REMANANT OF EARLY NOACHIAN CRUST ON MARS FROM MARTIAN METEORITES, IN SITU AND REMOTE SENSING DATA. Sautter1, V. Payre2, D. Baratoux3, M. Tople3, A. Cousin1, S. Bouley1, P. Beck2, L. Krämer Rugiu6, IMPMC-Sorbonne Université (61 rue Buffon, 75231 Paris France), violaine.sautter@mnhn.fr, 2Rice University (USA), 3IRAP (France), 4GEOPS, 5IPAG (France), 6CEREGE (France).

Introduction: Mars' Southern hemisphere is older, and higher in elevation by 6 km compared to the Northern plains. This dichotomy was formed between 4.5 and 4 Gyr ago (1). The Moon and the Earth show a wide diversity of crustal components (e.g. mare basalt and anorthosite crust on the Moon, basaltic oceanic or andesitic continental crust on Earth) and the topography of these two bodies may be correlated with the composition of the crust (isostatic compensation). In contrast, most of the known crustal materials from Mars - Martian meteorites collection, and in-situ and remote sensing observations, are uniformly basaltic in composition. In this context, the higher elevation in the southern hemisphere should be isostatically compensated by a thicker crust (> 100 km) (3). Such a thick crust appears to be inconsistent with the geoid-topography ratio and geochemical mass-balance of heat-producing elements (K and Th) present in the crust (4). In addition, the elevated density of iron-rich Martian basalts is incompatible with the inferred average density of an exclusively mafic crust (5). The simplistic vision of “a basaltic world” has been challenged, and a light felsic crustal component, buried beneath subsequent basaltic materials over the Noachian southern highland has been inferred to reduce the average crustal density to a value < 3.1 g/cm³. Here, we review evidences for low density igneous rocks recognized so far in the ancient southern hemisphere from Martian meteorites, in situ data and orbiting spectrometers, and we discuss the significance of these observations for the lateral extension and volume of the low density crustal component(s).

Orbital datasets: Elemental and mineralogical information retrieved from gamma ray and visible to infrared data sets indicate that exposed surface material is spatially dominated by basaltic compositions (5). However, the dust cover and secondary coatings obscure the signature of primary rocks whereas feldspar and quartz are spectrally neutral in the VNIR domain. Despite these difficulties, overlying the Si, Fe, K, Th maps (Fig 1) with that of geological units (6) reveals that six distinct regions enriched in incompatible elements K > 0.38 wt. %, Th > 0.57 ppm and depleted in Fe (Fe < 15.4 wt. %) are present in the southern hemisphere. Together, these areas form 2.9 % of the Southern hemisphere, or 2 % of the Noachian terrains. Considering the coarse spatial resolution of these chemical maps, the interpretation of these elevated concentrations are ambiguous. Do they represent sedimentary rocks or regional exposure of igneous rocks, or a combination of these materials?

Fig.1 Simplified geological map from (6). Si- K- Th- relatively rich areas hatched in yellow. Stars indicate Noachian terrains with remotely detected feldspar-rich rocks (CRISM, TES)

Meteorites: Only 2 specimens out of more than 150 SNC meteorites are Noachian (> 3.7 Gyrs): an orthopyroxenite (ALH8400) and a regolith breccia (several paired stones including NWA7033/7533/7445) (7). The latter is the first polymict breccia from Mars representative of the heavily cratered ancient surface of the southern hemisphere. Zircons found within lithic clasts dated at 4.43 Ga make them the oldest materials currently described from Mars. These breccias consist of a mixture of igneous coarse-grained clasts including up to 0.30 % of felsic (trachy-andesites, trachytes and monzonites strikingly enriched in K, Rb, Ba and Th-rich compared to SNC meteorites) materials, together with mafic olivine-free clasts, monomineralic fragments (pyroxenes and feldspars), and clast laden impact melts in a fine-grained crystalline matrix. High Ni and PGE concentrations measured in this breccia argue for at least 5% of a chondritic impactor. The evolved lithologies probably resulted from the differentiation of an ancient crust re-melted by a large impact, likely producing a melt sheet 4.428 Ga ago (7). More recent high precision-Pb ages and unradiogenic initial Hf-isotope compositions on zircons from NWA 7034, record an enriched andesitic-like crust extracted from a primitive mantle no later than 4.547 Ga ago (8). This would be the first evidence for an early evolved andesitic crust on Mars formed as early as 20 Myr after solar system formation.

