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21. Mars: water, climate & geology

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21. Mars: water, climate & geology

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21.1

Mars, Water, Habitability

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With the data acquired by the ongoing space missions, Mars history is profoundly re-visited. It now exhibits an ancient era where sustained liquid water has likely been present, as recorded by specific hydrated minerals. Mars might have harboured habitable conditions, before the end of the heavy bombardment, while its dynamo was still operating. It happens that sites having preserved this record are still present at its very surface. If life emerged other than on the Earth, the upcoming Mars missions (NASA/MSL and ESA/ExoMars) should be able to find bio-relics, in a few areas well documented, and accessible to rovers. Moreover, their exploration will give unprecedented clues on the environment which characterized the early Earth, when life appeared. Astrobiology is truly entering its scientific era.

21.2

Mars, the most interesting, now accessible, remote geological object.

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Mars is far away, small and dry but it is, apart the Moon, the most accessible large celestial body. Its gravity is twice that of the Moon. It has days of 24h40 minutes, instead of 14 days. It has water ice at the poles, in the subsoil almost everywhere and in veils of clouds in its sky, much more than the traces detected on the Moon. During its early geological history, liquid water has run on its surface and altered the magmatic and lava rocks into hydrated rocks. It has an atmosphere even though very thin and unbreathable (CO_2). Almost all erosion stopped 3.5 billion years ago and since there has been no plate tectonic, the surface has almost not changed, providing an open book for what our Earth could have been at such an early stage, when life started to emerge.

We have been there with robots and we learnt a lot but men on the spot could be much more efficient and facilitate exploration. Sending them there, would be feasible within ten years if we decided to. Thanks to the "Mars Direct" theory, we could use nowadays technology and stay within a budget smaller than that of the International Space Station. If we use the Martian atmosphere to produce locally the fuel and combustive necessary to return to Earth, then the mass which we need to propel off the Earth gravity pit would be reduced to the level at which we can use the equivalent of the Saturn V rockets which carried men to the Moon forty years ago.

