Mars' Crustal Evolution from Remote Sensing: Current Understanding and Outstanding Questions

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GAMMA RAY AND INFRARED GLOBAL DATA SETS

Mars Global Surveyor (MGS)
1996-2006
Thermal Emission Spectrometer (TES)

Mars Odyssey
2001-present
Thermal Emission Imaging System (THEMIS)
Gamma Ray Spectrometer (GRS)

Mars Express
2003-present
Visible and Infrared Mineralogical Mapping Spectrometer (OMEGA)

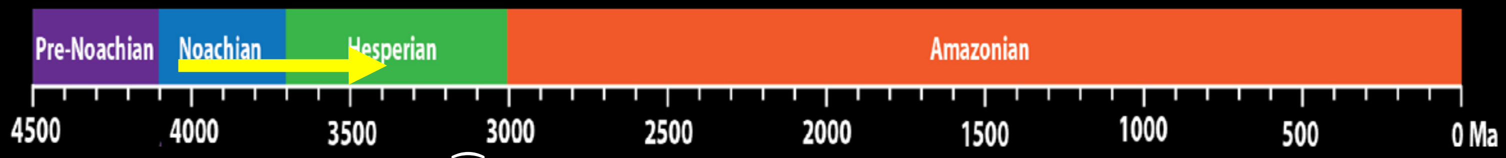
Mars Reconnaissance Orbiter (MRO)
2006-present
Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)

With thanks to:
Mariek Schmidt
Brock University, Canada
(see also LPSC 2019 Abs. 2419)

Tharsis Face of Mars
Mars Global Surveyor (MGS)
Mars Orbital Camera (MOC)
NASA/MSSS

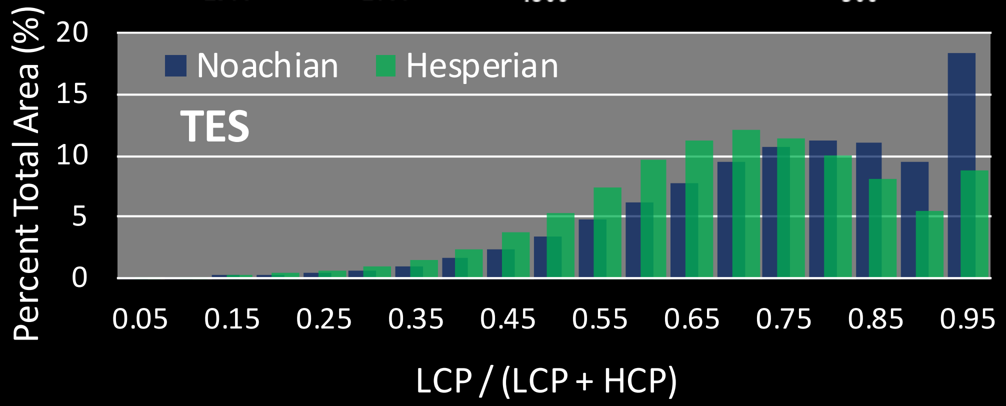
Evolving Interior – Noachian to Hesperian

Differences in mineralogy and chemical abundances between Noachian and Hesperian terrains



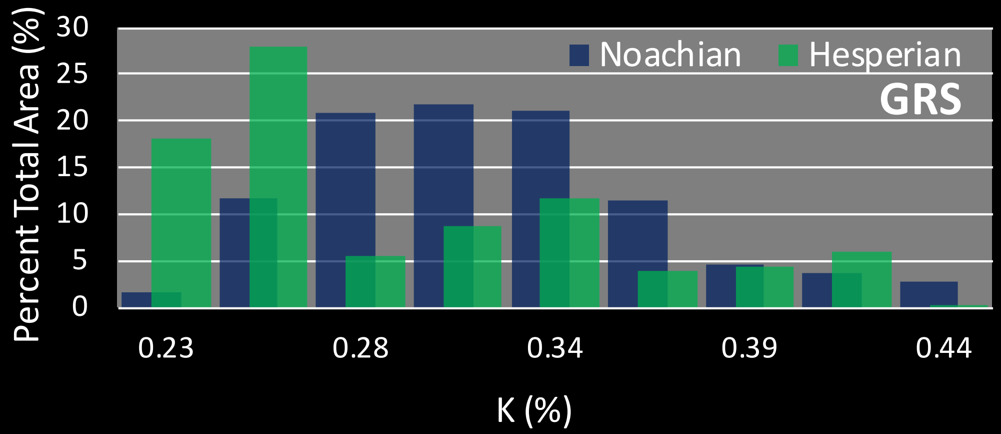
Decreased abundance ratio LCP:(LCP+HCP)

- Consistent with lower degrees of partial melting caused by a cooling mantle and thickening lithosphere



Decreased K (and Th) abundance

- This would suggest *increased partial melting in the Hesperian* (not consistent with LCP:HCP trends)
  - Noachian crust built by a more complex set of processes than the Hesperian, with varying degrees of magmatic differentiation to produce higher K



Better understanding of the precise mineralogy, prevalence of alkaline volcanics would help constrain Noachian crust-building processes.

