"MARS EXTANT LIFE: WHAT'S NEXT?" CONFERENCE REPORT. B. L. Carrier[1], D. W. Beaty[1], M. A. Meyer[2] (conference leads), and J. G. Blank[3,4], S. DasSarma[5], D. J. Des Marais[3], J. L. Eigenbrode[6], N. L. Lanza[7], A. C. Schuerger[8], P. Schwendner[9], H. D. Smith[3], C. R. Stoker[3], J. D. Tarnas[9], K. D. Webster[10]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. [2]NASA Headquarters, Washington, DC, [3]NASA Ames Research Center, Moffett Field, CA, [4]Blue Mable Space Institute of Science, [5]University of Maryland School of Medicine, Baltimore MD, [6]NASA Goddard Space Flight Center, Greenbelt, MD, [7]Los Alamos National Laboratory, Los Alamos, NM, [8]University of Florida, N. Merrit Island, FL [9]Brown University, Providence, RI, [10]Planetary Science Institute, Tucson, AZ.

Introduction:
The conference "Mars Extant Life: What's Next" was convened from Nov. 5th-8th, 2019, in Carlsbad, NM. This three-and-a-half-day conference focused on understanding and discussing strategies for seeking possible extant life on Mars. Inspired by the prior conference, *Biosignature Preservation and Detection in Mars Analog Environments* (May 16–18, 2016; Lake Tahoe, CA), that addressed the search for ancient life, this conference promoted broad community discussion of numerous extant life hypotheses that have evolved in response to discoveries by on-going Mars orbiter and surface missions. The conference had 82 abstract contributions and 71 participants in attendance (from the U.S., Mexico, Germany and France). The venue of Carlsbad was chosen because offers the opportunity for field observations at two important terrestrial analog environments (caves and salt deposits), and in Mars planning, it is always imperative to remember that first and foremost, Mars is a field location.

Purpose and Scope:
The purpose of the conference was to review and discuss constraints on the possibility of extant life on Mars as well as possibilities for advancing this sector of science. A specific goal was to answer two questions of practical relevance to NASA's Mars Exploration Program: 1) Where, on Mars, should we advocate looking for evidence of extant life (and how strong are the relevant technical arguments), and 2) What detection methodologies would be most effecive? Planetary missions are expensive and challenging, with inherent risk, and thus their motivating hypotheses must be clear and compelling, their test(s) unambiguous, and their objectives must be endorsed by the scientific community.

Preliminary Conference Findings:
The discussions at the conference were carried out at multiple levels: 1) Short, presentation-level discussion at the end of each oral talk, 2) Longer session-level discussion after each session, which allowed the papers in a given session to be compared and contrasted, 3) Theme-based, small-group discussion and idea integration to produce consolidated messages from the oral, poster, and print-only abstracts, and 4) Presentation and discussion of the consolidated messages in the conference's concluding session. On the basis of these discussions, the following consensus positions were developed:

1. A significant subset of the actively publishing Mars science community who are experts in various disciplines of relevance to interpreting habitability and astrobiology concluded that there exists a realistic possibility that Mars hosts indigenous microbial life and that there are testable hypotheses for seeking it. As such, the conference participants concluded that the search for extant life on Mars remains an important scientific objective.
2. A powerful theme that permeated the conference is that the key to the search for martian extant life lies in identifying and exploring refugia (an "oasis"), where conditions are either permanently or episodically significantly more hospitable than average. Mars life, if it was once more widespread, could have retreated to one or more of these refugia, where it may have been able to survive long-term.
3. Based on our existing knowledge of Mars, four martian environments were highlighted during the course of the conference as having the potential to be such a refugium. For each of these, multiple advocates were present at the conference.

a. Caves
More than 1,000 candidate volcanic cave entrances on the surface of Mars have been identified using MRO orbiter data. The cave environment has protection from harsh weather, solar radiation, and desiccation. Caves provide direct access to the shallow subsurface, where relatively stable temperatures and humidity conditions could persist over geologic timescales and host ice and salts that are other high priority targets in the search for extant life. Extant life could persist in biominerals on cave walls, and in cave wall fractures and pore space in the cave environment.

