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DIM ESEE-2 innovative workshop

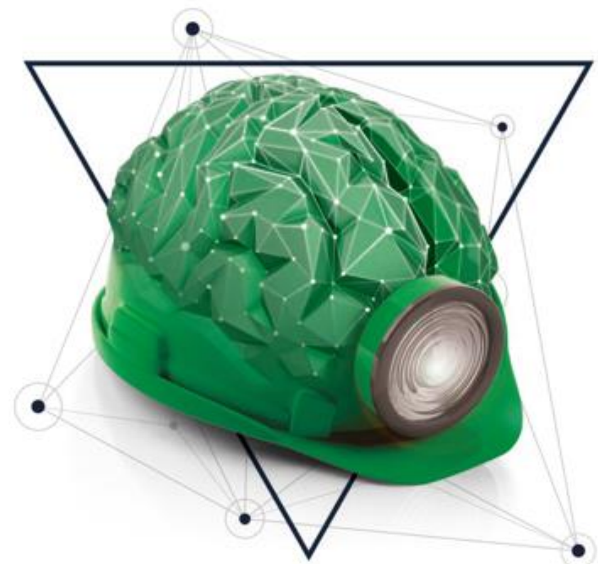
DIM ESEE 2021: Innovation in exploration

Prof. Dr. Norbert Péter Szabó

University of Miskolc, Department of Geophysics

22 October 2021

Shallow geophysical investigations by combining seismic, geoelectric and direct-push logging methods



October 20th – 22nd, 2021
IUC Dubrovnik, Croatia / online

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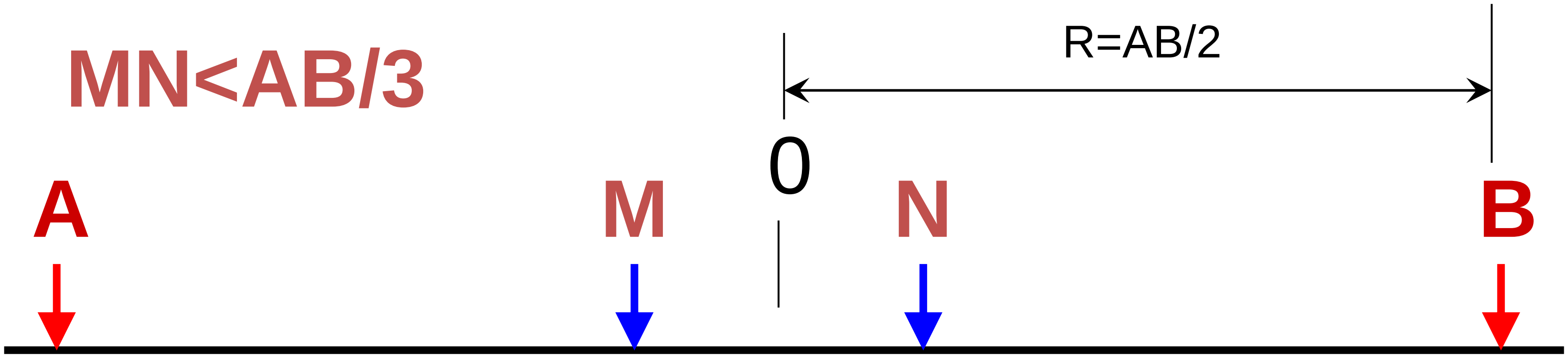
Course Description

- Shallow geophysical methods in brief: seismic refraction, multi-electrode direct current geoelectric method, direct-push logging (borehole engineering sounding) methods
- Environmental investigations made by combining seismic, geoelectric and direct-push logging methods
- The workflow of inverse modeling methods
- The problem of estimating the layer boundaries in joint inversion of surface geophysical data
- Joint inversion of different direct-push logging datasets
- Evolutionary meta-algorithmic inversion method. Estimating the petrophysical and zone parameters of near-surface structures as input for soil mapping and mining (e.g., gravel) applications

DC Geoelectric Method

MN<AB/3



(Wenner array: MN=AB/3)

Depth of investigation ≤ AB/3

Apparent Resistivity: $\rho_a = k\frac{\Delta U}{I} = k\frac{\Delta U_{MN}}{I_{AB}}$

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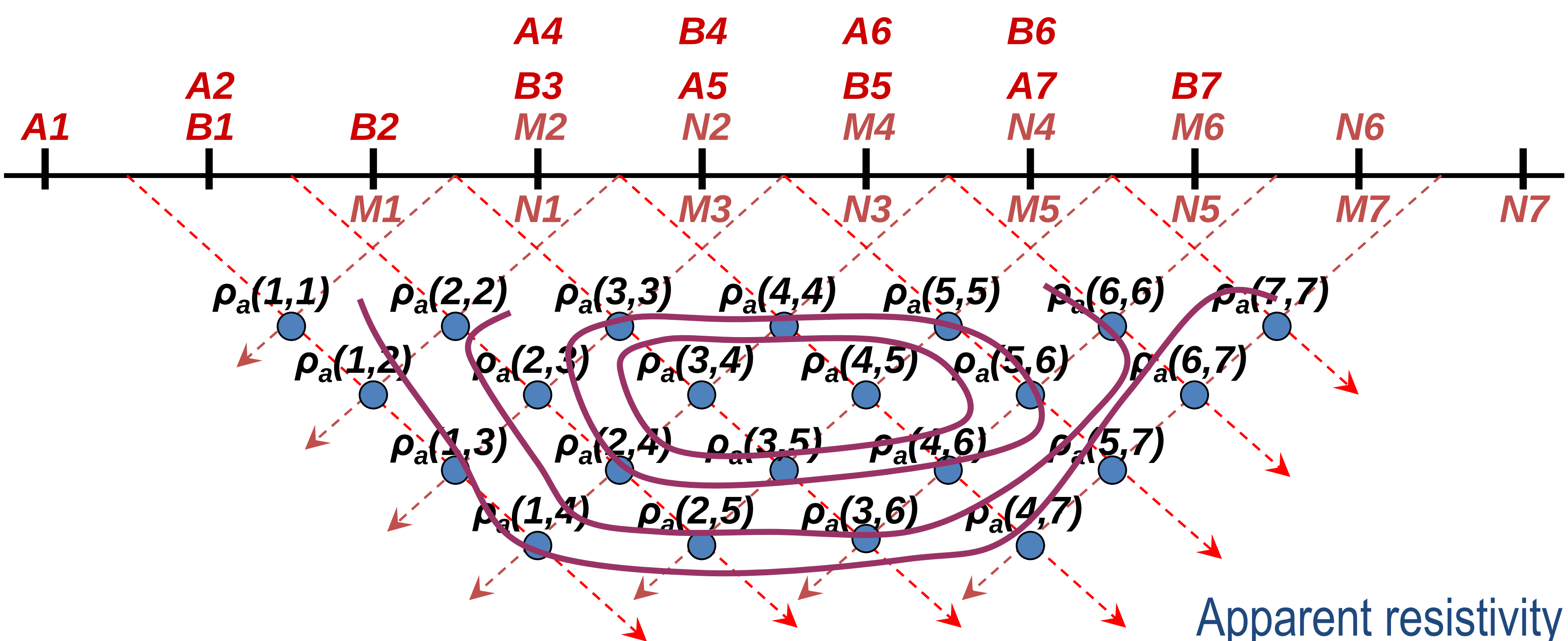
Multielectrode (ERT) method

Dipole-dipole array

(Reference depth = $R_{(AB/2,MN/2)}/2$)



Apparent resistivity (anomaly) pseudosection

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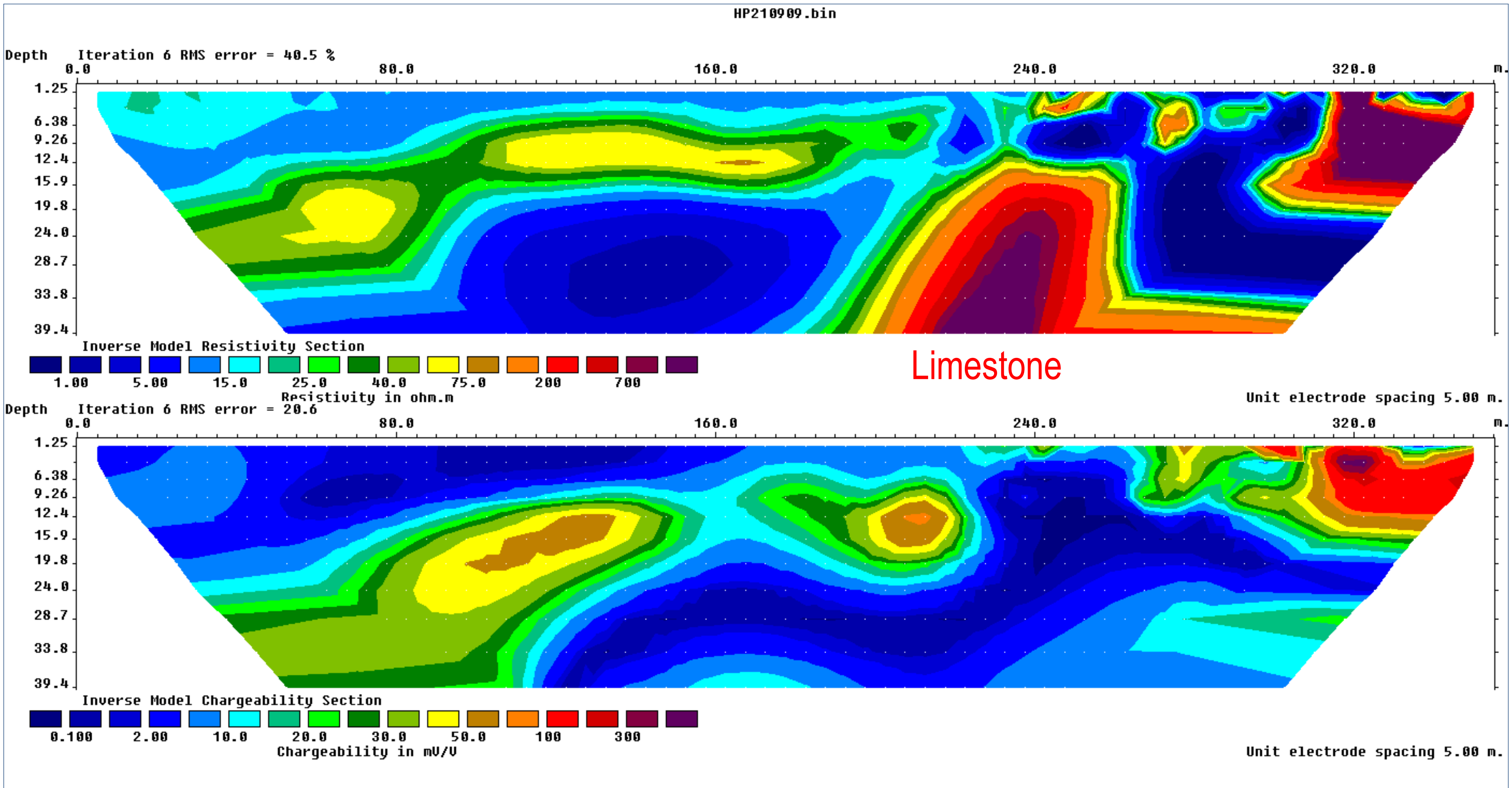
ERT Survey Along Riverbank



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Hejő River (Turai, 2009)

