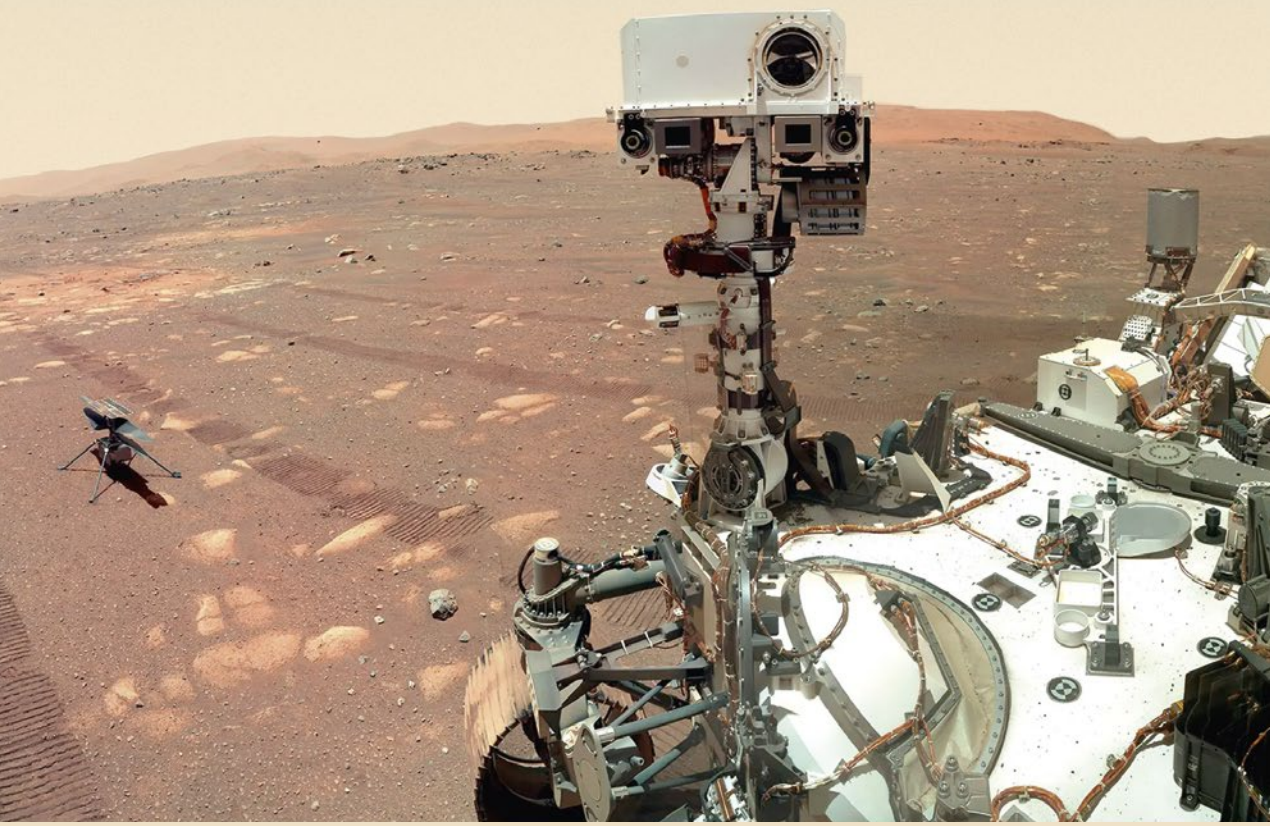
# Perseverance and the Mars 2020 Mission

## Follow the Science to Jezero Crater

Manfred "Dutch" von Ehrenfried



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Evolution of a Martian

This artist's illustration shows NASA's four successful Mars rovers: Sojourner (on the left), Spirit & Opportunity, and Curiosity. Next, there is the Mars 2020 Perseverance rover and the Ingenuity Helicopter that arrived at Jezero Crater on February 18, 2021. Also depicted is a concept for how the NASA Mars Ascent Vehicle could be launched from the surface of the planet carrying tubes of rock and soil samples for a future Mars sample return mission. And finally there is a human explorer. Image courtesy of NASA

# Dedication

It is hard to believe how many people have devoted themselves to the study of Mars; yet no one has ever been there! What is it that attracts so many to work decades, even their entire careers to gain a little bit more knowledge about an object over a hundred million miles away? When I look at Mars in the evening sky it is a mere dot on a black canvas. While many cannot imagine working on such a project, there are untold thousands that can't imagine pursuing any other type of work.

