Diagenetic Features in Yellowknife Bay, Gale Crater, Mars: Implications for Substrate Rheology and Potential Gas Release*

Linda C. Kah[1], Katie Stack[2], Kirsten Siebach[2], John Grotzinger[2], Dawn Sumner[2], Alberto Fairen[3], Dorothy Oehler[4], Juergen Schieber[5], Richard Leveille[6], Lauren Edgar[7], Melissa Rice[8], and the Mars Science Laboratory Team[9]

Search and Discovery Article #51021 (2014)**
Posted September 22, 2014

*Adapted from oral presentation given at 2014 AAPG Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014

[1]Earth and Planetary Sciences, University of Tennessee, Knoxville, Tennessee, US (lckah@utk.edu)
[2]California Institute of Technology, Pasadena, California, US
[3]University of California, Davis, California, US
[4]Cornell University, Cornell, New York, US
[5]NASA Johnson Space Center, Houston, Texas, US
[6]Indiana University, Bloomington, Indiana, US
[7]Canadian Space Agency, St-Hubert, Quebec, Canada
[8]Arizona State University, Tempe, Arizona, US
[9]Jet Propulsion Laboratories, Pasadena, California, US

Abstract

Multiple diagenetic features have been observed in clay-bearing mudstone exposed within Yellowknife Bay, Gale Crater, Mars. These features occurred during at least two separate episodes: an early generation of spheroidal concretions that co-occur with a dense networks of mineralized fractures, and a later generation of mineralized veins. Concretions consist of mm-sized spheroids (0.4 to 8.0 mm, mean diameter of 1.2 mm) that are distinctly more resistant than the encompassing mudstone. Dissected spheroids suggest an origin via compaction and incipient lithification of the substrate at the perimeter of syndepositional void space. Concretions are generally patchy in their distribution within clay-bearing mudstone, but in places can be the dominant fabric element. Locally dense networks of mineralized fractures occur in regions of low concretion abundance. These consist of short (< 50 cm), curvilinear to planar mineralized voids that occur across a range of orientations from vertical to subhorizontal. Fractures are filled by multi-phase cement consisting of two isopachous, erosionally resistant outer bands, and a central less

resistant fill. Physical relationships suggests that original fractures may have formed as both interconnected voids and as discrete cross-cutting features. Co-occurrence of early diagenetic concretions and fracture networks suggests a common origin via gas release within a subaqueous, shallow substrate. We suggest that gas release within weakly cohesive subsurface sediments resulted in substrate dewatering and an increase in the cohesive strength of the substrate. Local differences in substrate strength and rate of gas production would have result in formation of either discrete voids or fracture networks. A second generation of mineralized veins is characterized by a regionally low spatial density, predominantly vertical or horizontal orientations, and a single phase of Ca-sulfate mineral fill. These veins cross-cut the early diagenetic elements and intersect a greater thickness of stratigraphy within Yellowknife Bay, suggesting a later-diagenetic origin via hydraulic fracturing.

Selected References

Pollock, M.D., L.C. Kah, and J.K. Bartley, 2006, Morphology of Molar-Tooth Structures in Precambrian Carbonates: Influence of Substrate Rheology and Implications for Genesis: Journal of Sedimentary Research, v. 76, p. 310–323.

Siebach, K.L., J.P. Grotzinger, L.C. Kah, K.M. Stack, M. Malin, R. Léveillé, and D.Y. Sumner, 2014, Subaqueous shrinkage cracks in the Sheepbed mudstone: Implications for early fluid diagenesis, Gale crater, Mars: Journal of Geophysical Research: Planets, v. 119/7, p. 1597–1613.

Stack, K.M., J.P. Grotzinger, L.C. Kah, M.E. Schmidt, N. Mangold, K.S. Edgett, D.Y. Sumner, K.L. Siebach, M. Nachon, R. Lee, D.L. Blaney, L.P. Deflores, L.A. Edgar, A.G. Fairén, L.A. Leshin, S. Maurice, D. Z. Oehler, M.S. Rice, and R.C. Wiens, 2014, Diagenetic Origin of Nodules in the Sheepbed Member, Yellowknife Bay Formation, Gale Crater, Mars: Journal of Geophysical Research: Planets, v. 119/7, p. 1637–1664.

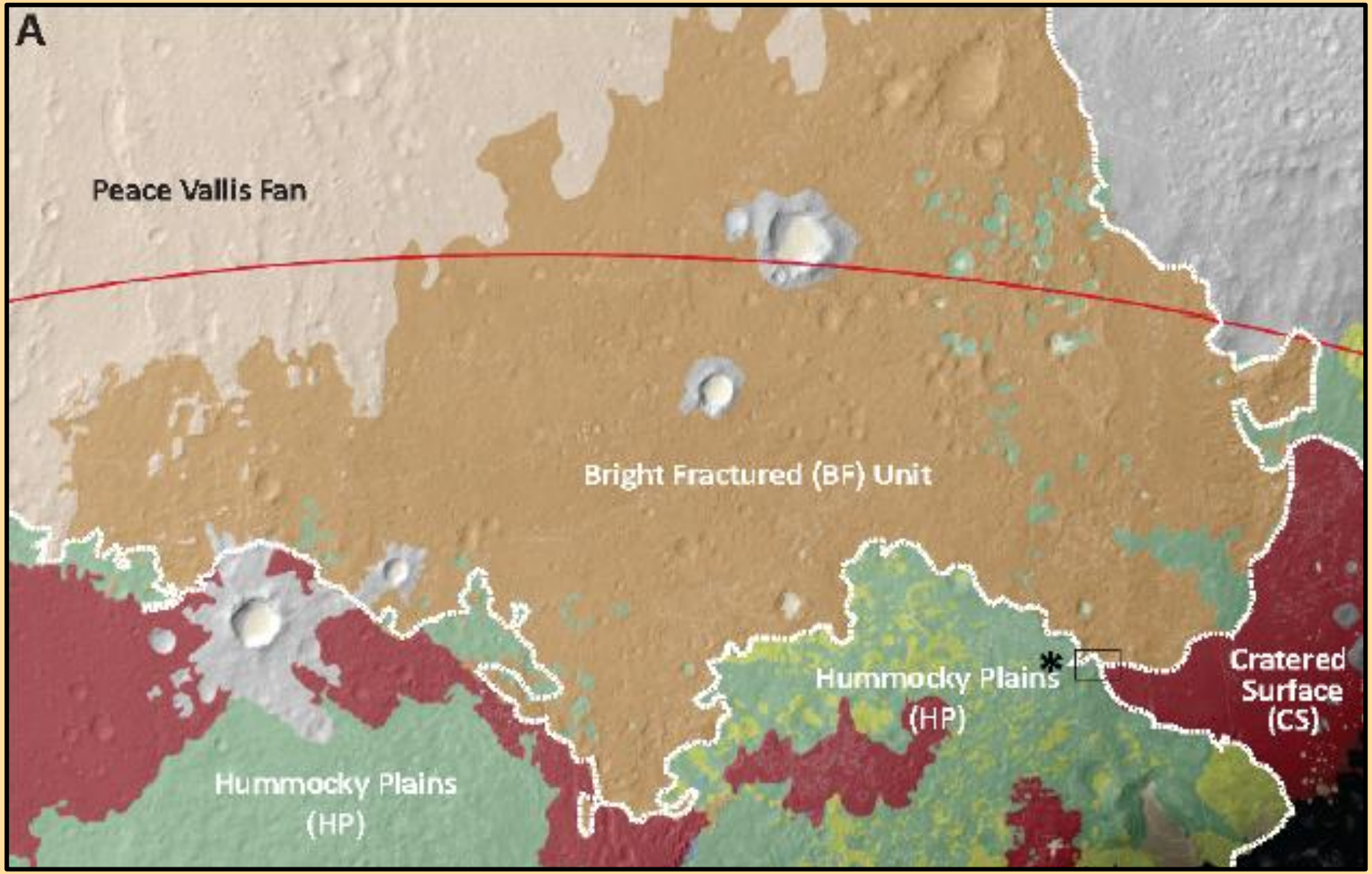
Diagenetic features in Yellowknife Bay, Gale Crater, Mars: Implications for substrate rheology and potential gas release

L.C. Kah
University of Tennessee

K. Stack, K. Siebach, J. Grotzinger, D. Sumner, A. Farien, D. Oehler, J. Schieber, R. Lévillé, L. Edgar, M. Rice, and the MSL Science Team

