Localizando água subterrânea com campos eletromagnéticos

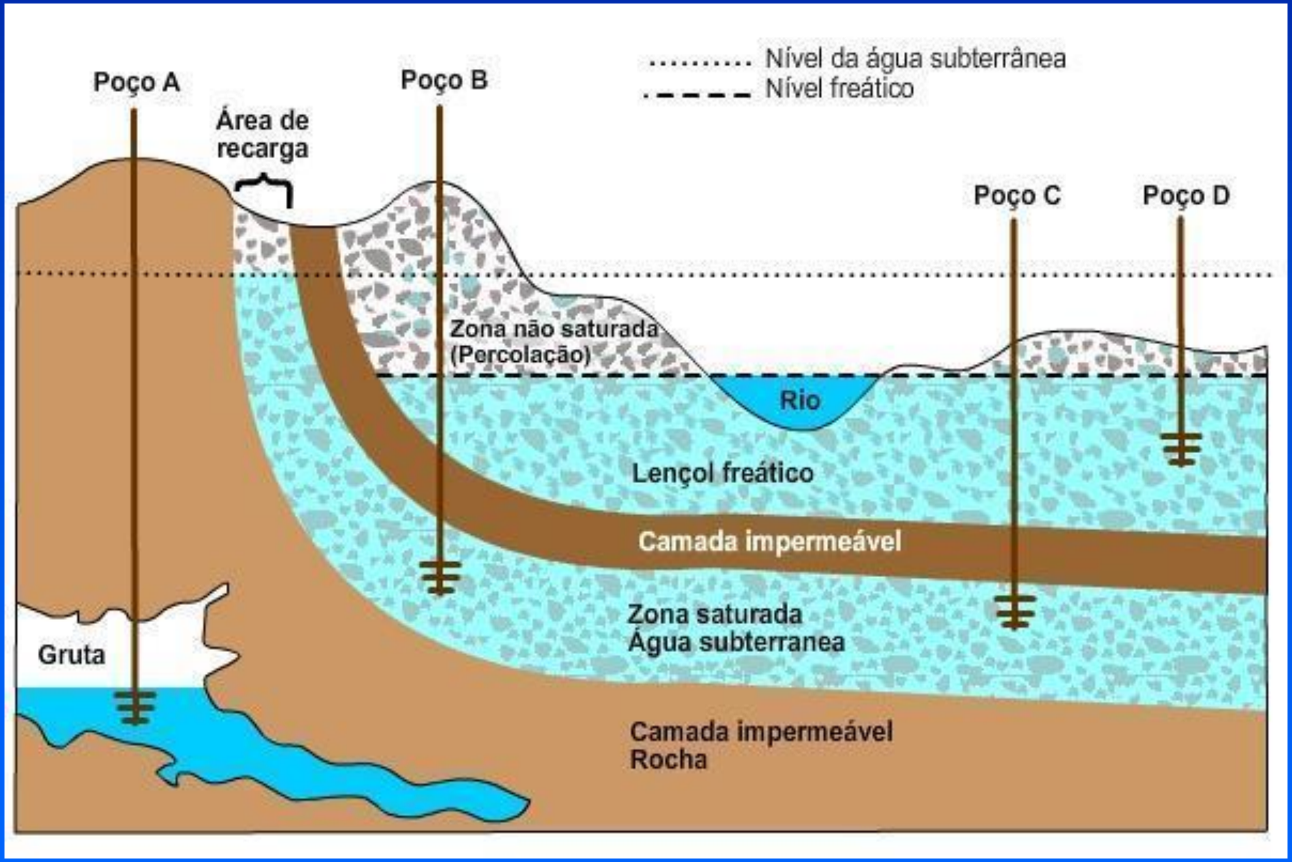
Jorge Luís Porsani
Departamento de Geofísica – IAG/USP

Universidade de São Paulo
Instituto de Astronomia, Geofísica e Ciências Atmosféricas
Departamento de Geofísica – http://www.iag.usp.br

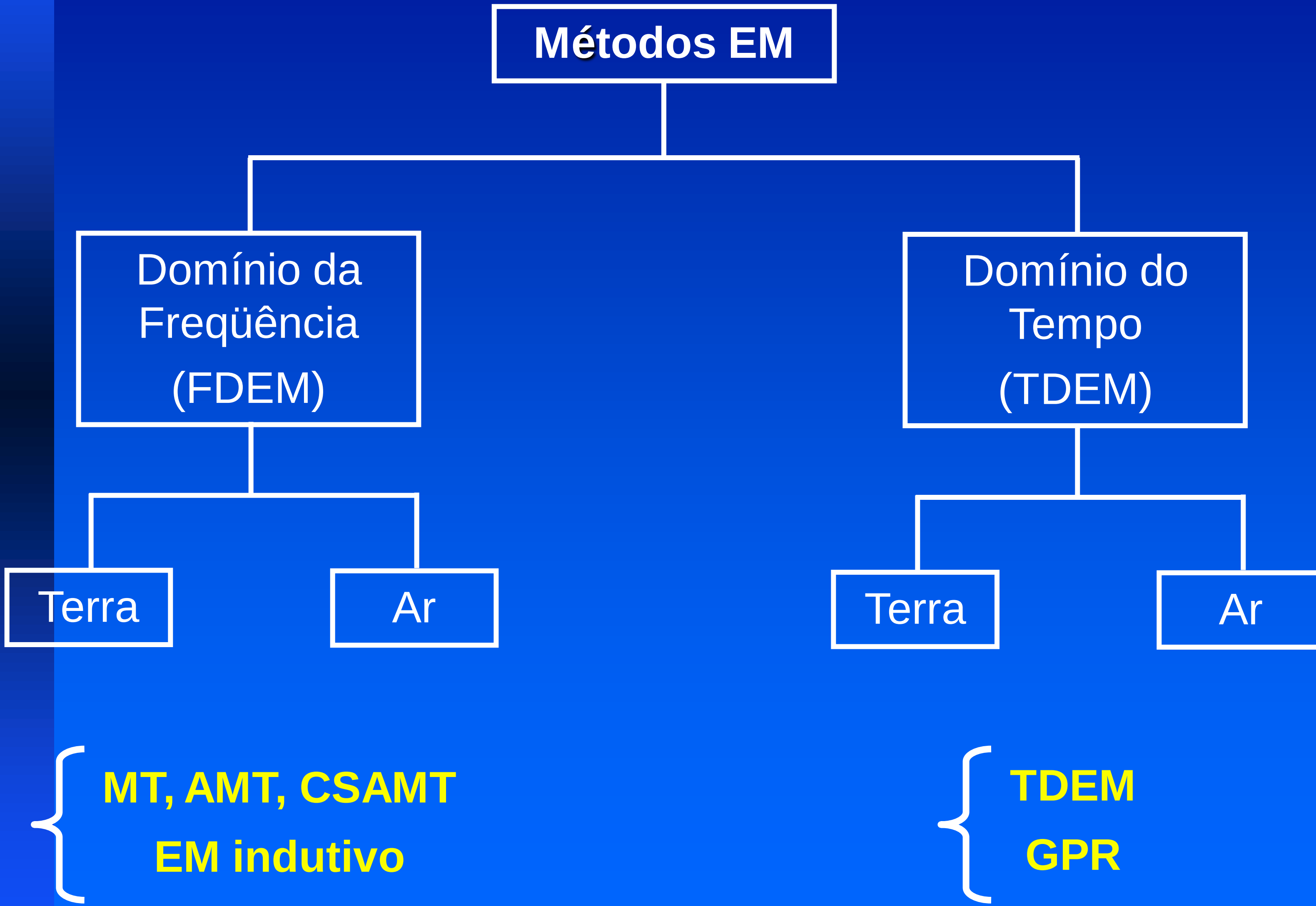
Brasil X África

A SÊCA no Brasil e no Mundo tem Solução ?

Poços Semi-Artesianos



Classificação dos Métodos EM



Introdução

✓ O método TDEM consiste em injetar corrente contínua por meio de um loop transmissor disposto na superfície e na medida do decaimento do campo magnético secundário em função do tempo que está relacionado com a resistividade elétrica das rochas da subsuperfície.

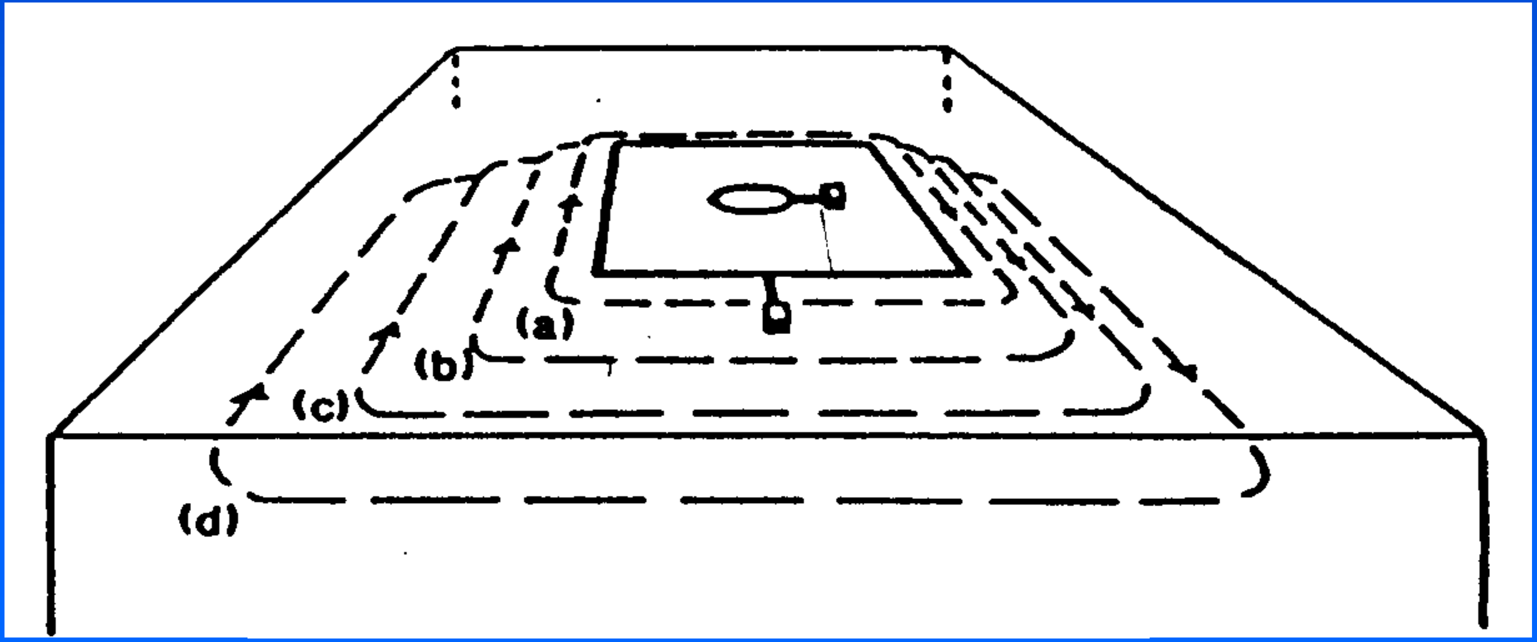
Fontes TDEM:

As antenas transmissora são normalmente grandes “loops” quadrados e os receptores são bobinas pequenas.

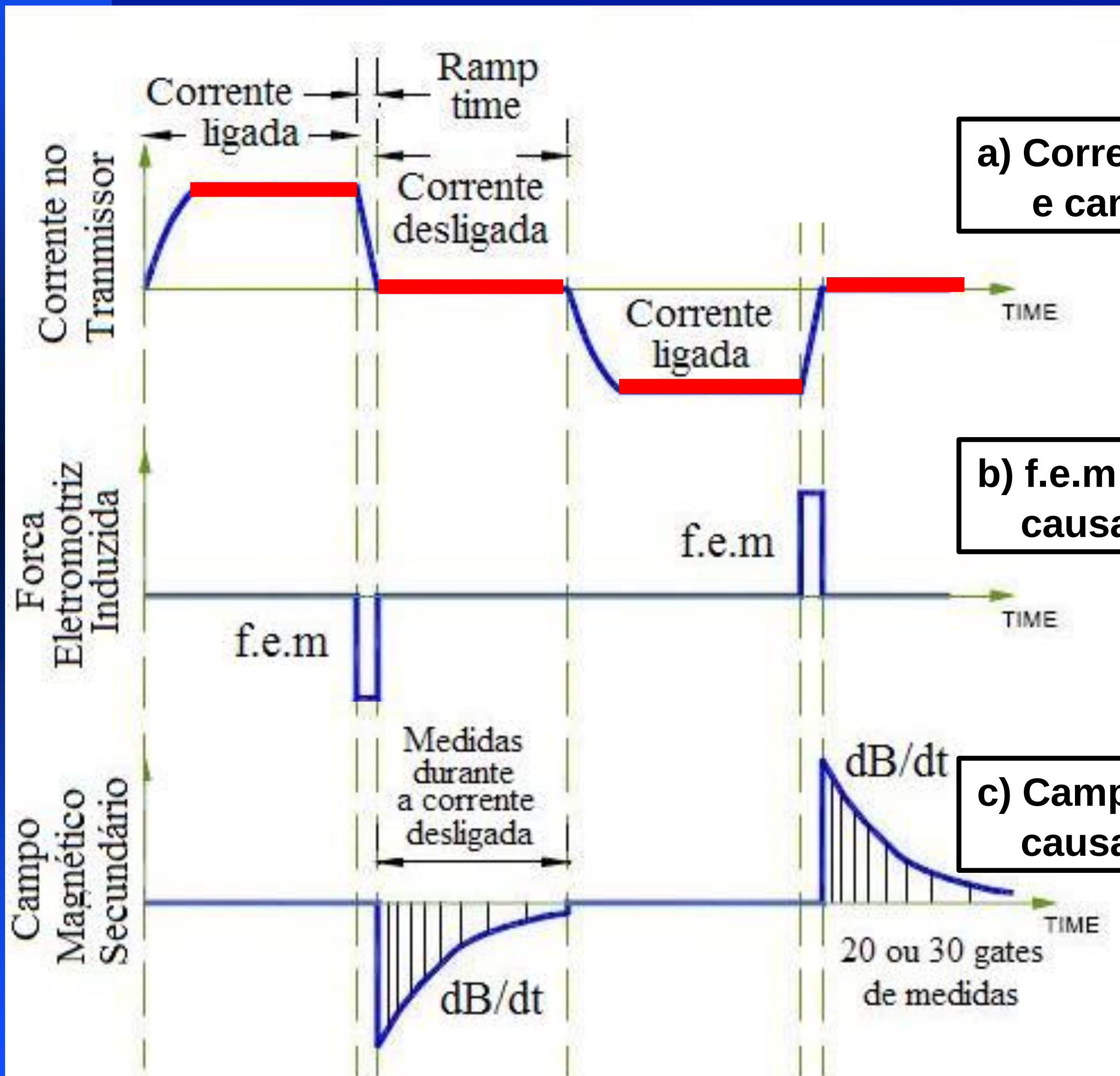
Princípios teóricos do método TDEM

✓ Quando a corrente do “loop” é subtamente cortada, pela Lei de Indução de Faraday as correntes induzidas no substrato se propagam na forma do “loop” transmissor.

→ **Efeito Fumaça**



Princípios teóricos do método TDEM

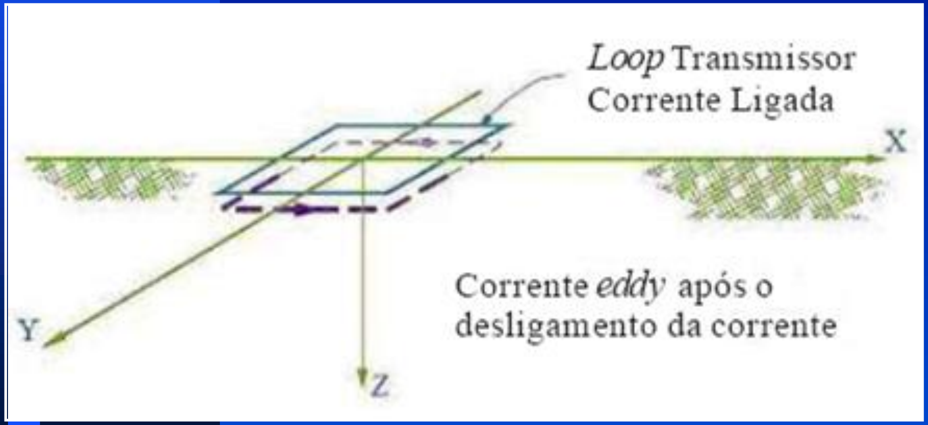


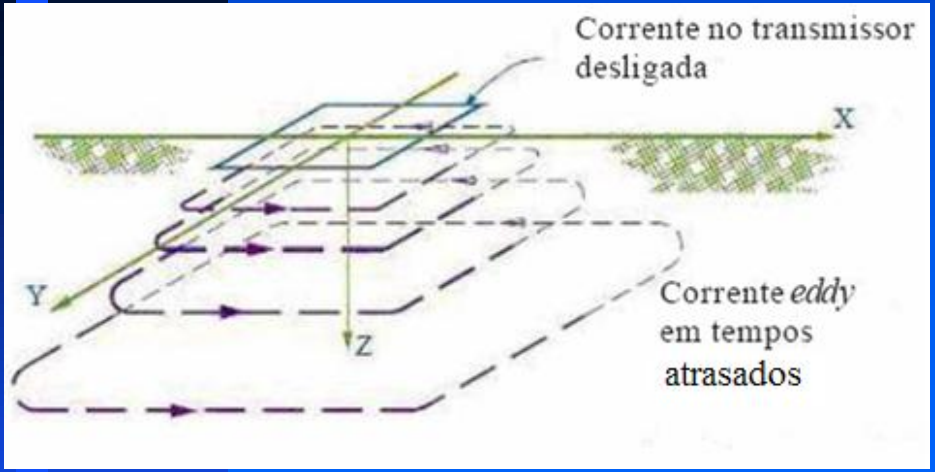
a) Corrente no loop transmissor e campo magnético primário

b) f.e.m induzida na Terra causada pela corrente no Tx

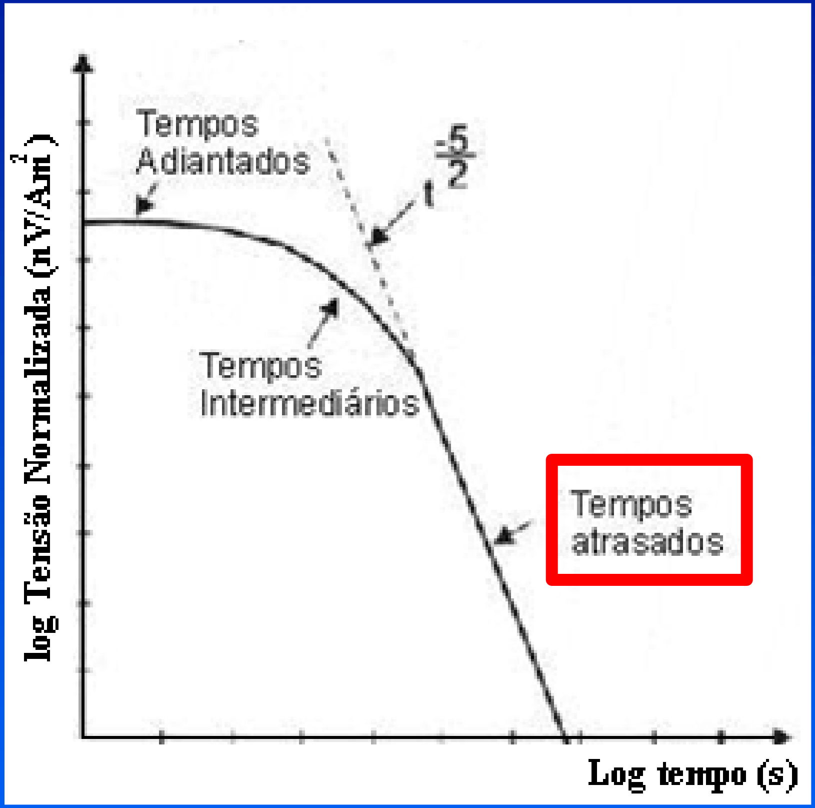
c) Campo magnético secundário causado pelas correntes Eddy

Princípios teóricos do método TDEM





Comportamento das Correntes Eddy



Comportamento do sinal medido pela bobina Receptora

Cálculo da resitividade aparente

Nos tempos atrasados, a voltagem medida é uma função que está relacionada com a condutividade e com o tempo, dada por:

$$e(t) = \frac{k_1 M \sigma^{3/2}}{t^{5/2}} \quad \Rightarrow \quad \rho_a(t) = \frac{k_1 M^{2/3}}{e(t)^{2/3} t^{5/3}}$$

onde:

$k_1 = \mu_0^{5/3} M / 20\pi$, sendo $\mu_0 = 4\pi \times 10^{-7}$ H/m;

t = tempo (segundos);

M = Momento do magnético, $M = IA$ ($A.m^2$);

ρ_a = resistividade elétrica (Ohm.m);

$e(t)$ = Tensão Normalizada medida por uma bobina unitária de área 1 m^2.

Profundidade de investigação

$$d(t) = \sqrt{\frac{4{,}37\,t}{\sigma\,\mu_0}}$$

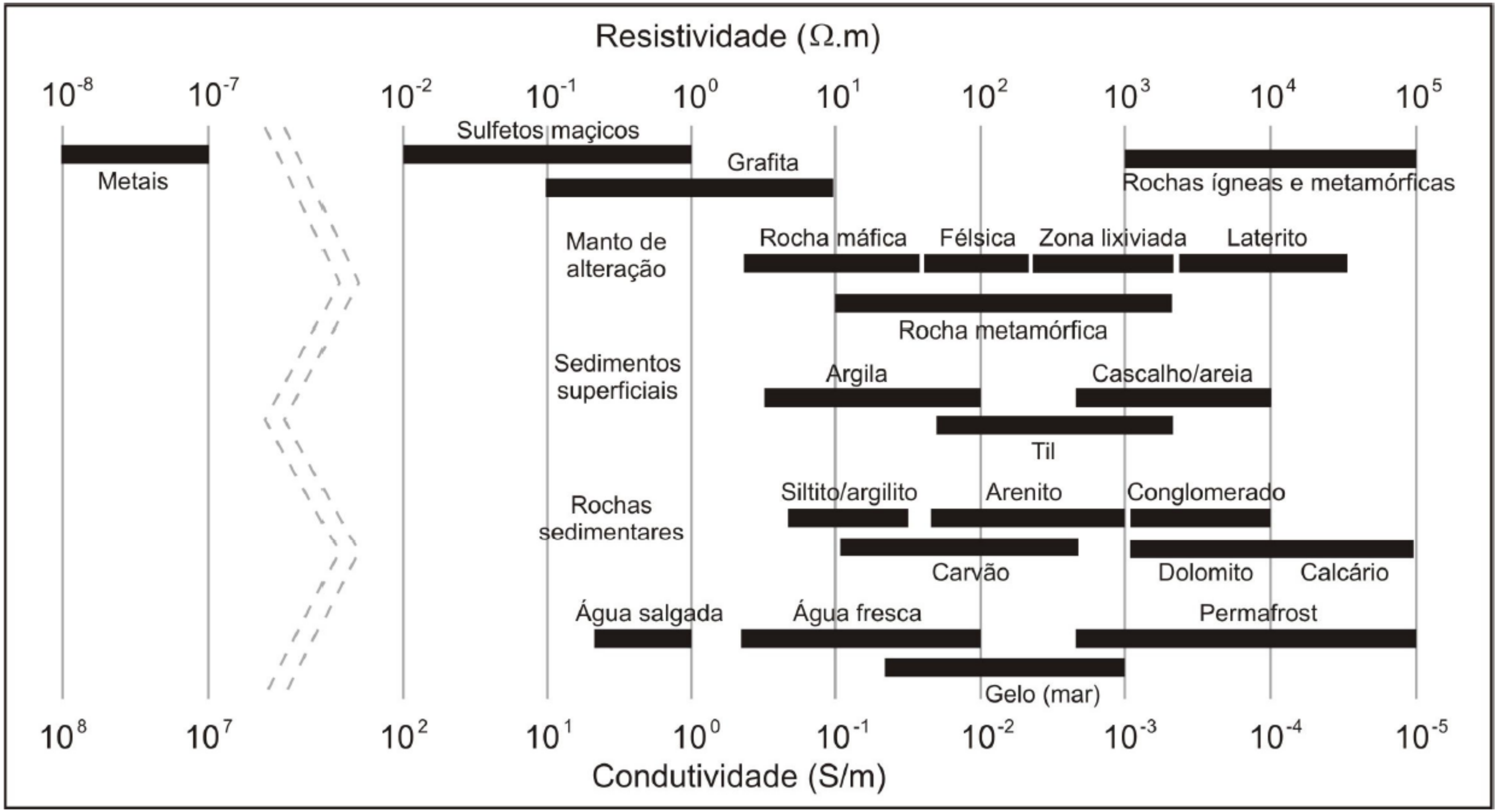
$$\delta(f) = 503{,}3\sqrt{\frac{\rho}{f}}$$

Skin depth

Profundidade de investigação: 5 – 5000 m de profundidade.

