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WatSen: searching for clues for water (and life) on Mars

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Abstract: There is plenty of evidence for fluid on Mars: large-scale (planet-wide) features have been captured over four decades by a procession of orbiting satellites equipped with cameras with increasingly higher spatial resolutions. Imagery of the surface shows channels, valleys, ice-caps, etc. Small-scale, more local evidence for fluid has come from images obtained by rovers on the Martian surface. Images that water produced many of the features are supported by spectroscopic measurements (again both planet-wide and local) over a range of wavelengths, which show the presence of minerals generally only produced in the presence of water (haemetite, jarosite, etc.). Results from meteorites continue this picture of fluid activity taking place over significant periods of Mars' history. Despite all these indicators of water, direct detection of water has never been performed. We have reviewed the evidence for water on Mars' surface, and have described WatSen, a combined humidity sensor and infrared IR detector, which can be employed to search for water at and below Mars' surface. WatSen is designed to be part of the suite of instruments on the mole that will be deployed as part of the Geophysics and Environment Package on ExoMars. The objectives of the package are as follows: (i) to detect water within Martian soil by measuring humidity and IR spectral characteristics of the substrate at surface and at depth; (ii) to determine the mineralogy and mineral chemistry of surface soils (this measurement will provide the mineralogical context for the elemental results that come from other instruments mounted on the landing platform); (iii) to determine how mineralogy changes with depth. The utility of WatSen is that it will not only detect the presence of water, but will also be able to record which minerals are present and their chemistry; it is also sensitive to many organic species. WatSen is a new instrument concept specifically designed to search for clues of the presence of water, and to look for evidence of life on Mars.

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Key words: water, mars, life, infra-red, spectroscopy.

Introduction

The past five years have seen a dramatic increase in the number, resolution and quality of images and compositional data from Mars' surface returned by both orbiting spacecraft and rovers. Investigation of Martian meteorites has also shown that they have been affected by water. One result from image and spectral data has been a gradual change in perception of the fluvial history of Mars. The paradigm for many years was the 'warmer and wetter' scenario, in which water was stable over vast areas of Mars' surface, implying a thicker atmosphere and warmer temperatures during past epochs, resulting in active circulation of fluids between atmosphere, hydrosphere and lithosphere (Pollack *et al.* 1987; Squyres & Kasting 1994; Carr 1999; Craddock & Howard 2002). It is now thought more likely that, apart from the very earliest period (the Noachian epoch, approximately the first 500 million years (Hartmann & Neukum 2001), Mars has been cold and dry for much of its history, with transient fluvial events, often short-lived catastrophic flooding, triggered by increases in magmatic activity (Baker 2001; Carr & Head 2003; Neukum *et al.* 2004). Under a 'warmer and wetter' regime, with pervasive and persistent bodies of standing water, there would be an extended hydrological cycle in operation. In contrast, a 'cold and dry' climate for most of Mars' history would curtail any hydrological cycle (Baker *et al.* 2005). The difference between the two climate models is of great significance for the potential evolution of life on Mars. However, despite all the evidence that water has played an active role in the modification of Mars' surface, there has not yet been a direct measurement of water on Mars. We review here the evidence for water on Mars, and describe an instrument (WatSen) that is a combined infrared (IR) detector and humidity sensor. This will be able to not only determine the presence of water below Mars' surface but could also identify different mineral species (primary magmatic and secondary alteration) occurring in a stratigraphic section through the regolith. The first possible

