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SOME LABORATORY ELECTROMAGNETIC STUDIES OVER RESISTIVE BODIES IN A CONDUCTIVE ENVIRONMENT

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Scale model experiments over resistive bodies in a conductive medium have been carried out to study the application of electromagnetic methods in prospecting for groundwater and construction materials. Also, some computational results have been reviewed.
Freshwater buried stream valleys, freshwater lenses in sand dunes and in sand and gravel bodies are often embedded in clays or surrounded by layers containing saline water. The constitution of these bodies is geoelectrically equivalent to the presence of a non-conducting body in a conducting medium.
The electromagnetic response of a resistive body in conducting homogeneous and heterogeneous half-spaces has been studied for the case of a horizontal coil prospecting system. The EM anomalies obtained are caused by(i) variations in the current-path geometry in the host medium (ii) changes in the magnitude of the induced currents, and (iii) interaction between the conducting flanks, when a resistive body is immersed in a conducting medium. A field example is shown of the application of horizontal-coil EM method in delineating a fresh-water burried stream in clays.

Com a finalidade de estudar a aplicabilidade dos métodos eletromagnéticos na localização de corpos resistivos imersos em meio condutivo, foram realizados experimentos com modelos reduzidos. Tais situações são comumente encontradas na prospecção de aquíferos e materiais de construção, por exemplo, paleocanais em argilas, lentes de água doce em ambientes de água salobra e bolsões de areia e cascalho em camadas de argila e till. É reconhecidamente útil a aplicação da eletrorresistividade nesses casos, embora as medições sejam extremamente custosas e lentas. Mesmo assim, em terrenos favoráveis, levantamentos EM são altamente convenientes.
Respostas EM de situações geoelétricas sob estudo referem-se a: (i) corpo resistivo em meio infinito condutivo; (ii) corpo resistivo entre "slabs" de largura e profundidade limitadas. A primeira situação é simulada por uma placa de acrílico em uma solução condutora dentro de um tanque e a segunda, por dois slabs idênticos de grafite separados de uma certa distância (ar livre).
Anomalias EM significativas obtém-se em ambas situações para profundidades e dimensões variáveis dos alvos. Outros fatores que governam as anomalias são o número de indução do meio encaixante e o arranjo das bobinas utilizado nas medições. Visto que nenhuma corrente pode ser induzida num isolante, estas anomalias são causadas por: (i) variação do trajeto da corrente no meio encaixante condutivo quando um corpo não condutivo é imerso nele; (ii) mudanças na magnitude total das correntes induzidas; e (iii) interação das margens condutivas no limite com o corpo resistivo.
Desta maneira, o presente estudo demonstra a potencialidade dos métodos EM na pesquisa de água doce e materiais de construção existentes num ambiente condutivo, como por exemplo, aquíferos de água salobra e argilas. A demarcação de paleo-canais contendo água potável na Ilha de Marajó, no Estado do Pará, revelou-se como uma aplicação bem sucedida de métodos EM.

INTRODUCTION

Burried stream valleys, periodically recharged freshwater lenses in sand dunes, and enclosed elongated sand-gravel bodies are important sources of groundwater in arid and semi-arid regions (Flathe, 1967; Ogilvy, 1967; Van Dam, 1976). Often the burried valleys and other sand-gravel bodies containing freshwater are found embedded in clays or are present in saline-water media. Sand and gravel are also important construction materials. The geological situation of their occurrence, approximate geoelectric conditions and the scale-model representation are shown in Fig. 1. Geoelectrically the geological structure may be represented by a non-conducting body in a conducting medium.

