Why Mars: a prologue

As the next wave of robotic exploration of Mars commences in the early 2020s, led by a multiplicity of space-faring nations and emerging commercial entities such as SpaceX and Blue Origin, the possibility of paradigm-shifting discoveries about the Red Planet is high. In this midst, the always-lurking question of "*why Mars?*" merits reconsideration. The answer ranges from seeking to enhance high-tech prowess and leadership, evolving our understanding of geology, chemistry, physics, and meteorology, to providing intellectual inspiration to a broad cross-section of the society.

To some, Mars is a "state of mind" whose enigmas are an opportunity to challenge a tangible frontier with the best of what "New Space" can offer, while building on a foundation that began in the late 1960s with the first wave of groundbreaking NASA-led Mars missions. Mars, today, engenders fascination because of the perplexing and still undiscovered aspects at each step of its exploration. There are just enough similarities between the Red Planet and the Earth to invite persistently novel if not beguiling interpretations and speculation, both with regard to current conditions and those of the deep past. At each step a "new Mars" emerges, connecting enigmas to key questions we often need to ask about our own planet.

"Why Mars?" embraces more than the simple question as stated. Like Earth, Mars operates as a system of systems, with time-variable and multi-scale interactions between its atmosphere, hydrosphere, lithosphere and, possibly, a biosphere. As with our continuing discoveries about Earth and its sensitive climate system, Mars appears to have experienced episodic environmental-upheavals coupled with its planetary evolution. In some ways, this is an ideal "control experiment," with obliquity and associated orbital parameters driving its long-term climate in ways much more severe than on Earth. For example, absence of a strong internal magnetic field, Mars provides an end-member vantage point from which to investigate over four billion years of solar-wind stripping; this contrasts sharply with the Earth which remains cocooned from radiation by its fulsome magnetic field.

Scientifically, Mars offers a test-bed of planetary-scale experiments, including the unavoidable issue of "life." Over the course of the past 20+ years, the quest for real or "imagined" signs of life beyond Earth has expanded to Mars and outwards, in ways unimagined less than a generation ago. NASA's current strategic plan raises questions such as "Are we alone?" and Mars is the first and easiest place other than Earth to investigate this ennobling question.

Most recently, well-organized teams of investigators have developed new approaches for evaluating "agnostic bio-signatures" (Johnson *et al.*, 2018) as part of NASA's Research Coordination Networks that evolved from the 20+ years of investment in the NASA Astrobiology Institute (NAI). The search for agnostic biosignatures embraces Mars as a critical challenge for scientists seeking to escape our terrestrial biases and seeking pathways for recognizing extant or preserved signs of biology, if the signatures are different from those on Earth. "Why

Mars?" is the first test of the guiding principles in the search for agnostic signs of life and amplifies the potential scientific value of returning samples from Mars to Earth by the early 2030s.

As we explore the universe in the pursuit of grand challenges such as "*Are we alone?*," Mars becomes increasingly relevant. The Red Planet is one of the most accessible destinations within our solar system, making it a target for exploration via an ever-growing myriad of technological innovations. Mars comprises a concrete, tangible frontier for affordable experimentation, guided by questions that are connected to widely accepted concerns here on Earth, including rapid environmental change. By exploring Mars, we can evaluate aspects of our own planet that might otherwise not have been considered. Even in the 1970s, using Mars as a window into the geological evolution of Earth was conceived and seminal studies suggested that Mars was a one *geological-plate* planet, with much of its dynamical evolution in the long-distant past. Lacking definitive measurements from networks of surface seismic and meteorology stations, surface samples from targeted sample returns, and unambiguous information about the distribution of shallow sub-surface water ice, a great many testable hypotheses remain whose answers will continue to drive the compelling case for Mars. Even with definitive datasets about topography and key aspects of atmospheric chemistry, a myriad of foundational issues remain, just as for our own planet Earth.

Perhaps Mars figured prominently in the earliest waves of robotic exploration because "it is there" and technologies for visiting it were viable. Beyond the Moon, Mars was also the most observable astronomical object, even before the space age that commenced with *Sputnik* and *Explorer-1*. Yet, Mars as a frontier that we can reach has presented challenges, and it was not until the *Viking* Landers of the mid-1970s that investigations tied to "*are we alone?*" began in earnest.

