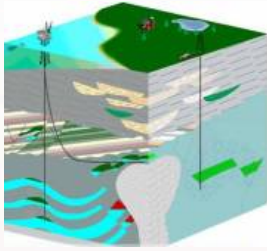




Advanced in EM for geothermal exploration

K.M. Strack, June 2011, USC Distinguished Lecture

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Advanced in EM for geothermal exploration

Strack, K.

KMS Technologies, USA



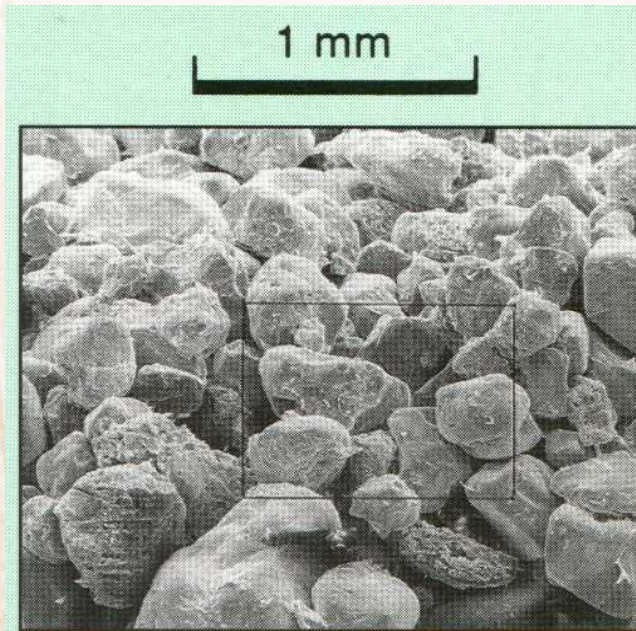
- **Introduction**
- **Why EM for geothermal?**
- **Case histories**
 - **Iceland case history**
 - **Hungary success**
 - **EU island – 3D**
- **Summary**
 - **Future**
 - **Array systems**

Introduction >>> Case histories >>> Summary

Why EM for geothermal?

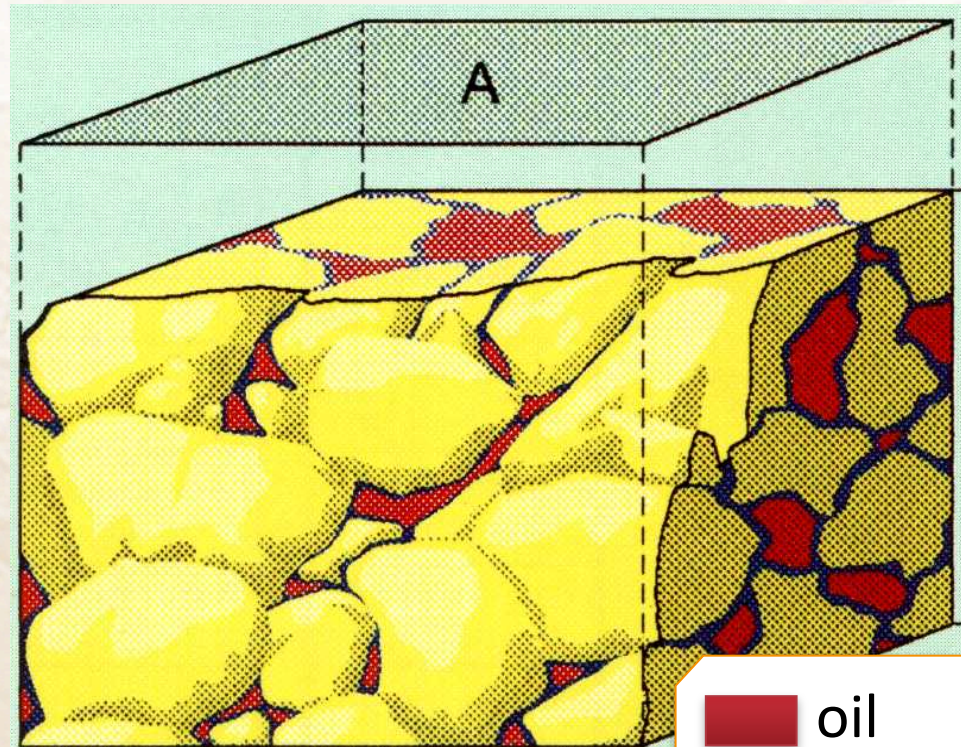


Scanning electron
Microscope image



After Van Ditzhuijzen, 1994

Bulk volume
model



- Bulk resistivity dominated by fluid
 - Water conductive
 - Heated fluid conductive



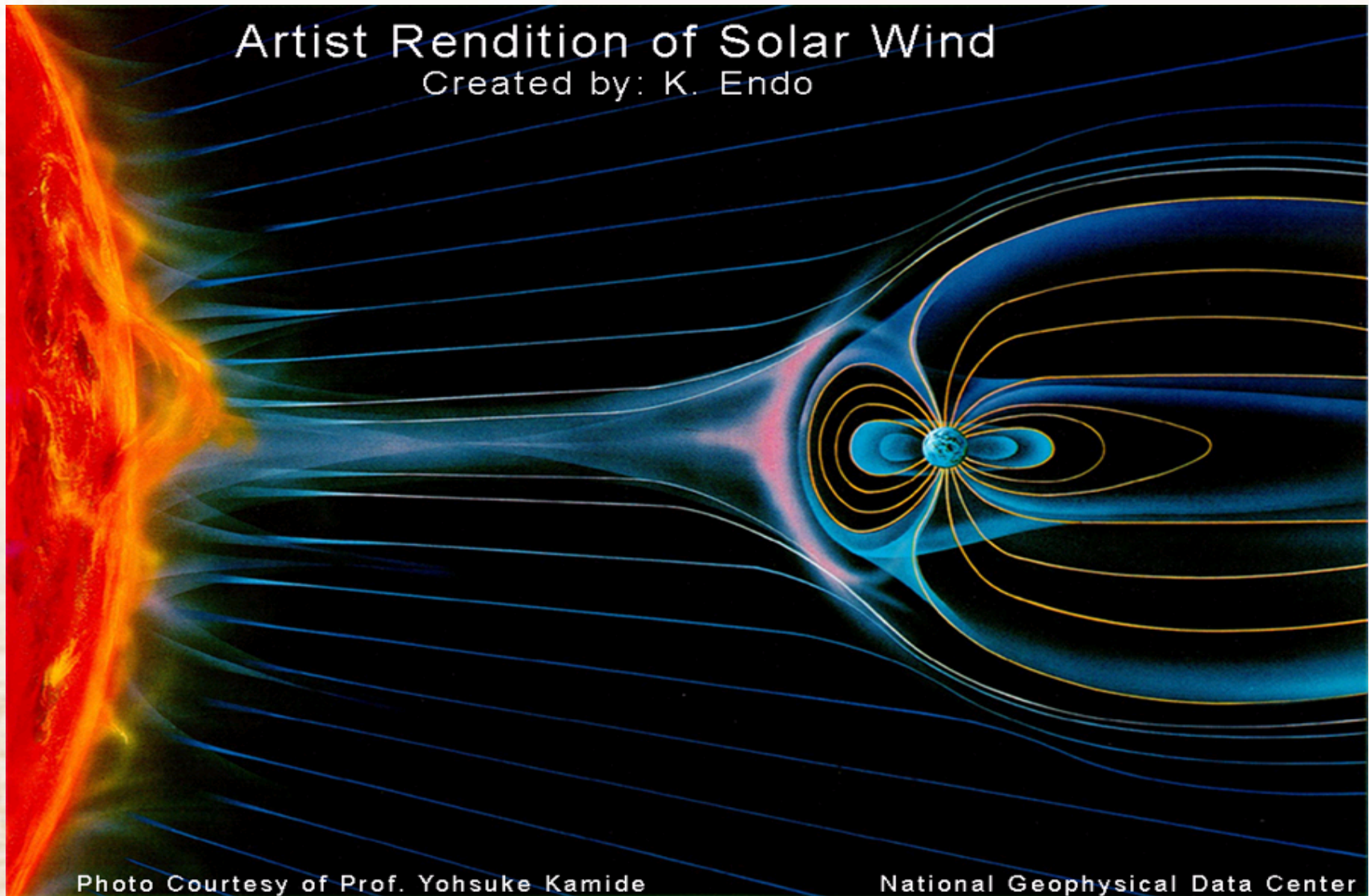


ElectroMagnetic methods used:

- DC: dipole - dipole – historic, low resolution
- Induced Polarization: shallow, near surface effects
- Magnetotellurics: standard reconnaissance
- CSEM (Lotem): great for pre-drill targeting
- Here: only MT case histories others are too old!!