In conducting the research for the book, I was amazed at the caliber of scientists and engineers working on the Mars 2020 Program, now an operational mission. They come from all over, and from many different backgrounds and disciplines. They are so lucky to be part of the program and to work in such a unique place, namely the Jet Propulsion Laboratory (JPL) which is operated jointly by NASA and the California Institute of Technology (CalTech) in Pasadena. There are of course many others working on the Mars 2020 mission at other NASA Centers and at the establishments of our international partners. They too are dedicated to the program and the mission.

This book is therefore dedicated to the many different "teams" involved in the mission, including the science and engineering teams, the Perseverance team, the Principal Investigators, the Ingenuity team, the test and checkout team, the launch team, the cruise team, the EDL team, the surface team, the sample team…the list goes on. Having been part of an operations team in my distant past, I'm partial to those who're operating Perseverance and Ingenuity on the surface of Mars. I take it back, I'm envious!

So Go Mars Team Go, this book is dedicated to all of you. Enjoy it while you can, give it all you've got, and know that you are truly blessed to be part of something special, something grand, something historic! What stories you will be able to tell your grandchildren if the mission discovers life on another world!

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There are many other scientists whose reports I read in researching for this book and I have listed their works in the References section.

In addition, I acknowledge the assistance of Wikipedia and Google, and also the exceptional website of NASA/JPL-CalTech. These sites enabled me to fill in the pieces of the puzzle on just about any subject. Their inputs are woven into many sections.

Also, many thanks go to the people who have given me the opportunity to write about this unique program, particularly Hannah Kaufman, Associate Editor with Springer in New York, Clive Horwood of Praxis in Chichester, England, and the cover designer Jim Wilkie in Guildford, England. A special thanks to David M. Harland in Glasgow, Scotland who edited this, my eighth Springer-Praxis book. After over seven years of communications solely by email, I hope eventually to meet and thank him in person.

Thanks everyone, I hope you like the book and find it a handy quick reference.

# Foreword

Philosophers and scientists have been struggling to understand our place in the universe for millennia. Finally, we are a step closer to obtaining real data that might just answer at least one of the questions. The Mars 2020's Perseverance rover is equipped with the tools to gather samples of the rocks and soils which will hopefully one day be returned to Earth so that we can directly investigate their biological potential. There are scientists who focus on what it takes for life to develop in the rocks and soils of distant worlds. These are the astrobiologists, geobiologists and others who probe the smallest of realms. One such scientist is Tanja Bosak, a professor of Geobiology in the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology who is also involved in plans for analyzing samples of Mars that are returned to Earth.

The following is based on a statement Dr. Bosak made to the Subcommittee on Space and Aeronautics Committee on Science, Space and Technology of the US House of Representatives on April 29, 2021, titled: 'What do Scientists Hope to Learn with NASA's Mars Perseverance Rover?'

> How, where and when life originated is one of humanity's great unsolved questions. Until now, we were only able to explore this question on our own planet, where the record of life before 3.5 billion years ago is absent. In contrast, Mars has preserved a rock record up to a billion years older than the oldest well-preserved rocks on Earth. Studying these rocks will enable us, for the first time, to probe the emergence of life on another planet. This is the goal of the NASA Perseverance rover that landed in Jezero Crater on Mars. To achieve this, the mission aims to collect thirty samples of rocks and soils for future return to Earth as part of the international Mars Sample Return campaign.

**Fig. 1** Dr. Tanja Bosak

Scientists will then be able to analyze these samples in laboratories. These will be the first set of samples from another planet that are relatable to specific locations and rocks or soils that were formed in established sequences of geologic events. Just as the Apollo program did for the Moon, these samples will revolutionize our understanding of Mars science and will stimulate enormous interest in science and technology for decades to come.

The scientific community has identified many questions that can be addressed by studies of the returned samples. These include looking for past life, tracking changes in the climate and atmosphere of Mars and its habitability through time, establishing when rivers and lakes existed, determining how impacts and weathering have affected the surface, and understanding the evolution of Mars' interior. Some of the returned samples will be collected in environments which were likely habitable during the time from which we have little record on Earth. For the first time ever, the scientific community will be able to look for the earliest stages of life by applying the criteria which were developed to investigate organic compounds and other potential signs of life in rocks from Earth.

Analyses of returned samples can tell scientists what the earliest habitable environments looked like, whether early Mars received abundant building blocks for organic life from comets or asteroids, and whether some conditions at its surface enabled the synthesis of more complex organic compounds. Even more ambitiously, we can even ask whether any early life may have been transferred between Earth and Mars.

The Perseverance rover has left its landing site to explore an ancient lakebed inside Jezero Crater. During this traverse, the science team has acquired remote imaging, radar and chemical data to characterize the geology of different regions at centimeter to kilometer scales and establish the time sequence in which the rocks were deposited.

