ELECTROMAGNETIC INVESTIGATIONS OF A DEEP WATER TABLE IN THE WEST EGYPTIAN DESERT: LITHOLOGIC AND GEOTHERMAL VAPOR EFFECTS ON CRUSTAL RESISTIVITY AND GPR PERFORMANCE, WITH POTENTIAL IMPLICATIONS FOR MARS.

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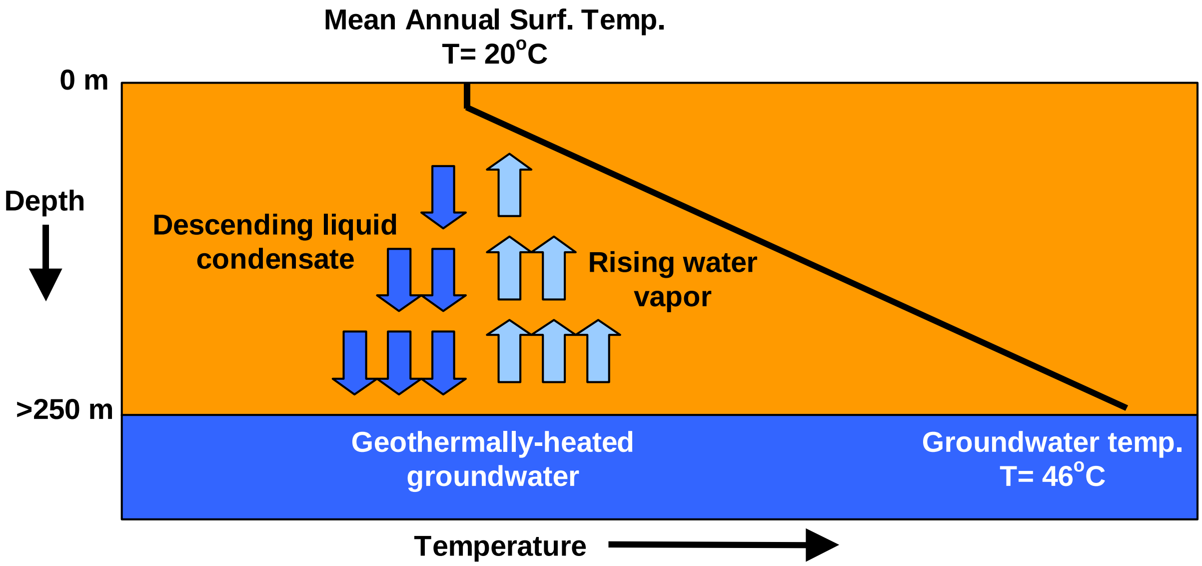
Introduction: One of the primary objectives of current Mars orbital radar sounding investigations is the potential detection of subpermafrost groundwater, at depths of a km or more beneath the surface. On Earth, the opportunity to investigate deep aquifers with low-frequency ground-penetrating radar (GPR) is often limited by the high moisture content of the overlying rock and soil, a consequence of the long-term infiltration of rainfall and other surface water. However, the Frafrah Plateau, in the West Egyption Desert, is a location which possesses both a moderately deep water table (several hundred meters) and has experienced no appreciable precipitation for the past several thousand years. For this reason, the plateau was considered a good hyper-arid Mars analog environment for assessing the subsurface investigative potential of a variety of electromagnetic techniques, including both commercial and spacecraft prototype GPR (covering a combined frequency range of ~2 – 500 MHz)

However, subsequent measurements of the resistivity of the plateau revealed it to be highly conductive, which impaired the sounding performance of the GPRs. The two most plausible casues for the high conductivities we observed were: (1) the presence of clay and shale in the local stratigraphy and (2) a higher than expected subsurface moisture content arising from the condensation of geothermally-driven water vapor from the underlying Nubian aquifer. Our present efforts are focussed on quantifying the relative contributions of these two causes and understanding how GPR performance is impacted by low-resistivity conditions as function of its design characteristics (i.e., central frequency, power, dynamic range, etc.). The results of these studies are expected to provide further insights into the extent to which conditions within the vadose zone and the operational characteristics of spacecraft radars are likely to influence the potential detectability of deep subpermafrost groundwater tables on Mars.

Background: In November 2005, research teams from the Lunar and Planetary Institute (LPI), Southwest Research Institute (SwRI), and Centre d'étude des Environnements Terrestre et Planétaires (CETP), conducted electromagnetic sounding investigations on the Frafrah Plateau in the West Egyptian Desert, located approximately 600 km southwest of Cairo and ~18 km northwest of the Frafrah Oasis [1-3]. The plateau's principal stratigraphic units consist of layers of limestone, shale, limestone, and chalk, with the local water table of the Nubian Aquifer lying ~240 m beneath the surface. Electromagnetic sounding data was acquired at four sites, spaced along a 5-km long profile on the plateau. These investigations included: transient electro-magnetic (TEM) and Schlumberger DC resistivity vertical electrical sounding (VES), GPR (using multiple instruments and techniques, at central frequencies ranging from 2 – 500 MHz),. and the collection of field samples from cliff exposures for later laboratory characterization of the principal stratigraphic units..

