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Mapping geothermal reservoir using broadband MT survey in Þeistareykir, Iceland.

Yu, G., Allegar, N., Gunnarsson, A., He, L. F., He, Z. H., Strack, K.-M., Tulinius, H.

SEG Las Vegas 2008 Annual Meeting

Mapping geothermal reservoir using broadband MT survey in Þeistareykir, Iceland

Yu[1], G., Allegar[1], N., Gunnarsson[2], Á., He[4], L. F., He[4], Z. X., Strack[1], K.-M., & Tulinius[3], H.

[1]KMS Technologies

[2]Landsvirkjun

[3]Mannvit (former VGK-Hönnun)

[4]BGP

Outline

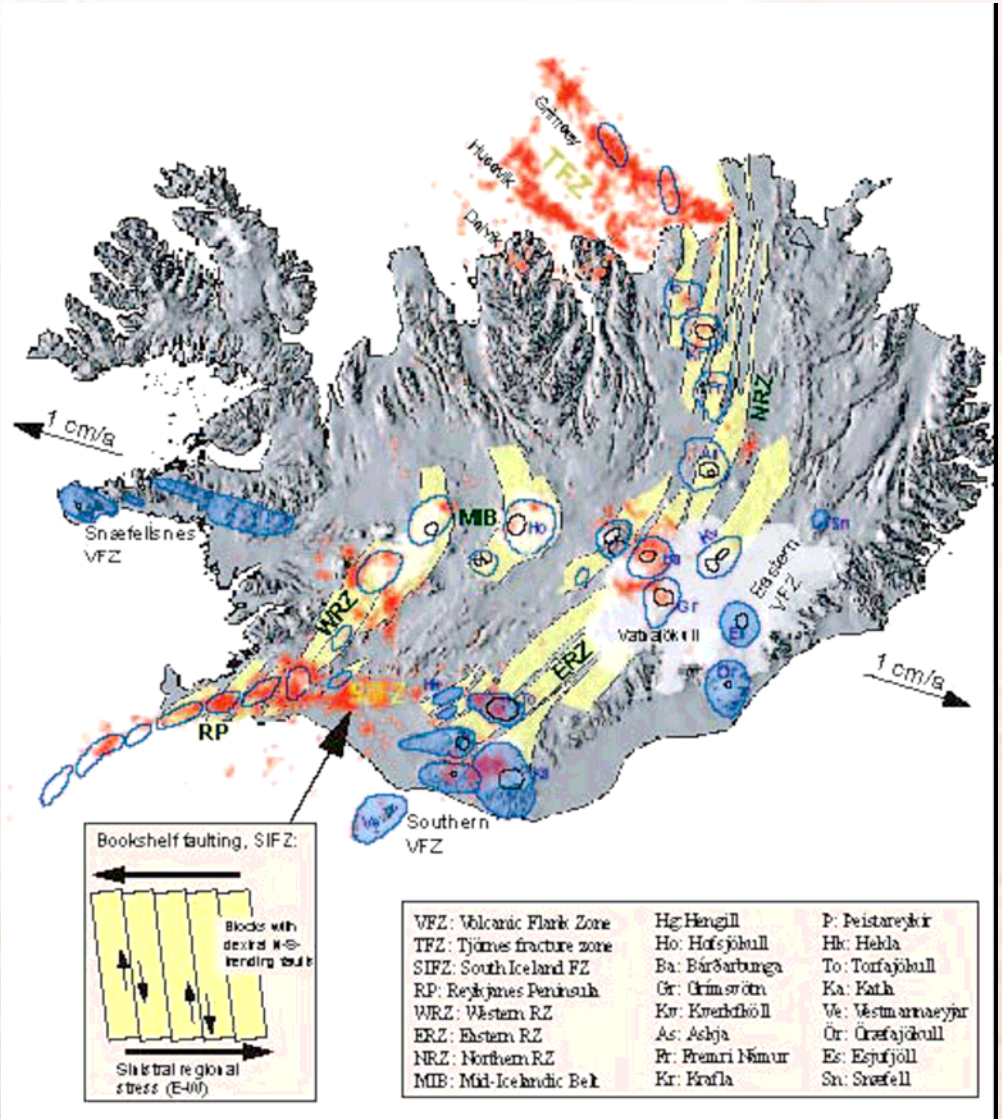
- Introduction
- Project objectives
- Data acquisition
- Data processing
- Modeling & inversion
- Interpretation
- Conclusions

Introduction

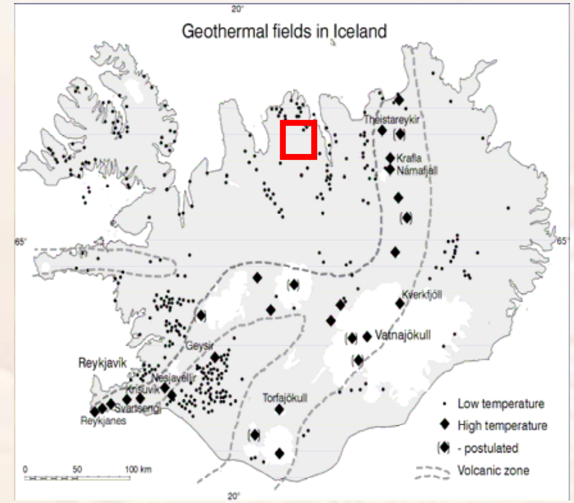
- Much of Iceland's energy supply is geothermal energy;
- Geothermal power station site selection to build new aluminum mills;
- Geothermal field E&D are key elements for sustaining development;
- Existing TEM has very limited depth penetration (<800 m);
- Using MT to explore deep geothermal reservoirs.

Introduction

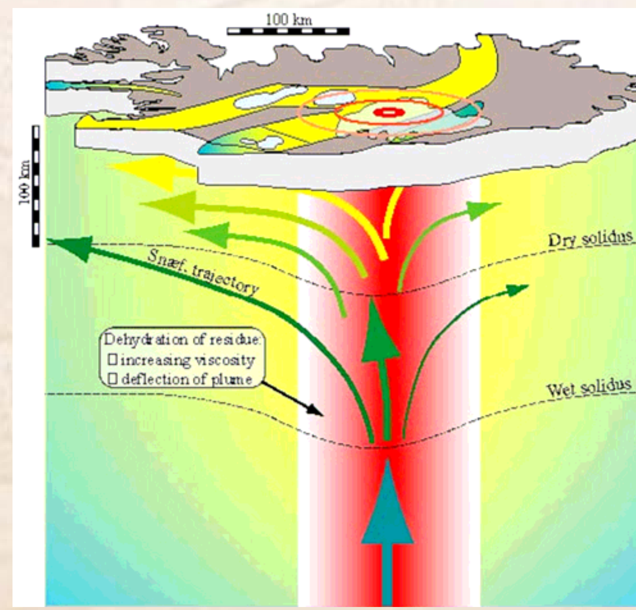
Introduction



(Trønnes, 2002)



Armannsson 2000



Wolfe et al., (1997), Shen et al., (2002)& Ito (2002)

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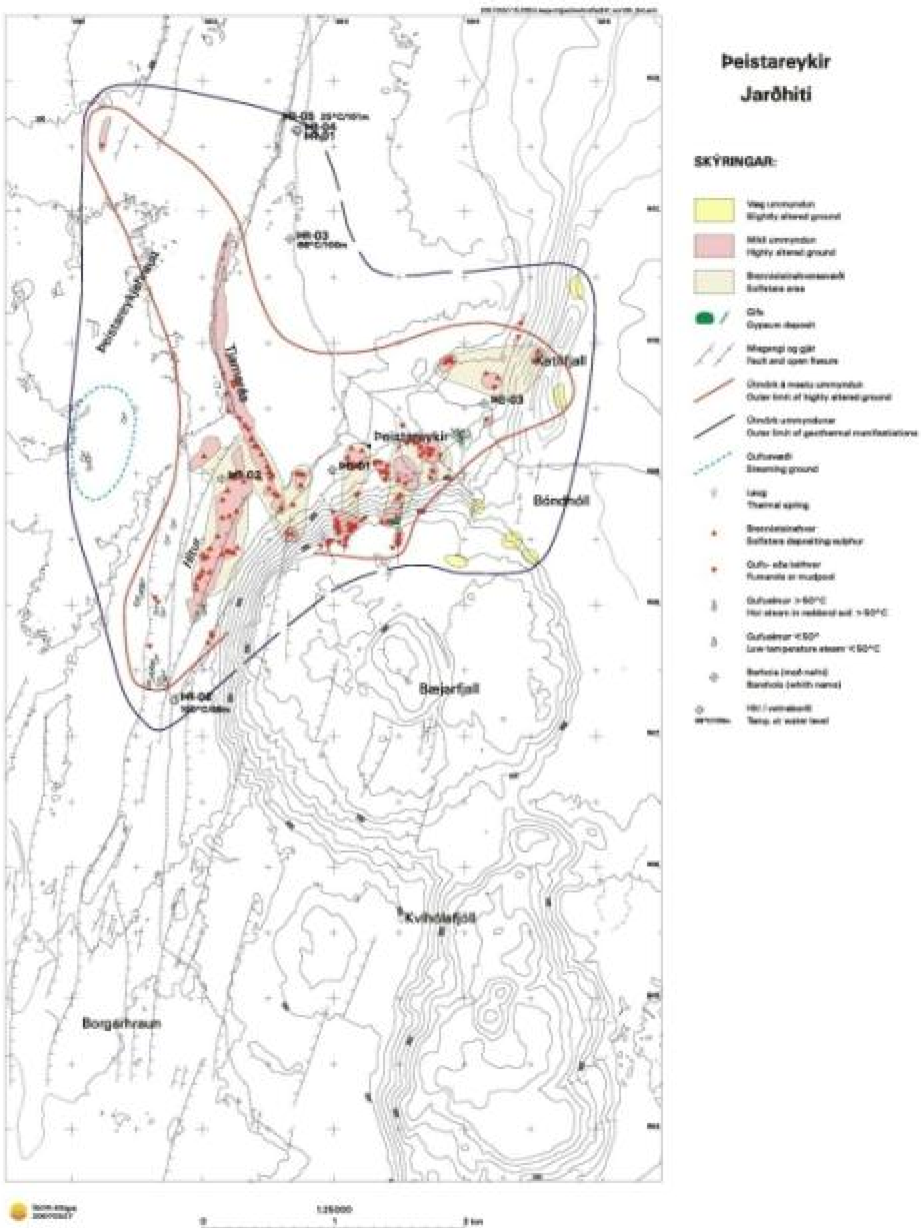
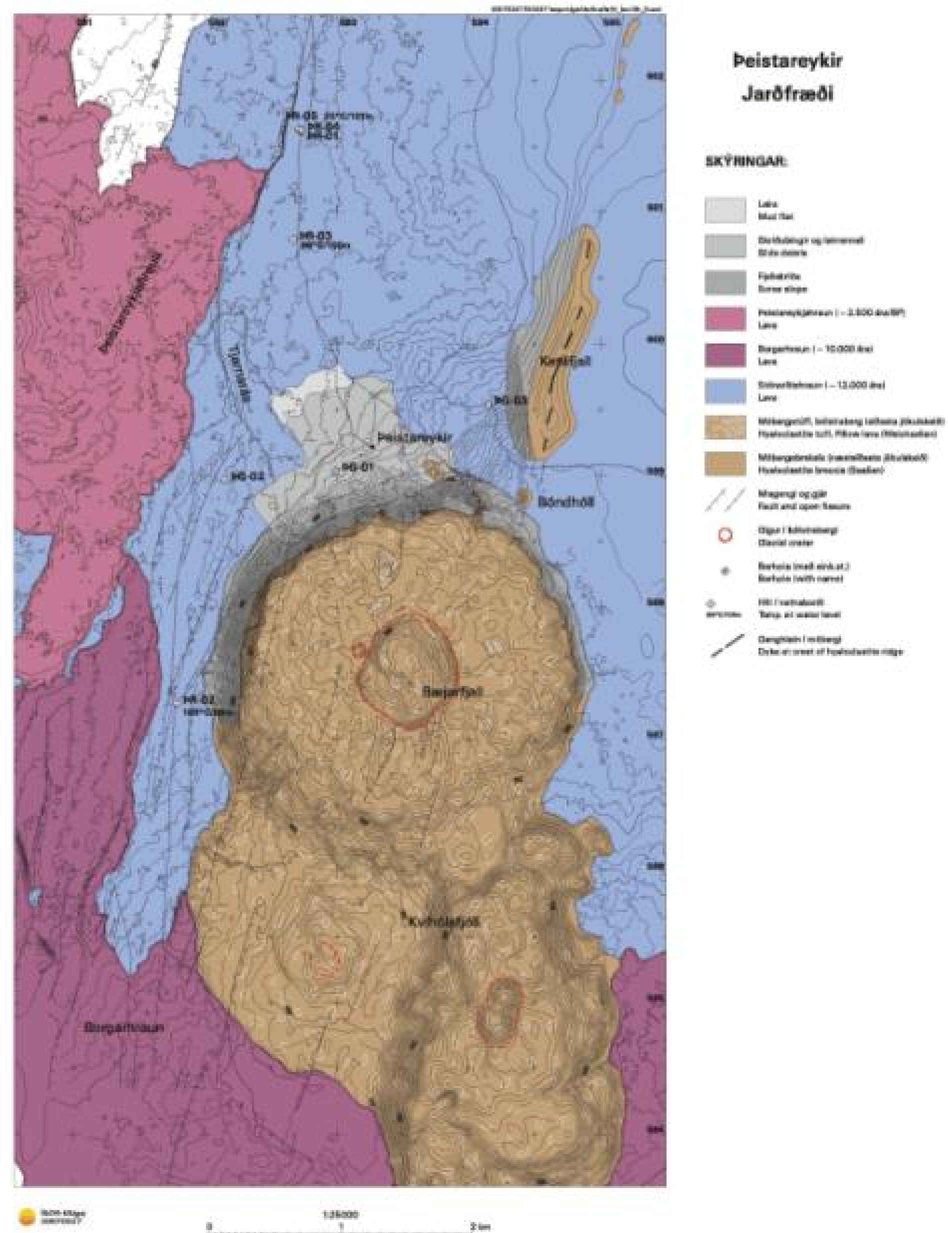
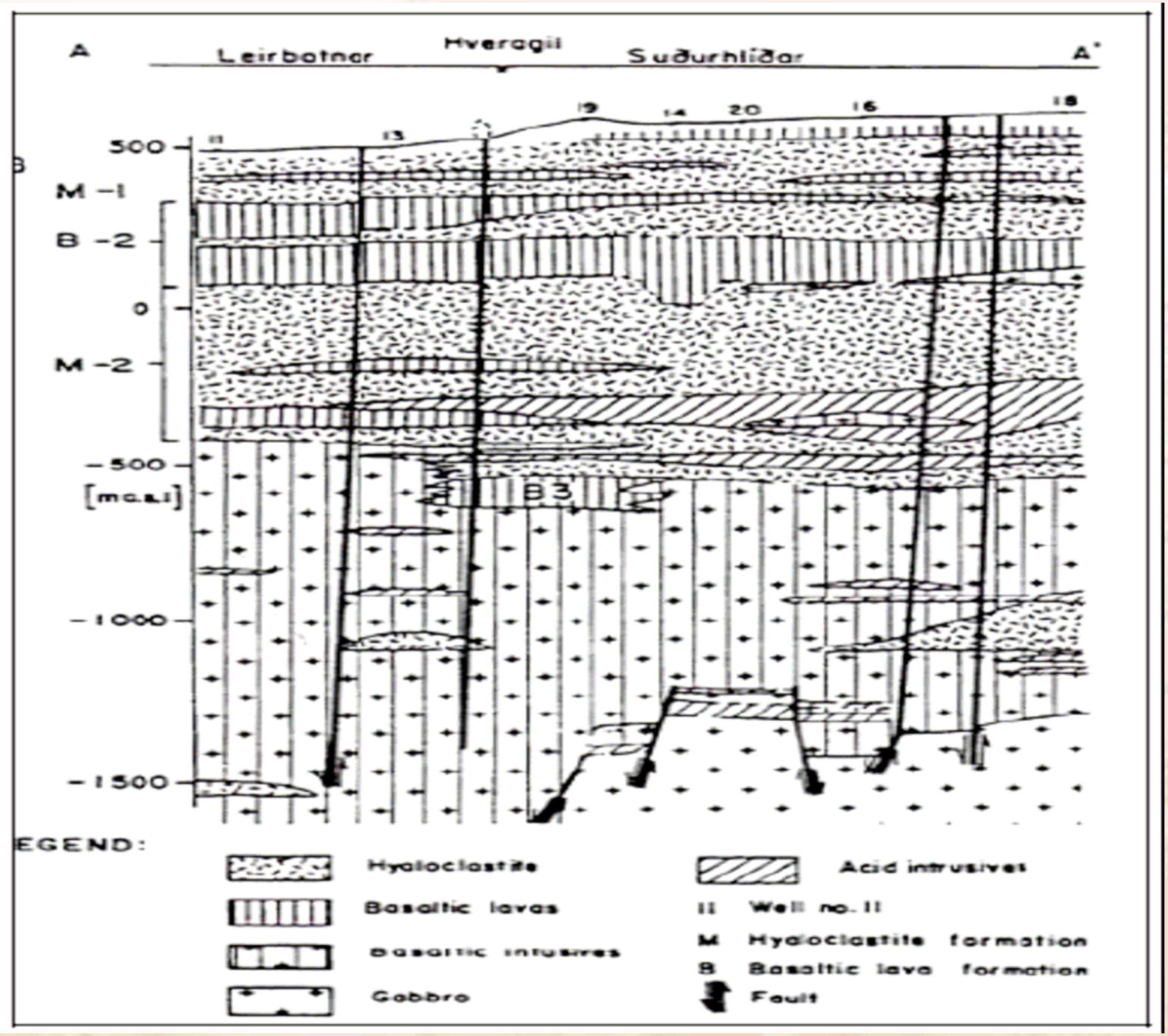
Þeistareykir geothermal & geology maps





Geological section in NW-SE direction across Krafla hydrothermal system



Jonasson, 1994

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Project objectives

- Confirm TEM survey findings of a high temperature reservoir under survey area;
- Outline better boundaries of the reservoir;
- Provide basis to map temperature & permeability variation.

