Composition, Impact Deformation, and Geological History of Noachian Basement Surrounding the Isidis Impact Basin

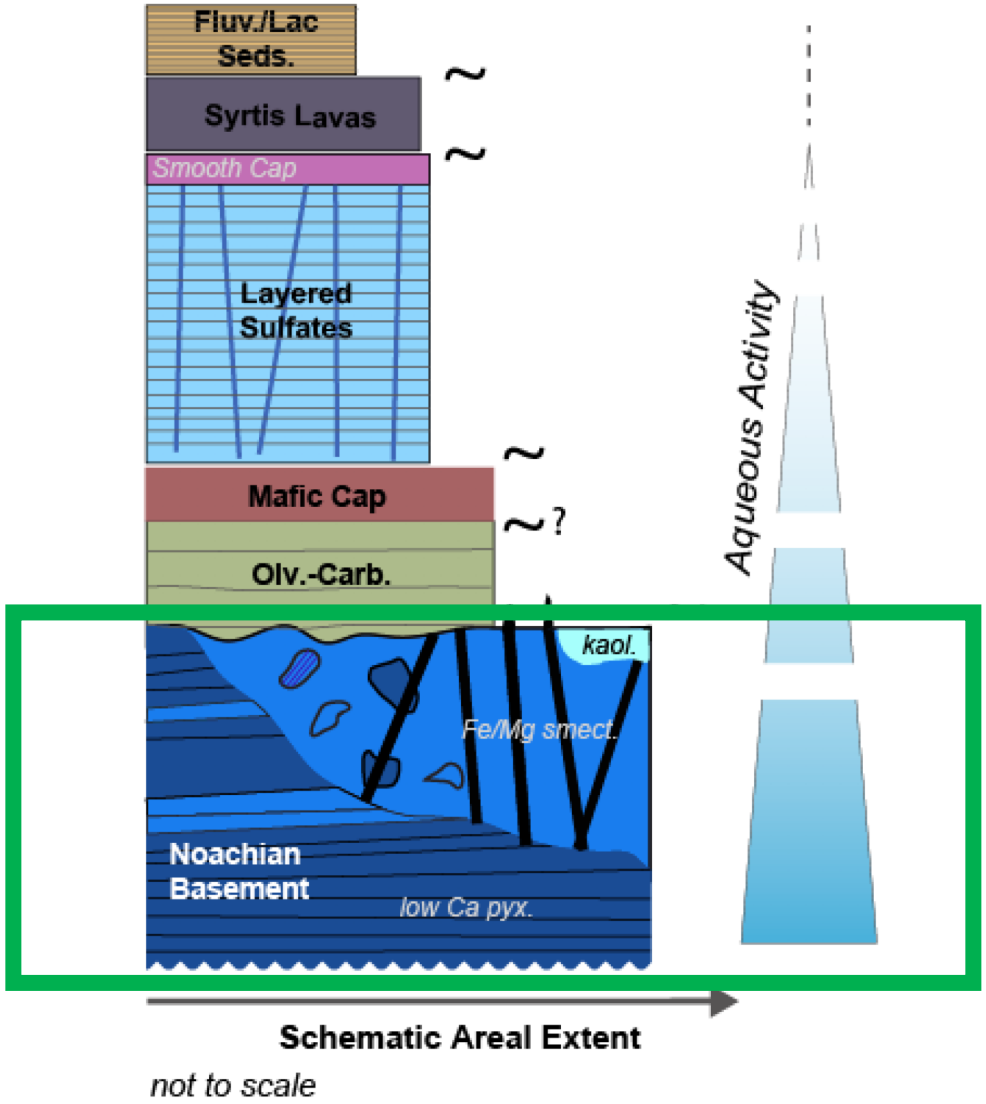
Eva L. Scheller[1] & Bethany L. Ehlmann[1,2]

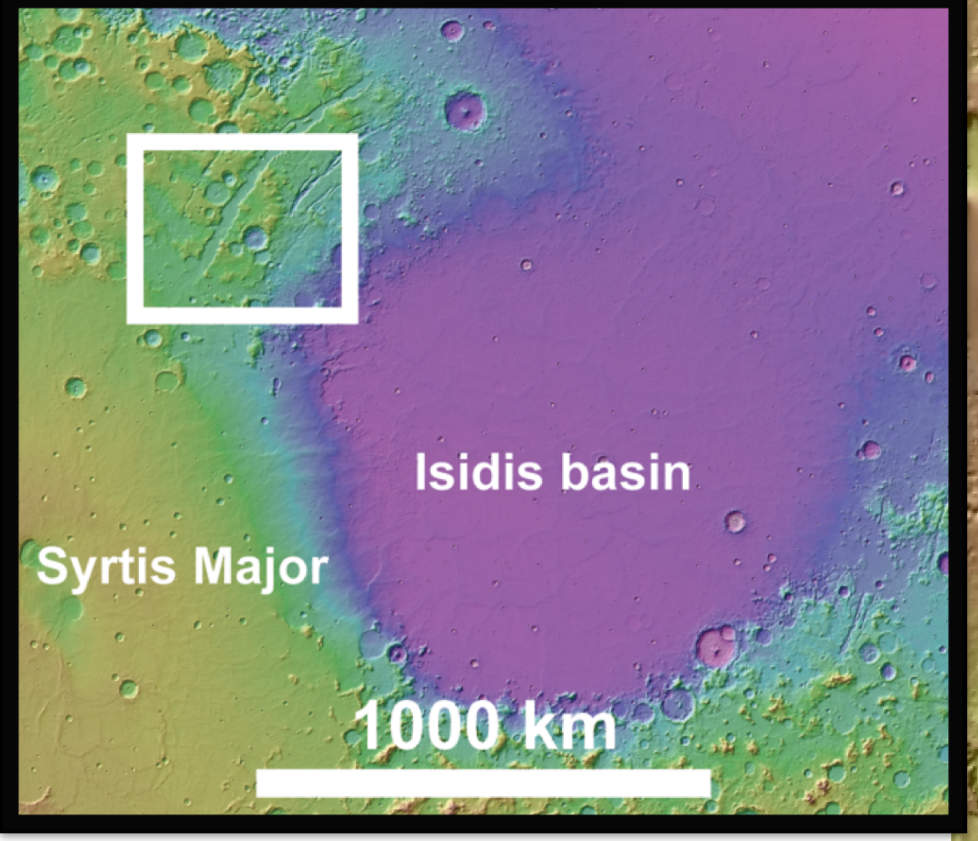
[1]Division of Geological and Planetary Sciences, California Institute of Technology
[2]Jet Propulsion Laboratory, California Institute of Technology

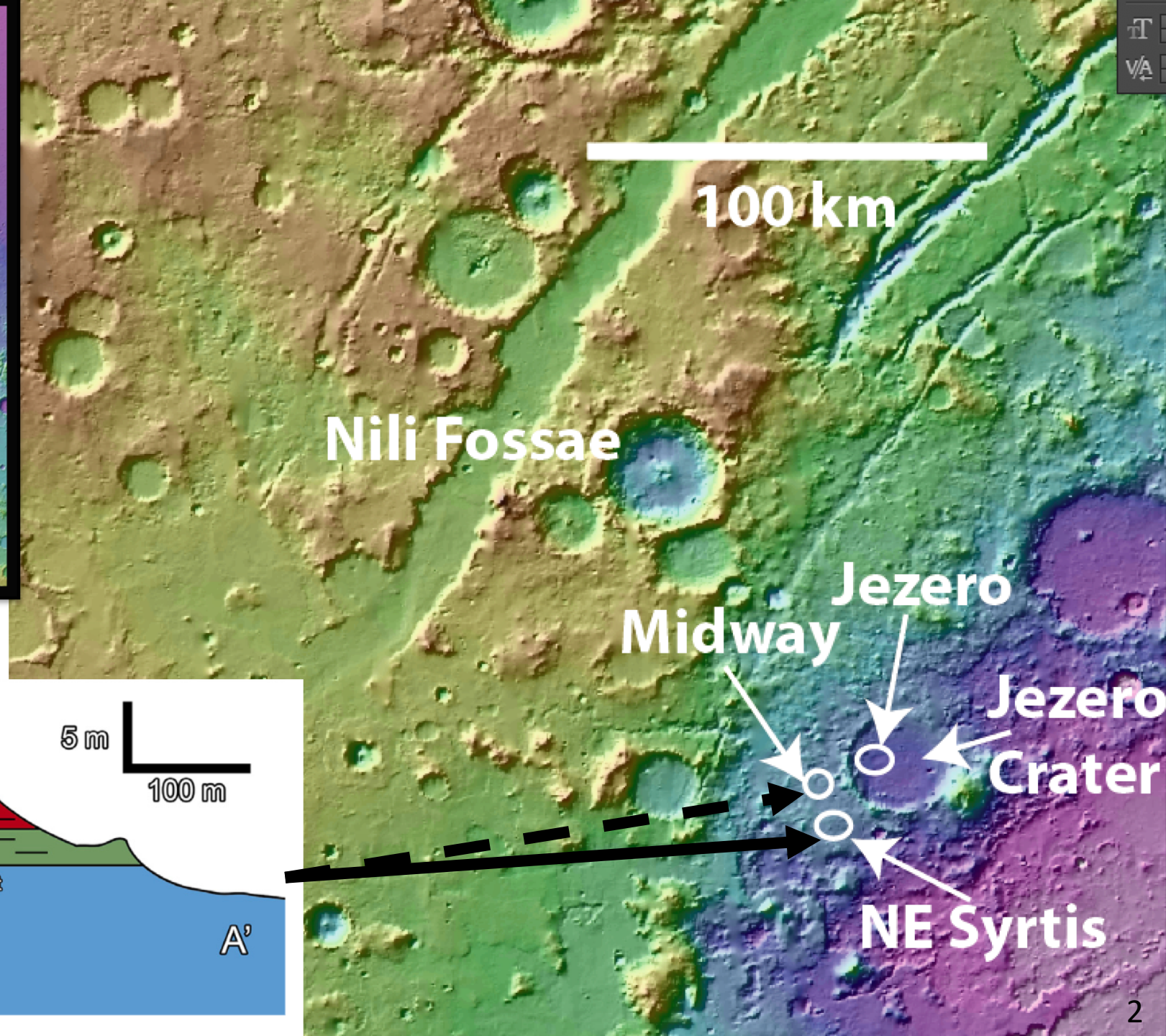
NOTE ADDED BY JPL WEBMASTER: This content has not been approved or adopted by NASA, JPL, or the California Institute of Technology. This document is being made available for information purposes only, and any views and opinions expressed herein do not necessarily state or reflect those of NASA, JPL,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

Noachian stratigraphy for Mars 2020
- summary by site

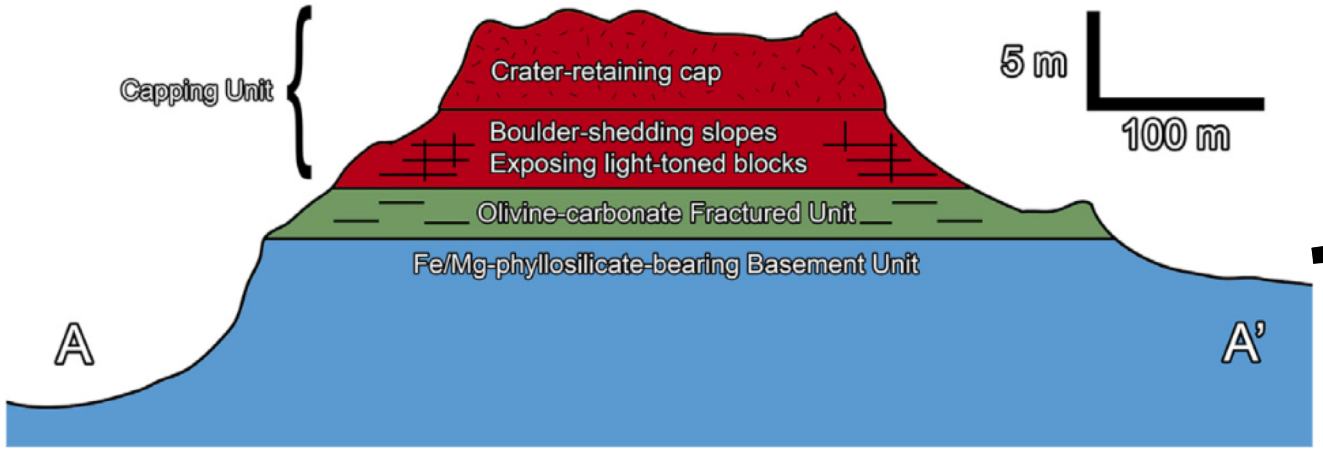
- NE Syrtis: Noachian stratigraphy is present
- Midway: Noachian stratigraphy is present
  – But no high-resolution CRISM
- Jezero: Noachian stratigraphy detrital material is present
- Gusev: Noachian materials; No Noachian stratigraphy





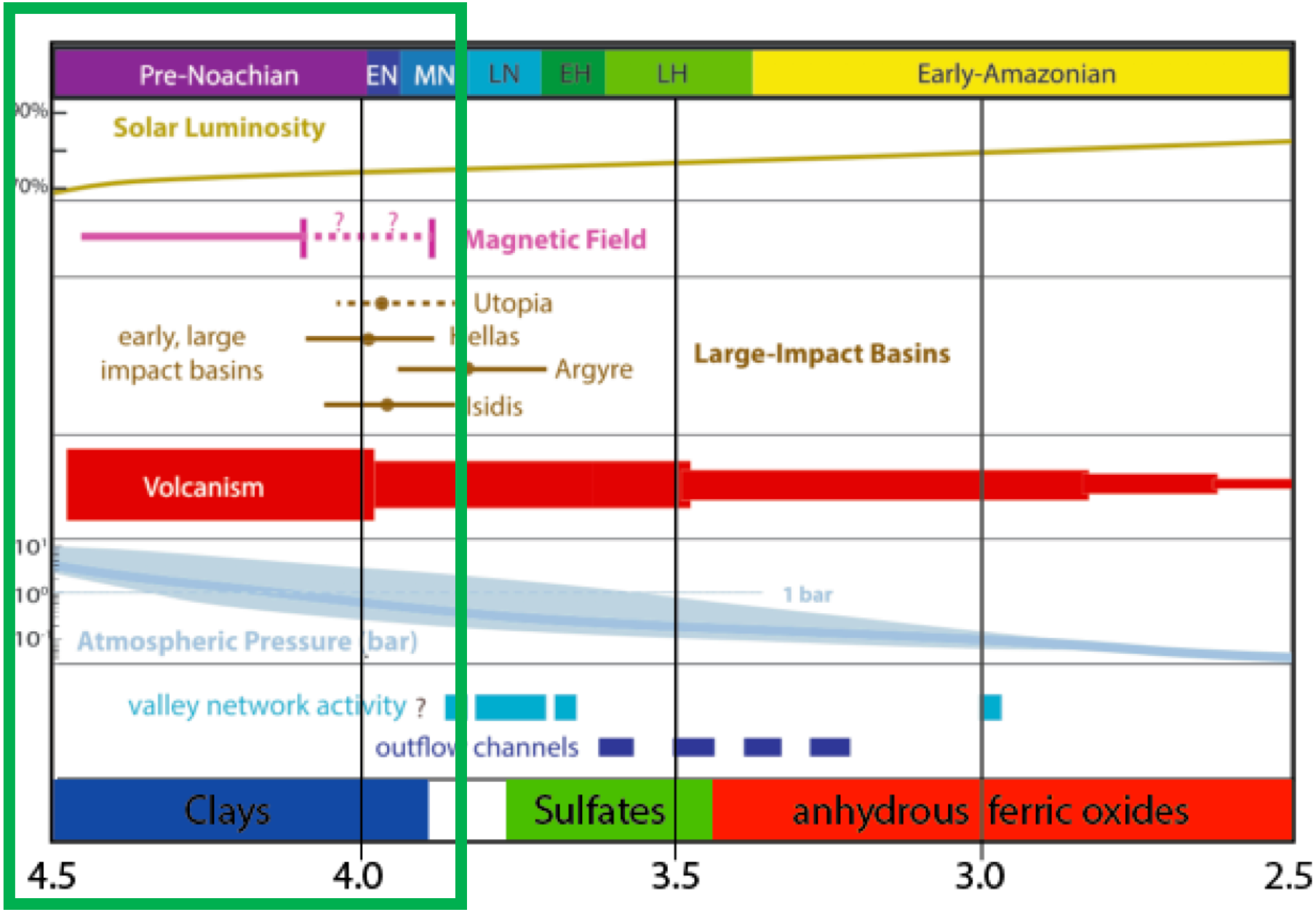


Bramble et al. (2017)



Why the Noachian Basement Formation?

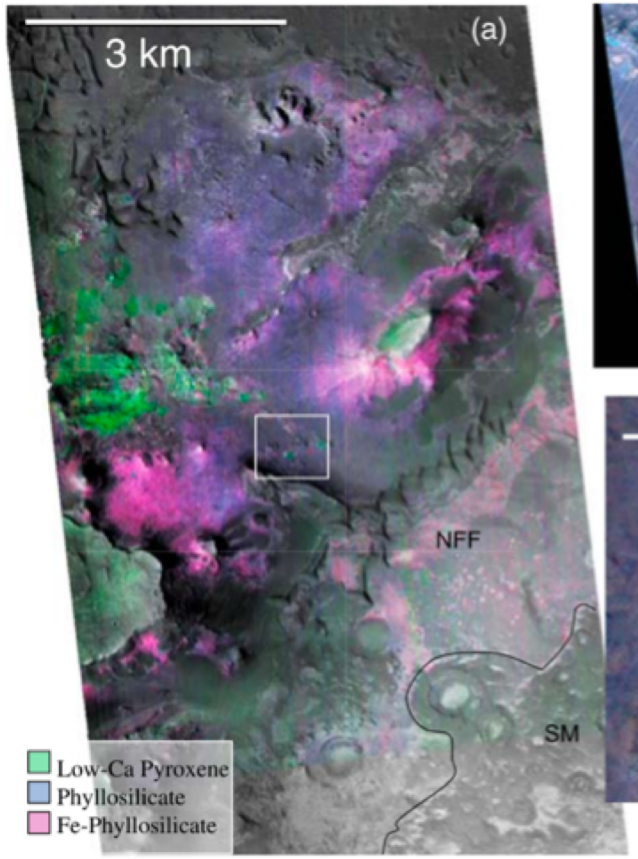
Exposed early Noachian crust is very rare
- But very important



Modified from Ehlmann et al. (2016)

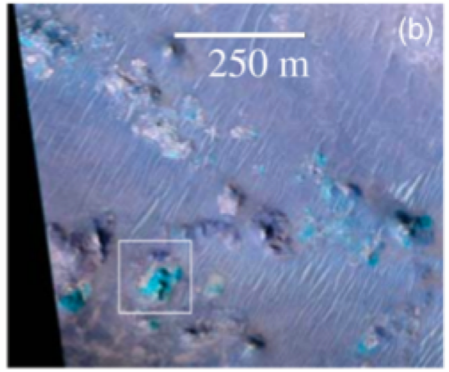
Units of Noachian Basement Formation

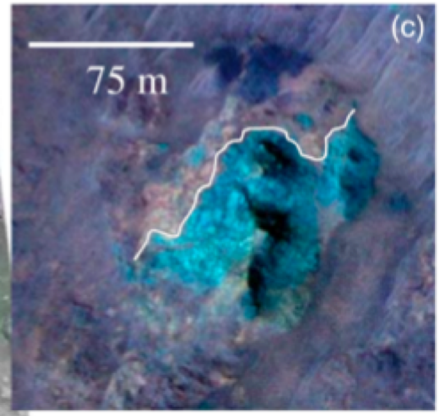
1. Low-Ca pyroxene
2. Fe/Mg-smectite



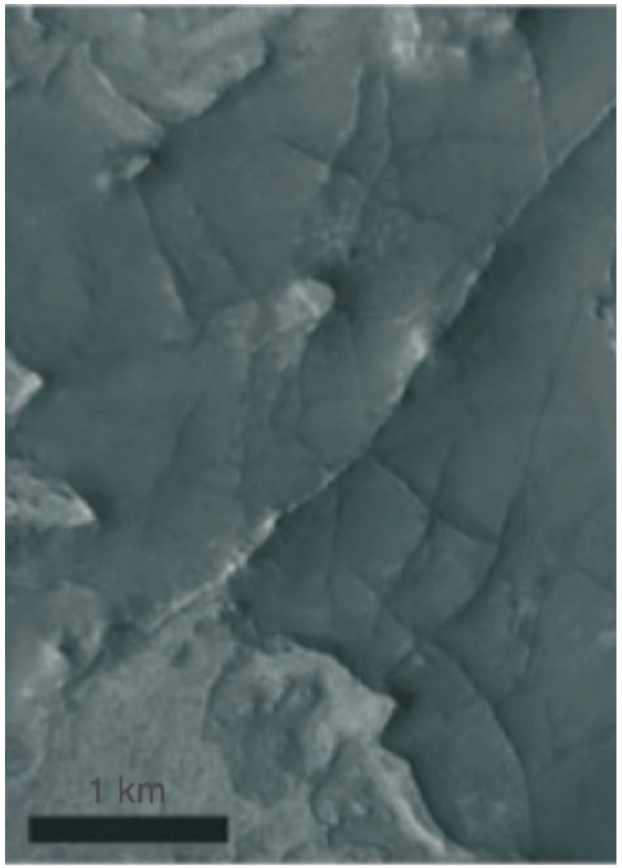
Mustard et al. (2009)

3. Megabreccia



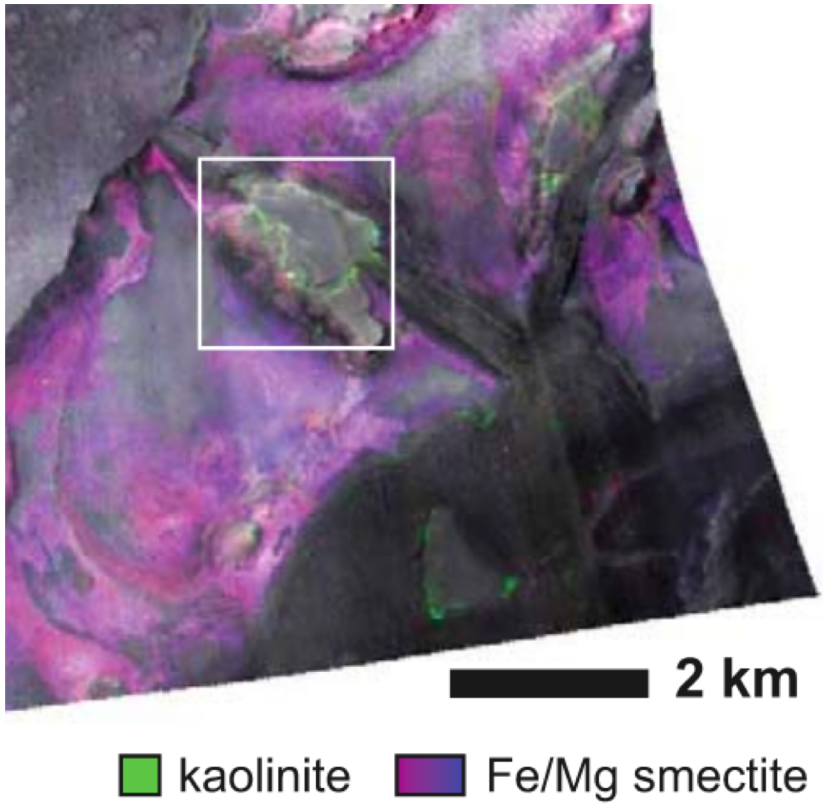


4. Ridges



Saper and Mustard (2013)

5. Kaolinite



Ehlmann et al. (2009)

What can we learn from Noachian basement ?

