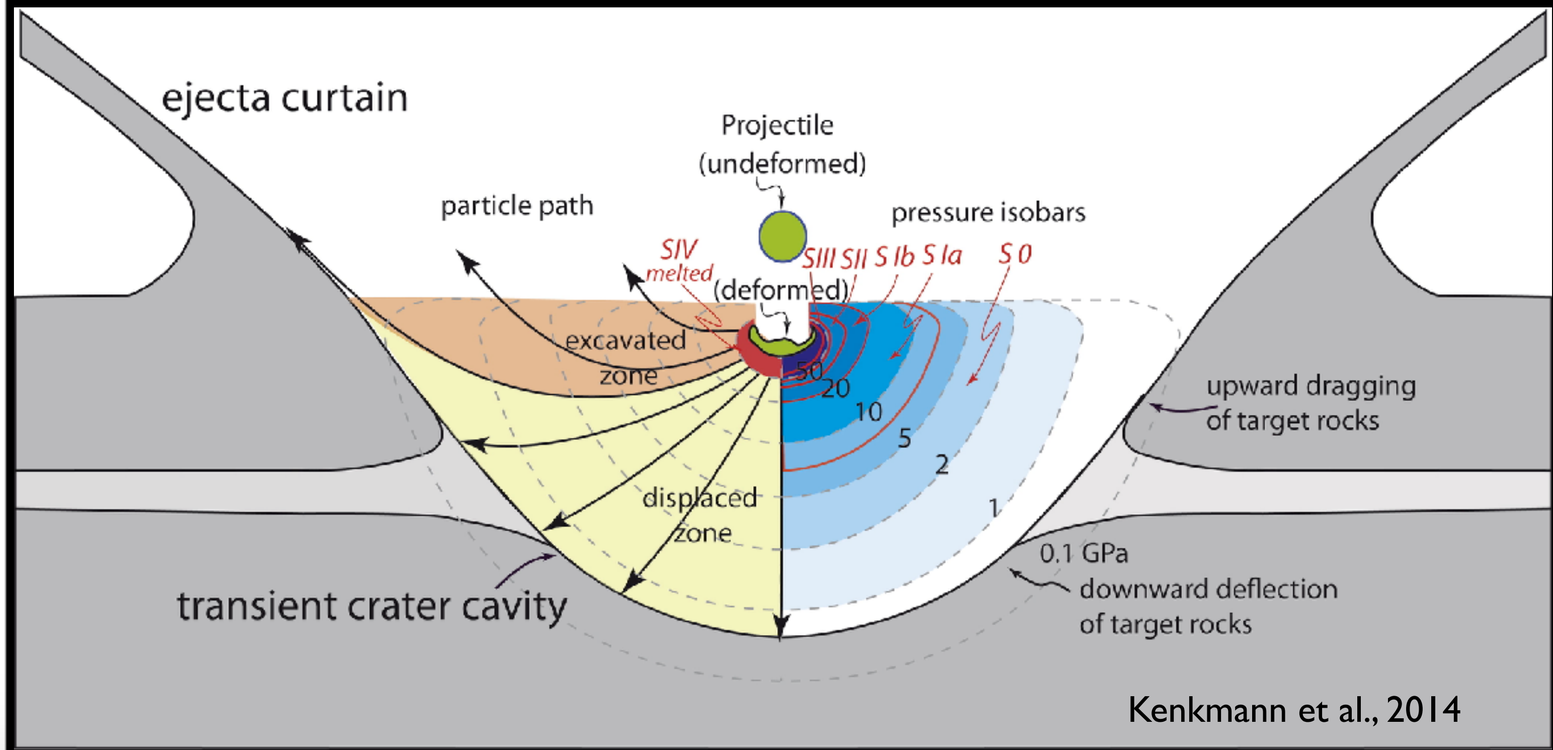
H. M. Sapers, G. R. Osinski, A. Pontefract, C. S. Cockell, C. M. Caudill, L.L Tornabene, K. M. Cannon, J. F., Mustard

Impact cratering process

- Three main stages: 1) contact/compression; 2) excavation; 3) modification
- Well-defined models and stratigraphy
- Excavation flow lines cross pressure isobars mixing shock level in breccia (no, low, high shock material)



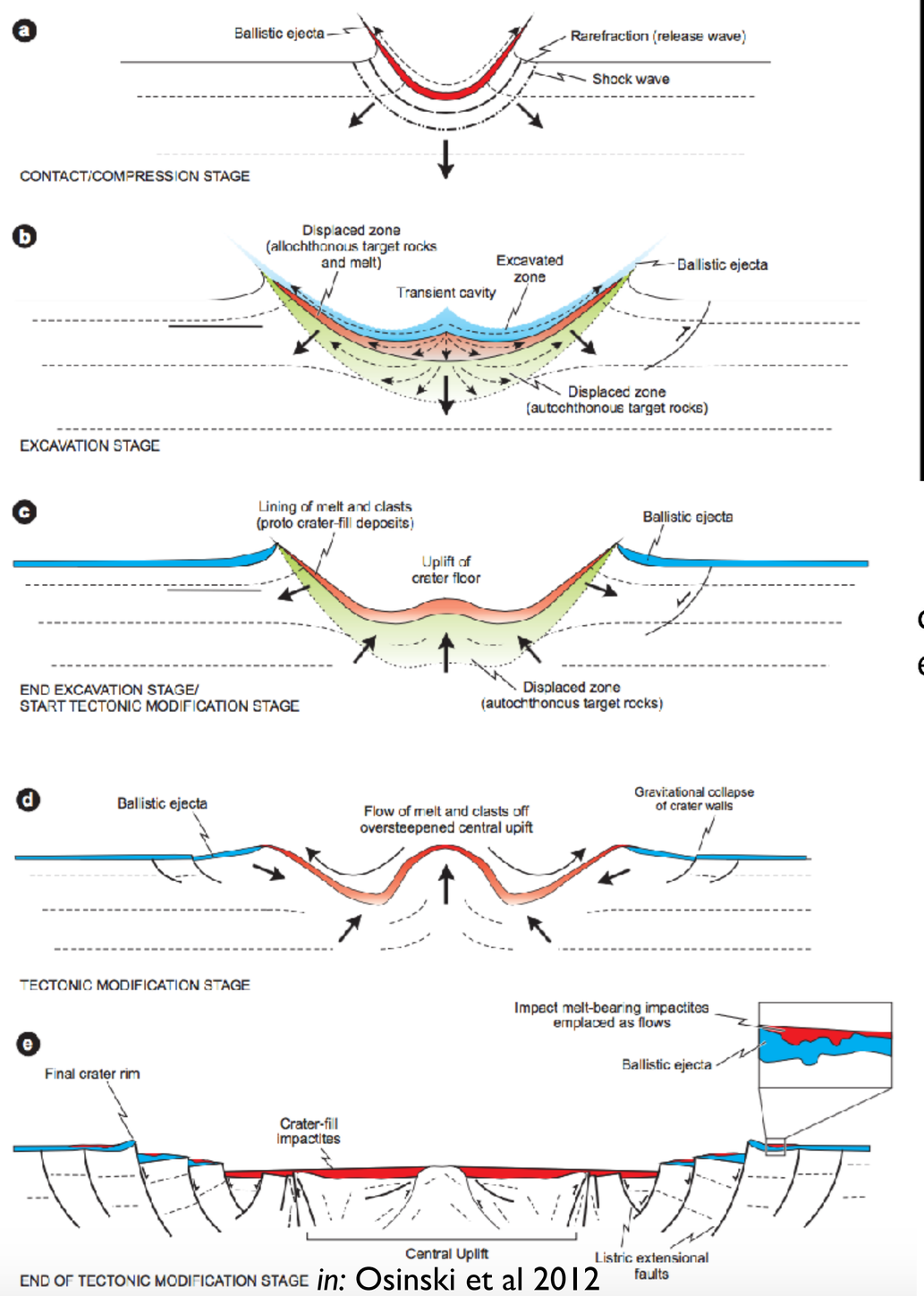
in: Osinski et al 2012



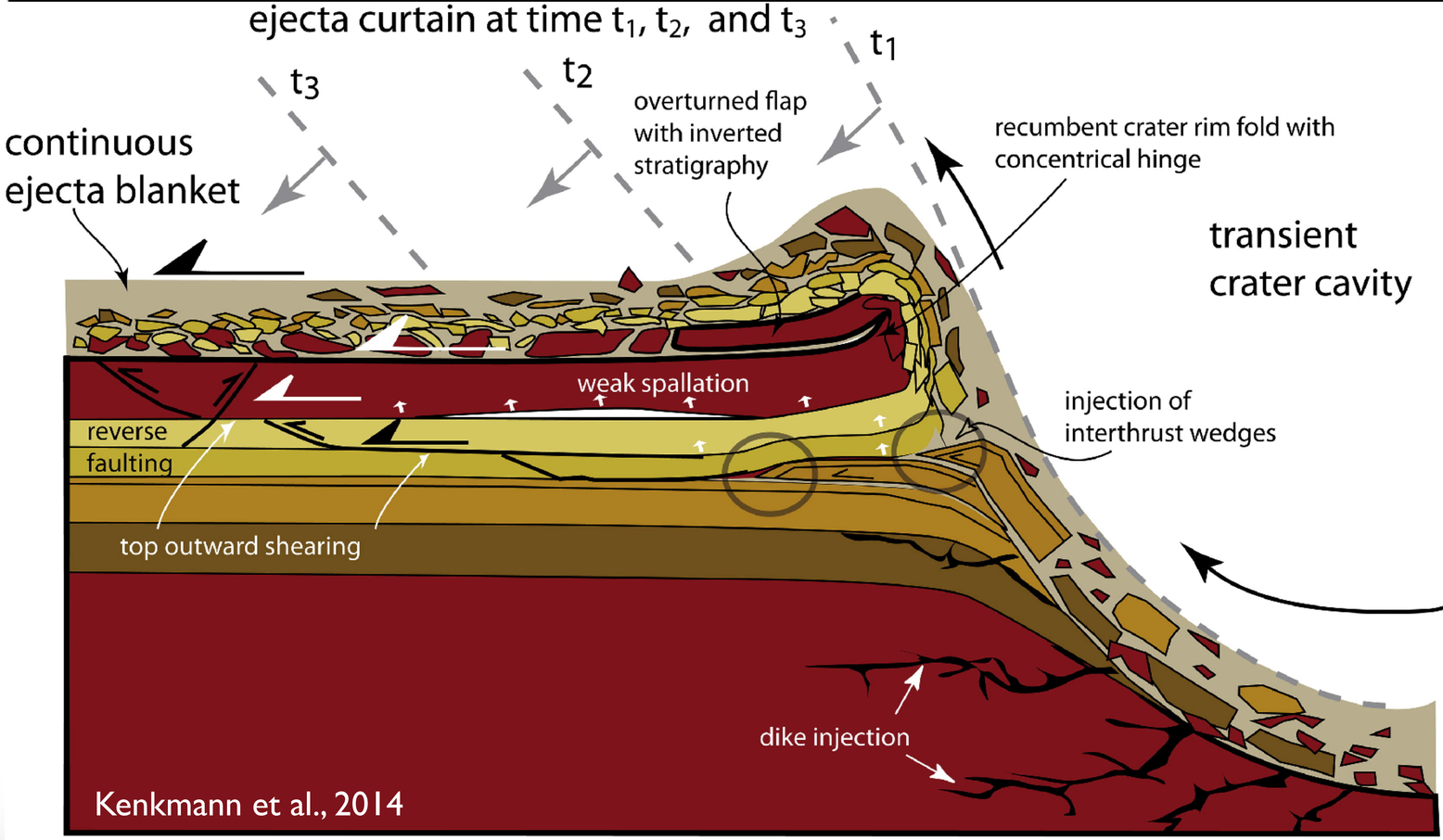
Kenkmann et al., 2014

Impact cratering process

- Impactite lithologies range from glass, melt, through to fractured samples: intact, pre-impact lithologies
- Breccia contain variable amounts of melt and glass forming a continuum between coast-free melt and melt-free lithic breccia

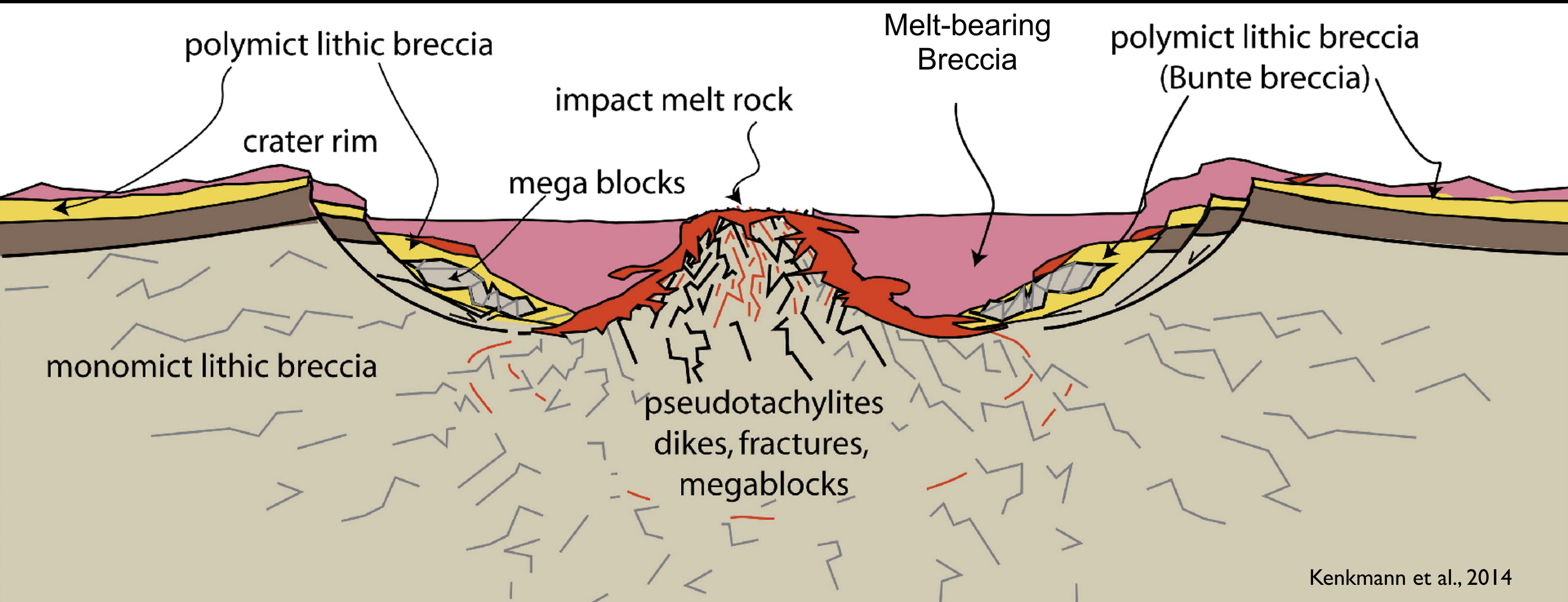


in: Osinski et al 2012

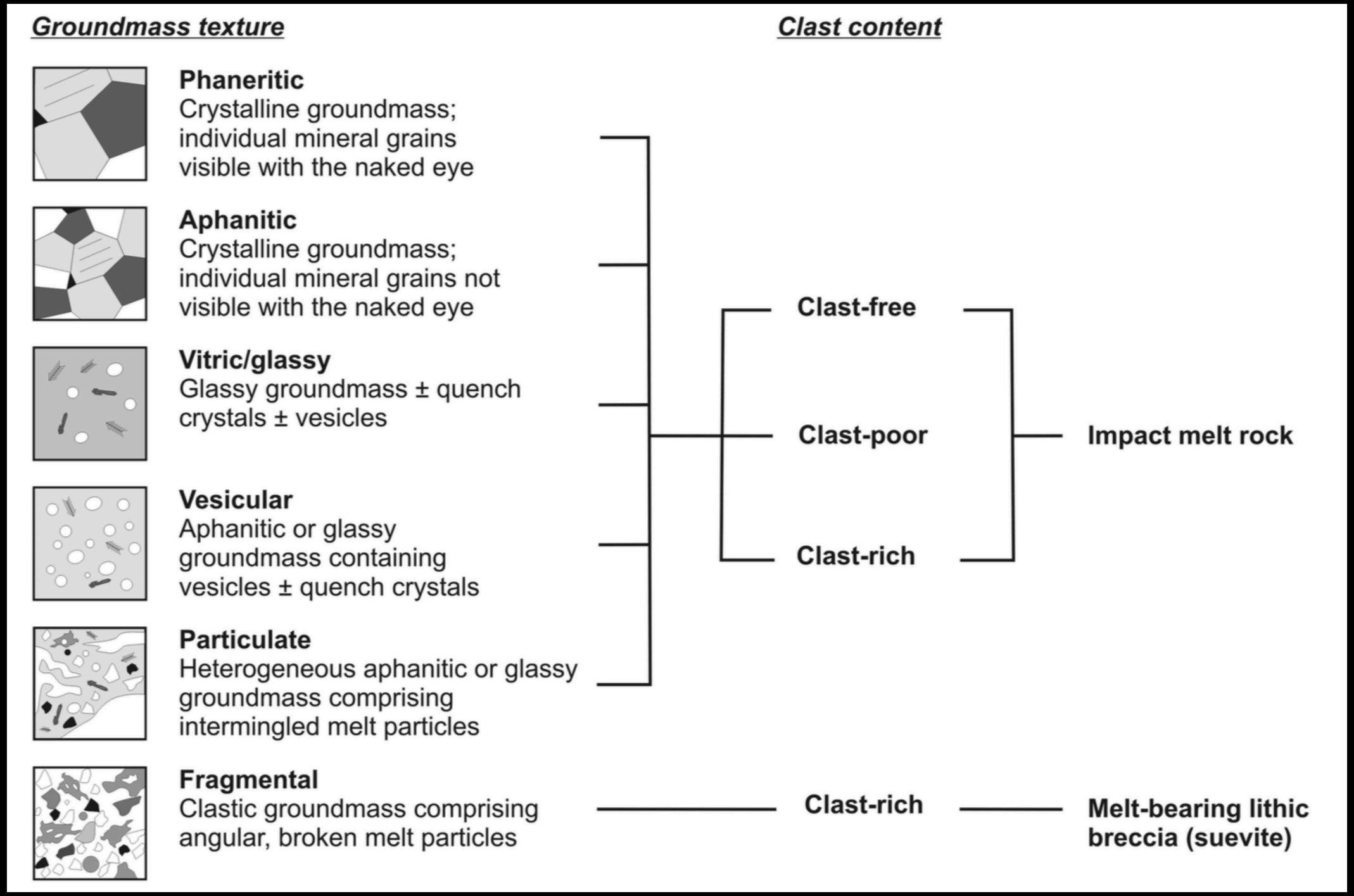


Kenkmann et al., 2014

During transport breccia mix with melt forming melt breccias. Melt and glass clasts are common in lithic breccias. Melt occurs as massive lenses, injected into dykes, as clast, and matrix material in breccia ejecta. Melt bearing breccia at Ries overlay, lower temperature melt-free breccia forming a distinct separation between (pre-impact) impact excavated clays and (post-impact) clays derived from the weathering of metastable impactites.