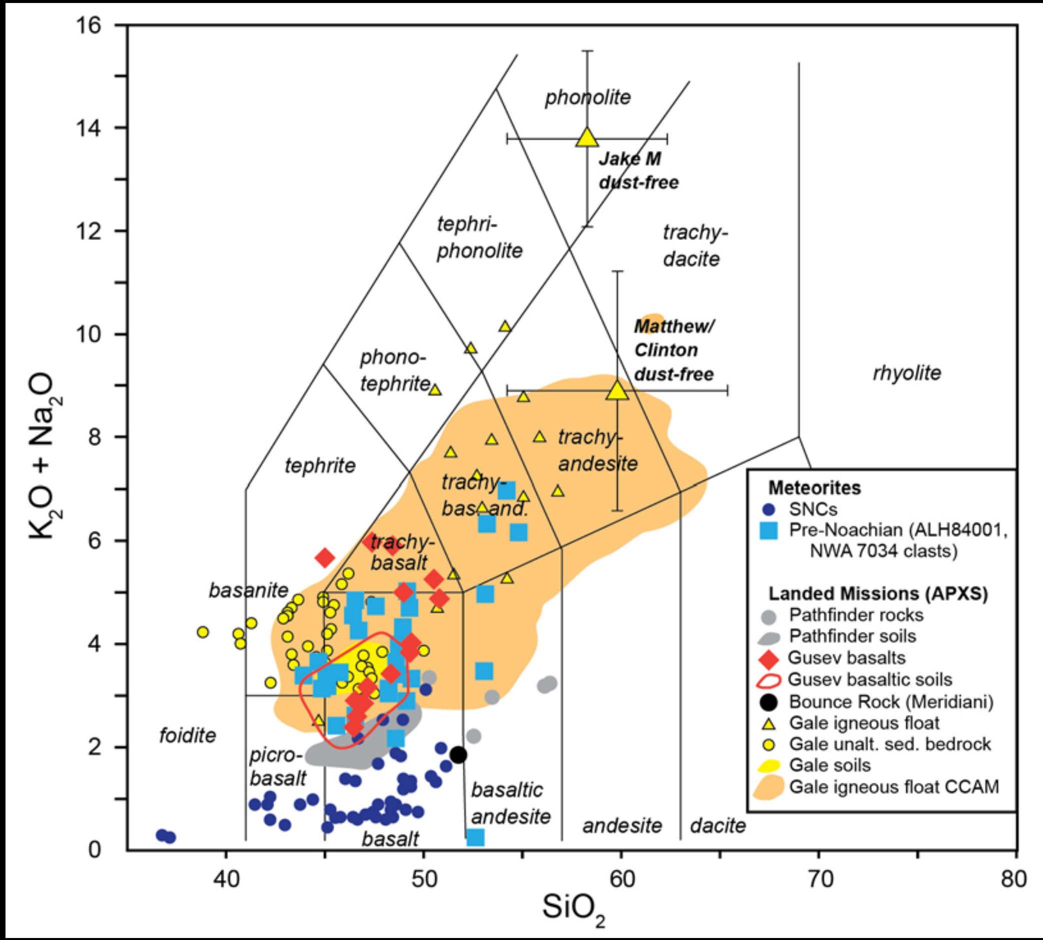
Baratoux et al. (2013); Rogers and Hamilton (2014) Mustard et al. (2005); Rogers and Christensen (2007); Poulet et al. (2009); Ody et al., (2012); Riu et al., (2019)

IN-SITU OBS. AND METEORITES PROVIDE EVIDENCE FOR ALKALINE VOLCANISM IN THE NOACHIAN

- *In-situ*: Subalkaline to alkaline basalts to andesites at Columbia Hills and Gale crater

- Ancient meteorites NWA 7034: Noachian regolith breccia with clasts:
    - Basalt (tholeiitic and alkali)
    - Basaltic andesite
    - Trachydacite
    - Fe-Ti-P-rich lithology

Santos et al., 2015; McCubbin et al., 2016

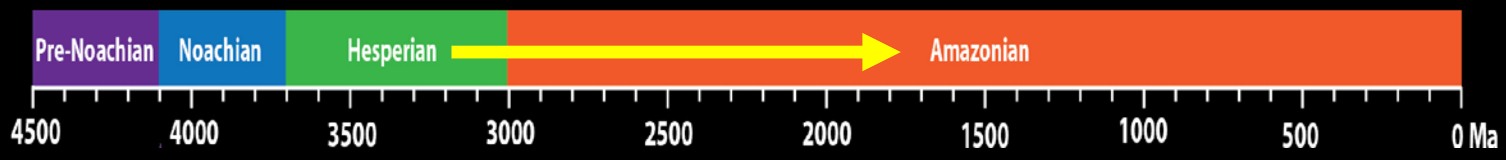


Meyer, (2009) and references therein; Santos et al. (2015); Brückner, J et al. (2003); McSween et al. (2006); Ming, D.W. et al. (2008); Zipfel, J. et al. (2011); Schmidt et al. (2014); Schmidt et al. (2017)

