LATE STAGE AQUEOUS ALTERATION IN THE NORTHERN PLAINS OF MARS: HYDRATED SILICA IS THE KEY. J. Carter[1,2], M. Pineau[2], N. Mangold[3], L. Le Deit[3] [1]IAS, CNRS/Paris-Saclay University, Orsay, France (john.carter@ias.u-psud.fr). [2]Laboratoire d'Astrophysique de Marseille, CNRS/Aix-Marseille University, France. [3]Laboratoire de Planétologie et Géosciences, Nantes University, France.

Introduction: The northern plains of Mars (NP) are a collection of geologic units topographically depressed with respect to the southern highlands. These units are overwhelming younger than the Noachian epoch, mostly lacking aqueous alteration signatures to the exception of craters (impact-generated or excavated [1]). Continued study of aqueous alteration in the NP is warranted by lingering questions relative to e.g. the putative existence of ancient buried sediments or even an ancient northern ocean. Expanding from a previous survey [2], we review here a number of locations of the NP which show signs of localized aqueous alteration, and which are not related to remnant highland alteration or impact processes. We focus on selected sites which are most consistent with igneous and mud volcanism.

Methodology: For the purpose of this study we utilize CRISM/MRO data [3] looking for hydrated absorption features in the 1-2.6 µm range. The methodology is described in [4]. We focus on 3 regions of the NP: site A (Acidalia, ~5E 45N), site B (Utopia, ~100E 30N), site C (Arcadia, ~175E 40N). Within each site we detected several occurrences of the same mineralogy in seemingly the same context and within a coherent geologic unit, suggesting that we are seeing regional processes at Mars and not a freak event.

Site description: We searched for the full diversity of secondary hydrated minerals but only found two classes: hydrated (opalized) silica (HySi) and poly-hydrated sulfate salts (PHS). No phyllosilicate, carbonate, or high temperature phases (e.g. talc, prehnite) have been found, contrarily to what is more commonly found within NP impact craters. Example detections at each site are given in Figure 1. Site A has four localities with roughly similar occurrences of HySi ±PHS in a specific geomorphic context. These are found within or at close proximity to the lobate thumbprint terrain unit [5]. HySi is found i) associated with km-sized mounds (either on them or likely as lag deposits from mound erosion), ii) within sinuous features themselves sprouting cone-like features, and iii) within small pitted cones. The latter two features pertain to lobate units which are interpreted as flows. In one instance (Fig 1A) the dome or mound is partially covered in PHS and HySi, it has fissures interpreted as vents (1A, blue box), and from the mound is seemingly spewing the lobate flow unit. Within that lobate unit is found a cluster or small pitted cones typically 10-100s m in size (1A, red box). The other location shown at Site A (Fig 1B) exhibits a field of pitted cones and light-toned "splotches" closely associated with them. Site B (Fib. 1C) resembles site A with a similar association of a PHS-rich dome and sinuous features which exhibits pitted cones in them and also around them. The sinuous features form a network connected to the dome, and may be similar to the curvilinear chain of mounds reported in [6]. These cones, often in clusters, and the sinuous features here too exhibit HySi. Site C differs in that only altered domes (sometimes with HySi only, sometimes with PHS) are present, they lack small cones or sinuous features and are heavily eroded.

Discussion: Our observations of HySi ±PHS argue in favor of localized aqueous alteration that is authigenic to the NP. The domes, cones and flow features cannot be individually dated but they pertain to geologic units that postdate the Noachian. While the domes have visibly undergone some erosion, there is no argument in favor of them being erosional remnants of an older unit, but rather to be an extrusive feature postdating the geologic unit age. The same goes for the pitted cones and sinuous/flow features. Their precise stratigraphic relationship remains to be studied.

Mud volcanoes come in a wide variety of shape and sizes [7]. These include large domes when the eruptive phase is dominated by viscous mud (low water content), but more often as pitted cones. Clusters of pools and small mud cones (gryphons) are also known to occur. The potential for Mars to have harbored mud volcanoes is long know, and several NP features as reported here (pitted cones, curvilinear features, «splotches») have been proposed as possible mud volcanoes (e.g. [8]). For site A in Acidalia, there is a striking correlation of the alteration signature with features found within the lobate thumbprint terrains, which cones have previously been interpreted as mud volcanism based on morphology alone [5] and these terrains themselves have been interpreted as tsunami deposits from a Hesperian ocean.

Generally, the pitted cones of site A and their associated mineralogy also resemble other features further south (~20°N) in Chryse Planitia [9] where they have also been interpreted as mud volcanoes. The mineralogy there is also HySi.

Site B in Utopia Planitia is just west of the study area of [10] which proposes mud volcanism to be a regional process expressed as erupted etched flows within the

Vastitas Borealis Formation (VBF). Our site is precisely at the contact between the VBF and a smooth plain unit, any may be another regional expression of mud volcanism triggered by overburden from rapidly emplaced sediments.

For sites A-B, in addition to the pre-existed morphological criteria in favor of mud volcanism, we can now add the mineralogical footprint. More work is required to understand how (fast) HySi or PHS can precipitate in such context, especially if formed when liquid water was not stable at the surface of Mars.

Site C is interpreted differently. The buttes are degraded and partly buried by the latitude-dependent mantle. It is a regional occurrence on a number of buttes over 100s of km sometimes co-located with fissures that could have played as feeding dikes. Igneous volcanism is possible here with vents or springs such as found e.g. in Nili Patera [11]. Of high interest, one such site has been proposed as a landing site for human exploration, for which the HySi deposits would provide strong science and ISRU rationale.

Perspectives: This ongoing study expands the known diversity of aqueous environments in the NP which took place after the Noachian. The mechanism of HySi formation in a mud volcano context needs to be understood. If confirmed, it will strengthen the mud volcanism hypothesis for a large number of sites where such hypothesis had been proposed usually on the basis of morphology alone, and not only within the NP (e.g. [12,13]) . Of particular interest we will be attempting to characterize the source of the water reservoir (ice vs sediments) and the energy source (entirely sedimentary volcanism or with an igneous contribution?).

References: [1] Pan L. et al. (2017) 10.1002/2017JE005276. [2] Carter J. et al. (2012) LPSC 43, #1978. [3] Murcie S. et al. (2007) 10.1029/2006JE002682. [4] Carter J. et al. (2022) 10.1016/j.icarus.2022.115164. [5] Di Pietro I. et al. (2021) 10.1016/j.icarus.2020.114096. [6] Orgel C. et al. (2018) 10.1029/2018JE005663. [7] Mazzini A. et al. (2017) 10.1016/j.earscirev.2017.03.001. [8] Farrand W. et al. (2005) 10.1029/2004JE002297. [9] Komatsu G. et al. (2016) 10.1016/j.icarus.2015.12.032. [10] Ivanov M. et al. (2014) 10.1016/j.icarus.2013.09.018. [11] Skok J. et al. (2010) 10.1038/ngeo990. [12] Dapremont A. et al. (2020) 10.1029/2020JE006390. [13] Pondrelli M. et al. (2011) 10.1016/j.epsl.2011.02.027

Figure 1. CRISM mineral maps (cyan is HySi, green is PHS) over CTX background. Top are site A. Bottom-left is site B, bottom-right is site C. North is up.