What is the Noachian Basement Formation?

Heterogeneous: Multiple units that record ≥5 distinct geological processes

Goals for Noachian Basement Formation:

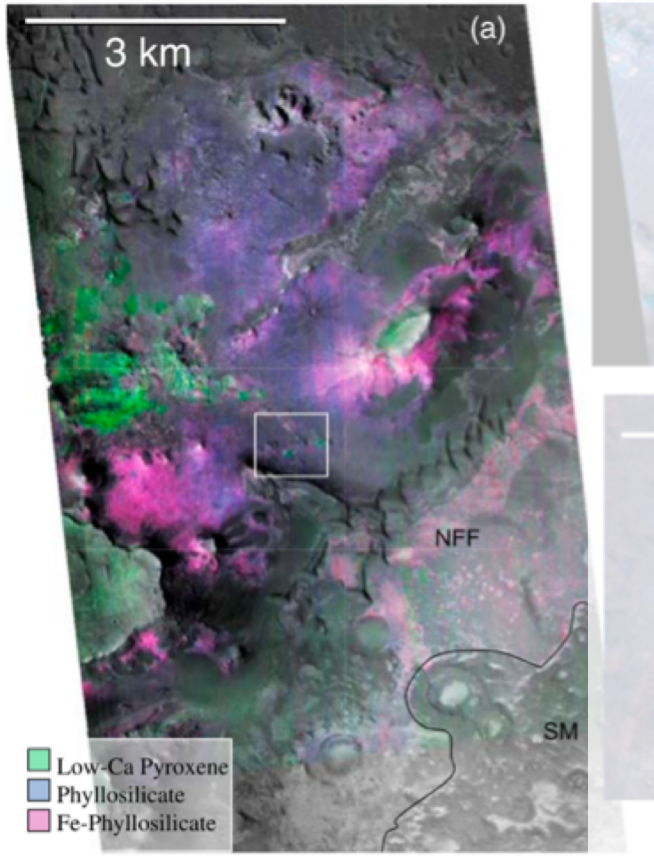
1) Determine nature of Pre-Isidis crust and search for biosignatures
2) Determine petrogenesis of LCP-bearing lithologies
3) Determine nature of clay formation, habitability, and search for biosignatures
- And sample!

Why?

- **Understanding the evolution of planetary interiors**
  - Differentiation, crustal formation, volcanic processes, magnetic fields, age-dating/timing
- **Understanding ancient environments on Mars and Earth**
  - Water processes, habitability, search for biosignatures
- **Understanding basin-scale impact processes on terrestrial bodies**
  - Megabreccia formation: where and how? How much melt?

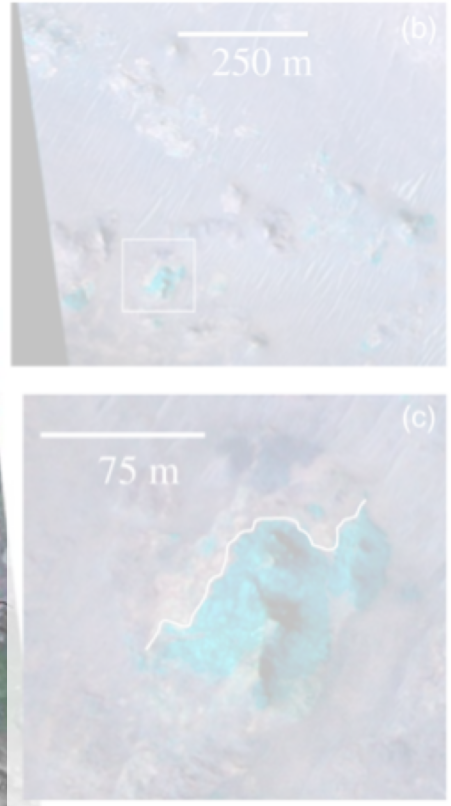
Units of Noachian Basement Formation

1. Low-Ca pyroxene
2. Fe/Mg-smectite



Mustard et al. (2009)

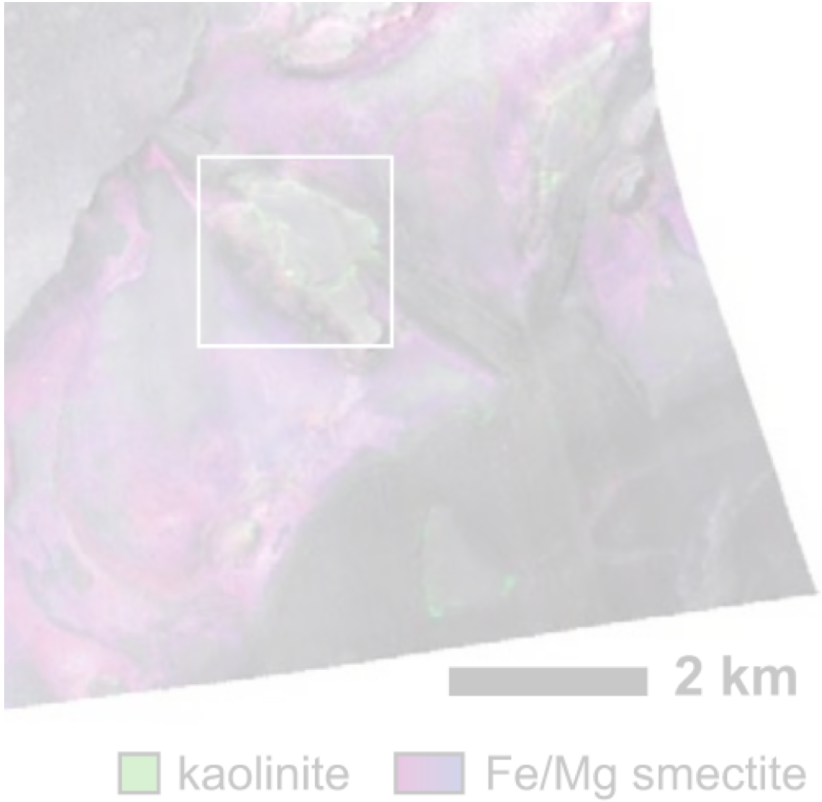
3. Megabreccia



4. Ridges

Saper and Mustard (2013)

5. Kaolinite

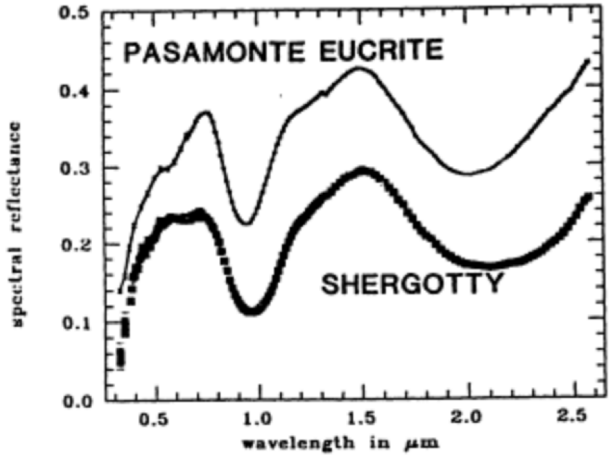


Ehlmann et al. (2009)

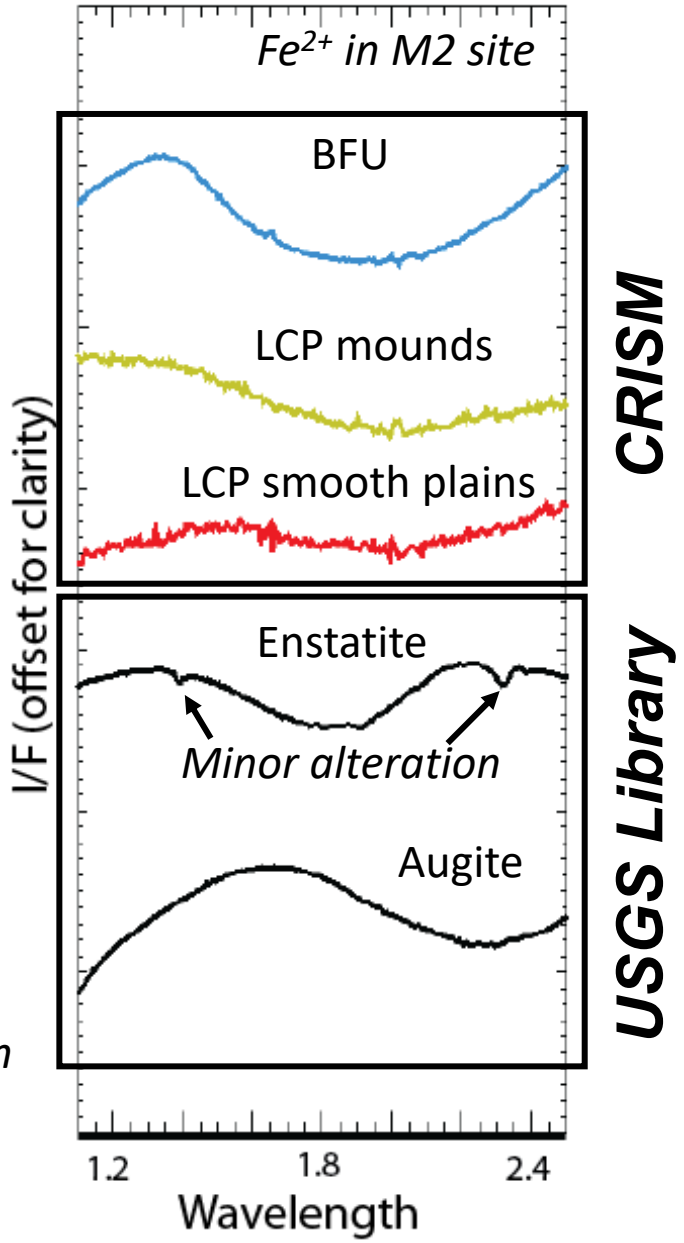
Low-Ca pyroxene-bearing lithologies

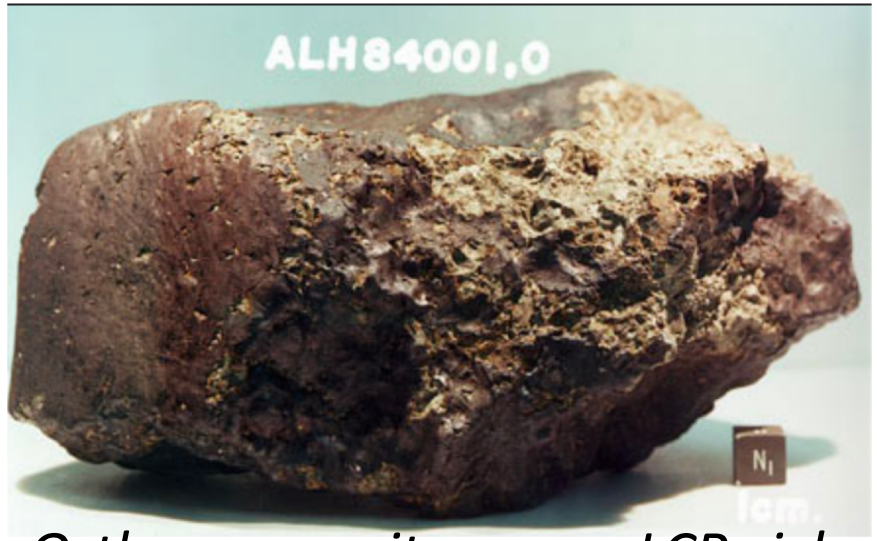
Three geomorphological and spectral types of LCP:

- Blue Fractured Unit (BFU)
- LCP-rich mounds
- Smooth plains of LCP
  - Present in between mesas in NE Syrtis and Midway



Spectra from McFadden, 1988





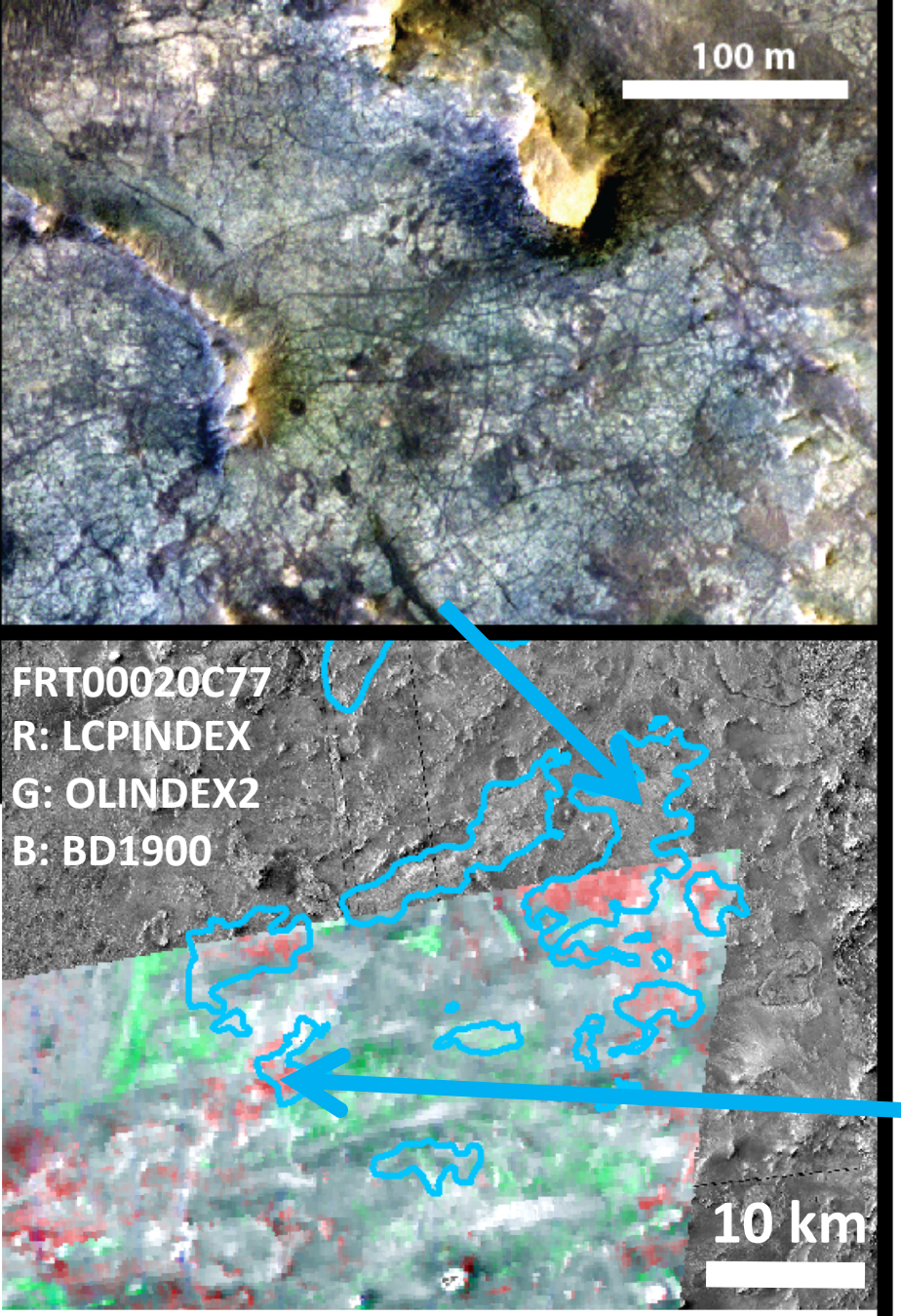
Orthopyroxenite – very LCP-rich

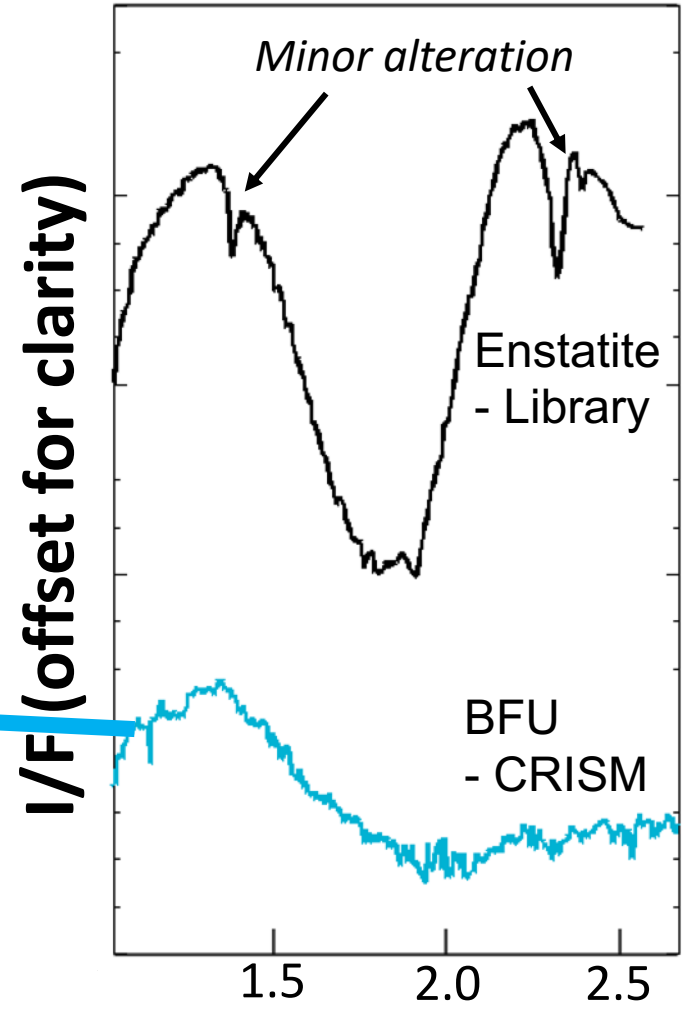
Shergotty basalt – HCP and LCP

1. Low-Ca Pyroxenes

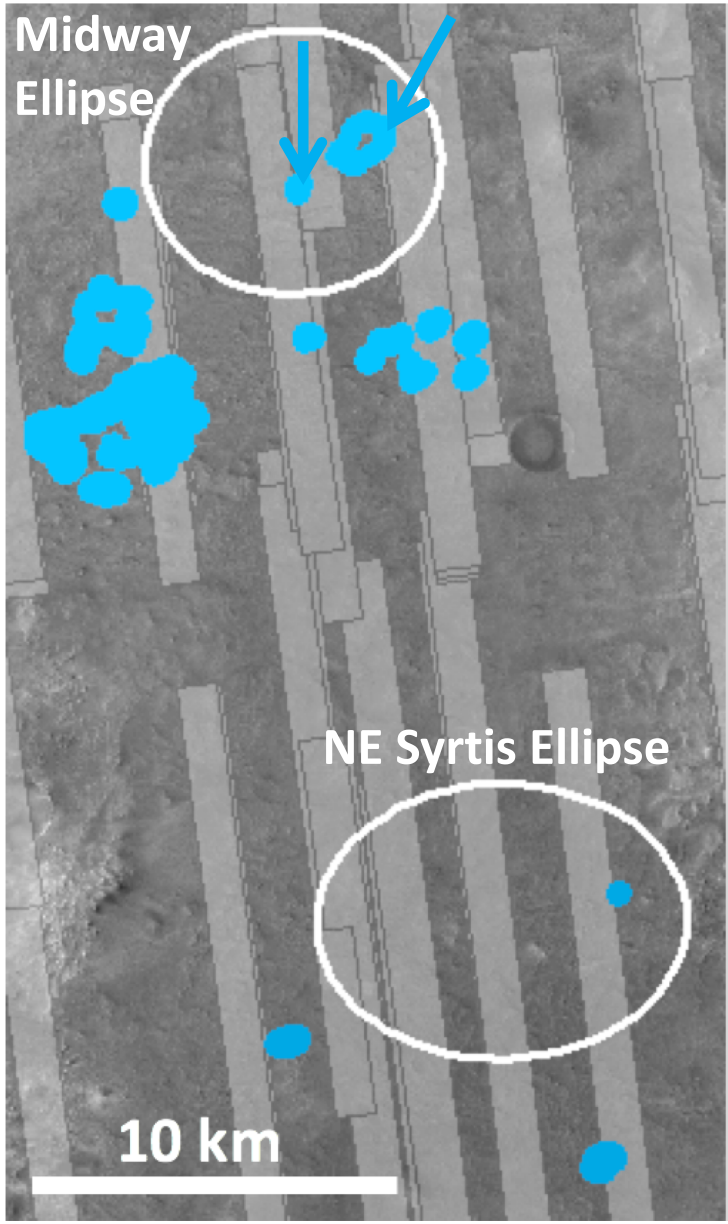
LCP-rich Blue Fractured Unit

- Strong LCP signature and fractured texture that is different from general basement
- More abundant in Midway ellipse





