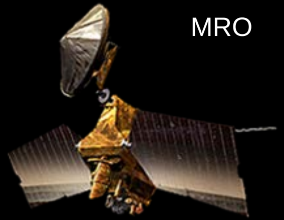
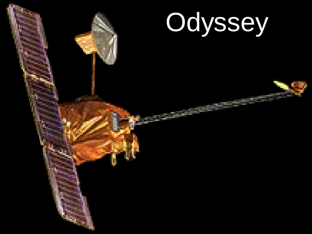
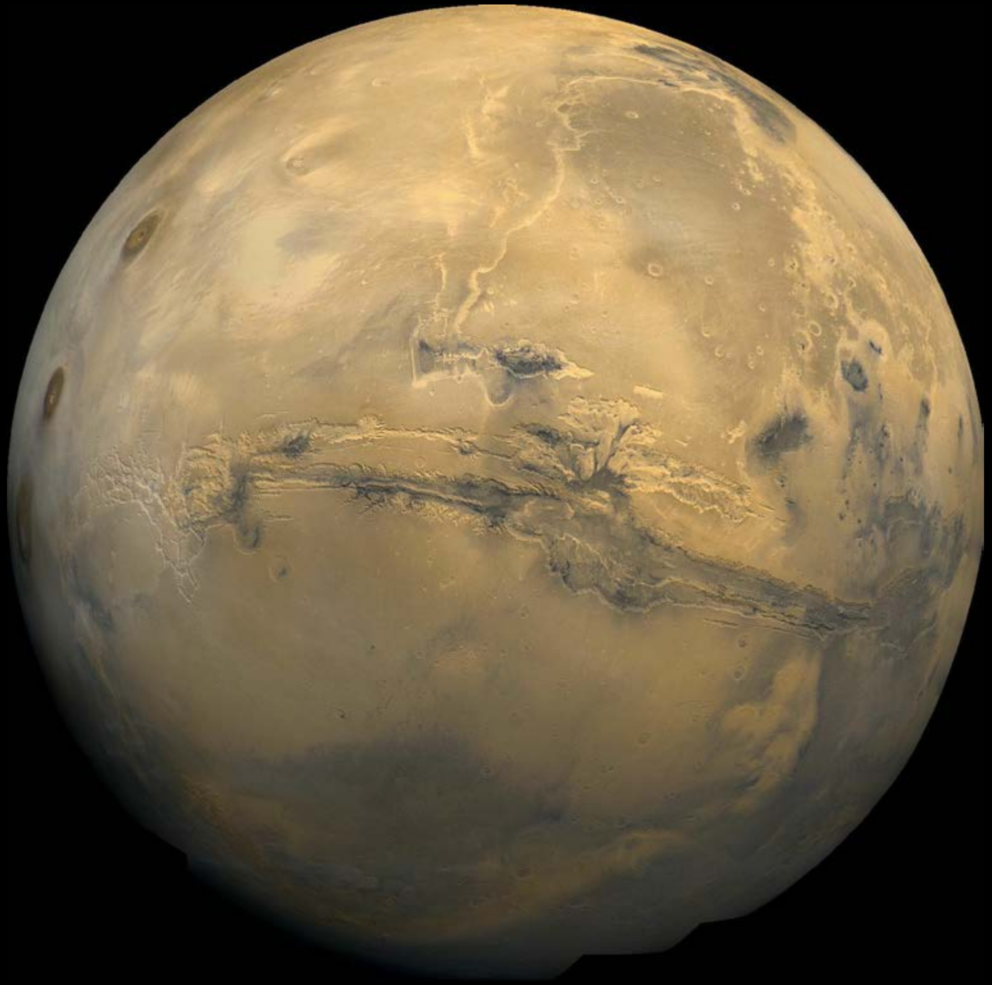
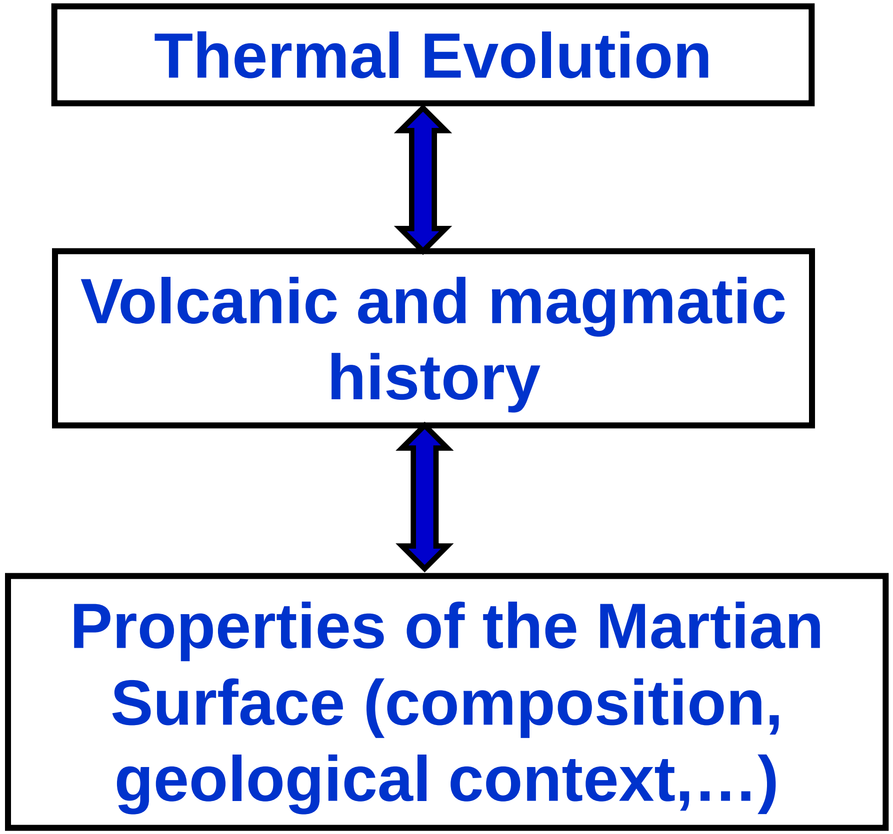
Thermal evolution of Mars as viewed from remote sensing observations

