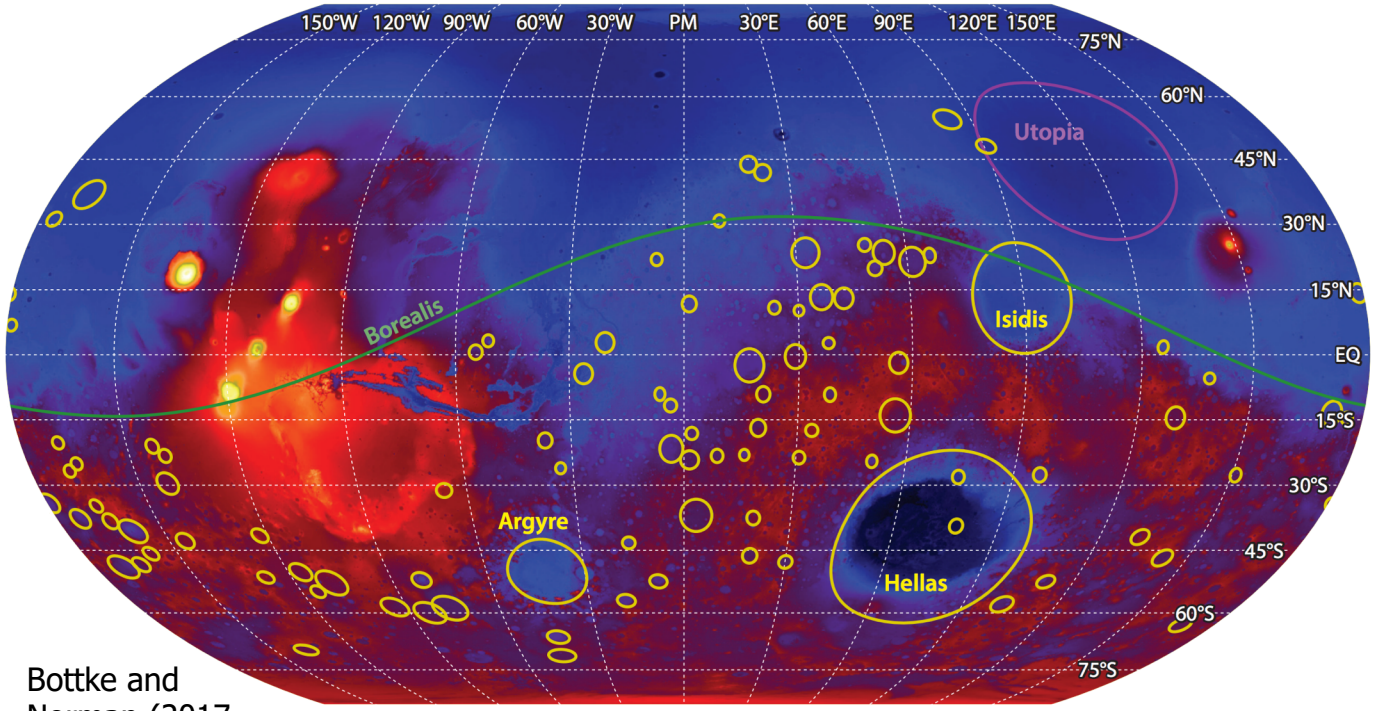
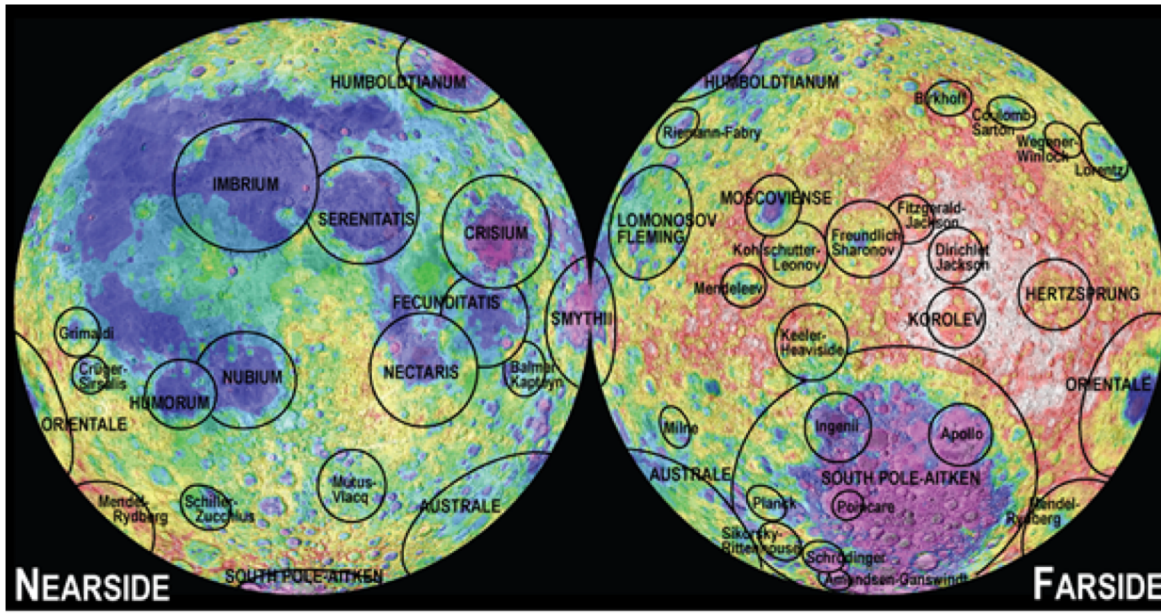


Bottke and Norman (2017, Annu. Rev.)

J.F. Mustard, M.S. Bramble, C.H. Kremer, J. Tarnas and A.C. Pascuzzo Outstanding Mars and Planetary Science Questions with Returned Samples Collected from NE Syrtis, Midway and/or Jezero Delta



Credit: LPI (Paul Spudis and David Kring)

Solar System and Rocky Planet Science

- Date basin formation on a second planet
- Determine igneous evolution and crust formation
- Magnetic field samples of a third rocky planet