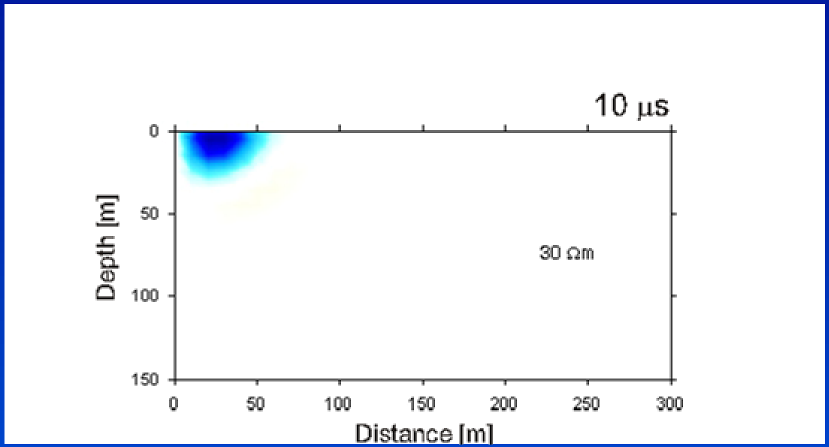
A profundidade de investigação depende de vários fatores:

- ✓ **resistividade elétrica do meio**
- ✓ **corrente no loop transmissor (potência do gerador)**
- ✓ **largura do loop**
- ✓ **freqüência de repetição**

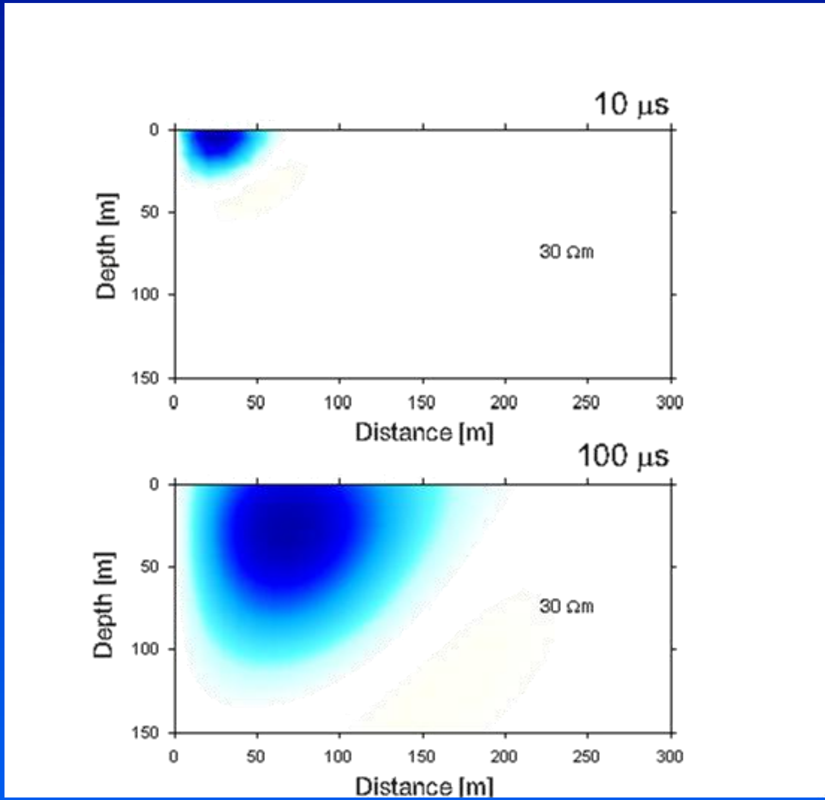


Resistividade (Ω.m)
10-8
10-7
10-2
10-1
10 0
10 1
10 2
10 3
10 4
10 5
Sulfetos maçicos
Metais
Grafita
Rochas ígneas e metamórficas
Manto de alteração
Rocha máfica
Félsica
Zona lixiviada
Laterito
Rocha metamórfica
Sedimentos superficiais
Argila
Cascalho/areia
Til
Rochas sedimentares
Siltito/argilito
Arenito
Conglomerado
Carvão
Dolomito
Calcário
Água salgada
Água fresca
Permafrost
Gelo (mar)
10 8
10 7
10 2
10 1
10 0
10-1
10-2
10-3
10-4
10-5
Condutividade (S/m)

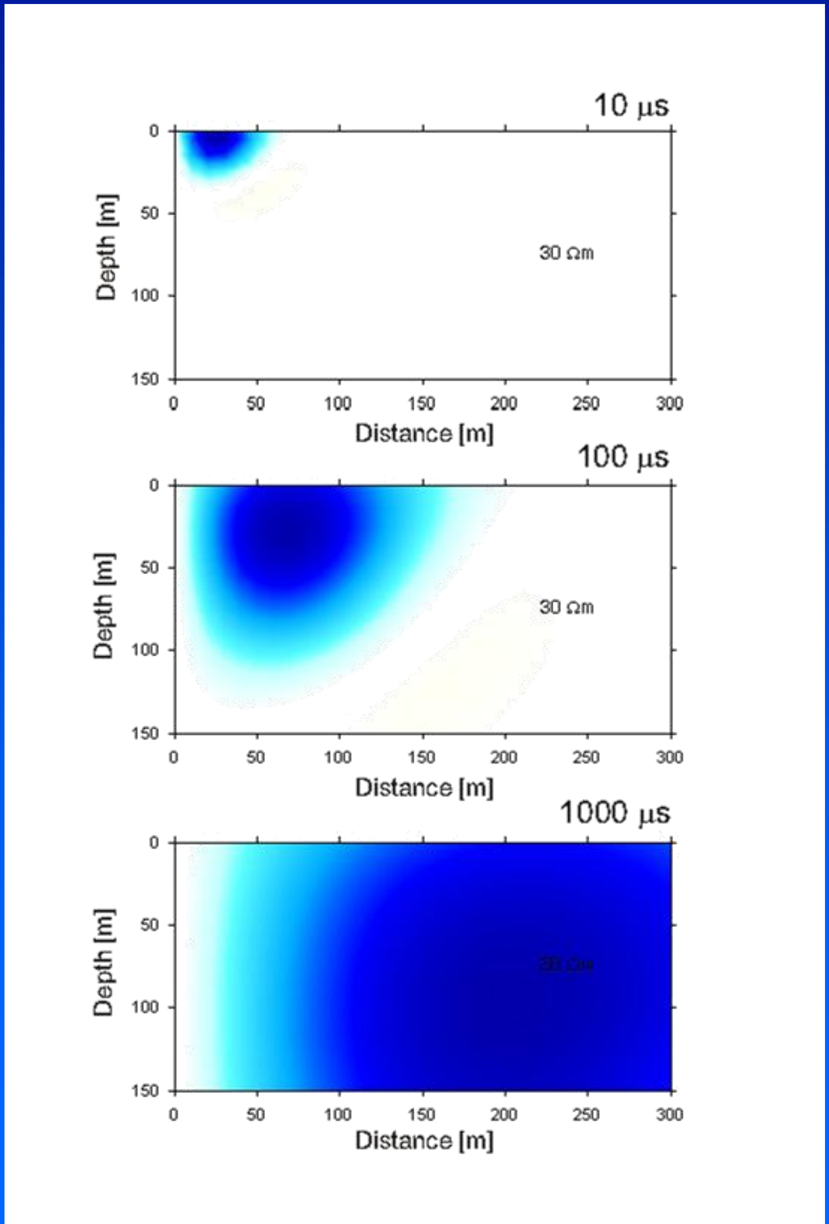
Current diffusion in the Earth



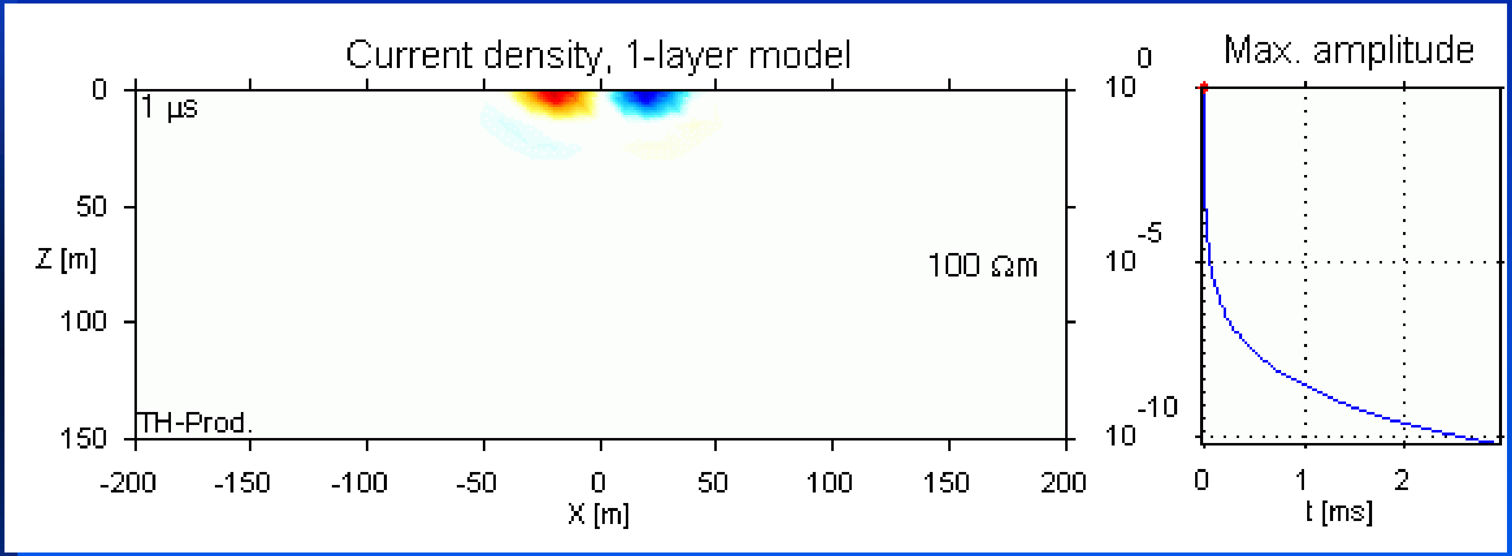
Current diffusion in the Earth



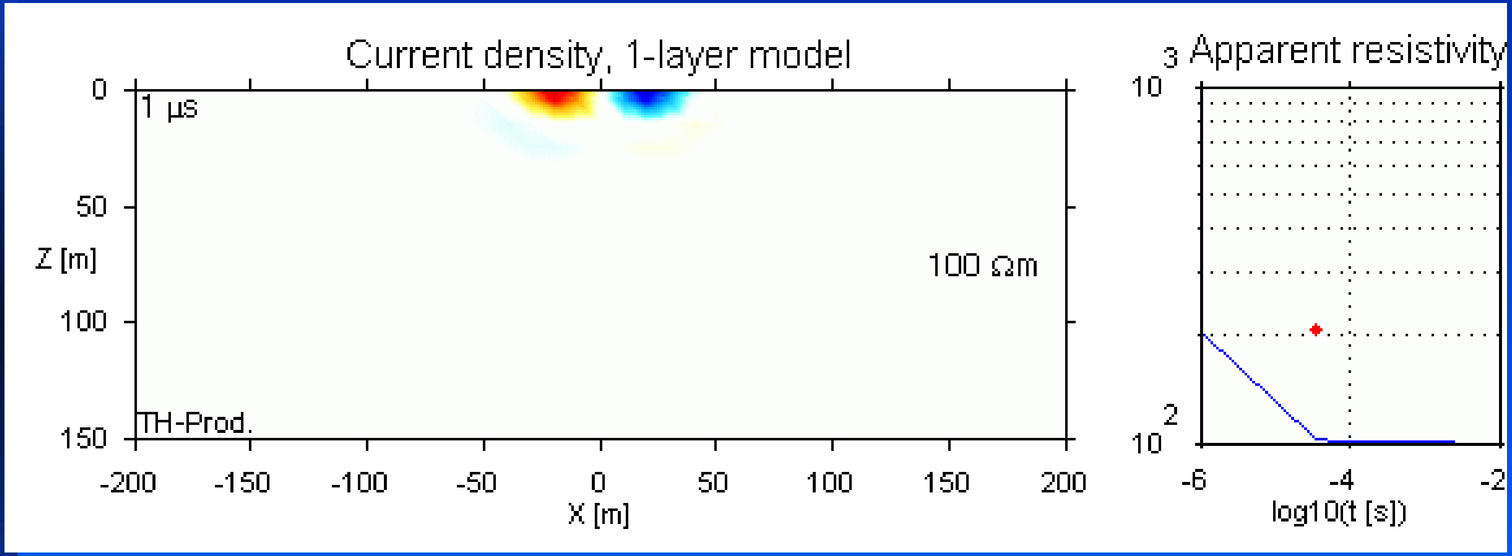
Current diffusion in the Earth



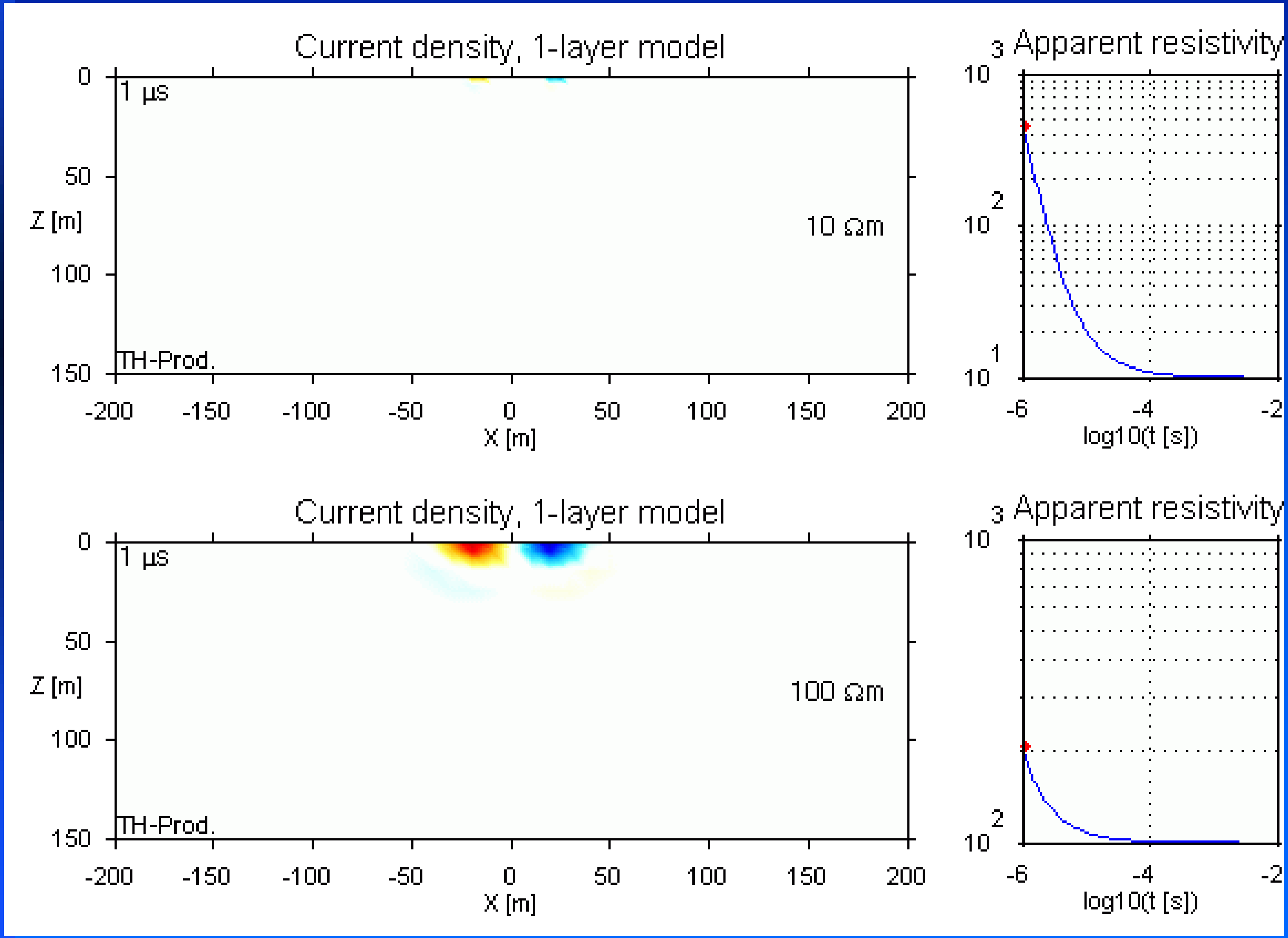
Current diffusion in the Earth – 10 ohm.m



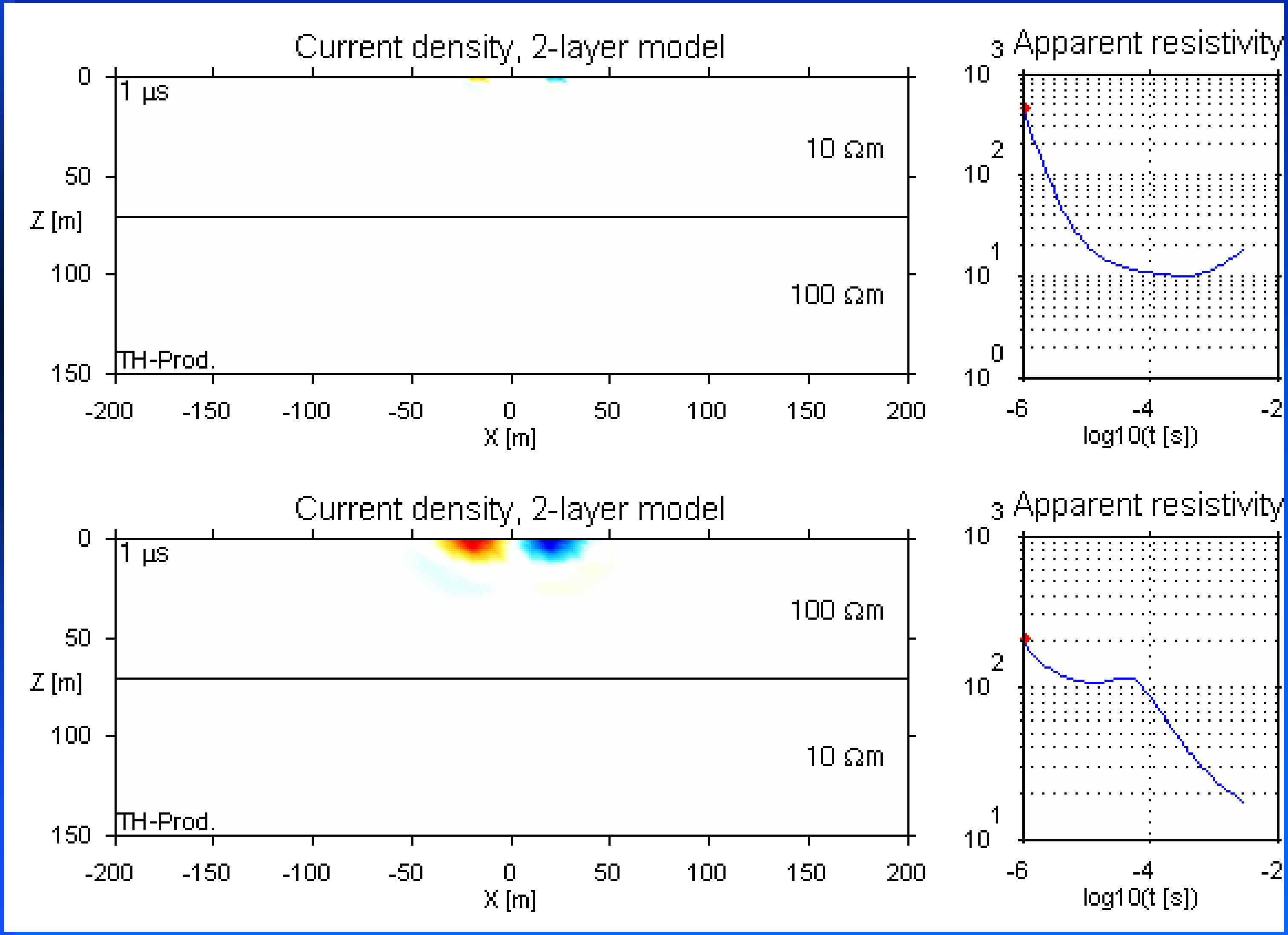
Current diffusion in the Earth – 100 ohm.m



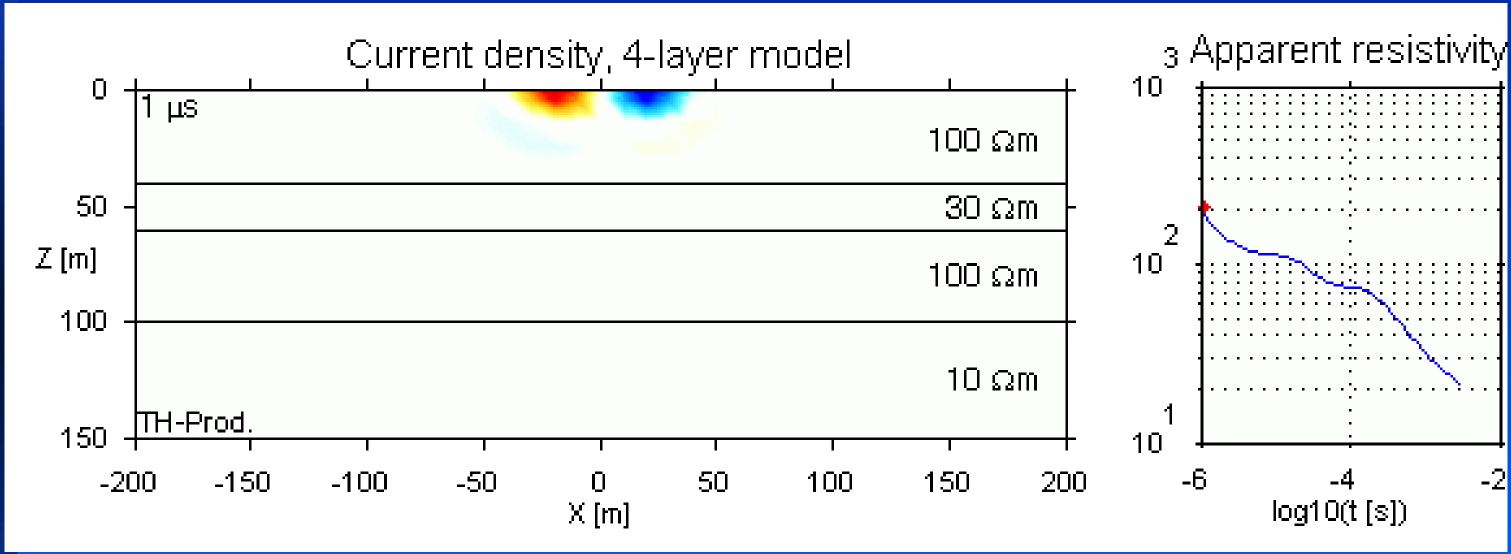
Current diffusion in the Earth – 10/100 ohm.m



Current diffusion in the Earth



Current diffusion in the Earth



Aplicações do método TDEM

- ✓ **Exploração de água subterrânea:** mapeamento de aqüíferos sedimentares, zonas de fraturas em rochas cristalinas, intrusão de água salgada próximo à aqüífero costeiro

- ✓ **Estudos de contaminação do meio ambiente**

- ✓ **Exploração mineral:** sulfetos maciços

- ✓ **Estudos geotermais**

- ✓ **Corrigir o "static shift" nas sondagens MT**

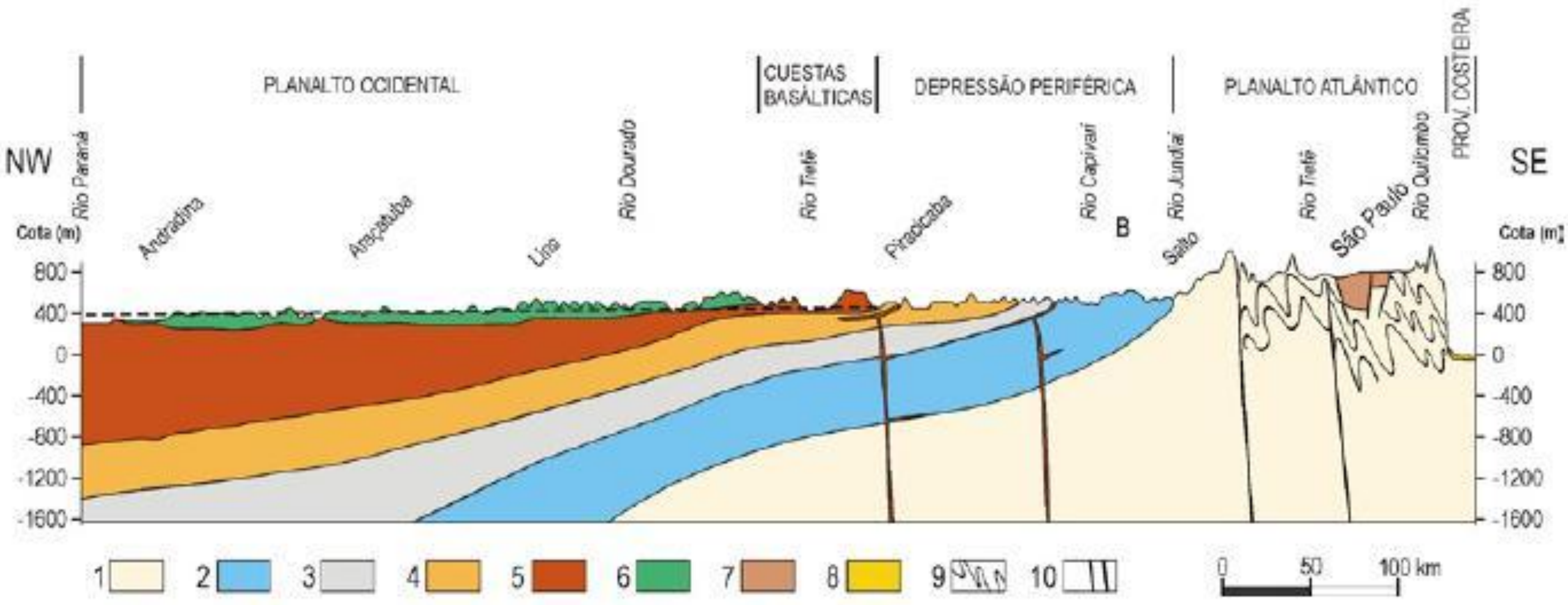
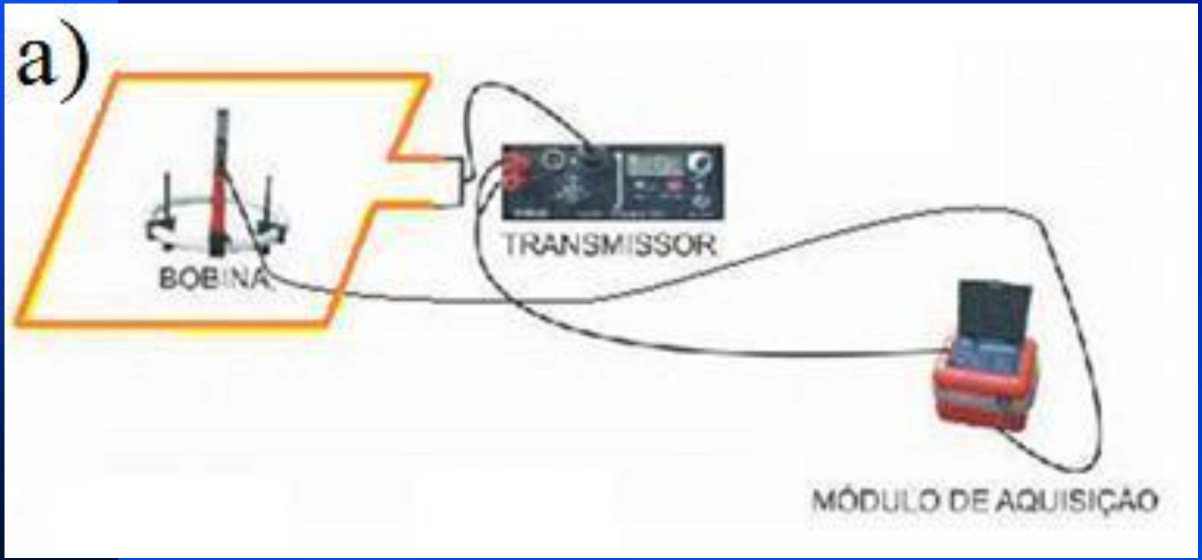
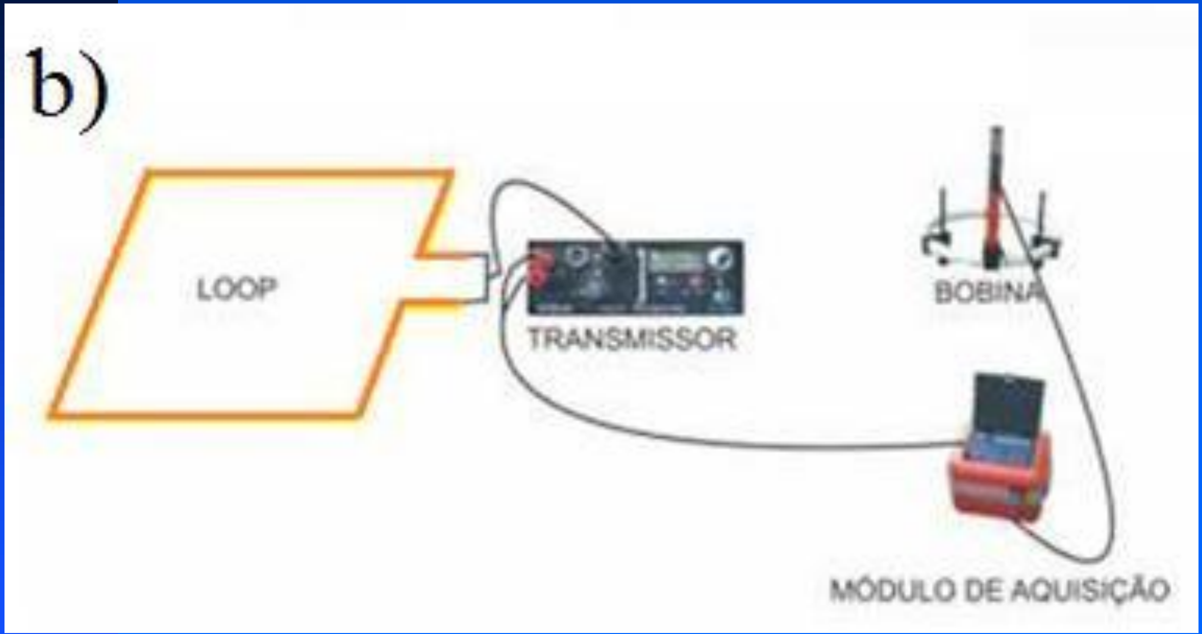