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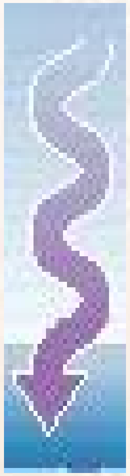
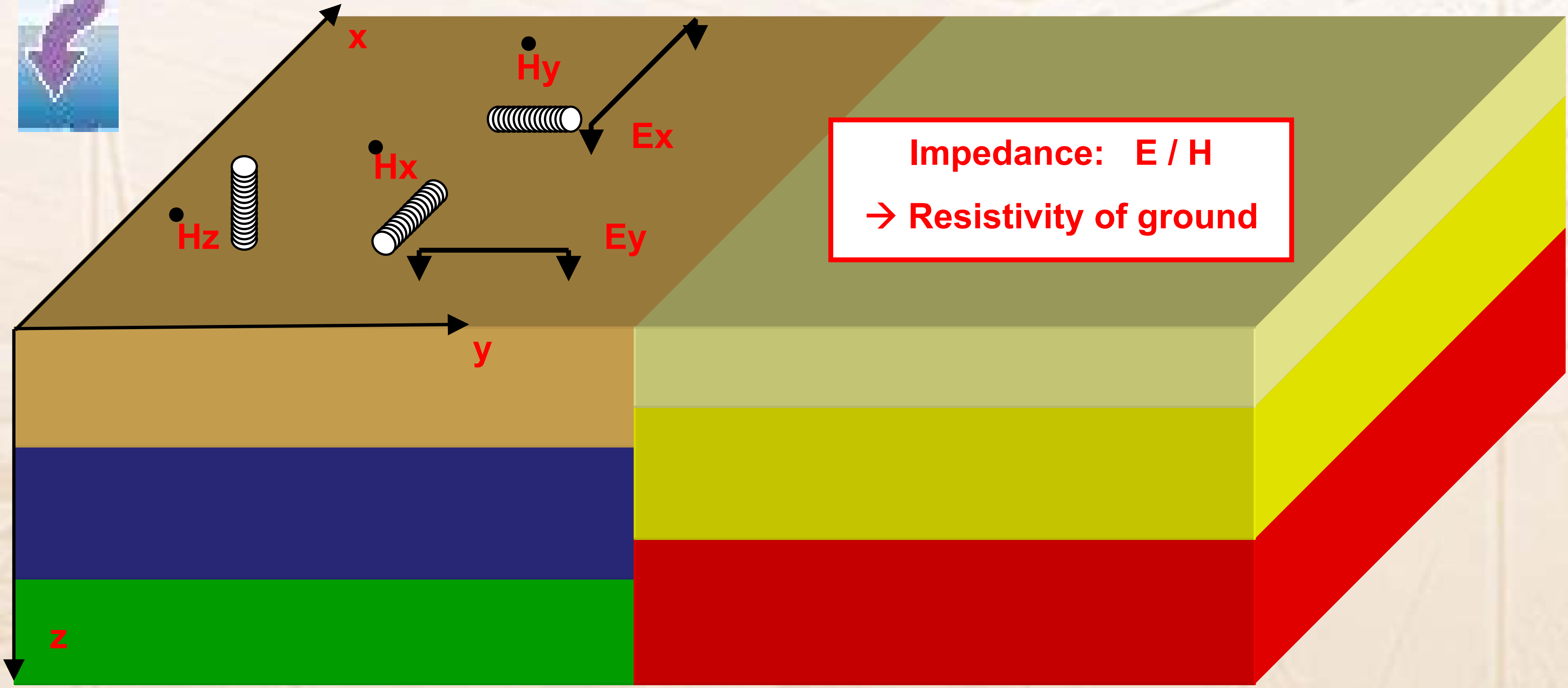
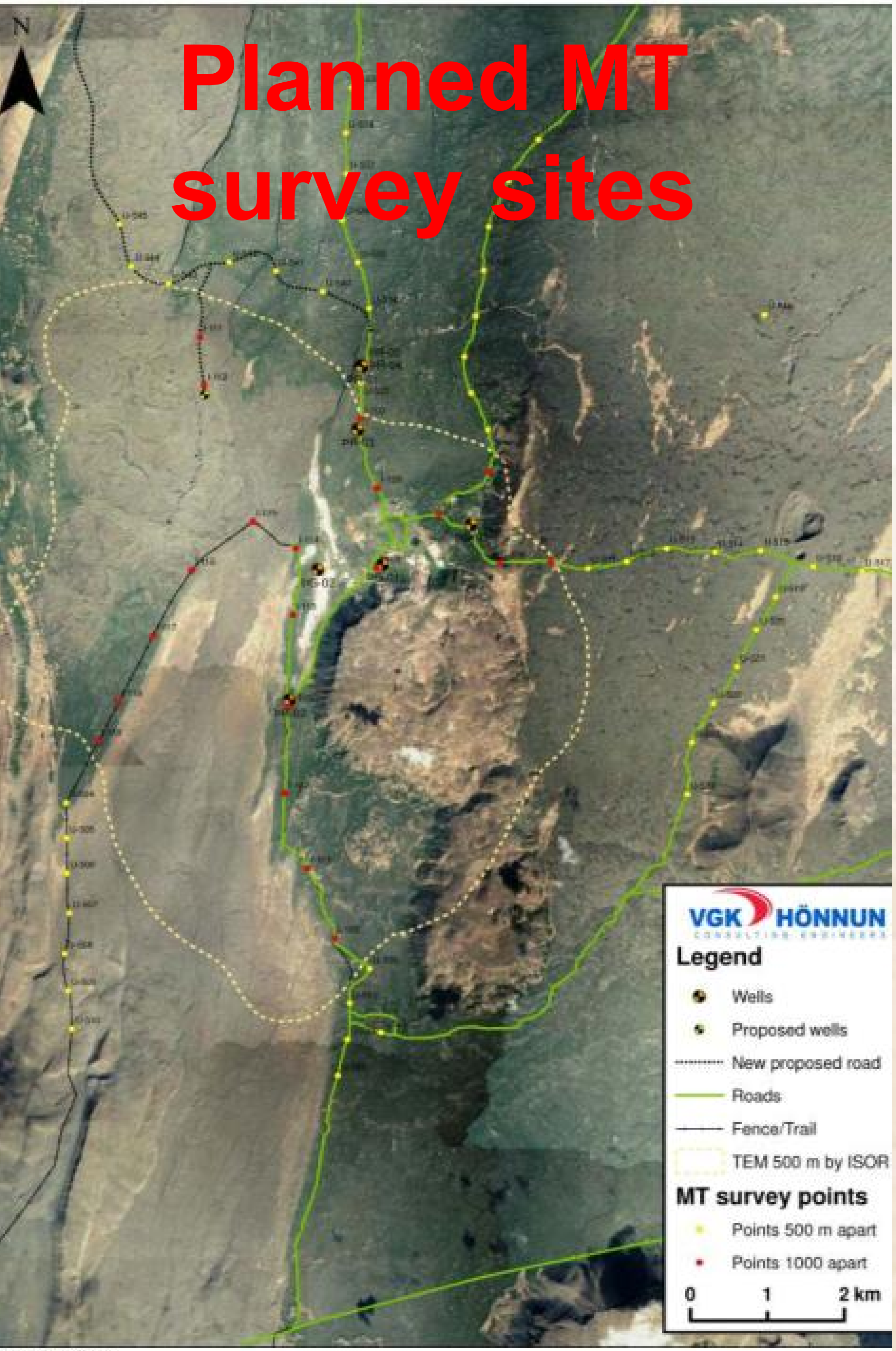
Magnetotelluric (MT) method

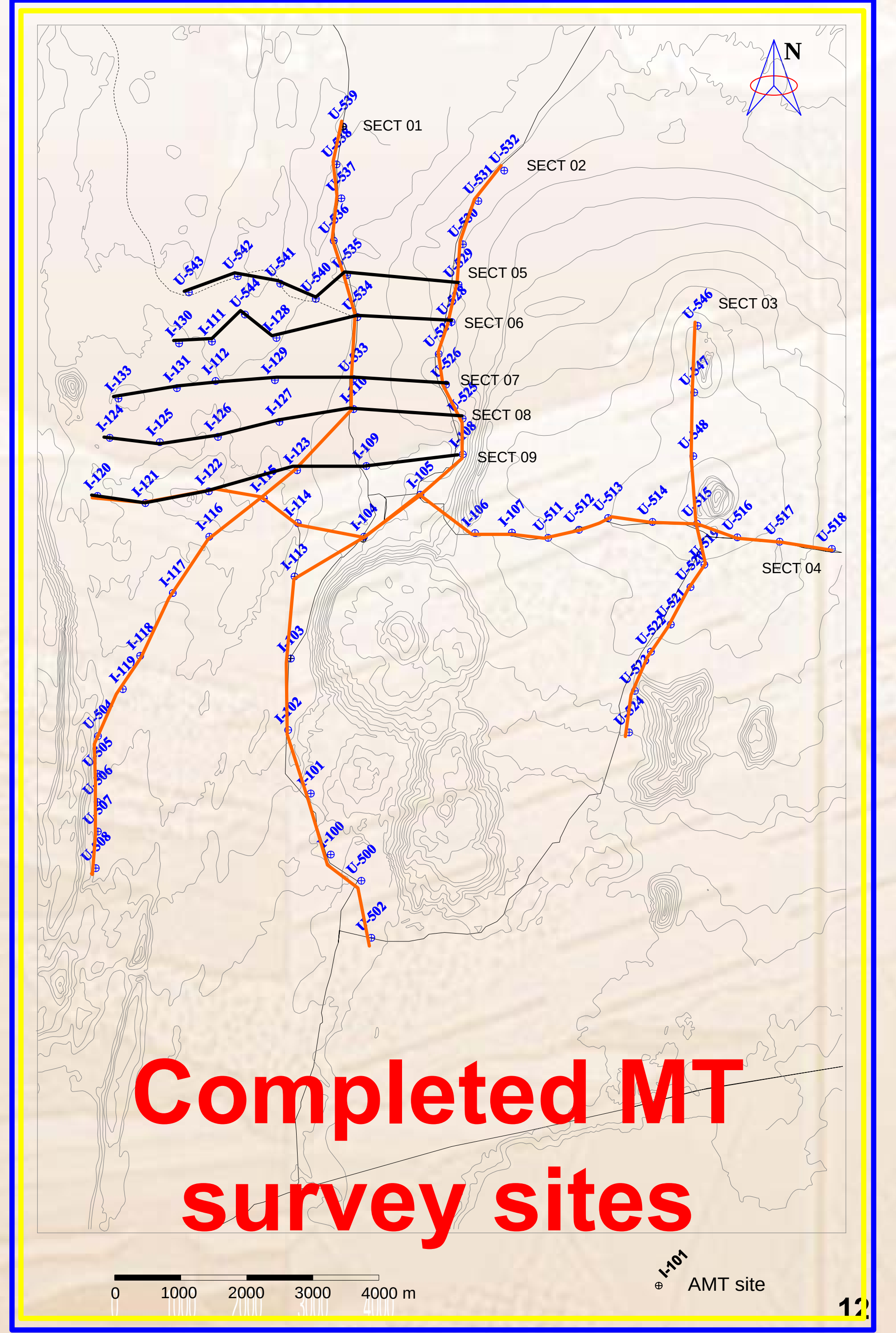


Measures natural variation of EM field
source: ionosphere & world wide thunderstorm activity;

Source field can be handled as vertical incident plane wave, influenced by ground conductivity.

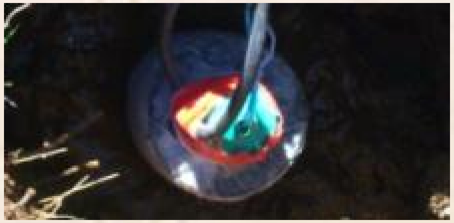



Planned MT survey sites
N
VGK HÖNNUN
Legend
Wells
Proposed wells
New proposed road
Roads
Fence/Trail
TEM 500 m by ISOR
MT survey points
Points 500 m apart
Points 1000 apart
0 1 2 km


N
SECT 01
SECT 02
SECT 05
SECT 06
SECT 03
SECT 07
SECT 08
SECT 09
SECT 04
Completed MT survey sites
0 1000 2000 3000 4000 m
I-101
AMT site

Field MT data acquisition





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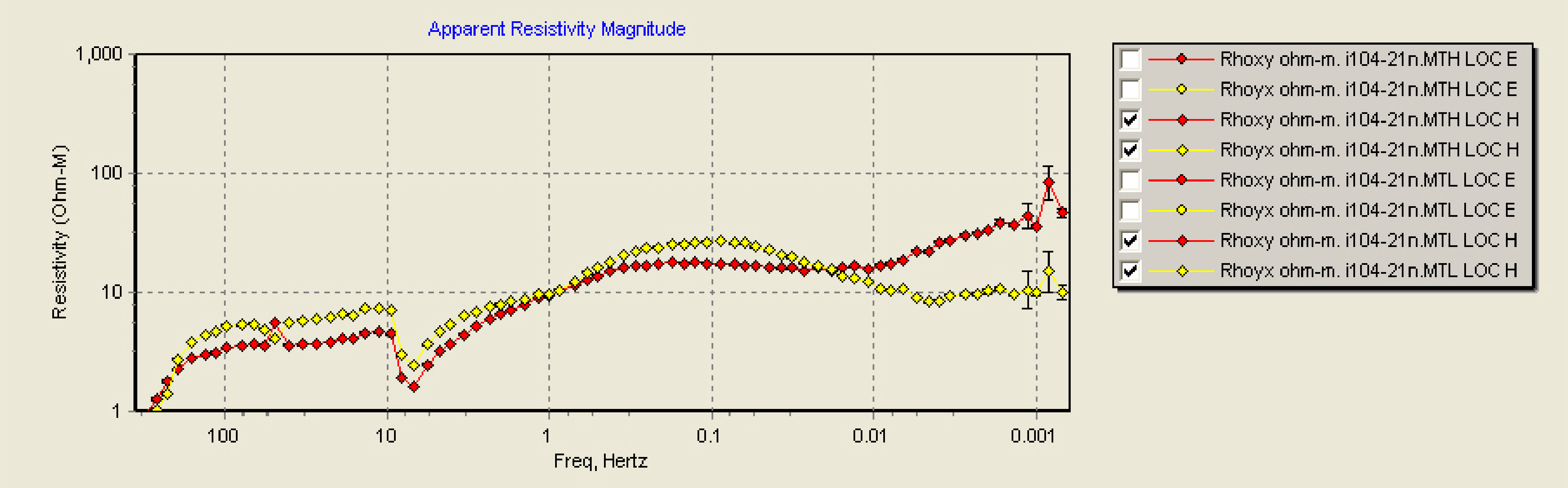
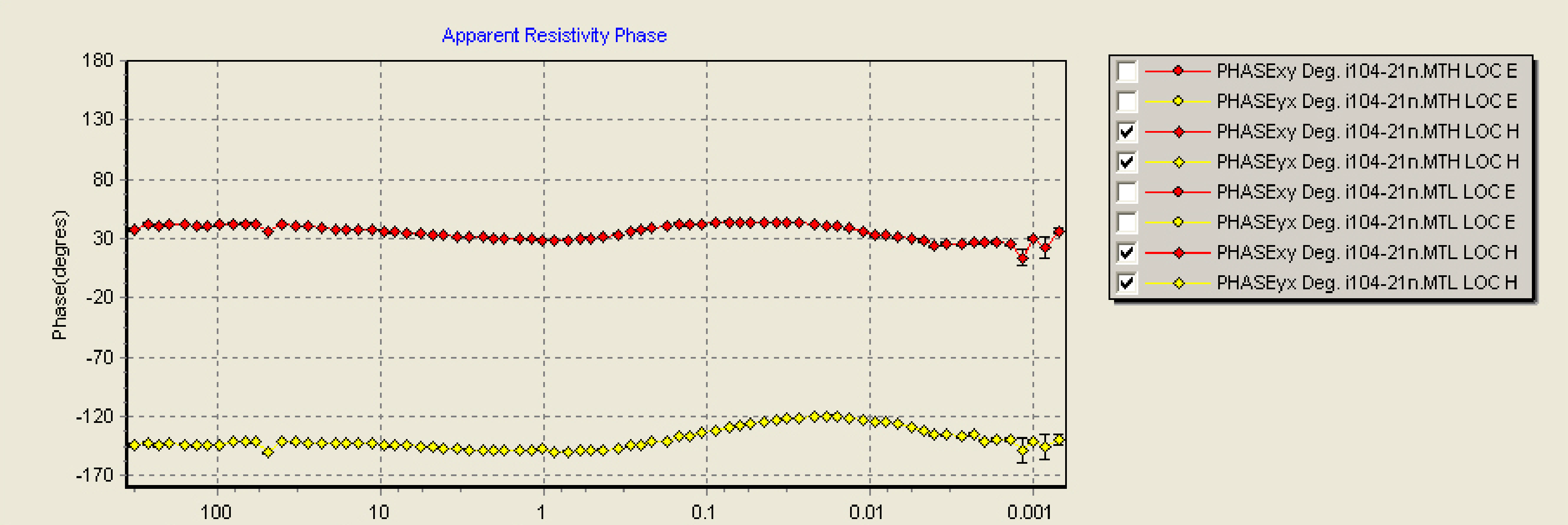
Raw MT data display (I-104)





