Crust Modelling Around JUNO

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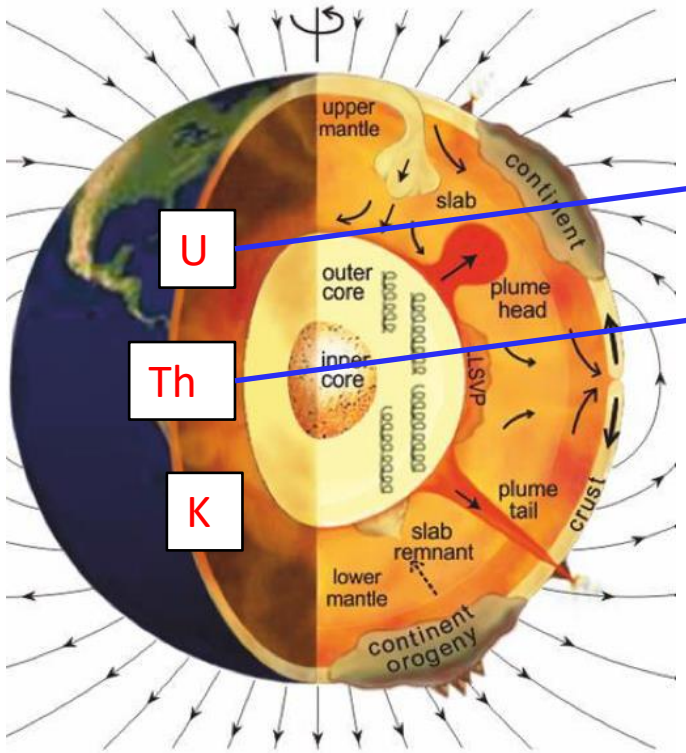
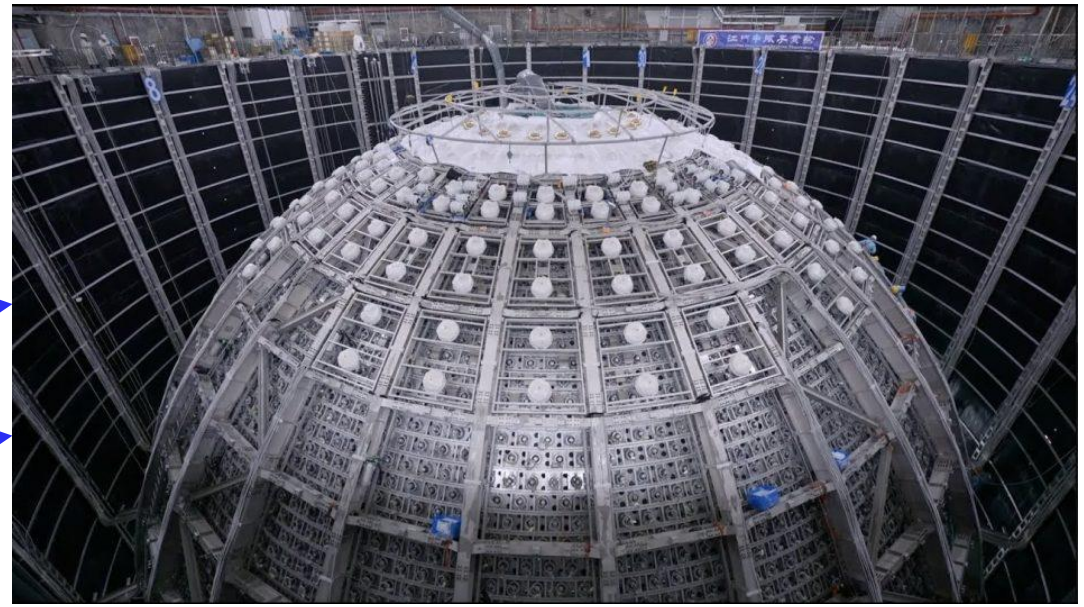
Neutrino Geoscience 2025 Kingston

Geographical location

Geoneutrino



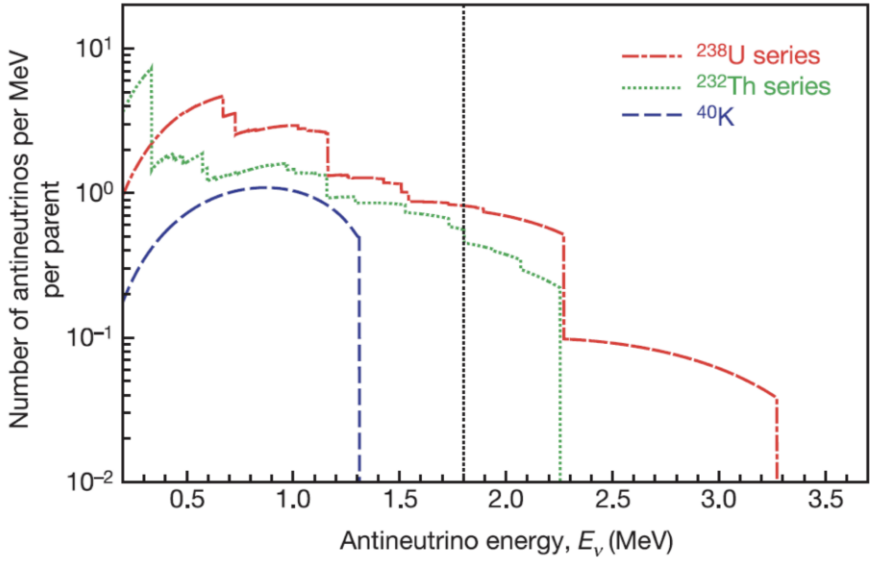
JUNO liquid scintillator detector



$$^{238}\mathrm{U} \longrightarrow {}^{206}\mathrm{Pb} + 8\,\alpha + 6\,\mathrm{e}^- + \mathbf{6\,\bar{\nu}_e} \quad + 51.698\mathrm{MeV}$$

$$^{232}\mathrm{Th} \longrightarrow {}^{208}\mathrm{Pb} + 6\,\alpha + 4\,\mathrm{e}^- + \mathbf{4\,\bar{\nu}_e} \quad + 42.652\mathrm{MeV}$$

$$^{40}\mathrm{K} \xrightarrow{89.3\%} {}^{40}\mathrm{Ca} + \mathrm{e}^- + \mathbf{\bar{\nu}_e} \quad + 1.311\mathrm{MeV}$$



(from S.T. Dye)

What to model

Activity and number of produced geoneutrinos

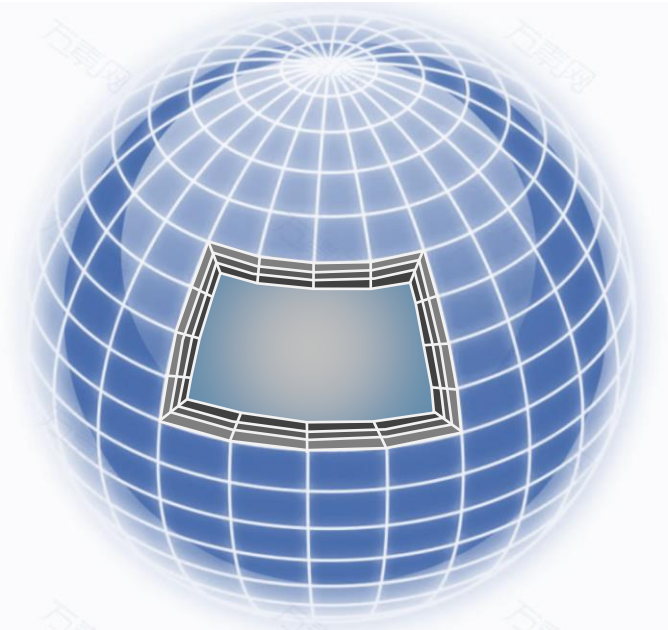
Volume of source unit

$$\Phi_i = A_i \cdot n_i \cdot P_{\nu_e - \nu_e}(E_\nu, |\vec{L}|) \cdot \int_V \frac{a_i(\vec{L}) \cdot \rho_i(\vec{L})}{4\pi |\vec{L}|^2} \cdot dV$$

Survival probability function

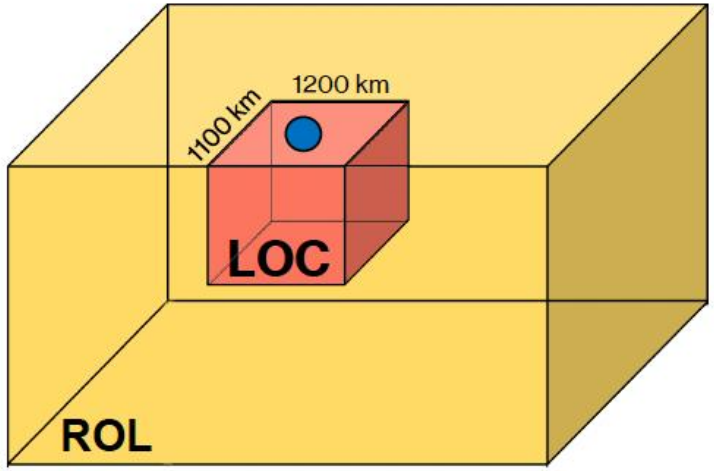
Abundance and density of the source unit

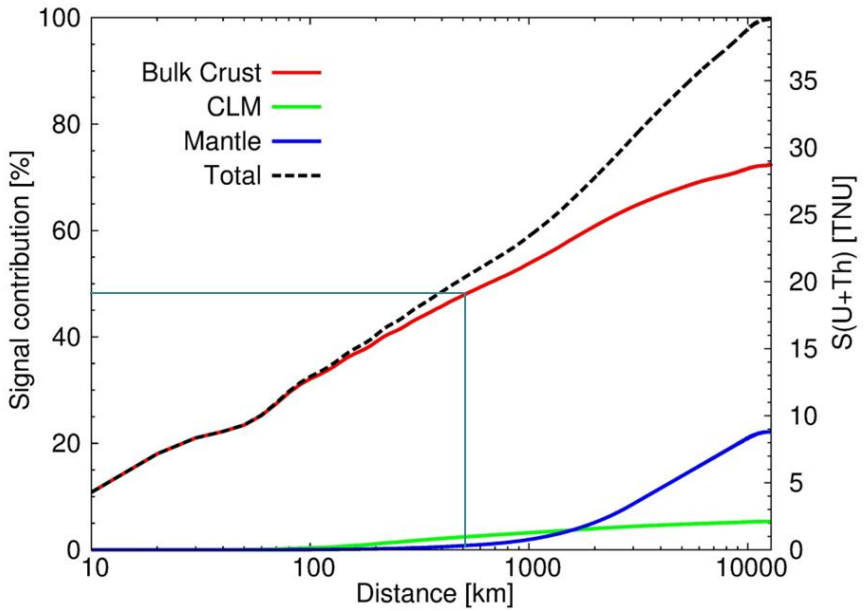
Distance between source unit and detector



- **Geophysical models**
  - Density of source unit
  - Structure: Thickness of UC, MC, LC, Moho
- **Geochemical models**
  - U and Th abundances of source unit

LOC model

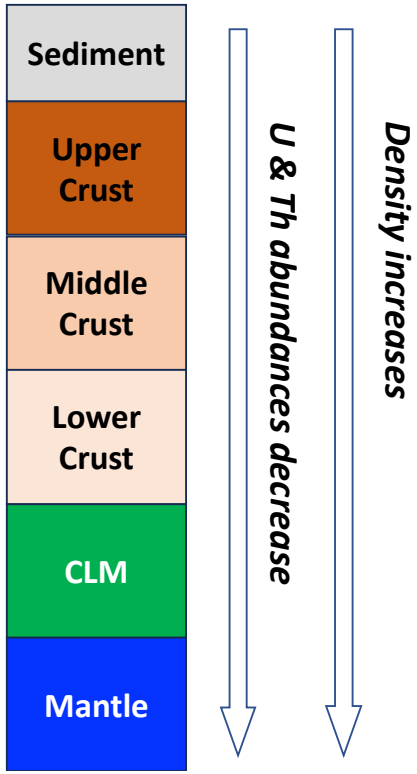




LOcalCrust(**LOC**): the portion of crust centered in JUNO

Rest Of Lithosphere (**ROL**): the remaining crust subtracting the Local crust + the Continental Lithospheric Mantle *Reference Earth model, Huang et al. 2013*