Kenkmann et al., 2014


Groundmass texture
Clast content
Phaneritic
Crystalline groundmass; individual mineral grains visible with the naked eye
Aphanitic
Crystalline groundmass; individual mineral grains not visible with the naked eye
Vitric/glassy
Glassy groundmass ± quench crystals ± vesicles
Vesicular
Aphanitic or glassy groundmass containing vesicles ± quench crystals
Particulate
Heterogeneous aphanitic or glassy groundmass comprising intermingled melt particles
Fragmental
Clastic groundmass comprising angular, broken melt particles
Clast-free
Clast-poor
Clast-rich
Impact melt rock
Clast-rich
Melt-bearing lithic breccia (suevite)

Clast content

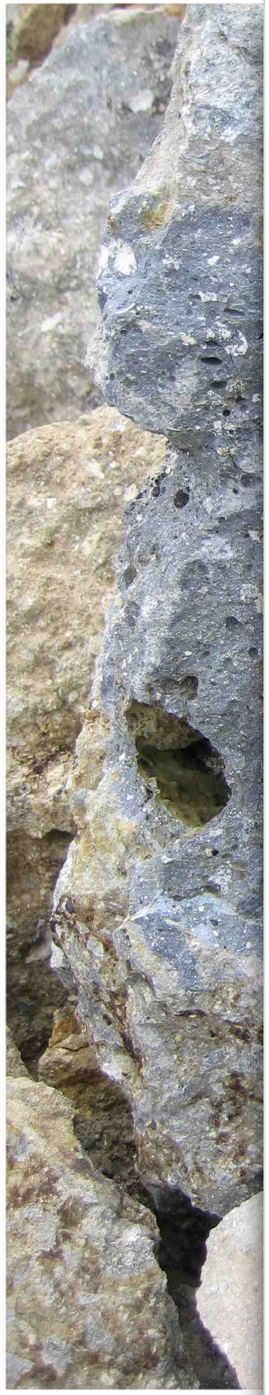
- Clast-free
- Clast-poor
- Clast-rich

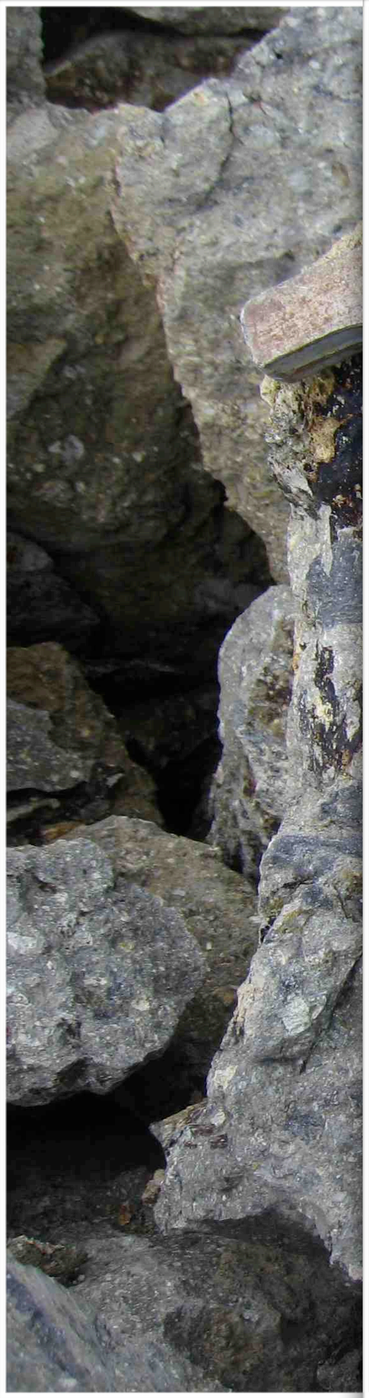
→ Impact melt rock

- Clast-rich → Melt-bearing lithic breccia (suevite)

rock

lithic
vite)



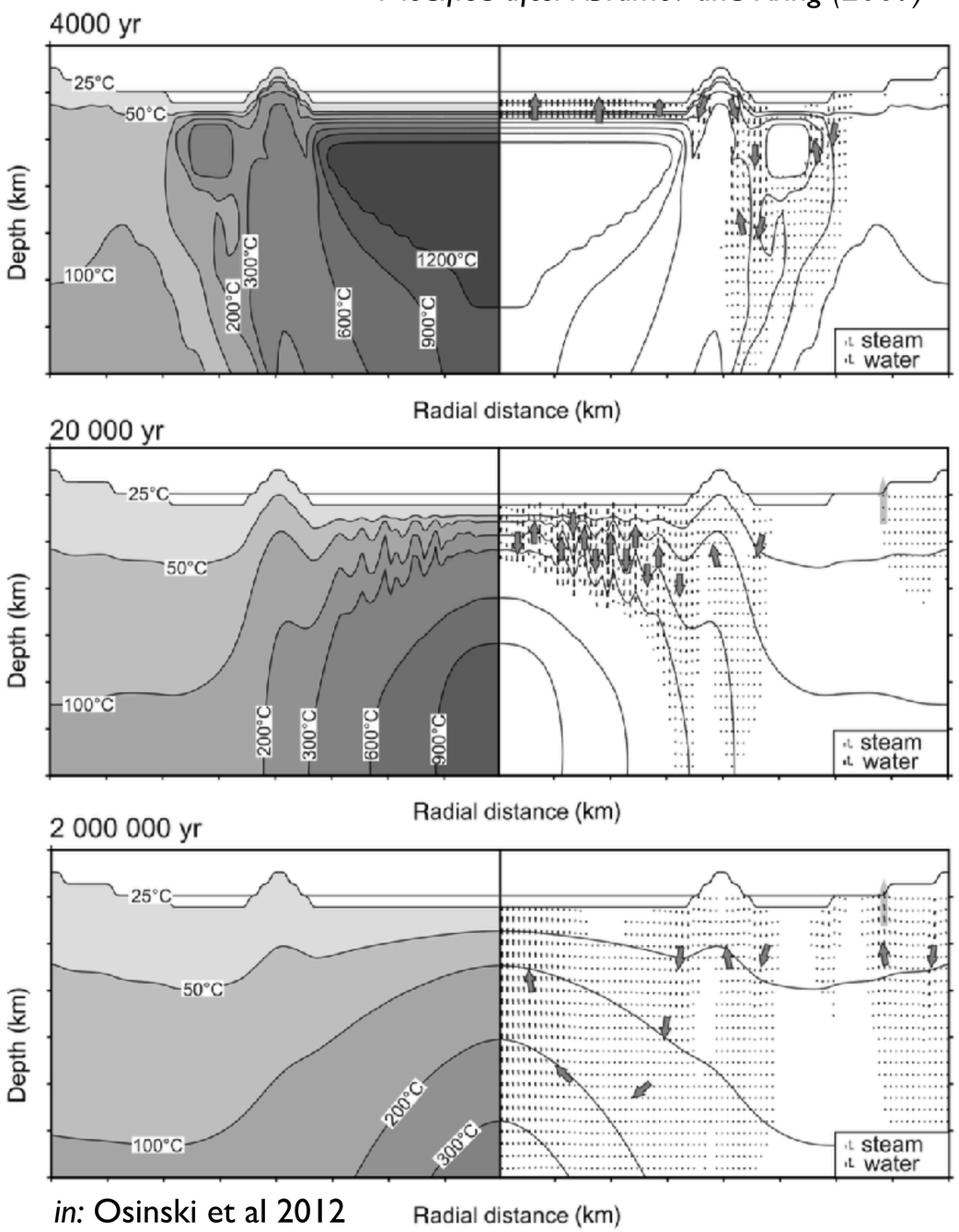


ERCB | AGS
centimetres
inches

Hydrothermal activity

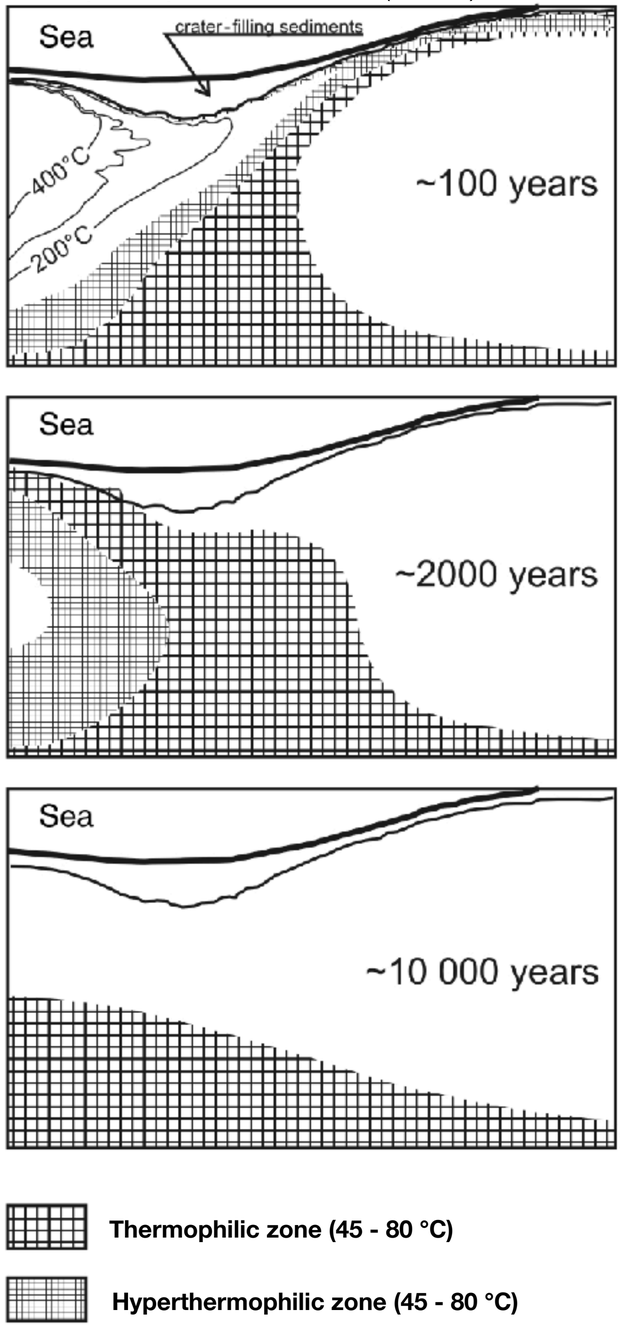
- movement of warm (~50 ℃) to hot (> 500 ℃) fluids in the subsurface (Pirajno, 1992)
- Modelled habitable zones at Kärdla Impact structure (4 km; ~455 Ma) Versh et al 2006)
- Cooling of the Chicxulub impact structure (150 km; ~66Ma) Abramov and Kring (2007)
- **any hypervelocity impact capable of forming a complex impact structure has the potential to generate a hydrothermal system** (Osinski et al., 2013)
- Create alteration clays and habitats for colonization and preservation

Modified after Abramov and Kring (2007)

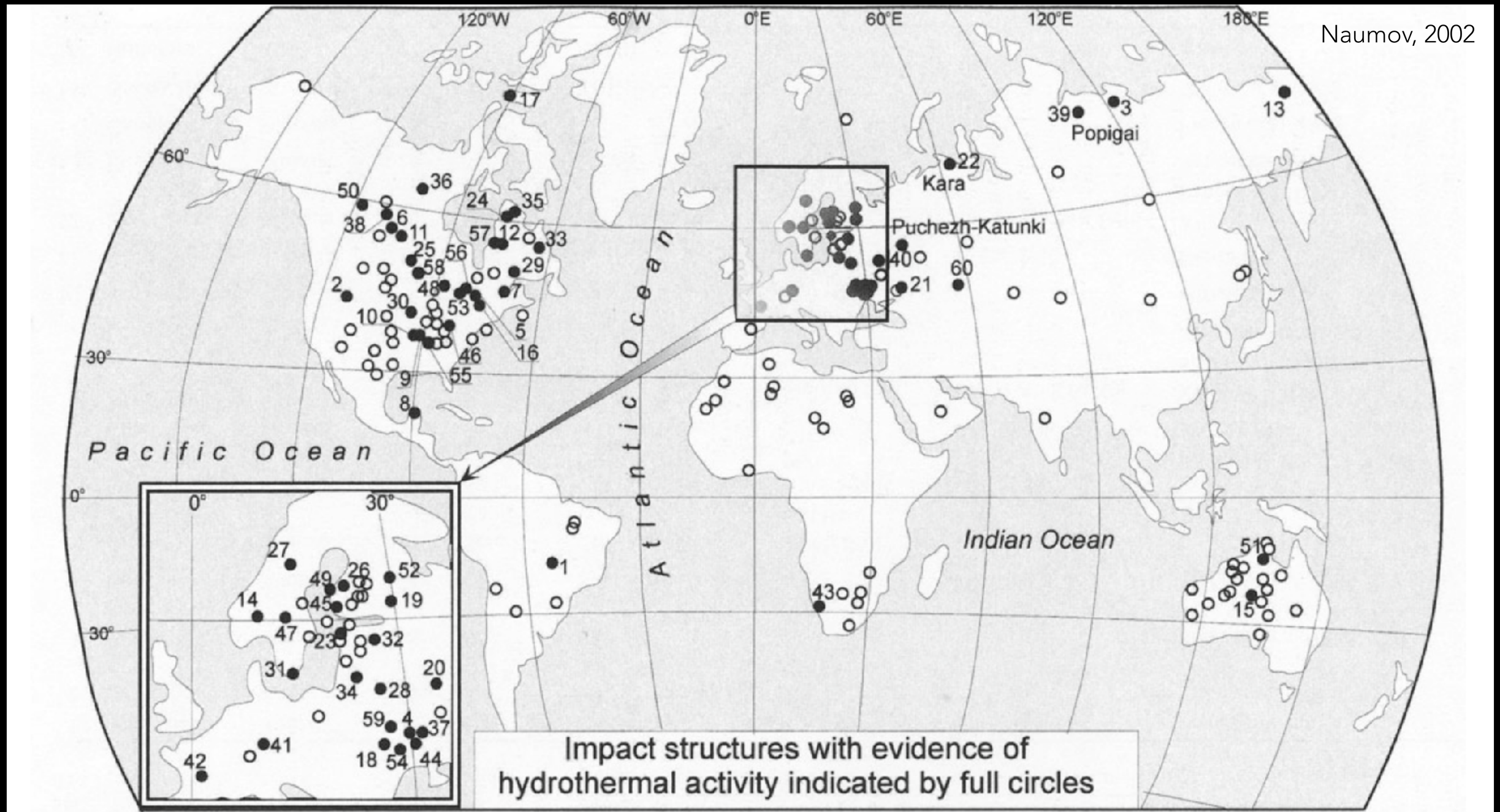


in: Osinski et al 2012

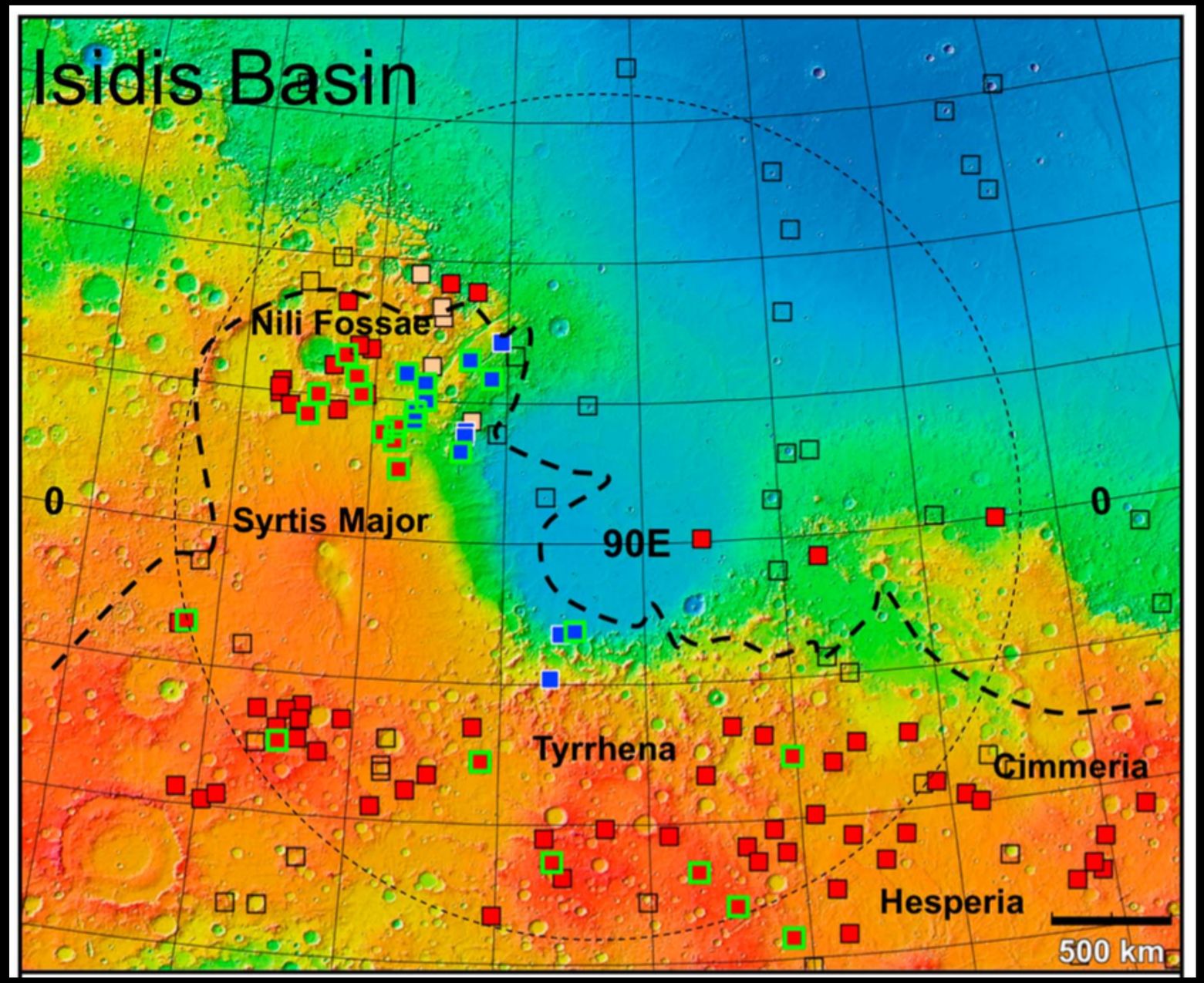
Modified after Versh et al. (2006)



Evidence for hydrothermal activity at 70 of ~190 terrestrial impact structures



Hydrated Silicates Associated with Megabreccias



mega-breccia

hydrated silicates ('crustal')