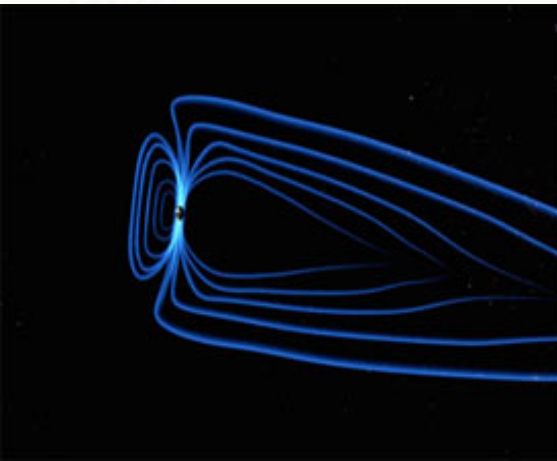
Introduction >>> Case histories >>> Summary

Ionosphere sources of MT field

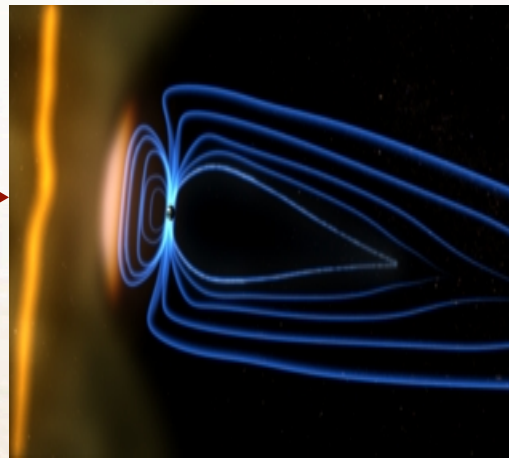


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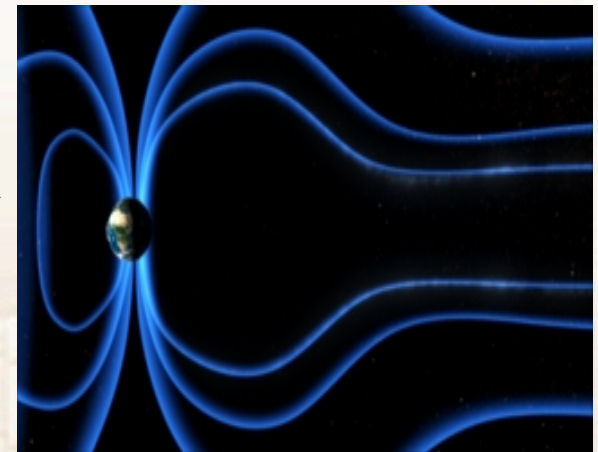
Methods: magnetotellurics – the events



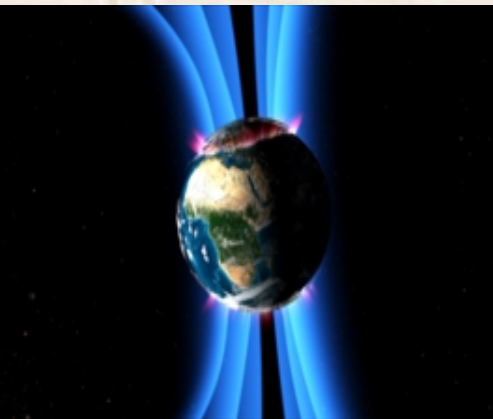
Earth's Magnetic Field



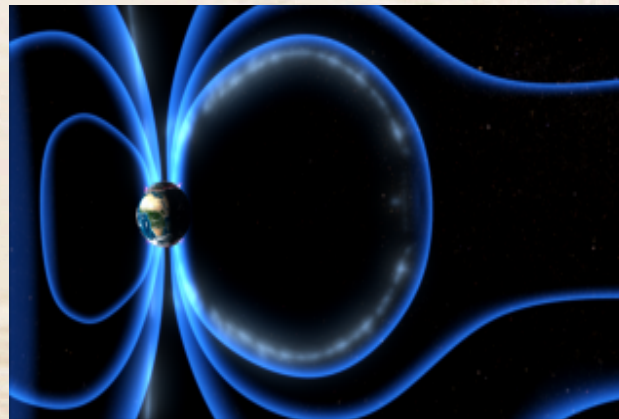
Massive solar outburst travels on the solar wind



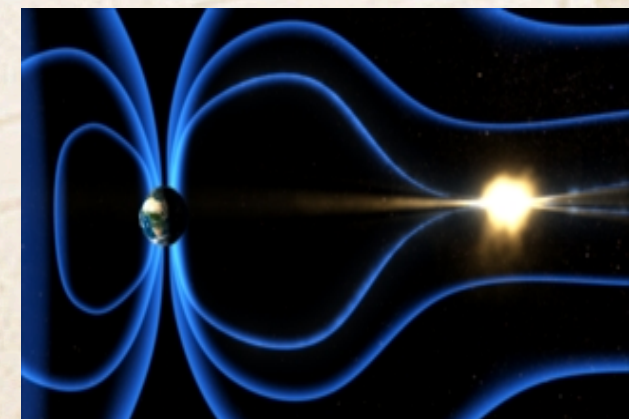
The solar wind distorting earth's magnetic field



It induces electric field in ionosphere and in extreme cases produces Auroras.



This fired particles towards the earth



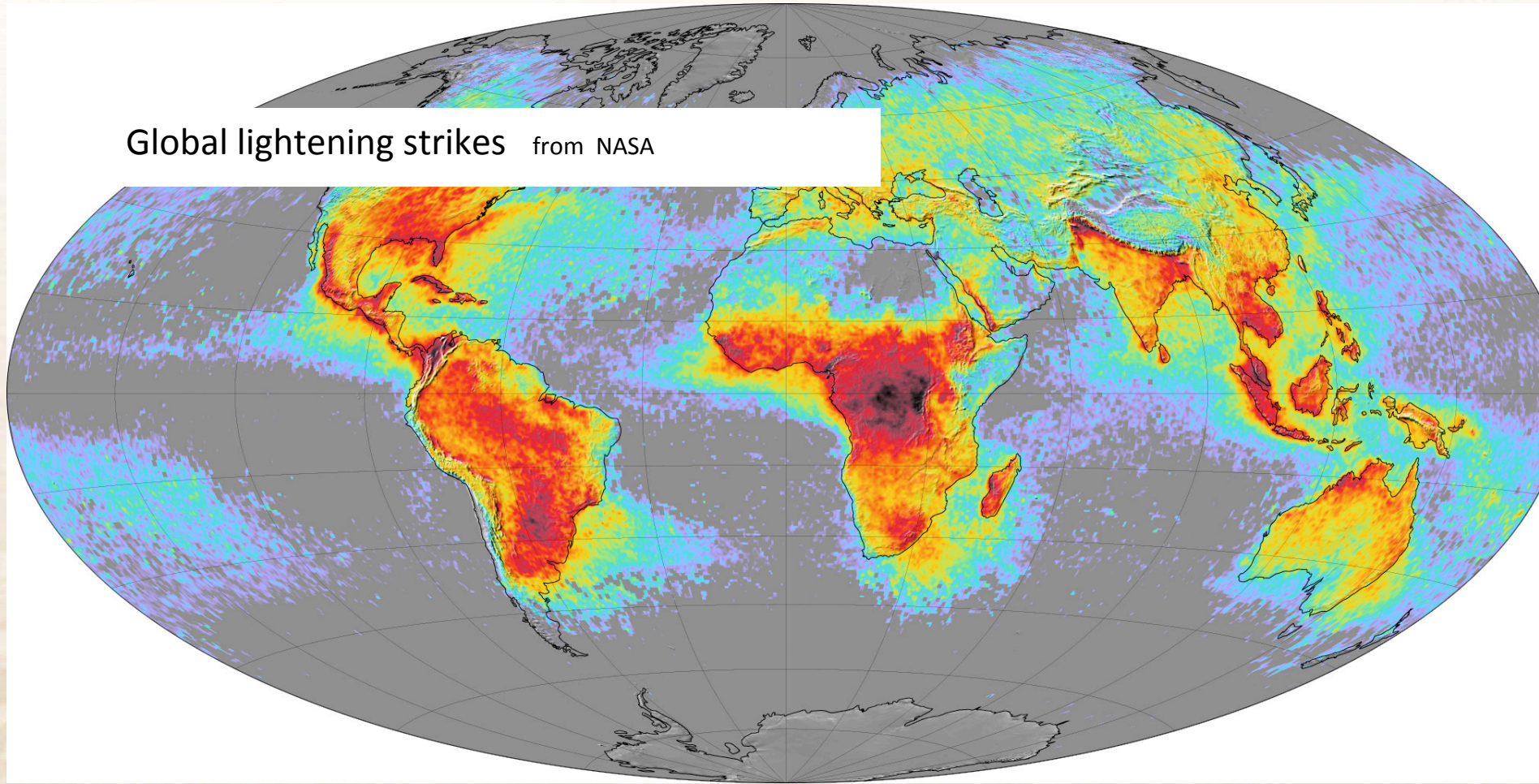
Two magnetic field lines are reconnecting

