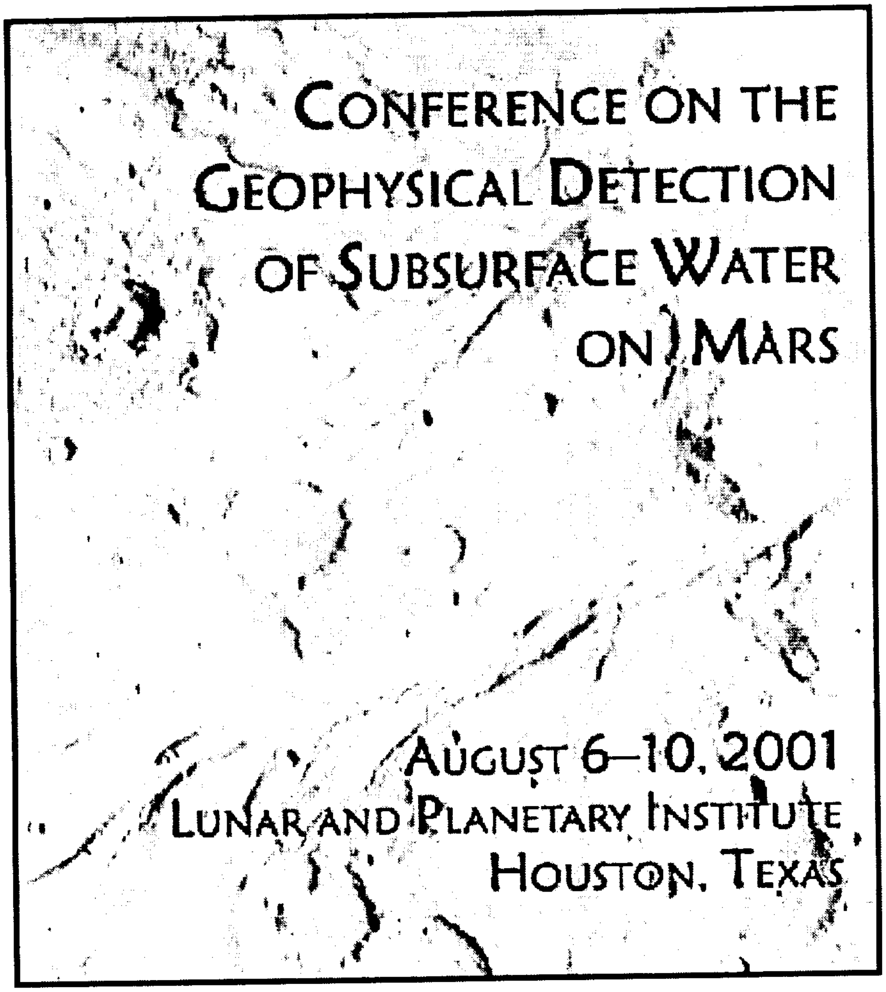

Abstract Volume

LPI

LPI Contribution No. 1095

Conference on the Geophysical Detection of Subsurface Water on Mars

Lunar and Planetary Institute
Houston, Texas
August 6–10, 2001

Conveners

Stephen Clifford, Lunar and Planetary Institute
Jeffrey George, NASA Johnson Space Center
Carol Stoker, NASA Ames Research Center

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This volume may be cited as

Author A. B. (2001) Title of abstract. In *Conference on the Geophysical Detection of Subsurface Water on Mars*, p. xx. LPI Contribution No. 1095, Lunar and Planetary Institute, Houston.

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Preface

This volume contains abstracts that have been accepted for presentation at the Conference on the Geophysical Detection of Subsurface Water on Mars, August 6–10, 2001. The Scientific Organizing Committee consisted of Bruce Banerdt *(Jet Propulsion Laboratory),* David Beatty *(Jet Propulsion Laboratory),* James Blacic *(Los Alamos National Laboratory),* Geoffrey Briggs *(NASA Ames Research Center),* Michael Carr *(U.S. Geological Survey, Menlo Park),* Angioletta Coradini *(Institute d'Astrophysique Spatiale),* Francois Costard *(Université de Paris),* James Cutts *(Jet Propulsion Laboratory),* James Garvin *(NASA Headquarters),* John Grant *(National Air and Space Museum),* Ronald Greeley *(Arizona State University),* Robert Grimm *(Blackhawk Geometrics),* Walter Kiefer *(Lunar and Planetary Institute),* Philippe Lognonné *(Institut de Physique du Globe de Paris),* Humboldt Mandell *(NASA Johnson Space Center),* Gary Olhoeft *(Colorado School of Mines),* Roger Phillips *(Washington University),* Jeffrey Plaut *(Jet Propulsion Laboratory),* and Larry Soderblom *(U.S. Geological Survey, Flagstaff).*

Logistics, administrative, and publications support were provided by the Publications and Program Services Department of the Lunar and Planetary Institute.

Contents

Regional Imaging of the Subsurface of Mars Using Teleseismic Events, Claudia M. Aprea, Douglas M. Alde, and James T. Rutledge, Los Alamos Seismic Research Center & EES-11, MS-D443, Los Alamos National Laboratory, Los Alamos, NM 87545

Introduction

We present a plausible method to map the subsurface structure of Mars using distant events (such as teleseismic marsquakes or distant meteor impacts) and a sparse distribution of recording stations. The goal is to obtain a computed reflectivity image of a localized region of Mars, a 3-D map of the locations of impedance changes within the crust and upper mantle. We have tested this method in the mapping of the crustal structure beneath the Jemez Volcanic Field in northern New Mexico quite successfully. The image was obtained by applying a novel adaptation of the Kirchhoff wavefield imaging method to digitally recorded teleseismic data. It could be also valuable for mapping the Mars subsurface as it is not very sensitive to station distribution and origin of sources.

Kirchhoff migration

The Kirchhoff migration method has been widely used to obtain high-resolution images of the shallow Earth's crust for petroleum exploration. It has recently been applied for basic research studies of deeper Earth structure [1][2]. Kirchhoff migration has also proven useful in the study of crustal scatterers near small-aperture arrays [3] and characterization of lower mantle heterogeneities [4]. We developed and used a modification of the classic Kirchhoff migration geometry to map the crustal structure beneath the Jemez Volcanic field quite successfully using teleseismic data (distant earthquakes) as sources.

In conventional migration applications, a source is initiated on or near the Earth's surface and the resulting seismic field propagates into the Earth. Velocity and density contrasts scatter portions of the wavefield back towards the surface where it is recorded by an array of receivers (Figure 1a). The field recorded at the surface can be extrapolated back into the interior of the Earth using one of various forms of the wave equation. This extrapolation requires an a-priori model for the Earth's velocities and density. Our modified version uses distant events as sources, and unlike the typical seismic exploration, the characteristics of the sources are unknown. However, the following assumptions can be made: the initial arrival is the direct path compressional wave. Plane-wavefronts from the source arrive at the base of the region being imaged as in the case of teleseismic travel time tomography [5], and the incident wavefront direction vector of the source pulse is nearly vertical near the Earth's surface. This implies the energy associated with the P (compressional) wave mode dominates the vertical component of motion. In order to separate the forward-scattered P-waves from the direct arrival the geometry of our imaging approach differs from the conventional (Figure 1b). We image using waves that are reflected first from the free surface, and after propagate down to a scattering location, where it is scattered back towards the surface where it is recorded.

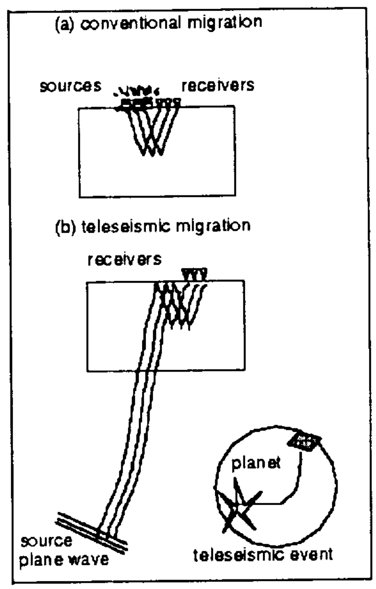

Figure 1

Because high frequency wavefields can be well described by the asymptotic ray theory we need only the determination of the ray amplitudes and ray travel times, which are done by ray tracing on an initial velocity model. This model can be constructed from geophysical/geological information available and can be improved on through the process of migration, though sometimes this is not required as Kirchhoff migration has been shown to be robust in terms of the initial model, particularly in regions of only mildly heterogenous velocity stucture. The number and distribution of stations are important for the spatial resolution of the result, but they do not need to be uniformly distributed. The key is to work with a sufficiently large number of events to obtain a statistically robust image. The spatial resolution of the image is a function of both the station spacing and the frequency content of the data.

Each event (or group of events) will produce an independent reflectivity image. These images are then stacked together, in a well defined way, to produce an

IMAGING THE SUBSURFACE OF MARS, Claudia Maria Aprea, Douglas M. Alde, and James T. Rutledge

average image. Finally, the result is tested statistically to assure us the procedure is correct.

Case study - Jemez volcanic field, NM

An example of the application of this method is the computation of a reflectivity image for the Earth beneath the Jemez volcanic field in northern New Mexico. The Jemez volcanic field (JVF), located at the intersection of the Jemez lineament and the western boundary of the Rio Grande Rift, is the home of one of the most famous giant resurgent calderas, and perhaps one of the most studied volcanic systems in the world. Volcanism in the JVF began as early as 16.5 Ma and continued in different ways and time spans until the most recent eruption occurred, at ~50 ka. Geology of the area has been extensively studied. The data come from the multidisciplinary Jemez Tomography Experiment (JTEX). It comprised both active and passive seismology, geology, gravity and electromagnetic data collection efforts conducted from 1993 to 1995 attempting to improve our geophysical knowledge of the region [6]. The active and passive seismic experiments, with different degrees of resolution, resulted in a three dimensional P velocity model and helped elucidate the heterogeneous structure of the JVF [7][8][9][10].

The resulting migrated 3-D image along with station locations (triangles) is shown in Figure 2. The figure shows zones of strong intensity with different polarity (cold colors and warm colors) distributed over a zero intensity background (green). The high-amplitude areas in the images indicate boundaries between media of different impedances. Significant features seen in the image include the base of the caldera fill; several reflectors in the crust associated with residuals coming from the mantle and or other crystallized chambers such as the chamber seen in tomographic images as a low velocity zone; two strong reflectors coincident with the crust-mantle interface, and a zone of layered reflections from the base of the crust consistent with basaltic underplating.

Conclusions

This adaptation of the conventional Kirchhoff migration algorithm appears to be a good candidate for future exploration of Mars' structure. Some of the benefits this method presents are:

- An artificial seismic source is not required; regional crustal images could be derived passively using Martian teleseisms [11][12] or possibly distant meteor impacts [13];
- Little detailed information is required of the source characteristics;
- Although the spatial resolution of the image does depend on number and the distribution of stations, an acceptable image can be obtained from a reasonably uniform, but not necessarily regularly spaced, seismic array on the Mars surface.

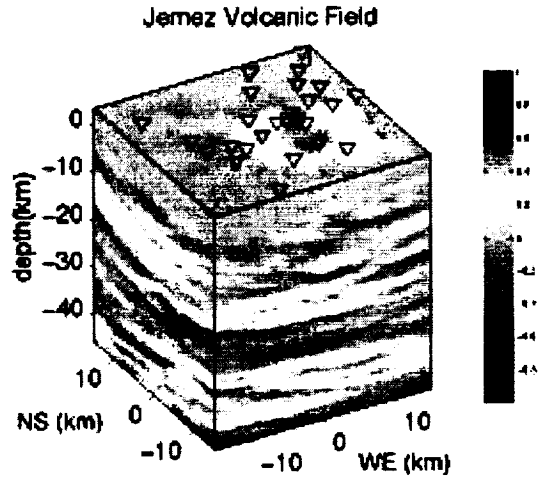

Figure 2

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A Miniaturized Seismometer For Subsurface Probing On Mars. W. B. Banerdt and W. T. Pike, M.S. 183-501, Jet Propulsion Laboratory, Pasadena, CA 91109, bruce.banerdt@jpl.nasa.gov.

Introduction: Seismology is one of the most powerful tools for investigating the subsurface structure of a planet. The mechanical structure information derived from seismic measurements is complementary to other methods of probing the subsurface (such as gravity and electromagnetics), both in terms of spatial and depth resolution and the relevant types of material properties being sensed. In the near-surface, the propagation of seismic waves is especially sensitive to density and degree of compaction. In addition, interfaces between layer with contrasting properties can be relatively easily delineated.

The subsurface of Mars provides an obvious target for seismic investigations. Searching for the presence of water is among the highest priority goals of the Mars Exploration Program, but there are many other important science questions that could be addressed by a seismic profile of the upper layers of the crust.

We have developed an extremely small, lightweight, low-power seismometer for planetary applications [see 1-4] which is ideally suited for use on Mars. This instrument has previously been proposed and selected for use on a comet (on the Rosetta Lander [2], subsequently deselected for programmatic reasons) and Mars (on the NetLander mission [4], with an emphasis on global structure determination).

Seismometer Description: The seismometer, which is being developed by the Microdevices Laboratory of JPL, is designed to meet the constraints of extraterrestrial applications, in particular having very low mass, volume and power requirements (~200 gm, 2x2x3 cm, and 100 mW, respectively, for a 3-axis sensor), while delivering performance comparable to that of a conventional terrestrial seismometer (5×10^{-9} m/sec^2/$\sqrt{\text{Hz}}$ over a 0.05 to 100-Hz bandwidth). The design uses a micromachined mechanical structure consisting of the suspension mechanism, proof mass and capacitor plates, and a highly sensitive capacitive displacement transducer that employs a force-rebalance feedback system. The current design has been optimized for relatively low frequencies and continuous operation in order to study ambient seismic activity on the NetLander mission. For a active seismic experiment a higher frequency band would be used, with a higher sampling rate, lower mass, and less concern about power (due to the short duty cycle).
The suspension is of a symmetric design, incorporating three wafers bonded together (Fig. 1). The central wafer incorporates a set of flexures allowing motion of the proof mass in the plane of the wafer (Fig. 2). The flexure geometry is designed to maximize the robustness of the suspension; end-stops prevent any motion induced by accelerations greater than about 1 g. The proof mass is free to move under gravity (≤ Earth gravity) to an equilibrium position. Capping wafers carry the metallized fixed electrodes. The displacement signal and feedback actuation result from the changing overlap between electrodes on the fixed plates and the patterned surface of the silicon proof mass. The use of a lateral detection scheme reduces damping effects and hence the fundamental noise floor by two orders of magnitude compared to the more conventional parallel opposed-plate approach.

The small volume available for the microseismometers limits the resonant frequency of the suspension to 10 Hz. This relatively stiff suspension requires a correspondingly sensitive position transducer to measure the deflection of the proof mass. A low-noise switched-capacitance transducer determines the lateral movement between the moving proof mass and fixed electrodes above and below the proof mass to a precision of about 10^{-14}m. The seismic signal from each axis is anti-alias filtered before being digitized with a multiplexed 16-bit analog-digital converter.

The low mass and volume of this device is well-suited for use in seismic arrays that are necessary for active seismic profiling. This, along with the high intrinsic sensitivity of the instrument and the expected low-noise environment on Mars, should allow greater depths of penetration than on the Earth for conventional seismic profiling.

This device provides a high-quality seismic measurement which should be capable of elucidating many of the fundamental questions concerning the subsurface of Mars.

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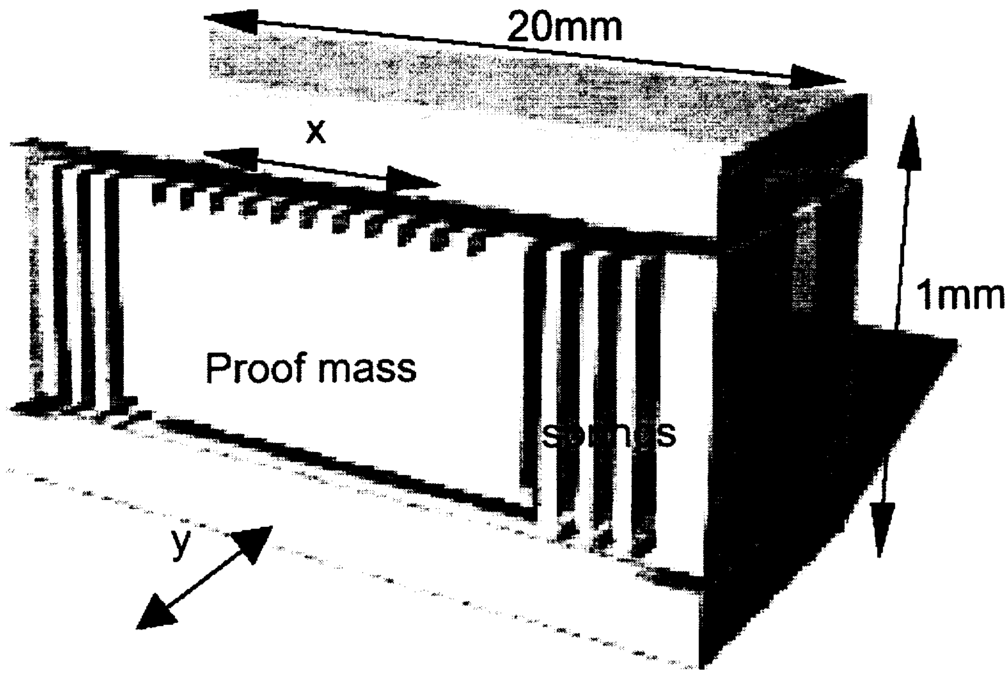

Fig.1: Cutaway drawing showing the geometry of the sensor.

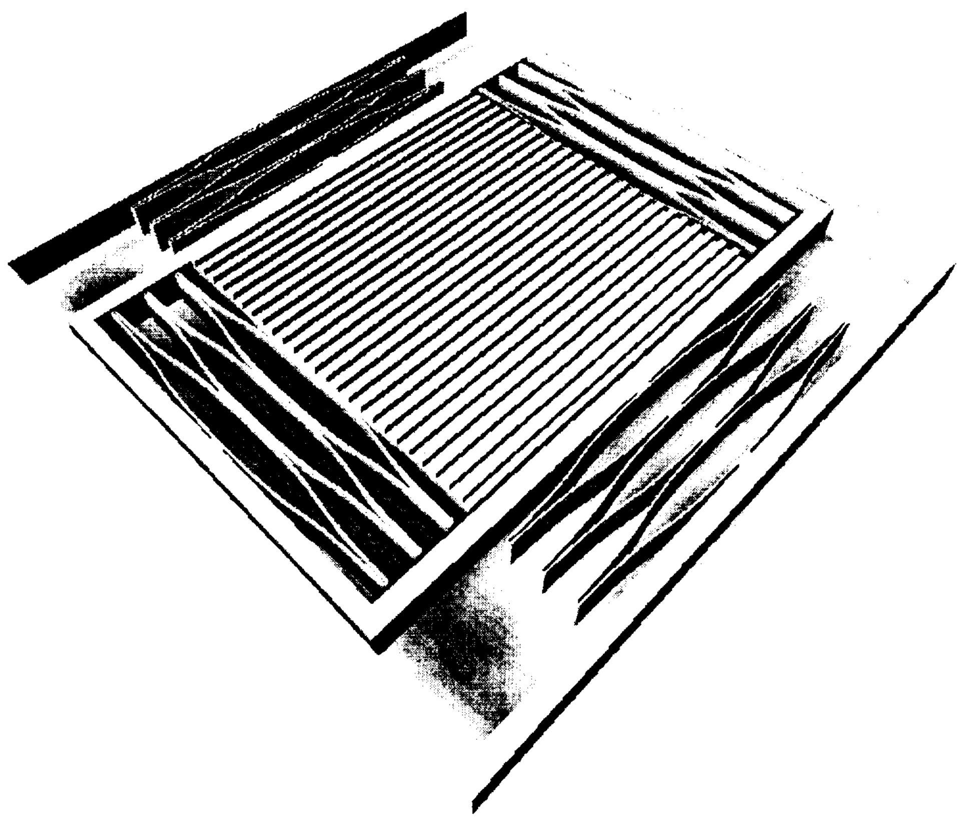

Fig.2: Central wafer, comprising proof mass and suspension.

IMPACT CRATERS AS INDICATORS OF SUBSURFACE VOLATILE RESERVOIRS. N. G. Barlow, Dept. Physics, Univ. Central Florida, Orlando, FL 32816 ngb@physics.ucf.edu.

Introduction: The distribution of subsurface volatile reservoirs on Mars has been proposed based on surface conditions and the expected geothermal gradient [1, 2]. These models suggest that ice is stable in contact with the surface at high latitudes (poleward of ~40°) and extends to depths on the order of a few kilometers. In the equatorial region, a thin dessicated surface zone protects underlying ice from sublimation. The ice zone extends to 1 to 2 km, below which liquid water reservoirs may exist. The near-surface ice zones are expected to follow the surface topography while the deeper aquifers are less affected by surface variations.

This model of the subsurface distribution of volatiles can be tested using impact craters. Impact craters provide a natural mechanism for studying the properties of the Martian substrate. In addition, craters are found over most of the Martian surface, unlike other geologic features such as channels which are localized in extent. Craters excavate to varying depths and these depths can be estimated using established depth-diameter relations [3]. Thus, impact craters can be used to study regional variations in subsurface properties.

Fresh Martian impact craters are surrounded by ejecta blankets which display different morphologies depending on crater size and location (Figure 1). Most fresh craters in the 5 to 45 km diameter range are surrounded by one of three types of fluidized, or layered, ejecta structures. These morphologies are named based on the number of ejecta layers identified [4]—craters surrounded by only one ejecta layer are called single layer (SL) craters, those with two ejecta layers (one superposed on the other) are called double layer (DL) craters, and those craters with three or more complete or partial ejecta layers are called multiple layer (ML) craters. Craters with non-fluidized ejecta patterns show similarities to the radial ejecta pattern typically seen around lunar impact craters—this morphology is called the radial (Rd) ejecta morphology.

Two theories have been advanced to explain the prevalence of fluidized ejecta morphologies seen on Mars. One model proposes that these features are formed by impact heating and vaporization of subsurface volatiles during crater formation [5]. The other model argues that interactions of the ejecta with the thin Martian atmosphere can produce these ejecta morphologies [6]. Both models are able to reproduce many of the observed characteristics of the ejecta blankets, but the strong diameter-latitude-morphology relationship reported by [7] is best explained by the subsurface volatile model. This is the model we utilize in this study.

Observations. Barlow and Bradley [7] conducted a global survey of the correlations between ejecta morphology and crater diameter, latitude, and terrain. They found that SL morphologies dominated at all latitudes and on all terrains, but the diameter range was dependent on latitude. In the equatorial region, the SL morphology dominated among craters in the 5 to 25 km diameter range but at higher latitudes the range extended up to 60-km-diameter. In the equatorial region, the ML morphology was found around craters in the 25 to 50 km diameter range. Craters displaying the ML morphology were rare at higher latitudes. The DL morphology shows strong regional concentrations, primarily in regions where water-rich sediments have been emplaced (i.e., floors of possible lakes [8] and in the depositional regions of outflow channels [9]). The Rd morphology is found primarily around very large craters and around moderately sized craters on the flanks of the young Tharsis volcanoes. Analysis of Viking imagery suggested that the smallest craters also are surrounded by the Rd ejecta pattern, but new investigations using the higher resolution MGS MOC imagery brings this claim into question.

Noting the size-latitude relationship for the different ejecta morphologies (particularly the complementary relation for the SL and ML morphologies), Barlow and Bradley computed the excavation depths of the ejected material and compared the results with the theoretical distribution of subsurface water proposed. They found a strong correlation between the depths of excavation and the latitudinal distribution of subsurface volatiles. Craters displaying the SL morphology excavate into material proposed to be ice-rich while the ML morphology craters are excavating into areas which can contain liquid water. The Rd morphology is associated with craters excavating into target material which has a low volatile content. This led Barlow and Bradley to propose that ejecta morphology is telling us about the amount and physical state of subsurface volatiles: SL morphology result from impact into ice, ML from excavation into liquid reservoirs, Rd from impact into volatile-poor material, and DL from impact into layered targets with varying volatile concentrations.

The diameter at which a particular morphology begins to appear (i.e., the onset diameter) provides constraints on the depth to the target layer responsible for this morphology. Thus, the onset diameter for SL and

ML morphologies provides constraints on the depth to the ice-rich and water-rich reservoirs. Kuzmin et al. [10] found that the onset diameter for SL craters decreased from about 5-7 km diameter in the equatorial region to <1 km near the poles. This result is consistent with the proposed distribution of subsurface volatiles. Calculation of the actual depths to the volatile-rich layers depends on knowing the concentrations of volatiles necessary to produce the different ejecta patterns, an area where finite-element modeling is only now beginning to provide constraints [11].

New Results. Our recent studies have focused on regional variations in the distribution of specific ejecta morphologies [9] and the onset diameters of SL craters [12] within the equatorial region (±30° latitude zone). We find that SL craters dominate across the equatorial region, regardless of regional variations. Craters with the ML morphology are concentrated in three primary areas: near the hematite area in Sinus Meridiani (0°-25°N 315°-10°W), in the Mangala Vallis region (10°-20°N 240°-270°W), and in the Solis Planum region (15°-30°S 65°-85°W). DL morphology craters are rare within the equatorial region (most are found in the northern plains between 40° and 55°N), but a concentration is seen in the outwash deposits at the mouth of Kasei Valles (20°-30°N 50°-90°W).

Our analysis of onset diameters for the SL morphology shows regional variations as well [12]. Several localized concentrations of smaller than normal onset diameters (i.e., 3-5 km diameter as opposed to the normal 5-7 km diameter range found by [10]) are correlated with the locations of possible paleolakes. A particularly large area of anomalously small onset diameters is found in the Solis Planum region. In this area, depth-diameter relations suggest that the ice-rich layer may be as close as 110 m below the surface. Tharsis-related tectonic uplift of an ancient drainage basin may have helped to concentrate volatiles in this region, both as near-surface ice (as indicated by the smaller onset diameters for SL morphologies) and an extensive liquid reservoir (indicated by the concentration of ML morphologies in this same region) [13].

Exploration Strategies. The results of these impact crater studies suggest that regional variations in the concentration of subsurface volatiles exist within the equatorial region of Mars. In some places, ice reservoirs are apparently quite close to the surface. Thus future missions seeking near-surface volatile reservoirs are not limited to high latitude regions. Geophysical techniques such as ground penetrating radar and seismic surveys will help provide ground truth for the scenarios suggested by the impact crater studies. We propose that regions where near-surface volatiles have been suggested by the crater studies be targeted for future geophysical exploration.

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Figure 1. Examples of the SL and ML ejecta morphologies. Image is centered at 19°S 70°W. ML crater is 24 km in diameter.

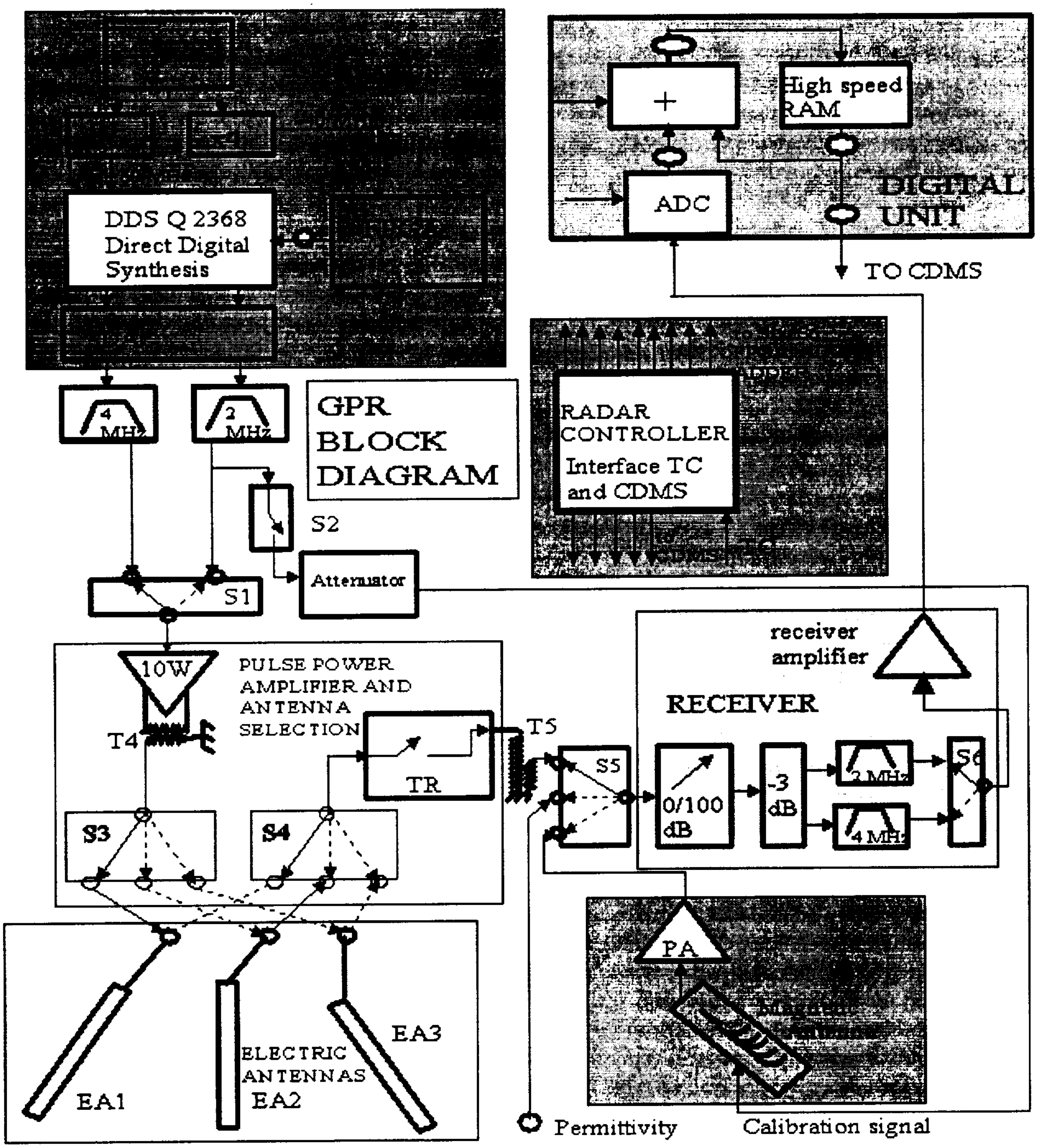
THE GPR EXPERIMENT ON NETLANDER: OBJECTIVES, DESCRIPTION OF THE INSTRUMENT AND SIMULATED PERFORMANCES. J.-J. Berthelier (1), R. Ney (1) and the NETLANDER/GPR team, CETP/IPSL, 4 Avenue de Neptune, 94100 SAINT-MAUR, France.

One of the major objectives of the NETLANDER mission, foreseen to be launched in 2007 by CNES, is to study the structure and properties of the planet from the subsurface down to the deep interior. In accordance with these objectives, we have proposed to fly a Ground Penetrating Radar (GPR) which aims at characterizing the geological entities and structures in the vicinity of each of the 4 landers and at detecting possible water reservoirs under the form of ground ice or even liquid water down to depths on the order of ~2 kilometers. This instrument can also be used as an ionospheric sounder to probe the lower ionosphere and, in a passive mode, to measure the planetary radio-electric background and HF emissions generated by electrical discharges during dust storms.

Among the various possible techniques to explore planetary sub-surfaces, the GPR presently appears to be the most suitable due to its relatively reasonable requirements in terms of mass and power. In the NETLANDER mission, the landers will remain at fixed positions. To overcome this limitation we have proposed a novel concept for the instrument: in addition to the determination of the range of the reflectors, the GPR, will also measure the direction of the propagation vector of the returning waves which gives access to the direction of the reflectors, thus providing a sub-surface imaging capability to the radar. The measurement of the propagation vector is achieved through the simultaneous measurement of the electric and magnetic components of the reflected electromagnetic waves. Due to the very large interest for the detection of water reservoirs which are presently thought to be at depths of more than a kilometer in near equatorial regions, a low frequency of 2 MHz was selected for the nominal mode of operation in order to lessen the absorption as well as the diffusion on small scale irregularities. During daytime this frequency is smaller than the critical frequency of the ionosphere which then provides a useful shield against the galactic noise and allows to significantly improve the signal over noise ratio and the resulting performances of the radar. We plan to use 3 monopole electric antennas deployed on the ground for both transmission and reception; they will provide 2 horizontal electric components of the returning waves. The 3 magnetic components of the electromagnetic waves will be measured using a single magnetic antenna which will be rotated and successively positioned along 3 mutually orthogonal directions. The 3 electric antennas provide a way to operate with 3 independent linear polarizations; subsequent numerical synthesis of the data on the ground will allow to simulate the case of a planar, quasi-circular polarization. The determination of the characteristics of the reflectors in the subsurface as a function of the polarization will help in their characterization. As shown by numerical modeling, a convenient phase shift between the signals applied to each of the 3 monopoles also allows to control their global radiation pattern: this feature is of particular interest since it allows to vary the "illumination" of the subsurface in a number of ways and thus significantly improves the imaging capability of the instrument. In order to enhance the S/N ratio, hence to increase the maximum depth of penetration, the onboard data acquisition system is designed to provide a large number of coherent additions, from 2^{16} on the electric to 2^{24} on the magnetic antenna owing to its lower sensibility. Two transmitting schemes are presently foreseen for the radar operation: the first one uses a single pulse either 0.5 μs or 1 μs in duration to probe the upper sub-surface down to a few hundreds of meters, the second one makes use of a BPSK code with a 10 μs long pulse to probe down to the lowest possible depths. A detailed evaluation of the radar performances using an electromagnetic model of the sub-surface built from the available geological information on Mars and terrestrial analogues has shown that a liquid water interface at a depth of 2.5 km could be detected under these conditions. The electronic block diagram of the GPR is given in the figure below.

In this paper we shall summarize the present state of development of the laboratory prototype which has allowed to check the performances of all the sub-systems of the GPR. The most interesting results obtained from a significant effort in numerical simulation will be shown to demonstrate the radar capabilities and the anticipated characteristics of the detected signal. Companion papers will describe in more details the methods and algorithms used in numerical simulation and some on-going studies on signal analysis to retrieve the direction of propagation and the sub-surface properties.

Field tests are foreseen in the near future at sites which display electromagnetic properties not too different from the martian sub-surface, in particular the expected negligible moisture content of the soil. The first site which was selected is a cold high altitude glacier in the French Alps. In a second step we anticipate to operate the GPR in a desert dry region in south Egypt.



THE MARS HIGH RESOLUTION ADVANCED RADAR FOR 2005 SPACE MISSION. D. Biccari[1], G. Picardi[1], R. Seu[1], A. Coradini[2], R. Orosei[2], [1]INFOCOM Dept., University of Roma La Sapienza, Via Eudossiana 18, 00185 Rome, Italy, [2]IAS/CNR, Via Fosso del Cavaliere, 00100 Rome, Italy.

Introduction: In January 2001 the Mars Reconnaissance Orbiter (MRO) Science Definition Team (SDT) recommended that a subsurface profiling radar be flown sometime as part of the Mars Exploration Program (MEP) and that, for the 2005 launch opportunity, be considered for flight as a Group II Science objective. Further to this recommendation, NASA and ASI (the Italian Space Agency) are considering the possibility of a shallow subsurface sounding radar (SHARAD) to be flown on the MRO. Given the nominal characteristics of the 2005 mission, ASI envisaged an instrument whose *scientific objectives* must be complementary to the MARSIS experiment [1], defined in the context of the objectives of the Mars Express mission, and in the more general frame of the current open issues in the study of Mars. The primary objective of SHARAD is to *map the distribution of water, both liquid and solid, in the upper portions of the crust of Mars (the penetration depth shall be 300÷1000m), at range resolution scales of tens of meters and spatial resolution of the order of some hundred of meters.*

Crust Composition Models and Characterization of the Martian Surface: Although a multitude of different chemical compositions is present at the surface of Mars, it is necessary to select a few representative materials as most meaningful for electromagnetic studies. Among them we have considered various forms of basalt, carbonate, eolian, fluvial and indurated sediments, crater ejecta and volcanic ash. As a matter of fact, given the values of their dielectric constant, these materials can be considered end members of the range in which the first layer of the Martian surface materials may vary. For the sake of simplicity all the considered materials have been grouped in six categories according to their dielectric properties that are listed in Tab. 1.

	ε'	tangδ
I -1	5	0.004
I -2	8	
II -1	1.5	0.03
II -2	5	
II -3	9	
III	7.1	0.014

Tab. 1 Reference categories of materials.

The reference interface models representing the most likely detection scenario are the following:

- *Ice/water interface detection scenario (I/W):* the porosity of the Martian megaregolith is considered maximum at the surface and its decay with the increasing depth is given by an exponential law (the decay constant has been assumed in the order of 2.8 km). The pores are filled with ice from the surface down to a depth below which liquid water is stable and becomes the pore-filling material. The change of the pore-filling material causes a discontinuity of the overall dielectric constant, which can be detected by the radar sounder.
- *Dry/ice interface detection (D/I):* here the pore-filling material is considered to be gas or some other vacuum-equivalent material up to a depth, below which ice fills the pores. Hence the interface to detect is between dry and ice-filled materials.

These models will be used to estimate the penetration performance under typical operative condition.

Moreover it should be noted that, since porosity depends on the depth, so will do the effective dielectric constants of the mixture. In order to evaluate the mixture dielectric constants, we have applied the Maxwell-Garnett model [1].

In order to characterize Mars' *surface geometric structure*, we have taken into account that recently attempts have been made to describe the structure of the planets surface by means of *fractals*. Tests on randomly selected MOLA topographic profiles have shown that H (Hurst exponent) with very high probability lies in the range 0.6÷1 and the rms slope (evaluated between points separated by a distance of Δx=100 m) is in the range $10^{-1} \div 10^{-2}$ [3].

Moreover we have assumed that the surface can be described as a random distribution of heights, characterized by a variance σ_h, and a spatial correlation function

$$\rho(\Delta x) = \exp\left(-\frac{|\Delta x|^{2H}}{\ell^{2H}}\right)$$

where the correlation length ℓ lies in the range 3÷12 Km [3]; we have also noted that H, s(100) and ℓ appear uncorrelated.

Surface and Subsurface Reflectivity and Attenuation: To assess the interface detection capabilities of our radar sounder it is required to evaluate the back scattering cross sections of concurrent echoes coming from the surface and subsurface layers. These can be expressed as $\sigma_s = \Gamma_s f_s(H_s,s_s,\lambda)$ and $\sigma_{ss} = \Gamma_{ss} f_{ss}(H_{ss},s_{ss},\lambda)$ being Γ_S and Γ_{SS} the Fresnel Reflectivity terms, which deal with the surface and subsurface dielectric properties and f_s and f_{ss} the scattering terms, which deal with the geometric structure of the surface and subsurface. As it is well known, the Fresnel reflectivity for nadir incidence on a surface is given by

$$\Gamma_s = \left| \frac{1 - \sqrt{\varepsilon_{r1}(0)}}{1 + \sqrt{\varepsilon_{r1}(0)}} \right|^2 = R_{01}^2$$

being $\varepsilon_{r1}(0)$ the real dielectric constant of the crust evaluated at the surface (z=0). The models given in the section above provide, for the Fresnel reflectivity, values in the range from –7 to –17 dB for the I/W scenario and from –7 to –32 for the D/I scenario.

The Fresnel reflectivity of a subsurface layer located at depth z is given by

$$\Gamma_{SS,z} = R_{12,z}^2 \left(1 - R_{01}^2\right)^2 10^{-0.1\int_0^z \alpha(\zeta)d\zeta}$$

being $R_{12,z}^2$ the reflection coefficient of an interface located at depth z

$$R_{12,z}^2 = \left| \frac{\sqrt{\varepsilon_{r1}(z)} - \sqrt{\varepsilon_{r2}(z)}}{\sqrt{\varepsilon_{r1}(z)} + \sqrt{\varepsilon_{r2}(z)}} \right|^2$$

and $\alpha_{dB/m}(\zeta)$ the two-way unit depth attenuation due to dielectric dissipation in the crust, expressed in dB/m

$$\alpha_{dB}(\varsigma) = 1.8 \cdot 10^{-7} f_0 \sqrt{\varepsilon} \tan \delta$$

Again taking into account the models mentioned above, an evaluation of the Fresnel reflectivity terms for the subsurface layer (with good approximation independent from z for depth lower of 0.5 Km) and of the attenuation is possible and we obtain values of the interface reflectivity in the range –9.5 to –21 dB (I/W) and –17 to –33 dB (D/I). The two-way attenuation varies from 1 to 13 dB/Km/MHz (either I/W and D/I).

By considering a penetration depth requirement of 300 m and a useful dynamic range of the signals of 60 dB a transmitted frequency of 20 MHz can be used, strongly reducing ionosphere propagation problems. The required bandwidth should be in the order of 10 MHz in order to obtain a range resolution better than 15 m. With these values also the antenna matching problems appear reduced with reference to the MARSIS design [2].

Surface Backscattering Models: According to the surface model already described above and taking into account the Hagfors backscattering model, we can write [5] for the *surface backscattering coefficient*

$$\sigma_0 \cong \frac{\Gamma_s}{2 m_f^2} \left(\cos^4 \vartheta + \frac{1}{m_f^2} \sin^2 \vartheta \right)^{-3/2}$$

where ϑ is the scattering angle and

$$m_f = \left(2\sqrt{2}\pi\right)^{(1/H)-1} \left(s_\lambda\right)^{1/H} \sqrt{\frac{H}{\Gamma\left(\frac{1}{H}\right)}}$$

being the rms slope evaluated between points separated by a distance equal to λ given by

$$s_\lambda = s(\Delta x_0) \left(\frac{\lambda}{\Delta x_0} \right)^{H-1}$$

It is worth noting that this backscattering coefficient has been also validated by means of a simulation program where the facet model has been used for the surface modeling.

By means of this model we can finally either write the radar equation in order to give appropriate requirements on specific radar parameters and also write the subsurface signal to surface clutter power ratio. This last ratio is in particular significant since the clutter is likely to be the most important limiting factor of the achievable penetration depth (rather than the noise): from its knowledge we can assess the system performance and give requirements on particular processing techniques (like for instance doppler and interferometric processing) which can help in the improvement of the signal to clutter ratio.

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Basic Concepts in Terrestrial Groundfreezing P. B. Black, ERDC, TACOM-ARDEC, Bldg 3002, Picatinny Arsenal, NJ 07806, Patrick.B.Black@erdc.usace.army.mil.

Introduction: Any study of water behavior in the Martian regolith should begin with an examination of our current understanding of terrestrial groundwater. The terrestrial analog provides a wealth of readily available information to help formulate and test new ideas. Known behavior of terrestrial frozen groundwater should be of particular importance in assisting our understanding of the behavior of water on Mars. This talk presents a general overview of the basic concepts involved in terrestrial groundfreezing.

Background: In a hydrophilic system like terrestrial soil, there are two general observations made regarding liquid water. First, any liquid water is always found adjacent to the soil surface. Second, the mechanics of water adsorption on the soil surface is short ranged and originates at the soil surface. For a given mineral, the thickness of the mineral does not influence the amount of adsorbed water so it is concluded to be a surface effect. The mechanics are considered to be short ranged because the behavior of water is that of bulk water at distances of tens of layers of water from the mineral surface.

These two observations lead to a simple classification scheme in which soil water is considered to be either adsorption water or capillary water. In the former, water is in a region very close to the mineral surface and the adsorption forces emanating from the mineral surface control its behavior. All remaining water in the soil-water system is in the capillary space of the latter classification and its behavior is governed by the rules of surface tension-viscous forces.

This soil water classification simplifies the modeling of water behavior in soil. When the adsorption space dominates, then only those mechanism (electric potentials, ion distributions, heat of wetting, etc) need to be modeled. On the other hand, when the system is the traditional hydrologic behavior of water flow, then the capillary forces due to viscous flow and capillary pressures are modeled through such laws as LaPlace and Darcy.