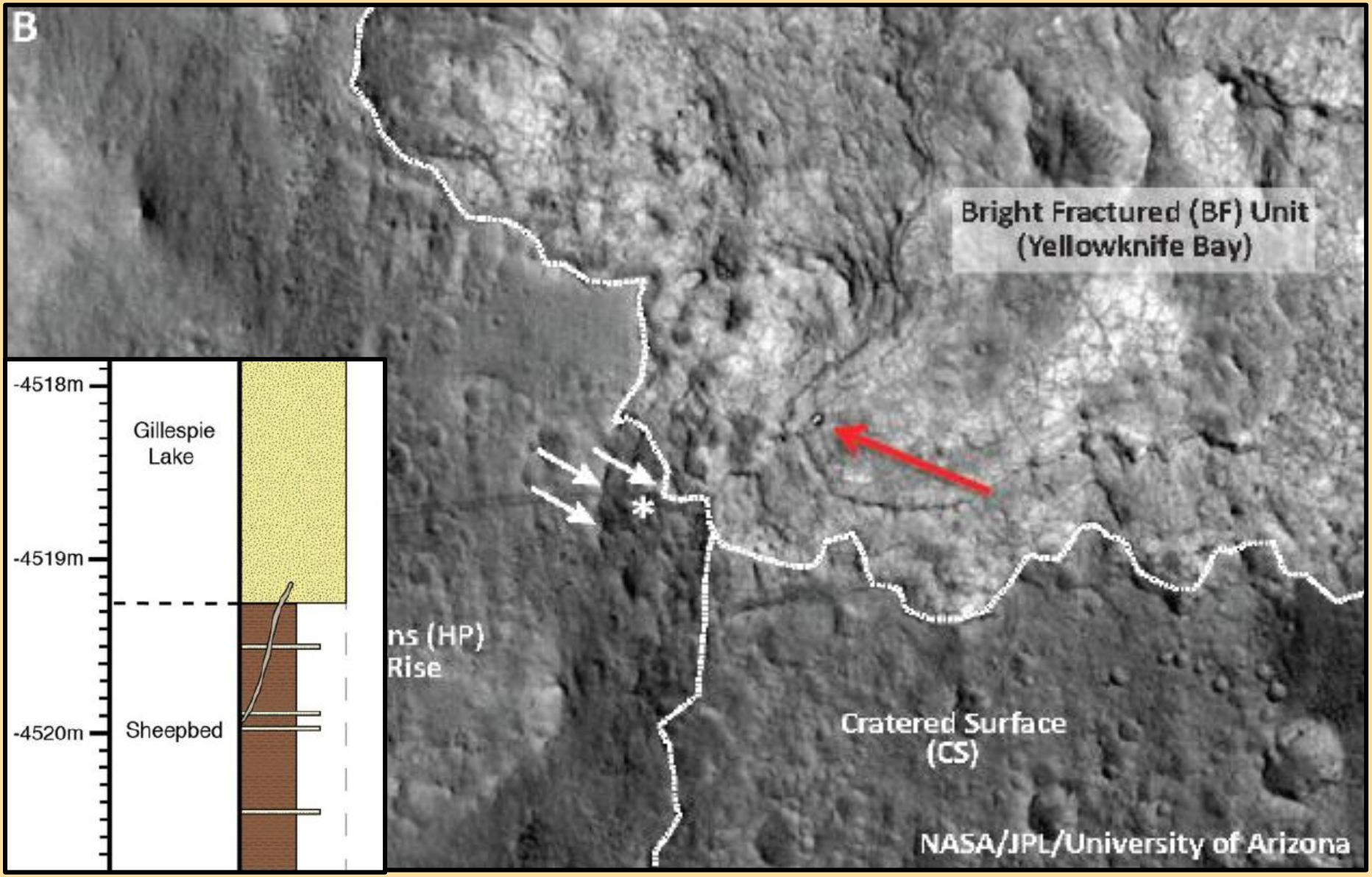
April 2014

Mars Science Laboratory



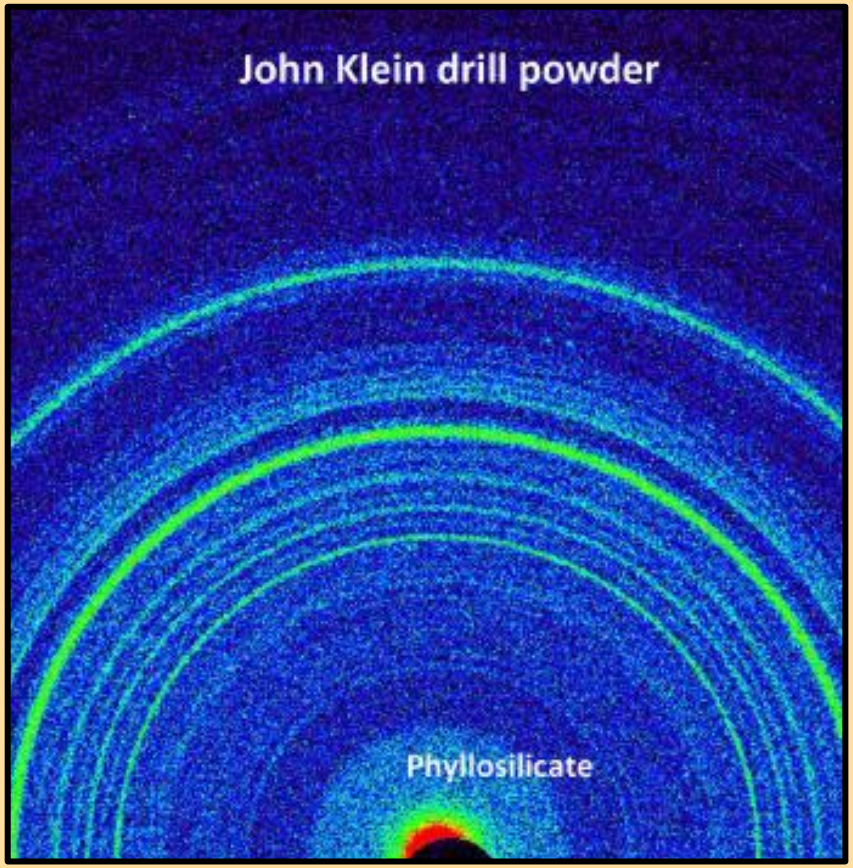
L.C. Kah et al.
AAPG 2014

Sheepbed Formation Mudstone



L.C. Kah et al.
AAPG 2014

Regional Context



Vaniman et al., 2013, Science

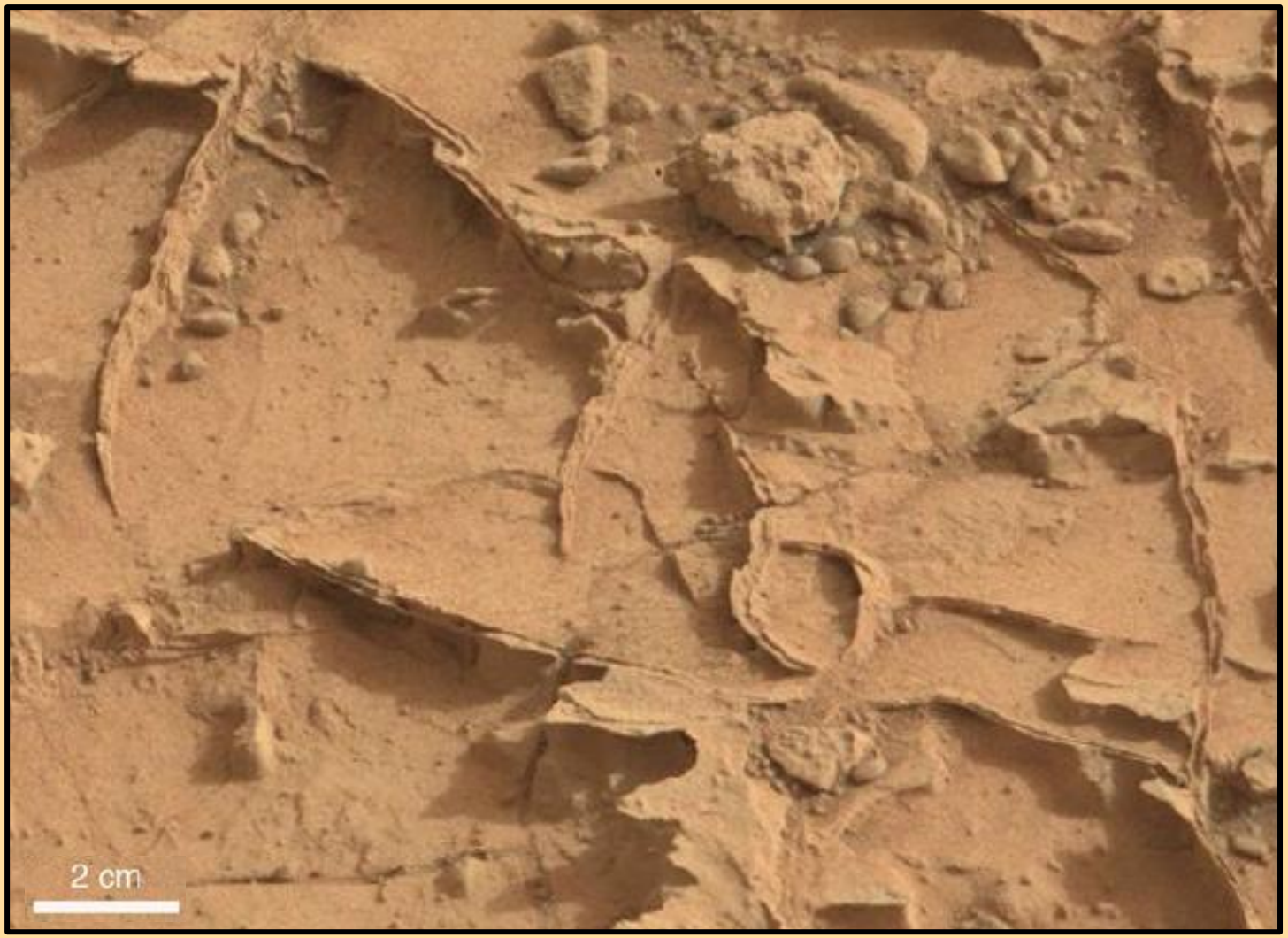
Sheepbed mudstone is compositionally of basaltic provenance, containing substantial (up to 30%) clay fraction