4.4 Ga Zircon in alkali-rich basaltic clast in Black Beauty
>>Confirms ancient alkali magmatism

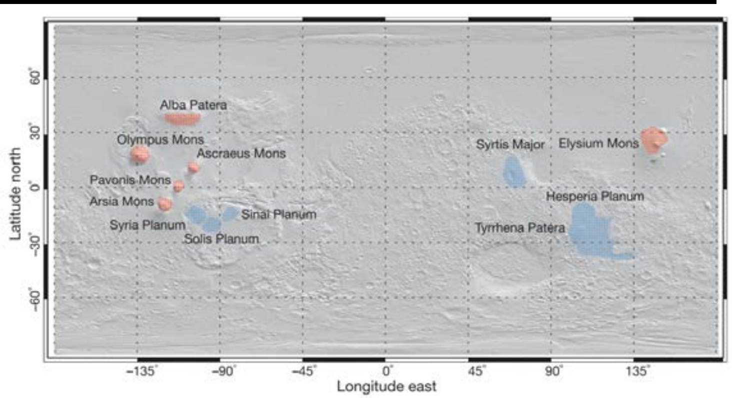
Evolving Interior – Hesperian to Amazonian

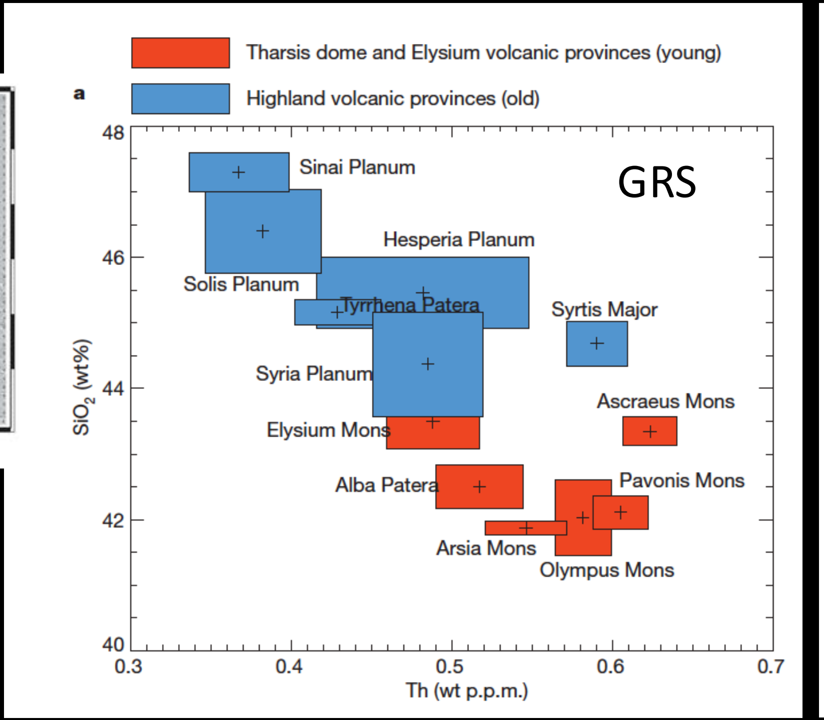
Differences in elemental abundances between Hesperian and Amazonian volcanic provinces

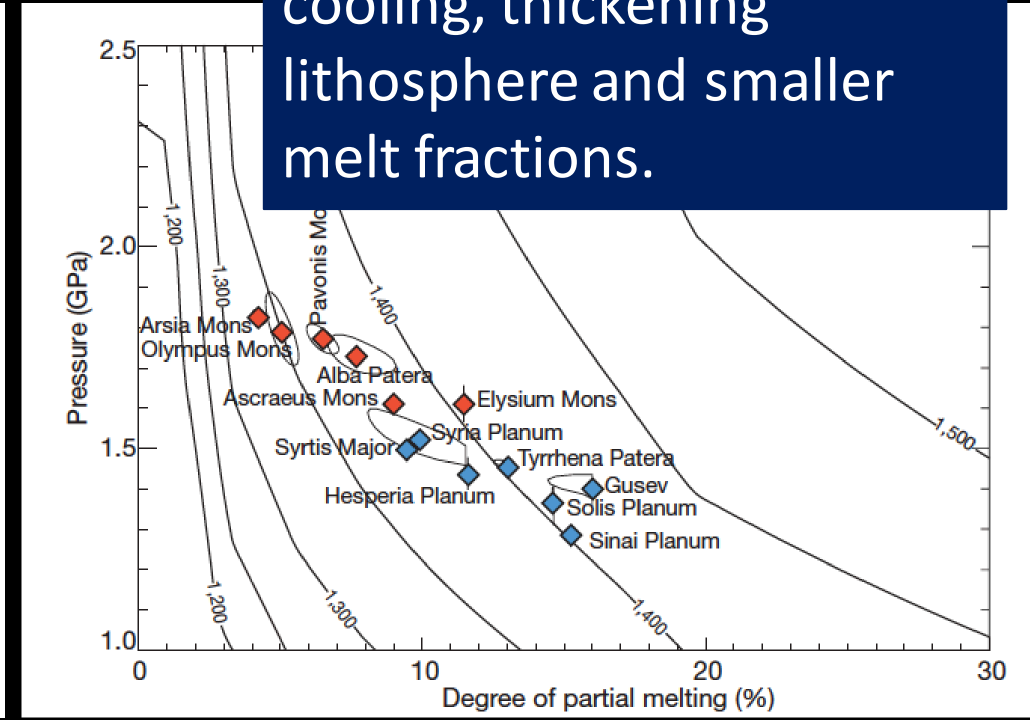


- Lower SiO_2, higher Th in Amazonian

→Continued mantle cooling, thickening lithosphere and smaller melt fractions.

