Forward Modelling and Inversion for Survey Design

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ASEG Inversion Workshop -Perth 2014

Why do it?

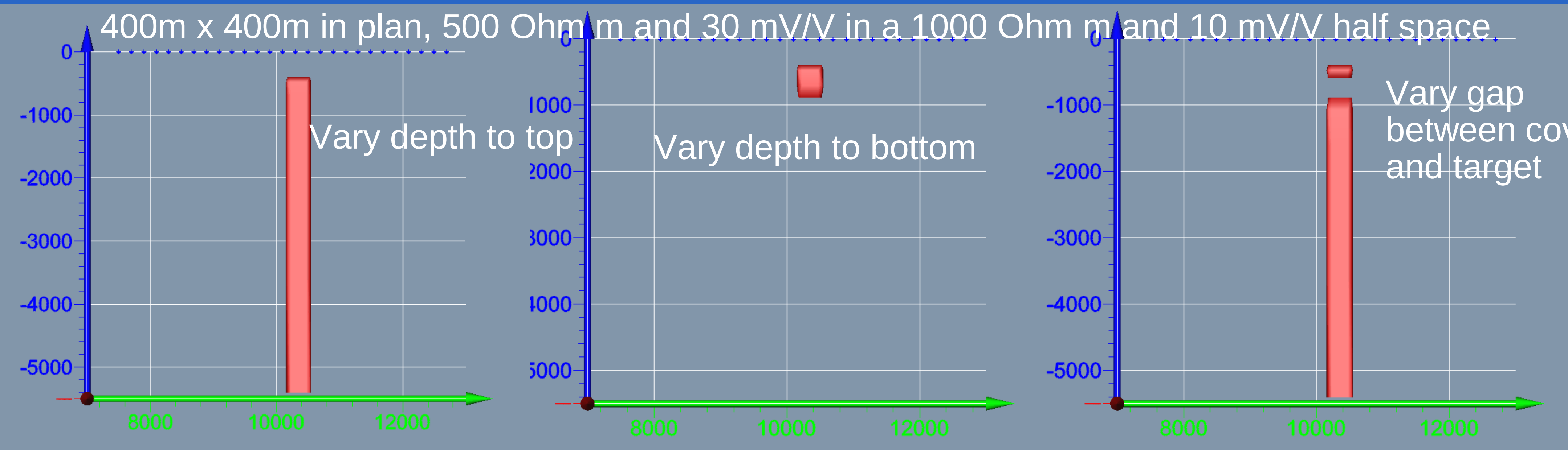
- Modern acquisition systems offer a greater range of options than historically available
- Budgets are tight and users want the maximum bang for their dollars
- Our ability to intuitively interpret data has been surpassed by the computer's ability to massage it. Caveat Emptor!

Case study 1

Array optimisation

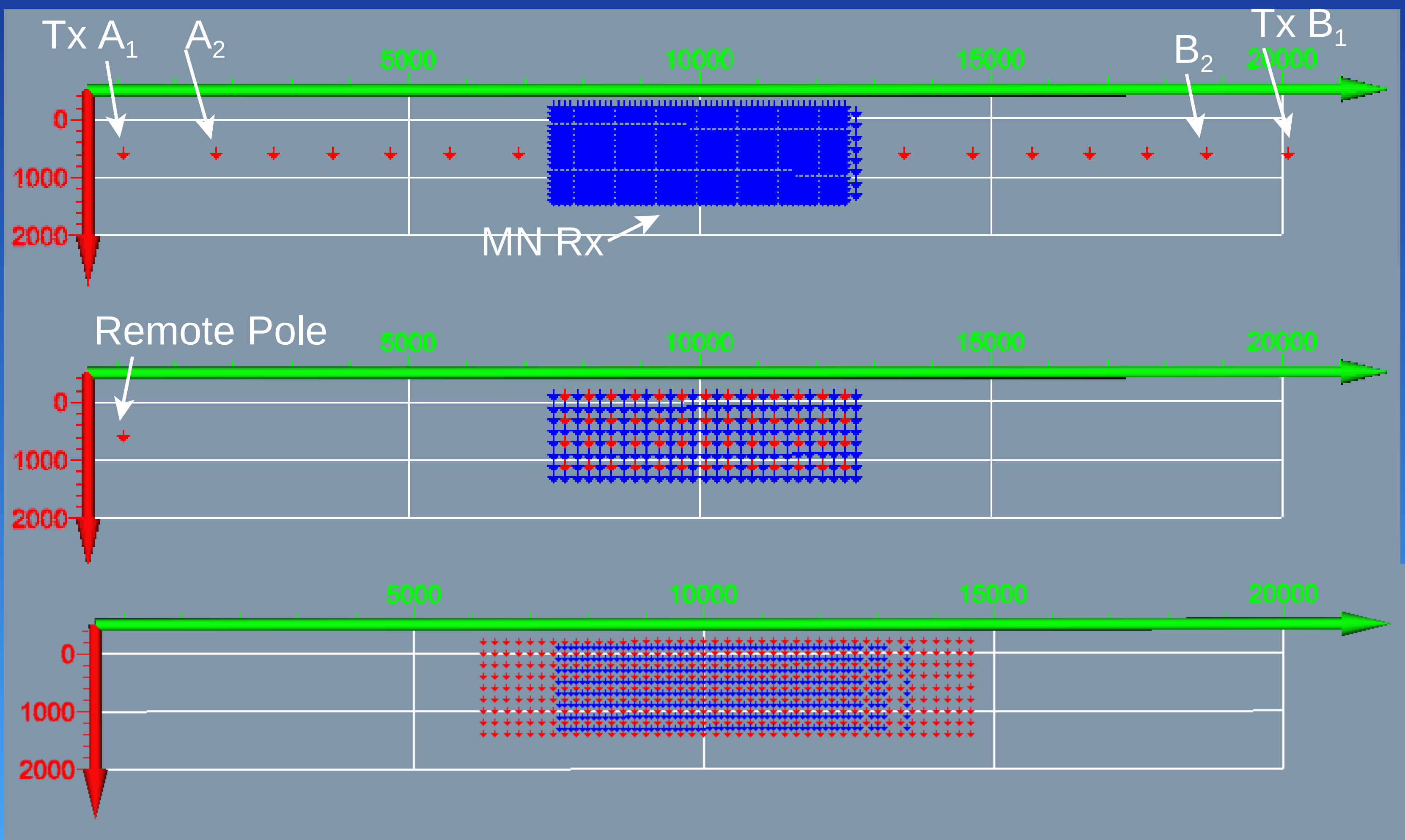
Which IP array will provide the best value for money looking for porphyries in Mongolia?

Use the Mongolian porphyry model from previous paper “How Real is Real Section”



Array Selection

Arrays currently being used to acquire survey data for deep targets



Expanding Gradient Array - "Zeus"

3D Pole-Dipole Array -"Orion"

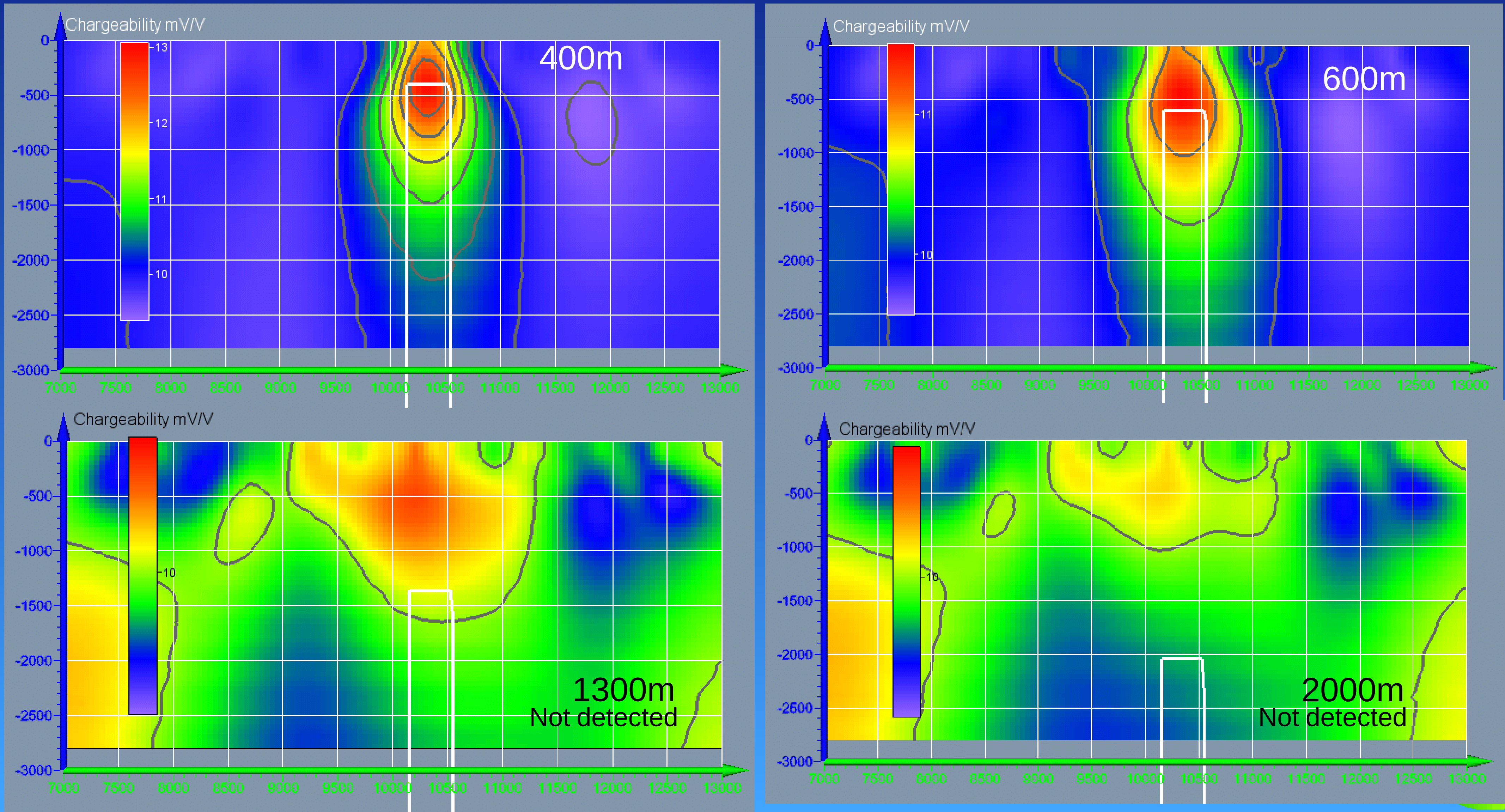
2.5D Offset Dipole-Dipole or Pole-Dipole Array