Introduction >>> Case histories >>> Summary

Methods: magnetotellurics – the events



Global lightning strikes from NASA



after <http://svs.gsfc.nasa.gov/>

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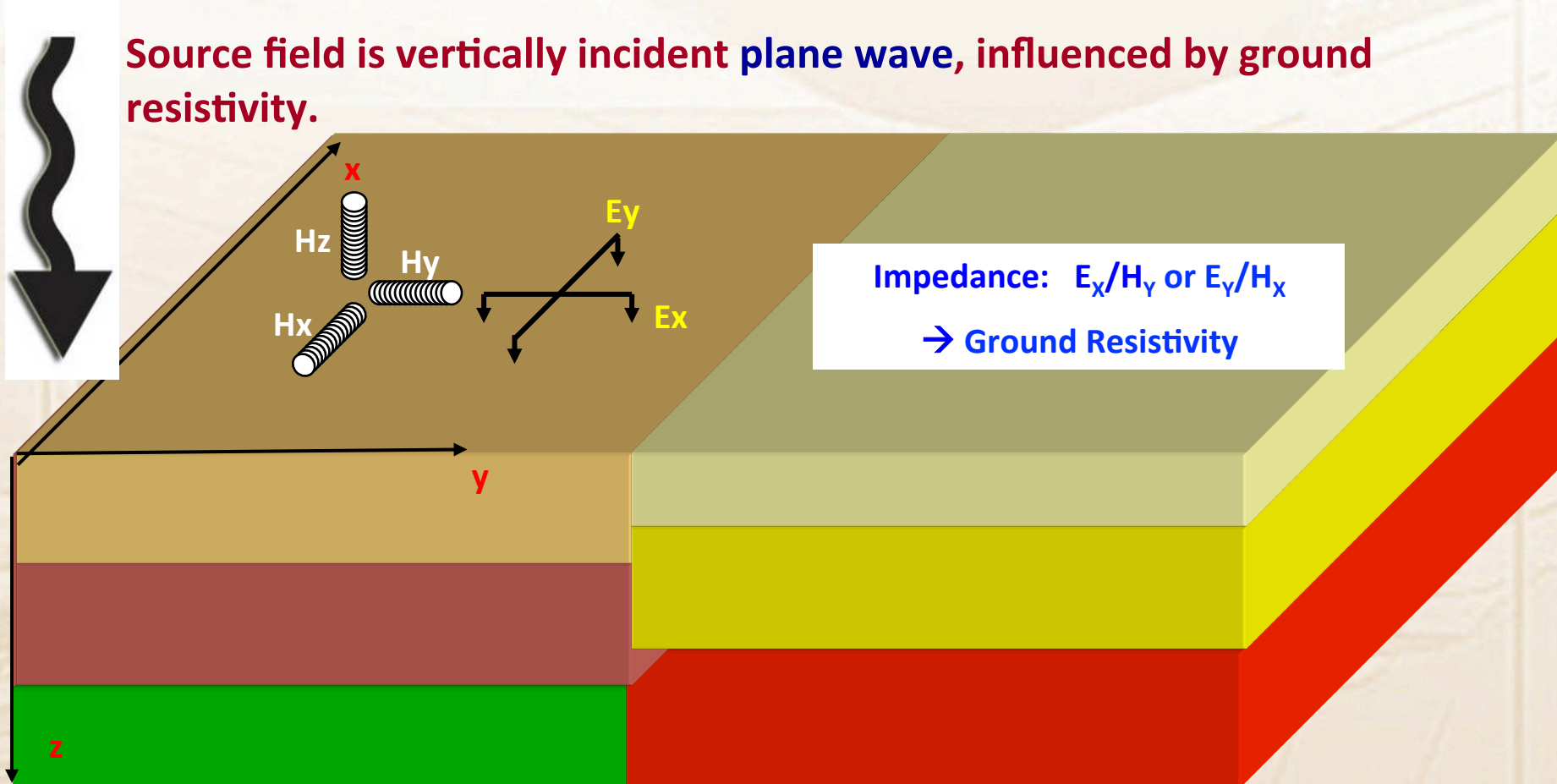
Magnetotelluric (MT) method



Measure natural variation of EM field;

Source: ionosphere & worldwide thunderstorm activity;

Source field is vertically incident **plane wave**, influenced by ground resistivity.



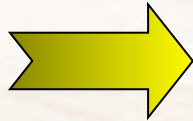
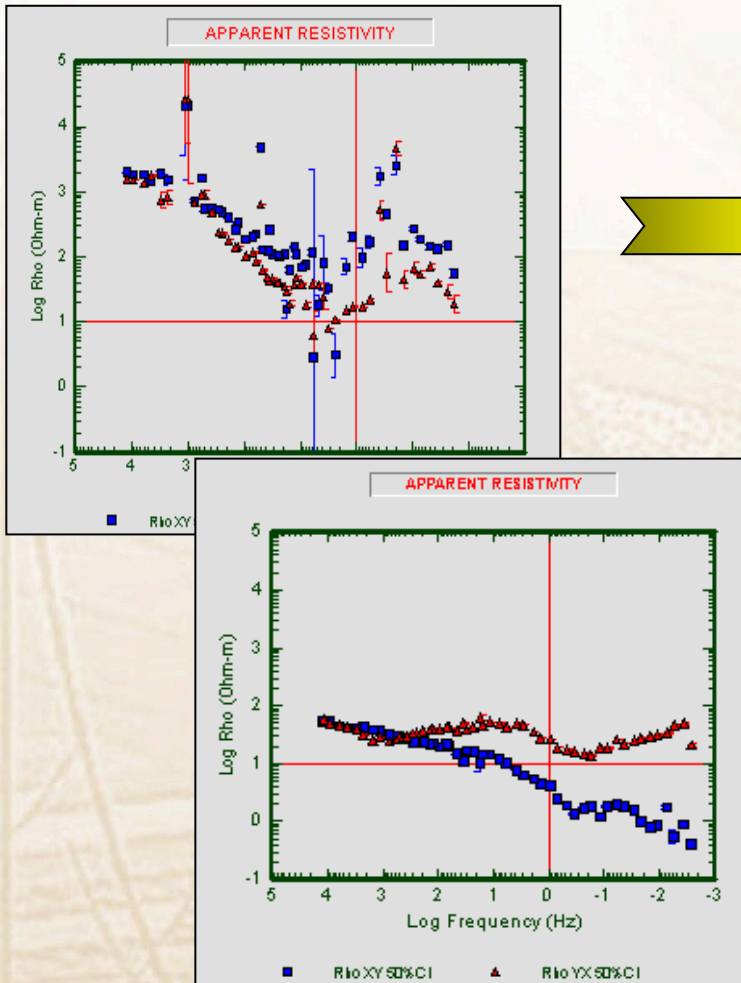


Introduction >>> Case histories >>> Summary

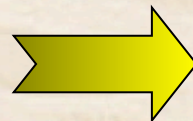
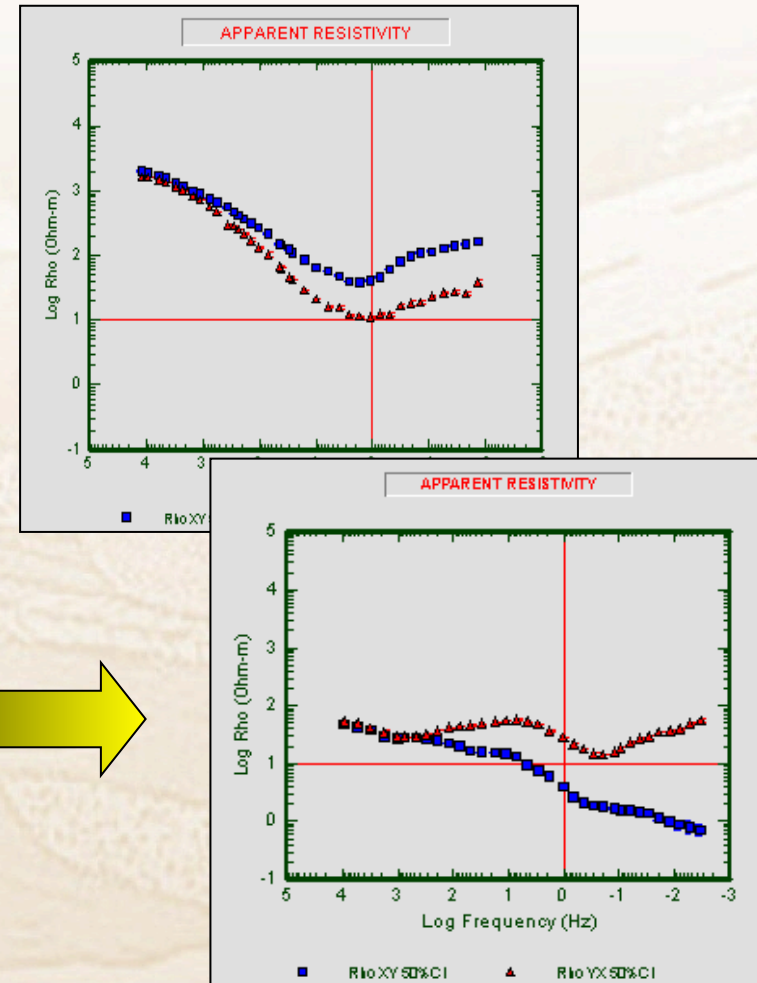
MT Processing & Interpretation - quick tour