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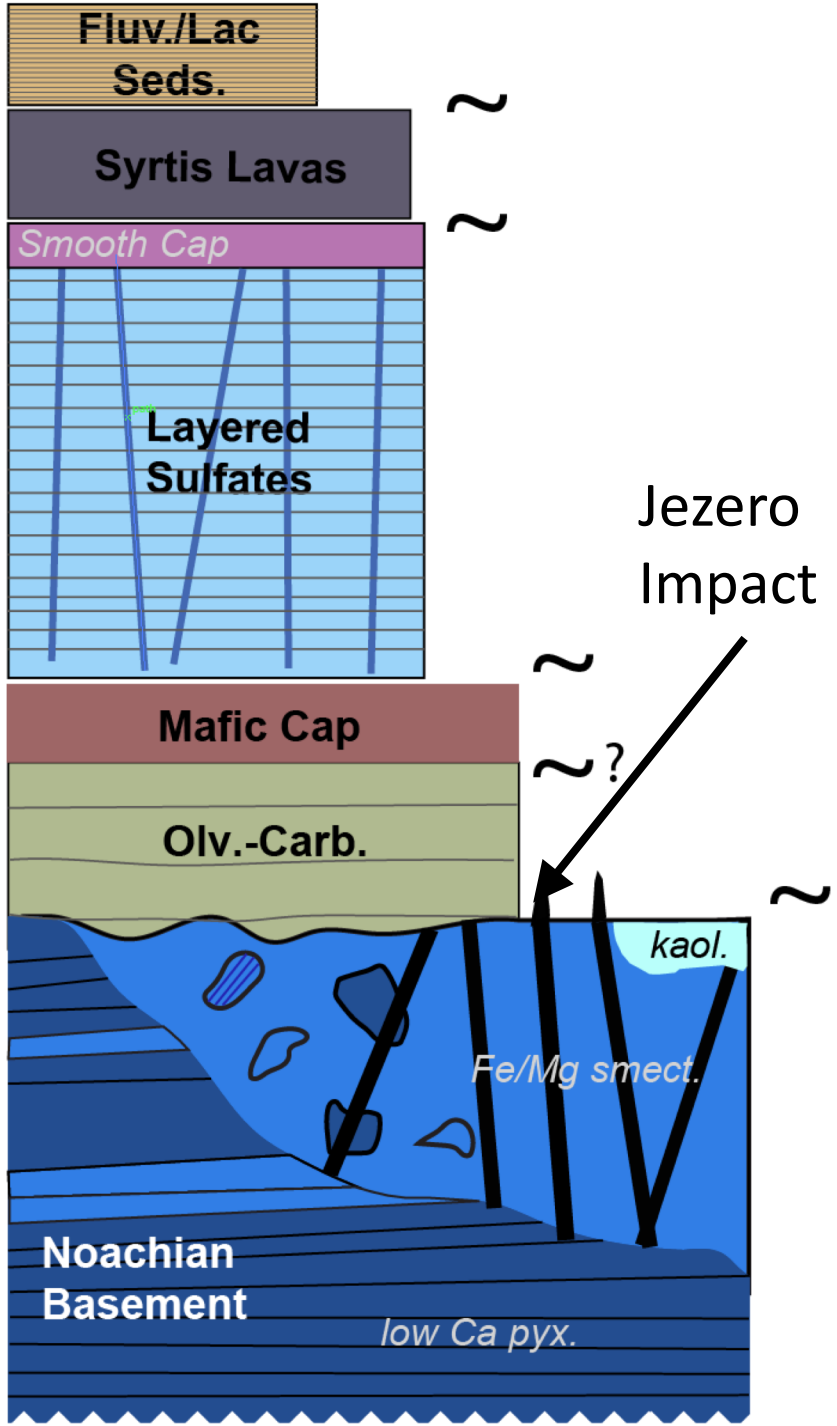
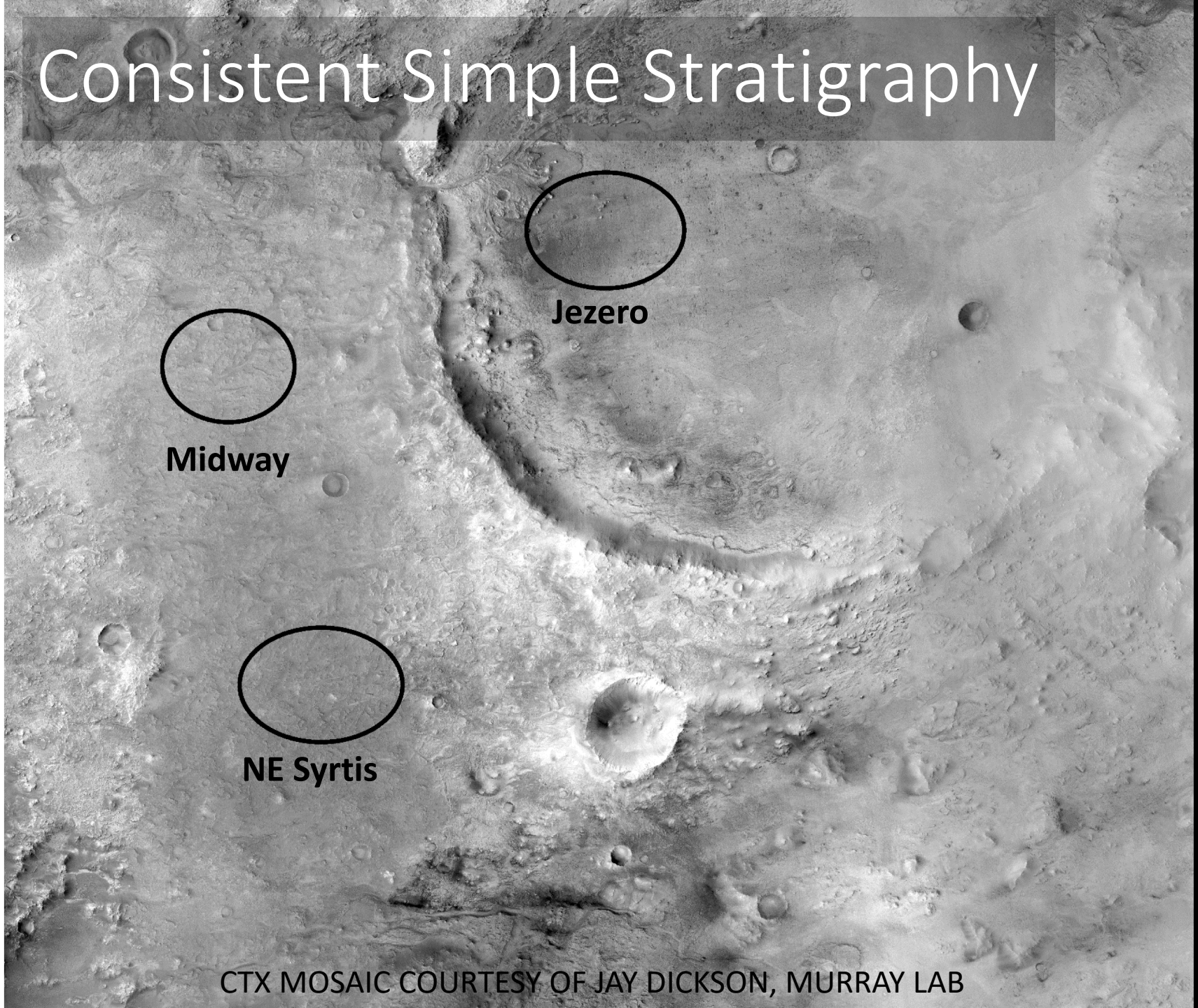
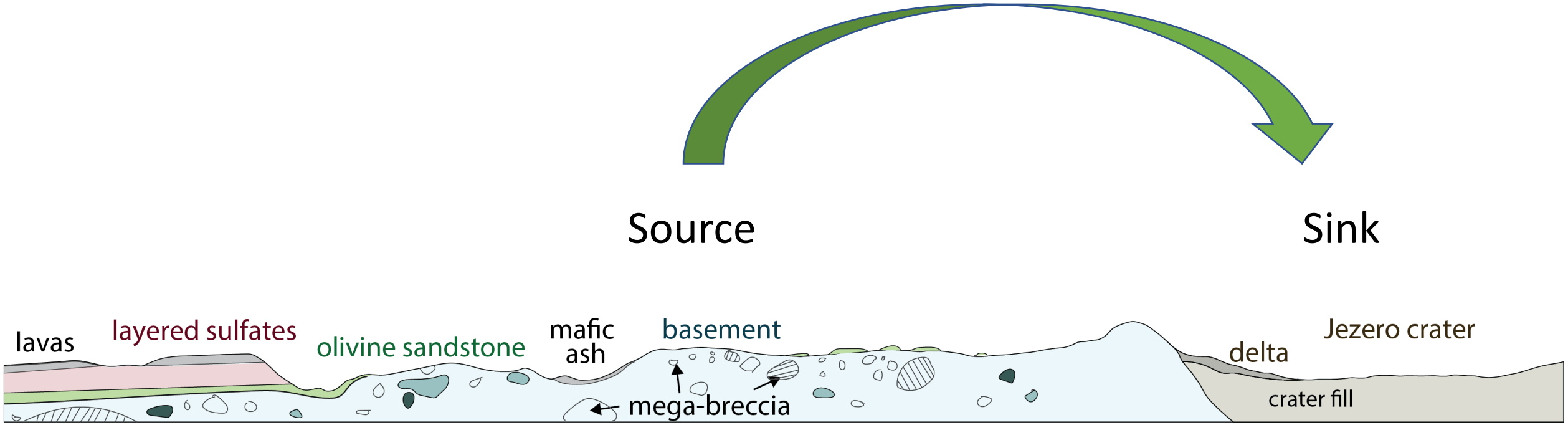
Consistent Simple Stratigraphy





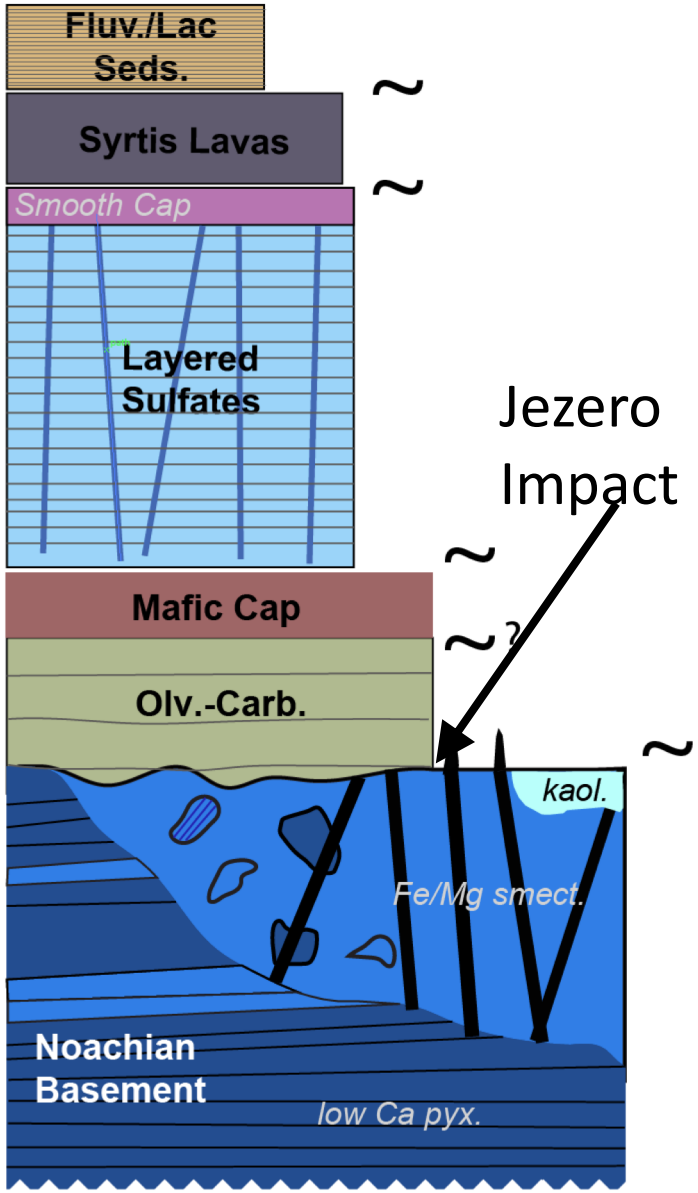
CTX MOSAIC COURTESY OF JAY DICKSON, MURRAY LAB



Bramble, Kremer, Mustard (in prep)

Compelling Fundamental Mars and Astrobiology Science

- Bedrock strata in-situ representing four distinct environments of aqueous alteration where reactants and products are together
  - early crustal: creation or distribution by impact? Phyllosilicate formation
  - carbonate/serpentine: surface alteration or hydrothermal?
  - layered phyllosilicates (Al- over Fe/Mg)
  - sedimentary sulfate formation
- Hydrothermal, pedogenic and sedimentary environments
- Multiple, diverse igneous units of distinct age
- Analysis of Noachian in situ (Midway) gives fundamental context for interpretation of Jezero sediments (see talk by Mike Bramble)



Significant Science Questions 1

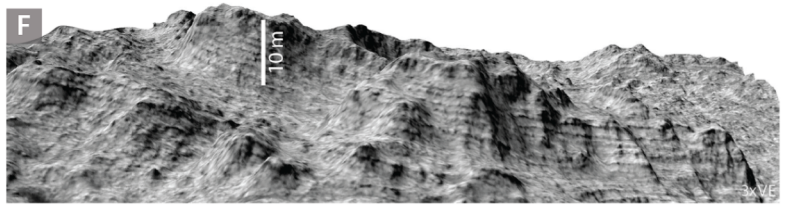
- What is the Noachian-Hesperian evolution in volcanic composition? (Fundamental change from Noachian basalts dominated by Low-Ca pyroxene to Hesperian basalts dominated by High Ca-Olivine basalts)
- What is the geologic setting and origin of the enormous olivine-bearing unit in Nili Fossae? (see talk by Chris Kremer)
- What are the ages recorded in the igneous lithologies (olivine unit, mafic igneous breccia blocks)? Seeking signatures of Borealis and Isidis basins. History of the magnetic field and origin of anomalies. (talks by Wadwah, Herd, Weiss yesterday)