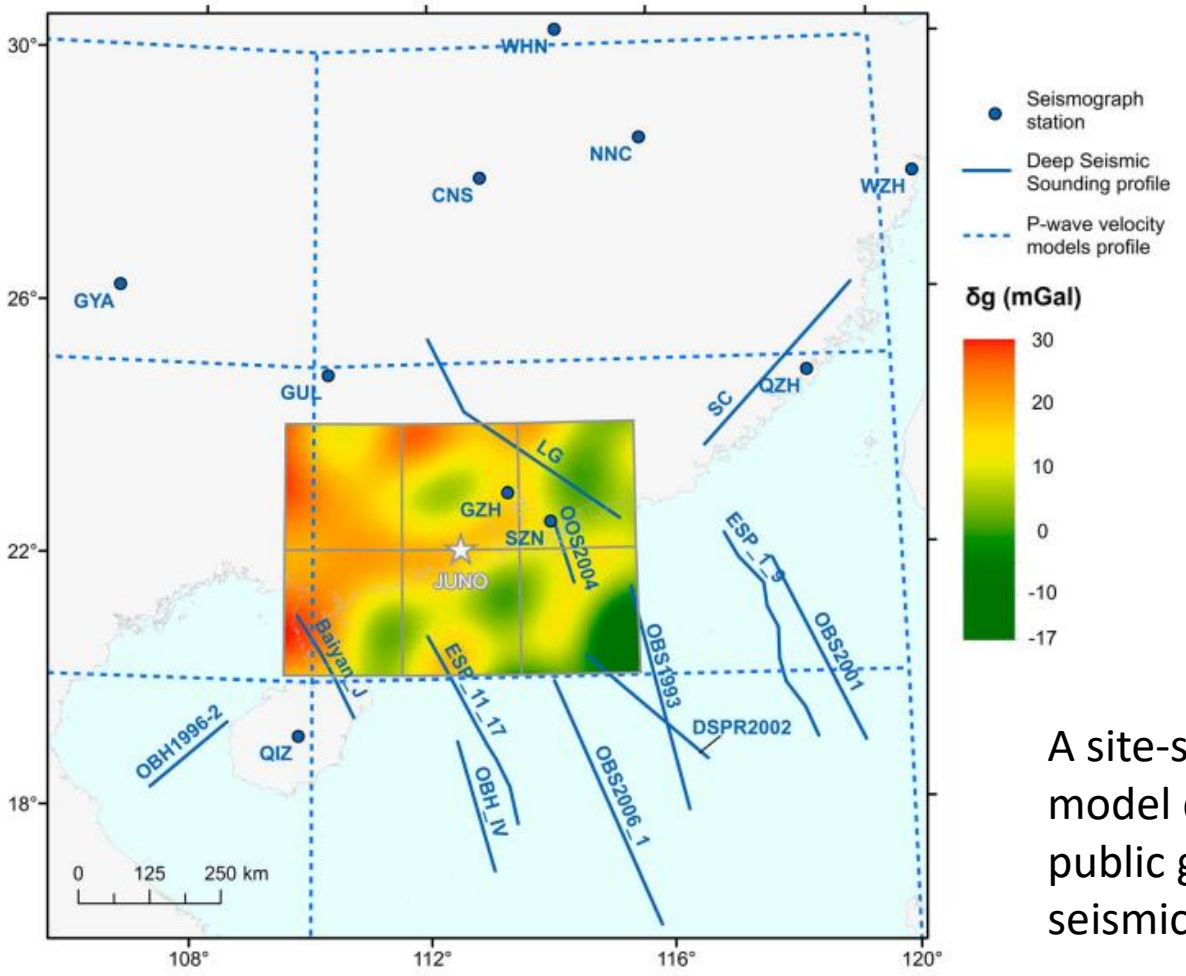
- **Geophysical models**
  - **Density** of source unit
  - **Crustal structure**
- **Geochemical models**
  - **U and Th abundances** of source unit



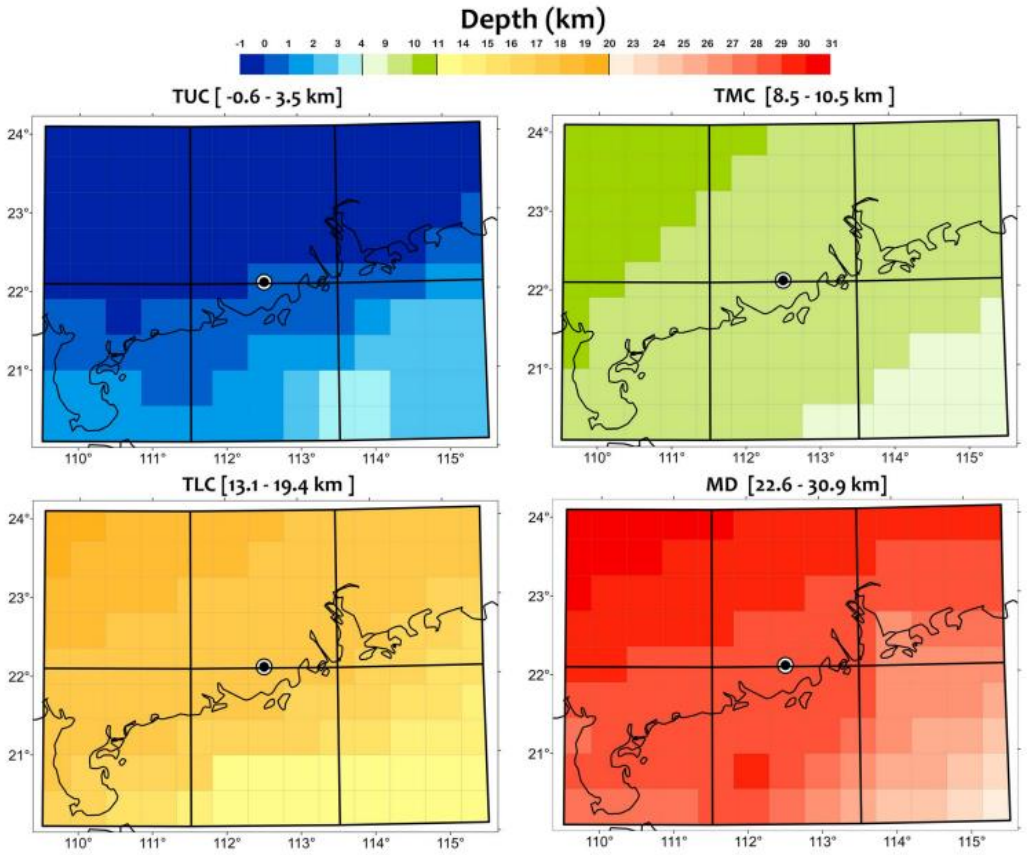
Major LOC models

Models	GIGJ	JULOC	JULOC-I
Author	Reguzzoni et al.	Gao et al.	Han et al.
Published year	2019	2020	2024 (preprint)
Area	6° ×4°	10° ×10°	10° ×11°
Resolution	50×50×0.1 km	0.5° × 0.5° ×1 km	0.4° × 0.4° ×1 km
Methods	Gravity and seismic data	Seismic data	Gravity and seismic data
Geophysical model	Yes	Yes	Yes
Geochemical model	No	Yes	Yes

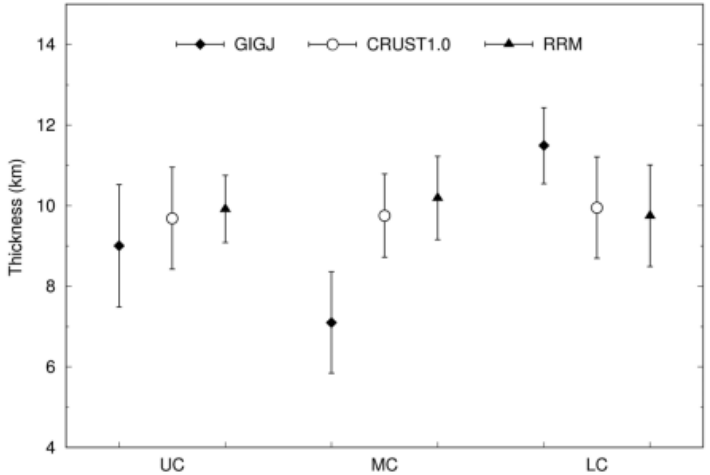
GIGJ Model



Reguzzoni et al., 2019

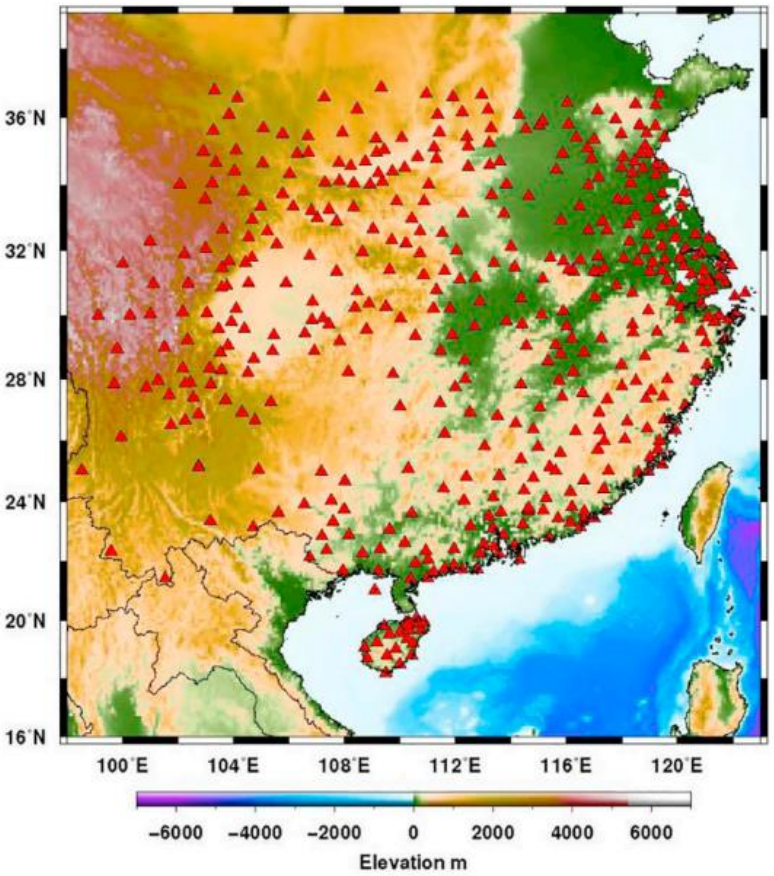


A site-specific density model derived from public gravity and seismic data



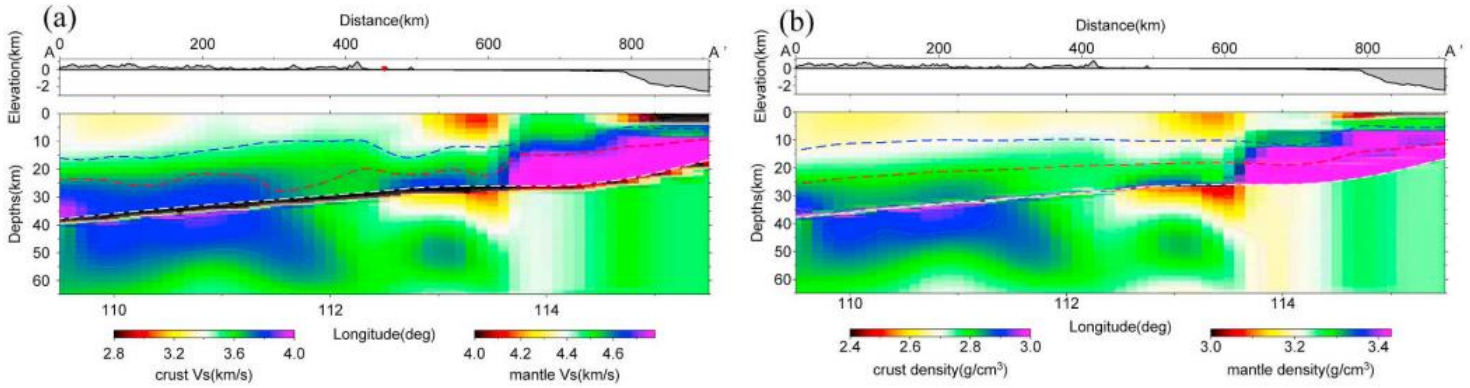
JULOC Model

Seismic ambient noise tomography

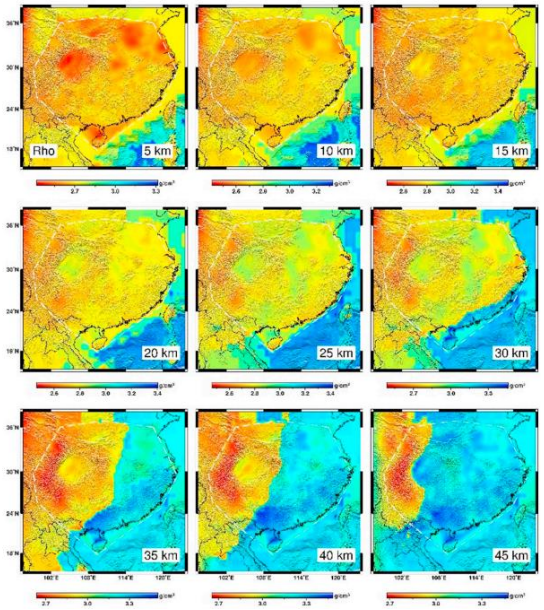


Gao et al., 2020

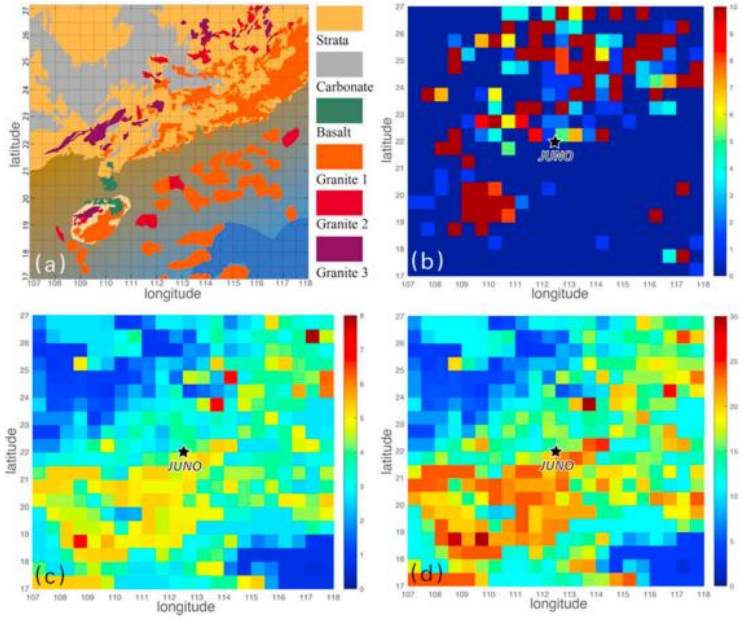
Shear-wave velocity model (Vs) -> Density model