Instruments on the rover's arm have also imaged the rocks at scales comparable to those shown by a hand lens in order to determine the composition of minerals and look for potential signals of organic in rocks. Samples which are judged to have the greatest potential for answering the key science questions will be collected, documented and cached for return to Earth. The selection of a returnable sample cache is critical for the success of the subsequent legs of the Mars Sample Return campaign. It requires the identification of samples most likely to preserve organics under conditions that operated in habitable environments on early Mars.

On Earth we can use a great diversity of instruments to determine the origin and ages of the Mars samples, reconstruct past climate change, characterize organic matter and search for signatures of past life. But owing to the small size of the collected samples, only small amounts of returned material will be available for analyses and most analyses will have to be performed at very small spatial scales, ranging from nanometers to millimeters. Nevertheless, such analyses can lead to a new understanding of the climate, the cycling of sediments, water, and inorganic and organic carbon on and within Mars. Any organic carbon present in the returned samples can also shed light on processes that control planetary habitability and lead to life. In the coming decades the returned samples will likely stimulate new developments at the intersection of geology, geochemistry, geobiology, materials science, mass spectrometry, microscopy, spectroscopy, planetary science, chemistry, and astronomy.

The following is taken from an article by Dr. Bosak in the March 2021 issue of Universe Today.

The most direct test of the genetic relatedness of any Martian and terrestrial life would come from the comparisons of the information molecules (DNA and RNA) and the presence of such molecules in anything we find. In the best-case scenario we would find fossils of microbes or some such "biosignature." Of course DNA and RNA do not preserve over billions of years (from the time when surface life was possible on Mars) but if we see something that looks like fossil cells upon sample return and detect some organic biosignatures, that would support there being similarities between past life on Mars and life on Earth.

Second, the discovery of evidence for past life on Mars is likely to lend some credibility to the theory that life still exists there today. Much like the disappearance of Mars' surface water, it is theorized that microbial life could have also migrated underground as a result of changes in the planet's climate. In fact, research has been conducted that demonstrated how microbes could survive beneath the surface in briny patches of water. The scientific consensus is that modern surface life on Mars is highly unlikely – which is why Perseverance aims to collect samples that will preserve evidence of past life. Nevertheless, the existence of past life will make the issue of planetary protection all the more pressing when human missions to Mars start, especially if we establish an enduring presence there.

Already, robotic missions are forced to exercise care in the vicinity of potential sites for microbial life, a good example of which is the time the Curiosity rover came upon a discolored patch of sand (thought to be a surface brine) and was forced to divert its path to go around it. If human habitats are ever built on Mars the possibility that we could be causing harm to Martian organisms will always be there.

The Perseverance rover will not provide the final word on this subject, but the data which it collects and the sample return it will perform will provide an essential piece to the puzzle. After all, the search for life on Mars is like the search for meaning in the universe: ongoing!

Dr. Tanja Bosak
Professor of Geobiology,
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Cambridge, MA

# Preface

Since ancient times, Mars was at the forefront of astronomical observations as we struggled to understand our place in the universe. It was named for the god of war and was once thought to be a harbinger of death and plague. But then in the 19th century, telescopes trained on Mars by such observers as Giovanni Schiaparelli in Italy and Percival Lowell in the United States prompted imaginations to popularly envision an inhabited and vegetated planet.

However, with more advanced telescopic observations and the dawn of the space age, it was clear that Mars has a cold, dry environment that appeared to be devoid of life. The Mars 2020 mission is the first NASA mission to hunt for life since the Viking Program, almost a half century ago. As we continue to explore Mars, it is becoming increasingly apparent from orbiter and rover results that the planet was a very different place in the ancient past. Mars had periods of stable liquid water on its surface and for a significant period conditions were habitable. Orbital and in-situ observations show evidence of volcanic and hydrothermal environments that could have provided the energy required for life. The planet also had access to organic carbon, both from meteorites and by syntheses at hydrothermal vents. Dr. Luther Beegle, one of the Principal Investigators for Mars 2020, points out: “Three and a half billion years ago, Mars seems to have had everything the Earth did when life started on Earth, so, the question is did life start there? And if not, why not?”

“No evidence of life on Mars has ever been found. Each rover mission has inched closer to that goal, however,” observes Dr. Abigail Allwood, an astrobiologist and Principal Investigator for one of the mission’s instruments. Hence, the search for life continues with the understanding that science, and indeed humanity, requires an enormous burden of proof for the verification of ancient or indeed existing life on Mars. Consequently, it is not likely that NASA will declare that life has existed on Mars until the samples are brought back to Earth and analyzed in sophisticated laboratories.