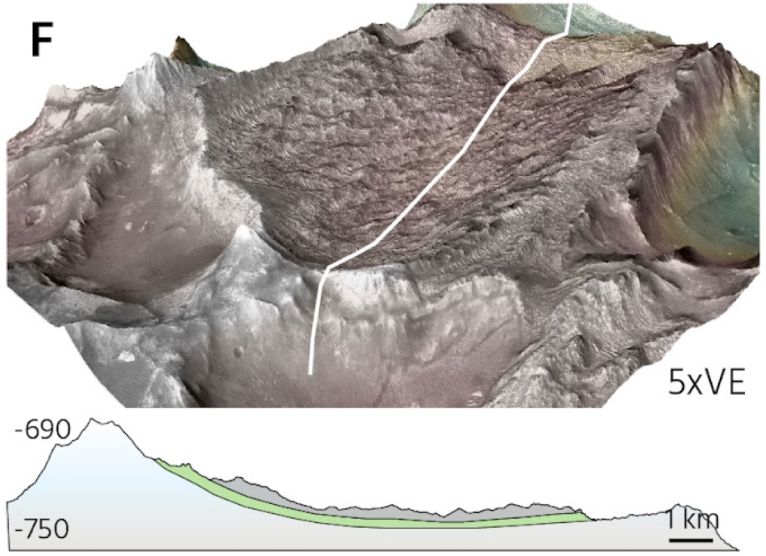
Significant Science Questions 2

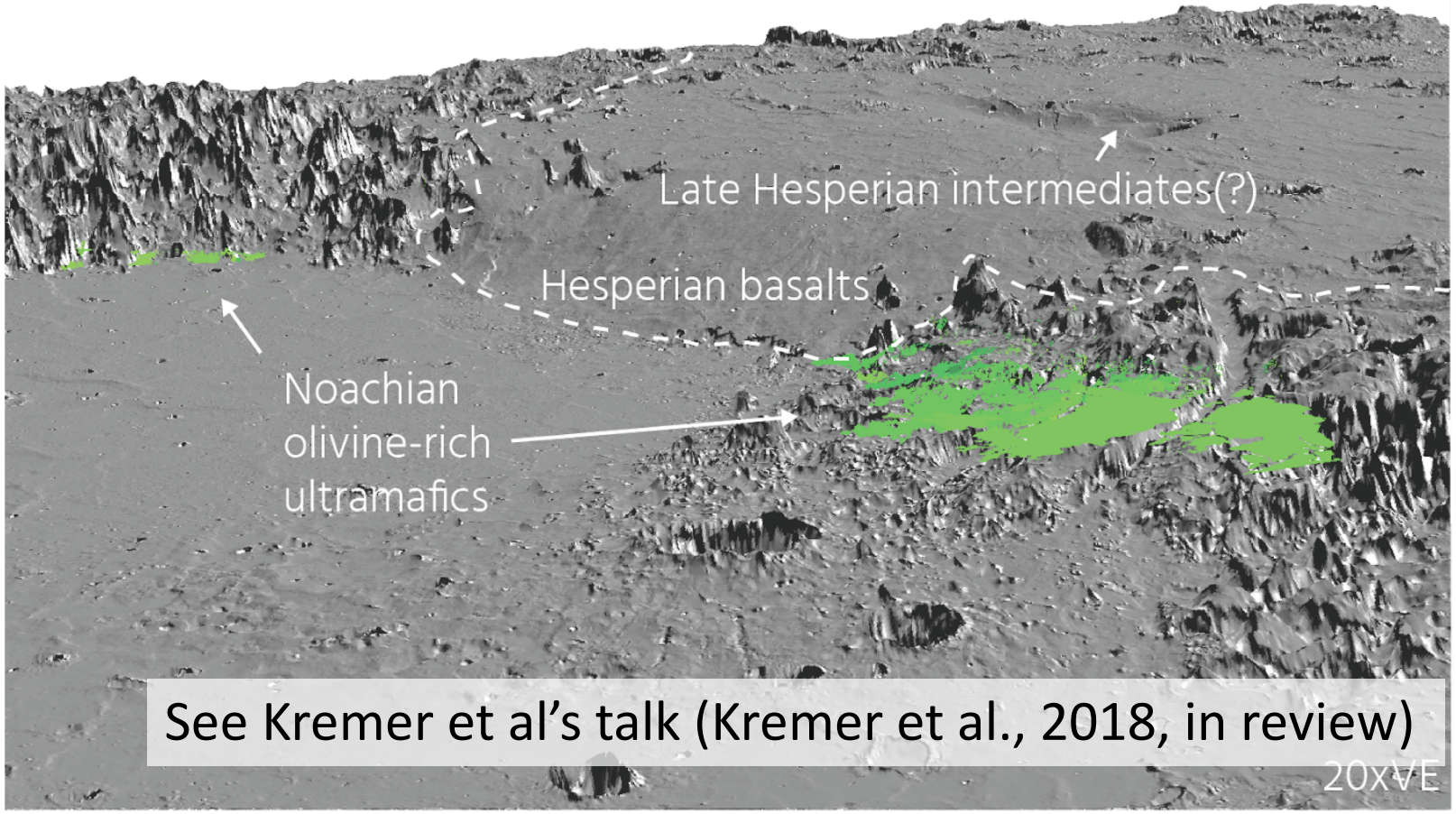
- What were the processes of carbonation leading to the formation of magnesite in association with olivine?
  - Is magnesite the only carbonate? Are other minerals found in association?
  - What is the detailed physical context for the alteration?
- Meters-high ridges exposed by erosion ripe for analysis: *In situ* composition and texture, organic surveys, returned samples for detailed investigation
- What is the redox state of Noachian phyllosilicate-bearing basement?
- Seek minerals associated with redox reactions and traces of carbon and diagnostic biosignatures in ridges and basement rocks. (see Onstott's talk)

Detailed physical and chemical character of banded olivine

Volcanic flows, impact melt or precipitates, eolian deposits, airfall clastic of volcanic origin)

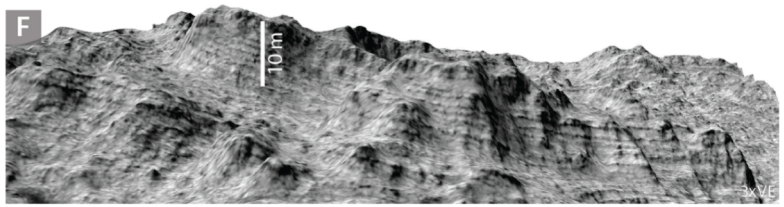


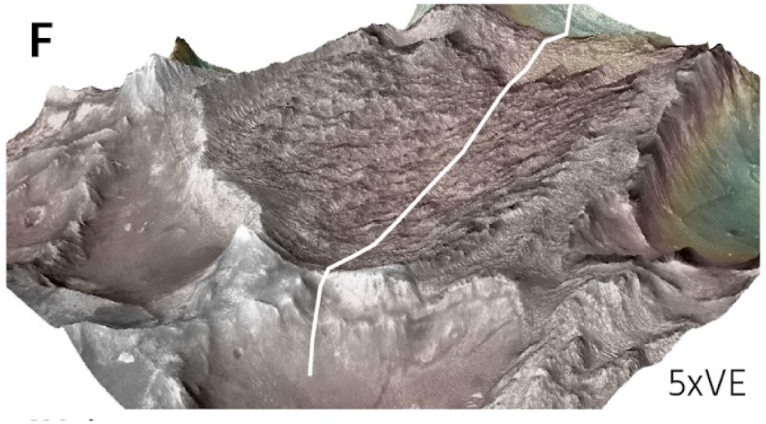




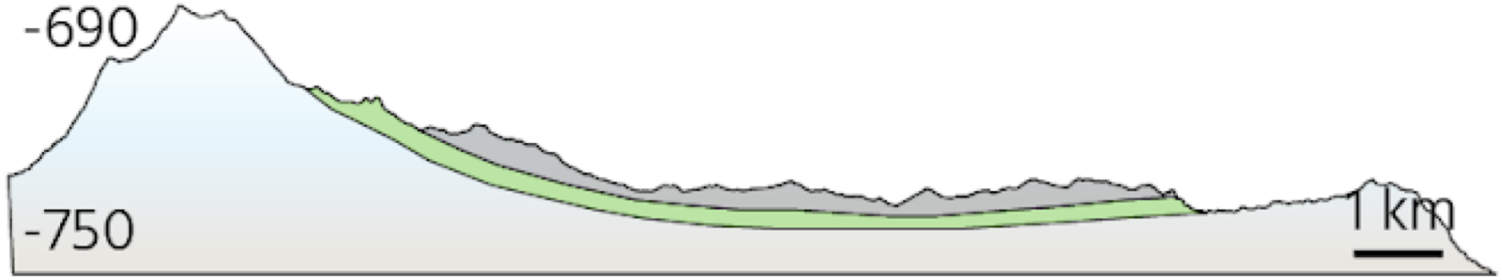
See Kremer et al's talk (Kremer et al., 2018, in review)

Mars 2020 In situ Measurements of Banded Olivine





- Olivine grain size: modeled as 1 mm
  - Airfall ash, volcanic tephra, eolian, other clastic processes (e.g. Rogers et al., 2018)
- Chemical composition of the olivine
- Texture of olivine host:
  - crystal igneous, angular clastic, rounded clastic



(Kremer et al., 2018, in review)

Mars 2020 In situ Measurements of Banded Olivine

Road cut through tephra Izu Oshima, Japan showing bedding and structures.