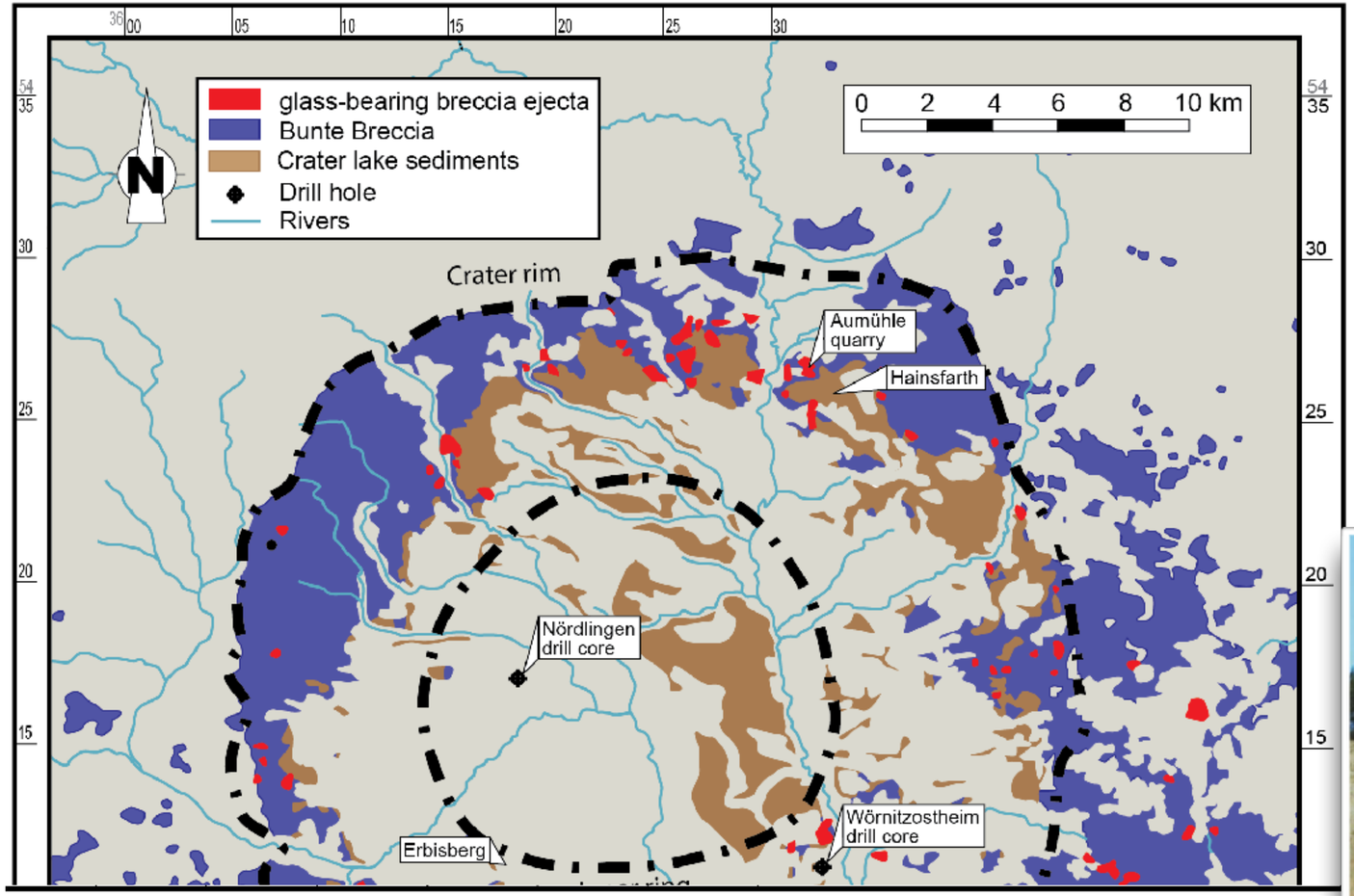
hydrated silicates ('stratigraphic')

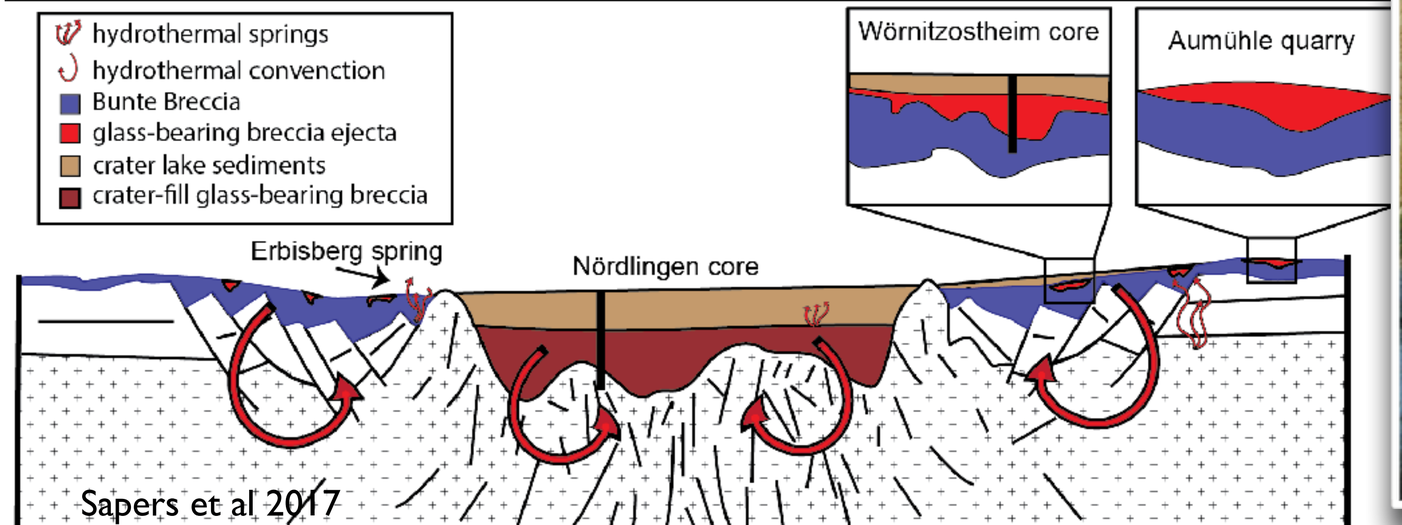
Tornabene et al 2013

Ries impact structure: Aumühle quarry

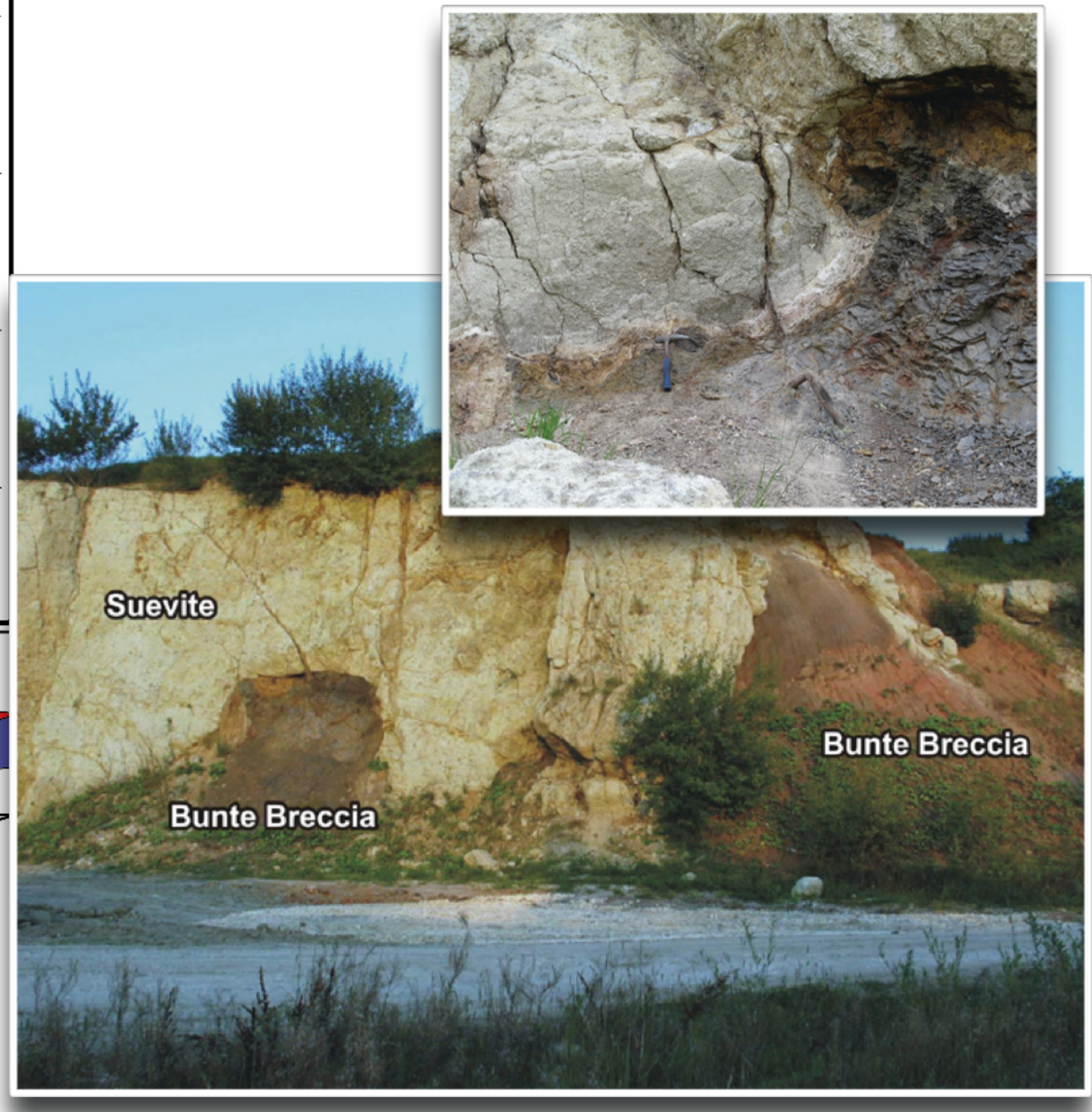
Suevite: impact-generated clays (post impact)

Bunte: impact-excavated clays (pre impact)





Sapers et al 2017

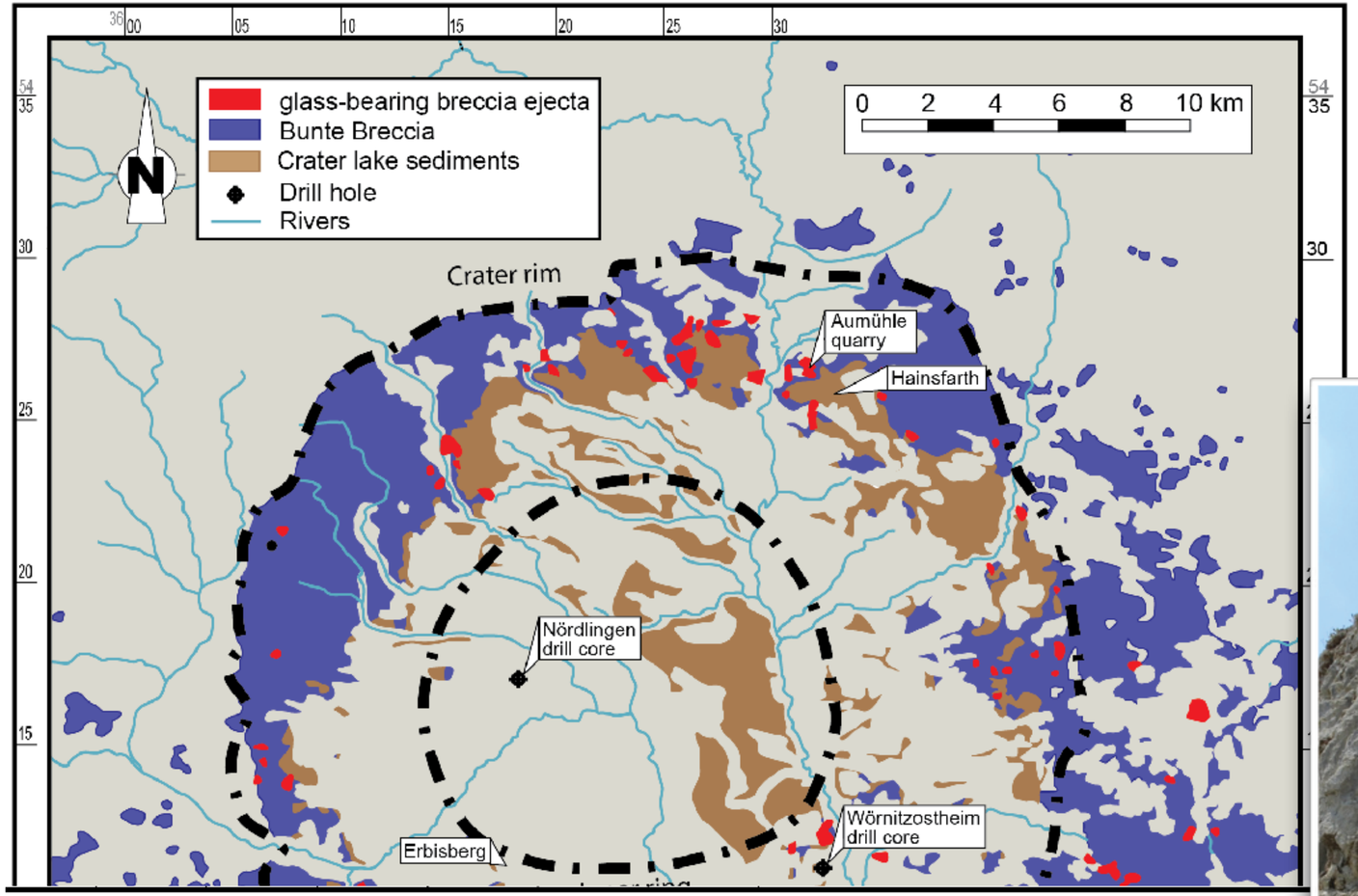


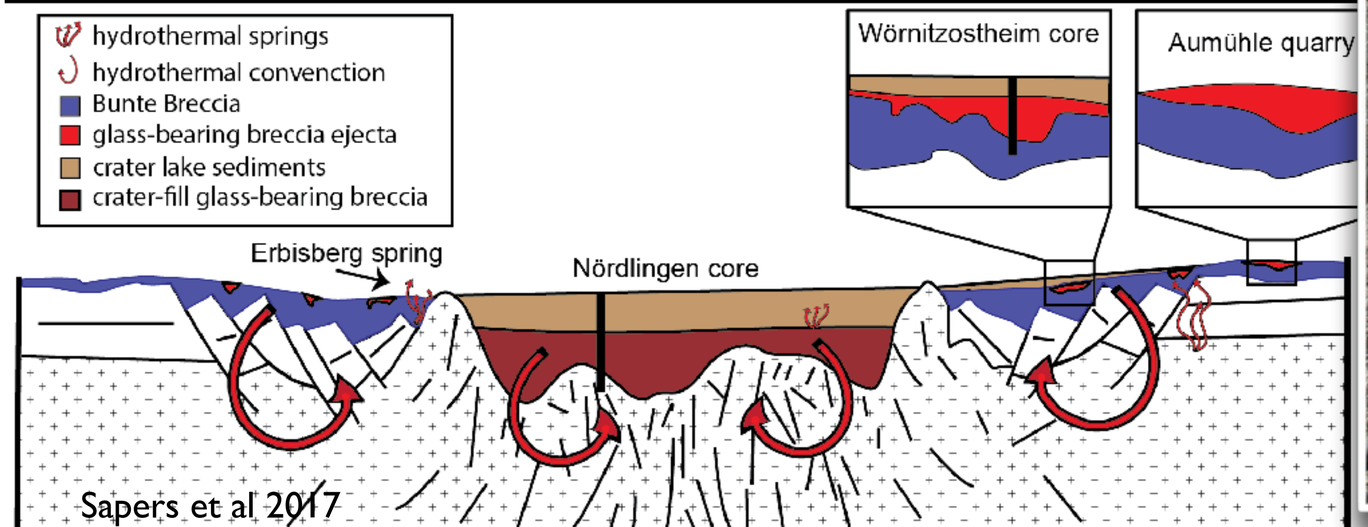
Ries impact structure: Aumühle quarry

Suevite: impact-generated clays (post impact)

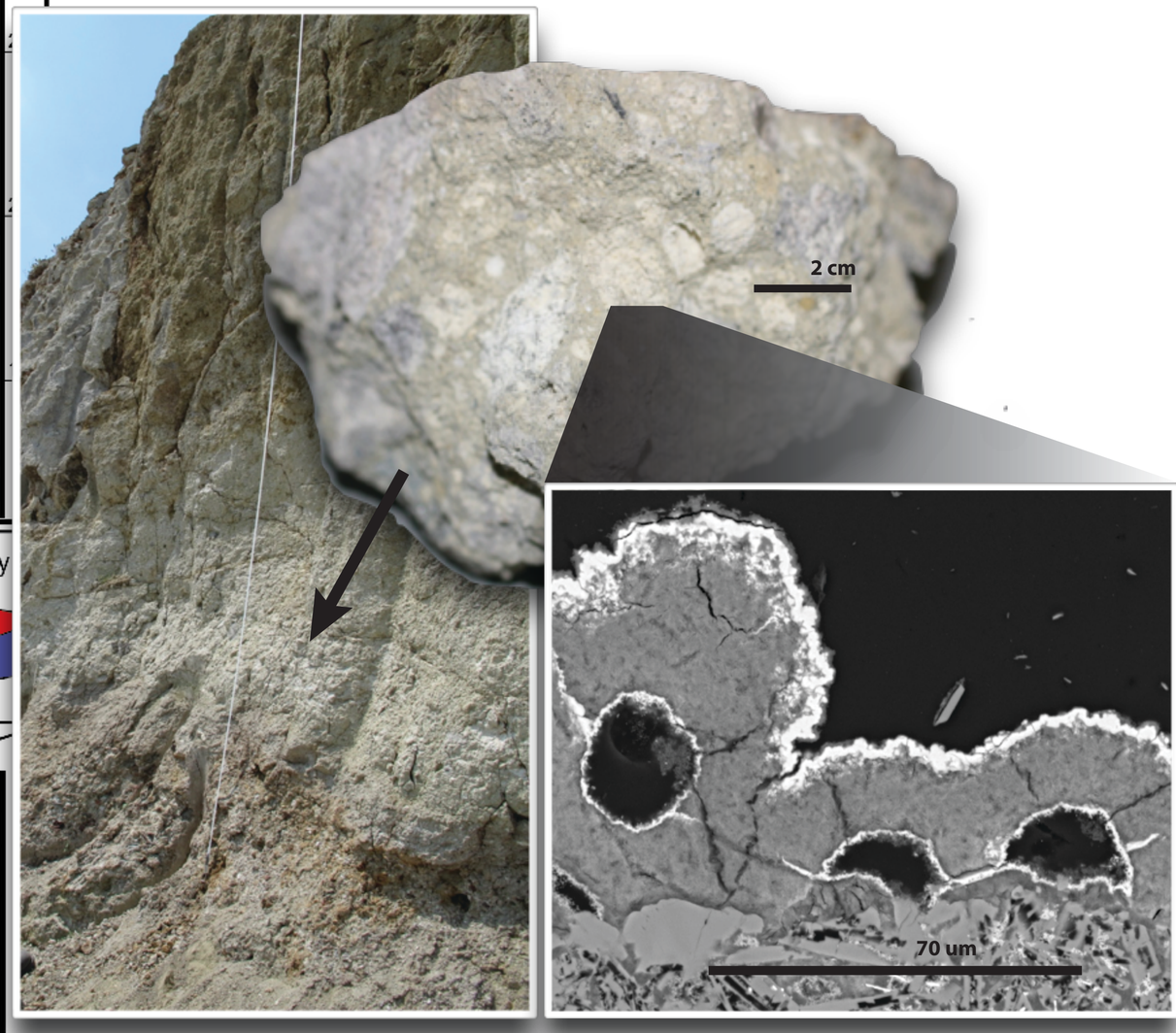
Bunte: impact-excavated clays (pre impact)