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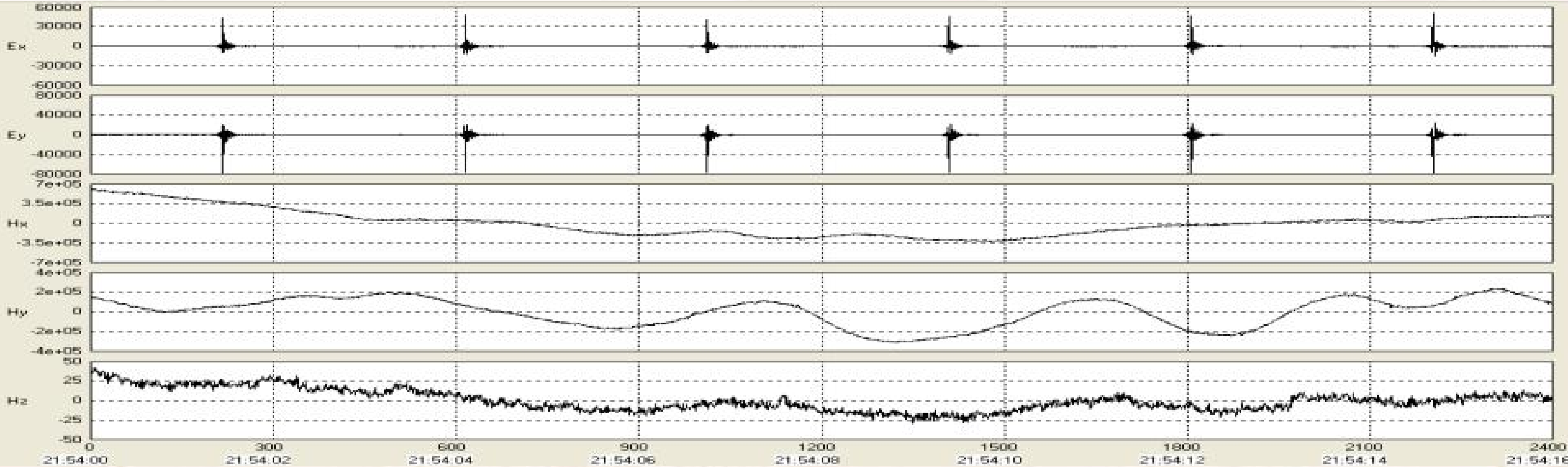
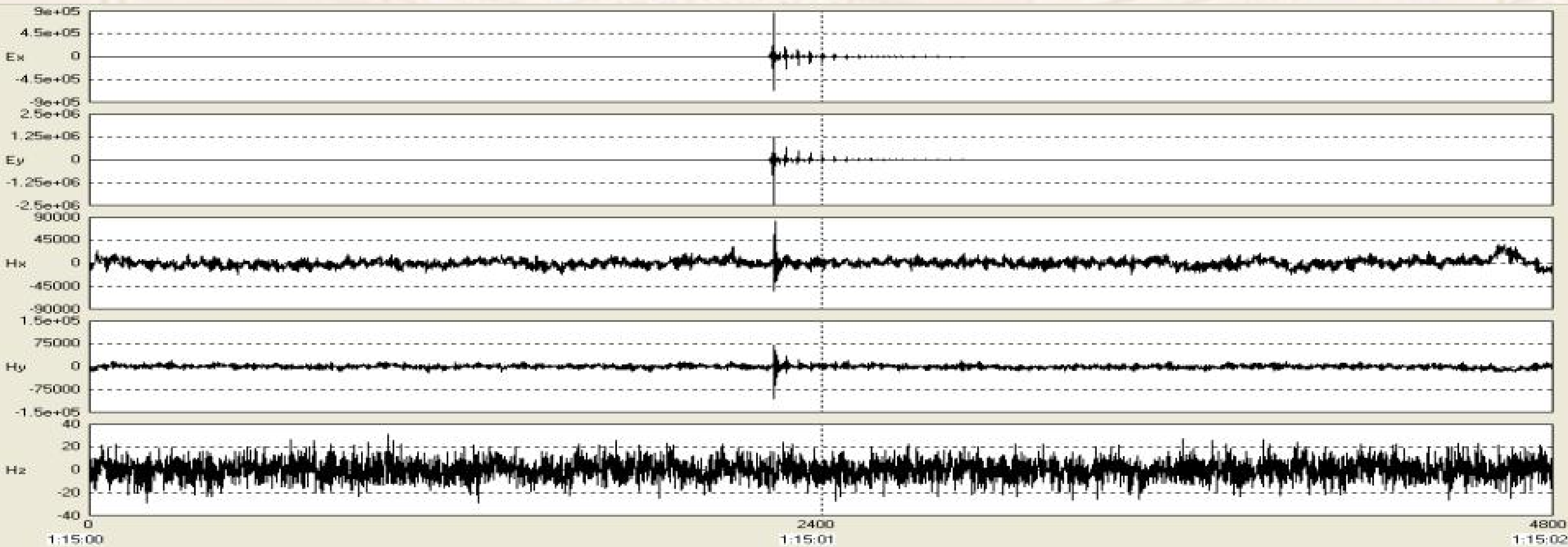
High level noise in I-103, I-102, & I-101





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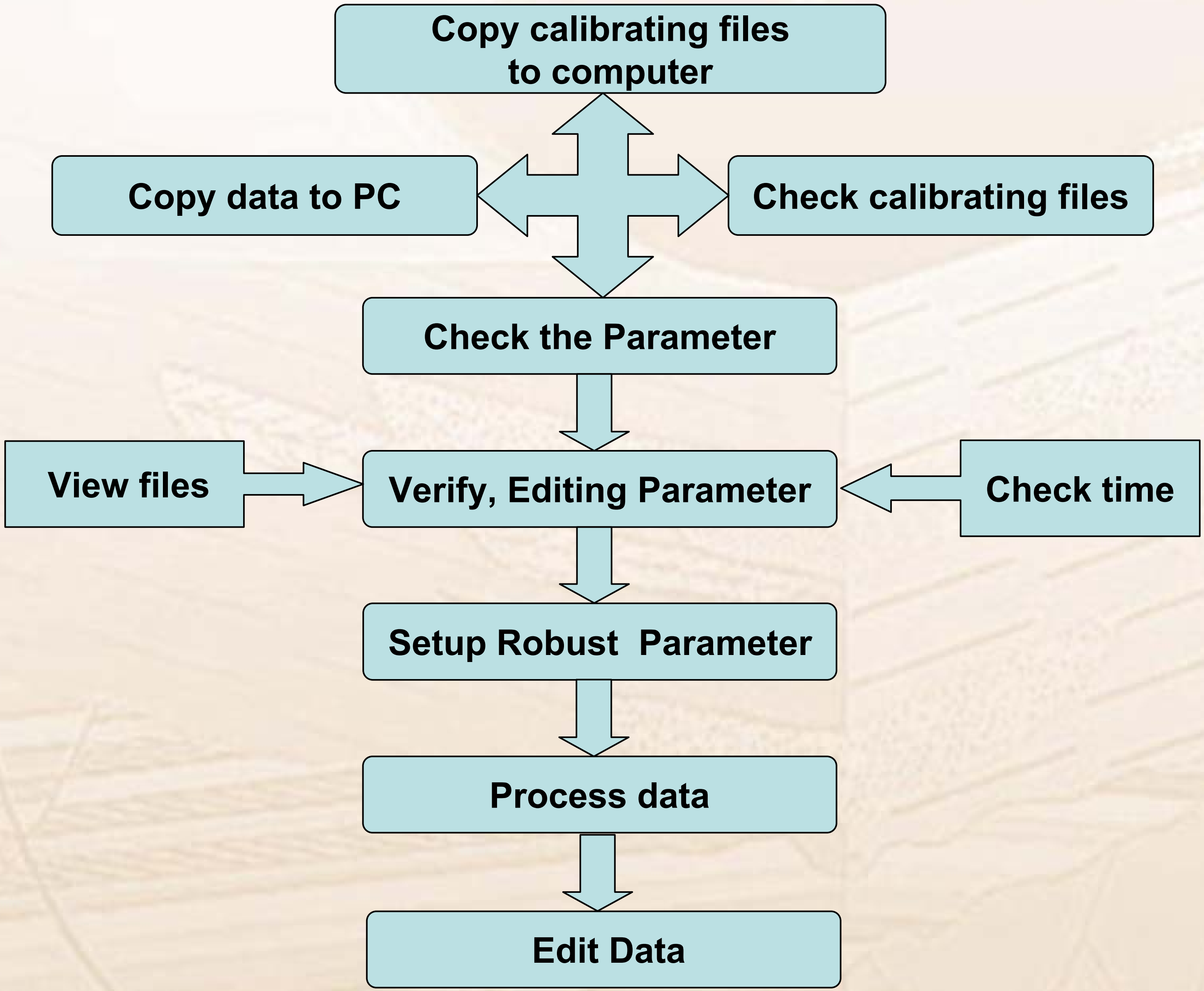
MT data processing flowchart



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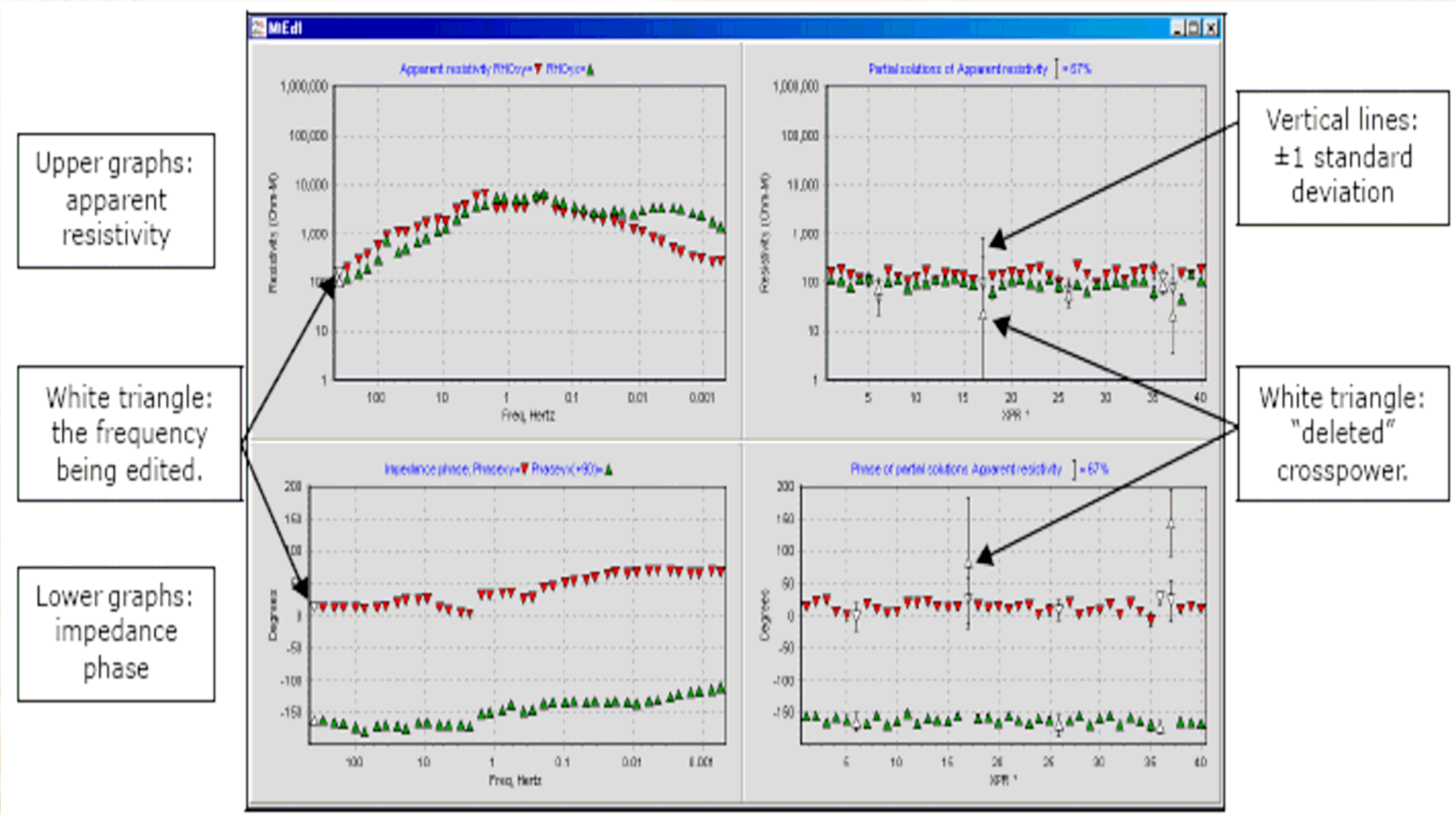
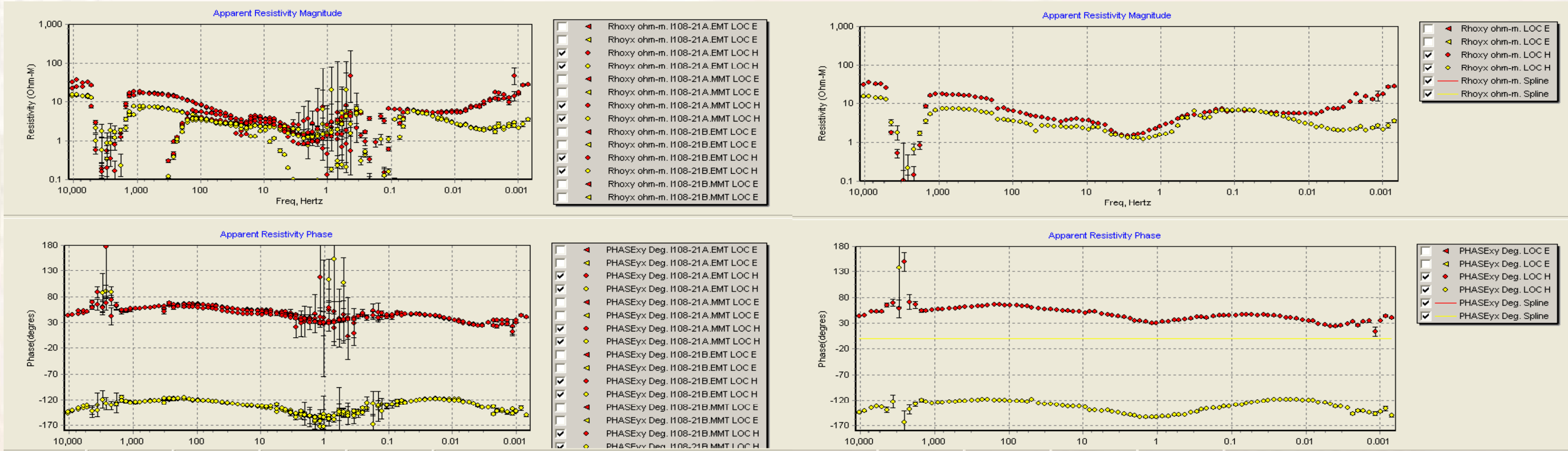
Cross power editing

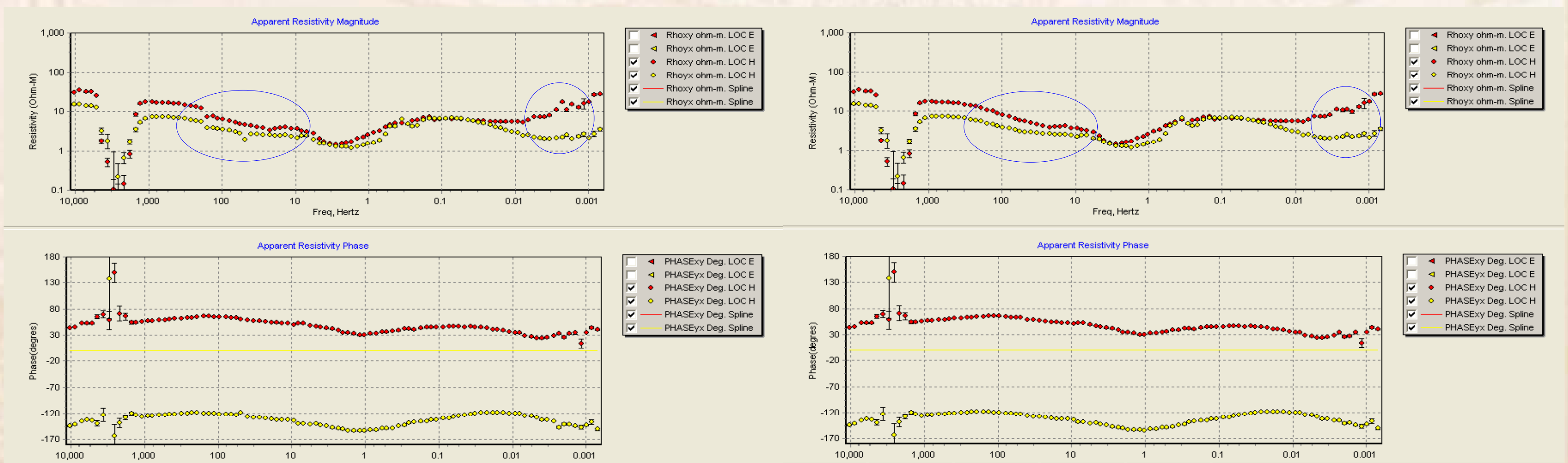


Editing is done through deleting or restoring individual cross powers in the two graphs on the right.