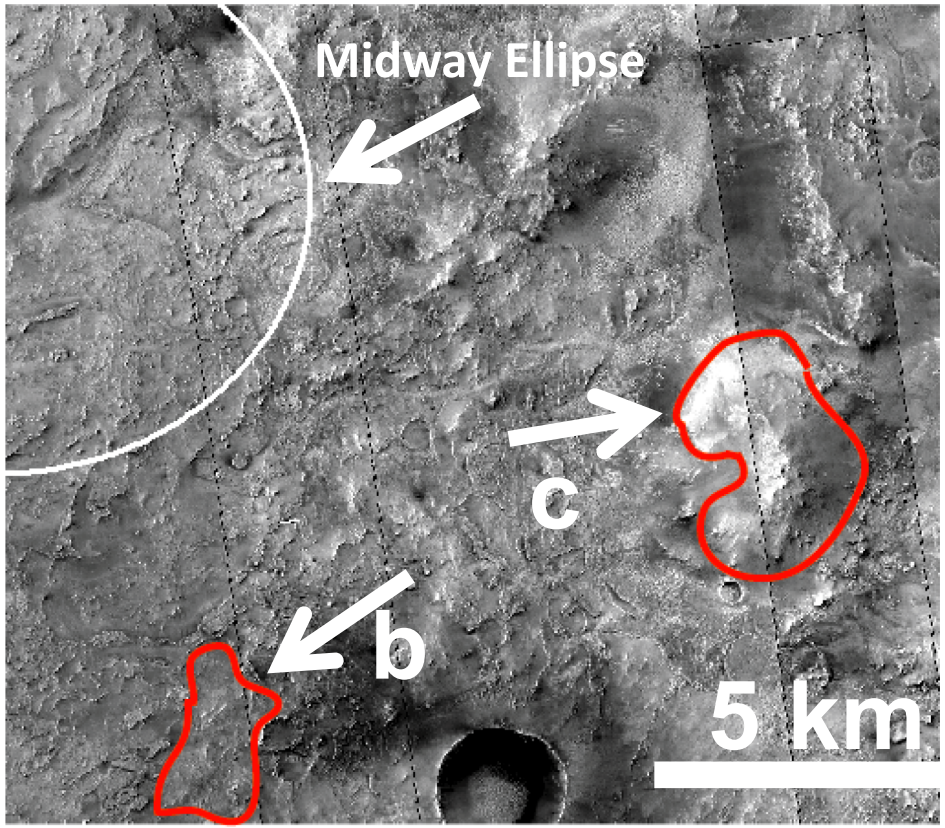
potential mission targets

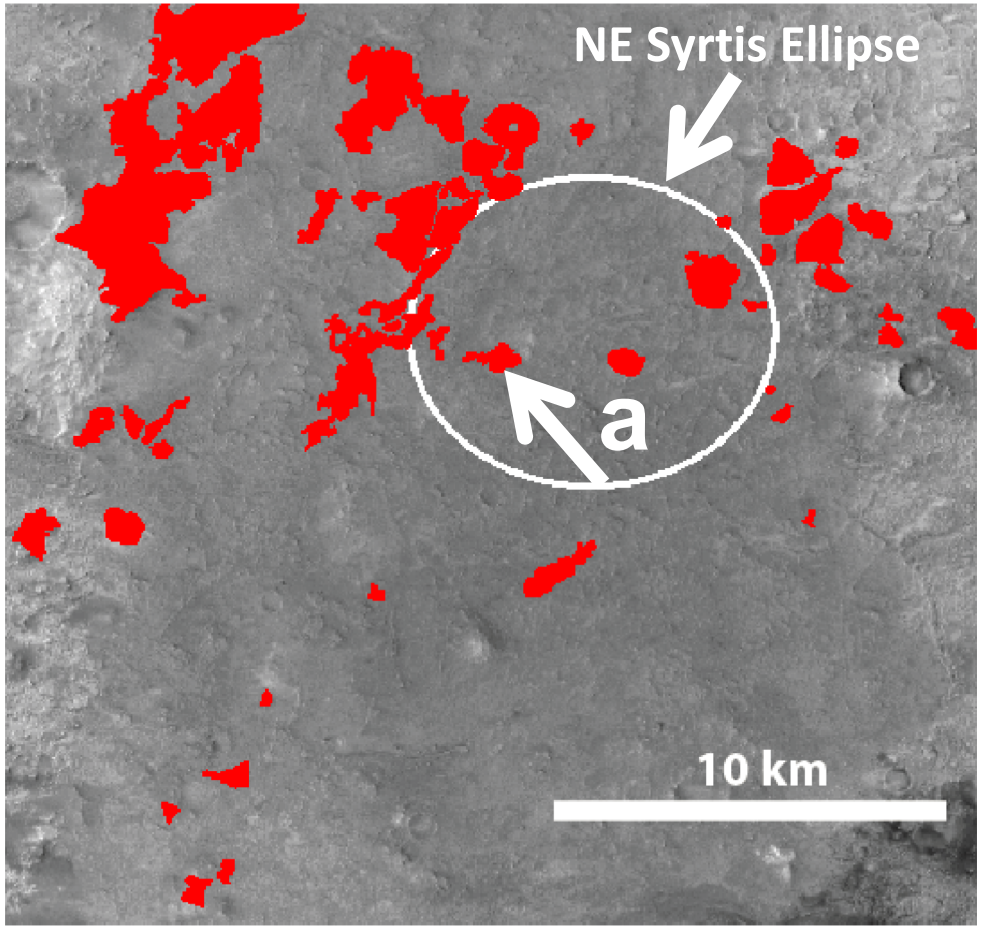


1. Low-Ca Pyroxenes

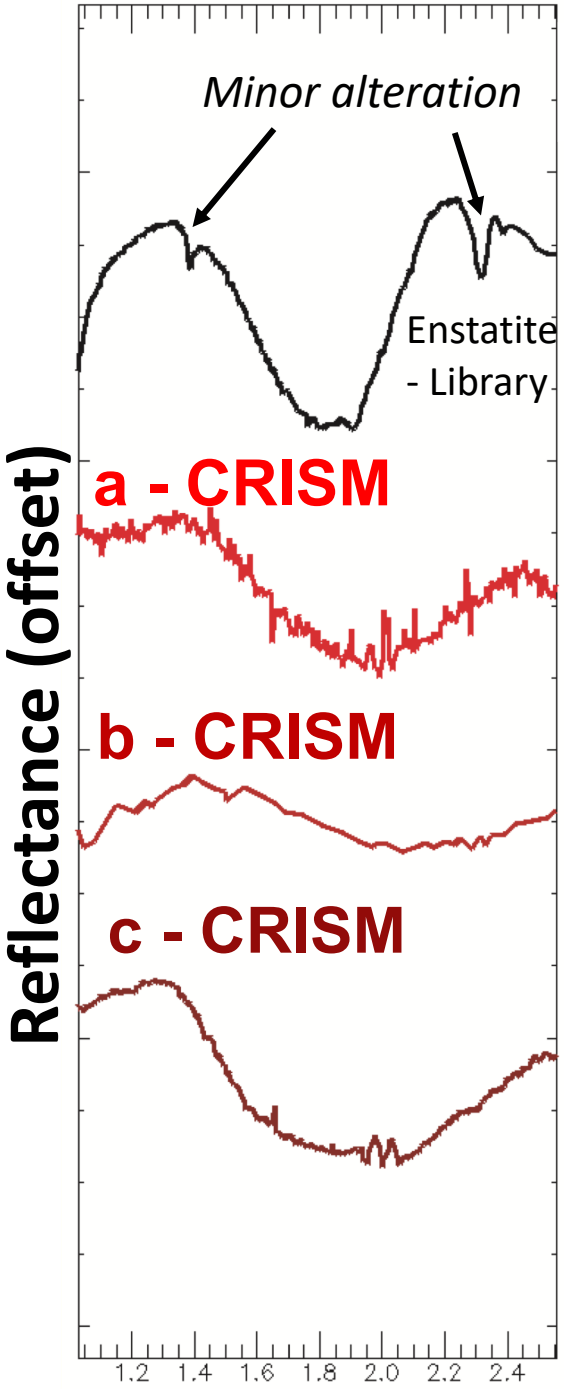
Low-Ca pyroxene-rich mounds

- LCP-rich mounds detected in and near both NE Syrtis and Midway





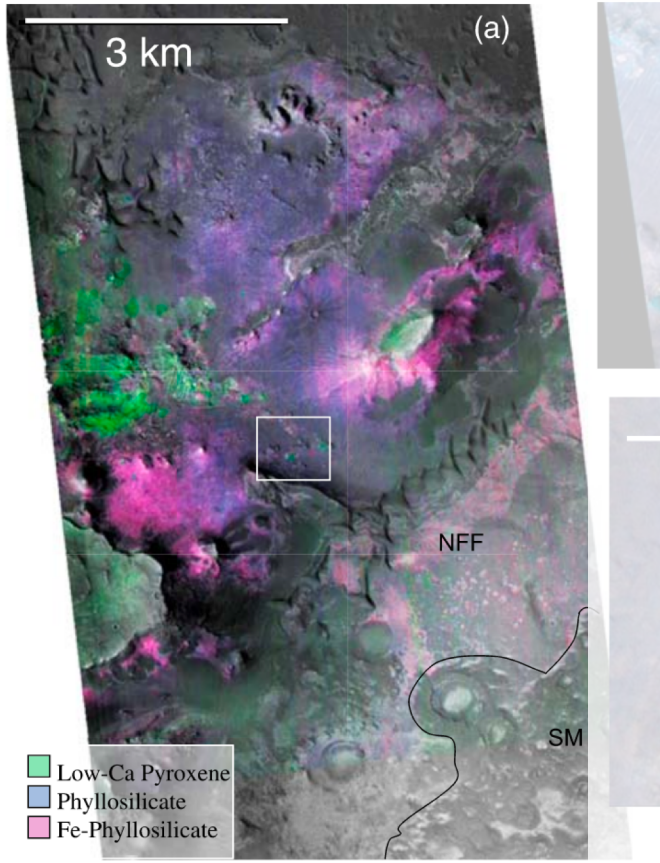
Map is modified from Bramble et al. (2017)



1. Low-Ca Pyroxenes

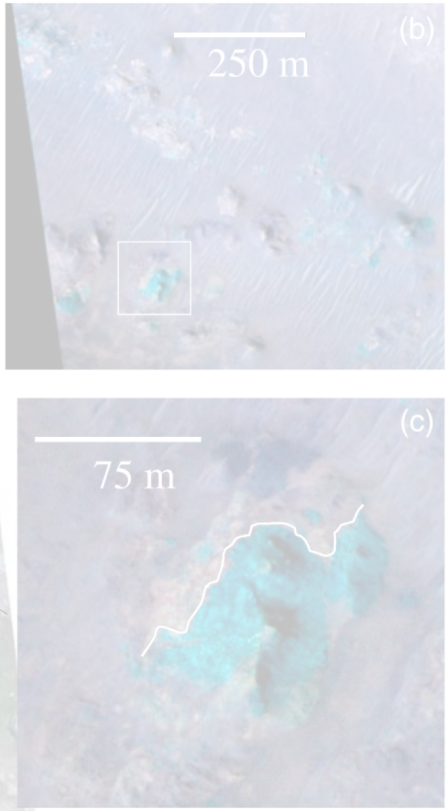
Units of Noachian Basement Formation

1. Low-Ca pyroxene
2. Fe/Mg-smectite



Mustard et al. (2009)

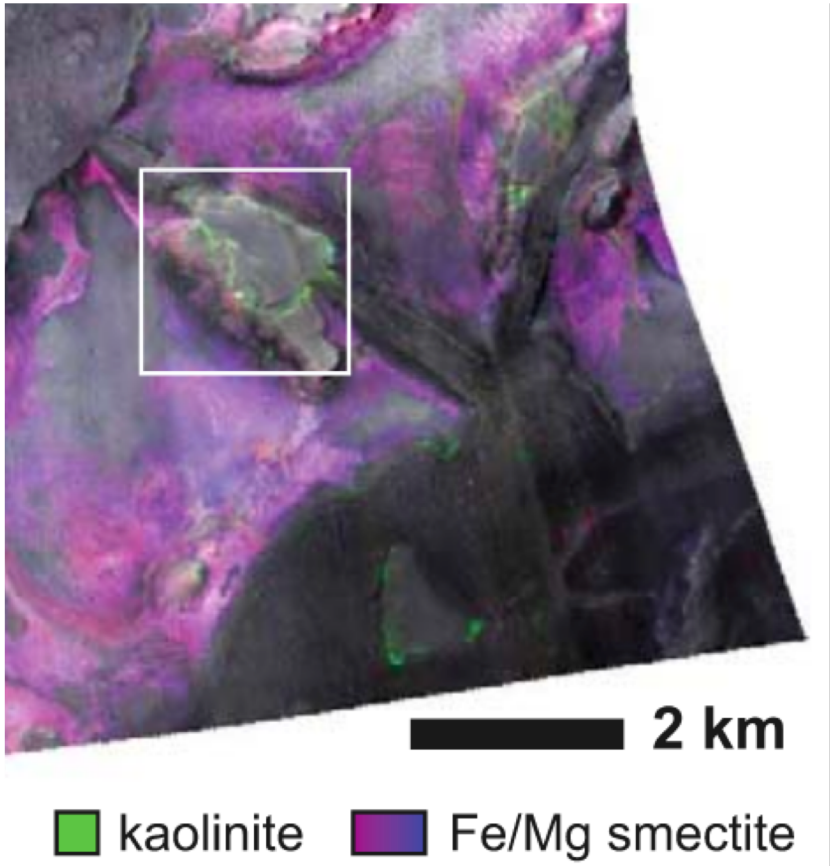
3. Megabreccia



4. Ridges

Saper and Mustard (2013)

5. Kaolinite

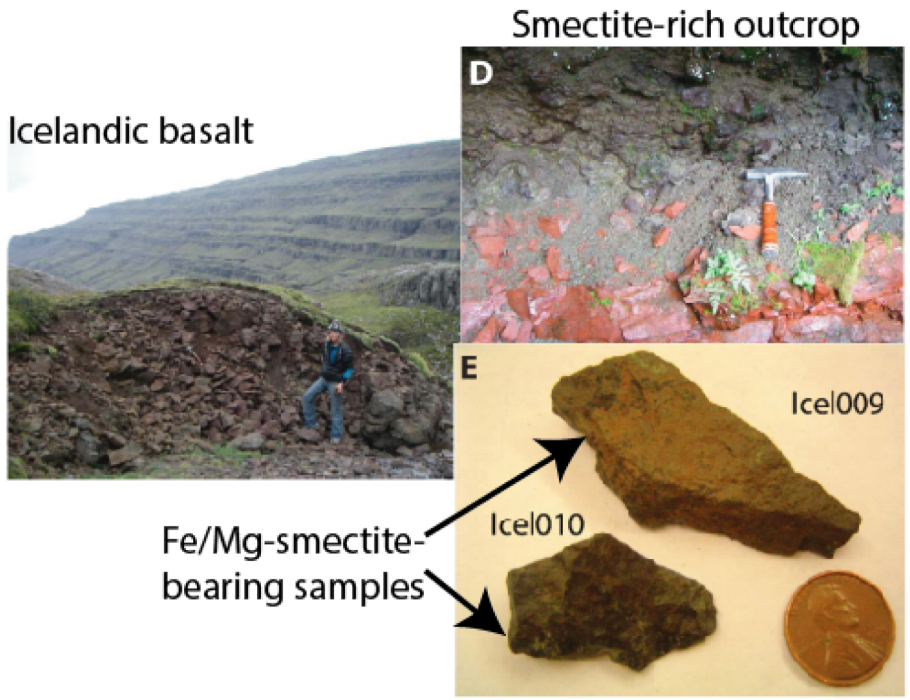


Ehlmann et al. (2009)

Clay formation

Four formation events of clay:

- 1: Massive Fe/Mg-smectite
- *Stratified Fe/Mg-smectite*
  - no definite exposures locally in traverse areas
- 2: Ridges of Fe/Mg-smectite
- 3: Zones of Kaolinite mineralization



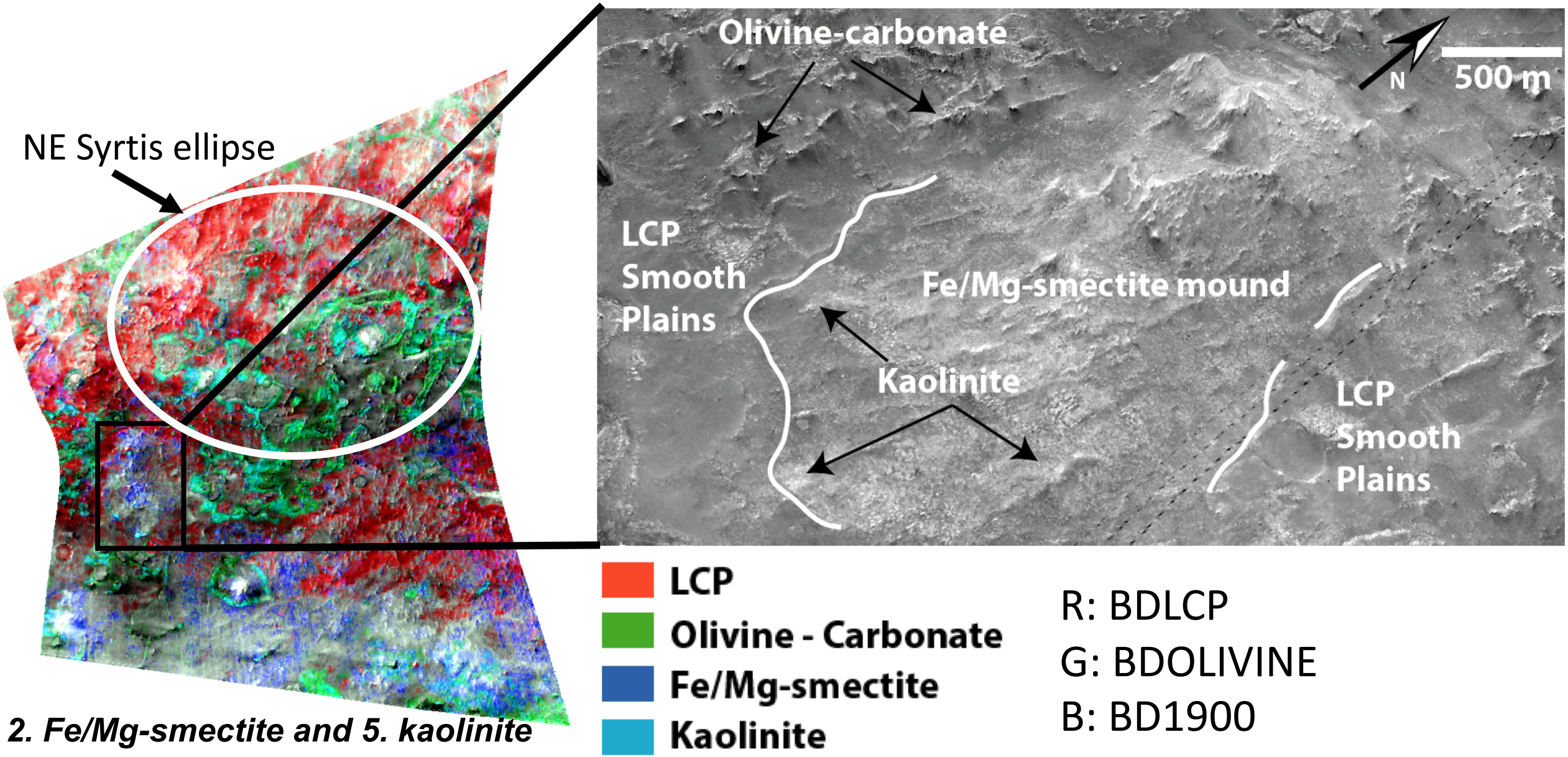
1: Hydrothermal alteration of Icelandic basalt

Modified from Ehlmann et al., 2012

2: Mineralized fracture from Sudbury crater
Credit: Haley Sapers

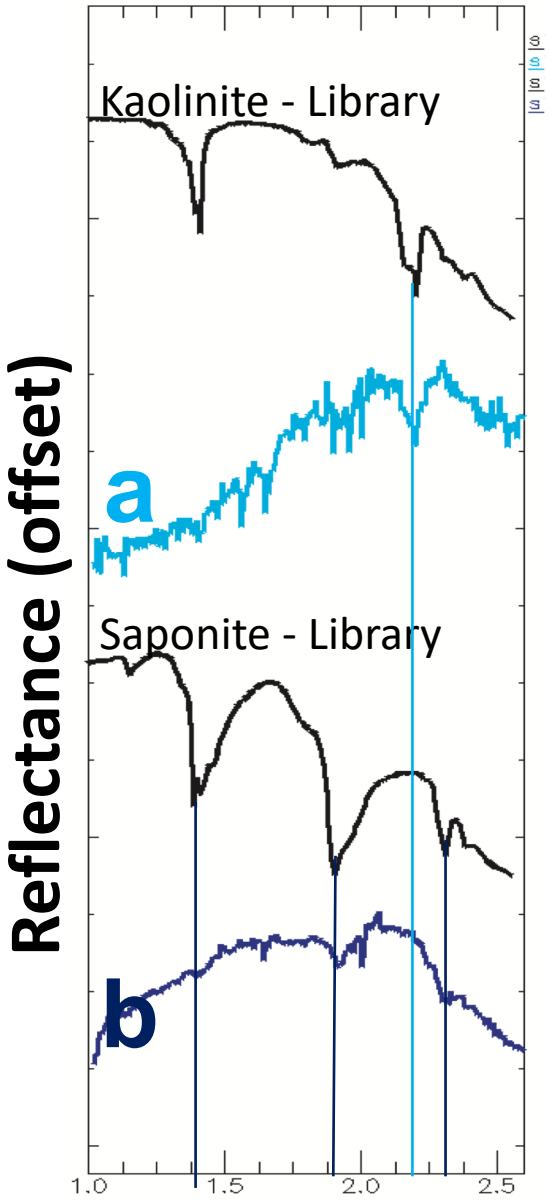
3: Weathering horizon
Credit: Jack Mustard