After more than 60 years of spaceflight, our scientific portrait of Mars remains woefully incomplete. To some, Mars is a masterpiece as yet unfinished—in effect, a series of tiles not yet fitting a coherent and evocatively beautiful mosaic. To others, it represents the hope of discovering that we are not alone as living organisms in our countably infinite universe. Having leapt to conclusions about the workings of Mars only to find out later that our basic assumptions were unfounded, we are perpetually surprised, if not astonished, by the extent to which our understanding continues to evolve well beyond its previous confines.

With the realization that some meteorites discovered on Earth are from Mars, we have a randomized grab-bag of Martian samples to examine, and discoveries from these priceless "emissaries" have further demonstrated the key role water has played on the Mars we have come to know. Some would say that ever-broadening discoveries about the inventory and role of water in Mars evolution has been a major factor in the "why Mars?" story. Indeed, a strategy known as "*follow the water*" (FtW) was established in the late 1990s as a crosscutting scientific element of a community-based strategy for Mars exploration, which initiated NASA's new Mars Exploration Program circa 2000. Although FtW may have advanced beyond simple detection and discovery of water in any context on Mars, it remains in vogue today as a key puzzle-piece in an integrated set of priorities associated with Mars, including those outlined in the US National Academy of Sciences Decadal Surveys (Visions and Voyages, 2011).

Water is being discovered in places where it was never believed to have been possible, such as ice deposits on the Moon and at Mercury (and as buried liquid oceans beneath the icy crusts of some Saturnian and Jovian moons); however, nowhere in the solar system other than the Earth is the connection between water and the geological evolution of a planetary or lunar body clearer than on Mars (Fig. 1). Recent discoveries from the Mars Science Laboratory (MSL) *Curiosity* rover [cf: A. Fraeman *Chapter 1* in this

