RATIONALE FOR THE DEPLOYMENT OF A MAGNETIC GRADIOMETER ON MARS. E. I. Alves[1] and V. M. C. Madeira[2], [1]Centre for Geophysics, Univ. Coimbra, Av. Dr. Dias da Silva, 3000-134 Coimbra, Portugal (e.ivo.alves@netc.pt), [2]Department of Biochemistry, Univ. Coimbra (vmcm@ci.uc.pt).

Introduction: In this paper we intend to show how a classic geophysical exploration tool on Earth – magnetic gradiometry – can, if deployed on the surface of Mars, increase our knowledge of the planet's life sustainability. As important by-products, a geomagnetic gradients traverse could help us select a landing site for the first human explorers and also increase our knowledge of the geology and geological evolution of Mars.

Conditions for the Development and Sustainability of Life: The most restrictive conditions are the presence of liquid water, the availability of energy sources and protection from radiation.

Liquid water: Liquid water is mandatory for the existence of life as we know it. If liquid water is absent, we can forget about the existence of life on Mars in the present. Other important condition is a suitable range of temperature and temperature stability. The proposed range is based in the knowledge of earth life, i. e. from 0 to *ca*. 100 ˚C. Whatever the temperature, water must be liquid. Obviously, the pressure range is very important since it conditions the state of water together with temperature. Therefore, the search for Martian present life requires a very complete information on the space- and time-distribution of atmospheric temperature and pressure. The crustal surficial thermal and baric gradients must also be more fully understood and modelled.

Energy: Another requirement for life is the availability of energy. Visible light can not operate as an energy source in "buried" domains, as it operates photosynthesis on Earth. Nevertheless, there are photosynthetic centers energized by the near infrared of *ca*. 1000 nm that are collected by special bacteriochlorophyls. Suitable modifications of the porphyrin may result in an effective collection of far infrared photons extending to 1000 cm^{-1} (10000 nm) [1]. This warm radiation may penetrate deeper and reach microdomains where living communities might settle.

Although visible light is the major form of energy that supports life on Earth, "energetic" inorganics also support restricted living communities in the vicinity of marine hydrothermal vents (black smokers). The most important chemical is H_2S, efficiently oxidized by chemolithotrophs to yield useful energy for life and biomass accumulation. The chained organisms in the community are subsidiaries of the lithotrophic primary producers. Other communities living at considerable depths (mines) depend energetically on H_2S biochemistry.

Less expressive lithotrophism depends on the use of H_2 in methanogenic organisms which generate methane by reduction of CO_2. Still other microorganisms process lithotrophic biochemistry through the oxidation of pyrites (lixiviation to ferrous or ferric sulphate), but have little expression in terms of life support on Earth [2]. Nevertheless, these can not be excluded as possible forms of life on Mars.

Protection from Radiation: If conditions for the availability of liquid water and energy are found on Mars, one of the main foreseeable hazards to the possible life-forms are cosmic rays and solar wind radiations.

These radiations are extremely harmful to every known form of life. Biomolecules, particularly polymers and macromolecules, are rapidly destroyed by energetic radiations. Generation of radicals is very likely to occur. In most cases, radicals undergo chain reactions turning into cyclic autocatalysis and autoamplification. This is a major issue of the effects of radicals towards biomolecules and living structures [3].

Although the presence of regional magnetic fields is putatively required to allow life activity, it is not absolutely mandatory. The magnetic field(s) may be present in the organisms themselves, similarly to what is found in magnetotactic bacteria [4] which contain inclusions, called magnetosomes, arranged in rows along the cell to generate magnetic field(s) at the microscopic scale, not easily detected by magnetometers. These organisms on Earth are *ca*. 2 μm in length, the limit of the optical microscope. Therefore, search for magnetic organisms in Mars samples, if not strictly impossible, looks a rather difficult task, unless a more powerful microscope (electron?) would be available.

On Earth, magnetotactic bacteria are very scarce. It is our planetary permanent dipolar magnetic field that protects Earth's surface, and life as a whole, from radiations of cosmic and solar origin.

How can we conjugate these three factors – availability of liquid water and energy and presence of magnetic fields – into a strategy to find evidence of life on Mars? Furthermore, if it happens that we do not find life on Mars, does our strategy provide us with information that is useful in other Martian research areas?

Water on Mars: There are plenty of evidences of the presence of liquid water on Mars in the past [5, 6], evidences that are morphological, geochemical and geophysical. The presence of liquid water in the pre-

sent is much more difficult to stipulate, although there are recent indications of water induced processes as recent as less than three years old [7].