Galvanic resistivity and seismic methods are widely used in the exploration for groundwater and construction materials. They produce excellent results, but are tedius in operation. On the other hand, inductive electromagnetic methods are easier to operate in a favorable terrain. To help evaluate the use of EM methods in prospecting for groundwater and construction material, some results of scale-

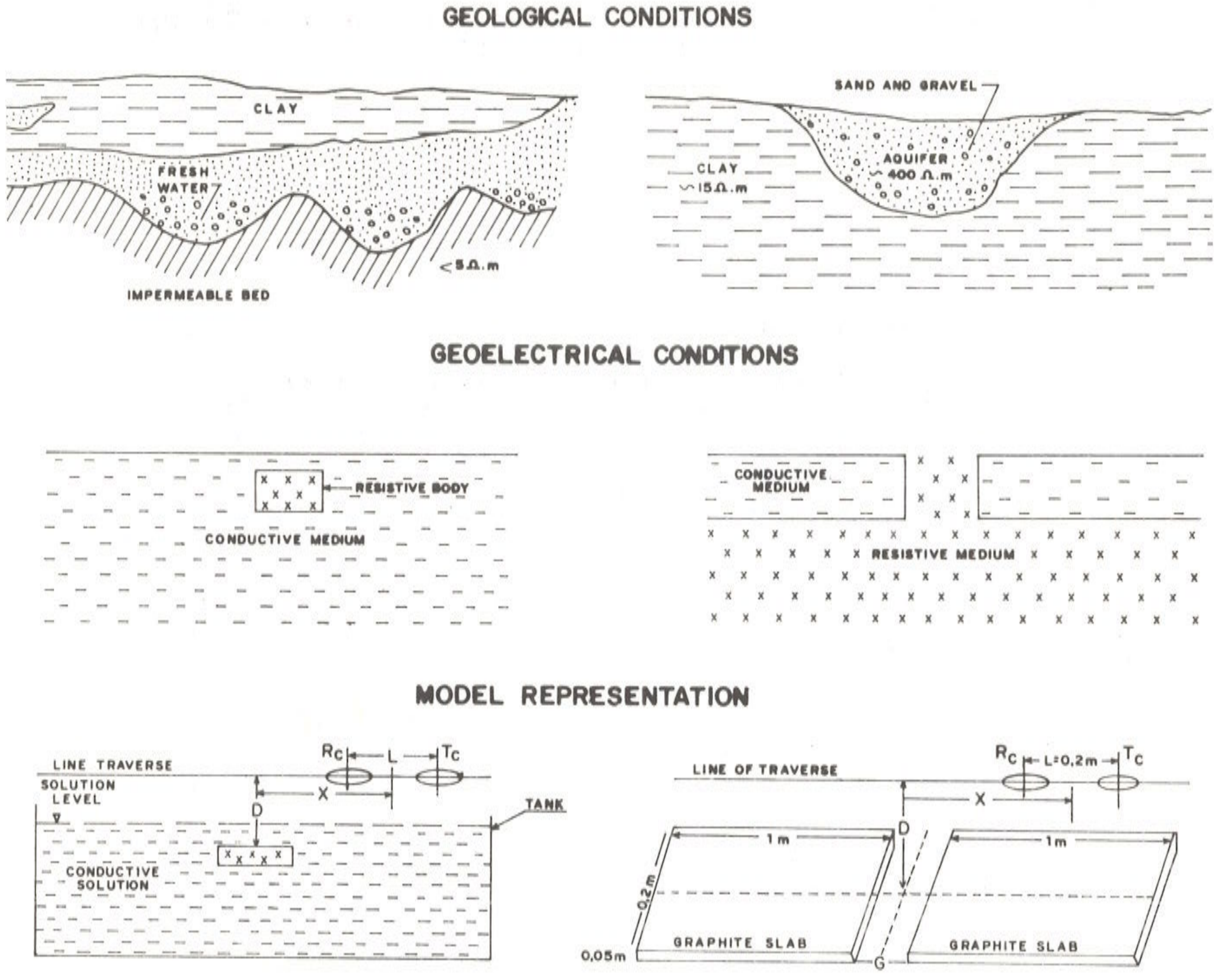

Figure 1 – Geological and equivalent geoelectrical conditions of the occurrence of groundwater and construction materials, and the small-scale model representation.

modelling and computation are analyzed. Palacky et al. (1981) successfully applied HLEM techniques in the prospecting for groundwater present in fractured zones in Precambrian terrains in the Republic of Upper Volta. Also, HELM response over valley-like inhomogeneity in an overburden was studied by Villegas-Garcia and West (1983).

