

EM: Natural Sources

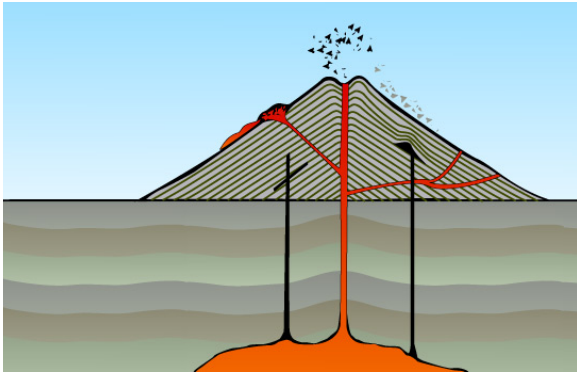


Outline

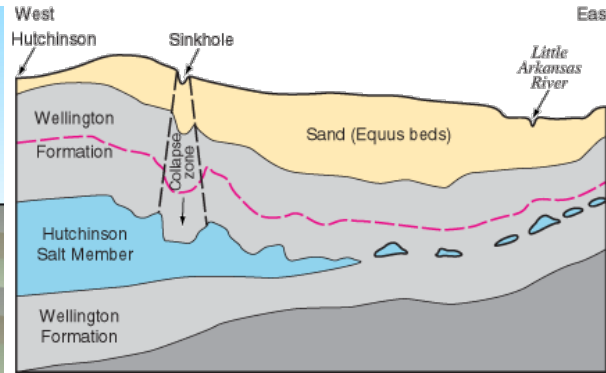
- Background on natural source EM methods
- Magnetotellurics
- Case history: Minerals
- Z-axis tipper electromagnetics
- Case histories (ZTEM): Geologic Mapping, Minerals

Motivation

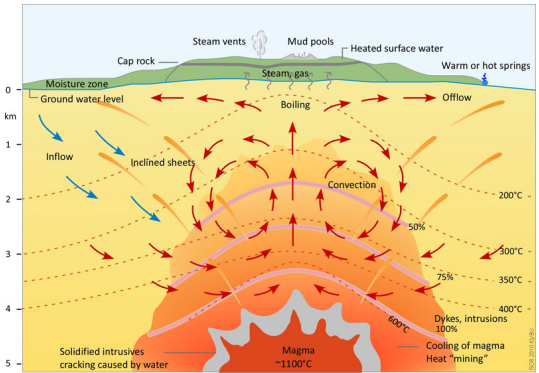
Volcanoes



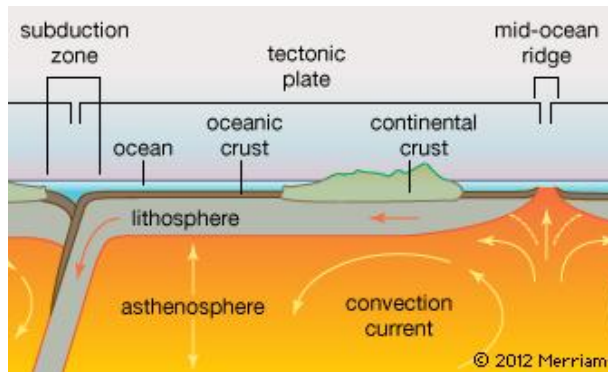
Base of salt



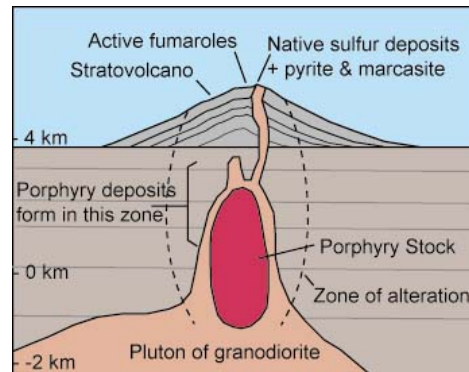
Geothermal



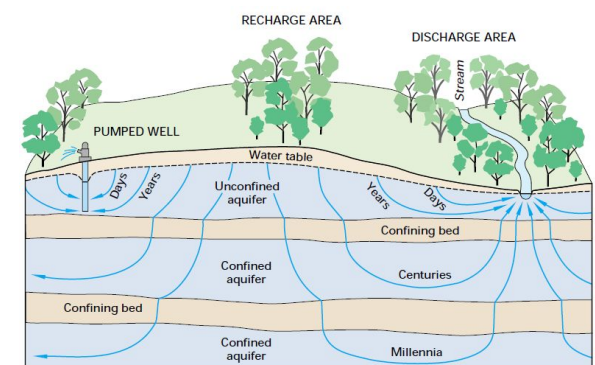
Tectonic settings of top few km



Mineral targets



Groundwater



Common challenge: getting enough energy into the ground

What is required to see deeper?

- Penetration depth depends upon system power

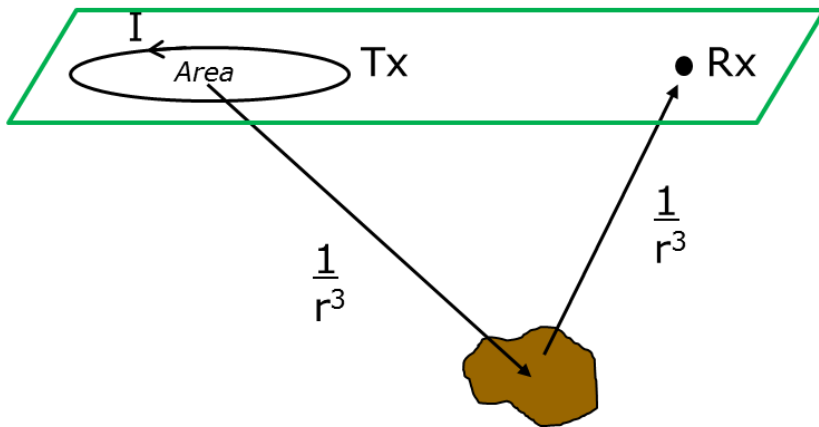
- Controlled source:

- Using a small loop
- Magnetic moment

$$m = IA$$

- Total geometric decay

$$\sim \frac{1}{r^6}$$

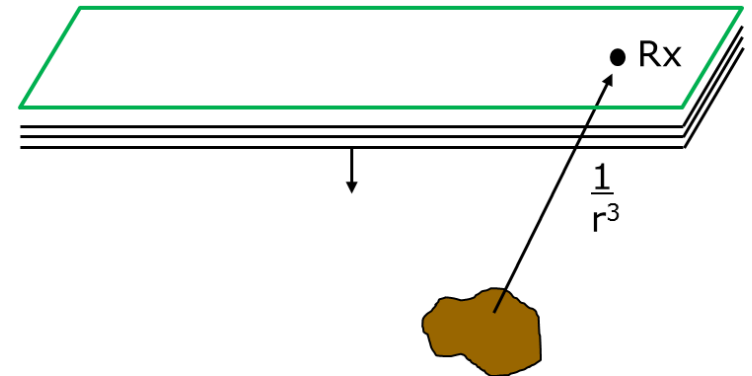


- Infinitely large loop source

- Sheet currents generate plane waves

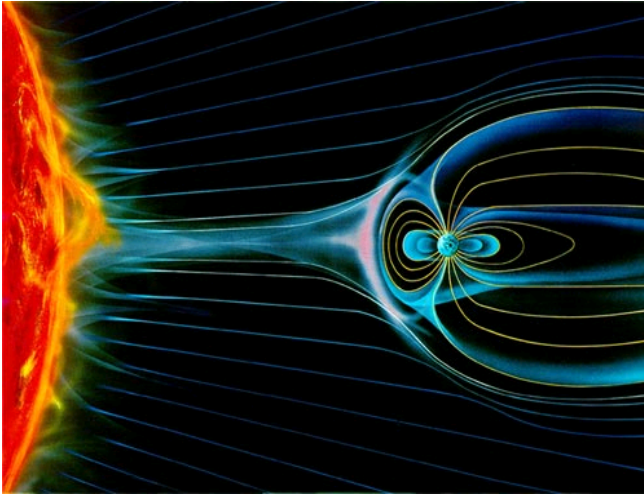
- Total geometric decay

$$\sim \frac{1}{r^3}$$

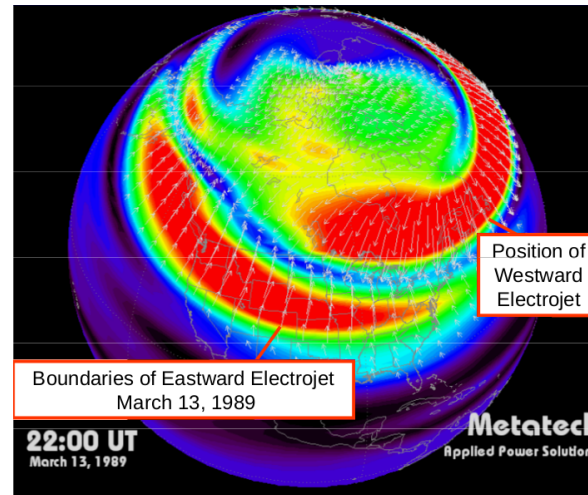


Natural EM sources

Sun and magnetosphere, solar storms



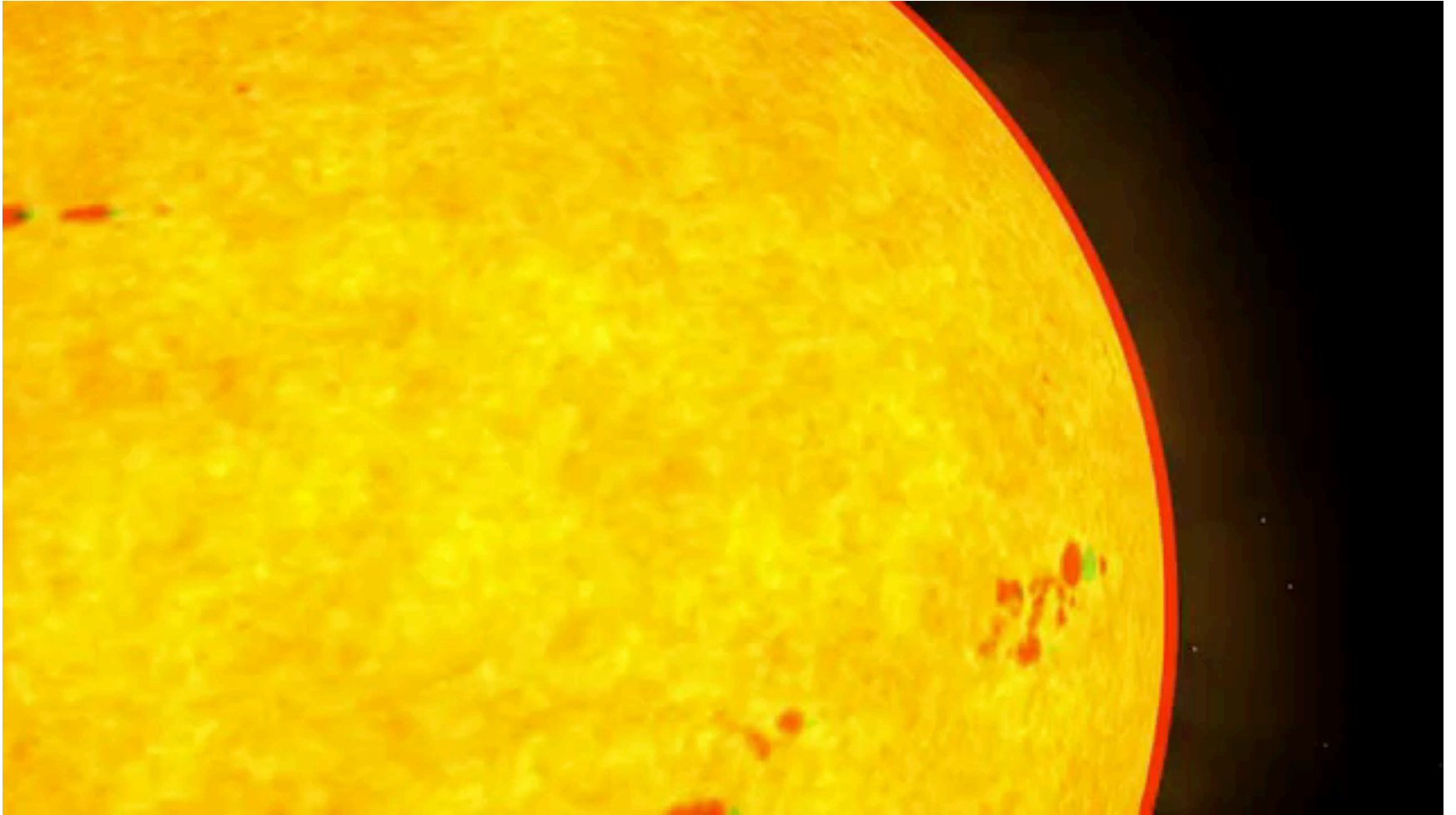
Auroral electrojet; aurora



Lightning

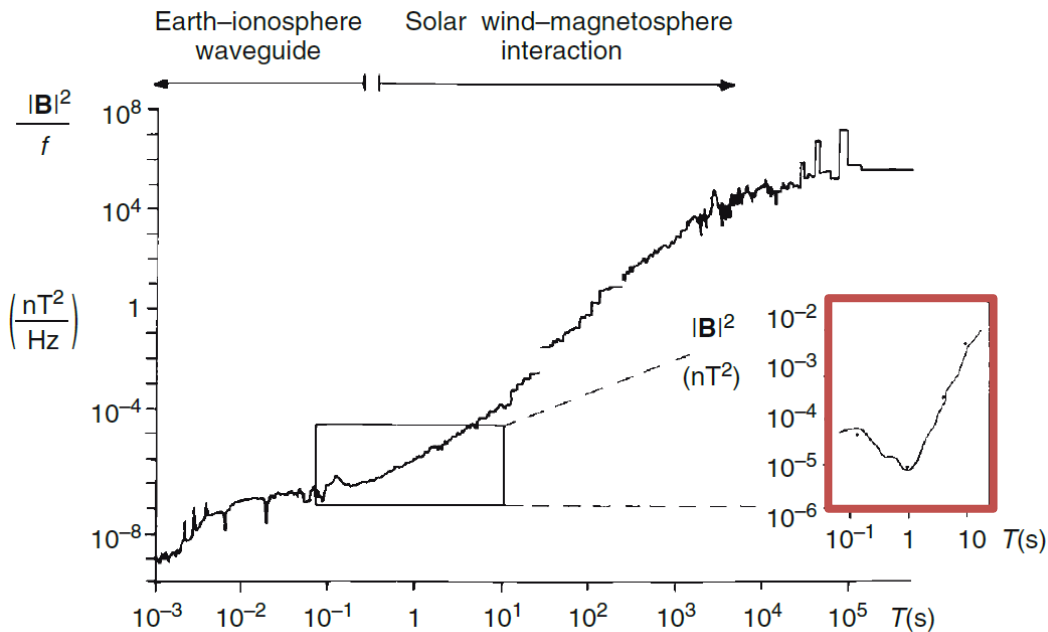
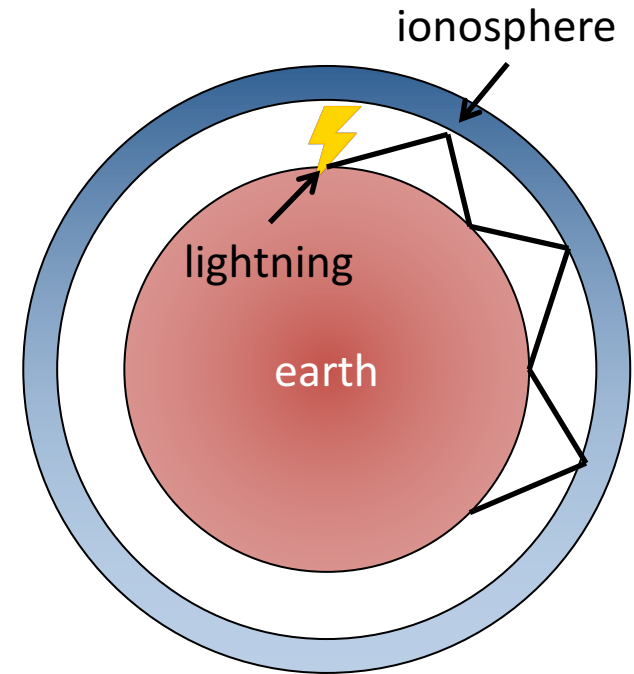


Aurora movie



Earth as a waveguide

- EM waves bounce between earth and highly conductive ionosphere
- Travel as plane waves



- Dead band: difficult to collect frequencies in notch (~1 Hz)

Refraction of waves

- Snell's law

$$k_i \sin \theta_i = k_t \sin \theta_t$$

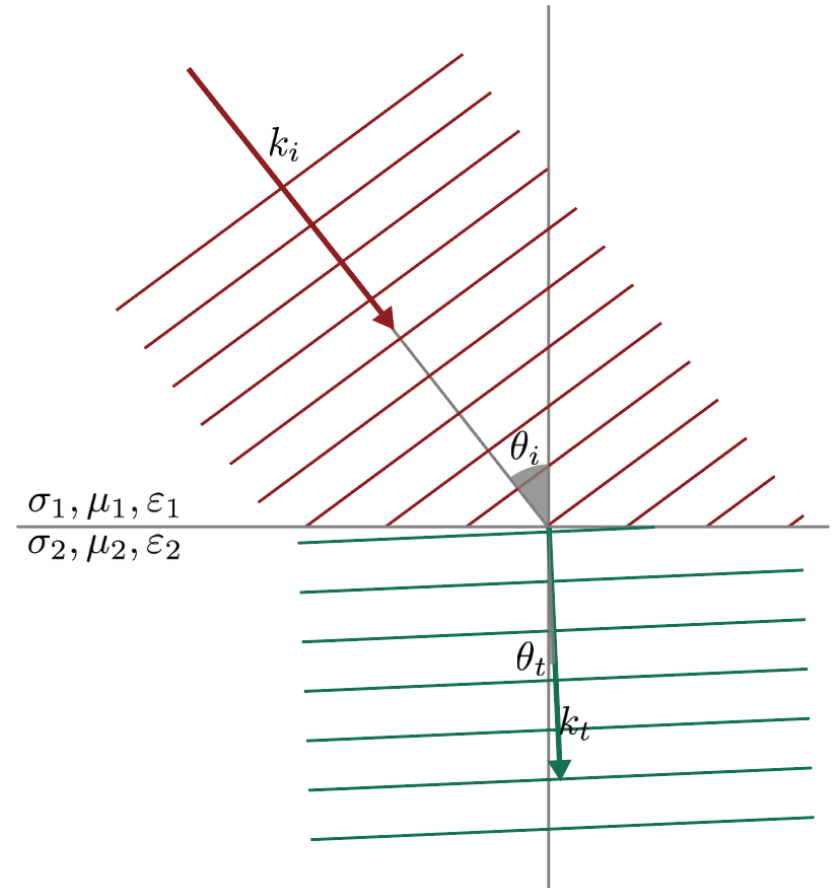
- k is complex wave number

$$k^2 = \omega^2 \mu \epsilon - i \omega \mu \sigma$$

- Quasi-static: $\frac{\omega \epsilon_0}{\sigma} \ll 1$

$$\sin \theta_t = \sqrt{\frac{2\omega \epsilon_0}{\sigma}} \sin \theta_i$$

- Angle of refraction is $\theta_t = 0^\circ$ in almost every instance



Example for 10,000 Hz

$$\sigma = 10^{-3} \text{ S/m}$$

$$\theta_i = 89^\circ$$

$$\text{Then } \theta_t = 1.35^\circ$$

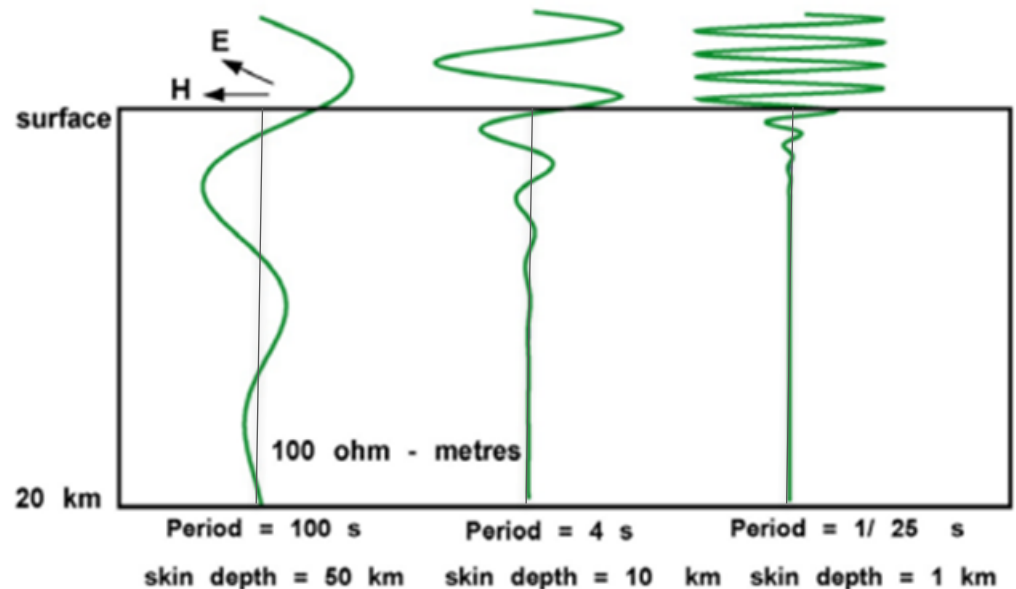
Plane waves and skin depth

- Skin depth (meters)

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = 503\sqrt{\frac{1}{\sigma f}}$$

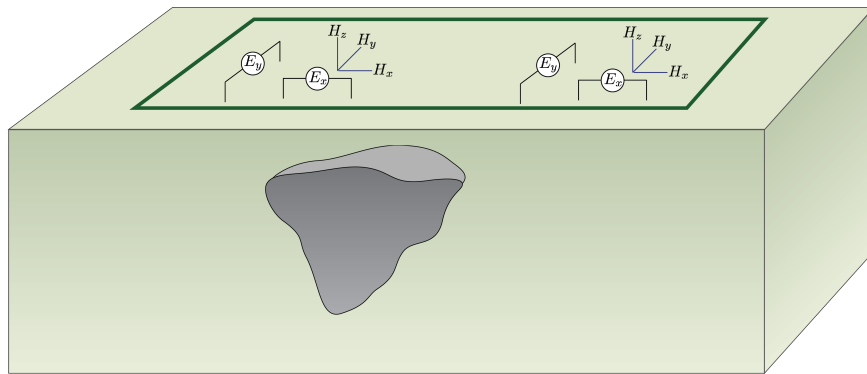
- Low frequency waves propagate further

- Depth of propagation
 - A few skin depths
 - Only a portion of a wavelength

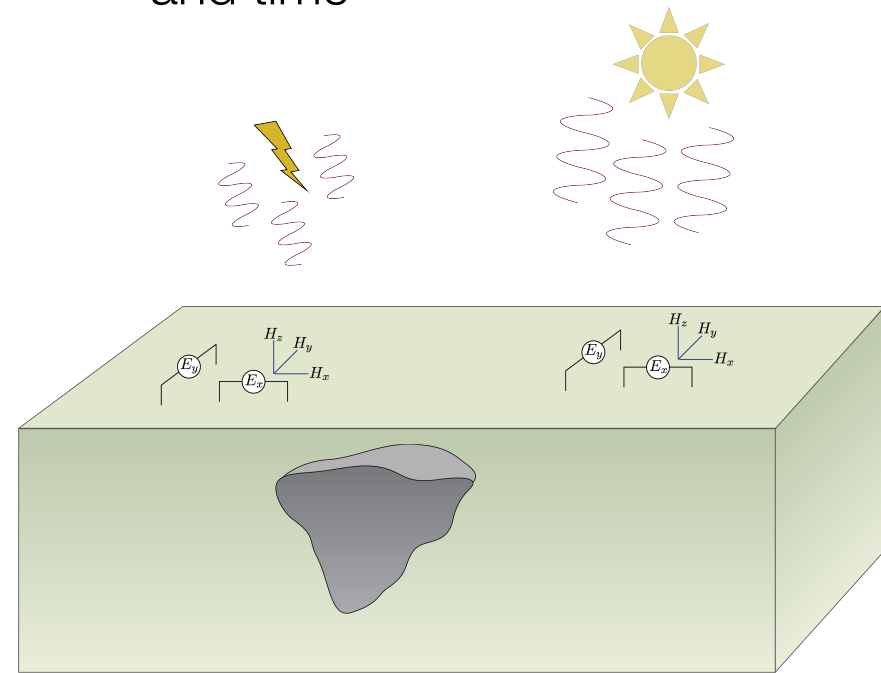


Control source vs Natural source

- Controlled source
 - Well-defined location, geometry, and amplitude



- Natural sources
 - Sources are random in space and time



MT Station

- Maxwell's equations:
 - Linear in J_s
 - E and H affected in the same way
- Effects of unknown source removed by taking ratio
- Transfer function

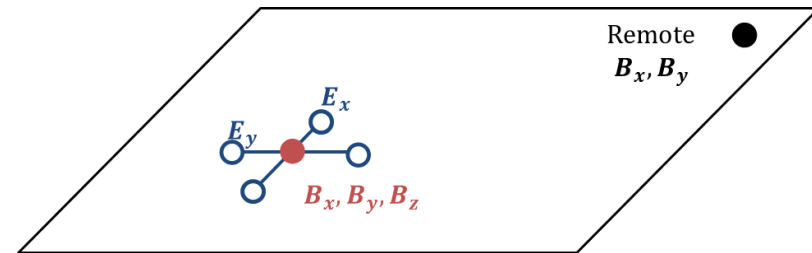
$$\nabla \times \mathbf{E} + i\omega\mu\mathbf{H} = 0$$

$$\nabla \times \mathbf{H} - \sigma\mathbf{E} = \mathbf{J}_s$$

$$\mathbf{E} = \mathbf{ZH}$$

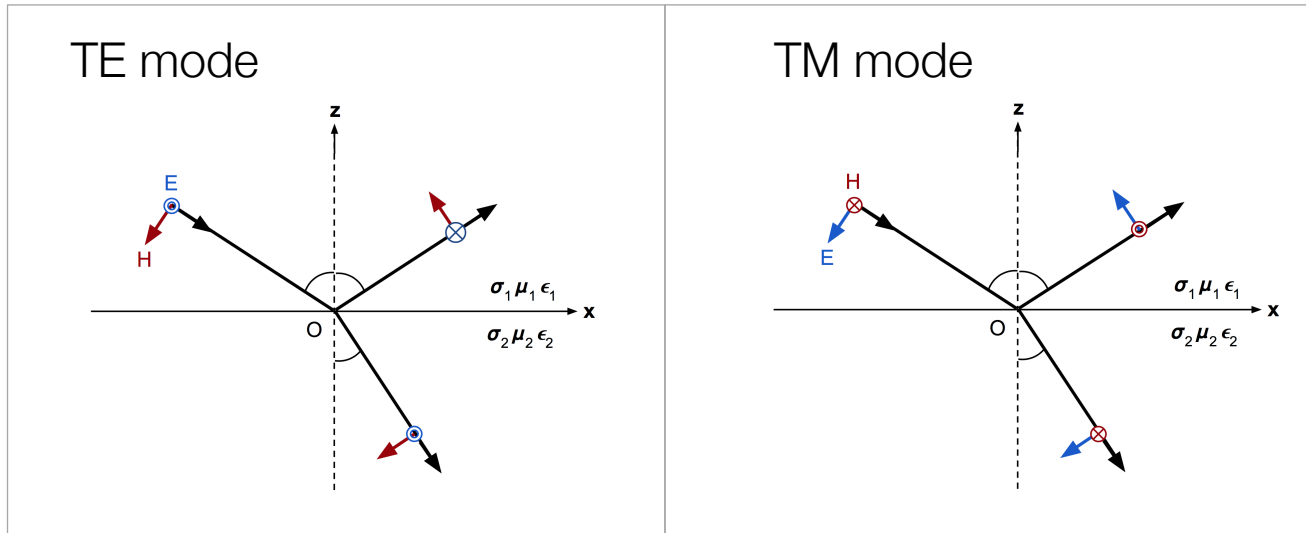
impedance (matrix)

$$\begin{pmatrix} E_x \\ E_y \end{pmatrix} = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix} \begin{pmatrix} H_x \\ H_y \end{pmatrix}$$



Impedance and resistivity

- Plane wave in homogenous media:
 - E and H fields are perpendicular



Homogeneous half space

<p>Impedance</p> $Z_{xy} = \frac{E_x}{H_y}$	<p>Resistivity</p> $\rho = \frac{1}{\omega\mu} Z_{xy} ^2$	<p>Phase</p> $\Phi = \tan^{-1} \left(\frac{\text{Im}(Z_{xy})}{\text{Re}(Z_{xy})} \right) = \frac{\pi}{4}$
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MT soundings in 1D

- In general:

$$Z = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix}$$

- Apparent resistivity:

$$\rho_a = \frac{1}{\omega\mu_0} |Z_{xy}|^2$$

- Phase:

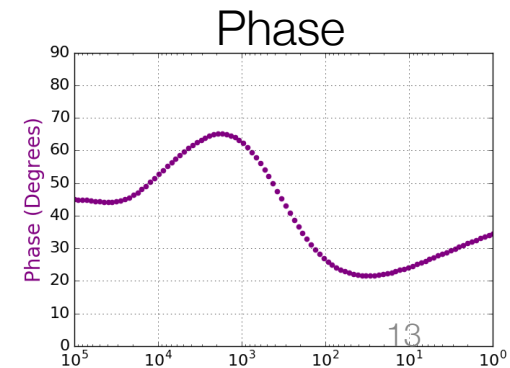
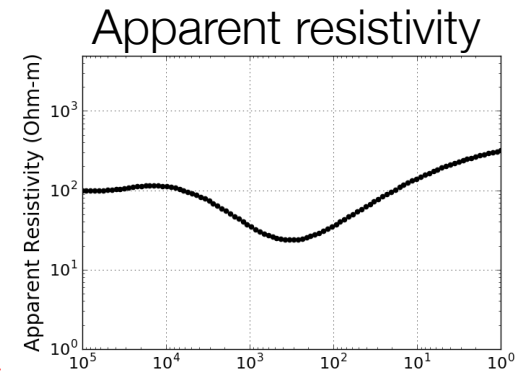
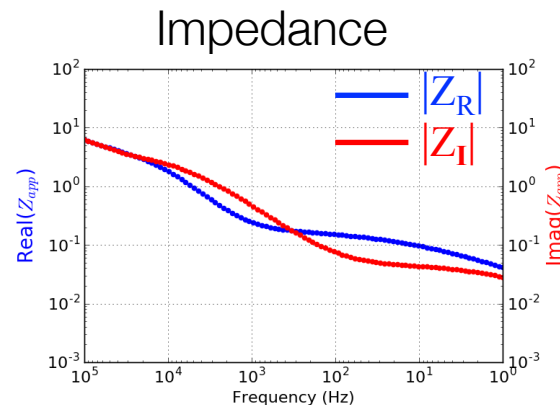
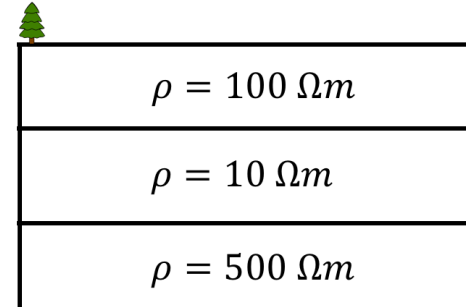
$$\Phi = \tan^{-1} \left(\frac{\text{Im}(Z_{xy})}{\text{Re}(Z_{xy})} \right)$$