Figura 12 – *Perfil geológico A-B através da Bacia do Paraná, com indicação da seqüência estratigráfica das camadas, a partir de: (1) Embasamento Cristalino– rochas ígneas e metamórficas; (2) Grupo Tubarão – sedimentos glaciais e pós-glaciais; (3) Grupo Passa Dois – sedimentos marinhos; (4) Formações Pirambóia e Botucatu – arenitos fluviais a desérticos; (5) Formação Serra Geral – basaltos de inundação, e corpos intrusivos básicos; (6) Grupo Bauru – arenitos fluviais; (7) Sedimentos neogênicos; (8) Sedimentos marinhos; (9) Estruturas do embasamento; (10) Falhas (Modif. de Gov. Est. São Paulo. / Cons. Est. Rec. Hídricos 2005)*

Técnicas de aquisição dos dados: Terrestre



Loop central



Loop loop

Equipamento – TEM-47

Protem D

Transmissor (< 2,5 A)

Bobina Receptora

(Geonics)

Equipamento – TEM-57-MK2

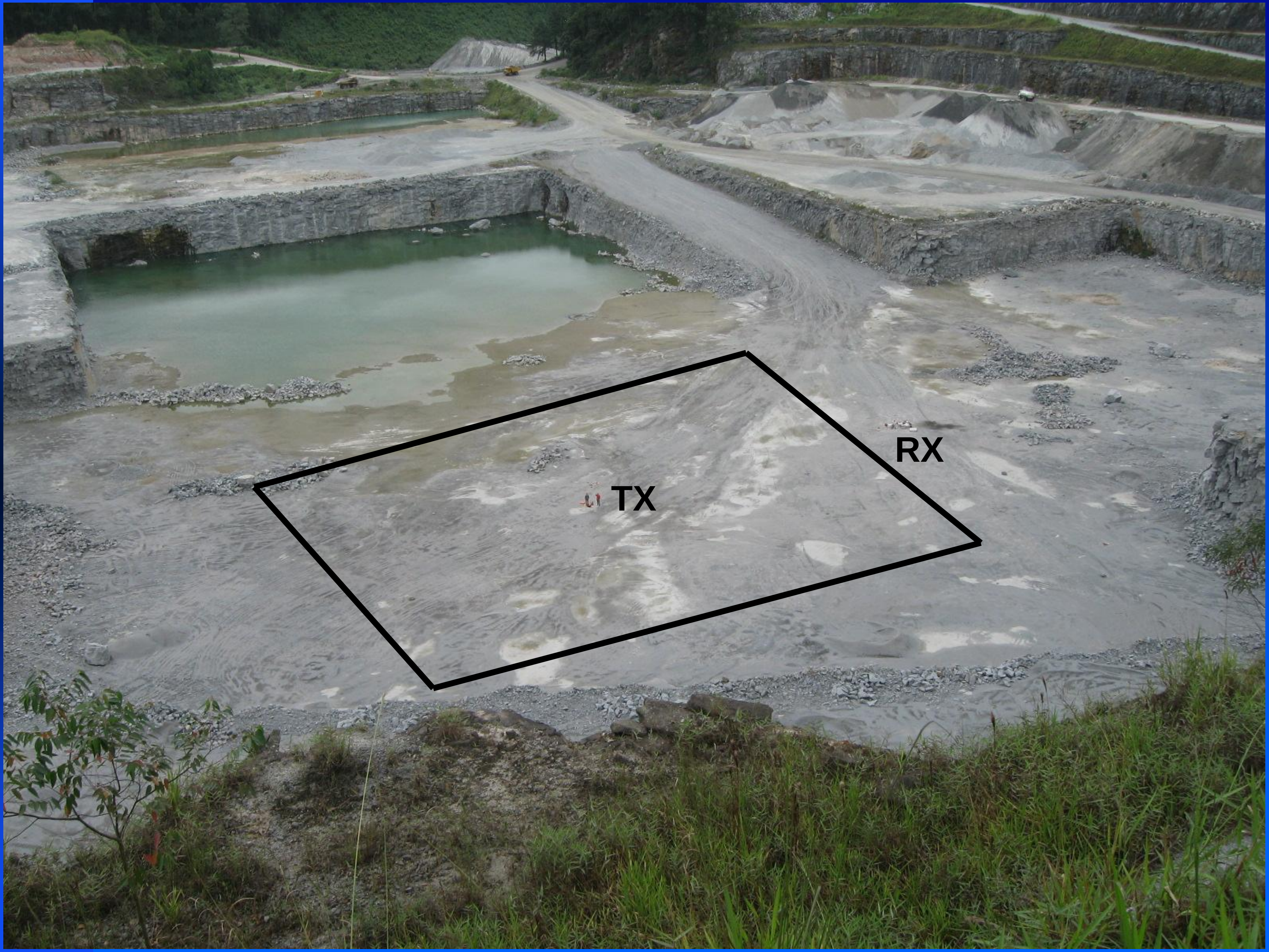
Protem D

Transmissor (< 30 A)

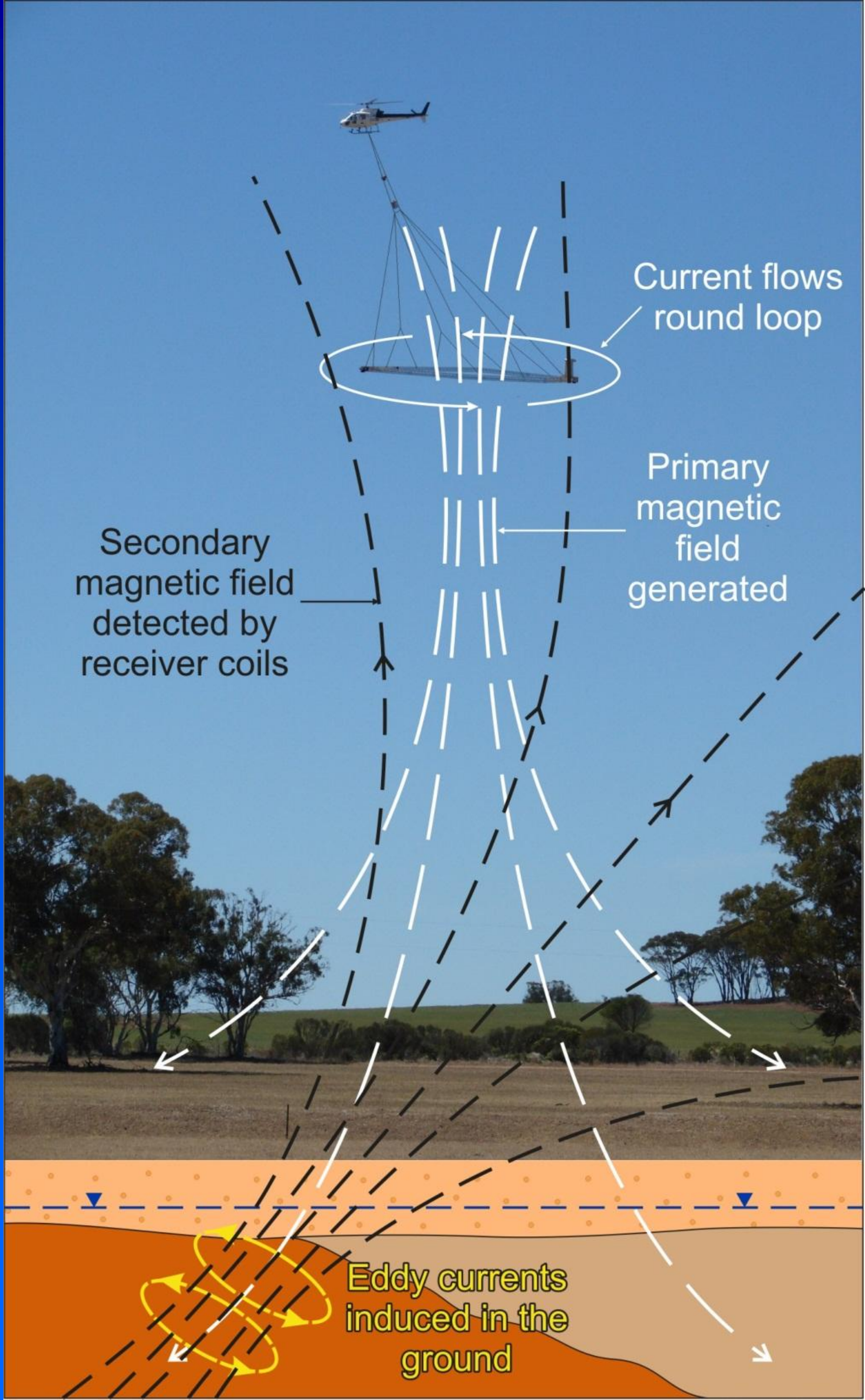
Gerador

Bobina Receptora

(Geonics)

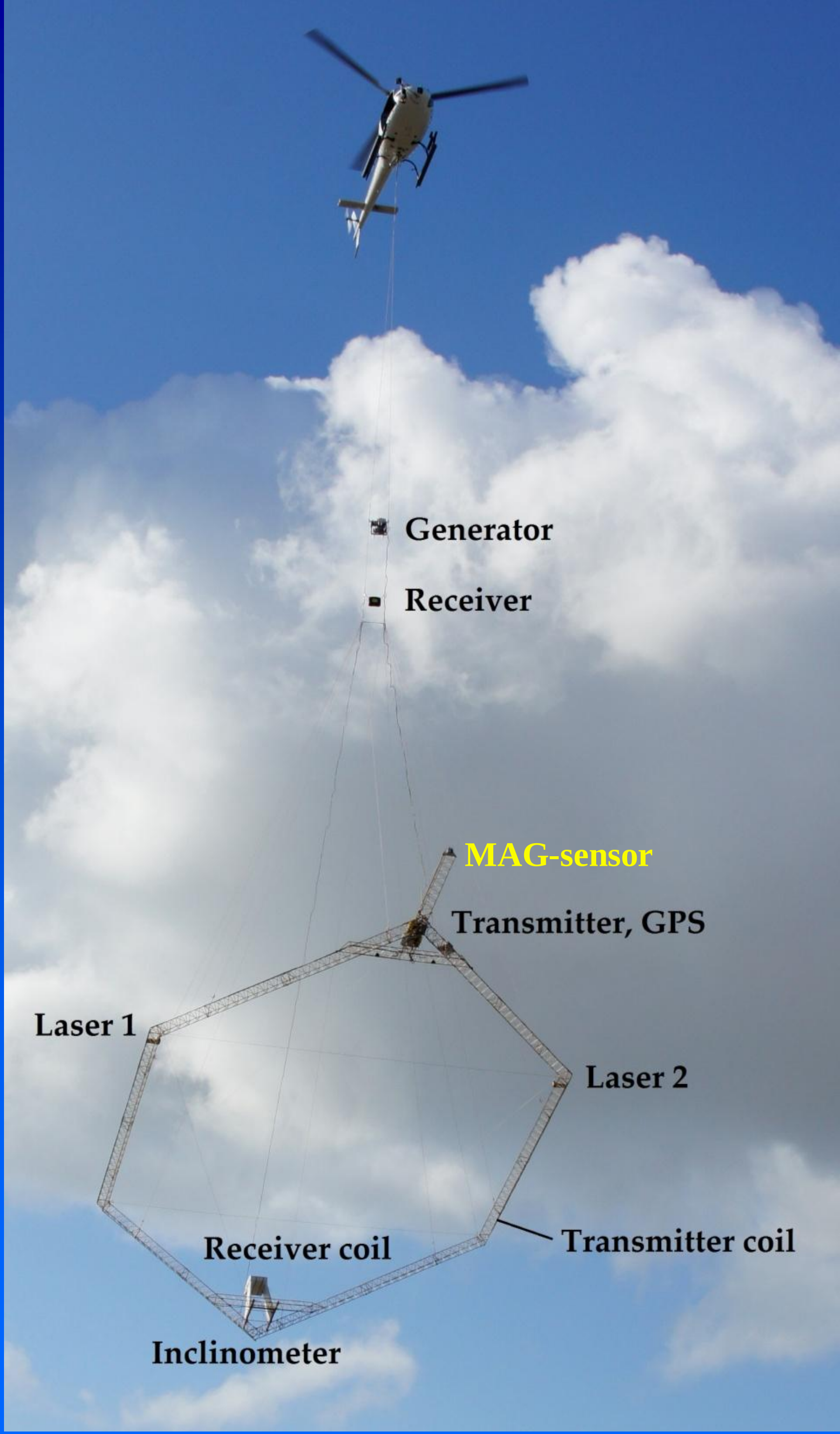

RX
TX

TDEM Aéreo

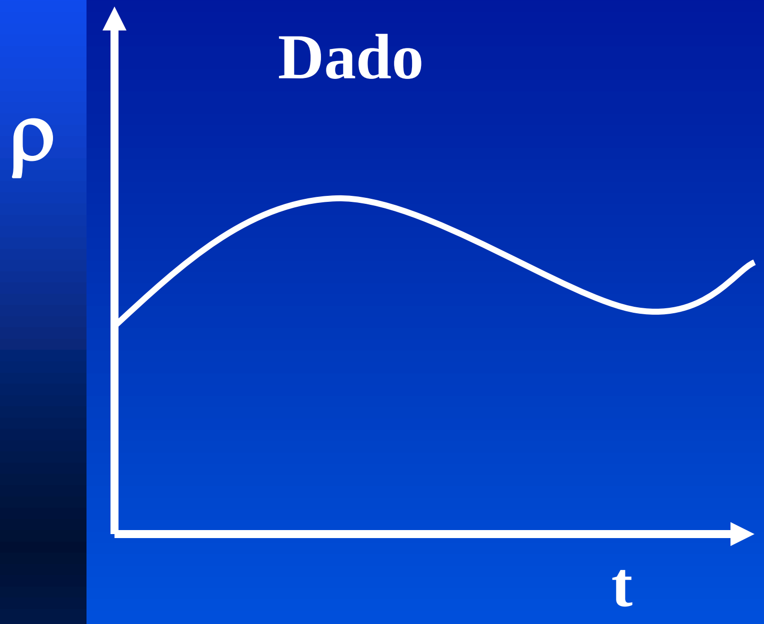


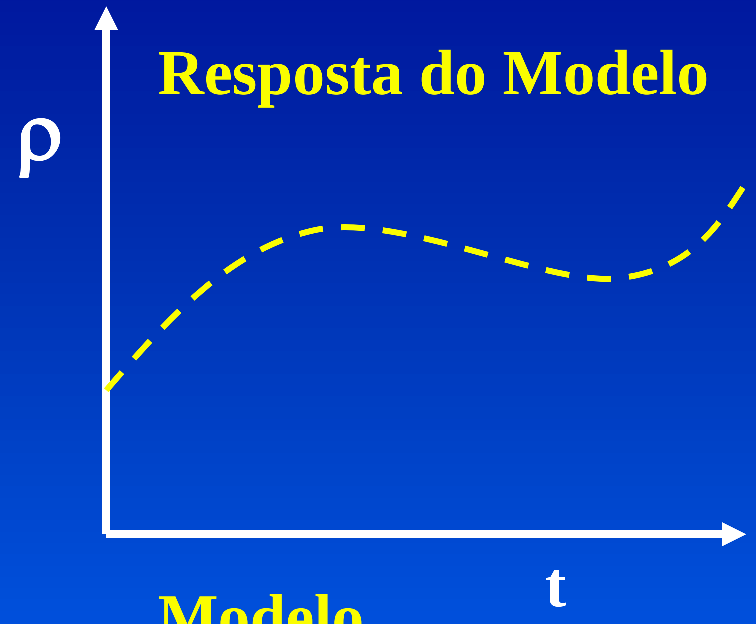
Current flows round loop
Primary magnetic field generated
Secondary magnetic field detected by receiver coils
Eddy currents induced in the ground

SkyTEM

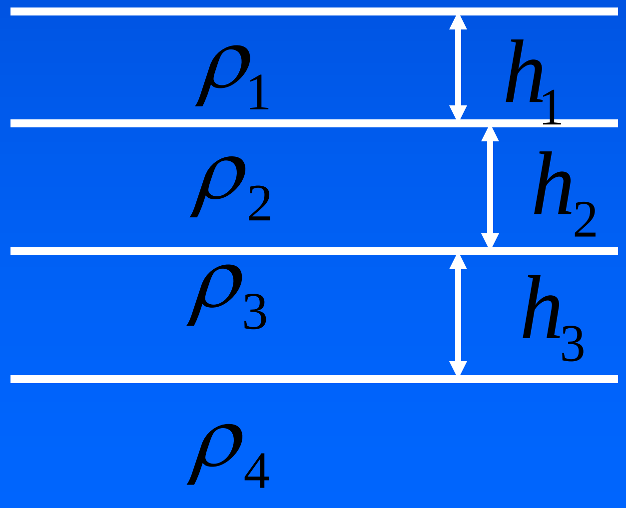

Generator
Receiver
MAG-sensor
Transmitter, GPS
Laser 1
Laser 2
Receiver coil
Transmitter coil
Inclinometer

Inversão:

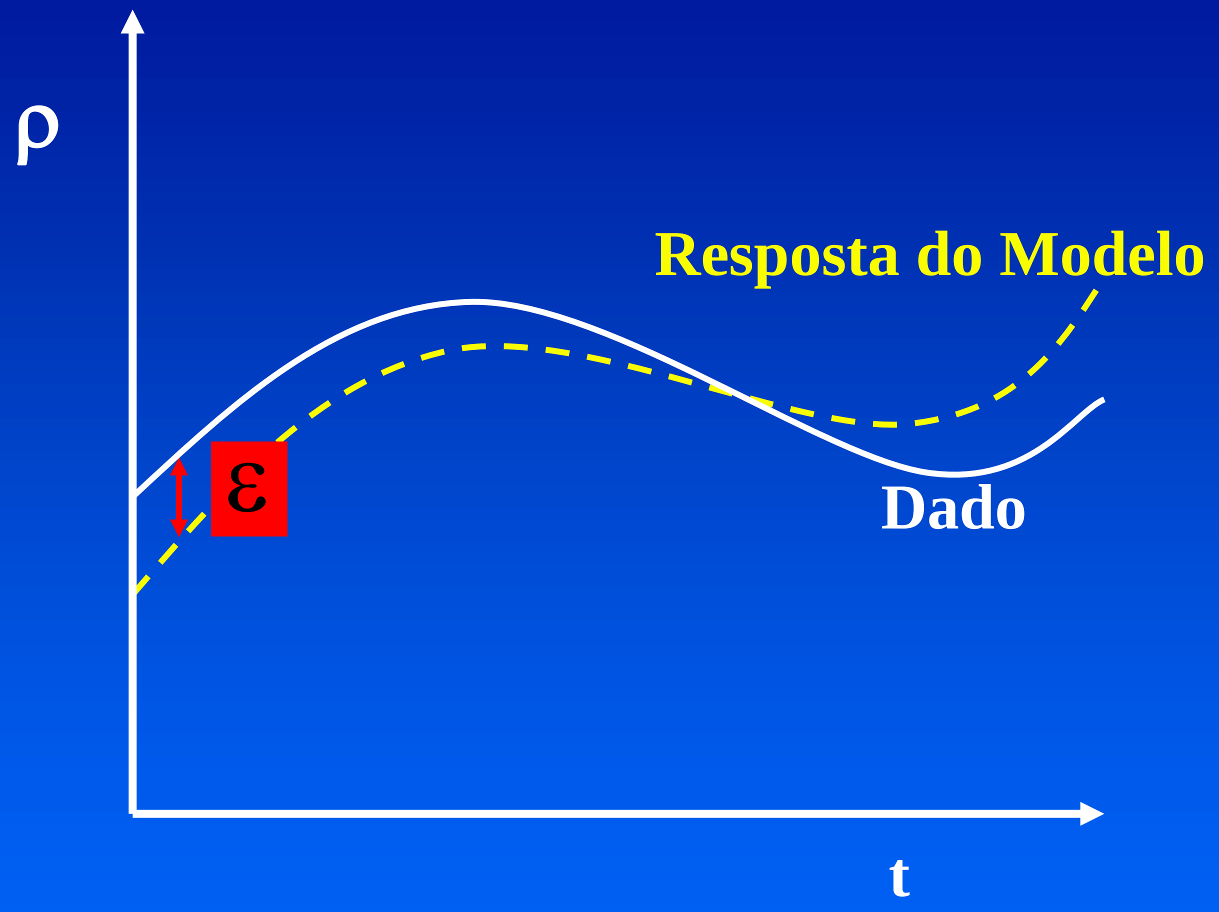




Modelo



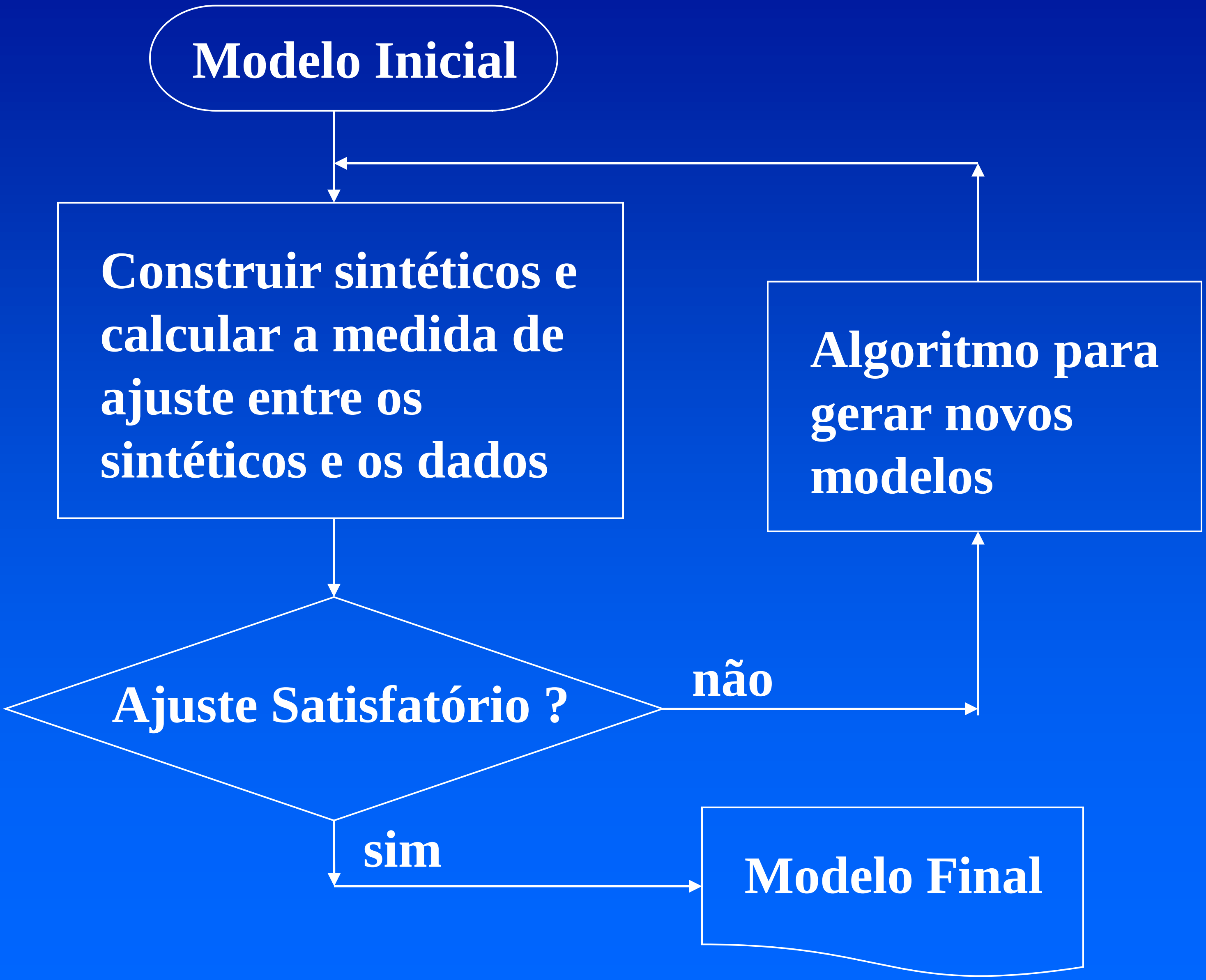
Comparando os dados e a resposta do modelo:



