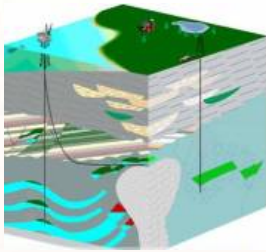


KMS Technologies – KJT Enterprises Inc.
An EMGS/RXT company

**Exploring for geothermal reservoirs
using broadband 2-D MT and gravity
in Hungary**

Tulinius, H., Adam, L., Halldorsdottir, H., Yu, G., Strack, K.-
M., Allegar, N., He, L. F., and He, Z. X.

SEG 2008 Las Vegas Annual Meeting



MANNVIT
VERKFRÆÐISTOFA

PANNERGY



Exploring for geothermal reservoirs using broadband 2-D MT and gravity in Hungary

Tulinus², H., Ádám², L., Halldórsdóttir², H., Yu¹, G., Strack¹, K., Norman¹, A., He³, L. F., and He³, Z. X.

¹KMS Technologies

²Mannvit (formerly VGK-Hönnun)

³BGP

Outline

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

Introduction

- Hungary is rich in low heat entropy geothermal resources;
- Reliability of previous data was poor;
- Earlier surveys not aimed for geothermal exploration;
- MT & gravity survey to outline potential geothermal areas;
- Data processing & integrated interpretation on going.

Outline

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

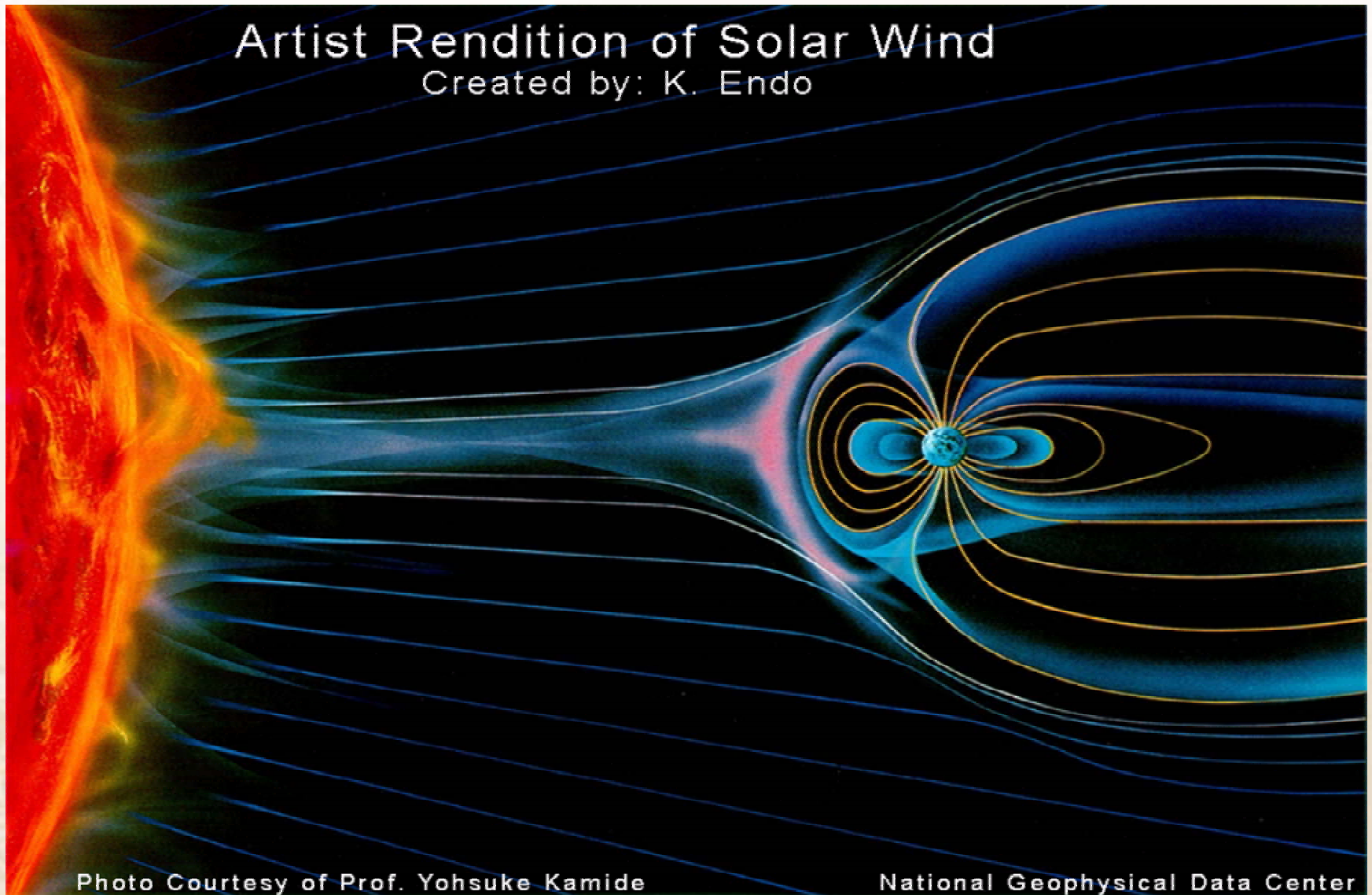
Project objectives

- **Find geothermal area for electricity & space heating:**
 - **Detail exploration at potential geothermal locations;**
 - **Outline boundaries of potential geothermal area;**
 - **Help to study temperature & permeability variation.**

Outline

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

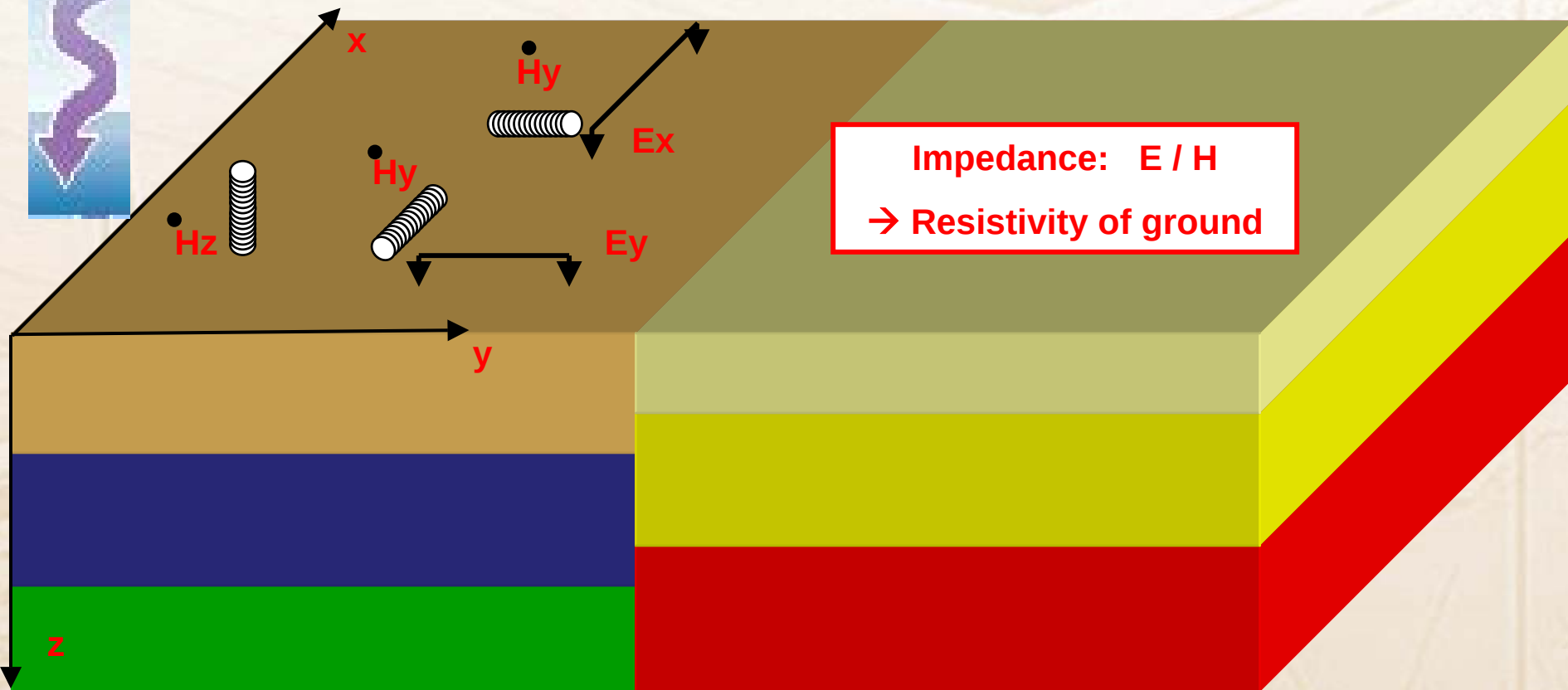
Ionosphere sources of MT field



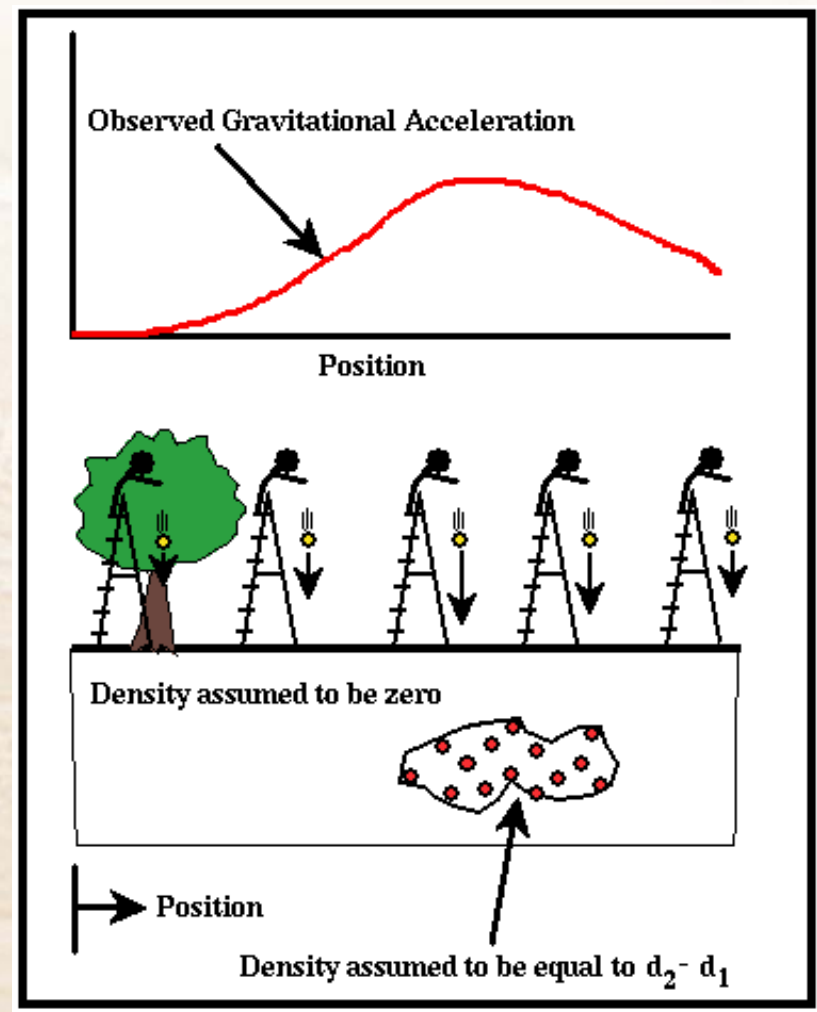
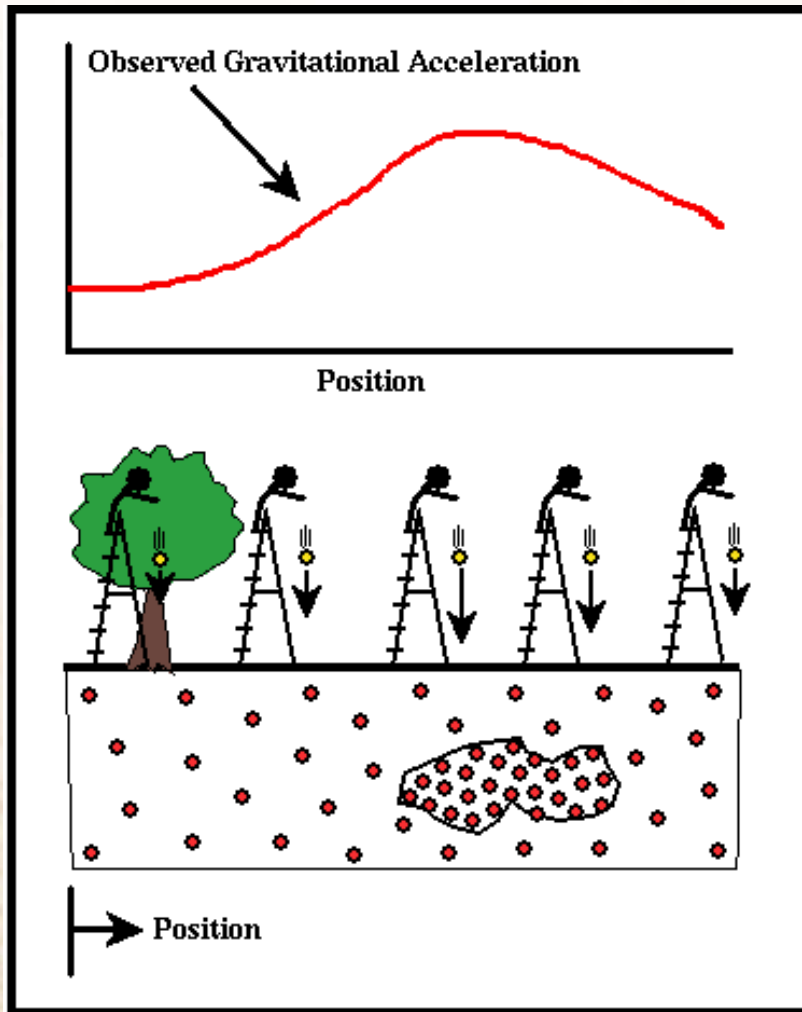
Magnetotelluric (MT) method

Measure natural variation of EM field;
source: ionosphere & worldwide thunderstorm activity;

Source field as vertical incident **plane wave**, influenced by
ground conductivity.



Relevant geologic parameter is not density, but density contrast



After Soc. Expl. Geophys., 1998

Gravity method applications

- Gravity used for geological structures definition at regional scale;
- Close spacing survey provides density distribution at small scale;
- Especially useful if integrated with more accurate geophysical data, i.e. MT & seismic;
- Provide useful constraints for MT modeling & inversion.