In situ igneous ancient materials: Pathfinder analyzed 5 igneous rocks in Ares Vallis potentially from late Noachian to early Hesperian time, that were Si-rich and alkali-poor (SiO₂ ~ 57.7 +/- 1.7 wt. %; Na₂O+K₂O ~ 5.3 +/- 0.7 wt. %) identified as andesites (10) or altered basalt (9,10). At Gusev crater, the MER rover identified an evolved alkali-rich lithology at Co-
lumbia Hills that could represent a central uplift of older Noachian crater floor (11). At Gale crater, the Chemcam instrument analyzed 180 igneous rocks along a 20 km rover traverse (12, 13). They form 2 unexpected magmatic suites including five groups of rocks: an alkaline trend gathering basalts, basanites, gabbros, norites, trachy-andesites, and trachytes that are likely the source of sanidines in the Kimberley sedimentary formation (14), and a sub-alkaline trend including diorites and quartzo-diorites (Fig.2). As a whole, exploration by in-situ rovers describes 2 igneous series, an alkaline one (Colombia Hills, Gale) and a sub-alkaline suite including potential andesites (Ares Vallis, Gale). These different datasets, point to the genesis of various types of evolved rocks during the Noachian era with variable Na+K/Si.

![Fig.2 Total alkali vs. SiO2 of in-situ data, SNC and the Martian breccia.](image)

**Discussion:** The data presented above point to a complex picture of the Noachian magmatism with unexpected petrological diversity, including low density felsic rocks. Orbital data indicate occurrences of felsic rocks at localities distant by hundreds of km, isolated within spatially dominant mafic/basaltic terranes. Whether representing a buried ancient evolved crust or localized plutons, they point to lateral extension of felsic materials within the southern hemisphere. Sparse samplings corresponding to the meteorite breccia and in-situ data have amply shown that the Noachian crust is more complex than previously thought with 2 unrelated types of evolved compositions (andesitic sub-alkaline and alkali-rich) not necessarily contemporaneous. Regarding the sub-alkaline compositions (Ares Vallis and Gale), if these findings scattered across Mars’ southern hemisphere are associated in time, they would indicate a common andesitic early crust that could correspond to that extracted from primitive Martian mantle no longer than 4.547 Ga, ago (i.e., only 20 My after solar system formation) as inferred by analysis of NWA 7034. Interestingly, alkali igneous clasts and interclast matrix within the NWA 7533 look like fragments of the felsic alkali-rich rocks from Gale crater (15). While the evolved lithologies found in the meteorite breccia were formed 4.43 Ga ago by differentiation and fractional crystallization within an impact melt sheet, reworking the andesitic 4.547 Ga old protocrust (8), the alkaline rocks from Gale crater have been formed by fractional crystallization of a basaltic melt (16) potentially coming from an impact or partial melting of primitive mantle (17). Such alkali-rich lithologies have been never observed in Amazonian shergottites, which are olivine basalts similarly to materials detected from orbit in Hesperian and Amazonian lava flows covering the southern hemisphere (18). Note that within this large data set (meteorites and in situ data) plagioclase compositions range from oligoclase to andesine precluding anorthositic rocks observed in the lunar highlands’ primitive crust (19).

**Conclusion:** The occurrence of a dozen felsic widely scattered early Noachian-aged exposures in the southern hemisphere of Mars, along with the identification of felsic materials in Gale crater and in ancient Martian meteorite breccias, suggests a lateral extension of felsic materials, and a regional to global significance of these local observations. These felsic areas may be rare exposures of an extensive ancient andesitic crust deeply impacted during heavy bombardment early in Noachian and later buried under Hesperian and Amazonian basaltic volcanism. This would solve the paradox concerning the average crustal density that is too dense to be purely basaltic (g>3.1 g.cm$^{-3}$) considering the density required by geophysical models (between 2.7 and 3.1 g.cm$^{-3}$ for a crustal thickness around 60 km in the southern hemisphere). This conclusion is in agreement with (5) that explained this discrepancy by buried early felsic crustal materials. If Mars surface is essentially basaltic, its crust is possibly far from being uniform in composition, like the Earth crust, but with no evidence for a lunar-like anorthositic flotation crust. A more comprehensive representation of the different components of the Martian crust, and their respective volumes will hopefully emerge from the analysis of InSight data.

**References:**