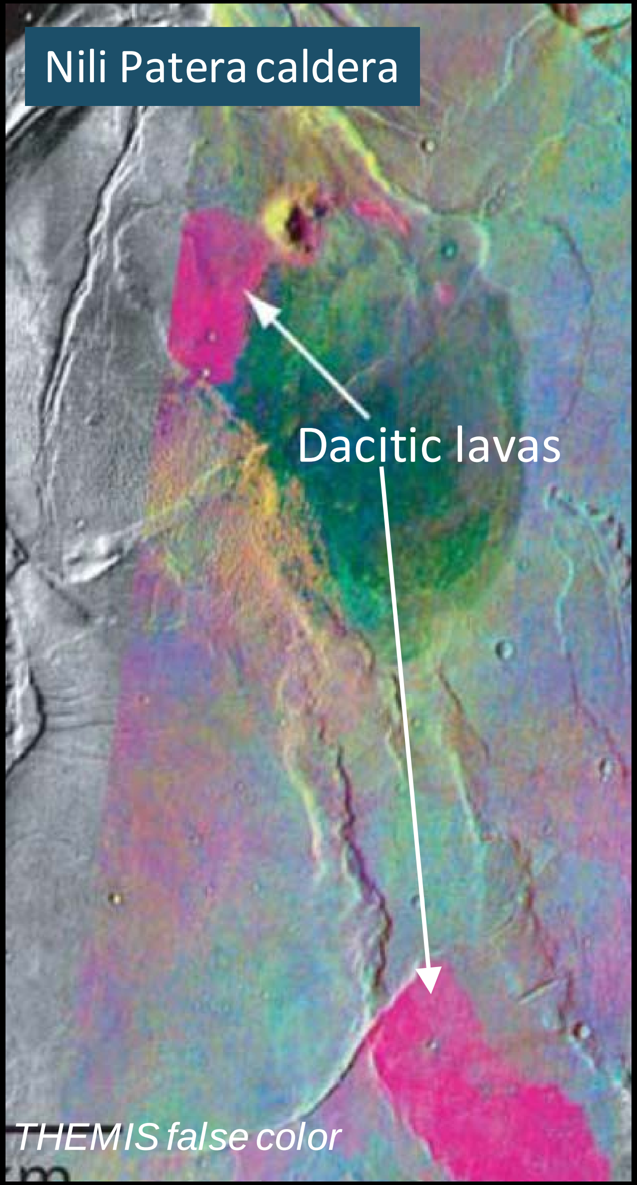






Baratoux et al., 2011

Evolved Magmas



Christensen et al., 2005

Al-rich Jake M class

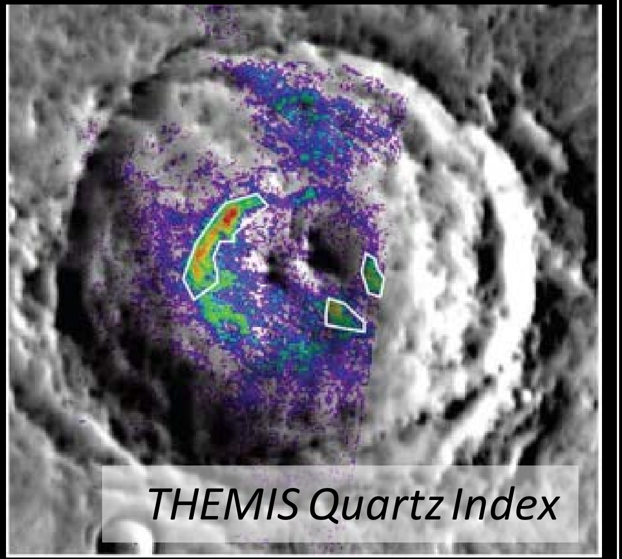
Porphyritic feldspar clasts in conglomerate

Rare dacitic, trachydacitic, trachyandesitic lithologies

- Evidence for fractional crystallization of basaltic magmas

Rare quartz detections in NW Syrtis Major are likely diagenetic in origin

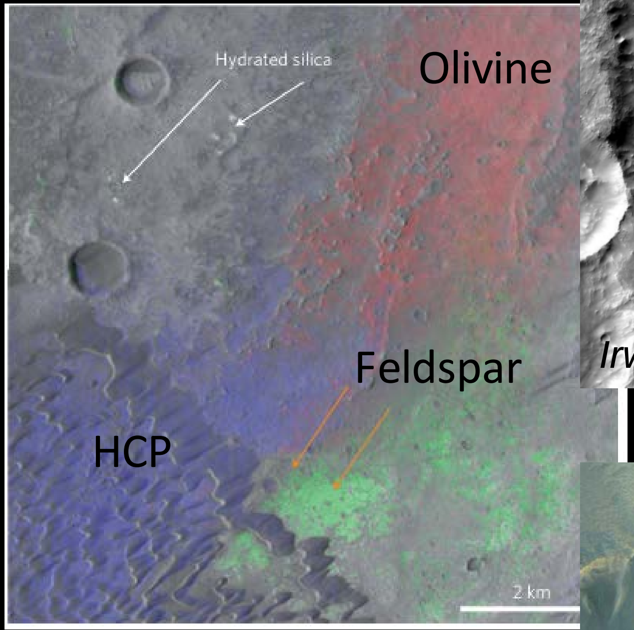
Smith and Bandfield (2012)