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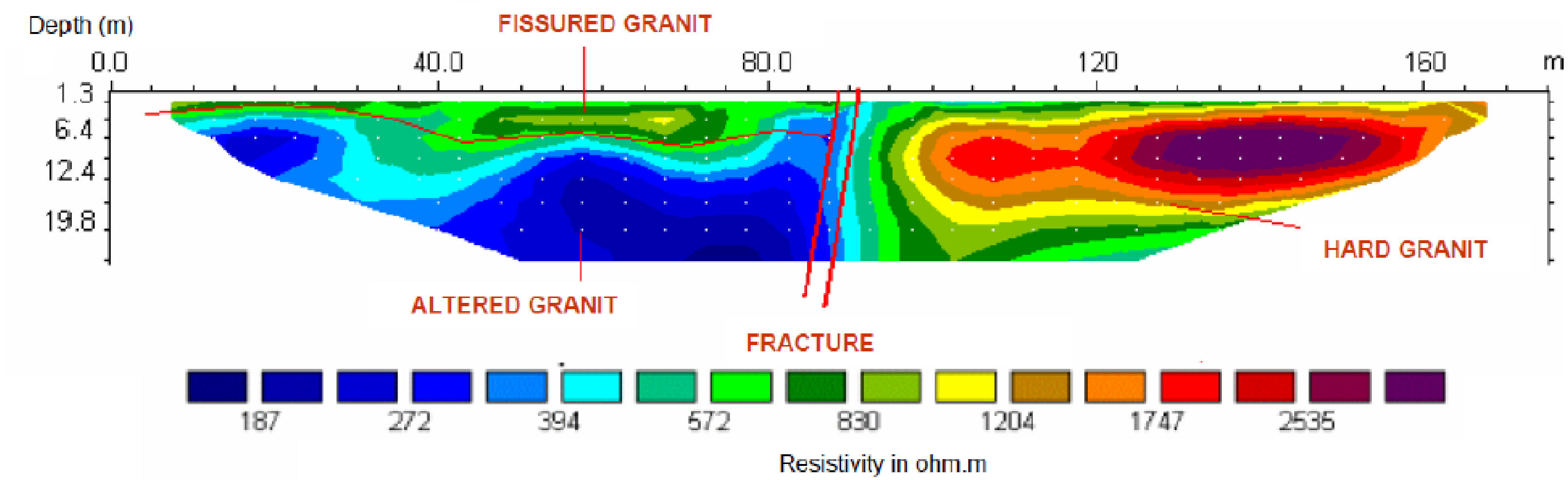
ERT Survey for Rock Differentiation



EQUIPMENT: SYSCAL R1 Plus *SWITCH*-48

CONFIGURATION: Schlumberger-Wenner

NUMBER OF READINGS: 362

SPACING BETWEEN ELECTRODES: 5 m

SITE: Spain

GEOLOGY: granitic area with altered and fractured zones

DURATION OF MEASUREMENTS: 1 hour (system set-up + reading taking)

altered granit: less than 200 ohm.m

hard granit: more than 2 000 ohm.m

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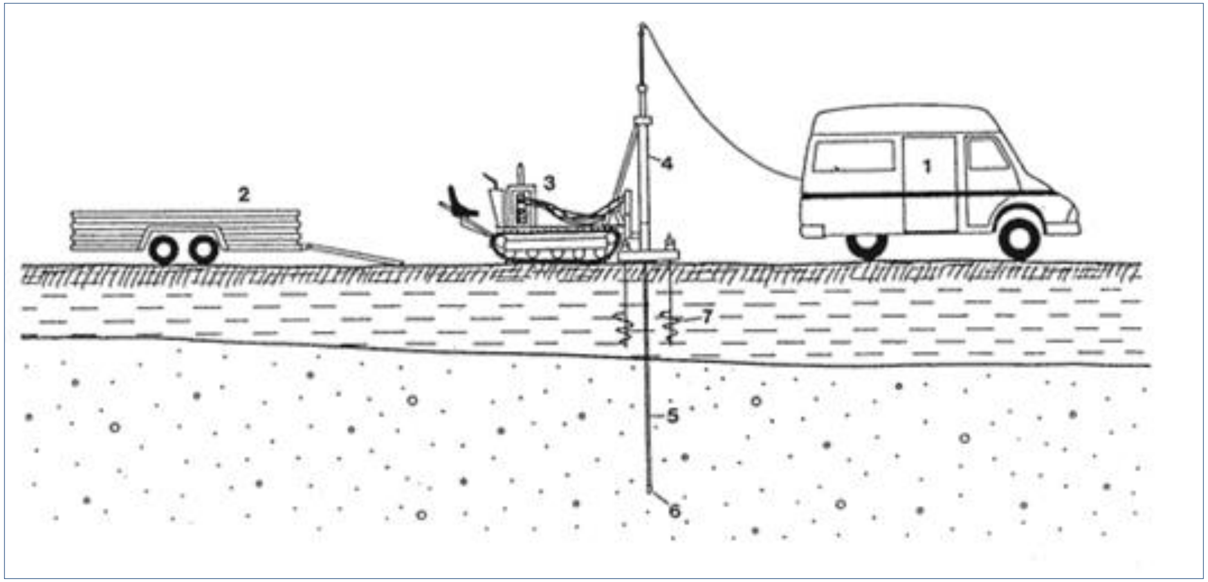
Direct Push (Logging) Method

Engineering Geophysical Sounding



1 – Vehicle
2 – Semitrailer
3 – Hydraulic machinery
4 – Pressure piston
5 – Measuring tube
6 – Measuring head
7 – Anchor

Fejes and Jósa (1990)

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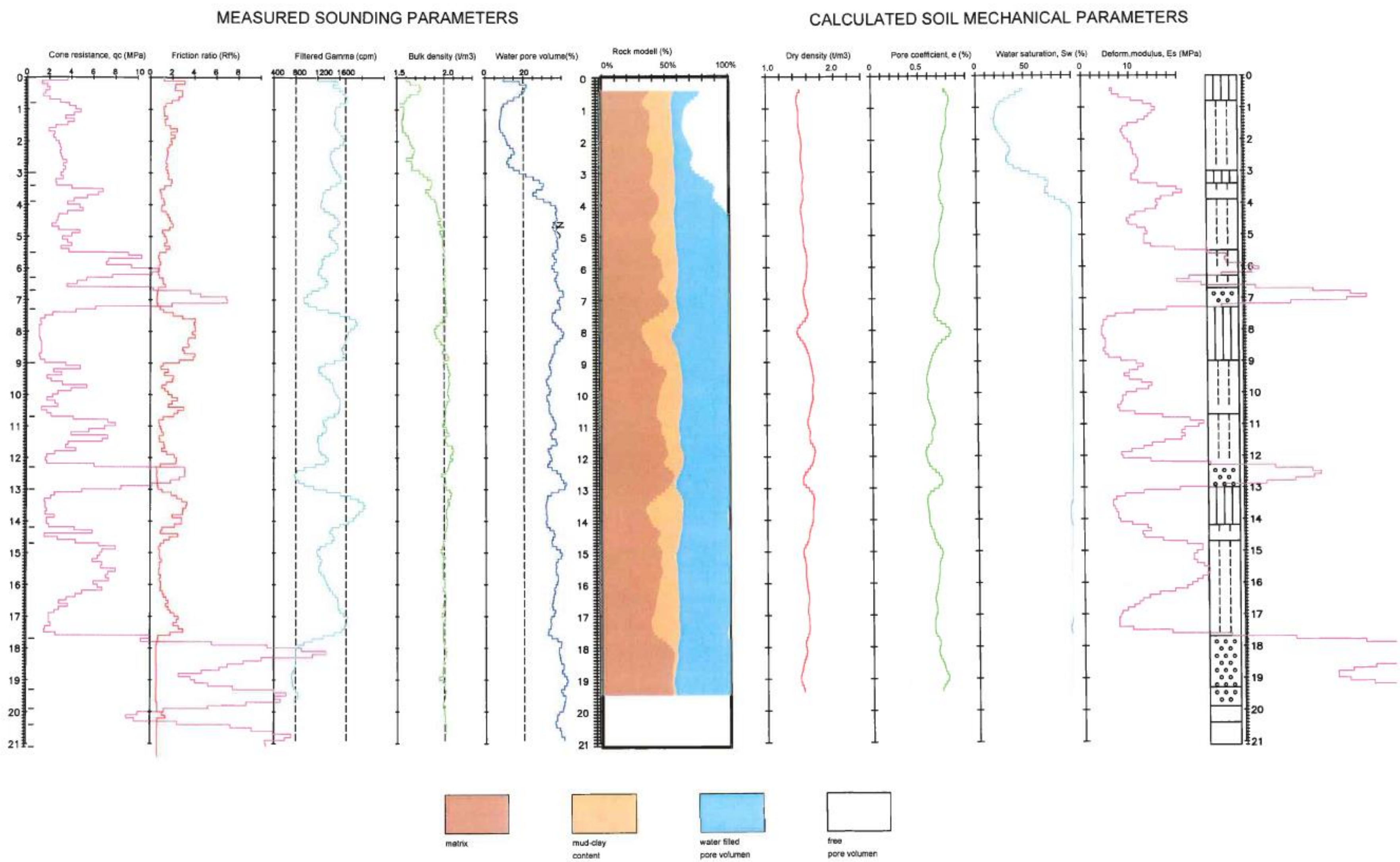
Characterization of Soils



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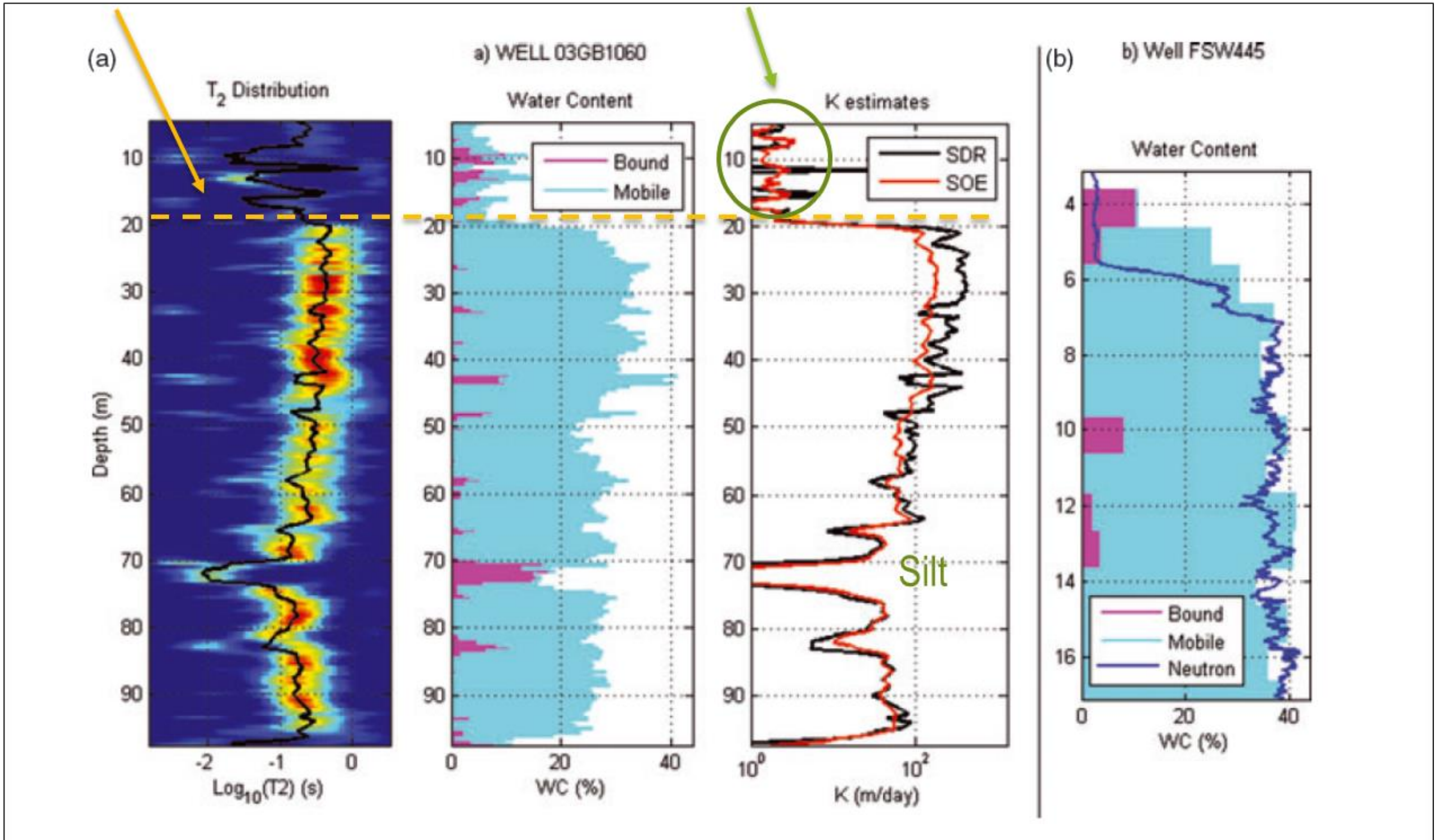
Direct Push NMR Logging

