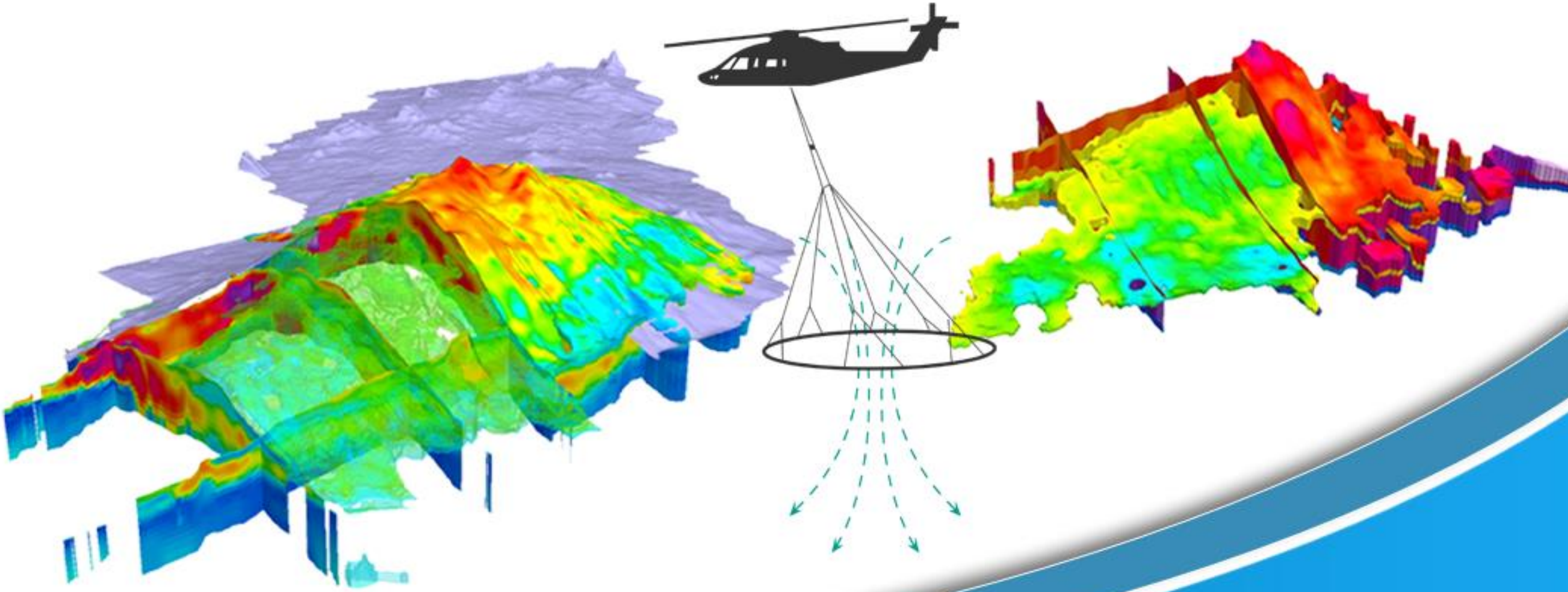


From data to knowledge

Examples of modelling IP in AEM data: synthetic and real data

Andrea Viezzoli — Aarhus Geophysics Aps
Vlad Kaminski — Aarhus Geophysics Aps
Gianluca Fiandaca — HGG- Arhus University

Aarhus Geophysics

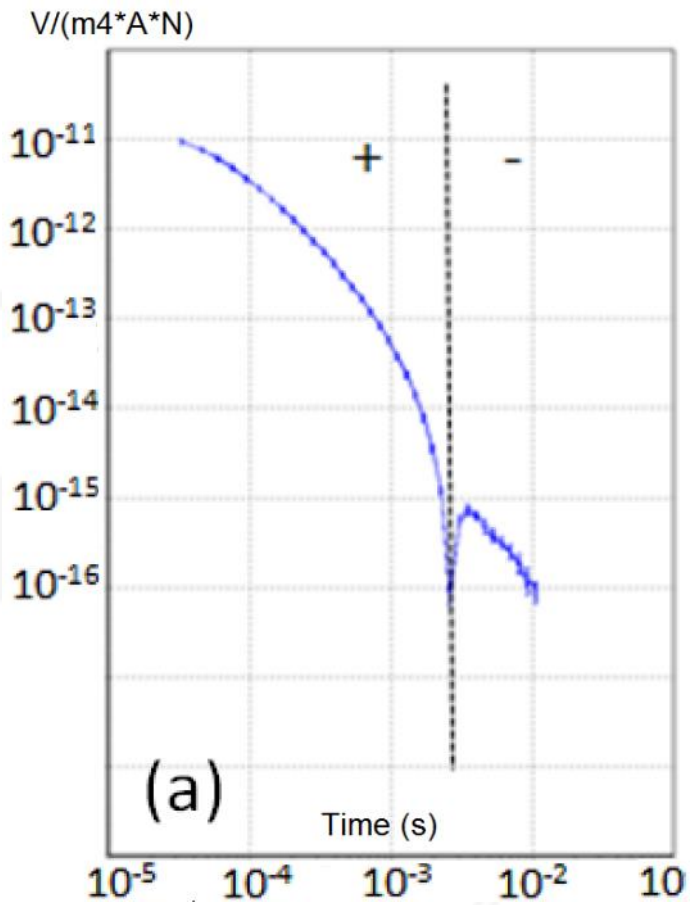
What will you hear

- IP effects can be visible and measurable in AEM data
  - Signature is varied, beyond simple sign change
- IP can be modelled from AEM data, both synthetic and real. We can recover corrected resistivities and some IP parameters
  - Large degree of non uniqueness, which can be reduced by constraints and apriori
  - Chargeability can be recovered down to some depth
- Failure to model IP in IP affected AEM datasets produces:
  - Erroneous resistivity sections
  - Loss of extra information about the subsurface that might be relevant for mineral exploration and other applications

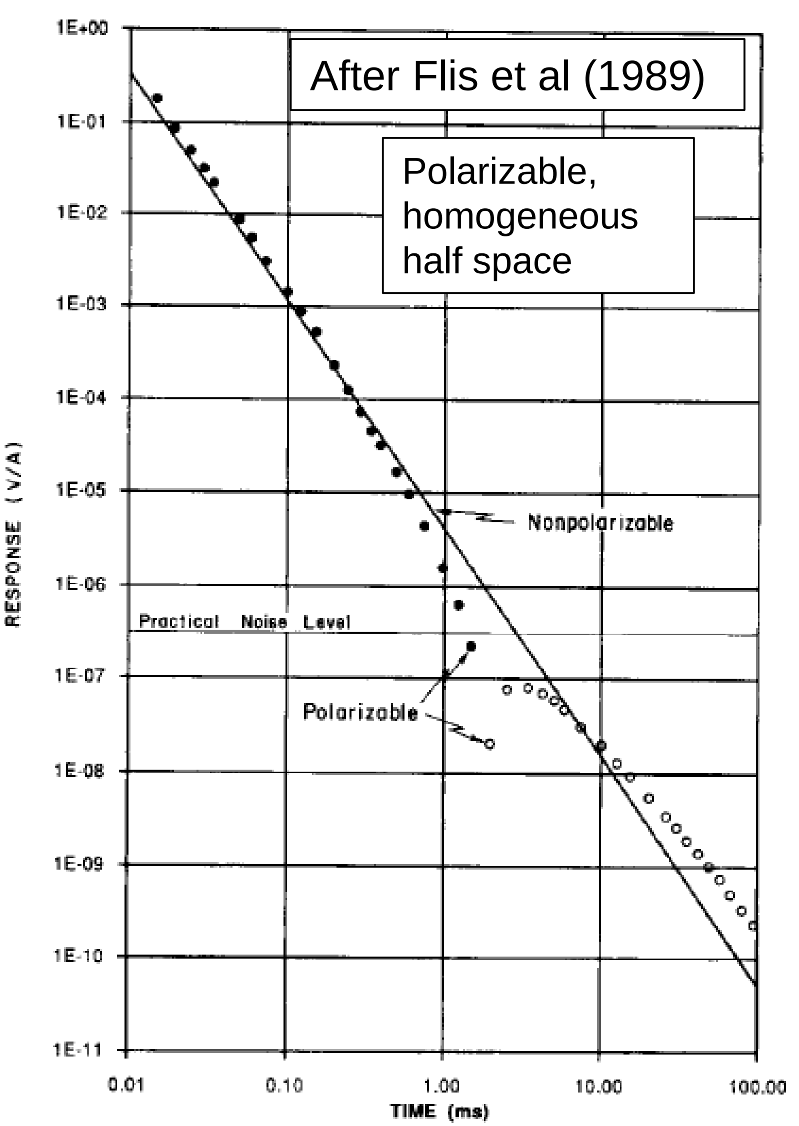
IP effect in TEM data

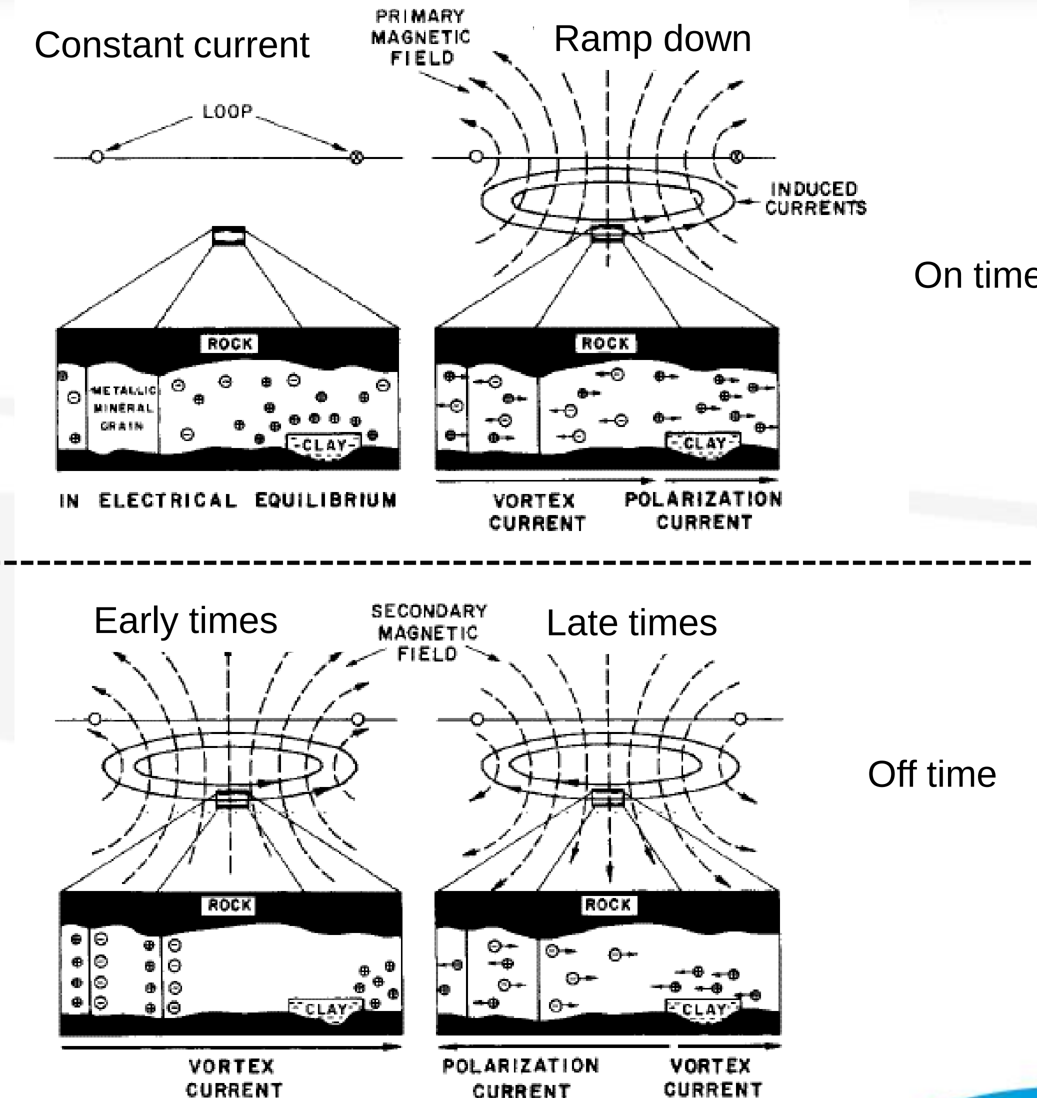
- The evidence
  - Sign changes in central loop* TDEM systems
  - Calls for a frequency dependent resistivity $\rho(\omega)$
- The explanation
  - presence of chargeable (polarizable) material
- The models
  - **Cole Cole (DC** or ∞ frequency limit)
  - GEMTDIP (more parameters)
  - Others with less paramaters

The evidence



The explanation





The model

- **Cole Cole** model (**DC** limit - *Flis et al*.)

$$\sigma(s) = \sigma_0 + \Delta_0\, \hat{\sigma}(s)\,, \quad s = i\omega$$

$$\Delta_0 \hat{\sigma}(s) = \frac{\sigma_0 \mathrm{m}(s\tau)^c}{1 + (1 - \mathrm{m})(s\tau)^c}\,.$$

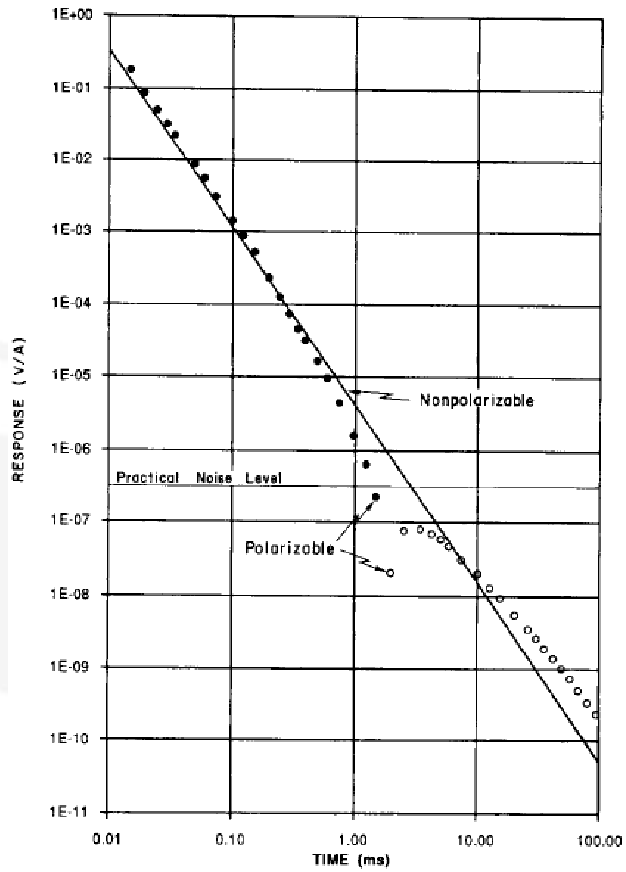
- Cole Cole model (∞ frequency limit - *Smith*)

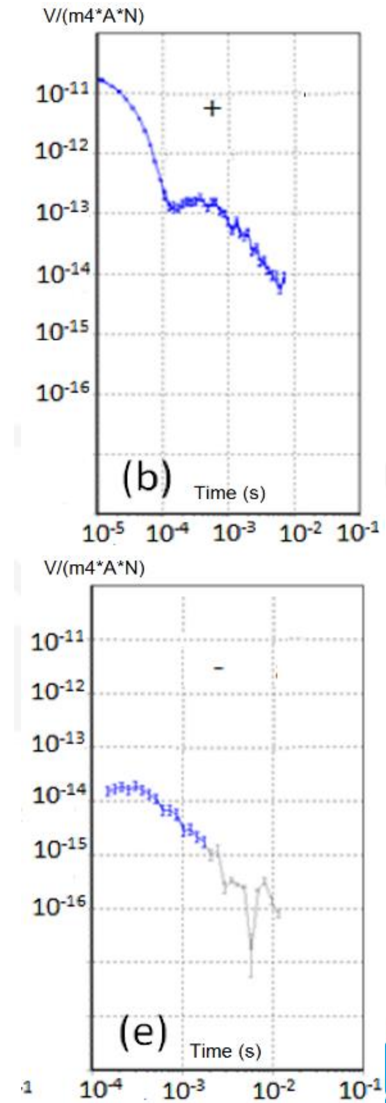
$$\sigma(s) = \sigma_\infty + \Delta_\infty \hat{\sigma}(s), \quad s = i\omega$$

$$\Delta_\infty \hat{\sigma}(s) = \frac{-\sigma_\infty \mathrm{m}}{1 + (1 - \mathrm{m})(s\tau)^c}\,,$$

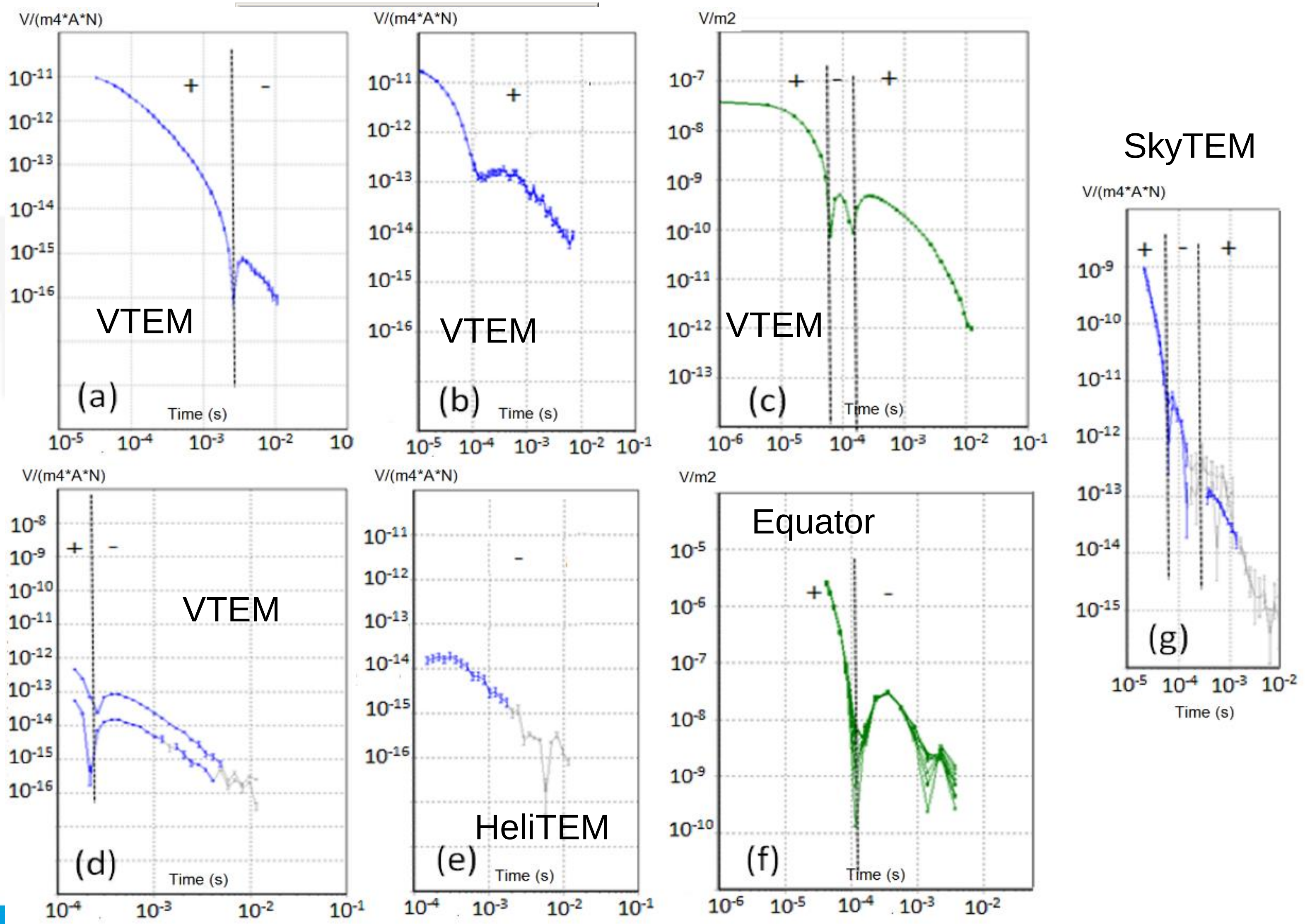
IP effect in TEM data: **BIG FAT WARNING !**

- Even in presence of **IP effect** measureable by a given AEM system, its transients can be distorted **without** ever **changing sign** ! This can be due to:
  - Noise level
  - Bandwidth
  - Combinations of Cole Cole Parameters within a given layer
  - Combination of layers



