Geophysics for Natural Risks and Resources
ENVIRONMENTAL and ENGINEERING GEOPHYSICS

Introduction to GEOPHYSICAL PROSPECTING for ENGINEERING

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ELECTRICAL METHODS for the Engineering

Geophysical methods for the subsoil prospecting

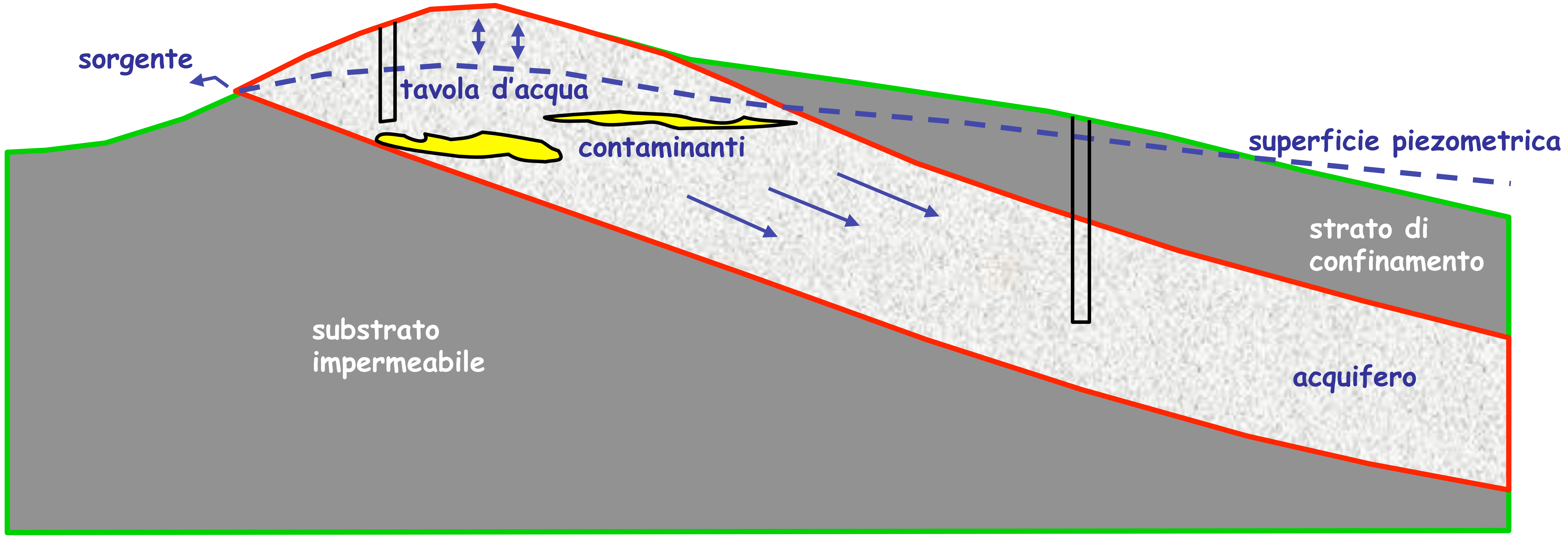
Method	Structure	Dynamic
Seismic	+ +	
Electro-Magnetic	+	++
DC resistivity methods	++	+++
Ground Penetration Radar	++	+
Distributed Temp. Sensing		++
Magnetics	+	
Gravimetry	+	+
Spectral Induced Polarization	+	
Self Potential		+
Borehole logs	+ +	+

Physical Properties (P)

- Seismic Elastic moduli and density
- Gravimetry : Density
- Magnetic meth. Magnetic susceptibility
- ERT meth. Electrical resistivity
- Electro-magnetic meth. Electrical conductivity
- Induced Polarization Electrical complex conductivity
- Spontaneous Potentials Electrical conductivity
- Ground penetrating Radar Dielectric constant

Environmental problems

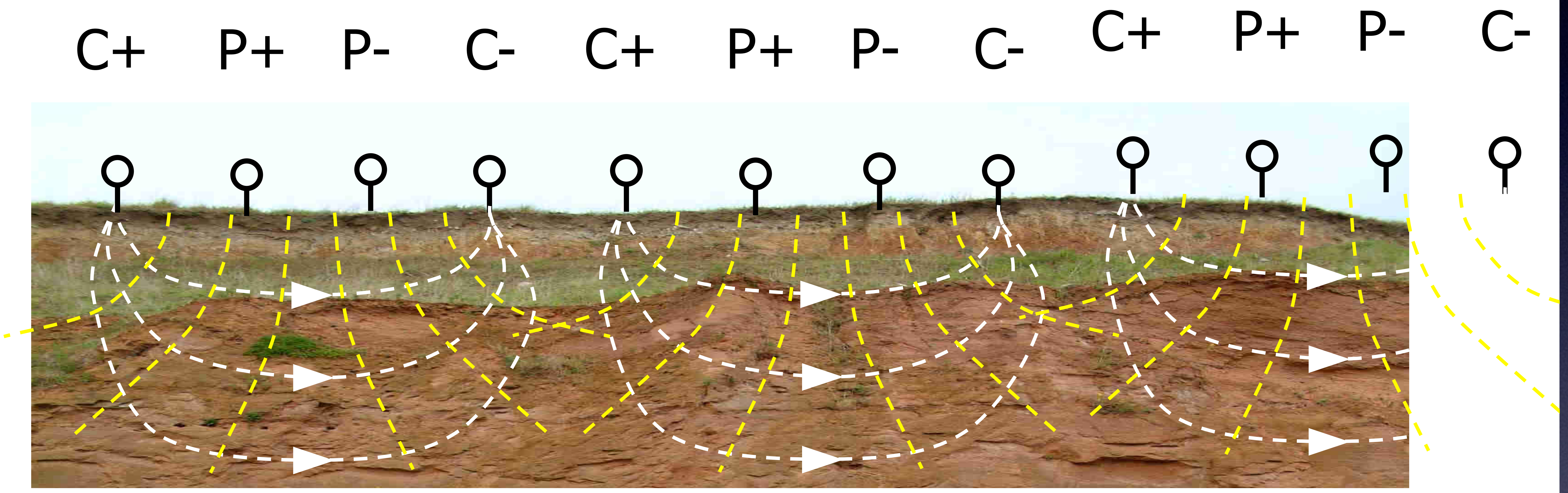
- Subsoil structure
- Fluids Dynamic
- Pollutants presence



ERT (Electrical Resistivity tomography)

Resistivity profiling

We can profile the subsurface by moving our array



The depth we are sensitive to will depend on the array configuration and the subsurface properties. For the array above we may assume that the apparent resistivity is at about half the electrode spacing.

If the media is homogenous σ is uniform in the space, we can use Laplace equation

$$\nabla^2 V = 0$$

is the sum of the second derivatives in the space

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0$$

Diffusion Equations for currents fluxes

Ohm's Law

es in x

$$j_x = -\sigma_x \frac{\partial V}{\partial x}$$

$$\frac{dV}{dx} = E$$

Electrical Field

cond.

$$\vec{J} = \sigma \vec{E}$$

Charges density

Electrical Field (forcing conditions)

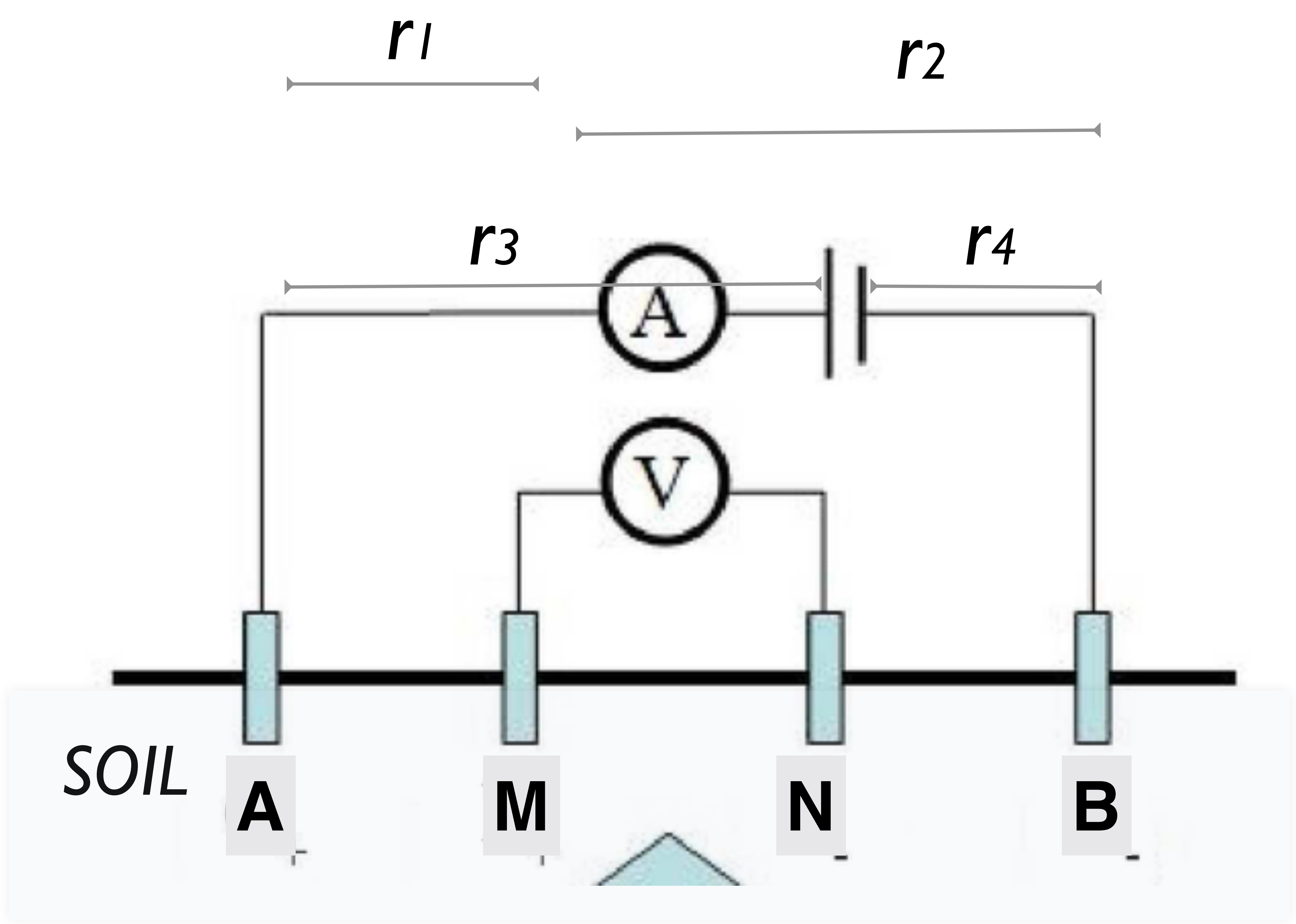
Ohm's Law (vectorial)

ELECTRIC QUADRIPOLE

1) $$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1} - \frac{1}{r_3}\right) - \left(\frac{1}{r_2} - \frac{1}{r_4}\right)\right]$$

K

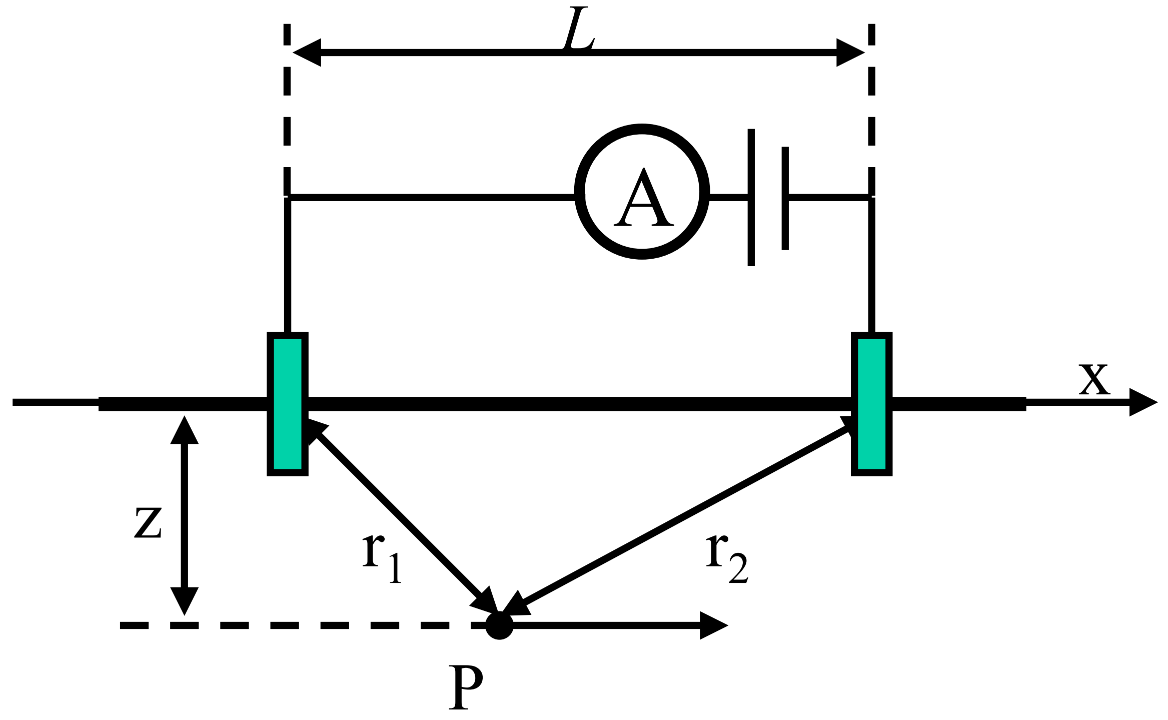
Geometric Factor



Apparent Resistivity

$$\rho_a = \frac{k\Delta V}{I}$$

Current distribution in depth



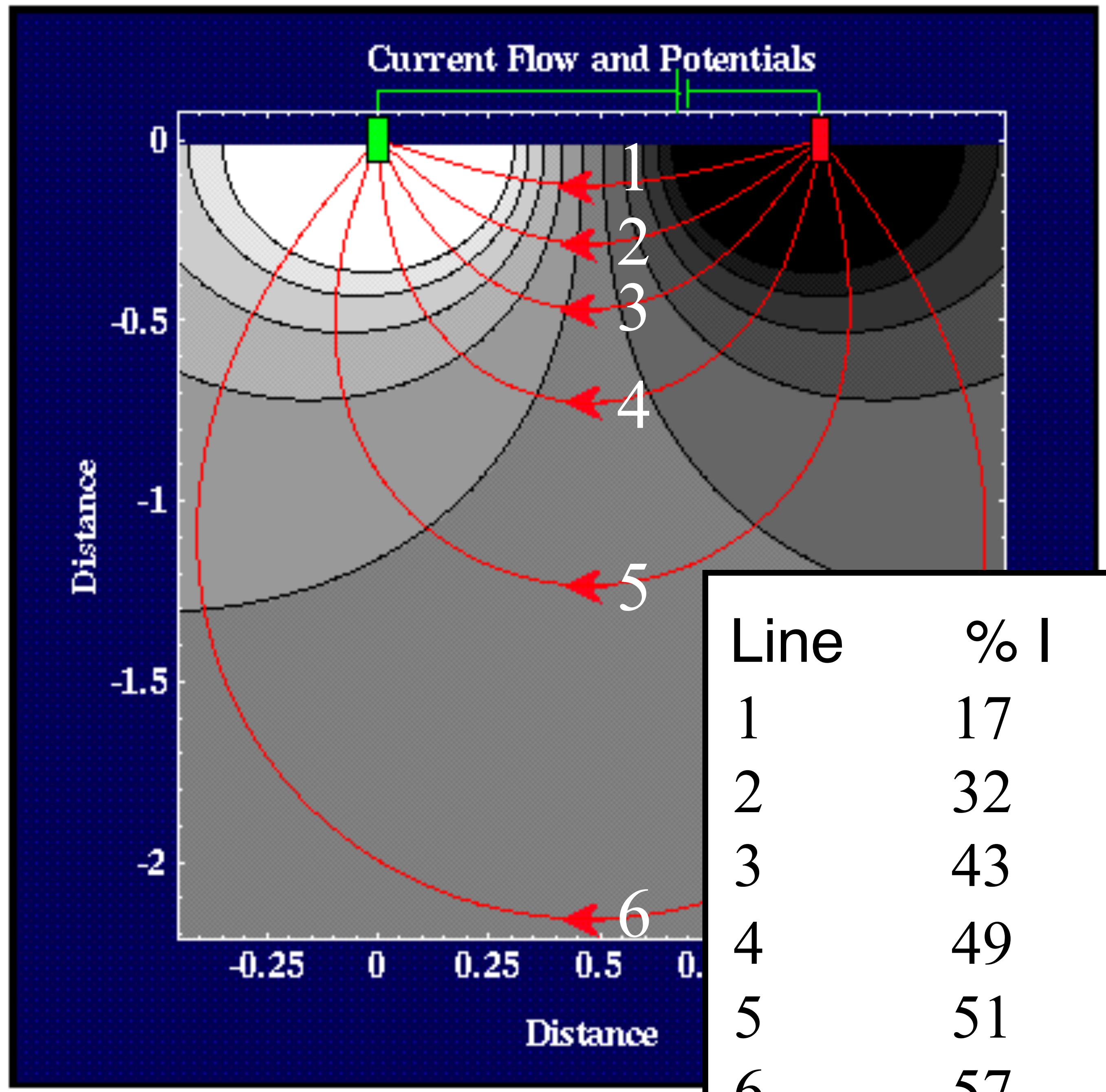
$$V_p = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad J_x(P) = -\sigma \frac{\partial V_p}{\partial x}$$

Half way from the electrodes

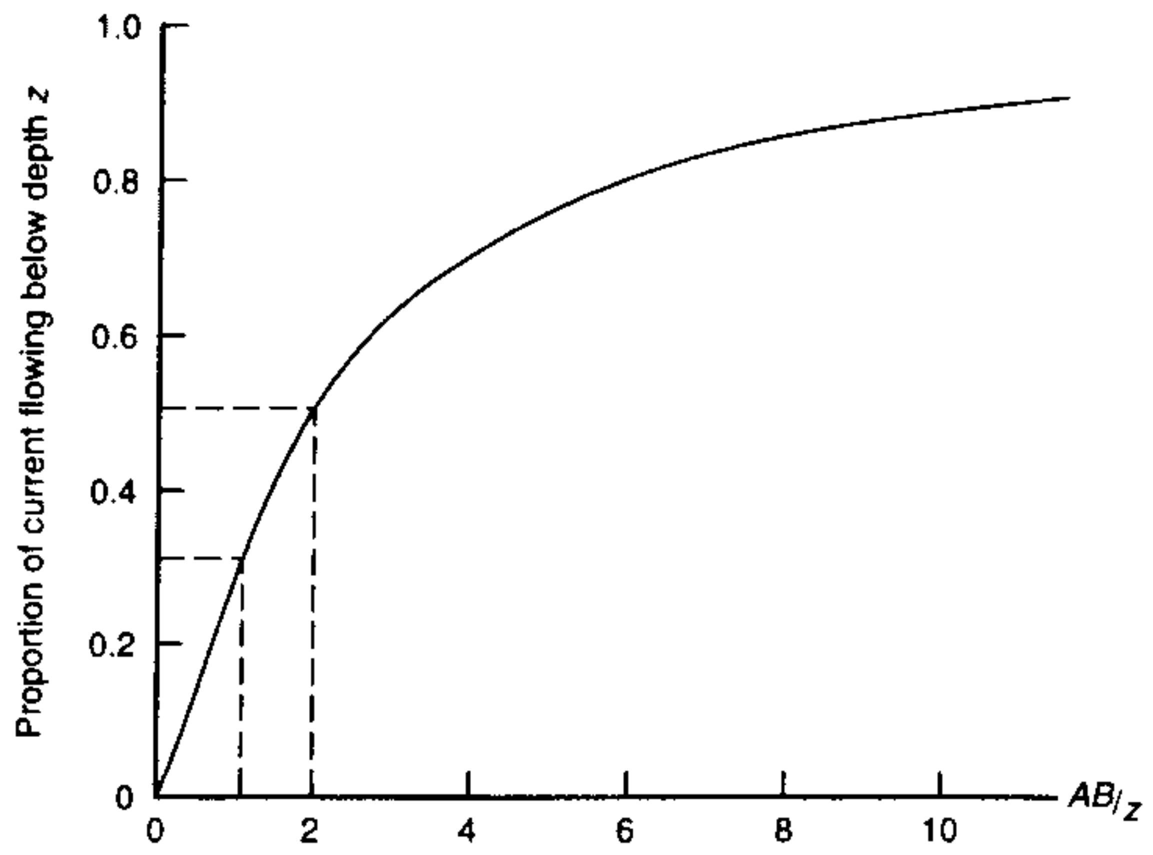
$$J_x(P) = \frac{I}{2\pi} \frac{L}{\left(z^2 + L^2/4\right)^{3/2}}$$

Current at depth Z

$$\frac{I_z}{I} = \frac{2}{\pi} \arctan\left[\frac{2z}{L}\right]$$



Line	% I
1	17
2	32
3	43
4	49
5	51
6	57



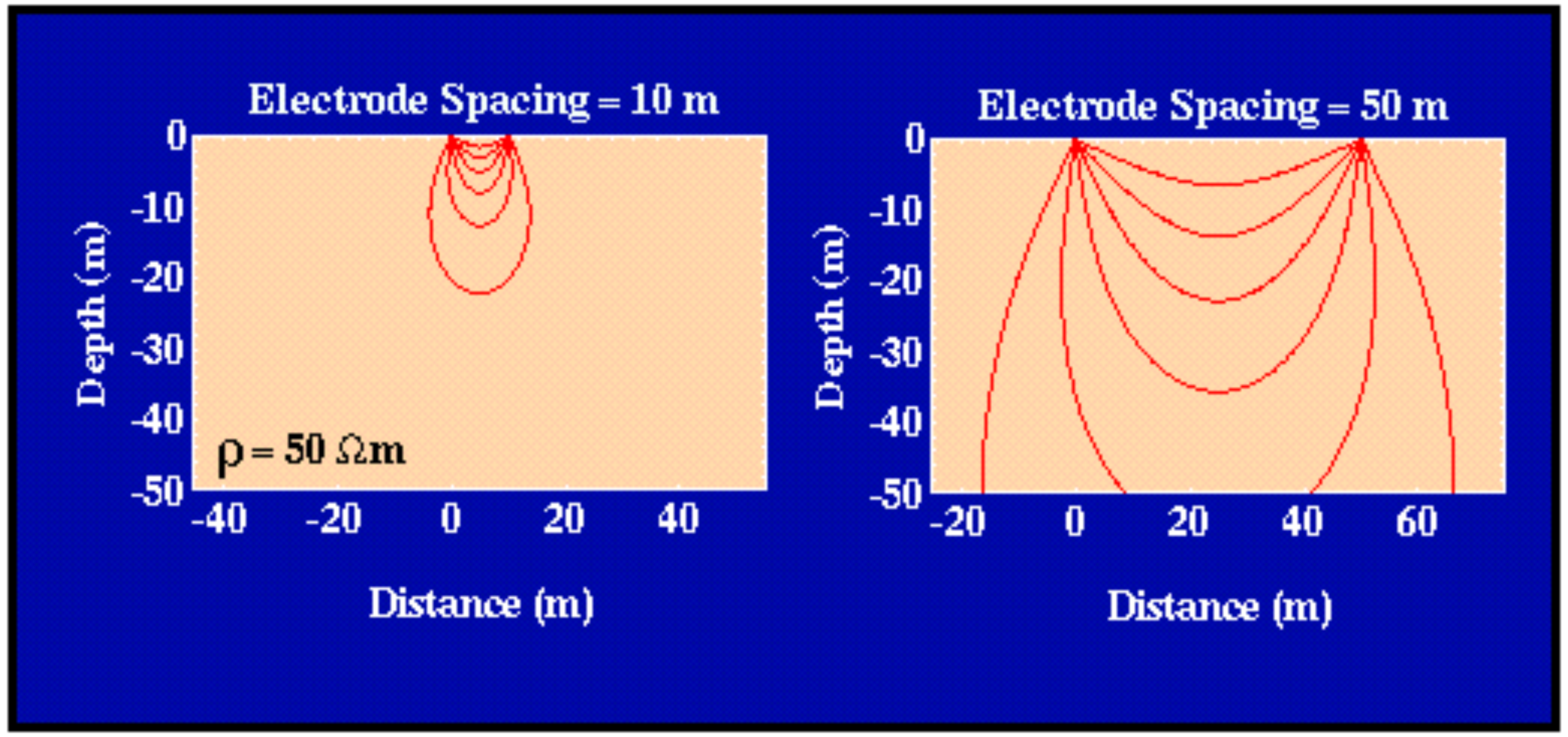
Current distribution in depth

Larger the electrodes distance, larger the depth of exploration

Current in z is:

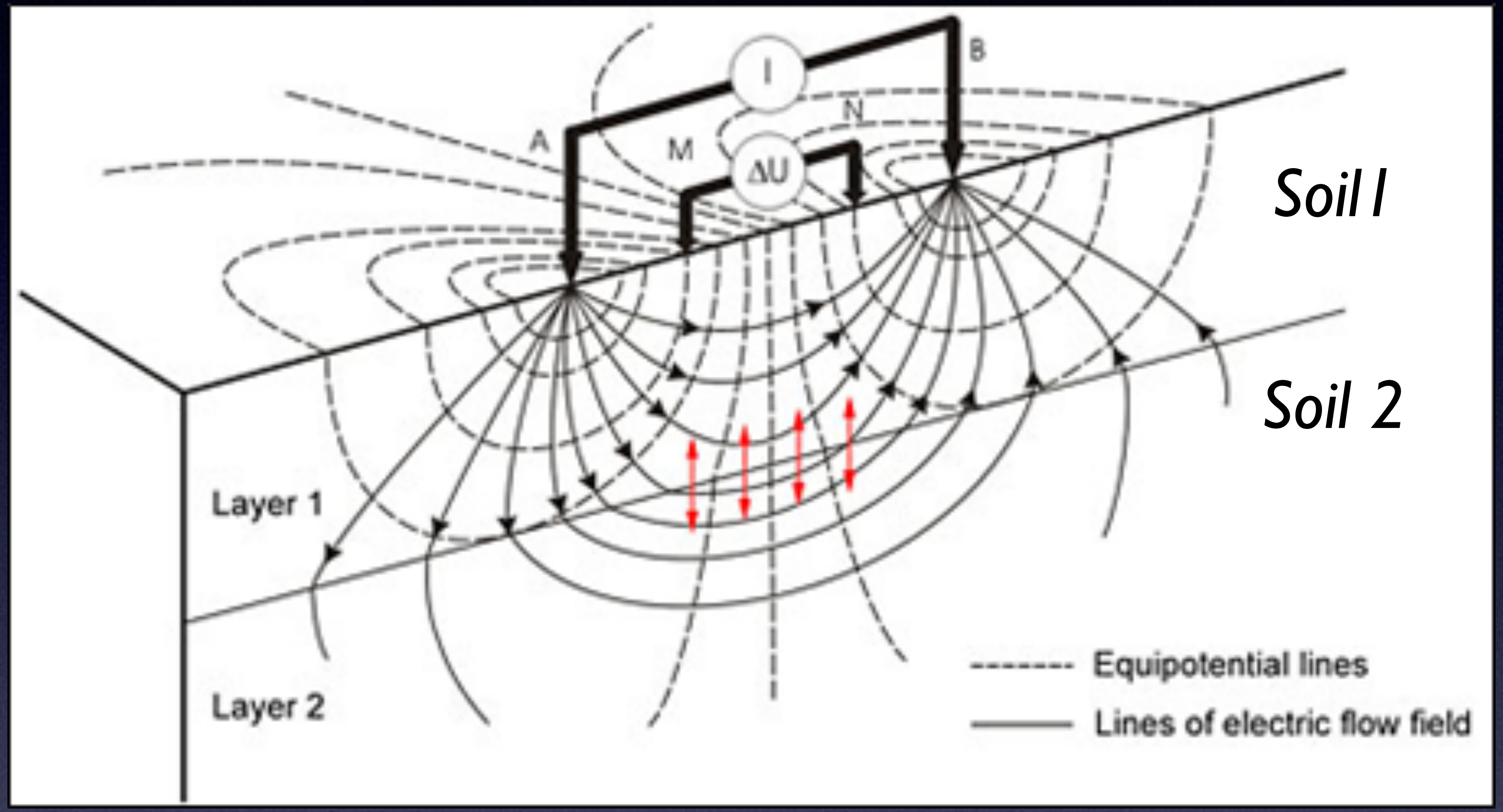
$$1 - \frac{I_z}{I} = 1 - \frac{2}{\pi} \arctan\left[\frac{2z}{L}\right]$$

Array Length L is crucial for depth investigation

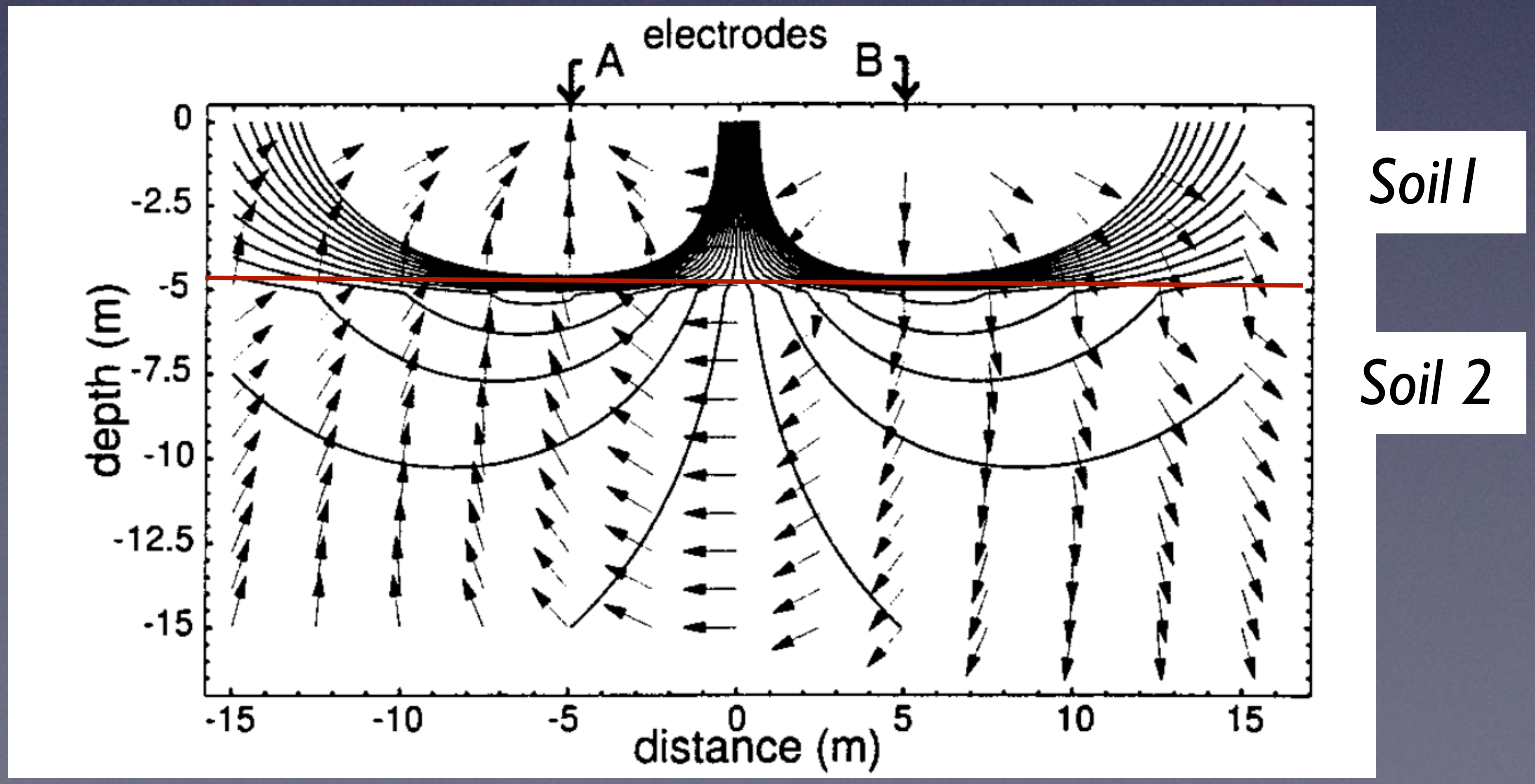


Geo-electrical methods

In case of different soils, we will have different currents distribution (and different voltages)



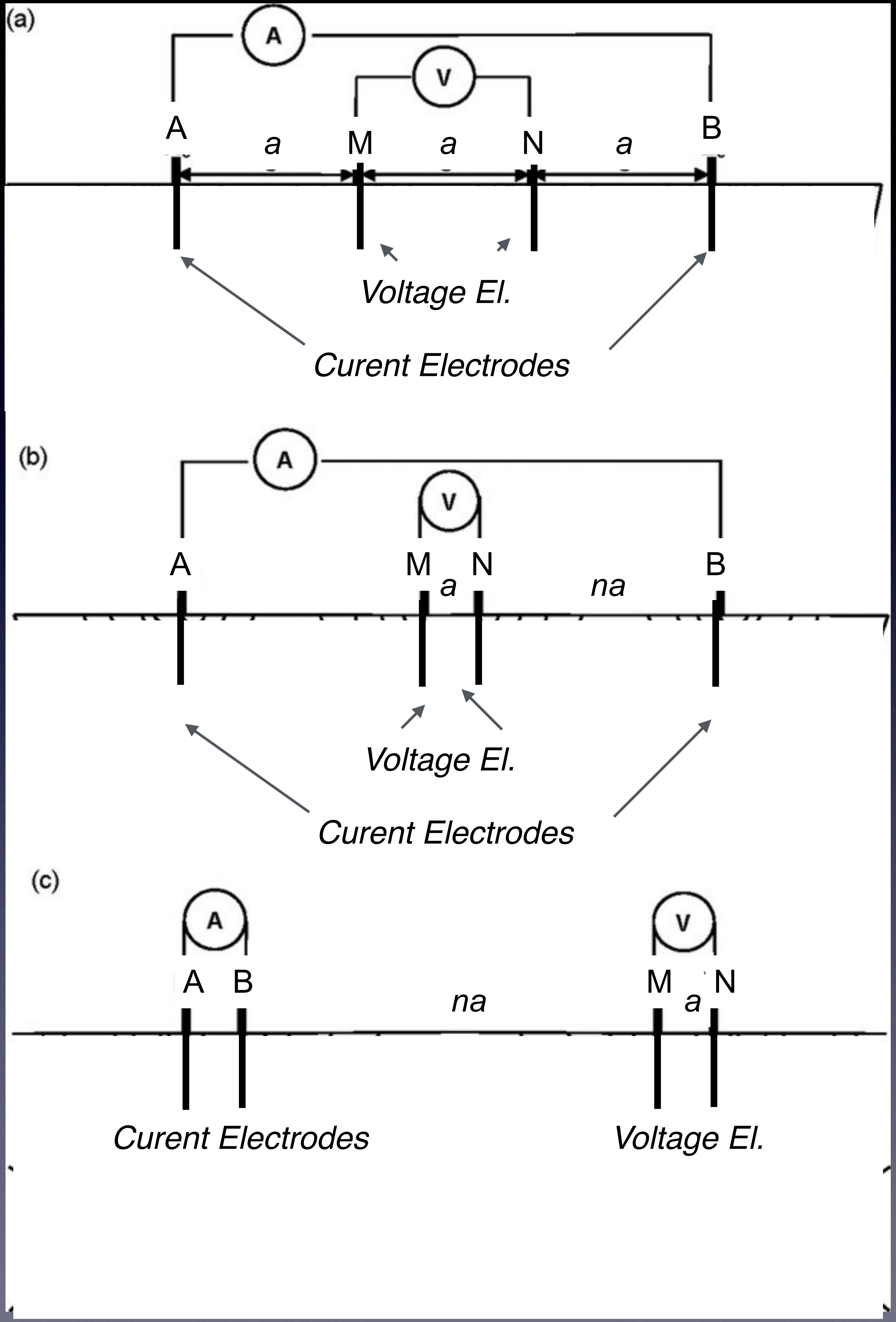
Soil 2 less resistive than 1



Soil 2 more resistive than 1

ARRAY CONFIGURATIONS

AB = current electrodes
MN = voltage electrodes



a) Wenner array

AM=MN=NB

b) Schlumberger array

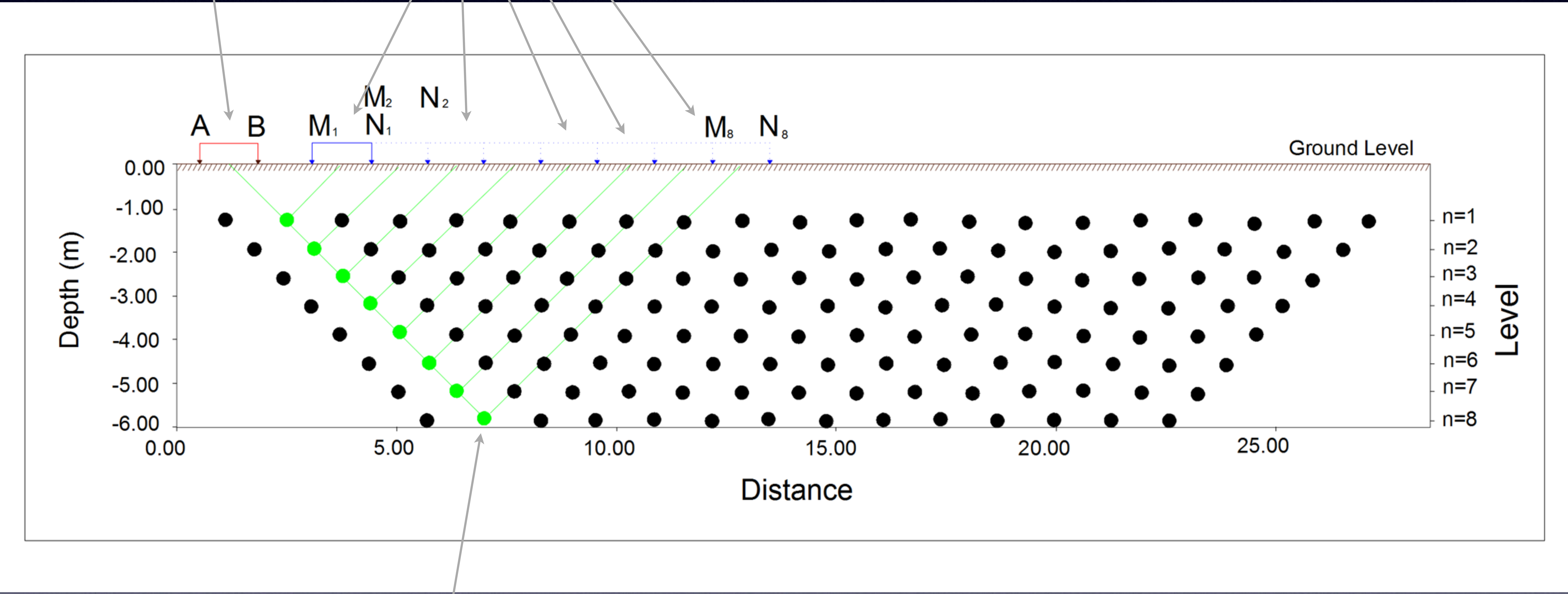
AM= n MN

c) Dipole-dipole array

AB= MN

Moving quadripoles we can retrieve 2D section on 3D volume

Inject I *Measure V*



Point where I measure ρ_a

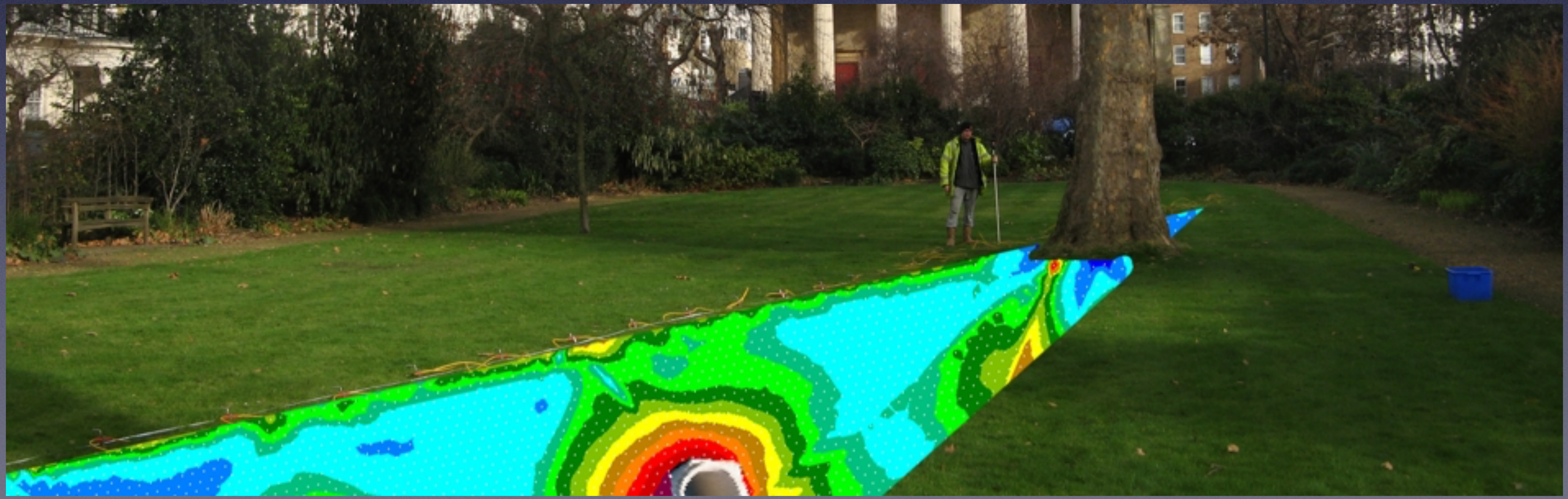
We can do it automatically with a multi-electrodes system

MULTI-ELECTRODES

ERT

ELECTRICAL RESISTIVITY TOMOGRAPHY

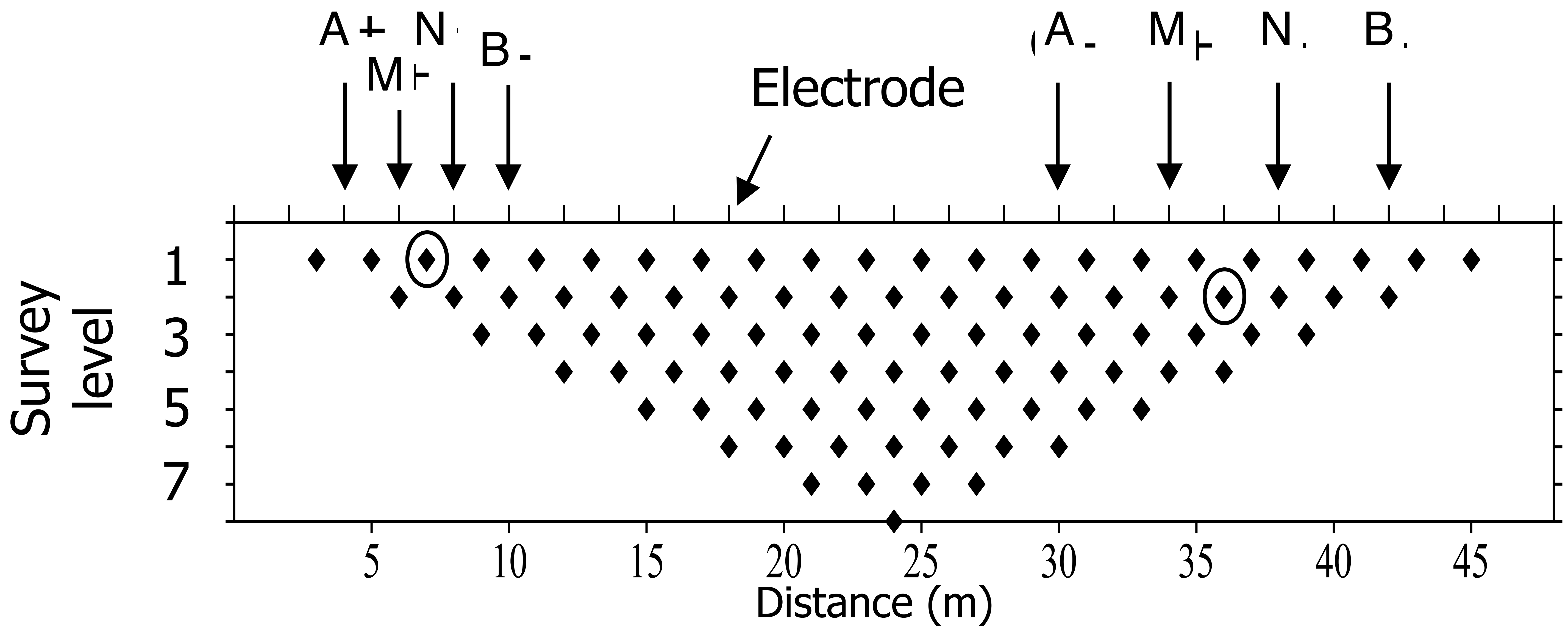
An image of the subsoil…..



Electrical resistivity tomography

With ERT we can
Retrieve 2D and 3D images of the subsoil electrical properties.

Different array have different penetration depth and resolution



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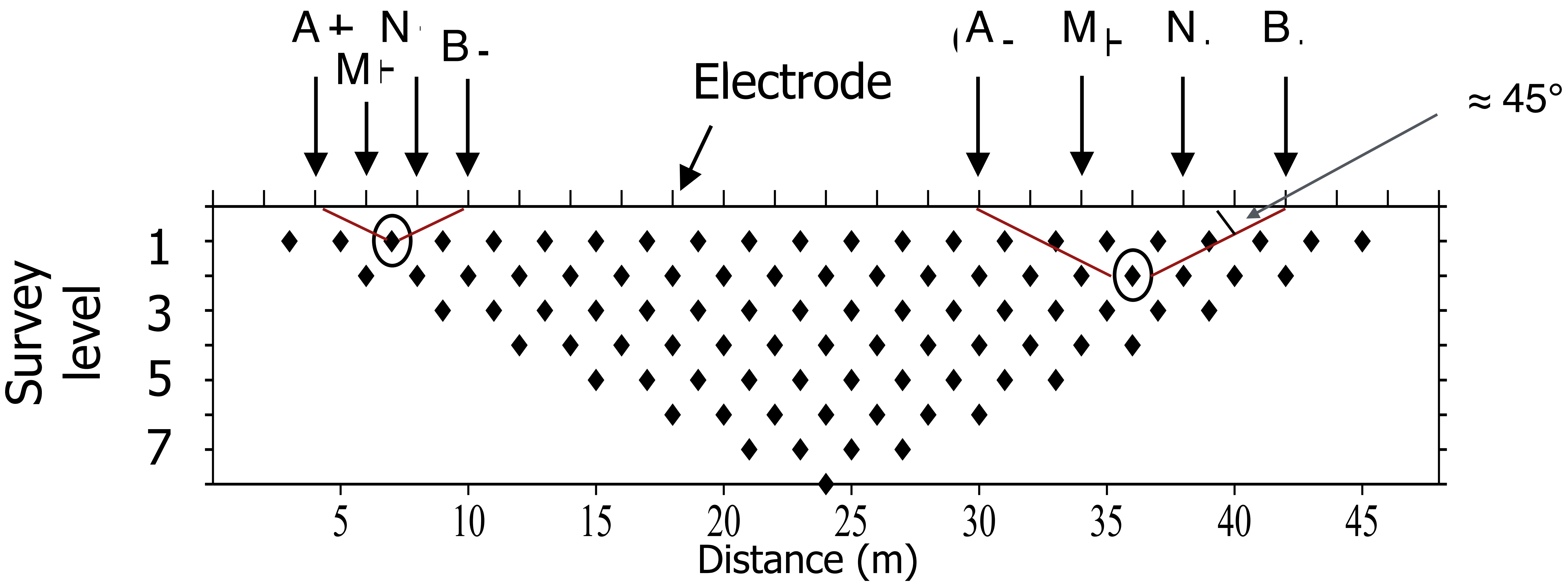
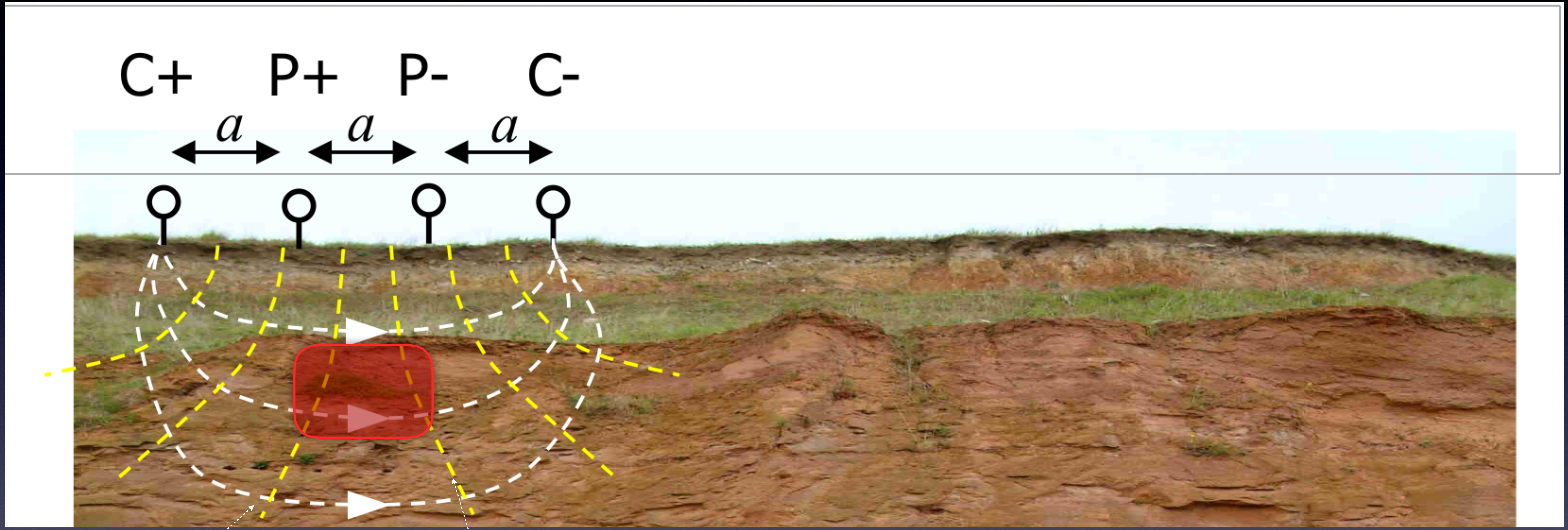


Geo-electrical methods

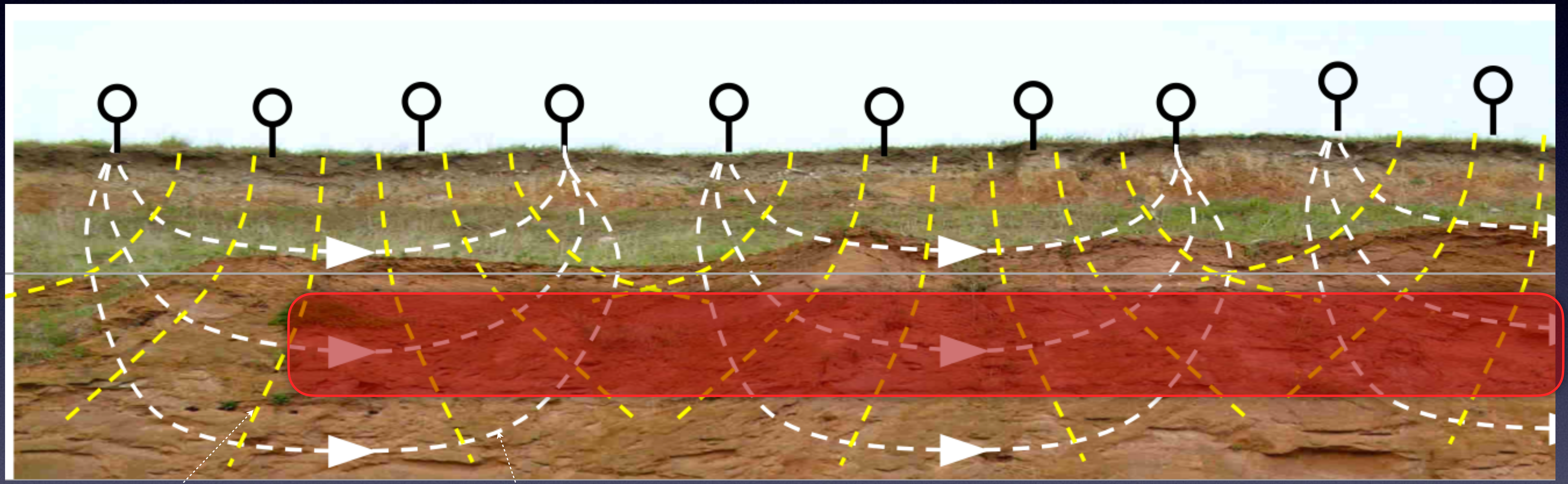
Area of interest in depth ?



Current lines

equal-Potential lines

Geo-electrical methods

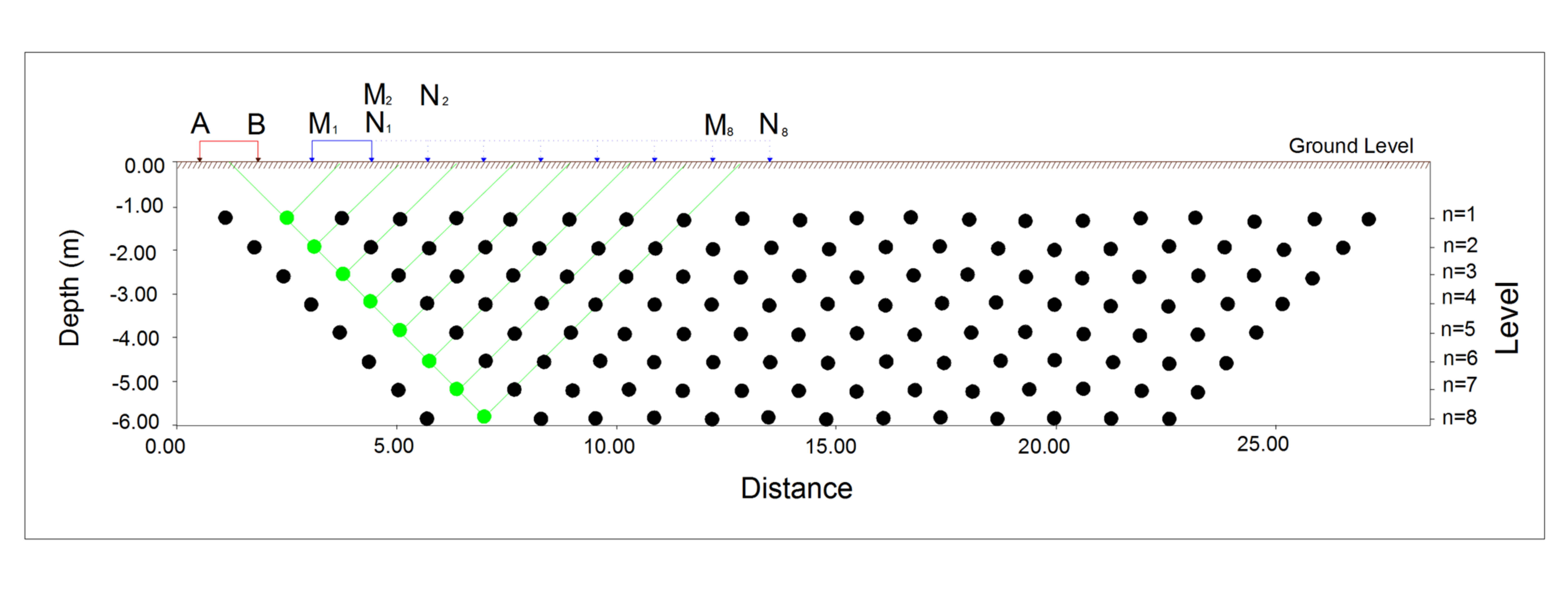


Current lines

equal-Potential lines

Geo-electrical methods

Dipole Dipole example



RESISTIVITY collected in the field are APPARENT

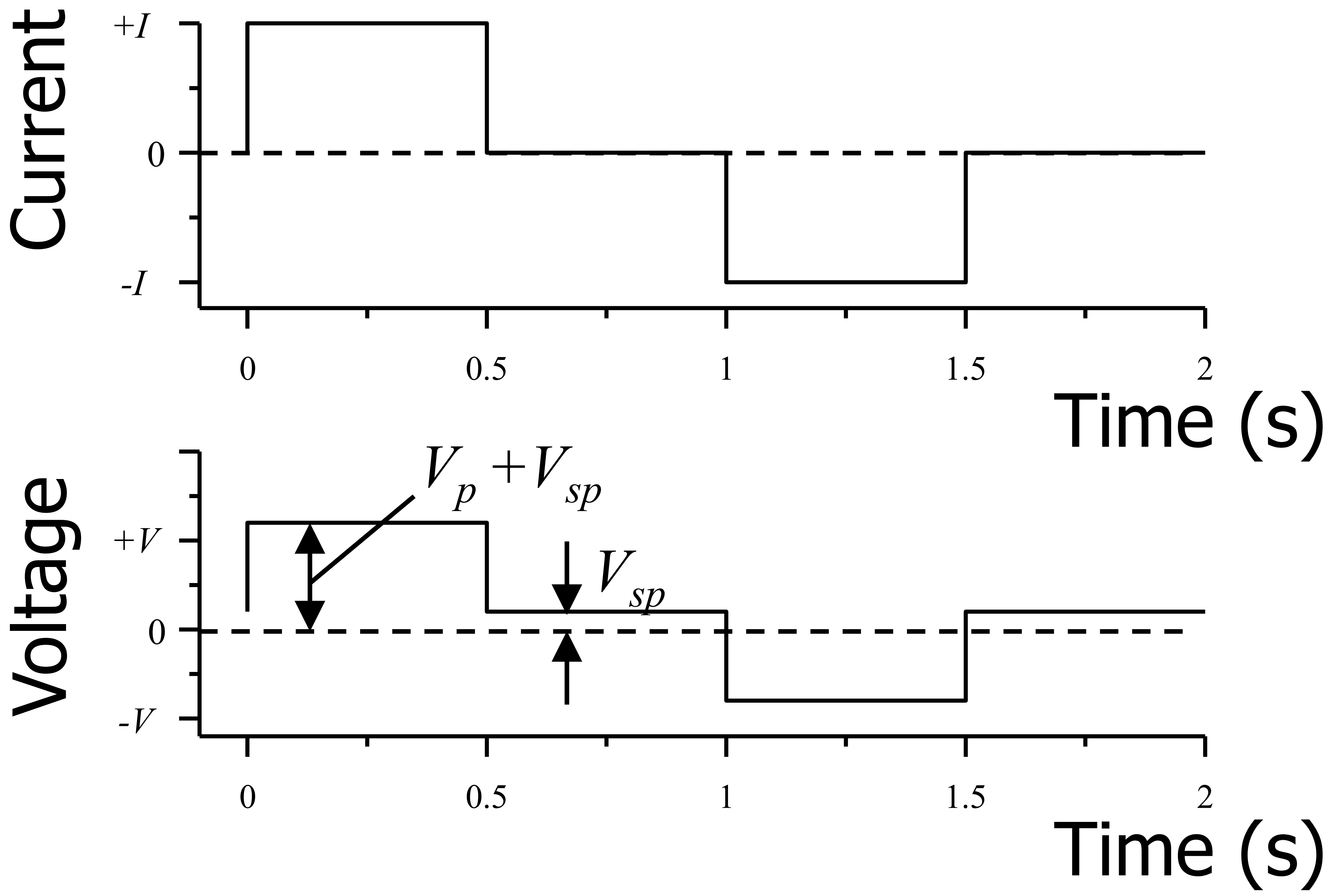
We call this

PSEUDO SECTION

(to retrieve REAL values of RESISTIVITY we need an inversion process)

Current is normally injected as a switched square wave

Why is this ?



Polarization of media…

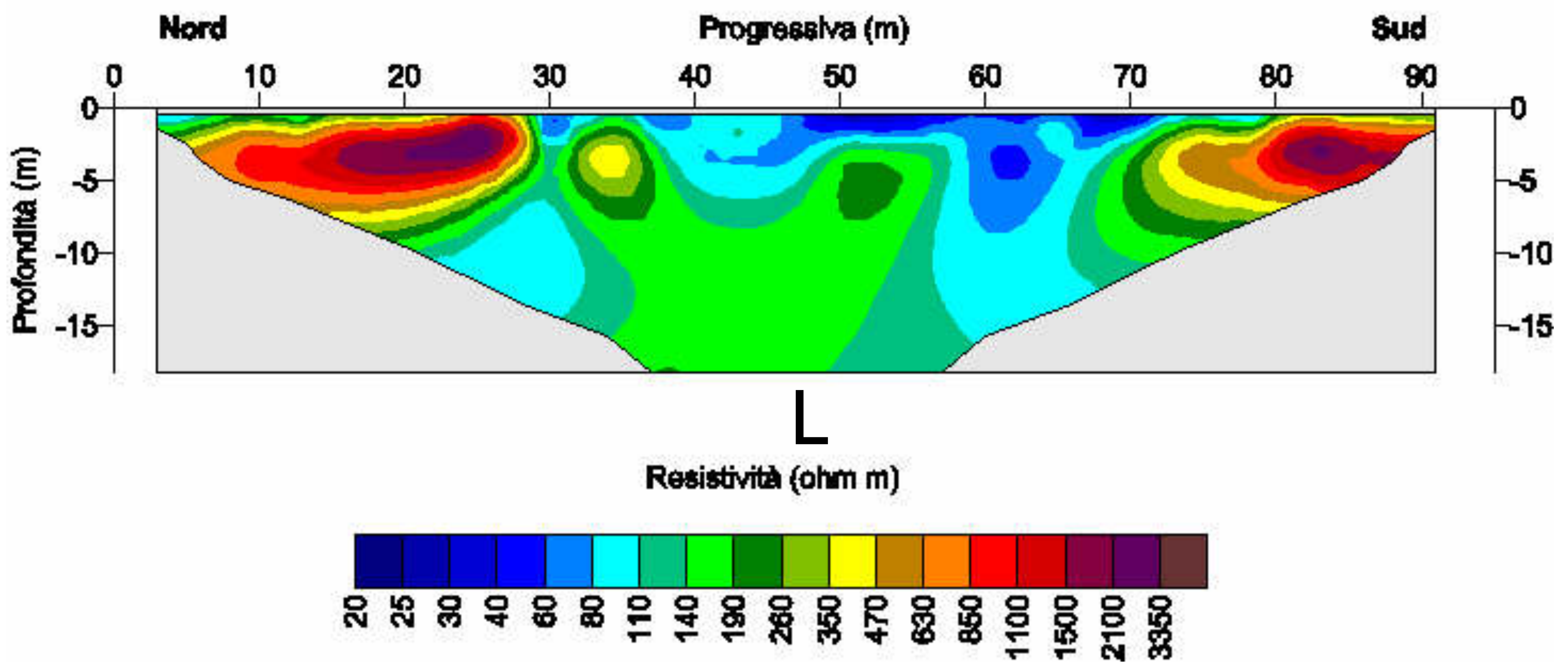
ELECTRICAL SURFACE TOMOGRAPHY

Pro

- *Correlate changes of electrical properties to change of* del *water content and salinity*
- *Cheap,*
- *good resolution*

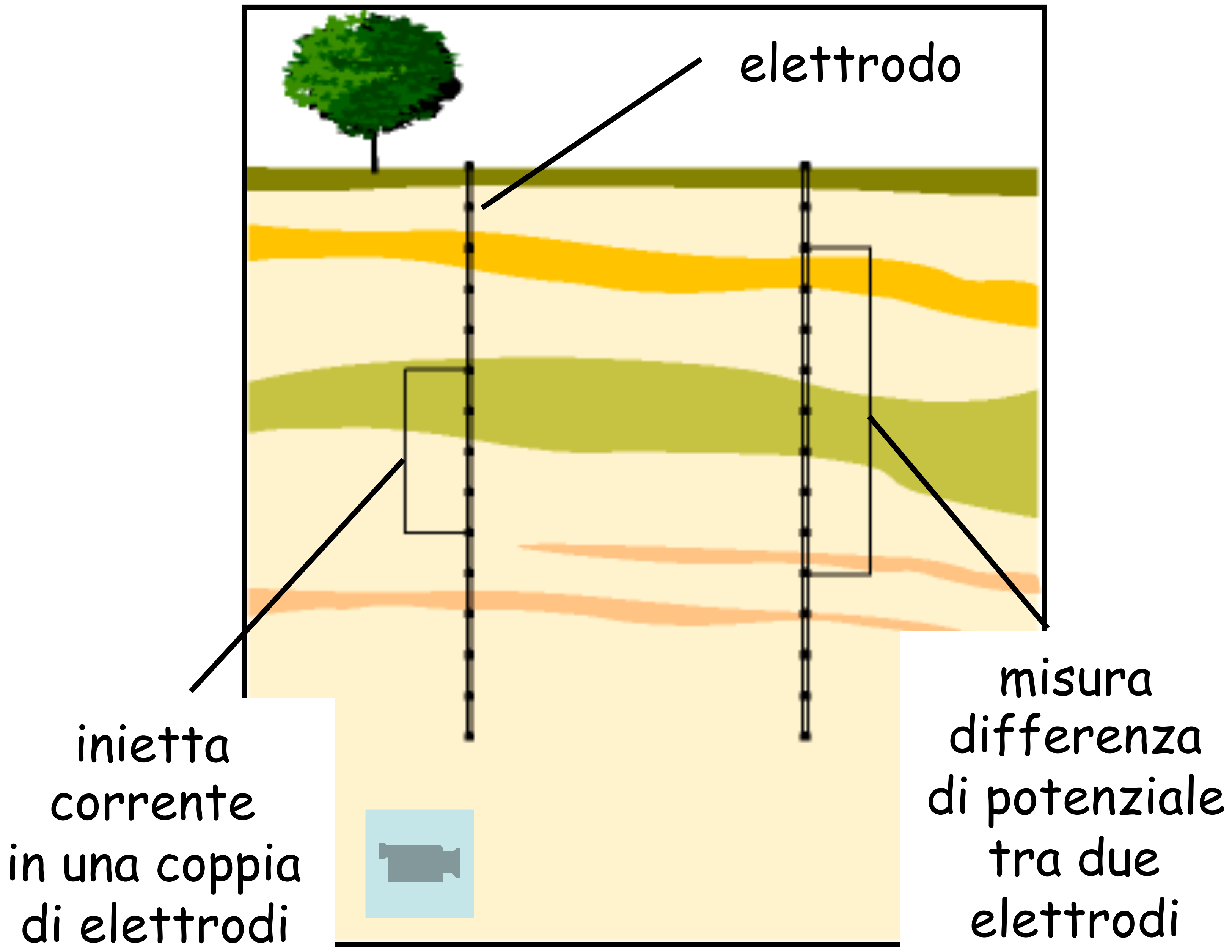
Cons

- *Sensitive to surface heterogeneities*
- *Loose resolution in depth*



ELECTRICAL BOREHOLES TOMOGRAPHY

Overcome the problems of
Surface geo-electric
Going into the domains
To observe



Greater resolution in depth!

Electrical conductibility $\sigma = (1/\rho)$

↖ Resistivity

Archie's law

Archie's constants

$$\sigma = a \; \sigma_w \, S_w^{\,n} \, \phi^{m}$$

- σ: Cond-ucibility (S/m)
- σ_w: Pore Water conducibility
- S_w: Water Saturation
- ϕ: Porosity
- a, n, m: Archie's constants

Formation	Electrical resistivity range
Sea water	0.1 0.3 Ωm
Salted water	0.3 0.9 Ωm
Brackish water	0.9 5 Ωm
Leachate	0.9 5 Ωm
Fresh water	5 80 Ωm
Clay	5 30 Ωm
Wet sand	20 150 Ωm
Sandstone	30 300 Ωm
Limestone	100 800 Ωm
Dry sand	250 4000 Ωm
Granite	1000 20,000 Ωm

Archie's constants (empirical)

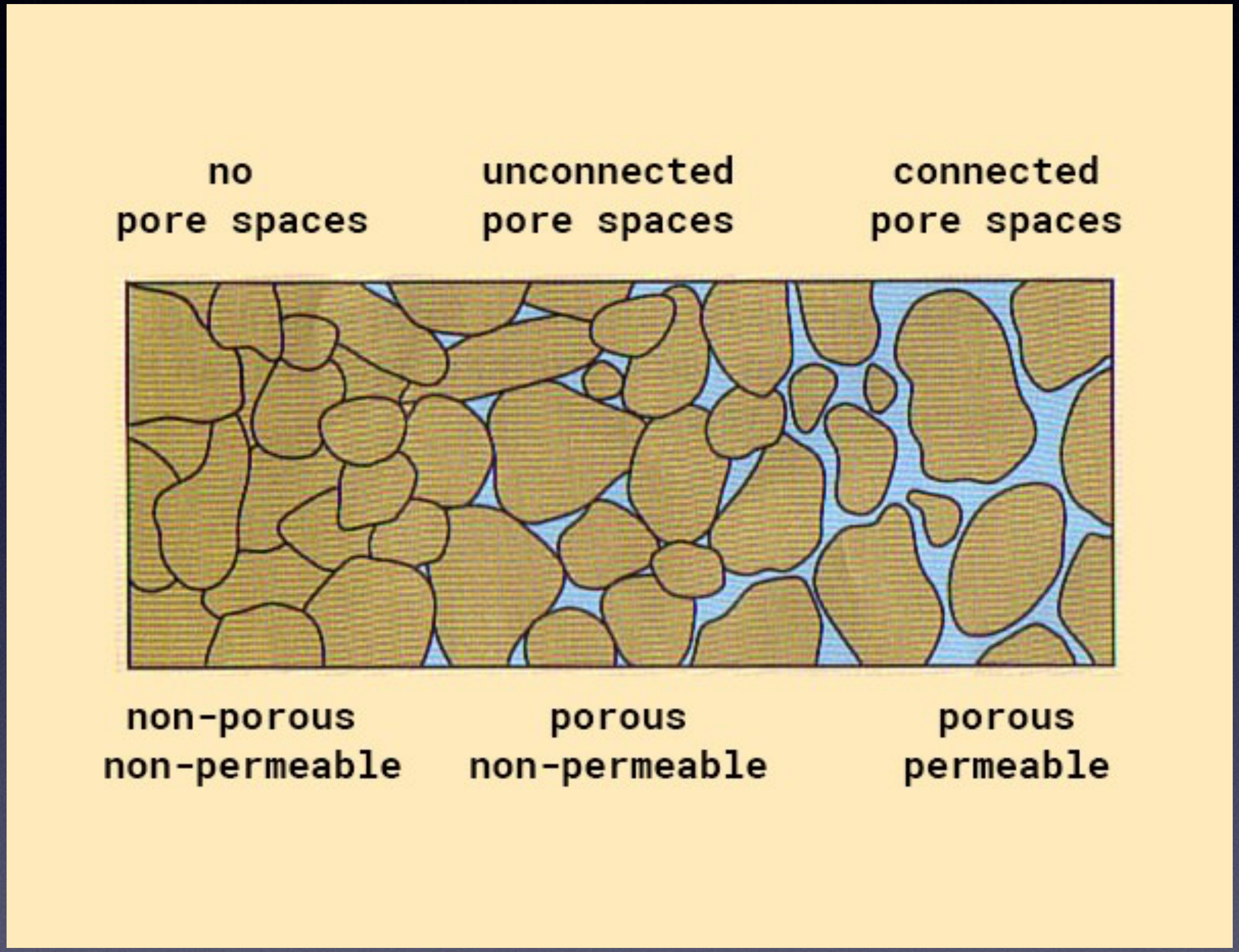
$a \approx$	0.5-1.5	f (tortuosity, grain size, clay content , etc.)
$n \approx$	2	exp factor
$m \approx$	1.2-2.3	Cementation factor

Formation factor (for Sw =1)

$$F = \frac{a}{\phi^m} = \frac{\sigma_w}{\sigma}$$

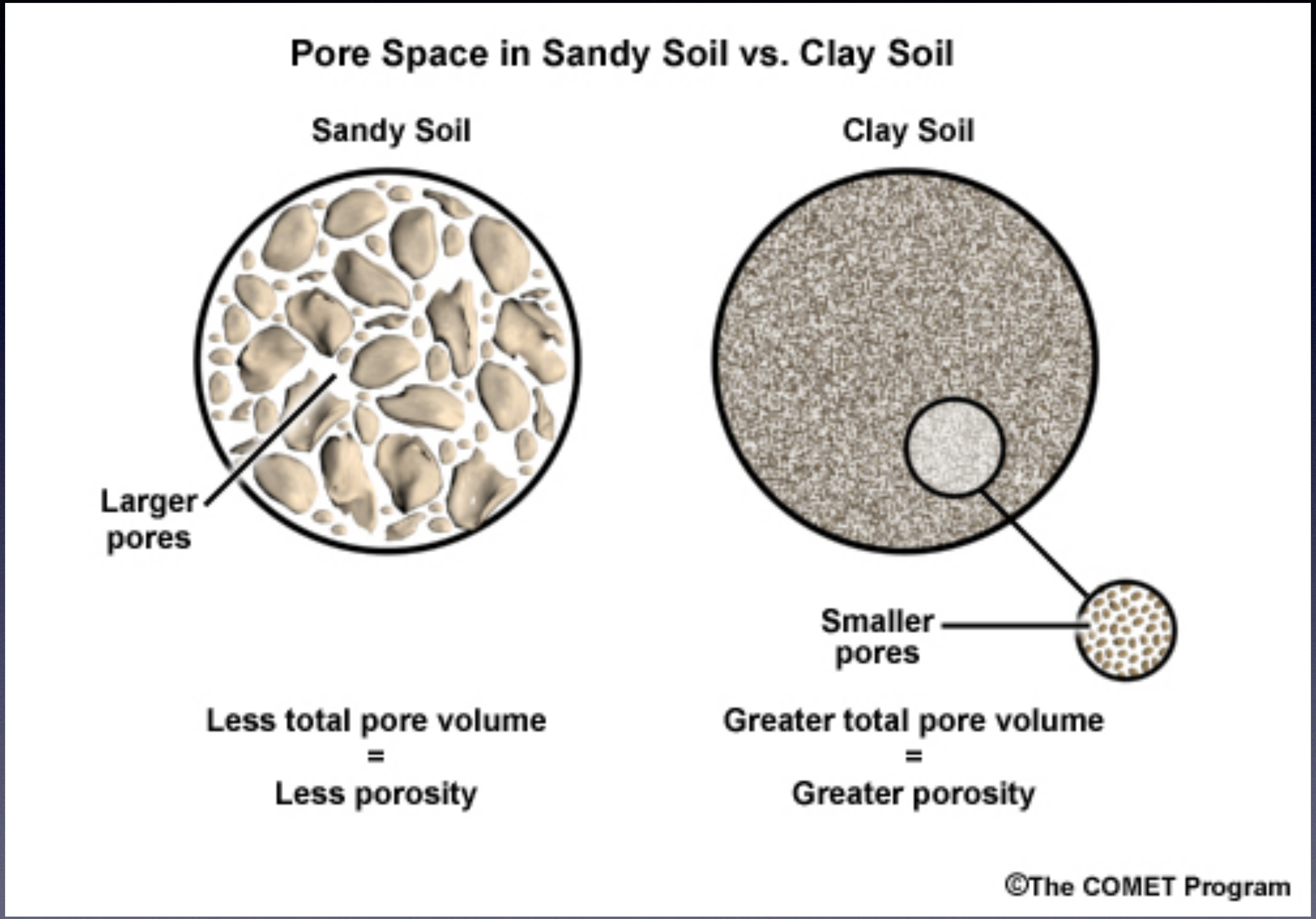
Porosity $\phi = Vv \,/\, Vt$ Pore Volume / Total Volume

Soil porosity



$$\phi = \frac{\text{Voids Volume}}{\text{Total Volume}} = \frac{Vv}{Vt}$$

Soil porosity



EXAMPLES

$\phi_{Clay} \approx 50\%$

$\phi_{Sand} \approx 30\%$

Gravel/sand have larger pore
But less in Volume → In saturated media $\sigma_{pores} > \sigma_{grains}$ → $>> \phi >> \sigma$

TIME LAPSE ERT

If values of σ (ρ) vary in time ?

Geology = constant

Saturation S_w= *can vary in time*

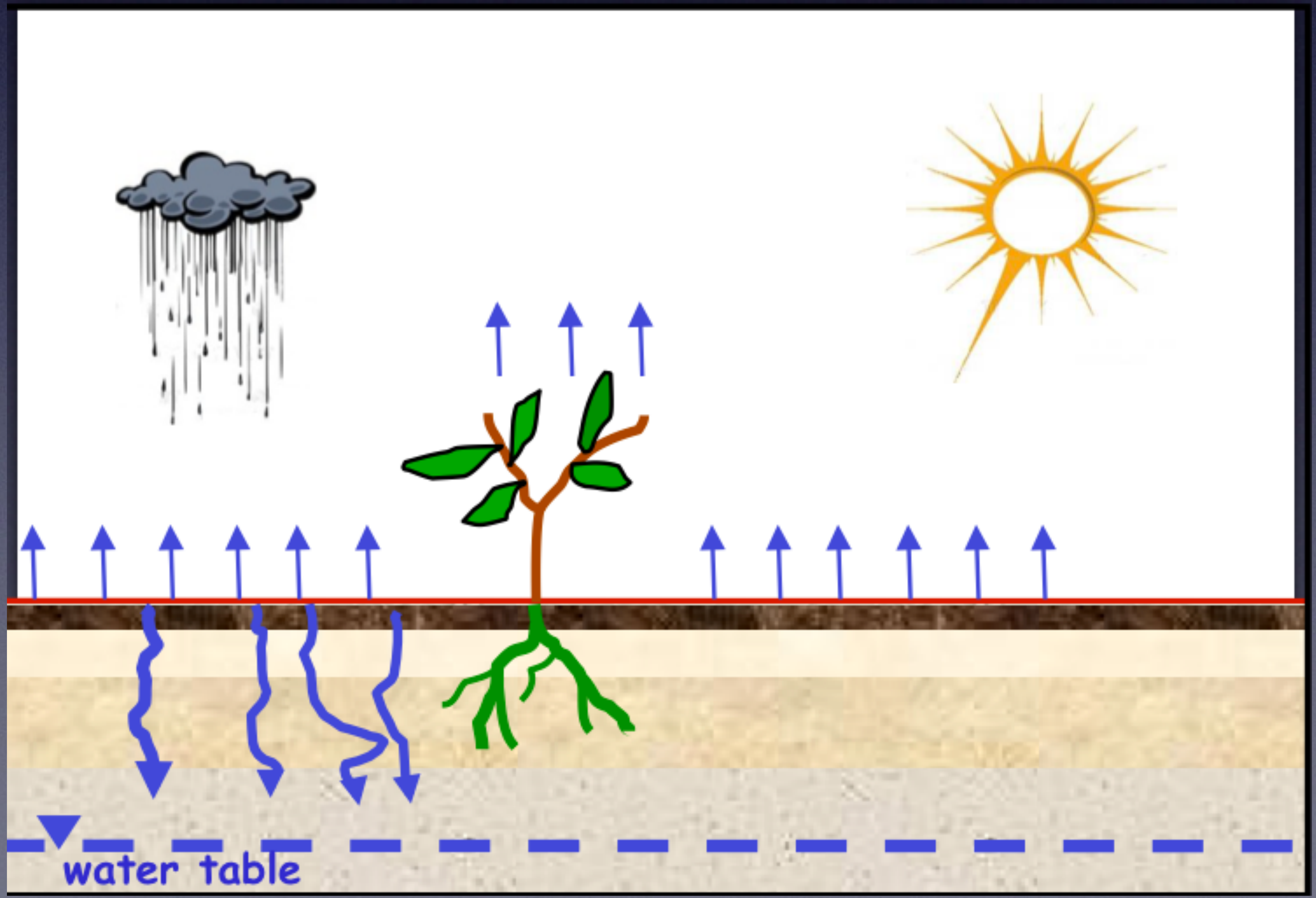
info on fluids dynamic!

Archie's law

$$\sigma = a\ \sigma_w S_w^n \phi^m$$

If Electrical properties Change in time

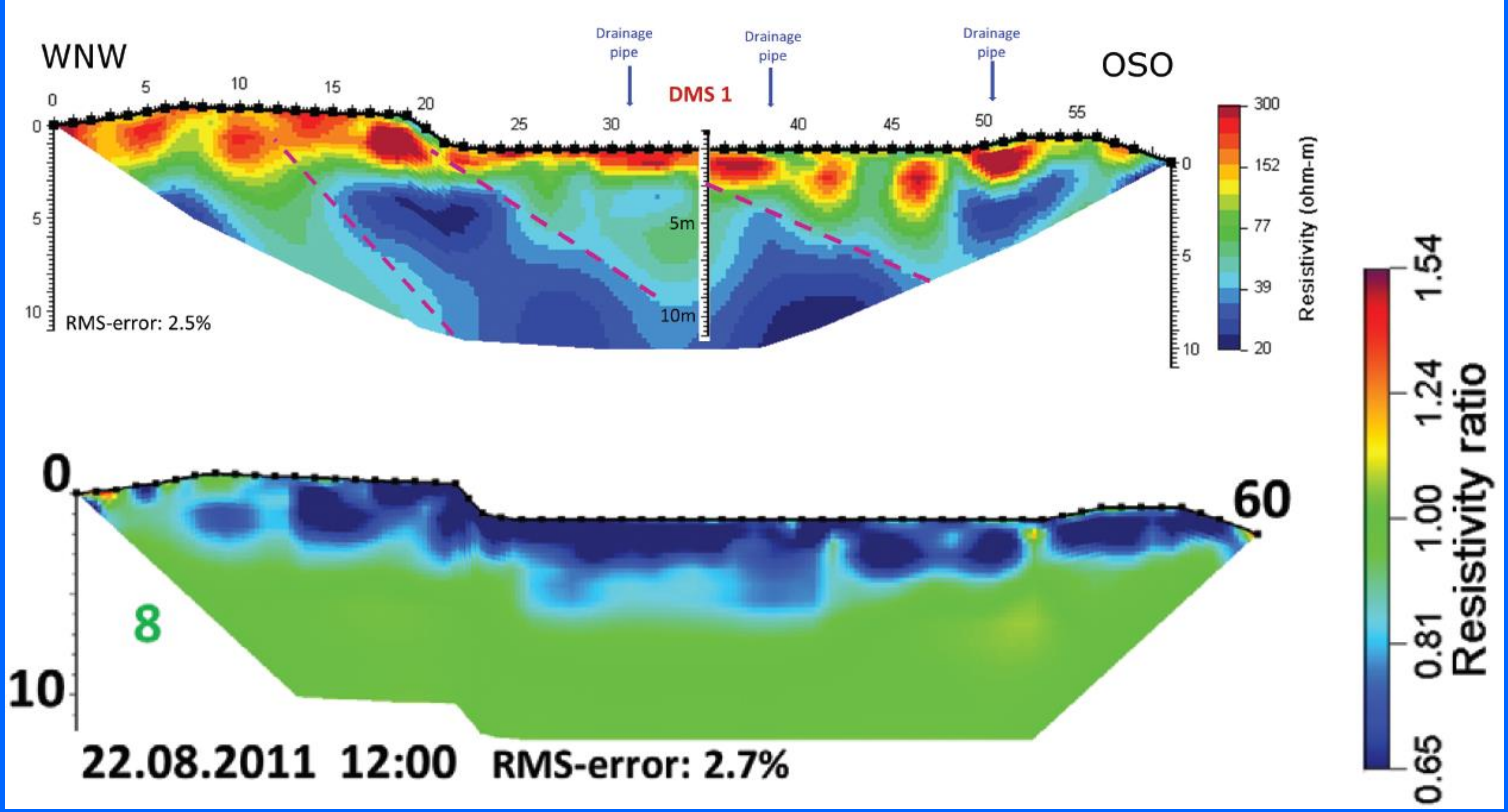
Is due to SATURATION CHANGES (Fluids Dynamic)



TIME LAPSE ERT

2010s : 4-D surveys

Time-lapse surveys are used to detect changes with time to monitor flow of fluids, possible landslides, landfill changes, leakage from dams. Below is a landslide monitoring example from Austria that shows resistivity change after 1.5 years.



Supper, R., Ottowitz, D., Jochum, B., Kim, J.H., Römer, A., Baron, I., Pfeiler, S., Lovisolo, M., Gruber, S. and Vecchiotti, F., 2014. Geoelectrical monitoring: an innovative method to supplement landslide surveillance and early warning. Near Surface Geophysics, 2014, 12, 133-150

TIME LAPSE ERT

UNIVERSITÀ DEGLI STUDI DI PADOVA

DIPARTIMENTO DI GEOSCIENZE

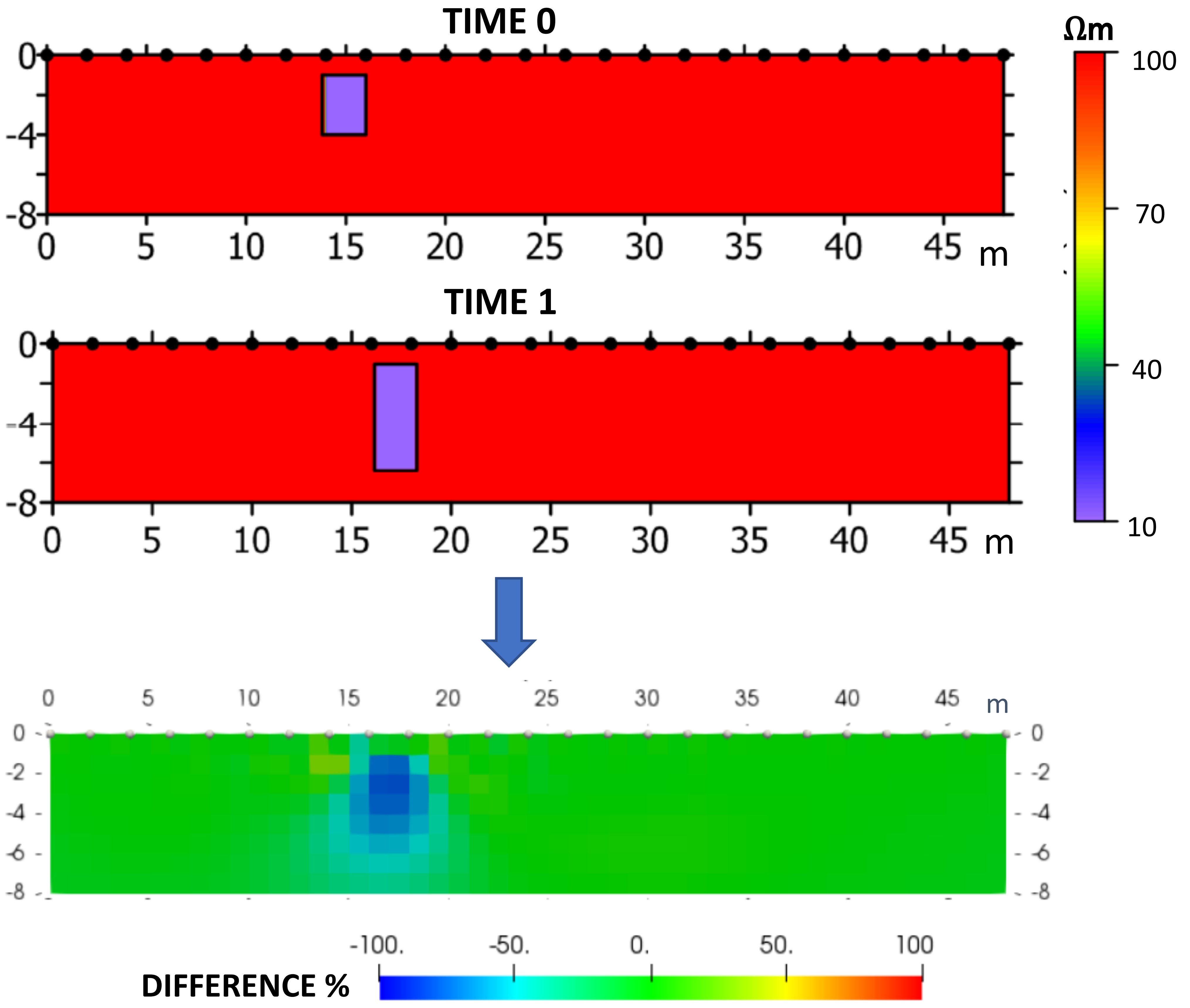
<u>TIME LAPSE based imaging</u>

In order to highlight changes in resistivity, the same electrodes line is measured several times with the same configuration. A ratio inversion approach is typically used

$$R_{ratio} = \frac{R_t}{R_0} \times 100\ \%$$

R_t = Resistance measured at time t

R_0 = First Resistance measured



M Pavoni

Geo-electric survey

In practice….

Geo-electrical methods

Geo-electric survey

Steps	What
1. Design the acquisition	*A priori info a, electrodes number, array length, configuration, location, logistic, cost*
2. Put on the ground the array	*Logistic limits,* *Installation of electrodes with good galvanic contact, deploy cables*
3. Set the instrument and acquire the data	*Instrumental Setting and data storage*
4. Data Processing and interpretation	*Quality check, INVERSION, interpretation, Results presentation*

Geo-electrical methods

Geo-electric survey

Steps	What
1. Design the acquisition	*Cost:* *Based on:* *-Travel expenses* *-Access to the site* *-Person/hour count* *E.g. 72 channels, 3 m spacing need:* *2 person and 1/2 day workin flat grass site;* *3-4 persons and entire daywork in mountain steep slope*

Geo-electric survey

1. Acquisition design

Get all the possible info available about the site!