Before processing

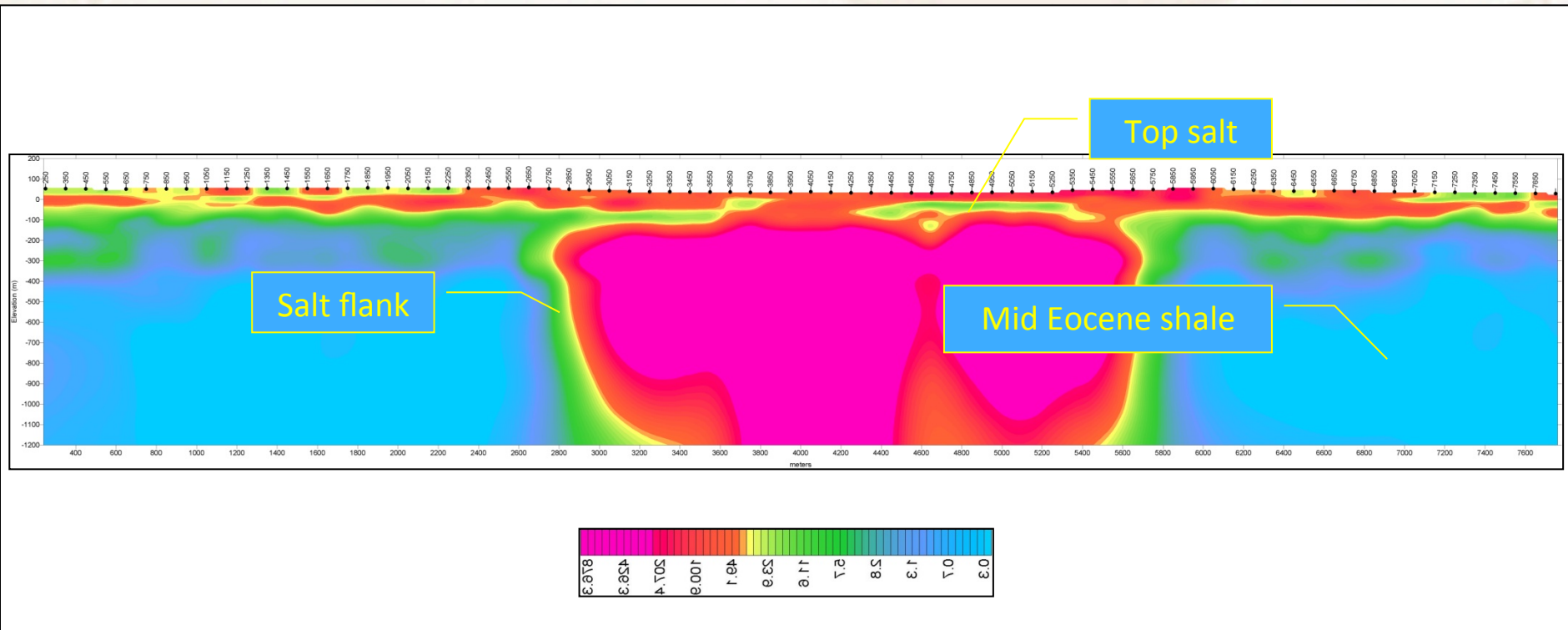


After processing



Introduction >>> Case histories >>> Summary

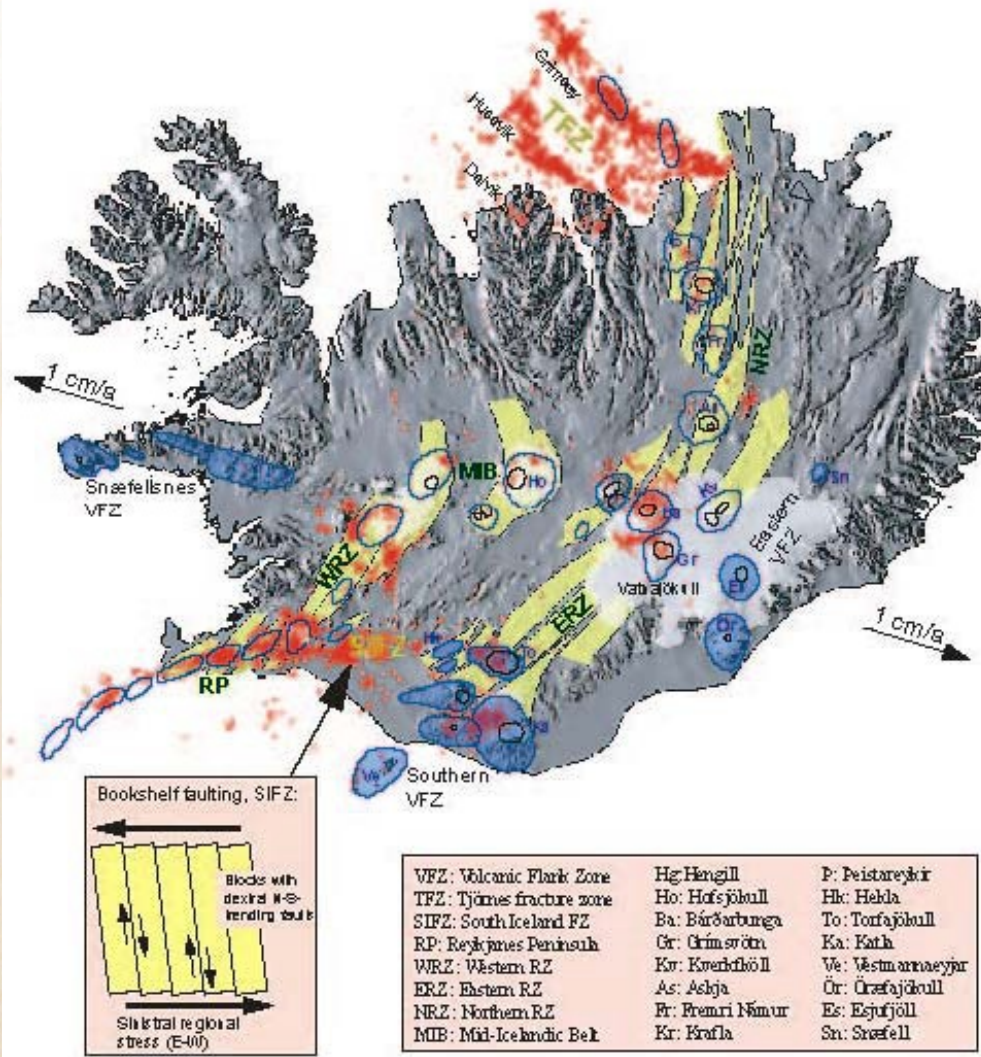
MT Processing & Interpretation - quick tour



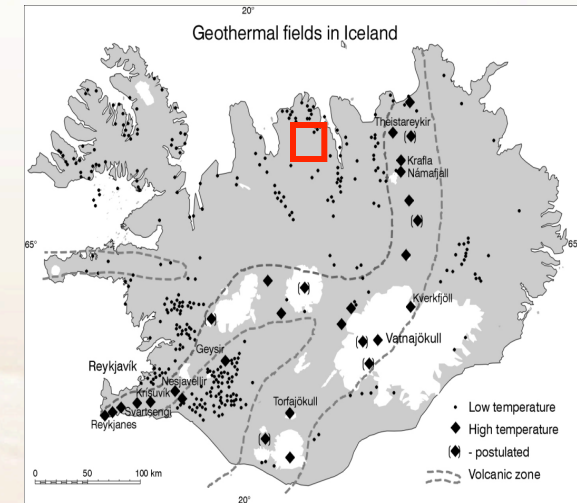


- All volcanic material
- Target zone was additional reservoir to feed power plant
- Survey mapped resistive & conductive targets
- Data to be integrated with all others data

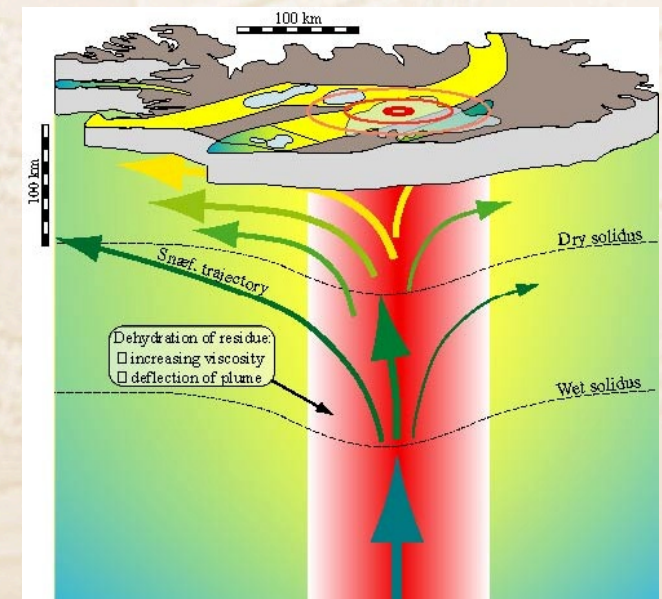
Introduction >>> Case histories >>> Summary Iceland geothermal field distribution



(Trønnnes, 2002)



