

# Chapter 12

## Searching for Life on Mars: A Brief Summary



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**Abstract** Mars is today a cold, dry and sterile world with a thin atmosphere made of CO<sub>2</sub>. The geologic and compositional record of the surface reveals however that in the past Mars had a thicker atmosphere and liquid water flowing on its surface. For this reason, it has been postulated that life could have developed and that some primitive life forms may be existing even today. This paper will summarize the main discoveries that have led to the current understanding of the geologic, climatic and potentially biologic evolution of Mars, and will provide an overview of current developments and near-future plans for the search for life on the red planet.

### 12.1 Introduction

Mars is the fourth planet of the Solar System and the second smallest, preceded only by Mercury. Differentiated in a metallic core and a silicate mantle, Mars has a mass of about one-tenth that of our planet, a diameter slightly less than half the Earth's, and a surface area approximating that of terrestrial landmass. The Martian day is only slightly longer than Earth's, and its rotation axis has a similar inclination.

The Martian surface can be subdivided into three main morphological provinces: the Southern hemisphere consisting of a cratered highland reminiscent of the Moon, the topographically depressed and smooth Borealis basin, covering most of the Northern hemisphere, and the Tharsis plateau, a highland of volcanic origin 5000 km across centered on the equator and encompassing some of the largest volcanoes in the Solar System.

Other major features of the Martian surface are Valles Marineris, the largest canyon in the Solar System with a length of 4000 km and a depth of up to 7 km, and the two impact basins of Hellas Planitia and Argyre Planitia, with a diameter of 2300 km and 1800 km respectively. Mars also possesses two permanent polar ice

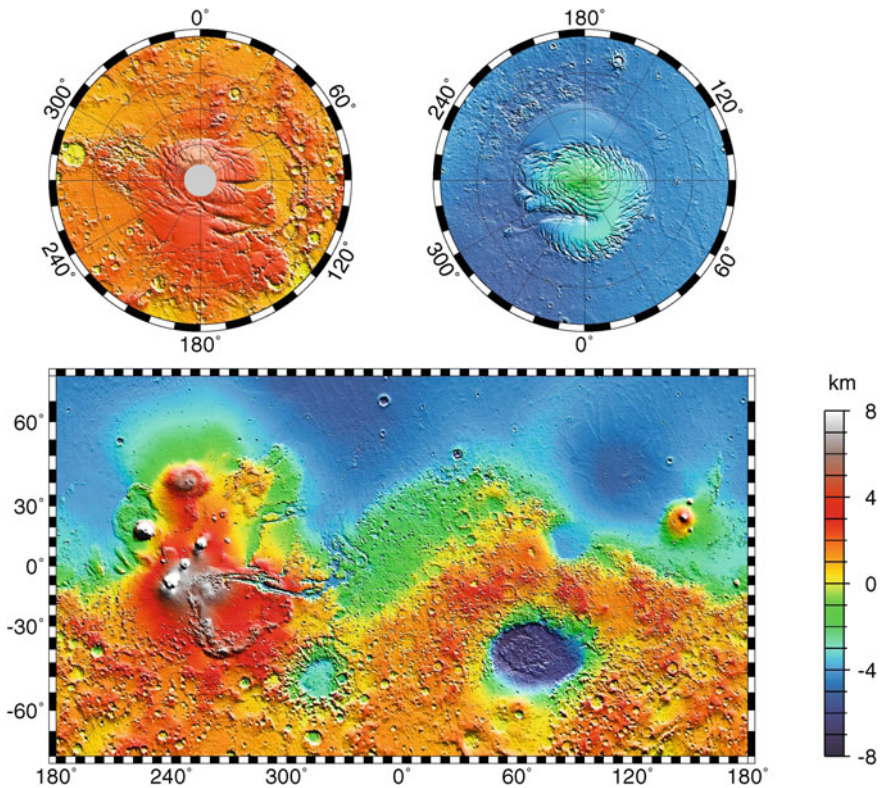
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**Fig. 12.1** Maps of Mars' global topography. The projections are Mercator to  $70^\circ$  latitude and stereographic at the poles with the south pole at left and north pole at right. The Tharsis volcano-tectonic province is centered near the equator in the longitude range  $220^\circ$  E– $300^\circ$  E and contains the vast east-west trending Valles Marineris canyon system and several major volcanic shields including Olympus Mons ( $18^\circ$  N,  $225^\circ$  E), Alba Patera ( $42^\circ$  N,  $252^\circ$  E), Ascraeus Mons ( $12^\circ$  N,  $248^\circ$  E), Pavonis Mons ( $0^\circ$ ,  $247^\circ$  E), and Arsia Mons ( $9^\circ$  S,  $239^\circ$  E). Major impact basins include Hellas ( $45^\circ$  S,  $70^\circ$  E) and Argyre ( $50^\circ$  S,  $320^\circ$  E). The map uses an aerocentric coordinate convention with east longitude positive (Image Credit: NASA/JPL/GSFC)