The Mars 2020 robotic rover named Perseverance is even more advanced than its sister rover Curiosity, which has been roaming Gale Crater for almost a decade.

In some cases, Perseverance's instruments are a couple of orders of magnitude more sensitive than any instrument previously sent to Mars.

But this time it is different; much different. Earlier missions did not collect and cache samples; they were focused solely on investigating the surface to answer science questions about whether locations such as Gale Crater were habitable in the distant past. For Perseverance, on the other hand, the goal of collecting and caching samples changes the Mars 2020 team's approach to science exploration. This time the scientific exploration and analysis supports the innovative goal of caching those samples that best represent Mars as a planet and leaving them on the surface for a subsequent mission to collect and return to Earth for analysis.

One advantage of writing a book while the mission unfolds is that actual mission operations can be explained, presenting photos and videos of both successes and failures. But this book is also about the future, since it may be many years before the results of the Mars 2020 mission can be told. The samples that Perseverance leaves behind may not be brought back to Earth until the early 2030s. That joint NASA/European Space Agency program is known as the Mars Sample Return (MSR) mission and although it is described in this book, only the basic concepts and vehicles are presented. The current planning for this future program is for the Sample Retrieval Lander to be launched in 2028. The Earth Return Orbiter could launch in either 2027 or 2028 but the return of the samples, once planned for 2031 has already been delayed until 2033, and may well slip further. Only at that time will the detailed analysis of the samples in state-of-the-art laboratories be able to determine whether life existed, or still exits on Mars and what type of life is it?

As NASA Ames astrobiologist Dr. Christopher P. McKay states, "There may be life on Mars that shares a common ancestor with life on Earth. Hence the search for a 'second genesis' must focus on biochemistry and genetics. Only if we find evidence of life with a different biochemistry or genetics can we conclude that we've found evidence of a second genesis of life." What will that tell us about ourselves? Are we alone? If not, then what else is out there? Does life populate the solar system; the universe? What will it mean for humanity?

The current Mars 2020 effort began in 2013 with the development of the science community's wishes for Mars 2020 investigations and a series of workshops over a period of five years to decide on the best landing site to search for evidence of life, past and present. Needless to say, this was both a national and international quest for the optimum instruments and the optimum site involving thousands of scientists, engineers and mission planners. This book will describe that effort and the resulting definition of the Mars 2020 Goals, Science Objectives and Mission phases which guide the mission to this day.

In addition, much detail is included about the Perseverance design, components, stages and instruments. The seven major instruments are described in detail.

An Appendix gives the Principal Investigators for the instruments, along with other mission scientists and engineers. Also described are the flights of the helicopter technology demonstrator called Ingenuity.

On July 30, 2020 an Atlas V rocket launched NASA' Perseverance rover and Ingenuity helicopter toward Mars. They were tucked away in their aeroshell protected by the heat shield and guided by the cruise stage for over seven months. Like Curiosity nearly a decade earlier, Perseverance survived the famous "Seven Minutes of Terror" on February 18, 2021 and accurately and safely landed at the chosen landing site, on this occasion in Jezero Crater. Perseverance is presently exploring, probing and collecting samples in this ancient lakebed and the fan-shaped delta that fed it, seeking signs of past or existing life and collecting rock and soil samples. Some samples are to be sealed in super clean metal tubes and left on the Martian surface in the hope that a future mission will collect them and transport them to Earth for further analysis. The plan is for the mission to last at least a Mars year of 687 Earth days. If it is as successful as Curiosity, which has been operating on the planet for over nine of our years, the science community will be overjoyed.

While Perseverance has significant autonomous capabilities, such as driving itself across the Martian landscape, hundreds of Earthbound scientists are still involved in analyzing its results and planning further investigations. Although thousands of people have been involved with the mission over the years, there are almost 500 people on the current Mars 2020 science team. The number of participants in any given action by the rover is on the order of 100 people. It is an ongoing, real-time operation. Fortunately, JPL issues timely reports of the activities, many of which have been included in this book; for example, the approaches to selecting drilling sites and collecting samples are described. Also of interest is how the team have based their decisions on both Perseverance's instruments and data gleaned from the Ingenuity helicopter's views above and ahead of the rover's track. On April 19, 2021, Ingenuity achieved the first powered flight by any aircraft on another planet, an event as significant as the first flight at Kitty Hawk by the Wrights in 1903.

I hope you enjoy this description of the ongoing Mars 2020 mission. As it could go on for a decade or more, stay tuned for a possible sequel that further describes the successes and failures of NASA/JPL attempts to determine whether life once existed or currently exists on Mars and the ramifications of those discoveries for humanity.