Know the target of prospecting

RESOLUTION

PENETRATION

BEST ARRAY CONFIGURATION

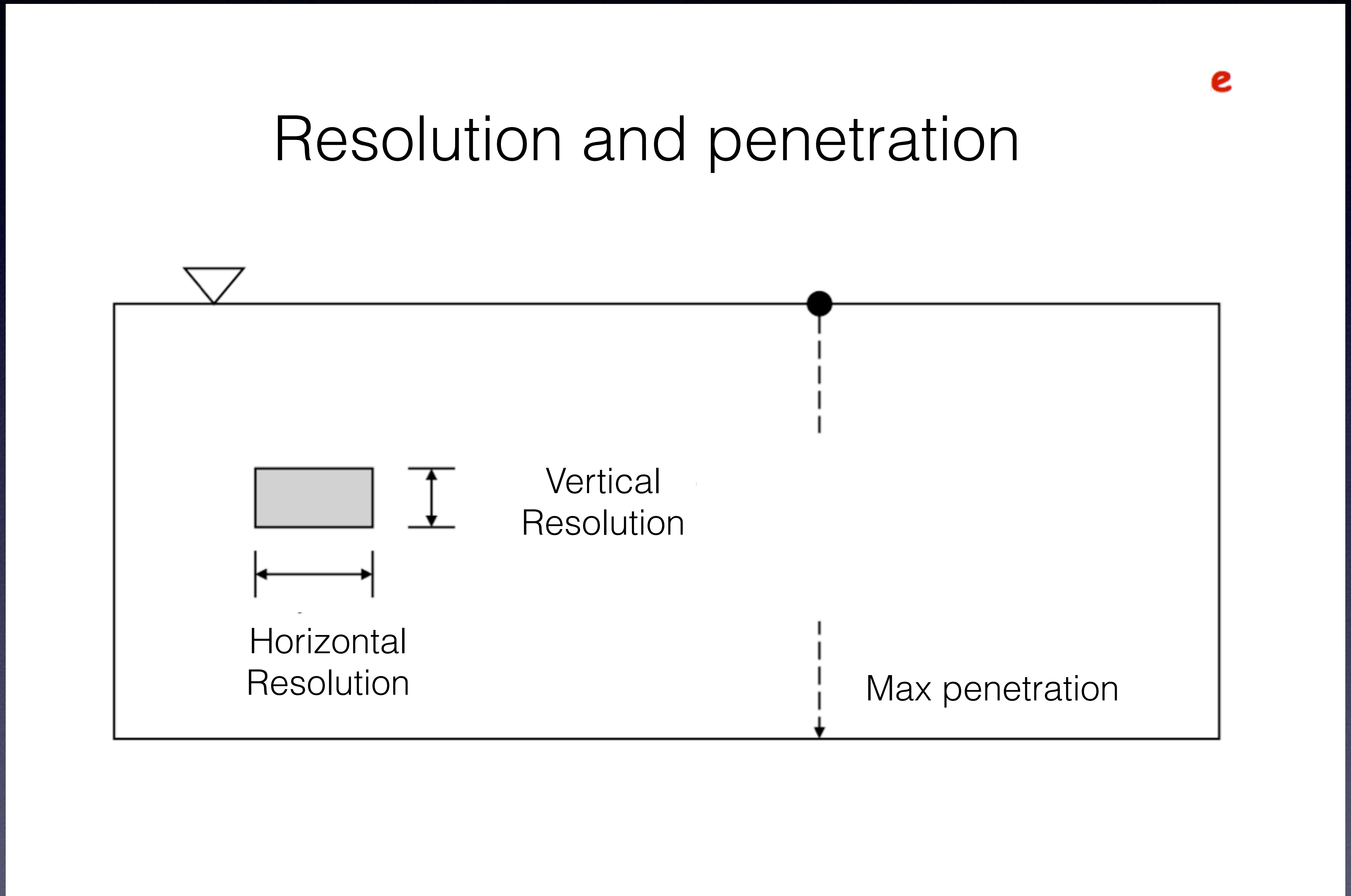
Overall: COST and LOGISTICS

Geo-electrical methods

Geo-electric survey

1. Acquisition design

RESOLUTION



In geo-electric
Is a function of
Electrodes spacing

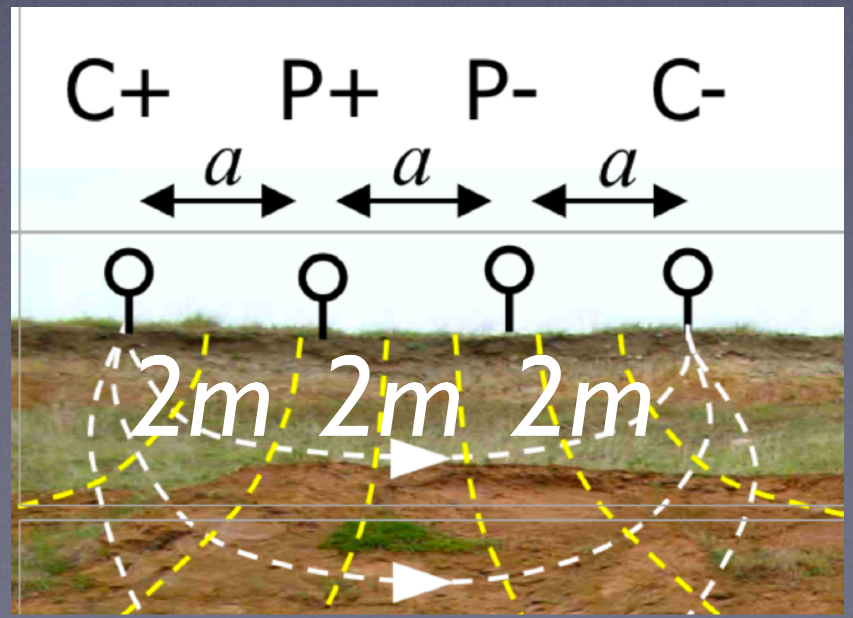
Resolution capacity

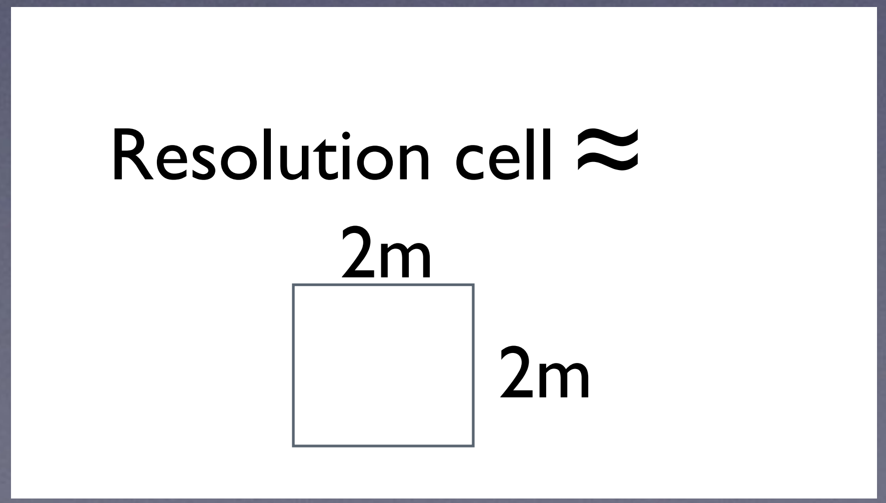
Rule of thumb

≈

Distance between electrodes
(spacing)

eg. Electrodes spacing= 2m





(Cell 2X2)

Geo-electrical methods

Geo-electric survey

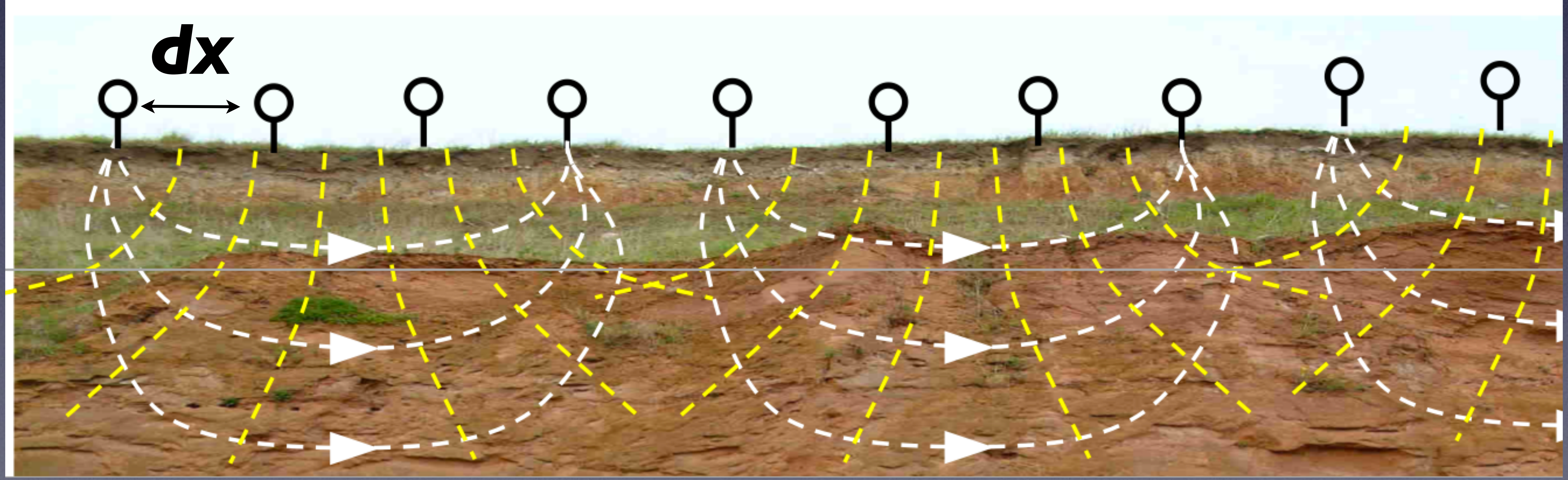
Which georesistivimeter I need ?

1. Acquisition design

Number of electrodes ***N*** *available*
*
Electrodes spacing ***dx***

=

Total length ***L***
of the electrical array



L

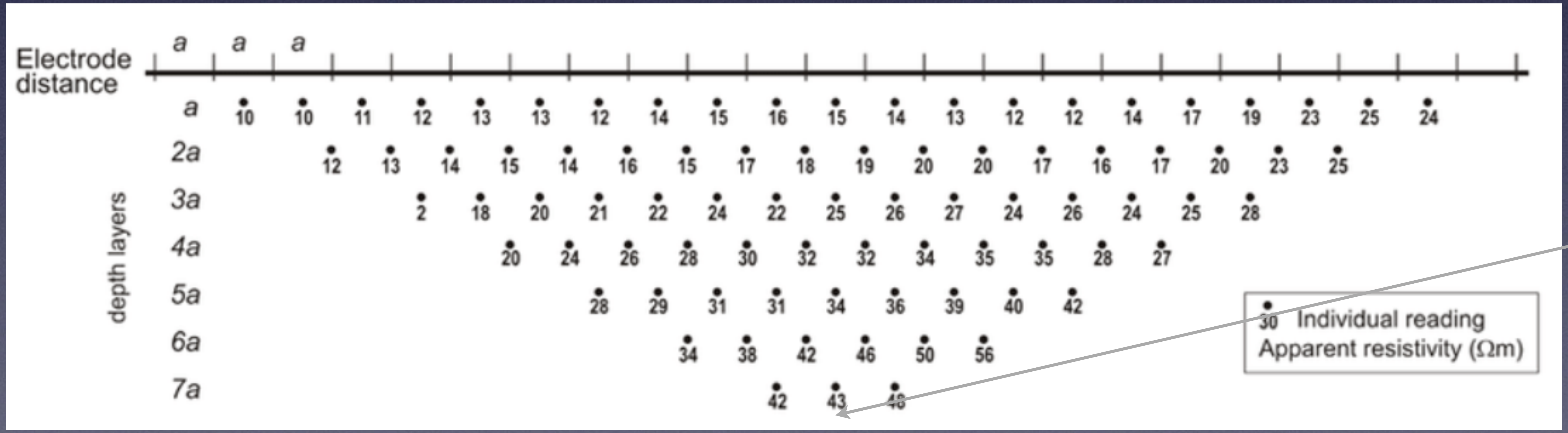
es:

N = 10
dx = 2
L= 18 m

1. Acquisition design

PENETRATION

Rule of thumb *Penetration depth* ≈ 1/5 *Array total length* ***L***



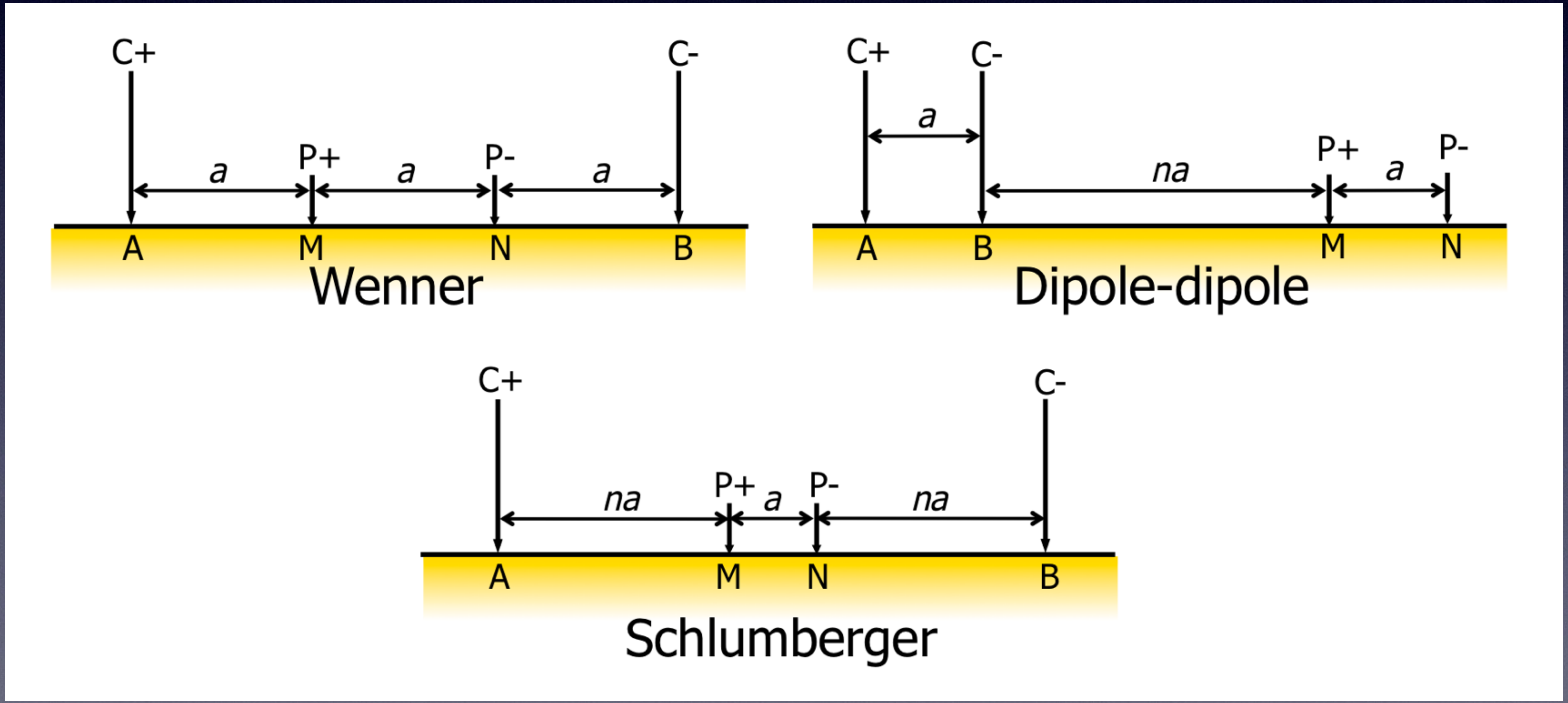
Note: Maximum penetration is in the middle of array L !

es: N= 48, dx= 2m, L=94 m *Penetration max (middle)* ≈ 19 m

Geo-electric survey

1. Acquisition design

ARRAY CONFIGURATION CHOOSE



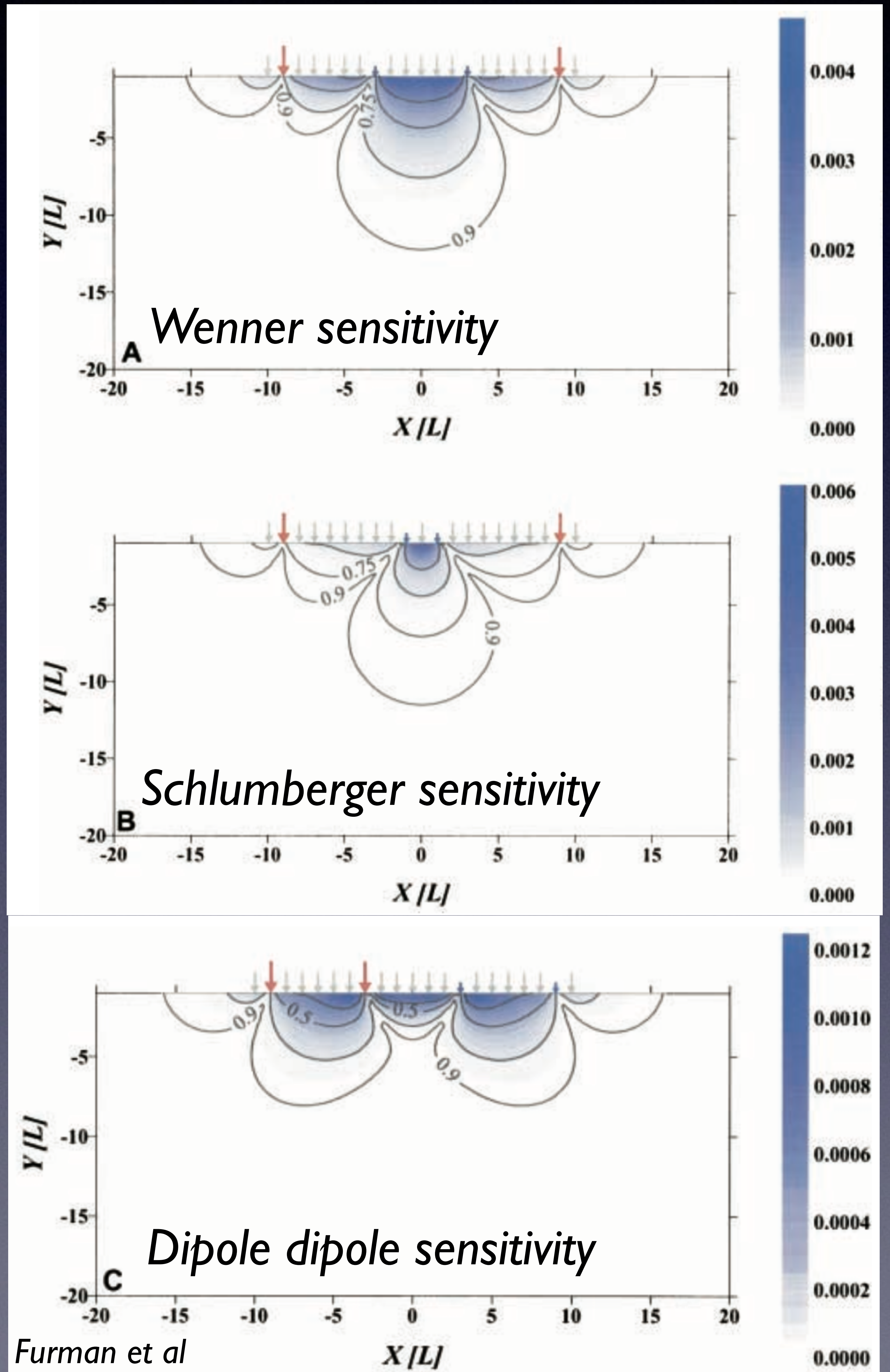
o general combinations, as Wenner-Schlumberger, dipole skip , Pole - Dipole ecc.

Geo-electrical methods

Geo-electric survey

1. Acquisition design

ARRAY CONFIGURATION CHOOSE



Current lines distribution change, than the measurement SENSITIVITY

$$S = |\Delta V|$$

sensitivity

Magnitude of the Potential voltage measurable

es.

Wenner-Schlumberger
Better in depth image

Dipole-Dipole
Better in lateral resolution

Geo-electrical methods

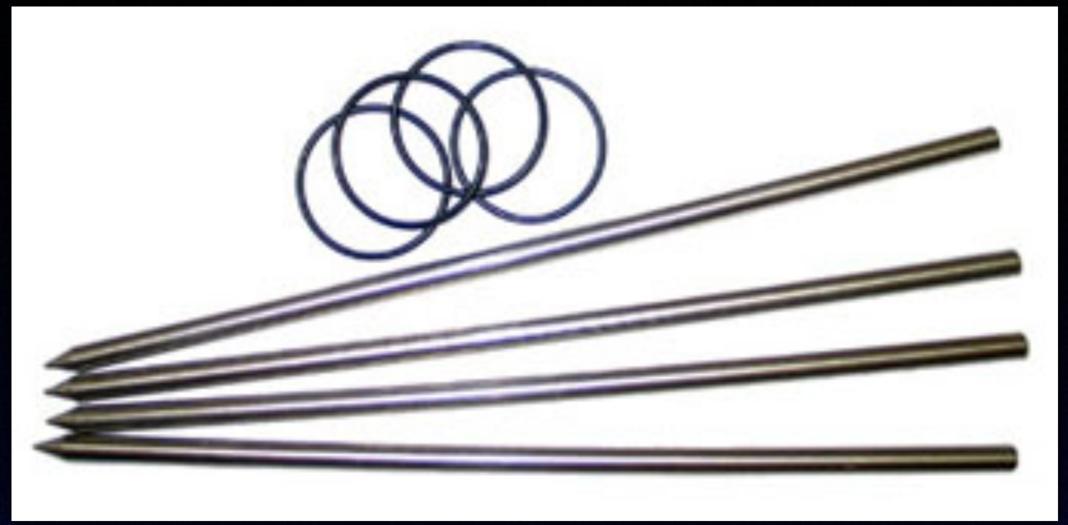
Geo-electric survey

Steps	What
2. Put on the ground the array	*Logistic limits: array length* *Ruling depth info and resolution* *e.g.* *2/3 Arrays: 1 battery 60AH* *If galvanic contact is poor: more batteries* *than more weight, more peoples need, more time, etc.*

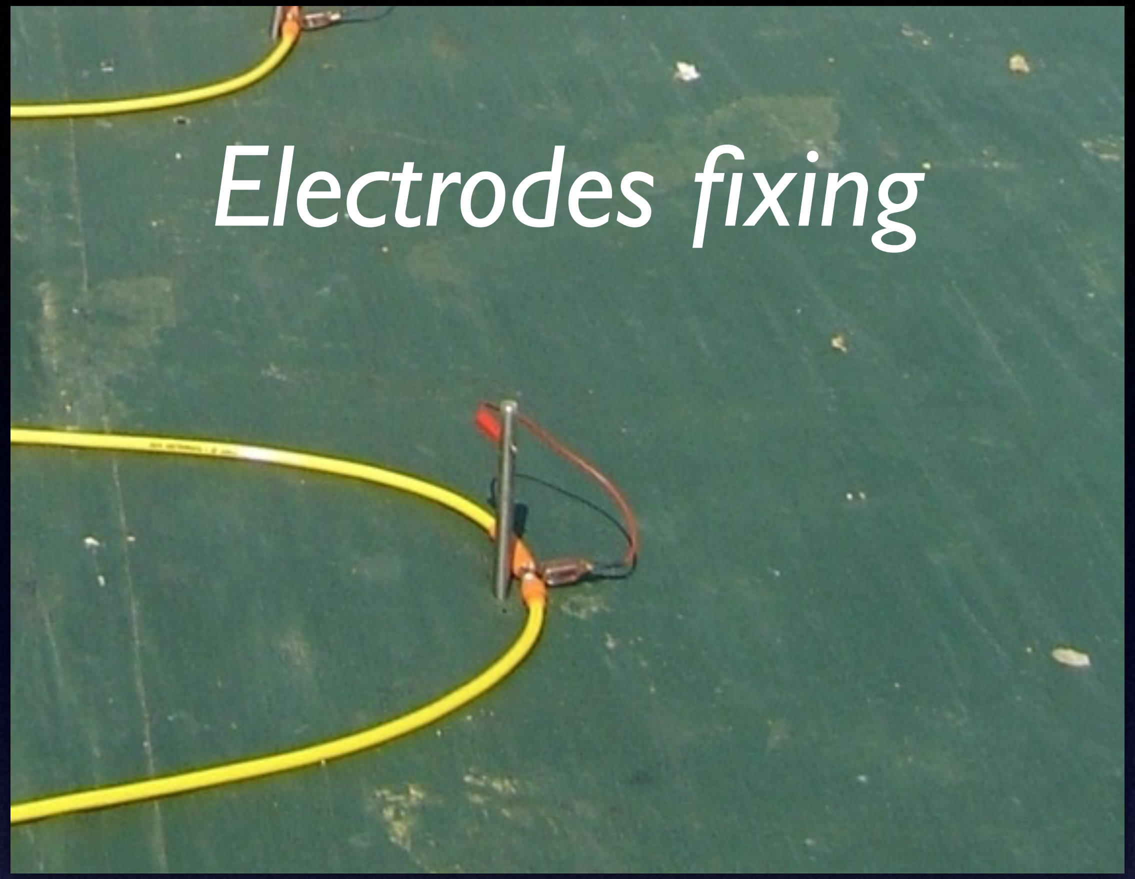
Geo-electrical methods

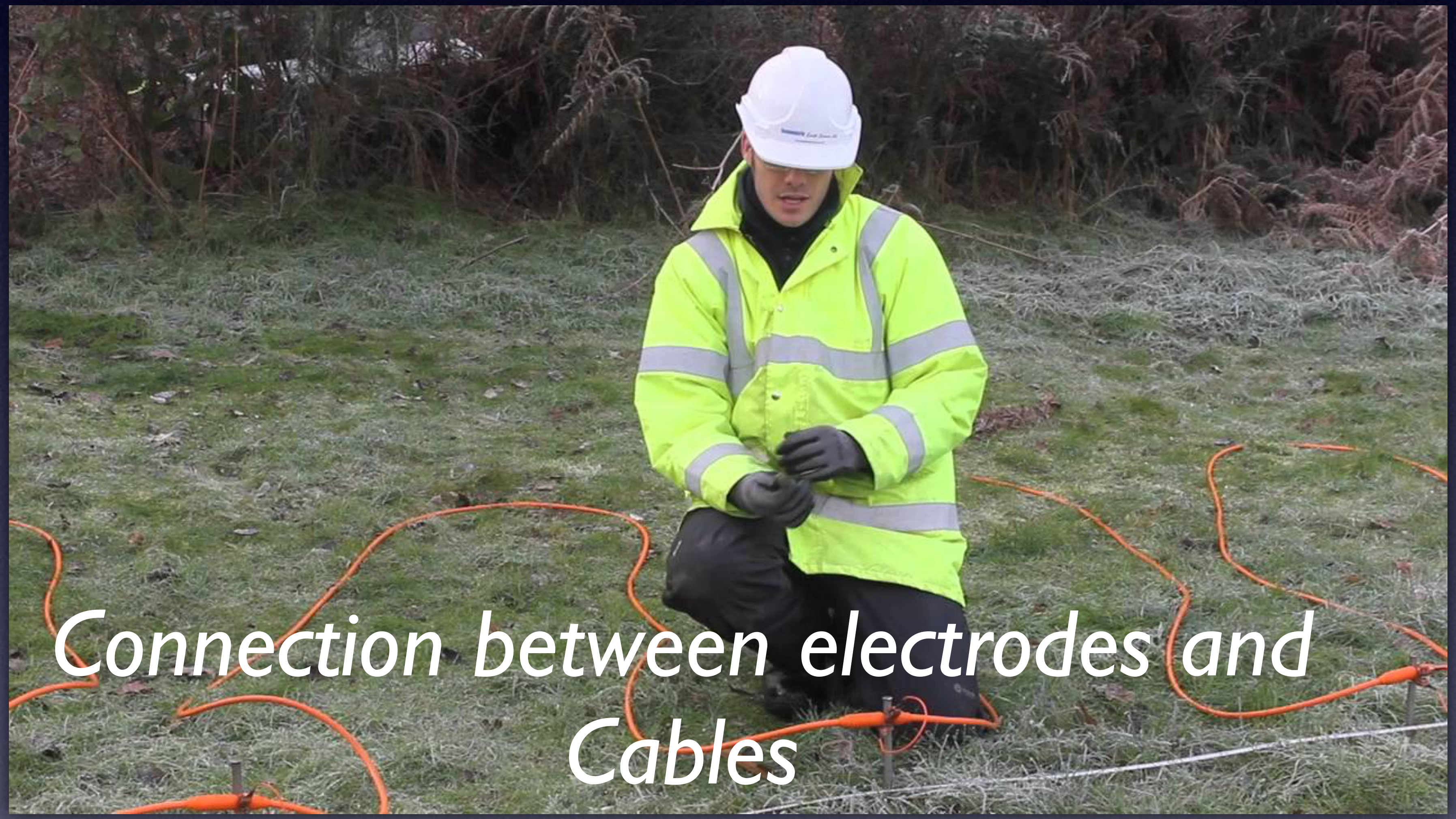
Geo-electric survey

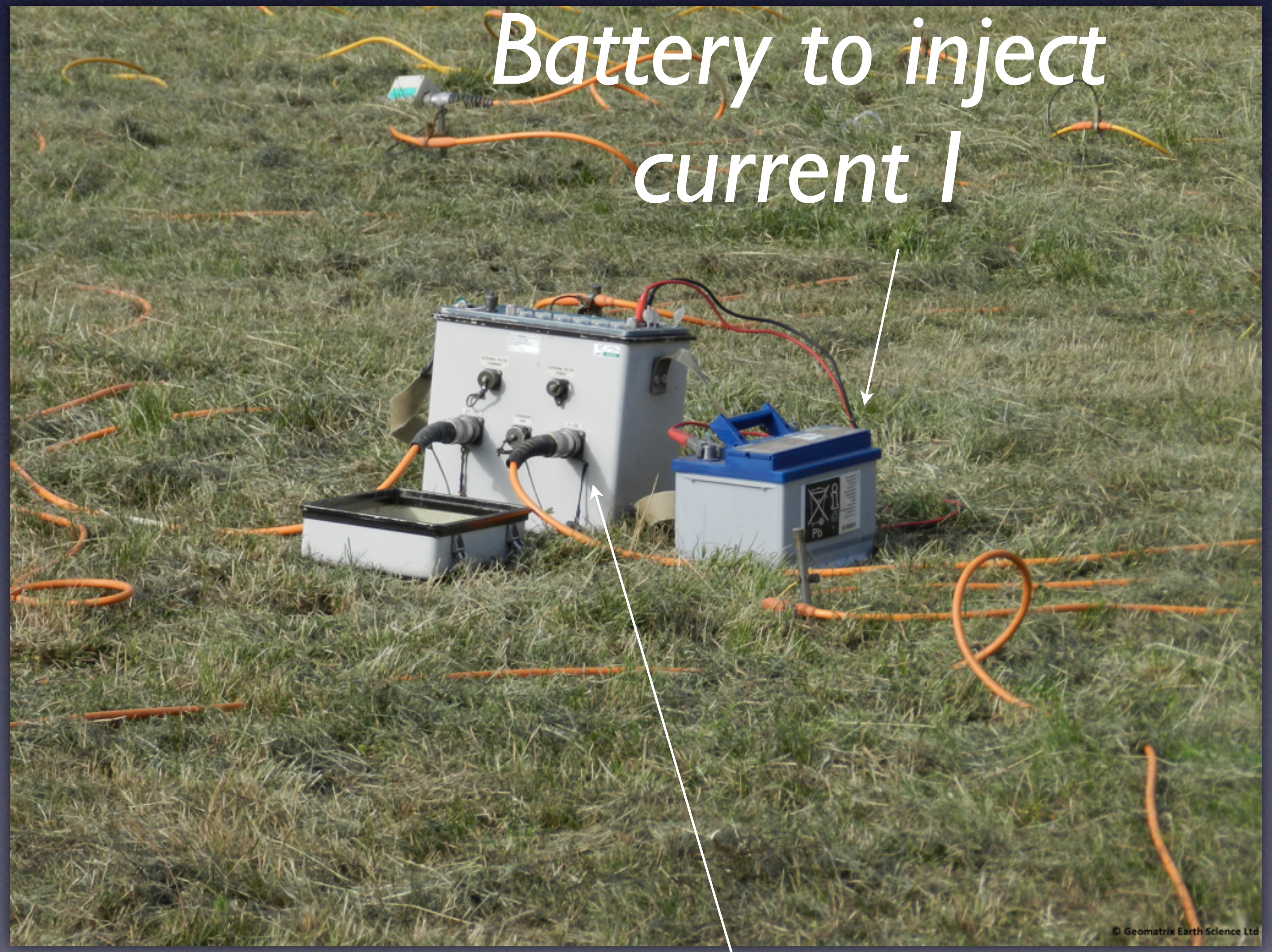
2. Putting on the ground
The array



Electrodes (st, steel)





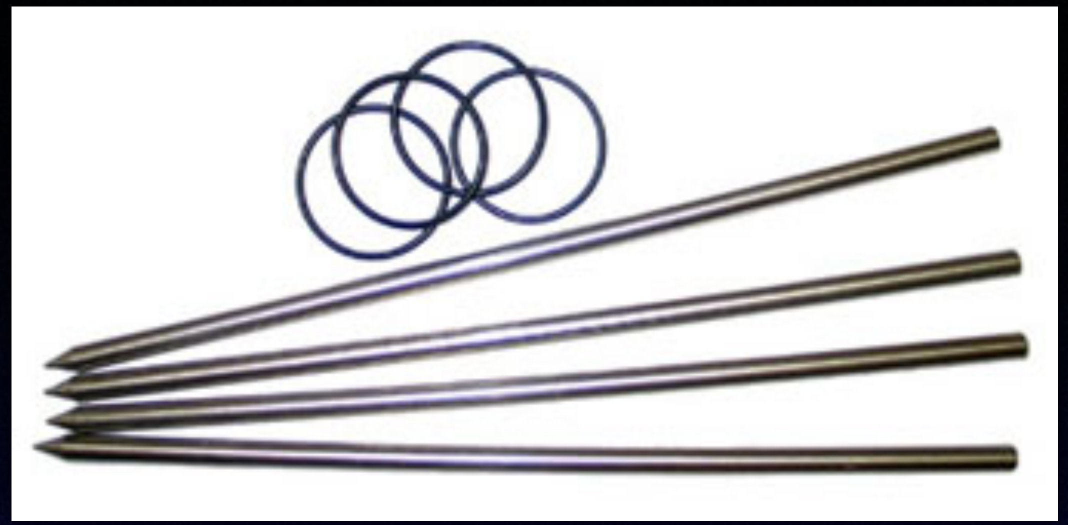


Cables to the
GEO-RESISTIVIMETER

Geo-electrical methods

Geo-electric survey

2. Putting on the ground
The array



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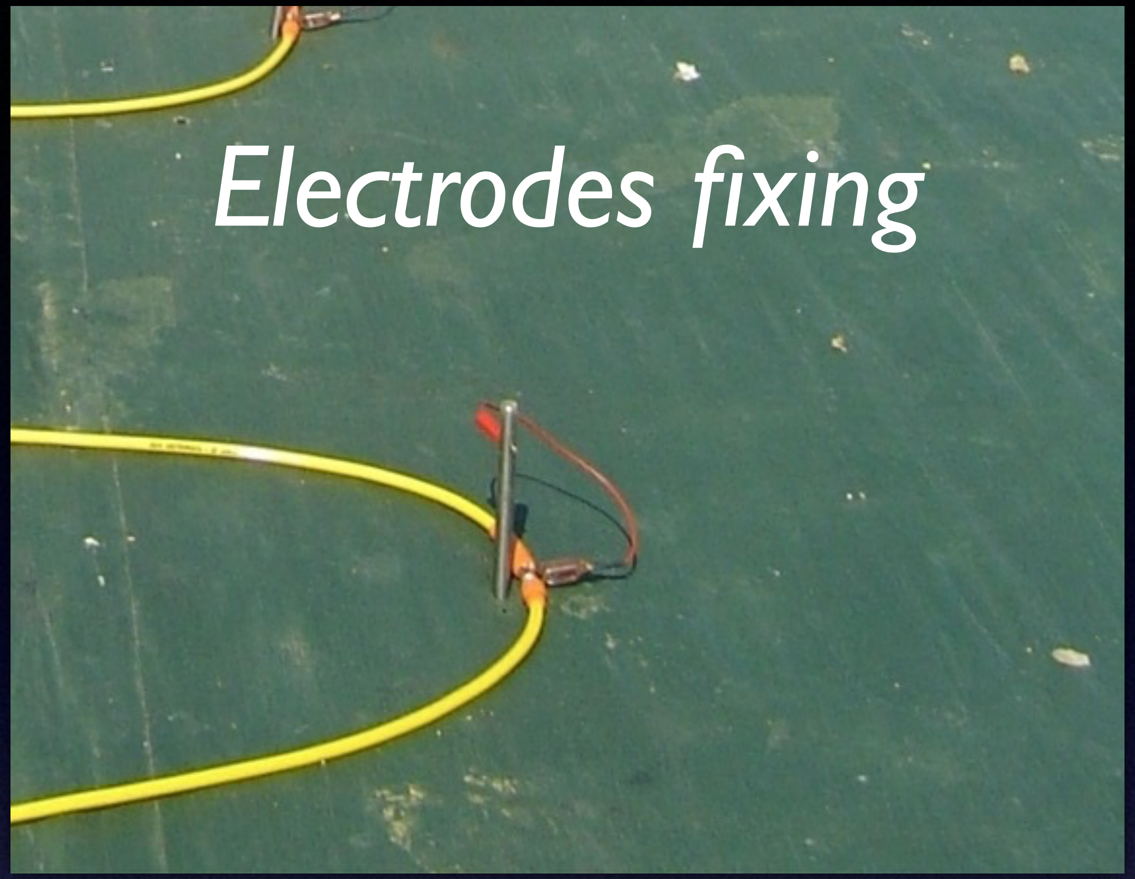


***Galvanic contacts*: the MAIN PROBLEM**

Good contact: 1-50 K Ohm
Poor contact: 50 - 300 K Ohm
Bad contact: > 300 K Ohm

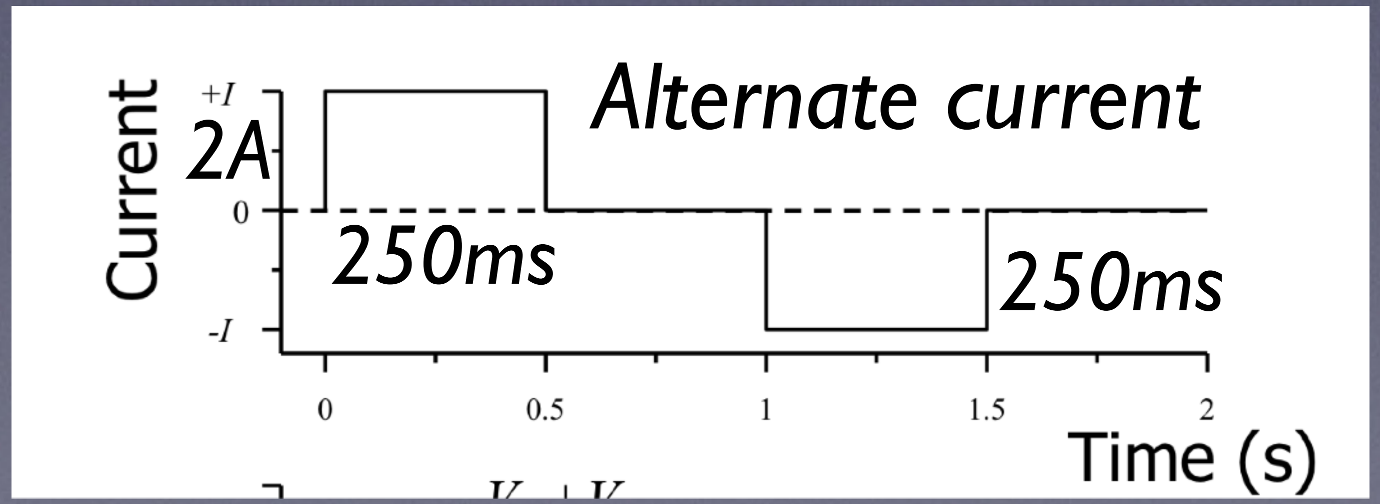
999 K Ohm means electrode unplug !

Battery supply

Common 150m array: 20Ah 12V battery (e.g. internal one)
More than single array: 60 Ah 12V battery
Several array: 2 60Ah batteries or 120Ah big battery need

Geo-electric survey

3. Setting instrument and Acquire the data



Setting:

- Acquisition sequence (wenner, dipole, etc)
- Time of current Injection (eg 250 mS)
- minimum voltage to consider (eg 5 mV)
- maximum current to inject (eg 2.5 A)

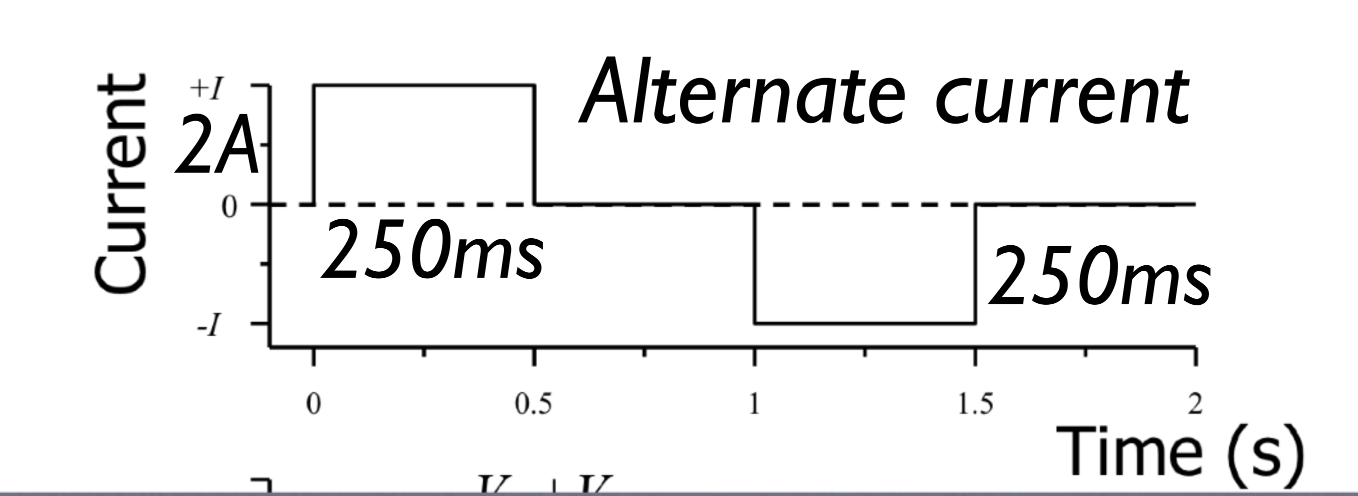
Geo-electric survey

3. Setting instrument and Acquire the data

Some instrument do not allow to fix the current injected,
But set the maximum voltage you can reach peak to peak

e.g Iris Syscal has a maximum of 800 V

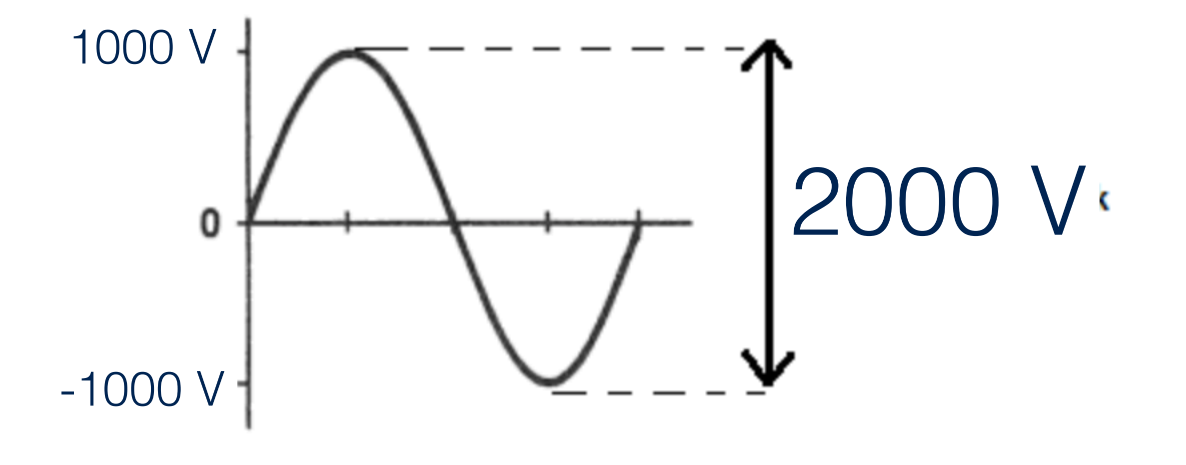
Maximum current 2,5 A
Maximum power 250 W



Abem terrameter
Can reach 600 W

3. Setting instrument and Acquire the data

New Iris Instrument has a peak tp peak maximum voltage of 2000 V



Up to 1200 W if connected to a electric generator

Geo-electric survey

3. Setting instrument and Acquire the data

Iris Syscal

Iris Instrument has an internal resistance of 100 MOhm

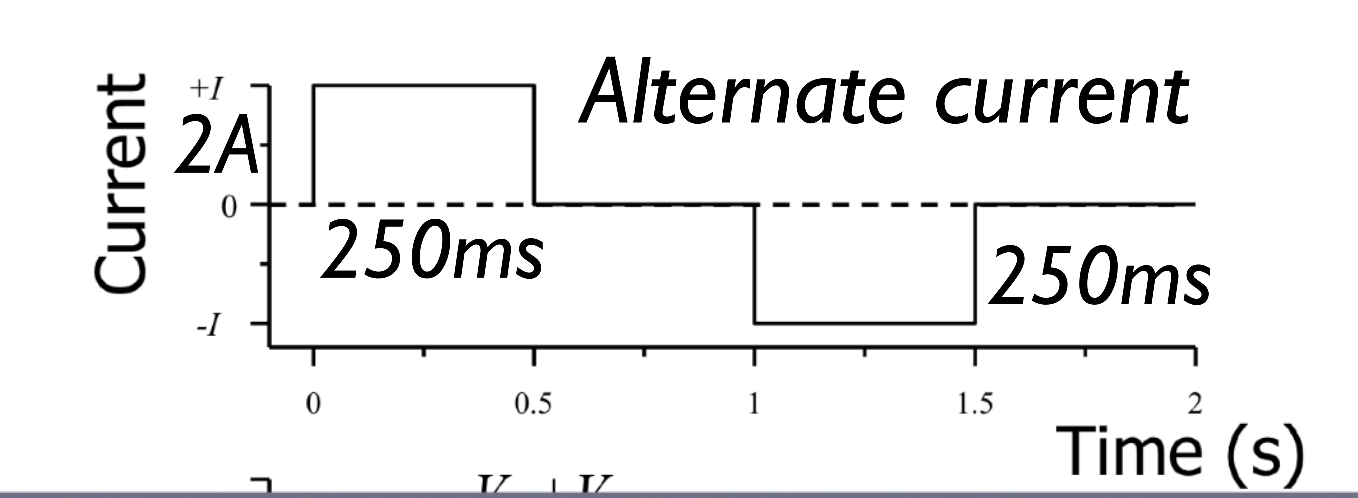
Geotom

Abem terrameter 200 M Ohm

GEOTOM 1000 M Ohm

Better for high galvanic contact terrains !!

Abem



Geo-electrical methods

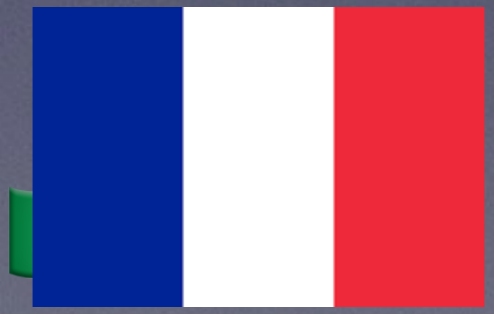
Geo-electric survey

3. Setting instrument and Acquire the data

Instruments choice

The Geo-resistivimeter

Syscal Iris Pro



ABEM

MAE

Integrated PC

Geo-electric survey

3. Setting instrument and Acquire the data

Instruments choice…

- *electronic quality (mV !)*
- *toughness (fieldwork)*
- *NUMBER OF CHANNELS (same-time measurements to be taken)*

+

- ***NUMBER OF ELECTRODES (nodes)*** *manageable*

+ ELECTRODES =

> RESOLUTION (< dx)

> PENETRATION (> L)

>> $$$

Geo-electrical methods

Geo-electric survey

3. Setting instrument and Acquire the data

Instruments choice…

Examples

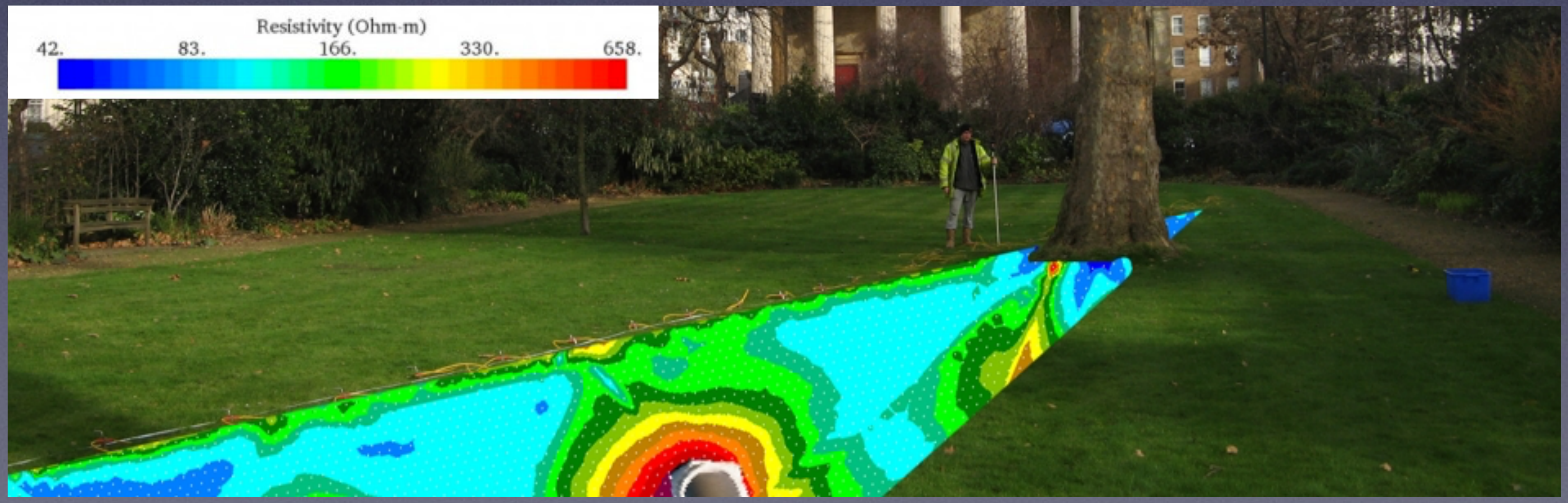
	Channels	N Electrodes	Electronic	Cost
Syscal 	10	From 48 To 120	Excellent Very though	≈ 30-50 k Euro
MAE 	>30	From 48 To 96	Poor Less robust	≈ 20 k Euro
ABEM 	>30	From 48 To 120	Excellent	≈ 30-50 k Euro

4. Data processing

Graphic results

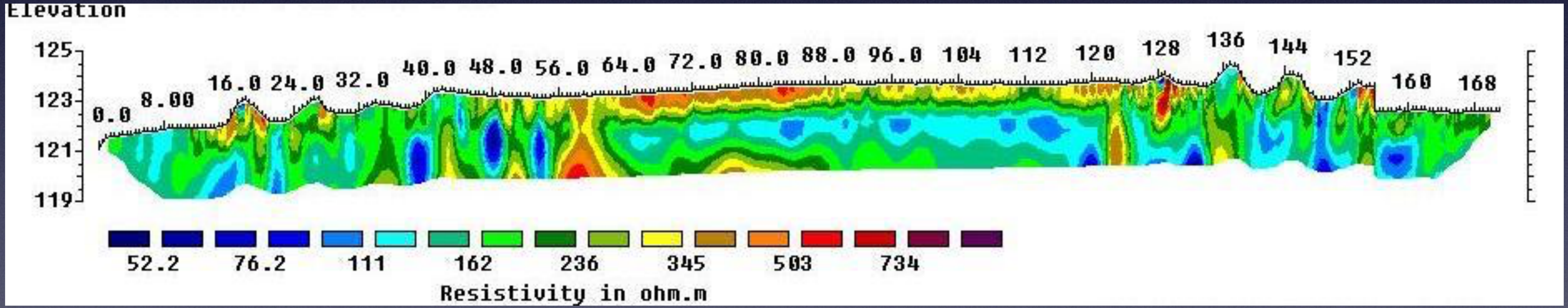
Spatial interpolation *e.g. Kriging, Natural Neighbor, etc*

Final ERT Section



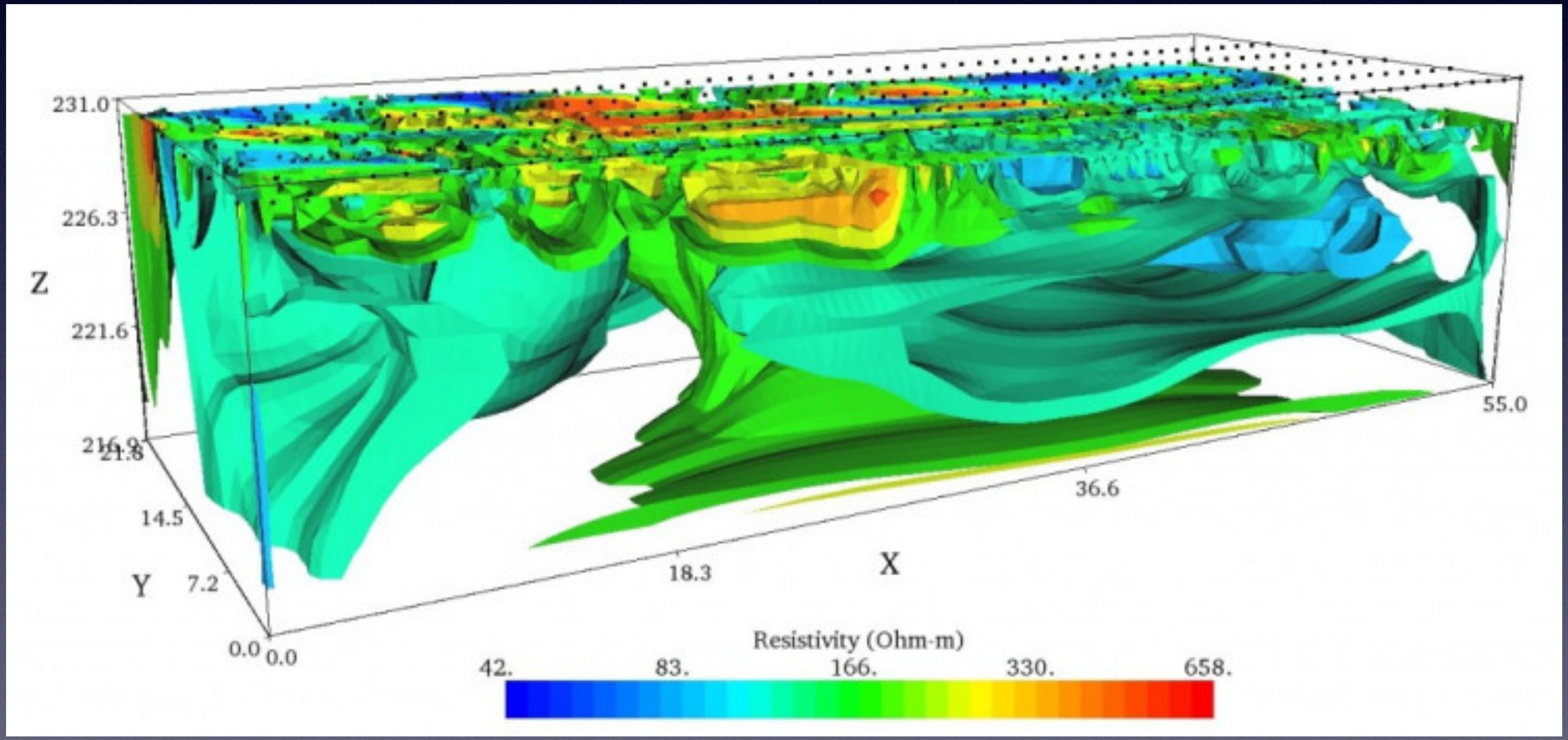
4. Data processing

2D



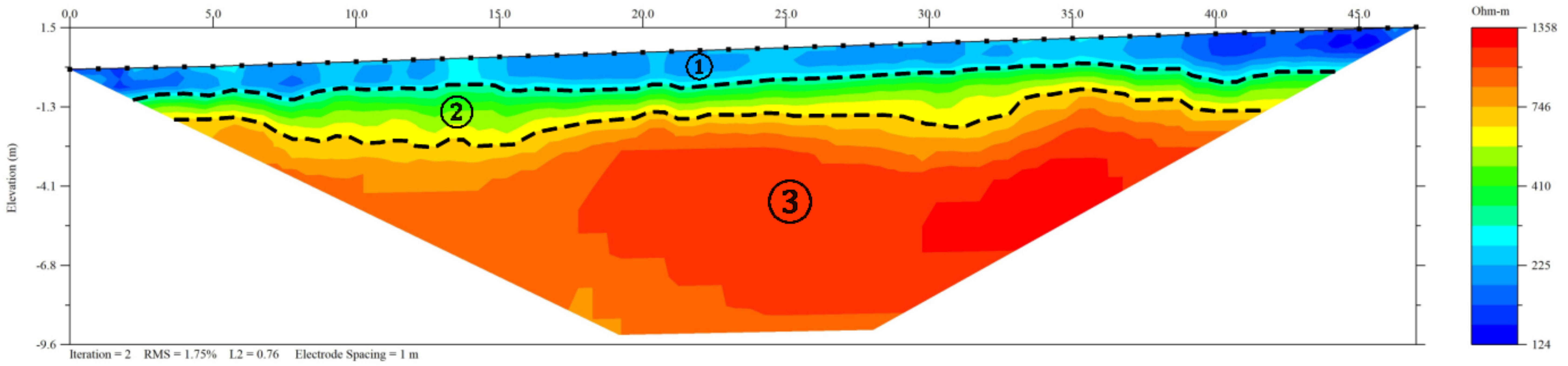
4. Data processing

3D



4. Data processing

INTERPRETATION



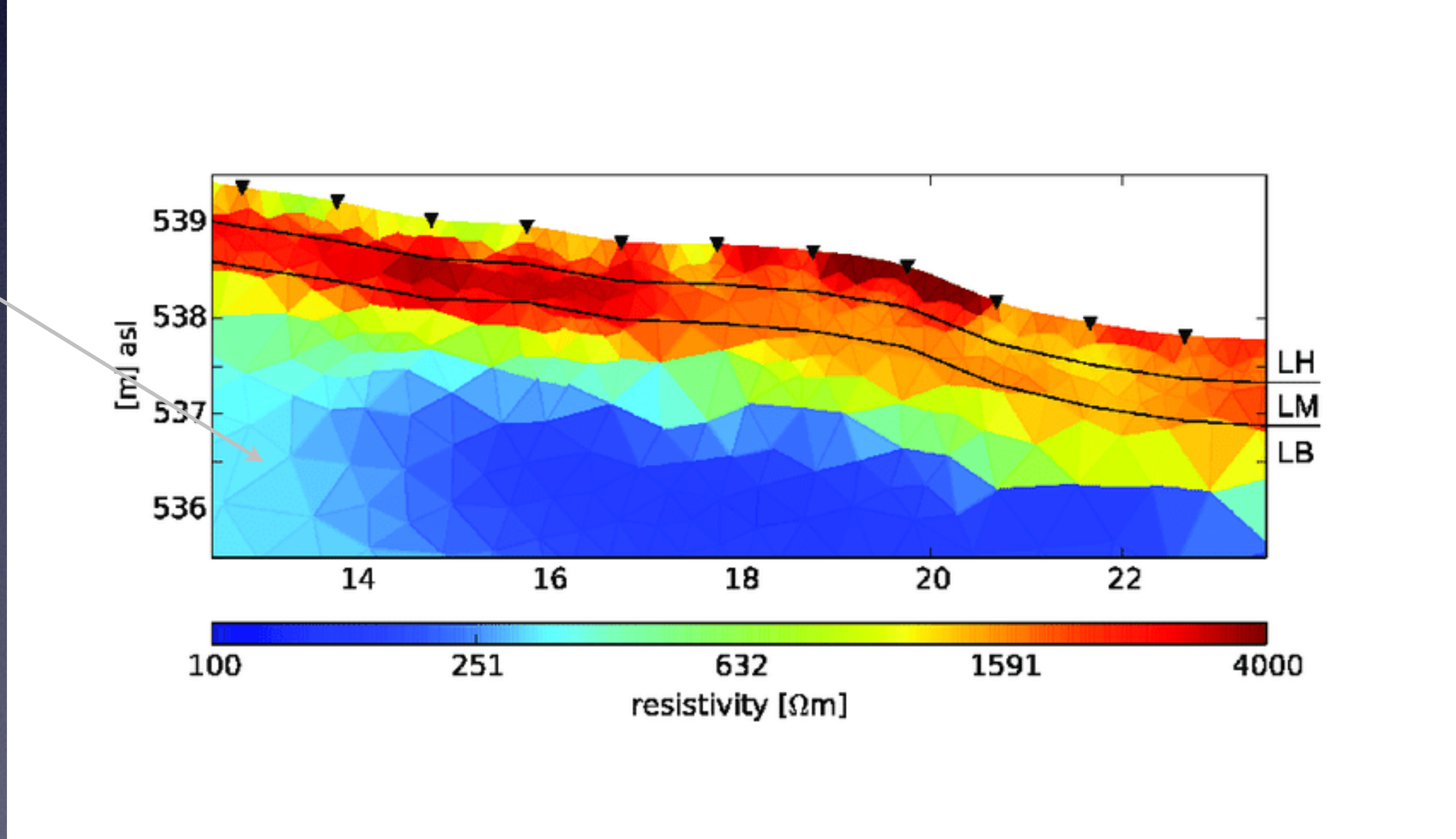
① - Top soil ② - Weathered layer ③ - Bedrock

4. Data processing

INTERPRETATION

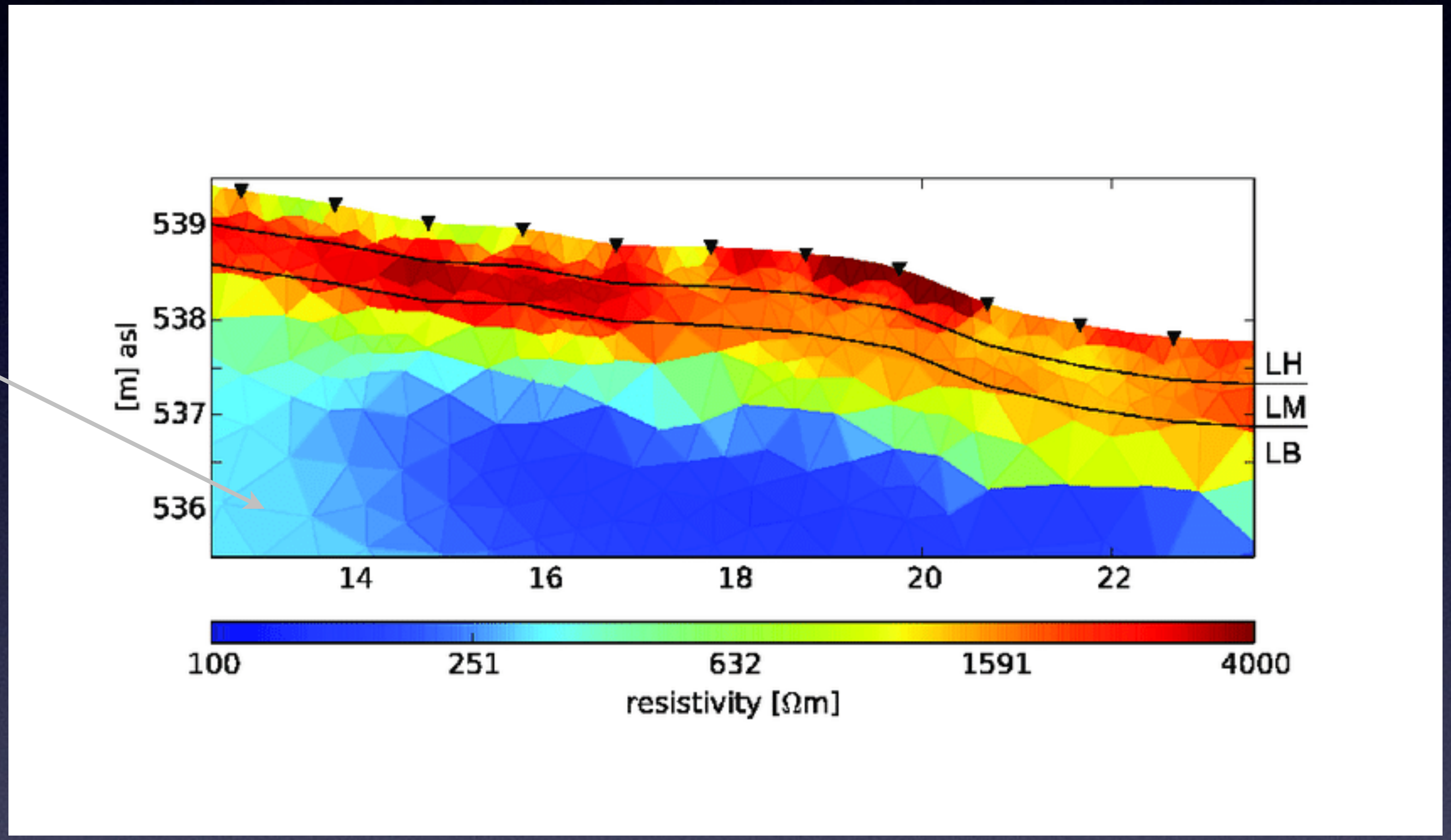
Zone with less saturation
(lower resistivity) ?

Fractured zone ?



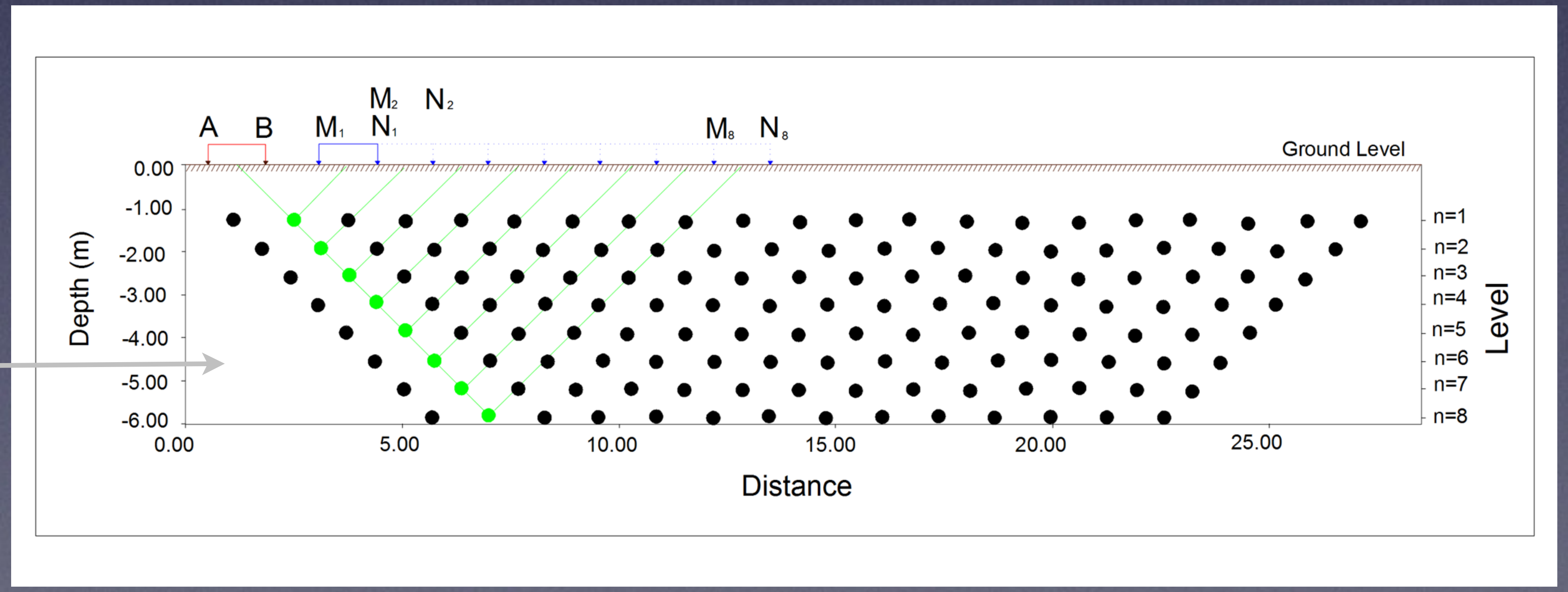
4. Data processing

Zone with less saturation
(lower resistivity) ?

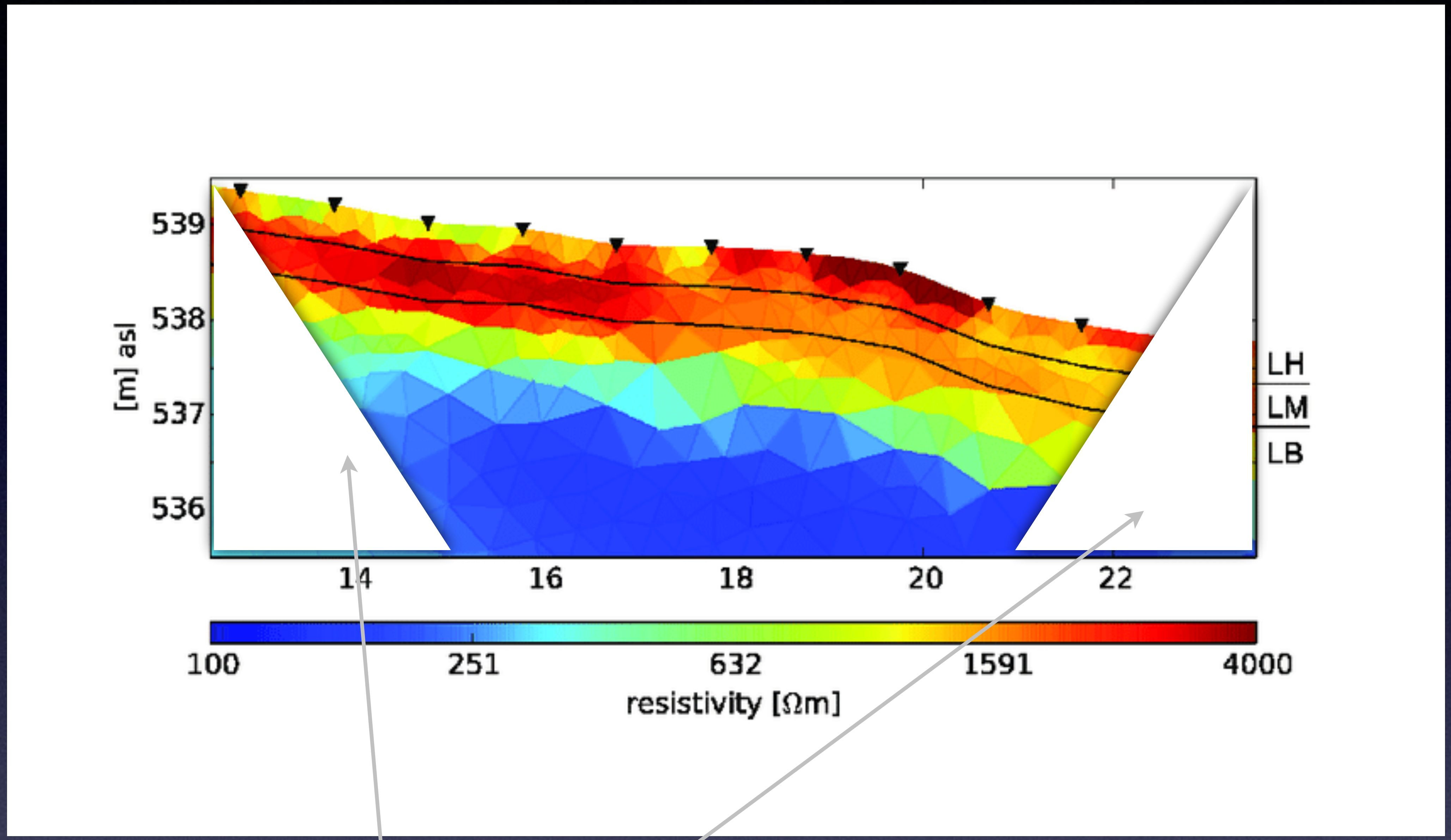


NO !

At the lower margin we in surface ERT we have the 'shadow zones'

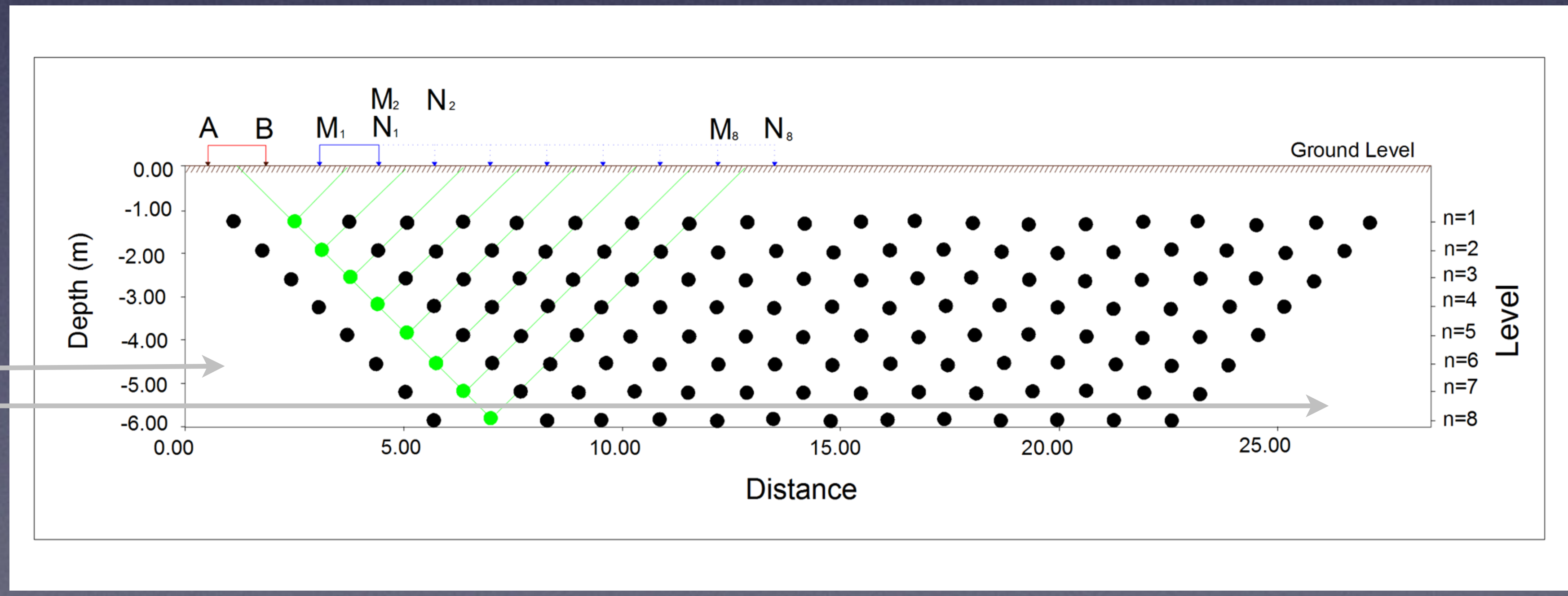


4. Data processing

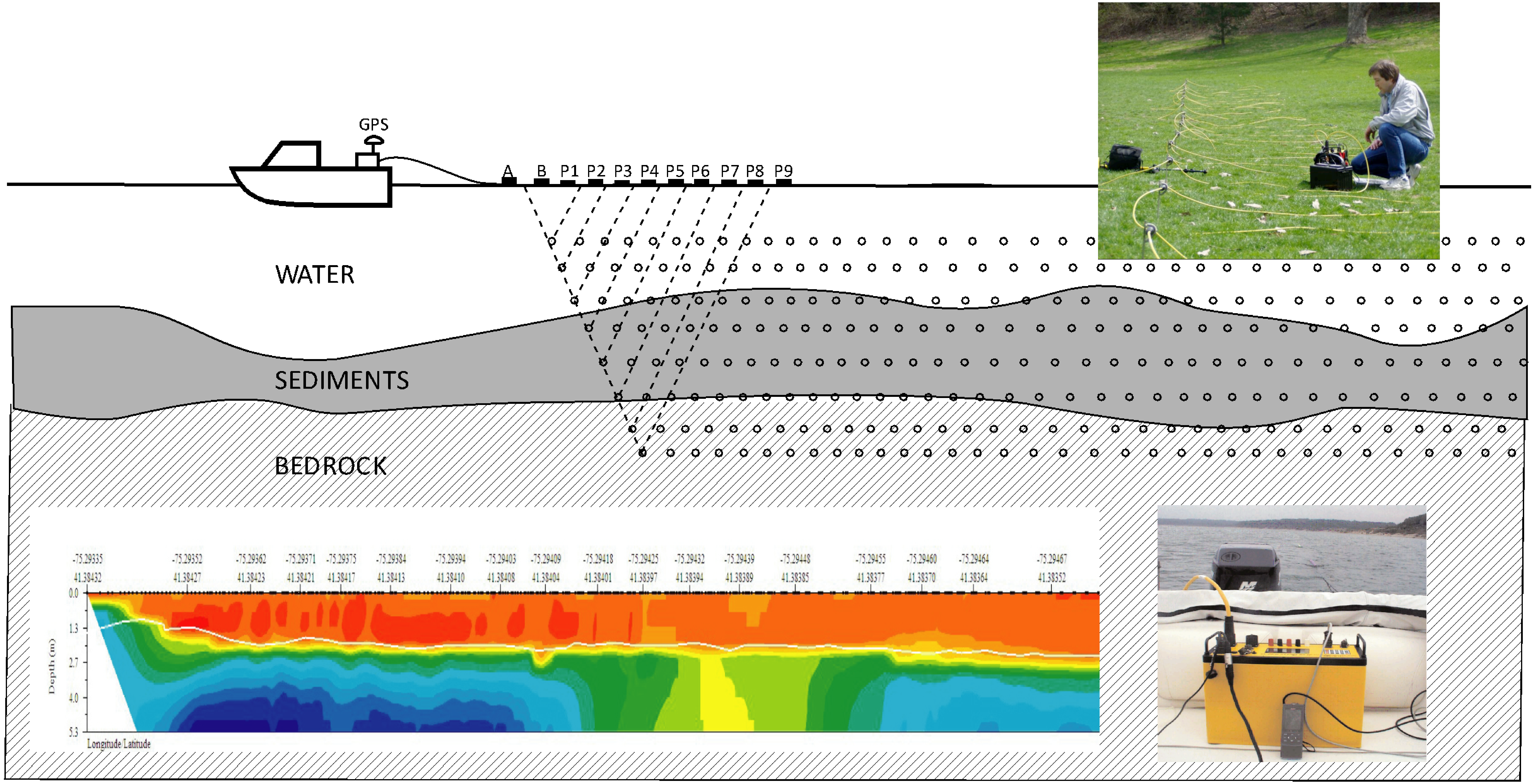


YES !

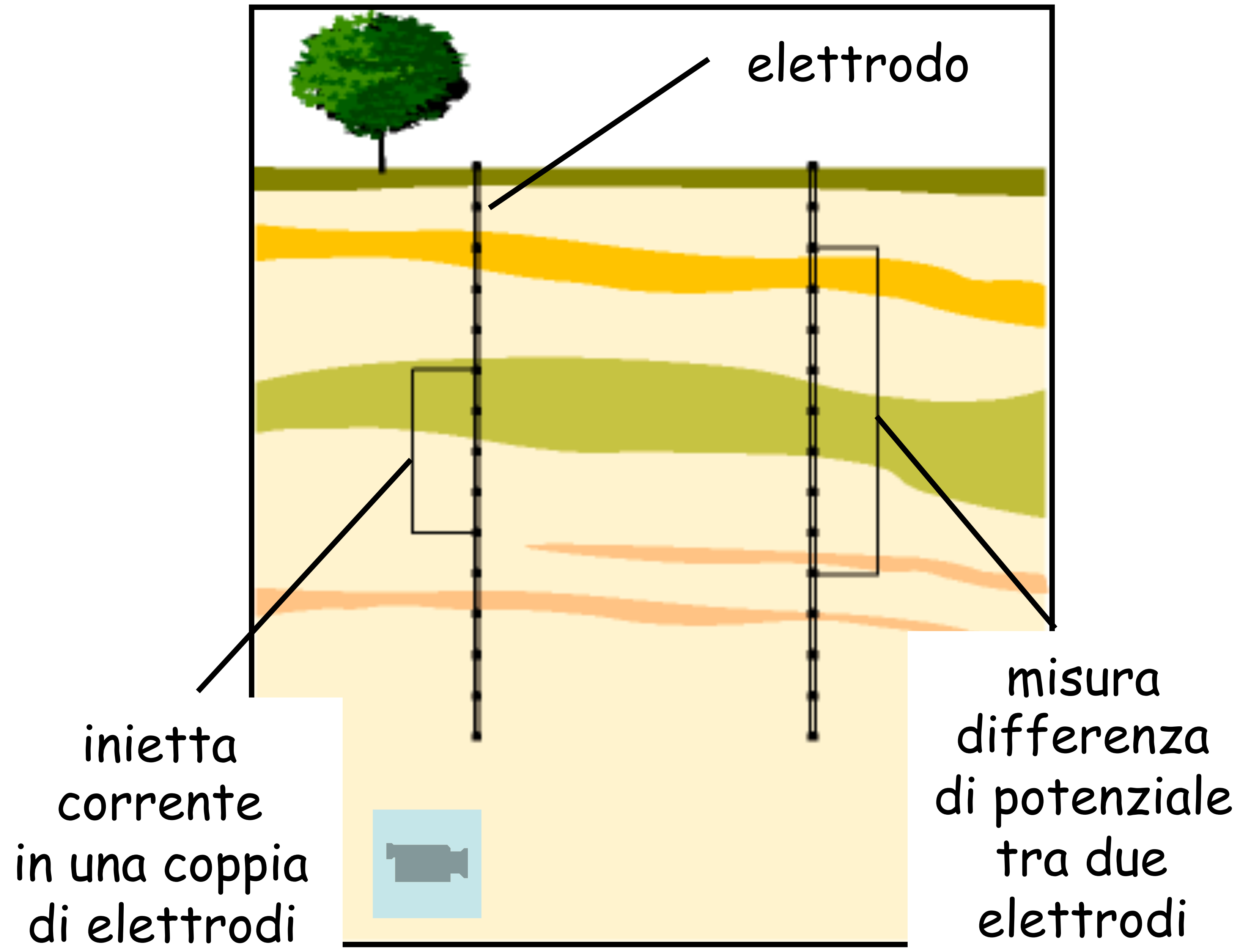
At the lower margin we in surface ERT we have the 'shadow zones'



Surface resistivity imaging based on continuous surveys have been developed for land and marine investigations



ELECTRICAL BOREHOLES TOMOGRAPHY

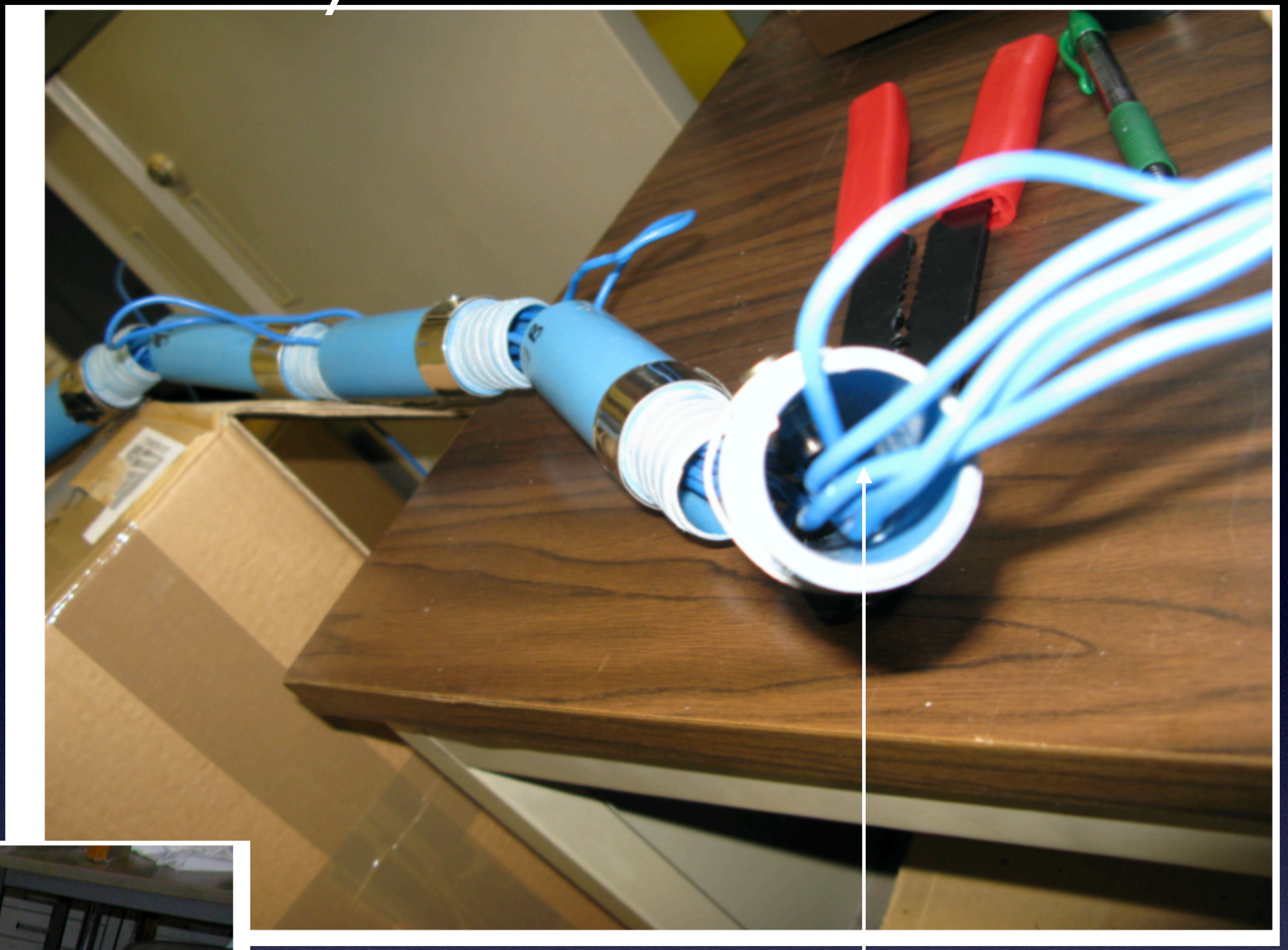


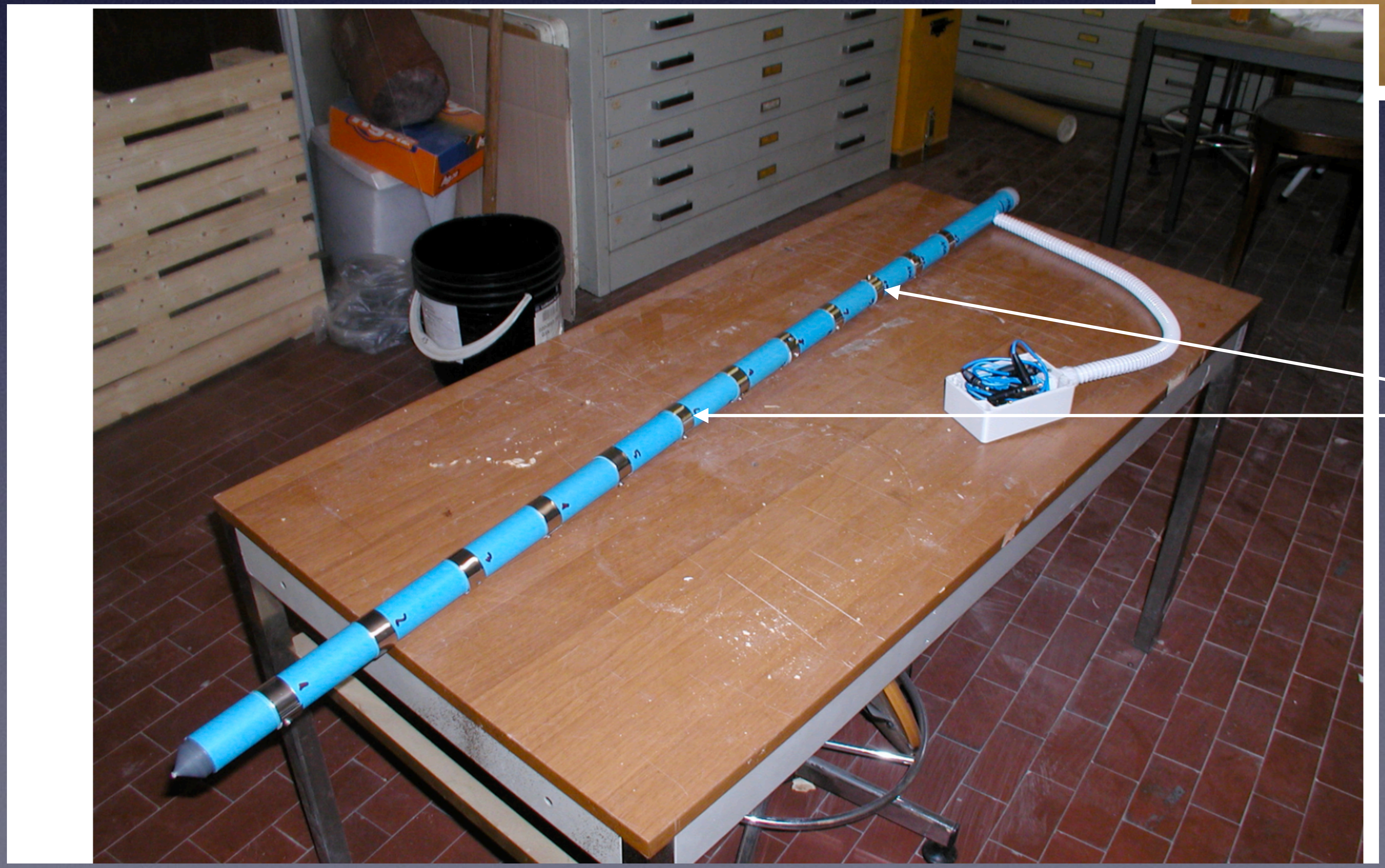
Overcome the problems of Surface geo-electric Going into the domains To observe

Greater resolution in depth!