Another observation is that any ice that forms in the soil-water system is separated from the mineral surface of the soil by liquid water. Beskow [1] was one of the first to realize the existence and importance of the unfrozen film in groundfreezing mechanics. The origin of the unfrozen water is a combination of the adsorption force emanating from the mineral surface along with other physical properties of the ice surface that requires a liquid transition layer on the surface of the ice. This behavior is similar to that of air and water with the air always being separated from the mineral surface by liquid water.

Discussion: The observed behaviors of freezing and frozen soils depend upon the physical and chemical properties of the soil. The temperature at which freezing first occurs, the freezing point depression, is a function of solute concentration, pore size for capillary soils and surface chemistry for adsorption space dominated soils. When subjected to a temperature gradient, a freezing front forms at the location equal to this temperature.

The presence of solutes in colloidal soils can result in the existence of unfrozen water down to extremely cold terrestrial temperatures. Granular soils and gravels would display very little unfrozen water at these extremes.

Fine-grained soils have additional forces influencing the phase composition of the soil water when all three phases of water are present. By working with the different surface tensions and curvatures, it is shown that a stable condition exists that results in a pore containing only ice.

Frozen soil is shown to perform as a semipermeable membrane resulting in water migrating toward regions of high solute concentration. The thin films of adsorbed water act as a filter, which selectively pass water but not solutes.

To end, thermally induced regelation is discussed as of possible interest to Martian water studies. This phenomena result in a mineral grain migrating towards the warm end of an ice column subjected to a temperature gradient. The speed of migration increases exponentially as it approaches the freezing front. It is responsible for frost heave and could create interesting effects over long temporal scales. It is described by coupling equilibrium thermodynamics with capillary phenomena.

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A PROPOSAL FOR DETAILED MAPPING OF MARTIAN AQUIFERS USING PENETRATORS. L. W. Brownlow[1], G. A. Dorn[2], and T. J. Mosher[3], [1]The Aerospace Corporation, El Segundo, CA 90245, Leonard.W.Brownlow@aero.org, [2]The University of Colorado, Bolder, CO 80309, gdorn@colorado.edu, [3]The Aerospace Corporation, El Segundo, CA 90245, Todd.J.Mosher@aero.org.

Introduction: "Follow the water" has become a central theme of the Martian science program, especially as it pertains to finding past or current life. Geological surveys of the Martian landscape reveal surface features that appear to have been eroded by the flow of water further fueling the quest for water on Mars [1,2]. There are many possible ways to remotely sense the presence of water, but water on Mars is most likely deep underground. Because the capability to sense the presence of water is greatly reduced by the altitude of the sensor, penetrators will deliver seismic sensors into the Martian surface and allow a high resolution mapping of a pre-selected subsurface region.

Given that remote sensing techniques are advanced enough to map out a reasonable area in which the probability of the presence of water is high, we propose a method of accurately mapping a small (300 m by 300 m) region of the Martian landscape to depths of 300 m using an array of surface based sensors. Studies by Costard [3] and Kuzmin [4] suggest the presence of ice at depths less than 200 m in the higher latitudes.

Sensors would be deployed directly from a low altitude vehicle and delivered into the Martian surface using established penetrator technology. The sensory array will provide data which can be visualized in a three dimensional virtual environment, similar to that used by the oil and gas industry, for the purpose of mapping underground aquifers.

Mission: The search for water on Mars can be approached in several different ways. The first, and easiest, is to remotely sense potential reservoirs using an advanced radar sounder. The sounder will identify areas with the highest probability of water. This could further be examined using a global network of satellites that sense the presence of water using an array of electromagnetic sensors. This is essentially the proposed NETLANDER mission developed by CNES. Once a potential target has been established, a higher resolution mission is required. Again, there are several ways this may be accomplished. Areas identified with the highest probability could be mapped at a higher resolution using sensors installed on balloons, aircraft, or rovers. To date, no aircraft have ever been deployed on Mars. Balloons, which are highly dependent on the prevailing winds, may not target the intended area, and rovers are severely limited in range and reliability. Practices established by the oil and gas industry provide an alternate method of a high-resolution search for water. An array of seismology sensors delivered into the Martian surface by penetrators can be used to map a region of Mars up to 300 m x 300 m across and 300 m deep. The array would be able to map the region to a resolution of 50 m (this is not fine enough to identify small water reserves, but the resolution and depth increase as the distance between sensors is decreased). This process is commonly employed before drilling to ensure that a well is located exactly where it should be. Drilling for water on Mars will be a daunting task, given that the drill bit is usually cooled with mud and that power requirements necessitate a prohibitively large solar array. It is likely that the drilling power source will be nuclear, and the drilling process slow given the limited cooling options on Mars. However, these complications are only issues after a likely source of water is discovered on Mars. A three-dimensional mapping of the subterranean area is essential to locate water closest to the surface. The reduced drilling depth obtained from the mapping process will alleviate the ultimate complexity of the drilling process.

Koroshetz and Barlow [5] have identified an area in the Solis Planum region, which is south of the Valles Marineris, with a high probability of near surface water (< 200m). The craters located at Solis Planum exhibit features consistent with an impact in a liquid reservoir. The area is also at a lower height than the surrounding land, which would provide a perfect location for liquid to collect.

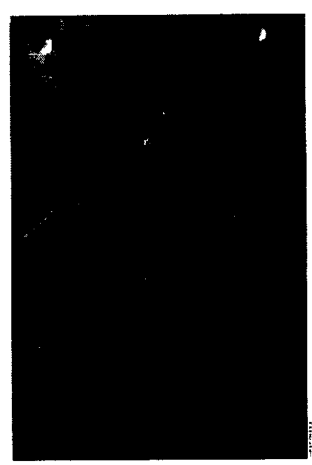

Figure 1: Solis Planum

System: Several space missions have been designed using penetrators; Mars 96 and the LUNAR-A missions were designed using penetrator technology to perform soil sampling and seismology experiments. The Mars mission proposed here would be the first to launch an array of nine penetrators. The nine penetrators would form an array 3 x 3 covering an area of at most 300 m on a side. Seismic sensors are capable of detecting features sizes of 100 m across at depths of up to 300 m. For a more detailed mapping, the array size could be reduced to as little as 25 m on a side, which would permit the detection of feature sizes of 25 m at depths to 600 m. Because the identified area of potential subterranean water is about the size of Arizona [5], a detailed mapping may be more appropriate.

Mass requirements for a Mars mission are a primary design constraint. The pentrators on the Mars 96 and LUNAR-A missions were heavy at about 45 kgs. The high mass was due to the heavy instrumentation and soil sampling equipment. The payload for the peneatrators proposed here would be significantly lighter due to the simplicity of the sensors and of the mission. DS2 penetrators, shown in Figure 2, weighed approximately 3.6 kg, and are slightly smaller than the ones proposed here. A coin is included in the picture to give an idea of the physical dimensions of the probe.

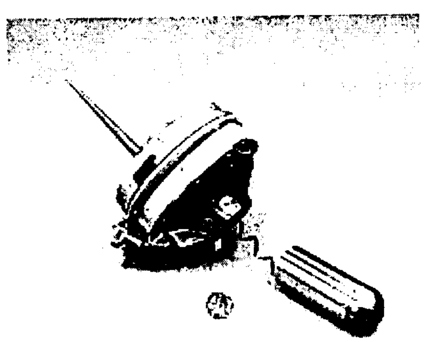

Figure 2: DS2 Probe

The potential sensor systems available for this mission call for the use of reflective seismology, refractive seismology, or electromagnetic soundings. Reflective and refractive systems would require an event to trigger seismic waves that provide readings to the sensors. The event could be obtained from an active sensor that emits signals, or by a one-time impact or detonation. A second impact, or detonation, would help increase the signal-to-noise ratio of the data.

The simplest system uses electromagnetic soundings using low noise triaxial vector fluxgate magnetometers. Impedance estimates from the array can be used to identify reservoirs of water using a method developed by Pinçon et al. [6]. At this stage, electromagnetic soundings appear to yield the simplest and lowest risk architecture.

The delivery of the penetrators requires a high degree of accuracy. Typical payloads to Mars have been delivered within 2 km to the target location, however, the penetrators themselves must be accurately located (to within meters) with respect to each other. This requires the design of a secondary delivery vehicle that takes the set of penetrators from orbit to near the Martian surface before firing the penetrators. A low altitude injection of the penetrators will ensure the cohesiveness of the sensor array. Only a suitably structured sensory array will provide useful data for the subsequent evaluation.

Data Visualization: One of the more unique aspects of the mission will be the handling of data. Techniques have been developed to visualize the data in an immersive three-dimensional virtual environment. The virtual environment is created using and immersive CAVE™ facility. Similar facilities have been used by ARCO to reduce cycle time and improve the accuracy of making well location decisions. Typically, sensors spacing of 12.5 – 20 m have been used to detect feature sizes of 10 – 20 m at depths of up to 600 m. Data obtained from the mapping process is readily visualized in the immersive CAVE™ environment as shown in Figure 3. Methods have been derived to accurately interpret 3-D seismic data [7,8], and provide data in a format that is readily understood.

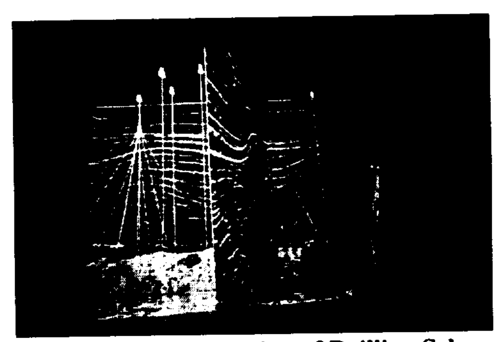

Figure 3: 3-D Visualization of Drilling Schemes

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APPLICATION OF GEOPHYSICAL TECHNIQUES FOR MAPPING ICE-BEARING SEDIMENTS, MACKENZIE DELTA, WESTERN ARCTIC, CANADA. H. T. Calvert[1], S. R. Dallimore[1] and J. A. Hunter[1]. [1]Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8

Introduction: Since the early 1970s the Geological Survey of Canada has been investigating the use of geophysical techniques to map ice-bearing sediments in the Mackenzie Delta of the Northwest Territories. The techniques used have included gravity, seismic refraction, electromagnetics, ground penetrating radar (GPR), resistivity and down-hole geophysical logging.

A map showing the location of permafrost study sites in the Mackenzie Delta is shown in Figure 1. Two of these sites have undergone intensive geophysical investigations. Lousy Point is located on the east side of Richards Island. A 7.4 km long transect across undulating permafrost terrain has been established at this site. Involuted Hill is located in the central portion of Tuktoyaktuk Peninsula. A 2 km by 2 km survey grid has been established for this site.

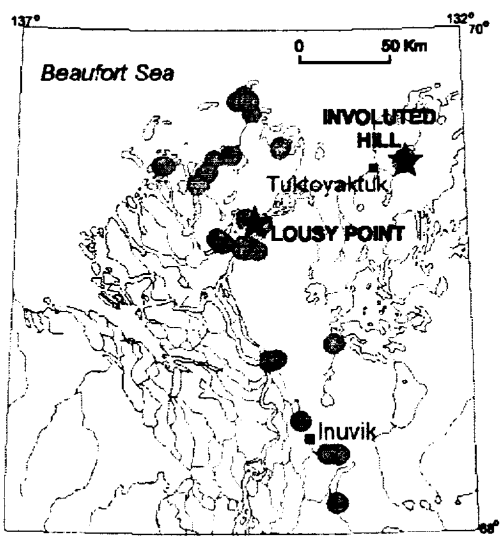

Figure 1. Permafrost study sites (circles) in the Mackenzie Delta.

Geology: The Mackenzie Delta is underlain by unconsolidated Pleistocene sediments. Permafrost thickness varies from over 750 m in the north to approximately 350 m in the south. Thick permafrost, widespread ground ice, taliks and cryopegs are present in the region of the Lousy Point transect. Most of the topography along this transect is a result of the presence or absence of excess ice. Involuted Hill, shown in Figure 2, is an ice-cored hill which rises 20 m above the surrounding terrain. A cross-section of a portion of Involuted Hill is shown in Figure 3.

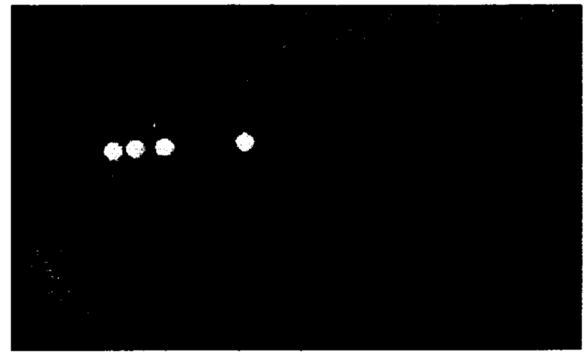

Figure 2. View of Involuted Hill with location of cross-section.

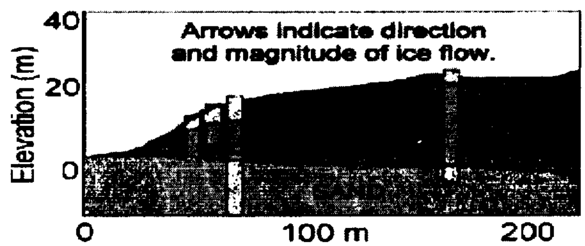

Figure 3. Borehole cross-section from Involuted Hill.

Geophysical Studies: Numerous geophysical surveys have been conducted at the study sites in order to characterize ice-bearing sediments. A few examples of these surveys are presented below:

Gravity Surveys. Gravity profiles have been obtained for the Involuted Hill Site [1]. A modeled gravity survey line from Involuted Hill is shown in Figure 4. Modeling and subsequent drilling indicates that the hill has core of massive ice.

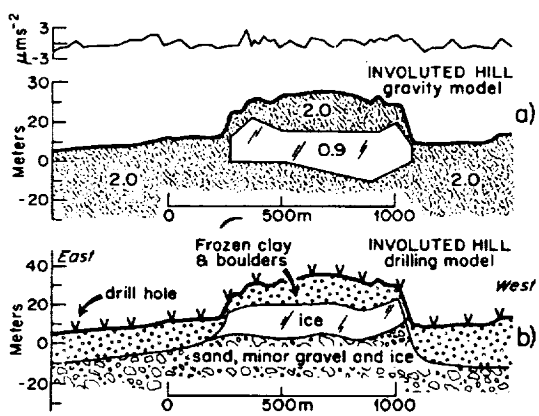

Figure 4. (a) Model for gravity profile of Involuted Hill with gravity residuals between observed and calculated gravity. (b) Geological model constructed from drill hole logs [1].

GEOPHYSICAL TECHNIQUES FOR MAPPING ICE-BEARING SEDIMENTS: H.T. Calvert, S.R. Dallimore and J.A. Hunter

Seismic Refraction Surveys. Seismic refraction surveys have been conducted at several sites including Involuted Hill. The results indicate that seismic velocities of permafrost vary between 1900 and 4200 m/s and are dependent on ice content and temperature. The seismic velocity for massive ice was found to be between 3200 and 3800 m/s.

Electromagnetic Surveys. Electromagnetic ground conductivity meters, such as the Geonics EM-34, have been used extensively to identify areas of permafrost. This method can be used to cover a large area efficiently and provides electrical conductivity profiles to depths of up to 60 m. Areas with low electrical conductivity were found to correlate with permafrost.

The transient electromagnetic (TEM) method has been used to investigate deep permafrost and gas hydrates in the Mackenzie Delta. At Lousy Point, a Geonics EM37 system was used with a 400 m by 400 m square transmitter loop to obtain apparent resistivity soundings to depths of up to 600 m. The TEM survey indicated that there were significant changes in permafrost depth along the transect.

Ground Penetrating Radar Surveys. Ground penetrating radar (GPR) data were acquired at Involuted Hill in 1975. High propagation velocities were attributed to air bubbles within the ice.

The Lousy Point transect was profiled with GPR in 1986 and again in 1991. A section of the 1991 GPR profile is shown in Figure 5. Areas underlain by ice are characterized by low signal attenuation due to their low electrical conductivity.

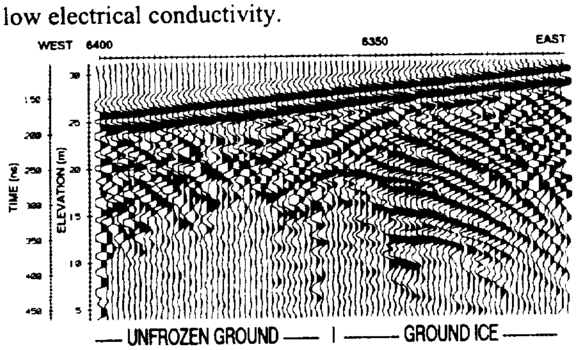

Figure 5. Portion of GPR profile along Lousy Point transect.

Electrical Resistivity Surveys. Capacitive-coupled resistivity systems [2] were used to obtain apparent resistivity profiles along the Lousy Point transect. Unlike conventional resistivity systems, direct contact with the ground is not required, allowing the system to be towed across the terrain. This method is well suited to highly resistive surface conditions where galvanic contact with the ground is problematic.

A comparison of apparent resistivity profiles obtained by capacitive-coupled resistivity (VCHEP, RUSCAN) and electromagnetic conductivity (Geonics EM-34) methods is shown in Figure 6. The capacitive-coupled resistivity profiles provided better resolution of high resistivity zones.

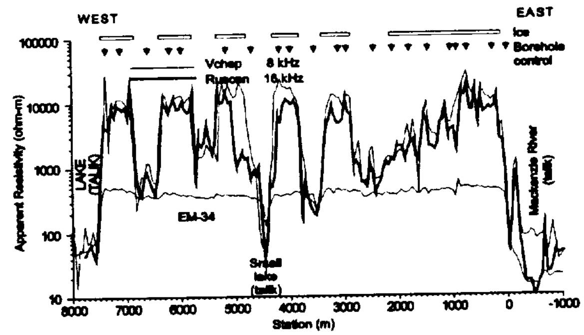

Figure 6. Comparison of capacitive-coupled resistivity profiling and electromagnetic conductivity profiling for Lousy Point.

Downhole Geophysics. Geophysical logging of boreholes has provided a means to check the validity of interpretations made from surface geophysics. Temperature, electrical conductivity, gamma and magnetic susceptibility logs have been collected at many of the study sites. In addition, slope indicators have been installed in several boreholes to measure subsurface movement. The geophysical log from Borehole 91-9 for Lousy Point is shown in Figure 7. In this borehole, segregated ice has low natural gamma counts whereas glacial ice has low to moderate gamma counts.

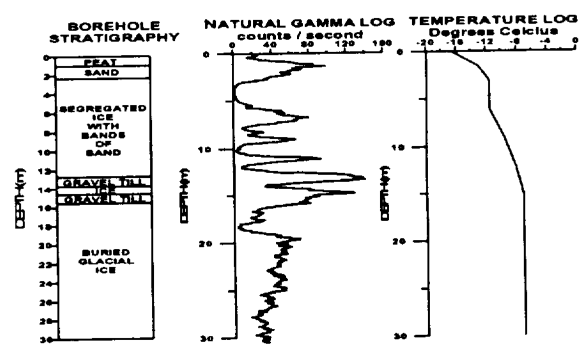

Figure 7. Geophysical logs for borehole 91-9, Lousy Point.

Summary: The Involuted Hill and the Lousy Point sites have been subject to extensive geophysical, geological and geotechnical investigations that have characterized ice-bearing sediments. These sites may be suitable terrestrial analogs for evaluating geophysical techniques for exploring ice-bearing areas of Mars.

References: [1] Rampton, V. N. and Walcott, R. I. (1974) *Can. J. Earth Sci., v. 11, 110-122.* [2] Timofeev V. M. et al. (1994) *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems,* EEGS, 701-715.

ORBITAL IMAGING RADAR AND THE SEARCH FOR WATER ON MARS. Bruce A. Campbell[1], Donald B. Campbell[2], John A. Grant[1], Scott Hensley[3], Ted A. Maxwell[1], Jeffrey J. Plaut[3], Paul Rosen[3], Michael K. Shepard[4], Richard Simpson[5]. [1]Center for Earth and Planetary Studies, Smithsonian Institution, MRC 315, Washington, DC 20560 (campbellb@nasm.si.edu); [2]NAIC, Cornell University; [3]JPL, [4]Bloomsburg University, [5]Stanford University.

The surface of Mars has been modified by a range of geologic processes, and many regions are mantled by varying depths of wind-blown dust, volcanic ash, and fluvially deposited or other water-lain sediments. We are proposing an orbital mission carrying a synthetic aperture radar (SAR) that can penetrate a significant depth of overlying material to reveal the detailed geomorphology as it relates to the changing fluvial, eolian, volcanic, and cratering history of Mars. Moreover, the data to be returned are of direct relevance to the search for past and present occurrences of liquid water, life, changing martian climate, and geologic history (e.g., origin of the northern plains, mechanisms for past and possible present valley formation, and genesis of widespread mantling deposits), the validation of potential landing sites for rover safety, and evaluation of sub-surface accessibility for drilling.

Much attention has been focused on the ubiquitous dust cover of Mars that constrains the ability of visible and near-IR instruments to detect compositional variations. As shown by MOC images, however, that effect extends to the meter scale, and widespread eolian mantles and dunes are now known to obscure many of the key geologic relations. A SAR system capable of revealing the presence of buried drainage is necessary to locate the potential sinks of water in the regolith. With an extended mission, radar mapping may be used to determine variations in both location and possibly the depth of a subsurface ice-regolith interface.

The proposed radar mapping mission employs a transmitter with wavelengths of approximately 3 cm (X band), 25 cm (L band), and 75 cm (P band). A 5-m deployable main antenna is used to collect synthetic aperture radar images of the surface, at all three wavelengths, with a nominal incidence angle of 45°. A secondary parabolic X-band antenna is used for data downlink prior to main antenna deployment, and functions as a near-nadir radar altimeter/scatterometer during the mapping phase of the mission.

The primary scientific goals are to:

- Map variations in sub-meter scale surface roughness across Mars at a spatial resolution of 100 m, necessary for characterization of volcanic flows, eolian erosion of the surface, tectonic fractures, and the properties of geologic materials.
- Map variations in sub-surface structure or dielectric properties within 5 m of the surface at a spatial resolution of 500 m, necessary for identification of buried channels, near surface aquifers, and geologic units buried by eolian materials.
- Map the dielectric constant of the upper surface layer; yields increased knowledge of lithology of volcanic flows, plains and highland materials, and regolith properties.
- Detect seasonal surface changes that may be linked to volatile migration (frosts, snow); adds to knowledge of climate cycling of water ice and potential habitats for life.
- Map the surface roughness of potential landing sites and selected areas of high scientific importance at a spatial resolution less than 10 m; necessary for certification of future landing sites and identification of the most promising sites for biologic investigations.
- Characterize the distribution and minimum thickness of eolian and other mantling deposits.
- Provide morphologic information related to the origin of fluvial, possible lacustrine, and other water-related features on Mars.

These goals will be accomplished by the following measurements:

- A global radar map of Mars at L-band wavelength with nominal 100-m spatial resolution (275 km orbit).
- A global radar map of Mars at P-band wavelength with nominal 500-m spatial resolution.
- Fresnel reflectivity estimates for the entire surface using the X-band secondary antenna, and for areas of interest using the main antenna and L- or P- band systems.
- High-resolution (<10 m) X-band imaging of potential landing sites.

Additional goals and supporting measurements include radar interferometry for surface height mapping and layer thickness estimation, bistatic radar measurements of surface reflectivity, and improved gravity measurements through two-way radio tracking.

The proposed mission scenario uses a 7-day repeat-cycle orbit. During each day, the spacecraft will be oriented to collect north-south image swaths, followed by a period of DSN downlink using the main antenna for X-band communications. Successive mapping periods will be used to fill in gaps left by earlier downlink periods. This should permit full coverage of the planet in 20-30 weeks.

Radar backscatter measurements are sensitive to roughness at scales comparable to the illuminating wavelength, and to the microwave dielectric properties of the near-surface environment. At longer wavelengths (e.g., L- and P-band), radar signals may penetrate several meters of dry or frozen material and be scattered by buried rough interfaces (Fig. 1). Short-wavelength echoes (e.g., X-band) are more amenable to high spatial-resolution imaging, and are dominated by surface scattering, providing a tool for mapping roughness and dielectric constant.

Radar data for Mars are presently limited to Earth-based observations, but S-band (12.6 cm wavelength) signals are clearly capable of penetrating 10's of cm in the

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martian dust [1]. Given that these data are collected in the same-sense circular polarization mode (LL), we are confident that an L- or P-band VV observation will penetrate several meters of fine material.

The global long-wavelength radar maps will be used to identify buried volcanic, fluvial, tectonic, and impact features. A vertical-polarized transmitted and received signal (VV) will maximize echoes from buried surfaces. By using two radar wavelengths, we may also estimate the depth and character of the mantling deposits and the roughness of the underlying substrate. For the polar regions, long-wavelength radar probing will permit estimation of ice depth, and monitoring of volatile migration in near-surface layers (including frost or snow cover) throughout the martian year. Repeat-pass interferometry may be used to infer surface height, and the amount of phase decorrelation between passes can also be used to estimate the depth of an ice [3] or porous dust layer.

The L- and X-band high-resolution maps will be used to characterize the diffuse-scattering surface roughness of potential landing sites. While the spatial resolution of these data (on the order of 10 m for X-band) is less than that achieved by orbital cameras, the radar data will provide information on sub-meter scale roughness within a pixel that is not available from visible imagery.

The secondary X-band antenna, intended primarily for communications during cruise and aerobraking, will be used as an altimeter system, with Doppler processing to sharpen the along-track resolution. The scatterometer-like measurements will be used to estimate the Fresnel reflectivity and wavelength-scale roughness properties of the surface. While altimetric data may also be recovered, this will not be of a spatial resolution comparable to that of MOLA. For areas of particular interest, or locations too rough at X-band scales to create a strong near-nadir return, we may use the main antenna and L- or P-band systems to collect similar data.

An orbital SAR system with long-wavelength (L- or P-band) capabilities is complementary to orbital sounding systems such as MARSIS, which penetrate to depths of several km but have relatively coarse vertical resolution. Particularly for the case of drilling to depths of a few meters, SAR data provide the only remote-sensing method for mapping near-surface layering. These measurements also complement ground-penetrating radar systems deployed on Mars rovers, and will provide regional context for data obtained during surface traverses [4].

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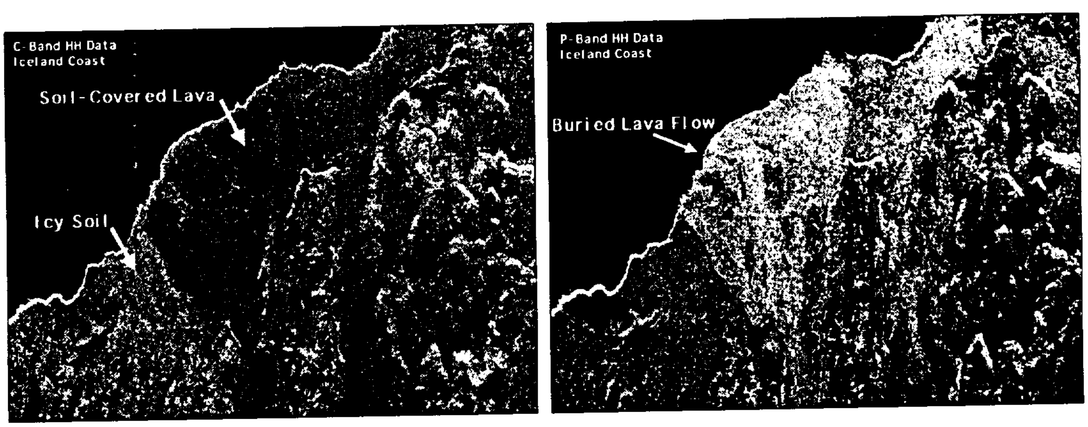

Figure 1. AIRSAR images of the coast of Iceland. In the C-band image (5.7 cm wavelength), the lava flow of interest is hidden by frozen moss and soil. The P-band (68 cm wavelength) signal penetrates this mantling layer and scatters from the rough lava surface.

THE GPR EXPERIMENT ON NETLANDER : PRELIMINARY RESULTS ON THE DETERMINATION OF THE PROPAGATION VECTOR OF REFLECTED WAVES. V.Ciarletti[1], J.J. Berthelier[1], R. Ney[1], A. Reinex[2] and B. Martinat[2], [1]CETP/IPSL 10-12 avenue de l'Europe, 78140 Velizy, France, ciarletti@cetp.ipsl.fr, [2] IRCOM, UMR 6615 CNRS-Université de Limoges, Limoges, France.

Introduction: The GPR on NETLANDER aims at measuring the distance of the underground structures which reflect the transmitted electromagnetic waves as well as the direction of propagation of the reflected waves. The idea is thus to achieve a 3D imaging of the subsurface using only a single monostatic radar at a fixed position. The propagation vector **k** is deduced from the electric and magnetic components of the returning waves. The GPR makes use of 3 monopole electric antennas deployed on the ground and disposed according to the presently foreseen geometry of the solar panels: monopoles 2 and 3 are at 144° from monopole 1 which is along the X axis. These antennas are used both for transmission and reception. In reception they provide the horizontal vector $\mathbf{E_h}$ of the electric field. There is one receiving magnetic antenna which can be positioned along 3 mutually orthogonal directions, thus providing the 3 components of the vector magnetic field **H**. From **H** and $\mathbf{E_h}$ one can compute **E**. The **k** vector is then obtained through **ExH**, by making the hypothesis, in a first step, that the returning wave can be considered as a plane wave, which has been proved to be consistent with the simulation results.

In this paper we display some initial results obtained by a numerical simulation aimed at investigating the main capabilities of the GPR. The martian subsurface has been represented by a series of layers with various thickness and electromagnetic properties. These parameters have been chosen in accordance with the present best estimates of the martian underground structure. However, results presented in this paper do not depend on the adopted values of these parameters and can apply in a wide range of situations. To present the most important radar capabilities and performances, we have concentrated on waves reflected at the interface between the [sediment + ice] and [basalt + ice] layers which is located at a depth of 400 meters in our model. For most of the cases which have been considered, and to ease the interpretation of the results, we have worked with a simplified 1D geometry with only 2 electric monopoles opposite to each other

Electric Antenna Radiation Pattern: An important characteristics of the GPR is to have a movable antenna pattern, which allows to vary the "illumination" of the subsurface. Some results are shown in more details in the general presentation of the instrument. In the simplified 1D geometry that is considered here, this is obtained by shifting the phase of the signal feeding the monopole 2 relative to the signal feeding monopole 1. This phase shifting is, in fact, achieved on the data recorded from the successive independent operations of each monopole: the antenna pattern will thus be numerically synthesized off line. With no phase shift the radiation pattern has a maximum along the vertical direction; with a 120° phase shift applied to monopole 2 the radiation pattern is displaced along the X axis enabling a larger part of the reference interface plane at 400 meters to be conveniently illuminated.

Propagation and Reflection in the case of inclined or non plane interfaces : We have first checked the accuracy of the numerical model in the simplified 1D configuration with a smooth plane interface at 400 meters inclined at 20° with respect to the horizontal plane or even with non plane interfaces. The direction of the propagation vector **k** for the returning waves is in perfect agreement, within less than 1°, with the anticipated value.

Propagation and Reflection in the case of a rough interface : In this section we present similar results as above but in a more realistic case where the boundary between the [sediment + ice] and [basalt + ice] layers is a non plane rough interface. For the seek of simplicity and in accordance with the 1D geometry of the 2 monopoles, we have only considered a 1D roughness along the X direction. It is evidently not possible to ascertain the validity of the chosen roughness parameters for the martian conditions. Nevertheless, for the large scale, the calculated interface profile appears to correspond fairly well to geological situations which can be observed on Earth and, for the smaller scale, certainly to a roughness larger than what can be deduced from published images of the surface of Mars.

A detailed analysis of the returning waves will be presented for 2 different sets of roughness parameters. The most intense signals correspond to specular reflection on parts of the interfaces which displays the convenient orientation. Using a plane wave approximation we were able to interpret the characteristics of the returning signals in terms of the geometrical properties of the layered structure beneath the location of the transmitter.

From a number of simulated cases with different set of roughness coefficients, we have been able to reconstruct the main statistical properties of the frequency spectrum of the intensity of reflected waves. Statistically the increase loss on the reflected signal is less than ~6 dB thus very small compared to the average propagation loss and also compared to the uncertainties of our model. This seems to indicate that, within the range of validity of our model, the diffusion on rough interfaces will not significantly affect the radar performances.

A PROPOSAL FOR AN INTEGRATED GEOPHYSICAL STRATEGY TO "FOLLOW THE WATER" ON MARS, S. M. Clifford[1], J. A. George[2], C. R. Stoker[3], G. Briggs[3], and D. W. Beaty[4]. [1]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058, clifford@lpi.usra.edu. [2]NASA Johnson Space Center, Houston, TX 77058, jeff.george@jsc.nasa.gov. [3]NASA Ames Research Center, Moffet Field, CA 94035, cstoker@mail.arc.nasa.gov, gbriggs@ mail.arc.nasa.gov. [4]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, David.Beaty@jpl.nasa.gov.

Introduction. The search for subsurface water has become a primary focus of Mars exploration. Its abundance and distribution (both as ground ice and groundwater) have important implications for understanding the geologic, hydrologic, and climatic evolution of the planet; the potential origin and continued survival of life; and the accessibility of a critical *in situ* resource for sustaining future human explorers.

For these reasons, a principal goal of the Mars science, astrobiology, and the HEDS programs is to determine the 3-D distribution and state of subsurface H_2O, at a resolution sufficient to permit reaching any desired volatile target by drilling [1]. The three targets most often discussed are: groundwater, massive deposits of near-surface ground ice (associated with the ponded discharge of the outlfow channels or the relic of a former ocean), and ice-saturated frozen ground. Based on the present best estimates of mean annual surface temperature, crustal thermal conductivity, geothermal heat flow, and groundwater freezing temperature, the mean thickness of frozen ground on Mars is expected to vary from ~2.5-5 km at the equator to ~6.5-13 km at the poles [2]. However, natural variations in both crustal heat flow and thermal conductivity are likely to result in significant local departures from these predicted values. The recent discovery of "young" fluvial-like features, emanating from the slopes of local scarps, raises the possibility that liquid water may also exist episodically at shallow (~100 – 500 m) depth [3]; however, the true nature and absolute age of these features remains highly uncertain.

Although the belief that Mars is water-rich is supported by a wide variety geologic evidence, our ignorance about the heterogeneous nature and thermal evolution of the planet's crust effectively precludes geomorphic or theoretical attempts to quantitatively assess the current geographic and subsurface vertical distribution of ground ice and groundwater [4]. For this reason, any exploration activity (such as drilling) whose success is contingent on the presence of subsurface water, must be preceded by a comprehensive high-resolution geophysical survey capable of assessing whether local reservoirs of water and ice actually exist. Terrestrial experience has demonstrated that the accurate identification of such targets is likely to require the application of multiple geophysical techniques [5].

In this abstract we propose an integrated strategy for the geophysical exploration of Mars that we believe represents the fastest, most cost-effect, and technically capable approach to identifying the state and distribution of subsurface water. Challenges and alternatives to this strategy will be invited and discussed during the week-long *Conference on Geophysical Detection of Subsurface Water on Mars* that will be held at LPI August 6-10, 2001.

Global vs. Local Investigations. One of the most critical issues for developing a coherent geophysical strategy to assess the distribution of subsurface water is the appropriate role and timing of global vs. local investigations. The principal attributes of local investigations (such as lander-based GPR) are their relative simplicity and their ability to "map" local variations in dielectric properties (that are potentially indicative of variations in lithology and volatile content) at high resolution. However, given the natural scale and variability of crustal properties, the structure, lithology, and distribution of H_2O, is likely to differ significantly from one location to another [4]. Therefore, to have any confidence in accessing a particular volatile target, drilling operations must necessarily be limited to those sites where local geophysical investigations have already been performed.

A strategy to search for water by proceeding directly to the use of high-resolution local surveys has a significant drawback – for while such surveys may help determine the local distribution of volatiles to high precision, they provide no global context. Thus, while a high-resolution investigation might suggest the presence of a specific volatile target at a depth of 500 m at one location, it could well miss the opportunity – located only 20 km away – where that same volatile target was present at a depth of 100 m. Differences of this magnitude could well be critical to the success or failure of any follow-on drilling effort.

The above argument suggests that local investigations are most effectively employed following the completion of an initial global geophysical reconnaissance. Although such surveys may be unable to resolve the fine-scale distribution of ground ice and groundwater, they can aid in the identification of moderate- and regional-scale characteristics that can be used to identify the most promising local sites for further study. In this way, global investigations can be used to target local surveys (conducted by aerobots, dense local surface networks, and other techniques) that can verify and map the distribution of potential volatile targets at a resolution sufficient to direct the placement and operation of both shallow- and deep-subsurface drills [1].

Proposed Strategy. Based on the above reasoning, we propose a two-phase approach to the search for subsurface water on Mars. The first consists of missions devoted to characterizing the large-scale global distribution of volatiles within the top ~5-10 km of the crust. Currently, the most promising candidates for such a survey are: (i) a polar-orbiting radar sounder/interferometer (consisting of two or more spacecraft with radars that operate at the same frequencies), and (ii) a 20+-station global geophysical network, employing both seismic and electromagnetic techniques. The second "high-resolution" phase would then follow this initial global reconnaissance with more focussed investigations of promising local sites ($<10^2$ km^2 in area) identified from the global data.

Polar-orbiting radar sounder/interferometer. An orbital radar sounder has a distinct advantage over other water-detecting geophysical methods in that, given an optimal design, such a sounder has the potential to provide global coverage at moderate resolution using a single spacecraft – a potential that no other technique comes close to approaching.

The first attempt at such an investigation will be made by the 2003 Mars Express mission, which will include a multifrequency radar sounder called MARSIS. Given ideal conditions, MARSIS is designed to detect the presence of liquid water at depths ranging from ~1 – 5 km. MARSIS represents a major milestone in the study of water on Mars, because it marks the

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transition from debates over poorly constrained geomorphic and theoretical analyses to discussions of actual data regarding the potential distribution of water and ice in the subsurface.

However, because Mars Express includes a number of other high-level investigations, MARSIS has been forced to accept some compromises in mission and spacecraft design that have limited its potential capabilities. Chief among these is the high eccentricity of the spacecraft's orbit, which significantly reduces both the time at which MARSIS is at its optimal sounding altitude and its ability to utilize data from previous orbits to reduce noise and improve resolution. For this reason, even a simple reflight of MARSIS in a more circular orbit would realize significant benefits – permitting data from adjacent orbits to be coherently processed to create an effective 2-dimensional aperture that would virtually eliminate cross-track clutter and increase cross-track resolution [6].

Additional improvements that could be made to future orbital radar investigations include enhancements in antenna size and geometry, transmitted power, number and range of operational frequencies, bandwidth, receiver sensitivity, utilization of alternate signal waveform designs and the flight of two (or more) receivers – either boom-mounted on the same orbiter or, ideally, located on separate polar-orbiting spacecraft. The opportunity for orbital interferometry, created by flying radars on multiple spacecraft, could greatly aid the 3-dimensional characterization of the crust – helping to discriminate between structural, lithologic and volatile signatures in both the near- and deep-subsurface [6].

Global geophysical surface network. Although a ~20+-station seismic and electromagnetic network will not have sufficient spatial resolution to verify the orbital radar sounder observations in detail, the seismic and electrical properties of the crust, assessed by such a network mission, could provide an important independent test of the large-scale volatile distribution and stratigraphy inferred from the radar data. Higher-resolution studies could also be performed in local regions by distributing the geophysical stations in clusters of 3-4, providing important data on crustal properties that could significantly aid the identification of lithologic and volatile units. This ability would be further enhanced by the inclusion of multiple geophysical investigations, such as seismometers, magnetotelluric instruments and GPR, onboard each station. Such a mission might also include the acquisition of local compositional and thermophysical data that could assist in both interpreting the geophysical sounding results and characterizing the global range of material properties that might be encountered in drilling. A network of this type could be emplaced by either a single mission (with stations dispersed from a polar-orbiting bus) or be built up incrementally, over two or more successive launch opportunities. The four-station NetLander mission in 2007 is an important first step in this effort, which could potentially be augmented (by CNES, NASA, or ESA) with the additional stations required to create a 20+-station global network in 2009.

High-Resolution Characterization of Local Sites. An expected result of the first phase of global reconnaissance will be the identification and prioritization of candidate sites for more focussed investigations. There are a variety of potential platforms and instruments that might be employed in such an effort, ranging from high-density surface networks to aerial surveys conducted by aircraft, aerobots, or balloons. For this reason, the only requirement for this type of investigation is an operational one – that, whatever its design, it be capable of resolving the location of a potential volatile target at sufficiently high spatial resolution to guide the placement and operation of a follow-on drilling investigation.

Summary. Knowledge of the distribution and state of subsurface water is of fundamental importance to astrobiology, human exploration, and to our understanding of how Mars has evolved as a planet. Developing a comprehensive geophysical strategy to address these issues represents the next logical step in any effort to "follow the water". The single most important investigation in such an approach would be the flight of an advanced, polar-orbiting radar sounder/interferometer that could potentially be flown during the second half of this decade. Such a mission would be most logically followed by a 20+-station global geophysical network to provide complimentary data on the global- and regional-scale seismic and electromagnetic properties of the crust.

In recognition of the importance and technical complexity of these issues, the *Conference on Geophysical Detection of Subsurface Water on Mars* is being held to:

- clarify the reasons why a global geophysical reconnaissance of Mars is needed,
- identify the types of investigations (orbital, global surface network, and high-resolution local) that are best suited for determining both the state and 3-dimensional distribution of subsurface water,
- assess the diagnostic limitations and potential environmental complications associated with such investigations, and
- determine what other areas of Mars science would benefit from the acquisition of this proposed suite of geophysical data.

Given the enormous base of experience that already exists in these areas within the terrestrial research and exploration communities, the participation of terrestrial scientists is actively encouraged.

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GEOPHYSICAL METHODS TO DETECT GROUND ICE PRODUCED BY RECENT FLUID FLOWS ON MARS. N. M. Coleman, Member of the American Geophysical Union and the Health Physics Society (252 Johnston Lane, Mercersburg, PA 17236, nmc@nrc.gov).

Introduction: Geologically recent fluid flows have eroded gullies in steep slopes at the surface of Mars [1]. Ancient gullies have not yet been seen, perhaps because steep slopes on Mars are highly susceptible to physical erosion and backwearing. Nearly all of the flows occurred where liquid water is unstable at the surface throughout the Martian year [2]. This suggests that the fluids are brines, and if so, they present unique opportunities to directly sample ice derived from Martian groundwater and any extant life it may contain. Aquifers provide suitable refuges for the long-term survival of life that may have evolved early in Martian history [3]. Possible evidence of life in Martian meteorites [4] is an incentive for this search. As experiments on Earth have shown, spore-forming bacteria 250 million yrs old can be isolated and grown [5]. If brines have been released, deep drilling through rock may no longer be needed to recover groundwater samples. The flows formed gullies along steep slopes of depressions at mid to high latitudes where temperatures allow water ice to be stable near the surface [6]. The released water should have quickly refrozen at the base of the steep slopes below the outflow points. Current rover technology can be adapted to detect shallow ground ice in the floors of depressions where the groundwater outflows would have collected, infiltrated, and frozen. A test of this model would be the detection of shallow ground ice and evaporites at the infiltration sites. These sites are promising targets for sample return missions, but large target areas are needed to accommodate the uncertainty ellipses in landing zones. Sites like this can be surveyed by Mars Odyssey, which will study the mineralogy and abundance of H in surface layers. Other useful sites to study from orbit include landslides in the Valles Marineris, which have exposed the interiors of ancient aquifers, and the lowest points in Hellas, where groundwater-fed lakes may have existed for long periods.