Geological map of pre-tertiary basement

 Subsurface geologic map of Pre-Tertiary Basement



Part of Geological Map of Hungary constructed in the Geological Institute of Hungary

MT instrument field calibration



Field gravity survey environment



Hungary Gravity Base Network

4145. Csákán

Y= 513 961;

X= 133 820;

Elevation: 126.653 m

G = 980 718.679 mgal



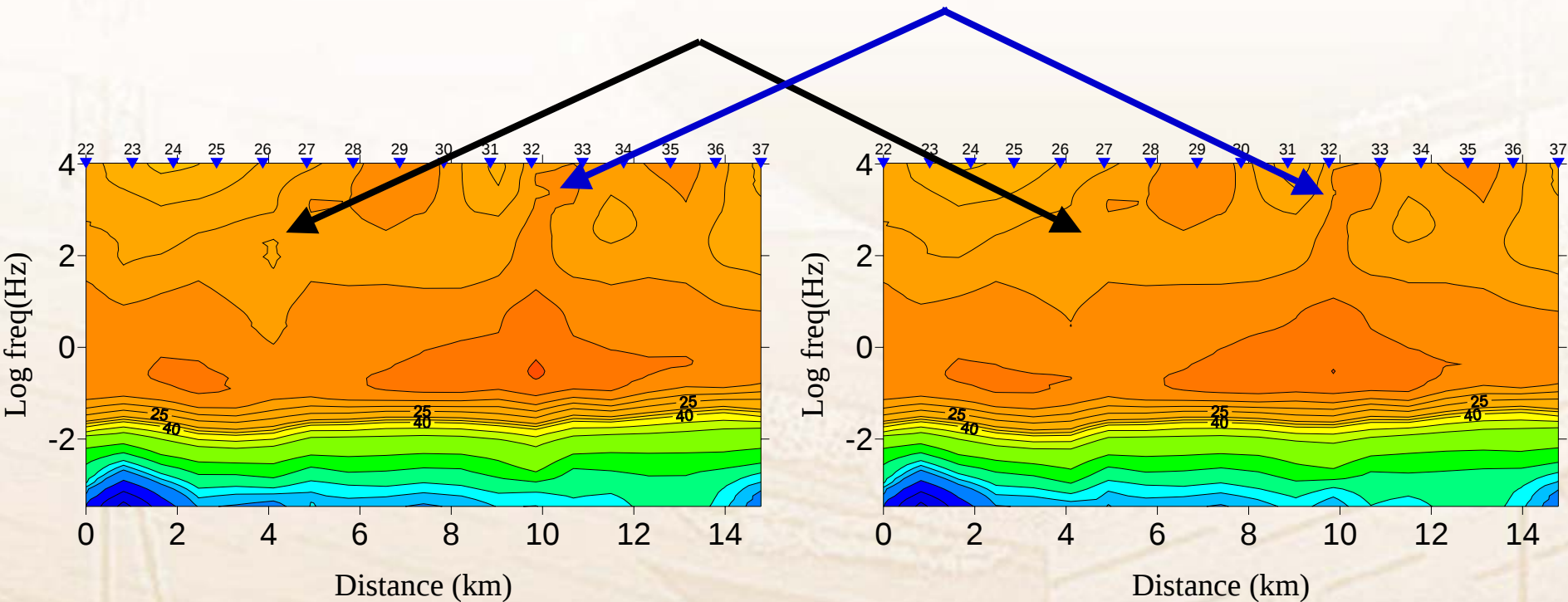
Outline

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

Data processing

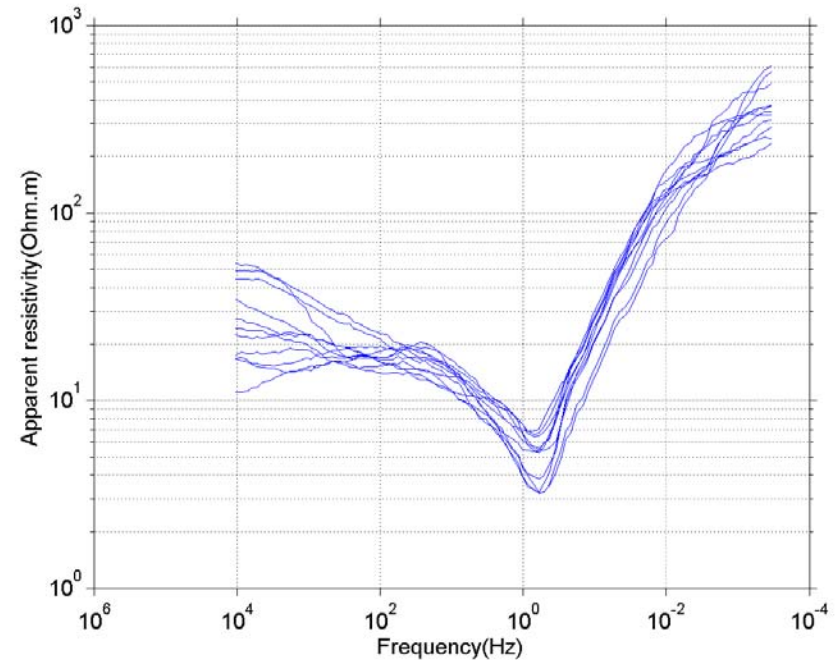
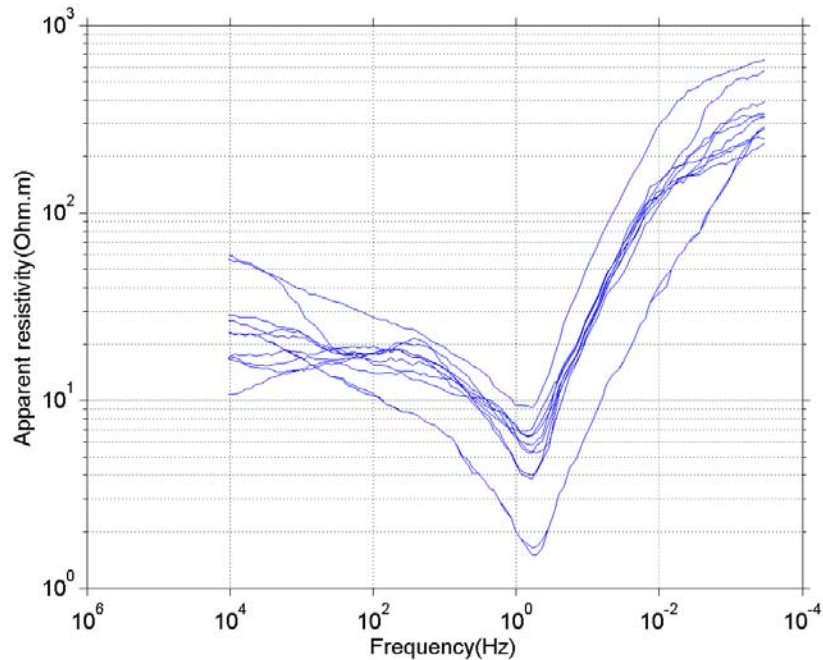
- **MT data processing**
 - Edit data
 - Static correction
 - Remove near surface inhomogeneities (electrical property)
 - Terrain correction
- **Gravity data processing**
 - Upward continuation
 - Gravity gradient calculation
- **Cooperative inversion of MT & gravity data**

MT data processing: Terrain correction



Pseudosections comparison between real data (left) & terrain correction data (right) of Line 04 MT data.

MT data processing: Static correction

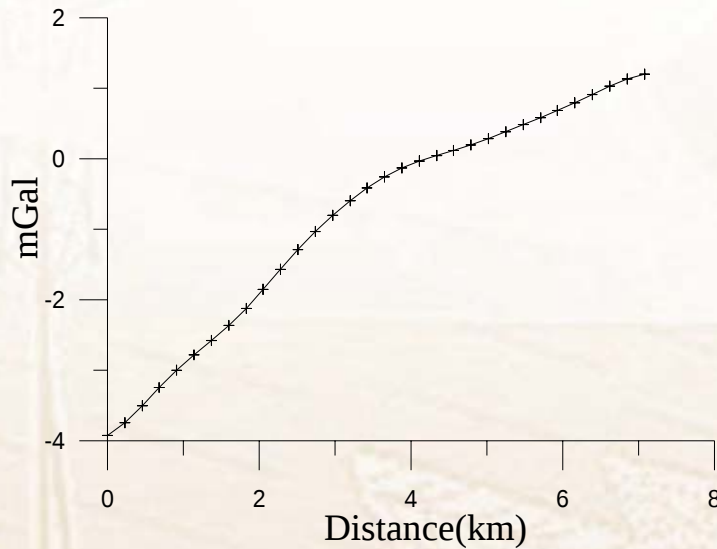


MT data from 11 sites of Line 02B

Before static shift removal

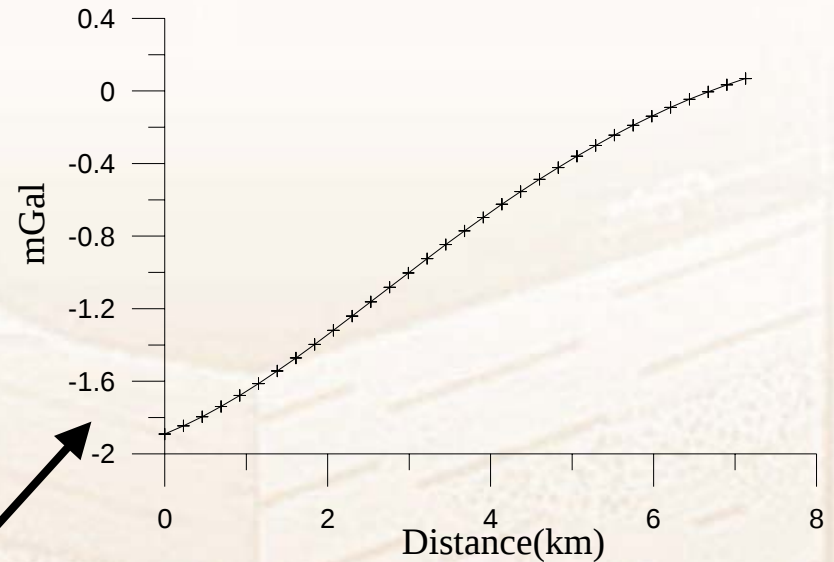
After static shift removal

Gravity data processing



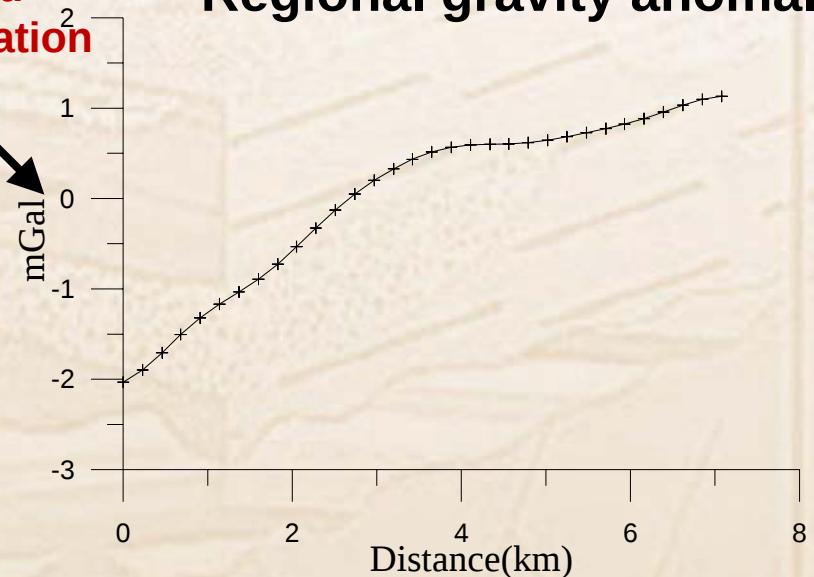
Bouguer anomaly

**Potential field
upward continuation**



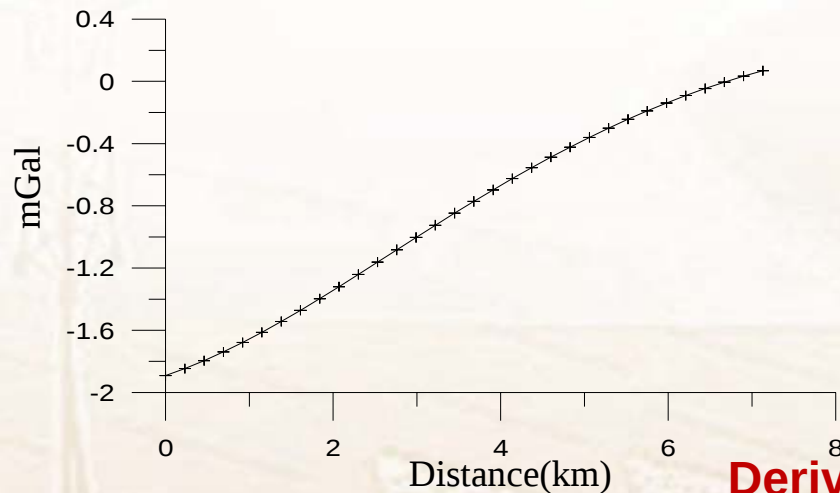
Regional gravity anomaly

Residual gravity anomaly:
Bouguer anomaly - regional gravity
(Reflects different of density above basement)