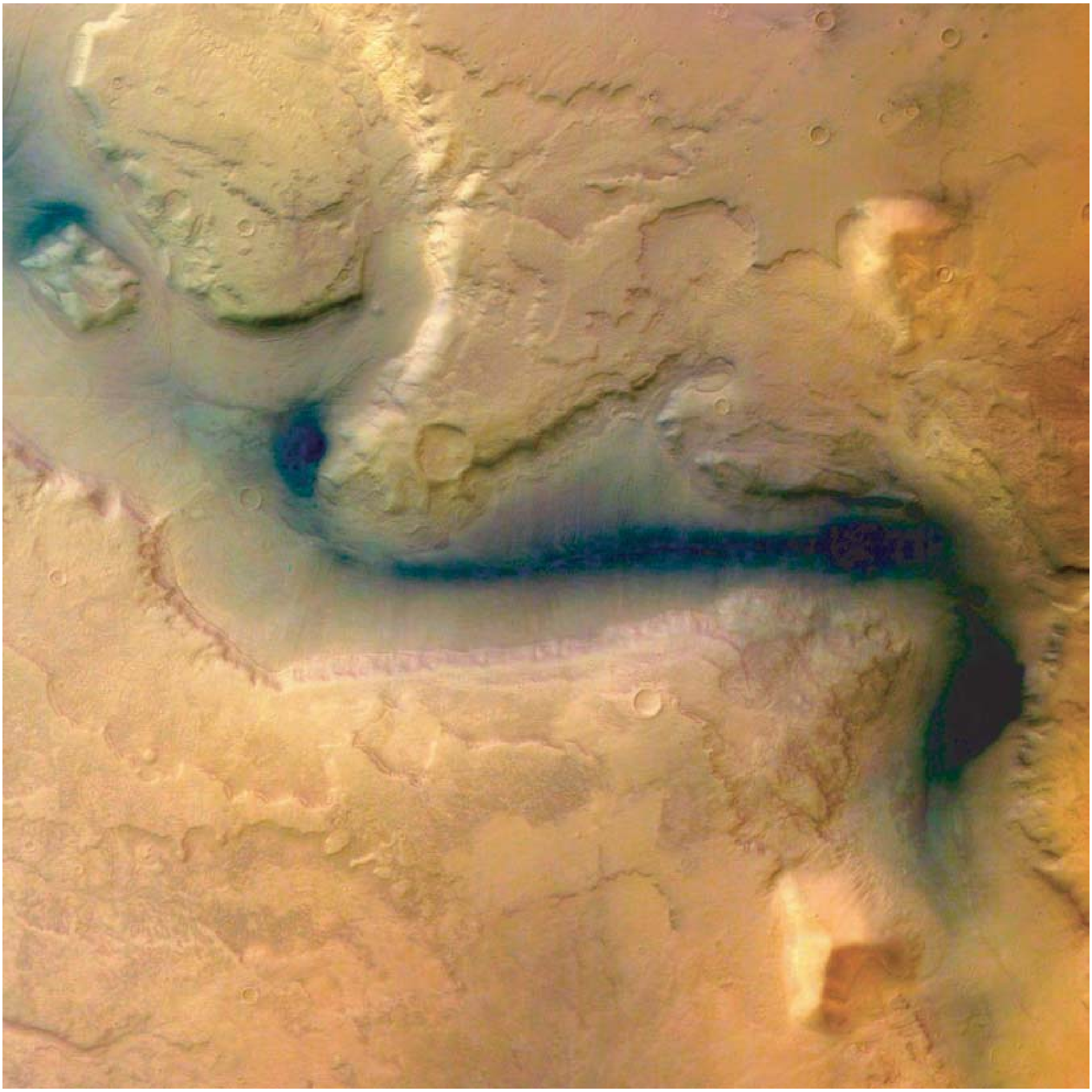

Fig. 1. Martian river valley. Part of the Reull Vallis, east of the Hellas Basin (41°S; 101°E) taken from a height of 273 km by the HRSC on Mars Express. The area is 100 km across, North is at the top. Image credit: ESA/DLR/FU Berlin (G. Neukum).

opportunity for deployment of the WatSen package is as part of the Instrumented Mole System (IMS) that is part of the proposed Geophysics and Environment Package (GEP) for the European Space Agency's (ESA's) ExoMars mission (currently scheduled for launch in 2011, but likely to be postponed until 2013).

Water on Mars: evidence from images

There is abundant evidence from satellite imagery that the surface of Mars has been shaped by the action of water: images from spacecraft orbiting Mars have shown networks of channels and other features that have been interpreted as having been produced by fluid flow. It is clear that many of the features have been caused by liquid, almost certainly liquid water. Some of the channels appear to be narrow and deep, whilst others are broader and flatter (Fig. 1). They exhibit all the features that are exhibited by rivers on Earth at different ages. Older rivers on Earth meander across flat plains producing features such as cut-off lakes and terraces, and these too can be seen on images from Mars. Features indicative of standing water (lakes, seas, etc.), flowing water (rivers, streams, etc.), flash floods (gullies) and continuous seepage have also been identified, showing that the Martian surface has experienced a complex history of aqueous alteration. Large-scale evidence for a frozen sea has also been published (Murray *et al.* 2005) where it is thought that ice below the surface covered with dust created the features. Ice has also played a role in modifying the landscape; ice-caps (of mainly CO_2 ice) at both north and south poles are still evident, and some of the broader, flatter surface channels might have been carved by glaciers. Indication of sub-surface ice has also come from results from the MARSIS radar instrument on Mars Express, which is currently using ground-penetrating radar to map the extent and depth of ice below Mars' surface; the instrument should also be able to detect any significant subsurface water reservoirs, should they exist (Picardi *et al.* 2005).

There is also local, small-scale evidence for water: cameras on the Mars Exploration Rovers (MER) Spirit and Opportunity have acquired images that show how water has affected the surface of Mars (Squyres *et al.* 2004). One of the first images seen of the Opportunity landing site at Meridiani Planum was of pale rocks standing out from the reddish sandy coloured horizon. A closer examination of the rocks showed them to contain small (sub-millimetre) spherules. These haematite-rich 'berries' weather out of the rock and are strewn across the surface. Comparison with terrestrial features described from the Utah desert suggests that the 'berries' are concretions that were formed by deposition from groundwater flowing through the host rock (Chan *et al.* 2004).