Various ideas seek to explain the groundwater outbreaks, including the melting of ground ice by heat from igneous intrusions, meteorite impacts, or tectonic movements [7, 8]. Given that average annual surface temperatures are < 220°K, the fluids must be either brines or CO_2 as a liquid or gas [9]. Models that invoke release of CO_2 may be viable because theoretical studies [10] suggest that the Martian cryosphere is ~2-6 km thick. However, Table 1 (using eq. 2 of [10]) shows that a eutectic NaCl brine (freezing point ~252 K) could exist at shallow depths in places where ice-free layers of low thermal conductivity exist at the surface (dry soils and some vesicular basalts can have thermal conductivities <0.2 W/mK [10]). These layers may consist of eolian deposits and impact ejecta. Under these circumstances brines could interact strongly with the atmosphere, consistent with a recent isotopic study [11].

Table 1. Estimated Depth to 252°K Isotherm

	Present obliquity ~25°		*Obliquity ~38°	
Lat.°	MAT	Depth (km)	MAT	Depth (km)
80	157	0.42	173	0.35
60	179	0.32	191	0.27
40	206	0.20	206	0.20
20	215	0.16	213	0.17

Geothermal flux ~ 45 mW/m^2
Melting point ~ 252 °K
Thermal conductivity of ice-free layer ~ 0.2 W/mK
MAT is mean annual surface temp (°K)
* Maximum obliquity may reach ~49° [12]

Over eons, Martian groundwater has almost certainly evolved to a strong brine, considering long residence times, rapid rates of surface evaporation, and atmospheric loss of volatiles. The brine composition will vary spatially as a function of physical conditions, solute species and strength, and the types of stable and metastable salts in contact with the fluids. Viscous cold brines would reside in high-permeability zones (basalt flow-top breccias or impact ejecta) which would permit them to slowly migrate under small pressure, concentration, and thermal gradients. Lateral migration toward outcrops is favored because permeability in layered strata tends to be larger horizontally than vertically.

Geophysical Methods: Geophysical methods can readily assess the presence and abundance of shallow ground ice. Electrical methods could also be used, but this report focuses on nuclear techniques, especially neutron methods, because they are highly sensitive to the presence of H as a surrogate for liquid or frozen water, or water chemically bound in clays and other minerals. The key to evaluate the abundance of ground ice is to *simultaneously* map the subsurface bulk density and relative H abundance along continuous rover transects. Density data cannot be obtained from orbit – a lander or rover is needed. The methods described below are extensively used in exploration for groundwater, hydrocarbons, and nondestructive materials testing.

Neutron methods. Neutron detectors were used on Lunar Prospector and are onboard the 2001 Mars Odyssey mission. Neutron logging is commonly used on Earth to evaluate the water-filled porosity in a rock

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formation adjacent to a borehole, or to evaluate the volumetric content of moisture in unsaturated zones. Fast neutrons emitted by an active source pass through the surrounding media and are slowed (thermalized) to varying degrees by collisions with atomic nuclei. Hydrogen is especially effective. In colliding with a H nucleus, a neutron loses, on average, 63% of its energy compared to 12% lost colliding with an O nucleus [13].

Different types of neutron logs are made by counting scattered neutrons at various energy levels. Measurements of epithermal neutrons (0.1 to 100 eV) provide the highest % of response due to H and are least affected by other elements that are also good moderators (e.g., B and Cl) [13]. Neutron methods are so sensitive to the presence of water that they can be used to study infiltration and volumetric moisture content in unsaturated rocks and sediments in desert regions [14]. Variations in water content of a few % can be discerned. An excellent detector for thermal neutrons in the presence of a gamma field is the BF_3 detector [15]. It is a gas-filled detector that uses B-10 enriched to ~96% for increased sensitivity. B-10 has a very high cross section (σ = 3840 barns) for thermal neutrons. These neutrons interact with and are absorbed by B-10, which then emits charged particles (alphas and lithium ions) which are easily detected [16]. Various shields can be used with a BF_3 counter to absorb thermal neutrons and detect higher-energy neutrons in the epithermal range. Detecting both thermal and epithermal neutrons helps to determine whether moderators such as Cl are abundant in the target in addition to H. He-3 counters (σ = 5330 barns) are also used for neutron detection, but gamma ray discrimination is more difficult than for equivalent BF_3 tubes [16]. Various neutron sources could be used. Cf-252 spontaneously fissions and has a high emission rate of 2.3E6 neutrons per second per microgram Cf-252 [15]. The average value of the neutron energy distribution is 2.3 MeV. Hybrid sources produce neutrons by bombarding Be with alpha particles. Ra-Be sources produce average neutron energies of 5 MeV with a yield of 1.7E7 neutrons per sec per Ci [15]. This hybrid is also a strong gamma source, which can help assess the density of surficial materials.

Gamma density logging. The density of near-surface materials can be estimated by logging the formation response to a gamma source. Gamma rays interact with rock or soil mainly by Compton scattering. The intensity of the scattered gamma rays is an exponential function of the density of the target materials [13]. This gives a more complete picture of subsurface conditions when used with neutron methods. Density data can only be obtained using a lander or rover.

Discussion: Nuclear methods provide efficient and reliable ways to detect shallow ground ice, and have the advantage that the sources require no power and the detectors need little power to operate. The depth of penetration of the methods discussed depends on underground properties and the intensity of the nuclear sources. Modest penetration of <2 m will suffice because the goal is to locate rich deposits of near-surface ground ice derived from recent groundwater flows. This would guide future missions to collect samples for in situ analysis or Earth return. The most promising areas would have the strongest epithermal neutron scatter combined with bulk density variations consistent with interstitial ice. A strong Cl signature may also be present. The more distance a rover can cover, and the longer it survives, the greater the chance of finding shallow ice. To ensure long life for a rover, power and heat can be obtained from radioisotope thermoelectric generators (RTGs) and heater units. RTGs continue to power deep space probes decades after launch. Sagan Memorial Station (Mars Pathfinder) might still be active if it had Viking-era power sources to warm it through the frigid Martian nights.

Conclusions: Geologically recent fluid outbreaks on Mars present unique opportunities to recover possible extant life. Current rover technology can be adapted to use nuclear sources and detectors to locate shallow ground ice for sample return missions. As experiments on Earth have shown, 250-million-year-old microbes can be isolated and grown [5]. The recovery and return of Martian life constitutes a "Holy Grail" of planetary exploration. A possible path to that prize is in sight.

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DETECTION OF SUBSURFACE WATER ON MARS BY CONTROLLED AND NATURAL SOURCE ELECTROMAGNETIC INDUCTION

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Detection of subsurface liquid water on Mars is a leading scientific objective for Mars exploration in this decade. We describe electromagnetic induction (EM) methods that are both uniquely well suited for detection of subsurface liquid water on Mars and practical within the context of a Mars exploration program. EM induction methods are ideal for detection of more highly conducting (liquid water bearing) soils and rock beneath a more resistive overburden. A combined natural source and controlled source method offers an efficient and unambiguous characterization of the depth to liquid water and the extent of the aqueous region. The controlled source method employs an ac vertical dipole source (horizontal loop) to probe the depth to the conductor and a natural source method (gradient sounding) to characterize its conductivity-thickness product. These methods are proven in geophysical exploration and can be tailored to cope with any reasonable Mars crustal electrical conductivity. We describe a practical experiment and discuss experiment optimization to address the range of material properties likely encountered in the Mars crust.

AN INTEGRATED TECHNOLOGICAL PROPOSAL FOR DRILLING AND IN-SITU SCIENCE FOR THE 2007 MARS LANDER MISSION. A. Coradini[1], F. Angrilli[2], M. C. De Sanctis[1], E. Flamini[3], S. Espinasse[3], R. Orosei[1], E. Re[4], [1]Istituto di Astrofisica Spaziale - CNR, Roma, Italy, [2]CISAS, Padova, Italy, [3]Agenzia Spaziale Italiana, Roma, Italy, [4]Tecnospazio S.p.A., Milano, Italy.

Introduction: Drilling the Martian subsurface are motivated by different scientific and engineering interests associated with the geologic, hydrologic, and climatic history of the planet, the search for life and the identification of potential hazards and resources for future robotic and human exploration. The main objectives of a drilling program for Mars are:

- to understand the distribution and state of subsurface water and other volatiles
- to understand the geology and evolution of the upper crust and regolith
- to determine the nature and distribution of oxidants as function of depth
- to search for organic molecules and other potential indicators of past or present life
- to characterize the geophysical properties, including heat flow, stress and strain
- to characterize volatile-bearing mineralogy with depth.

Drilling into the near-surface crust will provide an opportunity to assess variations in composition, texture, stratification, unconformity, etc. that will help define lithology and structure, and provide important clues regarding origin and subsequent modification. Mineralogical analysis is required to identify and quantify the mineralogical constituents with respect to water content. Mineralogical and chemical compositions, texture, and primary structure are important parameters for identifying igneous, metamorphic and sedimentary rocks. These parameters are best characterized in context by drilling into Mars. The composition of the Martian crust (elemental, chemical and mineralogical) is the single most important parameter that can be measured as a function of depth. The composition of the regolith and crustal rocks provides important information about the geologic evolution of the near-surface crust, the evolution of the atmosphere and climate, the existence of past or present life, and the presence of potential resources and hazardous materials for both human explorations and advanced robotic missions

Down-hole science can determine the composition and granularity of different layers, and identify the mineralogy of individual grains through dedicated miniaturized instruments, that can be allocated into the drill. Furthermore, temperature and thermal diffusivity sensors, radioactivity dosimeters and spectrometers, resistivity and/or dielectric constant sensors can be allocated in the drill.

The drilling program for Mars's exploration developed by MEPAG foresees to reach different depths in successive mission. There are three primary breakpoints in the issue of science return vs. depth of drilling: 1-5 m, 10-20 m, 50-150 m. Investigations extending to depths of 1-5 meters would provide key information regarding regolith physical properties, petrology, and volatile transport. Depth of 10-20 m is so that there is a chance of penetrating below the surface oxidized layer (estimated to range from ~1 - 10 m), which would enable critical studies of organic geochemistry and astrobiology. This depth is additionally needed to measure the heat flow, and it may also be sufficient to reach ice-saturated frozen ground (depending on the latitude of the landing site). Accessing bedrock is possible in a 10-20 m hole, but it is much more likely in a 50-150 m hole. Depending on the landing site, a 50-150 m hole may reach segregated bodies of massive ground ice, and it would likely access a significant region of ice-saturated frozen ground.

With present technology, investigations to depths of as little as a few meters would provide significant opportunities for improving our knowledge of Mars, proving data that are critically needed to plan future investigations.

Description of the Italian Proposal: The proposed solutions here reported have been identified according the possible allocated resource of mass, energy and time, and the time constraint for the 2007 mission. These constraints ask for not only deep miniaturization as well as low power but also for sufficiently mature technological developments.

The development of different instruments is strongly dependent on the Drill configuration considered. In fact, a drill able to collect and distribute samples will be associated with both in situ experiments and with a small micro-laboratory able to perform detailed analyses on the collected samples. In what follow, we report, as an example, the instrument package selected for the 2003 NASA lander mission. Obviously other suites of experiments can be added depending on the lander resources and sharing between partners.

The instruments here described, as well as the concept of the shallow drill have been already studied, not only at laboratory level, but also with selected Industrial Prime Contractors. The Phase A of the drill, minilab and experiments has been already concluded, therefore the breadboard of them can surely be ready in less then two years.

Tecnospazio has studied the Drill Sampler Tool (DST) concept under direct guidance of the Italian Space Agency (ASI), as a multi-purpose tool to be used in different space missions. In fact a similar sampler device has been already developed for the lander of the Rosetta mission. The original Drill Sampler Tool, during the assessment and the Phase A, was modified in order to be used as a real scientific system. Moreover it was also foreseen to calibrate the drill torque/force in order to use it as a tool to characterize soil mechanical properties. The scientific team, therefore, was also involved in the definition of the new drill configuration. ASI has proposed this concept to JPL for the missions in 2003 and 2005; in that occasion the system was named DeeDri.

Ma_Miss (Mars Multispectral Imager for Subsurface Studies) is a miniaturized imaging spectrometer designed to provide imaging and spectra in VIS/NIR for studies of Martian subsurface layers. The instrument can be integrated into the drill and will be able to provide an image of a "ring", to determine the composition and granularity of different layers, and to identify the mineralogy of individual grains. Ma_Miss main objectives are to detect the presence of layers containing clays, carbonates and alteration products, to identify the grain size distribution and grain structure at different depths along the walls of the hole, and to study the mineralogy of single grains through their spectrum.

IPSE (Italian Package for Science Experiments) is a scientific autonomous micro-laboratory for Mars's soil and environment analysis providing the capability to serve, handle and manage scientific miniaturized instruments accommodated inside its envelope. The IPSE concept has been developed by the CISAS group of the Padua University, in strict co-operation with the prime contractor Tecnomare. A small robotic arm is stowed inside the envelope and provides the capability to deliver soil samples to the instruments from the Drill. Its general configuration is based on a structure with an external envelope to fit also the small lander. IPSE is designed to operate in Martian environmental conditions and for a lifetime of one Earth year with the aim to be upgraded at each launch opportunity. A modular philosophy has been implemented to allow the maximum level of de-coupling between IPSE and the experiments. IPSE includes the four scientific instruments here after described (IRMA, MA-FLUX, MAGO, MARE-DOSE)

IRMA (Infra-Red Microscope Analysis) is a hyperspectral microscope for the in-situ mineralogical analysis of Martian samples. It works in the 1-5 μm spectral range, with a spectral resolution of 8 nm. Its spatial resolution is 38 μm and the overall field of view is compatible with the sample dimension collected from the DEEDRI drill (12-mm diameter). The investigation carried out by IRMA has the goal to quantitatively characterize the mineral and the micro-physical properties of Martian subsurface samples.

MA_FLUX (Mars X FLUorescent Experiment) will investigate the Martian surface using the X-ray fluorescence technique, thus allowing the detection of the major and trace chemical elements in the Martian soil, down to a few ppm, using simultaneously the gamma scattering method and the X-ray fluorescence technique. This instrument investigates the interior of samples to a depth ranging between one mm and one cm.

MAGO (Martian Atmospheric Grain Observer) measures cumulative dust mass flux and dynamical properties of single intercepted particles as a function of time. It allows determination of grain mass, size and shape distribution, and dynamic behavior of airborne dust. It is a single instrument including three different detection sub-systems: three micro-balances as detectors of mass deposition, a grain detection system, and an impact sensor.

MARE-DOSE (Mars Radioactivity Experiment-DOSimeter Experiment) is an experiment for monitoring the β and the γ radioactivity during the Earth to Mars cruise phase and at the surface of Mars, in the range 30-300 keV. It consists of lithium-fluoride doped pills which can be exposed to the radiation, reset and readout by heating the pills within a thermo-luminescent process during heating cycle and the emission of an optical signal flux proportional to the absorbed dose.

Deep drill concepts could probably not allow the sample delivery due to the complexity of such an operation; nevertheless deep drill concepts can include the Ma_Miss and the already mentioned temperature, thermal flux, diffusivity and radioactivity sensors. The selection of the solution will be tied to the specific depth objectives of the drilling activity, the risks that are willing to be taken, and the geologic material of the drill site. Generally the solutions range from the low risks of the DST that can attain depths of 2 metres, to the higher risk drilling technologies, currently under study at Tecnospazio, that can reach a few tens of metres of depth, or, in the case of the innovative worm concept, even hundreds of metres.

DEBRIS FLOWS ON MARS: COMPARISON WITH TERRESTRIAL ANALOGS. F. Costard[1], F. Forget[2], N. Mangold[1], D. Mercier[3] and J.P. Peulvast[1], [1]UMR8616, ORSAYTERRE, Equipe de planétologie, Université Paris-Sud, 91405, Orsay Cedex, France. fcostard@geol.u-psud.fr, [2]Laboratoire de Météorologie Dynamique, Université P. & M. Curie, Jussieu, France, [3]Université Paris-Sorbonne, UFR de Géographie et d'Aménagement, Paris, France

Introduction: The new discovery of recent runoff landforms on Mars [1] has renewed the question of liquid water stability in the surface and subsurface of Mars. Malin and Edgett [1] proposed a subsurface origin for the liquid flow. However there is a large variety of such landforms which are distributed in very different geological context and latitudes from 30° to 72°. We suspect that different processes could have played a role in the development of recent run-off features. According to terrestrial analogs in periglacial regions we discuss the possibility to explain some of these landforms by debris flows only due to surface and near-surface (<10 m) melt of volatile-rich material. Such interpretation has important consequences in term of recent climate change.

Observations on Mars: Debris flow is the term used by Malin and Edgett [1] to describe downslope flow of debris mixed with a significant amount of water within the walls of impact craters. They mostly occur in a latitudinal band higher than 30°. The upper part of the walls have a steep slope that is dissected by channels whereas thick accumulations of debris cover the bases of escarpments. The upper part of the slopes (mostly south facing slopes in the southern hemisphere) exhibits alcoves, with generally broad and deep runoff channels. They are characterized by their distinct V shaped channels with well-defined levees. Individual channels exhibit low sinuosity and deep erosion down to the fans that bury the lower parts of the crater walls (fig. 1). As it was previously suggested, the morphology of these debris flows suggests several rapid mass movements of debris [1].

Terrestrial analogs: On Earth, debris flows occur in periglacial environments when soils begin to be heavily saturated with water after the melting of the snow cover and/or the ground ice [2]. The initiation process of flow is still not yet fully understood. Their formation on Earth in periglacial environments occurs when soil begin to be charged with water after the melting of the snow cover and/or the near surface ground-ice. This initiation can be either due to water saturation by a peak intensity of rainfall events, or to a rapid snowmelt (or melting of ground ice) with subsequent saturation or to a seismic event [3 to 6]. Liquefaction process is also proposed.

Field observations indicate that snow covers play an important role on the dynamic of these debris flows. Materials in the regolith are generally coarser and poorly sorted. The duration of these debris flows is extremely variable and may occur as a single or multiple events. The deposition occurs along the narrow channel in levees of very coarse materials with boulders. The end deposits are lobate form

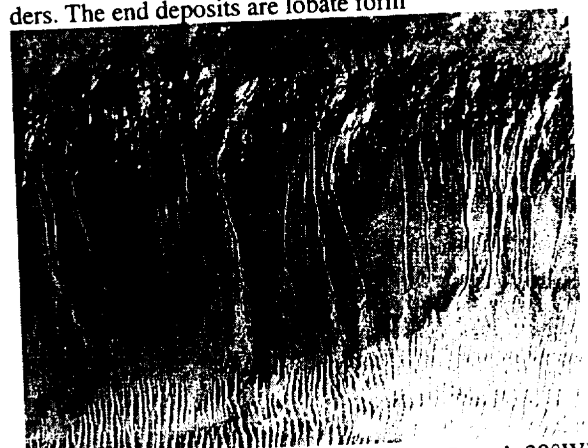

Figure 1: Debris flows on Mars (29°S and 39°W). MOC image, MSSS. Total length of debris flows is 900 m.

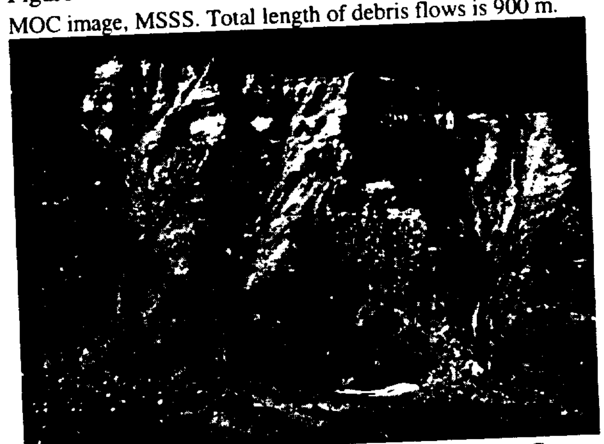

Figure 2: Debris flows in Jameson Land (East Greenland). The mean length of the transport zone is about 500 meters (Costard and Peulvast, 1987).

Debris flows were observed by two of us (F. Costard and J.P. Peulvast) in East Greenland (Jameson Land) during a field trip in 1987 and 1989 [7]. Jameson Land (70 to 71°N) is located north of the Scoresby Sund fjord and comprises wide plateaus of 600 to 1000 m high mainly composed of clastic sediments (sandstones, mudstones and shales from Permian to Lower Cretaceous age). The mean annual temperature is –10°C, so the ground is permanently frozen. This

C, so the ground is permanently frozen. This implies that no water sources were observed on the field. Summer maximum and winter minimum temperatures are +20°C and -43°C respectively. Rain is likely to exist and produce some of these landforms though this region is submitted to a dry climate and showers are not frequent.

Several debris flows were studied on the eastern slope of a 500 m elevated cuesta. Below simple or multiple channels, their deposits form fans whose top is found up to 60 m above the base of the slope. The source areas of the flows corresponds to deep alcoves of about 15 m to 60 m high and 20 to 100 m wide. The mean length of the transport zone is a about 300 to 500 meters, on a slope of about 25-30° (fig. 2). Levees are observed on both side of these channels as a continuous and narrow ridges rising 10 to 50 cm above the surrounding slope.

Their characteristics are similar to those of the Martian debris flows [8]. Seasonal snow covers occur in the alcoves. Interstitial ice is found within the soil. It occurs under the surface and can be seen to a depth of several meters. These landforms all result from surface processes due to snow melting and permafrost melting near the surface [8].

Stability of liquid water and climatic implications. The comparison between Martian and terrestrial landforms leads to the conclusion that surface processes could explain many of the described features. Such processes imply that liquid water can appear in the first meters of the Martian subsurface. Every landforms are located at latitudes higher than 30°. Therefore, they are located in regions where the Martian permafrost is supposed to contain ground ice in the near-subsurface, less than 10 meters deep [9]. This ground ice may represent one source of liquid water for the debris flows. However, this conclusion is contradictory with the usual consideration that liquid water can not exist at the surface because of the low pressure and temperatures [9].

Recent climatic changes, may be possible considering the large pseudo-cyclic variations of the obliquity and excentricity of the planet at the scale of 100,000 years. An obliquity of more than 40° would increase both maximal temperatures in polar regions and atmospheric pressure due to CO_2 sublimation. Recent martian landforms produced by liquid flows are rare and only associated to hillslopes. They probably represent transient processes that might occur when climatic conditions were at one extremity of the possible ranges of conditions in the recent past.

A near surface perched talik ?: As it was previously proposed by Malin and Edgett [1], some of these debris flows would result from springs fed by shallow aquifers. Among this large variety of surface runoff features, two unusual examples of large-scale debris flows retain our attention. In both cases, the most spectacular erosion landforms occur precisely at the intersection zone between crater rims and wrinkle ridges [10]. These hypothetic ground water layers are similar to taliks observed in Siberia. They correspond to unfrozen zones within the ground ice [2]. Some of these taliks are due to the thermal disturbance of rivers or lakes. Other taliks result from local heat sources, including ground water circulation. In Siberia, some taliks occur along fault structures and water, under hydrostatic pressure, is injected along the fractured rocks. Water usually emerges from the lower part of the slope producing springs. But, under hydrostatic pressure, springs may occur in the upper part of hills or slopes. On Mars, the fault structure in association with the impact crater and the wrinkle ridge must favor a relatively high porosity. According to Clifford, a few billions years ago, thermal vapor diffusion may have led to the development and maintenance of near-surface perched aquifers (estimated depth 100-150 m) [11]. The emergence of water under pressure along fractures or faults would reach the crater rim producing a large slurry flow of a volatile rich rock debris.

Geophysical sounding : Further works has to be done to fully understand the formation of these landforms and learn if some of them are related to subsurface reservoirs of liquids. The only way to test the debris flow formation is to propose a geophysical sounding of these features. However, different kind of gullies are related to these runoff features, different processes can therefore be implied in their formation [1, 8, 11]. We do not rule out the possibility that some of them are connected to subsurface seepage, especially for the most developed gullies [10]. The detection of an aquifer is of prime interest and should have deep implications in the understanding of the Martian debris flows. A geophysical sounding near debris flows, on the plateau, will offer a unique opportunity to explore the subsurface in order to detect an aquifer.

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Acknowledgements: This work is supported by Programme National de Planétologie de l'Institut National des Sciences de l'Univers (CNRS, France).

MARTIAN VOLATILE-RICH-RESERVOIRS: A REVIEW OF THE NETLANDER PAYLOAD CONTRIBUTION. F. Costard[1], and Ph. Lognonne[2] , B. Banerdt with the ATMIS, GPR, MAGNET, NL-SEIS, and NEIGE teams. [1]UMR 8616, CNRS, Orsay, France, fcostard@geol.u-psud.fr, [4]IPGP, FRE2315/CNRS, 4 Av. de Neptune, 94100, Saint Maur, France, lognonne@ipgp.jussieu.fr

Introduction : Geological and theoretical modeling do indicate that, most probably, a significant part of the volatiles present in the past is presently stocked within the Martian subsurface as ground ice. The detection of liquid water is of prime interest and should have deep implications in the understanding of the Martian hydrological cycle and also in exobiology. In the frame of the 2007 joint CNES-NASA mission to Mars, a set of 4 NETLANDERS developed by an European consortium is expected to be launched in June 2007 [1]. The geophysical package of each lander will include a geo-radar (GPR experiment), a magnetometer (MAGNET experiment), a seismometer (SEIS experiment), a meteorological package (ATMIS experiment) and a Mars Geodesy Experiment (NEIGE experiment) The NETLANDER mission offers a unique opportunity to explore simultaneously the subsurface as well as deeper layers of the planetary interior on 4 different landing sites. The complementary contributions of all these geophysical soundings onboard the NETLANDER stations are presented.

Water reservoirs : The presence of valley networks and outflow channels [2] suggests that liquid water has been present on the surface throughout most of Martian history [3, 4]. Morphological studies (e.g., rampart craters, periglacial features, terrain softening), theoretical modeling [5, 6] and analysis of SNC meteorites, both strongly suggest that a large amount of volatiles (H_2O, CO_2, chathtrates) might still stored within the Martian megaregolith as a deep and global underground ice [5, 7, 8, 9]. Theoretical estimates of the ground ice thickness range from 3 to 7 km near the poles to between 1 and 3 km near the equator [5, 10]. Due to sublimation processes and to the porous nature of the megaregolith, the ground ice table is covered by a dry layer of 100 m to 1 km thick. It is expected that, under the ground ice, liquid water exist, at least at middle latitudes. The depth of the 0°C isotherm could be reduced by both pressure and solute effects [6].

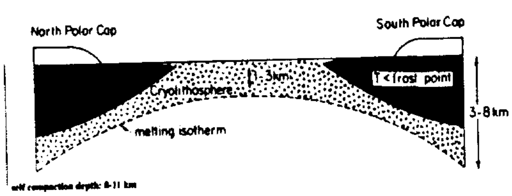

Fig. 1: The Martian ground-ice (from Squyres et al., 1992) [5].

We therefore propose to fly on each of the 4 landers of the NETLANDER mission a set of geophysical instruments to explore the first few kilometers of the subsurface with, as major objectives, the detection of possible water rich layers and the characterization of the main features of the geological structures of the superficial planetary crust. The study of the subsurface, including the ground ice, will be actively performed with a geo-radar, and passively with the magnetometer and seismometer. These geophysical instruments will probe the uppermost kilometers of Mars to search for signatures of ice reservoirs and possible transition to liquid water layers. Simultaneously geophysical studies will give access to the main structural and geomorphological features of the subsurface.

Geo-radar investigations (GPR experiment) : We plan to use a set of 3 monopole electric antennas angularly spaced by 120° and a magnetic receiving antenna to determine the directions of the returning electromagnetic waves and, therefore, obtain a 3D imaging of the subsurface. Three monopole electric antennas powered by a 10 W transmitter are used to transmit electromagnetic waves at a central frequency of 2 MHz with linear as well as planar (circular or elliptical) polarization. Two electric and three magnetic components of the electromagnetic waves returning to the radar are measured. The subsequent signal analysis performed on these data will allow to retrieve the direction of propagation of the returning waves and thus the direction of the reflectors while their distance is obtained from the propagation time of the waves [11]. The possibility to operate with various polarization schemes provides a capability of significant interest for the GPR instrument since it will allow to study in more details the backscattering properties of the reflectors in the subsurface.

A numerical simulation has been performed to assess the performances of the GPR instrument. The model subsurface consisted in a number of layers with depth, thickness and physical properties representative of the expected average Martian subsurface. Results are consistent with the simpler calculation which were performed to design the radar and show that a liquid water interface should be detectable at depths of approximately 2.5 km. During nighttime we foresee to operate the GPR instrument in a passive mode in order to receive the waves emitted by a possible radar onboard MRO.

MARTIAN VOLATILE-RICH-RESERVOIRS: THE NETLANDER CONTRIBUTION : F. Costard and Ph. Lognonné

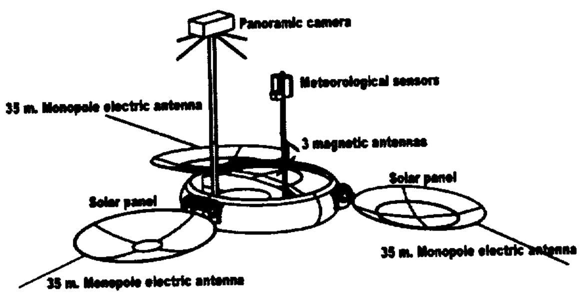

Fig. 1: baseline configuration of the geophysical soundings.

Electromagnetic soundings (MAGNET experiment) : The magnetometer experiment consists of a net of identical ultra small low noise and light triaxial vector fluxgate magnetometer sensor, with a resolution of 0.025 nT. The magnetometer sensor is placed at the surface of Mars, outside the lander, by means of a light deployable boom [12]. The impedance of the internal structure will be deduced from the ratio of the vertical component of the magnetic field and the horizontal gradients of its horizontal component. With simultaneous recordings from three stations or more available, the impedance will be estimated from the frequency-wave vector spectrum of the electromagnetic field using a high-resolution method developed by Pinçon et al., [13]. Below 1-2 km, the determination of the mean resistivity profile will be done with the magnetometer. This will allow the determination of the thickness of the resistive ground ice, and will provide information about the presence (or absence) of liquid water under the ground ice. As the resistivity of the permafrost is very high, the presence of liquid water at the bottom of the ground ice will then correspond to a decrease of the resistivity by two or more orders of magnitude. Simulations have been made with models of resistivity distribution within the Martian ground ice. The model resistivity profiles have been extrapolated from laboratory measurements on water saturated porous rocks for temperature ranging from $-25°C$ to $+5°C$ [14]. The measurements have been made on a sandstone sample of 18% porosity saturated with salted water of conductivity 1 S/m. The obtained results make clear that knowing the apparent resistivities within a precision of about 16% for frequencies ranging from 10 to 0.001 Hertz allows to evidence a conductive layer associated to liquid water below the permafrost, and to get relevant estimates of its depth and integrated conductivity.

Seismological investigations (SEIS experiment): A last piece of information will be done with the seismometer. The output used will be those of the BRB Short period 3 axis seismometer, which will record seismic signals in the band 0.05-50 He with a resolution bettor than $5\ 10^{-9}\ ms^2/Hz^{1/2}$ [15]. The body wave will then be the subject of site effect (see Vinnick et al., 2001 [16] for the use of the receiver function also on the Moon) and the analysis does not need the location of the seismic source, which will allow the use of seismic signals released by the regional quakes. Two parameters will be searched: the first will be the position of the subsurface discontinuities, the latter being smoothed by the magnetic inversion, mostly sensitive to the resistivity jumps. The second will be the seismic high frequency attenuation, which is very sensitive to the water content at depth below the 0°C isotherm.

Climate and water cycle : Netlander also include a meteorological package **(ATMIS experiment)** which will provide some observations of interest to study the climate water cycle. The local relative humidity during warm hours will be monitor day after day from the four landers by the Humicap sensors. Clouds and condensat will be observed by the Optical Depth Sensor (ODS) and the camera. Such observations should allow us to constrain the diurnal and seasonal exchange between the regolith and the atmosphere (adsorption and condensation) as well as the vertical distribution of the water vapor above the Lander.

The objective of the Mars Geodesy Experiment **(NEIGE experiment)** is to obtain new information about the surface/atmosphere interactions (e.g., the seasonal cycling of CO_2). This information would be obtained from measurements of the Doppler shifts of the radio links between the Orbiter and the landers and between the Earth and the Orbiter [17].

Conclusion : The results of these various investigations are clearly complementary, and combining their results would greatly improve our knowledge of the geology and the water cycle at the Netlander landing sites.

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PROPOSED MODEL OF THE MARTIAN SUBSURFACE FOR THE GPR EXPERIMENT ON NETLANDER.
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Introduction: In the frame of the 2007 joint CNES-NASA mission to Mars, a set of 4 NetLanders developed by an European consortium is expected to be launched in June 2007 [1]. The geophysical package of each lander will include a Ground Penetrating Radar (GPR experiment) that will be used to map the Martian subsurface and detect groundwater down to several kilometers. In order to test the performance of such a GPR on Mars, various models of the Martian subsurface will be proposed from simple one to more complex one. In order to carry out a more precise evaluation of the GPR performances with realistic environmental (i.e. lander and subsurface) conditions, a numerical model have been developed for the electric antennas, and the subsurface electromagnetic properties and propagation. Each of these models of the Martian subsurface will take into account the depth of the main interfaces, the supposed origin of each layer (aeolian, fluvial, glacial, or volcanic deposits), the reflection characteristics at the interfaces (roughness), the geothermal gradient and the porosity as well as the presence of volatile materials (ground-ice, liquid water), evaporates (halite, gypsum) and iron oxides (hematite, maghemite).

TheGPR experiment [2]: We plan to use a set of 3 monopole electric antennas angularly spaced by 120° and a magnetic receiving antenna (cf. Fig. 1) to determine the directions of the returning electromagnetic waves and, therefore, obtain a 3D imaging of the subsurface. Three monopole electric antennas powered by a 10 W transmitter are used to transmit electromagnetic waves at a central frequency of 2 MHz with linear as well as planar (circular or elliptical) polarization [2].

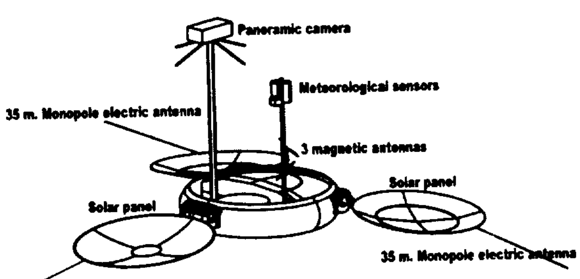

Fig. 1: Schematic overview of the small autonomous NetLander station.

Two electric and three magnetic components of the electromagnetic waves returning to the radar are measured. The subsequent signal analysis performed on these data will allow to retrieve the direction of propagation of the returning waves and thus the direction of the reflectors while their distance is obtained from the propagation time of the waves [2]. The possibility to operate with various polarization schemes provides a capability of significant interest for the GPR instrument since it will allow to study in more details the backscattering properties of the reflectors in the subsurface.

Subsurface geological and electromagnetic description: Numerical simulation of the GPR performances requires to describe the structure and electromagnetic properties of the Martian subsurface. A first model of the subsurface is given in Fig. 2. It is intended to represent a composite average of the various layers which are thought to exist in the Martian soil. From a landing site to another, there may be significant departures from this average model since one of the goals is to explore sites with different geological structures. These variations may primarily affect the extent of the upper layers, and consequently the depth of the ground-ice and liquid water rich layers, but probably not so much the values of the electrical parameters.

In the present state of knowledge, the structure of the Martian megaregolith may be described by 3 main layers [3, 4] :

- a first zone resulting of the impact processes, sedimentary deposits and, in particular locations, volcanic flows. The uppermost part of this zone is a dry material with a negligible water content ; deeper layers may already contain ice. The lower limit of this region is believed to be in the range of a few hundred of meters to 1 to ~2 km.

- a second zone consisting of the fractured, porous megaregolith that can extend to considerable depth with a porosity which is, on the average, decreasing exponentially as a function of depth with a scale height of the order of 4 to 6 km. This zone represents the most probable water reservoir where ice and, below the melting level (from 2 to 6 km deep), liquid water is stored in the pores and fractures of the basalt. It is thought that the lower limit of this zone can reach ~10 km in extreme cases.

- the third zone is the solid basaltic basement either unfractured or where lithostatic pressure as well as other physical and chemical compaction processes have resulted in a vanishing porosity.

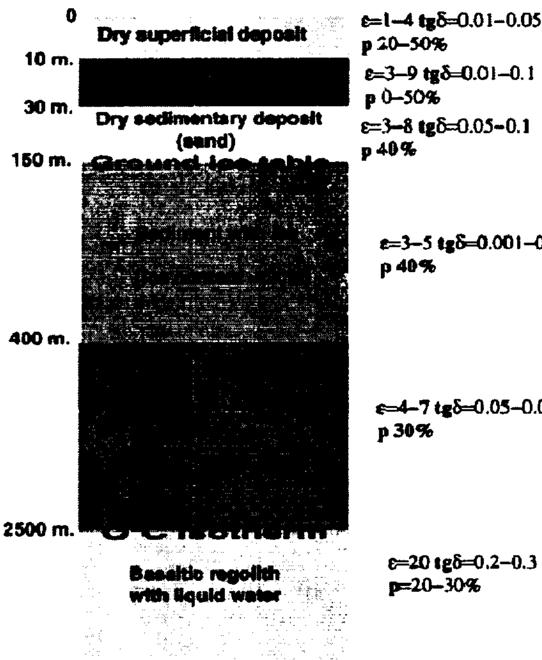

Fig. 2: One of the proposed model of the Martian subsurface at 35° latitude.

In the first model which we have used [2], the first zone extends down to 400 m and is already partially filled with ice below 150 m. The second zone, starting at 400 m, is filled with ground-ice down to 2500 m, where the melting point is reached and liquid water is present. As indicated above, this is supposed to be an average situation but actual conditions may prove to be very different from site to site, in particular at equatorial latitudes where the water layer could well be significantly nearer to the surface.

Values of the relative permittivity have been taken from data available from direct in situ or remote sensing measurements for the superficial layers and from average values obtained from laboratory measurements on corresponding materials for deeper layers [10, 11]. The most uncertain parameter, and the most critical to estimate the GPR performances is the loss tangent ; the adopted values are thought to be conservative.

In previous studies, the magnetic properties of the soil have been in general ignored. However recent results [5, 6] have shown that the Martian subsurface is likely to contain ferromagnetic materials such as maghemite. Other iron bearing materials such as hematite, which could result from the hydrothermal alteration of iron rich basalts, have also been detected in the Martian soil [7, 8].The high degree of oxidation of the superficial layers of the soil with a corresponding enrichment in iron oxides will be taken into account in the near future. Various authors [9, 10, 11] indicate the possibility of a significant increase of the magnetic permeability and propagation losses for HF electromagnetic waves, combined to higher loss tangent around 2 MHz. Such an effect in the case of our experiment have been reported by Paillou et al (2001) [10].

Numerical simulation: A numerical simulation has been performed to assess the performances of the GPR instrument [2]. The model subsurface consisted in a number of layers with depth, thickness and physical properties representative of the expected average Martian subsurface. Results are consistent with the simpler calculation which were performed to design the radar and show that a liquid water interface should be detectable at depths of approximately 2.5 km.

Conclusion: In the near future we plan to refine this model by introducing a more detailed description of the interfaces to study the effect of their roughness on wave scattering, to take into account new permittivity ranges derived from laboratory measurements, and to evaluate the influence of less abrupt changes in the electromagnetic properties at the interface level. We also anticipate to introduce rock blocks of various sizes in the various layers, to estimate the possible influence of multiple partial reflections on the received signals.

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THE NETLANDER MISSION: A GEOPHYSICAL NETWORK AIMED AT INVESTIGATING MARS ATMOSPHERE, SUB-SURFACE AND DEEP INTERIOR. J. L. Counil, F. Ferri, Ph. Lognonne, O. Marsal, F. Rocard, and R. Bonneville.

The NETLANDER mission aims at deploying on the surface of Mars a network of four identical landers which will perform simultaneous measurements in order to study the internal structure of Mars, its sub-surface and its atmosphere. It will then be the first mission of its kind.

The NETLANDER program is conducted in a European and international co-operative framework under the leadership of the French CNES. A NETLANDER consortium composed of France, Finland, Germany, Belgium has been established in 1999 and a dozen of international partners have hardware contributions to the Payload (nine instruments). The NETLANDER mission will be launched in 2007 together with the CNES Orbiter aimed at preparing the first sample return mission.

The scientific rationale of the NETLANDER project is to investigate the interior, the surface, the atmosphere and the interior of MARS planet. These investigations will be performed thanks to the first network of geophysical station ever installed on the surface of the red planet. Given our very poor knowledge of the planet and in particular of its subsurface and interior, the scientific objectives of the mission are of first priority with respect to MARS exploration.
The NETLANDER mission will be able to answer to crucial question with regard to MARS formation and evolution such as: is there a core like on Earth and how deep is it? is this core liquid or solid? is there still seismic activity? what has been the role of the magnetic field in the evolution of the planet (atmospheric depletion, surface radiation rate...)?
The becoming of the water is also a key question. Although clear evidence of flooding can be seen on the surface, and sedimental layers have been recently evidenced, the today localization and abundance of water is still unknown. NETLANDER will be able to quantitatively answer whether or not the water is frozen in the uppermost layers of the subsurface.
All the recorded data will be used to determine the physical state of the Mars interior (mineralogical composition, conductivity profiles, thermal profiles,...) to characterize the surface process (regolith composition,...), the surface-atmosphere coupling (dust devil triggering and propagation), and the global atmospheric circulation (seasonal and secular variations, ...).

To fulfil the overstated objectives with respect to MARS interior, subsurface, atmosphere and ionosphere investigation, the NETLANDER mission will carry a payload composed of nine instruments:
SEISM: Seismometer; PI: Ph. Lognonné, IPG, France
PANCAM: Panoramic camera; PI: R. Jaumann, DLR, Germany
ATMIS: Atmospheric sensors, PI: A.M. Harri, FMI, Finland
ARES-ELF: Atmospheric electricity sensor, J. J. Berthelier, CETP, France
NEIGE: geodesic and ionospheric measurements, PI: J.P. Barriot, GRGS, France
SPICE: Spoil properties measurements, PI: T. Spöhn, univ Münster, Germany
GPR: Penetrating Radar, PI: J. J. Berthelier, CETP, France
MAGNET: Magnetometer, PI: M. Menvielle, CETP, France
MICRO: Microphone, PI: G. Delory, Univ. Berkeley, USA

Mission scenario

The NETLANDER mission scenario is as follows:

- The 4 NetLander probes are launched in 2007 : during the launch and the cruise phase to Mars, they are attached to the carrier responsible in particular of the propulsion,
- On arrival at MARS, they are ejected from the carrier according to a sequence depending on the choice of their landing sites. In order to allow precise orbit determination during the NetLander separation, 4-day intervals are necessary between two lander separations. Hence, the separation sequence starts several weeks before arriving at Mars
- After the coast phase and the atmospheric entry phase, the probes land on Mars. The landers are initialised and their antenna is deployed to begin exchanging data and commands with the Earth,
- During their operations on the surface of Mars, the NetLander probes communicate with the Earth via an Mars orbiter (the CNES 2007 orbiter and/or any telecom satellite in Martian orbit)

Landing sites

The choice of landing sites will result from a compromise between scientific objectives and technical constraints.
The technical constraints are mainly the co-ordinates (reachable from the orbit), the altitude (a too high altitude prevents the parachutes to work properly), the site characteristics (slopes, rocks percentage, ...)
The scientific requirements are primarily driven by the objectives of network science, which are expressed in terms of network shape, latitudinal and longitudinal coverage, distances between the stations. Each network experiment

(seismology, magnetism, meteorology) has its own requirements. In addition, the network must be robust to the accidental lose of one NETLANDER during the cruise, at landing or during operations at MARS. Sites of specific interest have also been identified (e.g. sites where water reservoirs can be expected at low depths) and should be as much as possible included in the network.
The final configuration that can impact the NETLANDER design is expected to be settled at the end of phase B.

