Environmental Geophysics

Giorgio De Donno

5. DC electrical methods

Induced Polarization (IP)

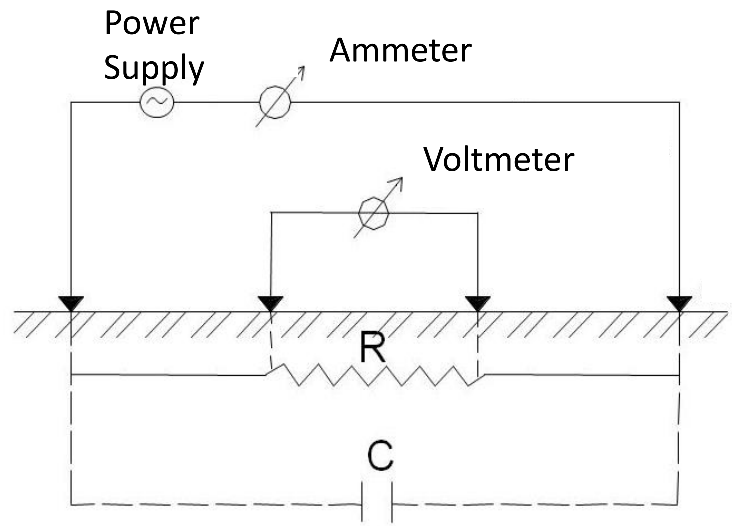
"Sapienza" University of Rome **-** *DICEA Area Geofisica*

phone: +39 06 44 585 078
email: giorgio.dedonno@uniroma1.it

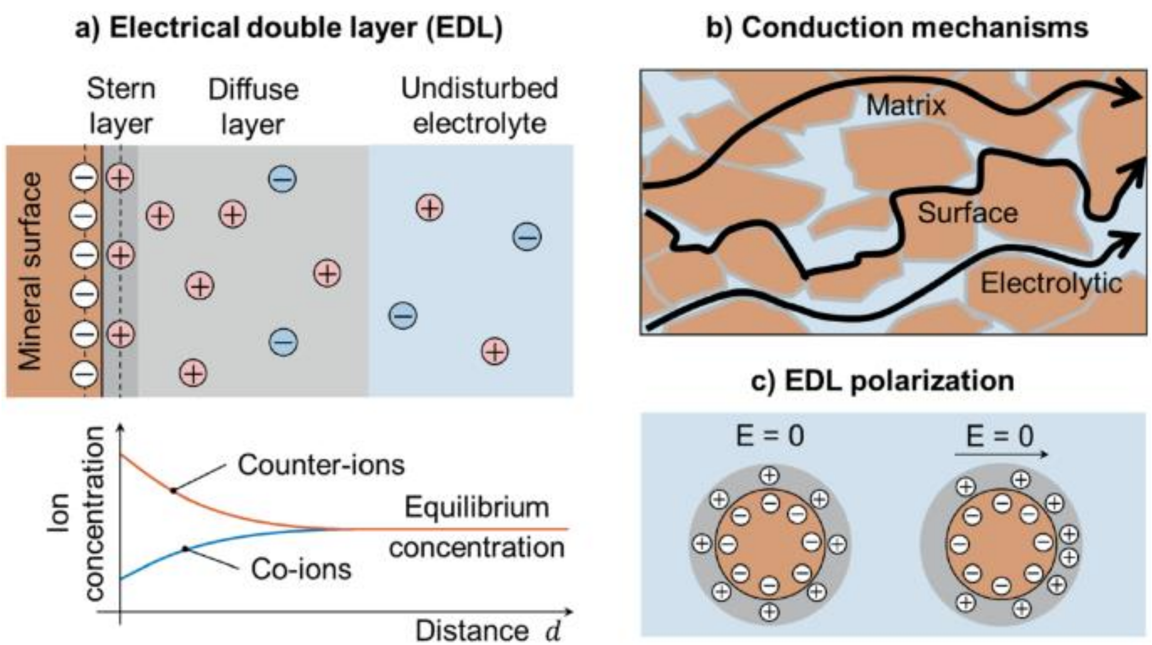
Induced Polarization – low frequency IP

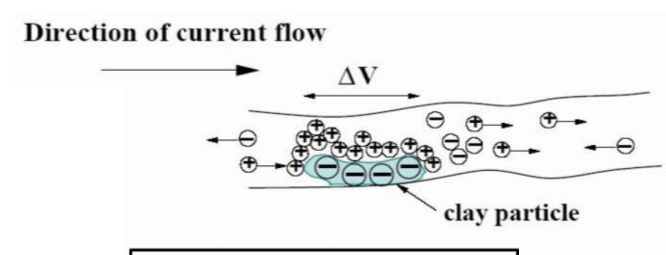
Time-domain IP (TDIP)

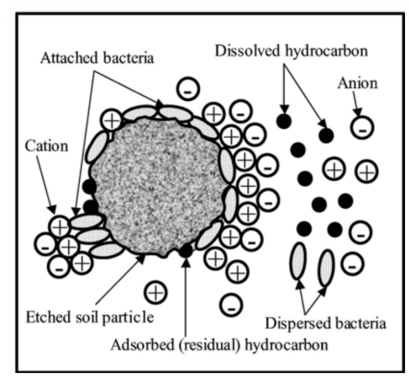
Input: Switch-on/off a DC current
IP effect: Voltage variation with time