Level of water table

Silty unsaturated zone



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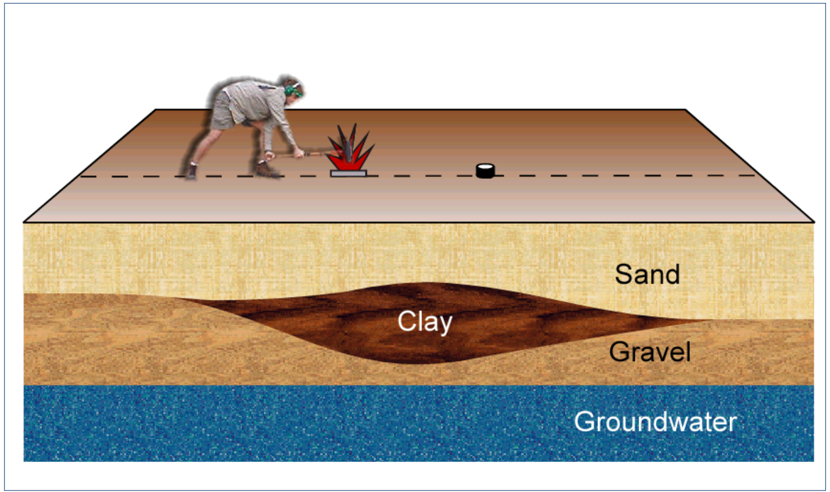
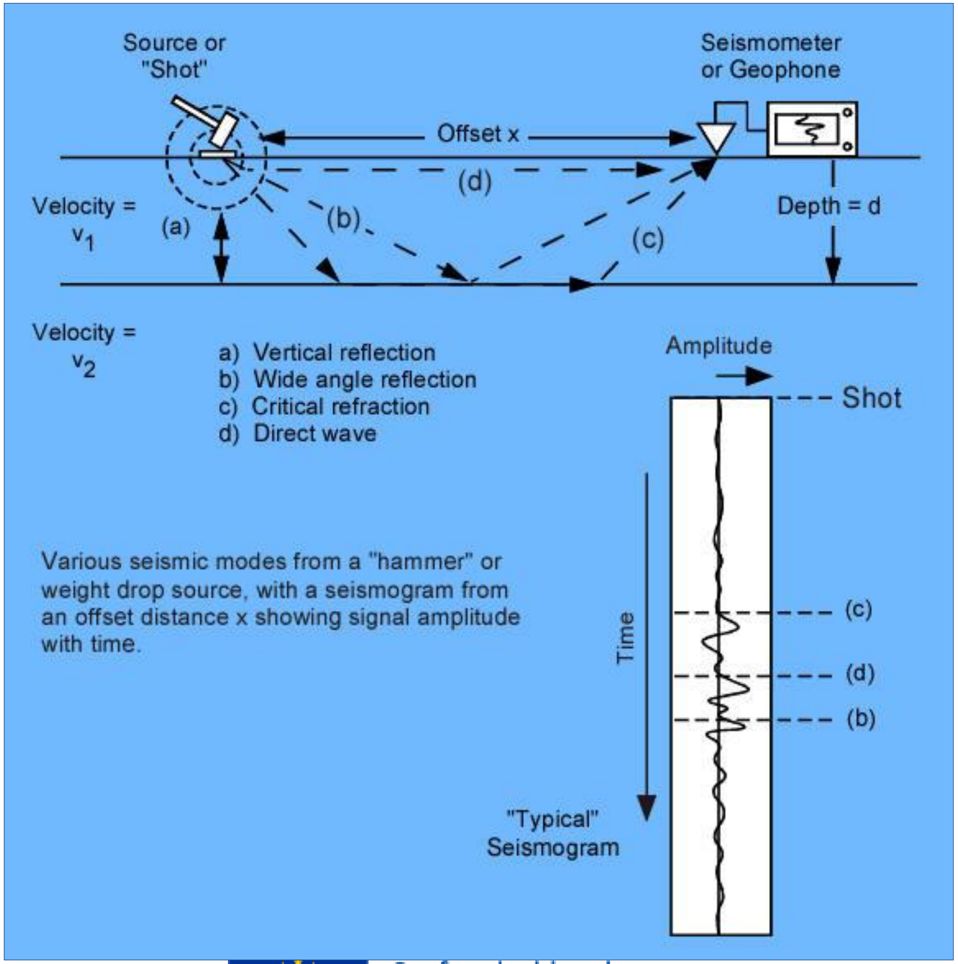
Seismic Method





a) Vertical reflection
b) Wide angle reflection
c) Critical refraction
d) Direct wave

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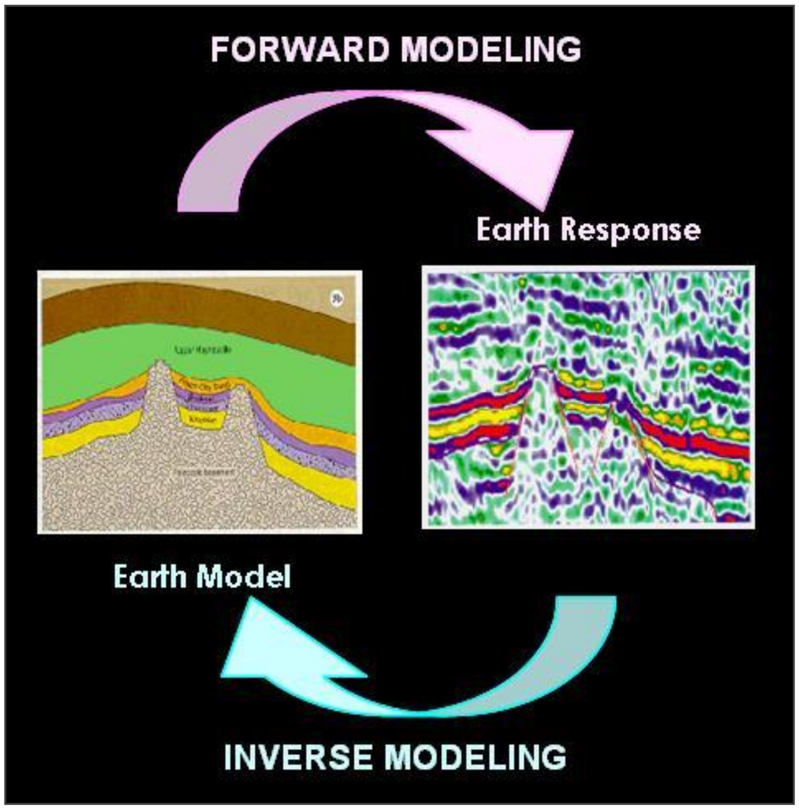
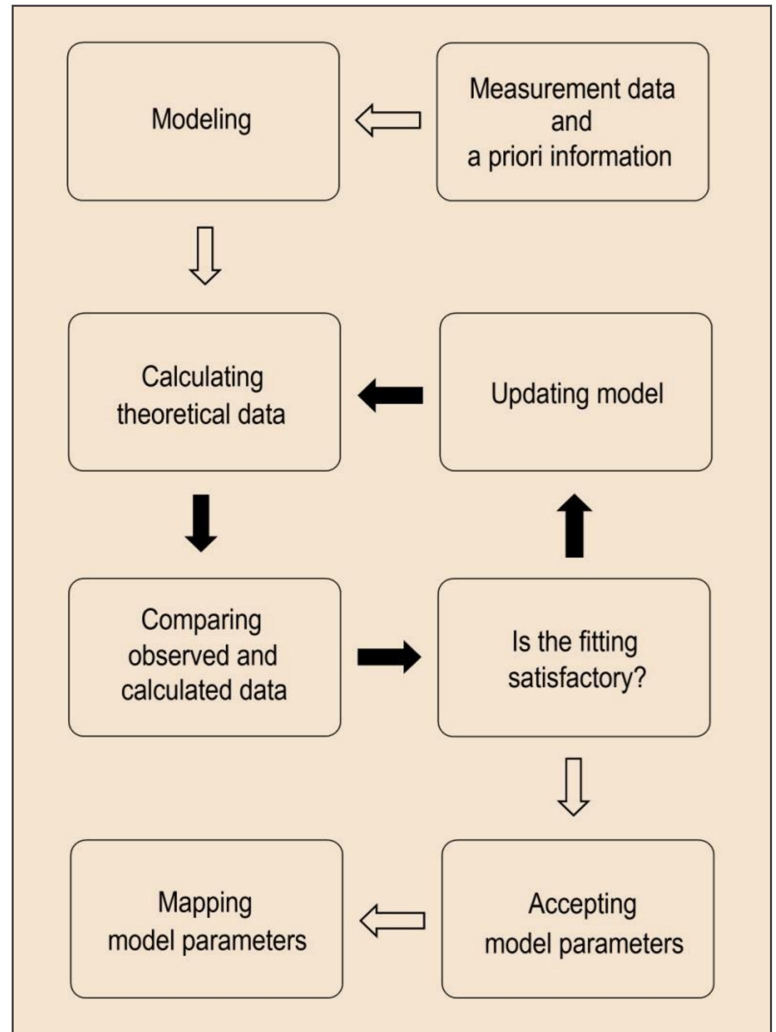
Workflow of Inverse Modeling





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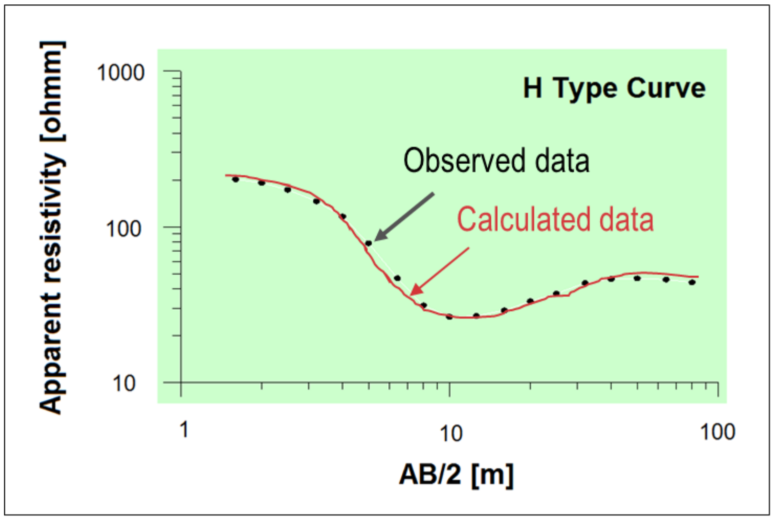
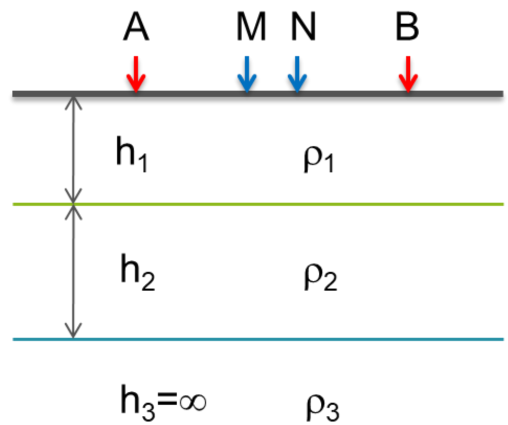
1D Inversion of Vertical Electric Sounding Data





H type: $\rho_1 > \rho_2 < \rho_3$

Q type: $\rho_1 > \rho_2 > \rho_3$

K type: $\rho_1 < \rho_2 > \rho_3$

A type: $\rho_1 < \rho_2 < \rho_3$

- We assume that the layers are homogeneous and isotropic
- Estimated parameters of the 1D model are:
  h_i: layer thicknesses and
  ρ_i: layer (true) resistivities