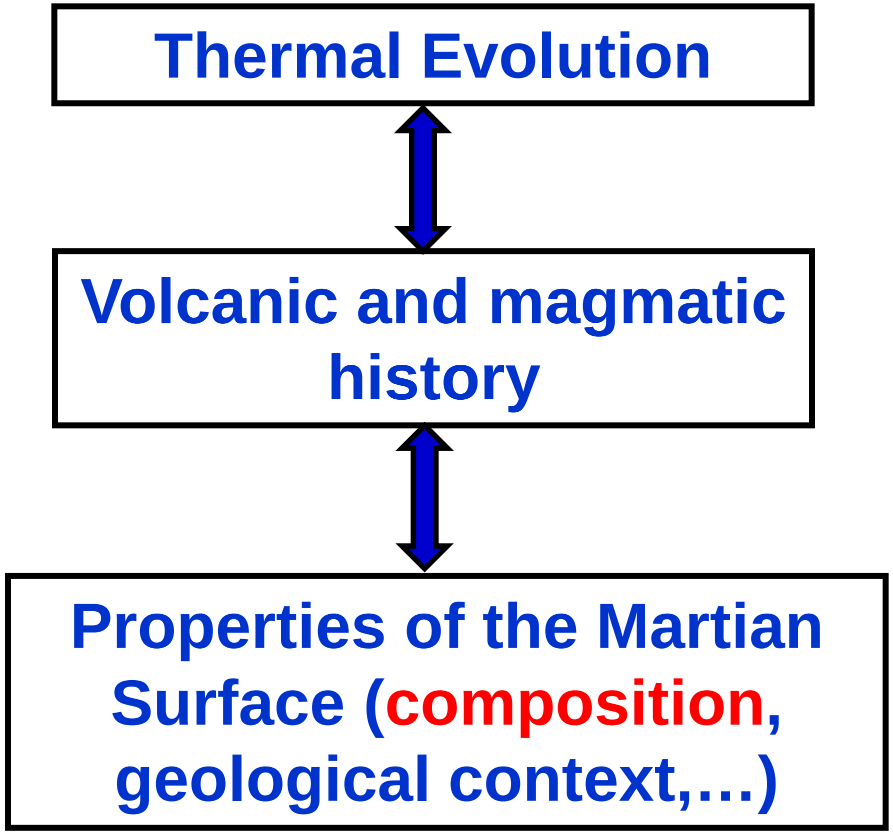

MRO


Odyssey

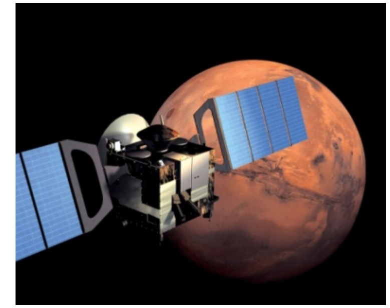


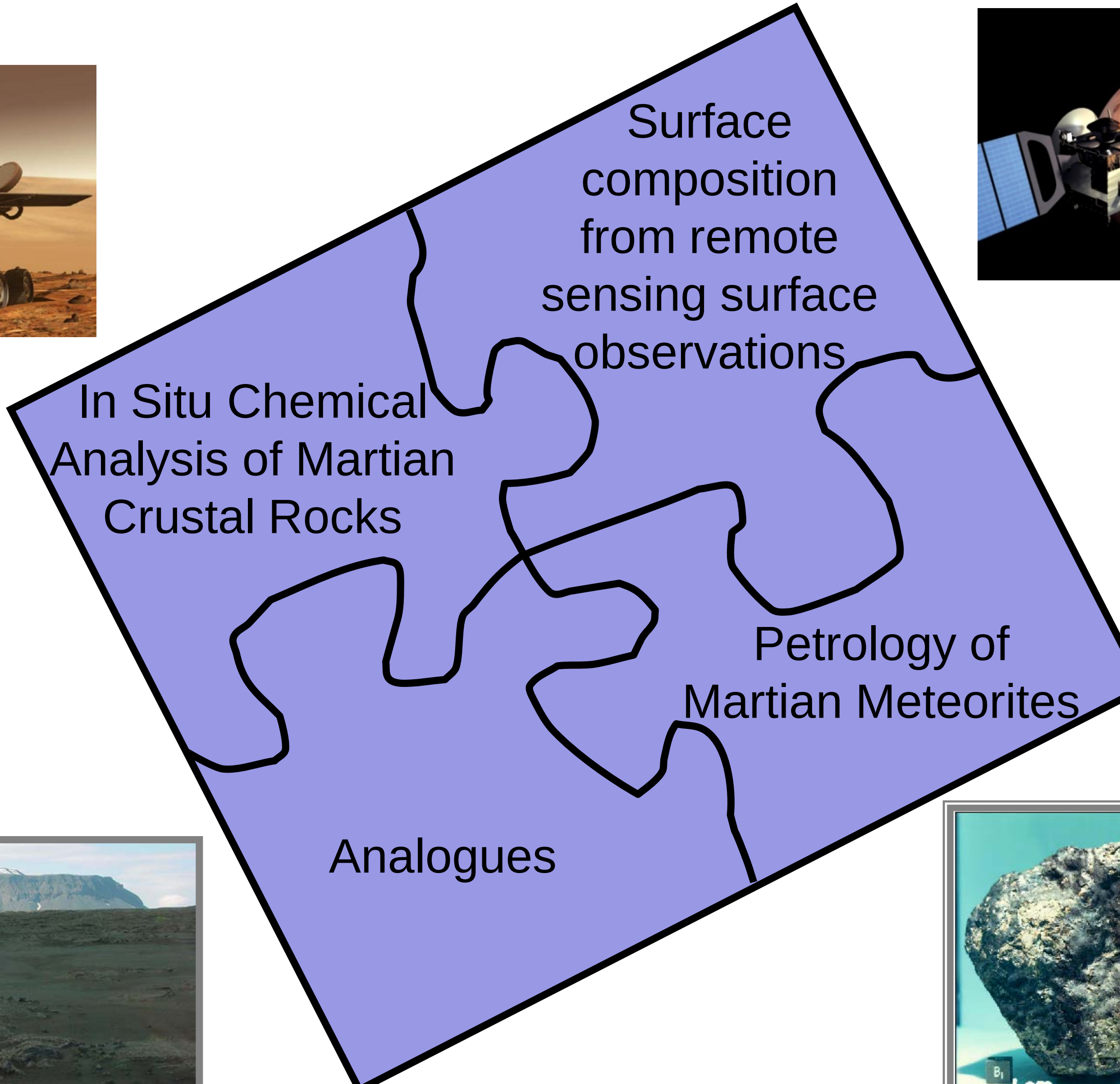
ESA/Mars Express

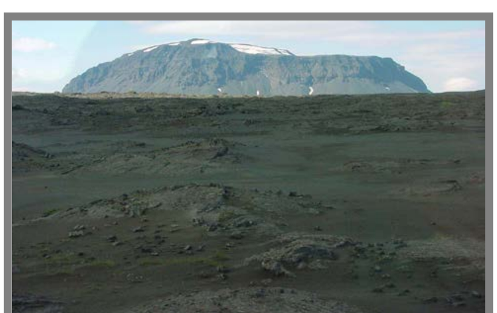

Thermal Evolution
Volcanic and magmatic history
Properties of the Martian Surface (composition, geological context,…)

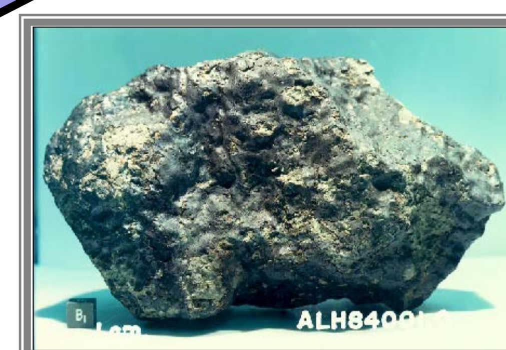

Thermal Evolution
Volcanic and magmatic history
Properties of the Martian Surface (composition, geological context,…)