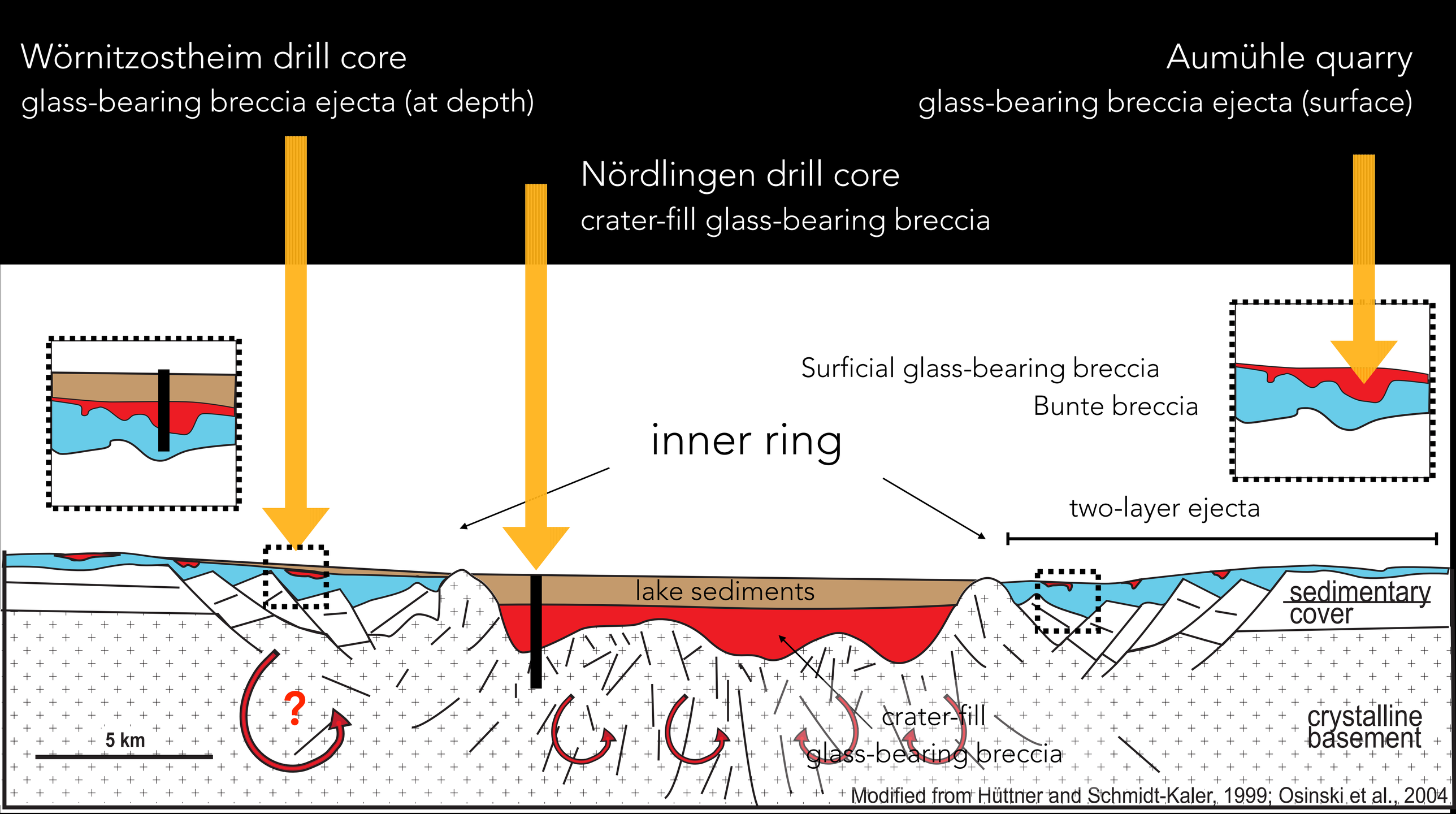
Impact-generated hydrothermal alteration

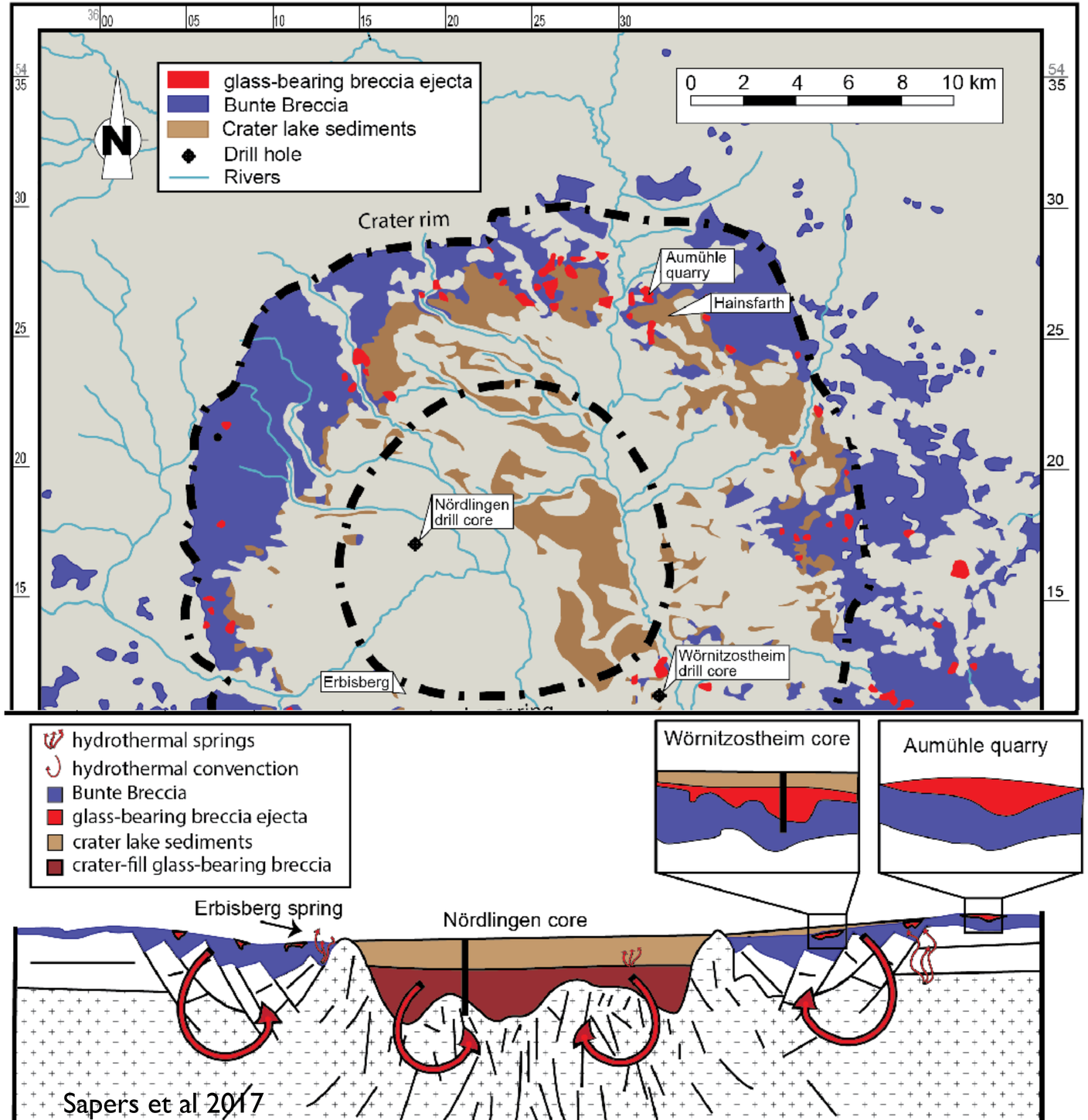




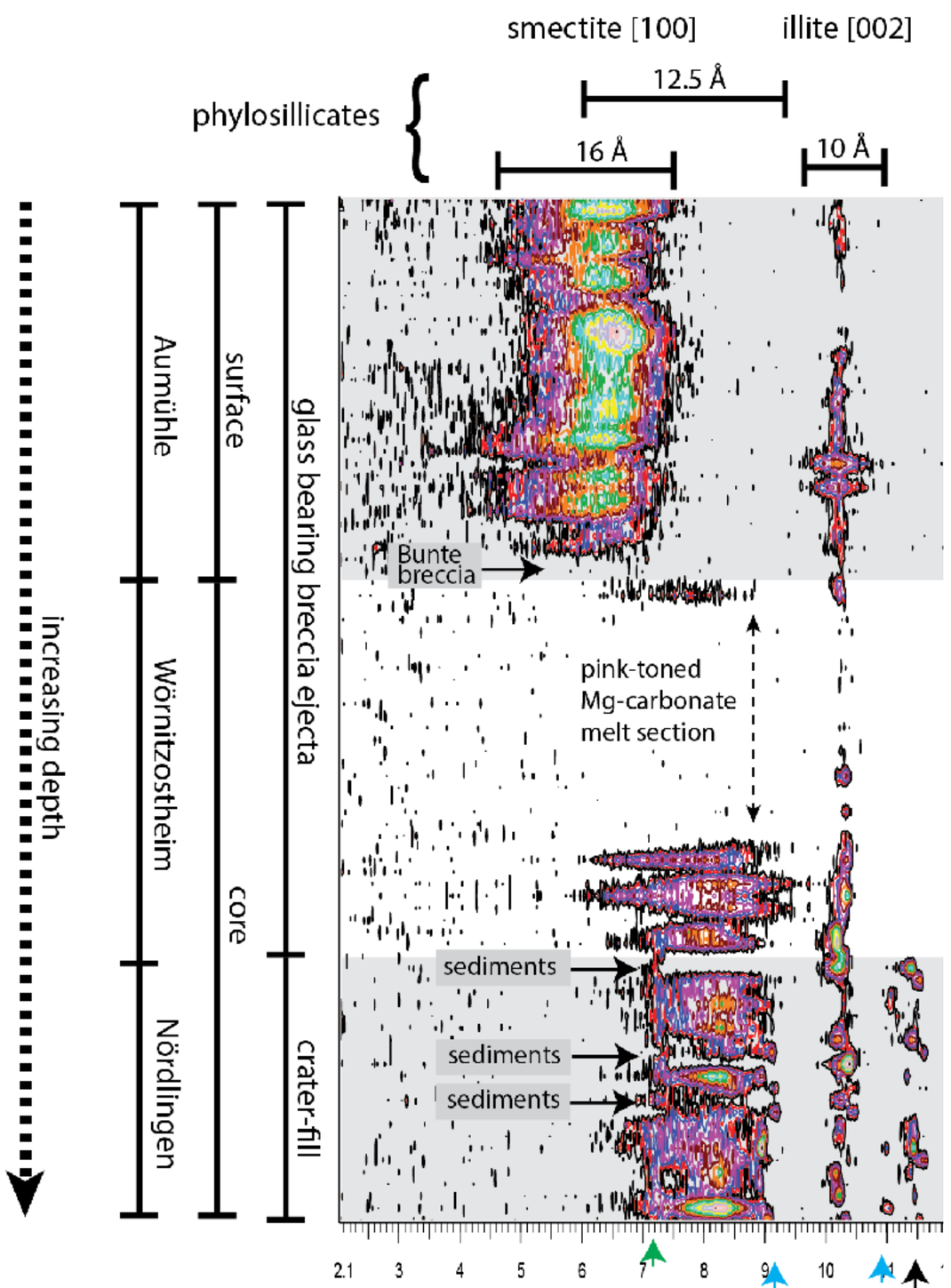
Sapers et al 2017



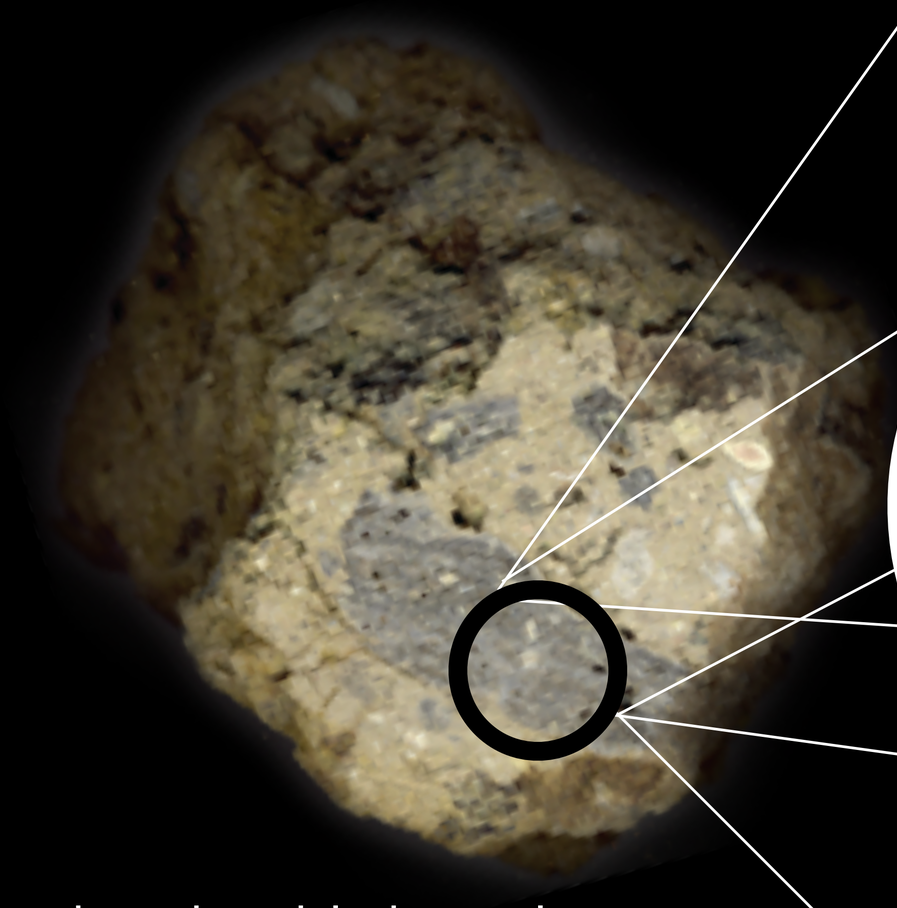

Wörnitzostheim drill core
glass-bearing breccia ejecta (at depth)
Aumühle quarry
glass-bearing breccia ejecta (surface)
Nördlingen drill core
crater-fill glass-bearing breccia
Surficial glass-bearing breccia
Bunte breccia
inner ring
two-layer ejecta
lake sediments
sedimentary cover
?
5 km
crater-fill glass-bearing breccia
crystalline basement
Modified from Hüttner and Schmidt-Kaler, 1999; Osinski et al., 2004