- In 1D:

$$Z = \begin{pmatrix} 0 & Z_{xy} \\ Z_{yx} & 0 \end{pmatrix}$$

$$Z_{xy} = \frac{E_x}{H_y}$$

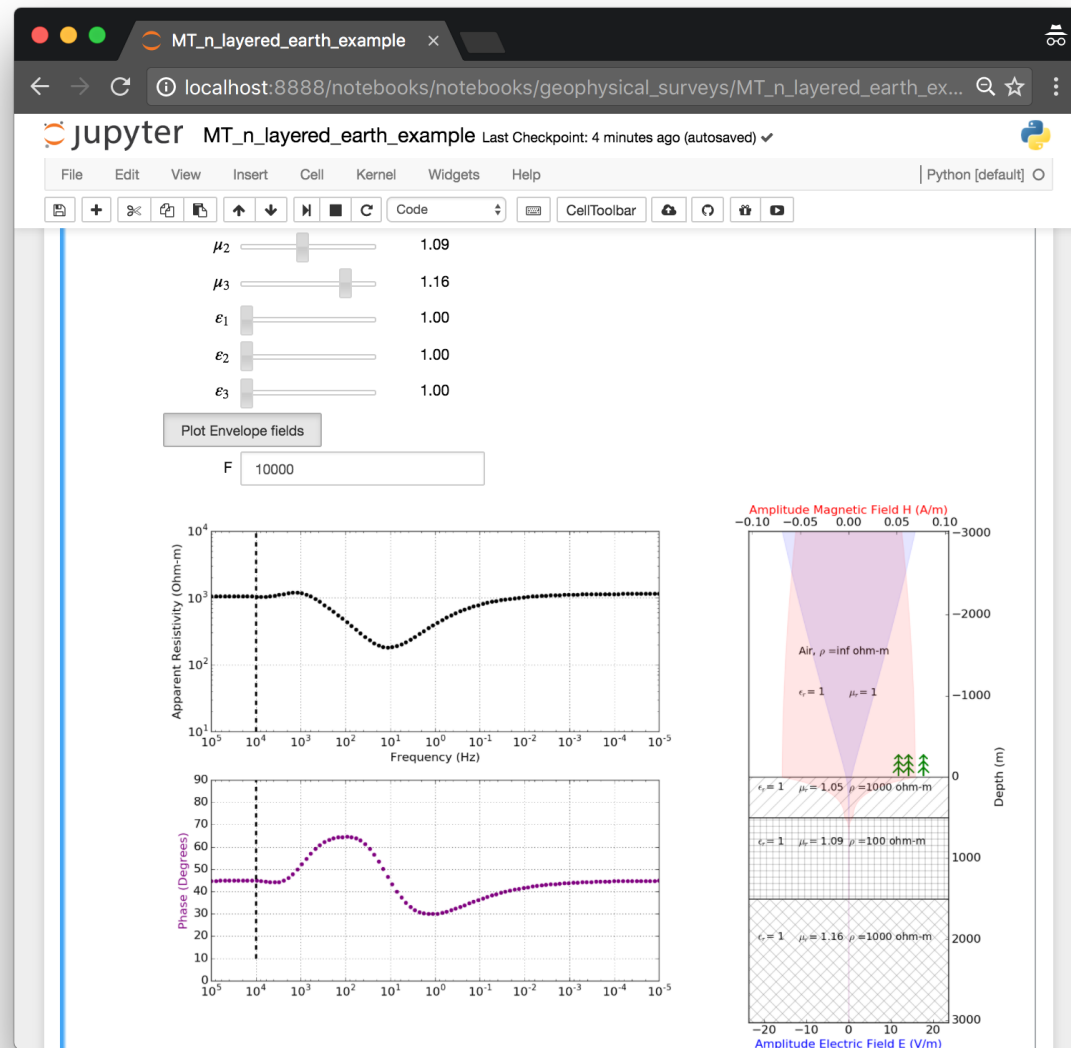
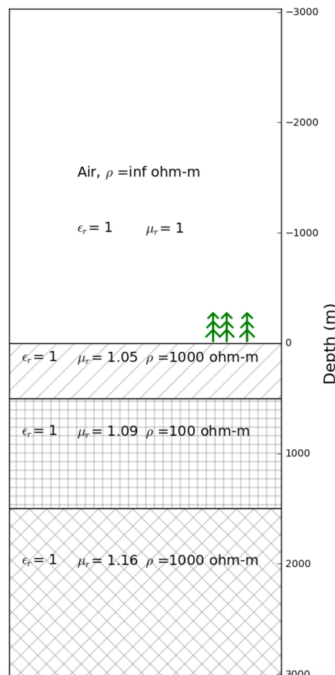
$$Z_{yx} = -Z_{xy}$$



1D MT app

$$\nabla \times \mathbf{E} + i\omega\mu\mathbf{H} = 0$$

$$\nabla \times \mathbf{H} - \sigma\mathbf{E} = \mathbf{J}_s$$



MT soundings in 2D

- In general:

$$Z = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix}$$

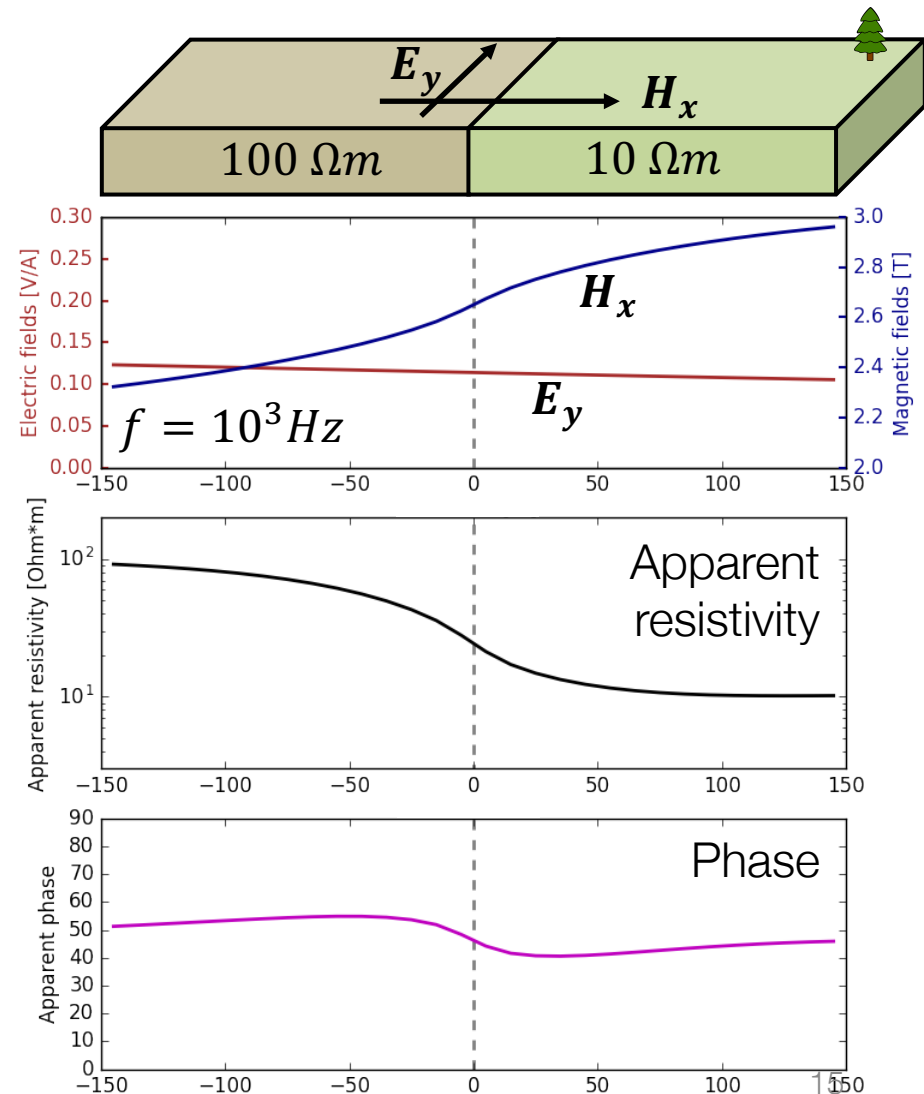
- In 2D:

$$Z = \begin{pmatrix} 0 & Z_{xy} \\ Z_{yx} & 0 \end{pmatrix}$$

$$Z_{xy} \neq Z_{yx}$$

- TE mode
 - E-field parallel to structure

$$Z_{yx} = \frac{E_y}{H_x}$$



MT soundings in 2D

- In general:

$$Z = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix}$$

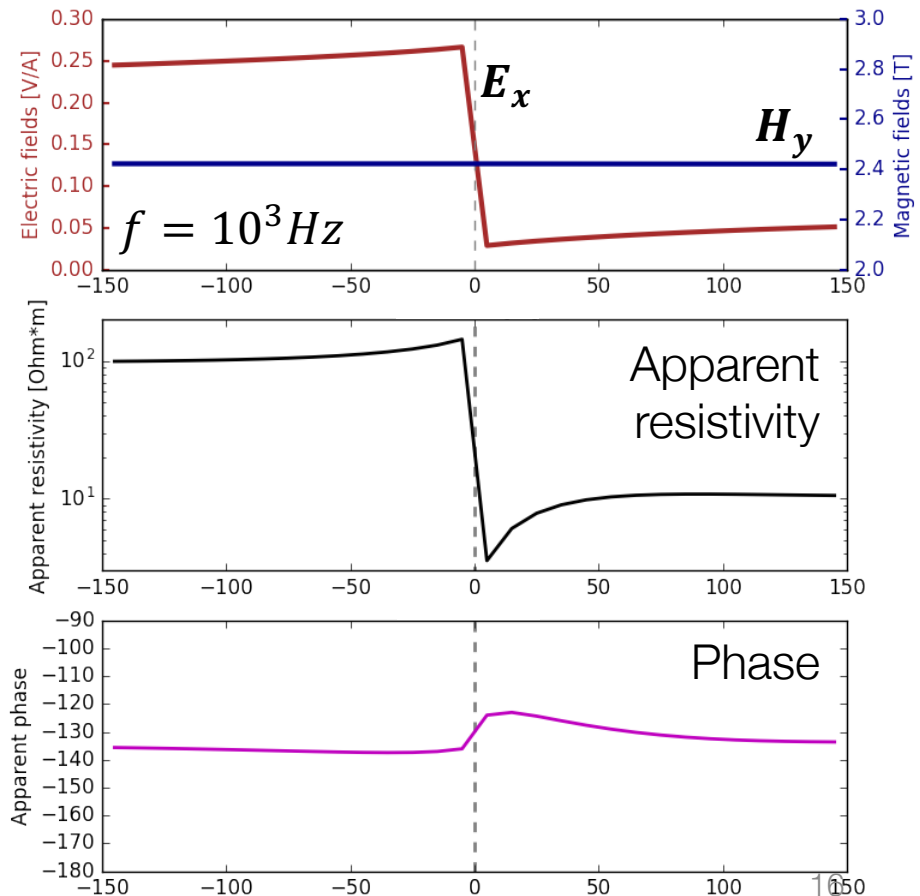
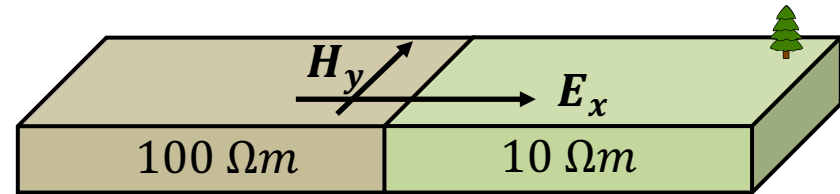
- In 2D:

$$Z = \begin{pmatrix} 0 & Z_{xy} \\ Z_{yx} & 0 \end{pmatrix}$$

$$Z_{xy} \neq Z_{yx}$$

- TM mode
 - H-field parallel to structure
 - E_x discontinuous

$$Z_{xy} = \frac{E_x}{H_y}$$



MT soundings in 3D

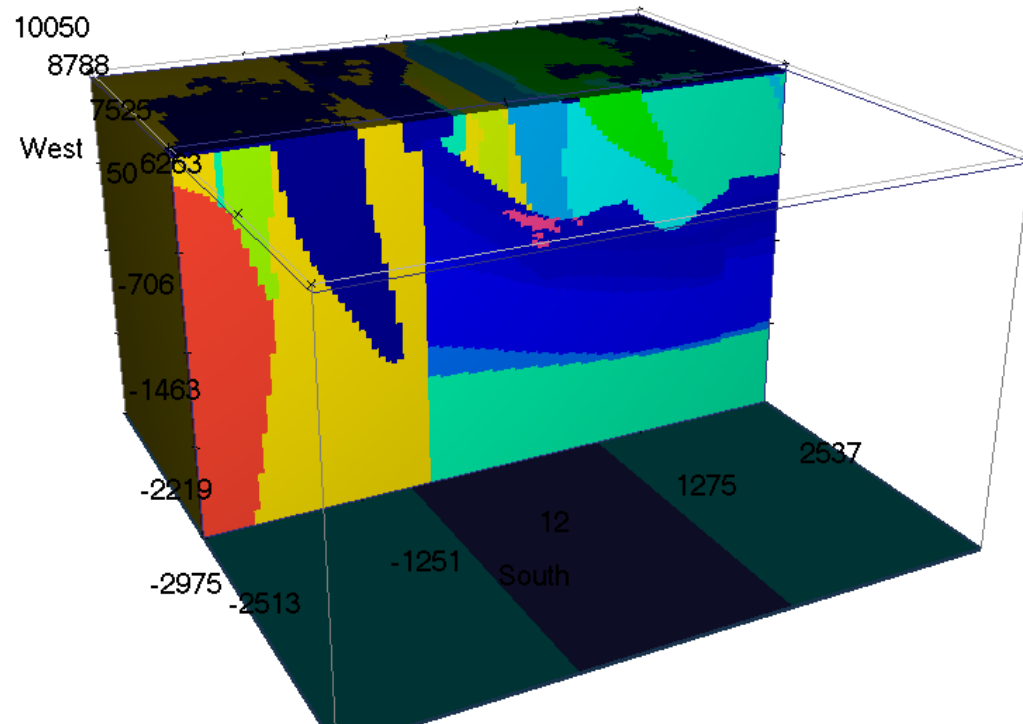
- In general:

$$Z = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix}$$

- In 3D:

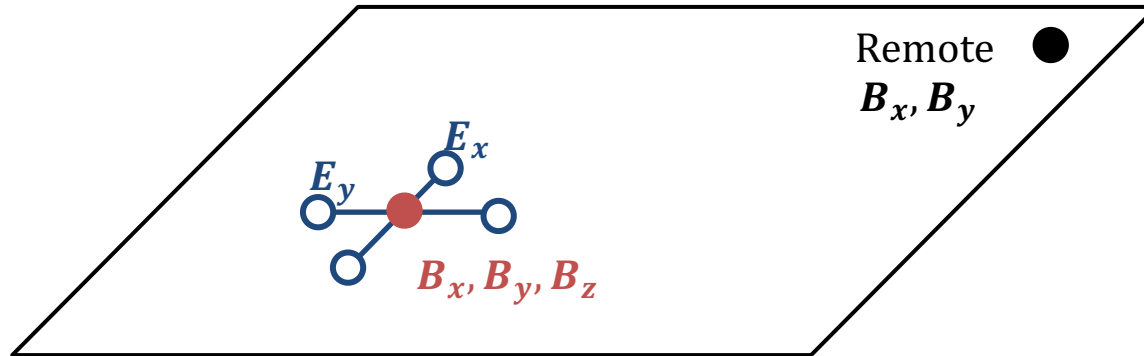
$$Z = \begin{pmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{pmatrix}$$

- No symmetry or special conditions



Measuring MT data

- Basic acquisition

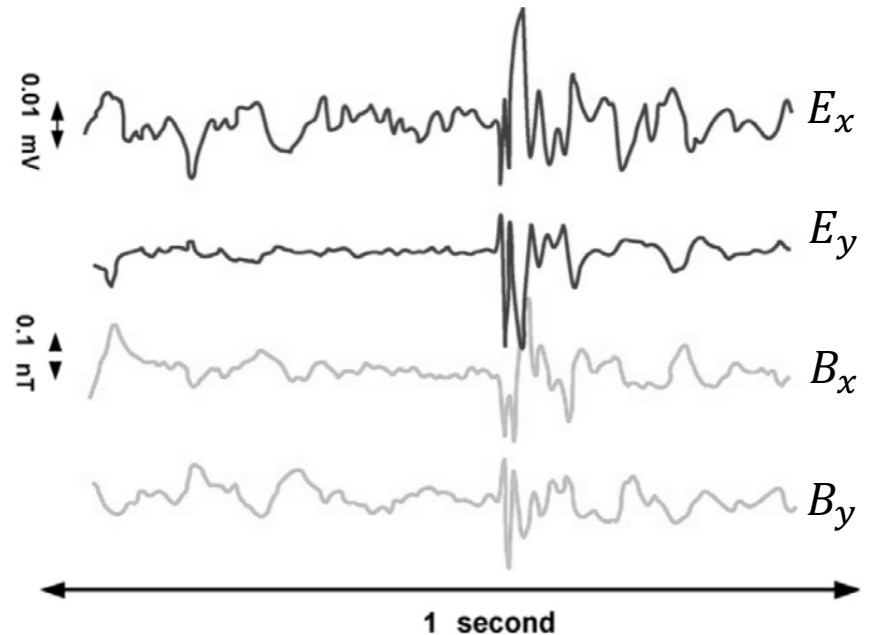


- At each station, measure:

$$E_x, E_y, B_x, B_y, B_z$$

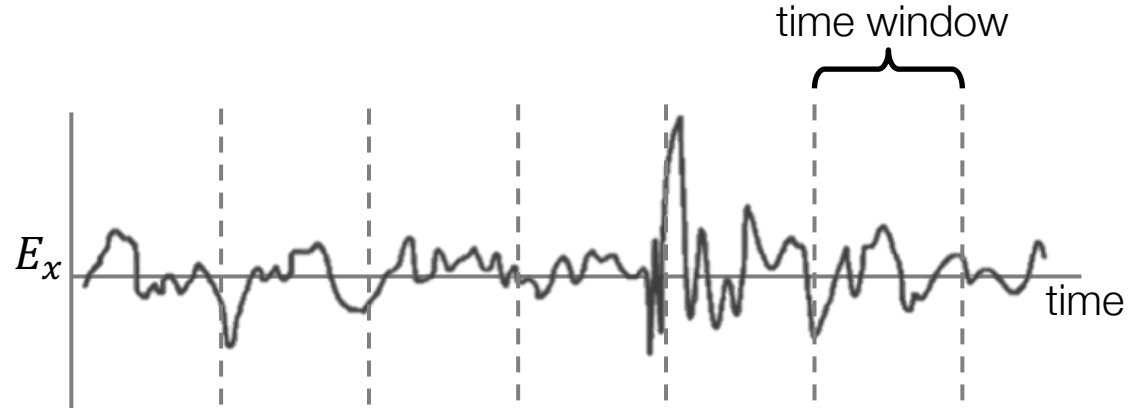
- At remote reference, measure:

$$B_x, B_y$$



Processing MT data

- Divide time series into time windows



- Apply Fourier transform
 - For each station:

$$\begin{aligned} e_x(t) &\rightarrow E_x(\omega) \\ h_y(t) &\rightarrow H_y(\omega) \end{aligned}$$

- For the remote reference:

$$h_y^R(t) \rightarrow H_y^R(\omega)$$

- Form the impedance tensor:

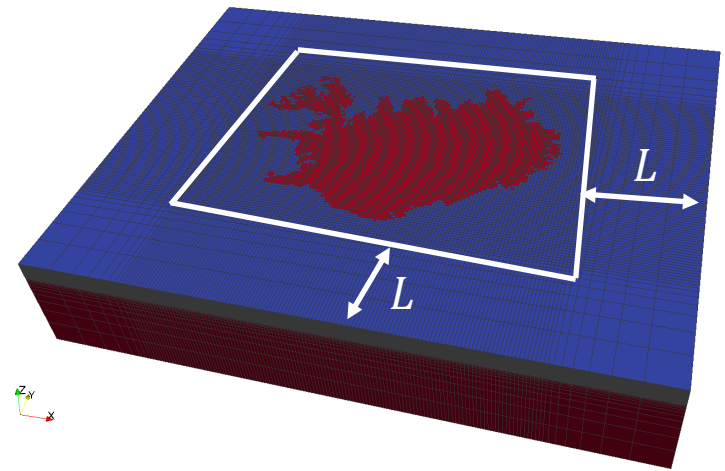
$$Z_{xy}(\omega) = \frac{\langle E_x(\omega) H_y^{R*}(\omega) \rangle}{\langle H_y(\omega) H_y^{R*}(\omega) \rangle}$$

(*) complex conjugate

<> average over multiple samples

Inverting MT data

- Boundary conditions important for modelling
- Mesh size:
 - MT: extended grid
 - L : a few skin depths from data area
- Challenge: Unknown boundary conditions
 - Possible channeled currents
 - Data can be affected by distant structures
- Otherwise, inversion of MT is essentially same as CSEM data

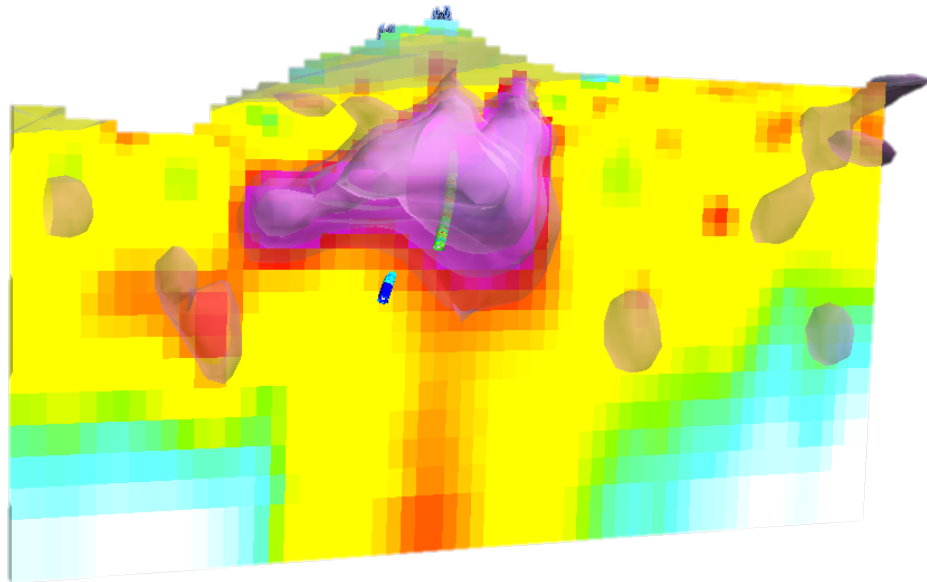


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- Magnetotellurics
- Case history: Minerals
- Z-axis tipper electromagnetics
- Case histories (ZTEM): Geologic Mapping, Minerals

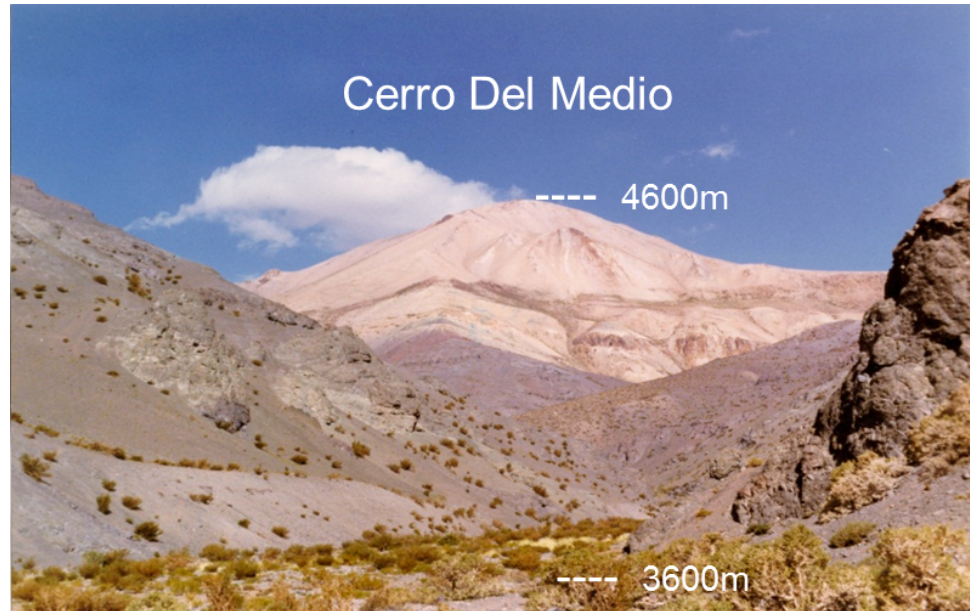
Case History: Santa Cecilia Porphyry System, Chile

Bournas and Thomson, 2013



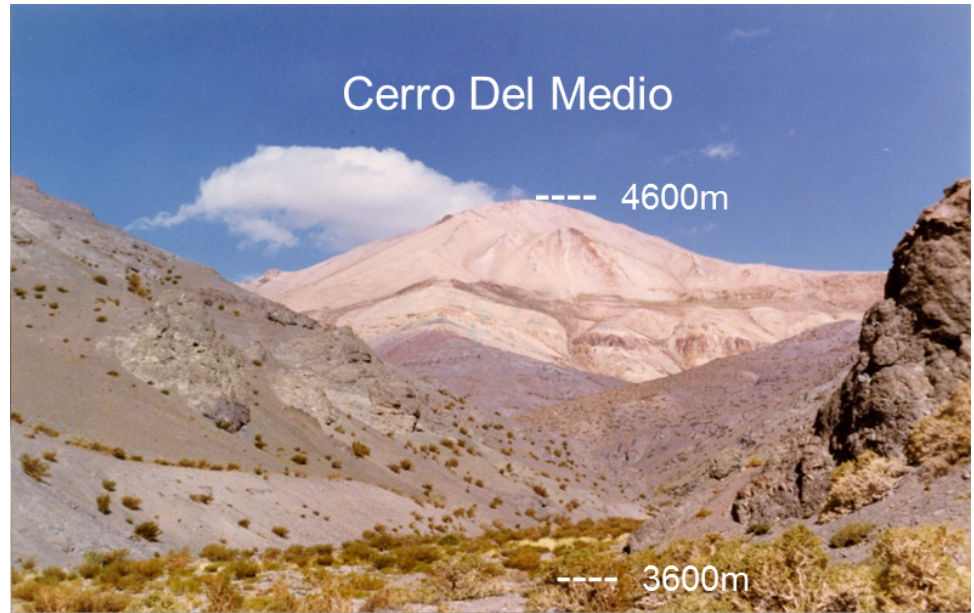
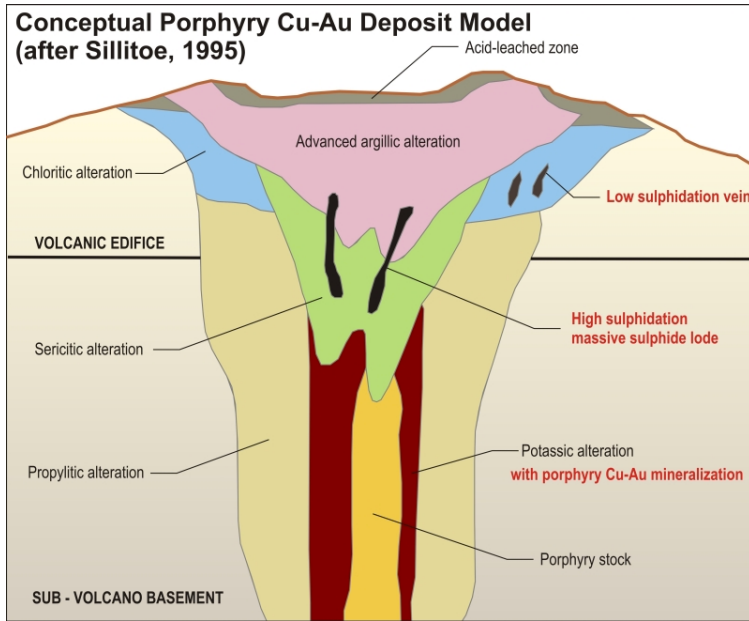
Thanks to Rob Hearst at [Quantec](#)

Setup



- Within the Maricunga Metallogenic Belt which hosts known gold-copper deposits
- Intense hydrothermal alteration (elevation between 3600 – 4600 m)
- Main mineralization: gold, silver, and copper

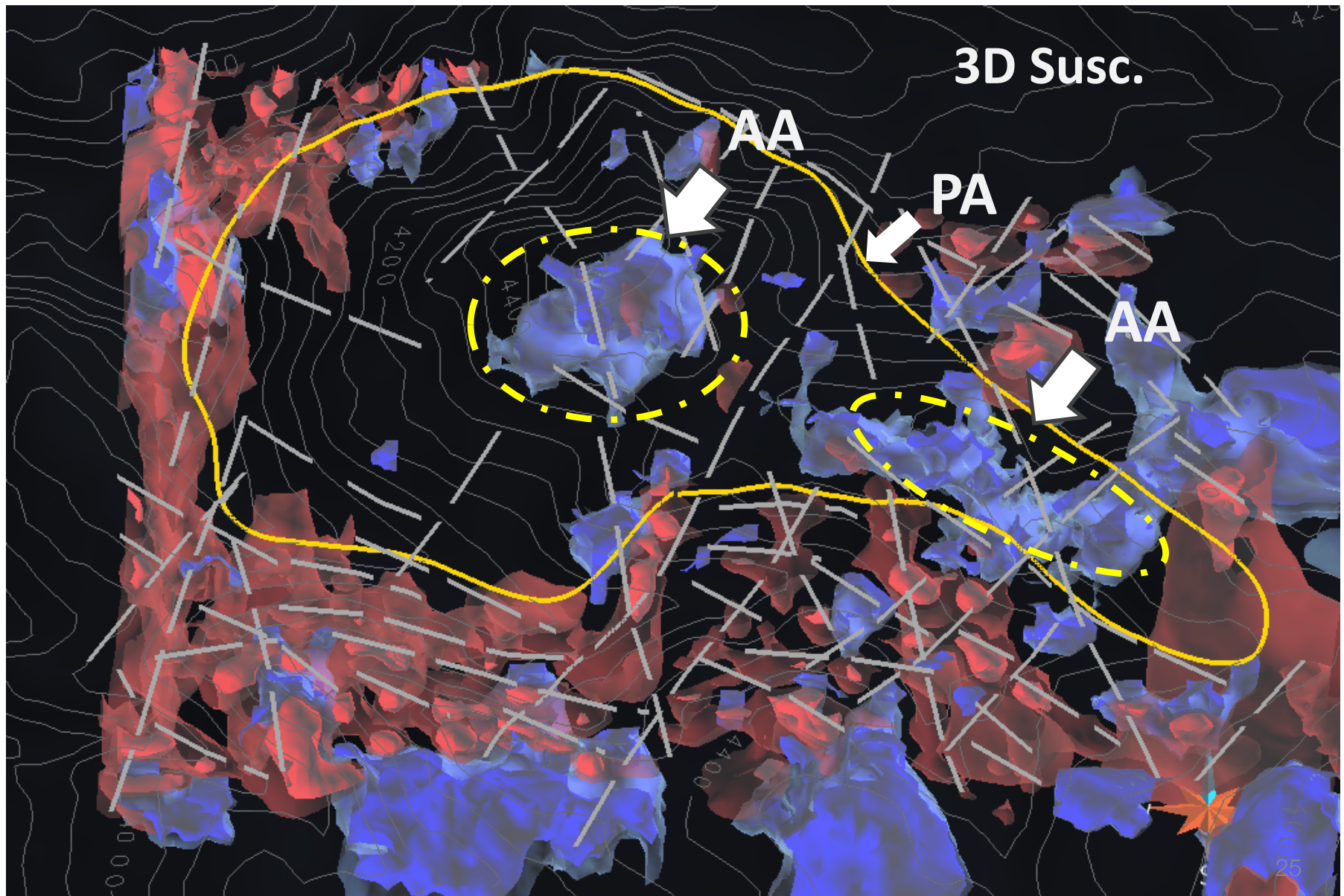
Setup



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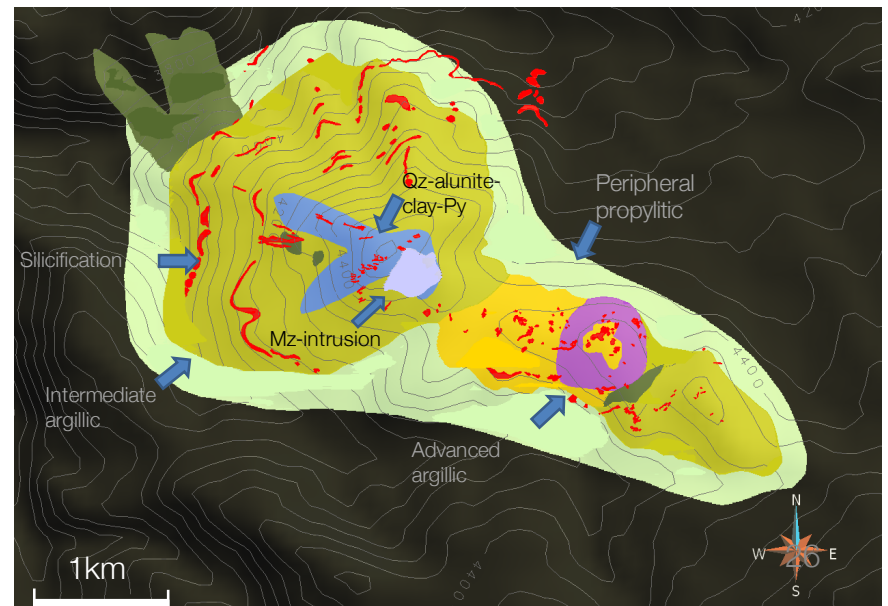
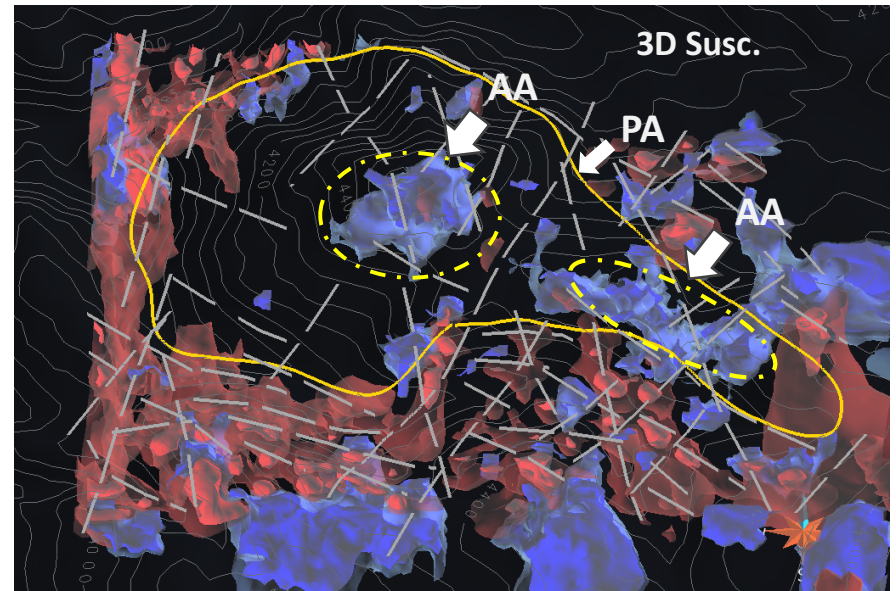
Can we image the porphyry system?

