POTENTIAL CRYOSPHERIC MUD VOLCANISM IN THE NORTHERN PLAINS OF MARS: GEOLOGIC AND ASTROBIOLOGICAL IMPLICATIONS. J.A.P. Rodriguez[1], Jeffrey S. Kargel[1], Dorothy Z. Oehler[1], David A. Crown[1], Victor R. Baker[2], Goro Komatsu[3]. [1]Planetary Science Institute (1700 East Ft. Lowell Rd., Suite 106, Tucson, AZ 85719-2395 – alexis@psi.edu), [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092, [3]IRSPS, Università d'Annunzio, 65127, Pescara, Italy.

Introduction: The Vastitas Borealis Formation (VBF) is a sedimentary unit that covers most of the northern plains on Mars [1] and could be a marine deposit that formed in association with a Late Hesperian ocean or the ocean's sublimation lag [2]. The VBF contains tens of thousands of potential mud volcanoes (MVs) [3-7]. MVs occur both within the VBF materials that cover the northern plains interior basins' depocenters [6] and its boundary materials [7]. Based on knowledge of terrestrial mud volcanism, it has been proposed that the expulsion of fluidized sediments resulted from compaction of rapidly emplaced, thick deposits of fine-grained sediments. Methane and carbon dioxide typically accompany these fluids, either being generated by thermogenesis of kerogen during burial or by the release of methane from clathrates [6].

Evidence of younger northern plains mud volcanism: The VBF also includes MVs that populate broad, extensively fractured, hilly plains, which also include widespread pedestal craters (Figs. 1 and 2). These craters are thought to represent ejecta blanket armored remnants of former, higher standing paleo-surfaces that underwent large-scale erosion [8]. Accurate reconstructions of these paleo-surfaces at regional scales would be complicated. However, the presence of MVs that immediately adjoin the eroded, irregular flanks of the pedestals implies that local paleo-surface reconstructions are sufficient to determine relative ages between these features. While the absolute ages of these MVs remain uncertain, their formation likely postdated the ocean's removal as well as significant pedestal-crater-forming plains erosion.

Martian mud volcanism in the presence of a cryosphere: Martian paleo-climatic evolution suggests that a thick cryosphere, including several kilometers of intermixed rocks and ice, has existed beneath the Martian surface since the Early Hesperian [9]. Thus, the younger MVs likely formed in the presence of a multi-kilometer thick cryosphere. The extremely cold, ice-bound, cryosphere-forming geologic materials would have increased structural stability, thereby generally hindering compaction [7]. High-velocity ascension of fluidized mud through cryospheric fractures could have resulted from the exsolution of buried gas-saturated (e.g., CO_2, CH_4) fluids and clathrates. These flows could have potentially traversed the cryosphere without freezing. Assuming that compaction was hindered within the cryosphere, eruptive episodes of these gas-rich fluids provide a mechanism that can explain the formation of cryospheric northern plains MVs. This mechanism implies that gaseous overpressurization occurred much later than the ocean's formation and removal. It is possible that non-aqueous methane eruptions could have produced cones, morphologically similar to the MVs, but made up of mostly dust and lacking associated flow features. An important observation is the absence of surface salt deposits in association with MV locations. Pressurized water discharges, resulting from clathrate dissociation, would tend to have been mostly free of dissolved salts [2]. Faulting into the gas-rich regions, perhaps aided by changes in the cryosphere's thermal structure due to climate change [8], or decompression during major surface erosional events [8], could have triggered the eruptive episodes. A major northern plains landscape denudation stage is thought to have happened during the Middle Amazonian [8].

Potential VBF gas enrichment mechanisms: The collapse of highly pressurized highland aquifers [11], perhaps associated with the dissociation of deeply buried clathrates [12], released huge catastrophic floods, which possibly formed a northern plains ocean [13]. The hypothesis that the floods, some possibly reaching 100s of meters in depth, sourced from pressurized groundwater systems implies that they could have been gas saturated. The high pressures within the deeper waters could have made it possible for the flows to preserve and transport the gas, which then became trapped within the VBF sediments. Furthermore, if the ocean rapidly developed an ice cover [2], some of the gases could have also become trapped within the concealed marine waters and thereby retained within ice after the ocean froze. The burial thickness within the VBF, or below it, could have reached several kilometers. In this case, thermogenesis of abiotic organics delivered to Mars by meteorites and interplanetary dust particles (IDPs) and Fischer Tropsch Type reactions could have generated substantial amounts of abiotic methane [10]. An alternative, or complementary, scenario to explain the geographic exclusivity of MVs in the northern plains is that the gas had biogenic sources. A requirement, however, is that liquid aqueous environments need to have prevailed for a significant period for methanogenic life to produce the gas saturation.