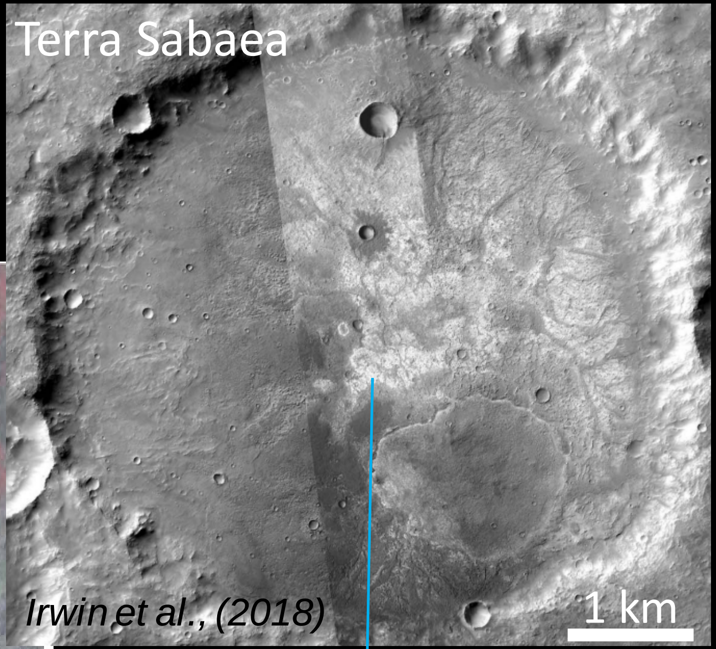
Rare Feldspar-Rich Lithologies

Nili Patera

CRISM spectral parameter map



Wray et al. (2013)



>20 other locations from orbit

Feldspar-rich (>~60 vol%) lithologies observed from orbit are not well understood.

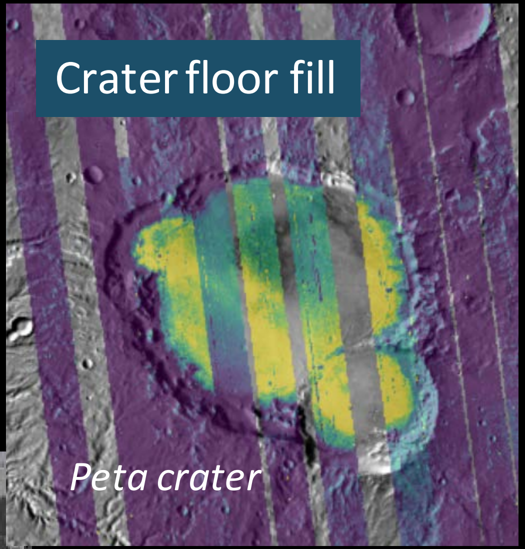
- Full areal extent/occurrences also are not well-constrained
- Variable contexts

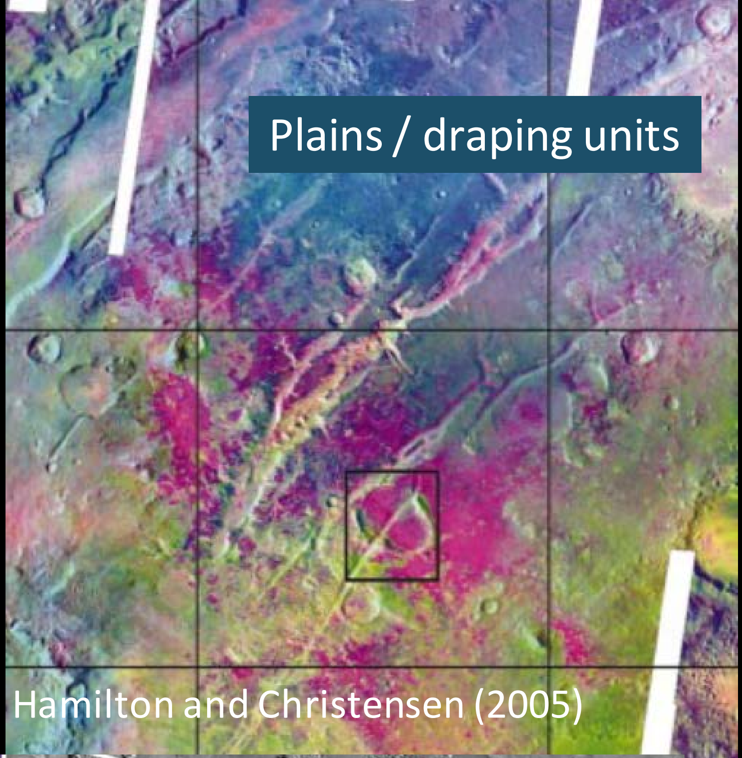
Proposed origin(s):