EM MODELLING CONDITIONS

The theory of electormagnetic scale modelling has been described by Grant and West (1965), Strangway (1966), Ward (1967) and Frischkenecht (1971), among others. A half-space can be simulated in the laboratory at a reduced scale by conserving the induction number, $\mu\omega\sigma L^2$, where μ is magnetic permeability, ω is angular frequency, σ is electrical conductivity and L is significant linear dimensions. The induction number of an extended sheet is $\mu\omega\sigma Lt$, where t is the thickness of the sheet and L the distance between the transmitter and receiver coils.

The electromagnetic response of a horizontal-coil system has been studied for the following situations:

(i) A resistive body in a homogeneous, conductive half-space: The model is a plastic slab immersed in a conductive solution of dilute hydrochloric acid contained in a tank. A solution of conductivity 18 Sm^{-1} together with a coil separation of 0.5m and frequency 100kHz, would represent a half-space of conductivity of 0.09 Sm^{-1} for a coil separation of L = 100m and frequency 500Hz. The equipment and the system of measurement have been described by Verma and Gaur (1973).

(ii) A resistive body in a heterogeneous half-space: This is simulated by placing two identical graphite slabs with a gap between them (Fig. 1). The slab conductance of $\sigma t = 12.5 \times 10^3$S ($\sigma = 2.5 \times 10^5 Sm^{-1}$, t =

= 0.05m) at a frequency 500Hz and coil separation 0.2m, simulates a conductance of 25S at a frequency 500Hz and a coil separation 100m. Considering the full-scale sheet thickness as 25m, the conductivity of the material will be $1 Sm^{-1}$.

According to Flathe (1967) and Parasnis (1966) conductivity of $0.09\ Sm^{-1}$ to $1 Sm^{-1}$ is typical for aquifers containing saline water and clay beds (Fig. 2).

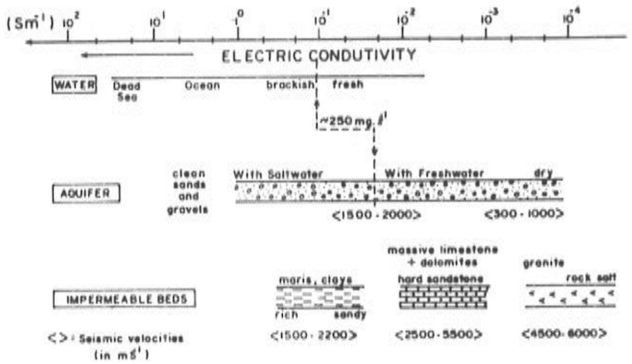

Figure 2 — Electrical conductivities of water, aquifer and impermeable beds (after Flathe, 1967).

DISCUSSION OF RESULTS

Resistivity body in a homogeneous half-space

The electromagnetic anomaly due to a horizontal perspex slab $(0.505 \times 0.088 \times 0.02) m^3$ immersed in a hydrochloric acid ($\sigma = 18 Sm^{-1}$) at depths of D = 0.02m and 0.05m is shown in Fig. 3. The anomaly pattern is found to be inverse to that of a conducting slab in a similar situation (Gaur et al., 1972). The anomaly amplitudes due to the resistive body are much smaller compared with those caused by a conducting body.