Erro Mínimo → Melhor Modelo

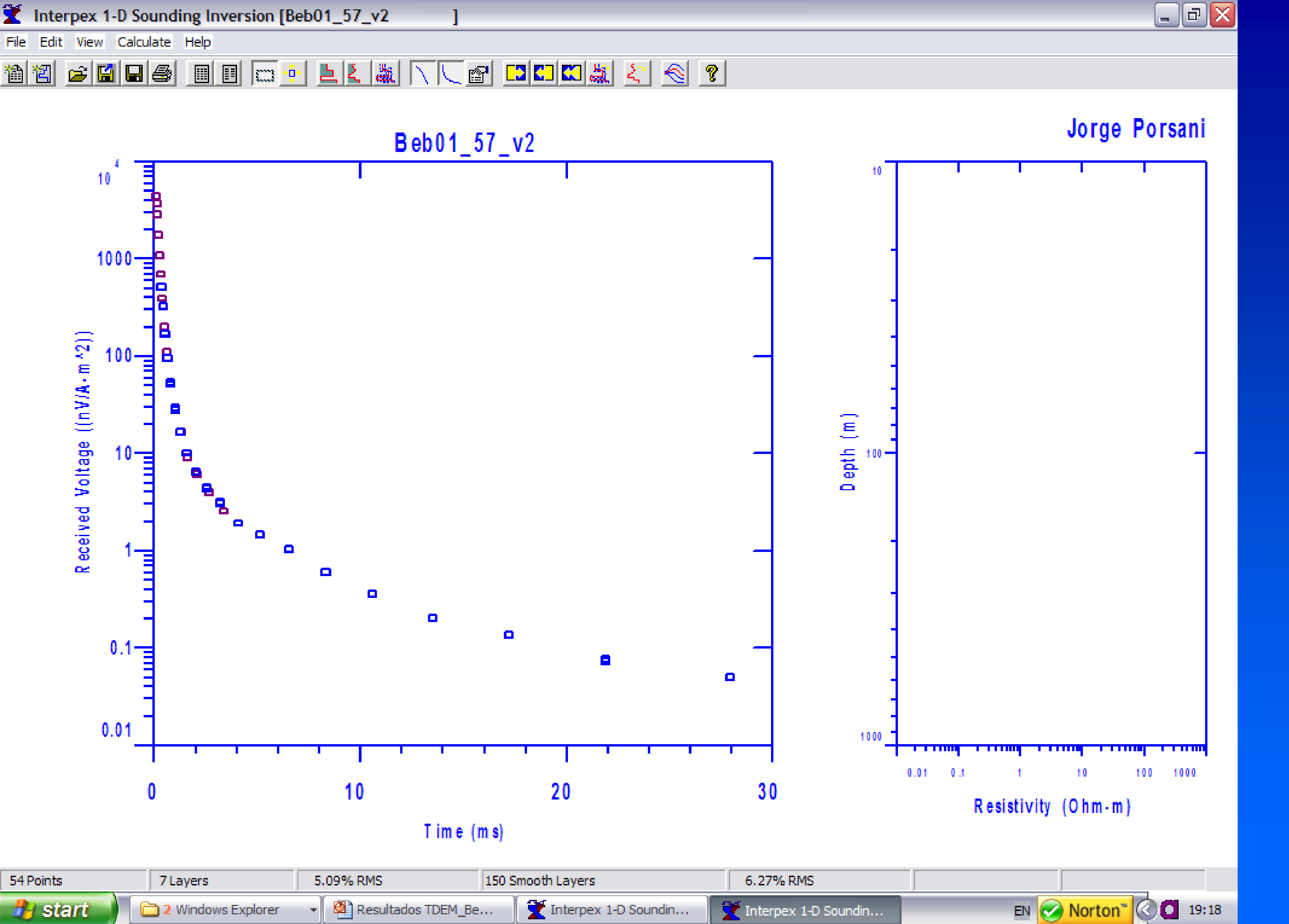
Critério de Minimização → Método dos Mínimos Quadrados

Fluxograma de algoritmo de inversão

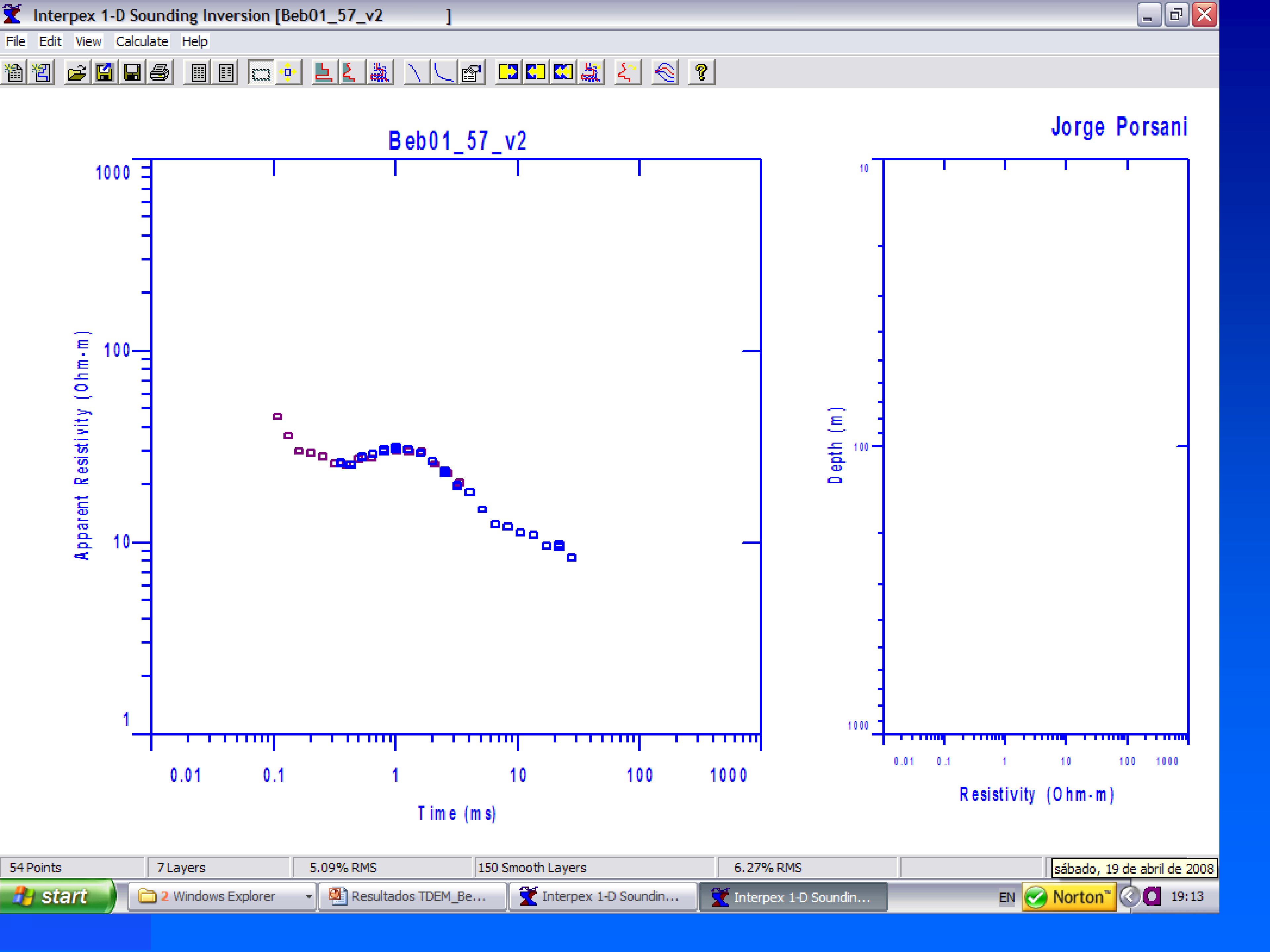


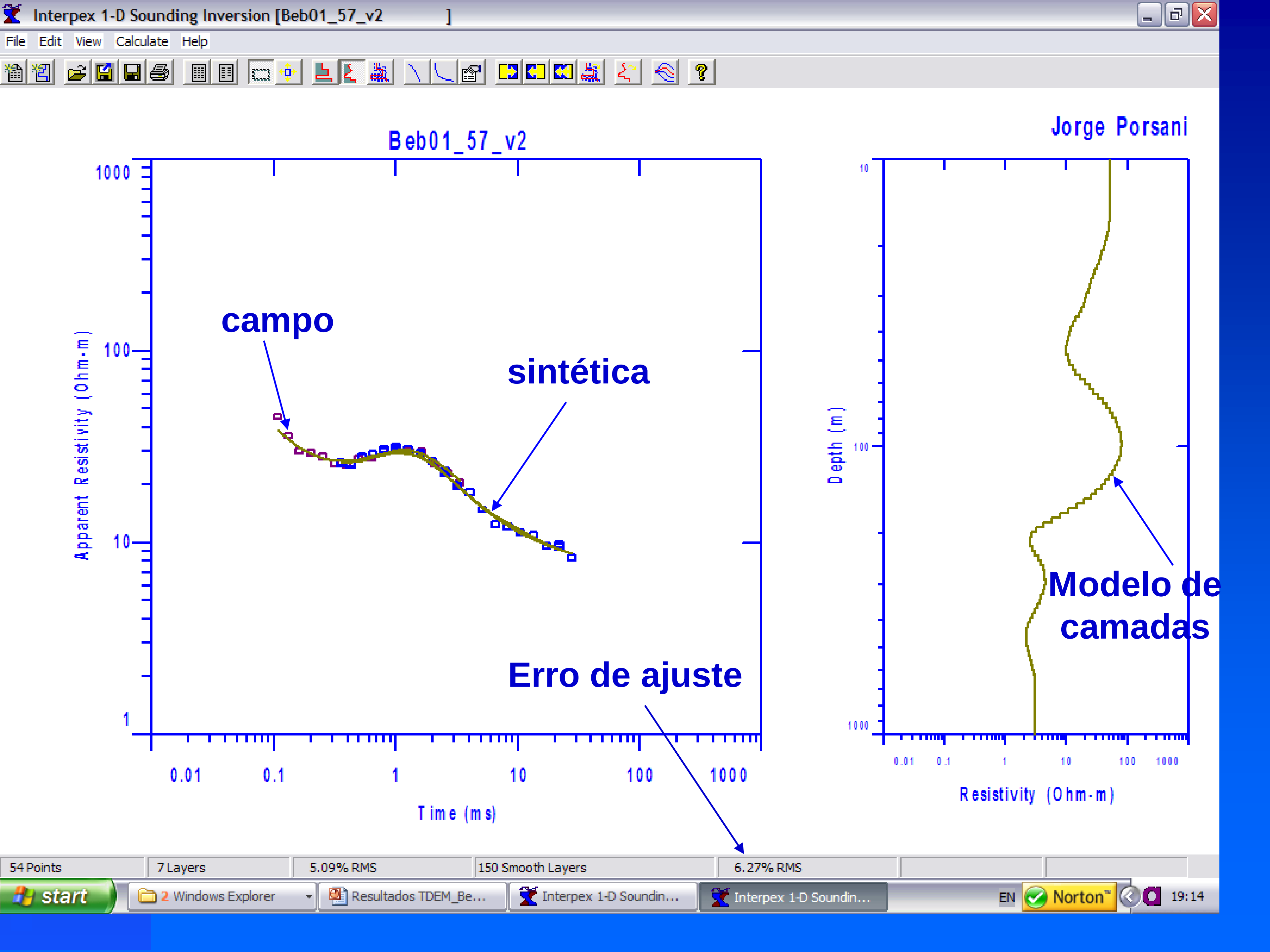
Apresentação dos resultados

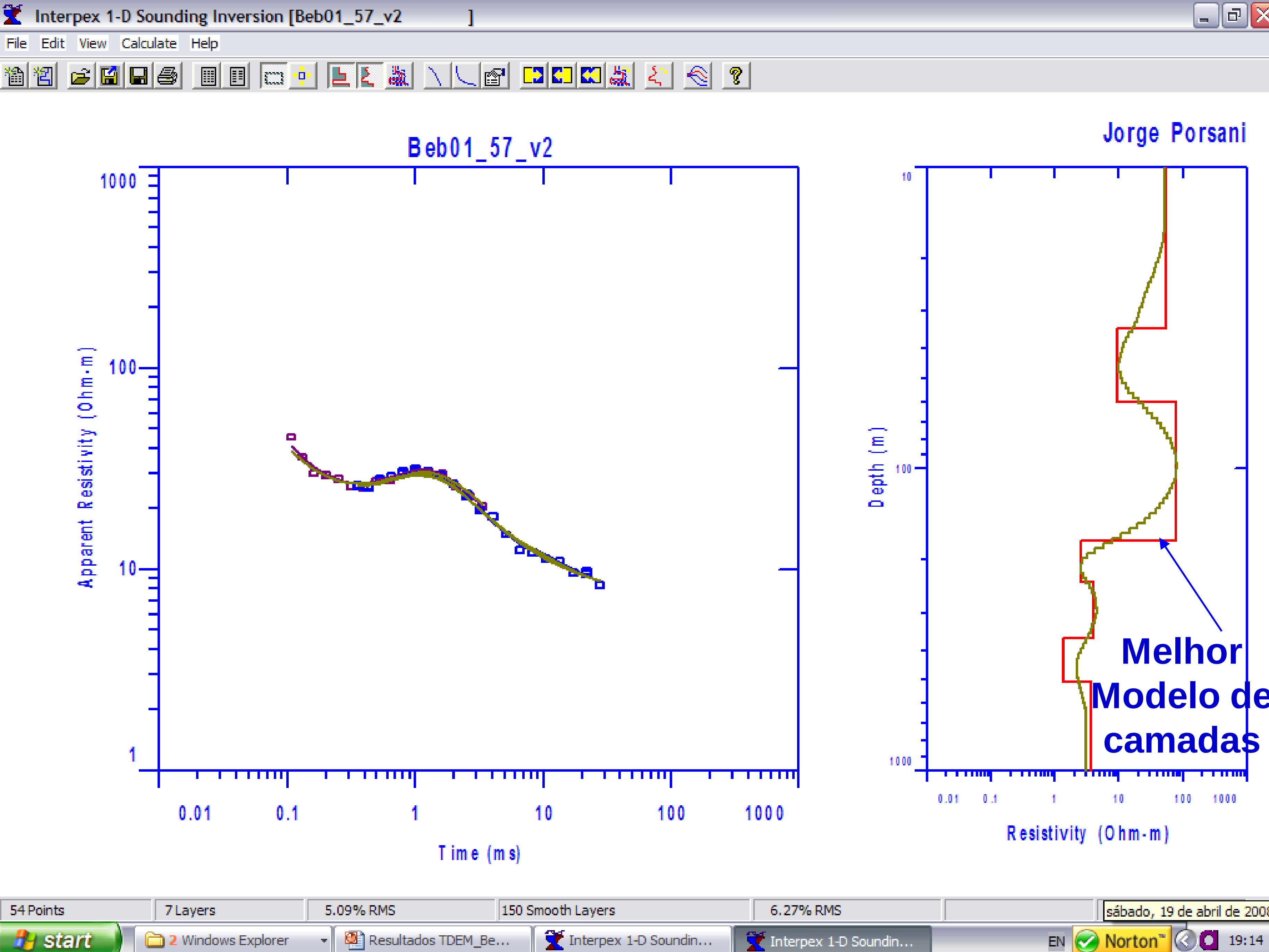
- ✓ “plot” em escala log-log do decaimento transiente da voltagem (microvolts) pelo tempo (milisegundos);
- ✓ “plot” em escala log-log da resistividade aparente (Ohm.m) pelo tempo (milisegundos);
- ✓ perfil de resistividade aparente (Ohm.m) pelo tempo (milisegundos) ou profundidade (m);
- ✓ mapa de contornos para um tempo selecionado para todas as estações na área do levantamento;



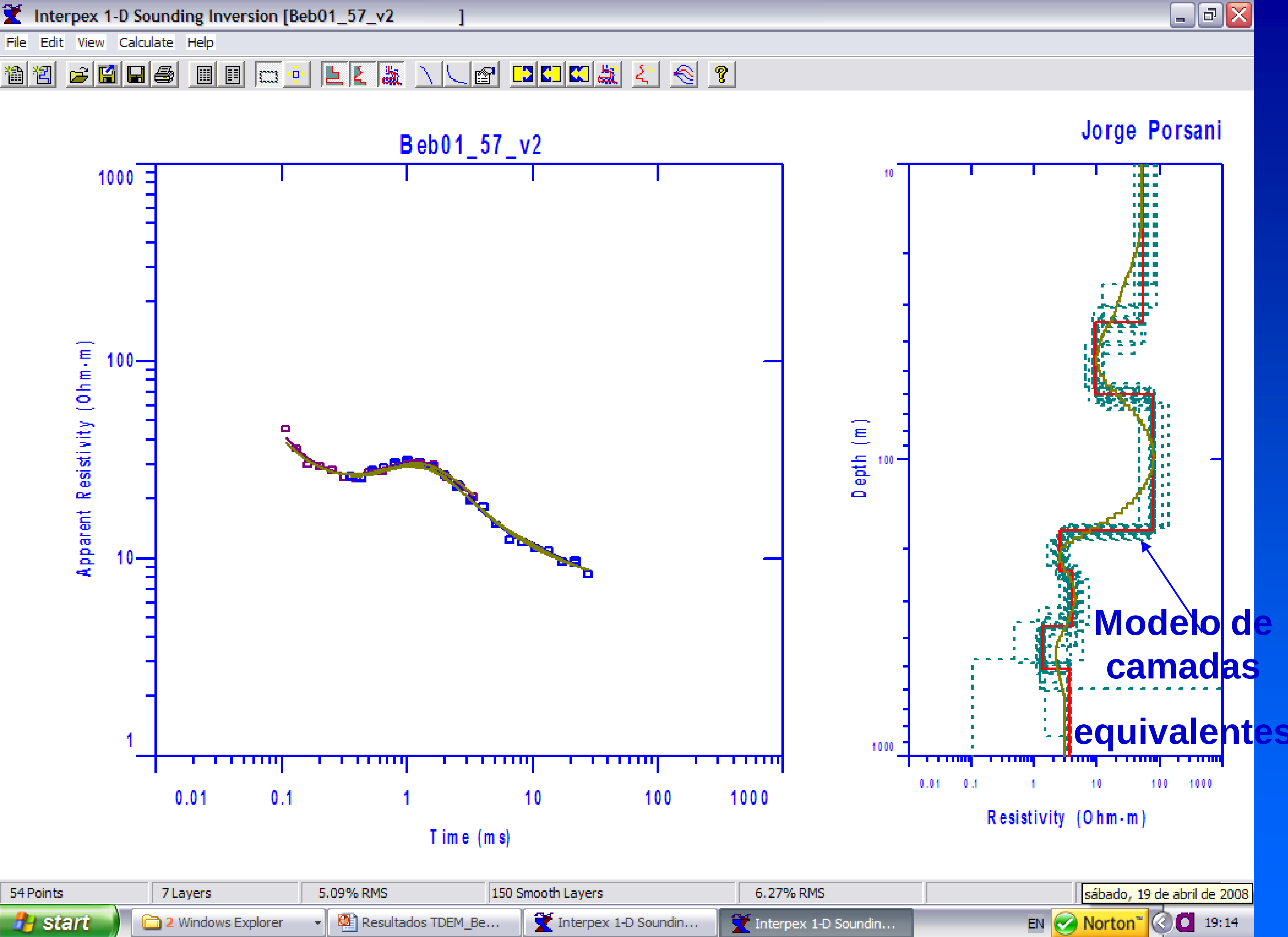
Interpex 1-D Sounding Inversion [Beb01_57_v2]
File Edit View Calculate Help
Beb01_57_v2
Jorge Porsani
Received Voltage ((nV/A·m^2))
10^4
1000
100
10
1
0.1
0.01
0
10
20
30
Time (ms)
Depth (m)
10
100
1000
0.01
0.1
1
10
100
1000
Resistivity (Ohm-m)
54 Points
7 Layers
5.09% RMS
150 Smooth Layers
6.27% RMS
start
2 Windows Explorer
Resultados TDEM_Be...
Interpex 1-D Soundin...
Interpex 1-D Soundin...
EN
Norton
19:18


Interpex 1-D Sounding Inversion [Beb01_57_v2]
File Edit View Calculate Help
Beb01_57_v2
Jorge Porsani
Apparent Resistivity (Ohm·m)
1000
100
10
1
0.01
0.1
1
10
100
1000
Time (ms)
Depth (m)
10
100
1000
0.01
0.1
1
10
100
1000
Resistivity (Ohm-m)
54 Points
7 Layers
5.09% RMS
150 Smooth Layers
6.27% RMS
sábado, 19 de abril de 2008
start
2 Windows Explorer
Resultados TDEM_Be...
Interpex 1-D Soundin...
Interpex 1-D Soundin...
EN
Norton
19:13


Interpex 1-D Sounding Inversion [Beb01_57_v2]
File Edit View Calculate Help
Beb01_57_v2
Jorge Porsani
campo
sintética
Modelo de camadas
Erro de ajuste
Apparent Resistivity (Ohm-m)
Time (ms)
Depth (m)
Resistivity (Ohm-m)
54 Points
7 Layers
5.09% RMS
150 Smooth Layers
6.27% RMS
start
2 Windows Explorer
Resultados TDEM_Be...
Interpex 1-D Soundin...
Interpex 1-D Soundin...
EN
Norton
19:14



Interpex 1-D Sounding Inversion [Beb01_57_v2]
File Edit View Calculate Help
Beb01_57_v2
Jorge Porsani
Apparent Resistivity (Ohm-m)
1000
100
10
1
0.01
0.1
1
10
100
1000
Time (ms)
Depth (m)
10
100
1000
Resistivity (Ohm-m)
Melhor Modelo de camadas
54 Points
7 Layers
5.09% RMS
150 Smooth Layers
6.27% RMS
sábado, 19 de abril de 2008
start
2 Windows Explorer
Resultados TDEM_Be...
Interpex 1-D Soundin...
Interpex 1-D Soundin...
EN
Norton
19:14



Interpex 1-D Sounding Inversion [Beb01_57_v2]
File Edit View Calculate Help
Beb01_57_v2
Jorge Porsani
Apparent Resistivity (Ohm-m)
1000
100
10
1
0.01
0.1
1
10
100
1000
Time (ms)
Depth (m)
10
100
1000
0.01
0.1
1
10
100
1000
Resistivity (Ohm-m)
Modelo de camadas equivalentes
54 Points
7 Layers
5.09% RMS
150 Smooth Layers
6.27% RMS
sábado, 19 de abril de 2008
start
2 Windows Explorer
Resultados TDEM_Be...
Interpex 1-D Soundin...
Interpex 1-D Soundin...
EN
Norton
19:14

8. Vantagens do método TDEM

As principais vantagens do método TDEM em relação às sondagens no domínio da freqüência são:

- ✓ tempo reduzido para a execução do levantamento
- ✓ as medidas são feitas com os transmissores desligados, ou seja, na ausência de um campo EM primário
- ✓ não usa eletrodos, portanto não ocorrem problemas de “static shift” comum nas sondagens MT
- ✓ detecta melhor as camadas condutoras

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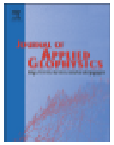

TDEM survey in urban environmental for hydrogeological study at USP campus in São Paulo city, Brazil

Jorge Luís Porsani [a,*], Cassiano Antonio Bortolozo [a], Emerson Rodrigo Almeida [a], Esther Novais Santos Sobrinho [a], Thiago Gomes dos Santos [b]

[a] *Universidade de São Paulo (USP), Instituto de Astronomia, Geofísica e Ciências Atmosféricas (IAG), Departamento de Geofísica, Rua do Matão, 1226, Butantã, 05508-090, São Paulo, Brazil*
[b] *Geophysicist (IAG/USP), Geosoft, Brazil*

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IAG/USP Test Site
São Paulo City
Brazil

A B S T R A C T

In this work, some TDEM (Time Domain Electromagnetic) results at USP (*University of São Paulo*) *campus* in São Paulo city, Brazil, are presented. The data were acquired focusing on two mains objectives: (i) to map geoelectrical stratigraphy of São Paulo sedimentary basin, emphasizing on hydrogeological studies about sedimentary and crystalline aquifers, and (ii) to analyze the viability of TDEM data acquisition use in urban environment. The study area is located in São Paulo basin border, characterized by Resende and São Paulo formations, which are constituted by sand-clays sediments over a granite-gneissic basement. Two equipments were used in order to acquire database: Protem47 (low power), and Protem57-MK2 (high power). Capacitive noise affect obtained data with Protem47 due to the presence of metal pipes buried at IAG/USP (Institute of Astronomy, Geophysics, and Atmospheric Science) test site at USP. On the other hand, capacitive noise did not affect acquired data with Protem57-MK2, and the data present high signal to noise ratio. Surveys helped in determining sedimentary and crystalline aquifers, characterized by a fracture zone with water inside basin basement (conductive zone). Results show good agreement with local geology obtained from lithological boreholes located in the study areas. Moreover, it shows that TDEM method can be used in urban environments with a countless potential in hydrogeological studies, offering great reliability. Studies showed that main TDEM-method limitation at USP was the lack of space for opening the transmitter loop. Results are very promising and open new perspectives for TDEM-method use in urban environments as this area remains unexplored.

1. Introduction

TDEM (Time Domain Electromagnetic) method emerged in the mid 80's with the need to deeply explore regions with little resistive layers, since other electromagnetic methods using frequency domain were not able to accomplish these investigations with good resolution (Christiansen et al., 2006). The history of TDEM application shows that TDEM is a reliable method, once data interpretation is usually in agreement with geological information obtained of groundwater exploration boreholes.

Several researchers have successfully used TDEM method in hydrogeology, geothermal studies, mineral exploration, environmental studies etc. (Christiansen et al., 2006; Fitterman and Stewart, 1986; Hallbauer-Zadorozhnaya and Stettler, 2009; Jens et al., 2003; Land et al., 2003; McNeill, 1994; Sørensen et al., 2003, among others). However, there are no more than few studies about its application in Brazil (Bortolozo et al., 2010; Carrasquila and Ulugergerli, 2006; Lucena et al., 2009; Morais and Menezes, 2005; Porsani et al., 2010a; Santos and Porsani, 2007). For that reason, further studies are required to aim hydrogeological ones in Brazilian soils, taking into consideration the country's great hydric potential. Besides, geophysical studies are usually conducted in environments far from urban centers in order to avoid data contamination by electromagnetic noise. Consequently, the challenge for the 21st-century geoscientists is to perform geophysical surveys in urban areas with high electromagnetic noise level. Until now, there are no records in the literature using TDEM method in urban environment. As a result, it still remains as an unexplored area.

Aiming at contributing to apply TDEM-method research in urban areas, this work presents results of some practical experiments surveyed at USP (*University of São Paulo*), in São Paulo city, Brazil (Fig. 1). Studies have had two objectives: (i) to map the distribution of electrical resistivity of several São Paulo sedimentary basin portions, with emphasis on mapping sedimentary and crystalline aquifers for hydrogeological exploration, and (ii) to analyze the viability in using TDEM data acquisition in urban environment inside USP with huge electromagnetic noise and several structures that may affect the sounding with some coupling effects, usual in large worldwide cities.

* Corresponding author.
E-mail address: porsani@iag.usp.br (J.L. Porsani).