Regional Context

A continuum of nodular features…

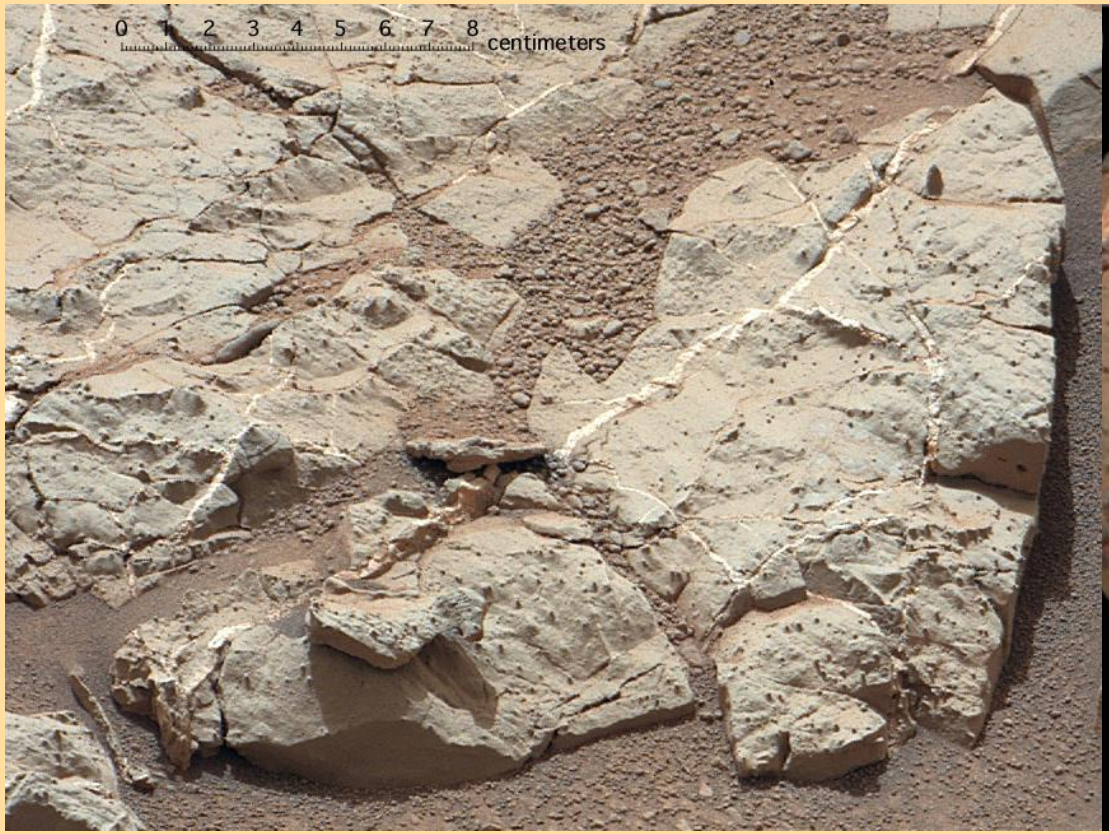
Three Distinct Diagenetic Features

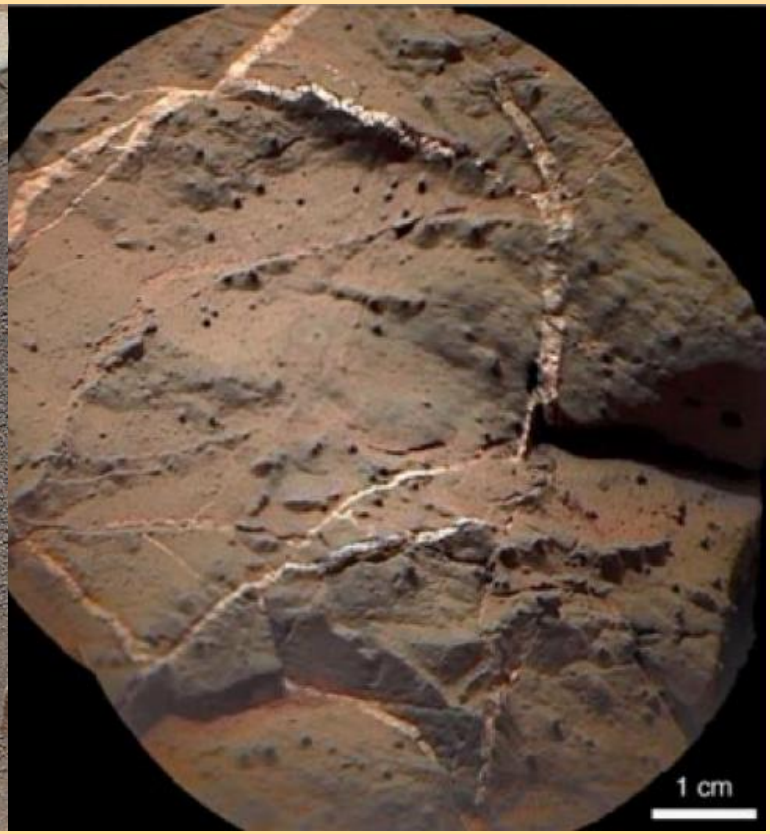
A variety of curvilinear, mineralized fractures…