Vary the depth to top

Expanding Gradient 100m Rx dipoles

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V

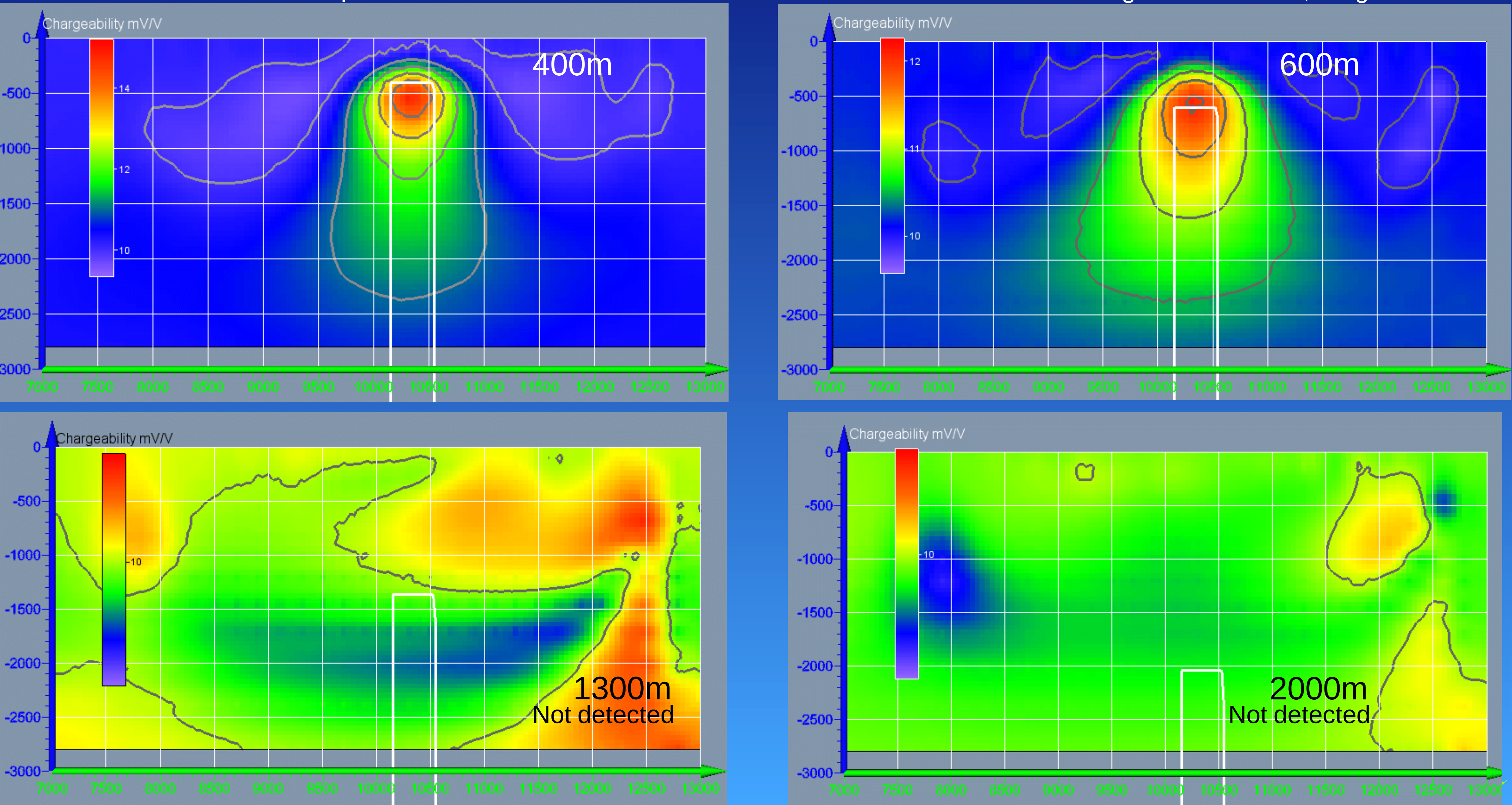


Vary the depth to top

3D Pole-Dipole 200m Rx dipoles

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V

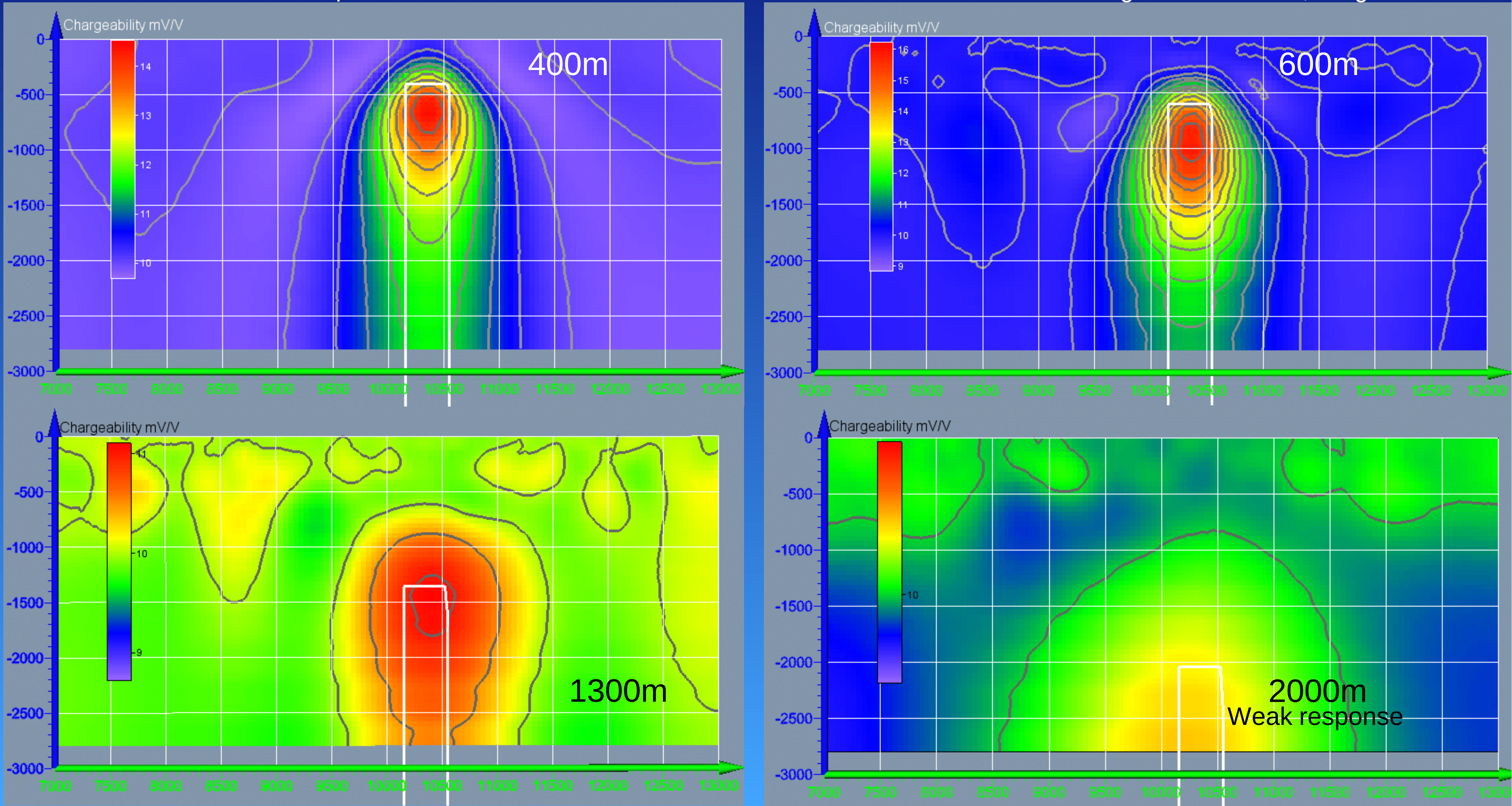


Vary the depth to top

2.5D Offset Dipole-Dipole 100m Rx dipole, 200m Tx dipole

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V

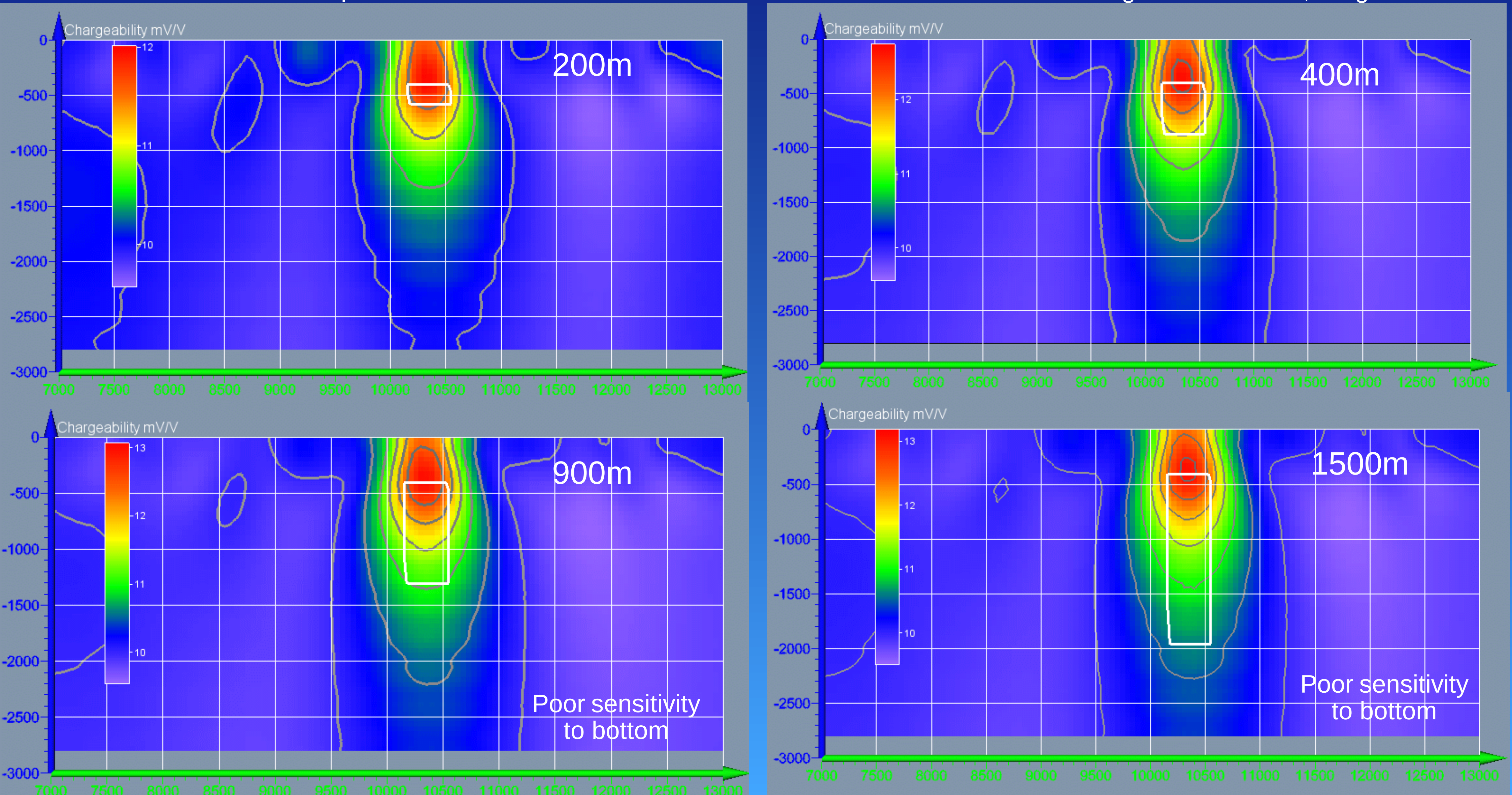


Vary the depth to bottom

Expanding Gradient 100m Rx dipoles

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V

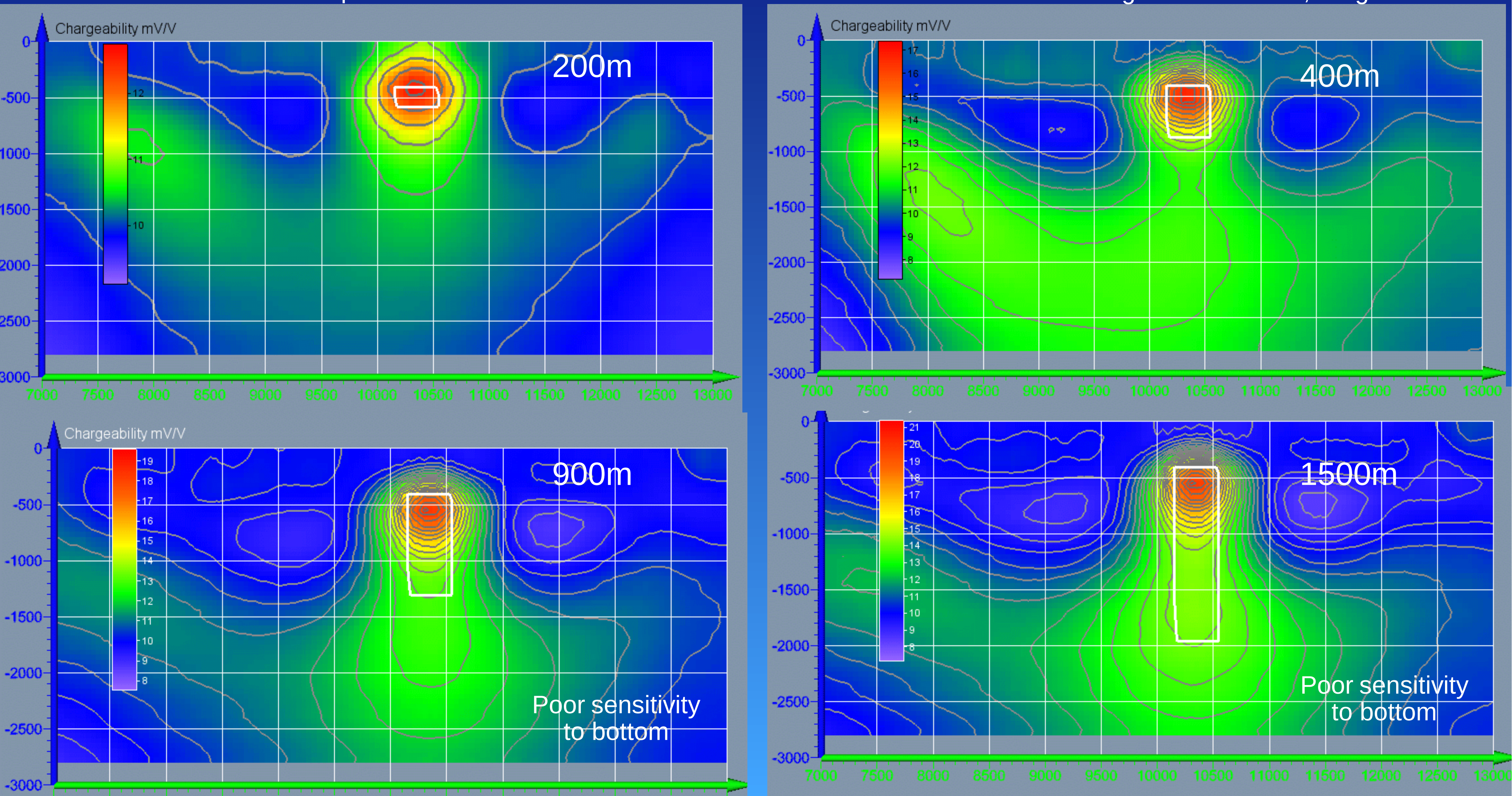


Vary the depth to bottom

3D Pole-Dipole 200m Rx dipoles

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V

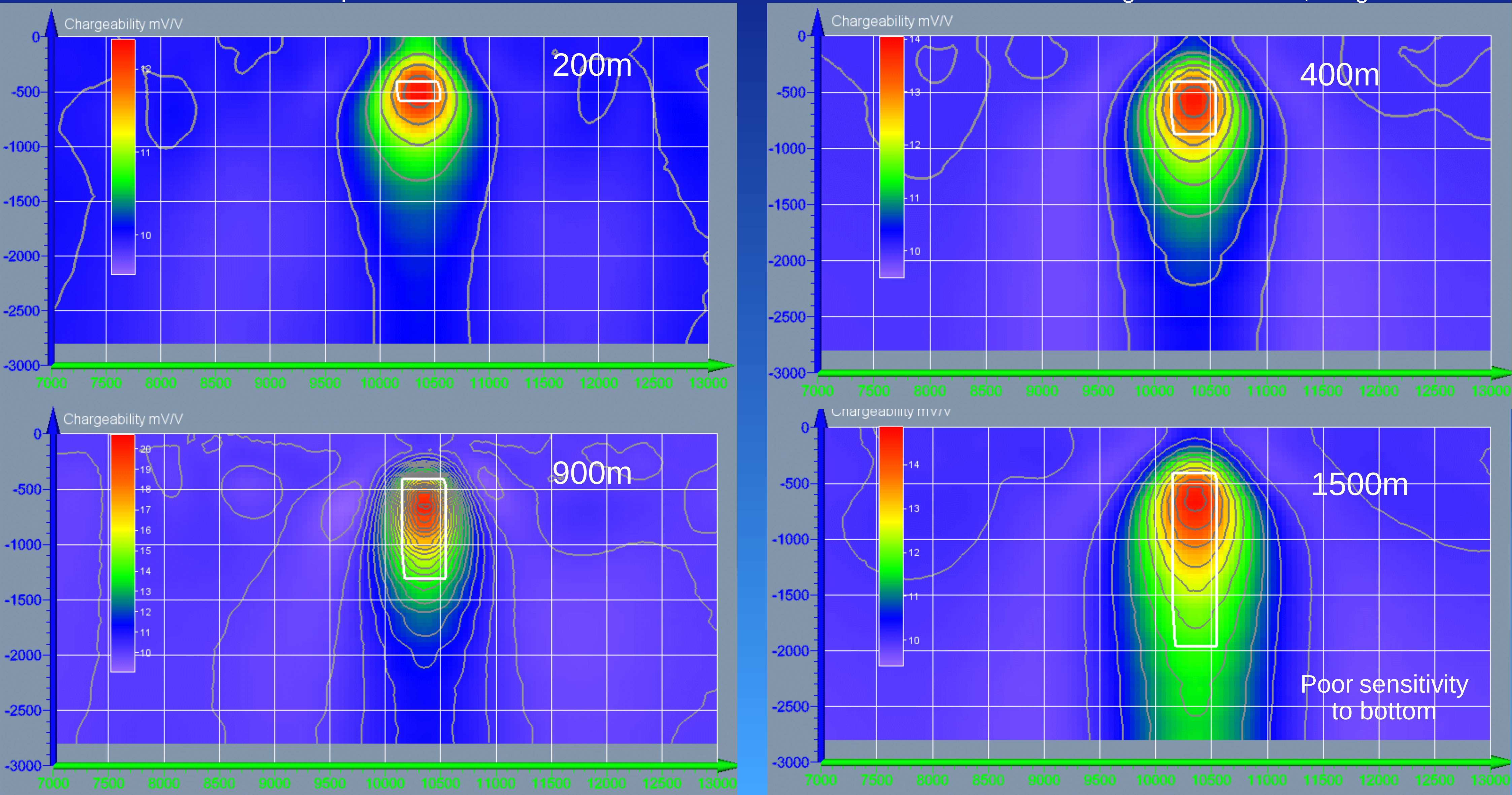


Vary the depth to bottom

2.5D Offset Dipole-Dipole 100m Rx dipole, 200m Tx dipole

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V

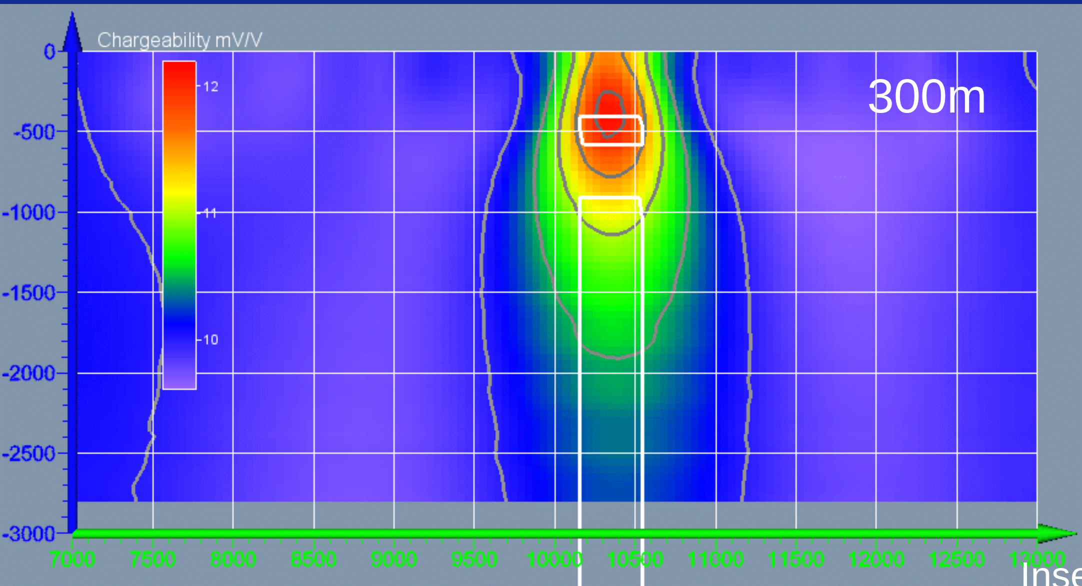


Vary the distance below a screen

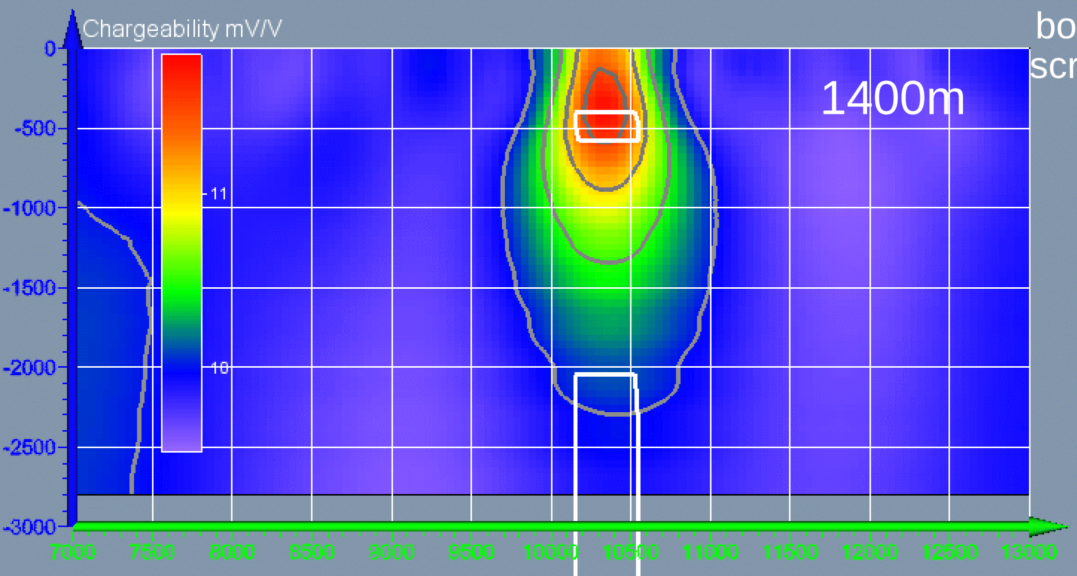
Expanding Gradient 100m Rx dipoles

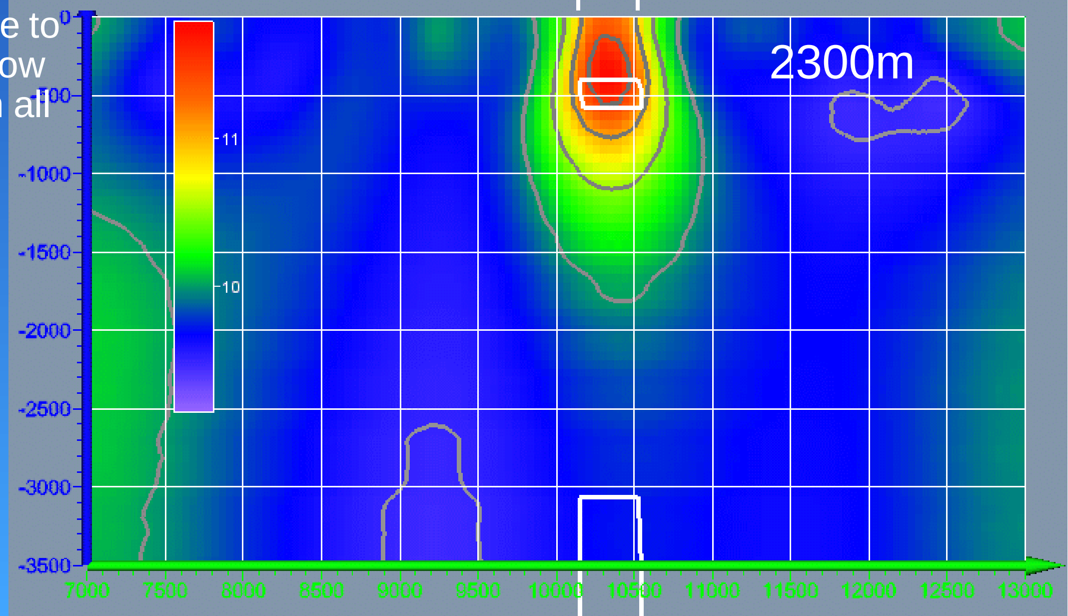
Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V



Insensitive to body below screen in all cases



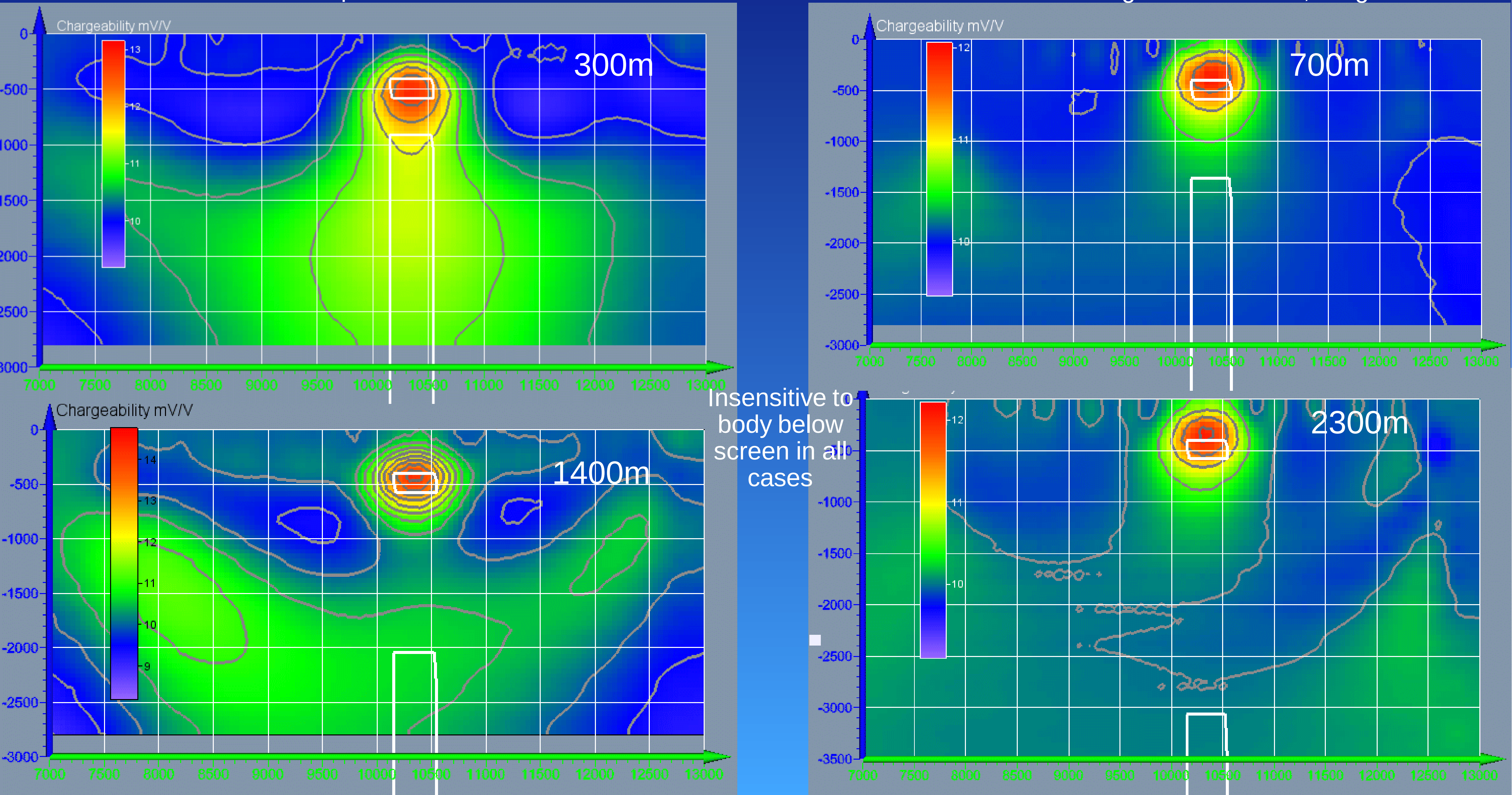


Vary the distance below a screen

3D Pole-Dipole 200m Rx dipoles

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V

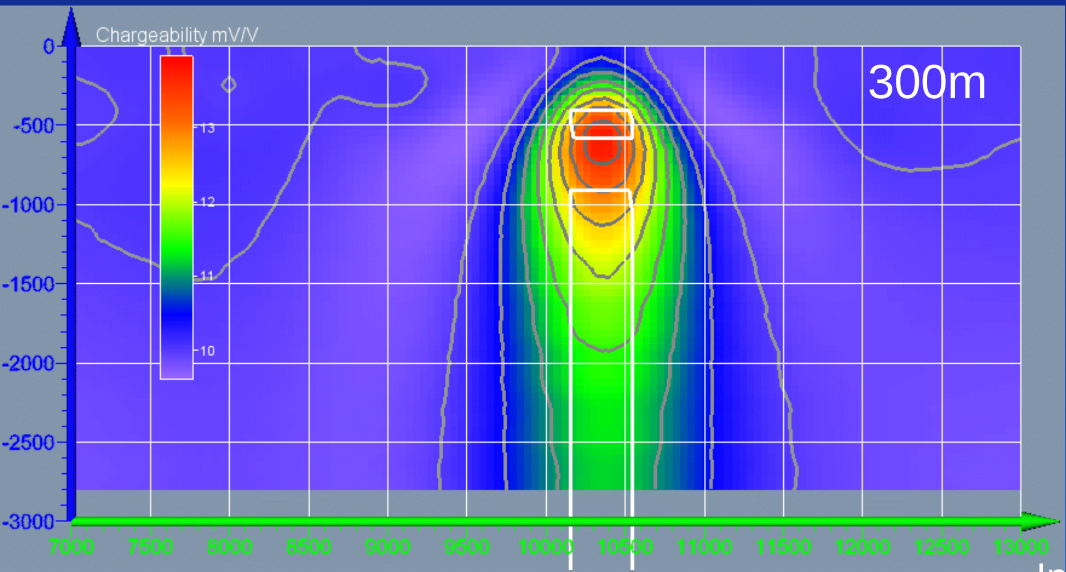


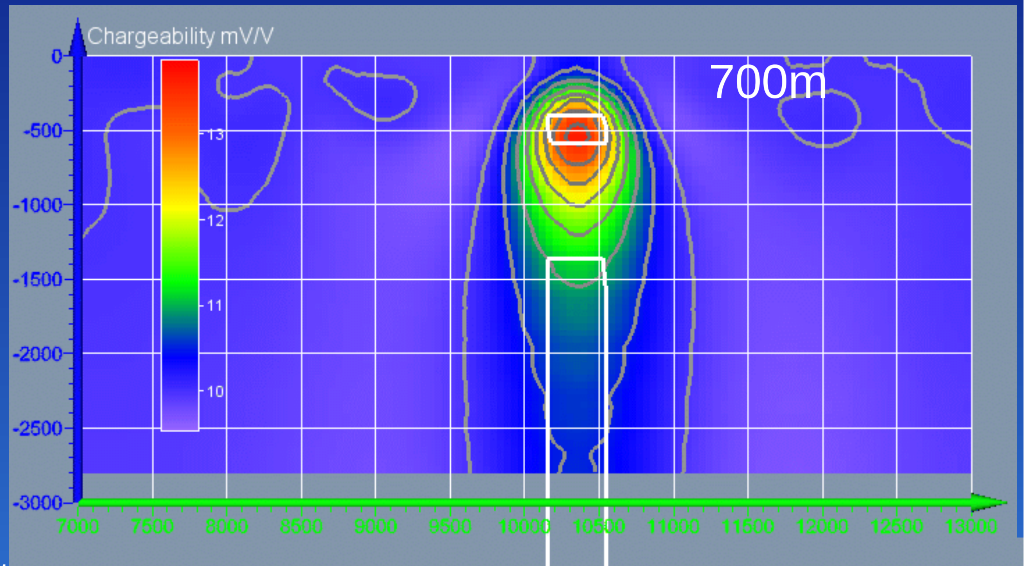
Vary the distance below a screen

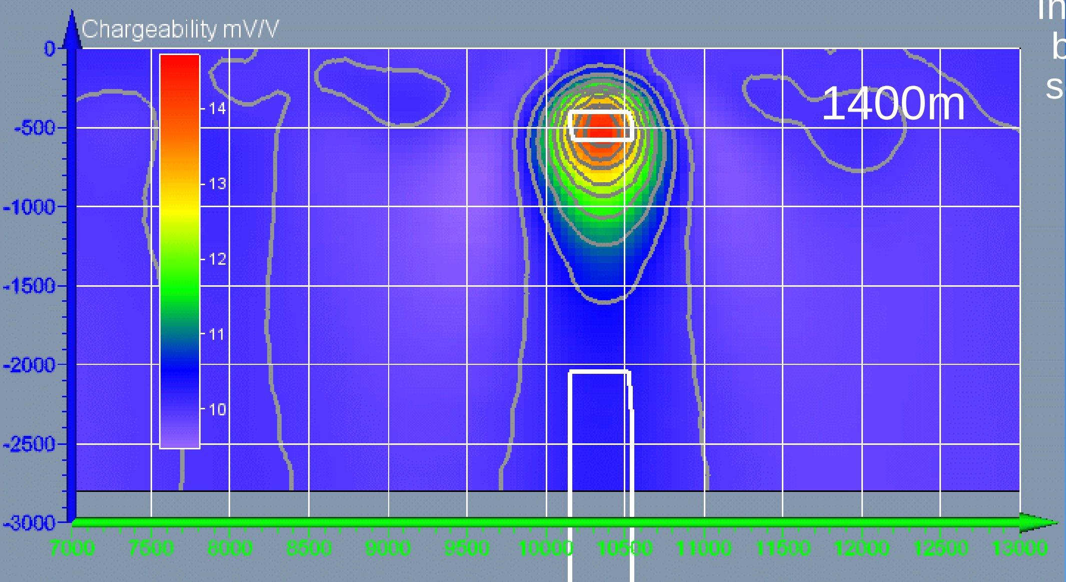
2.5D Offset Dipole-Dipole 100m Rx dipole, 200m Tx dipole