caps, consisting mostly of water ice admixed with some  $\text{CO}_2$  and dust, and extending for about 1000 km with a maximum thickness of a few kilometers (Fig. 12.1).

Mars is a terrestrial planet with a rocky surface with a composition corresponding to that of tholeiitic basalt, although parts are more silica-rich and may be similar to andesitic rocks [1]. The red-orange colour of the Martian surface is produced by nanophase particles of ferric oxides that constitute the dust covering the entirety of the planet.

## 12.2 The Exploration of Mars

Since the first detailed images of the Martian surface were acquired by automated probes, in the early seventies of the last century, it became obvious that the planet surface was sculpted by the action of water [2]. Imponent features such as valley networks and outflow channels were already visible in images from Mariner 9. The former are dendritic network of channels resembling a terrestrial fluvial system, while the latter are large stretches of terrain that appear to have been scoured by the flow of huge quantities of water. Other landforms, such as rampart craters and polygonal terrain, hinted at the present of ground ice.

These findings are at odds with the current climate of Mars. The current atmospheric pressure and temperature do not allow the survival of liquid water for any extended period, but the planet does have polar caps that appear to be constituted mostly by water ice [3]. Attempts to reconcile today's conditions on Mars with the evidence of past liquid water on the surface led to the hypothesis that Mars had to have a much denser CO<sub>2</sub> atmosphere in the past that was lost over the ages due to the weak gravitational pull resulting from a mass that is about one-tenth that of the Earth. Such dense atmosphere would produce a greenhouse effect capable of raising the mean surface temperature above the melting point of water [2].

The realization that Mars once had climatic conditions similar to those of the Earth led to the speculation that life could have been developing in the planet's past, and that it could exist even today. As a consequence, NASA launched the two twin Viking spacecrafts, each carrying a lander endowed with a set of experiments meant to detect life through the analysis of Martian soil. Most of the Viking experiments, which were based on the capability of living microorganisms to activate in the presence of liquid water or to use carbohydrates in their metabolism, produced no evidence for life [4], but some still debate whether one of them recorded signs of chemical activity that could be attributed to biotic activity [5]. In hindsight, this outcome could have been expected even if life still survived on Mars because its surface, due to the thin atmosphere, is constantly bombarded by ultraviolet radiation and high energy particles, which would make the survival of even the most tenacious terrestrial microorganisms extremely challenging.

These negative results led to the abandonment of Mars robotic exploration for more than a decade, during which the copious harvest of data collected by the Viking probes was slowly elaborated into a more detailed and consistent picture of the evolution of Mars through the ages. The geologic history of the planet was divided into three main eras, the Noachian, the Hesperian and the Amazonian. The Noachian, lasting a few to several hundred million years, was the age in which Martian climate was more favourable to life, while the Hesperian was characterized by intense volcanic activity, leading to the formation of the Tharsis plateau on which most of the main volcanoes of the planet are located, and by the presence of massive ice sheets. The Amazonian, the modern era of Mars, is the current arid and glacial age of Mars [2] (Fig. 12.2).



