TARGET LOCATIONS FOR THE SEARCH FOR LIFE ON MARS

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"ARE WE ALONE?"

- Planetary Science & Astrobiology Decadal Survey "Origins, Worlds, and Life" Question 11: Search for Life Elsewhere (NASEM 2022); "Vision & Voyages" subChapter 6: Determine if Life Ever Arose on Mars (NASEM 2011)
- MEPAG Goal 1: Determine if Mars Ever Supported, or Still Supports, Life (Banfield et al., 2020, Hamilton et al., 2015, Johnson et al., 2010, MEPAG 2005)
- Biosignature Preservation and Detection in Mars Analog Environments conference (Hays et al., 2017)
- An Astrobiology Strategy for the Search for Life in the Universe (NASEM 2019)
- Mars Extant Life: What's Next conference (Carrier et al., 2020)
- Standards of Evidence for Life Detection workshop (Meadows et al., 2022)

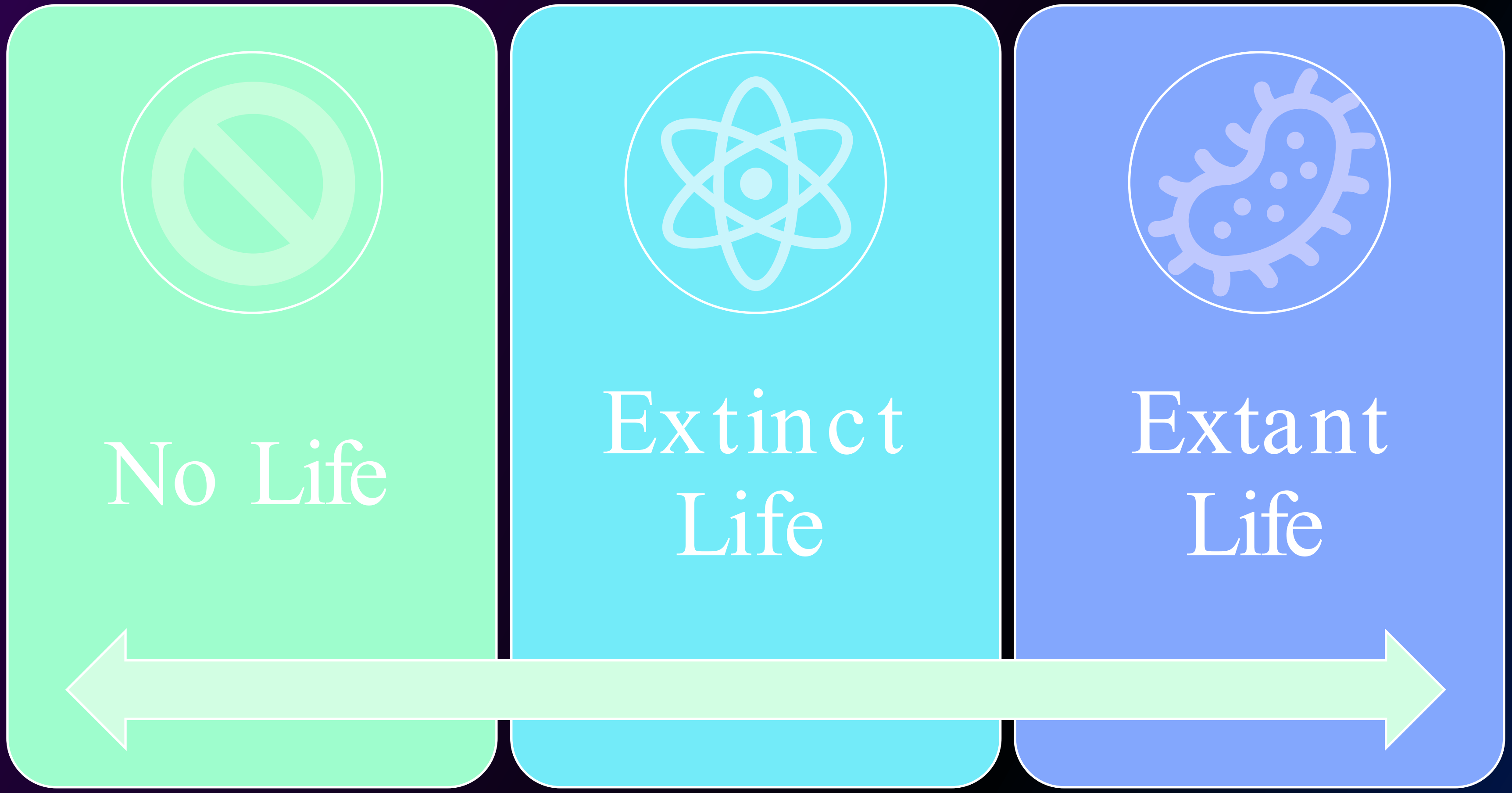
THE SEARCH FOR LIFE ON MARS

No Life

Extinct Life

Extant Life

THE SEARCH FOR LIFE ON MARS



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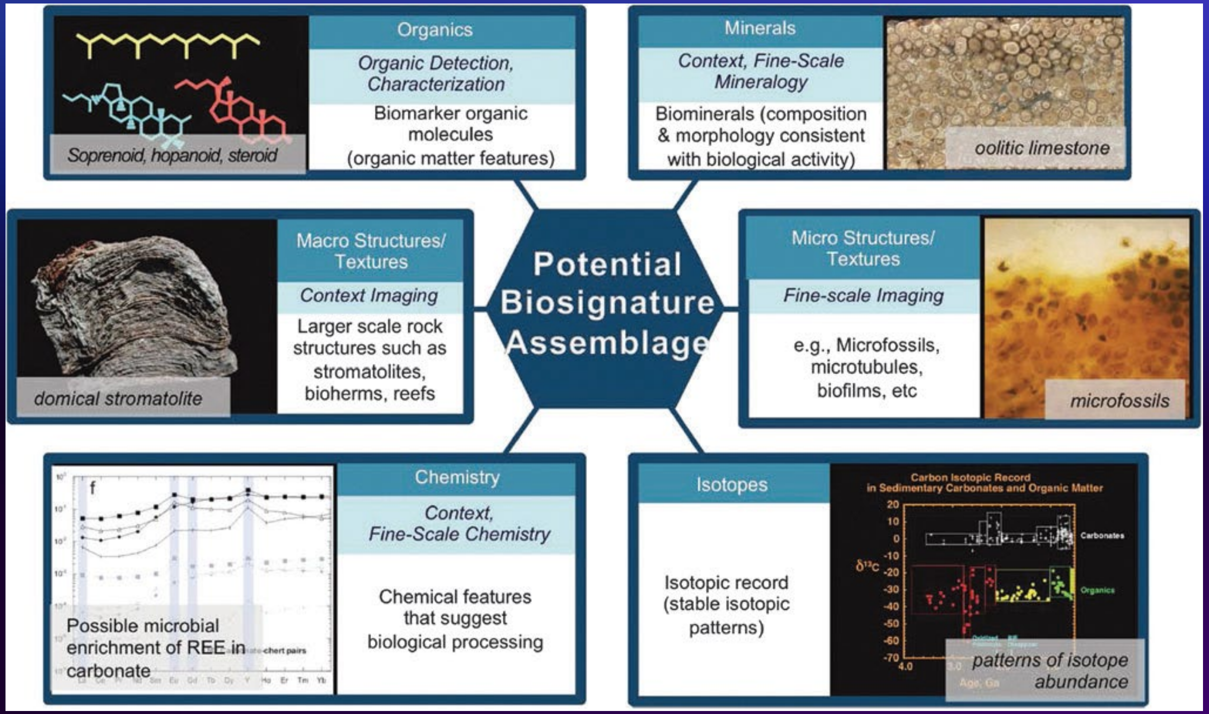
Review Article