Volcanic and magmatic history derived from composition

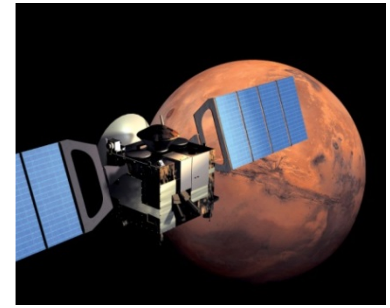


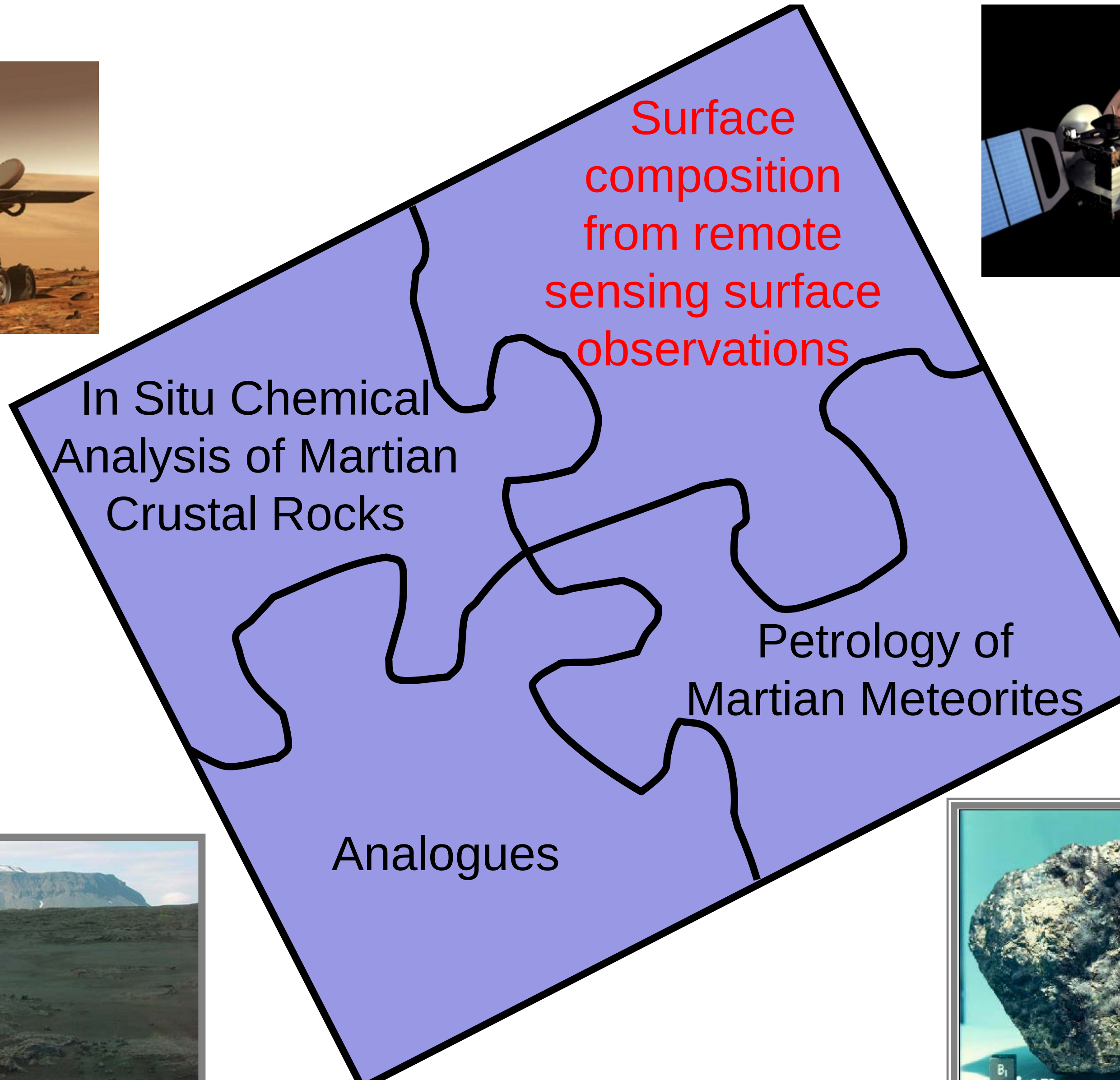


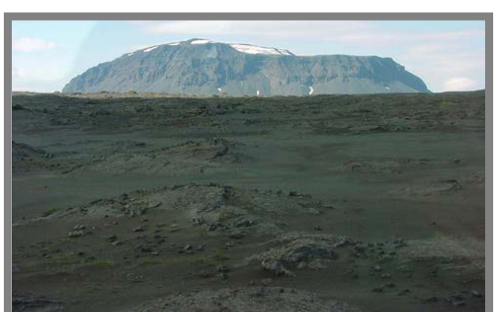




Volcanic and magmatic history derived from composition







Outline

Mineralogical diagnostics

1. Modal composition of mafic-rich regions
2. Olivine distribution

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Mineralogical diagnostics

1. Modal composition of mafic-rich regions
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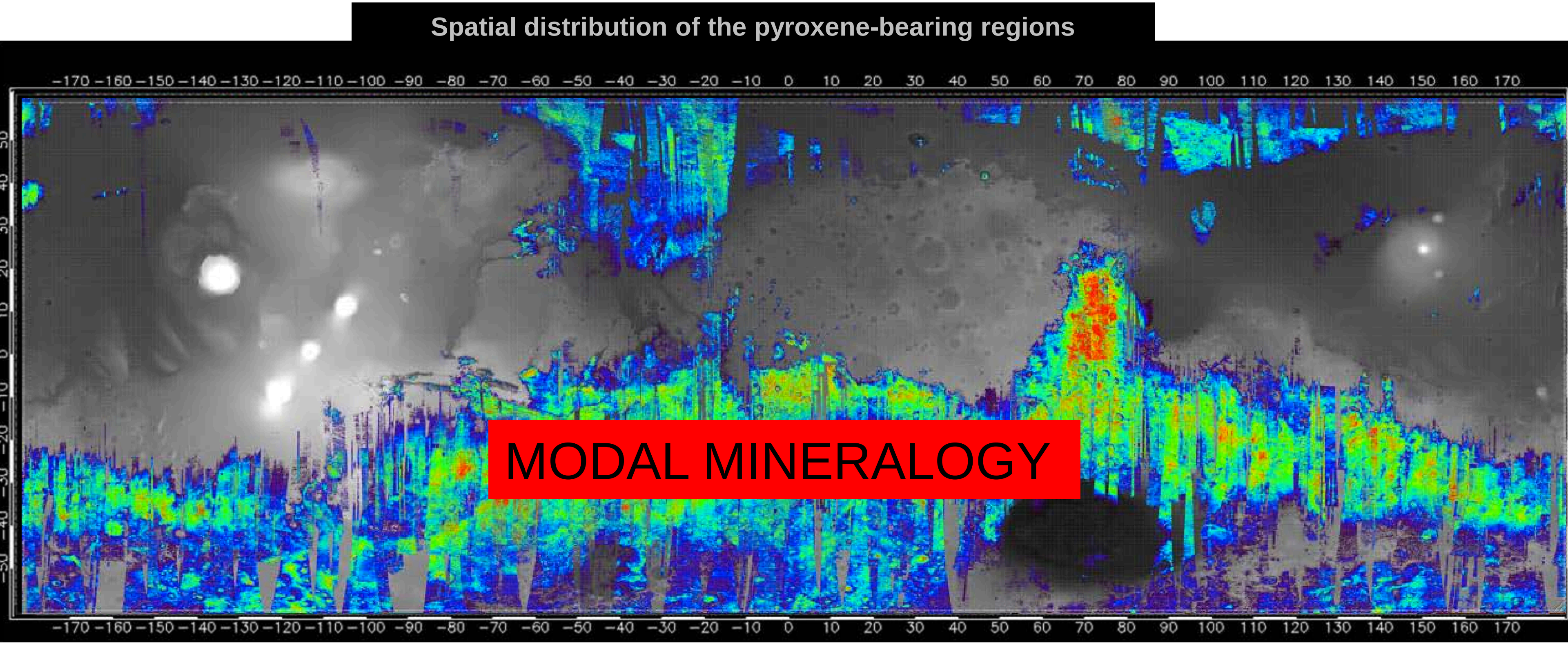
Mineralogical diagnostics :
OMEGA and CRISM observations

- Pyroxenes (High Calcium Pyroxene and Low Calcium Pyroxene)
- Olivine
- Anorthosite



