SBGf31099

Rapid single-loop TEM method for locating fracture-zone aquifers in deeply-weathered granite in northeast Brazil.

Maxwell A. Meju* and Sergio L. Fontes+
*University of Leicester, Leicester, England /ON-CNPq, Rio de Janeiro, Brazil.

ABSTRACT

The development of rapid transient electromagnetic (TEM) techniques for locating potential aquiferous fracture-zones in deeply-weathered crystalline basement terrains is a topical issue at the present time. Broadband TEM sounding with a single loop of small size (≤20 m on a side) is an attractive and efficient approach to depth profiling in difficult terrains. At a granitic test site in northeast Brazil where the weathered mantle is more than 60m thick across a known prolific (21000 l/hr) fracture-zone aquifer, single-loop TEM soundings were made using 10m- and 20m-sided square loops along two survey lines. The results obtained are similar for both lines and for both loop sizes. The TEM fracture-zone anomaly is band-limited with a consistent pattern of voltage response at various delay times enabling target identification. The composite single-loop signature for this particular fracture-zone is a peaked voltage response at very early times (< 0.1 ms for the 20m-sided loop and <0.05 for 10m-sided loop), a smoothly varying response at intermediate times, and spatially concordant trough-like response with peaked shoulders at later times (>0.14 ms for 20m-sided loop and >0.07 ms for the 10m-sided loop). We suggest that the single-loop TEM method has very good potential for locating deeply-concealed aquiferous fracture-zones in weathered granite.

INTRODUCTION

In many crystalline basement terrains, useable groundwater aquifers may be found at the base of the weathered layer with higher yields in zones of fractured rock, but locating prolific fracture-zone aquifers under a thick (>60m) weathered mantle is a major hydrogeological problem. Frequency-domain horizontal-loop electromagnetic (HLEM) methods provide a panacea for this problem and are now widely accepted as the standard tools for pin-pointing steep, narrow fracture-zones in crystalline basement terrains (e.g., Palacky et al., 1981; Lindqvist, 1987). In areas of deep weathering or highly conductive overburden, some prospective targets may be missed using the typical portable HLEM techniques owing to limited depth of signal penetration.

The time-domain or transient electromagnetic (TEM) method has been demonstrated to have good capability for mapping steep concealed conductors in mining environments (e.g., Peters and de Angelis, 1987) but has not been adapted to routine groundwater investigations in deeply-weathered crystalline basement terrains inspite of the potential advantages that they have over the conventional HLEM systems (improved penetration depth, more sophisticated modelling schemes, improved logistics). With state-of-the-art TEM equipment (e.g., Geonics Protem47, Sirotem Mk3, Zonge NanoTEM and Bison TDEM-2000), it is possible to image deep hard-rock features of hydrogeological significance using highly portable transmitters and receivers. It is also relatively more straightforward to interpret the conventional TEM depth sounding (i.e., vertical component) data in terms of resistivity-versus-depth information (e.g., Meju, 1998) enabling the depth to target aquifers to be determined (a vital piece of information for optimized post-survey drilling which is traditionally furnished by dc resistivity in combined HLEM-VES surveys). The single-loop TEM technique is a well established geophysical tool for mining and geological investigations. A rectangular loop serves as both the transmitter (Tx) and receiver (Rx) such that high efficiency can be achieved, even in difficult terrain conditions, with small loop sizes.

The structure of a typical fracture-zone in weathered basement terrains consists of a tabular or elongate completely weathered mantle (divisible into an upper leached or mottled zone and the saprolite zone) and an underlying discordant transition zone of partial weathering that grades downwards into fresh bedrock (e.g., Palacky et al., 1981). The saprolite zone is a very important marker zone, identified in many regions of the world as the most conductive layer in a weathered section (e.g., Peric, 1981), and the discordant fracture zone will be electrically conductive relative to the fresh rock making them good targets for the TEM method. It is also of exploration interest that the zones of intensive fracturing will be preferentially weathered and may contain vestigial structures compared to the surrounding rock leading to a lateral zonation of properties within a given weathered mantle (Meju and Fontes, 1999). For single-loop TEM measurements across such a fracture-zone, twin-peak anomalies would be expected over near-vertical conductive structures and a single peak anomaly over flat 3-D surficial weathered structures as known from mining applications. In this paper, we evaluate the potential of rapid single-loop TEM profiling technique for locating a known aquiferous fracture-zone in a granitic basement terrain in Piaui State in northeast Brazil. The fracture-zone is covered by about 60m thick weathered materials.