Manfred "Dutch" von Ehrenfried
Cedar Park, TX, USA
Winter of 2021–2022

# Contents

# 1

# Introduction

## A Brief History

Mars is similar to Earth in many ways, having many of the same "systems" that characterize our home world. Like Earth, Mars has an atmosphere, a hydrosphere, a cryosphere, and a lithosphere. In other words, Mars has systems of air, water, ice, and geology that all interact to produce the Martian environment. What we don't know yet is whether Mars ever developed or maintained a biosphere; an environment in which life could thrive. To discover the possibilities for past or present life on Mars, NASA's Mars Exploration Program is enacting a strategy called "Seek Signs of Life" that expands on the "Follow the Water" theme that motivated the Mars Global Surveyor and Mars Odyssey orbiters, the Spirit and Opportunity Mars Exploration Rovers, the Mars Reconnaissance Orbiter and the Mars Phoenix Lander (see Appendix 1).

## Book Summary

This book chronicles the path along which the science community embarked to address its questions about Mars. It starts with the Viking missions launched in 1975 and works its way forward in time to describe what has transpired in orbit around and upon the surface of the planet, including the Perseverance rover and its Ingenuity helicopter.

Chapter 2 describes the goals and objectives of the Mars 2020 mission. This work by the science community for the past two decades culminated in a well-defined and concise set of statements which guide the Mars Exploration Program

 
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to this day. This chapter also defines the various mission phases which are necessary in order to finally arrive safely on the surface of Mars.

Chapter 3 provides the history of how the Curiosity rover design influenced the Perseverance design, to the point of copying some features and improving upon some others by applying the latest in technology. Because the rover design team had many years of actual experience with Curiosity operating at Gale Crater, the lessons learned were applied to the new Perseverance design vehicle. Similarly, the science community was able to learn from the performance of Curiosity's instruments and come up with a new set of seven instruments for Perseverance, some of which are far more sensitive and state-of-the-art and more relevant for this new mission. As the old saying goes, "This isn't your father's Oldsmobile."

Chapter 4 describes the many years of effort by the science community to agree on where Perseverance should operate. The Landing Site Selection Committee is described, as well as the many criteria and considerations that went into the final selection. After many workshops involving hundreds of scientists, the committee finally came up with the recommendation that the Mars 2020 Perseverance rover should investigate Jezero Crater, an area on Mars where the ancient environment may once have been favorable for microbial life. And sure enough, that is where Perseverance is to this day taking samples that will, some day, hopefully answer the key questions about Mars. The Mars 2020 entry, descent, and landing (EDL) phase employed the same "sky crane" landing system approach and design that successfully delivered Curiosity to the Martian surface. However, this time the system used several new technologies and features that enabled the spacecraft to land at previously inaccessible landing sites. A suite of cameras and a microphone captured both the sights and sounds of EDL for the first time, always an anxious and exciting seven minutes.

Chapter 5 describes the actual on-going operations, including the Perseverance rover moving to prime targets for sampling. The entire Sample Caching System and operating procedures are described, as are the actual sampling attempts and assessments. Where pertinent, commentaries by the science and operations teams commentary have been included, both failures and successes. Incredible pictures are included of the operations, rocks, samples and results. Activities were paused temporarily when the solar conjunction occurred between October 2 and 14, 2021. That was when Mars and the Earth were on opposite sides of the Sun. There is a moratorium on sending commands to Mars when the planet is within 2 degrees of the Sun from our perspective, as data could be lost.

Chapter 6 describes what was initially planned to be simply a 30-day technology demonstration of a helicopter, but turned out to be far more than expected. Once Ingenuity had established it could fly, the plan had been to abandon it so that the team could focus on the Perseverance mission. The plan was for Ingenuity to fly up to five times at heights up to 3–5 m (10–16 ft) above the ground, for up to

90 seconds each. On April 19, 2021 the helicopter achieved the first powered flight by any aircraft on another planet. After only a few flights, Ingenuity achieved its original objective of proving its ability to fly in the rarefied Martian atmosphere, over a hundred million miles from Earth without direct human control.

With Ingenuity's energy, telecommunications, and in-flight navigation systems performing beyond expectation, an opportunity arose to allow the helicopter to continue to explore its capabilities without significantly impacting on the rover's scheduling. It operated semi-autonomously, performing a variety of maneuvers planned, scripted and transmitted to it by JPL. Having established that powered controlled flight is possible on Mars, the Ingenuity experiment embarked upon a new phase of operations, expanding its flight envelope to include exploring how aerial scouting and other functions could benefit future exploration of Mars and other worlds. Along with those initial one-way flights, there was more precision maneuvering, increased use of its aerial-observation capabilities, and a greater overall acceptance of risk. This chapter chronicles all the flights during this first campaign.