Water on Mars: evidence from spectroscopic analysis

Water alters the surface mineralogy: water-soluble salts are precipitated as evaporites (typically minerals such as anhydrite, gypsum and carbonates) and primary silicate minerals are hydrated and altered to clay minerals and hydroxides. Such secondary alteration products have been identified by thermal emission spectroscopy from orbit (Bandfield *et al.* 2003; Bibring *et al.* 2005). All the most recent missions to Mars have carried spectrometers capable of analysing the planet's surface at a variety of resolutions, and across a range of wavelengths, mainly from the near to mid-IR. The thermal emission spectrometer (TES) on NASA's Mars Global Surveyor (MGS) acquired data at 6–50 μm, at a surface resolution of 3 km. This instrument was the first to confirm the occurrence of wide deposits of haematite (iron oxide) on the surface of Mars, significant because this mineral is produced by water. In other words sedimentary rocks are present, implying bodies of standing water on Mars' surface (Lane *et al.* 2002; Chan *et al.* 2004). The same team that built the TES also built THEMIS, a thermal emission spectrometer on NASA's Odyssey orbiter. THEMIS mapped at higher spatial resolution than TES (at 100 m versus 3 km), taking data across 10 wavebands between 6–15 μm. One of the main discoveries of the THEMIS instrument was the finding of wide expanses of olivine-rich rocks exposed at the surface. Because olivine is a mineral that is rapidly broken down in the presence of water, the occurrence of olivine implies that the climate of Mars was drier (and probably colder) than previously envisaged (Hamilton & Christensen 2005). Spectral analyses of Mars' surface have also been acquired by the Gamma Ray Spectrometer (GRS) aboard Odyssey. Results from this instrument have been interpreted to suggest that water-ice is present within soils at the north pole, and water-bearing minerals occur near the equator. Also, currently in orbit around Mars is the ESA's Mars Express, carrying the OMEGA instrument. This operates in the near-IR, from 0.35 to 5.2 μm, at a variety of spatial resolutions from 350 m to 10 km. Results from OMEGA have allowed different generations of fluid alteration to be defined, implying three different alteration regimes, corresponding to separate eras of alteration, leading to a relative chronology for surficial processes on Mars (Bibring *et al.* 2006). The different eras ('phyllosian', 'theiikian' and 'siderikian') are characterized by clay minerals, sulphates and iron oxides, respectively, but do not correspond directly with the divisions (Noachian, Hesperian and Amazonian) defined in terms of crater counts (Hartmann & Neukum 2001).

Spectral analyses of Mars' surface have also been made at closer range (~1 m), from instruments on rovers. Direct measurements of the elemental composition of surface soils and rocks have been made by APX (alpha-proton X-ray) spectrometers on Pathfinder, Spirit and Opportunity. Each of the two MERs also has a mini-TES mounted on the camera mast (Christensen *et al.* 2004a, 2004b; Squyres *et al.* 2004). Results from the mini-TES suggest that some of the secondary products occur as maghaemite and jarosite, produced by hydrous alteration of bedrock (Christensen *et al.* 2004a, 2004b), results that were confirmed by Mössbauer spectroscopy (Christensen *et al.* 2004b; Klingelhöfer *et al.* 2004). Mössbauer spectroscopy is a valuable tool for mineralogical determinations because it is sensitive to the presence of iron (and can distinguish between Fe^{2+} and Fe^{3+}). However, Mössbauer spectroscopy is insensitive to the presence of iron-free minerals, such as calcite (calcium carbonate), epsomite (magnesium sulphate), etc., and neither can the technique detect water.

Water on Mars: evidence from meteorites

There are currently ~60 fragments from Mars, representing ~37 discrete samples removed from the planet's surface by impact. The rocks are all igneous, and the effects of water can be seen in some of the meteorites (Fig. 2), where two distinct types of alteration product can be found (Bridges & Grady 1999; Bridges *et al.* 2001). One alteration product is exemplified by 'iddingsite', a fine-grained mixture of the clay minerals smectite and illite, produced by the weathering along cracks within olivine grains. The second group of alteration products is of precipitated salts, including sulphates, chlorides and chemically and isotopically zoned carbonates (Bridges *et al.* 2001). The fact that the secondary minerals are

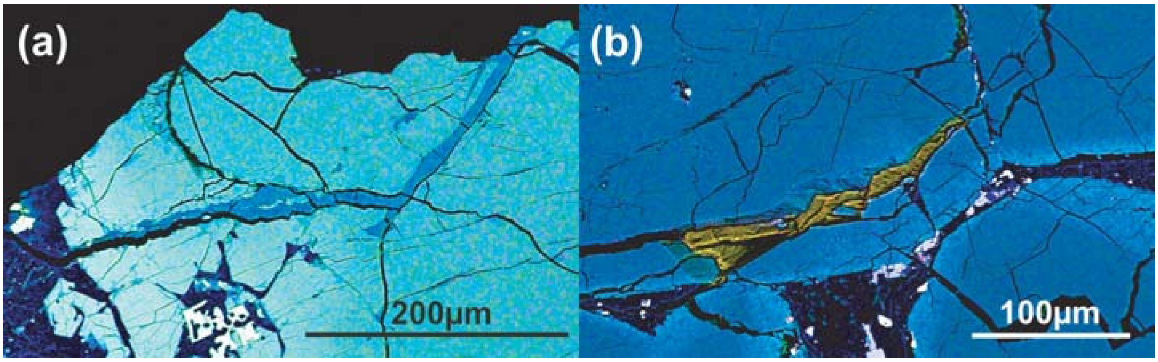

Fig. 2. False colour images of primary silicates in the MIL 03334 nakhlite, showing Martian weathering products: (a) a clay vein in an olivine grain, (b) sulphate vein in a clinopyroxene grain.