NetLander design

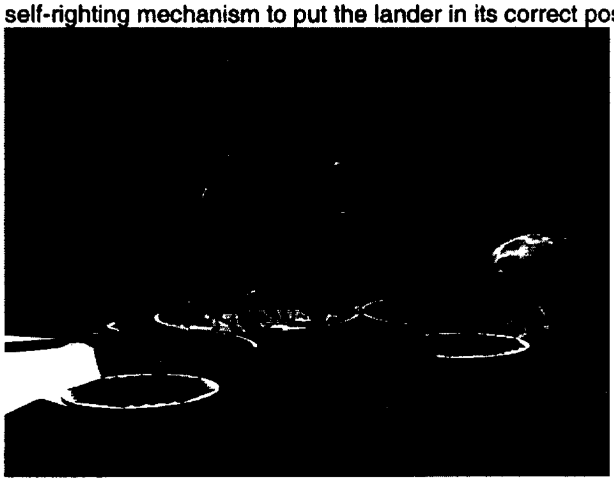
Each NetLander probe comprises two main sub-assemblies :
- the Surface Module,
- the Entry, Descent and Landing System (EDLS).

The EDLS function is to protect the Surface Module during all mission phases until its deployment on the surface of Mars. The atmospheric phase begins when the atmosphere is detected by accelerometer measurements. During the entry phase, the heat-shield reduces the velocity of the probe and the parachute system is activated when the probe velocity is low enough to allow parachute deployment. These conditions have to be obtained at high enough altitudes to maximise the efficiency of the parachute phase. Because of the low atmospheric density on Mars, the efficiency of the parachute system is limited : an additional landing system is necessary to reduce the landing shock.

After landing, first operations will consist in the deployment of the solar arrays and the telecommunication antenna. The scientific instruments are then activated and checked. Before starting the network mode, first camera images will be acquired in order to characterise the landing site, and radar measurements will be performed.

The NetLander mission duration is expected to last over one Martian year.

During the surface operations, solar panel provide energy during day-time. Rechargeable batteries are used to store energy for night-time operations. In order to provide enough solar energy, deployable solar arrays are necessary : they are located on the internal surface of petals which are unfolded after landing. One of the petals also serves as a self-righting mechanism to put the lander in its correct position if it lands upside down.



NETLANDER in deployed configuration

The total mass of the NetLander probe is 66 kg when it enters the Martian atmosphere. After landing and ejection of all EDLS elements, the mass of the Surface Module is 22 kg, of which 5,2 kg are allowed for scientific instruments.

MODELING THE COMPLETE PLANETARY SUBSURFACE RADIO REMOTE SENSING PROBLEM.

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Introduction: Ground penetrating radar methods are in the forefront of the search for subsurface water on Mars largely because of their platform versatility. In theory these instruments can operate from orbit, on the ground, and any altitude in between. Recent review papers [1] and white papers [2], [3] make the strong case for using GPR methods in subsurface water exploration.

But important questions have been raised recently about effect of unknown parameters on the ability to successfully obtain planetary GPR measurements. The almost completely unknown lower ionosphere on Mars may cause serious signal absorption problems for GPR instruments on orbiting platforms [4], and lossy upper layers of the ground may reduce the returned signal for any platform [5]. What is clearly needed is a minimum approximations, full-wave model of the complete GPR problem, including ionospheric dispersion and absorption, surface transmission, and subsurface scattering. We are developing such a model that is as general purpose as possible, allowing arbitrary ionospheric parameters, surface roughness, and subsurface inhomogeneities. We present some of the details of this model, and highlight some of its capabilities with numerical examples.

Some Model Details: The large electrical size of the complete GPR problem, especially from orbit, requires a modular scheme to complete all of the necessary calculations. We divide the problem into propagation and scattering components. The usually broadband excitation and strongly inhomogeneous ground make full-wave, time domain methods appropriate for simulating the scattering portion of the problem. The near surface incident fields are specified by the propagation component of the model, and these are used to find the subsurface fields and near surface scattered fields. There are very few approximations inherent this type of simulation, making it both accurate and versatile.

The propagation component of the problem, which involves tracking the incident fields from the source to the surface and the scattered fields back from the surface to the receiver is straightforward for ground-based and low altitude platforms. But for orbiting platforms, the ionosphere can play a significant role. Not only does the ionosphere disperse and absorb the signal, but the presence of narrow layers may render simple WKB-type approximations to transionospheric propagation invalid. For a general purpose model, we thus again require a full-wave finite difference simulation to ensure validity for an arbitrary ionosphere. We build on current methods for simulating wave propagation in a cold plasma [6] for this portion of the overall model.

The resulting model is able to accurately simulate all aspects of a very general GPR problem, and thus is not only a valuable tool for estimating instrument performance, but will be an important tool for interpreting any future data from this type of instrument.

References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] M. Goldman and F. M. Neubauer, Groundwater exploration using integrated geophysical techniques, *Surv. in Geophys.*, *15*, 331–361, 1994. [2] D. W. Beaty et al., *A Strategic Framework for the Exploration of the Martian Subsurface*, August 2000. [3] D. W. Beaty et al., *Analysis of the Potential of a Mars Orbital Ground-Penetrating Radar Instrument in 2005*, January 2001. [4] O. Witasse et al., HF radio wave attenuation due to a meteoric layer in the atmosphere of Mars, *GRL*, in review, 2001. [5] P. Paillou et al., Performances of Ground Penetrating Radars in arid volcanic regions: Consequences for Mars subsurface exploration, *GRL*, *28*, 911–914, 2001. [6] S. A. Cummer, An analysis of new and existing FDTD methods for isotropic cold plasma and a method for improving their accuracy, *IEEE Trans. Antennas Propagat.*, *45*, 392–400, 1997.

RADAR PENETRATION IN SOILS: THE POTENTIAL FOR SUB-SURFACE OBSERVATION OF BOTH EARTH AND MARS. J. Daniels[1] (wizard@mail.bgu.ac.il), D. G. Blumberg[1] (blumberg@mail.bgu.ac.il), V. Freiliker[2] (freiliv@mail.biu.ac.il), L. D. Vulfson[3], A. L. Kotlyar[3], T. Neta[1], J. Ben-Asher[1], M. Sprintsin[1], G. Ronen[4] and M. Linestky[1]. [1] Department of Geography and Environmental Development, Ben-Gurion University of the Negev, Israel; [2] Department of Physics, Bar-Ilan University, Israel; [3] Center of Aerospace Research of the Earth (ZAKIZ), Kiev, Ukraine; [4] Department of Geological and Environmental Sciences, Ben-Gurion University of the Negev, Israel.

Introduction: The aim of this work is to analyze the potential for subsurface detection capability of microwaves, particularly for X (3cm), C (5.3cm), L (24cm), P (68cm) and VHF (2m) bands, and thereby evaluate the potential for mapping sub-surface heterogeneities such as water/ice content, lithology variations or sedimentary structure. Our approach is to use: ground truth measurements; SAR and Scatterometer airborne and SAR space borne data; and in addition scattering models to understand the backscattering mechanisms and subsurface detection capabilities. The scattering modelling consists of three components: scattering from the soil surface; scattering from the sub-surface soil volume; and scattering from the sub-surface layer.

Sandy sites in the vicinity of the Ashilam farm and the Tseelim Kibbutz (both situated in the Northwest part of the Negev Desert, Israel) were selected as they are easily accessible, and have associated space borne radar sets available. Flat metallic and trihedral corner reflectors were constructed and immersed at varying depths as the initial candidates for sub-surface detection. We present here preliminary results: (1) the characterization of the soil surface/subsurface properties obtained through both ground instrumentation (a Ground Laser Scanner and a Time Domain Reflectometer) and air-borne instrumentation (SAR, a Scatterometer and a Passive Infra-red Sensor); (2) the identification of the soil surface/subsurface scattering mechanisms; and (3) the quantification of the depth range at which a subsurface specular reflecting object can be detected at 3, 68 and 2000 cm. We also present earlier results of the detection of the sub-surface continuation of the Mubra channel under the Shunra sand dunes in the Negev using the shuttle SIR-C instrument. Figure 1 is a schematic of the current flight experiment plan in the Negev, Israel.

We illustrate how some of the instrumentation and techniques utilized in these Negev experiments can be used to search for very shallow (< 50m) Martian sub-surface liquid water as well as provide sub-surface data on lithology variations and sedimentary structure; plus surface roughness data.

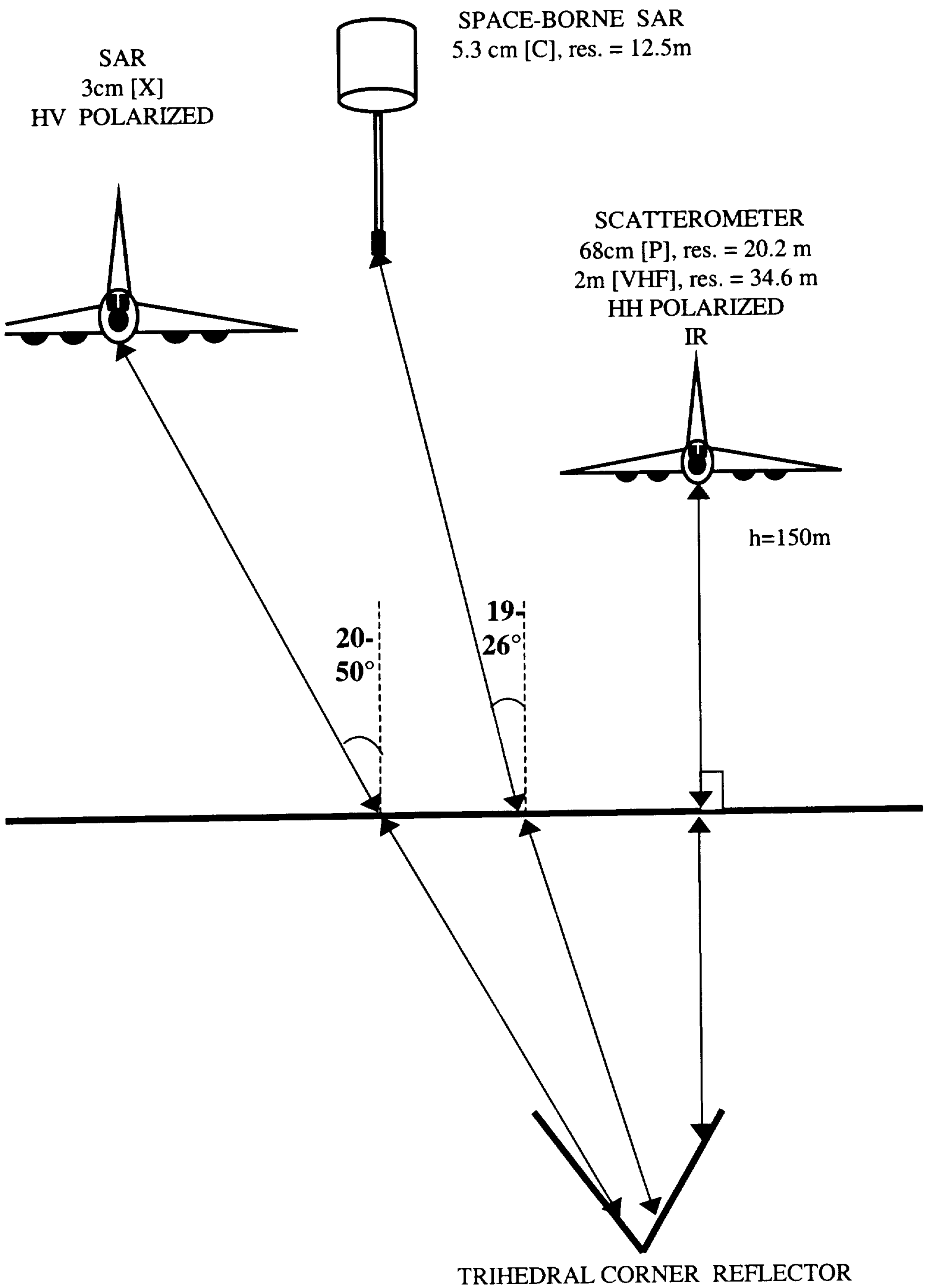

FIGURE 1: SCHEMATIC OF FLIGHT EXPERIMENT PLAN

A MODEL FOR THE DIELECTRIC ABSORPTION OF THE CENTRAL WEST ANTARCTIC ICE SHEET AT RADAR SOUNDING FREQUENCIES. J. A. Doebbler[1], D. D. Blankenship[1], D. L. Morse[1] and M. E. Peters[1], [1]University of Texas Institute for Geophysics, Austin, TX 78759 (blank@ig.utexas.edu)

The problem of characterizing the subglacial water systems of Earth's Antarctic ice sheet may be analogous to those for characterizing any sub-ice water systems on Mars. On Earth, an important component of the dynamics of the West Antarctic ice sheet is the evolution of subglacial water systems that form at the transition from the thick slow-moving ice of the interior to the thinner fast-moving ice streams which drain the interior. Similarly, understanding the formation and migration of water beneath the thickest portions of the East Antarctic ice sheet will be essential for understanding the evolution of subglacial lakes.

Active electromagnetic sounding of ice sheets at radar frequencies (10's to 100's of MHz) has proven to be a useful tool for the detection of large-scale subglacial water bodies (i.e., lakes and sea water). The echo strength and horizontal extent of the return from the subglacial interface has proven to be a consistent indicator of large water bodies, however, the detection and characterization of smaller scale subglacial water systems will rely more heavily on the accurate interpretation of radar echo strengths alone.

With possible exception of scattering at the interface, the largest uncertainty in determining the subglacial material composition from these echo strengths is establishing the dielectric absorption of the overlying ice sheet. Furthermore, the dielectric absorption is largely a function of the vertical temperature profile within the ice. Because of this, our efforts have focussed on studying the sensitivity of the dielectric absorption to the boundary conditions (i.e., surface temperature and accumulation rate as well as geothermal flux) and ice flow characteristics (i.e., vertical versus horizontal advection) for portions of the East and West Antarctic ice sheets where these subglacial water systems are likely to evolve. Based on this sensitivity analysis our objective is to present a computationally efficient model of the dielectric absorption with an accuracy sufficient to support the unambiguous detection of small scale water systems in typical airborne and ground-based radar sounding experiments.

THE MEASURED PERMITTIVITY OF CO_2 ICE GROWN UNDER MARTIAN POLAR CONDITIONS

J. R. C. Garry, Planetary and Space Sciences Research Institute, The Open University, Milton Keynes, England, (J.R.C.Garry@open.ac.uk)

Introduction: The relative electric permittivity, ε_r, of dense carbon dioxide ice has been measured, with the ice being formed directly from its gas at temperatures around 130 K under 1 mbar of pressure. At 1 kHz ε_r is 4.6 ± 0.2 and at 100 Hz ε_r takes a value of 5 ± 1. There appears to be no data in the literature for this near-DC property of CO_2 ice, especially for ice grown from the vapour phase at temperatures comparable to those at the surface of the Martian poles. Experiments at frequencies similar to those used by Ground Penetrating Radar (GPR) will be useful for future spacecraft missions aiming to reveal the stratigraphy and burial depth of Martian polar materials such as water ice.

GPR to come: The European Space Agency (ESA) spacecraft, Mars Express, will employ a radar science experiment during its mission. This package is designed to be capable of detecting strong discontinuities in the electromagnetic impedance of the Martian near-surface at depths of several hundred metres. Models of the electromagnetic properties of potential Martian sub-surface components, such as water ice and various rock types, have been studied [1] using laboratory measurements of the permittivity values for these analogues.

One such material has, however, not been considered in these experiments. Although CO_2 snows[1] made by manual compaction have had their ε_r values measured [2] at various bulk densities, there appear to be no data for ε_r of void-free ice grown from CO_2 gas under the low pressures and temperatures found in the Martian polar winters. This form of solid CO_2, in contrast to rapidly condensed snows, could be a close analogue for the major component of the seasonal Martian ice-caps. Accurate measurements of this substance's dielectric properties will be needed when Martian GPR data are processed.

Formation: A dedicated vacuum chamber has been built at the PSSRI for the study of the mechanical properties of cryogenic ices. This chamber, equipped with an instrumented drilling system, can condense ices from the vapour phase into a liquid-nitrogen cooled sample holder. Temperature measurements are made with small Pt 100 thermometer elements and the sample holder can be fitted with a mesh-plate capacitor, shown in the following figure.

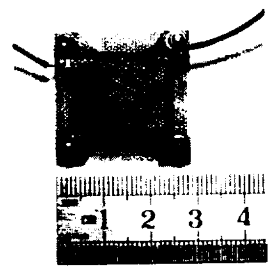

Figure 1. A small air-gap capacitor with a nominal capacitance of 16 pF.

CO2 growth. In contrast to the many geometries that may be displayed when forming water ice from its vapour [3], carbon dioxide shows a simpler set of 'habits'. The bi-pyramidal microstructure seen [4 and 5] when condensing the gas on a cryogenically cooled substrate is continued at larger scales, with 0.1 mm facets being easily seen in the growth of CO_2 ices. This 'randomly-glued-salt-grain' topology rapidly infills itself to form a smooth compact mass and is seen to form on cold surfaces away from the direct path of the admitted gas. Directly in the flow of the CO_2, the ice takes on the smooth, almost glossy, compact form more rapidly.

Analysis: The sensor was cleaned before and after its use in the vacuum system with a regime of acetone and deionised water flushes. In the chart below the total measured capacitance, which includes the stray capacitance of the sensor leads, is shown. Region (A) denotes the progressive covering of the sensor face by CO_2 ice to a depth of around 3 mm, and region (B) shows its emergence when the ice sublimates. Note that data were not taken at equal time intervals.

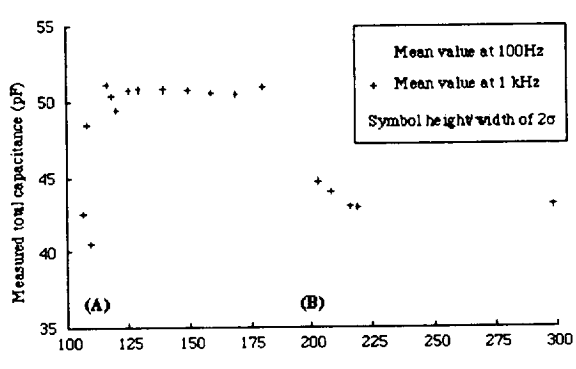

Figure 2: The changes in capacitance caused by CO_2 ice growth and decay over the course of ~5 hours.

[1] Source snow being made by the rapid expansion of pressurized CO_2 gas through a flow constriction.

PERMITTIVITY OF VAPOUR GROWN CO_2 ICE J. R. C. Garry

A non-polar liquid with known dielectric properties (toluene, grade assayed at >99% purity with < 500ppm water) was used as a calibration medium after the ice-formation experiment. The capacitor was submerged in toluene at room temperature and pressure, and the shift in measured capacitance from its value in air was noted. Care was taken to keep the device's lead lengths and positions mostly unchanged from their earlier arrangement in the vacuum chamber.

A figure of 2.391 [6] was used for the value of toluene's ε_r at 20°C and from this the permittivity of CO_2 ice could be inferred by comparing the capacitance shift from air to CO_2 with the corresponding change from air to toluene. Measurements were made at two frequencies, 100 Hz and 1 kHz using an AVO B184 LCR analyzer. Despite the more imprecise readings made in the 100 Hz range, two phenomena seen by previous workers [2] are supported. The values of ε_r for CO_2 ice do not appear to be strongly frequency dependent. Furthermore, the temperature sensitivity is also very small - this work fills the gaps between the two measurements at 113 K and 183 K of [2] made at higher frequencies.

Discussion: GPR models for Martian system architectures have used figures from 1.7 [2] to 3 [7] for the ε_r of dense CO_2. Viking orbiter radar data for regions of the Martian North pole suggest a surface ε_r of 1.5 [8]. The value of ε_r, inferred in this work from a calibration liquid, for vapour-grown dense CO_2 is larger than that predicted or presumed by previous studies. If correct, this value for solid CO_2's permittivity alters the signal budget for a GPR system. The return signal's strength is proportional to $(\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}) / (\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2})$ for media of ε_1 and ε_2. Thus, the backscattered echo from a plane water ice/CO_2 ice layer may be 0.1 of the input power in contrast to zero for media of the same ε_r.

The extra returned power from this higher-than-expected dielectric contrast may yet be only of marginal interest as surface backscatter from topography and buried features rough at the system wavelength can readily dominate radar echo strength. However, in trying to constrain the thickness of a CO_2 layer by echo-delay measurement from underlying discontinuities, the absolute permittivity of the material must be known. It is suggested that ice grown from the vapour phase should continue to be studied at more appropriate radar-like frequencies if the burial depth of polar features such as permanent water ice caps or permafrost is to be established with accuracy.

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[5] www.lpsi.barc.usda.gov/emusnow/MartianSnow/ms.htm
[6] Weast R. C. (Ed.) (1985) 66th CRC, Boca Raton,
[7] Chappell D. T., *Proc. of The Case for Mars VI* printed in Vol. 98 of the AAS Science & Technology Series (1996). [8] Simpson R. A. (1993) *IEEE Trans.. Geosci. and Rem. Sens. 31(2)*, 465-482.

Acknowledgements: This work is supported by a postgraduate research award to J. Garry from the UK Particle Physics and Astronomy Research Council.

A ROVER DEPLOYED GROUND PENETRATING RADAR ON MARS. J.A. Grant[1], B.A. Campbell[1], and A.E. Schutz[2], [1]Smithsonian Institution, Center for Earth and Planetary Studies, MRC 315, Washington, DC 20560, grantj@nasm.si.edu, [2]Geophysical Survey Systems, Inc., 13 Klein Drive, North Salem, NH, 01950.

Introduction: Radar is a fundamental tool capable of addressing a variety of geological problems on Mars via collection of data suitable for interpreting variations in surface morphology and reflectivity [e.g., 1-5]. Surface-deployed ground penetrating radar (GPR) can help further constrain the geology and structure of the near surface of Mars by directly measuring the range and character of *in situ* radar properties [6-7]. In recognition of this potential, a miniaturized, easily modified GPR is being developed for possible deployment on a future Mars rover and will enable definition of radar stratigraphy at high spatial resolution to depths of 10-20 meters. [7-8].

Ongoing development of a Mars impulse GPR with industry partners at Geophysical Survey Systems, Inc., focuses on design and testing of a prototype transducer array (with both high frequency bistatic and low frequency monostatic components) in parallel with fabrication of a low power, mass, and volume control unit. The operational depth of 10-20 meters is geared towards definition of stratigraphy, subsurface blocks, and structure at the decimeter to meter scale that is critical for establishing the geologic setting of the rover. GPR data can also be used to infer the degree of any post-depositional pedogenic alteration or weathering that has subsequently taken place, thereby enabling assessment of pristine versus secondary morphology at the landing site.

As is the case for most remote sensing instruments, a GPR may not detect water unambiguously. Nevertheless, any local, near-surface occurrence of liquid water will lead to large, easily detected dielectric contrasts. Moreover, definition of stratigraphy and setting will help in evaluating the history of aqueous activity and where any water might occur and be accessible. Most importantly perhaps, GPR can provide critical context for other rover and orbital instruments/data sets. Hence, GPR deployment along well positioned transects in the vicinity of a lander should enable 3-D mapping of stratigraphy and could serve to guide direct subsurface sampling.

Platform Constraints: Development of a GPR compatible with deployment on Mars requires consideration of rover interfaces, operational requirements, and associated likely limits on instrument mass, power, volume. We adopt the Mars Exploration Rovers (MER) design being tested for the 2003 Mars mission as a proxy for rovers to be operated on Mars in the next 10 years. Interface requirements associated with these rovers influence our targeted mass, power, and volume limits of 0.5 kg, 3W (peak), and 3400 cc, respectively. Because many rover components (including the wheels) will likely be metallic, and because electrostatic charging by dust may be important, the GPR will need to be in a sealed metal box and grounded to the rover frame. More significant design modifications required by electrostatic charging are unlikely: the above ground deployment of a bistatic transducer precludes the need for isolation from the rover and any unexpected problems associated with the low frequency component could ultimately be mitigated by utilizing the rover as part of the antenna.

Transducer Design: Development of a "breadboard" GPR antenna (Fig. 1) has produced a "generic" array that permits easy modification for optimizing performance (*e.g.*, by changing the width of the high frequency antenna fans to increase or decrease the center operating frequency). Because antenna frequency is a function of antenna length such modifications have no appreciable effect on system electronics.

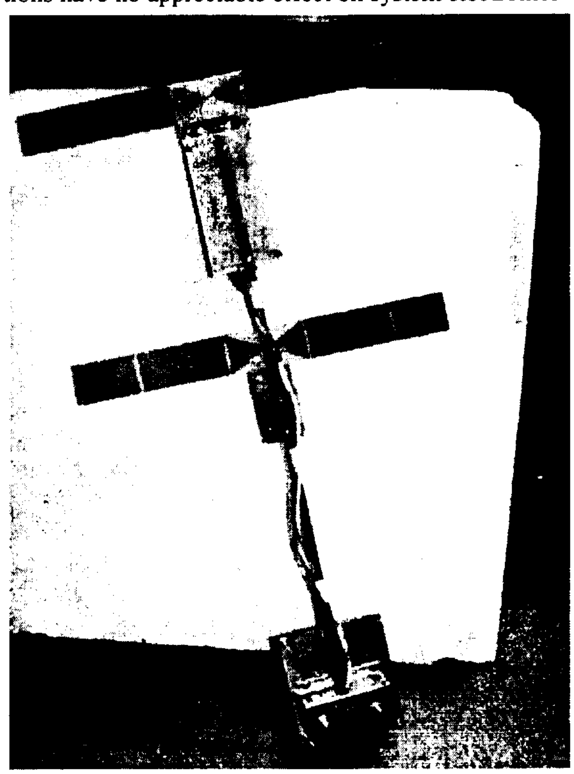

Figure 1. Field-tested breadboard transducer that has successfully defined radar stratigraphy to depths of ~15 meters (see Figs. 2 and 3). Note table leg for scale.

As a starting point, we assume that most Martian surfaces will be dry, possess dielectric values generally between 3-10, and have corresponding loss tangents of ~0.01 +/- 0.005 [*e.g.*, 5, 9].

The transducer array includes both high frequency bistatic and low frequency monostatic "rat-tail" components. Each consists of a high-speed sample hold circuit that can incorporate an rf amplifier on its front end if desired. Deployment will likely involve a retractable bar with antenna components mounted at the outboard end, thereby enabling good separation from the rover (see Fig. 1).

Sample output from the high frequency antenna component is displayed in Figure 2. The bistatic nature of the high frequency antenna minimizes the "clear time" required and the antenna operates at 1.68 ns/cycle. The antenna possesses a center frequency of 600 MHz, and is capable of distinguishing radar reflections corresponding to stratigraphy to depths of ~15 meters. Construction involved standard parts and utilizes 38 cm-long resistively loaded dipoles mounted on a dielectric rod at a height of 15 cm above the ground.

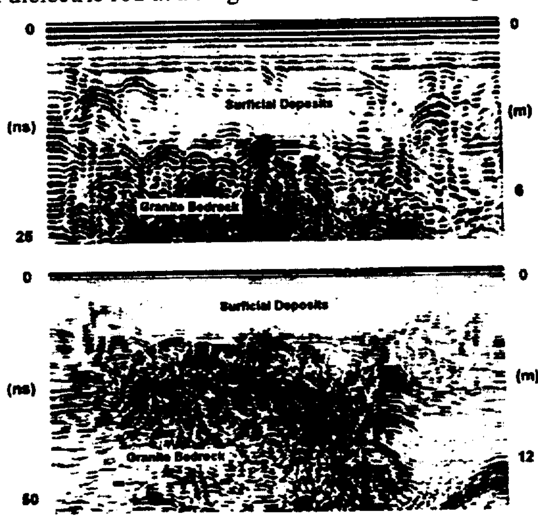

Figure 2. Sample data from high frequency bistatic transducer component. Data reveals stratigraphy associated with test-bed overlying unconsolidated sediments and granitic bedrock.

A prototype of a low frequency "rat-tail" antenna has also been tested (Figure 3). Initial operation required use of bi-statically configured, 40 cm long, resistivity loaded monopoles as antennas (central frequency 100 MHz) and confirmed the ability to distinguish reflections up to 15 m below the surface. A near-surface blind zone induced by ringing should be reduced by use of an improved T/R switch under development. Nevertheless, overlapping data from the higher frequency antenna component provides high resolution coverage of the "blind" zone.

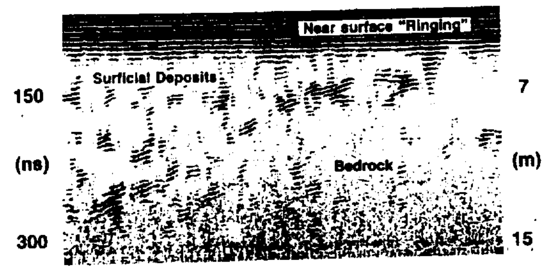

Figure 3. Sample data from the low frequency transducer component. Data corresponds to unconsolidated sediments overlying granitic bedrock.

GPR System Design: Design and construction of a complete "breadboard" impulse GPR is occurring simultaneously and involves consolidation of electronics and function to minimize mass and volume (e.g., onto a single board). Such a prototype rover-deployable GPR is a major stride towards achieving the stated mass, power, and performance requirements. The system will utilize the described antenna array and will operate at a range of up to 1000 nanoseconds. Antennas can be unshielded, as there will be no overhead objects that will behave as clutter targets, and because possible reflections from the rover will be stationary and therefore removable via post-processing of the data.

Synergy with a SAR: A Mars GPR provides an unique means of constraining data sets collected using alternate landed and orbital instruments. GPR data would be especially complementary, however, with that collected by an orbital synthetic aperture radar (SAR). An orbital SAR [10] operating at wavelengths comparable to a GPR (e.g., P-band or ~68 cm) can help constrain surface roughness, minimum thickness of surficial mantles, and occurrence of strongly absorbing deposits (e.g., carbonates). Hence, it could help target suitable landing sites for more detailed exploration using the rover-deployed GPR. Work funded by NASA PIDDP Grant NAG5-9658.

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LOW-FREQUENCY ELECTROMAGNETIC EXPLORATION FOR GROUNDWATER ON MARS.

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Water with even a small amount of dissolved solids has an electrical conductivity orders of magnitude higher than dry rock, and is therefore a near-ideal exploration target on Mars for low-frequency, diffusive electromagnetic (EM) methods. In contrast, high-frequency, wave methods such as radar attempt to sense much smaller differences in dielectric constant and are also subject to strong scattering. Models of the temperature- and frequency-dependent electrical properties of rock-ice-water mixtures are used to predict the response of the martian subsurface to vertically incident plane waves. Detection of ice is difficult unless it is massively segregated, and identification of ice from its relaxation loss is obvious only within ~20 K of melting. In contrast, liquid water profoundly affects soundings and even even a small amount of unfrozen (adsorbed) water in contact with mineral grains in the cryosphere can be detected. Subcryospheric water is readily distinguishable at frequencies as low as 100 Hz for relatively fresh water (30 mg/l dissolved solids) to 10 mHz for brines. Although the diffusive EM response to aquifers can span eight orders of magnitude in frequency, the optimum frequency band to determine the depth to water in all cases is 100 Hz–1 kHz. These responses can be measured by using either natural or artificial sources. ULF signals from solar-wind and diurnal-heating perturbations of the ionosphere are likely, but may lie at frequencies too low to be most useful. ULF perturbations of the fields generated by regional strong crustal magnetism and their interaction with the ionosphere may also be observable. Spherics, or ELF-VLF signals from lightning discharge, would be observable in the optimum frequency band; however, lightning may be the least likely of the possible natural sources. If spherics do exist, the presence of widespread upper-crustal conductivity—possibly in the form of regional groundwater—can be verified at a single surface station by determining the lower cutoff frequency of the waveguide. Among the active techniques, only the time-domain (TDEM) method can accommodate a closely spaced transmitter and receiver and sound to depths of hundreds of meters or more. A mobile rover or aircraft-based TDEM system of several kilograms can detect water to a depth of several hundred meters, and a system of tens of kilograms featuring a large, fixed, rover-deployed loop can detect water to several kilometers depth.

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LOCALIZATION OF MARS SUB-SURFACE ICE / WATER BY MEANS OF A MOBILE GROUND PENETRATING RADAR IN COMBINATION WITH A MUTUAL IMPEDANCE PROBE. M. Hamelin [1], R. Trautner[2], [1]CETP-IPSL, Saint Maur, France, michel.hamelin@cetp.ipsl.fr Fax: +33 1 48894433, [2] SSD-ESTEC, Noordwijk, The Netherlands

The use of satellite based Ground Penetrating Radars (GPR) on Mars orbiters should provide a general map of the ice and water distribution in a few km depth range under the surface of Mars. A major issue for future robotic and manned exploration is the availability of water close to the surface. With this objective, the next generation of landers and rover missions would be targeted to the regions selected on the basis of geomorphology and satellite GPR data, searching for ice or water in any form in a reduced depth range from 0 to some hundreds of meters.

Electric and electromagnetic detection are the most convenient methods for ice / water remote sensing from a mobile vehicle on the ground. The Mutual Impedance (MI) technique, using a set of electrodes along a cable trailed by a rover, would scan the close sub-surface down to about the size of the system (a few tens of meters) and determine the complex permittivity of the upper surface layers. On the contrary, a GPR operated at about 10-20 MHz is blind in this upper domain, but it can explore the domain beneath, down to a few hundreds of meters. It is essential to guide the vehicle towards the best accessible reservoirs of water / ice for an attempt to a direct access. The MI and GPR techniques are complementary, providing a full coverage of the sub-surface down to a few hundreds of meters. The two instruments could also share electrodes / antennas and part of the electronic circuits.

We study here the configuration and characteristics of a GPR using trailed antennas and electrodes shared with a MI instrument. The capabilities of the proposed instrument combination to detect and characterize underground materials are presented with special attention to water and ice. The coordination of measurements and searching strategy is discussed.

MEDUSAE FOSSAE FORMATION AS VOLATILE-RICH SEDIMENTS DEPOSITED DURING HIGH OBLIQUITY: AN HYPOTHESIS AND TESTS: J. W. Head[1] and Mikhail A. Kreslavsky[1,2], [1]Department of Geological Sciences, Brown University, Providence, RI 02912 USA, James_Head@brown.edu [2]Kharkov National University, Kharkov, Ukraine.

Summary: On the basis of the similarity of the Medusae Fossae Formation to polar and circumpolar deposits, we propose that the unit formed 1) from airborne volatile-rich sediments emplaced during periods of high obliquity when equatorial regions were colder and/or 2) at other times when the northern lowland-highland topographic boundry favored upwelling of water-rich air and preferential deposition of volatiles there. Sources of water vapor include polar regions undergoing concurrent sublimation at high obliquity, and subliming of frozen water deposited from outflow channels. The complex stratigraphy of the Medusae Fossae Formation suggests that periods of emplacement were interrupted by periods of erosion and volatile loss. Previous mapping of stratigraphic relationships suggests an extended duration of emplacement in the Amazonian, and recent mapping using MOLA data suggests that the record of this type of process might extend back into the Hesperian Period. This hypothesis can be tested using a variety of geophysical techniques.

Introduction: Thick (1-3 km), antipodal, unconformable layered deposits in the equatorial region of Mars have been interpreted to be remnants of ancient polar deposits formed during periods of true polar wander [1]. We agree with many of the observations of [1], but pursue an alternate interpretation that these deposits formed during periods of high obliquity and during and following emplacement of outflow channels.

The deposits described by [1] are accumulations of easily eroded material, with the grain size of the upper surface <0.1 mm. Early deposits are draped over underlying topography and evidence of stripping means that deposition has ceased and erosion has been going on for an undetermined period of time. Outliers suggest that the deposit covered a much broader region in the past. These deposits correspond in large part to the Medusae Fossae Formation (MFF) [2,3], which 'consists of relatively flat sheets that are generally smooth to grooved and gently undulating; deposits appear to vary from soft to indurated.' The MFF (Am) consists of three members: The lower member (Aml) is smooth to rough and highly eroded and interpreted [2,3] to be lava flows interbedded with pyroclastic rocks or eolian deposits. The middle member (Amm) is similar to the upper member but the surface appears rougher and more deeply eroded in places; it is cut by scarps and transected by intersecting joint sets [2,3] and interpreted to be welded and nonwelded pyroclastic rocks or layers of eolian deposits [2,3]. The upper member (Amu) consists of discontinuous but widespread deposits that are smooth, flat to rolling, and sculpted into ridges and grooves in places, with broadly curved, locally serrated margins. It is interpreted to consist of unwelded pyroclastics or thick accumulations of eolian debris, which have been wind-eroded, particularly along the margins [2-4]. The MFF is lightly cratered (<200 craters >2 km x 10^6 km^2) and interpreted to be Amazonian in age [2,3], with the lower boundary shown to be well into the Amazonian Period. Numerous hypotheses have been proposed to account for the origin of these deposits [see summary in 5, 7]

We have contributed to the assessment of the origin of these unusual units using new MOLA topography data: 1) to test the hypothesis that these units might have formed in a manner similar to deposits presently seen in and near the poles, and 2) to assess the stratigraphic relationships to other units in order to clarify the age of formation and modification of this unit [18]. We compared these deposits and their morphologic features to present polar deposits [8], and to ancient circumpolar deposits around the South Pole [9-11].

Present polar and paleopolar deposits: MOLA data have enabled researchers to determine the characteristics and stratigraphic relationships of polar and circumpolar deposits to a much higher degree than previously [8-11] and these views complement the characteristics determined from Viking data [12]. South circumpolar deposits (the Dorsa Argentea Formation) interpreted to be of Hesperian age [13] have the following characteristics [9-11]: they 1) are unconformable; 2) are smooth relative to other units at several scale lengths; 3) show evidence of a volatile-rich nature (channels, esker like features, cavi, chasmata, pedestal craters, etc.); 4) have a distinctive topographic profile (compared to volcanoes and other features); and 5) form thick deposits relative to adjacent terrain.

Characteristics of the equatorial deposits: MOLA data have provided detailed information about the configuration of the deposits, their relation to surrounding terrain, the stratigraphic relationships of individual members, and high-resolution altimetry to characterize the deposits. Viking images and mosaics overlain on MOLA DEMs provide an important perspective on these issues. The upper member (Amu) [18; Figure 1] is seen unconformably overlying the dichotomy boundary and rising up to elevations of about 0.5 km, ~3.5 km above Amazonis Planitia, indicating a comparable unit thickness. Portions of Amm lie at the northern edge of this occurrence and slope off into Amazonis Planitia. Highly modified portions of the middle member (Amm) have tear-dropped shaped hills separated by large valleys [14]. From this perspective, one gains the clear impression that Am is heavily dissected and modified at all length scales. Troughs within the MFF cut deeply (up to 2-3 km) into the unit over very short lateral distances, and trend generally down the regional slope, sometimes parallel to channels in the uplands. These features differ from troughs in polar deposits and are more similar in morphology and scale to polar chasmata [12]. To the west along the dichotomy boundary [18; Figure 2], more extensive exposures of Amm are seen; here the Noachian cratered uplands are embayed at the boundary by ridged plains, on which Am is superposed. Similar relationships to those in [18; Figure 1] are seen, with topography highest to the south rising up to -0.5 km, and sloping off to the north to about -2.5 km. The terrain here is also characterized by NW-trending valleys and troughs, broader here than in the first area. The observations outlined in this analysis underline previous conclusions that this deposit has been highly modified and significant parts of it have been eroded by a host of exhumation and modification processes. This raises the important question of what crater count–derived unit ages really mean. If the unit has been undergoing constant modification since its formation, then the Amazonian ages derived from counts of superposed craters will reflect the age of formation of the modified surface, not necessarily the age of the unit itself [see also 7,15].

Comparative characteristics of the equatorial deposits: Among the similarities in morphology and topography are: 1) thick central deposits mantling subjacent cratered terrain and thinning toward the margins; 2) unusually large thicknesses that are similar in scale to present polar deposits; 3) unusual smoothness of deposits at several scale lengths in some areas; 4) partially exposed impact craters, very similar to features in the south circumpolar deposits which have been partly to wholly embayed by polar deposits and then exhumed by sublimation and meltback; 5) narrow sinuous and braided ridge networks, which are often very similar to esker-like ridges in the south circumpolar deposits that are interpreted to represent melting, drainage and meltback of a former ice sheet; 6) craters marginal to the deposits which often show thick accumulations of interior layered deposits and are similar to impact craters surrounding present and previous north and south polar deposits; 7) pedestal craters, which are similar to those found around some south circumpolar deposits.

Differences between these deposits include: 1) the lack of abundant distinctive spiral troughs (although candidate examples exist); 2) the abundance of features interpreted to represent eolian stripping (e.g., yardangs) in the equatorial unconformable deposits; 3) the lack of pervasive fine-scale layering observed in polar deposits, 4) high kilometer-scale roughness in some areas.

Stratigraphic relationships and implications for age of formation of the MFF: Critical to the understanding of the origin of the MFF is confirmation of the age of formation and modification of this deposit, and knowledge of its interaction with regional units. We used MOLA topography data to examine the relationships between the MFF and other units to test the interpreted Middle-Late Amazonian age [2,3]. Previous studies using MOLA data have shown that the division of the MFF into overlying members [2,3] is not everywhere consistent with topographic relationships [5,7]. We examined specific topographic and stratigraphic relationships of the MFF with surrounding units and found: 1) there is significant variation in the elevation of the mapped subunit boundaries, suggesting that the three subunits show much more complex relationships than simple sequential flat layers; this supports previous observations [7]. 2) Amu clearly unconformably overlies the earliest aureole deposits (Aoa_1), but shows much more ambiguous relationships with Tharsis volcanics. In some places, units mapped as AHt_3 (which is completely stratigraphically older than the base of the MFF [2]), appear to overlie Amm and Amu. 3) In some cases, Hesperian-aged channel deposits seen in the uplands near the dichotomy boundary appear to reemerge to the north in portions of Amm. 4) In Elysium, there is evidence that modification of the MFF has led to channel development [see also discussion in 16]. On the basis of these data and evidence that the MFF has undergone very significant exhumation and modification, we conclude that original materials that now make up the Medusae Fossae Formation may have actually been emplaced and modified in much earlier times, perhaps at least partly in the Hesperian. Tracing of lava flow paths suggests that some of the major, presently-observed topography of the MFF may have also been in existence prior to the emplacement of Aht_3 (during the Hesperian?) [see also 14].

Conclusions: These comparisons support the interpretation that the thick, unconformable layered deposits in the equatorial region of Mars are remnants of ancient volatile-rich deposits [e.g., 1] that have subsequently undergone significant erosion and degradation. Stratigraphic evidence suggests that formation and modification of the MFF may have taken place at least partly in the Hesperian Period. We propose that the unit formed 1) from airborne volatile-rich sediments emplaced during periods of high obliquity when equatorial regions were colder and/or 2) at other times when the northern lowland-highland topographic boundry favored upwelling of water-rich air and preferential deposition of volatiles there. Sources of water vapor include polar regions undergoing concurrent sublimation at high obliquity, and subliming of frozen water deposited from outflow channels. The complex stratigraphy of the Medusae Fossae Formation suggests that periods of emplacement were interrupted by periods of erosion and volatile loss. Previous mapping of stratigraphic relationships suggests an extended duration of emplacement in the Amazonian, and recent mapping using MOLA data suggests that the record of this type of process might extend back into the Hesperian Period.