3D density model



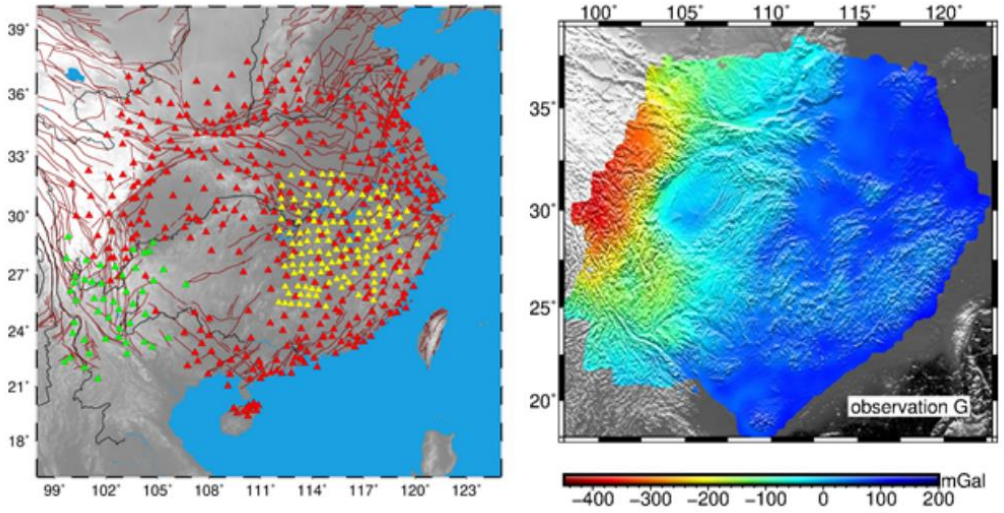
U & Th abundance models



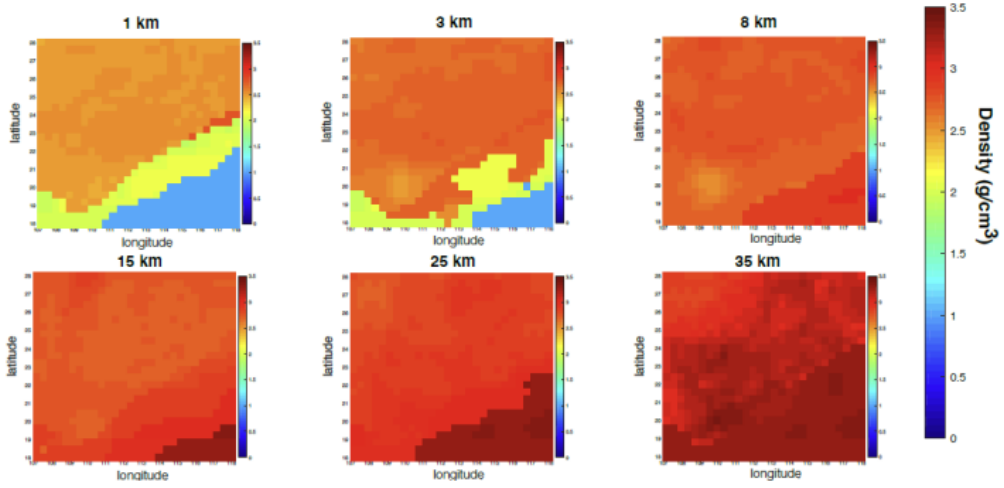
Seismic-derived 3D density model + geochemical sampling = neutrino calculation

JULOC-I Model

Joint inversion of surface wave dispersion and Bouguer gravity anomaly data (Li et al., 2023)

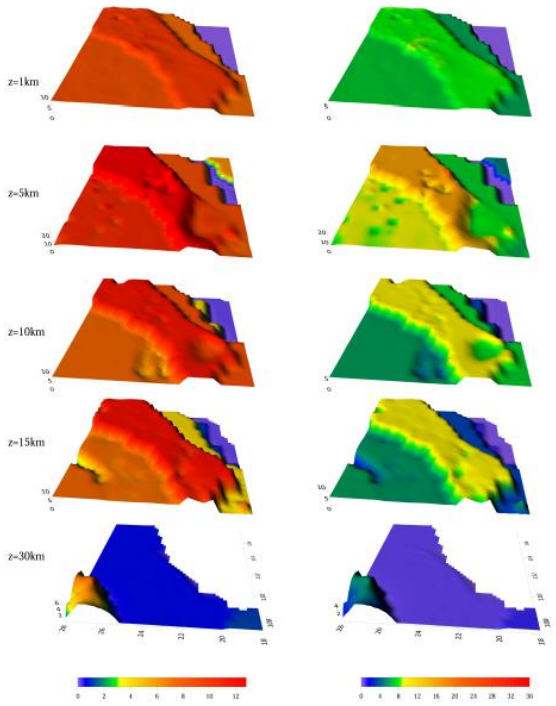


Density derived from shear-wave velocity model (more accurate)



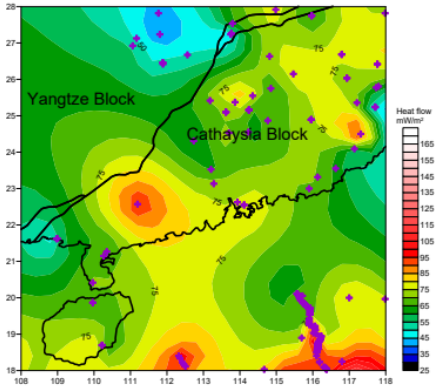
(Han et al., 2024)

3D abundance models of U and Th

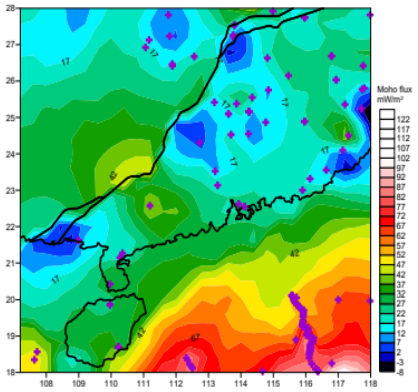


Validation by heat flow

Surface

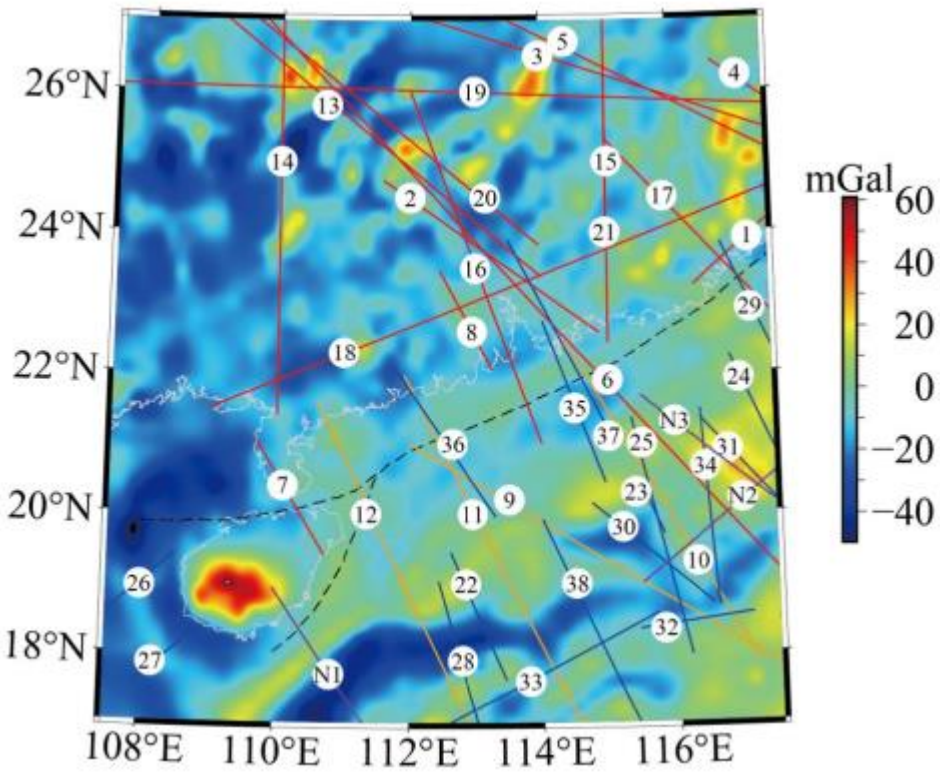


Moho



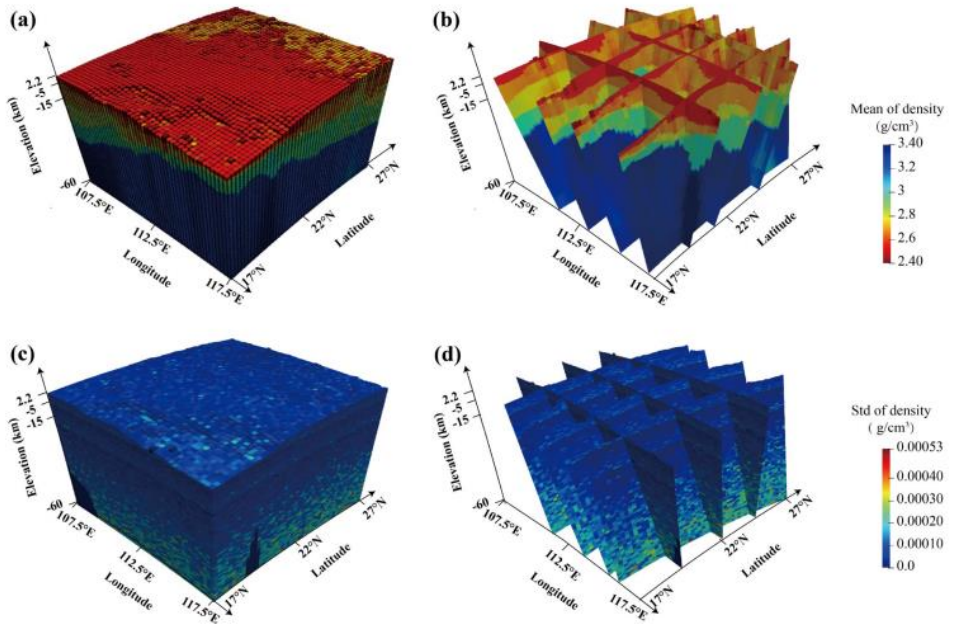
3D gravity inversion

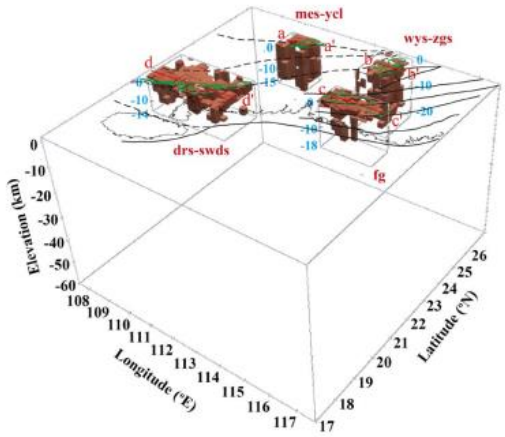
Gravity Data (WGM2012)



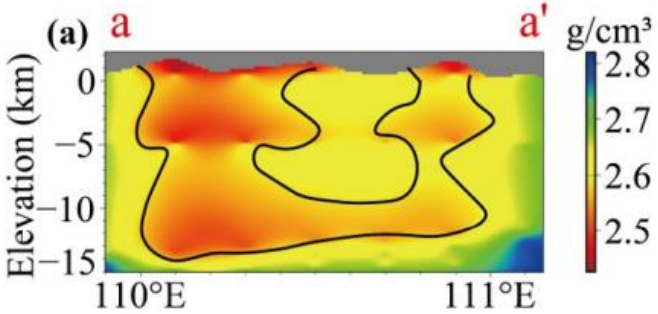
(Chu et al., 2025)

3D density model with seismic constraints
(initial model, boundaries, and validation)