found in meteorites that were collected immediately following their observed fall implies that the meteorites were altered by weathering on Mars' surface. Associated with the secondary products are low concentrations of Martian organic material (Carr *et al*. 1985). It has thus been suggested that nakhlites might contain evidence for a Martian biosphere (Wright *et al*. 1989). Recognition of salt (halite) with carbonates and clay minerals in Martian meteorites has allowed interpretation of the scale and mode of fluid flow on the surface of Mars. The complex assemblages of secondary minerals shed light on the temperature and salinity of the water that flowed across Mars' surface: results from the nakhlites imply that when water was present on the surface, it was warm and briny (Bridges & Grady 2000). The zoned nature of some of the minerals tells us how fluid composition has changed, either in terms of temperature or in terms of the salts dissolved in the fluid. The restricted nature of some of the alteration assemblages also indicate the restricted nature of the fluid flow: perhaps fluid was confined to an evaporating basin that occasionally overflowed in episodes of flash flooding, rather than to a river or a stream.

WatSen: a water sensor for Mars

Despite all the above instances where the presence, or effects, of water have been recorded, there have been no direct determinations of water within Martian surface soils. There has not been any instrument yet deployed below (or at) the surface of Mars that is capable of determining directly whether or not water is present within the pore spaces or coating the mineral grains that make up the soil. It is also true that none of the instruments described above has burrowed below the surface and analysed unoxidized material.

Although there are many techniques that can be employed to detect water, there are special environmental conditions that come into play when attempting to detect water on Mars. First, the low ambient temperature and pressure causes water to undergo phase changes (solid–liquid–gas) at temperatures very different from the usual values followed on Earth (Fig. 3). The diurnal temperature cycle is sufficient to generate frost, but of CO_2 not water, and Mars' low atmospheric pressure precludes the present day occurrence of liquid water at the surface. The selected detection technique will have to be capable at operating under conditions far removed from the usual 273–373 K at 10^5 Pa. The detector must also be highly sensitive, and capable of detecting very low quantities of water against a high (relative) background of CO_2.

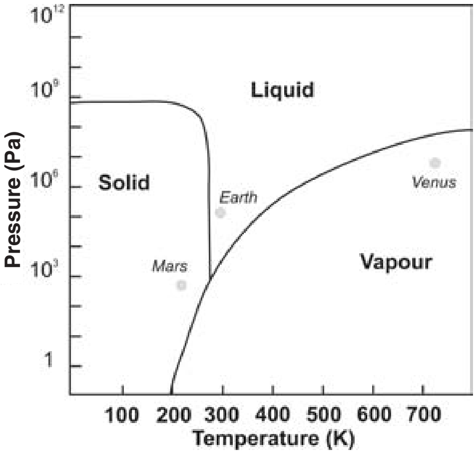

Fig. 3. Simplified phase diagram for water, showing the approximate temperature-pressure ranges pertinent to the surface of Mars, Earth and Venus.

One effective method for determining the presence, or absence of water, is IR spectroscopy. This technique utilizes energy changes during the stretching, bending and vibration of intra-molecular bonds. The WatSen instrument proposed here is an Attenuated Total Reflectance (ATR) sensor and humidity detector, and is a package that will record the presence of water within soils (the ATR sensor) and in the atmosphere (the humidity detector). The ATR sensor utilizes the effect that the reflectance properties of a mineral grain are altered when the grain is coated with a thin layer of water. As spectral reflectance features are almost always dependent on surface properties (flat or uneven, rough or smooth, etc.), the signal generated must be from a representative grain surface. This is best achieved by placing the sensor in direct contact with the surface of the grain; the most appropriate sensor type to achieve this measurement is an ATR sensor. Spectra of silicate minerals typical of Mars' surface are shown in Fig. 4.