Chapter 7 pays tribute to the various organizations at NASA Headquarters, JPL-CalTech and the international partners that contributed to the success of the Mars 2020 mission. Biographical outlines of many of the people in these organizations are given in Appendix 3.

Chapter 8 describes the follow-on Mars Retrieval Mission that is planned for the years 2026 to 2031. This mission will include a very complicated and technically challenging set of flights in order to retrieve the samples cached by Perseverance and return them to Earth. Also discussed is how samples will be disseminated to specially designed and equipped laboratories in which they will be analyzed and curated for future scientific research. Related to this are the Planetary Protection requirements and protocols.

In Chapter 9, I conclude with my assessment of the ongoing Perseverance and Ingenuity missions and my predictions for the future.

Appendix 1 gives an historical context for the Mars Exploration Program, going back to its origins in 1994 and explaining why the program was restructured in 2003. It discusses successes and failures along the way. Appendix 2 provides the conclusions from the Mars 2020 Science Definition Team. Appendix 3 provides many biographical outlines of the scientists and engineers of the mission, broken down into teams. Appendix 4 explains Dr. Christopher McKay's thoughts on the search for life on Mars, one of the major reasons for the exploration of Mars and indeed other solar system bodies. Other Appendices include notable quotes and a mission timeline up to the time of writing in late 2021.

It is envisioned that the Perseverance rover will still be roaming in Jezero Crater many years after this book is published. While you are hearing about events, you can use this book as a reference to better understand how they relate to the overall

Mars 2020 mission, and what will happen when the samples are returned to Earth. Like the Apollo lunar samples that are still being analyzed to this day by another generation of scientists, the samples collected by Perseverance over the next few years will be the focus of studies far into the future. Should life be discovered by this mission, who knows what the consequences will be for humankind!

# 2

# The Mars 2020 Mission

The Mars 2020 mission with its Perseverance rover forms part of NASA's Mars Exploration Program, a long-term effort of robotic exploration of the Red Planet. The mission addresses high-priority science goals for Mars exploration, including key astrobiology questions about the potential for life on Mars.

The Perseverance rover is investigating a region where the ancient environment may have been favorable for microbial life. This involves probing the rocks for evidence of past life. Throughout its investigation, the rover will collect samples of soil and rock and cache them on the surface for potential return to Earth by a future mission.

Perseverance is carrying an entirely new subsystem to collect and prepare rocks and soil samples that includes a coring drill on its arm and a rack of sample tubes. About 30 of these sample tubes will be deposited at select locations for return by a potential future sample retrieval mission. Such specimens from Mars could be analyzed in laboratories on Earth for evidence of past life on Mars, and to assess possible health hazards for future human missions.

Two science instruments mounted on the robotic arm will be used to search for signs of past life. These will provide information to determine where to collect samples by analyzing the chemical, mineral, physical and organic characteristics of Martian rocks. On the vehicle's mast, two science instruments provide high-resolution imaging and three types of spectroscopy for remotely characterizing rocks and soil, in order to help in determining which rock targets to explore up close.

The Perseverance rover was provided with the same "sky crane" landing system developed for Curiosity, but with two enhancements to make more rugged sites eligible as safe landing candidates.



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## 2.1 SCIENCE GOALS

**Background**

NASA's Mars Exploration Program (MEP) had requested the Mars Exploration Program Analysis Group (MEPAG) to maintain the document named MEPAG Mars Science Goals, Objectives, Investigations and Priorities. This was initially released in 2001 as a statement of the Mars exploration community's consensus regarding its scientific priorities for investigations to be undertaken by (and in support of) the robotic Mars flight program. This document is regularly updated to respond to discoveries made by the missions of the Mars Exploration Program and changes in the strategic direction of NASA, the latest version being issued in 2020.

Historically, MEPAG has found that the pace of change in our knowledge of Mars is such that updates are needed roughly every two years. The MEP's intention is to use this information as one of its inputs into future planning, with no implied timeline for conducting the investigations. The rate at which investigations are pursued is at the discretion of NASA as well as other space agencies around the world that provide funding for flight missions. A separate, unrelated process for forward planning, similar in some ways to the Goals Document is the Planetary Science Decadal Survey which is prepared once every ten years by the National Academies of Sciences, Engineering and Medicine (NASEM), such as its Vision and Voyages for Planetary Science in the Decade 2013–2022.

