COMPARING TRANSIENT ELECTROMAGNETICS AND LOW FREQUENCY GROUND PENETRATING RADAR FOR SOUNDING OF SUBSURFACE WATER IN MARS ANALOG ENVIRONMENTS. J. A. Jernsletten[1] and E. Heggy[2], [1]1917 Florida Dr., Seabrook, TX 77586, joern@jernsletten.name, [2]Lunar and Planetary Institute, Houston, Texas, heggy@lpi.usra.edu.

Introduction: The purpose of this study is to compare the use of (diffusive) Transient Electromagnetics (TEM) for sounding of subsurface water in conductive Mars analog environments to the use of (propagative) Ground-Penetrating Radar (GPR) for the same purpose. To provide a baseline for such studies, and to show how these methods differ and complement each other, we show data from three field studies: 1) Radar sounding data (GPR) from the Nubian aquifer, Baharia Oasis, Egypt; 2) Diffusive sounding data (TEM) from Pima County, Arizona; and 3) Shallower sounding data using the Fast-Turnoff TEM method [11] from Peña de Hierro in the Rio Tinto area, Spain. The latter is data from work conducted under the auspices of the Mars Analog Research and Technology Experiment (MARTE) [1-6].

The GPR and TEM methods are discussed and compared in terms of their strengths and weaknesses in the following areas; resolution, sensitivity to highly conductive layers (clay, ore bodies, brines, metal-rich fluids, etc.), depth of investigation, sounding frequencies, logistical efficiency, and appropriate applications.

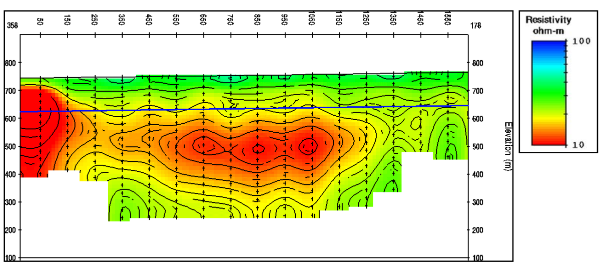

Figure 1. Line 2 TEM Data from Arizona Survey.

Potential of TEM: The TEM method has been used extensively for mapping of groundwater [7-8], and of metal-bearing acid solutions in leaching operations. Fig. 1 shows data from a TEM survey that was carried out in Pima County, Arizona, in January 2003. Data was collected using 100 m Tx loops and a ferrite-cored magnetic coil Rx antenna, and processed using commercial software [8-9]. The sounding frequency used in this survey was 16 Hz, a frequency sensitive to slightly salty groundwater [8, 10].

Prominent features in Fig. 1 are the ~500 m depth of investigation and the ~120 m depth to the water table (horiz. blue line). Note also the conductive (~20-40 Ωm) clay-rich soil above the water table. The blue line marks the ~120 m depth to the water table found in several USGS test wells in the area.

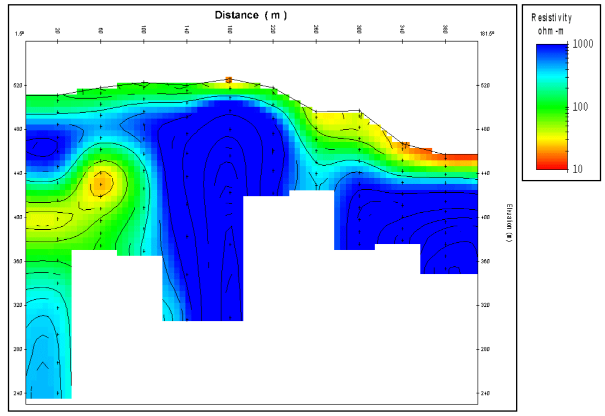

Figure 2. Line 4 Fast-Turnoff Data, Rio Tinto.

Fig. 2 shows data from Line 4 (of 16) from the Rio Tinto Fast-Turnoff TEM survey, collected using 40 m Tx loops and 10 m Rx loops, with a 32 Hz sounding frequency [1, 11]. Note the ~200 m depth of investigation and the conductive high at ~80 m depth below Station 20. This is the local water table, with the same 431 m MSL elevation as the nearby pit lake. The center of the "pileup" below Station 60 is spatially coincident with the vertical fault plane located here.

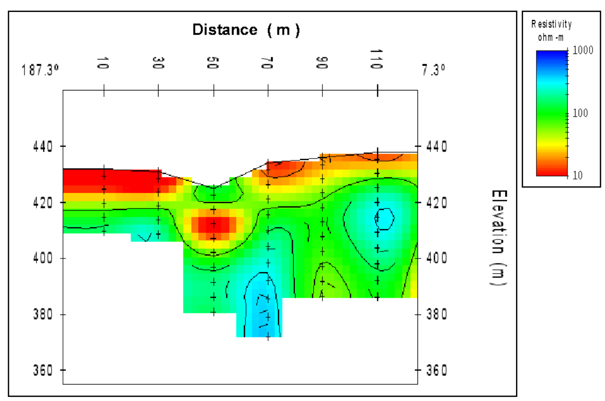

Figure 3. Line 15 Fast-Turnoff Data, Rio Tinto.

Fig. 3 shows Fast-Turnoff TEM data from Line 15 of the Rio Tinto survey, collected using 20 m Tx loops and 10 m Rx loops, again with a 32 Hz sounding frequency [1, 11]. Note the ~50 m depth of investigation and the conductive high at ~15 m depth below Station 50, interpreted as subsurface water flow under mine tailings matching surface flows seen coming out from under the tailings, and shown on maps. Both of these interpretations (Line 4 and Line 15) were confirmed by preliminary results from the MARTE ground truth drilling campaign carried out in September and October 2003 [1, 6].