- Olivine grain size: modeled as 1 mm
  - Airfall ash, volcanic tephra, eolian, other clastic processes (e.g. Rogers et al., 2018)
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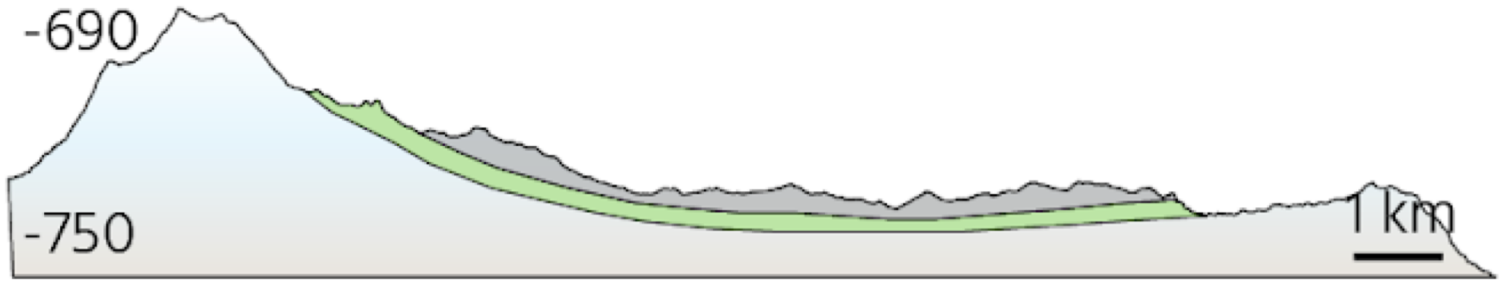
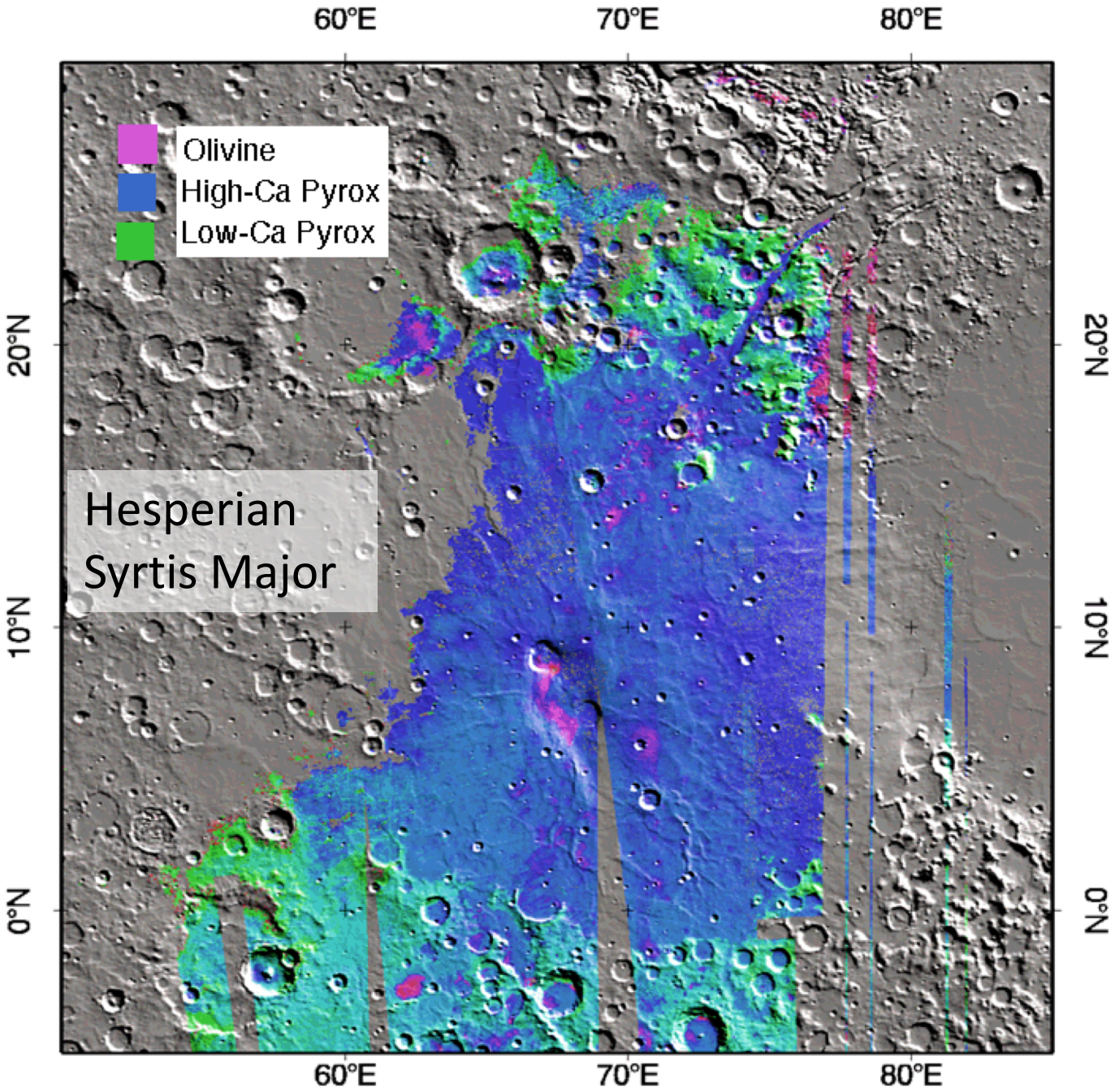


(Kremer et al., 2018, in review)

Ancient Crust

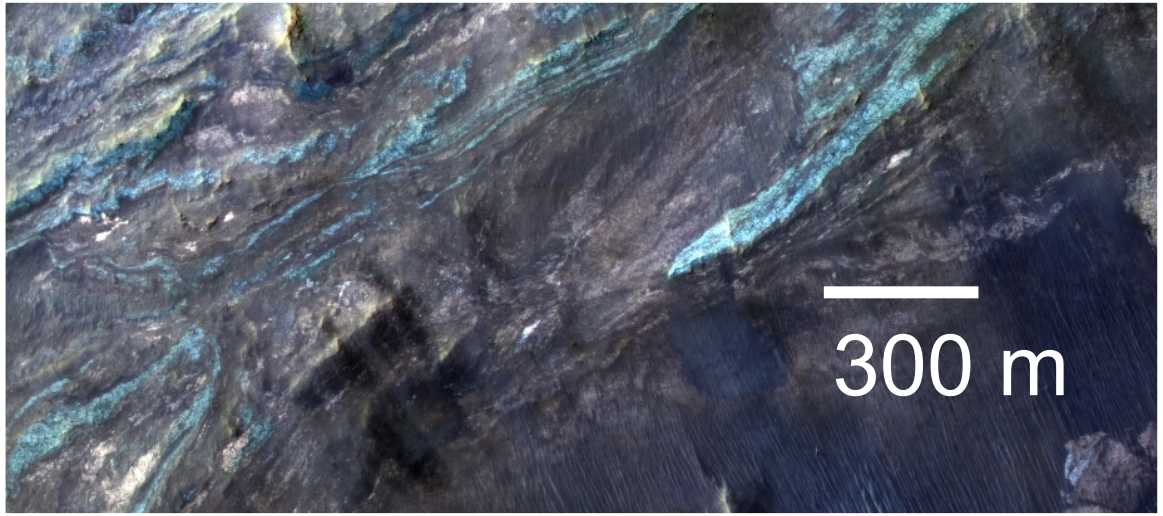
- Visible-infrared data show Noachian surface rocks and many central peaks are enriched in Low Calcium Pyroxene (LPC) compared to Hesperian surface rocks
- Why is that? What does it tell us about planetary evolution and comparative planetology?
- Low hanging fruit for Mars 2020 *in situ* and returned sample science



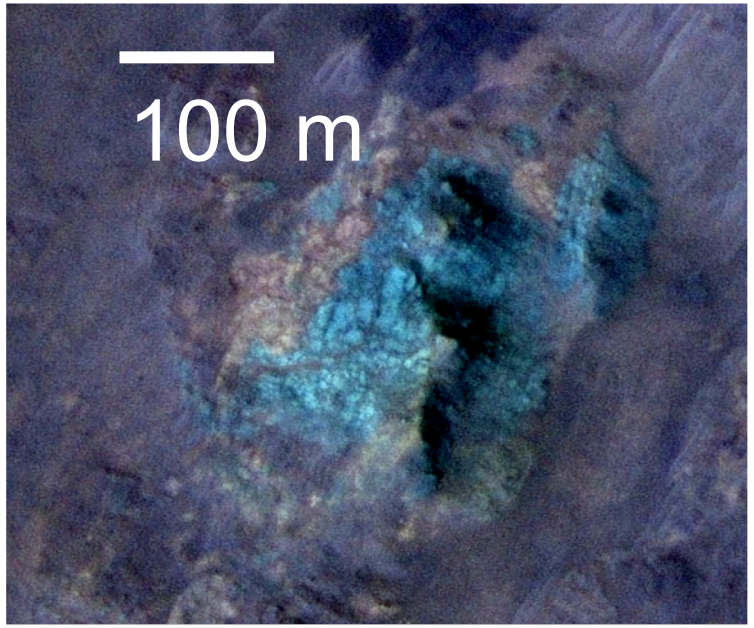
OMEGA data processed by JF Mustard, Mustard et al., 2005)

Ancient Crust

- *In Situ* analysis and collection of unaltered igneous samples from the megabreccia (Scheller, this meeting)
- Primary crust from magma ocean (e.g. Elkins-Tanton et al., 2008), Noachian volcanic crustal formation or crustal magmatism
- Baratoux et al. 2013 modeling of a cooling mantle predicts systematic change from low-Ca pyroxene (Noachian) to High-Ca pyroxene (Hesperian)
  - Test the hypothesis by measuring the mineralogy and chemistry in situ of the LCP-rich blocks and other mafic igneous rocks
  - Texture of the rock with SHERLOC used to assess Plutonic vs Volcanic!
- *In situ* and returned samples from the Noachian from the Midway to Jezero traverse will shine a unique perspective on rocky planets



