ON THE DETERMINATION OF LOCAL SITES FOR SHALLOW GROUND WATER PROSPECTION USING LOW FREQUENCY SOUNDING RADARS ON MARS. E. Heggy[1], P. Paillou[1], F. Costard[2], N. Mangold[2], S. Clifford[3], J. J. Berthelier[4], [1]Bordeaux Observatory, Floirac, France, (heggy@obs.u-bordeaux1.fr), [2]Université Paris-Sud, Orsay, France; [3]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX, ; [4]Centre d'Etudes Terrestres et Planetaires, St Maur, France.

Low frequency sounding radars should be able to probe the Martian subsurface layers down to varying depths, depending on the geo-electrical properties of the sounded sites. We present in this work four frequency dependent geo-electrical models of the Martian subsurface in the 1-20 MHz frequency band, based on laboratory electromagnetic characterization of Martian soil analogues. Those models correspond to local Martian sites, where we considered particular interest for the search of water using mainly the Ground Penetrating Radar (GPR) instrument of the Netlander mission. Results and discussion are also valid for both sounding experiments MARSIS and SHARAD. The four models of the Martian subsurface are designed to represent terrains where recent fluvial like features suggest the presence of near subsurface ground ice and probably liquid water. We performed measurements on volcanic and sedimentary materials that may be present on these sites under the appropriate geophysical conditions that may exist in those terrains. We then simulated the backscattered radar echo arising from each site in the 2 MHz frequency band, using the Finite Difference Time Domain (FDTD) algorithm, in order to evaluate the instrument performances to probe the subsurface stratigraphy of each site. Our results confirm that the near subsurface rich iron oxide mineralogy controls the instrument performances in terms of penetration depth and signal to noise ratio in the 2 MHz frequency band. We also discuss the geophysical and geo-electrical sounding conditions that could lead to an ambiguous detection of shallow subsurface water on Mars for the Netlander GPR. Finally we hope to present by the conference time a terrestrial test analogue site selected according to those creteria where deep sub-surface water have been detected 600 m deep using a prototype of the 2 MHz Netlander GPR in a field survey performed last febrary in the eastern part of the Egyptian desert.

Introduction: Models of the thermal structure of the Martian crust suggest that the thickness of frozen ground (the depth at which the local temperature rises above the ice fusion point) range from ~2.5-5.0 km at the equator to ~6-12 km at the poles [1,2]. Recently high resolution images from the Mars Orbital Camera (MOC) onboard the Mars Global Surveyor (MGS) orbiter reveal the possible presence of water layers in the near subsurface of Mars, at a depth of few hundreds meters. Water could flow out from an underground ice rich saturated layer covered locally by volcanic altered materials [3].

Efficient sounding methods are required in order to detect the water present in the Martian subsurface a hundred meters or a few kilometers deep. One of the best suited is based on sounding radars. Water, even if still present on Mars at shallow depth (less then 300 m), will be difficult to detect using drilling and seismographs. Radar sounding methods, either from orbit or from surface based systems, represent the adequate geophysical tool to inform us about subsurface water abundance and distribution, a parameter of primary importance to understand the history of the planet [4,5].

Three radar instruments are planned in the current decade to probe the Martian subsurface and detect the presence and distribution of subsurface water layers. The performances of all of these radar systems are strongly dependent on the petrology and mineralogy of the Martian subsurface [6,7], which define the electrical behavior of each geological layer of the sounded sites. Most of the Martian surface presents a volcanic context and is covered by an iron oxide-rich dust layer, more probably constituted of altered basalts [8], hematite [9], maghemite and other ferromagnetic minerals [10]. This dust material is overlaying volcanic layers of fractured basalt and lava flows, with a geographically and stratigraphically variable component of massive and interstitial ice [1,2]. Deeper subsurface material could be mainly constituted of fractured ground ice. If we assume this configuration to be representative of the Martian subsurface, then materials present in the first few hundred of meters of the subsurface could significantly attenuate the probing radar signal, due to electric and magnetic losses, thus limiting the penetration depth to few hundreds of meters at the 2 MHz frequency [7].

Radar sounders should then operate at specific sites where the geo-electrical context is locally less conductive and where local geothermal conditions could lead to the presence of liquid water at shallow depths [2]. In this paper, we present the geo-electrical modeling of such favorable sites in order to define future potential landing sites for the GPR experiment of the Netlander mission, and derive some criteria for optimal sounding sites for future radar experiments. Numerical simulations of the radar echo for the selected sites are presented and discussed.