Setup: Ground Magnetics Inversion

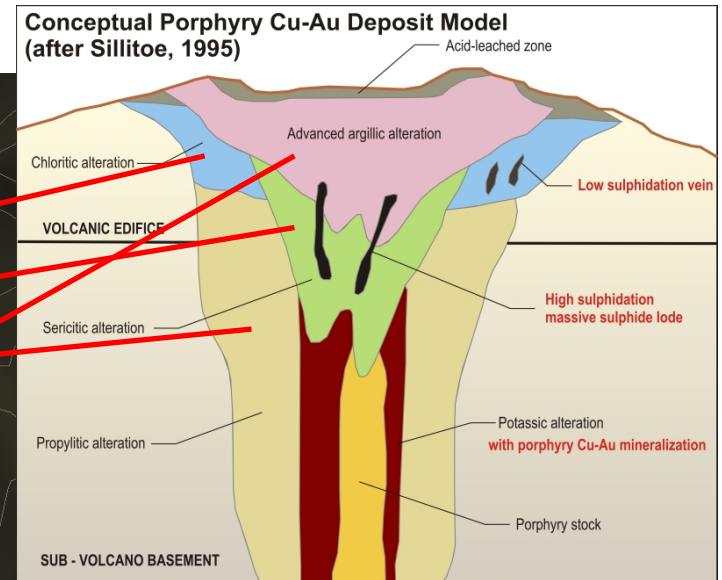
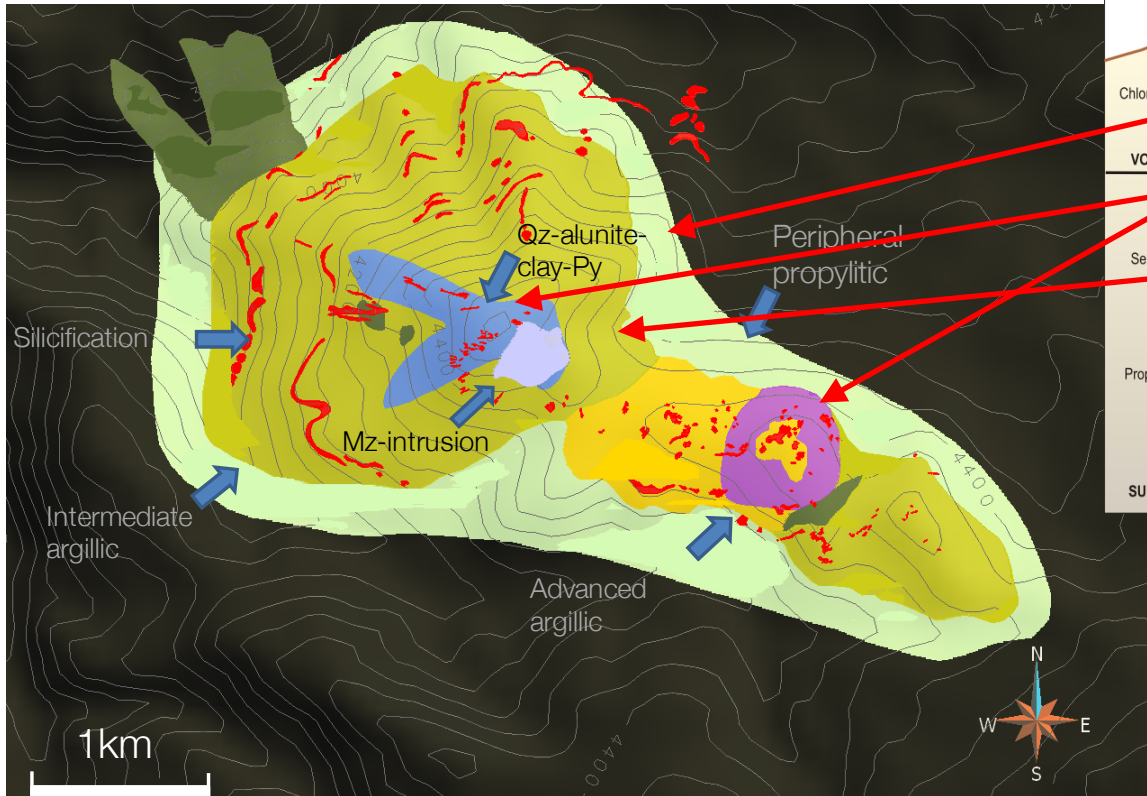


Setup: Discovery

- Ground magnetic data
 - Delineate alteration zones
- Mobile Metal Ion (MMI)
 - Gold and copper anomalies
- CSAMT
 - To test MMI
 - Found large conductor
- Two discovery holes
- ORION 3D: DC/IP & MT

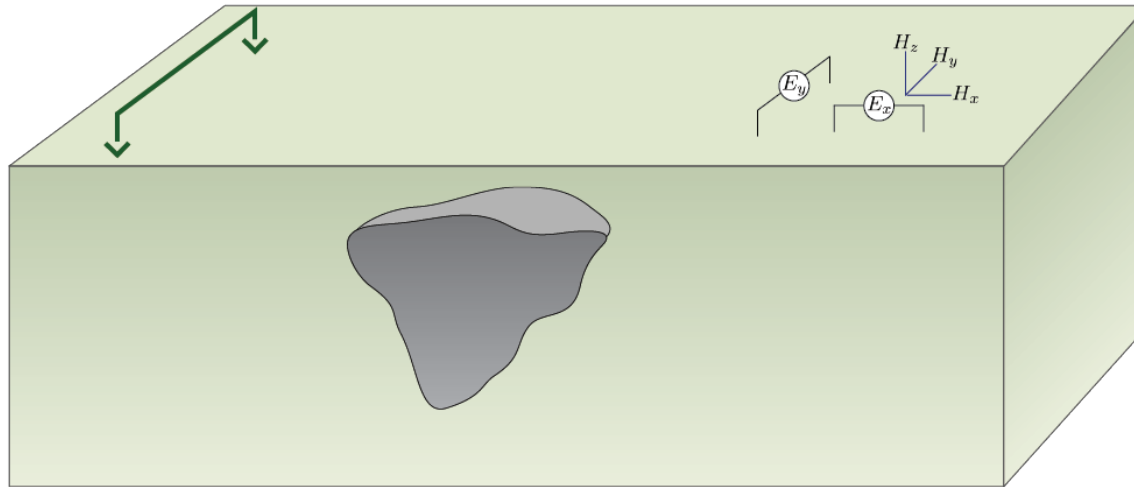


Properties



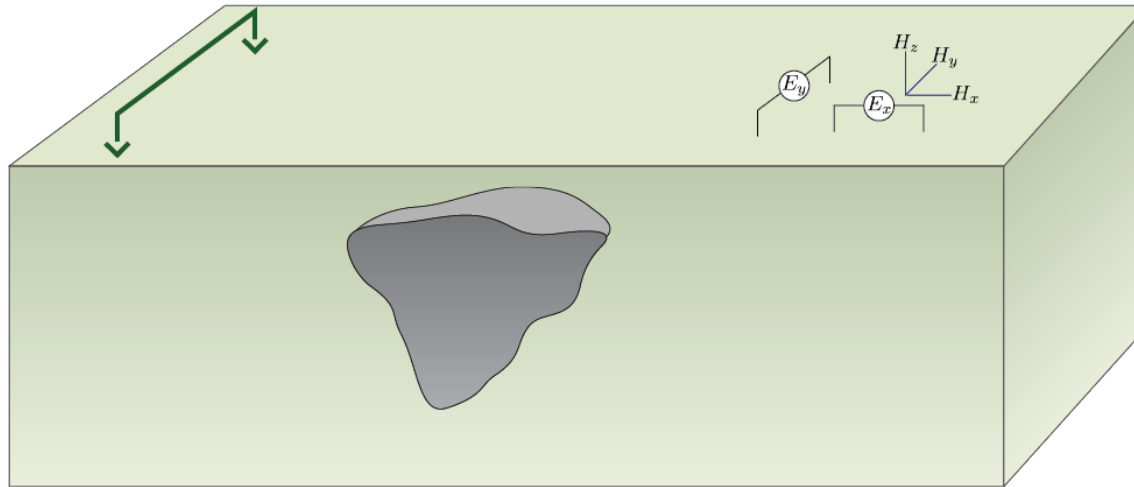
Units	Resistivity	Chargeability	Susceptibility
Host rock	High	None	Moderate
Stock	Moderate	Low	Moderate
Alteration zones	Low - Mod.	Mod. - High	Low

CSAMT



- Controlled Source Audio Magnetotellurics
- Plane wave assumption
 - Receivers need to be far away from source (several skin depths)
- Uses MT inversion algorithm

Survey: Discovery

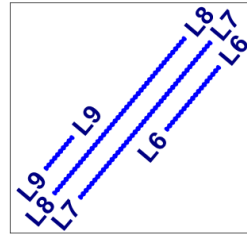
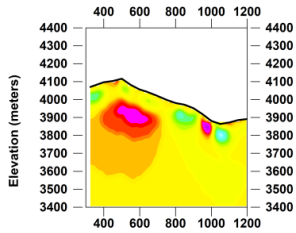


- Controlled Source Audio Magnetotellurics
- Transmitter
 - 3.5 km dipole
 - Frequencies: 2-9000 Hz
- Receivers
 - 10 km from source

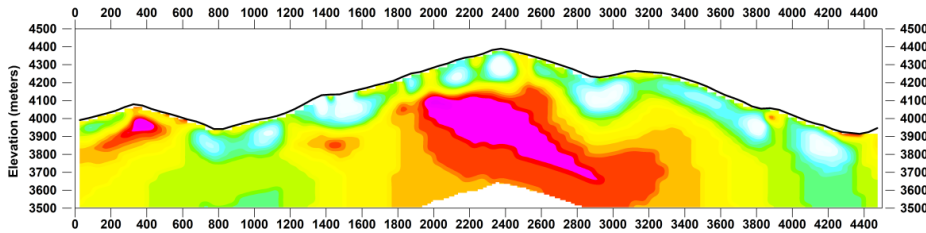
Processing: Discovery

2D resistivity sections

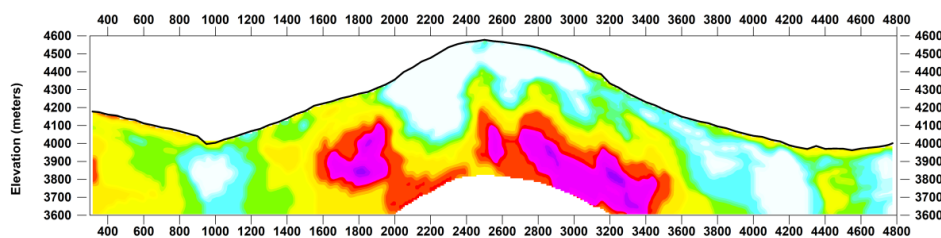
L9 2-D RLM Inversion



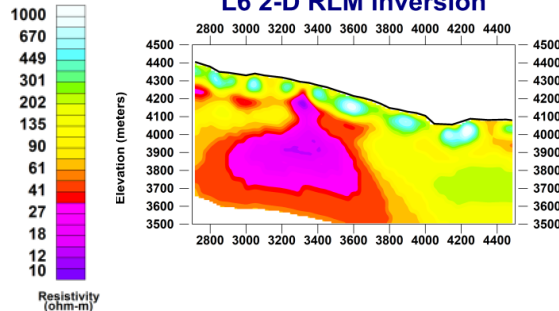
L8 2-D RLM Inversion



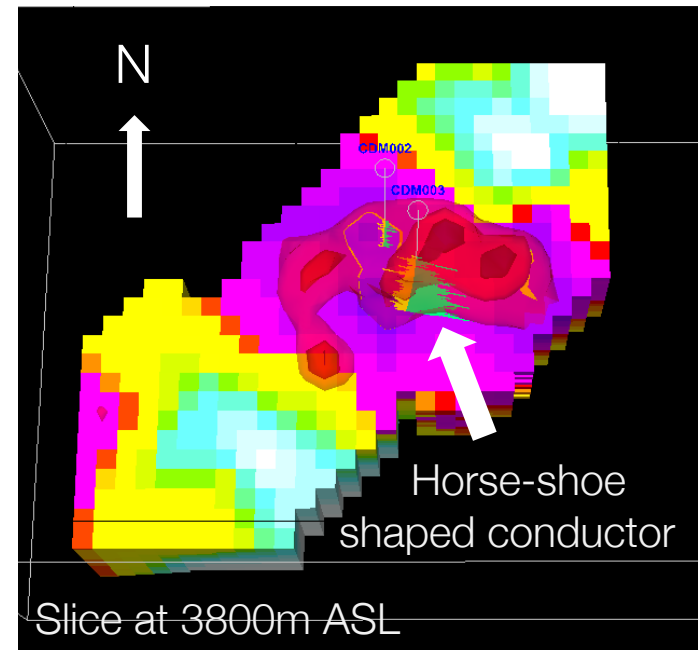
L7 2-D RLM Inversion



L6 2-D RLM Inversion

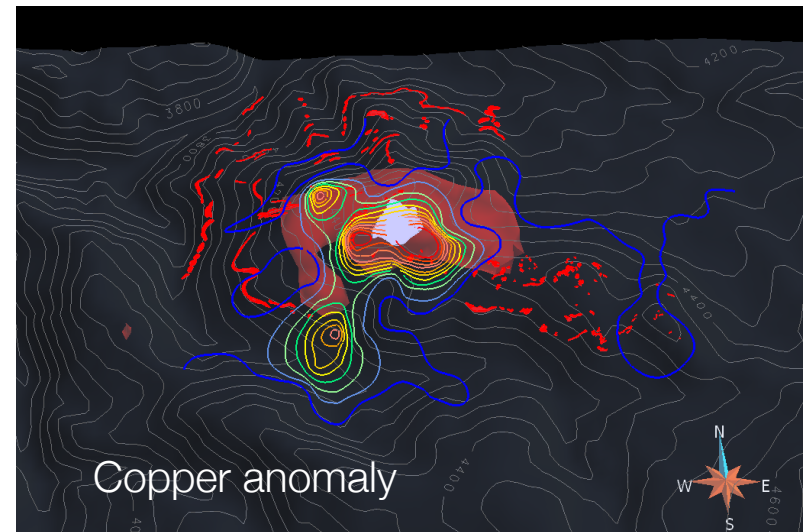
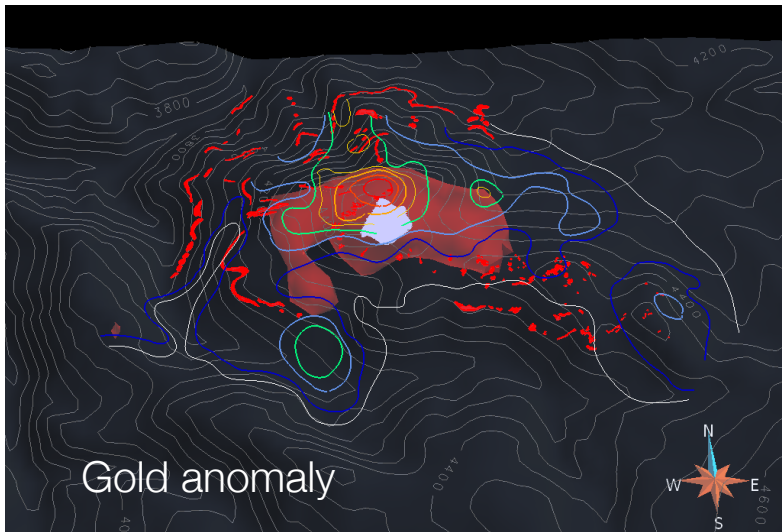


- Recovered horse-shoe shaped conductor



Interpretation and Synthesis: Discovery

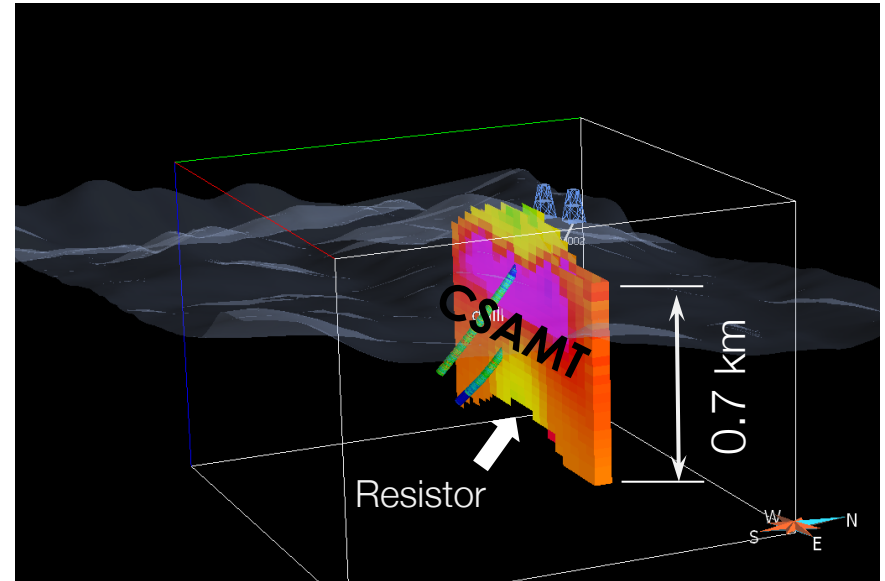
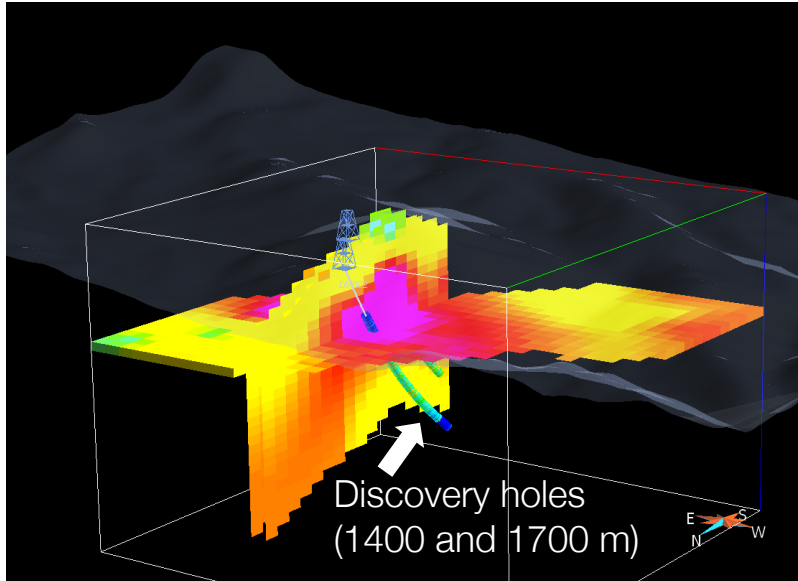
3D cut-off volume from CSAMT



- Recovered conductor consistent with Au and Cu anomalies from MMI

Interpretation and Synthesis: Discovery

2D resistivity sections with drill holes

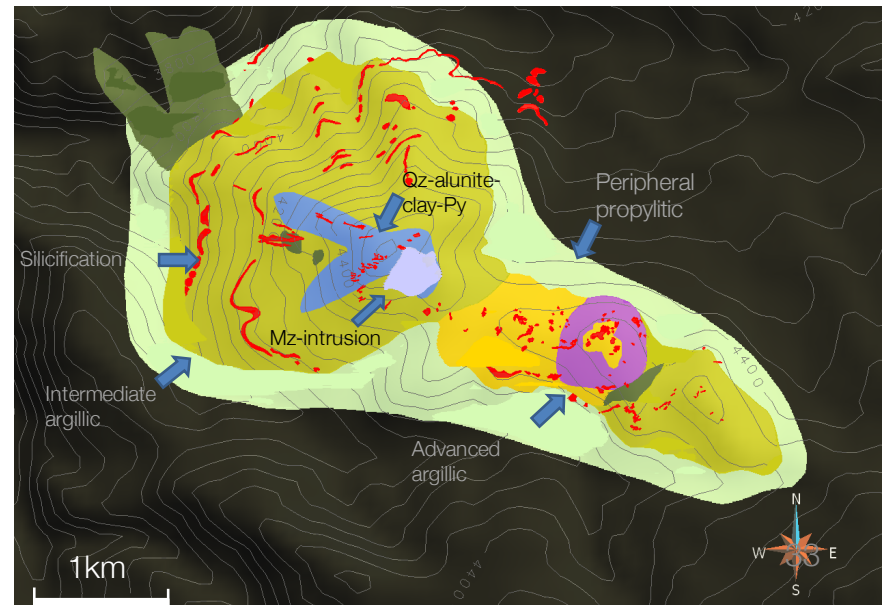
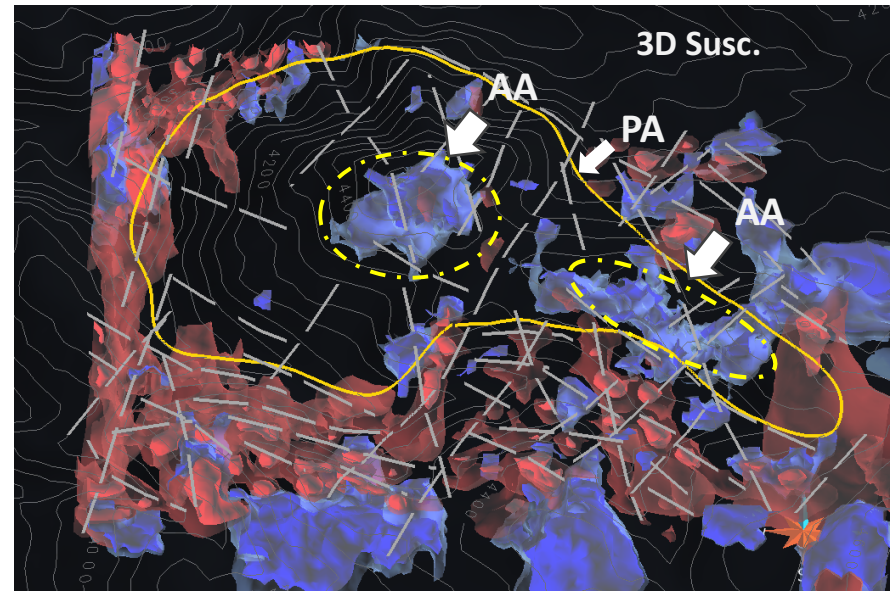


- Two holes are drilled and found mineralized zones (2011)
- Mineralization extends beyond CSAMT conductor
 - Lowest frequency in CSAMT (24 Hz, $\rho=10$ ohm-m)

$$\delta = 500 \sqrt{\frac{\rho}{f}} \sim 325 \text{ m}$$

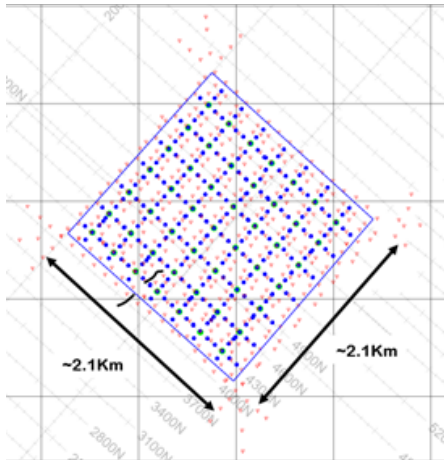
Setup: Evaluation

- Ground magnetic data
 - Delineate alteration zones
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 - To test MMI
 - Found large conductor
- Two discovery holes
 - Need to see deeper...
- ORION 3D: DC/IP & MT

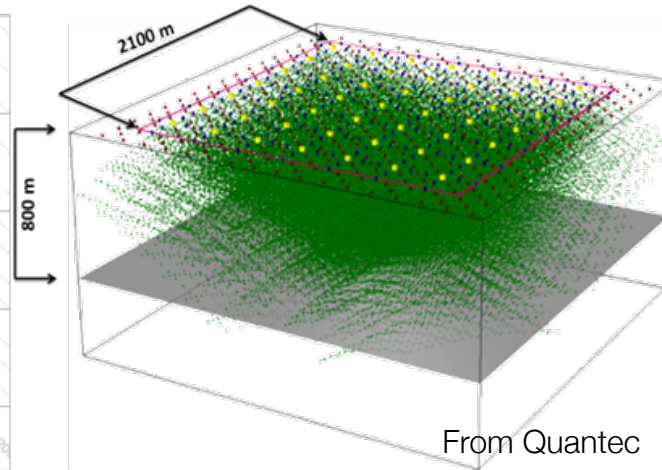


Survey: Evaluation

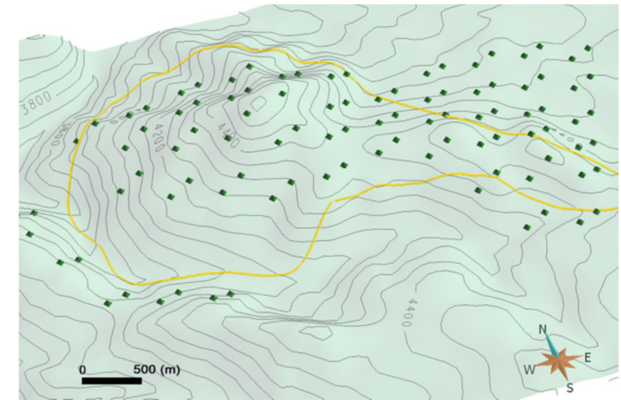
Orion 3D survey



Layout



Coverage



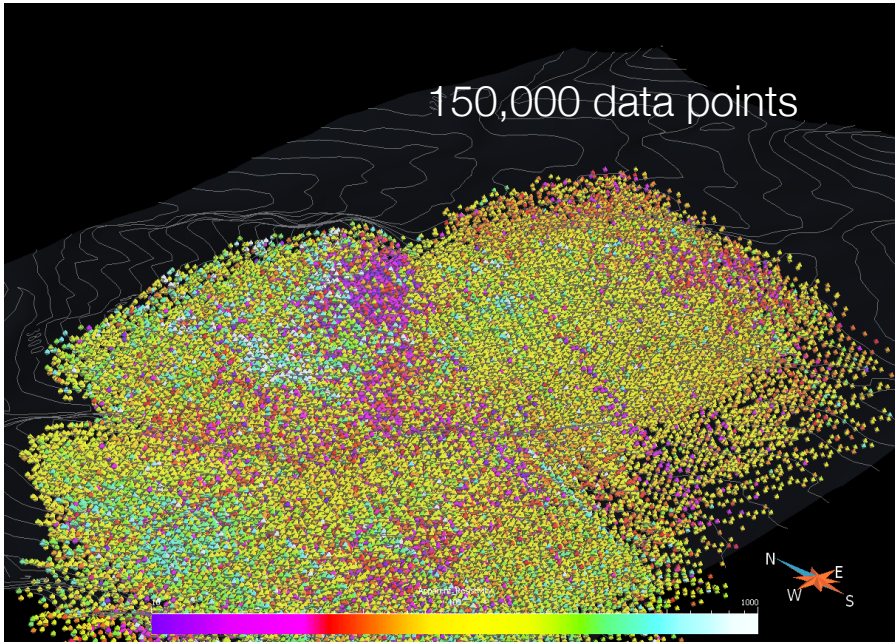
100 MT sites

- DC-IP
 - 539 transmits
 - 200 receiver dipoles
 - Pole-dipole
 - 150 m dipole length

- MT
 - 150 m dipole length
 - Two orthogonal induction coils
 - 450 m spacing
 - Acquired over night
 - Frequency range: 250-0.001 Hz

DC Data

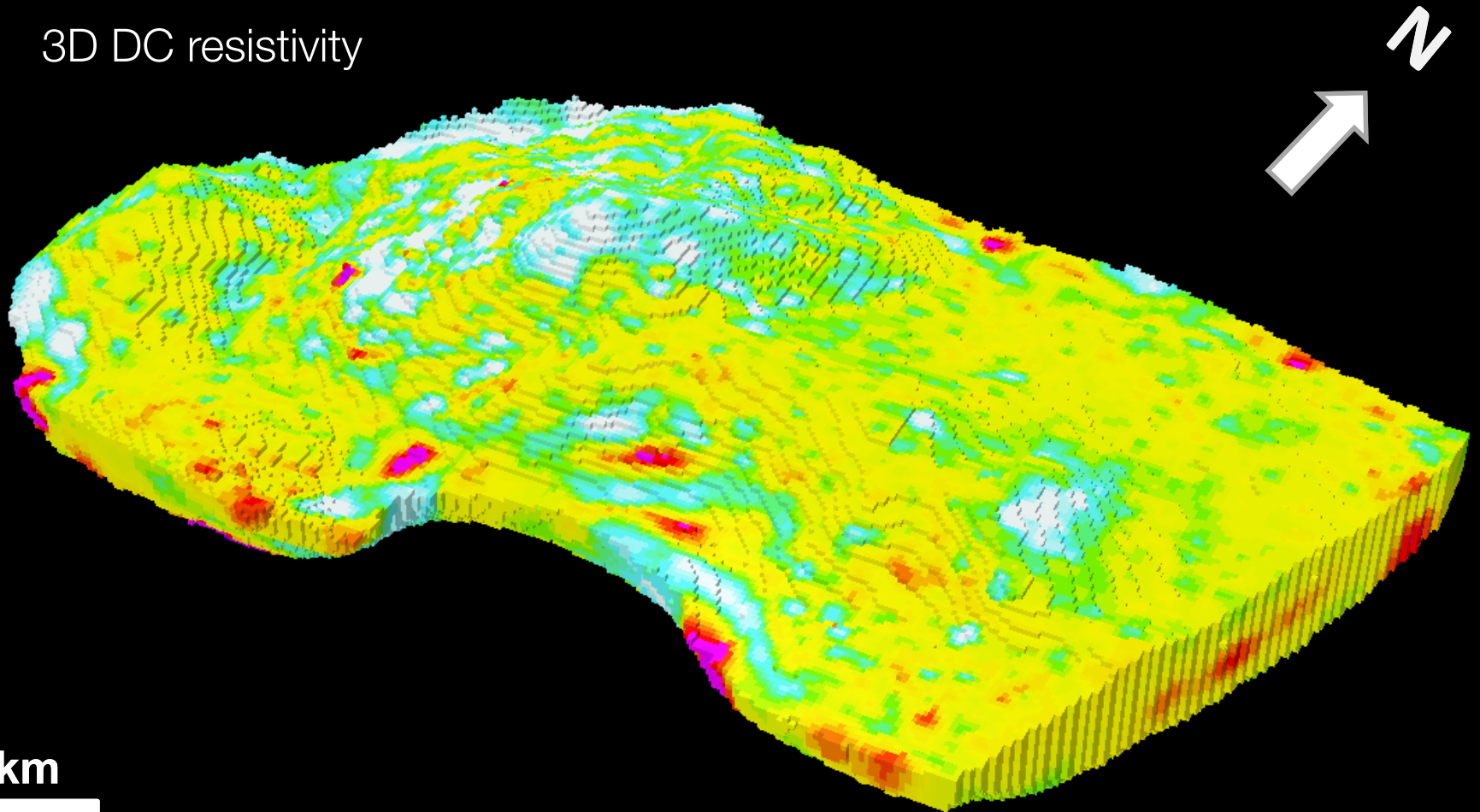
Apparent resistivity



- 150,000 data points from
 - 540 sources
 - 300 dipole receivers
- Hard to visualize and interpret data
- Need to invert