Mounds of massive Fe/Mg-smectite in NE Syrtis

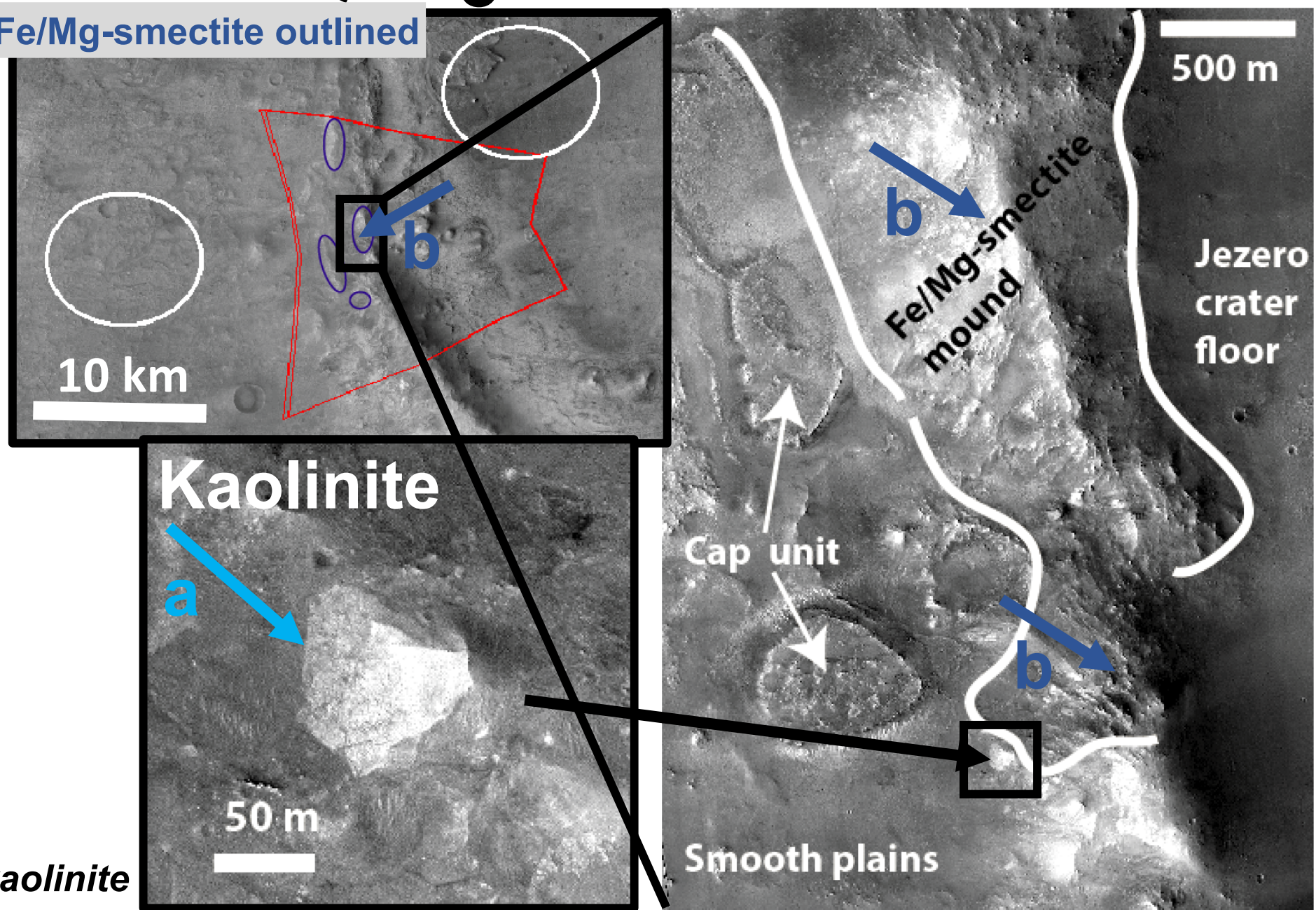


2. Fe/Mg-smectite and 5. kaolinite

Mounds of massive Fe/Mg-smectite in Jezero rim



2. Fe/Mg-smectite and 5. kaolinite

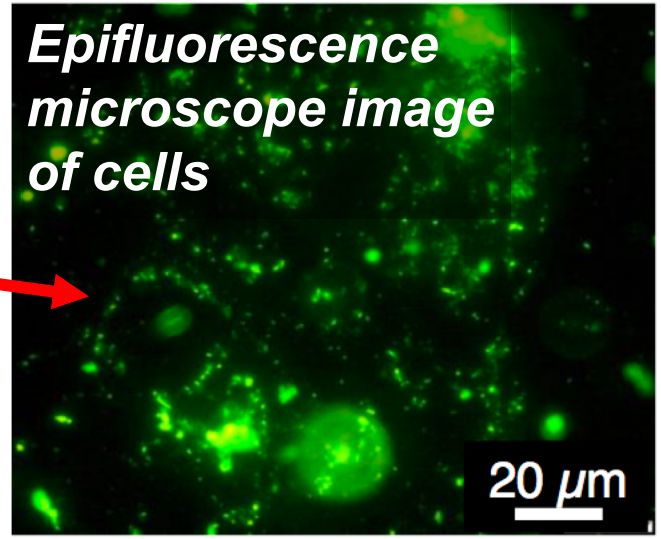


Potential biosignature preservation in Fe/Mg-smectite-bearing lithologies

- Subsurface alteration of basalt provides habitable environments on Earth - diverse microbial communities are observed

- We observe biosignatures in the form of organic material, microfossils, chemical signatures from these environments

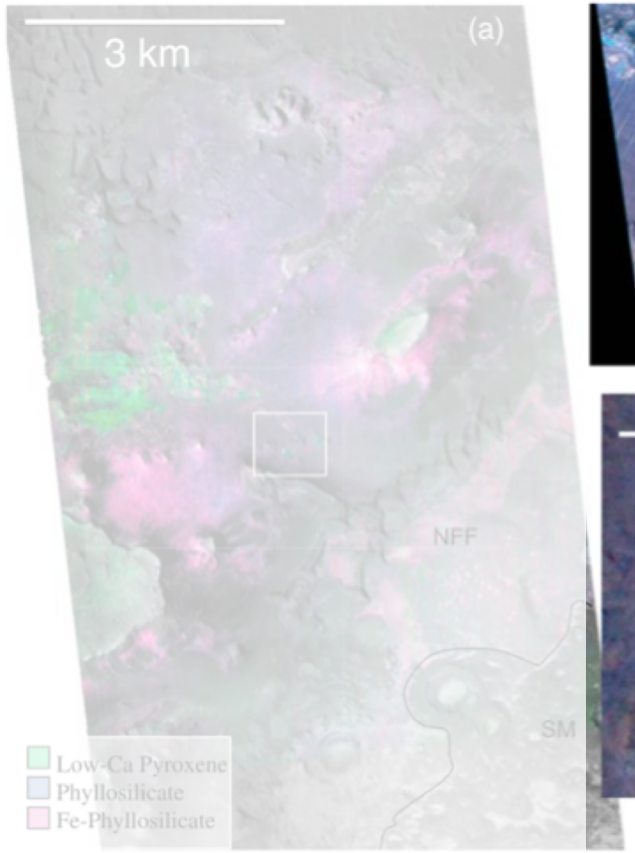
Altered basalt core



Modified from Trias et al. (2017)

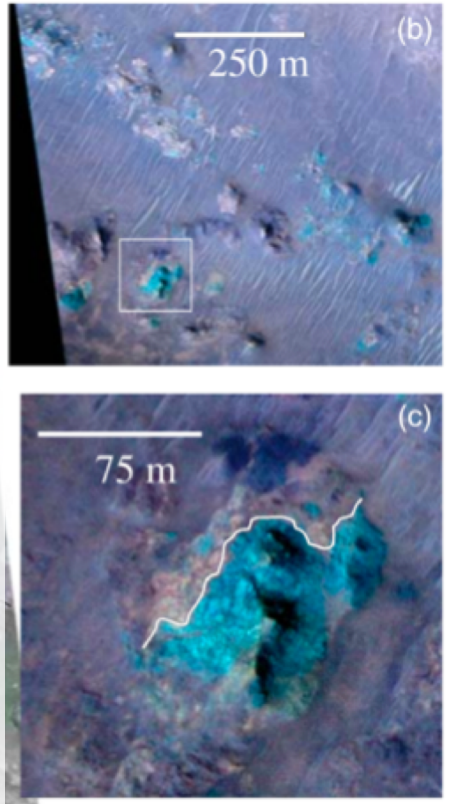
Units of Noachian Basement Formation

1. Low-Ca pyroxene
2. Fe/Mg-smectite



Mustard et al. (2009)

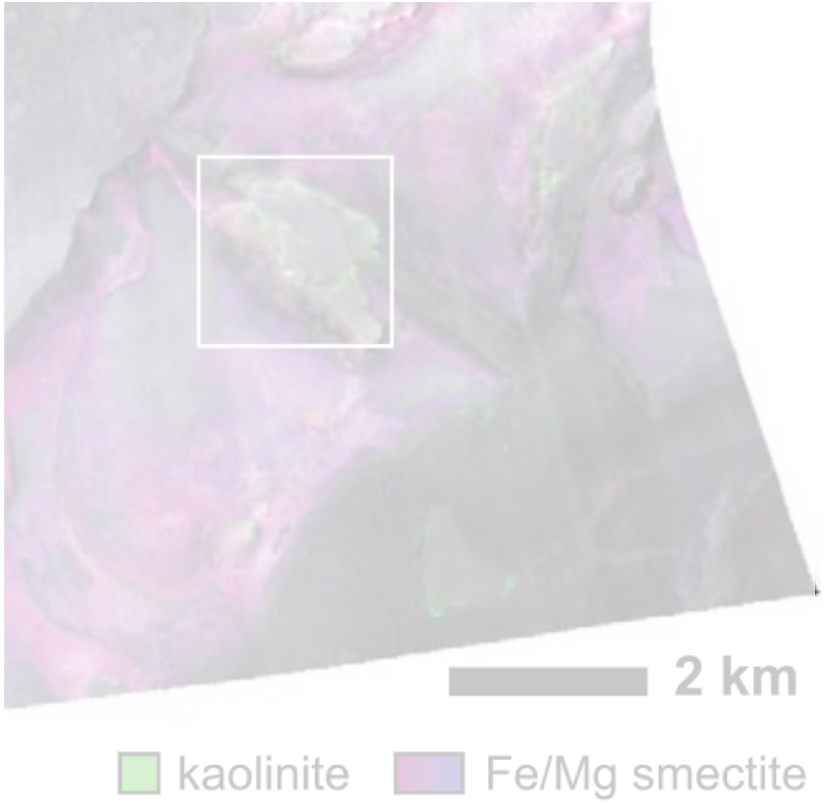
3. Megabreccia



4. Ridges

Saper and Mustard (2013)

5. Kaolinite



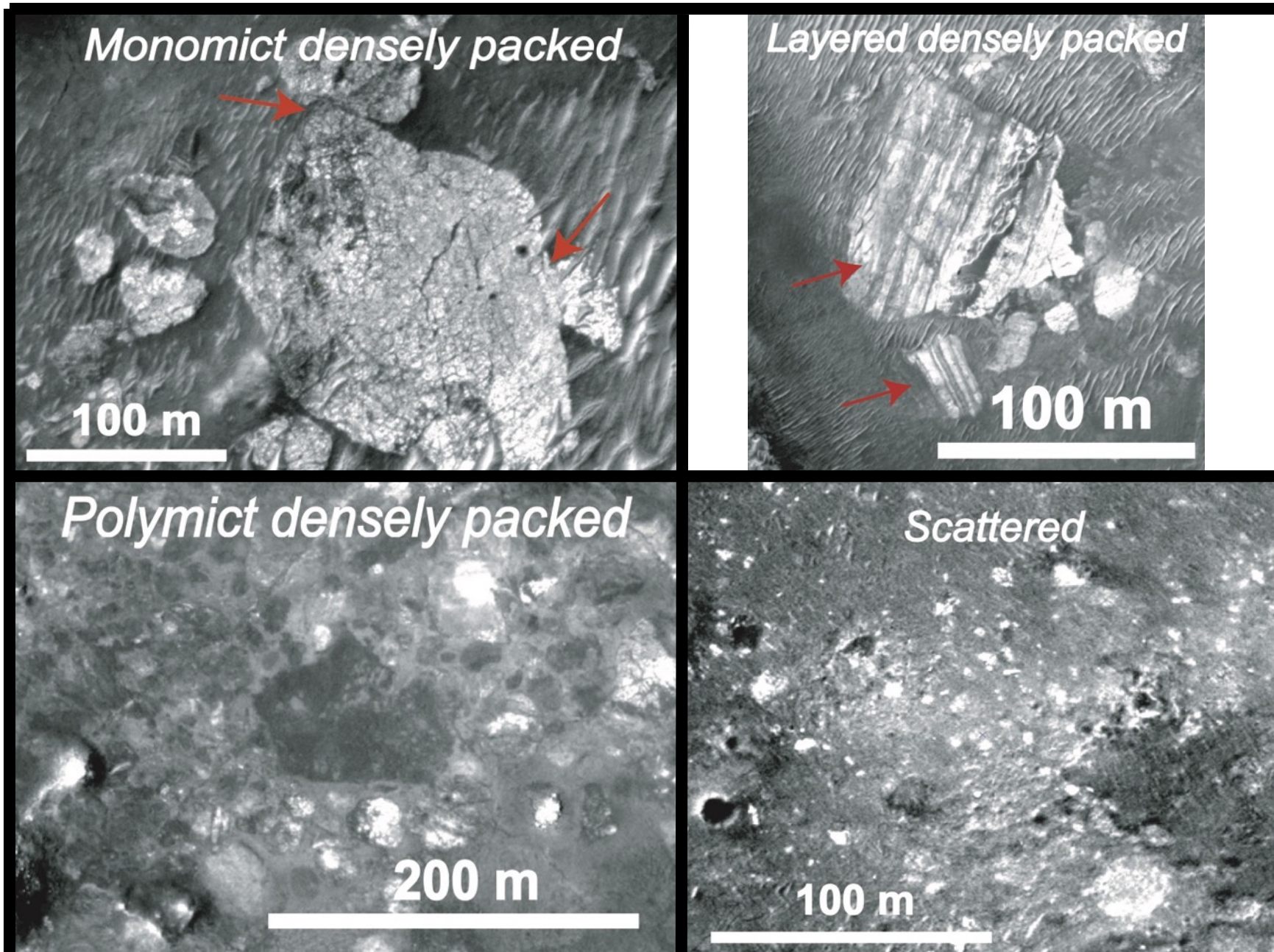
Ehlmann et al. (2009)

Megabreccia and Pre-Isidis materials

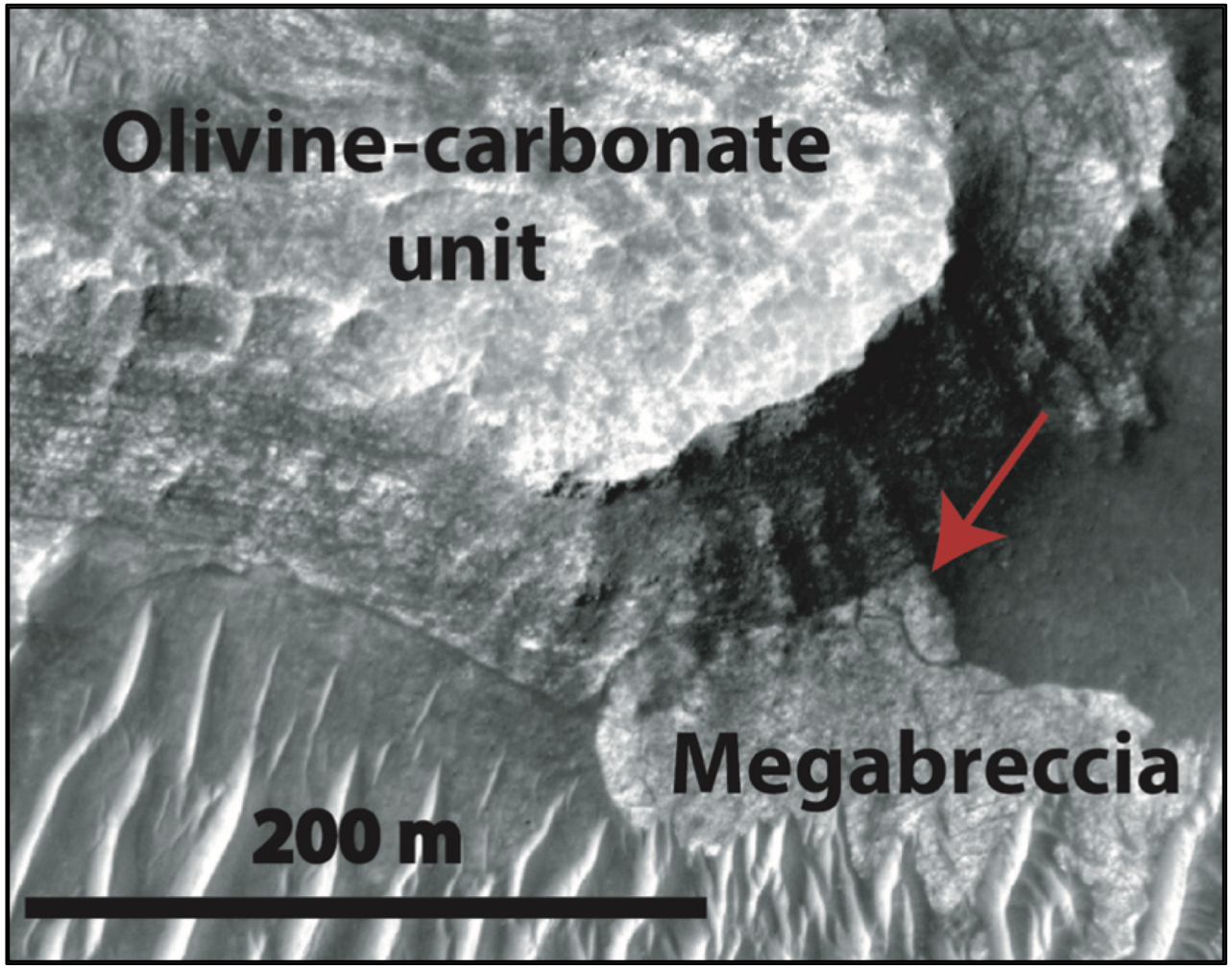
- Megabreccia are Pre-Noachian/Early Noachian materials

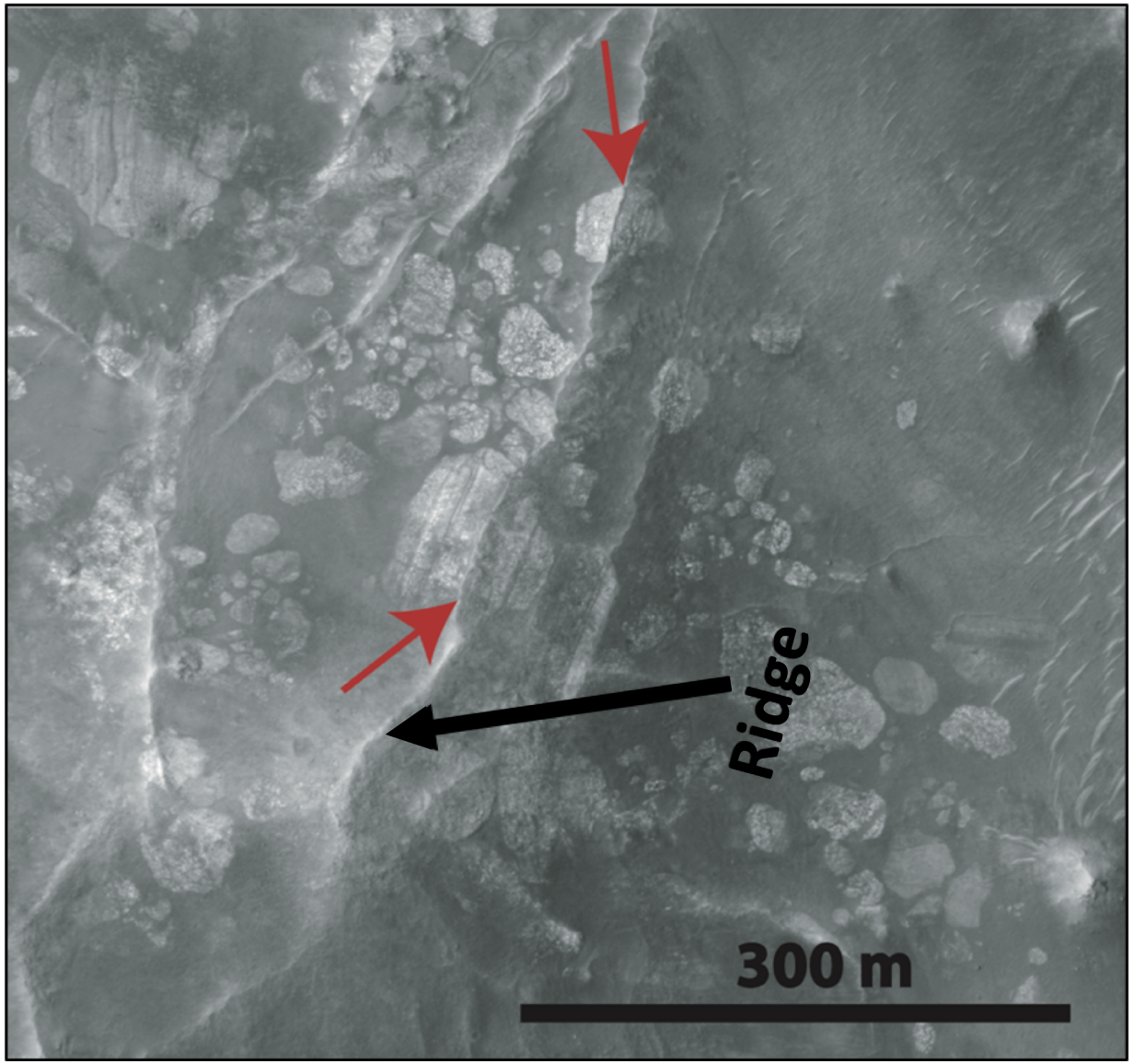
Our megabreccia map constrained

- Distribution
- Relative age
- Diversity of materials
  - Lithological
  - Textural