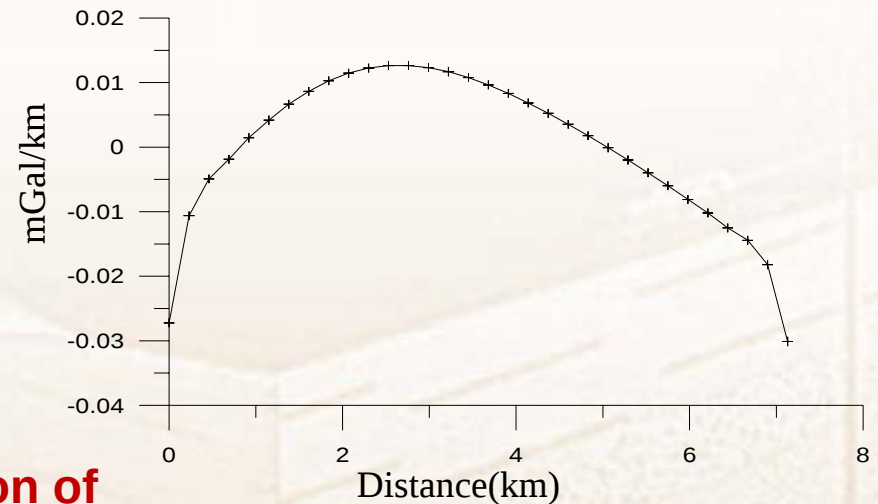


Residual gravity anomaly 18

Gravity gradient calculation

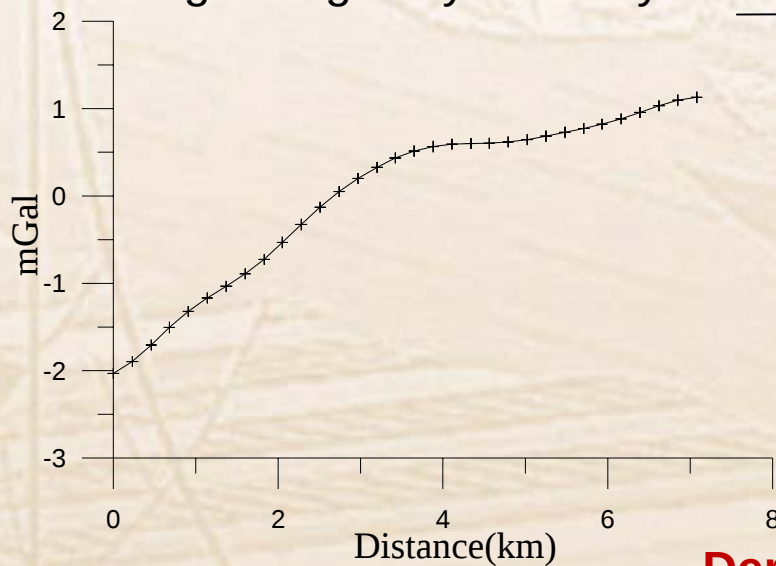


Regional gravity anomaly

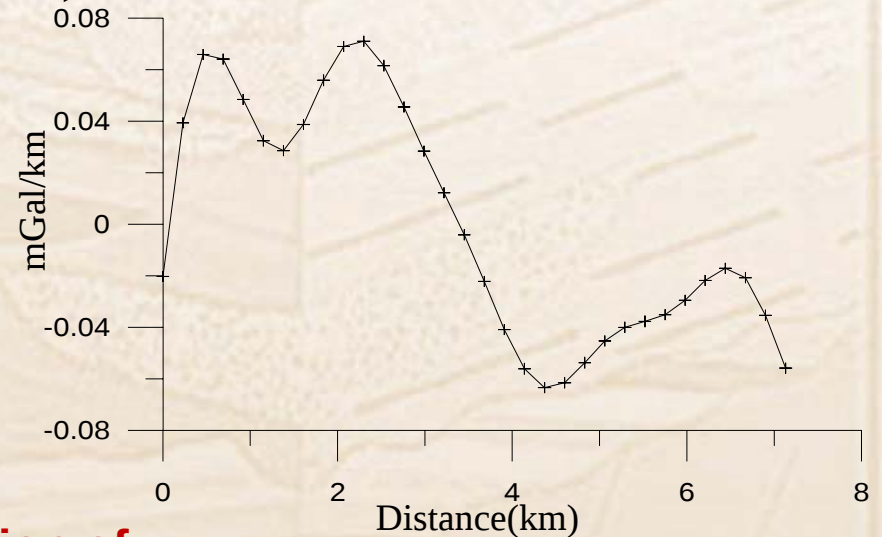


Regional gravity horizontal gradient

**Derivation of
distance**



Residual gravity anomaly

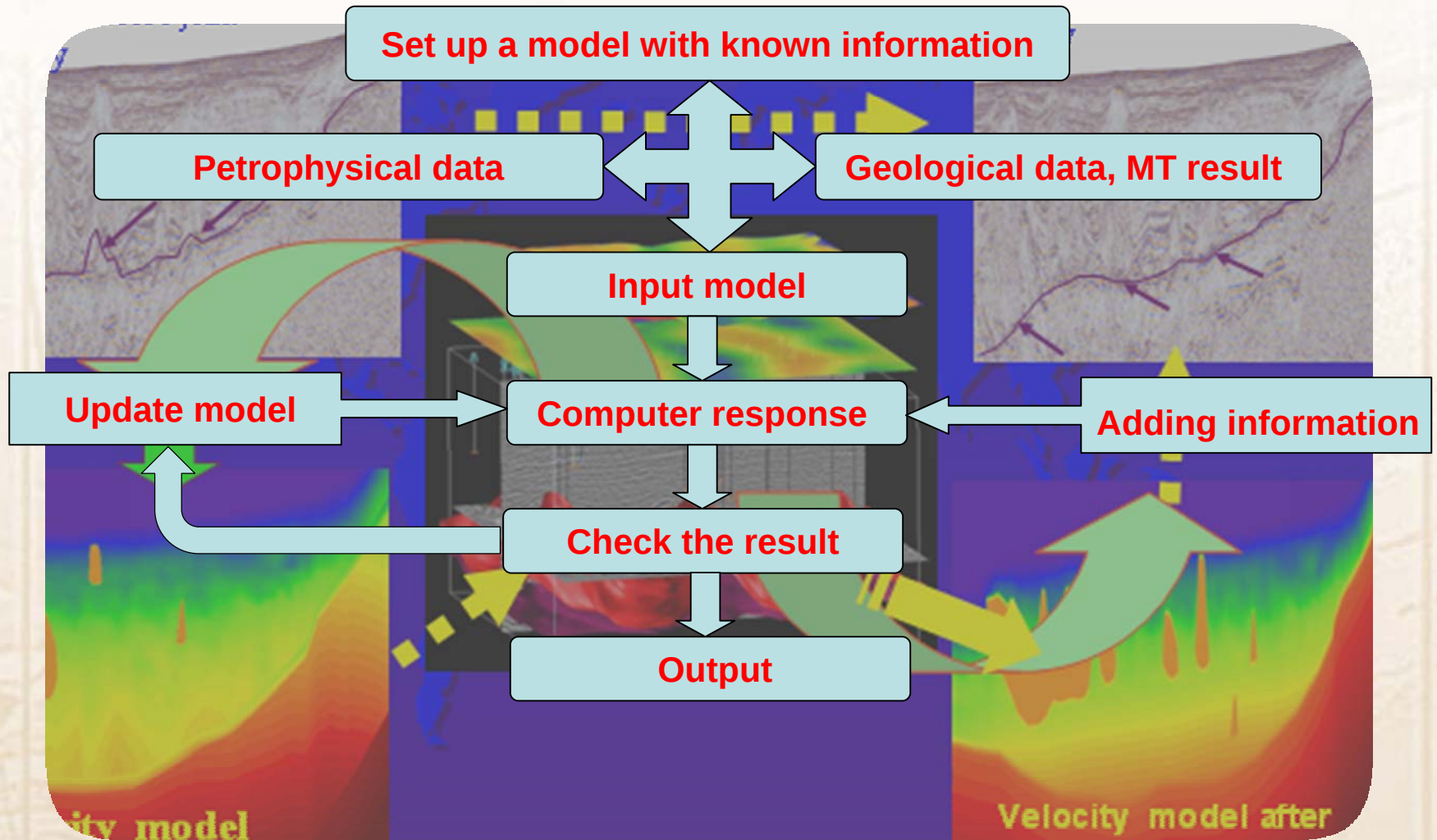


Residual gravity horizontal gradient

**Derivation of
distance**



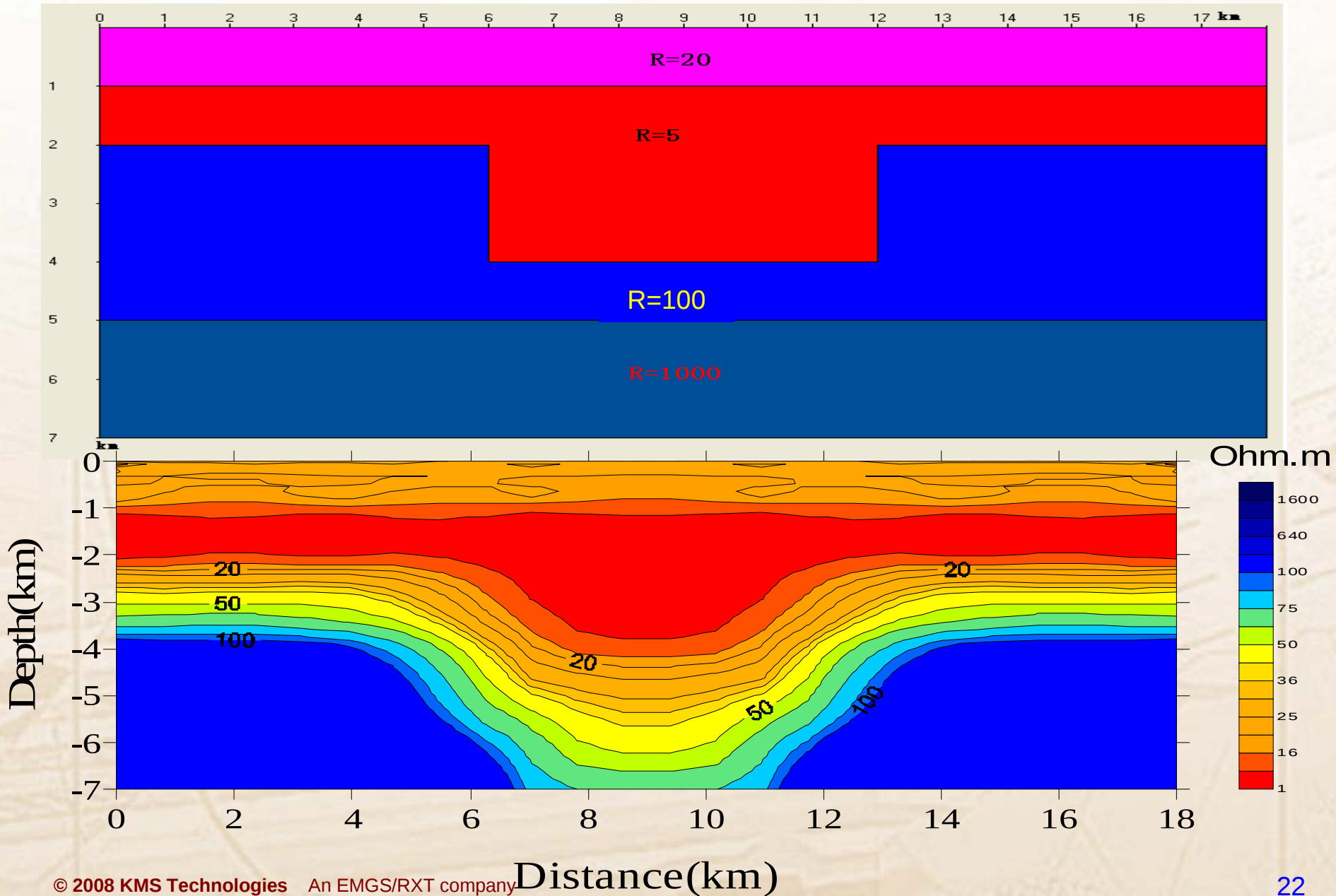
Gravity modeling work flow



Outline

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

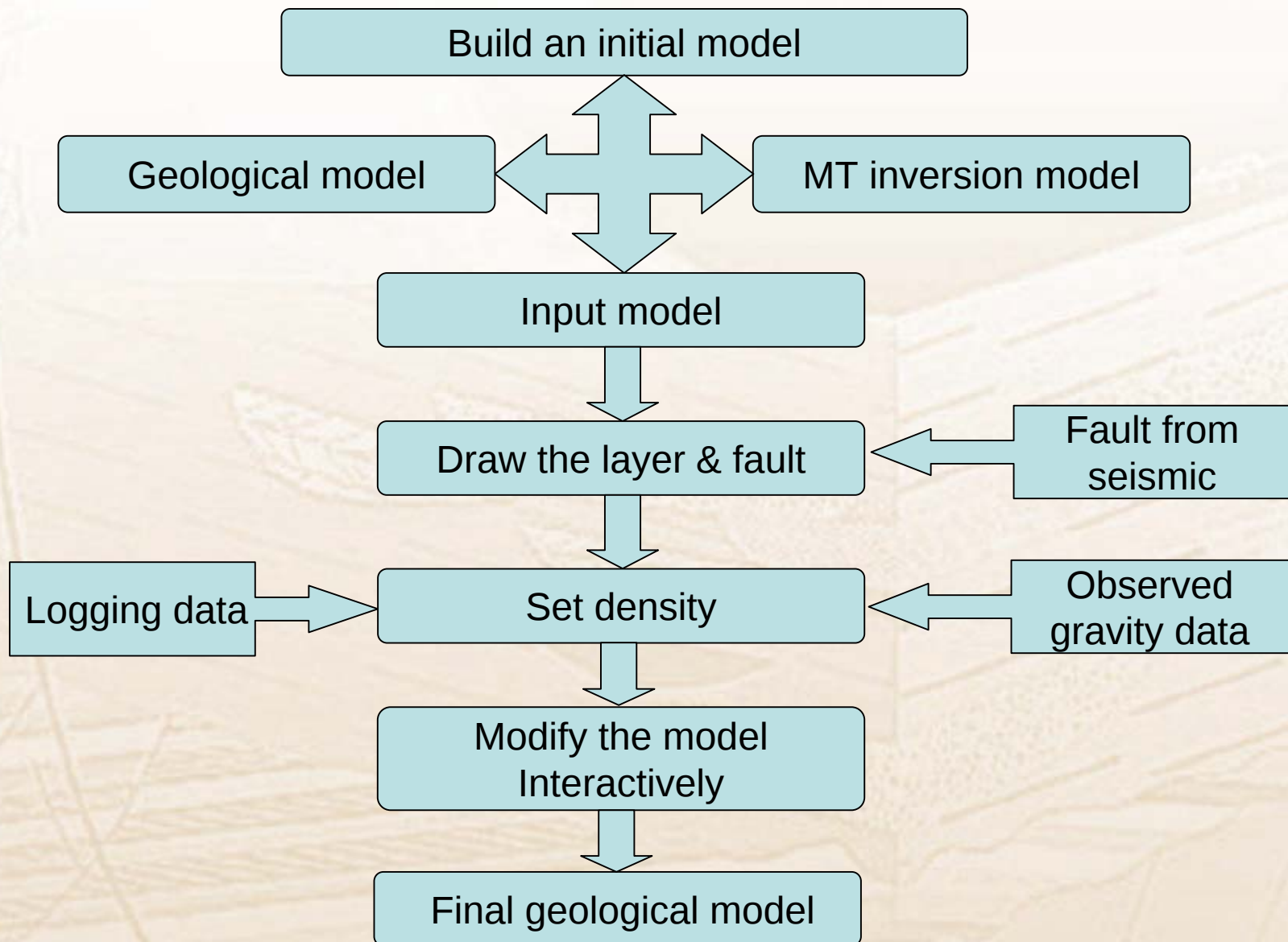
Resistivity model & 2-D continuous media inversion



Outline

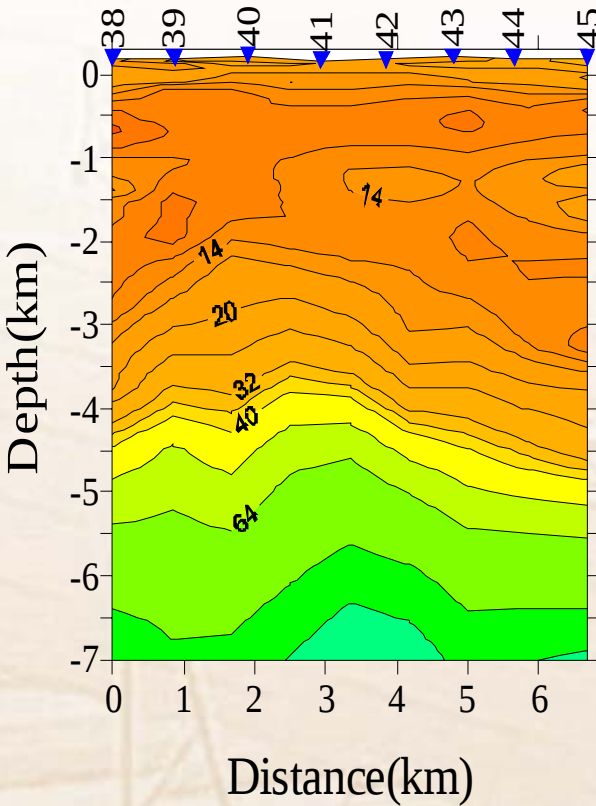
- **Introduction**
- **Project objectives**
- **Data acquisition**
- **Data processing**
- **Modeling & inversion**
- **Interpretation**
- **Conclusions**

Cooperative inversion of MT & gravity

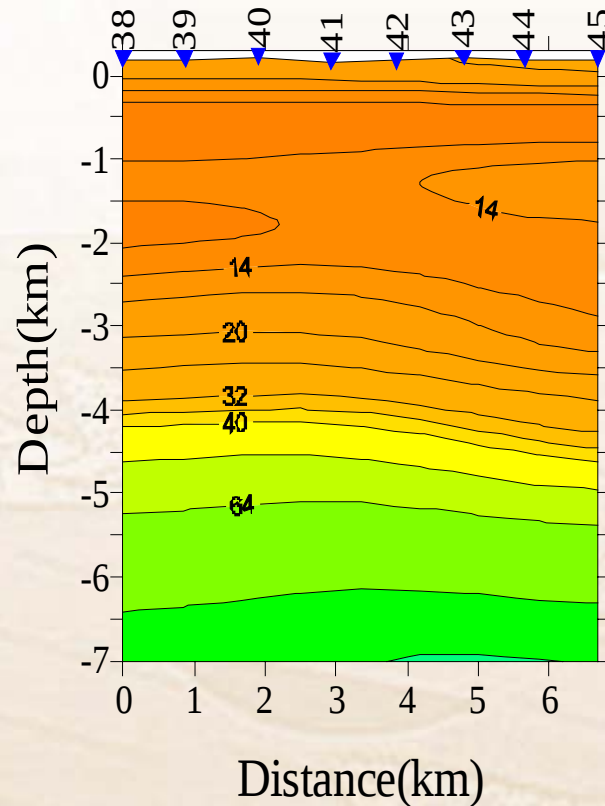


MT data processing:

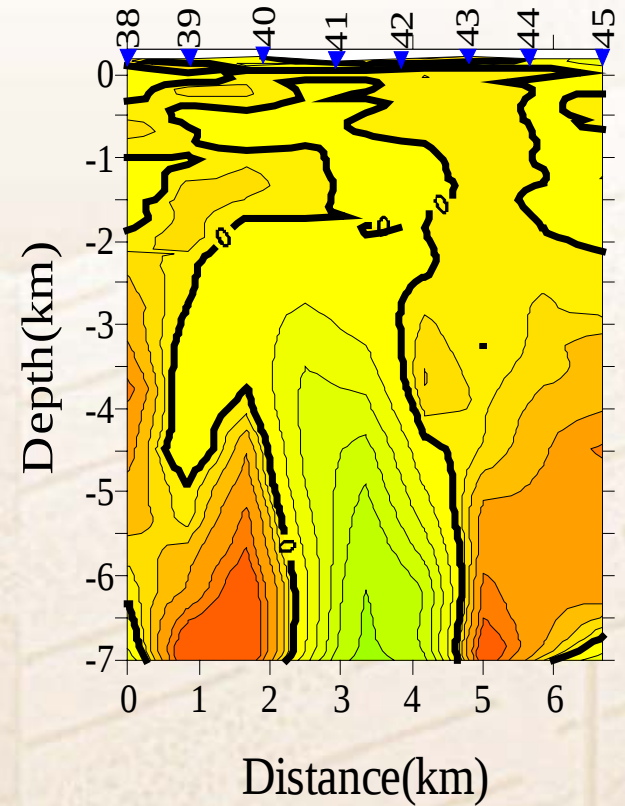
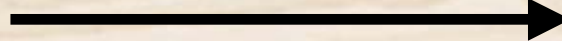
Calculate residual resistivity profile