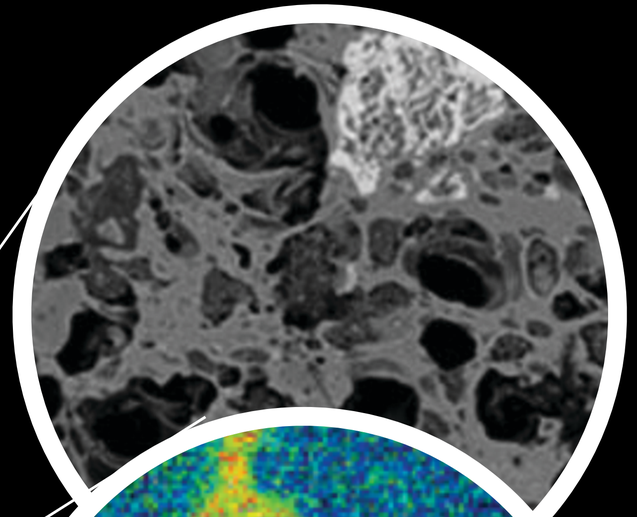


Sapers et al 2017

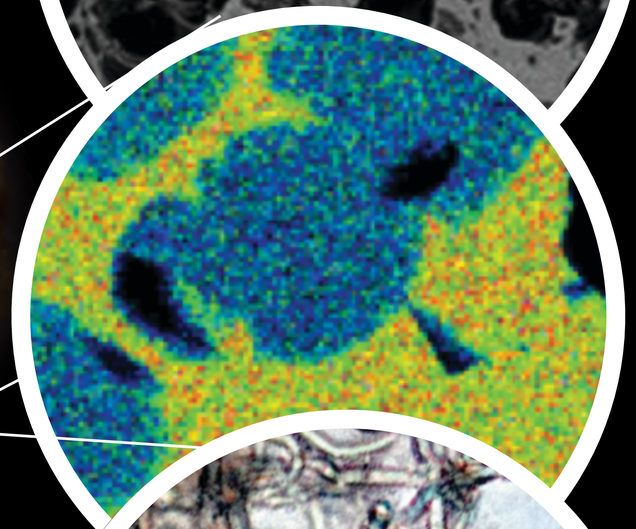


Impact Breccia

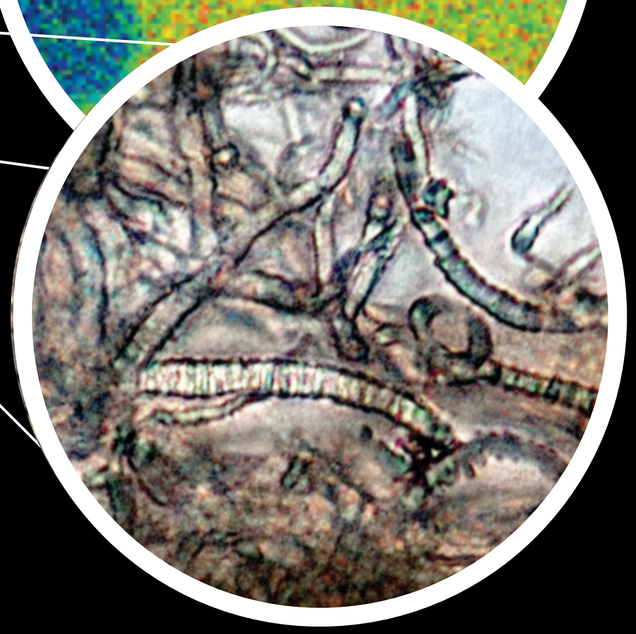




porosity and permeability = habitats



geochemical heterogeneity = metabolic energy



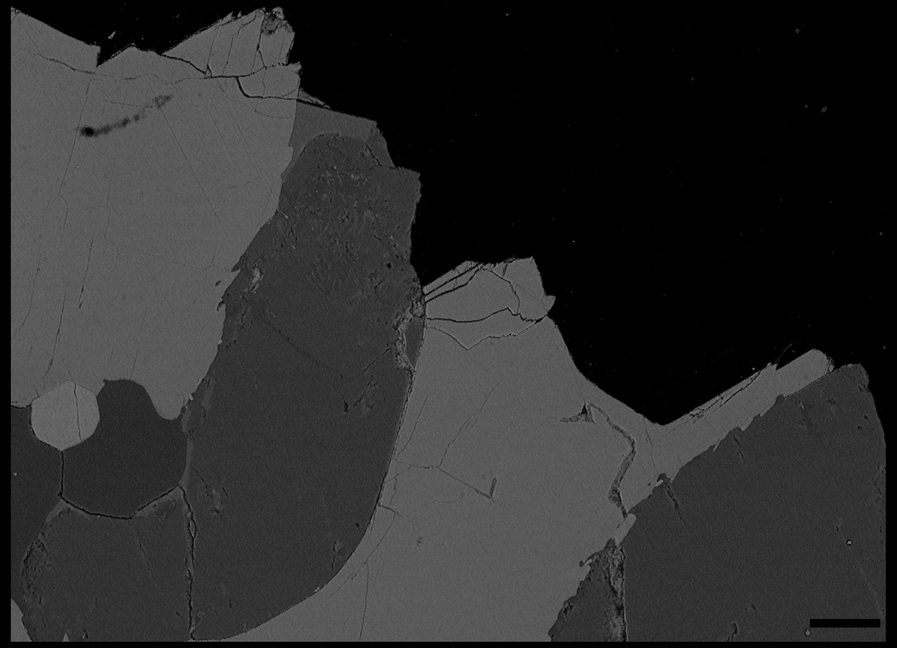
habitat + energy = colonization

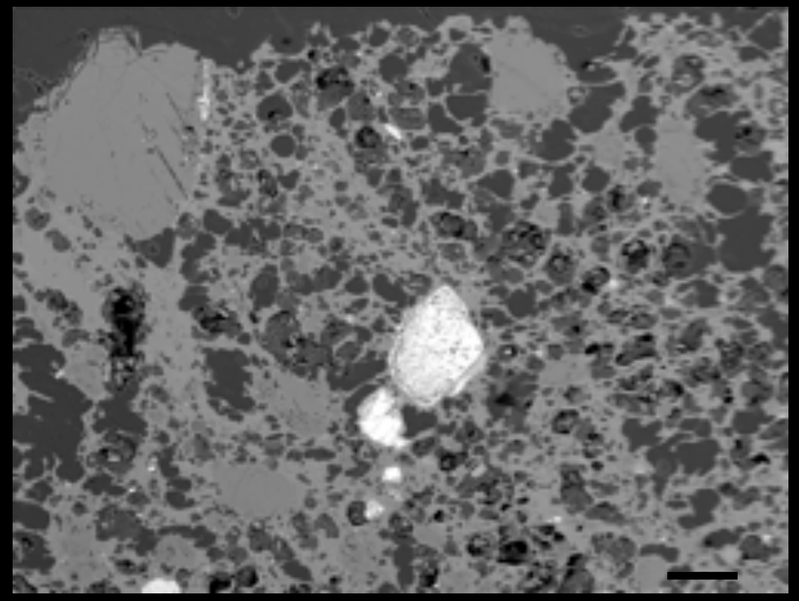
Variably shocked lithic clasts,
Hydrothermal mineralization
Impact glass/melt

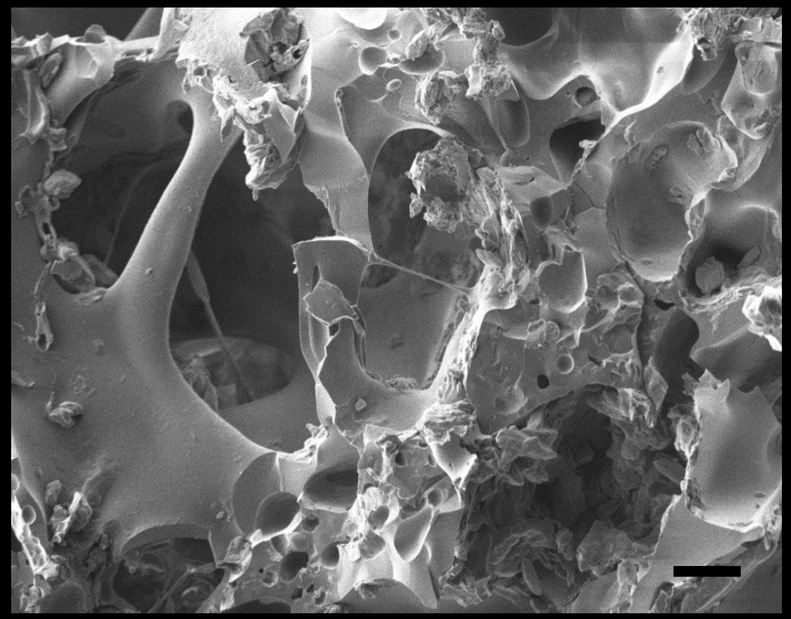
Crypto- and Chasmo-endoliths

Microorganisms living within fracture, voids, pore space in rock

- increase in porosity
- increase in pore space
- increase in translucence



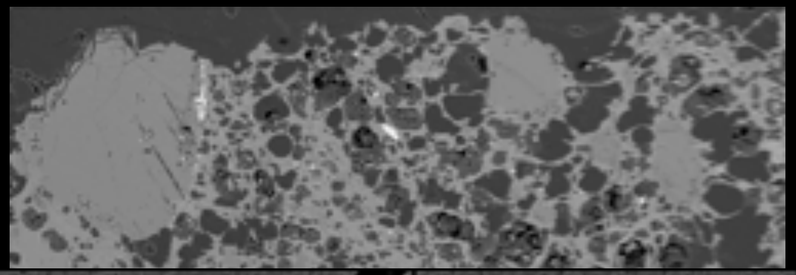


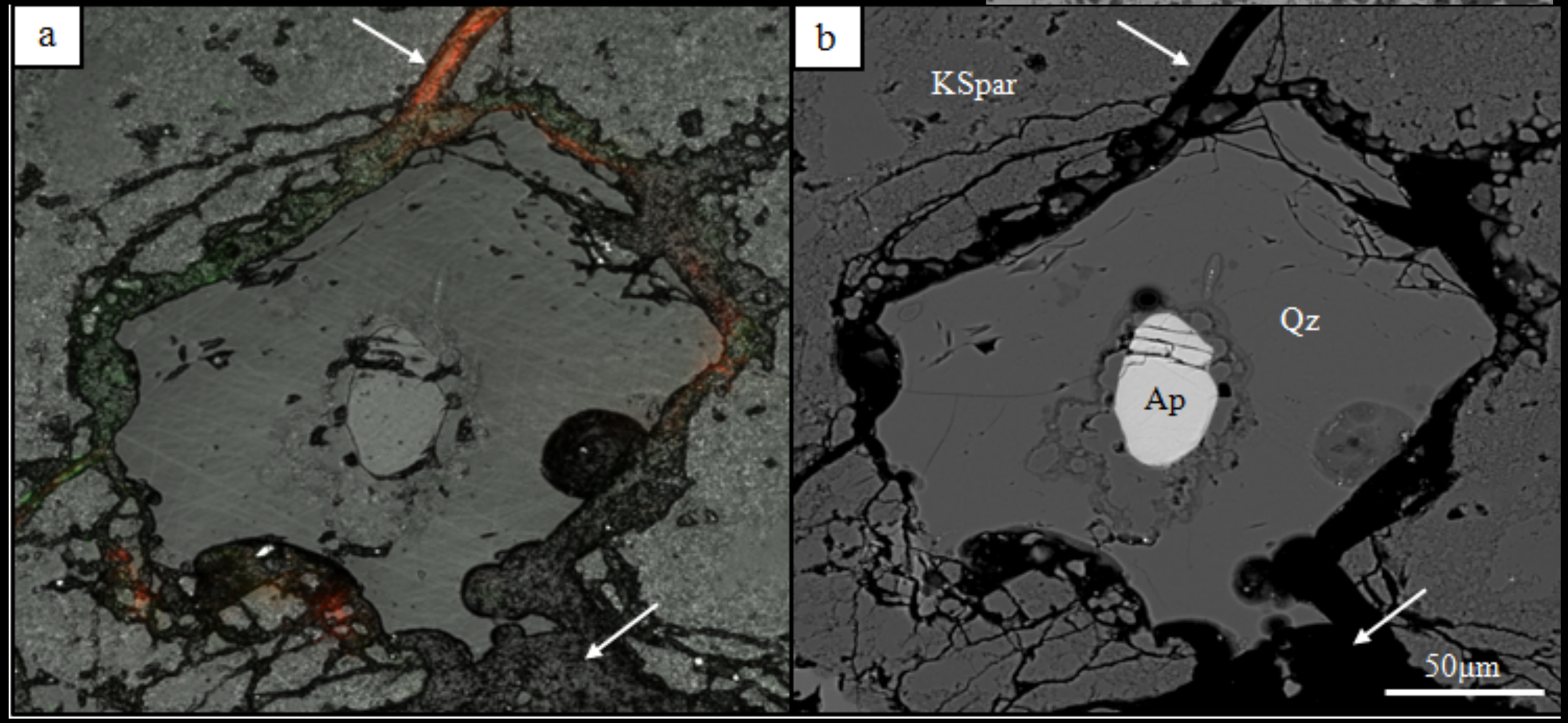


Pontefract et al., 2014

Crypto- and Chasmo-endoliths

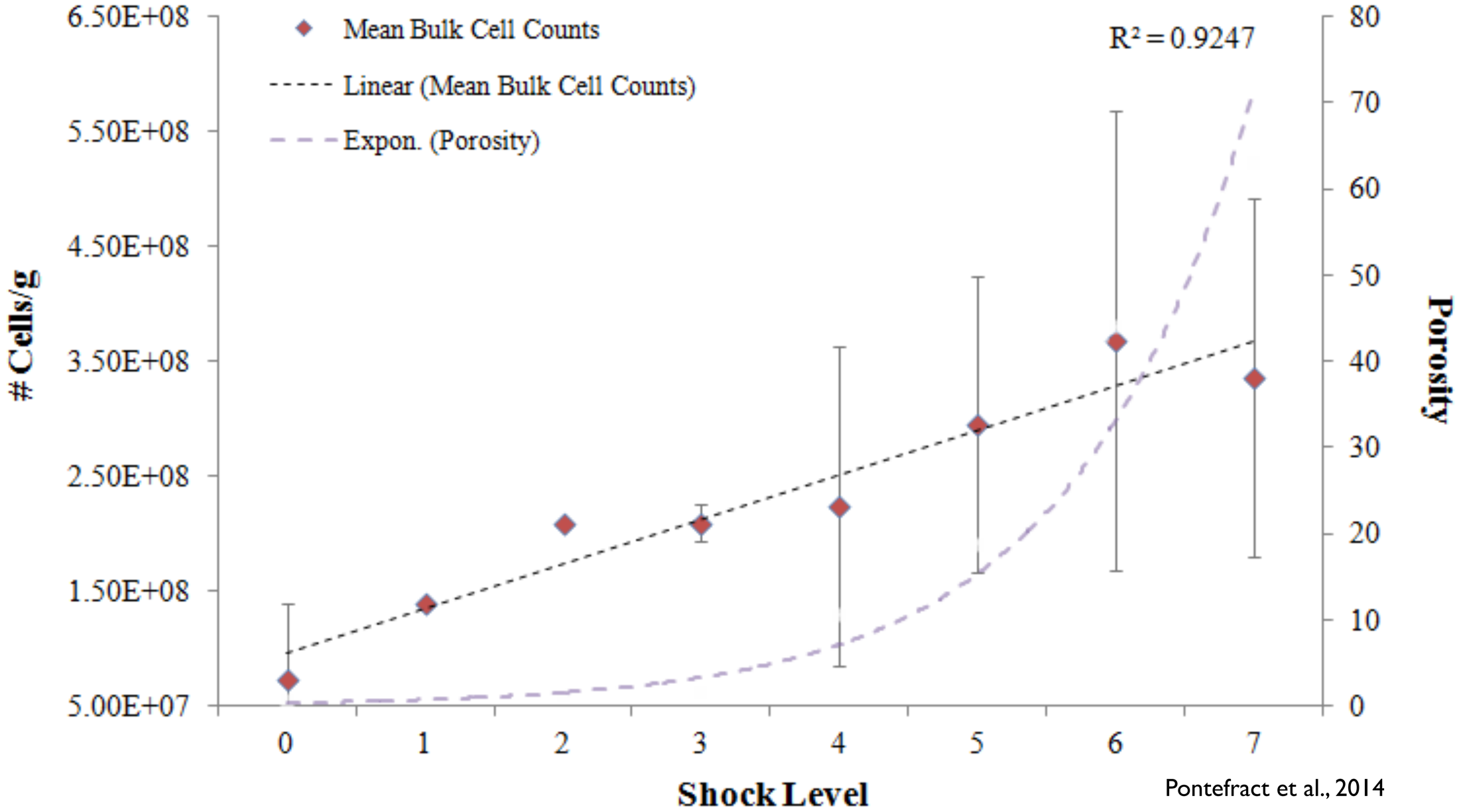
Microorganisms living within fracture, voids, pore space in rock