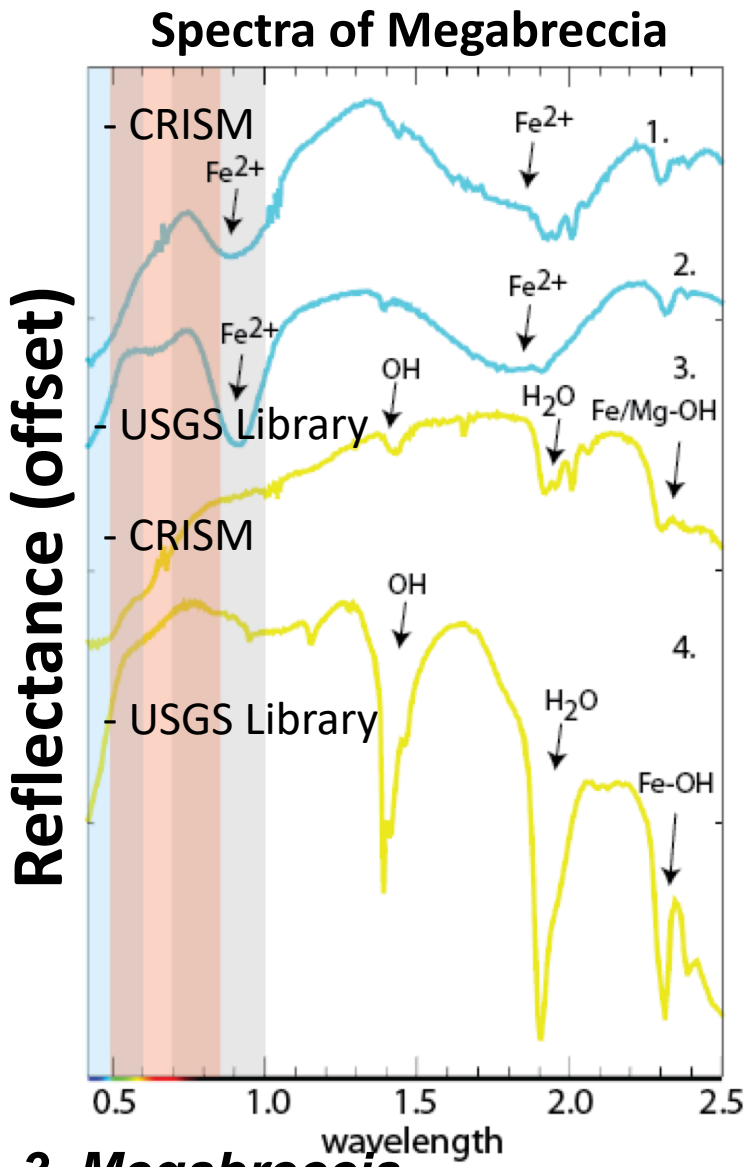
Megabreccia are constrained by cross-cutting relationships implying Pre-Isidis age for megabreccia materials

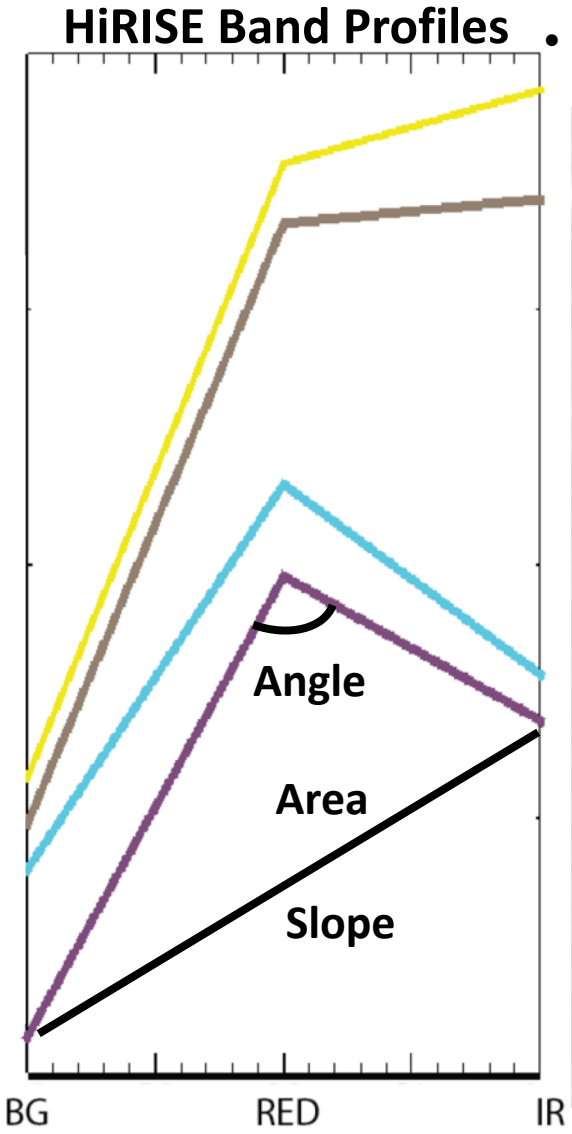




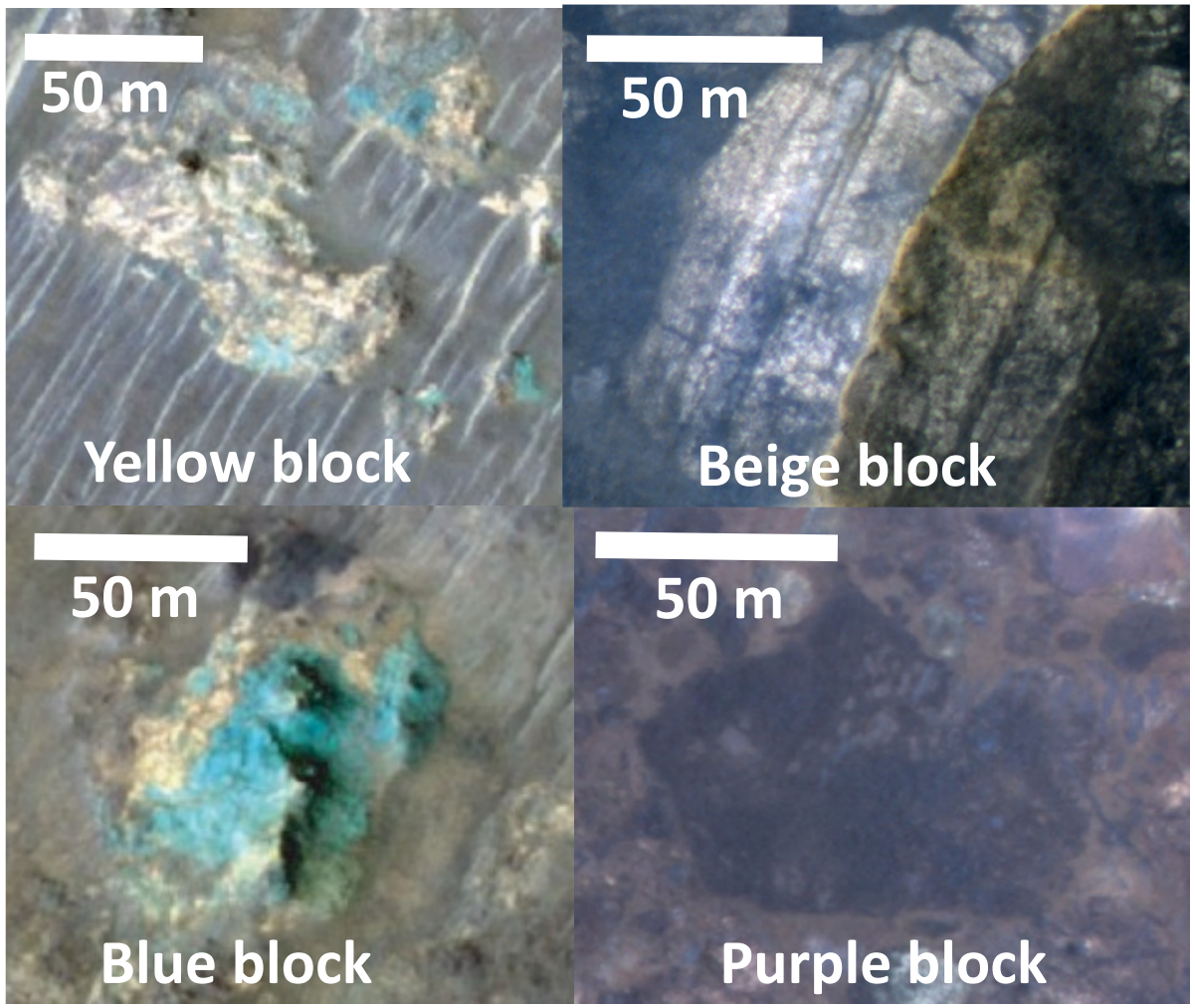
3. Megabreccia

Megabreccia Contain Pyroxenes and Clay Minerals





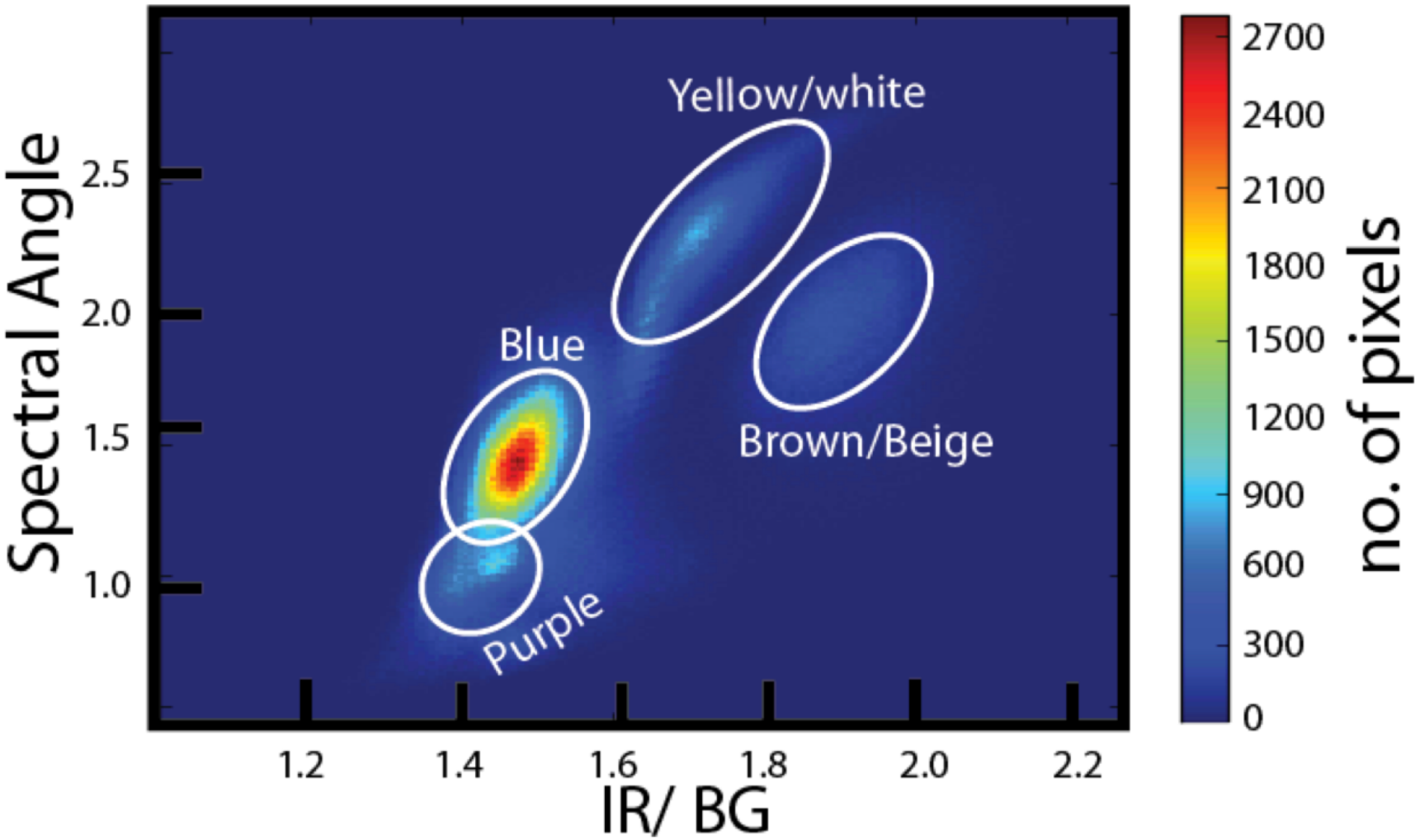
- Few blocks have CRISM coverage
- HiRISE color images used for mineralogical analysis



3. Megabreccia

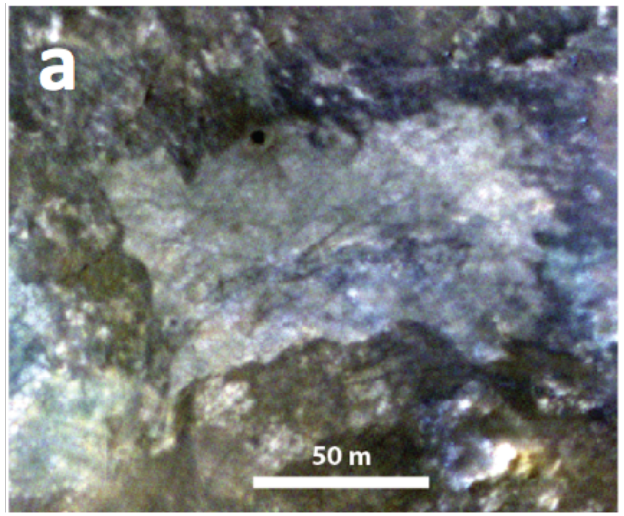
Four endmember Lithologies of Megabreccia

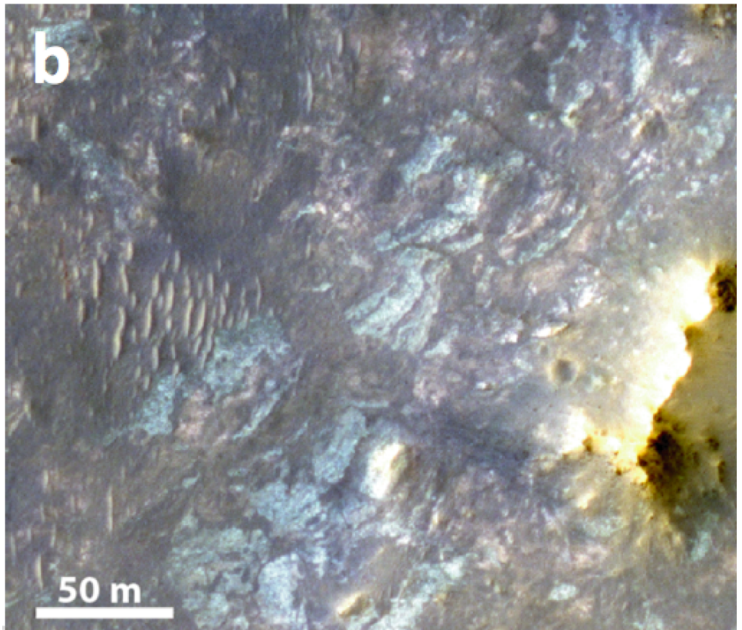
- 4 distinct lithologies in color HiRISE from 8 different images
- Blue (LCP) and Yellow (Fe/Mg smectite) lithologies
- Beige and purple materials are distinct lithologies, not captured by CRISM

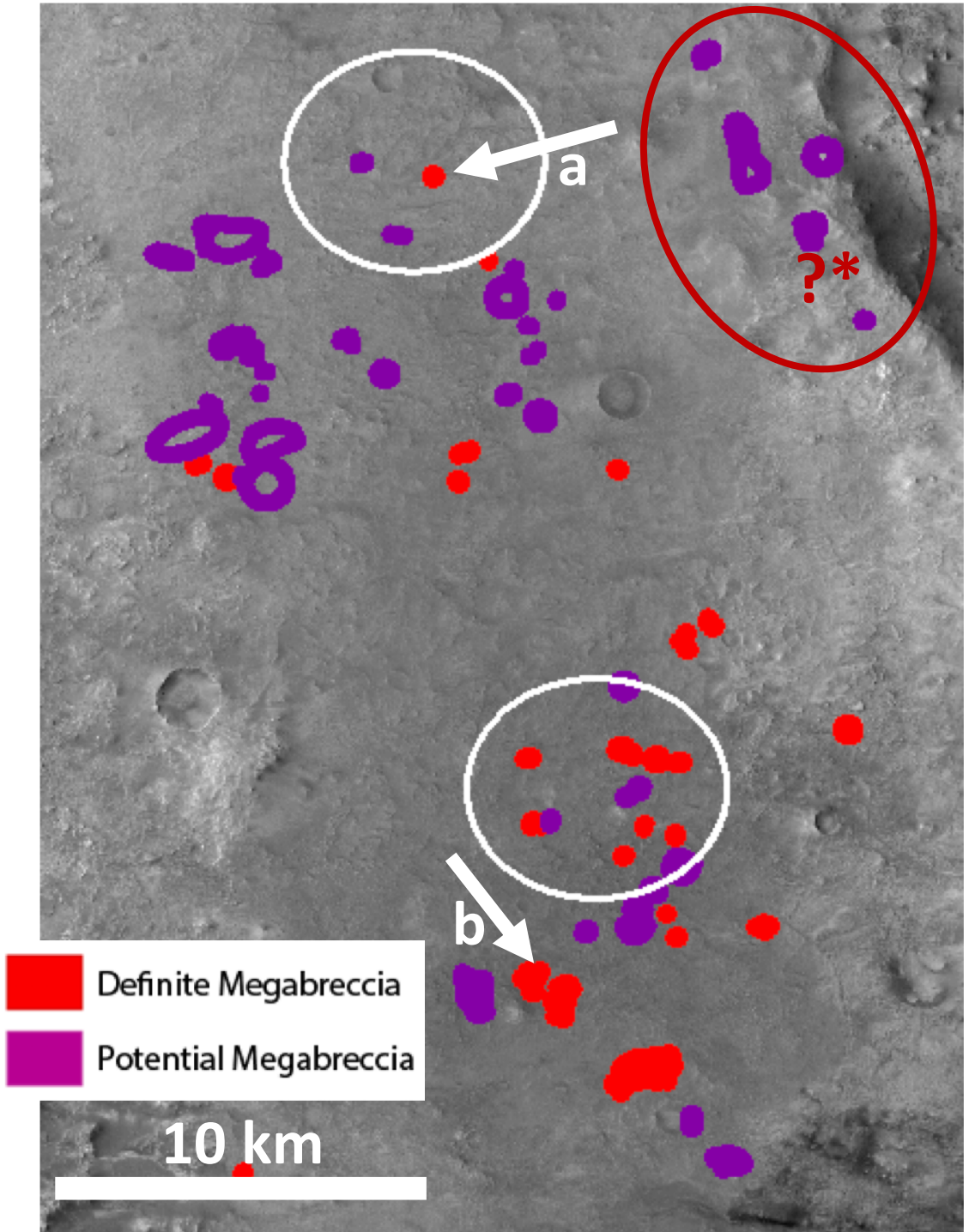


Megabreccia in and Around the Ellipses

- Megabreccia are present around both ellipses
- Both Fe/Mg-smectite and LCP-bearing blocks present based on established color correlations





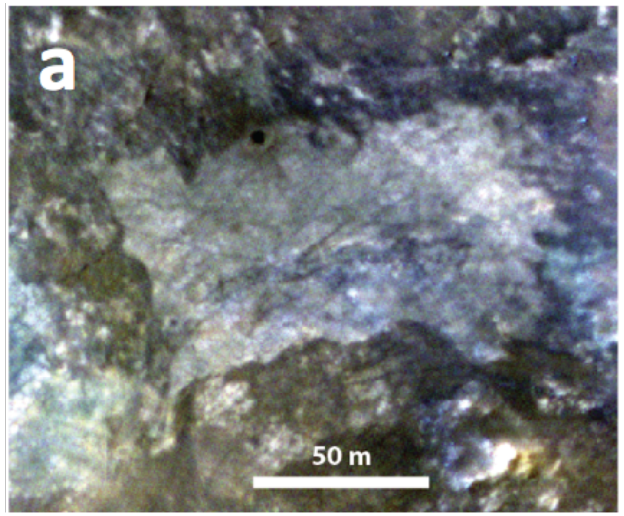


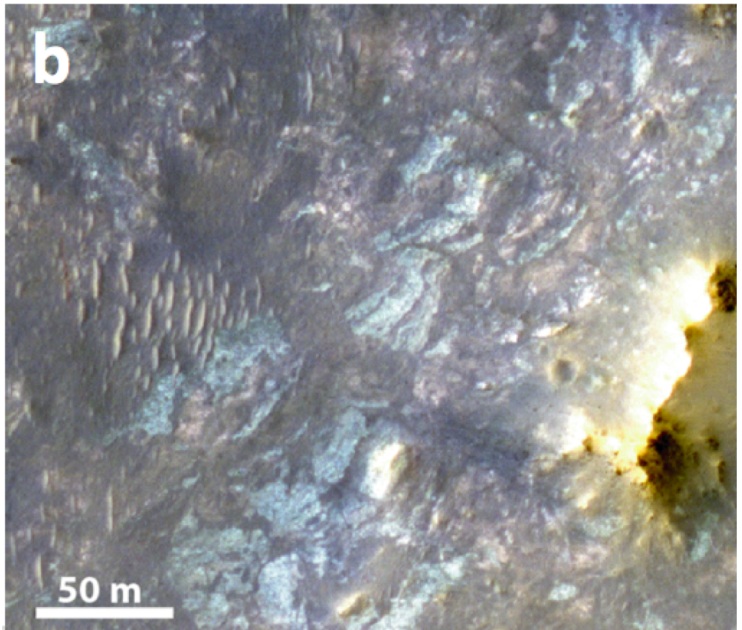
?*=Uncertain if these megabreccia are related to Jezero or Isidis