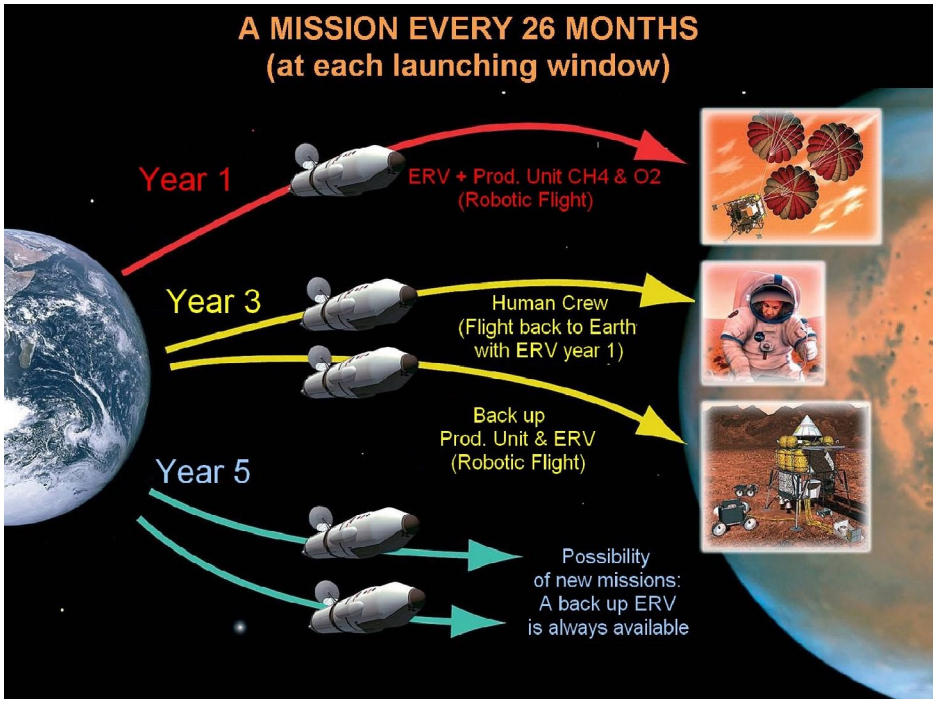

Image Association Planète Mars

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21.3

Putative oceans and hydrothermal activity on Mars

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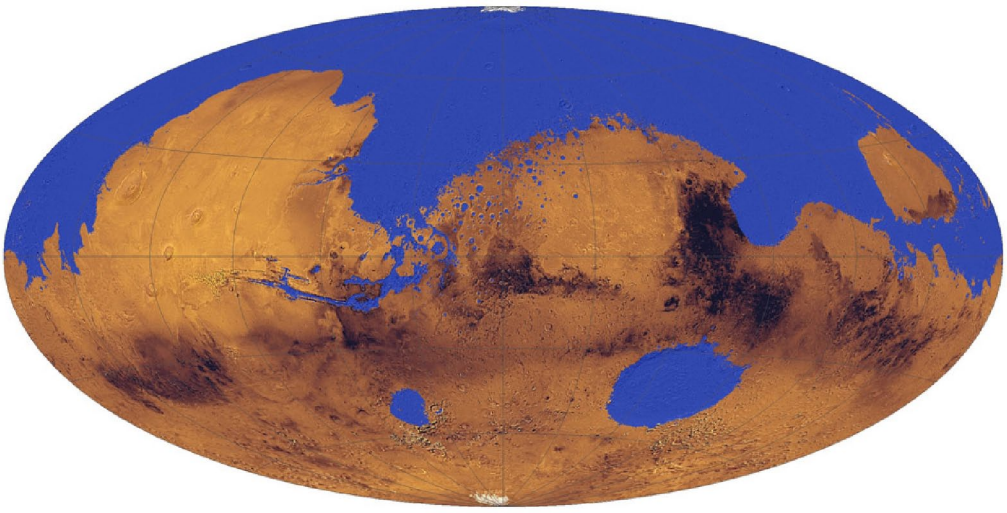
Mars has a rich water history. The ancient Southern highlands show evidence of rainfall with runoff recorded by river systems that have shown up at higher resolutions to constitute denser, more integrated networks than previously believed [1]. This early Noachian period also coincides with clays identified from orbit (see presentation by J.P. Bibring).

Abundant water reemerges from the ground in later events throughout the history of Mars, most notably during the Hesperian period, approximately 3.8 billion years ago. Evidence includes catastrophic outflow channels out of the highlands towards the Southern hemisphere Hellas impact basin and most importantly towards the Northern lowlands. Recognition of the extreme smoothness of the Northern plains and of the common altitude at which channels flow into this boreal basin have led to the hypothesis of an ancient sea occupying the basin, nicknamed Oceanus Borealis [2]. We examine the status of this theory [3].

Since volcanism and vast amounts of underground ice and liquid water have interacted in the past, it is fair to assume that hydrothermalism has been prevalent throughout Martian history, probably up to this day. Indirect evidence has come in the form of mineral associations found on the ground, such as streaks of opaline silica discovered by the Mars Exploration Rover Spirit [4]. The search for hydrothermal mounds from orbit is also accelerating, as we shall examine [5,6]. The search for life on Mars is bound to focus in the future on these promising sites.



Putative oceans on Ancient Mars (University of Colorado)

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21.4

AFM MEASRUREMENTS OF MARTIAN SOIL PARTICLES – RESULTS FROM THE PHOENIX MISSION

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Light scattering experiments conducted on Mars [i] indicated that soil particles have dimensions around 1 µm. Particles in that range play an important role in the gas exchange between sub-surface water ice and the atmosphere. The Phoenix mission [ii] therefore decided to analyze soil and dust particles in the sub- range using an Scanning Force Microscope (SFM) for the first time on another planet.