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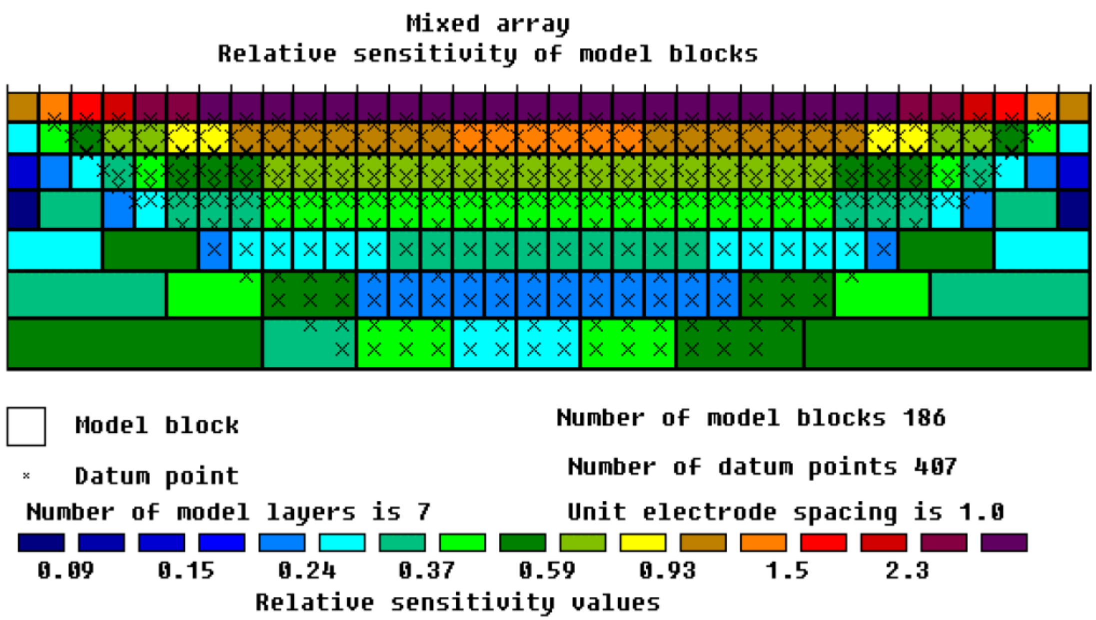
2D Inversion of Geoelctric Datasets



$$(\mathbf{J}^T\mathbf{J} + u\mathbf{F})\mathbf{d} = \mathbf{J}^T\mathbf{g}$$

$\mathbf{F} = \mathbf{f}_x\mathbf{f}_x^T + \mathbf{f}_z\mathbf{f}_z^T$

$\mathbf{f}_x$ = horizontal flatness filter

$\mathbf{f}_z$ = vertical flatness filter

$\mathbf{J}$ = matrix of partial derivatives

u = damping factor

$\mathbf{d}$ = model perturbation vector

$\mathbf{g}$ = discrepancy vector

GeoTomo Software (2010)

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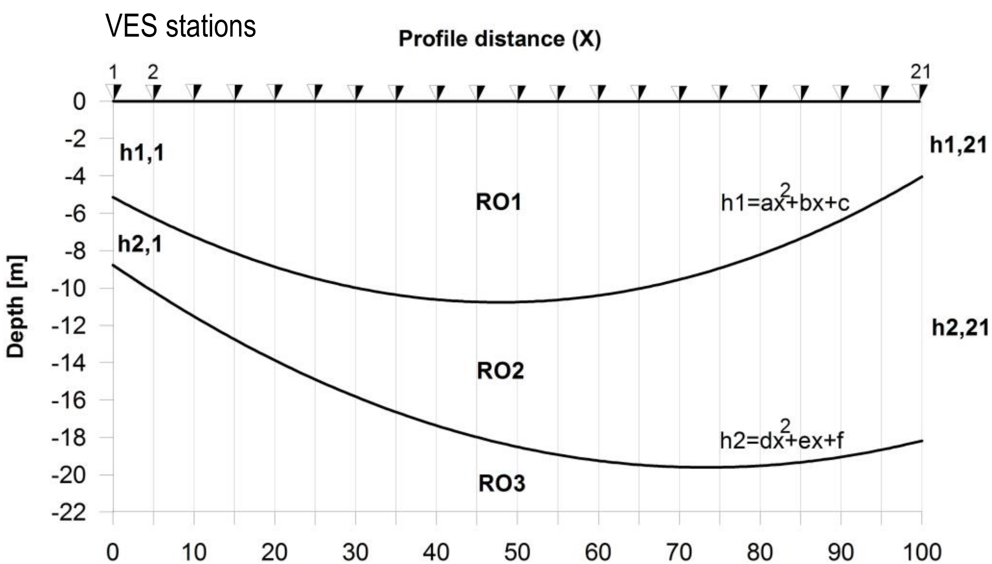
1.5D Inversion of Geoelctric Datasets



Gyulai et al. (2014)

- Variations of layer boundary and resistivity along the profile are described by continuous functions – **Joint inversion scheme**
- Discretization of layer parameters is based on series expansion (Dobróka, 1993)

$$m_i(x)=\sum_{q=1}^{Q^{(i)}} B_q^{(i)}\Phi_q(x)$$

where m_i denotes the i-th physical or structural parameter, B_q is the q-th expansion coefficient, Φ_q is the q-th basis function (up to Q number of additive terms)

- Number of unknowns is
  - Set of 1D local inversions = 105
  - Series expansion-based 2D inversion = 9
- Highly overdetermined inverse problem is solved for the expansion coefficients (the basis functions are known quantities)
- Higher accuracy, reliability, resolution and stability (no smoothness constraints)

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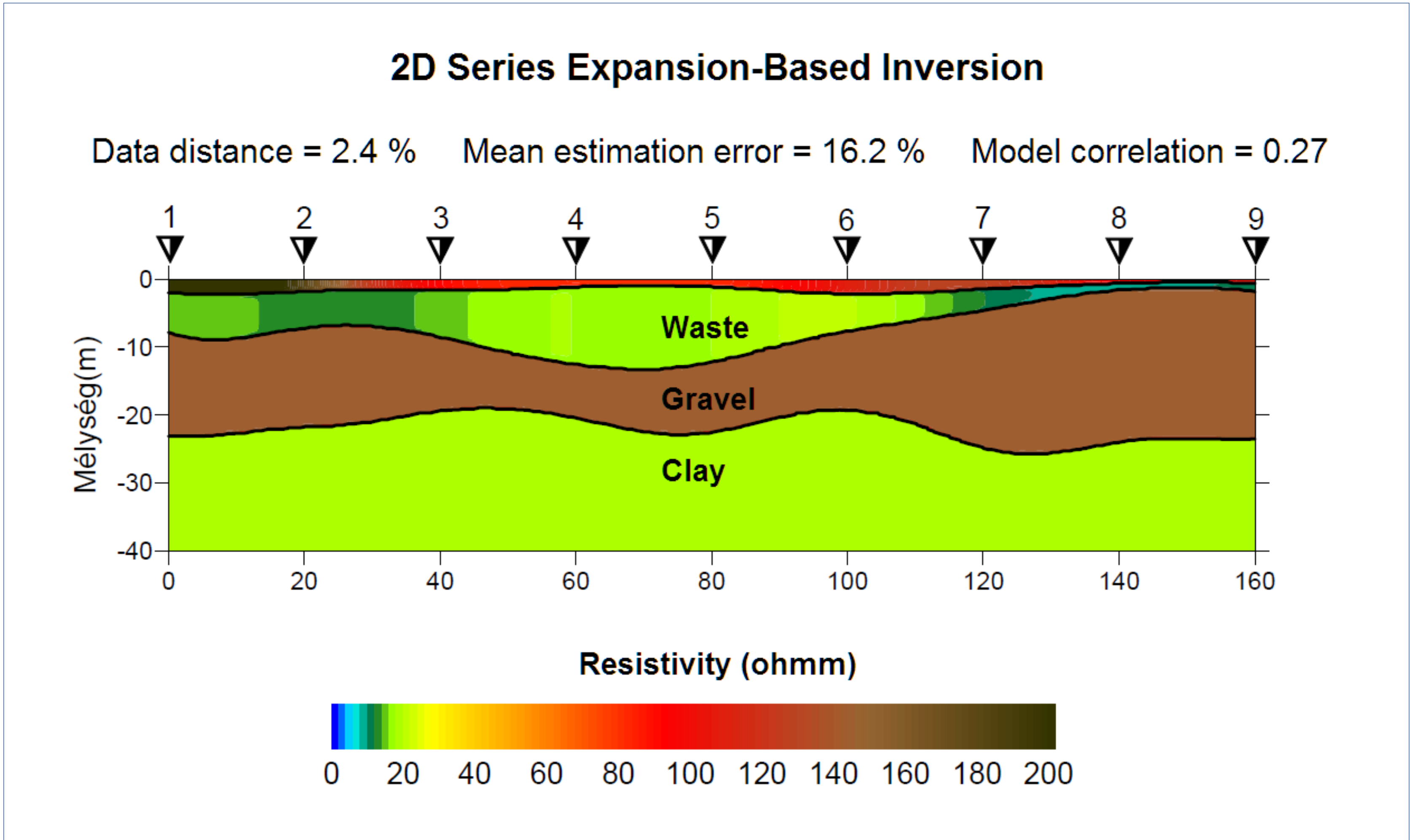
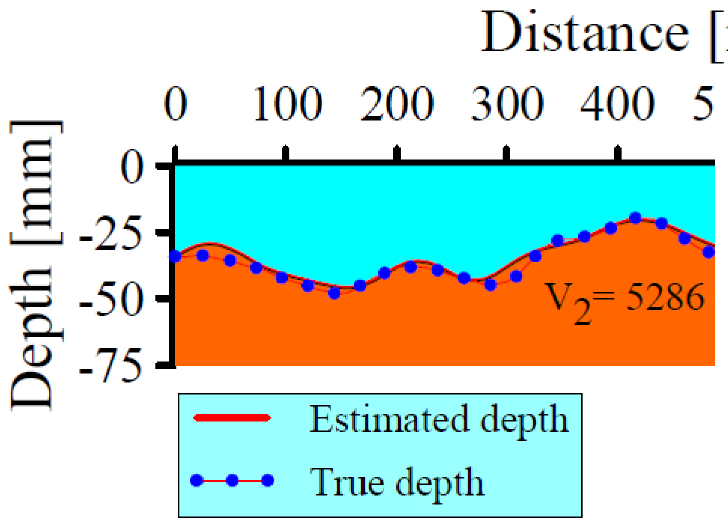
Joint Inversion of Geoelctric Datasets