LCP-enriched mafic rock Phyllocilicate-bearing rock

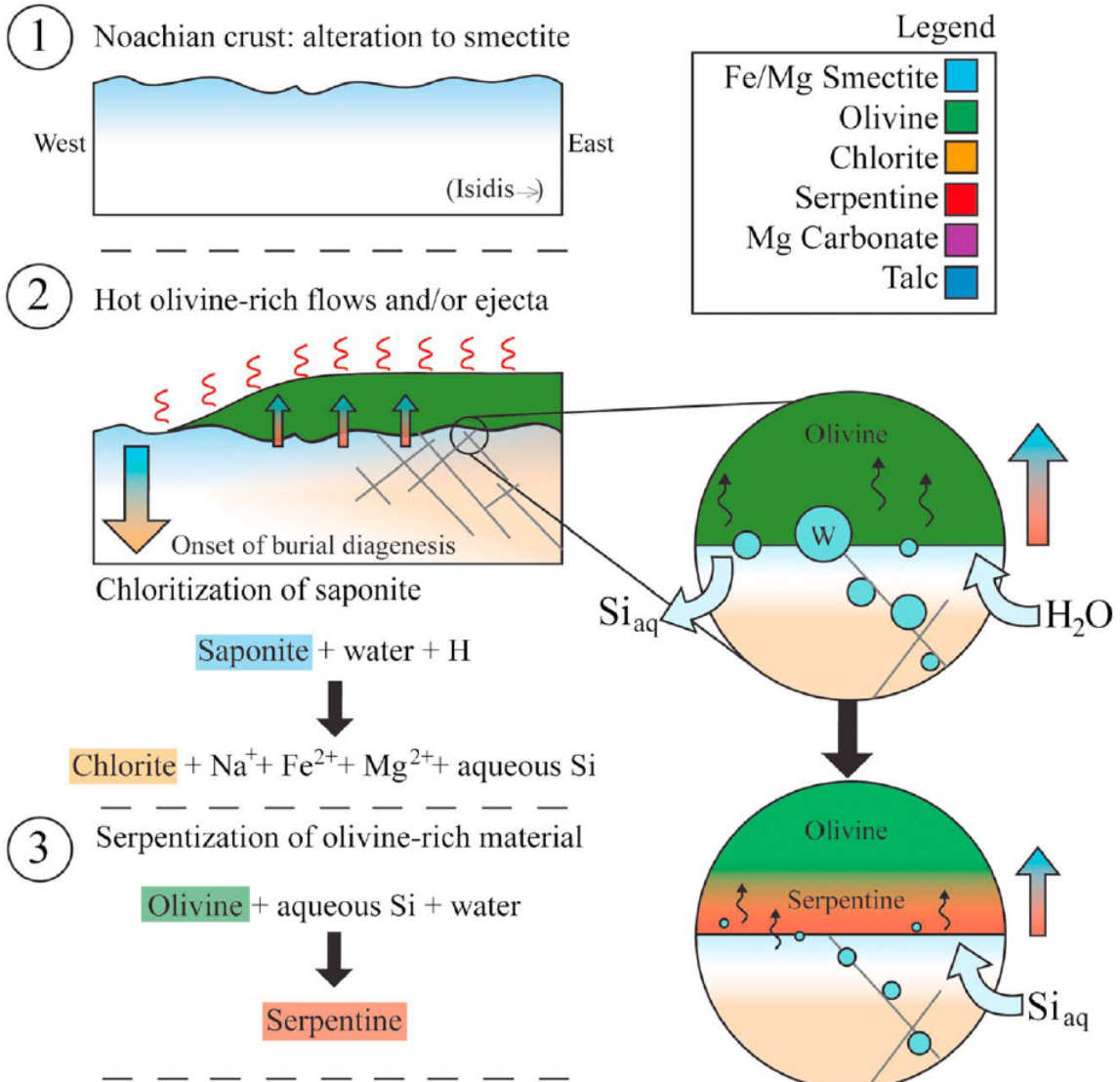


Hypotheses Proposed for Mg-Carbonate (Magnesite) Deposits in Nili Fossae

- Near-surface aqueous weathering
- Serpentinizing hydrothermal system
- Deep hydrothermal convection cells
- Aqueous alteration in a metamorphic setting
- Sedimentary/lacustrine deposits within ultramafic catchments

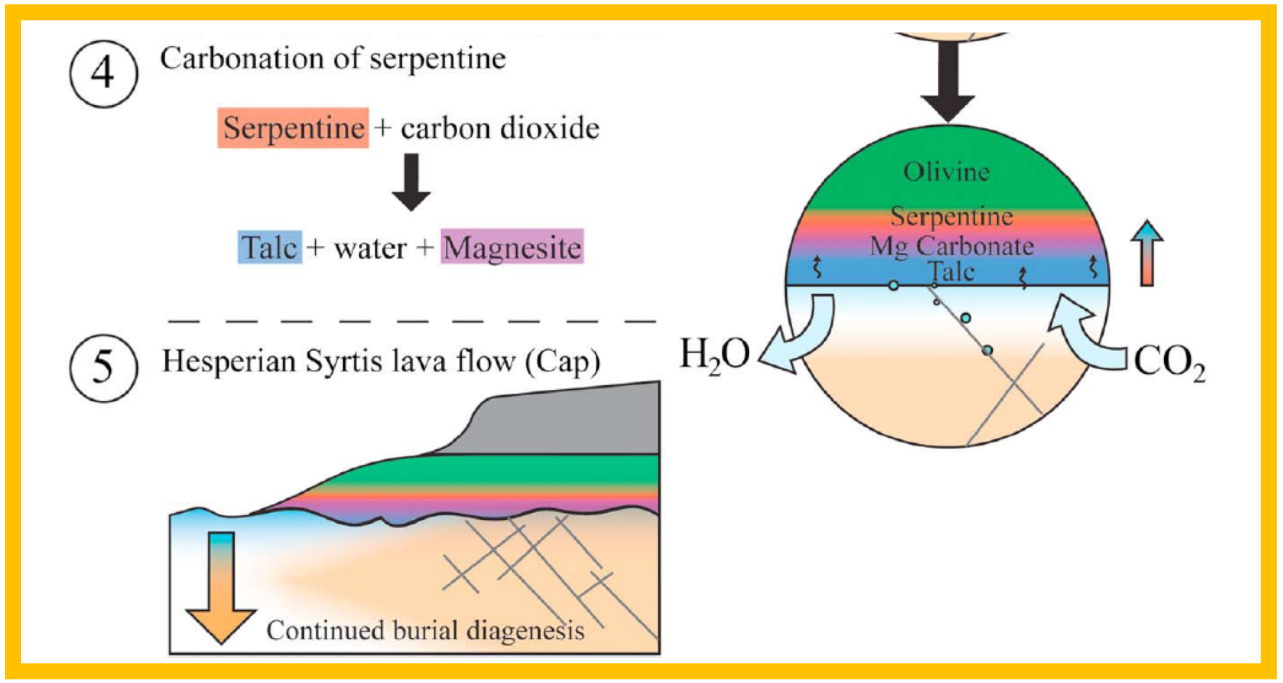
Carbonate – Phyllosilicate Stratigraphy / Formation

Hypothesis 2, favored by Brown et al., 2010, Viviano et al., 2013

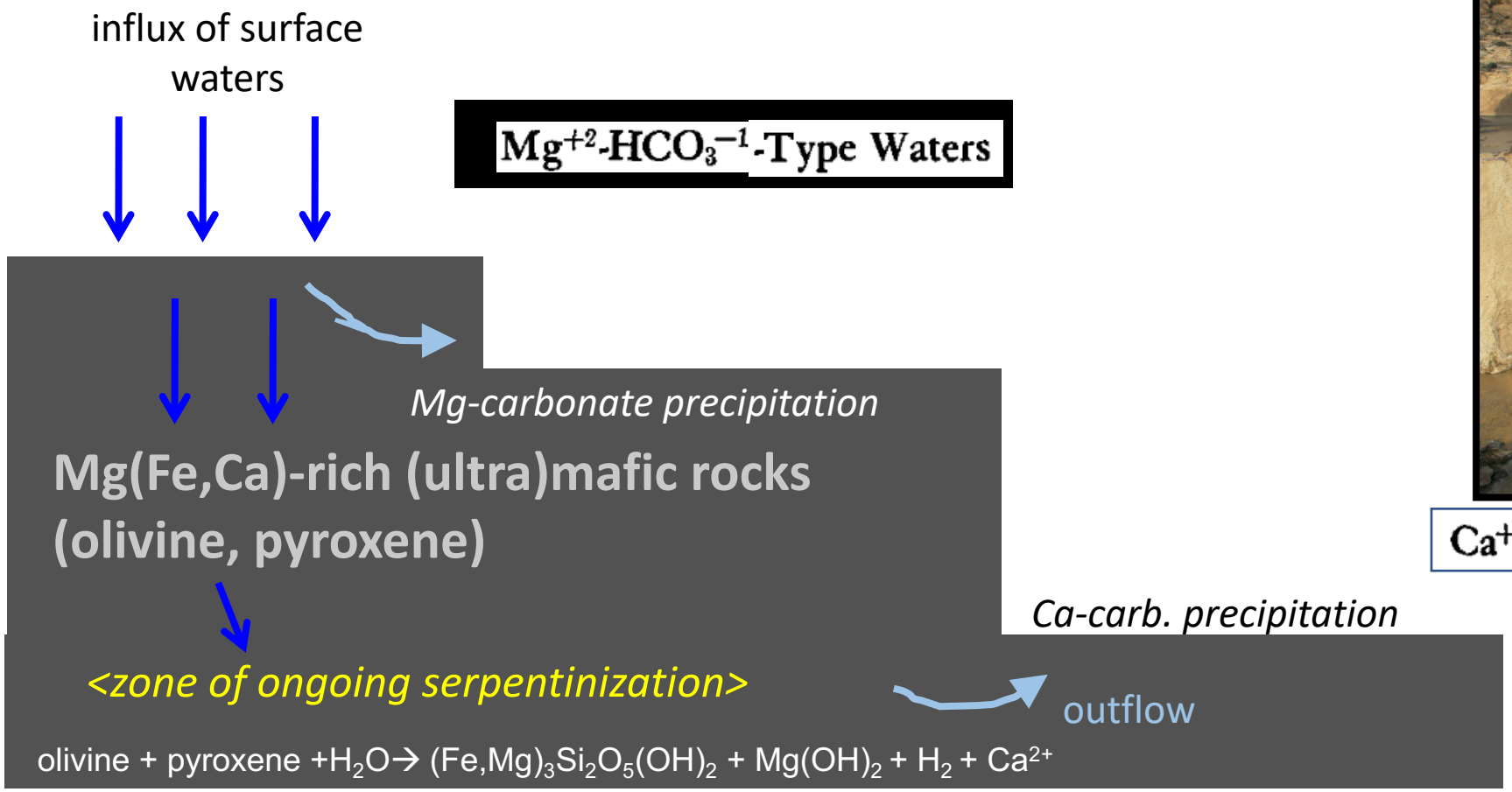


Viviano et al., 2013

- Top-down hydrothermal alteration of crust results in olivine > serpentine > magnesite > talc stratigraphy.