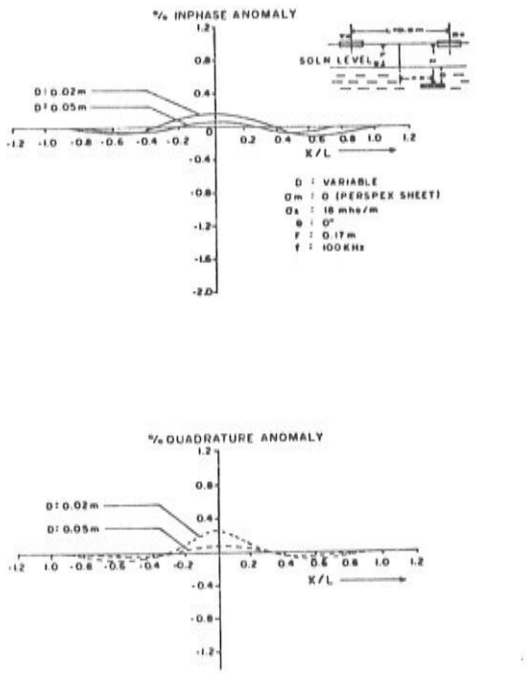

Figure 3 — Anomaly profiles over a resistive horizontal slab immersed in a conductive solution at the depths of 0.02m and 0.05m.

Gupta Sarma and Maru (1971) observed a substantial quadrature and a small inphase anomaly over a vertical backelite sheet partially immersed in a salt solution ($\sigma = 14.9 Sm^{-1}$). The anomaly profiles are similar to those of a vertical conductor but displaced above zero-anomaly level.

Resistive body in a heterogeneous half-space

Figs. 4, 5 and 6 demostrate the effect of the variation in the air-gap between the graphite slabs for different

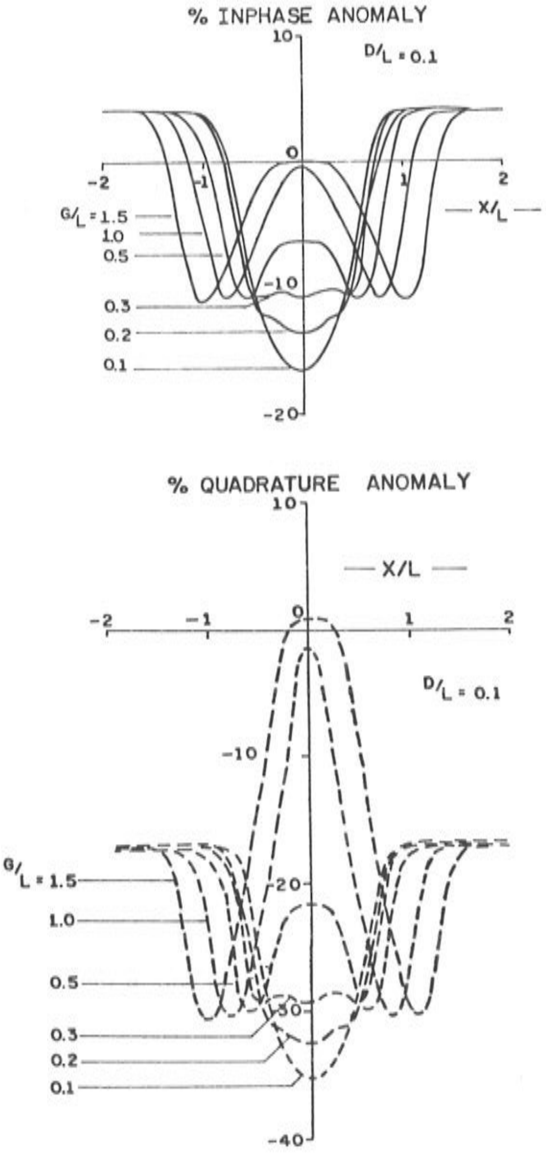

Figure 4 — Anomaly profiles over a resistive gap between graphite slabs for D/L = 0.1.