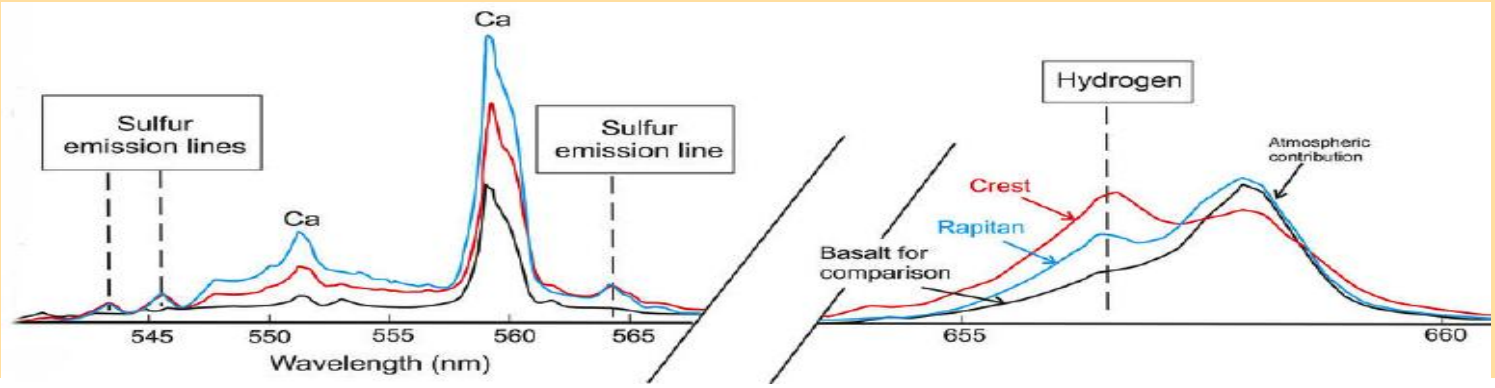


A series of throughgoing, $CaSO_4$-filled fractures…

Three Distinct Diagenetic Features



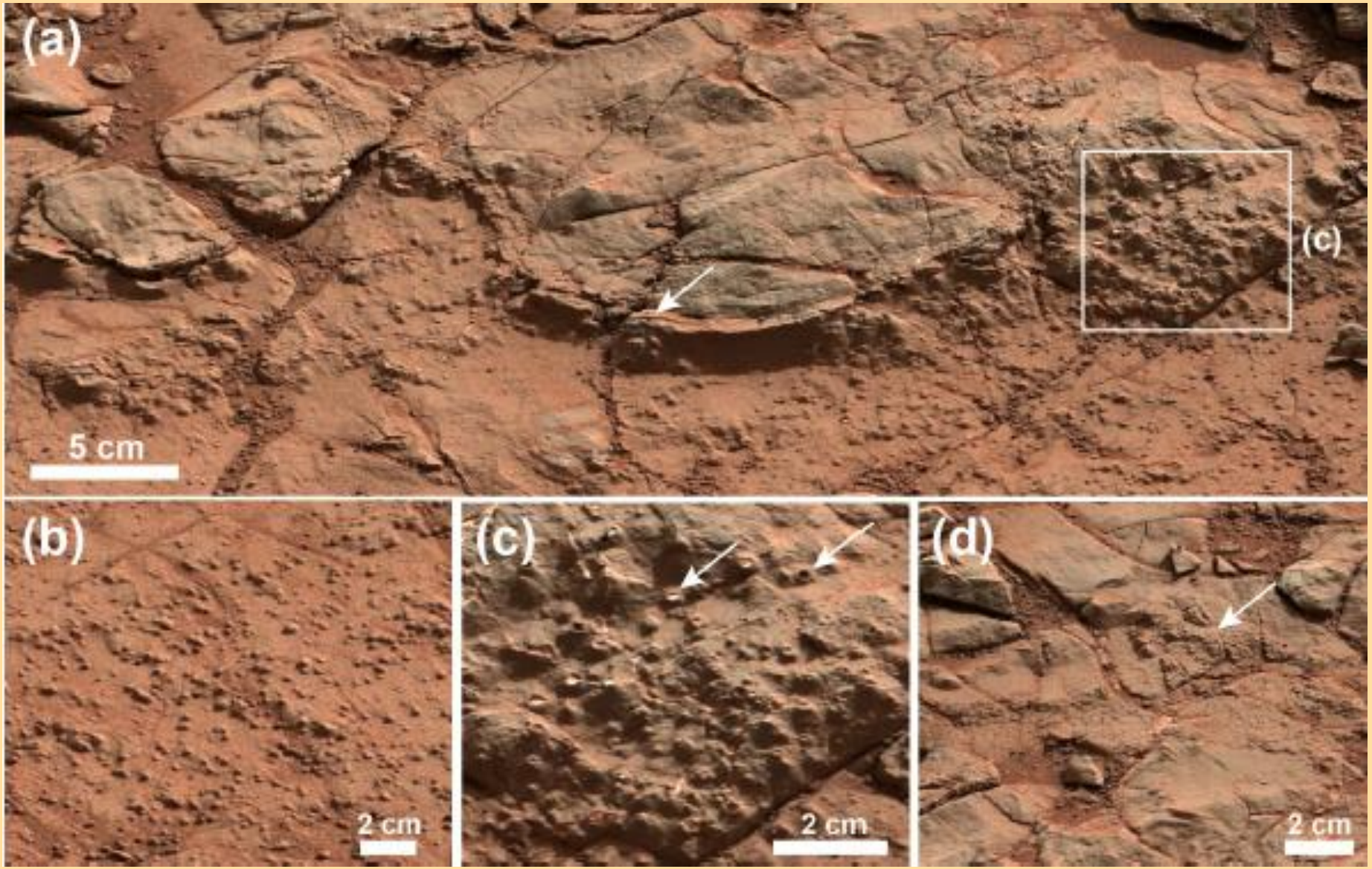




Nachon et al.,
In revision,
JGR-Planets

L.C. Kah et al.
AAPG 2014

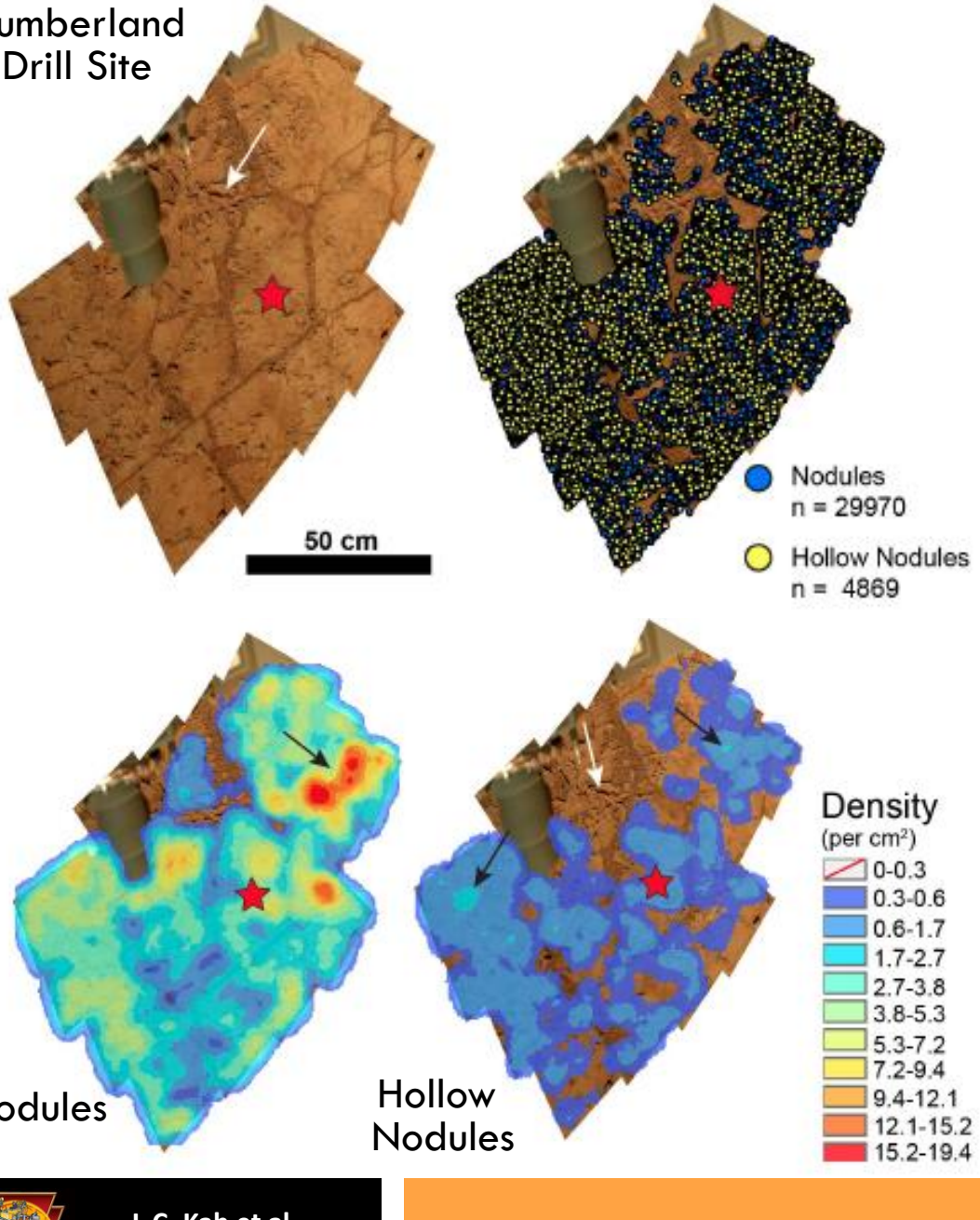
$CaSO_4$-filled Fractures



Stack et al., in revision, JGR-Planets

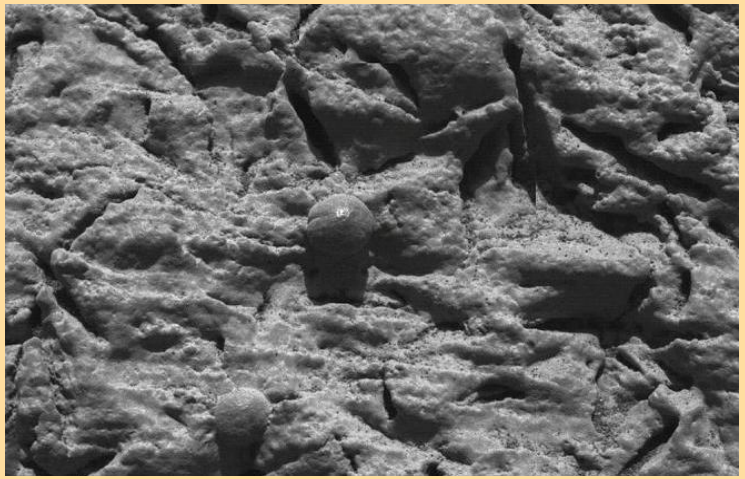
Concretions, Nodules, Hollow Nodules

Cumberland Drill Site



Continuum of size and morphology of nodular forms suggests a common mechanism of formation

- Simple concretions

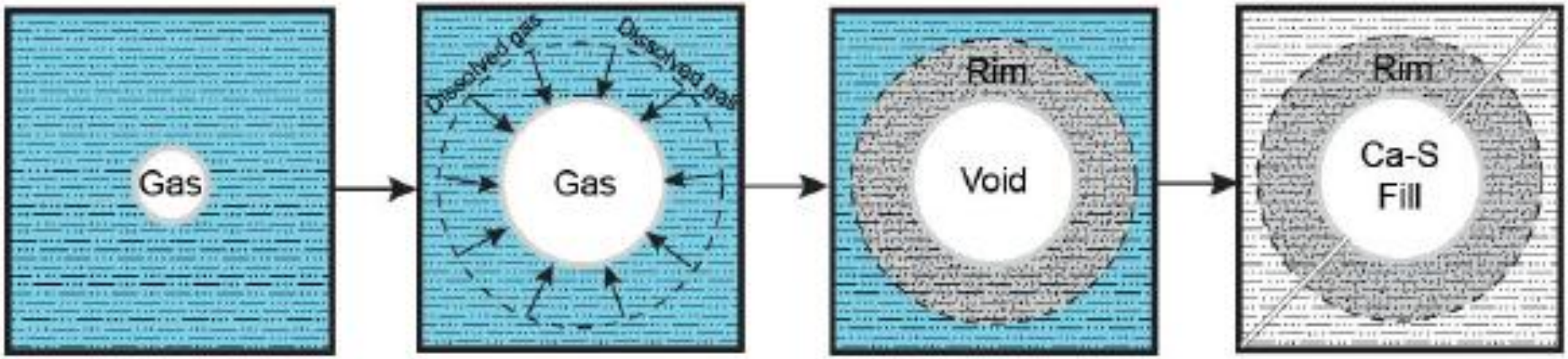


- Hollow nodules

Were hollow nodules originally concretions of a different mineral phase?