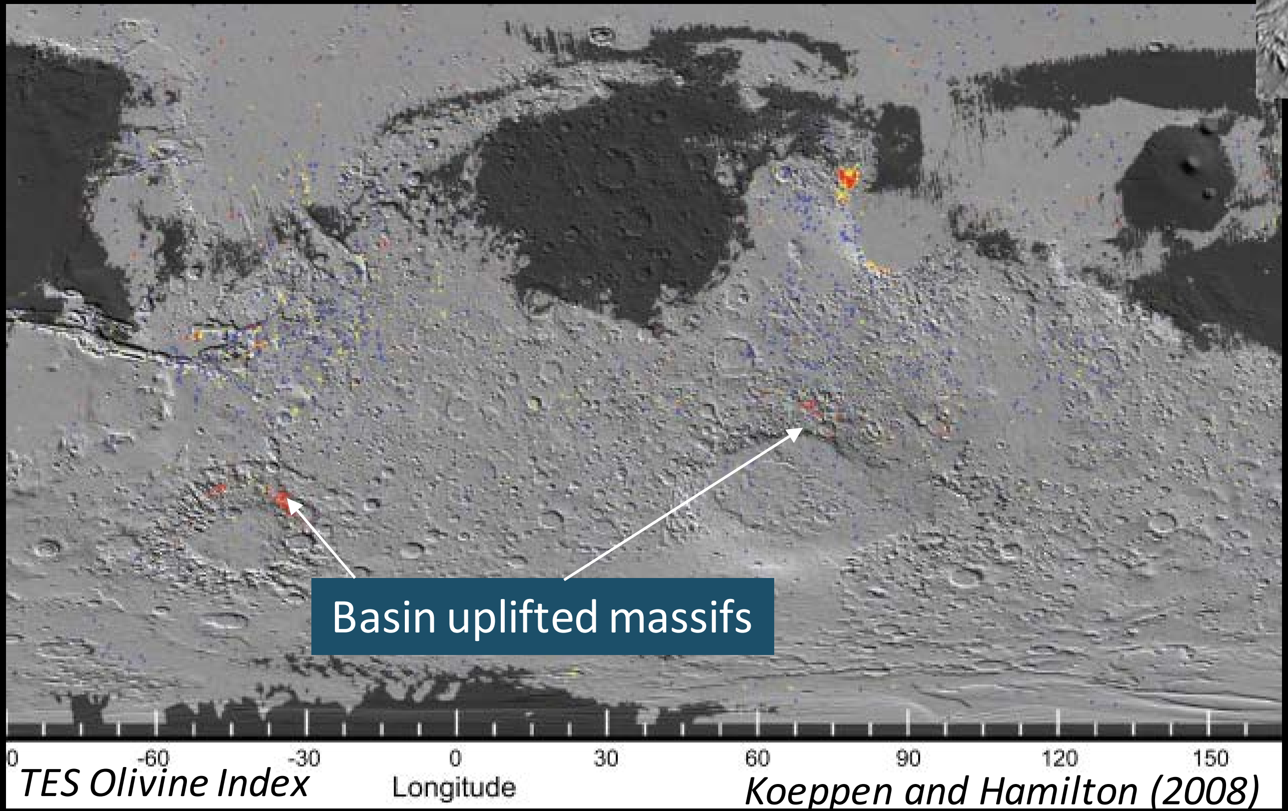
- Anorthosites *(Carter & Poulet, 2013)*
- Felsic volcanics / intrusions *(Wray et al., 2013; Irwin et al., 2018)*
- Fractionally crystallized basaltic magmas *(Rogers & Nekvasil, 2015).*
- Alkaline igneous *(Farrand et al., 2021)*
- Arkosic sandstones *(Irwin et al., 2018)*