Zones of Low-Temperature (15-50ºC) Serpenitinization and Tracing the Process through Carbonate Chemistry



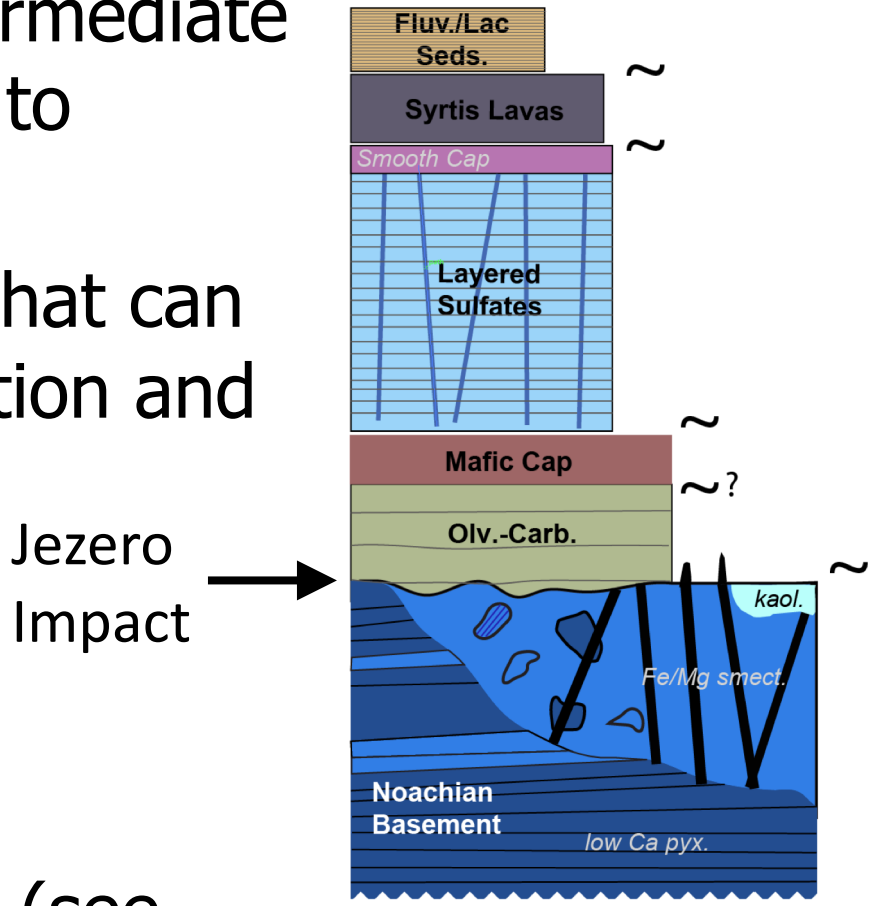
process described further in *Barnes & O'Neil, 1969*

Kelemen & Matter, 2008; Streit et al., 2012 describe Oman deposits

What was the Process of Carbonation of Olivine?

$$Mg_2SiO_4 + 2H_2O + 2CO_2 \rightarrow 2MgCO_3 + H_4SiO_4$$

- Multiple reaction pathways with different intermediate products (e.g. talc, serpentine): critical input to hypothesis testing
- Pathways will leave a trail in the mineralogy that can be tested with Mars 2020 in situ instrumentation and with returned samples
- We observe
  - Magnesite always with olivine
  - Serpentine etc. is rare
- Significant liberation of SiO_2: what is its fate? (see Tarnas' Talk for possible detections)



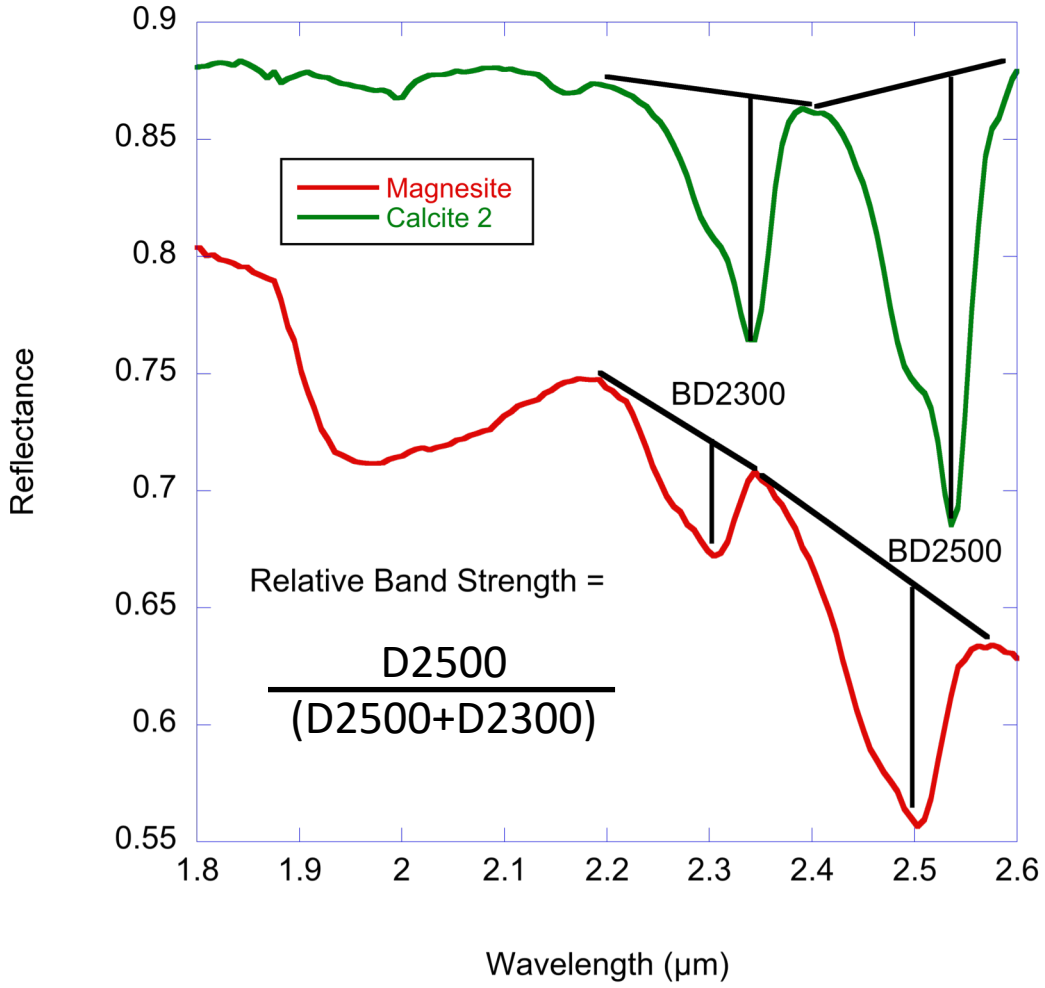
Quantifying Carbonate Absorption Bands

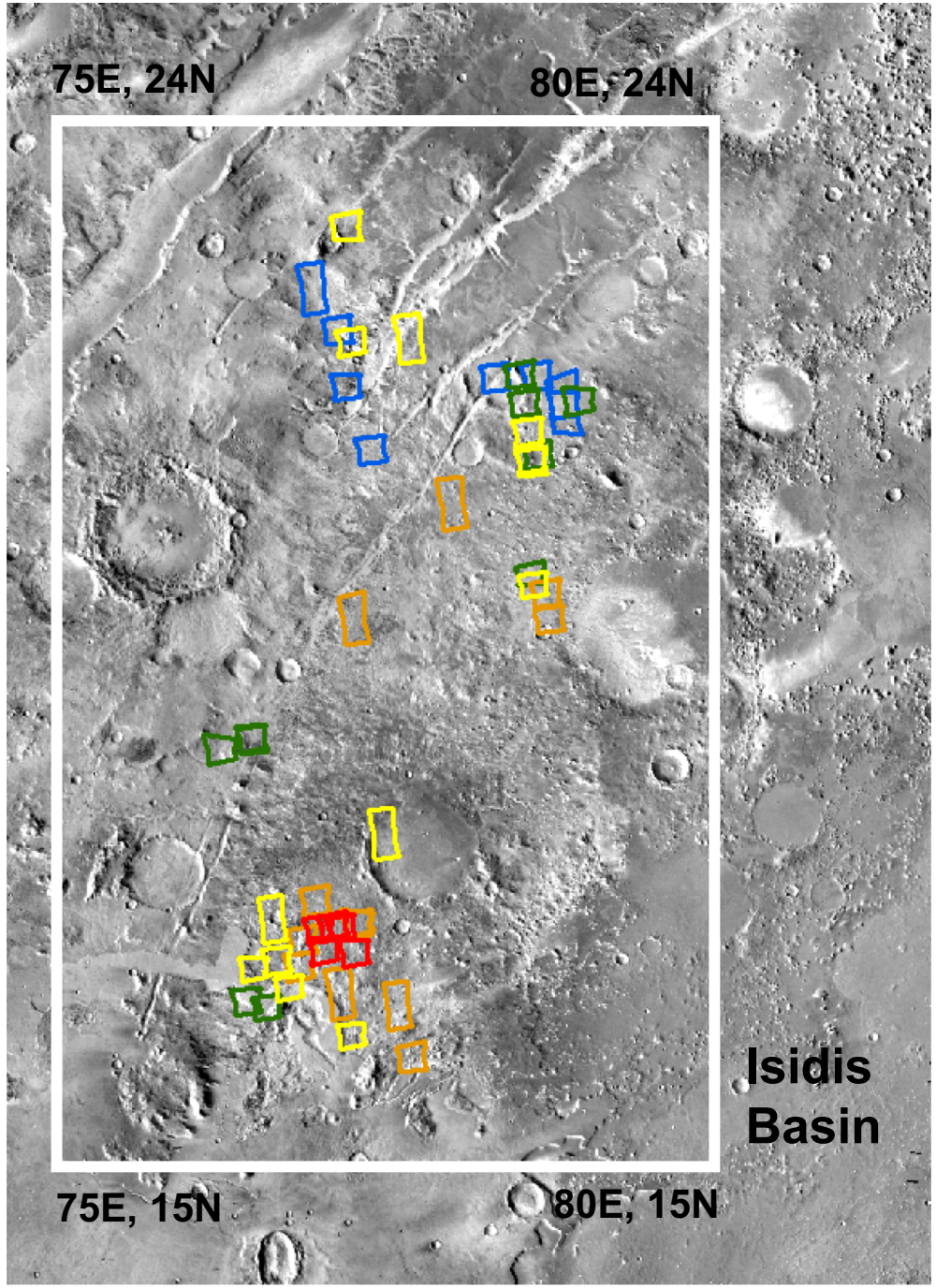
- The presence of carbonate is strongly indicated by the paired absorptions at 2.3 and 2.5 µm
- Fe-Mg Phyllosilicates have 2.3 µm band but no 2.5 µm band