2-DMT inversion result

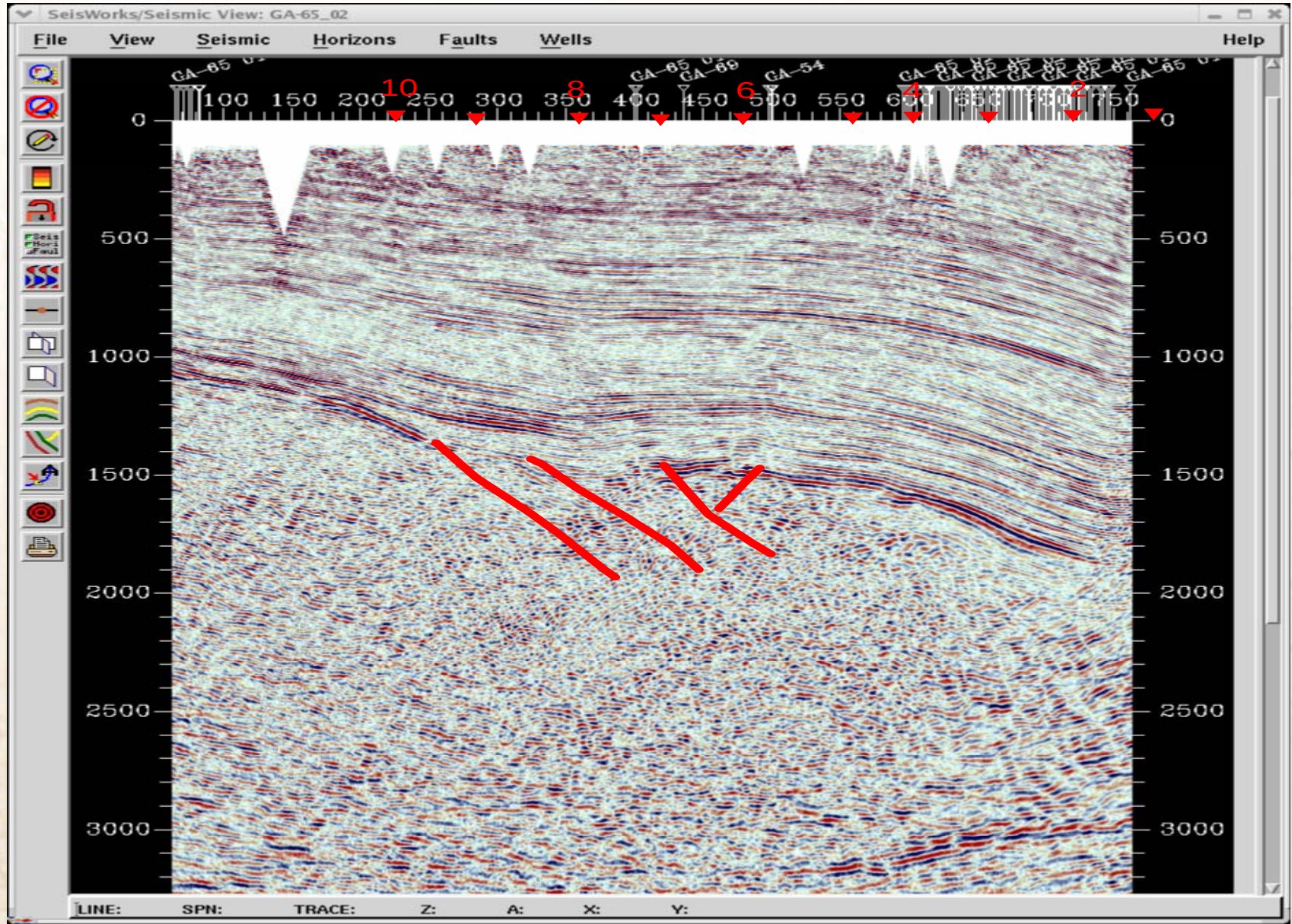


Subtracts
the regional resistivity field

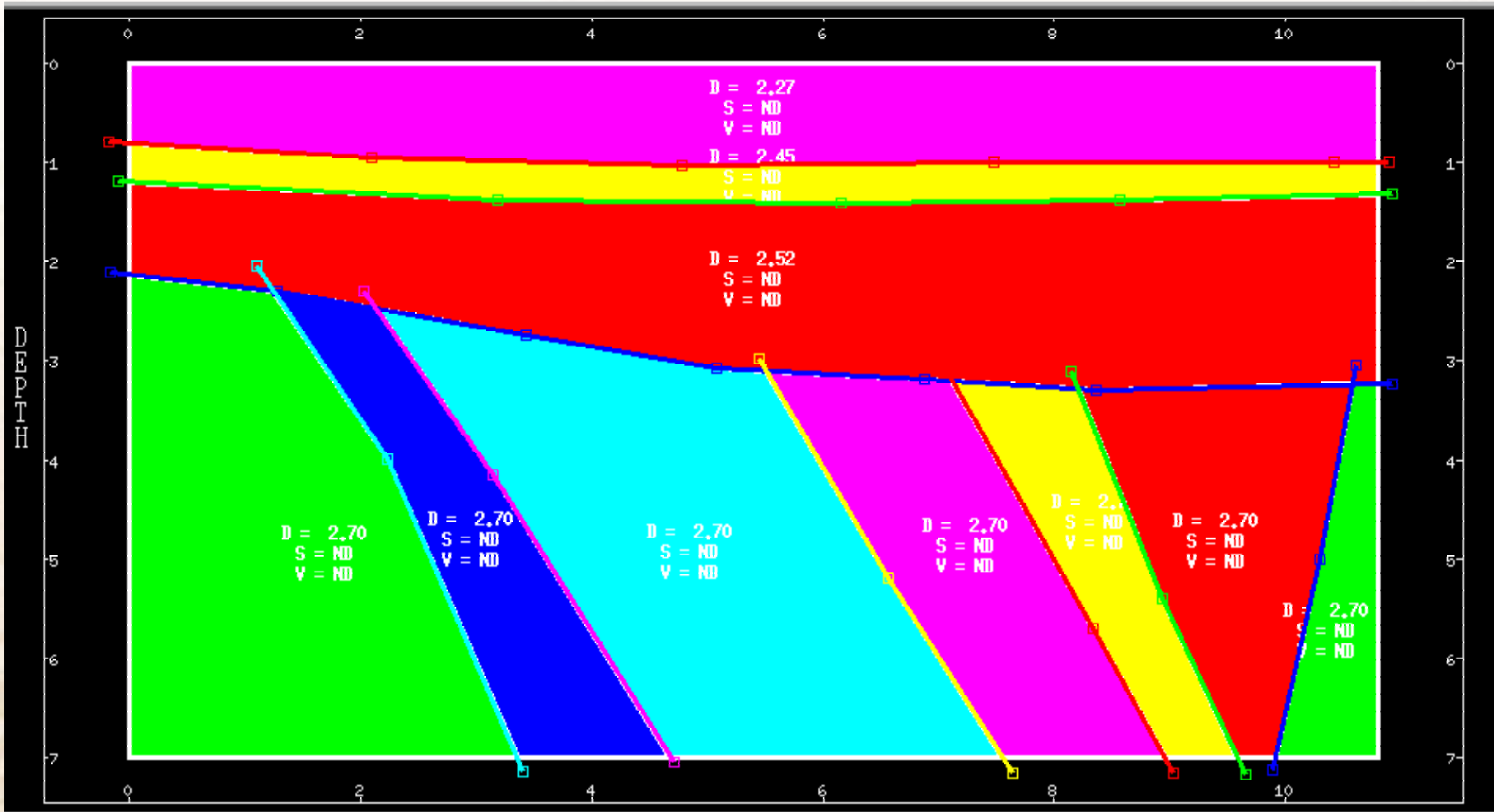


Residual resistivity profile

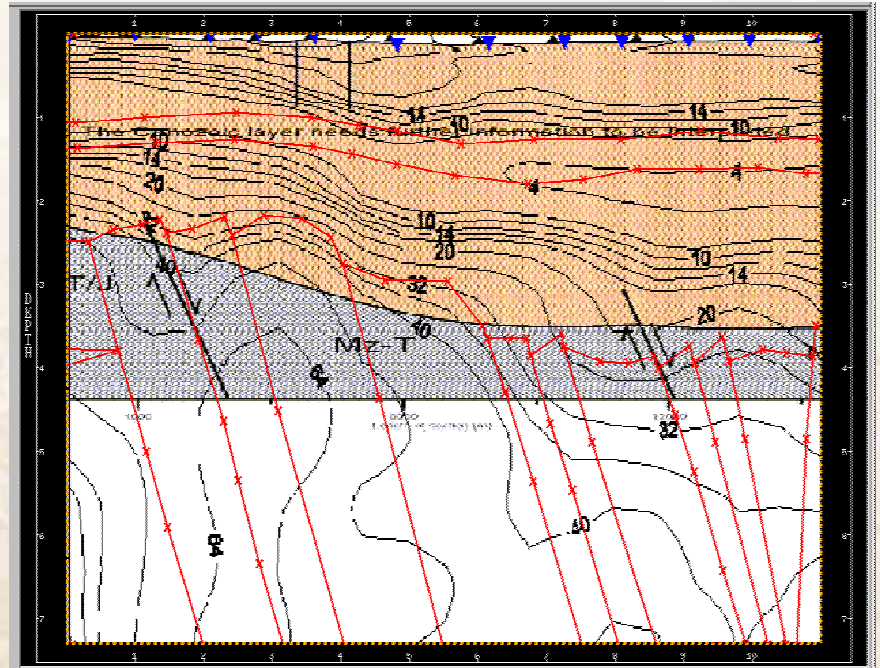
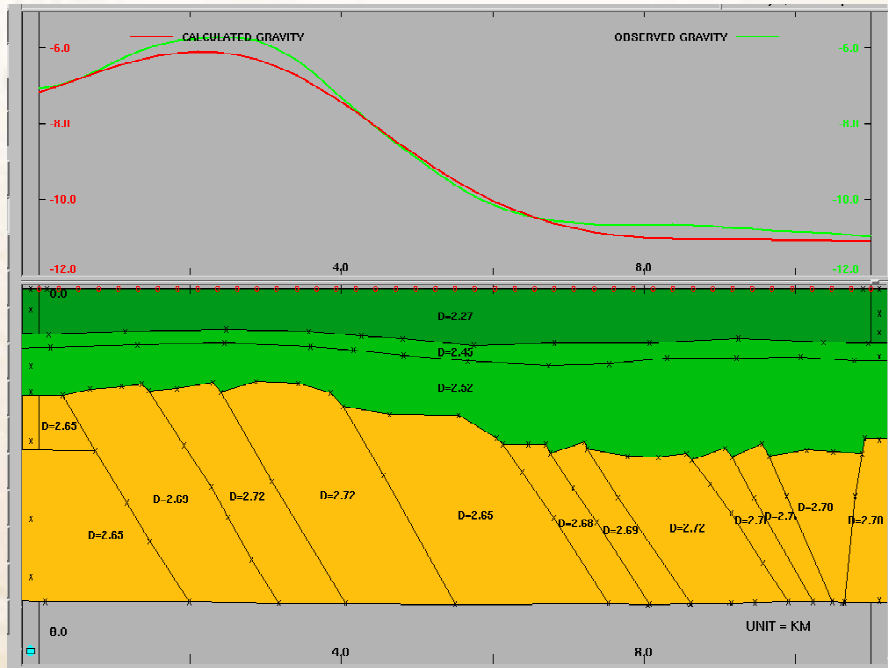
Line A seismic line fault interpretation



MT/Gravity cooperative inversions: Building density model from logs

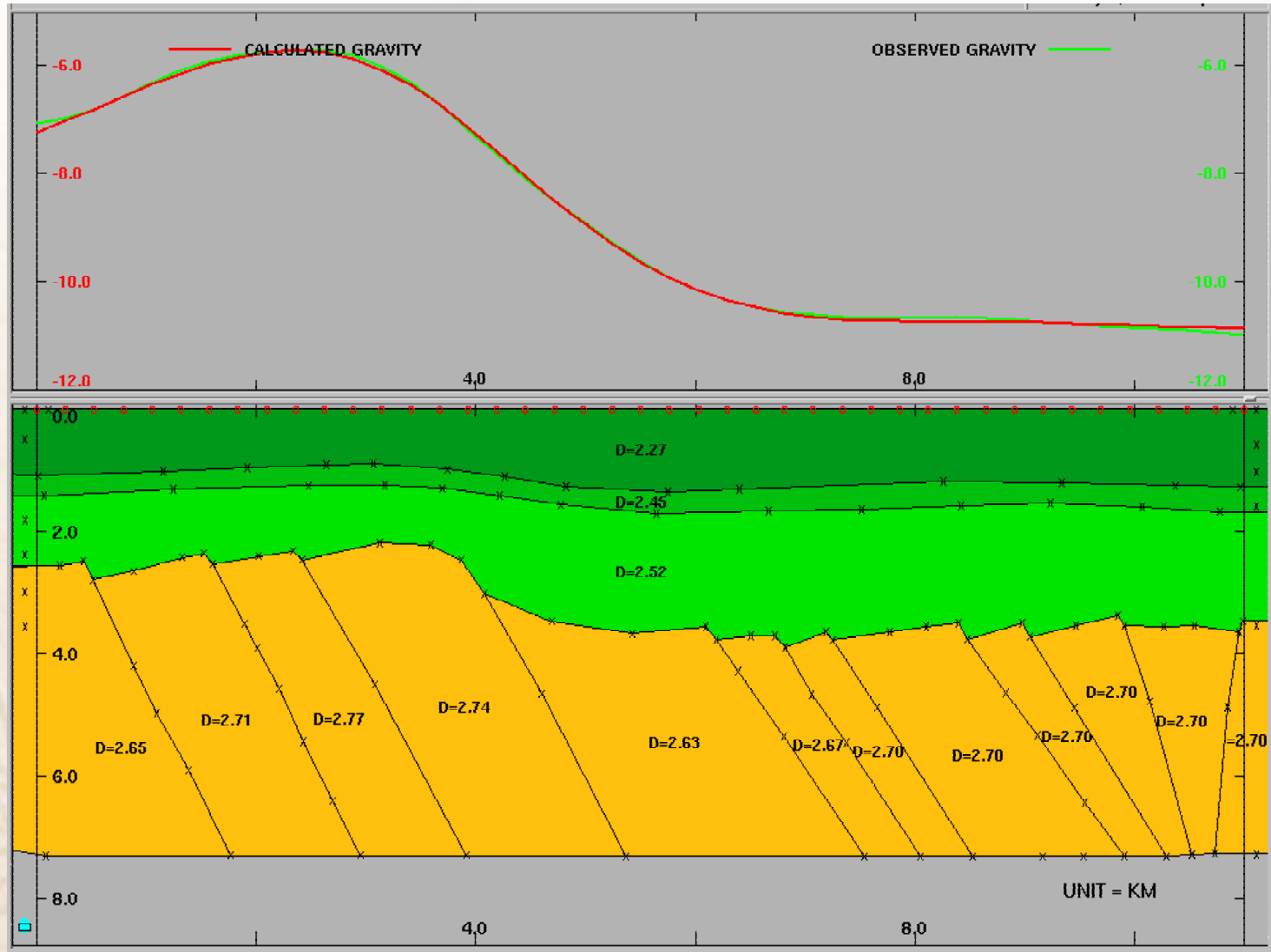


MT/Gravity cooperative inversions: Input gravity data & modify model interactively