L.C. Kah et al.
AAPG 2014

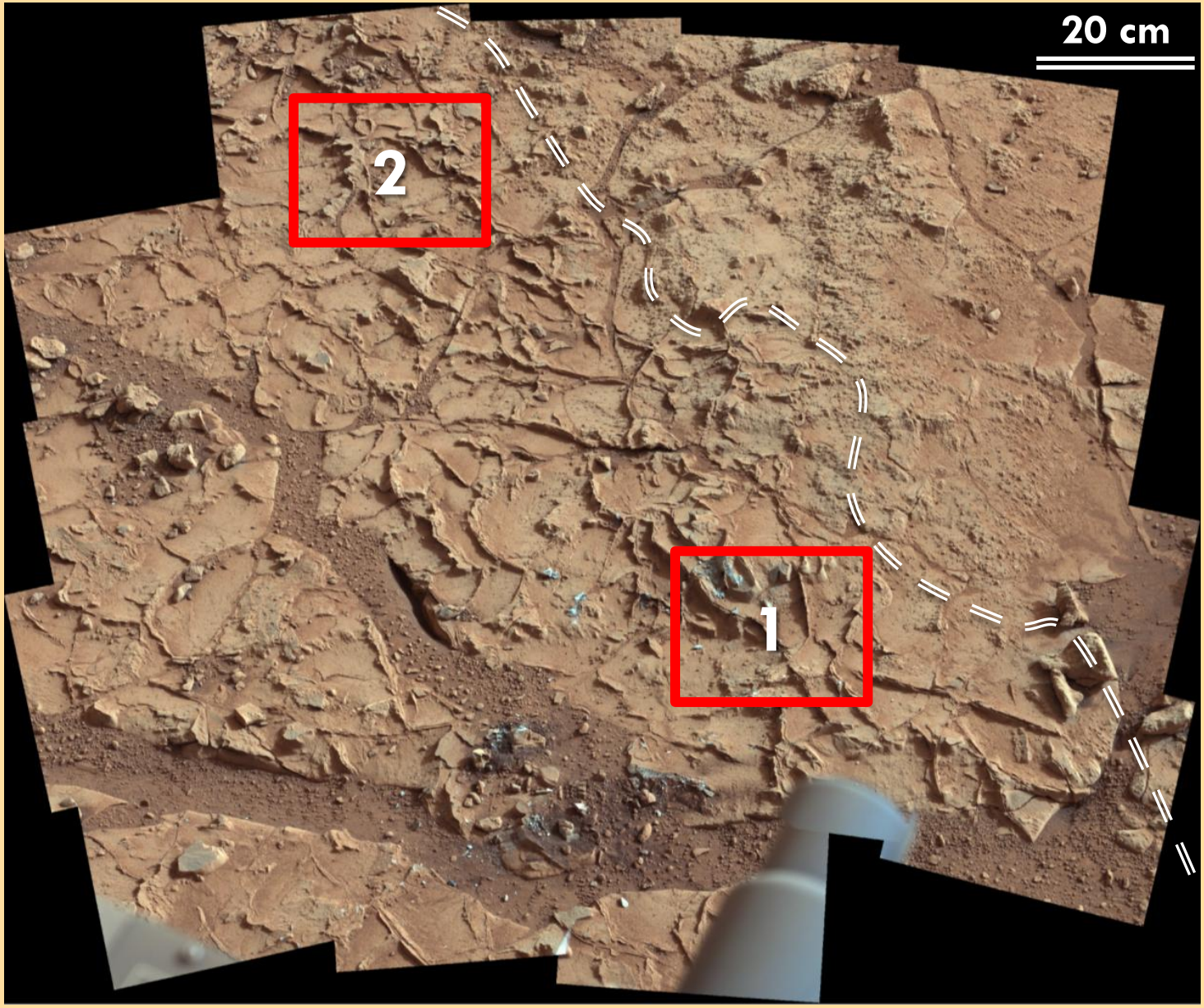
Concretions, Nodules, Hollow Nodules



Stack et al., in revision, JGR-Planets

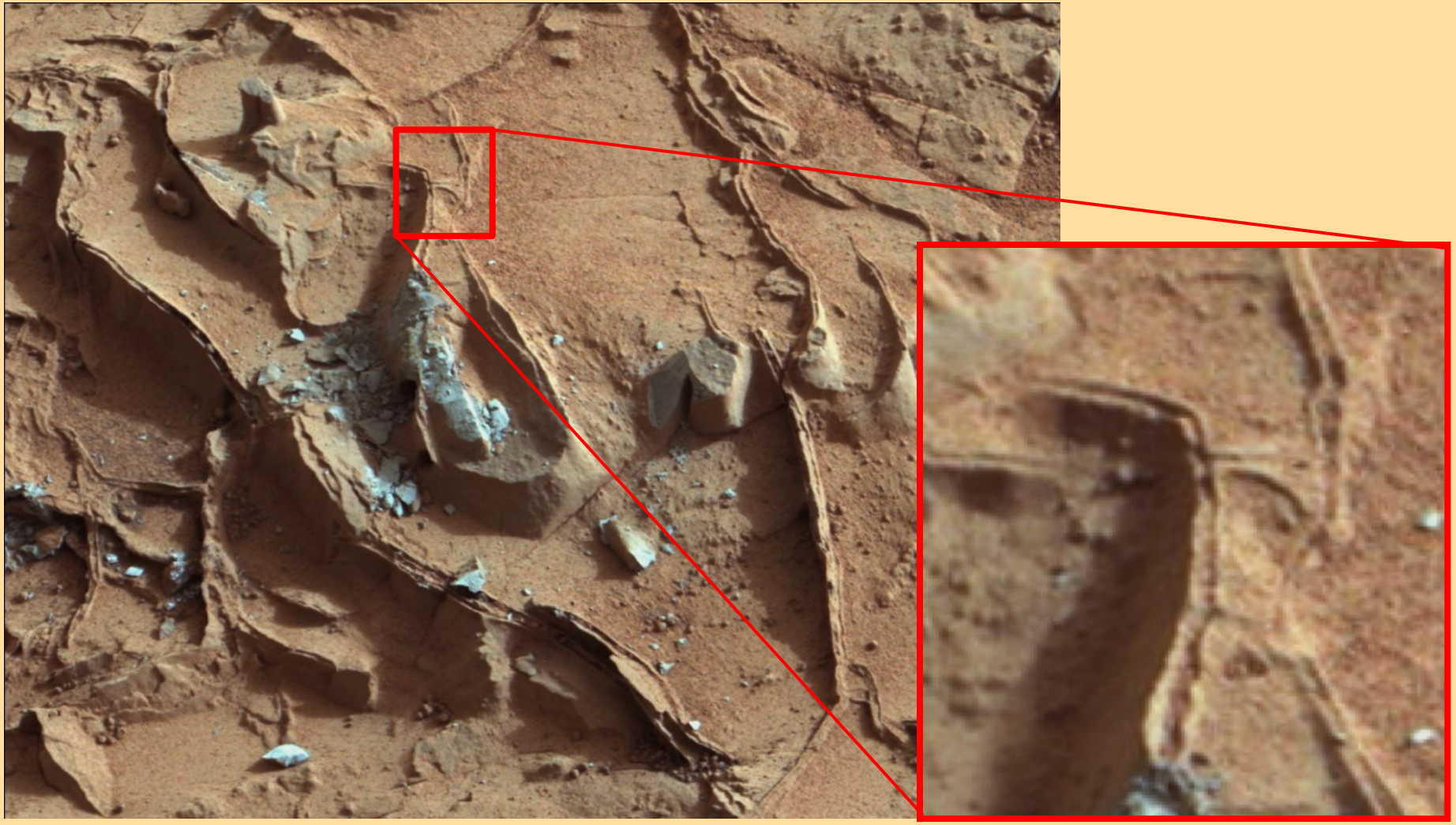
- **Exsolved gas from substrate pore fluids initiates bubble formation**
- **Bubble growth from continued diffusion of gas from surrounding pore fluids**
- **Removal of gas from pore fluids shifts chemical equilibrium at the void edge, favoring mineral precipitation….analysis shows rims compositionally indistinguishable from matrix**
- **Intersection of voids by late-stage $CaSO_4$-bearing fluids result in infilling of hollow nodules**