Normalized Carbonate Doublet ratio using band strengths of absorptions at 2300 and 2500 nm

$$\frac{D2500}{(D2500+D2300)}$$

Large ratio: more pure carbonate





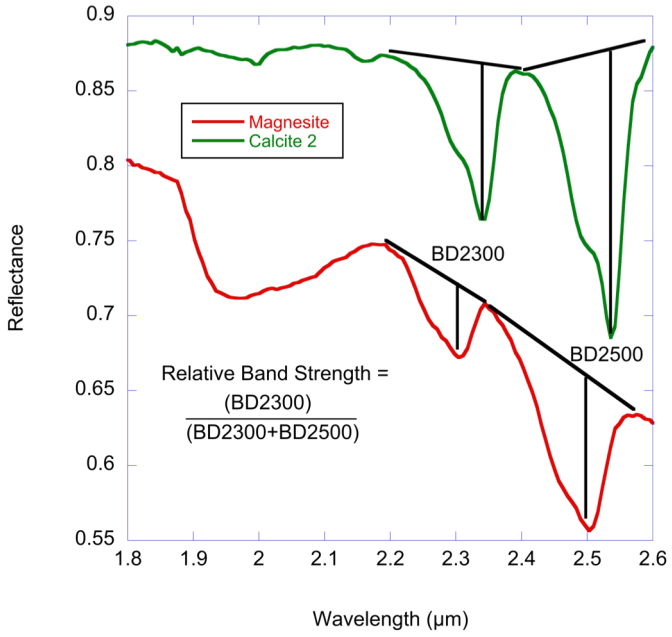
Normalized Carbonate Doublet ratio

$$\frac{D2500}{(D2500+D2300)}$$

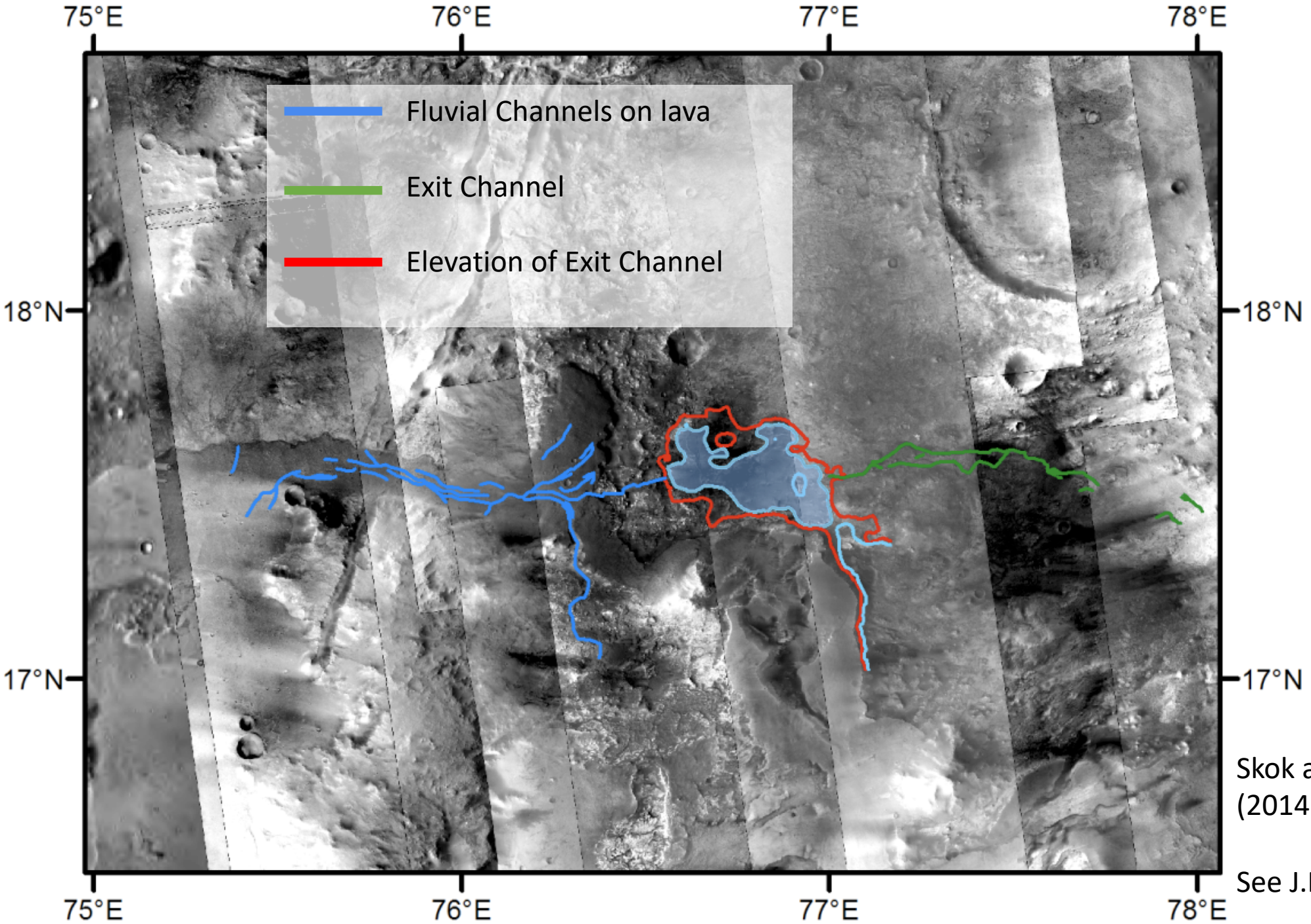
Large ratio: more pure carbonate

$$\frac{D2500}{(D2500+D2300)}$$

- 0.30 – 0.35
- 0.35 – 0.40
- 0.40 – 0.45
- 0.45 – 0.50
- 0.50 – 0.55



Midway to Jezero provides exceptional in situ and returned sample science



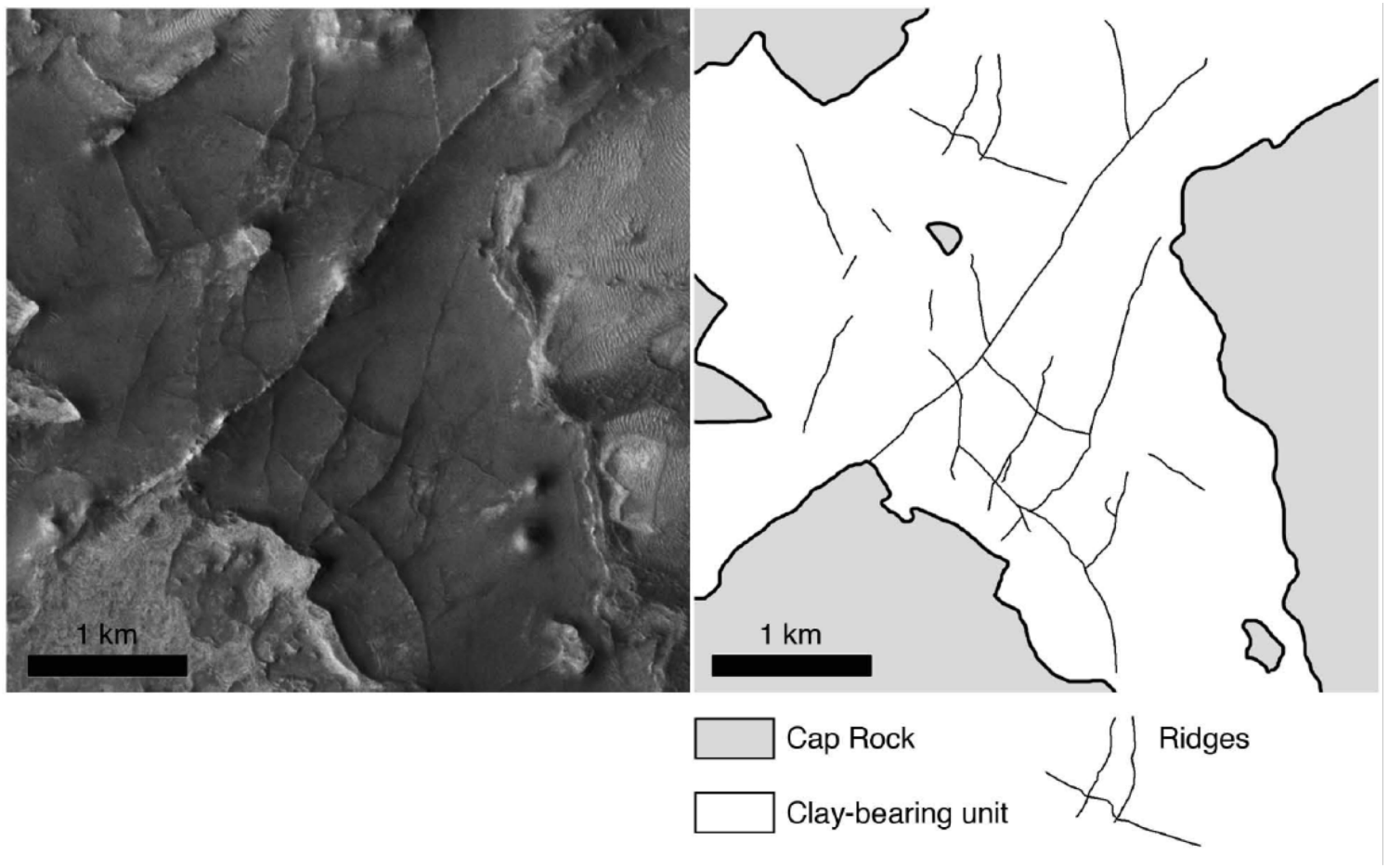
Skok and Mustard, (2014)

