Deep Trek: exploring the modern-day subsurface habitability & life on Mars

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1. Pitch: The goal of this white paper is to lay out the scientific motivation for taking on the exploration of the Martian subsurface with a focus on modern-day subsurface habitability and signs of subsurface life. We think that the answers to the driving questions that led us to Mars might be hiding beneath the wheels of our rovers and that it is time to explore this, as yet unknown, world. By doing so, we are embracing the recommendation to 'Go deep' by the National Academy of Sciences Committee on the Strategy for the Search for Life in the Universe from 2019. A companion paper, entitled "Deep Trek: technology & mission concepts to explore the Martian subsurface habitability & life" will lay out how these questions can be addressed with mission concepts, from SmallSats to New Frontiers-type, existing instruments or technologies in near reach. We are standing at an exciting point in time, when we finally have the technological tools to start exploring one of the most promising targets for past and especially present life on Mars, the Martian subsurface. Join us for the beginning of this "Deep Trek".

2. Rationale: The Martian subsurface is of enormous scientific interest—to astrobiology, climate sciences, geophysics and *in situ* resource utilization (ISRU). Of all those intertwined subsurface objectives, the one closest to NASA's prime directive is the 'quest for life'. In contrast to the surface which, at best, was only potentially habitable early in Martian history, the deep subsurface is likely the largest and longest-lived potentially habitable environment on Mars – possibly existing until the present day.

In the Martian deep, life could flourish similarly as life does within Earth's subsurface rock fracture habitats: on the Earth, subsurface life has been found to depths of >5.3 km in the continental crust, and could exist at even greater depths that have not yet been explored. It is estimated to contain ~10^{30} cells, comparable to ~10% of the biomass in the surface biosphere and perhaps up to 90% of the total microbial biomass on Earth. In the deep terrestrial subsurface, microbial communities are concentrated in rock-hosted fracture fluids that have often been isolated from surface waters for up to ~10^{7}-10^{9} years, similar to groundwater isolation timescales expected for Mars, which lacks a significant meteoric water cycle. Organisms with similar metabolisms to those found in the terrestrial deep subsurface could exist in the deep subsurface of Mars today, powered by these same water-rock reactions that require the common geochemical ingredients of radionuclides, water, and reduced Fe in silicates and sulfides amongst other potential energy sources. CO_2, also a requirement for some of these autotrophs, is likely present in the Martian subsurface as it is in Earth's deep subsurface. If CH_4 produced via methanogenesis or abiotic Fischer-Tropsch type (FTT) reactions, as it occurs in Earth's subsurface, is available in the Martian crust, then methanotrophic metabolisms could also exist. The presence of CO and/or O_2 could support additional metabolisms in the deep Martian subsurface. Deep subsurface sites represent our best chance of finding modern Martian life, as *in situ* physicochemical conditions likely yield sufficient Gibbs free energy for various microbial metabolisms to proceed. These microbial communities could persist over geologic timescales, segregated from increasingly inhospitable surface conditions.

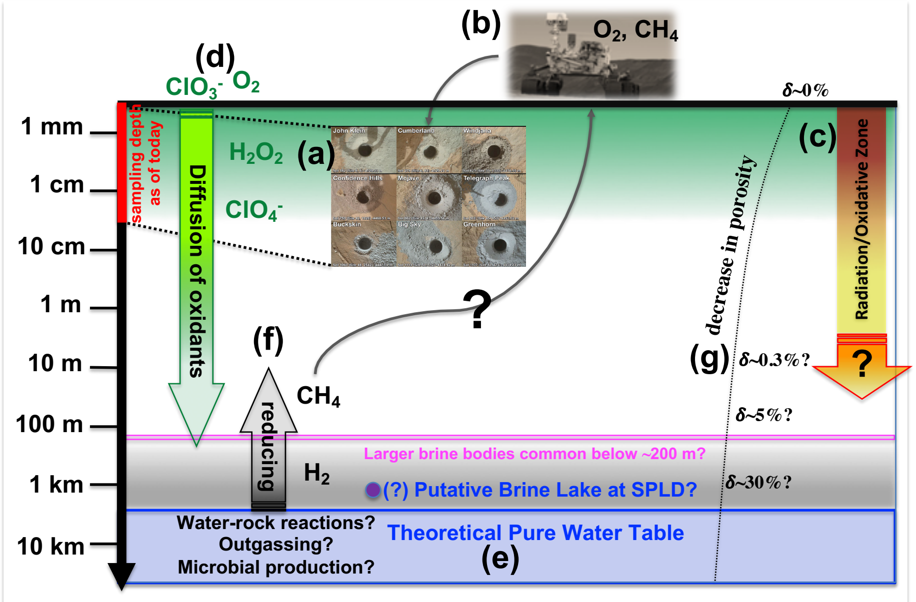

Figure 1—Deep Science: (a) Redox state transition in the upper few cm as shown by MSL drilling samples. Current sampling depth ~6 cm. (b) Atmospheric methane possibly derived from rock-water reactions ($H_2 \rightarrow CH_4$). (c) Penetration depth of oxidizing/radiation environment estimates vary from 1-10 meters. (d) Oxidants in near-surface environments, possibly linked to CH_4 destruction (?). (e) Depth of "pure" water table is latitude dependent, and in the km to 10s km range. Brines could be locally shallower but have a low water activity close to the surface. (f) Water-rock reactions producing H_2 (e.g., radiolysis, serpentinization, oxidation of ferrous silicates) and possibly $\rightarrow CH_4$ with Sabatier-type reactions. (g) Porosity with depth is key to estimate the potential for groundwater and subsurface life. Pink denotes the depth of ~200 m above which large-scale brines seem to be uncommon based on SHARAD/MARSIS data.

Moreover, in deep subsurface environments, likely little to no significant biological adaptation would be required for Earth-like organisms to survive and thrive—as opposed to the modern surface and near-surface, no matter whether that were in regolith, salts, rocks, or ices.

As part of a deep subsurface exploration strategy, we would address, amongst other factors, the depth-dependent trades in groundwater activity, chemistry and availability, the changes with depth for redox gradients, nutrients, and porosity, and the variability with depth in radiation levels, organics, oxidizers, and possible signatures of life. Our driving goal is to reach deep without neglecting critical habitability information from shallow subsurface regions.

3. Status of the white paper effort so far/planned schedule for its development: There already has been large community efforts in this field, from two white papers to the NAS in 2018 and ESA in 2019, a community paper in Nature Astronomy in 2019, a KECK KISS workshop in 2018, a NAI Workshop Without Walls in 2019 and two large AGU sessions (2018, 2019) amongst others.

4. The sort of involvement/collaboration we are seeking: We have lots of material to work with (see 3.) and are seeking additional co-authors, reviewers and co-signatories across the spectrum, from scientists to engineers.