**Fig. 12.2** Mariner 9 view of part of Nirgal Vallis. Nirgal Vallis is a 670 km-long east–west trending valley network (Image Credit: NASA/JPL-Caltech)

Several points remained open to debate. The early Sun was perhaps only 70% of its current brightness, and climate models were unable to reproduce sustained periods of warm temperature even in the presence of a thick CO<sub>2</sub> atmosphere (see e.g. [6] for a discussion). Estimates of the quantity of water needed to carve the water-related geologic features observed on the surface of the planet are much greater than the total ice present on the Martian surface [2]. Much uncertainty remained on the onset and decline of volcanic activity of the planet, and on its capability to influence Martian climate and habitability. It was clear, however, that the early Mars presented all factors required for habitability, that is for a living organism to survive, and that such conditions persisted for a time comparable to the one required on Earth for the emergence of life. The study of Mars could thus provide the answer to many questions still lingering on the emergence of life on Earth, and on its likelihood of happening on other planets outside the Solar System. Because of the enormous importance attributed to this scientific endeavour, the exploration of Mars was resumed by NASA in the late eighties of the twentieth century.

### 12.3 The Search for Life

The initial driver behind the new wave of missions to Mars was summarized by the slogan “Follow the water”, because of its importance in understanding the geological, climatic and biological evolution of the planet. As NASA orbiters were followed

by landers and rovers, and other space agencies started launching their missions to Mars, more and more evidence was found for an ancient environment in which liquid water persisted on the surface for extended periods of time, the atmosphere was denser than today and a global dipolar magnetic field similar to Earth's protected it from erosion by the solar wind [7]. High resolution images of the surface showed features that were interpreted as due to the recent occurrence of liquid water on the surface [8], although only in limited locales and for brief periods during the warm season. Neutron spectroscopy detected the presence of permafrost in the first meter of soil, extending from the poles to mid-latitudes [9]. Radar sounding allowed the identification of water ice as the predominant constituent of the polar caps [10]. Finally, the measurement of the current erosion rate of the atmosphere due to the solar wind allowed more precise estimates of the total atmospheric loss, including water vapour, over the age of the Solar System [11].

The discovery of methane in the atmosphere of Mars both from the Earth [12] and from Martian orbit [13] started a debate on its origin that is still ongoing. Methane is destroyed by ultraviolet radiation in a relatively short time, and its presence, however small, implies an active source. On Earth, the main processes releasing methane in the atmosphere are volcanism and biologic activity, both of which could not be observed on Mars. A currently operative mission dedicated to the study of trace gases in the Martian atmosphere has yet to provide a definite answer to the question of methane origin, but the recent detection of seasonal variability in the quantity of atmospheric methane seem consistent with sources located at the surface or in the subsurface [14], rather than in the atmosphere.

Another recent development has been the detection of a system of liquid water bodies beneath the south polar cap of Mars [15]. In spite of the theoretical difficulties in reconciling this presence with the very low mean annual temperature at the poles, requiring at a minimum the presence of dissolved salts depressing the freezing point of water [16], and perhaps some thermal anomalies in the crust beneath this area [17], no alternative interpretations have yet been proposed for the radar observations leading to the detection. These subglacial bodies of water constitute the first potential habitat on Mars, being thermally stable and protected from the radiation flooding the surface. However, the lack of any information on the chemical composition and availability of redox pairs in such an environment prevents any assessment of this hypothesis.

Accessing the Martian subsurface to search for evidence of past or present life is considered a high-priority goal in the exploration of the planet, but the technical challenges for such an endeavour are daunting. The Rosalind Franklin rover, to be launched in 2022, will carry a drill capable of reaching a depth of two meters [18], while a recent mission concept for landing a drilling station on Mars foresees a maximum penetration of the order of a hundred meters [19]. Current and planned missions for the search of life on Mars focus on the detection and collection of samples from sedimentary beds or mineral deposits formed in an aqueous environment and accessible on the surface [20].

The detection of life, on Mars and elsewhere, is a complex problem that cannot be solved through a single measurement technique [21]. Because of potential differ-

ences between terrestrial and extraterrestrial life, of the relative fragility of complex molecules such as those of biological chemistry, and of the complex alterations induced by a harsh environment such as Mars', the unambiguous identification of life traces will require the simultaneous detection of several biomarkers in the same sample [18]. For this reason, there is a risk that a robotic mission performing in-situ analysis of potential biologic samples will not be able to obtain a definite answer even in the presence of biomarkers. This is why the main goal for Mars exploration in this decade is the return of samples to Earth in pristine conditions [22].

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