The first attempt of a global mapping of the distribution of water in the Martian soils was a consequence of data acquired by the gamma ray spectrometer (GRS) instrument suite onboard the 2001 Mars Odyssey spacecraft, in particular by the neutron spectrometer [8, 9, 10].

Figure 1 (adapted from [8]) shows the epythermal neutron count (roughly inversely proportional to the hydrogen content) that was obtained by the GRS neutron spectrometer.

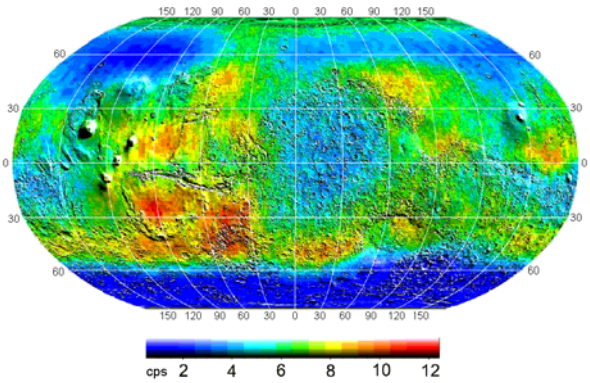

Figure 1 – Epithermal neutron flux (counts per second). Adapted from [8].

The present pressure-temperature conditions on the surface of Mars indicate that most of the charted water must be either solid, as a subsurface permafrost, or incorporated in mineral chrystalline structures. It is possible, however, that some water may sometimes be in the liquid phase [11], thus available for biochemical processes.

The Martian Magnetic Field: Mars does not possess a dipolar field such as the one on Earth.

However, recent data from the Mag-ER instrument onboard the Mars Global Surveyor orbiter has shown large regions of magnetic anomalies, mainly on the southern highlands, many located on possible water-bearing areas.

The magnetic anomalies are interpreted as resulting of rock remanent magnetisation, being palimpsests of a time (Noachian) when Mars had an internal dynamo [12,13] and possibly even global tectonics – which is suggested by the parallelism and symmetry of the anomalies, not unlike what can be seen on terrestrial ocean floors and continental rifts.

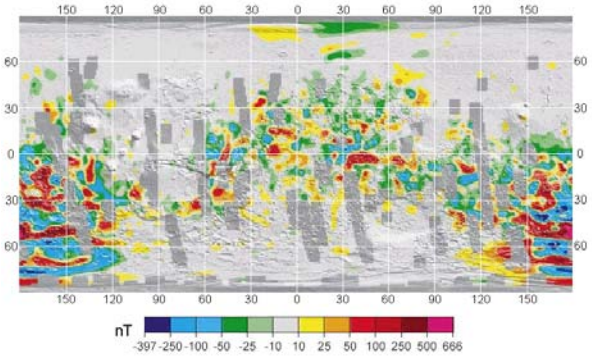

Figure 2 – Magnetic anomalies, normalised to 200 km altitude. Adapted from [12].

Figure 2 (adapted from [12]) shows a map of the magnetic anomalies that were measured by the Mag-ER instrument, normalized to an altitude of 200 km.

"Exobiologically Interesting" Areas: A comparison of figures 1 and 2 allows us to locate the broad areas where the largest water contents are expected in the soils and, simultaneously, the strongest magnetic anomalies are found.

The most important areas are two, represented on figure 3:

A – between Arabia Terra and Terra Sabaea;

B – between Terra Cimeria and Terra Sirenum.

Being within ±30º of the Martian equator, these areas are also likely to have the highest diurnal temperatures, hence increasing the probability of liquid water, even if sporadic.

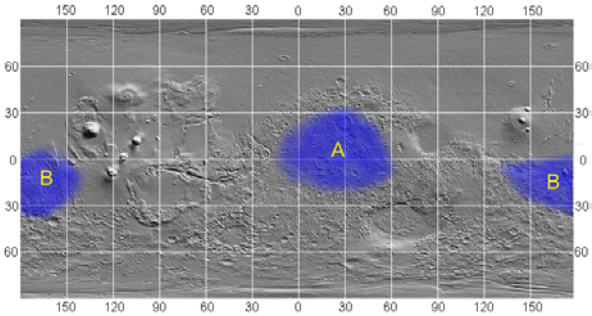

Figure 3 – Areas where there are good odds of finding saturated soils that are protected from solar wind radiation by the remanent magnetic fields. Topographic base: [14]

The European Space Agency (ESA) ExoMars Mission: These "exobiologically interesting areas" are among the most likely landing sites for a long-ranged Rover, such as the one that is being considered for the ESA ExoMars mission, part of the Aurora Project.