Geophysical tests. Radiophysical properties of ice loaded with dust favors its probing with radar sounders. The "stealth region", detected in the microwave radar experiments partly coincides with the MFF. This is consistent with icy material with a relatively high load (20-70%) of fine-grained (<1 mm) sediment. The ice, especially with low or modest dust load, is transparent for the radio waves in comparison to other target terrains. This provides the possibility to map the internal stratigraphic boundaries in the MFF. Probably, an advanced *ground-penetrating radar* technique would be able to confirm or reject the hypothesis of MFF as icy deposits. *Gravity data* of enhanced resolution (e.g., Doppler tracking of an orbiter with low pericenter at low latitudes) could be used to distinguish between icy or more dense deposits; however the data interpretation might be not unique.

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ON SOUNDING RADAR PERFORMANCES FOR MARTIAN SUBSURFACE WATER DETECTION.

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Abstract: Several radar experiments are foreseen to map the Martian subsurface down to several kilometers, searching for underground liquid water reservoirs, all based on the penetration property of the radio frequency waves. The penetration depth of low frequency radar is mainly related to the electromagnetic properties of the investigated medium. Thus a good knowledge of the Martian subsurface dielectric profile along the first kilometers is necessary for the future water identification and data interpretation. We have investigated in this work the electrical and magnetic properties of the Martian surface and subsurface, using terrestrial analogues of the Martian materials and laboratory measurements in the frequency range 1-500 MHz. It covers the frequency domain of the MARSIS experiment on board the Mars Express mission (ESA–2003), the NetLander GPR instruments (CNES–2007), and other future radar systems (MEEM project). We combined these results in a most common geological model of the Martian subsurface, in order to estimate the radar penetration depth. This work will be used to simulate the radar backscattered signal for various Martian subsurface scenarii, with respect to the instrumental parameters of the different radars planned to be used for the Mars exploration.

Introduction: Radar sounding performances are generally related to three surface and subsurface parameters: 1) the surface and interface slope (i.e. the subsurface geometry), 2) the surface and layer interface roughness, and 3) the dielectric properties of the geological materials. For the 2 MHz Ground Penetrating Radars on board NetLander and the orbiting sounder on board Mars Express, the surface and subsurface interfaces can be assumed to be smooth according to the first order approximation of the Rayleigh criterion. We consider as a first approximation that the Martian subsurface layer interfaces are horizontal and parallel, according to the observed stratigraphy on the exposed wall rock of Valles Marineris [1]. Thus the main factor governing the detection of water reservoirs will be the electrical behavior of the geological layers covering it. Water detectability using sounding radar is conditioned by two main factors: the ability of radar waves to penetrate down to the depth of the ground ice / liquid water interface (supposed to vary between 2 and 6 km [2]), and the strength of the dielectric contrast between the ground ice and the wet megaregolith layer containing the water reservoir.

Experimental results: In our approach, we constructed experimentally a most common dielectric profile representative of the Martian subsurface by measuring the electric permittivity and magnetic permeability of well defined mixtures of volcanic and sedimentary materials that have been reported for Mars (basalt, hematite, maghemite, etc. [3]). We considered the subsurface geological model proposed by Clifford in 1993 [4]. We mixed basalt, iron oxides and evaporites (gypsum) that may be present on Mars with representative amounts, supposed to represent the Martian geological context under the most common petrophysical and geophysical conditions, along a typical subsurface profile. We conducted the electromagnetic characterization of synthetic samples of the Martian subsurface materials under adequate conditions of porosity and temperature that should exist along the first 2.5 km of the upper crust. Dielectric measurements show that the first layers of the Martian subsurface (first hundreds of meters), which are mainly constituted of volcanic iron rich materials, could dramatically decrease the radar initially foreseen penetration depth, thus limiting the deep subsurface exploration [5].

		Measured values		Previous values	
Geological layer	depth (m)	ε'	tg δ	ε'	tg δ
Dust layer	0-10	3-9	0.06-0.15	1-4	0.01-0.05
Basalt altered rock	10-50	15-25	0.1-0.9	3-9	0.01-0.1
Lava + regolith	50-200	12	0.1	3-8	0.05-0.1
Sedimentary deposits	200-400	5	0.15	3-5	0.001-0.05
Basaltic regolith with ice	400-2500	6	0.05	4-7	0.005-0.05
Basaltic regolith with water	> 2500	36	0.3	20	0.2-0.3

Table I: The measured dielectric properties of the laboratory analogues at 2 MHz. for the Martian most common geological profile.

Table I presents a dielectric profile resulting from our sample measurements for the most common Martian geological profile considered by Clifford, as compared to previously used permittivity values [6]. Our experiments showed that the porosity of samples has a more important impact on the electrical properties than the effect of temperature for dry geological materials [7]. Our laboratory samples appear to be more conductive at low frequencies than the values previously considered for the MARSIS experiment of Mars Express. We show in particular that larger loss tangent should be considered for the 2 MHz sounding radars.

Magnetic permeability measurements were performed using a magnetic cell for powder of hematite and maghemite. They show a significant frequency dependency and a strong increase of μ' and μ" values below 2 MHz as presented in Fig. 1. Thus, NetLander and Mars Express radar experiments should take into account the absorption due to magnetic relaxations in the dust layer that covers the whole surface of Mars and could contain both hematite and maghemite.

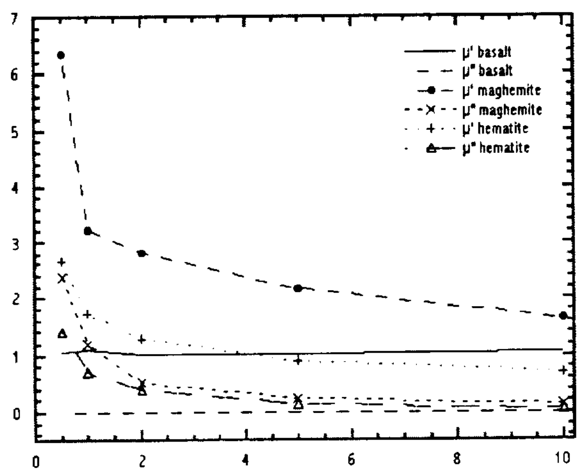

Fig. 1: Magnetic properties of the iron oxide rich samples as a function of frequency in MHz.

We computed the radar penetration depth δ_P at 2 MHz for each of the mixture presented in Table I, using the equation:

$$\delta_P = \frac{\ln(J)c}{4\pi f}\left\{\frac{\mu\varepsilon'}{2}\left[\sqrt{1+(tg\,\delta)^2}-1\right]\right\}^{-1/2} \qquad (1)$$

None of the considered materials gives a penetration depth higher than 1.7 km for the 2 MHz frequency. It seems than radar penetration larger than one kilometer will be very hard to achieve at 2 MHz under the actual hypothesis for the Martian subsurface geology, thus reducing the chances to detect the ground ice / liquid water interface [7].

Water detection: Beside the radar penetration depth capability, another factor to be considered for subsurface water detection is the strength of the dielectric contrast corresponding to the wet interface. We need a sharp ice / water transition, compared to the radar wavelength, at the interface between the frozen soil and the wet regions. Considering that the pores of a frozen soil are likely to contain amounts of unfrozen water at temperatures below 0°C [8], the Martian subsurface is likely to present a moisture gradient, leading to a local vertical permittivity gradient near the ground ice / liquid water interface. Considering models for water content in frozen basalts [9] and a typical Martian geothermal gradient to be $\Delta T=-10°C\ km^{-1}$, we computed that the moisture gradient should spreads over at least 500 m, more than three times the sounding radar wavelength at 2 MHz (150 m). This should produce a considerable effect on the dielectric profile by increasing gradually the real and imaginary part of the ground ice layer before reaching the water interface. The ground ice / water interface would then not appear on the radar echoes as a sharp peak as expected, but rather it would produce a broad flattened low amplitude peak. Even if this last discussed feature seems to be a problem for water detection, it could be used to differentiate an ice / water interface from other dielectric contrasts due to the presence of a layer of strong conductive materials (e.g. evaporites and clays) among other geological materials.

Future work: We shall now consider specific Martian sites that could present in particular relatively low conducting geological layers combined to and a sharp ground ice / water transition, in order to optimize the penetration depth versus radar resolution ratio. We selected a variety of specific sites on the Martian surface, for which we constructed a dielectric model of the subsurface in the frequency range 1-500 MHz, for which we shall simulate GPR profiles using numerical methods such as FDTD. This work will support the selection of optimal landing sites for the four GPR of the NetLander mission.

Acknowledgements: The authors would like to acknowledge J.-J. Berthelier and N. Mangold for helpful discussions. This research was supported by the French CNRS and is a part of the NetLander development work within the CNES Mars exploration program.

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Modern geothermal gradients on Mars and implications for subsurface liquids. N. Hoffman, Earth Sciences, La Trobe University, Melbourne 3086. Email: n.hoffman@latrobe.edu.au

Introduction: Historically, Mars has been viewed as an Earth-like planet and the consensus for geothermal gradients has been close to that for Earth or no less than 50% of that value [1]. As a consequence, liquid water is envisaged as a likely occurrence in the relatively shallow subsurface (1-2km). Recent data from MGS, however, has added weight to the alternative view [2] that Mars is in fact much less thermally active than the Earth and has significantly lower heat flux and geothermal gradients (1/4 to 1/3 that for Earth). Consequently, liquid water requires exceptional local conditions before it will be found in the upper few km of the regolith and the most likely liquid in the subsurface may be liquid CO_2.

Heat Flow on Mars: There are two principal contributors to the modern heat flow on Mars: The amount of radiogenic heat and the efficiency over geologic time of heat loss processes. For modern heat flow, questions such as the effective temperature of accretion and the timing of core differentiation are essentially irrelevant. Their effect has decayed to negligible proportions at present day.

Radiogenic Heat: The standard approach assumes that Mars has an Earth-like distribution of elements, and therefore its radiogenic heat will scale with mass compared to the Earth. However we know that this cannot be true since Mars has a mean density of 3.9 compared to Earth's 5.5, therefore there is a significant light vs. heavy element fractionation between Earth and Mars (i.e. heavy elements on Mars are diluted by more light elements than on Earth).

This makes for a difficult analysis, since one of the long-lived radioisotopes – Potassium – is a light/volatile element and should be enriched on Mars compared to Earth, while two – Uranium and Thorium are heavy/refractory and should be diluted. In the space available here, let us simply acknowledge that radiogenic heat on Mars will be proportionally less than on Earth, say 75% per unit mass. As we will see later, this agrees with values of lithospheric thickness and surface age distributions.

Heat Flux: This will essentially scale as heat production (barring gross differences in the heat storage properties of Mars' internal convection compared to Earth), with a correction for the surface area to volume ratio of the smaller sphere of Mars. Again, the lower mean density of Mars requires that its radiogenic heat be spread further than on Earth. We find that heat flux per unit area would be 38% of Earth's without correcting for the dilution by light elements but is 28% once dilution is factored in. On Earth, the mean geothermal gradient is 61.5 mW/m^2 for both oceanic and continental crust. Therefore on Mars we expect 28% of this i.e. 17.5 mW/m^2. This is at the low end of the range of 17-24 mW/m^2 found by [2].

Reality Check: We can confirm the accuracy of these figures for heat flow by comparing lithospheric thicknesses for Earth and Mars. On Earth, old continental lithosphere is around 100km in thickness. On Mars, we do not have direct seismic evidence for the lithospheric thickness but the elastic thickness of the outer shell can be determined from the ratio of gravity anomaly to topographic depression. MOLA data show that the lithosphere of Mars has grown with time [3]. The Tharsis rise, the largest gravity and topography feature on the planet dates back to Noachian times, but already had an effective elastic thickness of 150 km. Younger features have greater thickness. Olympus Mons, for example is around 1 Ga in age, and has an elastic thickness of 250 km. A reasonable estimate of the present-day elastic thickness is in excess of 300 km [4]. Therefore the ratio of gross crustal heat flux of Earth to Mars is about 3:1, which confirms the values calculated here from first principles.

Geothermal Gradients: For a given heat flux, geothermal gradients depend on thermal conductivity. On Earth, typical geotherms are around 30-35 K/km. Everything on Earth is water saturated, and water is actually a relatively poor conductor of heat (although in convecting systems it is an excellent advector). In the upper layers, at least, of Mars we expect water to be frozen. Ice is a much better conductor of heat, especially at lower temperatures, so for ice-filled porosity on Mars we expect conductivity ~ 25% better than on Earth. For dry but compacted regolith, we expect conductivities ~25% worse than on Earth. Consequently in dry regions of Mars we might find geothermal gradients of ~ 10.6 K/km, while in ice-saturated zones we would expect values of a mere 6.4 K/km.

Depth to liquid water: The melting temperature of brine is significantly lower than that of liquid water, while clathrate formation tends to increase the melting point, even for a brine. The combination of both leads to moderate freezing-point depression by say, 25 K. Therefore the vital isotherm on Mars is ~250K.

Equator: For equatorial mean surface temperatures of ~ 220K, only 30K of temperature increase is required to reach the first aqueous liquids – very strong brines. These will be found at depths of 30/6.4 km (4.7

km) for a uniformly ice-saturated regolith and 30/10.6 km (2.8 km) for a uniformly dry regolith.

It is generally accepted that the upper few hundred metres of the equatorial regolith is dry [5], but the regolith should begin to have appreciable ice content below 500m so an average of these two values (3.7 km) is probably a slightly optimistic estimate of the depth to the first eutectic brines on Mars.

Fresher waters require a further 25 K of warming and would not be expected for a further 4 km – i.e. a total depth of ~8 km

Temperate Mars: A typical mean annual temperature of 200-210 K requires 40-50 K of warming to the first melt depth. Small quantities of aqueous liquids will first occur at depths of (3.8 or 6.3) to (4.7 or 7.8) km – say 5-6 km.

Polar regions: below the permanent polecaps, year-round temperatures are buffered to ~150 K by subliming CO_2 ice. 100 K of warming is required for even the most potent eutectics. The ground is saturated by ice from the surface and high conductivities prevail. Melting will not, therefore, occur until depths of 100/6.4 = 15.7 km. This is below the base of any expected porosity in the regolith and essentially means that the polar cryosphere cannot melt at any depth.

Cryosphere: In summary, a cryosphere of permanently frozen water ice (or clathrate) is anticipated to extend from the base of the desiccated zone to depths of 4 km in equatorial regions, deepening to 5-6 km in temperate zones before plunging to over 15 km in polar regions. The fraction of ice in this zone will depend on the available H_2O inventory of Mars and the actual porosity of the regolith, but is capable of accounting for over 1km global equivalent layer of H_2O.

Depth to liquid CO_2: Liquid CO_2 forms above 216 K, at pressures of at least 5.1 bars. Providing that a barrier of water ice or clathrate exists at some point in the cryosphere, the pressure can be contained by lithostatic load. Below about 45 degrees latitude, the surface temperature exceeds the melting point of liquid CO_2, so pockets, veins and layers of liquid CO_2 – "liquifers" are possible within a few tens of metres of the base of the desiccated zone – assuming that a pore-occluding water-ice or clathrate region exists. The liquid CO_2 will occupy voids, fissures, and pores in the regolith that are not filled by cements and water ice.

Poleward of 45 degrees, the subsurface temperature is initially too cold for liquid CO_2 and a dry ice permafrost layer becomes likely. Again, this will still require a pressure barrier since above ~145 K, the vapour pressure of dry ice exceeds the atmospheric pressure of Mars. Both dry ice and clathrate will coexist (water ice cannot co-exist as well over geologic time since the phase equilibrium permits only one end-member of the H_2O-CO_2 system, and the ratio of CO_2 to H_2O on modern Mars is expected to grossly exceed the stochiometry of clathrate). The depth to the base of the dry ice will deepen poleward, reaching perhaps as deep as 10 km at the poles due to the thick and H_2O-rich ice present in the polecap and underlying regolith.

Implications for Mars: The recognition of multiple lines of evidence for low geothermal gradients on Mars leads us inexorably to a planet where exceptional conditions are required to bring liquid water to reasonable drilling depths (e.g. 2 km for a light portable and automated drilling rig). Evidence of very recent volcanic activity should be sought to find intrusive centres less than 10^6 years old whole thermal halo has not decayed away.

At the same time, liquid CO_2 is thermodynamically stable in the regolith at much shallower depths and models of Mars regolith must recognise the physical and chemical effects of this. Even if only small quantities are present at any one time, over geological time much of the regolith will have been flushed by liquifers of CO_2 with its unusual solvent properties.

The existence of liquid CO_2 in the regolith represents an important energetic source of vapour for generating cryovolcanic features [6] and major density flows [7]. It also represents a significant drilling hazard in an environment when conventional drilling mud may be precluded due to cryogenic temperatures and to the expectation of severe losses into porous and brecciated regolith.

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Quantities and sources of liquid Carbon Dioxide in the subsurface of modern and ancient Mars. N. Hoffman, Earth Sciences, La Trobe University, Melbourne 3086. Email: n.hoffman@latrobe.edu.au

Introduction: The focus on liquid activity on Mars has been on water, but in fact the temperature and pressure conditions in the subsurface of Mars are ideal for liquid CO_2 over a wide range of latitudes and depths [1,2]. Potentially, that liquid CO_2 may be the major agent in erosion, diagenesis, and chemistry on Mars [2]. The key question is how much liquid CO_2 there may be and the balance between escape processes and resupply. Here we attempt to estimate the global inventory of liquid CO_2 and its supply to the deep regolith and use surface data to infer escape over geologic time.

The problem: Liquid CO_2 is a potent cryogenic volatile that has the potential to significantly modify subsurface conditions on Mars and to interact with H_2O in a variety of interesting ways. Clathrate formation extends the stability field of ice by about 10 K and deepens the H_2O cryosphere by ~ 1km (at realistic geotherms of 10 K/km). Excess CO_2 beyond the 1:5.75 stochiometry of clathrate must be either retained in or expelled from the subsurface.

Due to its high vapour pressure and low viscosity, liquid CO_2 will rapidly exploit any pathway to lower pressure compartments and ultimately to the surface. In the process, non-polar solvent action of the liquid CO_2 will lead to diagenesis of the regolith in ways not encountered on Earth, and the formation of non-aqueous evaporate species.

However, without a mechanism for return of CO_2 to the deep regolith, this process will diminish exponentially over geologic time and at the present day one might expect to find only small and isolated pockets of liquid CO_2 in the subsurface [3]. This issue is comparable to that faced by water recycling models for the origin of chaos zones and many of the concepts used there can be applied to this issue, although the details of subsurface temperature and pressure appear to work more favourably with CO_2 as the volatile rather than H_2O.

CO_2 Inventory: The first question to be tackled is the total amount of CO_2 on modern Mars. This is a surprisingly poorly known value and at extremes of the possible range, very different situations may apply. The issue is also linked to the total H_2O volume on Mars and to the H_2O:CO_2 ratio. It is reasonable to suppose that Mars had a similar initial H_2O:CO_2 ratio as the other terrestrial planets – about 3:1. Over time, Mars has lost water to space, as attested by the D/H ratio of the atmosphere, but the denser CO_2 has been retained preferentially. Therefore at the present day the ratio of H_2O to CO_2 should be around 1 or 1.5:1. This is an important constraint that we need to refer to.

Location: A small amount of CO_2 is present in the atmosphere and seasonal polecaps amounting to ~ 10 mbar. This is a minute fraction of the primordial inventory of 1 to 20 bars that Mars might have been endowed with (corresponding to an original global water supply equivalent to 50 m to 1 km). Where is the rest of Mars' CO_2?

On Earth, the majority of CO_2 is chemically bonded as carbonate rock. Searches for carbonate on Mars have been disappointing to say the least and a number of models suggest that it is present, but invisible to IR detection. However, each bar of CO_2 corresponds to about 20 metres global thickness of carbonate rock. We would expect to find carbonates preferentially in lowland basins, which cover ~1/4 of Mars surface at most. Therefore, the search for carbonates is a search for an average thickness of 80 to 1600 metres of carbonate rock and the higher the volatile inventory, the thicker the carbonate.

We can rule out the higher values since this would require the lowland plains to consist of over 50% carbonate, which would have been immediately detected by surface landers. The lower values are possible, so if Mars had a very limited initial inventory of both water and CO_2, we need look no further. (The small carbonate fraction in ALH84001 could account for a bar or two of CO_2, if large volumes of old igneous rocks share this chemistry).

The polecaps. All that we know of the permanent north polar cap is that it consists of H_2O-rich ice. It may be normal water ice or clathrate. Since deposition of solid CO_2 occurs every winter, one would expect clathrate as the H_2O-bearing phase. Therefore, the polecaps may contain up to 300 mbar of CO_2 (20 metres global equivalent of water). Thick polar permafrost represents a potential ice reservoir up to ten times the volume of the caps, so some 3 bars of CO_2 may be stored as clathrate in the polar regions, putting us well into the higher ranges of volatile inventory.

Given the expected ratio of CO_2 to H_2O, we have an excess of CO_2 to account for of about 3 times this value – i.e. 1 to 9 bars. If the permanent polecaps are <u>not</u> formed of clathrate, but of normal ice, the excess CO_2 amounts to 4 times the polar inventory – up to 12 bars.

So where are these ~10 bars of CO_2? We have already seen that it is highly unlikely that this much sedimentary carbonate could exist in the northern plains. There are only two remaining reservoirs – CO_2 permafrost and liquid CO_2.

CO_2 permafrost may be present in distributed form or in layers or lenses in the sub-polar regions. It may also be present as occasional layers within the polecap itself. If CO_2 permafrost extends down to 45 degrees latitude, and has a mean thickness of 4 km and a saturation (or relative fraction) of 20% then this accounts for some 10 bars of CO_2 - the excess inventory we are seeking to account for. There is therefore an extensive polar and sub-polar reservoir of solid CO_2 is available for melting at depths of 2-6 km. The question then becomes one of the frequency and scale of thermal events that may occur over the sub-polar regions.

Evidence and mechanisms for melting

Past Melting Events: The acme of the outburst "floods", at 3 to 3.5 Ga in the late Hesperian appears to represent an epoch of escape of potent volatiles from near-equatorial regions. White Mars models [2] propose that liquid CO_2 was generated by local thawing of a global CO_2 permafrost, leading to high local concentrations of energetic subsurface liquid CO_2. Subsequent to that time, no events on this scale are recorded, so the Hesperian is seen as a one-time melting of the equatorial regions.

Recent Melting Events: Small hills with summit craters have been noted around the north polar cap [4]. These may be large cryptovolcanoes and are exactly what would be expected if basal melts of CO_2 escaped to the surface and erupted as geysers or cryovolcanoes. Various tracts of "thumbprint" terrain can be interpreted as extensive fields of cryovolcanoes [5]. Thus many "volcanic" hills where lava flows are not seen may in fact be signs of cryogenic circulation of CO_2 from basal melts back to the atmosphere, where it will then redeposit in the permafrost and polecap.

Global melting events: At depths of 2 km or more, the base of the CO_2 cryosphere is protected from short & medium period orbital variations. Only events on a timescale of 10^5 years or more will penetrate to these depths. On this timescale, orbital variations of $10°$ in obliquity and 0.02 in eccentricity are calculated [6]. variations on this scale can lead to fluctuations of 20% in zonally-averaged insolation at higher latitudes (50-80°), leading to a 5% surface temperature variation i.e. 10-20 K. This would produce a change in the base of the CO_2 cryosphere by 1 to 2 km.

If the change is a warming, then this would lead to extensive generation of liquid CO_2 over a 1-2 km depth interval, beneath a thick seal of still-frozen CO_2. If the change is a cooling, then CO_2 will freeze-out. Calculations of recent change appear to suggest a recent obliquity increase of modest proportions, so perhaps only a few hundred metres of newly melted CO_2 is available at the present day.

Local Geothermal events: Mars has a very focussed pattern of volcanism with large and long-lived stratovolcanoes, yet many smaller volcanic centres exist, some of which have relatively young ages. Just as one would expect intrusions of hot magma to melt ground ice and mobilise a hydrothermal circulation, so too would it melt clathrate and dry ice. Providing that the whole system were not so shallow and energetic as to break through to the surface (where it would form a cryptovolcano as discussed above), then the circulation would organise into a multi-layer "onion-shell" system. The hot magma would form the central core. Around this would be a modest-sized hydrothermal system (with carbonated water), and surrounding that would be a more extensive liquid CO_2 system.

An individual intrusion has enough thermal energy to melt 1-5 times its volume in ice, but around 2-10 times its volume in CO_2, at lower temperatures. Furthermore, as the intrusion cools the central wet core will freeze first while the outer CO_2 zone will contract inwards and replace the liquid water hydrothermal system, thus a senescent hydrothermal system will contain a very small watery core and a proportionally larger liquid CO_2 zone.

Implications for Mars: Any detected liquid water zone in the shallow regolith (< 2 km) is likely to be a local or temporary feature related to geothermal heating. In these circumstances, each occurrence of liquid water will be surrounded by a shell of liquid CO_2, which will represent a significant hazard to future attempts to drill into these pockets.

Due to recent orbital fluctuations, large areas of Mars have experienced modest surface warming over the past 10^5 years or so, which means that regional liquifers of CO_2 are likely at the base of the CO_2 cryosphere in most high-latitude areas (above 50°). These liquifers will be a few hundred metres thick and are relatively young, therefore will not have had time to dissipate. The base of the CO_2 cryosphere ranges from ~2 km depth at 45° to 6-8 km depth in polar regions for realistic geotherms of 10 K/km.

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FUTURE EXPLORATIONS ON CHEMICAL COMPOSITIONS OF SEEPAGE WATER AND GROUND ICE ON MARS DETECTED BY GAMMA-RAY SPECTROMETER, GC-MS, AND ION CHROMATOGRAPH. J.-S. Jean[1] and C.-H. Yang[2], [1] Department of Earth Sciences, National Cheng Kung University, Tainan, Taiwan, R.O.C., e-mail: jiinshuh@sparc4.cc.ncku.edu.tw, [2]Department of Applied Geology, National Central University, Chungli, Taoyuan, Taiwan, R.O.C., e-mail: yang@app.geo.ncu.edu.tw.

The 2001 Mars Odyssey's gamma-ray spectrometer (including neutron spectrometer) and THEMIS (Thermal emission imaging system) will find evidence for present near-surface water and locate hematites and carbonates from past water activity, which may prove the existence of liquid water on Mars. However, liquid water can exist only at water's triple-point of the present-day martian vapor pressure of 6.1 mbar and the temperature of 273 K [1]. Because average temperatures of Mars are below 273 K, liquid water is not likely to be found at the surface at such a low atmospheric pressure [2]. Even if liquid water exists, it easily evaporates as volatiles into the atmosphere and then into outer space due to the low gravity of Mars (~38% of Earth). The liquid water on the martian surface and water vapor in the atmosphere would have eventually disappeared from Mars.

As of January 2000, ~150 high-resolution images acquired by the Mars Global Surveyor Mars Orbiter Camera showed ~120 locales as the results of fluid seepage and surface runoff, in which the one at the inner walls of southwestern Newton Crater (41.1°S, 159.8°W) was demonstrated as evidence for the presence of sources of liquid water at shallow depths beneath the martian surface [2]. However, in their work they did not specifically address the debate over whether liquid water or some other liquid is responsible for fluid erosional landforms on Mars. We consider in this study the recent groundwater seepage and surface runoff on Mars to be water containing certain antifreeze compounds or to be some other liquid, which can decrease evaporation and resist to freeze, such as brines with a salt base (e.g., sodium and calcium chlorides), brines with low-temperature heat transfer (e.g., methylene chloride, trichloroethylene, trichlorofluoromethane, trichlorotrifluoromethane, dichlorofluoromethane, carbon tetrachloride, acetone, methanol, ethanol), brines with a glycol base (e.g., ethylene glycol, propylene glycol), isopropanol, glycerol, alkanes (e.g., pentane, hexane, heptane, octane), etc. The freezing points and boiling points of these antifreeze compounds are shown in Table 1. One of these compounds in Table 1 may possibly have mixed with or without water as aqueous antifreeze solutions on Mars, thus facilitating to produce the erosion, transport, and deposition, and then to develop fluid erosional landforms (e.g., gullies, channels, valley networks, etc.).

Doran and Forman [3] proposed that the martian discharge is saline or hypersaline, which could reduce the freezing point and evaporation of liquid water. At such low atmospheric pressure (~6.1 mbar) as presently exists on Mars, the freezing temperatures of brines with a salt base can be at 209 K or –64 °C [4]. Groundwater seepage, surface runoff, eroded gullies, and sedimentary formations were recently demonstrated by Malin and Edgett [2, 5]. The erosion of the martian outflow channels and valley networks has been known in the literature. Water has been considered as one of the agents to form these features. However, whether it is in a pure H_2O form, or in other liquid form, or contains salts or some other antifreeze compounds is still something of enigma. It is crucial to identify these characters for human colonization in future. This study proposes an approach to detect chemical compositions on the seepage water and/or ground ice by gamma-ray spectrometer, GC-MS (gas chromatograph-mass spectrometer), and ion chromatograph (Table 1) mounted with a lander for future Mars explorations.

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Table 1. Properties of antifreeze compounds at 1 atmospheric pressure

Compounds	Freezing or melting point (K)	Boiling Point (K)	Detection method
Methylene chloride	175.4	313.1	GC-MS
Trichloroethylene	200	359.7	GC-MS
Trichlorofluoromethane	162	296.6	GC-MS
Trichlorotrifluoromethane	236.6	320.7	GC-MS
Dichlorofluoromethane	138	281.9	GC-MS
Carbon tetrachloride	250	349.5	GC-MS
Acetone	255	329.2	GC-MS
Methanol	175.2	337.5	GC –MS or IC
Ethanol	155.7	351.3	GC-MS or IC
Ethylene glycol	259.5	470.2	GC-MS or IC
Propylene gly[illegible]	213	460.3	GC-MS or IC
Pentane	143.3	309.1	GC-MS
Hexane	178	341.7	GC-MS
Heptane	182.4	371.4	GC-MS
Octane	216.2	398.7	GC-MS
Isopropanol	187	355.4	GC-MS
Glycerol	291	563	GC-MS
Sodium- and calcium- chloride solutions			IC
Water	273	373	Gamma-ray spectro-meter

Water is included for comparison. GC-MS: gas chromatograph-mass spectrometer; IC: ion chromatograph.

The System and Implementation aspects of the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS). R. L. Jordan[1], D. Biccari[2], O. Bombaci[3], D. Gurnett[4], W.T.K. Johnson[1], D. Kirchner[4], G. Picardi[2], J. Plaut[1], A. Safaeinili[1], R. Seu[2], K. Wheeler[1] and E. Zampolini[3].
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Introduction: MARSIS is a radar sounder operating in the HF frequency range to sound the surface of Mars, which will operate from the ESA Mars Express spacecraft [1]. It is scheduled for launch from Baikonour, Russia in June 2003 and arrives in orbit around Mars in early 2004 for a two-year mission. This system is the result of an international collaboration between NASA, the Italian Space Agency (ASI), and European Space Agency (ESA). The MARSIS instrument is a 17 Kilogram total mass sounder consisting of a 40 meter tip-to-tip dipole antenna, a 7 meter long monopole antenna and the electronics module.This design of MARSIS is a tradeoff between the expected penetration into the Martian subsurface that is proportional to the wavelength of the system and the desire to operate at a short wavelength in order to minimize the effects of the ionosphere.

Instrument Characteristics: The main objective of MARSIS is to search for water if it exists in liquid form under the surface to a depth of 5 Km. It will also attempt to map and characterize the subsurface geological structure of Mars, which is hidden under a layer of surface dust. In addition to its subsurface exploration goals, MARSIS will study the ionosphere of Mars providing the most extensive amount of data on Martian ionosphere to date. In order to penetrate the martian surface to a depth of 5 Km, it is necessary to operate at a frequency which is as low as possible consistent with the Martian ionosphere. The instrument design incorporates 5 separate subsurface sounding modes [2] as well as the active and ionospheric modes. A mode identifies the number of frequencies and method of data acquisition and is separate from the frequencies used for sounding. MARSIS uses 4 frequency bands for sounding the subsurface that have center frequencies of 1.8, 3.0, 4.0 and 5.0 MHz. Operation at each of these bands has a bandwidth of 1 MHz. Operation for the active ionospheric sounding mode covers the 0.1 MHz to 5.5 MHz frequency range. For the subsurface sounding mode of operation, transmission at two simultaneous bands is possible with time displacement used as the method for isolating the returns. Radio signal transmission is through the 40 meter tip-to-tip dipole antenna and as shown in the MARSIS block diagram of Figure 1, echo reception is in both the dipole and monopole antennas. The antenna length is limited by the design of the Mars Express spacecraft. The dipole antenna length is naturally resonant at a frequency of 3 Megahertz. In order to radiate at frequencies other than the resonant frequency, two wideband matching networks are incorporated into the design. The transmitted signal is a nominal 250 microsecond linear frequency swept pulse.

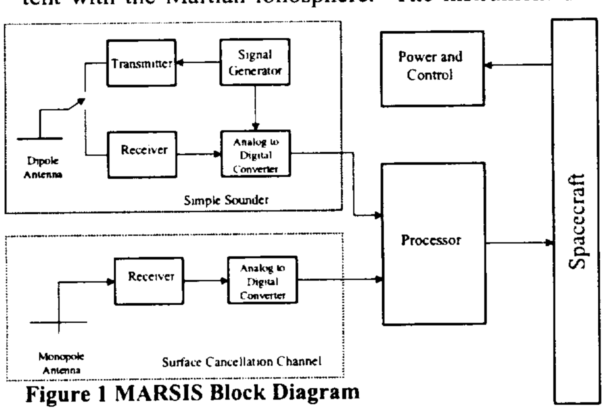

Figure 1 MARSIS Block Diagram

Instrument Operation: The MARSIS instrument is designed to operate in an elliptical orbit with a periapsis of 250 Km and an apoapsis of 10,124 Km. over the Martian surface. The sounder will acquire ionospheric data when the orbiter reaches altitudes below 1200 Km above the Martian surface and subsurface sounding data is aquired when the orbiter altitude is below 800 Km. The selection of the operating frequency band will be made based on the expected local solar zenith angle. For significant penetration of the surface, it is desired to operate at a RF frequency that is as low as possible. The limitations to operating at very low frequencies is the ionosphere of Mars [3,4,5]. The ionosphere of Mars prevents operation at frequencies below 2.5 MHz when the solar zenith angle is less than 80 degrees and at frequencies below 0.5 MHz during nighttime.

An examination of the surface slope distribution from the MOLA laser altimeter indicates that the surface of Mars has a RMS slope of less than 2 degrees with an RMS height distribution of 3 meters for 90 percent of the surface. For a surface with this roughness, the subsurface returns are expected to be stronger than the surface clutter after the planned Doppler filtering. For the remaining 10 percent of the surface of Mars, the surface roughness has a greater slope distribution and a higher RMS height. For these rough areas, the return from the surface clutter is expected to dominate over the subsurface returns. In order to separate the surface returns from the subsurface returns, the MARSIS design incorporates a second receive only channel with an antenna that exhibits a null in the nadir direction. The purpose of this second, or surface clutter cancellation channel is to receive mostly off-nadir surface returns. These surface returns can be subtracted from the returns of the main channel reducing the effects of the surface clutter level. This clutter removal takes place on the ground as both returns from the dipole and clutter cancellation channel are separately sent to the ground. The antenna for the surface cancellation channel consists of a 7-meter monopole. The receive channel electronics after the antenna is identical to the subsurface sounding channel.

Each of the two receiver channels has first RF amplification prior to down conversion to an intermediate frequency of 0.7 Megahertz. The returns are filtered in their native frequency range and subsequently at the intermediate frequency. The receivers have a range of gain between 33 and 73 dB prior to conversion to a digital format by an 8 bit A/D converter. The data are first buffered prior to transmission to the data processor. The digital processing section can take a portion of the digital data in an unprocessed form for telemetry to the ground or it can process the return echos in a dual DSP processor.

The control of the MARSIS instrument is via an Operation Sequence Table (OST) which contains all the necessary control parameters for a data pass. It is possible to command the instrument in approximately 1 second intervals. This OST is calculated on the ground and telemetered to the Mars Express Spacecraft prior to each orbital pass.

Data Processing: The subsurface sounder operates at a nominal pulse repetition rate of 130 pulses per second and acquires sounding data in blocks of approximately 1 second in duration. If the sounder is operating at a frequency close to the local plasma frequency, the return signal from the surface is expected to be dispersed and attenuated by the ionosphere to a level inversely proportional to the instantaneous frequency. The return echos are converted to digital form at a rate of 2.8 Megasamples per second and a duration of 350 microseconds. The return echos for a block of data (approximately 1 second duration) is then coherently integrated in the on-board digital processor prior to telemetry to Earth. Depending on the mode selected, the data may be combined from separate doppler filters to form multilook data or the returns from a single doppler filter returned to the ground. The data returned are in the frequency domain in order to reduce computation demands on the processor and data volume per block of data. These data contain the dispersion effects of the ionosphere and this phase distortion is detected from the front surface reflection. The effects of the ionospheric distortion are then removed from the sounder data on the ground.

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THEORETICAL ASSUMPTIONS ON SUBSURFACE ICE MELTING ON MARS. A. Kereszturi (Department of Physical Geography, Eötvös Loránd University, H-1083 Budapest, Ludovika tér 2., Hungary (E-mail: irodaweb@irodaweb.hu)

Introduction: The purpose of this work is only to show a theoretical approach of a possible subsurface water related process on Mars. The martian climate evolution modells suggest an early warm climate with liquid surface water in the Noachian [1, 2], and the later, "colder" Hesperian and Amazonian ages with less liquid or episodic surface water. Based on the new MGS results there are evidences for short and temporary warmer periods after the Noachian too [3, 4, 5, 6]. Summarizing the climatic changes the early water rich circumstances turned into cold climate, where the water froze into the regolit creating the criosphere. The melting of criospere's ice is depending on the geothermal heat flux and on the depth of the base of the criosphere. There is somewhere a melting isotherm, above this we can find ice, and below this we can find water. The question is: how can ice or water get below the melting isotherm. There are two possibility: 1. the isotherm rise because hot-spot like activity or because crustal thinning (by great impact for example) which causes faster heat escape at the region, 2. the criosphere sank below the isotherm. In the folowing part the second possibility is summarized from a theoretic point of view.

The modell: 1. During the late Noachian, and Hesperian great volume of the water froze into the regolit creating a criosphere. During the decrease of the average surface temperature and pressure we can suppose a global decrease in the planet's heat flux based on the thermal evolution modells. 2. While the criosphere was thickened the upper mentioned melting isotherm sank more and more deeper. If we suppose a near exponential decrease in the heat flux, we expect smaller changes in the last 1-2 billion year than before. 3. We can get ice below the melting isotherm with tectonic or volcanic processes during the last 1-2 billion years, when the ice rich blocks of the criospere sank below the isotherm.

We cant expect great tectonic activity in the last 2 billion years, but the following events can cause the sank of ice rich crustal blocks: 1. remove of lithospheric root by convective eddies and subcrustal erosion [7], 2. volcanic lava effusion into the surface causing isostatic sink of the terrain 3. magma injection thickening the crust, causing similar process. We do not expect crustal thickening caused by colliding lithospheric plates (known from the Earth) on Mars.

Future work: This article only summarised some theoretical assumptions on getting ice below the melting isotherm. In the future we would like to analyze the possible degree of sank of crustal blocks (best places for this are in the Tharsis and Elysium province) and compare the result to the supposed thickness of the criosphere. If we will be able outline good regions for this modell, there are other factors (the effect of magmatic activity, the effect of the state of the lithosphere and the craks within, where subsurface water can flow) which must be included too in the estimation.

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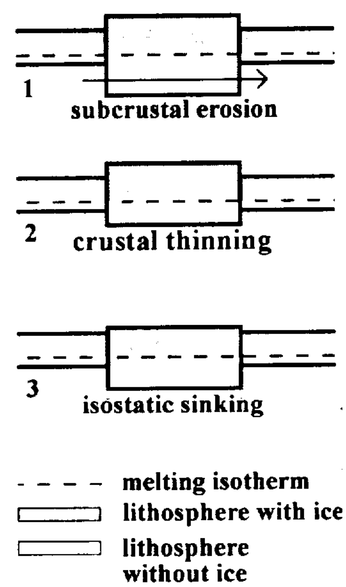
Fig. 1.: The subcrustal erosion + isostatic sinking scenario



WATER OR ICE: HEAT FLUX MEASUREMENTS AS A CONTRIBUTION TO THE SEARCH FOR WATER ON MARS

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The thermal structure of the upper crust of Mars is an important component of the search for water on Mars: if water is present, is it liquid or solid? Measurements of the surface heat flux, combined with a model for the increase of thermal conductivity with depth and the heat conduction equation, can be used to predict the thermal structure of the crust as a function of depth.

Experimental Methods

Estimates of the present-day mean surface heat flux on Mars are in the range 15 to 30 $mW\,m^{-2}$ [1,2]. Finite element mantle convection simulations suggest that there can be lateral variations of about 50% relative to the mean value [3]. The thermal conductivity for an intact basaltic crust is in the range 2–3 $W\,m^{-1}\,K^{-1}$ [e.g., 4]. For a granular regolith, the thermal conductivity would be significantly reduced [5]. On the Moon, the measured thermal conductivity in the Apollo 15 and 17 boreholes is 0.009 to 0.013 $W\,m^{-1}\,K^{-1}$ [6]. If lunar-like thermal conductivities occur in the martian regolith, thermal gradients could exceed 1 K/meter in the upper several meters of the regolith.

In marine geophysics, heat flux is measured using probes about 6 meters long. Themistors are located at spacings of 1 meter, each with a measurement accuracy of about 1 mK [7]. The resulting thermal gradient has a measurement accuracy of 0.2 K/km. The thermal conductivity is also measured *in situ* (see below); the heat flux is determined as the product of the thermal gradient and the thermal conductivity. On Mars, it is unlikely that a 6 meter long probe will be feasible during the first measurements. However, it will be desirable to make measurements over the largest practical depth range to increase the accuracy of the thermal gradient measurement. A deep measurement would also get below the immediate surface layer, where the seasonal thermal wave is strongest and the regolith's thermal conductivity probably has its greatest variability. The accuracy of thermistors on a martian heat flux probe may depend on how the probe is emplaced; thermistors designed for use on a penetrator probe might not be as sensitive as those used in terrestrial studies. Assuming a 3 meter long probe and 3 mK measurement accuracy for the thermistors, the thermal gradient could be measured to an accuracy of 1 K/km on Mars.

The thermal conductivity can be measured *in situ* by measuring the transient response to energy input from an electrical heater. This approach works very well in marine geophysics [7]. This was also attempted on the Moon but was not very successful due to the variability of thermal conductivity in the upper part of the regolith. A better approach on the Moon turned out to involve measuring the thermal wave associated with the month-long "day-night" thermal cycle [6]. The martian experiment should include the capability to perform transient heating measurements of thermal conductivity. However, it will also be desirable to make measurements over most or all of a Mars year so that measurements of the seasonal thermal wave can be used to constrain the thermal conductivity. The energy dissipated during probe emplacement (whether by drilling or penetrator) will cause a temporary heating of the probe site. Measuring the transient cooling from this event might also be a way to constrain the conductivity, but further analysis of this approach is needed. With measurements of both thermal gradient and thermal conductivity at the surface, one can use the heat conduction equation to estimate temperatures at greater depths. The thermal conductivity will increase with depth due to the closing of

HEAT FLUX MEASUREMENTS ON MARS: W.S. Kiefer

pore space with increasing pressure. Other geophysical methods (seismic, electro-magnetic sounding) may be used on the same mission to characterize regolith and crustal structure. By constraining porosity as a function of depth, such experiments may contribute to estimates of how thermal conductivity increases with depth.

In addition to the thermal wave associated with the annual seasonal cycle, there will also be thermal waves associated with climate variations due to long-term orbital and rotational variability. Observational characterization of these climatic fluctuations would require drilling to depths exceeding a kilometer. While that is a worthy goal for future climate studies of Mars, it will not be feasible on robotic missions. Removing the effects of these long-term climatic fluctuations from the heat flux data will require theoretical modeling that builds on existing studies [8].

