TIME DOMAIN ELECTROMAGNETICS IN MARS ANALOG ENVIRONMENTS: COMPARING TWO FIELD STUDIES

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The purpose of this study is to evaluate the use of (diffusive) Time Domain Electromagnetics (TEM) for sounding of subsurface water in conductive Mars analog environments. To provide a baseline for such studies, I show data from two field studies: 1) Diffusive sounding data (TEM) from Pima County, Arizona; and 2) Shallower sounding data using the Fast-Turnoff TEM method from Peña de Hierro in the Rio Tinto region of Spain. The latter is data from work conducted under the auspices of the Mars Analog Research and Technology Experiment (MARTE).

A TEM survey 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. The survey used a 16 Hz sounding frequency, which is sensitive to slightly salty groundwater. Prominent features in the data from Arizona are the ~500 m depth of investigation and the ~120 m depth to the water table, confirmed by data from four USGS test wells surrounding the field area.

During May and June of 2003, a Fast-Turnoff (early time) TEM survey was carried out at the Peña de Hierro field area of the MARTE project, near the town of Nerva, Spain. Data was collected using 20 m and 40 m Tx loop antennae and 10 m loop Rx antennae, with a 32 Hz sounding frequency. Data from Line 4 of this survey show ~200 m depth of investigation and a conductive high at ~90 m depth. This is interpreted as the water table, matching the 431 m MSL elevation of the nearby pit lake. Data from Line 15 and Line 14 of investigation and show conductive highs at ~15 m depth, interpreted as subsurface water flow under mine tailings matching surface flows seen coming out from under the tailings, and shown on maps. Both of the interpretations from Rio Tinto data were confirmed by preliminary results from the MARTE ground truth drilling campaign carried out in September and October 2003.

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INTRODUCTION

Surface geophysical methods to look for deep groundwater on Mars is a technology being considered for future missions to Mars. Electromagnetic geophysical methods are attractive in this context for two primary reasons: Their relative light footprints and logistical simplicity compared to some other geophysical methods (seismics, etc.), and a history of use in groundwater mapping, making them a mature technique I a wide range of terrestrial contexts.

The purpose of this study was to evaluate the use of two variant techniques of Time Domain Electromagnetics (TEM) for sounding of subsurface water in different conductive Mars analog environments. The two studies were:

1) Diffusive sounding data (TEM) from Pima County, Arizona Figure 1; and
2) Shallower sounding data using the Fast-Turnoff TEM method [1] from Peña de Hierro in the Rio Tinto region of Spain Figure 2. The latter is data from work conducted under the auspices of the Mars Analog Research and Technology Experiment (MARTE) [2-7].

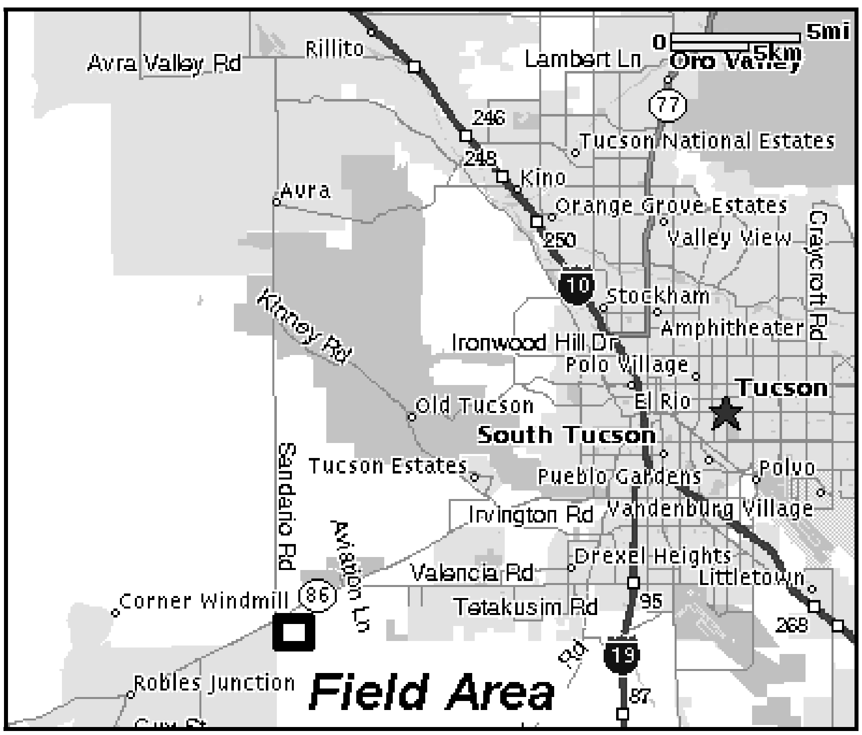


Figure 1. Tucson field area location map.

The goal of this work is to begin defining basic parameters (frequencies, antennae sizes, etc.) appropriate for sounding conductive (saline, mineralized) groundwater to great depths (100's of meters to kilometers). Such depths are almost certainly required for groundwater to exist in a liquid phase on Mars, even if such water is assumed to be saline to the point of nearly being eutectic brines [8].