SINGLE-LOOP TEM SURVEY AT CURRAIS

The village of Currais is located south of the city of Sao Raimundo Nonato in southeast Piaui State. The site map is shown in Figure 1. On aerial photographs, there appears to be a NE-SW linear feature in the vicinity of the village. A 62 m deep borehole, located with the aid of dc resistivity profiling across the photolineament by a geophysical company (Geofisica - Geological Services Ltd, Fortaleza, 1997), found water in the weathered (fractured?) zone and gave a yield of 21000 l/h. The Currais site is underlain by strongly foliated granite which outcrops in a dry stream valley near the borehole site. The granite outcrop is lenticular in shape with a sharp, steeply-dipping $(\sim 80^0)$ southeastern flank between the borehole site and the stream channel. There is a thick lateritic cover especially over the southeastern part of the site. TEM soundings were performed in July and September 1997 across the borehole site using the Sirotem Mk3 equipment and square loops along two SE-NW survey lines (Figure 1). For each survey line, TEM data were acquired using contiguous 20 m- and 10 m-sided loops for comparison. The time taken to set-up and effect a sounding ranged from 4 to 6 minutes for 10m-sided loops and from 6 to 12 minutes for the 20 m loops at this site.

The results of profiling with a 20 m-sided loop on line 2 are shown in Figure 3. Notice the similarity with those described above for line 1. The anomaly occurs at positions 80 to 120 m along line 2. There is a single-peak anomaly approximately centered at the projected borehole location at delay times earlier than 0.149 ms. The anomaly has double-peaks at delay times of more than 0.149 ms and the borehole location is marked by low amplitude response.

For the more rapid soundings with a 10m-sided loop, the induced-voltage profiles at eight delay-times (from 0.035 to 0.197 ms) are presented in Figure 4 for line 1 (comparable results were obtained for line 2). Notice that the response pattern is strikingly similar to that of the 20 m-sided single-loop profiles (cf. Figures 2 and 3) but the anomalous features are better defined by the smaller loop data. The anomalous zone stretches from position 80 to 120 m. The profiles show a single-peak anomaly across the borehole site at delay times of 0.035 to 0.047 ms and twin-peaks with peak migration at later times. The borehole location is marked by depressed field values at delay times of 0.059 to 0.111 ms. There is no anomalous TEM signature at delay times greater than 0.15 ms in these small-loop recordings. In any case, the concordant response patterns from the 20 and 10 m-sided loops seem to suggest that the position of the steep target zone may be identified using densely sampled, single-loop data at sufficiently early delay times. It is noteworthy (and perhaps of practical significance) that the delay time at which a given profile pattern is seen in the 10m loop profiles is half that for the 20m loop recordings.

COMPARISON WITH HLEM PROFILES

ince HLEM methods are the standard tools for pin-pointing steep, narrow fracture-zones in crystalline basement terrains (e.g., Palacky et al., 1981; Lindqvist, 1987), it would be instructive to compare our single-loop TEM profiles with dual-loop HLEM data acquired over the same survey line. For comparison, HLEM data were acquired at 8 frequencies (14080, 7040, 3520, 1760, 880, 440, 220 and 110 Hz) along line 1 using the APEX Max-Min II equipment with a Tx-Rx separation of 50 m and a station interval of 10 m. The HLEM inphase data are presented in Figure 5 and those for the quadrature component in Figure 6. The HLEM data suggest the presence of a steeply-dipping relatively conductive zone at the borehole site. The anomaly is well defined at all frequencies in the quadrature measurements but only at high frequencies (3520 to 14080 Hz) in the inphase data. The large quadrature anomaly at 14080 and 7040 Hz indicates a thicker conductive (lateritic) overburden southeast of the borehole position than elsewhere on the survey line in accord with field geological observation and TEM results. Edge effects (cf. Macnae, 1979, Fig. A-2) are suggested near positions 55 and 115 m by the inphase data at 1760 Hz and the lower frequencies. It is obvious that the same fracture-zone anomaly was detected by both the TEM and HLEM methods. It is of practical significance that a one-person crew could easily conduct TEM soundings with a 10m-sided loop in this terrain.

CONCLUSION

We have demonstrated that the single-loop TEM technique can be used to locate a known aquiferous fracture-zone at a granitic test site where there is about 60m of weathered overburden. The data were recorded using the Sirotem Mk3 field equipment and the results obtained for soundings with 10m- and 20m-sided square loops are very similar; but the smaller loop profiles are better able to resolve short-wavelength anomalies. The composite single-loop signature for the Currais fracture-zone is a peaked voltage response at the earliest times, a smoothly varying response at intermediate times, and spatially concordant trough-like response with peaked shoulders at later times. We suggest that the single-loop technique is a viable tool for fracture-zone mapping in comparable basement terrains.

ACKNOWLEDGMENTS

The authors thank CAPES, The British Council in Rio de Janeiro and the mayor of Sao Raimundo Nonato for support. We are grateful to Emin Ulugergerli, Carlos Germano, Emanuele F. La Terra and Ronaldo M. Carvalho for field assistance.