Experiment Emplacement Mechanisms

The proposed experiment requires measurements taken at least one to a few meters below the surface. Two different experiment emplacement mechanisms deserve consideration, insertion of a probe in a drilled borehole, and insertion as part of an impact penetrator probe. Use of a drilled borehole has the potential advantage of a relatively long measurement probe. By increasing the measurement depth range, the thermal gradient and hence the heat flux can be measured with greater accuracy. Also, a probe attached to a surface lander has the potential for a relatively long measurement lifetime. This would allow time for the thermal anomaly associated with drilling to decay and for the seasonal thermal wave to be accurately measured and separated from the background heat flux. On the other hand, robotic drilling to depths of several meters may be quite difficult - at two of the three sites where deep drill holes were made on the Moon, the drilling turned out to be unexpectedly difficult, even with the support of a human crew [9]. In addition, the expense of soft landers means that this approach to heat flux measurements will be possible at no more than a few locations.

The alternative approach is to emplace the experiment using an impact penetrator, similar to the Deep Space 2 microprobes. This should have lower costs per spacecraft, allowing heat flux measurements to be made at a larger number of locations. However, the experience with the Deep Space 2 probes shows that penetrators remain a high risk technology. The limited length of such penetrators (the DS2 probes were 0.6 meters long) sets a lower limit on the uncertainty in the thermal gradient and hence in the heat flux. If penetrators are used for this purpose, it will be necessary to measure the inclination of the penetrator from the vertical so the vertical component of the thermal gradient can be accurately determined. Another concern with this method is the possibility of a very short mission lifetime. For heat flux measurements to be useful, they must be made over a sufficiently long period of time that the background thermal flux can be distinguished from heating due to mechanical dissipation of energy during penetrator emplacement and from the seasonal thermal wave.

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HIGHLY CONDUCTIVE EUTECTIC BRINES RATHER THAN WATER EXPECTED IN THE MARTIAN SUBSURFACE L. P. Knauth, D. M.Burt and J. A. Tyburczy, Department of Geological Sciences, Box 871404, Arizona State University, 85287-1404; Knauth@asu.edu, Dburt@asu.edu, Jim.tyburczy@asu.edu.

Due to low temperatures, subsurface water on Mars is unlikely. However, highly concentrated brines can have exceptionally low freezing points and are also remarkably susceptible to supercooling. Brass [1] reviewed brine compositions and concluded that eutectic brines could be stable under current martian temperatures. Kuz'min and Zabalueva [2] used Brass's work to suggest that subsurface brines could account for the "softened" terrains as well as other peculiar aspects of martian topography. Brines with freezing points lower than average current martian surface temperatures (ca -65°C) are found on Earth, so concentrated brines are excellent candidates for martian subsurface fluids if there is a mechanism by which they could have developed on Mars. We argue here that IF: 1) a hydrosphere was outgassed early in martian history; 2) large amounts of H_2O subsequently escaped from the atmosphere; and 3) the planet subsequently froze down; THEN: highly concentrated brines reside today in the megaregolith. The electrical conductivity of such brines should be vastly greater than that of pure H_2O and should therefore be much easier to detect geophysically.

The conventional view is that on Earth, Mars, and Venus, H_2O was outgassed following accretion. Cl is a volatile element that does not fit readily into silicate minerals and would therefore have outgassed as HCl along with the H_2O. In the earliest hydrospheres, HCl was therefore an important dissolved constituent. Subsequent leaching of Na from the earliest crust produced largely NaCl-bearing hydrospheres. On Venus, the initially high CO_2 levels resulted in a runaway greenhouse in which most of the water was lost via gravitational escape. On Earth, greenhouse temperatures were moderate enough to allow retention of the early hydrosphere, and it has persisted. The Earth's earliest hydrosphere appears to have had a salinity 1.5 – 2 X the modern value and that salinity declined with time as evaporite and brine deposits became sequestered on evolving continental platforms [3]. If the Cl/H_2O ratio of outgassed volatiles on Mars was similar to that on Earth, then the earliest martian hydrosphere would have had a similarly high salinity. However, the apparent absence on Mars of continents with huge sedimentary basins sequestering giant salt deposits precludes using the subsequent development history of terrestrial brines as an analog for martian brine.

Hydrogen produced by photodissociation of water vapor in the upper atmosphere escapes from Mars much more easily than it does from the more massive Earth. Based on the high D/H ratio of water vapor in the current atmosphere, up to 95% of the original martian hydrosphere was lost by this mechanism [4]. Loss of water to space leaves the residual hydrosphere enriched in its nonvolatile dissolved constituents. The early martian hydrosphere therefore necessarily evolved into a NaCl brine. This brine became pore fluid in a megaregolith composed of high surface area particles (fractured and fragmented glasses, impact breccia, pyroclastic debris, ash sheets, melt sheets, and small rock fragments) of basaltic or komatiitic composition. Chemical interaction with these particles was inevitable and would have converted the NaCl brine into a concentrated Ca-Mg-Na-Cl brine with numerous other dissolved constituents. Mars subsequently froze, and the subsurface brines underwent eutectic freezing to produce a mixture of H_2O ice, salts (mostly $NaCl{\bullet}2H_2O$ and $CaCl{\bullet}6H_2O$), and highly concentrated brine. Such brines could still be seeping out of escarpments and readily account for the remarkable and otherwise perplexing outflow gullies recently reported [5]. Eutectic brines therefore inevitably follow from current ideas regarding initial outgassing of volatiles, atmospheric water loss, and later freeze-down.

If the scenario above is correct, past (and any present) surface and ground waters on Mars should have been primarily brines with concentrations greater than that of modern terrestrial sea water. During the "warm, wet" early history of Mars, fresh water could have occurred locally as rain, runoff, and groundwater reservoirs. Amounts of such precipitation-derived water would have been very limited because erosional channels attributed to runoff (as opposed to catastrophic outflow) are not developed planet-wide. However, freeze-down of the planet should have generated widespread and extensive amounts of subsurface H_2O ice cements as a consequence of eutectic freezing. Later melting of this ice by igneous activity could have produced liquid H_2O in convecting cells and possible hydrothermal springs. On the other hand, such geothermal heating would also mobilize eutectic brines and re-melt ice-brine-salt eutectic mixtures where they were still physically associated. Mixing of these diverse fluids during hydrothermal circulation combined with dissolution of megaregolith salts would probably prevent sustained hydrothermal reservoirs of dilute H_2O for any significant length of time.

The physical and electrical properties of brines are vastly different from those of pure H_2O. For eutectic brines, models of subsurface martian hydrology need to consider flow of near-freezing, highly viscous (possibly even gel-like) fluids with specific gravities of 1.3 to 1.4. The electrical conductivity is likely to be greatly enhanced for brines, so geophysical methods to detect subsurface fluids may work far better than expected.

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THE P-BAND RADAR TO STUDY POLAR CAPS, THE SHALLOW SUB-SURFACE AND PALEO-CHANNELS ON MARS. W. Kofman[1], A. Herique[1], and F. Costard[2], [1]Laboratoire de Planétologie de Grenoble, CNRS/UJF, B.P. 53, 38041 Grenoble Cedex 9, France; wlodek.kofman@obs.ujf-grenoble.fr, [2]UMR8616, CNRS, Orsayterre, Orsay, France

Introduction: The radar technique is able to detect discontinuities and layers within the first meters to a few kilometers of the subsurface. This technique is often used on the Earth for geophysical studies and we propose to implement it on Mars.

One of the most surprising discovery arising from Mars exploration is the role played by water and ice in the history of this planet. The existence of liquid water in the past seems to be proved by the observation of typical geomorphological features (runoff and outflow channels, debris flows, layered deposits, rampart craters ...). It seems that large quantities of water are still buried in the sub-surface at various depths. We should not forget that the search of water on Mars is a priority for the forthcoming missions, which should detect and characterize the Martian permafrost and find fossil traces of water within the subsurface. The search for water on Mars is also a necessary step in order to understand the geological, geomorphological and climatic evolution of the planet.

The scientific objectives of the radar in the frequency range 100-300 MHz are:
1. The observation of the polar caps with the measurements of their depth, their stratification, the observations of the variability of their size in function of the seasons.
2. Studies of the near-surface ground ice and of the stratification of some typical morphological features (Aeolian deposits, stratified deposits).
3. Studies of the paleo-channels

1. Polar Caps:
The polar caps have their own H_2O and CO_2 ice reservoirs. They play an important role in the atmospheric processes, determining the proportion of CO_2 and water vapor. The stratified deposits around the polar caps spread up to 80° of the latitude with a depth of a few kilometers. They are the proof of climatic variations and are probably deposits of ice and of ice/dust mixtures. It is important exactly to quantify the volume of the ice layers in order to better understand the present and past water cycle. The MOLA experiment determined only the altitude of polar caps, the proposed radar experiment will be able to measure their bottom base and therefore to measure their volume. It is the same for the stratified layers of the South polar caps. The extension of their volume is unknown. In this case, the radar will also be able to estimate the volume of their stratified deposits by measuring exactly the depth of the interface ice/rocks.

2. Structure of the Ground Ice of the Superficial Sub-Surface and of the Surface Deposits:
The megaregolith of kilometric depth, which is likely to be porous, is probably filled by water or water ice. The distribution of the megaregolith, water and ice inside triggered eventual phenomena like the circulation of water, the flows which are responsible for a number of channels and for the morphology of the craters.
The deep permafrost probably still exists and defines the behavior of the superficial layers. The previous studies situated these volatile materials (ground-ice, liquid water, perched aquifer) at 1 to 3 km below the surface at the equator and at a few kilometers around the poles. In the equatorial zones, the depth of the top of the ground-ice layer depends on the sublimation rate of the water and on the porosity of the surface rocks. However, it seems that the ice is present, at low latitudes at depths ranging from a few hundreds meters to kilometers.
However, it is probable that the liquid water, perched aquifer or the ice (massive icy beds) still exist within the ground-ice. The recent MGS observations show the geomorphological structures which could be, similarly to the terrestrial structures, attributed to the water drain from the shallow permafrost. The proposed radar will be able to show if this ground-ice still exists, how deep and how thick it is.
We know almost nothing about the volume of the superficial structures on Mars surface. The estimation of the volume of lava and of the fluvial deposits will provide important information about the volcanic activities and the water cycle. The dust and sand deposits and their seasonal variability are also important to study.

3. Study of Paleo-Channels:
The presence of numerous branched valleys and the chaotic terrains prove the flow of water of various origins, the fluvial periods, the melting of the frozen subsurface and the water-table. Recent images show Aeolian deposits in the bottom of valleys. The new gravimetric data indicate the flow episodes in the Northern plains. It is very probable that the channels are totally or partially recovered by wind deposits. The detection and the studies of these valleys are nonetheless very rich in information about the evolution of Mars. The radar technique is the only one able to detect and observe these paleo-channels.

THE P-BAND RADAR TO STUDY MARS: W. Kofman, A. Herique and F. Costard

4. Measurement techniques:

To fulfill these scientific objectives, we propose to use a P-band nadir-looking SAR radar (100-300 MHz). This mode of functioning is similar to the Marsis experiment which is under development for Mars Express/ESA mission (Picardi et al., 1998; Hagfors et al., 1998) and to the MIMOSA project, dedicated to the studies of the Antarctic glaciers, which was proposed to the CNES (French space research center) as an answer to an Earth Opportunity Mission AO (ESA) in 1998 (Bauer et al., 1998; Herique et al., 1999).

The polar circular orbit will permit the covering of the whole planet and the optimization of the signal to noise and signal to surface clutter ratios. We show that the VHF frequency is an optimal one for our scientific objectives. The received signal is a mixture of echoes from the sub-surface and the signal reflected by the surface.

The first signal corresponds to the specular reflection from the first Fresnel zone which is a coherent signal, the second type of echoes corresponds to the incoherent signal diffused by the illuminated surface. The signal to clutter ratio depends on the surface roughness. For regions of low roughness (compared to the wavelength), the coherent signal is dominant, which enables the sounding of large depths (for instance, the polar caps). The horizontal resolution corresponds to the Fresnel zone and the vertical one to the bandwidth of the signal. To improve the signal to clutter ratio, a Doppler filtering and the antenna lobe synthesis will be performed. For regions of high roughness, the incoherent signal is dominant and in this case the SAR approach will be necessary.

We plan three radar modes:

- the radar in altimetric mode, functioning in strip map mode. This mode is for deep sounding of the polar caps and of the shallow sub-surface sounding elsewhere.
- the "burst" mode will reduce the data transfer, thus implying a resolution loss.
- the "SAR" mode will require the antenna lobe formation or a platform slant.

The scientific objectives, the appropriateness of the radar to answer the scientific issues and the technical solution will be shown in our presentation.

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DESIGN OF A GROUND-PENETRATING RADAR FOR MARS: SIMULATIONS AND EXPERIMENTS.

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Introduction: There is evidence that Mars has undergone considerable geological change over its history, and that surface water played an important role in those changes. "Some researchers suggest that early Mars was warm and wet, and conditions changed early to the frigid conditions of today [1]." If discovered, the presence of water would be important for three major reasons. First, it could provide a better understanding of the geological history of the planet. Second, water is the key to life on Earth, and on Mars it could indicate the possibility of past life. Finally, any accessible reservoirs could provide crucial resources for future manned exploration. It is obvious that a radar system/systems will play an important role in the completion of these objectives, and it is also probable that orbital and rover-based systems will need to be used in conjunction to obtain both the global coverage along with high-resolution mapping.

This paper considers the simulation, design, and preliminary testing of a ground-penetrating radar GPR system to probe the Martian subsurface for aqueous layers in either liquid or solid state. Depth of a few hundred meters to a kilometer are required with a resolution of a few tens of meters. The geophysical objectives are surface characterization, determining soil properties at microwave frequencies, and three-dimensional stratigraphy mapping.

An essential step in designing such a system is to simulate the radar responses from geophysical models based on what could be expected on Mars. Inputs for the simulation include the geophysical model and system parameters. A GPR profile is generated from the electrical properties and mixing formulas appropriate to the modeled stratigraphy. Finally, the profile along with additional system and geophysical information are input to the simulator and a radar response is generated.

Geophysical Model: The upper surface of Mars is largely a result of resurfacing by volcanic, fluvial, aeolian, periglacial, and impact processes. On a large scale, the stratigraphy of Mars can be interpreted as a weathered soil with an exponentially decaying porosity. Within the pores could exist a significant amount of water as ice near the surface and as liquid at greater depths. On a smaller scale, "it is likely that this ejecta (resurfaced) layer is discontinuously interbedded with volcanic flows, weathering products, and sedimentary deposits, all overlying a heavily fractured basement [3]".

The surface and subsurface layers of Mars will exhibit both large and small scales of roughness. Each height scale can be described by a Gaussian random variable with r.m.s. height, σ, correlation length, l, and r.m.s. slope, s, where $s^2 = 2\sigma^2/l^2$. To an orbiting radar, the major contribution will be due to the large scale of roughness at small incident angles, which can be represented by the geometric-optics approximation for the backscattering coefficient [4].

If the soil is interbedded with rocks and debris, an effective permittivity is used to account for the change in dielectric constant and attenuation due to scattering [5]. For the rocky surface of Mars, the size and distribution of rocks is estimated to be 1 centimeter to 7 meters and less than a 30 percent volume fraction. These properties are assumed to be indicative of the near-subsurface characteristics.

Electrical Properties: From a radar perspective, the subsurface is characterized by the distribution of the electrical properties, especially permittivity and permeability. The primary resources for estimating the electrical surface properties include surface measurements from the Viking Landers and Pathfinder Mission, analogies to lunar samples, SNC (Shergotty, Nakhla, Chassigny) meteorites, and interpretations from visible images. An exhaustive search of these resources indicates that the dielectric constant (real part of the permittivity) varies from 2.5 to 9 depending on the porosity of the medium. However, there is little information on the permeability and electrical losses of the soil.

Simulation: For an orbit-based GPR, where the height of the radar is much greater than the depth of penetration, the transmission and reflection of the incident pulse can be approximated as a plane wave propagating through a layered media. For a rover-based system, simulating the radar response in a realistic environment becomes complicated and more complex methods must be used such as the finite-difference time-domain FDTD method. Table 1 shows the stratigraphy, lithology and resulting complex permittivity for a one-dimensional simulation model of an equatorial site. A 10 MHz center frequency, 5 MHz bandwidth, modulated Gaussian pulse is used as the incident waveform.

Fig. 1 shows the radar return for the two cases when a specular reflection and a rough surface response are considered for a multiple layer model. The specular, one-dimensional response can be viewed as the ideal or upper bound for the radar return, whereas the rough surface response shows a more realistic situation. Noise calculations show the minimum detectable signal to be approximately –140 dB. Using this minimal detectable signal level, this model would show a maximum penetration depth of about 400 meters.

This model is only one example of what could be encountered. The penetration depth of a GPR on Mars is highly dependent on the stratigraphy and lithology of the subsurface layers. Since the electrical properties governing scattering and propagation of these layers are, to a large extent, unknown, predicting the performance of a radar is complicated and will involve extensive simulations over a wide range of models from simple two- to three- layer configurations to many-layer configurations of different geological locations. Additional simulations will be presented.

Multi-Dimensional Processing: GPR can be used to collect data over a two-dimensional grid for three-dimensional migration processing to reduce clutter from masking weaker returns. Knowledge of the three-dimensional structure combined with the additional context and understanding provided by the planet's surface geology, terrestrial analogs, and some basic physics could greatly enhance the ability to identify a particular volatile target to a much higher level of confidence than possible from a simple one-dimensional sounding. Aperture synthesis may add some important capabilities to a sounder. For an orbit-based radar, obtaining the necessary spacing and accuracy will be difficult, but for a rover-based system, multi-dimensional processing will be a valuable asset.

Prototype System: For preliminary tests, a simple GPR system was constructed using evaluation boards and connectorized components to serve as a testbed for antenna design and field experiments. The system uses swept-frequency modulation and operates between 1 and 120 MHz depending on the antenna bandwidth. For the preliminary experiments, two 5-meter bowtie antennas where built using a wire mesh. When placed on the ground the antennas showed greater than a 3-to-1 bandwidth operating from 10 to 120 MHz. Additional antenna subsystems include a high input-impedance dipole receive antenna and a coil-loaded dipole antenna. Experiments are planned in Lawrence, KS and also in Alaska. Results from these experiments will be presented for monostatic and bistatic configurations.

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TABLE 1
SIMULATION MODEL
IRON CONCENTRATION C = 10% ,VOLUME DEBRIS a=1meter, f_v = 10%

depth	lithology	ϕ%	s%	fill	ε_r'	ε_r''
400km	air	100	-	-	-	-
1	eolian sediment	50	0	air	2.8	0.01
3	indurated sediment	15	0	air	5.9	0.05
5	sediment-filled basalt	50	0	air	2.8	0.01
10	dense basalt	5	0	air	7.2	0.07
100	layered basalt	10	0	air	6.4	0.06
110	eolian sediment	50	100	ice	5.1	0.04
150	layered basalt	10	50	ice	6.9	0.06
152	fluvial sediment	20	0	air	5.3	0.04
160	volcanic ash	50	0	air	2.8	0.01
200	layered basalt	10	0	air	6.5	0.06
220	crater ejecta	20	100	ice	6.7	0.06
250	layered basalt	10	100	ice	7.3	0.07
255	eolian sediment	50	0	air	2.8	0.01
350	layered basalt	10	0	air	6.5	0.06
355	fluvial sediment	20	0	air	5.3	0.04
500	layered basalt	10	0	air	6.5	0.06
750	layered basalt	10	100	ice	7.3	0.07
760	volcanic ash	50	100	ice	5.1	0.04
900	layered basalt	10	100	ice	7.3	0.07
1000	layered basalt	10	100	ice	7.3	0.07

The first layer represents the height of the radar.

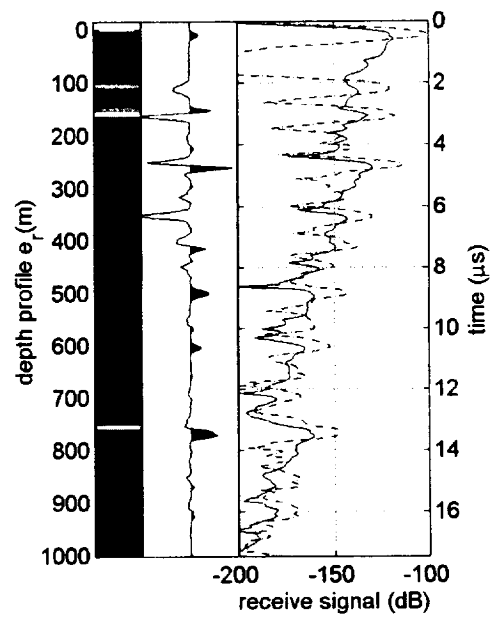

Fig 1. Simulation results. From left to right are the permittivity profile, one-dimensional amplitude response with a quadratic gain, dB plots normalized to the transmit signal for one (dashed) and three (solid) dimensional simulations.

AN IDEA FOR AN ACTIVE SEISMIC EXPERIMENT ON MARS IN 2008. Ph. Lognonne[1] , B. Banerdt[2], D. Giardini[3] and F. Costard[4] with the NL-SEIS team. [4]IPGP, FRE2315/CNRS, 4 Av. de Neptune, 94100, Saint Maur, France, lognonne@ipgp.jussieu.fr , (2) (ETHZ, Switzerland), (3) (JPL, USA) , (4) (Univ. Paris-Orsay, France)

Introduction : The detection of liquid water is of prime interest and should have deep implications in the understanding of the Martian hydrological cycle and also in exobiology. In the frame of the 2007 joint CNES-NASA mission to Mars, a set of 4 NETLANDERS developed by an European consortium is expected to be launched in June 2007. We propose to use a second spacecraft going or landing to Mars to release near one of the Netlander a series of artificial metallic meteorites, in order to perform an active seismic experiment providing a seismic profile of the crust and subsurface.

Introduction

The rationale for searching water in the subsurface of Mars is given by Costard et al., this issue. As noted in this abstract, 4 Netlander will be deployed in 2007 on Mars, with a set of instruments related to the search for water. This study of the subsurface, including the ground ice, will be actively performed with a geo-radar, and passively with the magnetometer and seismometer. These geophysical instruments will probe the uppermost kilometers of Mars to search for signatures of ice reservoirs and possible transition to liquid water layers. Simultaneously geophysical studies will give access to the main structural and geomorphological features of the subsurface.

Seismological investigations (SEIS experiment): The best seismic signal for the search for water will be the short periods outputs, especially those of the BRB Short period 3 axis seismometer, which will record seismic signals in the band 0.05-50 He with a resolution better than $5\ 10^{-9}$ $ms^2/Hz^{1/2}$ [1]. A first piece of information will be given by the analysis of signals generated by natural events. The body wave will indeed be the subject of site effect (see [2] for the use of the receiver function also on the Moon) and the analysis does not need the location of the seismic source, which will allow the use of seismic signals released by the regional quakes. Two parameters will be searched: the first will be the position of the subsurface discontinuities, the latter being smoothed by the magnetic inversion onboard NL, mostly sensitive to the resistivity jumps. The second will be the seismic high frequency attenuation, which is very sensitive to the water content at depth below the 0°C isotherm.

Active Seismic Sources: We propose to extend the measurements by a series of active seismic experiments near one or several of the Netlanders. This will assume that another spacecraft, presumably a NASA spacecraft, will have to carry about 20 kg of extra mass to Mars. This second spacecraft will be equipped with several high density metallic spheres (e.g. Tungsten), which will be released for direct impact several days before the final orbit insertion or landing of this spacecraft. Each sphere might have a radius of 3 cm, and therefore a mass of about 2000g. It can be shown that the energy lost in the entry will be small compared to the kinetic energy. Indeed, for an object impacting with an almost constant velocity v_0, the relative lost is given by

$$\Delta E/E_0 = C_x M_{atm} * S/M$$

where C_x is the air-drag coefficient, which for a sphere and the regime of turbulences will be about 0.4, M_{atm} is the mass of the atmosphere on the ground per square meter (150 kg/m^2), and where M/S is the mass of the impactor divided by its cross section (700 kg/m^2). Less than 10% of the energy is expected to be lost, which leads to an impact velocity of 5 km/s with the expected entry conditions.

This very small interaction with the atmosphere of Mars will also be an important parameter with respect to the ellipse error of the impacts positions. These impactors must indeed be targeted about 10 km away from the targeted Netlander. Even if a complete analysis remains to be done, a very precise targeting, mainly depending on the error in the position of the spacecraft at the release time, might be expected.

Estimate of the Seismic signal : The seismic source can be modeled simply by a point force, expressed by

$F(t,x)=mv_0/\tau \, P(t/\tau) \, \delta(x)$,
where m is the mass of the impactor, v_0 the velocity, τ the duration of the impact, and $P(t/\tau)$ is the gate function with a duration of τ. For a penetration down to 5 meter and a constant deceleration, the source duration is expected to be 2 ms. Each impactor of 2 kg carry a kinetic energy comparable to 6 kg of TNT. Note that the maximum mass of the explosives used by the Apollo Seismic experiment [3] was about 1 Kg. An estimate of the amplitude can be done by using expression 4.23 of [4]. The amplitudes of the spherical waves are expressed by

$$a_p = (4 \pi \rho c_p^2 r)^{-1} F(t - r/c_p),$$
$$a_s = (4 \pi \rho c_s^2 r)^{-1} F(t - r/c_s),$$

where c_p, c_s, ρ are the P, S velocities and density, r the distance. The figure 1 gives the amplitude, after correction from attenuation, for different distances. Very likely, such signals can be observed by the instruments at about 10 km of distance.

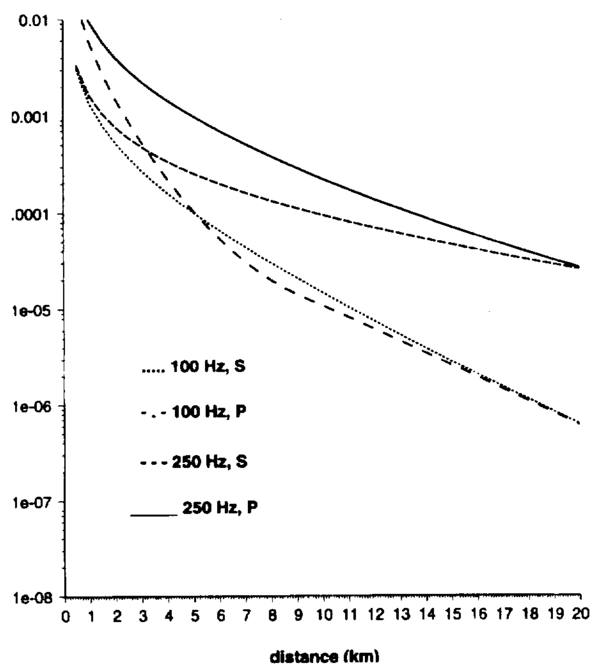

Figure 1: Acceleration Amplitudes with respect to distance of the seismic signals in km. The impact velocity is 5 km/s, the depth of penetration is 5 m, the duration of the source is 2 ms. The P, S velocities and density are for relatively non-consolidated materials and respectively equal to 2000 m/s, 1000 m/s and 1000 kg/m³. Qp and Qs of 2000 and 1000 are used, which may be ok for the upper most kilometers of the crust.

Conclusion : With several impactors, a seismic profile will be possible. The measurements done by this active seismic experiment will be complementary to the other Netlander investigation for Water. Combining their results would greatly improve our knowledge of the geology and the water cycle at the Netlander landing sites.

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LOBATE DEBRIS APRONS AS POTENTIAL TARGETS FOR GROUND ICE DETECTION ANALOGS TO TERRESTRIAL ROCK GLACIERS. N. Mangold, Orsay-Terre, Equipe Planétologie, UMR 8616, CNRS et Université Paris-Sud, Bat. 509, 91405 ORSAY Cedex, France, mangold@geol.u-psud.fr

Topography of lobate debris aprons on Mars: The surface of Mars is affected by a large variety of features assumed to be related to ground ice like lobate debris aprons, softened craters or fretted channels [1]. Lobate debris aprons take place at the foot of kilometer high scarps in the regions located 35° to 55° in latitude. These features have been interpreted as the result of viscous creep of an ice-rock mixture because of their huge length of 20 km and their convex shape [2,3]. This interpretation is consistent with the stability of ice at these latitudes [1]. Many MOLA topographic profiles of lobate debris aprons also display convex shapes [4]. This shape can be compared to the theoretical profiles calculated from terrestrial ice sheets. Such theoretical profiles are different assuming that the deformation of ice inside the debris aprons follows a plastic or a viscous behavior. The shape is that of a parabola if

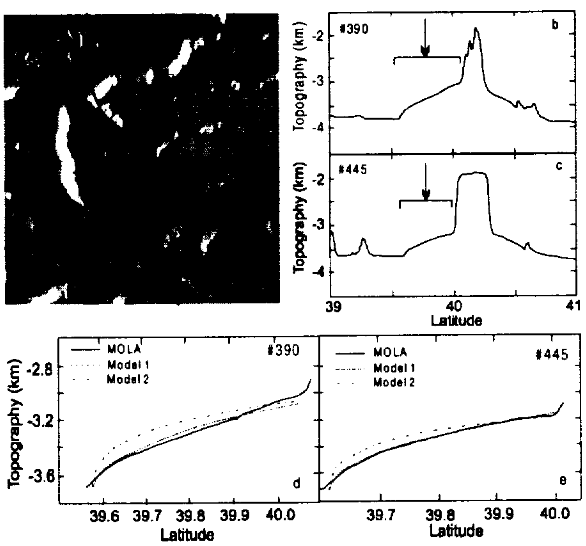

Fig. 1: (a) MOLA profiles 390 and 445 crosscutting a plateau and the surrounding debris aprons (Viking image 675b64). (b) Profile 390 displays the scarp and a lobate debris apron (under the arrow) (c) ibid. with profile 445. (d) MOLA profile 390 compared to model 1 (plastic behavior) and model 2 (viscous behavior). (e) ibid. with profile 445. From [4].

We assume that the glacier is at plastic equilibrium [5]: $(h/H)^2+(x/L)=1$; where H and L are the thickness and length of the lobate debris apron, x and h are the horizontal and vertical coordinates. The shape due to the viscous power law of polycrystalline ice is given by [5]: $(h/H)^{2+2/n}+(x/L)^{1+1/n}=1$ where n corresponds to the usual exponent of the power law relation, n~3 for pure ice. The result of this simple modelling is shown for two MOLA profiles (Fig. 1 taken from [4]). In each case, the first model (plastic) is a very good estimate of the measured MOLA topography. The accuracy between the model described by the first relation and the measured profiles is very satisfying. The lobate debris aprons are therefore due to the deformation of ice-rock mixtures confirming what was deduced from geomorphic analyses [e.g. 3]. Lobate debris aprons are thus analogous to terrestrial rock glaciers.

Proportion of ice in terrestrial rock glaciers: On Earth, rock glaciers are common landform of unconsolidated debris in alpine and periglacial environments (Fig. 2). They result from the creep of ice-rich moraines, ice-filled debris, or permafrost on hillslopes and bottom of valleys. The velocities of these glaciers are very low, of about several cm or tens of cm per year [6]. Geophysical techniques like drilling, gravimetry and ground penetrating radar (GPR) have been used recently to estimate the proportion of ice inside the ice-filled debris of rock glaciers. The borehole of the Murtel-Corvatsch rock glaciers in the Swiss Alps shows a 20 m thick bottom layer with an ice content of 30 to 40% [6]. A major rock glacier of the Kunlun Shan, China contains from 29% of ice at 25 m depth to 57% at 39 m depth [7]. The Fireweed glacier in Alaska is composed of debris mixed with a proportion of ice estimated of more than 50% [8]. Ice-supersaturated layers of debris containing 40 to 75% of ice are found in several tongue rock glaciers in Svalbard, Norway [9]. Supersaturated means that rocky debris are not in

Fig. 2: Talus rock glaciers of W. Svalbard, Norway (from Barsch, 1996).

contact, so the ice content is higher than the interstitial volume content of voids in the same debris without ice. Segregation lenses of pure ice are also possible inside such rock glaciers. In summary, most measurements on terrestrial rock glaciers conclude to a fraction of ice higher than 30% in volume with an average between 40 to 60% [10].

Surveying Martian rock glaciers by orbital radar: As Martian rock glaciers are also due to the deformation of mixture of ice and rock, they may also contain such high proportion of ground ice of more than 30 %. Moreover, experimental data on ice-rock mixtures predict that a proportion of ice of more than 28% is necessary to produce a viscous deformation [11]. These features have therefore interesting characteristics to be potential targets for the orbital detection of ground ice on Mars (Fig. 3):

(1) Their proportion of ground ice is probably high (>30%);
(2) Their age is young (Late Amazonian, probably few 100 My), so ground ice could have remained inside porosity even these landforms may be currently inactive;
(3) Their geometry and location are well constrained by MOLA profiles and Viking pictures showing convex shapes overlying flat plains;
(4) Their length of about 20 km does not need high spatial resolutions of instruments;
(5) Their thickness of several hundred meters is adapted to radar penetration depth such as MARSIS;
(6) Calibration of instruments can be done on terrestrial rock glaciers.

This last point is interesting because GPR data on rock glaciers already exist and can be developed in the future easily because rock glaciers take place in many accessible places (Alpes, Rocky Mountains, Alaska, etc.).

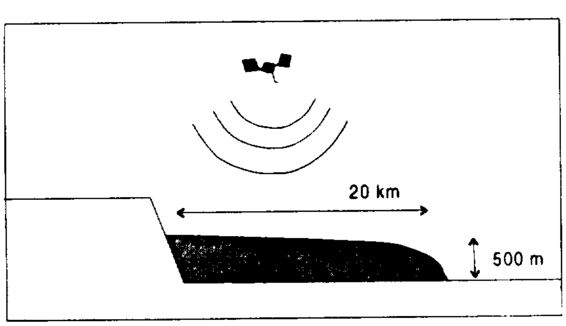

Fig. 3: Surveying Martian rock glaciers by orbital radar.

Conclusions: For all these reasons, lobate debris aprons and fretted channels (same kind of materials inside relict valleys) are potential targets for the detection of subsurface ice on Mars by orbital instruments. Results of radar investigations would give indications on the real proportion of ice inside these landforms, on their internal layering and difference with surrounding terrains, in order to understand their genesis and evolution. They are also ideal landforms for the calibration of instruments and therefore the interpretation of radar data on the whole planet.

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Acknowledgement: We are grateful to the MOLA team for the availability of MGS data on the web. This study is supported by the Programme National de Planétologie (PNP) of Institut National des Sciences de l'Univers (INSU), France.

TERRESTRIAL METHANE HYDRATE: A POTENTIALLY UNIVERSAL PLANETARY ATTRIBUTE. IS HYDRATE A KEY TO HUMAN HABITATION OF OTHER PLANETARY BODIES? M.D. Max, MDS Research, Suite 461, 1120 Connecticut Ave. NW, Washington DC 20036 <xeres@erols.com>.

Introduction: Terrestrial gas hydrates comprise ice-like crystalline compounds of gas (mainly methane) and water which are stable both at very low temperatures in permafrost regions, and in the low temperature - high pressure regimes present in the deep oceans on Earth [1]. Methane and other gases are thermodynamically stabilized within gas hydrates by hydrogen bonding in a crystalline lattice of water molecules [2]. Hydrate forms in both primary and secondary pore space and fractures in sediments as a diagenetic mineral. The presence of hydrate, which replaces water in pore space, strongly alters the physical properties of the sediments in which it occurs. Although hydrate is generally referred to as an 'ice-like' material and some of the physical properties of hydrate are similar to water-ice, they are different in some respects (Table 1).

Property	Ice	Hydrate
Dielectric constant at 273 °K	94	~58
NMR rigid lattice 2nd moment of H2O protons(G2)	32	33 ± 2
Water molecule reorientation time at 273 °K (μsec)	21	~10
Diffusional jump time of water molecules at 273 °K (μsec)	2.7	>200
Isothermal Young's modulus at 268 °K (109Pa)	9.5	~8.4
Pressure wave Velocity (km/sec)	3.8	~4
Transit time (μsec/ft)	3.3	92
Velocity ratio Vp/Vs (272 °K)	1.88	1.95
Poisson's ratio	0.33	~0.33
Bulk modulus (272 °K)	8.8	5.6
Shear modulus (272 °K)	3.9	2.4
Bulk density (gm/cm3)	0.916	0.912
Adiabatic bulk compressibility at 273 °K 10-11Pa	12	~14
Thermal conductivity at 273 °K (W/m-K)	2.25	0.50±0.02
Heat of fusion (kJ/mol)	6	54*, 57**

Table 1. Physical properties of water ice and methane hydrate [3]. * Measured, ** Calculated.

On Earth, hydrate concentrates methane produced in the deep biosphere by bacteriological decomposition of organic matter [4, 5], especially on passive continental margins where plunging plate boundaries and subduction zones are not present to provide pathways for deep-sourced thermogenic methane. Gaseous methane migrates upwards, and is concentrated within and immediately beneath a zone in which hydrate is thermodynamically stable. This is the Hydrate Stability Zone (HSZ), that extends downward from the cold seafloor in water depths greater than about 500 m water depth in non-Polar, open ocean conditions, and in permafrost regions from some depth within the water-ice permafrost zone (~200 m) to some depth that is determined locally by rising temperature.

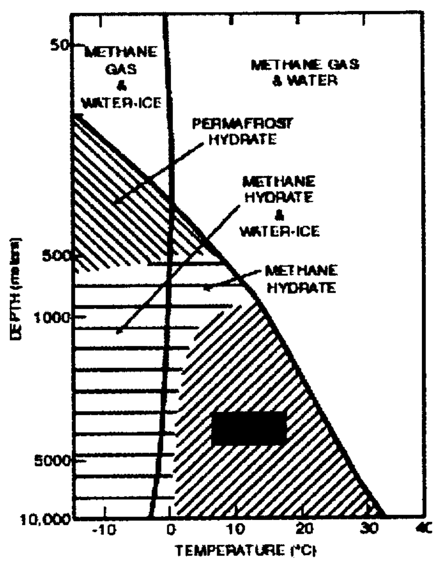

Figure 1. Earth P-T stability field of methane hydrate.

Methane hydrate occurs in two general environments on Earth; in a compound hydrate-cryosphere in permafrost regions and in oceans, mainly on upper and middle water depth continental slopes. Oceanic hydrate contains up to 95% of all naturally occurring hydrate worldwide. On cold planets such as Mars, however, where no deep oceans now occur, gas hydrate would be found entirely in the cryosphere and its analog on Earth is hydrate that is found in permafrost regions.

Permafrost hydrates exist at low pressures and temperatures (Fig. 1). On Earth they occur as part of a compound water-ice and hydrate permafrost on land and on continental shelves of Alaska, Canada, and Russia. Methane hydrate and water-ice form a compound cryogenic zone (Fig. 2). Water-ice is stable from the surface at about 0 °C whereas hydrate is stable from some depth below the surface (depending on average surface temperature, total pressure, and geothermal gradient) to some depth below the base of the water-ice stability zone. In Alaskan permafrost, local thermal variations result in maximum hydrate stability depths of 600 - 1075 m with associated crustal temperatures of ~285 - 287 K [6].

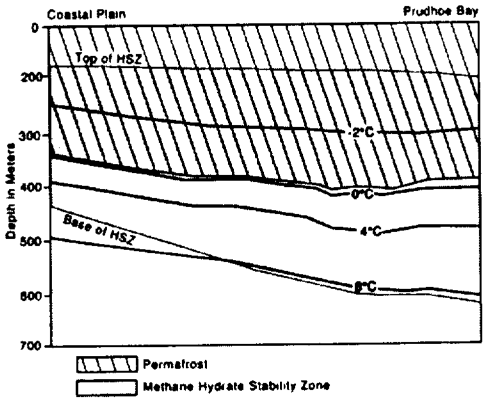

Figure 2. Cross-section of compound water ice – methane hydrate 'cryosphere'.

Methane may have been recovered from hydrates in Russia from permafrost-associated gas hydrates at the Messoyakha field in western Siberia for over 15 years. Recovery tests of methane from similar gas hydrates in the Prudhoe Bay field have yielded methane recovery rates similar to those in Russia and techniques of methane recovery from hydrate in the Alaskan and Canadian permafrost terrane are underway now with international participation [7].

At the 200 °K average surface temperature of Mars, hydrate is not stable at less than a depth of ~15 m (assuming an ice-saturated permafrost density of 2.5×10^3 kg m^{-3}). The base of the Martian HSZ should then extend to depths that lie from several hundred meters to as much as a kilometer below the base of the water-ice cryosphere. Thus, the total thickness of the Hydrate Stability Zone on Mars is likely to vary from ~3 km at the equator, to ~8 km at the poles [8].

Energy potential of natural gas hydrate: Hydrate formation forces methane molecules into closely-packed guest lattice sites, which has the effect of concentrating the methane. One cubic metre of naturally occurring methane hydrate contains ~164 m^3 of methane (at STP) and ~0.87 m^3 of pure water [1, 3] at an approximate ratio of methane and water [$CH_4 \cdot 6.1$ (±0.1%) H_2O]. Although the essentially pure water in hydrate on Earth occurs in very large volumes, it is mainly the energy content of the methane hydrate that is of primary interest [1].

The amount of methane held in the form of gas hydrates on Earth is estimated to be at least 1×10^4 gigatons of carbon [2], or about twice as much as all known fossil-fuel deposits (coal, oil, and natural gas). Methane associated with the hydrates appears to represent an important potential energy resource. Methane hydrate has a high energy density (184,000 Btu/ft^3 compared with 152,000 BTU/ft^3 for liquid methane, and 1,150 BTU/ft^3 for methane gas at STP). The methane occurs both in the hydrate itself and in gas deposits associated with the hydrate-rich horizons.

Impact of widespread methane hydrate in the Solar System: Of primary importance, the raw products of dissociation of methane hydrate are virtually pure water and methane; the water of life and fuel. Methane can be used as a feedstock for producing higher energy density liquid fuels or used directly or as a source of pure hydrogen in fuel cells. Second, water, methane, and CO_2 can be used as primary industrial feedstock in a wider petrochemical industry wherein fabricated items can be manufactured.

Because the conditions for the formation of methane hydrate occur on several planets (Earth and Mars at least) and on water-rich bodies such as some of the moons of Jupiter, methane hydrate is likely to be found distributed widely in the solar system and beyond. Thus, a space exploration technology based on the concept of survivability exploiting the down-stream benefits of methane and other gas hydrates, which have concentrated substances vital to support human habitation away from Earth, may prove to be the key to early self-sufficient colonization of space.

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SUBSURFACE GEOPHYSICAL DETECTION METHODS TO UNIQUELY LOCATE WATER ON MARS

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Introduction: Water is involved in many geological and biological processes and has many unusual properties. The unique detection of water requires looking for a method that can characterize something unique about the existence or ocurrence of water or of some process that is a result of the behavior of water. There are many methods that can detect the presence of water but few that can unambiguously and uniquely identify it as being water. Most methods rely on detecting the motion of all or parts of the water molecule. Each method has advantages and disadvantages in subsurface exploration, and they are discussed in terms of shallow to deep subsurface exploration potential.

Infrared: Bending and stretching motions of bonds between the hydrogen and oxygen atoms in the water molecule produce distinct and unique identifying features in the infrared spectrum [1] that may be used to uniquely identify the presence and amount of water. Unfortunately the depth of penetration is only microns, limiting this technique to surface characterization and making it unsuitable for subsurface investigations. It is however suitable for use from orbital and earth based remote sensing observations.

Neutron: Neutrons are scattered by the cross section of hydrogen in water [2], allowing a water detection method that is commonly used in oil well and water well logging [3]. However, this requires a source of neutrons and the depth of penetration is only tens of centimeters, severely limiting its potential for deep subsurface investigation. Gamma ray methods [3] are also used sometimes but the depth of investigation is also limited to tens of centimeters.