Low-frequency polarization effects

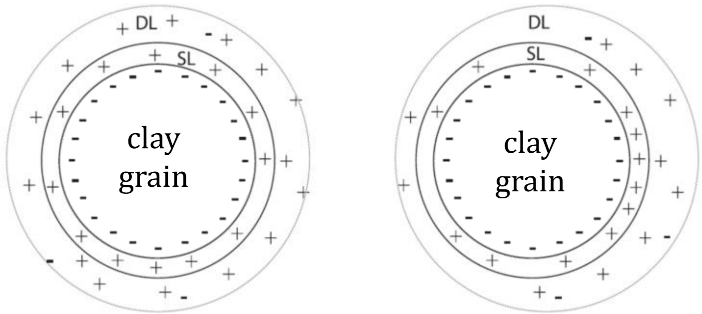


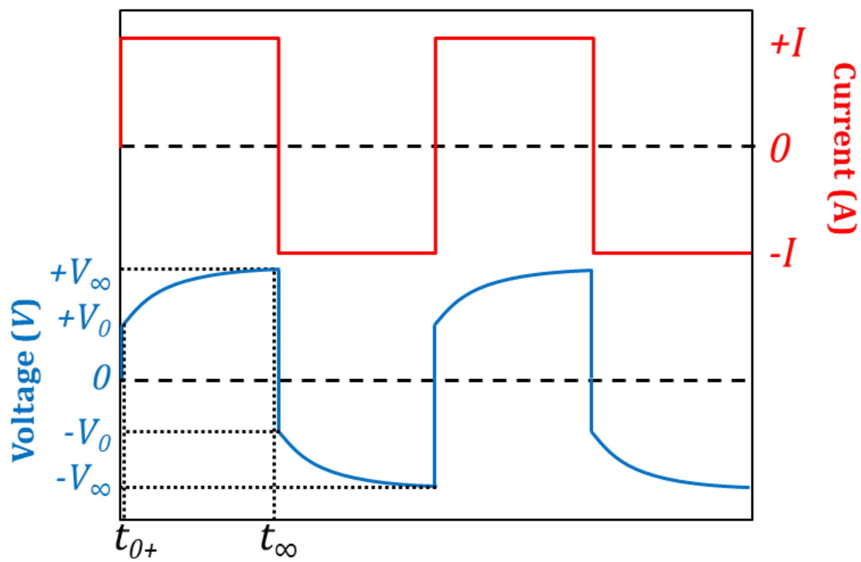




Model parameters – Time-domain IP (TDIP)

All EDL ions free to move		EDL ions blocked (new equilibrium)
σ_0		σ_∞
$t = 0^+$	$\xrightarrow{E}$	$t \to \infty$





$$\sigma_\infty = \sigma_0 (1 - M) \Rightarrow \frac{\sigma_\infty}{\sigma_0} = 1 - M$$

Chargeability
[dim-less or mV/V]

$$M = \frac{\sigma_0 - \sigma_\infty}{\sigma_0} = \frac{\sigma_s}{\sigma_0}$$

Ratio between surface σ_s and bulk σ_0 conductivity

Ideally *M* ranges [0,1] or [0,1000 mV/V] but often M is between few mV/V to 100 mV/V. **Therefore, the IP effect is 1 or 2 order of magnitudes weaker than the resistive one.**

Surface conductivity
[S/m]

$$\sigma_s = M \sigma_0$$

If the ground is homogeneous, we get:

$$M = \frac{V_\infty - V_0}{V_\infty}$$

Otherwise, we can measure only an **apparent chargeability:**

$$M_a = \frac{V_\infty - V_0}{V_\infty}$$

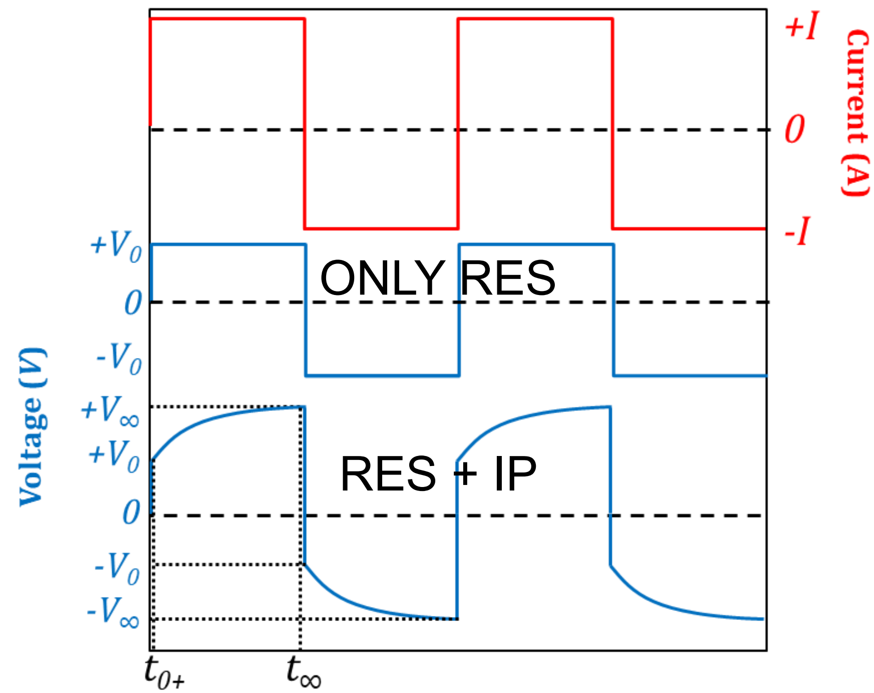
Observations – Time-domain IP (TDIP)

We use the same multi-electrode configuration already seen for ERT, in which **both apparent resistivity and apparent chargeability** values are acquired **in the same investiga**tion.

