Methane on Mars: possible geomorphic indicators of methane emissions in three impact craters

METHANE ON MARS: POSSIBLE GEOMORPHIC INDICATORS OF METHANE EMISSION IN THREE IMPACT CRATERS. E. Mariani[1] and P. Allemand[1], [1]Université Claude Bernard Lyon 1, LGL-TPE, France (elettra.mariani@unich.it)

Introduction: From 1999 methane was detected in the atmosphere of Mars through terrestrial ground-based observations, then from 2004 by the instrument PFS (Planetary Fourier Spectrometer) on board of Mars Express (from 2004). In 2012 NASA MSL mission's Curiosity rover also detected methane plume emissions in Gale crater. Other detections were realised by the ACS (Atmospheric Chemistry Suite) and NOMAD (Nadir and Occultation for MArs Discovery) on board of ESA-Roscosmos ExoMars Tracer Gas Orbiter in 2018 and after. After the Global dust storm in 2018 the concentration of methane decreased drastically (10 to 100 time lower [5]) and TGO stopped detecting it, as opposed to the Curiosity rover, which continues to this day to detect plumes of methane [8][9]. The topic stirs much debate in the scientific community, not only for its astrobiological implications but also regarding possible theories that reconcile current and past observations from the orbiters and the Curiosity rover [5][15]. In the attempt to bring some clarity the purpose of this work is to map possible paleoindicators of methane emissions, considering presence of possible reservoirs of methane in the subsurface of Mars active until now (i.e. Gale crater, Mars [14].

Methods: The aim of this study is to compare the geology and geomorphology three impact craters (Gale, Gusev and Vernal crater) in which methane has been detected from orbit and/or from ground. We draw geological and geomorphological maps using satellite and in situ hyperspectral data (for Gusev, Spirit - for Gale, Curiosity), as well as high-resolution Context Camera (CTX) and HiRISE images (MRO mission) were also considered. Digital Elevation Models (DEM) were calculated from the highest resolution images that are available.

Results: Fig. 1 shows the geomorphological map of Gusev crater (Mars) based on CTX, HiRISE and CRISM images in addition to Spirit rover observations in Columbus Hills area. This crater is located at the dicothomy boundary between north and south hemisphere of Mars. It is also filled with both volcanic sediments from Apollinaris Patera from north and fluvial-lacustrine sediments from Ma'adim Vallis from south. The potential candidate areas for fossil methane emissions are marked by Swollen terrain unit and Columbus Hills unit where besides mounds and knobbed terrain, it was detected opaline silica mineralogical traces that corresponds to possible methane indicators [11].

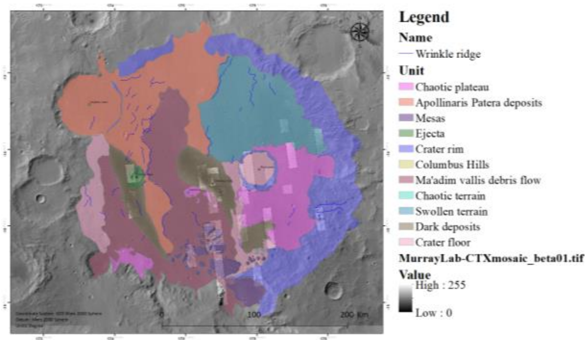

Fig. 1. Geomorphological map of Gusev crater (Mars).

A similar configuration units and paleo-geomorphological indicators have been found and mapped in Vernal crater (Mars) (Fig. 2). This crater is located in SW of Arabia Terra and by its configuration it's seems to be filled by volcanic deposits in the North and lacustrine deposits in the south [1].

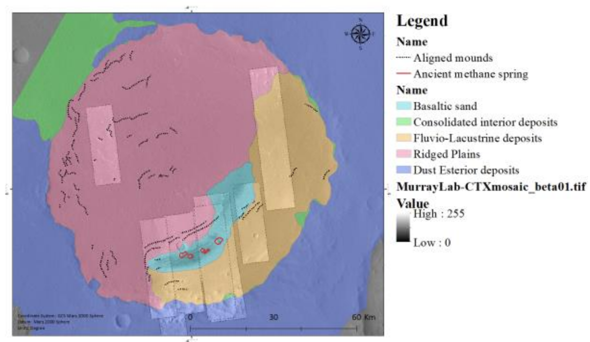

Fig. 2 Geomorphological map of Vernal crater (Mars) SW of Arabia Terra.

The division of these two environments is well delimited by allined mound that limits the volocanic deposits and well cemented basaltic sands which contains mounds feature-like (Fig. 3) that represents possible methane indicators for fossil methane emissions and traces of opaline silica materials. Unlike Gale crater (Mars) where there was and it is still detected methane spikes and presence of sulfates [6] [8], Gusev and Vernal crater (Mars) present similar units and mineralogical traces. Opaline silica, in fact, occurs in several locations on Mars and confirm the presence of aqueous environments. This trace is very important because it infers the possible interaction between water and mafic (Mg- and Fe-rich, silica poor) rocks which rapidly reacts with olivine and pyroxene (presence confirmed by CRISM images in the areas selected as possible methane spots for ancient emissions in Gusev and Vernal crater, Mars) and it could have been precipitated in hydrothermal or lacustrine evaporitic environment, which corresponds to the past environments found in these two impact craters (Gusev and Vernal crater) [2].