Potential of GPR: Ground Penetrating Radars can probes the subsurface layers to varying depths depending on the sounding geometry and the geoelectrical and geomagnetic properties of the soil at the sounded sites [12]. A Test experiment was carried in February 2003 in the Baharia Oasis in the western Egyptian desert in order to detect the Nubian aquifer water table at depth ranging from 100 to 900 meter, using a 2 MHz monostatic GPR [13]. The geological cross section of the studied area is shown in Fig. 4.

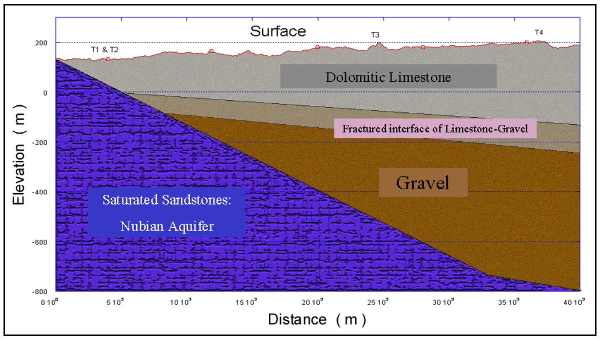

Figure 4. The hydro-geological model along the track of the GPR test experiment in the Baharia test site.

The survey demonstrated the ability of this technique to detect the Nubian Aquifer at a depth around 900 m beneath thick layer of homogenous marine sedimentary quaternary and tertiary structures constituted mainly of highly resistive dry porous dolomite, illinite, limestone and sandstone, given a reasonable knowledge of the local geoelectrical properties of the crust [14].

In the locations were the water table was located at shallower depths of less then 200 meter (cf. Fig. 4; T1 and T2), but with a presence of very thin layers (less the half a meter) of reddish dry clays, the technique fails to probe the moist interface and also fails to map any significant stratigraphy.

Fig. 5 shows an example of the data collected in the site T4 (indicated on Fig. 4) where the water table was located 900 meter deep. The GPR was able to map the first interface between the dolomitic limestone and the gravel (The first reflection occurring around 10 us in Fig. 5) while the detection of the deep subsurface water table remain uncertain due the uncertainties arising from some instrumentational and geoelectrical problems.

Conclusions: GPR excels in resolution, productivity (logistical efficiency) and is well suited for the shallower applications, but is more sensitive to highly conductive layers (result of wave propagation and higher frequencies), and achieves considerably smaller depths of investigation than TEM.

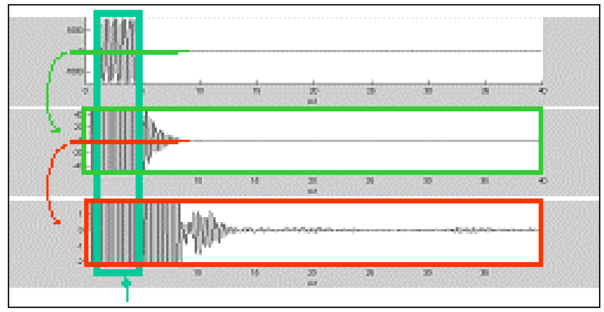

Figure 5. Monostatic radar sounding data collected in Egypt using the 3.5 MHz band of the GPR [15].

The (diffusive) TEM method uses roughly two orders of magnitude lower sounding frequencies than GPR, is less sensitive to highly conductive layers, achieves considerably deeper depths of investigation, and is more suitable for sounding very deep subsurface water. Compared with GPR, TEM suffers for very shallow applications in terms of resolution and logistical efficiency.

Fast-Turnoff TEM, with its very early measured time windows, achieves higher resolution than conventional TEM in shallow applications, and somewhat bridges the gap between GPR and TEM in terms of depths of investigation and suitable applications.

References: [1] Jernsletten J. A. (2003) *Fast-Turnoff Transient Electro-Magnetic (TEM) Geophysical Survey*. MARTE field report. [2] Fernández-Remolar et al. (2003) *JGR*, 108/E7, 16-1 – 16-15. [3] Stoker C. R. et al. (2003) *Drilling Campaign Plan V0.1*. MARTE working document. [4] Stoker C. R. et al. (2003) *Drilling Plan CRS 4-20-2003*. MARTE working document. [5] Stoker C. R. et al. (2003) *LPSC 34*, abstract no. 1076. [6] Stoker C. R. et al. (2003) *Initial Results From the 2003 Ground Truth Drilling Campaign*. MARTE working document. [7] Reynolds J. M. (1997) *An Introduction to Applied and Environmental Geophysics*. [8] Zonge K. L. (1992) *Introduction to TEM*. In: *Practical Geophysics II, for the Exploration Geologist*. [9] MacInnes S. and Raymond M. (1996) *Zonge STEMINV manual*. [10] Palacky G. J. (1987). In: *Electromagnetic Methods in Applied Geophysics, Volume 1, Theory*. Nabighian M. N., editor. [11] Zonge K. L. (2001) *NanoTEM – A Very Fast-Turnoff TEM System*. Zonge Engineering case study. [12] Olhoeft, G.R., (1998), *7th Int. Conference on GPR*, Lawrence. [13] Berthelier, J.J., and Netlander Team, (2000) Planetary and Space Science, 48, pp. 1153-1159. [14] Heggy et al., (2001) *Icarus*, Vol. 154, N2, pp. 244-257. [15] Berthelier J.J. et al., *CNES technical report*, 2003.