Colour scale varies between plots

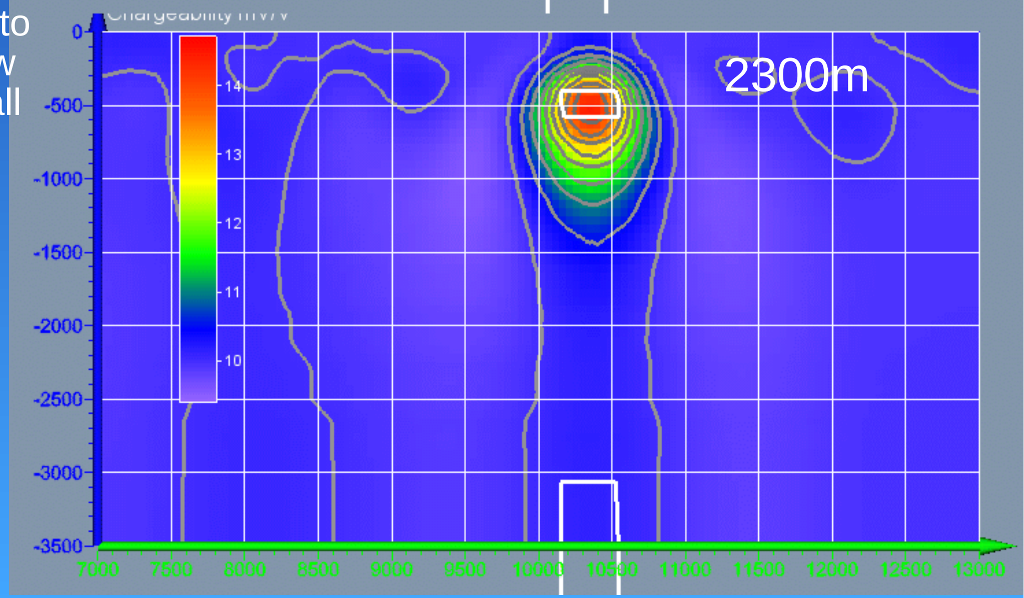
Background 10 mV/V, Target 30 mV/V







Insensitive to body below screen in all cases

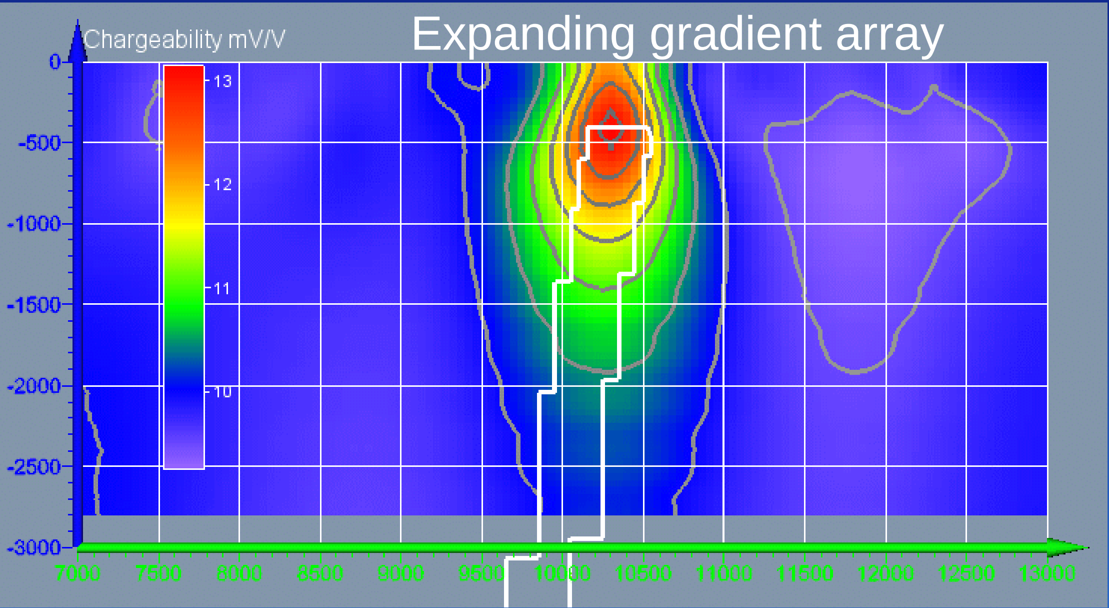


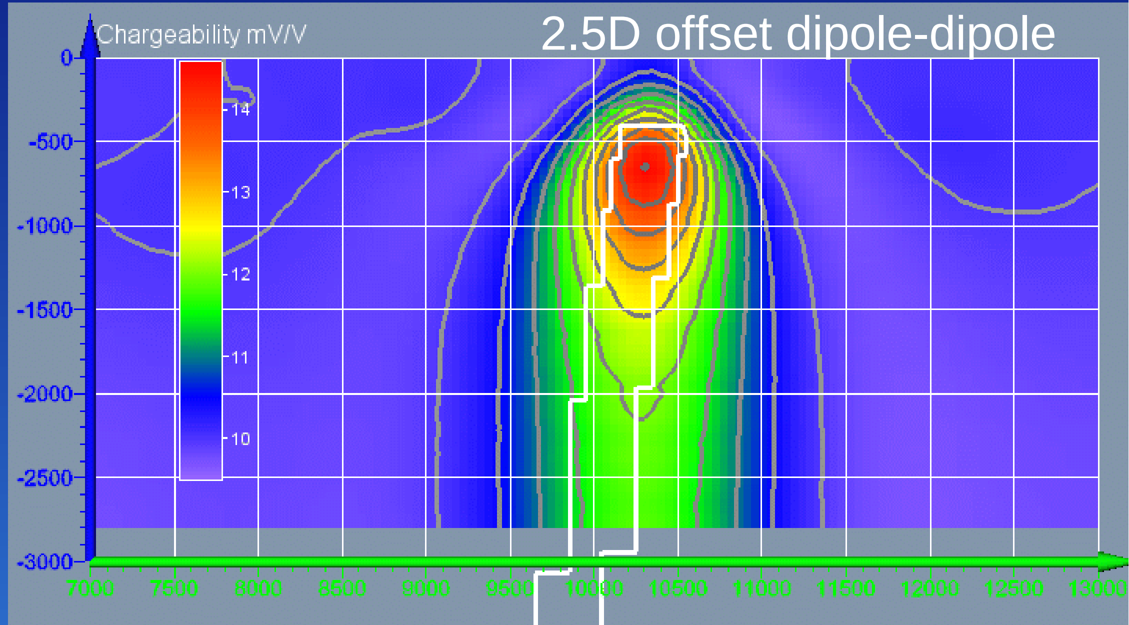
Mapping dip

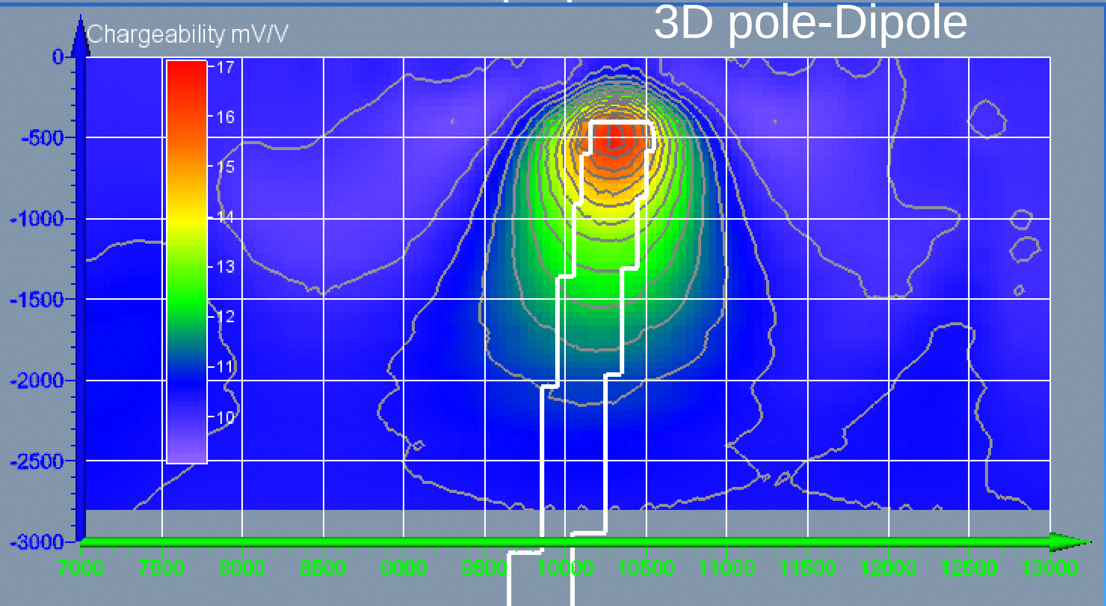
Body dips to the left

Colour scale varies between plots

Background 10 mV/V, Target 30 mV/V







All arrays are insensative to dip

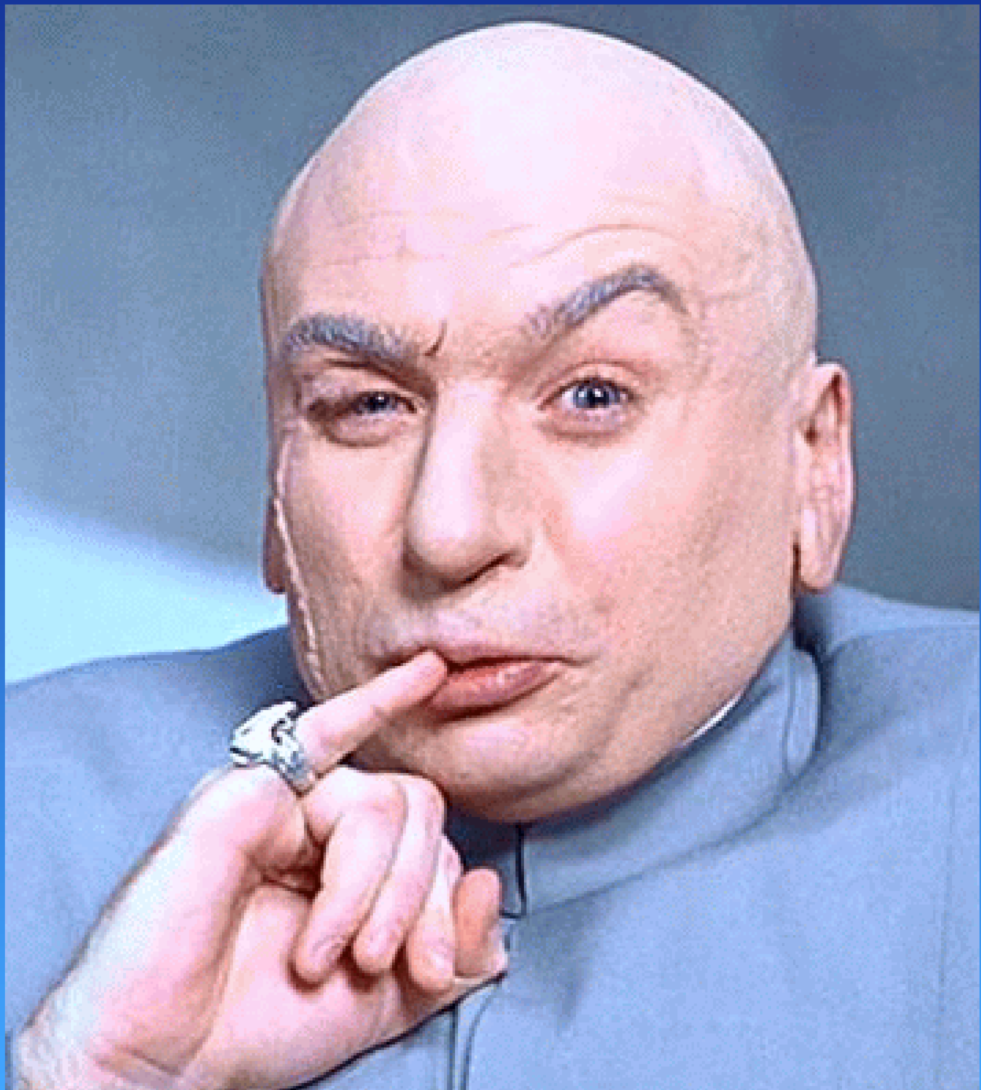
Conclusions

- Even using 20km current dipoles the gradient array is only seeing the top of the body and then only to <1300m - MN is overriding AB
- Using a 10km current dipole the 3D pole-dipole array is seeing the upper part of the body but not seeing to 1300m - MN is overriding AB
- None of the arrays do a good job of seeing a target below a screen
- None of the arrays do a good job of mapping dip at depth


WHY?

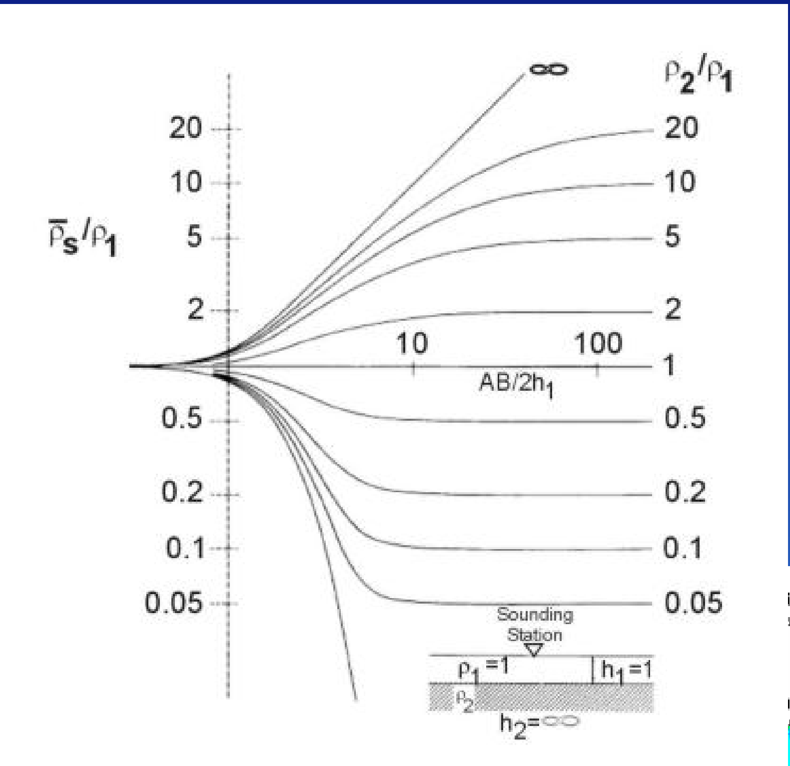
Sensitivity

See appendix - Sensitivity changes with electrode spacing



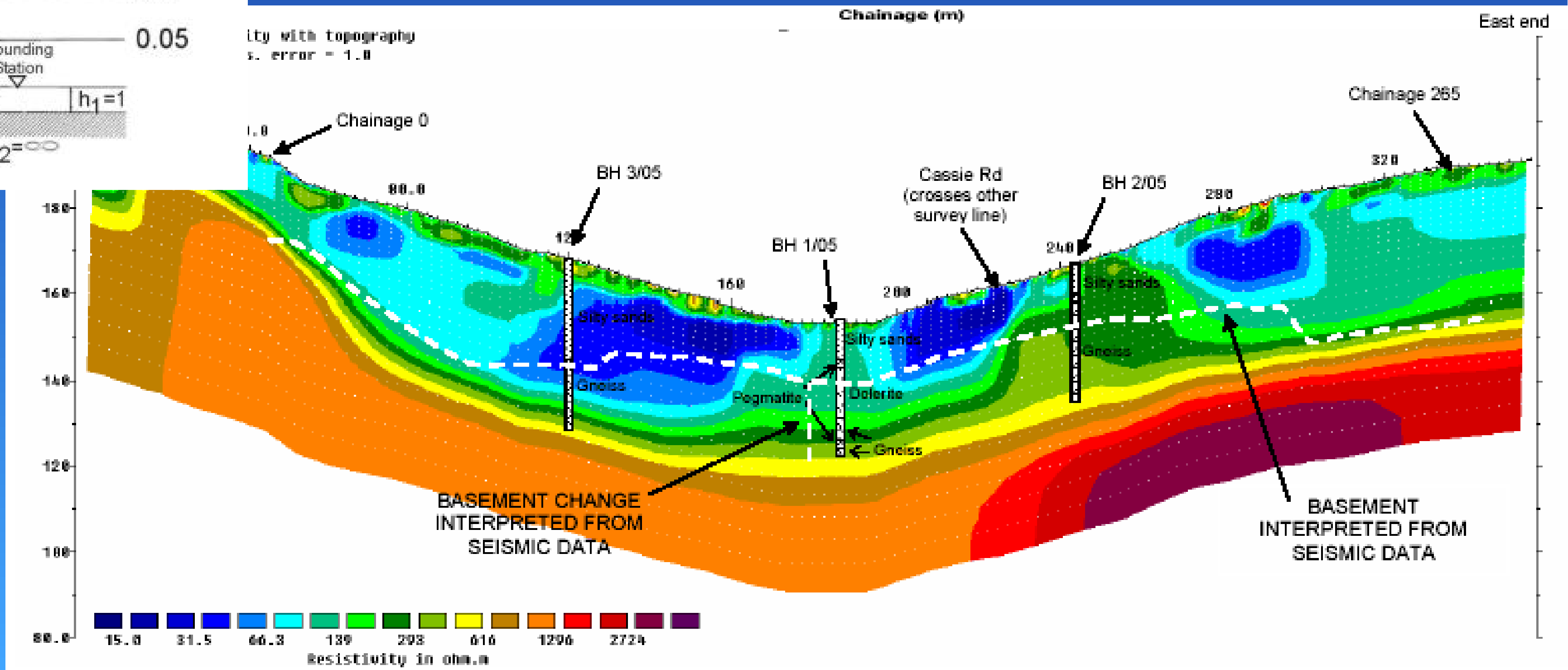
How can we use this to our advantage? - See appendix.

1D resistivity profiling to ERI



The near surface geophysicists have gone from simple 1D soundings to electrical tomography by using multi-resolution arrays with varying MN, AB and n.