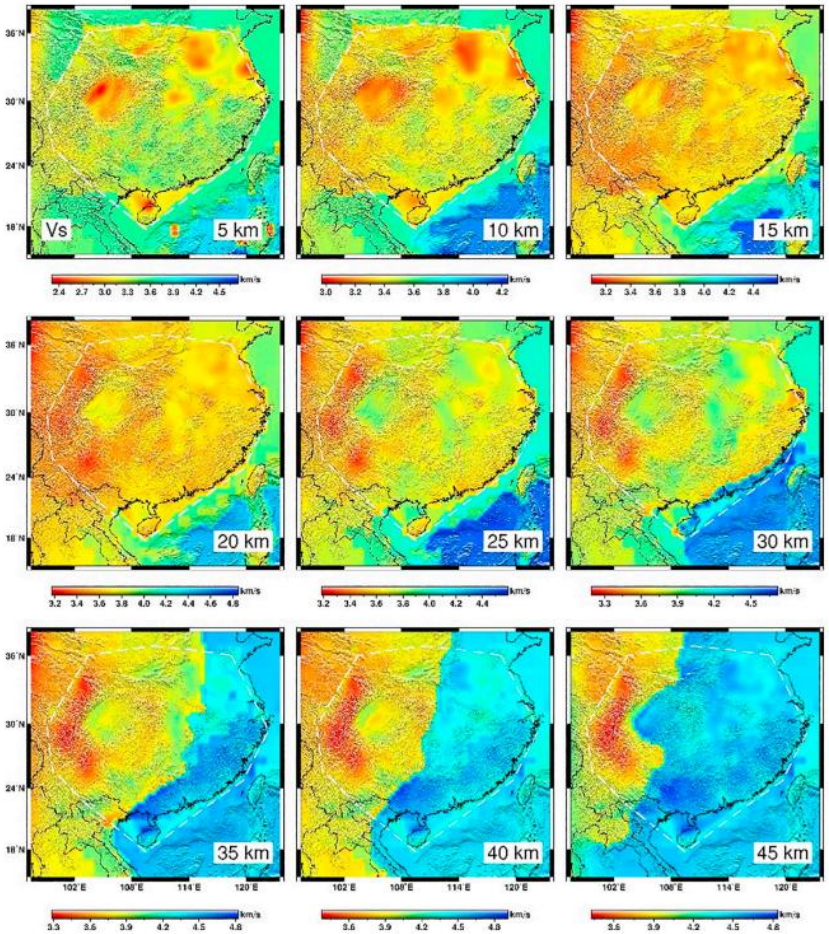


3D geometry of granitic bodies

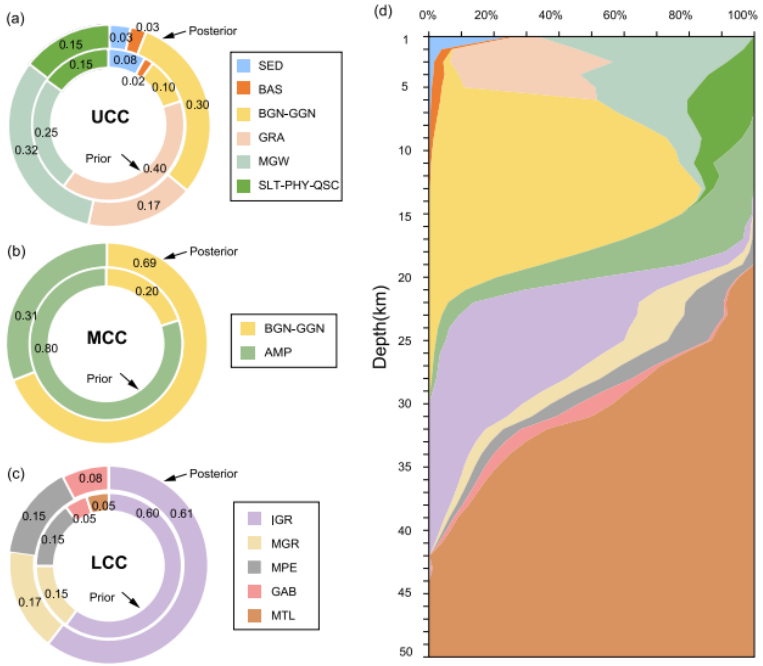


From velocity to abundance

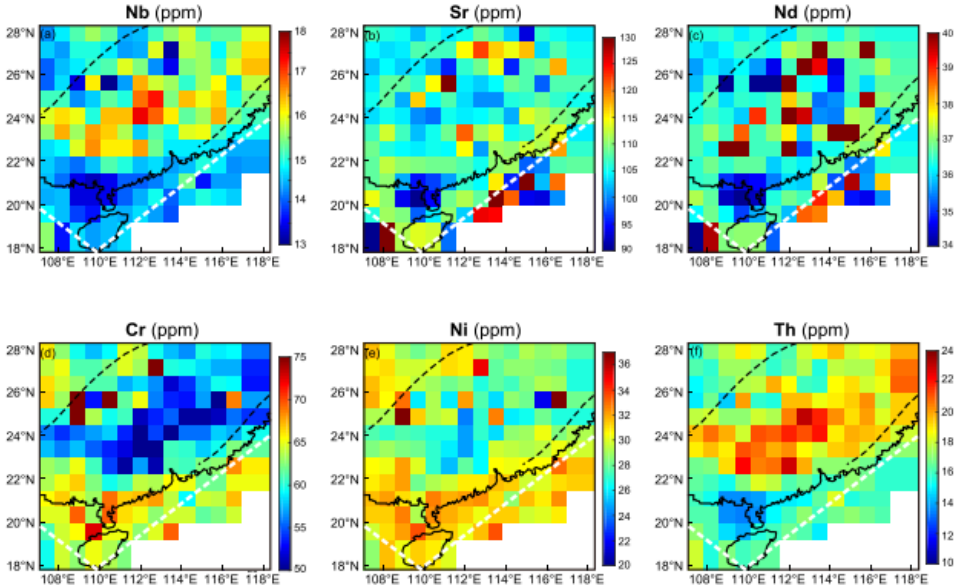
3D seismic velocity model
(Gao et al., 2020)



Seismic velocity to the most probable rock type (lab test)