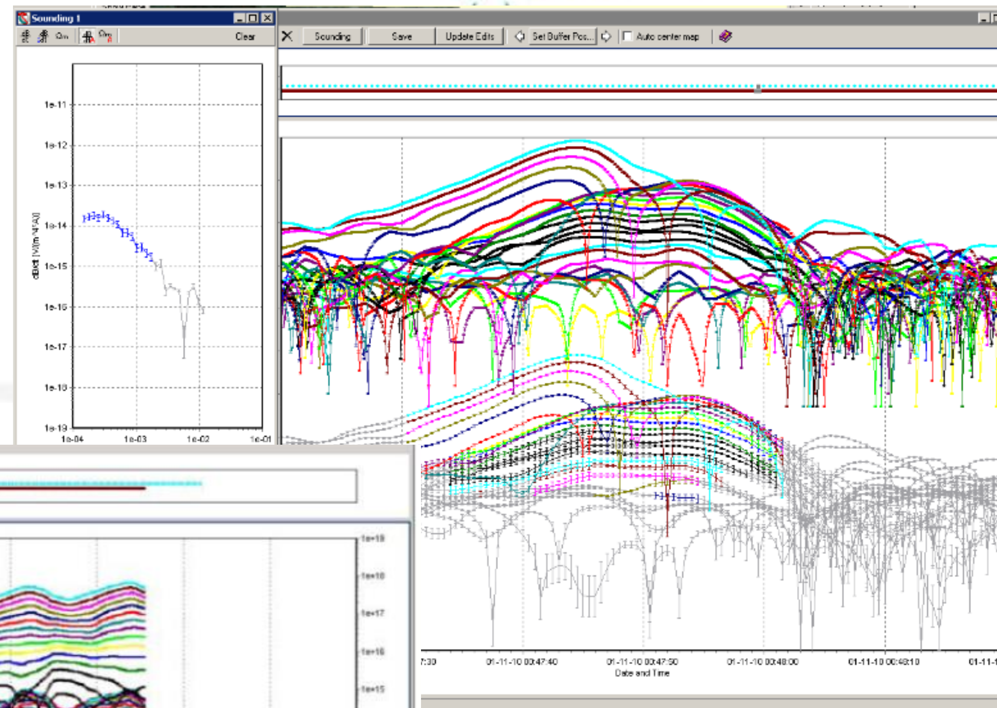


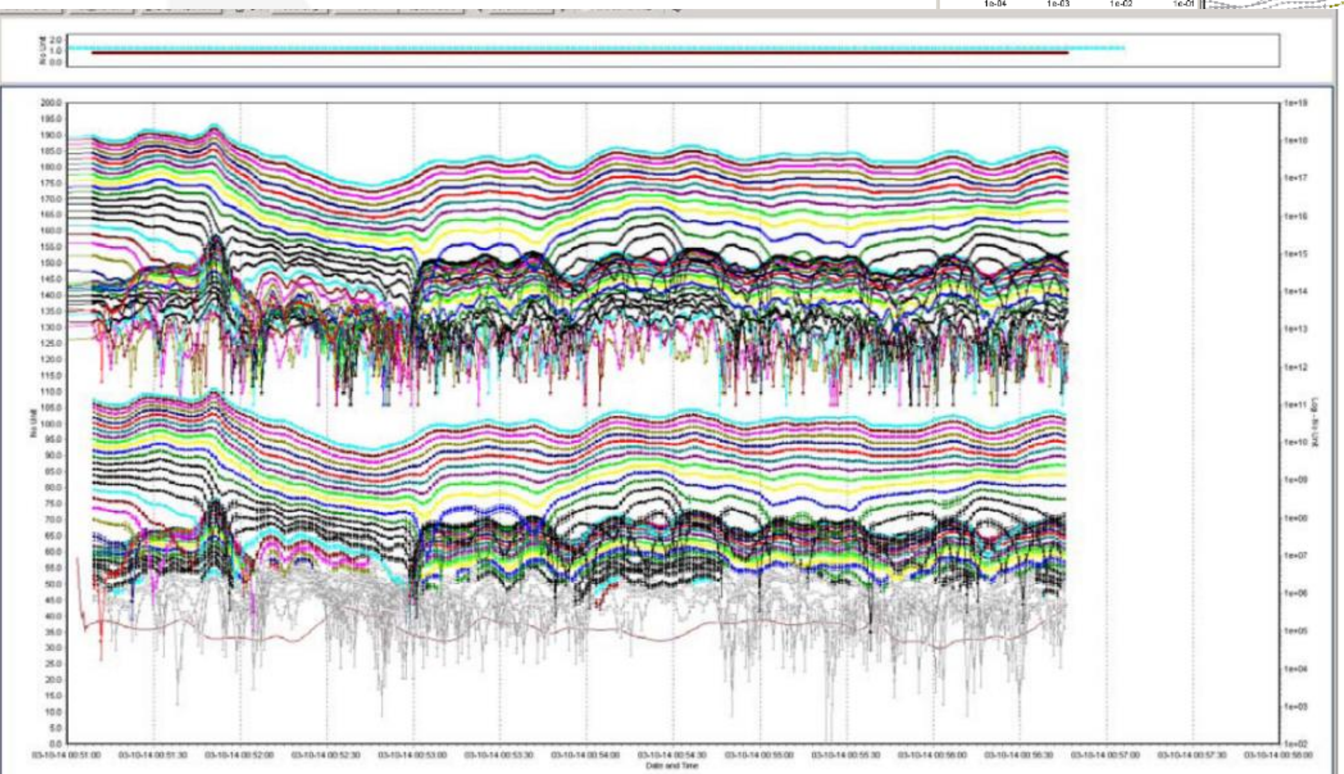
Different IP effects: transients from different AEM systems



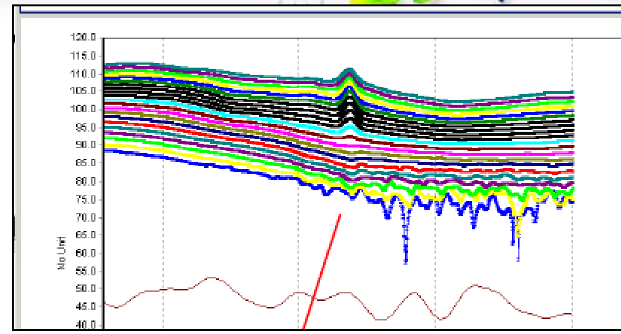
Different IP effects: channels profiles, obvious effects

- SkyTEM
  - Copper (Greenland)
  - BIF (Australia)
- HeliTEM
  - Base metals (Canada)

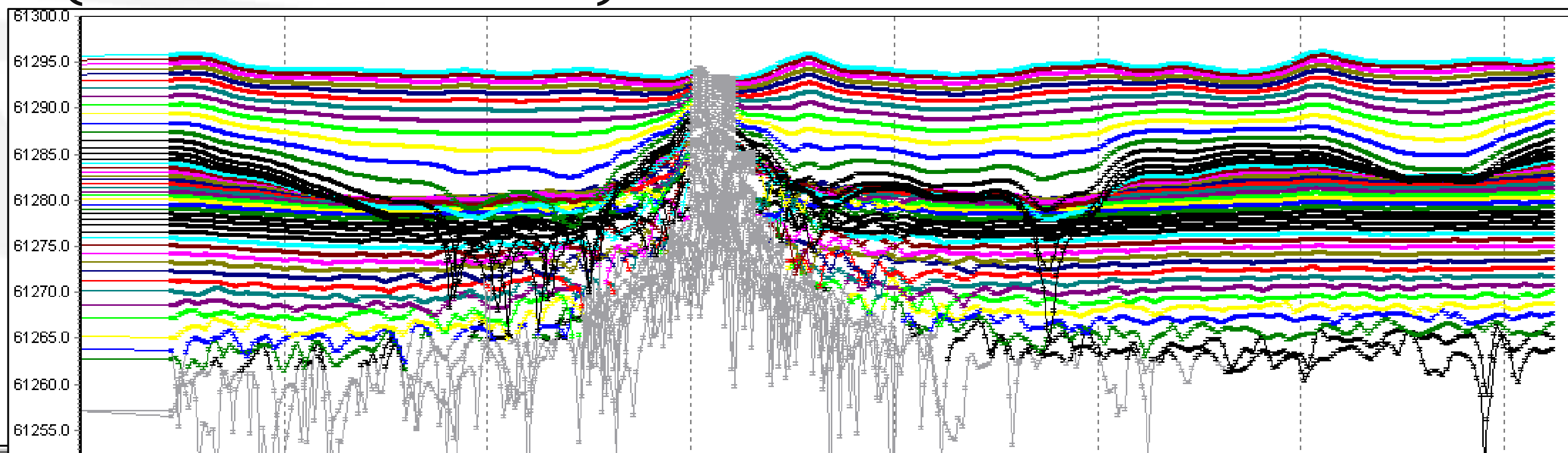


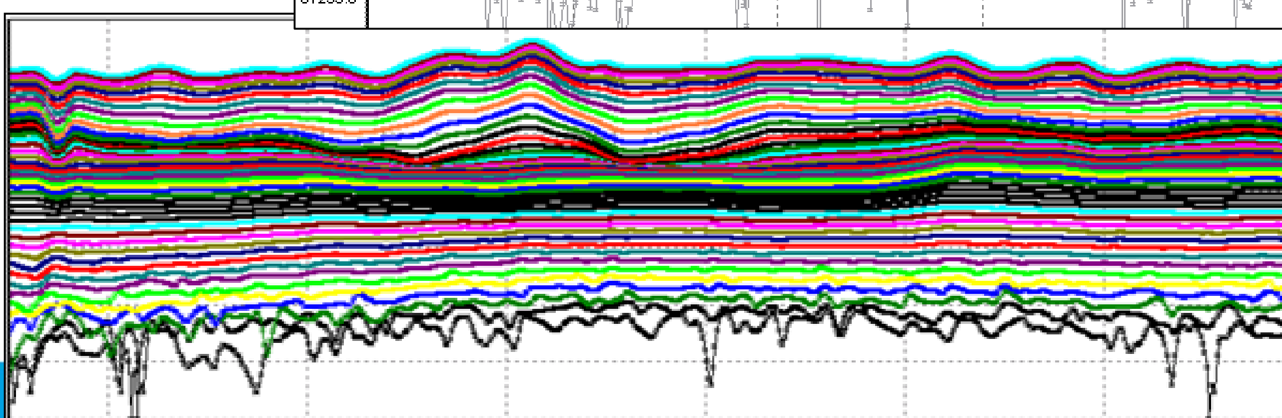


Different IP effects: channels profiles: more subtle effects



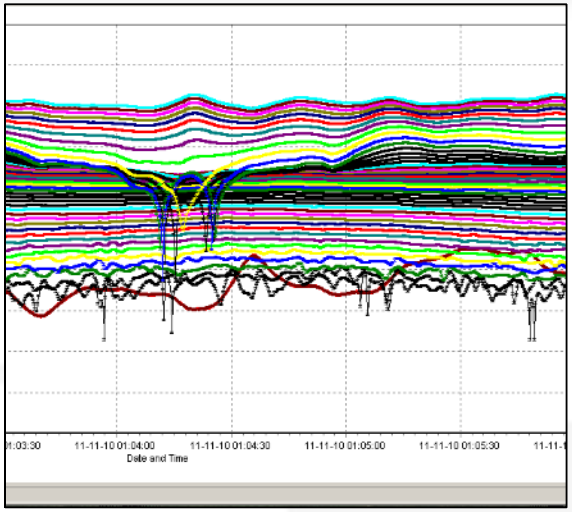
- VTEM
  - Kimberlites (Russia)
  - Permafrost (Russia)
  - Gold (arabic Peninsula)

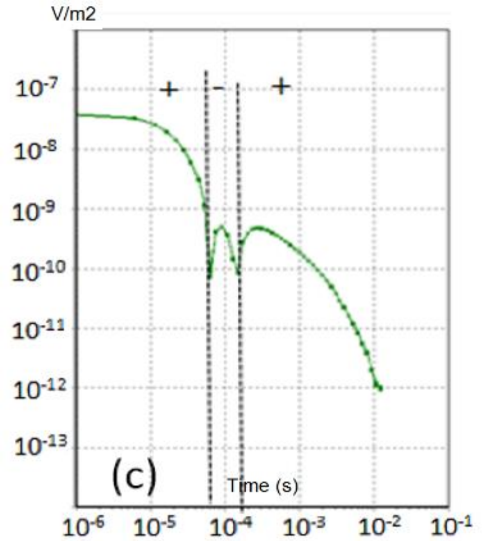


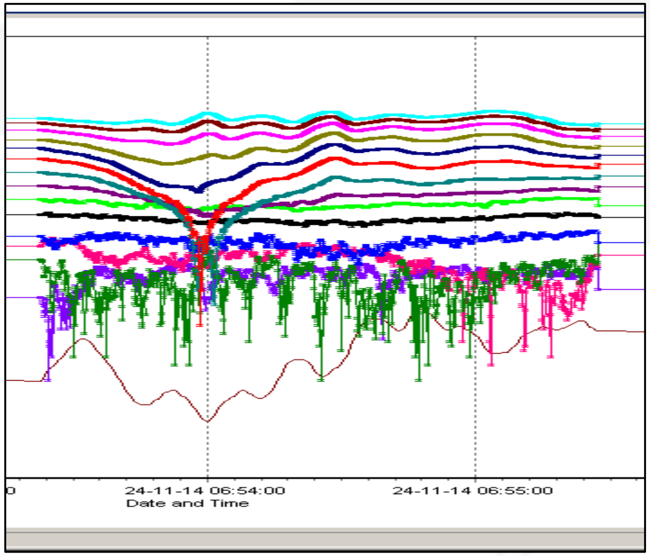


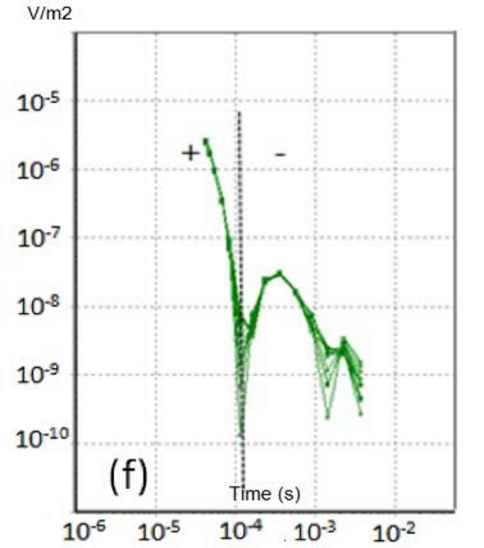
Different IP effects: Same target, 2 AEM systems