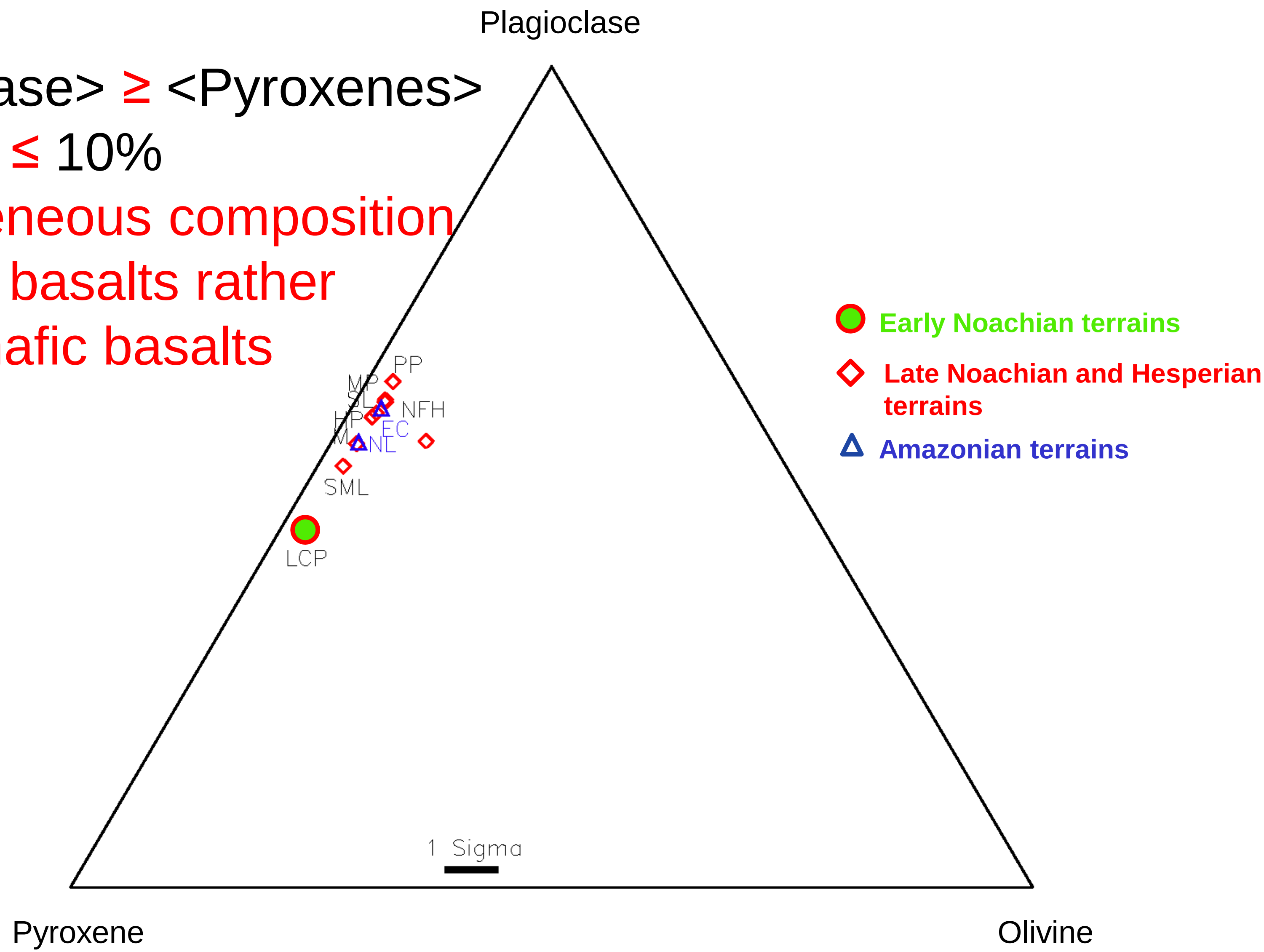
Poulet et al. 2009a, Icarus

Mineral classification : volcanic provinces + LCP

- <Plagioclase> ≥ <Pyroxenes>
- <Olivine> ≤ 10%

⇒ Homogeneous composition

⇒ Evolved basalts rather than ultramafic basalts

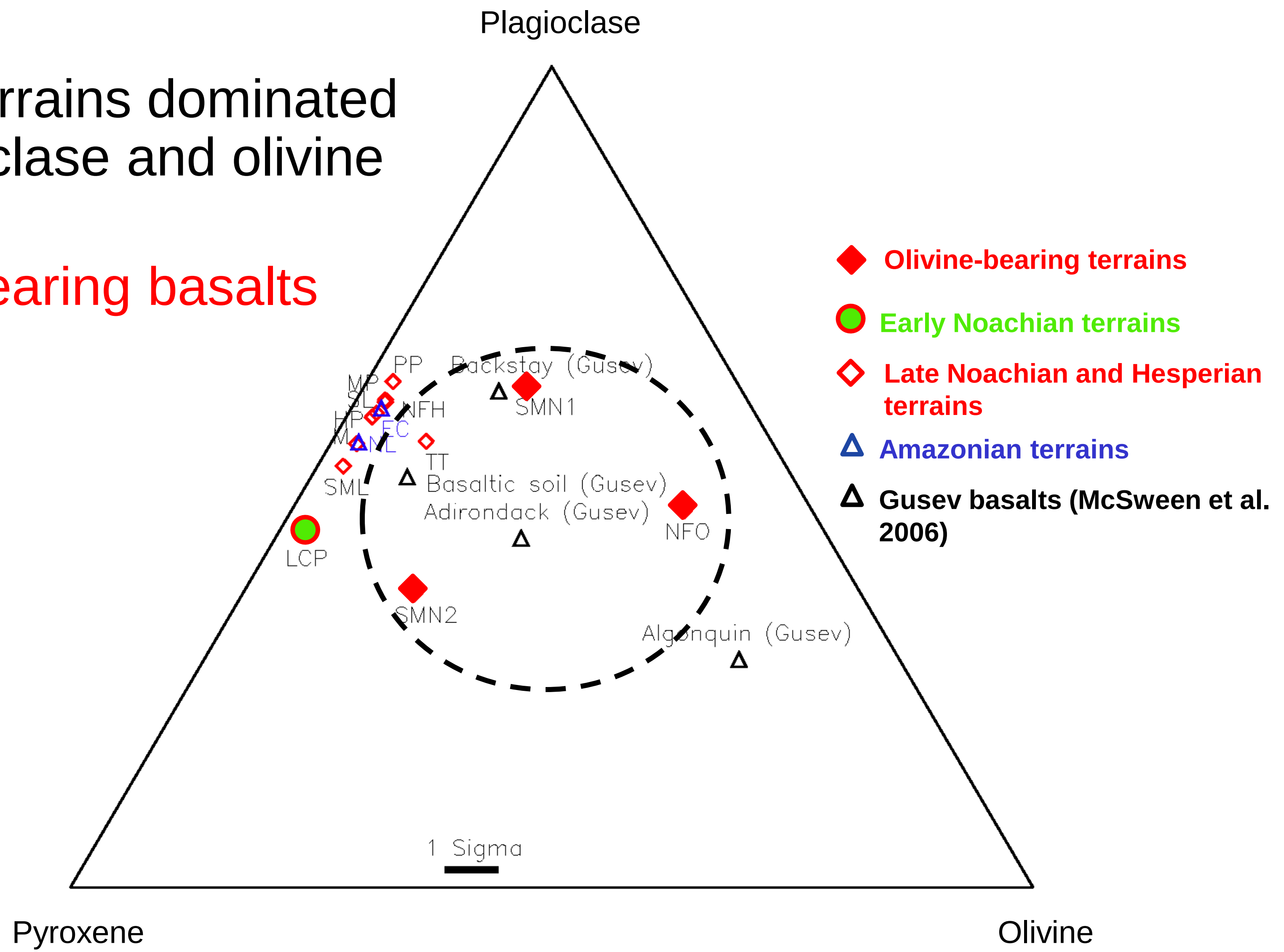


Poulet et al. 2009b, Icarus

Mineral classification : volcanic provinces + LCP + Olivine-bearing

Localized terrains dominated by plagioclase and olivine minerals

⇒ Olivine-bearing basalts

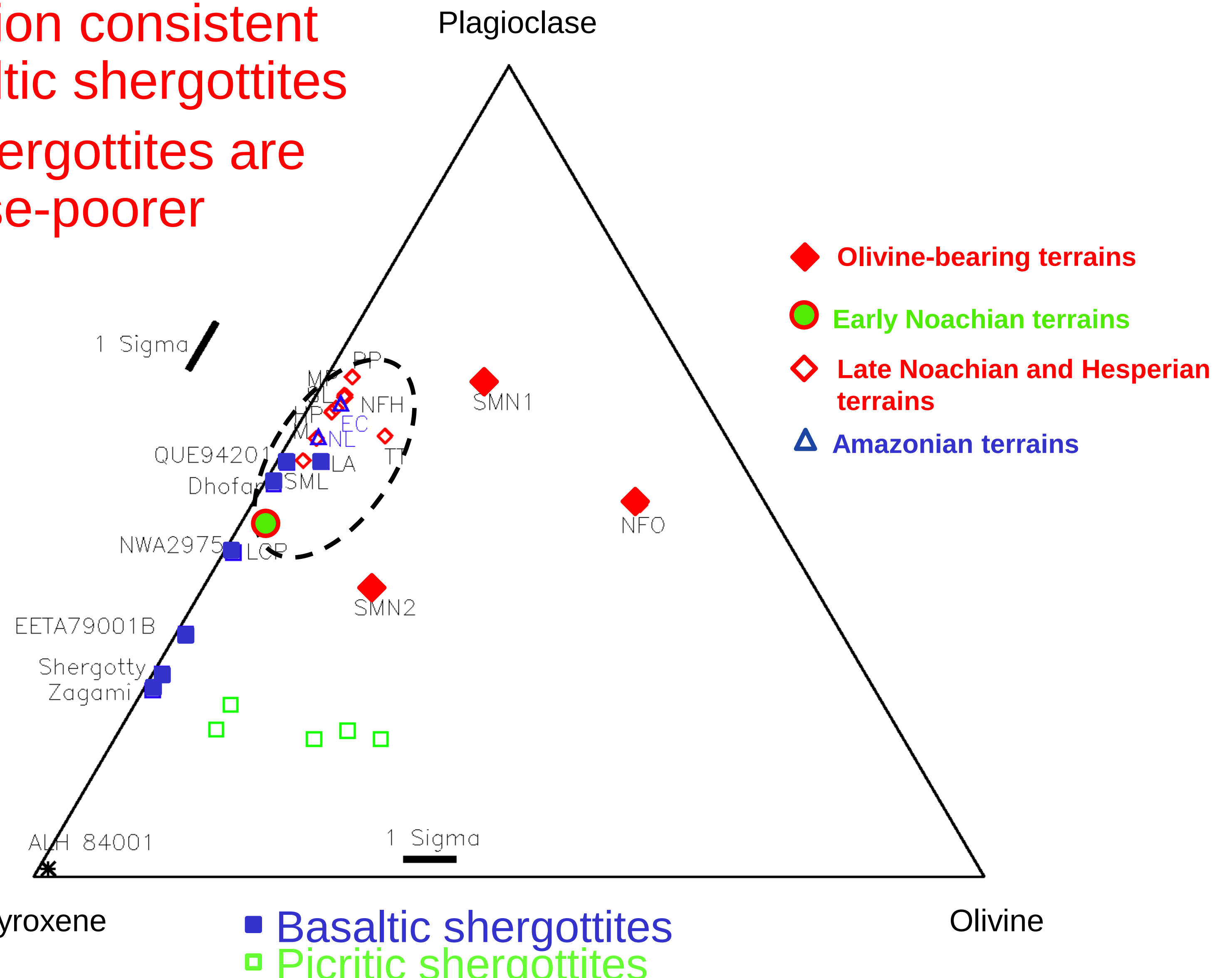


Poulet et al. 2009b, Icarus

Mineral classification : Comparison with SNCs

⇒ Composition consistent with basaltic shergottites

⇒ Picritic shergottites are plagioclase-poorer



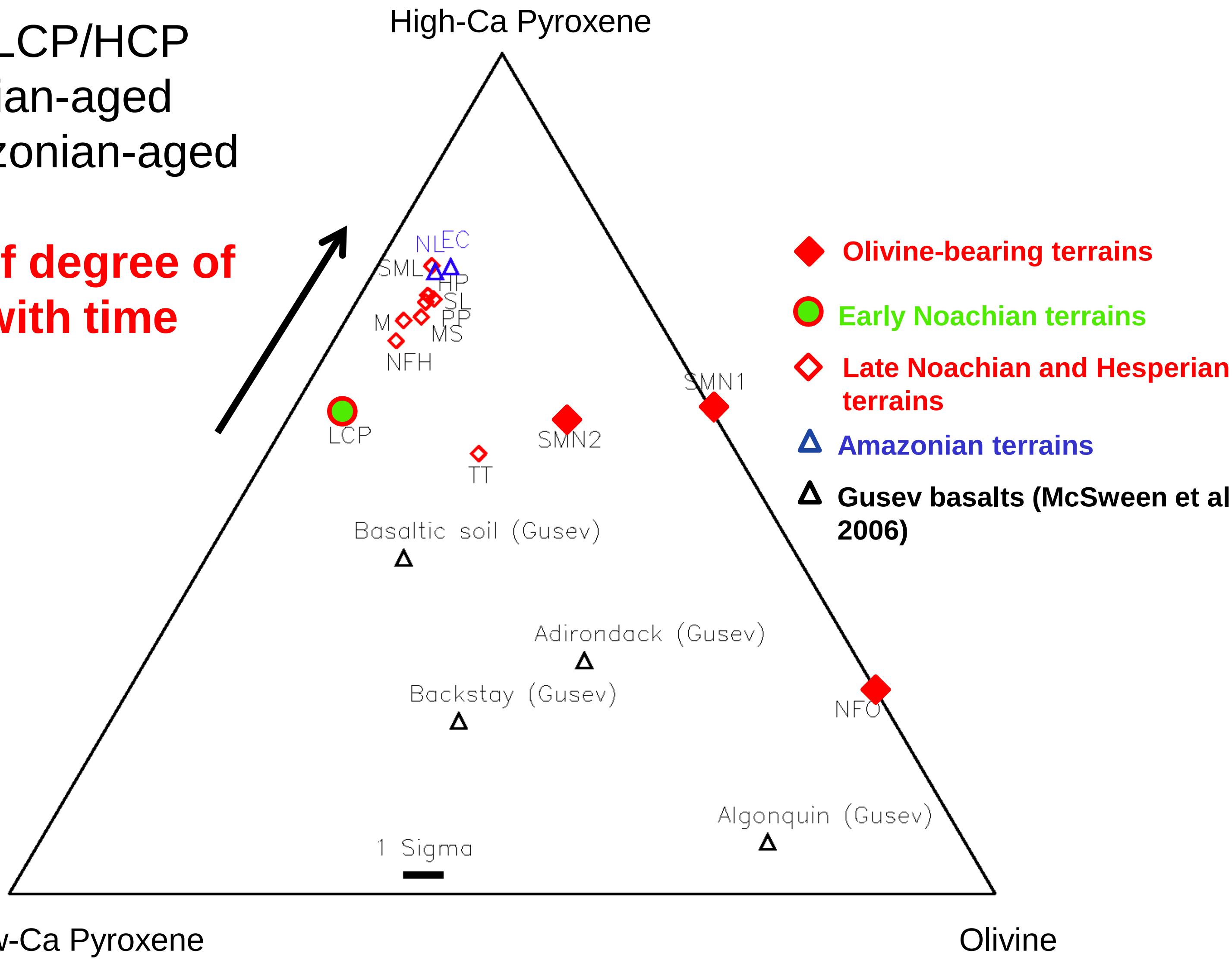
Poulet et al. 2009b, Icarus

Mineral Classification : HCP-LCP-Olivine diagram

Decrease of the LCP/HCP ratio from Noachian-aged outcrops to Amazonian-aged lava flows

⇒ Decreasing of degree of partial melting with time

(Baratoux et al. 2011)



Poulet et al. 2009b, Icarus

Conclusion (1)

- Mafic-rich provinces are evolved basalts (gabbros) with Plagioclase, HCP, LCP as the dominant phases

=> Dry volcanism and decreasing of degree of partial melting with time

- Olivine <10%

=> Lack of primitive magma… BUT olivine is found in localized and well-defined settings of early Hesperian ages (see next outline)

- No pyroxene cumulate

- Composition is pretty homogeneous

=> Convection on Mars was strong enough to manage a sweeping of ocean magma down into its mantle and reduced heterogeneity

Conclusion (2)

- Early Noachian outcrops have intermediate composition between basaltic shergottites and evolved basalts of late Noachian and Hesperian ages

$\Rightarrow$ Evolution through the Noachian Martian crust could be the result of 1) partial melt of ultramafic rocks

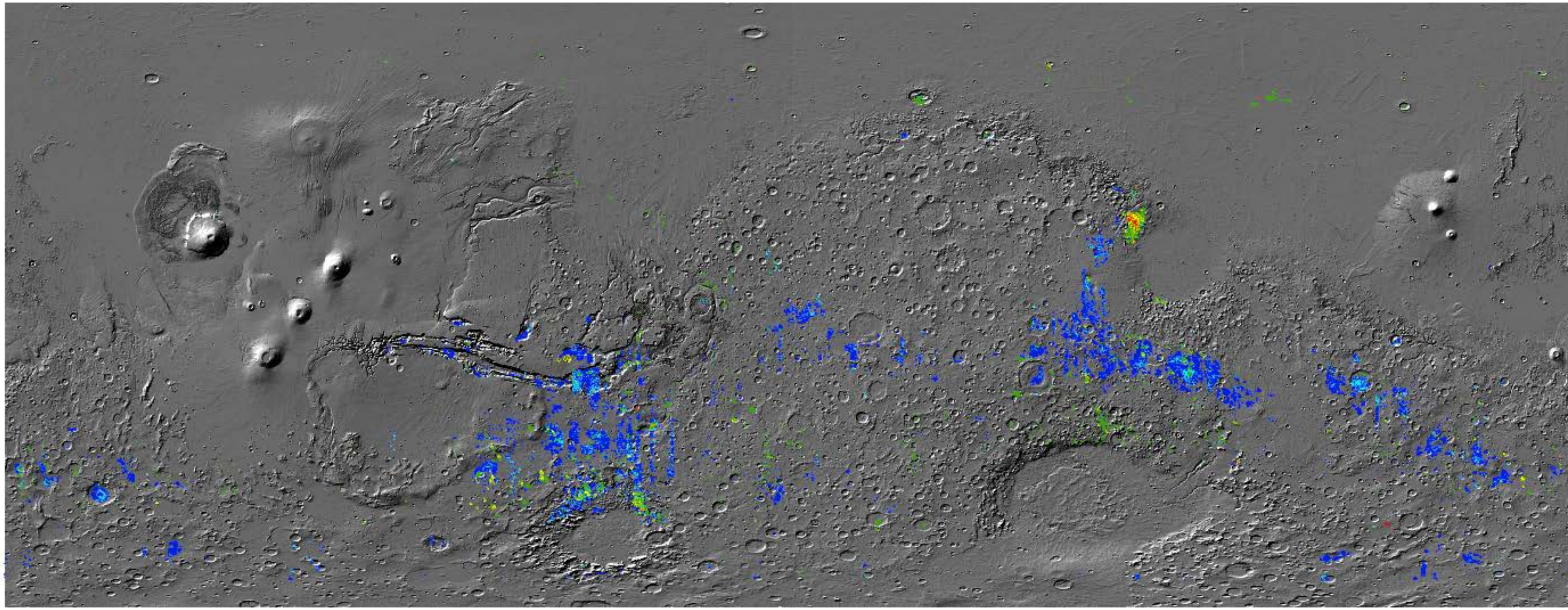
2) basaltic magma differentiation, which formed the basaltic shergottites and evolved basalts of the Martian surface