REFERENCES

Lindqvist, J.G., 1987, Use of electromagnetic techniques for groundwater exploration in Africa: Geophysics, **52**, 456-458.

Macnae, J.C., 1979, Kimberlites and exploration geophysics: Geophysics, **44**,1395- 1416.

Meju, M.A.,1998, A simple method of transient electromagnetic data analysis: Geophysics, **63**, 405-410

Meju, M.A. and Fontes, S.L.,1999, The use of TEM, HLEM and dc resistivity methods to locate fracture-zone aquifers in lateritized deeply-weathered crystalline basement terrains in Piaui State, northeast Brazil: Geophysics.

Palacky, G.J., Ritsema, I.L. and De Jong, S.J., 1981, Electromagnetic prospecting for groundwater in Precambrian terrains in the Republic of Upper Volta: Geophys. Prosp., **29**, 932-955.

Peric, M., 1981, Exploration of Burundi nickeliferous laterites by electrical methods: Geophys. Prosp., **29**, 274-287.

Peters, W.S. and de Angelis, M., 1987, The Radio Hill Ni-Cu massive sulphide deposit: a geophysical case history: Explor. Geophys., **18**, 160-166.

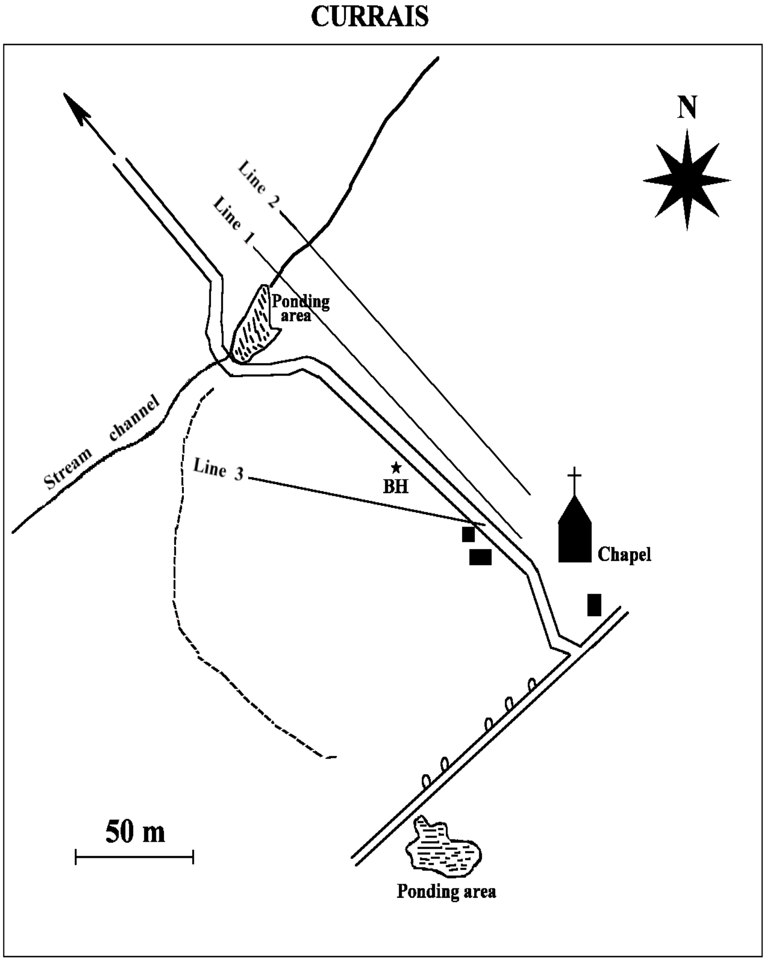

FIG. 1. Currais site plan showing borehole location and TEM survey lines.

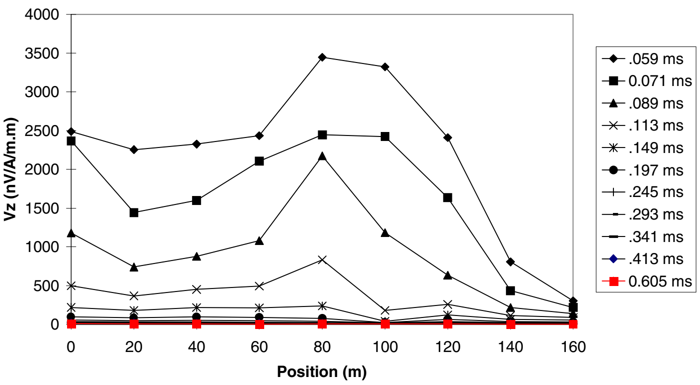

FIG. 2. Profiles of TEM responses obtained using 20m-sided Loops on line 1.

