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Preface

Special issue of Planetary of Space Science Planet Mars II: A new image of Planet Mars

The international workshop "Planet Mars II" which took place at the Centre de Physique in Les Houches (France) on May 23–June 1, 2005, led to vivid and fruitful discussions about the new results which have recently come out of the Mars Global Surveyor, Mars Odyssey, Exploration Rovers and Mars Express space missions. Following the first workshop which took place on April 28–May 9, 2003 (Encrenaz and Sotin, 2004), about 50 scientists of all horizons listened to tutorials and exchanged latest results concerning all aspects of the planet's physics, chemistry, geology and environment: internal structure, gravity field, magnetic field, surface morphology, cratering and mineralogy; atmospheric composition and escape; past climate of Mars and obliquity effects; search for past or present traces of life. These discussions demonstrated that our understanding of Mars' evolution and, in particular, the question of the water cycle over its history has been quite modified by the recent results of the Mars Exploration Rovers and Mars Express.

1. Early Mars

One major discovery of MGS is that Mars had a magnetic field in its history (Acuna et al., 1999). This magnetic field was recorded in the old crust of the southern hemisphere when the crustal temperature decreased below the Curie temperature, allowing the rocks to retain a remanent magnetic field that can be measured today. Then the dynamo stopped. The reasons for the dynamo extinction remain to be understood. But it may be closely connected to the possible escape of the early martian atmosphere, as some efficient non-thermal escape processes, like sputtering, are favored in the absence of a magnetic field (Chassefière and Leblanc, 2004; Chassefière et al., 2006).

The hypothesis of a warm, wet early Mars was suggested in order to explain how liquid water may have flowed at the surface of Mars, leaving, in particular, the valley networks that we observe today (Pollack et al., 1987). An early atmospheric escape was then invoked to explain how the dense primordial atmosphere disappeared (Brain and Jakosky, 1998), and also to account for isotopic enrichments on Mars (in particular $^{15}N/^{14}N$ and D/H; Nier and McElroy, 1977; Owen et al., 1988). Since the Viking results on the isotopic composition of the atmosphere, it was generally accepted (Owen, 1992) that nitrogen has escaped (which would explain the ^{15}N excess) while the reservoir of CO_2 was trapped in the surface (which would explain the terrestrial isotopic ratios of CO_2).

However, one of the major results of the OMEGA/Mars Express mineralogic observations is the absence of carbonates at the martian surface (Bibring et al., 2006). If carbon dioxide is not trapped in the surface, when and how did it escape? Another argument in favor of a global outgassing of Mars' early atmosphere is the N_2/CO_2 ratio, equal to a few percent on both Mars and Venus today, and also comparable to the primitive value of the Earth atmosphere. An important goal would be to revisit the determination of the isotopic atmospheric ratios. Another key measurement will be the determination of the escape rates in the upper Martian atmosphere. Such experiments could take place aboard future spacecraft devoted to Mars exploration (Chassefière et al., 2006).

The hypothesis of a wet, warm early Mars also faces other difficulties. The first one deals with the assumed luminosity of the early Sun. From models of stellar formation and activity, the solar luminosity is expected to have been about 70% of its present value during the first Gy of its history. In order to maintain a temperature high enough for water to stay liquid at the surface of Mars, a greenhouse effect of 77 K would have been required, which seems incompatible with a pure CO_2 atmosphere (Kasting, 1991). Other active greenhouse gases, like SO_2 or CH_4, as possible products of volcanic activity, might have helped sustaining for some time a dense and warm atmosphere, but we have no evidence for it. More work would be needed to better constrain the properties of the early Sun, in particular its mass, as the Sun's luminosity varies as the 6th power of this parameter.

As an alternative hypothesis to the early warm and wet Mars, one could imagine that Mars might have been episodically wet after impacts and strong volcanic events. Indeed, the assumption of an episodic activity of water seems to be supported by the recent mineralogic observations of the

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OMEGA instrument, which has conducted a systematic search for hydrated minerals (Bibring et al., 2006). Two classes have been found: phyllosilicates in the older (Noachian) terrains, and sulfates (also observed in situ by Opportunity), associated to younger regions (late Noachian and Hesperian). The OMEGA data have also shown that most altered mafic minerals do not contain water in their structure; they are highly oxidized, presumably from their interaction with the atmosphere, but they are not hydrated, and thus do not indicate the presence of subsurface water. In particular, no hydrated mineral is found in the lobate craters, the valleys or the outflow channels. As a consequence, there is no evidence that liquid water could have remained stable over long periods of time. Possibly giant outflows occurred early in Mars' history, at a time of intense volcanic activity, leading to the outgassing of sulfur species, oxidized in the atmosphere, and the formation of sulfates. At later stages, liquid water would have appeared only locally and episodically due to a change in the internal (volcanism) or external (impact) activity (Solomon et al., 2005).