- Kimberlites
  - VTEM
  - Equator

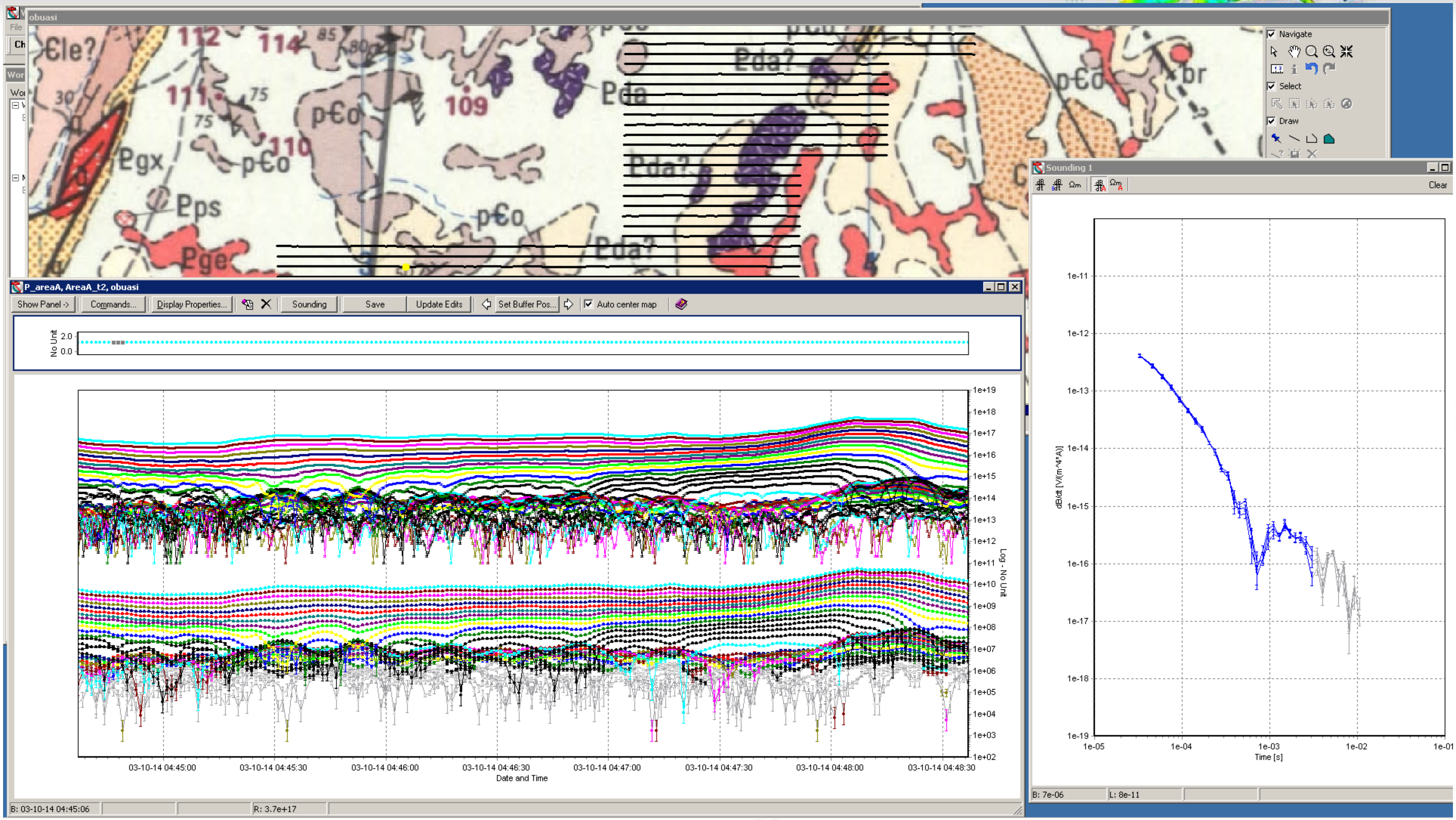




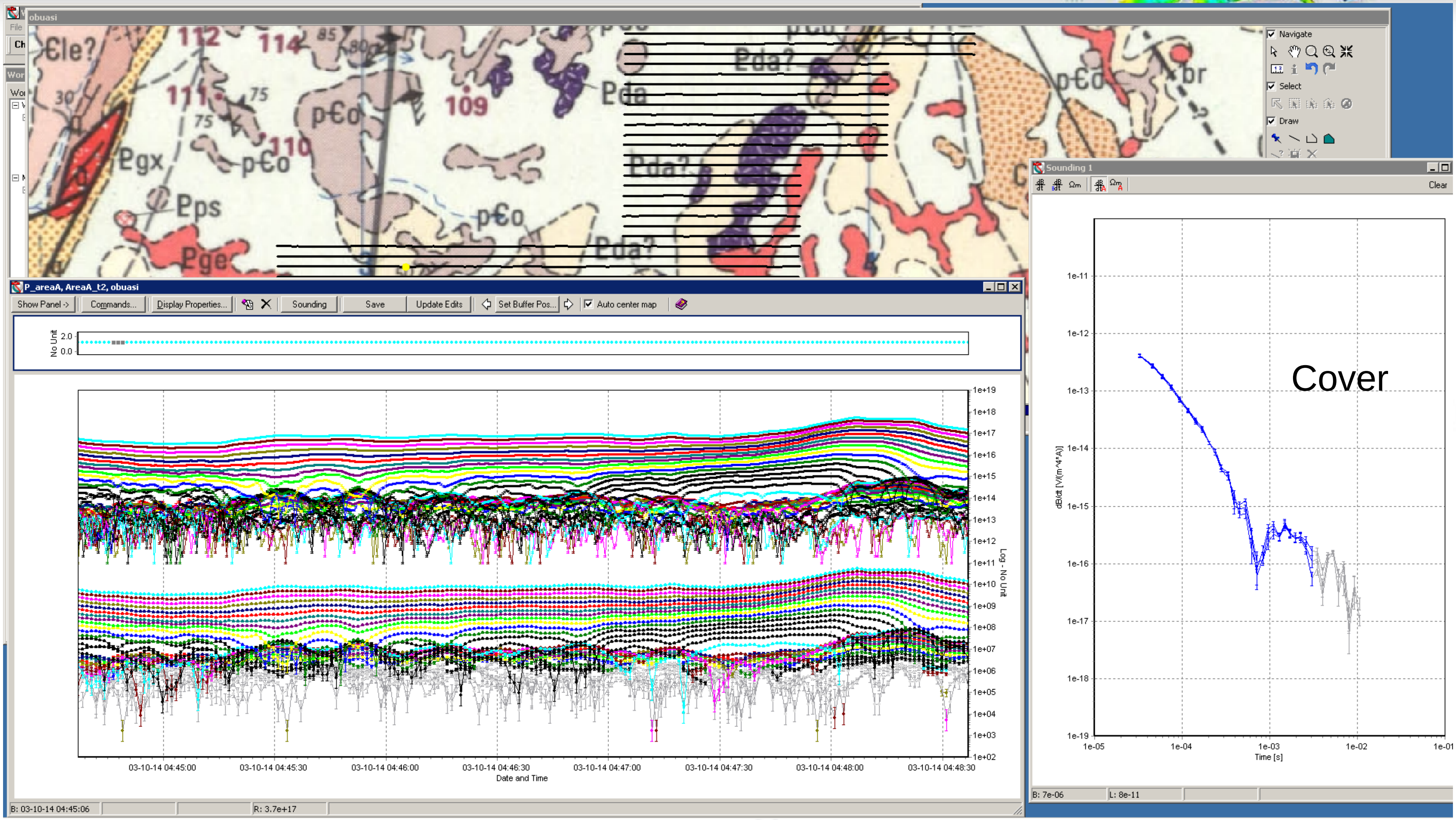




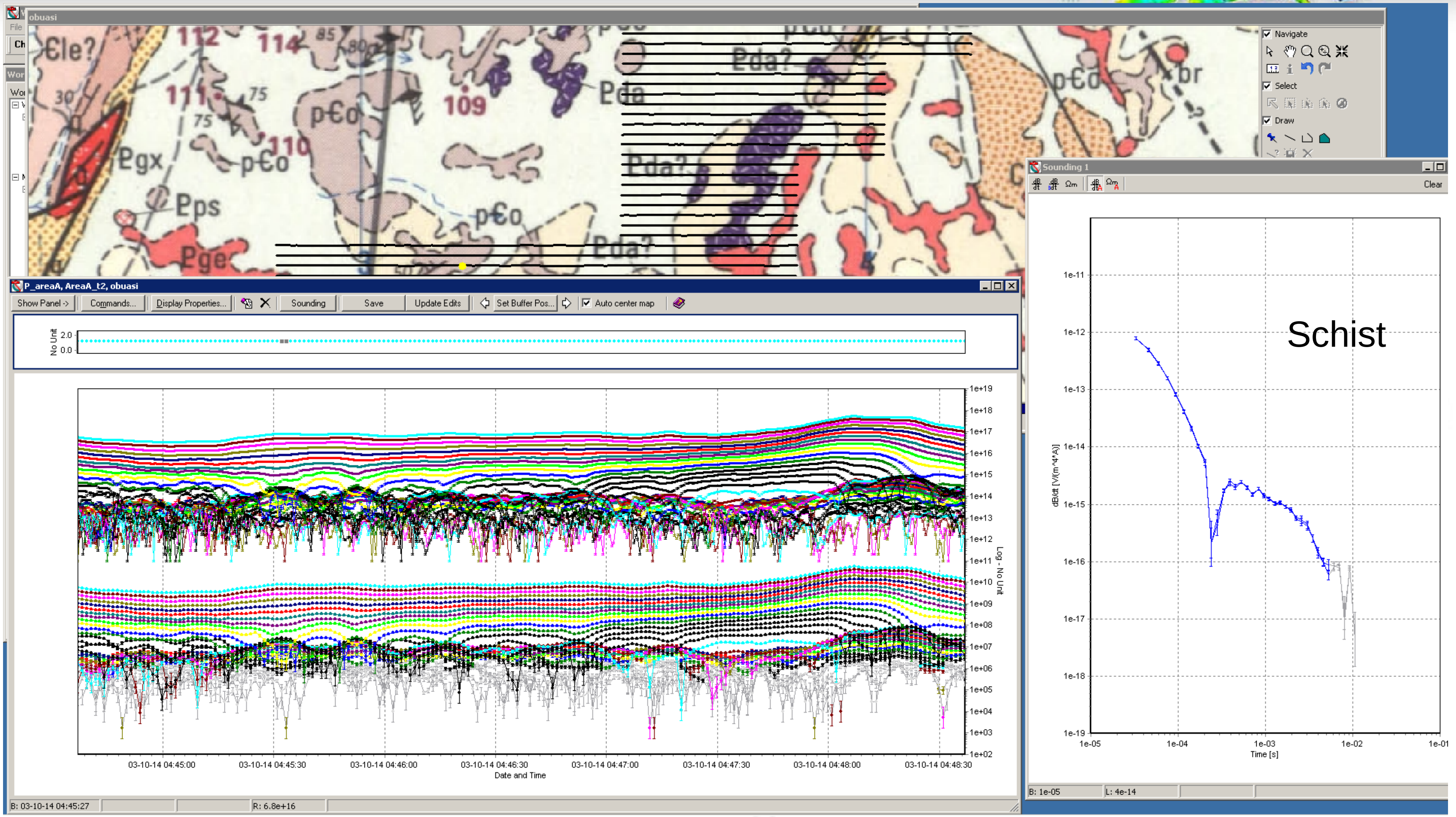
Different IP effects: Same survey, different geologies



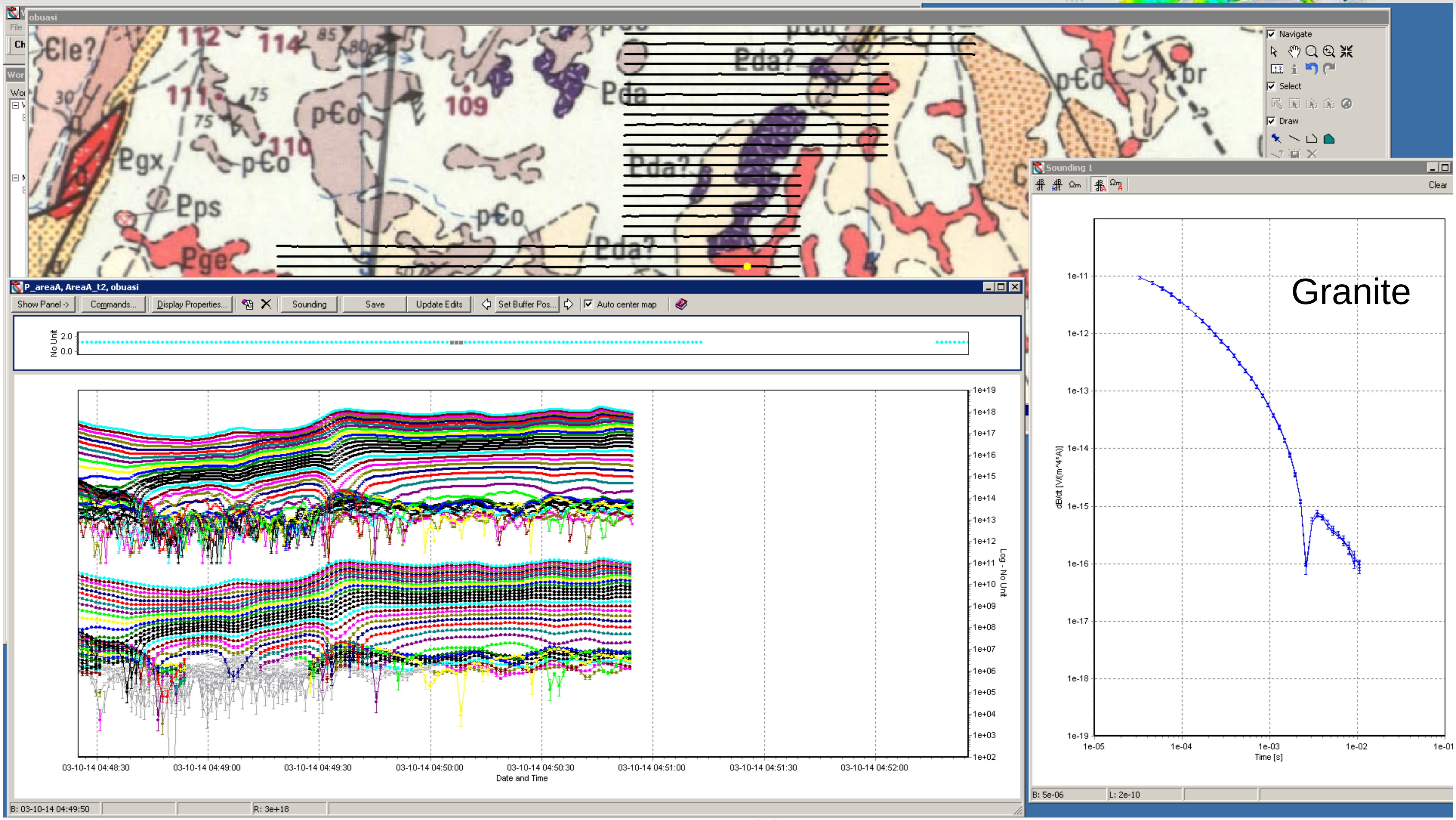
Same survey, different geologies



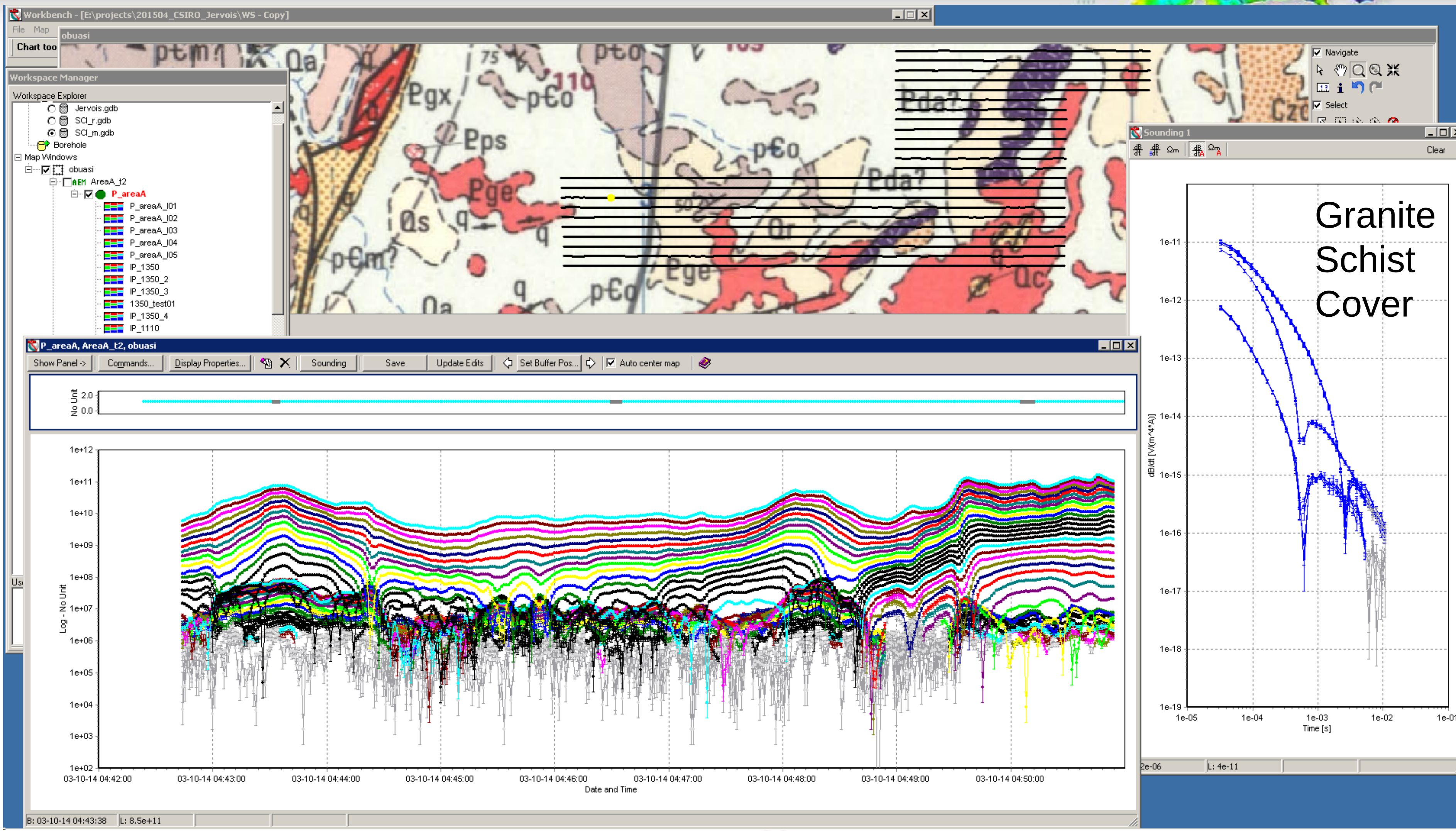
Same survey, different geologies



Same survey, different geologies



Same survey, different geologies



All in one line ! Distinctive features. Make good use of this info in inversion

Why is it important to model to model IP in AEM data

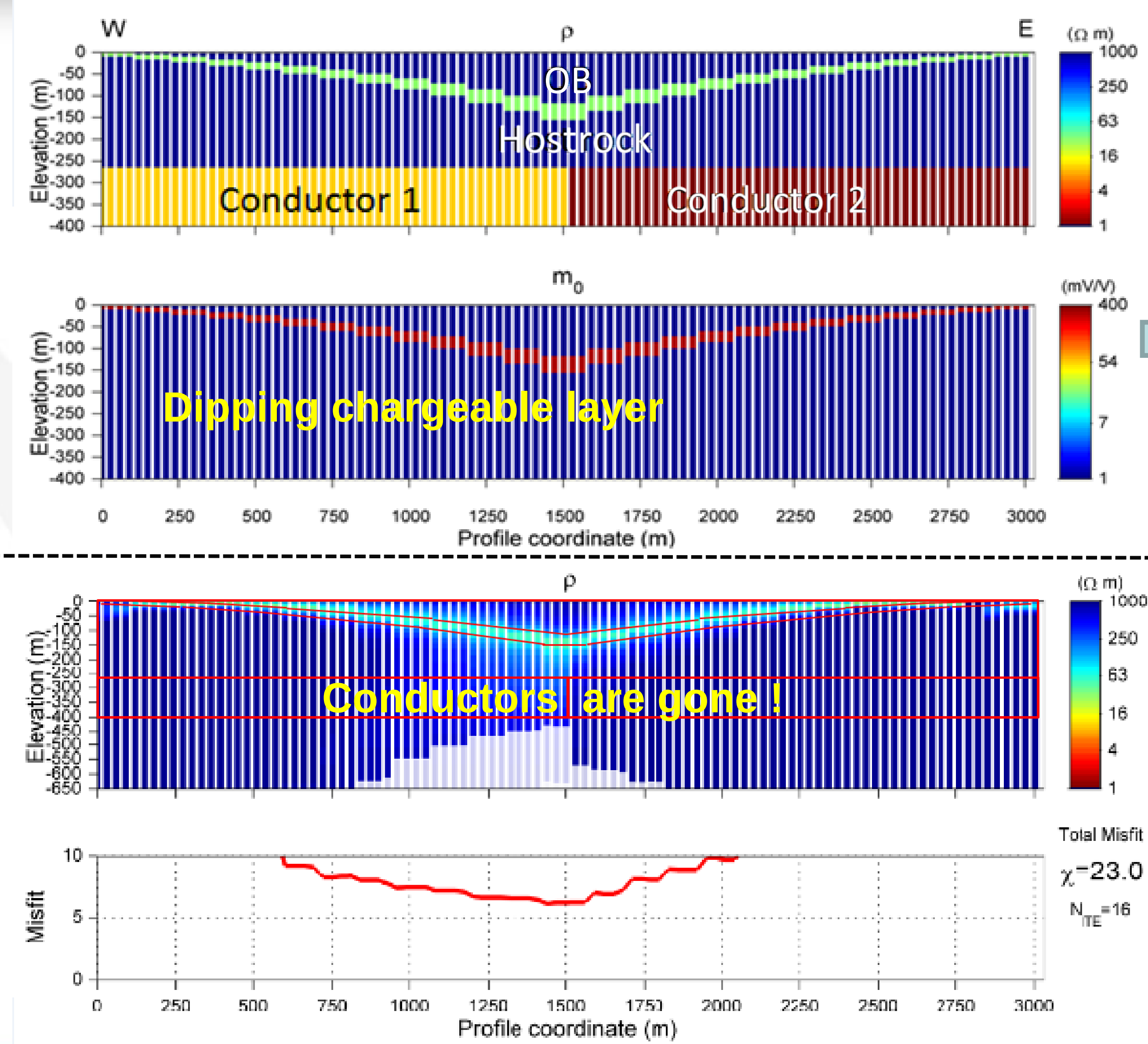
- Failure to model IP in IP affected AEM datasets produces
  - Erroneous resistivity sections
  - Loss of extra information about the subsurface that might be relevant for mineral exploration and other applications

- Chargeability can be recovered beyond the near surface (under some conditions)

