HYDROTHERMAL ALTERATION IN A LATE HESPERIAN IMPACT CRATER ON MARS. N. Mangold[1], J. Carter[2], F. Poulet[2], E. Dehouck[1], V. Ansan[1], D. Loizeau[3], Laboratoire Planétologie et Géodynamique de Nantes, CNRS/Université de Nantes, 2 rue de la Houssinière, Nantes, France, nicolas.mangold@univ-nantes.fr (2) Institut d'Astrophysique Spatiale, CNRS/Université Paris-Sud, Orsay, France, (3) ESA/ESTEC, Keplerlaan, Holland.

Introduction: Phyllosilicates, remotely identified by the OMEGA and CRISM imaging spectrometers, are strong indicator of the interaction between water and rocks in the early history of the planet [1]. Depending on the geological context and mineralogical composition, the phyllosilicate-bearing deposits suggest that several settings could have occurred including weathering, hydrothermal circulation at depth from geothermal gradient or volcanic activity. Impacts can provide heat and geological structures that generate and focus convective hydrothermal systems [2, 3], but to date, only rare examples have been reported as related to the hydrothermal activity of craters [4].

The example discussed here is the crater named Majuro exhibiting hydrated silicates inside its floor and peak. This crater presents a unique combination of mineralogy (hydrated minerals) and morphology (alluvial fans) providing strong evidence for the presence of past hydrothermal activity.

Observations: Majuro crater is 45 km in diameter and is located on the Northeastern Hellas Basin rim (33°S, 84°E). Majuro crater seems relatively fresh compared to degraded craters from Noachian highlands. Ejecta are observed all around the crater. A fluvial channel locally cuts these ejecta from North to South. Except this braided channel, no fluvial flow crosses the ejecta showing that no sustained fluvial erosion occurred after the ejecta emplacement. The interior of Majuro crater appears relatively fresh too with a 10 km-large central peak. The crater floor is located at an elevation of -4 km, 1.5 km below the crater rims, indicating that only limited infilling took place after the crater formation. Fluvial landforms are observed along inner rims, especially on the northern side, where wide gullies have cut large alcoves. This erosion has generated two depositional fans that are embedded due to the proximity of the two main tributaries. These accumulated deposits form a single 15 km wide, 20 km long alluvial fan. This wide alluvial fan displays inverted channels typically hundreds of meters long and tens of meters wide (Fig. 1). The observed alluvial fan is similar to the series of fans observed in the Northern Hellas region and two other regions of Mars [5]. Majuro crater appears to postdate the Noachian period because of the presence of ejecta superimposed over the Hesperian smooth plain to the East. The crater retention age of the smooth plain is estimated at 3.59 +0.04/-0.05 Gy, which corresponds to the beginning of the Late Hesperian epoch in the used dating system. The estimated age for the ejecta (3.41 +0.11/-0.39 Gy) is also consistent with the end of the Late Hesperian epoch.

We identify two hydrated mineral classes, Fe/Mg-bearing phyllosilicates and opaline silica using CRISM data (Fig. 2). The most spatially extensive mineral class corresponds to Fe/Mg-phyllosilicates (mapped in red, figure 2). It exhibits the same absorption features throughout the crater, centered at 1.41, 1.92 as well as a spectral shoulder centered at 2.31 µm. Comparison with laboratory spectra shows that the best match to our detections is a (Fe,Mg)-vermiculite phyllosilicate. These Fe/Mg phyllosilicate signatures cover a large section of the Northern flank of the central peak, part of the alluvial fan and small outcrops at the boundary between the floor and the inner rim walls. In THEMIS thermal images, there is a strong difference in brightness (temperature) between the section of the alluvial fans where phyllosilicates are detected, and the upward unaltered section. The higher alteration of the lower southern section of the fan suggests that the material is more indurated than the unaltered section of the fan.

In this altered section, inverted channels are still visible in this rougher material as well as layering as expected in alluvial deposits, showing that this area still corresponds to the fan. Small rounded structures appearing as small topographic domes are observed at the contact between unaltered and altered sections of the fan. Some of these domes cut unaltered sections of the fan, especially close to the boundary with the unaltered section of the fan. Similar domes have been observed in bedrock material in Toro crater [4] and interpreted as vents or mud volcanoes due to hydrothermal circulation.

In summary, the hydrated minerals are in light-toned layered fan deposits containing inverted channels and small rounded domes observed below an alteration front. The uppermost section of the fan above the alteration front is unaltered and exhibits a darker tone with less induration/cementation.