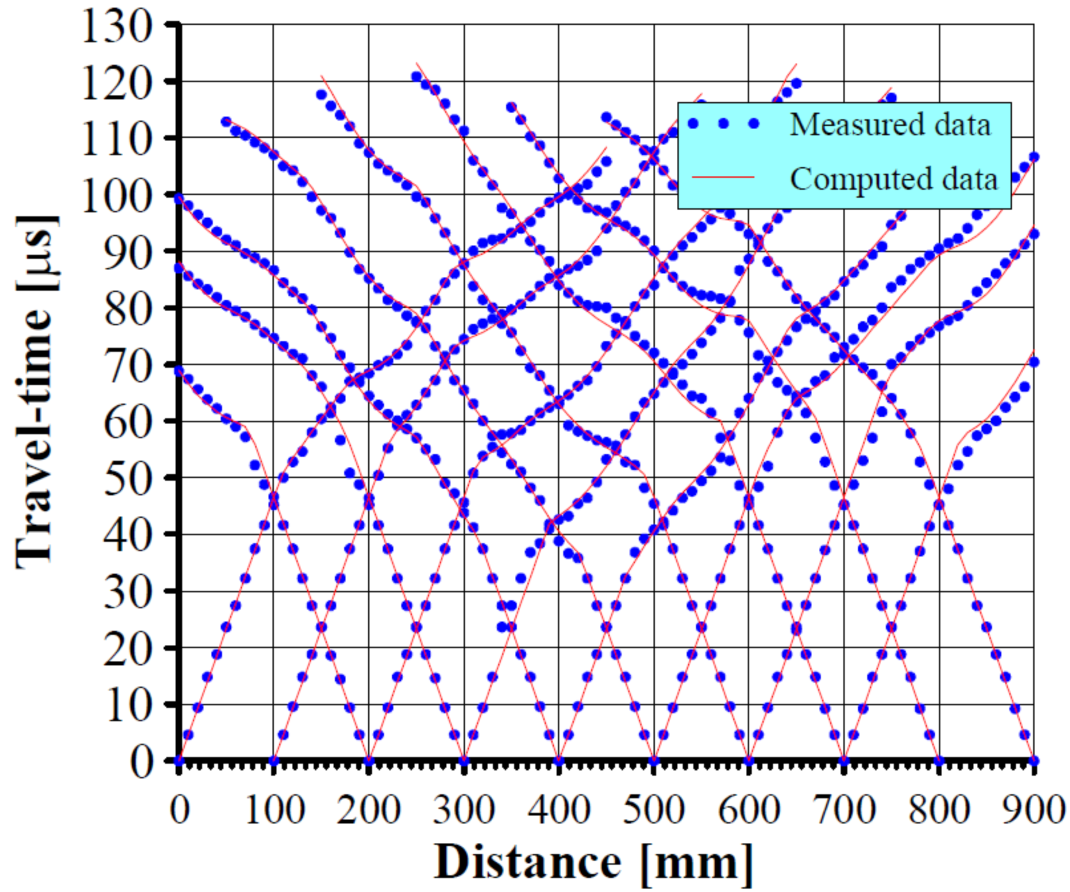


Inversion of Refraction Data

- Analogous Modeling Experiments -

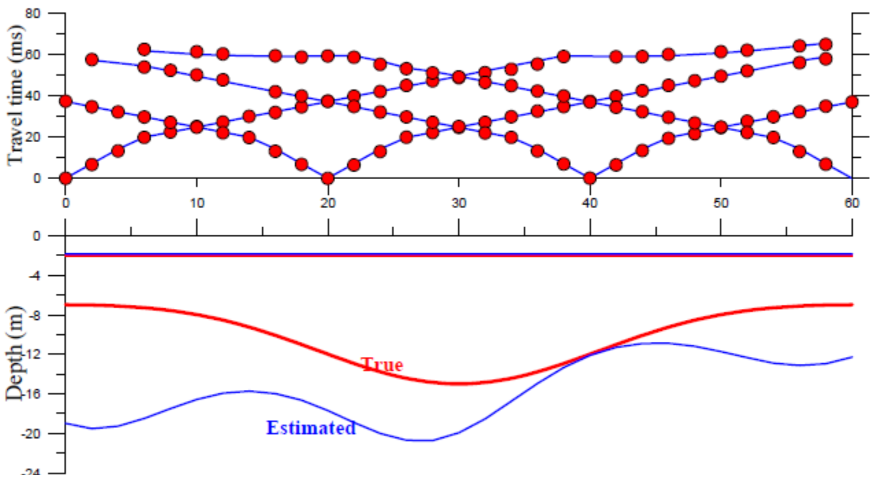


Tamás Ormos (2006)

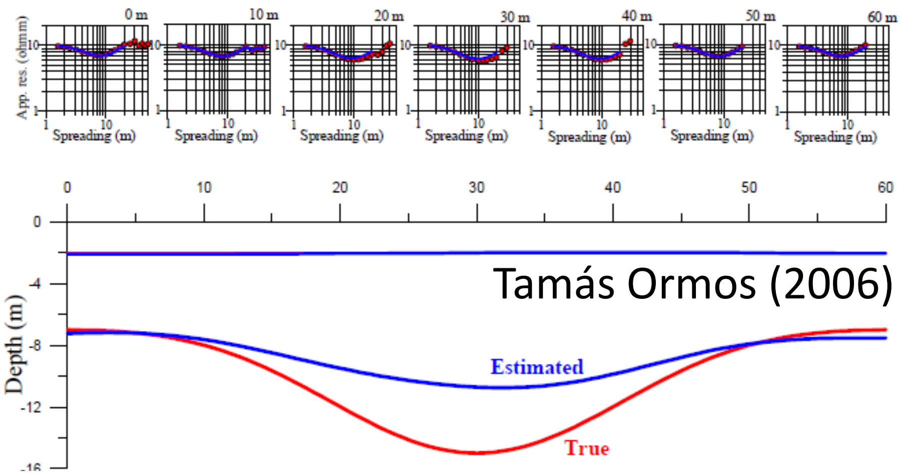


Inversion for Identical Layer Boundaries

Results of seismic inversion

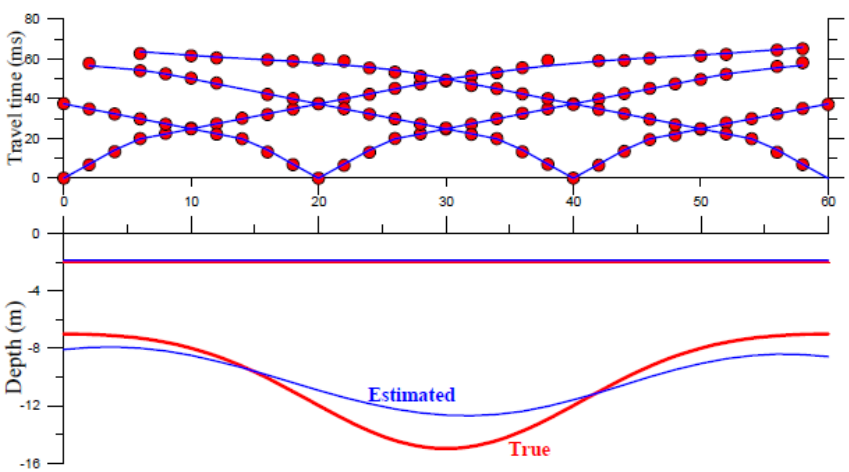


Results of geoelectric 1.5D inversion

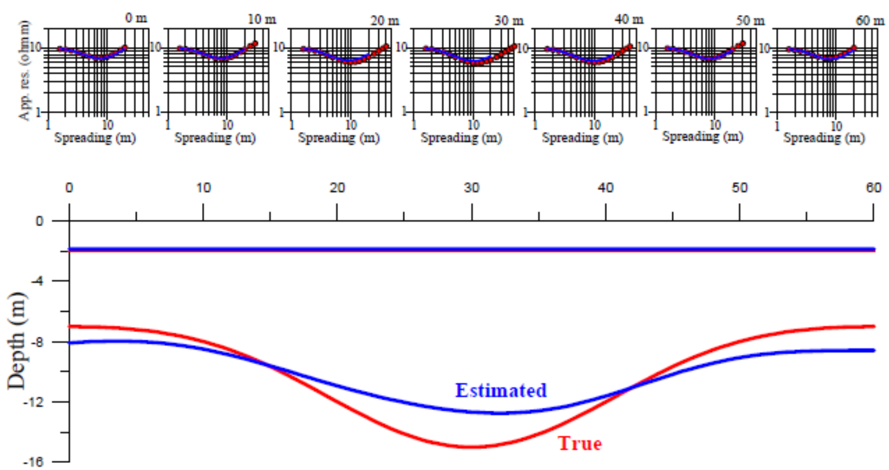


Tamás Ormos (2006)

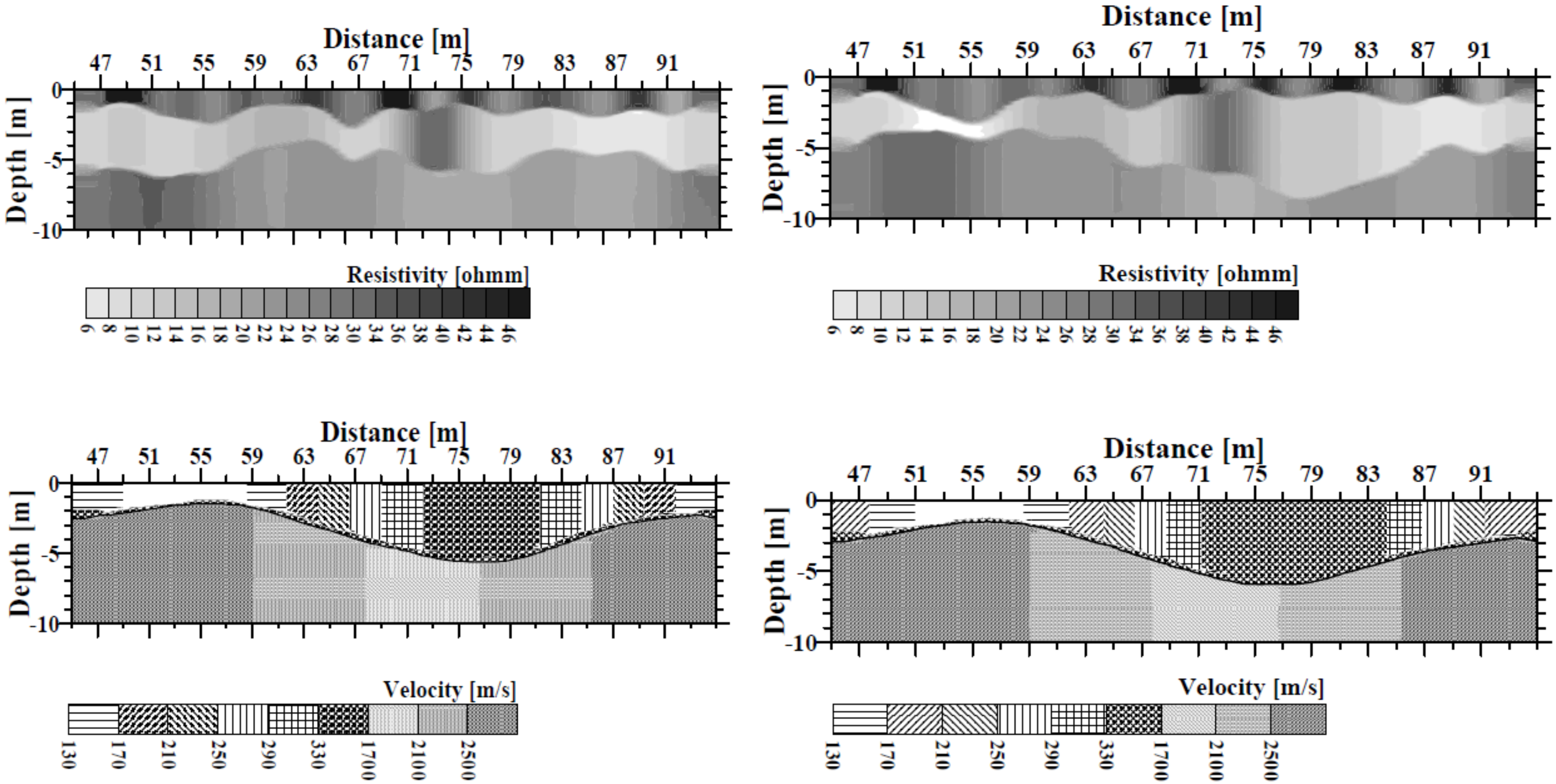
Results of geoelectric-seismic joint inversion



Results of geoelectric-seismic joint inversion



Inversion for Different Layer Boundaries



- Separate geoelectric and seismic inversion (left panels), average estimation error is **23 %**
- Joint inversion of geoelectric and seismic data (right panels), average estimation error is **11 %**