Why is it important to model it:improved resistivity sections

True model

τ = 0.001 s; c = 0.5

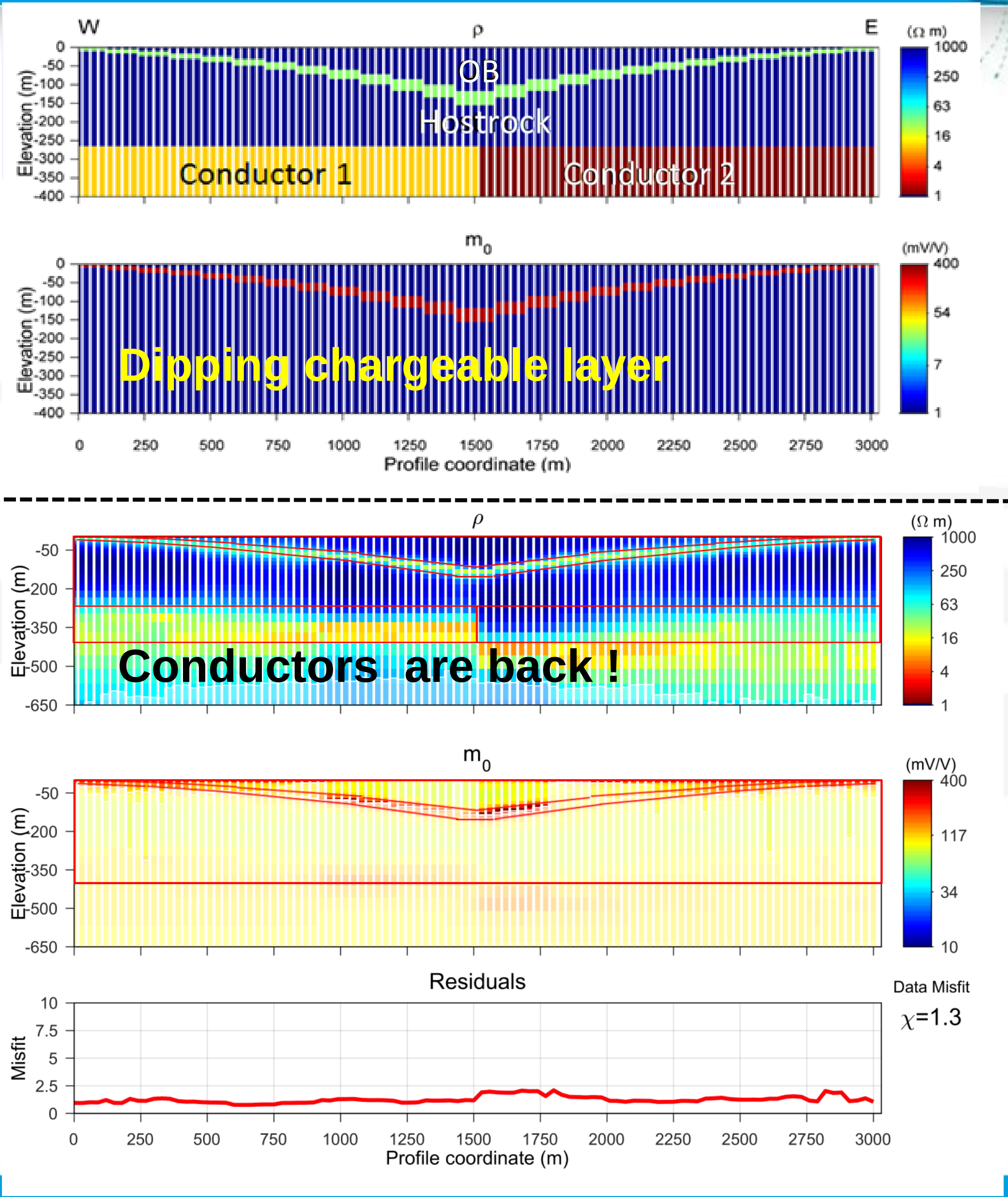


FWD, noise added, inverted ***without modelling*** *IP*

Recovered model

Why is it important to model it:improved resistivity sections

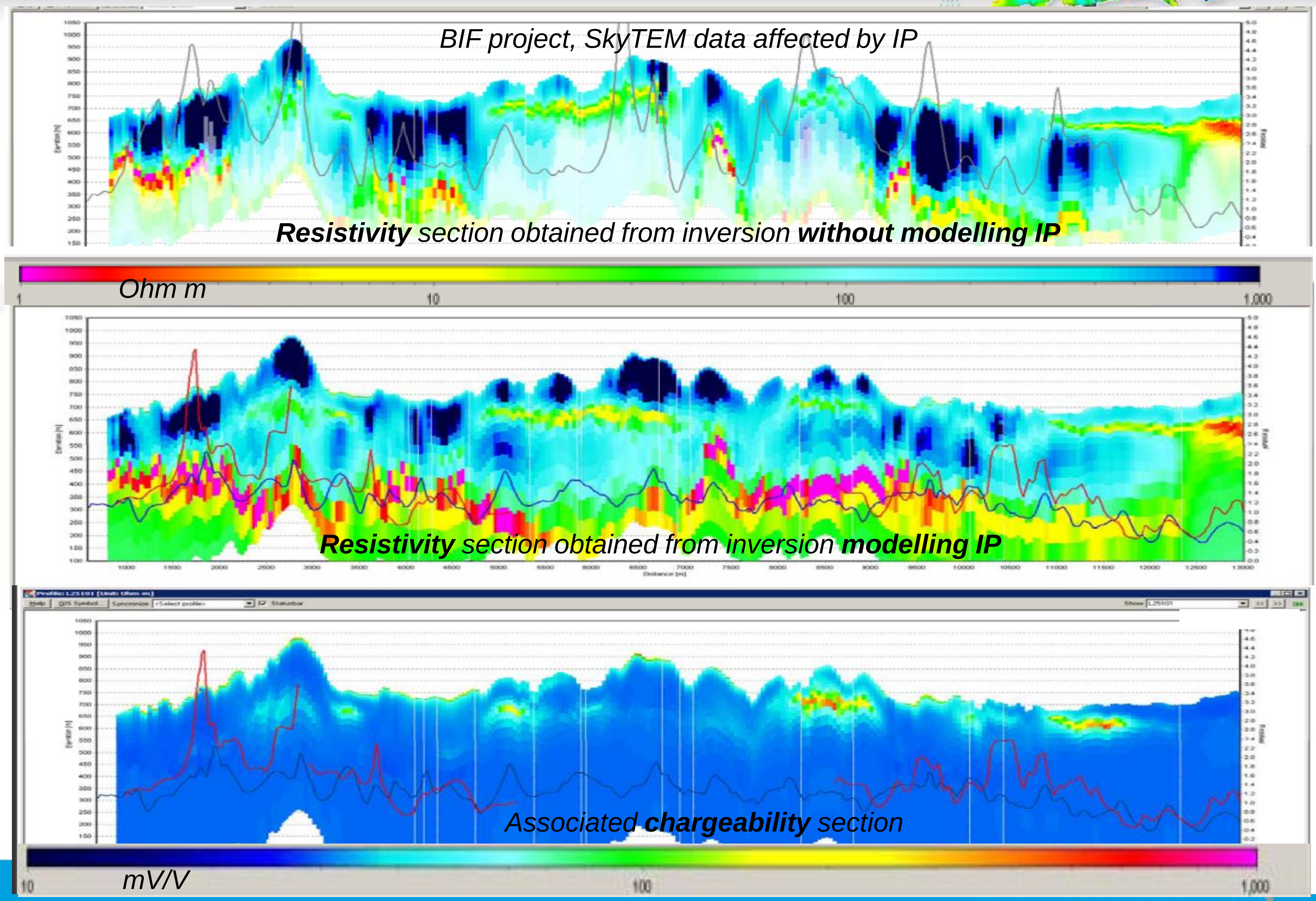
True model



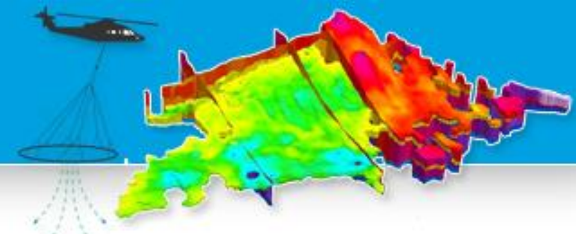
FWD, noise added, inverted ***modelling*** *IP (no apriori)*

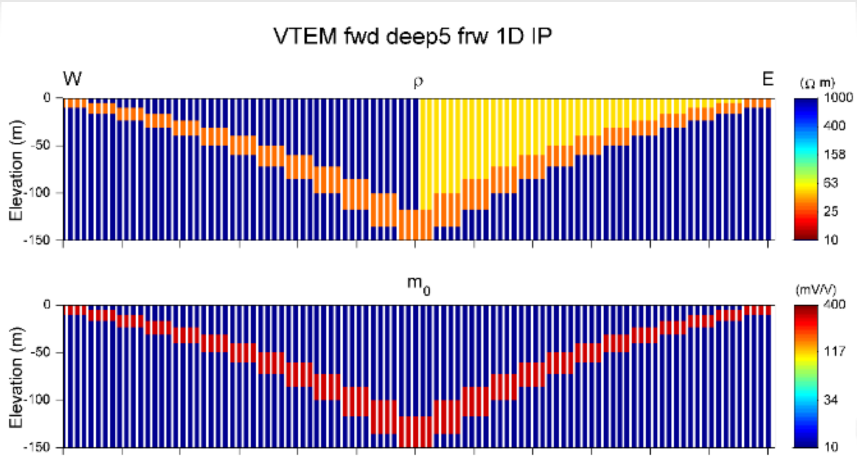
Recovered model

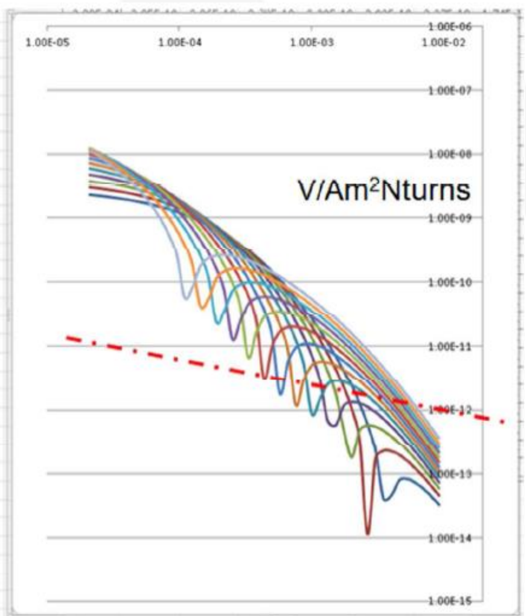
Why is it important to model it:improved resistivity sections



Why is it important to model it:it can recover *m* at some depth

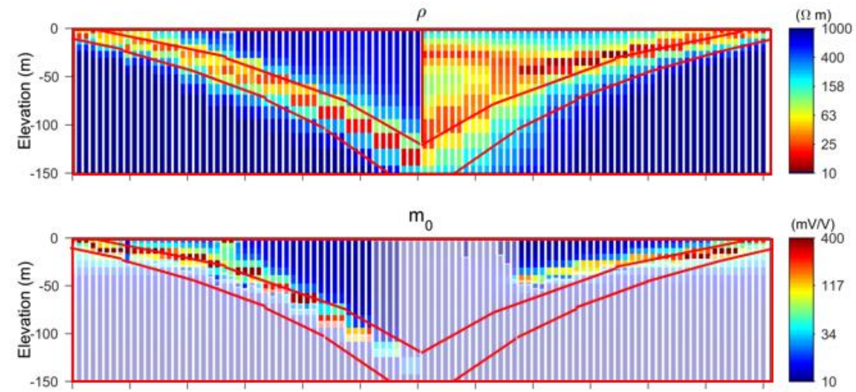




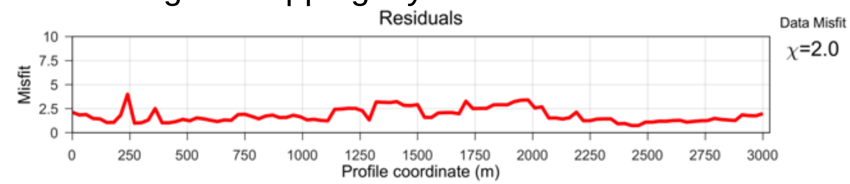


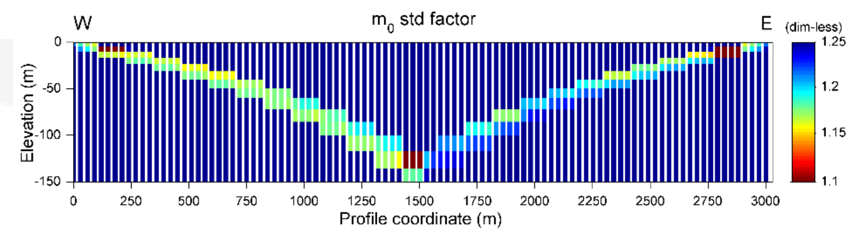
True model

*FWD, noise added, inverted **modelling** IP (no apriori)*



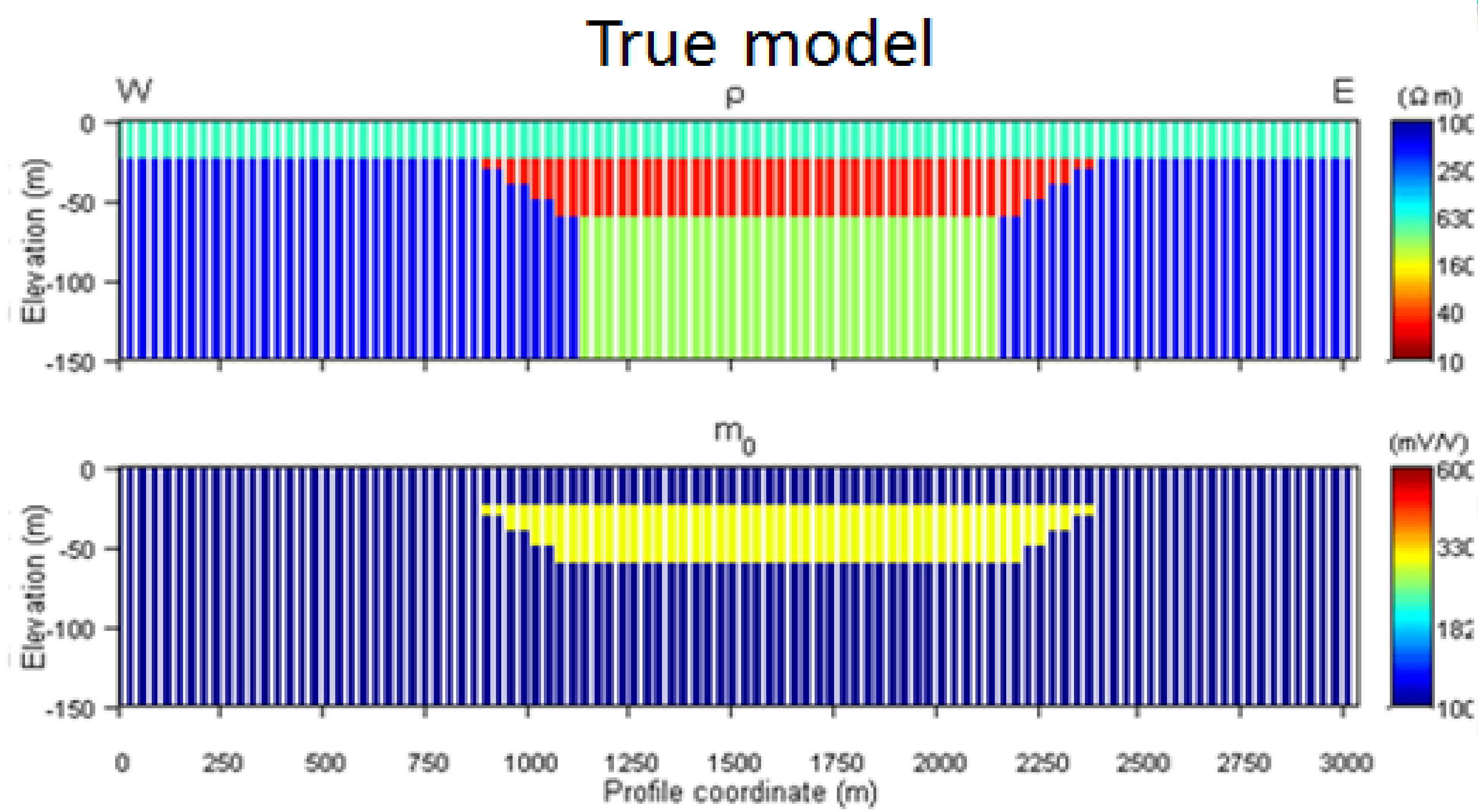
Charegable dipping layer tracked down to > 100 m





Recovered model

Kimberlite exploration: syhtetic data



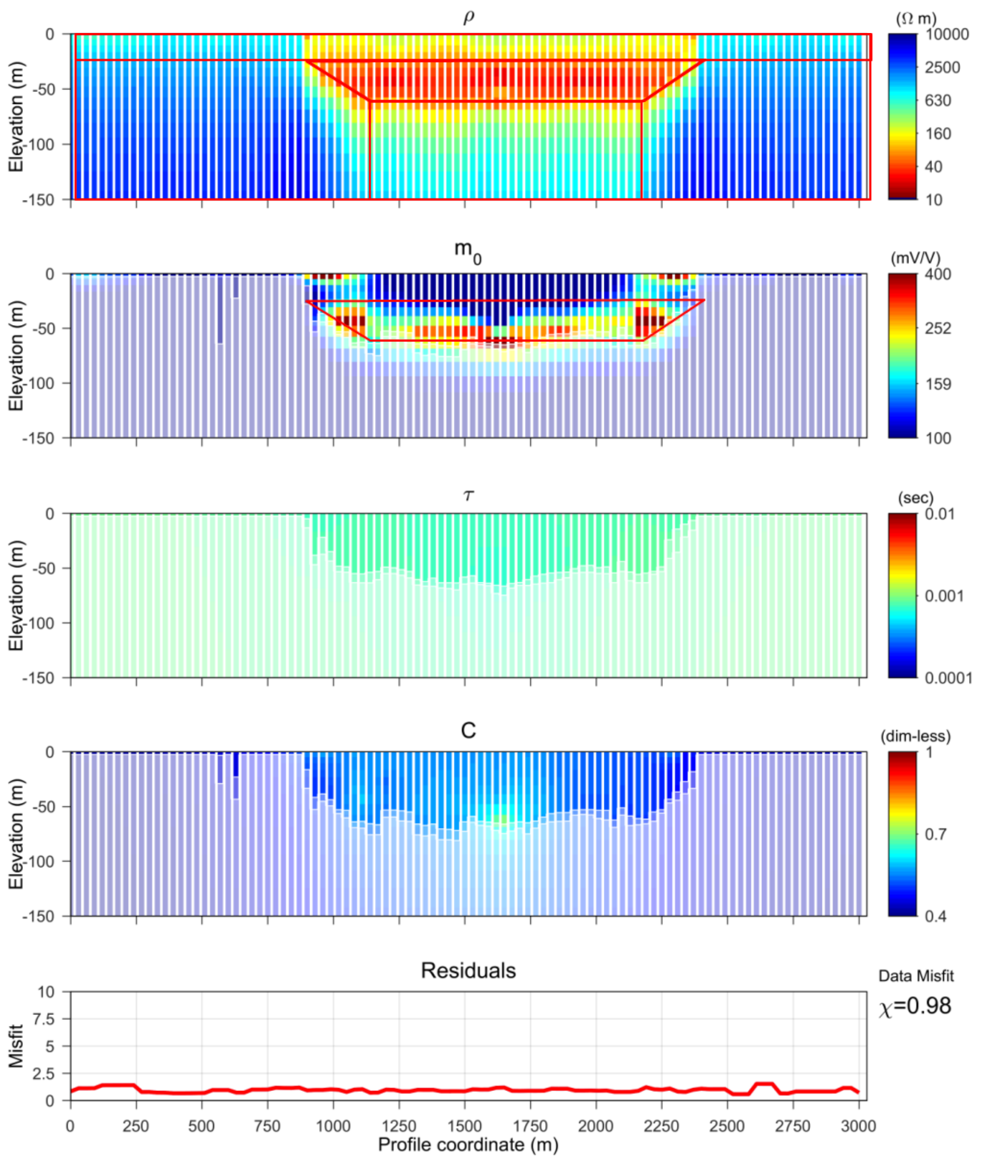
Overburden: rho = 500 Ohm m; m0 = 10 mV/V
Tau = 0.001; C = 1.0

Crater: rho = 30 Ohm m; m0 = 300 mV/V; Tau = 0.001; C = 0.5

Diatreme: rho = 250 Ohm m

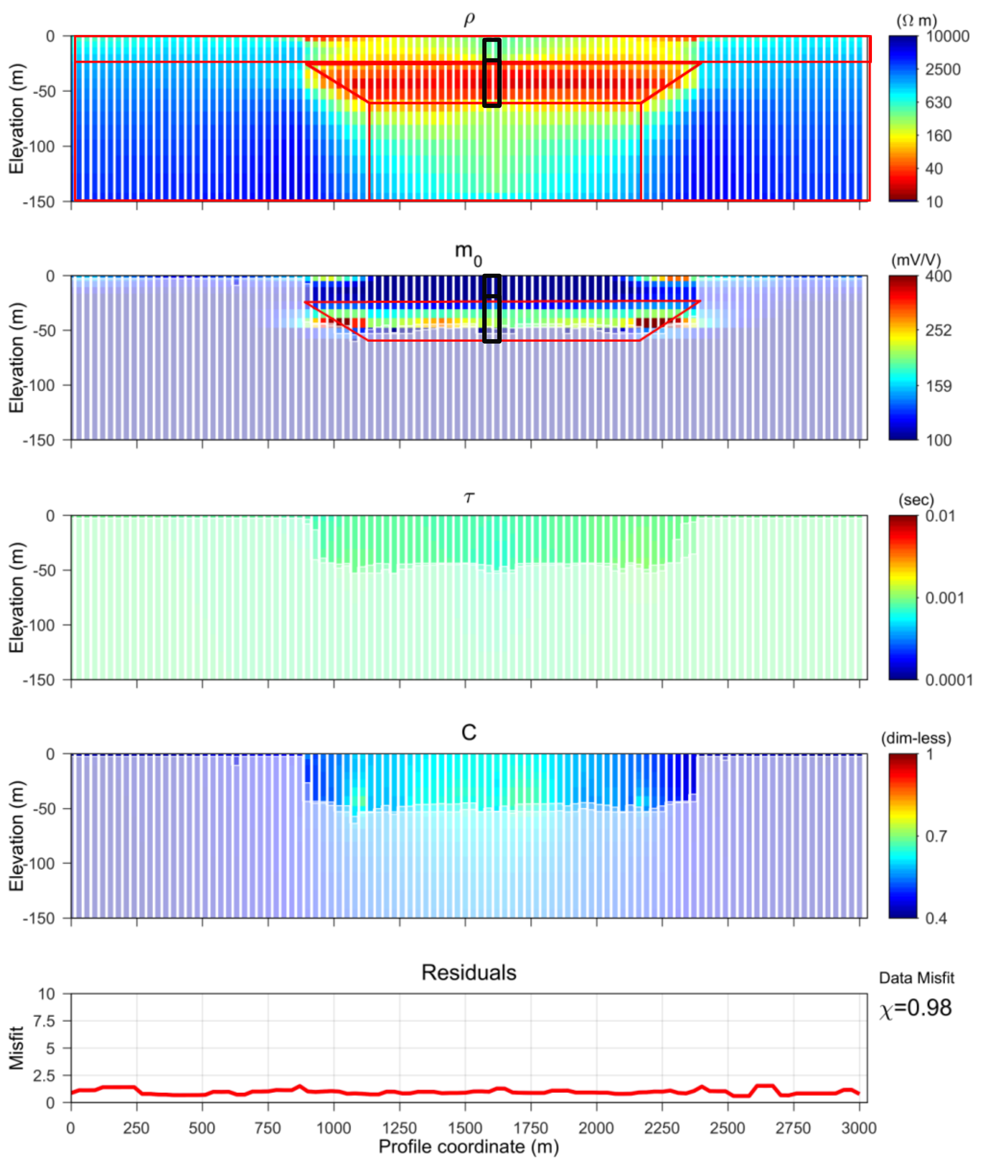
Host rock: rho = 5000 Ohm m

Inversion results (no a-priori, loose constraints)



Geometry of the kimberlite fairly resolved. Some artefacts

Inversion results (A-priori, tighter constraints)