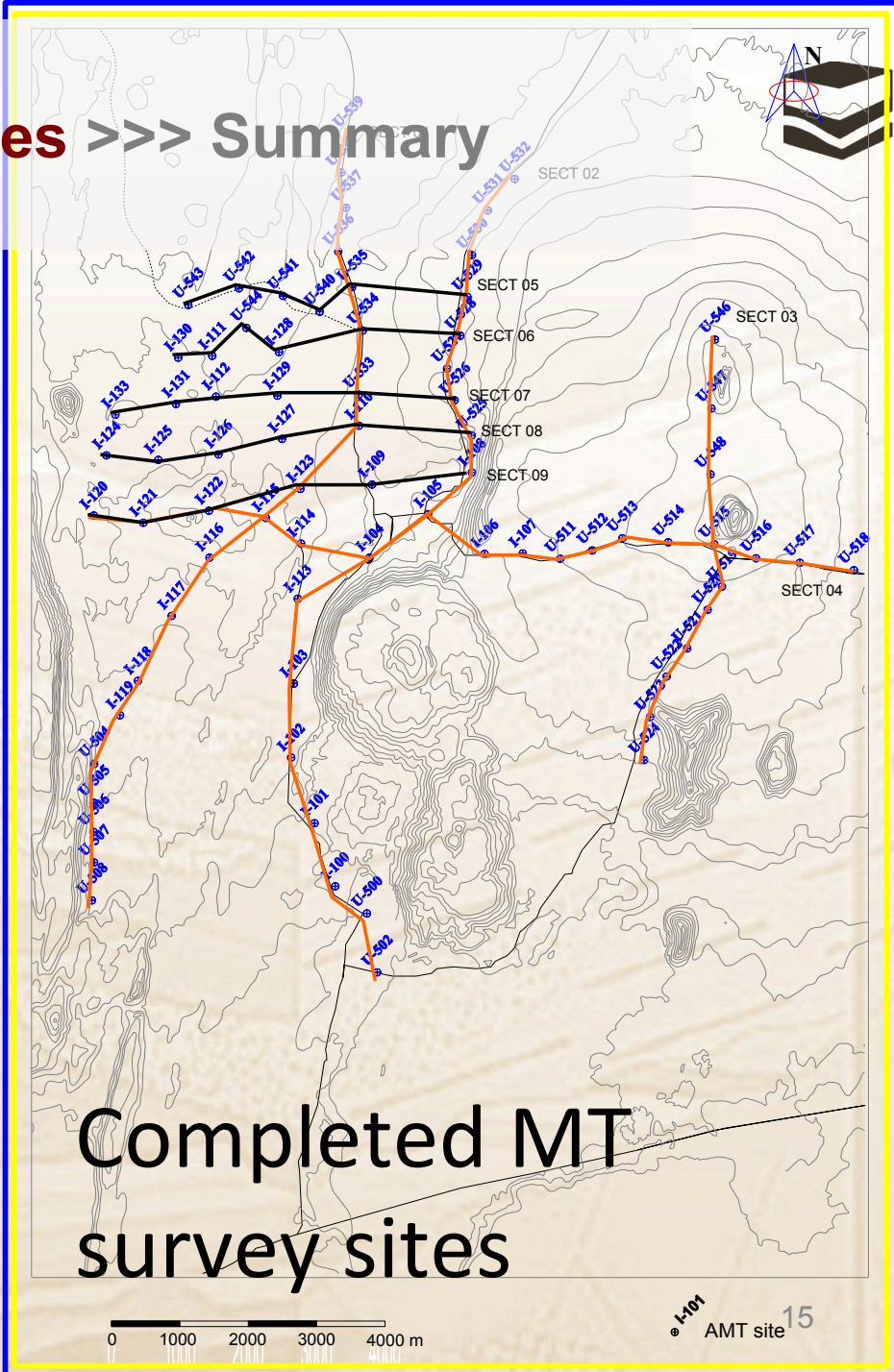
Armannsson 2000



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

Introduction >>> Case histories >>> Summary

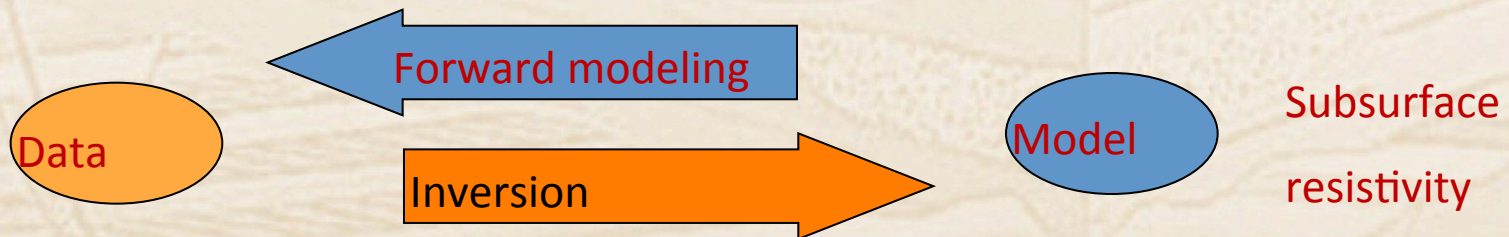
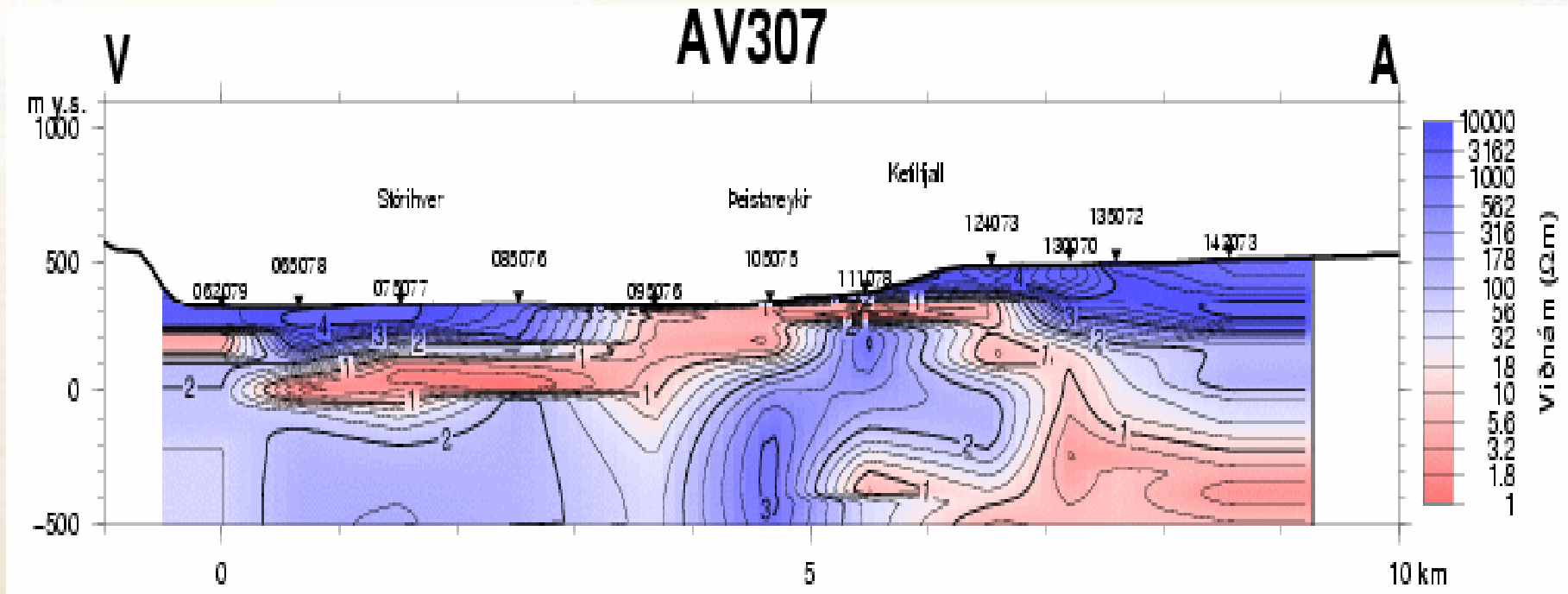
Planned MT survey sites



Completed MT
survey sites

Introduction >>> Case histories >>> Summary

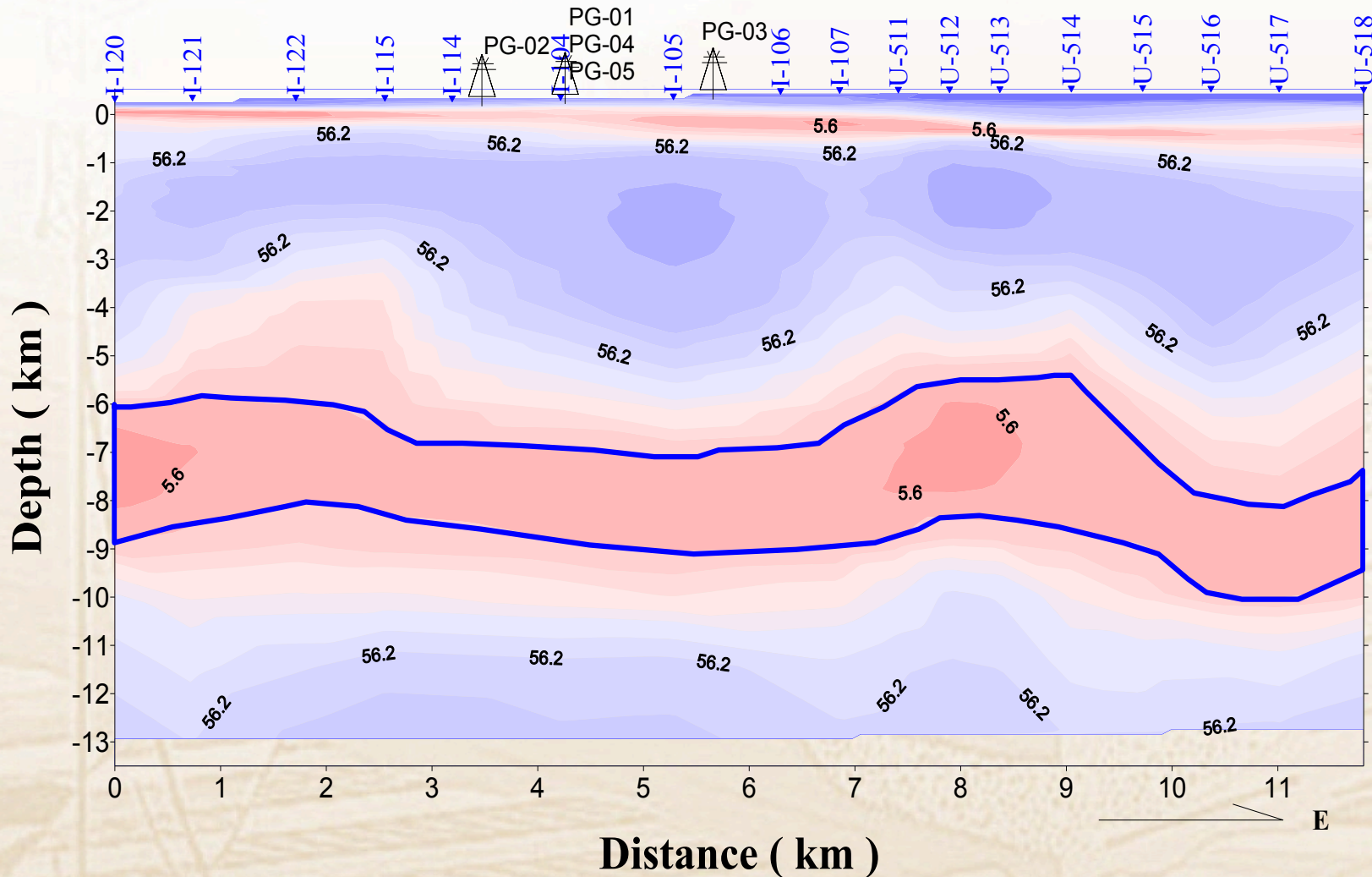
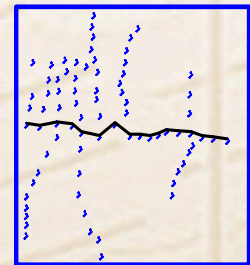
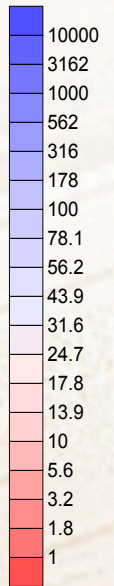
Iceland: TEM inversion result of profile 307