Geo-electric survey

Borehole
ERT





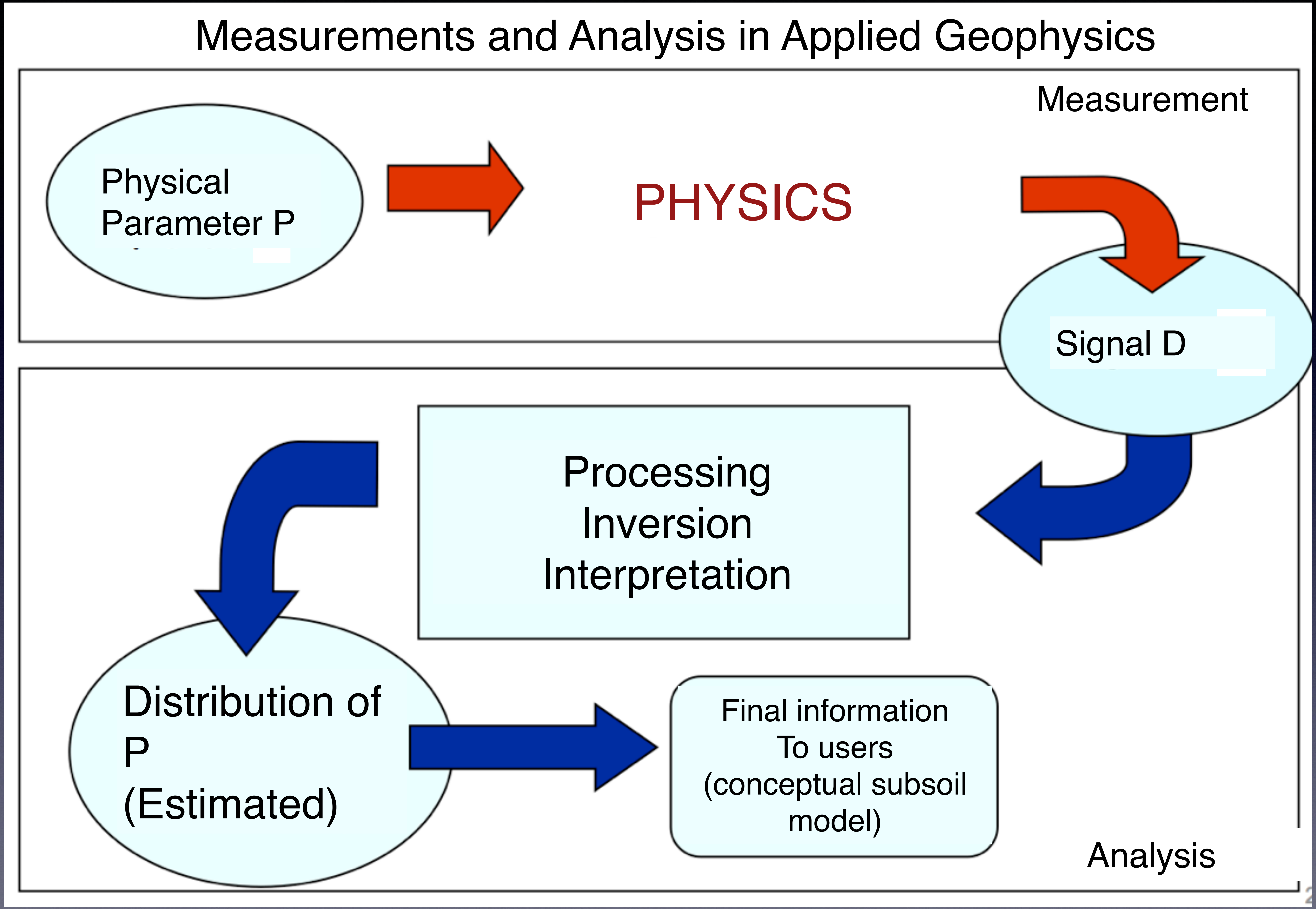
Cables

Electrodes

THE IMPORTANCE OF FORWARD MODELLING

Try to simulate what you should measure on the site, basing on a priori information

Unless:
- You do not have the budget (it takes time)
- You do not have a priori information


Measurements and Analysis in Applied Geophysics
Measurement
Physical Parameter P
PHYSICS
Signal D
Processing
Inversion
Interpretation
Distribution of P (Estimated)
Final information To users (conceptual subsoil model)
Analysis

Forward and Inverse MODELS

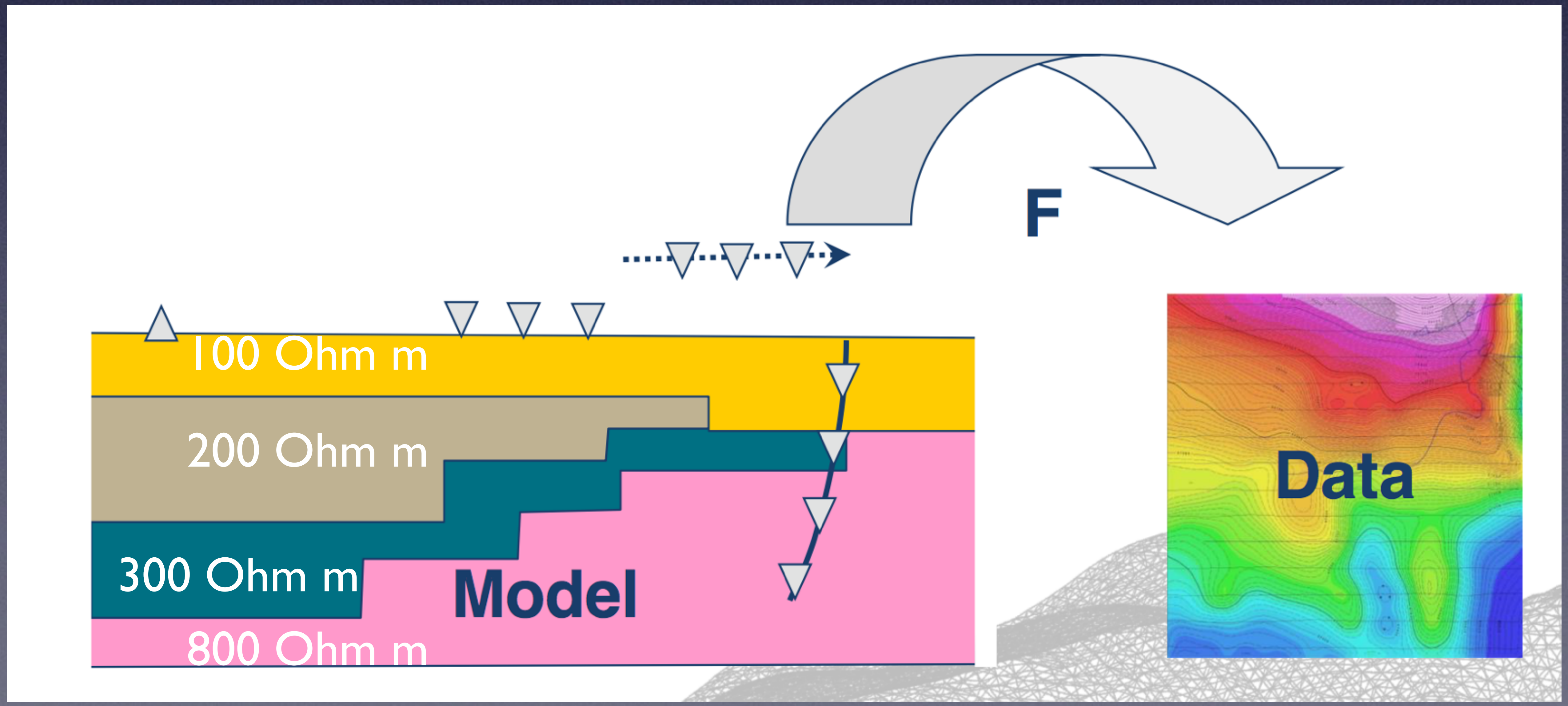
FORWARD MODEL

From a model M, I get a data distribution d

$$d = F(M)$$

output (d) — *input* (M)

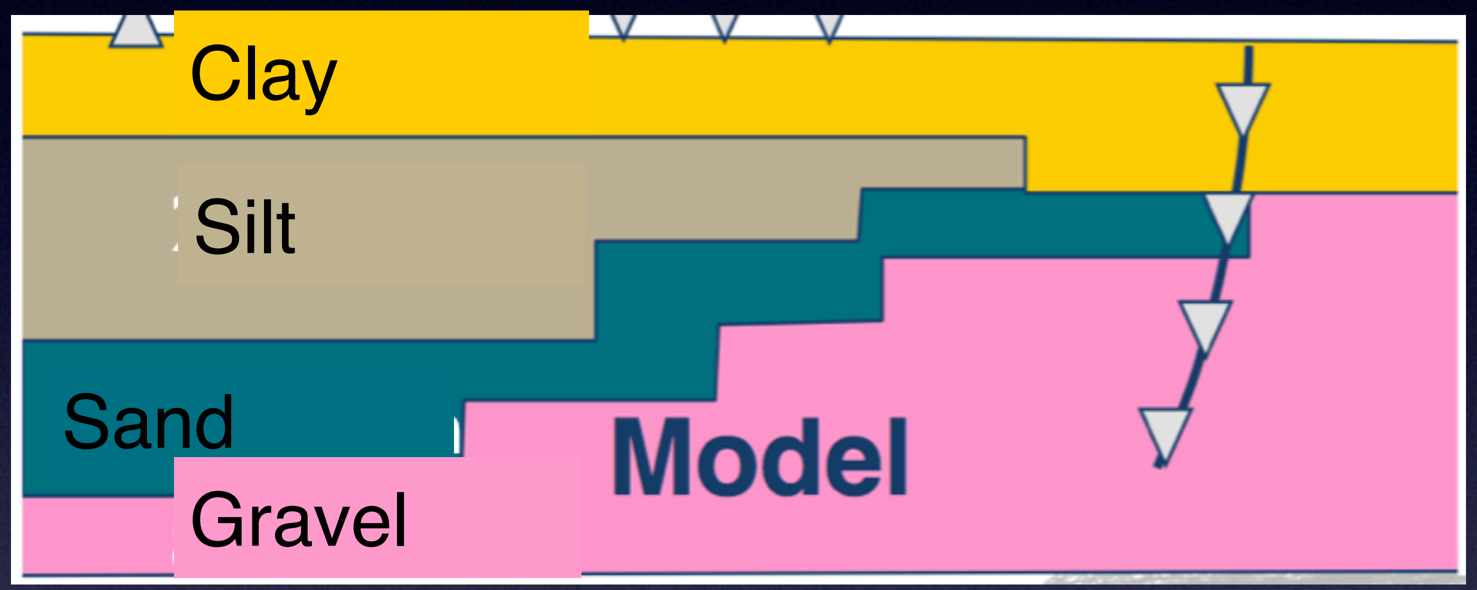
Where F is an operator which rules the relations between models and data



FORWARD MODEL

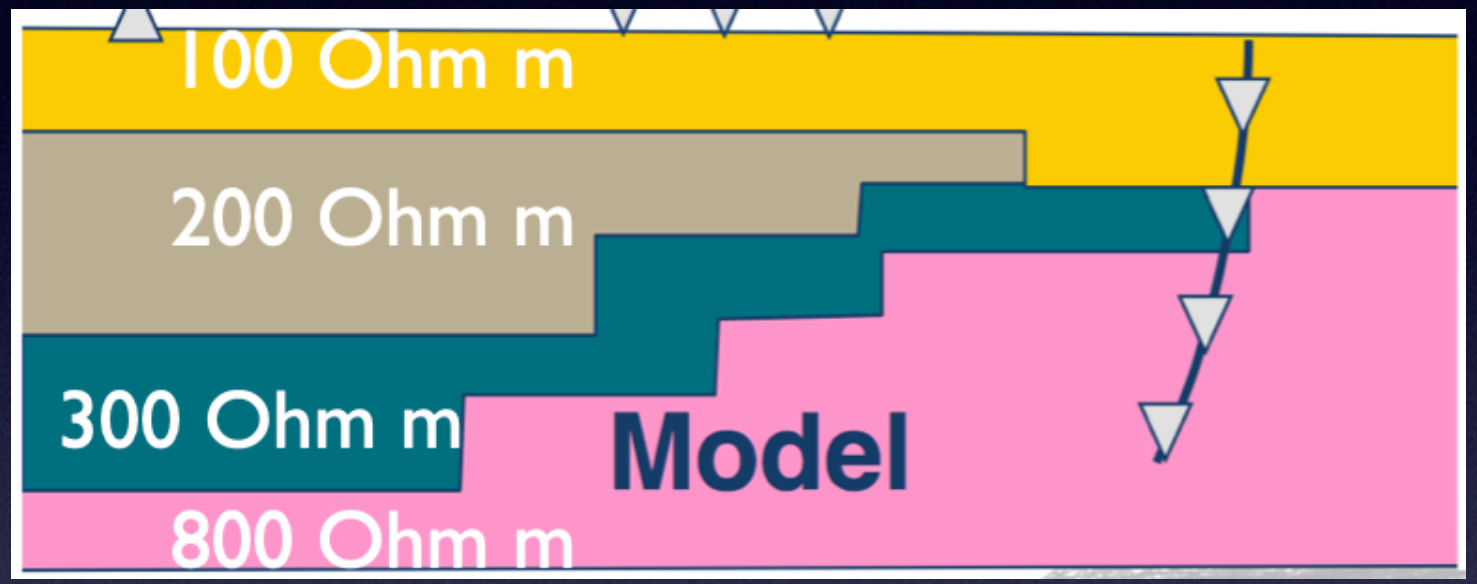
Example

1)



Model
of the subsoil

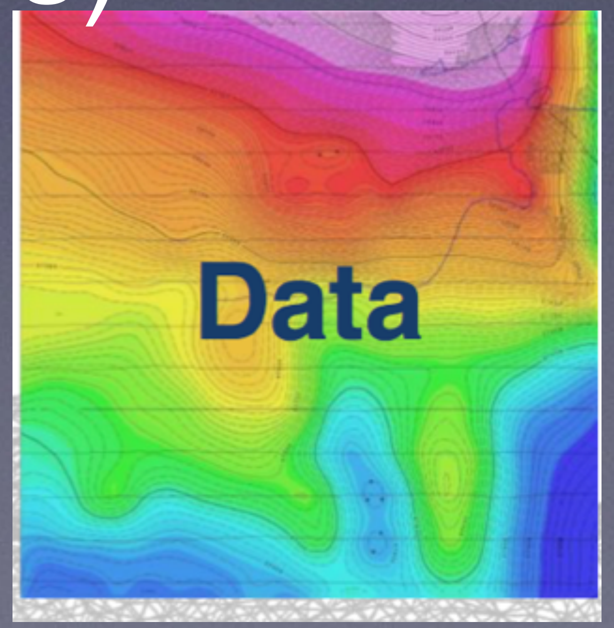
2)



Synthetical Electrical model
of the subsoil

Physics laws who rules
electrical distribution

3)



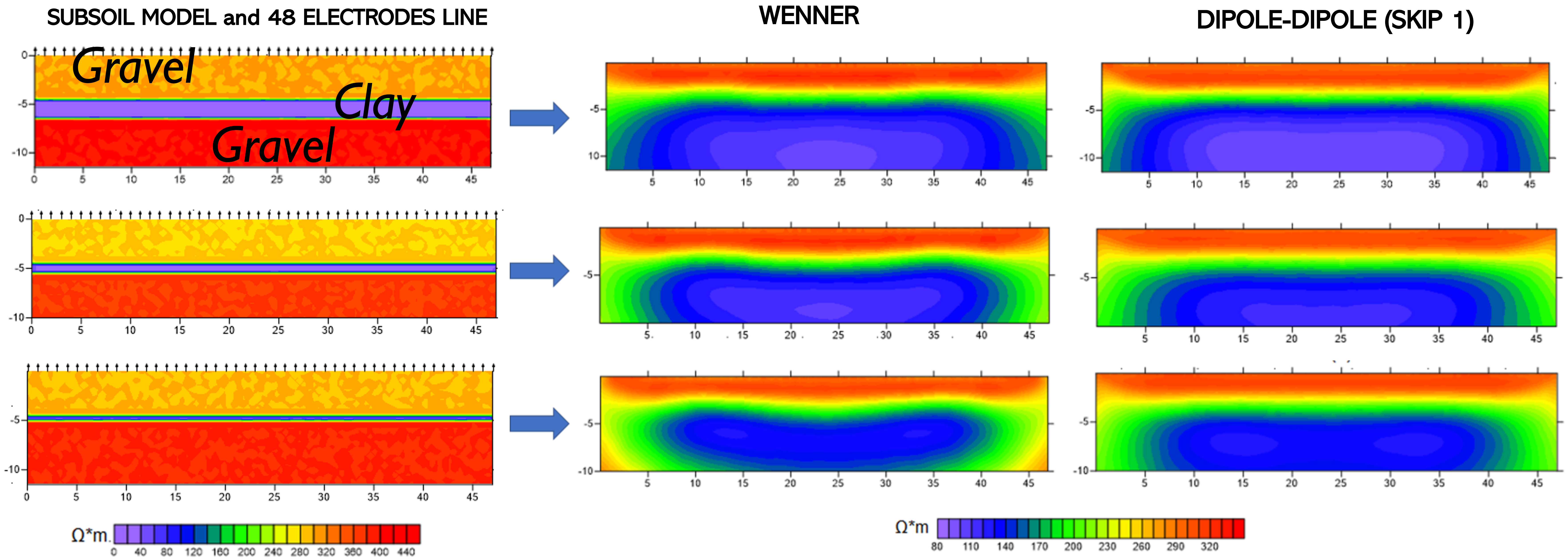
Knowing the physics,
I can simulate which DATA
I would collect in that subsoil

Geo-electric survey

SENSITIVITY and Resolution

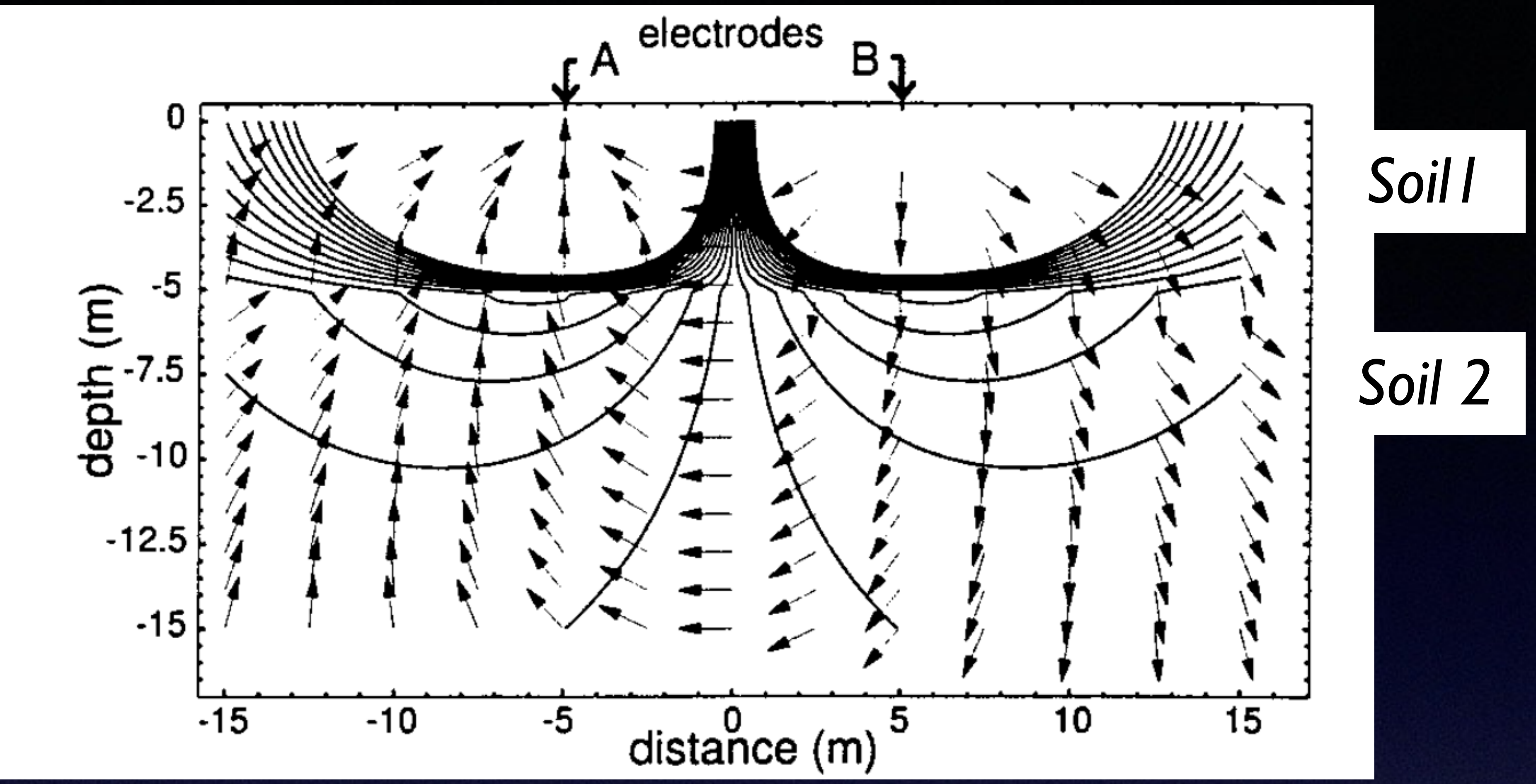
FORWARD MODEL for Clay level

Surface ERT



<u>The resistivity sections of the three subsoil model are very similar to each other and it is impossible to define the real thickness of the conductive layer using them</u>

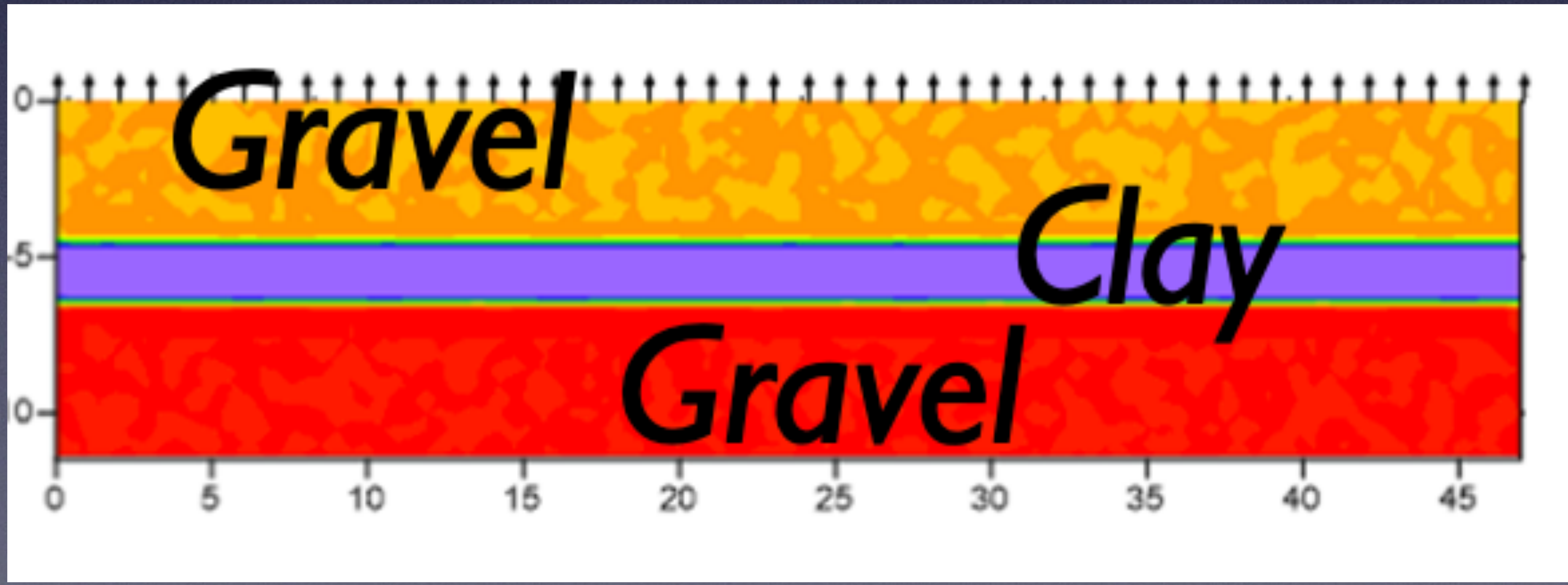
Geo-electric survey



Gravel = 300 Ohm m
Resistive

Clay = 50 Ohm m
Conductive

Currents flow in the conductive Layer!
Few currents go below…



Geo-electric survey

SENSITIVITY and Resolution

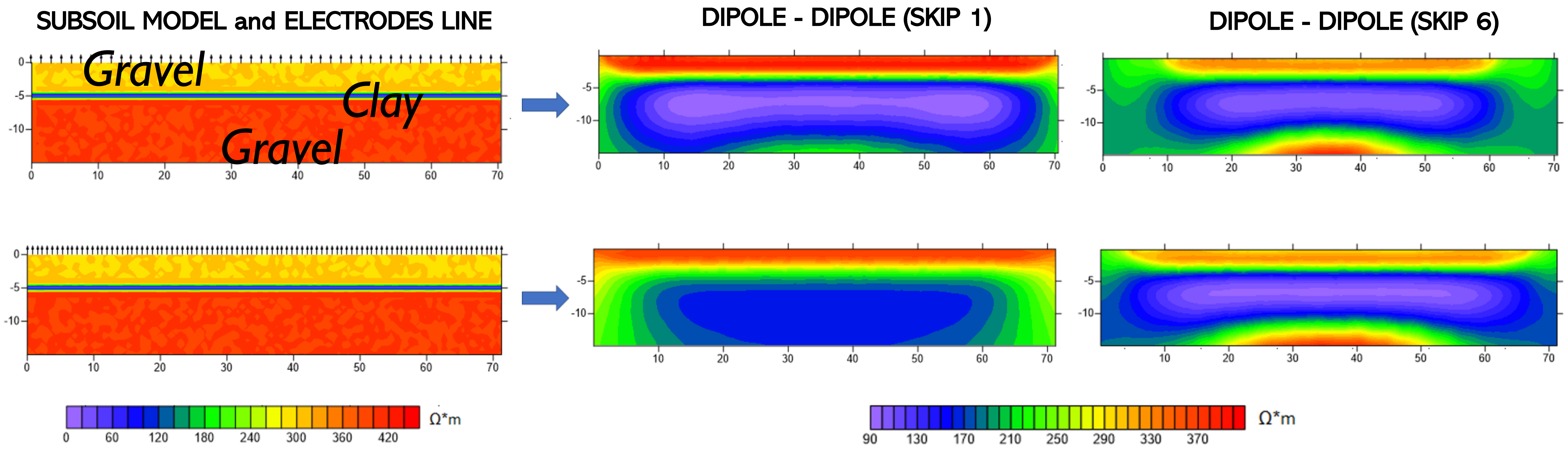
FORWARD MODEL for Clay level

UNIVERSITÀ DEGLI STUDI DI PADOVA

Surface ERT

DIPARTIMENTO DI GEOSCIENZE

Even by modifying the spacing of the electrodes and the length of the line we are not able to correctly define the real thickness of the conductive layer



<u>The ERT surface technique is not accurate if we want to define the actual thickness and depth of the layers !!!</u>

Pavoni M

SENSITIVITY and Resolution
FORWARD MODEL for Clay level

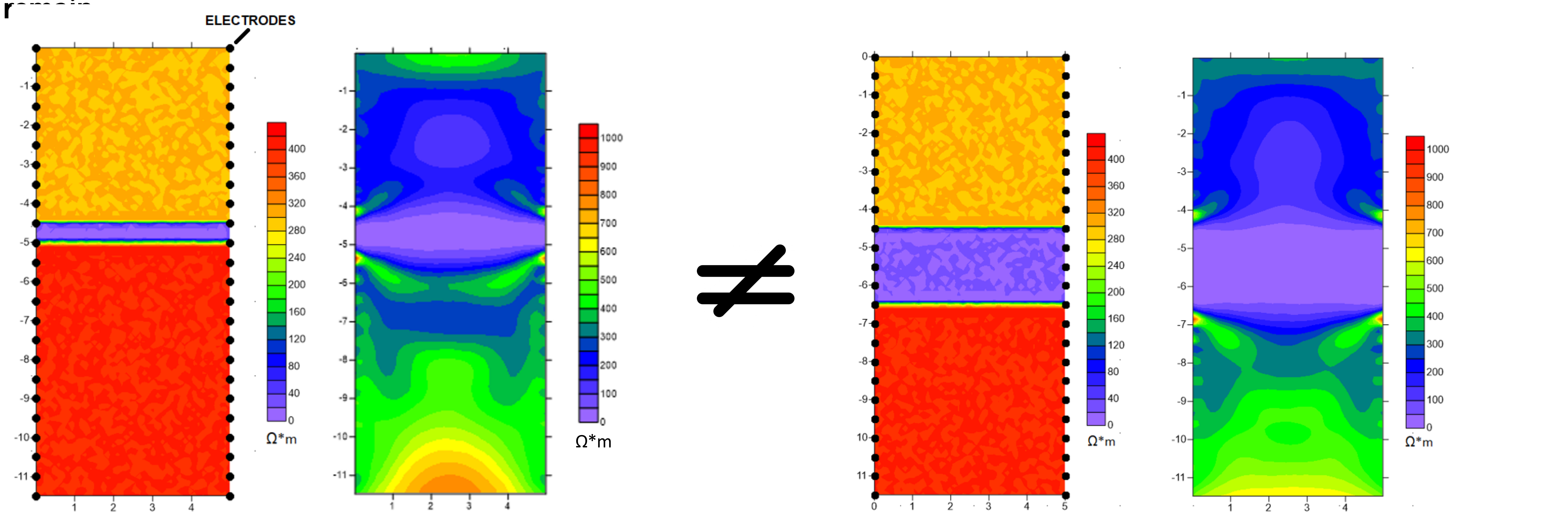
UNIVERSITÀ DEGLI STUDI DI PADOVA

Borehole ERT

DIPARTIMENTO DI GEOSCIENZE

PROBLEM: with the ERT surface surveys we can't define the real thickness and depth of the layers in the subsoil

SOLUTION: we can use the ERT CROSS BOREHOLE technique, even if some inversion artifacts still remain



<u>We are able to define the correct thickness of the layers and their depths !!!</u>

Pavoni M

Geo-electric survey

SENSITIVITY

Real data for clay level in gravel deposit

UNIVERSITÀ DEGLI STUDI DI PADOVA

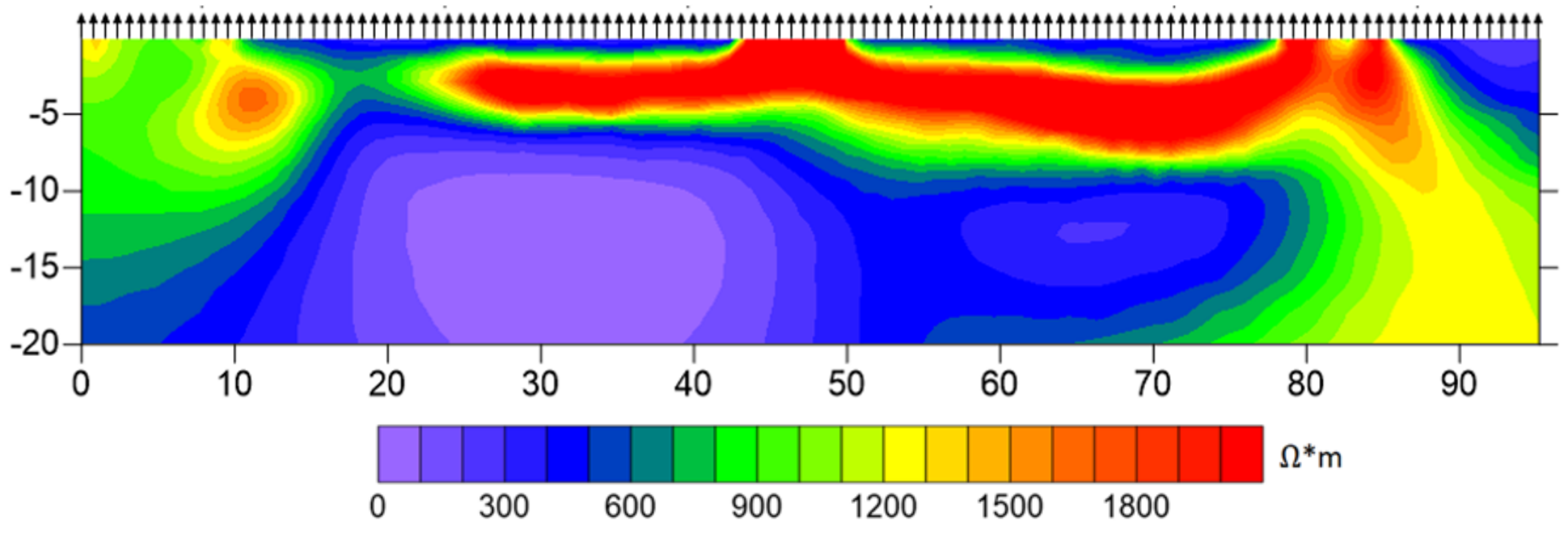
DIPARTIMENTO DI GEOSCIENZE

Surface ERT

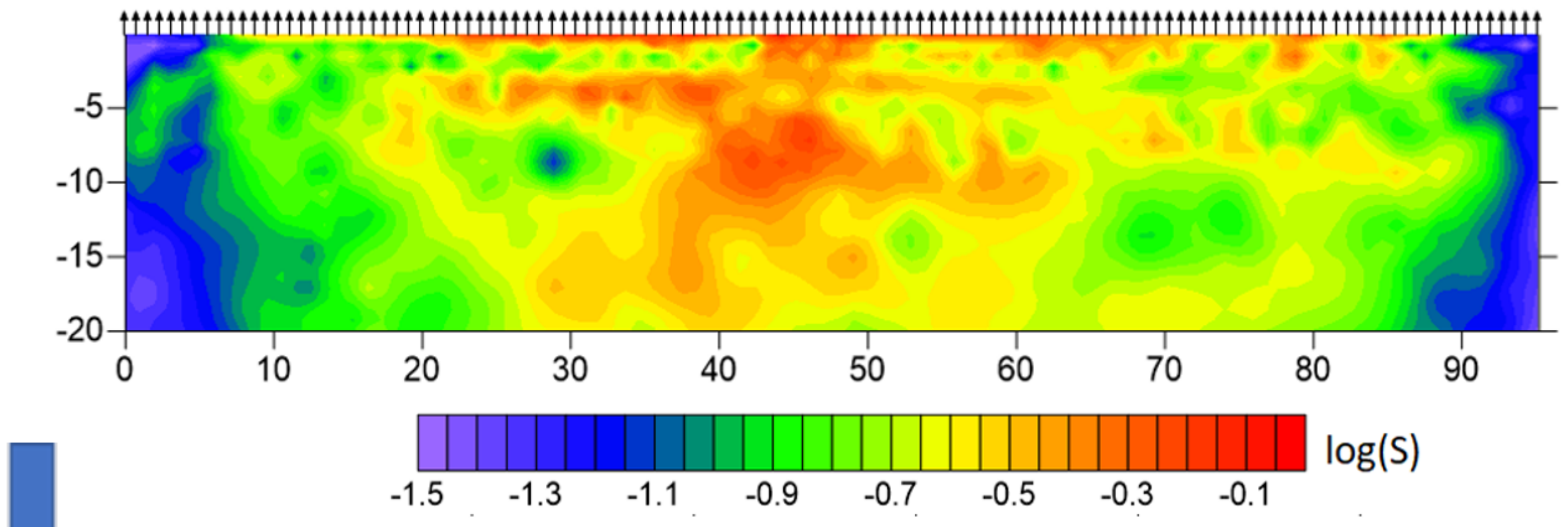
NB REAL DATA !!!

First surface line "S1" with 120 electrodes spaced 0.80 m and measurements performed with a Dipole-Dipole configuration skip 8

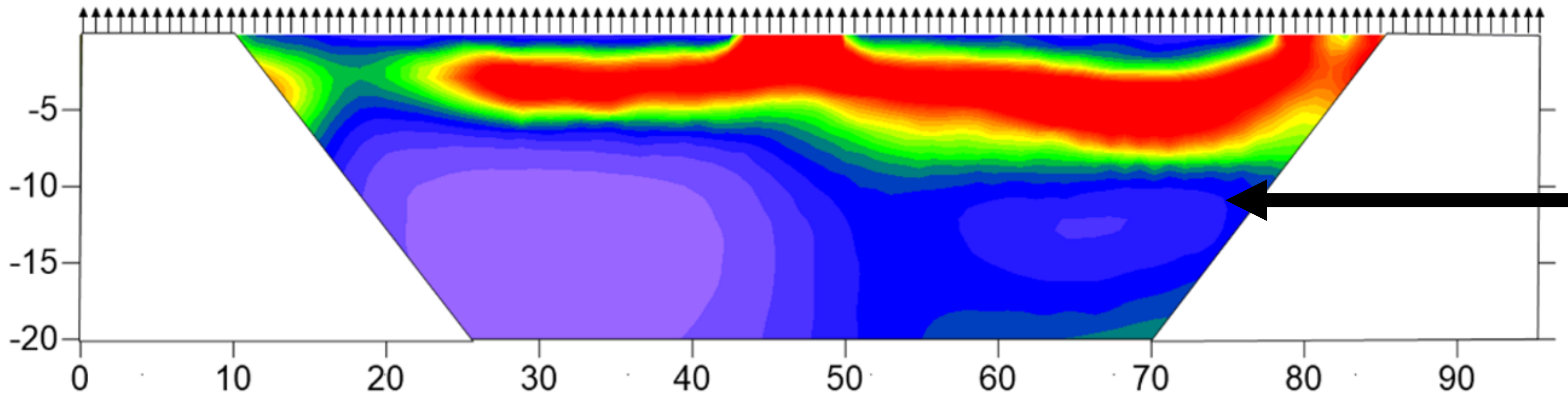
RESISTIVITY SECTION



SENSITIVITY SECTION



FINAL RESISTIVITY SECTION



<u>The conductive layer of clay is continuous but we cannot correctly define its thickness</u>

Pavoni M

Geophysical methods for the subsoil prospecting

Method	Structure	Dynamic
Seismic	+ +	
Electro-Magnetic	+	++
DC resistivity methods	++	+++
Ground Penetration Radar	++	+
Distributed Temp. Sensing		++
Magnetics	+	
Gravimetry	+	+
Induced Polarization	+	
Self Potential		+
Borehole logs	+ +	+

Physical Properties (P)

- Seismic Elastic moduli and density
- Gravimetry : Density
- Magnetic meth. Magnetic susceptibility
- ERT meth. Electrical resistivity
- Electro-magnetic meth. Electrical conductivity
- Induced Polarization Electrical complex conductivity (Chargeability)
- Spontaneous Potentials Electrical conductivity
- Ground penetrating Radar Dielectric constant

Induced Polarization methods - IP

- Physical principles

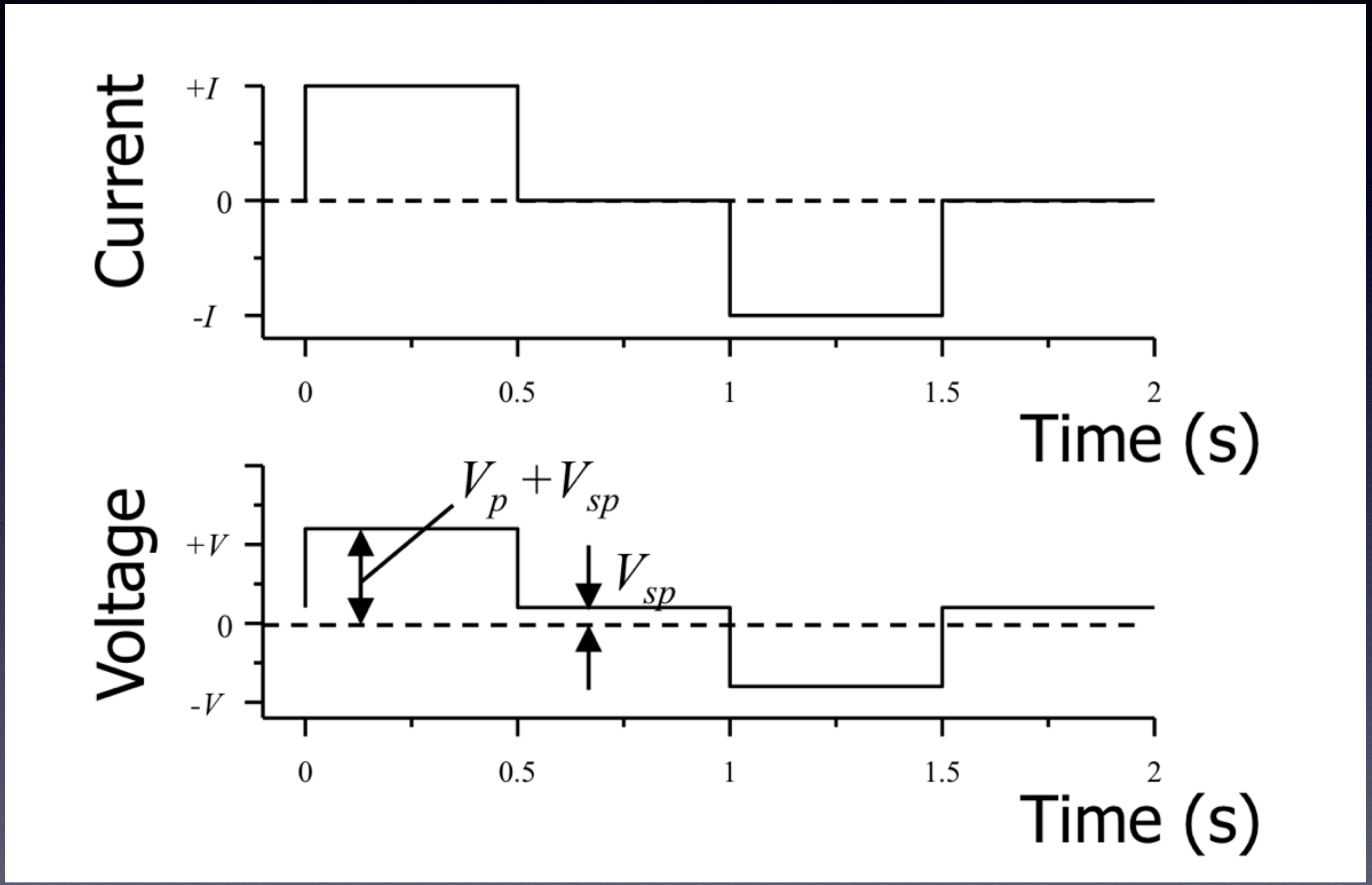
~~- acquisition~~ (like ERT)

- ~~processing~~ (like ERT)

- examples

Geo-electric survey

Induced Polarization methods - IP



When we inject current

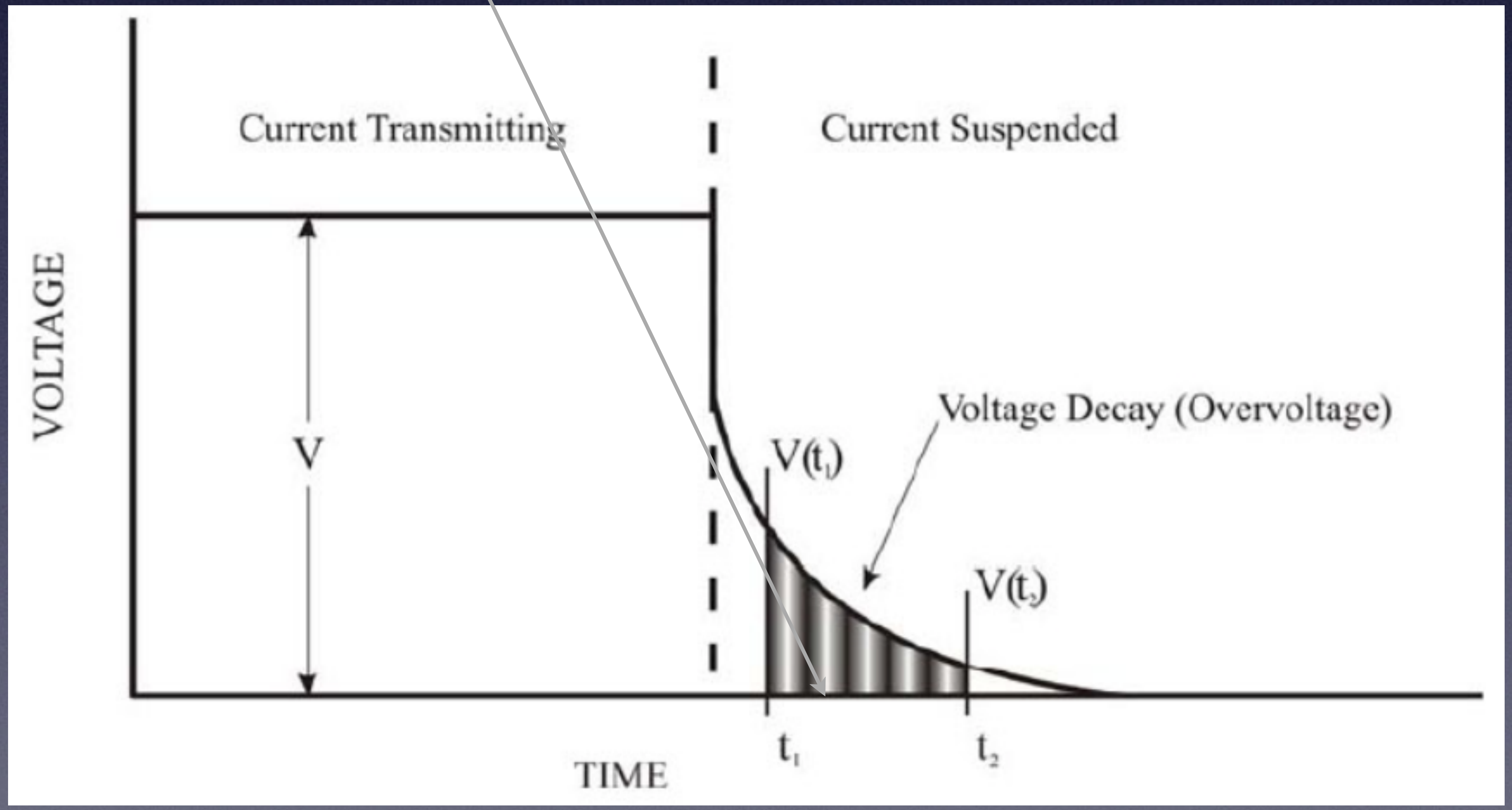
We polarize the media with residual voltage Vsp

If the subsoil is polarised we can study the soil chargeability (ability to keep the charges)

SOIL CHARGABILITY

Induced Polarization methods - IP

After current is switched off (or turned on), the voltage between potential electrodes takes 1s - 1 min to decay (or build up)
The soil acts somewhat like a capacitor.
Overvoltage decay times and rise times are measured and are diagnostic of the nature of the subsurface.



'Overvoltage effect'

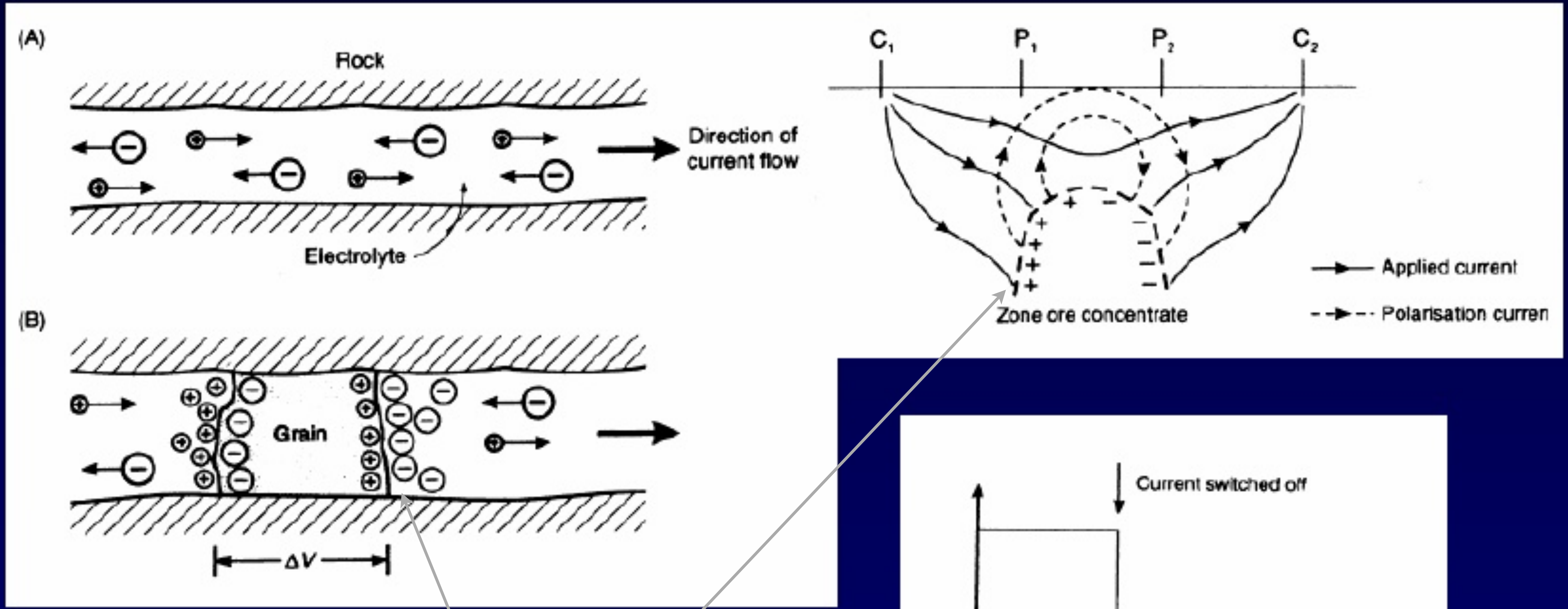
Environmental Applications:
Metallic deposits with low EM anomalies and high resistivity;
Disseminated Cu, Pb- Zn ores, Au;
Pyrite, chalcopyrite, magnetite, clay, graphite..

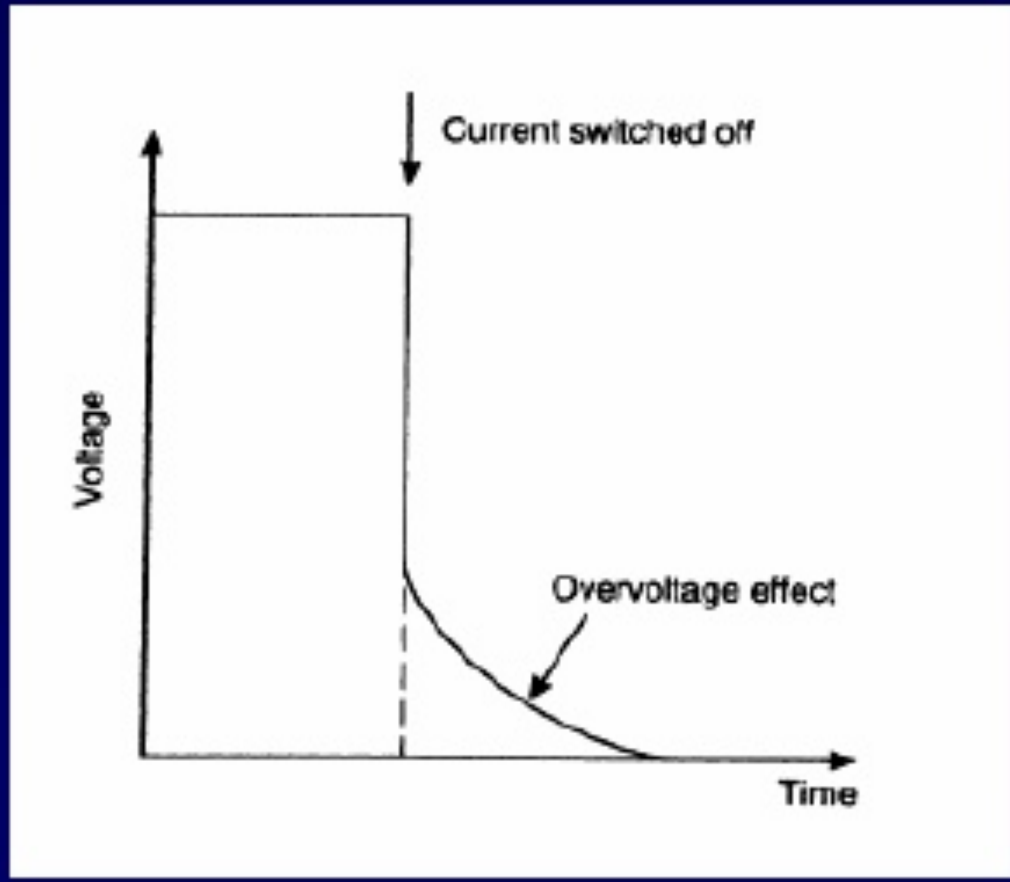
Geo-electric survey

INDUCED POLARIZATION IP

1Grain Polarization

Induced Polarization (IP)





grain or electrode polarization

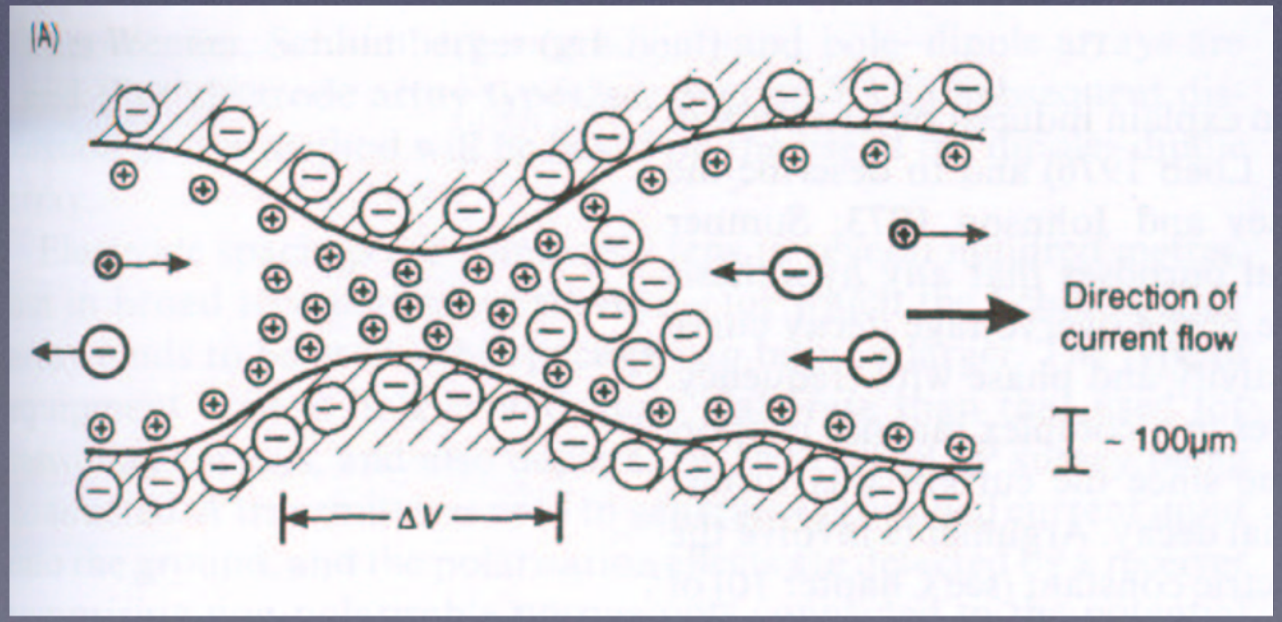
Charges can physically accumulate on the surface of grain

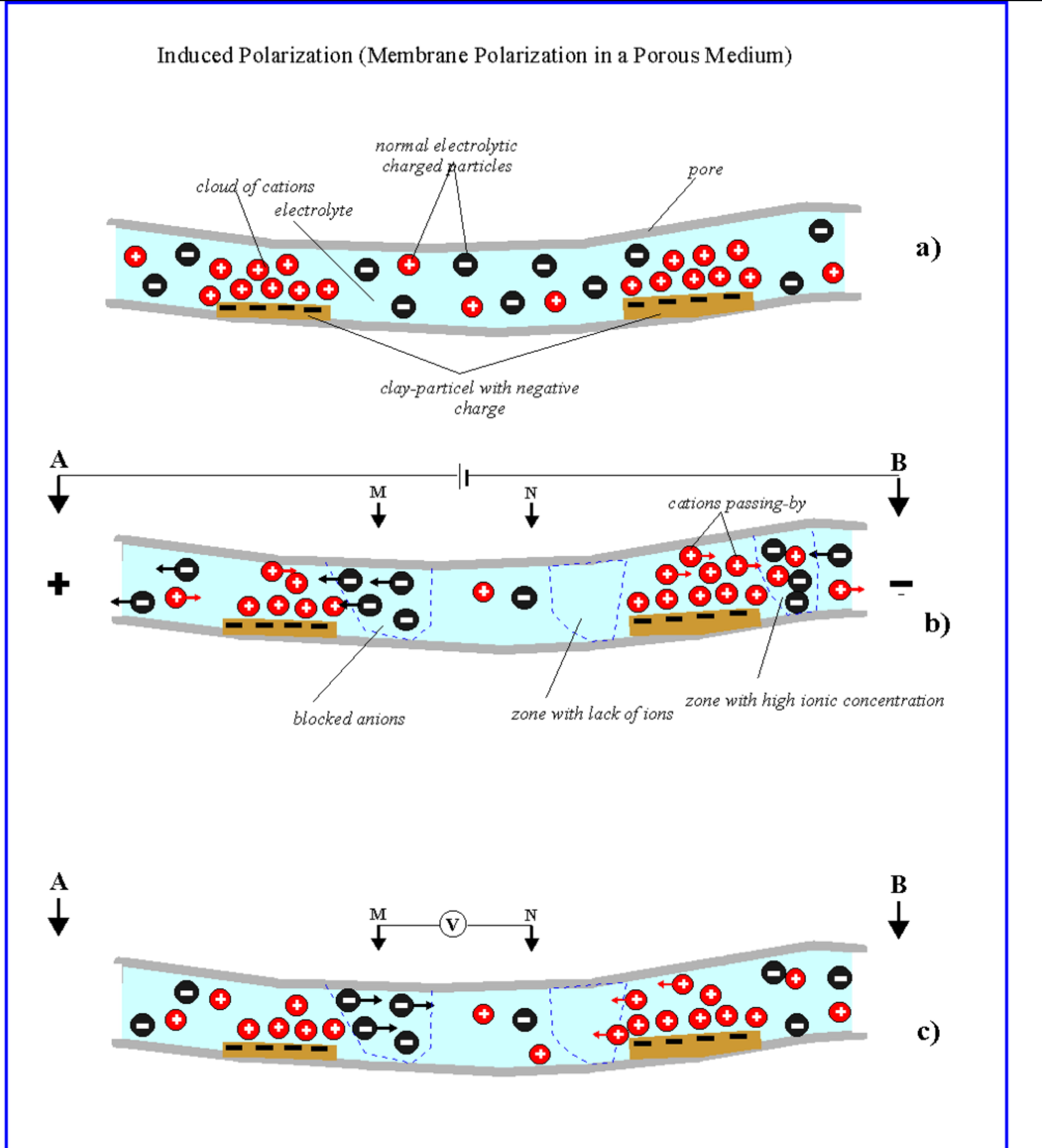
INDUCED POLARIZATION IP

2 Membrane Polarization

Charges can accumulate due
to the presence of clay minerals with negative charge (-) which attract cations (+)

or due to presence of physical restriction of pores





Geo-electric survey

INDUCED POLARIZATION IP

Time Domain

Varying current in Time

To measure the
'Overvoltage effect'
And estimate CHARGEABILITY
of soils

Varying the frequency of Current injection

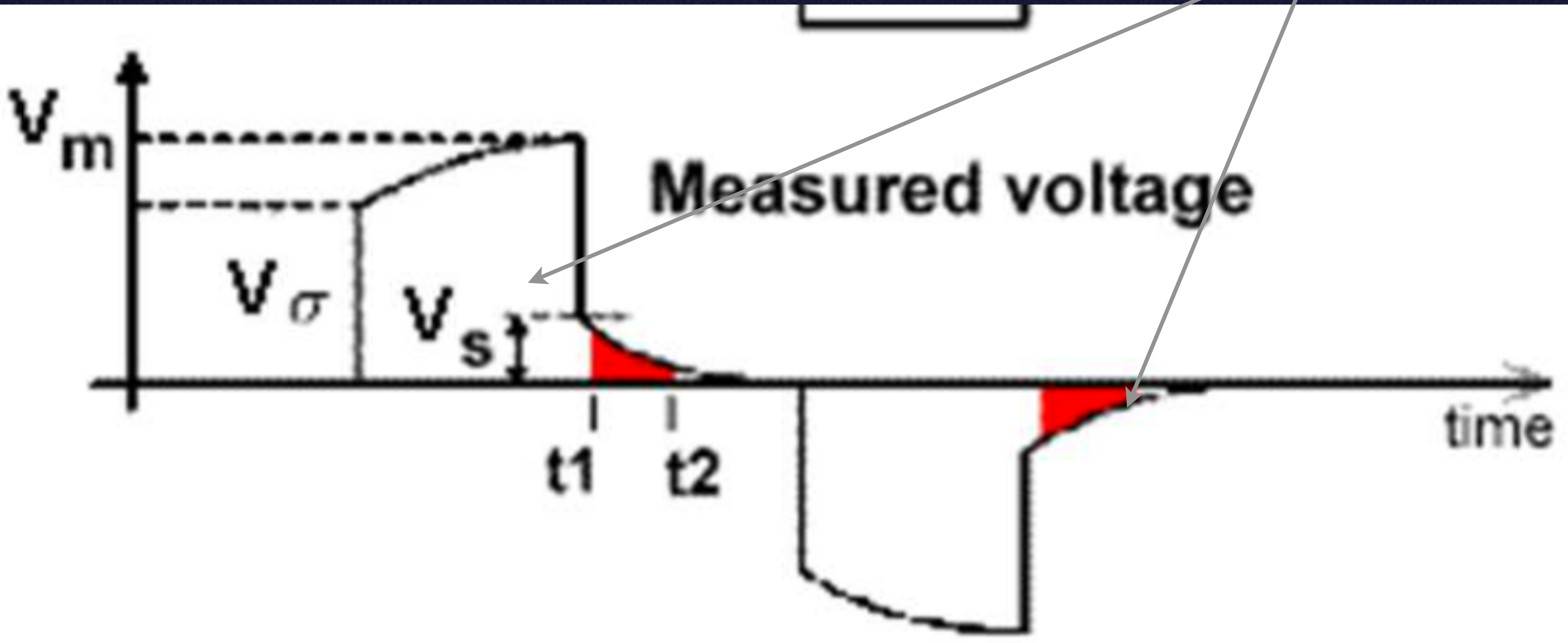
Frequency Domain
(complex resistivity)

Geo-electric survey

INDUCED POLARIZATION IP

Ma = Chargeability $_{\textit{Apparent}}$ (ms) *Milliseconds*

Overvoltage effect



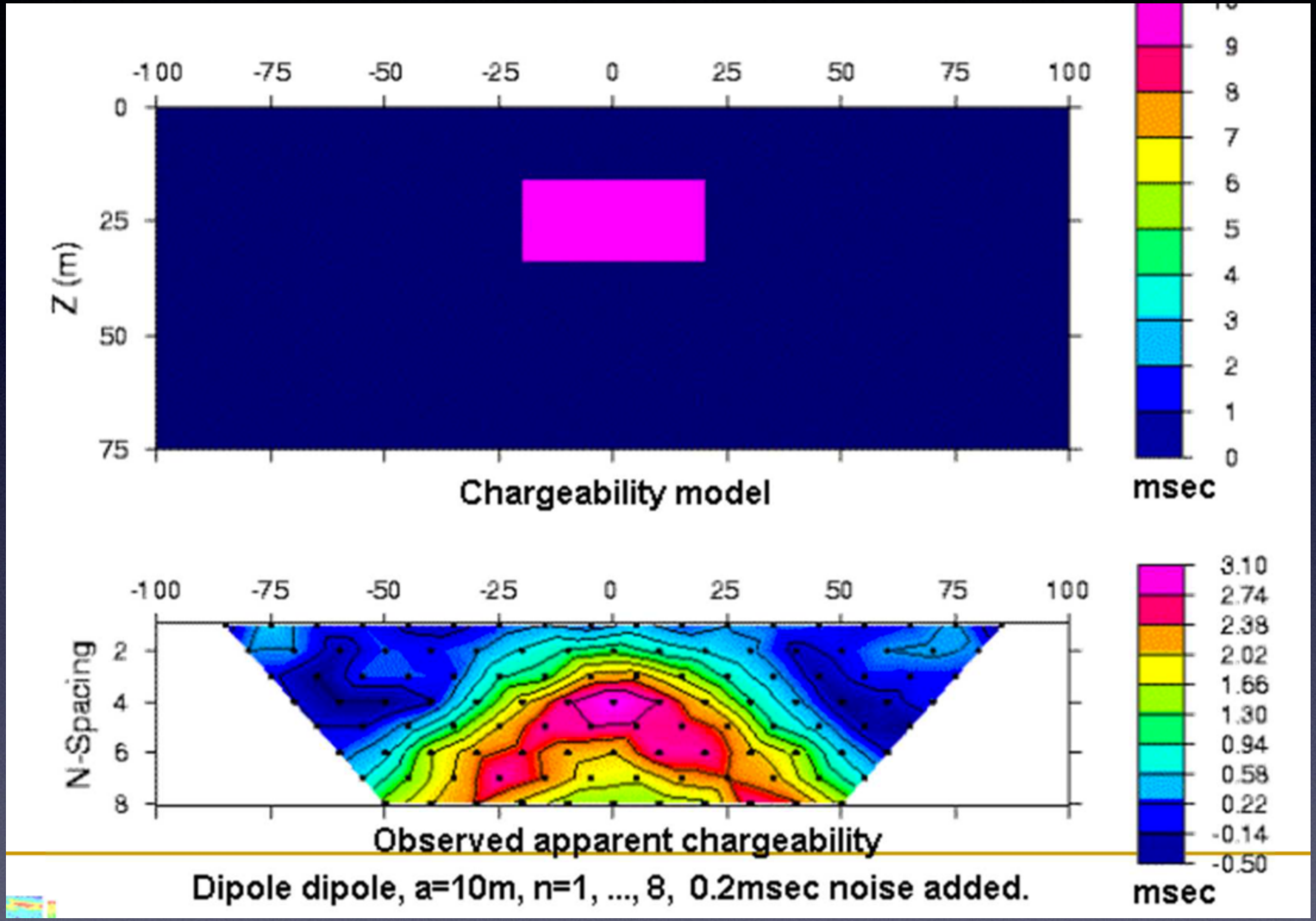
$$Ma = \frac{1}{V_m}\int_{t_1}^{t_2} V_s(t)dt \qquad \text{(msec)}$$

Geo-electric survey

INDUCED POLARIZATION IP

Model

Inversion

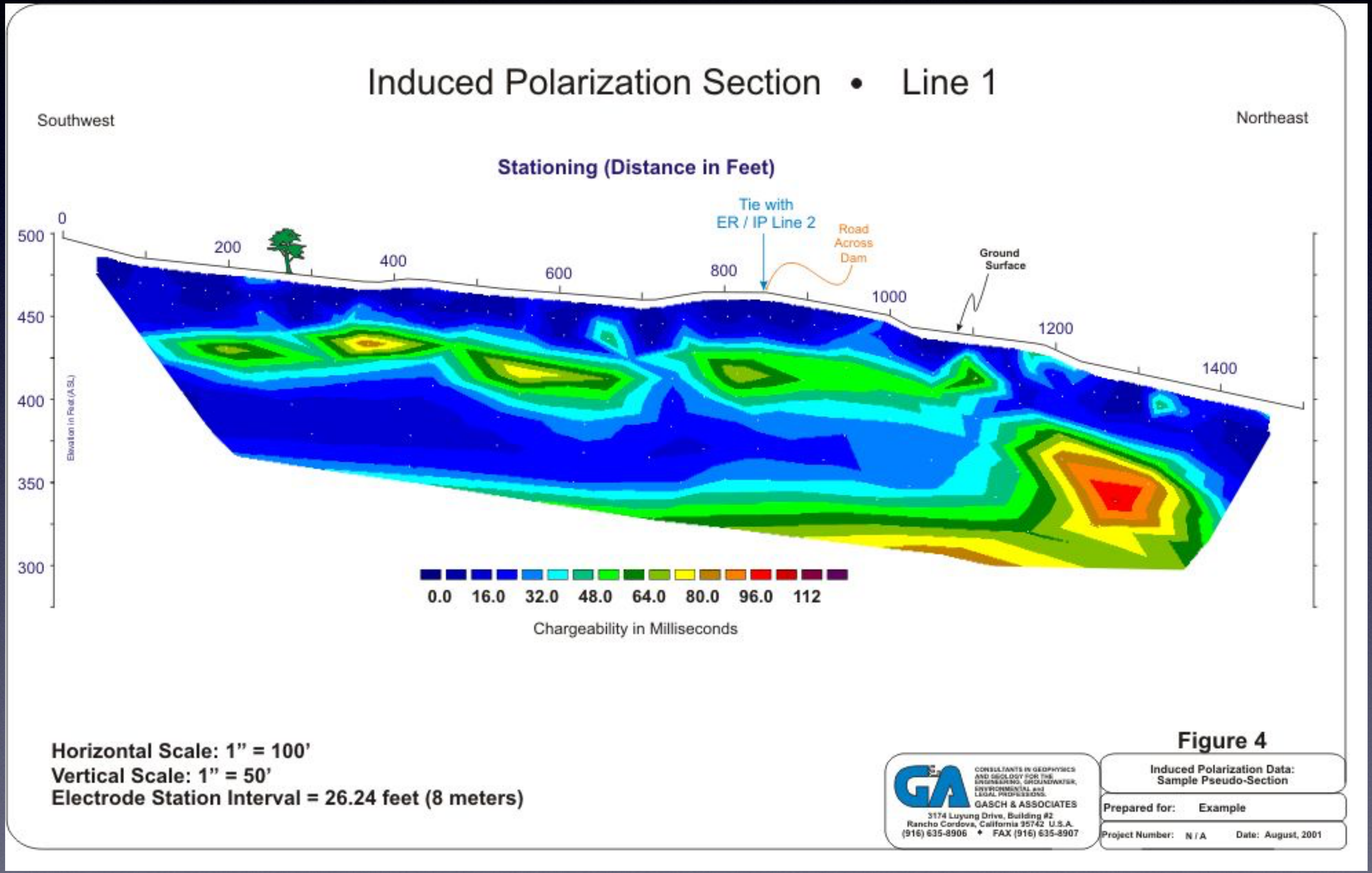


Same as ERT we need an inversion process to get the REAL chargeability

Geo-electric survey

INDUCED POLARIZATION IP

Changeability section M

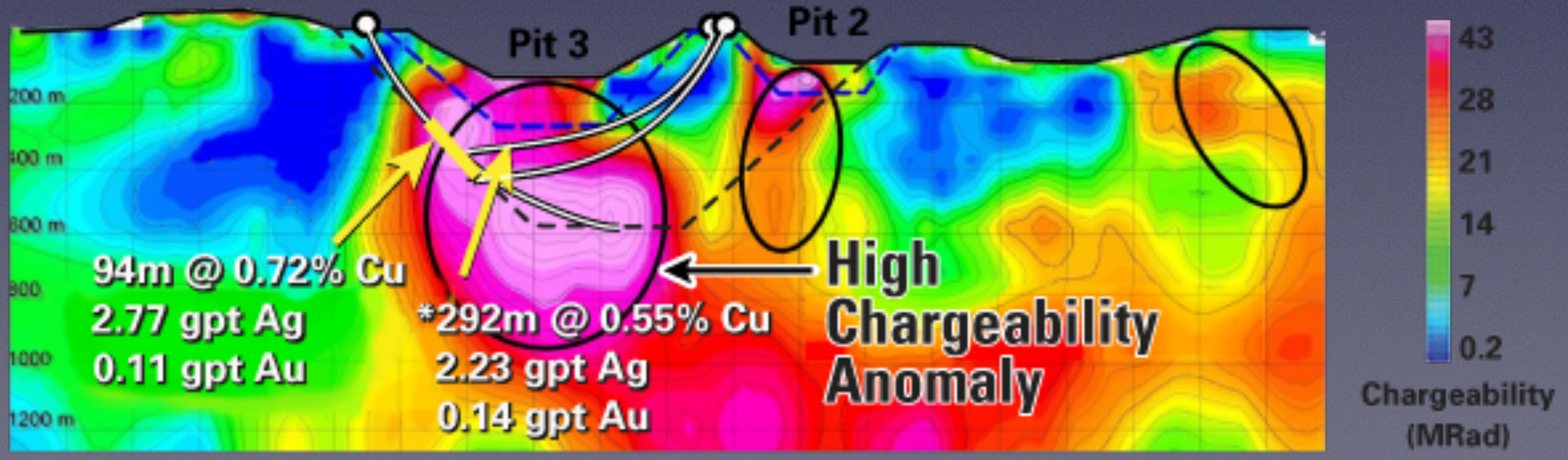


Geo-electric survey

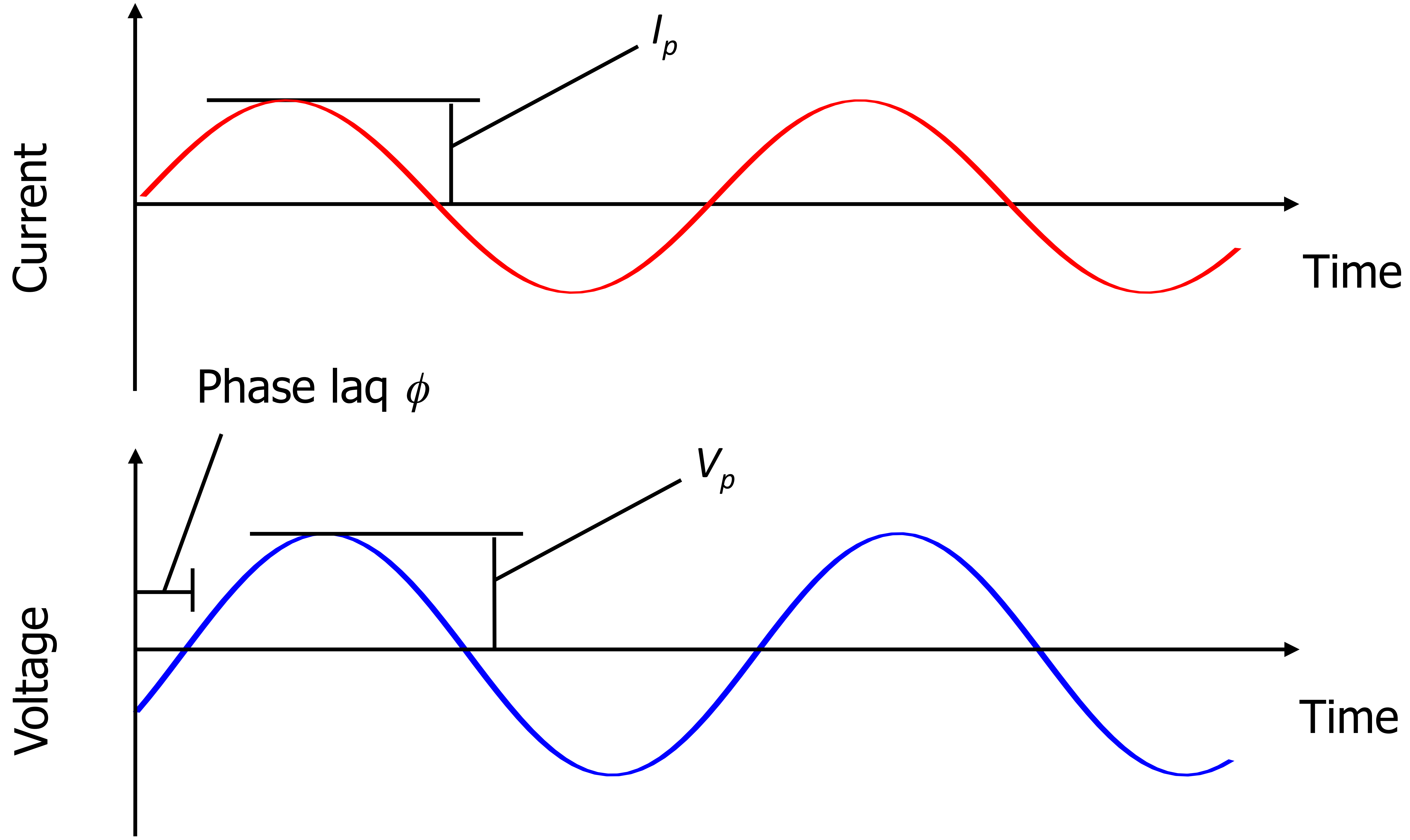
INDUCED POLARIZATION IP

Hard to interpretate

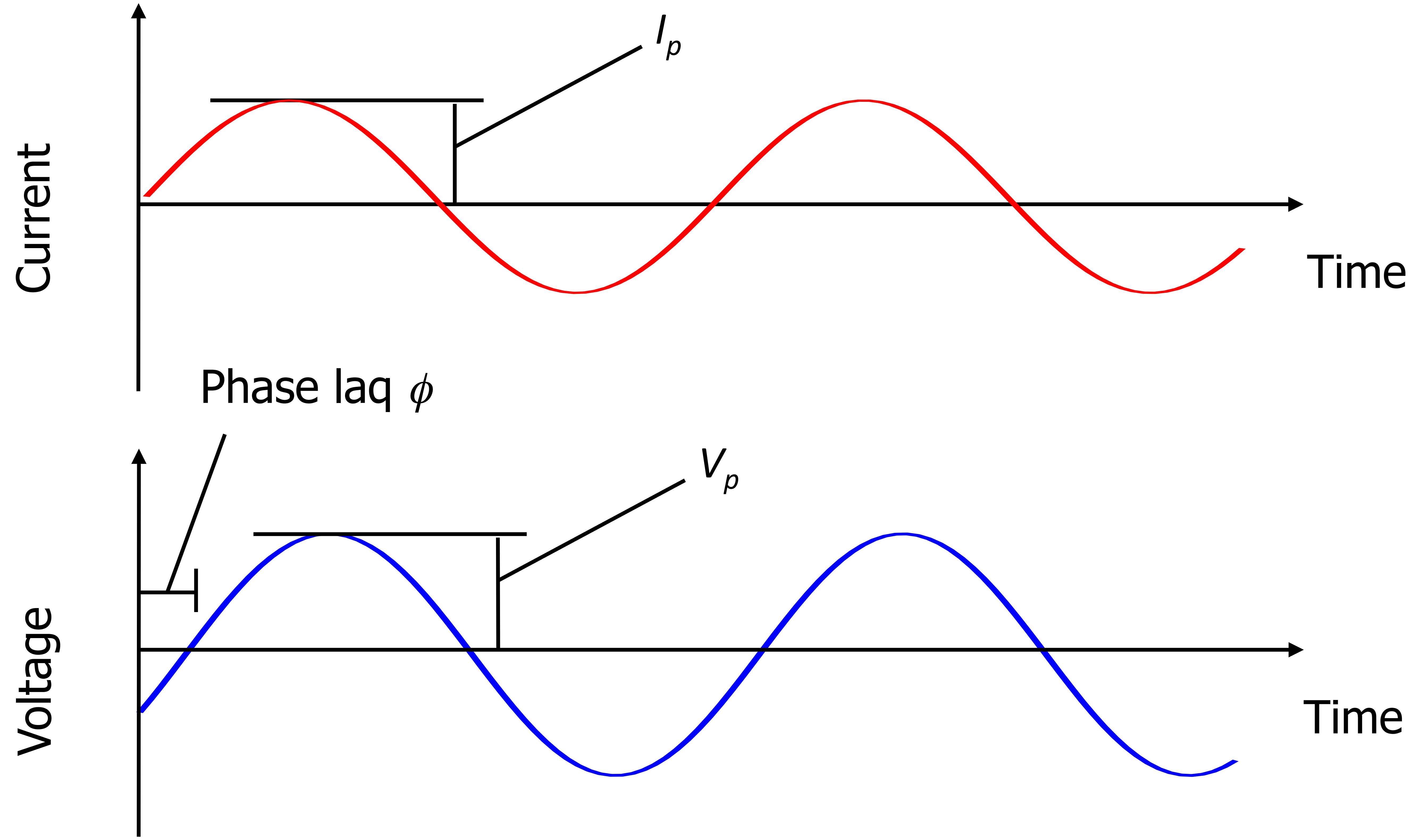
Pollutants (NAPL)
Mineral deposits (Cu, Pb)
.....



IP can also be measured in the *frequency domain* by looking at the change in amplitude and phase lag of an injected and measured signal.



The measurement is thus a complex resistivity with magnitude $|\rho| = V_p/I_p$ and phase ϕ



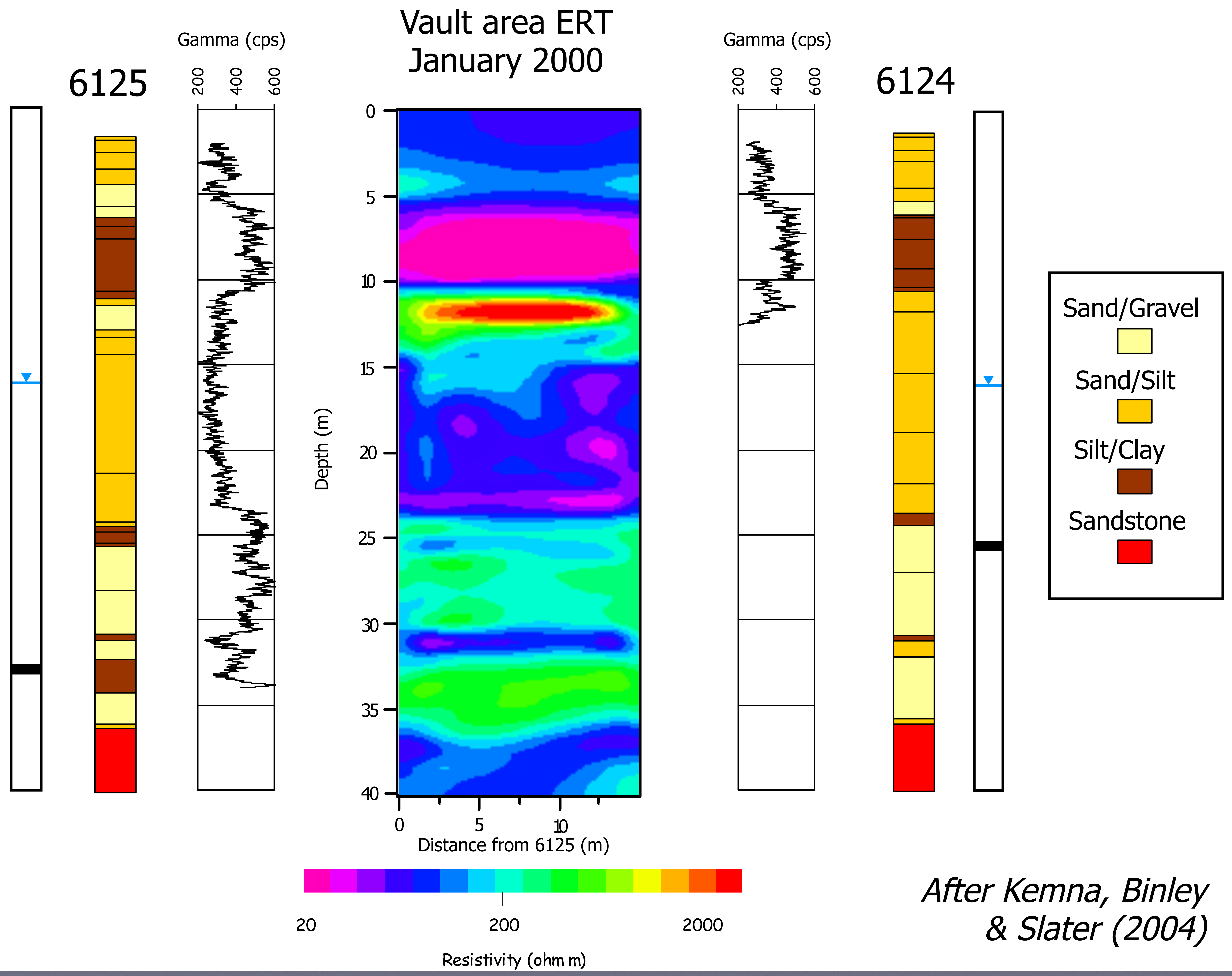
The advantage of the complex resistivity measurement is that it is an intrinsic measure.

Frequency domain instruments are typically more expensive than time domain IP instruments. Few multi-electrode systems are available.

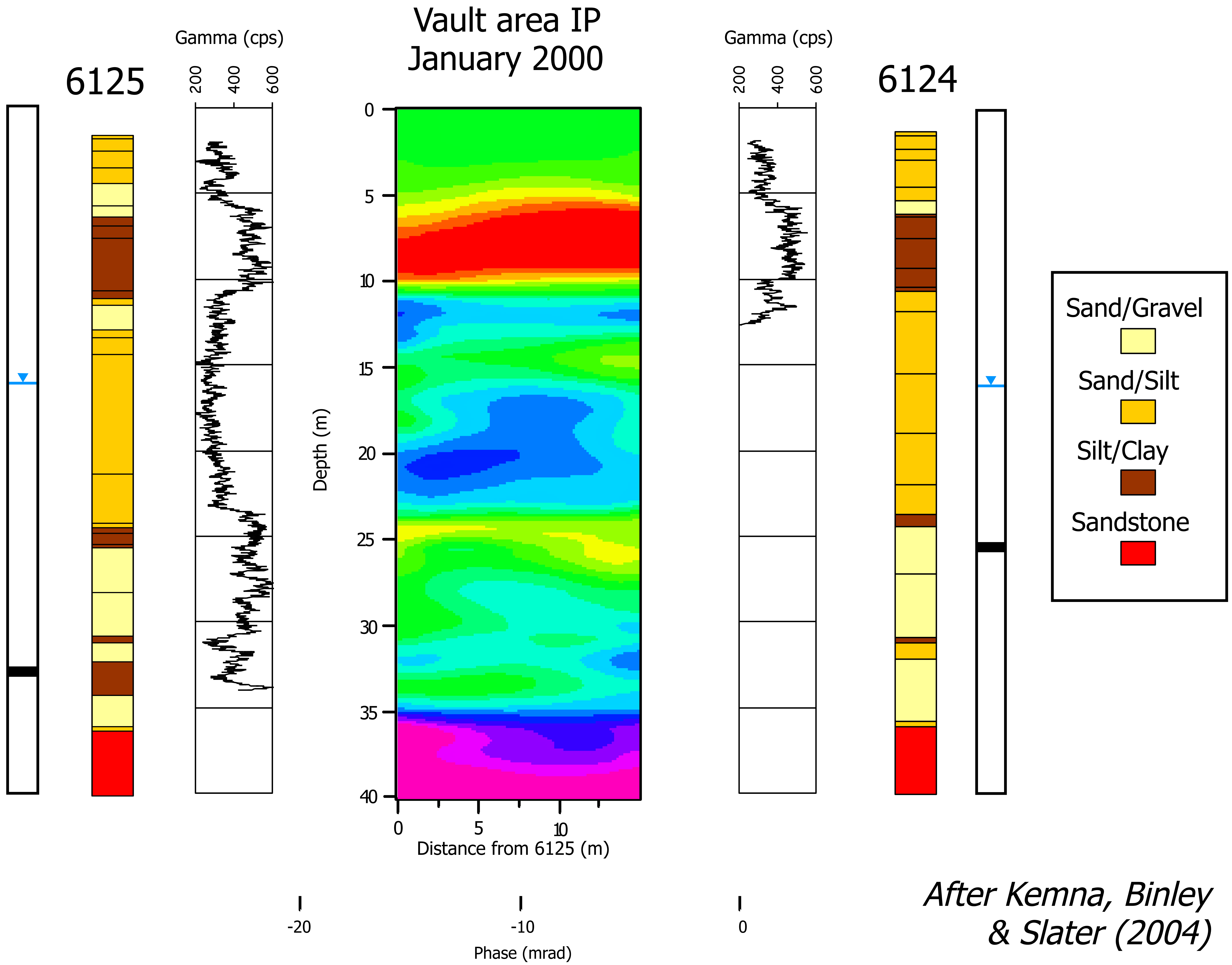
(a)

(b)

(a) SIP Fuchs II base unit and fiber optic cable reels
(b) Zonge GDP32 receiver



After Kemna, Binley & Slater (2004)



After Kemna, Binley & Slater (2004)

CASE HISTORIES

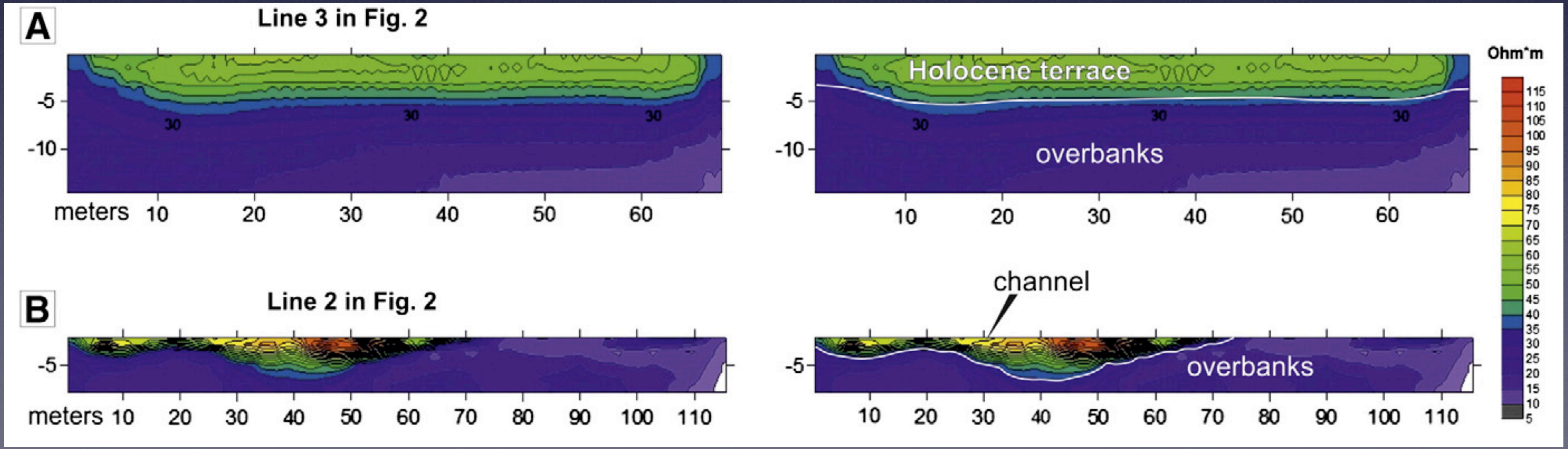
ERT

ERT Geological study

2D section of resistivity (Ohm m)

e.g. Valdarno Basin

R. Deiana



ERT uses

- Hydrological aims (e.g. water research)

- Subsoil geometry imaging

- Water paths evidence

- Environmental aim (pollutant presence and dynamic)

- Void presence

- Post intervention check (e.g. jet-grouting)

Geo-electrical surveys

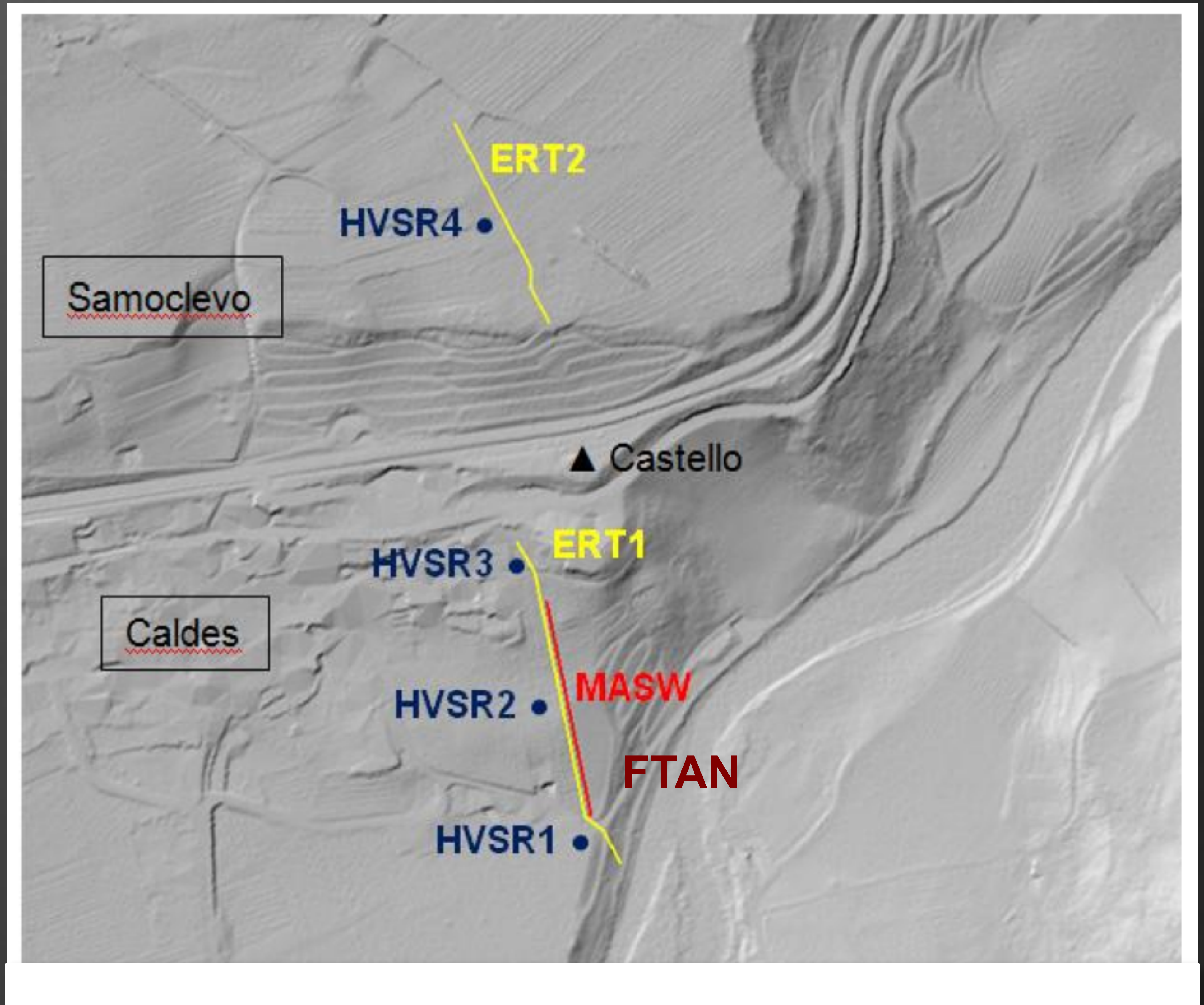
Indagini geofisiche

Indagini elettriche ERT

Indagini sismiche MASW

Indagini sismiche FTAN

Indagini sismica passiva HVSR



FTAN: 100m length, 1s rec.