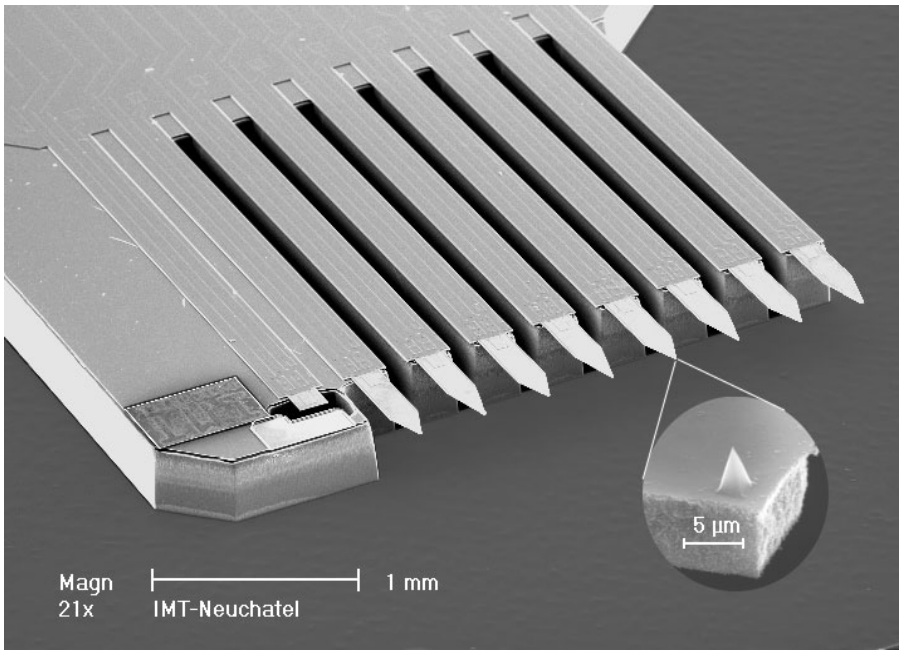

Figure 1: SEM image of the sensor chip with eight support beams and cantilevers. The inset shows the tip formed by KOH etching at the end of the cantilever.

A MEMS approach combined with mechatronic concepts for the scanner was selected for implementing the SFM. For redundancy, the sensor chip (Figure 1) featured eight, about 6µm thick cantilevers each with an KOH-etched 7 to 8 µm high silicon tip. The cantilevers could be cleaved off if contaminated. The cantilever deflection was measured using implanted, p-type piezo-resistors. Thermal drifts were compensated by a reference piezo-resistor. The chip was glued on a triangular platform, which was suspended from the rigid body of the scanner by means of symmetrically arranged polyimide springs. The later also contained the electrical contacts to the chip. Three magnets were attached in the corners of the platform. An electrical coil mounted underneath each magnet allowed deflecting them. The whole scanner measured 12mm×18mm×24mm and weighted 15g.

The sample stage featured 10 sets of 6 substrates and 10 calibration samples. It could be moved out of the enclosure to receive a soil or air-fall sample. Once rotated in front of the microscope, the sample wheel moved first to the focus position of the optical microscope. An OM image was taken on which, the position for the SFM measurement was selected. The stage was then used to approach the sample to the SFM tip.

During NASA's Phoenix Mission, which operated on the red planet from May to October 2008, we could demonstrate successful SFM operations (see Figue 2). The instrument produced data of soil particles for scientific analysis. From an engineering point of view, operating the SFM within the constraints of a mission was the biggest challenge.