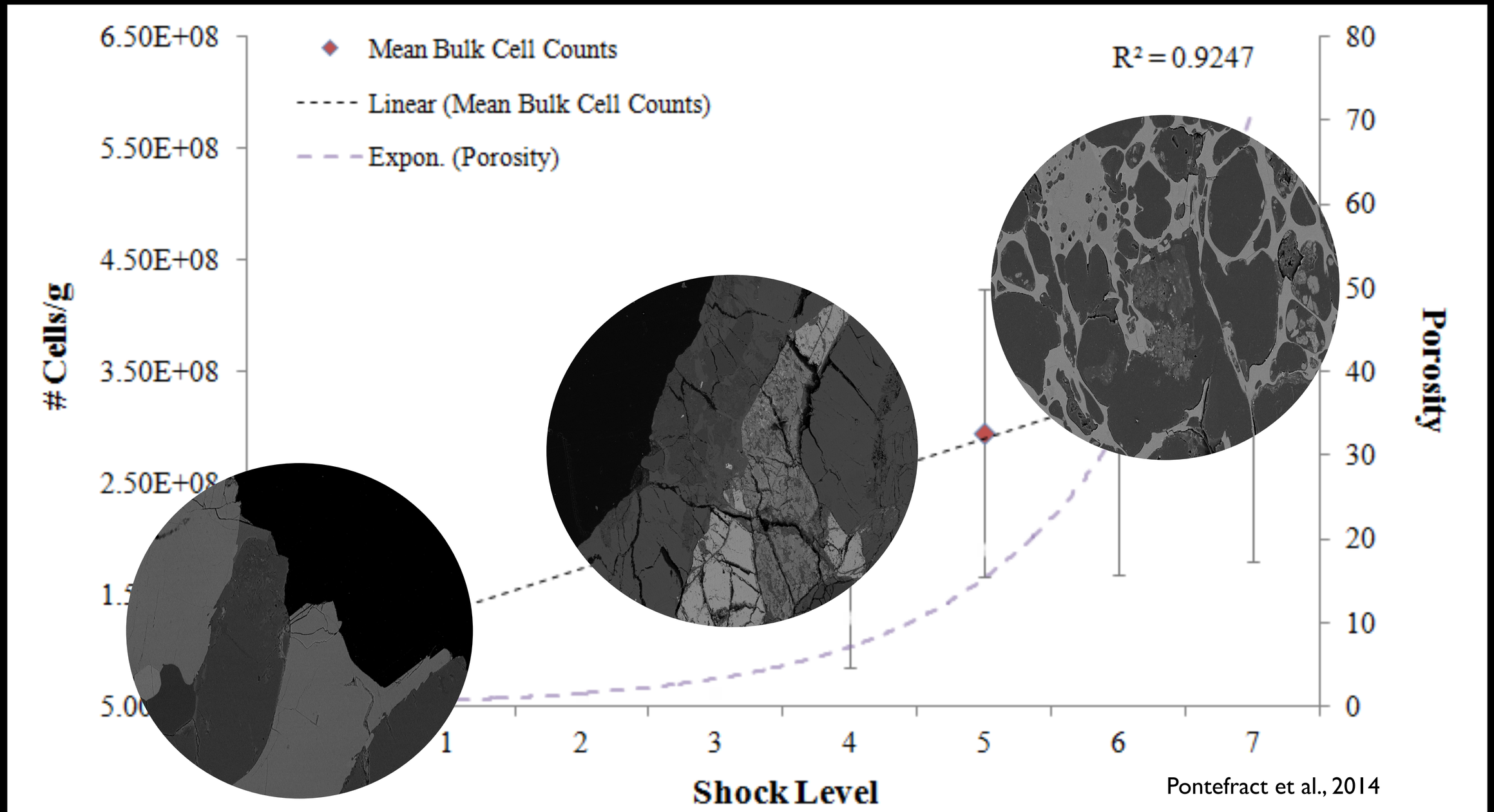
Pontefract et al., 2014

Crypto- and Chasmo-endoliths

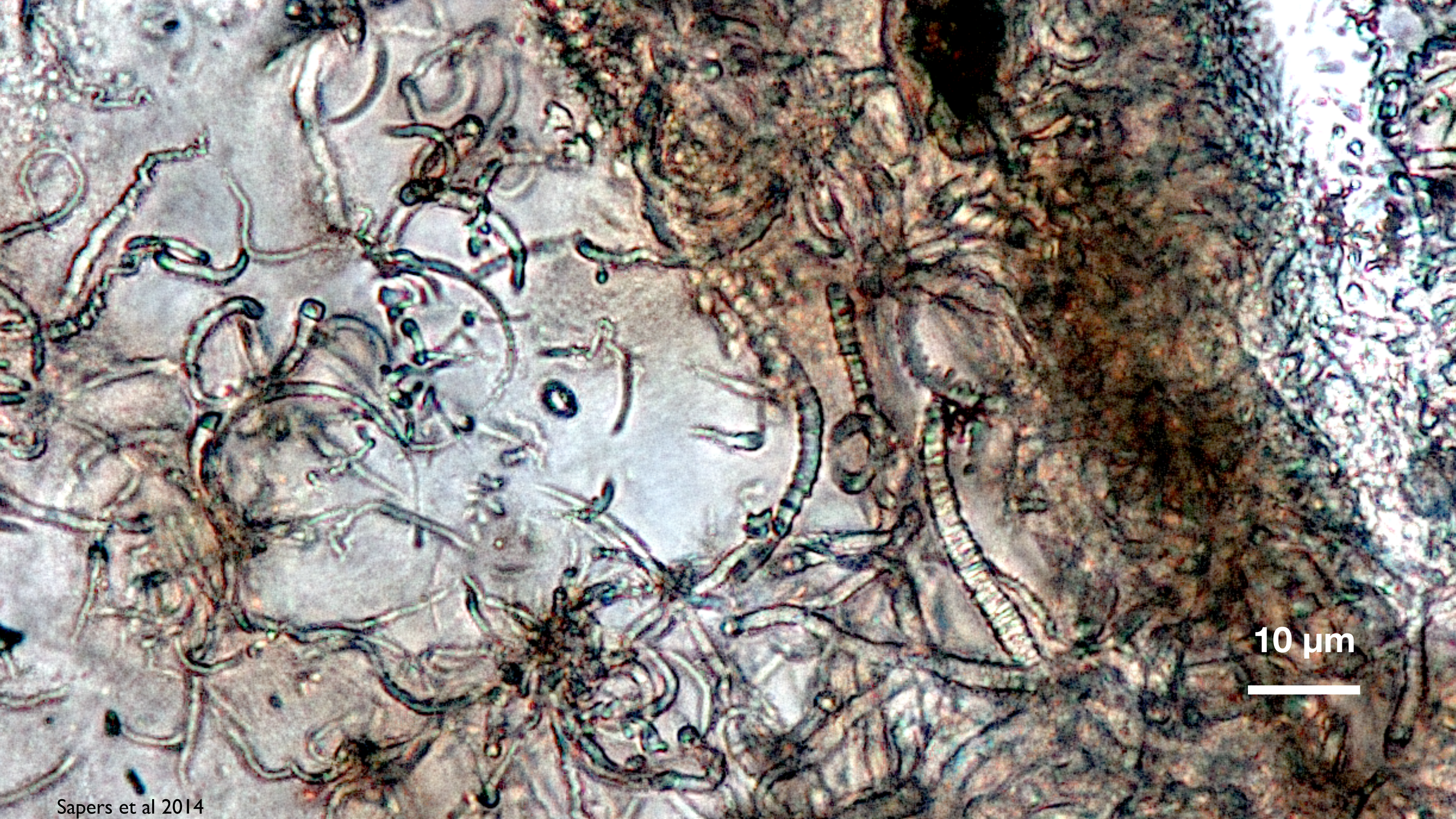


Pontefract et al., 2014

Crypto- and Chasmo-endoliths



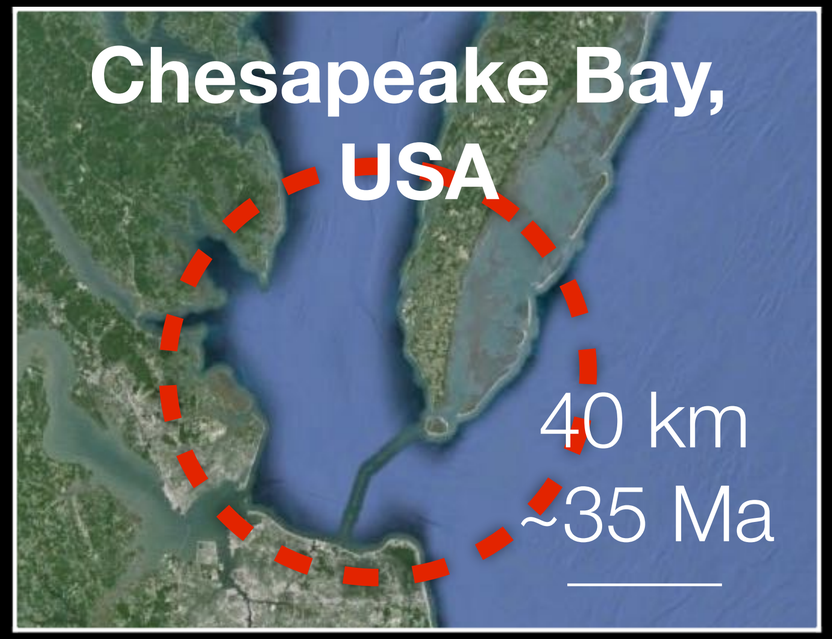
Pontefract et al., 2014

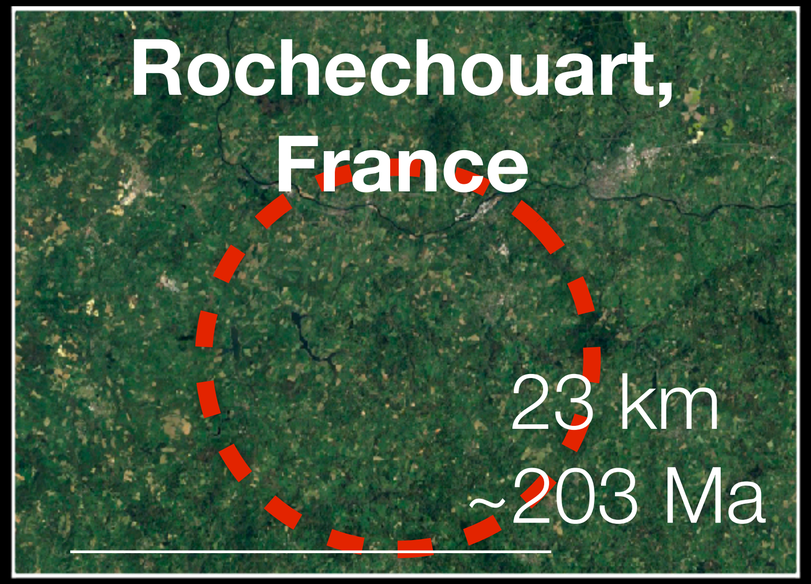


Sapers et al 2014

Evidence for Microbial Colonization

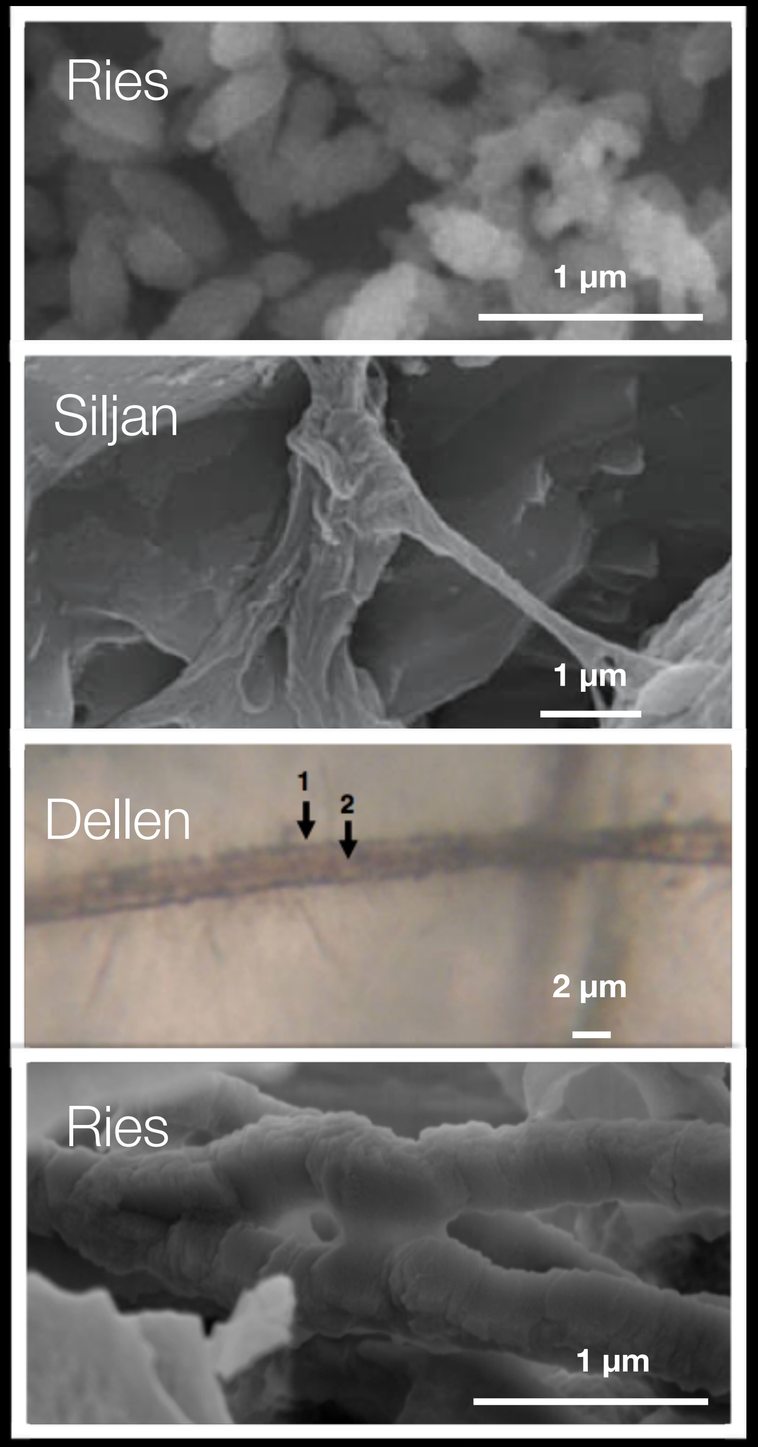
scale bar
~25 km



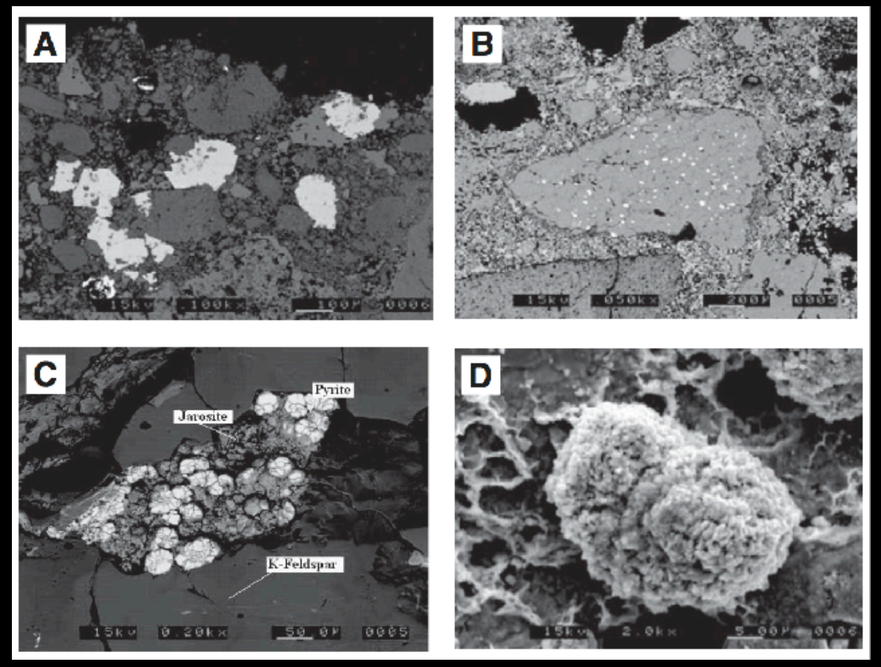


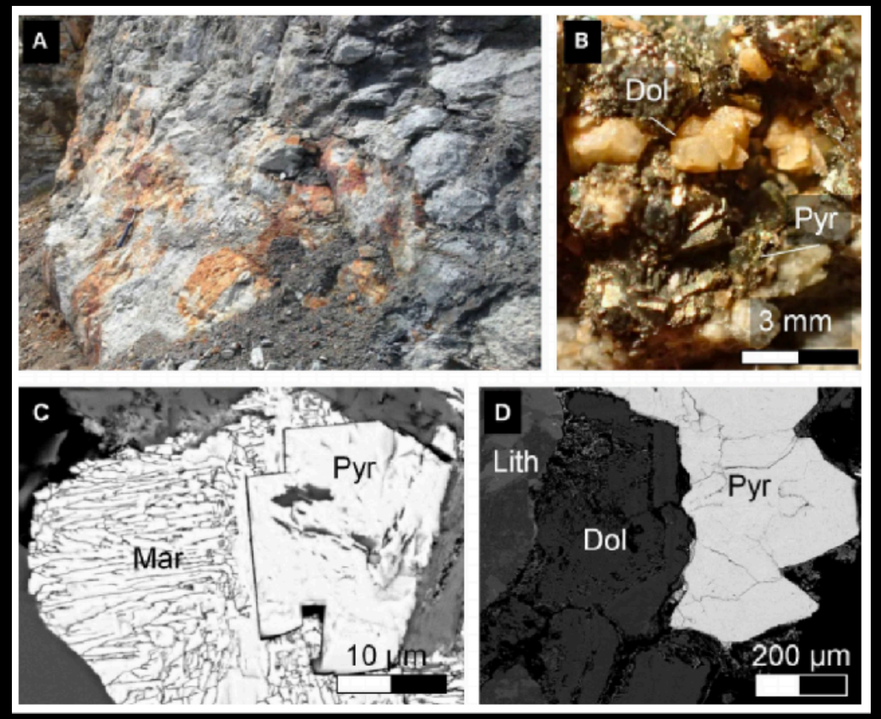
Putative Trace Fossils in Impact Generated Hydrothermal Systems

- **Ries** Glamoclija *et al* 2007; **Cheasapeake Bay** Glamoclija *et al* 2007.
  - features of potential morphological interest
- **Siljan** Hode *et al* 2008
  - evidence for EPS in hydrothermal veins
- **Dellen** Lindgren *et al* 2010
  - features of potential morphological interest
- **Ries** Sapers *et al* 2014; 2015
  - evidence for filamentous ichnofossils in impact glass