MASW: 48 canali – spacing 3m – L. 144m

ERT 1: 48 canali – spacing 5m – L. 235m – config. WS e DD

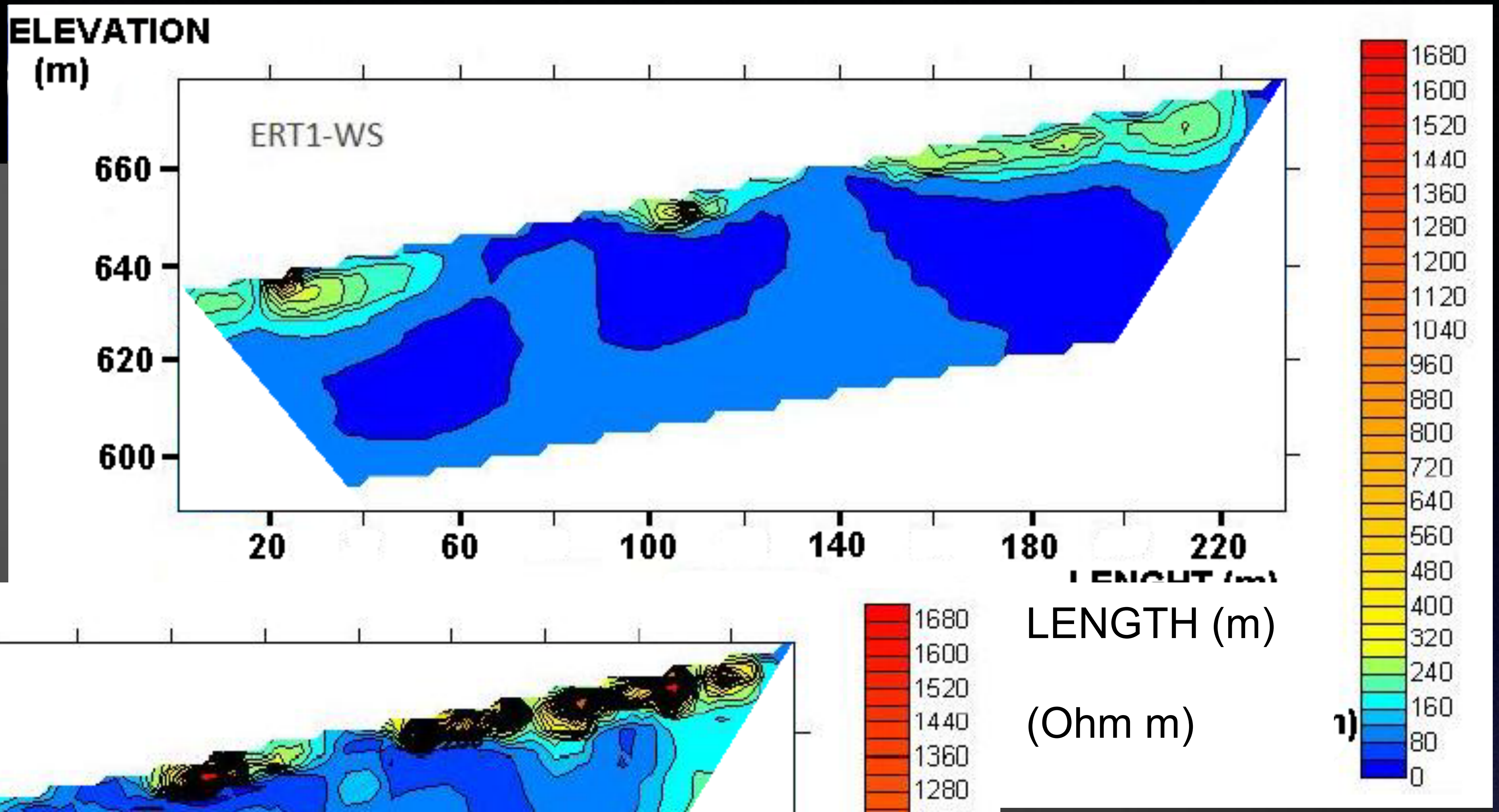
ERT 2: 48 canali – spacing 2m – L. 94m – config. DD

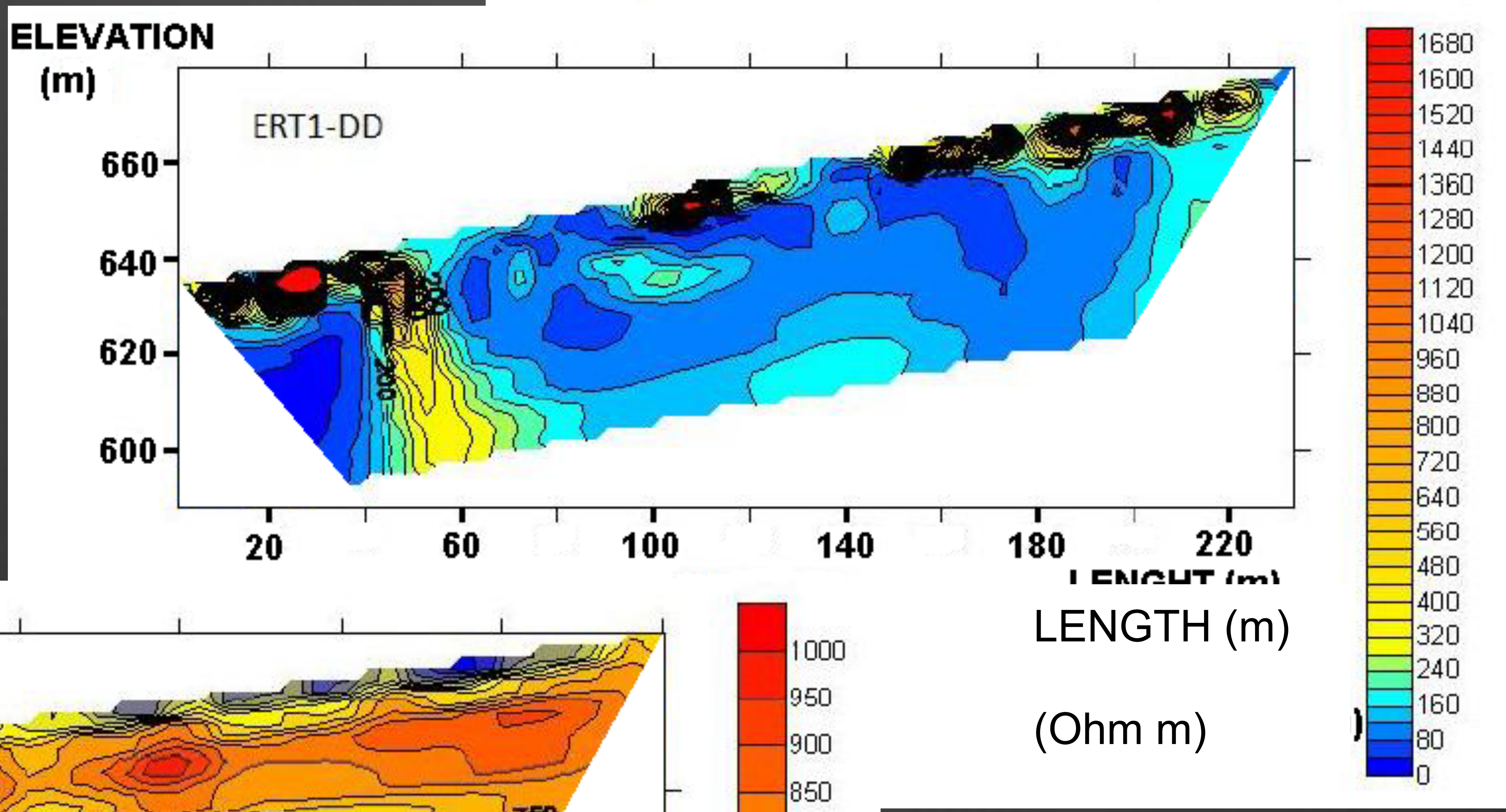
HVSR: 4 prove – rec.time 20 min.

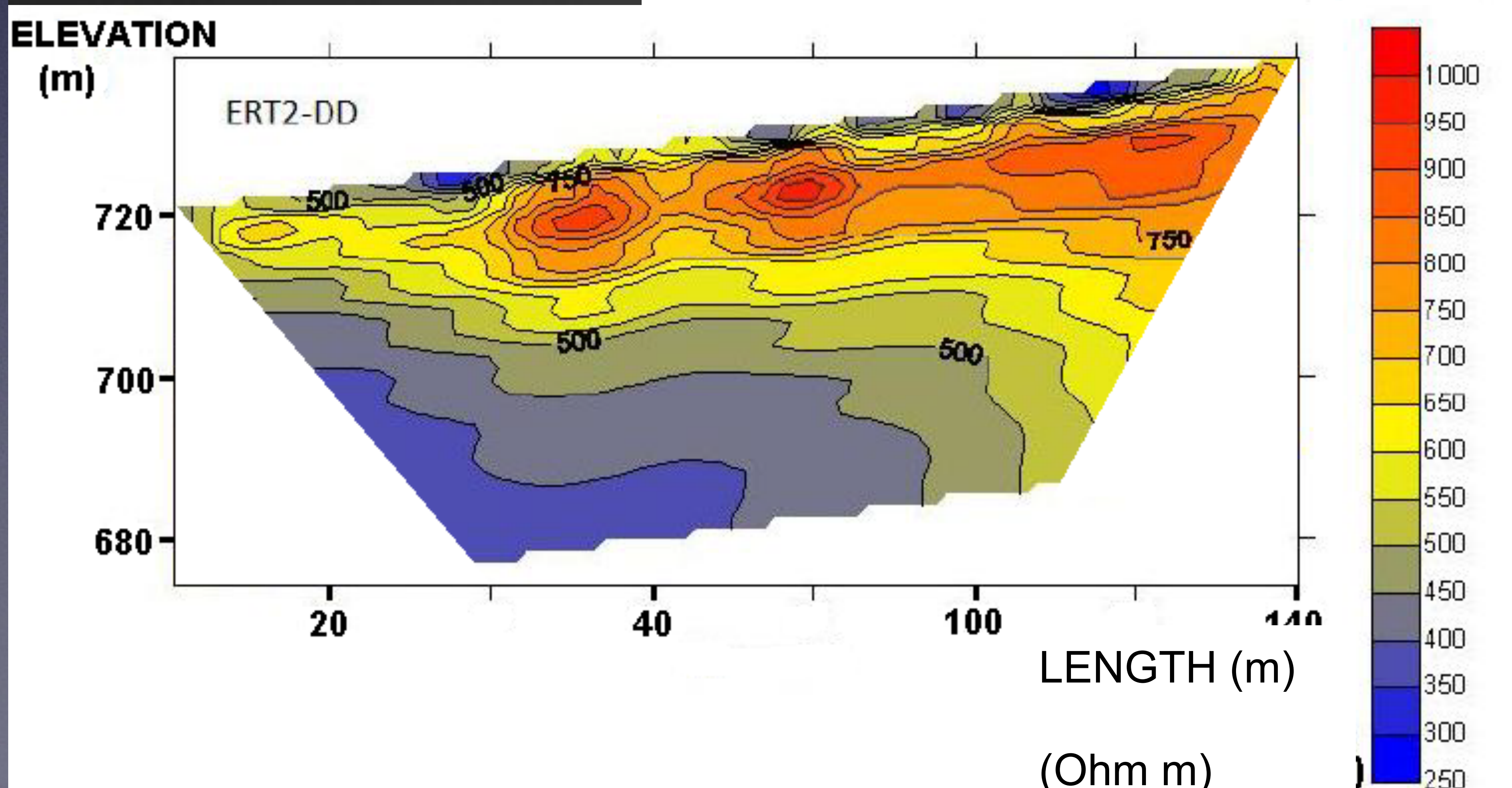
Geo-electrical surveys

Indagini geofisiche

CASTEL CALDES
ERT1





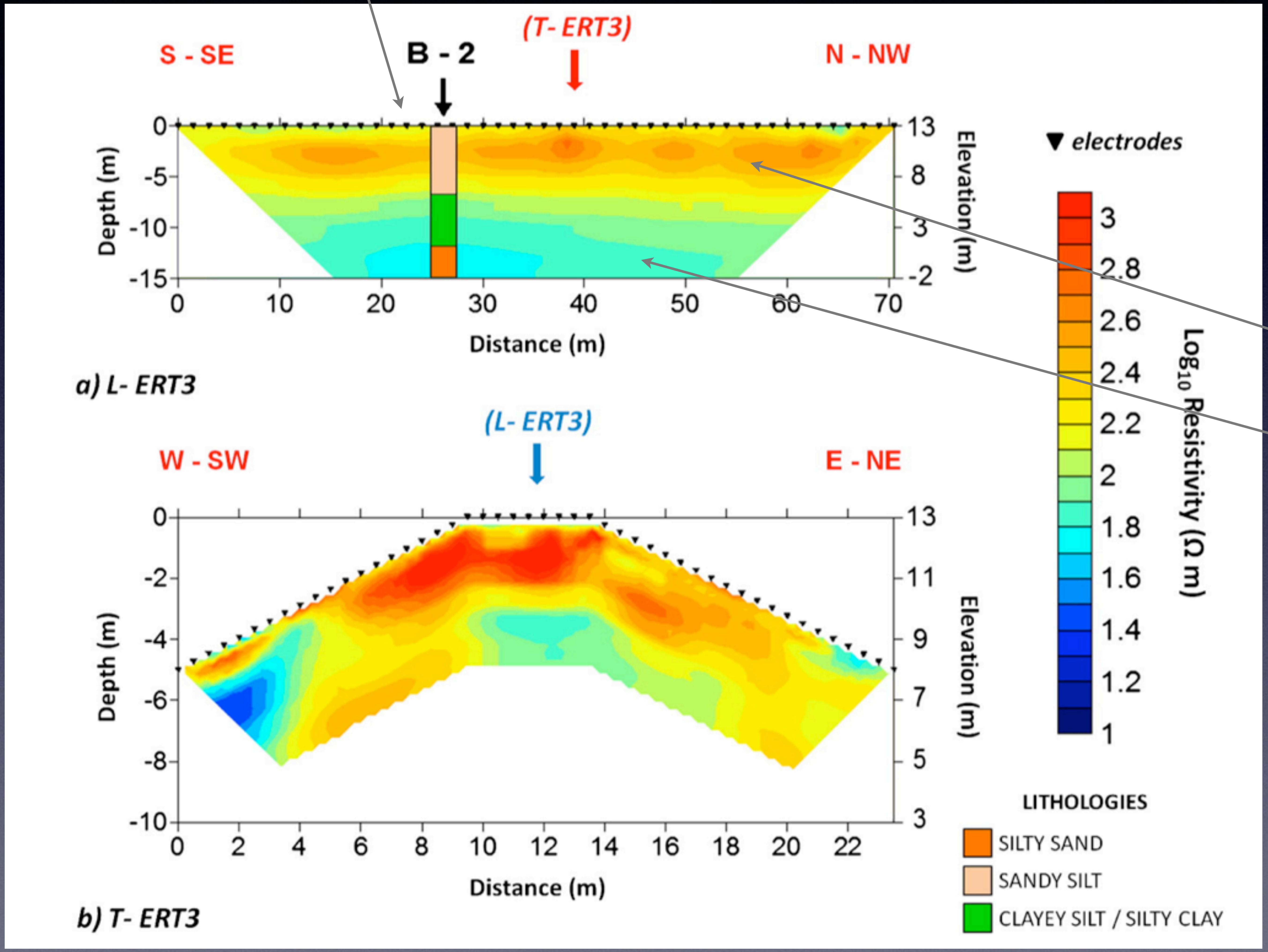


SAMOCLEVO
ERT2

ERT for levee studies

Fluvial levees monitoring

Borehole



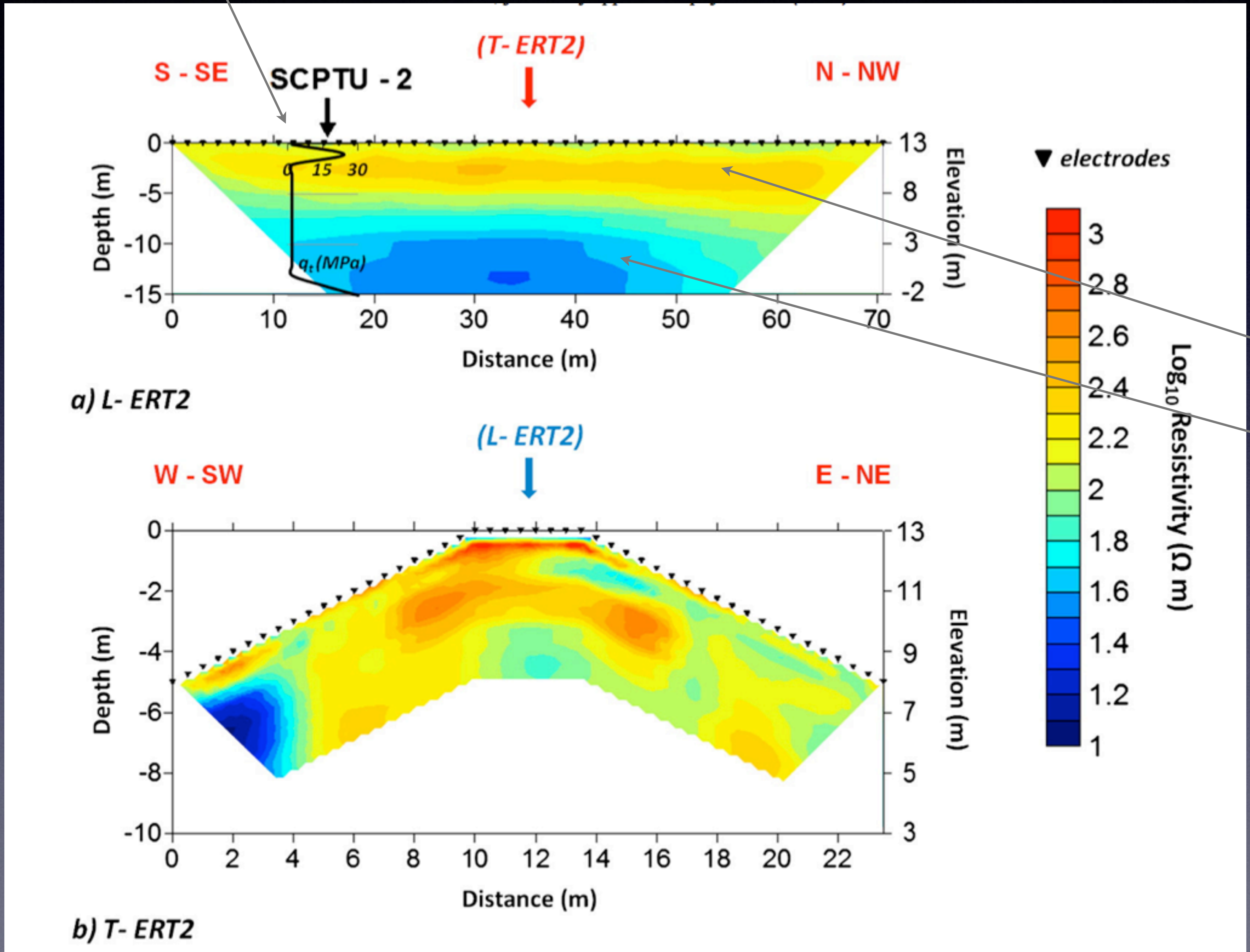
Sand

silt/clay

ERT for levee studies

CPTU test

Fluvial levees monitoring



Sand

silt/clay

Good agreement with geotechnical Info

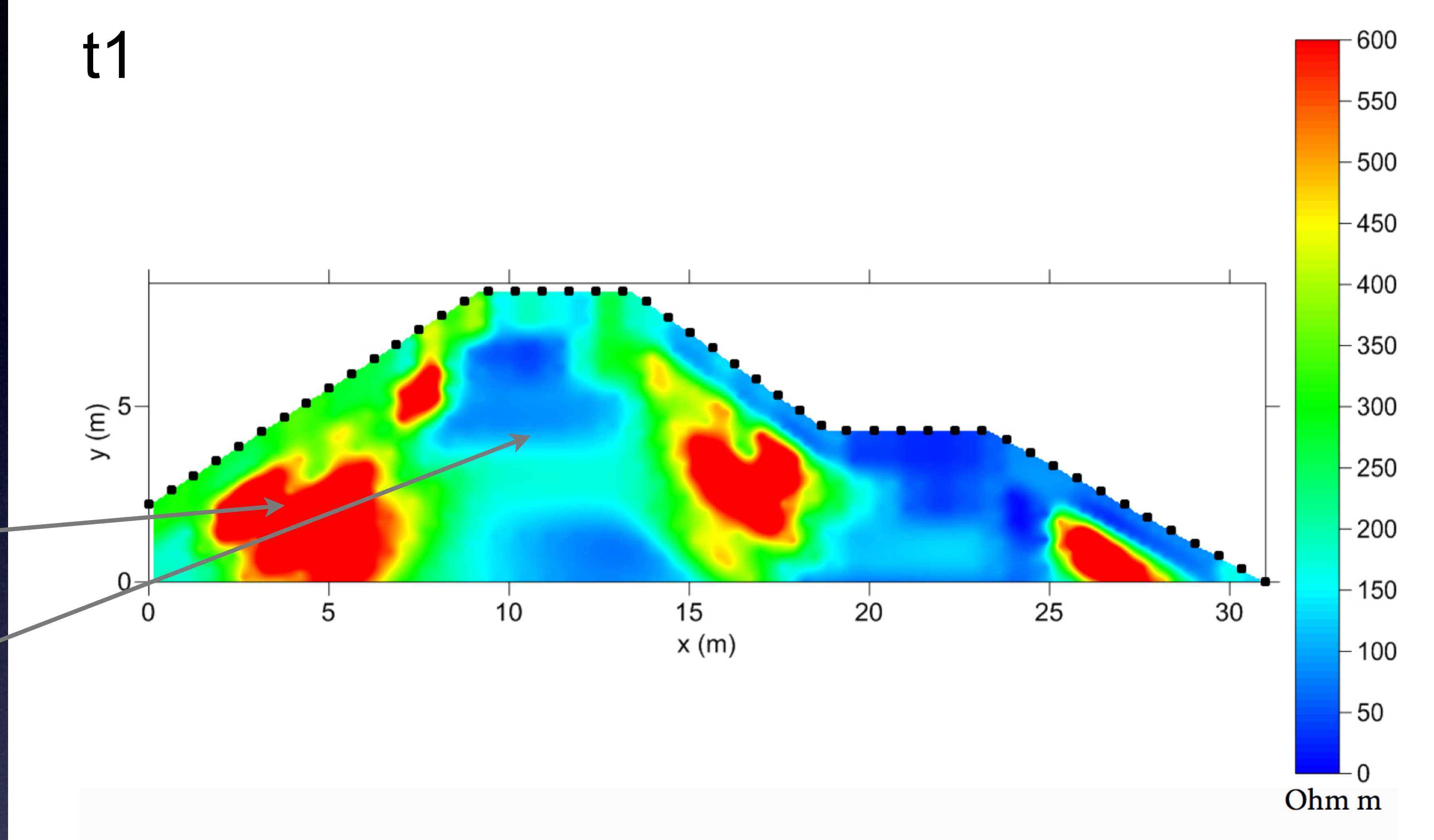
ERT for levee studies

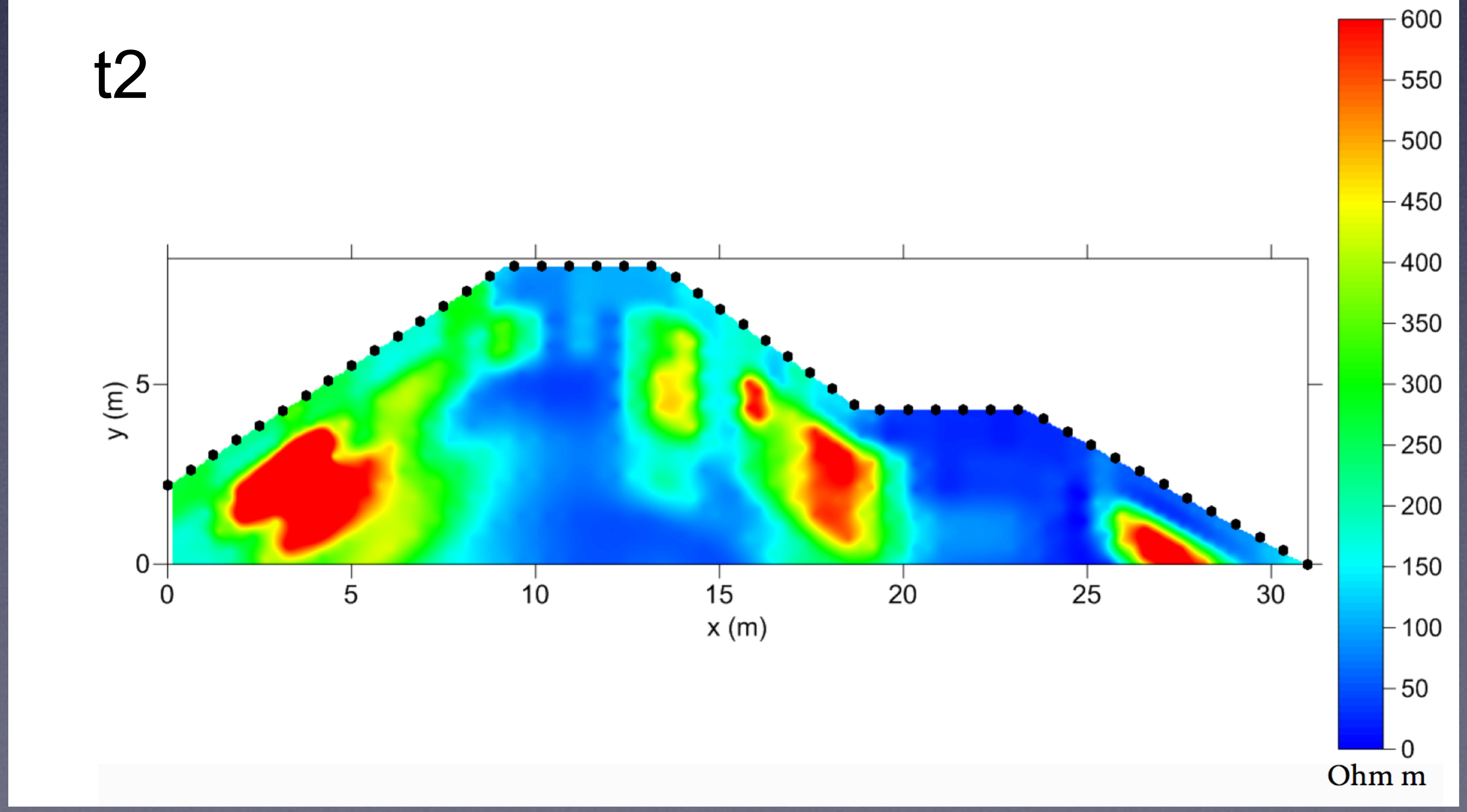
A. Binley R2 code

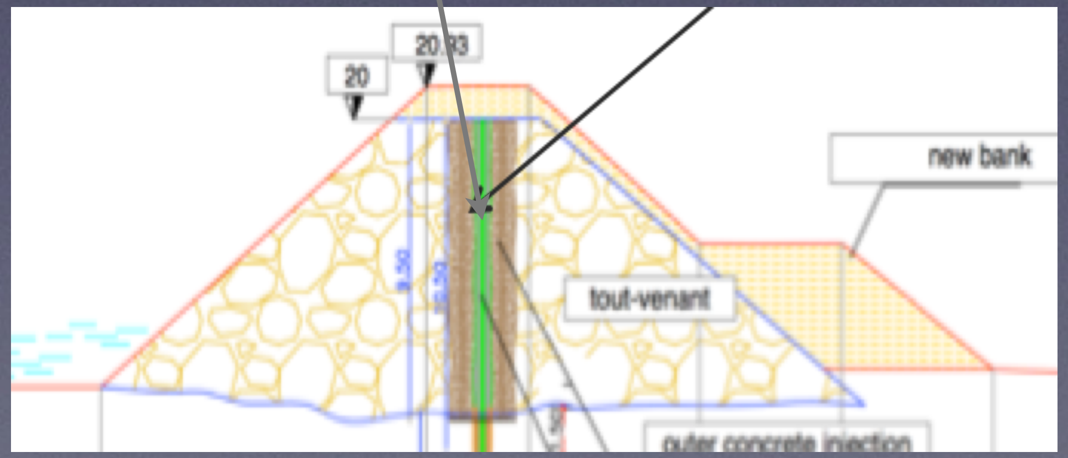
ERT transverse
- Top resolution
  - Ok for laterally extension

Tout Venant

Jet grouting
Septum







Geo-electrical surveys

ERT for landslide

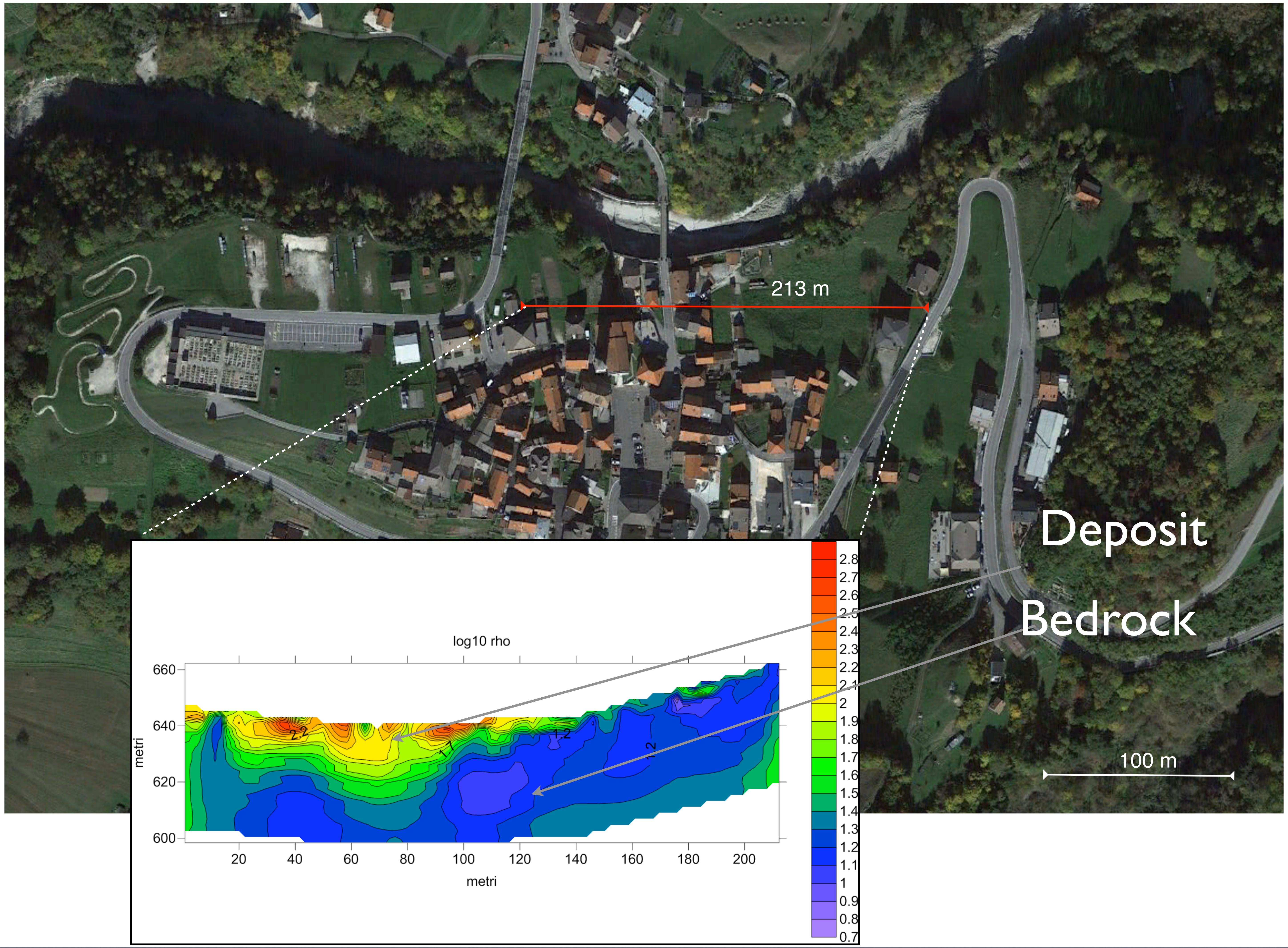
How much material in motion?

Lamosano (BL Italy)

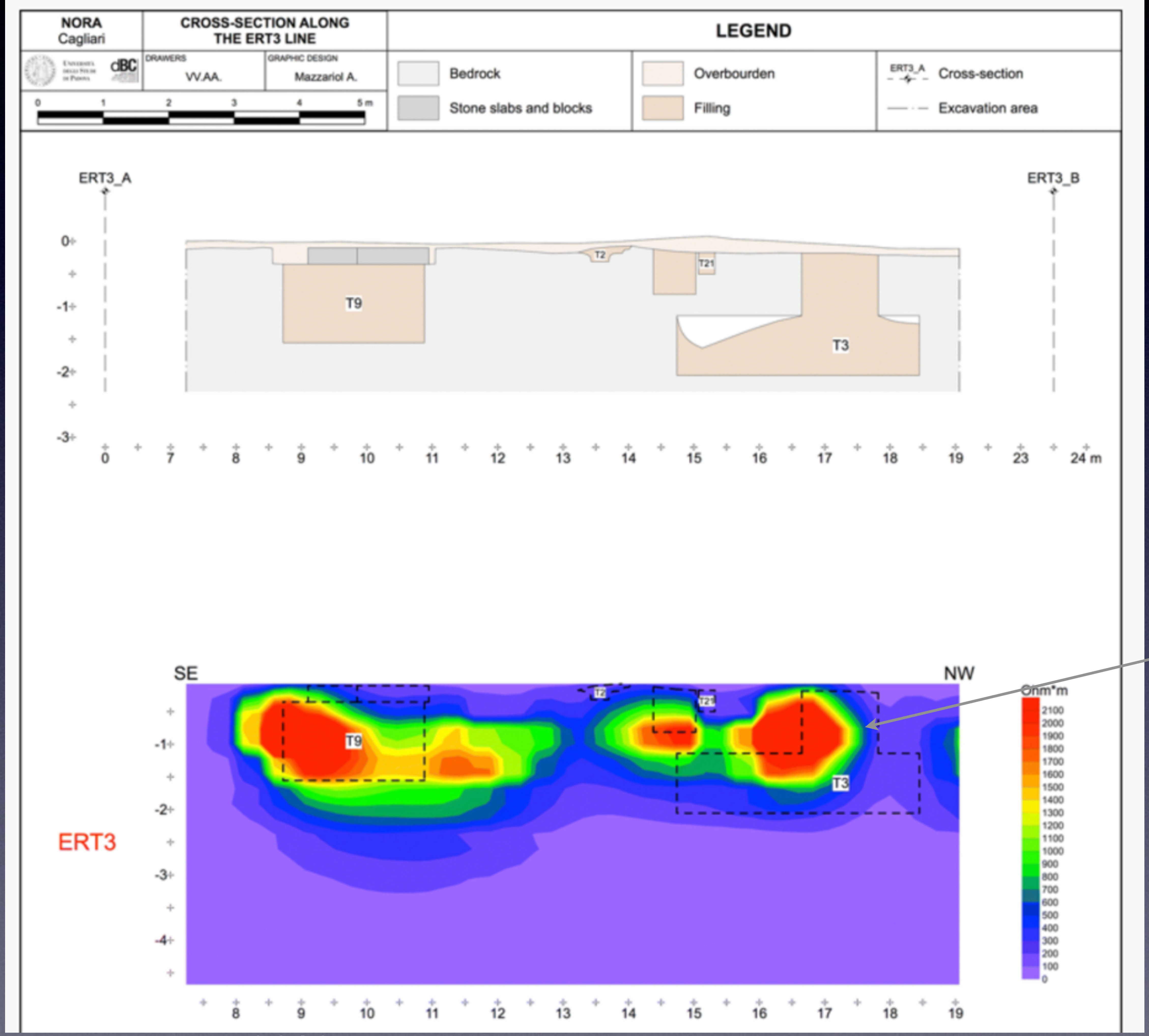
ERT Lines

Geo-elctrical surveys

ERT for landslide



ERT for Archeology



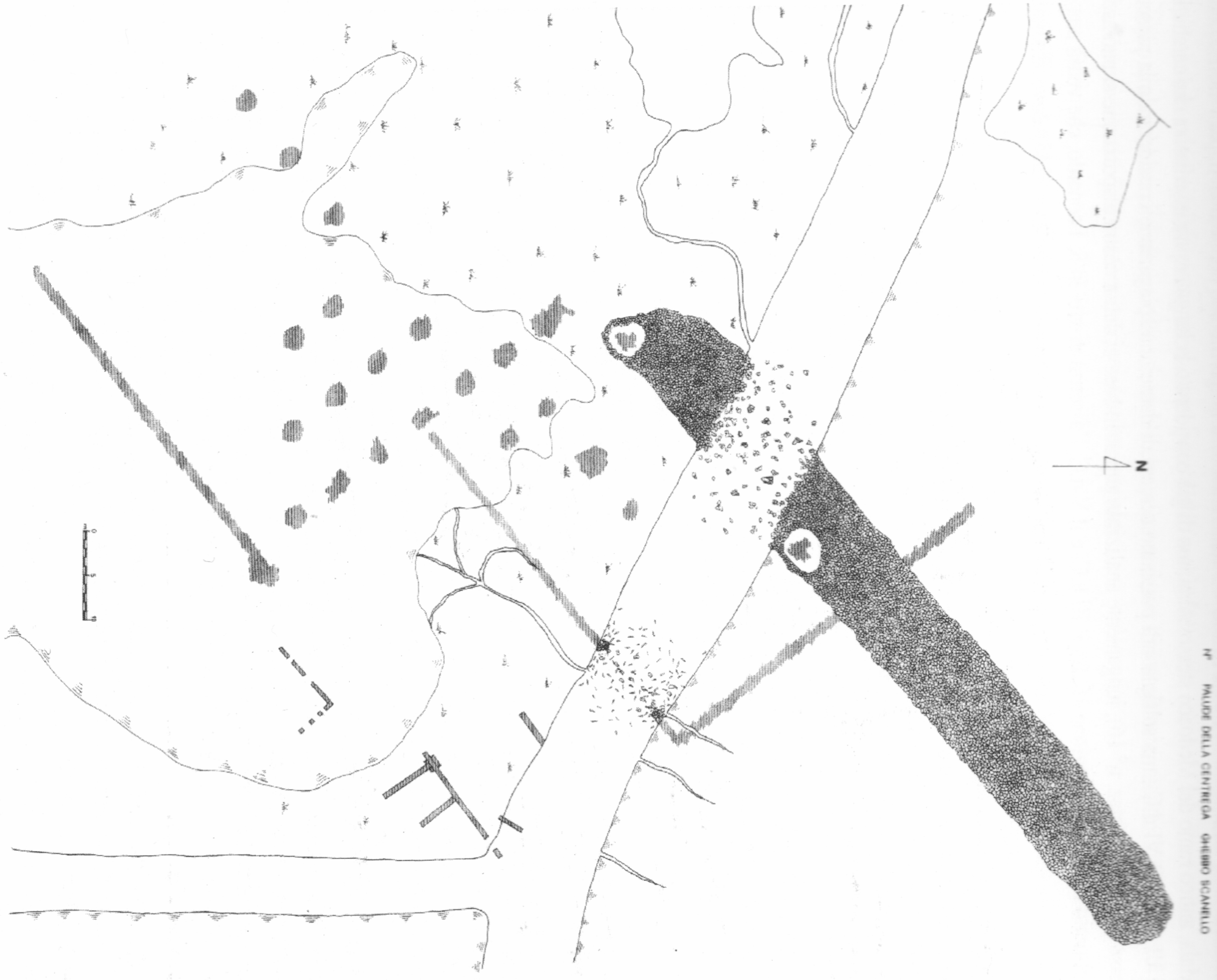
Deiana et al 2018

Buried tombs
Nora (Sardinia)

(Voids are highly resistive)

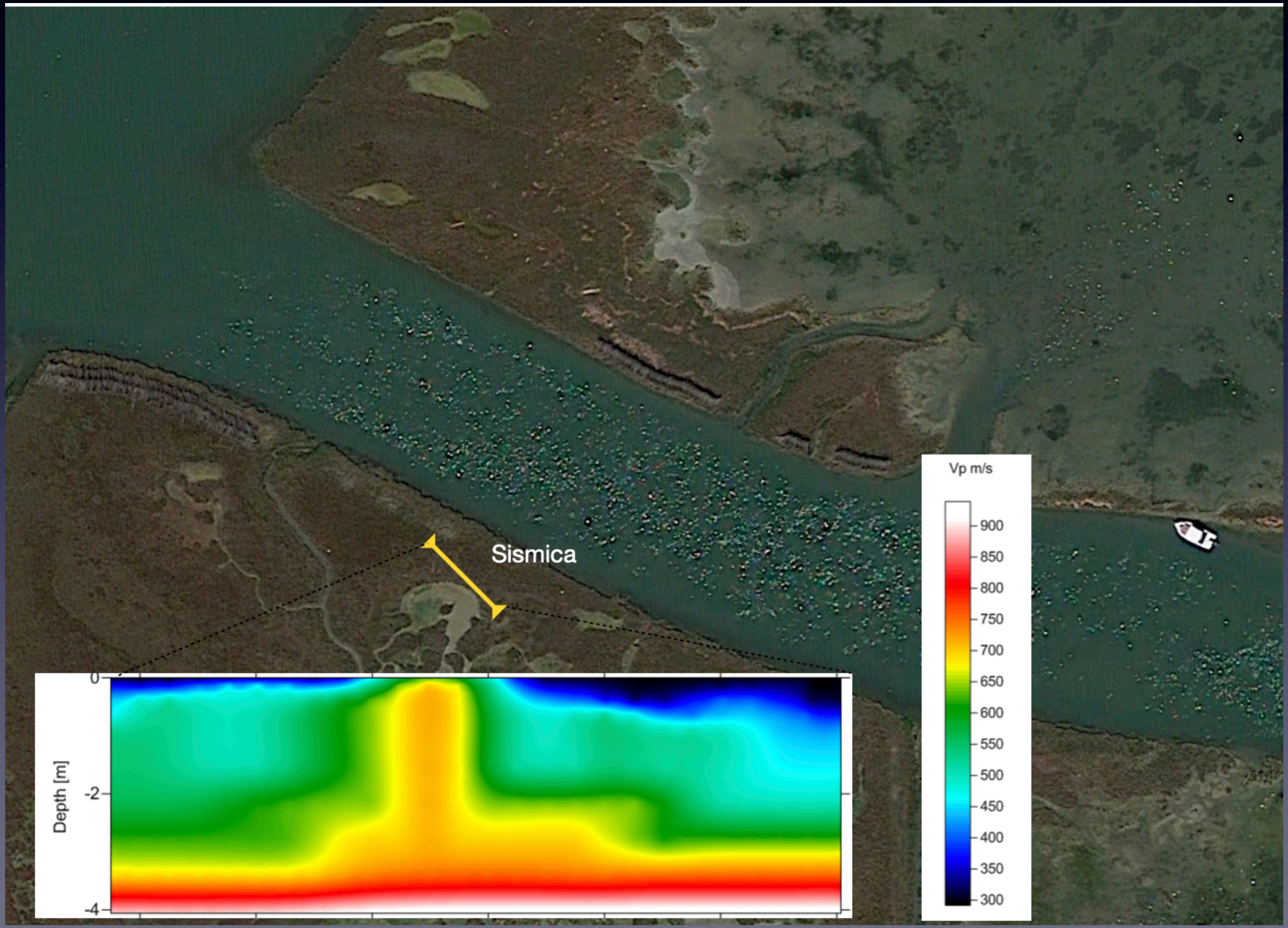
Venice lagoon- archeology

Tav. 17
Staz. 114 - 5 Particolare dell'area portuale di Altino
A - Magazzini
B - Edifici decorati con mosaici



Roman structures

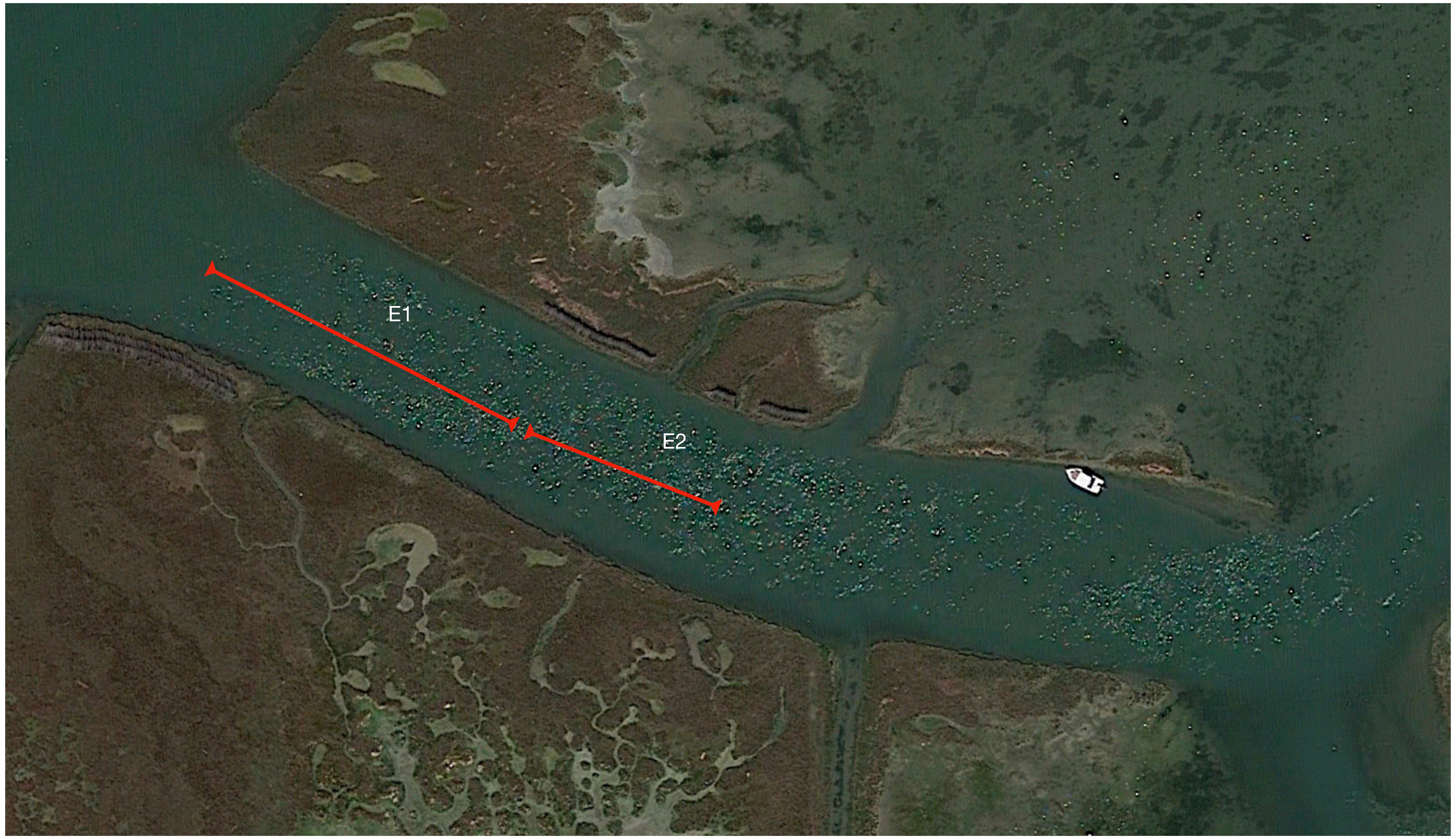
Venice lagoon- archeology



Seismic

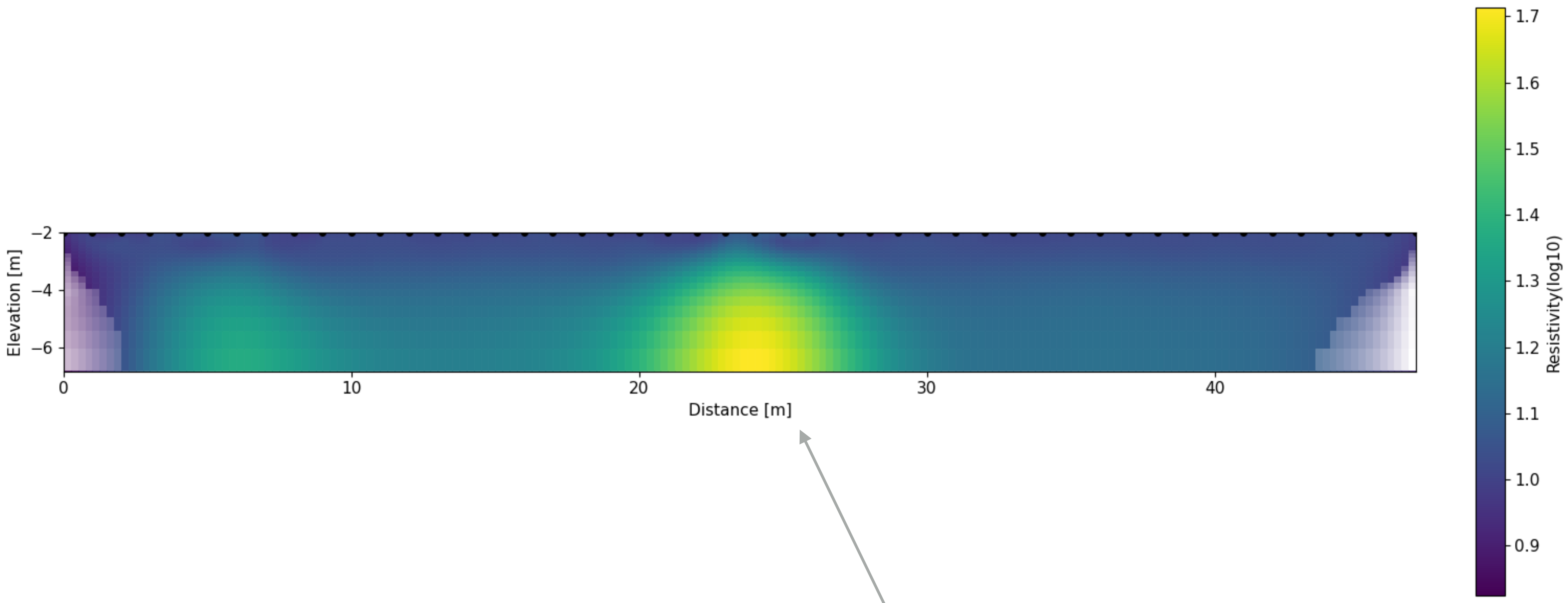
Marine ERT

Venice lagoon- archeology



Marine ERT

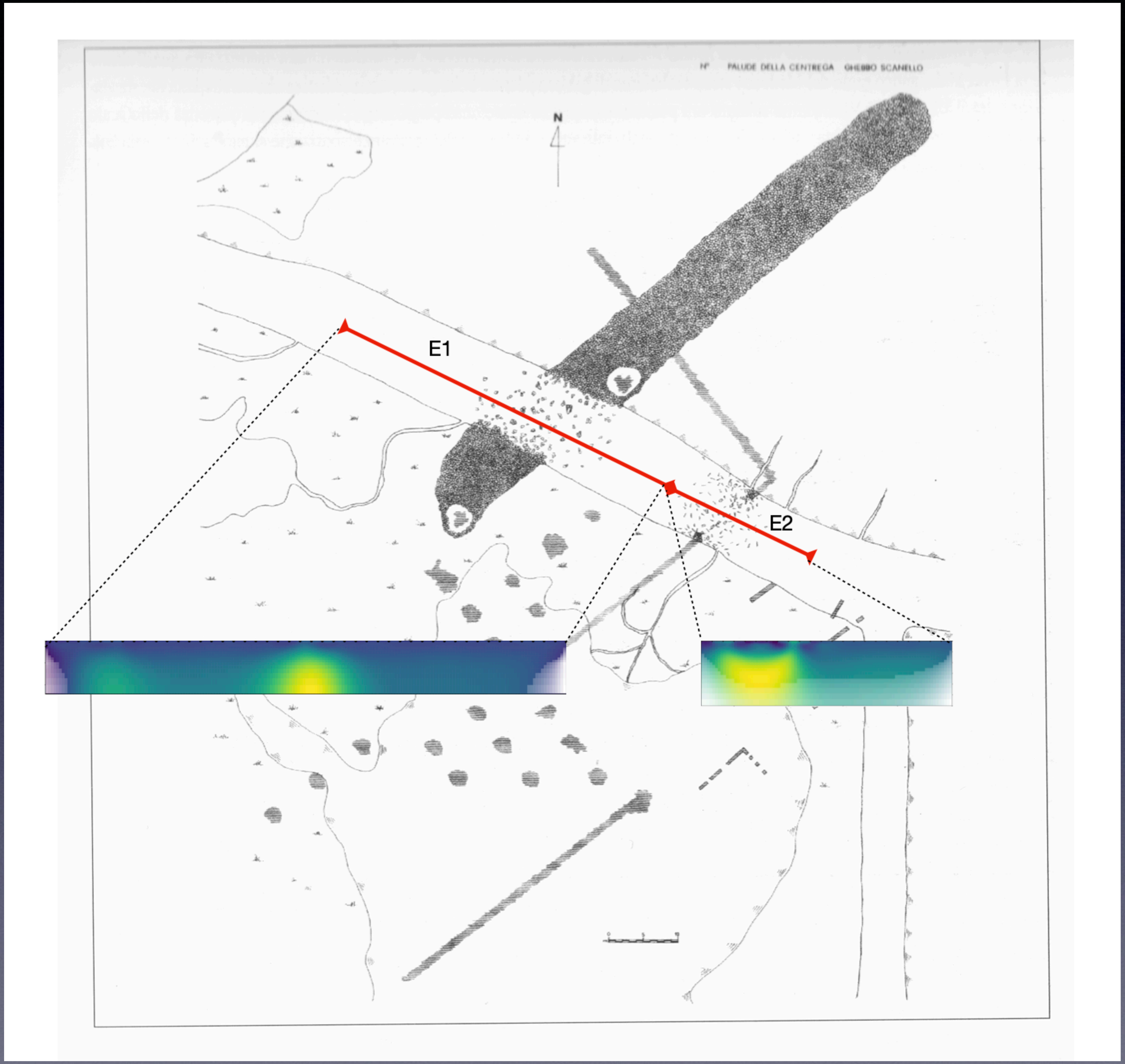
Venice lagoon- archeology



Resistive anomaly in salt water

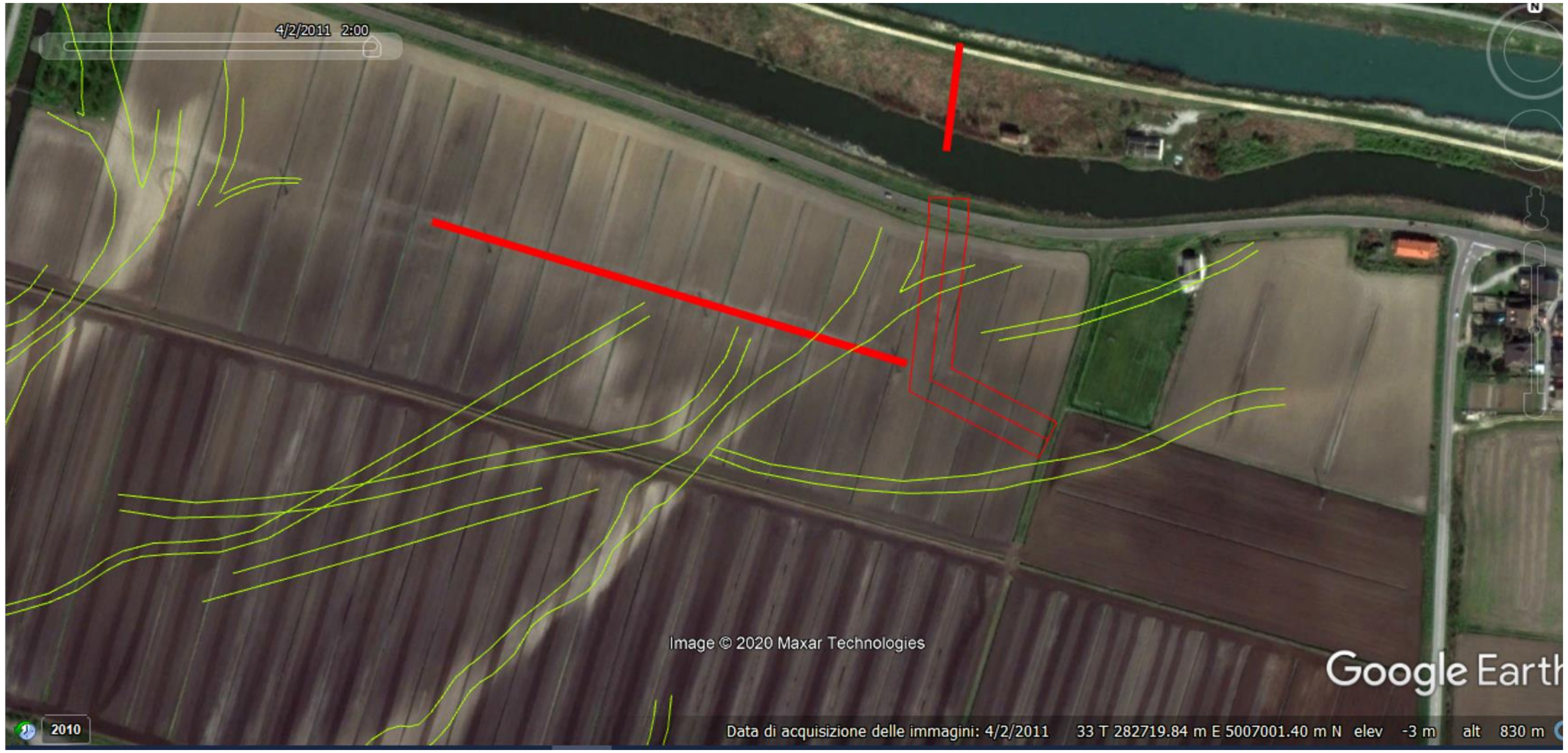
Marine ERT

Venice
lagoon-
archeology



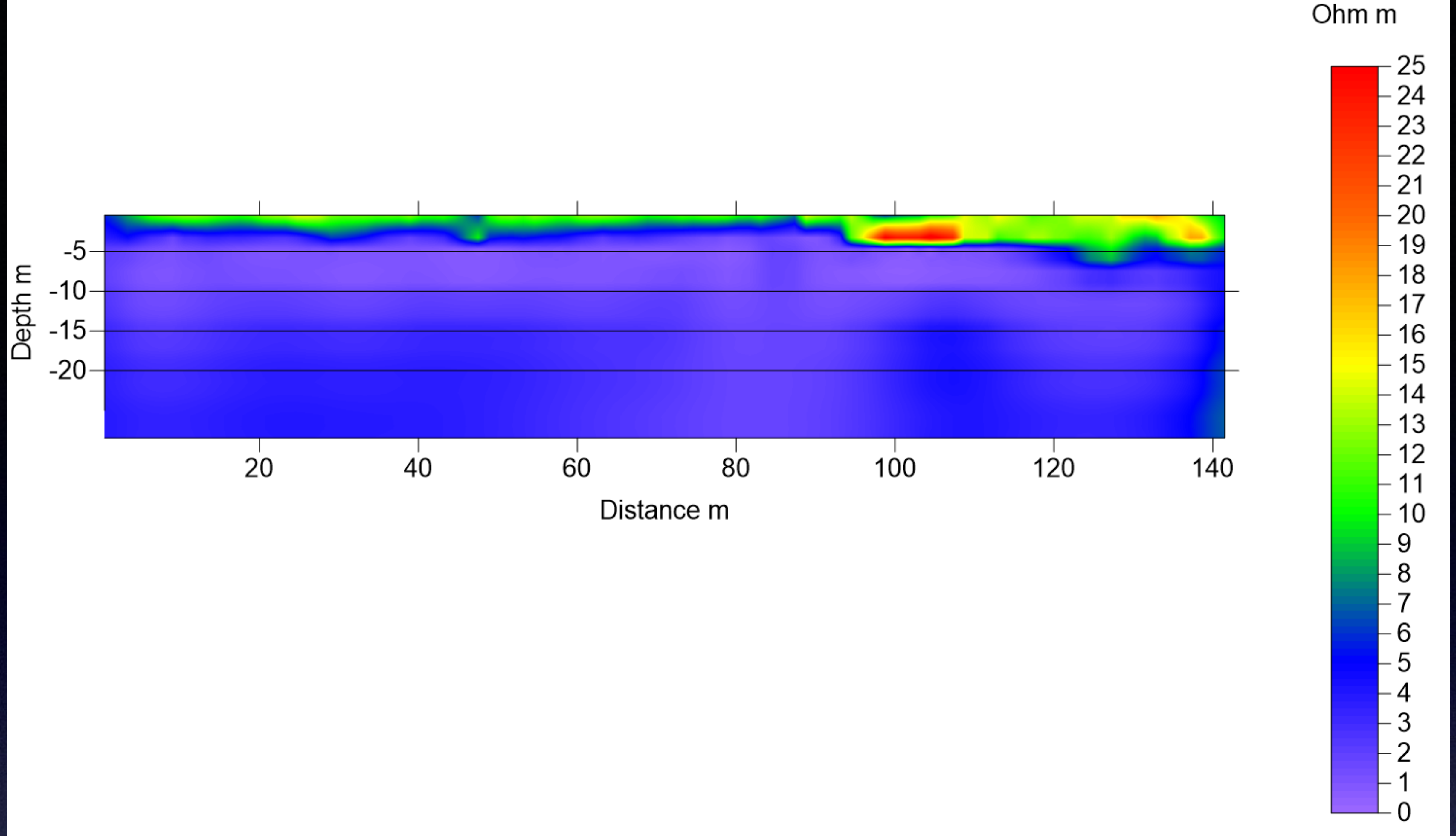
Resistive
anomalies

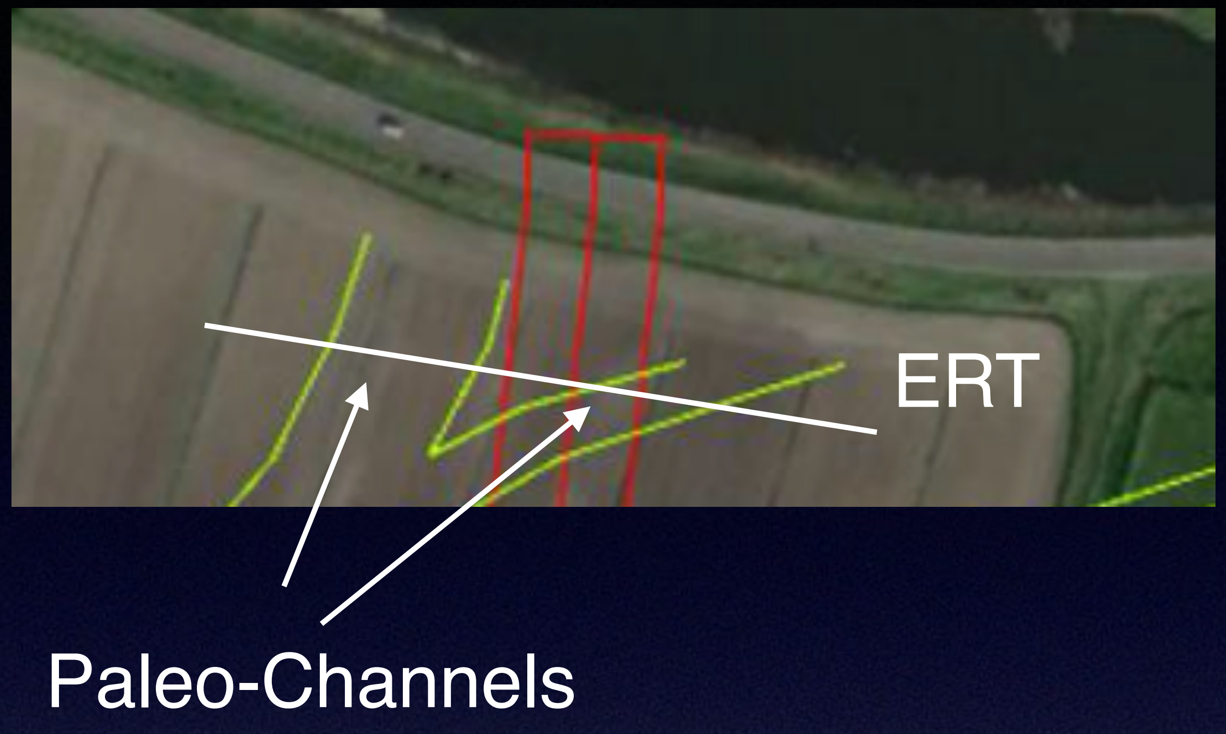
Marine ingression



Linee gialle: tracce paleocanali
Linee rosse metanodotti

ERT monitoring Paleo-Channel

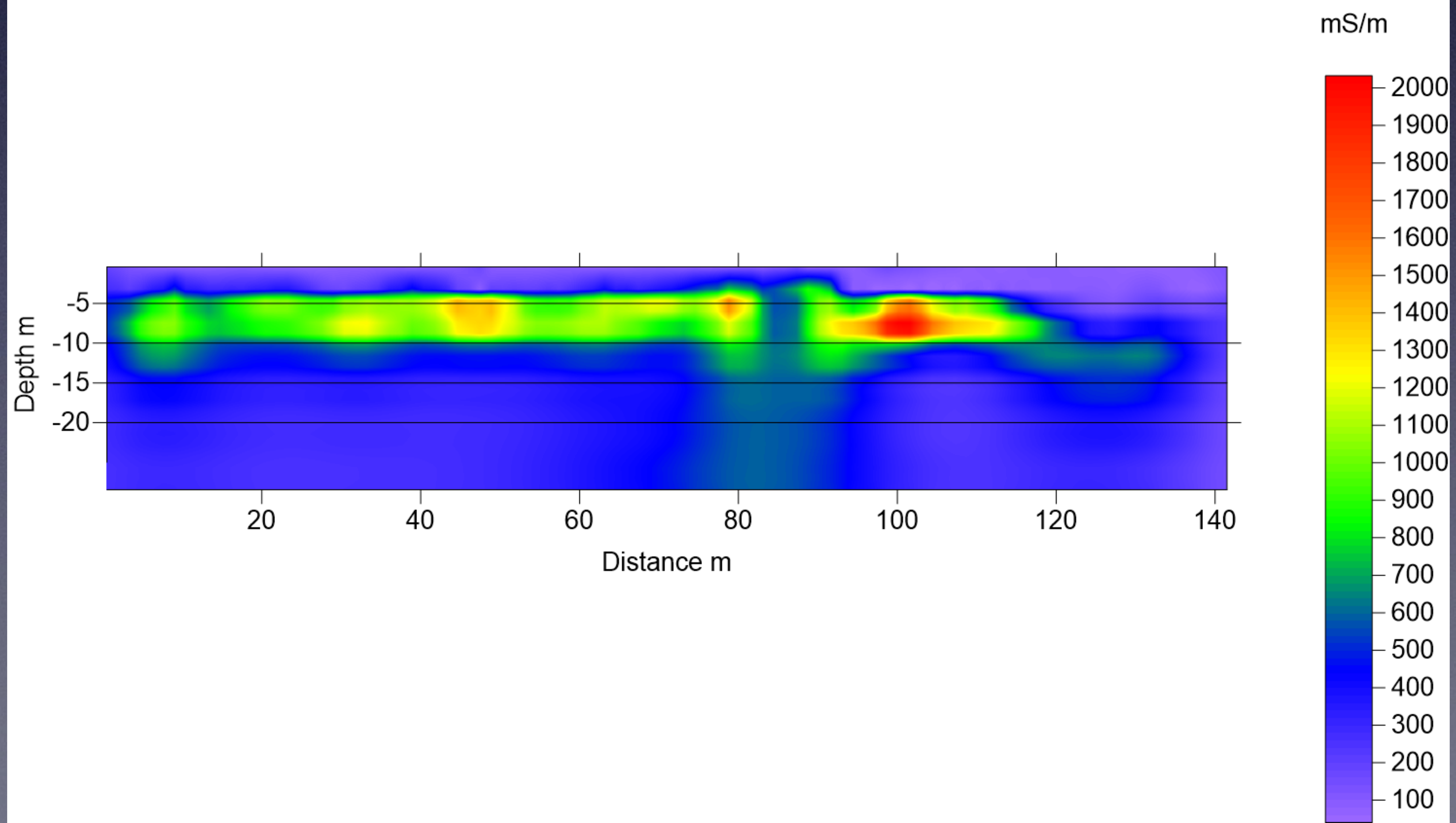




$$\rho = 1 / \sigma$$

Resistivity
Ohm m

Conducibility
S/m



Sandy layer (paleo channel) full of saline water

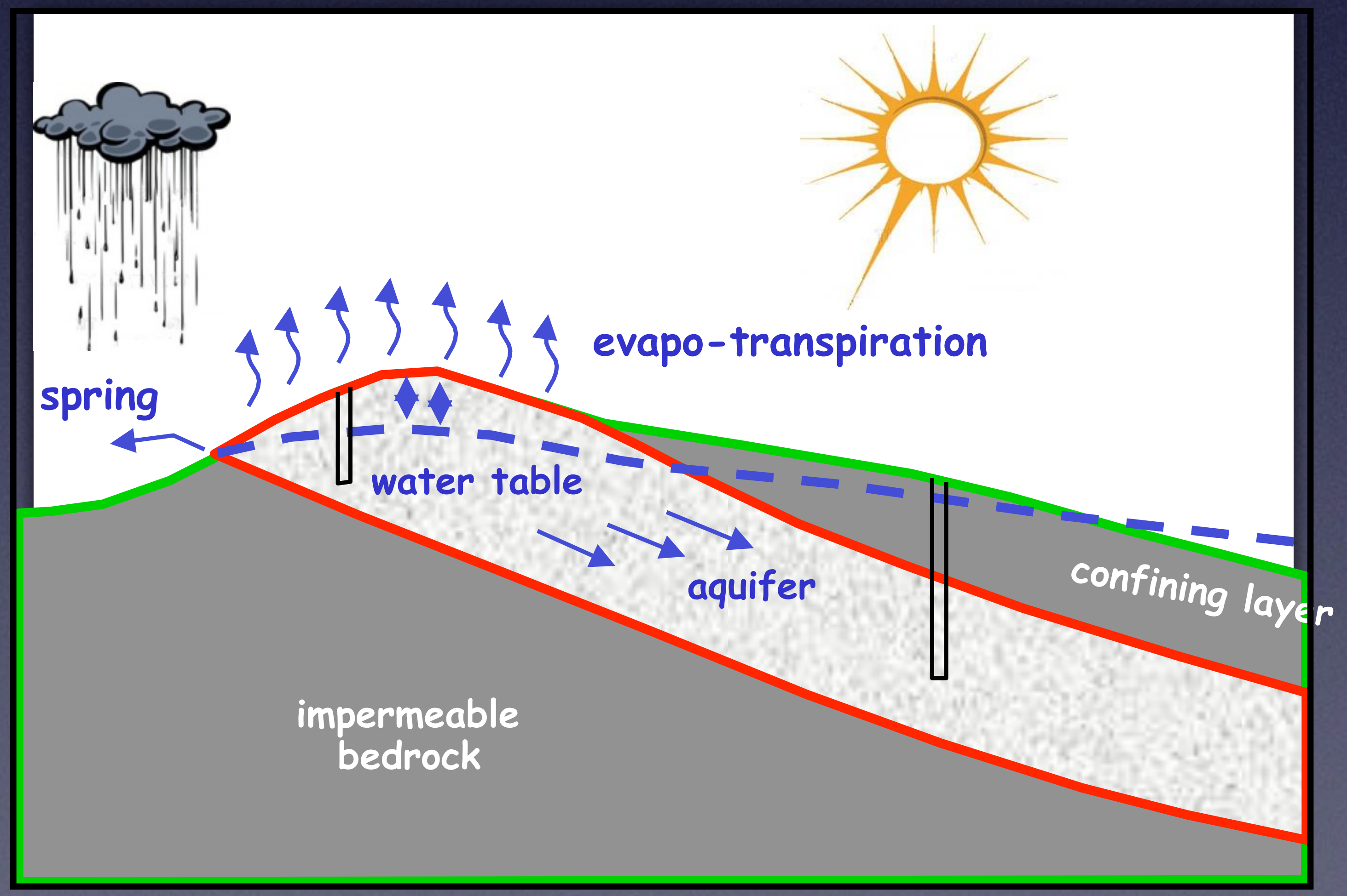
Sea water ≈ 2 S/m

ERT for Hydro-Geophysics
Water table studies, pollutants, etc.

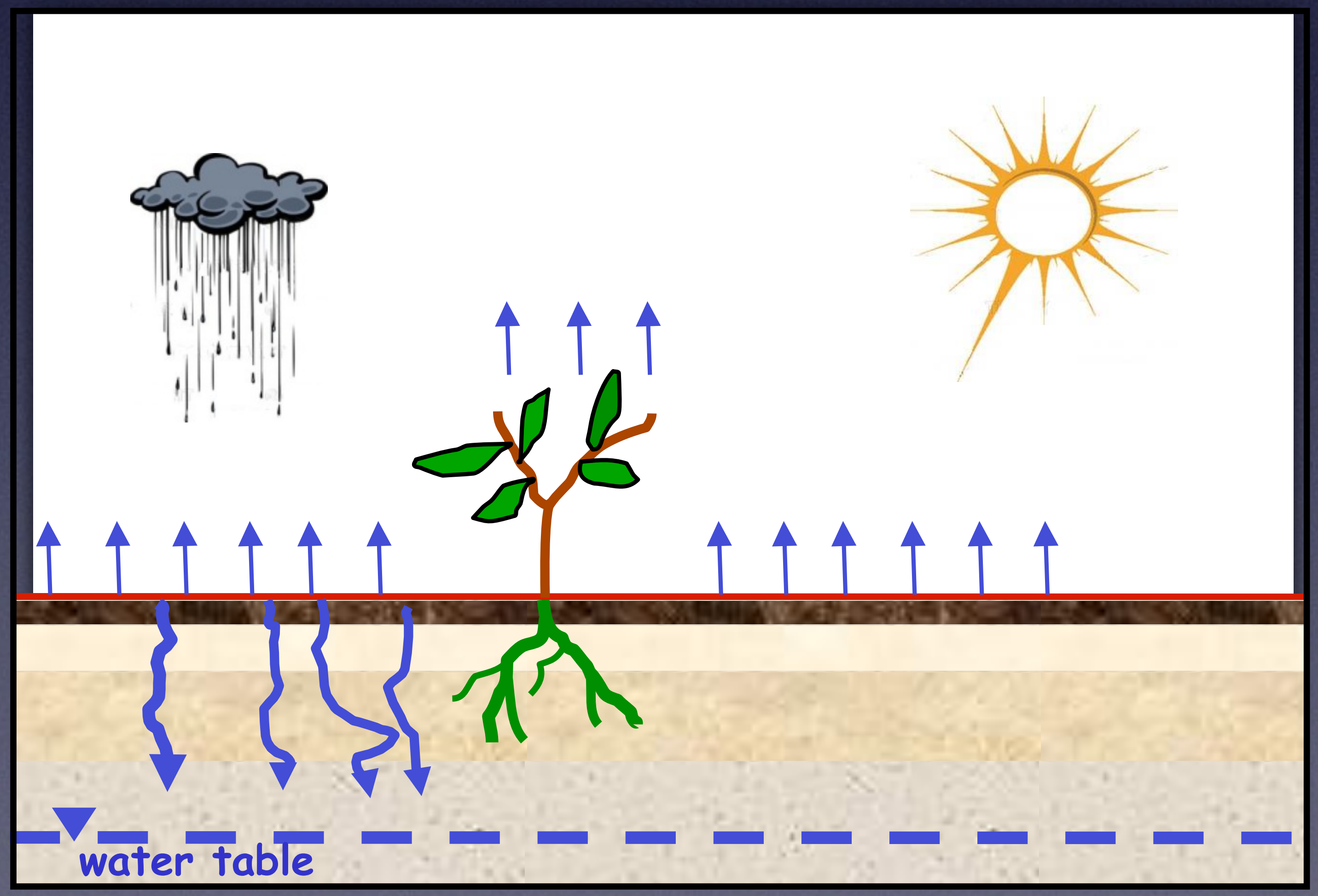
TIME LAPSE ERT

- structure / texture (Seismic methods, EM methods, Electrical methods, Gravity methods, Radar etc)

- fluid-dynamics: e.g. time-lapse evolution of moisture content (DC resistivity methods, EM methods, GPR etc)



large scale



small scale

ERT for Hydro-Geophysics
Water table studies, pollutants, etc.

TIME LAPSE ERT

Relazione della resistività con il contenuto idrico e la salinità dell'acqua

La classica relazione empirica è la legge (estesa) di Archie [1942]:

$$\sigma_b = \sigma_w \phi^m S_w^n + \sigma_s$$

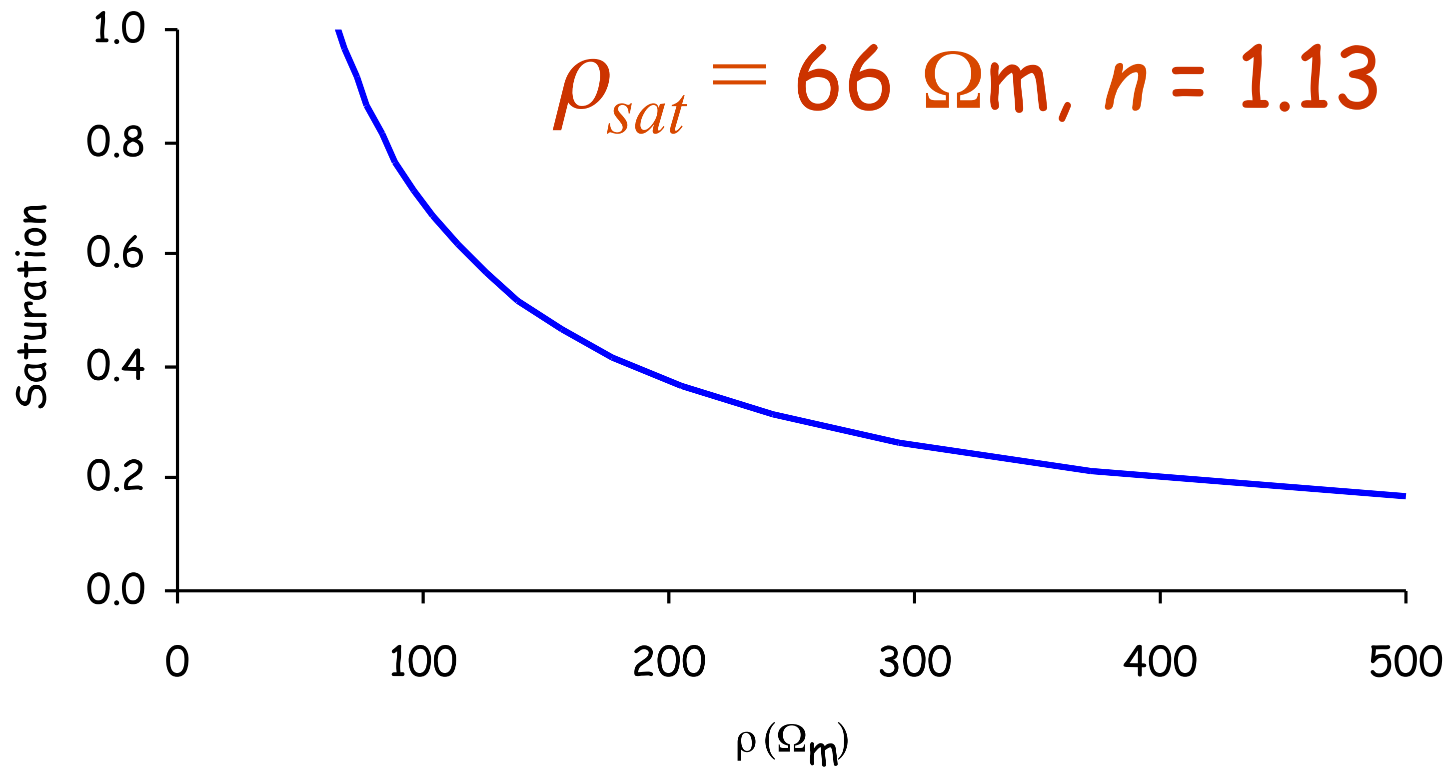
σ_b = conduttività bulk

σ_w = conduttività dell'acqua nei pori

ϕ = porosità

S_w = saturazione in acqua

σ_s = conduttività superficiale



n ed m sono parametri della formazione

Geophysical methods: the dynamic characterization

Glacial outflows must have an electric signal...

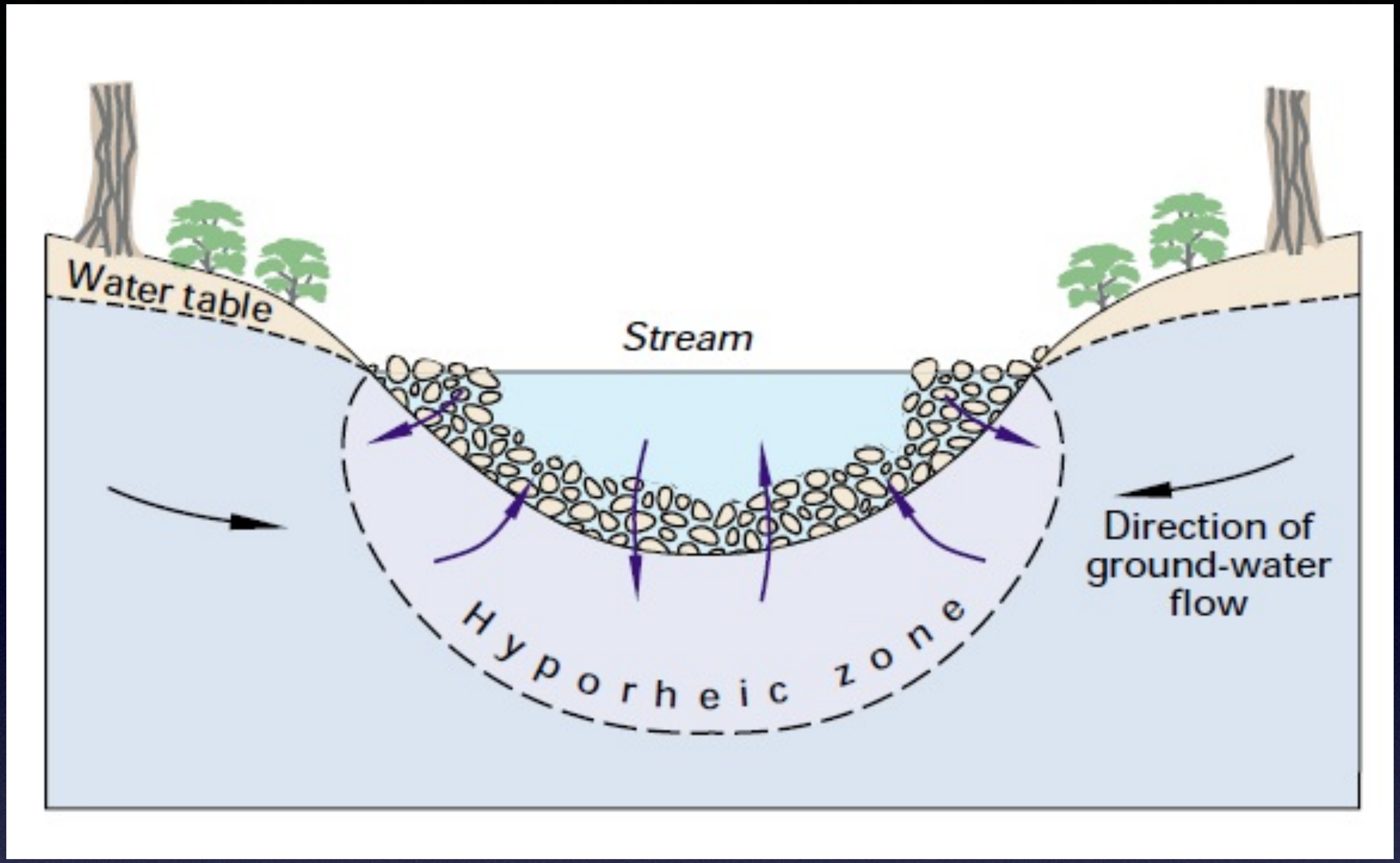
MESO-SCALE

Can we characterize the hyporheic zone beneath a river?

The Val di Sole site

FP7

GLOBAQUA



- monitor subsoil/river water exchanges (hyphoreic zone)

The hyporheic zone (part of the critical zone) is the transition region where the interactions between surface water and groundwater take place

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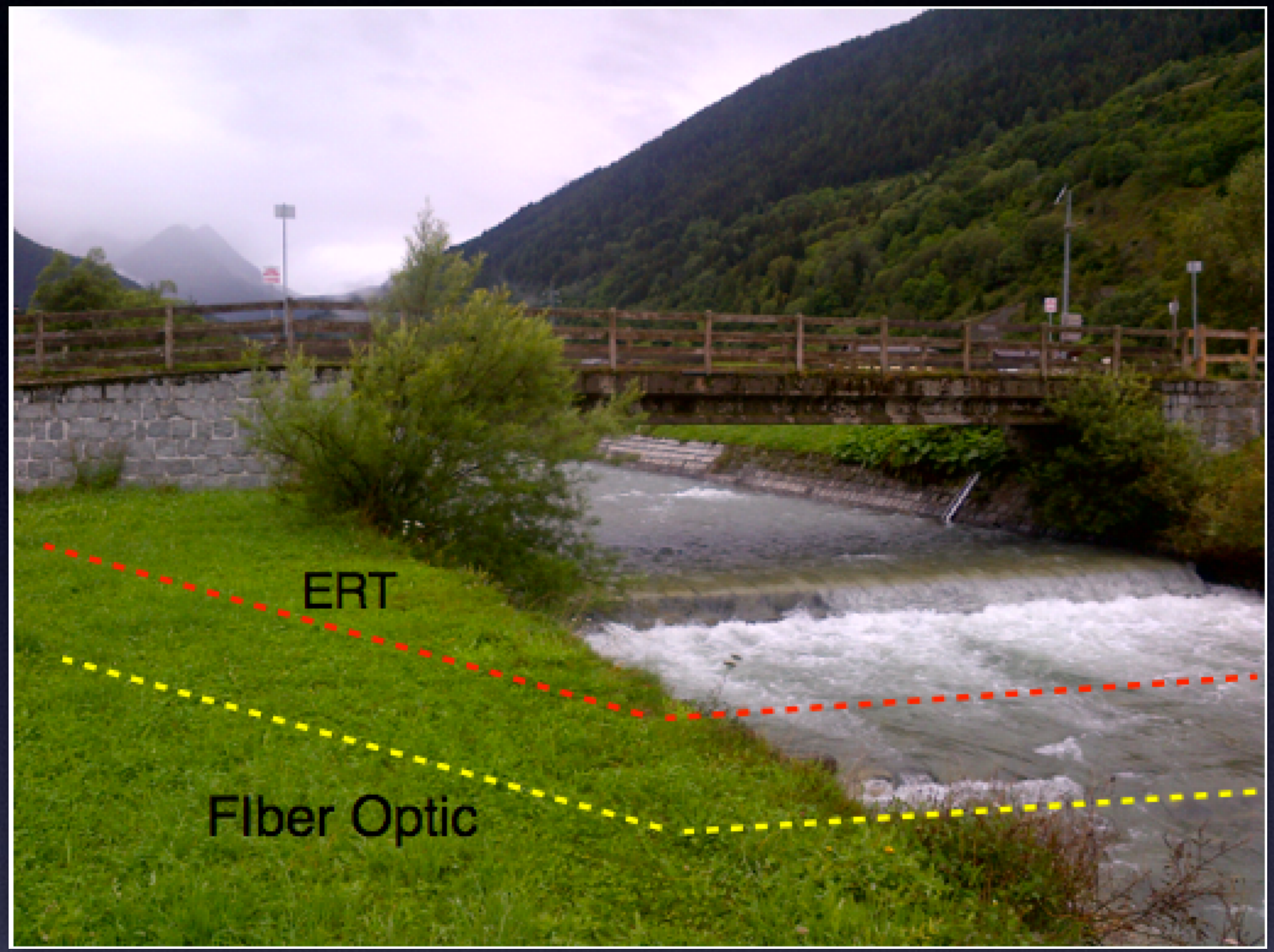
Geophysical methods: the dynamic characterization

Oriented Drilling boreholes:

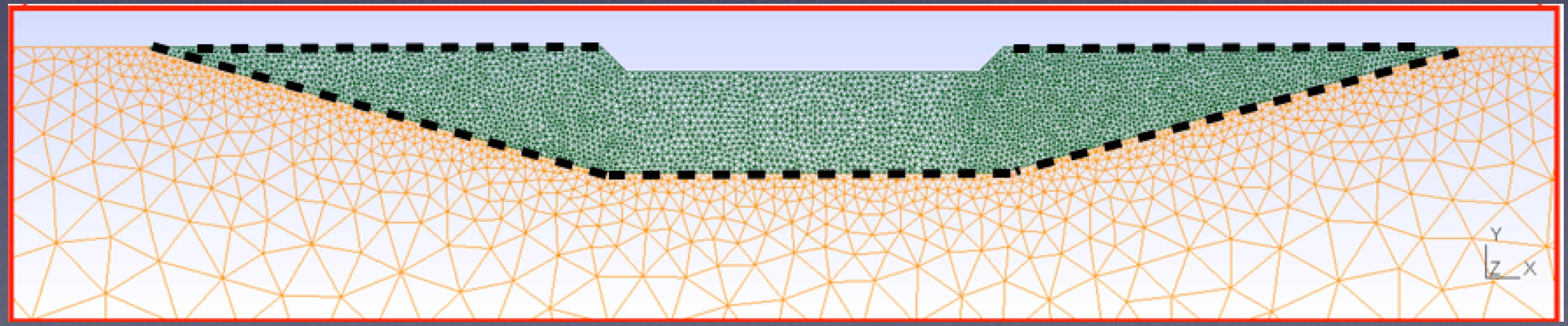
-ERT cable 5m under river's bed

-Hybrid FIBER OPTIC parallel to the ERT cable

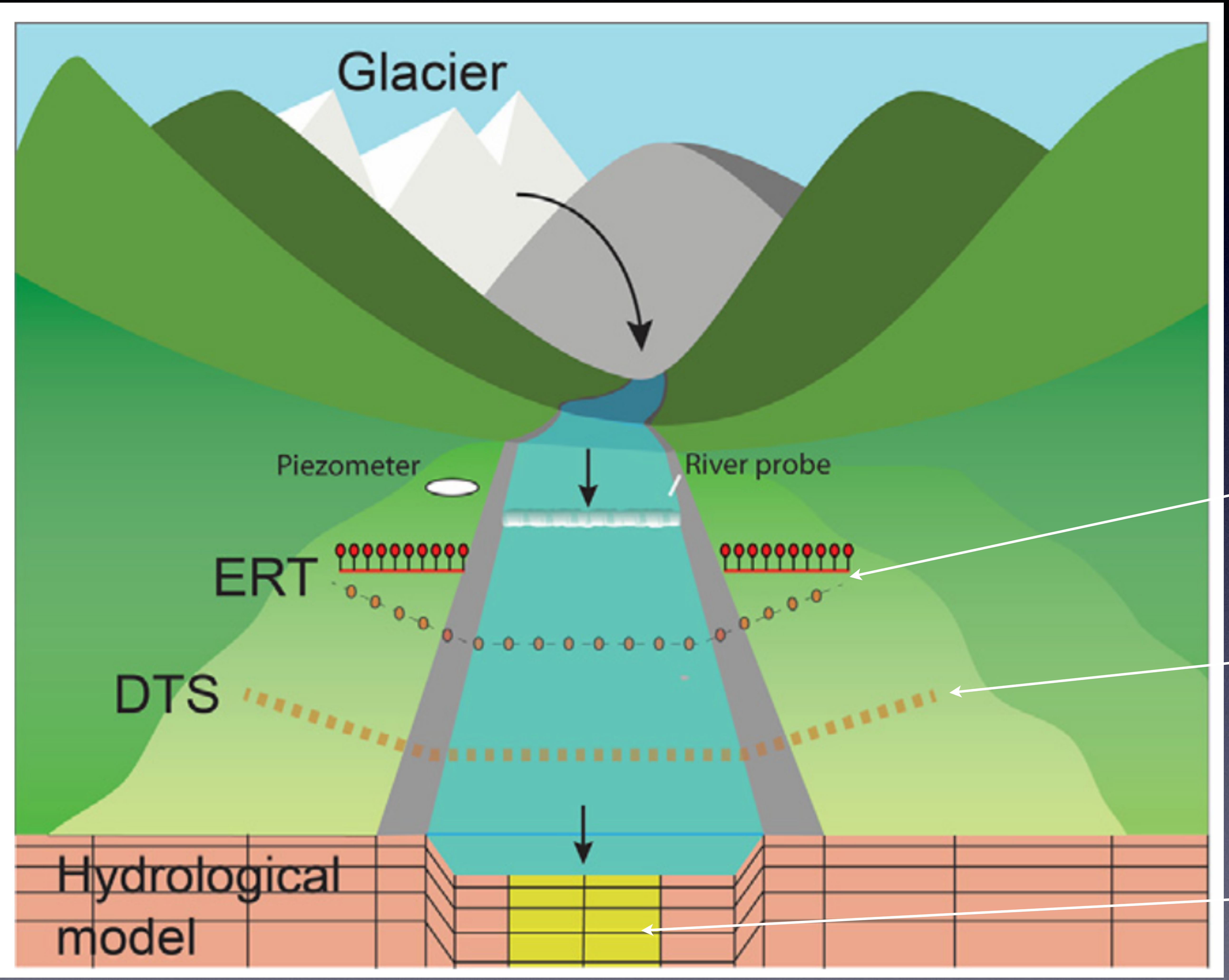


48 Electrodes beneath the river 1m spaced

+24 surface Electrodes



ERT for hyporheic studies



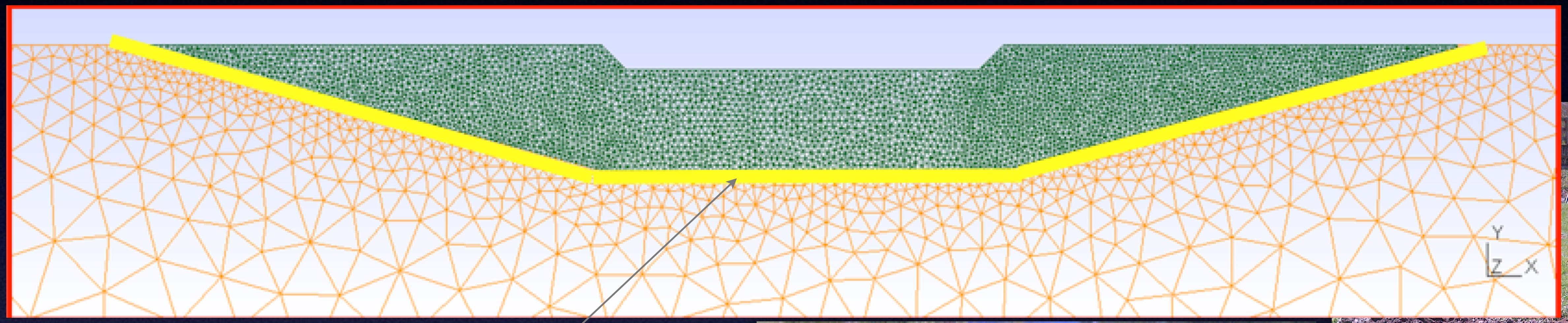
ERT

Optical fiber

Hyporeic zone

Geophysical methods: the dynamic characterization

DTS DISTRIBUTED TEMPERATURE SENSING



- 100 m hybrid fiber optic cable (with heating power copper wire), parallel to the ERT cable

- Ap-sensing Distributed Temperature Sensing (*raman* tech) 1m resolution

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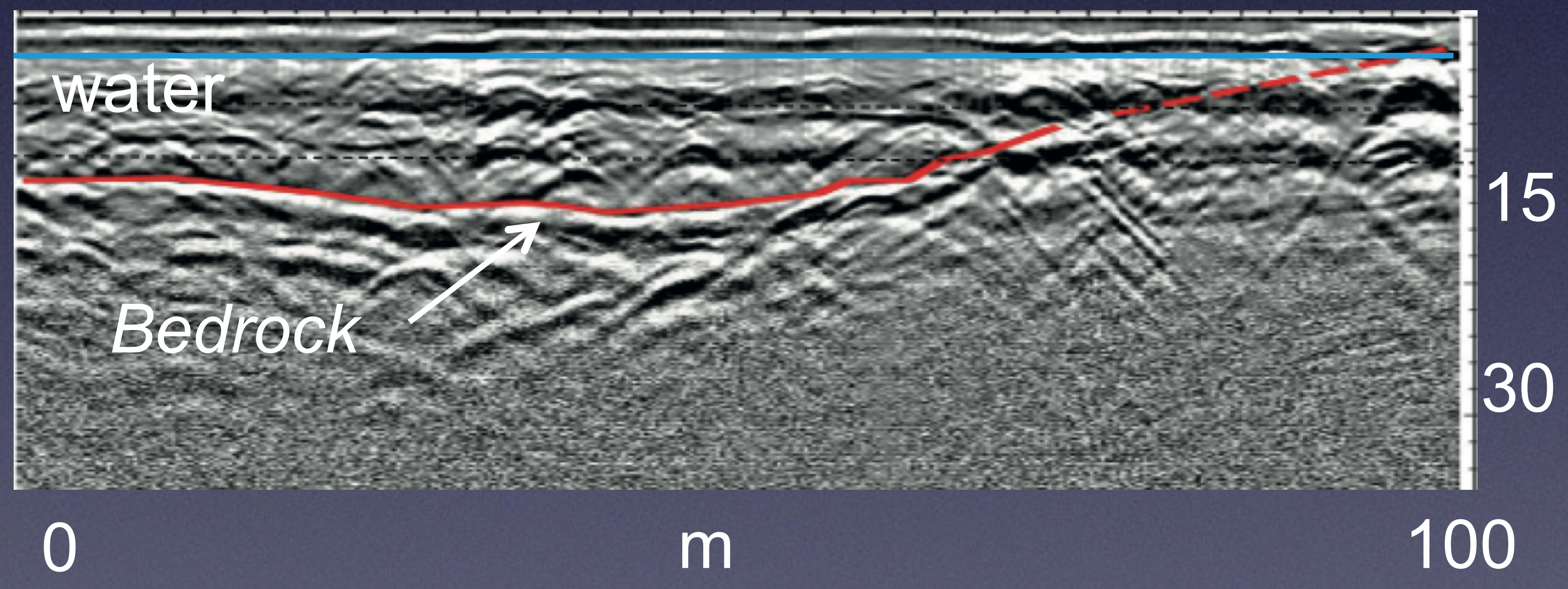
Geophysical methods: the dynamic characterization

Site preliminary characterization (static imaging)

Piezometer installation
+
Multi parameter probe in the river

- ERT
- SEISMIC
- GPR DATA

Typical heterogeneous glacial deposit, from boulders to silty clay….