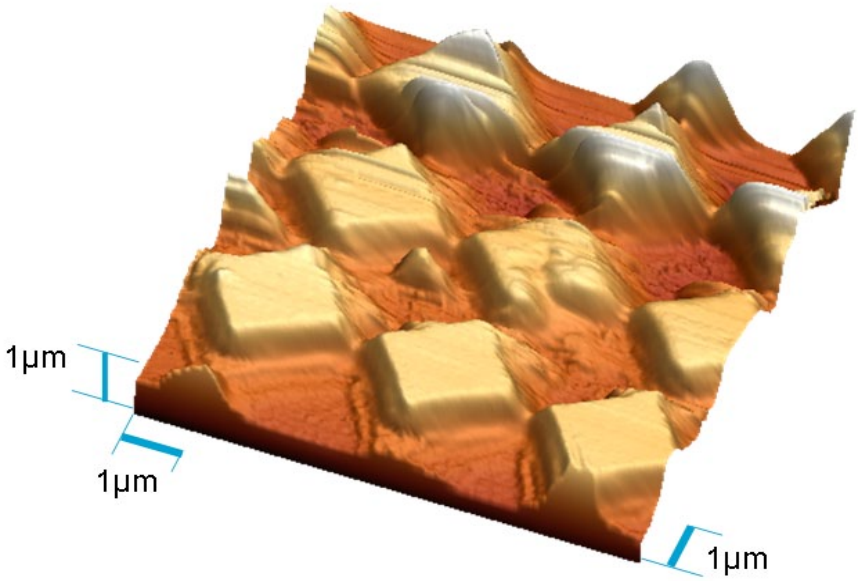

Figure 2: Dynamic mode SFM image of a 2D calibration sample recorded on sol 64 of the Phoenix Mission on Mars.

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21.5

Volatiles in the atmosphere of Mars: the effects of volcanism and escape.

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Habitability of terrestrial planets and of Mars in particular, is governed by their atmospheric conditions; that is the surface pressure and temperature and the abundance of diverse volatiles, such as water and CO_2. Over time, Mars has known several main phases of evolution that were characterized by vastly different surface conditions and sometimes the presence of flowing liquid water. To better understand the history of the planet, we study the long term influence of volcanism and atmospheric escape on the evolution of the conditions on the surface of Mars during the last four billion years. We use the recent observation and modeling to constrain our model with the help of isotopic data from Carbon, Nitrogen and Argon. Water is also a focus of our study.

CO_2 is the main object of our study, as it represents the bulk of the present, and probably past, atmosphere. Volcanic degassing and atmospheric escape through non-thermal processes are the two most straightforward processes that can have an effect on the atmosphere of Mars, and, as such, it is important to quantify their respective influences.

Volcanic degassing is obtained from crust production models, observation of the surface, and realistic volatile contents of the lavas. ASPERA measurements and modeling of the escape rates produced by ionic escape, sputtering and dissociative recombination constitute the sink of volatiles. History of Argon (and the $^{40}Ar/^{36}Ar$ ratio) constrains the maximum escape flux of CO_2. This imposes limited escape flux, consistent with the recent lowering of the expected escape efficiency on Mars. With low escape rates, our model is able to reproduce present day ^{36}Ar abundance and $^{40}Ar/^{36}Ar$ ratio.

We also show that the present-day atmosphere of Mars is likely to be constituted by a large part of volcanic gases, as it only takes 150 ppm CO_2 in the lavas to obtain a “volcanic/early” ratio of 50% and 90% or more are obtained with a content of 450 ppm. We also find that it is unlikely that lavas on Mars could have contained more that several hundred ppm CO_2. Likewise, the mean age of the atmosphere is estimated to be no more than 1.9 to 2.3 billion years old and could be less in case recent volcanism was more intense than taken into account in the model. Atmospheric pressures and variations on Mars are predicted to be low, as the result of degassing and non-thermal escape. In our model, they do not exceed 50 mbar during the considered period. This seems in line with the assumption of a heavy loss of volatiles during the first 500 Myr.

Isotopic ratios lead us to propose that Nitrogen is probably old in the Martian atmosphere and has been subjected to the fractionation of atmospheric escape. The $^{12}C/^{13}C$, on the other hand is more stable and indicates that Carbon is younger and that a part of it might come from cometary bodies. Water is moderately abundant on Mars during the whole 4 billion years evolution but is unlikely to reside in the atmosphere or in liquid form unless large scale perturbations occur (changes in obliquity, large input of greenhouse gases due to a short burst of volcanism).

