**PROBING THE MODERN-DAY MARTIAN SUBSURFACE HABITABILITY WITH VALKYRIE.** V. Stamenković[1], M. Mischna[1], N. Lanza[2], R. E. Grimm[3], J. Mustard[4], V. Orphan[5], K. Rogers[6], K. Zacny[7], B. Sherwood Lollar[8], B. Ménez[9], T. Spohn[10], A.-C. Plesa[11], J. Michalski[12], and M. Osburn[13].

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**Introduction:** Plans for Mars exploration currently focus upon the extraction, collection and return of surface samples in pursuit of the goal of identifying once habitable environments on Mars that may have been home to now-extinct life. Measurements of the surface environment by numerous landers have confirmed the present martian surface to be inhospitable to life due to environmental factors including a toxic radiation and oxidant environment, a paucity of liquid water, and a lack of adequate sources of energy to drive metabolic activity.

Many of these detrimental conditions can be mitigated by simply looking deeper into the martian subsurface. Following liquid water, potential habitats could be kilometers deep (see Figure 1) and similar to very common deep habitats here on the Earth, where water-rock reactions fuel diverse microbial communities. Technology exists today or is under development to start charactering the habitability of such potential deep habitats.

Here, we shall present the VALKYRIE mission concept designed to begin the process of probing Mars' 'third dimension' in pursuit of habitable environments, the chemical and physical elements required to sustain life and, ultimately, life itself. VALKYRIE stands for "Volatiles And Life: KeY Reconnaissance & In-situ Exploration".

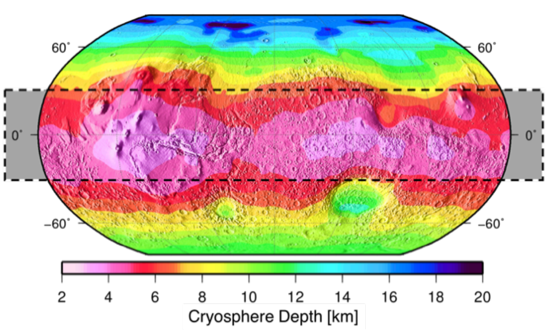


*Figure 2: Depth of the cryosphere/liquid water table interface (calculated based on simulated heat flow data with [1, 2]), depending on surface temperature and on local heat flux. In regions equatorward of 30° latitude, depth to liquid water may be only 2-6 kilometers. Larger depths to groundwater poleward of ±60° demonstrate that the polar regions are not ideal for liquid groundwater exploration.*

**Science Goals:** The science goals of the VALKYRIE mission concept are twofold. The first goal is to quantify subsurface habitability with depth; this is done through measurements of the depth, volume and composition of liquid water (brine) in the subsurface, profiling of the subsurface geochemistry and mineralogy with depth, and determining the stability of biomolecules against radiation and oxidation as a function of depth. Second, is a search for signs of extant subsurface life by measuring organic and inorganic signatures of metabolic activity

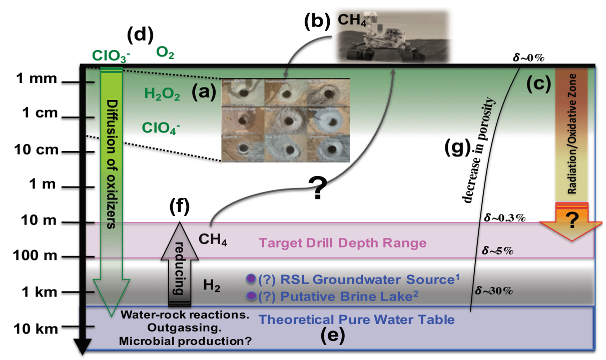


*Figure 1: The chemical diversity of subsurface environments with depth as could be explored by VALKYRIE. Description is in the text.*

and their changes with depth. Of particular importance are the measurements of subsurface redox gradients, which fuel life.

The chemical diversity of subsurface environments with depth as could be explored by VALKYRIE is illustrated in Figure 2: (a) Redox state transition in the upper few cm as shown by MSL drilling samples. (b) Atmospheric methane possibly derived from rock-water reactions ($H_2 \rightarrow CH_4$). (c) Penetration depth of oxidizing/radiation environment estimates (currently estimates vary from 1-10 meters0. (d) Oxidizing chemicals in near-surface environments, possibly linked to $CH_4$ destruction. (e) Depth of "pure" water table (it is latitude and location 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 measurements with depth will help constrain crustal water storage capacity and habitability models.

**Payload:** The VALKYRIE payload consists (see Figure 3) of two enabling technologies — a transient electromagnetic sounder capable of detecting the presence of saline liquid to depths of kilometers [e.g., $TH_2OR$, see 3-4], and a drill capable of depths of 10s-100s of meters or more, important for reaching environments not directly in communication with the surface. Targeting a drill depth range between 10-100 m captures much of this diversity, and greatly expands our knowledge of the abiotic and biotic processes responsible for the observed local chemistry. This depth is likely much shallower than putative habitats with liquid groundwater. We do not need to drill to liquid water but deep enough to be able to have enough depth leverage to extrapolate geochemical gradients to deeper putative habitats, and have a first reconnaissance of the habitability variability and the associated trade-offs with depth.