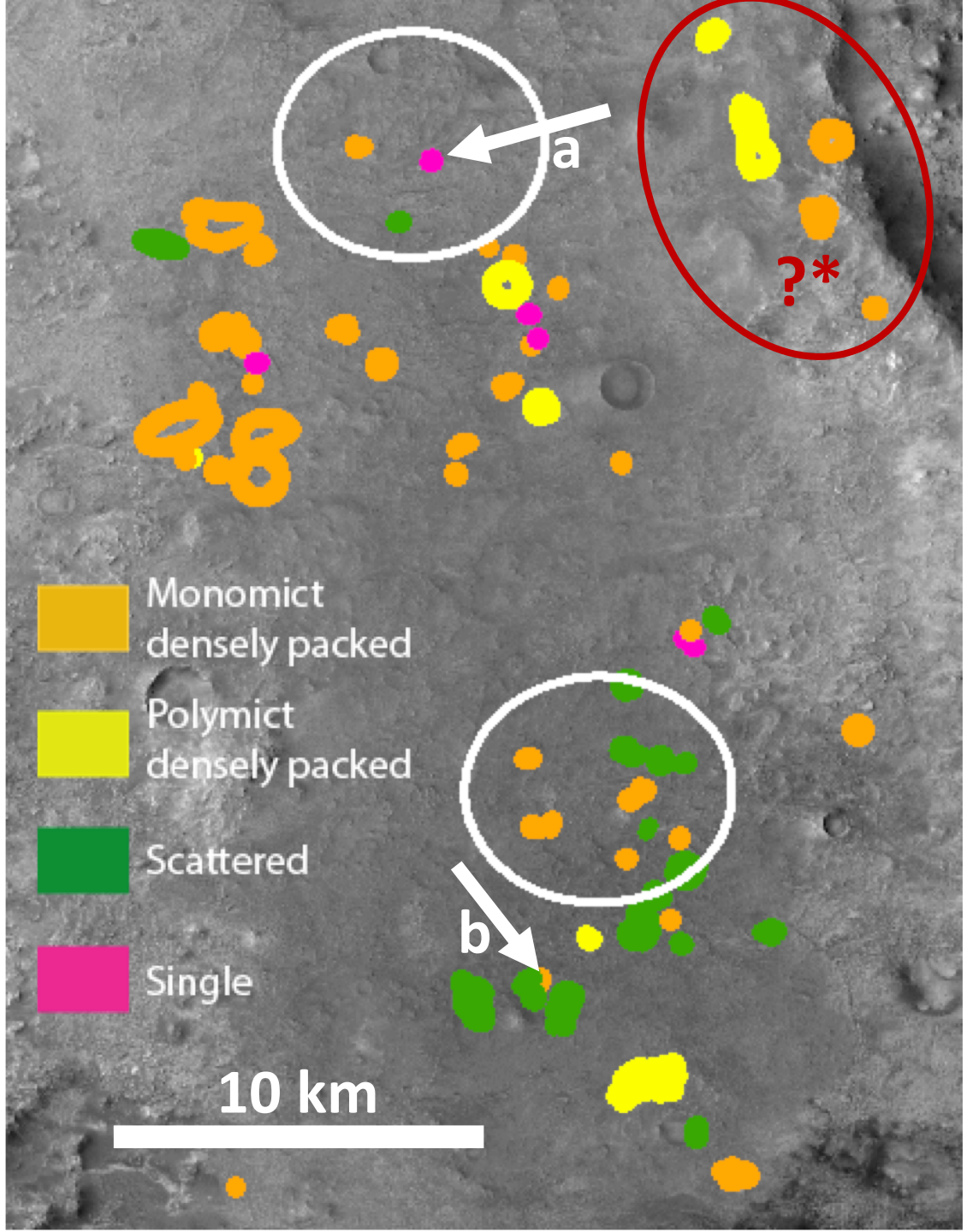
3. Megabreccia

Megabreccia in and Around the Ellipses

- Megabreccia are present around both ellipses
- Both Fe/Mg-smectite and LCP-bearing blocks present based on established color correlations







?*=Uncertain if these megabreccia are related to Jezero or Isidis

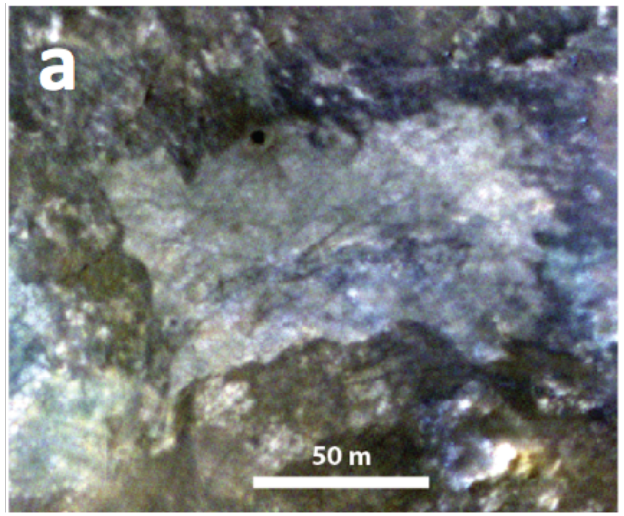
3. Megabreccia

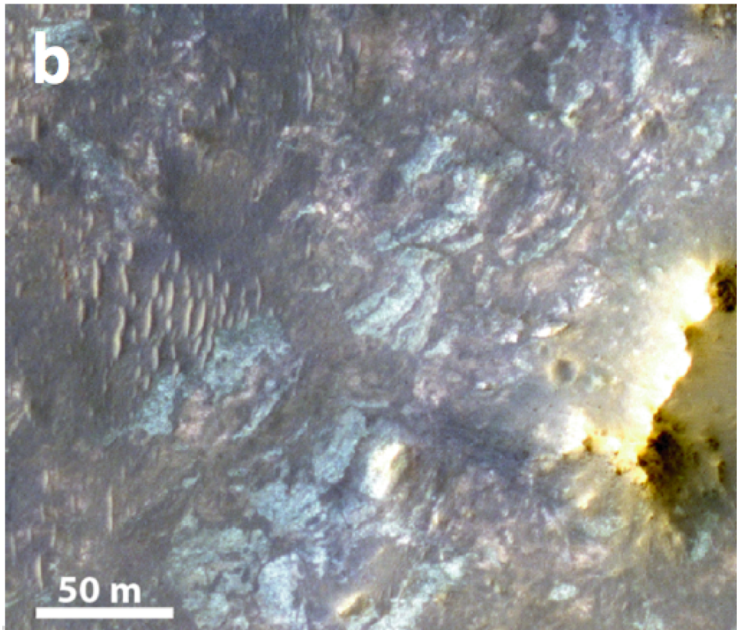
Megabreccia in and Around the Ellipses

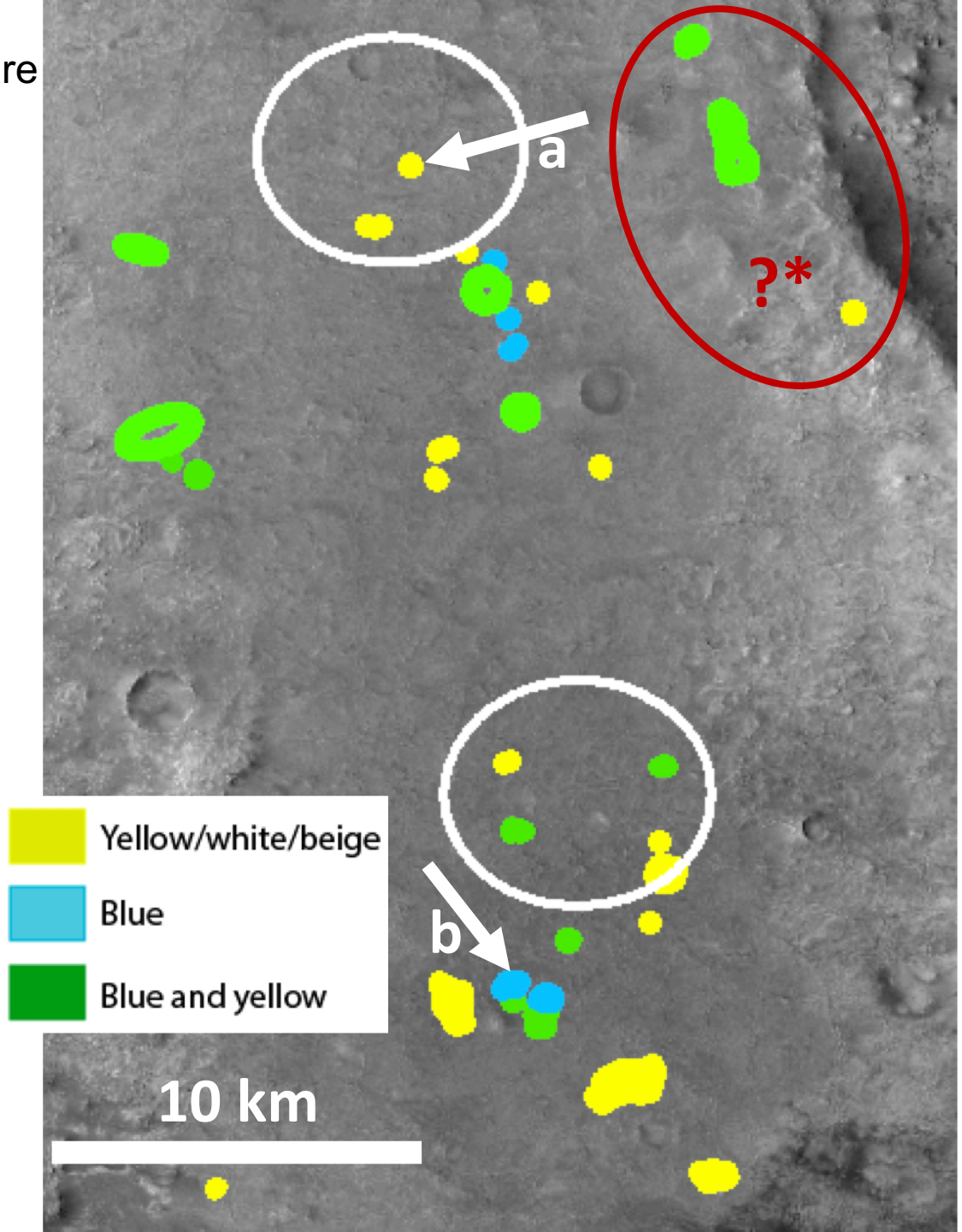
- Not all blocks are covered by color HiRISE

- Megabreccia are present around both ellipses

- Both Fe/Mg-smectite and LCP-bearing blocks present based on established color correlations





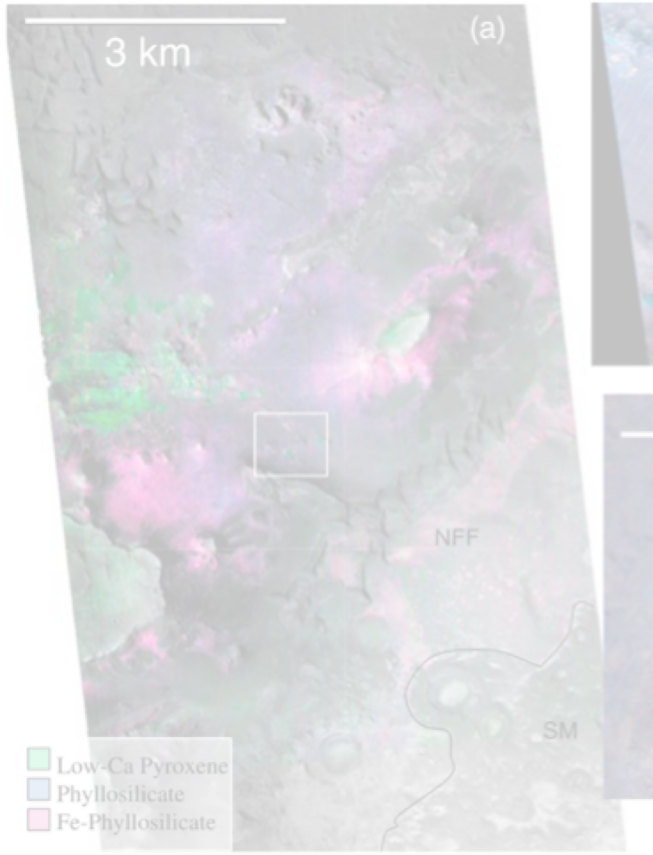


?*=Uncertain if these megabreccia are related to Jezero or Isidis

3. Megabreccia

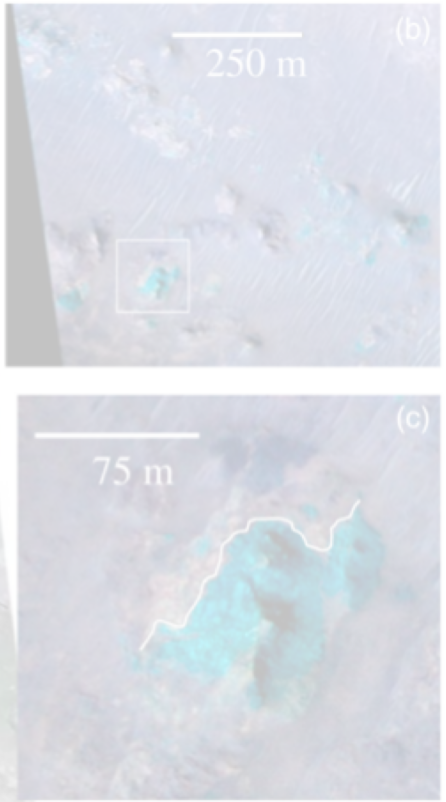
Units of Noachian Basement Formation

1. Low-Ca pyroxene
2. Fe/Mg-smectite

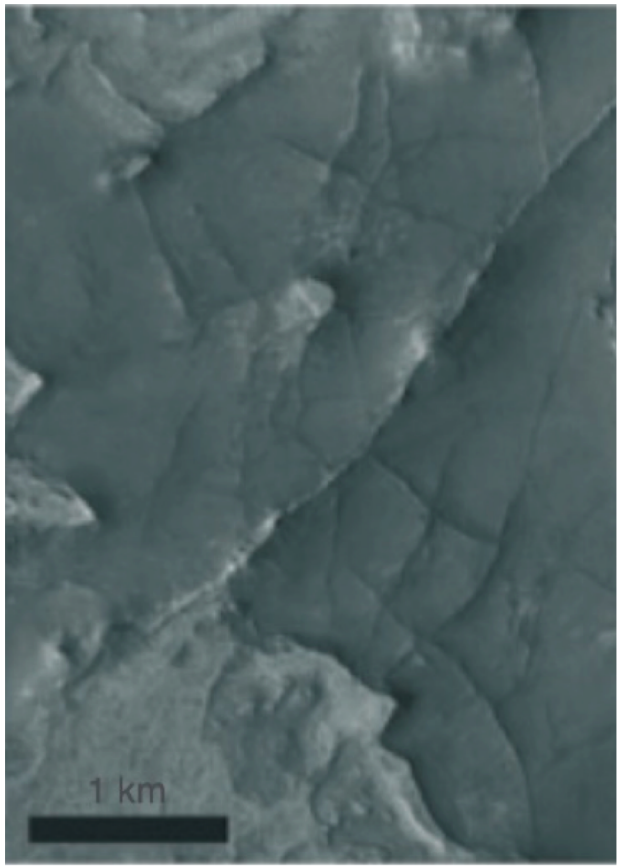


Mustard et al. (2009)

3. Megabreccia

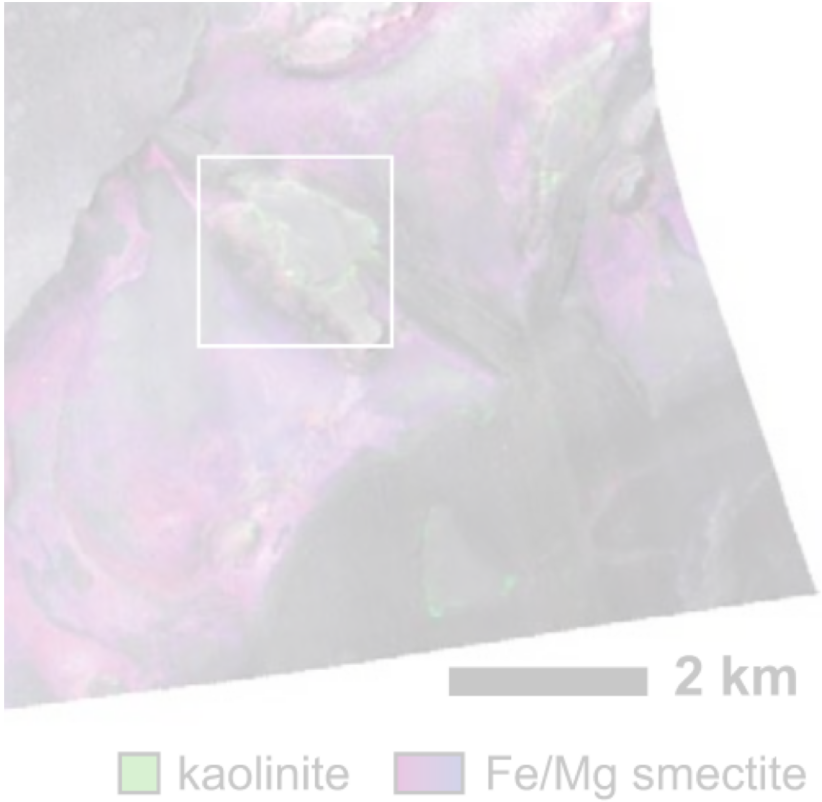


4. Ridges



Saper and Mustard (2013)

5. Kaolinite

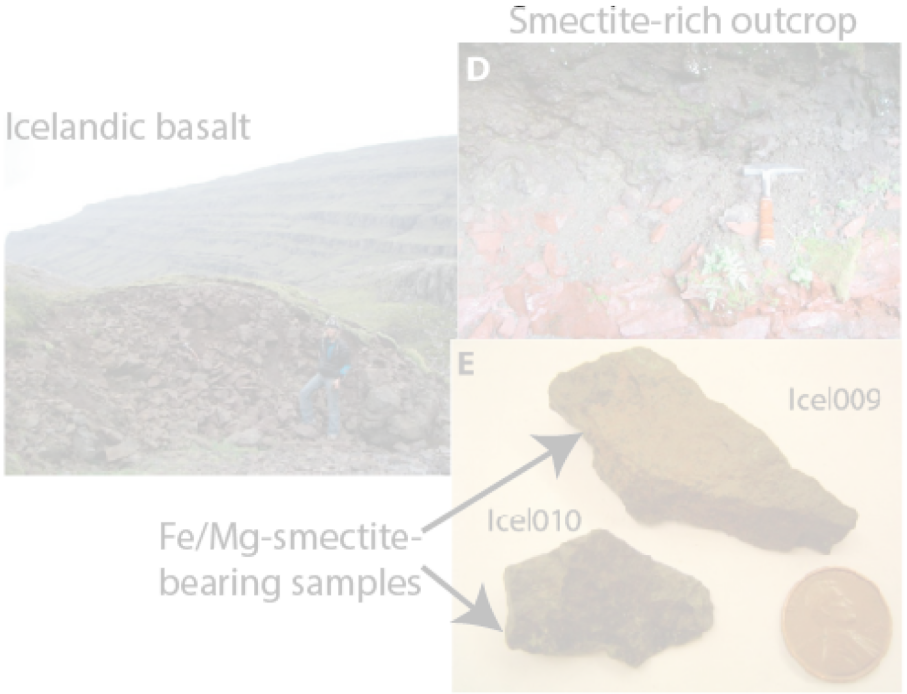


Ehlmann et al. (2009)

Clay formation

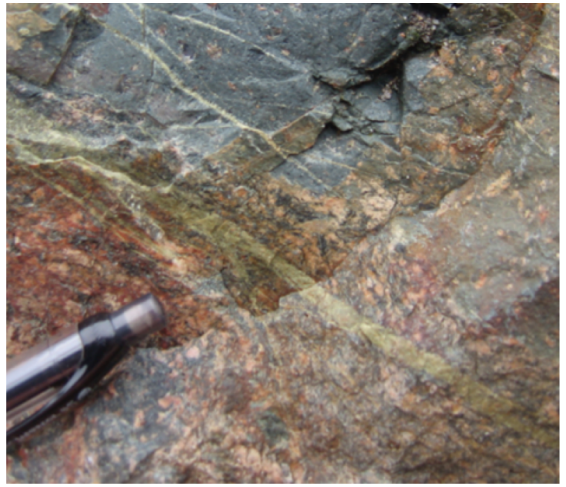
Four formation events of clay:

- 1: Massive Fe/Mg-smectite
- *Stratified Fe/Mg-smectite*
  - no definite exposures locally in traverse areas
- 2: Ridges of Fe/Mg-smectite
- 3: Zones of Kaolinite mineralization