NMR: Nuclear magnetic resonance is a method that exploits the precession of the proton spin as a magnetic field orientation is changed [4]. In terrestrial applications, one magnetic field is supplied by the earth and a second artificial field is generated to cause the proton to precess. The frequency is at or below the kilohertz range, allowing deep penetration, but the lack of a magnetic field on Mars and the power and weight requirements to generate two fields would be very costly on Mars. NMR can measure the unfrozen water content of soil-water-ice mixtures [5]. The presence of magnetic minerals may also complicate the interpretation of NMR measurements [6] so the answer is not unique.

Electrical: In the absence of water, nearly all rocks and most minerals are very good electrical insulators [7], which become more conductive upon the addition of water. The most sensitive indication of the presence of water is given by electrical resistivity or conductivity measurements, which can detect less than monolayer quantities of adsorbed water [8, 9]. These can see kilometers deep when appropriately configured, but require contact with the ground (and are thus not suitable for aircraft, orbital or other remote observations), and do not uniquely identify water [7, 8]. Streaming potential relies upon the electrokinetic response of water moving through fractured or porous materials [10], requires ground contact, and can only uniquely identify water if it can track the response through a known water pressure fluctuation in time (weather, seasons, climate, or see seismoelectric below) as otherwise it can be ambiguous with several electrochemical processes [11]. The dielectric relaxation from the orientational polarization of the liquid water molecule produces a unique indicator of water near 10 GHz [12], but at that frequency the penetration is less than a meter. A similar dielectric relaxation occurs in water ice near a few kHz [13, 14] and for clathrate hydrate ices near a few MHz [15]. These relaxations could be measured to depths of hundreds of meters using electrostatic capacitative coupling methods or electromagnetic techniques. In these cases, the dielectric relaxations would produce frequency dependence in electrostatic or electromagnetic measurements that can be used to determine water presence, state, and amount.

Electromagnetic: Electromagnetic methods respond to the electrical and magnetic properties of soil and rocks. These include low frequency electromagnetic diffusion (induction) methods [16] and high frequency electromagnetic wave propagation (ground penetrating radar) methods [17]. They do not require ground contact and may be performed (with limitations) from the surface, aircraft or orbit. At the lowest frequencies, electromagnetic responses are dominantly controlled by electrical conductivity and geometry, and at the highest frequencies they are controlled by frequency dependent dielectric permittivity and geometry. As they are electromagnetic measurements, the magnetic properties are also important, but we know little about the dynamic properties of magnetic minerals on Mars other than there are magnetic minerals [18].

It is expected that low frequency (below 1 kHz) instruments on Mars could detect the presence of liquid water to depths of kilometers [19], but not uniquely identify it. Instruments between 1 and 10 kHz could detect water ice and identify it by the ice dielectric relaxation peak frequency [14], probably to depths of hundreds of meters. Instruments at ground penetrating radar frequencies of 1 to 10 MHz could detect water ice to depths of tens to hundreds of meters and identify clathrate hydrate ices but not water ice. Instruments at ground penetrating radar frequencies of tens to hundreds of MHz could detect water ice to depths of tens of meters, but only identify it through geological context. There is a possibility of detecting liquid water at these frequencies to depths of tens of meters and bounding an identification through the observed frequency dependence of the response [20]. However, all these depths and possibilities are uncertain without knowing more about the radiofrequency noise levels, surface and volume electromagnetic scattering distributions and magnetic mineralogy on Mars [21].

Seismic: Elastic properties also respond to the motion of water. The Q (quality factor related to seismic attenuation) of the moon is in the tens of thousands because there is no liquid (water or other fluids) to move and lose energy through viscous dissipation processes [22, 23]. In contrast, the Q of the earth is typically in the tens because of the presence of fluids (not just water, but oil, and partial melts). A general observation on Mars that the Q is high and similar to the moon would rule out widespread water.

Water ice also produces an elastic relaxation similar to the dielectric relaxation noted earlier and by the same root mechanism [14]. Unfortunately, in the kilohertz range where it would be observed, acoustic elastic wave propagation exhibits very high attenuation in loose soils and high scattering from meter size blocks, so depth of investigation is limited to tens of meters. If both dielectric and elastic relaxations were observed, however, that would be a unique identification of water ice, and the relaxation frequency would indicate the temperature of the ice, while the relaxation amplitude would indicate the amount of ice present.

Seismoelectric: The propagation of an elastic wave through a porous material containing water causes the water to move relative to the host material, generating a streaming potential [10]. The combination of a seismic source producing an electrical response is a coupled process called the seismoelectric effect [24]. The water, oil and service companies hold great hope that this effect may be used to measure fluid conductivity in the ground [25, 26]. In terrestrial environments, it is a difficult measurement to make and the effect is not entirely understood. However, on a lower seismic and electromagnetic noise Mars (ignoring wind), it might be the best way to uniquely identify the presence of kilometers deep water.

Recommendation: To detect shallow subsurface water and ice on Mars, start with electromagnetic methods, which are the easiest to implement, then move to deeper searches with seismic and seismoelectic coupled processes. To uniquely identify water, use the dielectric and elastic relaxations or seismoelectric coupled processes.

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CHARACTERIZATION OF THE MARTIAN SURFACE SCATTERING AT DECAMETRIC WAVELENGTHS. R. Orosei[1], R. Bianchi[1], A. Coradini[1], S. Espinasse[2], C. Federico[3] and A. Ferriccioni[4], [1]Istituto di Astrofisica Spaziale - CNR, Roma, Italy, [2]Agenzia Spaziale Italiana, Roma, Italy, [3]Dip. Scienze della Terra, Università degli Studi di Perugia, Italy, [4]INFOCOM Dpt., Università "La Sapienza", Roma, Italy.

Introduction: New pictures from the Mars Orbiter Camera (MOC) onboard the Mars Global Surveyor (MGS) have provided evidence that, on Mars, sedimentary processes are more complex than anticipated before, and that they are possibly related to the water history on Mars. Moreover some of the MOC images seem to indicate that liquid water may have played a role in shaping some recent gully-like features found on the slopes of various craters, troughs, and other depressions on the red planet, thus suggesting the presence of shallow ice/water reservoirs.

After weighing various factors, including the likely timing of MARSIS data acquisition and analysis and the present absence of data characterizing the Martian subsurface, the Mars Reconnaissance Orbiter (MRO) Science Definition Team (SDT) recommended that a subsurface profiling radar be flown sometime as part of the Mars Exploration Program (MEP) and that, for the 2005 launch opportunity, it be considered for flight through the AO process as a Group II Science objective. The SDT further recommended that any radar considered for flight on MRO should focus on the detection of liquid water and the profiling of water ice in the uppermost 1 km of the Martian surface.

Since the deliberations by the SDT in January 2001, NASA has continued to study possibilities of enhancing future science return within the MEP. One activity well underway is the possible provision of a communications satellite for Mars to be built by the Italian Space Agency (ASI) and to be launched to support missions arriving at Mars after 2007. In return, NASA and ASI are considering flight of a shallow subsurface sounding radar (SHARAD) to be flown on the MRO.

Given the nominal characteristics of the 2005 mission, ASI envisaged an instrument to support investigations that complement the results of MARSIS. An instrument able to penetrate a few hundreds of meters below the surface with a finer horizontal resolution and a vertical resolution (on the order of 10 m - 20 m) would provide a unique insight into the Martian stratigraphy at scales comparable to those of optical images, thus offering a tremendous improvement in the understanding of sedimentary processes and recent geologic activity.

For these reasons, a concept for a radar sounder in the '05 MRO mission (called SHARAD) has been developed according to the above requirements.

The ability of SHARAD to achieve the science objectives will be largely dependent on the electrical properties, both permittivity and permeability, of the soil, degree of scattering off the surface and volumetric debris, and the stratigraphical layering of the subsurface. Although the level of uncertainty in the subsurface characteristics of Mars is high, the surface features such as surface roughness and slopes are better understood thanks to recent information from MGS (Mars Global Surveyor).

Method: We try to assess the extent and distribution of surface clutter (i.e. echoes from off-nadir portions of the surface) for SHARAD by making use of MOLA data for the Martian topography, and making some assumptions on the way in which certain statistical parameters of the topography change with scale. We assume that the topography is self-affine, i.e. its statistical parameters change with scale. Many authors have stated that the topography of the Earth, the Moon and Mars are self-affine [e.g. 1, 2, 3]. This property affects the way in which statistical parameters like the r.m.s. height of a given topographic profile scale with the profile length: if the surface were stationary, then the r.m.s. height of a profile would not depend on its length. On the contrary, in a self-affine topography such parameter increases with profile length according to a power law: the exponent of such law is called the Hurst exponent H. For the special case of H=0, the topography is stationary, whereas H=1 corresponds to the fractal (self-similar) case.

Tests on MOLA topographic profiles have shown that, indeed, r.m.s. height scales with profile length, but have also shown that the resulting H is not always constant over different profile lengths: in the literature it is recognized that self-affine behavior of the topography is usually valid over a limited range of scales, but we will make the assumption that we can stretch the validity of our results down to the scales relevant for SHARAD scattering.

We have determined two statistical parameters, the point-to-point r.m.s. slope and the profile r.m.s. height, from available MOLA topographical profiles, which have been broken down in 100-points long segments of topographic heights 300 m apart, for ease of treatment. We have also determined the Hurst exponent for each segment by means of the r.m.s. of the height variation between different points of the profile:

MARTIAN SURFACE SCATTERING AT DECAMETRIC WAVELENGTHS. R. Orosei et al.

$v(\Delta x)=(< [z(x)-z(x+\Delta x)]^2 >)^{1/2}$ (1)

which is also called the Allan variance. For a stationary surface, v is a constant, while, for a self-affine surface:

$v(\Delta x)=v(\Delta x_0)\ (\Delta x/\Delta x_0)^H$ (2)

Fitting a straight line to a logarithmic plot of v as a function of lag distance provides the Hurst exponent. Globally, both the r.m.s. heights of the 30-km-long profiles and the 300-m point-to-point r.m.s. slopes follow closely a log-normal distribution: for the r.m.s. height, the mean is 67.4 m and the standard deviation is 93.1 m, while for the r.m.s. slope the mean is 0.038 and the standard deviation is 0.039. The Hurst exponent is described very well by a Weibull distribution with a mean of 0.70 and a standard deviation of 0.19. We have attempted to determine if there is a correlation between the different statistical parameters that we have computed to characterize the Martian topography. Unfortunately, correlation on a global scale seems to be rather weak. For this reasons, we have selected six areas which we consider to be representative of the morphology of the Martian surface, and we have looked at the back-scattering properties of those areas in detail.

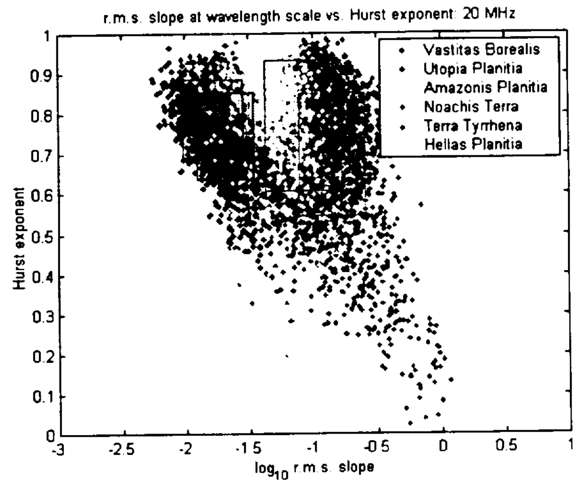
Selected Areas: We have selected the following six 10°×10° areas on Mars [4, 5, 6]:

Location	Geologic unit	Center longitude	Center latitude
Vastitas borealis	Hvk	335° W	63° N
Utopia Planitia	Hvm	275° W	55° N
Amazonis Planitia	Aa_3	155° W	27° N
Noachis Terra	Npl_1	318° W	31° S
Terra Tyrrhena	Npld	275° W	5° S
Hellas Planitia	Hh_3	295° W	42° S

The value of the r.m.s. slope at the SHARAD central wavelength (20 MHz frequency) provides an input parameter for clutter estimation over the Martian surface. For a self-affine surface, the r.m.s. slope falls off with increasing step size:

$s(\Delta x)=s(\Delta x_0)\ (\Delta x/\Delta x_0)^{H-1}$ (3)

We extrapolate the r.m.s. slope values computed at a step size of 300 m to the scale of the SHARAD wavelength by means of the above relation. A plot of the resulting r.m.s. slopes vs. the Hurst exponent is shown below:



Different geologic units have distinct signatures in the above plot. Most surfaces exhibit a Hurst exponent which is very close to 1, meaning that their scattering behavior is weakly dependent on the wavelength. The only exception is the location in Amazonis Planitia, which however exhibits low values of the r.m.s. slope, denoting an almost specular backscattering behavior. The distinction between the two hemispheres of the planet is evident also in the graph, with Hellas being a sort of intermediate member between the flat Northern plains and the rugged Southern highlands.

Conclusions: Most of the Martian topography exhibits self-affine properties at the scales between 300 and 3000 m. Statistical parameters of the topography relevant for the computation of surface scattering have been obtained. r.m.s. heights over distances of 30 km are below 50 m for the majority of the planet, denoting a very smooth surface. Similarly, r.m.s. slopes at 300 m scale are usually below 3°. The values of the parameter determining the change of the above properties with scale, the Hurst exponent, are close to 1 for most of the surface, meaning a scaling behaviour which is almost fractal-like: description of the Martian topography as a stationary random variable, for radar scattering computations, is thus inadequate, at least at the scales relevant for this study.

Extrapolating the values of the r.m.s. slope to SHARAD wavelengths, the Martian surface becomes rougher, as the step size is shorter than the 300 m spacing of MOLA samples. Still, the majority of the surface remains smoother than 6° r.m.s. slope.

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Possibilities of using MARSES instrument for long-term monitoring and subsurface studies in arctic and arid lands.

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Introduction:
The MARSES is the sounding instrument developed of searching for groundwater, water-ice or permafrost layers existing in some depth under the visible surface in the dry lands of Mars. One of the more important challenges facing natural resource managers today is how to identify, measure and monitoring the cumulative impacts of land use decisions across space and time. The secondary task is to measure the soil properties of Martian subsurface, which includes porosity, electrical resistance of the liquid phase, thermal conductivity, temperature dependence. A main task of the MARSES monitoring system is to examine changes in the subsurface properties of local areas regolith on the Martian surface on the base of the database of various soil slices in terrestrial conditions.

Comparative investigation of Martian and Terrestrial frozen rocks
The main goal of the MARSES monitoring experiment, based on the MARSES instrument is a comparative investigation of Martian and Earth's cryolithozone (possible investigation of subsurface relics of martian life), drylands soil slices, and the interpretation of geophysical data of subsurface soil structure [5], including :

- theoretical development of comparative models of subsurface frozen dryland structure for typical rocks which formed martian cryolithozone in the mixture of poligonites and montmorillonites;
- development of the software package for detailed analysis of subsurface martian structure - porosity, electrical resistance of liquid phase, thermal conductivity, temperature dependence, which are in agreement with the interpretation of data obtained in the field testing and laboratory supporting measurements;
- possibility to study subsurface frozen water component using TEM instruments and induced polarization (IP) device in several areas which are close to martian conditions: Antarctic, Iceland, Hawaii (volcanic area), arid lands;
- improvements of hardware and software on the base of field studies results in order to use in the Earth conditions, including environmental and geophysical application, and future space experiments on the Martian surface.

Preliminary results of field studies in the Arctic area and at Sir Bani Yas Island.
Results of the field season in the Arctic area revealed the existence of strong surface layer with high induced polarization (IP) effect. On the basis of gained results we have formulated the complex program of frozen soil structures sounding during future field expedition in the Arctic area. Various instruments are proposed to be employed including TEM and DC techniques.
The first field measurements on Sir Bani Yas Island (UAE) revealed the existence of thermodynamic balance between phase conditions of subsurface water, fresh and salted.

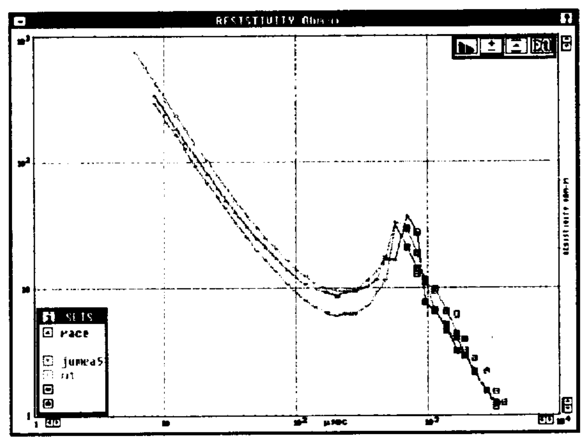
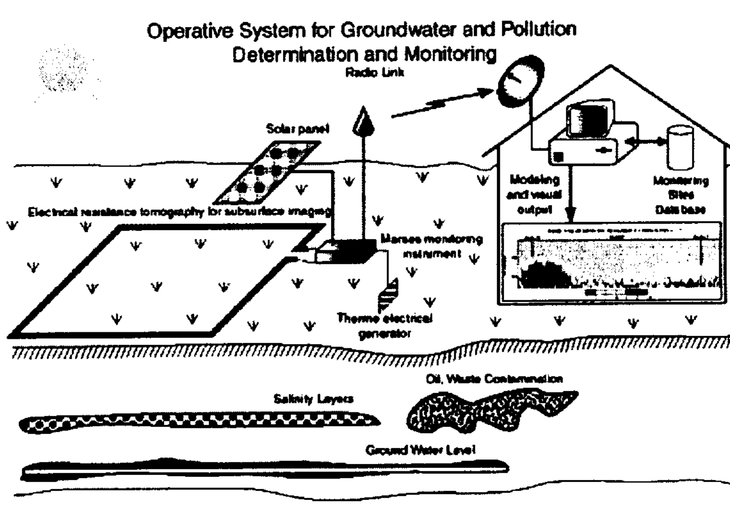


Figure 1 shows measurements on Sir Bani Yas Island, UAE



Controlling of this balance is an urgent task for operative monitoring subsurface system in drylands area in variuos regions of the world for long-term monitoring nature subsurface ecosystem.

Building of geographical slice using different instruments allows to obtain correct parameters for MARSES TEM in order to employ it in frozen soils sounding on the surface of Mars and for many applications for long-term monitoring and subsurface studies in the Earth's conditions.

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MEEM: AN ORBITAL SYNTHETIC APERTURE RADAR FOR MARS EXPLORATION. Ph. Paillou[1], T. W. Thompson[2], J. J. Plaut[2], P. A. Rosen[2], S. Hensley[2], Ch. Elachi[2], D. Massonnet[3], J. Achache[3]. [1]Observatoire Astronomique de Bordeaux, BP 89, 33270 Floirac, France, paillou@observ.u-bordeaux.fr. [2]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109, USA. [3]CNES, 2 pl. Maurice Quentin, 75036 Paris, France.

Introduction: The recent results of Mars Global Surveyor (MGS), in particular the ones of MOC (high resolution camera) and MOLA (laser altimeter), have revealed a new face of Mars [1]. They especially rise some crucial questions related to the past existence of liquid water at the surface of Mars [2] and the paleo ocean hypothesis in the Northern hemisphere [3] (geomorphological and sedimentary signatures). MOC images indicate that much of the surface of Mars has been intensely reworked by aeolian processes, and key evidence about the history of the Martian environment seems to be hidden beneath a widespread layer of debris (paleo lakes and rivers) [4]. The global analysis of the Martian topography was made possible by altimetric measurements of MOLA, which provided us a DEM (Digital Elevation Model) of the whole planet with a grid spacing of about one kilometer. Results published up to now relaunch the hypothesis of a northern ocean as an explanation for the North-South dichotomy of Mars, but there are still a lot of questions to answer, needing for finer topographic analysis and subsurface imaging, to understand the history of water on Mars: detection of shorelines and paleo rivers, smoothness of the ocean floor, dating of the associated geological structures.

SAR Capabilities: The Mars Environment Evolution Mission (MEEM) concerns a new instrument, fully original in the Mars exploration history, which allows imaging of the near subsurface geomorphology inaccessible to any other kind of sensor [5]. Earth-based radar imaging of Mars indicates that substantial penetration (meters) is obtained at 12 cm radar wavelength and shuttle radar observations of terrestrial deserts reveal subsurface structures invisible to other sensors (cf. Fig.1), to depths of about 2 meters using L-Band (24 cm) radar [6]. Recent laboratory measurements of terrestrial analogs for Martian soils and rocks, combined to numerical modeling, indicate that a P-Band (70 cm) SAR should penetrate at least 5 meters deep as shown in Fig.2 [7].

Using radar interferometry to produce high resolution DEMs [8] (cf. Fig.3), MEEM will also continue and improve the work initiated by MOLA, with a density of measurement points at least 400 times higher (cf. Fig.4), and the ability to very accurately monitor the temporal changes of the Martian surface [9, 10] (evaporation and deformation of polar caps, dust deposits, tectonics ?). A Mars radar mapping mission will also allow the high resolution mapping of the surface roughness. This roughness information will be used as a new tool to map – and even to perform relative dating of – the Martian geological units, and define future landing sites and rover paths [11]. Such data will permit a comparative study of Martian and Venusian surfaces, by combining MEEM and MAGELLAN radar images [12].

Proposed Mission: The proposed mission [13] would use a dual-frequency SAR (L and P-Bands) to map the planet at 50 m resolution, penetrating 5-10 m over much of the surface (cf. Fig.5). Selected targets will be imaged at 5 m resolution. Using repeat-pass interferometry, a 50 m resolution topographic map will be acquired within a year, and surface changes will be detected and monitored for two additional years. The instrument will also accommodate a nadir-looking high resolution sounding mode, to bridge the gap between the deep subsurface sounding of MARSIS on MARS EXPRESS [14] and the surface imaging of conventional sensors. The mission would launch in August or September 2009, followed by an Earth to Mars cruise with an arrival at Mars in July or August 2010. The orbit would be circularized using aerobraking. Data acquisition for a global radar map of Mars would commence in July 2011 and continue for a year until July 2012.

The Delta IV Med-lite launch vehicle would have a mass margin of over 600 kg which could be used for additional orbital instruments as well as piggyback surface probes or other micro-missions. We assumed an antenna that would support both the SAR and Direct-to-Earth data downlinks. This dual-use SAR/Downlink Antenna would have a 3 m solid interior and a deployed outer mesh creating an aperture with 6 m diameter. An antenna of this size would support data downlink of several Mbits/s, allowing the coverage of the whole Martian surface within the foreseen mission lifetime. The stowed antenna at launch would be only 3 meters in diameter, which fits within the Delta launch vehicle shrouds.

Acknowledgements: Team-X and radar engineers and scientists at JPL supported our study of this possible Mars orbital SAR mission, together with Radar Division at Alcatel Space, Toulouse, France. In addition, we thank the following individuals for participating in the study: R. Arvidson, M. Carr, R. Greeley, P. Mouginis-Mark, G. Schaber, L. Soderblom, F. Costard and P. Pinet.

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Fig.1: LANDSAT-TM / SIR-A composition of the Northern desert in Sudan (JPL/USGS, 1981). L-band radar reveals paleohydrology covered by dry sand.

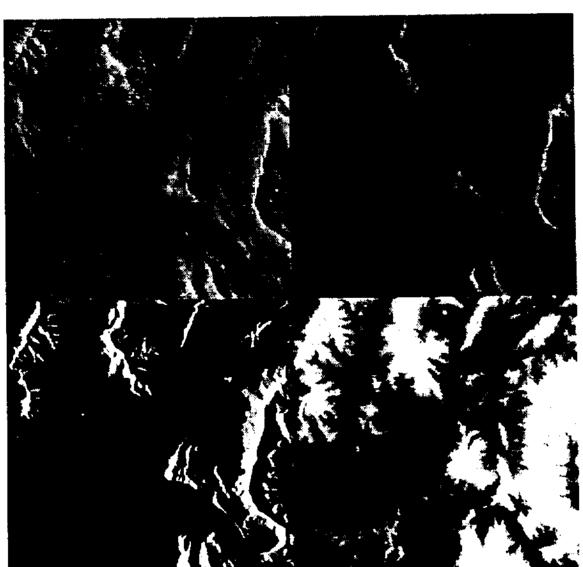

Fig.2: A simulated landscape (top left) covered by 4 m of sediments (top right), and corresponding C-Band (bottom left) and P-Band (bottom right) SAR images.

Fig.3: SRTM radar image of West Maui, Hawaii, with wrapped color as height (JPL/NASA, 2000).

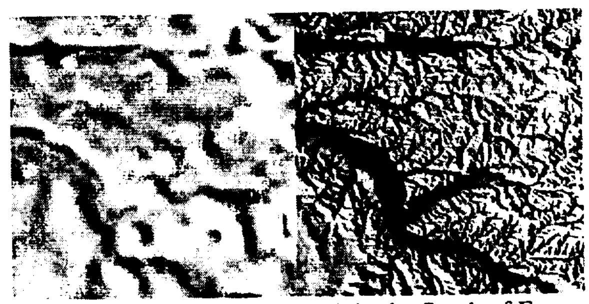

Fig.4: DEM of a valley network in the South of France (IGN, 2000), as seen with the MOLA 1 km grid spacing (left) and the MEEM 50 m grid spacing (right).

Fig.5: Artist's view of the MEEM mission.

METHANE AND CARBON DIOXIDE HYDRATES ON MARS: ARE THERE SUFFICIENT NATURAL RESOURCES ON MARS TO SUSTAIN HUMAN HABITATION? **Robert E. Pellenbarg**, MDS Research, Suite 461, 1120 Connecticut Ave. NW, Washington DC 20036, <rep15@hotmail.com>; **Michael D. Max**, also at MDS Research, <xeres@erols.com>; **Stephen M. Clifford**, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058, <clifford@lpi.nasa.gov>.

Introduction: The crust of Mars has been stable for enough time for methane formed by magmatic processes and/or as a byproduct of anaerobic deep biosphere activity to have risen toward the planet's surface. This methane would have been captured and stored as methane hydrate [1,2], which concentrates methane and water. Both CH_4 and carbon dioxide (CO_2, the predominant gas in the Martian atmosphere) are stable as gases on the Martian surface but could collect within the hydrate stability field in surface-parallel zones that reach close to the Martian surface.

In order for humankind to establish itself on Mars, colonies should be self-sustaining there as soon as possible. With hydrates of both carbon dioxide (CO_2,) and methane (CH_4), Mars would contain the basic elements for human habitation: fuel, potable water, and industrial feedstock in a near-surface situation suitable for controlled extraction by drilling. The presence of methane hydrate may prove to be the key to human habitation of Mars.

Instead of transporting to Mars the return-journey-fuel and all the items needed for human habitation of the planet, optimized standard industrial chemical plants can be designed for operation on Mars in order to manufacture a variety of plastic objects, such as shelter, ecohabitats, vehicles and other apparatus, in addition to synthetic liquid high-energy-density fuels.

The Formation of Hydrate Concentrates Gas and Water: A mechanism for the long-term concentration of methane exists on Mars as it does on Earth [3]. Methane produced in the subsurface migrates buoyantly upward in porosity until it reaches the Hydrate Stability Zone (HSZ), which is a region in which methane hydrate is stable. One m^3 of methane hydrate contains about 160 m^3 methane (Earth STP) and some 0.9 m^3 of fresh water. On Mars, the particular pressure-temperature and thermodynamic equilibrium associated with the cold Martian surface is favorable for the stabilization of a substantial HSZ [4].

Mining the carbon and oxygen compounds on Mars will follow techniques being developed for recovering gas and water from hydrate on Earth, where the newly discovered methane hydrate resources in permafrost and oceanic environments constitute an emerging major energy resource [1]. Techniques and equipment now being developed for commercial recovery of methane from terrestrial permafrost hydrate can be applied on Mars, especially for anticipated shallow Martian hydrate deposits.

Chemical Opportunities and Constraints on Mars: CO_2 is the principal Martian atmospheric constituent, albeit occurring at very low concentrations. Thus, Mars possesses fixed, oxidized, carbon. If, as seems increasingly likely, the Martian crust contains methane trapped as hydrate, the planet would thus also possesses fixed, reduced carbon. Importantly, CO_2 and CH_4 hydrates concentrate fixed carbon and water (H_2O) at the same location.

Consider reaction (1) below, which uses the constituents of methane hydrate as starting materials:

$$3CH_4 + 3H_2O \text{ --------> } 2CO + CO_2 + 9H_2 \quad (1)$$

(1) is desirable because it converts reduced carbon (CH_4) to oxidized carbon ([especially]CO and CO_2); oxidized carbon is a necessity for further organic chemical manipulations. However, the enthalpy of the system (+80 kcal) does not favor the reaction as written. Now, the reaction could be catalyzed, or run in a reactor permeable to hydrogen so that the reaction is driven to the right, or the reaction would be run under high temperature and pressure, requiring power. Alternatively, the water from methane hydrate could be electrolyzed, again requiring power, as in (2):

$$2H_2O \text{ ----------> } 2H_2 + O_2 \quad (2)$$

The resultant oxygen (O_2) could be reacted with the methane from the hydrate, as in (3):

$$2CH_4 + 3O_2 \text{ ---------> } 2CO + 4H_2O \quad (3)$$

(3) is energetically favorable, IF oxygen is available. The net desirable result of reactions (1) and (3) is to produce carbon monoxide. Keep in mind that carbon dioxide could be available on Mars directly from CO_2 hydrate, but it is desirable to have the chemical technology to convert/utilize CH_4, even if abundant CO_2 were available. Thus, it may be useful, depending on actual feedstock gases, to consider affecting the following reaction (4):

$$CH_4 + CO_2 \text{ ---------> } 2CO + 2H_2 \quad (4)$$

The net desired result is to obtain CO and H_2 as pure as possible, so that the Fischer Topisch Process (FTP) can be brought to bear. The FTP is a reaction of hydrogen with carbon monoxide, generically as follows (5, intentionally unbalanced):

H_2 + CO -----> $CH_3(CH_2)_nCH_3$ + $CH_3(CH_2)_nOH + H_2O$ (5)

carried out with an appropriate catalyst (e.g. Co, Ni, Fe, or Ru), and under suitable conditions of temperature and pressure. With proper selection of these three parameters, the FTP will yield liquid hydrocarbon fuels, oils, waxes, and a variety of organic chemicals.

For the purposes of colonization of Mars, access to a synthetic structural material, such as a plastic, will be critical. Consider the case of synthesizing polystyrene as a structural plastic. The "water-gas" reaction (6) is useful in this context:

$C + H_2O$ ----------> $H_2 + CO$ (6)

Note that hydrogen and carbon monoxide (obtained as outlined earlier) can be reacted in the reverse of (6) to give elemental carbon. Carbon will react with calcium oxide in an electric furnace to give calcium carbide (7):

3C + CaO ----------> $CaC_2 + (CO + CO_2)$ (7)

and calcium carbide will react with water to give acetylene (8):

$CaC_2 + H_20$ ----------> C_2H_2 + CaO (8)

Acetylene can be condensed to benzene (9):

$3C_2H_2$ --------> C_6H_6 (9)

which will react with ethylene (from dehydration of ethyl alcohol [10] from the FTP) to give styrene (11). Styrene can be polymerized to a rigid plastic (12):

CH_3COH -------> $C_2H_4 + H_2O$ (10)

C6H6 + C_2H_4 ---> $C_2H_3C_6H_5$ [Styr] + H_2 (11)

n(Styr) ----------> $(Styr)_n$ (12)

These few examples demonstrate the concept of creating useful materials for application on Mars. Beginning with very simple, essentially inorganic forms of carbon and water, it is possible to engineer a variety of useful organic-based materials that can be fashioned as required to support human habitation of Mars.

If abundant methane hydrate occurs in suitable proximity to the planet's surface, then synthetic FTP fuels can be manufactured. These fuels could be used to drive conventional turbine or reciprocating engines. Stirling engines, however, may provide a best solution for Mars because they operate under very low stress, and could be constructed from indigenous materials (e. g. plastic and ceramic materials, as opposed to combustion engines that require high technology metallurgy (assuming the availability of metallic ores). Alternatively, hydrogen stripped from the methane may be used in fuel cells to provide electricity.

Discussion: We have confined discussion of organic chemical engineering to producing useful organic compounds containing only carbon, hydrogen, and oxygen. However, there are many other organic materials which incorporate such atoms as Cl, S, P, or N, for instance, which would allow for very sophisticated materials to be manufactured. Martian colonists may wish to engineer polyvinyl chloride (PVC) as a structural material. For PVC, the colonists would need a source of chlorine, which is produced by the electrolysis of salt (NaCl). Are there salt deposits on Mars? Probably! If there was standing water on Mars there may well be salt deposits related to ocean evaporation. Such deposits could also contain nitrate (e.g., $NaNO_3$) or phosphate (e.g., Na_3PO_4), that would provide readily usable industrial feedstock, as well as fertilizer for growing plant biomass (giving food and cellulose, e.g. wood).

In the longer term, use of methane as a fuel and in other chemical processes will increase atmospheric CO_2 and will augment the greenhouse effect over time even without a planned atmospheric remediation plan. Increasing atmospheric density and enhancing the greenhouse effect of the atmosphere could render Mars more amenable to habitation in the longer term. Both methane and carbon dioxide are strong greenhouse gases, and if released in sufficient quantities, could lead to marked warming on the planet. Indeed, spills of methane into the Martian atmosphere are therefore, in theory, to be encouraged.

If methane and carbon dioxide hydrate deposits can be located on Mars, their location may provide the determining factor in selecting habitation and colonization sites. Specifically, gases and water from these hydrates will provide the basic elements necessary for human habitation: water, power, food, shelter and, most, if not all, of the industrial feed stocks required for sustained human habitation on Mars. Locally derived materials used in the inhabited installations will minimize the transport requirements of bringing such materials from Earth. For true colonization to be contemplated, the inhabitants of Mars must be as self-sustaining as possible.

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IMAGING SUBGLACIAL WATER SYSTEMS WITH COHERENT AIRBORNE RADAR SOUNDING TECHNIQUES. M. E. Peters[1], D. D. Blankenship[1] and D. L. Morse[1], [1]University of Texas Institute for Geophysics, Austin, TX 78759 (mattp@ig.utexas.edu)

The remote sensing of water systems beneath ice sheets is of great interest for reasons including the role of ice sheet dynamics in sea-level change and analogues to other planetary bodies in our solar system. Radar ice sounding at VHF is well suited for the detection and classification of sub-ice interfaces.

In general, radar echoes consist of both specularly reflected and diffusely scattered fields. Specular reflection results from smooth uniform interfaces, whereas diffuse scattering is a complicated function of interface roughness and the uniformity of the basal constituents. These phenomena are important to the analysis and interpretation of radar sounding experiments over subglacial water systems.

Radar ice sounding is highly effective for detecting subglacial water due to the high reflectivity of any smooth water layers, and easily extends to water present within smooth saturated sediments, such as those at the basal interface of active West Antarctic ice streams. However, because of scattering considerations, there are limits to our ability to classify rough and inhomogeneous basal interfaces using incoherent radar sounding experiments.

A unique radar data set was collected over the downstream portions of ice streams B and C, West Antarctica where they ultimately go afloat to join the Ross Ice Shelf. The experiment included a new data acquisition technique where both individual and ensemble averages of the radar signals were coherently recorded. The integration distance was about 40 meters and the unfocused synthetic aperture length was about 75 meters over these 500-800 meter thick ice streams. Analysis of the complimentary individual and integrated data sets yields significantly greater information about the reflection and scattering at the subglacial interface than can be obtained solely from reflection coefficient analysis. We present reflection and scattering images of the basal interface and discuss their implications for determining small-scale roughness and the distribution of subglacial water.

HIGH AND LOW FREQUENCY ELECTRICAL MEASUREMENTS OF MARTIAN SOIL SIMULANTS

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Introduction

The search for gaseous, liquid or ice water in the atmosphere or on/below the surface of the rocky planets and moons of Jupiter and Saturn represents one of the fundamental goals of the interplanetary missions. Spectroscopic methods are best to define the presence of water when studying the surface or atmosphere of a planet, however different methods, such as those developed for geophysical surveys on Earth, are required when exploring the subsurface environment. Some of these techniques are quite precise, such as neutron scattering or NMR, however their application to remote planetary missions is difficult because of high costs, the complexity of their measurements, and their typically large size and weight. In contrast electric and electromagnetic methods are simple, small, very robust and are relatively inexpensive, and thus have great potential for future missions.

Our group has proposed the construction, testing and use of electrical and electromagnetic probes within the Mars Surveyor Program (2003-2005) Lander Mission in an effort to measure the electromagnetic parameters of the shallow soil environment on Mars (up to a depth of 50cm) and, consequently, to determine the presence of H_2O liquid, H_2O ice or CO_2 ice at the landing site. Two different probes have been proposed: a low frequency (IP) probe that works below 10 KHz and which outlines the presence of H_2O liquid and ice, and a higher frequency (EM) probe that works above 800 MHz and which is able to define the presence of H_20 liquid. Both of the probes can be used either from on surface to investigate a large soil volume, or in a borehole to make point measurements.

Given the lack of electrical measurements on the hypothesized Martian materials under the Martian physical conditions, ad hoc experiments were curried out both in the higher and lower frequency ranges. Preliminary results obtained using both dielectric spettroscopy and TDR (Time Domain Reflectometry) methods to measure the dielectric constant of a mixture volcanic sand/H_2O (liquid and ice) and volcanic sand/CO_2 snow are discussed.

Experimental Methods

Broadband dielectric spectroscopy is a powerful method to investigate a sample's frequency-dependent dielectric response. It is based on the measurement of a complex quantity (i.e. admittance or impedance) as a function of the frequency of a sample sandwiched between two electrodes. The measured admittance is directly related to the complex permittivity and thus by fitting experimental data to an equation linking these two parameters, the real and imaginary components of sample permittivity can be derived. The apparatus consists of a dielectric interface and a frequency analyser covering the range 10mHz-65kHz. Temperature is measured by a controller that also regulates the power to the heater attached to the cold head of a homemade flow cryostat. Data acquisition is handled by a PC so that temperature stable frequency measurements are possible over the range 140-330°K.[1]

Time Domain Reflectometry (TDR) is a electromagnetic technique to obtain information on permettivity and conductivity of solid and liquid materials. The TDR sends e.m. waves into two parallel rods (balanced transmission line) which are inserted into the studied dielectric media. The instrument then measures reflection amplitudes as well as the time interval between the transmitted and reflected waves. The transmitted signal is a step-like voltage (band frequency 16.6 kHz - 1.75 Ghz) which is transmitted over a period of 10 ms followed by a pause of 50 ms [2].

Results

Figure 1 shows the results obtained on two different soil samples: 1) powdered lava (basalt) having different grain sizes and water contents; and 2) powdered granite sand, with the same grain sizes and similar water contents. As can be seen the technique is able to identify the presence of water (even at very low contents) on the basis of the frequency response of both the real (e') and imaginary (e'') parts of the complex permittivity.

ELECTRICAL MEASUREMENTS OF MARTIAN SIMULANTS: E. Pettinelli et al.

Figure 1

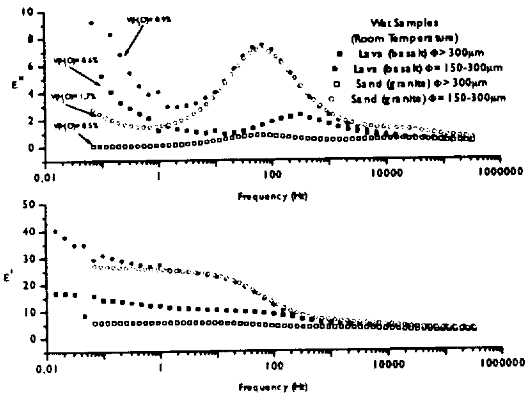


Figure 2 shows the TDR curves obtained in CO2-ice, CO2-snow and H2O-ice. It is quite significant that the air and CO2-snow have very similar curves, and as a consequence the have very similar apparent permittivities. The permittivity of CO2-ice (produced under a pressure of 200bars) is higher than that of CO2-snow (the curve is longer in terms of time) but is lower than that of H2O-ice.

Figure 2

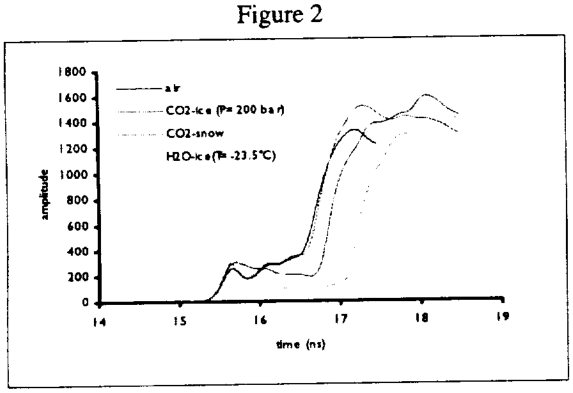
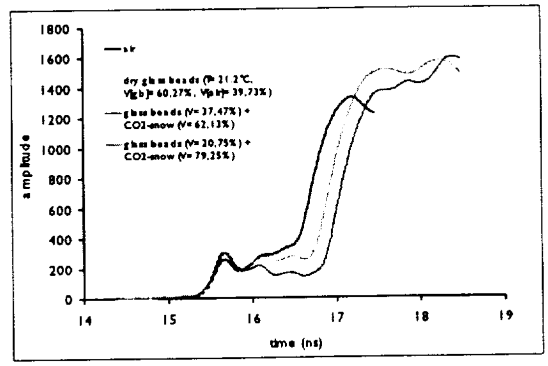


Figure 3 shows the TDR results obtained on a mixture of glass beads / CO2 - snow / air. As can be seen the increase in the amount of CO2-snow reduces the propagation time of the electromagnetic signal in the line due to the fact that it is reducing the apparent permittivity of the mixture.

Figure 3



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SUBSURFACE SOUNDING OF MARS: THE EFFECTS OF SURFACE ROUGHNESS. J. J. Plaut[1], R. Jordan[1], A. Safaeinili [1], G. Picardi[2], R. Seu[2], and R. Orosei[3], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, plaut@jpl.nasa.gov, [2]INFO-COM, University of Rome La Sapienza, Via Eudossiana 18, 00184 Rome Italy, [3]IAS-CNR, Via del Fosso del Cavaliere, I-00133 Rome, Italy.

Introduction: The Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) will conduct a global survey of Mars from the Mars Express Orbiter starting in 2004 [1]. The primary objective of the subsurface observations is to detect material interfaces in the upper several km of the crust of Mars, with a particular emphasis on mapping the 3D distribution of water and ice in that portion of the crust. In order to detect subsurface interfaces, the returned echo from the subsurface must be distinguished from noise and clutter, which can arise from a variety of sources. One source of clutter is surface topography that generates backscattered energy at the same time delay as the subsurface region of interest. Surface topography can affect the detectability of subsurface features in several other ways. Surface roughness at scales comparable or somewhat smaller than the radar wavelength reduces the coherency of the wave as it passes the upper interface. Also, surface slope (tilt) at scales of the radar footprint and larger (> 5km) affects the apparent Doppler signature of the echoes, and effectively disperses the wave transmitted into the subsurface, making processing and interpretation difficult. In this paper, we report on the roughness characteristics of Mars at these various scales as measured by the Mars Global Surveyor Laser Altimeter (MOLA), and consider the implications for achieving the subsurface sounding goals of MARSIS.

Regional slope: To characterize the slope of Mars at scales comparable and larger than the MARSIS footprint (> 5 km), the 1/8 degree MOLA global elevation dataset was analyzed for point-to-point slopes in the North-South direction (Figure 1a). This provides an estimate of the local slope at a 7.5 km scale in approximately the along-track direction of Mars Express, which has the largest effect on Doppler processing. As seen in the histogram of this parameter, 90% of Mars has a regional slope (at this scale) smaller than 1.5 degrees. Preliminary analysis of the slope effect on subsurface detection indicates that slopes less than 2 degrees are acceptable; therefore less than 10% of Mars will be eliminated from subsurface sounding due to this effect.