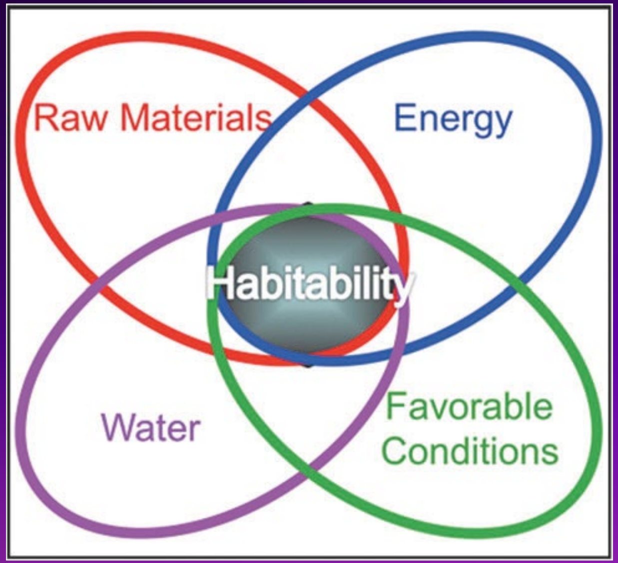
Biosignature Preservation and Detection in Mars Analog Environments

Lindsay E. Hays,[1] Heather V. Graham,[2] David J. Des Marais,[3] Elisabeth M. Hausrath,[4] Briony Horgan,[5] Thomas M. McCollom,[6] M. Niki Parenteau,[3] Sally L. Potter-McIntyre,[7] Amy J. Williams,[8] and Kennda L. Lynch[9]

1. How do we use biosignatures to interpret the presence or absence of life in ancient Earth analog environments?
2. How might we translate what we learn about preservation of biosignatures in Earth analogs to the different physical conditions/ environments on Mars?
3. How could/should this knowledge influence our strategies and priorities for the astrobiological exploration of Mars?



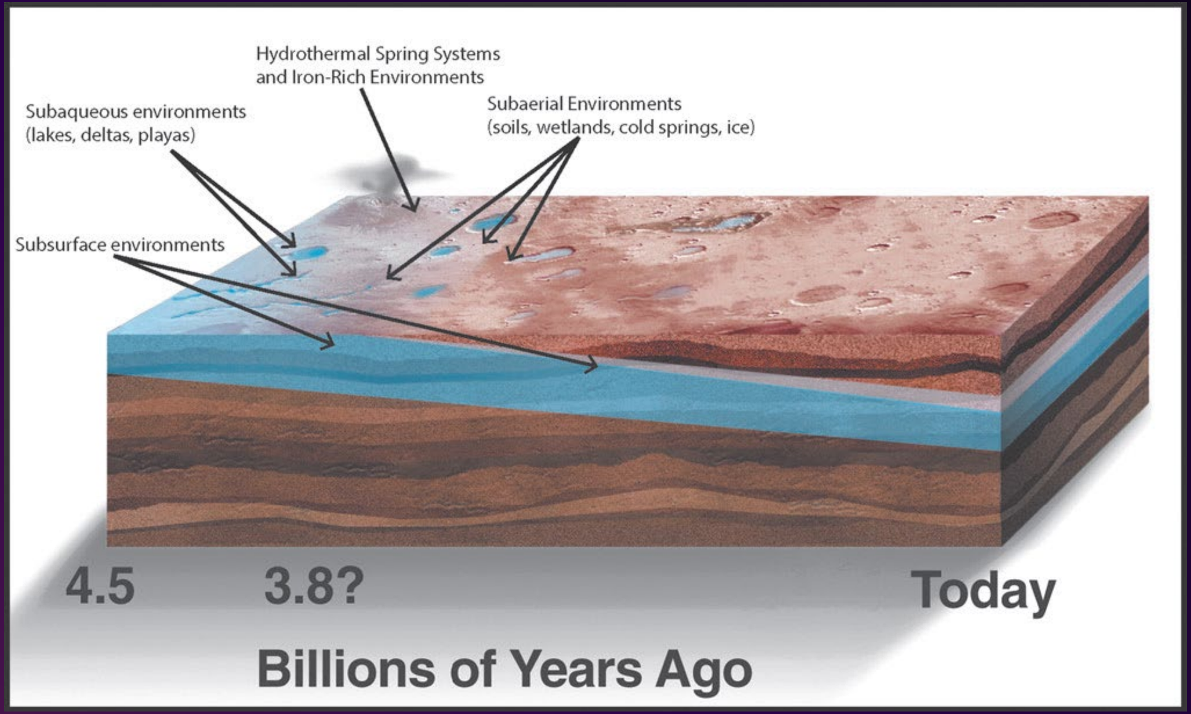
Mustard et al., 2013



Hoehler, 2007

BIOSIGNATURE PRESERVATION AND DETECTION IN MARS ANALOG ENVIRONMENTS

- **Hydrothermal Spring Systems**
- **Iron-Rich Environments**
- **Subaerial Environments**
  - Soils
  - Wetlands
  - Cold springs
  - Ice
- **Subaqueous Environments**
  - Lakes
  - Deltas
  - Playas
  - Shallow ocean
- **Subsurface Environments**
  - Shallow aquifers
  - Deeper igneous crust
  - Deeper sedimentary deposits
  - Caves