Comparison of noise editing



Comparison of before (Left) & after (Right) auto editing



Comparison of before (Left) & after (Right) manual editing

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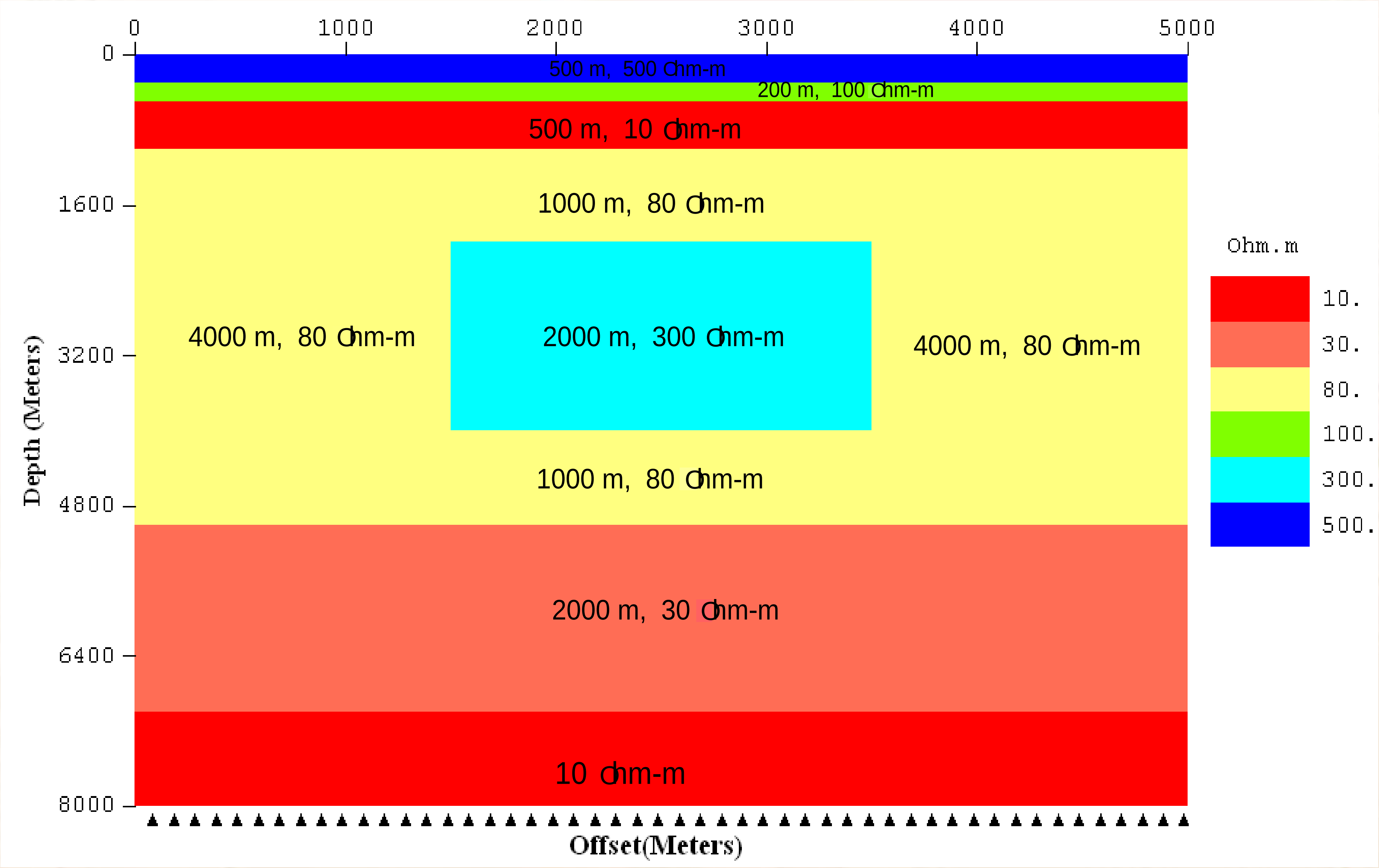
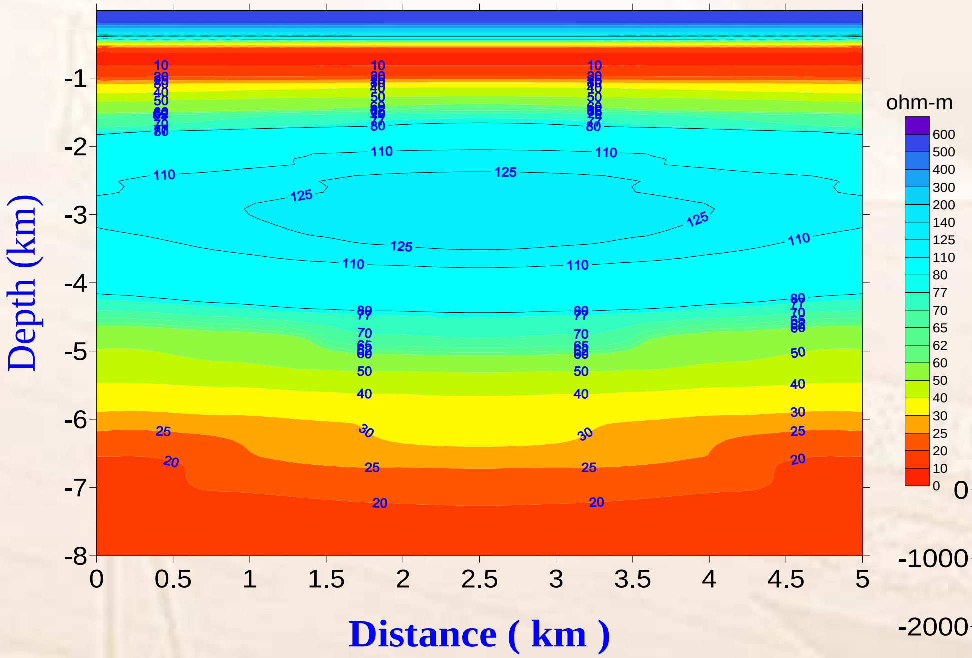
Resistivity model for the survey area

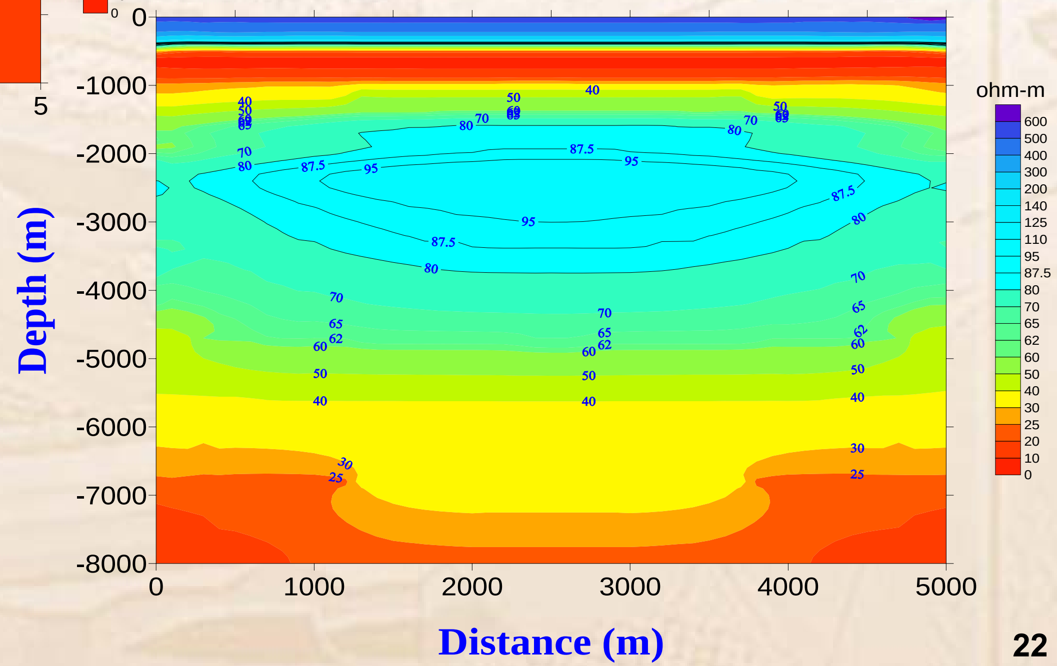


Continuous media & nonlinear conjugate gradients inversion result

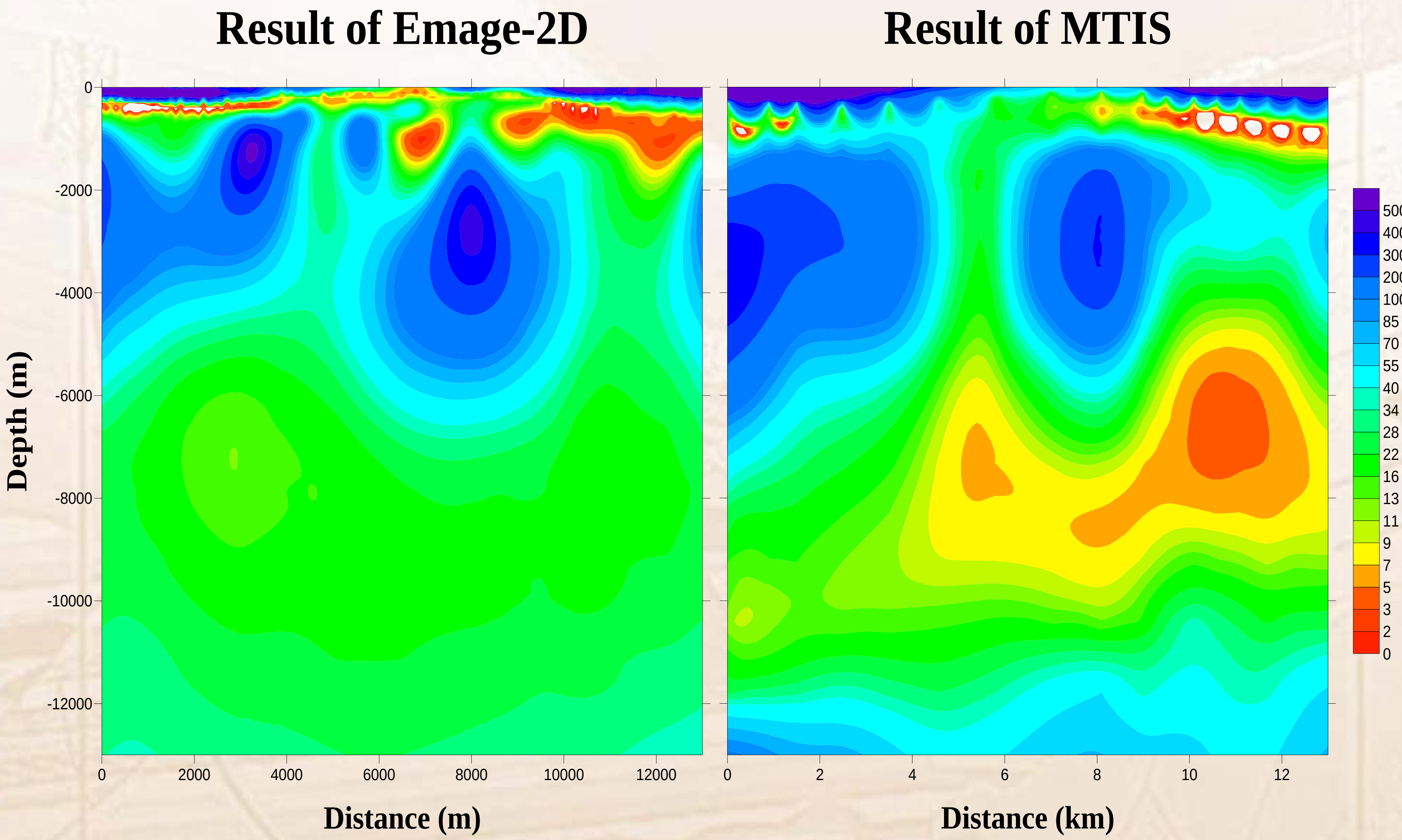
2D (MTIS) Inversion Result of Res-xy



NLCG Inversion Result of Res-xy



Comparison of NLCG (Emage-2D) & continuous media inversion (MTIS)



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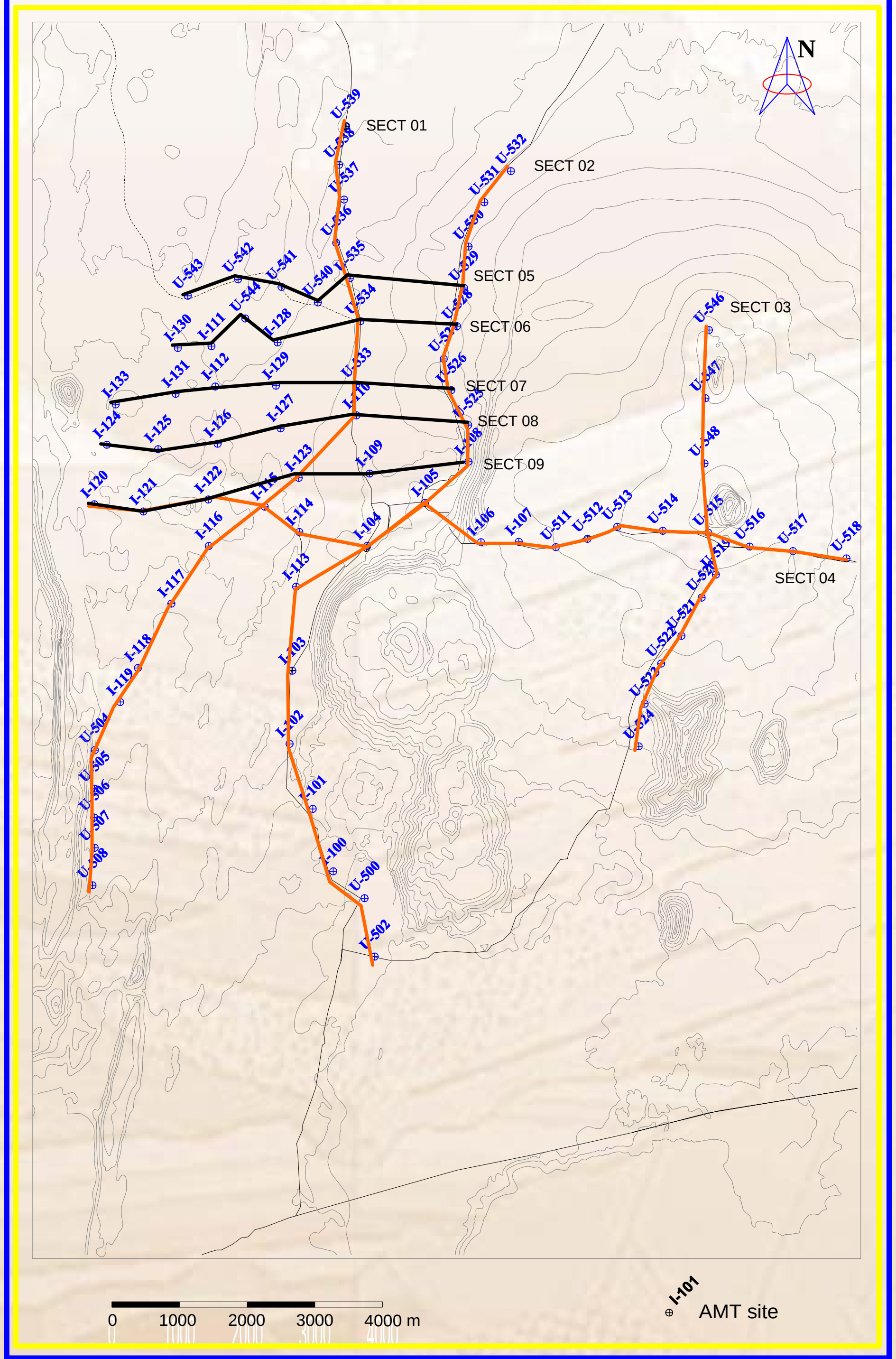
Þeistareykir MT survey profile layout