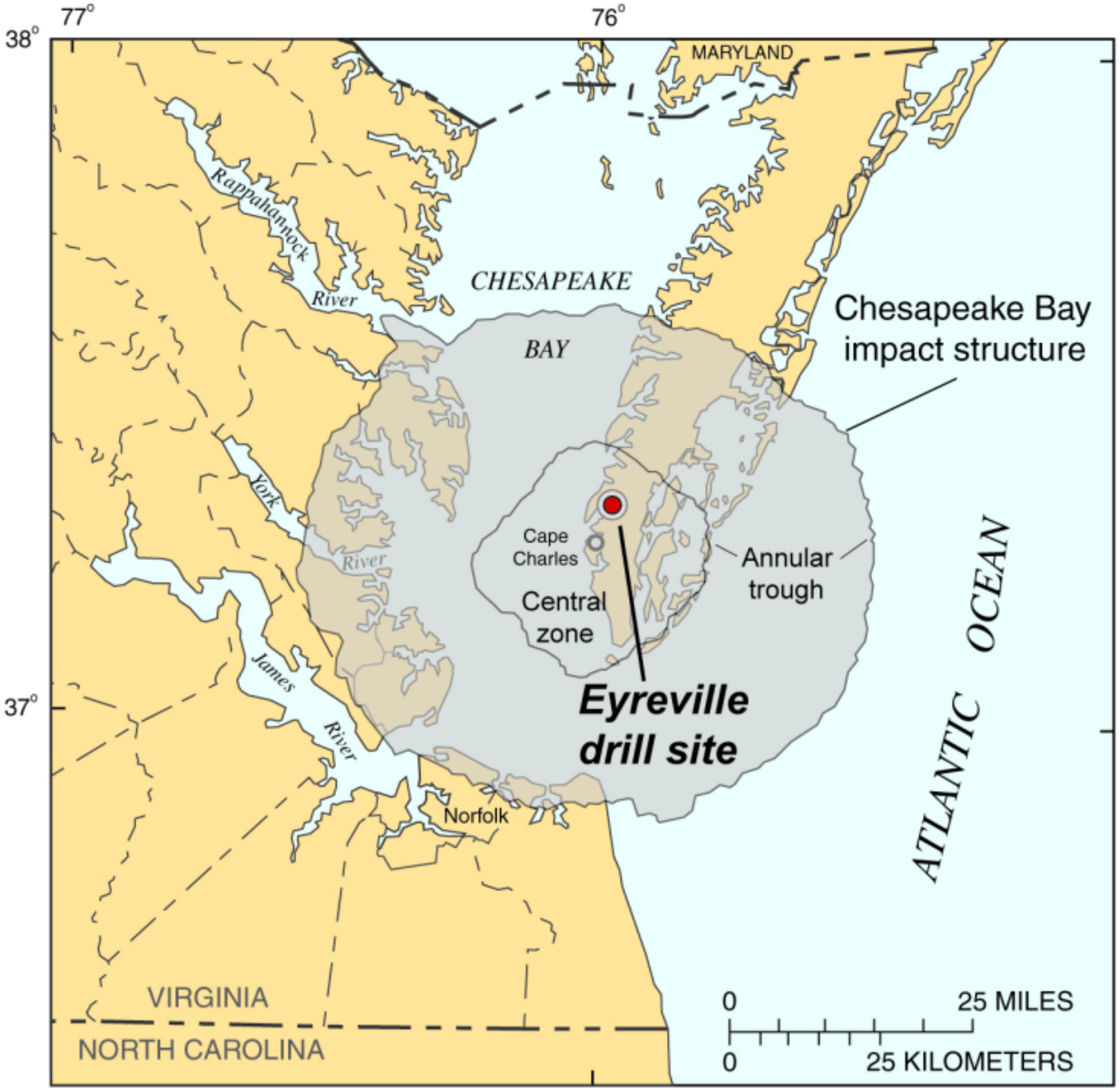


Sulfur Isotopic Evidence for Microbial Colonization





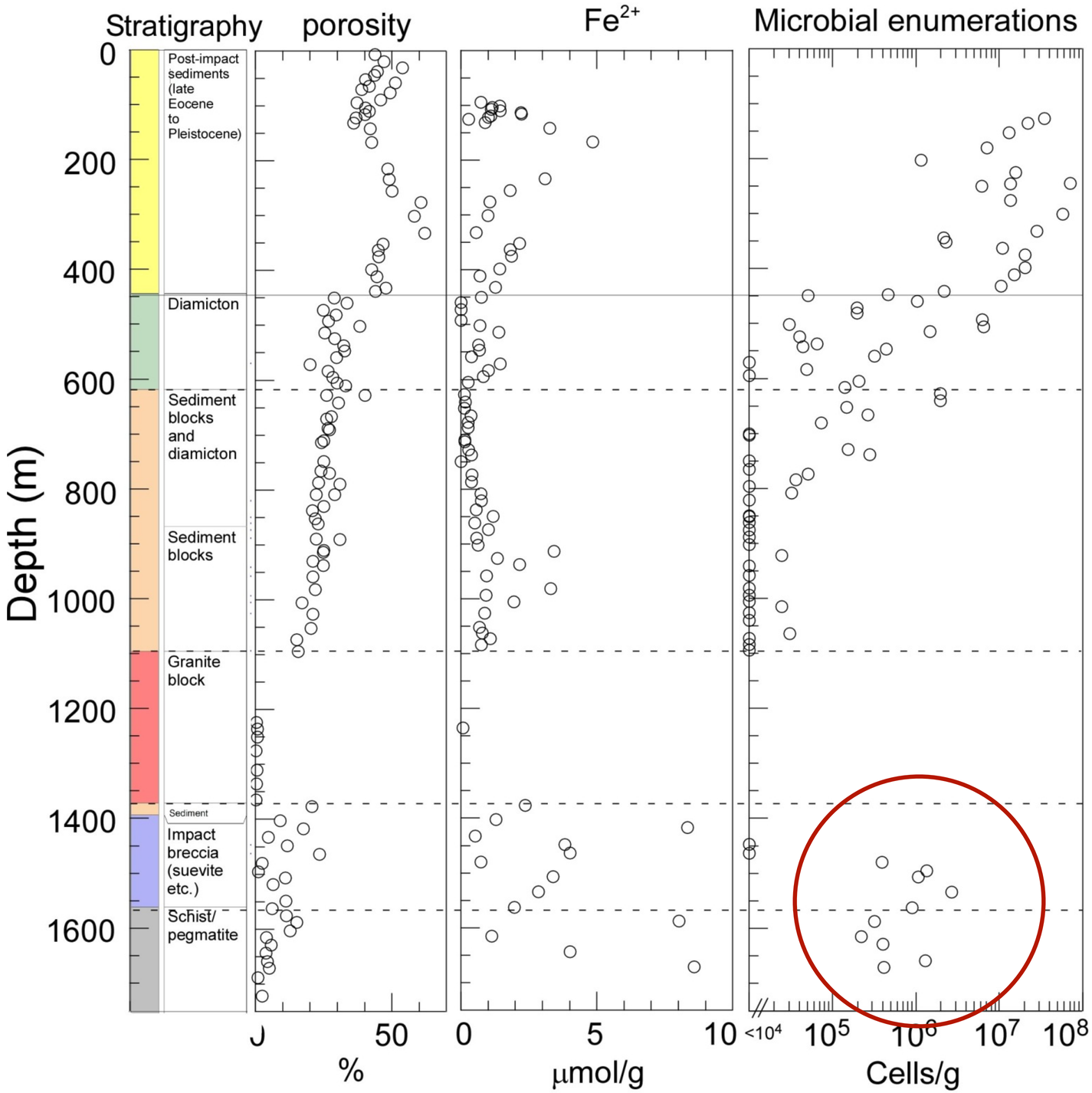
- Haughton (23 km diameter top, ~39 Ma; Parnell et al 2010) and Rouchechouart (23 km diameter; ~203 Ma bottom; Simpson et al, 2017) hydrothermal sulphide mineralization
- Extreme isotopic fractionation - microbial sulfate reduction
- Rapid and wide-spread microbial colonization during 'thermal phase of biology'
- Mineral context critical to interpretation of fractionation patterns - intact breccia samples

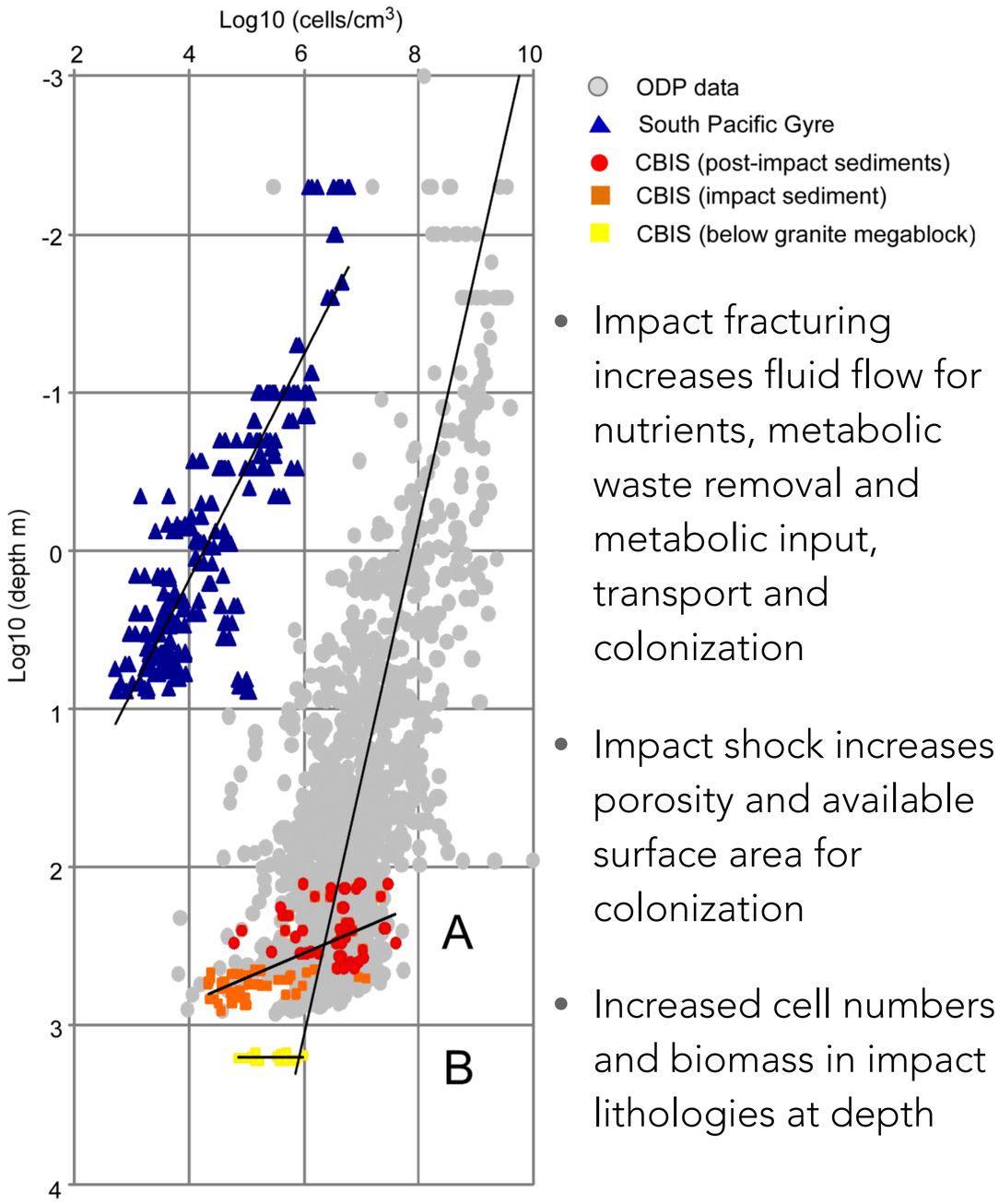


Deep Subsurface Refugia: Chesapeake Bay

- 85 km in diameter, 35.4 Ma
- Drilling campaign to assess microbial colonization of impactite lithologies at depth

Cockell et al., 2009; 2012

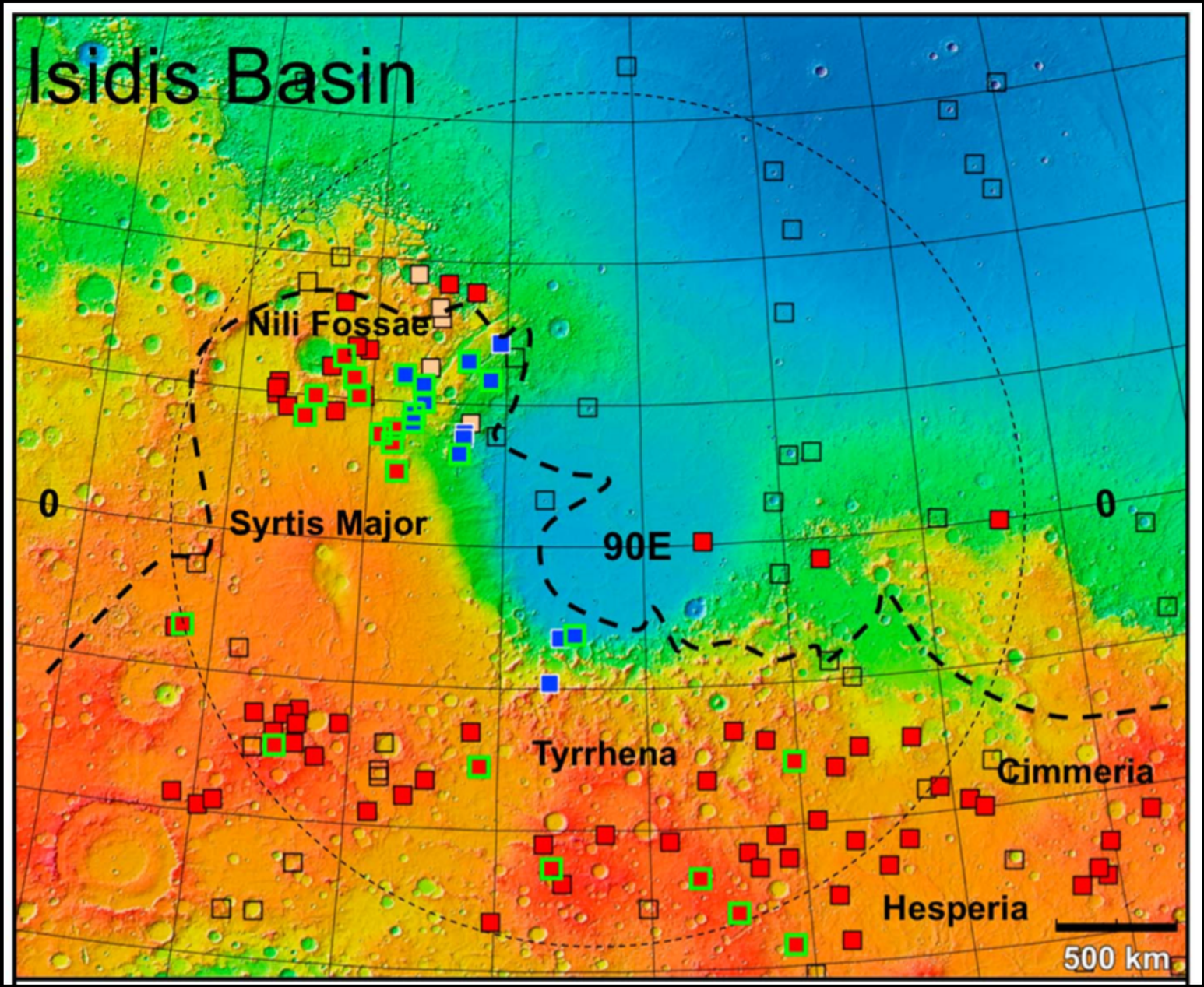




Cockell et al.,2012

- Impact fracturing increases fluid flow for nutrients, metabolic waste removal and metabolic input, transport and colonization
- Impact shock increases porosity and available surface area for colonization
- Increased cell numbers and biomass in impact lithologies at depth

Hydrated Silicates Associated with Megabreccias



mega-breccia

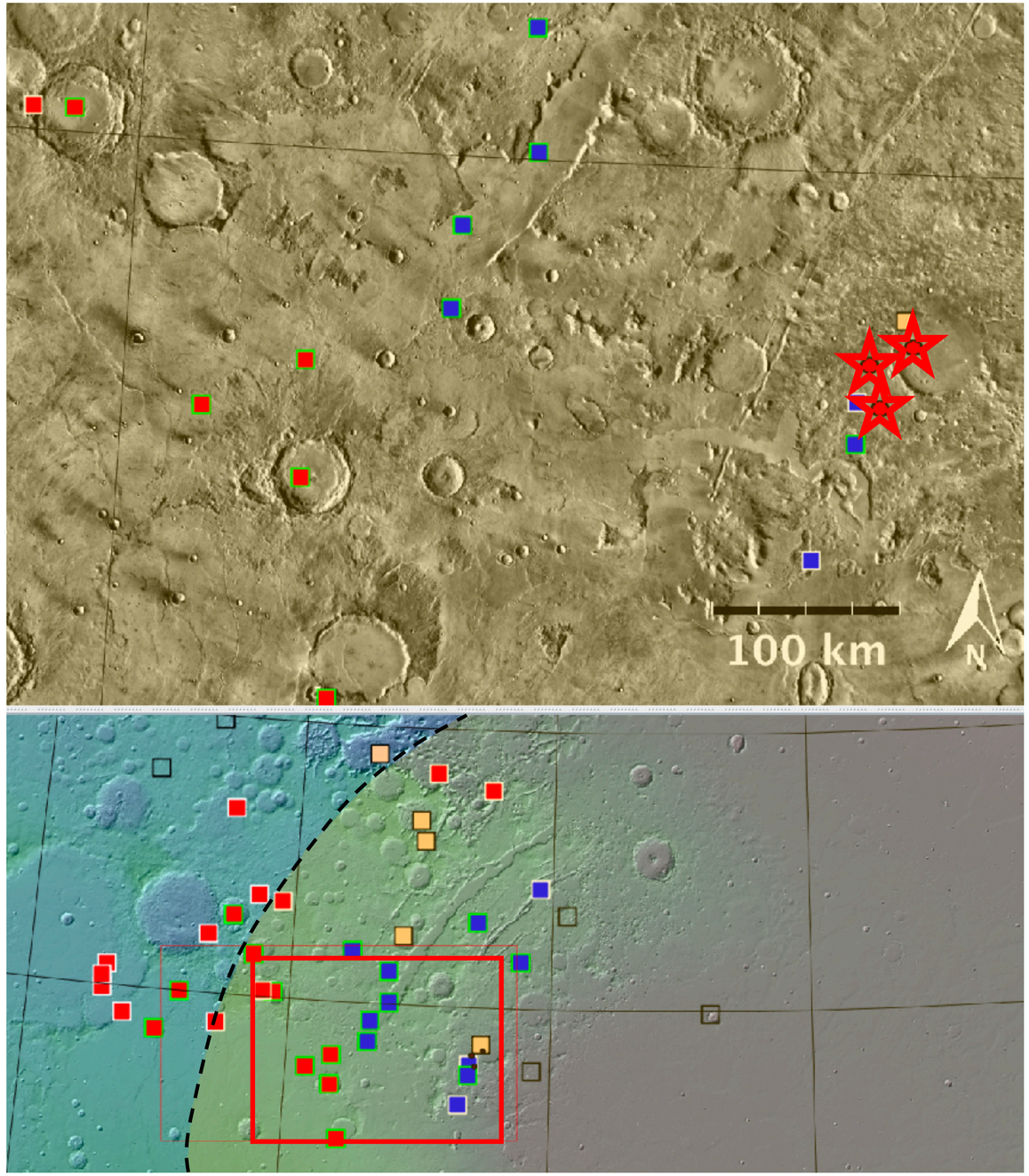
hydrated silicates ('crustal')

hydrated silicates ('stratigraphic')

Tornabene et al 2013; (CRISM; after Ehlmann et al. [2011])

Breccia and Impactites: Isidis Basin Range

- Megabreccias associated with Isidis - preserve ancient crust: window into a critical time period. (e.g. Ehlmann & Mustard, 2012; Bramble et al 2017)
- Breccias in terrestrial impacts wealth of information about pre-impact lithology, abundant hydrothermal alteration, excellent preservation of microbial colonization (morphological and geochemical)
- Mineralized ridges interpreted of hydrothermal activity - multiple generations of fluid flow excellent opportunity to investigate fluid/volatiles



CRISM detections of hydrated silicates associated with 'Crustal Clays' (after Ehlmann et al. 2011)

CRISM detections of hydrated silicates associated with 'Clay Stratigraphies' (after Ehlmann et al. 2011)

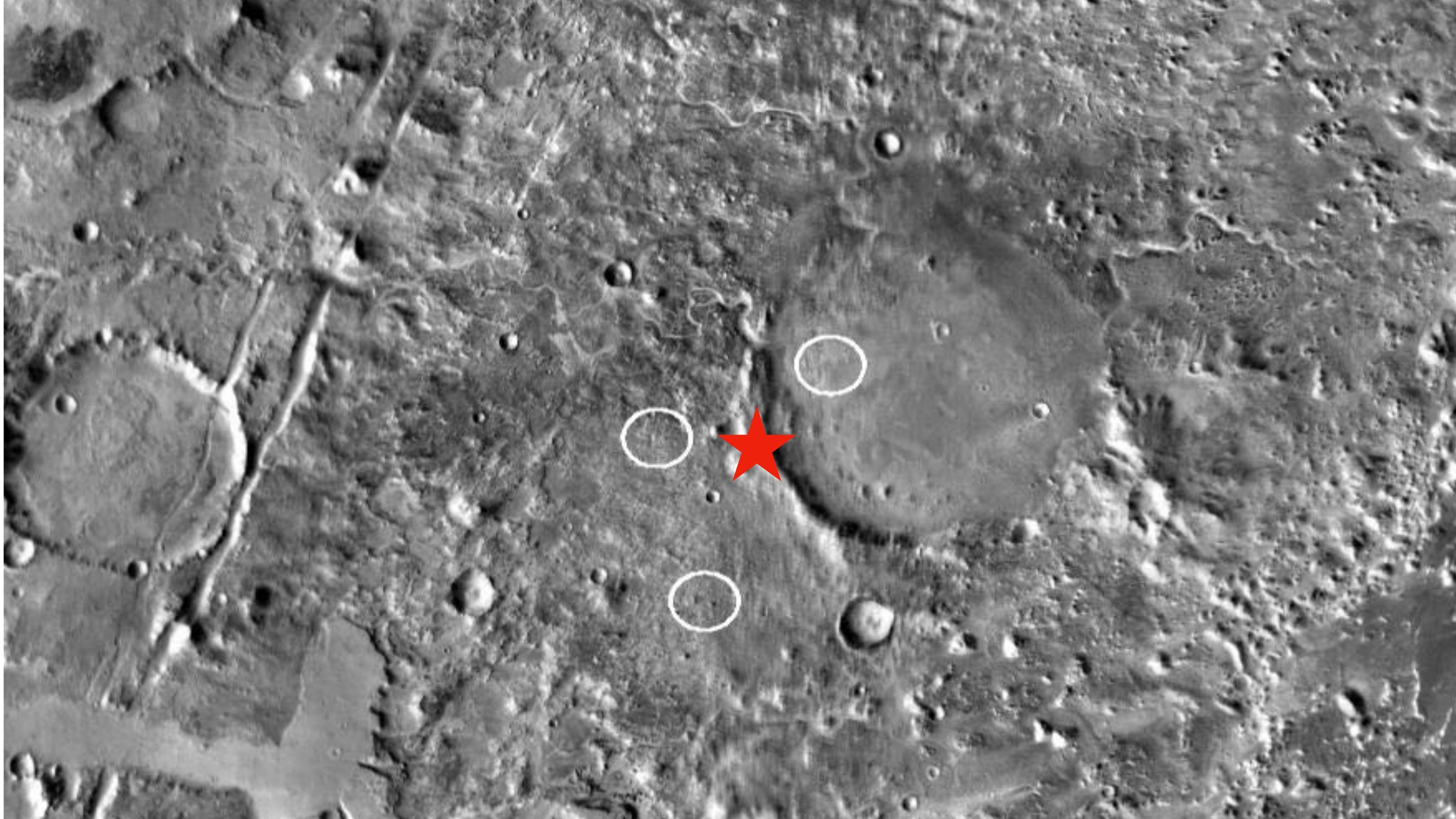
CRISM detections of hydrated silicates associated with 'Sedimentary Clays' (after Ehlmann et al. 2011)

