ACTIVE IGNEOUS AND HYDROTHERMAL ACTIVITY DURING THE EARLY-MIDDLE AMAZONIAN: INFERENCES FROM THE CHASSIGNITE AND NAKHLITE METEORITES AND IMPLICATIONS FOR ASTROBIOLOGY. F. M. McCubbin[1], M. Glamoclija[1], A. Steele[1], A. Smirnov[2], [1] Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Rd., N.W, Washington, DC 20015 [2] Department of Geosciences, Stony Brook University, Stony Brook NY 11794-2100.

Introduction: The current picture of the present-day martian surface presents a challenge to life [1]. Environmentally-informative mineralogy identified from orbital and in-situ exploration indicates that where water was present during recent times, conditions were largely saline, acidic and oxidizing [2]. The martian surface may only have been habitable during the Noachian to early Hesparian, where water was available before it was erased by the emergence of a cold, dry climate that persisted for ~3.5Ga [3]. Below the surface, however, aqueous environments on Mars may be elucidated from the detailed analysis of SNC meteorites; several of which record a magmatic source of water and the potential for young (early-mid Amazonian) subsurface hydrothermal activity that could stretch the envelope of martian habitability over both space and time [4-7].

The SNC meteorites represent a direct sampling of igneous processes on Mars, and they are some of the only detailed windows into the martian subsurface that scientists currently have. In recent years, the mineralogy of the SNC meteorites has expanded this insight to include subsurface hydrothermal activity on Mars. In particular, the volatile-bearing mineralogy of the Nakhlite and Chassignite meteorites, which includes apatite, amphibole, mica, and jarosite, have recorded both high-temperature and low-temperature interaction with a variety of fluid compositions, including those rich in water, chlorine, sulfur, carbon, iron and alkalis [4-6, 8, 9]. Moreover, many of these fluids were derived by magmatic degassing, indicating that the magmatic source regions were still contributing to the addition of these volatile constituents to the martian surface and subsurface as late as the early-mid Amazonian (the Chassignites and Nakhlites are dated at ~1.3 Ga [10]) [6]. In fact, the recent discovery of methane sources from volcanic provinces on Mars indicates that the same types of processes could even continue today [11].

Areas of young (Amazonian) volcanism have also been identified on Mars from orbital exploration, and several of these locations have been suggested to represent potential source regions for the SNC meteorites [12]. The Chassignites and Nakhlites have been suggested to originate from either thick lava flows or shallow layered intrusions [13], which would likely be associated with Amazonian volcanic provinces. The most prominent young volcanism on Mars is associated with the regions of Tharsis and Elysium. Provinces of Central Elysium Planitia (southeast of Elysium Mons and Noctic Labyrinthus) and Echus Chasma (east of the Tharsis region) were active until approximately one hundred million years ago [14, 15].

Hydrated light-toned deposits (probably hydrated sulfates or chloride salts) have also been identified in association with these young volcanic features [16]. These deposits are consistent with the presence of aqueous alterations under conditions similar to the current climate [16]; however, hydrothermal activity cannot be ruled out as a potential source for the deposits.

In this contribution, we attempt to synthesize the new findings of evidence for magmatically-derived hydrothermal activity from the Nakhlite and Chassignite meteorites with new observations from remote sensing on young Amazonian volcanism on Mars. From this compilation, we are able to make inferences about potential habitable zones at the martian surface and subsurface even after the onset of the cold, dry climate that has existed for much of the Hesparian and Amazonian epochs.

Evidence for Hydrothermal Activity from The Nakhlites and Chassignites: At least two types of magmatically-derived hydrothermal fluids have been identified from recent studies of SNC meteorites [4-6, 17]. Both of these fluids were inferred based on the mineral assemblages present within various textural regimes in the meteorites.

The water-rich nature of amphibole and mica within olivine-hosted melt inclusions from the Chassigny meteorite are consistent with magmatically derived fluids that are water-rich. The apatite from these melt inclusions indicate that chlorine was also present in the fluid, but it was not the dominant volatile species [5, 6]. These fluids are produced from the magma after reaching fluid-saturation during ascent and crystallization. At elevated temperatures, these fluids would contain primarily silica and un-ionized chlorides of sodium, potassium, iron, and hydrogen [e.g. 17-21]. Continued crystallization would produce more fluid that would become progressively more dilute (water-rich). At low temperatures, these fluids would be characterized by neutral to alkaline pH, with moderate-low salinity, although some variability could arise from wall-rock interactions.

A mineral assemblage consisting of Cl-rich amphibole, jarosite, hematite, goethite, pyrrhotite, and titanomagnetite was identified in pyroxene hosted melt inclusions from the Nakhlite meteorite MIL 03346 [4]. This mineral assemblage is consistent with formation from a hydrothermal fluid rich in chlorine, sulfur, and iron, with some water. This fluid was also derived by magmatic degassing, however the magma from which the fluid degassed contained abundant chlorine and sulfur, in addition to water. This fluid, depending on the surrounding wall rock mineralogy, would result in hypersaline, potentially very low pH fluids that are analogous to those implicated for jarosite formation at Meridiani planum [22].

Implications for Astrobiology: The discovery of evidence for geologically young hydrothermal fluids is not only important for potential implications for surface mineralogy and various types of alteration assemblages, but also because it identifies a potential source of nutrients and may give insight into geochemical processes that would be essential sources of energy for putative Martian life forms.

Many of the described settings of Amazonian volcanism and associated hydrothermal activity have been investigated previously on Earth as potential terrestrial analogues for habitable zones through geomicrobiological studies. These environments include acid mines [23, 24], mine waste environments [25], volcanic caves and lava tubes [26], and evaporitic/hypersaline environments [27].

Concluding Remarks: Both water-rich and water-limited hydrothermal activity were taking place in volcanic regions during the Amazonian, possibly wherever active volcanism occurred. The resulting environments were likely the last promising refuge for sustaining putative martian life, as the fluids would have been a source of both nutrients and energy. By integrating studies on SNC meteorites and results from remote sensing data, one can gain an unparalleled insight into Martian geology during the Amazonian. Perhaps more importantly, one can identify possible habitable zones on Mars, some of which may have remained habitable even after the onset of the cold dry climate that has existed for much of the Hesperian and Amazonian epochs. If martian volcanism is still active (supported by recent findings of methane release [11]), some of these environments could remain habitable even today.

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