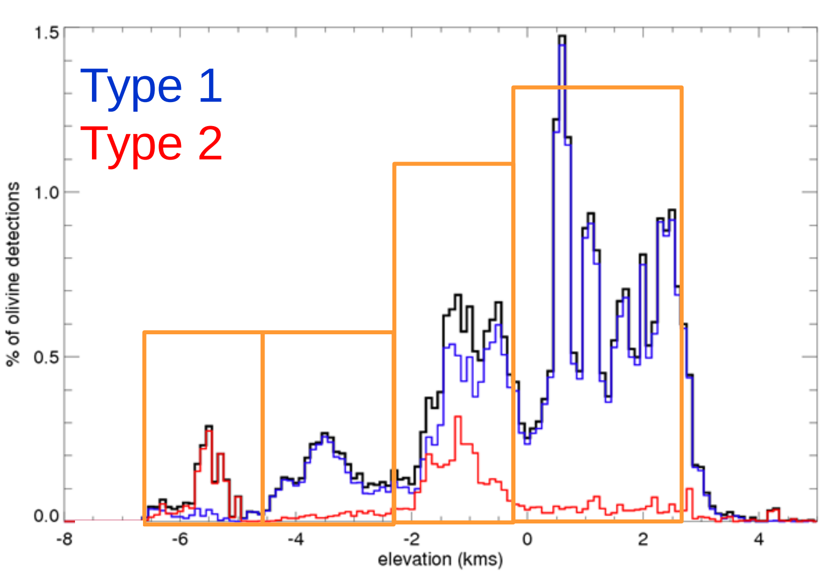
Outline

Mineralogical diagnostics

1. Modal composition of mafic-rich regions
2. Olivine distribution

Olivine spatial distribution

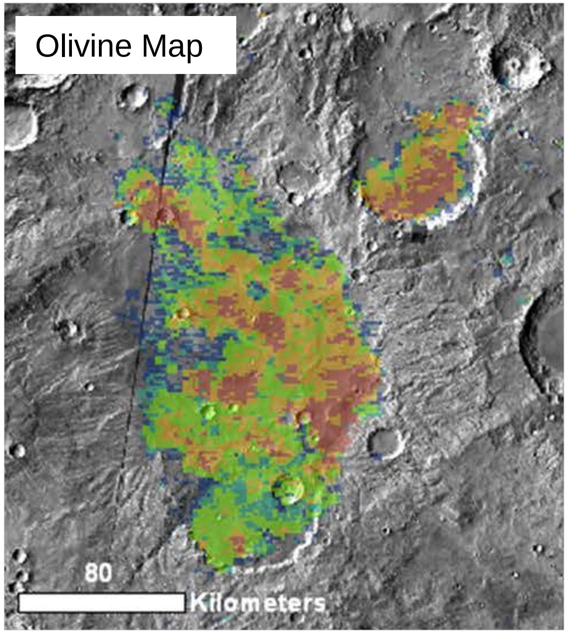


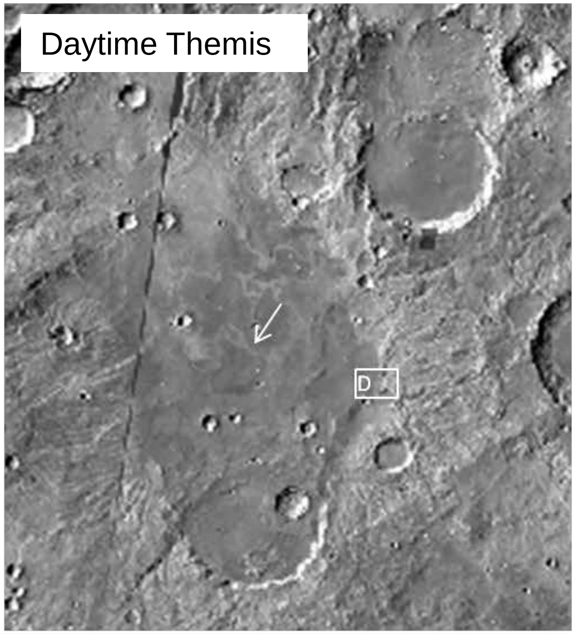


1. Smooth, flat and ridged plains and crater floors in southern highlands
2. Circum-basins
3. Valles Marineris
4. Northern plains

Ody et al. 2013 JGR

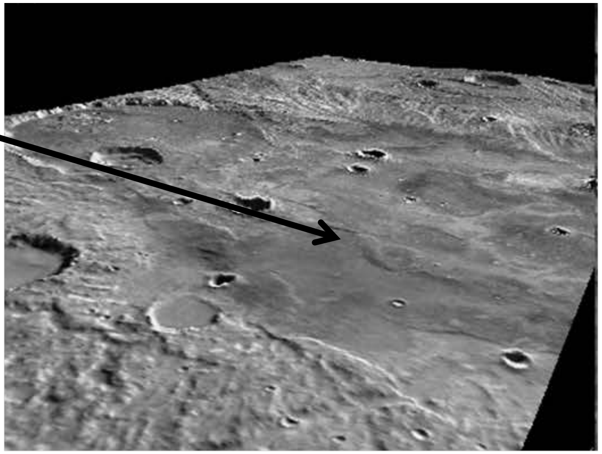
Olivine Setting: Flat and ridged plains and crater floors