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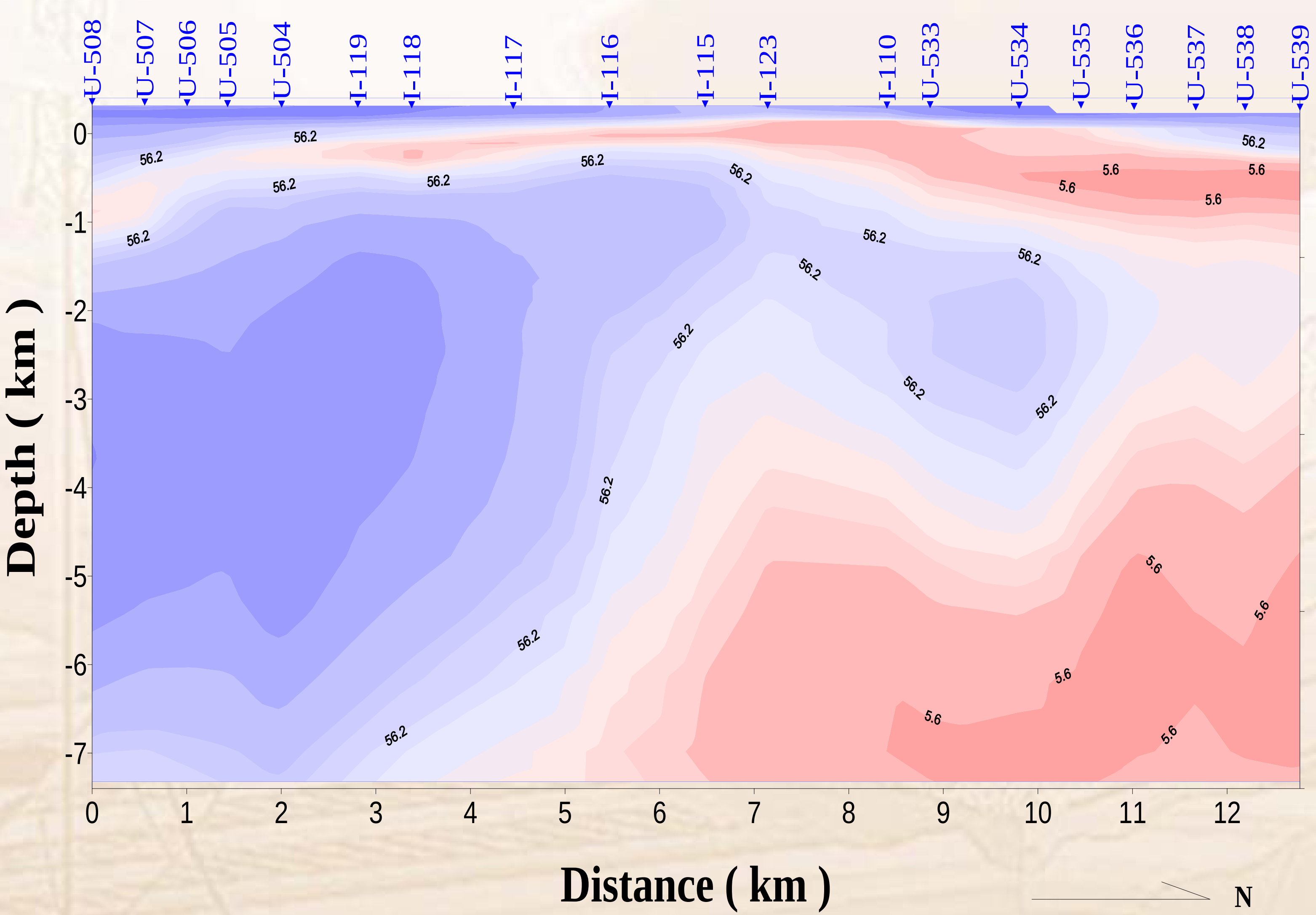
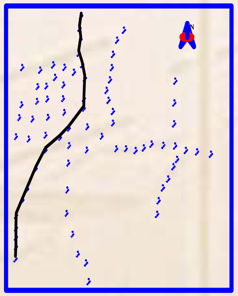
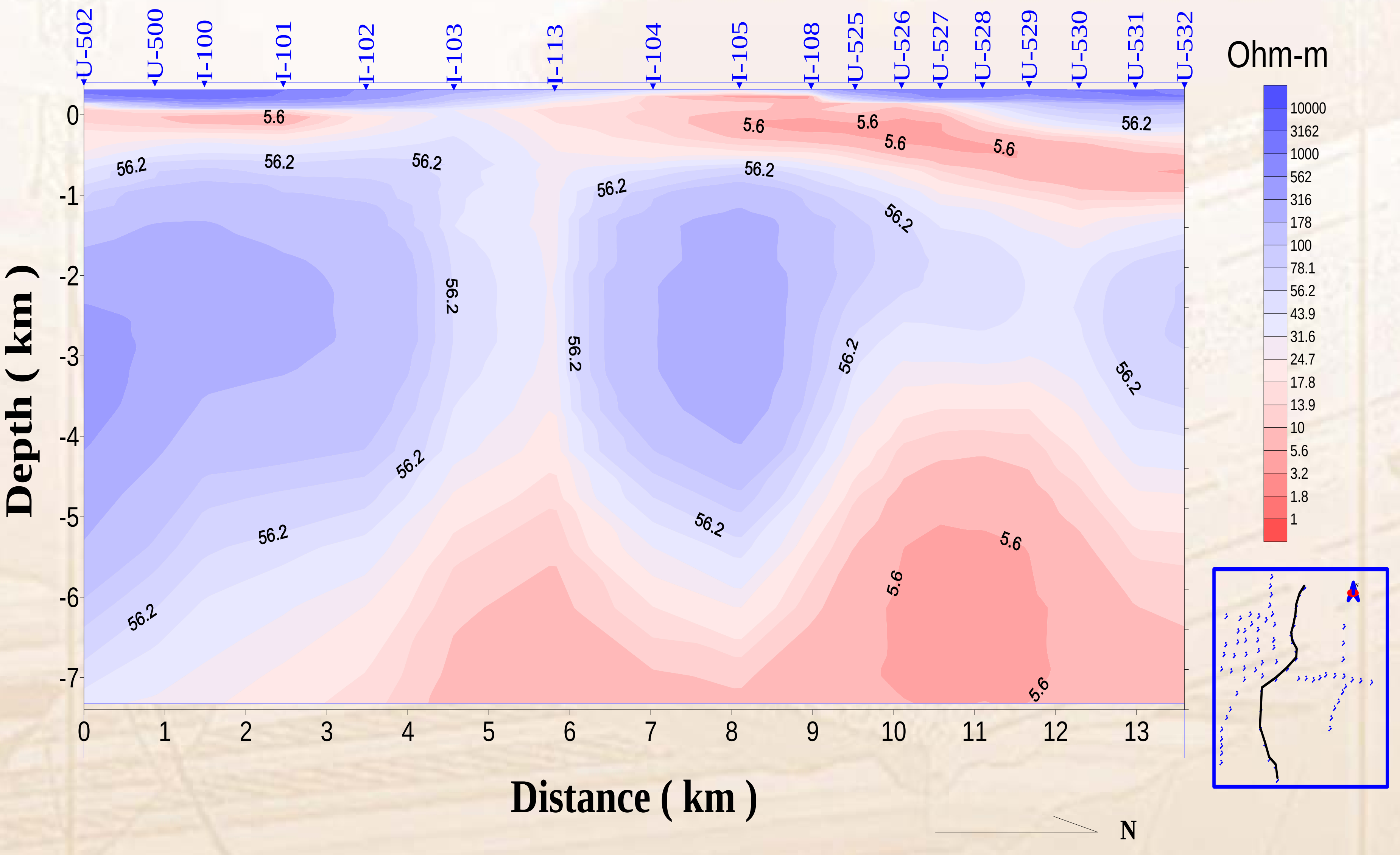
MT inversion result of Section 01

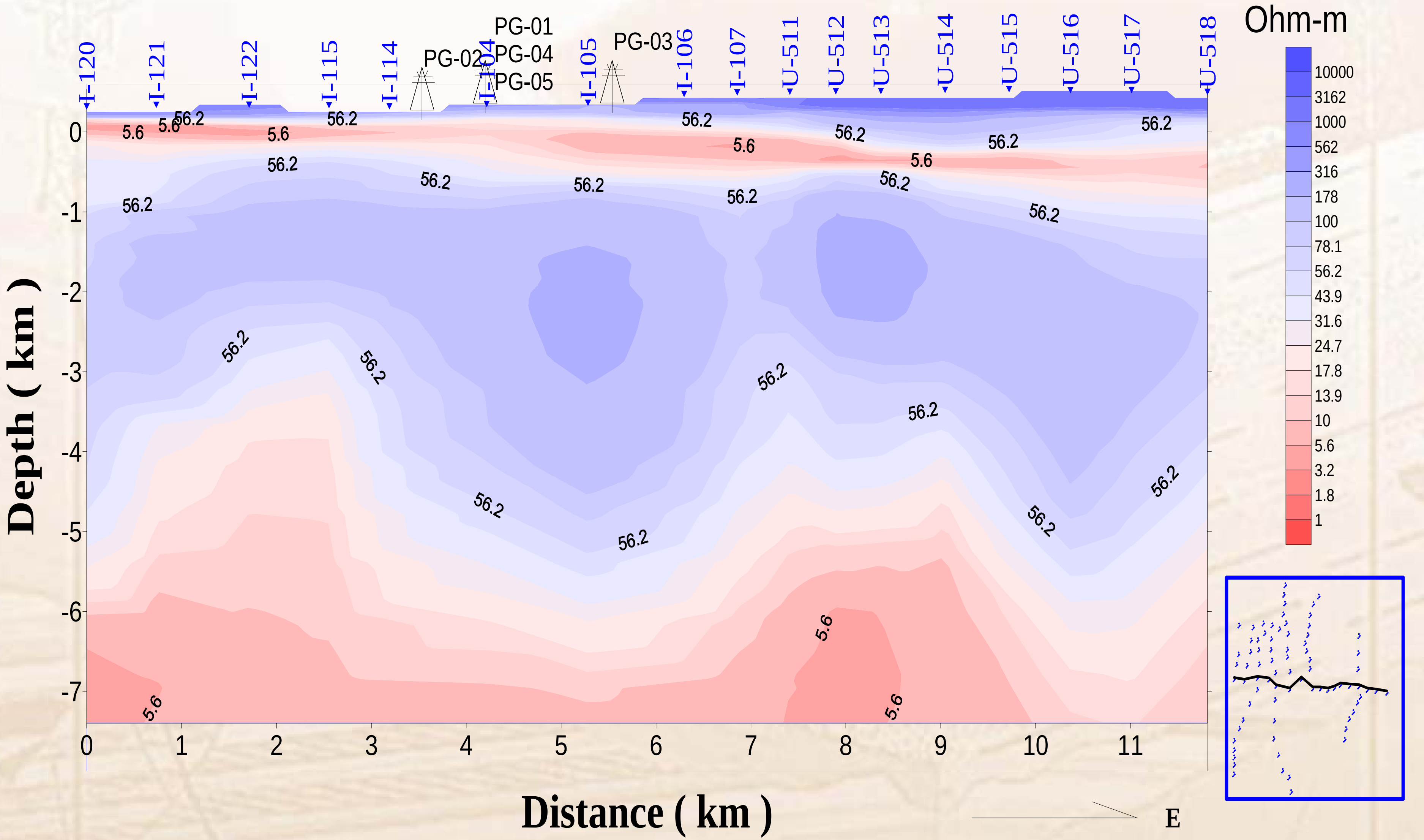




MT inversion result of Section 02



MT inversion result of Section 04



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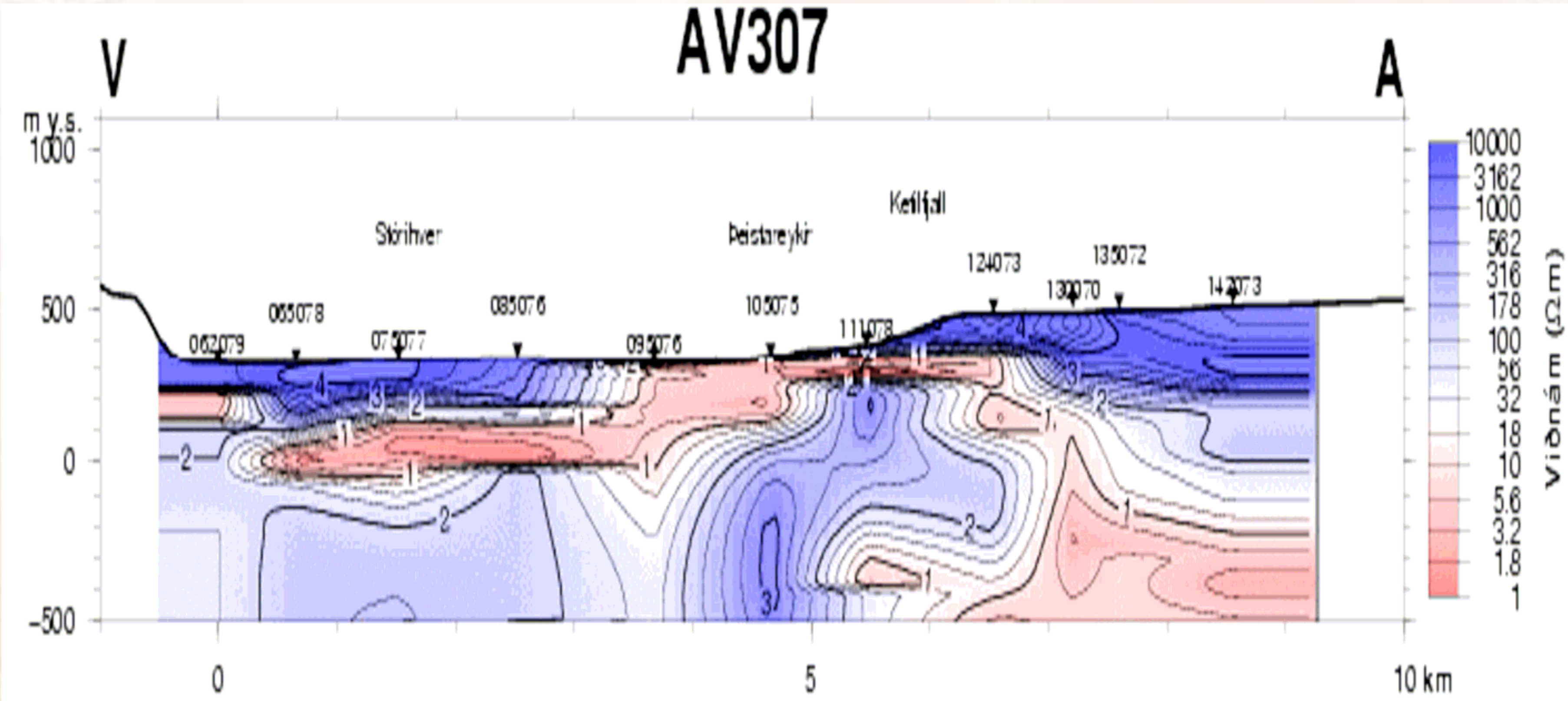
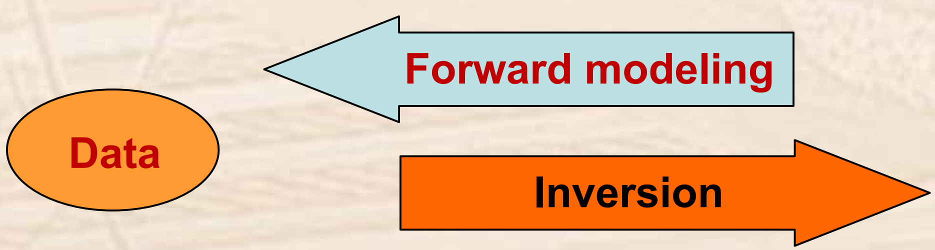
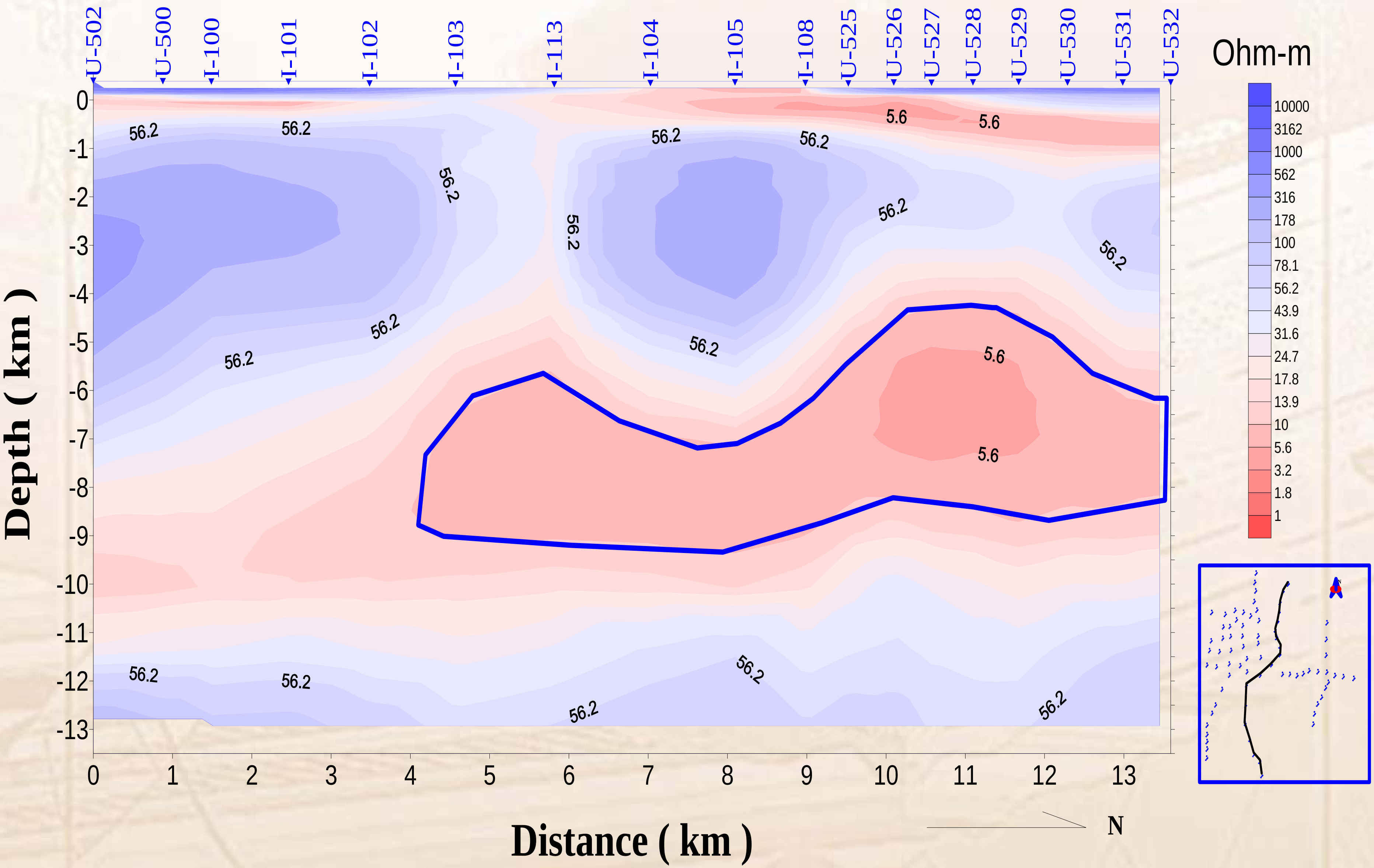
TEM inversion result of profile 307



