Prioritizing Putative Hydrothermal Sites on Mars. D. Schulze-Makuch[1], James M. Dohm[2], Alberto G. Fairén[3,4], Wolfgang Fink[5], Chaojun Fan[1], J.A.P. Rodriguez[6], and Victor R. Baker[2,7], [1]School of Earth and Environmental Sciences, Washington State University, Pullman, WA 99164, USA, dirksm@wsu.edu, [2]Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85721, jmd@hwr.arizona.edu, [3]Space Sciences Division, NASA Ames Research Center, Moffett Field, CA 94035,[4]Centro de Biología Molecular, CSIC-Universidad Autónoma de Madrid, 28049-Cantoblanco, Madrid, Spain, *agfairen@cbm.uam.es*,[5]Visual and Autonomous Exploration Systems Research Laboratory, California Institute of Technology, Pasadena, CA 91125, *wfink@autonomy.caltech.edu*, [6]Planetary Science Institute, Tucson, AZ, USA, email: alexis@psi.edu, [7]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, baker@hwr.arizona.edu

Introduction: Recorded geologic activity coupled with extensive evidence of past and present-day water/ice, above and below the martian surface, indicate that hydrothermal environments certainly existed in the past and may still exist today. Confidence in identifying such environments at the martian surface is based on distinct geologic, paleohydrologic, paleotectonic, topographic, geophysical, spectral, and elemental signatures. We have assembled a list of martian sites that exhibit indications for endogenic- and exogenic-driven hydrothermal activity [1], an extract being shown in Table 1. Our produced list is not meant to be exclusive, but rather provides a first attempt of listing sites that appear especially promising based on a set of selection criteria.

Selection Criteria: Our selection criteria for martian sites to exhibit indications of hydrothermal activity include: (1) geomorphologic evidence of the action of liquid water; (2) stratigraphic and geomorphologic evidence of volcanic constructs and/or lava flows; (3) stratigraphic and paleotectonic evidence for a center of magmatic-driven tectonism; (4) topographic depressions and/or valleys hypothesized to be the result of structurally controlled collapse and/or rifting, respectively, based on stratigraphic, geomorphic, topographic, and paleoteconic evidence; (5) geomorphologic evidence of impact craters in ice-rich regions; (6) identification of deposits usually associated with hydrothermal activity, such as carbonates, sulfates and sulfides, and metal hydroxides/oxides; (7) identification of deposits indicative of water alterations such as hydrated phyllosilicates, the minerals jarosite and hematite or Gamma Ray Spectrometer (GRS)-based elevated elements such as chlorine; (8) spectroscopic evidence for increased heat flow, especially in ice-rich regions; and (9) geological similarities to hydrothermal analog sites on Earth.

Exploration Strategies: The notion of Mars as a water-enriched internally still active planet is supported by the recent acquisition of geologic, hydrologic, topographic, chemical, and elemental information obtained by the Mars Global Surveyor (MGS), Mars Odyssey, Mars Express, and Mars Exploration Rovers (MER). The availability of water throughout martian history and its possible existence up to the present time, as well as the dynamic interactions among water and endogenic and exogenic events, render Mars a prime target for astrobiological investigations. Once life would have gained a foothold on Mars, it would be expected to adapt to the changing conditions on the planet [2]. In this case, we could expect to find life in microscopic form in the subsurface and most likely at current hydrothermal sites, if they exist. Given this potential, how can we best home in on prime candidate sites of potential life-containing habitats?

An ever expanding list of putative hydrothermal sites should be compiled. Both fossil and extant sites should be listed based on rigorous selection criteria incorporating the latest results from Mars missions. Prime sites could be selected now by evaluating the selected candidate sites using existing and yet-to-be-released remote stratigraphic, geomorphic, topographic, spectral, geophysical, and elemental information provided by the instruments onboard the Mars orbiters including the Mars Reconnaissance Orbiter (MRO), and the Sojourner and MER rovers. Some of the promising sites are geologicaly young, thus the impact record, which could indicate a volatile-rich substrate, is neglible. Also, some areas are too small or highly resurfaced/deformed (e.g., Valles Marineris) to provide an accurate assessment. Further, the lack of some selection criteria such as spectroscopic evidence of heat flow does not mean it does not exist, but rather means that the resolution of current instruments is wanting, that the target is below the ground or covered, and that a novel strategy is needed such as a "tier-scalable" reconnaissance mission concept, which integrates multi-tier and multi-agent hierarchical mission architectures [3].

References: [1] Schulze-Makuch D. et al. (2007) in review at *Icarus*. [2] Schulze-Makuch D. et al. (2005) *J. of Geophys. Res.* – Planets 110, E12S23, doi:10.1029/2005JE002430. [3] Fink W. et al. (2005) *Planetary & Space Science* 53, 1419-1426.

Table 1. Selected sites on Mars with some indications of hydrothermal activity

Name	Selection Criteria	Relative Age	Description/Interpretation
Elysium rise volcanic province	1,2,3,4,5,7,9	Hesperian – Amazonian	Shield volcanoes, lava fields, faults, channel systems, and depressions [j,k]. **Interpretation:** Magmatic complex that has evolved in a water-enriched region of Mars [l,m].
Tharsis: Central Valles Marineris Rise	1,2,3,4,7,9	Late Noachian – Early Hesperian and possibly younger activity	Topographic rise marked by faults that are radial and concentric about the central part of Tharsis [a-c]; canyons [d]; valleys in places [e]. **Interpretation**: Plume-driven uplift along a major crustal zone of weakness in the central part of an ancient, Noachian basin/aquifer system [a], as part of the growth of a tectono-magmatic complex, similar in many respects to those identified on Earth [f].
Northwestern Slope Valleys (NSVs)/Mangala Valles	1,2,4,5,7,9	Noachian - Late Amazonian	Lava flows, faults, valleys, Mangala Valles outflow channel system, sapping channels, dark slope streaks, elevated chlorine, magnetic and gravity anomalies [g]. **Interpretation:** Prime candidate site for future exploration; the highest concentration of chlorine recorded on the planet [h,i].
Meridiani Planum	1,5,6,7,9	Noachian and possibly younger	Outcrops of sedimentary sequences and mantle-forming materials including sulfate-rich layered deposits with hematite spherules, faults, and valleys. **Interpretation**: Near-surface aqueous oxidation of pyrite formed mineral deposition in acidic solutions, leading to the formation of jarosite assemblages, goethite concretions and, ultimately, coarsed-grained hematite, through an extended diagenetic history. Alternatively, volcanic lapilli have also been suggested as an origin for the hematite concretions [n]. Other interpretations include rock materials developed in sabka [o] and hydrothermal environments [p].
Gusev Crater	1,6,9	Noachian	Impact crater basin marked by younger impacts, lava flows, dust devil tracks; basin floor materials include secondary weathered basalt and sulfates. **Interpretation**: Noachian impact followed by a complex geologic and hydrogeologic history, which includes volcanic, fluvial (flooding), wind, impact, and secondary weathering activities [q,r].
Hale crater	1,5		Crater with dissections on its walls and central peaks, formed by gullies, indicative of liquid water activity. Gullied regions show low nighttime temperatures, apparently caused by unconsolidated materials [s].

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