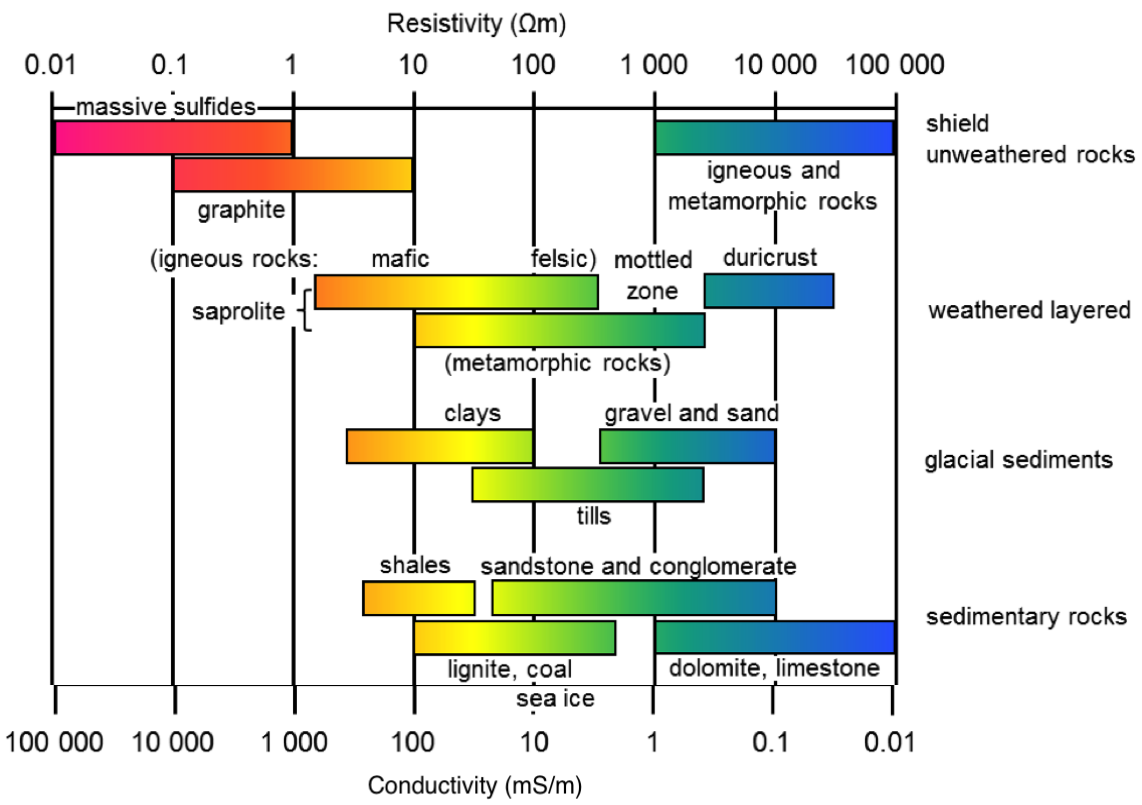


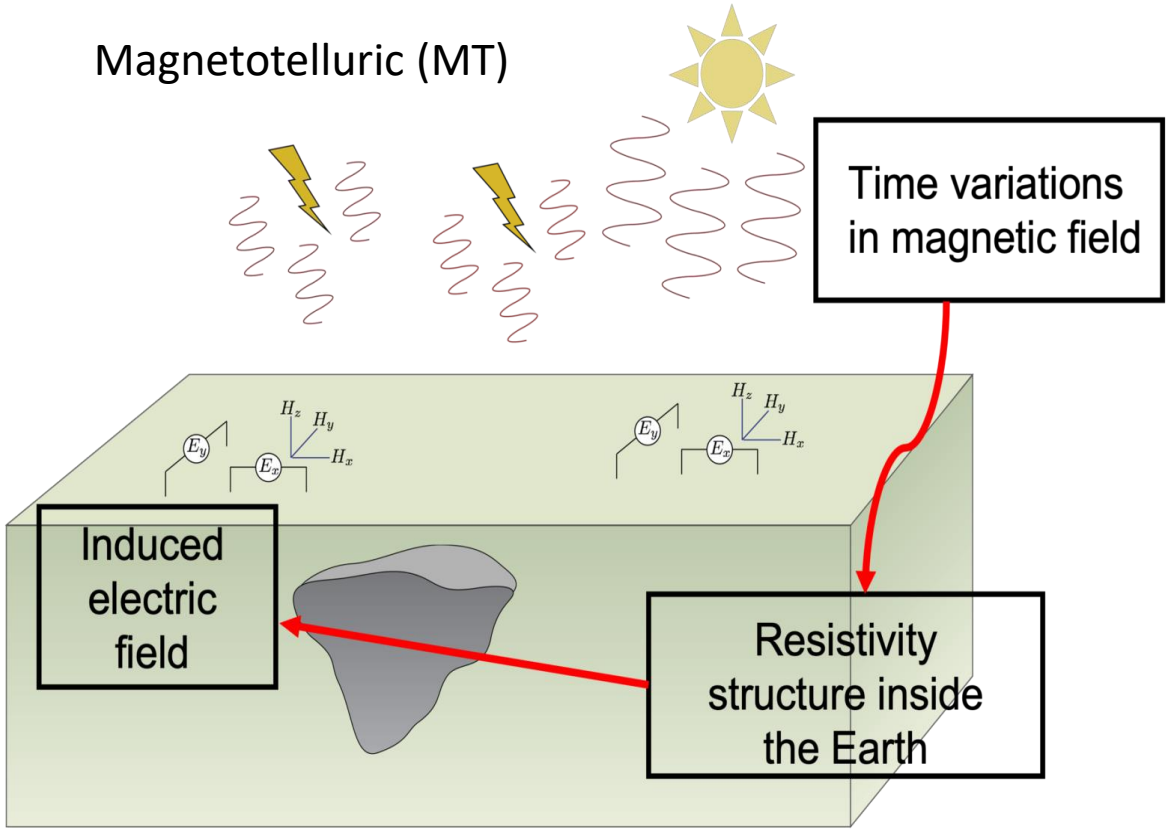
Abundance model



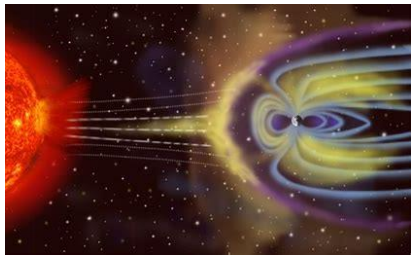
Sun et al., 2022

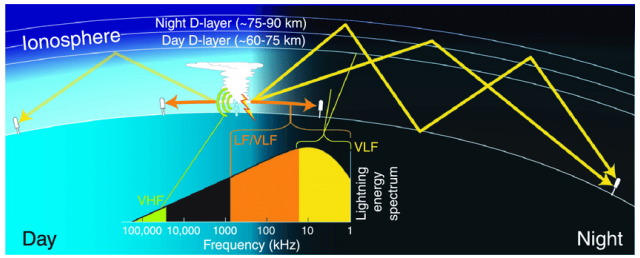
Earth's electric property





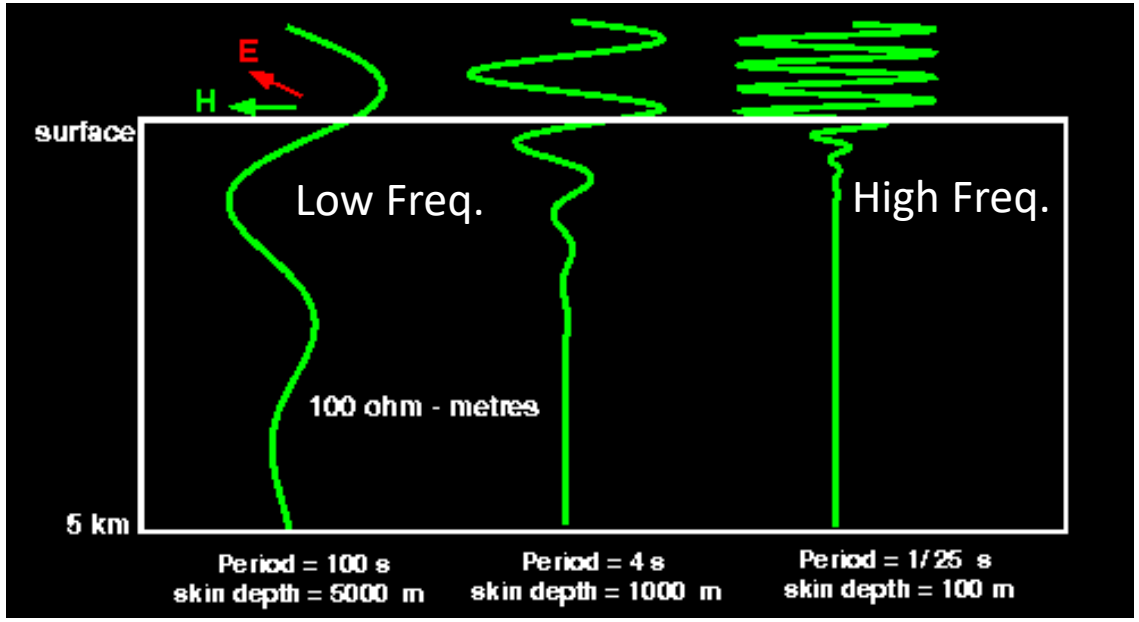
MT Method

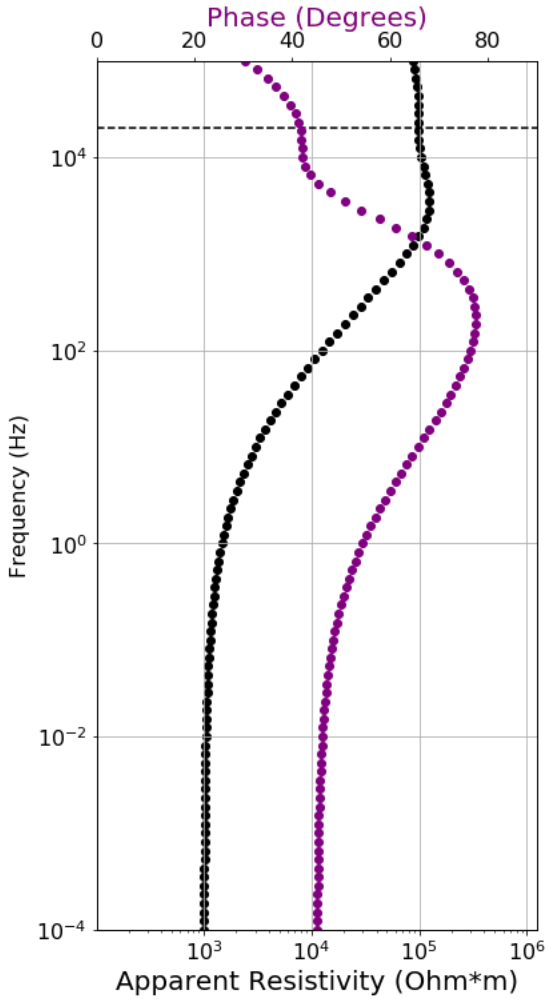


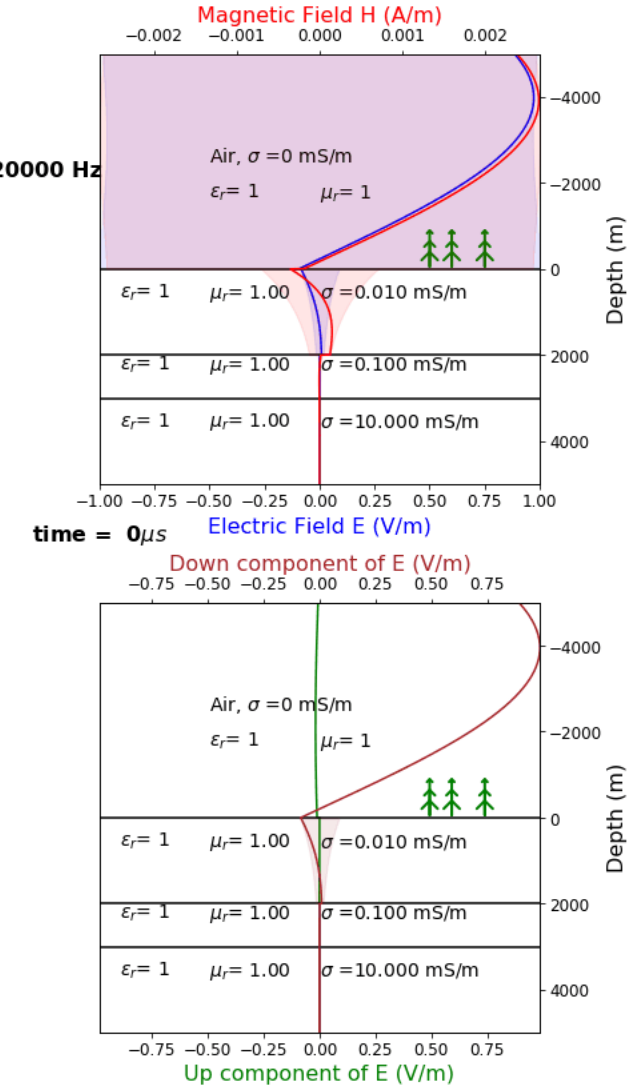


- Natural source electromagnetic method
- Source: magnetic storm, lightning
- Plane wave source
- Depth sounding: high freq. = shallow
- Skin depth:

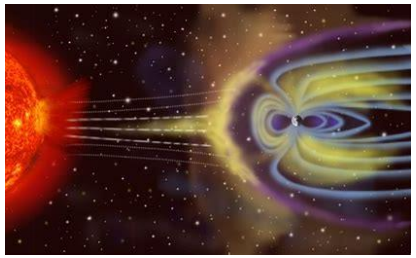
$$p = \sqrt{\frac{2}{\omega\mu\sigma}} \approx 500\sqrt{T\rho_a}$$

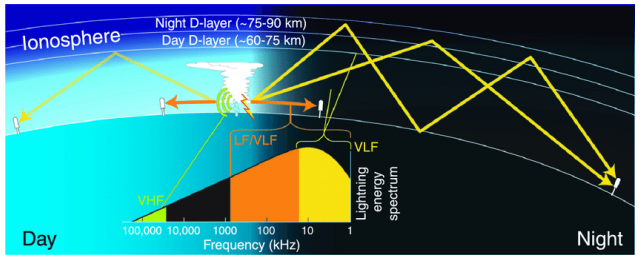






MT Method





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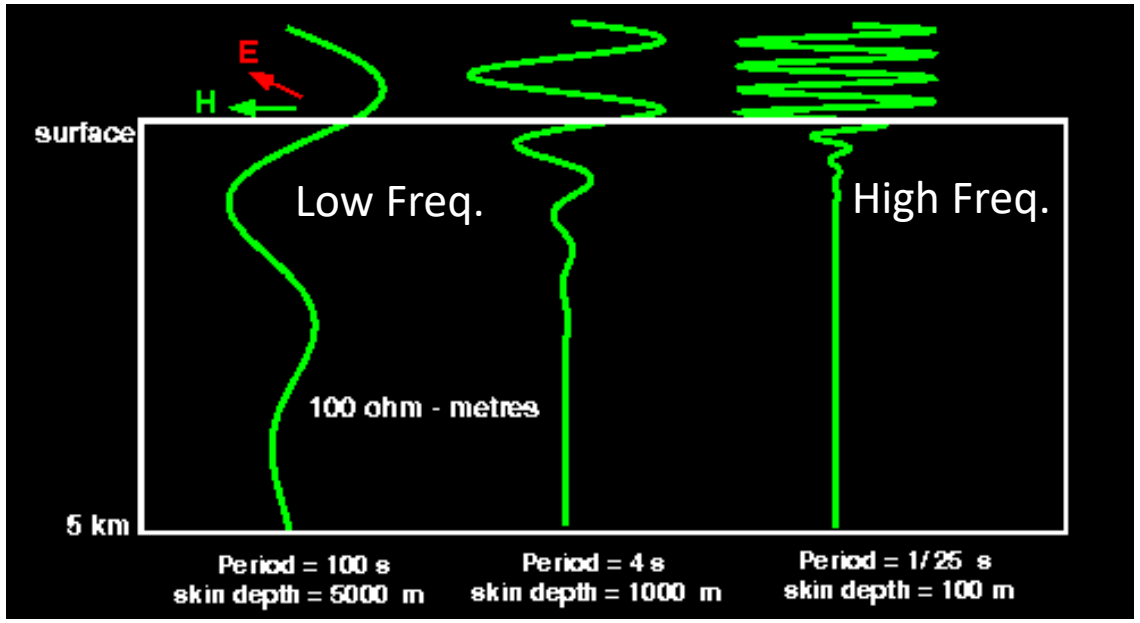
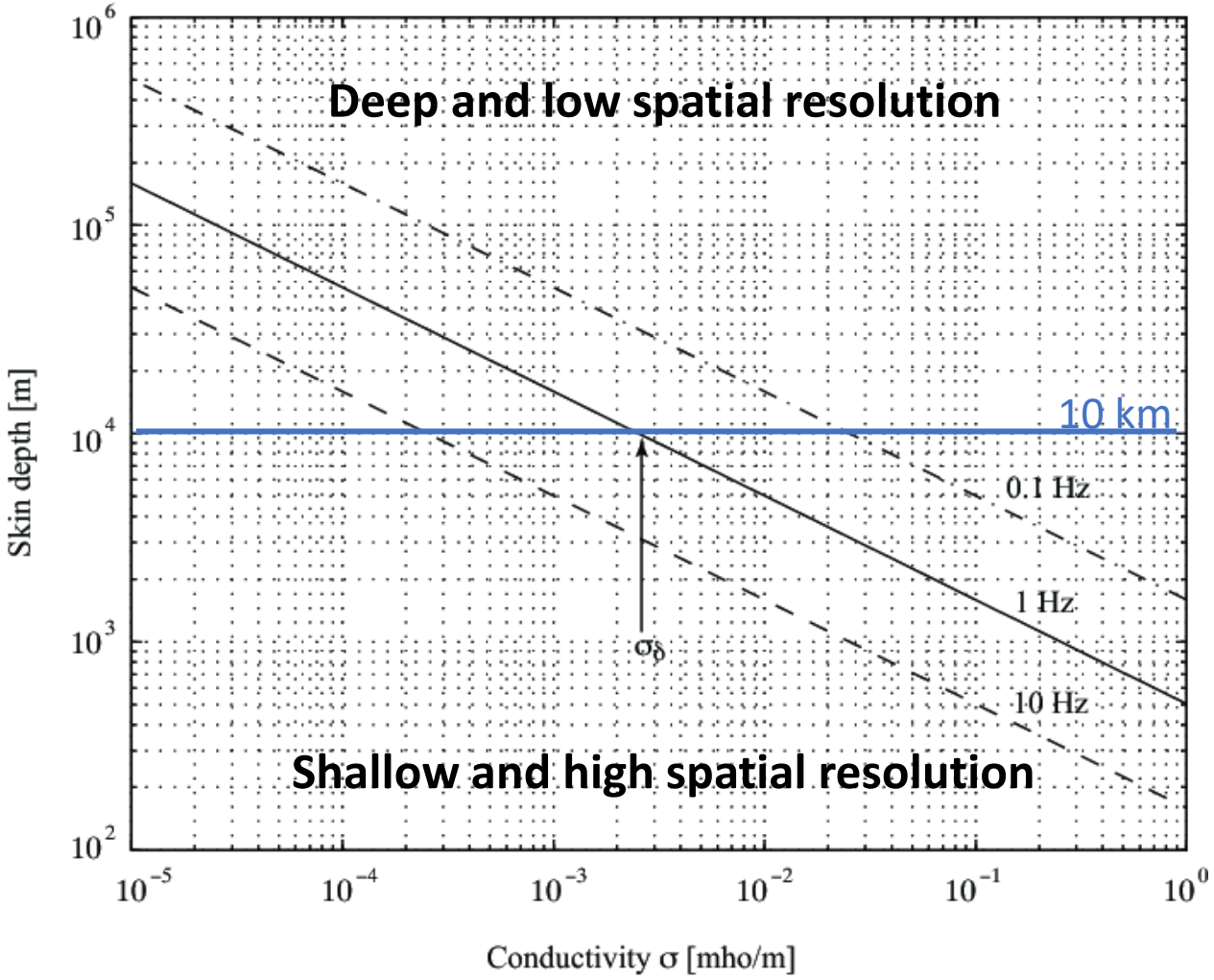
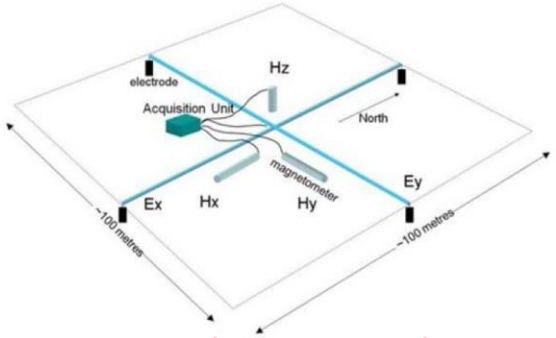