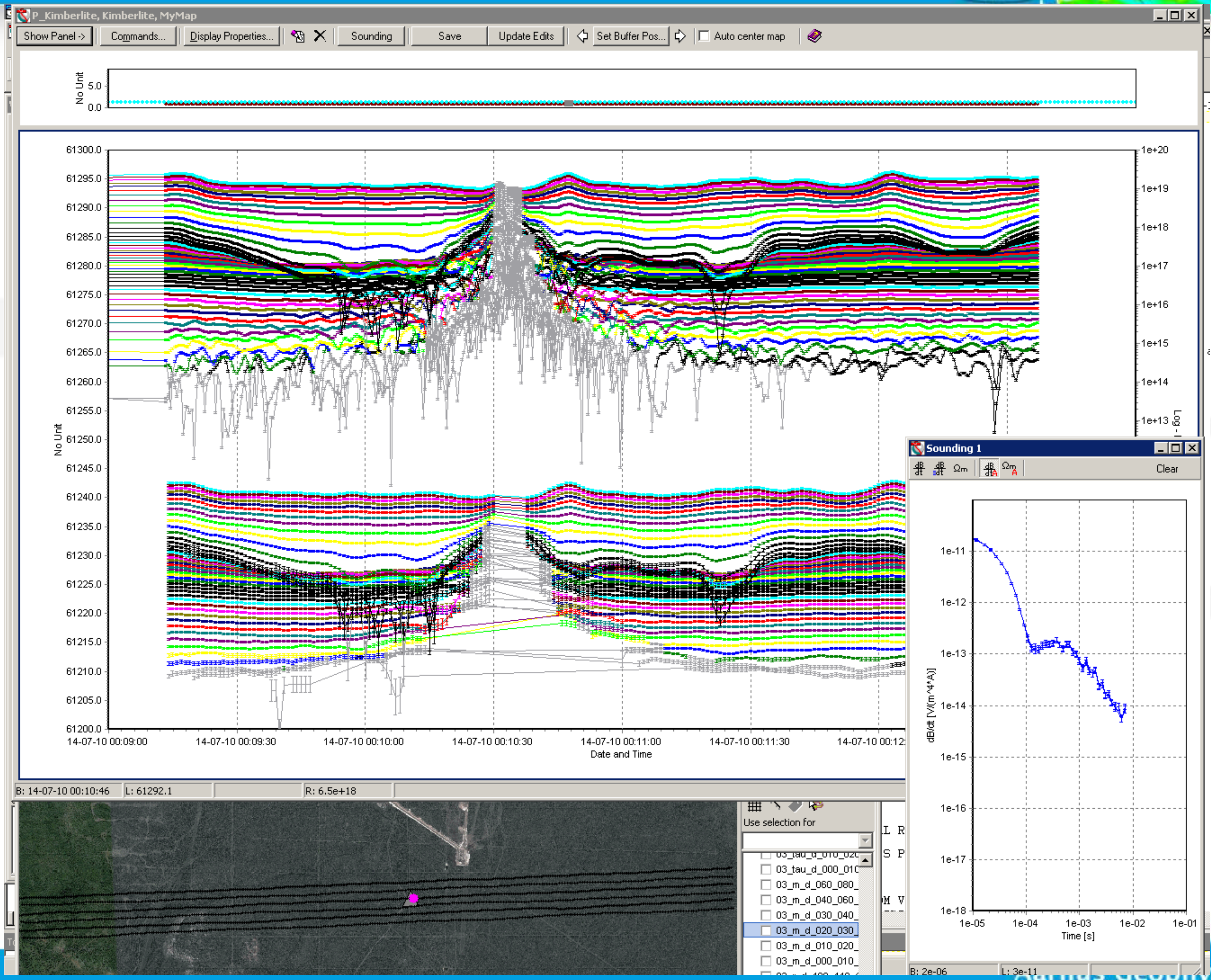


Geometry of the kimberlite resolved better. Artefacts decreases

Kimberlite exploration: case study 1, Amakiskaya pipe (VTEM)

Amakinskaya Kimberlite pipe results: From the geological standpoint, the area surrounding Amakinskaya kimberlite pipe belongs to a sedimentary basin with widespread outcrops of clays and alevrolites of Jurassic age (J_1or), which unconformably overlay Cambrean limestone complex ($Є_3$hl). Triassic basalts (βT_1kt) are also widespread in the area, especially to the north from the pipe. Amakinskaya Kimberlite pipe shows a great deal of anisotropy in the vertical direction, shifting from weathered, clayish upper facies, affected by permafrost to consolidated hard kimberlite below 30 m depth. This obviously has reflection in the physical properties of the kimberlite. Resistivity and chargeability changes with depth, showing lowering resistivity and increasing chargeability values in the upper facies of the kimberlite, while magnetic susceptibility increases with depth, as kimberlite consolidates (Bondarenko and Zinchuk, 2004).

The data

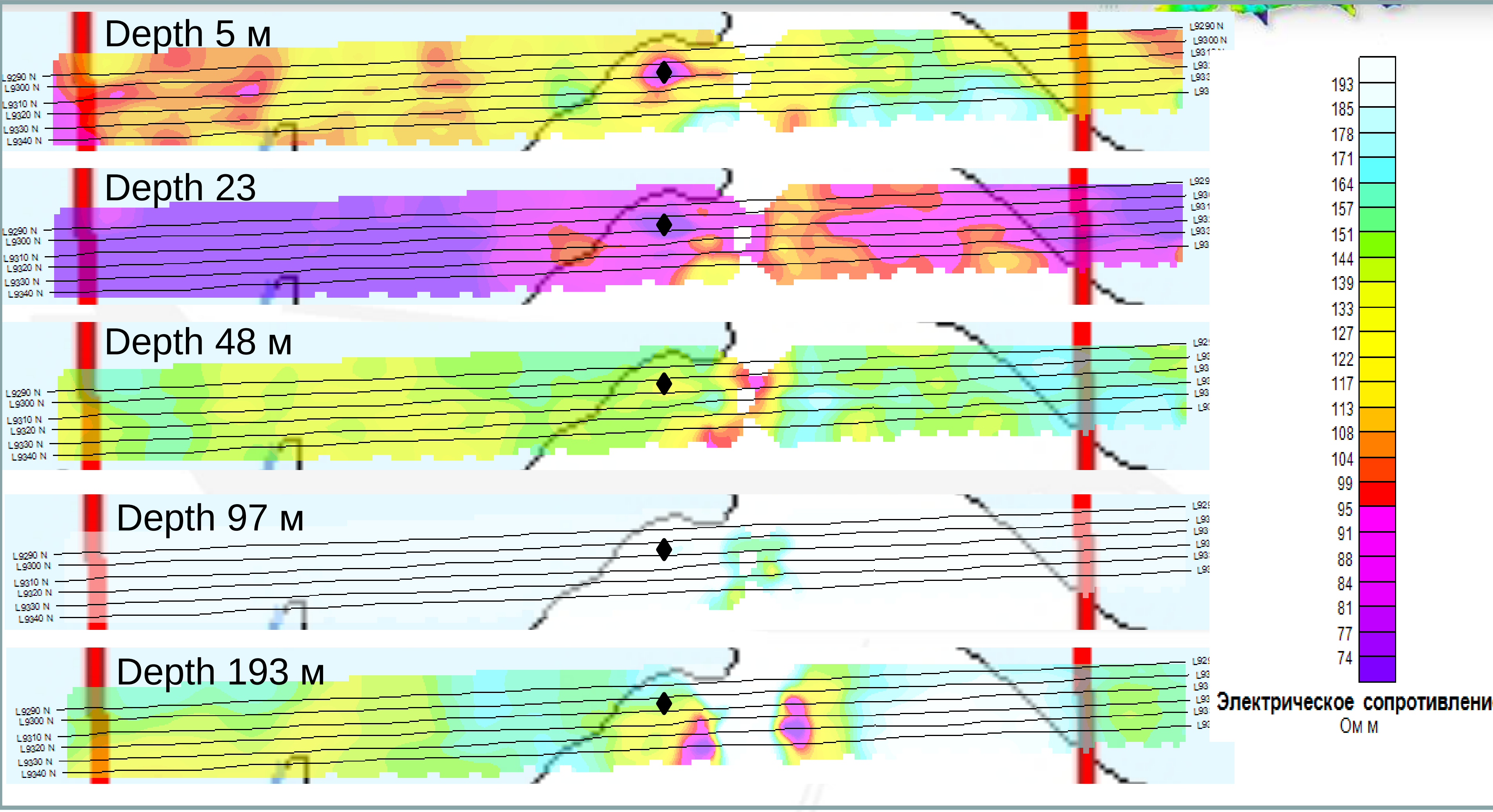


P_Kimberlite, Kimberlite, MyMap
Show Panel ->
Commands...
Display Properties...
Sounding
Save
Update Edits
Set Buffer Pos...
Auto center map
Date and Time
B: 14-07-10 00:10:46
L: 61292.1
R: 6.5e+18
Sounding 1
Clear
dB/dt [V/(m^4*A)]
Time [s]
Use selection for

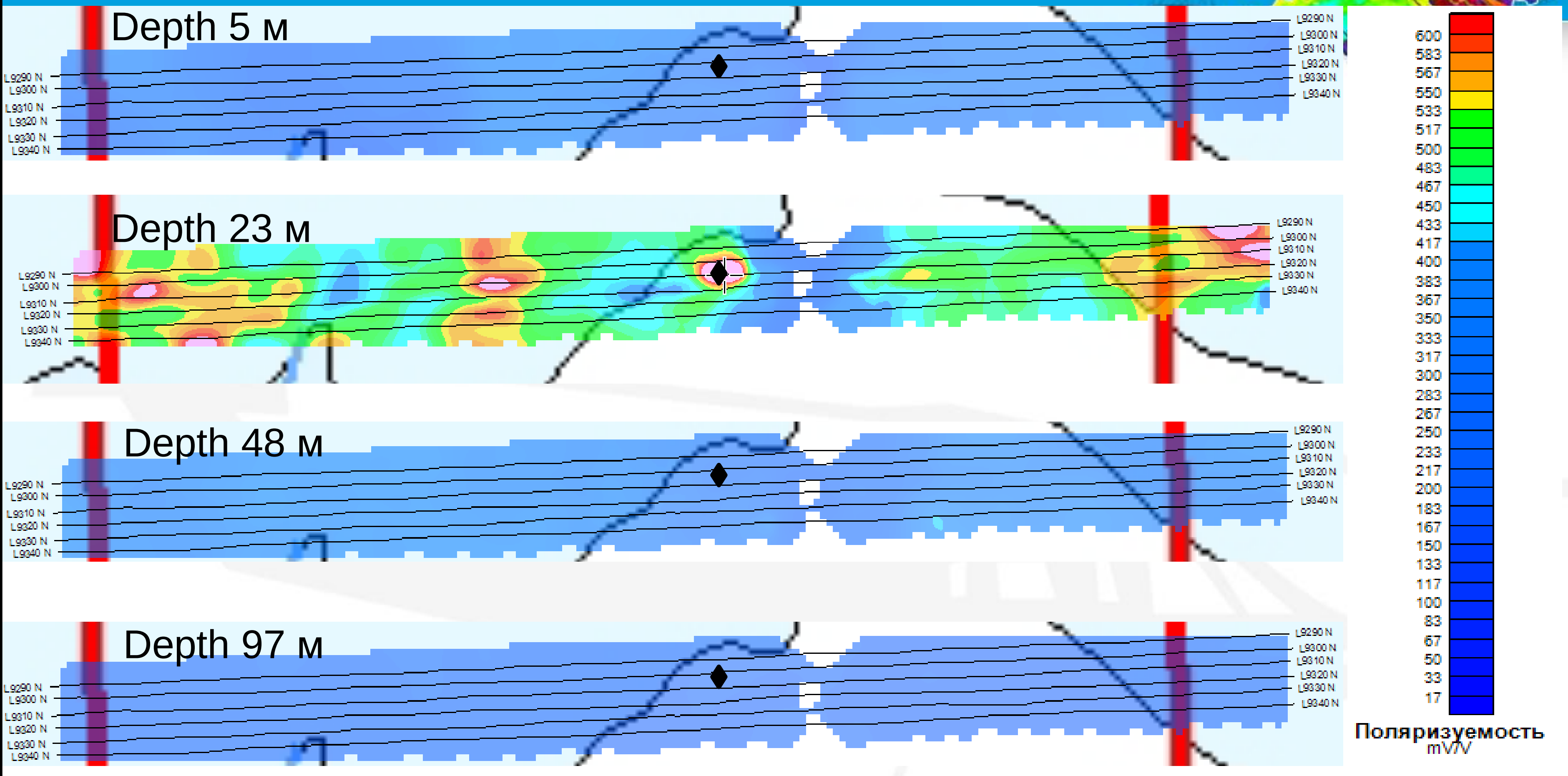
The workflow when working with actual AEM data

- Data processing
  - Recognize and mantain IP effects while increasing S/N and eliminating artefacts
- Inversion with IP modelling (AarhusInv)
  - Cole Cole modelling
  - No apriori
  - Solved for all parameters at once
  - Spatially Constrained Inversion (quasi 3D)
  - Many realizations, scanning the model and regularization space thouroughly
  - Tight spatial constraints on *c* and τ
- Careful assessment of results
  - General geological settings
  - Comparison with ancillary data