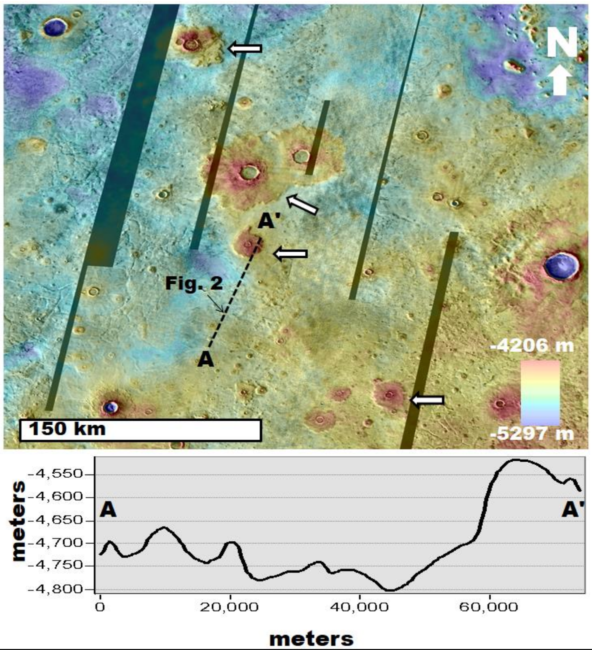

Fig. 1 View of part of Acidalia Planitia, which includes numerous pedestal craters (white arrows) as well as widespread MVs (e.g., Fig. 2). The MVs occupy regional plains surrounding the pedestal craters, and consequently, the region records a history of collapse and large-scale erosion (~200 m based on the elevation profile), which was followed by mud volcanism.

Geologic constraints on the distribution of cryospheric mud volcanism: The known distribution of Martian MVs indicates that, they preferentially occur within the VBF. Some of these MVs may have formed similarly to those on Earth, and these should be confined to basin depocenters infilled with mostly fine-grained sediments. The presence of cryospheric MVs in the northern plains indicates that a separate combination of unique geologic conditions occurred in the area of the VBF, which did not happen elsewhere on Mars. Other low-lying regions of Mars include potential marine, lacustrine, and fluvial sediments within and below the cryosphere. Hellas Planitia, for example, includes important geologic similarities to the northern plains. It is linked to outflow channels and includes sedimentary deposits up to several kilometers thick in a basin. As in the northern plains, there is evidence of of buried volatiles [14]. The sedimentary infills of these basins have the potential for the cryospheric trapping of abiotic and possible biogenic methane. However, MVs are mostly absent; suggesting that the distribution of sub-cryospheric methane/carbon dioxide saturation was heterogeneous and preferentially formed in the northern plains, or that another required constraint, such as occurrence of thick fine-grained deposits, was absent. The initial distribution of organic-rich meteorites should be random as well as the locations of the basins where these would have been deeply buried. However, Oehler and Etiope [10] indicate that outflow floods could have transported meteoritically delivered organics from a large catchment area and concentrated them with the fines in the distal depo-centers. If these conditions occurred, thermogenesis could have increased the gas content within the VBF.

These issues lead to the question on whether the non-random distribution of cryospheric MVs might represent the location of enhanced biogenic methane production due to the selective geographic adaptation, or due to the restriction of long-term life-friendly wet conditions within fine-grained sediments only within the northern plains. If so, the absence, or lower abundance, of potential organisms from other thick sedimentary deposits within the Martian hydrosphere, could explain the lack of MVs associated with those deposits.

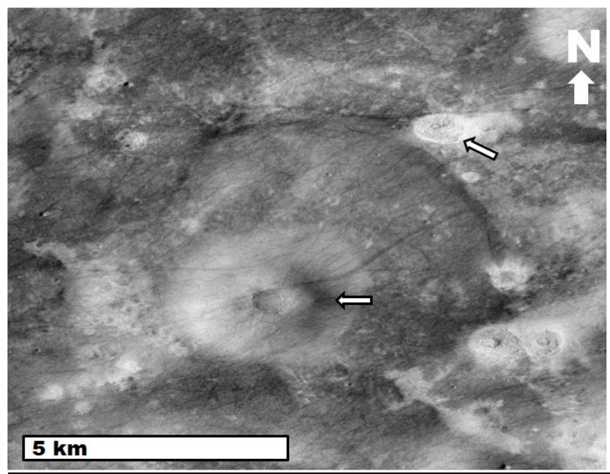

Fig. 2 View of possible supra-cryospheric MVs (white arrows). For context and location see Fig. 1.

References: [1] Tanaka et al. (2005) USGS SIM-2888. [2] Kreslavsky and Head. (2002) J. Geophys. Res. 107, 5121.[3] Tanaka, (1997) J. Geophys. Res. 102, 4131–4150. [4] Farrand et al. (2005) J. Geophys. Res. 110, E05005. [5] Skinner and Tanaka, (2007) Icarus 186, 41–59. [6] Oehler and Allen. (2010) Icarus 208, 636-657. [7] Rodriguez et al. (2012) Geo. Res. Lett, 39, L22201. [8] Skinner et al. (2012) Geology, 40(12) 1127-1130. [9] Clifford and Parker (2001) Icarus 154, 40-79.[10] Oehler and Etiope (2017) Astrobiology, 17, 1233–1264. [11] Carr (1979) Geophys. Res. 84, 2995–3007. [12] Rodriguez et al. (2006) Geophys. Res. Lett., 33, L18203. [13] Baker et al. (1991) Nature 352, 589-594. [14] Moore and Wilhelms (2001) Icarus, 154, 258-276.