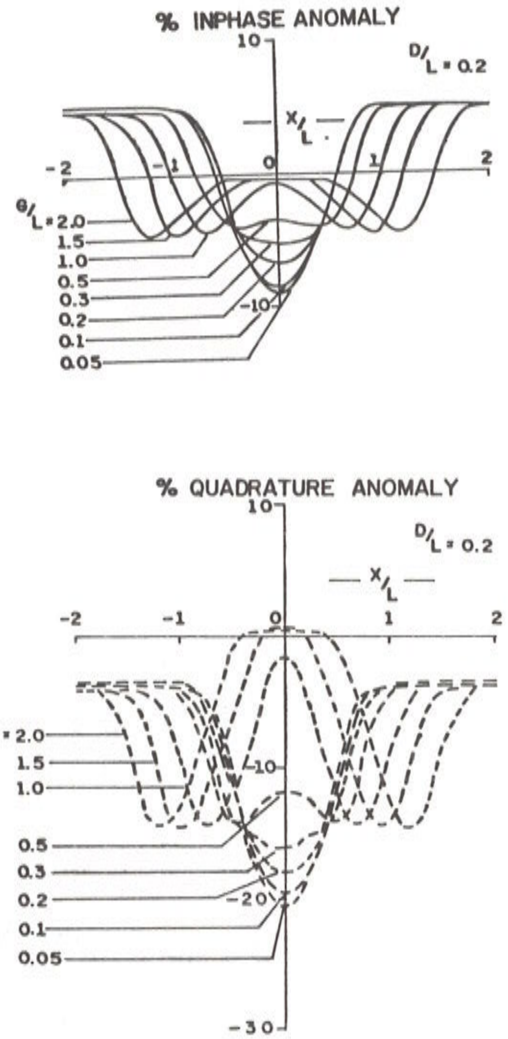

Figure 5 – Anomaly profiles over a resistive gap between graphite slabs for D/L = 0.2.

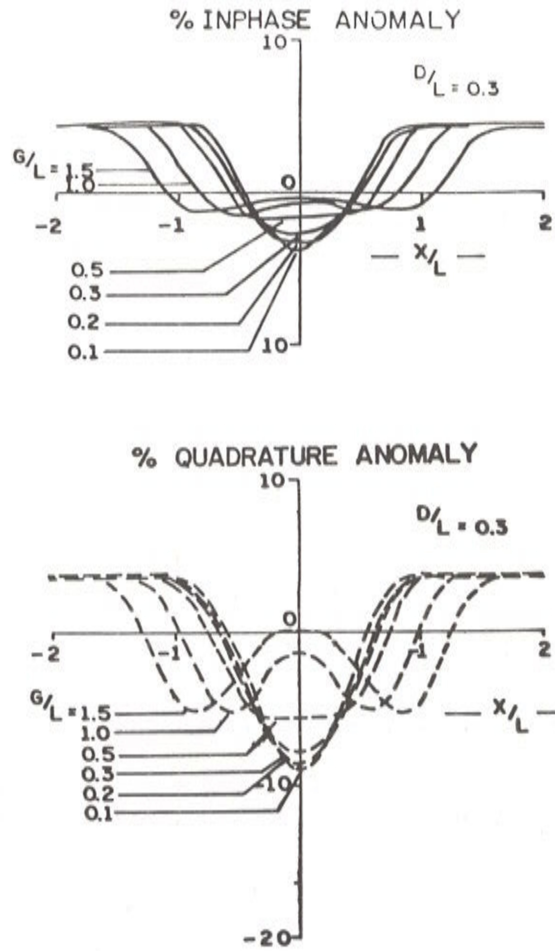

Figure 6 – Anomaly profiles over a resistive gap between graphite slabs for D/L = 0.3.

depths below the coil-system. At low values of the air-gap (i.e. for $G/L \leqslant 0.2$) a central negative peak is obtained. This gradually splits into two with a central hump when the gap is increased. Therefore, the negative-peak position is governed by the disposition of the edges of the graphite slab with respect to the coil separation. In general, the inphase anomaly profiles are found to shift upward whilst the quadrature moves downward with respect to the zero-anomaly reference-line, except in the case of $D/L = 0.3$ where both of them shift upward.