Model for Origin



L.C. Kah et al.
AAPG 2014

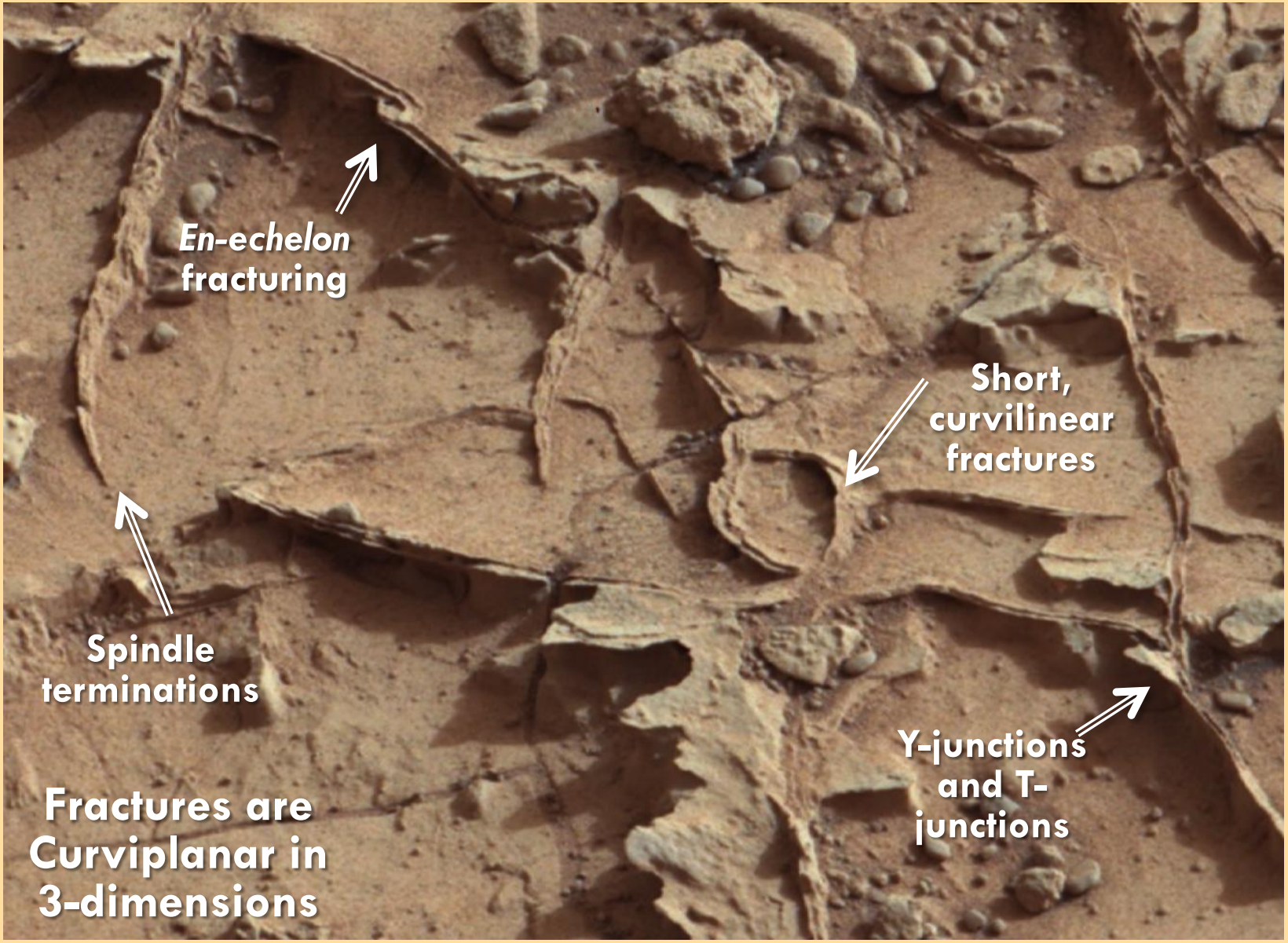
Mineralized Fracture Networks



Resistant, Isopachously banded mineral infilling

L.C. Kah et al.
AAPG 2014

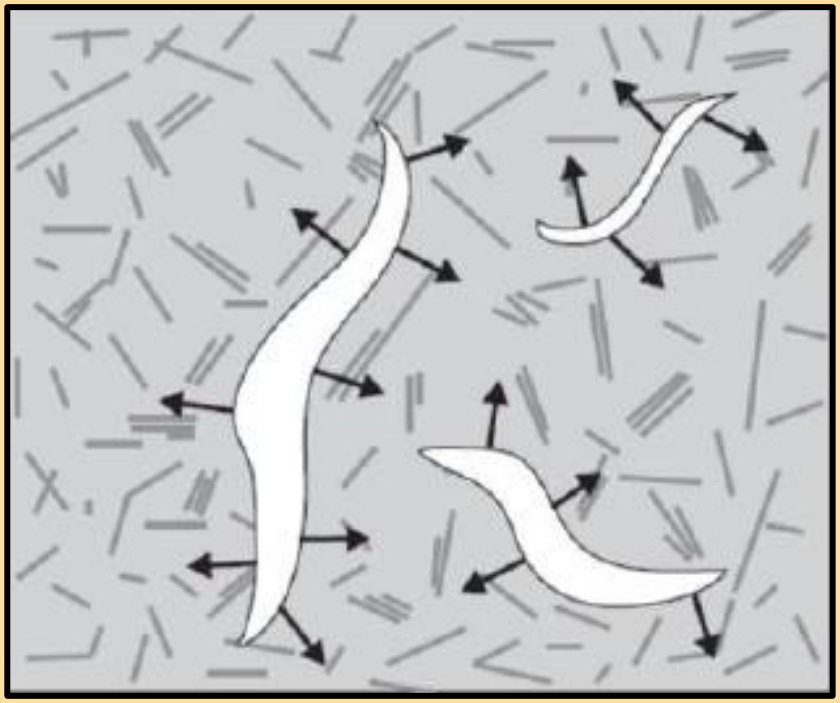
Mineralized Fracture Networks



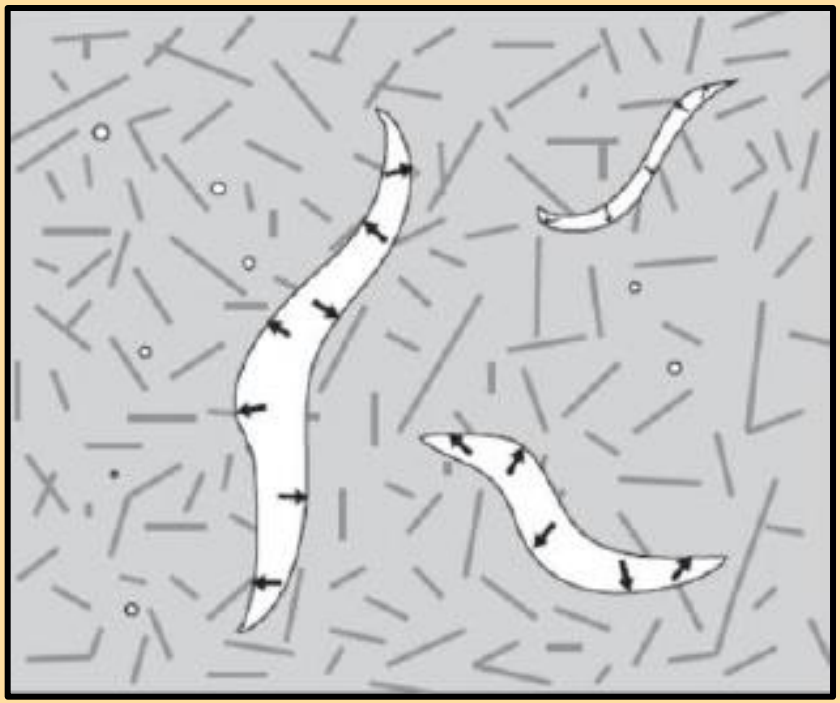
L.C. Kah et al.
AAPG 2014

Mineralized Fracture Networks

Model 1



Model 2



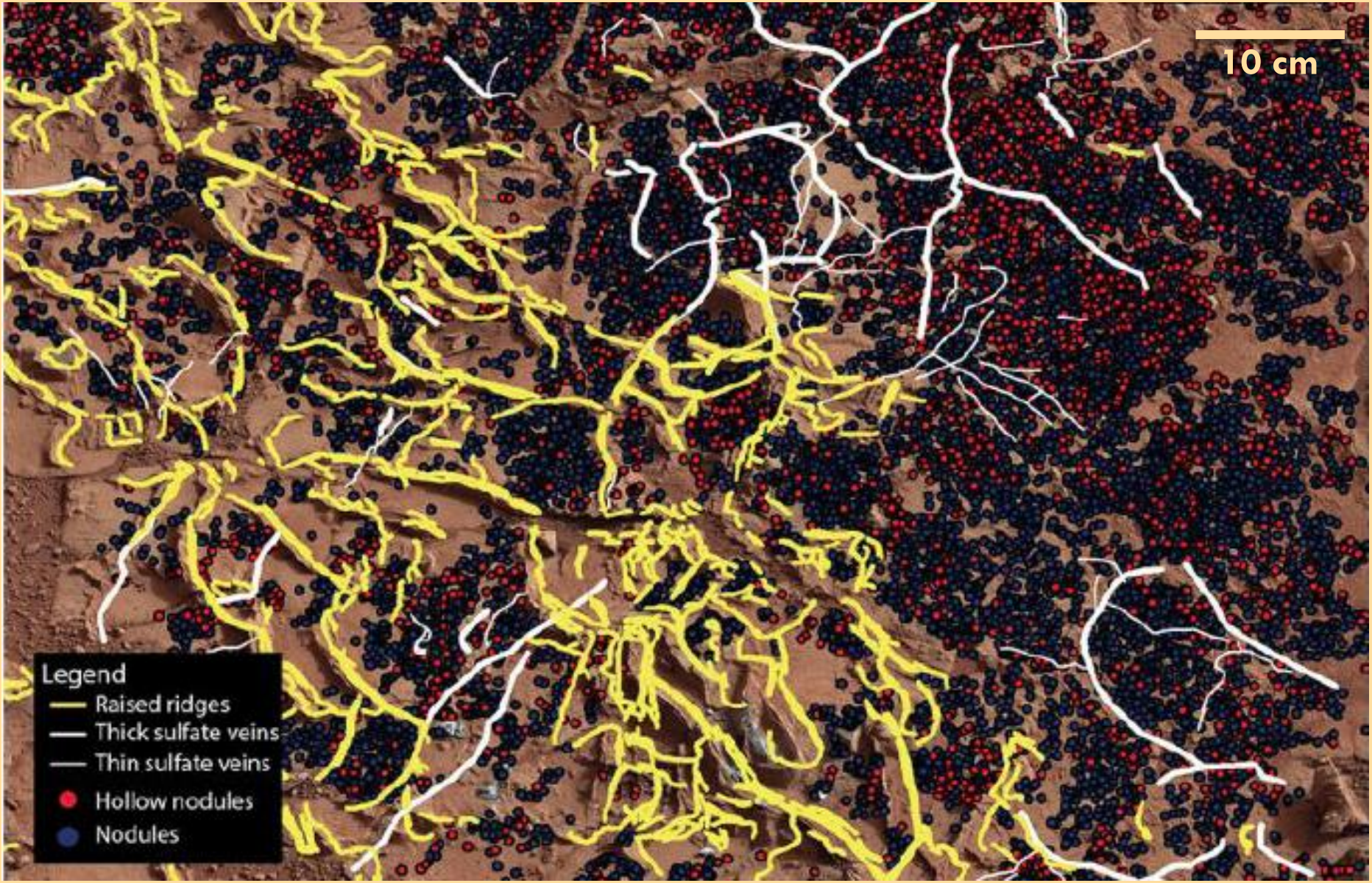
Siebach et al., in review, JGR-Planets

- **Salinity changes result in collapse of smectite clays; cracks result from subaqueous shrinkage**
- **High-volume of exsolved gasses from pore fluids; cracks result from gas expansion and migration**