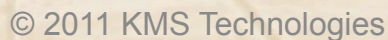
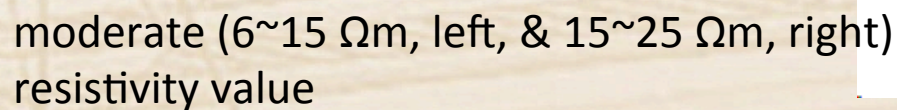


Iceland: MT inversion result of Section 04



Ohm-m



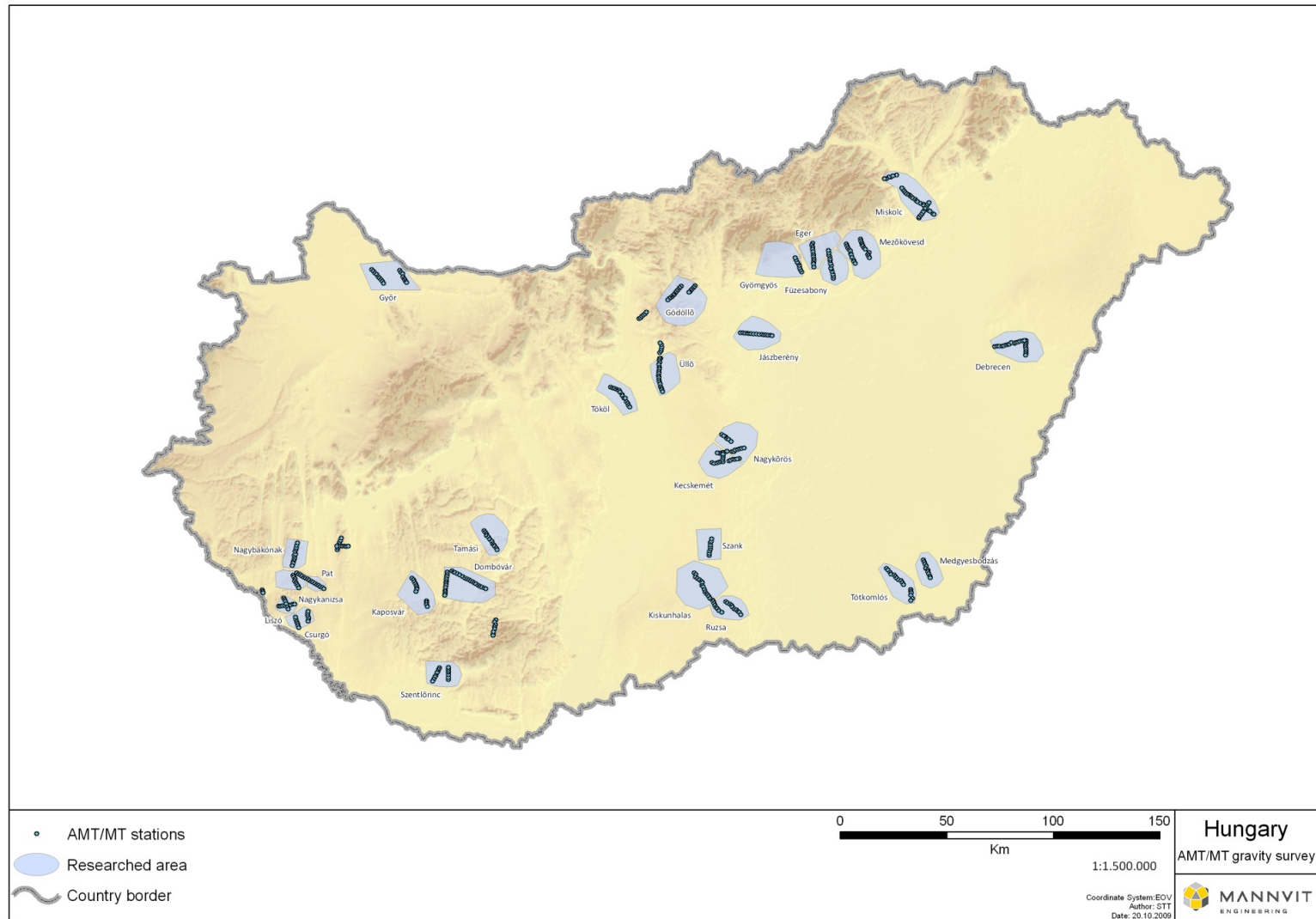




- **Find geothermal area for electricity & space heating:**
 - **Detail potential geothermal targets**
 - **Select drilling sites**
- **Technical**
 - **Use magnetotellurics & gravity**
 - **Invert independent & cooperative**
 - **Combine with geology**
- **One target was drilled & confirmed**
 - **4 MW geothermal energy from 1 well**

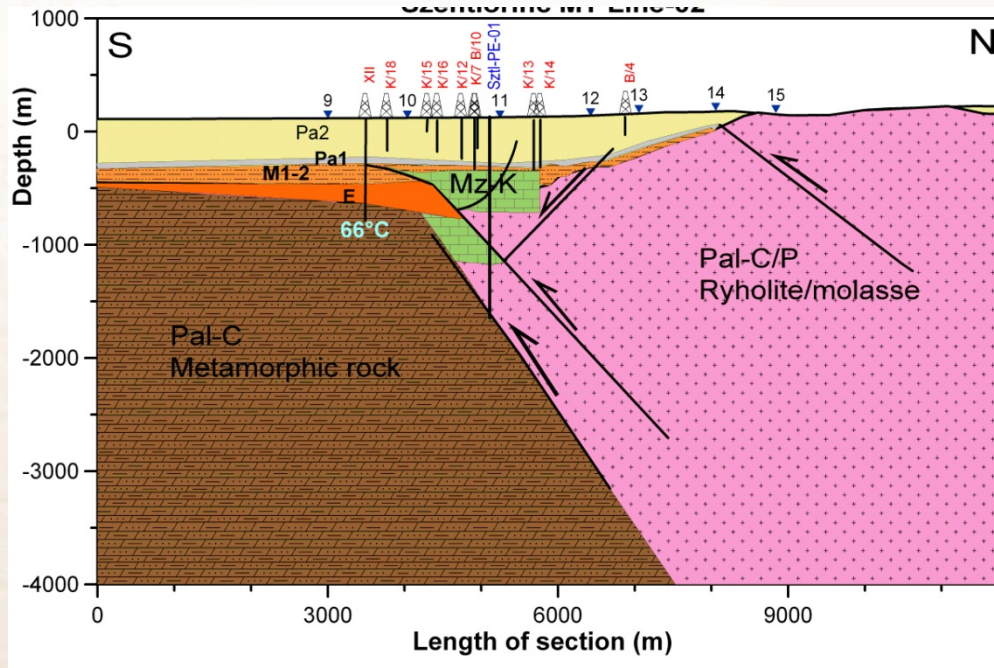
Introduction >>> Case histories >>> Summary

Hungary map

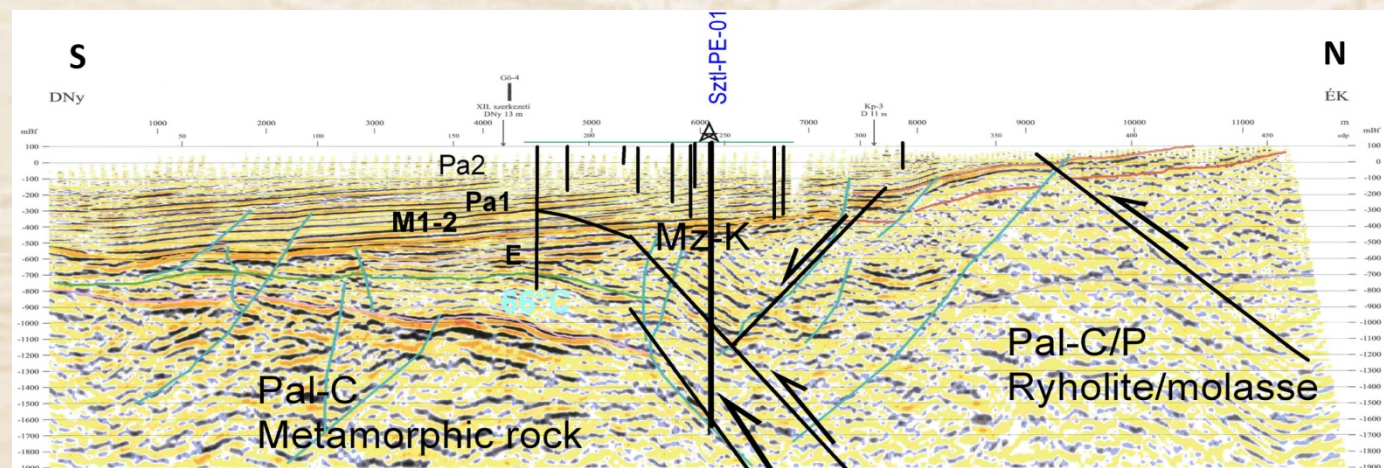


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Hungary: Integrated interpretation

