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Title: Search for Modern Life on Mars: Compelling and Achievable in the Coming Decade

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Introduction: Potentially habitable environments for life occur on modern Mars. We will make the case that a search for extant life should begin in the next decade. The paper is an outflow of the recent workshop, "Mars Extant Life: What's Next?". Four types of environments on Mars are identified which merit a search for life. They, along with potential approaches for the life search, are described.

Salts and Evaporites: The properties of evaporates and salts make them highly desirable and easily accessible environments in the search for life on Mars (Davila and Schulze-Makuch, 2016). On Earth, evaporites and associated brines provide refugia in many places across the globe, supporting a wide diversity of microbial communities including phototrophs, lithotrophs, and heterotrophs (DasSarma and DasSarma, 2017). Endolithic phototrophs are found associated with gypsum crusts, and halite-entrapped halophilic archaea and bacteria are commonly observed in enclosed brine fluids, with striking and easily detectable carotenoid pigment biosignatures (DasSarma *et al.* 2019). Halite and gypsum minerals offer radiation protection, by attenuating ultraviolet light, and serve as protection from long-term desiccation by deliquescence (Davila *et al.* 2010). Finally, dissolved salts also extend the temperature range for maintaining liquid water through freezing point depression and by formation of supercooled liquids, expanding the possibility of life processes at subzero temperatures (Toner *et al.* 2014). Concentrated brines are also common in ice vein networks, due to exclusion of dissolved salts during freezing point depression and ice formation.

Salts and evaporites are common at the surface and near-subsurface of Mars and are readily accessible to mobile platforms. The Thermal Emission Imaging System (THEMIS) has mapped the global distribution of chloride salts on the Martian surface with at least 600 regions identified to date (Osterloo *et al.* 2010). Many sites are located in local depressions that may have formed as a result of surface runoff, groundwater upwelling, and/or hydrothermal activity. A few examples include: (1) Eastern Margaritifer Terra which exhibits mineral precipitation in upwelling fluids from crater floor fractures (Thomas *et al.* 2017), (2) Columbus Crater in Terra Sirenum that possesses groundwater-fed paleolakes and evaporites (Wray *et al.* 2011), and (3) Jezero Crater, the selected Mars 2020 landing site, that has hydrated minerals in outflow deposits within river deltas.

Shallow Subsurface Ice: Ice rich terrains on Mars are important locations to search for martian life and are planetary protection special regions emphasizing their habitability. Ground Ice is accessible and wide-spread on Mars at latitudes above 35° N /45° S (Rummel *et al.* 2014; Piqueux *et al.* 2019). Ice migrates between higher and lower latitudes (Madelaine *et al.* 2009)as the intensity of incident sunlight changes with spin axis/orbital elements (obliquity, eccentricity, and precession, Laskar *et al.* 2004), as do the locations and timing of habitable conditions in the ice. Modern life forms may not be metabolically active under current conditions, but their biosignatures should be detectable. The subsurface ice at the Phoenix landing site is habitable when warmer at high obliquity when melting of subsurface ice may support biological growth down to 1 m depth (Zent, 2008; Stoker *et al.* 2010). Some locations in midlatitude near surface ice may be habitable currently and more research is needed to evaluate the most likely locations. It is crucial to determine if life persists there prior to human exploration activities that aim to use midlatitude ice as a resource.

Exploring for life in ice rich subsurface will require automated drilling technology and rovers with 1- and 2- m drilling systems will be flown in the near future, including Lunar VIPER (Colaprete *et al.* 2019) and ExoMars rovers (Vago *et al.* 2017). The ExoMars rover's 2-m core drilling system could reach and sample midlatitude ground ice with (presumably) minimal modification. Life detection instruments fed with a VIPER-like 1m drill have successfully identified biosignatures in Atacama

Desert Mars analog field tests (Stoker *et al.* 2019). Other scenarios involve multiple assets, such as a rover capable of high-resolution remote sensing and ground-ice-sample acquisition that delivers samples to a laboratory lander nearby, or multiple small rovers networked and operating autonomously with a base spacecraft orbiter, or human space station. This type of approach would be advantageous for expandable mission scenarios that would address other science objectives.