Processing: DC inversion

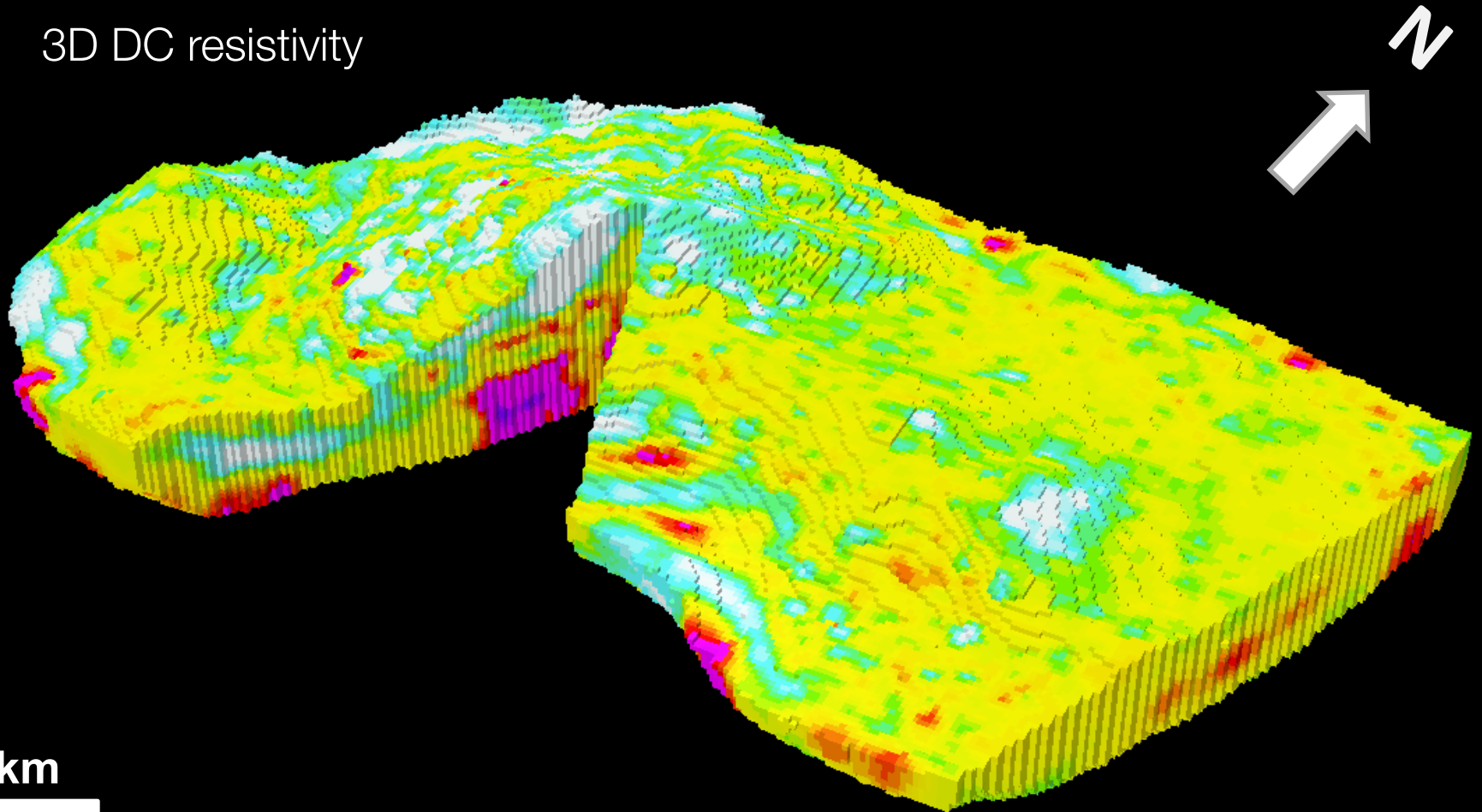
3D DC resistivity



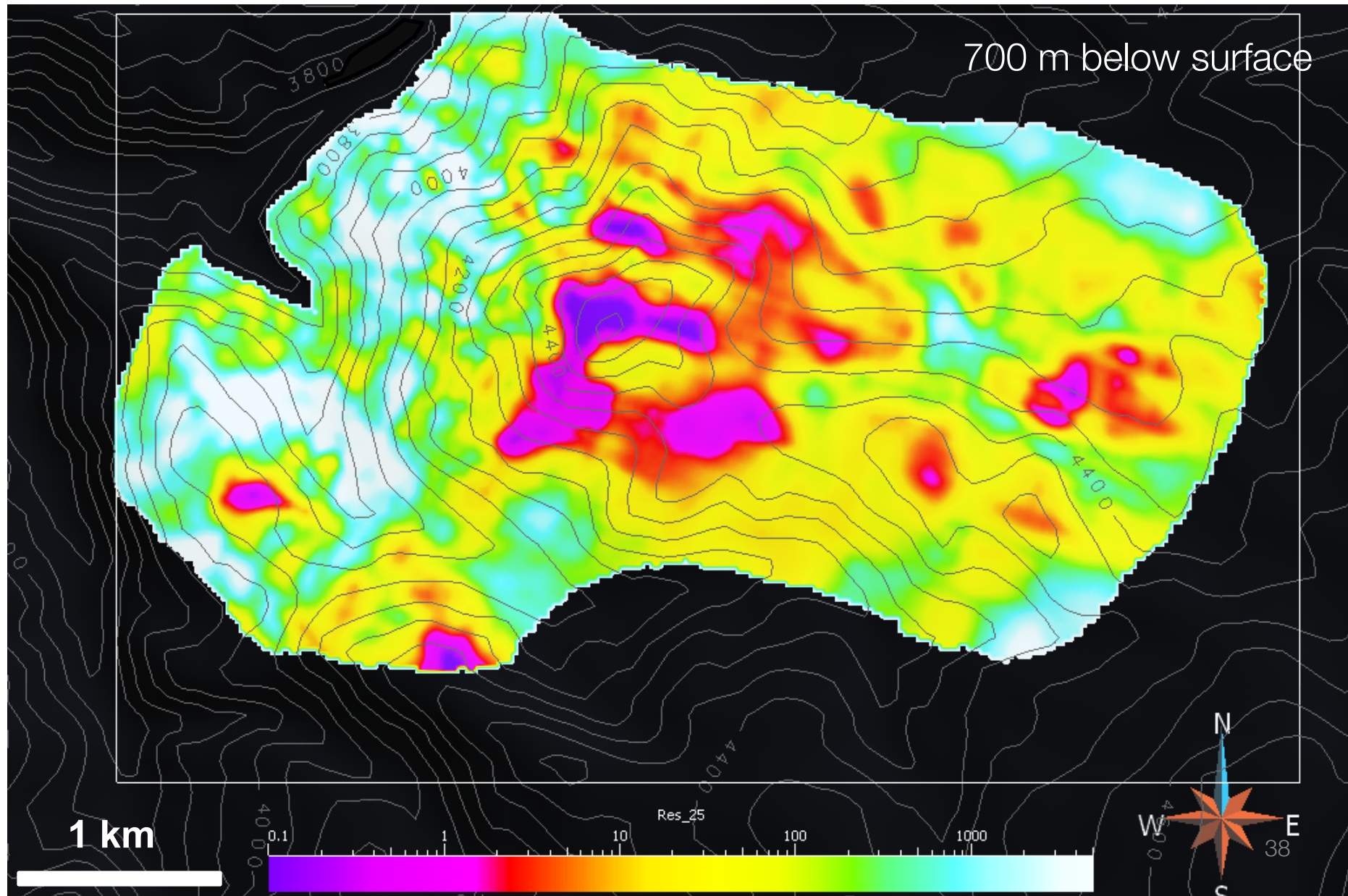
1 km

Processing: DC inversion

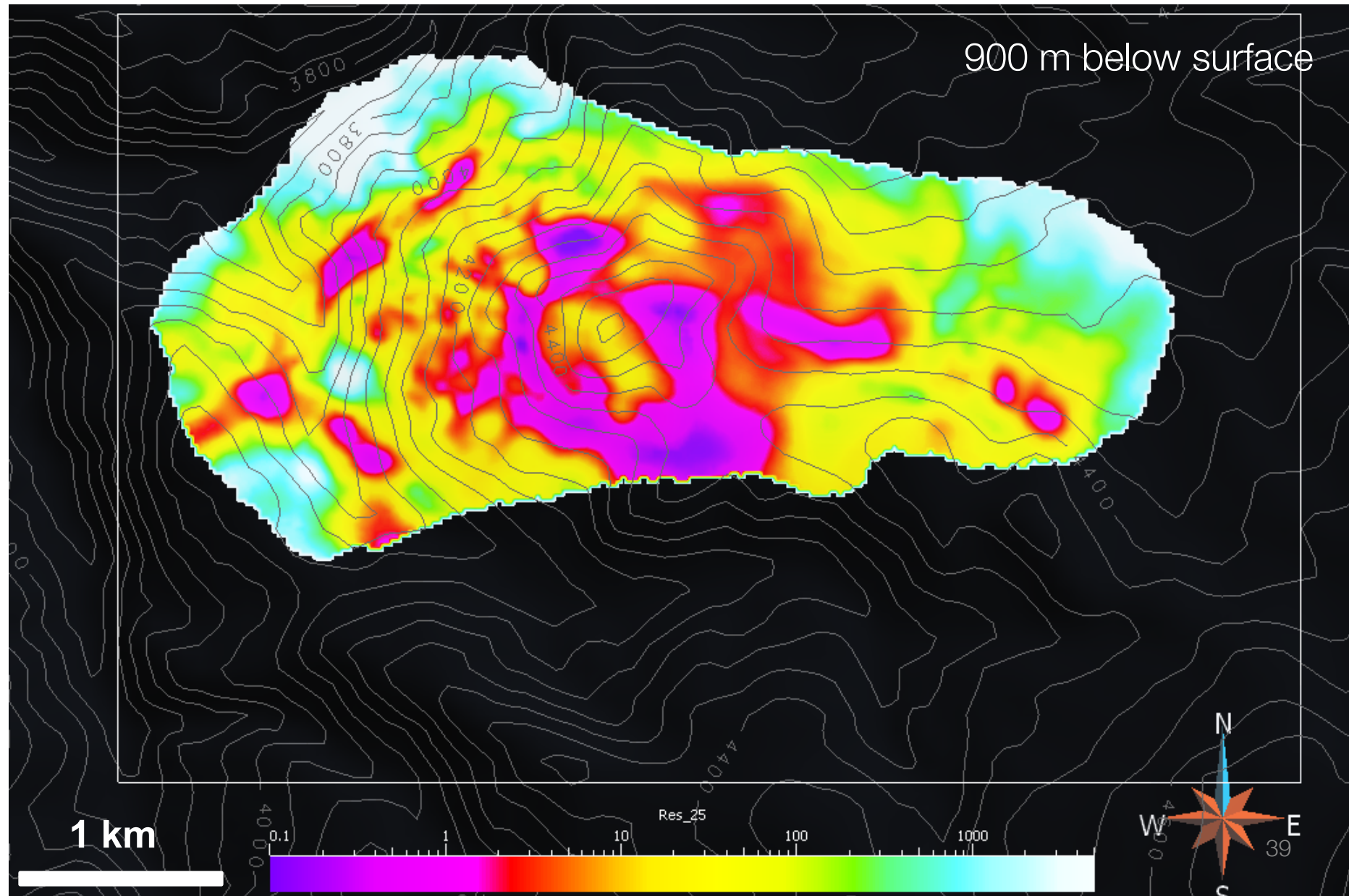
3D DC resistivity



Processing: DC inversion



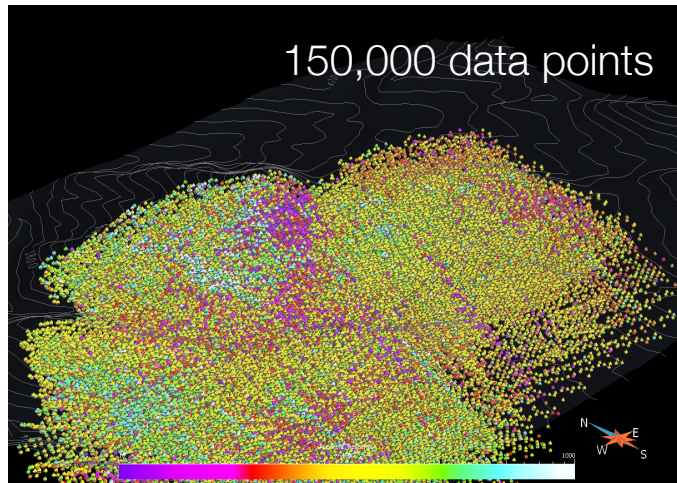
Processing: DC inversion



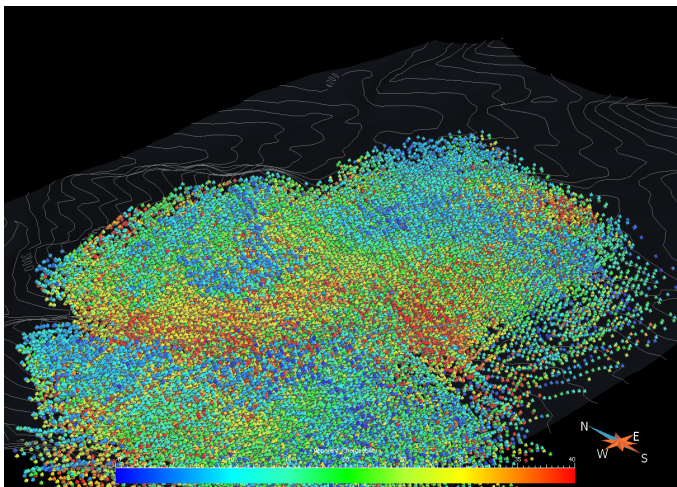
(we also have IP data)

DC-IP Data

DC data



IP data

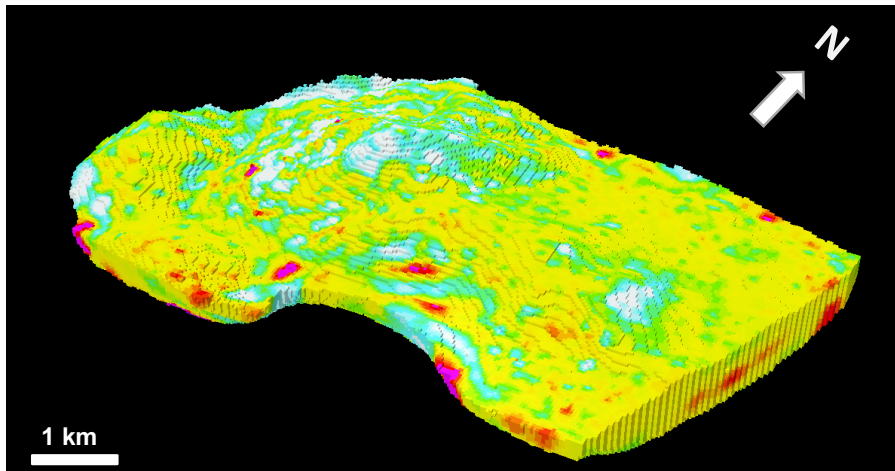


- 150,000 data points from
 - 540 sources
 - 300 dipole receivers
- Hard to visualize and interpret data
- Need to invert

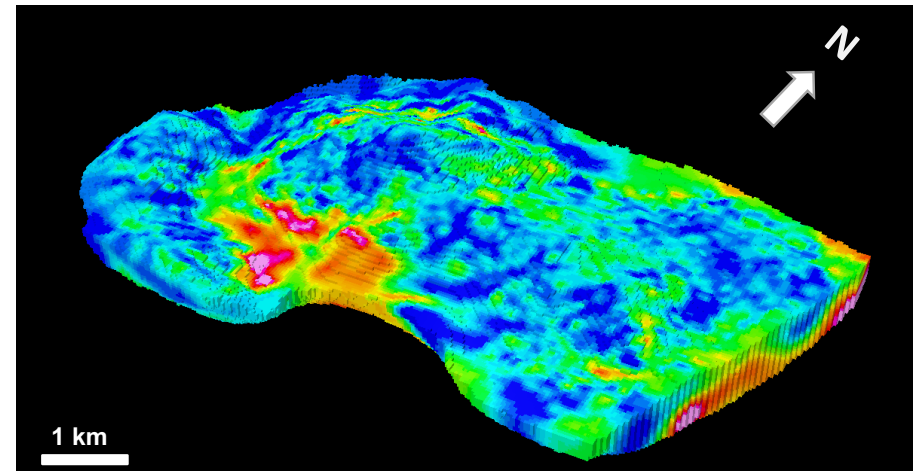
3D DC IP inversion

- Use DC conductivity
- Invert IP data, recover a 3D chargeability
- UBC DCIP3D

Resistivity

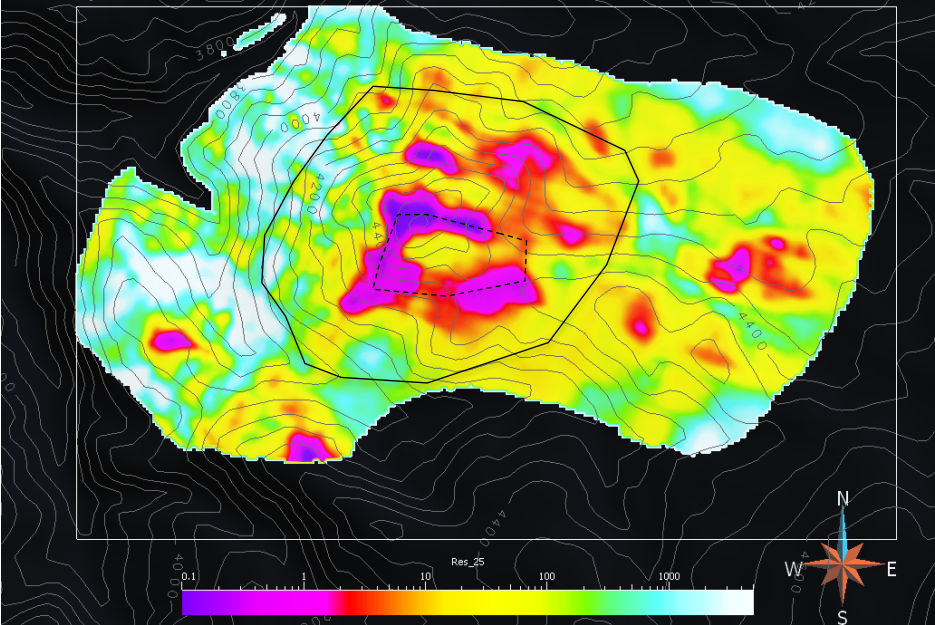


Chargeability

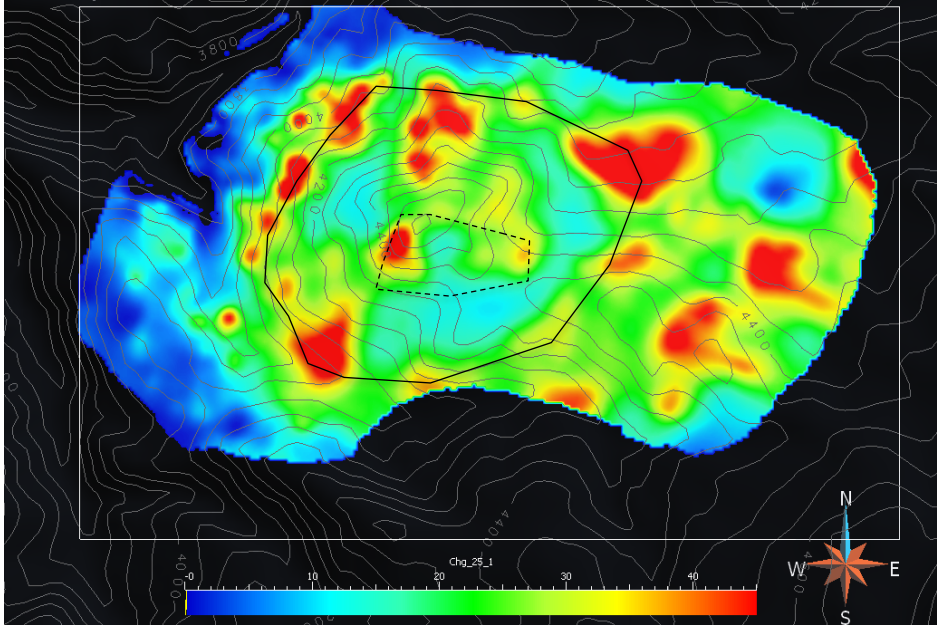


Interpretation: Resistivity & Chargeability

700m below surface



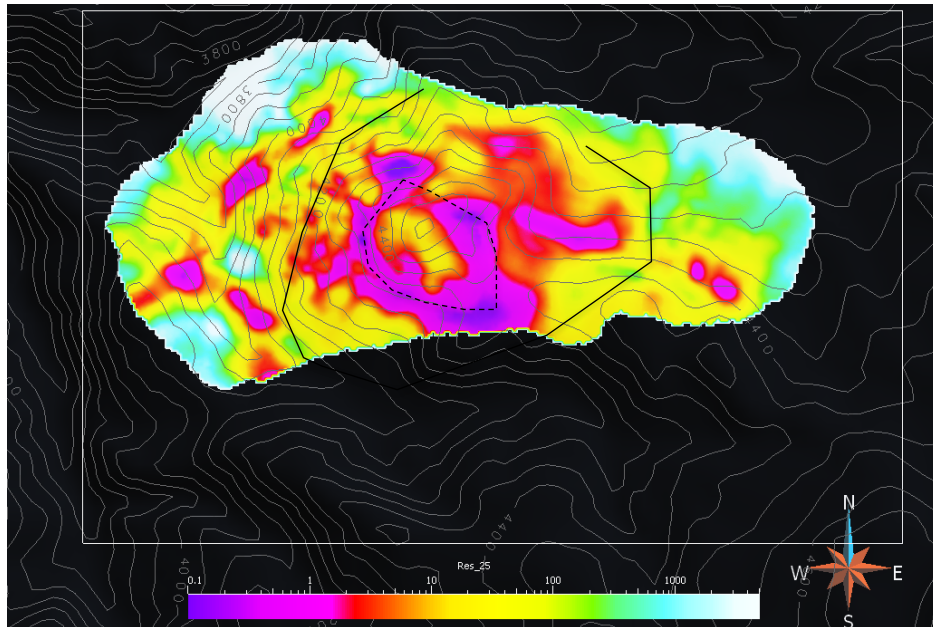
Resistivity



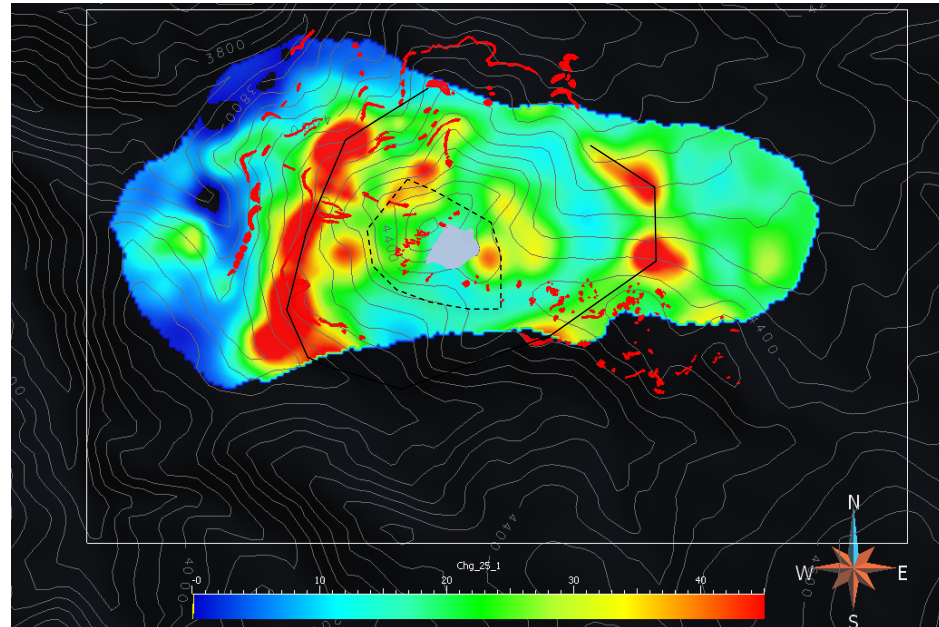
Chargeability

Interpretation: Resistivity & Chargeability

900m below surface

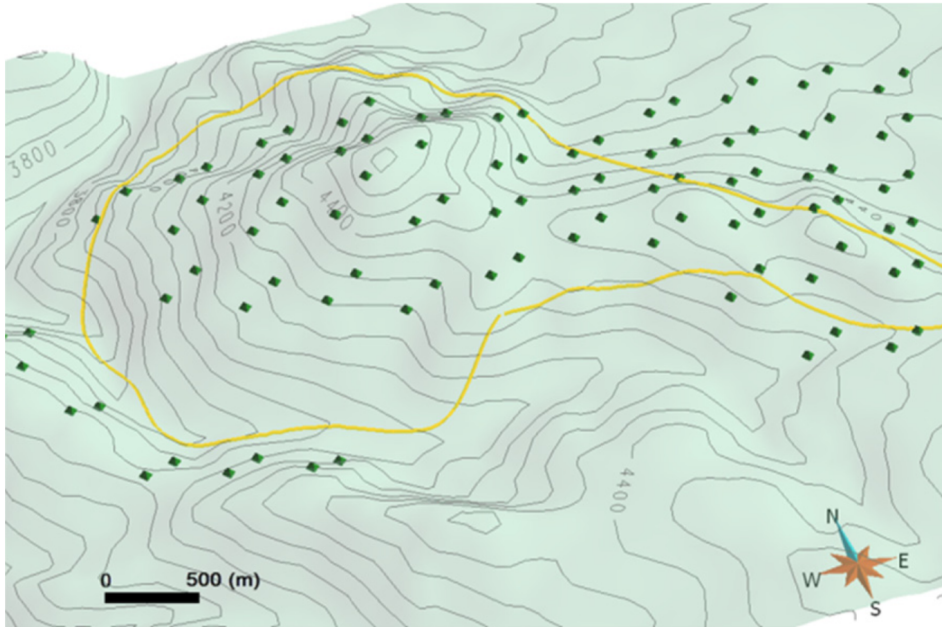


Resistivity



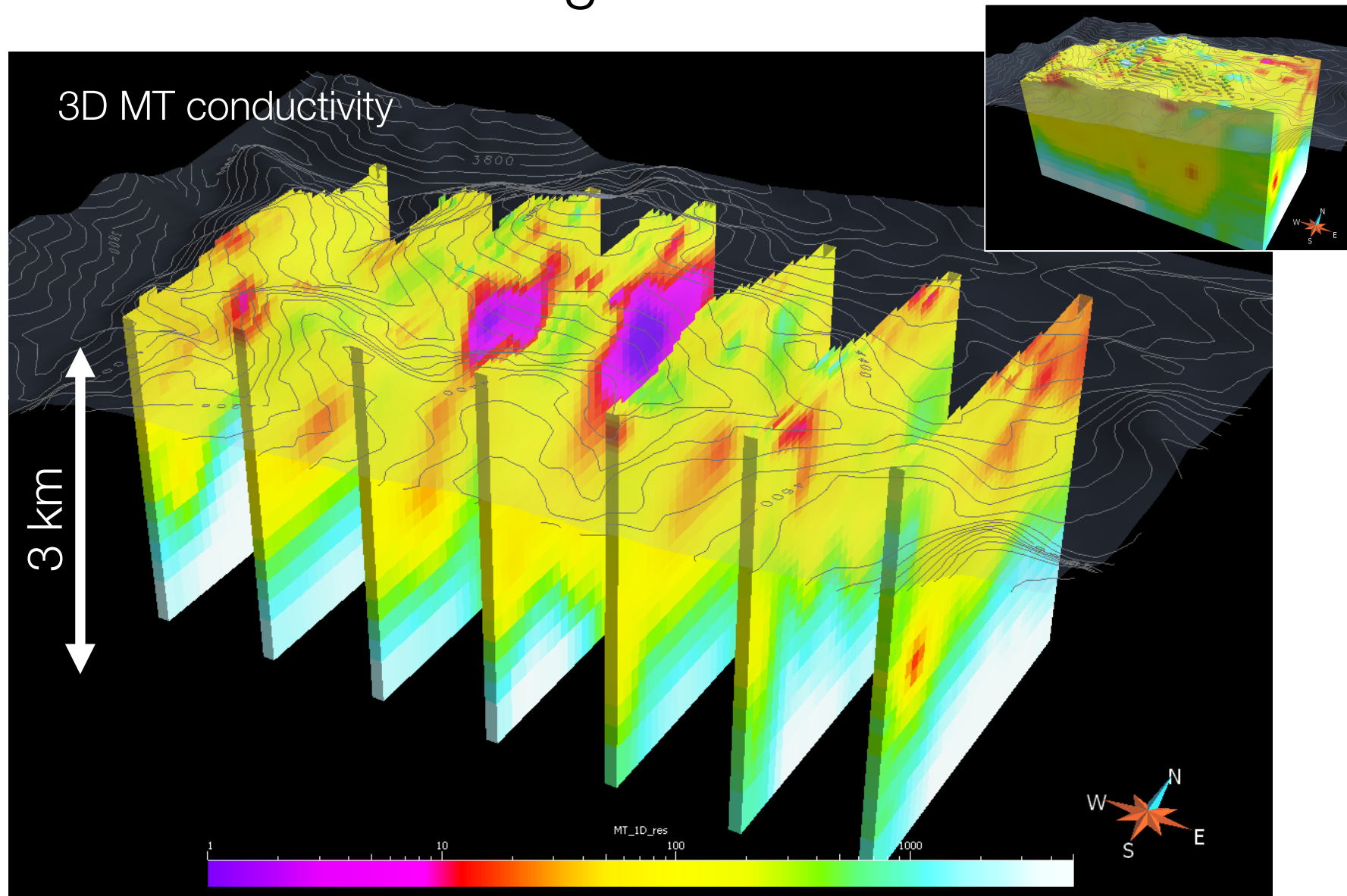
Chargeability

MT Data



- 100 MT Sites
- 150 m dipole length
- Two orthogonal induction coils
- 450 m spacing
- Acquired over night
- Frequency range: 250-0.001 Hz

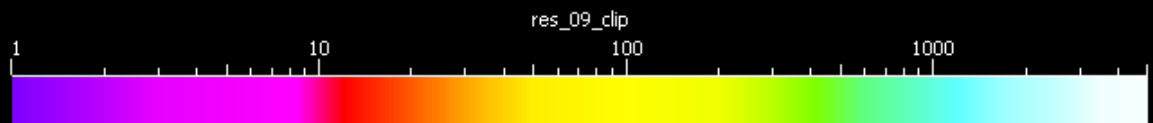
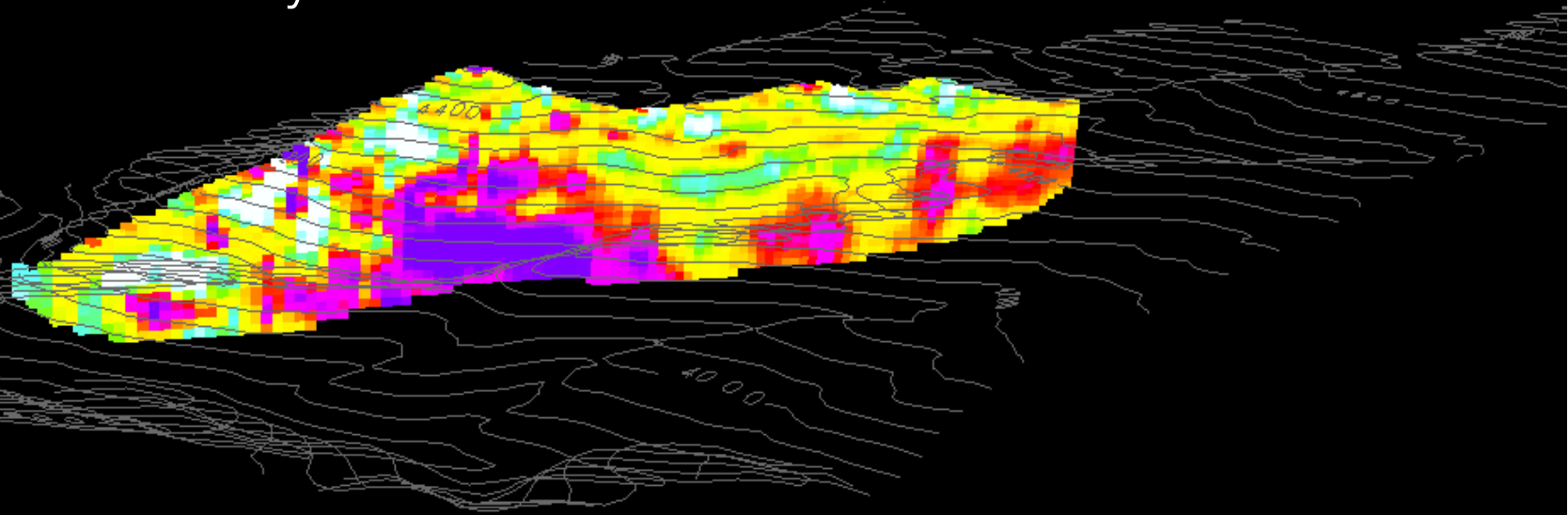
Processing: MT inversion



Interpretation

3D DC resistivity

1 km



Interpretation

3D DC and MT resistivity distributions

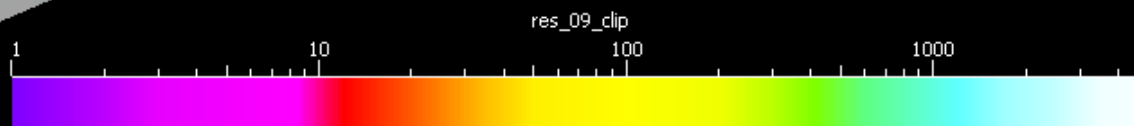
1 km

DC resistivity



Deep-seated
Conductor

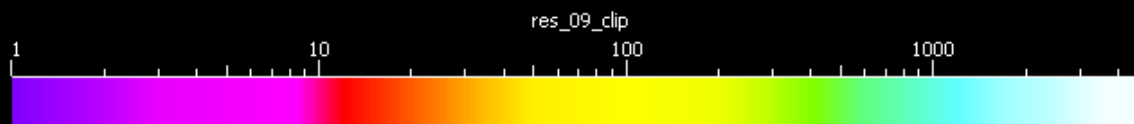
MT resistivity



Interpretation

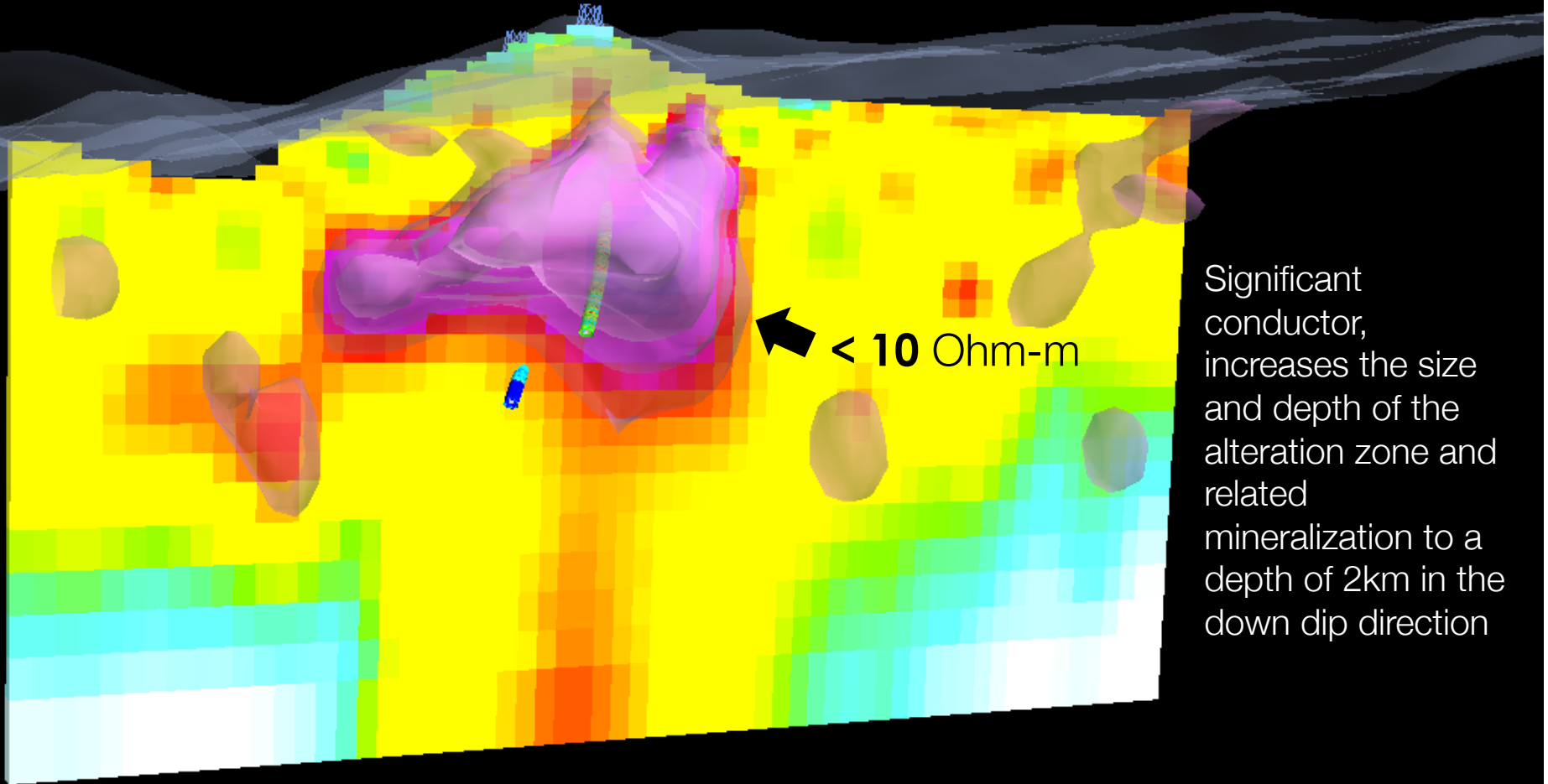
3D MT resistivity

CSAMT
Conductor

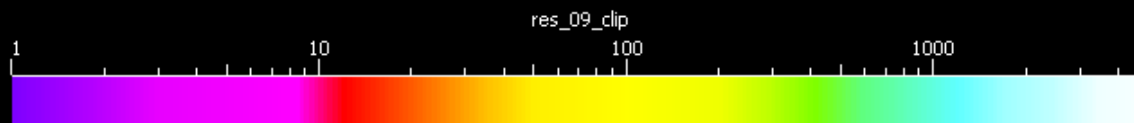


Synthesis

3D MT resistivity



Significant conductor, increases the size and depth of the alteration zone and related mineralization to a depth of 2km in the down dip direction