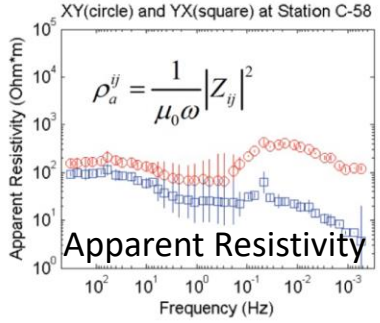


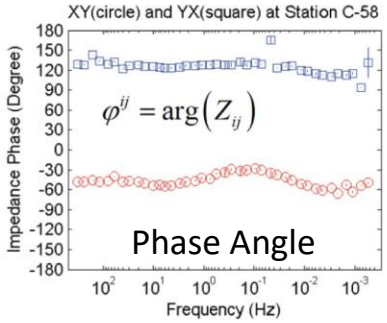
MT for local model



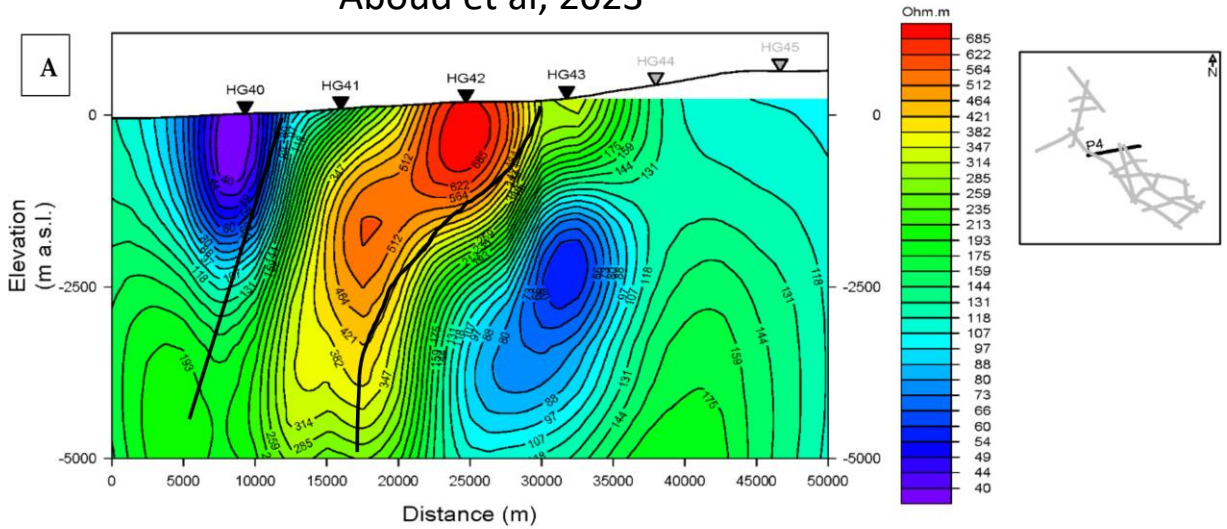
MT data: Impedance

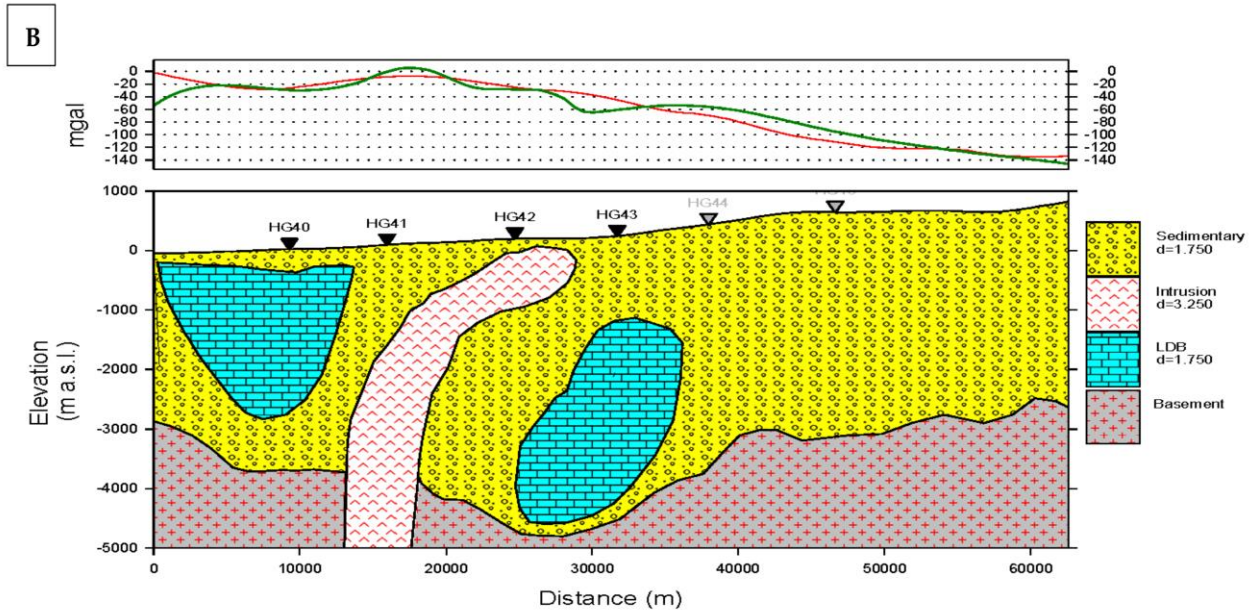
$$\begin{bmatrix} E_x \\ E_y \end{bmatrix} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \begin{bmatrix} H_x \\ H_y \end{bmatrix}$$