The increase in the coil-height (D/L) above the graphite slab results in a general reduction of the anomalies. Quadrature anomaly profiles gradually shift upward in their level as D/L is increased but the inphase counterpart remains unaffected.

CAUSE OF ANOMALY

Since no current can be induced in an insulator, the anomalies are caused by:

(i) variation in current path geometry in the conducting host-medium when a resistive body is immersed,

(ii) changes in over-all magnitude of the induced currents in the host-medium, and

(iii) interaction between the conducting flanks that surrond the resistive body.

surrond the resistive body.

These causes are evinced by Figs. 3 and 7. In Fig. 7, the anomaly profiles B are not equal to the profiles B′ over an air-gap $G/L = 0.1$, B′ being the algebraic combination of the profiles A and A′ due to the edges of a graphite slab individually positioned at $X/L = 0.05$ and -0.05.

This difference is caused by the interaction between the conducting slabs, which would be negligeable if the slabs were far apart. Thus the profiles C', which are the combination of those due to the edges, and C are the same over the air-gap for G/L = 1. However, the effect of interaction between the slabs is to reduce the anomalies.

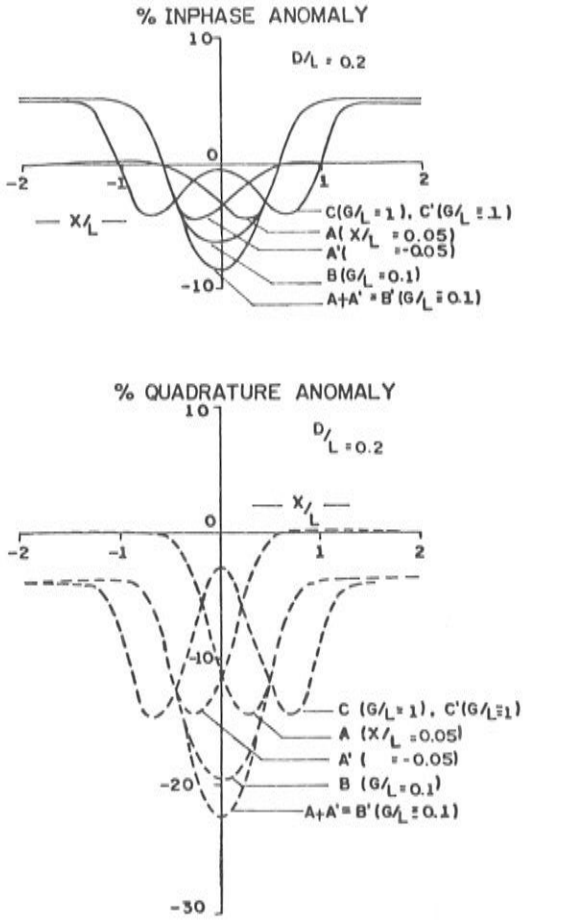

Figure 7 — Anomaly profiles for D/L = 0.2: A and A' due to the edges of a graphite slab positioned separately at X/L = 0.05 and −0.05; B and B' over the air-gap G/L = 0.1, B' being the combination of A and A'; and C and C' over the air-gap G/L = 1.0; C' being the combined curve due to the edges positioned at X/L = 0.5 and −0.5.

CONCLUSIONS

Results of analog models demonstrate that significant electromagnetic anomalies are caused by the presence of resistive bodies in a conductive host medium. The size of the anomalies is determined by the induction number of the conducting host medium and the dimensions and disposition of the resistive body in relation to the coil arrangement used for the measurement. Therefore, EM methods can be applied in prospecting for pockets containing fresh groundwater and in search for construction materials (sand and gravel) in beds with saline water or clays.