The MEPAG Goals Document constitutes one of many inputs into the Decadal Survey discussion, even though these two organizations operate independently. The current version is again a four-tiered hierarchy of Goals, Objectives, Sub-Objectives and Investigations. The Goals are organized around four major areas of scientific knowledge, commonly referred to as: Life (Goal I), Climate (Goal II), Geology (Goal III) and Preparation for Human Exploration (Goal IV) all of which are described below. MEPAG does not prioritize among these four Goals because developing a comprehensive understanding of Mars as a system means making progress in all three science areas, and because the Goal of preparing for human exploration is very different in nature. Each Goal includes objectives that embody the knowledge, strategies and milestones needed in order to achieve the goal. The sub-objectives include more detail and clarity about different parts of objectives but cover tasks that are larger in scope than individual investigations. Hence, the investigations that go into collectively achieving each sub-objective constitute the final tier of the hierarchy. Although some investigations could be achieved with a single measurement, others require a suite of measurements, some of which require multiple missions.

Each set of investigations is independently prioritized within the parent sub-objective. In some cases, the specific measurements that are needed to address an investigation are discussed; however, how those measurements should be made is not specified by the Goals Document, thereby allowing the competitive proposal process to identify the most effective means (i.e. instruments and/or missions) of making progress towards their realization. It should be noted that completion of all of the investigations in the MEPAG Goals Document would require decades. Given the complexity involved, it is also possible that they might never be truly complete, as observations which answer old questions often raise new questions. Thus, evaluations of prospective instruments and missions should be based upon how well investigations are addressed and how much progress might be achieved in the context of a specific instrument or mission.

Following the 2013 Announcement of Opportunities for the Mars 2020 mission further definition of the science goals and the design of the Perseverance rover, and even the instrument selection process, began with the establishment of the NASA Science Definition Team (SDT). The membership (selected by NASA from over 150 applicants) comprised scientists and engineers from a broad cross section of the planetary science communities whose areas of expertise included astrobiology, geophysics and geology as well as instrument development, science operations and mission design. The team was tasked to outline the Mars 2020 mission's objectives, realistic surface operations, a proof-of-concept instrument suite, and suggestions for threshold science measurements that would meet the proposed objectives. They were also to consider the Planetary Decadal Survey science recommendation for the highest priority "large mission" for the decade 2013–2022. The SDT effort occurred shortly after the successful landing of the Mars Science Laboratory's Curiosity rover on August 6, 2012 as the latest in a run of technological and scientific triumphs of the Mars Exploration Program. The SDT published its report on July 1, 2013.

Scientists and engineers on competitive teams focused on designing instruments to match the established criteria and goals. NASA selected optimal components from among the submitted proposals. It then openly competed opportunities for the specific payloads that would address the goals of the mission. The choice of the Mars 2020 rover science instruments was announced on July 31, 2014. The science instruments would support studies related to habitability, the search for any potential signs of past microbial life, identifying the most compelling samples for future potential Earth return and activities preparing for possible future human exploration.

In the following description of the science goals and objectives, the term "we" is used to collectively denote the MEPAG scientists who worked over the course of eight years to develop the Mars 2020 mission.

### 2.1.1 Goal I: Determine Whether Mars Ever Supported Life, or Still Does

The mission of the Mars 2020 Perseverance rover is focused on surface-based studies of the Martian environment, seeking preserved signs of biosignatures in rock samples that formed in ancient Martian environments with conditions that might have been favorable to microbial life.

It is the first rover mission designed to seek signs of past microbial life. Earlier rovers first focused on establishing that Mars once hosted habitable conditions. During the next two decades, NASA will undertake several missions to address whether life ever actually arose on Mars.

#### Conditions Needed for Life to Thrive

On Earth, all forms of life need water to survive. It is likely, though not certain, that if life ever evolved on Mars this occurred in the presence of a long-standing supply of water. On Mars, we will therefore search for evidence of life in areas where liquid water was once stable as well as below ground where it still might exist. There might also be "hot spots" on the planet, where hydrothermal pools (like those at Yellowstone) offer places for life. Recent data from Mars Global Surveyor hint that liquid water may exist just under the surface in rare places on the planet and the 2001 Mars Odyssey mapped subsurface water reservoirs on a global scale. We know that water ice is present in the Martian polar regions, so these areas will also be good places to search for evidence of life.

In addition to liquid water, life also needs energy. Future missions will therefore also be on the lookout for energy sources other than sunlight, because life on the surface of Mars is unlikely given the presence of "superoxides" that break down organic (carbon-based) molecules on which life is based. Here on Earth, we find life in many places where sunlight never penetrates: in dark ocean depths, inside rocks, and deep below the surface. Some forms of life on Earth exploit chemical and geothermal energy. Perhaps subsurface microbes on Mars could make use of such energy sources too.