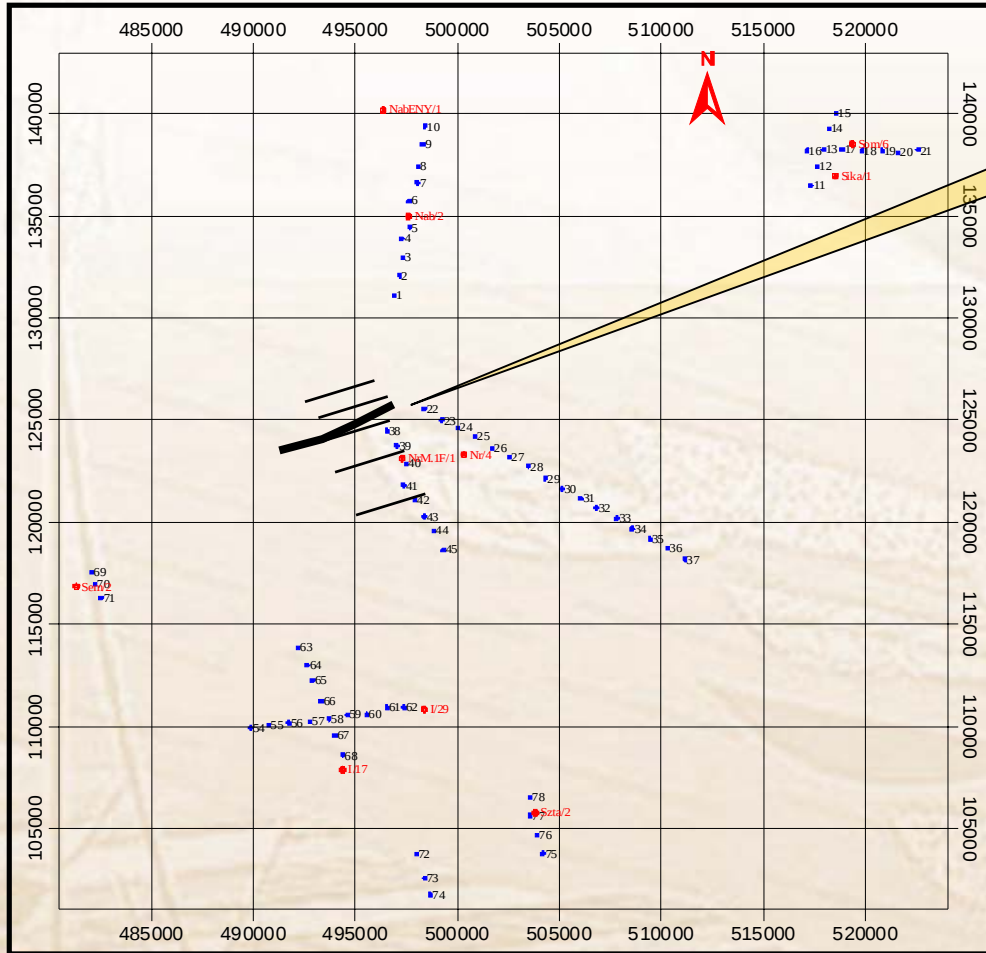


**Modify the model interactively until calculated
gravity field fits observed field well.**

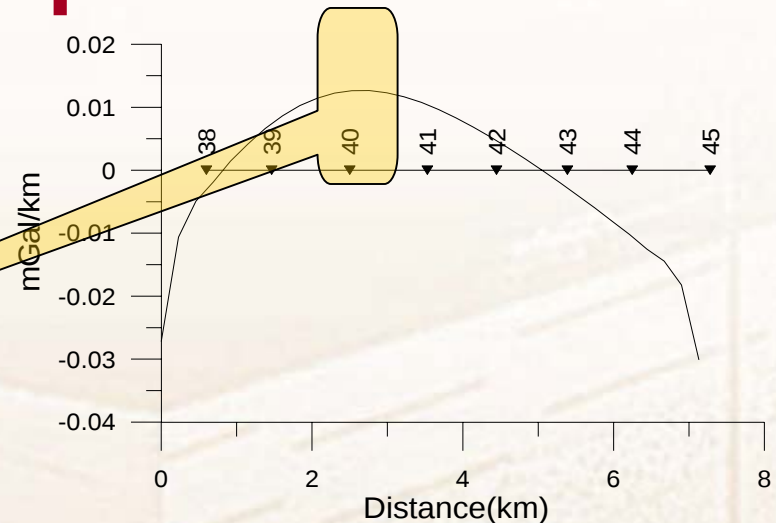
MT/Gravity cooperative inversions: Final geological model



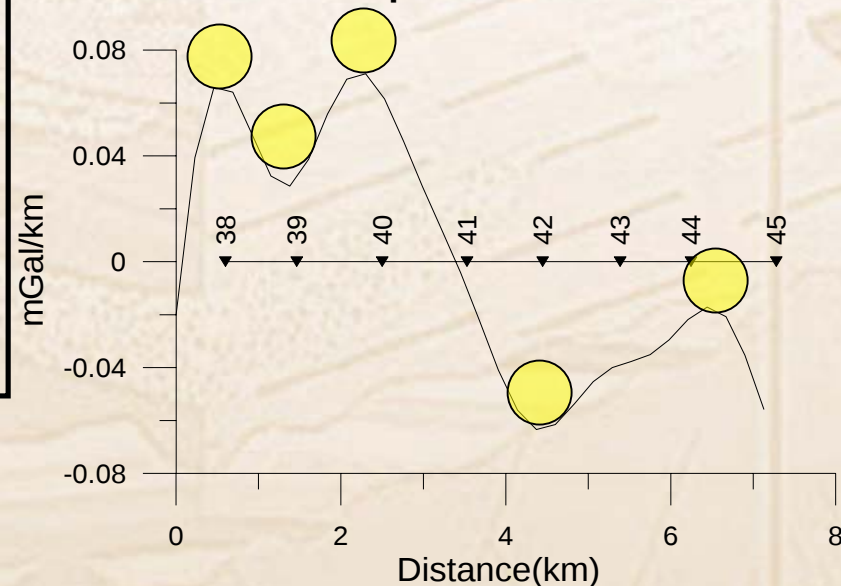
Gravity data interpretation



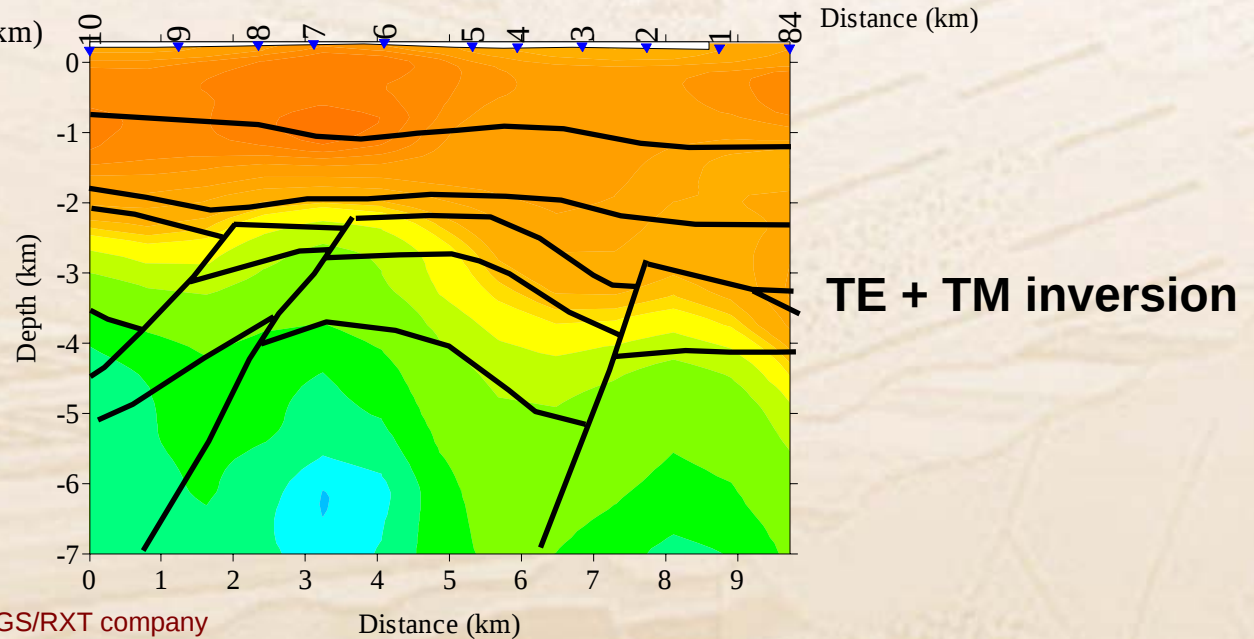
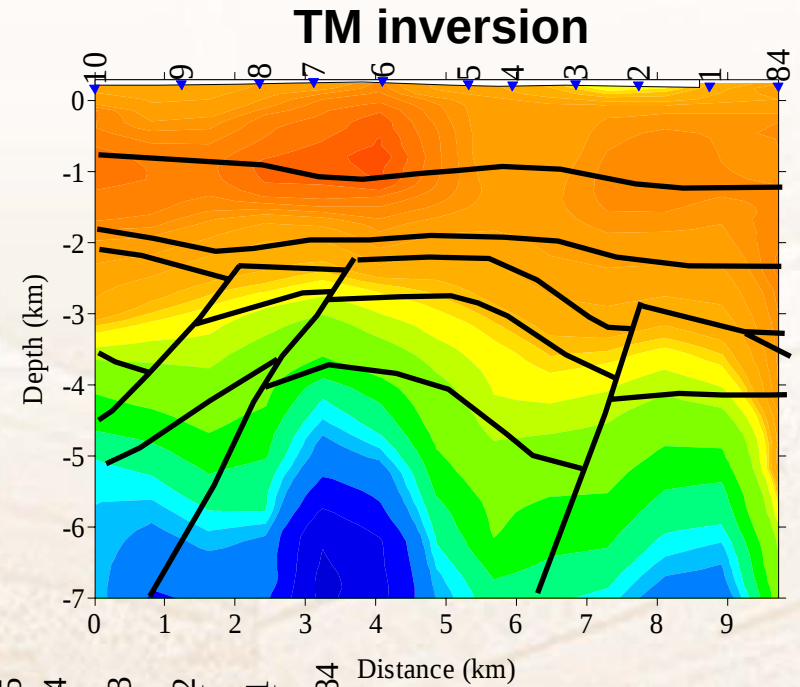
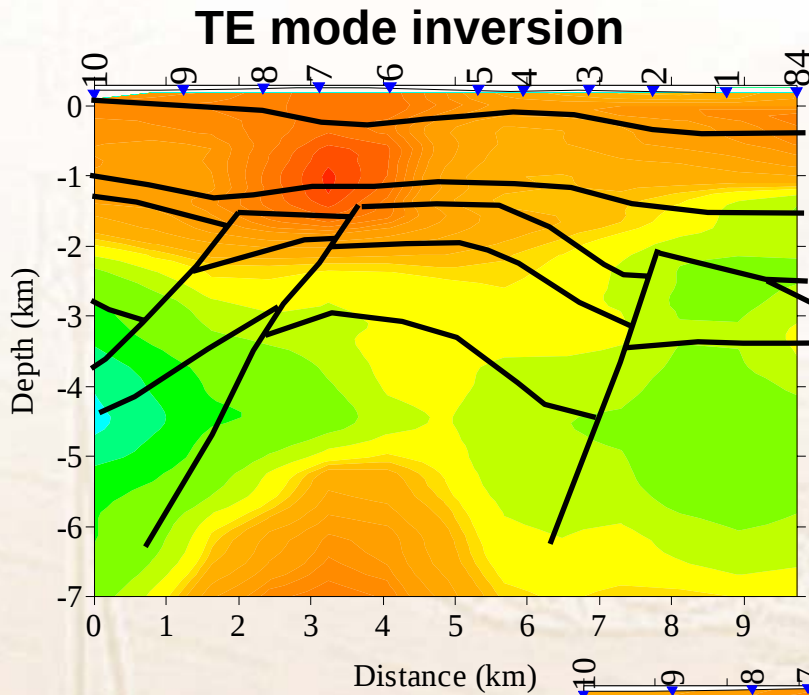
Extreme value position of residual gravity horizontal gradient may indicate local fault above basement



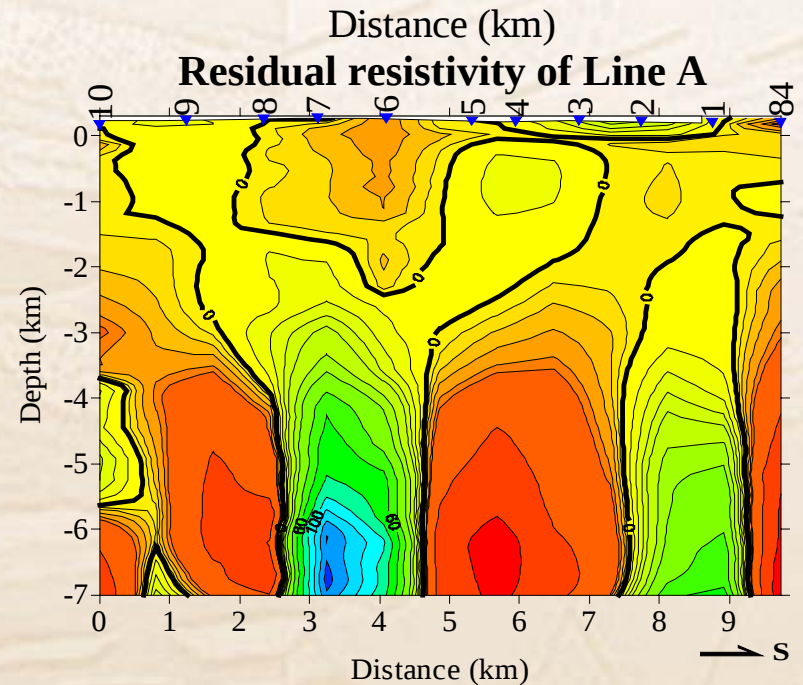
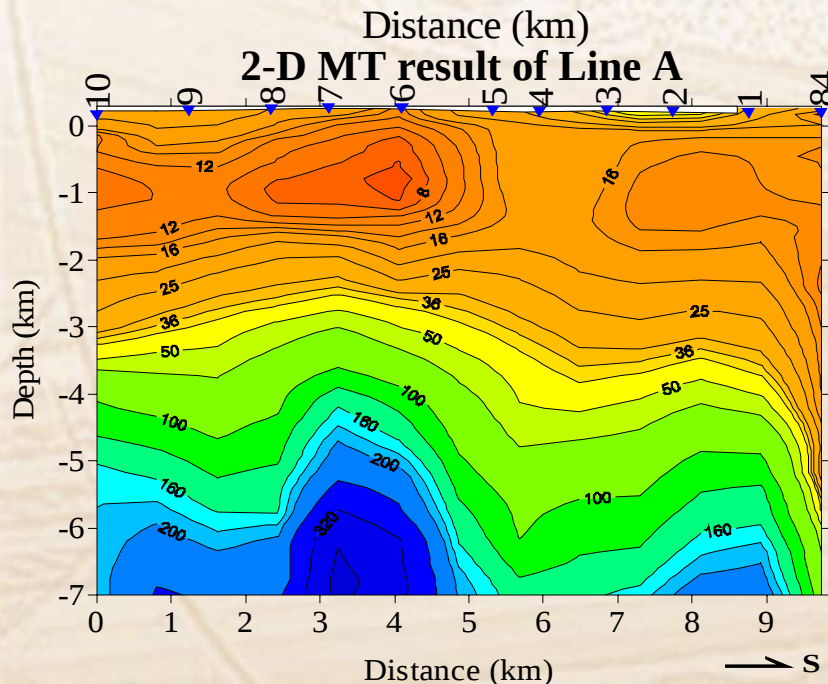
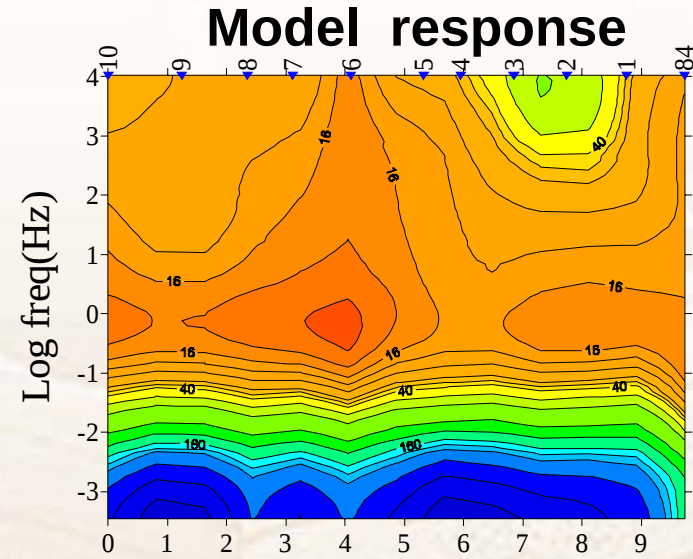
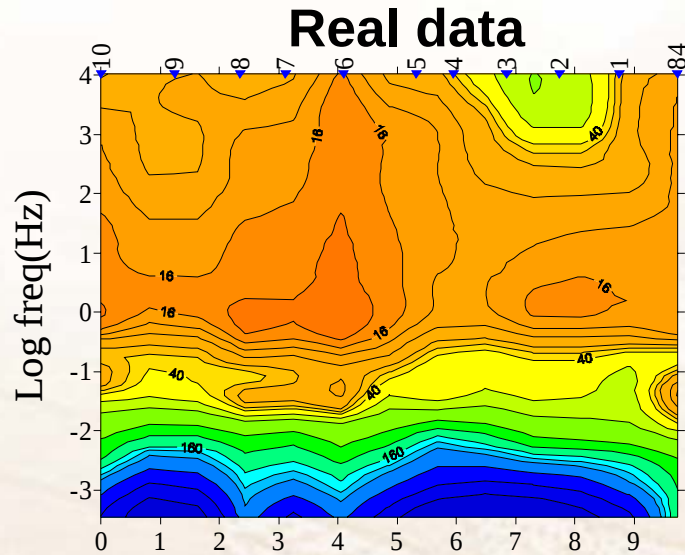
Extreme position of regional gravity horizontal gradient maybe indicate the deep fault center