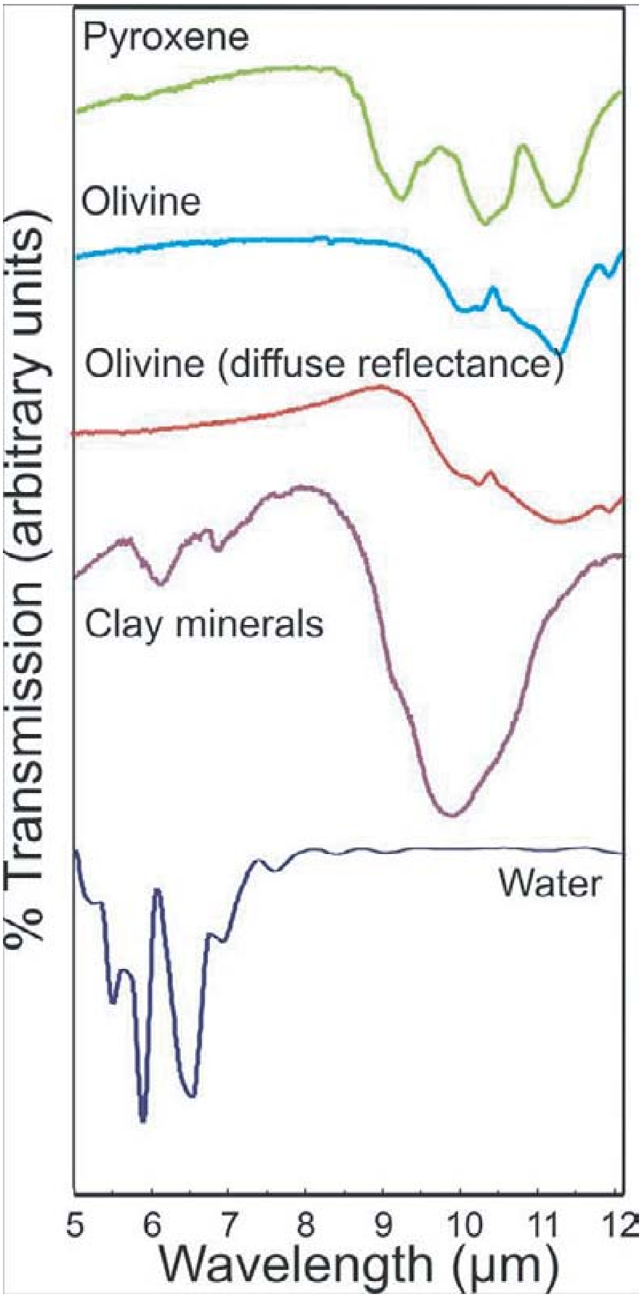

Fig. 4. IR spectra of minerals typical of Mars' surface, plus a spectrum of water. The spectra are offset from each other for ease of observation.

Water has an IR spectrum with features between 6–7 μm. Many rock-forming minerals are based on arrangements of SiO_4^{4-} tetrahedral in chains (single and multiple) and rings, with charge balance supplied by a variety of cations (Mg^{2+}, Fe^{2+}, Ca^{2+}, etc.). As a result of the vast array of possible arrangements of ions, silicate minerals are almost all IR active, and produce characteristic spectra that change systematically with major element composition. Major features in anhydrous silicate mineral spectra occur at longer wavelengths than in the water spectrum, at $\lambda > 9$ μm. In contrast, hydrated species, such as clay minerals, exhibit a combination of silicate plus water features. Organic species are also frequently IR active. IR spectroscopy is sensitive to variations in mineral composition, and to a lesser extent, temperature. The wavelength range of WatSen will be 5.5–11 μm, covering the spectral region of greatest interest at a resolution of better than 0.2 cm^{-1}. As Fig. 4 shows, there are readily observed differences in the IR spectra of major silicate groups that allow their identification. There are also more subtle differences that, given suitable calibration, allow mineral chemistry to be determined (Morlok *et al.* 2006a, c). Therefore, an IR spectrum can show not just that, for example, pyroxene is present, but that it contains x% Mg and y% Fe. This property will allow the WatSen package to address a variety of scientific questions. The combined water sensor and humidity detector will measure IR reflectance spectra of the surface and at depth, and in so doing will be able to identify whether and where water is present, identify which minerals are present and identify mineral chemistry. These measurements will not only enhance the science return of a Mars lander by providing mineral context for elemental data, but will also address directly the issue of whether micro-organisms are present within the Martian sub-surface.

The scientific objectives of WatSen

If WatSen is accepted as part of ExoMars, and becomes part of the GEP, carried on the mole as part of its suite of instruments, then the sensor will take data as the mole moves across the surface and then burrows to depths of 3–5 m. This will be the first time that measurements will have been made below the oxidized surface layer, and possibly below the zone of sublimation. The objectives of the package are as follows: (i) to detect water within Martian soil by measuring humidity and IR spectral characteristics of the substrate at surface and at depth; (ii) to determine the mineralogy and mineral chemistry of surface soils (this measurement will provide the mineralogical context for the elemental results that come from other instruments mounted on the landing platform); (iii) to determine how mineralogy changes with depth. Thus far, mineralogical composition has only been determined for surface materials, or, at best, at a depth of a few centimetres. The mole is designed to burrow to depths of up to 5 m, enabling measurements to be taken at regular intervals through the regolith, and possibly into bedrock. This will allow the depth at which water first appears to be determined, as well as the appearance (and disappearance) of salts produced by aqueous activity, and, potentially, the effects of biological activity to be observed.