Sinha (1973) computed airborne EM anomalies over a resistive sand gravel pocket ($\rho = 600\ \Omega$-m) for four types of coil systems at the Winkler area in Canada. Appreciable anomalies have been obtained with all the four systems. However, the maximum anomalies have been otained with a horizontal coplanar coil system followed by a vertical coplanar, a Tc-horizontal/Rc-vertical, and the vertical coaxial coil systems.

Porsani et al. (1980) have sucessfully used a horizontal coplanar coil system in demarcating the buried stream valleys containing fresh water on the Marajó Island (Pará), Brazil. These buried valleys are filled with sand and gravel ($\rho \approx 40$ Ohm-m) and embedded in clay and sand beds with saline water ($\rho = 0.4$-5 Ohm-m). Fig. 8 shows the horizontal-loop EM profiles across the burried valley

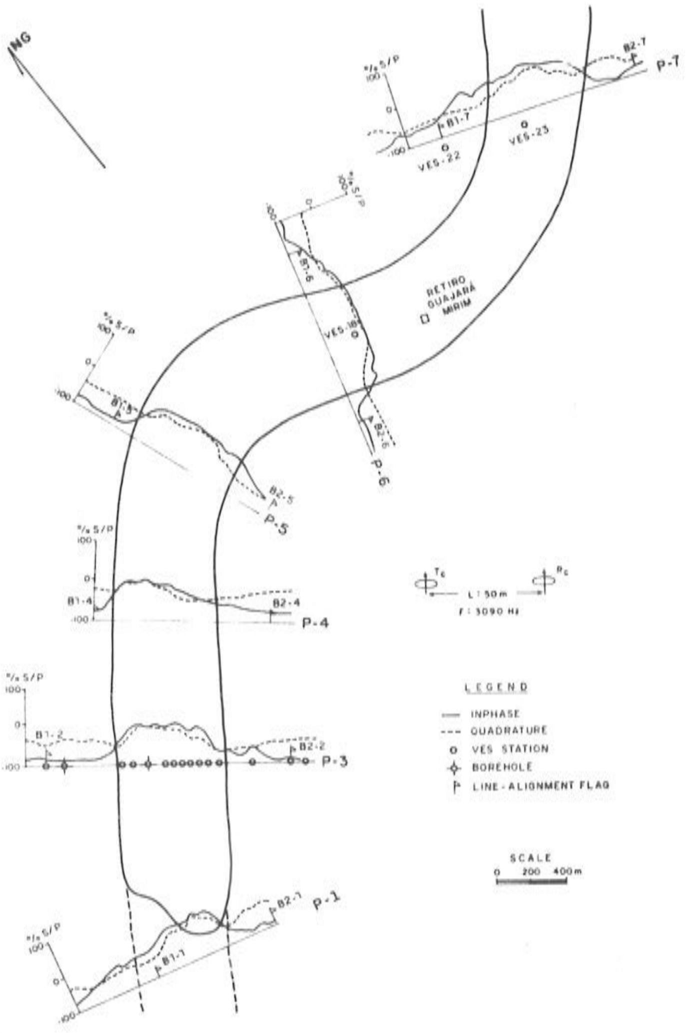

Figure 8 — Electromagnetic profiles across a burried stream channeal "Guajará Mirim", Marajó Island, Brazil (After Porsani et al, 1980).

"Guaraja Mirim". The width of the valley is about 600m (i.e. ⩾ 12L). As the equipment was calibrated on the valley, the response in general approaches zero, except close to its flanks where the inhomogeneity produces negative values. The field results are qualitatively comparable with the model results; see profile for G/L = 1.5 in Fig. 4. However, they are not equal because (i) the conductivity contrast at the border is sharp in the model whilst it is gradual for burried valleys, (ii) the response parameter of the graphite slab is higher than of the material in which the buried valley is placed, therefore the flanks in the model inphase profiles are positive, (iii) the cross-section of the valley will probably be irregular.

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