Within-footprint slopes (clutter): The scales of concern for off-nadir scattering (clutter) that may interfere with subsurface returns at the same time delay are from the Fresnel zone limit (~10 km) down to the wavelength scale (10s of m). Within this range are the MOLA point-to-point (300 m) elevation measurements analyzed extensively in [2]. Figure 1b shows a histogram extracted from figures of [2] of the rms slope of 300 m point-to-point heights evaluated in 35 km along-track windows. The 90% cumulative value of this parameter is about 5 degrees. Rms slopes at larger scales will have a 90% limit at even smaller values. This suggests that competing clutter is likely to be of concern over only a small portion (10-20%) of the surface. The smoothness of Mars, combined with the clutter analysis obtained by the MARSIS secondary (monopole) antenna reduces the concern that off-nadir clutter will seriously degrade subsurface detection by MARSIS.

Sub-wavelength roughness: The MOLA within-footprint (150 m diameter) pulse spread measurement gives an estimate of the total vertical relief within a MOLA footprint. As seen in Figure 1c (extracted from data provided in [3] by J. Garvin), the 90% cumulative value of this parameter is about 5 m. Considering this a proxy for rms height, which is commonly used as in input to radar scattering models, we suggest that this "small-scale" surface roughness will only be a concern for MARSIS observations at the higher frequencies, except for a small fraction of the Mars surface with unusually high values of this parameter.

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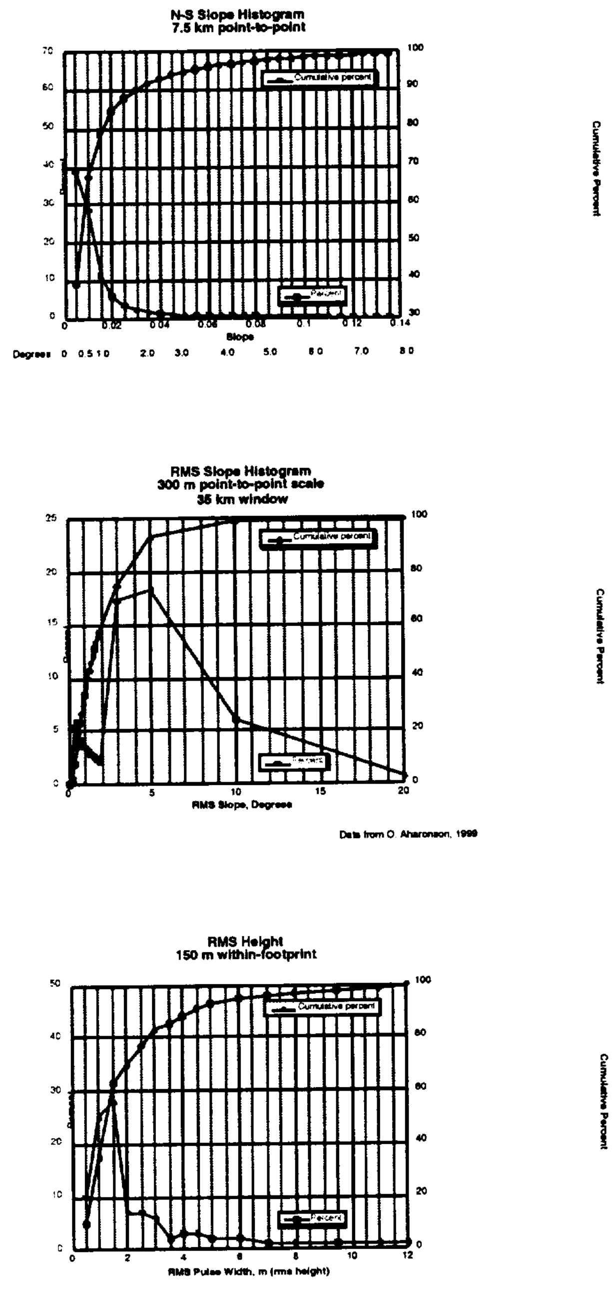

Figure 1. Histograms derived from MOLA of Mars surface roughness: a) 7.5 km point-to-point slopes in the North-South direction, b) 300 m point-to-point rms slope in a 35 km window, c) rms height as reported by the MOLA pulse-width within-footprint relief.

SUBSURFACE WATER DETECTION ON MARS BY ACTIVE SEISMOLOGY: SIMULATION AT THE MARS SOCIETY ARCTIC RESEARCH STATION

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The Mars Society has established a Mars Arctic Research Station (M.A.R.S.) on Devon Island, North of Canada, in the middle of the Haughton crater [1] formed by the impact of a large meteorite several hundred million years ago. The site was selected for its similarities with the surface of the Mars planet. During the Summer 2001, the MARS Flashline Research Station will support an extended international simulation campaign of human Mars exploration operations. Six rotations of a six person crew will spend ten days each at the MARS Flashline Research Station. International crews, of mixed gender and professional qualifications, will conduct various tasks as a Martian crew would do and perform scientific experiments in several fields (Geophysics, Biology, Psychology). One of the goals of this simulation campaign is to assess the operational and technical feasibility of sustaining a crew in an autonomous habitat, conducting a field scientific research program. Operations will be conducted as they would be during a Martian mission, including delays in radio communications with the Mission Control Center (located in Denver, Colorado) and Extra-Vehicular Activities (EVA) with specially designed suits.

One of the proposed experiments is to rehearse procedures and to conduct an active seismology experiment to detect the potential presence of subsurface water. A crewman wearing a Martian EVA suit will install a set of 30 seismometer sensors on the surface of the Haughton crater to record signals generated by a thumper, somehow similar to experiments conducted on the Moon [2]. The instrumentation will be provided by the Institute of Geophysics of Paris (IPGP), France. Recorded signals will be analyzed later on to extend the characterization of the Haughton crater structure by supporting scientists from the IPGP and the Royal Observatory of Belgium. This experiment can be seen as a possible extension of the future automatic Seismology and Gravimetry experiment (SEIS) aiming at characterizing the deep internal structure of Mars and of its direct subsurface to search for the presence of water. The SEIS experiment will be conducted during the NETLANDER mission, a cooperative program between France and the USA, to be launched in 2007.

The paper will present the first result of the experiment conducted during the simulation campaign at the Mars Flashline Research Station.

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FDTD METHOD FOR THE THEORETICAL ANALYSIS OF THE NETLANDER GPR.

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Introduction: This paper introduces an original theoretical way based on the FDTD method for the study of the GPR performances in the particular case of deep sounding applications. This particular version of the FDTD code has been developed for the NETLANDER GPR which will sound far deep regions into the Martian subsurface (about 2500 meters down from the surface) . In such a case, the usual FDTD method would require too important computational resources, as a consequence an original model has been investigated to overcome this drawback. Some of the main tools developed for this study and some typical results obtained will be presented.

Theoretical method : The FDTD method [1] is now a well-known method in the electromagnetic domain, so its principle will not be recalled. The main improvement for the present application will be detailed in the following :

Implementation of CPML : The FDTD method allows to model the antenna and the ground down to 500 meters approximately in the whole computational volume. Thus, it's possible to determine in the time domain the echoes diffracted by the different layers directly. To limit the computational volume, the PML (Perfectly Matched Layers) method developed by Berenger [1] is usually utilised. As it is used for absorbing diffracted waves in the vacuum, an extension has been made to take half-infinite lossy and conductive media into account. A CPML (Convolution PML) based on a convolution product recently developed by Gedney [2] has been implemented. Such a method allows to control the numerical parasitic reflection of the PML.

Extrapolation Method : In order to determine the magnitude of the signal diffracted by the deepest layers (-2500 m), a global computation would be too expensive in computational resources, and thus two different simulations have been made. The first one is a 3D-FDTD simulation and the second one is a 1-D FDTD simulation with a plane wave emitted from the surface which takes into account the attenuation due to the electromagnetic properties of the soil. The obvious interest of this 1-D simulation is a very large gain in CPU time. By using a very simple analytical calculation of the propagation losses (results 1D FDTD) and the geometric spreading in the far field region. The 3D method gives the gain and the effective surface of the antenna whereas the 1D method allows to compute the propagation losses on the direct and return traject .The total transfer function is the deduced from the coupling between the two approaches.

Rough of interfaces and diffusive rocks : The straight line to the plane interface is an ideal case. Some physical characteristics of the subsurface can decrease the performances of the GPR and damage the power budget. Two different causes of perturbations have been investigated : the roughness of the interface and the presence of diffusive rocks having a random distribution.

If the interface is limited to down 500 meters, the whole computation can be run in the same volume. In this case, a statistical approach has been investigated to give the power budget as a function of roughness or density of diffusion rocks.

For deep interfaces, the same methodology is employed with the difference that the reflection coefficients of the deep interfaces will be obtained from the computation of the RCS (Radar Cross Section) in a 3D-FDTD sub-volume around the diffusive rocks or around the non plane interfaces.

Results : Some typical results for the NETLANDER GPR will be now presented. To simplify the problem, The antenna will be modeled as a quasi continuously loaded resistive dipole (according to the Wu and King theory). The subsurface model is presented on figure (1).

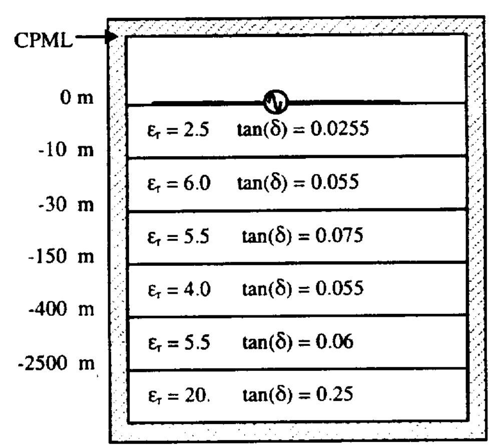


Figure (1) – model of the Martian subsurface

To validate the extrapolation method, the –400m interface will be considered. To have a reference case, the first simulation consists in considering the antenna and all the subsurface from 0 to –500 meters in the same computational volume. The transient current at the antenna level is a succession of wavelets which characterize the different reflections by the interfaces (figure(2)).

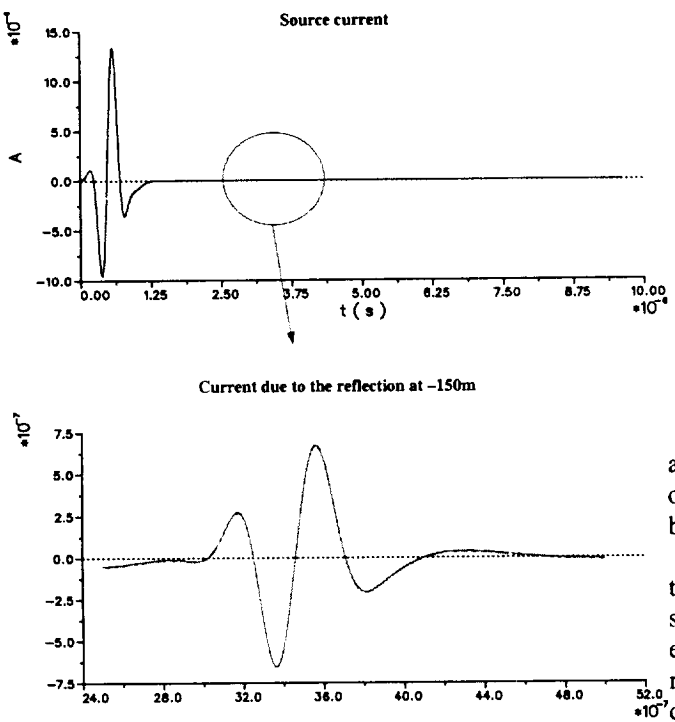
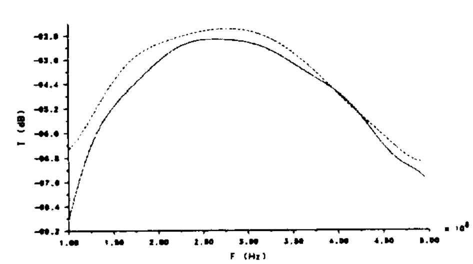


Figure (2) –transient current at the antenna level

Thus, a transfer function is defined as the ratio of the current at the receiver level reflected back from the interface to the generator current. The transfer function computed by the direct computation and using also the extrapolation method from the -400 m interface gives a good agreement (figure(3)). A difference less than 3dB can be observed.

Figure (3) – transfer functions versus frequency

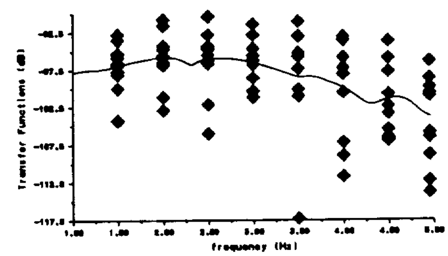


—— Direct computation with 3D-FDTD code
------ Extrapolation method

The computation for the –2500 meters layer would give a transfer function value about –200 dB.

To estimate the roughness effect on the power budget, some statistical rough profiles have been generated. The height of roughness is about 50 meters around –400 meters. The different results are presented on figure (4)

Figure (4) – effect of roughness for the –400m layer transfer function



—— Average of transfer functions
◆ Transfer functions

The figure 4 shows a difference of about 10 dB around the means values of the transfer function obtained for a plane interface in the [1-5] MHz bandwidth.

Conclusion : As the gain of CPU time is important, these new method allow us to run parametric simulations of the GPR in a modeled Martian environment with a good accuracy. These results are needed to help in the design of the instrument and to derive the convenient algorithm to analyse the data.

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THE ELYSIUM/UTOPIA FLOWS: EVIDENCE FOR RELEASE OF CONFINED GROUNDWATER IN THE CONTEXT OF A GLOBAL CRYOSPHERE-HYDROSPHERE SYSTEM. P. S. Russell and J. W. Head III, Dept. Geological Sciences, Brown University, Box 1846, Providence RI 02912. Patrick_Russell@Brown.edu.

Introduction: The hydrological model of Clifford [1,2] makes global-scale predictions regarding the cryosphere and hydrosphere on Mars throughout the planet's history. If these interpretations of the major factors governing large-scale distribution of water are accurate, they may have had profound influence on the evolution of surface geology, and would be an essential contextual consideration in interpretation of many geological processes. It is therefore important to test this model. As a result of such processes as magma ascent, dike propagation, cratering, and fracturing, insight into the state of the subsurface cryosphere and hydrosphere may be gained from examination of the geology at or near the surface.

We use MOLA data to examine potential areas of groundwater interaction with the surface, in particular evidence for lahars and associated fluvial channels in the Elysium/Utopia region [eg 3]. The major types of deposits and structures, relationships among them, and elevational patterns are characterized [4]. We then propose a model to account for the emplacement of the deposits, water associated with them, and their particular association with source fossae on the flanks of Elysium Mons. Elevational control of the source of water-rich flows supports the scenario of groundwater release from a confining cryosphere, potentially supporting the concept of [1]. Further considerations add constraints to the model of a global hydrosphere.

Geologic Setting and Background: Deposits exhibiting flow-like morphology stretch from the NW slopes of Elysium Mons well into the Utopia Basin. Deep radial fossae on the flanks of Elysium have been proposed as sources of these Early Amazonian-aged deposits and channels [3,5]. Christiansen [3] interprets these deposits as lahars (debris flows induced directly or indirectly by volcanic activity). He proposes that elevated heat flow associated with fissure eruptions on the flanks of Elysium melted ground ice. This water then mobilized sub-surface material and followed the pre-existing regional fractures to the surface. The deposits have also been described as erosional plains [6], pyroclastic flows [7], volcaniclastic flows later modified by ground ice interaction [5], and sub-ice erupted material [8]. The water responsible for channel incision has been postulated to be from melting of ground ice due to volcanism [3,7,9] and from tapping of groundwater by fracturing [5].

The fossae on the NW flanks of Elysium approximately radial to its center have been interpreted to be the consequence of tension fracturing at depth [10], regional loading by Elysium Mons and Tharsis [11], or subsidence following fissure eruptions [8]. Enlargement of fractures may be the result of fluvial or volcanic erosion or mass-wasting [5].

MOLA Observations: MOLA data, including detrended and gradient topography [12], clearly distinguish two main types of deposits extending from the NW flanks of Elysium into Utopia [4]. The first, comprised of distinct lobate flows with sharp flow boundaries and relatively smooth surfaces, are interpreted as lava flows originating on the Elysium rise. These correspond well with the Aps and Ael2 units of [5]. The second are characterized by irregular high-relief surfaces and are associated with incised medial channels. The intimate and parallel association of deposits and channels suggests their emplacement processes are related. These deposits are interpreted as debris flows of high water content, as suggested by the lahar hypothesis of [3]. The incision of well-developed channels suggests that later stages of flow were very water-rich [3] and probably followed the medial path of the debris flow. (Further topographic description of units and relationships was presented in [4].)

Most debris flows and channels can be traced back to fossae at or near the break in slope at the base of Elysium Mons. The floors of these flank structures at their terminal (NW) ends are in the -3900 m to -3500 m elevation range. The fossae from which debris flows emanate are graben-like fractures or termini of linear chains of pits. Galaxis Fossae is an extremely straight graben over 200 km long. Two reentrants at the base of the Elysium rise are irregularly shaped, with broad flat floors at elevations of -3800 m. The one to the S shows evidence of fluvial activity including an incised channel; the one to the N does not, beyond its smooth floor. Major fossae with floors above -3500 m do not have major fluvial channels and deposits directly downslope from them, but some are sources of lava flows.

The observed relationships of lava flows, debris flows, channels, and fossae, suggests their mechanisms of formation may be related. The following hypothesis is consistent in accounting for the majority of these features in one model.

The Cryosphere and Groundwater: We first consider plausible subsurface hydrological conditions as proposed by Clifford [1]. He argues that permeability of the megaregolith is high enough to sustain the existence of a globally interconnected groundwater system. He also demonstrates that under martian conditions, a cryosphere (a zone of the crust in which the temperature is always below the freezing point of water) extends from the surface to a latitudinally-dependent depth (~2.5 km at 30°N). This frozen zone inhibits the passage of water to the surface, which, in conjunction with high permeabilities, leads to the possibility of transmitting pressure head over great distances. In the absence of external factors, water may be contained as long as the local lithostatic pressure of the cryosphere is greater than the hydrostatic pressure exerted by saturated ground at higher elevations [2]. The principle of local pressure head overcoming the confining ability of frozen ground to produce outflow has been proposed for the initiation of the Chryse outflow channels on the periphery of Tharsis [13].

Clustering of channel sources at the base of the Elysium rise within an elevation range below -3500 m may reflect the minimum elevation of a subsurface water table. Any amount of water above this elevation would contribute to the hydrostatic pressure at this elevation. If the cryosphere were breached, water would flow to the surface on its own. Volume and discharge rates would largely depend on factors governing rates of flow (pressure, permeability) vs. freezing (see [13]).

Magmatism: Secondly, we consider a mechanism for the formation of the fossae and regional fractures generally oriented radially to Elysium Mons. Rising magma, as it reaches a zone of neutral buoyancy, will propagate vertically oriented dikes laterally in the direction 90° to that of the least principle stress [14, 15]. [16] demonstrate that a dike will propagate fractures ahead of it towards the surface, potentially resulting in graben formation. Many lunar graben, linear rilles, and pit chains, with or without associated volcanic features, have been interpreted as the surface manifestation of dikes stalled at various levels below the surface [17, 18]. Extensive graben radial to Tharsis may have been formed from dikes propagating laterally from a central plume [15].

At Elysium, morphology of fossae ranges from chains of pits, to depressions, to graben (isolated and in sets), to wide gently curving troughs. Interior and adjacent ridges, depressions, and smaller fractures suggest that the large troughs may have been initiated as multiple closely spaced fractures, as are seen elsewhere. The largest, open-mouthed troughs with smooth gently sloping floors appear to have been enlarged by high eruption rates of lava [5]. Enlargement of enclosed depressions may have been due largely to pyroclastic eruptions, leaving behind only diffuse deposits. Both types of eruption can be expected as the result of near-surface dike intrusion under martian conditions [19] and the possibility of magma-ground ice interaction [6, 8]. The orientation of these fossae is generally within 15° of radial to Elysium Mons [9]. This NW trend is complemented by long SE-trending graben on the SE flanks of Elysium. Both may be the result of dikes responding to consistent principle regional stress directions.

Model: We thus propose that the radial fossae on the flanks of Elysium were initiated by dikes propagating laterally from a magma reservoir at neutral buoyancy in the Elysium rise and approaching or reaching the surface on its flanks (Fig. 1). While melting of ground ice by magmatic intrusion may produce some meltwater, as demonstrated by [20] and suggested at Elysium by [3, 9], dike intrusion could thermally disrupt the cryosphere locally, facilitating a path for groundwater to the surface, similar to the proposal of [5]. Flow may have been forceful and sustained, as suggested by the extent of the deposits and channels, if the groundwater were under hydraulic head exerted by the level of the global water table. Dikes may also direct the flow of groundwater, providing it a preferred path to the surface along strike, thus concentrating outflow at points where dikes approach the surface. At fossae > -3500 m, extrusive volcanic activity exclusive of major groundwater outflow is also consistent with dike propagation. Volume estimates of the debris flows are greater than those of the fossae, suggesting the addition of material from the subsurface [3, 21], which could be provided by dike lavas or pyroclasitcs.

The fact that major deposits and channels only arise from those fossae with elevations below -3500 m may reflect the minimum level of the water table within the Elysium rise at the time of fracture formation/dike emplacement. If this water table were global in extent, its volume would be well within the range of estimates for martian water inventory [22]. If the higher fossae were formed at a similar time and do not conceal buried fluvial features, the maximum elevation of saturated ground within Elysium must have been less than that required to provide enough pressure head for flow to the surface at the minimum floor elevations of these higher fossae (~ -3000 m).

Conclusions and Implications: MOLA data support the presence of lava flows and debris flows among the deposits flowing into Utopia from Elysium. Radial fossae on the flanks of Elysium were initiated by lateral propagation of dikes. Those that are sources of the major debris flows and channels are clustered in a zone of -3900 to -3500 m. The dikes disrupted the cryosphere and channeled large volumes of

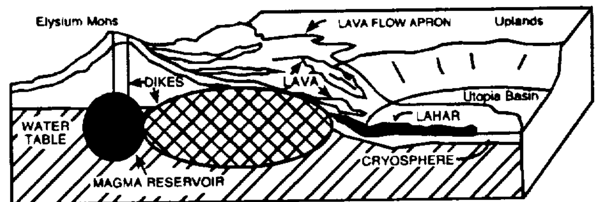

Fig. 1. Schematic cross-section of Elysium region illustrating how dike penetration of the cryosphere in the presence of groundwater accounts for the observed distribution of lavas and debris flows.

groundwater under hydraulic head to the surface at elevations reflective of a water table. The model of laterally propagating dikes disrupting a groundwater-confining cryosphere can account for the major features and units and their topographic and spatial relationships in Elysium/Utopia (Fig. 1).

Observations at Elysium are consistent with the global hydrological system proposed by [1]. They furthermore imply elevations of saturated ground > -3500 m at the time of formation. Further work on parameters of flow within Elysium may better constrain the maximum elevation of saturated ground expected. In this scenario, water in saturated ground at elevations < ~ -4000 m should not have been depleted and may still exist below the cryosphere. If the effusion of groundwater at Elysium occurred under conditions similar to today's, water in saturated deposits may have frozen [21], and still be present below depths affected by sublimation. Because the Elysium flows represent some of the most recent fluvial activity on the planet (possibly younger than Early Amazonian [21]), and large volumes were evidently involved, this region may be one of the most likely to contain near-surface ice.

The surface effusion of groundwater under hydraulic head as a result of disruption of a confining crysoshpere [1] by tectonic, magmatic, or impact activity, could potentially be a significant process in the formation of fluvial features on the martian surface. Identification of such instances gives information on the subsurface state of the local cryosphere and hydrosphere. Investigation of where groundwater-surface interaction might be predicted, for example deep craters in the northern lowlands [23], may help constrain the model. We will present a scenario for the exploration of such water and ice in the subsurface.

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Radar Sounding of Mars: A Focus on MARSIS. A. Safaeinili[1], D. Biccari[2], O. Bombaci[3], D. Gurnett[4], W.T.K. Johnson[1], R.L. Jordan[1], R. Orosei[5], G. Picardi[2], J. Plaut[1], R. Seu[2], E. Zampolini[3], and C. Zelli[3]

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Radar has the unique capability of looking under the dry and cold surfaces of Mars. The depth of penetration of radio waves depends on a number of surface and subsurface parameters such as surface topography, subsurface geological structure and surface and subsurface electromagnetic properties. Among these parameters, the surface topography is known best largely due to valuable data provided by Mars Global Surveyor's MOLA instrument. However, little information is available on the electromagnetic properties and subsurface characteristics of Mars.

In early 2004, Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) will attempt to reduce these uncertainties and look for evidence of present and/or past water on Mars. MARSIS is the result of an international collaboration between NASA, the Italian Space Agency (ASI) and European Space Agency (ESA) and is designed to sense the planets crust to a depth of up to 5 km. MARSIS' main objective is to search for water if it exists in liquid form under the surface. It will also attempt to map and characterize the subsurface geological structure of Mars. In addition to its subsurface exploration goals, MARSIS will study the ionosphere of Mars providing an extensive amount of direct measurements of the Martian ionosphere on a global scale. MARSIS is a challenging project and its design is pushing the envelope in all aspects including transmitter design, lightweight antenna design and on-board processing. MARSIS is designed with a high relative bandwidth over a frequency range extending from 0.1 MHz to 5.5 MHz. In the subsurface sounding mode, MARSIS has four distinct 1-MHz frequency bands centered at 1.8, 3.0, 4.0 and 5.0 MHz. Since operation at a low frequency is necessary in order to penetrate to a depth of up to 5 km below the surface, MARSIS has to be able to correct for the distortions that are introduced by the ionosphere. The ionosphere affects the MARSIS operation in three distinct ways: 1) radio wave dispersion, 2) radio wave attenuation, and 3) Faraday rotation.

The dispersion, if not compensated, impacts the depth resolution of the radar through broadening of the compressed radar pulse [1,2]. This broadening is a function of ionosphere electron column density and its profile shape (especially for frequencies close to the peak plasma frequency). For MARSIS, the ionospheric correction is carried out on the ground to maximize performance. In addition to dispersion, the ionosphere will also attenuate the radio wave. The level of attenuation depends on the ionosphere's electron density and its profile shape and the electron-neutral collision frequency [3,4,5]. Fortunately, information from past missions can provide some information on the expected level of attenuation. Figure 1 shows expected total radio wave attenuation under three different ionospheric conditions.

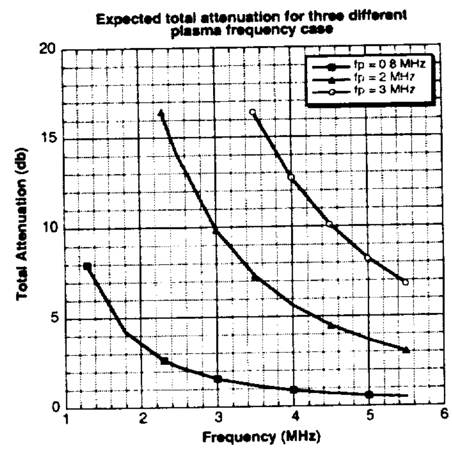

Figure 1: Expected ionospheric attenuation versus frequency for three different ionospheric conditions: 1) peak plasma frequency of 0.8 MHz (evening or High Solar Zenith Angle), 2) peak plasma frequency of 2 MHz corresponding to mid to late afternoon and 3) peak plasma frequency of 3 MHz corresponding to early afternoon conditions.

The third mechanism for the ionospheric distortion is the Faraday rotation [6]. When MARSIS was designed, the prevailing assumption was that the Mars magnetic field is so weak that, at HF frequency range, the impact due to the Faraday rotation is negligible. Recent MGS results have shown that this assumption does not hold for some areas of Mars, particularly in the southern hemisphere where regions with high magnetic field have been identified. Figure 2 shows the maximum expected Faraday rotation for about 80% of Mars where a maximum magnetic field of 50 nT is expected.

Due to limitations in the data down-link rate, on-board signal processing is required to reduce the data redundancy and maintain a reasonable data volume in order to achieve a significant coverage on a global scale.

This presentation will provide an overview of the spaceborne HF radar sounder operation at Mars with a focus on MARSIS operation environment and processing strategy. We will also discuss implications of lessons learned so far, in dealing with issues such as surface clutter and ionosphere, on the design of future orbiting sounders.

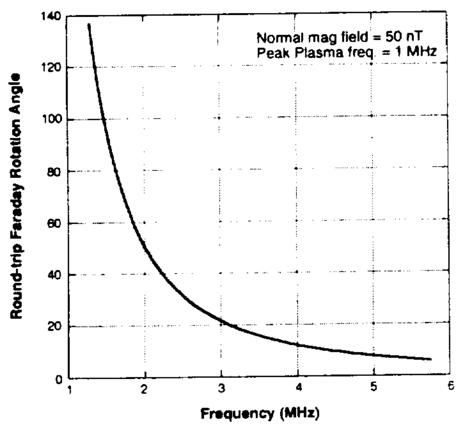

Figure 2: Expected Faraday rotation phase (degrees) for different frequencies when the peak plasma frequency of the ionosphere is 1 MHz and the surface-normal magnetic field component is 50 nT.

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The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautic and Space Adminstration.

MARTIAN UNDERGROUND WATER DETECTION: THERMAL MODEL AND SIMULATIONS OF RADAR PULSE PROPAGATION.

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Introduction:

One of the main goals of Mars Express project planned to be launched by ESA in 2003 is liquid water or ice detection under Martian surface by means of radar sounder MARSIS. In this report we present the thermal model for upper crust of Mars to reveal the conditions and depths for liquid water existence. On the base of this model we have carried out simulations of sounder signal propagation in structurally inhomogeneous crust to investigate the possibilities to detect subsurface structures and resolve the water.

Thermal Model of Martian Crust

To calculate the thermal regime of the Martian crust we admit the following model of its structure. We assume that the crust is heterogeneous in composition but this compositions are close to terrestrial ones like basaltic or andesites materials. It consists of interbedded layers of different materials in a sequence that depends upon local geological history [1]. Those materials can be considered as a disperse system consisting of a stiff skeleton formed by the material particles and voids between them which could be filled by ice or water. The main parameters of this structure are porosity p, coherency δ, saturation of porous by filled material s. The thermal properties of this medium is treated by the skeleton thermal conductivity coefficient k_{mc} and filled material k_{mp} [2]. The structure and parameters of model are presented in Tab.1.

Depth (m)	Lithology	P	δ	S	Phase
1	Eolian sediment	0.5	0.066	0	
3	Indurate sediment	0.15	0.141	0	
5	Vesicular basalt	0.5	0.8	0	
10	Dense basalt	0.05	1.0	0	
100	Layered basalt	0.1	1.0	0	
110	Eolian sediment	0.5	0.066	1	Ice
150	Layered basalt	0.1	1.0	0.5	Ice
152	Fluvial sediment	0.2	0.8	0	
160	Volcanic ash	0.5	0.2	0	
200	Layered basalt	0.1	1.0	0	
220	Crater ejecta	0.2	0.5	1	Ice
250	Layered basalt	0.1	1.0	1	Gas hydrate
255	Eolian sediment	0.5	0.066	0	
350	Layered basalt	0.1	1.0	0	
355	Fluvial sediment	0.2	0.8	0	
500	Layered basalt	0.1	1.0	0	
750	Layered basalt	0.1	1.0	1	Ice
760	Volcanic ash	0.5	0.2	1	Ice
900	Layered basalt	0.1	1.0	1	Ice
1000	Layered basalt	0.1	1.0	1	Ice

Tab.1

This model is presented as an example of the complex stratigraphy revealed by MOC images on Mars: it was kindly circulated by Dr. Clifford of LPI during discussion of the potential of ground-penetrating radars on Mars see http://cass.jsc.nasa.gov/meetings/geomars2001/radar.pdf)."

The thermal regime of the crust is governed by solar insolation and internal heat flux. The first heating mechanism is working only for depth's above a few tenths of meters. So, thermal regime of crust below this depth is determined by internal heat flux. Unfortunately, it's value is unknown and we can only make some reasonable assumptions from indirect data. At Fig.1 we present the temperature distribution for our model of Martian crust as a function of depth for various values of internal heat flux.. As can be seen from Fig.1, the brine with quite high salts concentration can exist from depths as small as a few tenths of meters. Meanwhile, the water like a sea one can exist on depth greater than 1 km only.

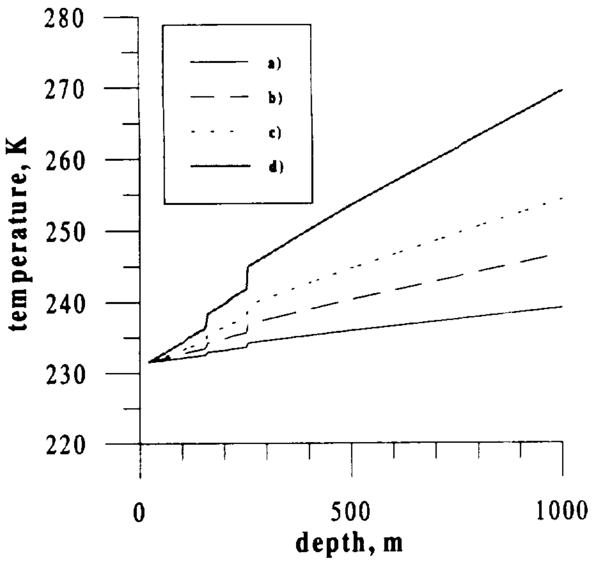

Fig.1 Temperature distribution for various heat flux values: a) 15 mW/m^2, b) 30 mW/m^2 [2], c) 45 mW/m^2, d) 82 mW/m^2 (Earth value)

Radar Signal Propagation in Structurally Inhomogeneous Martian Crust

To investigate a radar signal propagation in structurally inhomogeneous Martian crust described by our model (see Tab.1) we suppose that scattering of radiation in the crust volume and material dispersion are negligible for MARSIS wavelength range (working frequencies 1.9, 2.8, 3.8 and 4.8 MHz). The main electrodynamics parameters of our model under these assumptions are dielectric susceptibility and tangent of losses in layers. For porous composition material dielectric constant can be calculated as $\varepsilon_{eff} = (1-p)\varepsilon + ps\varepsilon_{fil} + p(1-s)$ where ε and ε_{fil} are dielectric constant for skeleton and filled material respectively. The tangent of losses can be calculated an analogous way. Our task is to find the temporal distribution of reflected power. To do that we should find initially the reflection coefficient for plane wave from our layered structure. Then we represent a radar signal as a series of a plane waves, multiply each harmonic at corresponding reflection coefficient and attenuation and apply an inverse Fourier transformation to obtain a temporal profile of reflected signal. To find the reflection coefficient for plane wave from layered medium we should solve the complex first-order ordinary differential equation for impedance in plane wave [3, 4]. Then reflection coefficient R(ω) can be find as $R(\omega) = \dfrac{Z(\omega,0) - Z_{vac}}{Z(\omega,0) + Z_{vac}}$ where Z(ω,0) is impedance value at the surface and $Z_{vac}=1$ for the case of normal incident.

The results of simulations are presented at Fig.2. In our simulations we modeling MARSIS signal as a pulse with rectangular 530 mks width envelop and chirped carrier with bandwidth 1 MHz. As follows from Fig.2, an ice existence under surface leads to changing of reflected signal amplitude at a few percents which is, in principle, well above MARSIS sensitivity. But presence of water influence on reflection amplitude dramatically. This is due to very high losses of radiation in the brine (losses tangent 0.5 – 1 [5]). The level of amplitude decreasing depends on depth of water structures and can be used to estimate this depth. An averaged size of subsurface structures can be estimated from characteristic temporal scales in reflected signal.

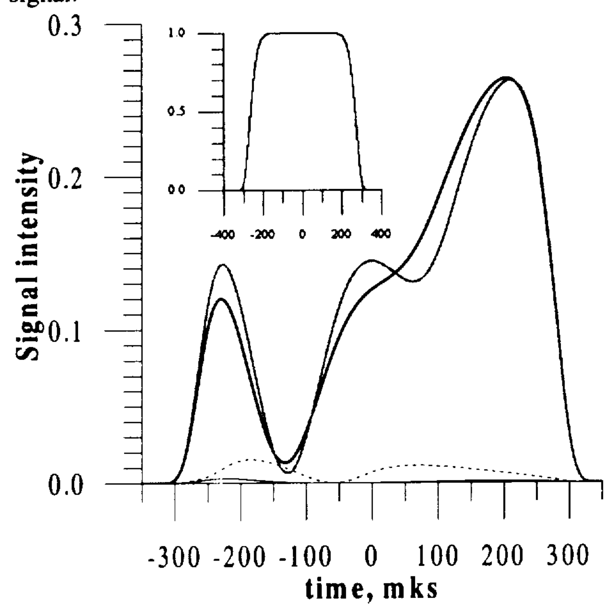

Fig.2 Reflected radar signal for carrier frequency 1.9 MHz (isert-incident signal, gray – no ice and water, bold black – ice, black – water at 110 m depth, dotted – water at 750 m depth)

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MARS OASIS DETECTOR. P. H. Smith[1], [1]LPL/U. Arizona, Tucson AZ 85721, psmith@lpl.arizona.edu.

Introduction: Fractured terrain, recent volcanic activity, and the promise of underground water reservoirs may combine in rare instances to produce water vapor vents. Vapor clouds near the surface can be detected using remote sensing techniques from orbit. I propose an instrument to search the entire surface of Mars for plumes at a resolution of 10 m. The optimum technique is to ratio the water band at 1.38 microns to the nearby continuum and search for localized patches with extra absorption against the local average atmosphere water abundance. Such an instrument would use several operational modes to measure the atmospheric water vapor abundance, to map water ice cloud distributions, to detect the presence of water ice and frost on the surface, to find evidence for vents, and to obtain high resolution images for geological confirmation.

Instrument Concept: The highest goal in the exploration of Mars is finding the location of water sources–springs, hydro-thermal vents, or seeps–that are active today. Although Mars is drier than any desert region on the Earth, there are significant reservoirs held in the polar caps and in the atmosphere. It is commonly believed in the science community that the largest reservoir of water is sequestered deep underground both as ice and below that a liquid hydrosphere. The locations of these aquifers are unknown, but if they are associated with remnant volcanic activity then we might well expect small cracks or vents where vapor is being released into the atmosphere. This source of vapor would likely be tiny on a global scale, yet vitally important as a habitable zone for micro-organisms. No instrument ever sent to Mars has had the ability to detect such features.

The Oasis Detector. Adding a water detector to a high resolution telescope is conceptually simple. A pickoff mirror next to the CCD arrays redirects light through a re-imaging system that scales the scene such that a pixel gives a ground resolution of 5 m. Two detectors filtered to receive the 1.38 micron water band and the nearby continuum, are optically overlapped using a beam splitter. The linear detector arrays are made of InGaAs that has a peak sensitivity near 1.55 microns. The arrays are held at a temperature of –20 °C where the thermal noise is acceptably low. The mass of the detector is estimated to be 1.5 Kg and requires about 8 W of power.

The detectors are read out every 1.7 msec and processed into ratios for storage into a large buffer. This buffer is periodically sampled to find moist areas compared to the surrounding relative humidity. If the averages are computed every 1 km, then a half orbit produces 3390• x 12 b = 125Kb/orbit x 12 orbits/day = 1.5 Mb/day x 687 days/Mars year = 1 Gb of data for a Mars year. In addition, when local wet spots are detected, each data dump will be about 0.5 Mb in size for a 1 sq km region; given 1 per orbit on average the total volume of this type of data is expected to be 4 Gb.

Science Goals and Operations: The Oasis Detector can be sent in conjunction with a high resolution imager or as part of a NIR thematic mapper. It's ability to trigger supporting data sets gives it the intelligence needed to search the entire planet with specific measurement goals. Otherwise, as with MOC, the global coverage is reduced to the 1-2 % level.

To begin the search for tiny water vapor vents, I propose to sweep the entire surface of Mars looking for signatures of vapor clouds on scales as fine as 10 m in diameter. The method that shows the greatest promise for detecting these vapors is the change in the band depth of the 1.38 micron water band when ratio-ed to the nearby continuum. Individual pixel ratios will set a flag when their value exceeds the local 1 x 1 km average by more than a threshold amount (typically 1-2 %). Setting the flag triggers a high resolution CCD image recording the local geology of the region enabling the moist area setting to be identified in the image. Finding frost or vent forms surrounding the water signature would support the conclusion of a vent.

Naturally, these features are subtle, we calculate that a cloud 100 m tall would increase the band depth by several percent (see Fig. 1). Yet with the high signal-to-noise ratio that we plan to achieve this should be adequate. False detections will force us to increase the threshold, and the lack of detections will cause us to decrease it until we find a compromise position with several detections per day. We call this the search mode. Even if we only find one defendable water feature after 2 years of orbiting Mars, the Oasis Detector will have been worth the effort.

It will also serve to test hypotheses, for instance, that the Malin and Edgett [1] gullies are currently active. When known features are being researched, all the data will be returned and the threshold will be deactivated. The edges of the polar caps, and volcanic regions where recent activity is suspected are attractive targets.

Finally, the regional averages against which the vents are compared will always be returned. These data will provide global maps of the water vapor abundance throughout all seasons with a resolution of 5 km on the surface. The data needed for such maps are a tiny amount of the total data volume expected from the imaging. We can expect to see the influence of ice clouds in these maps also since ice and vapor signatures are similar.

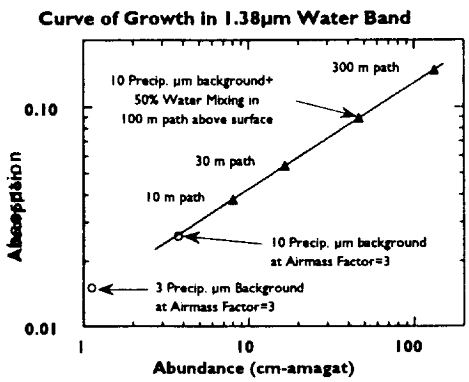

Figure 1. Absorption in 1.38 μm water band at the spectral resolution of the Oasis Detector versus water abundance. The abundance of the background atmosphere is shown, as is the total absorption for the background plus a column of 10 m to 300 m height at an airmass factor of 1 in which the water is mixed at 50% with the CO2 atmosphere. Absorptions of 10% are seen for columns 100 m high compared to 1.5% to 2.5% in case of background atmosphere having 3 to 10 precip. μm water.

Mission Opportunities: The ideal mission for the search for vents is the Mars Reconnaissance Orbiter to be flown in 2005. Either in conjunction with the high resolution telescope or the VNIR mapping spectrometer, the Oasis Detector would find all the local enhancements of water vapor. Locating these sites early before the sample return mission gives flexibility in the choice of sample collection sites with high probability of exobiological significance.

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LOCALISATION AND CHARACTERISATION OF SUBSURFACE ICE AND WATER DEPOSITS BY MEANS OF MUTUAL IMPEDANCE (MI) INSTRUMENTS

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Mutual Impedance Probes measure the complex permittivity of materials by means of a quadrupolar array of electrodes and associated electronics for generating, recording and processing waveforms. The measurement principle has been implemented successfully in both commercial and space applications (Huygens Probe, Rosetta Lander). Depending on the mobility of the instrument platform, MI probes can be used for surface / subsurface mapping and / or investigating temporal variations of material properties. The instrument characteristics depend very much on the geometry of the quadrupolar array.

The capability and limitation of a MI instrument such as accuracy, dynamic range, sensitivity and penetration depth are described. Recent MI probe developments for planetary missions and expected performance are presented.

Particular attention is given to the detection of subsurface water and ice and methods for the characterisation of deposits are suggested. The importance of MI measurements as part of an integrated strategy for the detection of subsurface ice and water is explained.

The results of previous field tests using MI probes are presented and discussed. Possible instrument configurations for future missions are suggested for both stationary and mobile platforms. Instrument mass and power requirements are estimated and possibilities for embedding MI probe functions into other instruments are discussed.

Finally, ongoing MI probe test and development activities at ESA/ESTEC are presented.