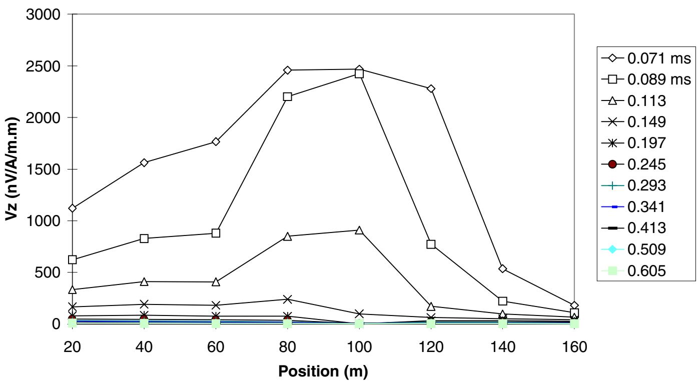

FIG. 3. Profiles of TEM responses obtained using 20m-sided loops on line 2.

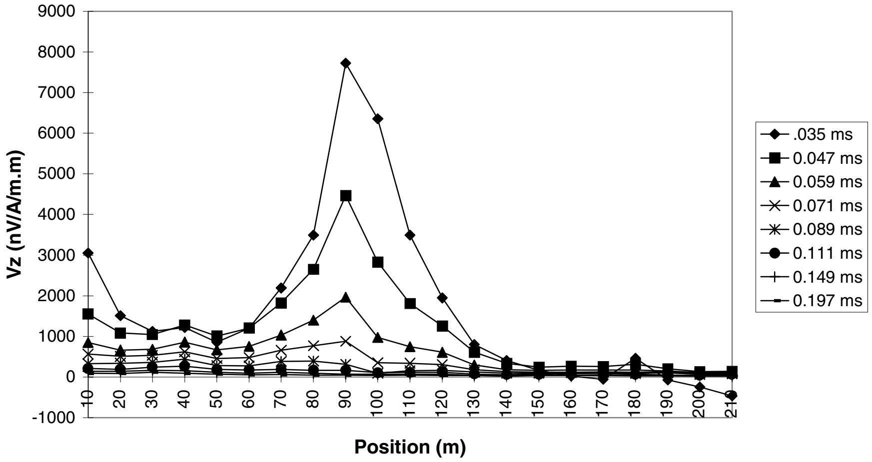

FIG. 4. Profiles of TEM data from 10m-sided single- loops on line 1

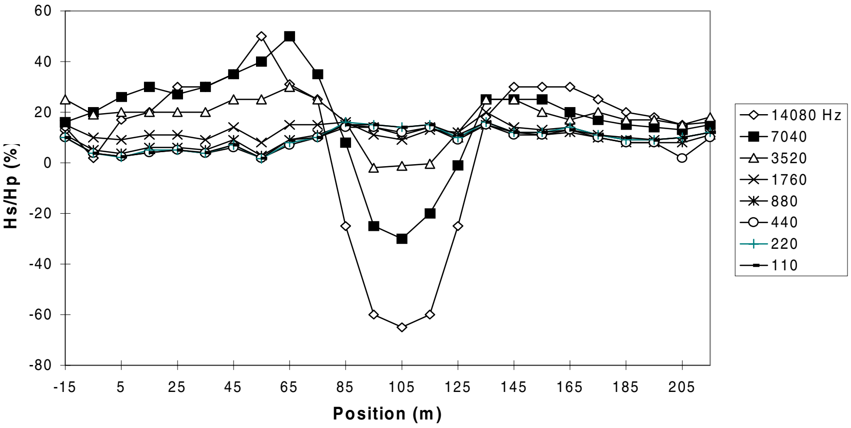

FIG. 5. HLEM inphase profiles for line 1.

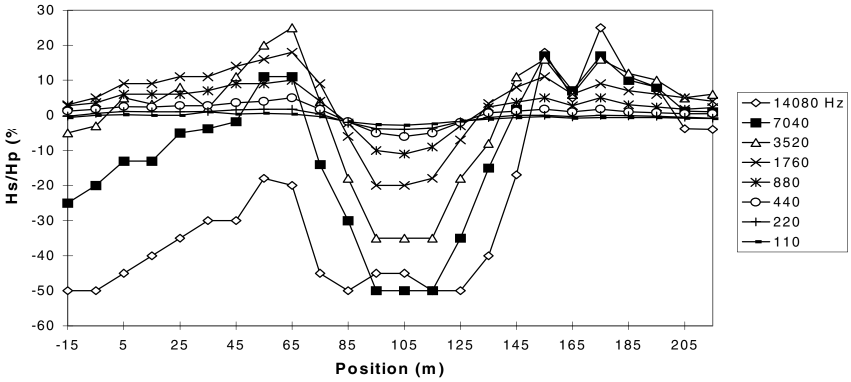

FIG. 6. HLEM quadrature profiles for line 1.