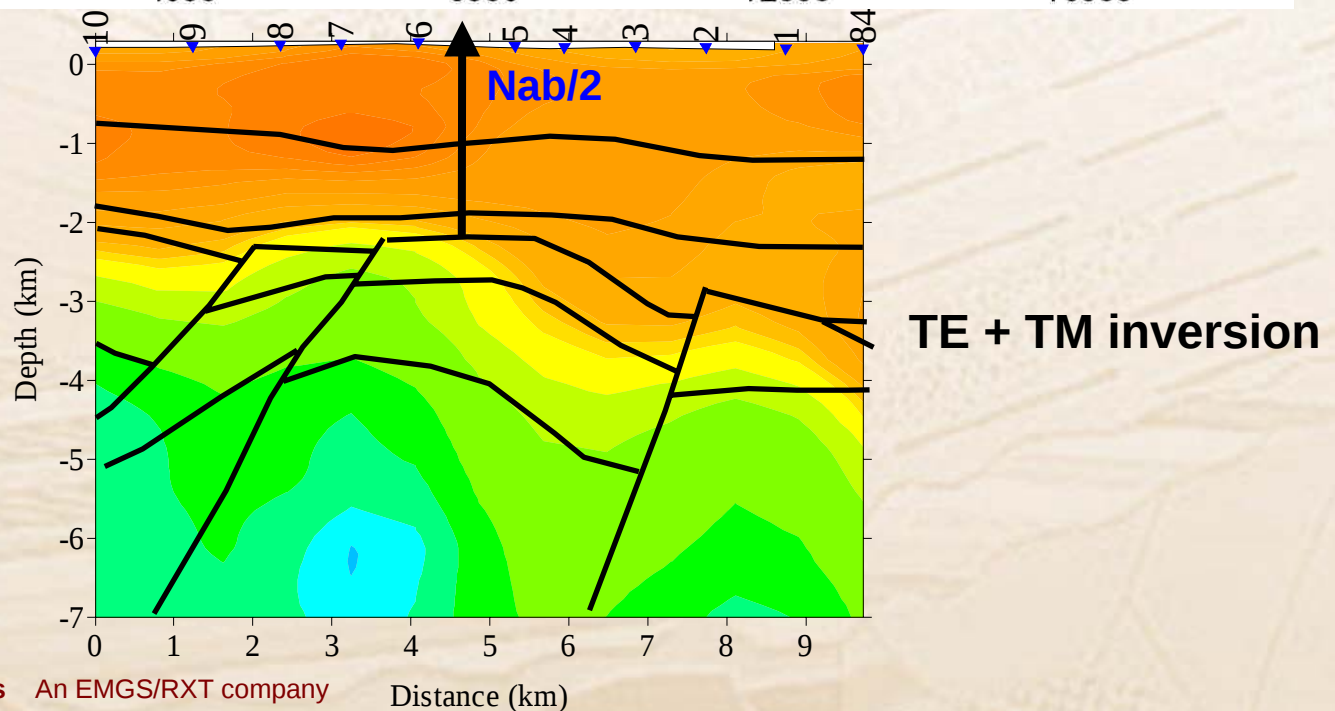
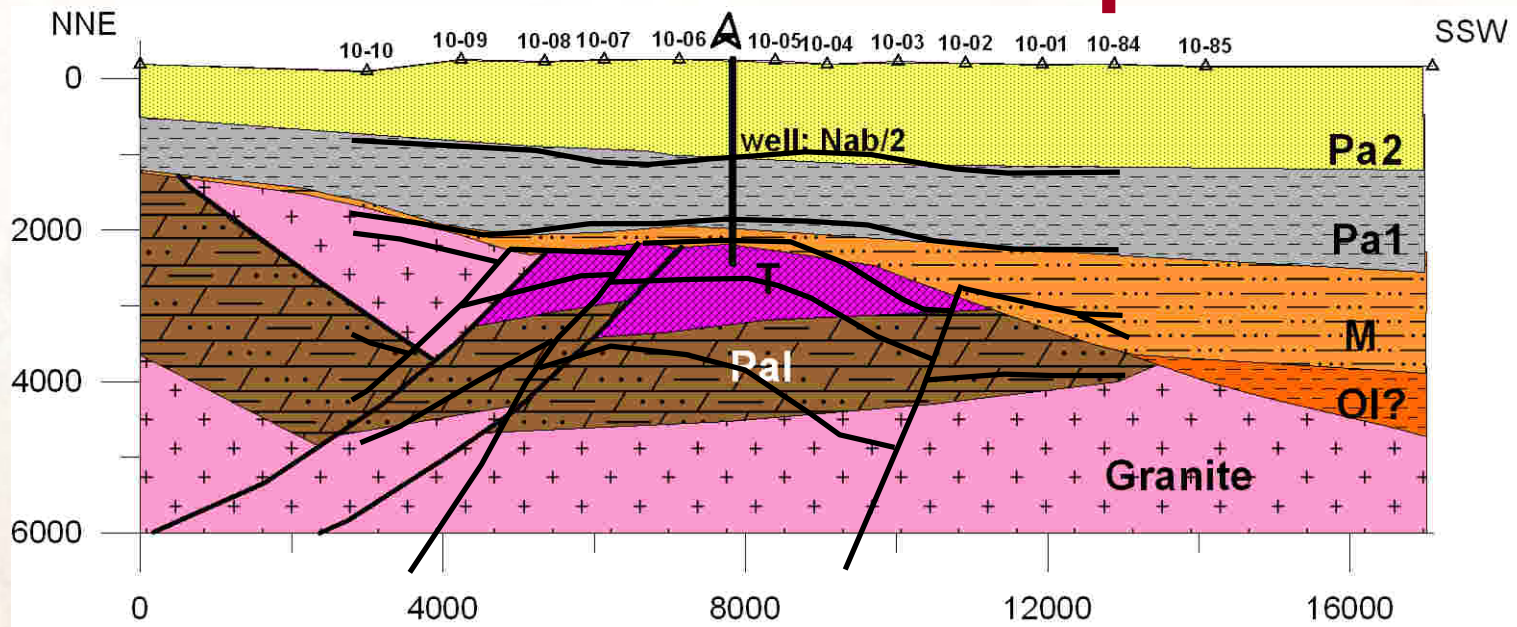
Line A inversion