Hays et al., 2017

FINDINGS FROM HAYS ET AL., 2017

1. “In many of the environments discussed, **there is a dichotomy between habitability and preservation**— many of the conditions that make an environment more habitable are destructive to one or more of the biosignatures of interest. One strategy for astrobiological exploration must be to seek out a ‘‘sweet spot’’ where these two balance each other so that long-term preservation is possible.

2. Studies of temporally appropriate terrestrial analogs of early Mars merit additional study. Specifically, **the Archean eon on Earth is probably the best environmental analog for early Mars**. Therefore, the limited rock record from this time period merits further investigation. One major caveat is that preservation from early Earth environments might have differed in important ways from preservation in similar early Mars environments, even during times such as the pre-Noachian/Noachian periods.”

FINDINGS FROM HAYS ET AL., 2017

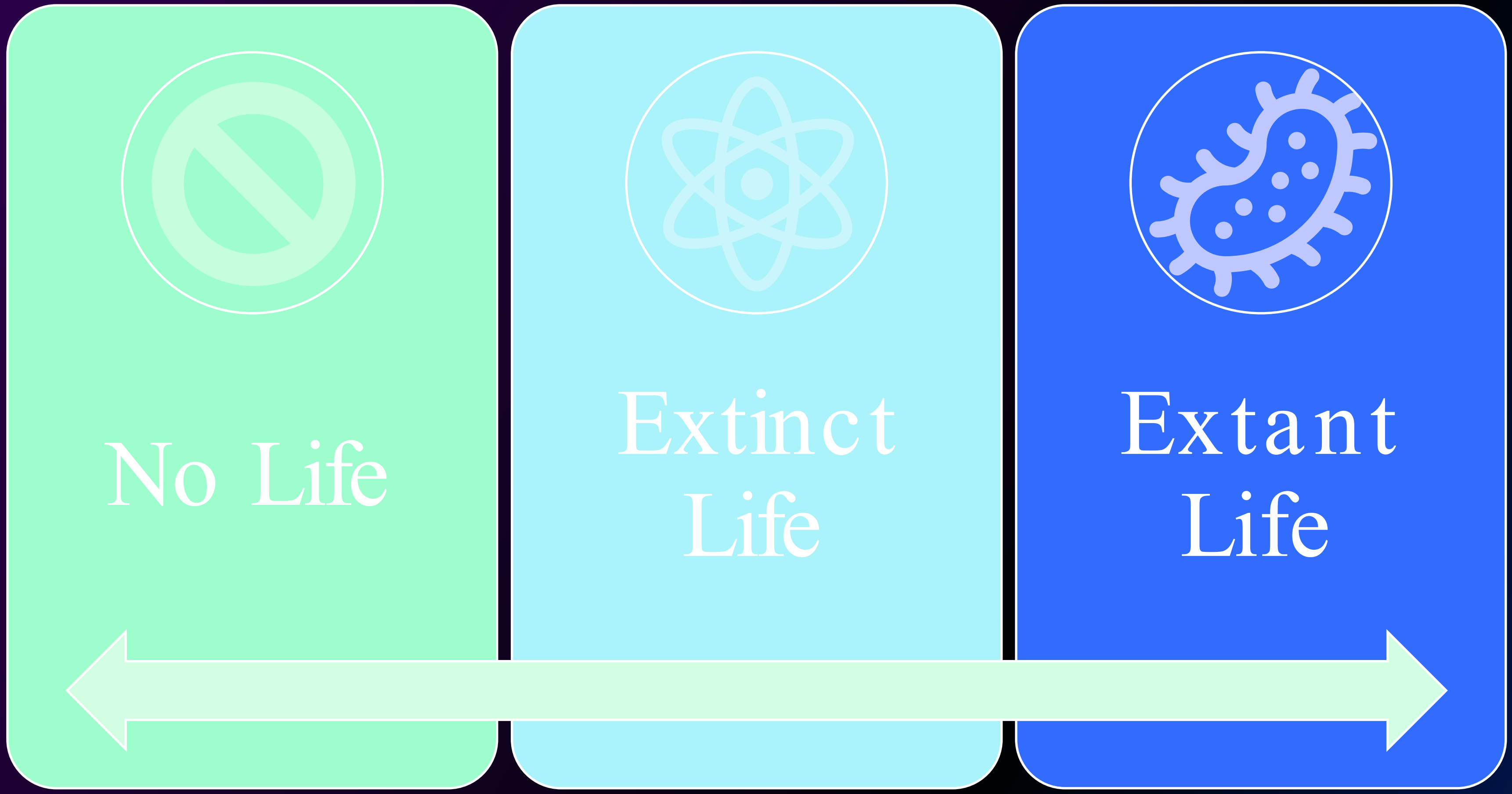
3. "The astrobiological exploration of Mars must be **coordinated across a broad range of spatial and temporal scales**.
4. **A site that includes a variety of geologic records indicative of habitable environments would be most desirable**. For example, if a hydrothermal system was adjacent to or within a fluvial-lacustrine environment, then a single mission might exploit the favorable attributes of both types of habitable environments.
5. Although organic biosignatures received considerable attention at the workshop, a consensus emerged that landed missions should also **seek a diverse suite of potential biosignatures**. Macrostructures could be identified with the cameras on the rover, patterns of isotopic abundance can indicate interactions between various local processes, and bulk isotopic signatures can exhibit better preservation potential than organic molecules over long timescales."