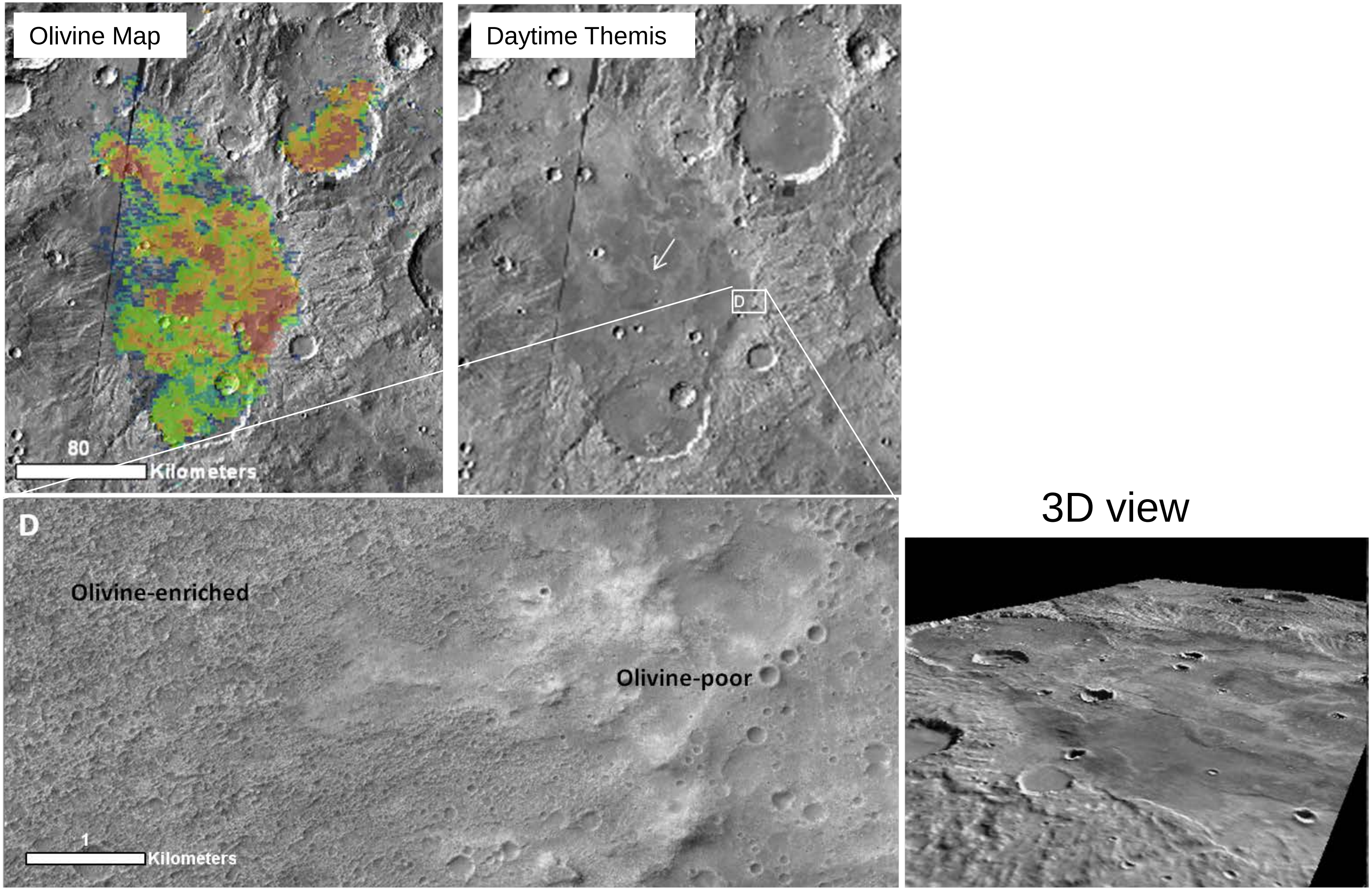


3D view

Ridge

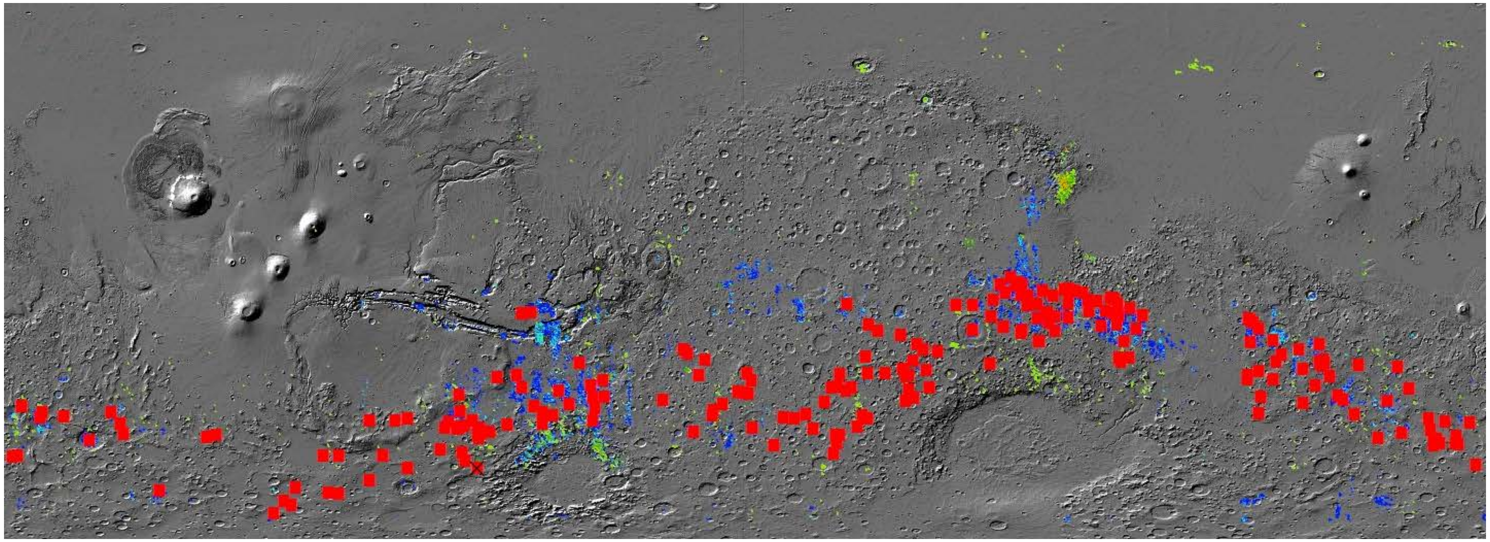


Olivine Setting: Flat and ridged plains and crater floors

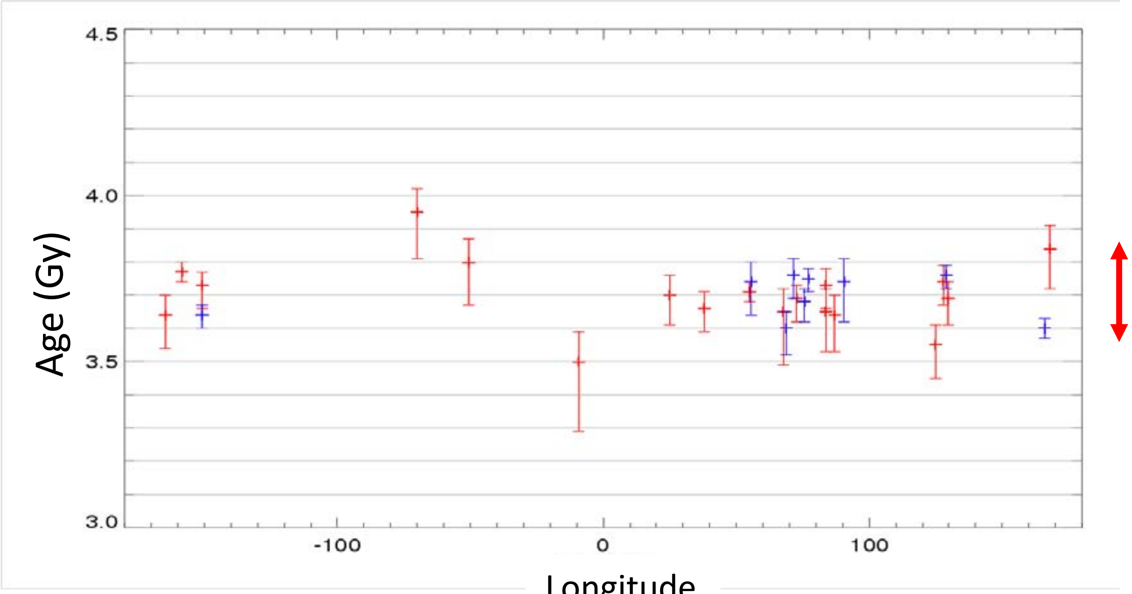


Olivine Setting: Flat and ridged plains and crater floors

Spatial distribution

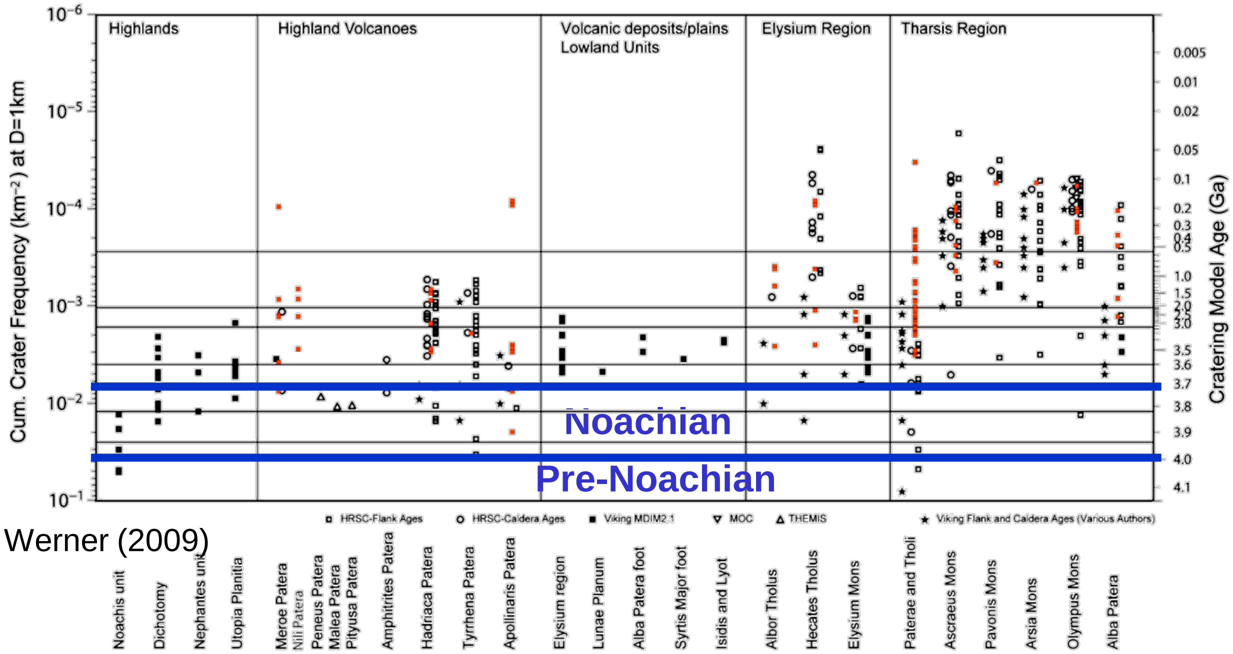


Age



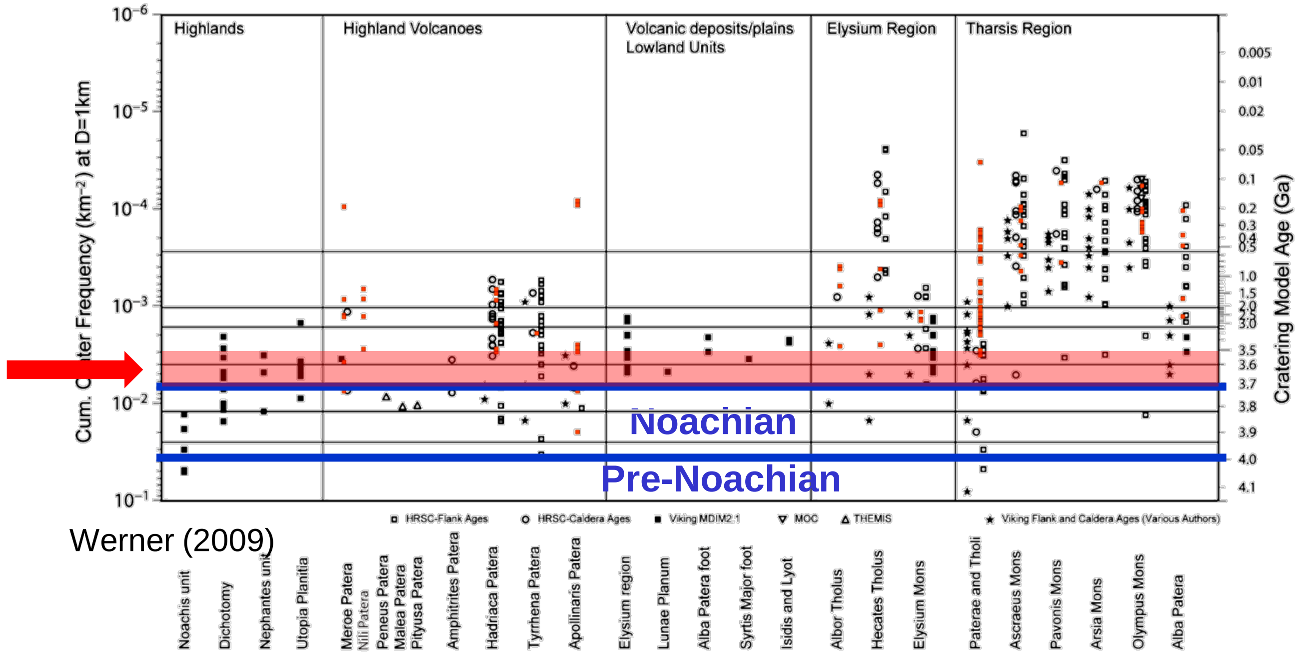
3.7+/-0.1Gy

Olivine Setting: Implication on volcanic activity



Werner (2009)