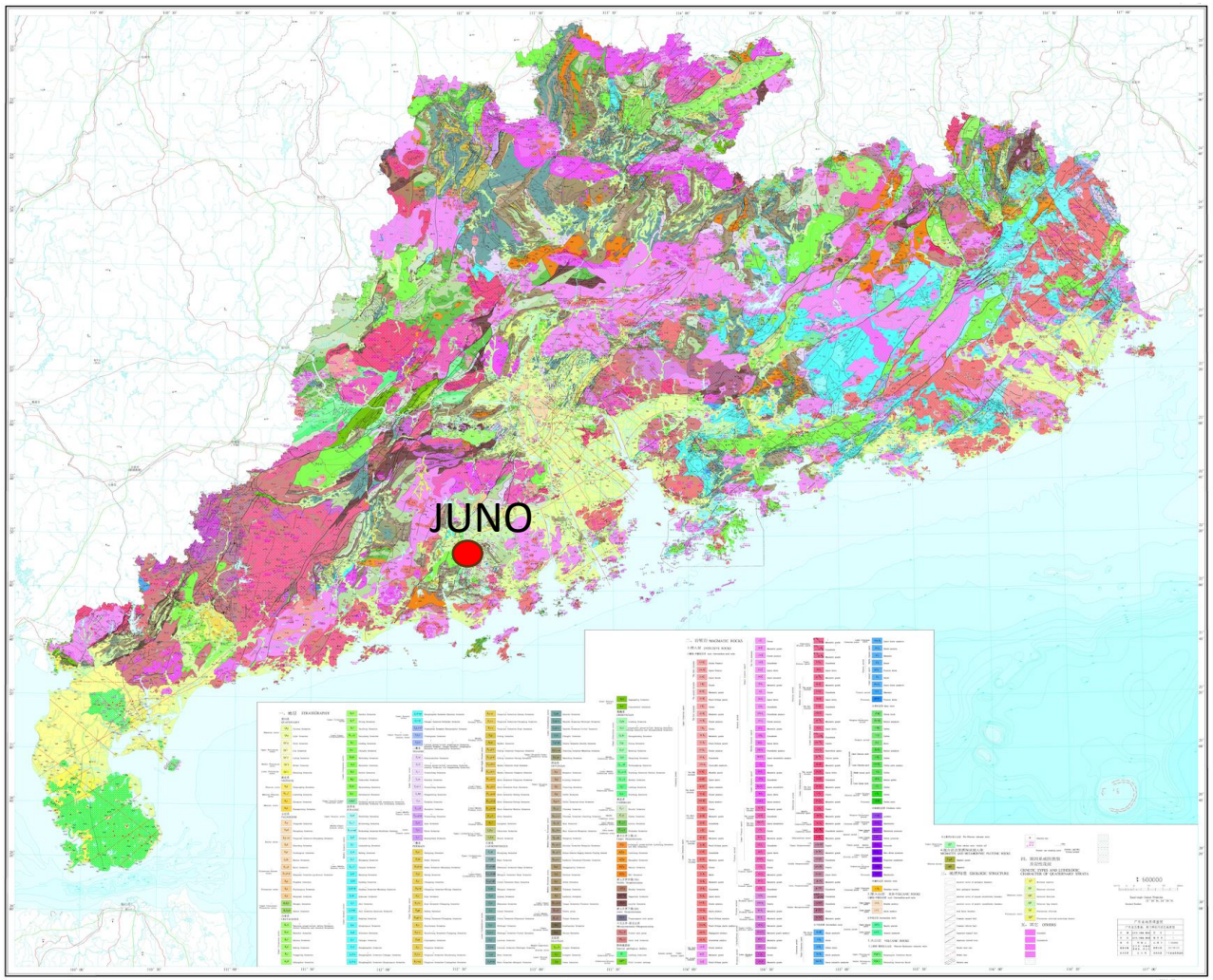


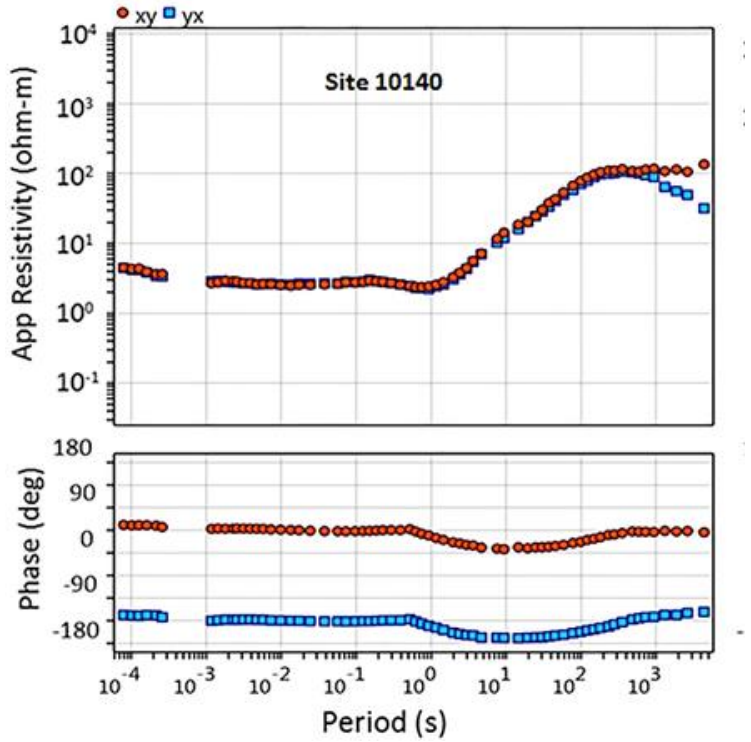
Aboud et al, 2023





MT in Guangdong





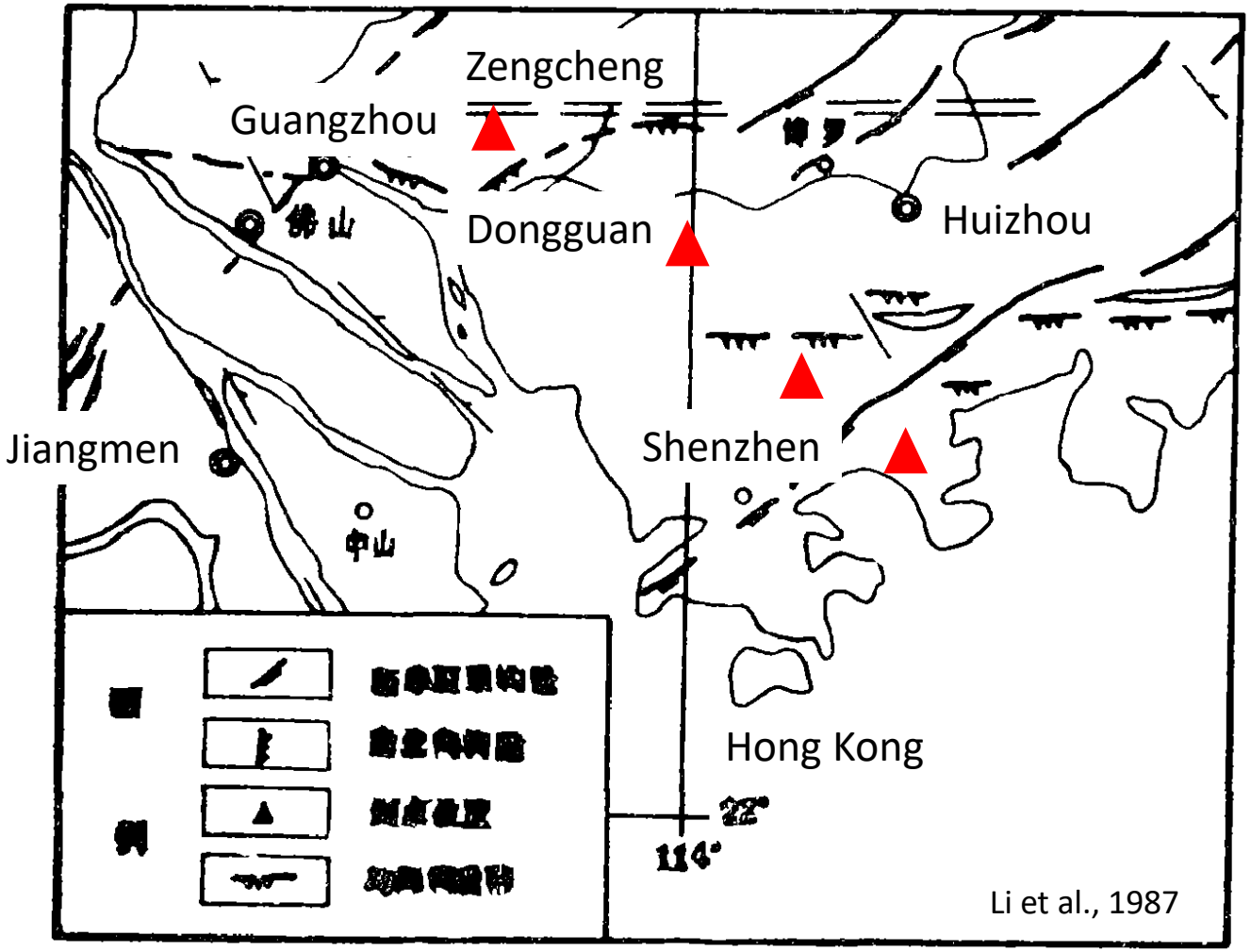
Audio-frequency MT: 1Hz ~ 10 kHz

- Infrastructure construction
- Geothermal/hot spring
- Minerals
- Geohazard

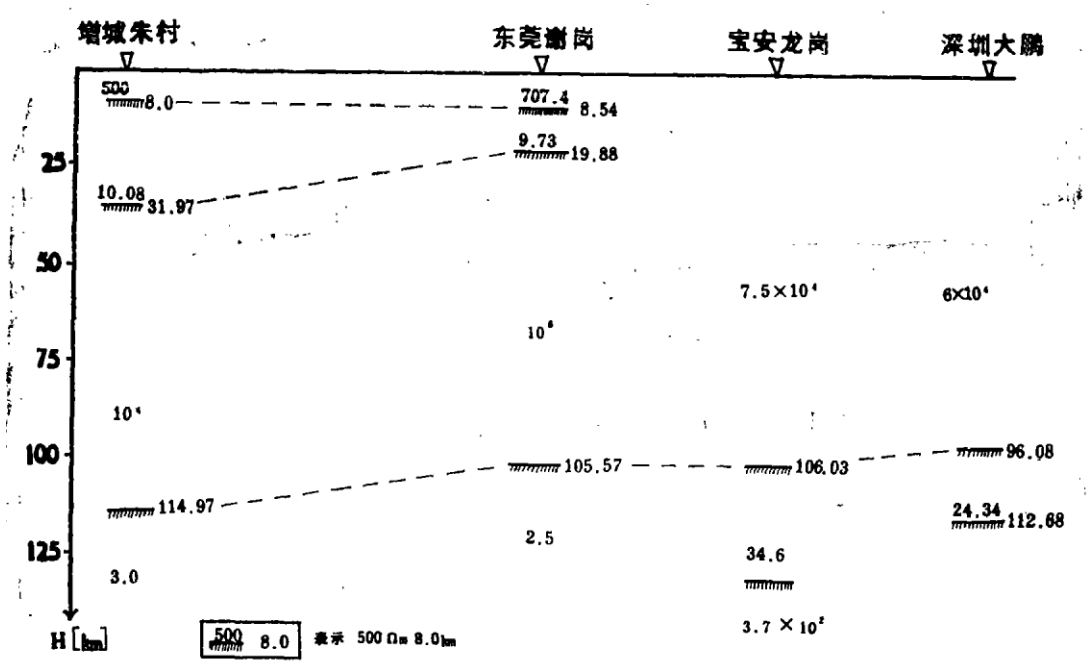
Regular and long-period MT: 0.0001 ~ 100 Hz

- Geodynamic
- Earthquake
- Marine

Historical Earthquake Administration Data

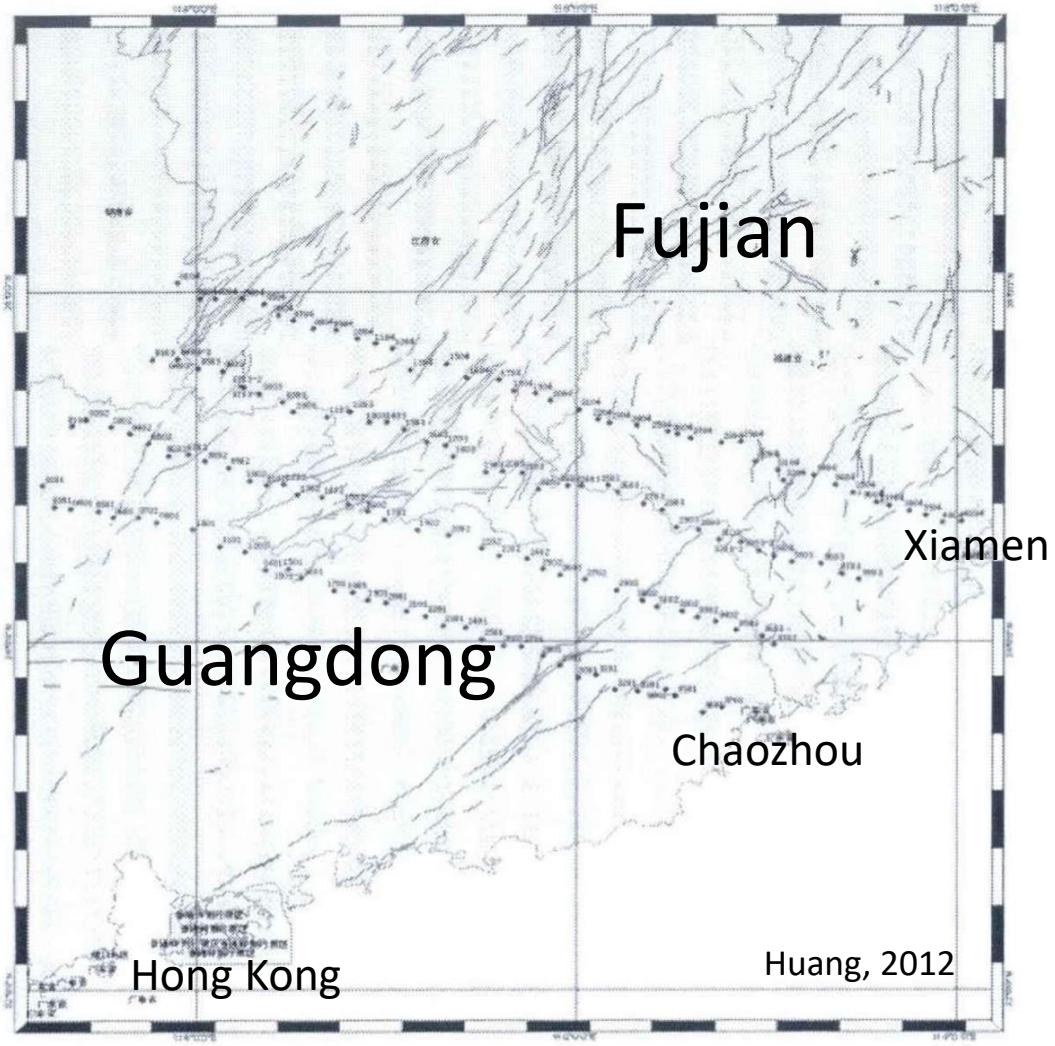


Li et al., 1987

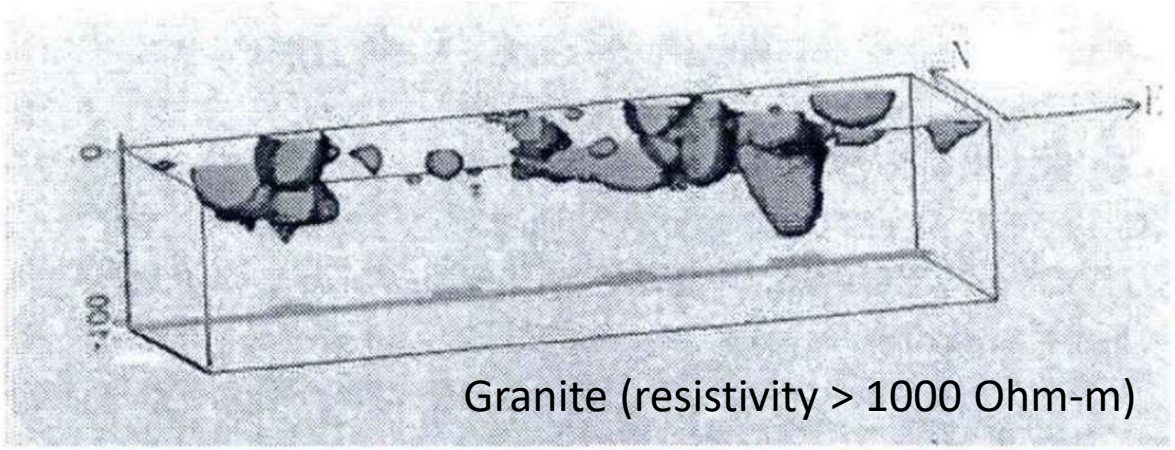


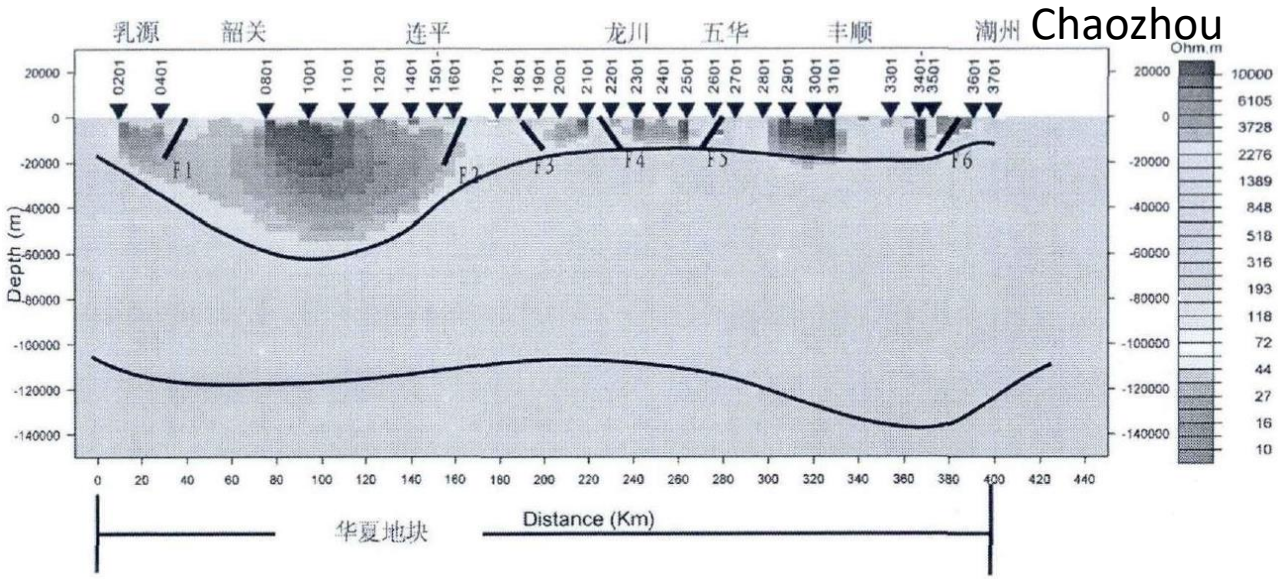
- Crust and upper mantle structure
- Vertical extent of granite

China University of Geosciences (Beijing)