b. Deep subsurface
In Earth's deep subsurface, microbial communities mostly exist 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. The primary producers in many of these deep ecosystems function completely independently from

photosynthesis and are chemoautotrophs that derive energy from redox nutrients generated by water-rock reactions such as radiolysis, serpentinization in peridotite systems, or oxidation of other ferrous silicates. On Mars, we will search for these exact same types of organisms, surviving on these exact same abiotic redox energy production mechanisms, and isolated from surface nutrients for similar timescales. As such, no currently undemonstrated biological adapation is required for Earth-like organisms to survive in the deep martian subsurface, in contrast to other proposed extant Mars life environments.

c. Ice

Ground ice on Mars is a compelling target to search for modern life because it can be accessed in a wide variety of locations within 1-2 m of the surface at latitudes from 35-90 N and about 45-90 S. Ice mixed with soil/sediments containing chemical and mineral compositions that can release soluble nutrients, electron donors and electron acceptors and sufficient carbon, nitrogen and phosphorus to enable biomass reproduction and growth, may have all of the components needed for modern martian life. Temperatures in the ground ice vary quasi-periodically driven by orbitally forced insolation changes. In some epochs ground ice temperature is sufficient to support active microbial growth so a stable biosphere is possible, growing when thermal conditions allow and remaining dormant at other times.

d. Salts

On Earth, salt deposits and brines are known to support a wide diversity of microbial life. Moreover, fluid inclusions trapped in solid and crystalline salts contain dissolved chemical nutrients, with enhanced preservation potential for biological materials, and viable extant life. Salt deposits are also widespread on the surface of Mars, and have been extensively mapped, and their near-surface accessibility make them prime targets for potential discovery of extant life.

We are aware that other possible refugia have been hypothesized in the literature but they were not discussed at this conference as no related abstracts were submitted which advocated consideration of these environments.

4. The conference group did not attempt to reach a consensus prioritization of these candidate environments. There are multiple considerations that would go into such an evaluation including overall potential for a discovery of life, the difficulty of accessing the environments, and the potential issues with performing conclusive measurements. The group was most comfortable with getting these options prioritized by means of a future competitive process.

5. There is an important implication of the "Refugium Model": If environments exist where conditions are significantly better than average, there must also be complementary environments where conditions are significantly worse than average. One example of the latter is the surface and very shallow subsurface (i.e. down to a depth of ~1 m) of Mars, particularly in the equatorial belt. These geological materials are constantly bathed in high-intensity radiation, including intergalactic cosmic rays and high-energy neutron fluxes, and this zone was is considered to be generally inhospitable to life as we know it due to the compounding number of adverse environmental and chemical factors (although it is recognized that we cannot reach definitive conclusions about what conditions would be truly inhospitable for martian life until we discover it and measure its properties). Nevertheless, the potential for discovery in this environment was generally considered to be low.

6. Geological strategies to search for biosignatures will be valuable at landing sites where extant life is currently absent but was present in the recent past, or if extant life currently exists elsewhere and its traces were delivered to the site. 'Geological' biosignatures include certain organic and inorganic compounds, minerals, sedimentary structures and textures, and stable isotopic patterns. The temporal and spatial distribution of any biosignatures of extant life will be highly heterogeneous due to the processes that control habitability and preservation. A key challenge is to identify and visit sites where any biosignatures are both accessible and sufficiently abundant to be detectible. If the origin of biosignatures can be confirmed as geologically recent, then they probably indicate that life still exists somewhere.

7. A number of different measurement techniques to detect evidence of extant life (if there is any life there to be detected) have been proposed. Again, it was not within the scope of this conference to prioritize these measurement techniques—that is best left for the competitive process. One specific note: The number and sensitivity of detection methods that could be implemented if samples were returned to Earth greatly exceeds the methodologies that could be used at Mars.

8. Important lessons to guide extant life search processes can be derived both from experiments carried out in terrestrial laboratories, on terrestrial analogs, and from modelling/theory.

9. If the habitability potential for extant martian life (and transported terrestrial microbial life) at the martian equatorial surface is very low, this fact should be factored into interpretations of forward and backward planetary protection risks for future missions to those regions. . This may specifically have implications for how to manage the risks associated with future human missions to Mars. We encourage further experimentation on the limits of life relevant to surface conditions on Mars in order to advance the discussions of the search for extant life on Mars.