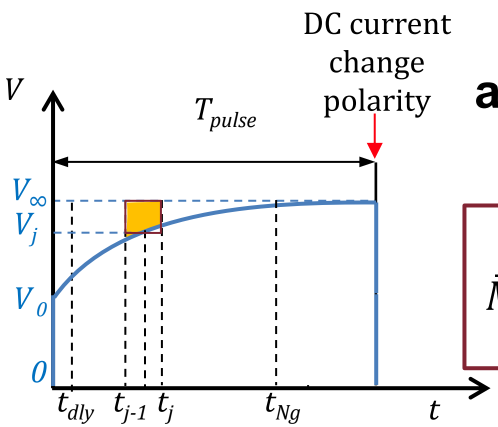
The stationary voltage observation V^{∞} for the apparent resistivity should be made after a certain time t_{∞} needed tor reach the new equilibrium of ions

Therefore, the pulse duration should be sufficiently long to ensure that the polarization mechanisms have been activated

Rule-of-thumb
Pulse duration: 2-8 s
Number of stacks: 2-4



Observations – Time-domain IP (TDIP)



Observed (integral) apparent chargeability

[dim-less or mV/V]

$$\overline{M}_{a,i}^{\,obs} = \frac{\sum_{j=1}^{N_g}(V_\infty - V_j)\Delta t_j}{V_\infty\left(t_{Ng} - t_0\right)}$$

$i = 1, 2, \ldots, N_{QUAD}$

V_0: **initial voltage** (**measure unfeasible** due to spikes and induction in the first 20 ms)

t_{dly}: delay time to avoid spikes and induction

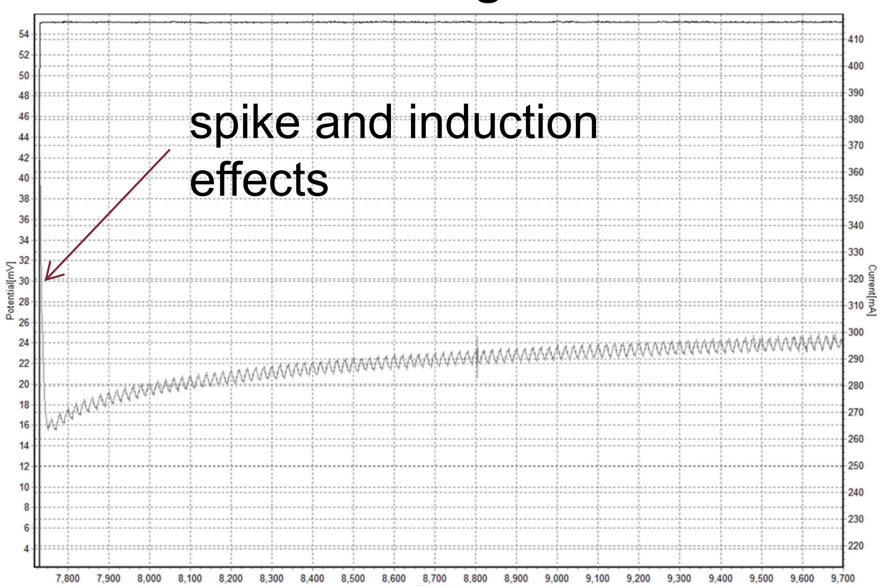
V_∞: **stationary voltage**

T_{pulse}: pulse duration

$\Delta t_j = t_j - t_{j-1}$, $j = 1, 2, \ldots, N_g$ **time window (GATE)**

Gate length is increased following a **logarithmic trend** (high voltage gradients after switch on, low voltage gradients at the end of the pulse)

Real signal



Predictions and observations will not share the same formulation. **The estimation of the true cheargeability will be biased** (only relative comparisons can be made)!

Q. How can we get a chargeability model for inhomogneous media?

Inversion – Time-domain IP (TDIP)

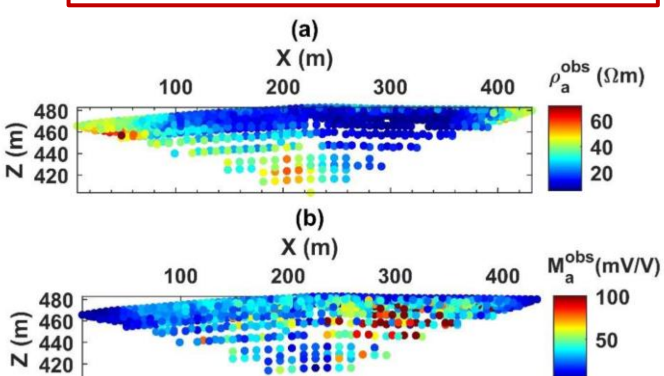
OBSERVED DATASETS

48 elec. spaced 5 m apart – DD a_{max}=5 n_{max}=6

N.	A	B	M	N	ΔV (V)	I (mA)	σ(%)	ρ_a(Ωm)	M_a(mV/V)
1	1	2	3	4	0.679910	101.45	1.20	42.72	2.10
2	1	2	4	5	0.266054	101.56	0.08	50.15	2.5
3	1	2	5	6	0.121435	101.43	2.02	45.78	3.2
4	1	3	4	6	0.172654	125.67	1.06	42.35	6.7
…									
945	45	46	47	48	0.54564	105.65	1.87	76.09	10.7