From 10 readings to 10,000 over the same site

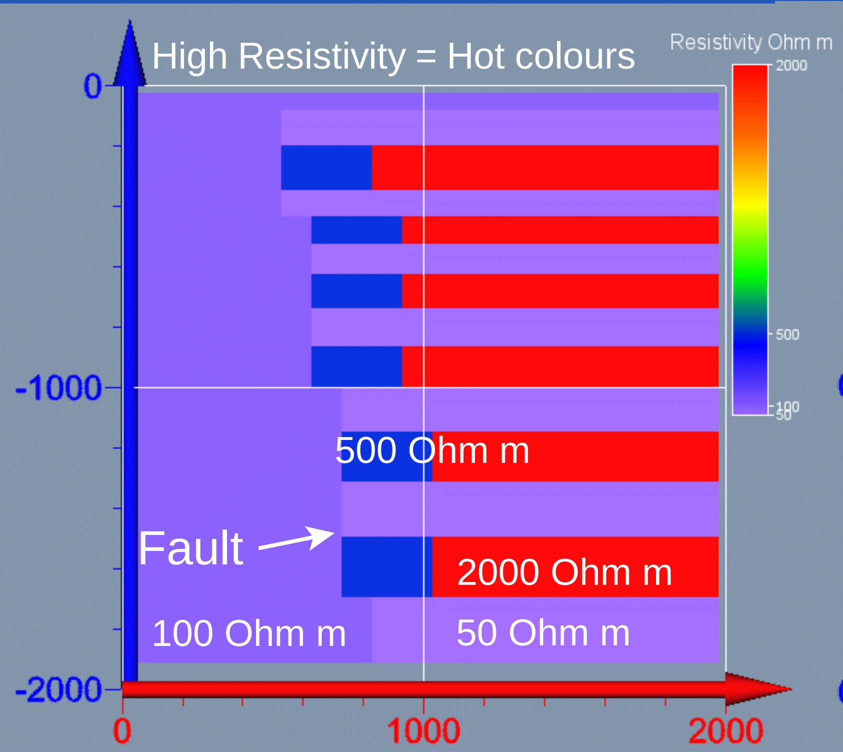


Case Study 2

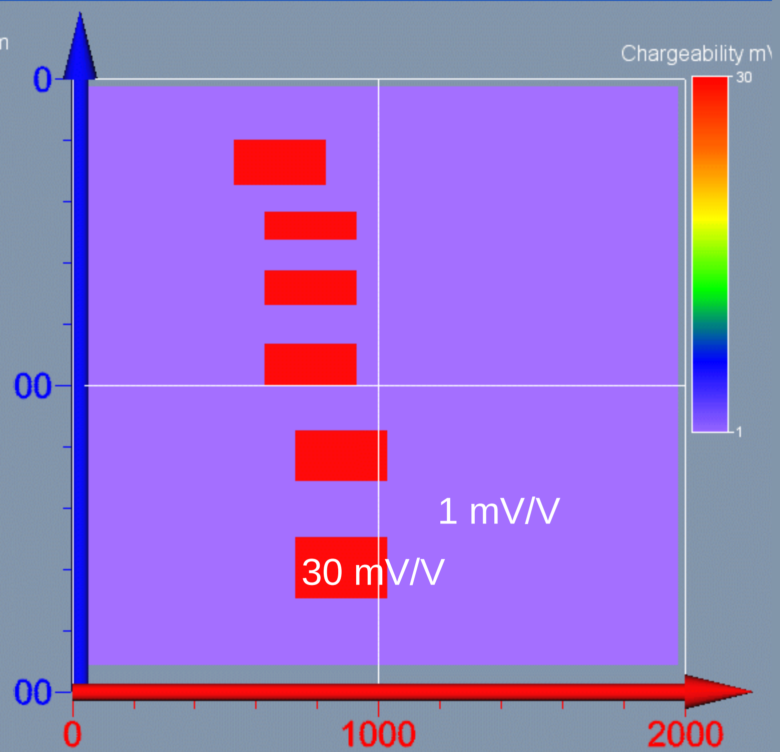
Array selection

Manto style mineralisation

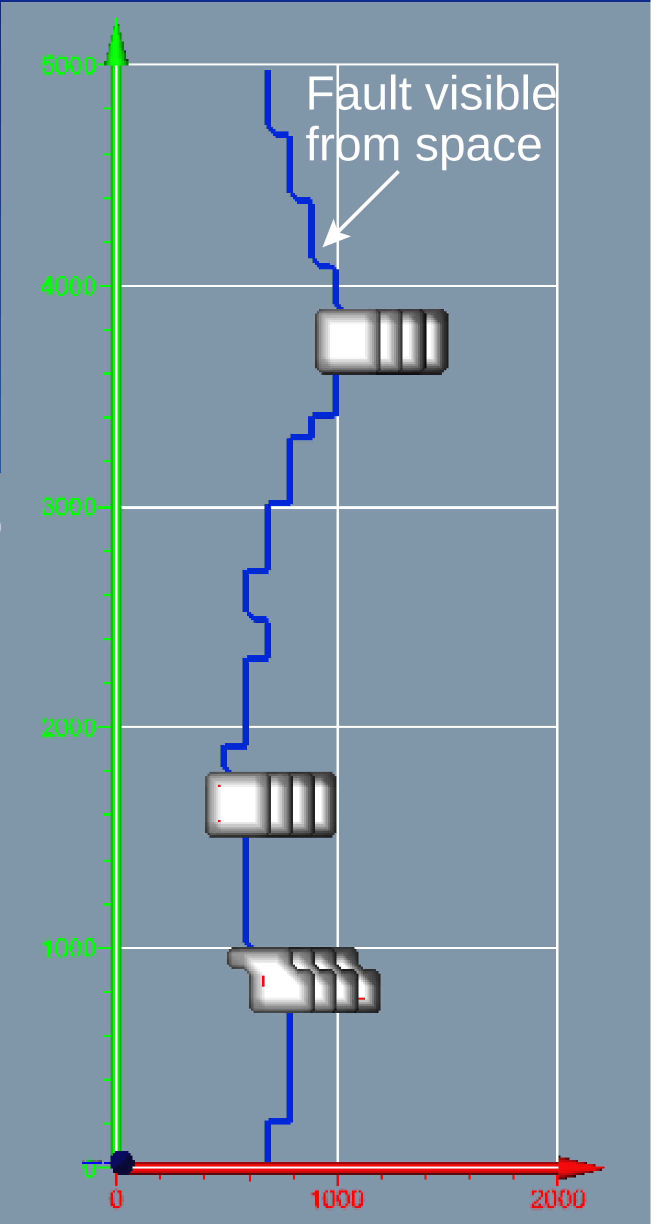
Resistivity section



Chargeability section



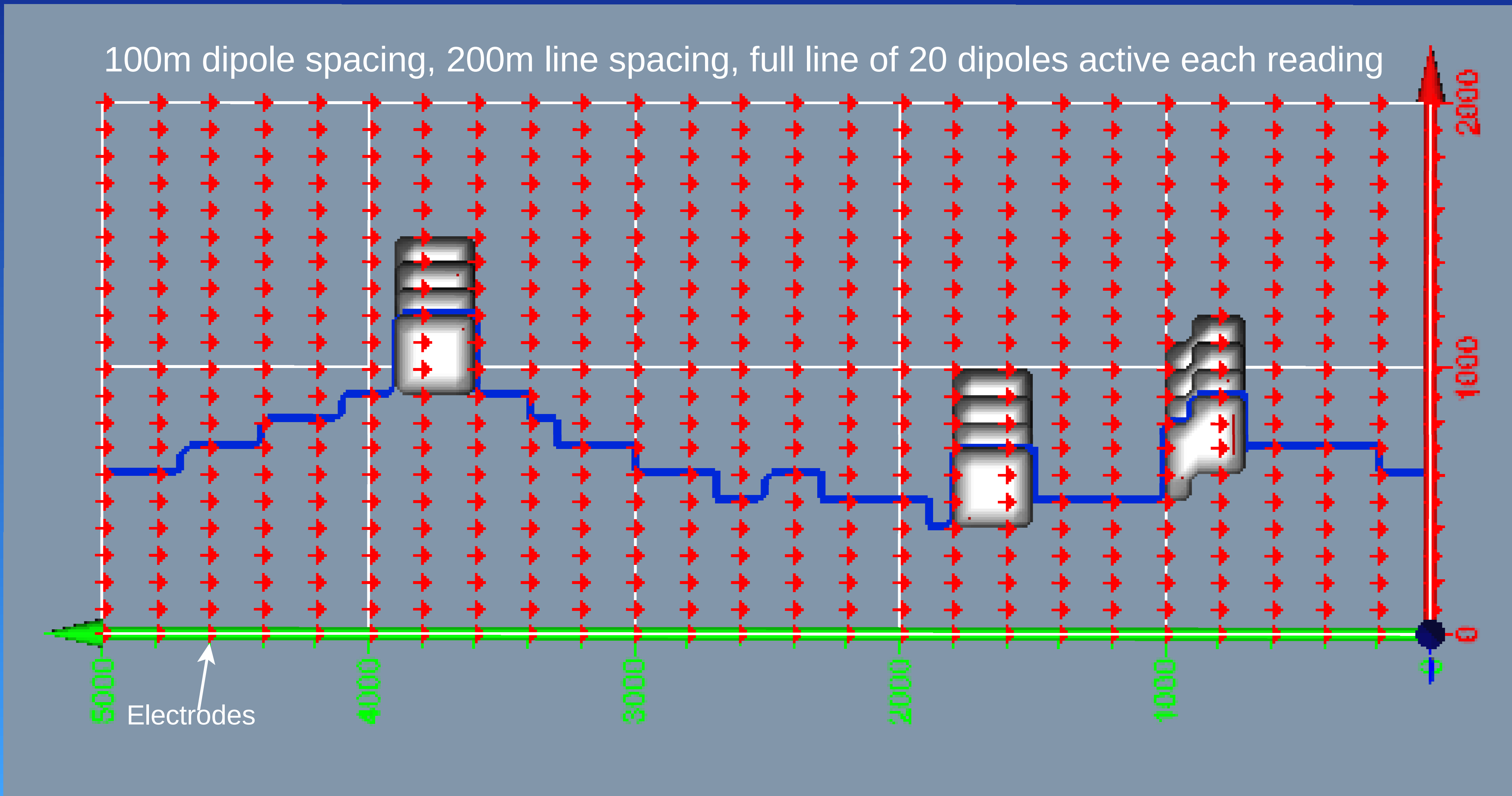
Chargeability Plan



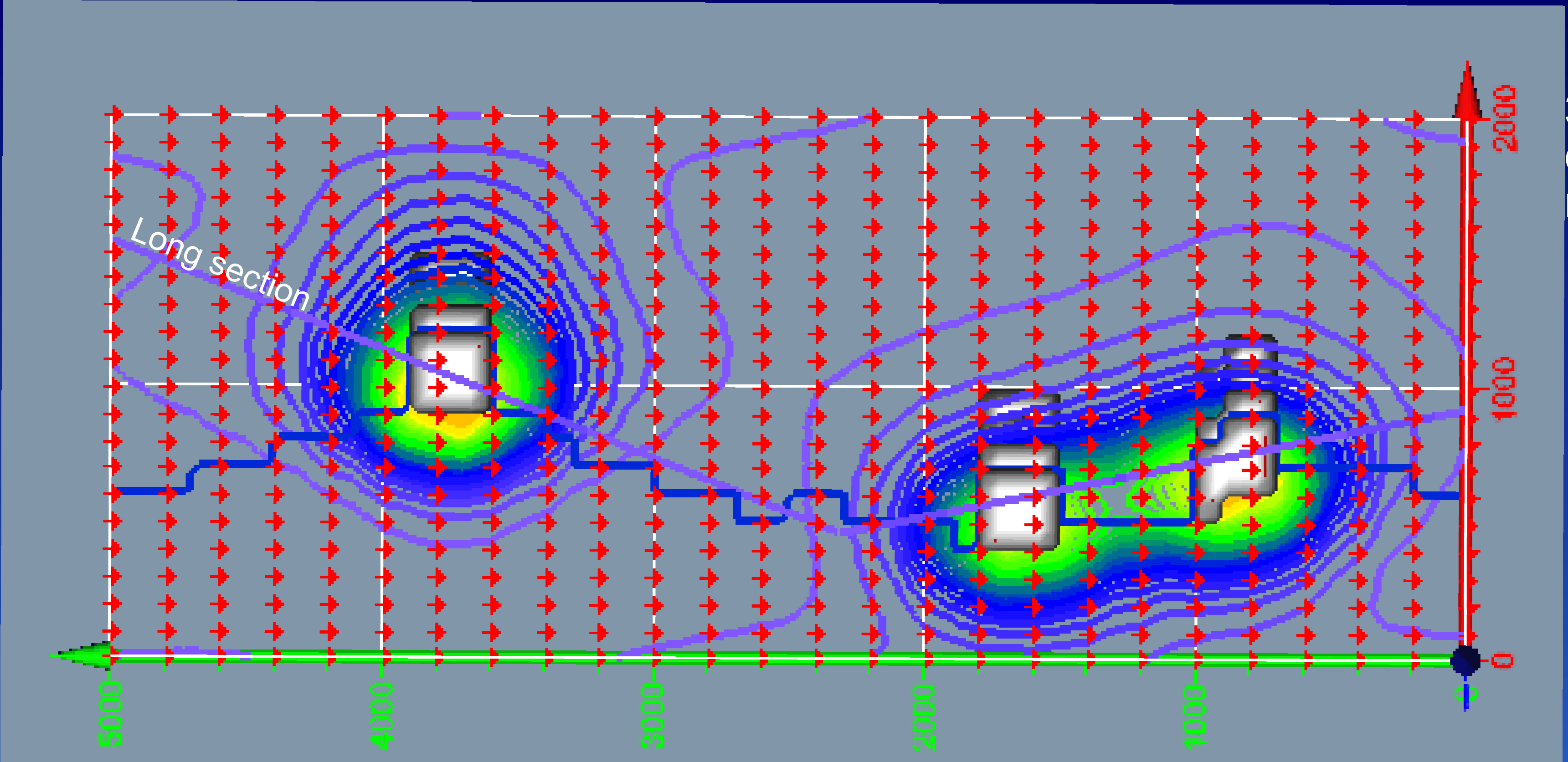
Old Style Contractor's Premium Selection

2D DIPOLE-DIPOLE

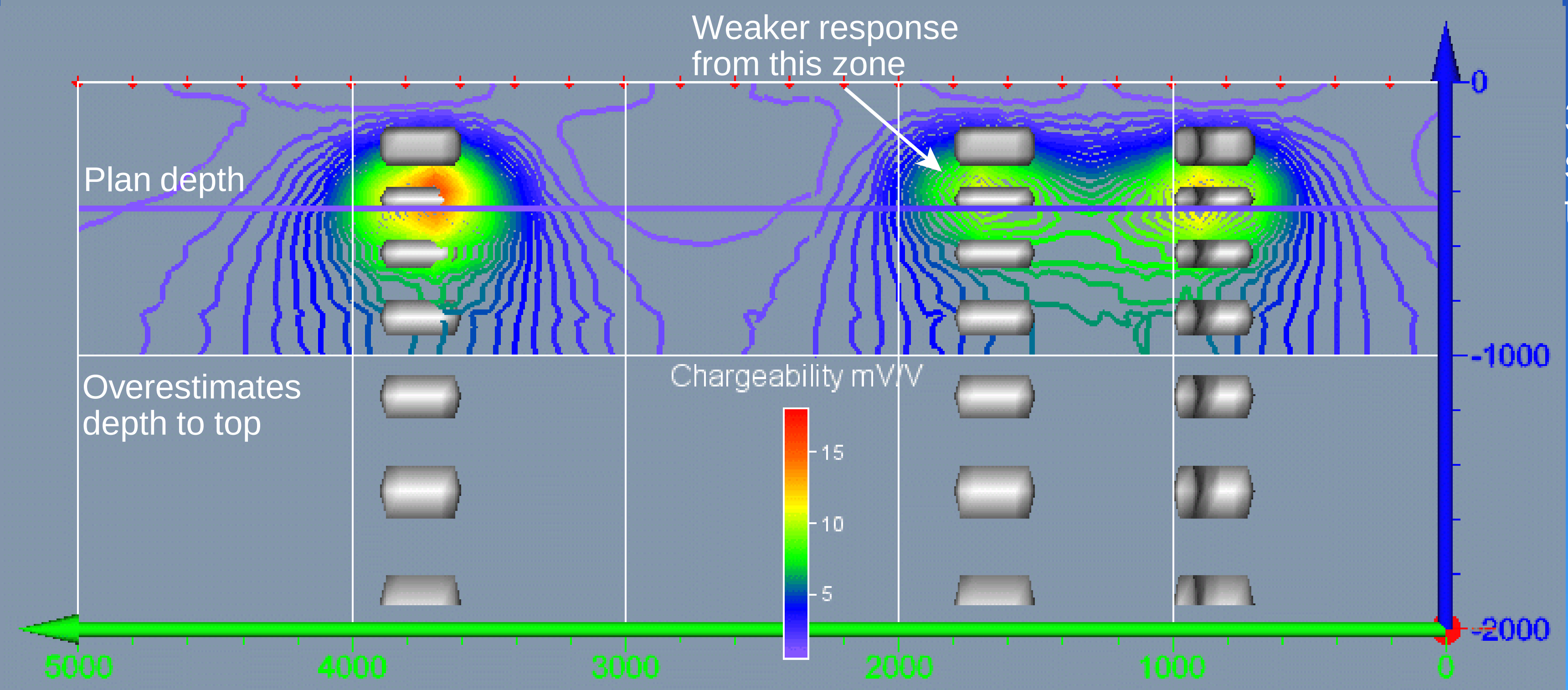
Line spacing matches target size



3D inversion - Plan view of contour slice through maximum response



3D inversion - Bent long section view of contours through body centres

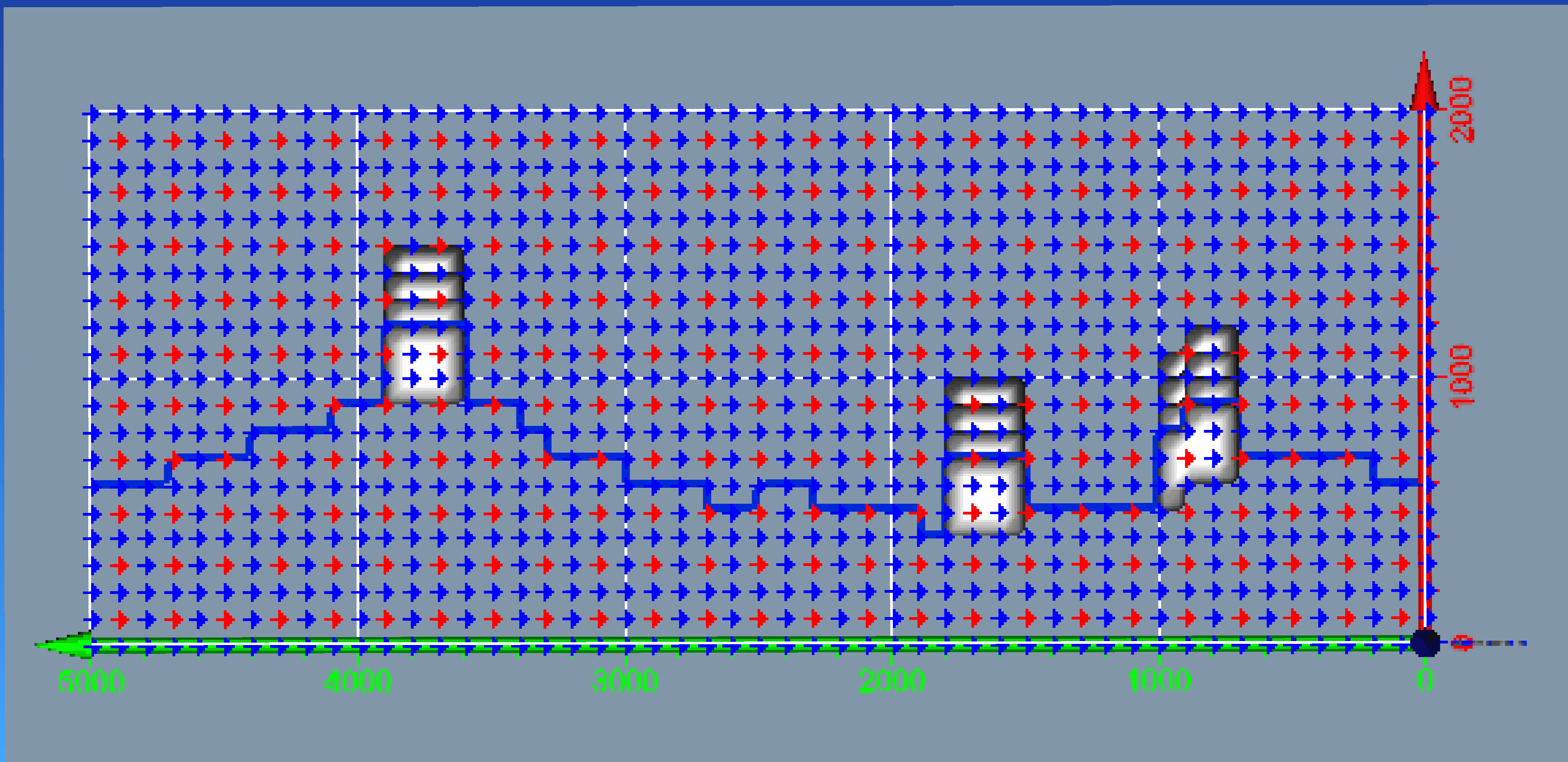


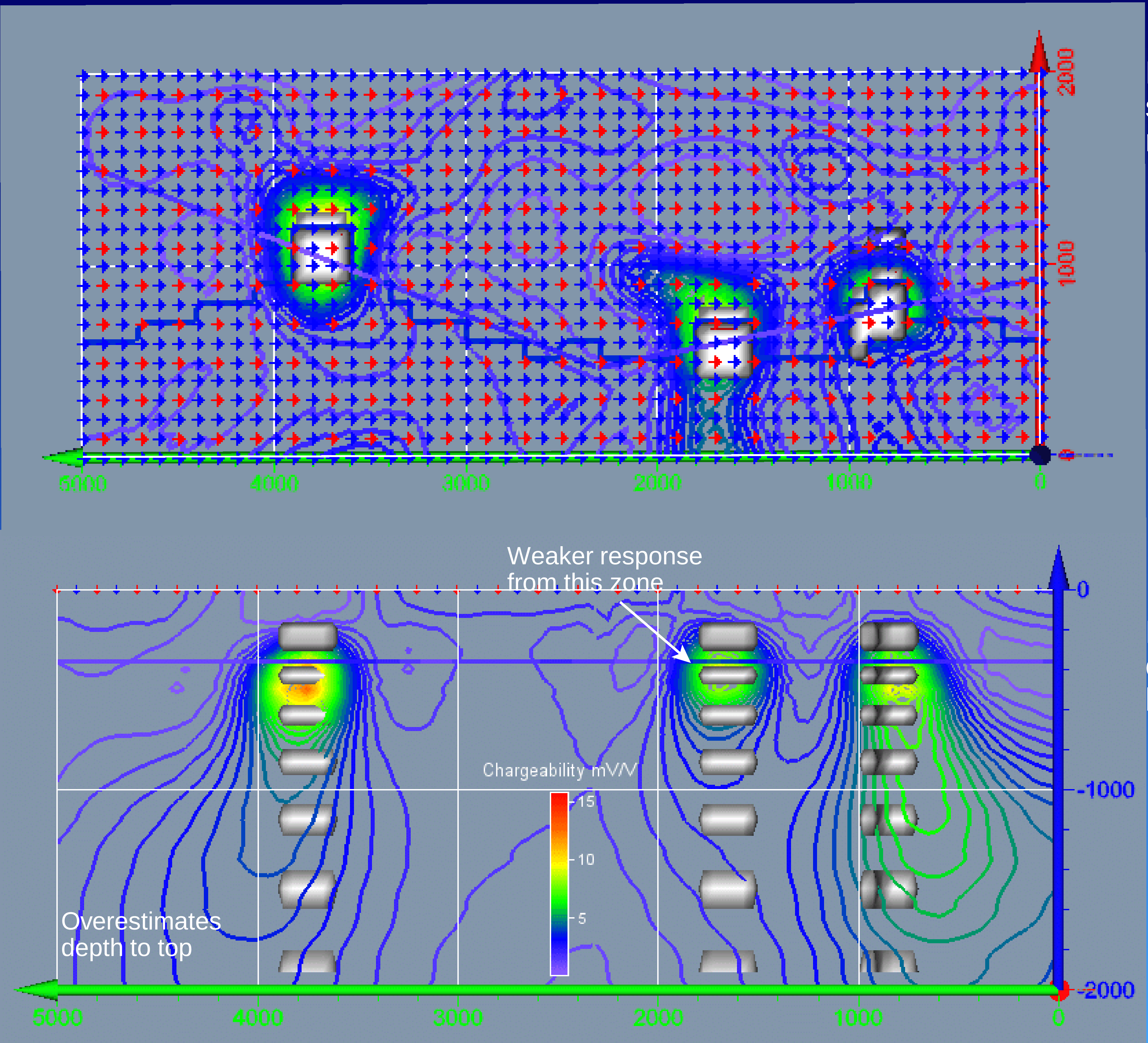
New Style Contractor's Premium Selection

3D POLE-DIPOLE

Arguably too small a dipole size for this target

100m dipole spacing, 200m line spacing, full array of 1000 dipoles active each reading





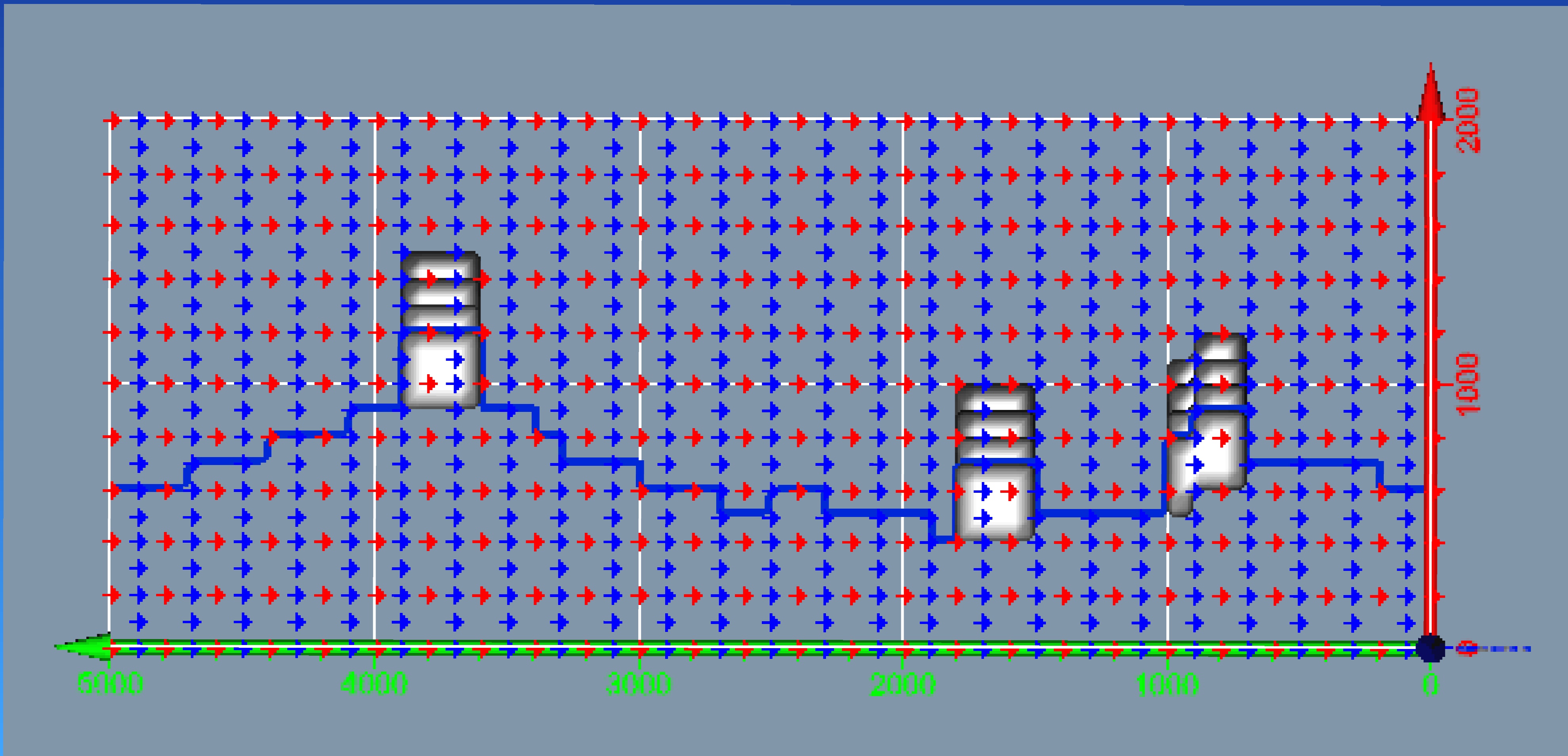
Plan view of contour slice through maximum response