Volcanic Caves: Volcanic caves are high priority environments in the search for extant life on Mars (e.g., Boston *et al.* 2001; Martins *et al.* 2017; Léveillé & Datta, 2010; Blank *et al.* 2018), as they protect their interiors from cosmic background radiation and energetic solar events, changing surface climatic conditions, and small-scale impact events. A cave with natural openings offers direct access to the subsurface, with a relatively stable thermal environment that can persists over geologic time (Williams *et al.* 2010), while voids with no surface openings are detectable via GPR and other geophysical methods and provide potential for sealed time capsules with relatively easy drill access. Microbial life in terrestrial volcanic caves is evident on and in a wide variety of mineral features, from silica-rich, to carbonate, to iron, and other metals which are distinctive from their basaltic host rock (Boston *et al.* 2001; Northup *et al.* 2011). Such features preserve extremely well in situ.

More than one thousand candidate cave entrances in volcanic terrain have been identified using orbital data from the Mars Odyssey THEMIS visible-wavelength and the Mars Reconnaissance Orbiter's Context (CTX) cameras (Cushing, 2017). A variety of robotic approaches have been proposed over the past twenty years to overcome obstacles related to ingress and navigation inside these features, including (1) Entry from the surface down into the lava cave system through a skylight, possibly via a large (>50 m) vertical drop, (2) Traversing an irregular floor surface and/or over large blocky obstacles, (3) Operations in darkness, (4) Autonomous operation and localization (out of line-of-sight to surface communications), and (5) Cushioned shock-proof tensegrity delivery. Relevant new technologies are being tested in the current DARPA Subterranean Challenge and in development for exploration of lunar sites (Agha *et al.* 2019; Kerber *et al.* 2020; Whittaker *et al.* 2020). Advances and lessons learned from subterranean exercises on the Earth and on the Moon will benefit Martian cave mission concept development and planning.

Deep Subsurface: Earth's deep subsurface is estimated to contain ~10^{30} cells, comparable to ~10% of the surface biosphere's total biomass and exceeding its microbial biomass (Whitman *et al.* 1998; Magnabosco *et al.* 2018 and references therein; Onstott *et al.* 2019). The deep subsurface is likely the largest and longest-lived potentially habitable environment on Mars – possibly existing from the Noachian or pre-Noachian (Michalski *et al.* 2013; Tarnas *et al.* 2018; Onstott *et al.* 2019) until present day, contrasting with the environments on the surface, where habitability was severely diminished early in martian history, as demonstrated by the geologic record (Fairén *et al.* 2010; Schulze-Makuch *et al.* 2013; Cabrol, 2018; Kite, 2019). Potentially habitable water-bearing deep subsurface environments could host martian life in chemical and physical conditions similar to those of Earth's deep subsurface environments (Tarnas *et al.* 2019). There would likely be no significant biological adaptation required for Earth-like organisms to survive and thrive in the subsurface of Mars.

Some of the proposed goals for the deep subsurface could be achieved with surface instruments deployed by small low cost spacecraft. This includes landed EM sounders to characterize liquid groundwater or instruments to localize and constrain the biological potential of released trace gases. Physical access to the subsurface would focus on detection of changes in geochemical potential at depths to ~100 m, a feat which is becoming technologically feasible today with low-mass wireline drills such as that recently tested in Greenland (Eshelman *et al.* 2019).

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References:

Agha-mohammadi *et al.* 2019. *Int'l J Robotics Res (IJRR)* 38:1352-1374.

Boston, P.J. *et al.* 2001. *Astrobiology* 1(1), 25-55.

Blank, J. G. *et al.* 2018. NAS White Paper https://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/ssb_190758.pdf

Cabrol, N. A. *et al.* 2018. *Astrobiology*, *18*(1), 1–27. /DOI:10.1089/ast.2017.1756

Colaprete, A., *et al.*. 2019 AGU fall meeting Dec. 2019, San Francisco, CA.

Cushing, G.E. 2017. USGS Astrogeol Sci Ctr Rep.