21.6

Core and early crust formation on Mars

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One of the most striking surface features on Mars is the crustal dichotomy. It is the oldest geological feature on Mars and was formed more than 4.1 Ga ago by either exogenic or endogenic processes (Nimmo et al., 2008; Keller & Tackley, 2009). In order to find an internal origin of the crustal dichotomy, located within a maximum of 400 Ma of planetary differentiation, the thermal state of the planet resulting from core formation needs to be considered. Additionally, it was suggested that a primordial crust with up to 45 km thickness can be formed already during the Martian core formation (Norman, 1999). We suggest that the sinking of iron diapirs delivered by predifferentiated impactors induced impact- and shear heating-related temperature anomalies in the mantle that fostered the formation of early Martian crust. Thus, the crustal thickness distribution would largely be a result of planetary core formation, late impact history and the onset of mantle convection.

In this study, we examine parameter sets that will likely cause hemispherical asymmetry in both core formation and onset of mantle convection. To test this hypothesis we use numerical models to simulate the formation of the Martian iron core and the resulting mantle convection pattern, while peridotite melting is enabled to track melting caused by shear and radioactive heating.

We perform 2D simulations using the spherical-Cartesian code I2ELVIS (Gerya & Yuen, 2007) for planetary accretion and the spherical code STAGYY (Hernlund & Tackley, 2008) for the consequent onset of mantle convection. We apply a temperature-, stress- and melt-fraction dependent viscoplastic rheology inside a Mars-sized planet. Radioactive and shear heating as well as consumption of latent heat by silicate melting are taken into account.

The depth of neutral buoyancy of silicate melt with respect to solid silicates is determined by the difference in compressibility of the liquid and solid phase. To self-consistently simulate the silicate phase changes expected inside a Marssized body, we use the thermodynamical database Perple_X (Connolly, 2005). As initial condition for core formation (I2ELVIS), we apply randomly distributed iron diapirs with 75 km radius inside the planet, representing the cores of stochastically distributed impactors. Additionally, we explore the effect of one giant impactor core on the planetary evolution.

Results indicate that the presence of a large impactor core induces hemispherically asymmetrical core formation. The amplitude of shear heating anomalies often exceeds the solidus of primitive mantle material and thus, the formation of a considerable amount of silicate melt is observed.

The resulting temperature field after core formation is then read into the mantle convection code STAYY. The hemispherical magma ocean induced by one late giant impactor favours a dichotomous crust formation during and shortly after core formation. Afterwards, the extraction of excess heat produced by the sinking of the giant impactor through the mantle leads to a localized region of massive magmatism, comparable to Tharsis, which is sustained during later evolution by a single plume forming beneath the province. The rest of the mantle is dominated by a sluggish convection pattern with limited crust formation that preserves the early formed dichotomous crustal structure until recent time.

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21.7

The potential of Close-up imaging on the surface of Mars

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Close-up imaging is here defined as imaging at resolutions of 10 to 100 microns per pixel, corresponding to macro-photography. Imaging of this type has been implemented in past Mars Missions (Beagle 2, 50micron/pixel b/w; Mars Exploration Rovers, 30 microns/pixel b/w; Phoenix, 23-120 micron/pixel colour) and similar instruments will be used during upcoming Mars surface missions (Nasa's Mars Science Laboratory, ESA's ExoMars). The resolution is intermediate between that of Panoramic cameras and of microscopes. In preparation for the ExoMars mission, where the Swiss Instrument CLUPI (Close UP Imager, 15 microns/pixel in colour, 2652x1768 pixel detector) will provide this type of information, we are performing tests to acquire knowledge concerning the types of information that can be gained from CLUPI-type images (Hofmann, 2008).

The main goal for ESA's ExoMars Rover Mission with the Pasteur instrument payload (launch planned for 2018) is to search for traces of past or present life using a sophisticated set of instruments for geological context characterization and life search. The operation strategy of the Pasteur Rover consists of a) search for an interesting site; b) site characterization; c) detailed investigation of selected sites including drilling to 2 m followed by drillcore analysis in a lab inside the rover. CLUPI will be used mainly in steps b) and c), possibly also a). During site characterization, CLUPI images will be crucial for the interpretation of the characteristics of soil and rock surfaces. During detailed investigations, CLUPI will yield images of drilling fines and of drillcores obtained (after this drillcores are destroyed for analyses). The preparation of image interpretation has two main goals:

First we aim to be able to characterize soils and rocks in the best possible way using CLUPI-type images, and to obtain information about the uncertainties involved by performing blind tests. A specific interest will be the recognition and characterization of evidence for the past presence of water.