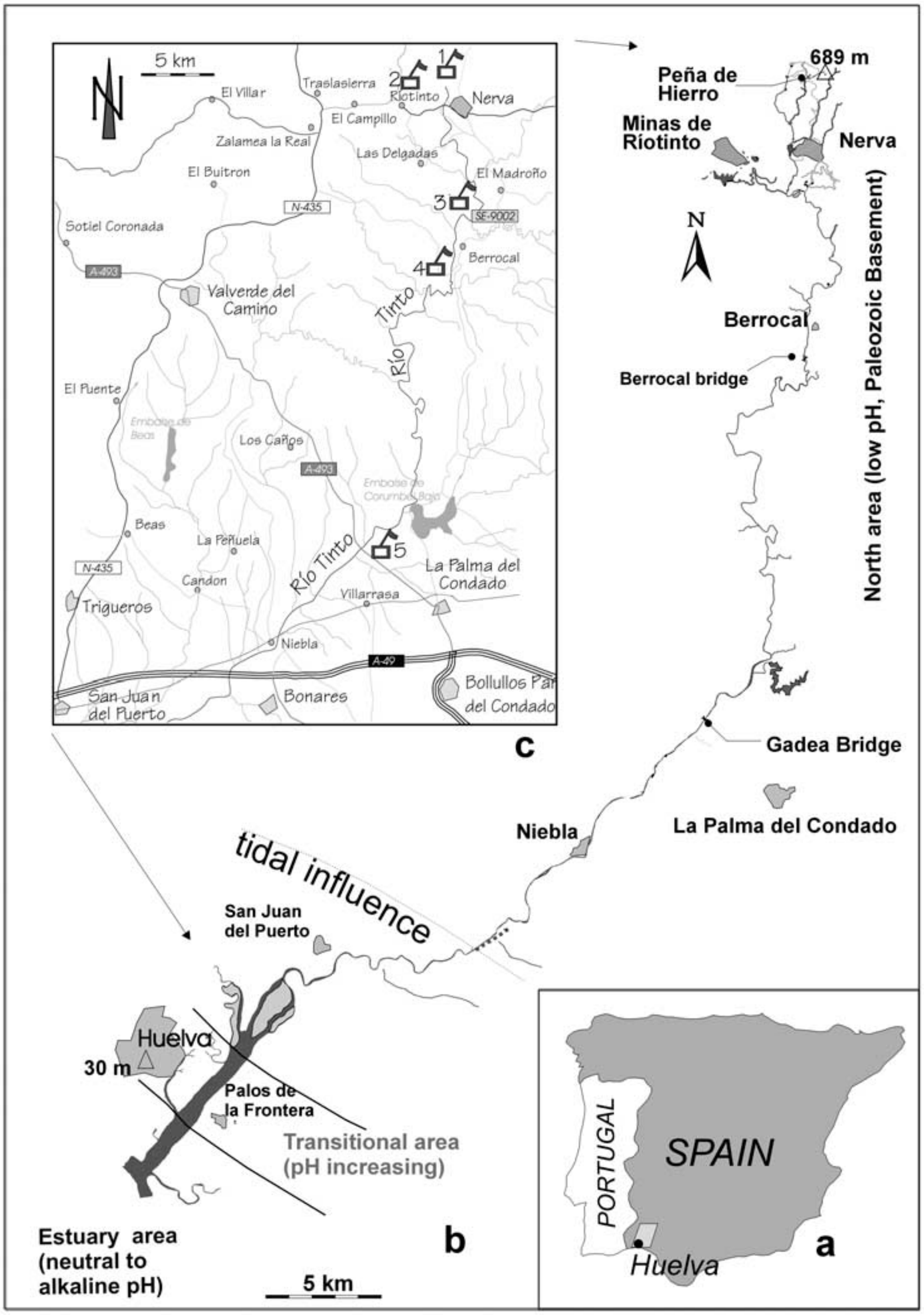


Figure 2. Peña de Hierro and Rio Tinto location map. Adapted from [3].

