GEOPHYSICAL METHODS TO SUPPORT MARS EXPLORATION CHALLENGES. R. E. Grimm[1] and D.E. Stillman[1], Department of Space Studies, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (grimm@boulder.swri.edu).

Introduction. Drilling on Earth, especially for resources, is commonly preceded by geophysical surveys, either for direct targeting or to reduce risk by screening out nonprospective areas. Geophysics can similarly assess the subsurface of Mars to depths of several meters or more for its resource, geotechnical, electrical, and perhaps even biological properties. The optimum methods for the top several meters of Mars are dielectric spectroscopy (DS) and ground-penetrating radar (GPR). In particular, H_2O abundance and phase (liquid, adsorbed, ice, or in hydrous minerals) in the subsurface can be uniquely determined when DS is combined with a neutron spectrometer. DS signatures of microbial metabolism have been measured in the lab and in the field. The dielectric constant, determined from DS or GPR, is a good proxy for density in dry materials. DS also yields ground electrical conductivity that is important to understanding dust and atmospheric electrification and will record ambient electromagnetic radiation, including lightning. GPR is not as sensitive to material properties as DS but it is much higher resolution, and thus provides details of subsurface structure and stratigraphy for geological context and hazard avoidance.

Investigations and Measurements. MEPAG [1] Goal IV (Mars Human Precursors) and the new Strategic Knowledge Gaps ([2], SKGs) call for measurement of H_2O abundance and physical properties in the top 3 m of the martian subsurface (MEPAG-2A, SKG-B5) as well as assessment of electrification (MEPAG-2C, 2D, SKG B4) and biological (MEPAG-1, SKG B2) hazards. While an orbital UHF radar can image the planet at <100 m resolution, sensing to several m depth [3], recovery of subsurface properties is highly model-dependent. A sounding mode, akin to MARSIS and SHARAD, results in poor cross-track resolution. Instead, rover- or lander-based geophysics can provide cross-sections of the shallow subsurface that support exploration challenges in situ (Fig. 1).

An NRC monograph [4] gives a good nontechnical overview of surface methods for noninvasive characterization of the shallow subsurface. For this application, we rule out potential-field methods (gravity and magnetics) in favor of surveys that are formally unique and have higher resolution and material sensitivity. Seismology is resource-intensive (vibratory or impulsive source, receiver array) compared to GPR, although it does yield elastic constants that are important for engineering. Electromagnetic (EM) methods (passive magnetotellurics, active time-domain, NMR) span a range of resource requirements but are better suited to "deep" exploration of hundreds of meters to tens of km, especially for groundwater [5-7]. Resistivity/Induced Polarization also requires a sensor array but has very good material when implemented in the frequency domain (dielectric spectroscopy). Nuclear methods are commonly used in geophysics; here neutron spectrometry is most relevant because of is ability to detect subsurface hydrogen.

Dielectric Spectroscopy (DS). The principle of DS is very simple: a sinusoidal current I is injected into the ground between two electrodes and voltage V is measured between two other electrodes. The amplitude and phase of V/I yields the electrical storage (permittivity or dielectric constant ε) and loss (conductivity σ). A spectrum is formed by sweeping across many frequencies, typically 1 mHz to 1 MHz. By moving the electrodes, or by using an array of many electrodes that can be variably used for I or V, a cross-section of the frequency-dependent electrical properties can be derived. The Huygens Permittivity probe [8], Phoenix TECP [9], and Philae MUPUS [10] are all fixed-geometry conductivity/dielectric sensors whose investigation depth is cm to tens of cm. Larger electrode separations with variable geometry will enable full cross-sectional imaging, and broadband measurements allow robust spectral deconvolution.

DS is very sensitive to H_2O and can discriminate liquid, adsorbed, and solid states [11]. Several groups have considered DS for detection of H_2O on Mars [12-16]; a companion abstract reviews our latest results and approach [17]. Here we note that DS in combination with a neutron spectrometer (NS) can uniquely measure the abundance and state of H_2O in all its forms. NS measures the total H content but is insensitive to its phase. DS discriminates all phases except hydrated minerals. Therefore NS gives the residual H_2O in hydrated minerals and gives a check on the total H_2O content.

The different states of H_2O cause intrinsic or interfacial polarizations that increase the dielectric constant ε with decreasing frequency. Above ~1 MHz, frequency dependence in the dielectric constant is usually weak (nearly constant Q) and in dry materials is related to density ρ as $\varepsilon = 1.9^{\rho}$ [18]. MEPAG calls for the measurement of ground conductivity to a minimum of 10^{-13} S/m. We routinely measure to ~10^{-12} in the laboratory using a minimum frequency of 1 mHz; sensitivity to lower conductivity requires longer integration times, which may be further exacerbated by field conditions.