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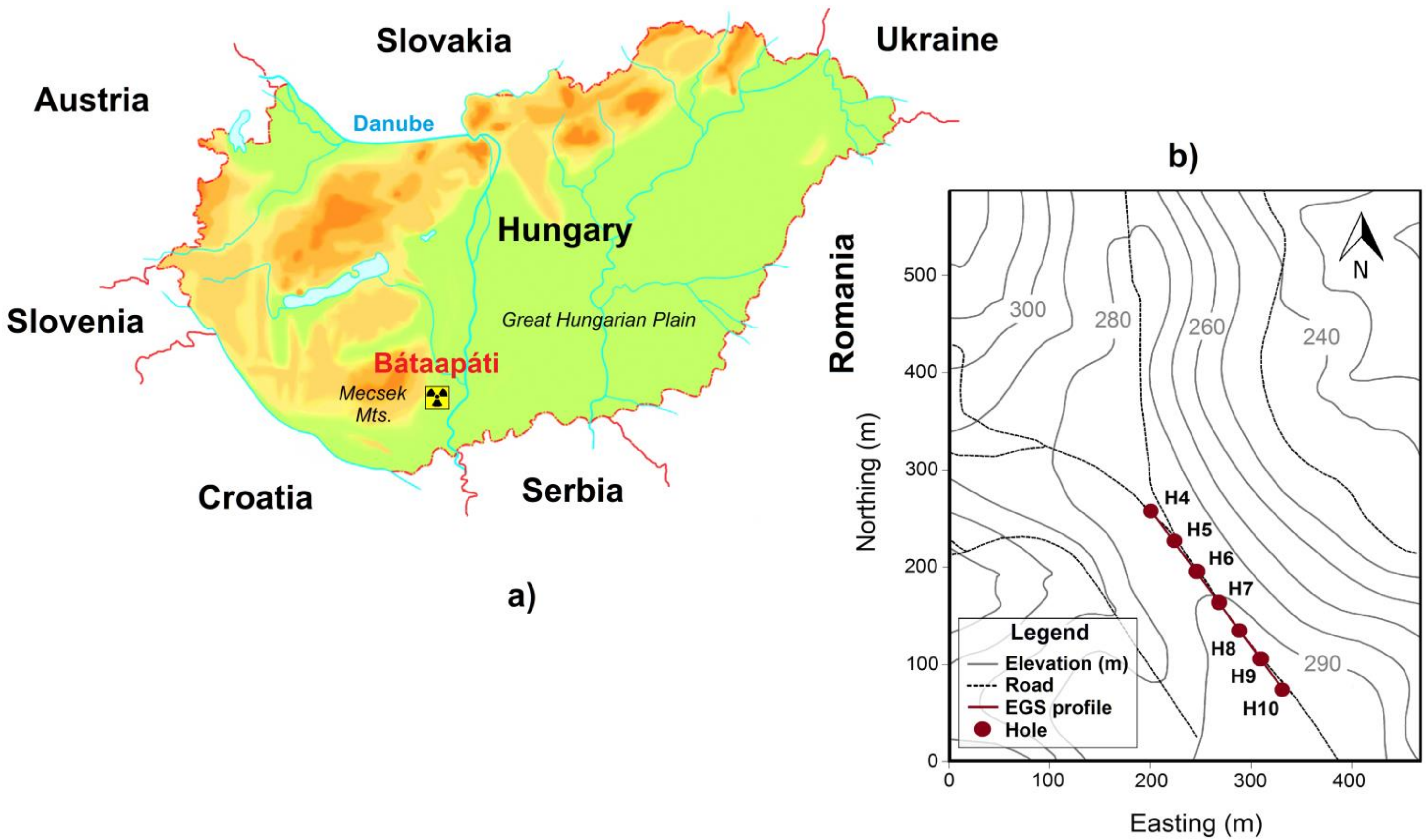
Tamás Ormos (2006)

Nuclear Waste Site Characterization



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Genetic Inversion of Direct Push Data

- Forward problem (model >> predicted data)

$$d_s^{(calculated)} = g_s\left(V_w, V_{cl}, V_{ma}, c\right)$$

- Zone parameters in the shallow unsaturated zone

$$\mathbf{c} = \left[GR_{cl}, GR_{ma}, R_{cl}, \rho_{cl}, \rho_{ma}, \Phi_{N,cl}\right]^T$$

- Fitness function of the 1D inverse problem

$$F\left(\mathbf{c}^{(j)}\right) = -\left[(NS)^{-1}\sum_{n=1}^{N}\sum_{s=1}^{S}\left(\frac{D_{ns}^{(m)} - g_s\left(\mathbf{m}^{(n)}, \mathbf{c}^{(j)}\right)}{D_{ns}^{(m)}}\right)^2\right]^{1/2}$$

- Fitness function of the 2D inverse problem

$$F^*\left(\mathbf{c}^{(j)}\right) = -\left[(N^*S)^{-1}\sum_{h=1}^{H}\sum_{n=1}^{N_h}\sum_{s=1}^{S}\left(\frac{D_{hns}^{(m)} - g_s\left(\mathbf{m}^{(hn)}, \mathbf{c}^{(j)}\right)}{D_{hns}^{(m)}}\right)^2\right]^{1/2}$$

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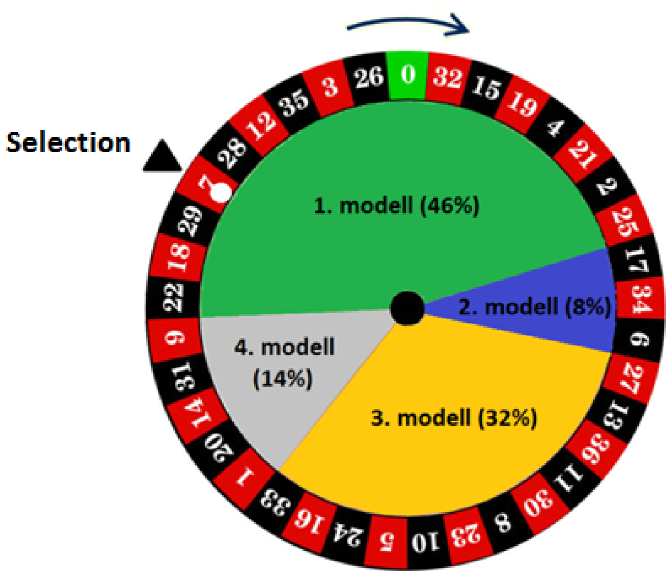
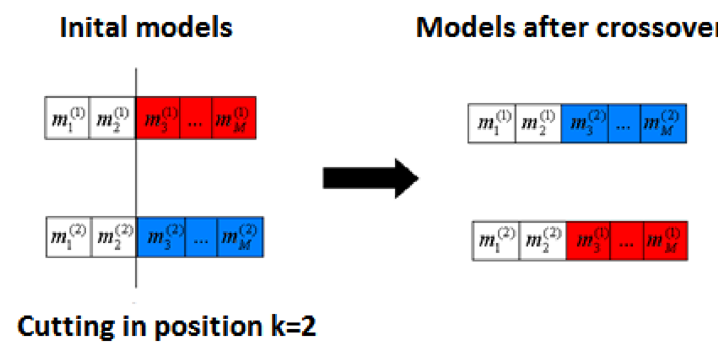
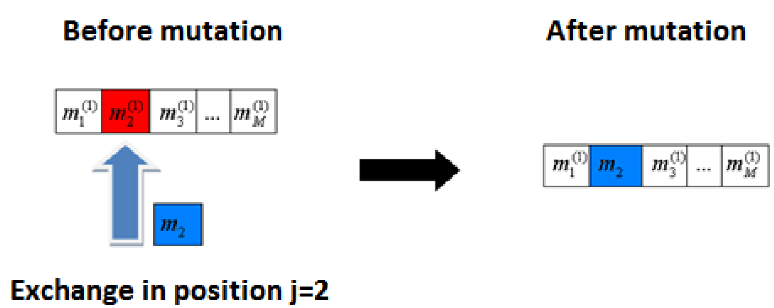
Genetic Algorithm Based Search







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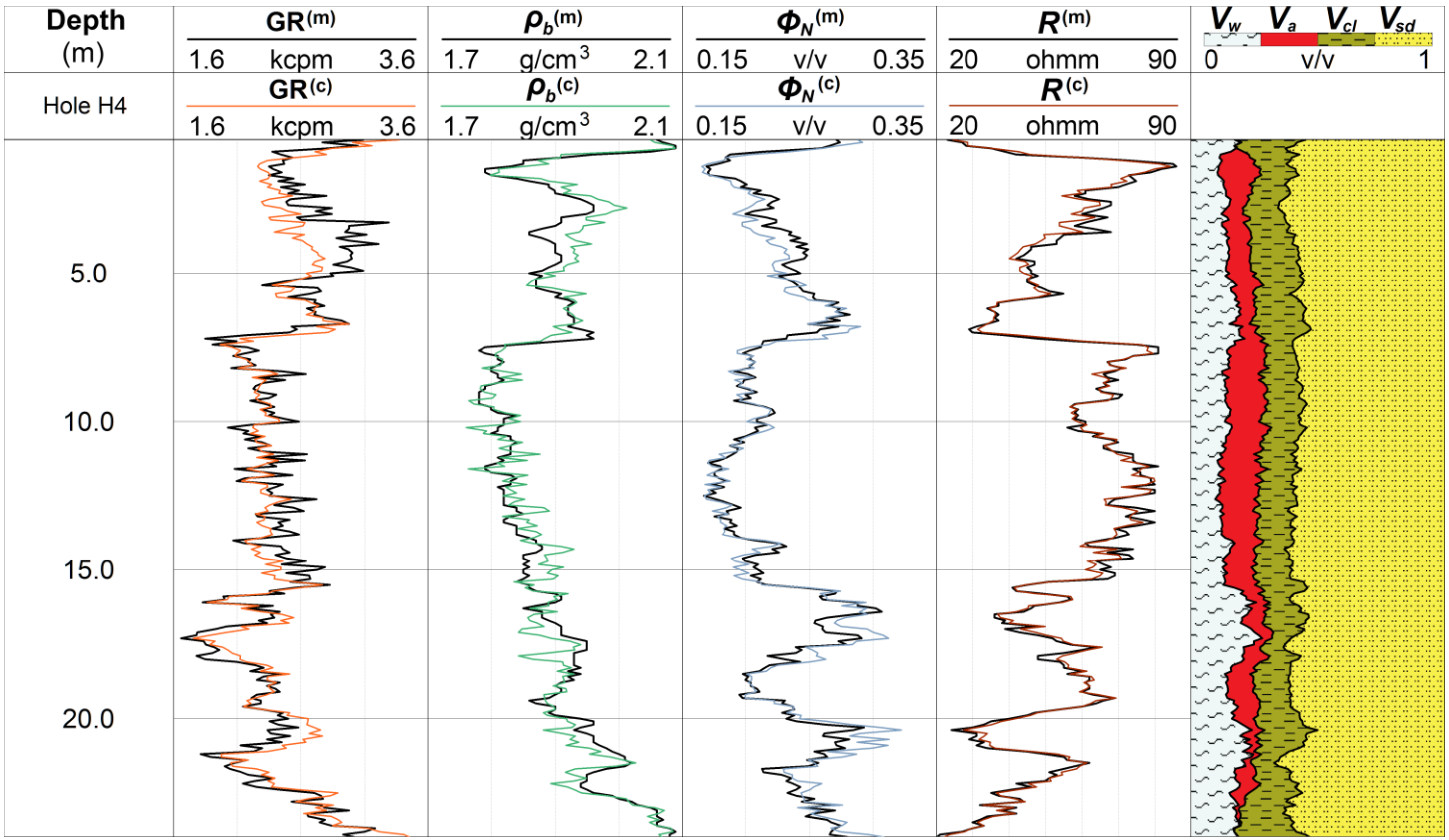
1D Inversion of Direct Push Logs