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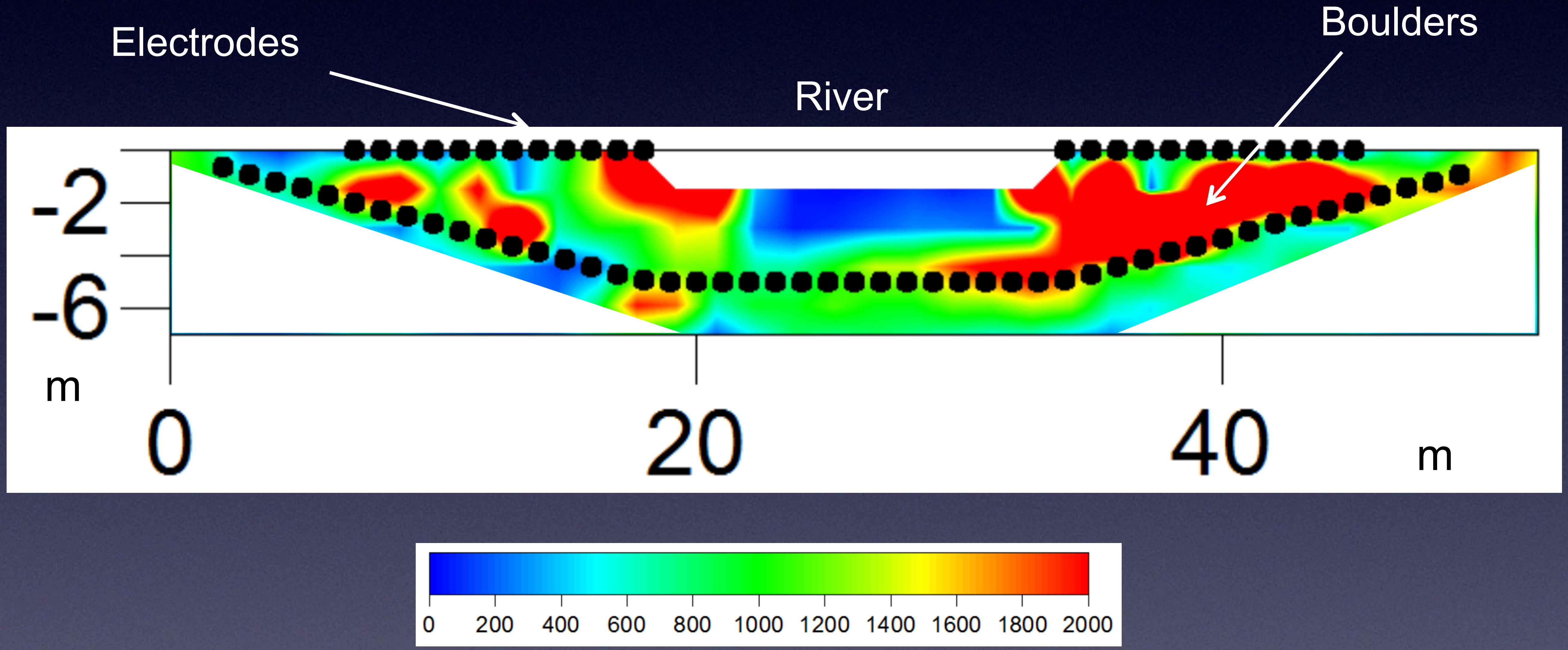
ERT static HZ imaging

R2 code, *Binley 2014*



Geophysical methods: the dynamic characterization

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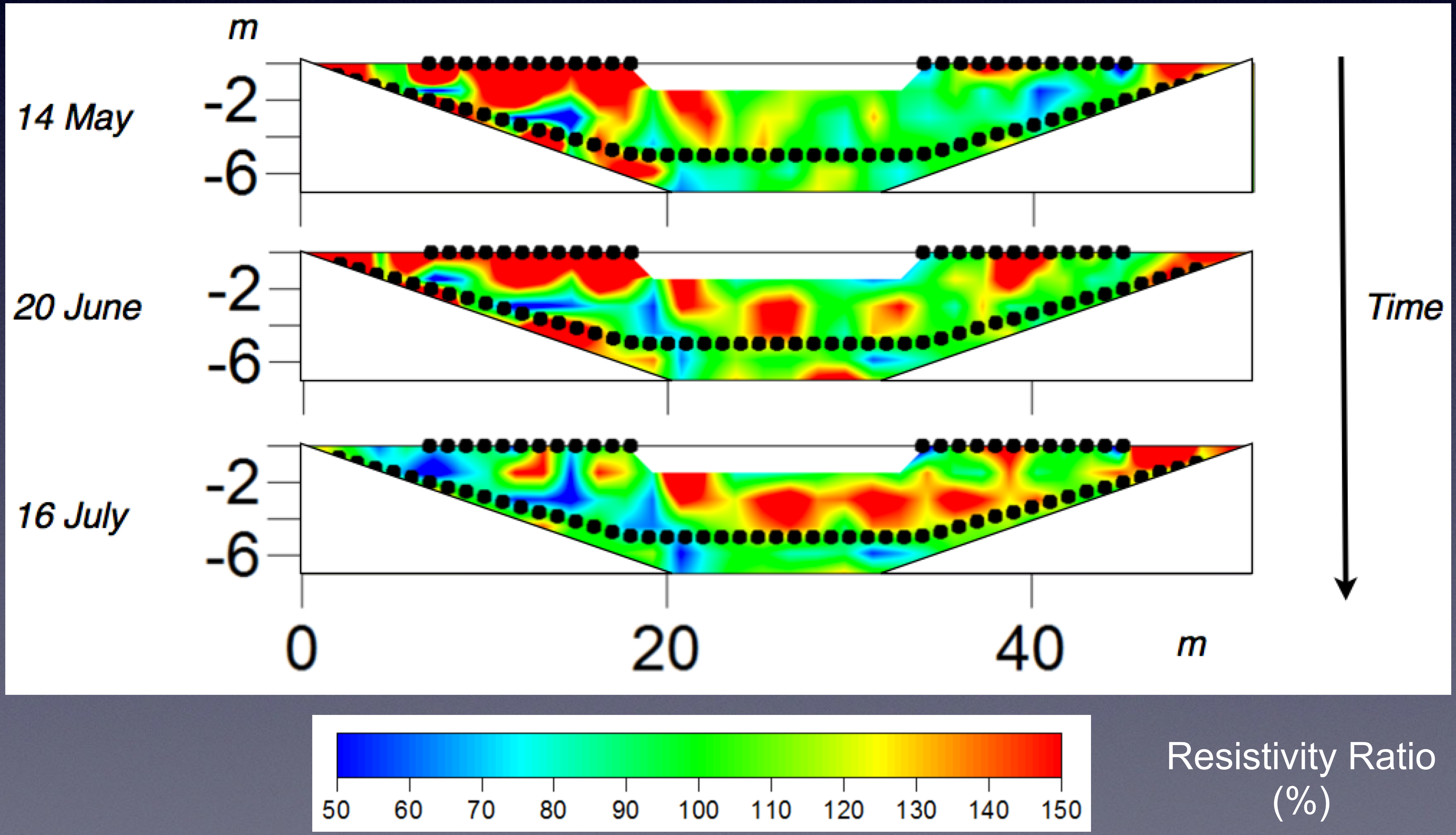
2. Time-lapse ERT results

R2 Code, *Binley 2014*

Res. Ratio = $(R_t / R_0) * R_{ohm}$



Resistivity Ratio (%)

Geophysical methods: the dynamic characterization

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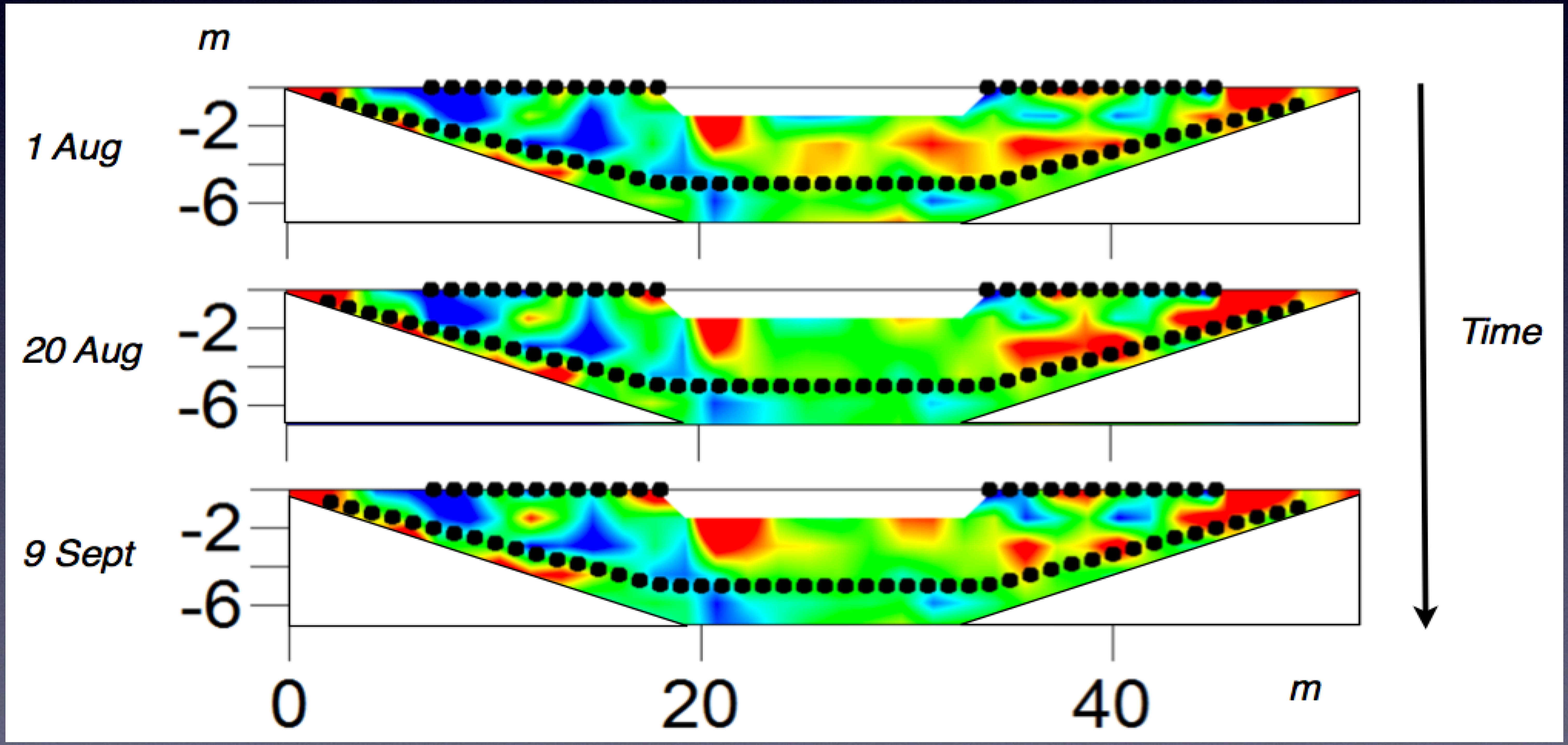
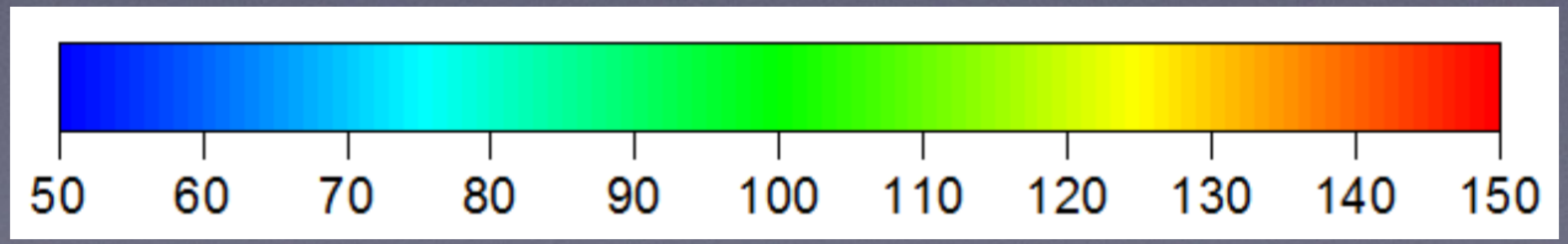
2. Time-lapse ERT results

R2 Code, *Binley 2014*

Res. Ratio = $(R_t / R_0) * R_{ohm}$





Resistivity Ratio (%)

Geophysical methods: the dynamic characterization

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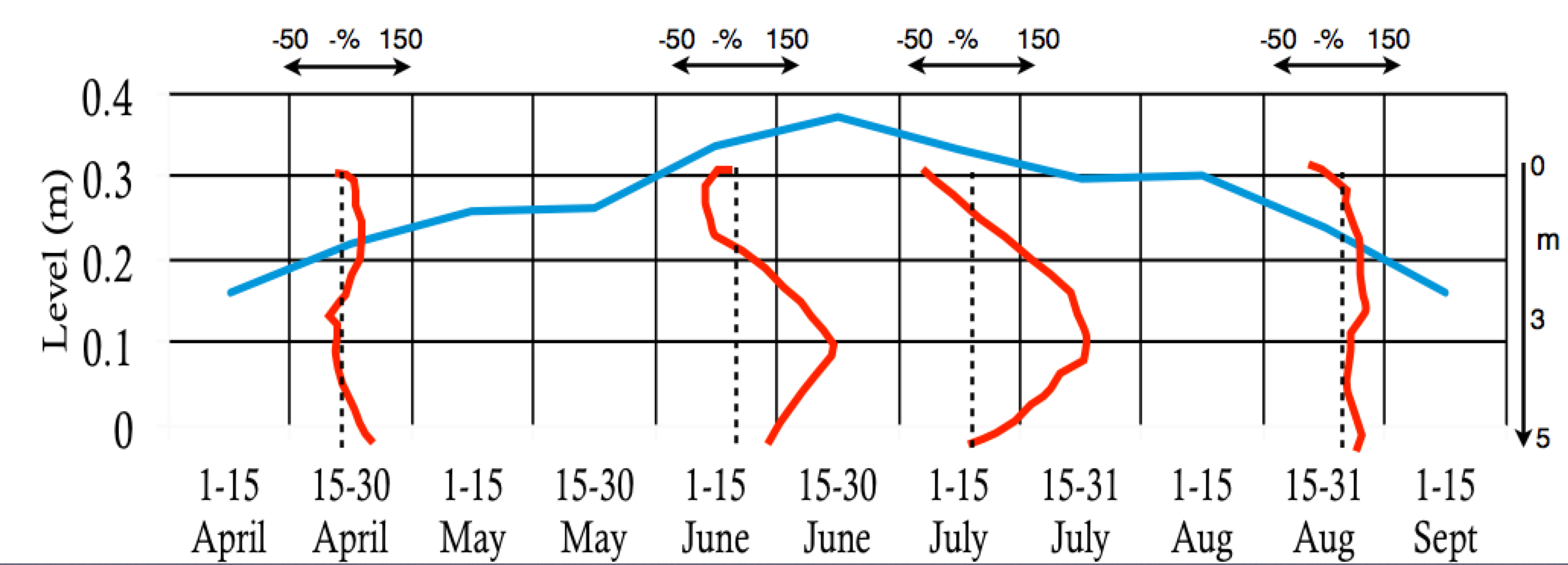
Average vertical ERT ratio and river level comparison

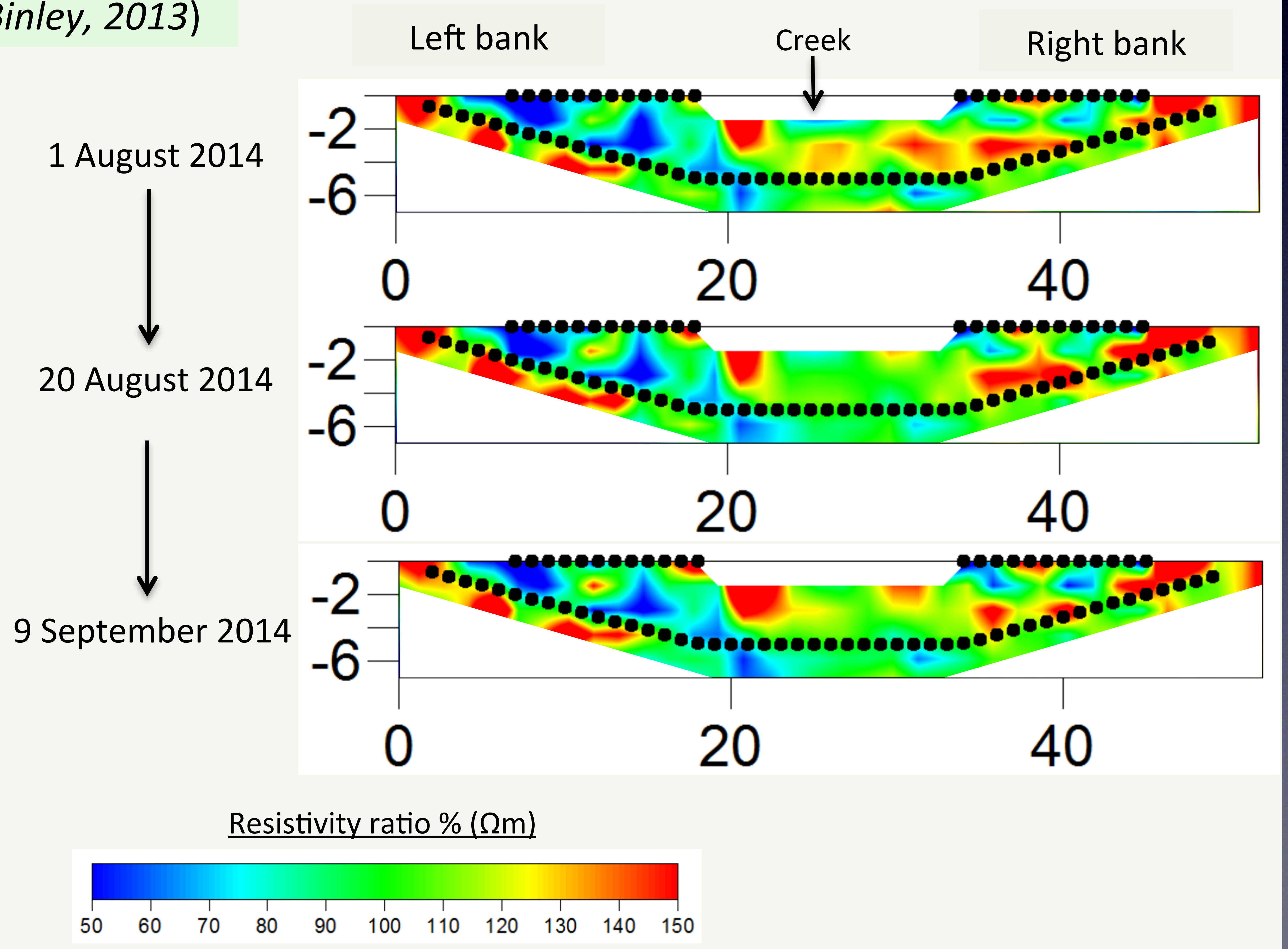


Preliminary ERT results: Time-lapse inversion

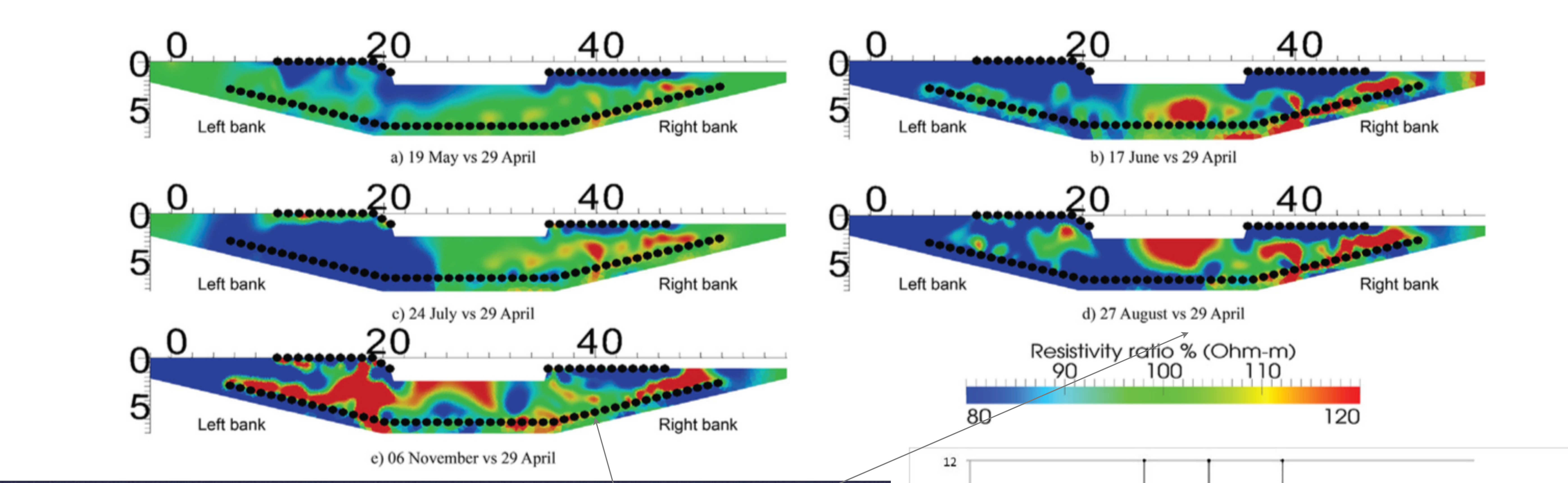
Resistivity variations over time, with respect to the background survey

R2, version 2.7a (*Binley, 2013*)

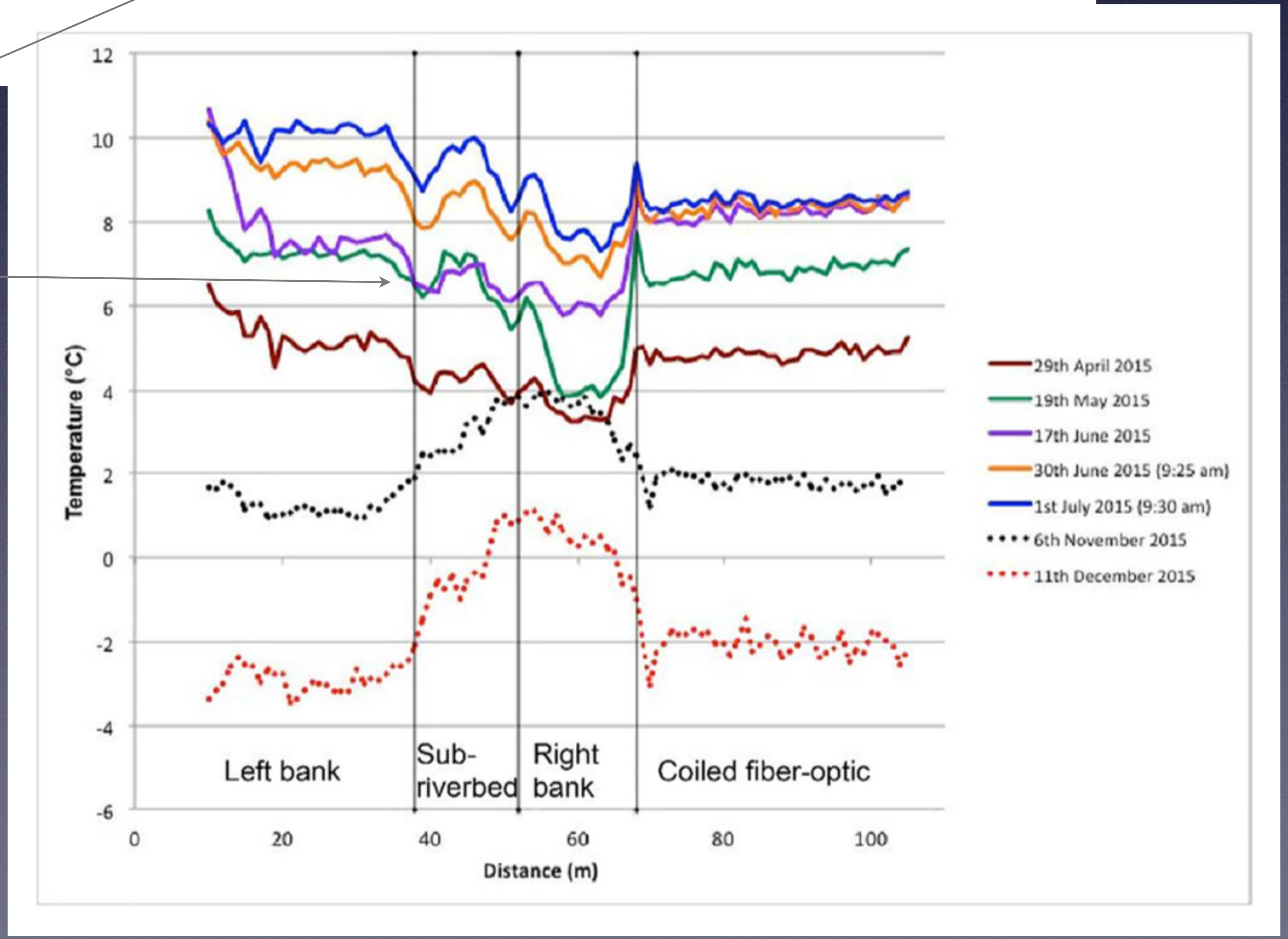
$$R_{ratio} = \frac{R_t}{R_0} R_{\mathrm{hom}}$$



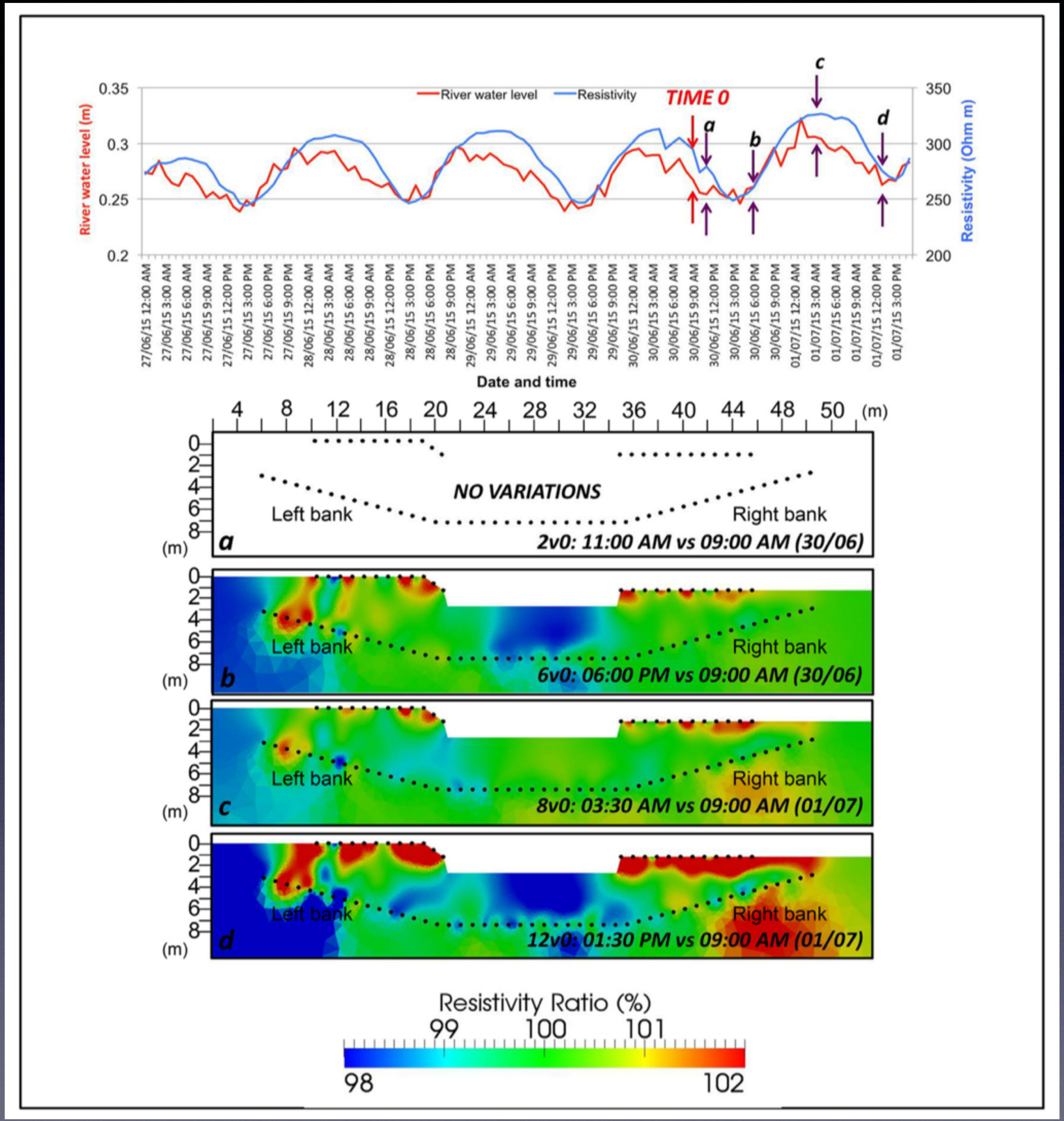
Long term Seasonal effect



Glacier melting effect



DTS
Fiber Optic temp



Short Term

Daily changes

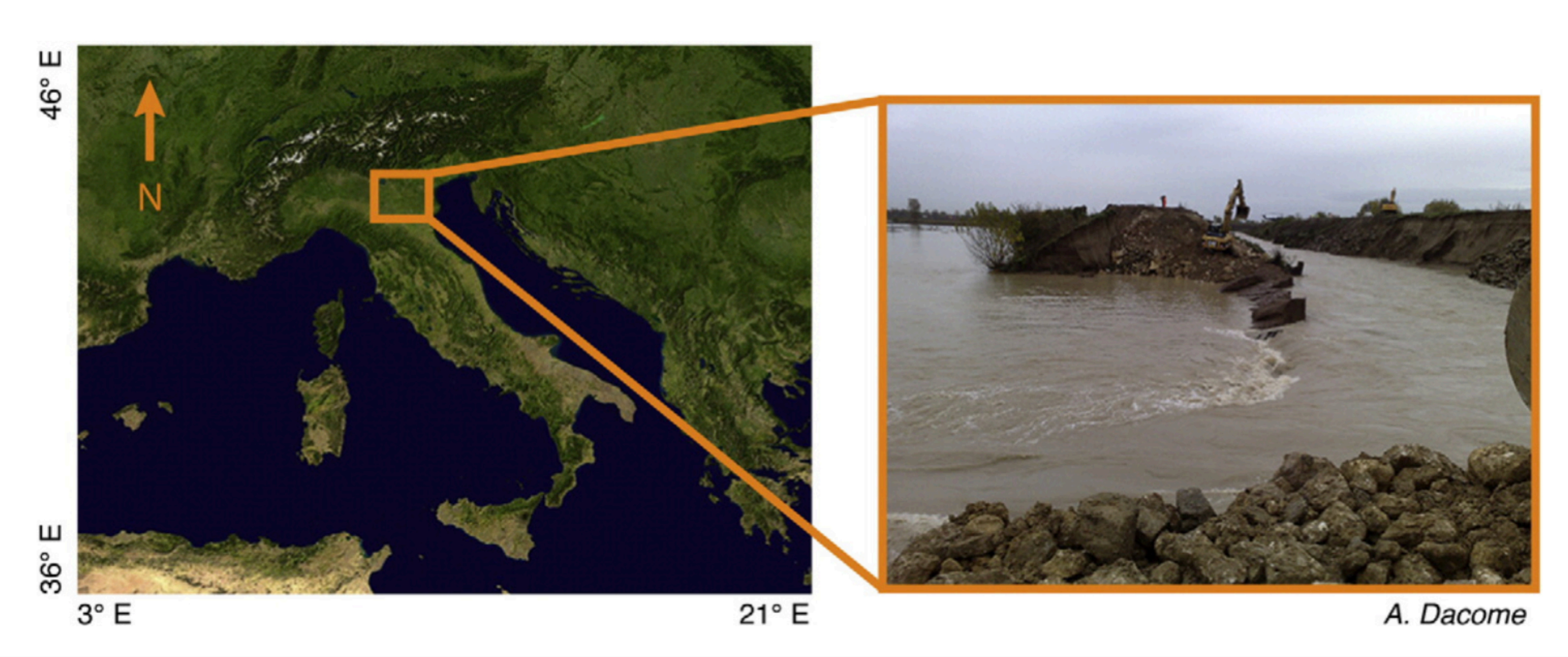
↓

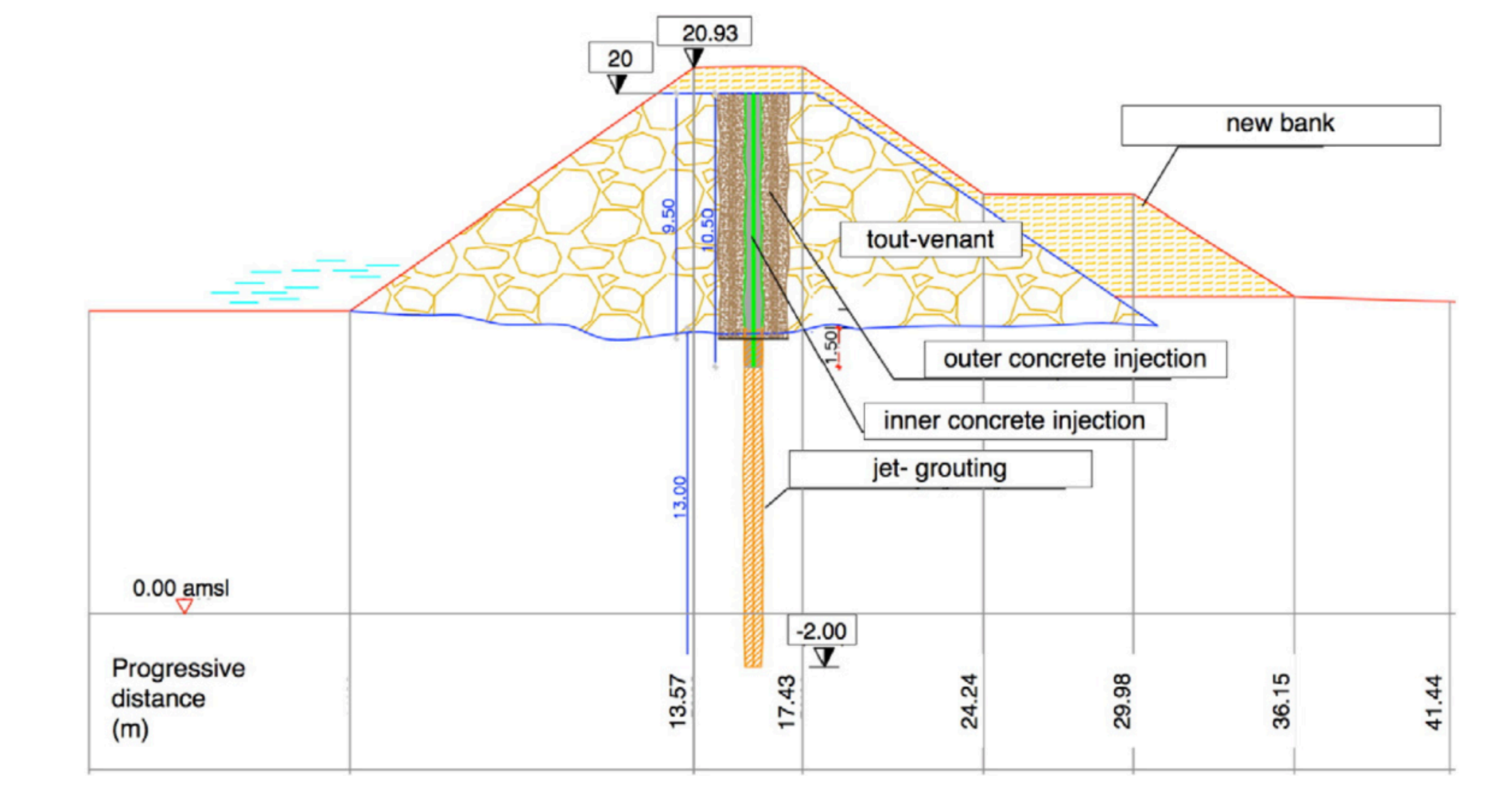
Hydrological models

Geophysical for the hydrological risks

2) Rivers management

Example the FRASSINE Reconstructed levee





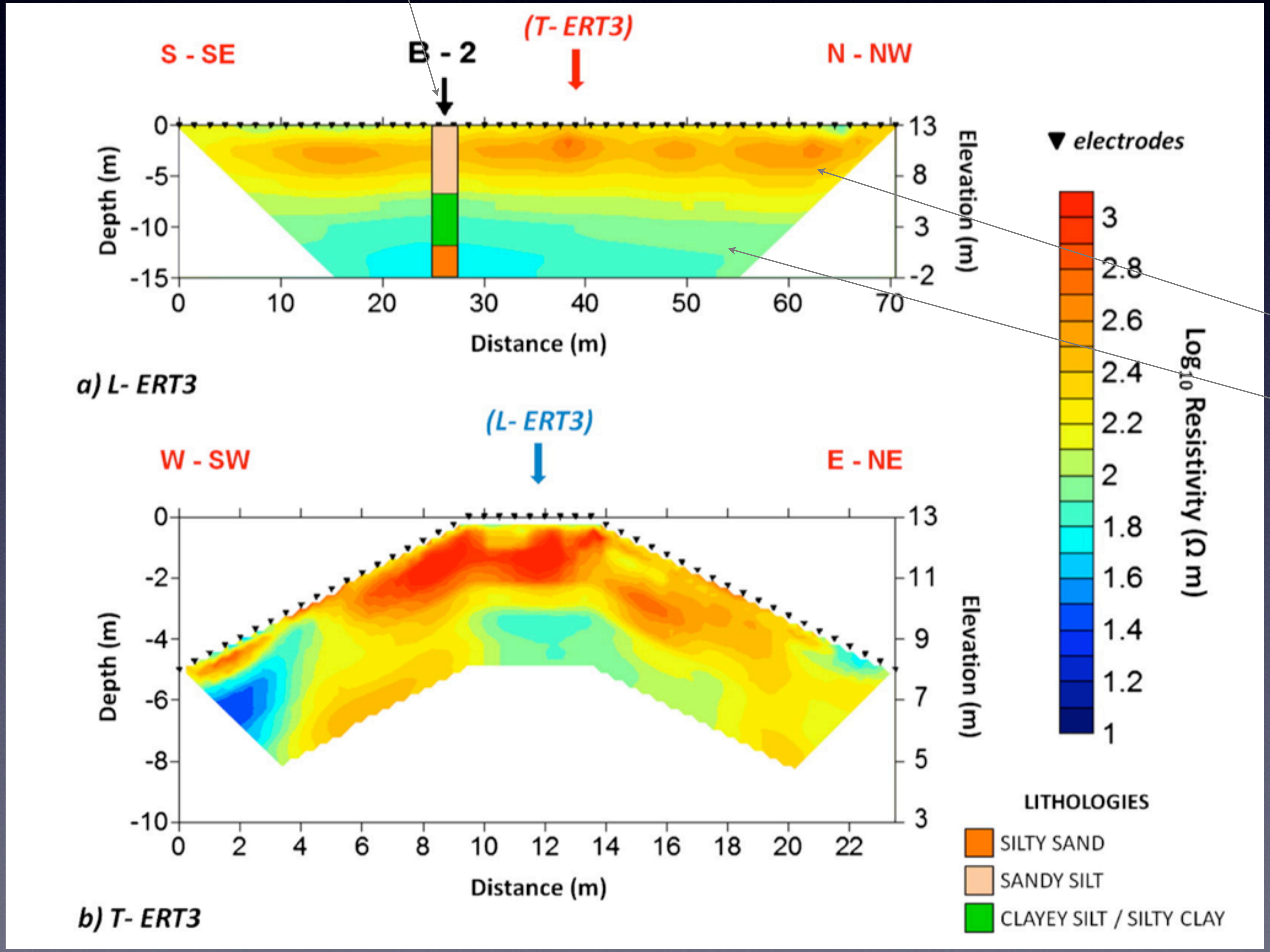
Jet grouting concrete septum

ERT for levee studies

Geophysical for the hydrological risks

Borehole

Fluvial levees monitoring



Sand

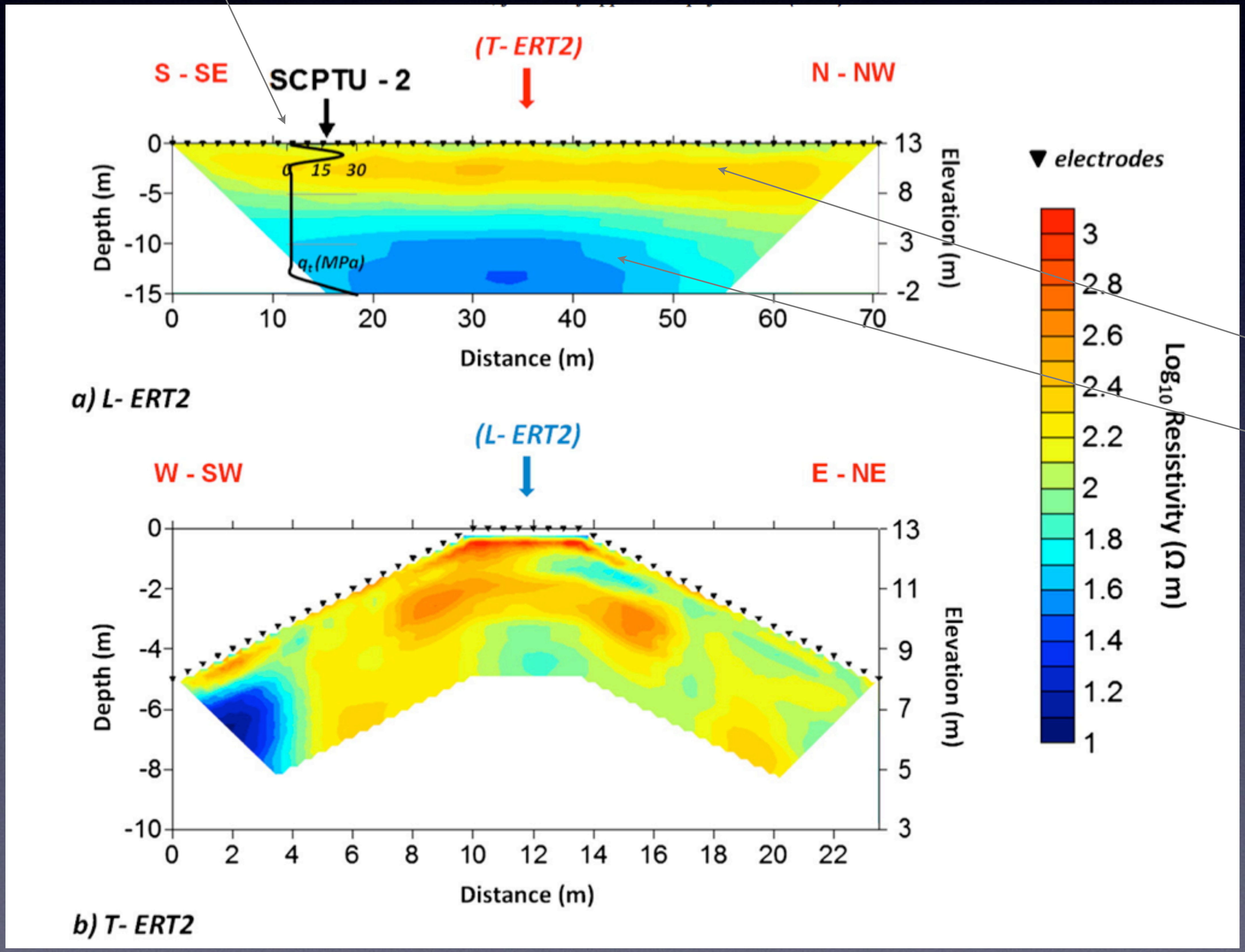
silt/clay

ERT for levee studies

Geophysical for the hydrological risks

CPTU test

Fluvial levees monitoring



Sand

silt/clay

Good agreement with geotechnical Info

ERT for levee studies

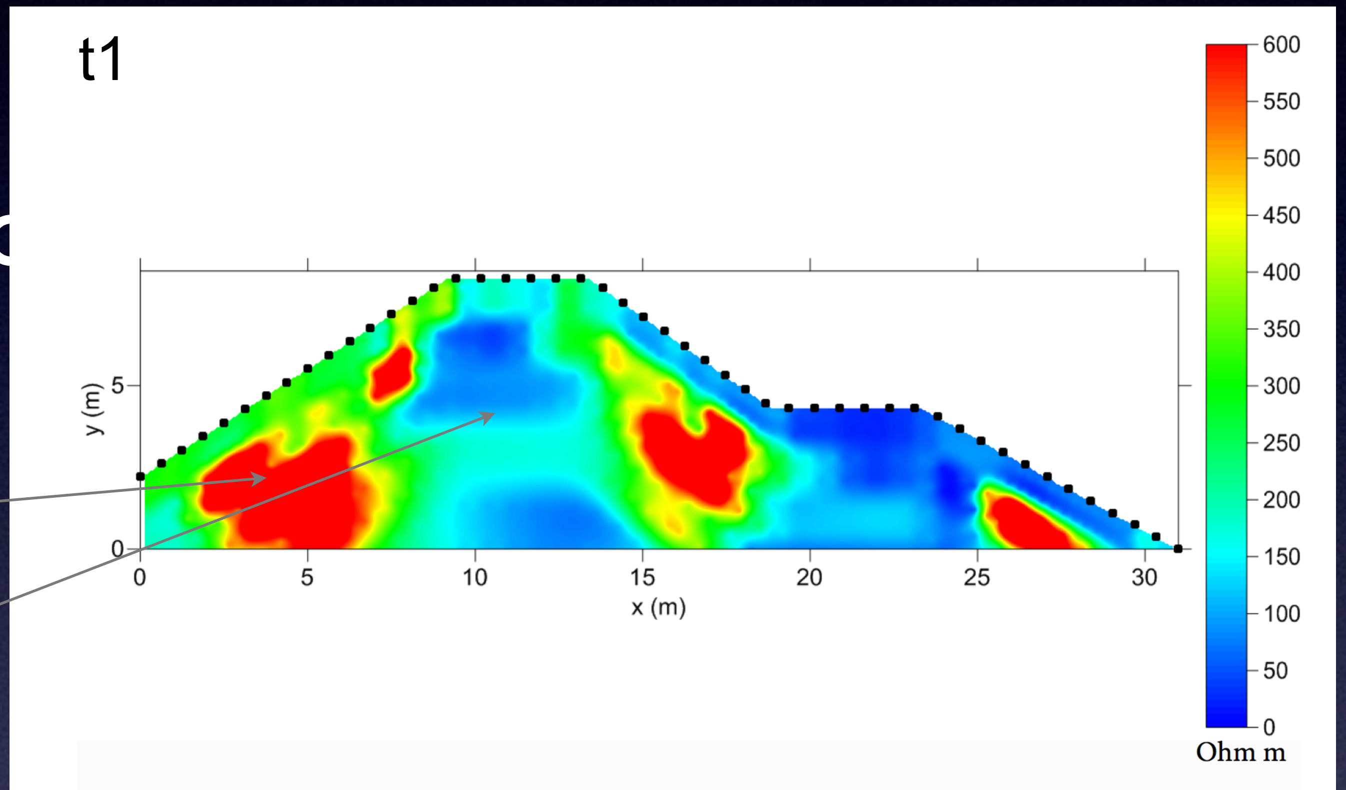
Geophysical for the hydrological risks

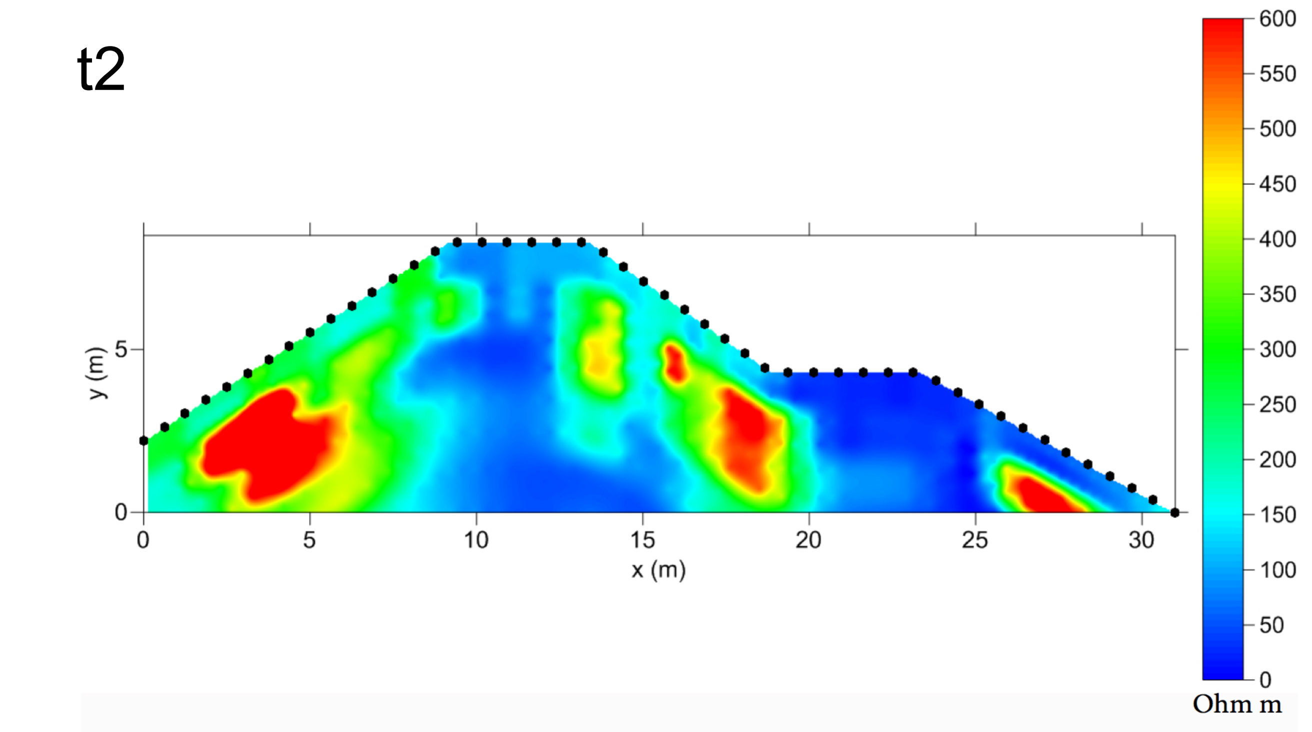
A. Binley R2 code

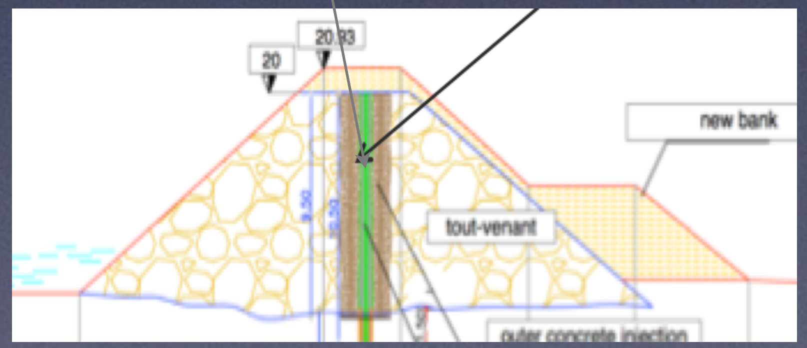
ERT transverse
- Top resolution
  - Ok for laterally extensi

Tout Venant

Jet grouting
Septum







3) Water resources management

ERT

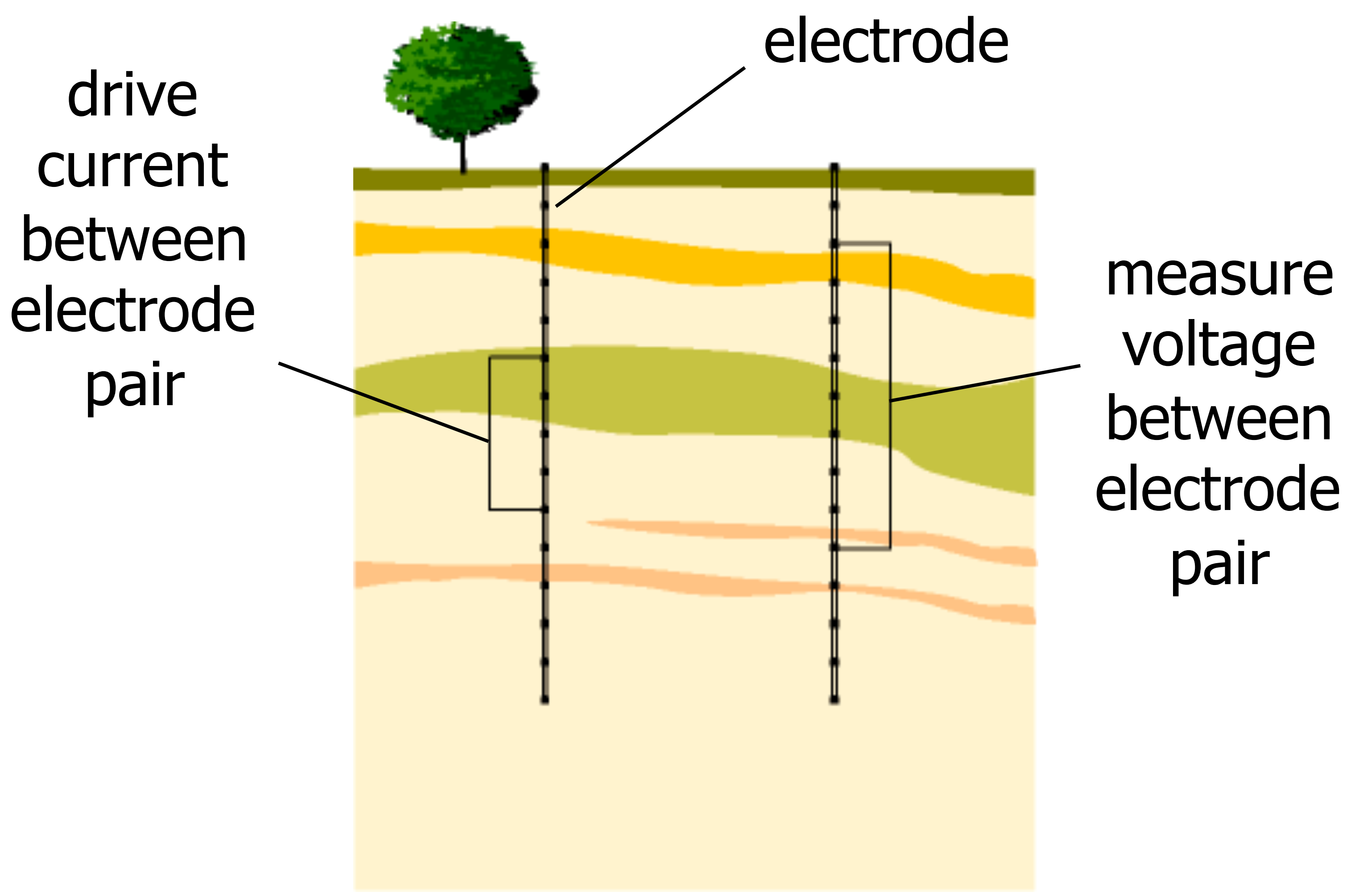
And

ERT in TIME LAPSE

Resistivity cross-borehole imaging

Electrodes in two (or more) boreholes can also be used to gain maximum resolution – *cross-borehole electrical resistivity tomography (ERT)*

Stainless steel mesh, copper and lead are common electrode materials.



DIPARTIMENTO DI GEOSCIENZE

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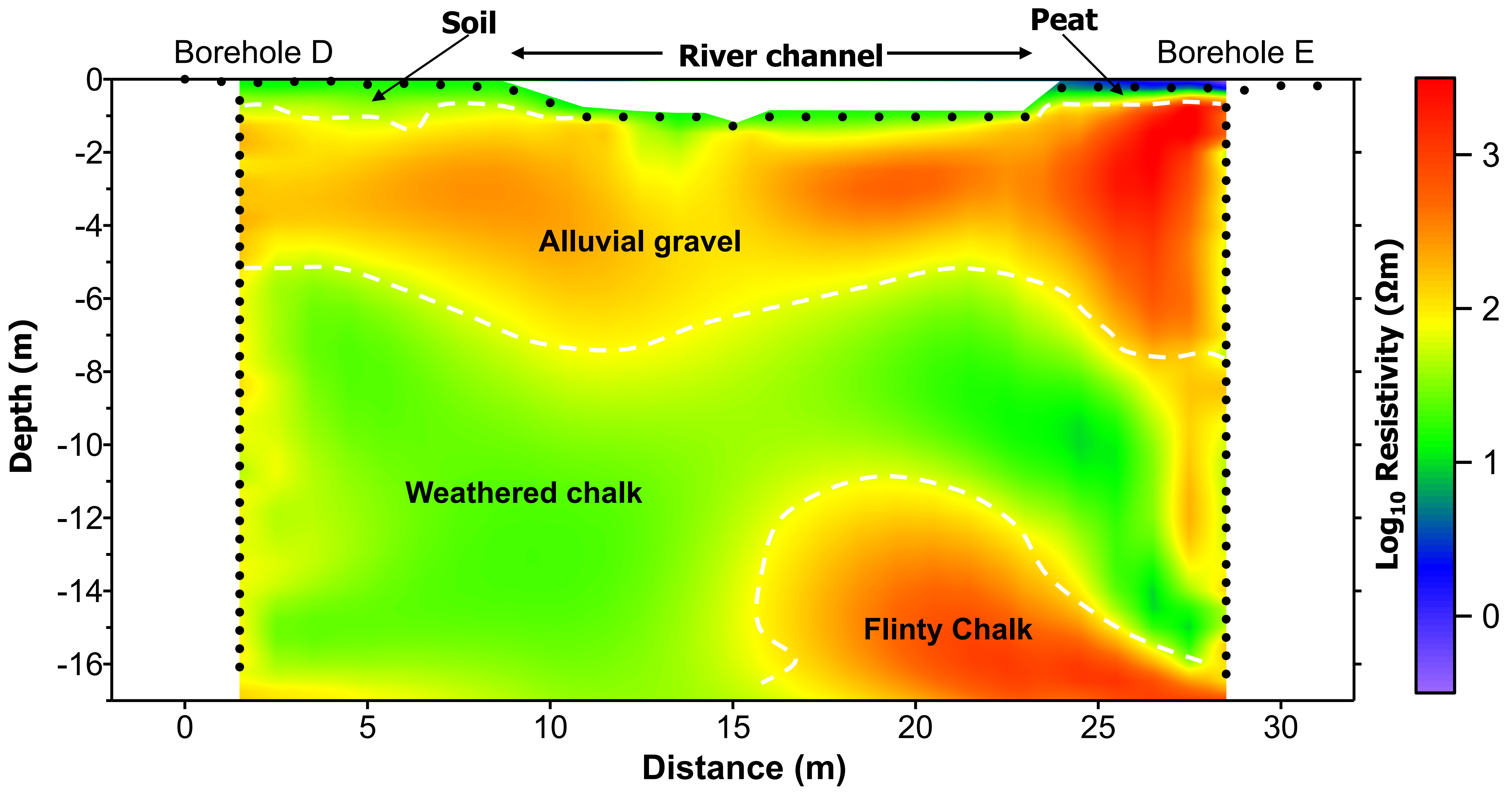
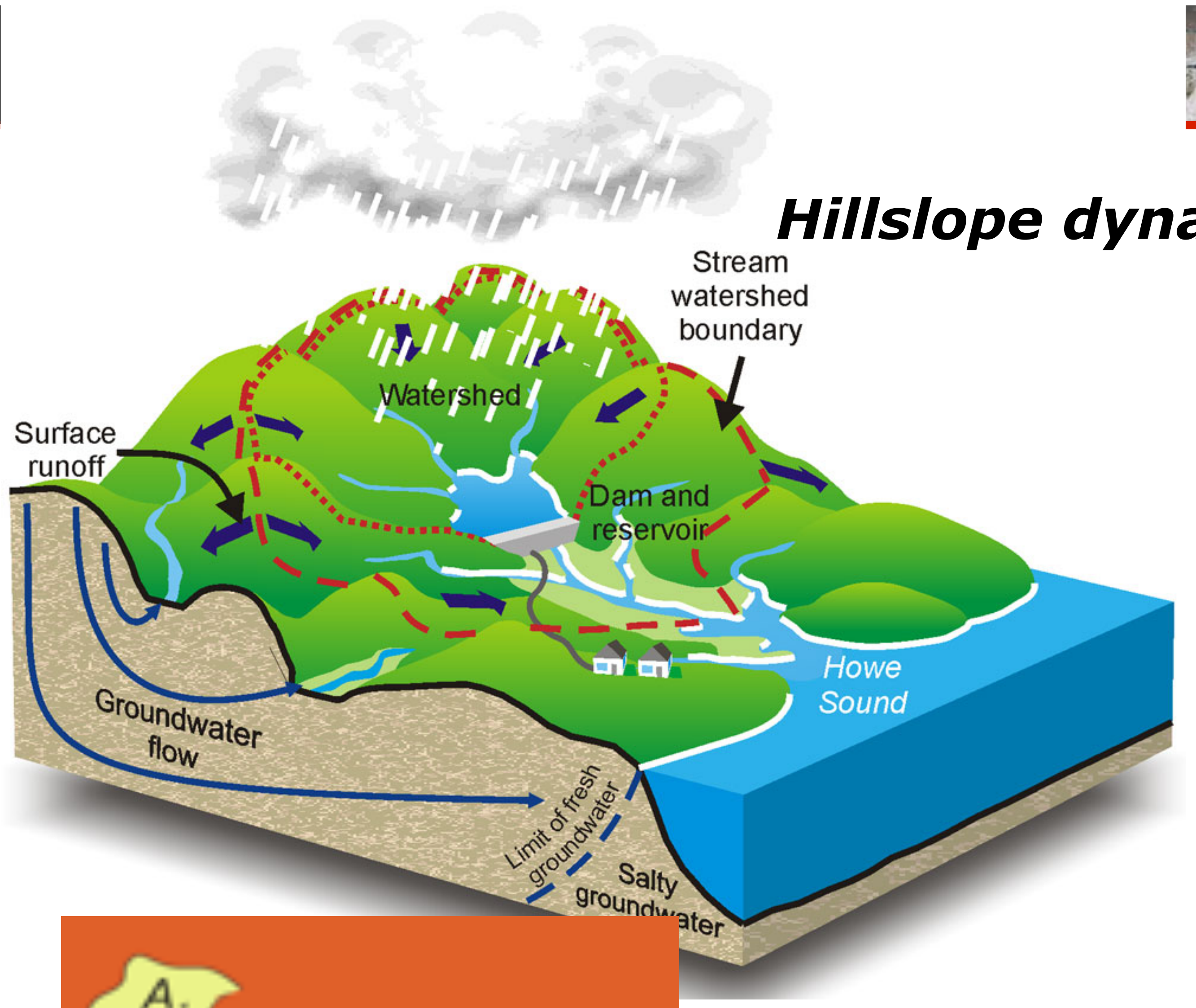
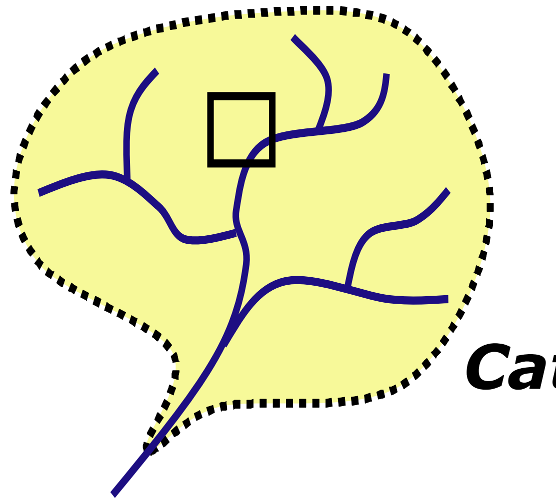
Example application to study subsurface structure beneath a river channel

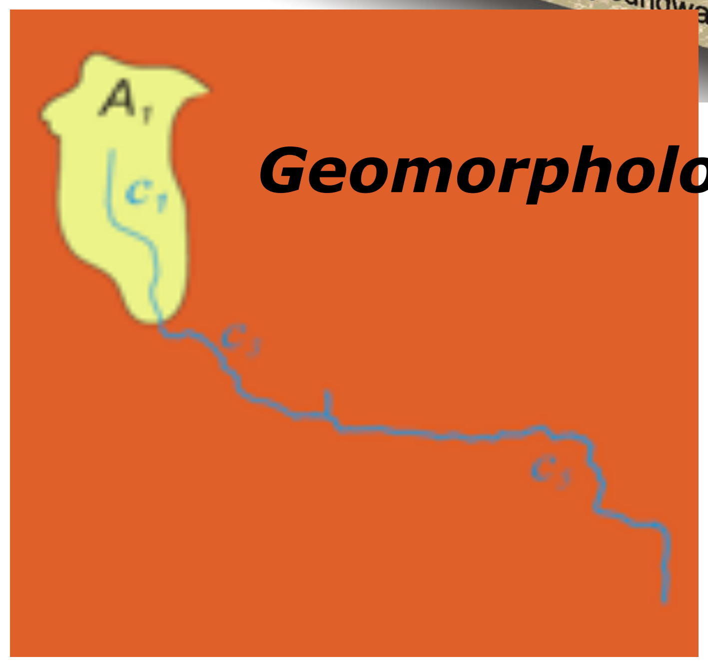




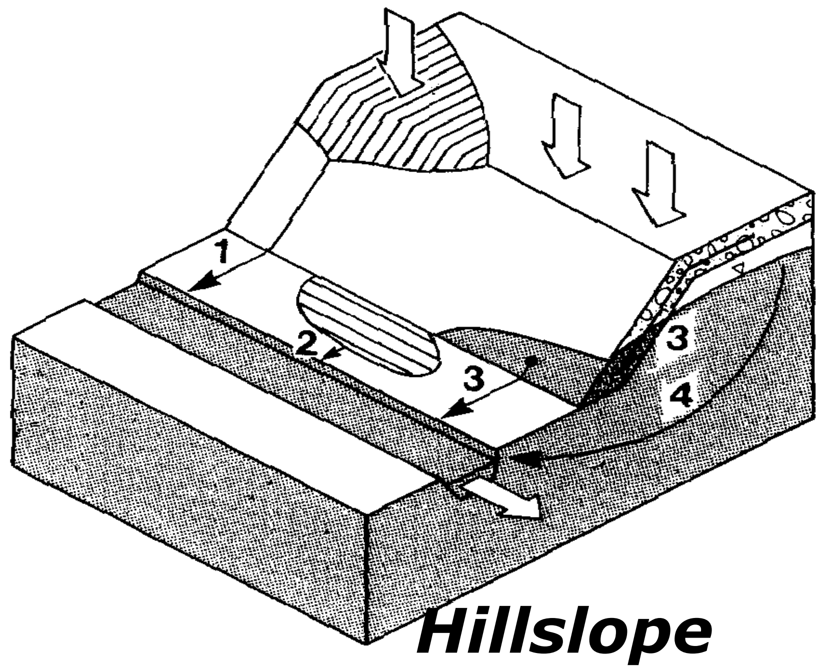
Hillslope dynamics



Catchment



Geomorphologic IUH



Hillslope

Deiana et al
2014

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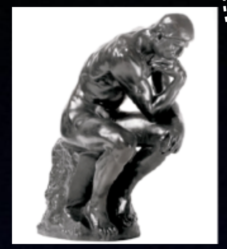
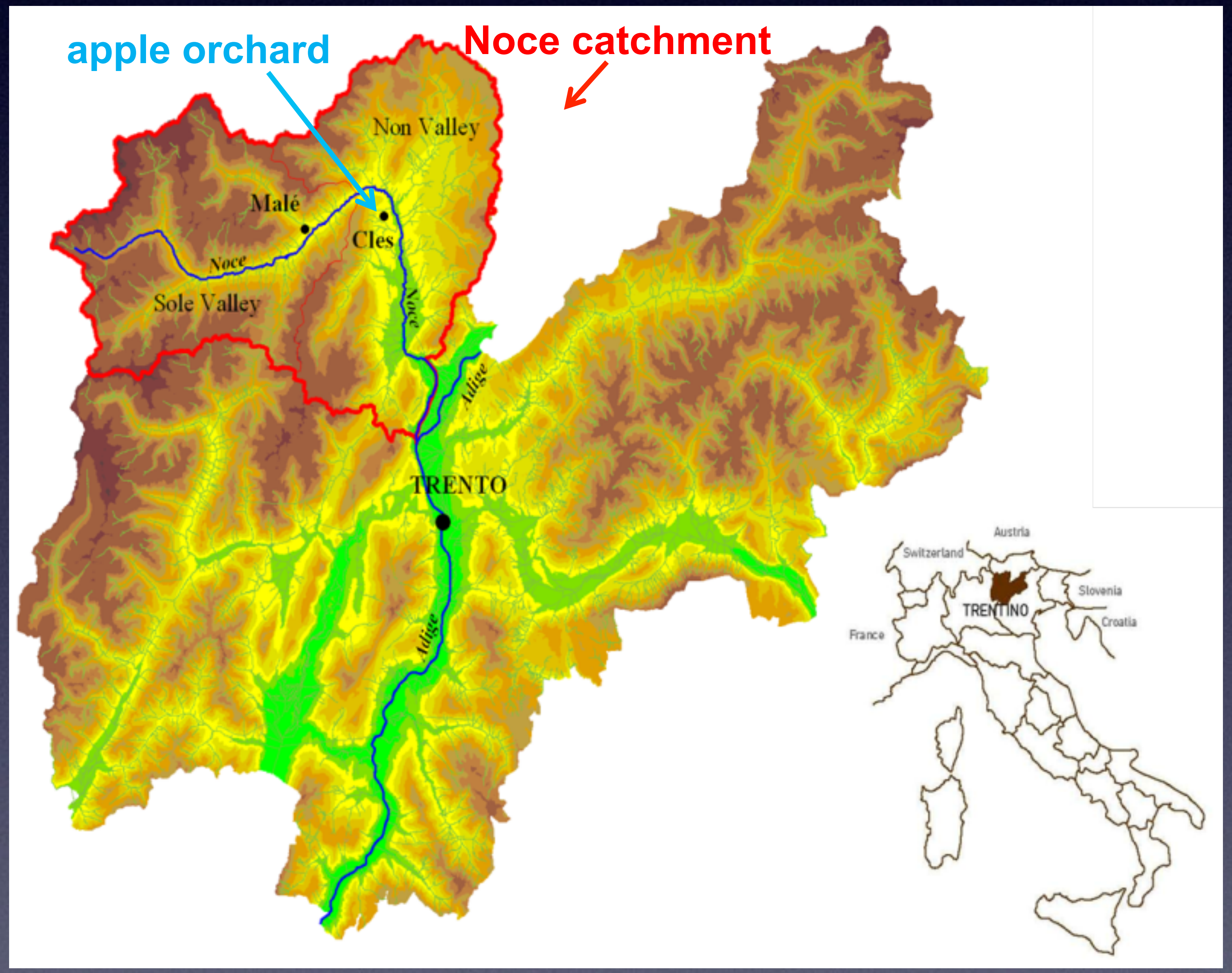
Geophysical methods: the dynamic characterization

"Val di Non" Apple Orchard



Tree water uptake has small scale

micro ERT time lapse case study

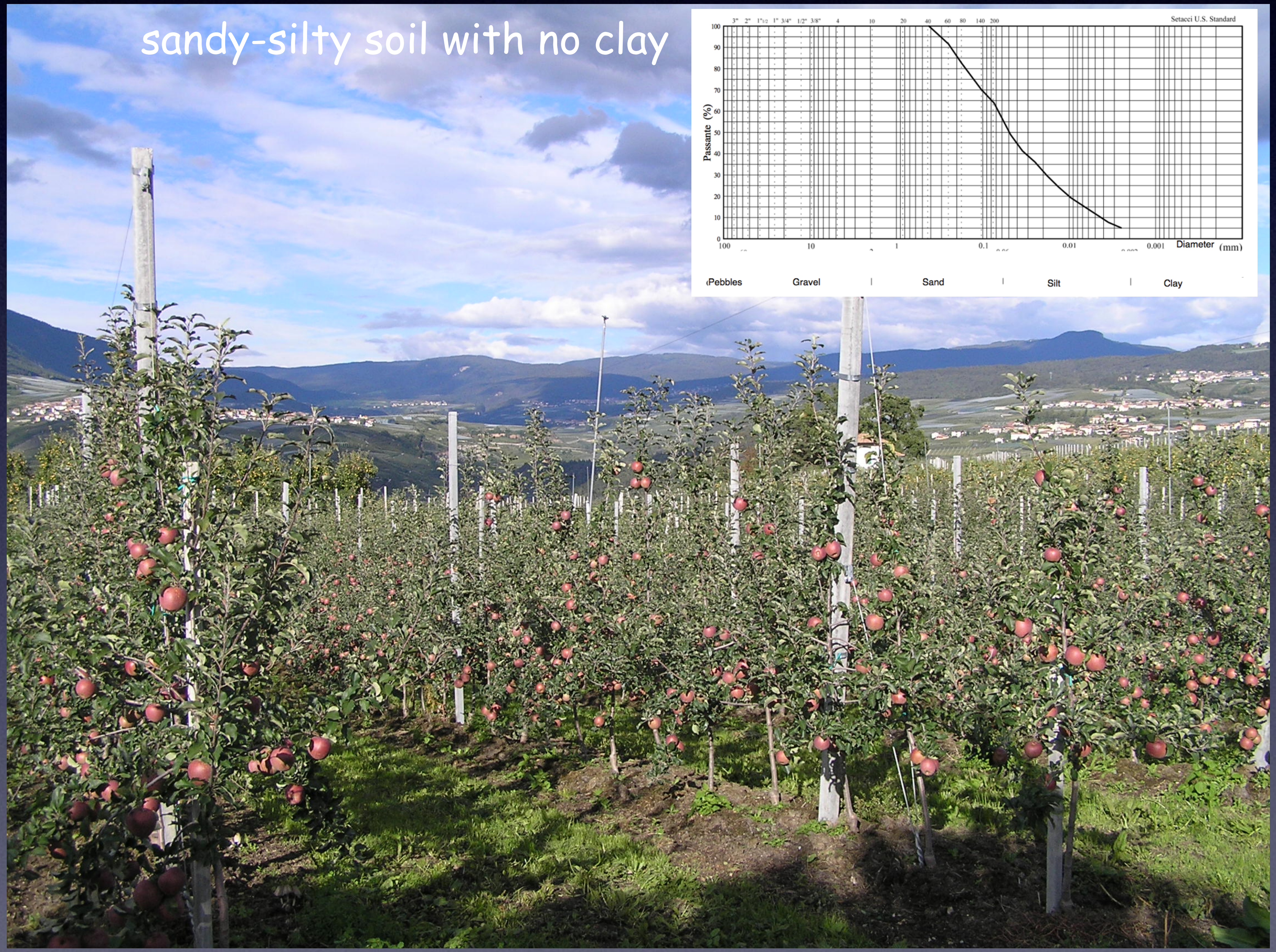


FP7

CLIMB

Geophysical methods: the dynamic characterization

Val di Non Apple Orchard case study



Geophysical methods: the dynamic characterization

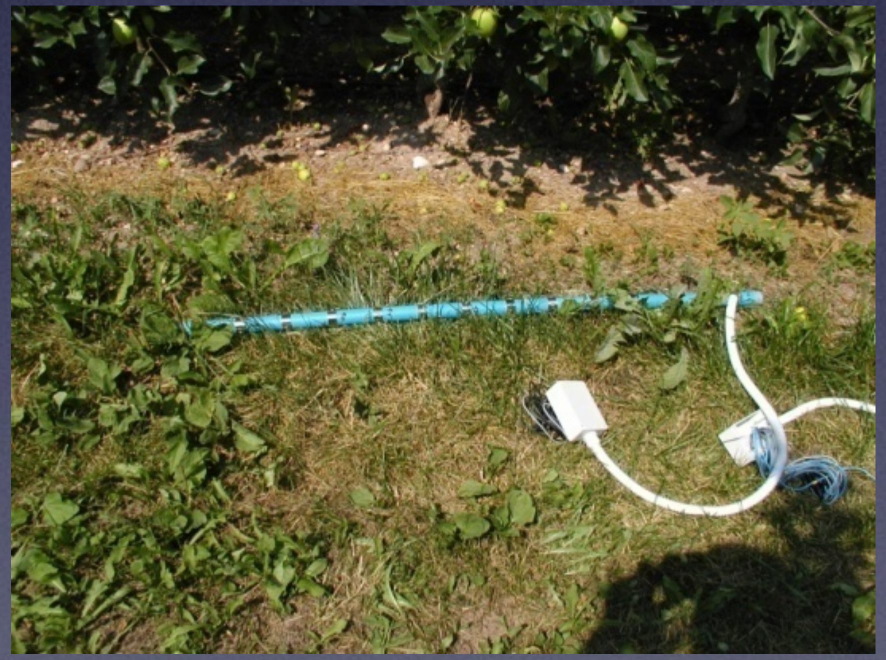
Construction of the micro ERT cross-borehole system

4 PVC tubes
Length =120 cm;
Ø= 1 inch

Totally internal wiring

Built with 10 cm water-tight segments to allow internal link operability

Stainless steel circular electrodes with height of 3 cm



Geophysical methods: the dynamic characterization

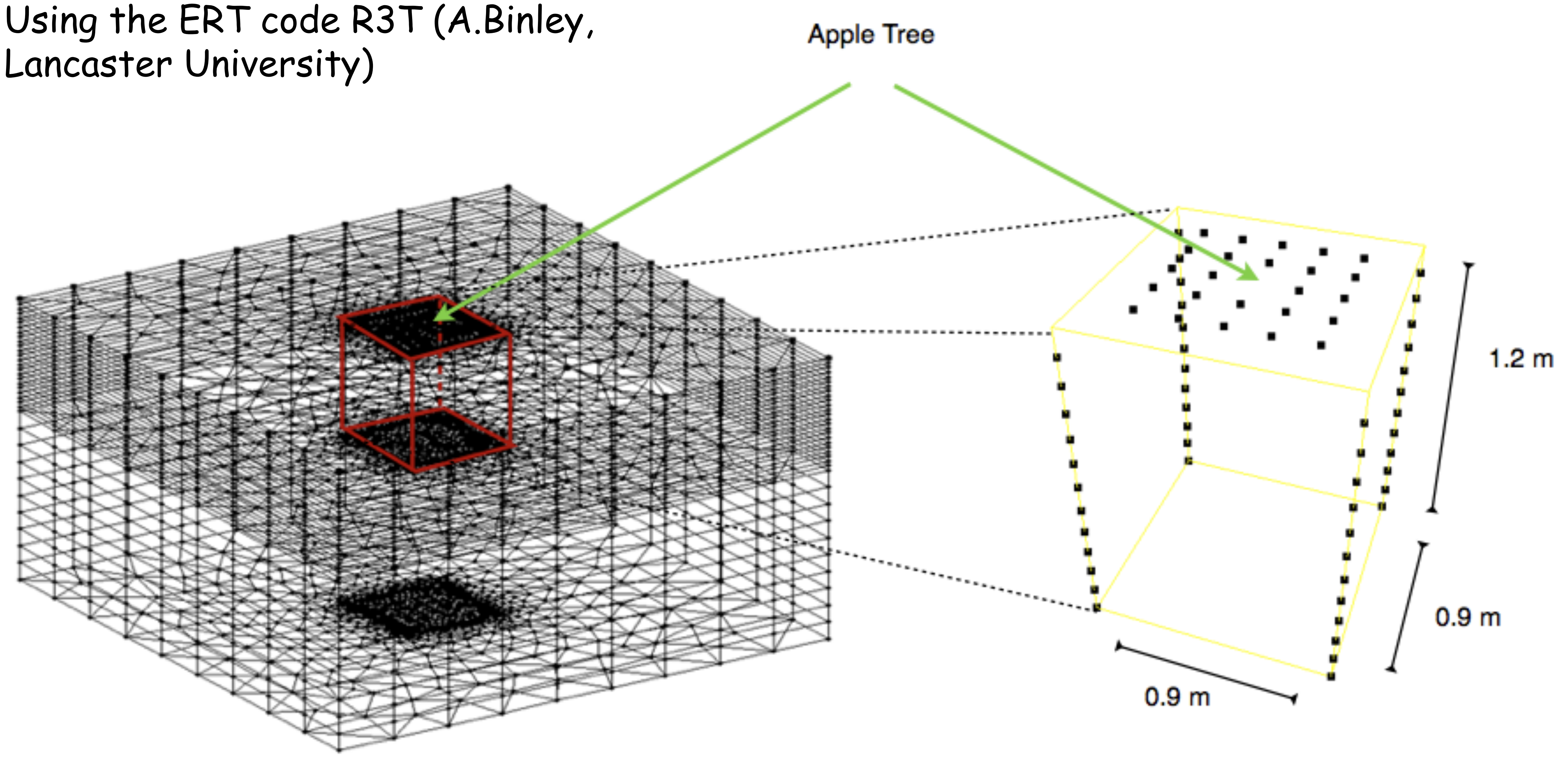
Installation without pre dig for the max electrode-soil coupling

Selected an apple tree already monitored by other means (dielectric probes)

Resistivimeter SYSCAL pro 72 channels (48 in boreholes, 24 on surface)

ERT inversion

Using the ERT code R3T (A.Binley, Lancaster University)



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Geophysical methods: the dynamic characterization

Repeated (seasonal) measurements

Date	Note
15/10/10	Installation and Measurement 1
14/01/11	Measurement 2
04/04/11	Measurement 3
28/04/11	Measurement 4
18/05/11	Measurement 5
06/07/11	Measurement 6
04/08/11	**Measurement 7 + Irrigation TEST**
07/09/11	Measurement 8
05/10/11	Measurement 9
03/05/12	**Measurement 10 + Irrigation TEST**
04/11/12	**Measurement 11 + Irrigation TEST**

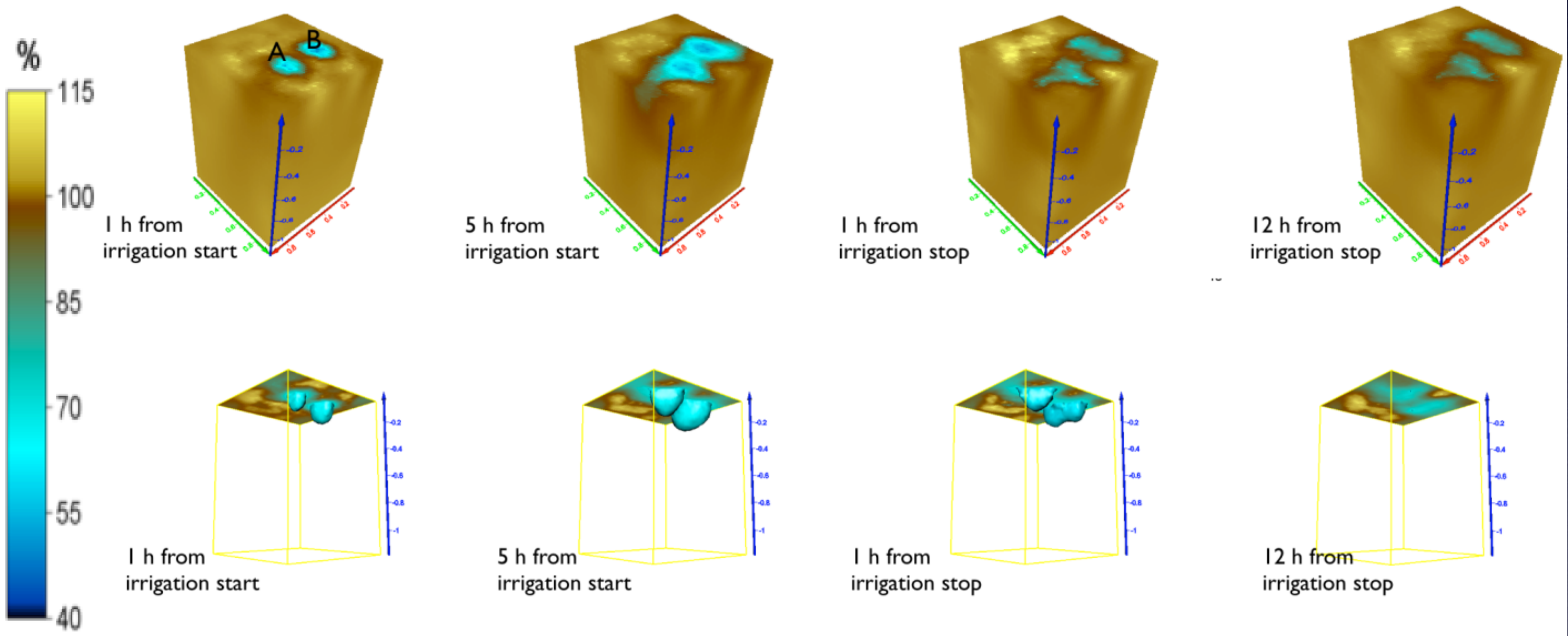
August 2011: irrigation performed via two drippers total flow rate =2.4 l/h for six hours, following a long dry period

May 2012: widespread irrigation performed via a sprinkler ; total water volume = 500 l over 2.5 hours, at the top of growing season.

November 2012: widespread irrigation performed via a sprinkler ; total water volume = 500 l over 5 hours, wet period following apple harvest (low ept).

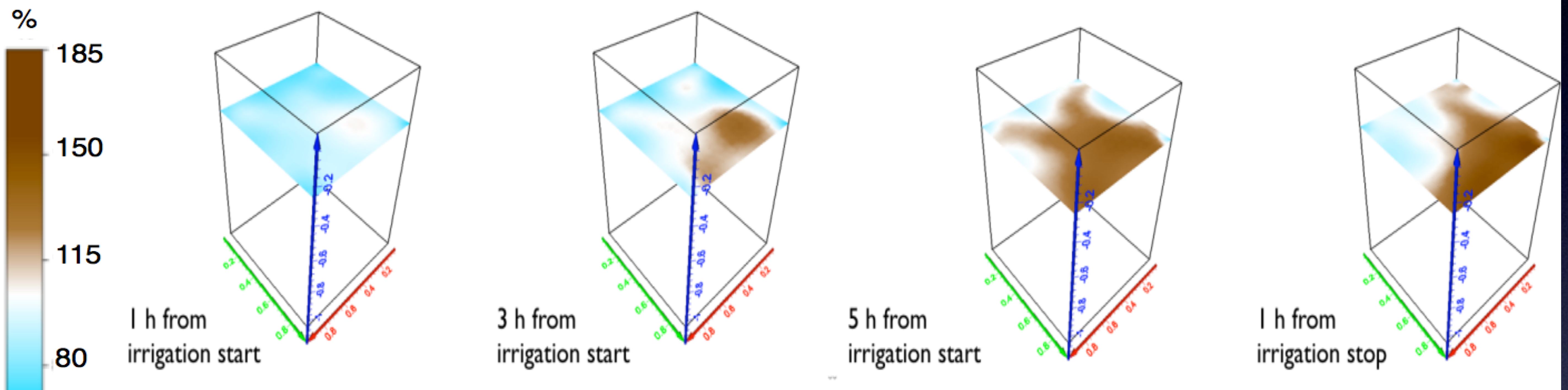
August 2011 experiment: resistivity ratio with respect to background at four time steps.