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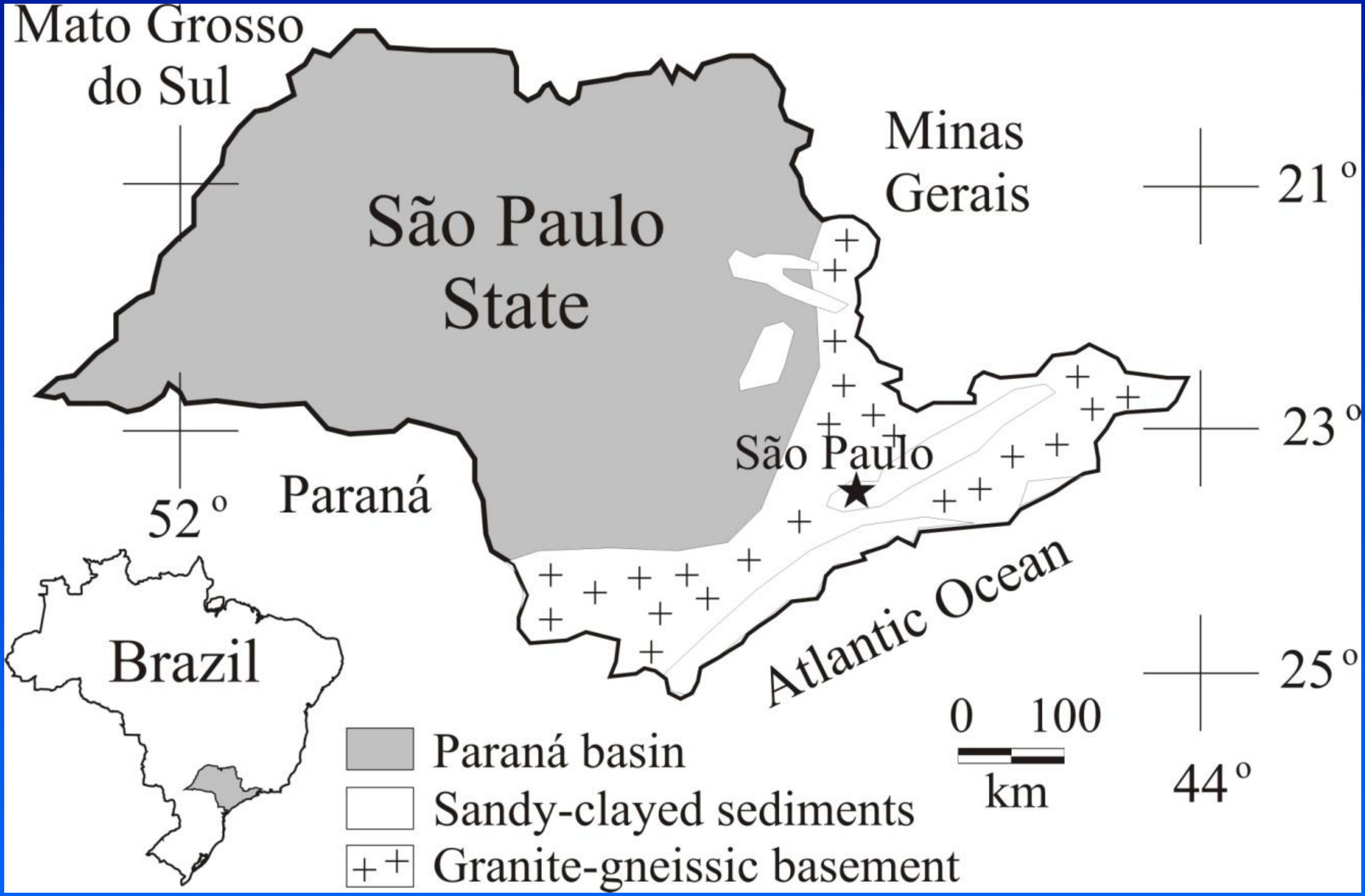
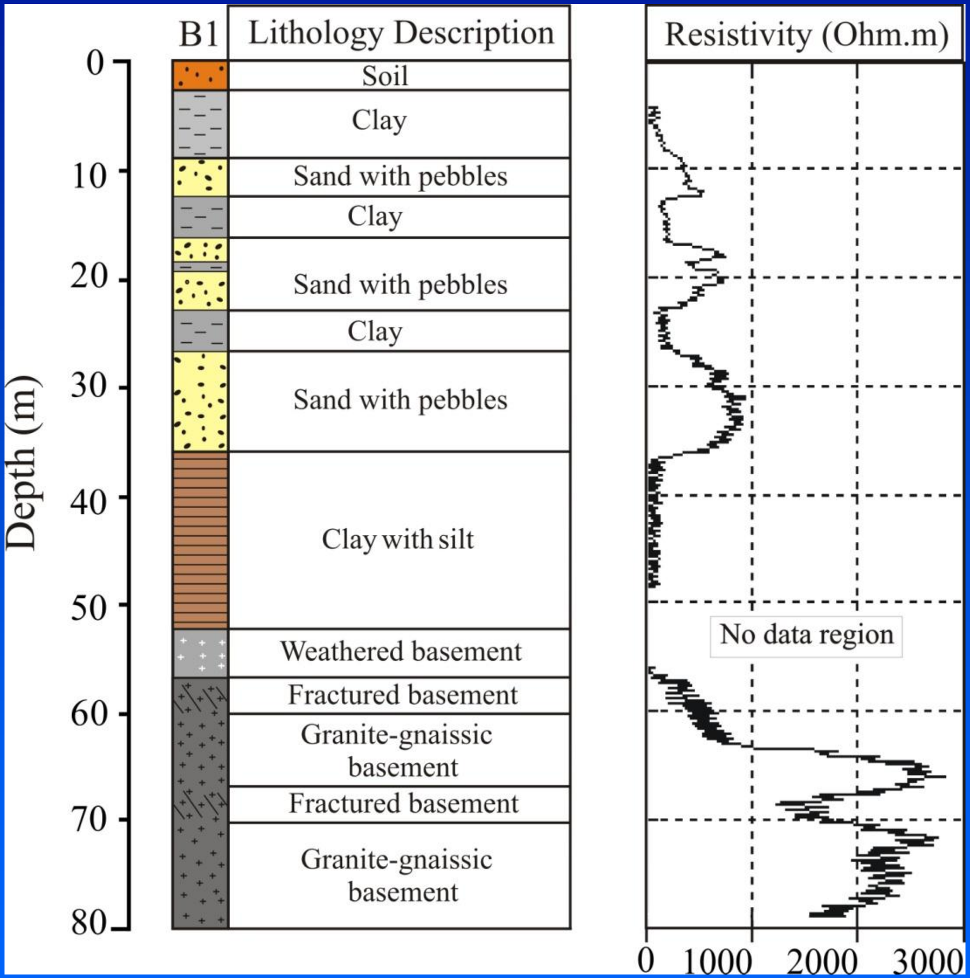
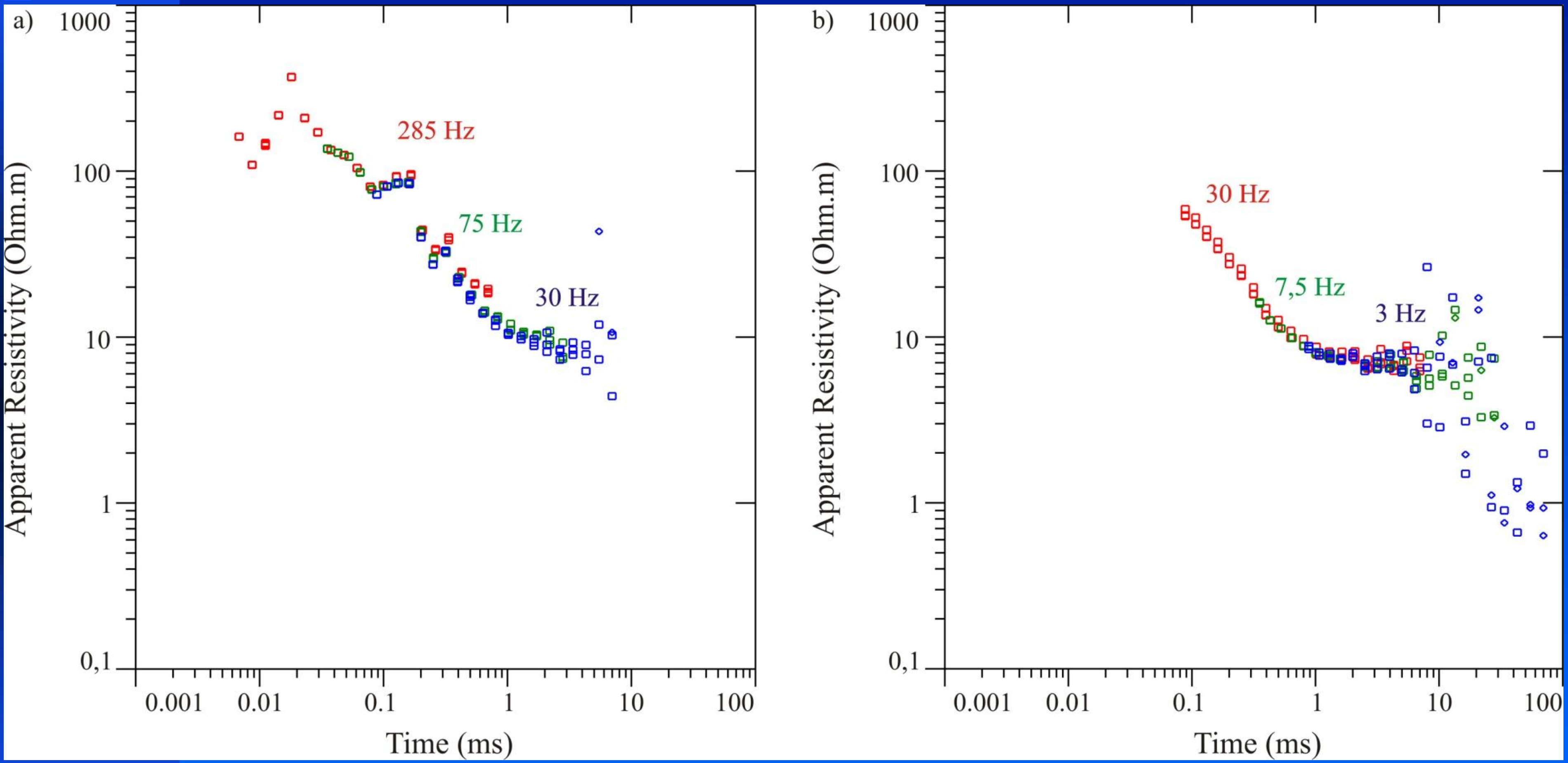

Mato Grosso
do Sul
Minas
Gerais
São Paulo
State
21 º
23 º
25 º
52 º
Paraná
São Paulo
Atlantic Ocean
Brazil
Paraná basin
Sandy-clayed sediments
Granite-gneissic basement
0 100
km
44 º


Olympic rawing lake
POLI
IPT
MAE
FEA
Banks
Clock Square
Students house
IME
IAG
IF
B1
FAU
CEPE
IPEN
IO
Reitory
IGc
FFLCH
FEF
FE
Forest area
HU
IQ
Butantã Institute
IB
FO
FV
SCALE
0 100
meter
LEGEND
TDEM Profile
TDEM Station
B1 - Borehole
IPT - São Paulo Research Institute
MAE - Museum of Archaeology and Etnology
HU - University Hospital
FO - School of Odontology
FAU - Faculty of Architeture and Urbanism
POLI - Politechnique School
CEPE - Sport Center
IAG - Institute of Astronomy, Geophysics and Atmospheric Science
IPEN - Nuclear and Energy Research Institute
IF - Institute of Physics
IB - Institute of Bioscience
IME - Maths and Statistic Institute
IGc - Geoscience Institute
FEA - School of Economy and Adminstration
FE - School of Education
FEF - School of Physical Education
FFLCH - School of Phylosophy, Letters, and Human Sciences
FV - School of Veterinary



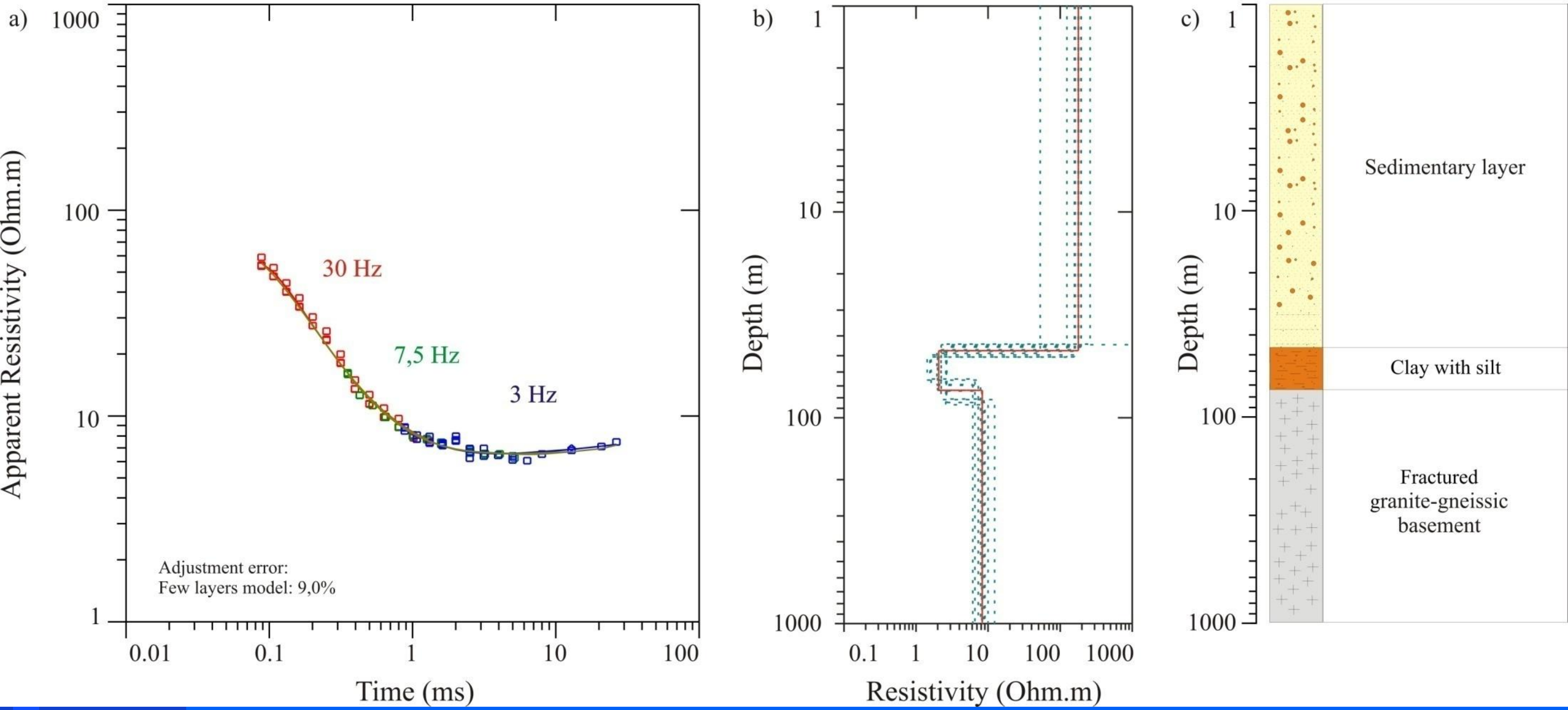
B1
Lithology Description
Resistivity (Ohm.m)
Depth (m)
0
10
20
30
40
50
60
70
80
Soil
Clay
Sand with pebbles
Clay
Sand with pebbles
Clay
Sand with pebbles
Clay with silt
Weathered basement
Fractured basement
Granite-gnaissic basement
Fractured basement
Granite-gnaissic basement
No data region
0
1000
2000
3000

SCGR



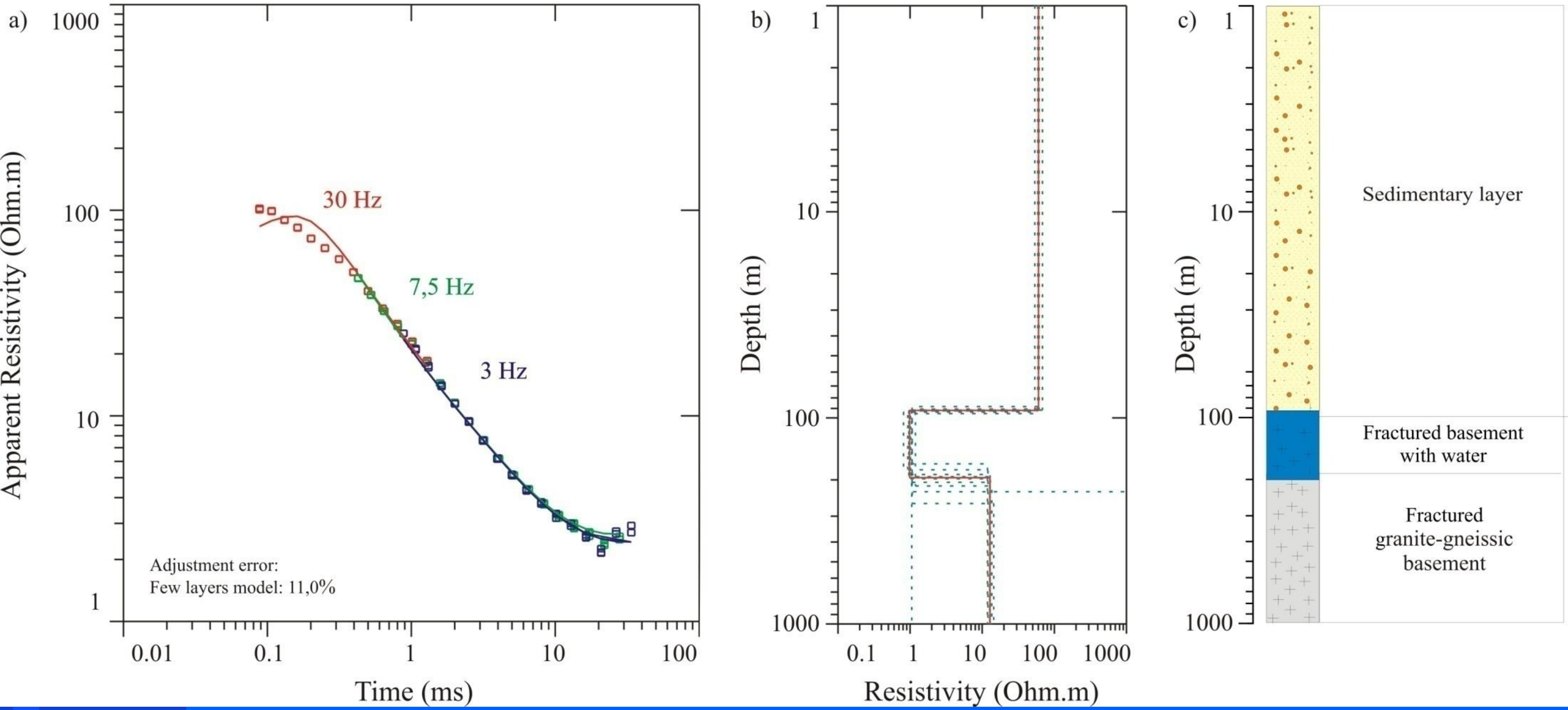
TEM-47 **TEM-57**

SCGR



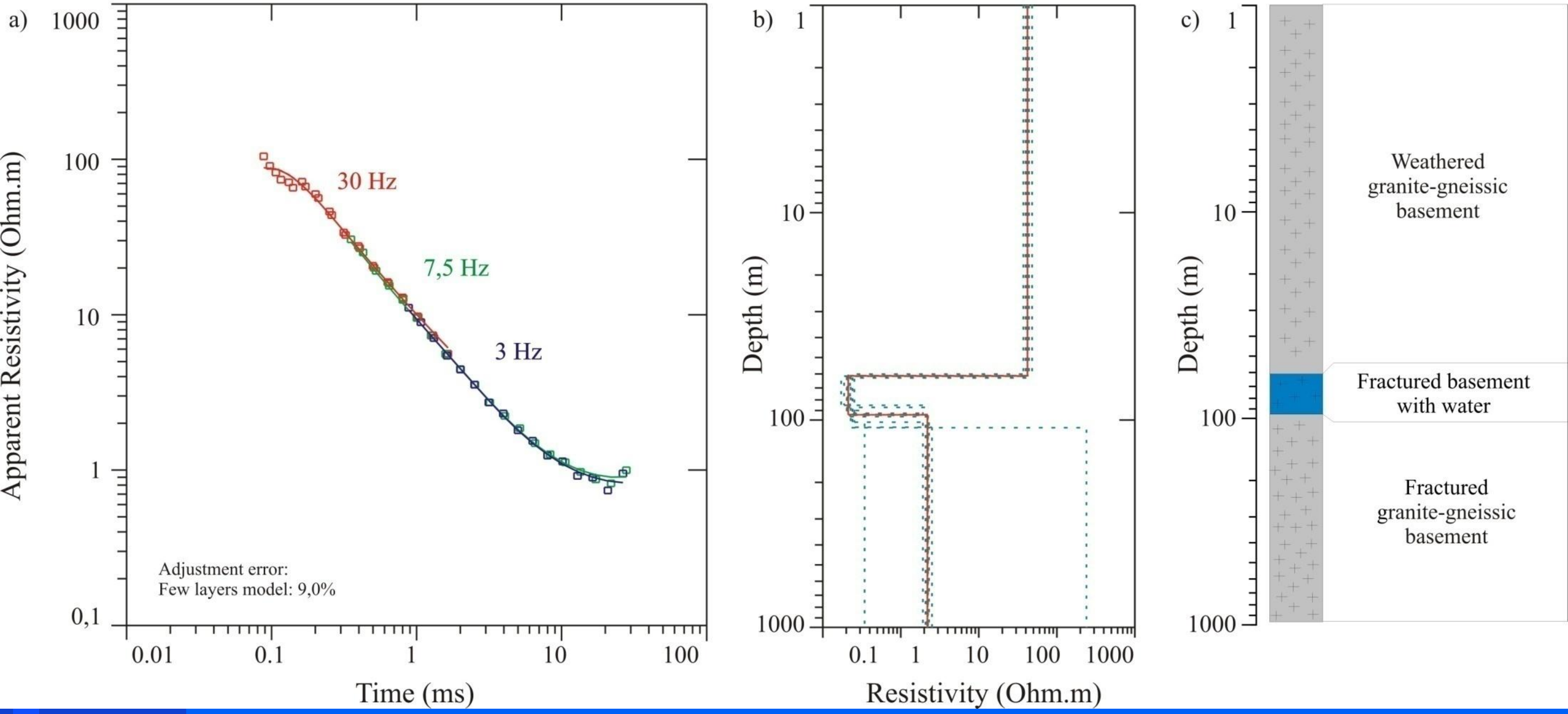
SCGR do IAG

Praça do Relógio



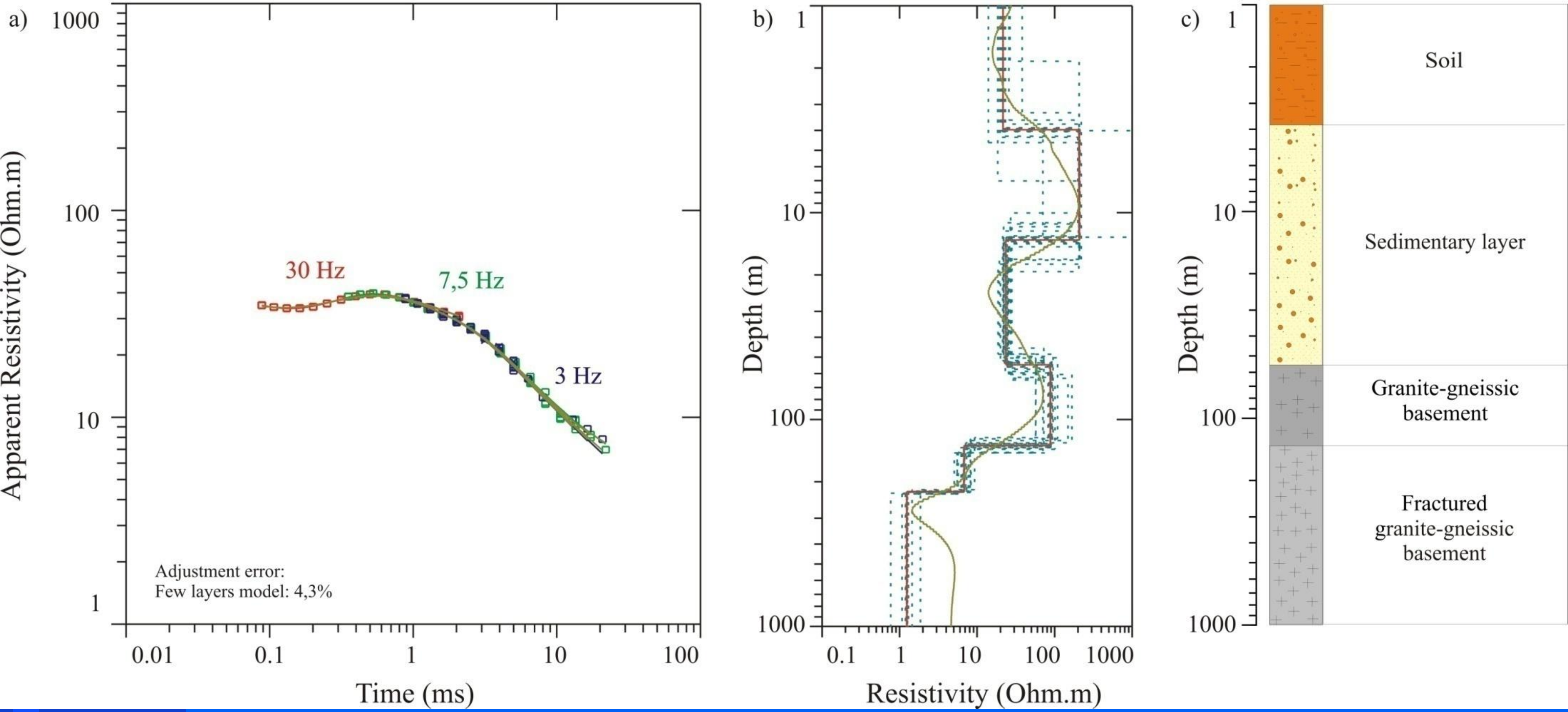
Praça do Relógio

IPEN



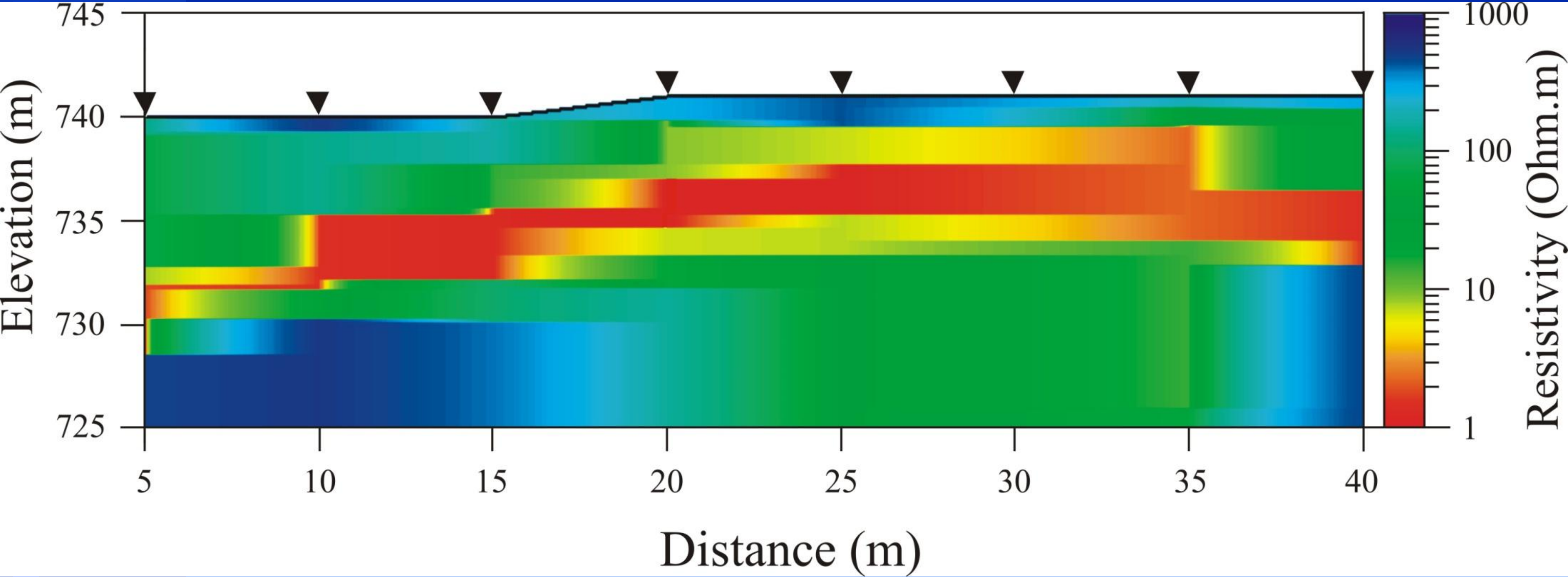
a)
1000
100
10
1
0,1
Apparent Resistivity (Ohm.m)
30 Hz
7,5 Hz
3 Hz
Adjustment error:
Few layers model: 9,0%
0.01
0.1
1
10
100
Time (ms)
b)
1
10
100
1000
Depth (m)
0.1
1
10
100
1000
Resistivity (Ohm.m)
c)
1
10
100
1000
Depth (m)
Weathered granite-gneissic basement
Fractured basement with water
Fractured granite-gneissic basement