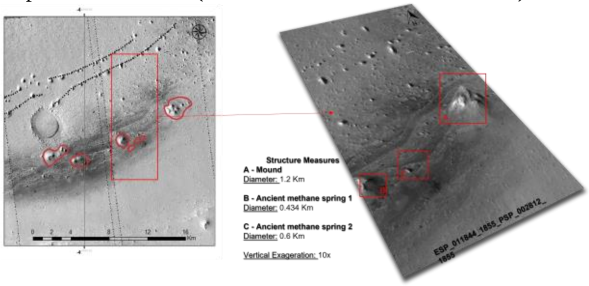

Fig. 3. Digital Elevation Model (DEM) of a stereo pair HiRISE ESP_011844_PSP_002821_1855 of mounds that have been classified as ancient methane spring also by Allen C.C. et al., 2007.

In this project it was also mapped Gale crater (Mars), in order to try to compare and understand the difference between ancient methane spikes (which mechanism was responsible for mound structure-like formations and developmente of all the past detections of methane in the atmosphere of Mars) and recent emissions of methane (registered in Gale crater by the rover MSL Curiosity). The area of Fig. 4 is where the MSL (Mars Science Laboratory) rover Curiosity's TLS (Tunable Laser Spectrometer) detected methane spikes until now. Gale crater (Mars) is located in a deep fault potential area due to it's closeness to the dichotomy boundary between north and south hemisphere and from its composition surface consisting mostly of sulfates.

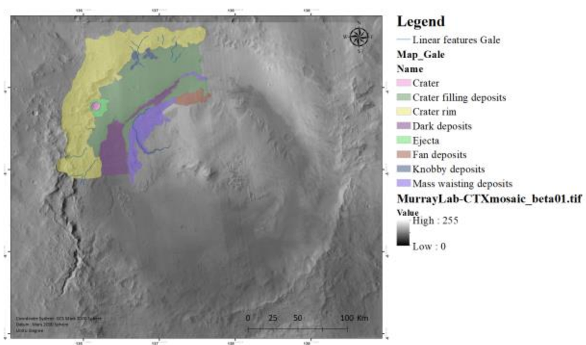

Fig. 4 Geomorphological map of methane spike emissions area delimited by Luo et al., (2021) from MSL rover detections from 2021 until nowadays.

This configuration could allow the presence of a methane reservoir formed in the past (when there were conditions that allowed the formation of this hydrocarbon gas) that over time, unlike other spots such as Gusev and Vernal crater has not been depleted; but on the contrary continues to gradually emit methane. These emissions occur mainly at night [15] and then disappear during the day. This may be explained by a near-surface production is occurring widely across Mars, it must be accompanied by a fast methane destruction or sequestration mechanism, or both. [13][15]. Both of these possibilities are already the subject of new studies to try to solve this issue.

Moreover the area represent the extend of the methane spikes detected since nowadays and it's possible to see from the map (Fig. 4) that the morphologies and units are really similar to the ones found in Gusev and Vernal such as Dark terrains, Mounds and Knobby terrains. By the current studies made on this topic and the geomorphological and mineralogical analysis made in this research it it possible to hypothesize that methane was formed in the past on Mars and stored in reservoirs all over the subsurface. Two types of "methane emission spots" can be seen in this work: the first encompassing Gusev and Vernal crater (Mars), indicate spots where the methane reservoir in the Martian subsurface has been depleted over time and left fossil traces of minerals such as opaline silica and paleostructures such as mounds that allow us to reconstruct their geological history. The second type, concerns points such as Gale crater (Mars) where the reservoir has not been depleted, on the contrary it continues to emit methane that fails to exceed a certain limit in the Mars atmosphere to be detected even by orbiters around the planet due to some mechanism of instantaneous destruction of this gas in the atmosphere. Unfortunately, there is still not enough data to allow the solution of this puzzle, but from the minimal concentration of methane recorded from 2018 to date by TGO, it is possible to infer that there are multiple points such as Gale crater on the surface of Mars that still emit methane from subsurface reservoirs [6][7]. In addition, to conclude, it seems that for now, the MSL rover Curiosity in Gale crater (Mars) provides the ground truth limit for methane detections on Mars nowadays. While TGO measurements provides the boundary conditions for methane detections in the atmosphere of Mars.

References: [1] Allen C.C. et al., (2007). [2] Encrenaz et al., (2008) *Advances in Space Research., 42(1)*, 1-5. [2] Hauber E. et al., (2011) *Encyclopedia of Astrobiology. Springer, Berlin, Heidelberg.* [4] Komatsu G. et al., (2011) *Planetary and Space Science, 59 (2-3), 169-181*. [5] Korablev O. et al. (2019) Nature, 568(7753), 517–520. [6] Luo et al., (2021) *Earth and Space Science, 8, e2021EA001915* [7] Max M.D. et al., (2013). *Energy Resources for Human Settlement in the Solar System and Earth's Future in Space (pp. 99–114)*. [8] Moores et al., (2019) *Geophysical Research Letters*, *46*(16), 9430–9438 [9] Oehler D.Z. et al., (2017) *Astrobiology, 17(12), 1233–1264*. [10] Pozzobon R. et al., (2019) *Icarus, 321, 938–959*. [11] Ruff S.W. et al., (2020) *Astrobiology*, *20*(4), 475–499. [12] Skinner J.A. et al. (2009) Marine and Petroleum Geology, 26(9), 1866–1878. [13] Smrzka et al., (2021) *Chemical Geology*, *580*, 120357. [14] Webster et al., (2020) *Astronomy & Astrophysics*, *641*, L3. [15] Webster et aòl., (2021) *Astronomy & Astrophysics*, *650*, A166.