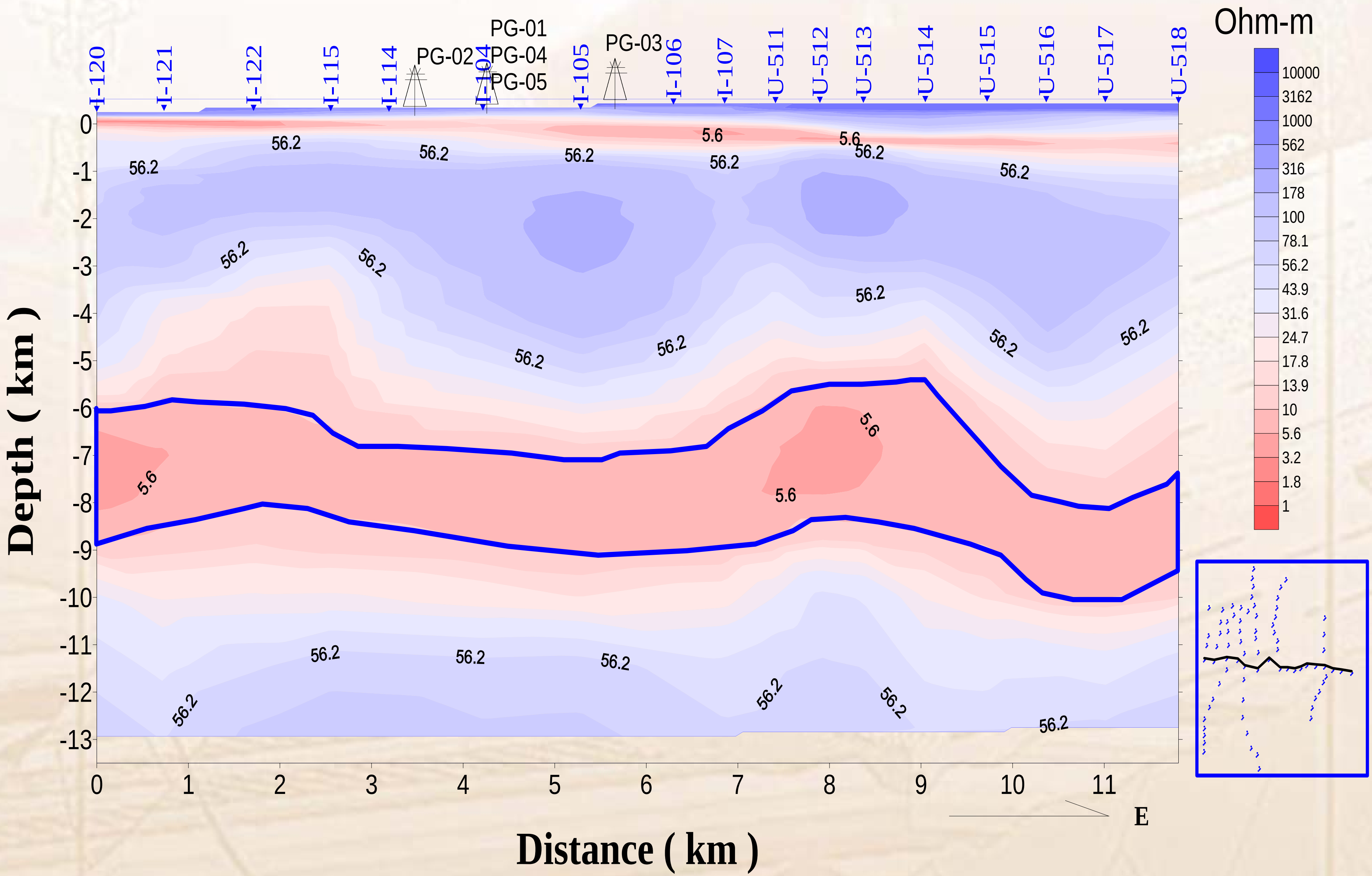


Subsurface resistivity

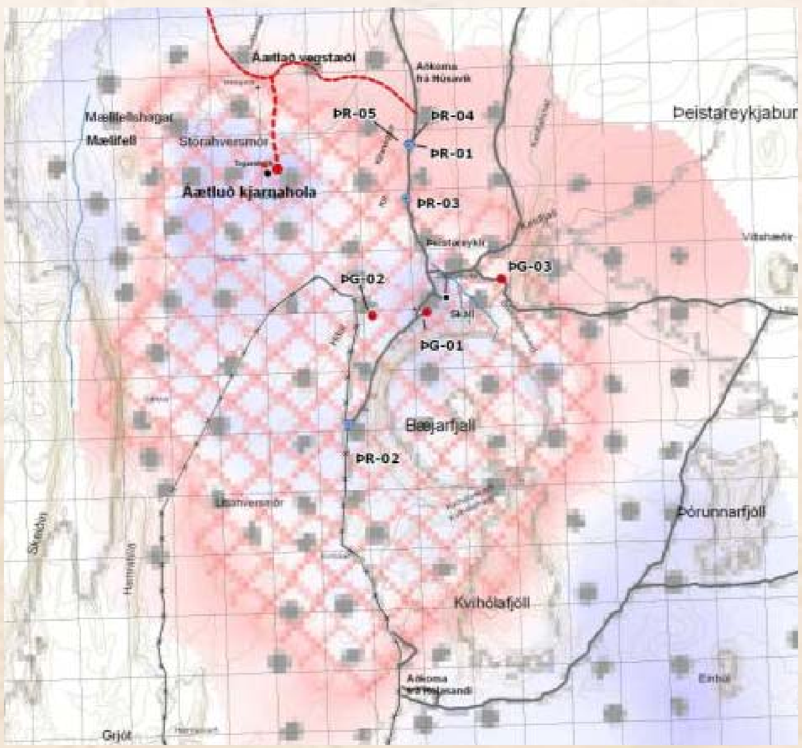
MT inversion result of Section 02



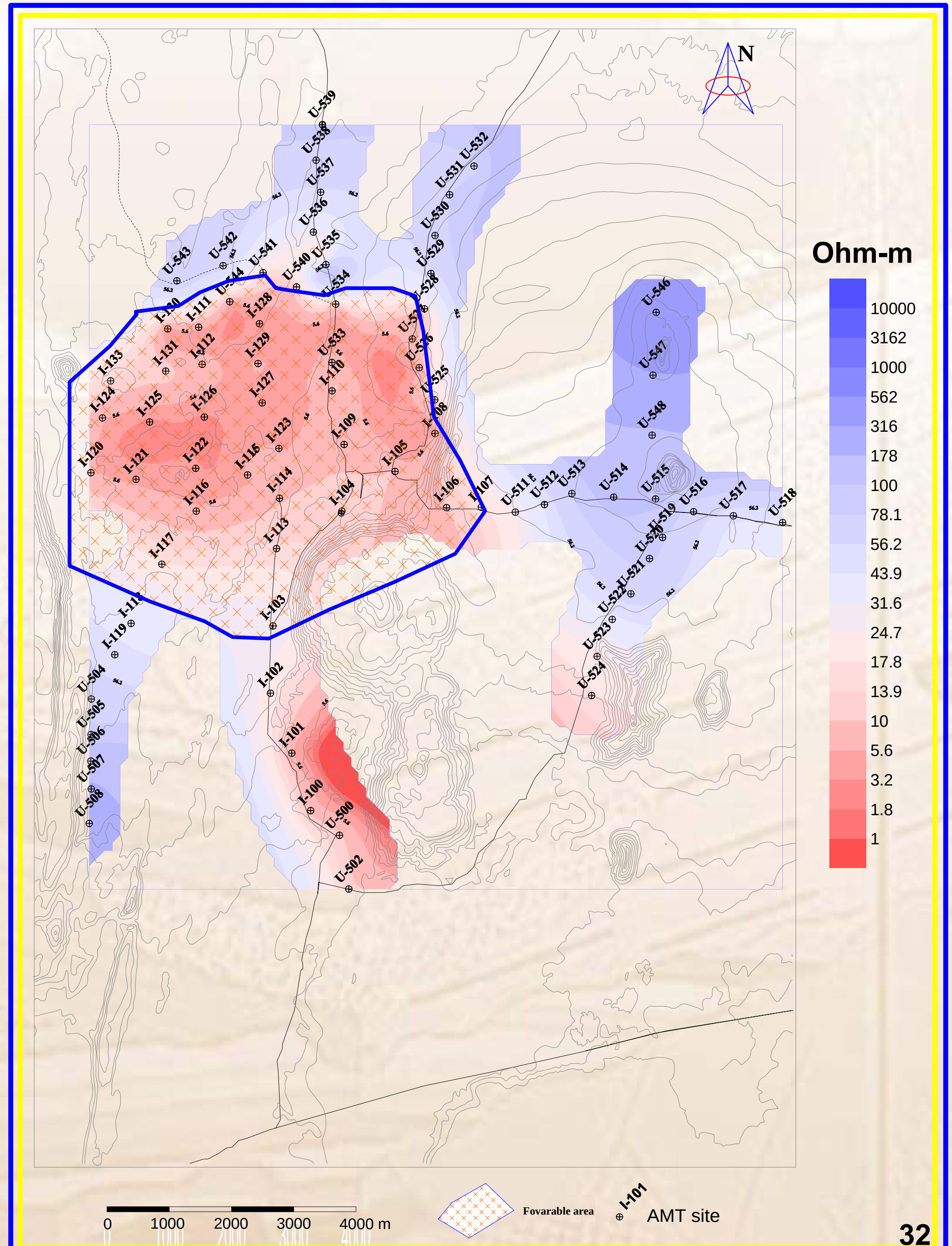
MT inversion result of Section 04



Upper (sea level) geothermal reservoir distribution range (~ 32 km^2)

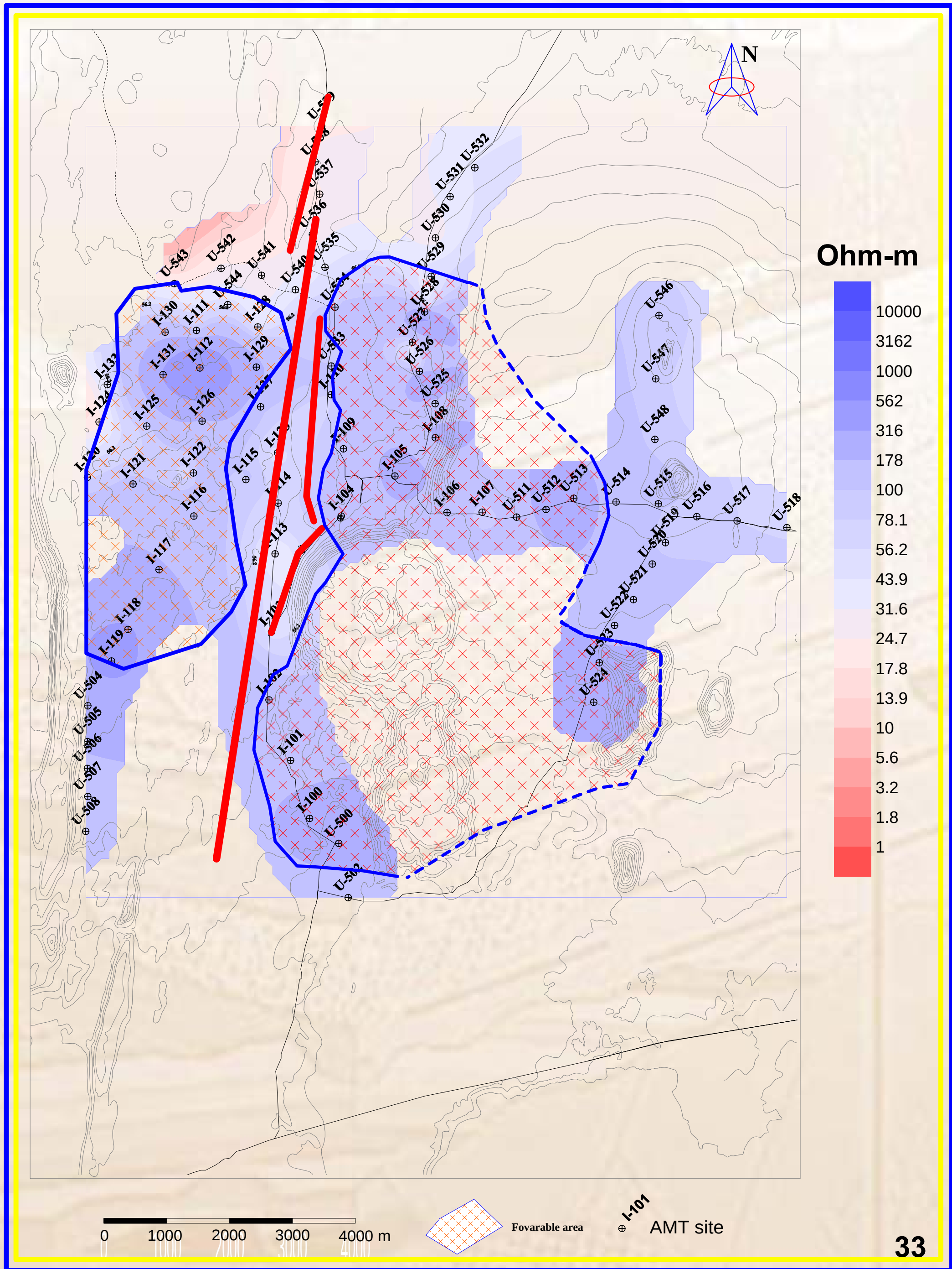


Distribution Range of the Upper Geothermal Reservoir (0m in elevation)



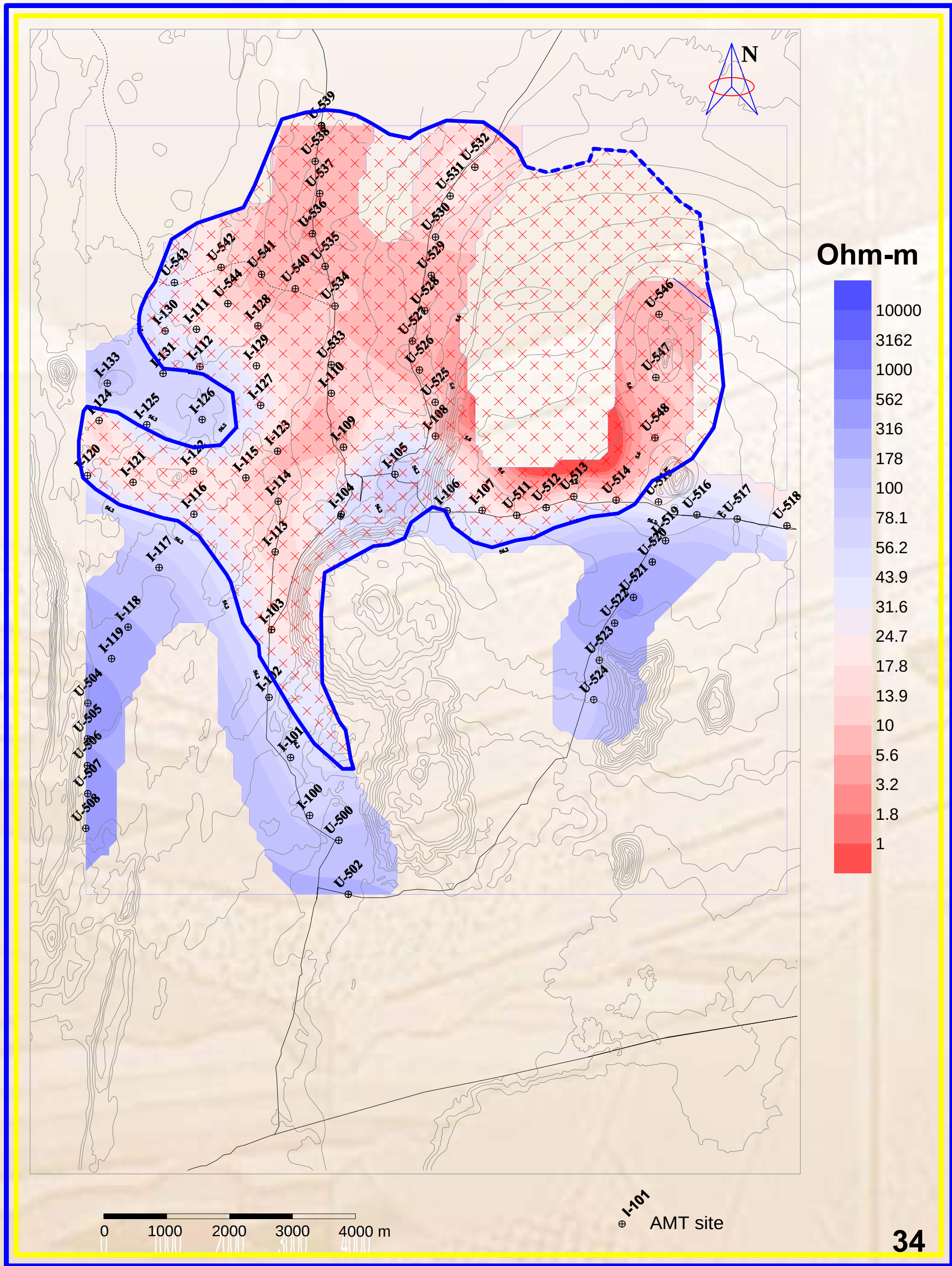
Lower (1,500 m below sea level) geothermal reservoir distribution range (~ 46 km^2)