$$\rho_{a,i}{}^{obs} = K\frac{V_{0,i}^{obs}}{I_i}$$

$$M_{a,i}{}^{obs} = \frac{\sum_{j=1}^{N_g}\left(V_{\infty,i}^{obs} - V_j\right)\Delta t_j}{V_{\infty,i}^{obs}\left(t_{N_g} - t_0\right)}$$



A. With data inversion!

First trial models
$\boldsymbol{\sigma}_0^{(1)}$ and $\mathbf{M}^{(1)}$

$$\boldsymbol{\sigma}_\infty^{(1)} = \boldsymbol{\sigma}_0^{(1)}\left(1 - \mathbf{M}^{(1)}\right)$$

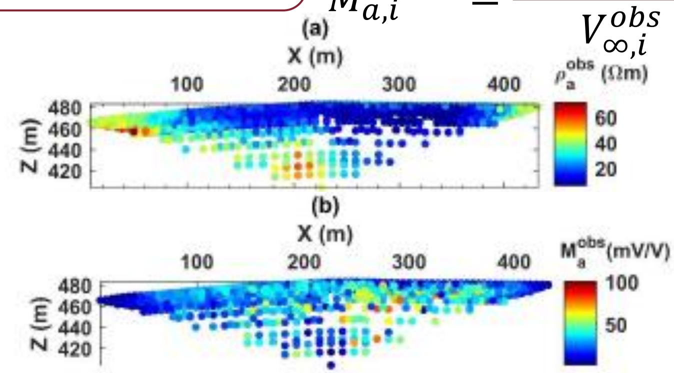
Solve two times the electrostatic field equation for potentials

$$1)\ -\nabla\cdot\left(\sigma_0(\mathbf{r})\nabla V_0(\mathbf{r})\right) = I\delta(\mathbf{r})$$
$$2)\ -\nabla\cdot\left(\sigma_\infty(\mathbf{r})\nabla V_\infty(\mathbf{r})\right) = I\delta(\mathbf{r})$$

Combine potentials for predictions

$$\rho_{a,i}{}^{pre} = K\frac{V_{0,i}^{pre}}{I_i}$$

$$M_{a,i}{}^{pre} = \frac{V_{\infty,i}^{obs} - V_{0,i}^{obs}}{V_{\infty,i}^{obs}}$$



Errors are low enough?

Inversion – Time-domain IP (TDIP)

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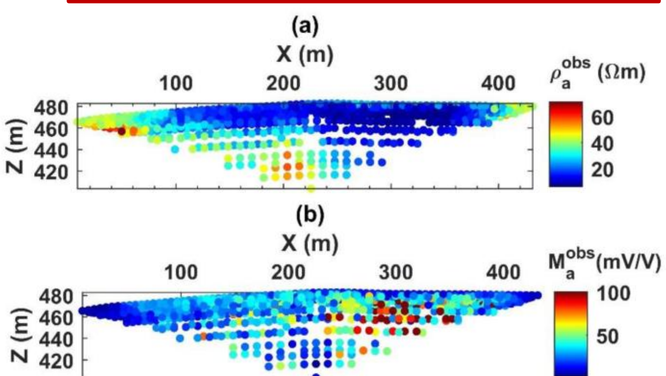
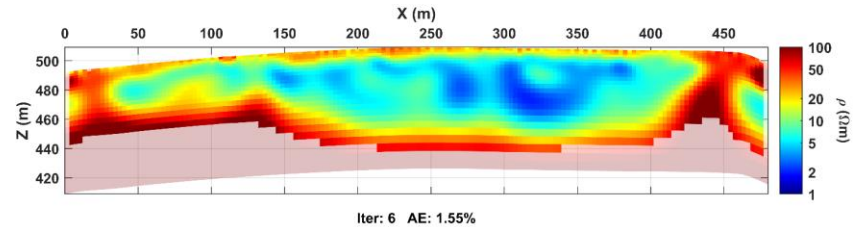


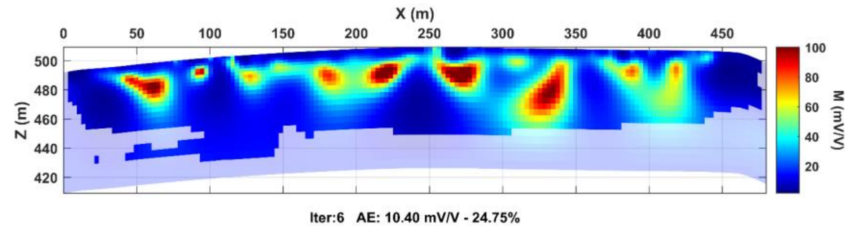
A. With data inversion!