1: Hydrothermal alteration of Icelandic basalt

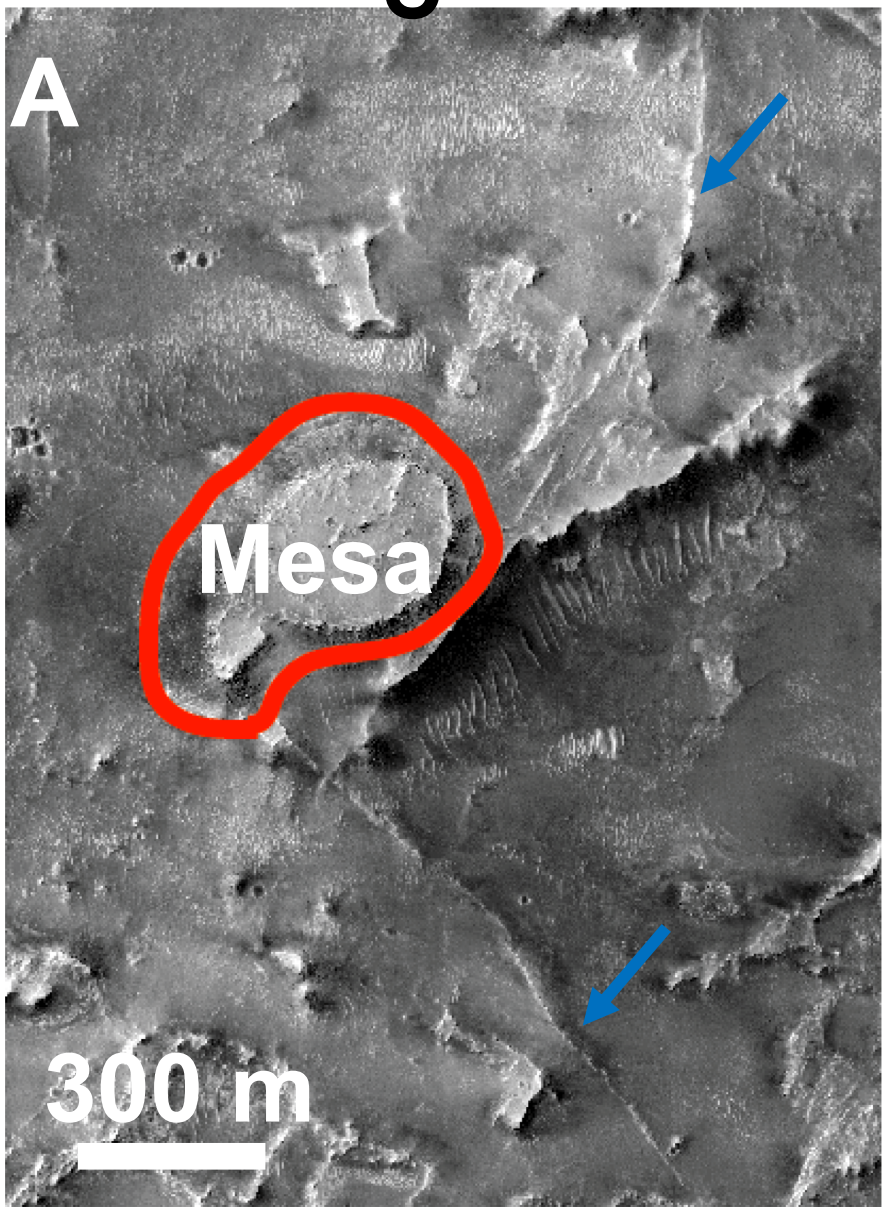
Modified from Ehlmann et al., 2012

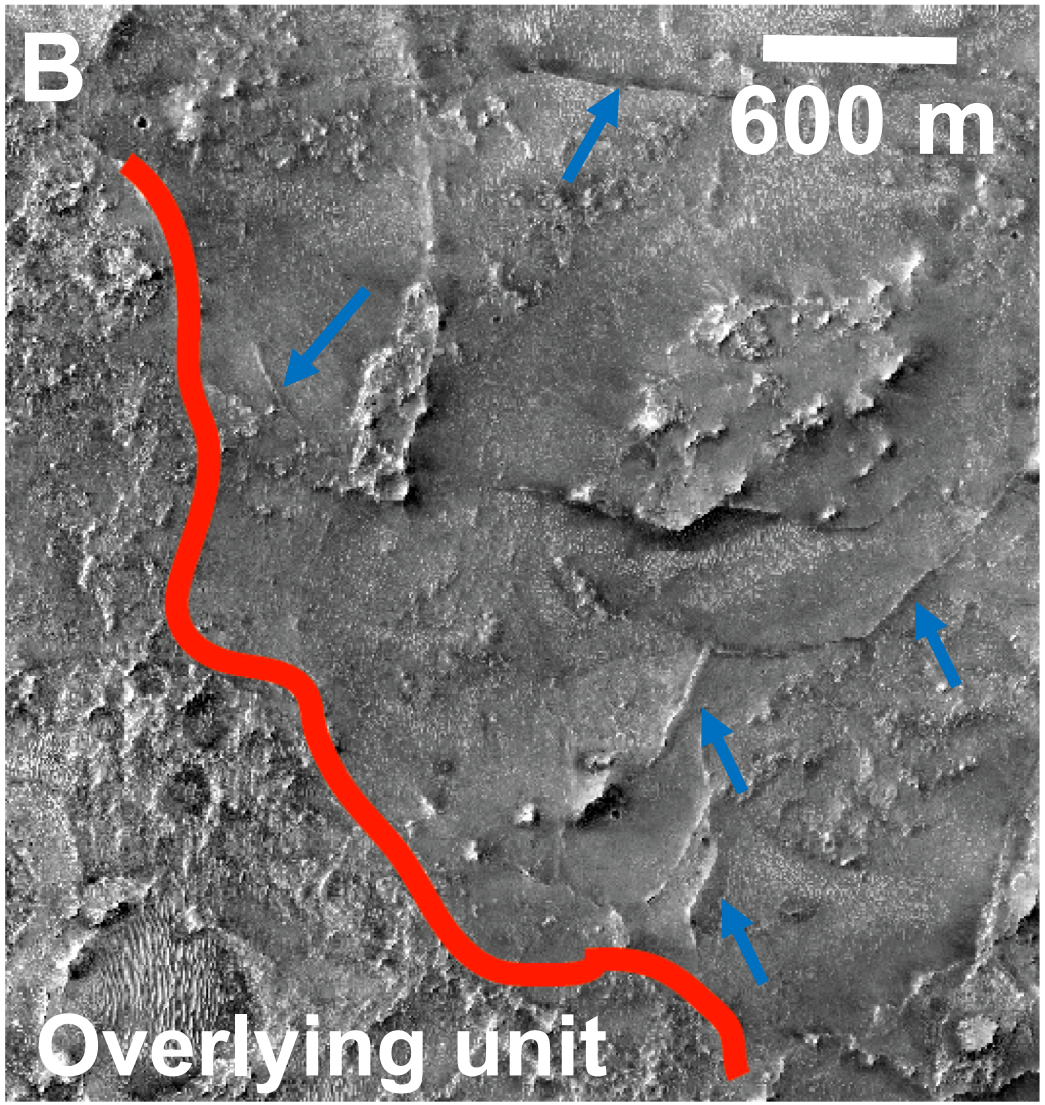


2: Mineralized fracture from Sudbury crater
Credit: Haley Sapers

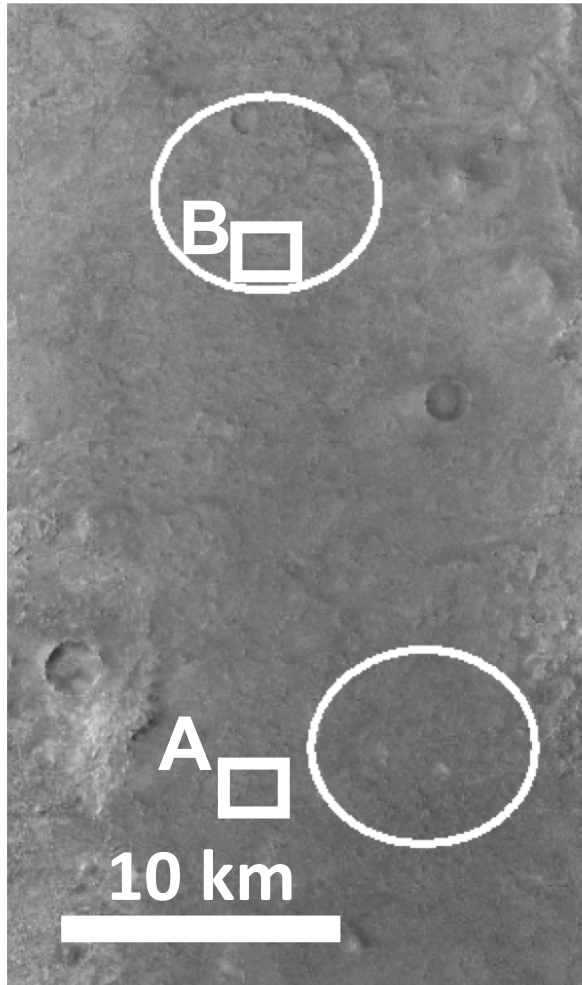
3: Weathering horizon
Credit: Jack Mustard

Ridges in NE Syrtis and Midway Ellipses





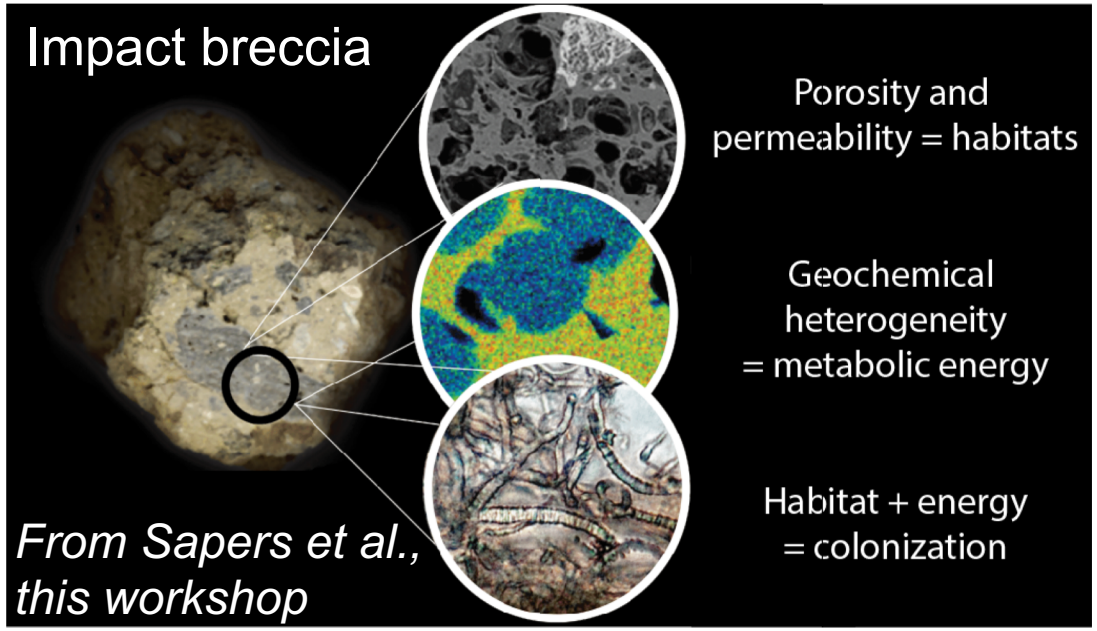
- Ridges in blue
- Fluid-filled fractures

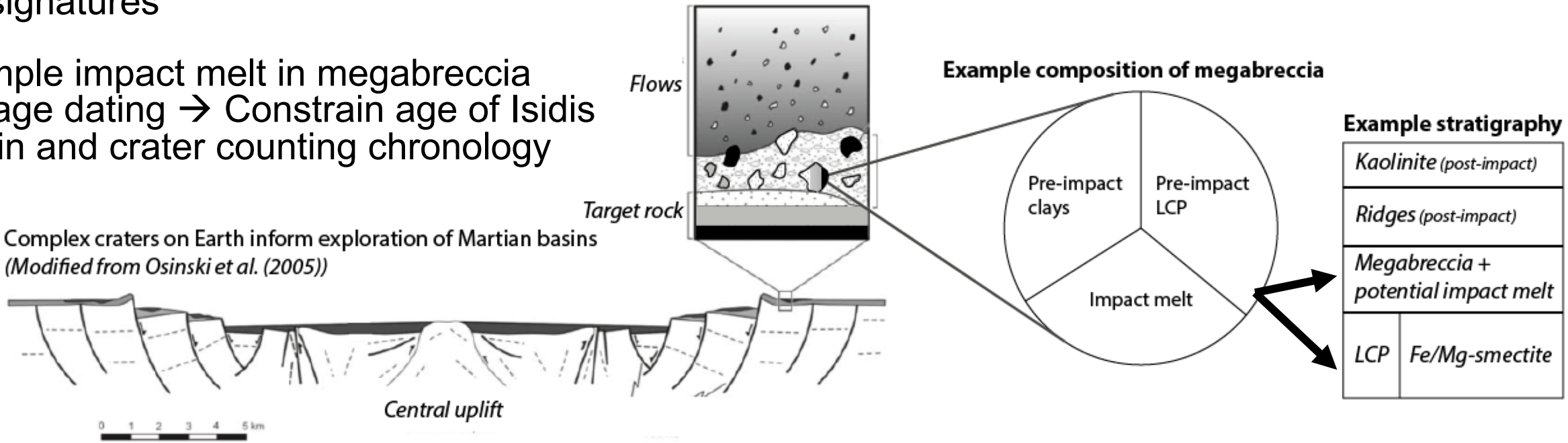


Goal 1: Determine Pre-Isidis crust and search for biosignatures

What can Mars 2020 do?

- Petrology of Pre-Isidis material in megabreccia → Understand prevalence of igneous and sedimentary processes on ancient Mars
- Field studies of megabreccia → Understand formation mechanism through basin scale impact processes
- Sample and analyze Pre-Isidis clay-rich materials from megabreccia for biosignatures
- Sample impact melt in megabreccia for age dating → Constrain age of Isidis basin and crater counting chronology





Complex craters on Earth inform exploration of Martian basins
(Modified from Osinski et al. (2005))

Goal 2: Petrogenesis of LCP-bearing lithologies

What can Mars 2020 do?

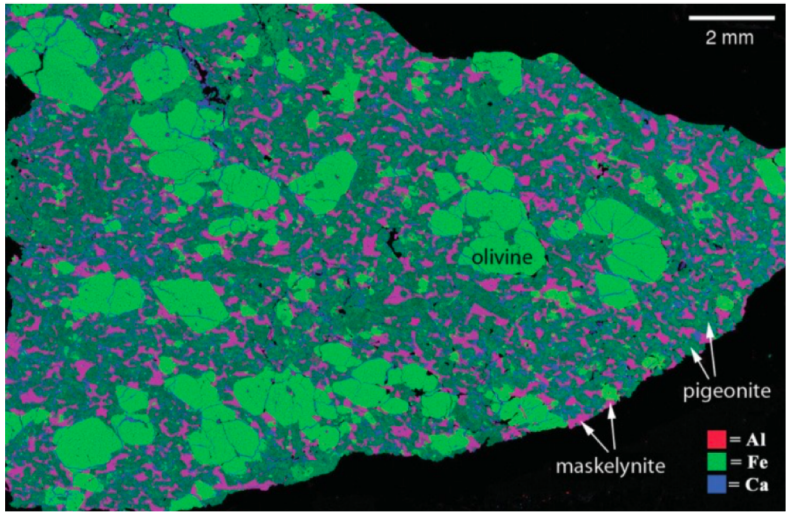
- Mineralogical and chemical analysis of ancient crustal basalt/orthopyroxenites → Composition of Martian partial melt, mantle, and understanding crustal formation processes

- Sample early/mid Noachian basalt/orthopyroxenites for age dating → Constrain lower age bound of Isidis basin formation and crater counting chronology

Where?

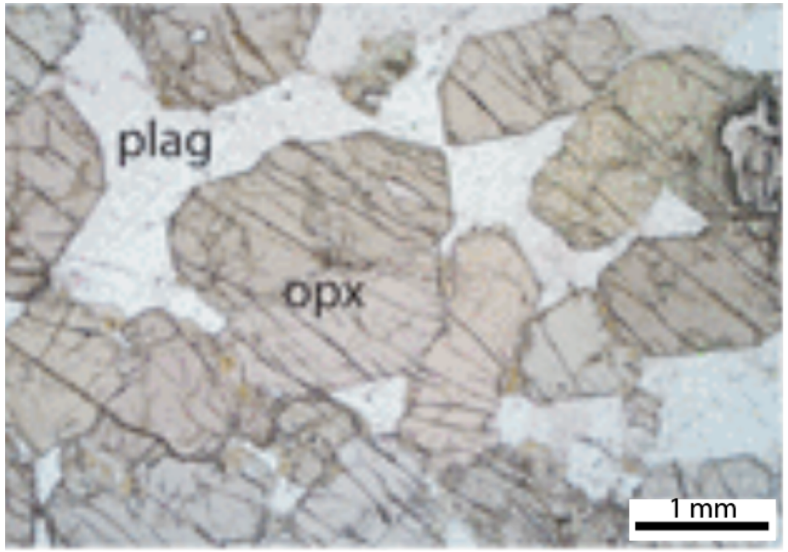
NE Syrtis, Midway or Midway-Jezero

Potential target: Basalt



Shergottite from Gill et al. (2010)

Potential target: Orthopyroxenite



Modified from Manoochehri et al. (2015)

Goal 3: Nature of clay formation, habitability, and search for biosignatures

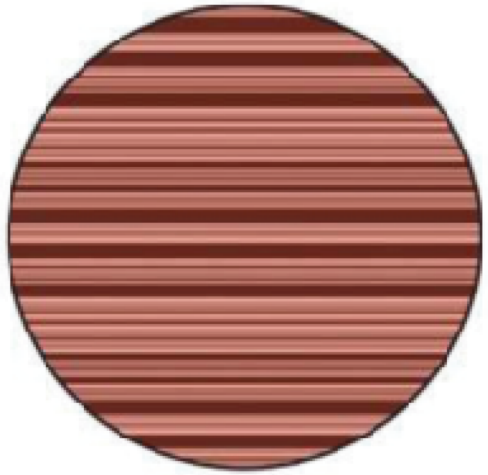
What can Mars 2020 do?

- Petrology of three different clay formation events → Determine environments of formation e.g. surface pedogenesis or subsurface alteration in an aquifer and search for biosignatures

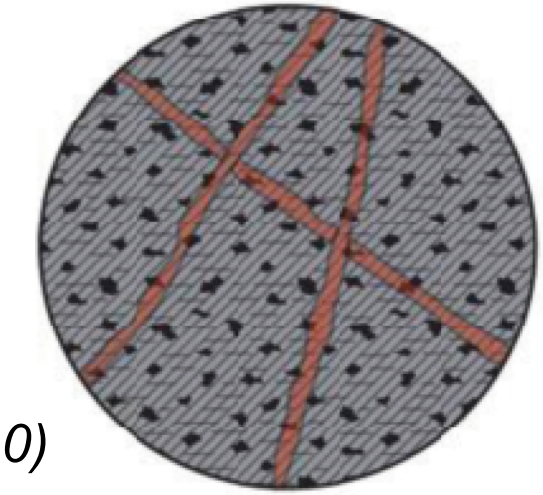
- Study mineral assemblages associated with clays → Determine T, pH, and water chemistry for fluid environments and assess habitability potential

- Sample smectite-bearing materials → Detailed analysis of biosignatures and fluid composition/origin through D/H and ^{18}O

Where?
NE Syrtis or Midway-Jezero traverse



clastic clays ?



veins and veinlets ?

Modified from Michalski et al. (2010)

EVALUATION OF LANDING SITES

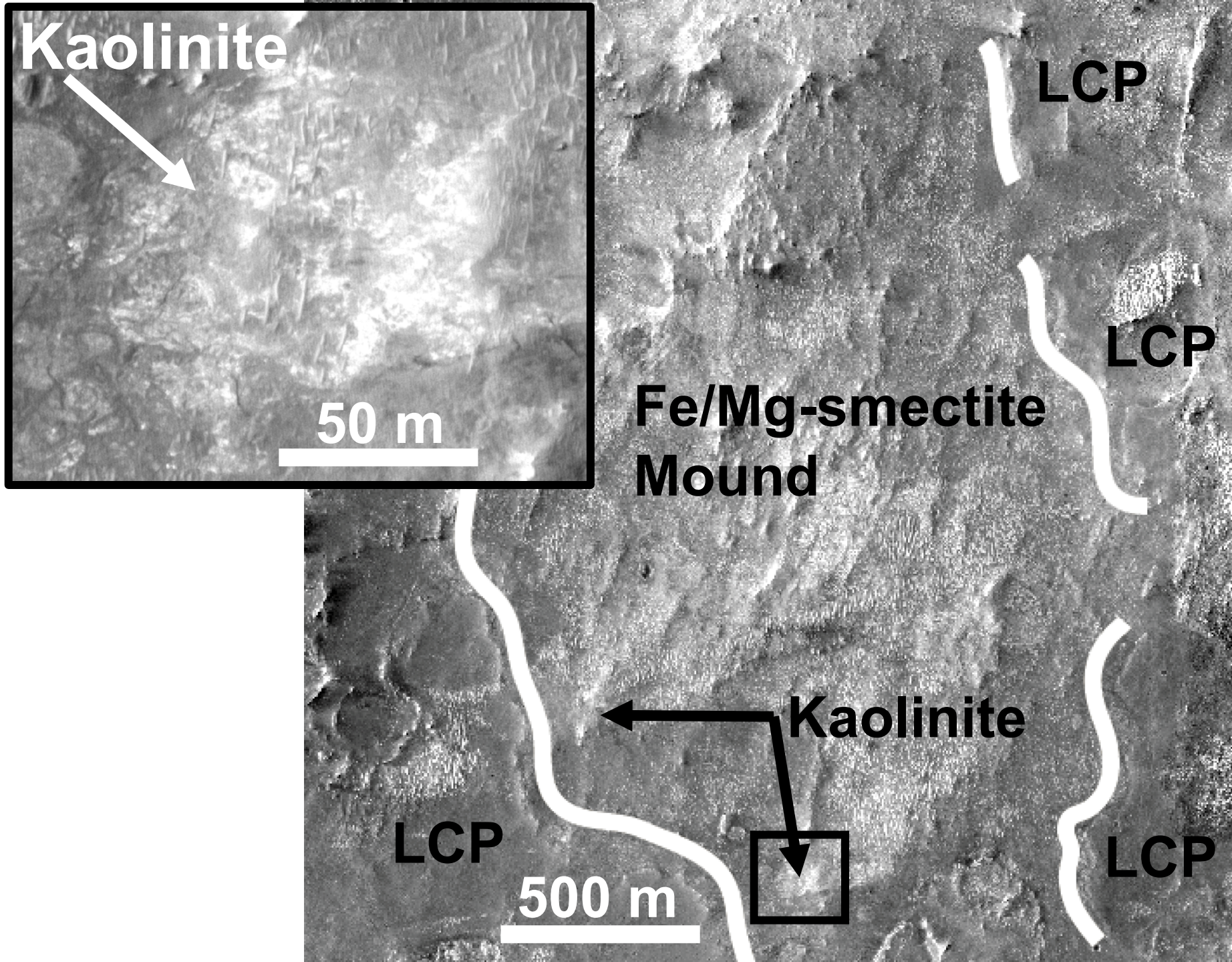
Noachian stratigraphy is only present in NE Syrtis and Midway