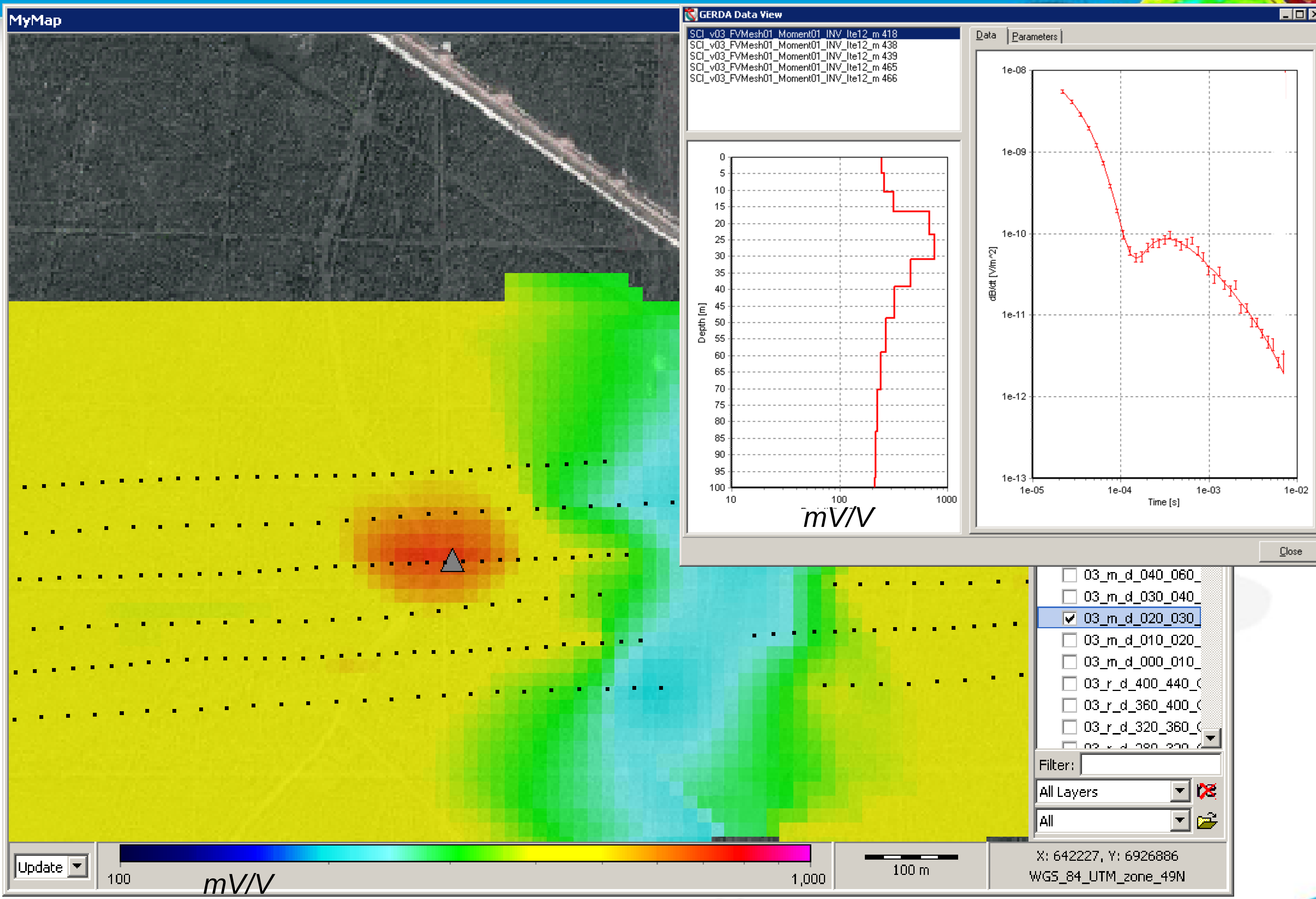
Resistivity slices



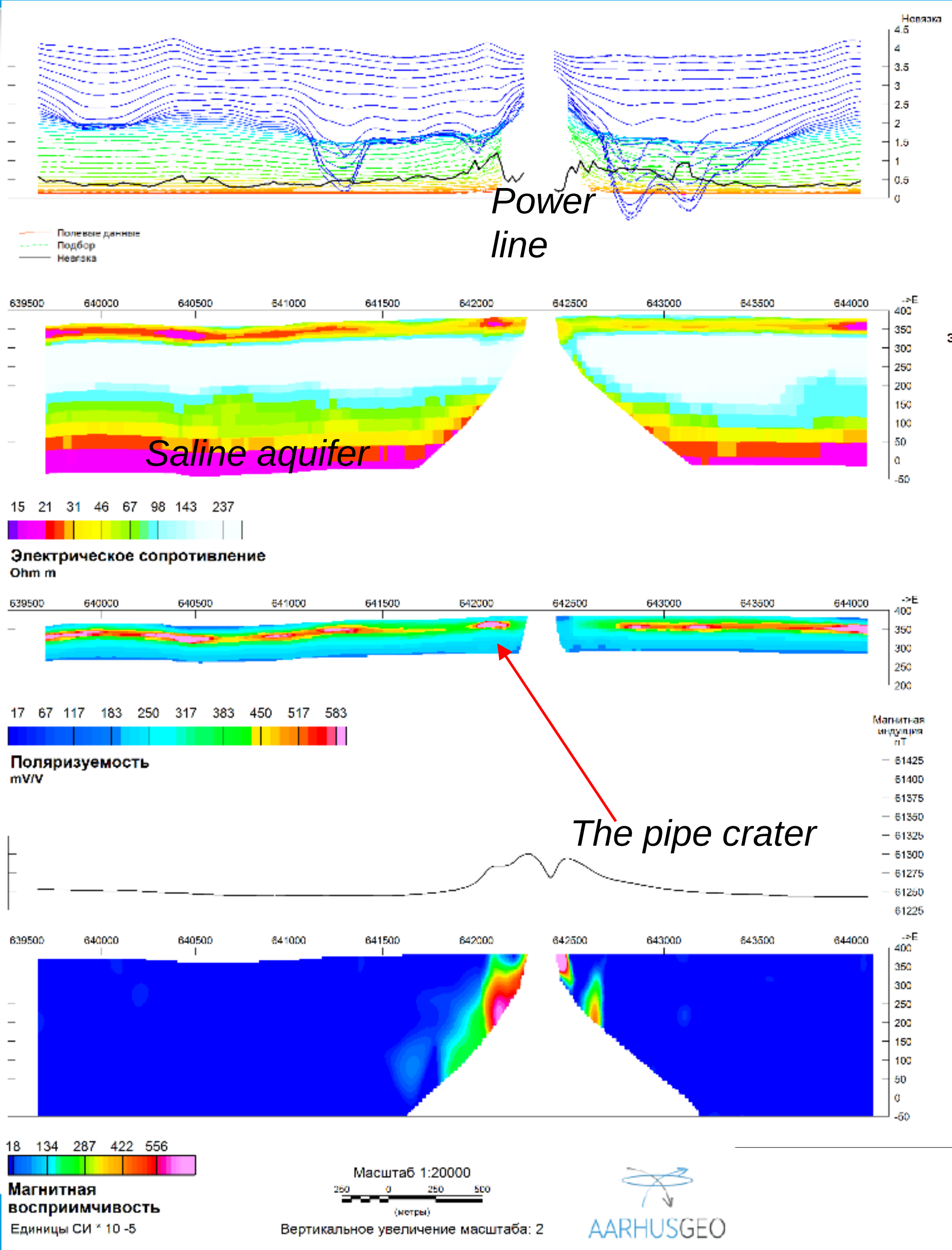
Chargeability slices

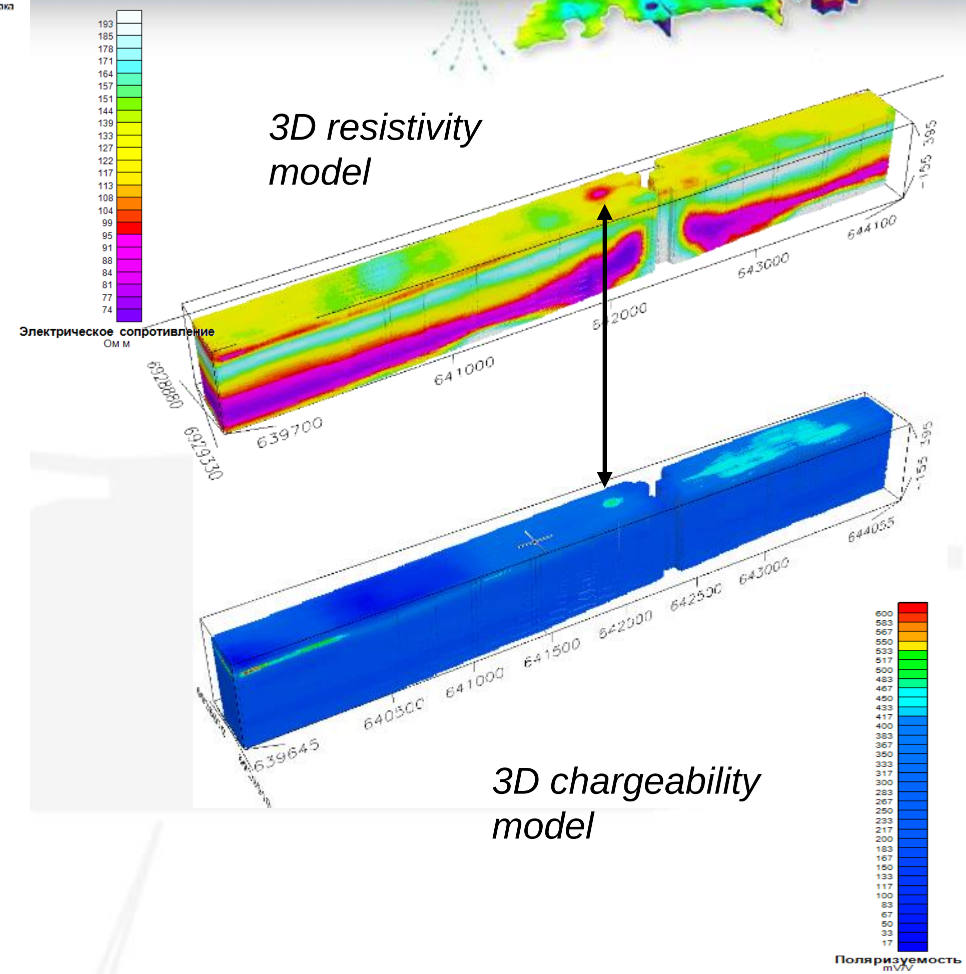


Close up on the pipe

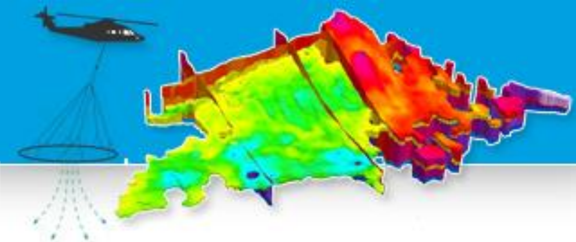


Res, m and mag vertical sections





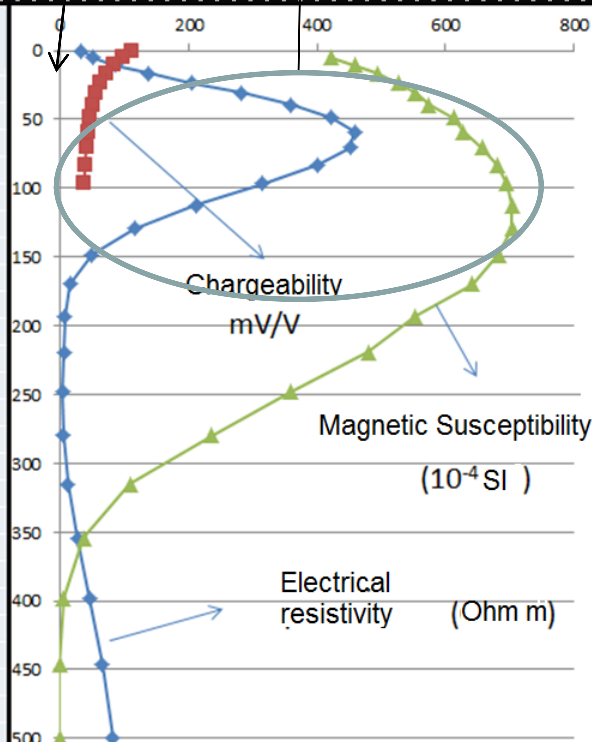
Comparing physical properties



Rock type	Formation	Electrical resistivity(ρ, Ohm m)	Magnetic susceptibility (10^{-5} SI)	Comments
Kimberlites	Amakinskaya pipe	30-60	100 - 900	Weathered, clayish
Kimberlites	Amakinskaya pipe	500 - 1000	100 - 900	Kimberlitic breccia
Kimberlites	Amakinskaya pipe	290 - 400	100 - 900	Carboniferous kimberlites
Clayish limestones	J_1uk	100 - 400	N/A	
Sandy silts	J_1uk	100 - 400	N/A	

Physical properties from ancillary data

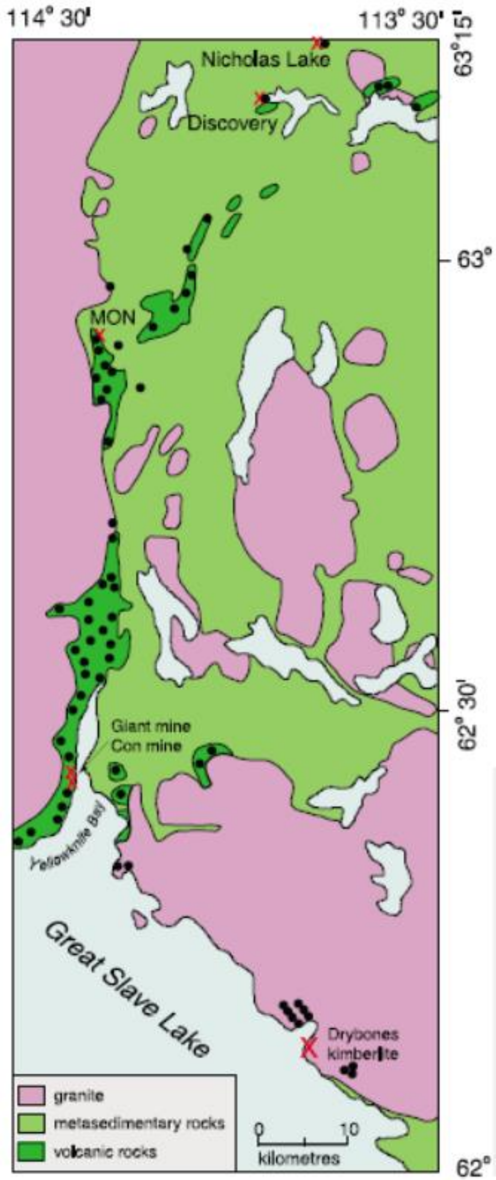
Depth	Abs. elevation	Electrical resistivity	Magnetic Susceptibility	Chargeability
0.00	221.7	34.2	N/A	112.4
5.00	216.7	52.0	422.30	98.6
10.5	211.2	86.5	459.10	84.00
16.6	205.1	138.2	493.10	72.4
23.4	198.3	205.6	525.70	63.6
30.9	190.8	283.00	552.40	57.00
39.3	182.4	360.00	574.20	51.9
48.6	173.1	423.00	611.80	48.00
58.9	162.8	458.7	627.90	44.7
70.3	151.4	452.00	656.70	42.2
82.9	138.8	401.7	679.80	40.1
96.9	124.8	315.00	695.40	38.4
112.4	109.3	211.6	702.90	N/A
129.6	92.1	116.6	702.60	N/A
148.7	73.00	49.6	682.50	N/A
169.9	51.8	16.4	641.00	N/A
193.3	28.4	7.7	552.80	N/A
219.3	2.4	6.4	479.60	N/A
248.1	-26.4	4.8	357.90	N/A
280.00	-58.3	5.7	236.80	N/A
315.4	-93.7	13.00	109.40	N/A
354.6	-132.9	27.4	37.00	N/A
398.1	-176.4	47.00	5.30	N/A
446.3	-224.6	66.8	0.00	N/A
500.00	-278.1	82.3	0.00	N/A

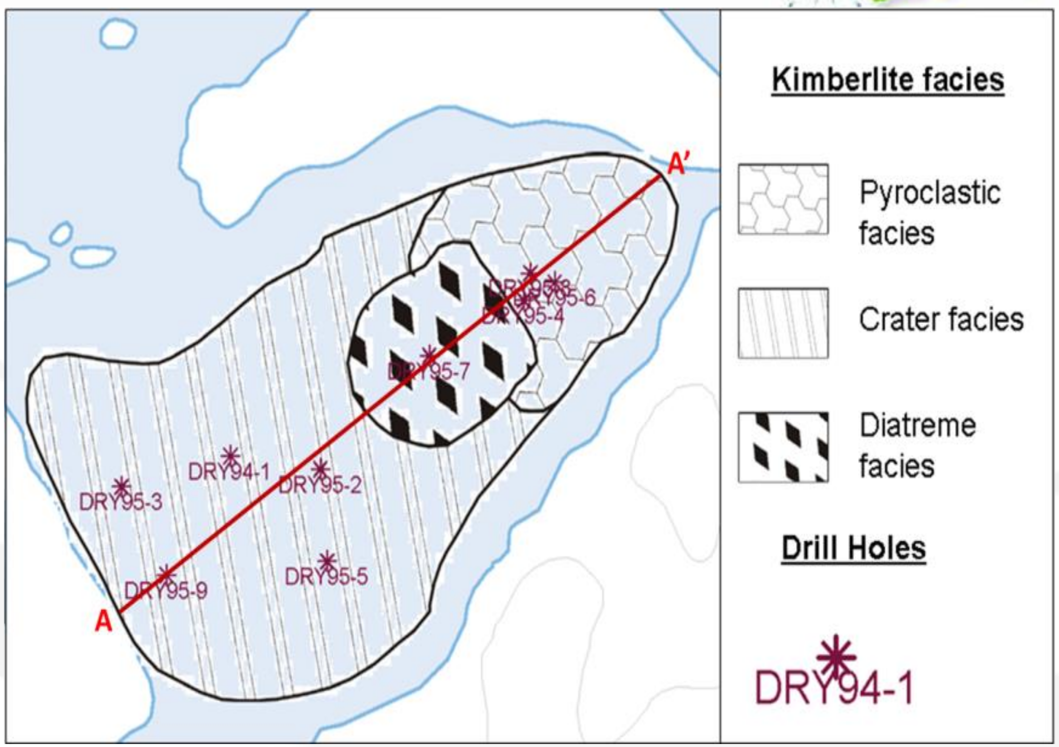


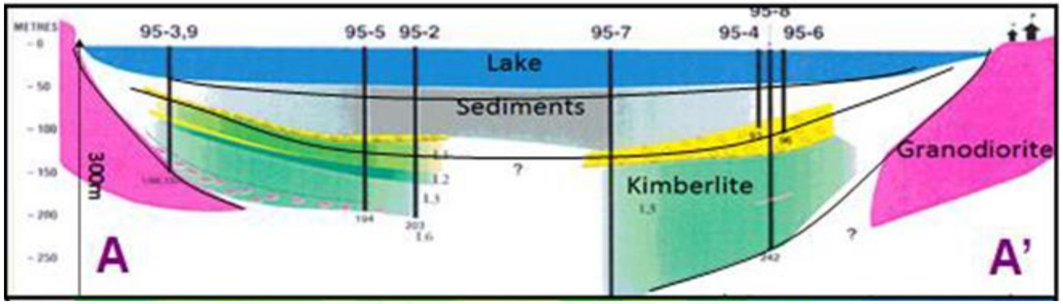
Physical properties from airborne geophysics

Kimberlite exploration: case study 2, Drybone pipe (VTEM)