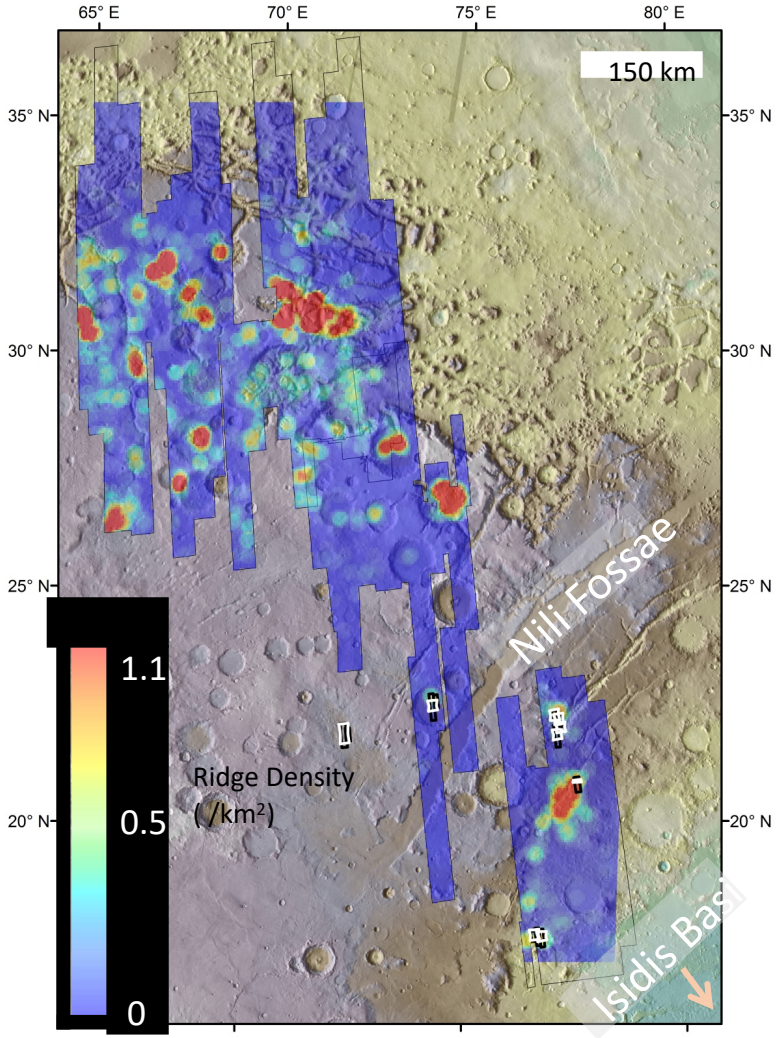
See J.R. Skok's talk

Mg-Carbonate Deposits in Nili Fossae At the Noachian-Hesperian Boundary

- Magnesite-Olivine assemblage traverses 5 km of vertical relief
- The prevalence of carbonate increases towards lower elevations and with fluvial systems
- Carbonate is present in deltaic deposits but not in other mobile units (i.e. dunes)
- In Situ investigation needed to resolve exact formation processes, returned samples for biosignature investigation
- Formation hypotheses covered in Amador's presentation

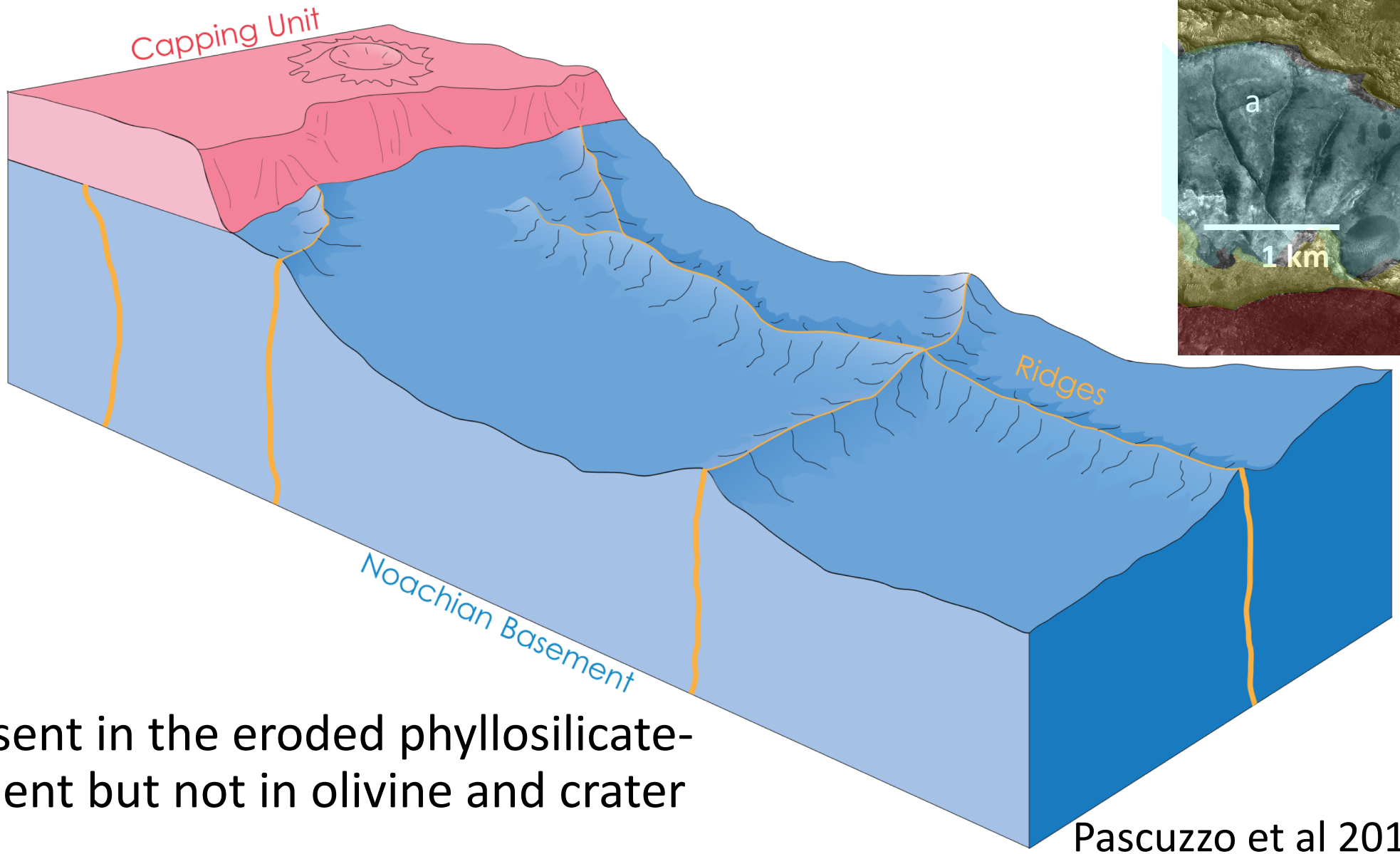
Meters High Ridges Exposed by Erosion

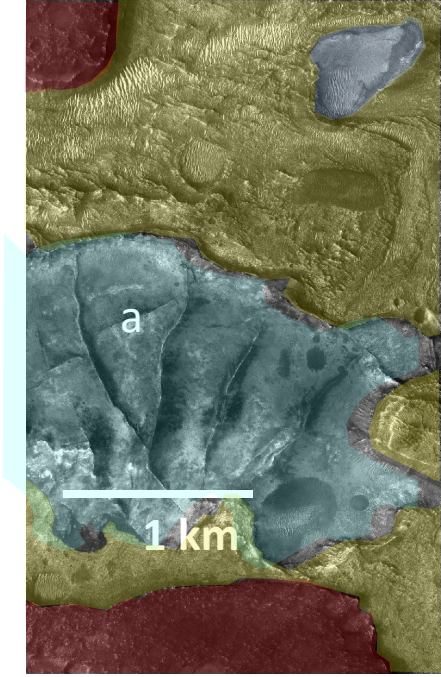




Pascuzzo et al 2018

Timing of Emplacement of Erosionally Resistant Ridges





Ridges are present in the eroded phyllosilicate-bearing basement but not in olivine and crater retaining units

Pascuzzo et al 2018

Formation Mechanism

Aqueous / Hydrothermal & Sedimentary Processes

- Aqueously altered magmatic intrusions or volcanic fill

  Kerber et al. (2017)

- Fractures acting as conduits for fluid and sediment flow to form mineralized veins.

  Mangold et al. (2007) Saper & Mustard (2013)

Igneous & Impact Processes

- Injection of host rock clasts, impact melt, &/ impact glasses into fractured host from impacts

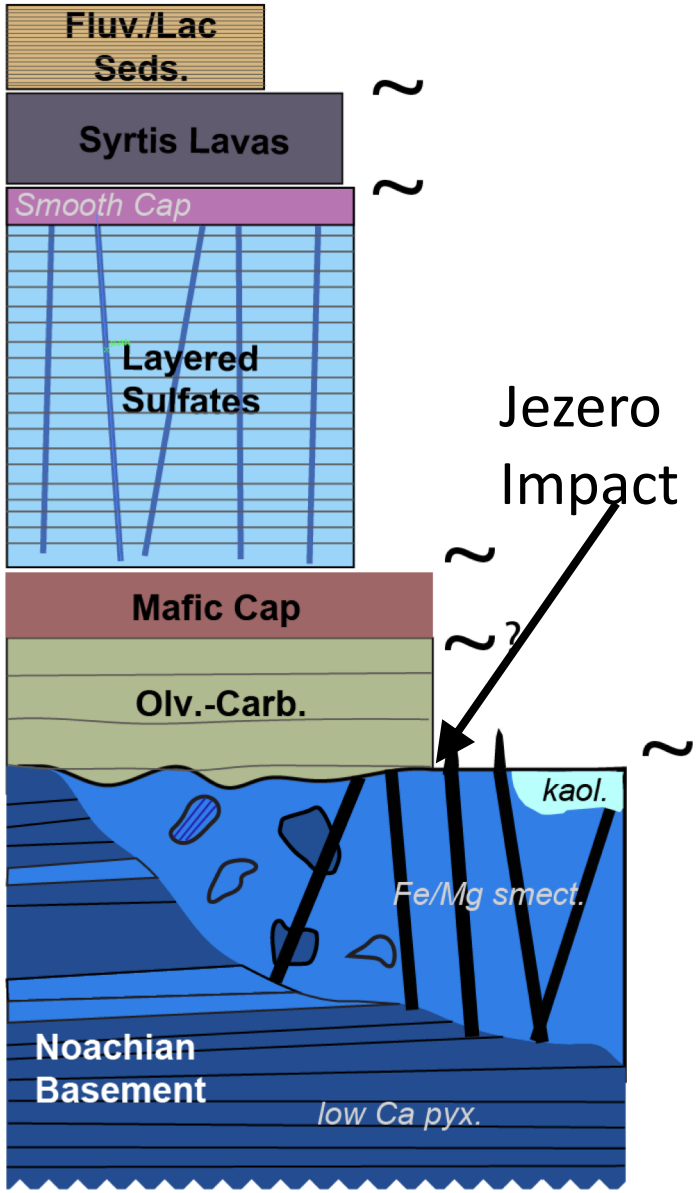
  Head & Mustard (2006)

- Unaltered magmatic intrusions or volcanic fill

  Kerber et al. (2017)

Important Science at the Ridges

1. Measure chemistry and mineralogy to test mineralized fracture zone hypothesis (e.g. SiO_2 rich?)
2. Seek samples at the contacts to assess preservation of material relevant to astrobiology
3. Establish key timing relationships with host
4. Assess relationship to carbonation and hydrothermal processes

Compelling Fundamental Mars and Astrobiology Science

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