The main goal of WatSen is to detect water within Martian soil. It is recognized that water will not be stable within the uppermost soil layers (the zone of sublimation): ambient pressure is such that liquid water would evaporate instantly and thin layers of ice sublime. Below the zone of sublimation (which is of unknown depth), depending on the porosity of the regolith, ice is likely to be stable, and possibly even water. The latter would exist not so much as a liquid, but within

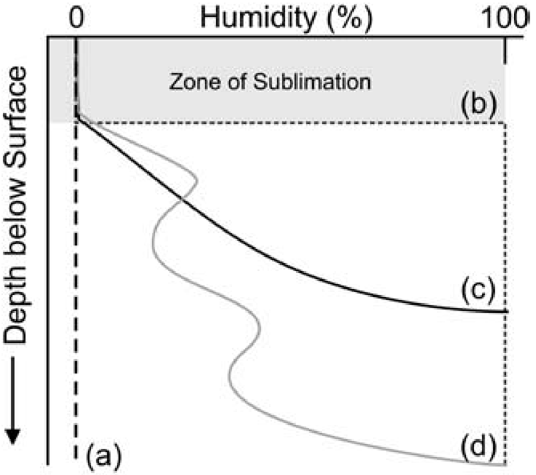

Fig. 5. Four possible scenarios for the variation of humidity with depth below the Martian surface: (a) the regolith is completely dry, (b) the regolith saturates below the sublimation zone, (c) a gradual increase in water content with depth, and (d) variable humidity. Interpretation of these curves in terms of stratigraphy is given in the text.

pore space gases with high humidity. It is not at all clear what predictions should be made concerning changes in humidity with depth. Fig. 5 indicates four possible scenarios: (a) there is no water; (b) there is a step-change from no water to saturation; (c) there is a gradual increase in water content until saturation; and (d) there is variable humidity. The difference between scenarios (c) and (d) will be related to the porosity of the regolith. In (c) there is a single rock type, perhaps with decreasing pore size (or increasing crystallinity), leading to a monotonic increase in relative humidity. In (d), humidity varies in a non-monotonic fashion with depth. This variation is again related to porosity, and is an extension of (c), as it might be the type of result expected if rock type changes several times during penetration of the regolith. It is clear that in order to interpret humidity data fully, a measure of the porosity of the substrate is required. This will come from permittivity data, acquired by the Heat Flow and Physical Processes Package (HP^3) that also sits within the instrumented mole.

The surface materials through which the mole will burrow should be representative of the rocks below, having been produced by mechanical weathering (freeze–thaw disaggregation, abrasion, saltation, etc.). This is a different situation from the generation of soil on Earth, which is almost always dominated by products of biological activity. Earth is not covered by a deep regolith resulting from millennia of mechanical weathering because its surface is in constant motion through plate tectonics, and is also chemically and biologically altered. We do not know how long a time interval a stratigraphic depth of 5 m will represent. Assuming the landing site is not a dune field (where only relatively recent dust layers would be sampled), there are several scenarios that should be considered. Of course the amount of information that can be extracted will depend on how tough the layers of substrate are, and how able the mole is to penetrate them. Potential sequences that might be encountered are shown in Fig. 6, and include soils derived from the following rock types: (a) a sequence of igneous rocks; (b) a sequence of sedimentary rocks deposited slowly from a basin of standing water; (c) a sequence of sedimentary rocks deposited rapidly from an evaporating basin; or (d) a sequence of intercalated igneous and sedimentary rocks. Note, these are not equivalent to the four humidity scenarios discussed above; relationships between the humidity and stratigraphic sequences will be drawn where appropriate.

We can look at the four stratigraphic scenarios in more detail. Sequence (a) is shown as a single igneous rock formation. There is a direct analogy for this in the nakhlite sub-group of Martian meteorites, which have been interpreted as coming from a thick sill or dyke (Lentz *et al.* 1999, Mikouchi *et al.* 2003, 2006). Differences in grain size and mineral composition reflect derivation from different depths within the rock pile, including sampling of the chilled margin at the edge of the intrusion. Silicate composition (both olivine and pyroxene) differ by approximately 40 mol% Mg from the inner to the outer edges of the cumulate pile (Mikouchi *et al.* 2003, 2006). This corresponds to a band shift of $\sim 0.2\ \mu$m for the main silicate features in olivine, and a similar magnitude in pyroxene (Morlok *et al.* 2006b, c). This wavelength shift is within the capabilities of the proposed detector, and so if the mole were to penetrate a weathered sill WatSen should be able to record the differences in primary anhydrous mineral composition that characterize depth within the igneous body. In terms of humidity, variation (c), above, is assumed to be the best representation of changes in water content with depth, as the degree of crystallinity of the igneous rock gradually increases with depth (assuming, that is, the mole does not penetrate through a top and bottom chill margin of a thin sill).

