Seeking out Life on Mars in the Next Decade

NRC Decadal Survey White Paper

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Introduction: Searching for evidence of life on Mars is an exciting scientific endeavor that will have profound implications regardless of the outcome. Are we alone in the universe? What are the prospects for life arising on other planets? Mars may hold the key to answering these deep questions, but how should we go about searching for life on another planet? The answer is simple – in every way we can. In the early days, astronomers trained their telescopes at the planet and searched for evidence of water or vegetation. Later, orbiters mapped the planet and found evidence for ancient water, but no obvious signs of life. Subsequently, two landers were sent to the surface of the planet to search for organic molecules or evidence for soil microbes, but no clear signals were identified. During the last four decades, the strategy for searching for life on Mars has focus on searching for evidence of habitable environments and signs of life from an earlier period on Mars history when Mars had a warmer and wetter climate than it has today. In this white paper, I make the case that our knowledge about Mars and our technology have reached the point where we are ready to vastly expand our efforts to search for evidence of life on Mars during the next decade, and that the focus of these new efforts should shift from only doing paleontology, to also searching for extant life.

The Case for Mars Paleontology: Webster’s Dictionary defines paleontology as “a science dealing with the life of past geological periods as known from fossil remains”. This the generally accepted definition of terrestrial paleontology (possibly with less emphasis on actual fossils) appears to be a fairly good match for our current dominant Mars exploration strategy. Its adoption has been motivated by both scientific and practical factors. On the scientific side, we now have a wide range of orbital and in-situ data have been interpreted as strong evidence that Mars once had long-lived environments that have supported the presence of abundant surface liquid water. On Earth, these environments represent prime habitats for life as well as geologic preservation zones for paleontological evidence for past life. If life ever had arisen on Mars, we would expect that it would have left analogous fossil traces of its existence in these locations. While the preservation interpretable terrestrial fossil evidence from billions of years ago is extremely rare, the situation on Mars may have been quite different due to the general winding down of aqueous and tectonic activity during the last ~2 billion years. For all we know, the cold, dry, icy environment that exists on Mars today could be a fossil-hunters paradise. On the practical side, searching for past “habitability” or “signs of past life” appears to be

accomplishable within our current technological and budgetary framework, and it can be accomplished within agreed upon guidelines for planetary protection.

The Case Against Mars Paleontology: There are two key issues with the current Mars paleontological life search strategy. The first and most obvious is the issue of preservation. Earth has been literally crawling with life for billions of years, but on Earth, preserved evidence for life, especially non-multicellular life, is rare. Trained terrestrial paleontologists can use geological clues to identify potentially promising sites to look for signs of life, but actually finding signs of life more often turns out to be a hit-or-miss proposition. Because of the rarity of preservation, and the cumulative effects of subsequent biologic, atmospheric, and geologic processes that tend to destroy evidence that may have initially been preserved, terrestrial paleontologists never conclude that a given paleoenvironment was uninhabited. This is because we know from observing the Earth today that life has colonized all habitable niches, and there is no reason to assume that the same wasn't true in the past. Therefore, if we never find any evidence for past life on Mars, we still won't be able to prove that it was never there.

The second issue has to do with the interpretability of paleontological evidence generally. Preserved remains of analogs to present-day organisms is the gold standard for terrestrial paleontology, and it is unlikely that question of past life on Mars will be settled conclusively without the same. The debate regarding ALH84001 meteorite demonstrates if anything, that a very heavy burden of proof is required for any claim regarding past Martian life. Given this situation, the probability that such evidence would be produced by one Mars sample return mission, or even a dozen Mars sample return missions, would seem to be very small indeed. Viewed in this perspective, the MER Curiosity Rover missions were successful in establishing the existence of past potentially habitable past Martian environments, but in terms of paleontology, they were basically failures. If we project our current strategy forward into the next decade, including Mars sample return, we could end up seeing an expensive succession of debatable fossil/pseudo-fossil finds, with no clear resolution to the life on Mars question. This is why we need to cover our bets and pursue a parallel strategy.

Why We Should be Searching for Extant Life on Mars: If we have learned anything about life on Earth since Viking, it is that life is amazingly adaptable. Life doesn't just die out. As long as there are habitable environments, life finds a way to survive. While the present-day Mars surface environment is known to be generally hostile to terrestrial life, the notion that Mars is currently uninhabitable is simply not correct. If we adopt the "one drop of water" definition for habitability that is accepted by most astrobiologists, then there are broad near-surface and subsurface regions on Mars today definitely habitable. These permanent or ephemeral liquid water environments on Mars today are the most likely places to find evidence for present-day life on Mars, as well as "signs of life" due to their comparative youth. Using observations in conjunction with physical and chemical models, we can now identify currently or recently habitable regions on Mars with much greater reliability than paleontologists can identify billion-year-old habitable regions with preserved signs of life.

There are three key advantages to searching for present-day life on Mars, vs. searching for signs of ancient life. The first is that testing for extant life in currently habitable Martian environments can yield definitive yes/no answers, with none of the ambiguities regarding

preservation of evidence that plague paleontology. If we sample some naturally occurring Martian liquid water, and detect elevated concentrations of complex organic molecules – it’s game over – there’s life on Mars! Second, if we find evidence for present-day life on Mars, the question of past-life on Mars is answered automatically. Third, and possibly the most important, is that the potential scientific payoffs for successfully finding evidence for present-day life on Mars would dwarf those for successfully finding evidence for past life.