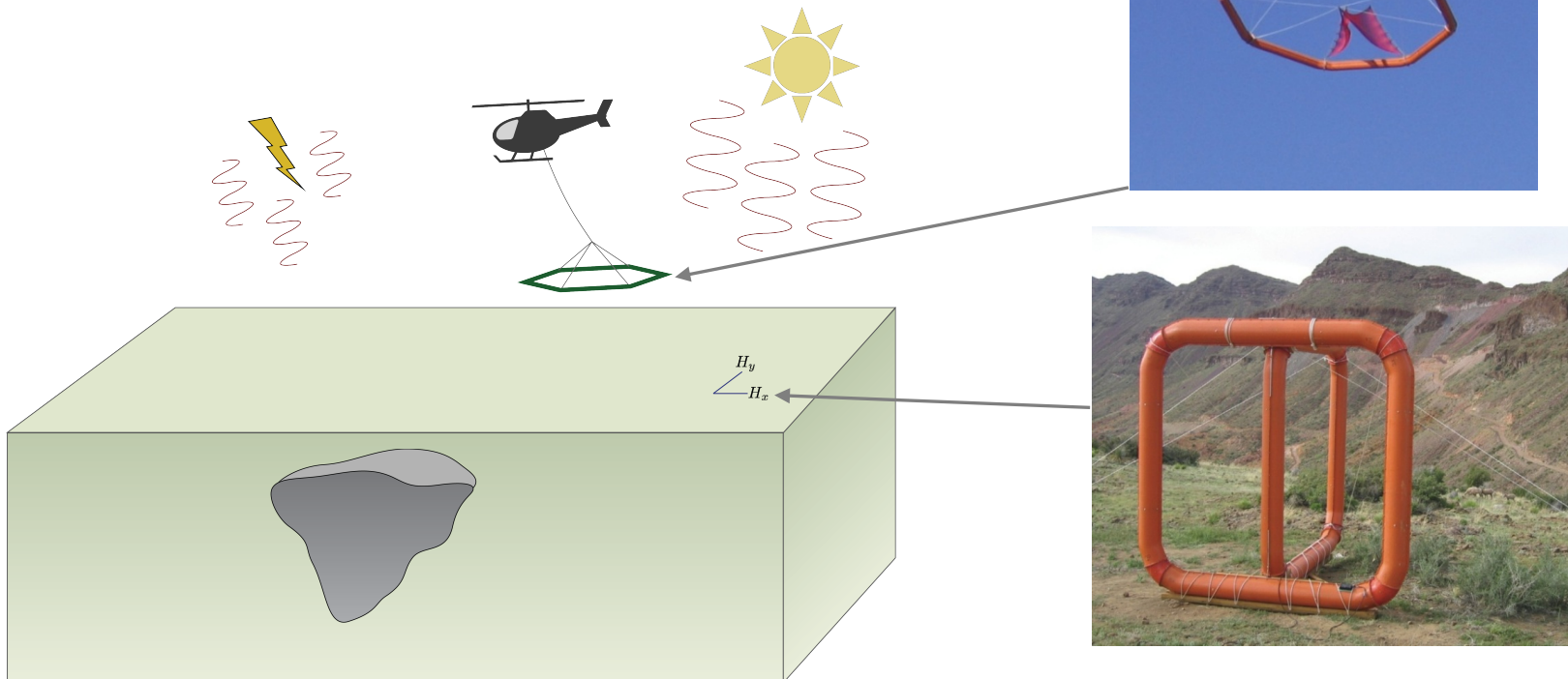
Tipper data (ZTEM)

- Magnetic transfer function

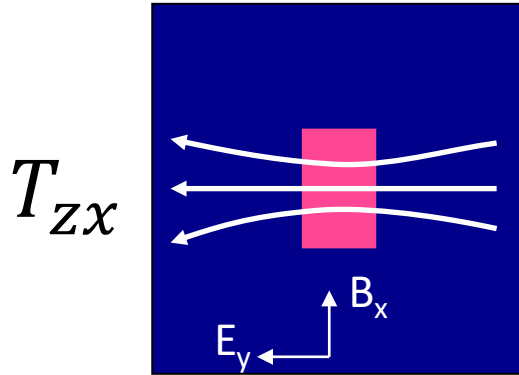
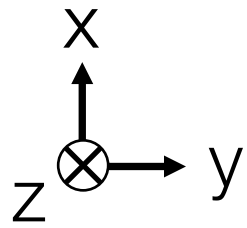
$$H_z = \mathbf{T}\mathbf{H}$$

$$H_z(r) = T_{zx}H_x(r_0) + T_{zy}H_y(r_0)$$

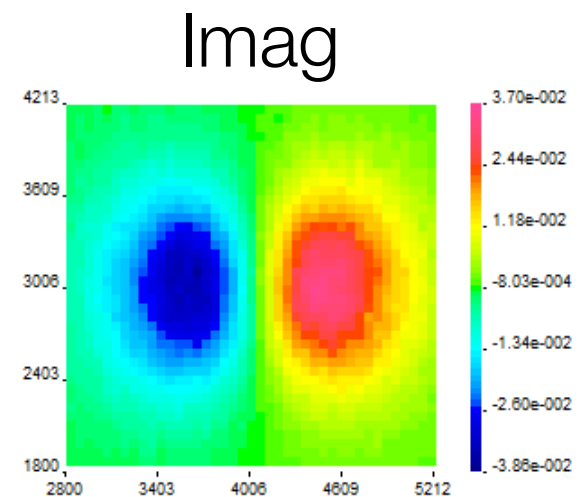
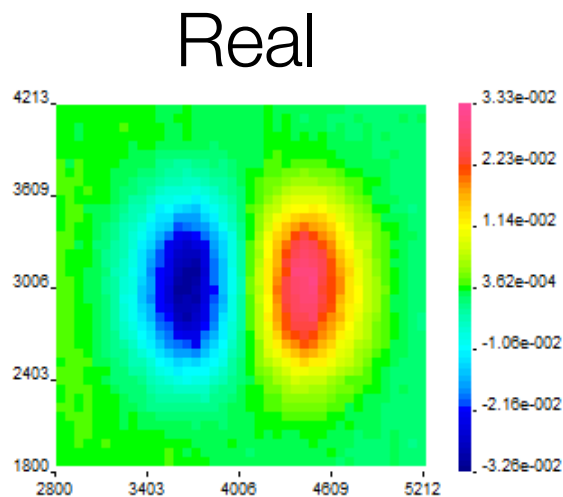
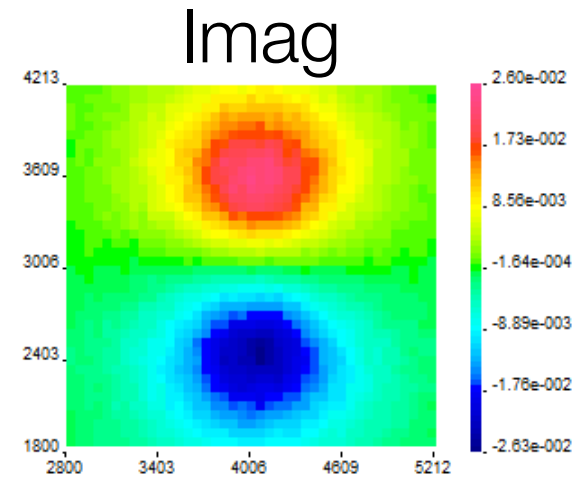
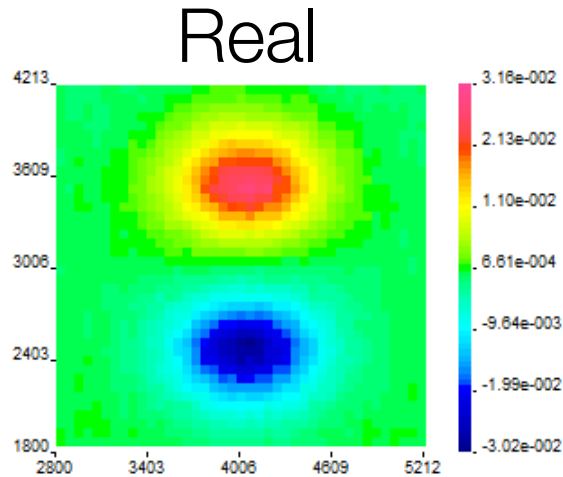
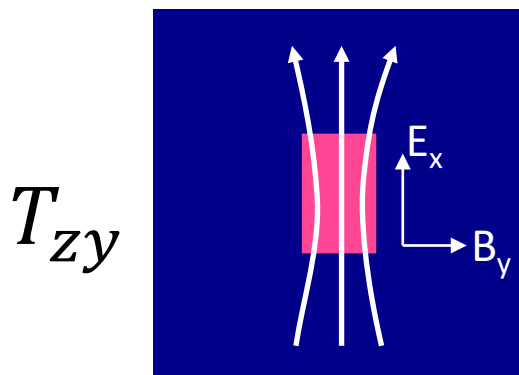
- Frequencies 30Hz – 720 Hz



Synthetic example

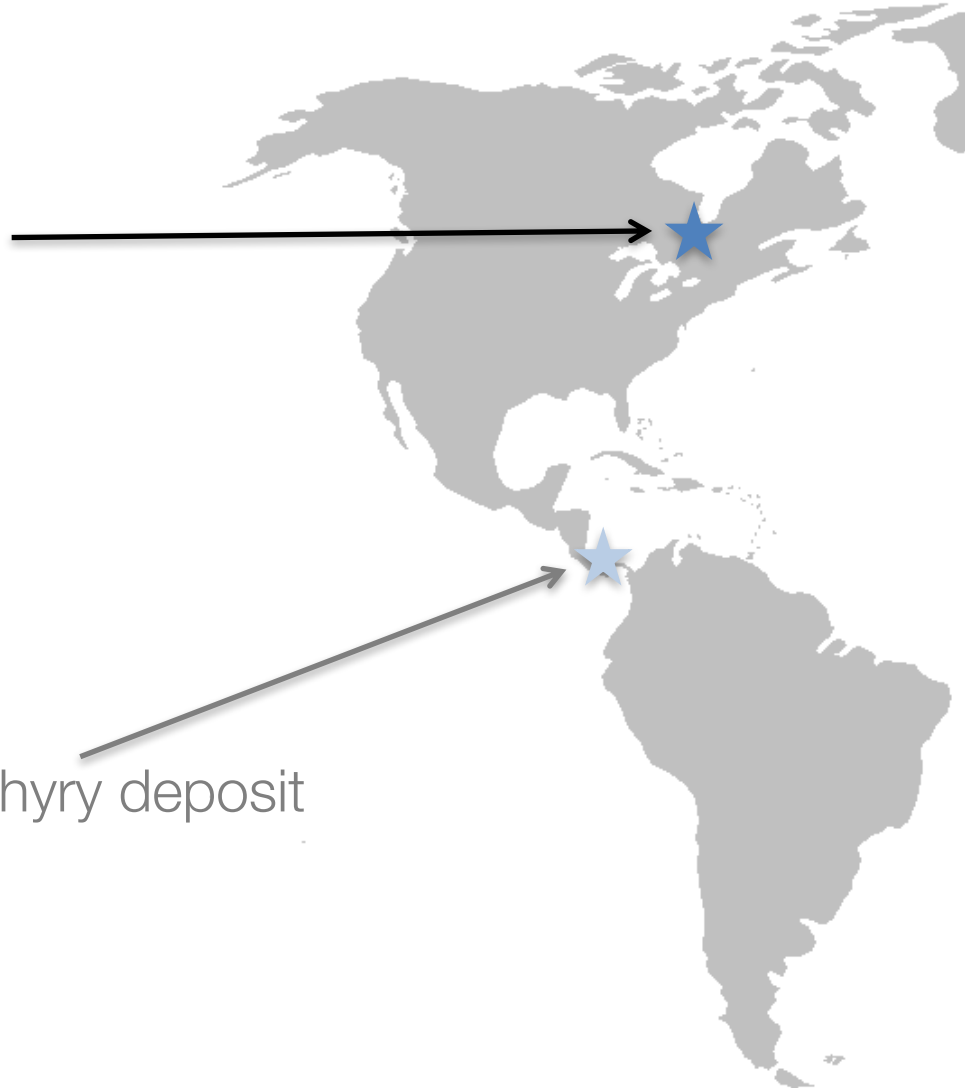


Conductor



ZTEM case histories

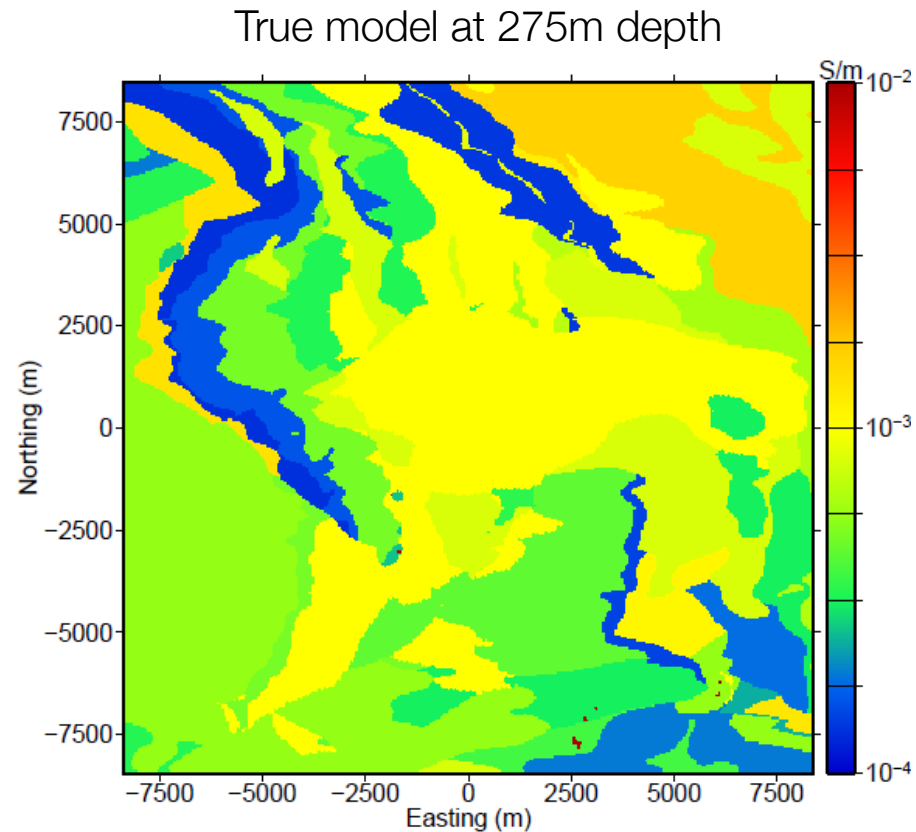
- Synthetic based on Noranda district



- Balboa copper porphyry deposit

Noranda district, Canada

- Hosts many deposits:
 - 20 economic VMS
 - 19 orogenic gold
 - Several intrusion-hosted Cu-Mo
- Physical properties
 - Synthetic from geologic model
 - 38 geologic units

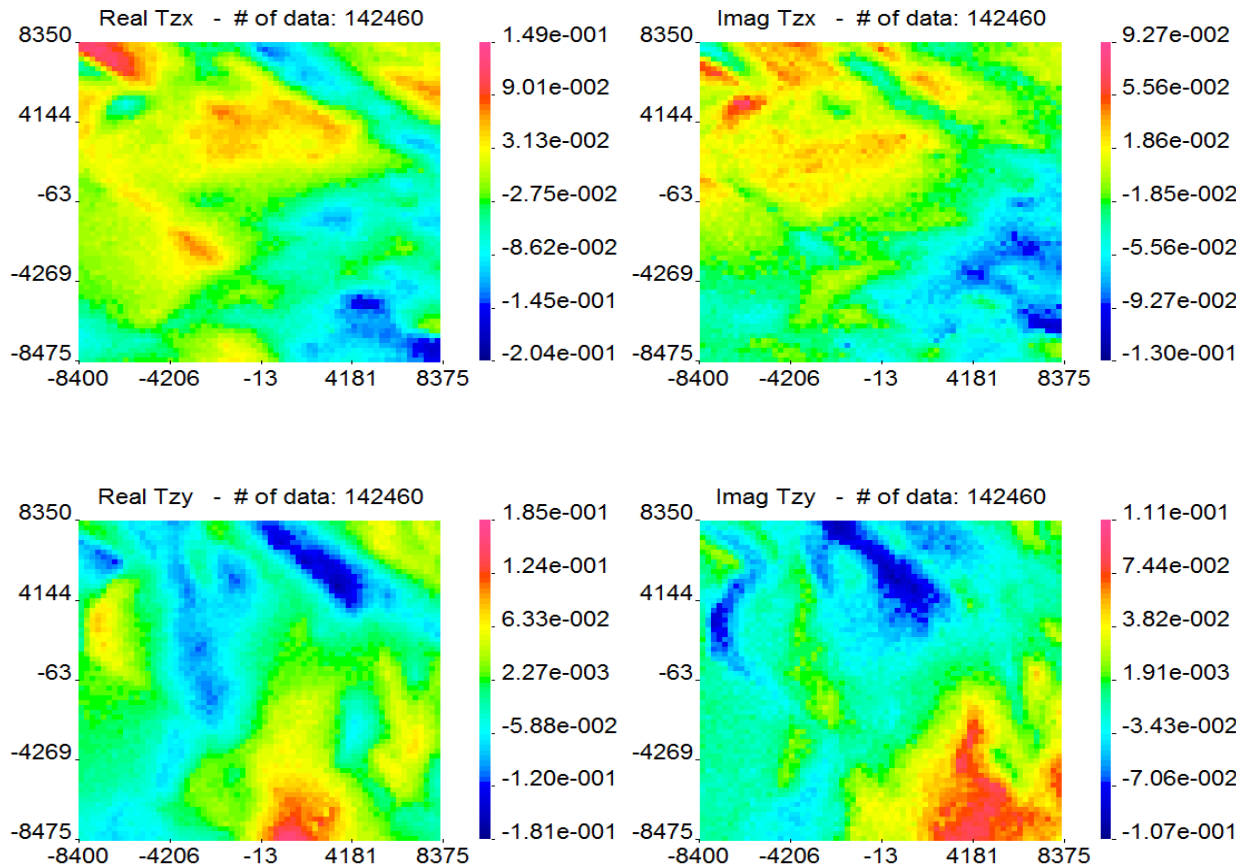
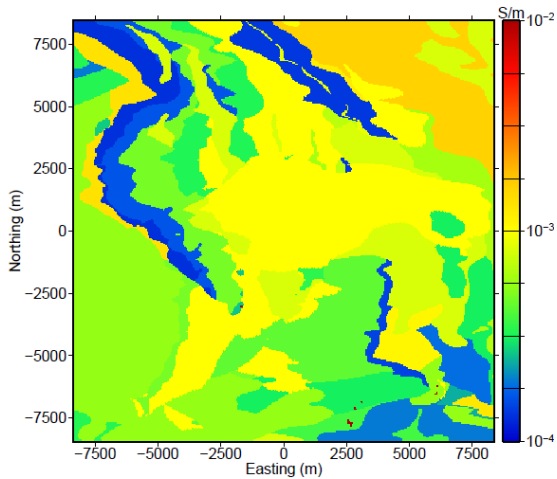


Data

- Forward model data at 6 frequencies
 - 30, 45, 90, 180, 360, and 720 Hz
- Need to invert data

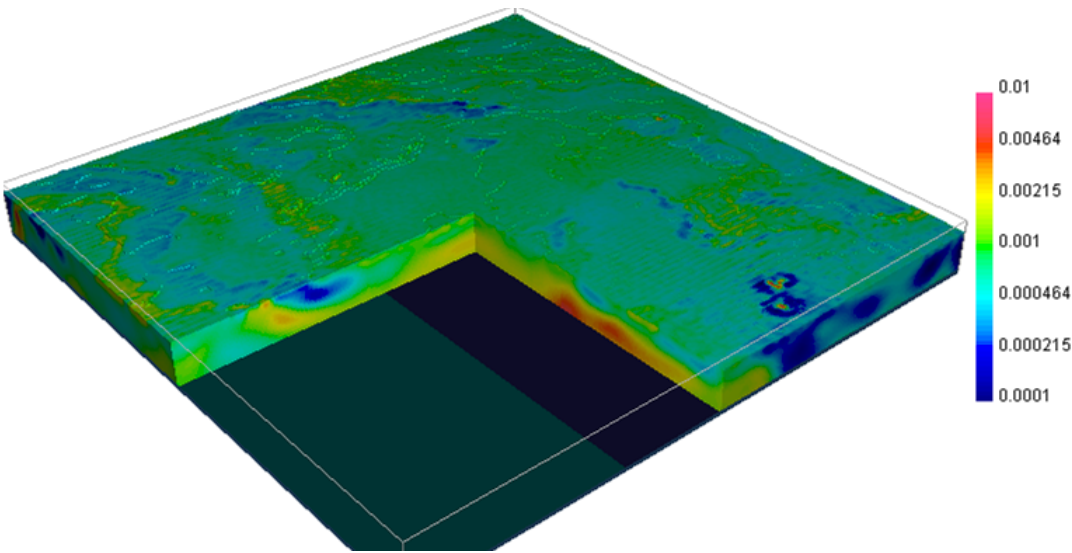
Observed (90 Hz)

True model at 275m depth

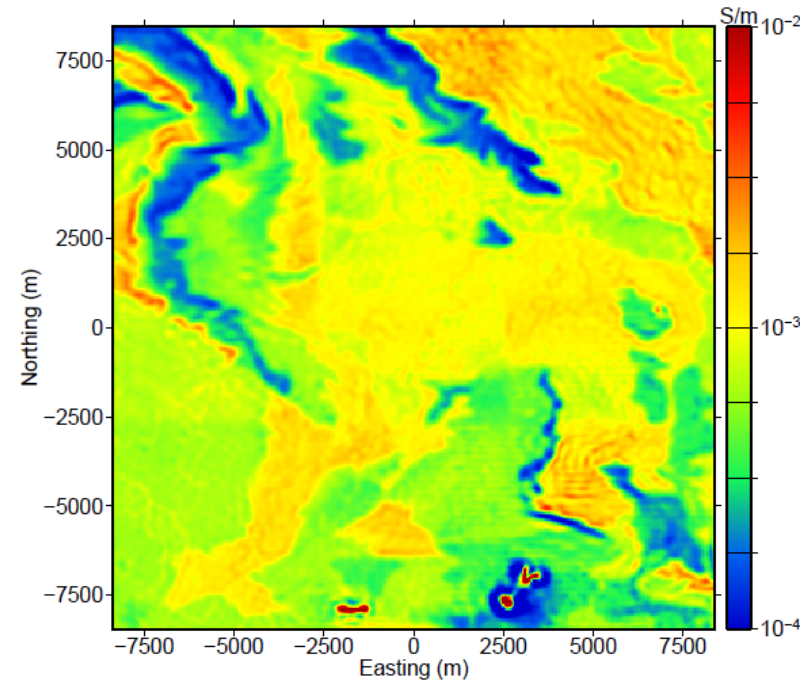


Interpretation

Recovered Model



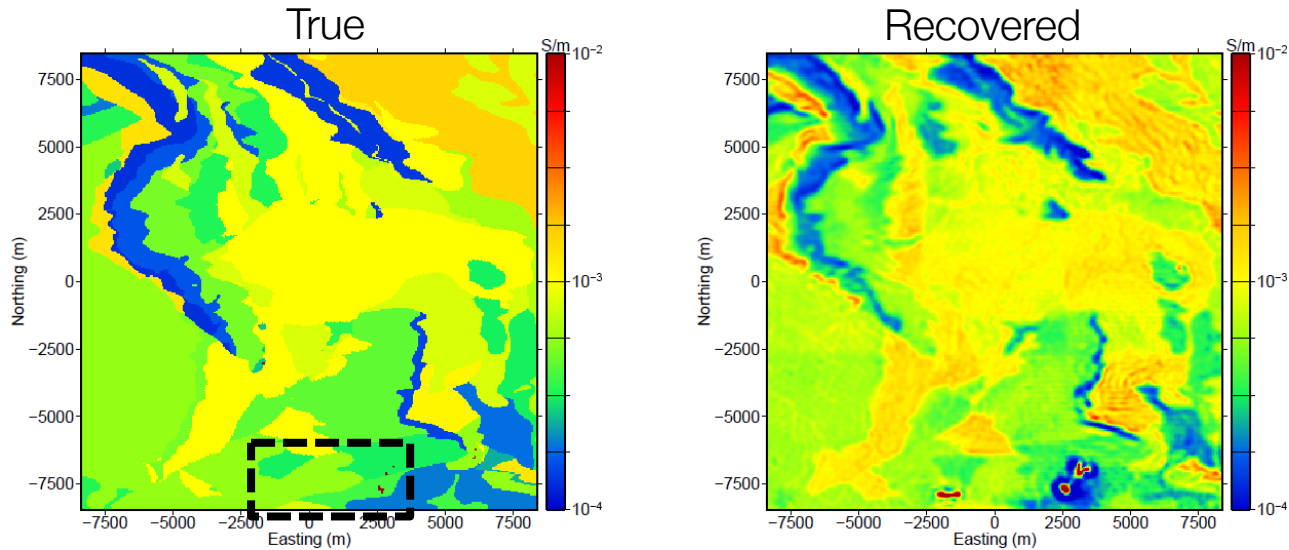
Model at 275m depth



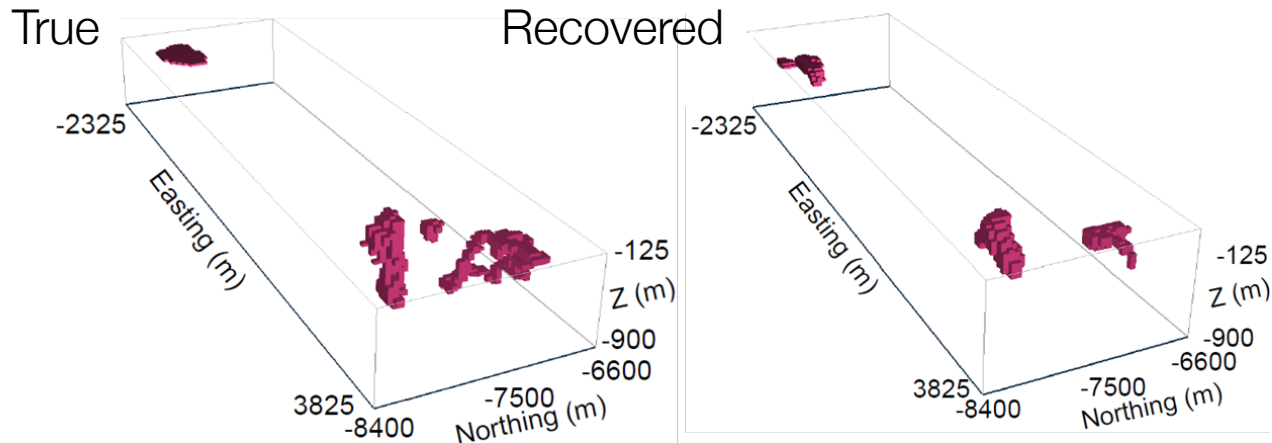
- Geologic units are well mapped
- Some mineralized bodies are located

Synthesis

- Recovered model represents the regional geology



- Mineralized zones are recovered



ZTEM case histories

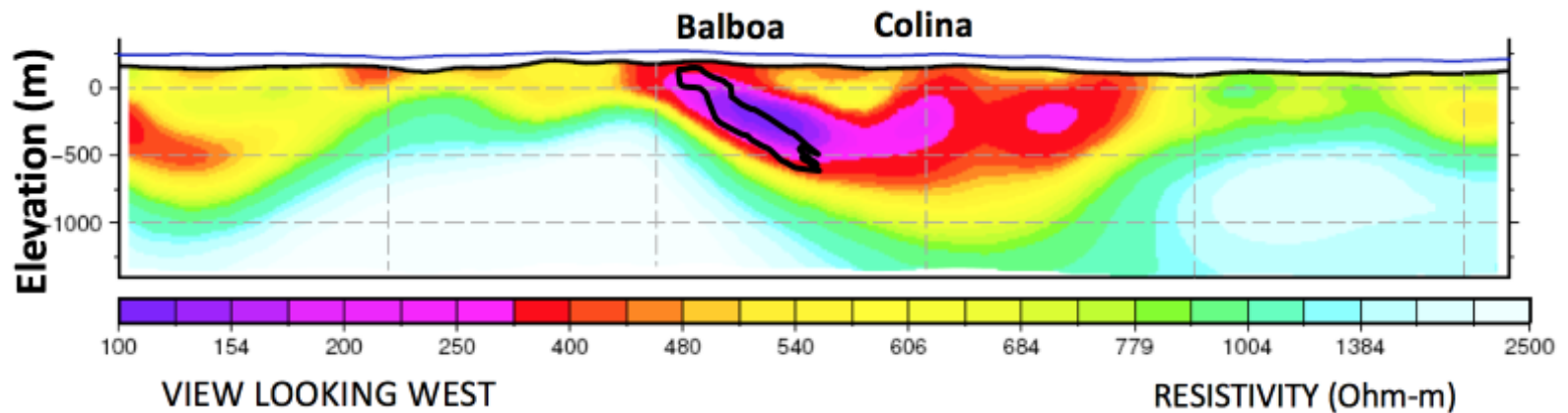
- Synthetic based on Noranda district



- Balboa copper porphyry deposit

Case History: The Balboa ZTEM Cu-Mo-Au porphyry discovery at Cobre Panama

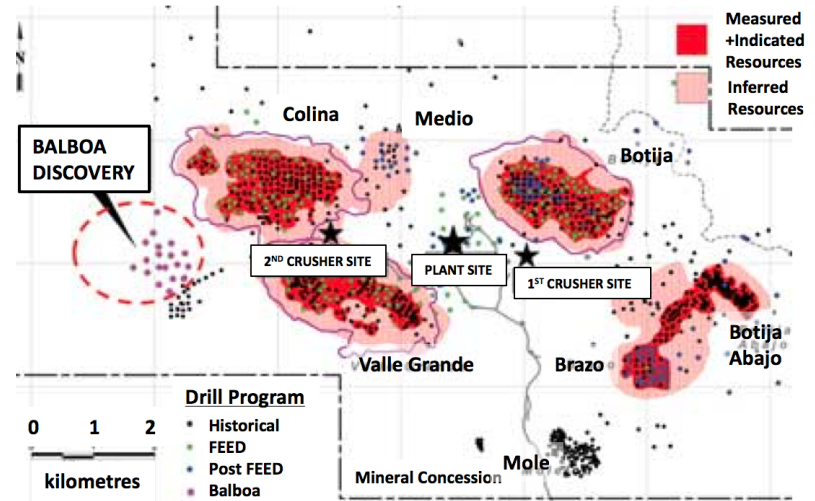
Legault et al., 2016



Setup



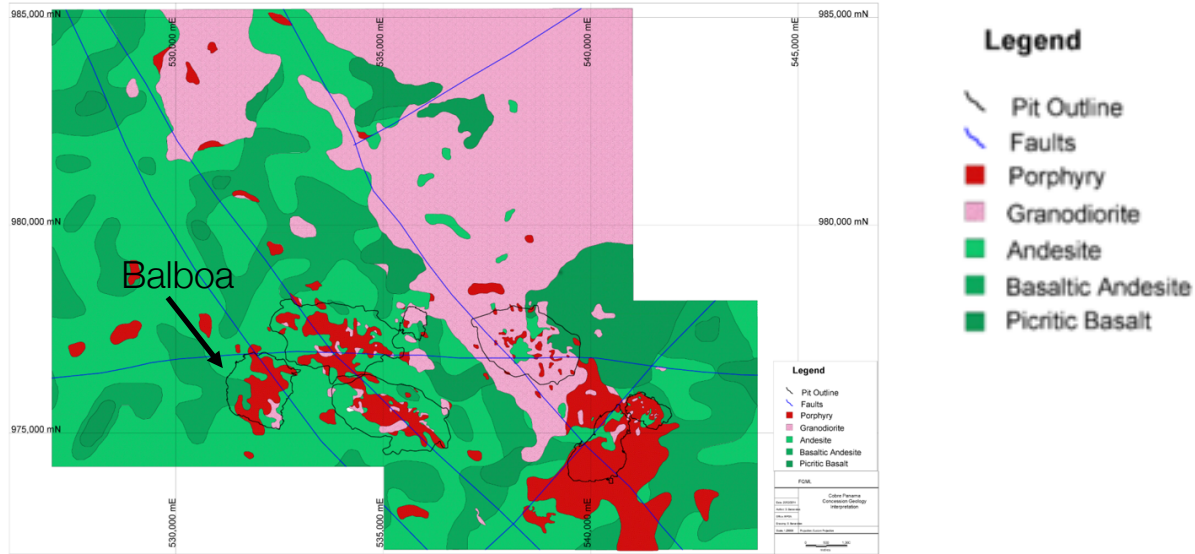
Resource map



- Balboa porphyry Cu-Mo-Au deposit
 - Located 1-2 km from known deposits: Colina, Medio, Botija, Valle Grande, Mole, Brazo, Botija Abajo
 - Most known deposits found with soil samples; followed by exploration programs

Setup

Geologic map

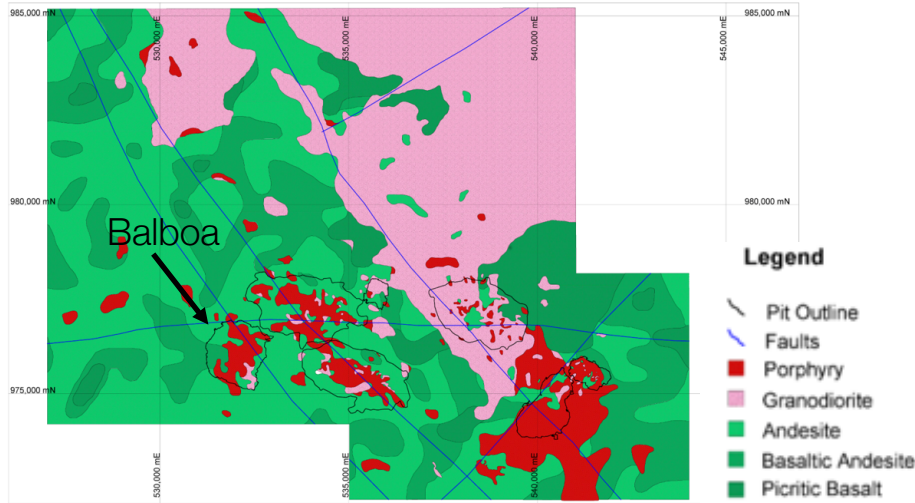


- Overburden: 20-30m of clay-rich saprolite
- Mineralization:
 - Mostly chlorite and chlorite-sericite alteration
 - Abundant disseminated chalcopyrite, pyrite and magnetite
- Previous helicopter TEM survey unsuccessful in detecting mineralized zones

Can ZTEM see mineralized zones below the conductive saprolite layer?