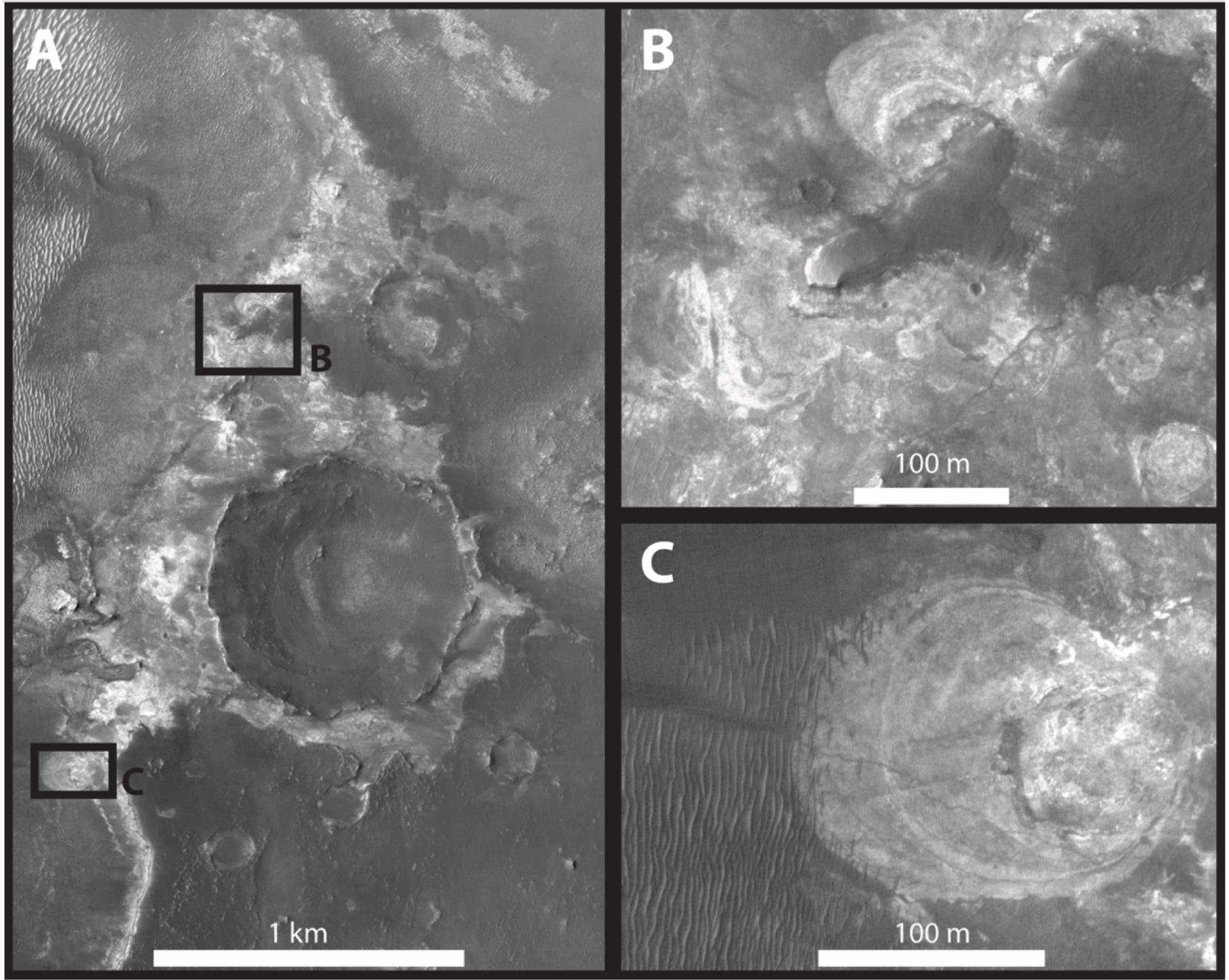
Units	NE Syrtis Ellipse	Midway Ellipse	Midway-Jezero Traverse	Jezero
Megabreccia	Present	Present	Present	Not present
Kaolinite	Present	*Unknown*	Present	Not present
Smectite Mounds	Present	*Unknown*	Present	Not present
Stratified basement	Potentially present	Potentially present	Potentially present	Not present
Ridges	Present	Present	Present	Not present
Mesas	Present	Present	Present	Not present
LCP Mounds	Present	Present	Present	Not present
BFU	Present	Present	Present	Not present

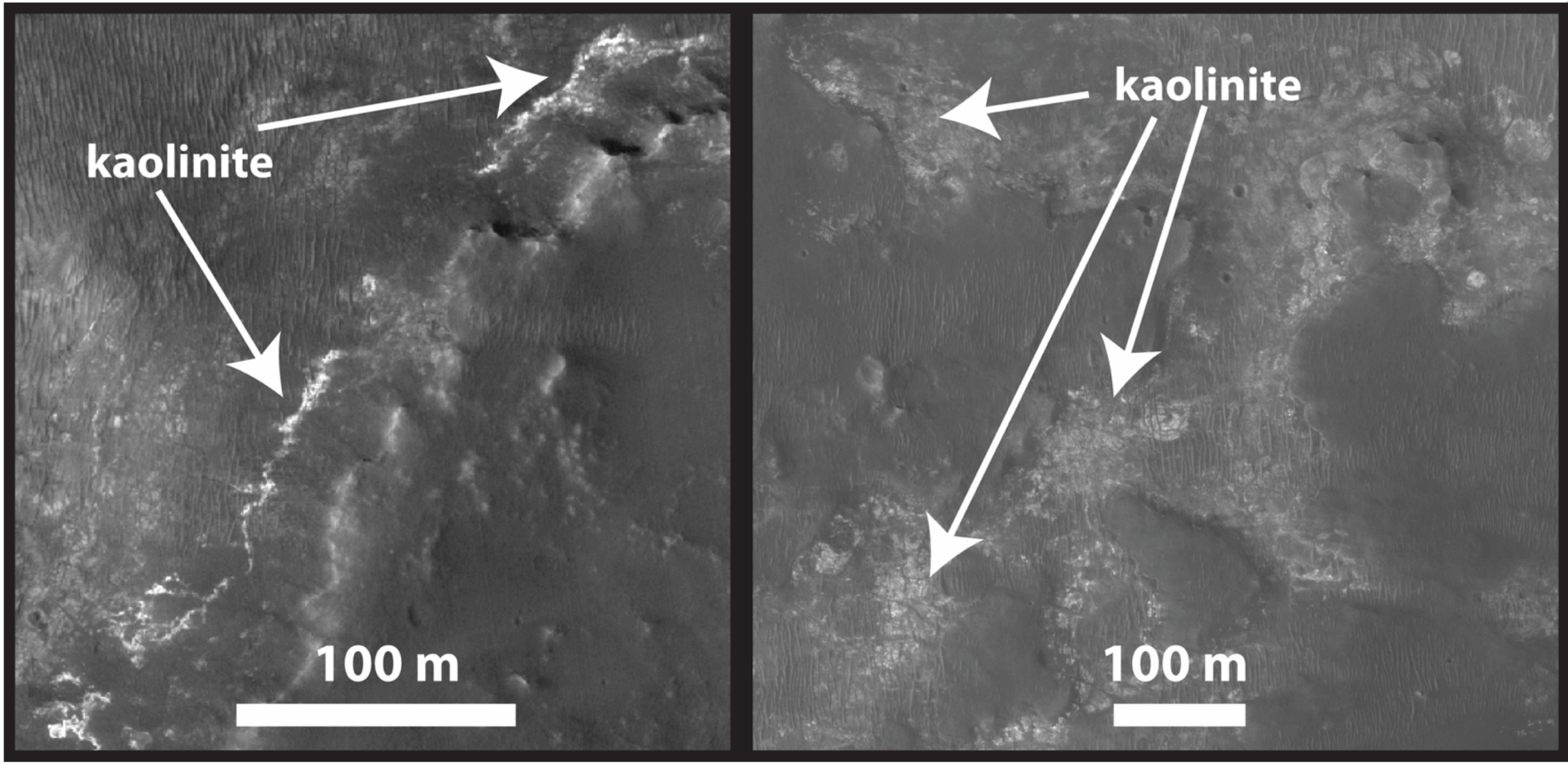
In NE Syrtis, we can sample Fe/Mg-smectite and kaolinite

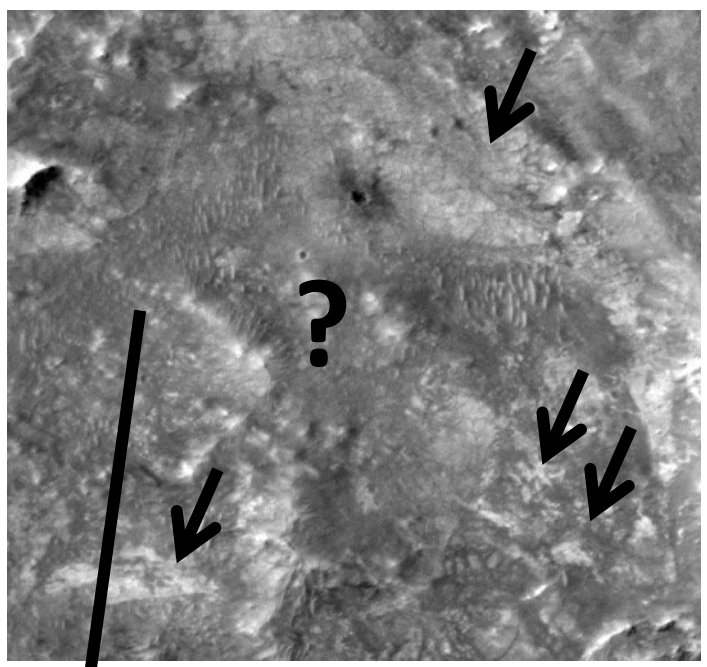
- Massive Fe/Mg-smectite: Subsurface fluid circulation or pedogenesis?

- Kaolinite: Surface alteration or hydrothermal

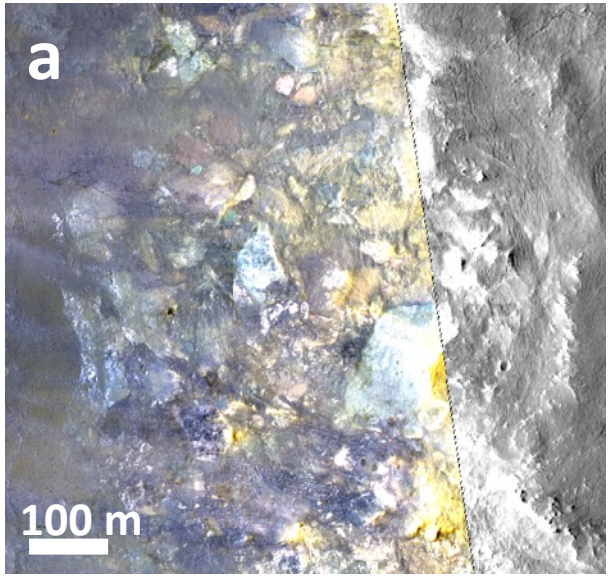


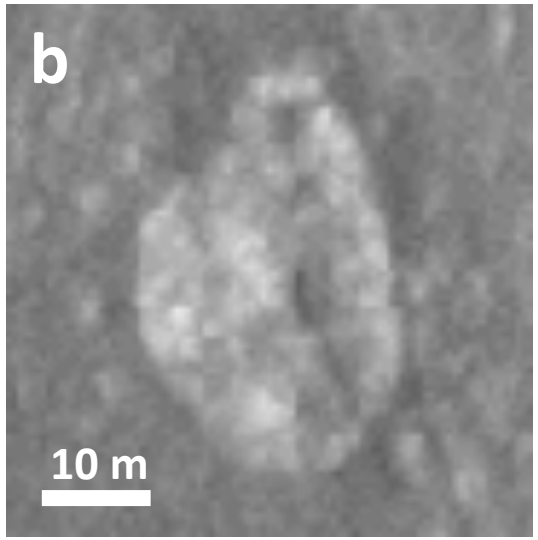

A
B
C
1 km
B
100 m
C
100 m

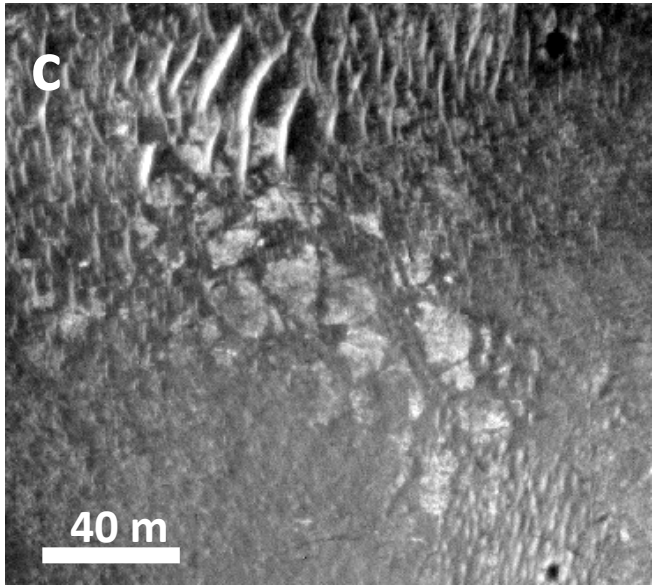

kaolinite
100 m
kaolinite
100 m

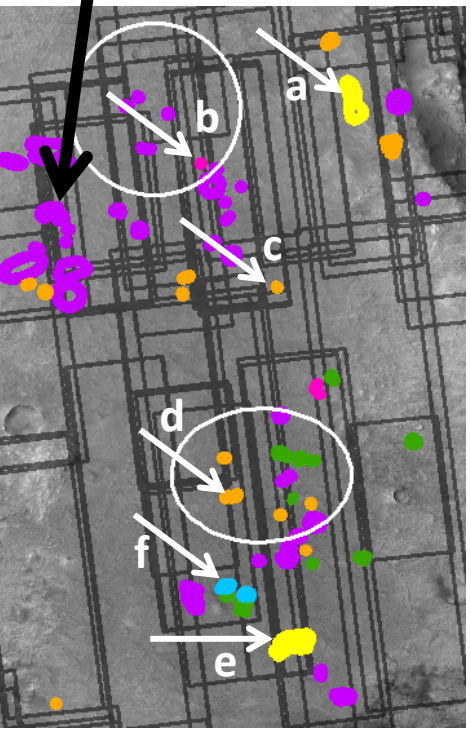


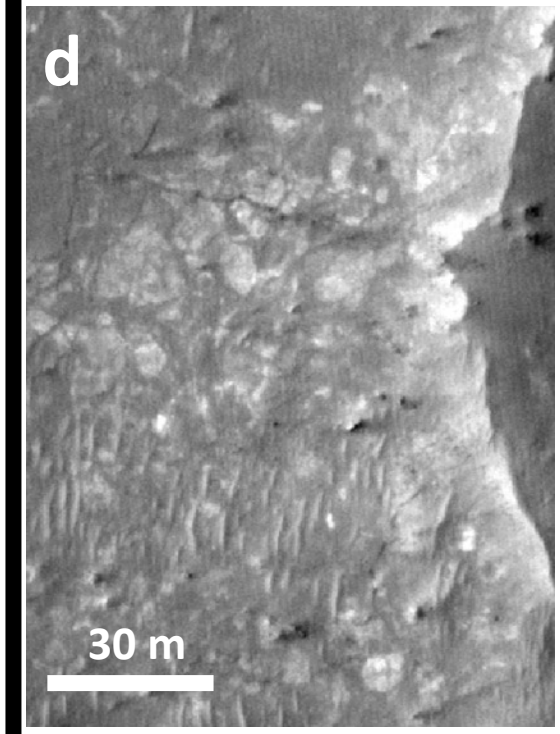
Examples of Midway Megabreccia



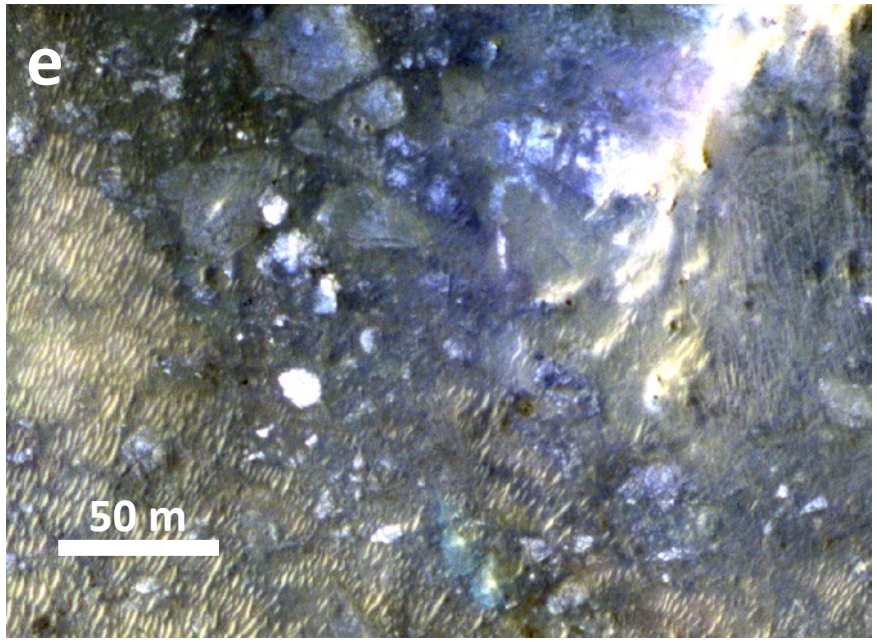


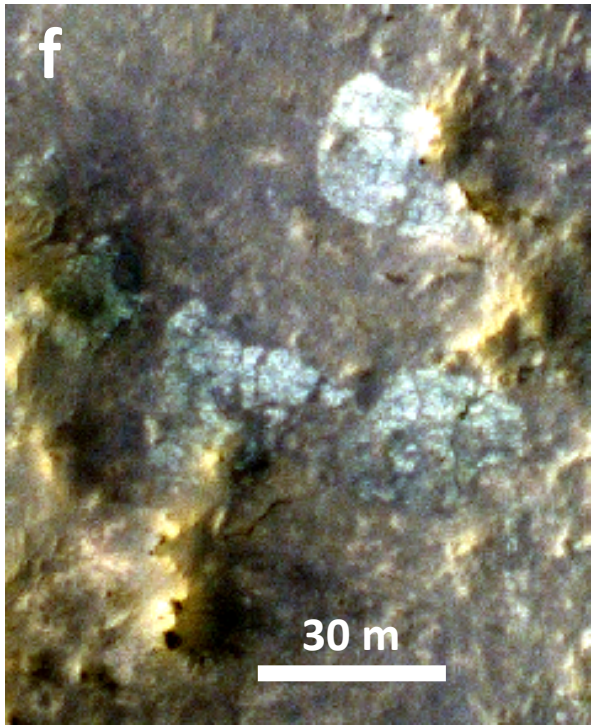
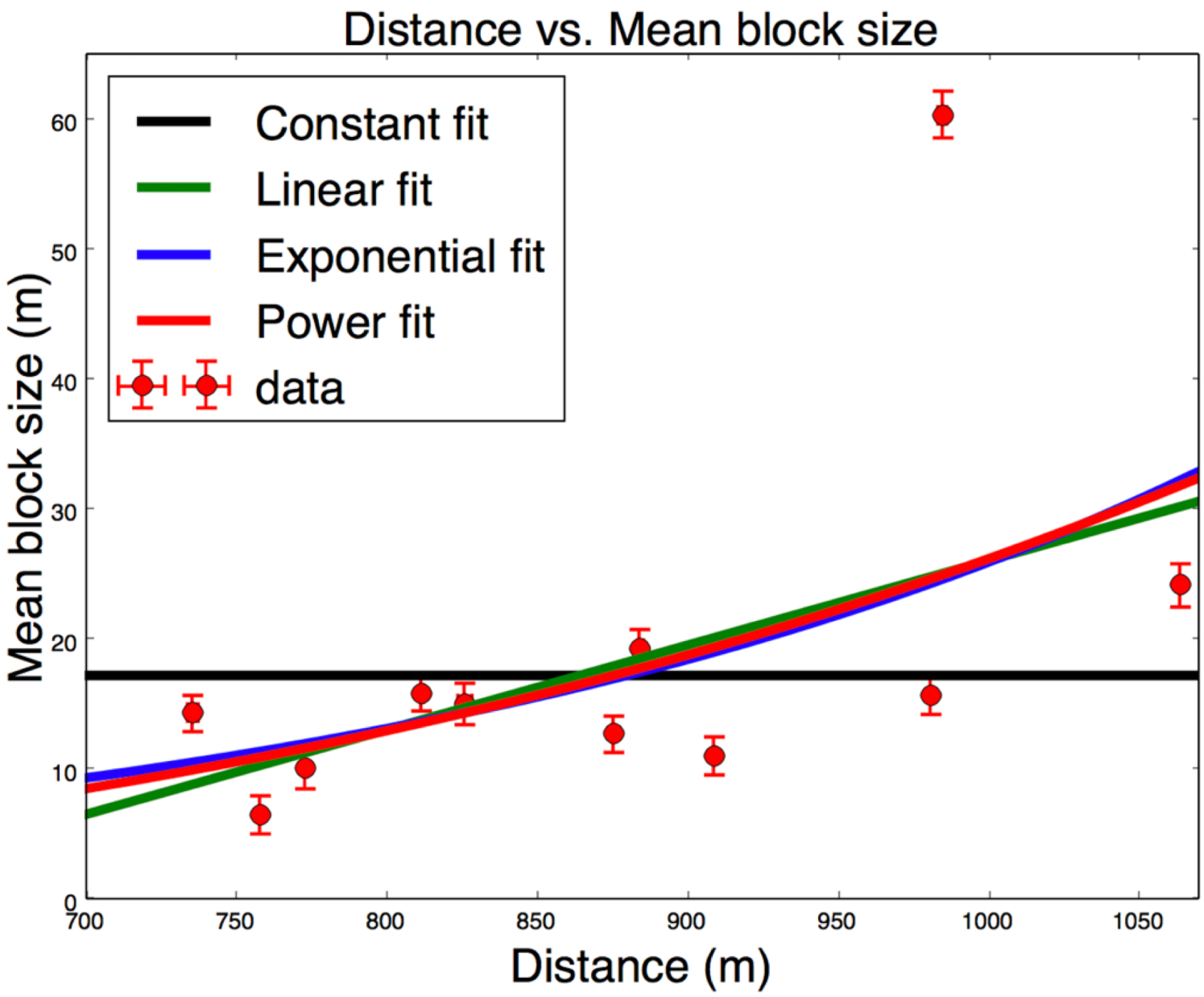






Examples of NE Syrtis Megabreccia





Megabreccia grain sizes