Get final models
$\boldsymbol{\sigma}_0^{(k)}$ and $\mathbf{M}^{(k)}$
at the end of iterations

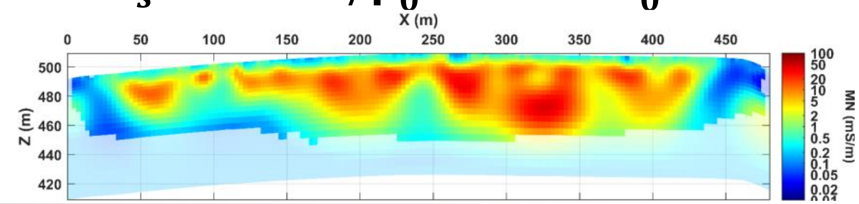
Resistivity model $\boldsymbol{\rho}_0^{(k)} = 1/\boldsymbol{\sigma}_0^{(k)}$



Chargeability model $\mathbf{M}^{(k)}$

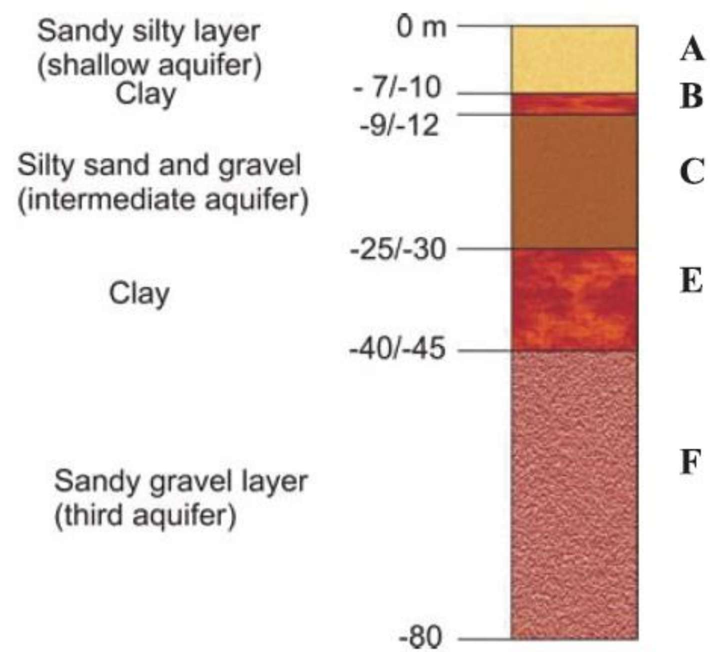


Surface conductivity model
$\boldsymbol{\sigma}_s^{(k)} = \mathbf{M}^{(k)}/\boldsymbol{\rho}_0^{(k)} = \mathbf{M}^{(k)}\boldsymbol{\sigma}_0^{(k)}$



TDIP – Contaminated site

Site polluted by waste products of the textile industries (TCE, PCE, etc.) which are classified as Dense Non-Aqueous Phase Liquids (DNAPLs)