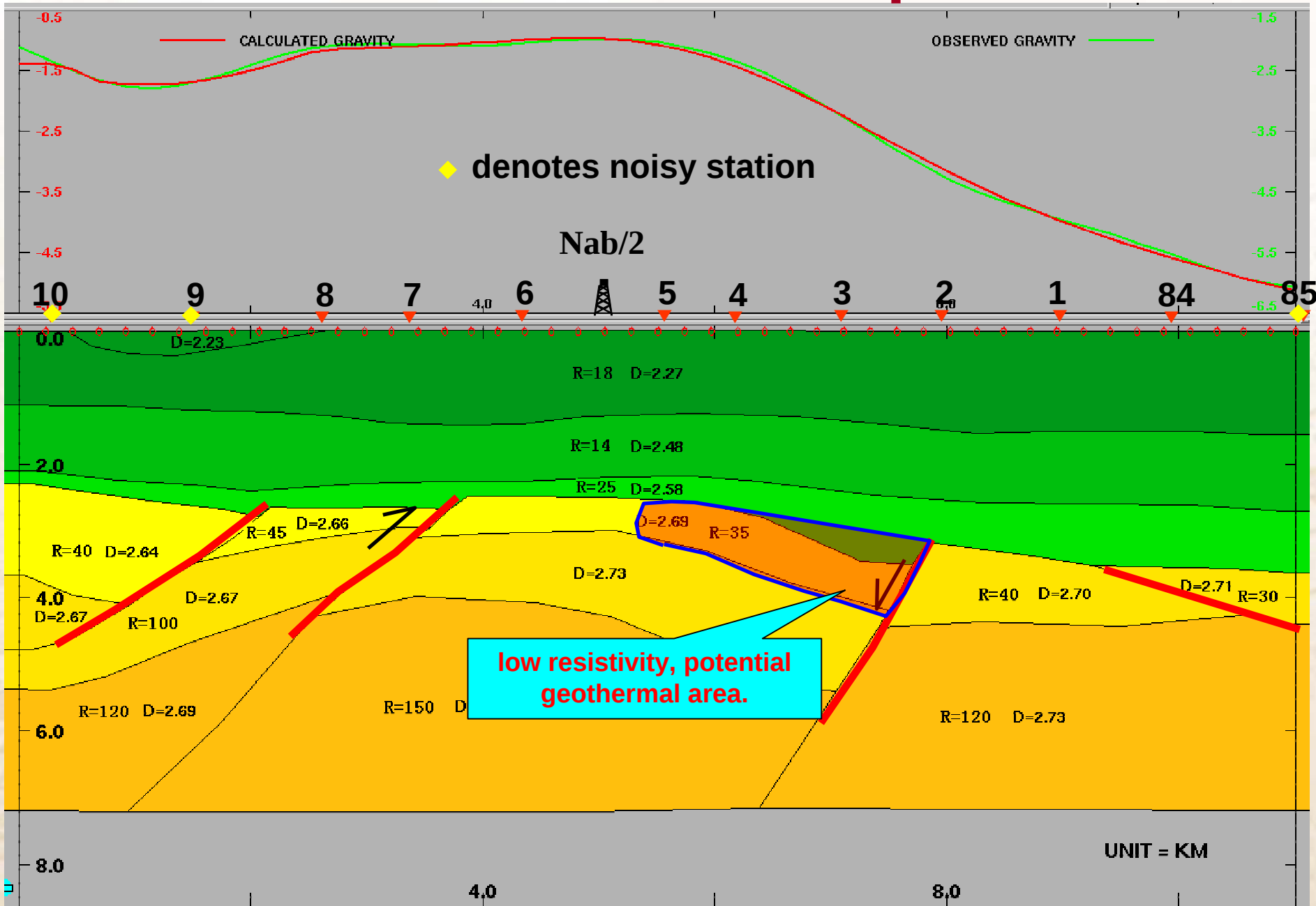
Line A inversion



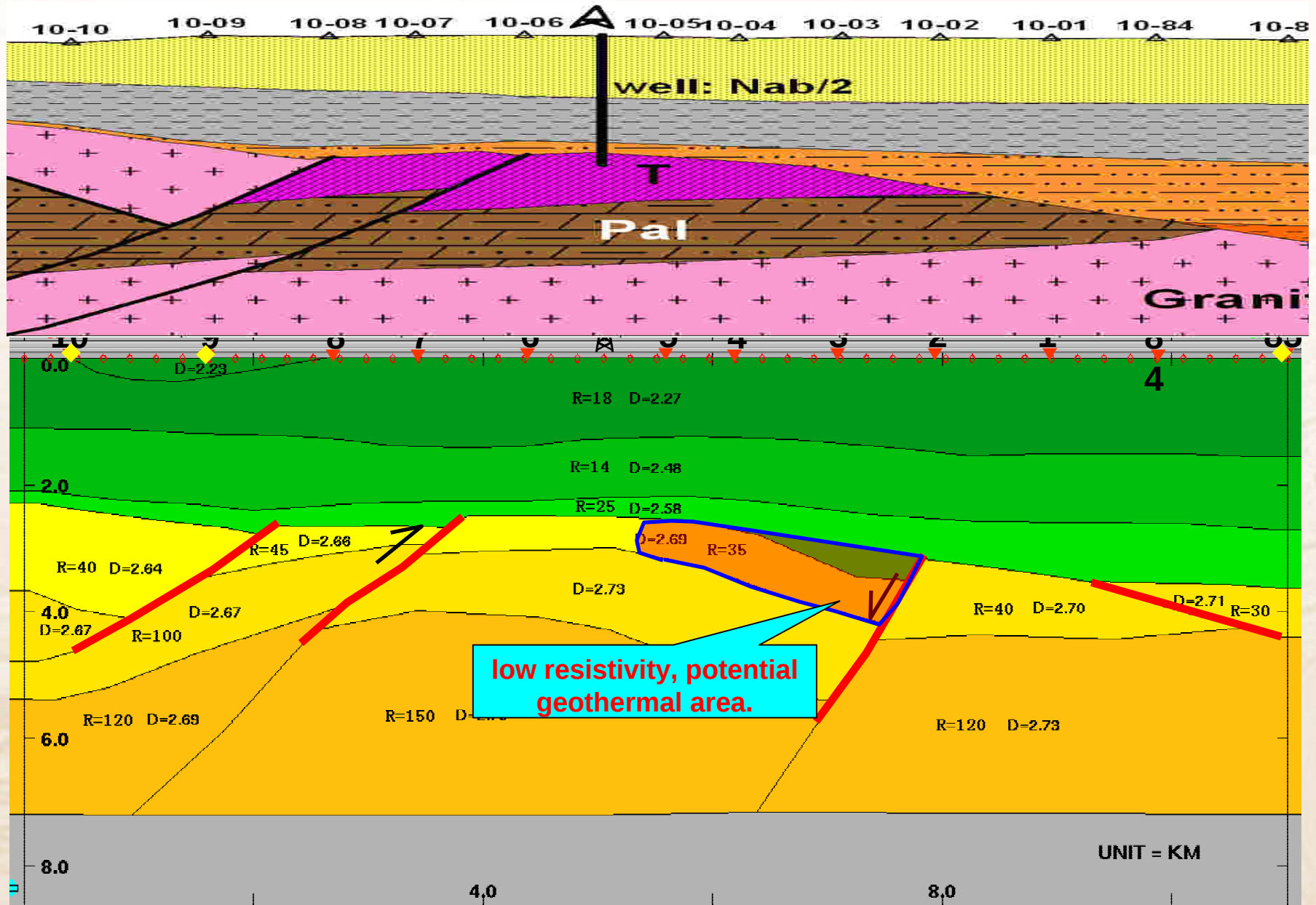
Line A inversion & interpretation



Line A inversion & interpretation

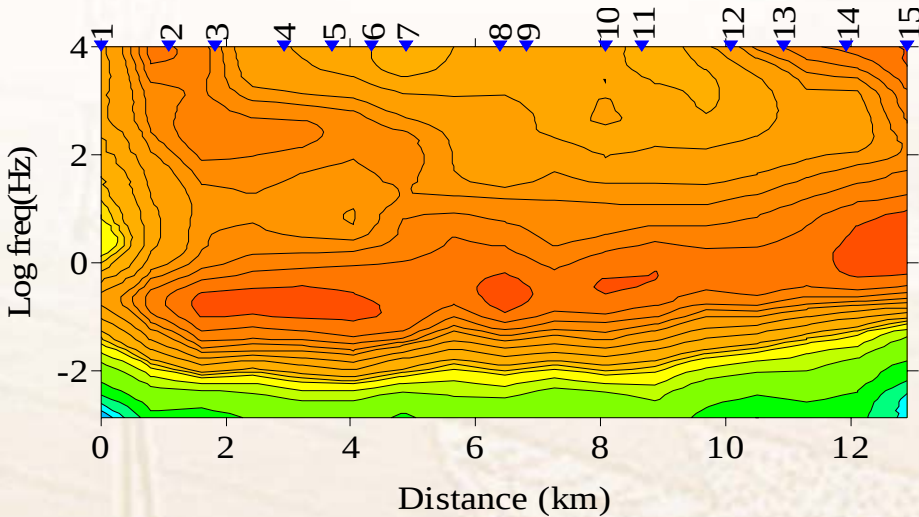


Line A inversion & interpretation

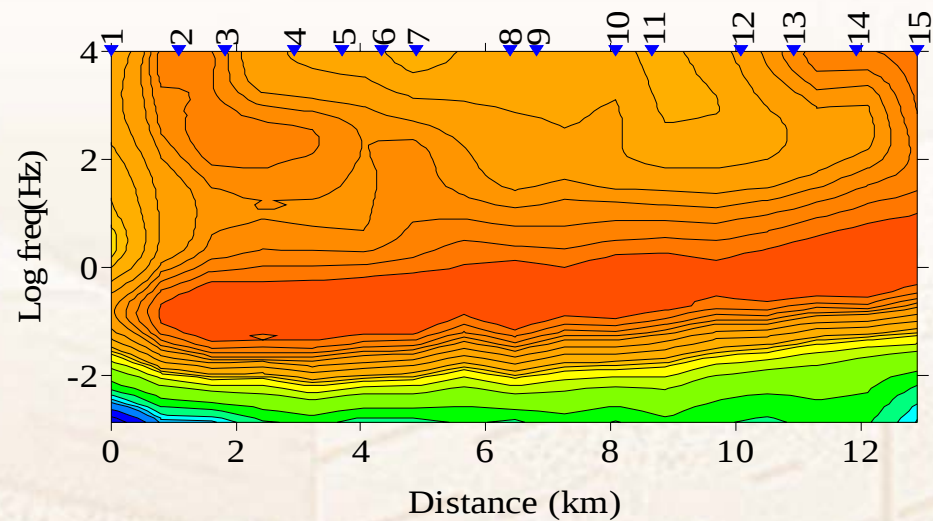


2-D MT inversion of Line B

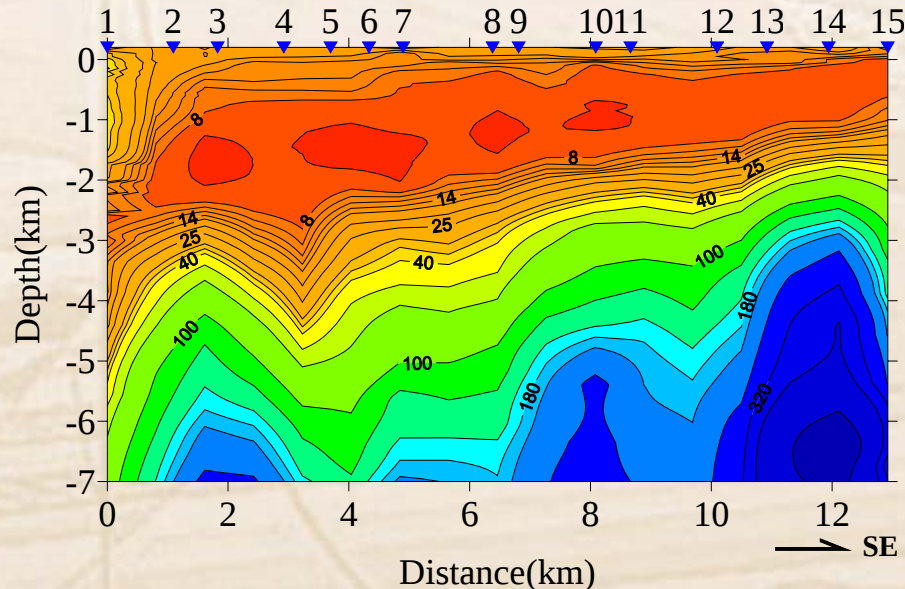
Real data



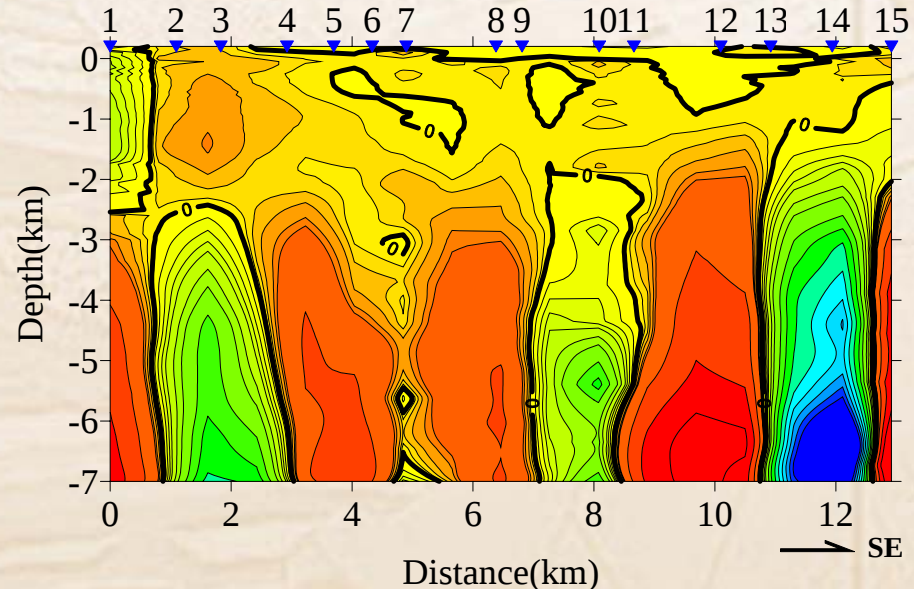
Model response



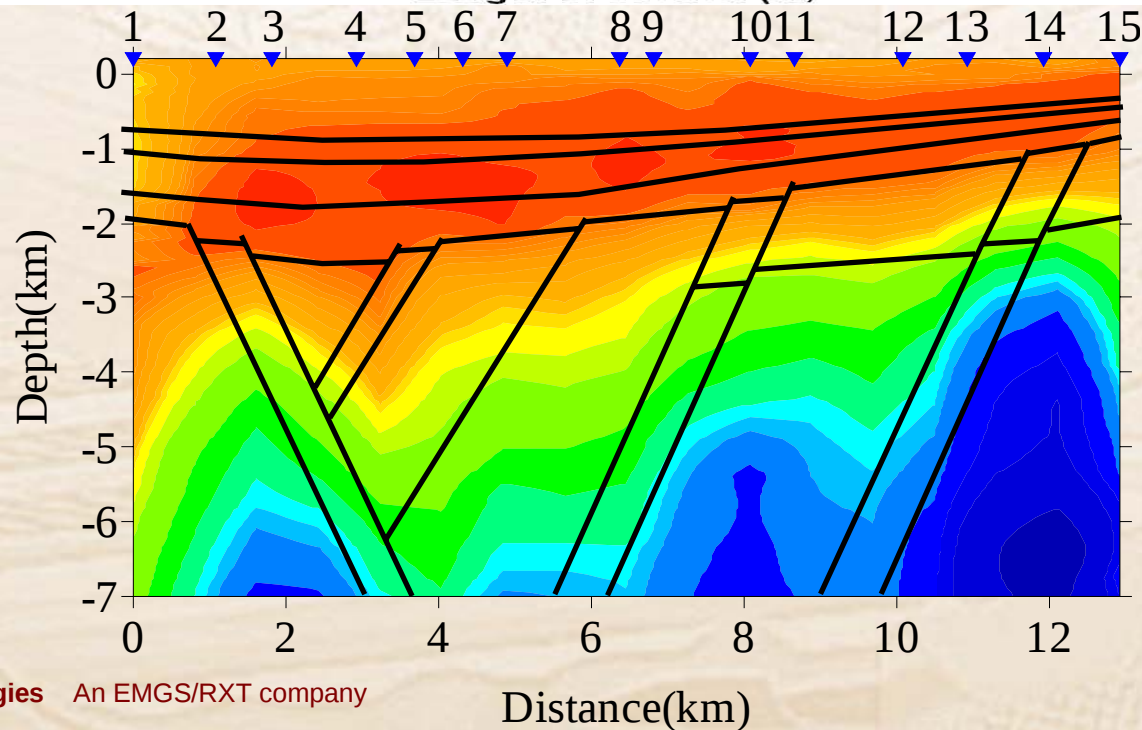
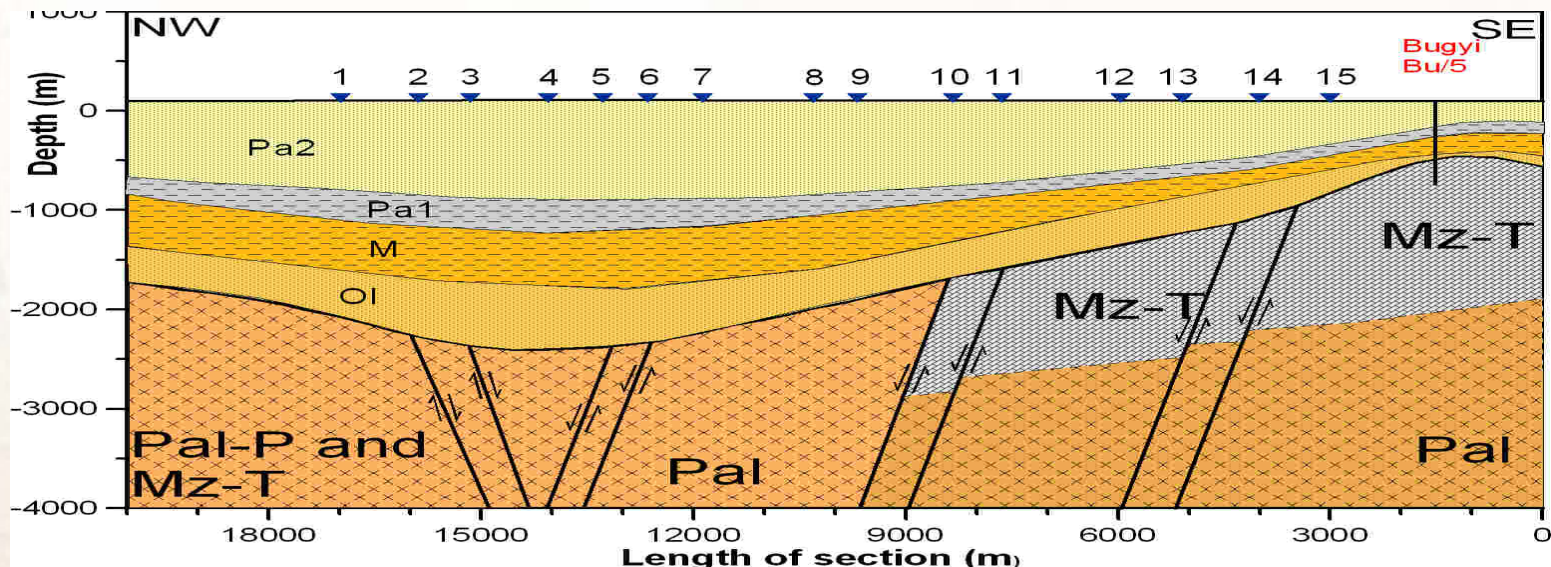
2-D MT result of Line 01