Distribution Range of the lower Geothermal Reservoir (1500 meters below sea level)

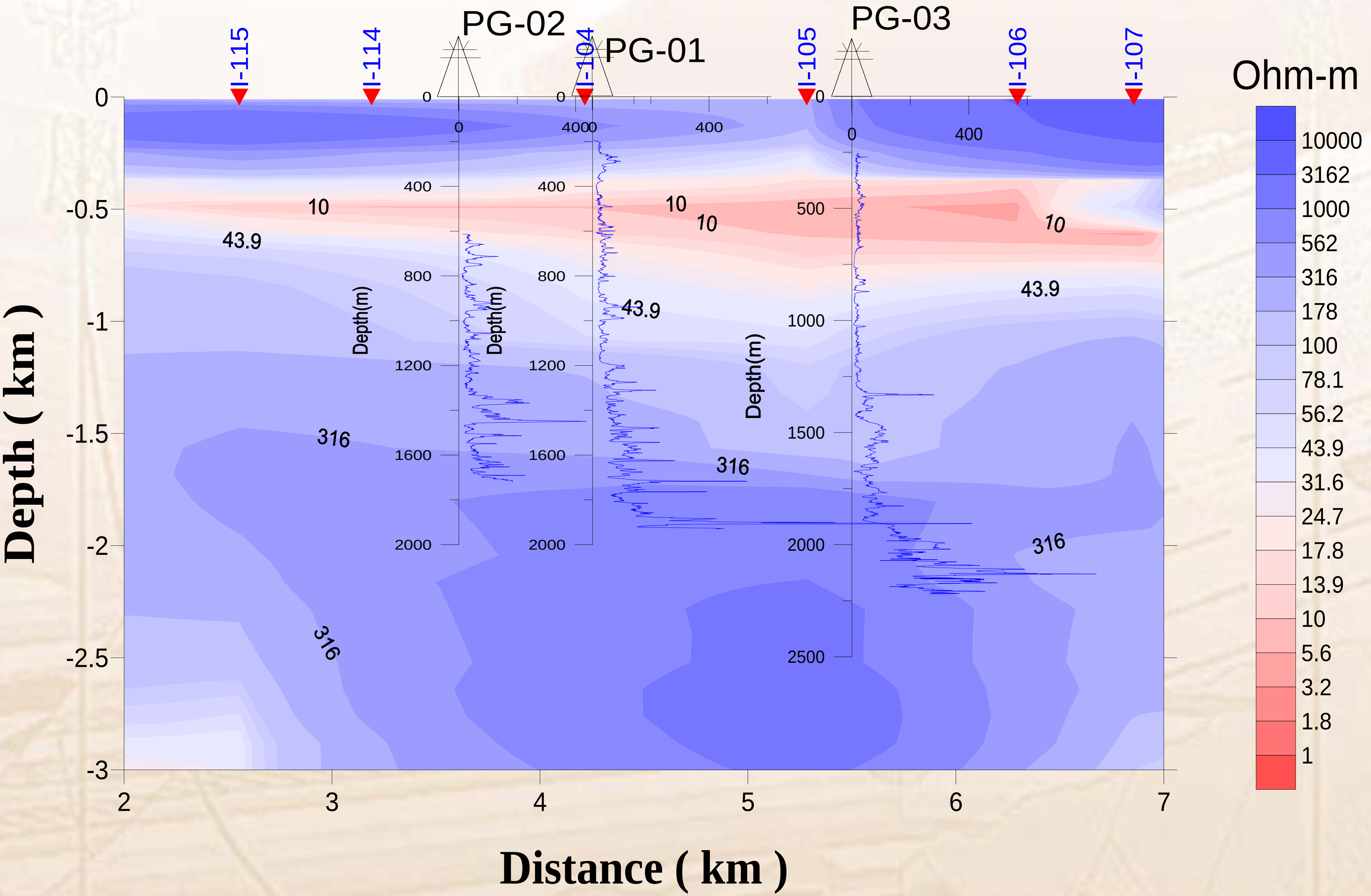


Deep (5,000 m below sea level) conductive geothermal reservoir distribution range (~ 54 km^2)

Distribution Range of the deep conductive Geothermal Reservoir (-5000 m)



MT inversion (cross well section)



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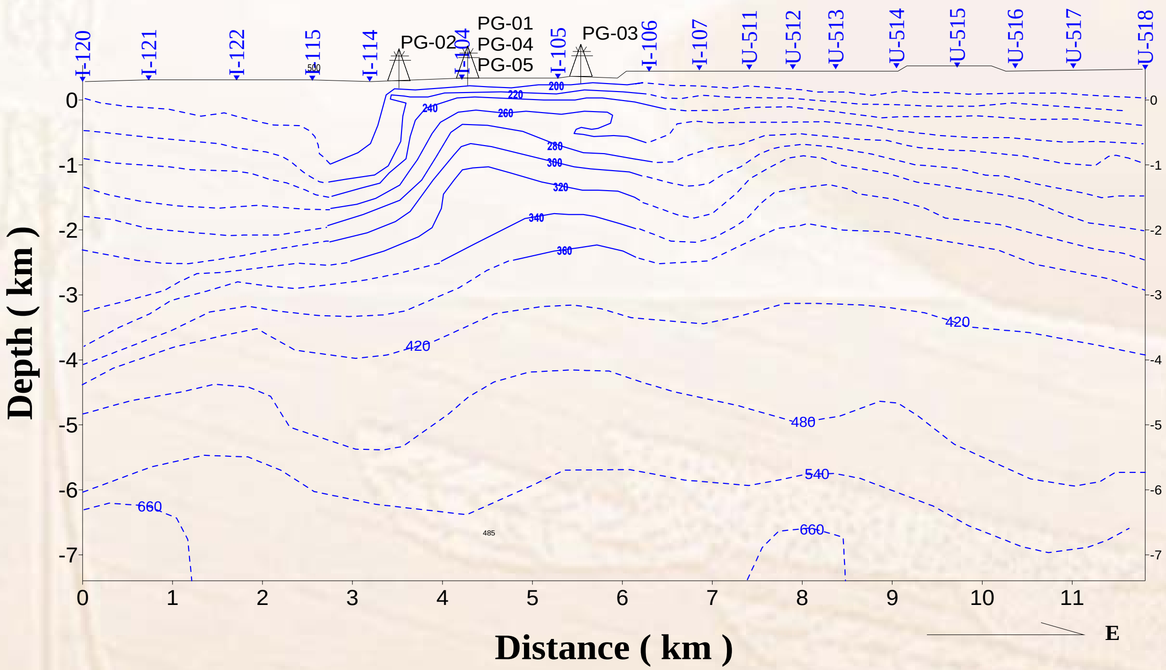
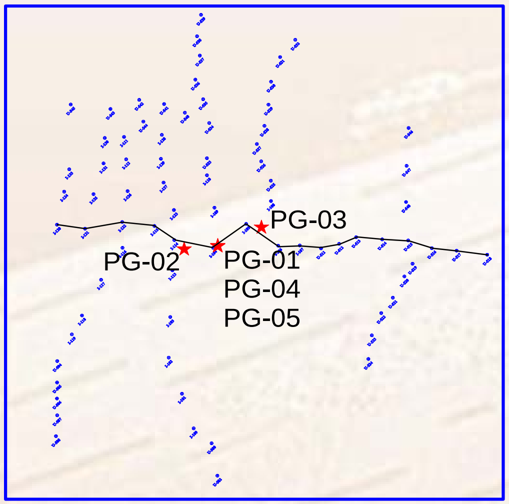
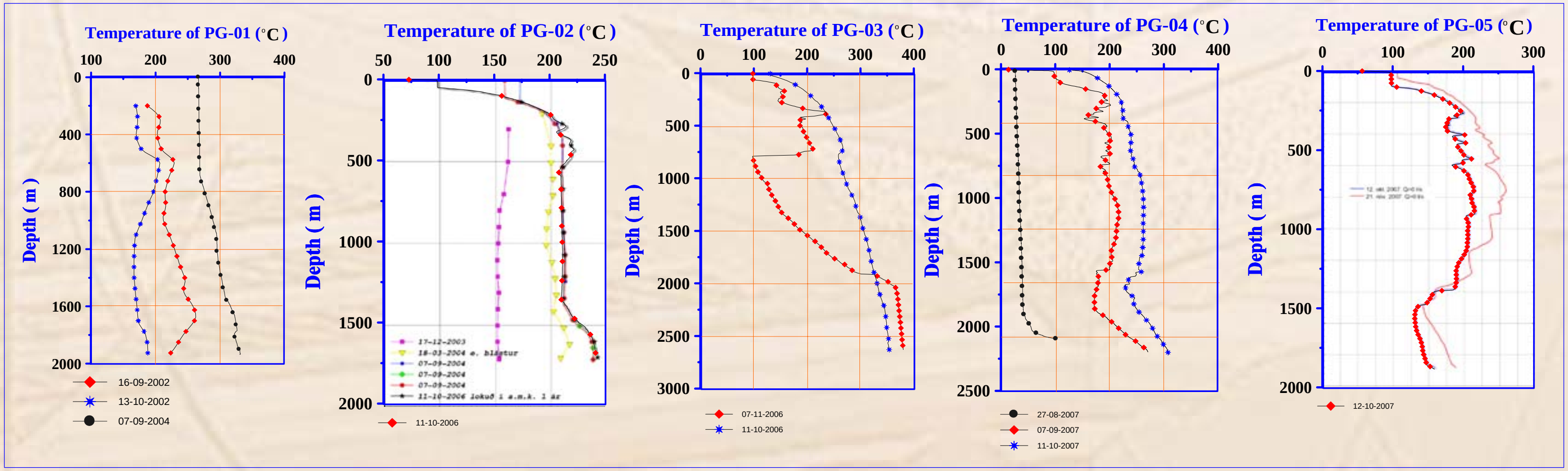
Comprehensive temperature preconception

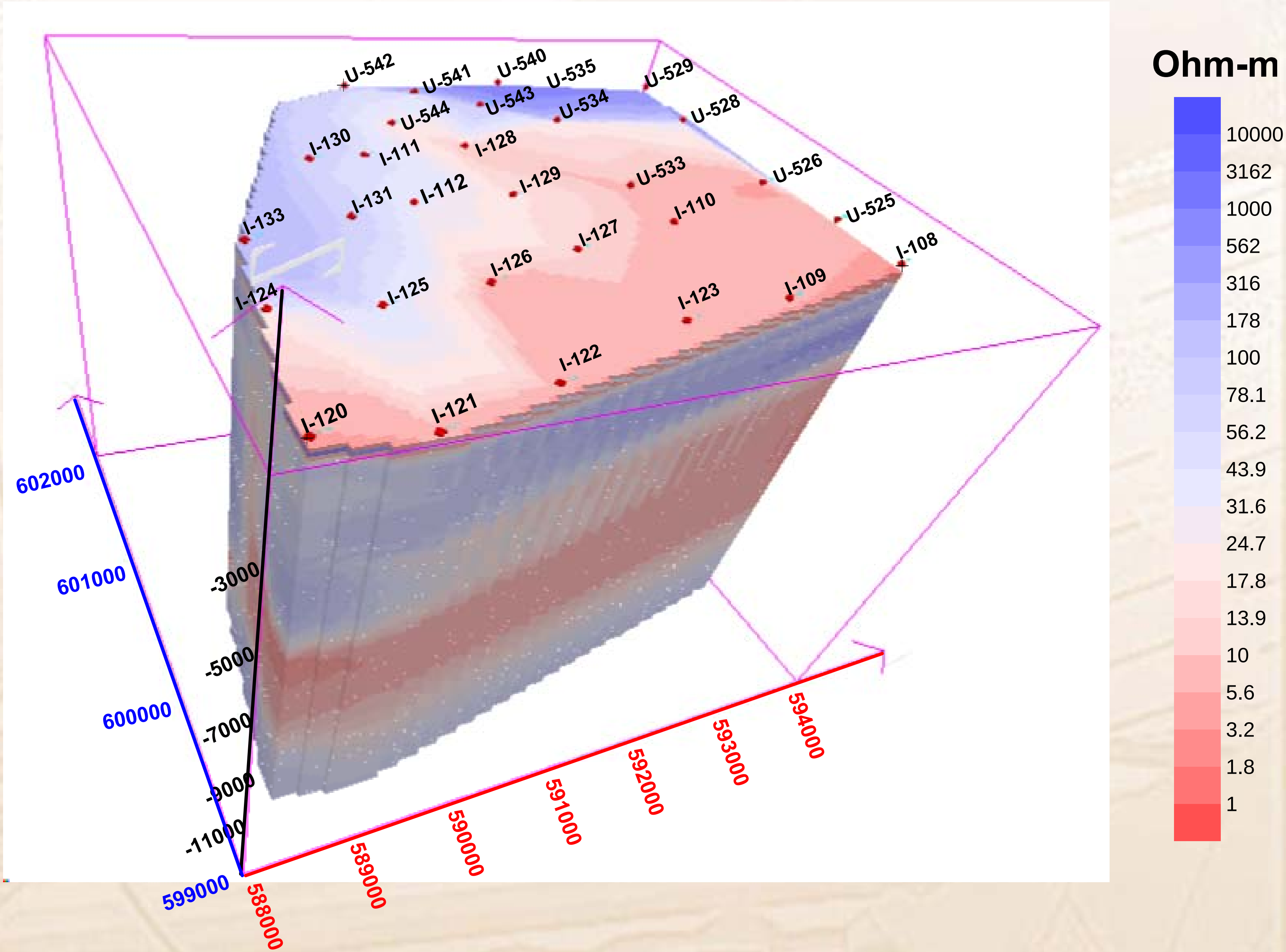
Comprehensive temperature preconception







3-D resistivity inversion result (northwest)