Main goal: locate the DNAPL plume

EXPECTED TO BE RESISTIVE AND CHARGEABLE

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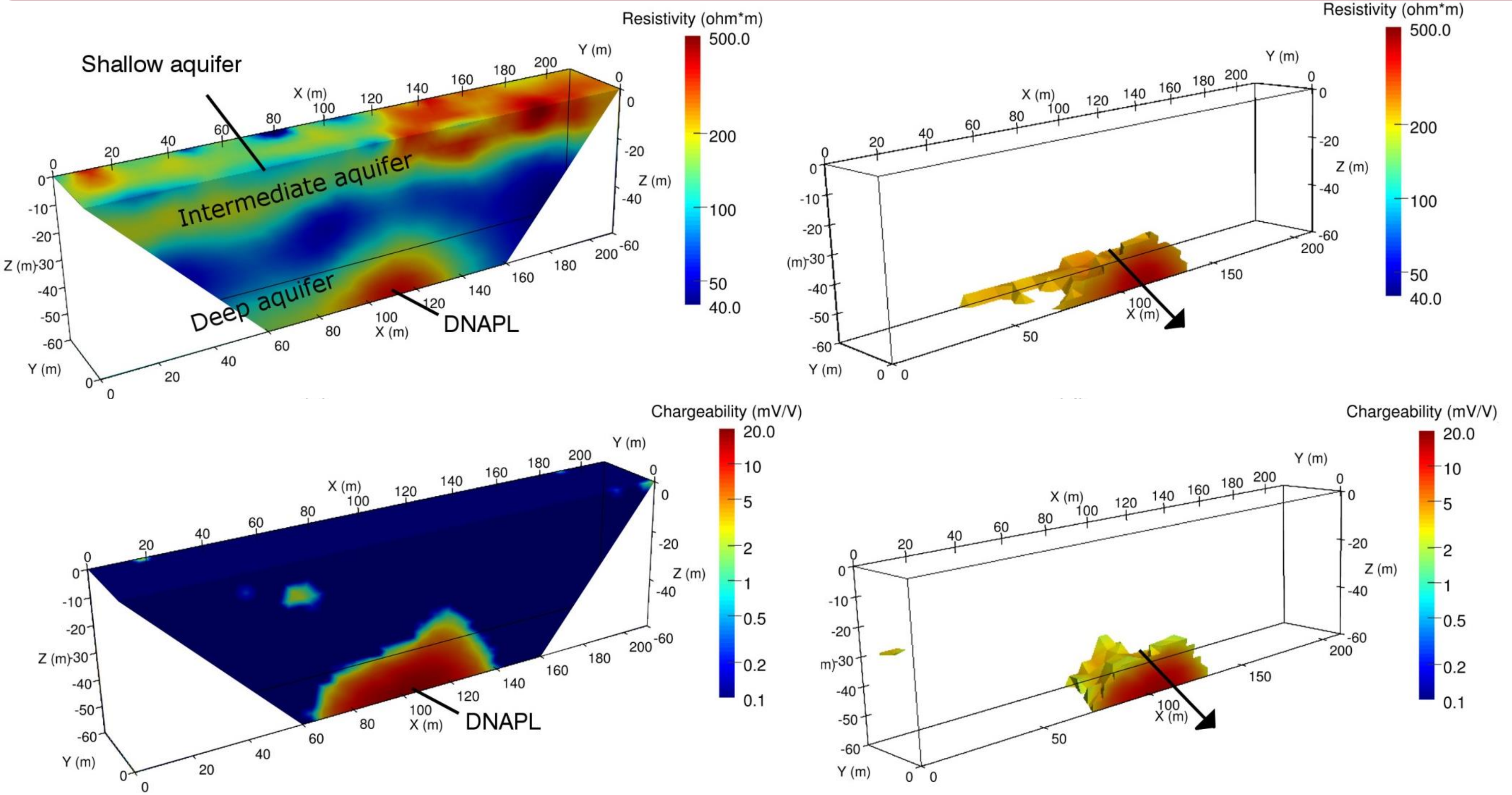
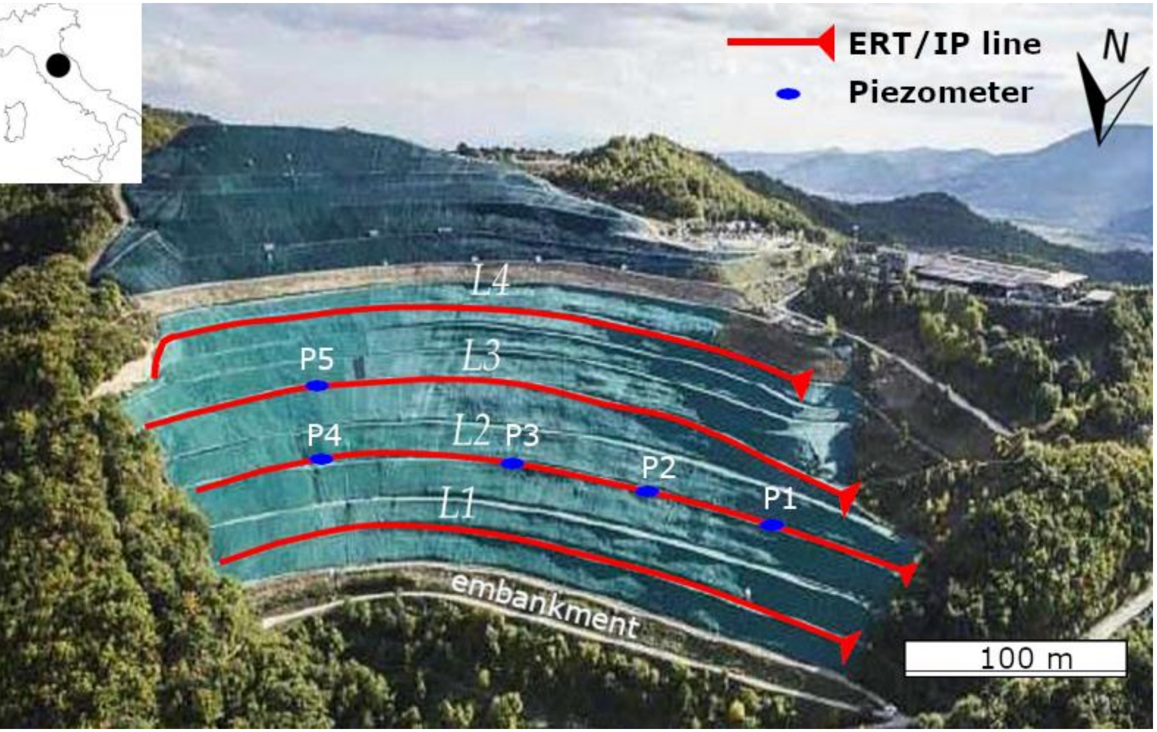