Model for Origin

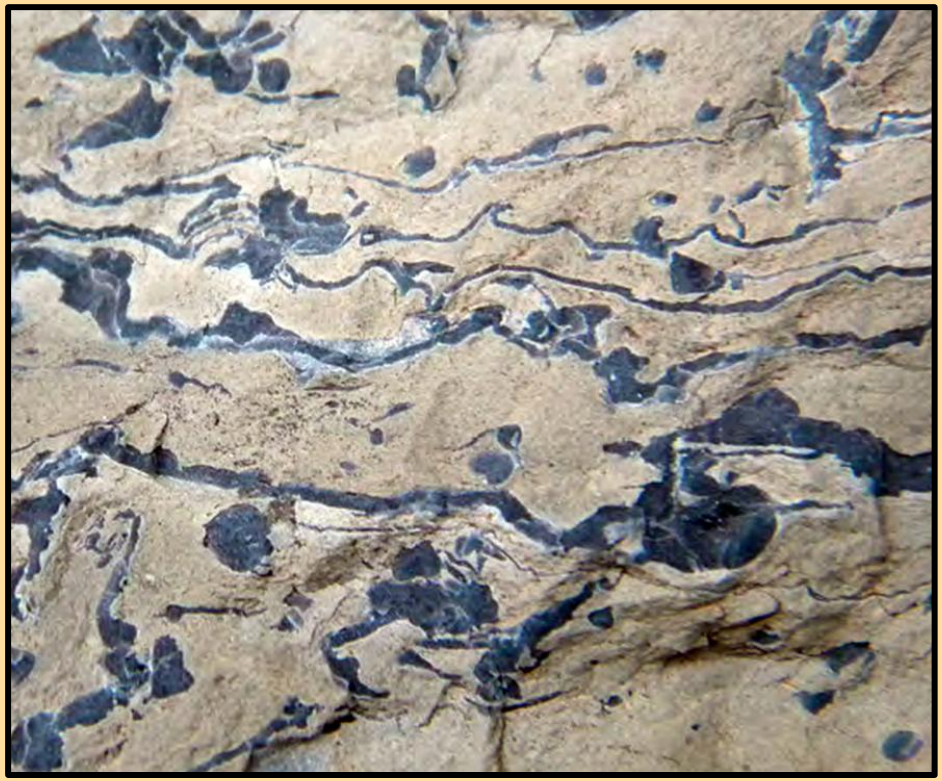
L.C. Kah et al.
AAPG 2014

Distribution of Nodules and Fractures

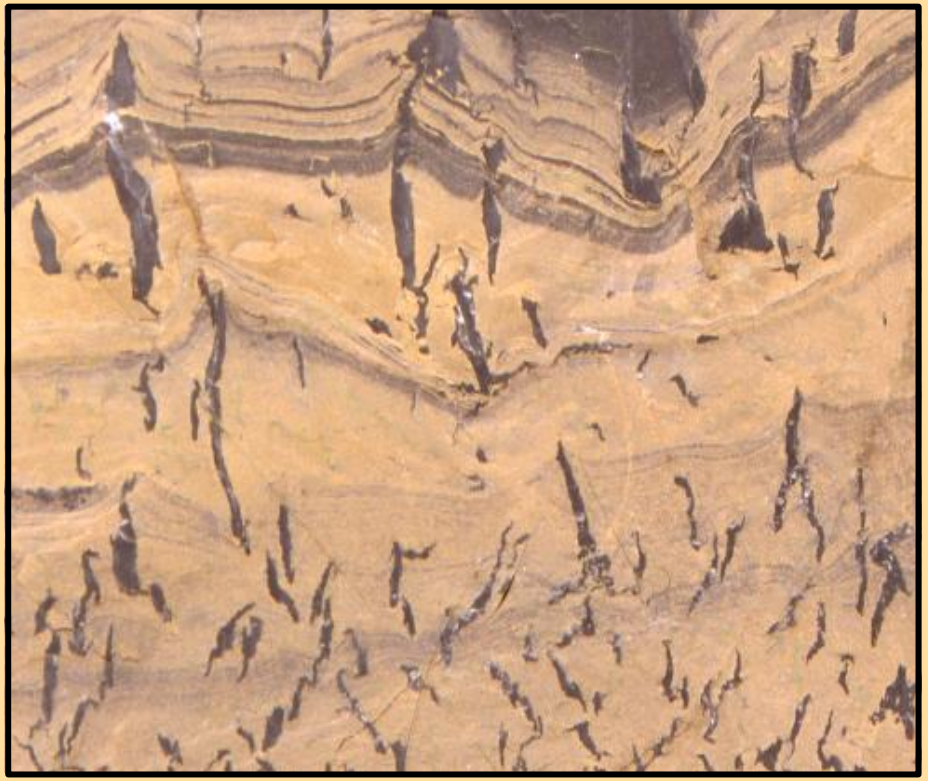


L.C. Kah et al.
AAPG 2014

Distribution of Nodules and Fractures



1.4 Ga Belt Supergroup, USA



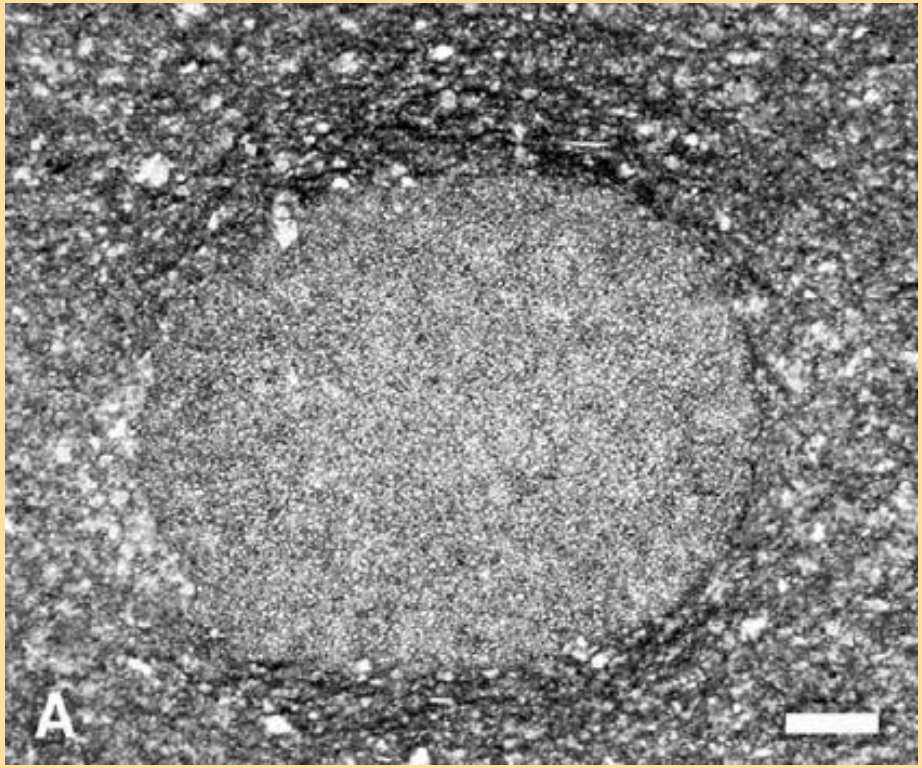
1.2 Ga Avzyan Group, Southern Urals

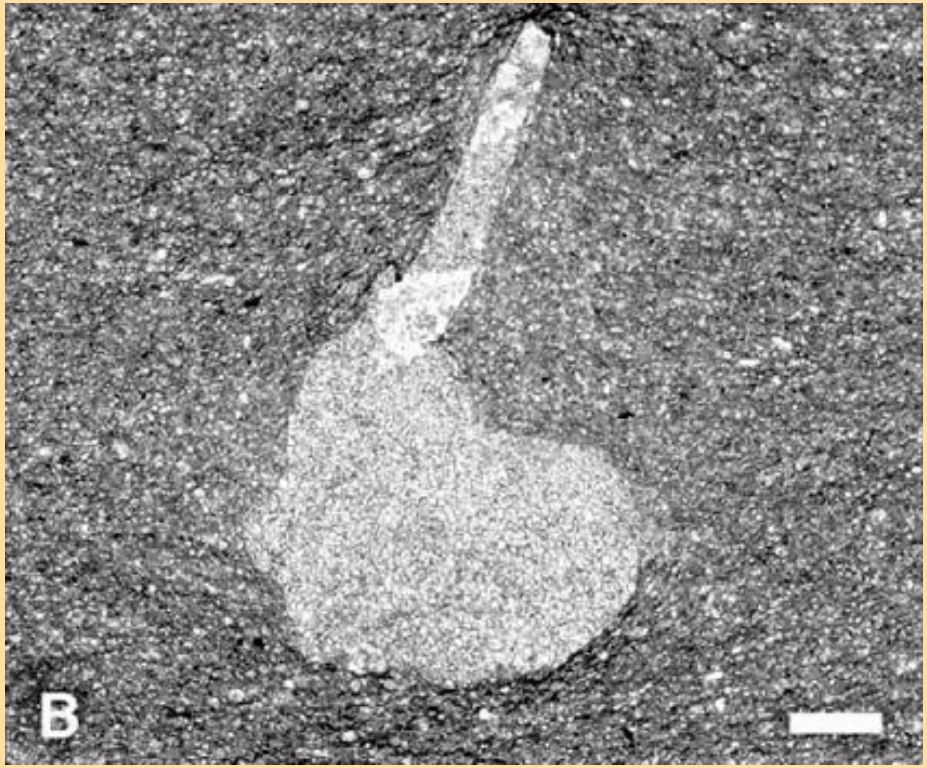
"Molar-tooth" is an enigmatic Precambrian carbonate fabric characterized by variously shaped subaqueous voids and cracks that are filled with a characteristically uniform, equant microspar

Primary hypothesis for void formation involves gas production (or exsolution) within substrate pore fluids

