Identifying Martian Hydrothermal Sites: Geological Investigation Utilizing Multiple Datasets.

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Introduction: Mars has had an active and varied geologic history, similar in many ways to that of Earth. Present-day conditions on Mars are characterized by a thin atmosphere, an extremely cold climate, and pervasive eolian modification as well as the emplacement of flow materials [1]. Geomorphic features, such as large outflow channels and valley networks of varying ages, however, indicate that water/ice-related processes have played a significant role in the modification of its surface during the geologic past. Both hydrothermal activity [2-19] and precipitation [e.g., 10,16, 20, 21] are viable contributors to valley formation. In fact, one probably contributed to the other, especially during certain episodes of geologic activity [22,23].

We are interested in martian landscapes that may have been modified by magmatic-driven hydrothermal activity. Such potential long-lived geologic environments (tens of thousands to a few million years; [24]), which could favor the development and sustaining of life [e.g., 25], are optimal target sites for future sample return missions. Detailed mapping, classification, and relative age dating of tectonic structures located in the Tharsis region of the Western Hemisphere of Mars, for example, coupled with the application of terrestrial analytical techniques, suggest that the Tharsis region was dominated by the formation of a complex, long-lived magmatic-tectonic system comprised of numerous regional and local concentrations of tectonic activity [26]. In addition, comparative analysis of erosional valleys, geologic materials and features (e.g., volcanoes, rift systems, and impact craters), and topography through time suggest that many of these tectonic concentrations may be the source regions for magmatic-related hydrothermal activity [19, 27]. Comprehensive geological investigation of such sites (e.g., **Table 1**), utilizing multiple datasets (e.g., existing geologic map data, MOC imagery, MOLA, TES image data, geophysical data, etc.), will yield prime target sites for future hydrological, mineralogical, and biological investigations.

Scientific rational: If life developed on Mars, it is likely to have left behind a fossil record especially concentrated in environments where long term energy sources and water coexisted [e.g., 28, 29, 30], such as at sites where long-lived, magmatic-driven, hydrothermal activity occurred [e.g., 25]. Small, single-celled creatures (prokaryotes), for example, are vitally important in the evolution of a planet; these prokaryotes are environmentally tough and tolerant of environmental extremes of pH, temperature, salinity, and anoxic conditions found around hydrothermal vents [31]. In addition, there is a great tenacity and ability for bacteria to survive long periods of geologic time in extreme conditions, including (1) the frozen soils of Siberian and Antarctic permafrost regions, and (2) hydrogen sulfide and sulfur on very hot rocks erupted from Mount St. Helens volcano [e.g., 31].

Thus, identification of potential environments, which are dominated by magmatic-driven hydrothermal processes, provides NASA with significant target sites for future sample return missions, since they (1) could favor the development and sustenance of life, (2) may comprise a large variety of exotic mineral assemblages, and (3) could potentially contain water/ice reservoirs for future Mars-related human activities.

Geological Conclusion: Comprehensive geological investigations using existing, new, and expected planetary data (including existing geologic maps) should be performed for these environments that appear to have been impacted by magma-driven activity. This work has the potential to reveal excellent target locations for future sample return missions. Such sites are revealed by the following indicators: (1) morphologic feature types, including isolated valleys and valley networks, depressions including pit crater chains, erosional scarps, volcanoes, volcanic valleys and rilles, and fractures, canyons, hills, and mesas which are commonly associated with chaotic materials, (2) geophysical anomalies indicative of possible underlying intrusive bodies, (3) MOLA profiles, combined with other geological evidence, indicative of magmatic-related uplift, and (4) spectral signatures that may reflect ancient and modern ground water environments and ancient surface water environments.

TABLE I. Examples of potential sites of magmatic-related hydrothermal activity. Identification based on * [26], **[27], and ***Other.

LOCATION	**RELATIVE AGE (based from [27])**	**INTERPRETATION BASED ON PREVIOUS WORK**
*Tempe Fossae 81°W, 35°N	Stage 1 – Noachian	Concentration of tectonic activity situated within the Tempe volcanotectonic province, which includes shield volcanoes [32; Moore, map in review] and possible intrusive bodies [33]. Center may represent single or multiple magmatic/tectonic events [34]. Materials record other centers of tectonic activity, which include Tharsis and Alba Patera.
*/**Warrego 95°W, 39°S	Stage 2 – Late Noachian to Early Hesperian	Concentration of magmatic/tectonic/hydrothermal activity associated with valley development [18, 19, 27]. Geologic arguments are as follows: (1) Warrego Valles formed concurrently with nearby Stage 2 fault and rift systems and collapse pits and depressions, and (2) Stage 2 faults appear deflected about and absent within the source region such as at other proposed sites of intrusive activity on Mars [33]
**Southern Coprates near 62°W, 28°S	Stage 2 – Late Noachian to Early Hesperian	Concentration of magmatic/tectonic activity evident from an apparent process linkage (e.g., spatial and temporal associations) between the troughs, rift systems, and depressions similar to that proposed for the Elysium and Galaxias regions of Mars where ground-ice melting due to volcanism may have provided the water that formed the channel distributaries [4,6,35]. Similar to the interpretation regarding the development of the valley networks of Warrego Valles, an intrusive body at depth with associated prolonged heating and tectonic and hydrologic activity, which includes groundwater flow, sapping, and related release of ground water as surface runoff, seems more likely to have resulted in the formation of large troughs than rainfall [19,27].
***East Valles near 49°W,15°S	Stage 4 – Late Hesperian to Early Amazonian and possibly Stage 3 activity	Concentration of magmatic/tectonic activity associated with late-stage development of Noctis Labyrinthus and Valles Marineris.
*Alba Patera 107°W, 37°N	Stage 4 – Late Hesperian to Early Amazonian	Concentration of tectonic activity associated with the development of a large shield volcano [e.g., 32]; valleys associated with development of shield volcano [e.g., 9].
*North Olympus Mons 135°W, 28°N	Stage 5 – Amazonian	Concentration of magmatic/tectonic activity that may represent the late-stage pulses of activity for the Tharsis region [23,26,36]. Some of the large fissures and associated flow materials on the northwest flanks of the Tharsis Montes shield volcanoes [37,38] may be related to such late-stage activity.