ExoMars mission objectives are "to search for signs of past and present life on Mars" and "to identify possible surface hazards to humans" [15].

The present mission constraints include landing at an altitude less than 2000 metres above the planetary datum, at latitudes between +10º and +45º or –10º and –45º. The rover is expected to perform a traverse 30 to 50 km long, periodically sampling atmosphere, soil and rock for evidence of existing, extant or past life.

The Pasteur scientific payload on the ExoMars Rover already has some of the instruments defined:

1. Multispectral, panoramic stereoscopic camera;
2. Subsurface electromagnetic sounder;
3. Drill for acquiring samples to a maximum depth of 2 m;
4. Sample preparation and handling system;
5. Optical colour microscope;
6. Raman spectrometer and laser-induced breakdown spectrometer;
7. Combined gas chromatographer/mass spectrometer.

The final composition of the scientific payload is still open.

Rationale for Surface Magnetometry: It has been suggested [16] that Martian local magnetic fields would be strong enough to offer protection from radiation to living organisms – which may including future human explorers.

Should it be proven true that local remanent magnetisations can protect living organisms from incoming radiations, this would have two main consequences:

1. The places with strong magnetic anomalies are those where it would be most likely to find present life on Mars, given other conditions, such as the, even episodical, presence of liquid water.
2. The kind of radiation shielding that will be necessary for a human mission landing on one of those sites would be much less demanding than on an unprotected site.

These are, however, educated conjectures, since Mag-ER data were obtained from high-altitude flight and are of very poor resolution – no one actually knows the nature, the ground configuration or the extension of the anomaly sources.

From a biological point of view, there is a great difference in survival opportunities with the size of the anomaly source. One large coherently magnetised body might offer one large niche for life to strive on; a region that, from 200 km altitude, seems coherently magnetised but is, in fact, composed of several small bodies with incoherent magnetisation, might not offer such a niche or, for that matter, a safe place for human landing.

The only way to resolve these indeterminations would be to perform a magnetic traverse on Martian ground.

Rationale for a Magnetic Gradiometer: The system we foresee is composed of two triaxial fluxgate magnetometers, located at two different heights on the rover, spaced at least 1 metre. For the ExoMars rover, this would mean one sensor in, or above, the camera boom and the other one beneath, or under, the rover chassis.

This arrangement will allow to perform a magnetic traverse along the rover's path yielding six vectorial data at each station plus, after processing, a set of vertical and horizontal magnetic gradients.

Each data acquisition would take only a few seconds, consume very little power and produce less than 1 kbit of data.

From a strictly theoretical point of view, one single magnetometer would be enough to fully characterise the local fields, overcoming the intrinsic difficulty in downward continuation of orbital data [17]. However, the gradiometer configuration has at least four advantages, which explain its widespread use in magnetic exploration on Earth [18]:

1. The gradients filter the diurnal variations of the field, as well as sporadic pulses;
2. They also yield directly the filtered residuals, free from possible regional trends;
3. Gradiometry enhances instrument sensitivity, dividing each individual instrument's sensitivity by the distance between sensors.
4. This configuration enables us to better estimate the depth of the anomaly source.

Gradiometry also adds a security factor: one problem with magnetic measures can be sensor contamination - the deposition of magnetic wind-borne particles on the sensor casing. With two sensors on different locations, the odds of having at least one clean sensor are increased.

Gradiometer data would complement other instrumental data.

Other fixed stations on Mars – such as the Netlander network [19] – would provide magnetic field background and time variations information.

Earth-based magnetic observatories, such as our own at the Geophysical Institute of the University of Coimbra, would provide an accurate monitoring of magnetic storms and substorms that could be extrapolated to Martian conditions.

Electromagnetic sounding, though an active technique, can be hindered in conditions of large background noise. Such noise could be extracted from gradiometer data and filtered.

It is foreseeable that ExoMars will carry a dedicated radiation counter. The results from this instrument, together with gradiometer data, will answer the

critical question if local magnetic fields do protect from radiation.

Conclusions: We are sure that a surface magnetic gradiometer mounted on a long-ranged rover can be a decisive asset to a future mission that aims to characterise the life potential of Mars.

Even if evidence for present, extant or extinct life is not found, gradiometer data will be very important for the understanding of Martian geology and geological evolution. Also, the characterisation of local magnetic fields may help define the landing site for a future manned mission to Mars.

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