While a deep drill mechanism can house instrumentation for measuring the physical environment within the borehole, return of drilled samples to a landed platform permits a variety of more sophisticated biogeochemical analyses that can provide a rigorous assessment of metabolic activity.

| Technology | TRL | Rational to Support TRL Claim | Lab Demo<br>Field Demo |
|---|---|---|---|
| **Water**:<br>Transient Electromagnetic Sounder. Ballistic Loop deployment. | 4 | Based on existing technology that has been used for over 40 years. Mars TEM systems are being developed. | Yes.<br>Started. |
| **Heat**:<br>Thermal Probe | 8 | Based on existing technology used on Earth. Simple, robust.<br>**NOT on a mole but on a drill!!** | Yes.<br>Yes. |
| **Subsurface Access**:<br>Drill (10-100 m) | 5-6<br>4 | PDD, AG2, & many more<br>ASGARD | Yes. Yes.<br>No. No |
| **Geobiochemical Analysis**:<br>• Trace Gases.<br>• Radiometer.<br>• UV/Raman Spectrometer<br>• GC-MS<br>• Optical microscope | 8-9 | All successfully flown on MSL or being prepared for Mars 2020. | Yes.<br>Yes. |
| **Surface Constraints**:<br>• Met Station<br>• Camera | 9 | Successfully flown on Phoenix, MSL | Yes.<br>Yes. |

*Figure 3: Potential payload for VALKYRIE.*

**Mission Concept Description: New Frontiers—**A Phoenix-type, solar-powered lander with (i) a liquid water sounder, sounding to ~10 km depth. (ii) a drill (not a mole) w/thermal probe to access samples to a depth of at least ~10-100 m. Together with measurements of groundwater salinity obtained with the liquid water sounder, estimates on the geotherm will better constrain water composition. (iii) geochemical analysis suite on the surface platform to constrain conditions for subsurface habitability (i.e., redox, hydration, salinity, composition, mineralogy, oxidants, porosity, permeability) from drilled samples (with Mars Exploration Rover-type instrument package or SHERLOC-type UV/Raman spectrometer to also account for organics); a potential add-on would be a gas sniffer on the surface (e.g., TLS) to detect $CH_4$, $H_2O$, $O_2$, $SO_2$, $NH_3$ and their associated isotopologues to constrain potential deeper water-rock reaction products. (iv) radiometer to measure ionizing particles in the borehole for constraints on cellular stability. (v) a camera & meteorology station for surface environmental context. The notional duration is one Martian year. Our target landing site is at near-equatorial regions, due to shallower depths to the putative water table, with evidence of recent groundwater release and low altitude, maximizing our chances for modern groundwater. Non-detection of groundwater is just as useful as detection for this first subsurface habitability assessment.

**Flagship—**Drill 100+ m with JPL wireline drill [ASGARD]. Add advanced biogeochemical analysis tools such as GC-MS & optical microscope for life-detection capabilities, and a 3-channel gas spectrometer in the borehole (e.g., mini-TLS with $CH_4$, $H_2O$, $O_2$) for additional "spatiotemporal" monitoring of metabolically-relevant byproducts. Possibility of a mobile asset.

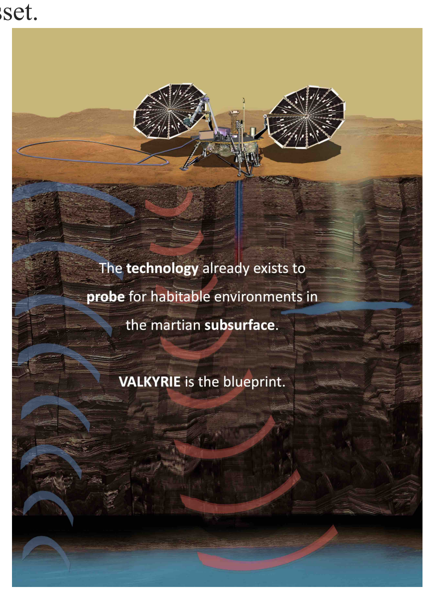


*Figure 4: Artist's concept of VALKYRIE. Credits NASA/JPL by Corby Waste.*

**References:** [1] Plesa, A.-C. et al., (2016), *JGR Planets,* 121 (12), 2386-2403. [2] Stamenković, V. et al., (2019), *LPSC Abstracts* 2019, LPI Contrib. No. 2132. [3] Burgin M. et al., 2019, AGU Fall Meeting, P44B-02. [4] Stamenković et al. (2019), *Nature Astronomy*, 3, 116-120.

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