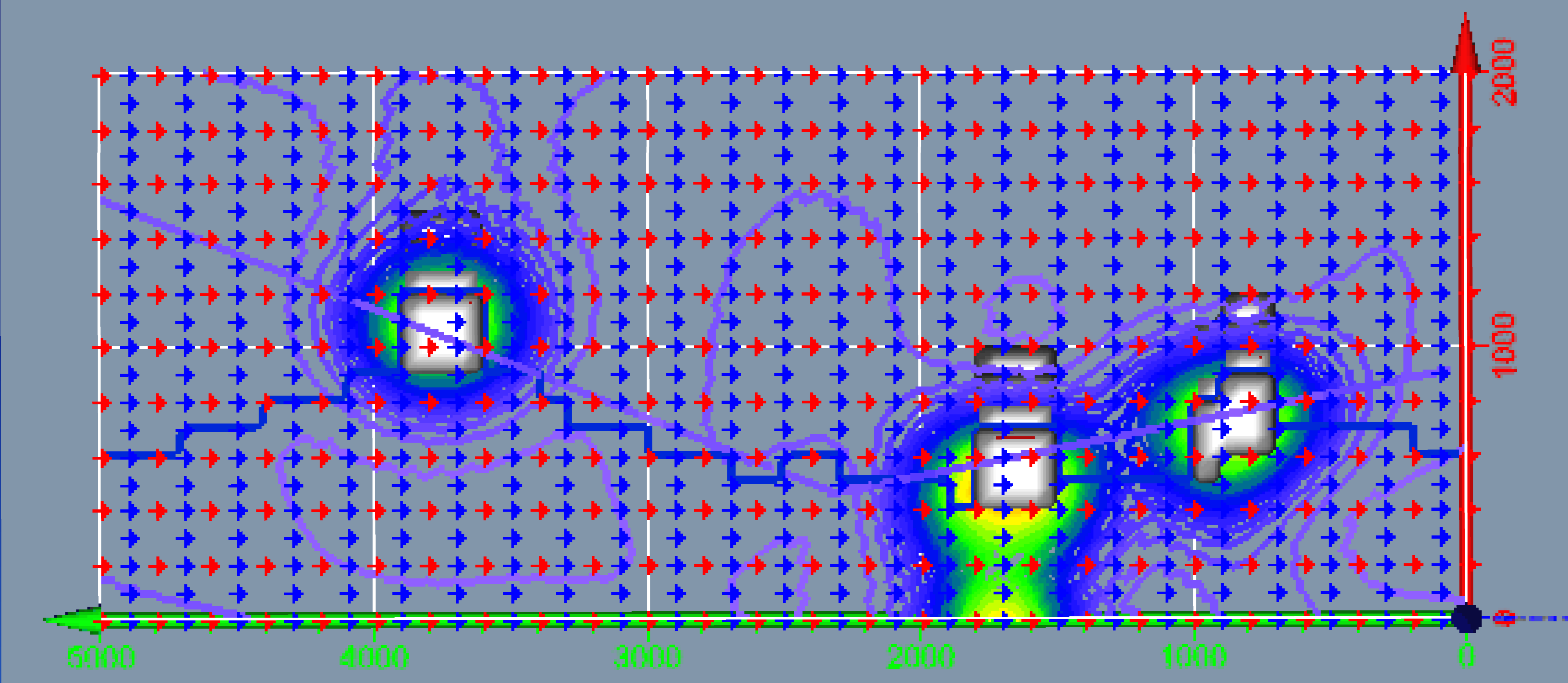
Bent long section view of contours through body centres

Consultant's Premium Selection

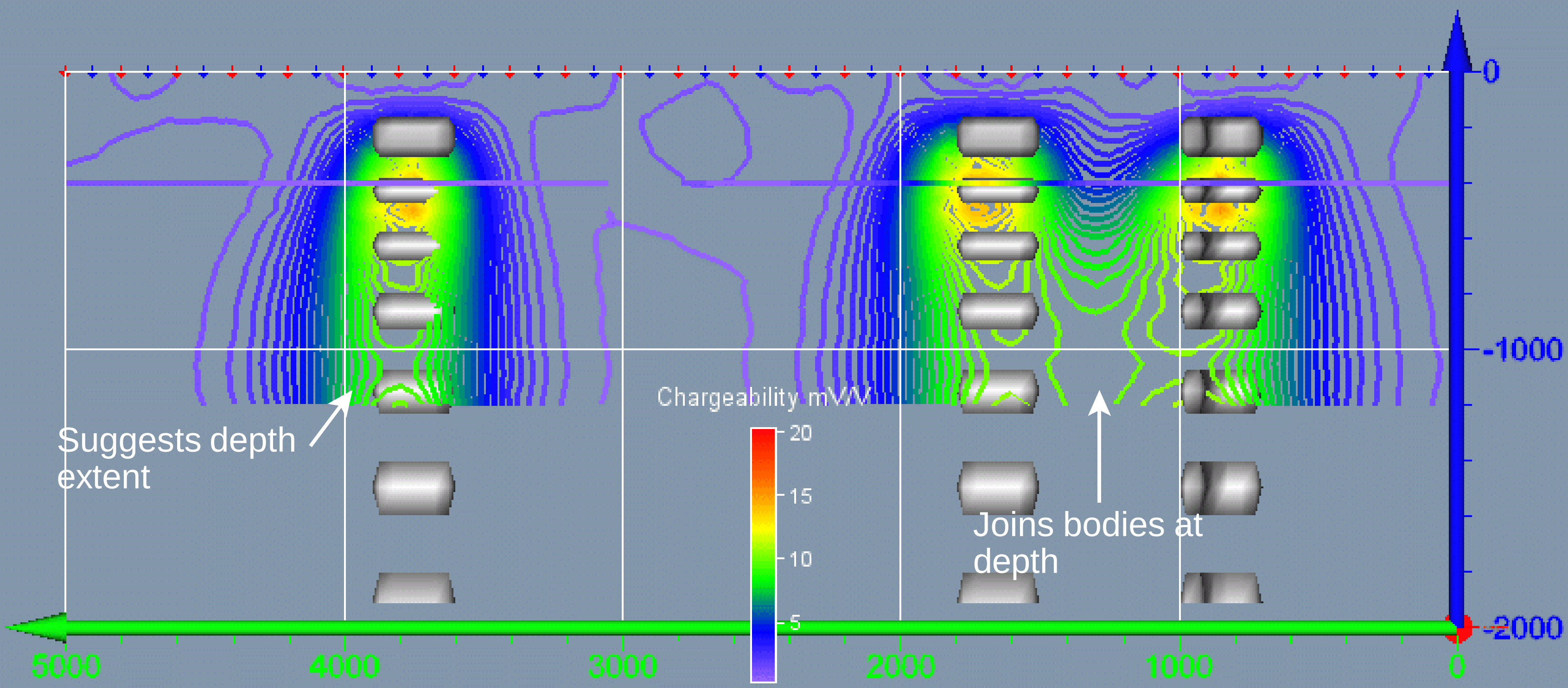
2.5D QUAD OFFSET DIPOLE-DIPOLE

100m dipole spacing, 200m line spacing, 4 lines of 20 electrodes active each reading





Plan view of contour slice through maximum response

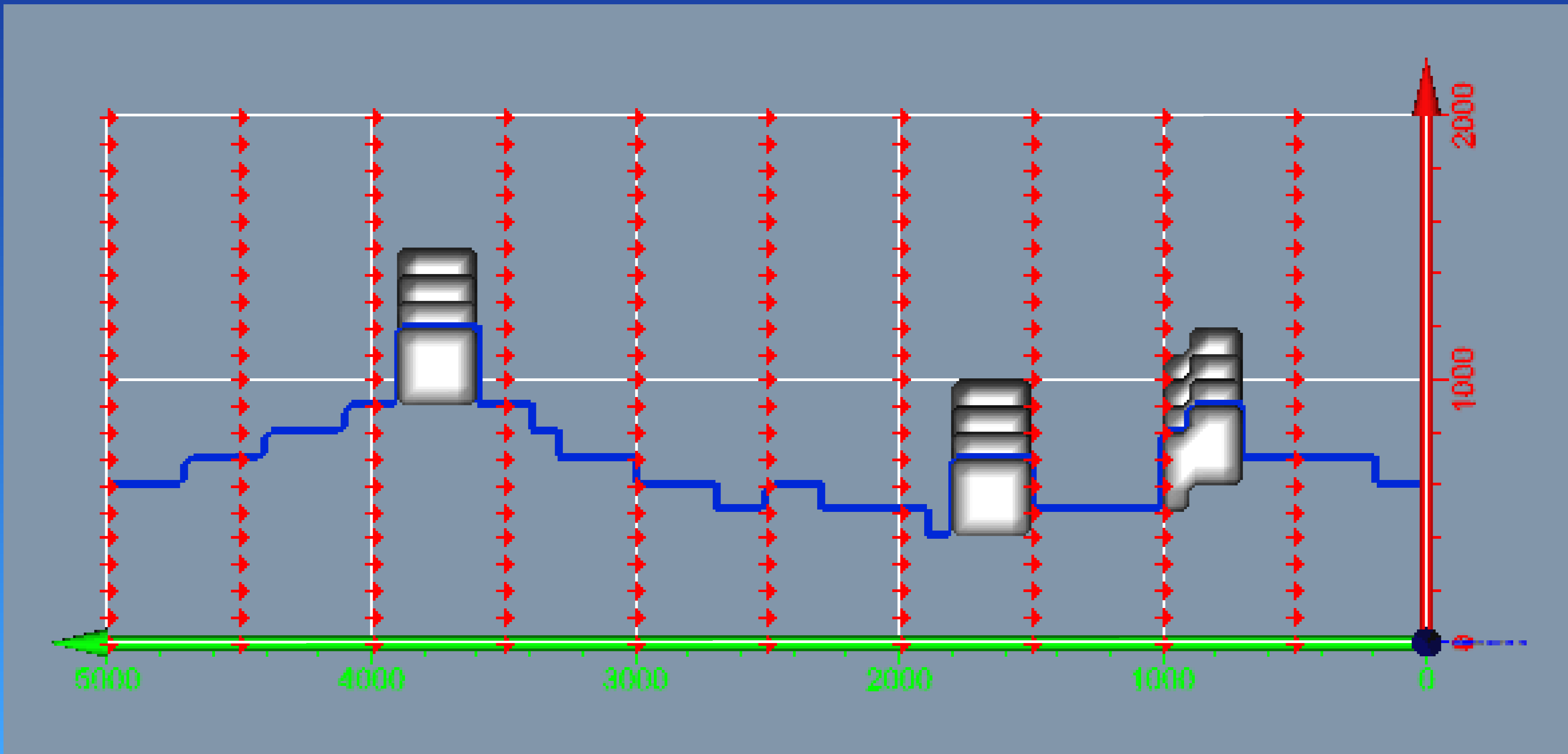


Bent long section view of contours through body centres

CFO’s Premium Selection

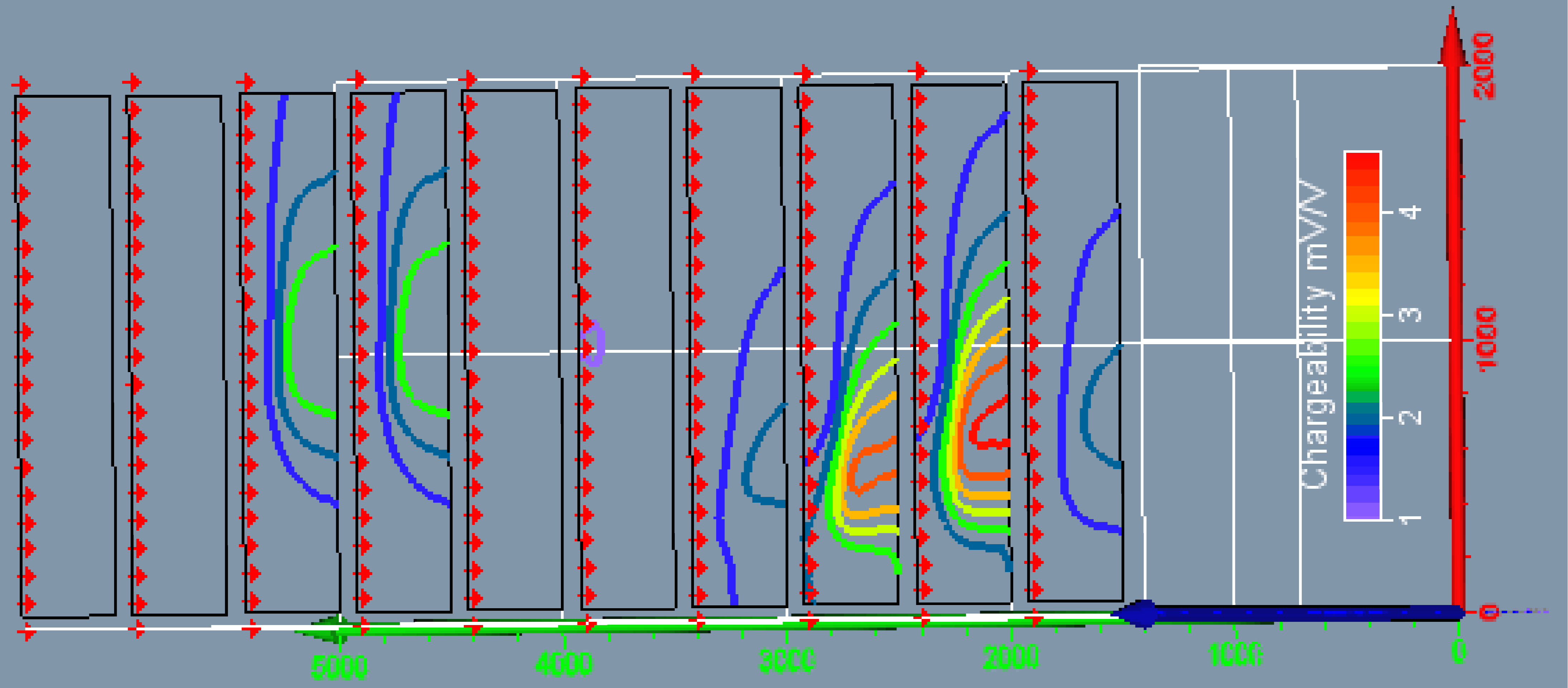
2D DIPOLE-DIPOLE

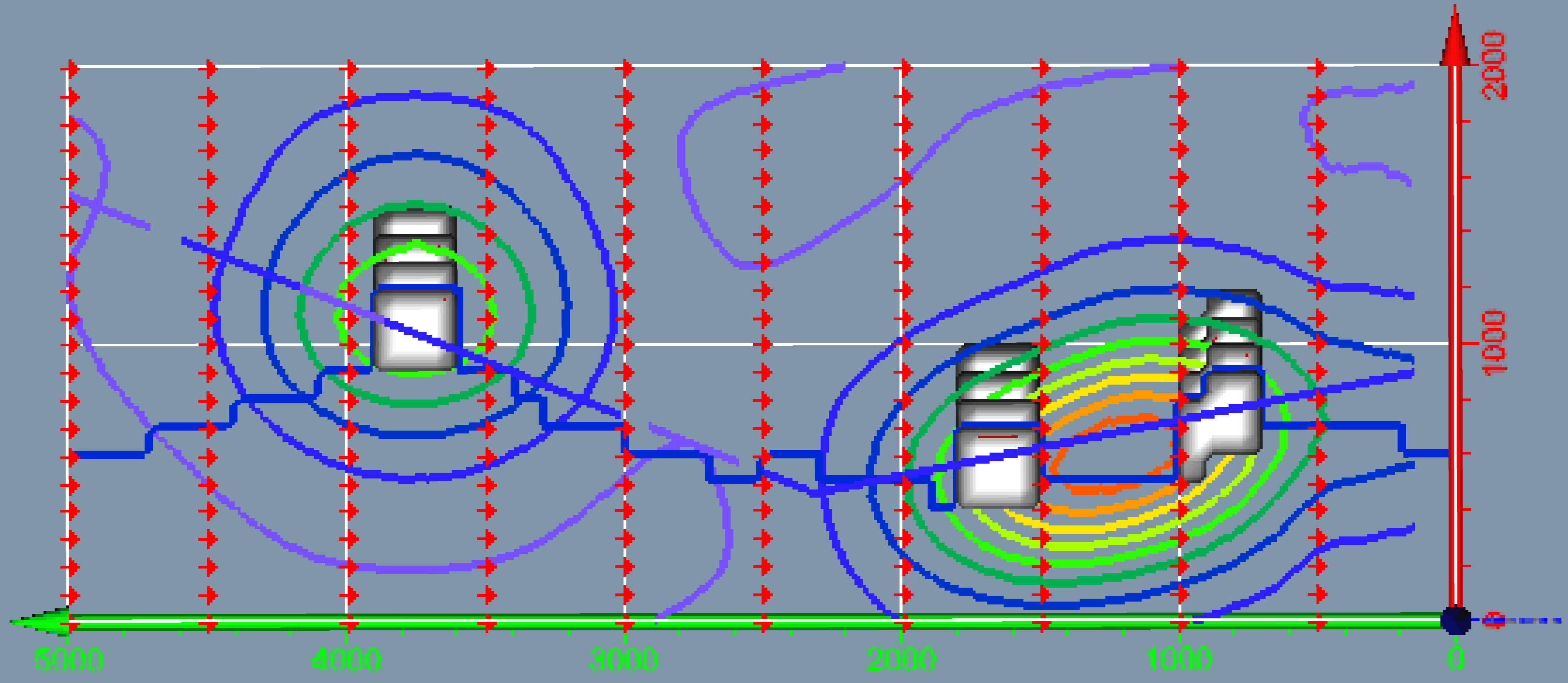
100m dipole spacing, 500m line spacing, all 20 electrodes active each reading
Note: No bodies lie under any of the lines!!!



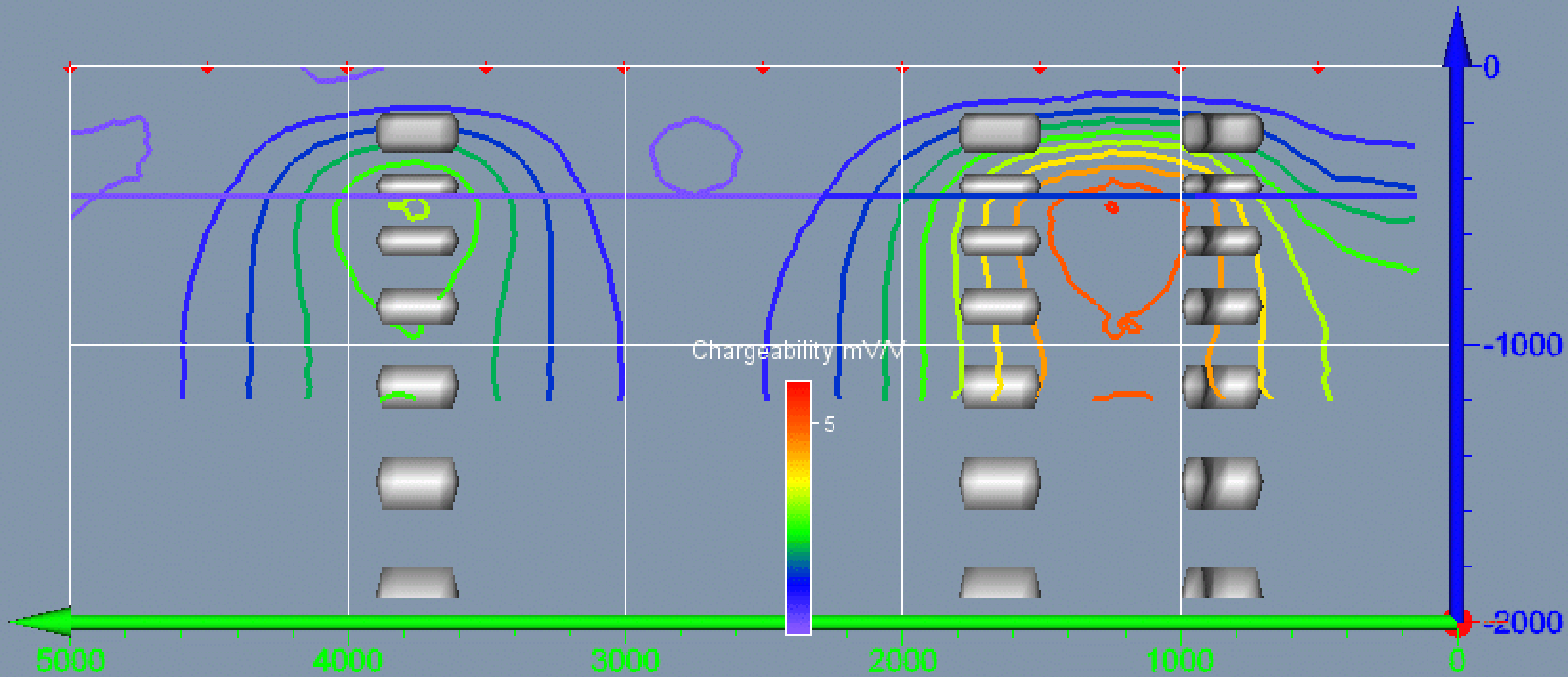
Broadside effects with 2D

Stacked 2D inversions - where would you drill?