From a deep-sounding perspective, the most interesting GPR results were obtained by the TAPIR instrument, fielded by the CETP team. TAPIR is a bistatic refinement of the radar developed for the cancelled 2007 NetLander mission [3]. It is a stationary imaging low-frequency GPR that operates from 2 to 4 MHz. Laboratory measurements of the dielectric constants of the field samples (obtained from strata exposed on the scarps of the plateau) ranged from ~6.5-9.5 (but with some loss tangents as great as 1.4). Given these measurements, the 45- and 100-m separation of the TAPIR transmitting and receiving antennas, the long time delays of some of the later signals imply reflections from depths of up to several hundred meters, or multiples associated with shallower interfaces.

However, the analysis of the VES and TEM data revealed a significant decline in crustal resistivity as a function of depth, falling below 9 ohm-m at a depth of 60 m. These low resistivities appear inconsistent with the maximum penetration depths inferred from the TAPIR sounding data. However, the TAPIR data was acquired with up to 2^{26} coherent integrations to improve signal-to-noise. It also has the ability to determine both the depth and inclination of a subsurface reflector by computing the direction of the propagation vector from the 2 (measured) horizontal electrical components and the 3 magnetic components of the reflected wave [3]. Initial analysis of this data appears to rule out either multiple reflections between shallower strata or surface clutter as the origin of the longer time-delay returns. This data, combined with the laboratory characterization of collected field samples and FDTD modeling, is helping to constrain the location, orientation, and nature of the sources.



An important additional dimension to this investigation is understanding the origin of the low resistivities detected at shallow depth within the plateau. To address this problem, we are currently conducting laboratory and theoreticl analyses to better understand the hydrologic, thermal, and conductive environment beneath the Frafrah Plateau – with a special emphasis on its implications for the sounding performance of low-frequency GPR.

This analysis suggests that the high geothermal heat flow of the region (as measured *in situ* in local oil wells and supported by the presence of thermal springs in the nearby Frafrah Oasis, [4]) has resulted in the formation of a low-temperature hydrothermal circulation system of ascending water vapor and descending liquid condensate (Figure 1). As the heated vapor rises from the water table and encounters the cooler temperatures at shallower depth, part of the ascending vapor condenses, ultimately draining back to the aquifer below – creating a dynamic balance of opposing fluxes and maintaining a steady-state moisture profile. If the water retained in the pores is sufficient to provide thin film continuity, the conductivity of the host rock may be significantly increased, thus potentially explaining the low values of electrical resistivity observed in the plateau.

To test this hypothesis, measurements of the composition, porosity, pore-size distribution, hydraulic and thermal conductivities, and permitivity as a function of frequency and water content, are being made for each of the stratigraphic samples obtained from the field. This data is being incorporated into a unified simulation of geothermal vapor transport, condensation, moisture retention, and saturated/unsaturated flow, within layered porous media [5-9] The electrical resistivities and radar attenuation characteristics associated with the resulting prediction of equilibrium water distribution will then be compared to the actual field data, to assess the relative contributions of lithology and moisture content to the observed properties of the plateau.

It has been proposed that similar hydothermal processes may occur in the vadose zone above a subpermafrost aquifer on Mars [5,6], where a geothermal gradient of as little as 15 K km^{-1} appears sufficient to drive a vertical vapor flux (per unit area) of ~10^{-4} m H_2O yr^{-1} from the water table to the base of the cryosphere (or the equivalent of 1 km of liquid water every 10^6-10^7 years). If so, the resulting increase in moisture content, above the aquifer, may significantly impact both the maximum depth achieved by a sounding radar and its ability to detect the dielectric contrast associated with the presence of the water table.

It is expected that the analysis of the Frafrah field data and samples will provide insights into the potential challenges that low-temperature hydrothermal processes may pose for current and future deep-sounding radar investigations of Mars. A more comprehensive analysis of these results is currently in preparation.

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References: [1] Clifford, S. M., E. Heggy, M. Ali, V. Ciarletti, C. Corbel, C. L. Dinwiddie, F. Dolon, A. Le Gall, R. E. Grimm, R. N. McGinnis, R. Ney, and S. K. Sandberg, 37th LPSC, abstract no.2442, 2006.; [2] Dinwiddie, C. L., S. K. Sandberg, R. N. McGinnis, and R. E. Grimm, 37th LPSC, abstract no.2335, 2006; [3] V.Ciarletti, A. Le Gall, J.J. Berthelier, C. Corbel, F. Dolon, R. Ney (2006) 37th LPSC, abstract no.2238, 2006 ; [4] Osman, S. S. (2004);Geologic applications of heat flow measurements, National Research Institute of Astronomy and Geophysics. 37 pp. [5] Clifford, S. M. (1991) Geophys. Res. Lett., 18, 2055-2058; [6] Clifford, S. M. (1993), J. Geophys. Res., 98, 10973-11016. [7] Schorghofer, N., Aharonson, O., JGR, Vol 110, E05003, 2005; [8] Celia, Michael A., Bouloutas, Efthimios T, Zarba, rebecca L., Water Resources Research, Volume 26, Issue 7, p. 1483-1496 ; [9] Lima-Vivancos, V., Voller, Vaughan R., Vadose Zone Journal 3:1031-1037 (2004).