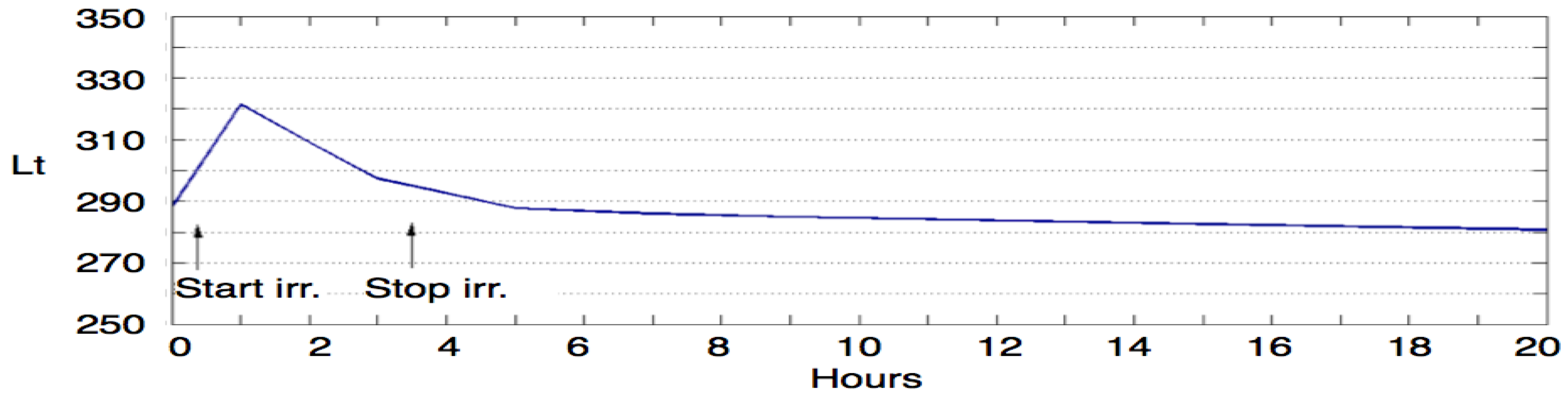
The iso-surface equal to 60 % of the background resistivity does not penetrate any deeper than 30-40 cm below ground surface.



Boaga et al., 2013

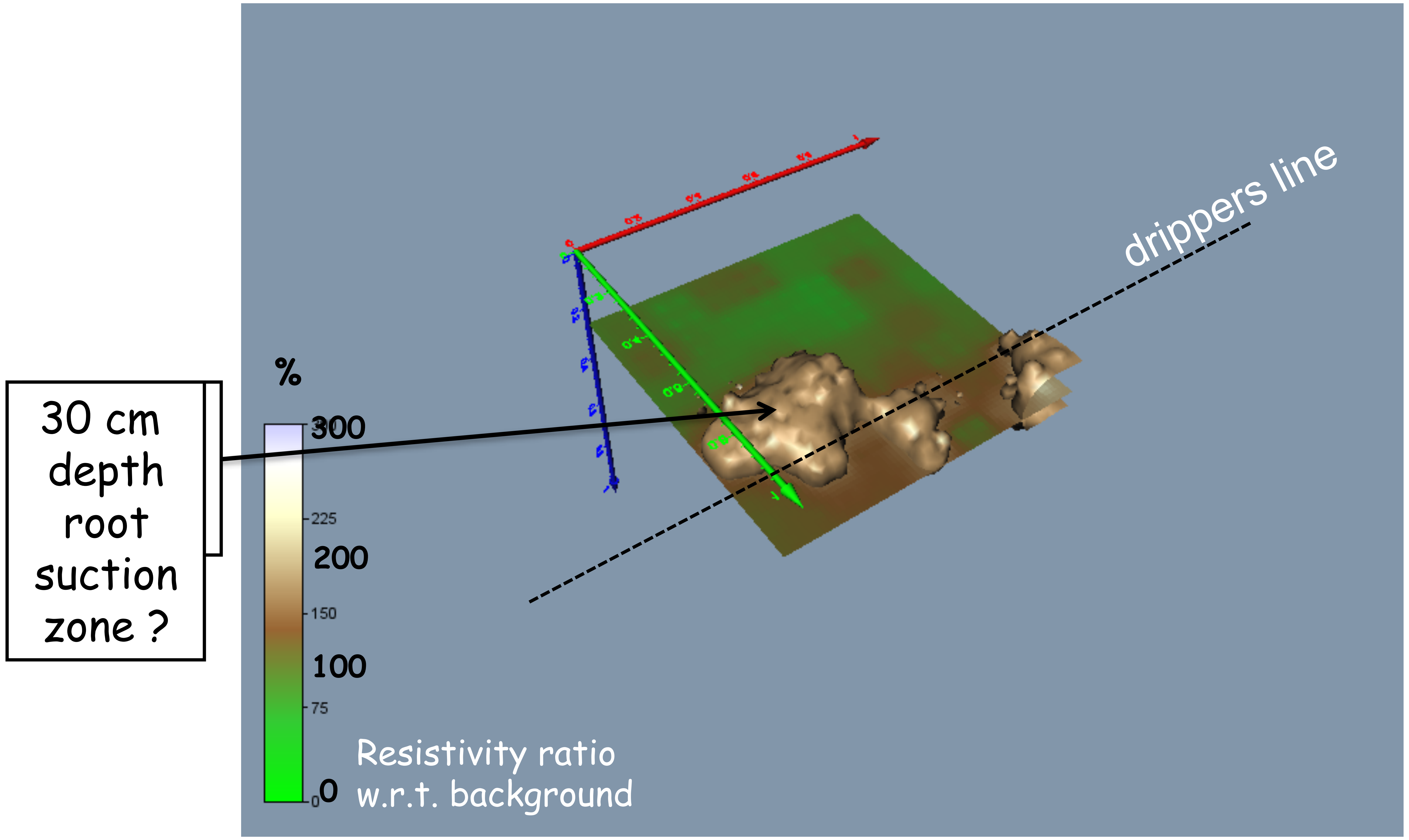
May 2012 experiment: resistivity ratio with respect to background at four time steps shown on the horizontal slice at 30 cm depth.





Moisture content measured by TDR in the top 32 cm.
The moisture content was already high at the start of the experiment.

<u>May 2012 experiment</u>: resistivity ratio with respect to background at 30 cm depth and at 8.5 hours after start of irrigation



Boaga et al., 2013

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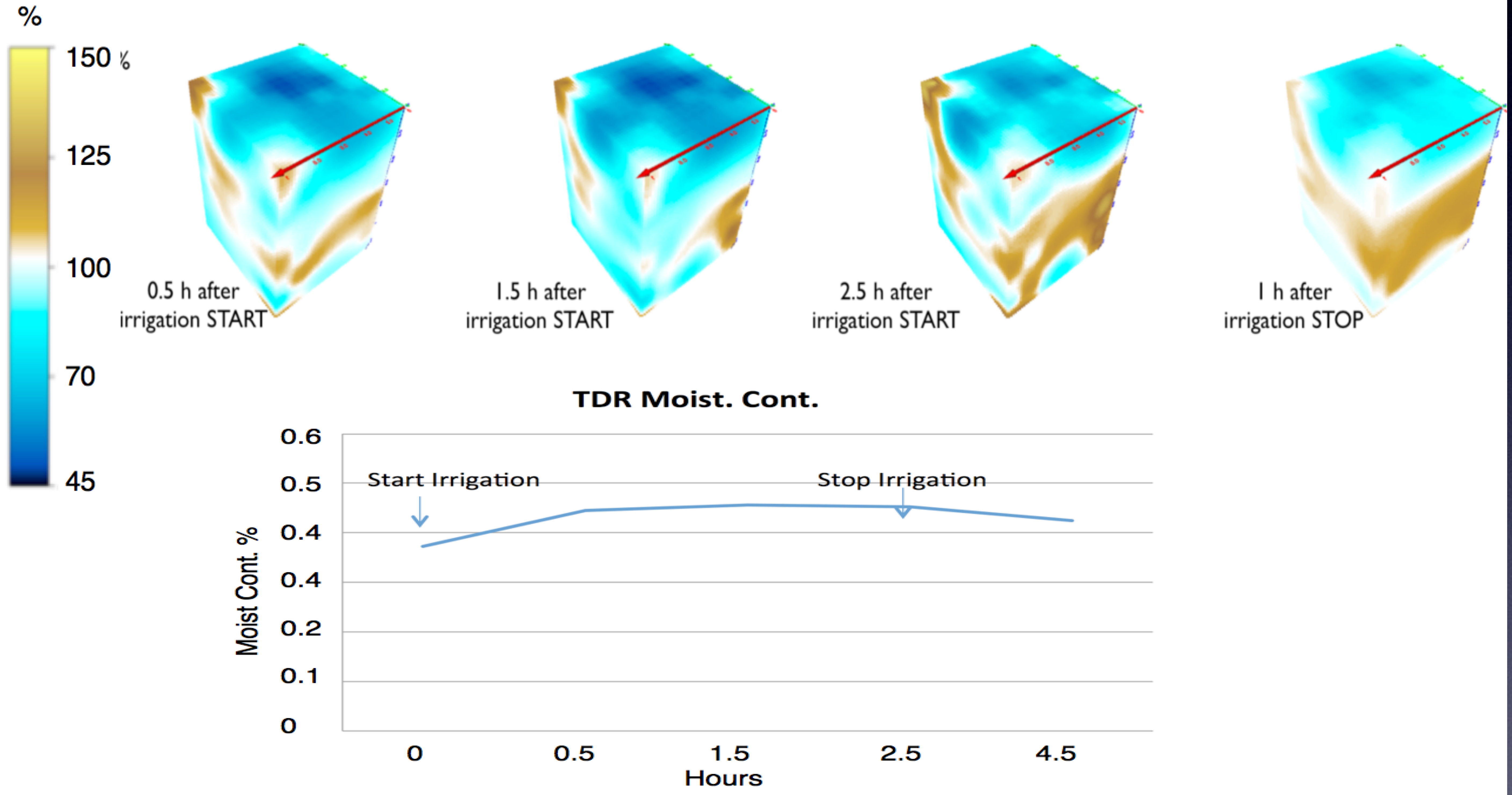
EU FP7 P CLIMB

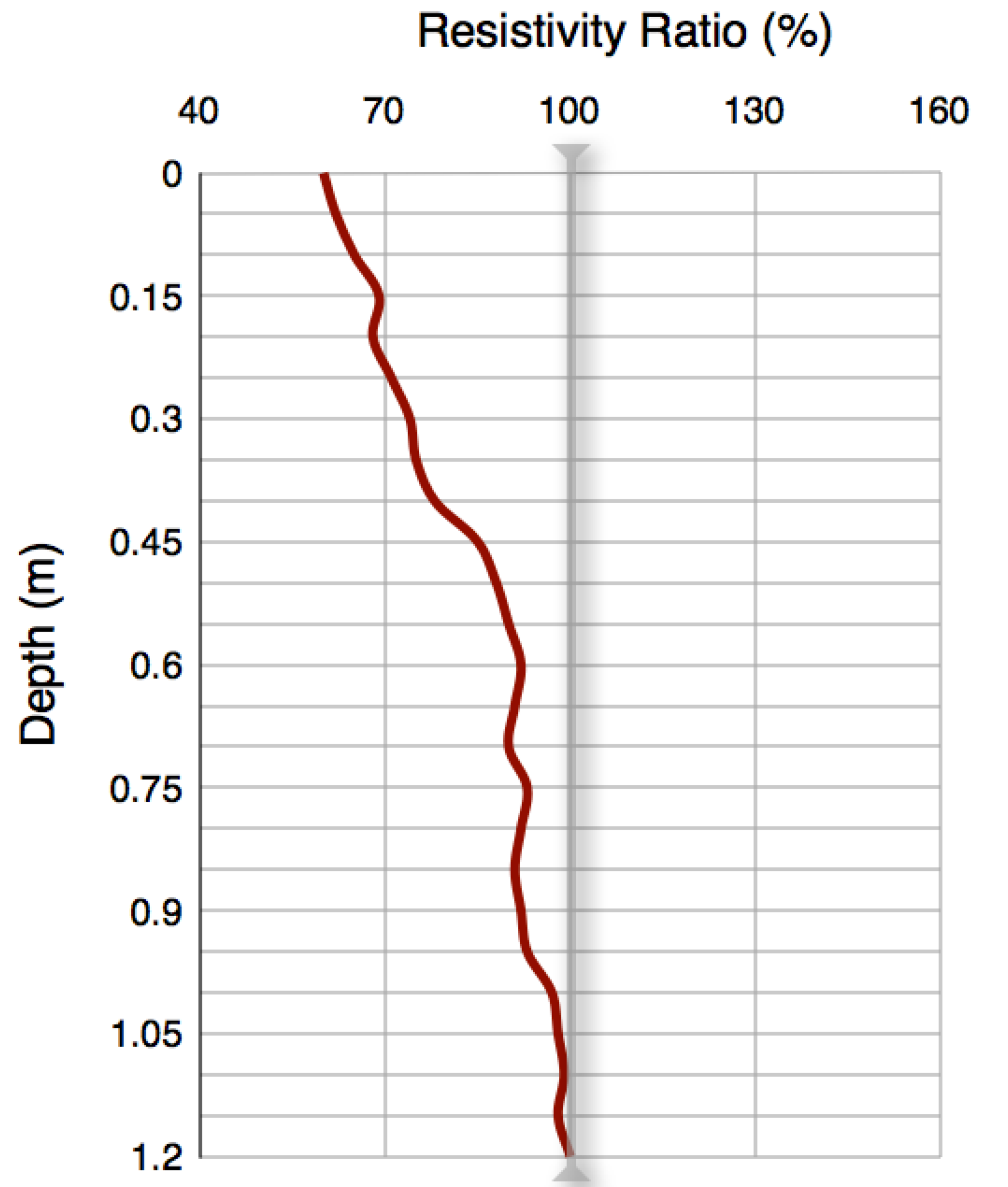
November 2012 experiment: resistivity ratio with respect to backaround at four time steps.



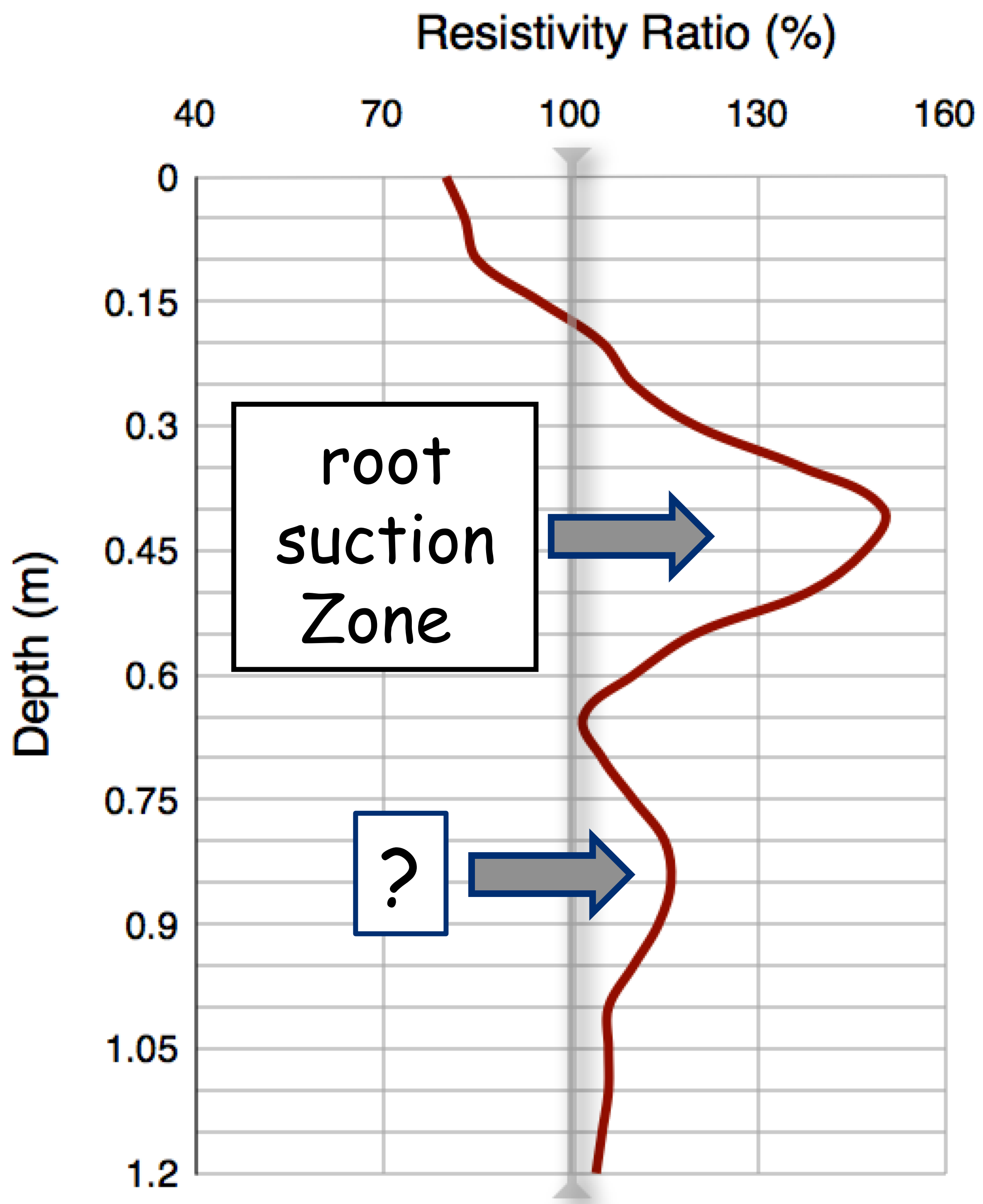
Moisture content measured by TDR in the top 32 cm.
The initial moisture content is higher than other experiments, low ept

Boaga et al., 2013

<u>May 2012 experiment</u>: resistivity ratio with respect to background averaged over horizontal slices



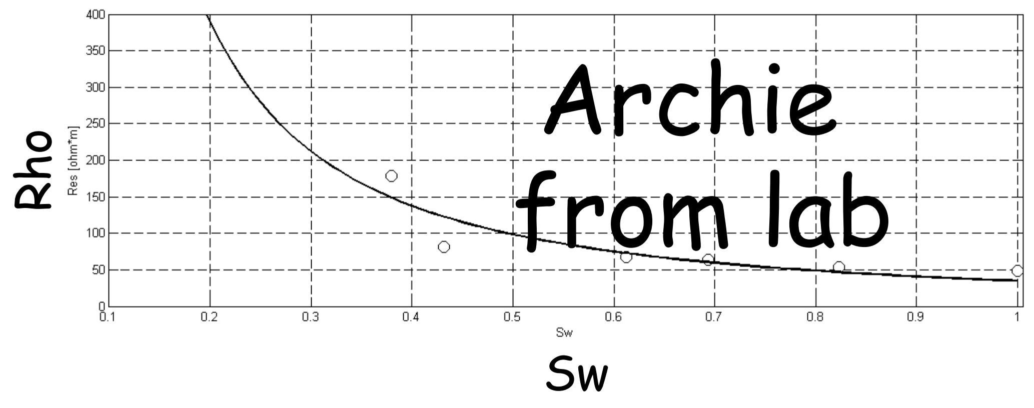
0.5 h after irrigation start

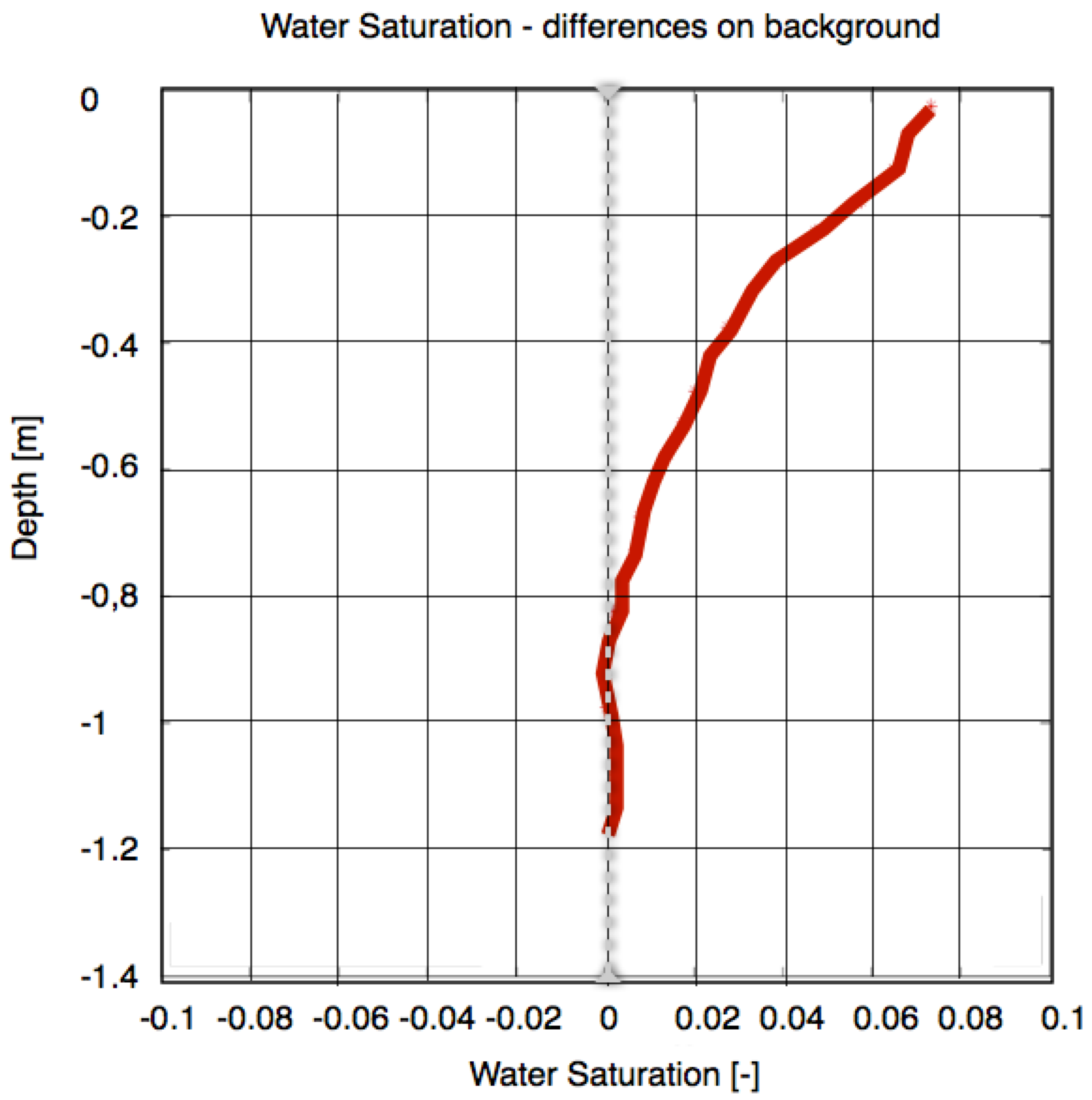


irrigation end at 2.5 h

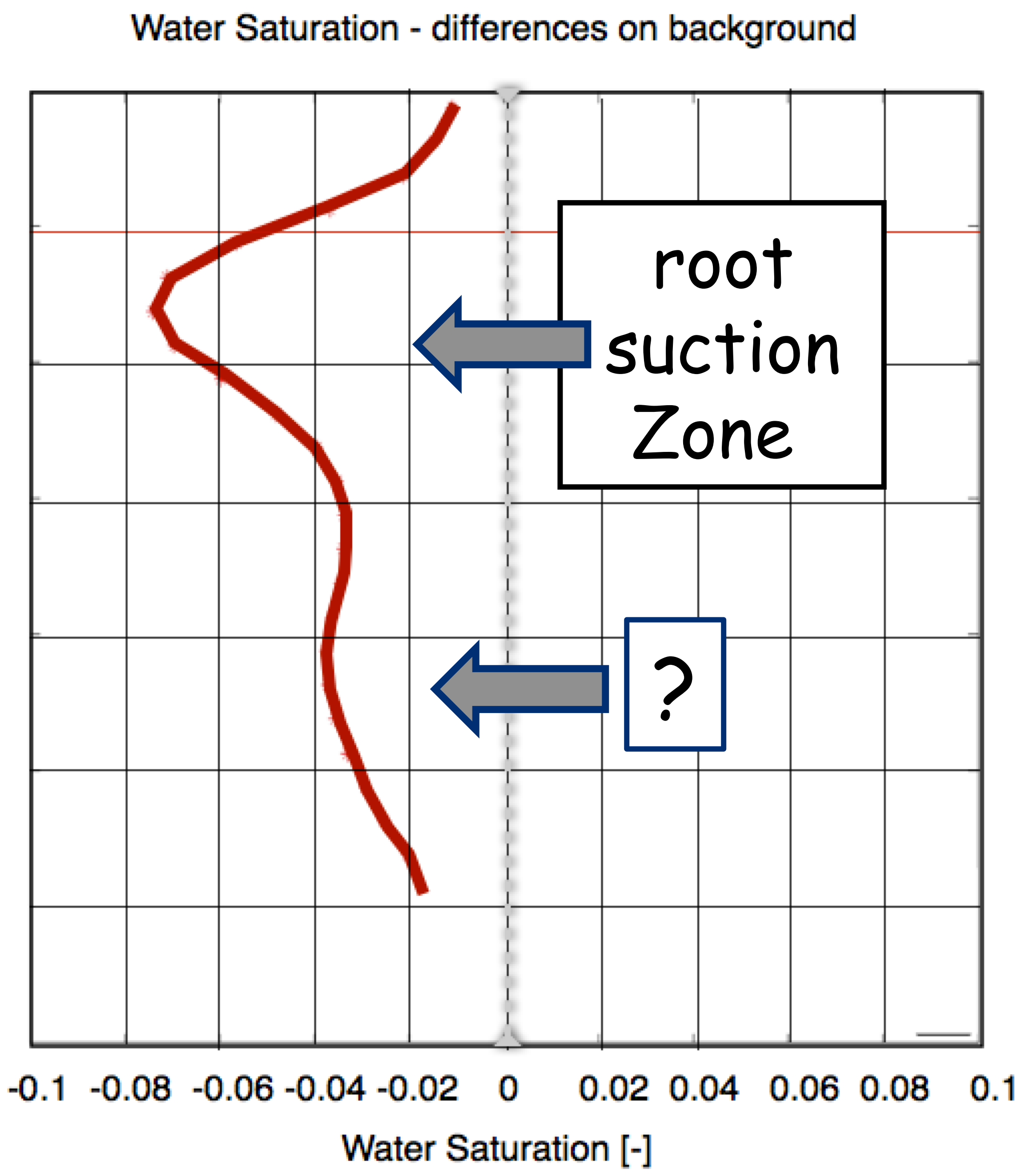
Boaga et al., 2013

<u>May 2012 experiment</u>: resistivity changes converted into **<u>saturation changes</u>** and averaged along horizontal planes.





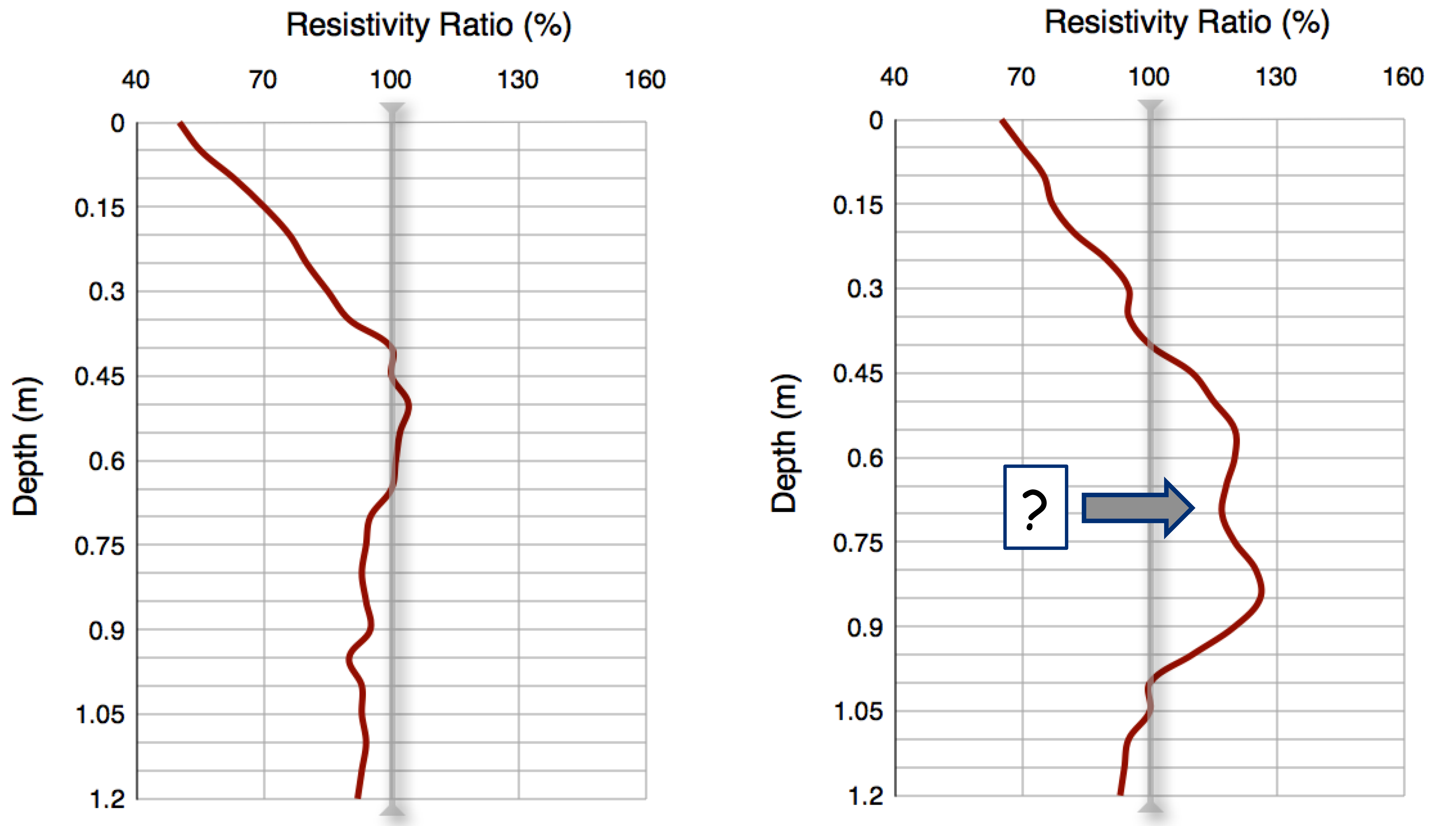
0.5 h after irrigation start



irrigation end at 2.5 h

Boaga et al., 2013

November 2012 experiment: **resistivity ratio** with respect to background averaged over horizontal slices

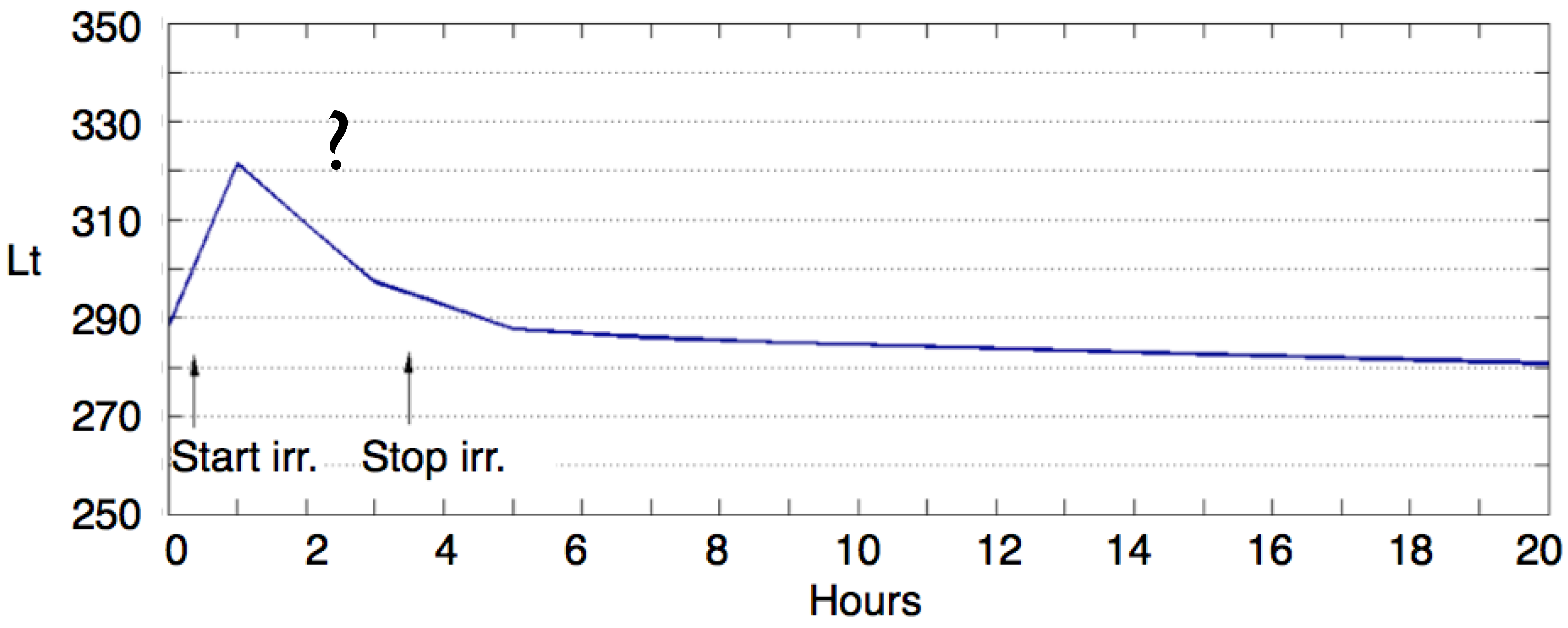


0.5 h after irrigation start

2.5 h after irrigation start

May 2012 experiment: mass balance issue from 3D ERT

Note that the total irrigated water amounts to 500 liters



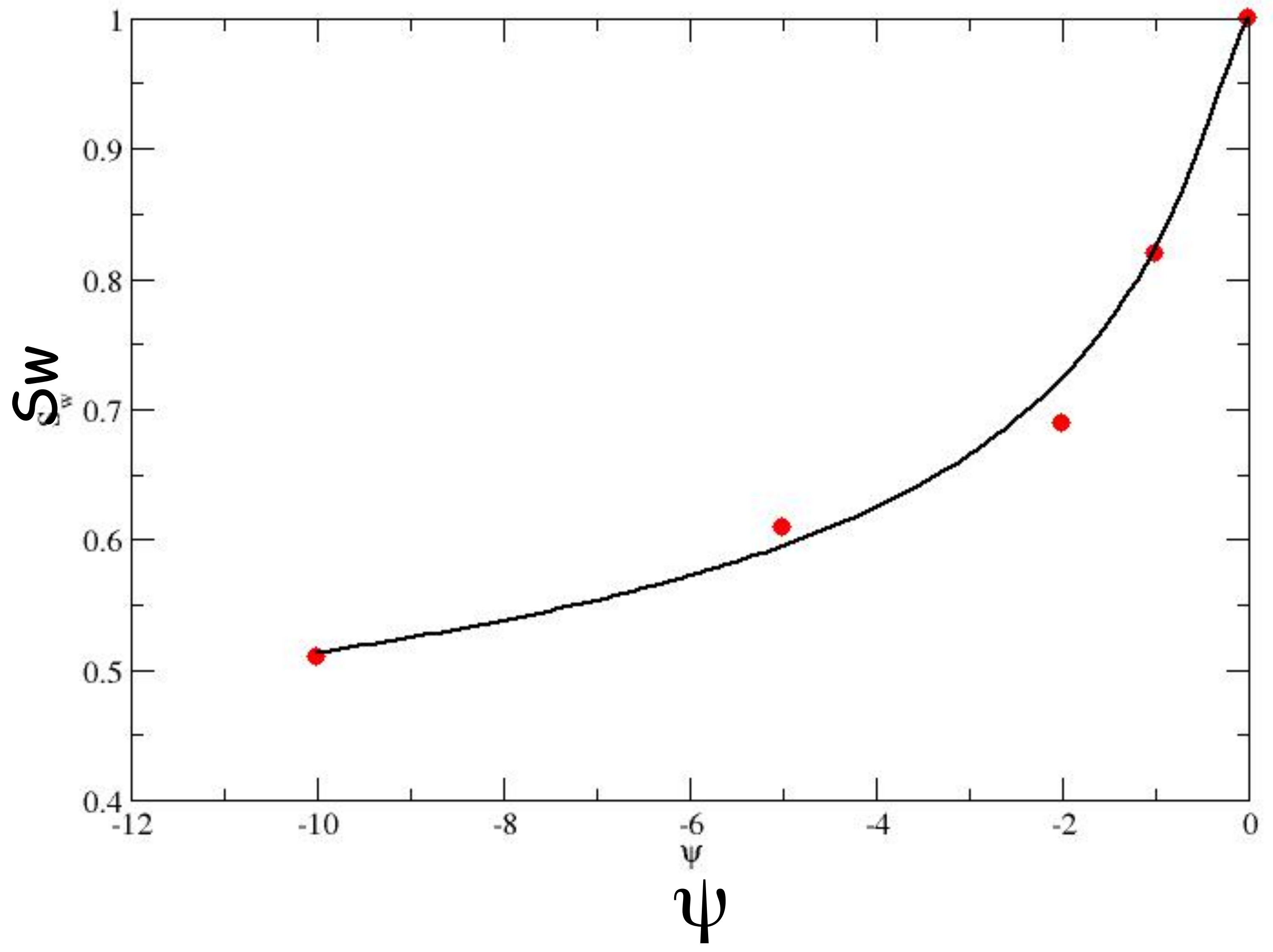
Boaga et al., 2013

We applied the **CATHY** (CATchment HYdrology) model [*Bixio et al, 2000; Camporese et al., 2010*], a physically-based 3D distributed model which uses Richards' equation to describe variably saturated flow in porous media.

We used the following parameters:

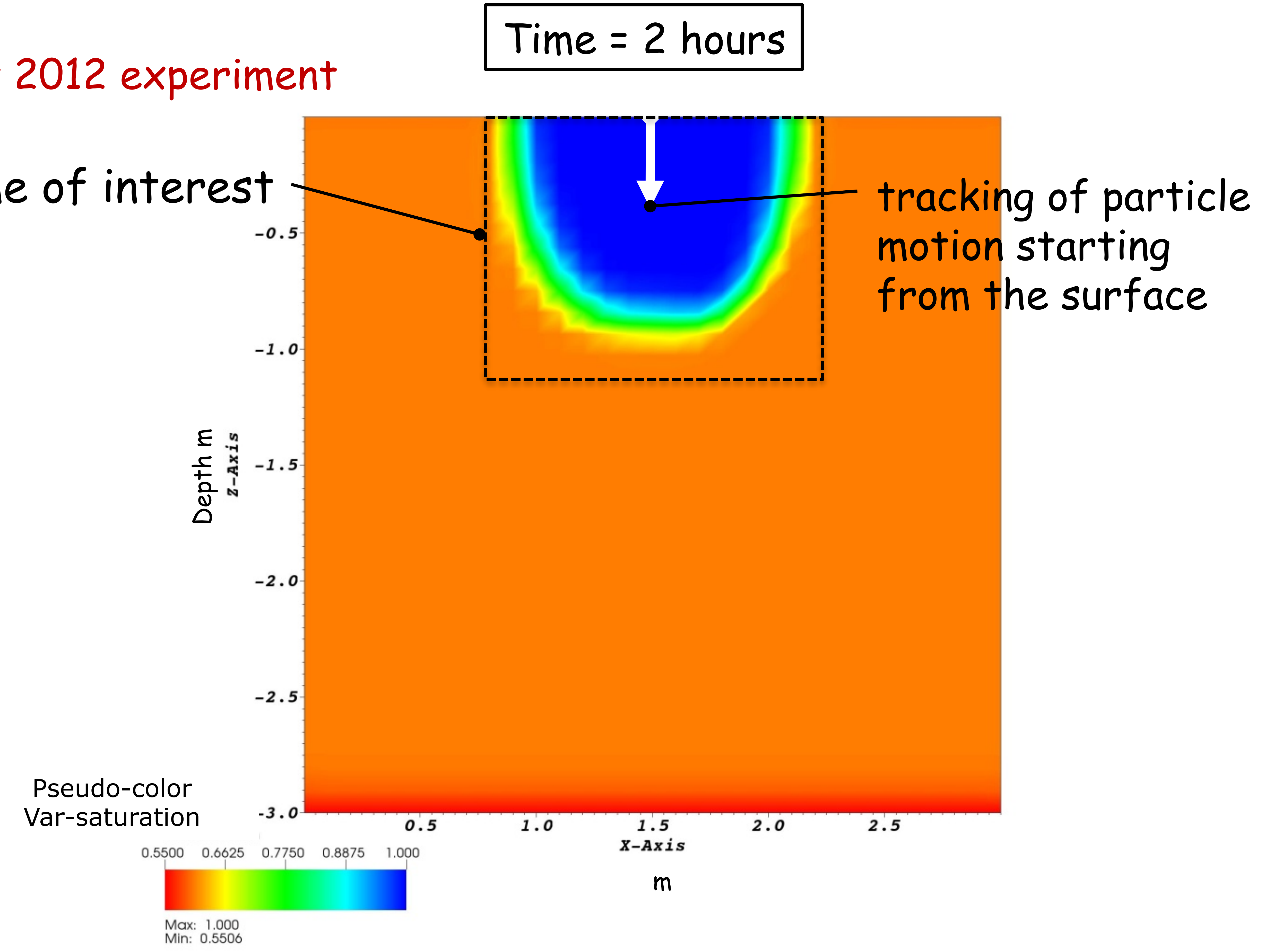
K_s = 6x10-5 m/s
Van Genuchten n = 1.35
Porosity = 0.5
θ_r = 8x10-2
ψ_a = -0.7

Thanks to Putti & co
Math Dept



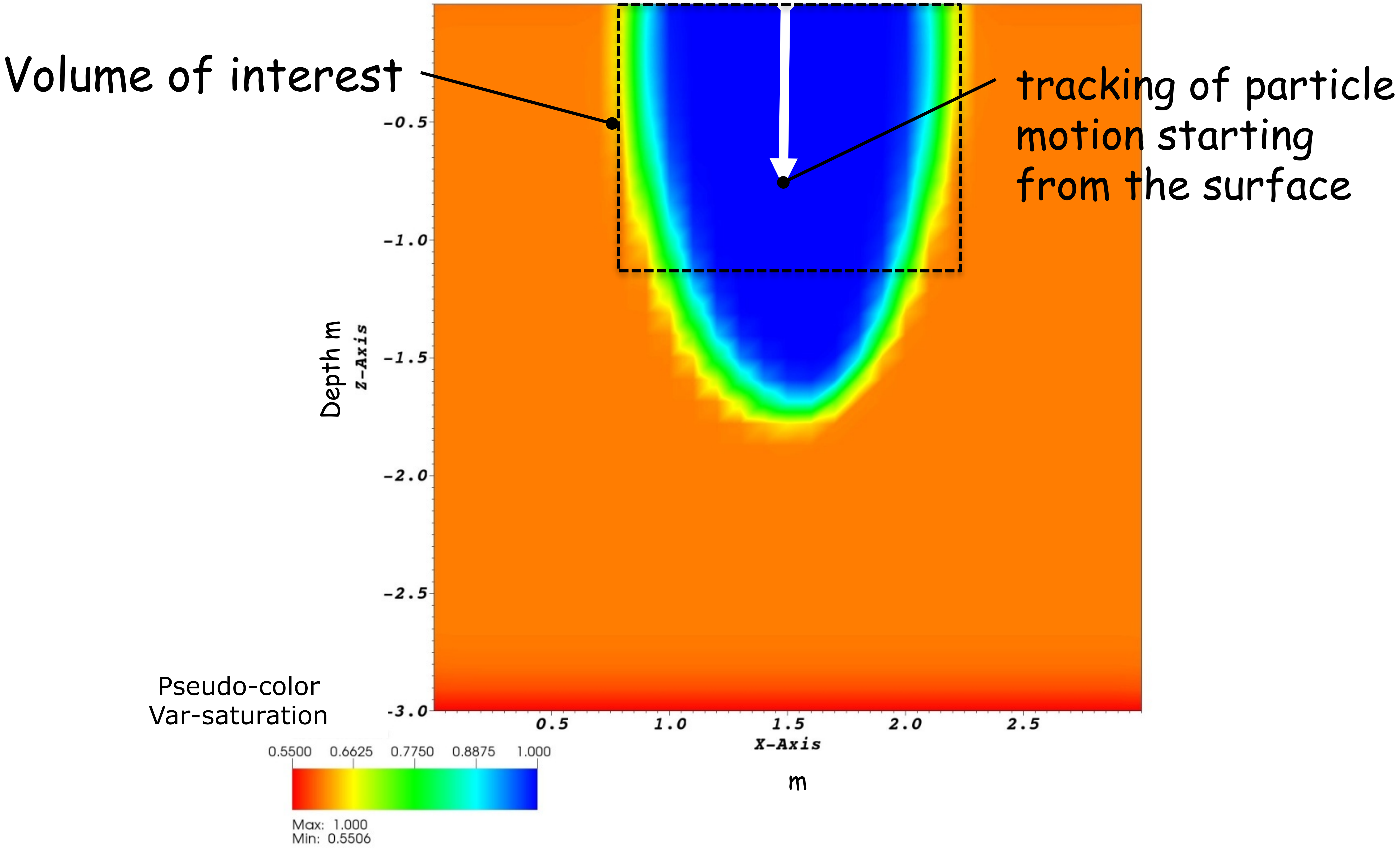
Boaga et al., 2013

May 2012 experiment



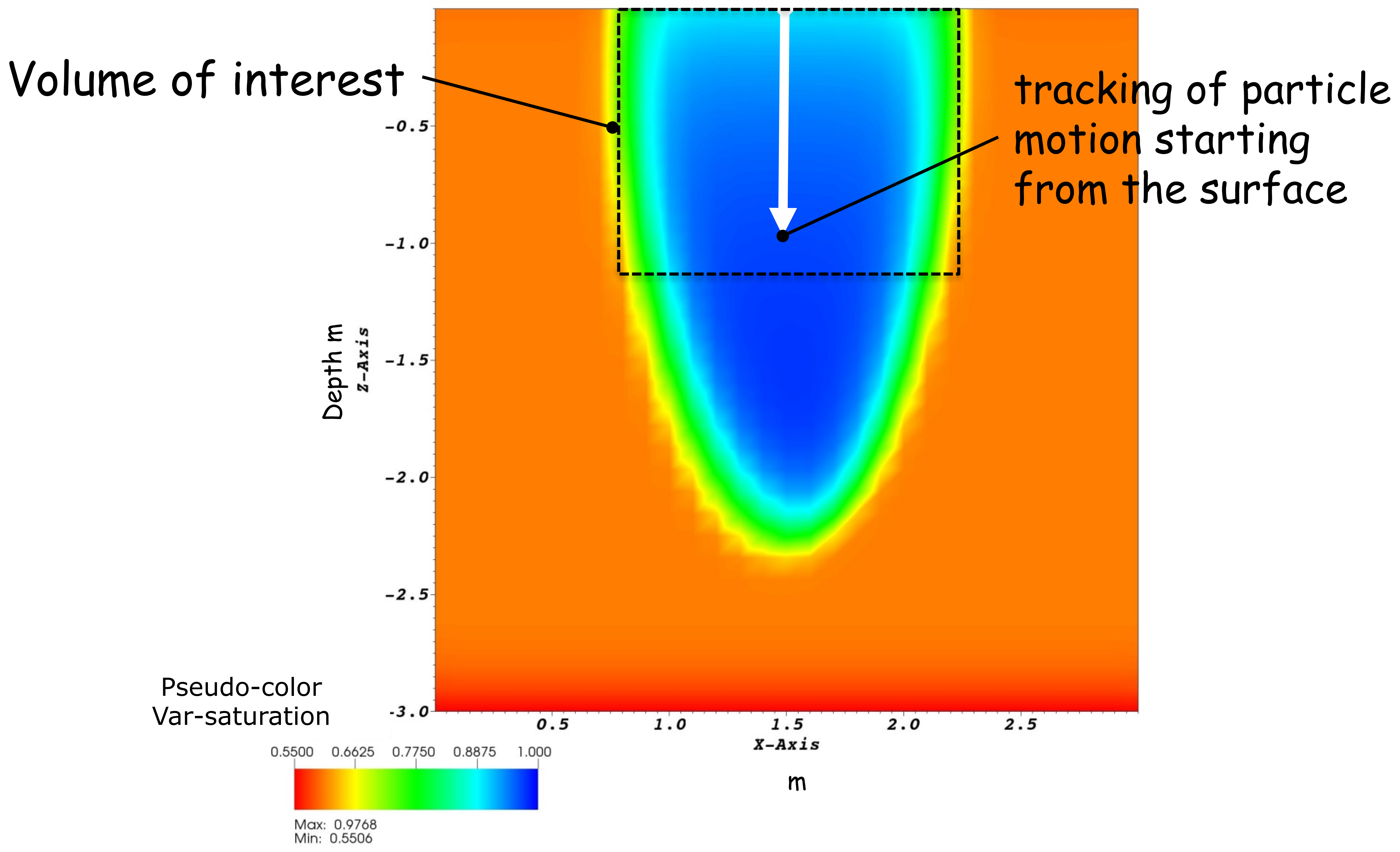
Time = 3 hours

May 2012 experiment



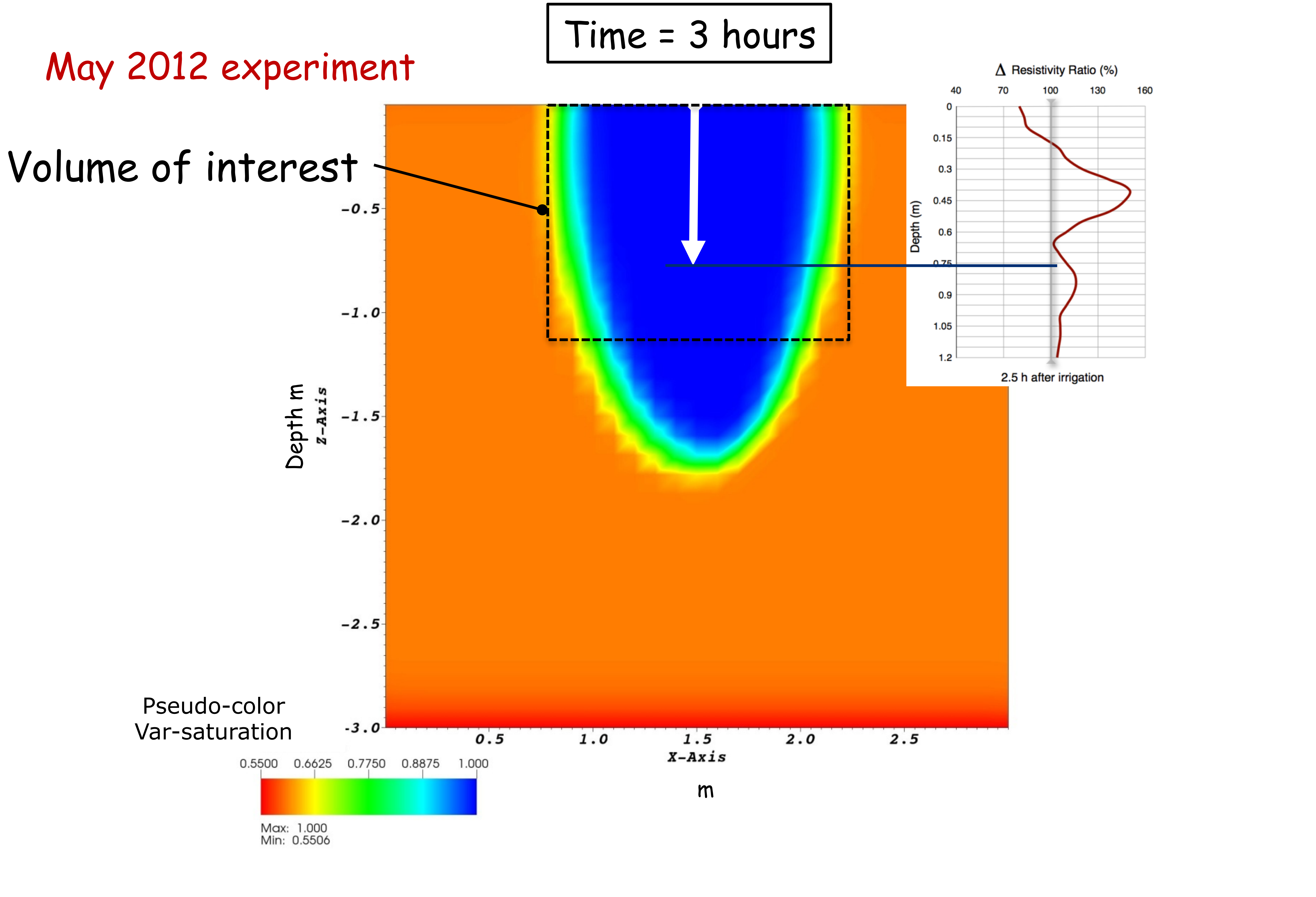
Time = 5 hours

May 2012 experiment



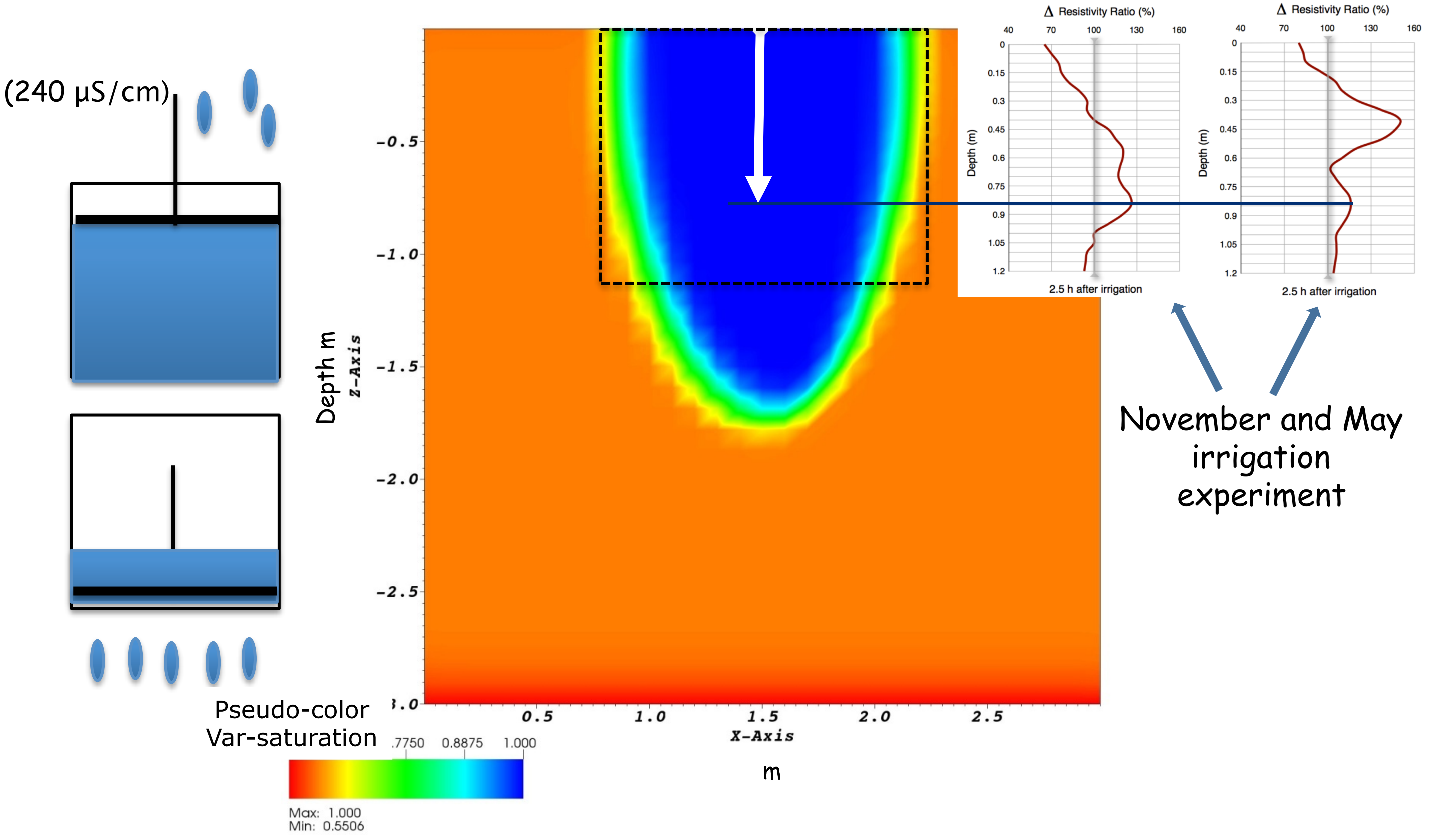
Università degli Studi di Padova Dipartimento di Geoscienze

EU FP7 P CLIMB



Piston effect ?

Time = 3 hours

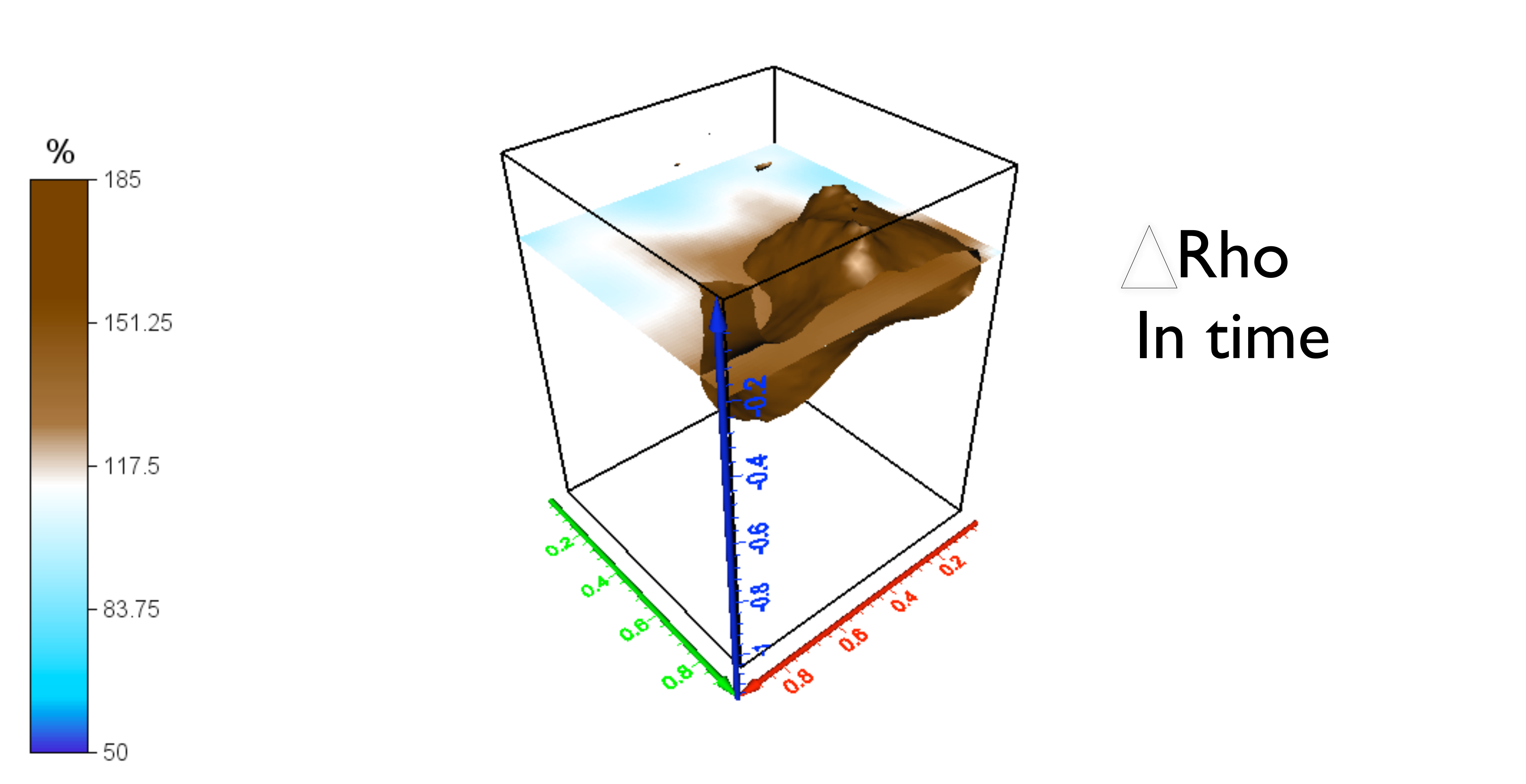


ERT for plants studies

Geophysical for the hydrological risks

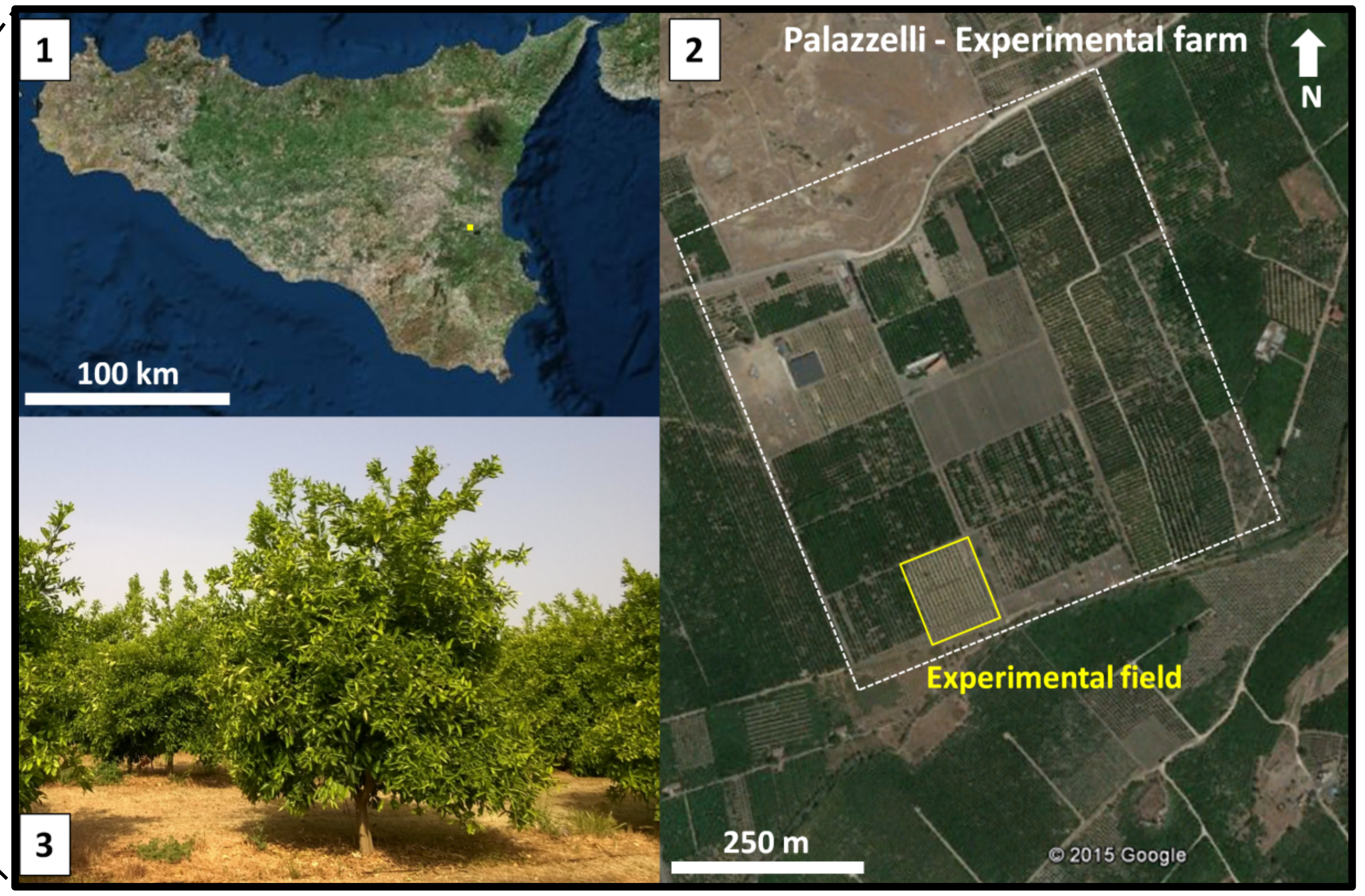
ERT 3D to study root plant activity

3) Water resources management



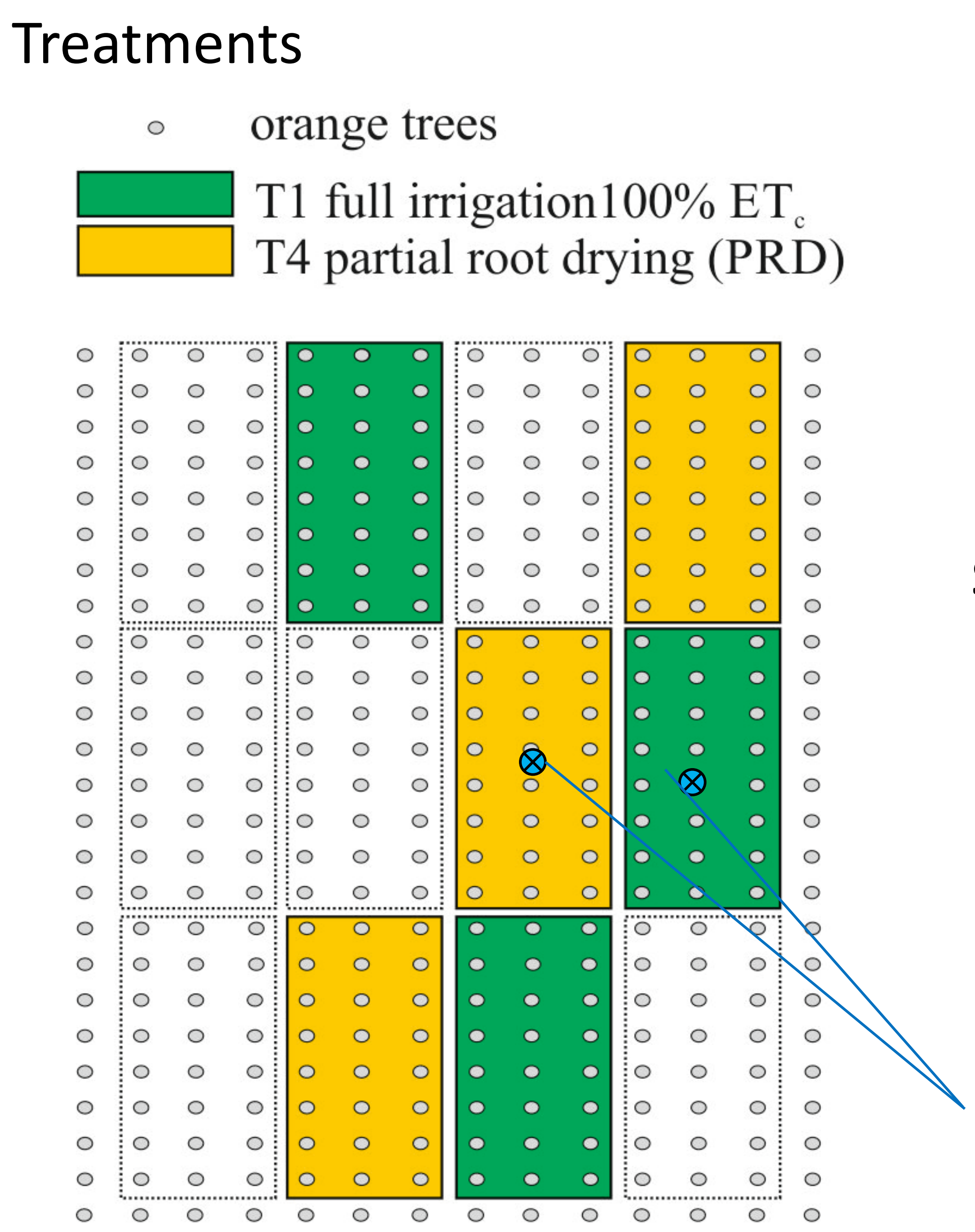
THE PALAZZELLI FIELD SITE

8 year old orange trees (6 m width and 4 m height)



Citrus sinensis (L.) Osbeck) cv 'Tarocco Sciara' grafted on Carrizo citrange [*Poncirus trifoliata* (L.) Raf. × *C. sinensis* (L.) Osbeck]

THE PALAZZELLI FIELD SITE



- meteorological tower
- sap flow probes (transpiration rate)
- soil moisture and soil temperature sensors

- different irrigation techniques
  - full irrigation - ET_c100% (T1)
  - partial root zone drying – PRD - 50% (T4)

- micro electrical resistivity tomography (ERT)

EGU2016-4608

3D ERT AT FIELD SITE- IRRIGATION SEASON 2015

full irrigation plot (T1 - ET_c100%)

irrigation start

pruning

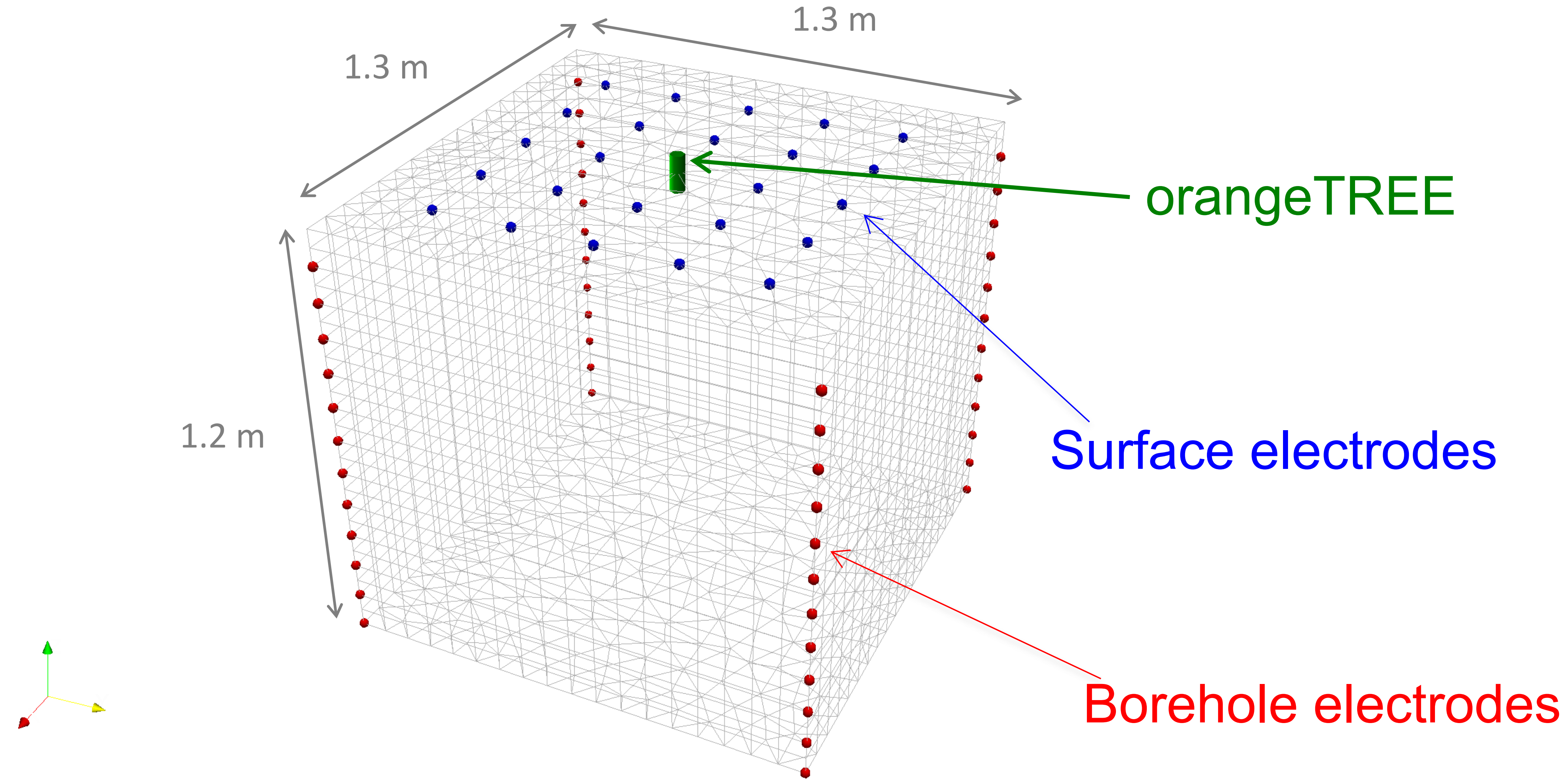
June 2015 | July 2015 | September 2015

partial root zone drying plot (T4 -PRD)

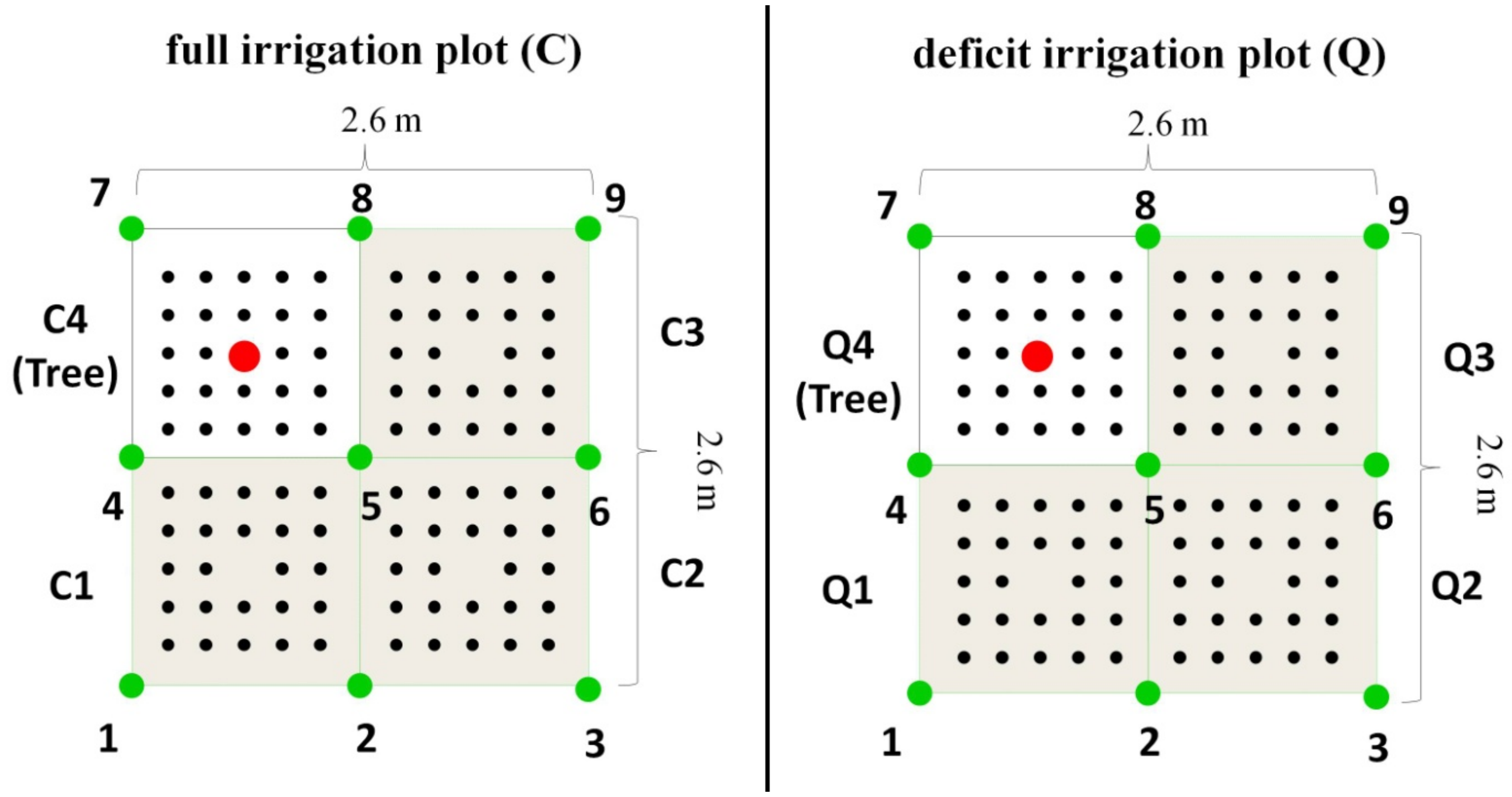
3D ERT monitoring scheme

- 24 superficial electrodes covering a 1.3x1.3 m^2 area
- 48 borehole electrodes, 12 in each of the 4 micro-boreholes
- Acquisition using a complete skip-0 dipole-dipole scheme with reciprocal was used for all acquisitions.
- Inversion using the ERT code R3t (*A.Binley*, Lancaster University)

S-P-A
interactions



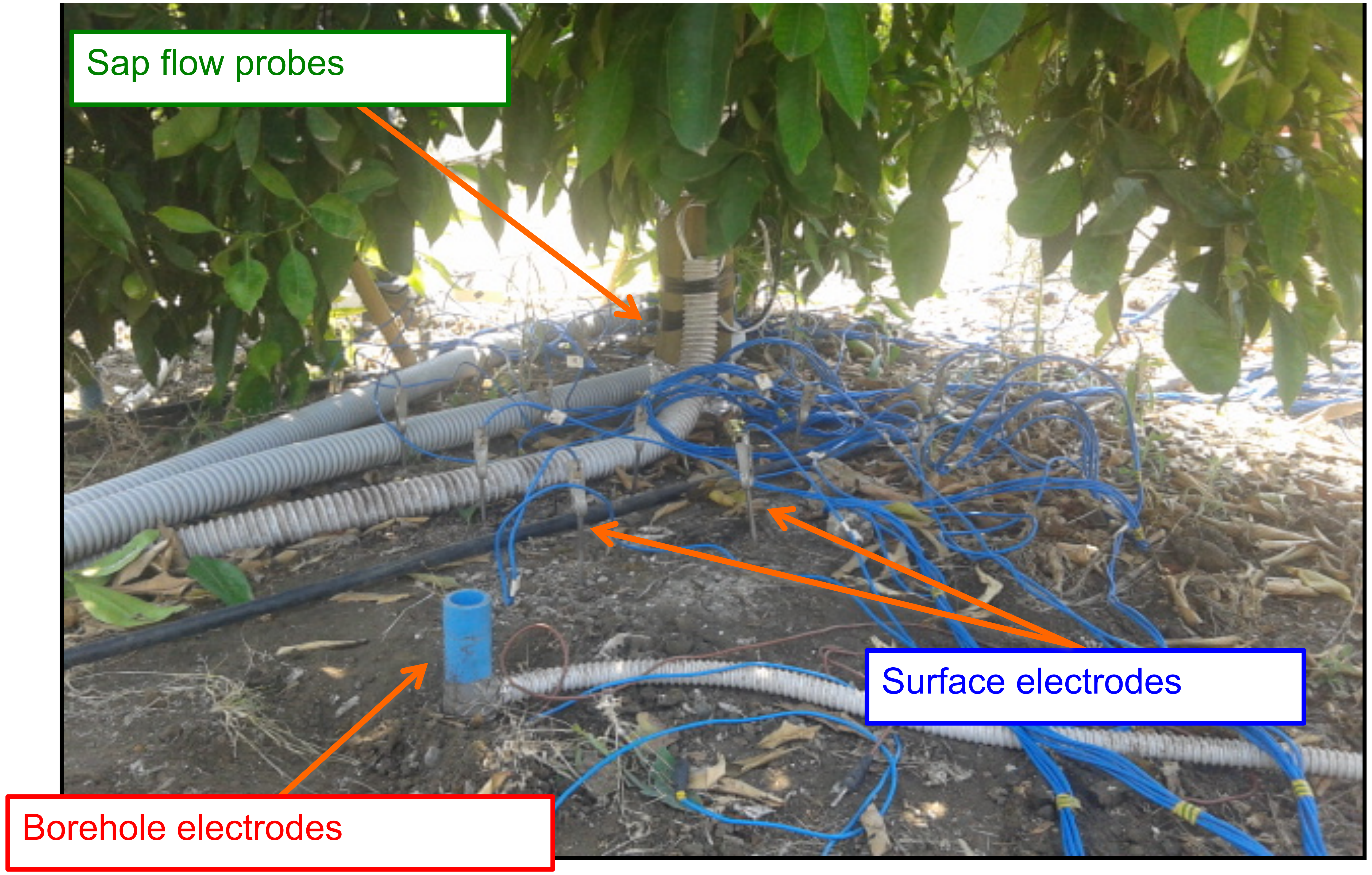
3D ERT MONITORING SCHEME



- ❑ 96 surface electrodes covering a 2.6 x 2.6 m^2 area (0.26 m spacing)
- ❑ 108 micro-borehole electrodes (1.3m depth)

- ❑ acquisition using a complete skip-0 dipole-dipole scheme with reciprocal was used for all acquisitions (quarter by quarter, 72 electrodes at the same time)
- ❑ ERT Inversion with the code R3t (A. Binley, Lancaster University)

3D ERT monitoring scheme



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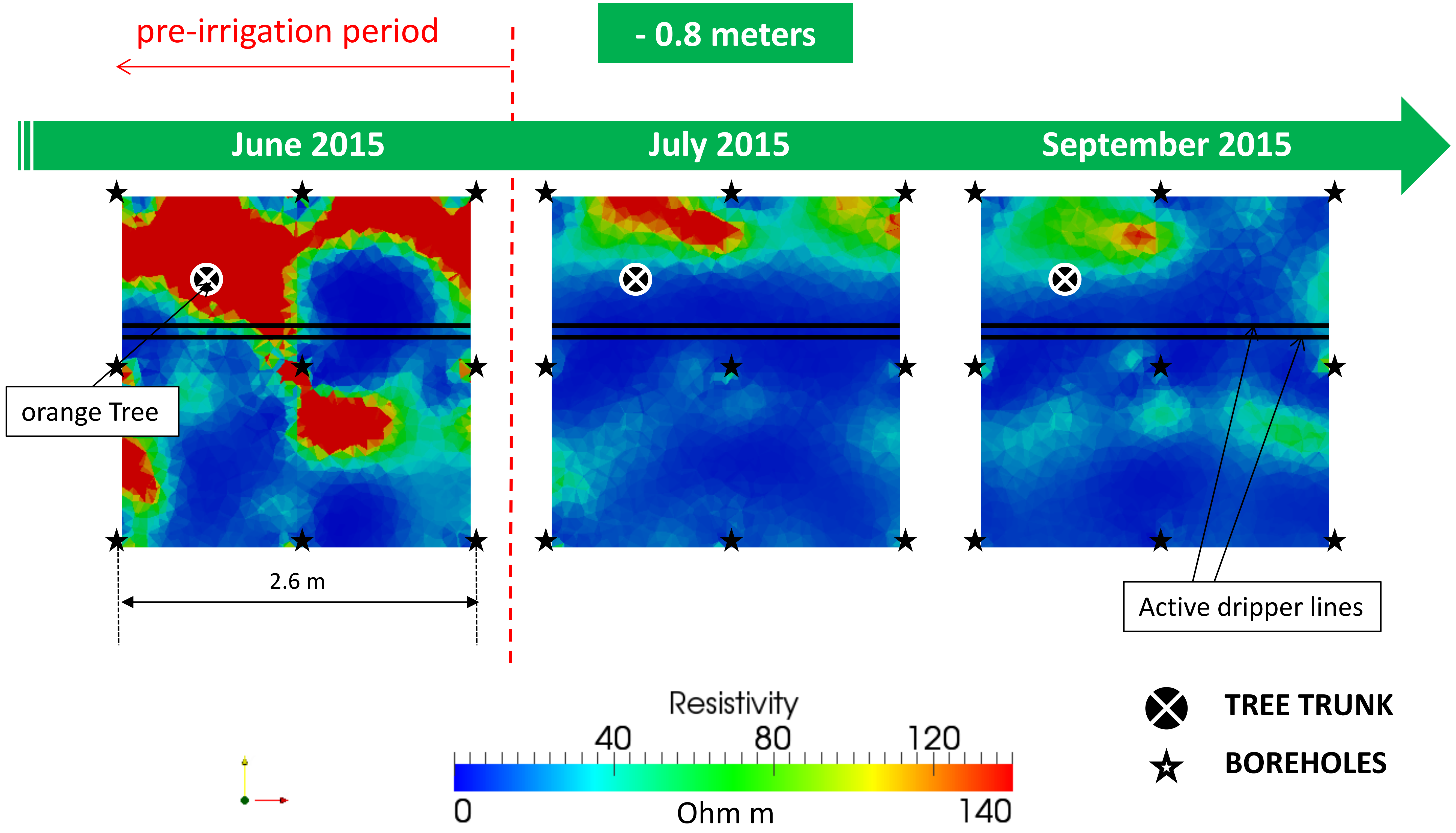
ERT BACKGROUND - FULL IRRIGATION PLOT (T1)

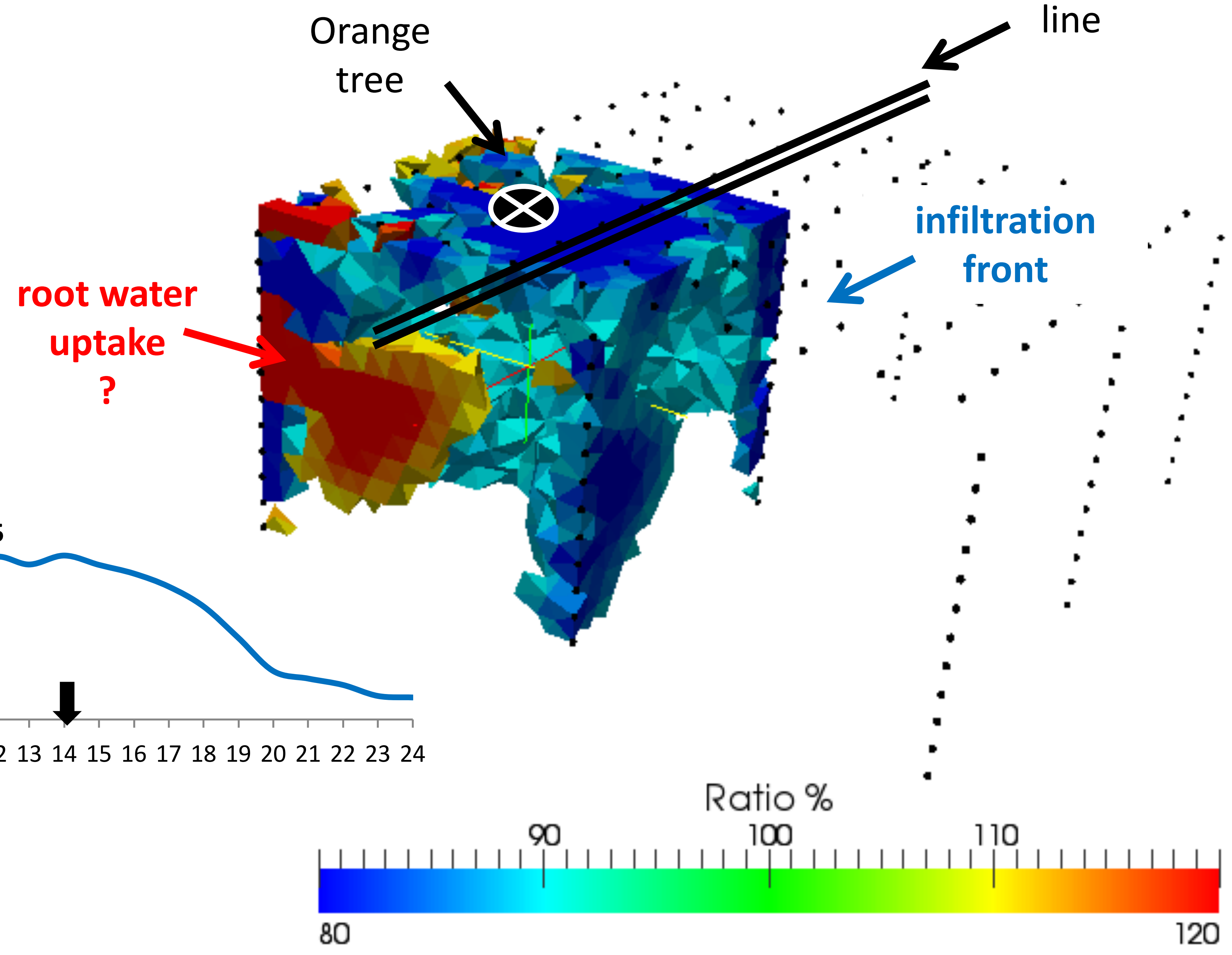


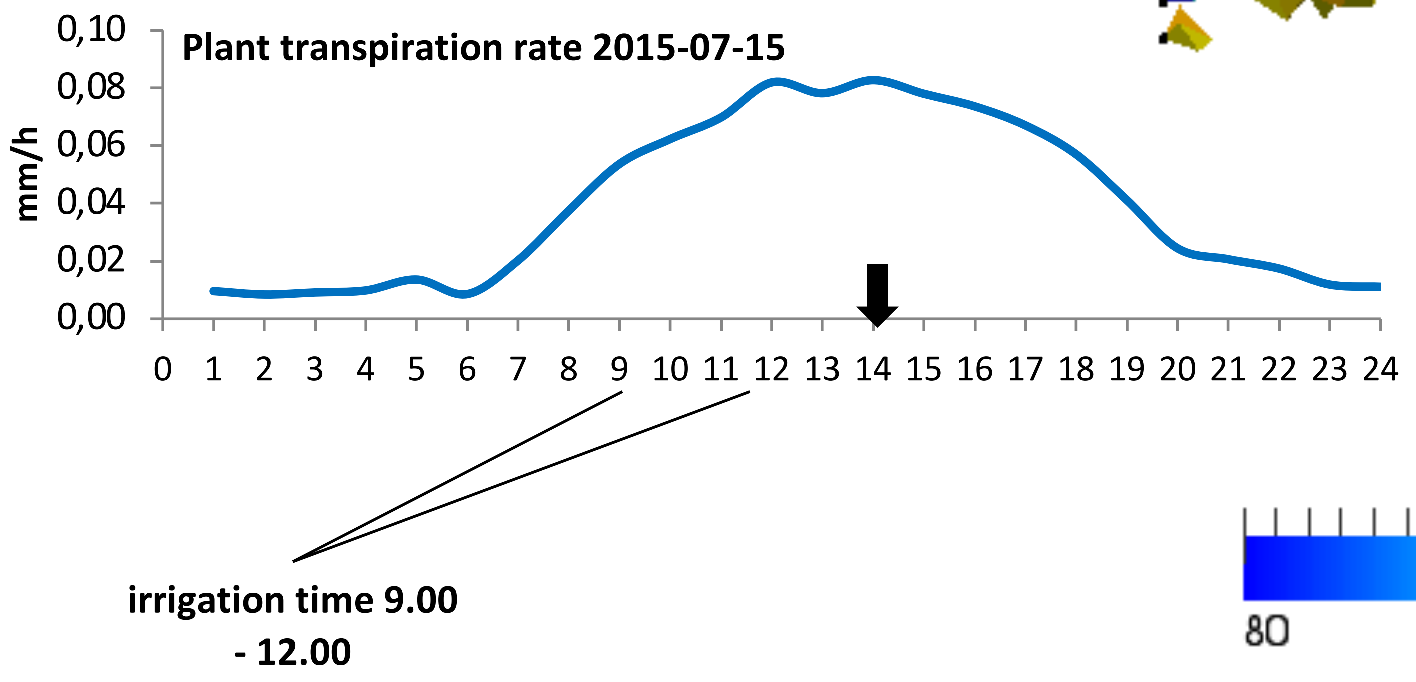
RESISTIVITY RATIO FULL IRRIGATION PLOT (T1) - 2015 JULY

background acquired the same day at 8.30 a.m.