FINDINGS FROM HAYS ET AL., 2017

6. "Missions should also **seek environments on Mars where life might have originated or where chemical reactions that could have spanned the prebiotic/ biotic transition could have been present**. Life may have never arose on Mars, so ancient Martian habitable environments might provide insights into the nature of conditions and processes that occurred prior to the origins of life on other rocky planets.

7. Investigations of certain environments (e.g., subaqueous settings, hydrothermal spring systems) are further advanced than others (e.g., subsurface) and discussions illustrated how this has a significant effect in shaping our current strategies. **More research into advancing our understanding of all of the environments, as well as the best ways to identify them remotely**, would allow the environments with the best potential past habitability and biosignature preservation to be prioritized."

THE SEARCH FOR LIFE ON MARS



"EXTANT LIFE IS A COMPONENT OF THE MEPAG GOALS DOCUMENT THAT HAS RECEIVED VERY LITTLE ATTENTION OVER THE LAST TWO DECADES, BUT FOR WHICH NEW SCIENTIFIC CONCEPTS AND UNDERSTANDINGS COULD LEAD TO EFFECTIVE STRATEGIES AND MISSION CONCEPTS.

KEYS ARE: WHERE TO GO?, AND WHAT TO MEASURE?"

(CARRIER ET AL., 2020)

FINDINGS FROM THE MARS EXTANT LIFE CONFERENCE

1. There was consensus that the following four candidate geologic environments are the best in which to look:

- Caves
- Deep Subsurface
- Ice
- Salts

- The conference group was not able to reach a consensus prioritization of the above options—there are multiple considerations.
- There are significant differences regarding perceptions of discovery potential, and the difficulty of carrying out a yes/no test.