3D inversion - Plan view of contour slice through maximum response



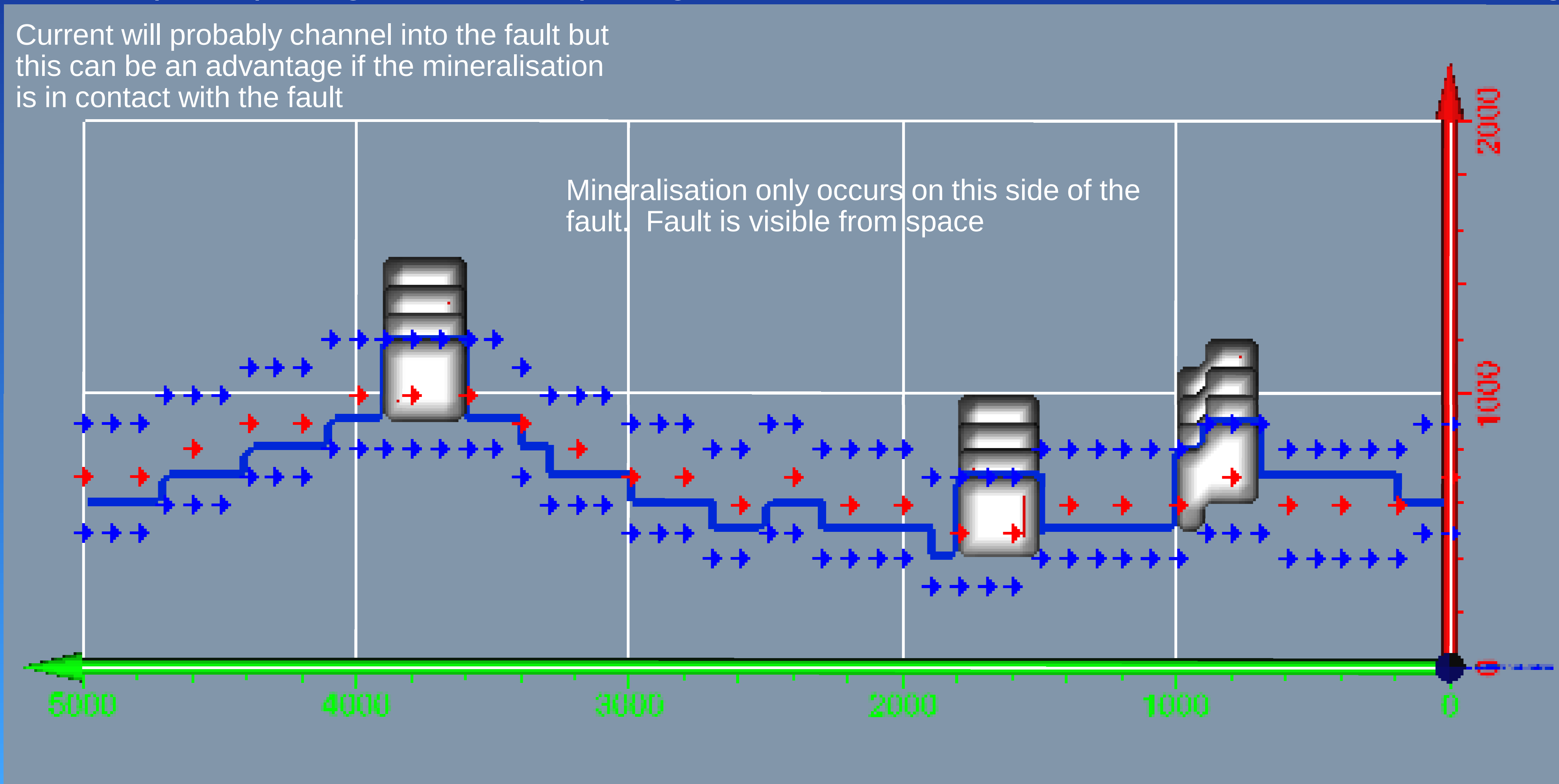
3D inversion - Bent long section view of contours through body centres

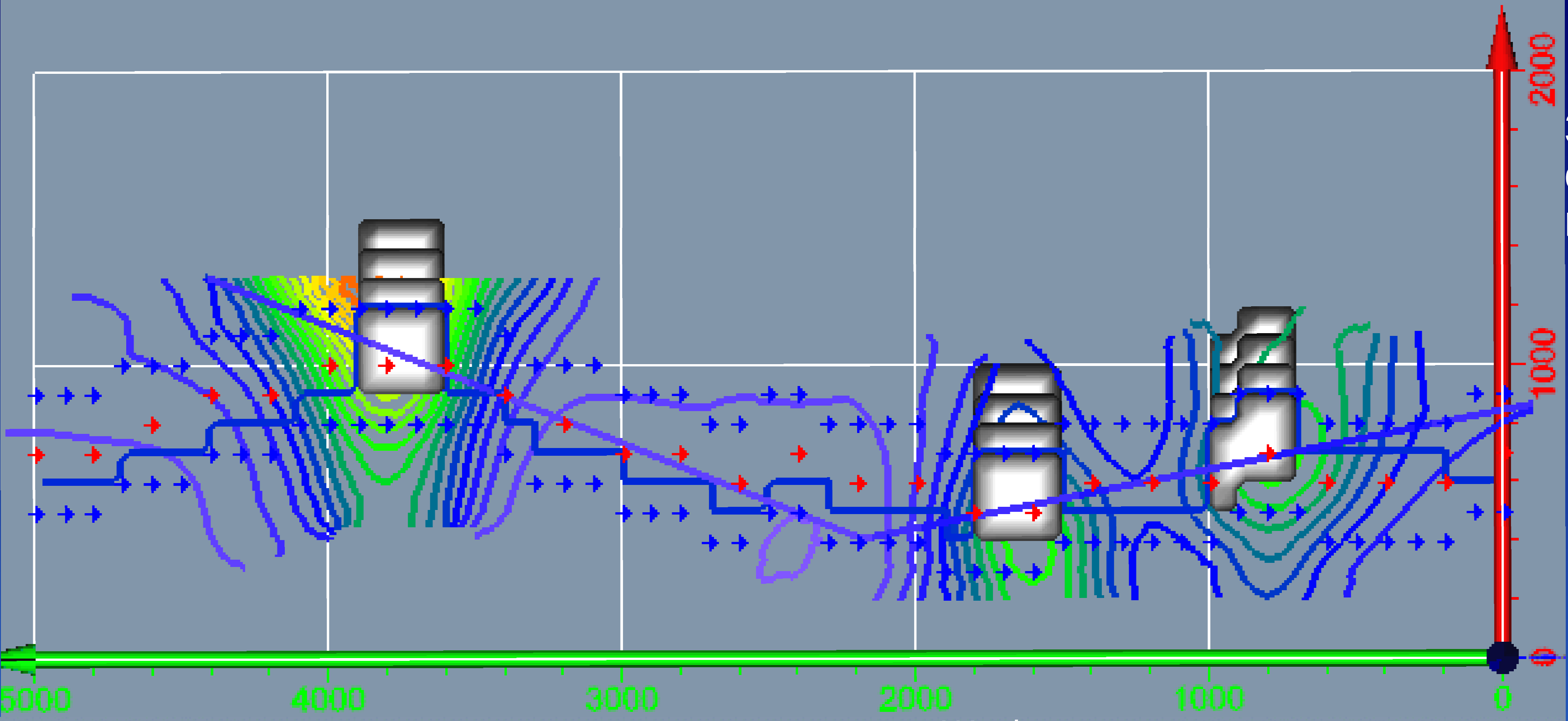
Drilling on section would only lead to tears. Drilling the bull's eyes would only get one of three bodies.

Consultant’s fallback position

Along strike 2.5D offset dipole-dipole

100m dipole spacing, 200m line spacing, two lines each of 16 electrodes active each reading





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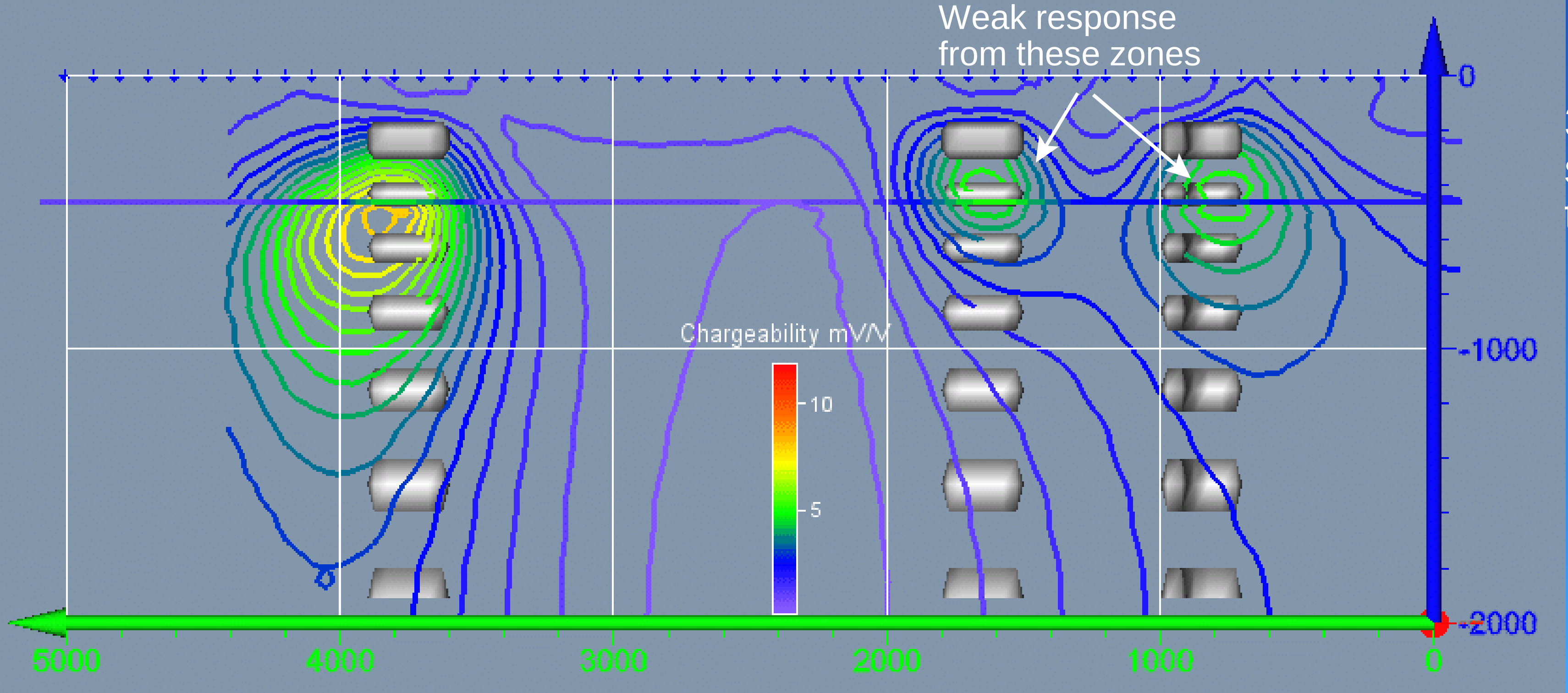


3D inversion - Bent long section view of contours through body centres

Conclusions

- The 2D Dipole Dipole combines the two close mineralised zones and may lead to barren holes
- 2D Dipole Dipole at wide line spacings is asking for trouble
- In this comparison the parallel to strike double offset dipole-dipole survey would have cost the least and still delivered good results.
- Things become even more complicated when we start pushing the middle zone down! Another story for another day!

What we have learned so far

- Relegate 2D to history along with the fax machine and log tables, 2.5D offers a better result at a lower cost
- WARNING! - Equipment or arrays named after gods, mythical beings or inclement weather may not have similar performance to their namesakes.
- Time spent modelling up front can save you money and improve your chances of success
- We still have some way to go in finding the best array

Acknowledgements

Rio Tinto

For supporting this modelling

Appendix

For the technical minded

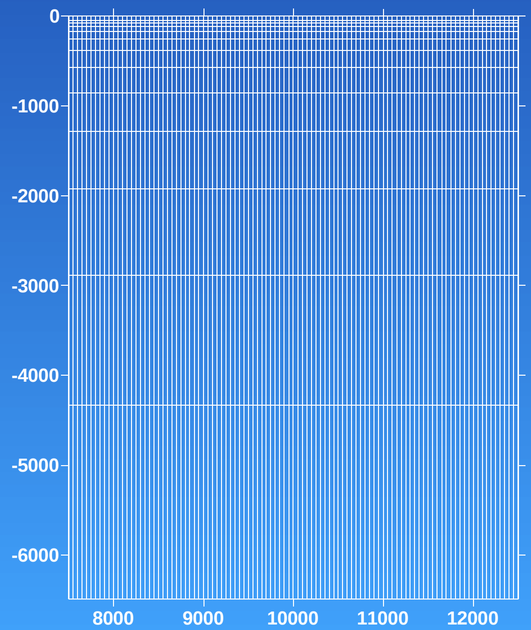
And other bits I could not fit into 25 minutes!

Case Study 1 - Forward Modelling Details

Forward modelling was undertaken using Res3Dmodx64 routine developed by Meng Heng Loke

The mesh consisted of 50m x 50m voxels over a 21000m x 2000m area with 13 layers increasing logarithmically in thickness from 50m to 2162m to achieve a maximum depth of 6487m. All electrodes (current and potential) were included in the mesh. The mesh size was 420 x 40 x 13

Continues at 50m spacing to 0m



Continues at 50m spacing to 21000m

How we added Noise

Noise was added to the forward modelled primary voltage as follows:

If $Vp > 0.1$ mV

$$Vp_{(noise)} = Vp + RN*Vp*0.1$$

If $Vp \leq 0.1$ mV

$$Vp_{(noise)} = Vp + RN*0.1$$

RN = Random number between -0.5 and +0.5

How we added noise to m

The apparent resistivity was then recalculated.

The chargeability had noise added proportionally to the noise in the primary voltage.

$$m_{(noise)} = m * Vp_{(noise)} / Vp$$

The noise adjusted apparent resistivity and chargeability were input to Res3DinvX64 after clipping the data to $Vp_{(noise)} > 0.1$ mV

Specs - Case study 1

Expanding gradient - 100m potential electrode spacing, 6500m to 21000m Tx dipoles.

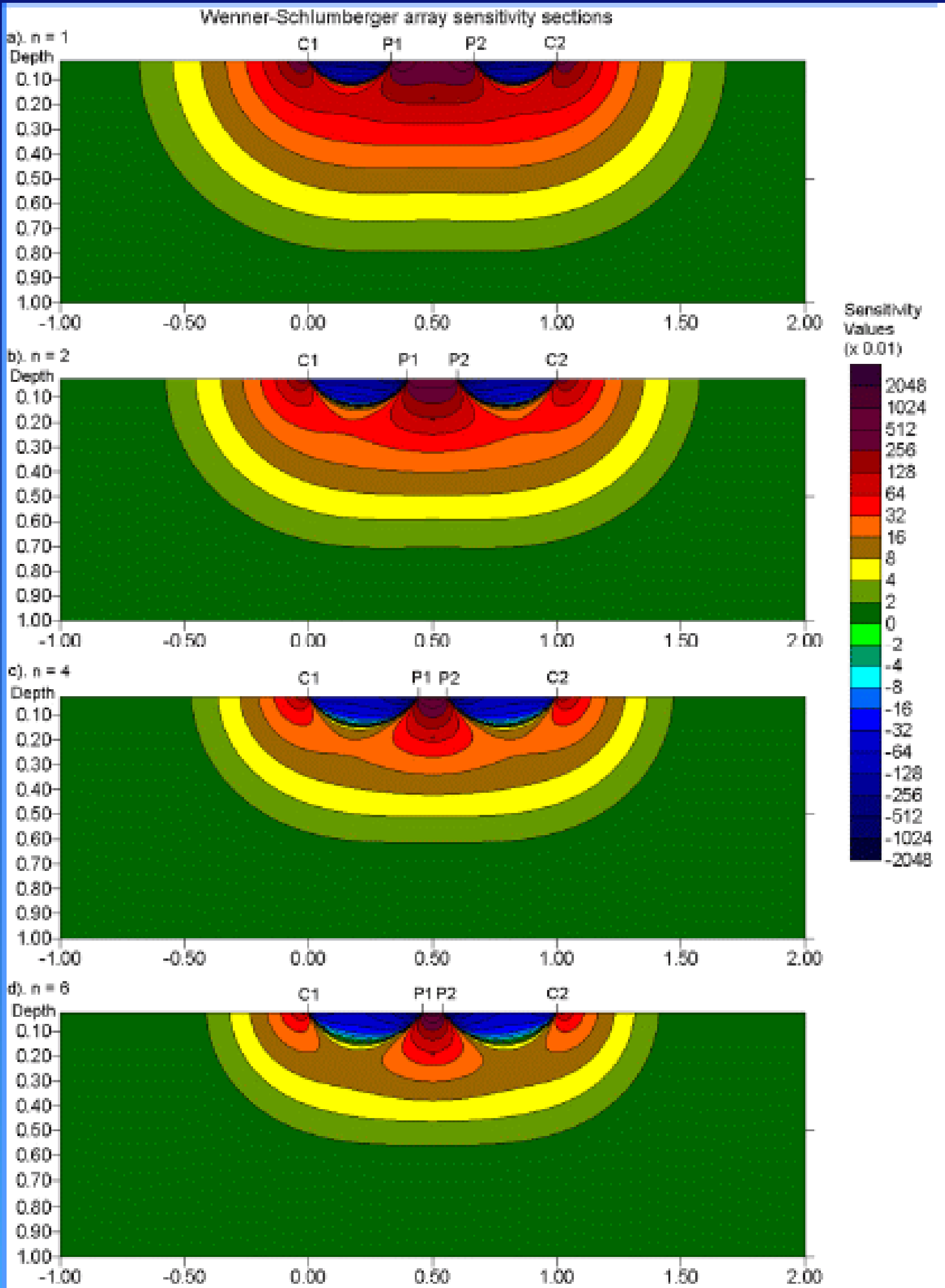
3D Pole-dipole - 200m potential electrode spacing with active current electrode in the centre of a 2 dipole x 2 dipole square and remote at 10 km.

Offset Dipole-Dipole - 100m Rx dipoles, 200m Tx dipoles

All sections are along line 1000 over the top of the body and use linear colour stretch applied to the section being displayed with 0.5 mV/V linear contours

Why arrays see different things

SENSITIVITY



Wenner/Sclumberger/Gradient array
Change in sensitivity for changing MN with constant AB

Note negative sensitivity areas

Reasonable sensitivity maxima at ~3 x MN for long AB

Loke 2010

SENSITIVITY

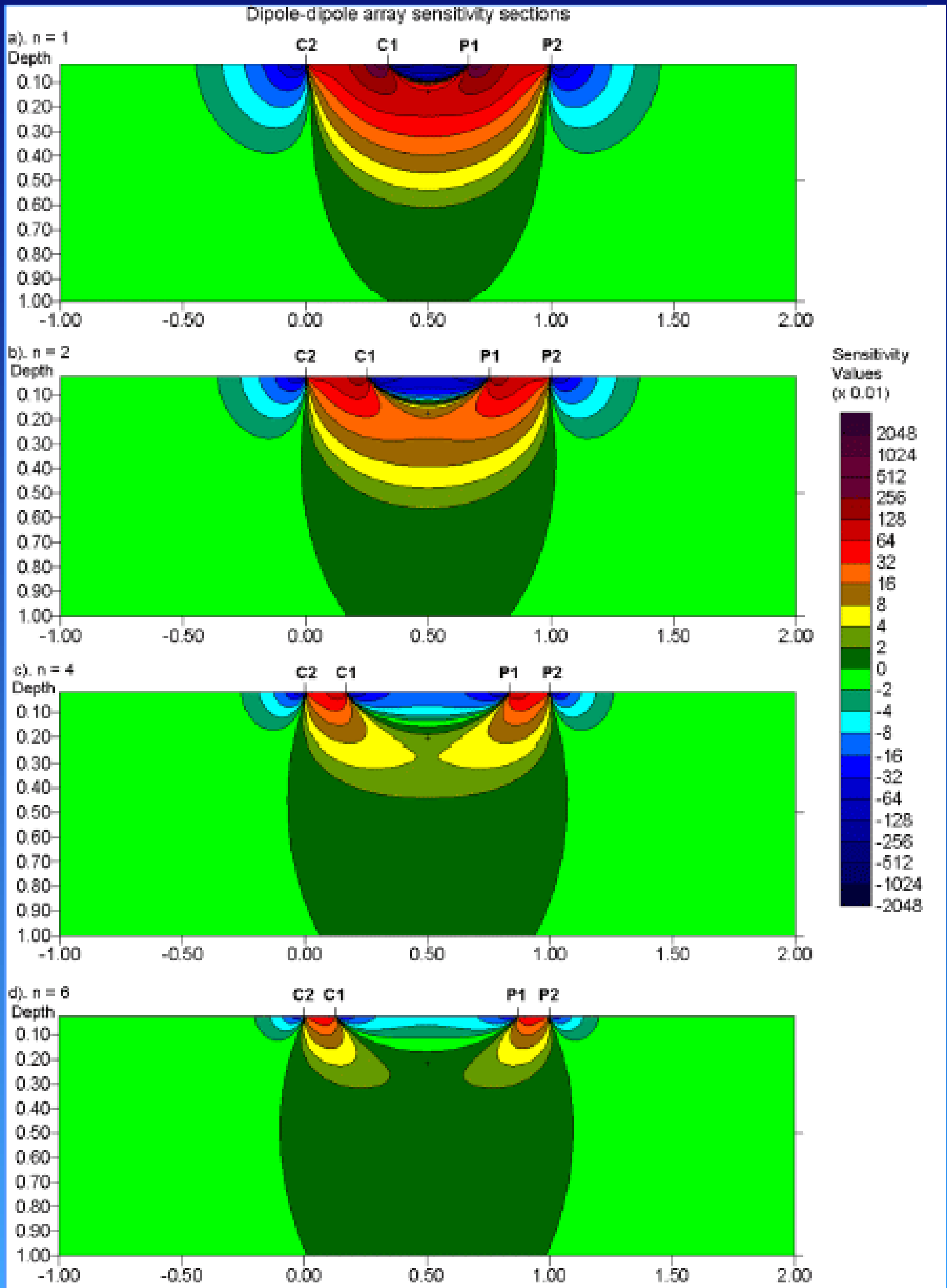
n

1

2

4

6



Dipole-dipole array

Change in sensitivity for changing “n” value

For dipole-dipole array the median depth derived from the sensitivity function is likely to underestimate the true depth of investigation by 20-30%

Reasonable sensitivity maxima at ~3 x MN or AB for large n but under the dipole NOT between them