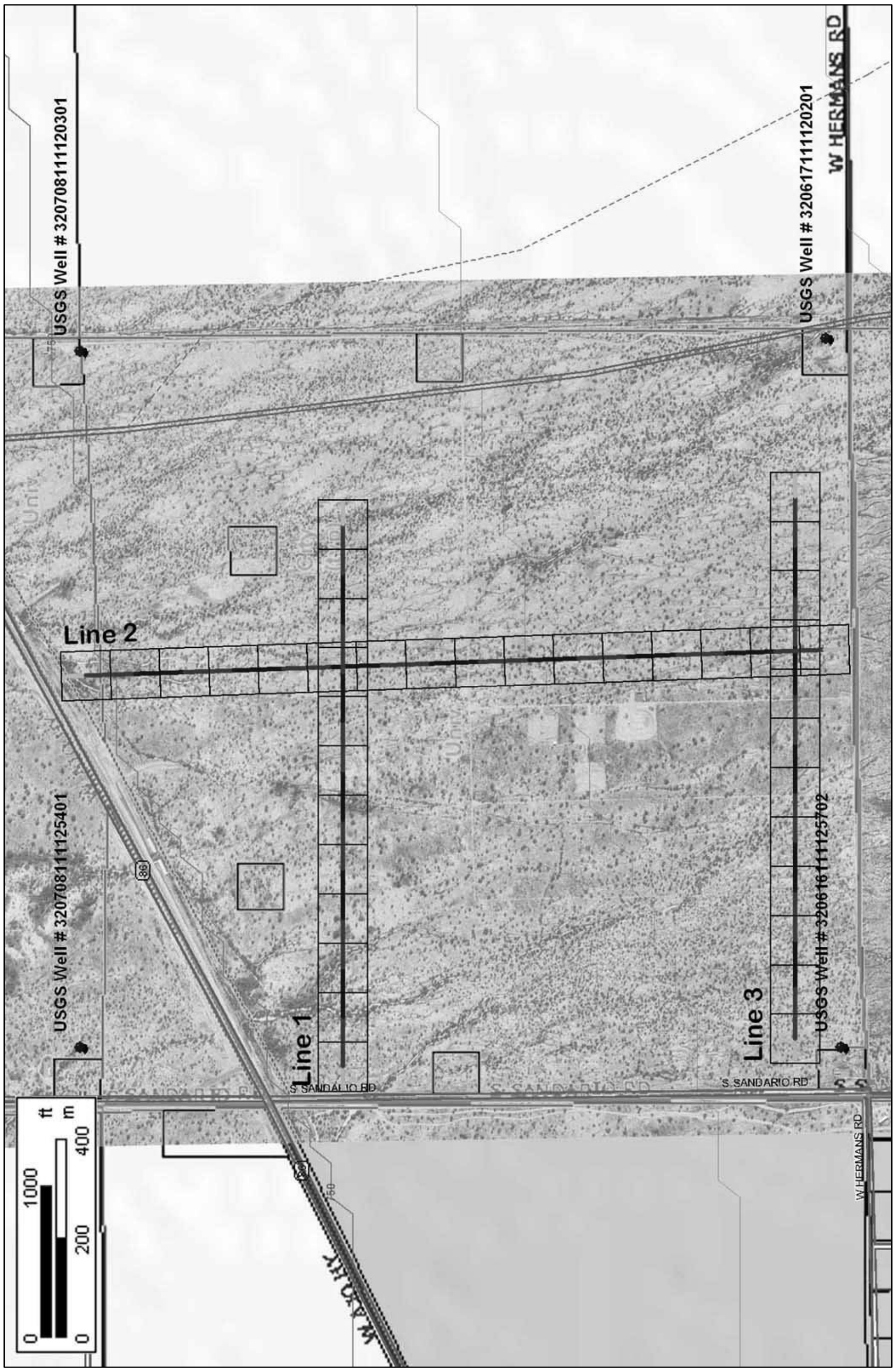


Figure 3. Pima County, Arizona Field Area.

Figure 4. Typical TEM Setup in the Field

SURVEY RESULTS AND METHODOLOGY

TEM Survey, Pima County, Arizona

A TEM survey intended to be the first step on a long road to the goal of geophysically searching for water on Mars was carried out in Pima County, Arizona, in January 2003. Figure 3 shows a map of the field area of this study, located about 35 miles southwest of the city of Tucson.

The TEM method has been widely used for mapping of groundwater [9-10], and of metal-bearing acid solutions in leaching operations. Figure 4 shows a typical TEM setup in the field, and Figure 5 shows model data from this survey. Data was collected using 100 m Tx loops and a ferrite-cored magnetic coil Rx antenna, and processed using commercial software [10-11]. The survey used a 16 Hz sounding frequency, which is sensitive to slightly salty groundwater [10, 12].

Prominent features in Figure 5 are the ~500 m depth of investigation and the ~120 m depth to the water table (horizontal lines). Note also the conductive (~20-40 Ωm) clay-rich soil above the water table. The horizontal line marks the ~120 m depth to the water table found in several USGS test wells in the area (Table 1).

Well Site Label	Water Depth (m)	Water Depth (ft)	Date of Latest Reading
USGS Well # 320708111125401	116.27 m	381.45 ft	12/10/1991
USGS Well # 320708111120301	120.24 m	394.50 ft	12/17/1986
USGS Well # 320616111125702	119.54 m	392.18 ft	12/07/1991
USGS Well # 320617111120201	124.68 m	409.07 ft	12/27/1990

Table 1. USGS Well Data.