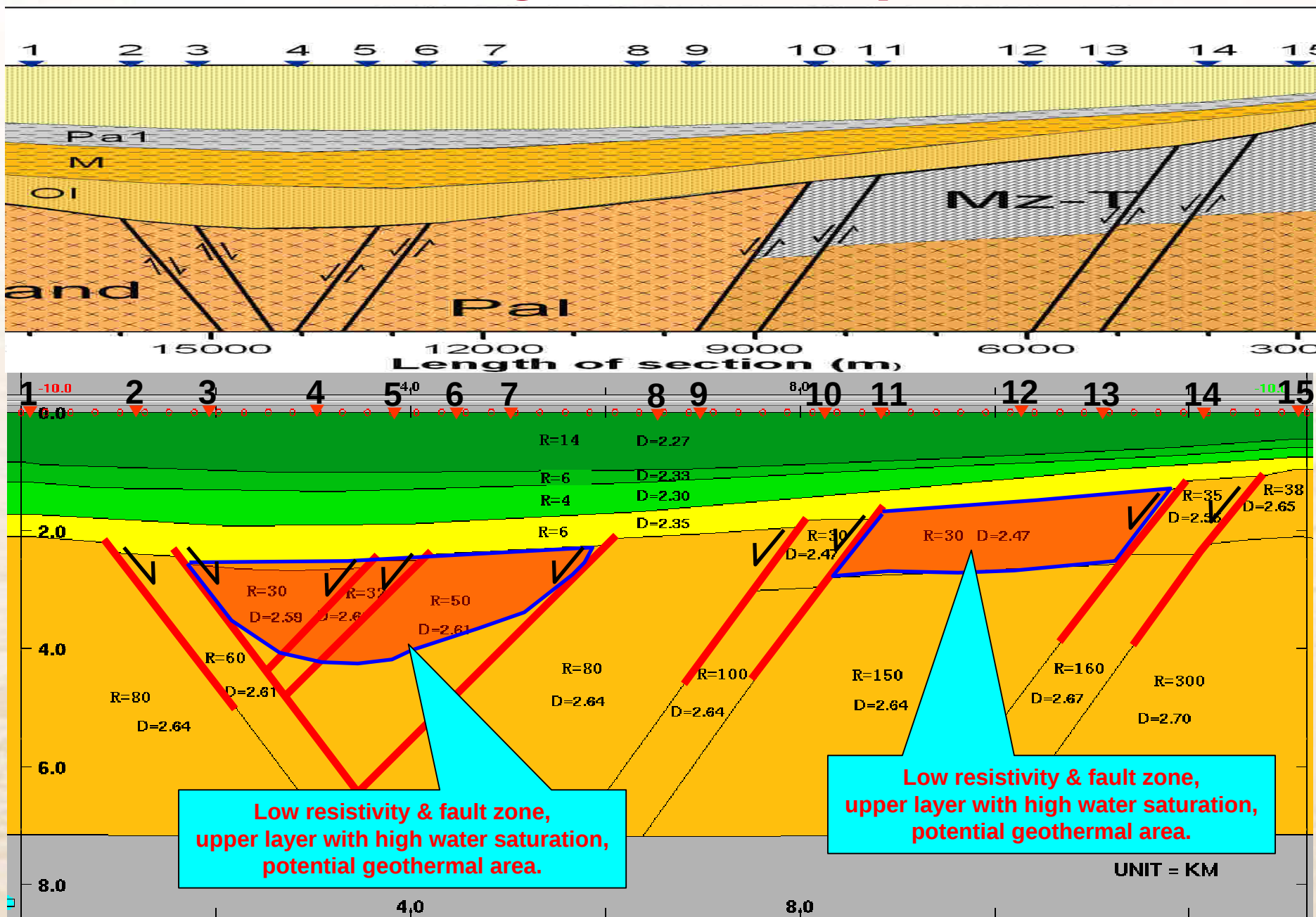
Residual resistivity of Line 01



Line B integrated interpretation

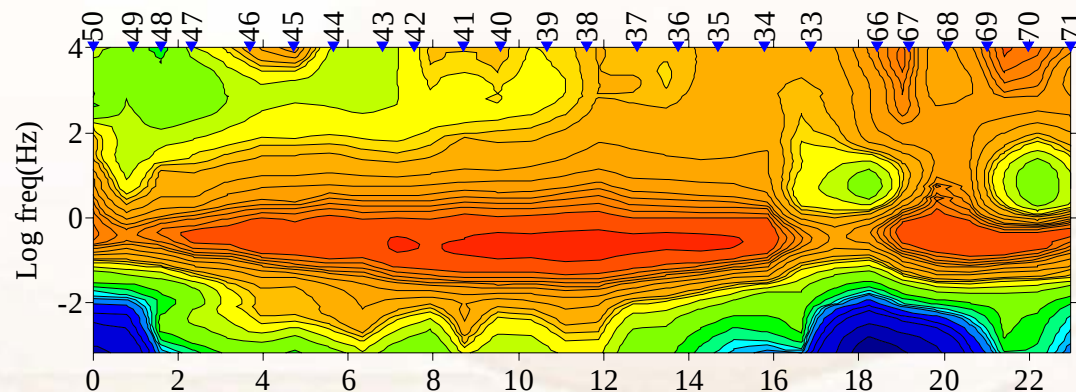


Line B integrated interpretation

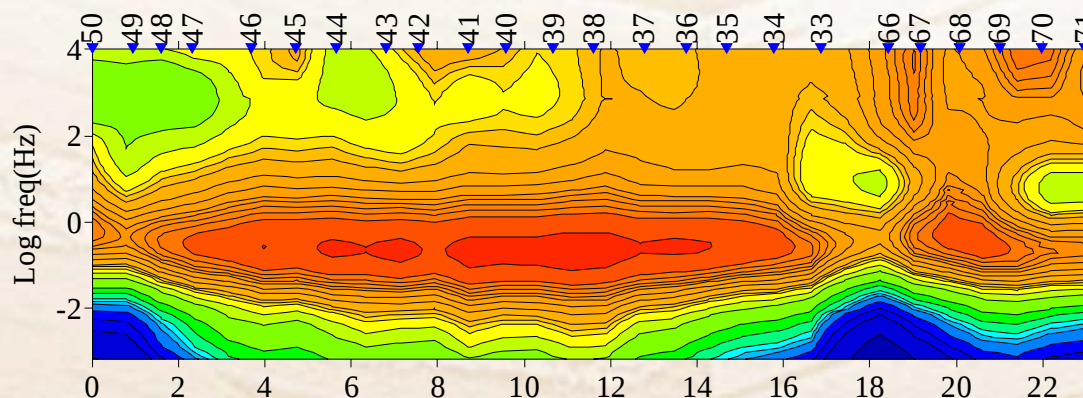


2-D MT inversion of Line C

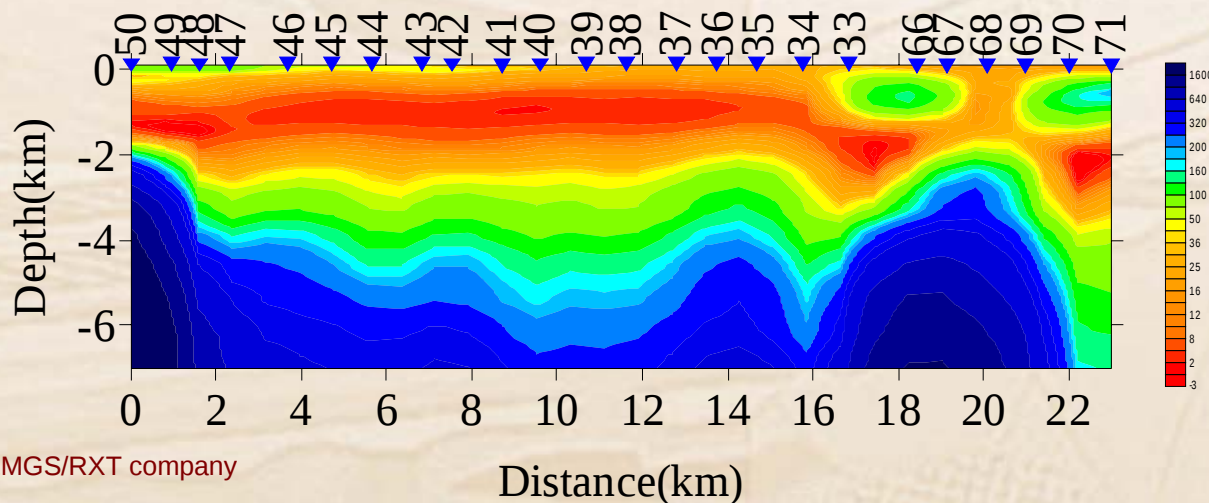
Real data



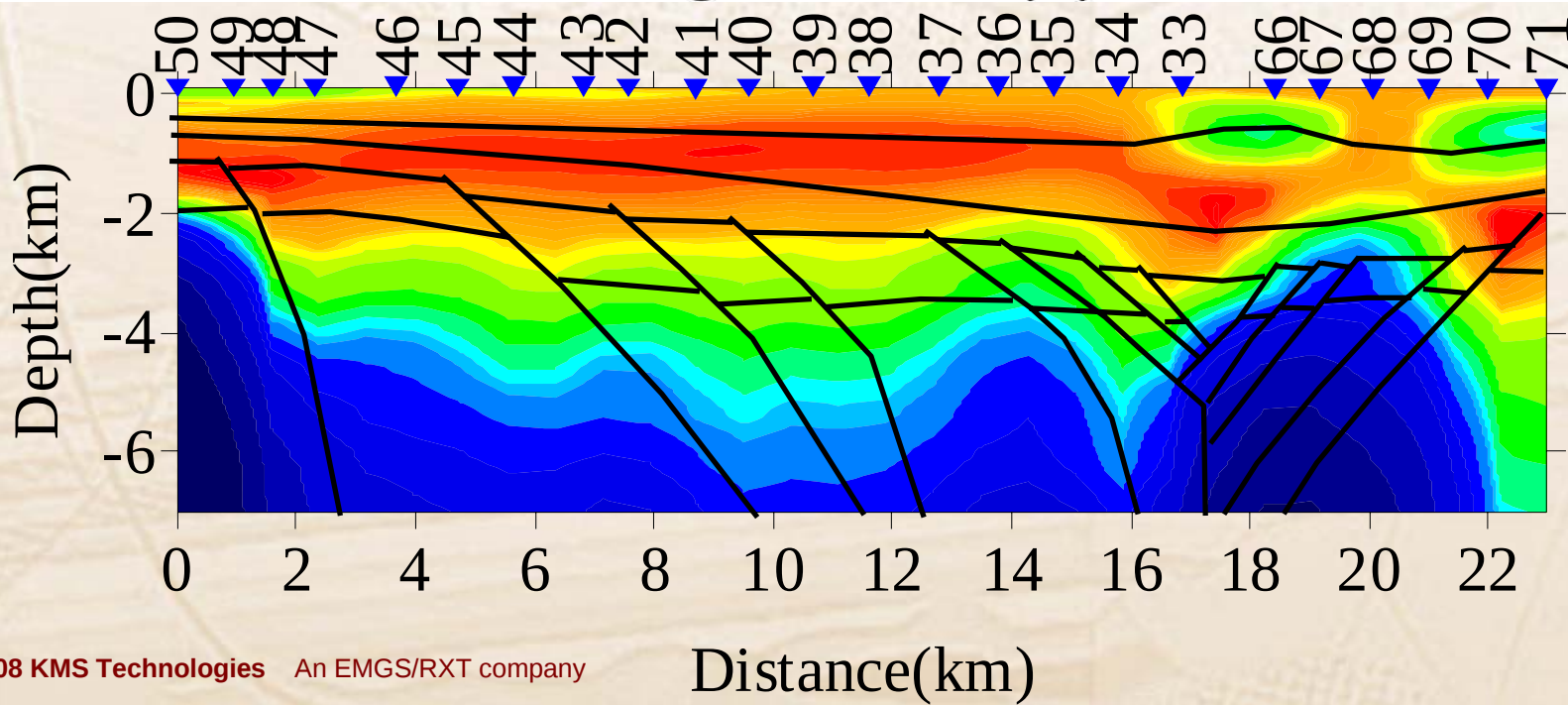
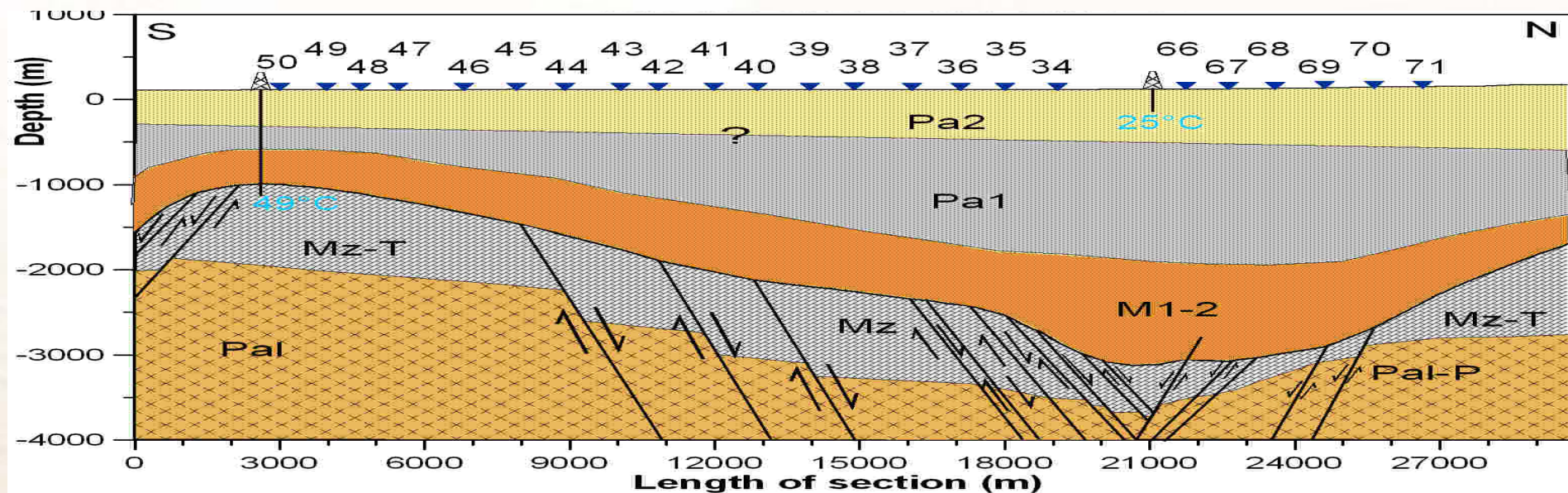
Model response



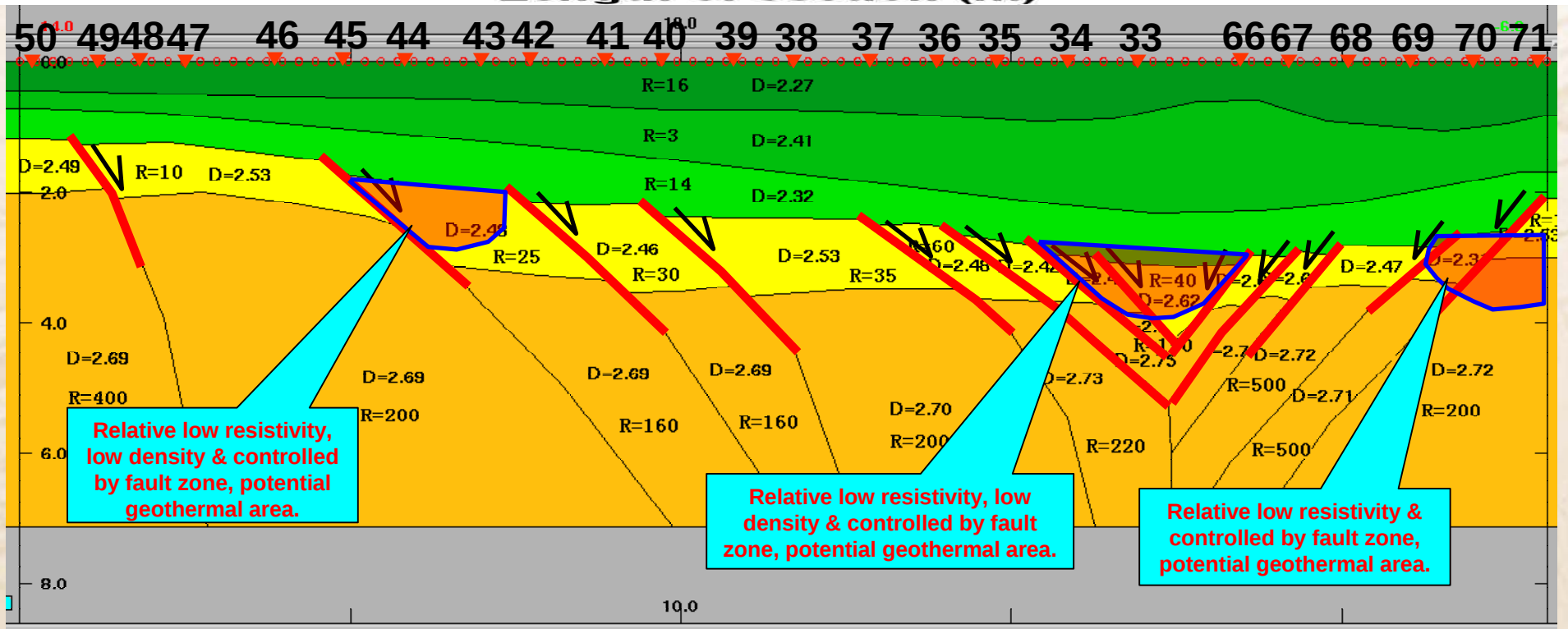
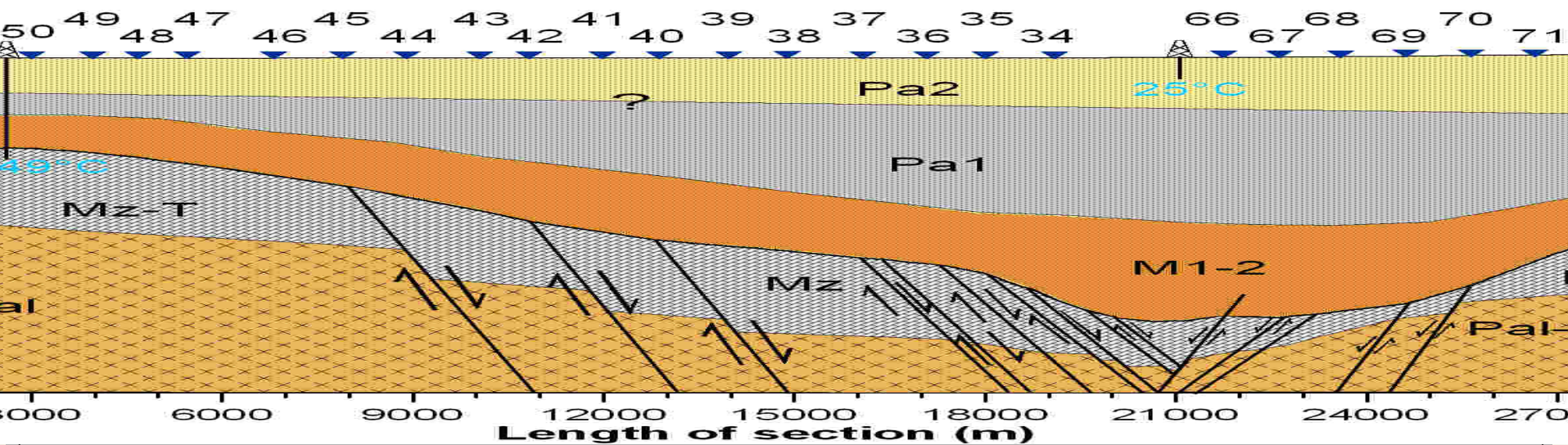
2-D MT result
of Line C



Line C integrated interpretation



Line C integrated interpretation



Outline

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

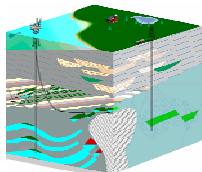
Conclusions

- Interpreted 26 first-class (deep faults) & 8 second-class (shallow faults) potential geothermal zones from Phase-I study;
- Anomalies buried depth between 2,000 m ~ 4,000 m;
- Conductive heat flow from magma through sediments to surface is main geothermal source;
- Deep fault may extend through crust & reaching mantel;
- Magma plumes rise & intrude into crust through deep fault, bringing heat relatively close to surface.

Acknowledgements

Thanks to many professionals at Mannvit (formally VGK-Hönnun), PannErgy, & BGP.

Special thanks also to Helgi Gunnar Vignisson, Balázs Bokorovics, Dénes Gyimóthy, Attila Juhász, László Lichner, & Ran Xuefeng for their great contributions to this project.



KMS Technologies – KJT Enterprises Inc.
An EMGS/RXT company

6420 Richmond Ave., Suite 610
Houston, Texas 77057, USA
Tel: +1.713.532.8144
Fax: +1.832.204.8418

www.KMSTechnologies.com