Loke 2010

SENSITIVITY

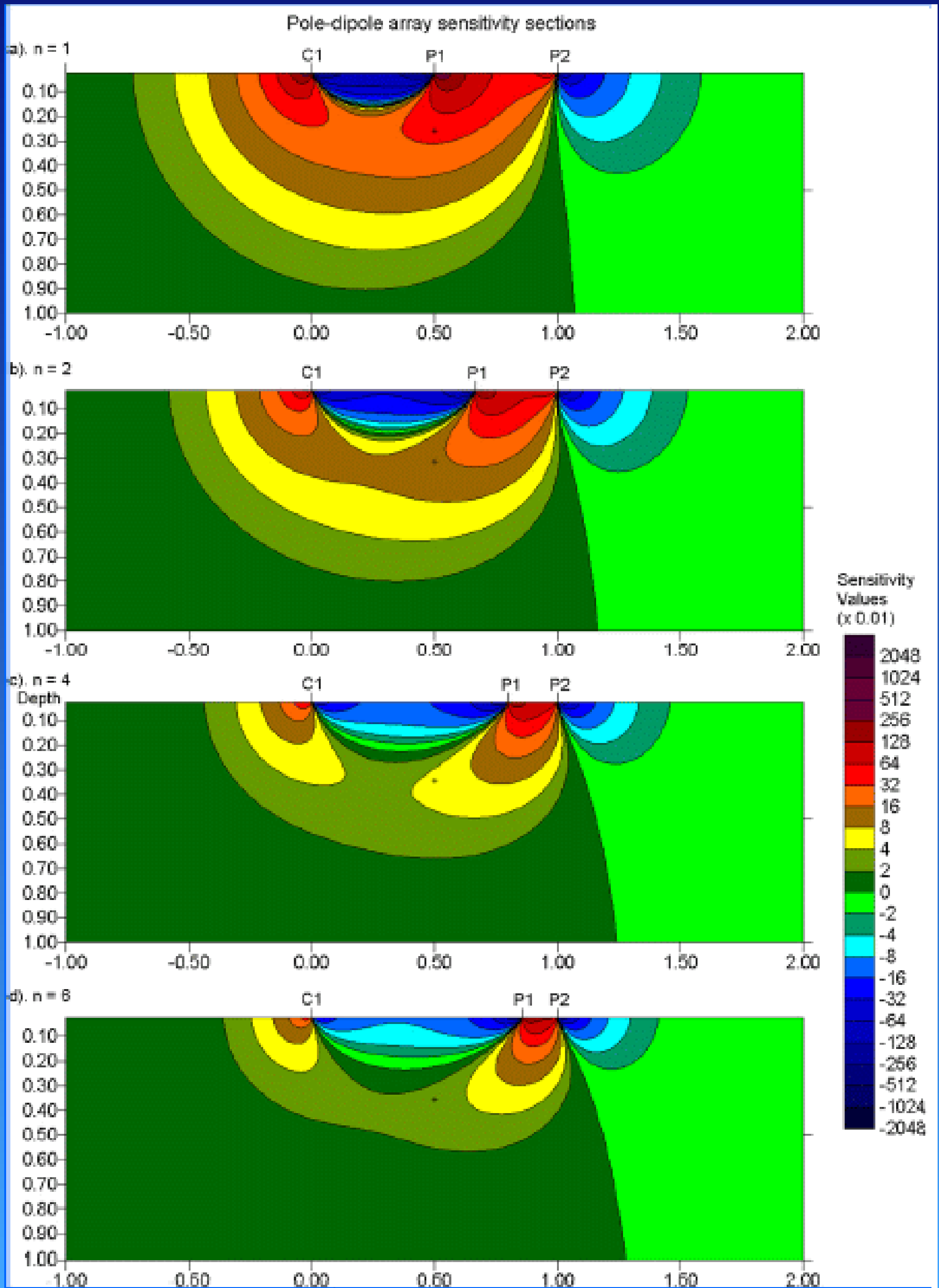
n

1

2

4

6



Pole-dipole array
Change in sensitivity for changing “n” value

Reasonable sensitivity maxima at ~3 x MN for large n but under the dipole NOT between the current and potential electrodes

Loke 2010

Using Sensitivity to our advantage

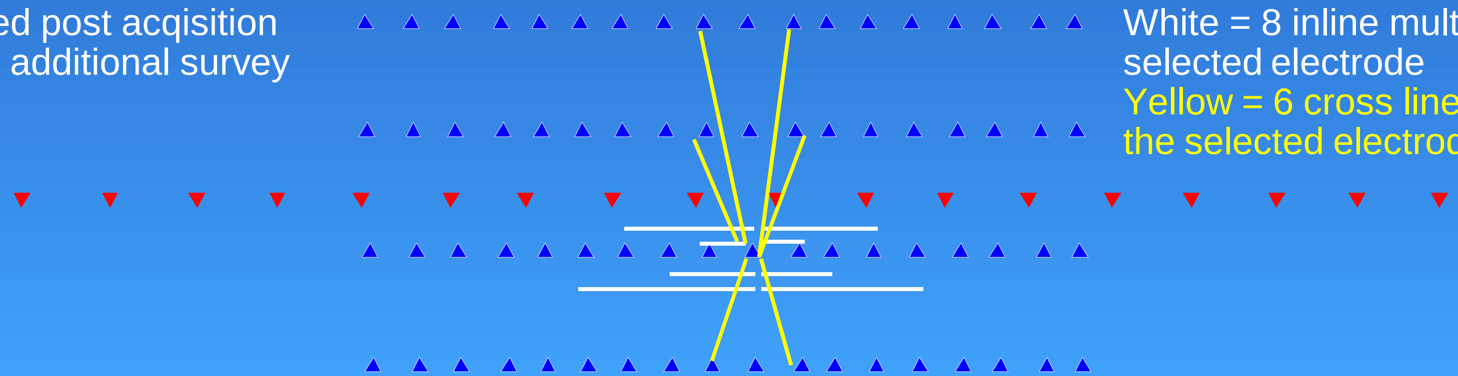
Examples of Quad Offset array processing 4 inline and 12 cross line (Herringbone) dipoles

Scale it up

- Quad offset array
- Multiple MN spacings acquired from the same electrodes at the same time
- Multiple AB spacings by reusing pits
- Measure both along line and cross line dipoles

100m electrode spacing and 200m Rx line spacing
delivering 100m, 200m 300m and 400m in line and 200, 400, 600m cross line Rx dipoles acquired simultaneously from readings using 200m and 800m Tx dipoles

Extra data provided post acqisition by processing, no additional survey cost

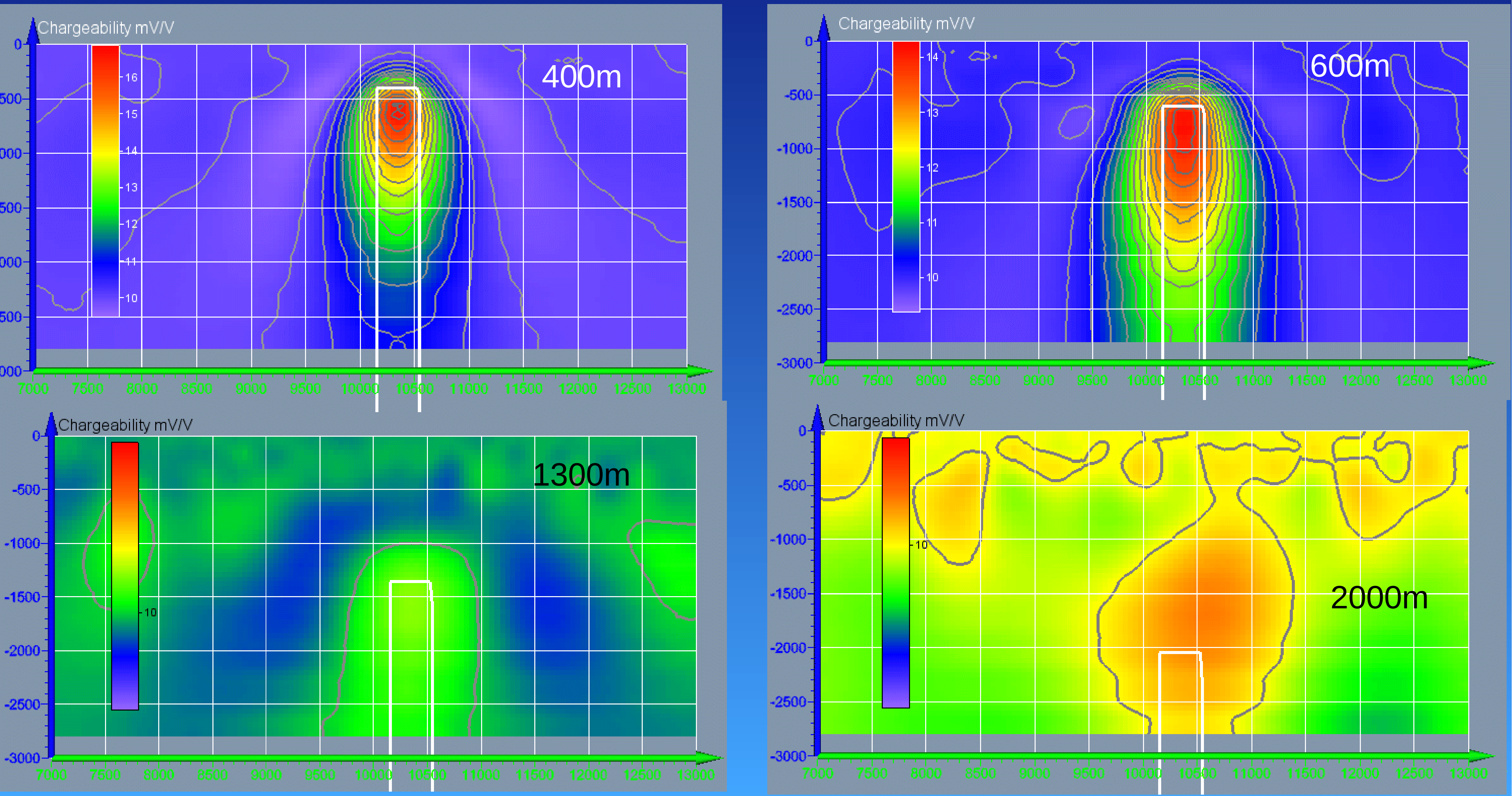


White = 8 inline multipoles using the selected electrode
Yellow = 6 cross line herringbones using the selected electrode

