PROGRESS IN UNDERSTANDING MARS AS A HABITABLE PLANET.

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Introduction: Each planetary body has unique characteristics that must to be understood in order to consider the possibility of extant or past life. Mars has a rich early history that is just beginning to be understood in terms of habitability, but also in terms of redox potential, groundwater, and chemistry. Here we survey recent advances in understanding of Mars as a habitable planet, projecting forward to the three missions in 2020, and the future.

Basic Questions: Extant life requires a habitable planet and would almost certainly have left clues in the sedimentary record. The MSL mission cemented our understanding of Mars as a water-rich planet in which open lakes, rivers, and potentially oceans existed on relatively long time scales of millions of years, extending into the early Hesperian (e.g., [1]), even if we do not yet understand the climate physics that facilitated this environment (e.g., [2]). While the chemistry of Gale lake water resulted in smectite clays (e.g., [3]), so far we still have relatively few clues on important details such as redox potential near shore vs. deep water [4]. Enrichments of elements like P and Mn, as well as Cu and Zn [5-11] suggest that some materials have precipitated from the groundwater (and maybe elsewhere) at relatively strong oxidation fronts, the nature of which is not understood. Manganese enrichments have also been found by the Opportunity rover, opening the possibility that Mn deposits are widespread on Mars [12]. Diagenetic features also speak to potential redox reactions. Iron-rich spherules have been found at Gale crater (unpublished data) as well as at Meridiani (e.g. [13]). Decimeter-size hollow spherules also suggest redox reactions [14].

Silica at Gale and Gusev: Silica-enriched sediments are considered important for taphonomy [15], given their prominence in terrestrial analog sites from the Archean. High-silica sites occur at both Home Plate in Gusev crater [16] and in Gale crater. The Gusev site is the first hydrothermal springs deposit found on Mars, of which many are expected (e.g., [17]) and some found [18, 19]. The silica-rich site at Marias Pass in Gale crater is likely a volcanic ash layer [20] that was later mobilized and altered by (possibly surface and) groundwater [21-23].

Groundwater on Mars has been modelled, and observed in orbital and ground-based missions [24]. In Gale crater, at least three stages of groundwater activity have been identified from vein deposits [25], and more stages, including high-temperature ones [26], may well have existed. Groundwater precipitates are dominated by calcium sulfates at both Gale and Meridiani [27, 28]; redox evolution and fluid composition [29], especially elements such as boron [30], play a role in the habitability of subsurface areas with groundwater.

Organics: The MSL mission also confirmed the long-expected existence of organic materials on Mars [31]. These are observed at low (ppb) abundances, but the observation of significant CO_2 releases at low temperatures in the SAM experiments, combined with the presence of perchlorates in the sediments as well as soils, allows the possibility that organics react during the heating process in SAM's oven. If that is the case, Mars organic molecule abundances could be substantially higher than SAM observed [32]. The next missions will explore that possibility. On the other hand, the low levels of atmospheric methane observed by SAM [33] appear to be a tantalizing clue but also a hard limit on the abundance of methanogenic extant life on Mars.

What Will We Learn in the Next Five Years? The three missions planned for Mars landings in 2020 (NASA's Mars 2020 rover, ExoMars, and the Chinese rover) should significantly expand our understanding of Mars as a habitable planet. NASA's Mars 2020 rover has two Raman spectroscopy instruments. SHERLOC is especially designed to search for organic niches at the microscopic scale. ExoMars has an in-situ Raman instrument as well, and the Chinese rover has a LIBS instrument patterned after ChemCam.

The landing sites for these rovers represent diversity that should provide important clues: All three candidate Mars 2020 sites contain carbonates, which have not been found at Gale and Meridiani. The study of carbonates on Mars may reveal much about its previous climate, especially why we do not see more carbon precipitated planet-wide. ESA's ExoMars landing site at Oxia Planum fulfils a wish to go to one of the most ancient sites, which may also reveal further clues to habitability in Mars' earliest era.

In the longer term, sample return from the Mars 2020 rover site is expected to eventually clarify many details of organics and the possibility of extant life.

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