2. Recent Mars

The past 2 years have seen tremendous progress in our understanding of the past climate of Mars, and how the obliquity changes have modulated the ice distribution over the planet. Several years ago, Head and Marchant (2003) documented the presence of huge cold-based tropical mountain glacier deposits on the northwest flanks of Olympus Mons and the Tharsis Montes, with their presence strongly suggesting that relatively recent climate conditions were such that polar ice could be mobilized and transported to equatorial regions. Global Circulation Models (GCM) have shown that, at high obliquity (45°) (Laskar et al., 2004; Levrard et al., 2004), ice accumulates at tropical latitudes (Forget et al., 2006). Due to circulation effects, glaciers form in specific locations, especially on the west side of Olympus Mons and the Tharsis Montes, and on the east side of the Hellas basin. A major success of the HRSC experiment has been the further documentation and characterization of these deposits, and the discovery of evidence for significant ice in the deposits on the eastern flanks of Hellas, exactly at the positions predicted by the models (Neukum et al., 2004; Head et al., 2005). These new data will permit an improved mapping of the glacier locations and will allow us to better constrain their distribution and their age. In turn, this will permit more detailed climate modeling and an understanding of the distribution of water on Mars with changing climate.

In 2002, the GRS experiment aboard Mars Odyssey detected, at low latitudes, a large abundance of hydrogen atoms below the surface (Boynton et al., 2002). An important objective will be to determine their nature (ice of hydrated minerals), and to estimate how much water is present. The radar experiments, MARSIS aboard Mars Express (Plaut et al., 2005) and SHARAD aboard MRO, will hopefully bring new inputs to this question.

3. Present Mars

In spite of the constant improvements of the global circulation models, the understanding of the present water cycle on Mars is still an on-going problem. What are the sources and sinks of water, and the surface/atmosphere interactions? What are the amounts of water trapped under the surface, at the poles and at mid-latitude? The observed cycle of water vapor is well reproduced by the GCM without the help of sources other than the polar ice caps, but this does not preclude the presence of water in a regolith. The stability of the southern polar cap is also an open question. OMEGA observations have shown that a thin, discontinuous CO_2 layer covers an underlying water ice reservoir (Bibring et al., 2004). The holes in the CO_2 layer seem to enlarge each year, implying the release of CO_2 into the atmosphere. Is the southern polar cap perennial, or will it disappear on a time scale of tens or thousands of years?

A major result of the Mars Express HRSC coverage has been the new dating of the martian terrains. Crater counting over the flanks of some volcanoes has shown evidence for areas no older than a few million years (Neukum et al., 2004), which modifies our previous view of the presence and abundance of recent volcanism. This new result may be connected to the tentative detection of methane on Mars (Krasnopolsky et al., 2004; Formisano et al., 2004; Mumma et al., 2004, 2005). Although this result still requires confirmation, some observations suggest the possible existence of transient and localized sources of methane. Such outgassing could be the result of serpentinization, an internal hydrogeochemical process which produces molecular hydrogen from the hydration of ultramafic silicates; the hydrogen, in turn, reacts with CO_2 to form CH_4 which could be outgassed through hydrothermal vents (Atreya et al., 2006). This is only a possible explanation, among others, for the existence of variable sources of methane on Mars. Other possible sources include volcanism, comets or meteorites, or biological activity. In view of its possible astrobiological implications, the search for methane and the spatio-temporal monitoring of its possible sources should be a major objective for the future exploration of Mars.

Finally, the major unknown about Mars is still its internal structure and tectonic activity. Recent analysis of the MGS radio science data (Yoder et al., 2003) suggests that the martian core is still liquid and that its radius is in between 1500 and 1900 km. It points back to the question of why the internal dynamo stopped. There has been strong progress in the modeling of thermal convection within planetary mantles (e.g. Spohn et al., 2001). These models predict that the martian mantle would be as hot as the Earth's mantle. This prediction is in agreement with the presence of a liquid core. But it is critical to obtain data which can constrain the internal characteristics of the planet as well as its present tectonic activity (Dehant et al., 2004).

Our knowledge of Mars is improving and changing as missions transmit new data. The vision that early Mars had conditions similar to early Earth when life occurred is not ruled out by these new data. However, its mineralogy suggests that liquid water did not remain on its surface during long periods of time. Although convection processes were active within the mantle of both planets, only Earth developed plate tectonics. The reason has still to be determined and we can hope that forthcoming missions will provide the data that will help resolve this issue. The NASA MRO and MSL missions, and the ESA ExoMars programme will provide new data sets that will feed future discussions and workshops on the red planet.

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