Vary the depth to top

3D Multipole array

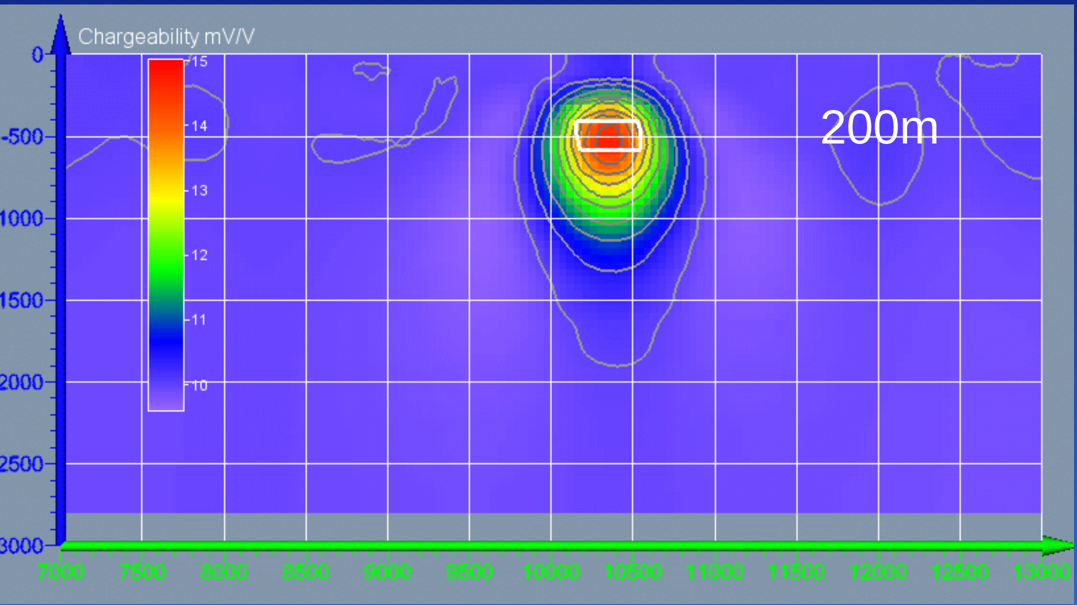
In-line Multipoles only - no Herrinbone

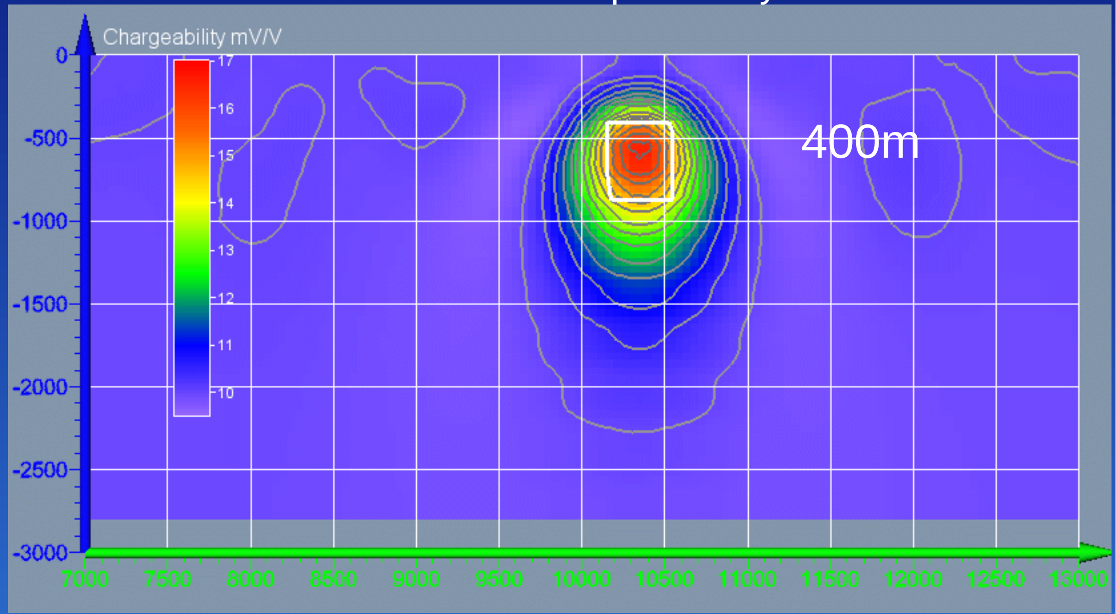


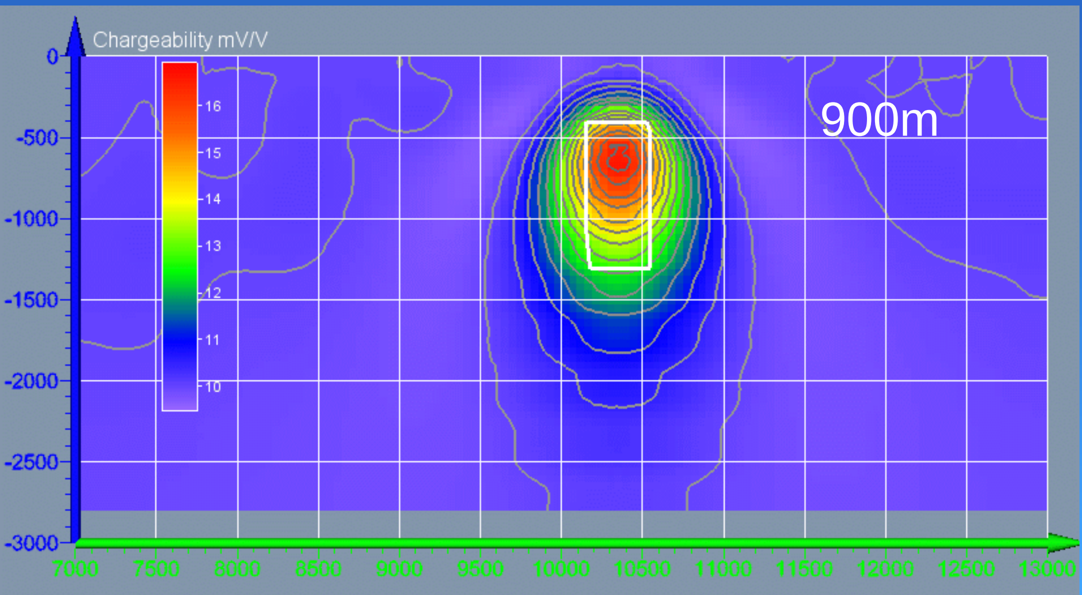
Vary the depth to bottom

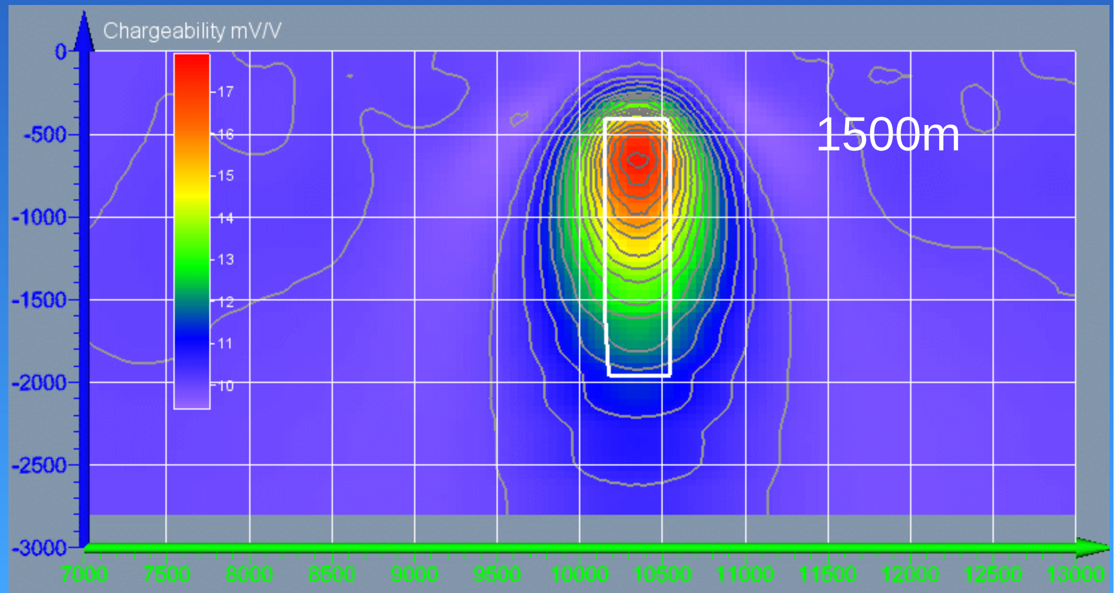
3D Multipole array

In-line Multipoles only - no Herrinbone





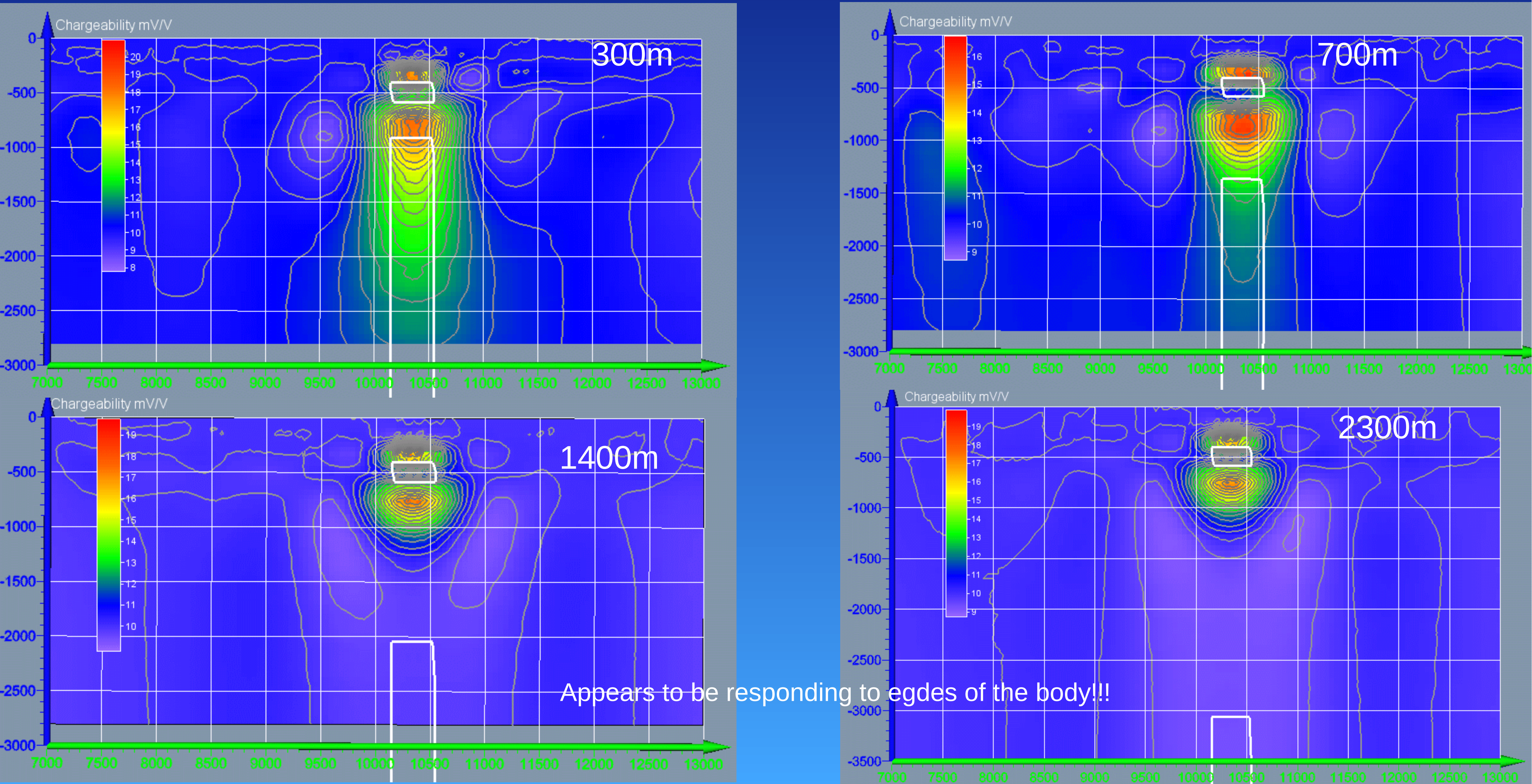




Vary the distance below a screen

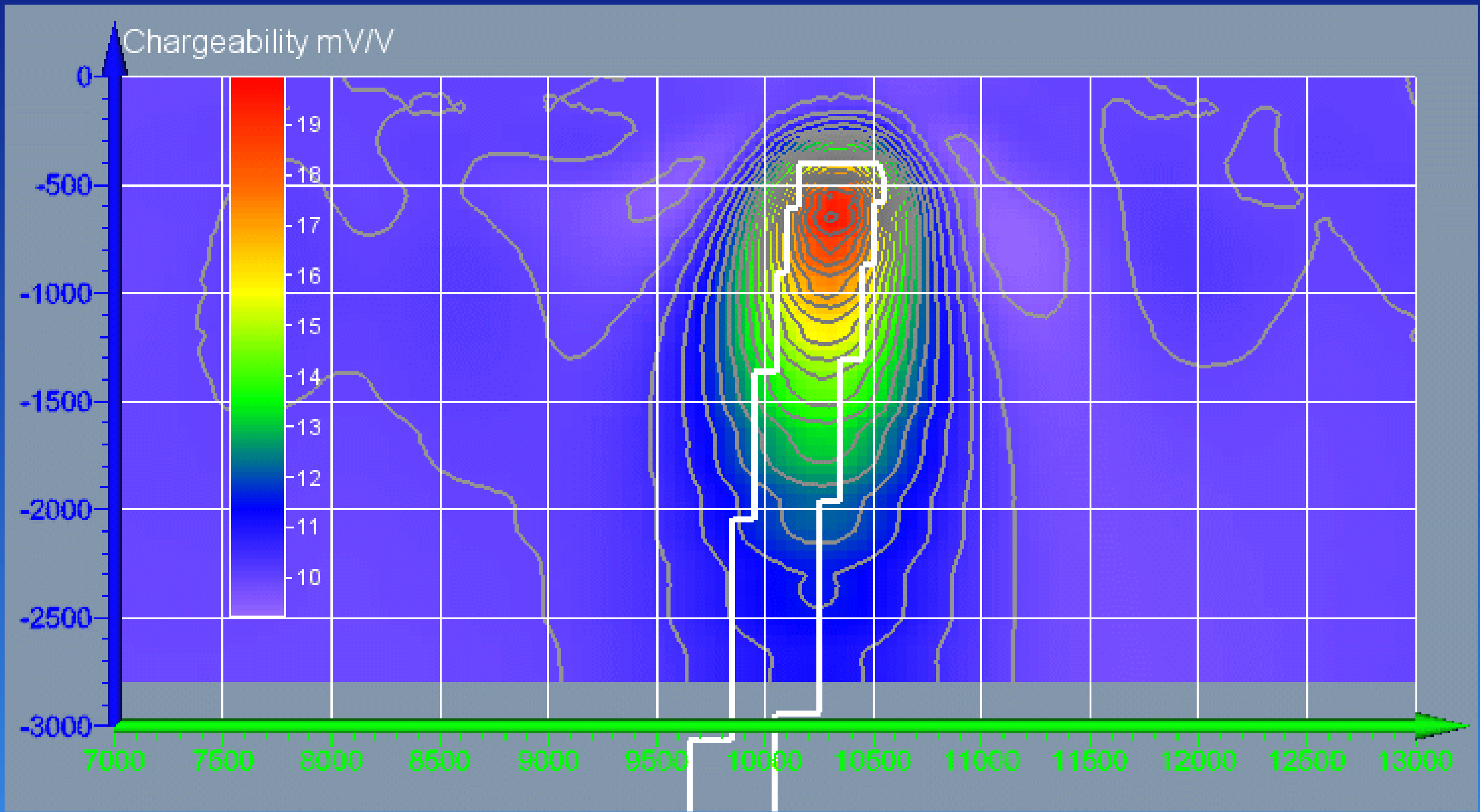
3D Multipole array

In-line Multipoles and Herrinbone used



Mapping dip

Body dips to the left



In-line Multipoles only
- no Herrinbone

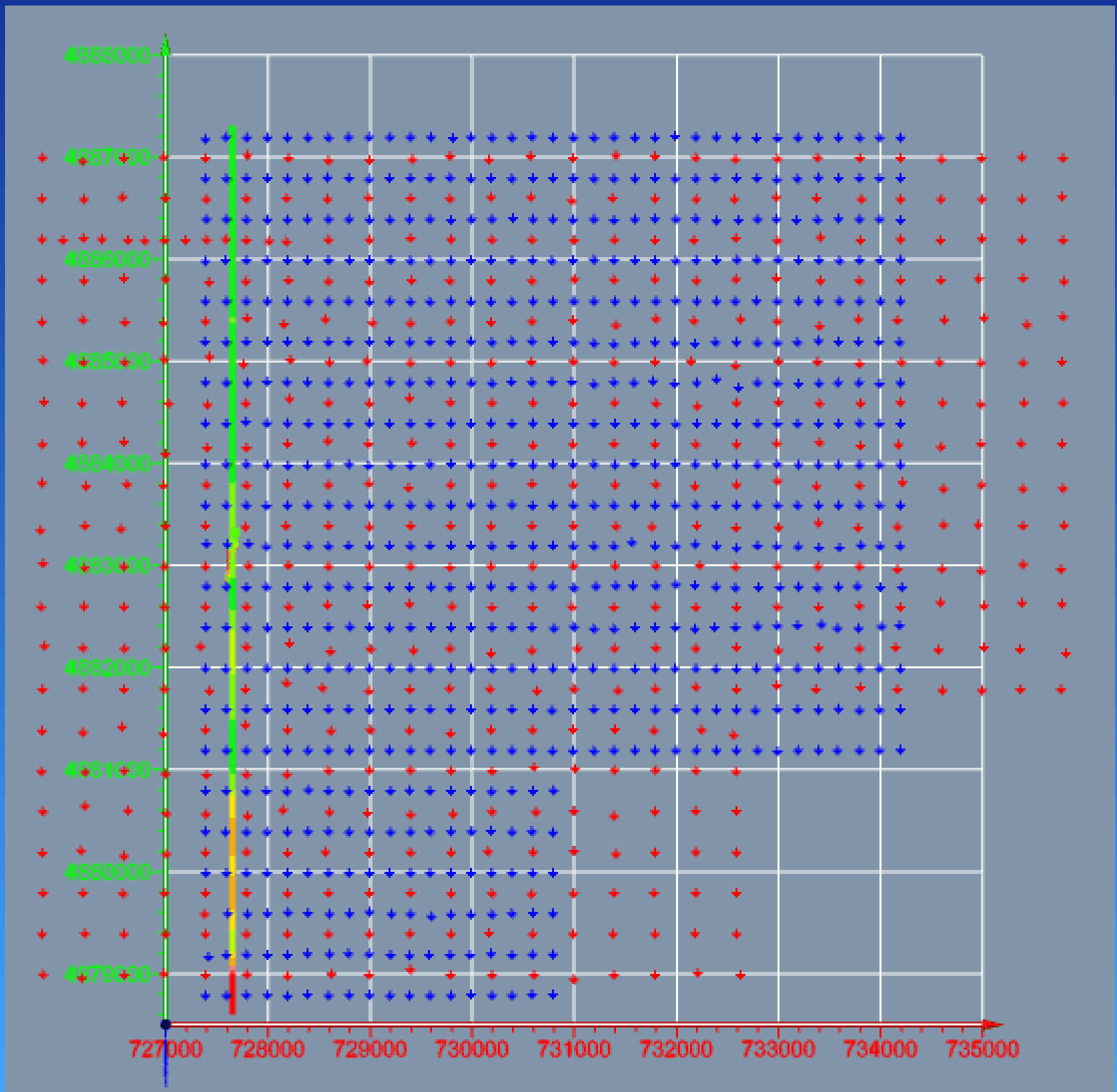
Subtle dip response relative to none on previous arrays

Conclusions

We are not quite there yet but by adding dipoles at different spacing and orientation we can change the resolution without an increase in survey cost or time. The processing time however more than doubles and speeding this up is worthwhile. Finding the right match of dipole sizes and orientations will be the key.

Real Case Study

Porphyry targeting in Mongolia - 50 km^2 area



Quad Offset dipole dipole array

200m Rx electrodes giving 200m, 400m, 600m and 800m Rx dipoles

400m Tx electrodes using 400m and 1200m dipoles

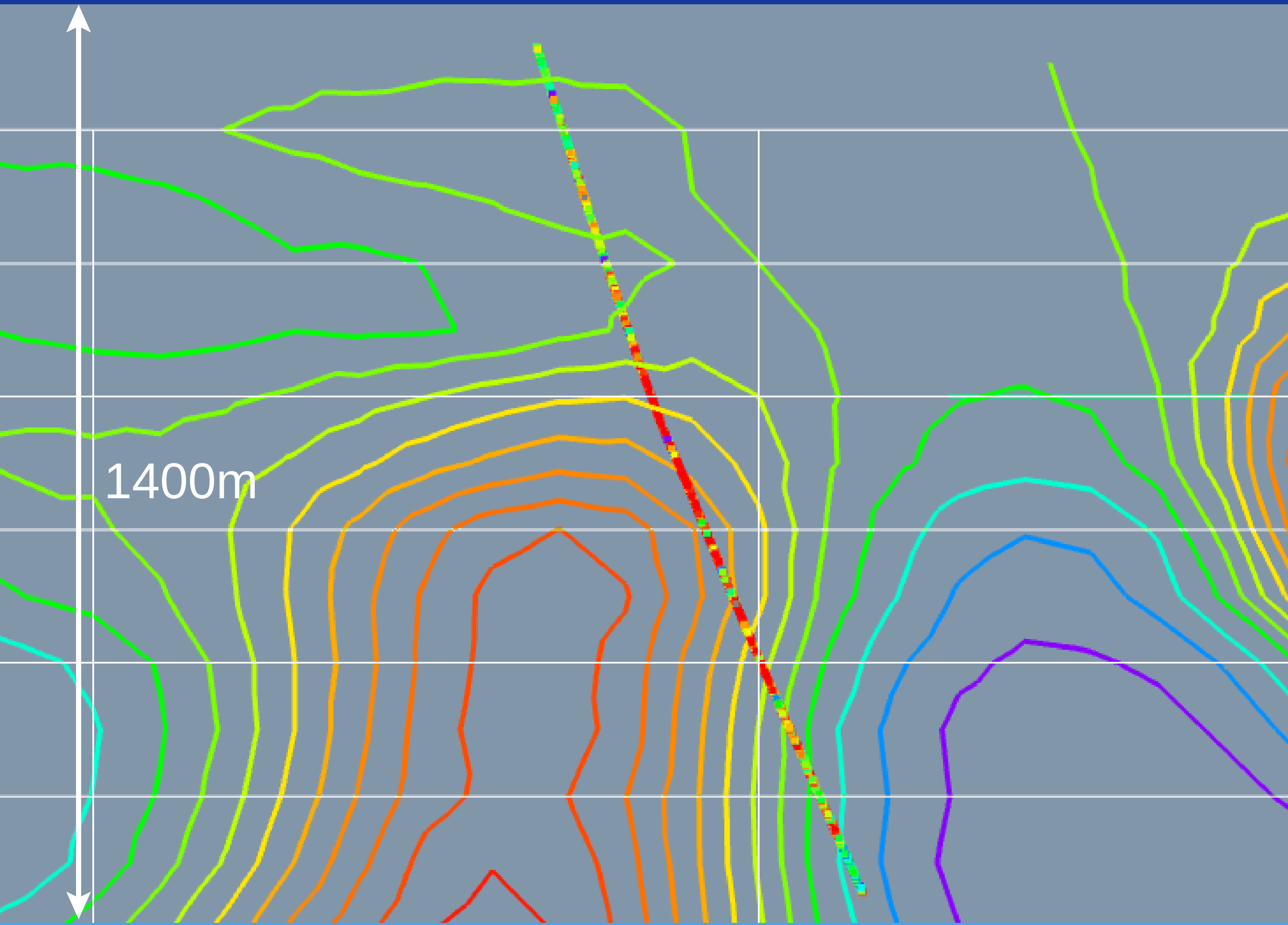
50 kVA transmitter injecting an average of 21A for the survey (6.6 to 66A)

1163 electrodes, 750,000 readings distilling to 230,000 readings after editing bad points and averaging repeats.

6 weeks to acquire - $600k all up including mob/demob of 2 tonnes of equipment from Australia and interpretation

Case Study

Comparison between IP and Cu grades in the deepest drillhole



2 mV/V contours of chargeability

Cu to 3.3%

Resistivity 100 -1000 Ohm m in this location

Good correlation to at least 1km depth

Specs - Case study 2

3D Pole-dipole - remote 2 km to the west

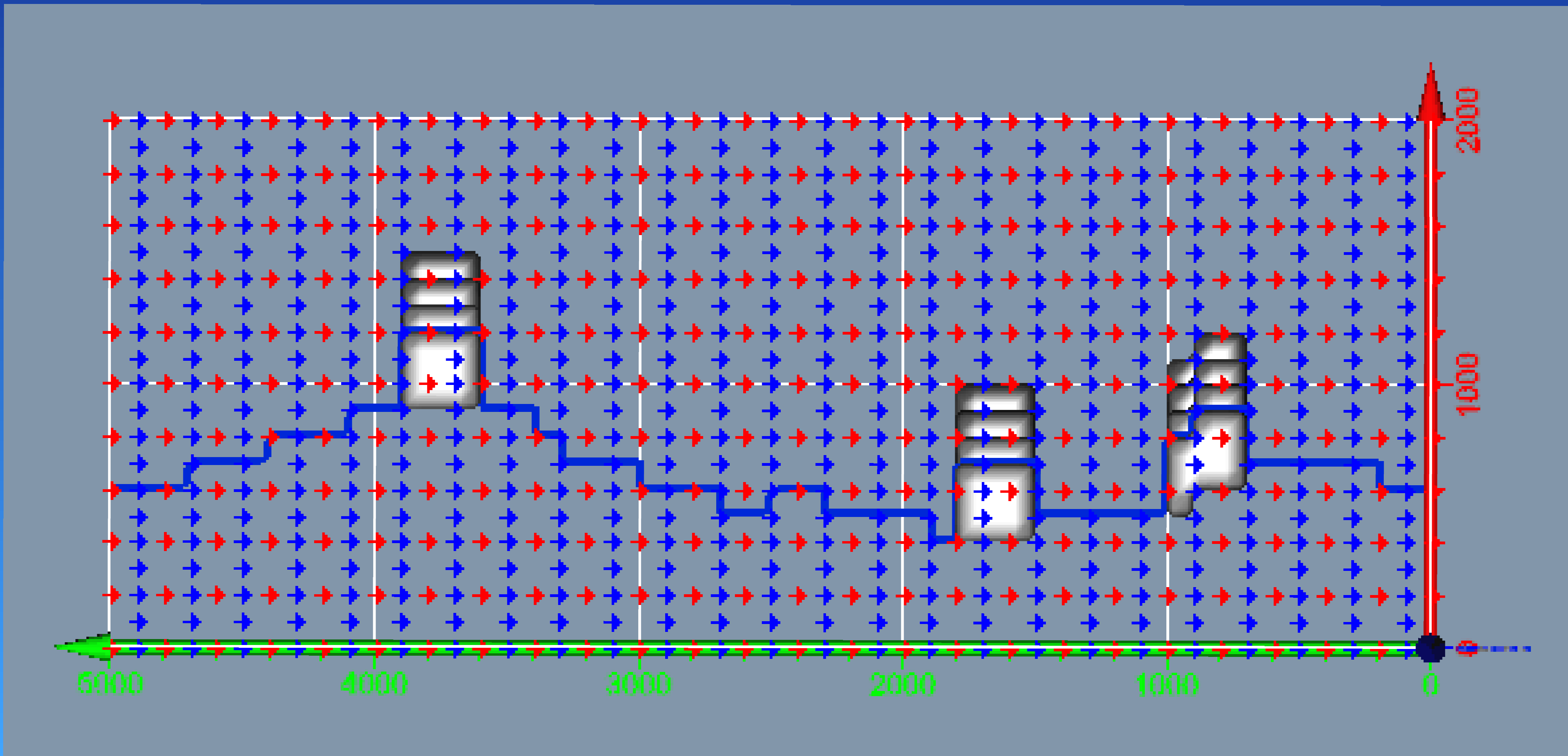
Offset Dipole-Dipole - 100m Rx dipoles, 200m Tx dipoles

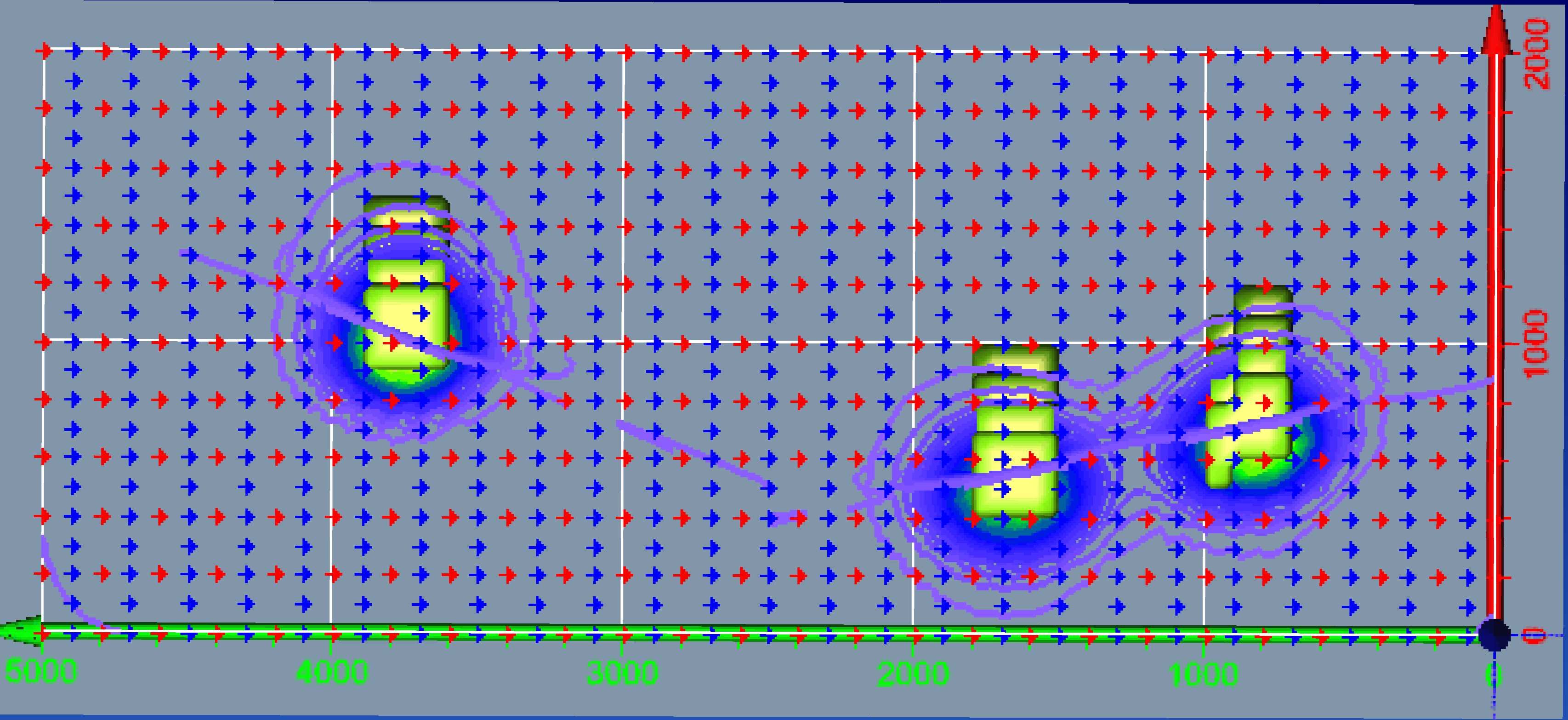
All contours use linear colour stretch applied to the data limits of that data set and 0.5 mV/V linear contours

Consultant's Super Premium Selection

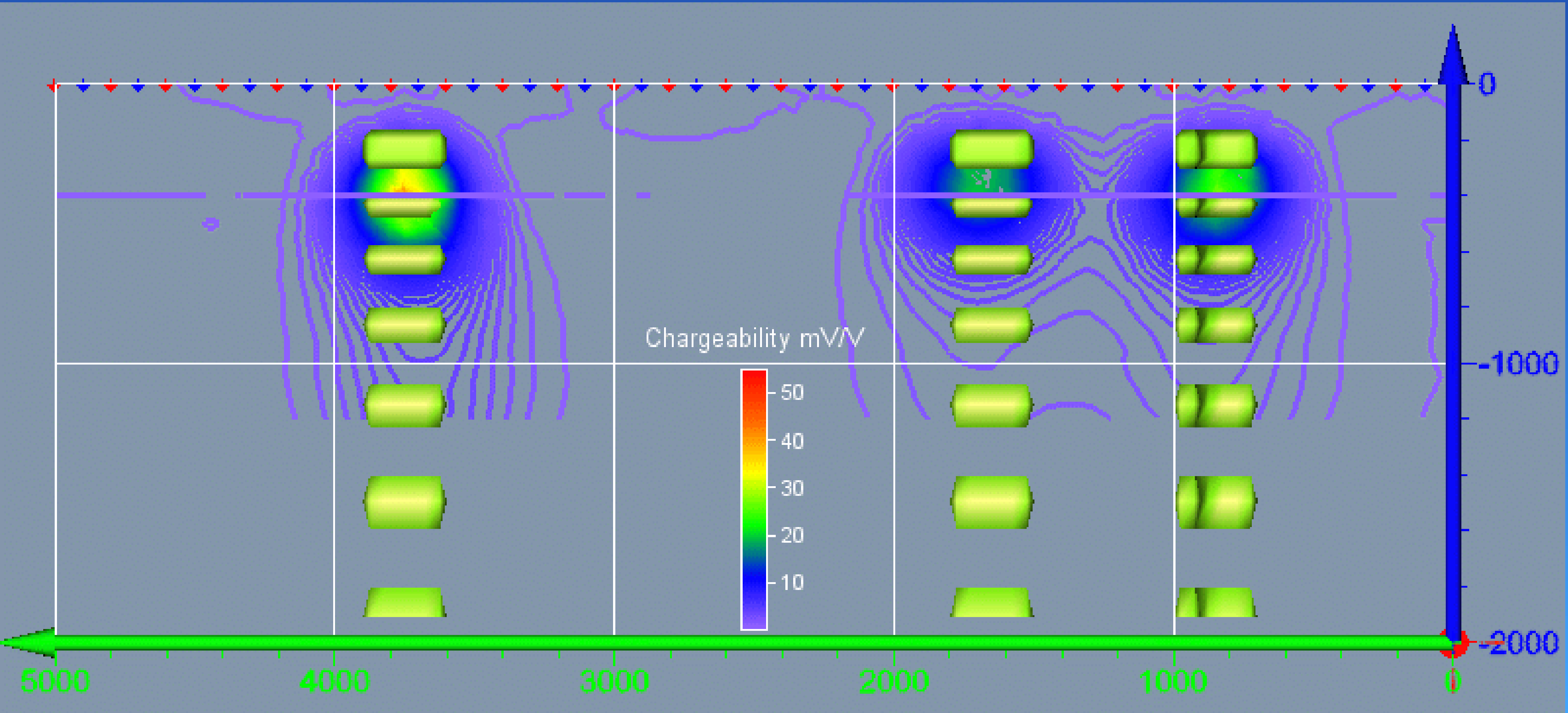
2.5D QUAD OFFSET DIPOLE-DIPOLE

100m dipole spacing, 200m line spacing, 4 lines of 20 electrodes active each reading - 4 multipoles





Plan view of contour slice through maximum response



Bent long section view of contours through body centres

Adding Multipoles has increased the resolution.