CPEUSP



a)
1000
100
10
1
Apparent Resistivity (Ohm.m)
30 Hz
7,5 Hz
3 Hz
Adjustment error:
Few layers model: 4,3%
0.01
0.1
1
10
100
Time (ms)
b)
1
10
100
1000
Depth (m)
0.1
1
10
100
1000
Resistivity (Ohm.m)
c)
1
10
100
1000
Depth (m)
Soil
Sedimentary layer
Granite-gneissic basement
Fractured granite-gneissic basement

Entre os poços no SCGR



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TDEM survey in an area of seismicity induced by water wells in Paraná sedimentary basin, Northern São Paulo State, Brazil

Jorge Luís Porsani [a,*], Emerson Rodrigo Almeida [a], Cassiano Antonio Bortolozo [a], Fernando Acácio Monteiro dos Santos [b]

[a] Universidade de São Paulo (USP), Instituto de Astronomia, Geofísica e Ciências Atmosféricas (IAG), Departamento de Geofísica, Rua do Matão, 1226, Butantã, 05508-090, São Paulo, Brazil
[b] Center of Geophysics, Lisbon University (CGUL), Lisbon, Portugal

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ABSTRACT

This article presents TDEM results from an area with recent induced shallow seismicity. The
on a geoelectrical mapping of sedimentary and fractured basaltic aquifers for better under
hydrogeologic setting. The study area is in the Paraná basin where flood basalts are overlain b
units near the city of Bebedouro, northern São Paulo State, Brazil. 86 TDEM soundings were
area of 90 km² in the Andes and Botafogo study areas. The soundings were chosen next to w
tion, and also along profiles crossing the seismically active areas. 1-D interpretation resu
general geoelectrical stratigraphy of this part of the Paraná basin. The upper geoelectrical laye
sedimentary aquifer (Adamantina formation) with less than 80 m thickness. The second geo
contains the upper basalts of the Serra Geral formation at about 60–80 m depths. A saturated f
zone between 100 and 300 m depths was identifiable on various TDEM soundings. This dep
sponds to the range of hypocentral depths for more than 3000 micro-earthquakes in this a
basalt layer was estimated to lie between 400 and 650 m depth. The deepest geoelectrical
by various TDEM soundings corresponds to the Botucatu sandstone (Guarani aquifer). Resu
the high-discharge wells are located in the fractured zone in the middle basalt of the Serra G
There is a good correlation between seismically active areas, high discharge wells (>190 m³/
zones in the middle basalt. The results reinforce the hypothesis that the shallow seismic
Bebedouro region is being triggered by high rates of groundwater withdrawal.

1. Introduction

The Time Domain ElectroMagnetic (TDEM) method is relatively new, when compared with frequency-domain electromagnetic resistivity methods. TDEM was introduced for ground water exploration in the mid-1980s where there was a need for deep exploration in the presence of low resistivity layers. In that environment, frequency-domain methods were not able to achieve adequate depth or resolution (Christiansen et al., 2006). Since the 1980s, TDEM data acquisition and processing techniques have been steadily developing and have been applied in various countries (Bortolozo et al., 2010; Monteiro Santos and El-Kaliouby, 2011; Porsani et al., 2012; Sørensen et al., 2003 among others).

The history of TDEM applications for hydrogeological studies has shown that it is a robust geophysical method with a fast data acquisition, and the results usually have good correlation with geological information from adjacent water wells. Because of its utility for

geoelectrical stratigraphy, the TDEM method is an exc
mapping sedimentary basins, groundwater and minera
environmental studies, geothermal studies, brine intrus
aquifer, etc. (Christiansen et al., 2006; Danielsen
Fitterman and Stewart, 1986; Hallbauer-Zadorozhnaya
2009; Jørgensen et al., 2003; Krivochieva and Choutea
et al., 2003; McNeill, 1994; Nielsen et al., 2007; Sørense

Many researchers have used the TDEM successfully
studies, but there is no record to our knowledge of usin
in an area where seismic activity has been triggered
from water wells. Additionally, this method has only b
a few studies in Brazil (Bortolozo et al., 2010; Ca
Ulugergerli, 2006; Lucena et al., 2009; Meju et al., 1
et al., 2010, 2012; Santos and Porsani, 2007), and there
need to obtain hydrogeological information over vast
with deeply weathered soils.

Earthquakes induced by filling of large hydroelectric
fluid injection under high pressure in deep wells are c
nomena that have been studied in several cases (Assu
2002; Chimpliganond et al., 2007; Ferreira et al., 2008;
Simpson et al., 1988; Talwani and Acree, 1984; Talwar

* Corresponding author. Tel.: +55 11 3091 4734; fax: +55 11 3091 5034.
E-mail addresses: porsani@iag.usp.br (J.L. Porsani), fasantos@fc.ul.pt (F.A.M. Santos).

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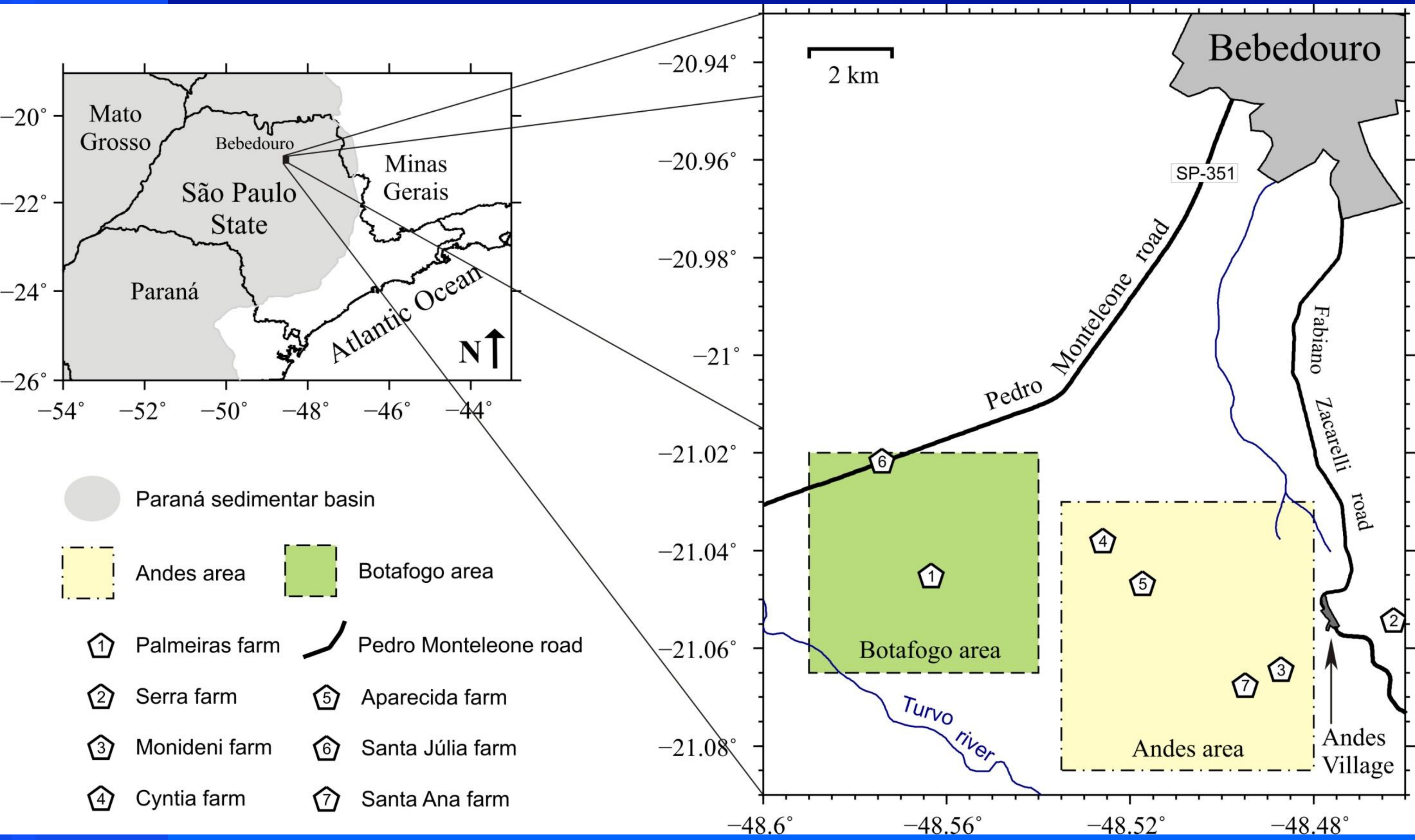
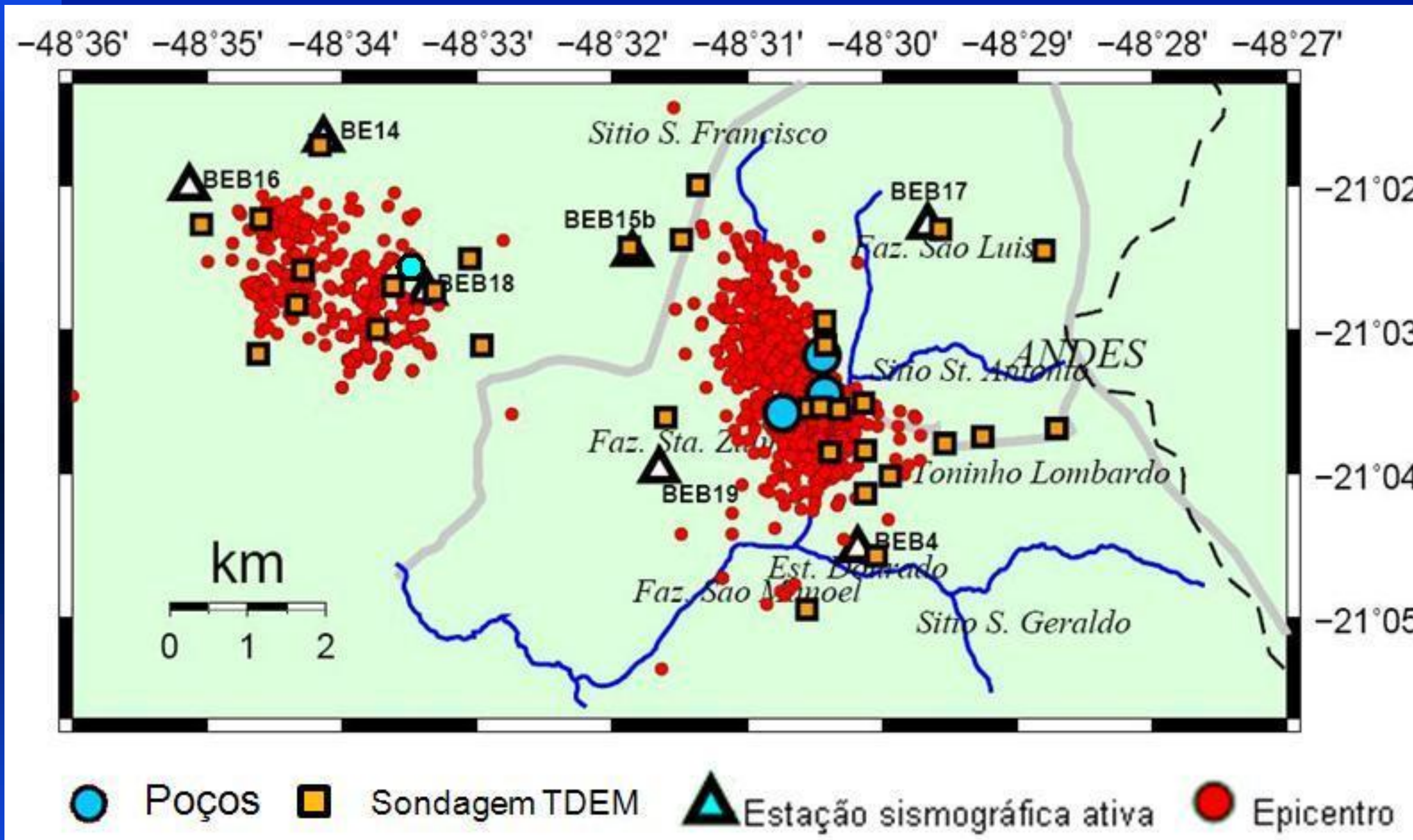
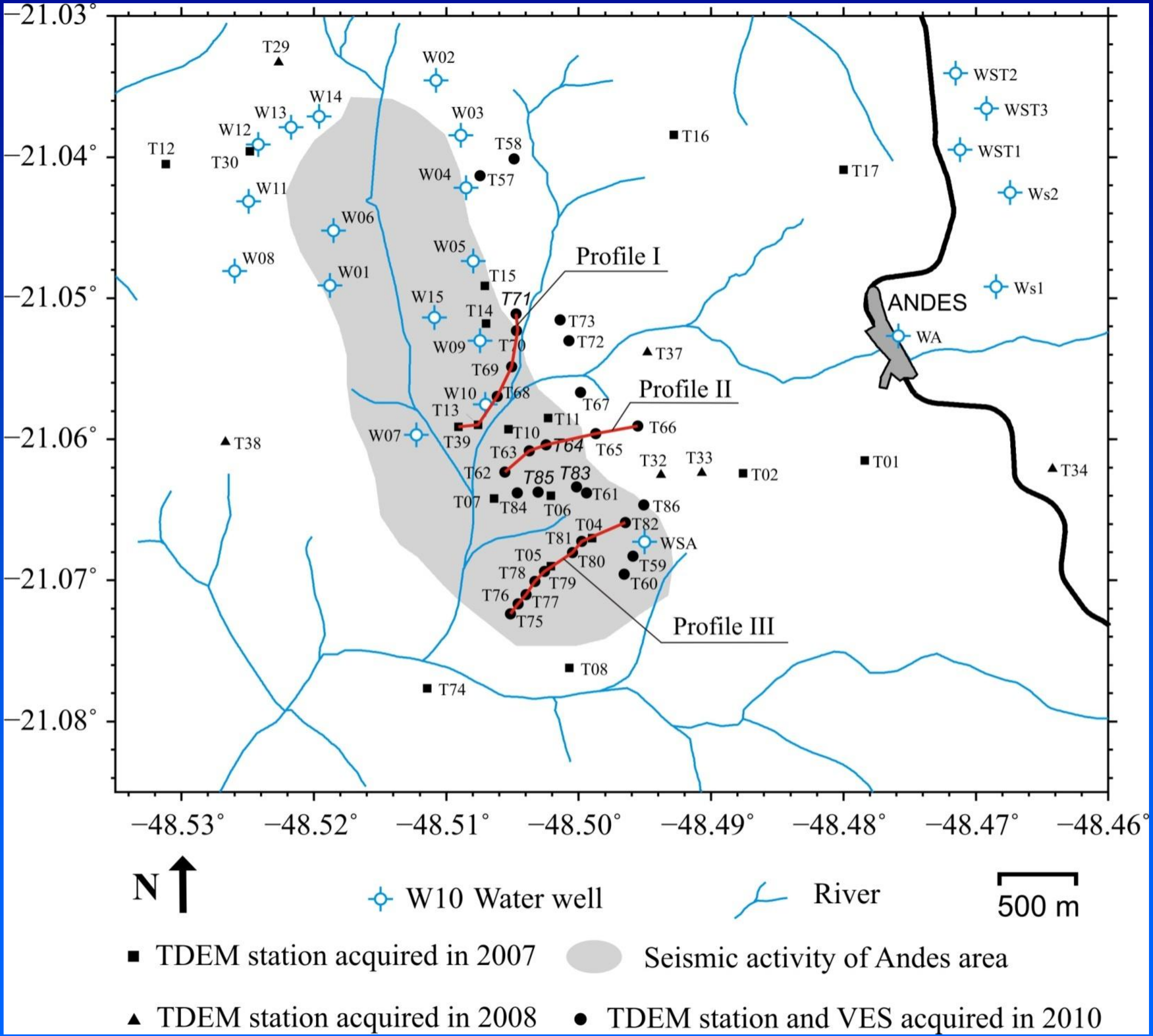
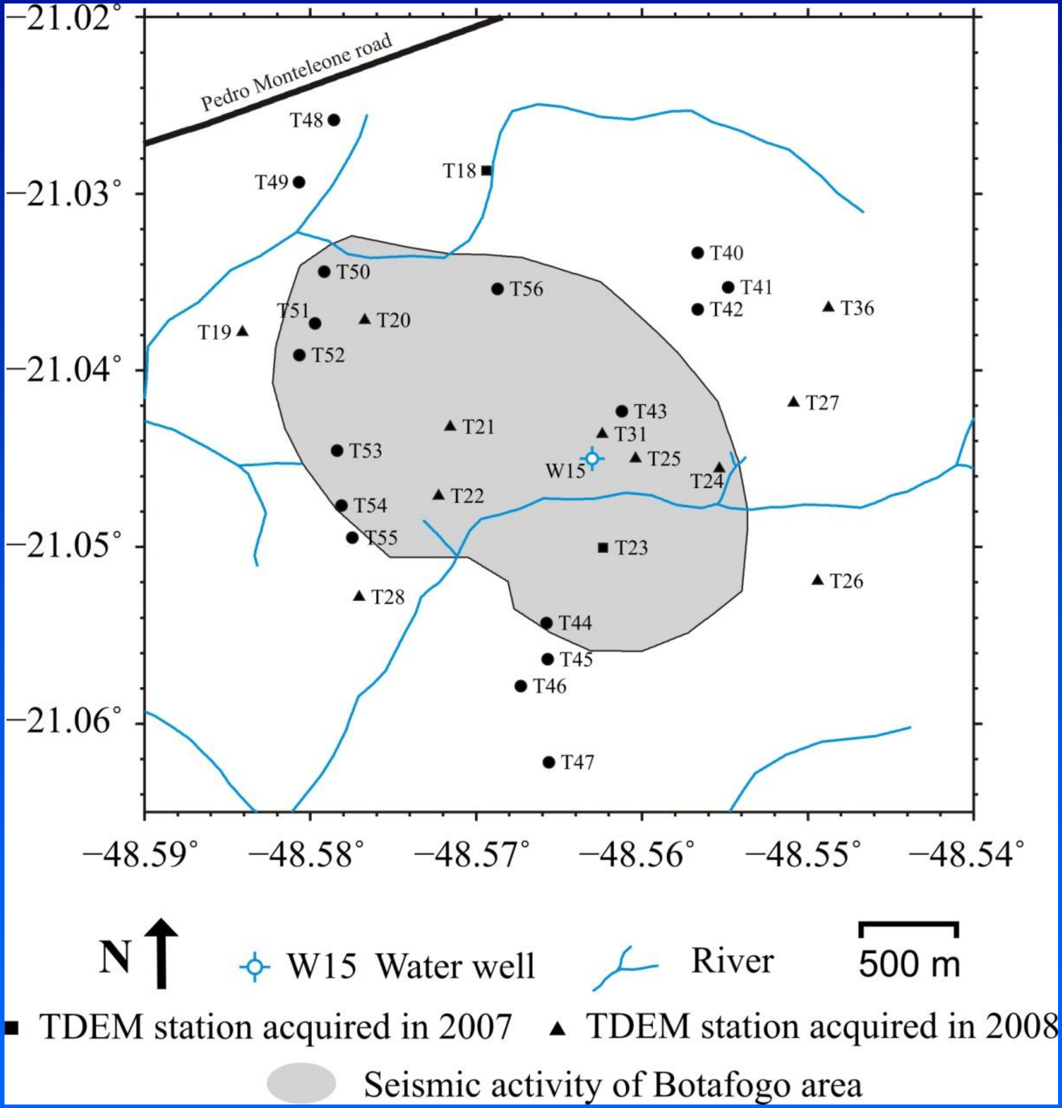

Mato Grosso
Bebedouro
São Paulo State
Minas Gerais
Paraná
Atlantic Ocean
N
−20°
−22°
−24°
−26°
−54°
−52°
−50°
−48°
−46°
−44°
Paraná sedimentar basin
Andes area
Botafogo area
Palmeiras farm
Pedro Monteleone road
Serra farm
Aparecida farm
Monideni farm
Santa Júlia farm
Cyntia farm
Santa Ana farm
Bebedouro
2 km
SP-351
Pedro Monteleone road
Fabiano Zacarelli road
Botafogo area
Andes area
Turvo river
Andes Village
−20.94°
−20.96°
−20.98°
−21°
−21.02°
−21.04°
−21.06°
−21.08°
−48.6°
−48.56°
−48.52°
−48.48°

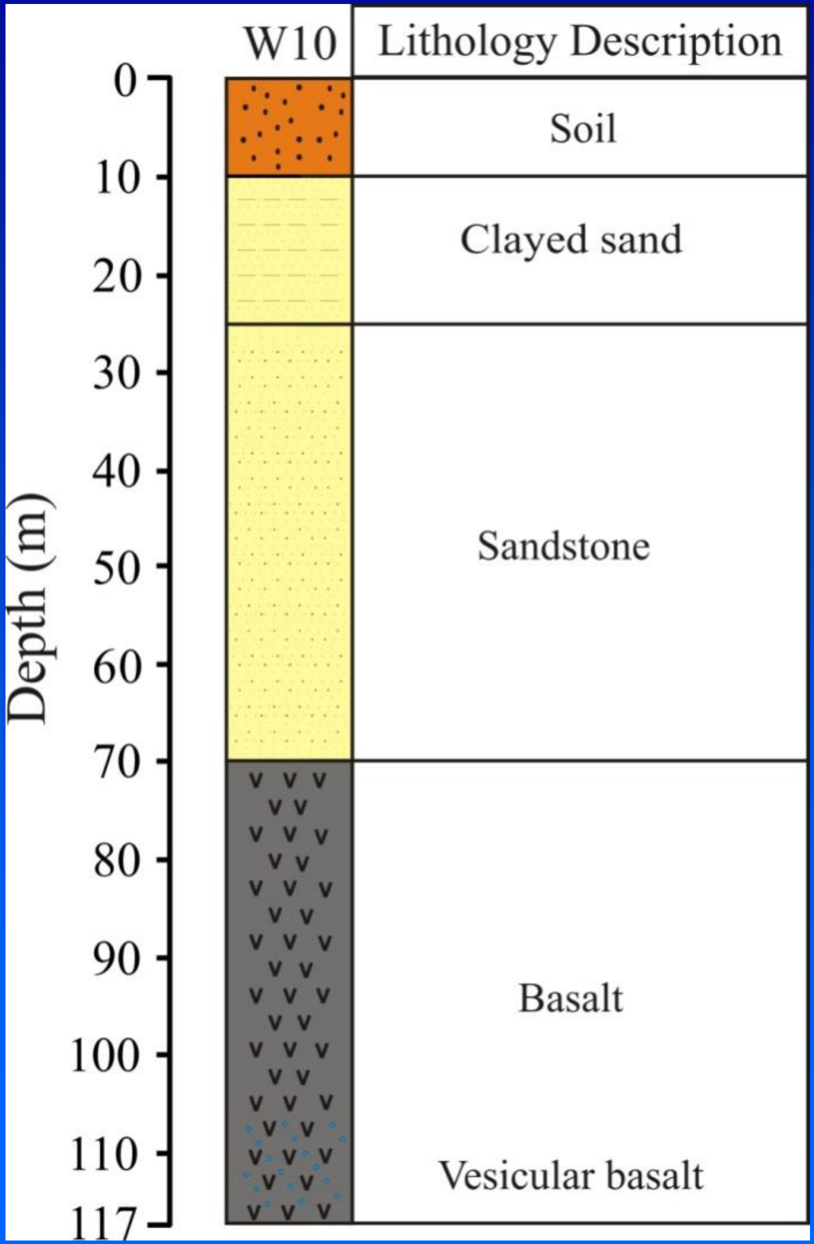

−48°36' −48°35' −48°34' −48°33' −48°32' −48°31' −48°30' −48°29' −48°28' −48°27'
−21°02
−21°03
−21°04
−21°05
BE14
BEB16
BEB18
BEB15b
BEB17
BEB19
BEB4
Sitio S. Francisco
Faz. São Luis
ANDES
Toninho Lombardo
Sitio S. Geraldo
km
0 1 2
Poços
Sondagem TDEM
Estação sismográfica ativa
Epicentro