Fast-Turnoff TEM Survey, Rio Tinto, Spain

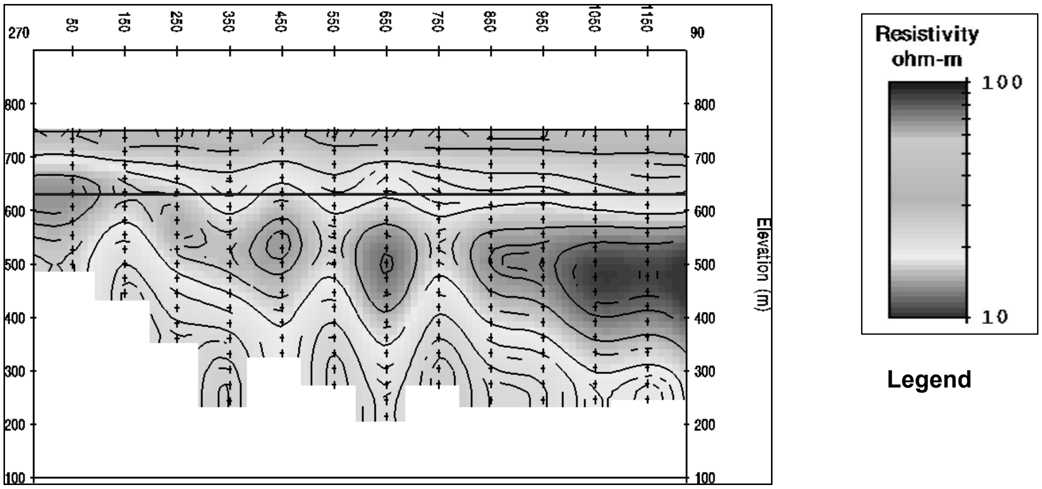
During May and June of 2003, a Fast-Turnoff (early time) TEM survey was carried out at the Peña de Hierro field area of the MARTE project, near the town of Nerva, Spain. Data was collected using 20 m and 40 m Tx loop antennae and 10 m loop Rx antennae, with a 32 Hz sounding frequency. Data from Line 4 (of 16) from this survey, collected using 40 m Tx loops, show ~200 m depth of investigation and a conductive high at ~90 m depth below Station 20 (second station of 10 along this line). This is the water table, matching the 431 m MSL elevation of the nearby pit lake. Data from Line 15 and Line 14 of the Rio Tinto survey, collected using 20 m Tx loops, achieve ~50 m depth of investigation and show conductive highs at ~15 m depth below Station 50 (Line 15) and Station 30 (Line 14), interpreted as subsurface water flow under mine tailings matching surface flows seen coming out from under the tailings, and shown on maps.

Figure 6 shows a map of the Peña de Hierro field area, near the town of Nerva, while Figure 7 shows photographs of Peña de Hierro and the working conditions in the field area.

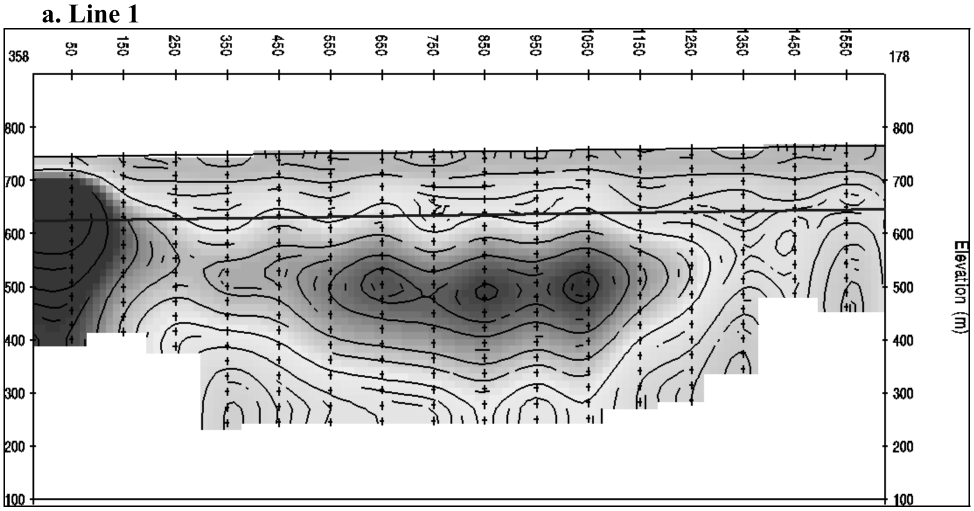
Figure 8 shows data from the MARTE Drill Site 4 area (Lines 4 and 7 of 16 total) from this survey, collected using 40 m Tx loops, 10 m Rx loops, and a 32 Hz sounding frequency [1, 2]. Note the ~200 m depth of investigation and the conductive high at ~80 m depth below Station 20 of Line 4 (Figure 8b). This is the water table, matching the 431 m elevation of the nearby pit lake. The center of the "pileup" below Station 60 of Line 4 (Figure 8b) is spatially coincident with the vertical fault plane located here. Line 7 data corroborates the ~80 m depth to the water table (Figure 8a).

Figure 9 shows Fast-Turnoff TEM data from the MARTE Drill Site 1 area (Lines 14 and 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, 2]. Note the ~50 m depth of investigation and the conductive high at ~15 m depth below Station 50 of Line 15 (Figure 9b) and Station 30 of Line 14 (Figure 9a), interpreted as subsurface water flow under mine tailings matching surface flows seen coming out from under the tailings, and shown on the map. (Figure 6).