SHORT TERM MONITORING

236' after irrigation starts





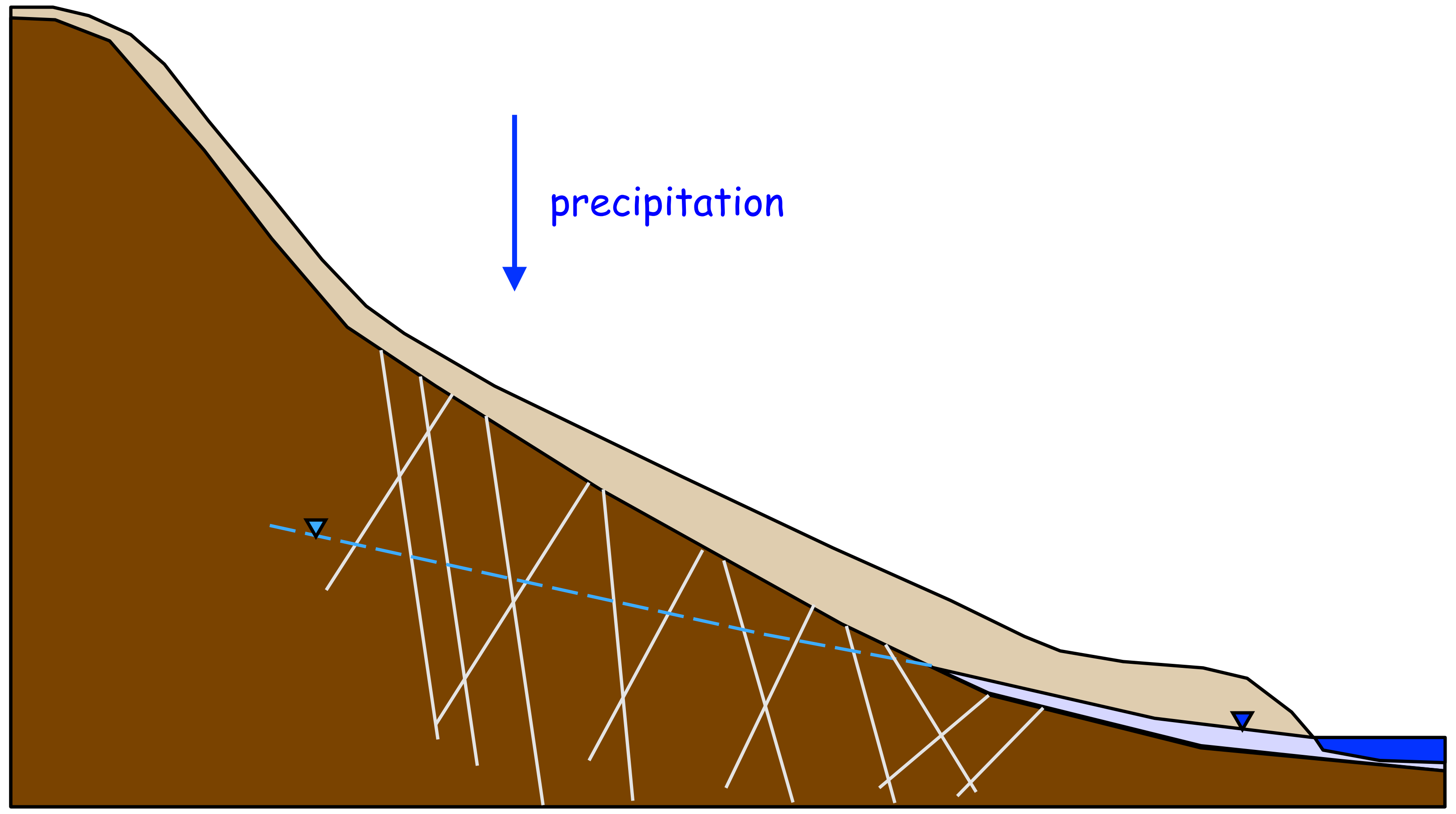
ERT for slope hydrology

Site description

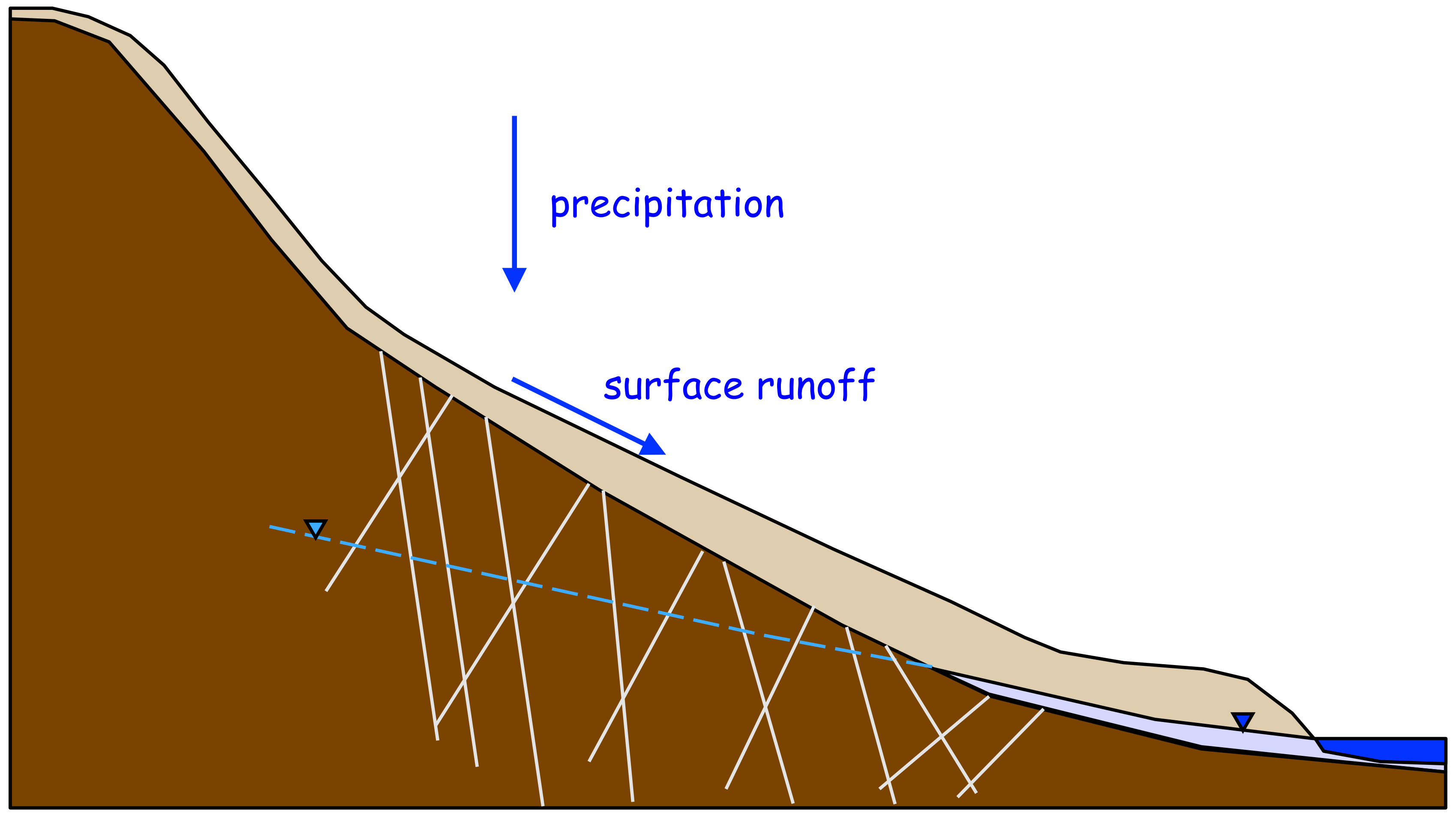
elevation: 1150 m a.s.l.
slope: 30-40 degrees
soil cover: 1-2 m thick, sand-gravelly moraine; low-medium hydraulic conductivity (10^{-6} m/s)
bedrock: medium grade paragneiss with subvertical foliation, friable?
vegetation: grass, surrounding forest with beech and birch

risk of soil slips and generation flash floods

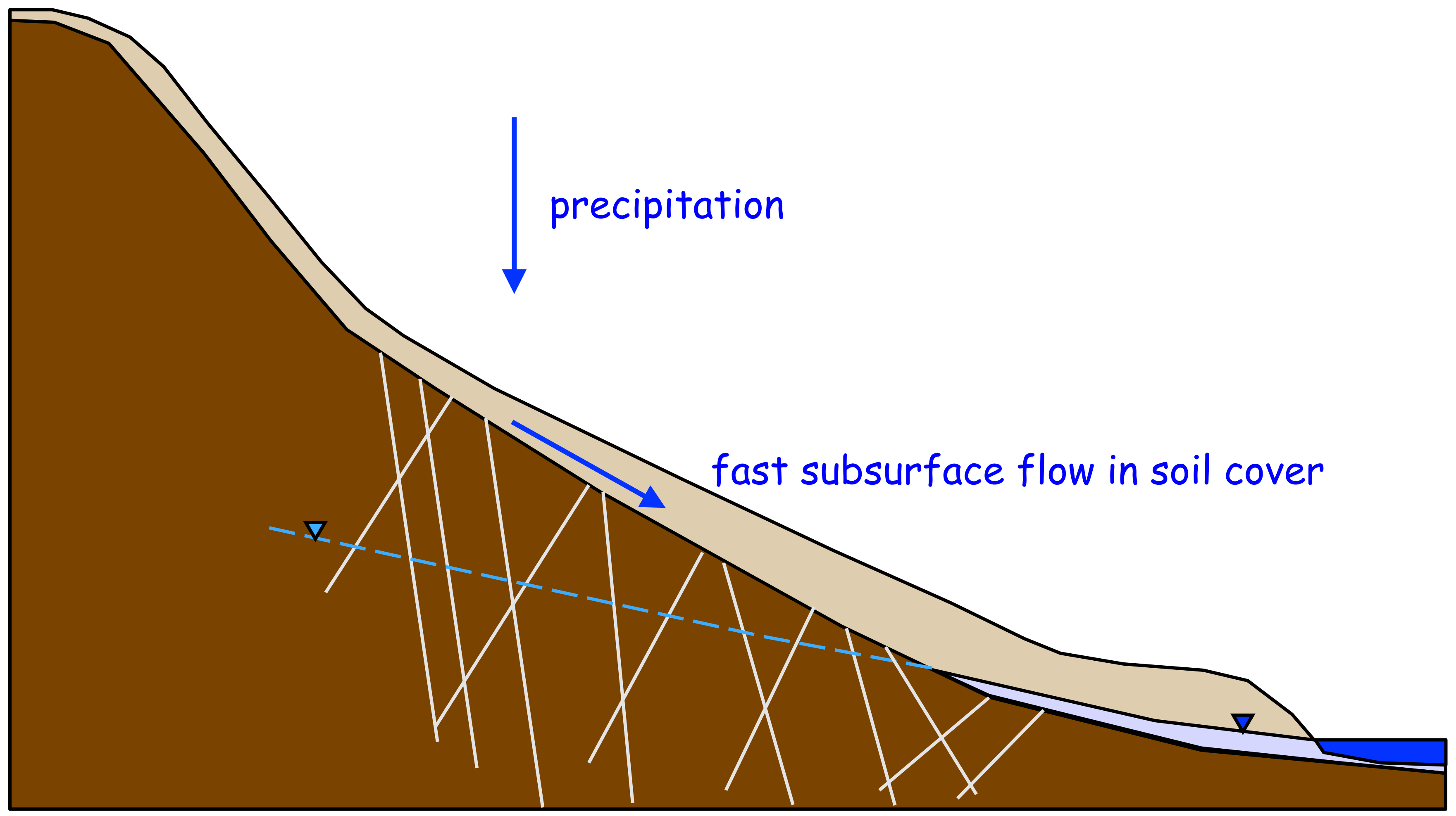
Old versus new water?



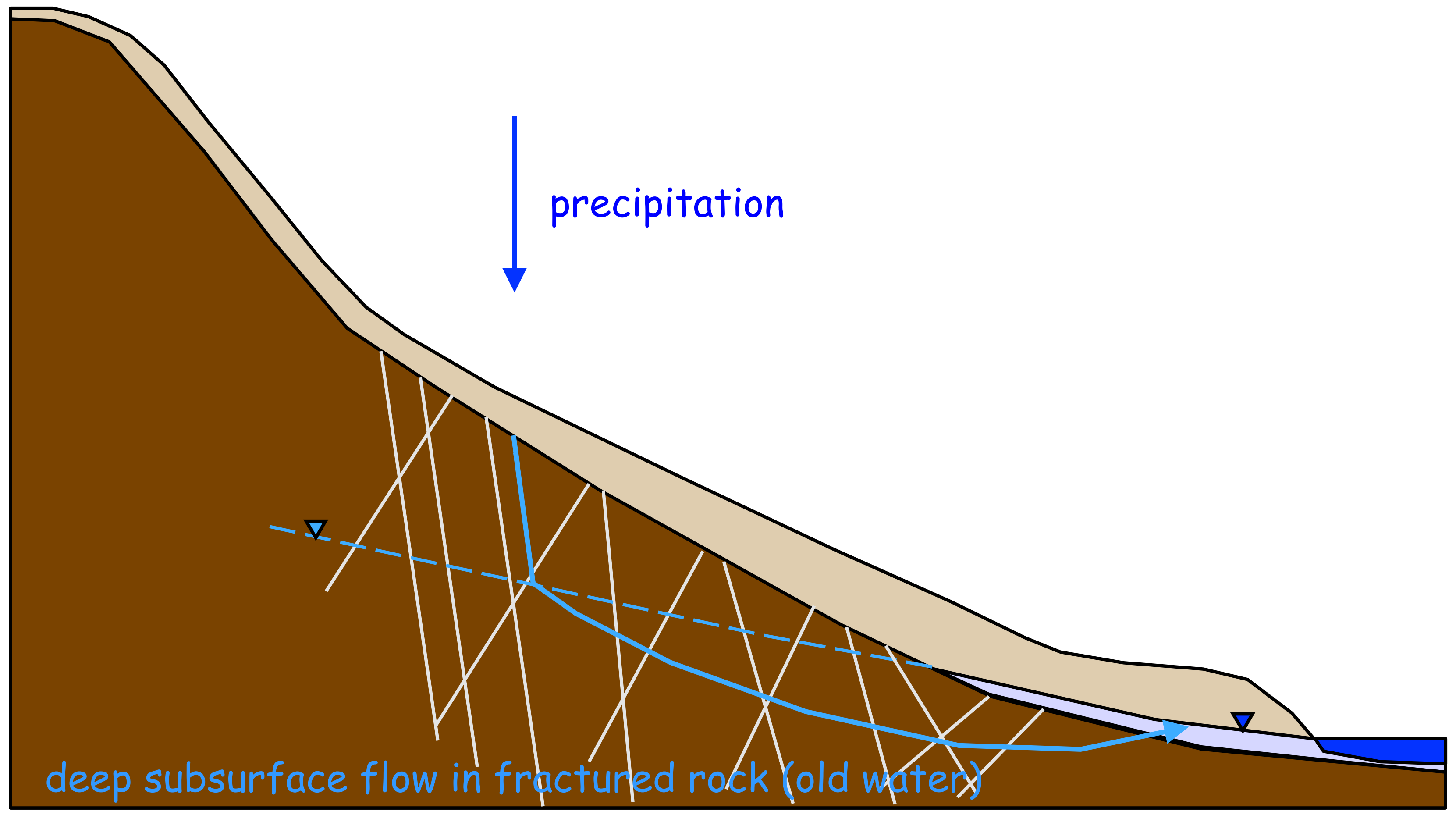
Old versus new water?



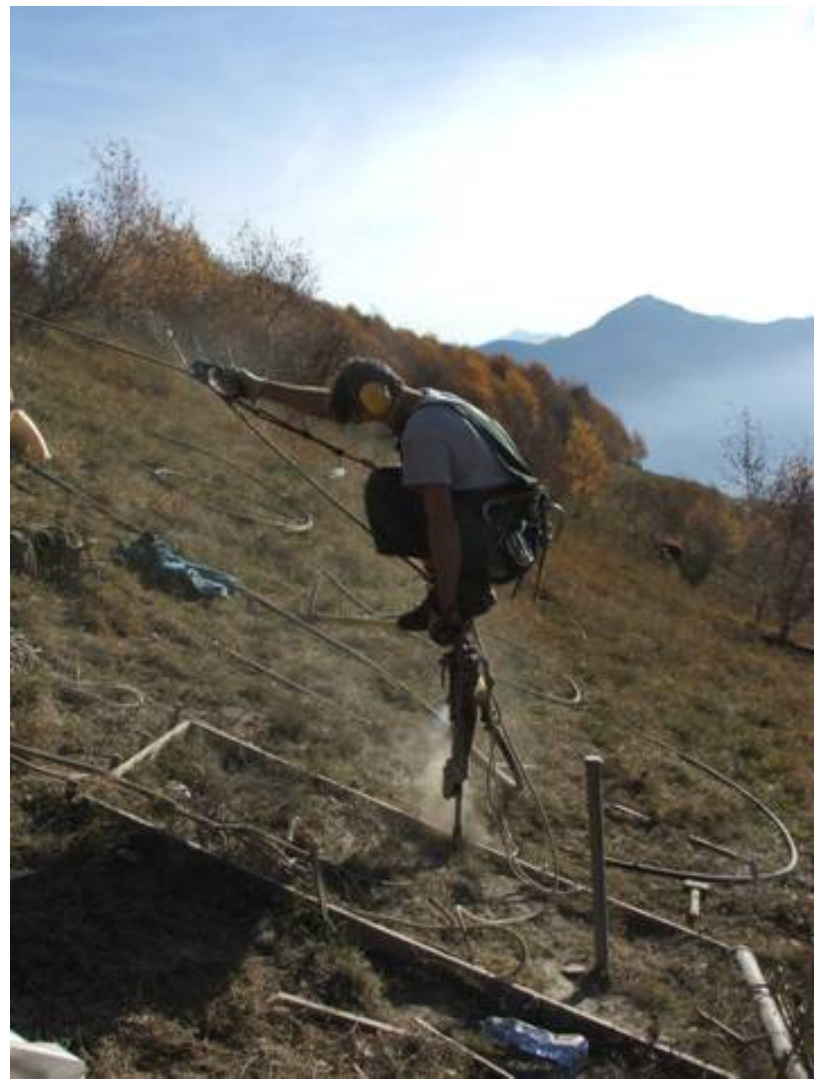
Old versus new water?



Old versus new water?

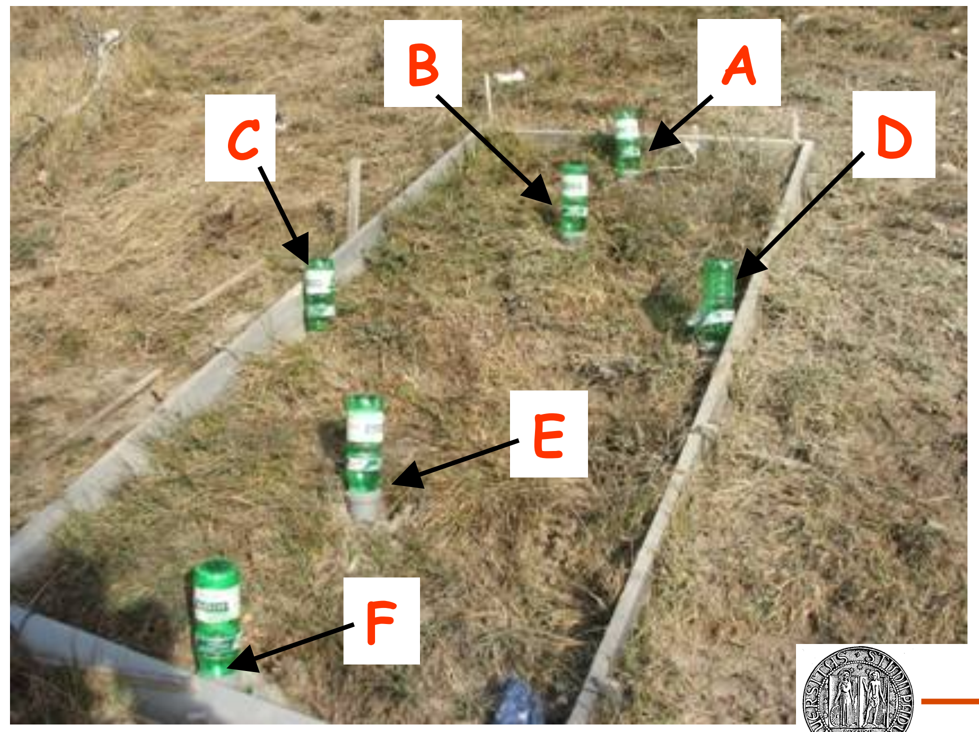


Installation of boreholes

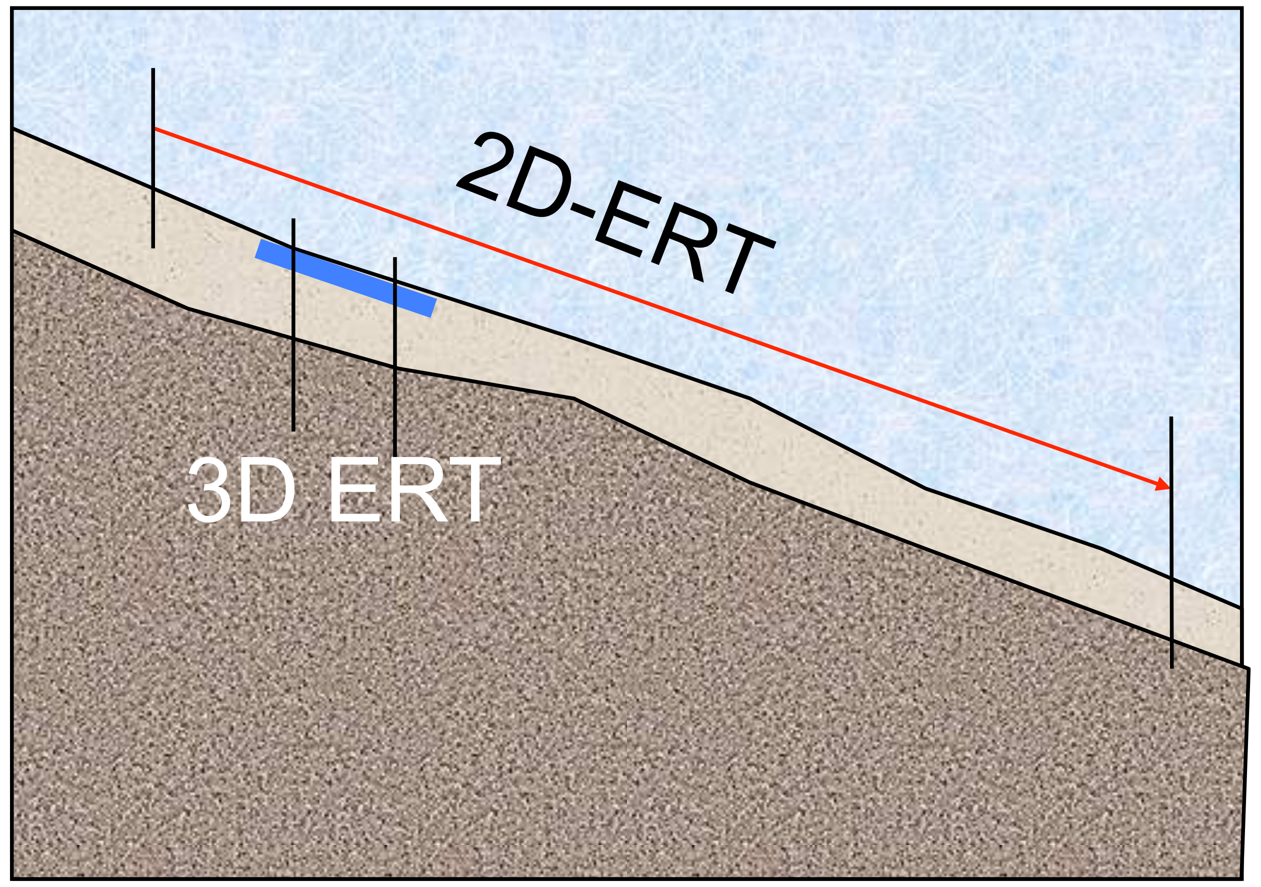


Six boreholes, 2 m deep.

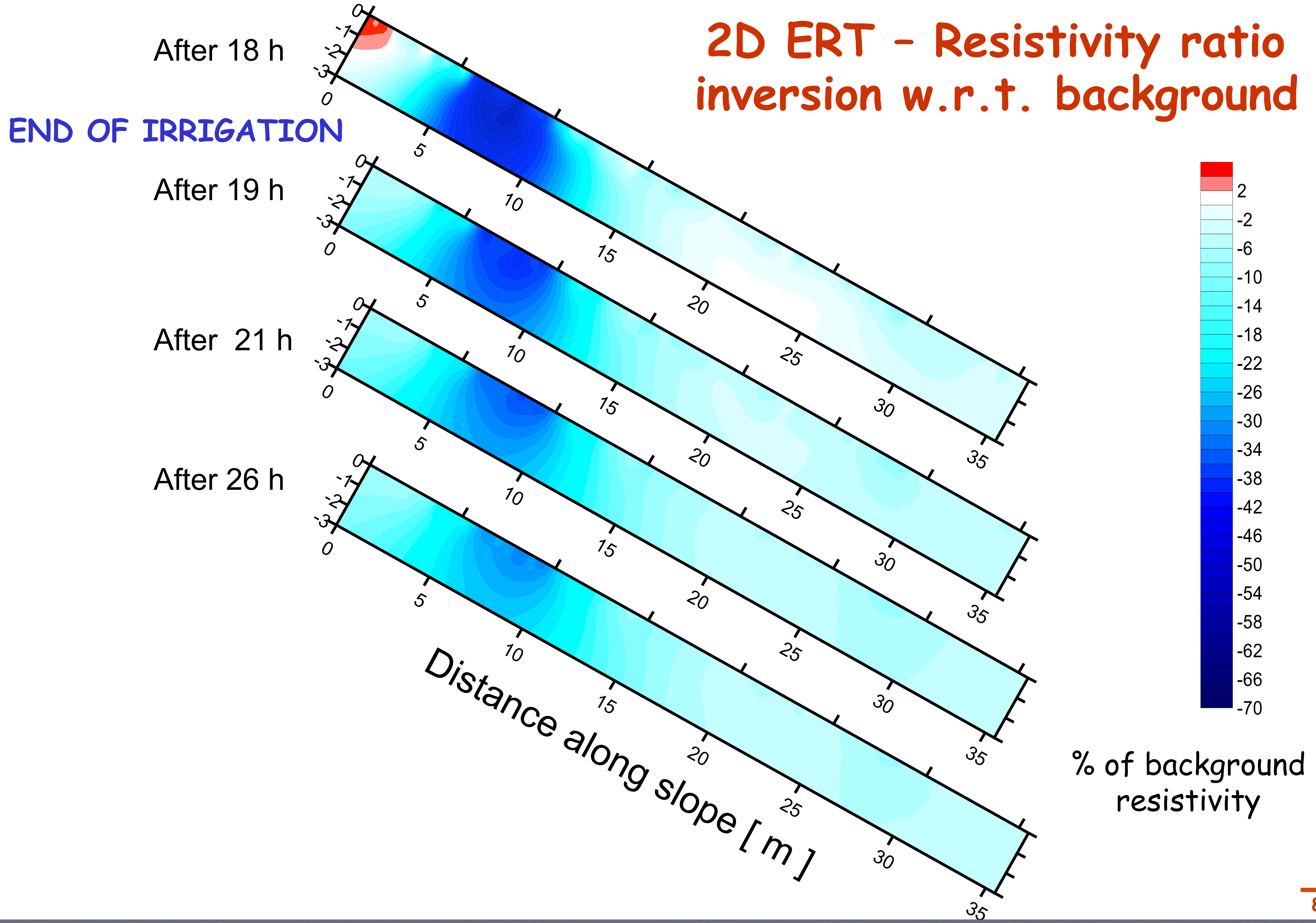
12 electrodes in each borehole.



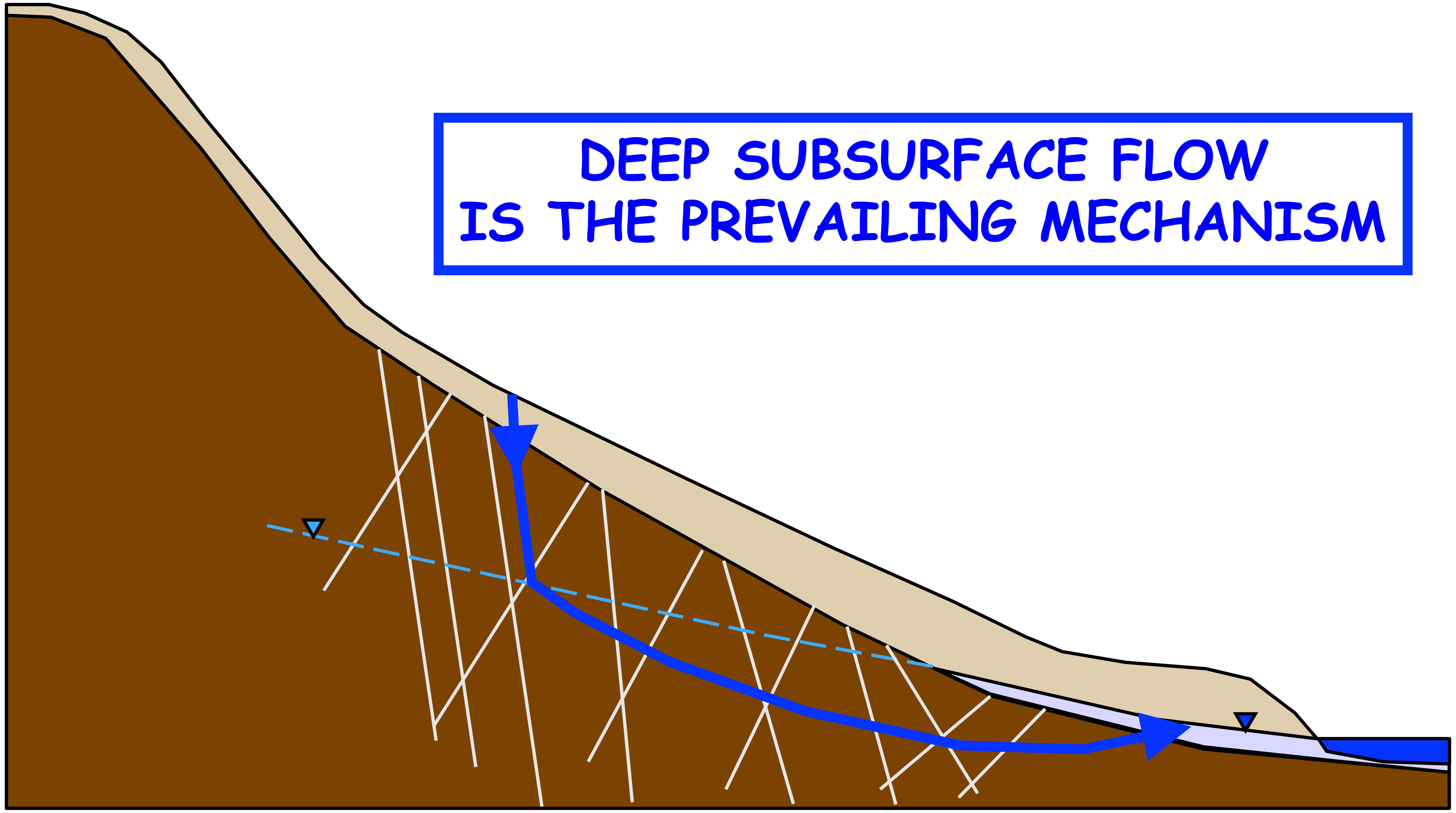
Monitoring along the 2D line



2D ERT – Resistivity ratio inversion w.r.t. background



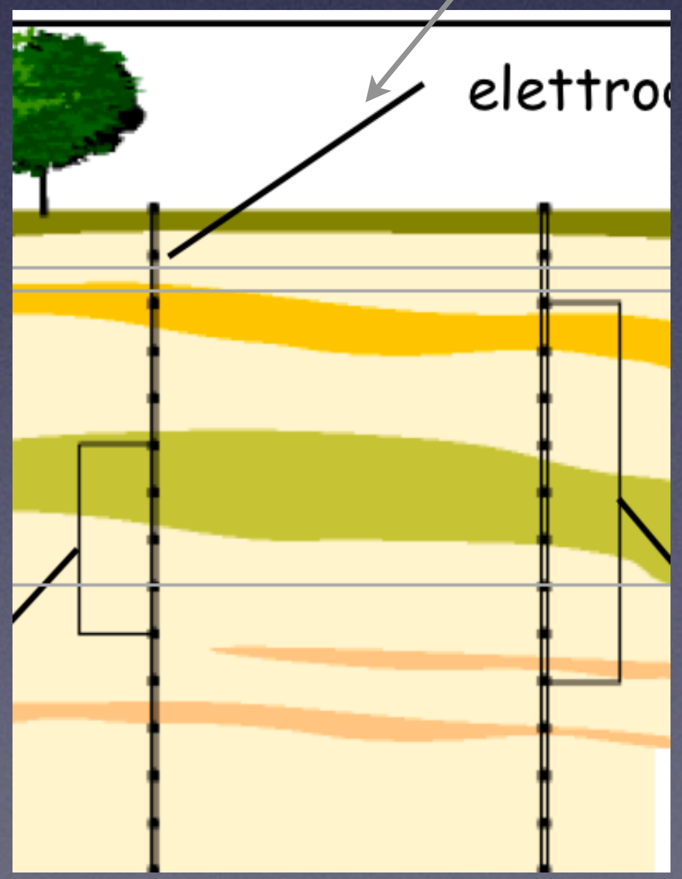
Old versus new water?

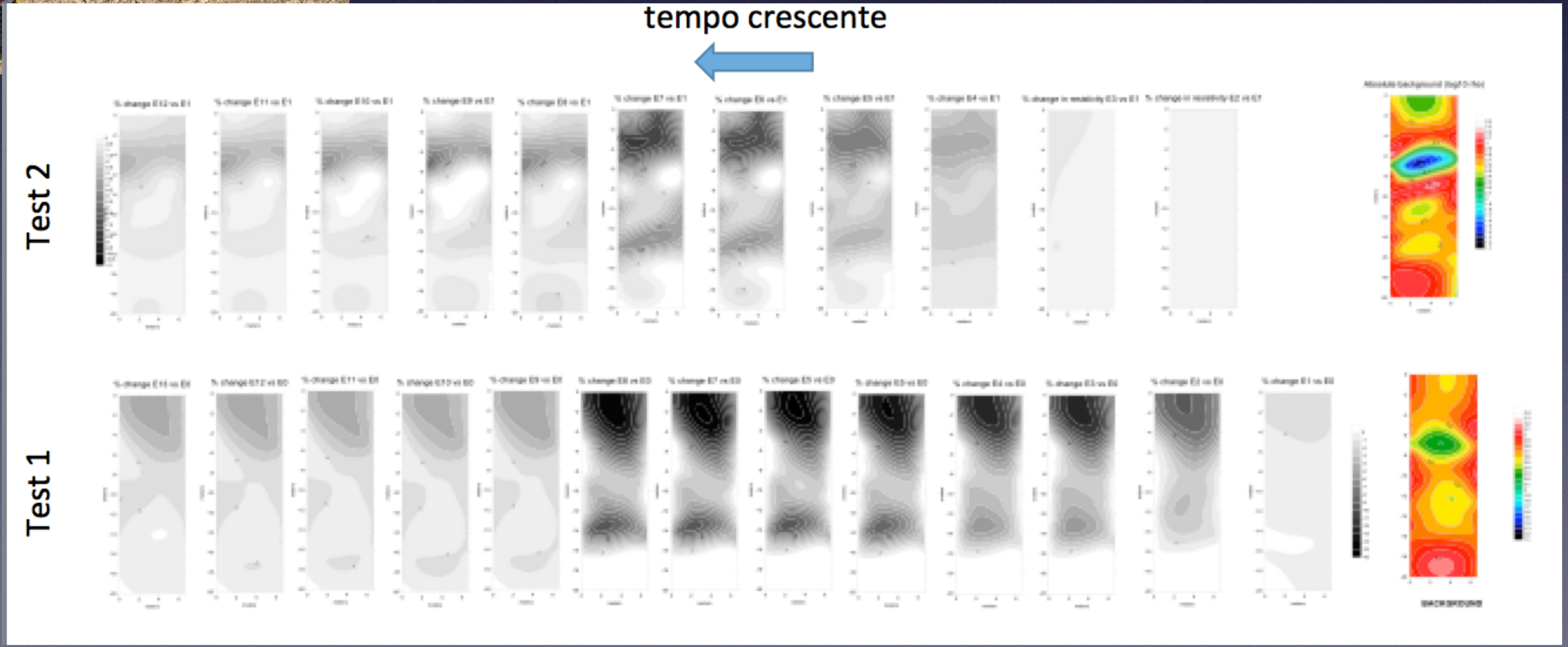


Borehole ERT

Infiltration test to
Estimate permeability

1400 lt in 10 h





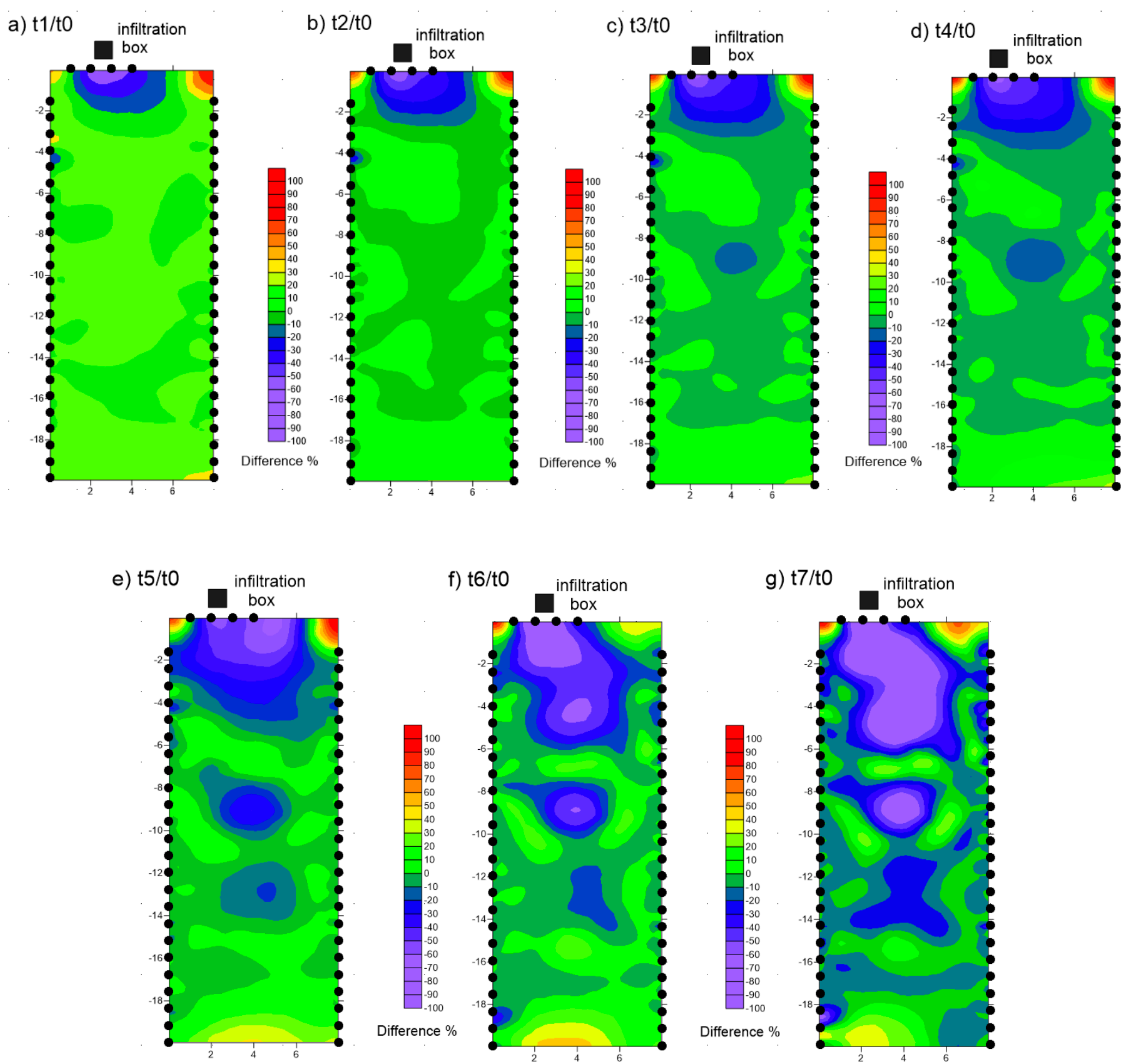


Figure 4.14 Resistivity ratio with respect to background (t0) at first seven time steps of the infiltration test

UNIVERSITÀ DEGLI STUDI DI PADOVA
eurac research
AUTONOME PROVINZ BOZEN SÜDTIROL / PROVINCIA AUTONOMA DI BOLZANO ALTO ADIGE / PROVINZIA AUTONOMA DE BULSAN SÜDTIROL
FREIE UNIVERSITÄT BOZEN / LIBERA UNIVERSITÀ DI BOLZANO / FREE UNIVERSITY OF BOZEN · BOLZANO

Permafrost Geophysical Measurements 2020 in South Tyrol and Veneto

J. Boaga, D. Mosna, C. Kofler, F. Minotti, C. Comiti, F. Sirch, M. Valt, V. Mair, M. Pavoni, ...

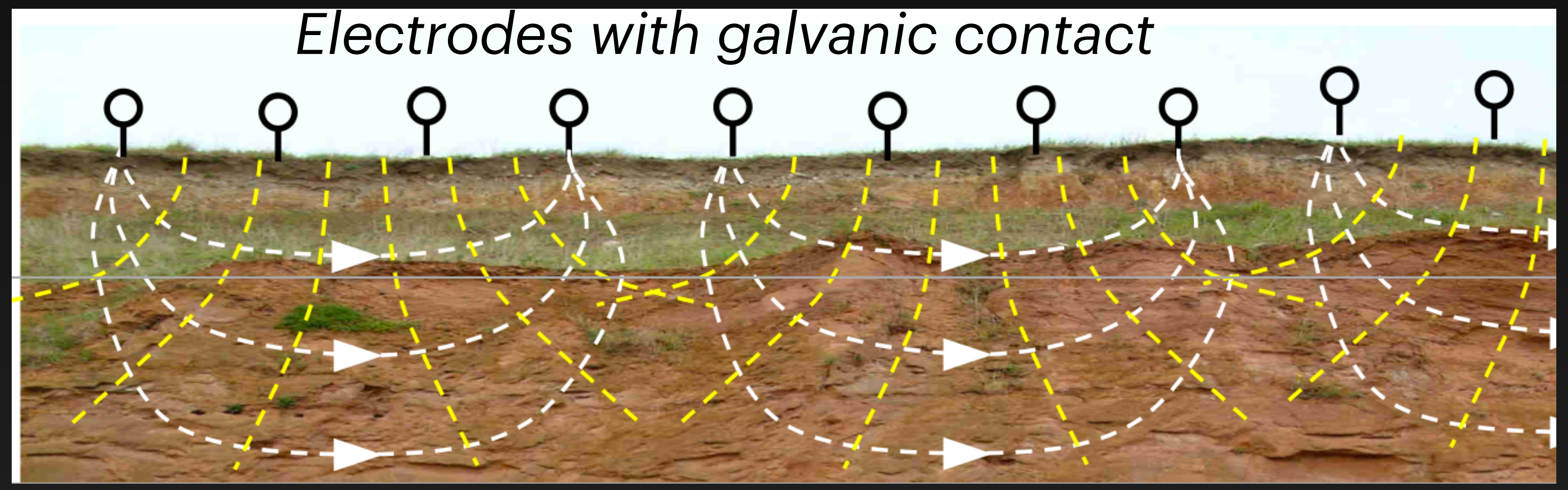
Permafrost Geophysical Measurements 2020

What ?

The methods:

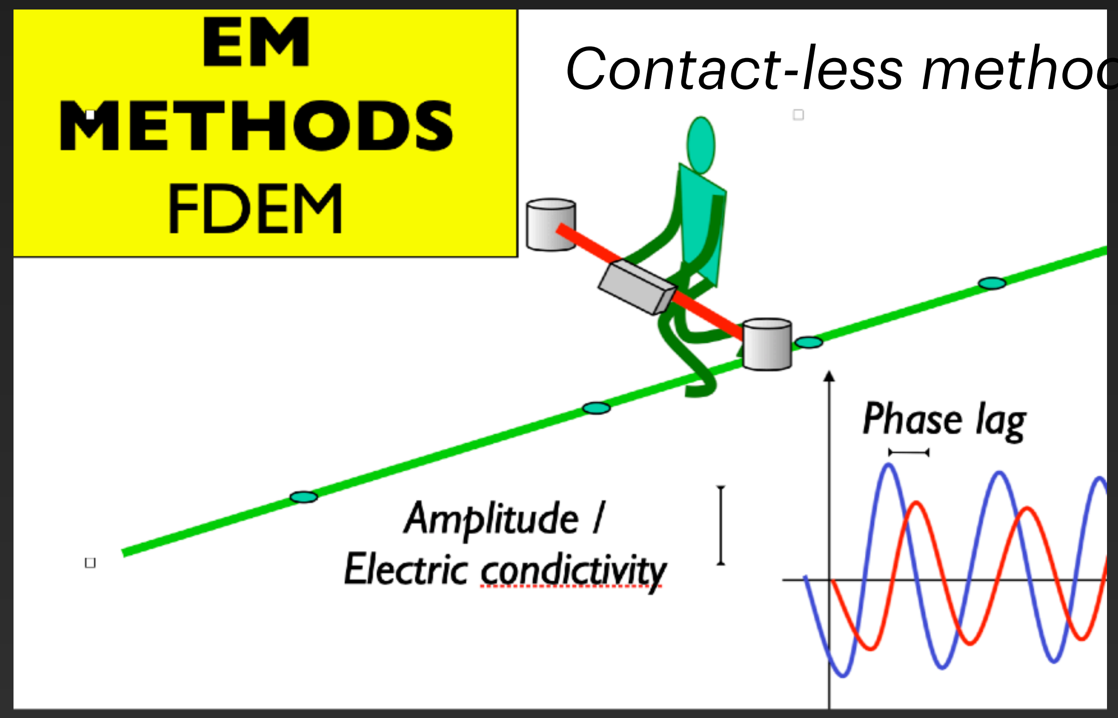
1) ELECTRICAL RESISTIVITY TOMOGRAPHY

ERT



2) FREQUENCY DOMAIN ELECTRO-MAGNETOMETER

EM



Permafrost Geophysical Measurements 2020

1) Murfreit Rock Glacier - Sella Group (Dolomites)

Active rock Glacier

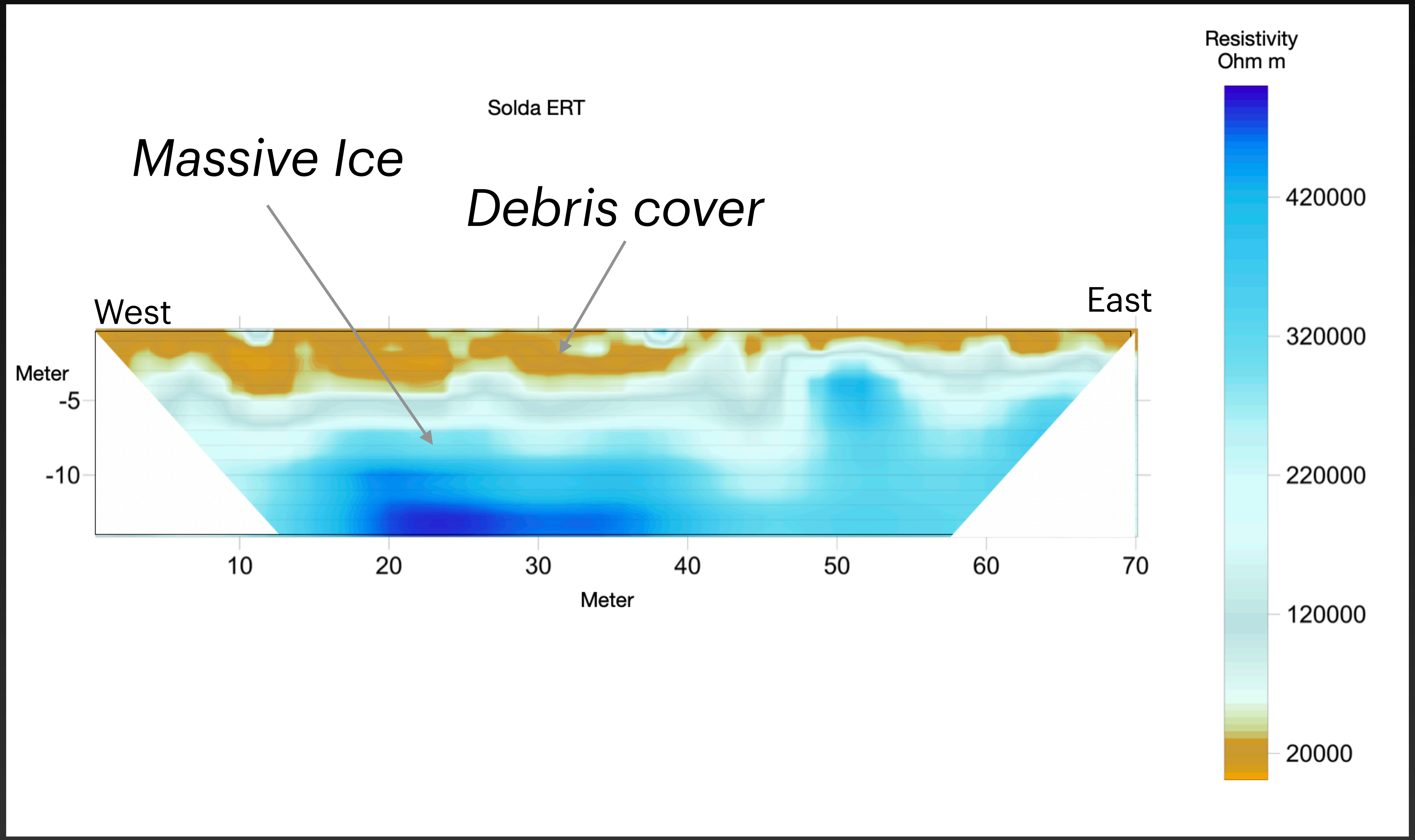
Krainer et al 2012
Mussner, 2014

Permafrost Geophysical Measurements 2020

2) Hintergrat Rock Glacier - Solda (Ortles)

ERT

Active layer ≈ 3-4 m



Permafrost Geophysical Measurements 2020

3) Piz Boè Rock Glacier - Sella Group (Dolomites)

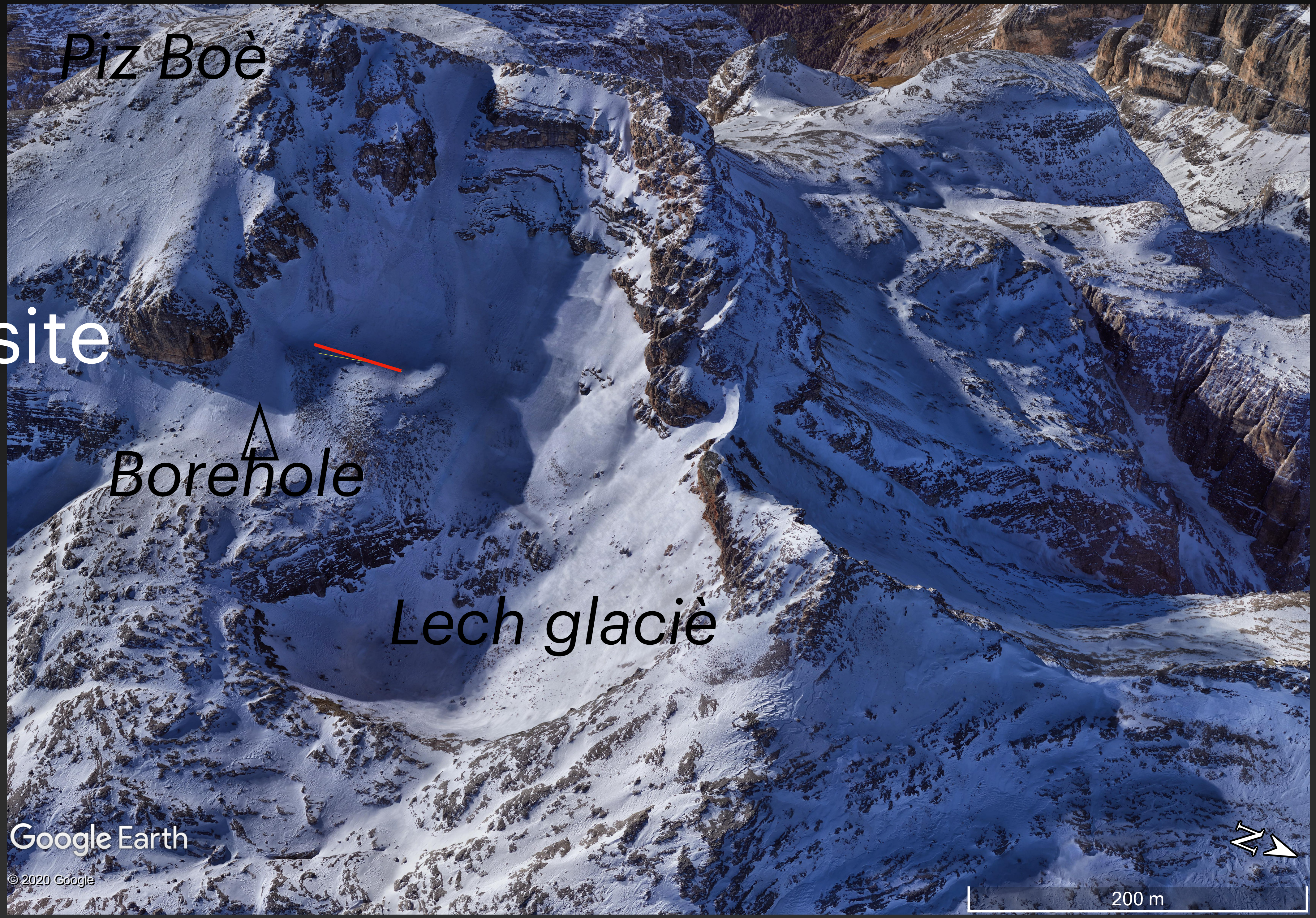
Piz Boè site

Close to the Permanet

Temperature Borehole site

(collaboration with

M. Valt, ARPAV Veneto)



Permafrost Geophysical Measurements 2020

3) Piz Boè Rock Glacier - Sella Group (Dolomites)

ERT Line

Length: 70.5 m

Elec: 48

Conf: dip/Ws

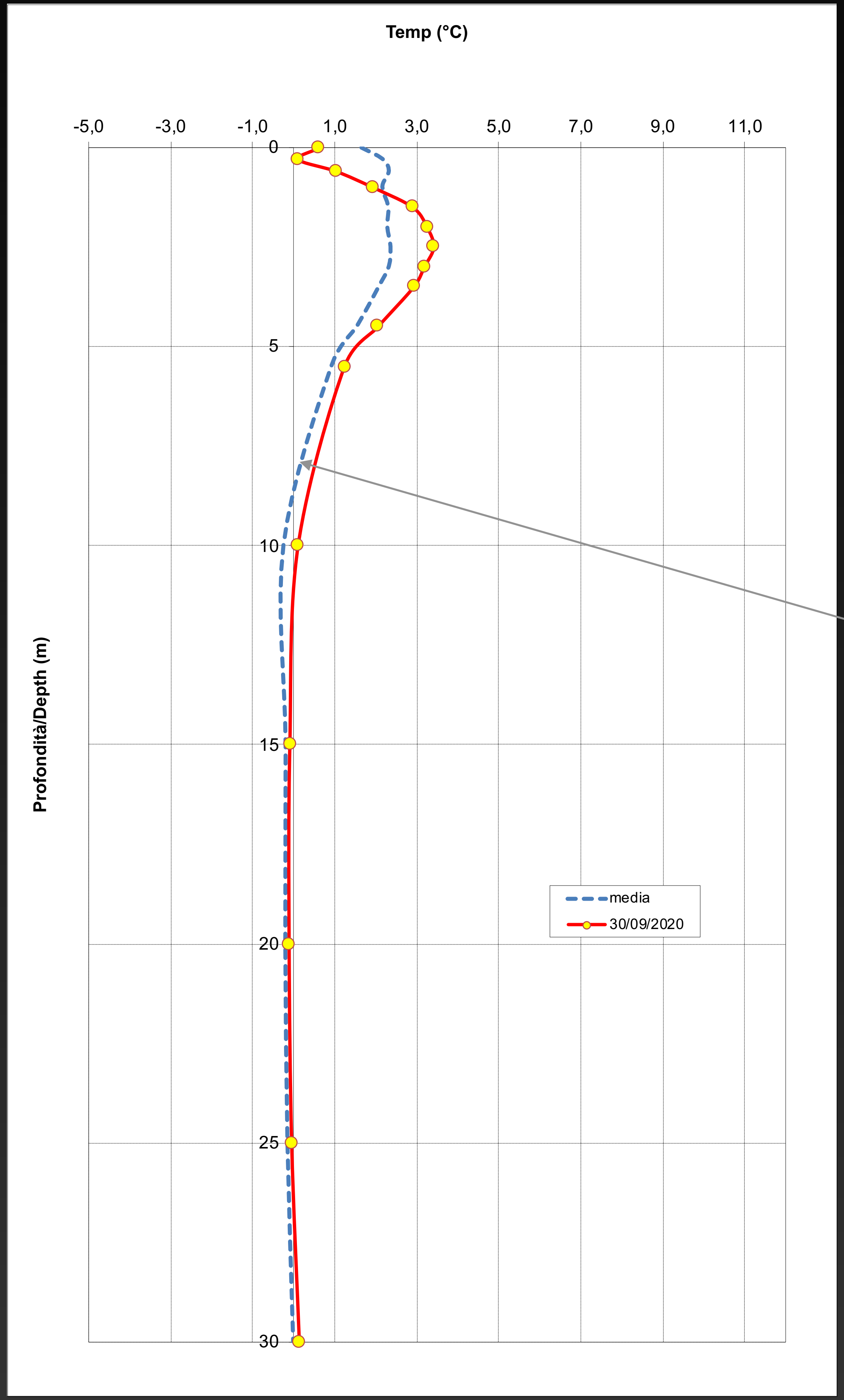
EM line

EM1 = 70.5 m

Permafrost geophysical surveys 2020 - Bz

Permafrost Geophysical Measurements 2020

3) Piz Boè Rock Glacier - Sella Group (Dolomites)

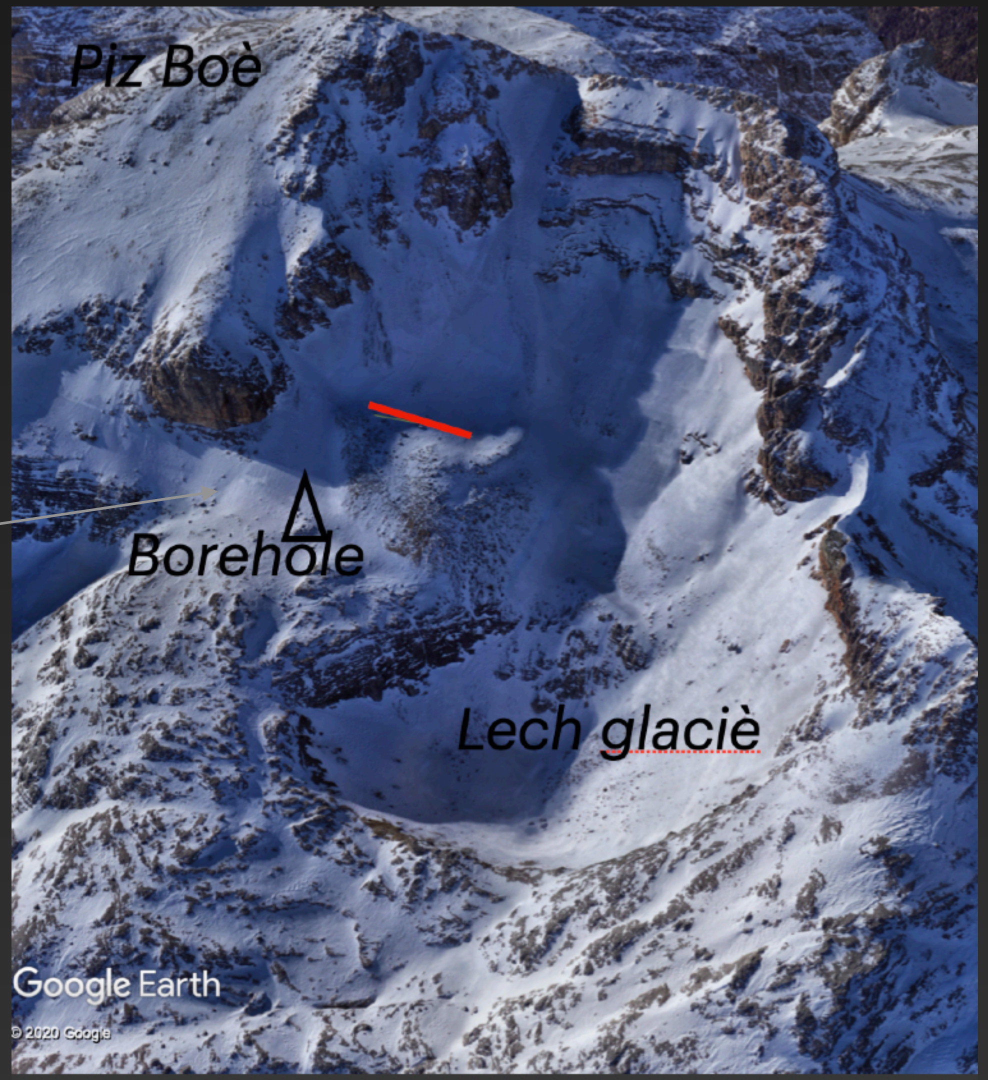


Borehole temperature

Average Active Layer

Thickness ≈ 8 m

Borehole in rock

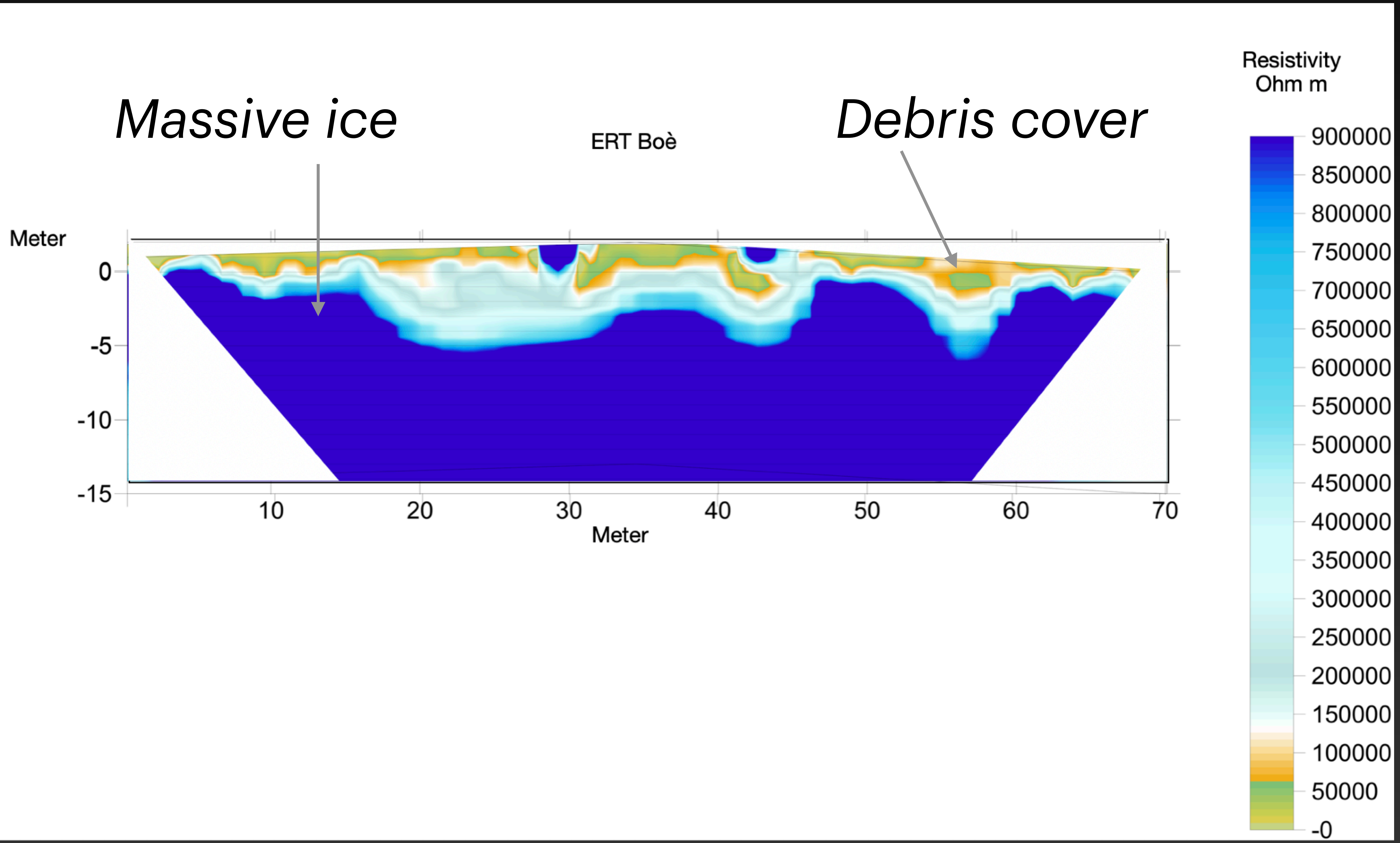


Permafrost Geophysical Measurements 2020

3) Piz Boè Rock Glacier - Sella Group (Dolomites)

ERT 2020

Active layer ≈ 2 - 3 m



Permafrost geophysical surveys 2020 - Bz

Permafrost Geophysical Measurements 2020

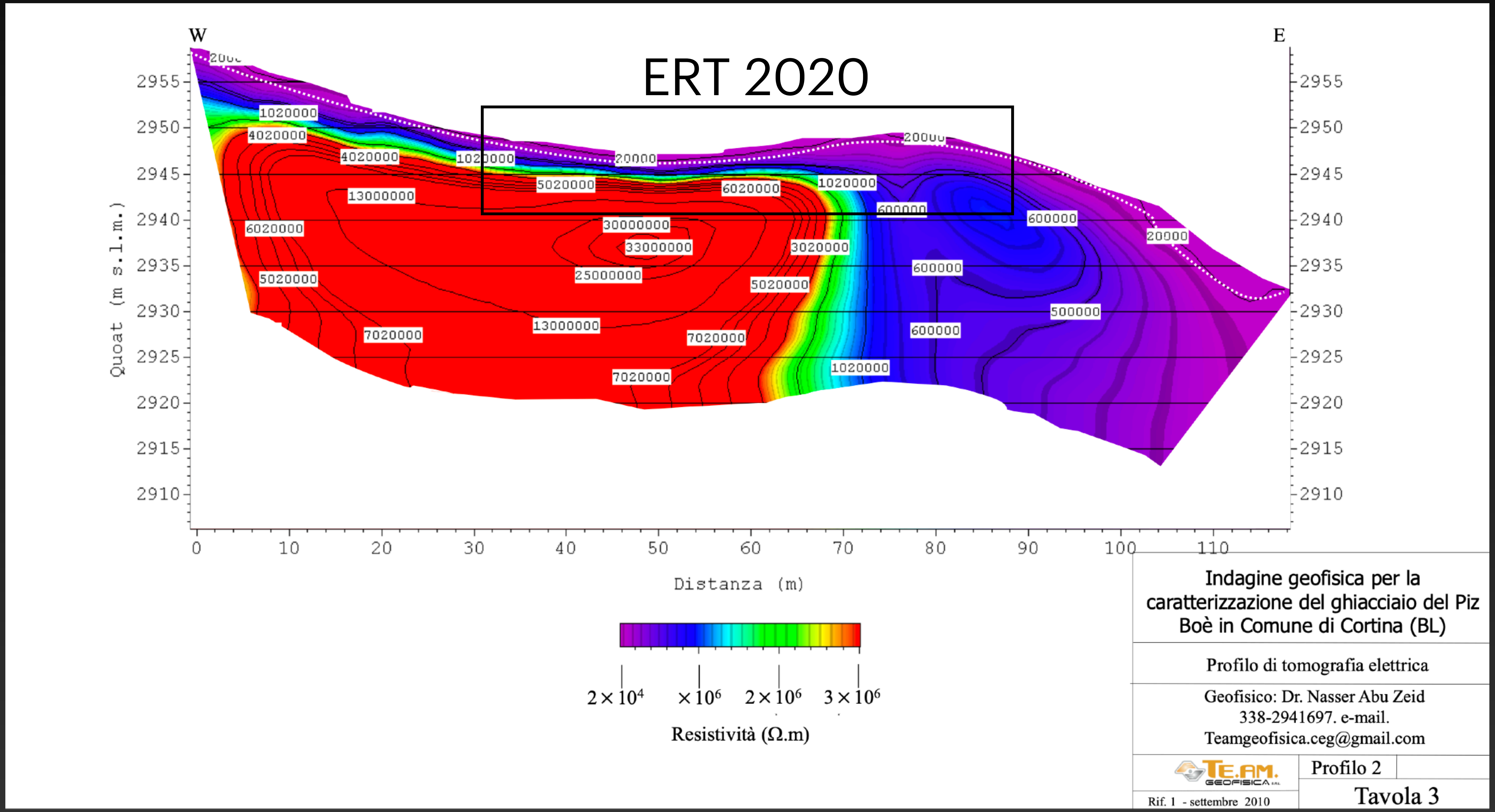
3) Piz Boè Rock Glacier - Sella Group (Dolomites)

ERT 2010

Active layer ≈ 2 m

In agreement with

2010 measurements



Permafrost geophysical surveys 2020 - Bz

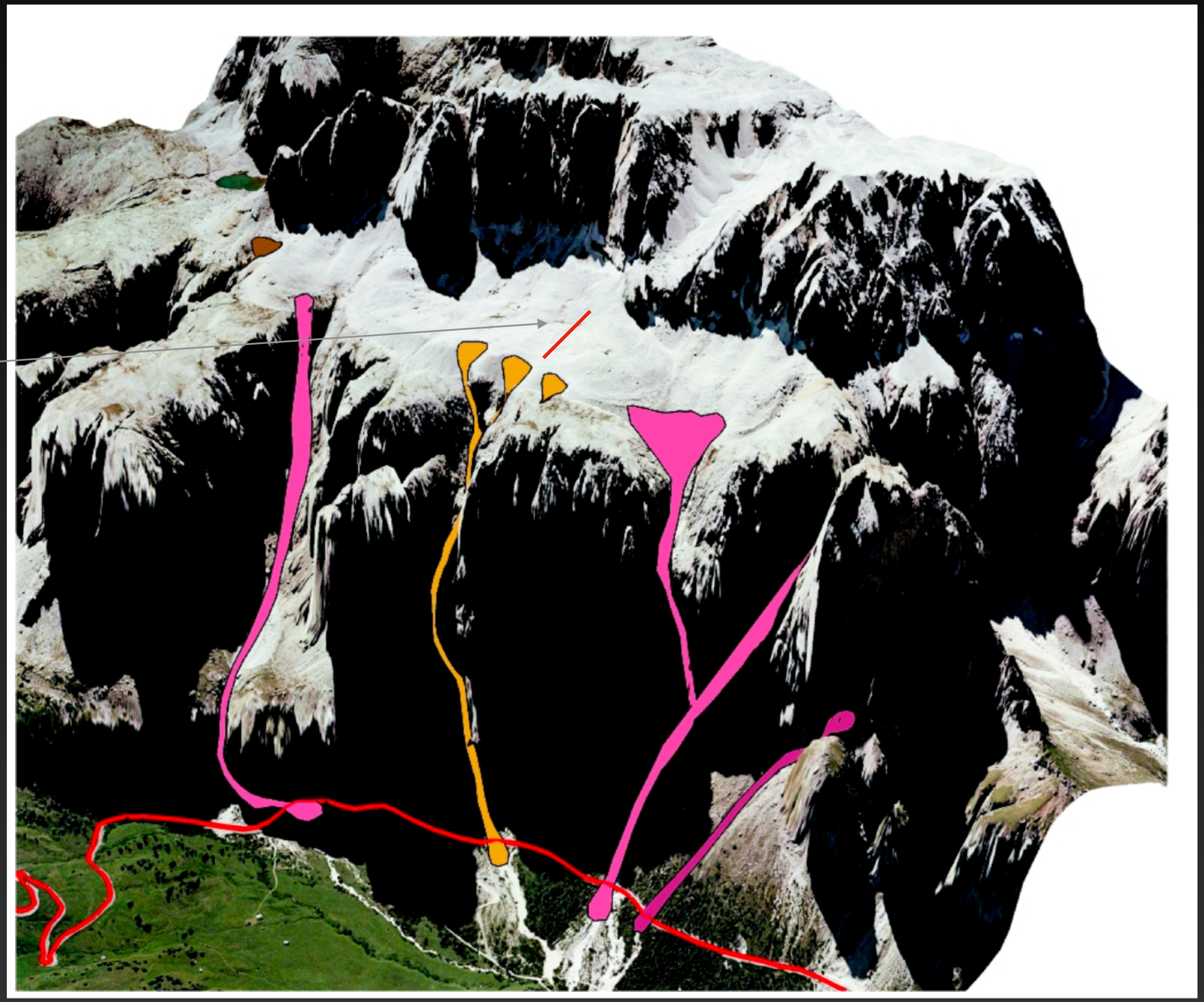
Permafrost Geophysical Measurements 2020

1) Mufreit Rock Glacier - Sella Group (Dolomites)

Related Active debris

Survey 2020

Gardena Pass Road



Krainer et al 2012

Permafrost Geophysical Measurements 2020

1) Mufreit Rock Glacier - Sella Group (Dolomites)

Survey 2020

Permanet Project Borehole

ERT Line

Length: 70.5 m

Elec: 48

Conf: dip/Ws

EM line

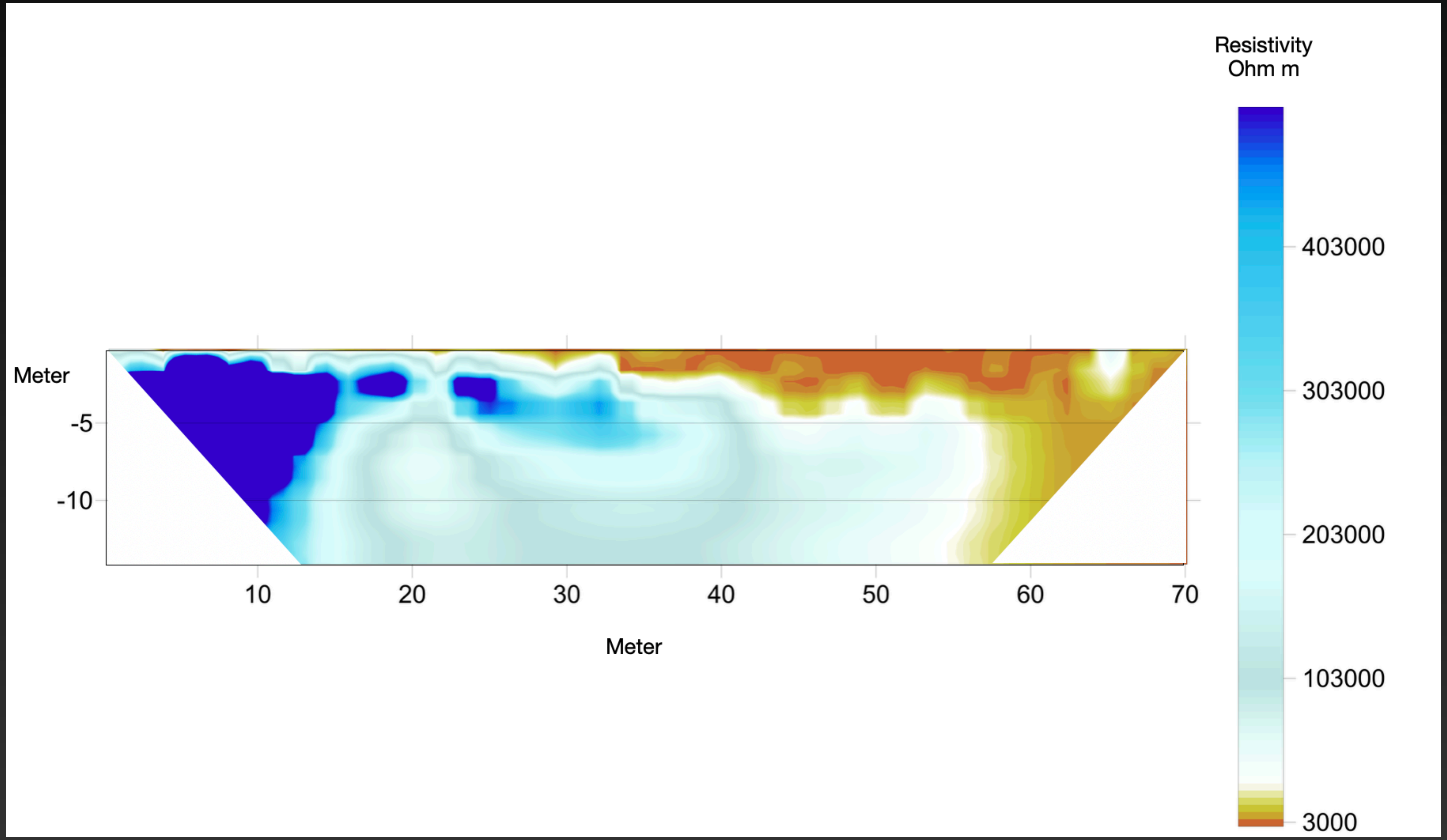
Explorer FDEM

Probe

Permafrost Geophysical Measurements 2020

1) Mufreit Rock Glacier - Sella Group (Dolomites)

ERT



Permafrost geophysical surveys 2020 - Bz

Permafrost Geophysical Measurements 2020

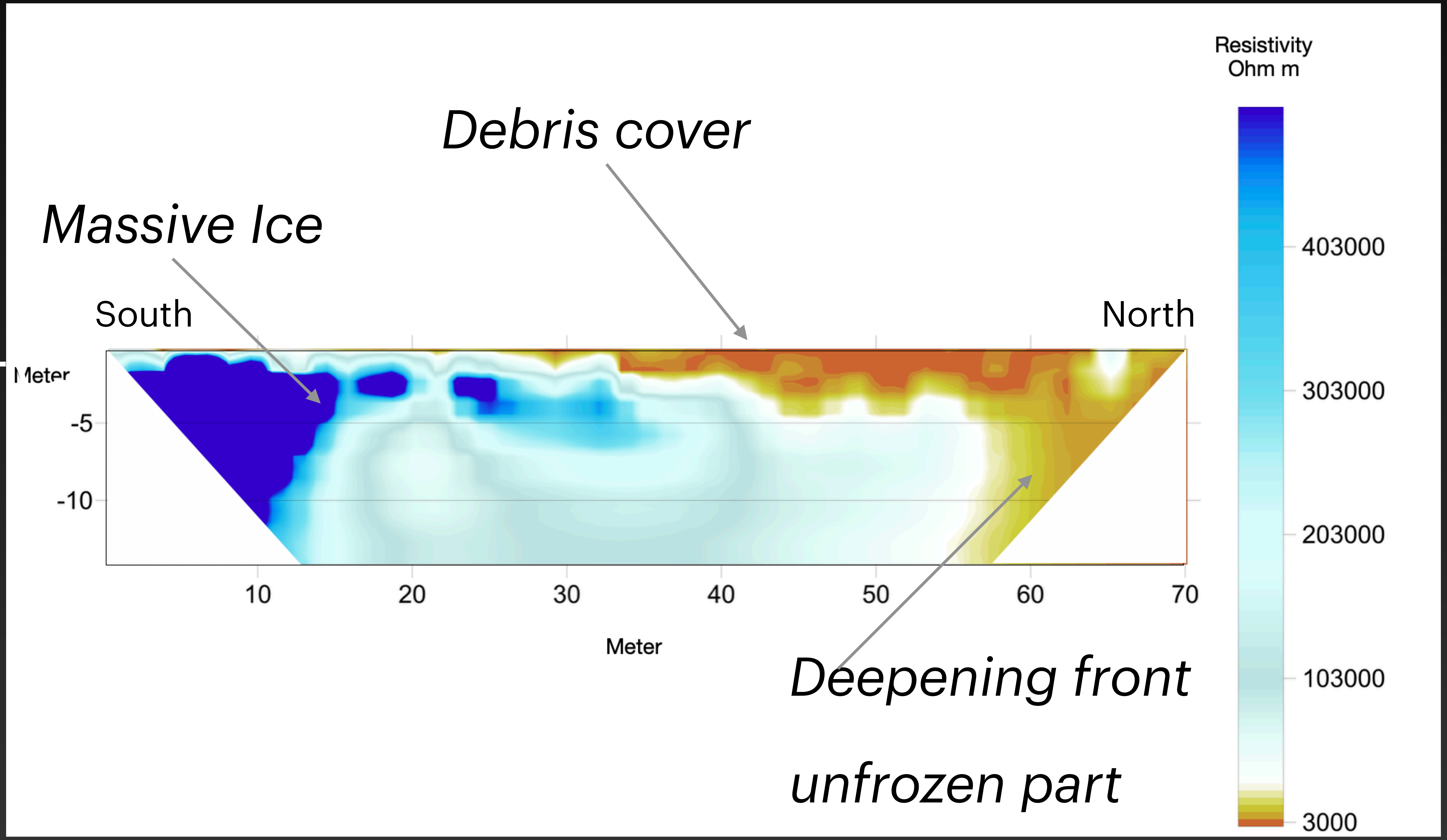
1) Mufreit Rock Glacier - Sella Group (Dolomites)

ERT

Active layer

Thickness (ALT)

0.5- 5m



Electrical methods

Applications and limits

Electrical methods

PRO

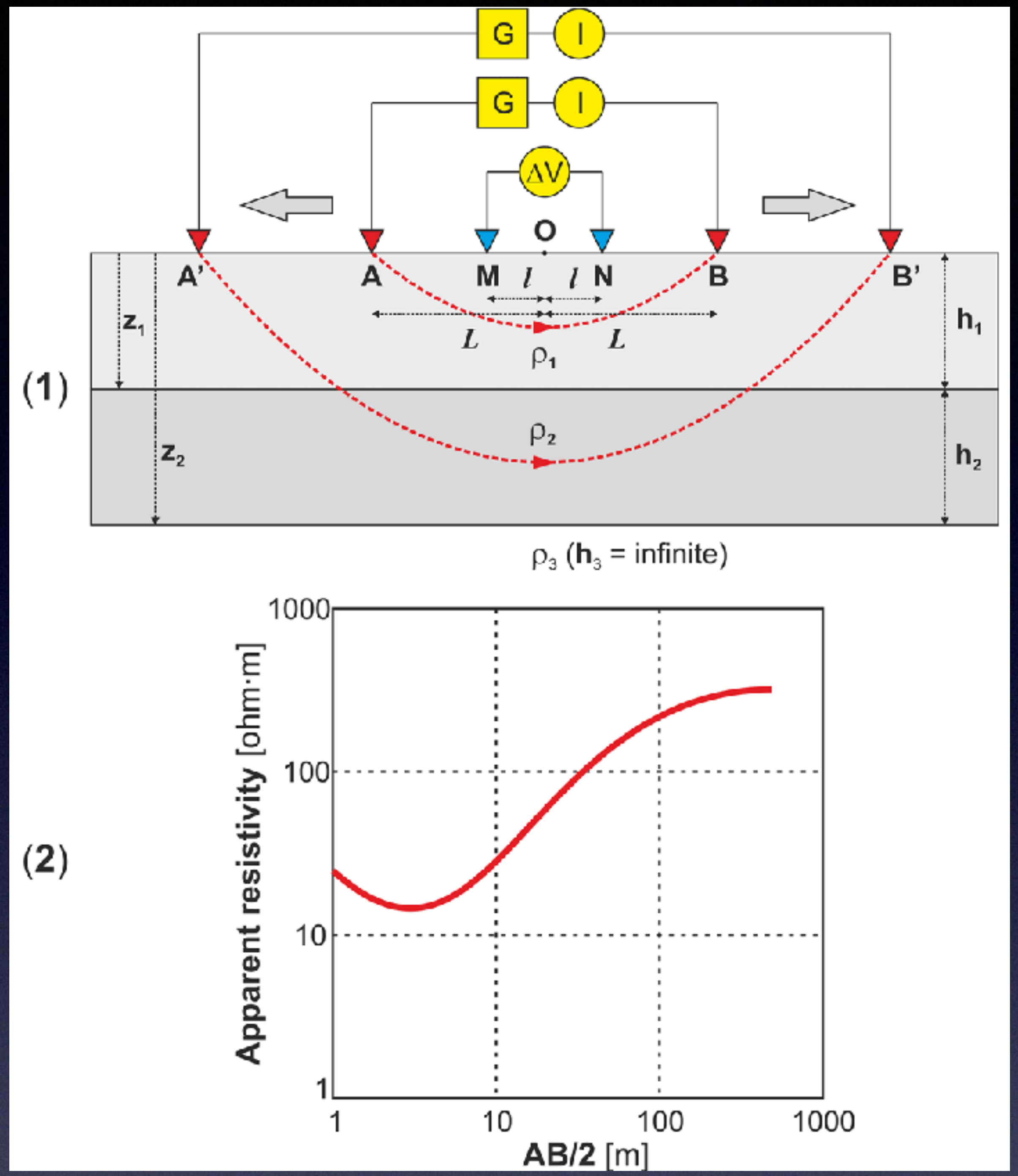
- Resolution (maybe the best survey possible)
- Logistically easier (than seismic)
- Time -effective
- Time-lapse possibility
- Huge polyvalent application (buy one, you will use it)

CONS

- Penetration (limited if not in borehole or 'wireless ert')
- Galvanic contact, a real issues in several environment (rock, debris, dry gravel, asphalt, etc.)
- Energy consumption (need battery)
- Length limtated by cable
- Quite with the interpretation (concept of equivalence)

Resistivity is one of the properties with greatest change in subsoil

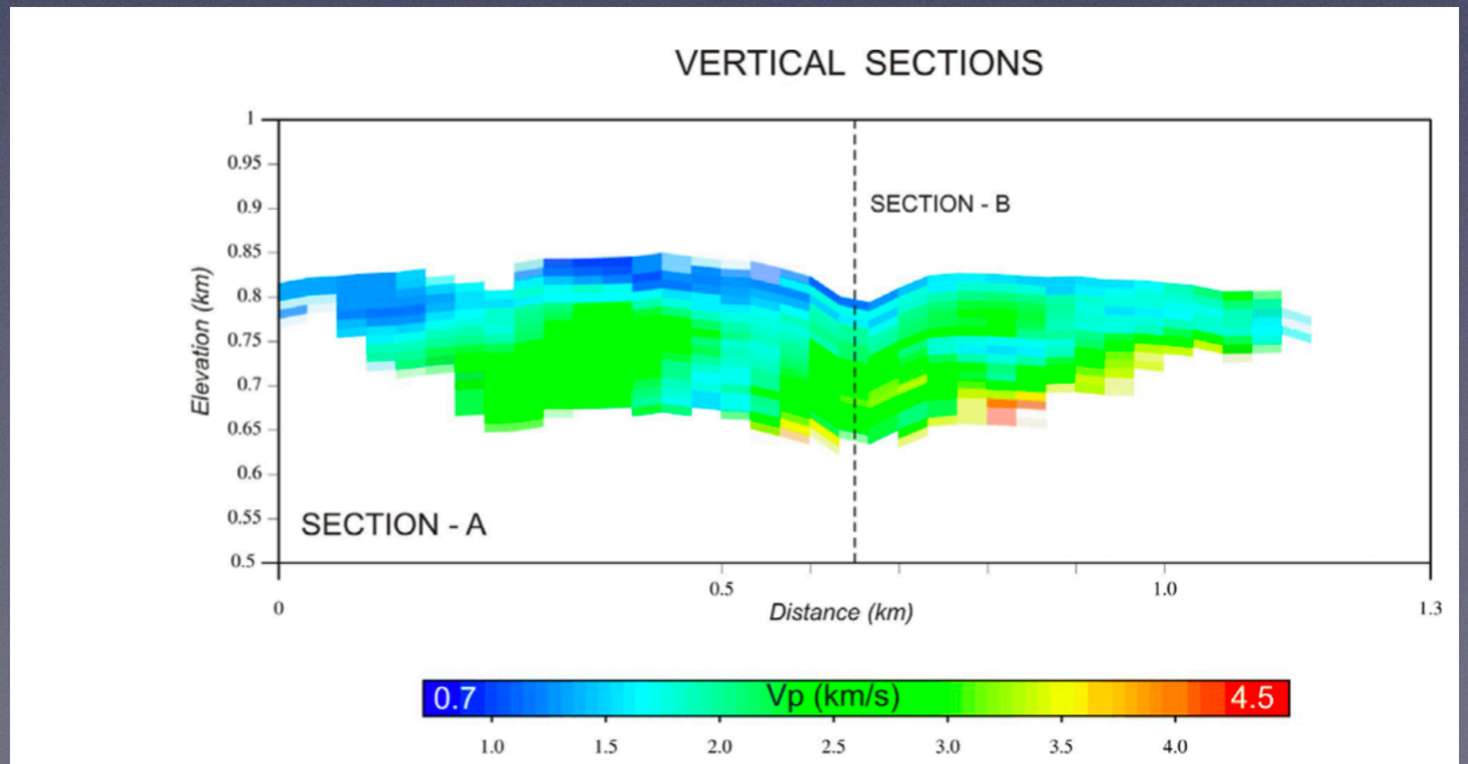
Electrical methods



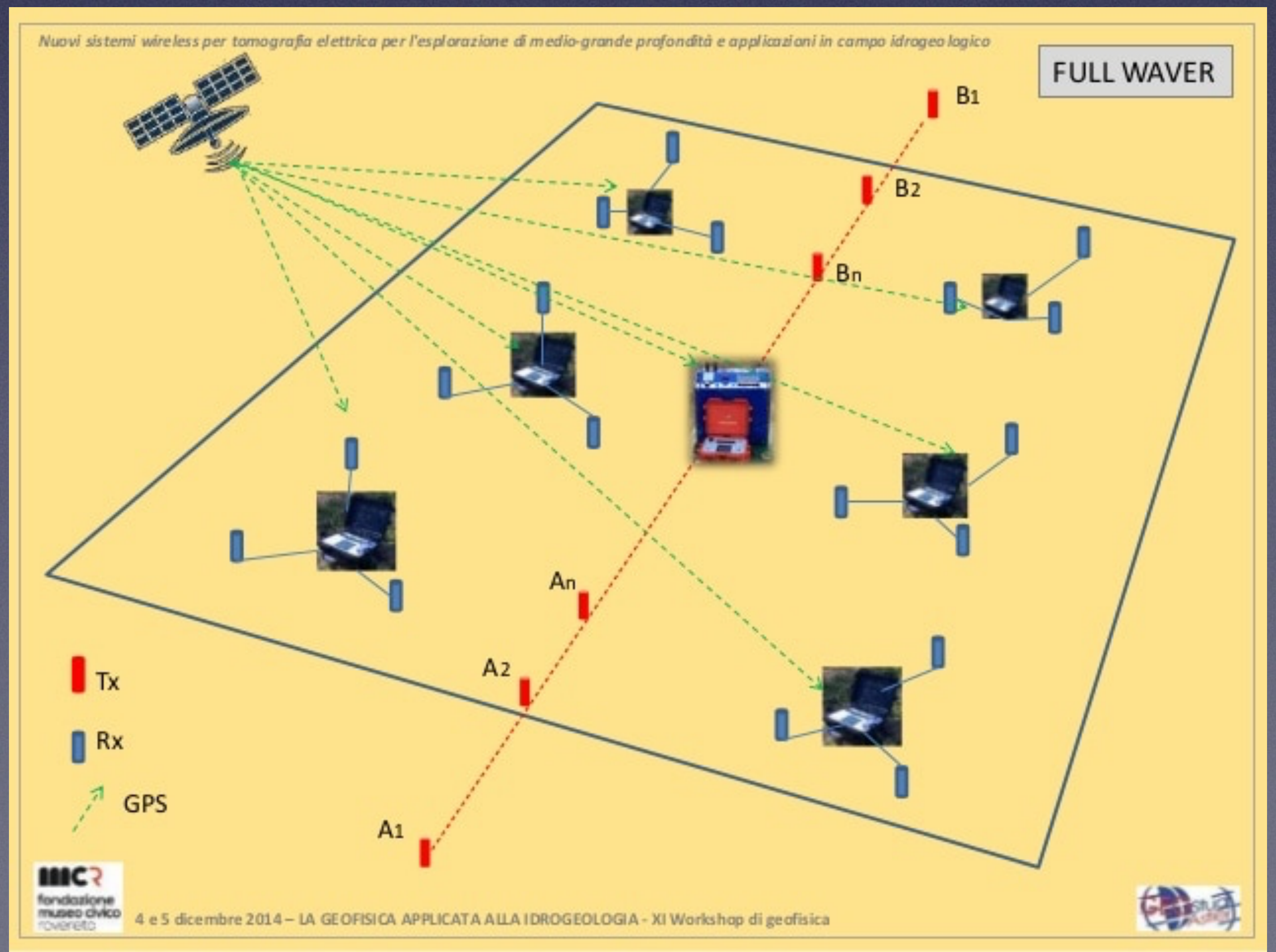
Use simplified approach to go deeper (e.g. Vertical Electrical sounding VES), logistically much easier

