PERMITTIVITY MAPPING AND THE CASE FOR RELICT ICE IN THE SHALLOW SUBSURFACE OF VALLES MARINERIS AND NOCTIS LABYRINTHUS USING SHARAD. D. Mège[1], L. Castaldo[1], G. Alberti[2] and W. Kofman[1,3], [1]Centrum Badań Kosmicznych Polskiej Akademii Nauk (CBK PAN), Bartycka 18A, 00-716 Warszawa, Poland, dmege@cbk.waw.pl), [2]CO.RI.S.T.A., Corso Novara 10, 80143 Napoli, Italy, [3]Univ. Grenoble Alpes, CNRS, CNES, IPAG, 38000 Grenoble, France.

Introduction: Valles Marineris exhibits a variety of landforms that testify to a huge diversity of processes, compositions, and physical properties. In particular, the presence of shallow water ice, that would have been deposited during periods of high obliquity and sublimated at lower obliquity, is debated. The abundance of ice in the shallow subsurface (≤ 15 m) is investigated using permittivity modelling of the first subsurface layer using SHARAD data. Several areas in the Valles Marineris region are discussed. Forward modelling of rock, porosity, and ice mixtures is performed and results are compared with geological observations made at selected sites where HiRISE images are available so as to infer plausible shallow subsurface compositions and ice content.

Ice in Valles Marineris: Ice is not stable at the surface, but there is a body of geologic evidence that ice has been significantly involved in the evolution of Valles Marineris. During periods of higher obliquities [1] snow may have cyclically deposited and ice sublimated or molten [2], contributing to the edification of the mounds of interior layered deposits (ILD) [2-4]. Glacial landforms are also pervasive in Valles Marineris [5-8]. Ice may also be a major component of the plateau layered deposits [9]. An attempt is made to assess the abundance of shallow surface ice in the present day using SHARAD data.

Methods:

First, by using the full set of data obtained by the SHARAD sounding radar since 2010 in the Valles Marineris region, the permittivity ε of the first layer (bounded to range resolution, i.e. 15 m in free space) is estimated and mapped. The method is based on evaluation of SHARAD power calibration constant on selected zone of Mars south pole (81°-85° S and 175°-205° E) and it accounts for surface scattering and either system and orbital parameters. The backscattering coefficient of the Martian surface is modeled by using a fractal characterization, with specific parameters (Hurst coefficient and topothesy) estimated by using High Resolution Stereo Camera (HRSC) digital elevation model of Valles Marineris with a resolution of 100 m.

Geological composition cannot be inferred from ε; nevertheless, rocks and volatiles may be discriminated if additional constraints are provided (Figure 1). In remote sensing, mixtures are generally treated as microscopically homogeneous and characterized by an effective permittivity. Effective permittivity of hetereogeneous material is calculated using fractional component volumes. The value of ε results from the combination of rock, porosity, and ice [10]. Using forward modelling of such mixtures, the relative abundance of ice is estimated at sites of high geologic interest in Valles Marineris where HiRISE imagery is available.

Results: In the Valles Marineris subsurface, ε is mostly between 2.5 and 7 (Figure 2). The lowest values suggest that in the first 15 m below the surface, rocks are composed of airfall deposits, such as volcanic ash, or basaltic sands [11], perhaps associated with ice. There is no general contrast observed between the troughs and the surrounding plateaus; rather, differences in ε are between plateau units of different age (Noachian or Hesperian, impact ejecta) and differences in floor material, such as ILD and floor units, or dune and other materials.

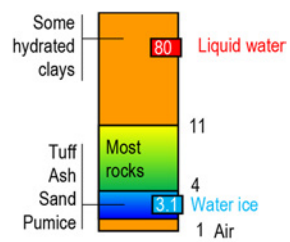

Figure 1. Summary of permittivity value for rocks, liquid water and water ice at typical Martian sounding radar frequencies (from the literature).

In polygons of the central depression of eastern Noctis Labyrinthus and Candor Chaos (Figure 3), $\varepsilon \approx 2$, which may be obtained by pulverulent volcanic rock of almost any composition [11], for instance volcanic ash erupted from a remote volcanic center [12] such as one of the Tharsis volcanoes. In Noctis Labyrinthus, suspected crater palimpsests (Figure 4a) would imply viscous, ice-rich subsurface in the past. Up to 10 vol% of remaining ice mixed with volcanic ash would increase ε to 2.1, consistent with the uncertainty in ε, in particular resulting from the topographic approximation used for scattering correction. The area of low ε in Candor Chaos perfectly coincides with the center of the area of highest water equivalent abundance measured by ExoMars/TGO FREND in the upper 1 m of the Valles Marineris subsurface, $40.3^{59.7}_{24.2}$ wt% [13]. Permittivity interpretation is similar to the one made for Noctis

Labyrinthus, with the possibility of relict ice. Polygon morphology is remarkably fresh (Figure 4b), indicating active surface rejuvenation, perhaps in relation to ice degradation, in contrary to e.g. polygons in eastern Candor Chasma (Figure 4c), where similar but older polygon surfaces have $8 < \varepsilon < 13$, indicating very limited geomorphological activity and massive rocks in the shallow subsurface.

Conclusion and perspectives: Permittivity mapping in Valles Marineris makes it possible to discuss the presence of relict ice that would date back to periods of higher obliquity. In-depth analyses will be presented at the conference.