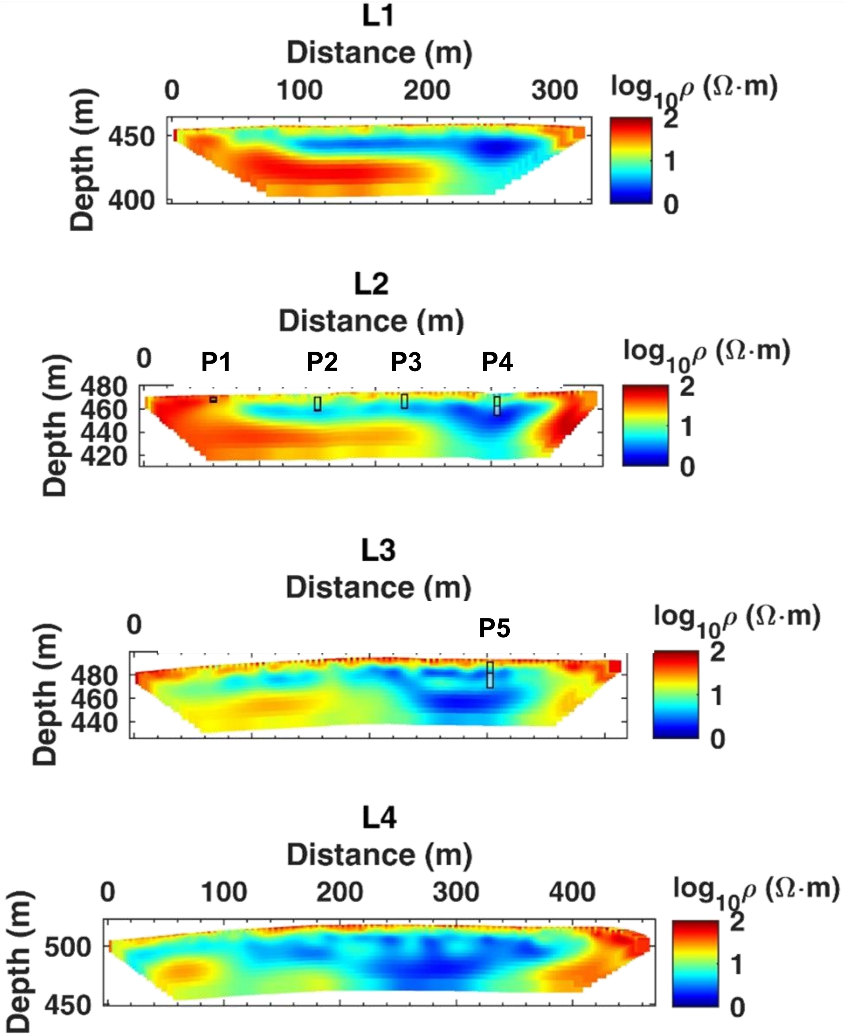
TDIP – Urban waste landfill



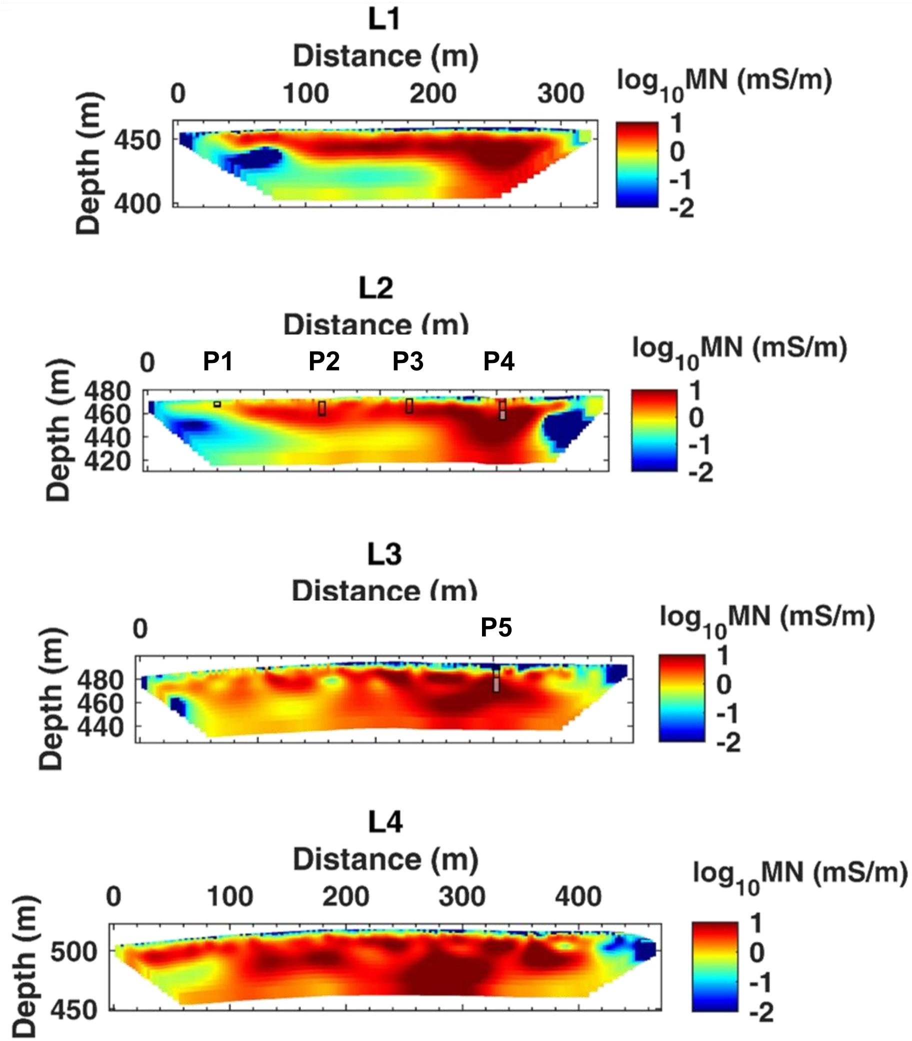
Main goal: mapping leachate accumulation which may trigger slope failure
Bedrock: marly-arenaceous flysch
Array: dipole-dipole
IP acquisition: T=2 sec, 20 log-sampled gates