#### Looking for Life Signs

NASA will also look for life on Mars by searching for certain "biosignatures" of current and past life. The element carbon, for instance, is a fundamental building block of life. Knowing where carbon is present, and in what form, would tell us a lot about where life might have developed.

We know that most of the current Martian atmosphere consists of carbon dioxide. If carbonate minerals were formed on the surface by chemical reactions between water and the atmosphere, the presence of these minerals would be an indication that water had been present for a long time, perhaps long enough for life to have developed.

On Earth, fossils in sedimentary rock leave a record of past life. Based on studies of the terrestrial fossil record, we know that only certain environments and types of deposits provide good places for preservation of fossils. On Mars searches are already underway to locate lakes or streams which may have left behind similar deposits.

So far, however, the kinds of biosignatures we know how to identify are those on Earth. Life on another planet may be very different. The challenge is to be able to differentiate life from nonlife no matter where one finds it, and irrespective of its chemistry, structure, and other characteristics. Life detection technologies under development will help us to define life in non-Earth-centric terms, so that we are able to detect it in all the forms it might take.

### 2.1.2 Goal II: Understand the Processes and History of Climate on Mars

Past Martian climate conditions are a focus of the Perseverance rover mission. Its instruments are looking for evidence of ancient habitable environments in which microbial life could have existed in the past. A top priority in our exploration of Mars is understanding its present climate, what its climate was like in the distant past, and the causes of climate change over time.

The current climate is regulated by the seasonal cycles of the carbon dioxide ice caps, the movement of large amounts of dust by the atmosphere and the exchange of water vapor between the surface and the atmosphere. One of the most dynamic weather patterns on Mars is the formation of dust storms that generally develop in the southern spring and summer. These storms can grow to encompass the whole planet. Understanding how these storms develop and grow is one goal of future climatic studies. An improved understanding of Mars' current climate will help scientists to model its past climatic behavior more effectively. To do this, NASA will need detailed weather maps of the planet and information about how much dust and water vapor are in the atmosphere. Monitoring the planet over one full Martian year (687 Earth days) will help us to understand how Mars behaves over its seasonal cycle and guide us toward understanding how the planet changes on timescales of millions of years.

The layered terrain of the polar regions also provides clues to the planet's past, in much the same way the rings of a tree document its history. When and how were these polar layers deposited? Was the climate of Mars ever like that of Earth? And if so, what happened to change the planet into the dry, cold, barren desert that it is today? Those are the questions that our missions still have to answer.

The Perseverance rover has a weather station known as the Mars Environmental Dynamics Analyzer (MEDA). It will help to study the shape and size of the dust in the atmosphere. This knowledge will shed light on how Mars' dust may affect human health. The instrument's measurements include wind speed and direction, temperature and humidity, as well as the amount and size of dust particles in the atmosphere. Such measurements will add to an understanding of the atmosphere as a whole.

To further our understanding of the temperature conditions in Mars' atmosphere, MEDA will also collect information during the entry, descent, and landing phase using a set of sensors attached to the heat shield and back shell to collect data as the spacecraft plunges through the atmosphere.

### 2.1.3 Goal III: Understand the Origin and Evolution of Mars as a Geological System

The Perseverance rover is designed to study the rock record to reveal more about the geological processes that created and modified the Martian crust and surface over time. Each layer of rock documents the environment in which it was formed. The rover seeks evidence of rocks that formed in water and that preserve evidence of organics, the chemical building blocks of life.

How did Mars become the planet we see today? What accounts for the differences and similarities between Earth and Mars? These questions will be investigated by studying Mars' geology. As part of the Mars Exploration Program, scientists want to find out how the relative roles of wind, water, volcanism, tectonics, cratering and various other processes have acted to form and modify the surface.

For example, Mars has some incredibly large volcanoes, 10 to 100 times larger than those on Earth. One reason for this difference is the absence on Mars of the process of plate tectonics by which the crust drifts over "hot spots." On Mars the immobile crust means the total volume of lava simply piles up to create massive volcanoes.

The discovery by Mars Global Surveyor of large areas of magnetic materials on Mars indicates that the planet once had a magnetic field, much like Earth does today. Because magnetic fields in general act to shield planets from many forms of cosmic radiation, this discovery has important implications for the prospects for evidence of past life on the Martian surface. The ancient magnetic field also helps us to understand the interior structure, temperature and composition of the planet in the past, suggesting Mars was once more of a dynamic Earth-like body than it is today.

Of fundamental importance are the ages and compositions of different types of rocks on the Martian surface. Geologists use the age of rocks to determine the sequence of events in a planet's history. Composition information tells us what happened over time. Of particular importance is the identification of rocks and minerals that were formed in the presence of water. Water is one of the keys to whether life might have started on Mars.