References

[1] Hartmann, W.K., et al.,1999, *31st Amer. Astron. Soc. Meeting, 31*, 1138. [2] Carr, M.H., 1979, *J. Geohys. Res., 84*, 2995-3007. [3] Newsom, H.E., 1980, *Icarus, 44*, 207-216. [4] Mouginis-Mark, P.J., et al., 1984, *Earth, Moon, and Planets, 30*, 149-173. [5] Brakenridge, G.R., et al., 1985, *Geology, 13*, 859-862. [6] Mouginis-Mark, P.J., 1985, *Icarus, 64*, 265-284. [7] Mouginis-Mark, P.J., 1990, *Icarus, 84*, 362-373. [8] Squyres, S.W., et al., 1987, *Icarus, 70*, 385-408. [9] Gulick, V.C., and Baker, V.R., 1989, *Nature, 341*, 514-516. [10] Gulick, V.C., and Baker, V.R., 1990, *J. Geophys. Res., 95*, 14,325-14,344. [11] MacKinnon, D.J., and Tanaka, K.L., 1989, J. *Geophys. Res., 94*, 17,359-17,370. [12] Wilhelms, D.E., and Baldwin, R.J., 1989, *Proceedings: Cambridge University Press and Lunar and Planetary Institute*, 355-365. [13] Clifford, S.M., 1993, *J. Geophys. Res., 98*, 10,973-11,016. [14] Tanaka, K.L., and Clifford, S.M., 1993, *LPI Tech. Rep., 93-04, Part 1*, 17-18. [15] Squyres, S. W, and Kasting, J. F., 1994, *Science, 265*, 744-749. [16] Scott, D.H., et al., 1995, *U.S. Geol. Sur. I-Map 2461*. [17] Carr, M. H., 1995, *J. Geophys. Res., 100*, 7479-7507. [18] Gulick, C., et al., 1997, *Icarus, 130*, 68-86. [19] Tanaka, K.L., et al., 1998, *J. Geophys. Res., 103*, 31, 407-31, 419. [20] Baker, V.R., et al., 1991, *Nature, 352*, 589-594. [21] Craddock, R.A., and Maxwell, T.A., 1993, J. Geophys. Res., 98, 3453-3468. [22] Baker, V.R., et al., *this edition*. [23] Dohm et al., *this edition*. [24] Henley, R.W., 1996, *In Evolution of Hydrothermal Ecosystems on Earth (and Mars?), Cib Found. Symp., 202*, 61-82. [25] Wilson, L., and Head III, J.W., 1997, *LPI Contribution 96*, 85-87. [26] Anderson, R.C., et al., 1998, *Lunar Planet. Sci., XXIX*, 1881-1882. [27] Dohm, J.M., and Tanaka, K.L., 1999, *Planet. & Space Sci. 47*, 411-431. [28] Mckay, C.P., and Stoker, C.R., 1989, *Geophys. Space Phys., 27*, 189-214. [29] Farmer, J.D., and Des Marais, D.J., 1997, *LPI Contribution 96*, 30-31. [30] Farmer, J.D., et al., 1997, *LPI Contribution 96*, 31. [31] Nealson, K.H., 1999, *Engineering & Science, California Institute of Technology, LXII,* 31-40. [32] Scott, D.H., and K.L. Tanaka, 1986, *U.S. Geol. Sur. I-Map* 1802-A. [33] Scott, D.H., and Dohm, J.M., 1990a, *in MEVTV Workshop "Evolution of Magma Bodies on Mars"*, 39-40. [34] Scott, D.H., and Dohm, J.M., 1990b, *Lunar Planet. Sci. Proc., XX*, 503-513. [35] Baker, V.R., 1982, *The channels of Mars: Austin, University of Texas Press*, 198 p. [36] Plescia, J.B., and R.S. Saunders, 1982, *J. Geophys. Res., 87*, 9775-9791. [37] Scott, D.H and Zimbelman, J.R., 1995, *U.S. Geol. Sur. I-Map 2480*. [38] Scott, D.H., et al., 1998, *U.S. Geol. Sur. I-Map 2561.*