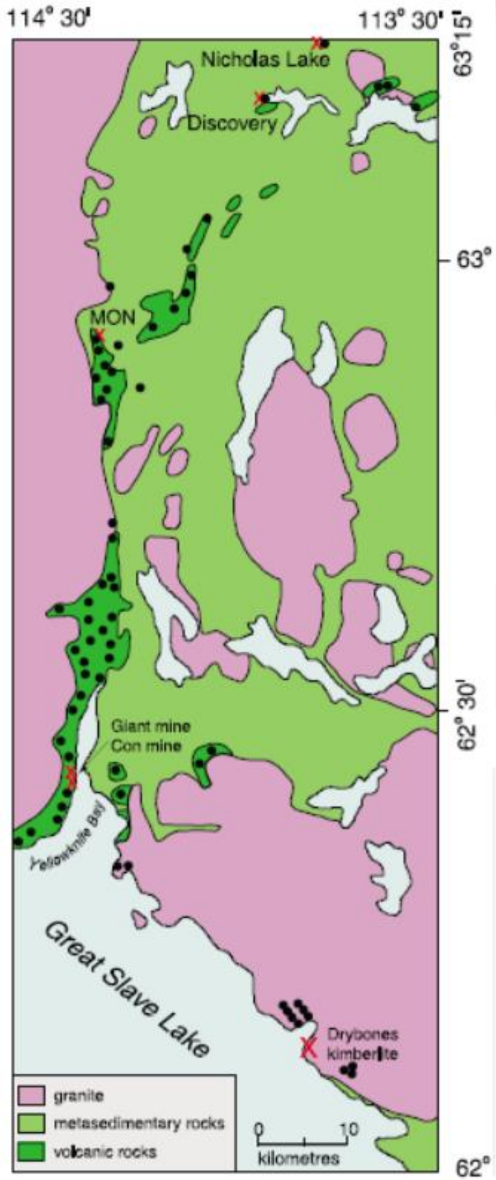
Drybones kimberlite geology

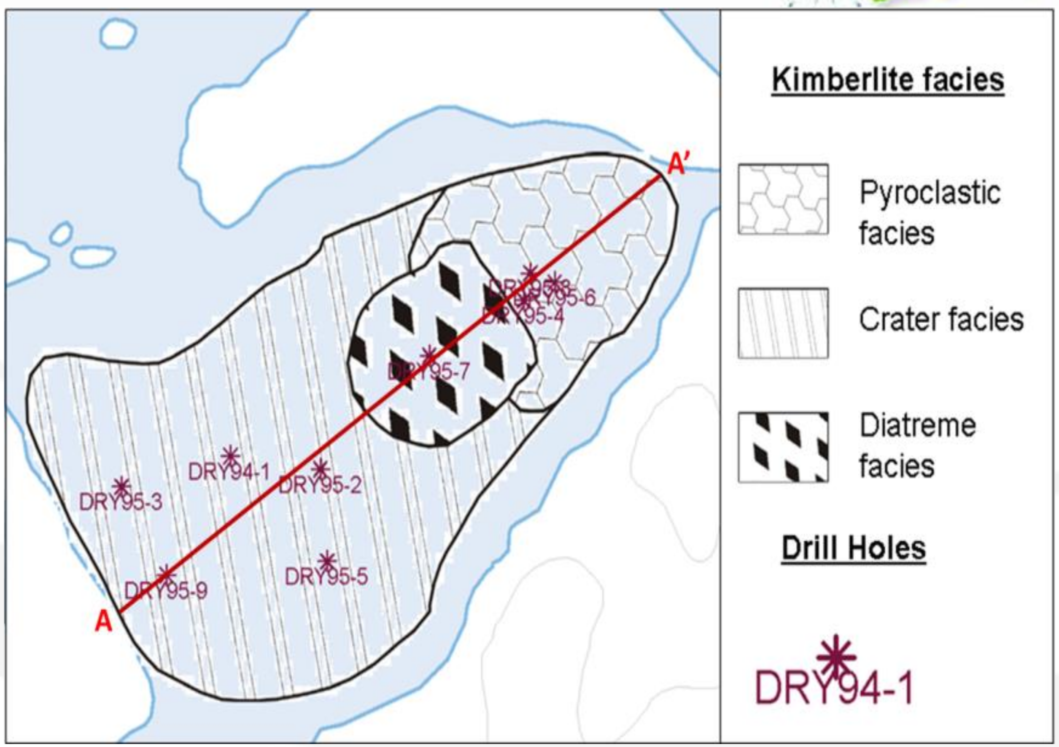


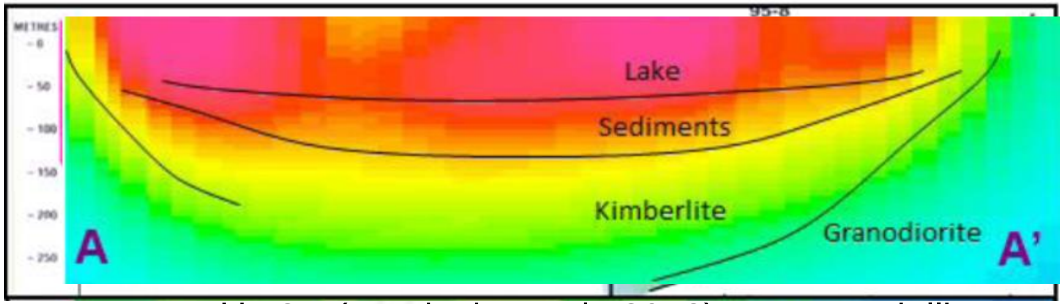




Drybones kimberlite geology

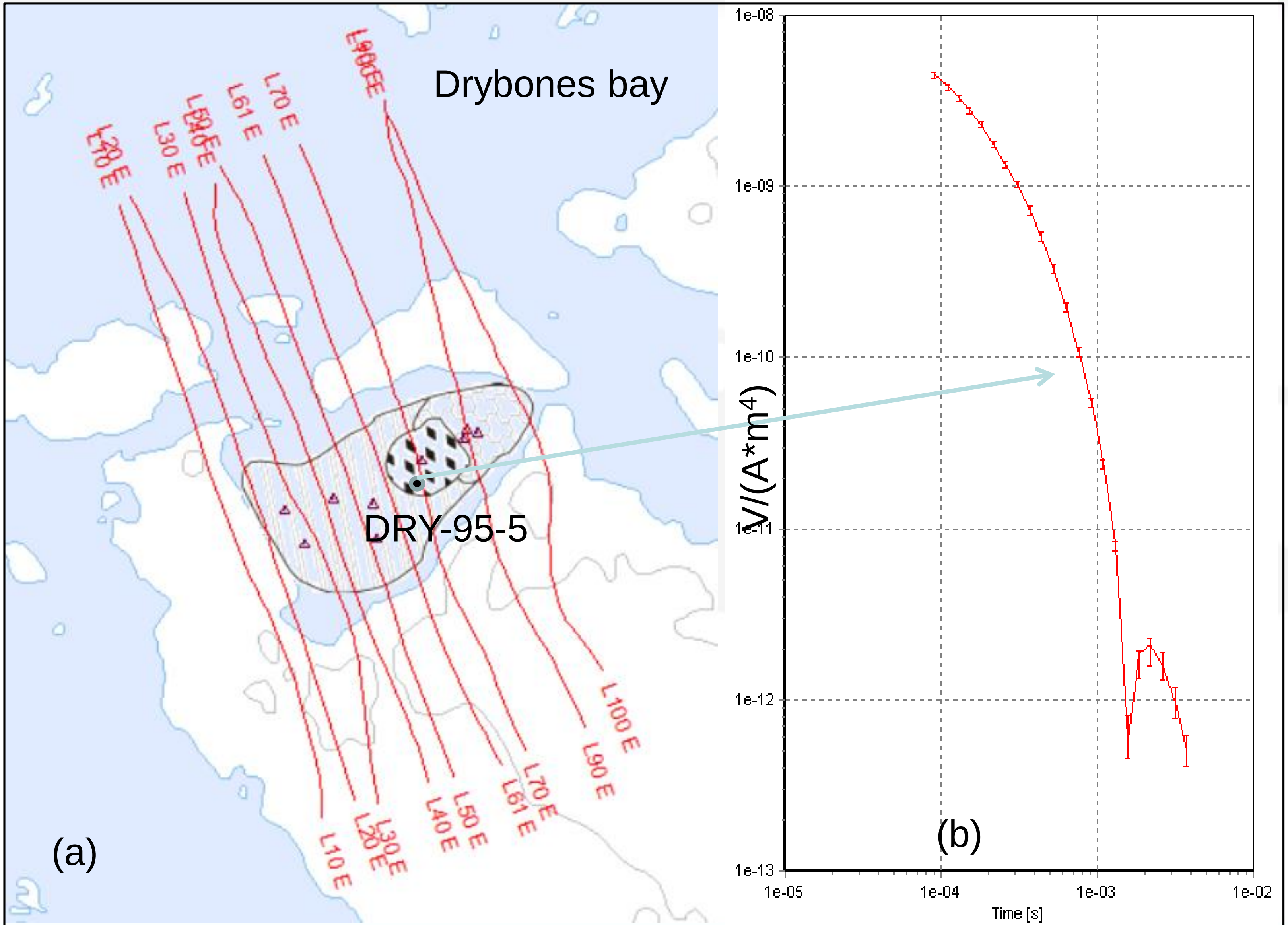




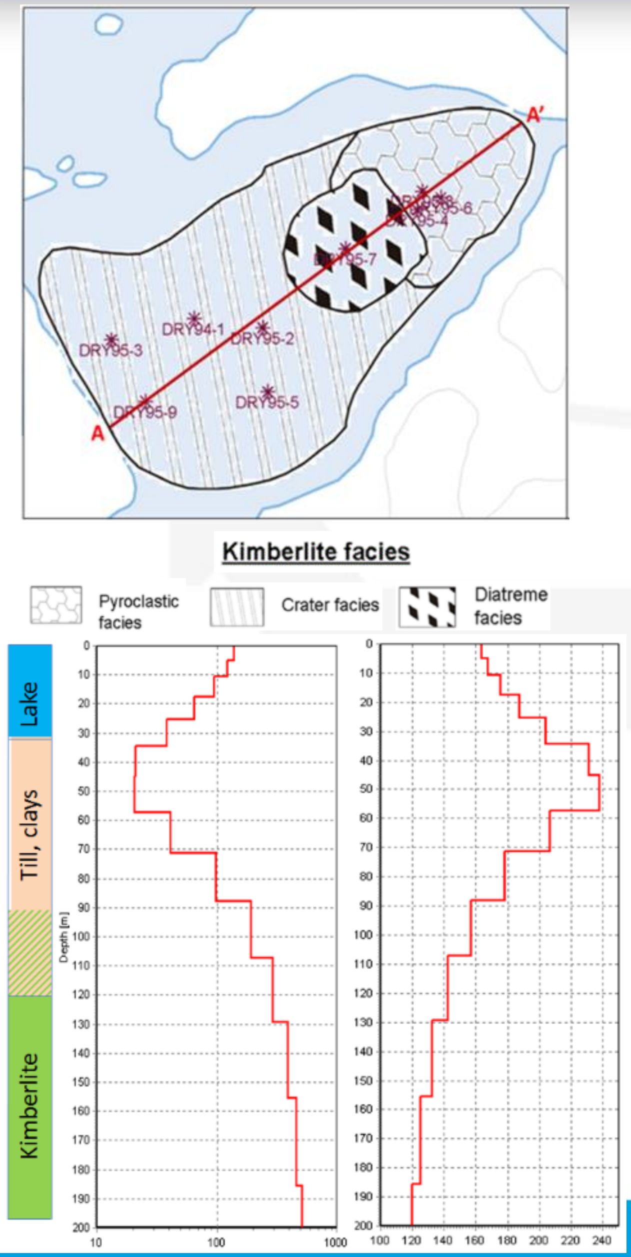


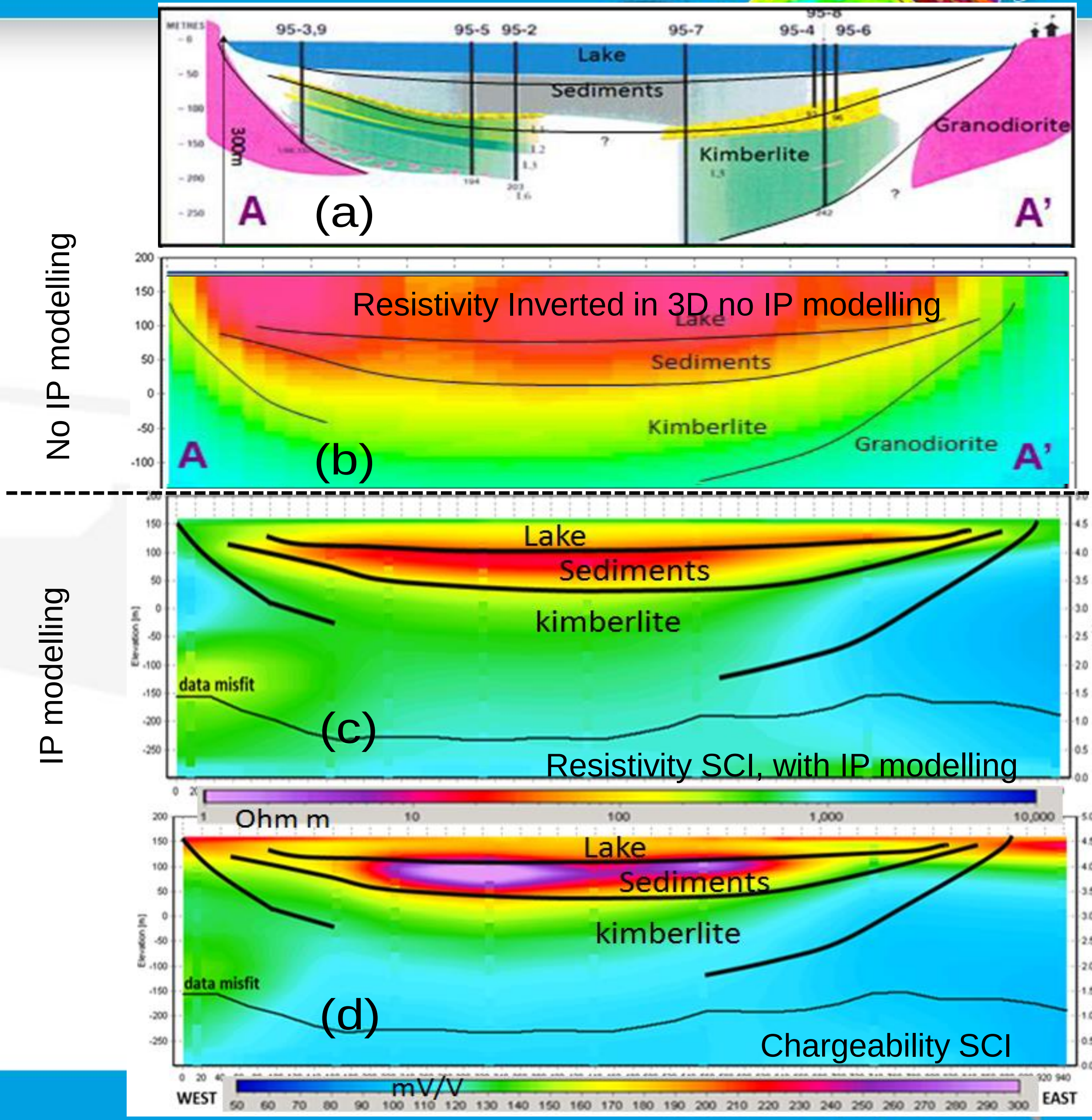
Inverted in 3D (Kaminsky et al., 2012), no IP modelling

Drybones kimberlite IP effect



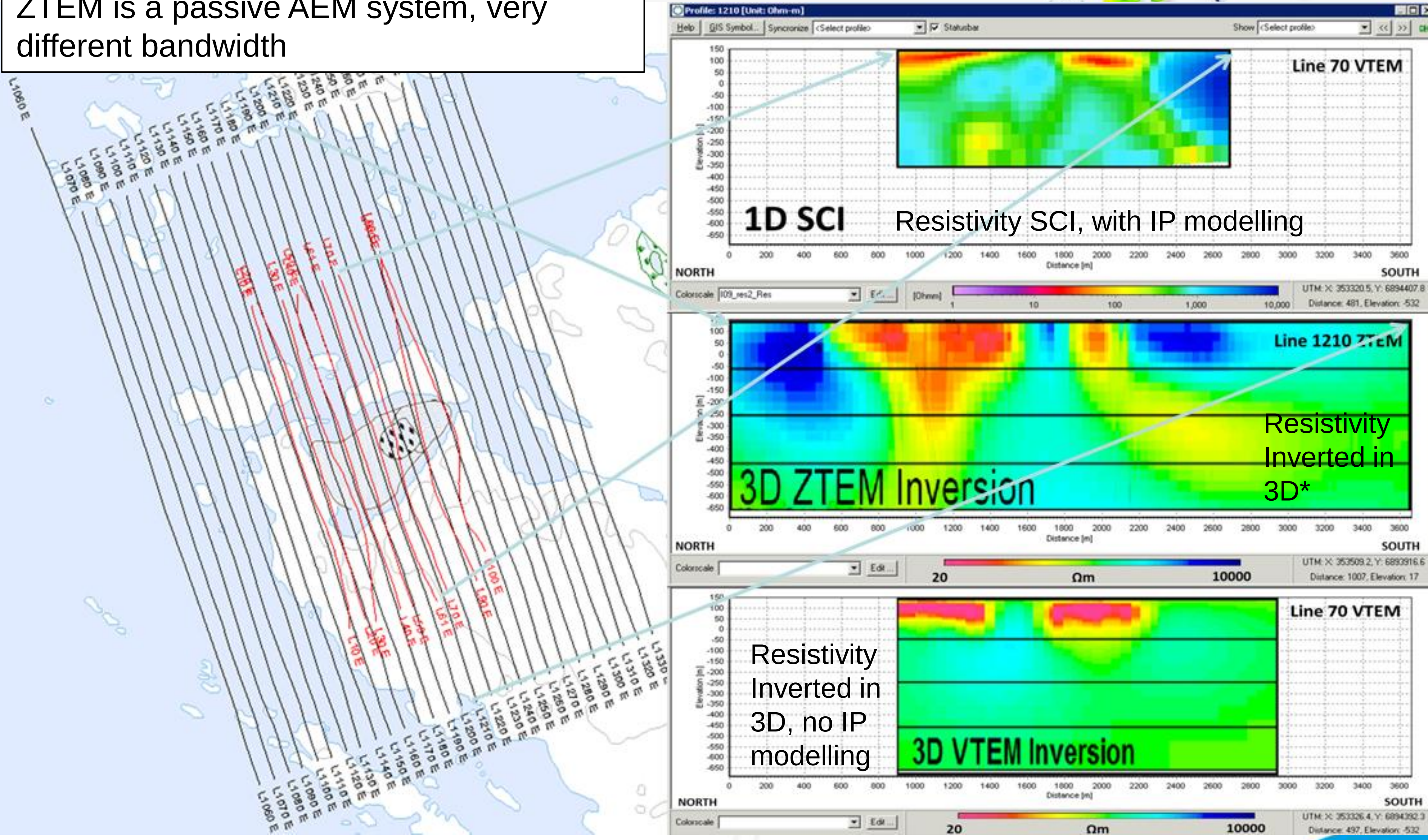
Drybones kimberlite comparison with previous inversions



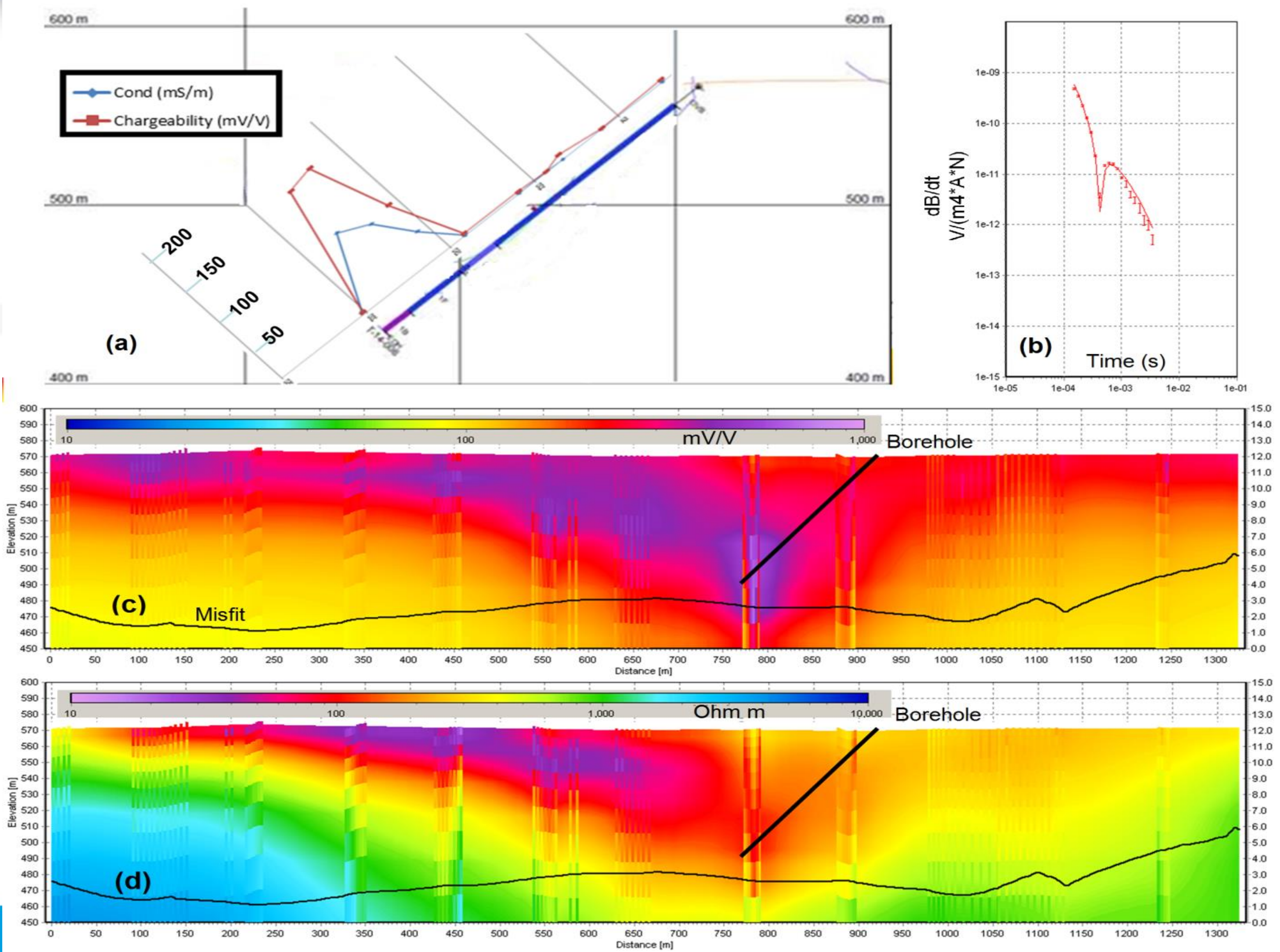


Drybones kimberlite VTEM/ZTEM

ZTEM is a passive AEM system, very different bandwidth



....base metal example...



Conclusions

- IP effects can be visible and measurable in AEM data
  - Signature is varied, beyond simple sign change
- IP can be modelled from AEM data, both synthetic and real. It is possible to recover corrected resistivities and some IP parameters
  - Large degree of non uniqueness, which can be reduced by constraints and a-priori
  - Chargeability can be recovered down to some depth
- Data needs to be understood and properly (pre)processed before attempting recovering IP
- Taking wrong assumptions on parameters (e.g., locking them to a predefined value) can lead to wrong models

Conclusions (continued)

- More research should focus on, e.g.,
  - Exploring IP models (not Cole Cole) ?
  - Using B field data
  - Different inversion strategies

- Failure to model IP in IP affected AEM datasets produces:
  - Erroneous resistivity sections
  - Loss of extra information about the subsurface that might be relevant for mineral exploration and other applications

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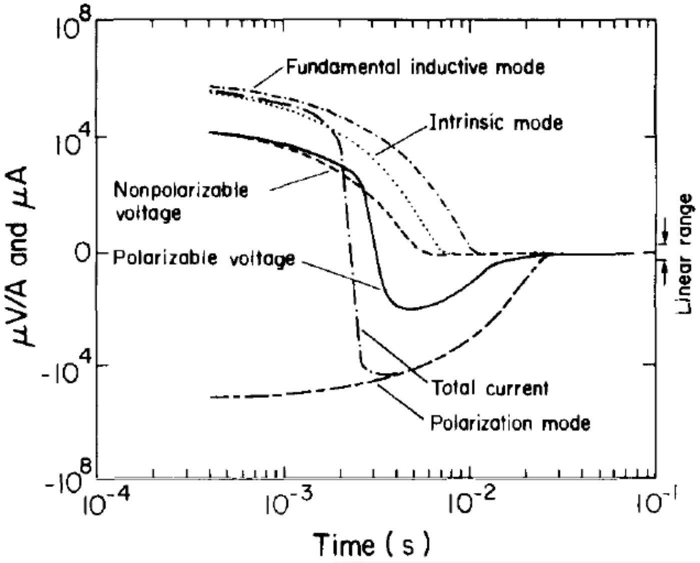
How much existing AEM data out there contains IP effects never looked at properly ?

Acknowledgments

- Geotech, Ltd
- Alrosa

IP effect in TEM data: ∞ freq. limits

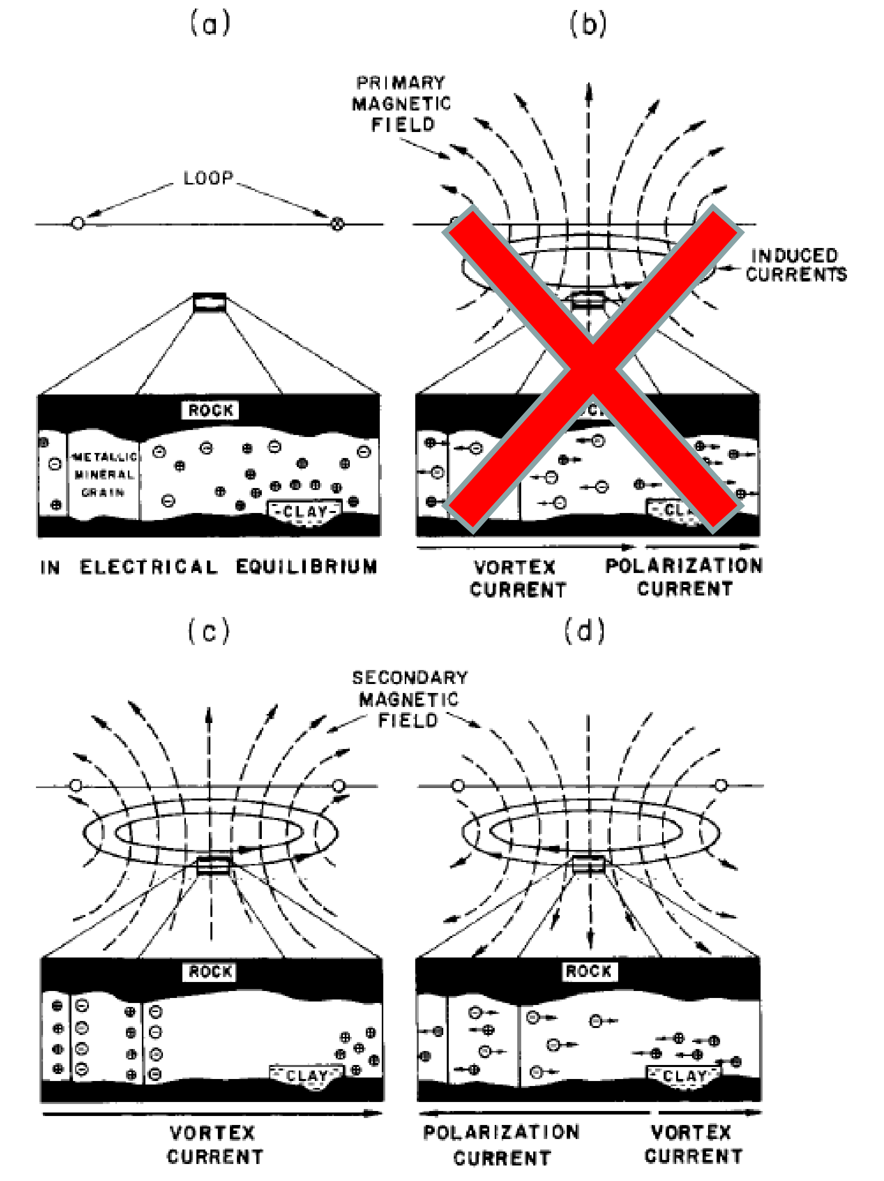
After Smith et al (1989)



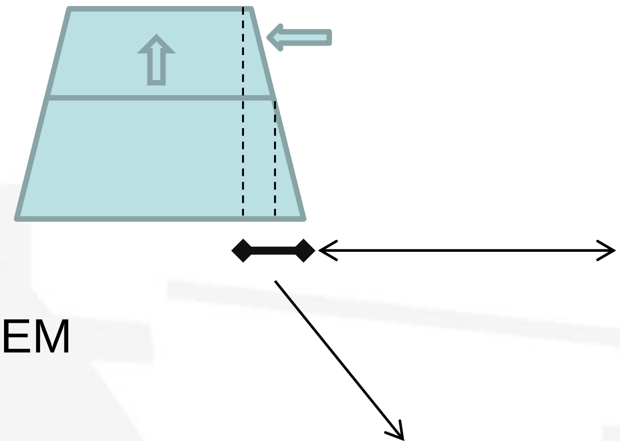
$$\sigma(s) = \sigma_\infty + \Delta_\infty \hat{\sigma}(s),$$

$$\Delta_\infty \hat{\sigma}(s) = \frac{-\sigma_\infty \mathrm{m}}{1 + (1 - \mathrm{m})(s\tau)^c},$$

