

DETECTING WATER/ICE IN PLANETARY REGOLITHS USING ELECTRICAL IMPEDANCE**SPECTROSCOPY** S. Seshadri¹, R.C. Anderson,¹ M. Schaap², V. Baker², J. Dohm², M. Tuller², K.B. Chin¹ and M. Buehler³, ¹Jet Propulsion Laboratory, California Institute of Technology, MS 315, 4800 Oak Grove Drive, Pasadena, CA 91109; ²University of Arizona, Tuscon, AZ; ³Decagon Devices Inc., 2365 NE Hopkins Court, Pullman, WA 99163.

Introduction: The search for water is a central goal of planetary science. Recent missions to Mars have confirmed the existence of water¹ and related fluvial processes² that imply the existence of an Earth-like hydrological cycle in the geologic past.³ Present-day Mars still cycles appreciable amounts of water, and groundwater processes similar to Earth may exist beneath its subsurface cryosphere.⁴ The Galilean satellites of Jupiter are water abundant, the most intriguing of which, Europa, may possess a vast ocean beneath its icy crust.⁵ Mercury and the Moon may have ice at their poles, most likely accumulated from cometary impacts.⁶ Water has also been detected emanating from Saturn's moon, Enceladus. While several outer planet missions are under consideration, Presently, Mars offers the most near-term option for further detailed study.

Terrestrial studies have demonstrated a close relationship between the depositional environment and the physical and chemical properties of soils.^{7,8} This evidence suggests that paleoclimate and environmental information can be extracted at a planetary landing site from soil analyses and characterization, including whether water played a significant role as a weathering agent. Implications of geomorphological and experimental evidence from the MER rover, Mars Odyssey, MRO and ESA Orbiter, suggesting that water may be globally present in the near-subsurface of portions of Mars, raises a number of important follow-on questions about the state and distribution of water in the upper regolith.

A first question relates to the spatio-temporal variability in the abundance and phase of water. Mars Odyssey Neutron spectrometer data are interpreted to provide evidence of heterogeneous near-surface with water abundances up to ~10 wt% in the near-equatorial regions on Mars.⁹ Reported amounts are too large to be purely from vapor transport from a deep sub-surface reservoir to the atmosphere, implying the presence of at least a water-bearing solid phase and, possibly liquid/water ice in the regolith.¹⁰ The fact that water ice is also thermodynamically unstable in these regions suggests that some of this

water may be present in hydrous silicates (smectites or zeolites) or hydrated salts.¹¹ However, while the potential suite of phyllosilicates and salt minerals is large, and while existing data demonstrate that several of these minerals are reasonable hosts for water molecules under present Martian surface conditions, the variety of possible intermediate hydration states makes measured hydrogen concentrations too high without implying the existence of hydrated minerals and even the existence of liquid water and/or water ice closer to the poles. *In-situ* measurements of the phase and abundance of water are needed to help resolve ambiguities in the spatio-temporal variability of the relative abundances of these phases of water and to clarify implications of these observations for the hydrologic and geologic history of Mars.

A second question relates to the vertical distribution between the mineral and water phases, and their relative composition in the regolith. Results from both MER rovers show no indication of liquid water (volatiles) in the top 15 cm though rover wheels expose salt deposits just under the surface.¹² In addition, sulfate beds detected by Opportunity are considered to be the result of ancient aqueous-related cross bedding.¹³ GRS data shows elevated hydrogen in the near sub-surface. *In-situ* measurement of the depth profile of the water/ice distribution at these locations would constrain the GRS-based signature of hydrogen, which is ultimately an estimate of wt % equivalent water content for materials at ~1/3 m depth.

A third question relates to water transport: The low water contents around equatorial regions relative to the poles can be explained as being due to an enhanced (vapor-phase) loss to the atmosphere. The increasing vapor pressure for ice and liquid water with temperature would, therefore, lead to more loss of water at the equator than at the poles. However, Mischna et. al. modeled the water cycle using a global circulation model and found that water ice migrates to the tropics during periods of high obliquity (> 40°).¹⁴ Measurement of flow direction, verti-

cally, will tell us whether this latitude variation is the result of fossil deposits of H₂O that are in equilibrium with the current climate conditions.

Measurement Methodology: The search for water is intimately tied to detection principles and methodology. Water can be found as (1) ground water in saturated aquifers or atop semi-permeable layers, (2) capillary water held by interfacial tension in soil pores, (3) thin films on mineral surfaces, (4) structural water in hydrated minerals or (5) ice. Soil textural differences will affect the retention and transport properties of both vapor and liquid phases of water in real soils. Few instrument methodologies directly interrogate the interaction between the water molecule and its environment. Electromagnetic (EM) techniques to detect water are widely used in terrestrial applications. These techniques rely on the induced polarization of a material due to the application of an electric field. Different polarization mechanisms give rise to relaxations (energy loss) at characteristic frequencies, above which these mechanisms do not respond. Electrical Impedance Spectroscopy (EIS) operates in a frequency range ($\sim 10 - 10^6$ Hz) in which induction and dissipation processes due to orientational polarization of permanent dipoles of polar molecules are dominant. This process is intrinsically sensitive to its environment, identifiable in the frequency dispersion characteristics of the impedance of the sampled regolith volume.¹⁵ Thus, EIS has the potential to detect and quantify water in a condensed state.

We will describe the design, operating principles and advantages of a simple (low power and mass), *in-situ* instrument that uses EIS to identify and measure the spatio-temporal variability the phase, abundance and salinity of water in undisturbed planetary regoliths at local scales.¹⁶ We will also show data on the detection sensitivity limits of the instrument, obtained from laboratory tests on a variety of soil/water mixtures and electrolyte type and content under Mars-like temperatures. The emphasis is on measurement of water that is not structurally bound to minerals because of the absence of instruments to measure the properties of regoliths bearing water in these states. Our measurements are non-destructive, so samples are available for subsequent analysis with instruments using complementary techniques. Results of our soil test matrix would be beneficial to the wider community of EM instrument designers to refine their analysis methodologies.

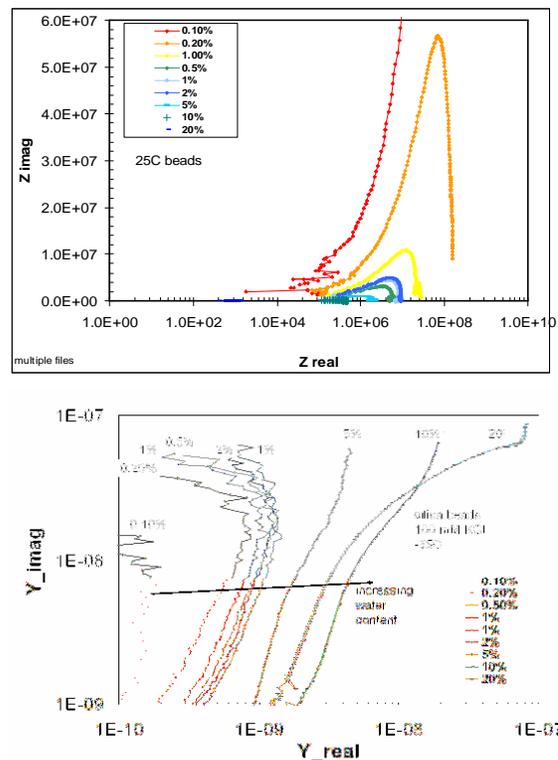


Figure 1: EIS sensitivity, visualized here in the complex impedance and admittance planes for liquid water and ice, respectively, for a sample of silica beads containing varying amounts of water at > 0.10 wt%.

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