Properties

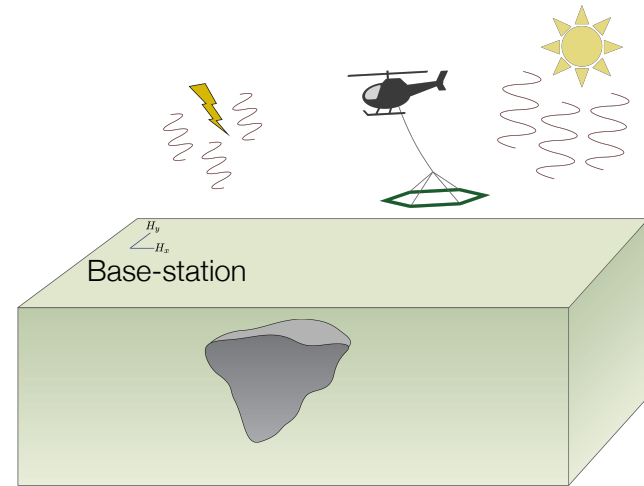
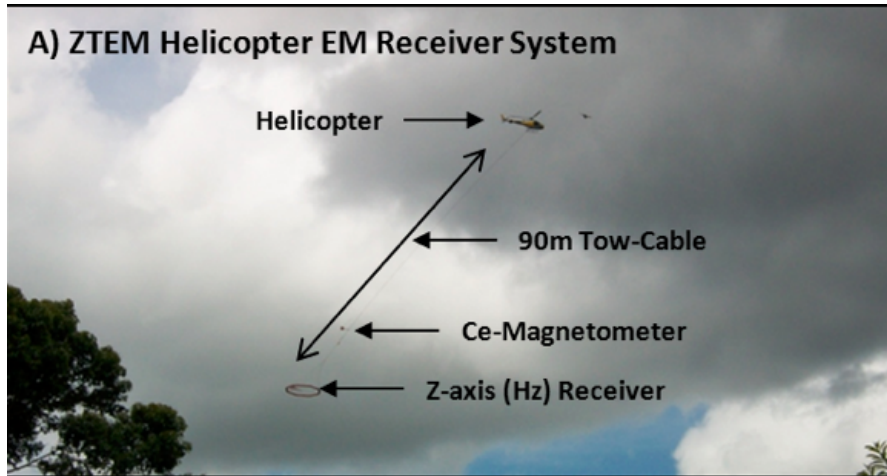
Geologic map



- Mineralized zone
 - High conductivity
 - Low magnetic susceptibility
- Highly conductive saprolite at surface (up to 30m thick)

Rock Unit	Resistivity ($\Omega \cdot m$)	Susceptibility (SI)
Saprolitic overburden	Low	Low
Host rock	High	Low
Granodiorite/porphyry (host rock; unmineralized)	Moderate	Moderate
Andesite/basalt (unmineralized)	Moderate	High
Mineralized/clay-altered	Low	Low

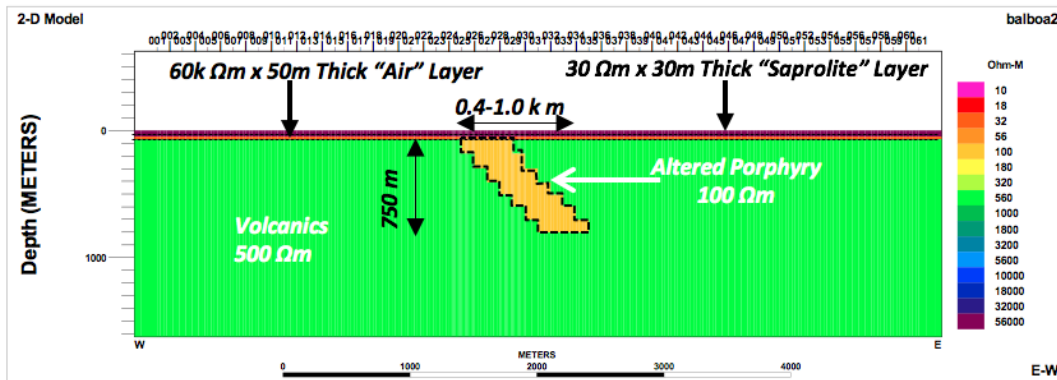
Survey



- System
 - 6 frequencies: 30-720 Hz
 - Hz: airborne receiver
 - Hx and Hy at base-station

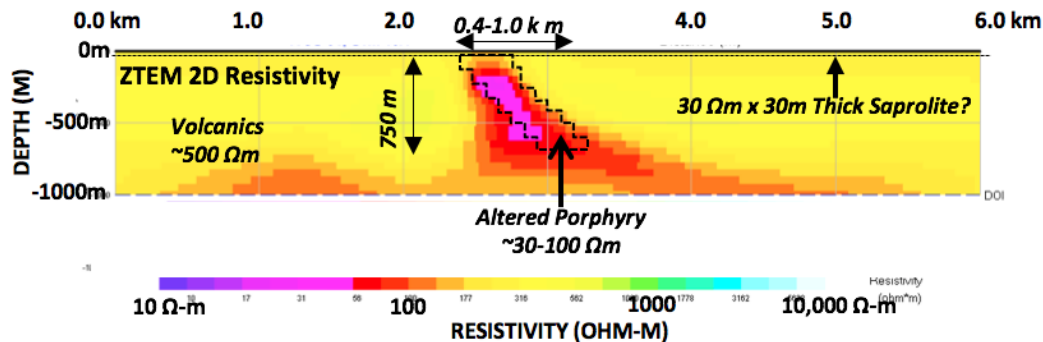
Survey design

A) 2D Synthetic Model for Balboa Porphyry below Saprolite



- Typical AEM survey can't see through conductive saprolite

B) ZTEM 2D Inversion Model for Balboa below Saprolite



- ZTEM insensitive to 1D conductivity

ZTEM can see through conductive overburden.

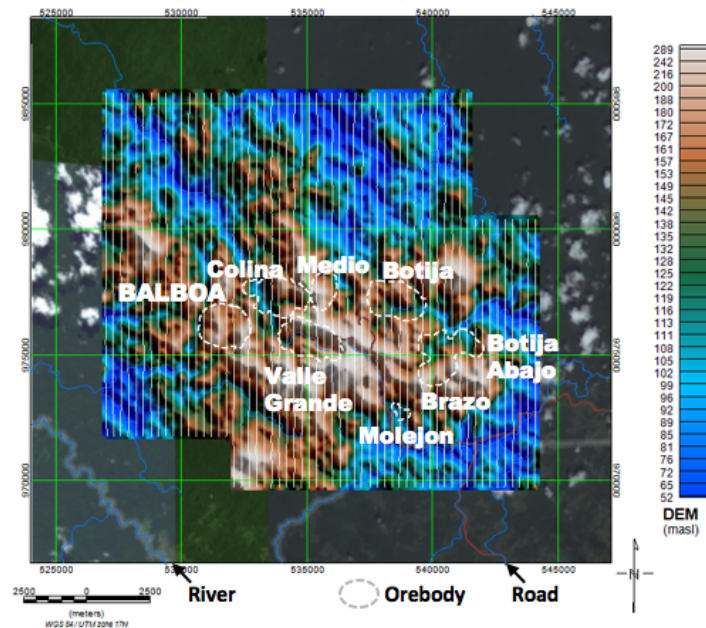
Data

- Tipper transfer function:

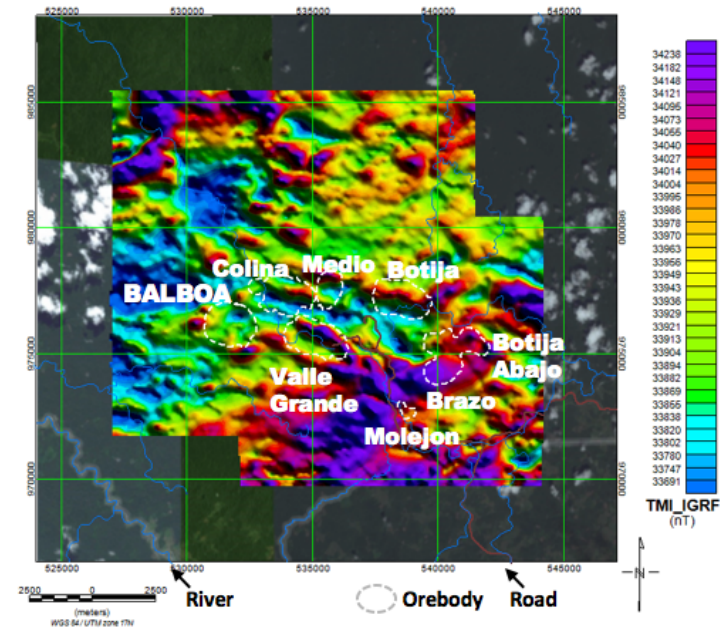
$$H_z(r) = T_{zx}(r, r_0)H_x(r_0) + T_{zy}(r, r_0)H_y(r_0)$$

- T_{zx} and T_{zy} obtained using similar processing as MT
 - H_x and H_y obtained from reference site (r_0)
- ZTEM survey also acquires magnetic data

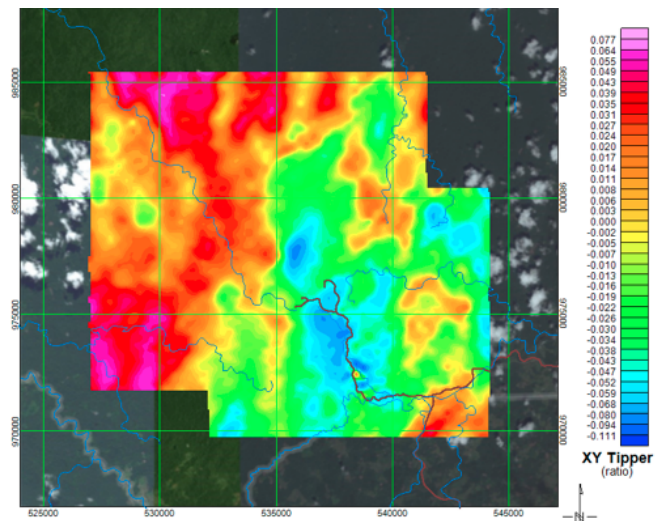
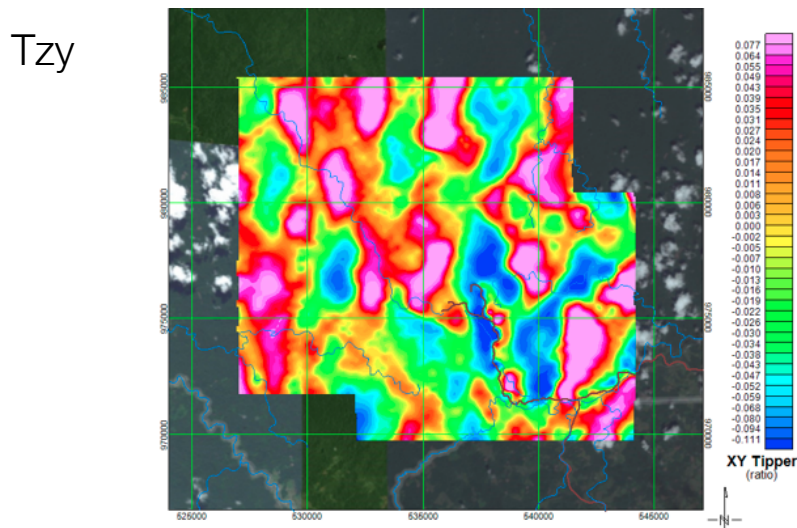
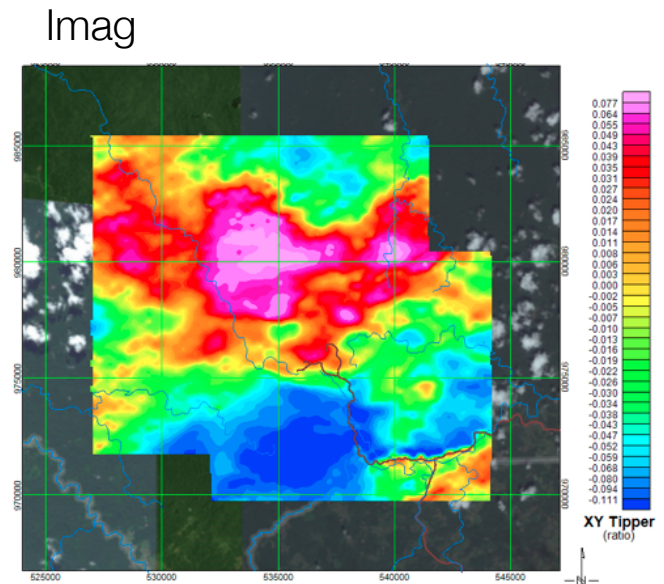
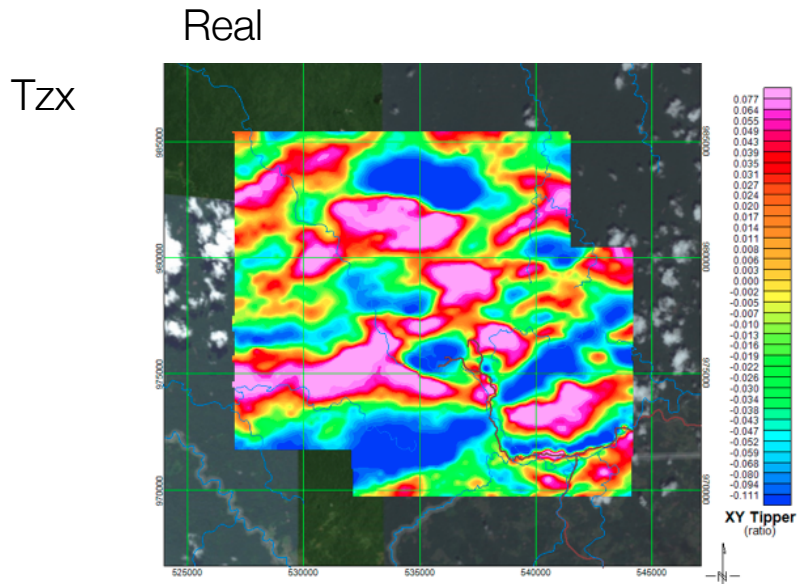
A) ZTEM Flight Line over Digital Elevation Model



B) Total Magnetic Intensity (TMI)



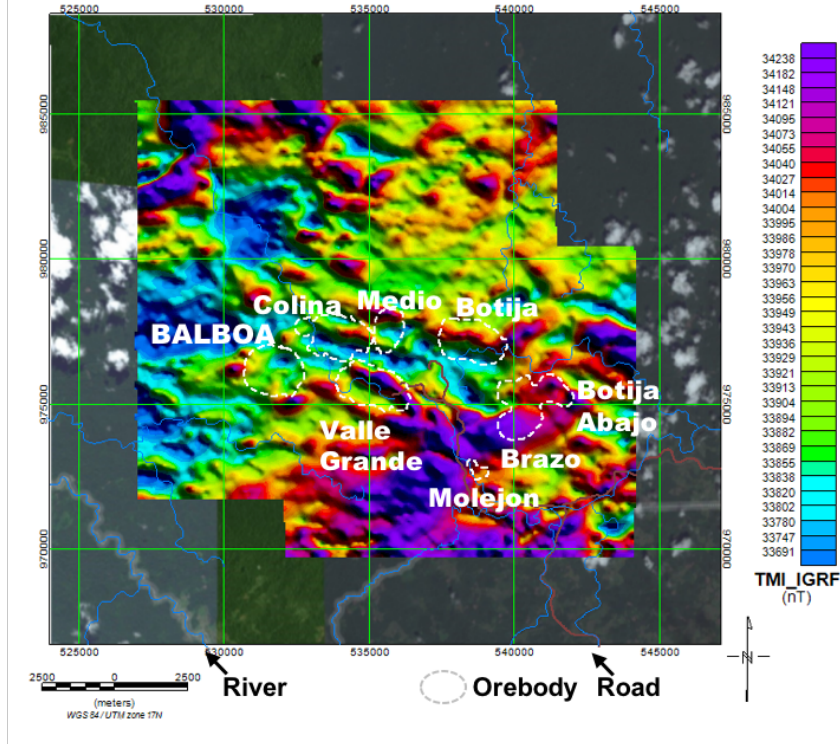
ZTEM data at 90 Hz



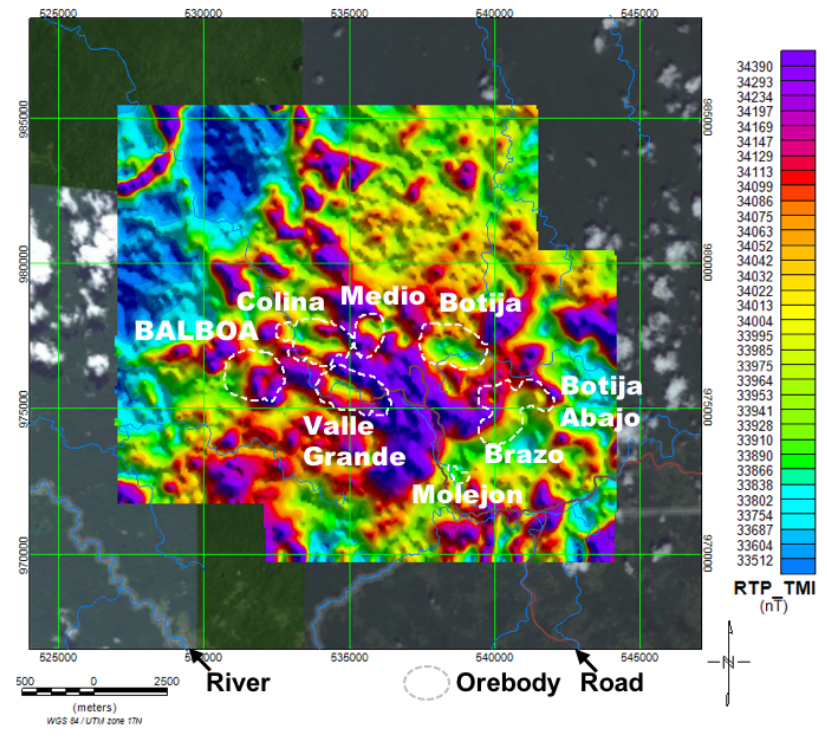
Processing: magnetic data

- Reduced to pole (RTP)

A) Total Magnetic Intensity (TMI)



B) Total Magnetic Intensity (Reduced to Pole)

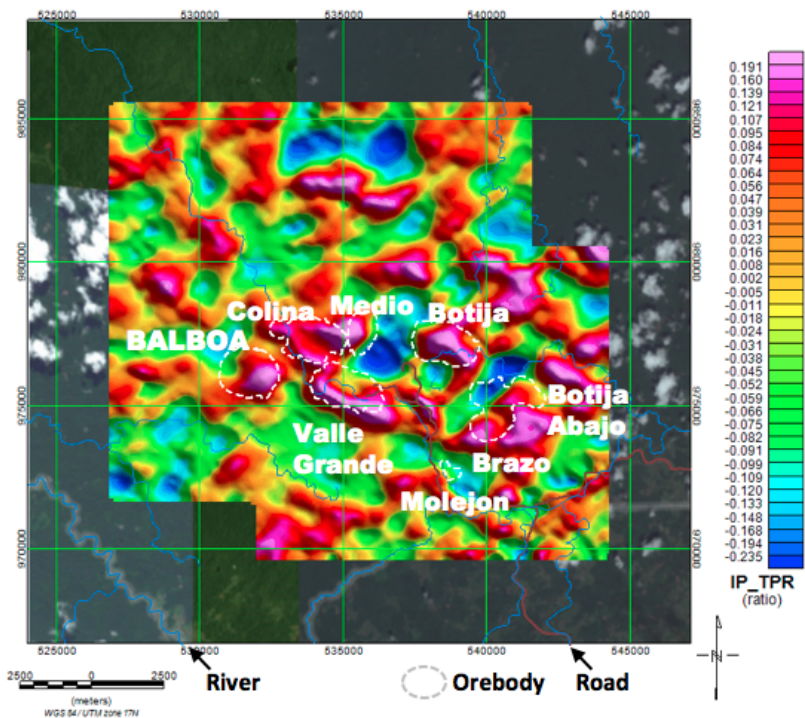


- Known deposits correlate with magnetic lows (after RTP)
- Demagnetized areas are due to alteration
- Balboa not delineated (has both high and low anomalies)

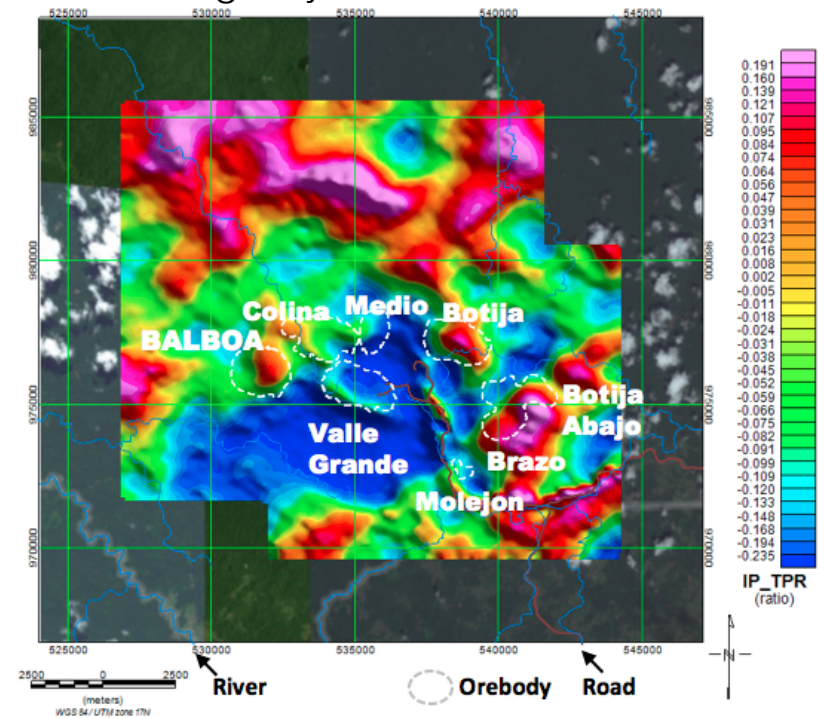
Processing: ZTEM data

- Total phase rotation (TPR)

TPR real at 360 Hz



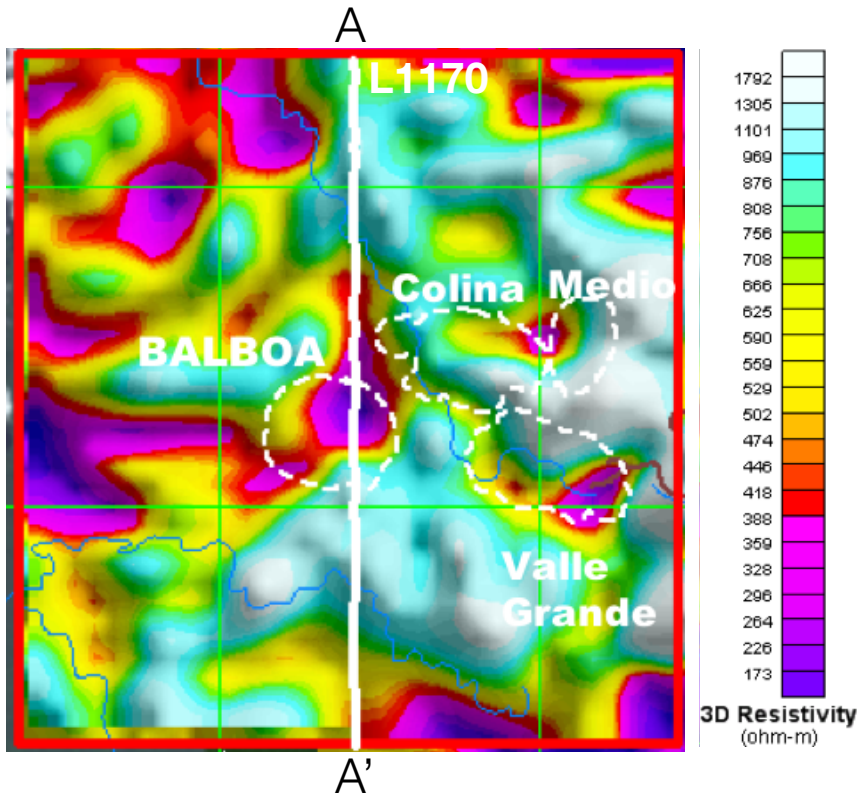
TPR imaginary at 30 Hz



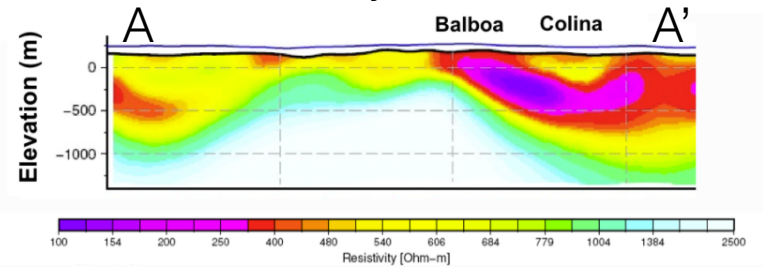
- At 360Hz, high values collocated with known deposits; some false positives
- At 30 Hz, regional resistive structure; deeper conductive structures collocated with some known deposits

Inversion and Interpretation

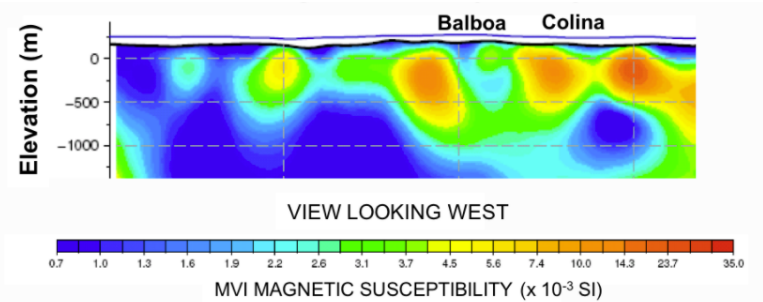
3D conductivity at 500 m depth



Vertical conductivity section at L1170



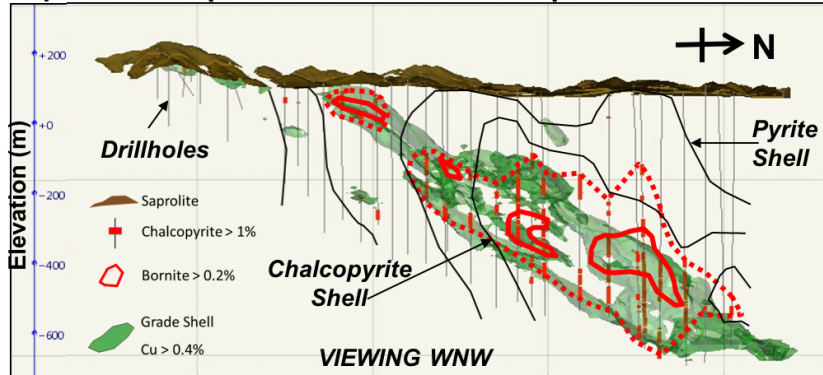
Vertical susceptibility section at L1170



- Balboa deposit
 - Conductor imaged at depth
 - Magnetic low at depth

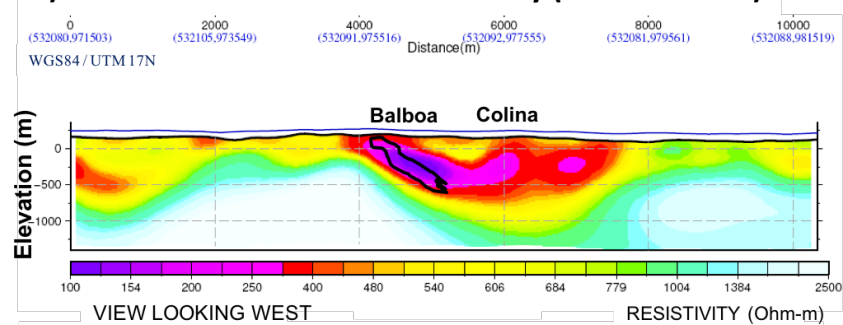
Synthesis

A) Balboa Deposit Cross Section – Sulphide & Ore Shells

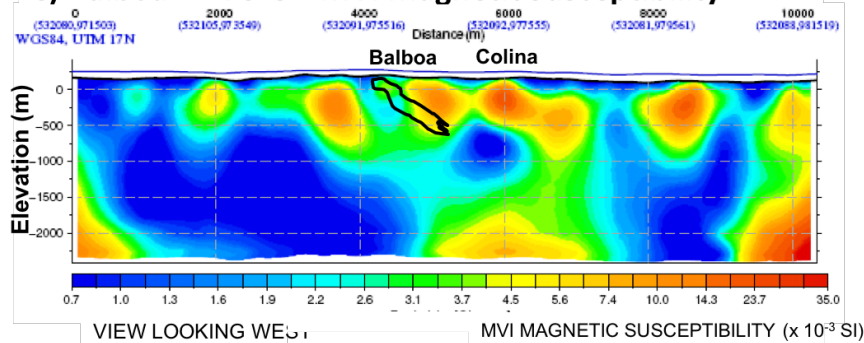


- Exploration and drilling motivated by soil sampling failed to identify Balboa
- Helicopter TDEM could not see through conductive saprolite
- Conductive anomaly collocated with Balboa deposit agrees with boundary of higher-grade zones from drilling

B) Balboa L1170 ZTEM 3D Resistivity (500 Ω m Start)