Olivine Setting: Implication on volcanic activity



Werner (2009)

Pronounced peak of volcanic activity in EH with flood-basalt-like plains volcanism (Tanaka et al. 1992; Head et al. 2002)

- The most prominent unit emplaced was Hesperian Ridged Plains (Hr, Hpl3) occurring within and outside craters throughout the lowland plains regions of both hemispheres
- The deposits were interpreted to be extensive lava flows erupted with low viscosity from many sources

=> Olivine-enriched lavas emplaced by fissural volcanism

Olivine: Witness of volcanic activity vs time

Extended deposits in low albedo highlands of early Hesperian age → Early Hesperian planetwide fissure volcanism

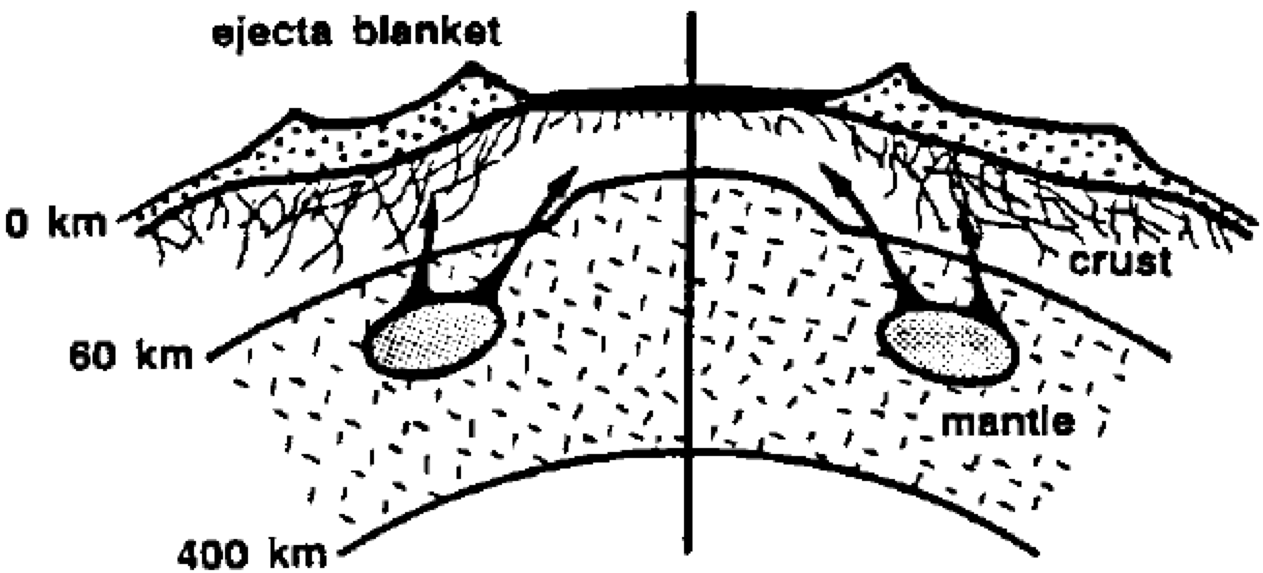
Olivine-poor in Noachian highlands →

1. Primary lithology deficient in olivine
2. Olivine has been depleted through later modification processes

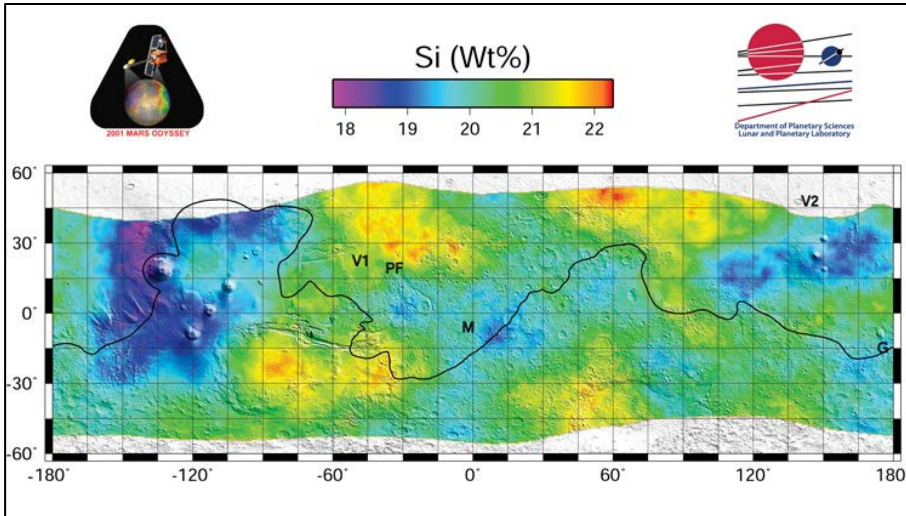
Thermal evolution of the planet

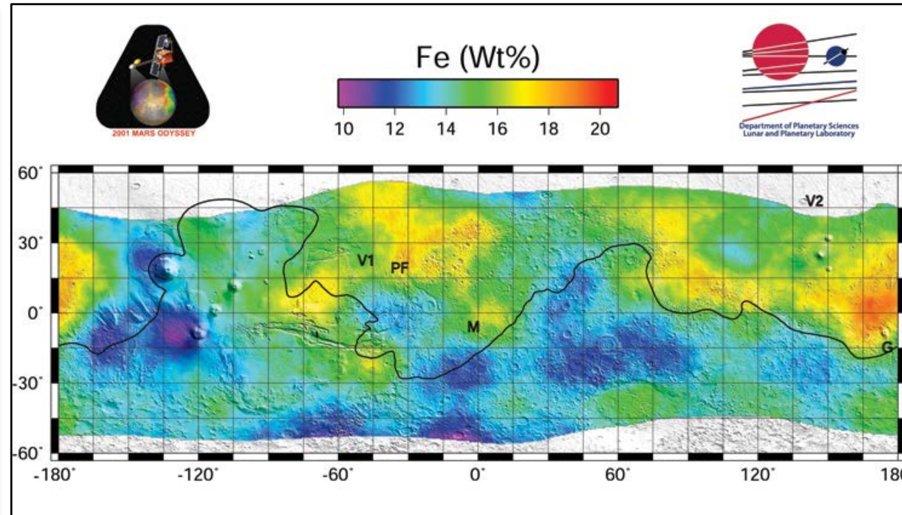
The enrichment in olivine of Hesperian lavas in comparison to Noachian lavas could be the result of the evolution of temperature of the mantle:

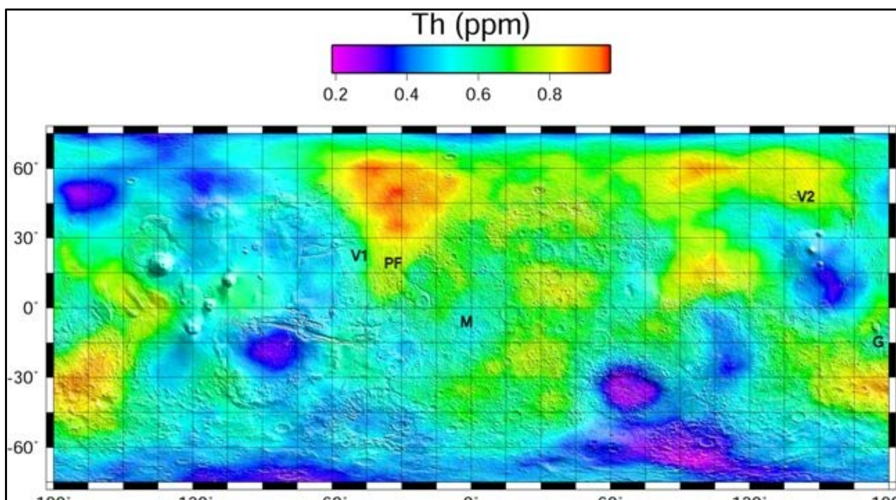
- Cooling during the Noachian could have precluded the olivine crystallization of olivine
- During early Hesperian, an increase of temperature could have occurred due to the radioactive elements (U, T, K) heating. This could have initiated partial fusion of the mantle and ascent of the magma through fissures formed by impacts (LHB).