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News & Views

Mars Extant Life: What's Next? Conference Report

Conference leads: B.L. Carrier,[1] D.W. Beaty,[1] M.A. Meyer,[2] Sub-Team leads: J.G. Blank,[3,4] L. Chou,[5,6] S. DasSarma,[7] D.J. Des Marais,[3] J.L. Eigenbrode,[6] N. Grefenstette,[8] N.L. Lanza,[9] A.C. Schuerger,[10] P. Schwendner,[10] H.D. Smith,[3] C.R. Stoker,[3] J.D. Tarnas,[11] K.D. Webster,[12] and Sub-Team contributors: C. Bakermans,[13] B.K. Baxter,[14] M.S. Bell,[15] S.A. Benner,[16] H.H. Bolivar Torres,[17] P.J. Boston,[18] R. Bruner,[19] B.C. Clark,[20] P. DasSarma,[7] A.E. Engelhart,[21] Z.E. Gallegos,[22] Z.K. Garvin,[23] P.J. Gasda,[9] J.H. Green,[24] R.L. Harris,[23] M.E. Hoffman,[22] T. Kieft,[25] A.H.D. Koeppel,[26] P.A. Lee,[27] X. Li,[28] K.L. Lynch,[29] R. Mackelprang,[30] P.R. Mahaffy,[6] L.H. Matthies,[1] M.A. Nellessen,[22] H.E. Newsom,[22] D.E. Northup,[22] B.R.W. O'Connor,[31] S.M. Perl,[1] R.C. Quinn,[3] L.A. Rowe,[32] B. Sauterey,[33] M.A. Schneegurt,[34] D. Schulze-Makuch,[35] L.A. Scuderi,[22] M.N. Spilde,[22] V. Stamenković,[1] J.A. Torres Celis,[17] D. Viola,[3] B.D. Wade,[36] C.J. Walker,[37] R.C. Wiens,[9] A.J. Williams,[38] J.M. Williams,[22] and J. Xu[39]

Abstract

On November 5–8, 2019, the "Mars Extant Life: What's Next?" conference was convened in Carlsbad, New Mexico. The conference gathered a community of actively publishing experts in disciplines related to habitability and astrobiology. Primary conclusions are as follows: A significant subset of conference attendees concluded that there is a realistic possibility that Mars hosts indigenous microbial life. A powerful theme that permeated the conference is that the key to the search for martian extant life lies in identifying and exploring refugia ("oases"), where conditions are either permanently or episodically significantly more hospitable than average. Based on our existing knowledge of Mars, conference participants highlighted four potential martian refugium (not listed in priority order): Caves, Deep Subsurface, Ices, and Salts. The conference group did not attempt to reach a consensus prioritization of these candidate environments, but instead felt that a defensible prioritization would require a future competitive process. Within the context of these candidate environments, we identified a variety of geological search strategies that could narrow the search space. Additionally, we summarized a number of measurement techniques that could be used to detect evidence of extant life (if present). Again, it was not within the scope of the conference to prioritize these measurement techniques—that is best left for the competitive process. We specifically note that the number and sensitivity of detection methods that could be implemented if samples were returned to Earth greatly exceed the methodologies that could be used at Mars. Finally, important lessons to guide extant life search processes can be derived both from experiments carried out in terrestrial laboratories and analog field sites and from theoretical modeling. Key Words: Mars extant life—Biosignatures—Life detection—Astrobiology—Life in extreme environments. Astrobiology 20, 785–814.

FINDINGS FROM THE MARS EXTANT LIFE CONFERENCE

2. Strategies can be identified to narrow the search space for extant life using various aspects of geology, chemistry, and geomorphology at different scales
   - IF biosignatures can be found in relatively young rocks (even up to 100My old) this would be taken as evidence that extant life still exists (somewhere) on Mars

3. Methods for detecting extant life vary depending on the assumptions
   - For Earth-like life: looking for biomolecules, detailed organic analyses through spectroscopy, structures (morphology, membranes) w/ microscopy, and metabolism
   - Agnostic life detection: patterns of complexity (structural, molecular, isotopic, elemental, geochemical); complex organic chemistry, biology
   - Far more detailed life assays are possible via MSR

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Caves

- There is evidence that large numbers of caves exist on Mars, mostly in the form of lava caves. They have been discovered by means of orbital surveys that have imaged skylights that have broken through to the surface.
- On Earth, caves are invariably associated with uniquely adapted life-forms. The presence of life in cave systems is marked and profoundly alters their physical character.
- There is more than one strategy to explore caves for life, including sending a remote vehicle into the cave, and investigating airflow exchange pathways.

Deep Subsurface

- There is evidence that liquid water exists in the deep martian subsurface, although we have thus far been unable to precisely quantify its depth. This environment is inferred to be exceptionally long-lived and stable, similar to its Earth subsurface environment.
- The terrestrial deep biosphere, which has only recently been discovered, is estimated to be the largest reservoir of cellular biomass on Earth.
- Putative martian microbes could utilize oxidants and reductants derived from the same geochemical processes that produce oxidants and reductants in Earth's deep subsurface.