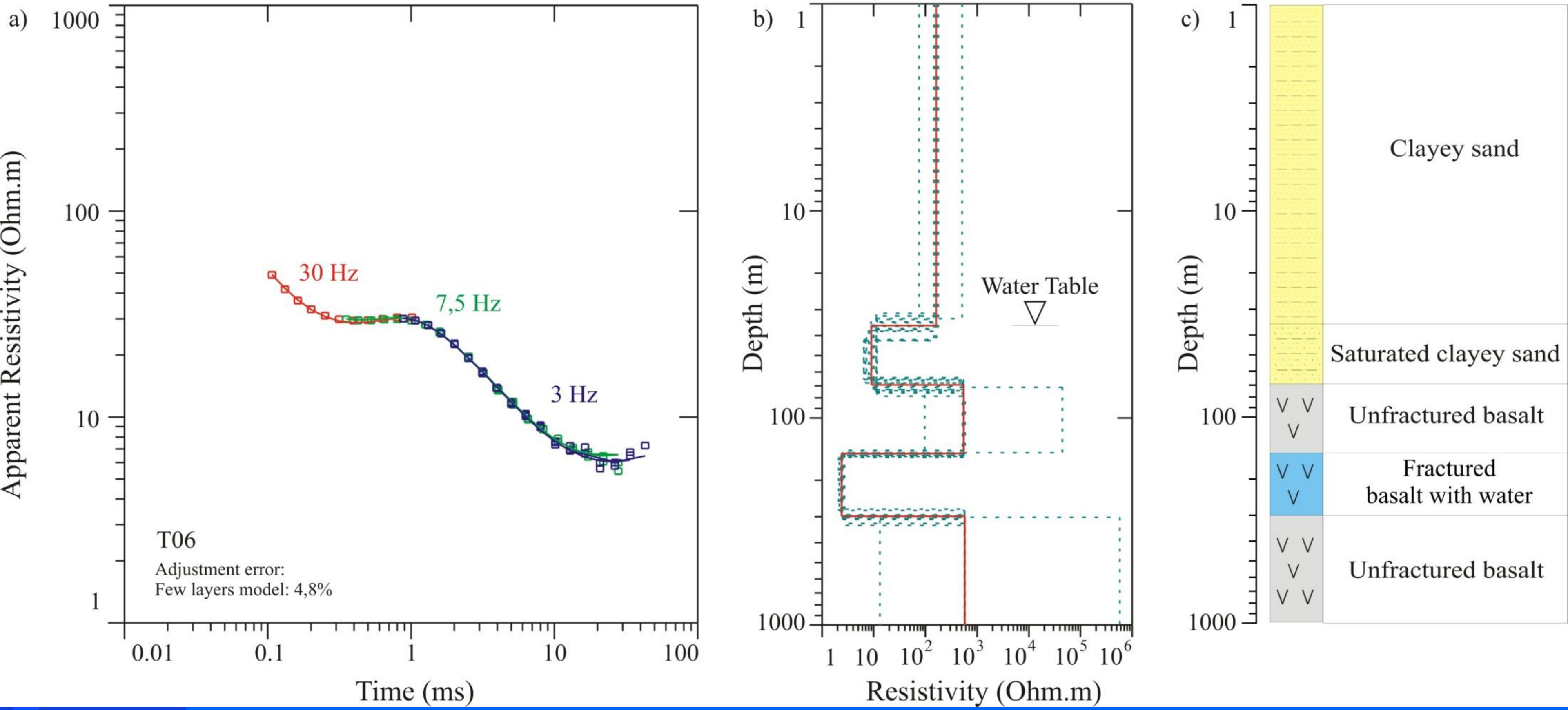
−21.03°
−21.04°
−21.05°
−21.06°
−21.07°
−21.08°
−48.53°
−48.52°
−48.51°
−48.50°
−48.49°
−48.48°
−48.47°
−48.46°
T29
W02
W14
W13
W12
W03
T12
T30
T58
T16
WST2
WST3
WST1
T17
Ws2
W11
W04
T57
W06
W05
W08
W01
T15
Profile I
T71
W15
T14
T73
T72
W09
T70
T37
T69
ANDES
WA
Ws1
W10
T68
T67
Profile II
T13
T11
T66
T38
W07
T39
T10
T64
T65
T63
T32
T33
T02
T01
T34
T62
T85
T83
T07
T84
T06
T61
T86
T04
T82
T81
WSA
T05
T80
T59
T78
T79
T60
T76
T77
T75
Profile III
T08
T74
N
W10 Water well
River
500 m
TDEM station acquired in 2007
Seismic activity of Andes area
TDEM station acquired in 2008
TDEM station and VES acquired in 2010



−21.02°
−21.03°
−21.04°
−21.05°
−21.06°
−48.59°
−48.58°
−48.57°
−48.56°
−48.55°
−48.54°
Pedro Monteleone road
T48
T49
T18
T40
T41
T42
T36
T50
T56
T51
T20
T19
T52
T27
T43
T31
T21
T53
W15
T25
T24
T22
T54
T55
T23
T26
T28
T44
T45
T46
T47
N
W15 Water well
River
500 m
TDEM station acquired in 2007
TDEM station acquired in 2008
Seismic activity of Botafogo area

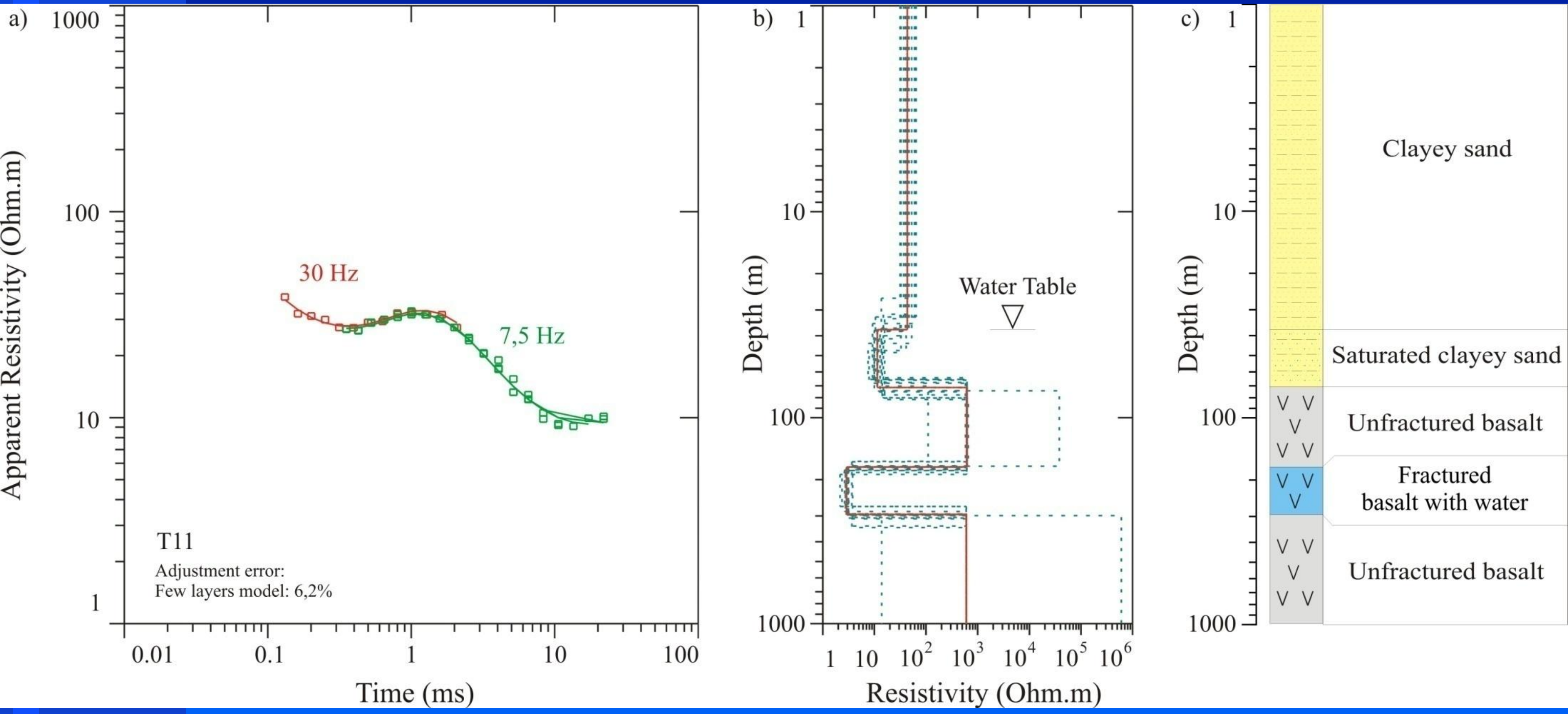

W10
Lithology Description
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
110
117
Soil
Clayed sand
Sandstone
Basalt
Vesicular basalt

Andes



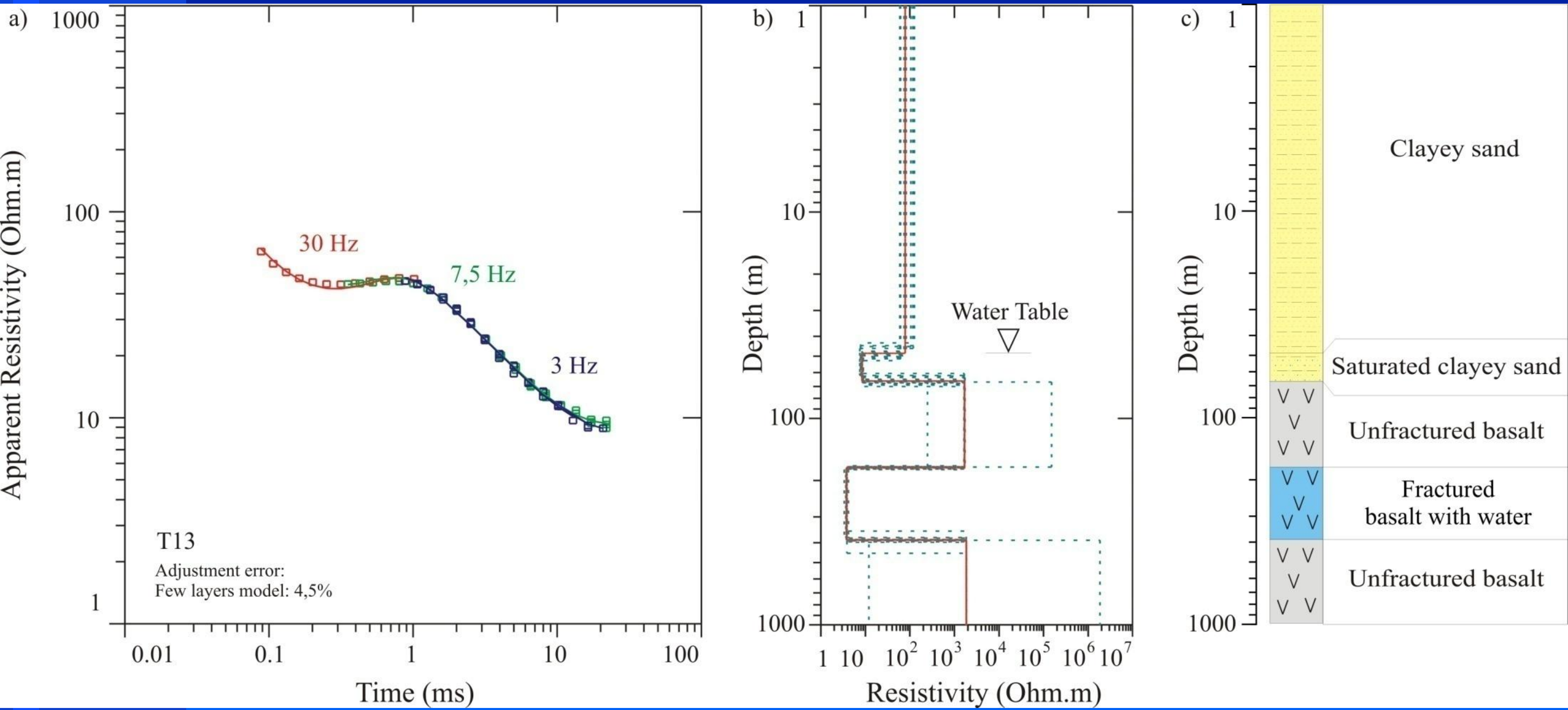
a)
1000
100
10
1
Apparent Resistivity (Ohm.m)
30 Hz
7,5 Hz
3 Hz
T06
Adjustment error:
Few layers model: 4,8%
0.01
0.1
1
10
100
Time (ms)
b)
1
10
100
1000
Depth (m)
Water Table
1
10
10^2
10^3
10^4
10^5
10^6
Resistivity (Ohm.m)
c)
1
10
100
1000
Depth (m)
Clayey sand
Saturated clayey sand
Unfractured basalt
Fractured basalt with water
Unfractured basalt

Andes



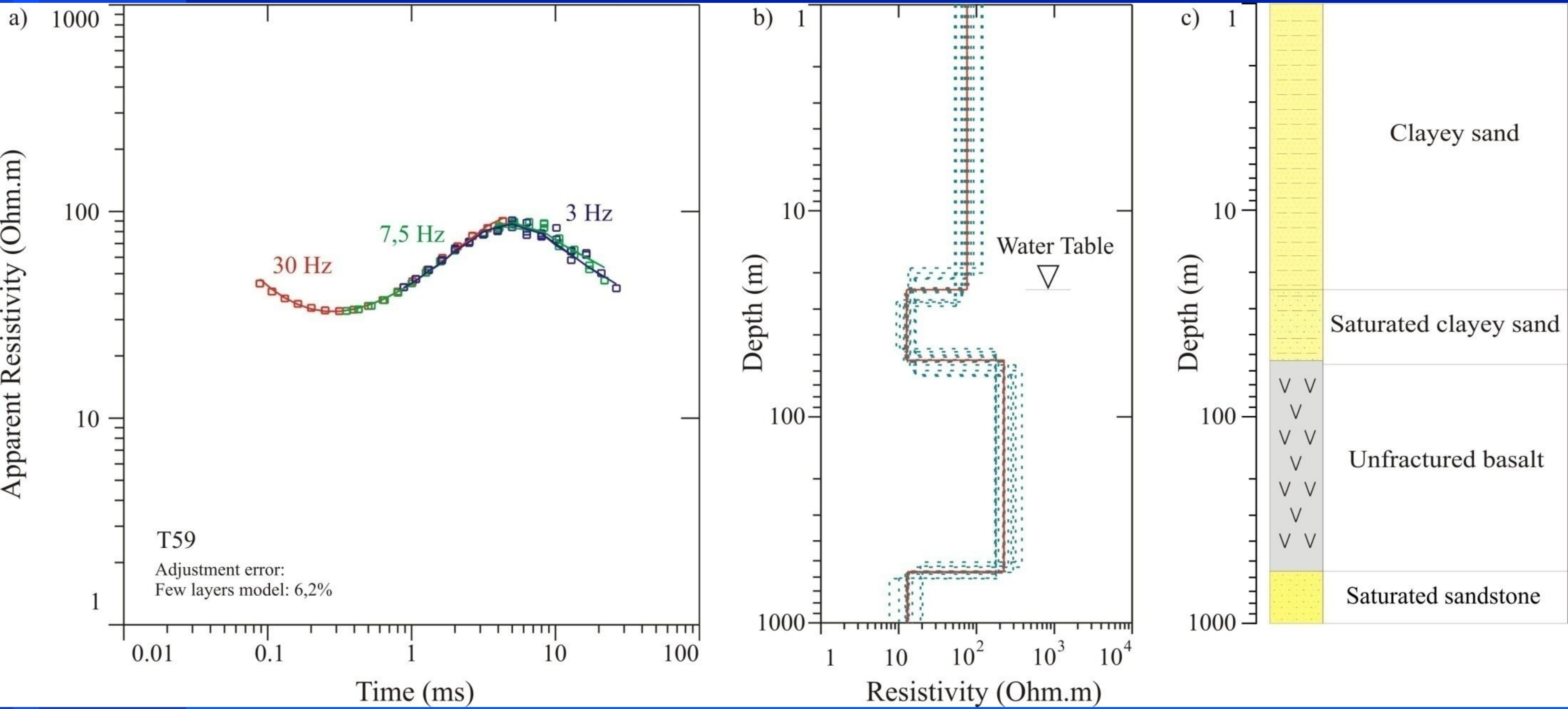
a)
Apparent Resistivity (Ohm.m)
30 Hz
7,5 Hz
T11
Adjustment error:
Few layers model: 6,2%
Time (ms)
b)
Depth (m)
Water Table
Resistivity (Ohm.m)
c)
Depth (m)
Clayey sand
Saturated clayey sand
Unfractured basalt
Fractured
basalt with water
Unfractured basalt

Andes

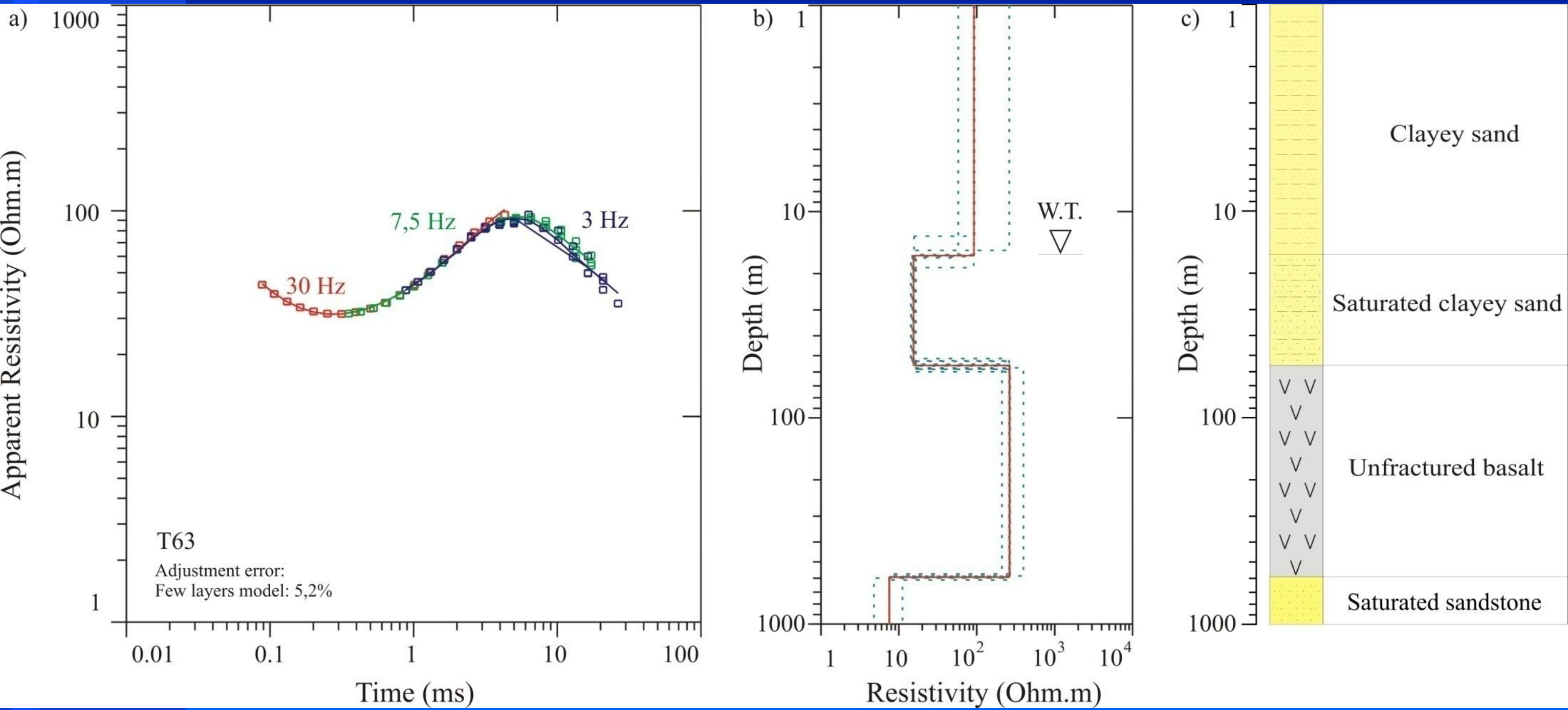


a)
Apparent Resistivity (Ohm.m)
1000
100
10
1
30 Hz
7,5 Hz
3 Hz
T13
Adjustment error:
Few layers model: 4,5%
0.01
0.1
1
10
100
Time (ms)
b)
Depth (m)
Water Table
Resistivity (Ohm.m)
c)
Depth (m)
Clayey sand
Saturated clayey sand
Unfractured basalt
Fractured
basalt with water
Unfractured basalt

Andes

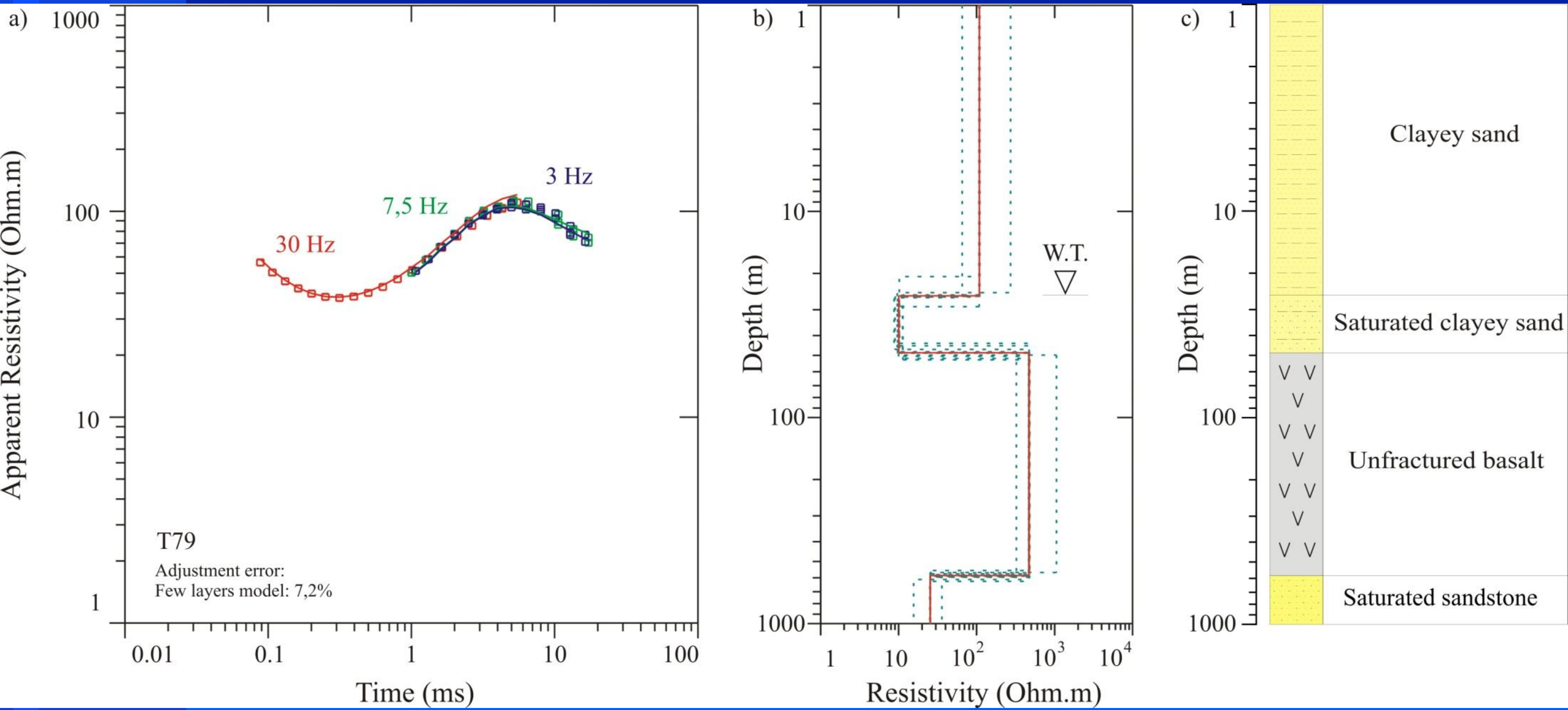

a)
Apparent Resistivity (Ohm.m)
Time (ms)
30 Hz
7,5 Hz
3 Hz
T59
Adjustment error:
Few layers model: 6,2%
b)
Depth (m)
Resistivity (Ohm.m)
Water Table
c)
Depth (m)
Clayey sand
Saturated clayey sand
Unfractured basalt
Saturated sandstone

Andes



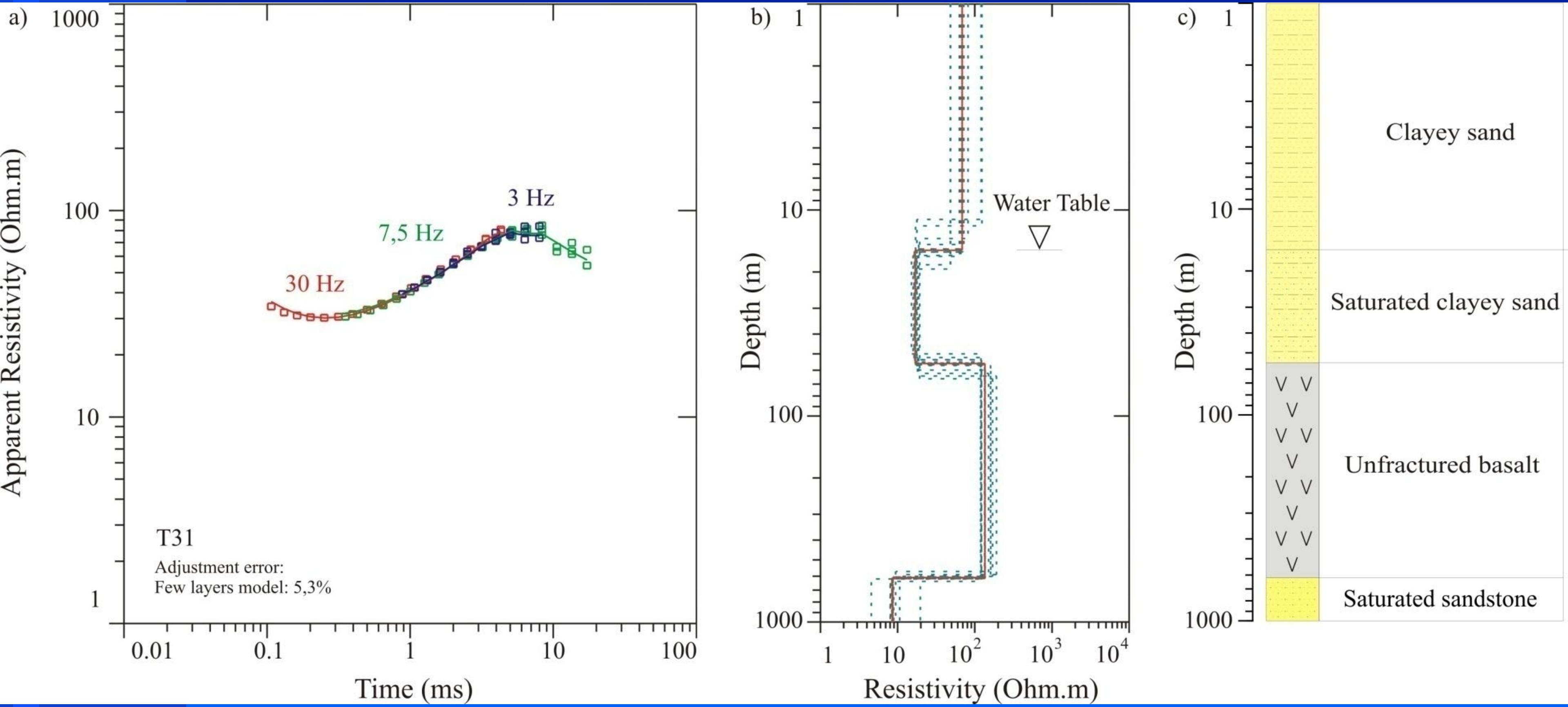
a)
Apparent Resistivity (Ohm.m)
1000
100
10
1
0.01
0.1
1
10
100
Time (ms)
30 Hz
7,5 Hz
3 Hz
T63
Adjustment error:
Few layers model: 5,2%
b)
Depth (m)
1
10
100
1000
Resistivity (Ohm.m)
1
10
10²
10³
10⁴
W.T.
c)
Depth (m)
1
10
100
1000
Clayey sand
Saturated clayey sand
Unfractured basalt
Saturated sandstone