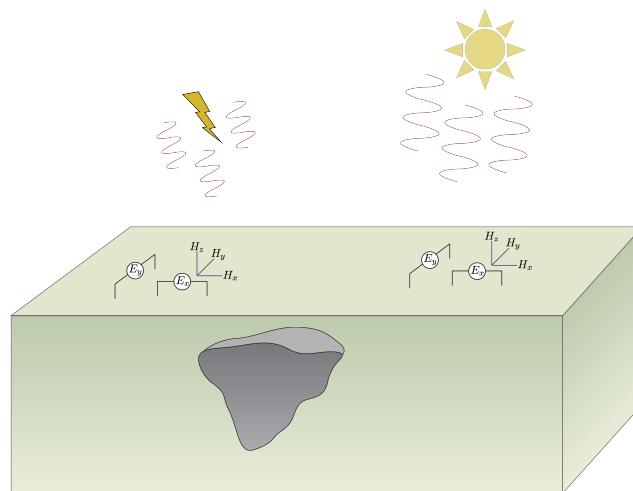


C) Balboa L1170 3D MVI Magnetic Susceptibility

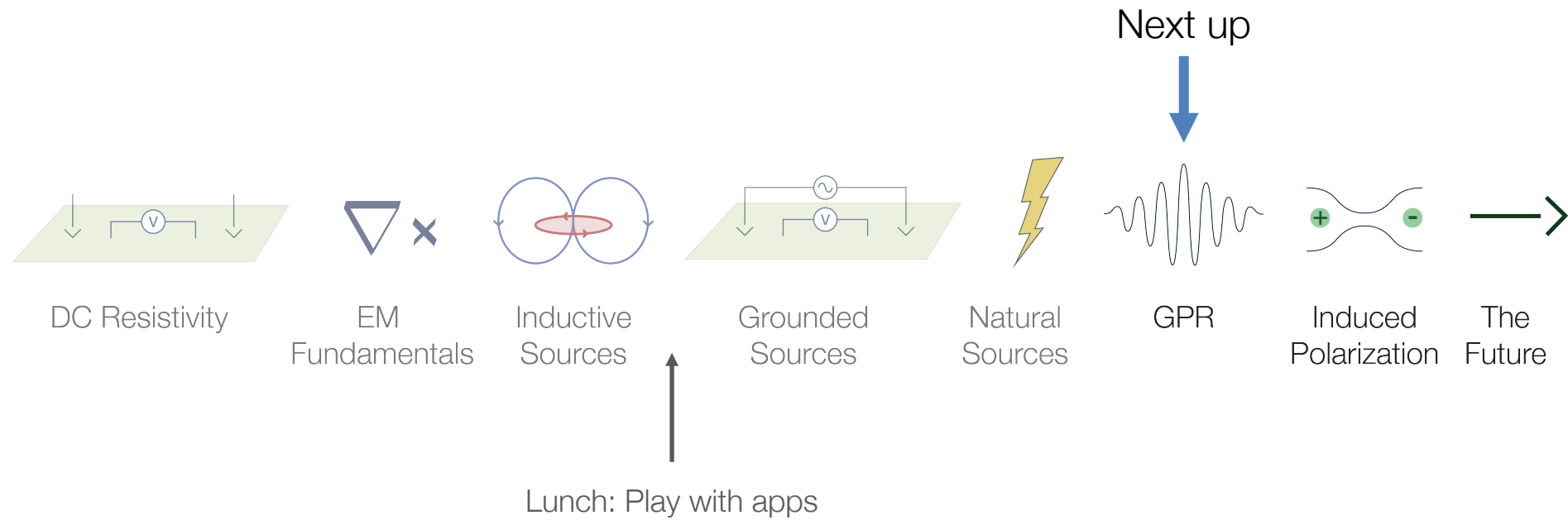


Summary

- Background on natural source EM methods
- Magnetotellurics
- Case history: Minerals
- Z-axis tipper electromagnetics
- Case histories (ZTEM): Geologic Mapping, Minerals



End of Natural Sources



Additional Material

- Case Histories:
 - Geothermal
 - Landfills

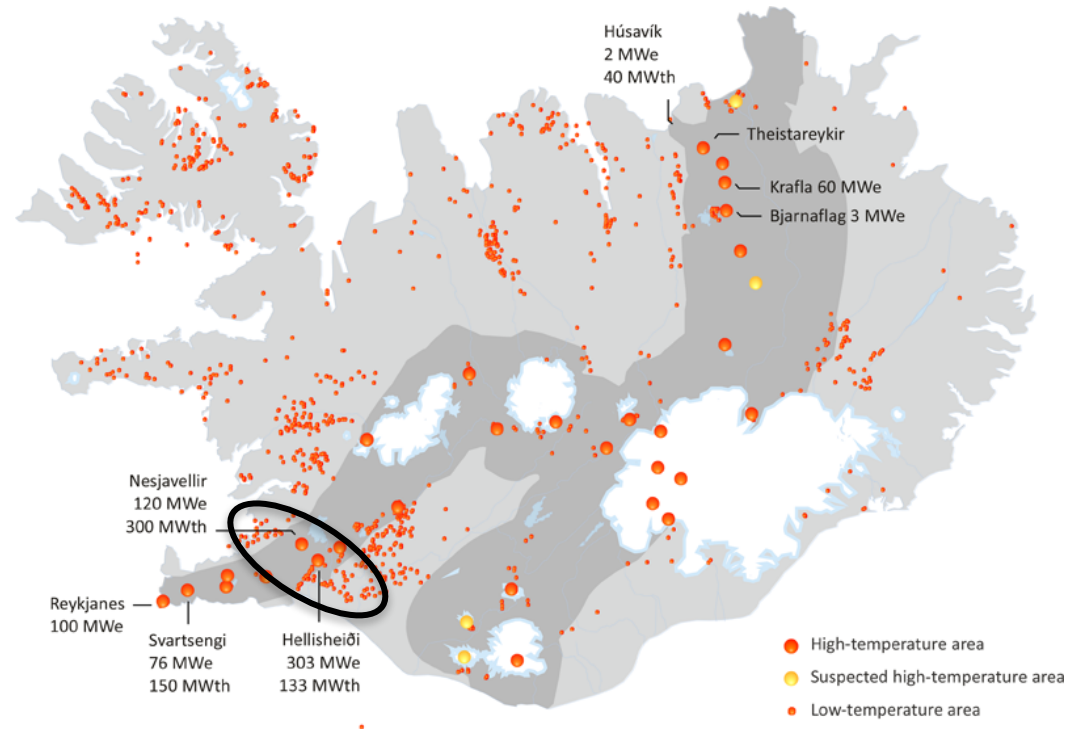
MT case history

- Iceland



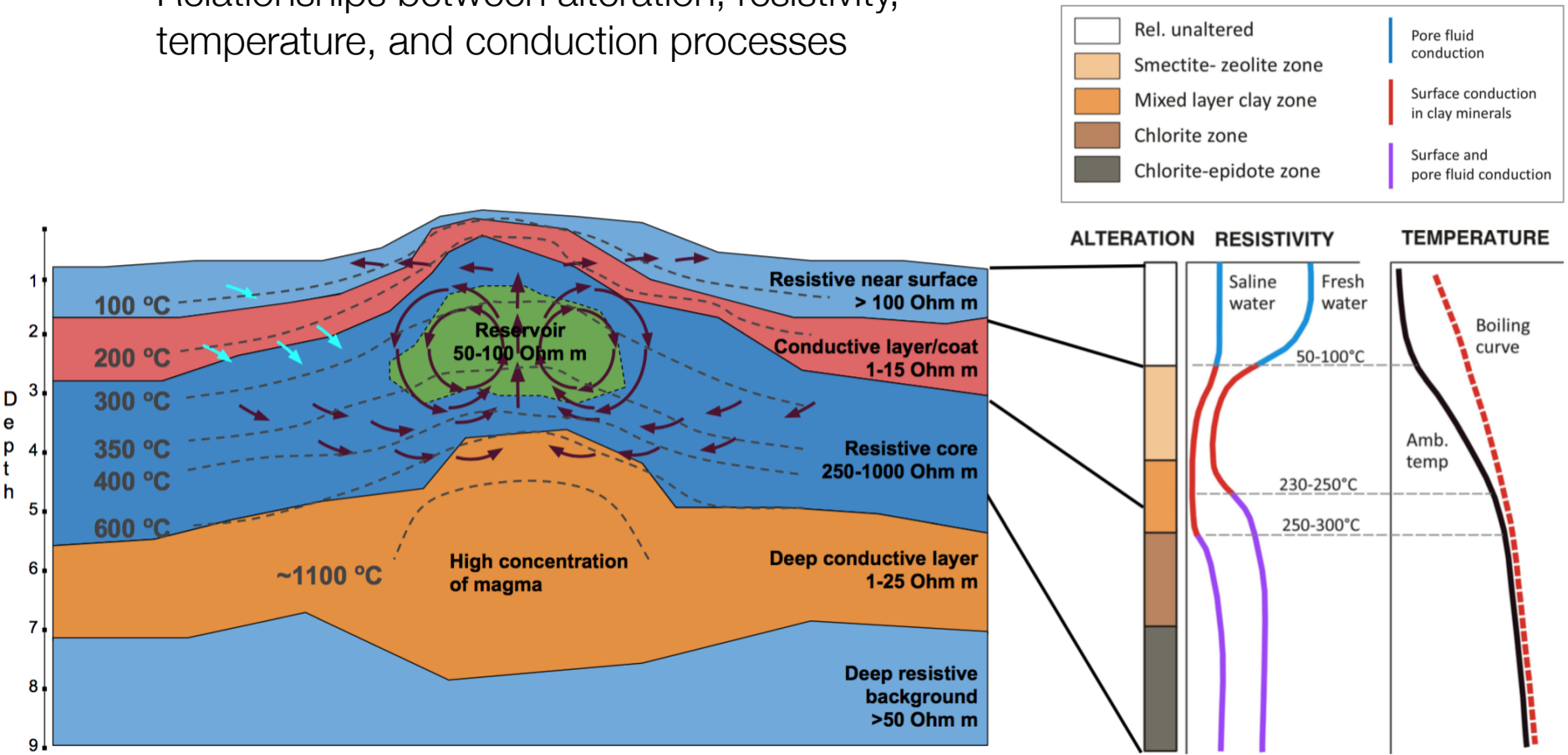
Hengill geothermal region: setup

- Iceland: geothermal hot spot
 - On the mid-Atlantic ridge
 - Hosts multiple high temperature geothermal systems
- Hengill geothermal area
 - Supplies majority of hot water in Reykjavik
 - Contributes ~450 Mwe to National power grid

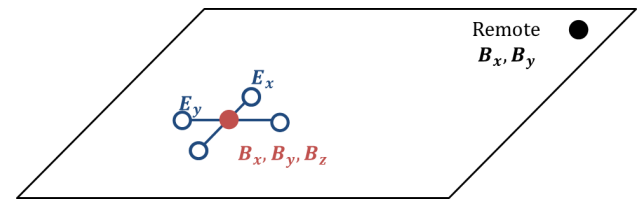


Physical properties

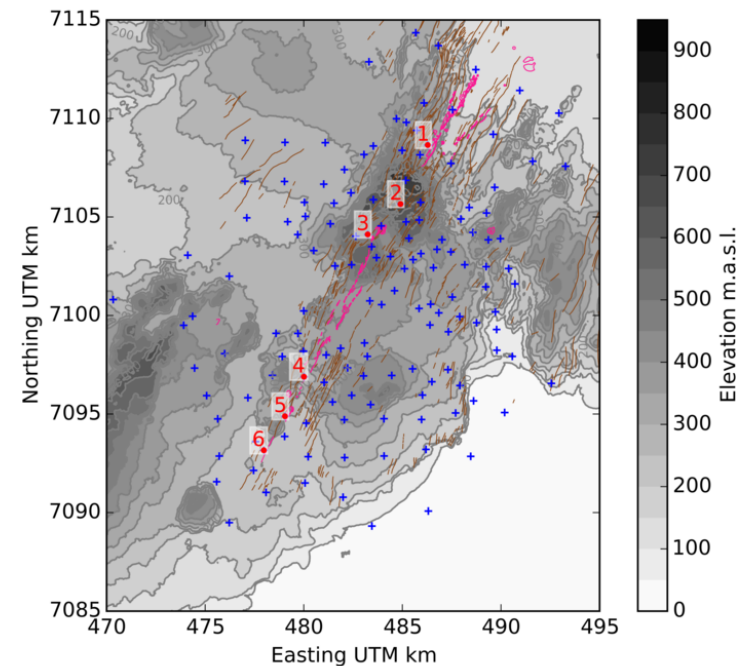
- Relationships between alteration, resistivity, temperature, and conduction processes



Survey

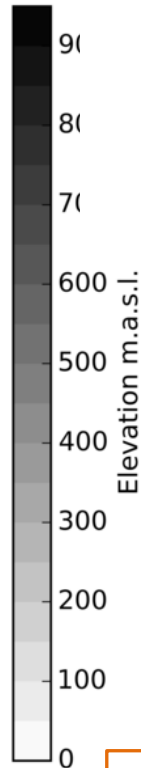
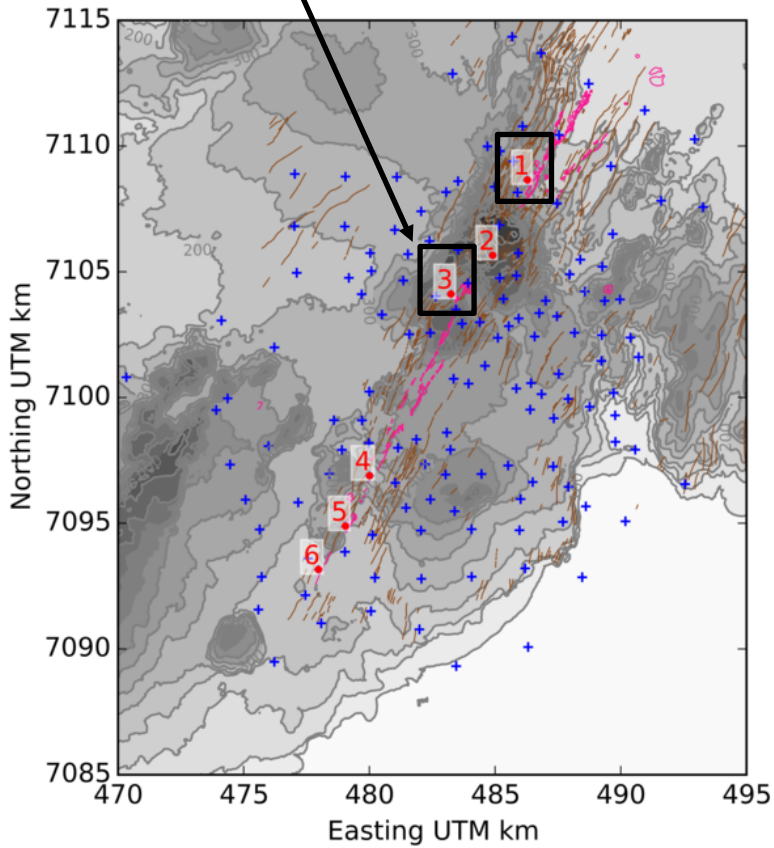


- MT instrumentation
 - Phoenix MTU5's
- Survey
 - 133 stations used
 - Combination of 2E and 2E+3H setup
 - Frequencies: 300 – 0.001 Hz
- Remote reference
 - About 40 km away
- Raw data processing using Phoenix software

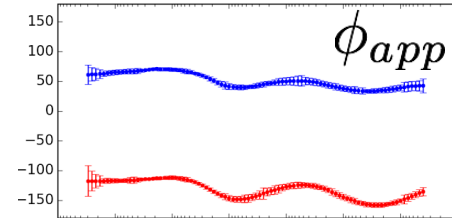
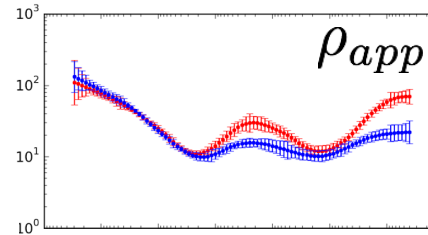


Data

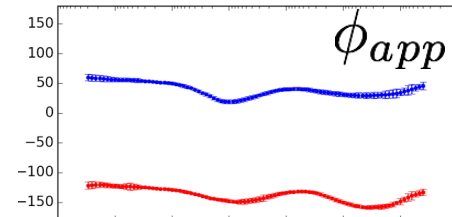
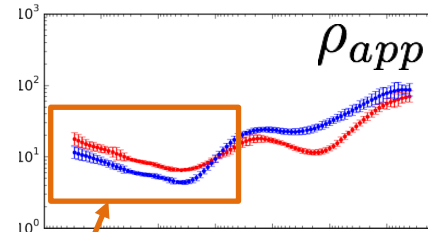
Surface alteration,
hot water, fumaroles



Location 1



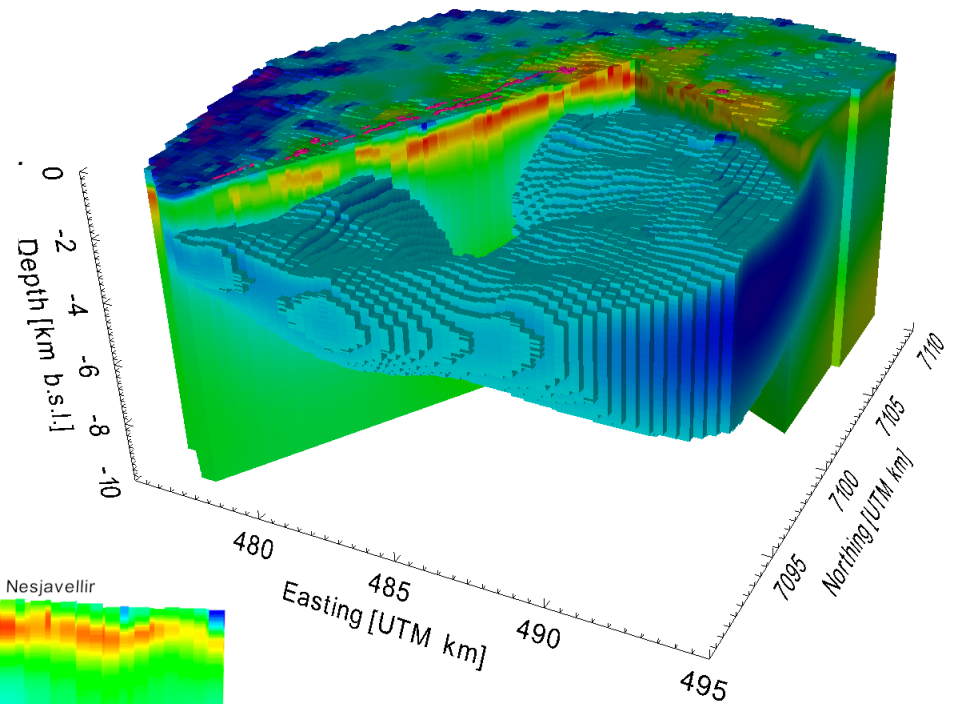
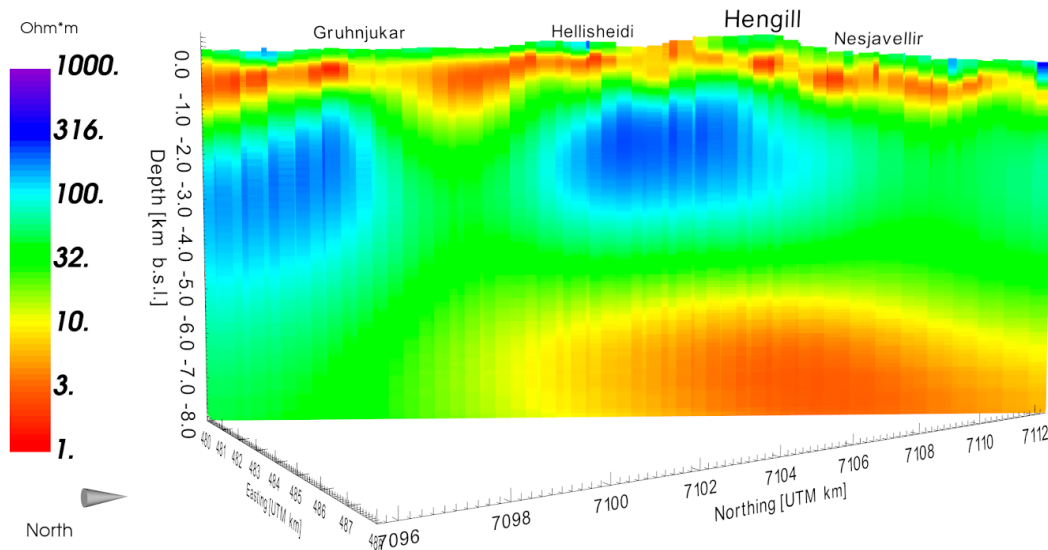
Location 3



Low apparent resistivity

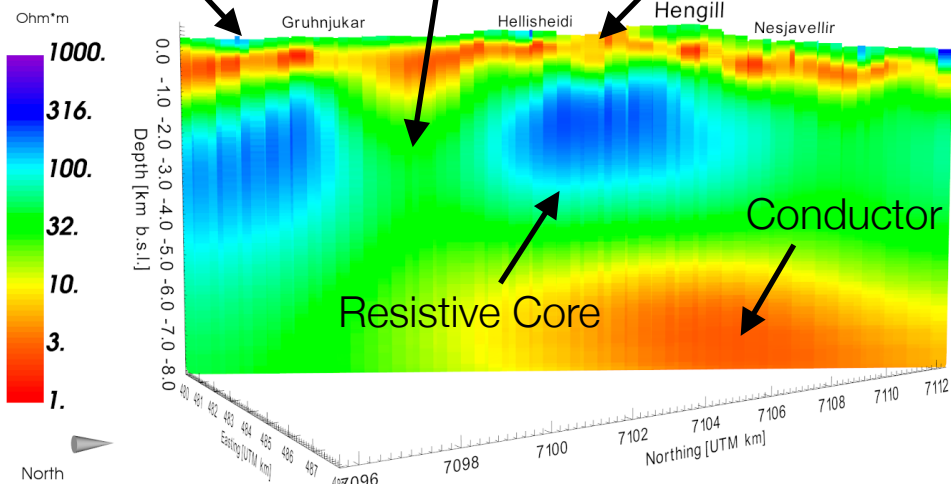
3D inversion

- Off-diagonal impedance (Z_{xy} and Z_{yx}) used
- Combined multi-frequency inversion (300 Hz – 0.001 Hz)

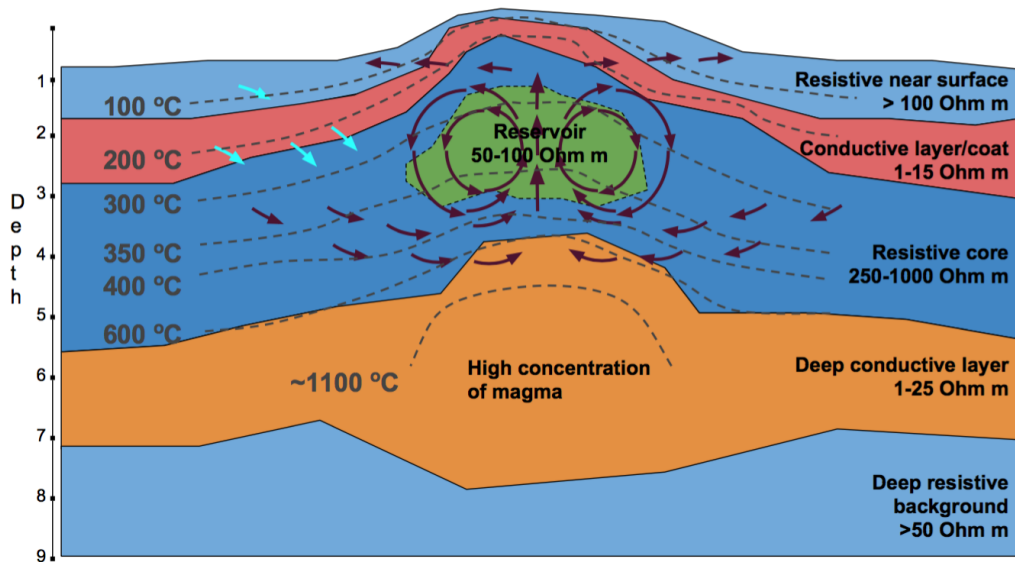
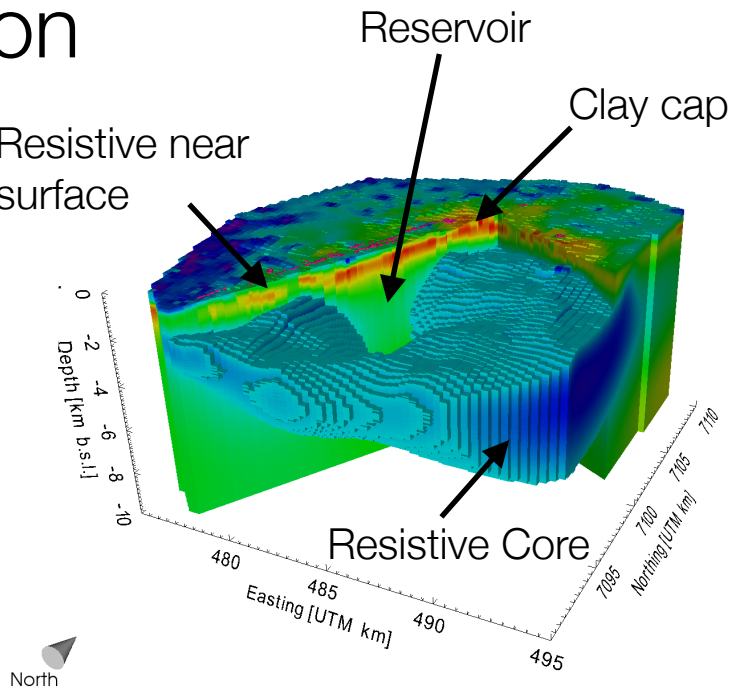


Interpretation

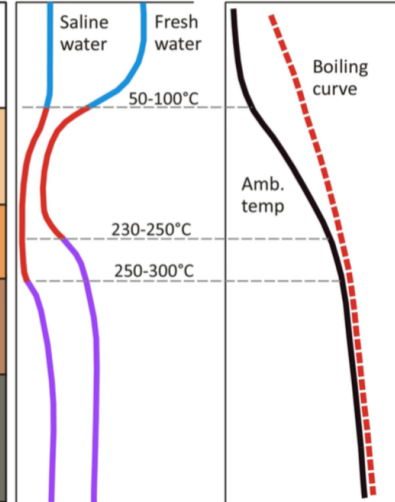
Resistive near surface



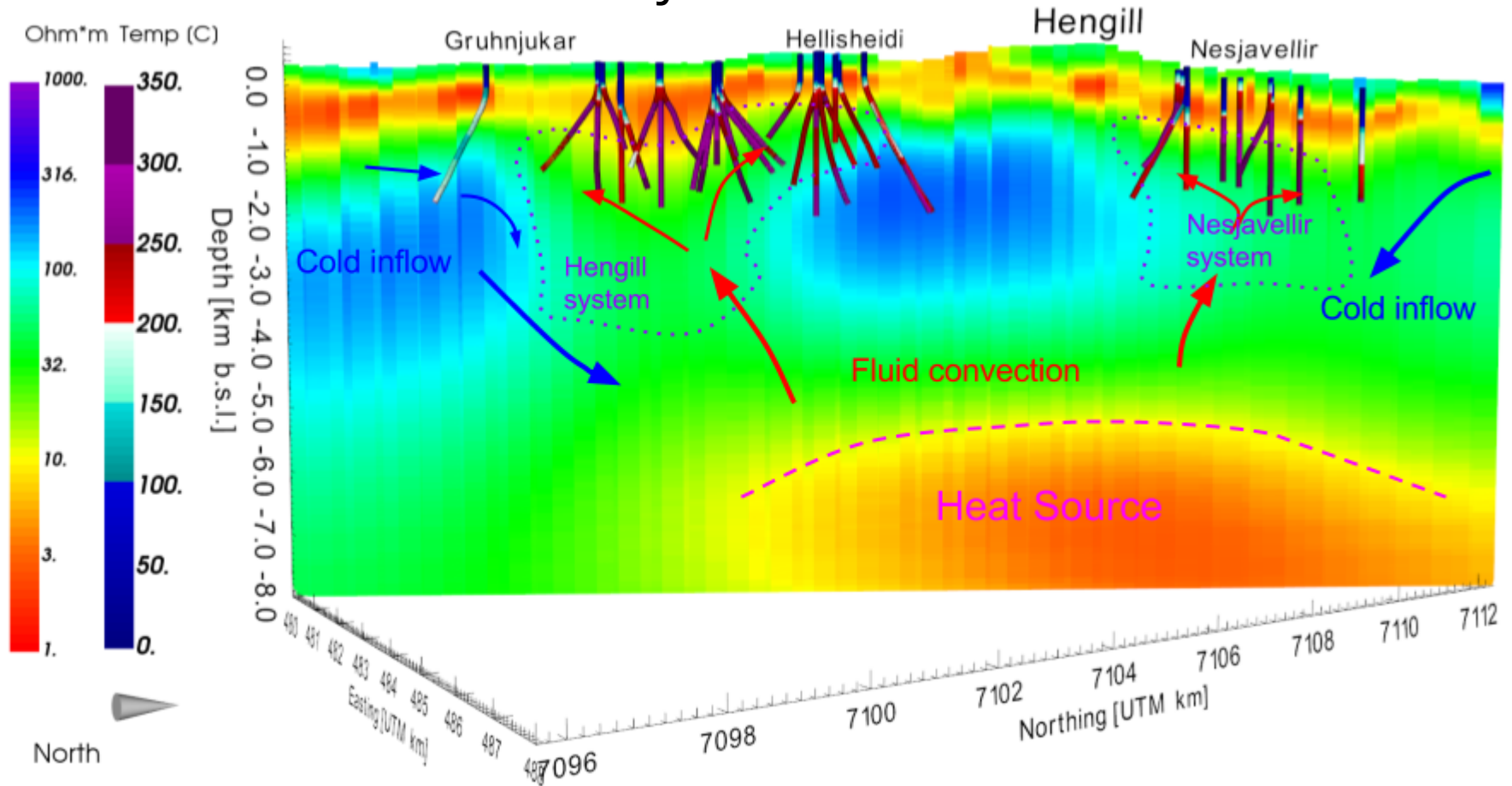
Resistive near surface



ALTERATION RESISTIVITY TEMPERATURE



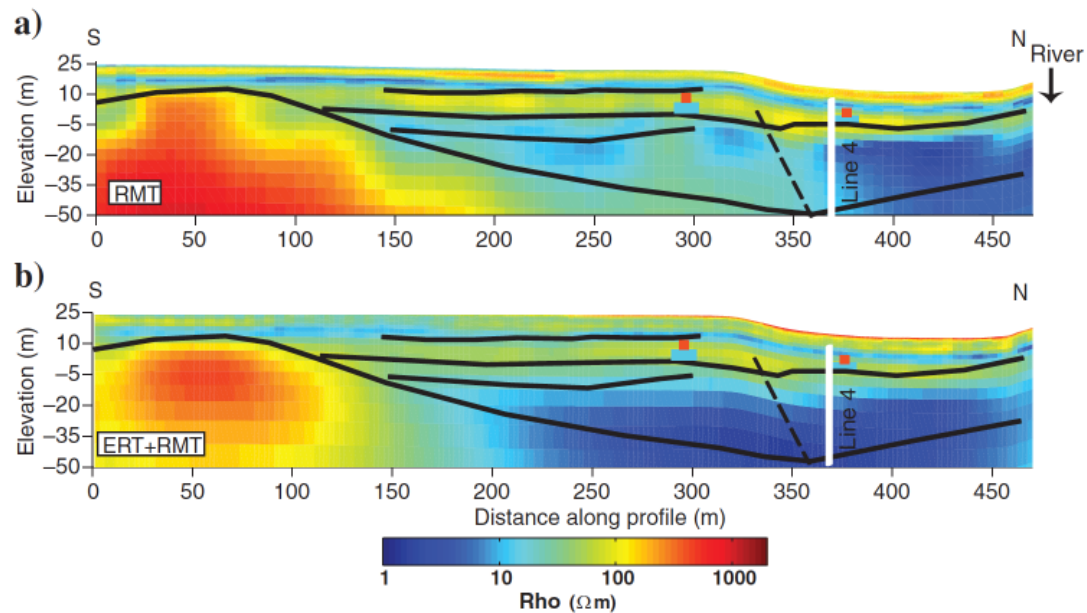
Synthesis



- Conductive layer corresponds with formation temperature
- Two main production fields: Hengill and Nesjavellir
- Deep conductive heat source

Case History: Landslides, Sweden

Shan et al., 2014



Landslides in Sweden



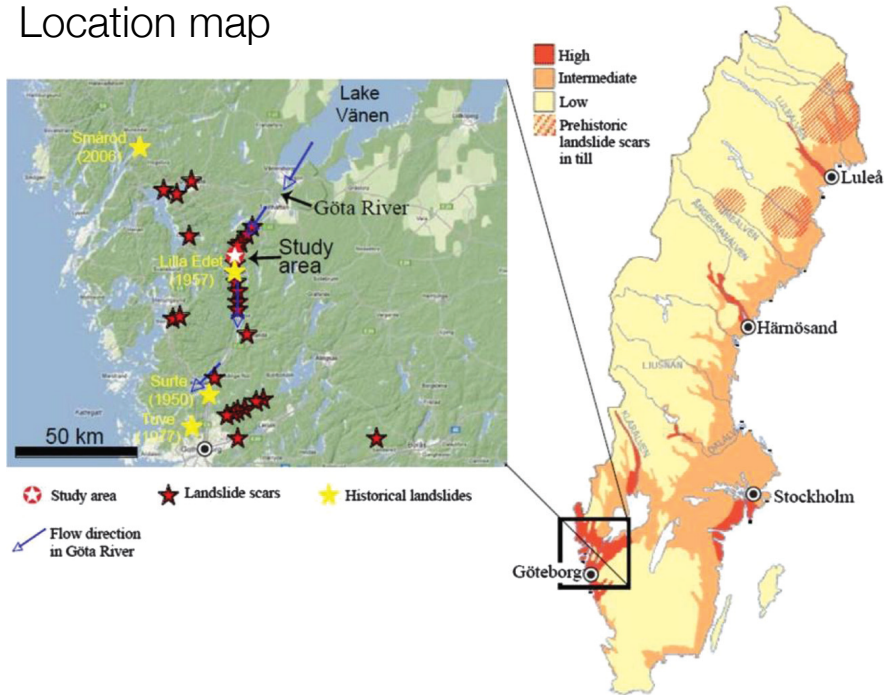
Photo: C Fredén, 1977, Tüve



Photo: Mats Engdahl, 2006, Munkedal

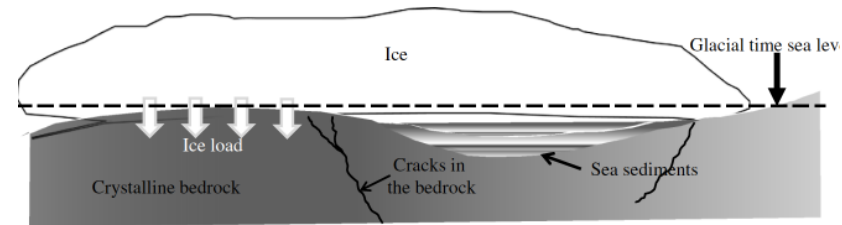
Setup

Location map

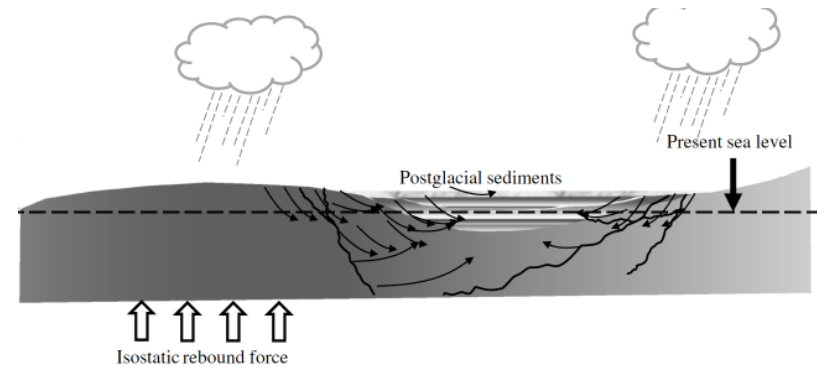


Formation of quick clays

The last glacial period



Land uplift and formation of quick clays



- Marine clay, deposited, uplifted then flushed with freshwater
 - Decreases salinity and reduces strength → quick clays

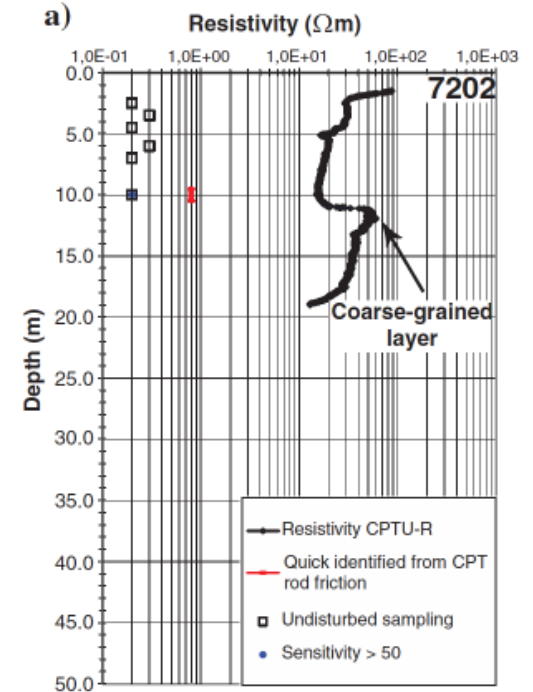
Can we detect quick clays?