The electrode array will also record ambient EM energy: impulsive, high-amplitude events such as lightning will be a source of noise to the DS, but they can be removed during processing and will provide data satisfying other objectives.

Finally, cell metabolism involves transfer of electrical charges and these charges can be probed with electric fields. DS was suggested as an in situ life-detection tool using a soil sample [19]. In the last decade or so, researchers recognized that microbial interactions with the geologic environment also produce electrical signatures, giving birth to the new field of biogeophysics [reviewed by 20]. Contemporary biogeophysics focuses on developing monitoring methods for environmental bioremediation and understanding microbe-mediated mineralization. This builds on prior work for geoelectrical detection of trace quantities of organic contaminants [e.g., 21]. The novel aspect of these studies is the ability to image these processes in the subsurface. Our calculations suggest microbial densities as small as 10^5 cells/cm^3 may be detected beneath an irradiated and oxidized sterile layer. This is facilitated by the simpler discrimination of dielectric signatures in cold regions [11]. Even if unique electrical biosignatures cannot be established, DS may be able to screen out sterile regions or areas below some minimum bioload.

Ground-Penetrating Radar (GPR). The value and efficiency of GPR in mapping subsurface structure and stratigraphy has been well elucidated in the literature [e.g., 22, 23]. Two groups proposed GPRs for MSL and GPR was selected for ExoMars [24]. Here we note that GPR can also identify minerals with dielectric or magnetic dispersion such as hematite and magnetite [25]. When such minerals are present, their temperature dependence can be used to track thermal waves in the ground. By illuminating subsurface targets from different positions, rover-based GPR can uniquely determine target depth and intervening dielectric constant, unlike orbital measurements.

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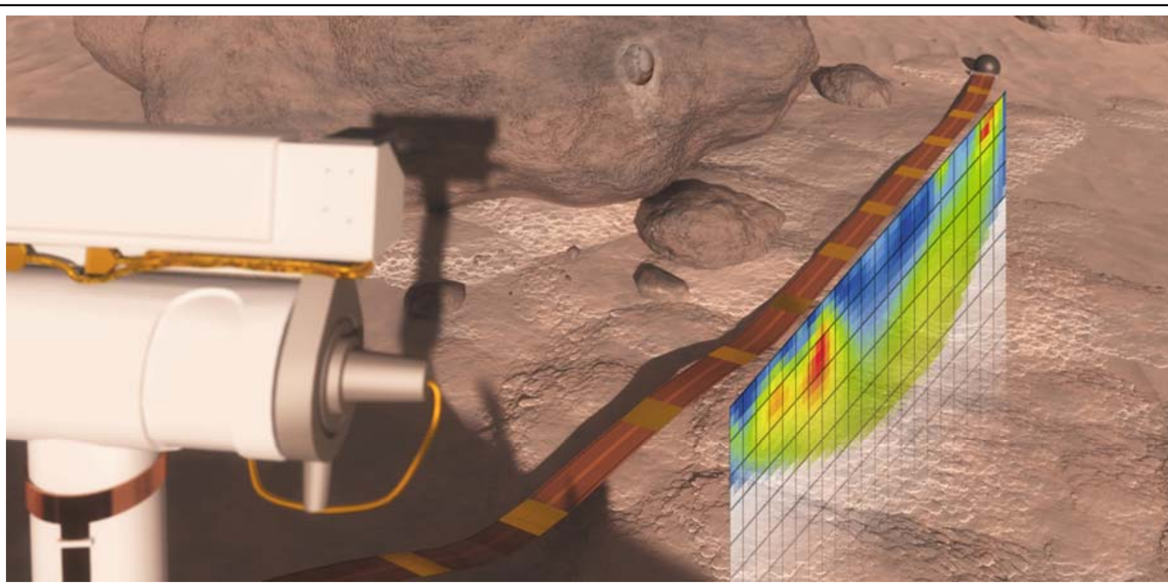

Figure 1. Artist's concept (D. Durda, SwRI) of dielectric spectroscopy on Mars. The electrode array must be at or near ground surface. Here electrodes are metal surfaces on a weighted ribbon cable. Investigation depth is proportional to the maximum electrode separation and resolution is comparable to the electrode spacing. The electrode array illustrated here could probe to a few meters depth. Electrodes incorporated into lander footpads or rover wheels would sense to tens of cm depth.