DasSarma, S., and DasSarma, P. 2017. Encyclopedia of Life Science, Wiley DOI:10.1002/9780470015902.a0000394.pub4

DasSarma, S. *et al.* 2020. *Extremophiles* 24, 31–41. DOI:10.1007/s00792-019-01126-3

Davila A.F. *et al.* 2010. *Astrobiology* 10, 617-628. DOI:10.1089/ast.2009.0421

Davila, A.F. and Schulze-Makuch, D. 2016. *Astrobiology,* 16, 2, 159-168. DOI:10.1089/ast.2015.1380

Eshelman, E.J. *et al.* 2019. Astrobiology 19(6), 771-784. DOI:10.1089/ast.2018.1925

Fairén, A. G. *et al.* 2010. *Astrobiology*, *10*(8), 821–843. DOI:10.1089/ast.2009.0440

Kite, E. S. (2019) *Space Science Reviews*, *215*(1). DOI:10.1007/s11214-018-0575-5

Laskar, J. *et al.* 2004. *Icarus* 170, 343–364

Léveillé, R.J. and Datta, S. 2010. *Planet Space Sci. Special Issue* 58(4):592-598.

Madelaine, J.B, *et al.* 2009. *Icarus* 203, 390-405. DOI:10.1006/j.icarus.2009.04.037.

Magnabosco, C. *et al.* 2018. *Nature Geoscience*, *11*(10), 707–717. DOI:10.1038/s41561-018-0221-6

Martins, Z. *et al.* 2017. *Space Sci. Rev.* **209**:43–81

McKay, C. P. *et al.* 2013. *Astrobiology* 13(4), 334-353.

Michalski, J. R. *et al.* 2013. *Nature Geoscience*, *6*(2), 133–138. DOI: 10.1038/ngeo1706

Mitchell, K.L. *et al.* 2020. *Intl. Planet. Cave Conf.* ***3****: 1079.*

Northup, D.E. *et al.* 2011. *Astrobiology* 11(7): DOI: 10.1089/ast.2010.0562

Onstott, T. C. *et al.* 2019. *Astrobiology*, *19*(10), 1230–1262. DOI:10.1089/ast.2018.1960

Osterloo, M.M. *et al.* 2010. *J. Geophys Res* 115:E10012. DOI: 10.1029/2010JE003613

Orosei, R. R. *et al.* 2018. *Science* 361, 490-493. DOI: 10.1126/science.aar7268

Piqueux, S. *et al.* 2019. *Geophys. Res. Lett.* 46, 14290-14298, DOI:10.1029/2019GL08394

Rummel, J. D. *et al.* 2014. *Astrobiology*, *14*(11), 887–968. DOI:10.1089/ast.2014.1227

Schulze-Makuch, D. *et al.* 2013. *Astrobiology*, *13*(7), 674–678. DOI:10.1089/ast.2013.0995

Stoker, C. R. *et al.* 2010. *J Geophys Res*, *115*, E00E20. DOI:10.1029/2009JE003421

Stoker, C.R. *et al.* 2019. [Abstract]Astrobiology Science Conference Seattle WA June 2019.

Stromberg, J.M. *et al.* 2019. *Planetary and Space Science* 176, 104683. DOI:j.pss.2019.06.007

Tarnas, J. D. *et al.* 2018. *Earth and Planetary Science Letters*, *502*, 133 145 DOI:10.1016/j.epsl.2018.09.001

Tarnas, J. D. *et al.* 2019 [abstract 5104]. In *Mars Extant Life: What's Next? Conference Abstracts*, LPI, Houston.

Thomas, N.H. *et al.* 2019. *Geophys. Res. Lett.* 46:754 DOI:10.1029/2019GL082764

Thomas, R. J. *et al.* 2017. *Geophys. Res. Lett.* 44:6579-6588 DOI:10.1002/2017GL073388

Toner, J.D. *et al.* 2014. *Icarus* 233:36-47, DOI:10.1016/j.icarus.2014.01.018

Vago, J.L. *et al.* 2017. *Astrobiology* 17(6&7), DOI:10.1089/ast.2016.1533.

Whitman, W. B. *et al.* 1998. *PNAS 95*(12), 6578–6583. DOI:10.1073/pnas.95.12.6578

Williams, K.E. *et al.* 2010. *Icarus* 209: 358-368.

Wray, J. *et al*. 2011. *J. Geophys Res* 116 E01001, DOI:10.1029/2010JE))3694
Zent, A. 2008. *Icarus*, *196*(2), 385–408. DOI:10.1016/j.icarus.2007.12.028