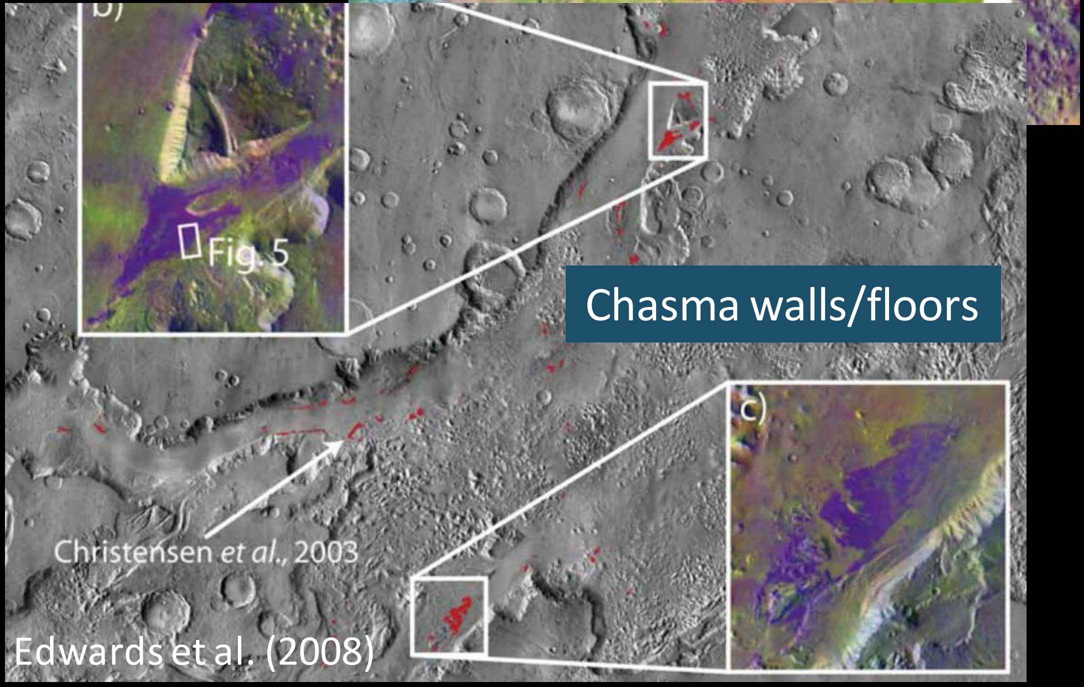
OLIVINE-BEARING LITHOLOGIES

- Occur in a variety of contexts and terrains
- Noachian and Hesperian outcrops
- Some associated with clastic / friable units



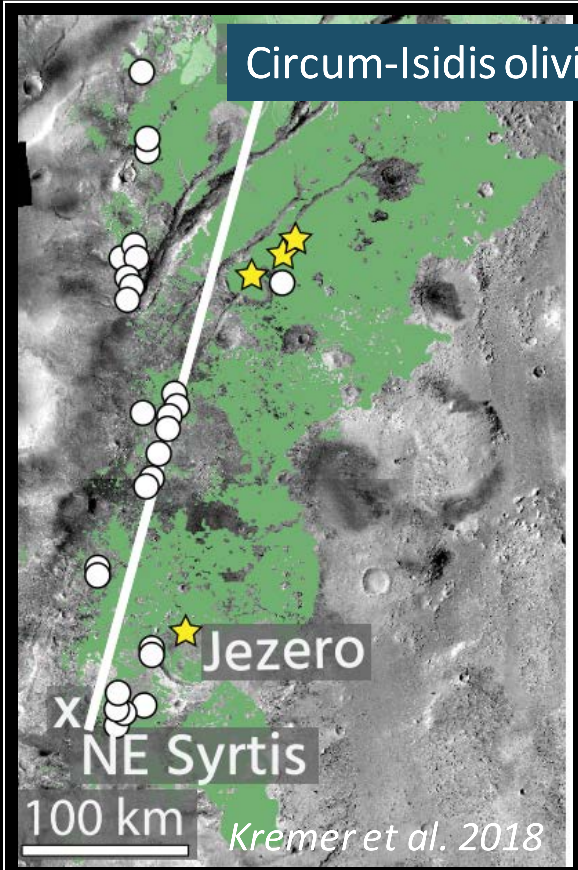






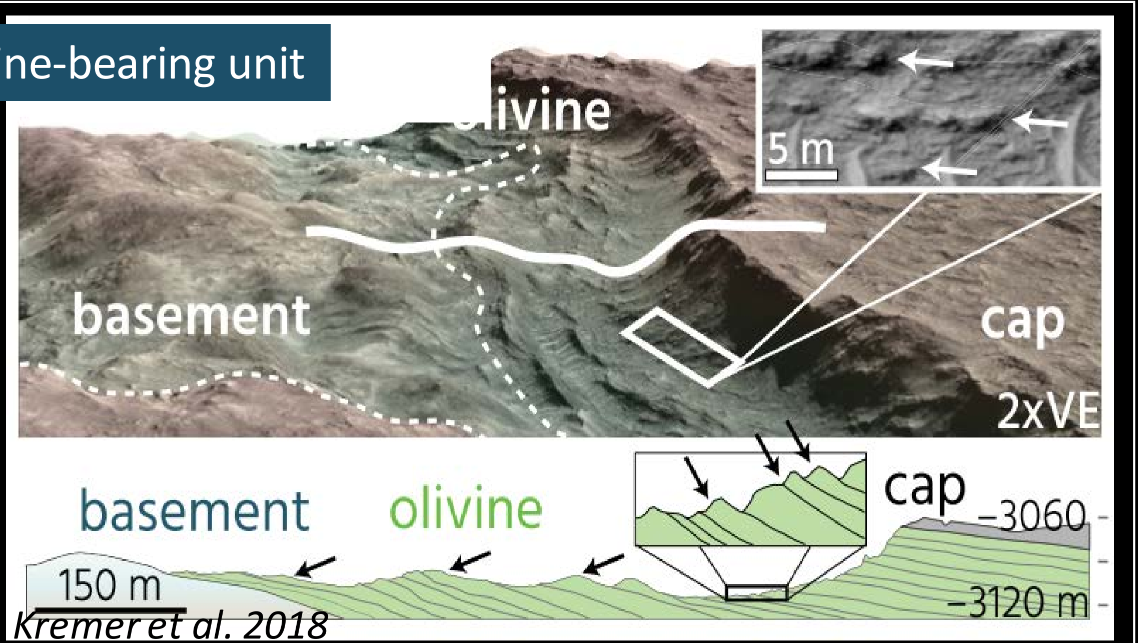
Evidence for Explosive Volcanism in the Noachian