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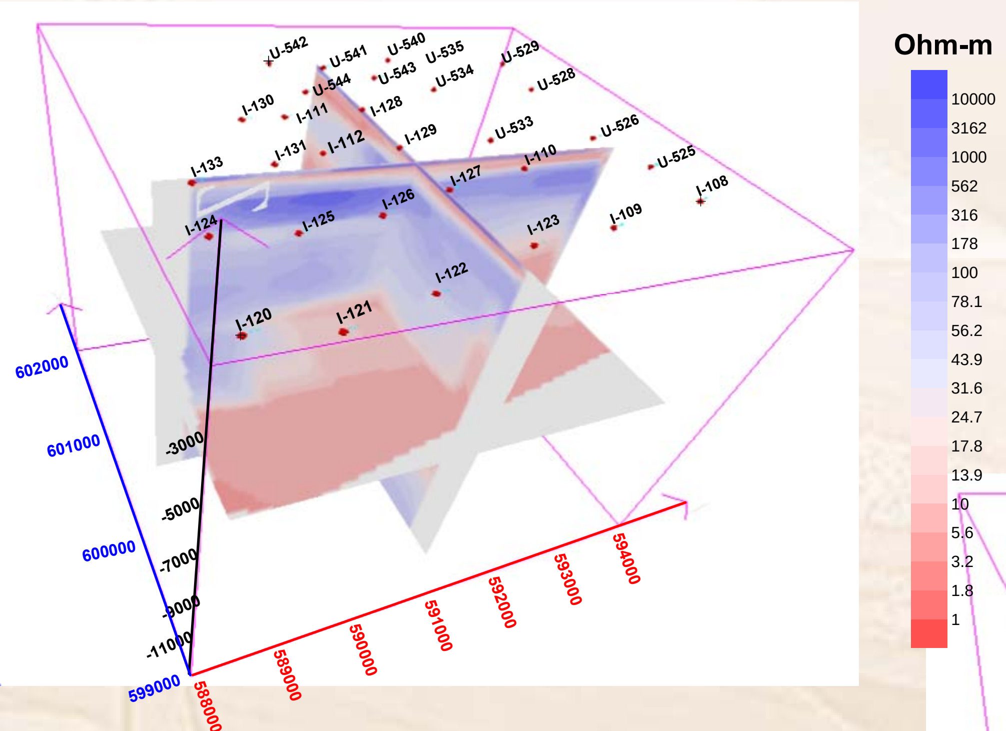
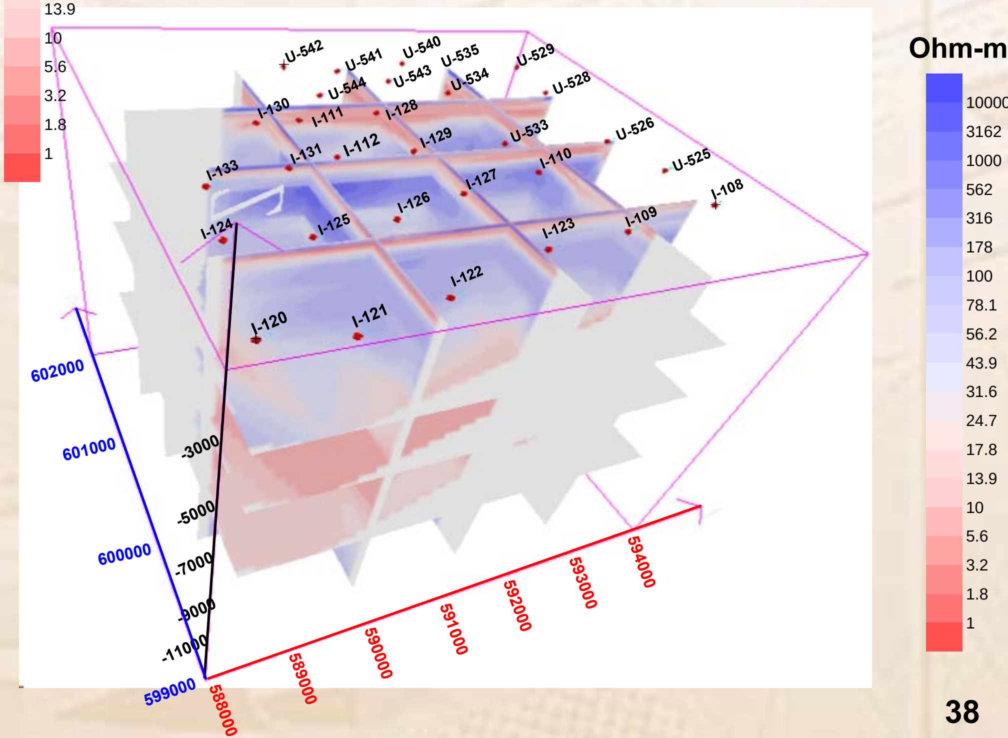
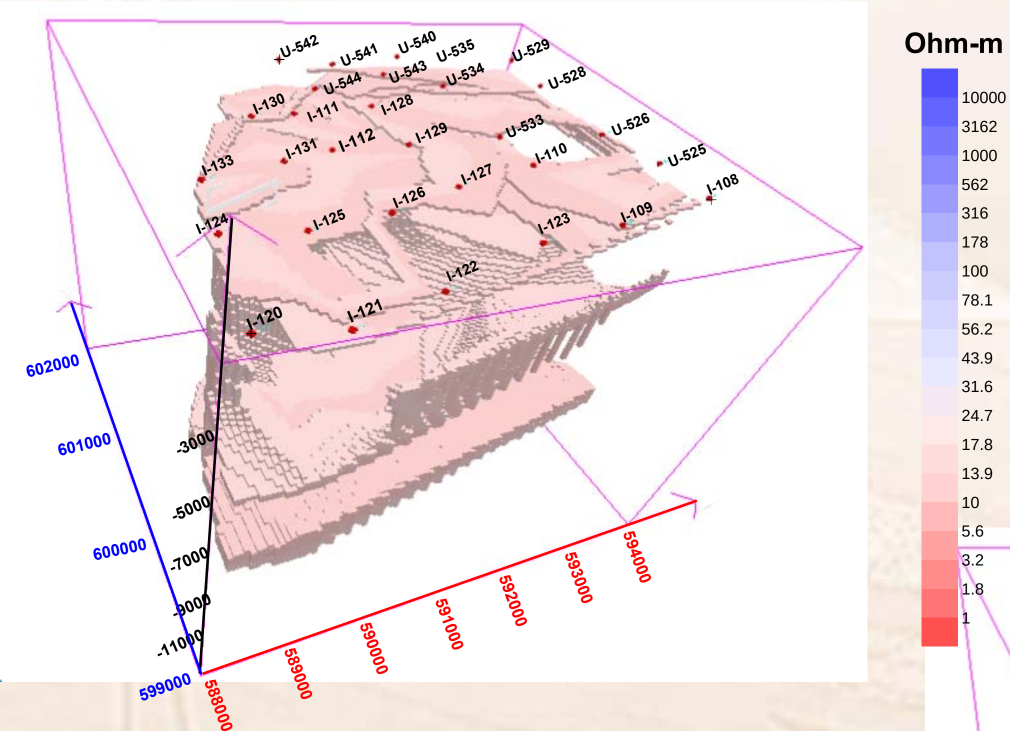
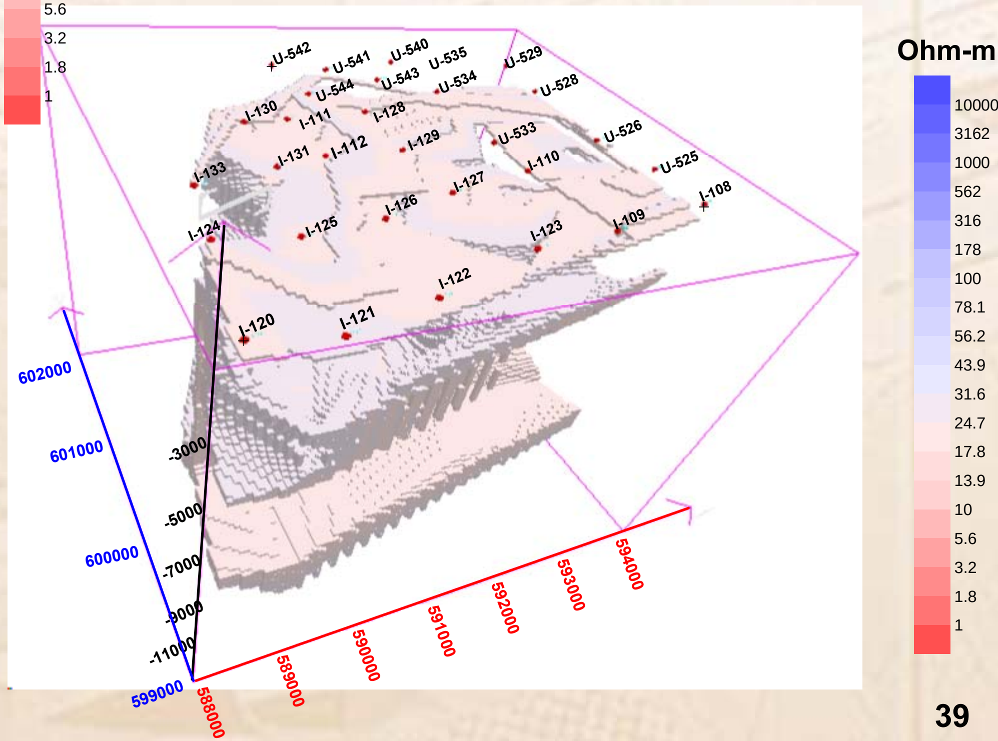
3-D resistivity slices in Z (depth), X (E-W) & Y (N-S) directions





3-D data volume shows contribution of moderate (6 ~ 15 Ωm, left, & 15 ~ 25 Ωm, right) resistivity volume





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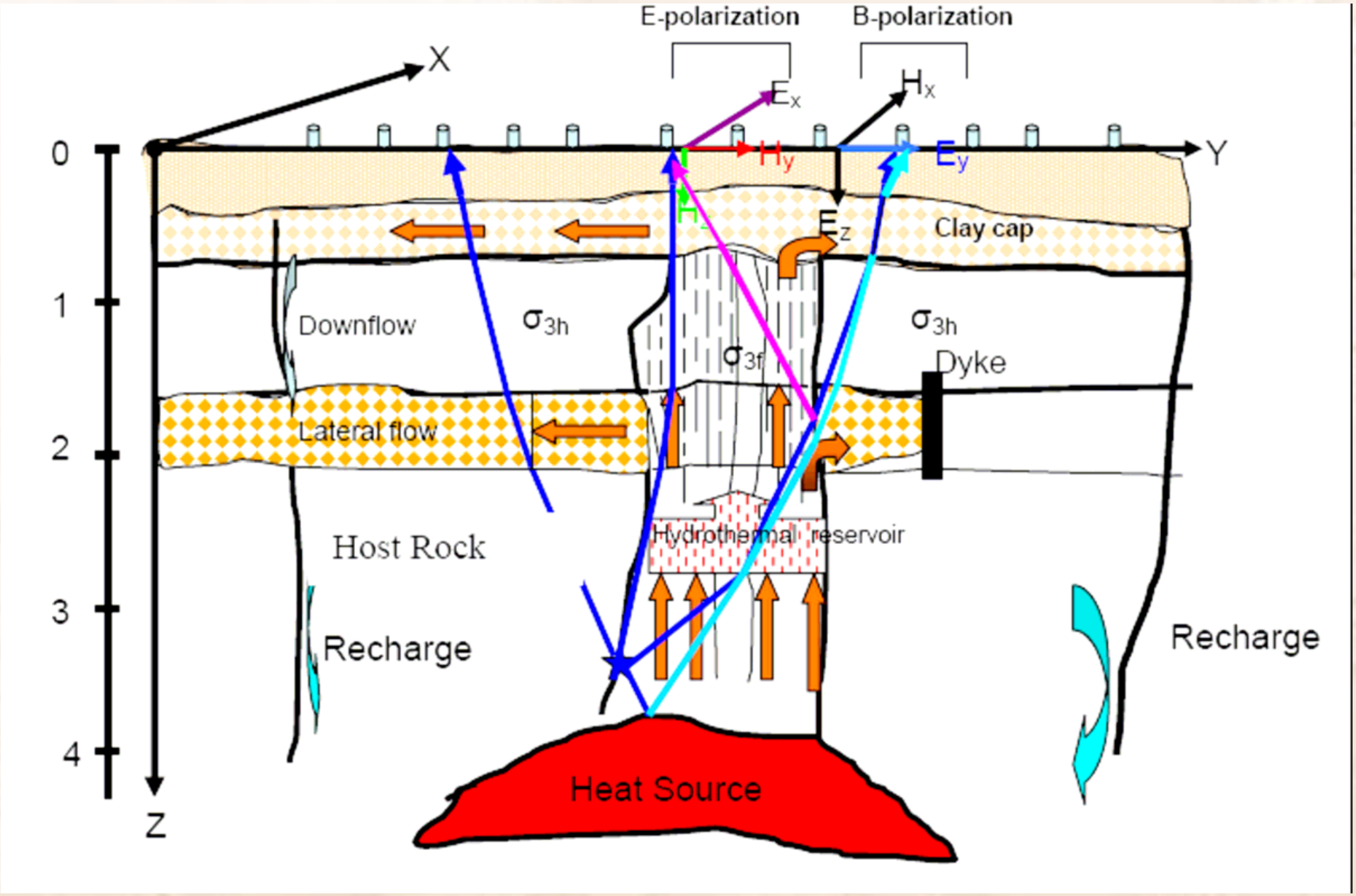
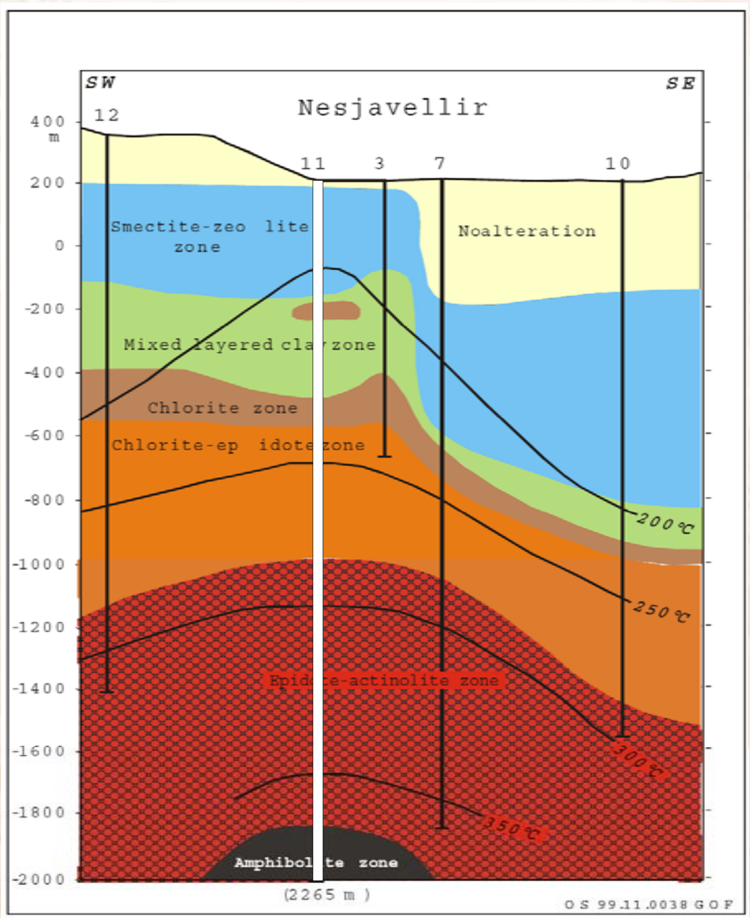
Model for resistivity data interpretation

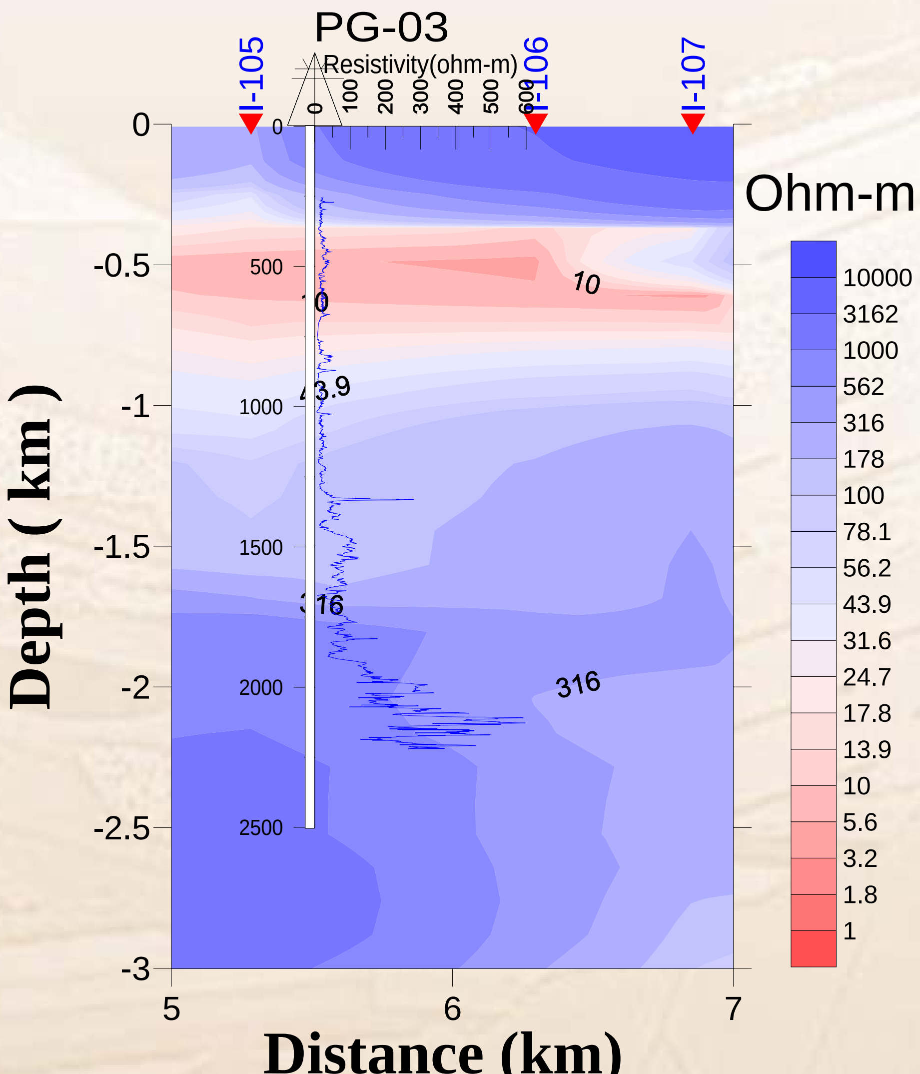
- Fracture zone defined by lower resistivity within high resistivity host rock;
- Clay cap occurs above hydrothermal system & heat source below;
- Resistivity contrasts below clay cap causes polarization & splitting in MT data.



(Malin, Onacha, and Shalev, 2004).

Comparison of geologic cross-section in SW Iceland with observed resistivity





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Conclusions

- MT is an effective method for hydrothermal exploration;
- Geoelectric structure in NW corner is a 4-layer model up to 7,000 m;
- Hydrothermal reservoir consists of two parts:
  - Upper part reservoir to 1,000 m is water saturated with a mean T ~205 ^{o}C;
  - Main aquifers in lower part link to fissures & intrusives with T from 300 ^{o}C to 350 ^{o}C or more;
  - Bottom of upper thermal part is 900 m ~ 1,200 m with coverage ~32 km^2;
  - High potential hydrothermal zone is from 3,200 m to 3,400 m & covers ~ 46 km^2;
  - A deep conductive geothermal reservoir with coverage of more than 54 km^2 from 4,000 m to 7,000 m, & T may be more than 500 °C.

Acknowledgements

Thanks to Landsvirkjun, Husavik Energy, & Mannvit in Iceland.

Support of Þeistareykir Ltd. management in facilitating project is specifically acknowledged.

Special thanks also to Hreinn Hjartarson, Ragnar Heiðar Þrastarson, Hilmar Sigvaldason, & Ran Xuefeng for their contributions to this project.

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