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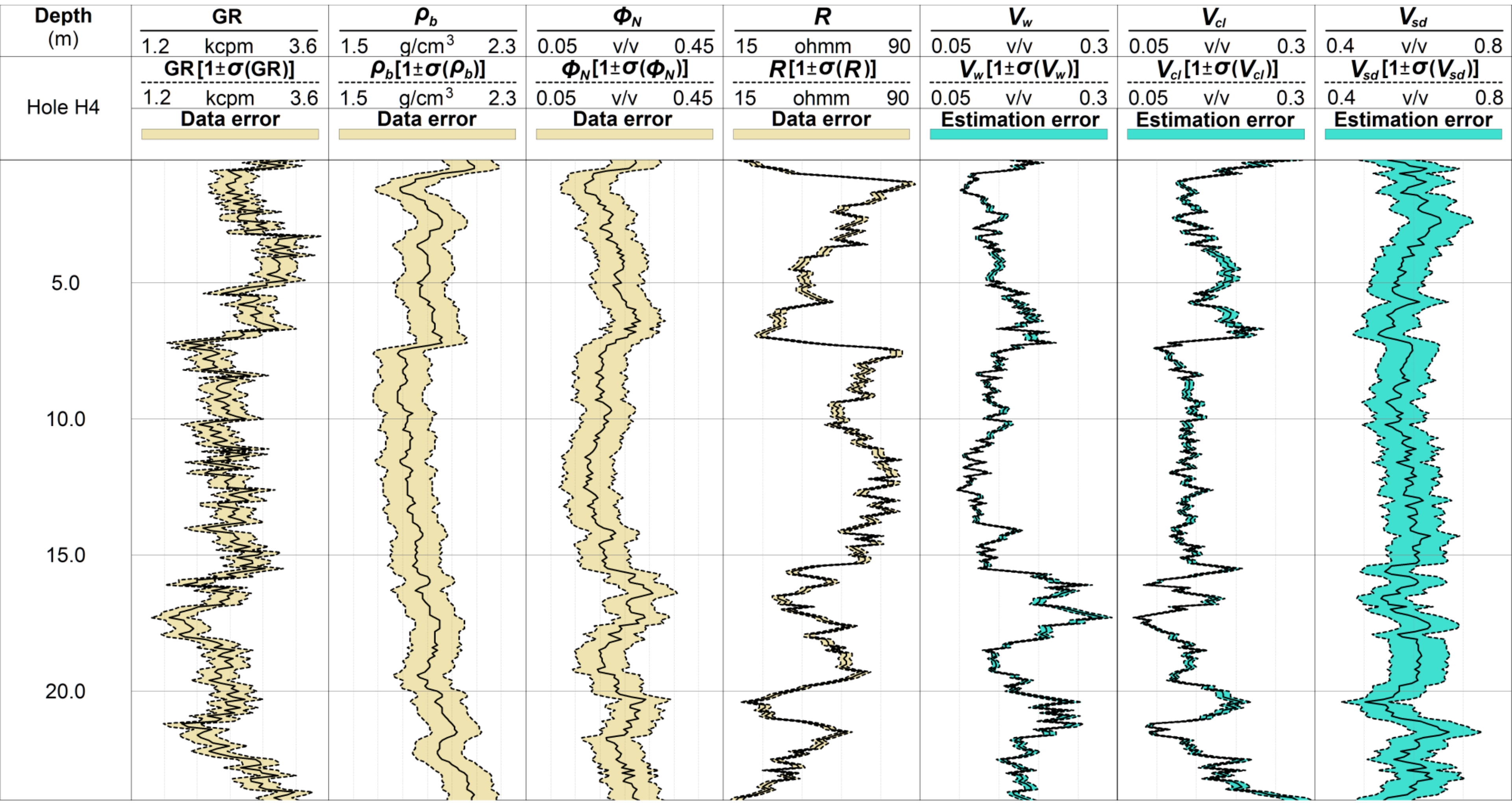
QC of Inversion Results



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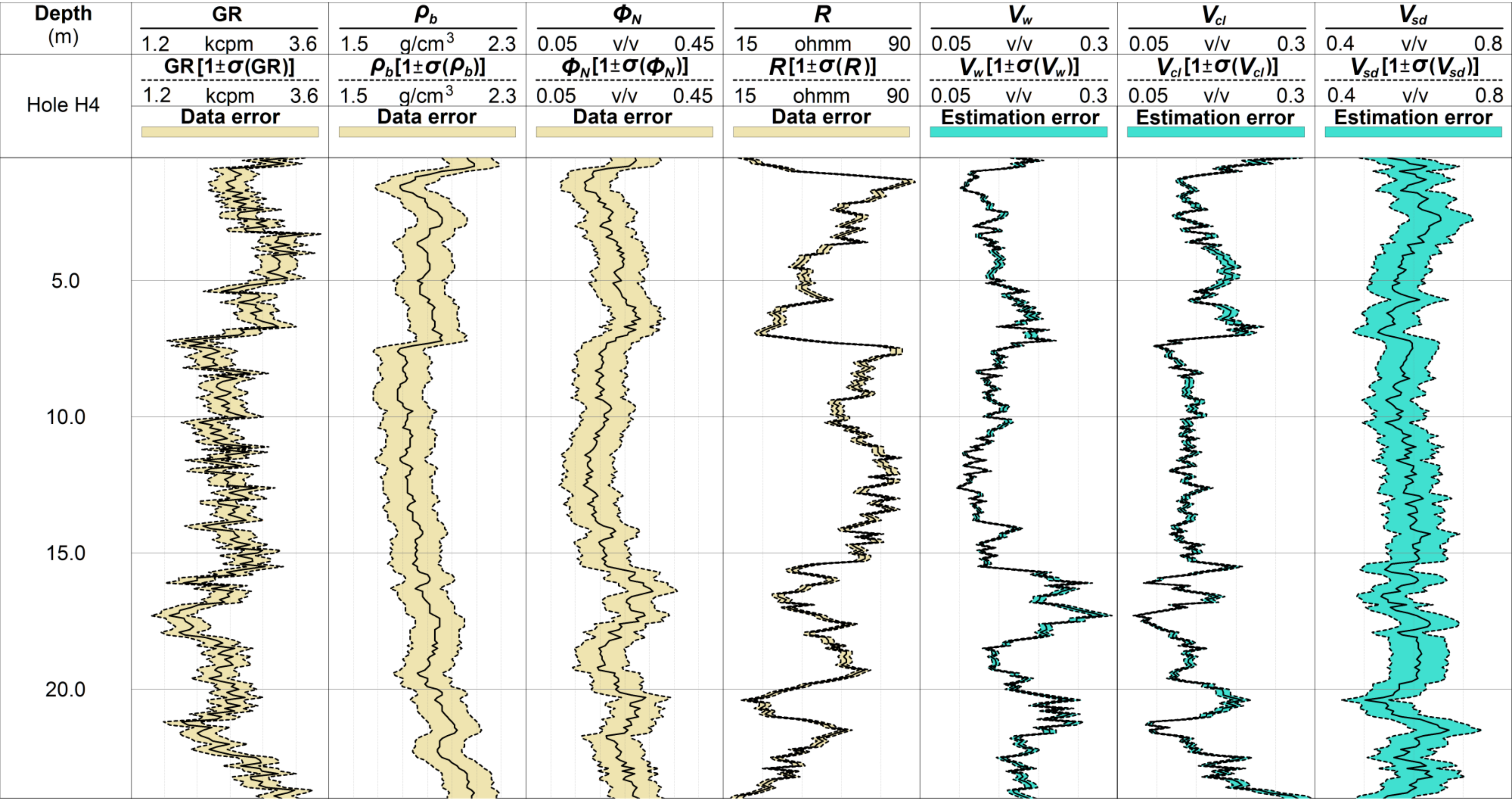
QC of Inversion Results



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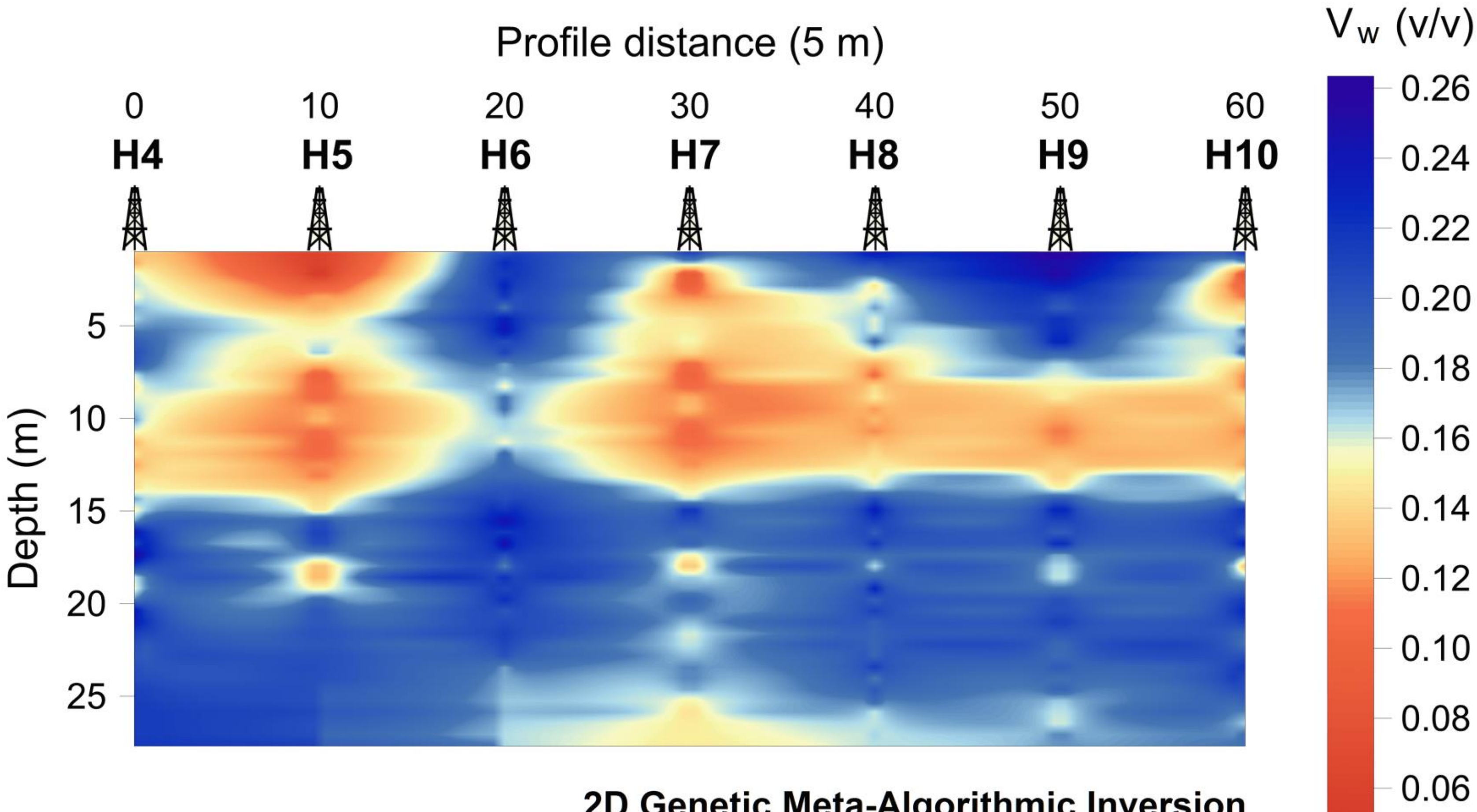
2D Inversion of Direct Push Logs