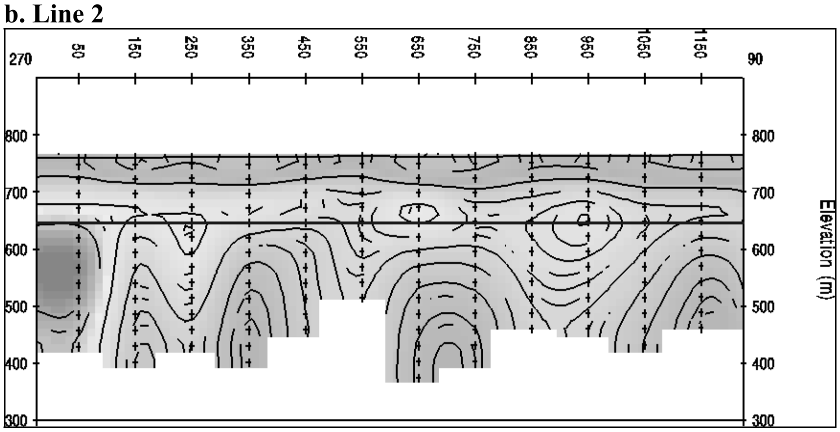
Both of the interpretations from Rio Tinto data (Line 4, Figure 8; and Line 15 (Figure 9) were confirmed by preliminary results from the MARTE ground truth drilling campaign carried out in September and October 2003 [2, 7]. Drill Site 1 was moved ~50 m based on recommendations built on data from Line 15 and Line 14 of the Fast-Turnoff TEM survey (Table 2).



a. Line 1



b. Line 2



c. Line 3

Figure 5. TEM Model Data from Arizona.

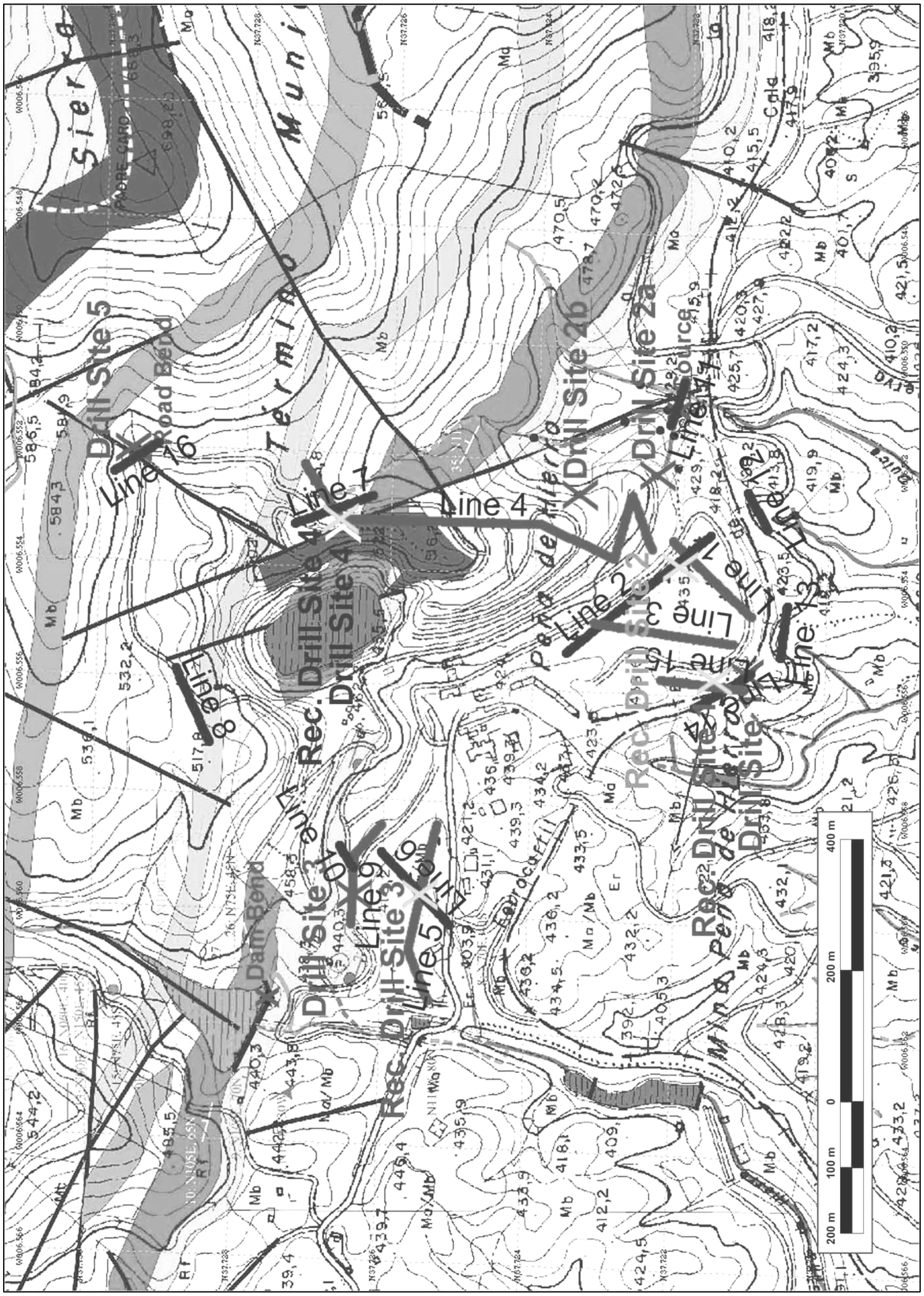
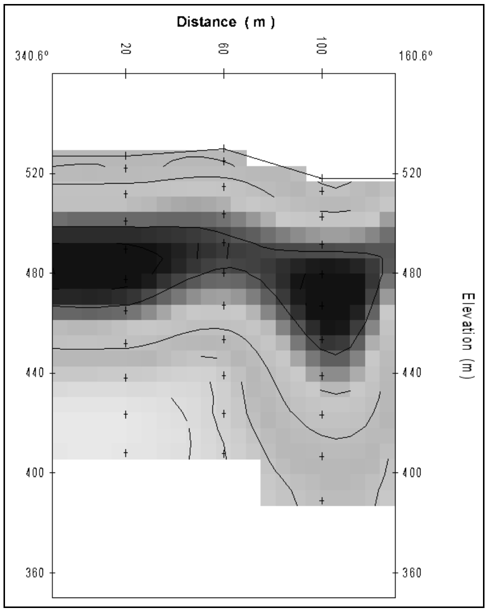
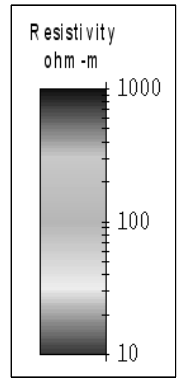