Second, we prepare for the search for and interpretation of possible signatures of life at CLUPI resolution. Stromatolitic textures in past surface environments and filamentous fabrics in past subsurface environments (Hofmann et al., 2008) are prime candidates of interest in this context. The types of biosignatures present on Earth at this resolution needs to be investigated and criteria for their interpretation (biogenic versus nonbiogenic) need to be evaluated.

Figure 1. CLUPI-type close-up image obtained with a commercial camera using the identical detector as CLUPI. Image width is 5.7 cm (corresponding to 21.5 microns per pixel). Inset shows detail in full resolution. The "stalactitic" fabric are encrustations of microbial filaments in a cavity in Mesozoic basalts from the Black Head Quarry, Ballina, NSW, Australia. Such fabrics are an example of an easily identifiable potential signature of past life on Mars.

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21.8

ExoMars Rover : Goals and instruments

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ExoMars is an approved Mars exploration programme of the European Space Agency (ESA) involving a broad cooperation with NASA. The programme is composed of two missions:

A first launch will take place in 2016, with three goals: deploy an orbiter module that will analyse trace gases of the Martian atmosphere; demonstrate ESA's capability to deliver a payload to the surface with an Entry, Descent and Landing (EDL) module ; and provide with the orbiter a communication relay between Mars and the Earth, in particular for the ExoMars rover.

In a second step, the ESA ExoMars Rover will be launched together with the NASA Max-C Rover. Using a NASA « Skycrane » descent module, the rovers will be delivered to the surface at the same time in early 2019.

Along with technological demonstration goals (surface mobility with a rover, access to sub-surface samples, sample preparation and distribution for analysis by scientific instruments), the programme has the following scientific aims:

- to search for signs of past and/or present life on Mars;
- to investigate the water/geochemical environment as a function of depth in the shallow subsurface;
- to investigate Martian atmospheric trace gases and their sources.

Research in geology and exobiology will be conducted using the scientific payload of the ExoMars rover. The Pasteur payload consists of 9 instruments. A first set of four instruments will conduct preliminary observations:

PanCam, an instrument equipped with wide-angle multi-spectral stereoscopic high resolution panoramic imagers, will provide a 3D model of research sites and geological information thanks to its optical filters.

CLUPI (CLose UP Imager) will provide high-resolution color images (2400 x 1700 x 3 bits per image with a 15µm/bit resolution at 20cm) of the immediate surroundings of drill spots and of retrieved samples. Space-X is the institute responsible for delivering CLUPI and the PanCam stereoscopic imagers to the ExoMars mission.

Together with these visible imaging systems, Ma_Miss (Mars Multispectral Imager for Sub-surface Science, a wide-range infrared spectrometer to conduct mineralogical investigations) and WISDOM (Water Ice & Subsurface Deposit Observations on Mars, a polarimetric ground-penetrating radar) will bring additional information to characterize the drilling sites.

At six drill sites during the 180-sol surface mission of the ExoMars rover, a core sample will be retrieved from two meters under the surface and delivered to the scientific instruments inside the rover. After having been imaged using CLUPI, the samples will be crushed and distributed to the following five instruments inside the rover:

MIRU (Micromega InfraRed Unit, Infrared Microscope for hyperspectral imaging), RAMAN IOH (Raman Spectrometer), MARS XRD (X-Ray Diffractometer), MOMA (Mars Organic Molecule Analyser, Gas Chromatographer / Mass Spectrometer) and LMC (Life Marcher Chip).

The combination of all the results produced by the ExoMars rover's Pasteur scientific payload will produce the first full set of data on sub-surface Martian samples.

Figure 1. ExoMars Rover.