In scenario (b), rocks deposited from standing water would have an approximately constant composition, and show only limited variability. One might encounter carbonates or sulphates, depending on the pH of the fluid. Identification of the type of salt would, of course, lead to an inference about pH and salinity. A similar variation in humidity as that given for the single igneous body is likely to apply to a massive sedimentary formation. On the other hand, in scenario (c) sediments are deposited from an area of restricted flow, such as would be expected from a fluid evaporating from an enclosed basin. This would result in a variety of secondary minerals precipitated as the chemistry of the fluid changed. One would expect to see carbonates and halides in close proximity. Sequence (d) is a regolith derived from an era of sediment deposition with intermittent volcanic activity. The minerals seen would vary with depth, and exhibit a range from primary magmatic minerals to high abundances of secondary carbonates, sulphates and halides. Both scenarios (c) and (d) would probably matched to humidity scenario (d), where humidity changes with depth in a fashion indicating that rock type has changed several times during descent of the mole through the regolith.

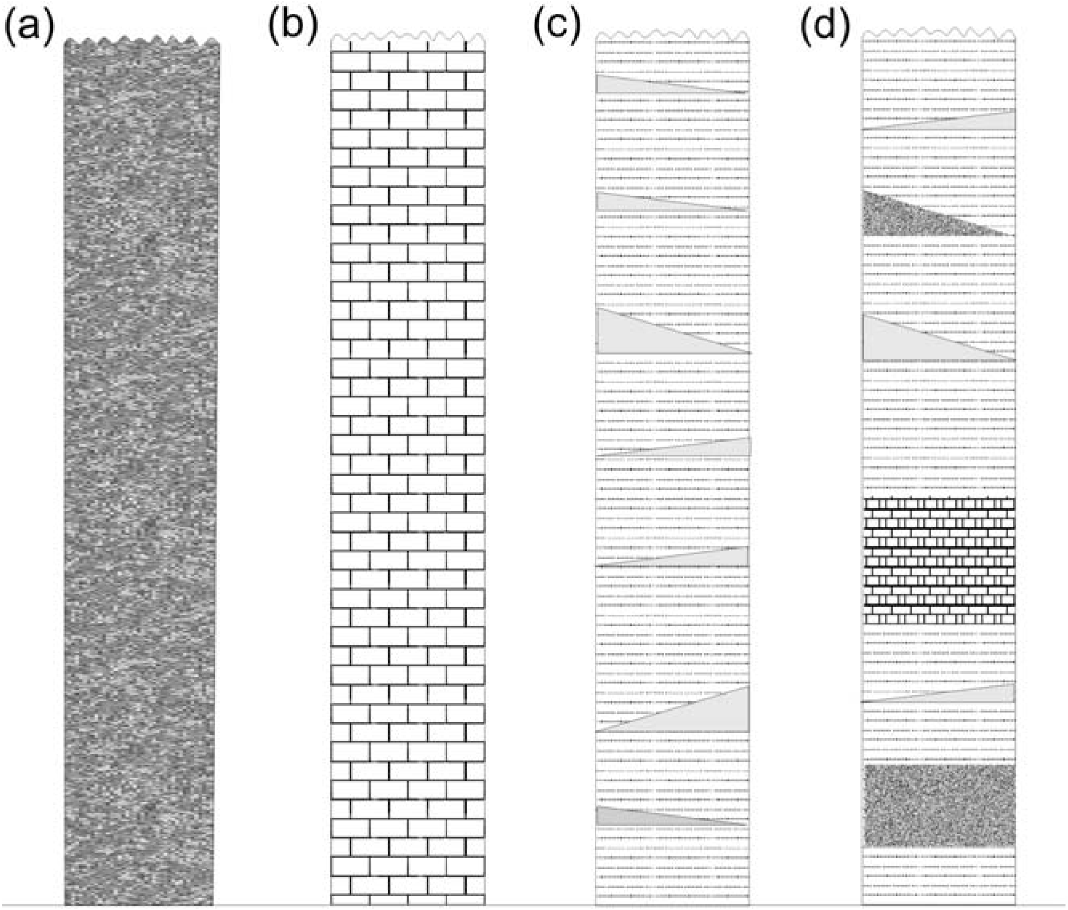

Fig. 6. Four possible stratigraphic sequences that might be encountered by the mole: (a) a single igneous body, (b) a massive sedimentary body deposited slowly from standing water, (c) a sequence of sedimentary rocks deposited from a rapidly evaporating basin, and (d) a sequence of igneous rocks intercalated with sedimentary rocks in a mixed sequence showing variable deposition conditions.