Andes

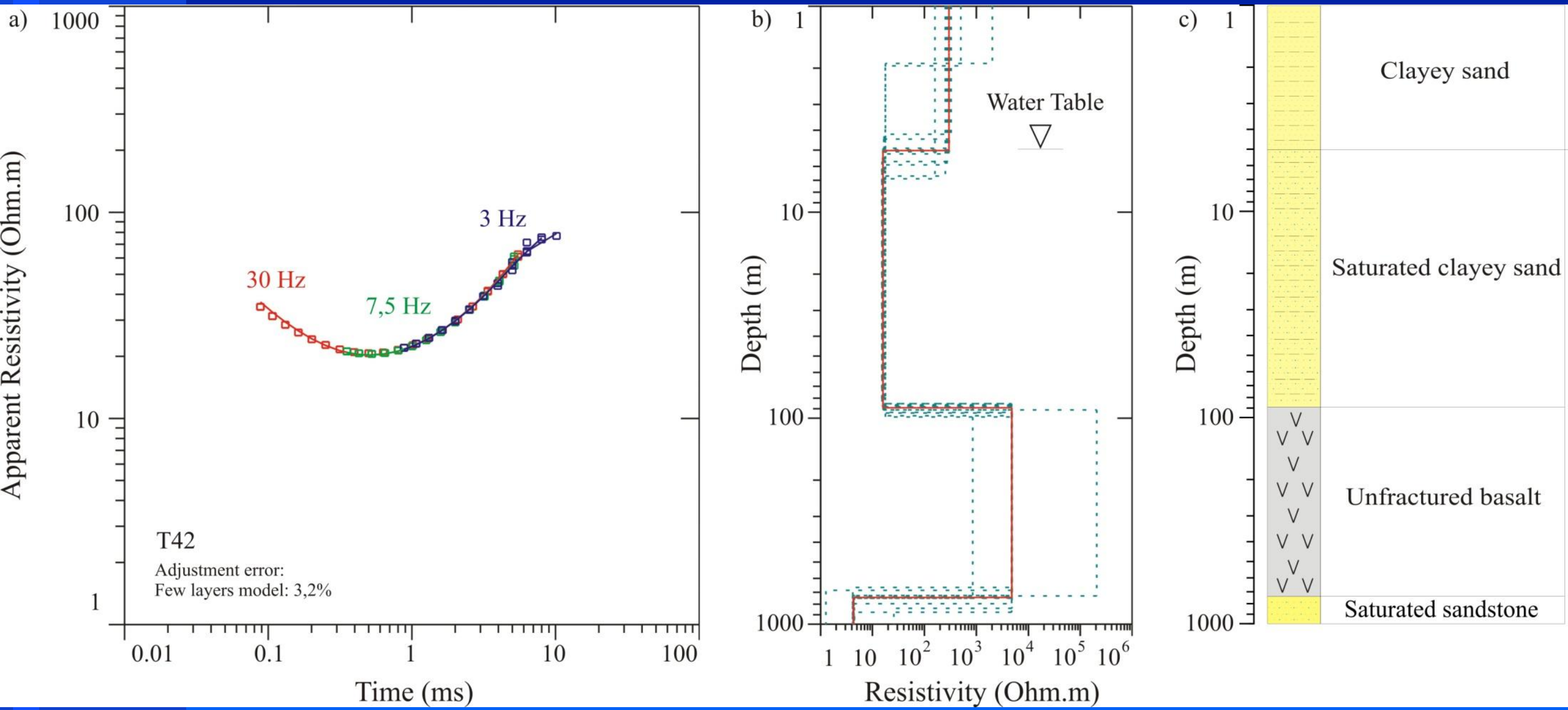


a)
1000
100
10
1
Apparent Resistivity (Ohm.m)
3 Hz
7,5 Hz
30 Hz
T79
Adjustment error:
Few layers model: 7,2%
0.01
0.1
1
10
100
Time (ms)
b)
1
10
100
1000
Depth (m)
W.T.
1
10
10^2
10^3
10^4
Resistivity (Ohm.m)
c)
1
10
100
1000
Depth (m)
Clayey sand
Saturated clayey sand
Unfractured basalt
Saturated sandstone

Botafogo

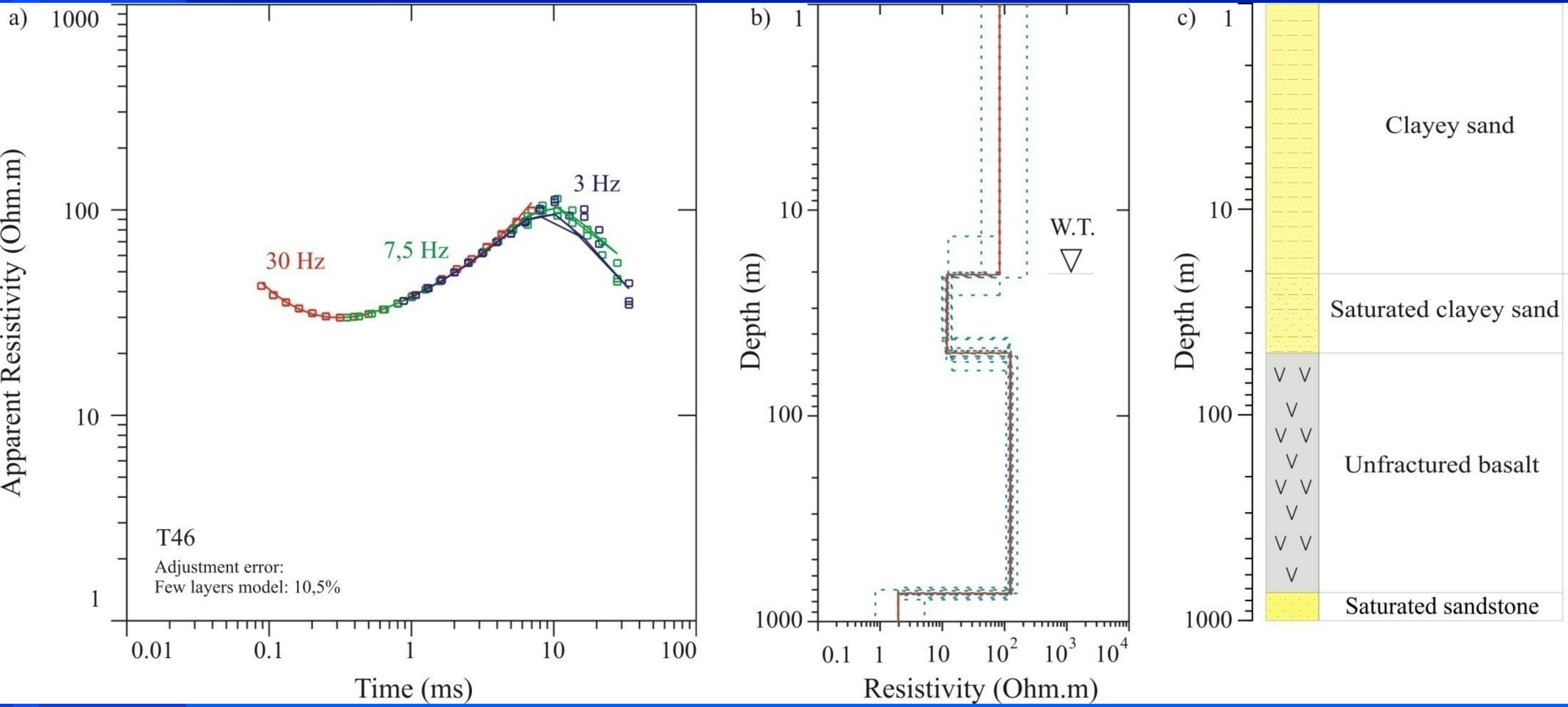

a)
1000
100
10
1
Apparent Resistivity (Ohm.m)
30 Hz
7,5 Hz
3 Hz
T31
Adjustment error:
Few layers model: 5,3%
0.01
0.1
1
10
100
Time (ms)
b)
1
10
100
1000
Depth (m)
Water Table
1
10
10^2
10^3
10^4
Resistivity (Ohm.m)
c)
1
10
100
1000
Depth (m)
Clayey sand
Saturated clayey sand
Unfractured basalt
Saturated sandstone

Botafogo



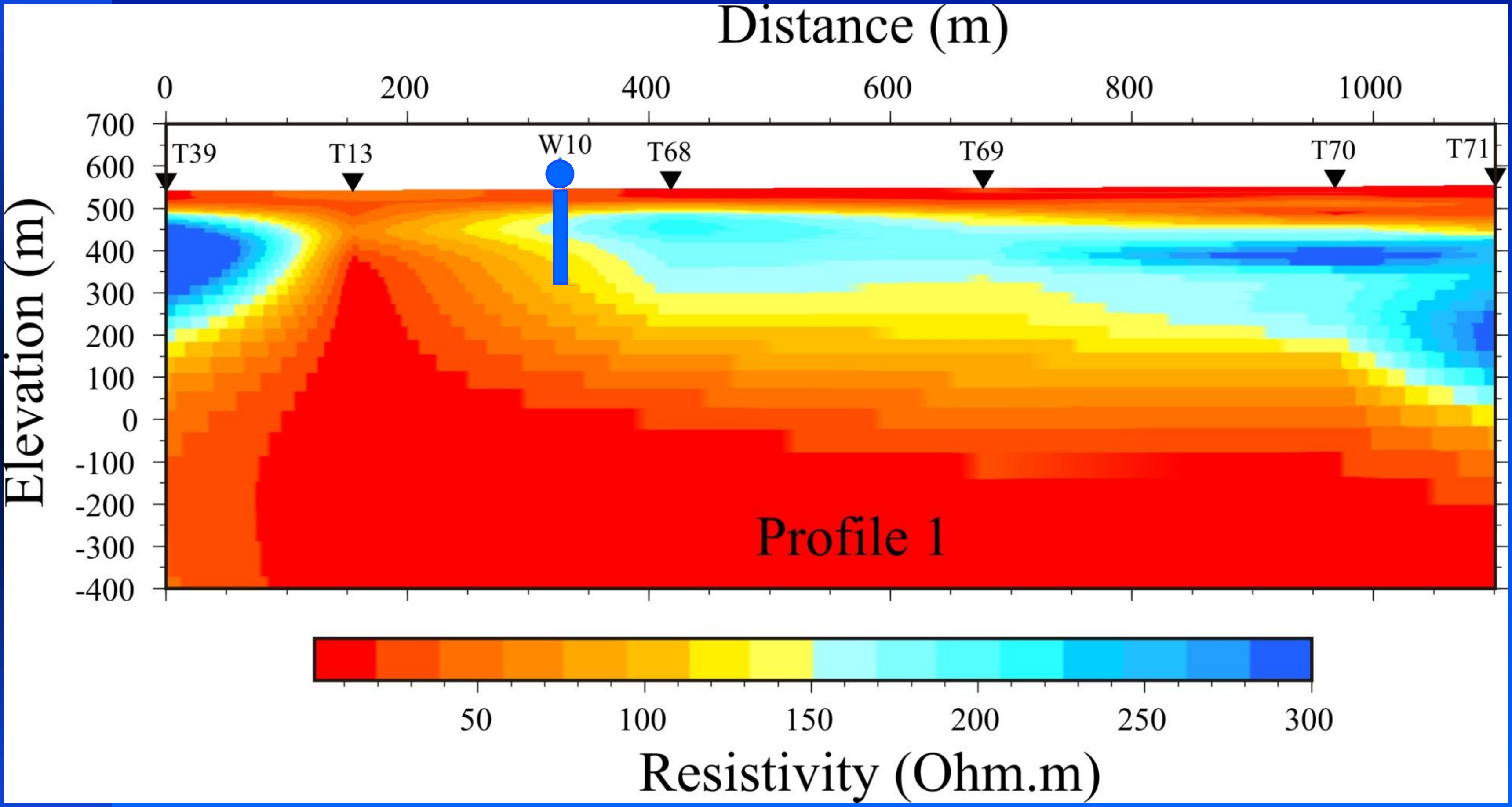
a)
Apparent Resistivity (Ohm.m)
1000
100
10
1
30 Hz
7,5 Hz
3 Hz
T42
Adjustment error:
Few layers model: 3,2%
0.01
0.1
1
10
100
Time (ms)
b)
Depth (m)
Water Table
Resistivity (Ohm.m)
c)
Clayey sand
Saturated clayey sand
Unfractured basalt
Saturated sandstone

Botafogo

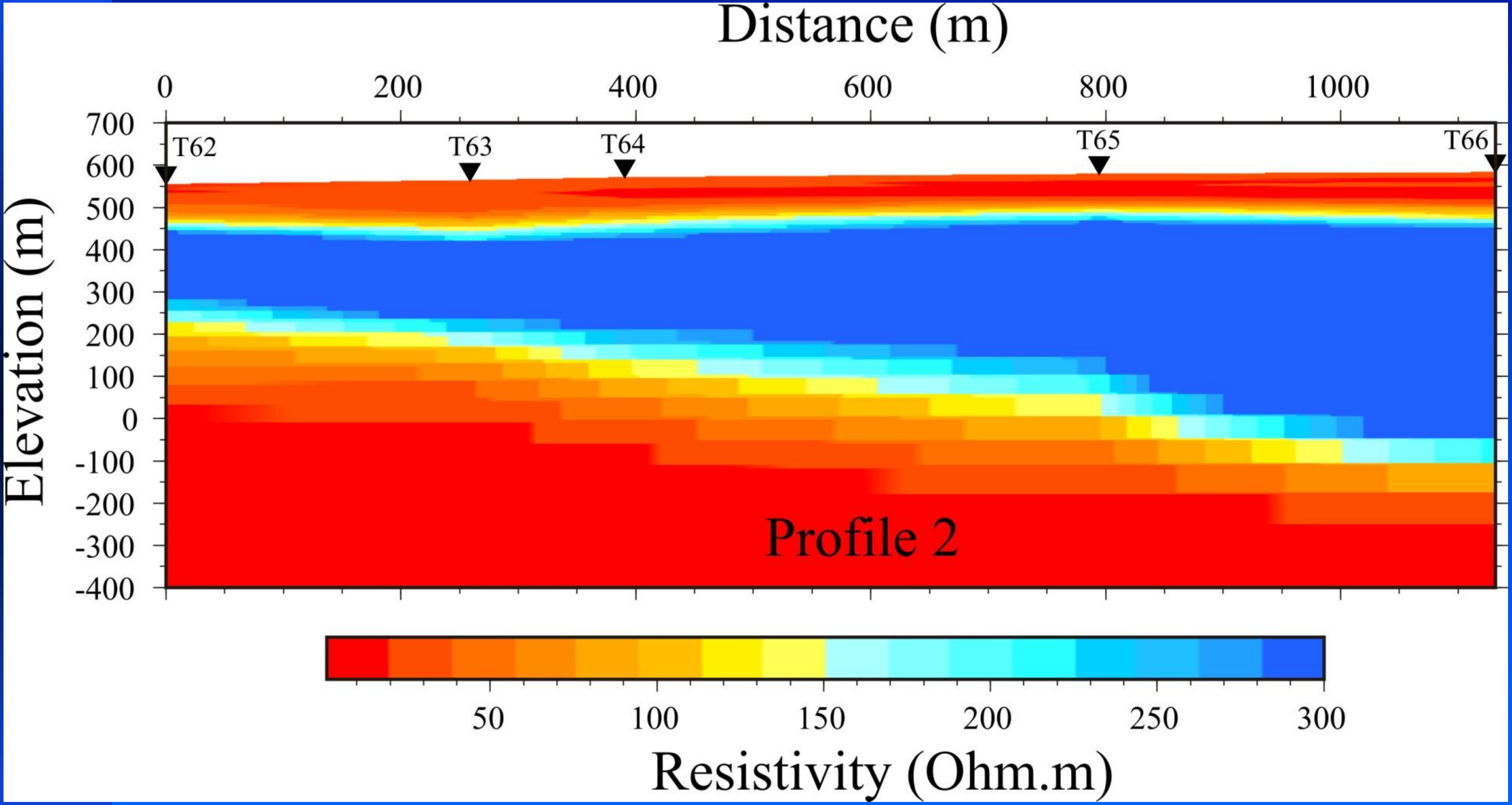


a)
Apparent Resistivity (Ohm.m)
1000
100
10
1
30 Hz
7,5 Hz
3 Hz
T46
Adjustment error:
Few layers model: 10,5%
0.01
0.1
1
10
100
Time (ms)
b)
Depth (m)
W.T.
0.1
1
10
10^2
10^3
10^4
Resistivity (Ohm.m)
c)
Clayey sand
Saturated clayey sand
Unfractured basalt
Saturated sandstone

Andes

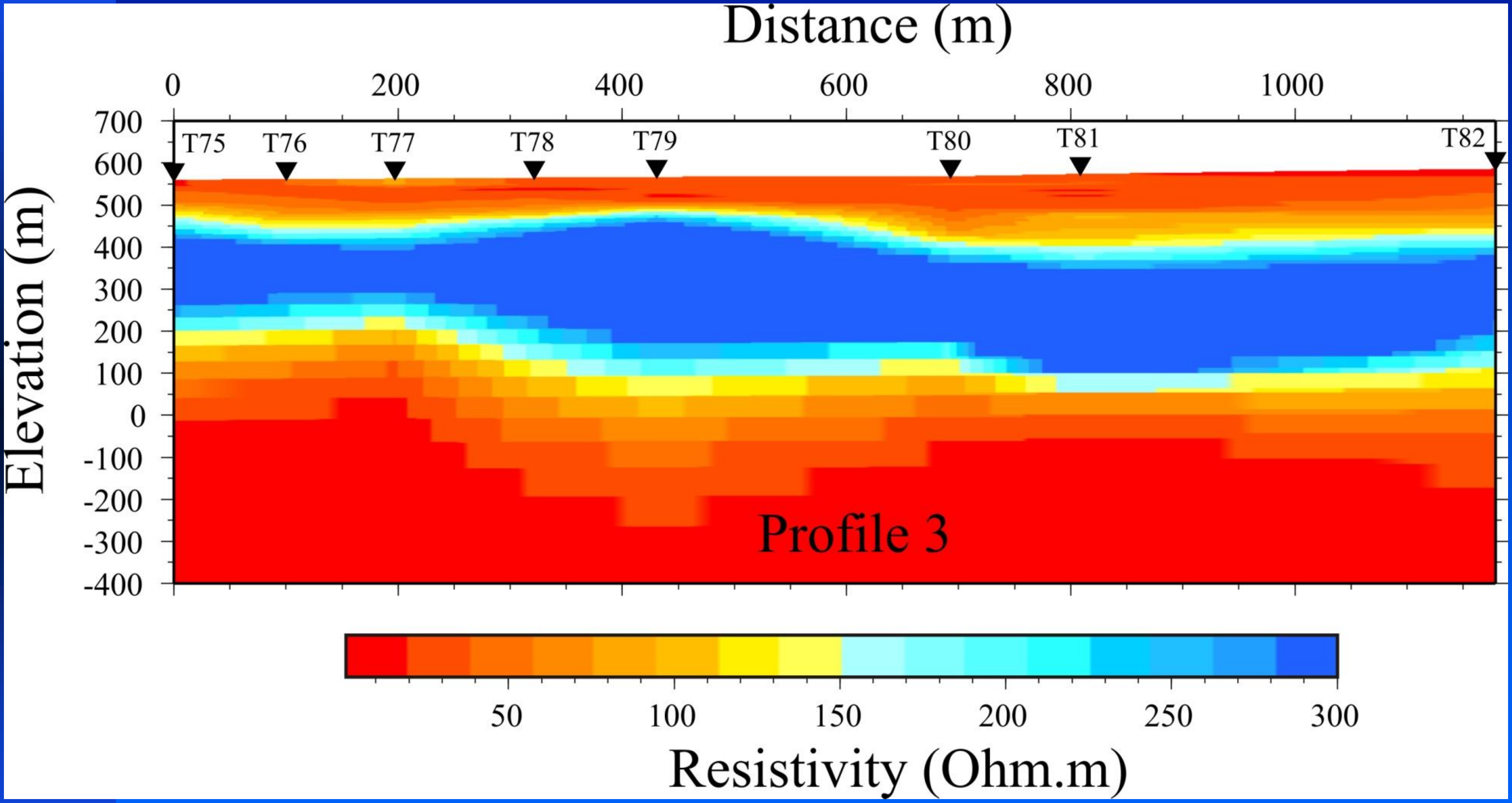

Distance (m)
0
200
400
600
800
1000
700
600
500
400
300
200
100
0
-100
-200
-300
-400
Elevation (m)
T39
T13
W10
T68
T69
T70
T71
Profile 1
50
100
150
200
250
300
Resistivity (Ohm.m)

Andes



Distance (m)
0
200
400
600
800
1000
700
600
500
400
300
200
100
0
-100
-200
-300
-400
Elevation (m)
T62
T63
T64
T65
T66
Profile 2
50
100
150
200
250
300
Resistivity (Ohm.m)

Andes



Distance (m)
0
200
400
600
800
1000
Elevation (m)
700
600
500
400
300
200
100
0
-100
-200
-300
-400
T75
T76
T77
T78
T79
T80
T81
T82
Profile 3
50
100
150
200
250
300
Resistivity (Ohm.m)

Perspectivas do método TDEM no Brasil ?

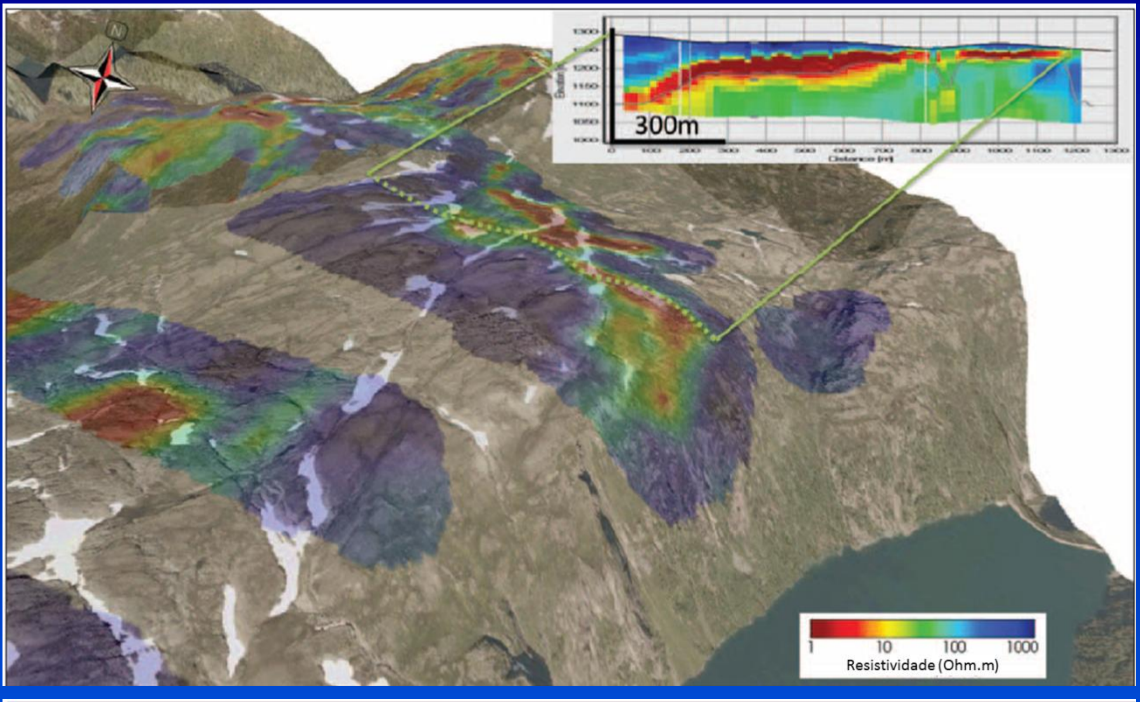
TDEM Terrestre:

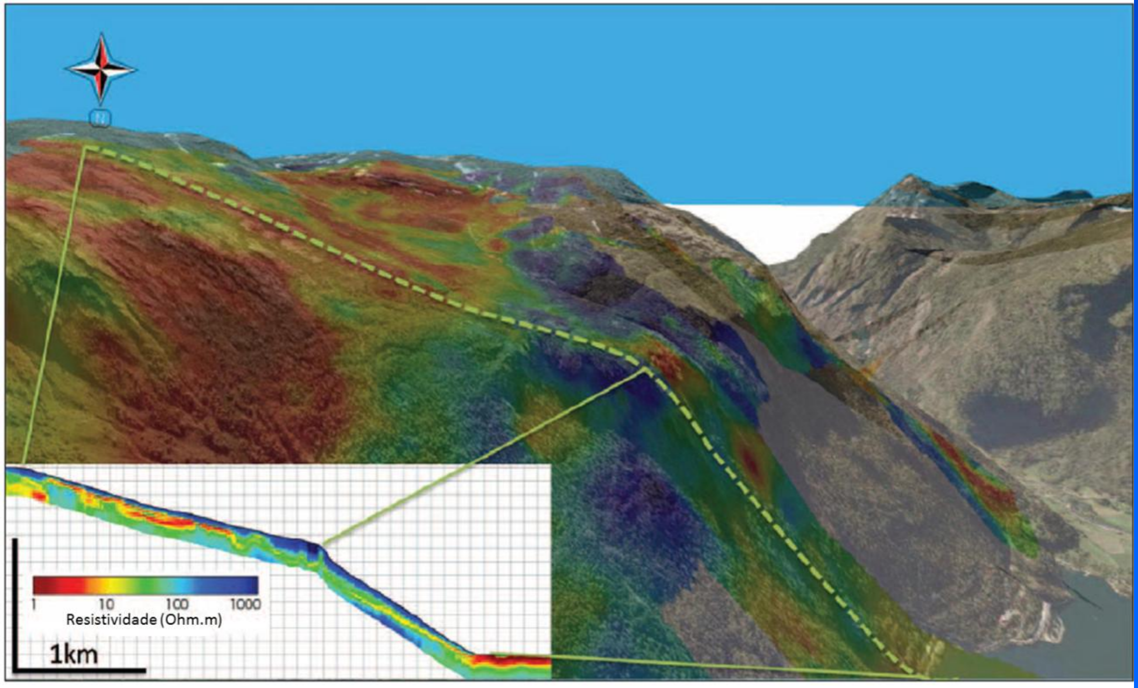
- **Exploração de água subterrânea;**
- **Exploração mineral (ouro, cassiterita etc);**
- **Estudos ambientais;**

TDEM Aéreo:

- ***Determinação de áreas de risco ....***

Resultados TDEM aéreo na Noruega (Pfaffhuber et al., 2010)





Obrigado