Penetration limit

Use wireless quadruples solutions (few diffusion, high cost)



Boehm et al



Electrical methods

Galvanic contact

Adopt strategy to:

- avoid bad galvanic contact
- Help the contacts with the ground

Wetting contact

With salt-water
Or wet Sponges

Conductive grease (polymer carbon gel)

Increase surface of contact

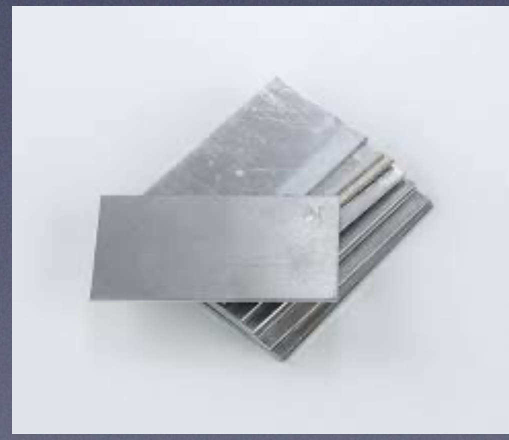


Plate electrode or multiple electrodes

DIPARTIMENTO DI GEOSCIENZE

UNIVERSITÀ DEGLI STUDI DI PADOVA

IMPROVING GALVANIC CONTACT RESISTANCE ON DEBRIS SLOPE: A COMPARATIVE TEST

Mirko Pavoni - Jacopo Boaga - Alberto Carrera

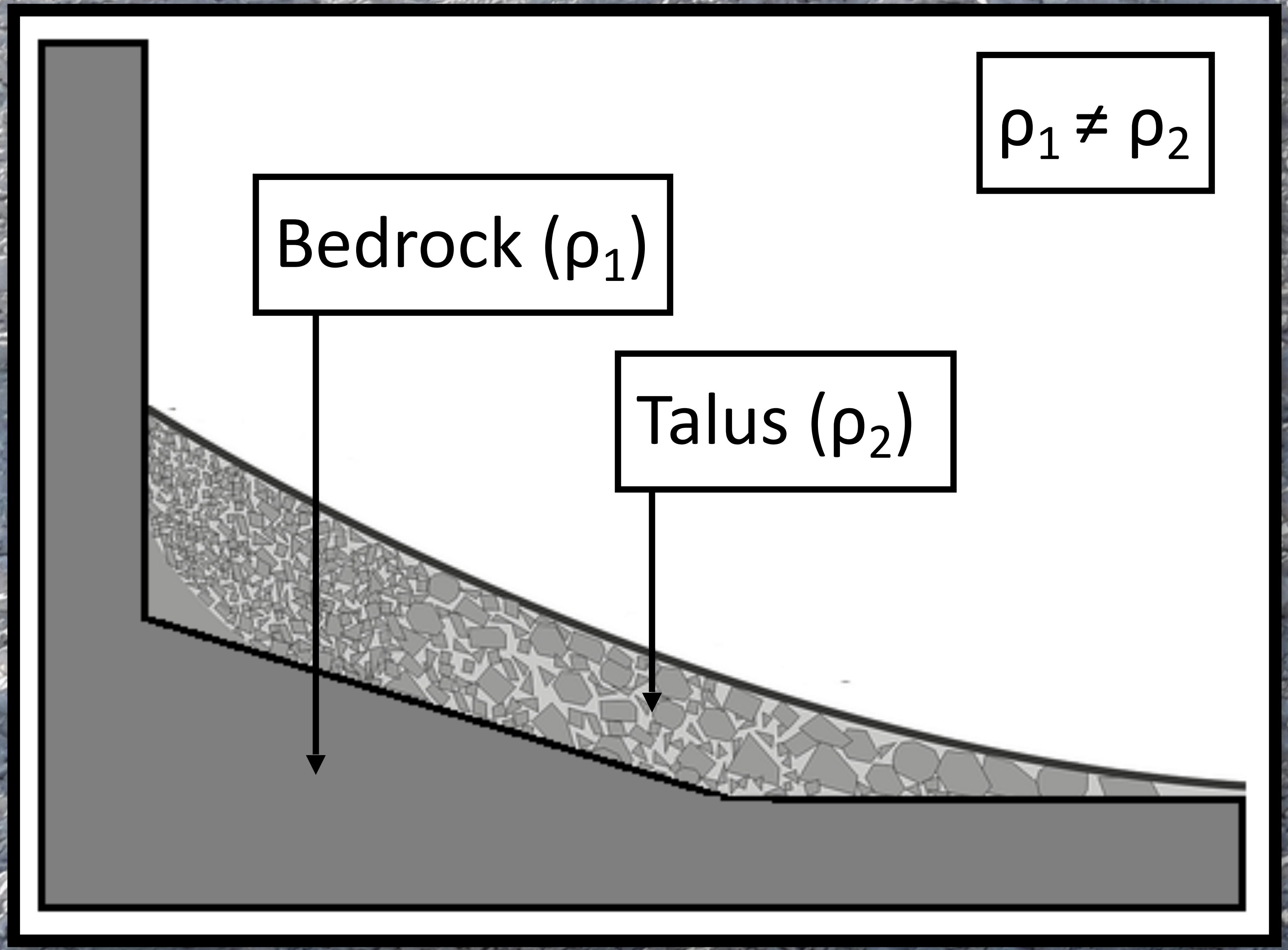
Gruppo Nazionale di Geofisica della Terra Solida

DIPARTIMENTO DI GEOSCIENZE

MOTIVATION

UNIVERSITÀ DEGLI STUDI DI PADOVA

ERT SURVEYS ARE USED FOR CHARACTERIZATION OF TALUS AND ROCKFALL DEPOSITS

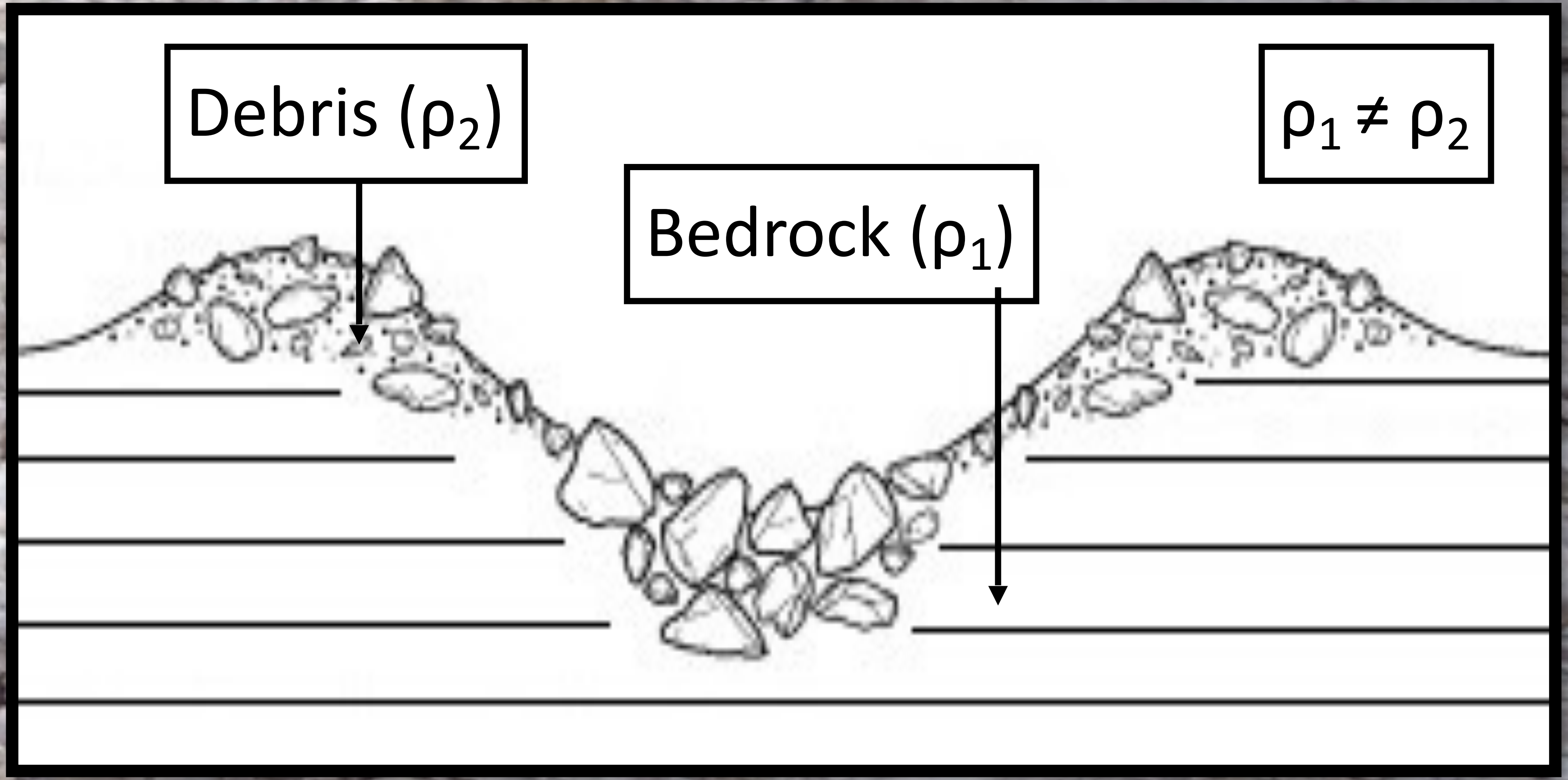


DIPARTIMENTO DI GEOSCIENZE

UNIVERSITÀ DEGLI STUDI DI PADOVA

MOTIVATION

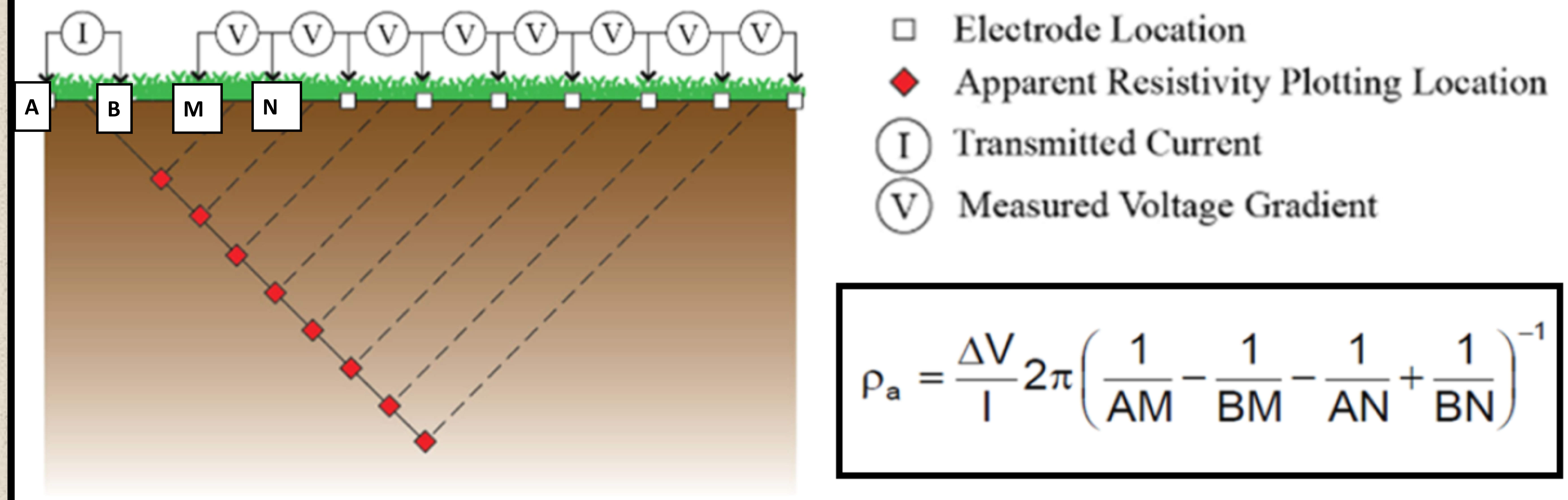
ERT SURVEYS ARE APPLIED ALSO FOR THE CHARACTERIZATION OF DEBRIS FLOW CHANNELS



DIPARTIMENTO DI GEOSCIENZE

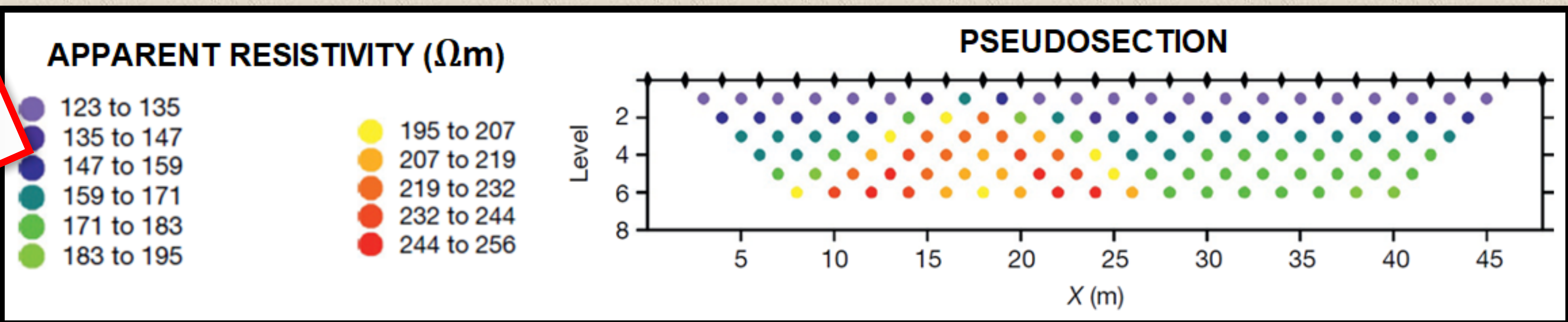
UNIVERSITÀ DEGLI STUDI DI PADOVA

METHOD



$$\rho_a = \frac{\Delta V}{I} 2\pi \left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN} \right)^{-1}$$

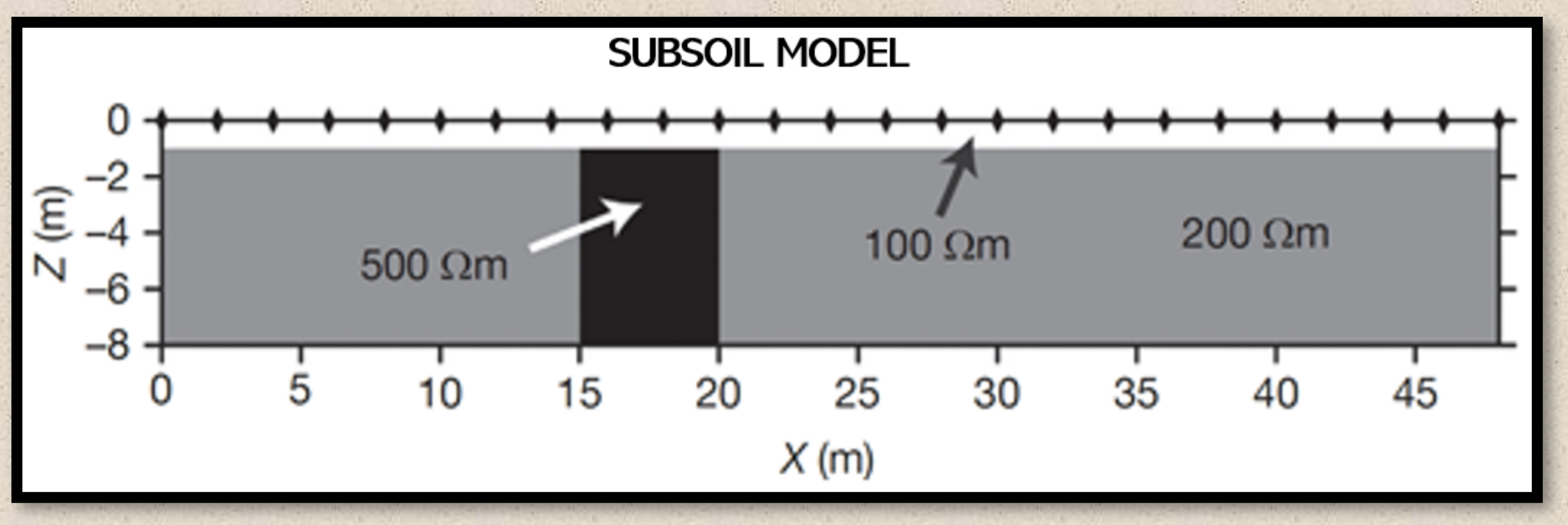
NOT THE REAL STRUCTURE OF THE SUBSOIL

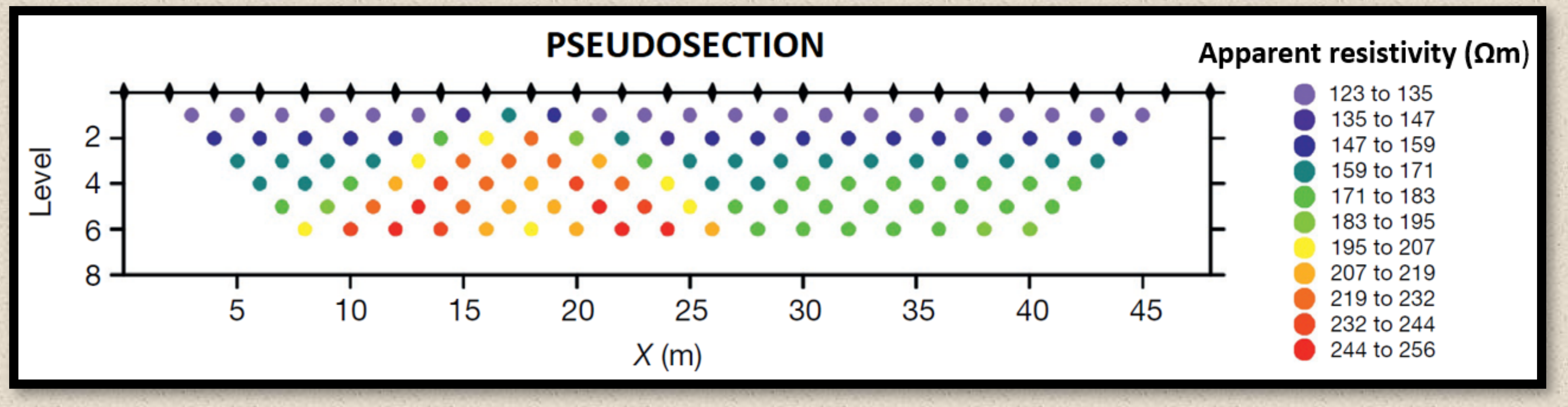


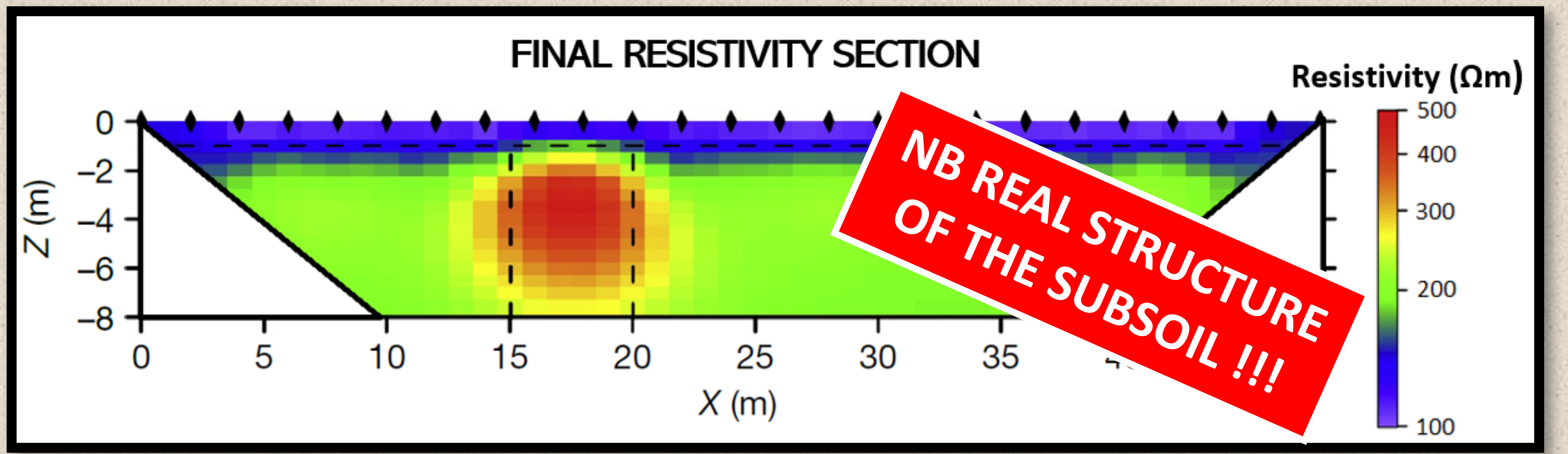
DIPARTIMENTO DI GEOSCIENZE

METHOD

UNIVERSITÀ DEGLI STUDI DI PADOVA







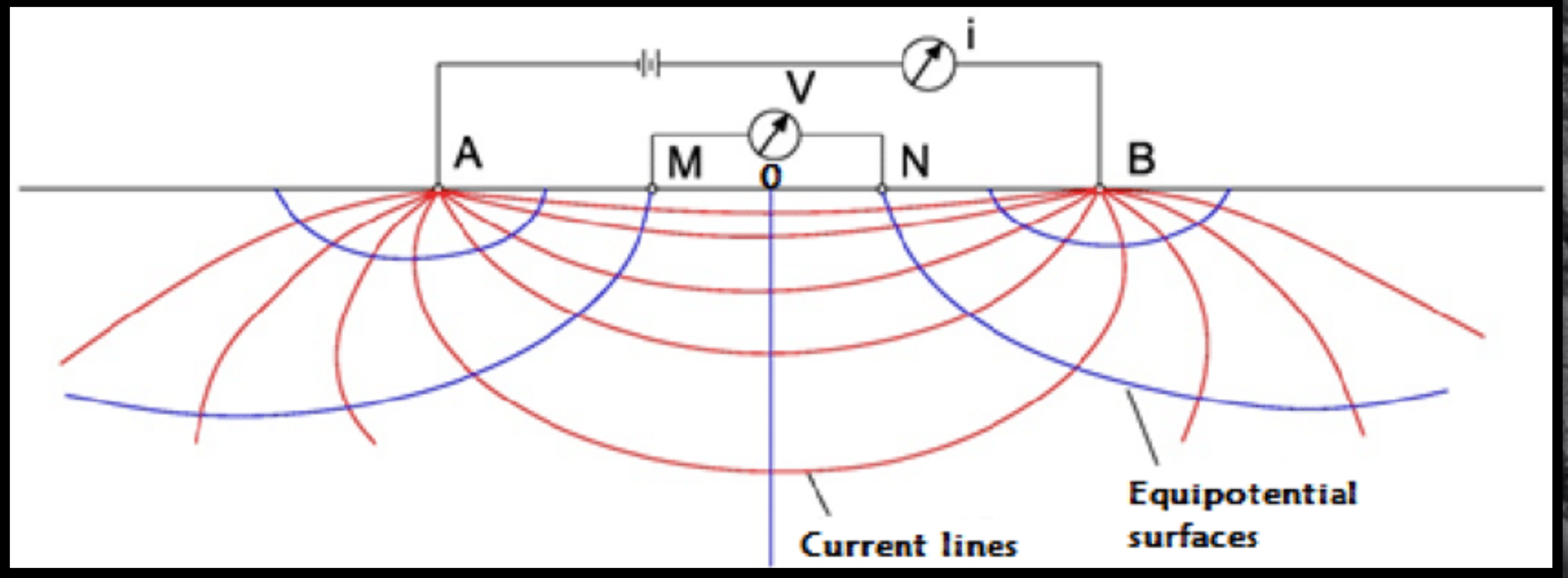
NB REAL STRUCTURE OF THE SUBSOIL !!!

FIELD MEASUREMENTS

INVERSE MODELING

ASSUMPTION

GOOD COUPLING & GALVANIC CONTACT BETWEEN ELECTRODES AND GROUND TO INJECT THE CURRENT!!!



DIPARTIMENTO DI GEOSCIENZE

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PROBLEM

WITH A ROCKY GROUND SURFACE COUPLING THE ELECTRODES WITH THE BOULDERS IS NOT TRIAVAL !!!

POOR GALVANIC CONTACT AND HIGH CONTACT RESISTANCES !!!

↓

POOR SIGNAL-TO-NOISE RATIO

↓

LOW QUALITY OF THE ACQUIRED DATASET !!!

↓

POOR RELIABILITY RESULTS

DIPARTIMENTO DI GEOSCIENZE

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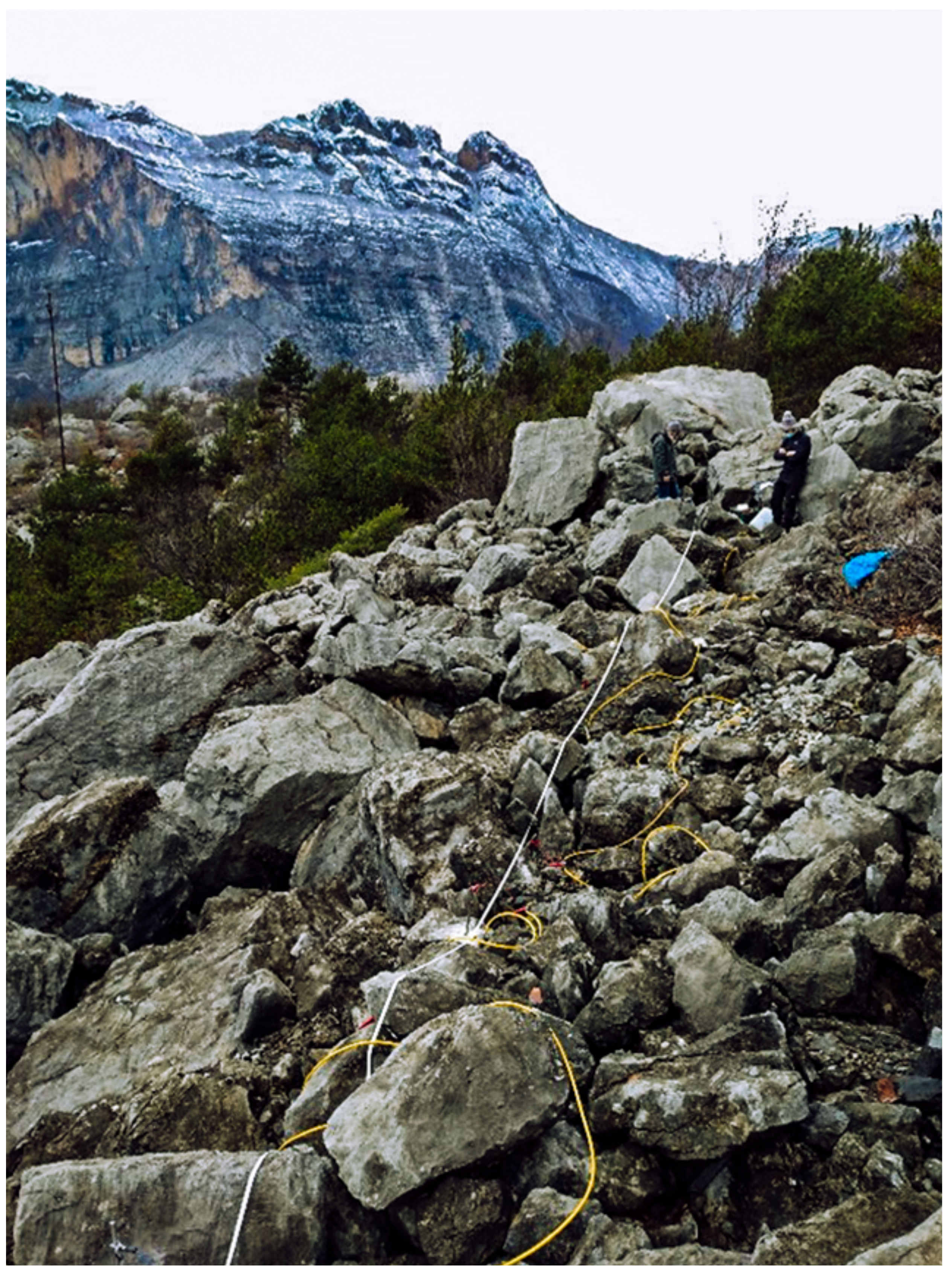
STUDY CASE



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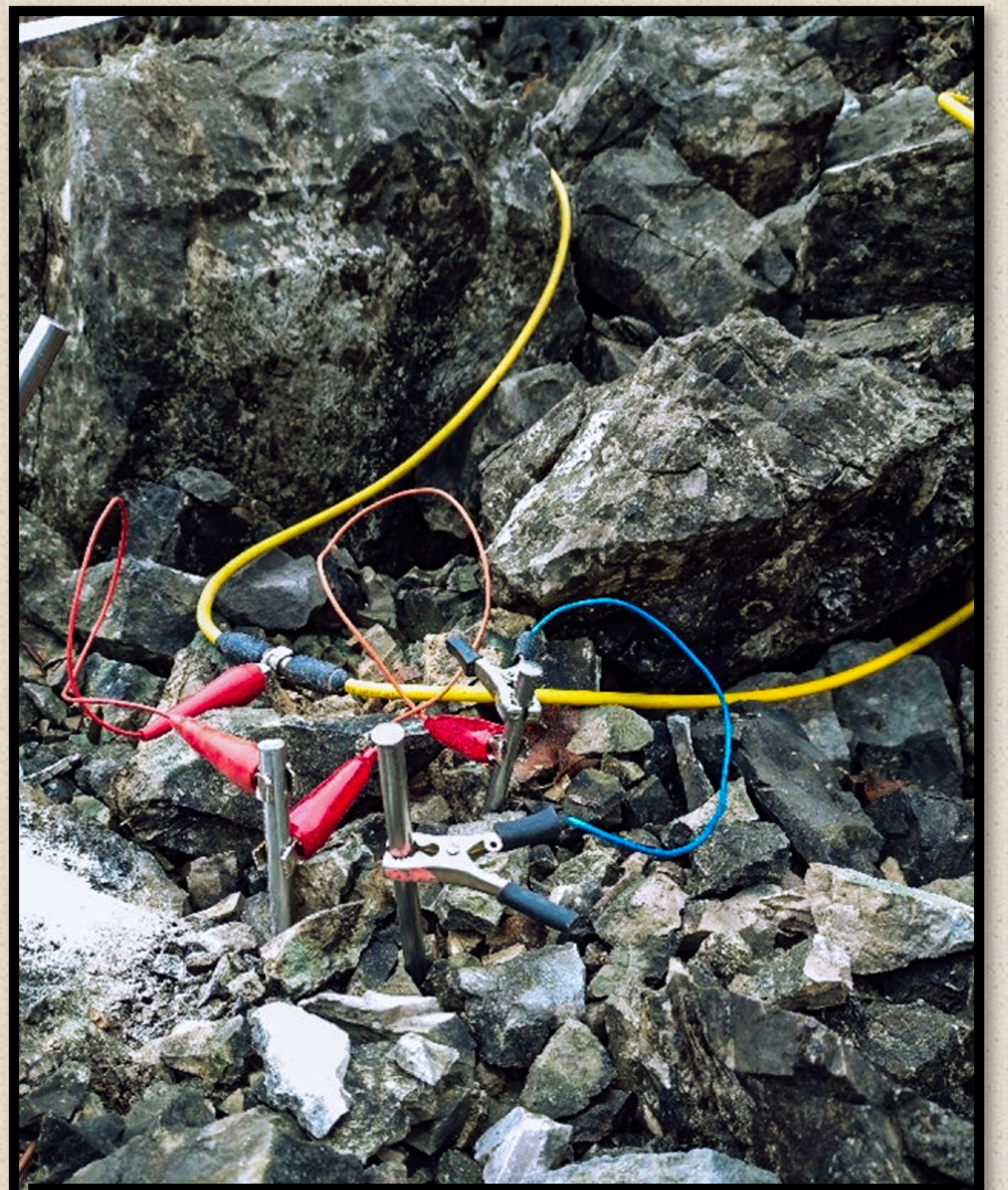
STUDY CASE

Survey line of 23 m → Spacing 1 m → 3 Different Electrodes Coupling

Single electrodes between boulders



Triplets between boulders

Electrodes drilled into the boulders

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STUDY CASE

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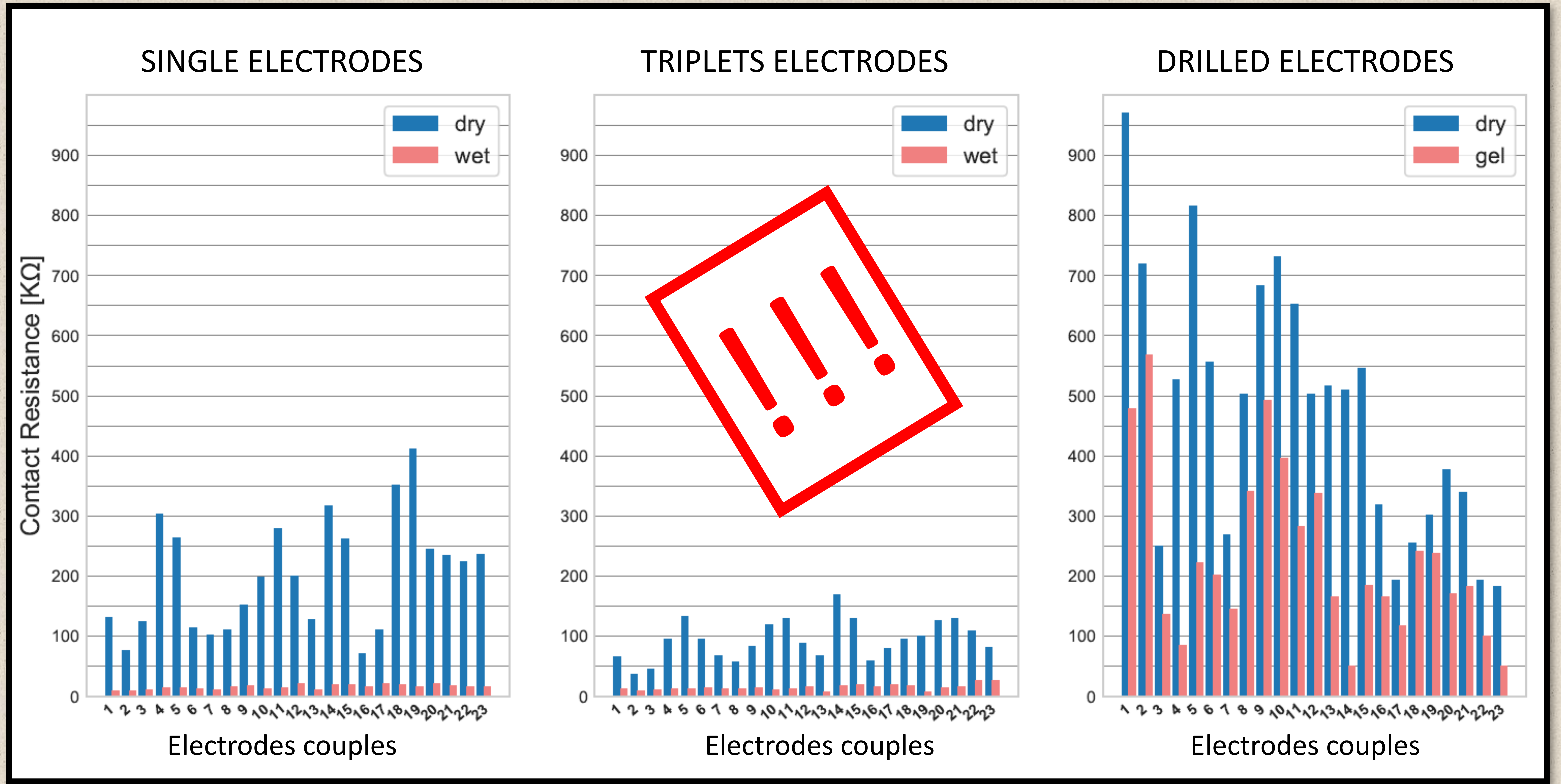
2 ways to improve the GALVANIC CONTACT and reduce the CONTACT RESISTANCES:

1° SALT-WATER around the electrodes

2° CARBOMER-BASED inside the holes

RESULTS

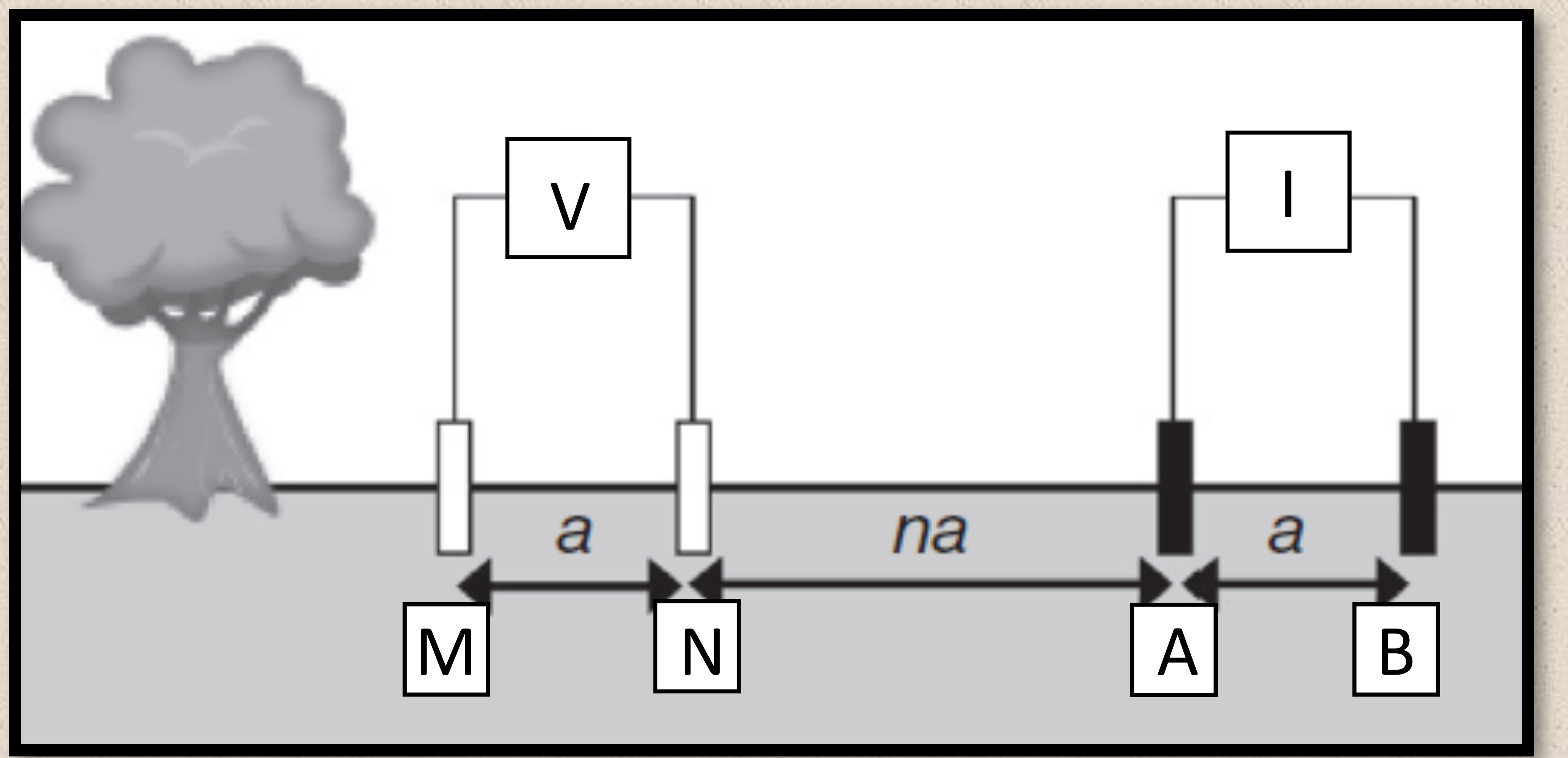
CONTACT RESISTENCES OF 6 COLLECTED DATASETS



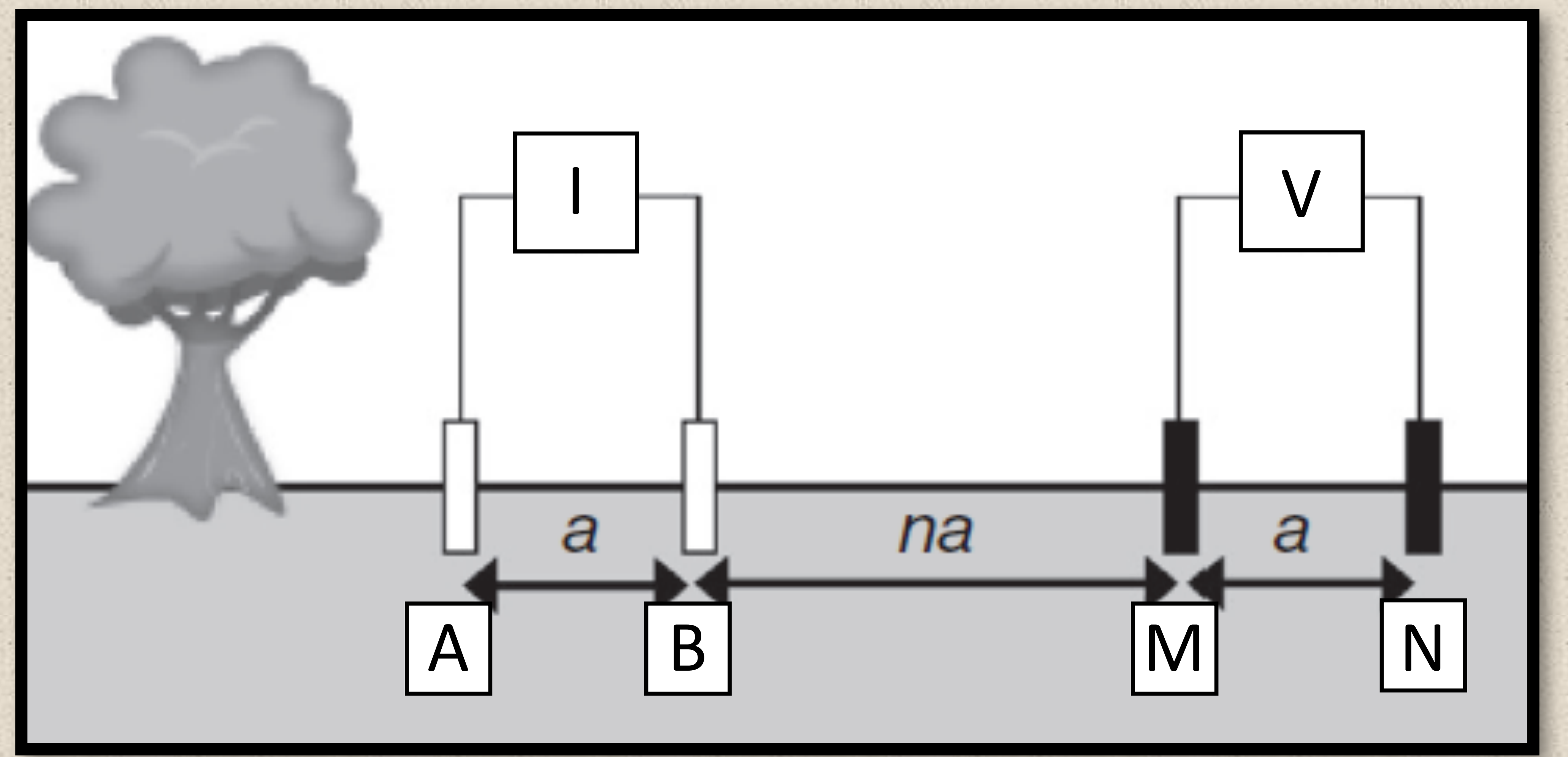
REMINDER

RECIPROCITY CHECK

Direct Measurement = ρ1



Reciprocal Measurement = ρ2



THEORETICALLY: ρ1 = ρ2

BUT IN REALITY: ρ1 ≠ ρ2

QUANTIFICATION OF NOISE AND ERROR IN MEASUREMENTS

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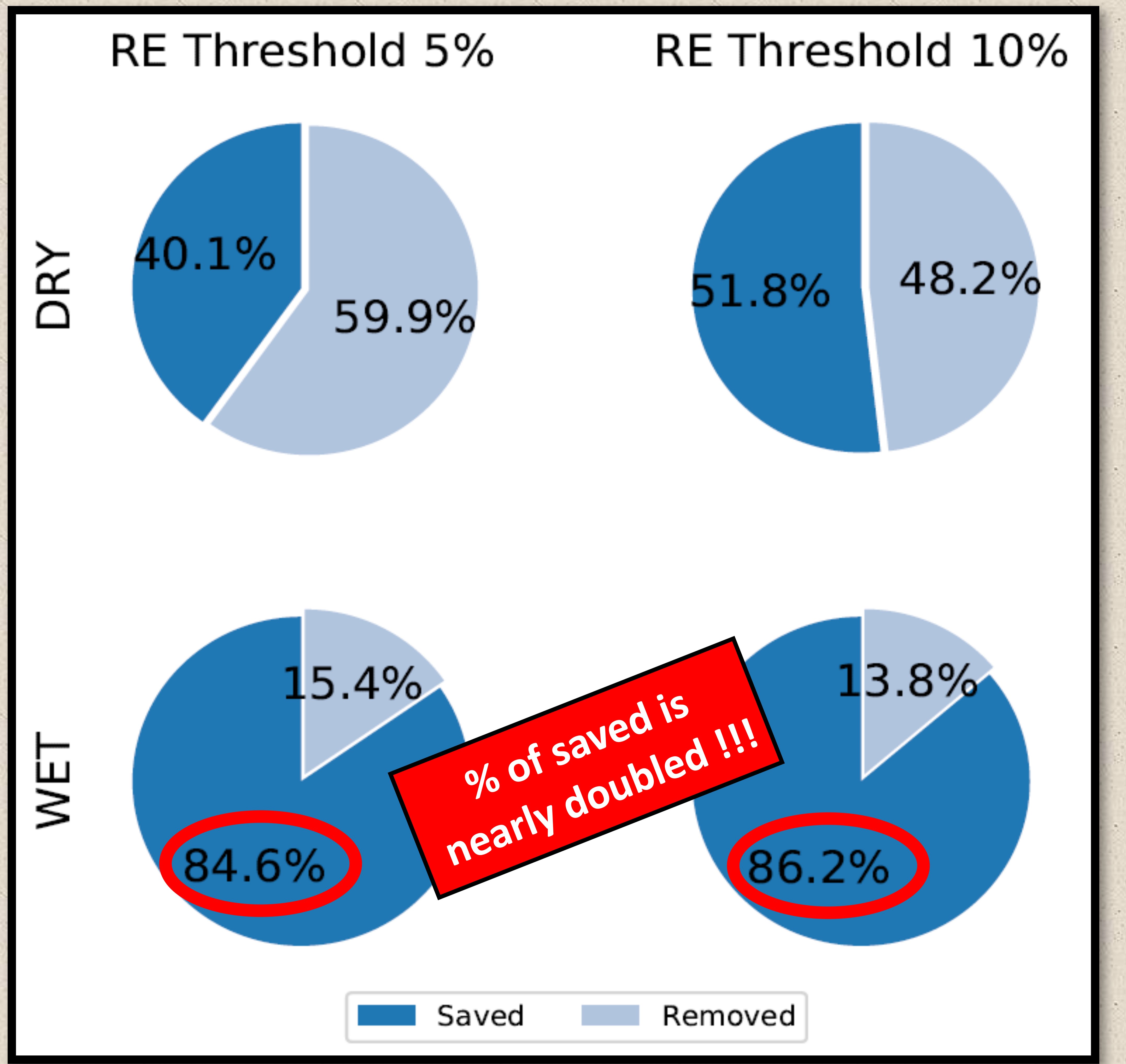
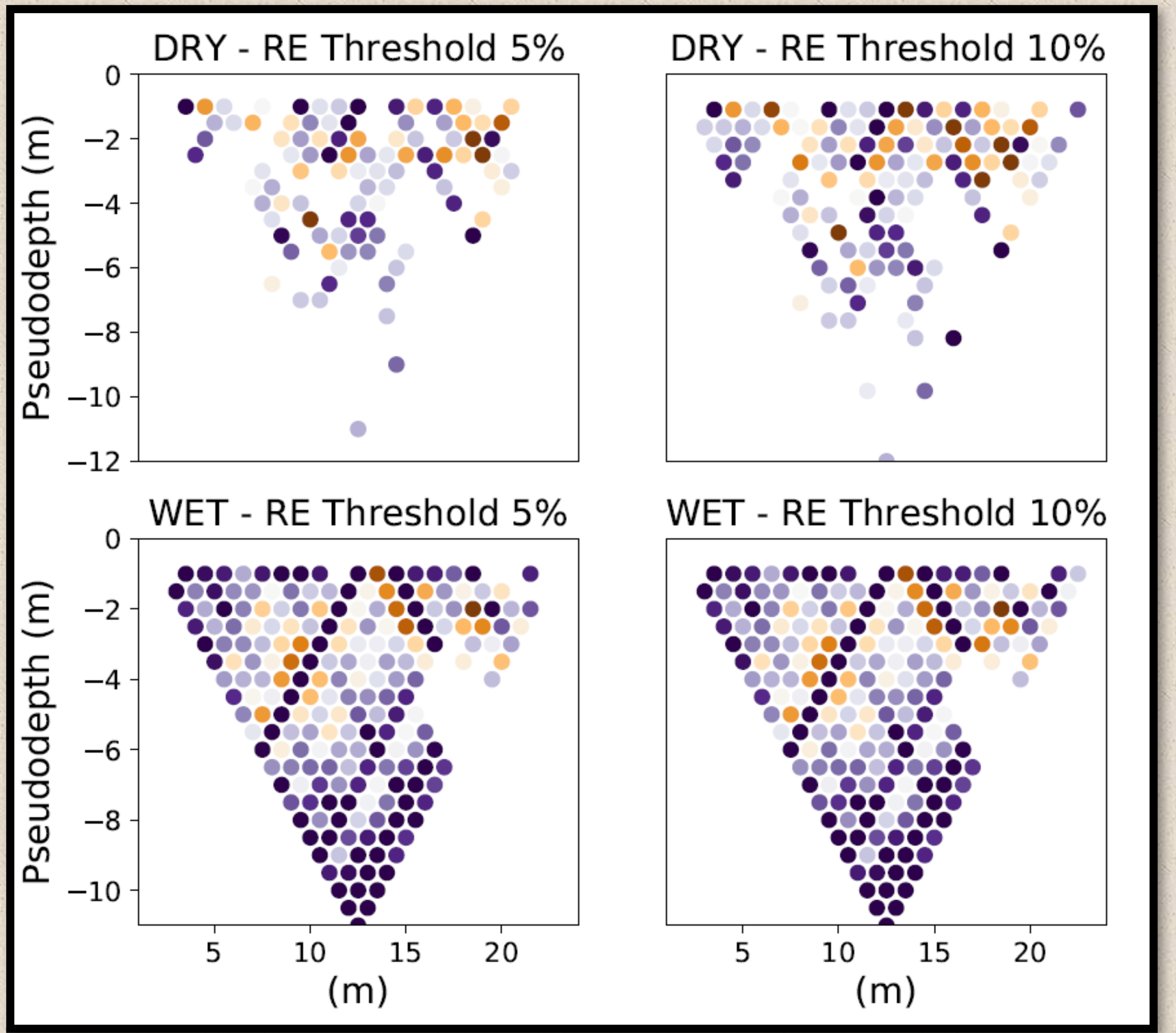
RESULTS

RECIPROCITY CHECK – SINGLE ELECTRODES CONFIGURATION

% OF SAVED AND REMOVED QUADRUPOLES



PLOT OF THE SAVED MEASURED POINTS



DIPARTIMENTO DI GEOSCIENZE

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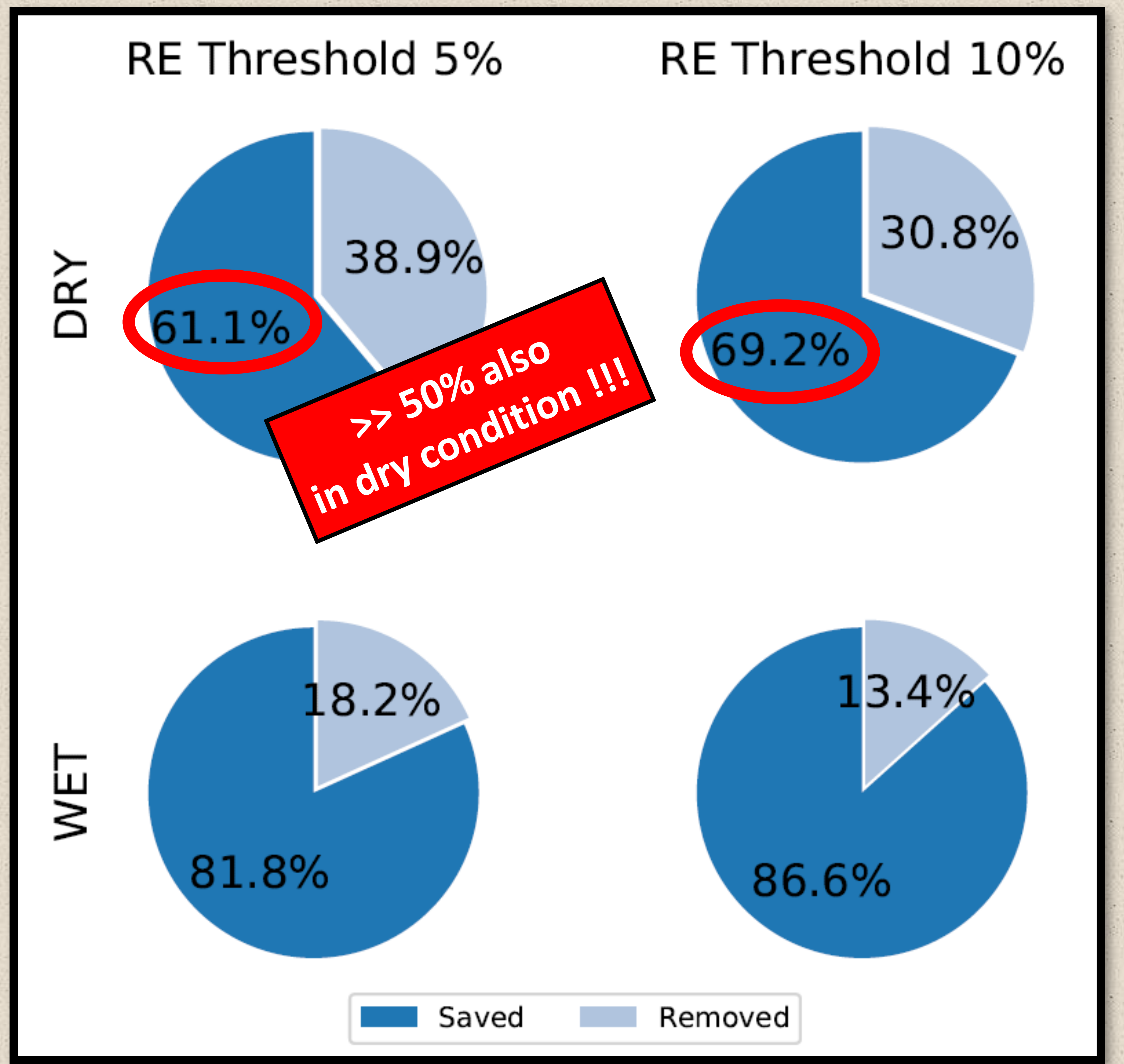
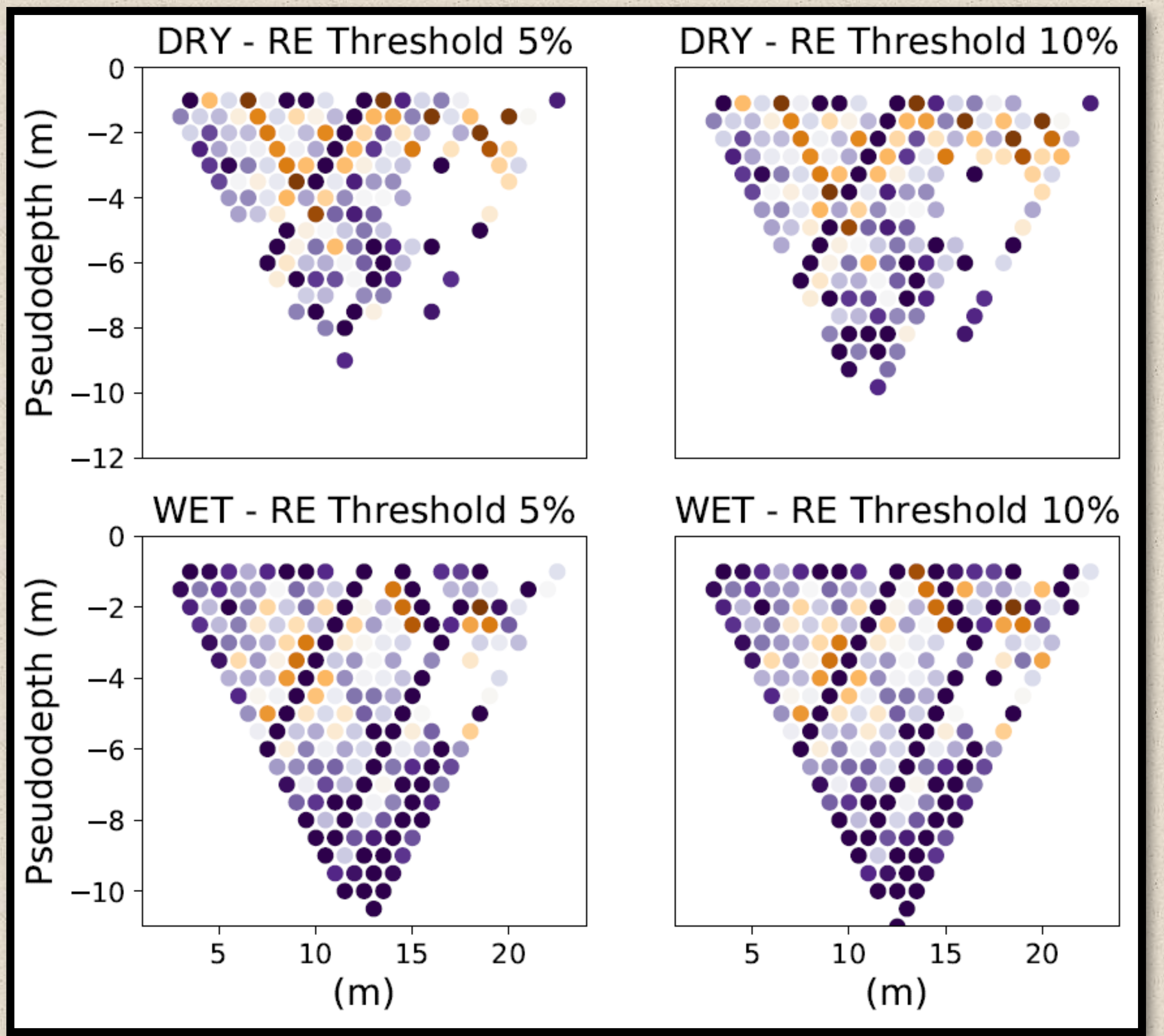
RESULTS

RECIPROCITY CHECK – TRIPLETS ELECTRODES CONFIGURATION

% OF SAVED AND REMOVED QUADRUPOLES



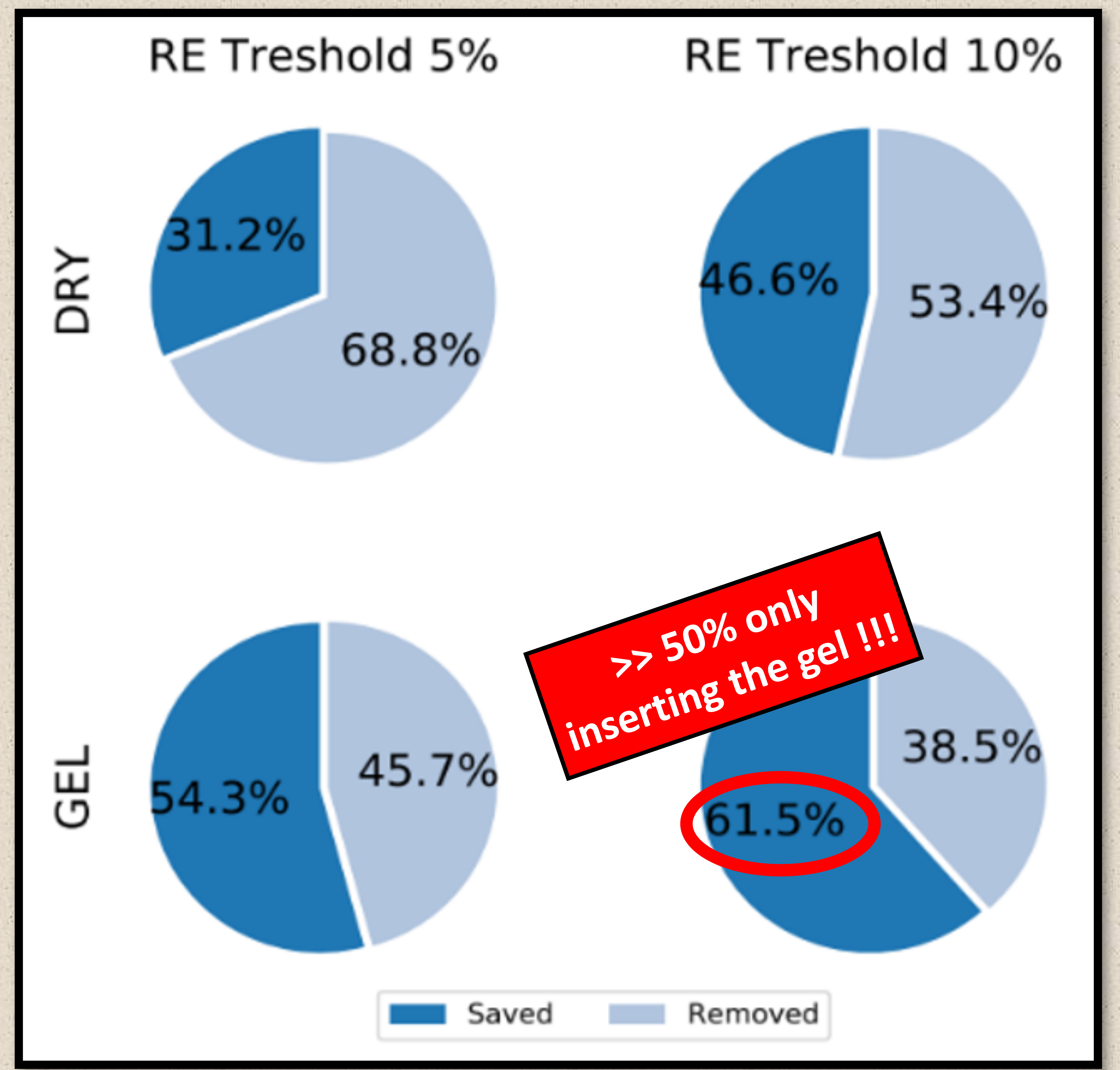
PLOT OF THE SAVED MEASURED POINTS



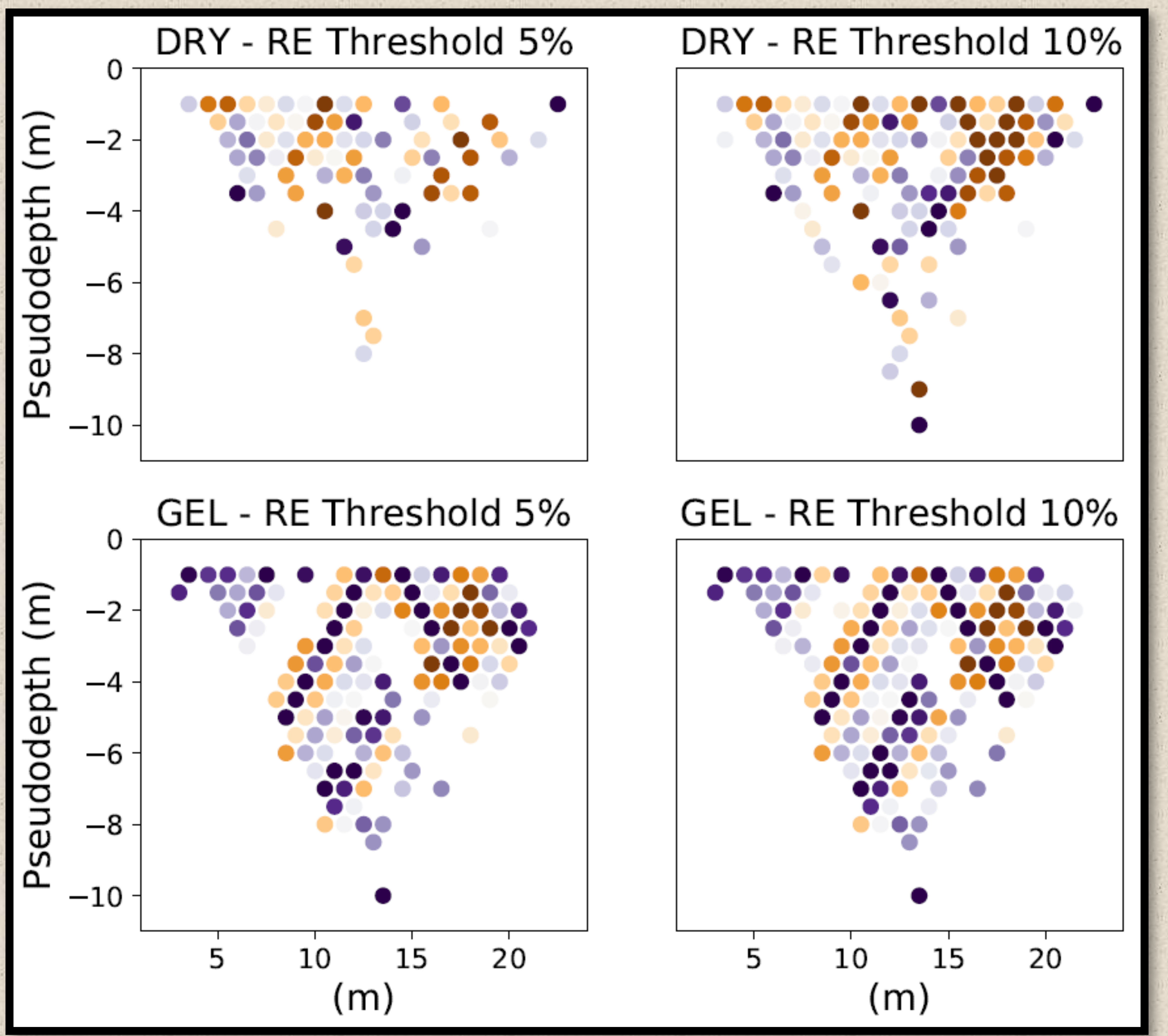
RESULTS

RECIPROCITY CHECK – DRILLED ELECTRODES CONFIGURATION

% OF SAVED AND REMOVED QUADRUPOLES



PLOT OF THE SAVED MEASURED POINTS



RESULTS

DIPARTIMENTO DI GEOSCIENZE

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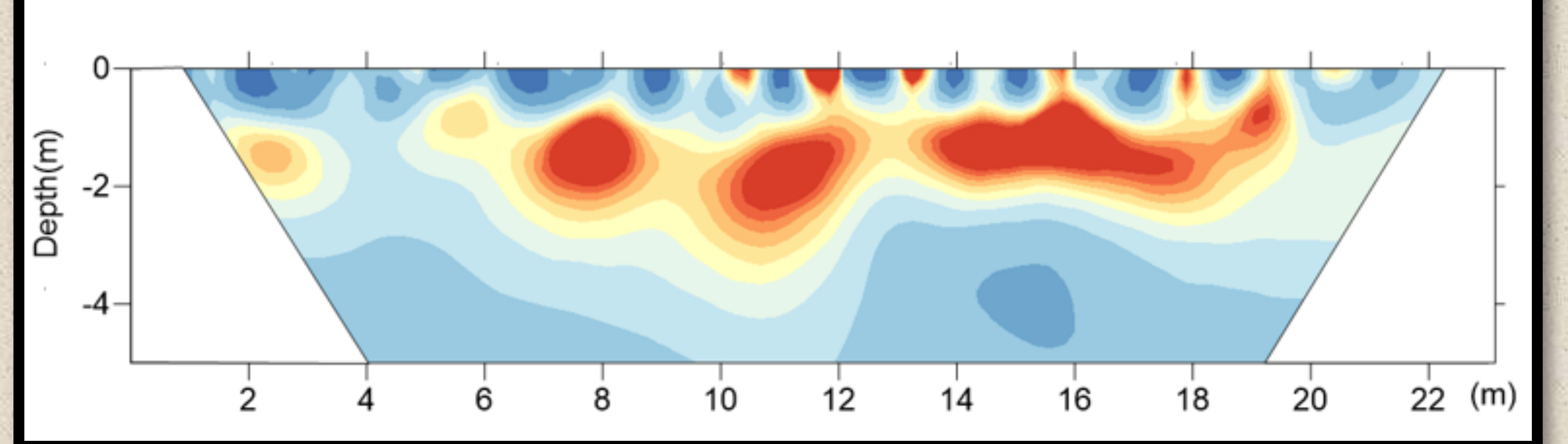
LOWER CONTACT RESISTANCES → **HIGHER % OF SAVED QUADRUPOLES** → **HIGHER QUALITY DATA**

The INVERTED RESISTIVITY SECTIONS with GREATER CONFIDENCE are:

Single wet electrodes – 5 % Expected data error



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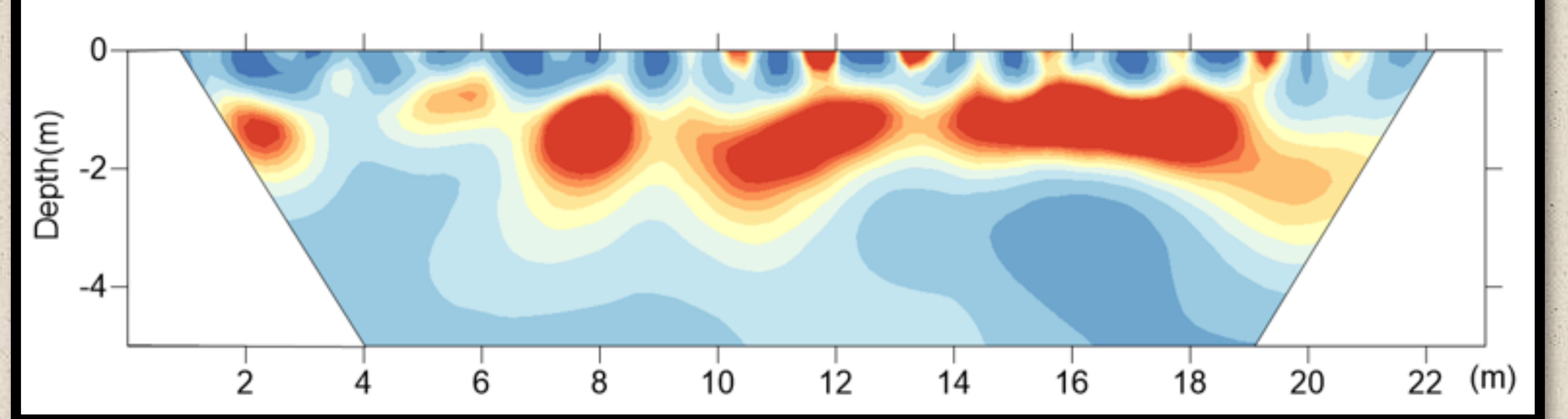
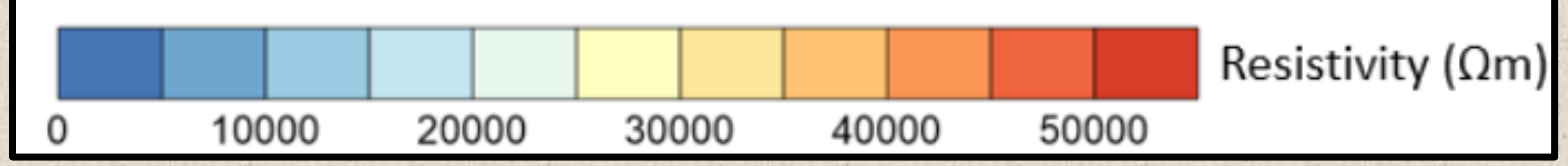
Triplets wet electrodes – 5 % Expected data error





THE RESULTS ARE IN AGREEMENT WITH THE SUBSOIL MODEL OF THE KAS DEPOSIT:

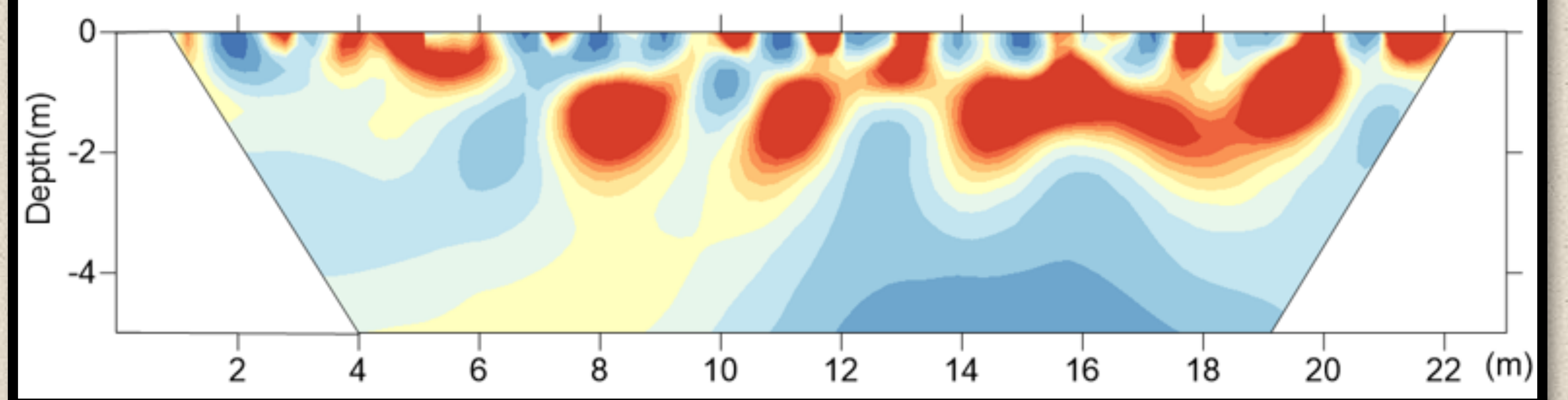
- large blocks at the surface of the deposit (ρ > 30000 Ωm)
- underlying sediment more heterogeneous with finer particle sizes (ρ < 30000 Ωm)

RESULTS

And if salt-water is NOT avaible ???

In natural DRY CONDITION the HIGHEST QUALITY DATASET is collected with the TRIPLETS ELECTRODES CONFIGURATION

Triplets dry electrodes – 10 % Expected data error



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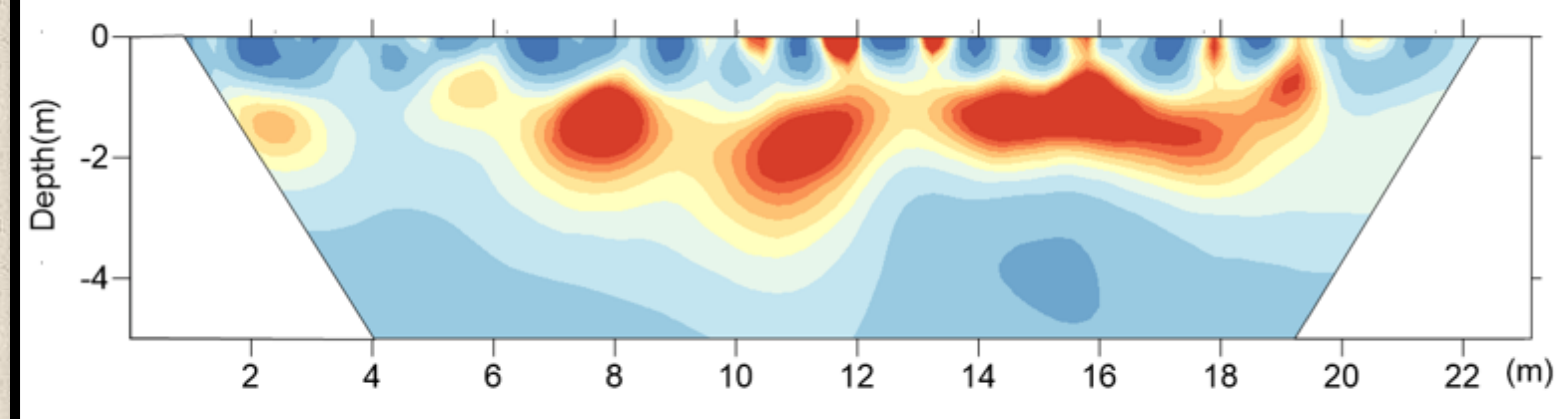
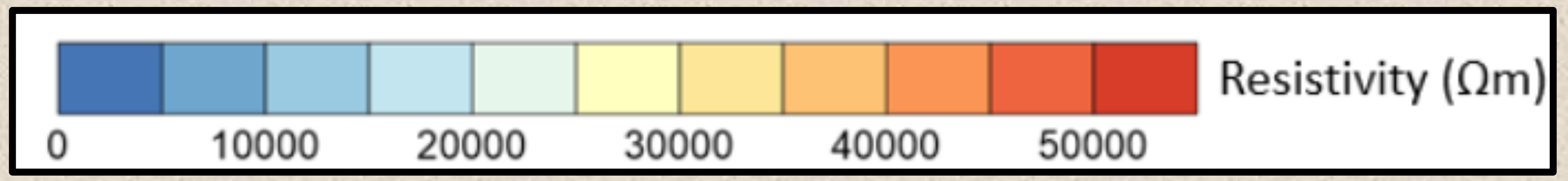
Single wet electrodes – 5 % Expected data error





The correct subsoil structure is still definible

MORE TIME & ELECTRODES ARE REQUESTED !!!

DIPARTIMENTO DI GEOSCIENZE

RESULTS

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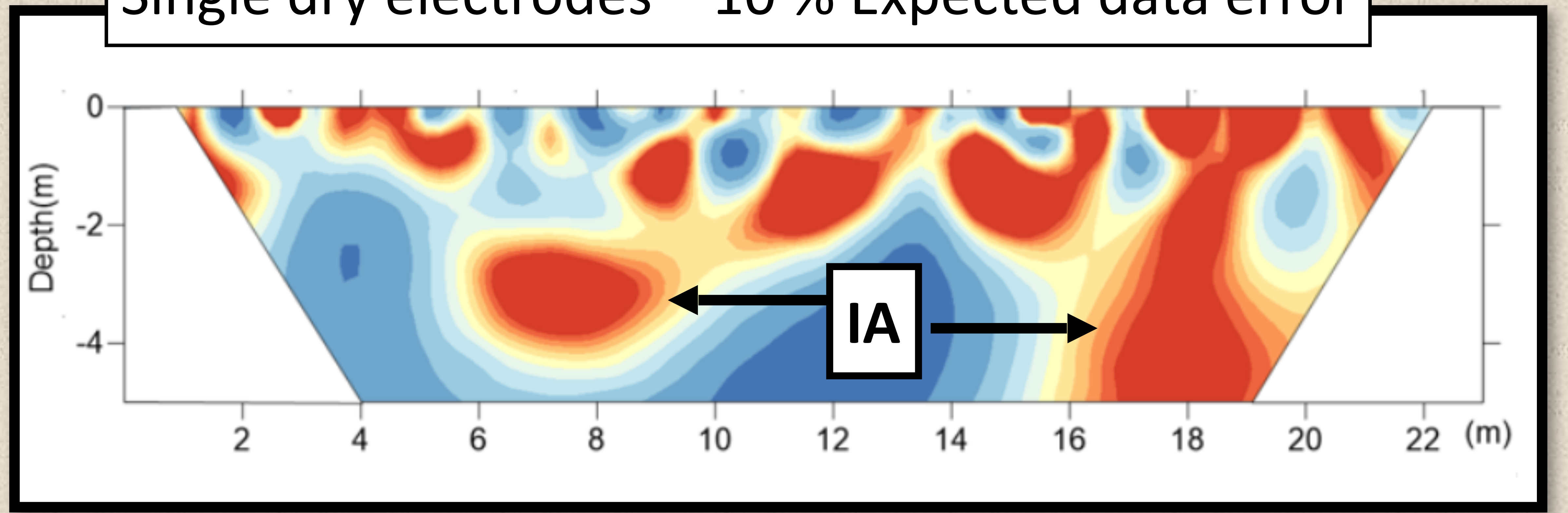
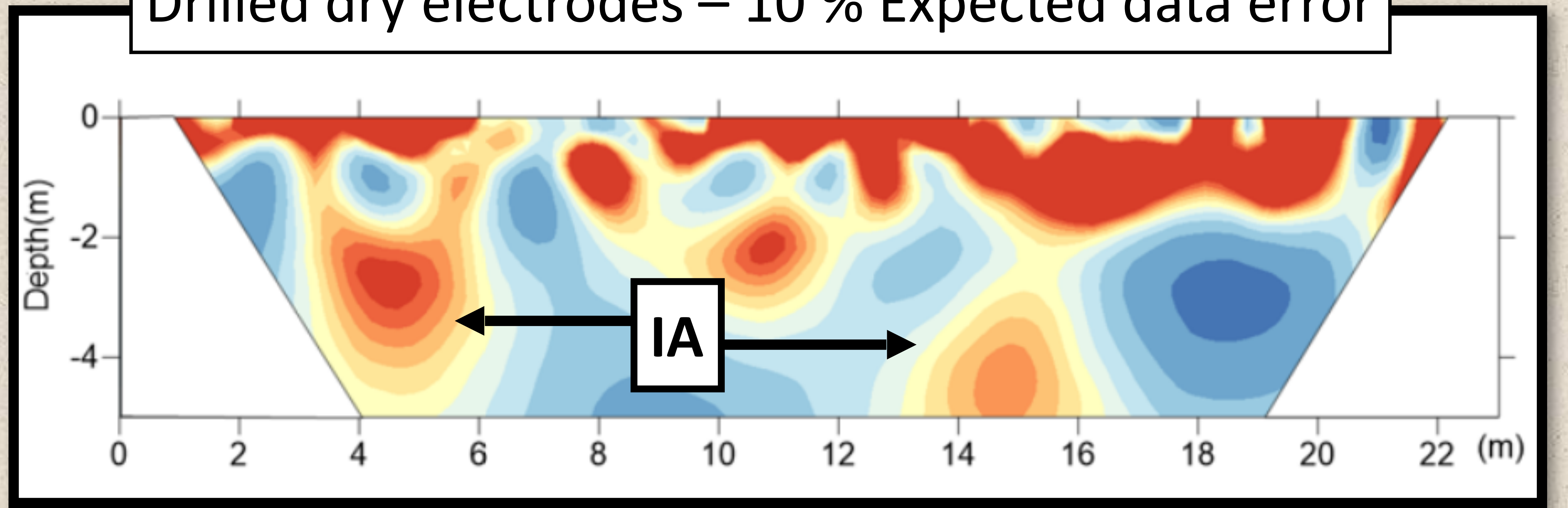
HIGHER CONTACT RESISTANCES → **LOWER % OF SAVED QUADRUPOLES** → **LOWER QUALITY DATA**

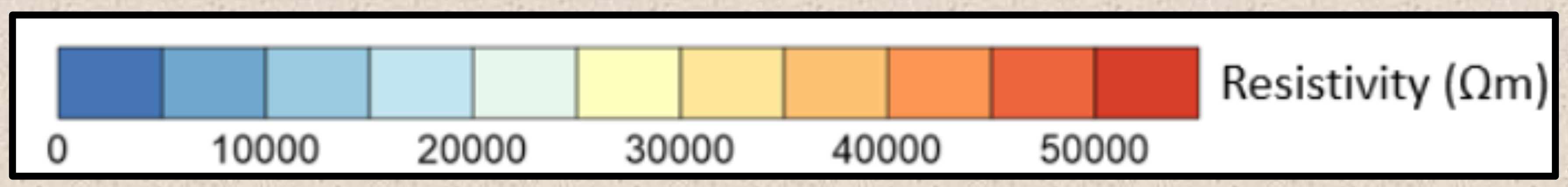
POOR RELIABILITY of the INVERTED RESISTIVITY SECTIONS

Single dry electrodes – 10 % Expected data error



Drilled dry electrodes – 10 % Expected data error





It is complicated to define the correct subsoil structure since INVERSION ARTIFACTS (IA) are present !!!

RESULTS

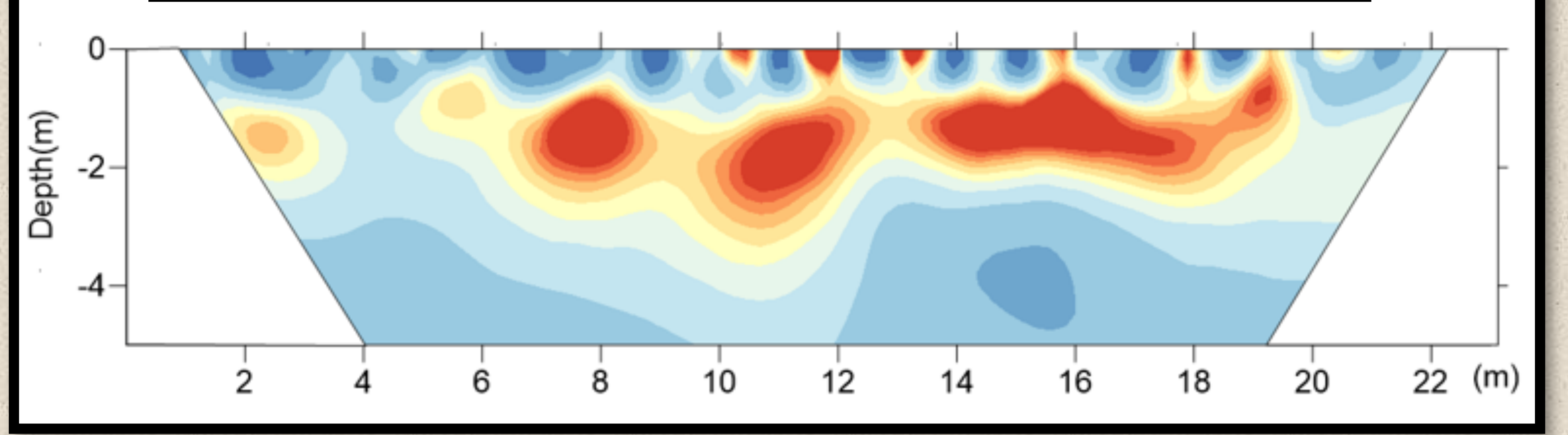
DRILLED ELCTRODES IN DRY CONDITION HAVE THE HIGHEST CONTACT RESISTENCES (>> 200 kΩ)

POOR SIGNAL-TO-NOISE RATIO & WORST DATASET ACQUIRED (<< 50% SAVED QUADRUPOLES)

ADDING THE CARBOMER-BASED GEL IMPROVED THE GALVANIC CONTACT AND THE DATA QUALITY

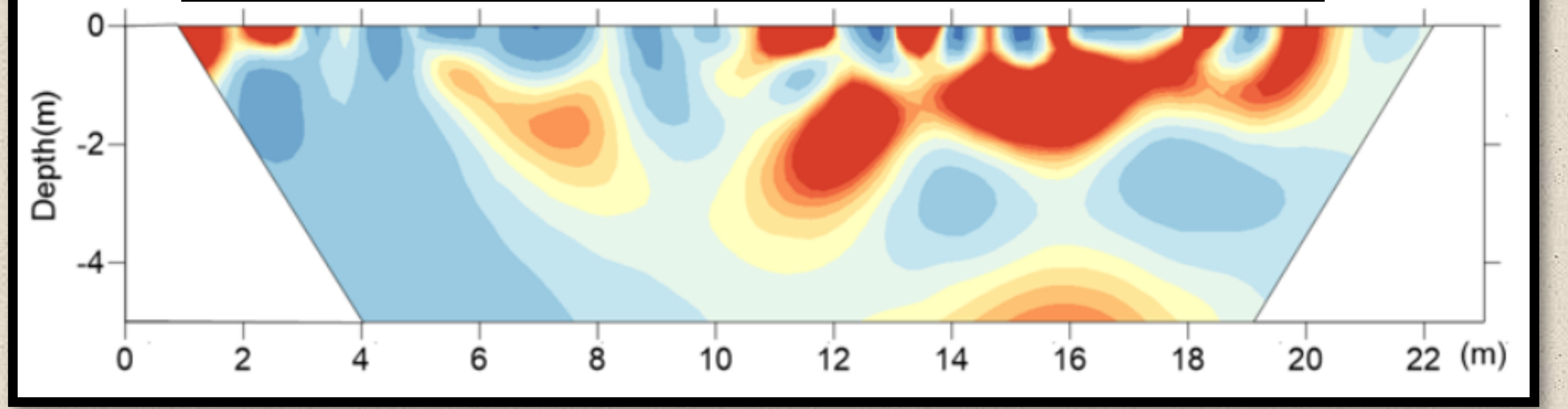
SUBSOIL MODEL OF REFERENCE

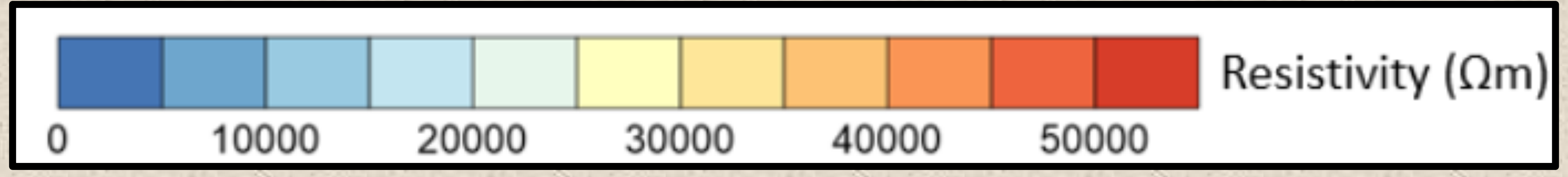
Single wet electrodes – 5 % Expected data error



INVERSION ARTIFACTS ARE MINIMIZED !!!

Drilled gel electrodes – 5 % Expected data error





BUT do you have TIME, WILL and DEVICES to drill the boulders ???

DIPARTIMENTO DI GEOSCIENZE

CONCLUSIONS

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ABOUT OUR EXPERIENCE WITH ERT SURVEYS IN A DEBRIS DEPOSIT

1. Placing the electrodes between the boulders is more advisable than drilling the boulders, more current is injected
2. If salt-water is avaible, the more convenient way to collect a high quality dataset is the single electrodes configuration
3. If salt-water is not avaible, the triple electrodes configuration can ensure the decreasing of contact resistances
4. If the drilled electrodes configuration is chosen, we recommend the use of carbomer-based gel inside the holes