Properties

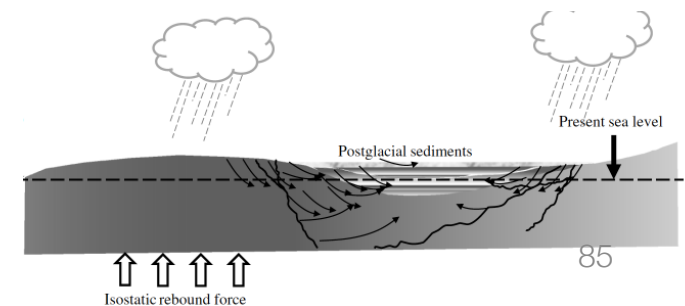
Soil material	Resistivity interval
Salt/intact marine clay	1–10 Ωm
Leached, possible quick clay	10–80 Ωm
Dry crust clay, slide deposits, coarser	>80 Ωm

- Clays
 - Conductive
 - Usually overlay sand / gravel
- Quick clays
 - Infiltration of water removes salt
 - More resistive than typical clays
- Coarse-grained layer
 - Resistive
 - Sand and gravel (porous)

Resistivity (induction log)

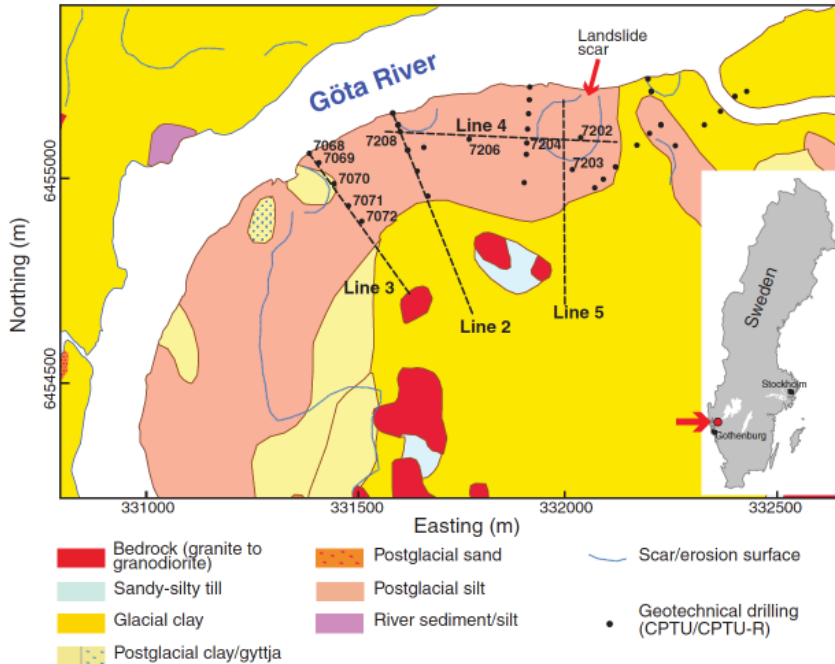


Formation of quick clays

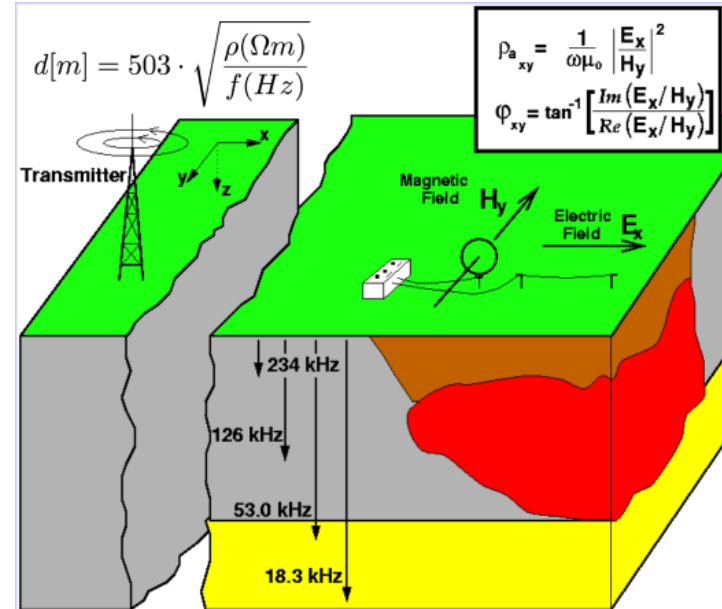


Surveys

Geologic map



RMT survey

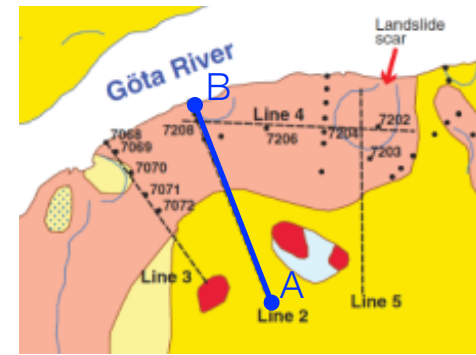


From Bulent (2017)

- DC (ERT)
 - Lines 2-5
 - ABEM system
 - Wenner array (5m spacing)

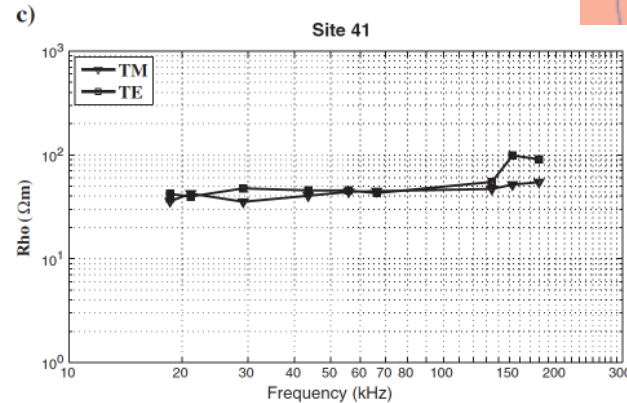
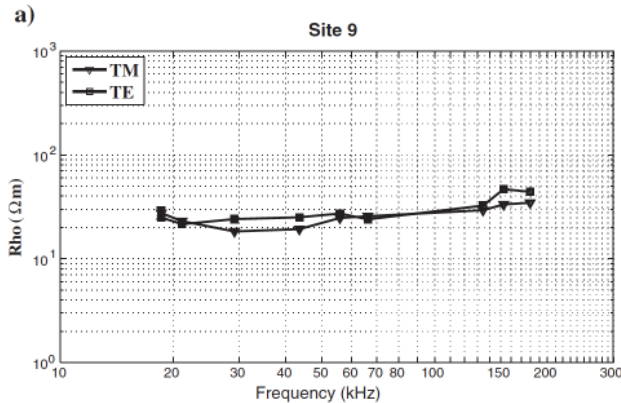
- Radio MT (RMT)
 - Same lines as DC
 - EnviroMT system
 - 21-28 radio transmitters
 - Frequencies: 18.3-183 kHz

RMT: sounding curves

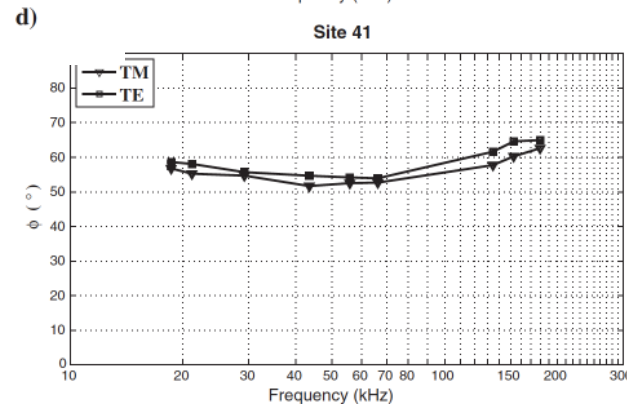
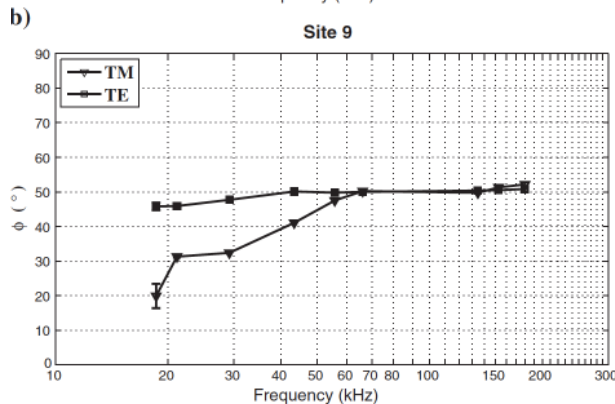


Line 2

Apparent resistivity



Phase

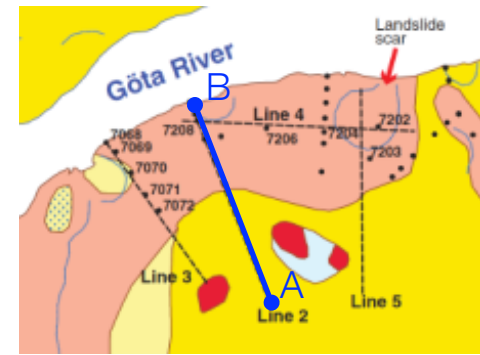


Computed using determinant of impedance tensor at two stations along Line 2

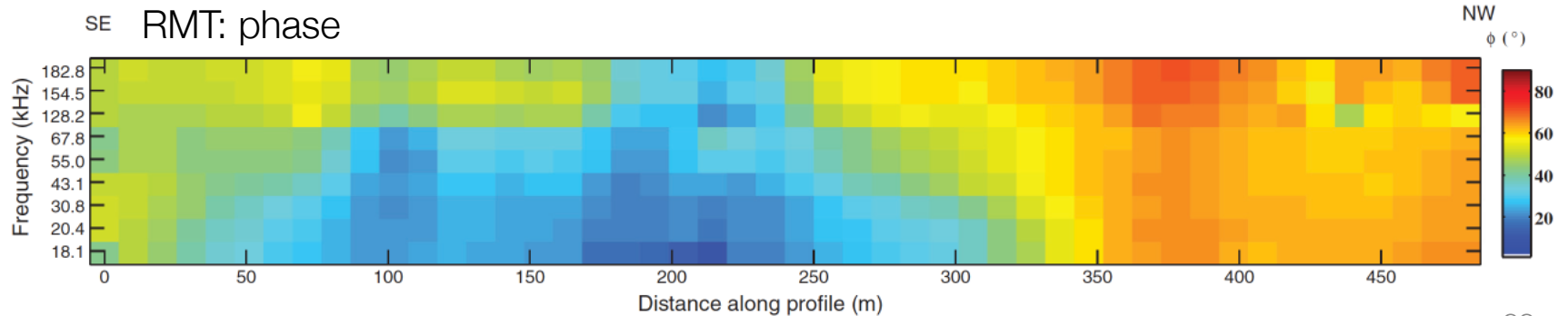
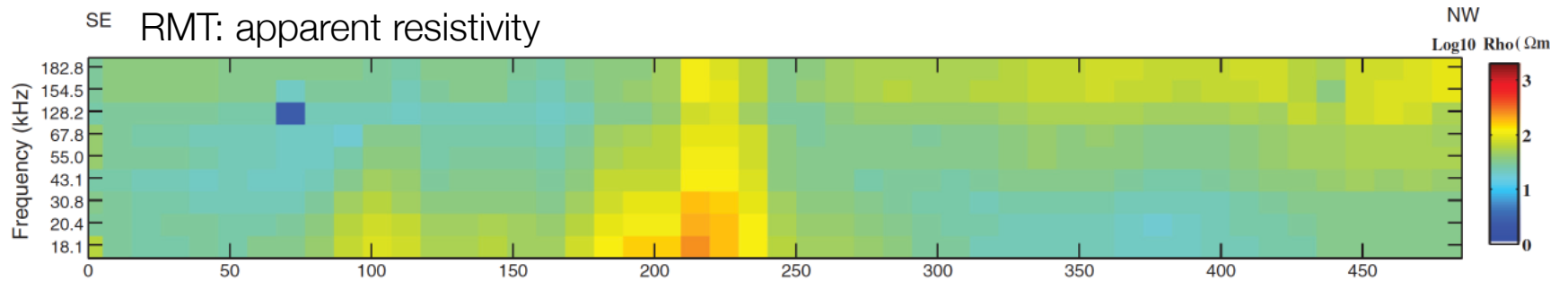
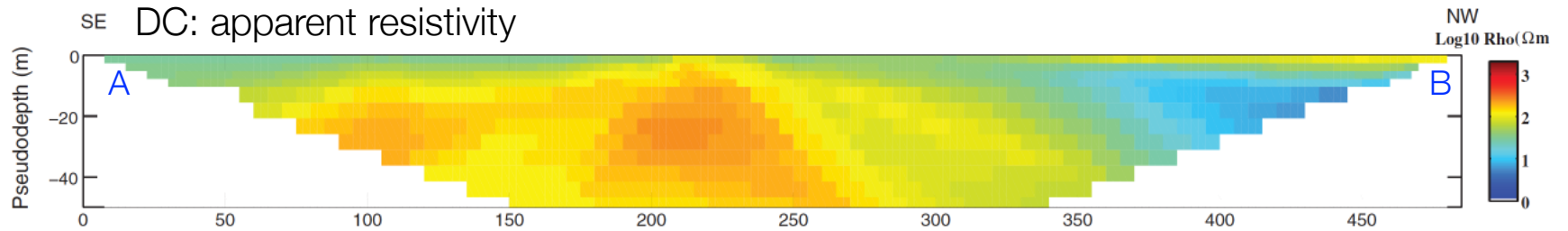
Impedance tensor:
$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix}$$

Determinant: (complex-valued)
$$Z_{\text{det}} = \sqrt{Z_{xx}Z_{yy} - Z_{xy}Z_{yx}}$$
 87

Pseudosections

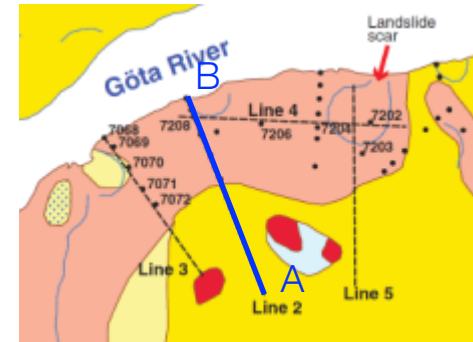
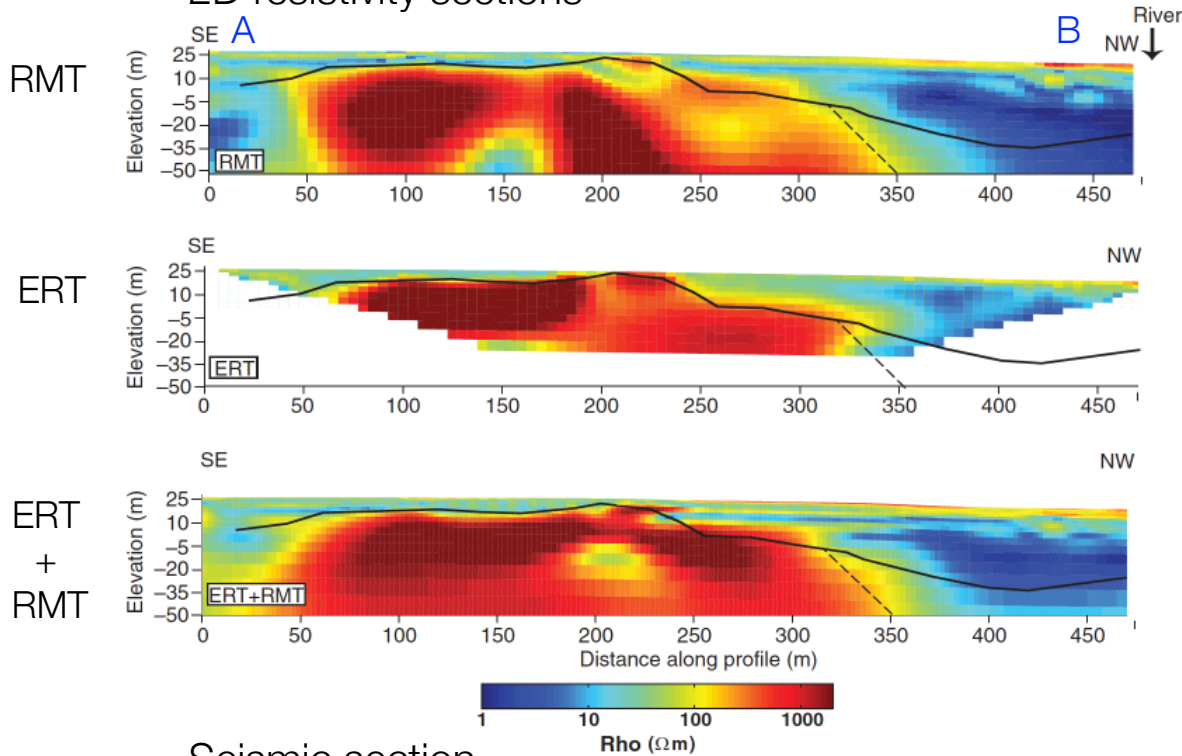


Line 2

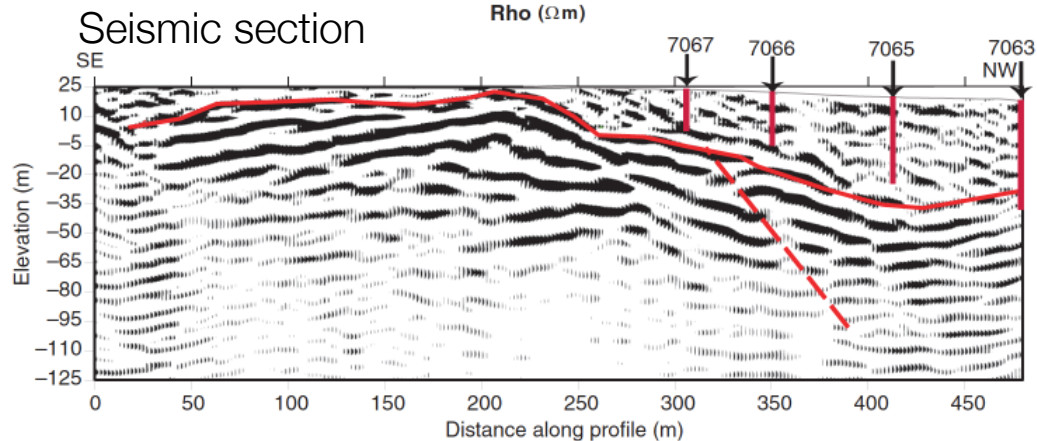


Processing and inversion

2D resistivity sections

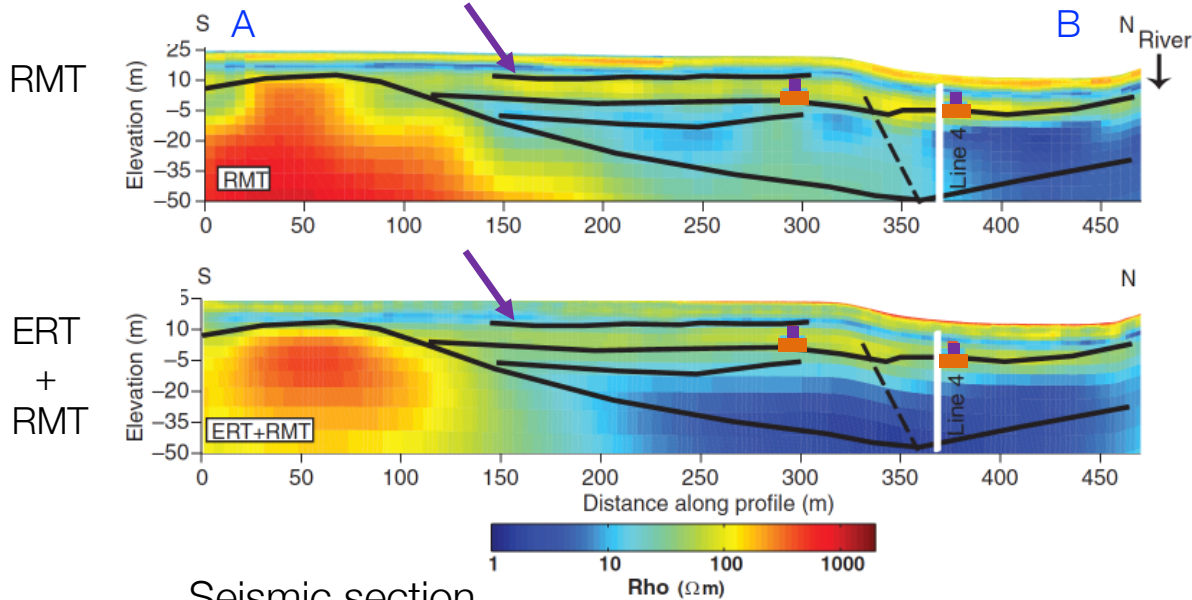


- ERT and RMT yield similar images
- Jointly invert ERT and RMT
- Correlates with seismic

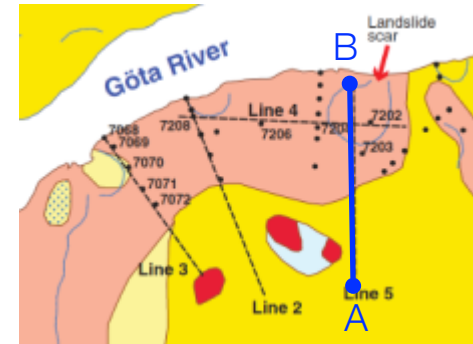
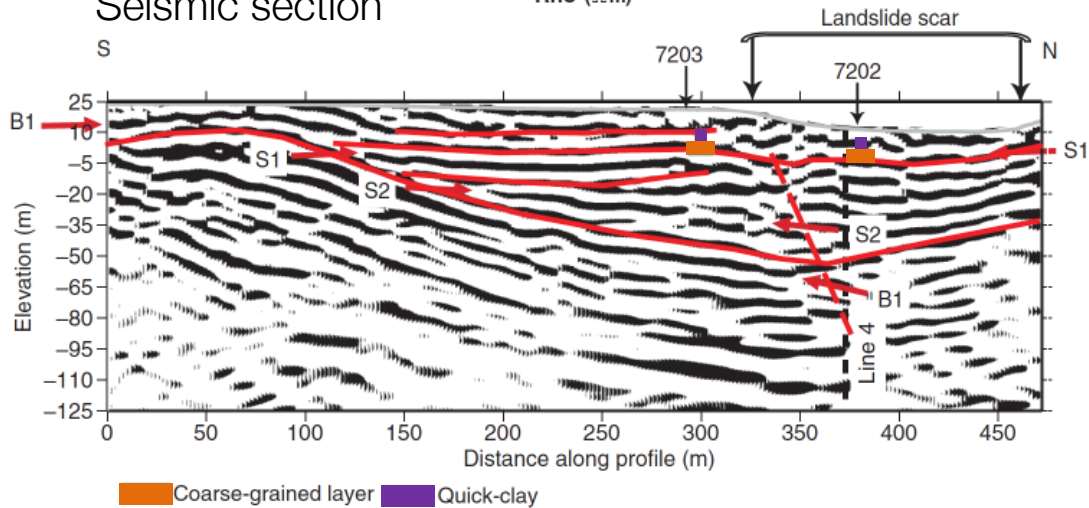


Processing and inversion

2D resistivity sections



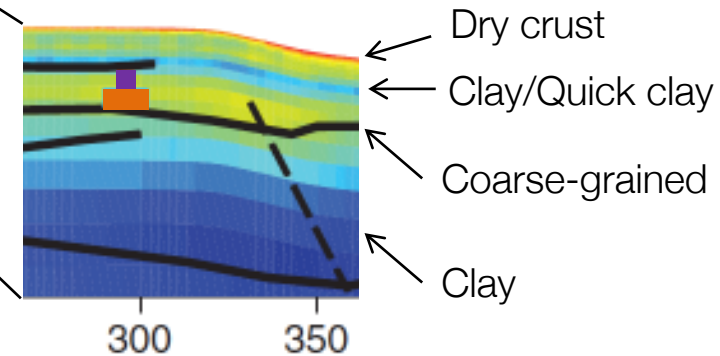
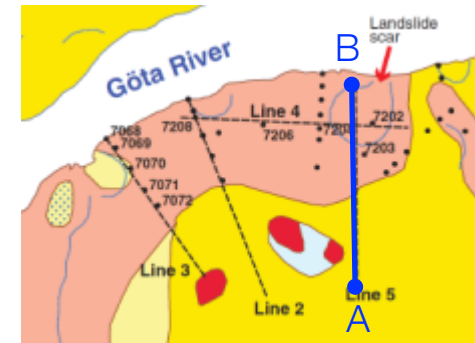
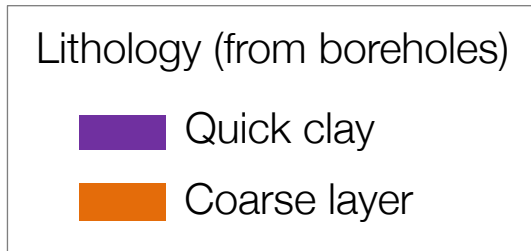
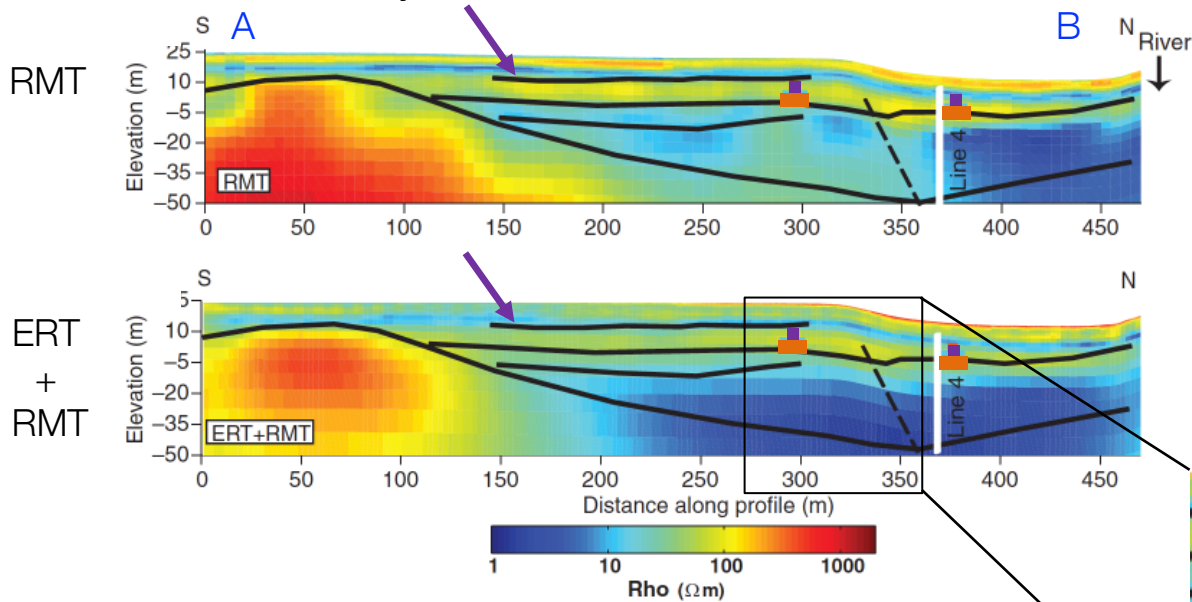
Seismic section



- Inverted RMT, ERT+RMT interpreted with seismic

Processing and inversion

2D resistivity sections



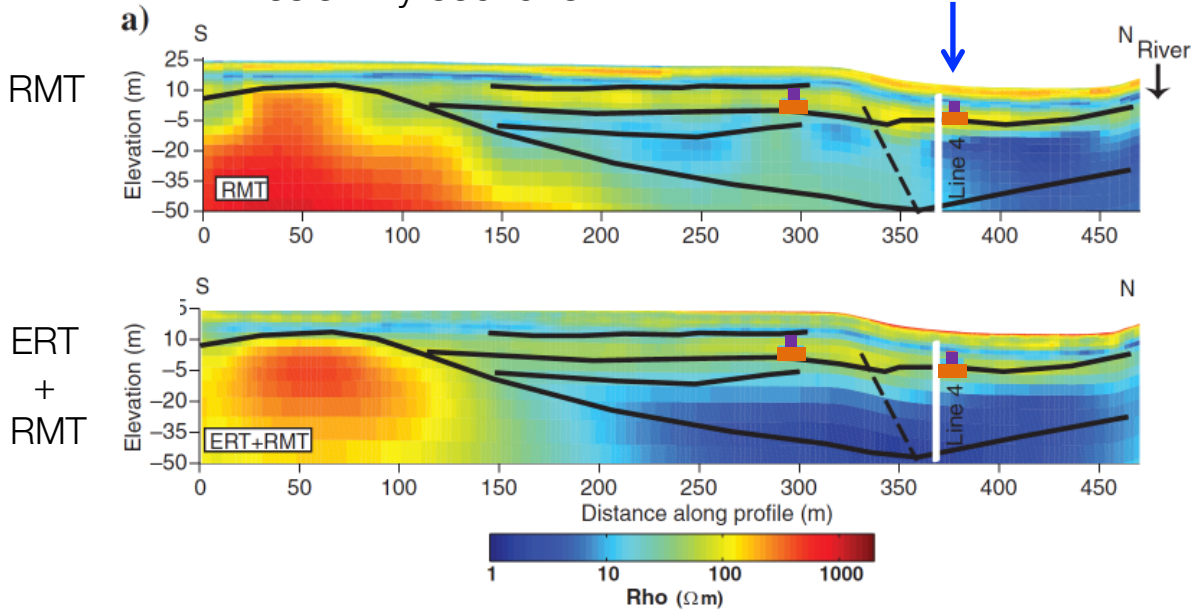
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Quick clay

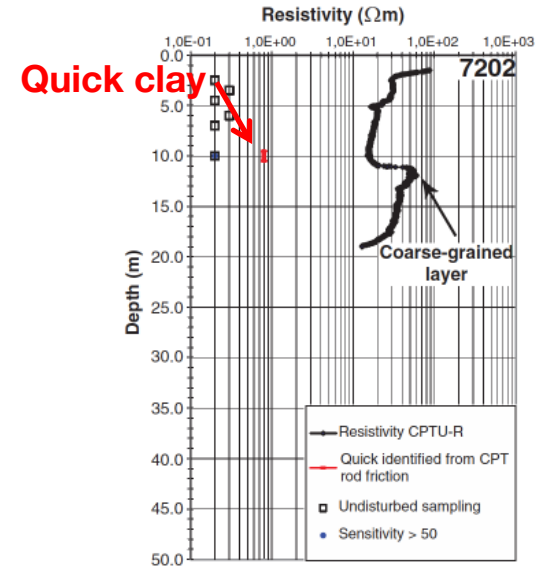
- Top interface: conductor to resistor
- Thickness difficult to estimate

Synthesis

2D resistivity sections



Resistivity log



- Resistivity is indicative of lithologic units → identify possible quick clays
 - Corresponds with seismic
 - Determining thickness is challenging