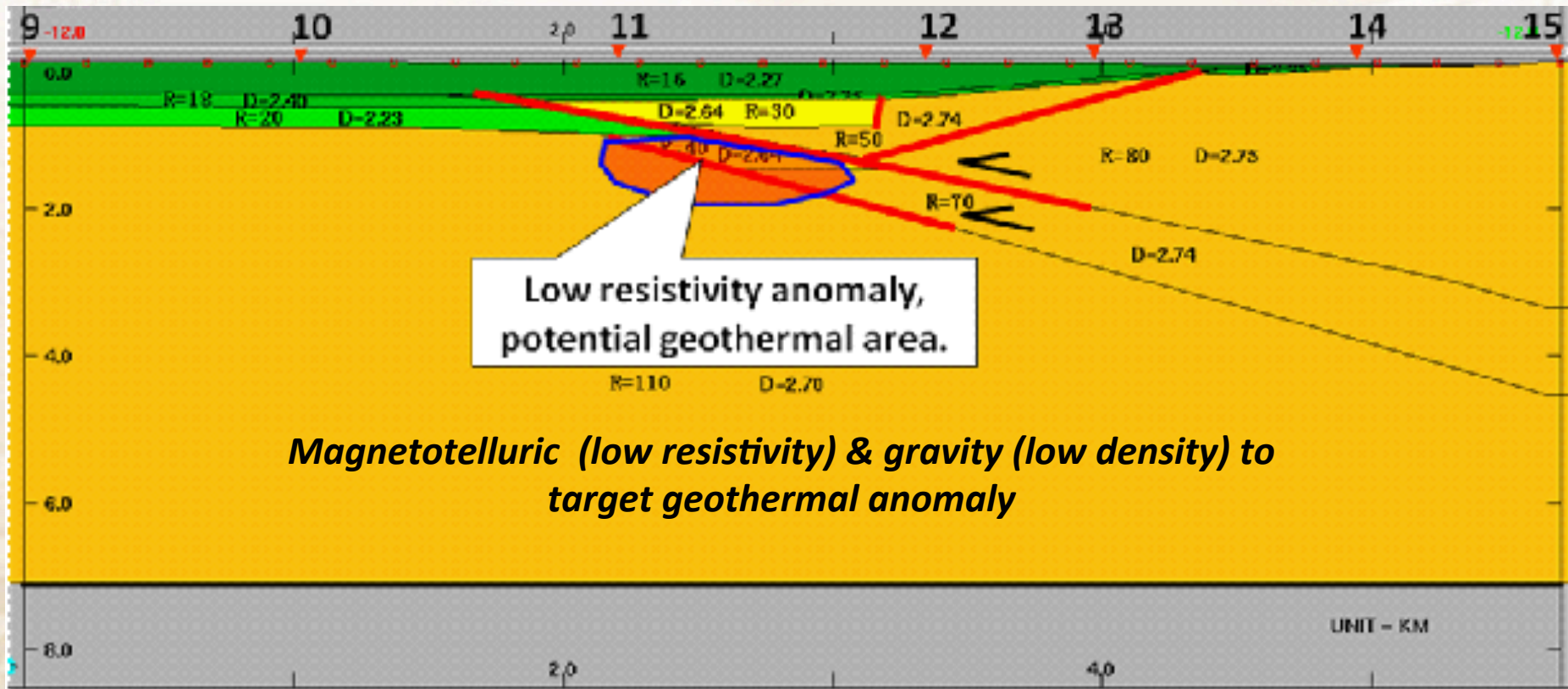


Seismic and geologic information for structures and lithology



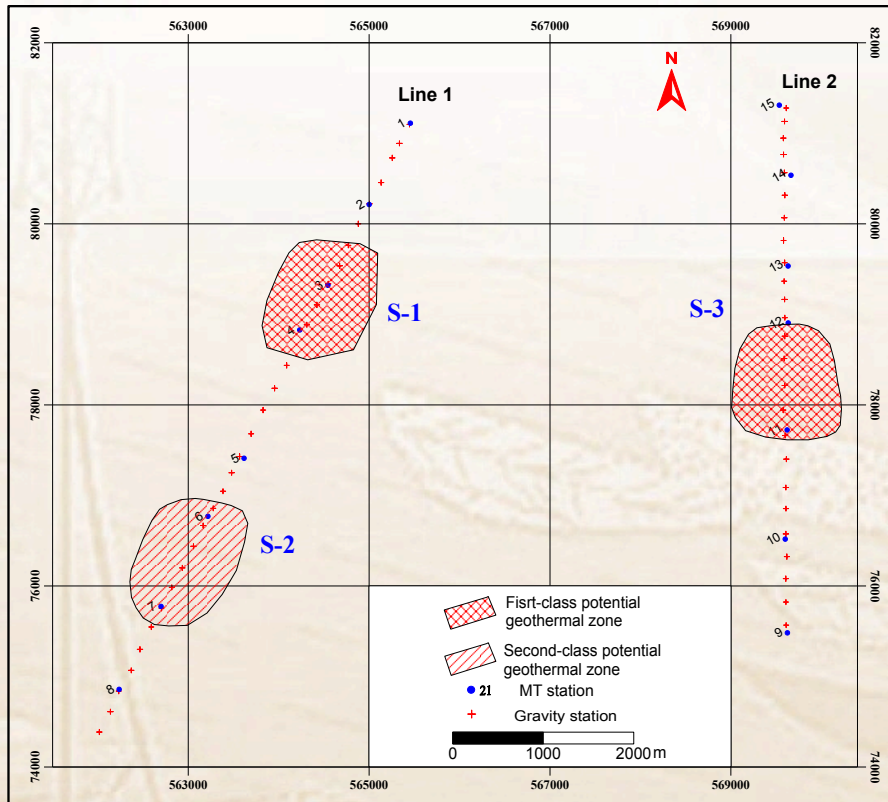
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Hungary: Integrated interpretation



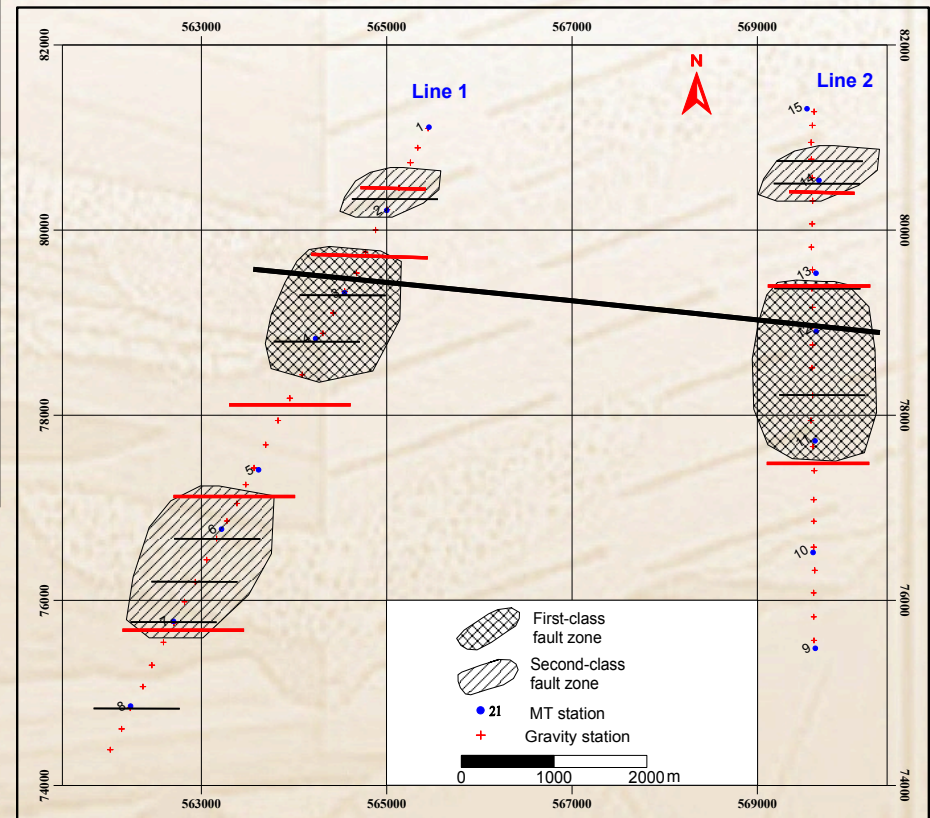
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Hungary: Integrated interpretation