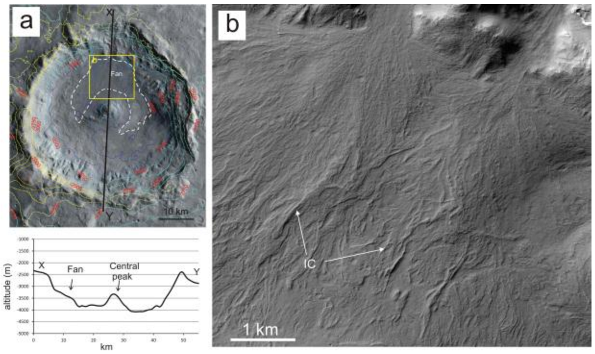

Fig. 1: (a) Close-up of HRSC image of Majuro crater. Topographic profile associated to HRSC DEM showing the crater. (b) CTX close-up on the two valley outlets of the northern rim with two intricate alluvial fans. Inverted channels (IC) are observed in sections of these fans scoured by wind.

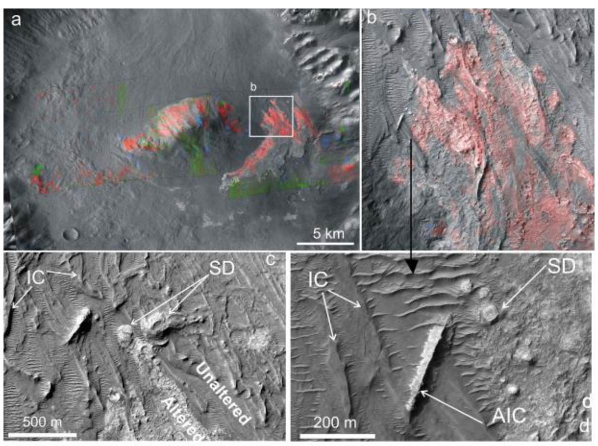

Fig. 2: Spectral map using three CRISM cubes on the crater floor and peak plotted over CTX image. Red: Fe/Mg phyllosilicates. Blue: Opaline silica. Green: Olivine. (b) Close-up over the southern part of the alluvial fan. Phyllosilicates are observed where the fan appears brighter and more indurated. (c) and (d) HiRISE image close-ups at the transition from the unaltered fan (dark) to altered section of the alluvial fan (bright).

Interpretation: Questions regarding the local origin of alteration exist for craters because excavation could have provided most of the altered (and non-altered) material in the central peak, rims and ejecta. However, excavation cannot explain material transported in fans. Alluvial deposits indeed contain sand grains and pebbles that would display an average proportion of altered material everywhere in the fan, and not in distinct levels. Alteration could be related to weathering at the surface of Mars. However, the small circular domes are easier to explain by bottom-up alteration, not by top-down weathering. An hydrothermal system is the easiest explanation to all observations. The most obvious process would be an impact-related hydrothermal system. Predicted duration for the heating due to a 45 km impact can reach several 10,000s to 100,000s years [3, 6], a period by far long enough to explain the observed hydrated silicates. According to this type of model, temperatures that could reach 100s of Celsius would allow minerals to alter quickly, i.e. at the scale of years. While alteration alone can be explained by melted subsurface ice, the formation of alluvial fans is difficult to explain by hydrothermal upwelling on the rim uppermost section. Alluvial fans are typical of overland flows on rims as a consequence of precipitation [5]. Previous studies suggested that a Late Hesperian climate is able to explain local runoff in transient episodic climate [e.g., 7]. Melting would be easier if the impact crater was still warm at the time of snow precipitation. It comes out that the easiest scenario to explain observations is: (1) formation of alluvial fan by snow deposition and melting (either climatic-related or impact related), (2) infiltration by water inside the fan, and (3) subsequent hydrothermal circulation due to the presence of the warm impact melt on the crater floor.

Conclusion: Majuro crater shows that late processes subsequent to the most intense alteration period in the early Mars are able to support local aqueous activity with alteration coupled to fluvial activity. Such local niche may be interesting for exobiological researches as if organisms were formed earlier, the local warming due to the crater could have reactivated them. Craters with alluvial fans and hydrated minerals are unique locations were multiple aqueous processes could have occurred and triggered biochemistry. Our example may therefore be interesting for a better understanding of hydrothermal processes during the cold Mars period, as well as for better constraining their role during earlier periods of Mars. The larger Gale crater selected as a landing site for the Mars Science Laboratory mission contains alluvial fans that may have experienced some of these processes and could give answers to these questions.

References: [1] Poulet et al., *Nature*, 438, 623-628, 2005. [2] Newsom, 1980, *Icarus*, 44 (1) 207-216. [3] Schwenzer and Kring, 2009, *Geology*, 37, 1091–1094. [4] Marzo et al., *Icarus*, 208 (2) 667-683. [5] Moore and Howard (2005) *JGR*, 110 (E4), E04005. [6] Abramov and Kring, *JGR*, 110, E12S09. [7] Mangold et al., *Science*, *305*(5680), 78 -81.