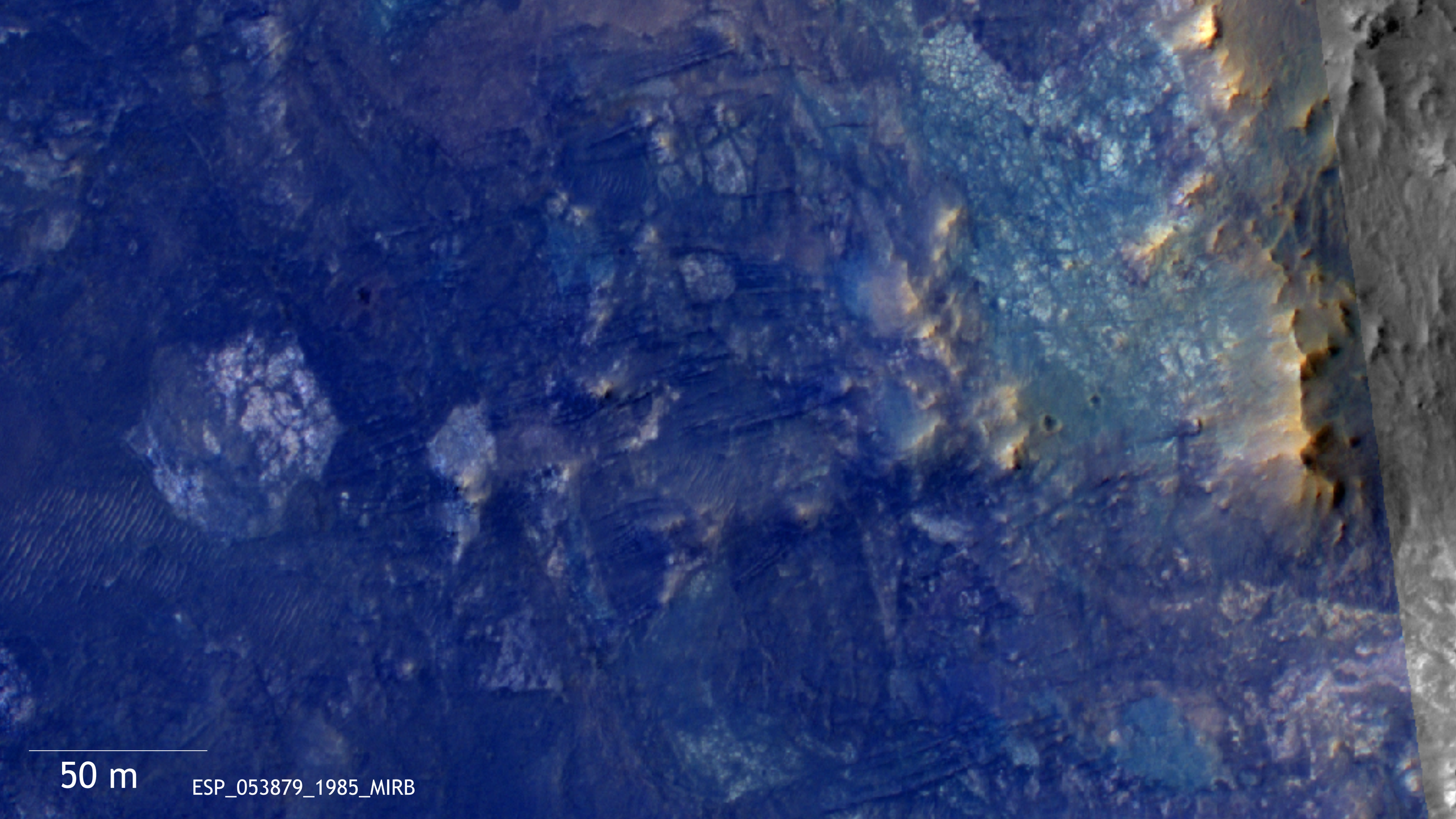
No detection of hydrated silicates

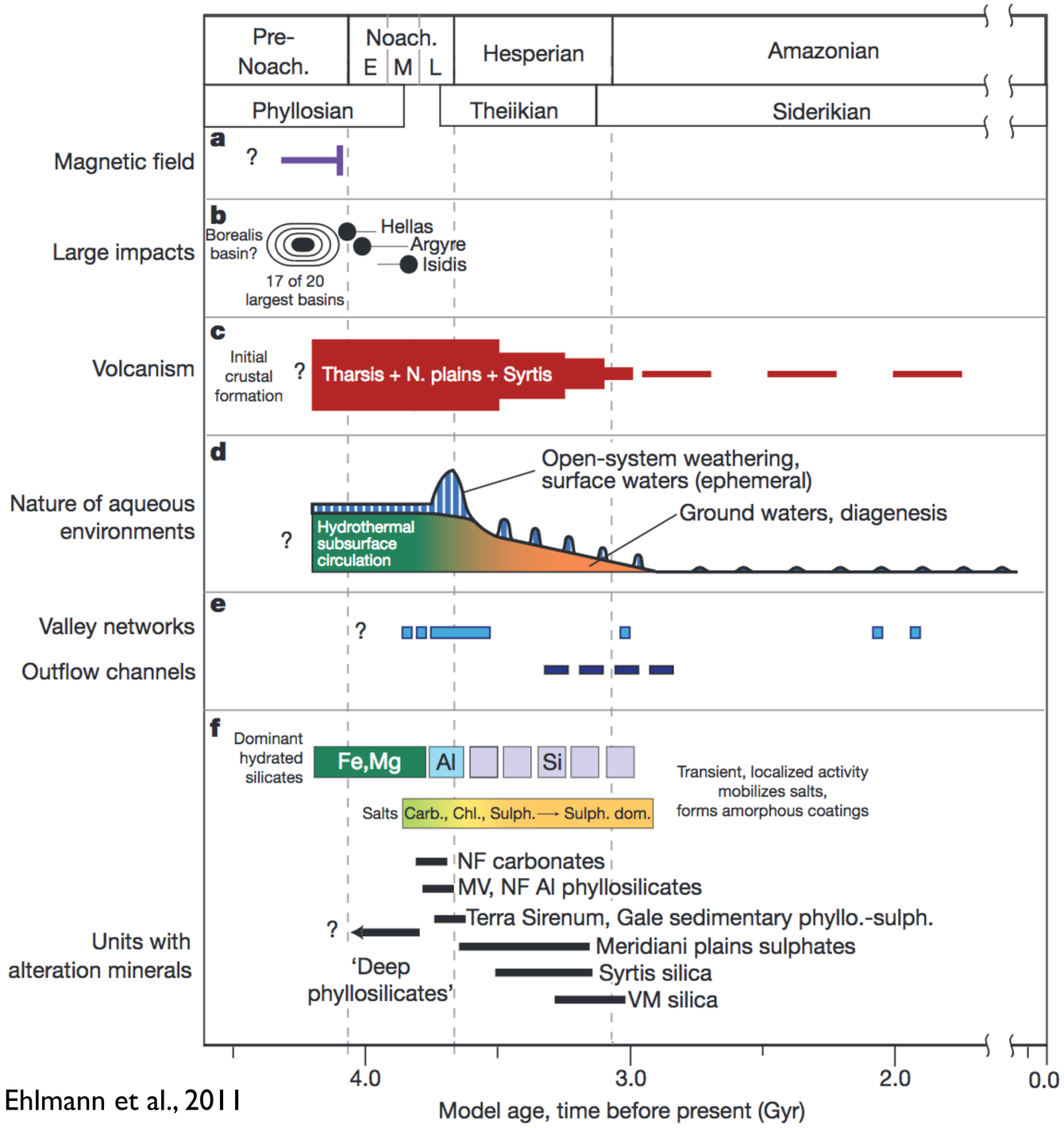
Those that correlate with HiRISE observations of megabreccias

2 crater radii estimate of the possible extent of continuous ejecta deposits assuming non-oblique trajectory

Tornabene et al. 2013 JGR



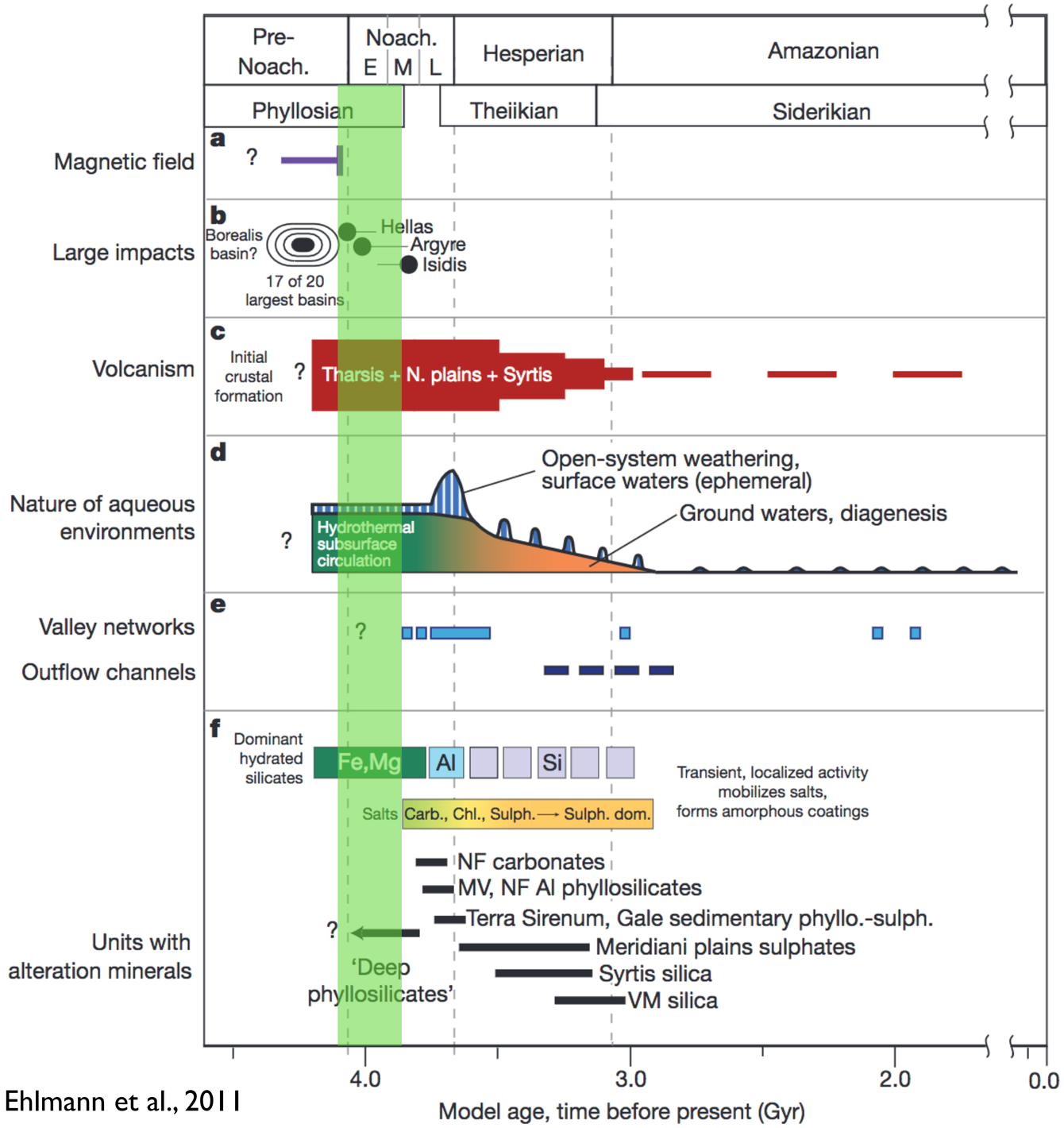

50 m
ESP_053879_1985_MIRB



Ehlmann et al., 2011

Biosignature Preservation

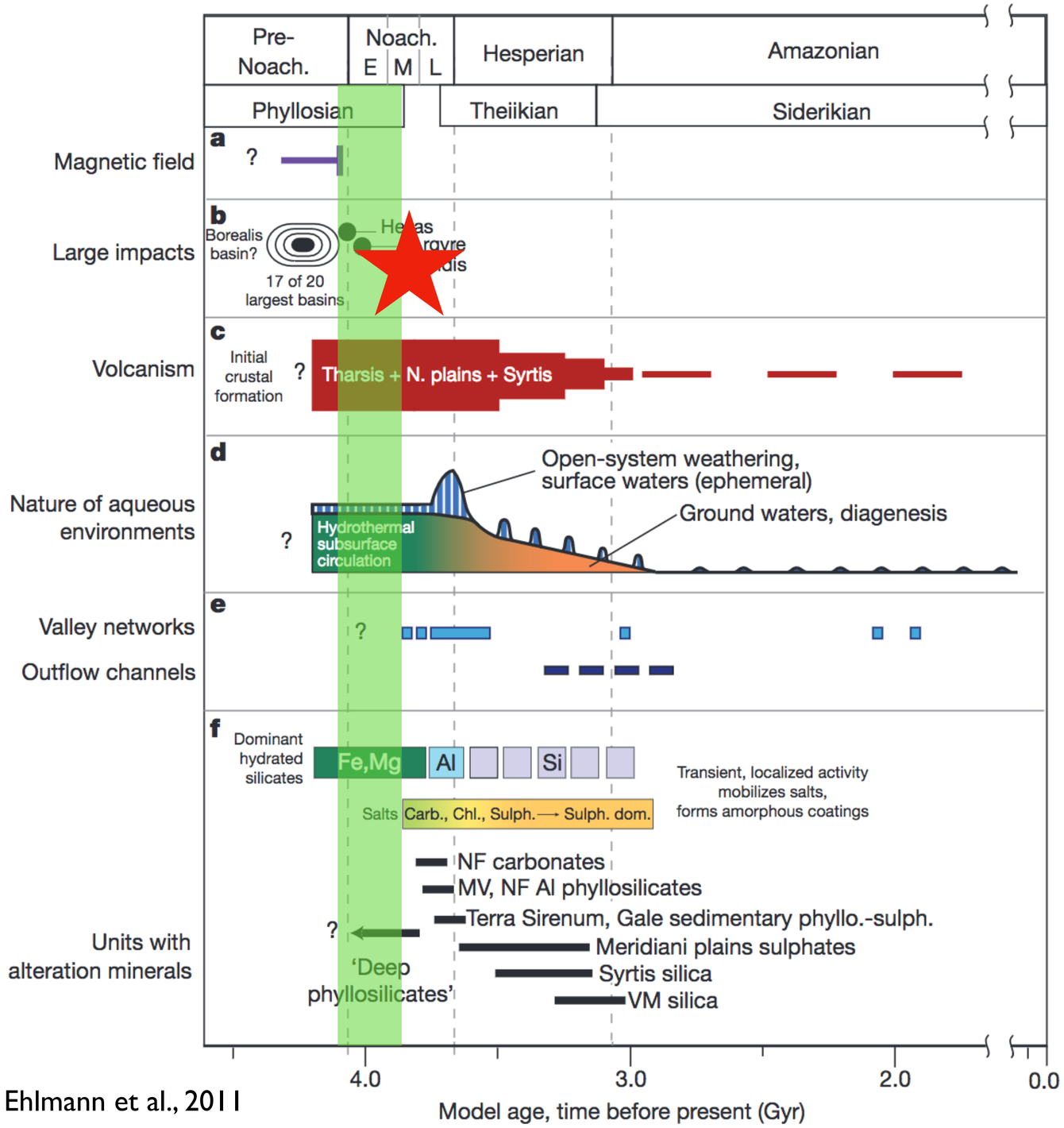
- Must be in significant enough concentration and distinct enough from abiotic processes to not be subject to attrition
- Time to build up biomass to sufficient quantity and biomass to imprint geological record
- Evidence for life on Earth ~4 Ga, required climatic stability to gain foothold and leave geochemical (isotopic) signature
- By this point Mars had already lost magnetic field and much of its atmosphere: surface already inhospitable?
- Subsurface refugia: impacts connect habitable zones



Ehlmann et al., 2011

Biosignature Preservation

- Must be in significant enough concentration and distinct enough from abiotic processes to not be subject to attrition
- Time to build up biomass to sufficient quantity and biomass to imprint geological record
- Evidence for life on Earth ~4 Ga, required climatic stability to gain foothold and leave geochemical (isotopic) signature
- By this point Mars had already lost magnetic field and much of its atmosphere: surface already inhospitable?
- Subsurface refugia: impacts connect habitable zones



Ehlmann et al., 2011

Biosignature Preservation

- Must be in significant enough concentration and distinct enough from abiotic processes to not be subject to attrition
- Time to build up biomass to sufficient quantity and biomass to imprint geological record
- Evidence for life on Earth ~4 Ga, required climatic stability to gain foothold and leave geochemical (isotopic) signature
- By this point Mars had already lost magnetic field and much of its atmosphere: surface already inhospitable?
- Subsurface refugia: impacts connect habitable zones

- impact breccia as a microbial habitat - fluid flow, metabolic consideration, porosity: clast targets - shocked lithic clasts, hydrothermal mineralization, impact melt and glass
- fracture systems and subsurface fluid conduits
- potential for volatile release due to impact induced hydrothermal activity
- rich geologic diversity; potential for ancient: Noachian-Hesperian window: access to the subsurface, window into critical time period
- biosignature preservation in impact materials - clays, hydrothermal mineralization - protect from degradation
- fundamental geologic process investigation: phyllosilicate associated with ejecta: excavation +/- hydrothermal alteration
- abundant geochemical, mineralogical, energetic interfaces
- ideal habitat for rock hosted life - extension of habitability - connectivity (temporal and spatial) to putatively habitat environments
- fundamental discoveries about deep biosphere - lessons for Earth
- Important pin on impact cratering record at a critical transition point