2D Genetic Meta-Algorithmic Inversion

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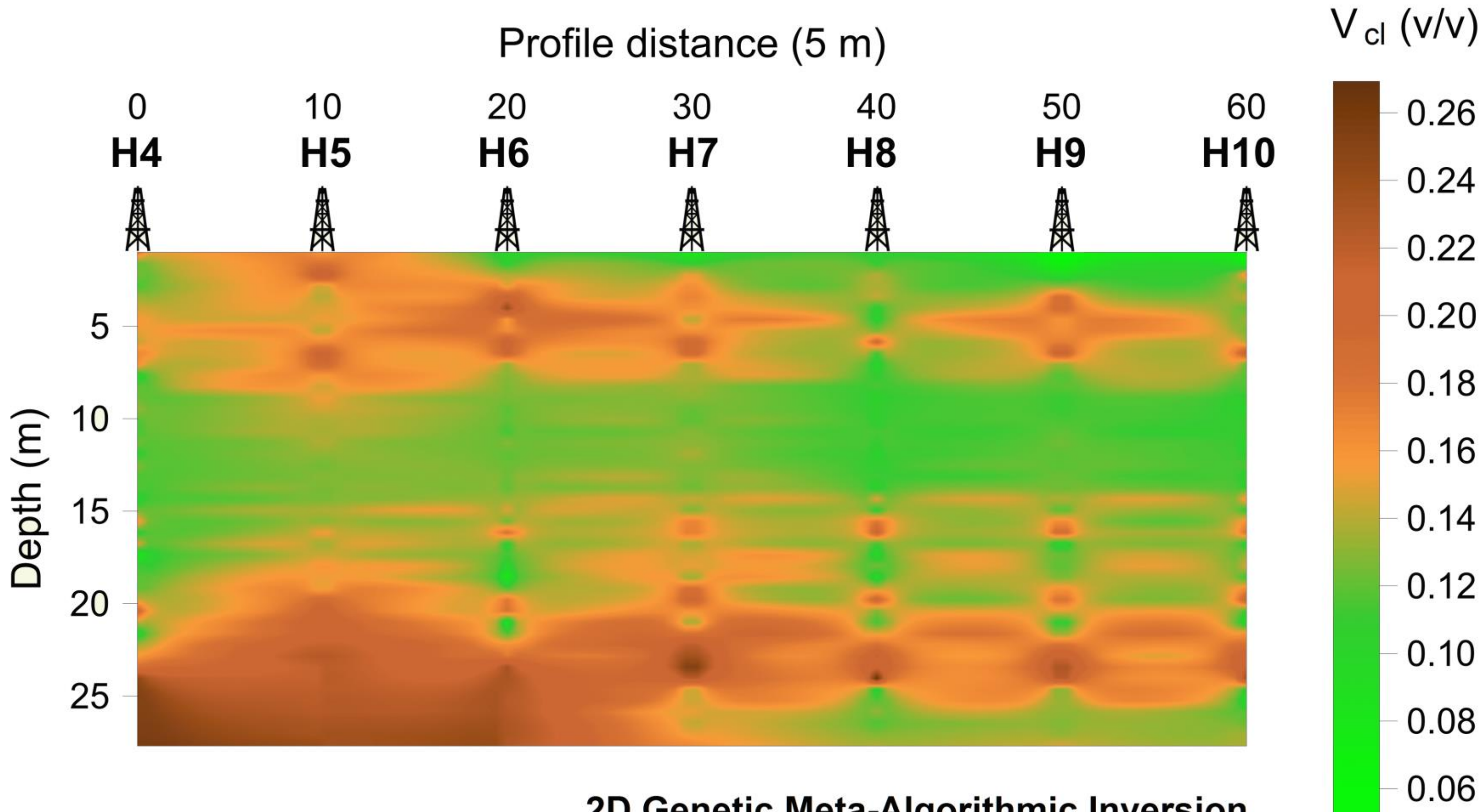
2D Inversion of Direct Push Logs



2D Genetic Meta-Algorithmic Inversion

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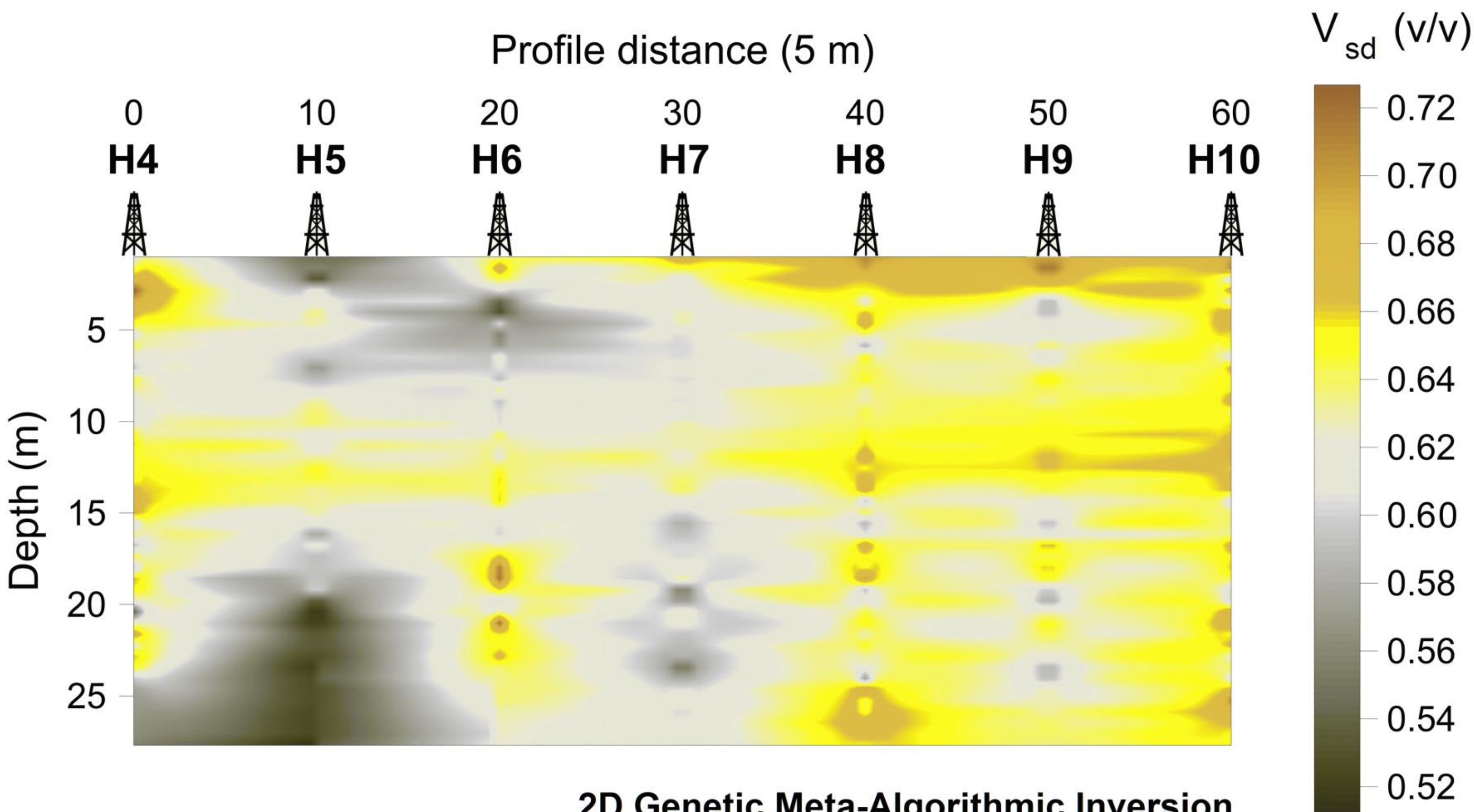
2D Inversion of Direct Push Logs



2D Genetic Meta-Algorithmic Inversion

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Hyperparameter Estimation for Zone Parameters

Zone parameter	Search domain	Estimated Value	Estimation Error	Unit
GR (clay)	8.0−12.0	8.02 (8.86)	0.17 (0.01)	kcpm
GR (matrix)	0−2.0	1.98 (1.83)	0.01 (0.01)	kcpm
ρ (clay)	1.9−2.3	1.97 (2.07)	0.03 (0.02)	g/cm^3
ρ (matrix)	2.3−2.7	2.31 (2.41)	0.01 (0.01)	g/cm^3
Φ_N (clay)	0.2−0.5	0.33 (0.43)	0.01 (0.05)	v/v
R (clay)	1.0−6.0	4.19 (4.56)	0.49 (0.61)	ohmm

*1D meta-algorithmic inversion
*2D meta-algorithmic inversion

Szabó N. P., 2018. A genetic meta-algorithm-assisted inversion approach: hydrogeological study for the determination of volumetric rock properties and matrix and fluid parameters in unsaturated formations. **Hydrogeology Journal** 26, 1935-1946, D1 ranked.

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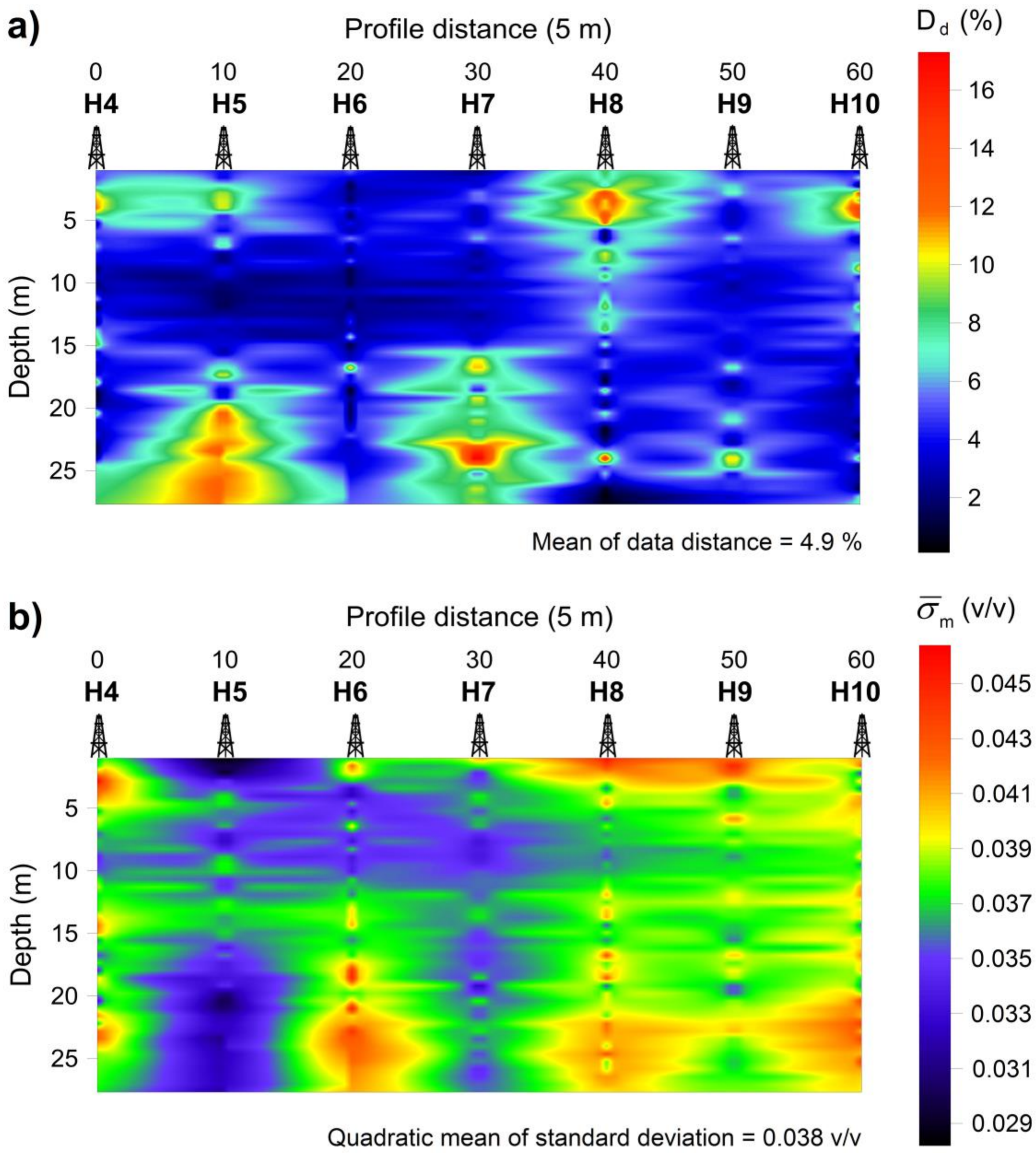

Quality Check of Inversion Results

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Thank you for your attention.

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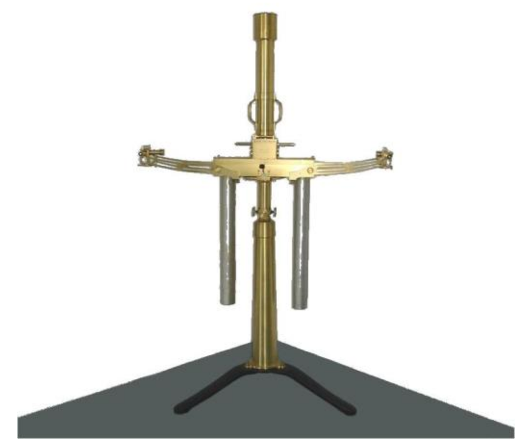

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