Geochemical diagnostics : Gamma Ray Spectrometer maps

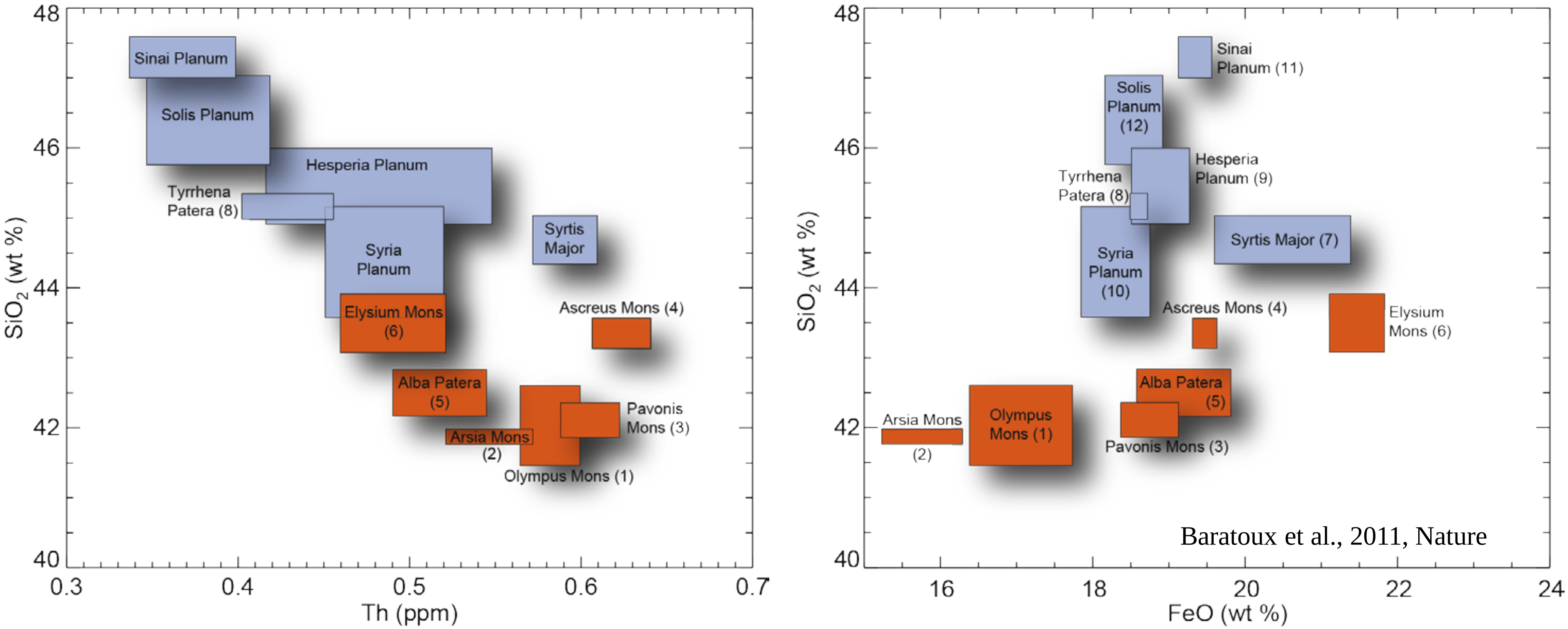






Geochemical diagnostics : Chemical changes over time

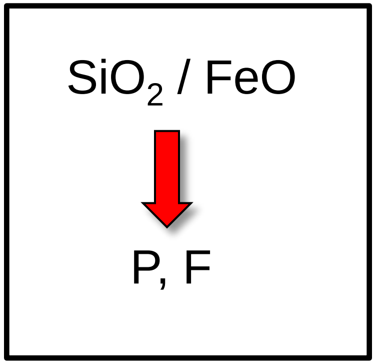
Young *volcanism* is Si-poor, old volcanism is Si-rich

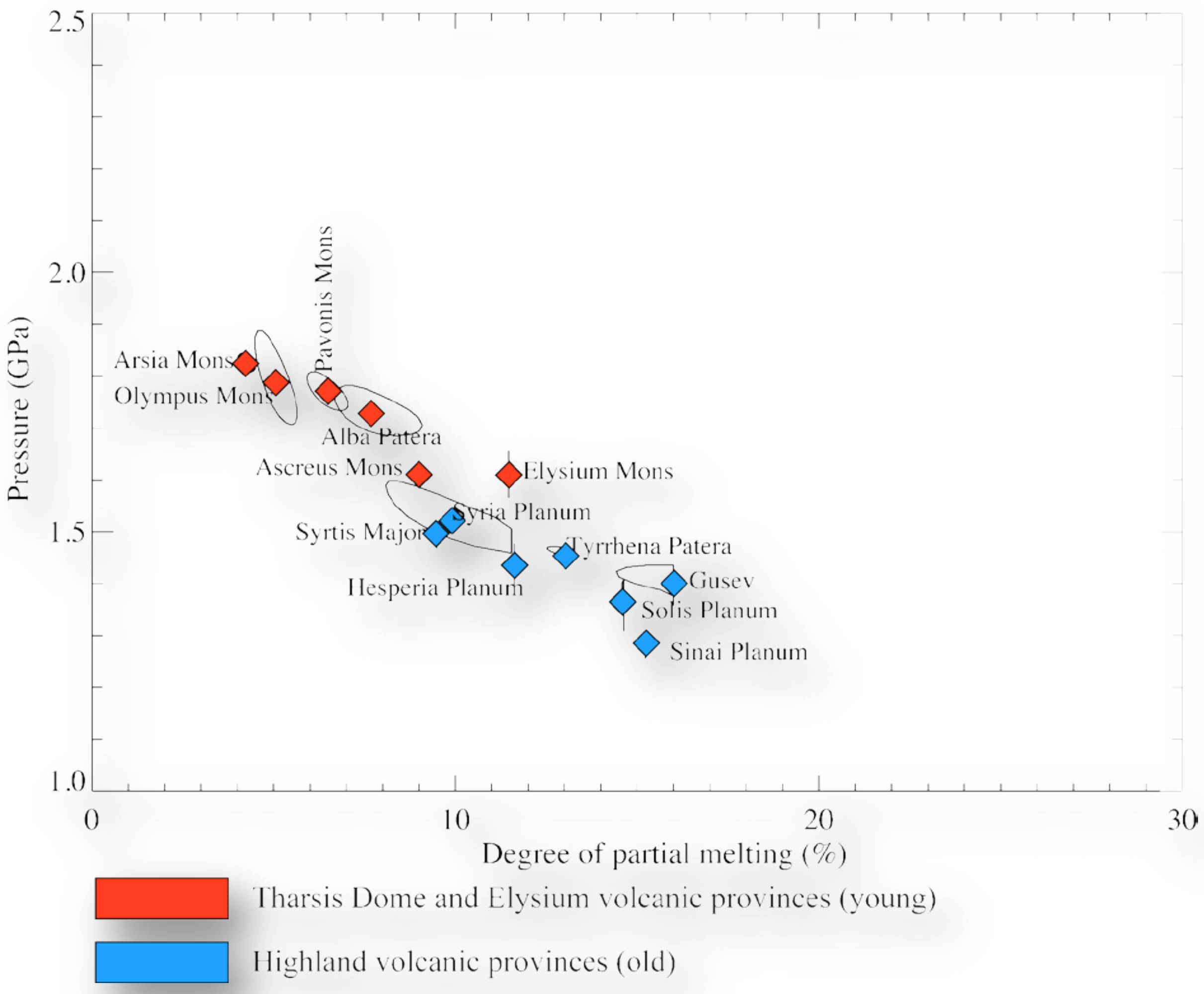


Si abundances -> Pressure : low Si – high pressure equilibrium melting
Th abundance -> degree of partial melting
Fe abundance -> linked to both pressure and degree of partial melting

Conditions of partial melting from chemical composition P / F from SiO_2, FeO, et Th abundances (wt%)

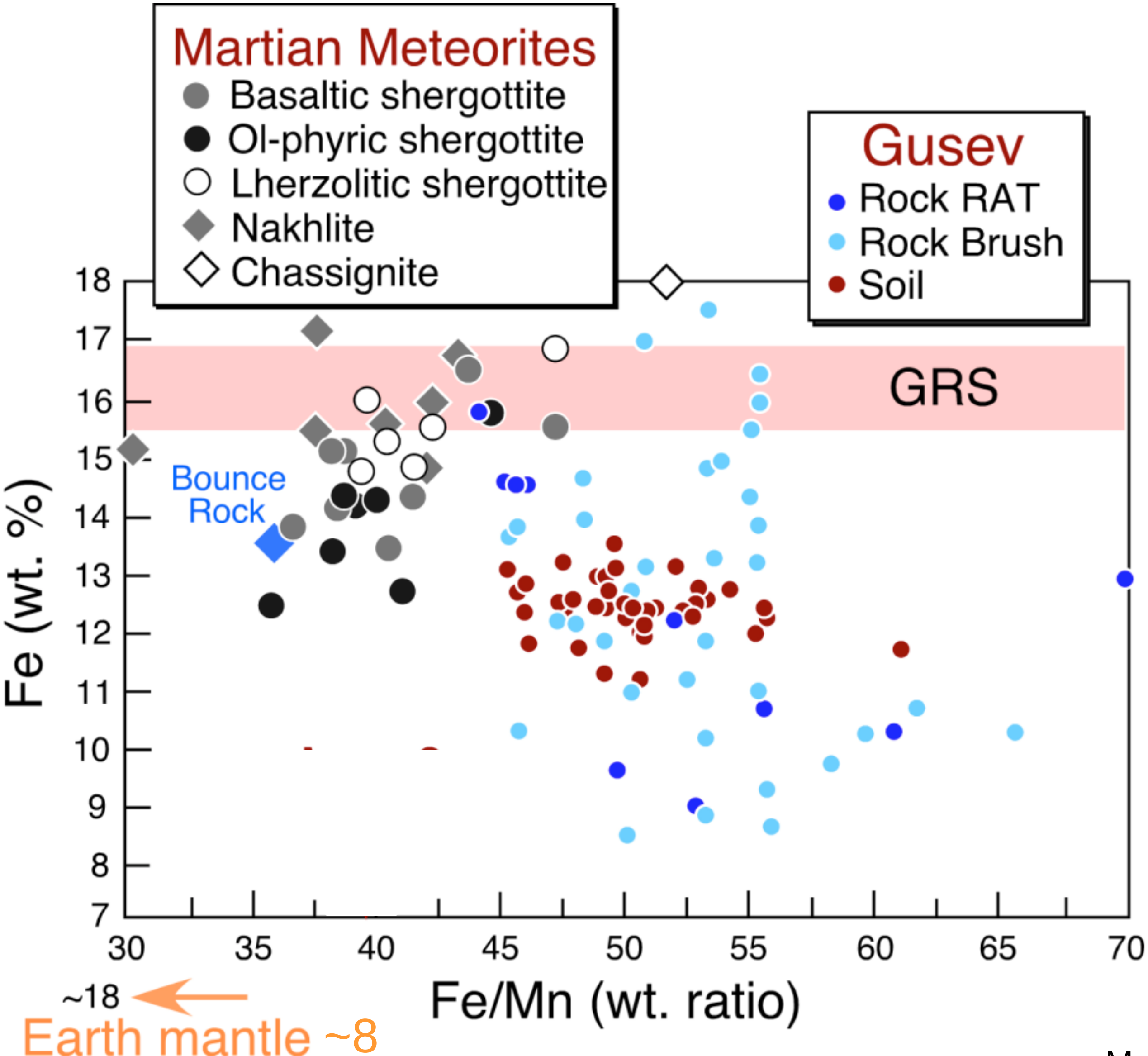
Starting point : DW85 mantle (Dreibus & Wanke, 1985)





Baratoux et al., 2011, Nature

Geochemical diagnostics (1): Fe content



McSween et al. (2009)

Geochemical diagnostics (2): Al content