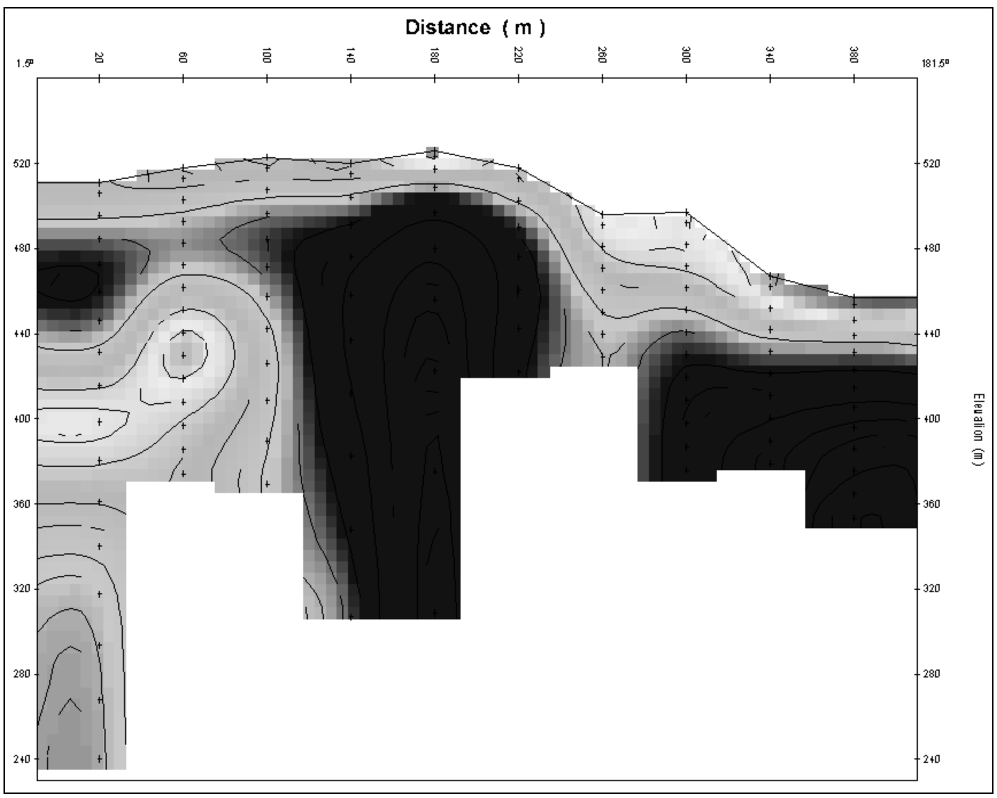
Figure 6. Peña de Hierro Field Map.

Figure 7. Peña de Hierro Working Conditions.





a. Line 7



b. Line 4

Figure 8. Site 4 Fast-Turnoff Data, Rio Tinto.

