INVESTIGATING AND CONSTRAINING THE HABITABILITY OF EARLY MARS THROUGH ANALYSIS OF RETURNED MARS SAMPLES.

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Introduction: The current surface conditions on Mars are relatively inhospitable to life as we know it due to factors including 1) the paucity of liquid water; 2) low temperatures; 3) thin atmosphere lacking significant amounts of oxygen; 4) lack of magnetic field leading to high levels of radiolysis and; 5) oxidizing conditions. However, there are multiple lines of evidence that the martian surface was once much more habitable, particularly during the Noachian and early Hesperian period. Observations from multiple orbital and rover missions show that Mars has changed drastically over time and once hosted a much thicker atmosphere, warmer temperatures, large amounts of liquid water on the surface, and active volcanism [1]

There may be environments on present day Mars that remain habitable, particularly in the subsurface, and life that potentially emerged during the Noachian could have evolved to move into those niches. The discovery of extant life on Mars would be absolutely priceless for furthering our understanding of the limits of habitability and the evolution of habitable environments over time.

The analysis of samples from Mars in terrestrial laboraties would be a key strategy for developing a more complete understanding of the evolution of Mars' habitable environments [2]. Lessons learned about Mars can also be applied to understanding the evolution of terrestrial planets throughout the galaxy. Planning is currently underway by NASA and ESA to return samples via a potential Mars Sample Return campaign. The Mars 2020 rover, which is scheduled to launch in 2020 with a landing site in Jezero crater, is equipped with a sample caching system capable of collecting rock and regolith samples from the surface (down to ~10 cm in depth), sealing them into sample tubes, and caching them on the martian surface for possible later return to Earth. The notional Mars Sample Return campaign includes a landed mission which would include a fetch rover for collecting the samples and a rocket for delivering the samples into Mars orbit. An orbiter would then collect the orbiting sample capsule in Mars orbit and return the samples to Earth.

The benefits of carefully selecting and returning samples from Mars and investigating them on Earth are numerous. We would be able to bring to bear the full breadth of state of the art instrumentation to make numerous measurements on single samples. There would be no need to miniaturize instruments or sacrifice sensitivity or selectivity in order to fit the instrument on a spacecraft or rover. The other major benefit would be the abaility to make discovery-driven choices in the investigation pathway. One shortcoming of in situ measurements is the long lead time needed to follow up on interesting discoveries, not the mention the inability to return to the precise location of the initial discovery to repeat the measurement or make a follow-on measurement.

There are several key areas of investigation, as outlined in the iMOST Report [2], which reflect open questions in our understanding of Mars, and some of these are especially important for developing a more complete understanding of the limits and progression of Mars habitability from the pre-Noachian through the early Hesperian and into today.

Geology: The geology and geomorphology of Mars provided the initial evidence that water once flowed across its surface. We now also see evidence in the geochemical record that hydrous weathering was once a dominant process, and the prescence of phyllosilicates indicates that these weathering processes took place under conditions conducive to the existence of microbial life. By investigating returned samples we would potentially be able to investigate different types of habitable environments which could include (depending on availability at the Jezero landing site) ancient hydrothermal systems, lacustrine deposits, subsurface and subaerial environments. Understanding the physical and chemical properties, extent, and duration of these habitable environments will be important to constraining the habitable periods on Mars and what the planet was like during its early history.

Geochronology: A key piece of the puzzle lies in better constraining the geochronology of Mars. This can best be achieved through isotopic analysis of returned igneous samples. The current dating system for Mars is heaviliy influenced by our knowledge of the lunar cratering record and has significant uncertainties. A more definite method for age-dating the surface and its craters, in concert with improved understanding of the evolution of habitable conditions on the planet, would allow for a clearer picture of the how long the habitable periods on Mars lasted and how they evolved through time.

Biosignatures and prebiotic chemistry: Assuming that the surface of Mars was indeed habitable during the Noachian and early Hesperian**,** it would make sense to look for biosignatures and evidence for prebiotic chemistry in returned samples as well. There are several proposed classes of potential biosignatures which could be targets of investigation in returned samples including 1) organic molecules; 2) biotic minerals; 3) morphological biosignatures such as structures and textures; 4) stable isotopic patterns; 5) other chemical evidence [2].

Mars Sample Return would allow us to look for all of these potential biosignatures, and if found, understand their geological and environmental context. This could substantially advance our understanding of the limits of habitability. If no biosignatures are found, this could also influence our future search strategies and constrain the limits of habitabilitiy on terrestrial planets, or at least on their potential for preservation.

Conclusions: Although it is commonly believed that the martian surface once hosted habitable environments based on current evidence from orbital and in situ rover data, there is much that can be done to better understand the limits and evolution of the habitability of the red planet.

References: [1] Carr, M.H.; Head, J.W. (2010). *"Geologic History of Mars". Earth Planet. Sci. Lett.* ***294****: 185–203.*. [2] iMOST (International MSR Objectives and Samples Team: co-chairs: D. W. Beaty, M. M. Grady, H. Y. McSween, E. Sefton-Nash; documentarian: B. L. Carrier; team members: F. Altieri, Y. Amelin, E. Ammannito, M. Anand, L. G. Benning, J. L. Bishop, L. E. Borg, D. Boucher, J. R. Brucato, H. Busemann, K. A. Campbell, A. D. Czaja, V. Debaille, D. J. Des Marais, M. Dixon, B. L. Ehlmann, J. D. Farmer, D. C. Fernandez-Remolar, J. Filiberto, J. Fogarty, D. P. Glavin, Y. S. Goreva, L. J. Hallis, A. D. Harrington, E. M. Hausrath, C. D. K. Herd, B. Horgan, M. Humayun, T. Kleine, J. Kleinhenz, R. Mackelprang, N. Mangold, L. E. Mayhew, J. T. McCoy, F. M. McCubbin, S. M. McLennan, D. E. Moser, F. Moynier, J. F. Mustard, P. B. Niles, G. G. Ori, F. Raulin, P. Rettberg, M. A. Rucker, N. Schmitz, S. P. Schwenzer, M. A. Sephton, R. Shaheen, Z. D. Sharp, D. L. Shuster, S. Siljestrom, C. L. Smith, J. A. Spry, A. Steele, T. D. Swindle, I. L. ten Kate, N. J. Tosca, T. Usui, M. J. Van Kranendonk, M. Wadhwa, B. P. Weiss, S. C. Werner, F. Westall, R. M. Wheeler, J. Zipfel, and M. P. Zorzano) (2019), The Potential Science and Engineering Value of Samples Delivered to Earth by Mars Sample Return, Meteoritics & Planetary Science, vol. 54 (3), p. 667-671 (executive summary only), https://doi.org/10.1111/maps.13232; open access web link to full report (Meteoritics & Planetary Science, vol. 54, S3-S152): https://doi.org/10.1111/maps.13242.