As WatSen is based on IR spectroscopy it will yield a mineral distribution profile with depth. Results will indicate whether magmatic silicates are present, to what depth and with what composition. Issues that will be questioned include identification of primary magmatic mineral assemblages: pyroxene + plagioclase ± olivine indicate basalt, whereas the presence of free quartz implies a more granitic (or processed) rock type. Perhaps more importantly than determining the composition of anhydrous magmatic silicates, as it relates directly to the aim of water detection, data from WatSen will show the presence (or absence) of secondary mineral assemblages produced by aqueous alteration. Haemetite and jarosite have already been identified at Mars' surface by instruments on the MER, and by spectrometers on orbiting satellites. Carbonates are widely predicted to occur because the main constituent of Mars' atmosphere is CO_2 and this dissolves readily in water, giving a solution from which carbonate can precipitate (Equation (1)). However, apart from in minor abundances in Martian meteorites (Bridges *et al.* 2001), and in dust (Bandfield *et al.* 2003), carbonates have not been observed in quantity at the Martian surface. Carbonate precipitation is highly dependent on the pH of the fluid in which CO_2 is dissolved. If the fluid is acidic, then the CO_3^{2-} anion remains in solution:

$$CO_2 + H_2O \rightarrow HCO_3^-(aq) \underset{pH>8.5}{\leftrightarrows} CO_3^{2-}(s) \qquad (1)$$

A slight increase in pH will tip the equilibrium such that carbonates are deposited. Detection, then, of carbonates by WatSen will lead to an understanding of the pH of the fluid present when the carbonates were deposited. This, in turn, is related to the composition of the atmosphere in equilibrium with the fluid, and fluid temperature. In other words, inferences can be drawn about the climate extant at the time of carbonate production.

Most of the foregoing discussion relates to the occurrence of calcium carbonate, which, on Earth, is a major indicator for climate variation. Carbonates identified so far in Martian meteorites, though, have not been calcite, but are more usually rich in iron and magnesium. On Earth, major deposits of sideritic carbonates are not common in the modern geological record, mainly because under normal oxidizing conditions iron is preferentially sequestered into silicates and oxides as Fe^{3+}. Siderite forms when more reducing conditions occur (for example, in restricted basins), and were more prevalent prior to the oxygenation of the Earth's atmosphere *circa* 2.2 Gyr ago. The occurrence of siderite in Precambrian deposits has been taken as a measure of the CO_2 content of the terrestrial palaeoatmosphere (Ohmoto *et al.* 2004). It is anticipated that similar inferences will be drawn from the analyses of the Martian regolith.

Mineral sequences will be related to the most recent description of different alteration eras on Mars, as indicated by the presence of sulphates, oxides and clay minerals (Bibring *et al.* 2006). Once the landing site for ExoMars has been selected, it will be characterized using data from orbiting spacecraft. On that basis, one will then be aware into which of the alteration 'epochs' the landing site falls. Using WatSen to carry out IR reflectance spectroscopy 'on the ground', we will be able to characterize and refine in greater detail the broad-brush mineralogy determined by OMEGA.

Prospecting for life

Sandstones from the Dry Valleys of Antarctica have been used as a terrestrial analogue for surface deposits on Mars. The fact that a considerable biomass exists in the surface layers of these rocks was a surprise when micro-organisms were first discovered there. However, we now know a lot more about extremophiles, and can understand the survival strategies of the assemblages. Evidence of biological activity might be observable and measurable if, for example, micro-organisms alter the surface and sub-surface layers of the regolith in the way that cryptoendoliths alter the surface layers of rocks on Earth (Blackhurst *et al.* 2004). It has been observed that, as a by-product of cryptoendolith activity, there seems to be a decrease in porosity of the host rock, presumably as pore spaces become filled with a combination of biomass and secondary alteration minerals (Blackhurst *et al.* 2005). As the mole burrows through the regolith, one of the instruments it will carry, HP^3, will be measuring the permittivity of the substrate. Along with a measure of humidity, this is related to the porosity of the medium. A coupled observation of decreasing porosity with changes in major element composition (mineral chemistry), as determined by IR spectroscopy, could indicate biological activity, especially if associated with the presence of organic materials. At depth, this would presumably be an extinct (or fossil) species, but in layers close to (less than 1 cm or so from) the surface, might indicate more recent (even current?) biological activity.

Summary

There is plenty of evidence for fluid on Mars: large-scale (planet-wide) features have been captured over four decades by a procession of orbiting satellites equipped with cameras with increasingly higher spatial resolution. Imagery of the surface shows channels, valleys, ice-caps, etc. Small-scale, more local evidence for fluid has come from images obtained by rovers on the Martian surface. Images that water produced many of the features are supported by spectroscopic measurements (again both planet-wide and local) over a range of wavelengths, which show the presence of minerals generally only produced in the presence of water (haemetite, jarosite, etc.). Results from meteorites continue this picture of fluid activity taking place over significant periods of Mars' history. Despite all these indicators of water, direct detection of water has never been made. We have reviewed the evidence for water on Mars' surface, and have described WatSen, a combined humidity sensor and IR detector, that can be employed to search for water at and below Mars' surface. WatSen is designed to be part of the suite of instruments on the mole that will be deployed as part of the GEP on ExoMars. The utility of WatSen is that it will not only detect the presence of water, but will also be able to record which minerals are present and their chemistry; it is also sensitive to many organic species. WatSen is a new instrument concept specifically designed to search for clues of the presence of water, and to look for evidence of life on Mars.

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