Geological models : Four geological models of Martian subsurface are proposed in order to highlight the effect of several components such as liquid water, magnetic minerals and sedimentary deposits. The presence of fine grained or coarse deposits of different petrology (especially with varying porosity and permeability) may substantially affect the ice content in the subsurface and hence the radar signatures. These models correspond to possible local stratigraphy on Mars but large uncertainties exist about the composition and nature of the subsurface material. Examples are given to illustrate each proposed model refers to locations on Mars where the subsurface could correspond to the model, but detailed thickness and composition of the layers are speculative. These models do not take into account the regional variability of the selected geological unit. The possibility of finding shallow aquifers in the Martian near-surface is low due to cold temperatures, and liquid water should not be present at less than 1 km according to realistic thermal gradients [1]. Nevertheless, we detail three examples where local residuals of subsurface water could be found at shallow depth. These locations would correspond to regions of high geothermal flow, outflow channels, or ice-rich northern plains. The last case does not consider liquid water but sediments formed by desiccation of an ancient lake.

Electromagnetic characterization and geo-electrical modeling: Once the geological models are set and well defined, we investigated representative laboratory samples, in terms of mineralogy and porosity, for each layer of the above-discussed models. In our analogy, the electromagnetic properties of each layer of a geological profile are reduced to the electromagnetic characterization of the representative laboratory sample. Samples are compositionally homogeneous, with different porosities, temperatures and a varying amounts of iron oxide-rich minerals (hematite, maghemite, magnetite) for samples representing volcanic layers. It must be kept in mind that this is a simple approach that does not reproduce the heterogeneous composition of rocks and their complex porosity. However, as we are mainly interested in the permittivity of the samples to build geo-electrical models to evaluate losses in wave propagation, homogenous mixtures of minerals and ice are relevant. For the permittivity measurements, we used two capacitive cells. The first one characterizes powder materials (porosity ranging from 30 to 50 %) and the second one measure pellets of compacted powder (porosity ranging from 15 to 30 %) or machined from a rock sample. For the permeability measurements, we used a self-magnetic cell. Each layer analog is described in terms of the real and imaginary part of its dielectric constant, its conductivity in S/m and its relative magnetic permeability μ (in this work we only considered the real part of the magnetic permeability, as mineral mixtures used to simulate the subsurface layers in the four models are not highly magnetic). It is important to note that the choice of analog materials to construct our samples is a first order approximation to illustrate the variation in the sounding radar performances in various possible Martian geo-electrical configurations.

Results and discussions: We have investigated in this work four models of the Martian subsurface that describe example of sites presenting potential interest in the application of low frequency sounding radars to the search for water on Mars. We used laboratory measurements on sample analog and numerical FDTD simulations of the radar pulse propagation, to derive what might be an appropriate site to detect the possible presence of shallow water saturated layer using landed and orbital sounding radars. We suggest that regions such as the Hadriarca Patera volcano could present a potential type of terrain for future radar sounding of shallow aquifers. Sites representing possible subsurface hydrothermalism combined with a rather low attenuation factor of overlaying volcanic layers constitute a favorable site for sounding radar techniques. A reasonable penetration depth of hundreds meters at 2 MHz could allow the detection of liquid water at specific sites. Our simulations also showed that several geological interfaces in the Martian subsurface can present important dielectric contrasts due to different concentrations in iron-rich minerals and to variations in porosity and could give a similar radar response to the one expected from an ice / water interface at shallow depths. It is important to note that even using simple models, the radar echo simulation shows complex behaviors that could be interpreted since we know where geological interfaces are located. Working with future real data from the Netlander GPR instrument or similar sounder will imply a "blind" inversion process that will certainly be more complicated. It will in particular be very difficult to interpret the presence of any interface appearing on the radar echo without a preliminary study of the geological context for each site. We expect ambiguities to increase with increasing the depth of investigation.

The reader must keep in mind that there is no unique description of the Martian geo-electrical properties, thus any sounding radar whether orbital or ground located can't have a unique evaluation of performances, results will be strongly depending on the investigation site.

The validity of the geological models presented and hence geo-electrical modeling and simulations is mainly related to our present day knowledge of the Martian upper crust mineralogy and stratigraphy. We expect data from the Gamma Ray Spectrometer (GRS) and the Thermal Emission Imaging System (THEMIS) onboard the Mars Odyssey mission and future chemical and mineralogical analysis of the Martian soil to be performed by the 2003 Mars Exploration Rovers (MER) to provide the missing information concerning the chemical and mineralogical composition of the Martian surface. We should then be able to improve the modeling of a more realistic case of the Martian subsurface. Such work is crucial for preparing the interpretation of data that will be produced by the future radar instruments.

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