Circum-Isidis olivine-bearing unit



Kremer et al. 2018

Can test with M2020 at Midway



Kremer et al. 2018

Circum-Isidis olivine unit:

- banded with clear draping relationships (Kremer et al., 2018)
- thermal properties consistent with friable material (Rogers et al., 2018)

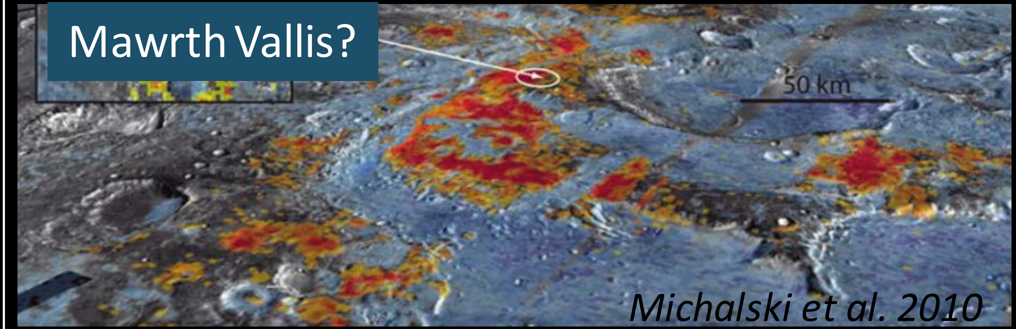
Columbia Hills

Ruff et al., 2014

Columbia Hills:

- Multiple rock classes exhibit clastic textures and have been interpreted as pyroclastic (e.g. Wishstone; Algonquin; Home Plate)

Mawrth Vallis?

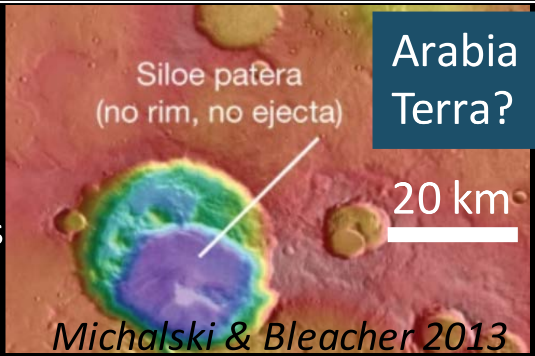


Michalski et al. 2010

Some layered clay-bearing units interpreted as *possible* diagenetically altered pyroclastics ←

→ Some rimless depressions interpreted as *possible* "supervolcano" calderas

Arabia Terra?



Michalski & Bleacher 2013

SUMMARY

- The early Mars magma ocean and associated planetary differentiation led to the formation of discrete, depleted and enriched mantle reservoirs.
- With time, the planet continued to cool and the lithosphere thickened, causing lower degrees of partial melting and melt generation at greater depths in the Mars mantle.
- While the early Mars crust was lithologically diverse, the Mars crust is generally basaltic.

Outstanding Questions	TIR img. spec	NIR img. spec (High-res)	Radar Img.	Hi-res img.	Gravity	In-situ	Why it matters. Implications for:
1. What was the extent and timing of explosive volcanism? • *Explosive – effusive transition LN/EH?* • *Which near-surface units are pyroclastic?*	X	X	X	**XX**	X	**XX**	• History of volatile inputs to the atmosphere • Mantle composition and interior evolution • Interpreting the aqueous history and habitability of the crust (e.g. material reactivity, mechanical properties/ erodibility, hydraulic properties, etc).
2. What is the structure of Noachian crust; what processes formed this crust? • *Is there a deep feldspathic component in the Martian crust? (Baratoux 2014)*	X	X		X	**XX**		• Interior evolution • Early crust development / possibility of crustal recycling
3. What was the spatial extent and timing of alkalic volcanism?	**XX**	X					• Mantle composition and interior evolution • History of volatile inputs to the atmosphere
4. What are the feldspar-bearing lithologies?	**XX**	X		X		**XX**	• Mantle composition; fractionation processes • Sedimentary processes?
5. What are the bulk compositions of <u>*lowland*</u> igneous materials and how do they differ from highland Hesperian volcanics?	**XX**	**XX**	?		X	**XX**	• Mantle composition and interior evolution • History of volatile inputs to the atmosphere
6. What are the bulk compositions of Tharsis/Elysium volcanics?	?	?			X	?	• Mantle composition and interior evolution • History of volatile inputs to the atmosphere
7. Is Mars still magmatically active? Where?	*Continued monitoring with imaging*						• Possibility of extant life / habitability • Interior evolution