Description	Latitude Longitude	Bearing from Plan	Distance from Plan	Elevation
Rec. reloc. of Drill Site 1	N 37.721510º W 6.555848º	335.5º	52.98 m	Unknown (L15S02: 431 m)
Rec. reloc. of Drill Site 4	N 37.726676º W 6.553161º	70.1º	10.92 m	Unknown (L04S02: 518 m)
Rec. reloc. of Drill Site 3	N 37.725473º W 6.559679º	180.9º	98.26 m	Unknown (L05S05: 421 m)
Rec. reloc. of Drill site 2	N 37.722011º W 6.553806º	254.5º (2a) 214.9º (2b)	146.05 m (2a) 189.79 m (2b)	Unknown (L02S06: 443 m)

Table 2. Recommended Drill Site Relocations.

CONCLUSIONS

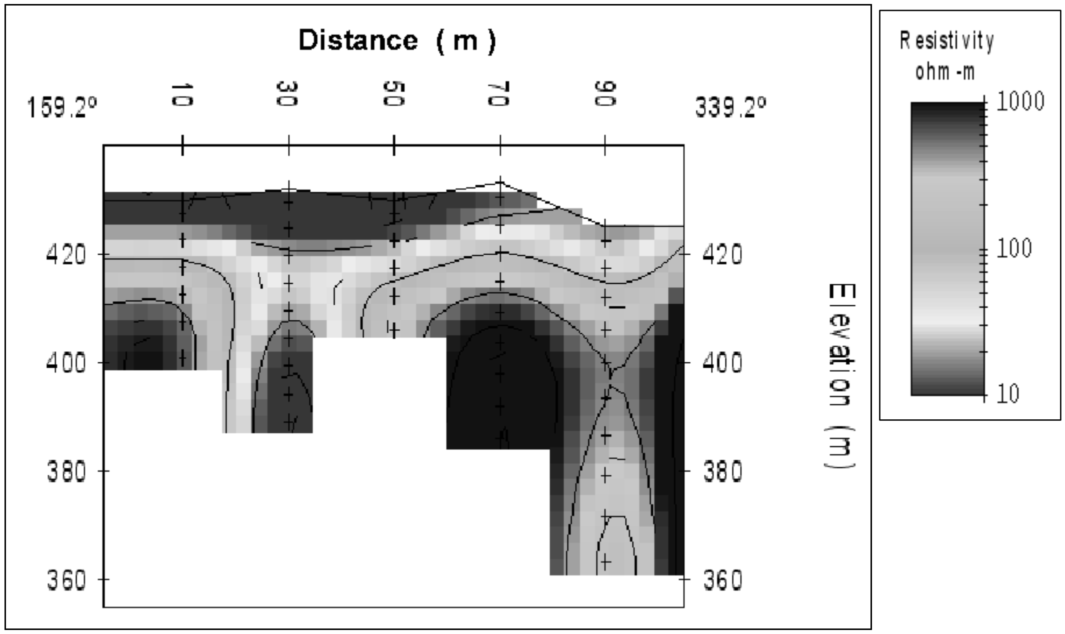
Results from the Pima County TEM survey were in good agreement with control data from four USGS test wells located around the field area (Figure 5, Table 1; for locations see Figure 3). This survey also achieved a very acceptable 500+ m depth of investigation.

Both of the interpretations from Rio Tinto data (Line 4, and Lines 15 & 14) were confirmed by preliminary results from the MARTE ground truth drilling campaign carried out in September and October 2003. Drill Site 1 was moved ~50 m based on recommendations built on data from Line 15 and Line 14 of the Fast-Turnoff TEM survey.

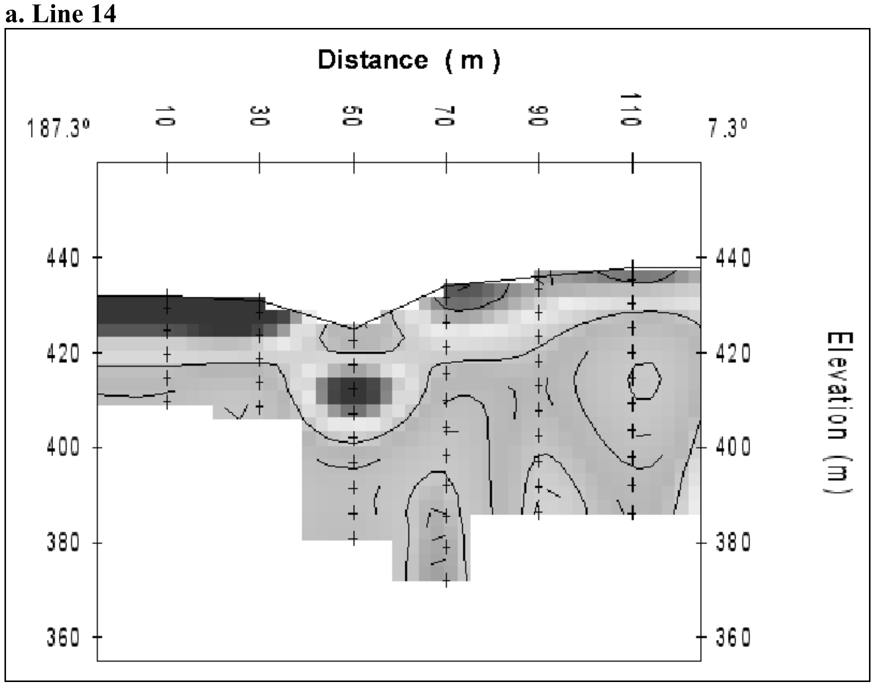
This work demonstrates that time domain electromagnetics is appropriate for sounding of deep groundwater (Arizona study) and of very conductive groundwater (Spain study), and as such hold promise for studies of deep groundwater in a Mars analog context. The next logical steps would be to study groundwater at greater depths (kilometers), and in hyperarid environments (ex. North Africa / Egyptian Sahara, Australia).