L.C. Kah et al.
AAPG 2014

Analogue in "Molar-Tooth" Cracks



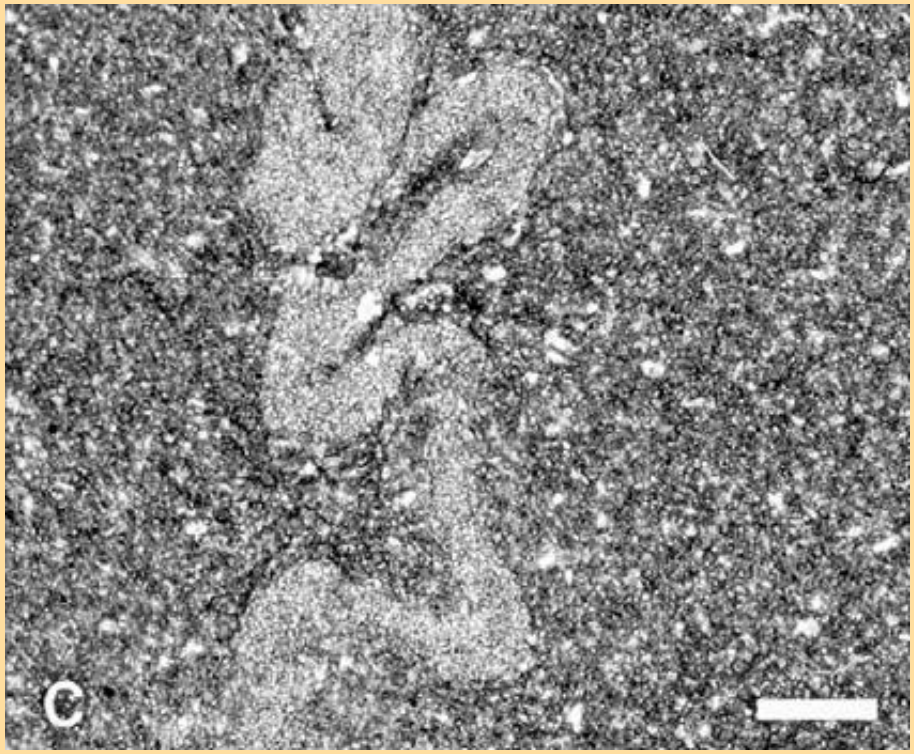


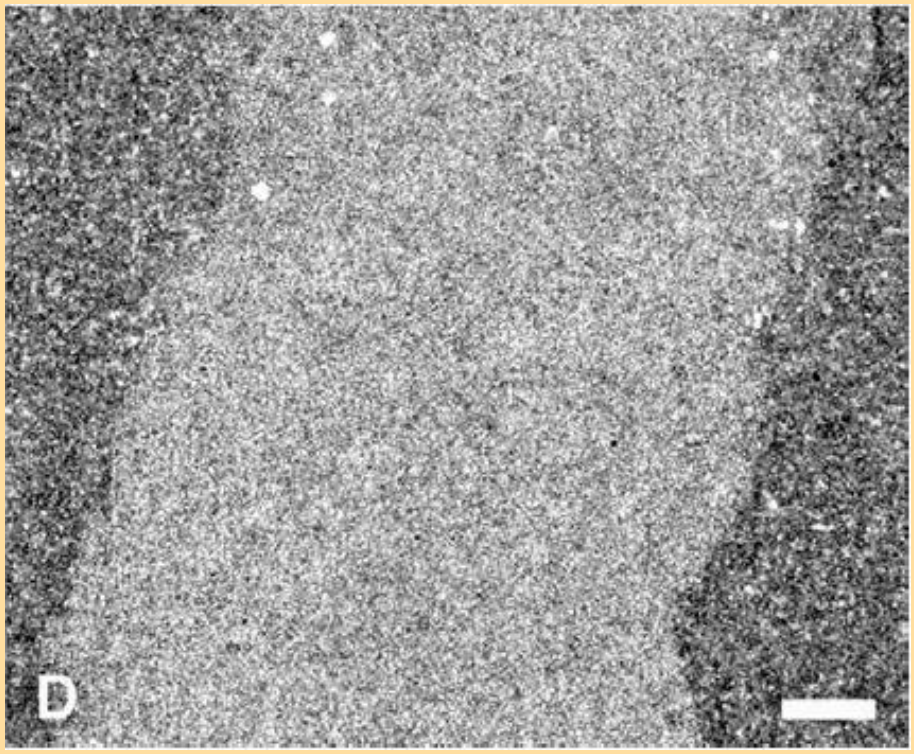
Pollock et al., 2006, JSR

Petrographic relationships provide and indication of void-substrate interaction

Low gas pressures deform local substrate forming bubble-shaped voids

Analogue in "Molar-Tooth" Cracks



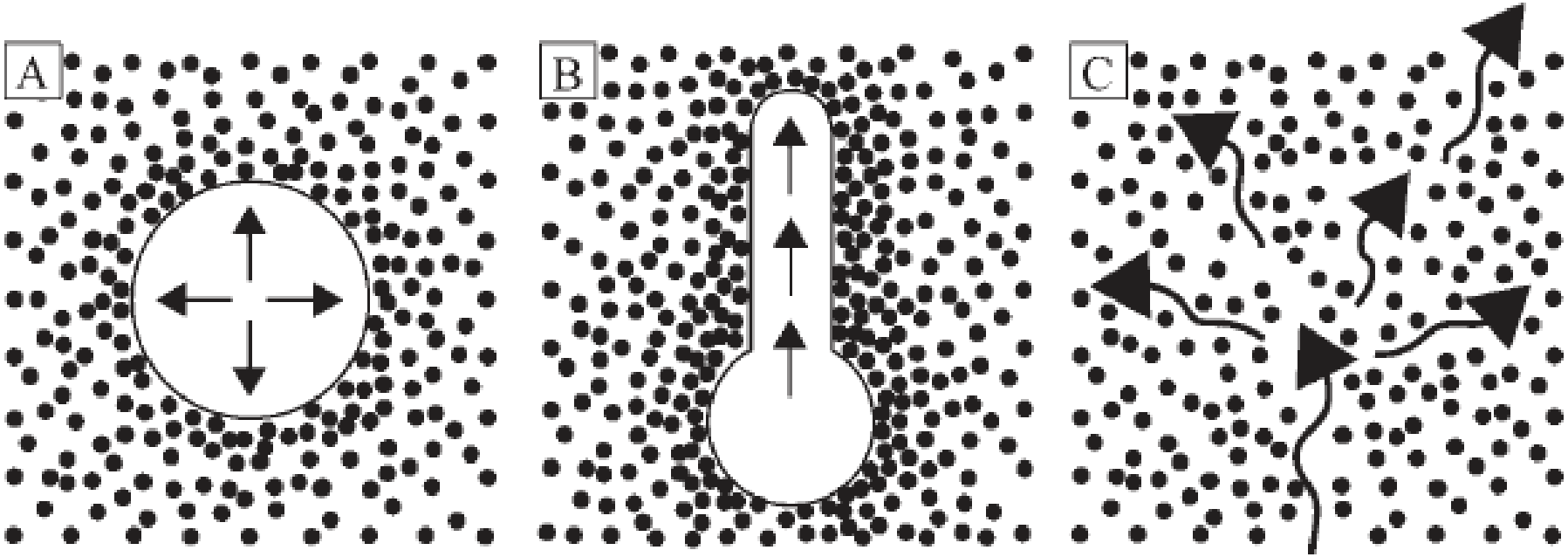


Pollock et al., 2006, JSR

Petrographic relationships provide and indication of void-substrate interaction

Higher gas pressures (combined with substrate inhomogeneities) allow ribbon-shaped fractures to develop in the substrate

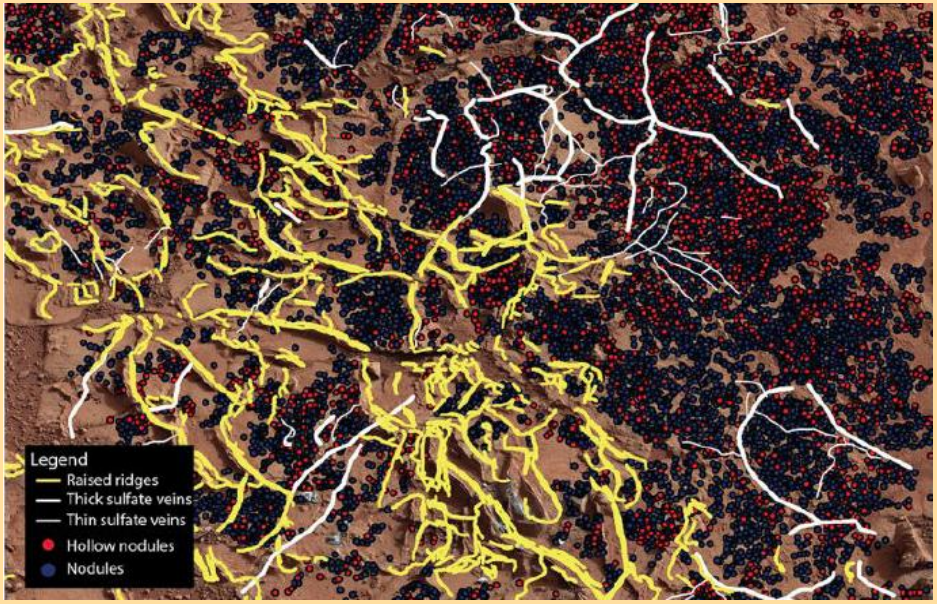
Analogue in "Molar-Tooth" Cracks



Pollock et al., 2006, JSR

- Gas pressures locally exceed grain-grain contacts, deforming substrate around void
- Crack formation triggered by gas pressures exceeding substrate strength (often at grain-grain inhomogeneities)
- Gas pressures that greatly exceed substrate strength results in wholesale disruption (fluidization) of substrate

Implications for Substrate Rheology



- Gas exsolution (if it occurred) in potentially “soupy” muds would leave little or no record; as muds dewatered,high clay content would impart substantial (heterogeneous) substrate strength
- Distribution of ‘blebs’ and ‘cracks’ may reflect either lateral differences in substrate strength, or spatial differences in the volume of gas exsolved from pore waters

Implications for Substrate Rheology