Salts

- On Earth, evaporites and brines are known to support a wide diversity of microbial life.
- Fluid inclusions trapped in solid and crystalline salts (on Earth) have enhanced preservation potential for biological materials, and considerable evidence for extant life itself (possibly of significant geological age).
- Salt deposits are widespread on the surface of Mars, especially in the southern hemisphere, and are readily accessible by rovers. Near-surface exploration accessibility makes salt deposits a favorable target for exploring for extant life on Mars.

Ice

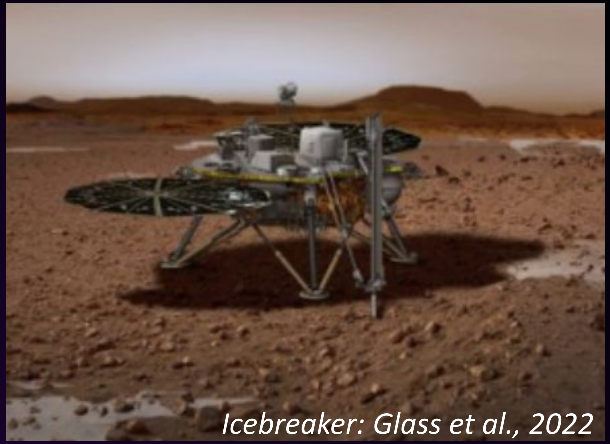
- Permafrost and ice mixed with regolith may have all the components needed for modern martian life including (1) Chemical and mineral compositions that can release soluble nutrients; (2) Electron donors and electron acceptors; and (3) Sufficient C, N, and P to enable biological reproduction and growth.
- Temperatures in shallow subsurface ice vary and some periods may allow shallow subsurface ice to be warm enough for brine stability.
- Ice is widespread in the near-surface of Mars, existing from ~35–90°N latitude and about ~45–90°S latitude. Many ice-rich targets in the near subsurface are accessible for exploration and sampling.

Image generated by Microsoft Copilot

SEARCH FOR LIFE MISSION CONCEPTS

- Recent mission concepts include stationary landers with drills and life detection instrumentation that would access the subsurface (1-2m) of the Martian mid-latitude ices.
- General landing site locales with ice near the surface were proposed for MLE as a proof-of-concept. Acceptable ellipses in the 10 km class are readily evident in regions of Arcadia Planitia (~45°N), Utopia Planitia (~45°N), and Phlegra Montes (35°N) .

Mars Life Explorer: Williams et al., 2021

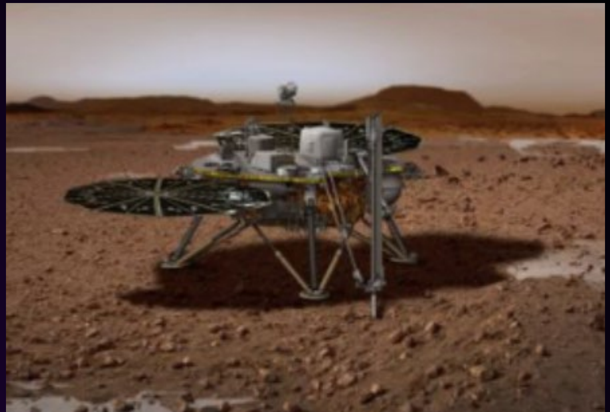


Icebreaker: Glass et al., 2022

SEARCH FOR LIFE MISSION CONCEPTS

- In 2024, NASA requested the formation of the Search for Life Mission Science Analysis Group (SFL-SAG) with agreement from MEPAG and the NASA representative for Astrobiology.
- The purpose of this Science Analysis Group is to refine the recommendation for a ‘Search for Life’ mission in the Decadal Survey by narrowing down the type of environment in which the SFL mission will be delivered, identifying the specific science and technology needs for a mission to that location, and identifying those mission elements that will offer the most conclusive answers, for a mission of this class, to the question of ‘Are we alone?’

Mars Life Explorer: Williams et al., 2021



Icebreaker: Glass et al., 2022

BACKUPS

FINDINGS FROM THE MARS EXTANT LIFE CONFERENCE

1. A substantial subset of the Mars community is actively interested in continuing the search for extant life on Mars
   - Recent advances, including improved knowledge of Mars' geologic diversity and history, terrestrial life in extreme environments, and measurement methods, would improve our search strategies.

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