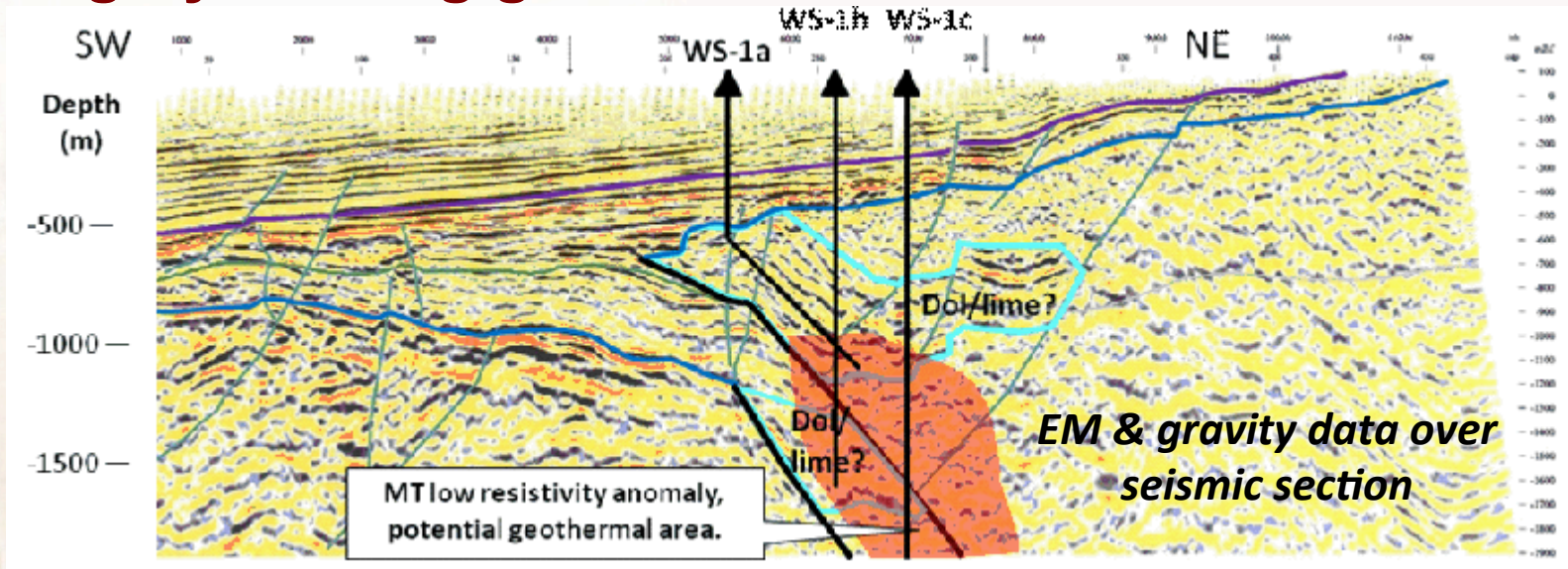
Geothermal zones

Fault zones



Introduction >>> Case histories >>> Summary

Hungary: Drilling gives 3 MW



Introduction >>> **Case histories** >>> Summary

Hungary: MT instrument field calibration





Hungary Gravity Base Network Data

4145. Csákán

Y= 513 961;

X= 133 820;

Elevation: 126.653 m

$g = 980\,718.679$ mgal



Introduction >>> **Case histories** >>> Summary

Hungary success:



- Interpreted two 1st-class (deep faults) & one 2nd-class (shallow faults) potential geothermal zones
- Anomalies buried at 1,000 m ~ 2,000 m
- Conductive heat flow from magma through sediments is main source
- Deep fault may go through crust & reach mantle
- Successfully drilled 1st evaluation well in 09/2009
- 85°C hot water → 4 MW from 1,620 - 1,790 m
- **The total project scope: Possible to supply 700,000 homes in Hungary with geothermal energy within next decade**

Outline



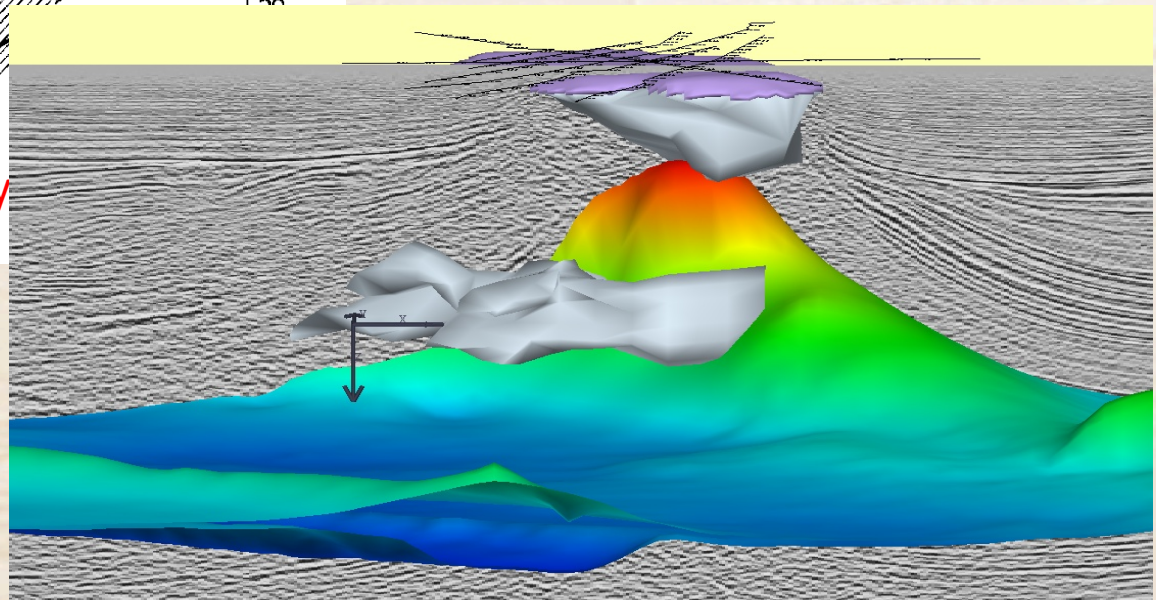
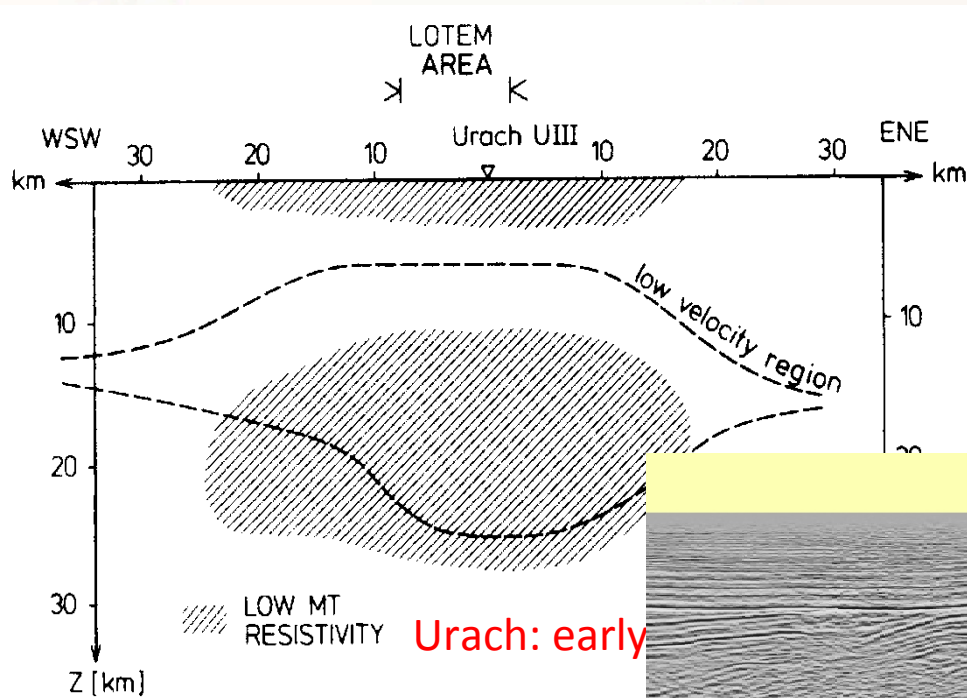
- **Background**
- **Iceland case history**
- **Hungary success**
- **EU island**
- **Conclusions**



- MT has come a long way from rough outlines to fully integrated images
- Acquisition is still not competitive and need newer systems (like seismic)
- MT needs to be integrated with CSEM where needed and seismic and other methods (everywhere)



MT: 30 years of progress

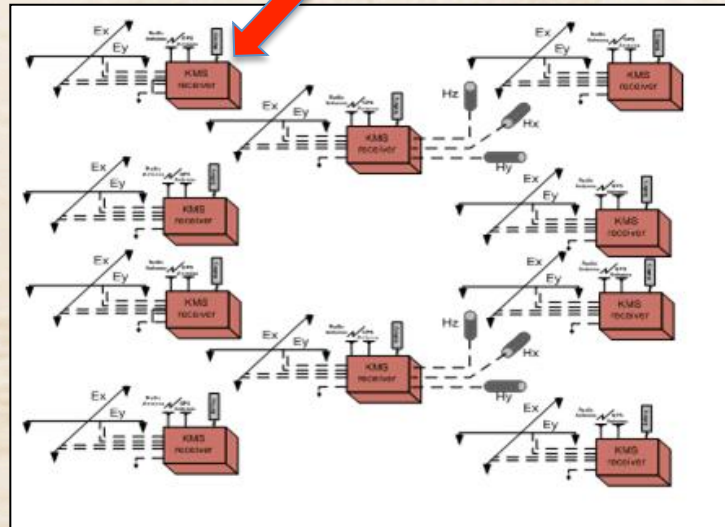


MT: 2002 vintage

UNPUBLISHED, courtesy
RWE-Dea



1981



Handheld QA/QC

2010



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