Planning for the Aftermath of Sample Return: Analyzing returned Mars samples has been a dream of the planetary community since the days of Apollo, and Mars sample return has been a consistent top priority in past decadal survey recommendations. Now, with the launch of the Mars Perseverance Rover mission, and planning for sample retrieval missions under way, it’s time to lift our sights and think about what we want to do next. There are some that would say that the next steps would be “more sample return missions”, and that would be a defensible position to take, given that we have nowhere near sampled the diversity of Mars’ paleo-environments, and based on the results of past and on-going rover missions, the chances of finding any definitive evidence for past life on Mars seem pretty remote. There are others that would say that the next big step should be human exploration to “extend man’s greatest adventure to the planets”. However, there many that would argue that sending humans to Mars without first establishing whether or not there exist and indigenous life forms today would be reckless or even unethical. Regardless of one’s scientific, political, or moral views on the subject, the fact that we don’t currently know whether life presently exists on Mars represents a gigantic gap in our present knowledge about the universe. However, just as with the dream of Mars sample return, the dream of finally learning the answer to the life on Mars question will soon be within our grasp.

Addressing the Counter Arguments: Suggestions from the scientific community to search for evidence for extant life or recently extant on Mars have traditionally been poo pooed using one or more of the following arguments:

1. Viking searched for life on Mars, and didn’t find any. It didn’t even find any organic molecules. Case Closed.
2. Viking’s unsuccessful search for life on Mars resulted in a 15-year hiatus in NASA’s Mars program. We can’t afford to let this happen again.
3. Current planetary protection protocols require the use of sterilized spacecraft for life detection missions, which would be prohibitively expensive and/or unachievable using modern technology

Today, each of these arguments are easily countered.

1. The Viking experiments were conceived when the field of astrobiology was in its infancy. Watch some of the 70’s era films that NASA released about Viking’s search for life – they are laughable in light of today’s knowledge. In the intervening decades, the astrobiology community has defined in detail the physical and chemical boundaries of terrestrial life forms, and it’s clear that the necessary conditions for extant life were not satisfied at

the Viking landing sites. We now know that there are much better locations to search for Martian life, and with the acquisition of more relevant data, we should be able to pinpoint these locations with high reliability. The case for extant life on Mars is definitely not closed, and nor should it be closed given the potential scientific bonanza that finding life on Mars would surely bring.

2. After Apollo, the Viking missions (which followed on the heels of Apollo) are still arguably the greatest planetary missions of all time. The hiatus in Mars exploration that followed was due more to larger US economic trends, as well as a shift in presidential/NASA priorities towards the space shuttle program. The fear that unsuccessful searches are the ruination of programs turns a blind eye to the true nature of science and exploration. If we are going to be successful at anything worthwhile, we can't just give up and quit trying. Plus, in today's world, the powers of social engineering are sufficiently powerful that missions can be made to seem successful regardless of their actual scientific outcome. Furthermore, most people in the country weren't even alive during the Viking missions, so to them, new missions to search for life on Mars would seem quite novel.
3. Planetary protection is a good thing, but the notion that we can't do it in the context of a life detection mission today is a complete canard. Viking sterilized their whole spacecraft, and Mars Perseverance sampling system has been built to extremely rigorous contamination standards. Heat tolerance and sterilization are common procedures for military and medical components, and it poses no fundamental technological barriers. The only modern spacecraft components that have proven difficult to sterilize are the aqueous chemistry components contained in batteries. Fortunately, driven by market pressure increase the range of electric vehicles, solid state battery technology has now come of age, and will soon be available in the commercial world. Adaptations of solid state battery technology for spacecraft will provide higher volumetric and mass performance, increased cold tolerance, and the ability to heat sterilize. While the costs of sterilized spacecraft will be higher, these costs are not going to be prohibitive when viewed in the context of the potential science investigations that they can enable.

Moving Forward in the Next Decade: Realistically, the unfinished goal of Mars sample return will continue to dominate our Mars exploration efforts during the next decade. However, in parallel with this major effort, there are multiple opportunities to lay the ground work for a much more exciting program of Mars exploration that will include a modern and serious search for Martian life. Here are some suggestions for key components that can be accomplished by NASA during the next decade:

1. Technology development for sterilized spacecraft and systems capable of accessing Mars' habitable environments such as rovers, drills, moles, liquid water detection etc.
2. Technology development for life detection in potential Martian aqueous environments
3. Mars robotic precursor missions capable of accessing in so-called "special regions" and searching for the presence of transient surface and sub-surface liquid water, as well as the presence of organic molecules

The history of NASA's programs has demonstrated that there is a strong correlation between public interest its programs and funding. While NASA's current Mars program offerings do generate considerable public interest, this interest is not nearly as high as it would be if we were actually searching for life. Anyone associated with NASA's Mars programs who has encountered the press or the public knows that there is deep yearning within the populous to know whether life exists on Mars. There is no question that we now have the technology to take the next steps towards answering this important question. We should now follow through on our potential and make the search for extant life on Mars a new and urgent priority for the next decade.