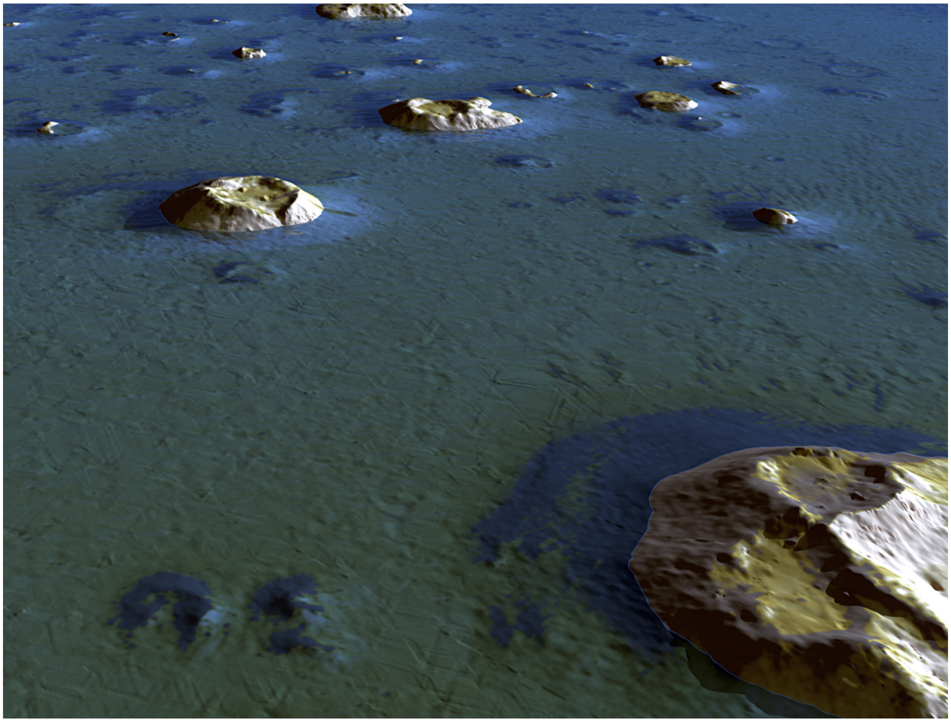

FIGURE 1 Perspective view of Mars surface in the Nephentes region, near the crustal dichotomy boundary showing small km-scale "cones." The latter possibly comprise hydro-volcanic features as "islands" in a former state of Mars when persistent liquid surface waters were present. "Why Mars" is compelling because of the water-geology-biology connections Mars presents. Regions with sustained hydrothermal activity like this one are but one example of the sometimes-enigmatic association of water with other processes, all possibly linked to biological potential. This simulated view takes advantage of NASA MRO imaging in stereo that enabled digital elevation models (DEM) to be developed, which were then artificially "flooded" to showcase what might have been a former state of ancient Mars. *Image developed at NASA GSFC by SVS under Cindy Starr with guidance by J. Garvin and others using MRO HiRISE DEM data, courtesy NASA/JPL/Univ. Arizona*.

volume] and from the *Mars Reconnaissance Orbiter* (MRO) have highlighted the changing but essential role water has played in the geological history of Mars. Even in its current environmental state, Mars comprises a water cycle with ever-increasing evidence of a massive, buried cryosphere. To some, Mars may be the embodiment of a "cryo-ocean world" in contrast to outer solar-system ocean worlds such as Europa where the liquid oceans are lurking under kilometers of ice-silicate crusts.

Thus, Mars is the most accessible and likely solar system body to have preserved evidence of biology and, potentially, to have extant subsurface (or within-ice) microbiological communities even today. To suggest this in 2020 after the apparent setbacks of the *Viking* biology experiments of the mid-1970s illustrates how far understanding has progressed from our first voyages of discovery to Mars. This sense of wonder as we explore, learn, discover, and connect has never waned with Mars, even after numerous mission failures. Perhaps our knowledge of Mars is "dangerous enough" to dare hope that it will offer us clues about life across the universe and that this may differ from our Earth-based paradigm. If only as a second data point in the quest for life, Mars is quintessential.

With a suite of missions set to launch and reach Mars in the early 2020s, including NASA's *Mars 2020* rover (and helicopter) and ESA's *ExoMars Rosalind Franklin* rover (with a molecular bio-signature experiment known as MOMA), as well as sample-return missions planned for the late 2020s, the prospects of detecting elusive biomarkers from the rock record of Mars are expanding rapidly. It would not be surprising if there were viable bio-signatures discovered within a decade or so, at least for ancient microbial life.

Mars is far more than a convenient, accessible, partially explored planetary neighbor! It represents the hope that sometimes radical, innovation-driven exploration delivers, with discovery potential that will change how we view ourselves forever. To me, Mars is our destiny in ways far beyond popular Hollywood movies such as "the Martian." Over the course of 50+ years of robotic exploration of Mars, each step has catalyzed future ones, so that we are now at a cusp in capabilities, understanding, and discovery. By ~2030, the Mars we know and explore will connect more closely to new space business-models, offering prospects for commercial access and utilization, as well as inventive new approaches for exploration at all scales. Until we visit Mars for ourselves, with women and men representing the collective of humanity on Planet Earth, we will continue to ask "why Mars?" Thus, the always-expanding litany of rationales will keep us going until we see ourselves as the Martians.

Perhaps Ray Bradbury and his "*Martian Chronicles*" was right after all (in the 1950s)—we will either realize that once we are there as people that we are the Martians, or that the *real Martians* are already there, waiting to be discovered by the creative imagination of our exploration. Mars waits for no one; once we understand its seemingly magical workings we will not cease from wanting to explore its evocative frontiers further. Rising from the enigmas Mars currently presents to us is a planet where we must go, both vicariously via robotics and Immersive Virtual Reality, and in person. "Why Mars?" is not a question we can definitively answer at this time, because the question keeps changing, expanding, and embracing more aspects of what makes all of us explorers. Mars embodies "*never wait to wonder*" as humanity moves away from Earth and pursues planetary frontiers well beyond the planned or current ones. As is stated in today's vernacular, Mars *rocks*!

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