TDIP – Urban waste landfill

Resistivity



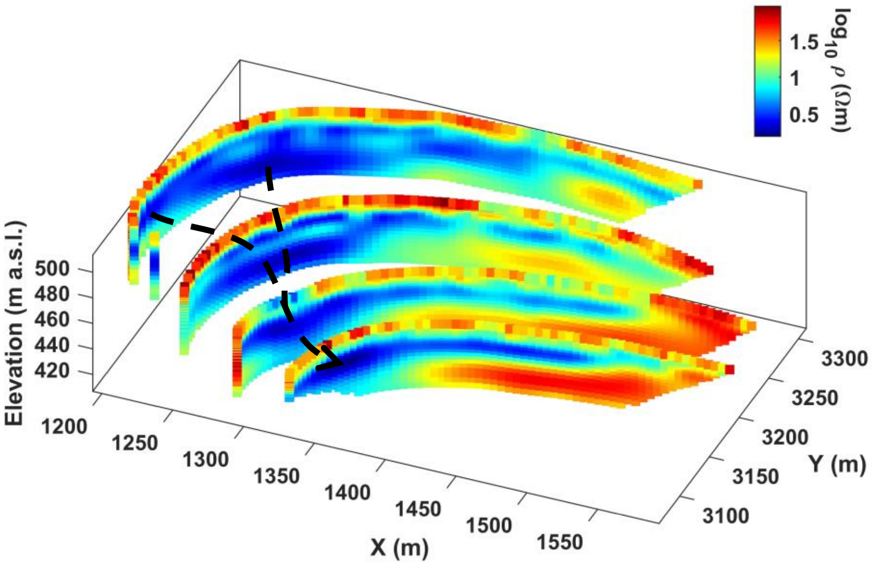
Surface Conductivity $\sigma_s = M\sigma_0$



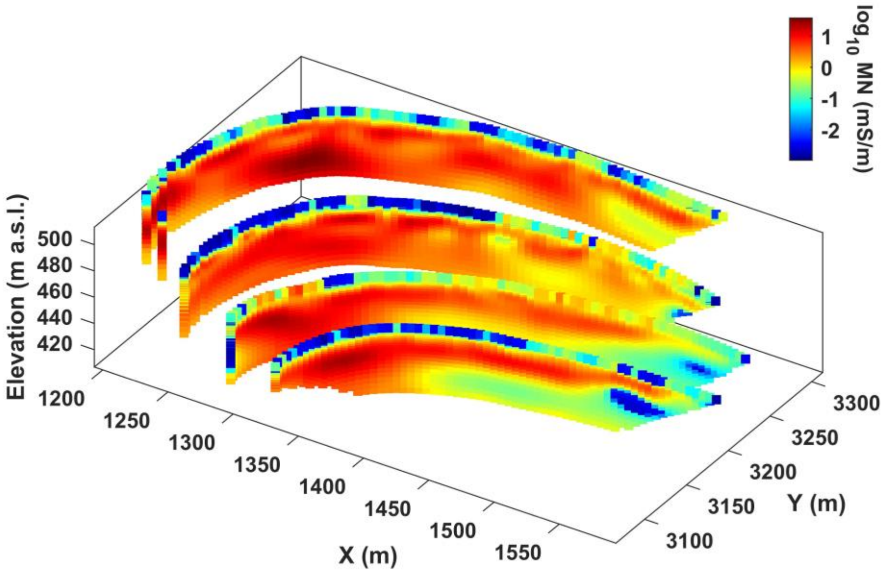
TDIP – Urban waste landfill

3D view

Resistivity



Surface Conductivity σ_s

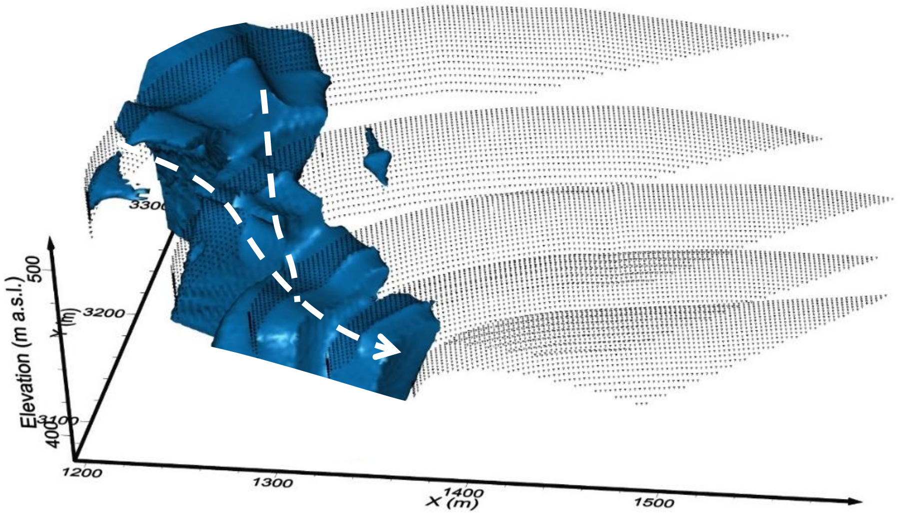


– – –> Leachate preferential path

TDIP – Urban waste landfill

3D volumes

Resistivity < 3 Ωm



Resistivity < 10 Ωm