With that perspective, it is important to point out that the deeper study presented herein (the conventional TEM survey in the Arizona desert) in itself by no means represent the top end of the scale of what is possible with TEM in terms of depths of investigation. It has indeed been demonstrated possible to use this method [10], or other EM geophysical methods that measure resistivity/conductivity (such as natural or active source magnetotellurics), to sound conductive features to depths of kilometers. This has been demonstrated extensively in mining exploration and in monitoring of copper leaching operations, for example [13, 14].

Electromagnetic geophysical methods, such as those discussed herein, hold the best promise for sounding groundwater to the depths required of true Mars analogs, that is, several kilometers. On earth, such environments are exceedingly rare - one example would be the Nubian aquifer in the Baharïya region in the Egyptian part of the Sahara desert, where depths to the groundwater table in some areas reach depths approaching 3 kilometers [15, 16, 17]. It is the intent and hope of at least this author that such work continue, and that the Mars scientific community will hold the geophysical search for deep groundwater on Mars (eventually) and in Mars analog environments on Earth up as a worthy scientific and exploration goal to pursue.



a. Line 14



b. Line 15

Figure 9. Site 1 Fast-Turnoff Data, Rio Tinto.

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REFERENCES

[1] Zonge K. L. (2001), *NanoTEM – A Very Fast-Turnoff TEM System*. Zonge Engineering case study.

[2] Jernsletten J. A. (2003), *Fast-Turnoff Transient Electro-Magnetic (TEM) Geophysical Survey*. MARTE field report.

[3] Fernández-Remolar et al. (2003), *JGR*, 108/E7, 16-1 – 16-15.

[4] Stoker C. R. et al. (2003), *Drilling Campaign Plan V0.1*. MARTE working document.

[5] Stoker C. R. et al. (2003), *Drilling Plan CRS 4-20-2003*. MARTE working document.

[6] Stoker C. R. et al. (2003), *LPSC 34*, abstract no. 1076.

[7] Stoker C. R. et al. (2003), *Initial Results From the 2003 Ground Truth Drilling Campaign*. MARTE working document.

[8] Clifford, S. M. (1993), *A model for the hydrologic and climatic behavior of water on Mars*, *J. Geophys. Res., 98*(E6), 10973-11016.

[9] Reynolds J. M. (1997), *An Introduction to Applied and Environmental Geophysics*.

[10] Zonge K. L. (1992), *Introduction to TEM*. In: *Practical Geophysics II, for the Exploration Geologist*. Van Blaricom, R., editor. Northwest Mining Assoc., Spokane, Washington.

[11] MacInnes S. and Raymond M. (1996) *Zonge STEMINV manual*.

[12] Palacky G. J. (1987), *Resistivity Characteristics of Geologic Targets*. In: *Electromagnetic Methods in Applied Geophysics, Volume 1, Theory*. Nabighian M. N., editor. Society of Exploration Geophysicists, Series: Investigations in Geophysics, Volume 3. Tulsa, Oklahoma.

[13] Zonge, K. L. (1992), *Introduction to CSAMT*. In: *Practical Geophysics II, for the Exploration Geologist*. Van Blaricom, R., editor. Northwest Mining Assoc., Spokane, Washington.

[14] Zonge, K. L. (2000), *NSAMT – Natural Source Audio-frequency Magnetotelluric Imaging*. Zonge Engineering and Research Organization, Inc., Tucson, Arizona.

[15] Jernsletten, J. A., and E. Heggy (2005), *Comparing transient electromagnetics and low frequency ground penetrating radar for sounding of subsurface water in Mars analog environments*, Abstract no. 6040, Workshop on Radar Investigations of Planetary and Terrestrial Environments, Houston, Texas, February 7 – 10.

[16] Jernsletten, J. A., and E. Heggy (2004), *Sounding of groundwater through conductive media in Mars analog environments using transient electromagnetics and low frequency GPR*, Eos Trans. AGU, 85(17), Jt. Assem. Suppl., Abstract no. P53A-01, AGU 2004 Joint Assembly, Montreal, Canada, May 17 – 21.

[17] Jernsletten, J. A., and E. Heggy (2004), *Sounding of subsurface water through conductive media in Mars analog environments using transient electromagnetics and low frequency ground penetrating radar*, Abstract no. 2089, 35th Lunar and Planetary Science Conference, Houston, Texas, March 15 – 19.