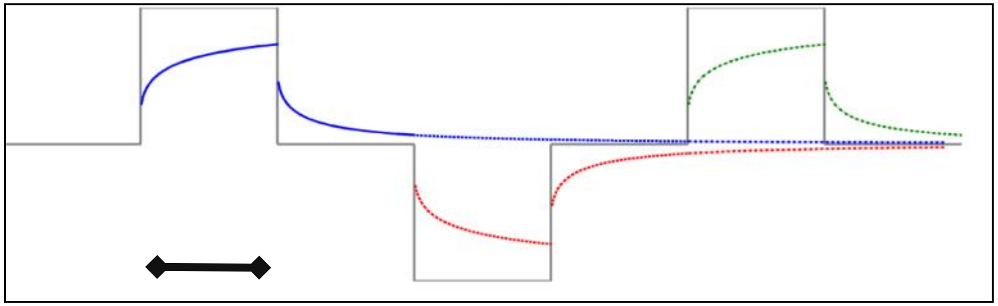
$$s = i\omega$$



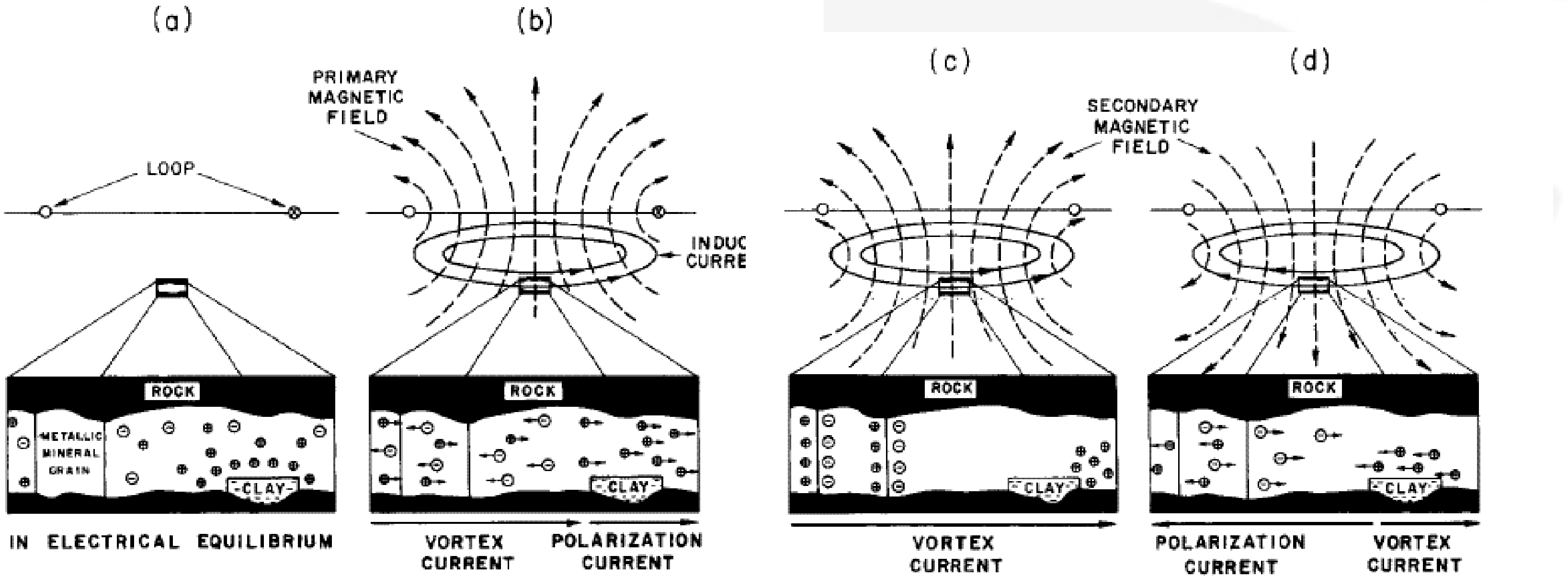
The charging up in TEM vs DC



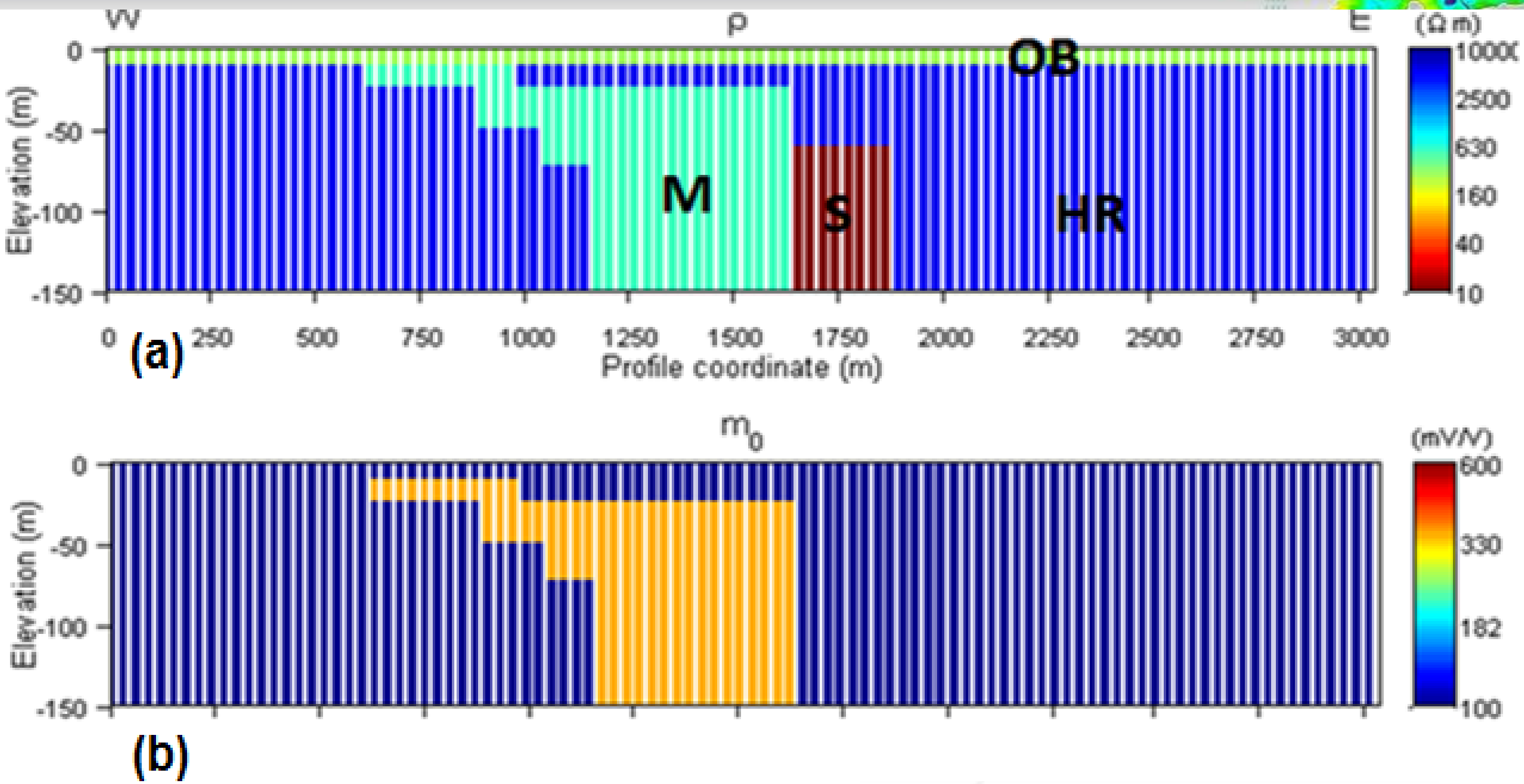
TEM



DC



Brief investigation into non uniqueness, and on locking *c*



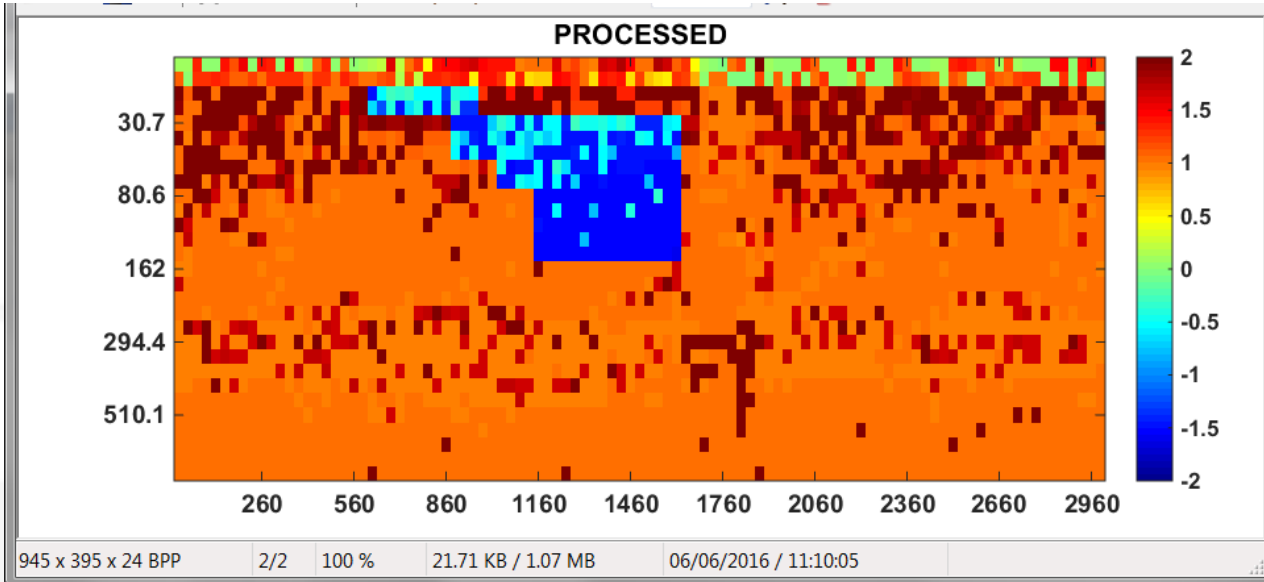
$$\Delta\, Par_{i,j}^{k} = \log_{10} Par_{i,j}^{Out(k)} - \log_{10} Par_{i,j}^{true}$$

$$Mode\left(\Delta\, Par_{i,j}\right)$$

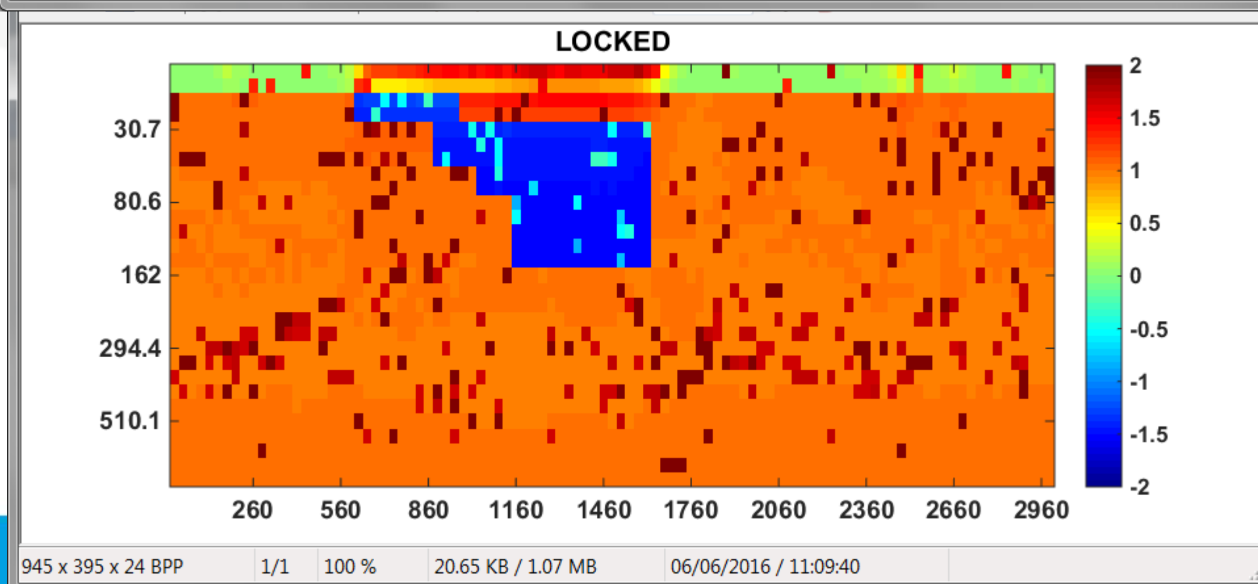
Brief investigation into non uniqueness, and on locking c

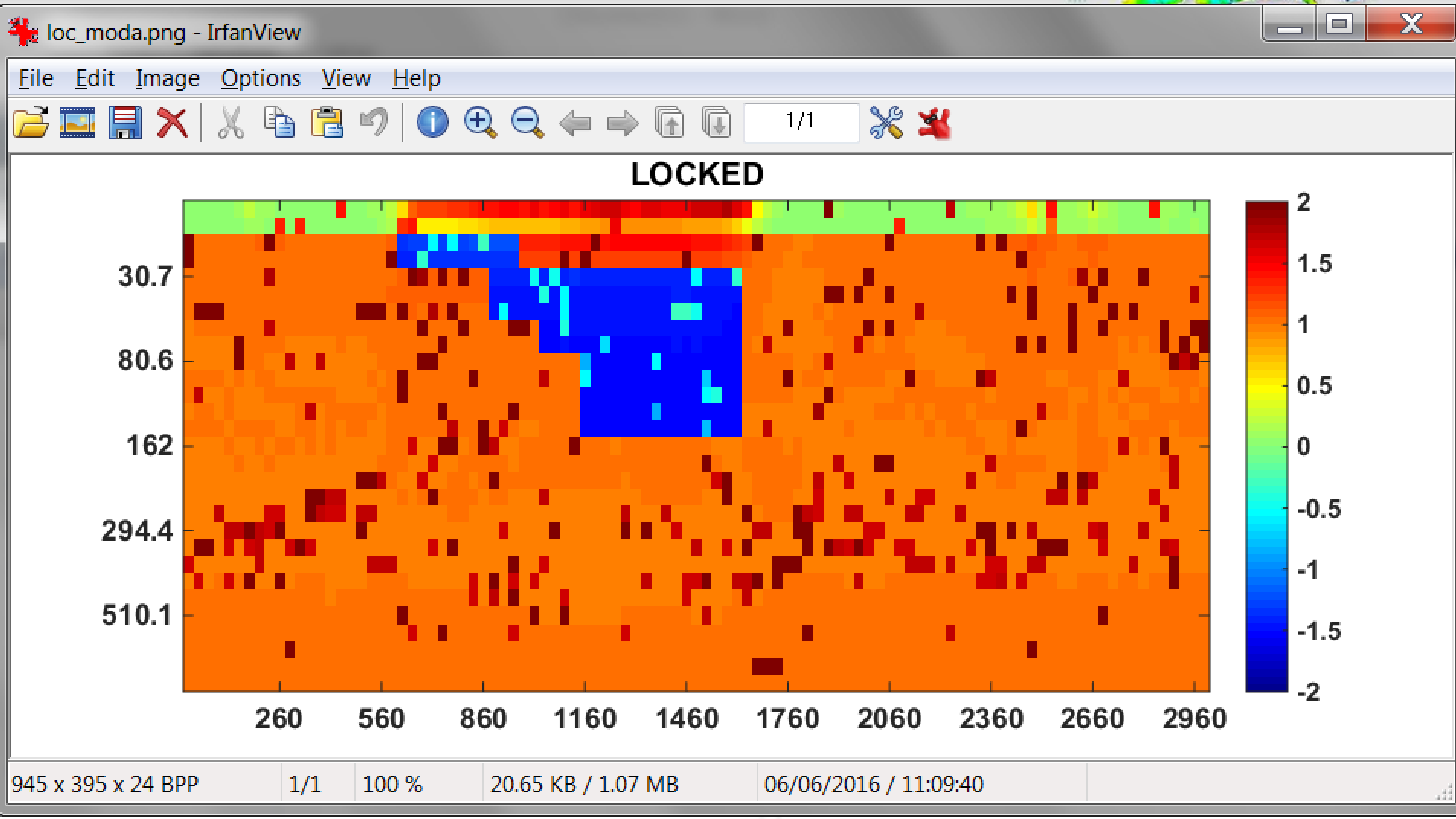
$$Mode\left(\Delta m_{i,j}\right)$$

- Locking c



- Solving for c

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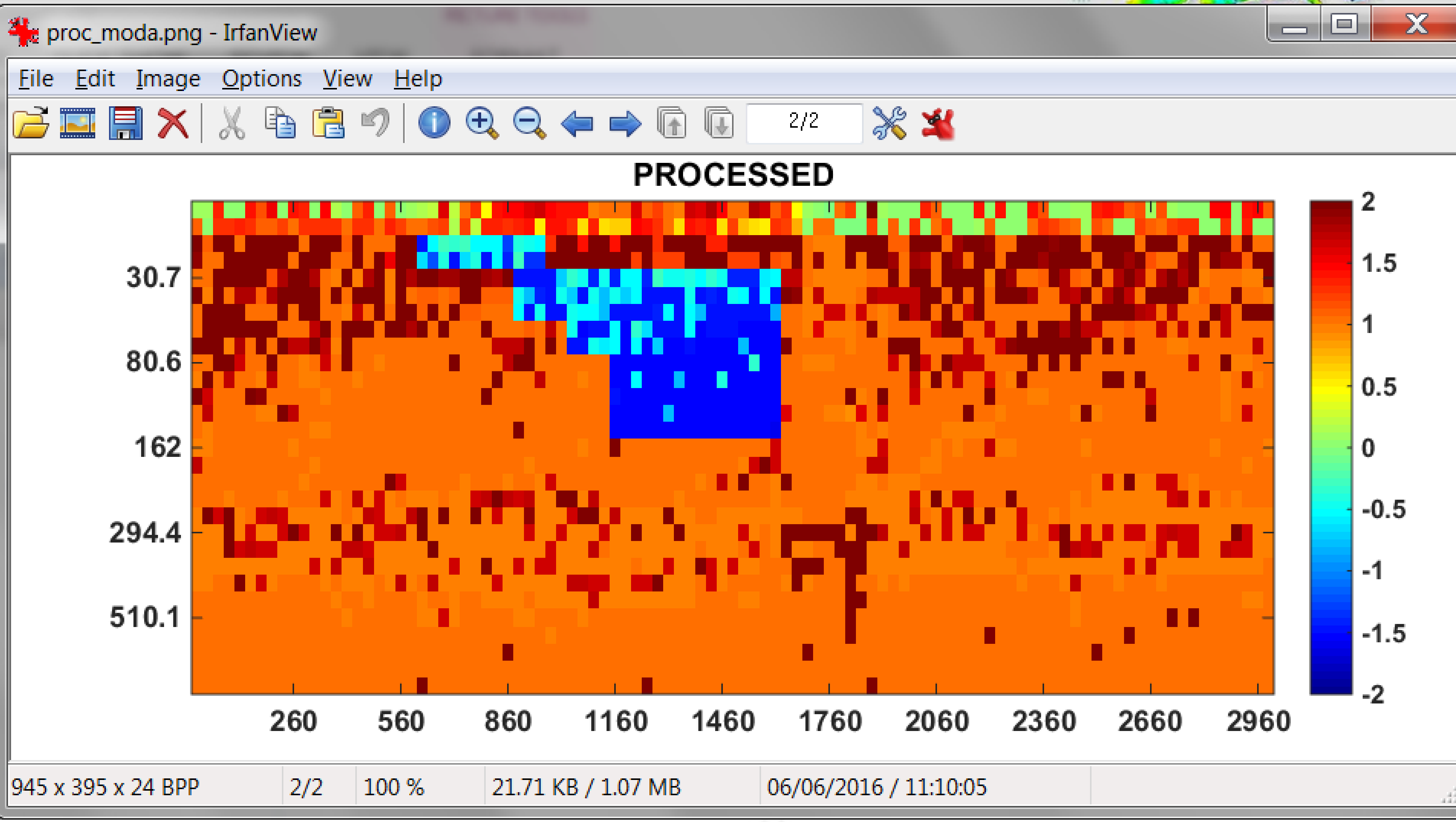
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