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References: [1] Laskar J. et al. (2004) *Icarus*, doi:10.1016/j.icarus.2004.04.005. [2] Kite E. S. et al. (2016) *J. Geophys. Res.*, doi:10.1002/2016JE005135. [3] Michalski J. and Niles P. B. (2012) *Geology*, doi:10.1130/G32971.1. [4] Grindrod, P. M. and Warner N.H. (2014) *Geology*, doi:10.1130/G35790.1. [5] Mège D. and Bourgeois O. (2011) *Earth Planet. Sci. Lett.*, doi:10.1016/j.epsl.2011.08.030. [6] Cull S. et al. (2014) *Geology*, doi:10.1130/G36152.1. [7] Gourronc, M. et al. (2014) *Geomorphology*, doi:10.1016/j.geomorph. 2013.08.009. [8] Mège D. et al. (2017) EPSC Abstracts, EPSC2017–326. [9] Le Deit L. et al. (2010) *Icarus*, doi:10.1016/j.icarus.2010.03.012. [10] Shivola A. H. and Kong J.A. (1988) *IEEE Trans. Geosci. Remote Sensing*, doi:10.1109/36.3045. [11] Campbell M. J. and Ulrichs J. (1973) doi:10.1029/JB074i025p05867. [12] Pyle D. M. (1989) Bull. Volcanol., doi: 10.1007/BF01086757. [13] Mitrofanov I. et al. (2021) *Icarus*, 10.1016/j.icarus. 2021.114805.

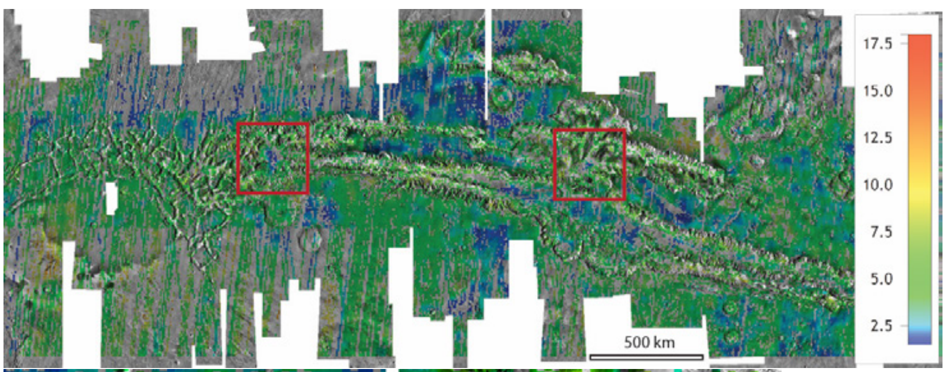

Figure 2. Permittivity map of Valles Marineris (resolution 0.25º/pixel, box-averaged 6x6). The discussed Noctis Labyrinthus and Candor Chaos areas are in the red boxes. Background image is THEMIS day mosaic.

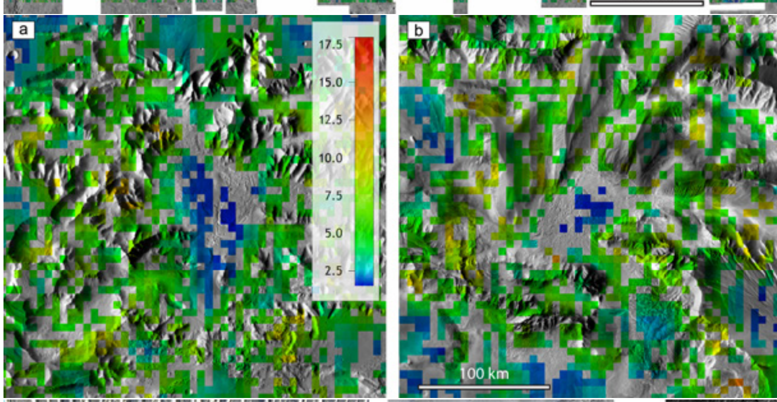

Figure 3. Permittivity (resolution 0.25º/pixel, box-averaged 4x4) of eastern Noctis Labyrinthus trough (a) and central Candor Chasma, with Candor Chaos in the center (b).

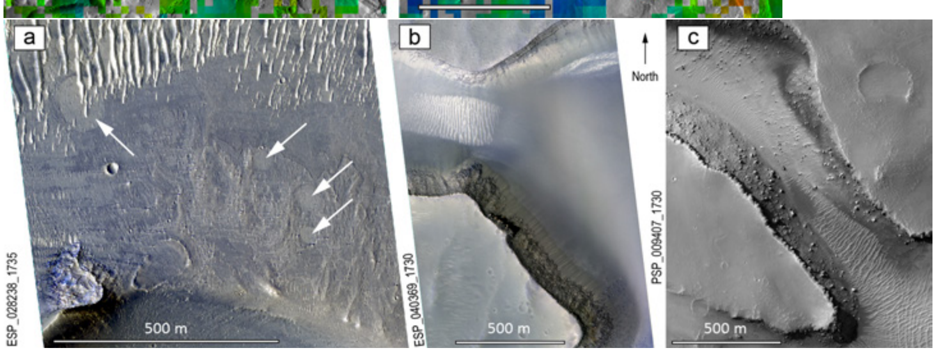

Figure 4. Noctis Labyrinthus (a) displays possible crater palimpsests. Polygons in Candor Chaos (b) have fresh walls and troughs, in contrary to e.g. polygons in eastern Candor Chasma (c). HiRISE images.