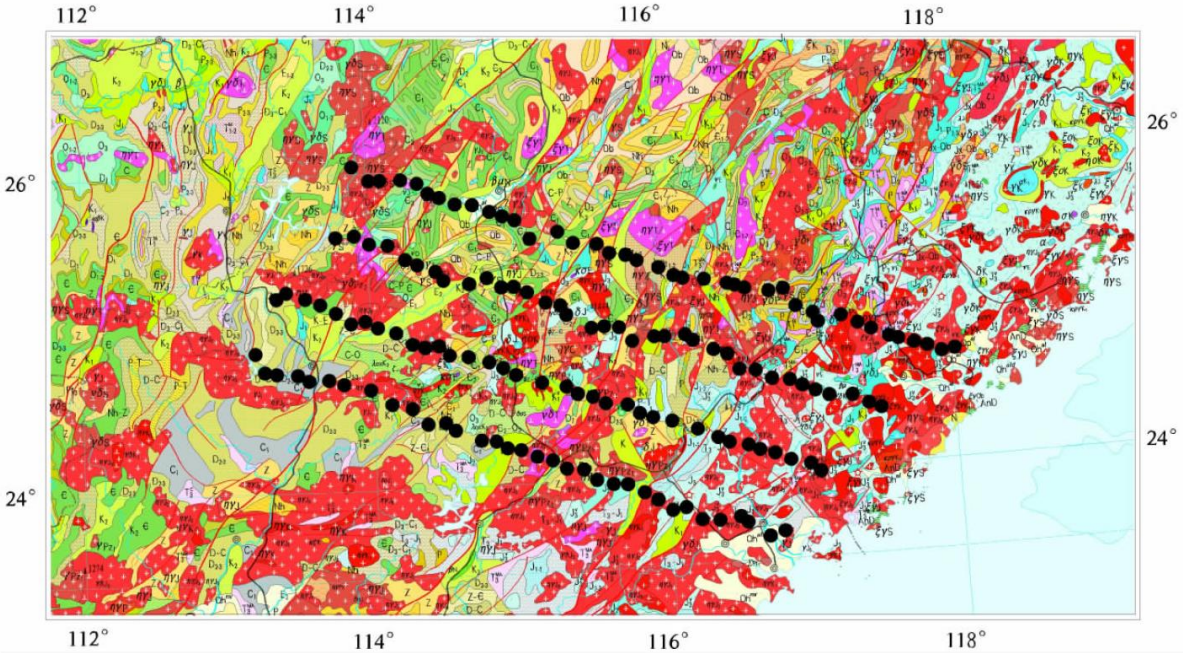


Huang, 2012

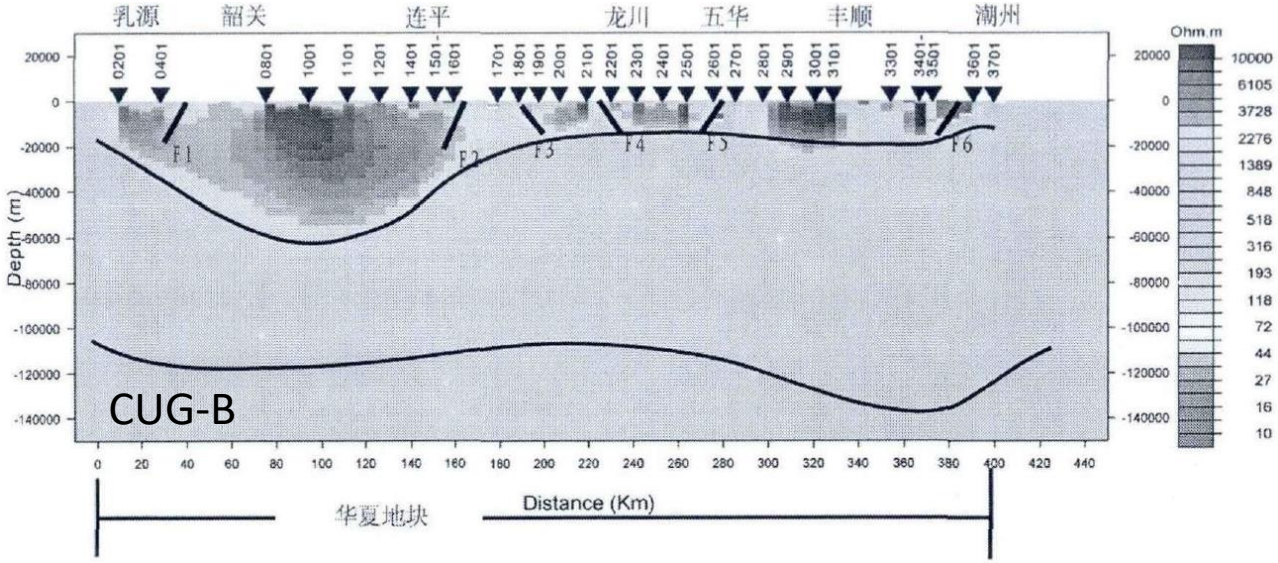


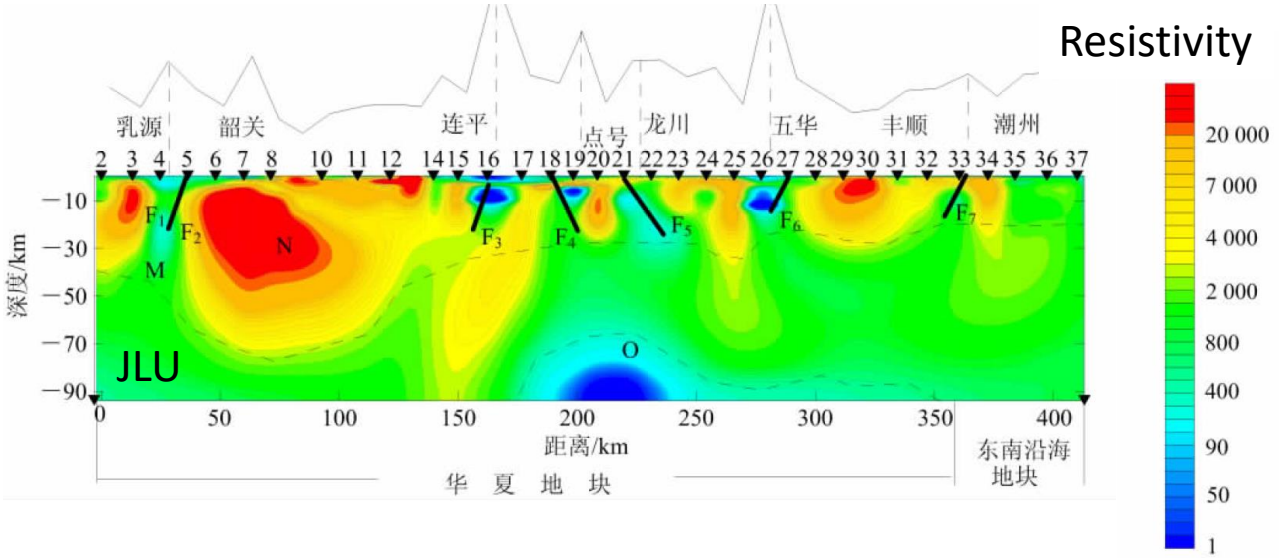


Jilin University

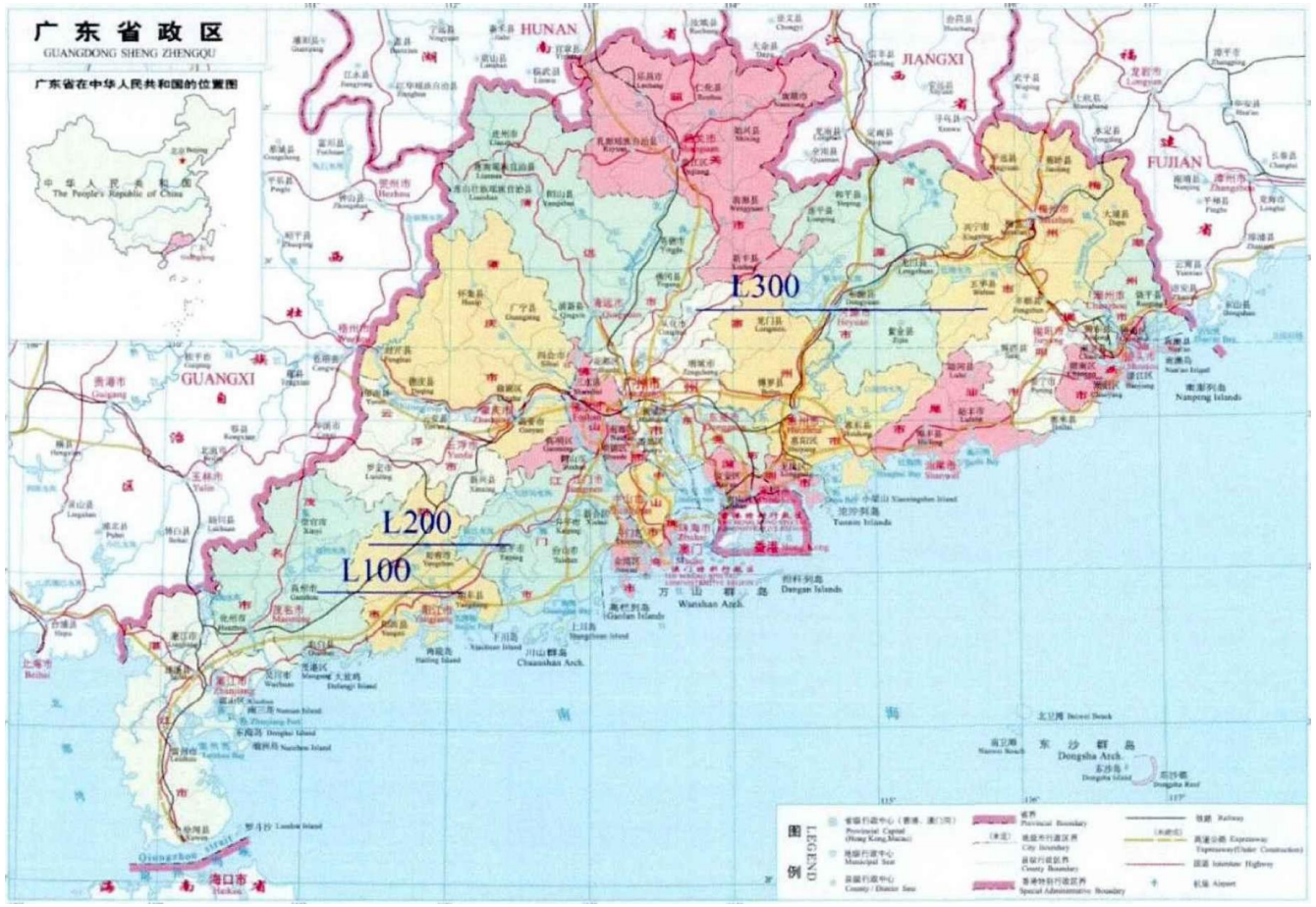


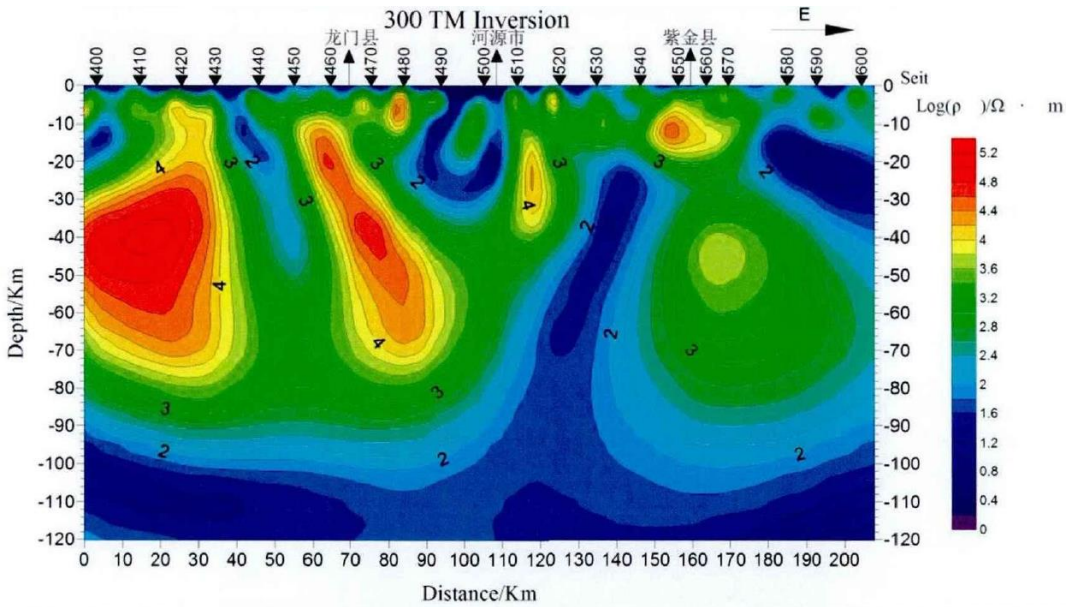
Liu et al., 2012

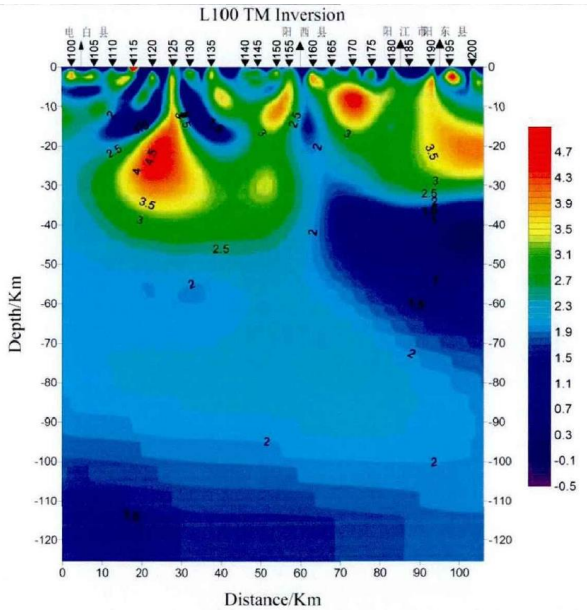


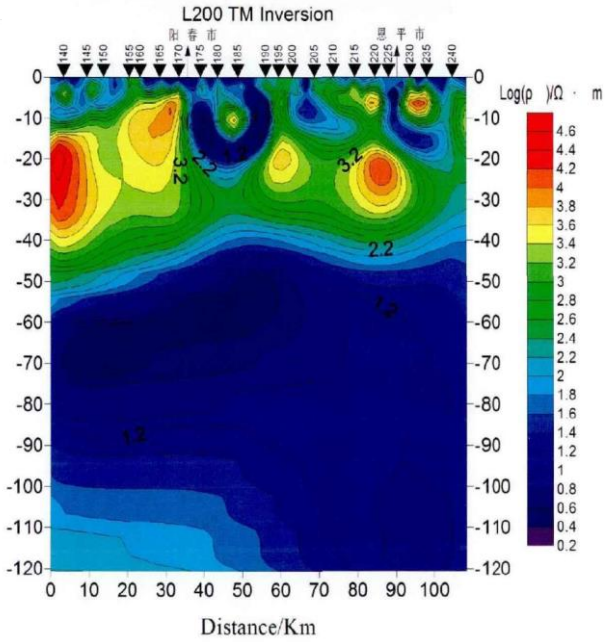


CUG-Wuhan



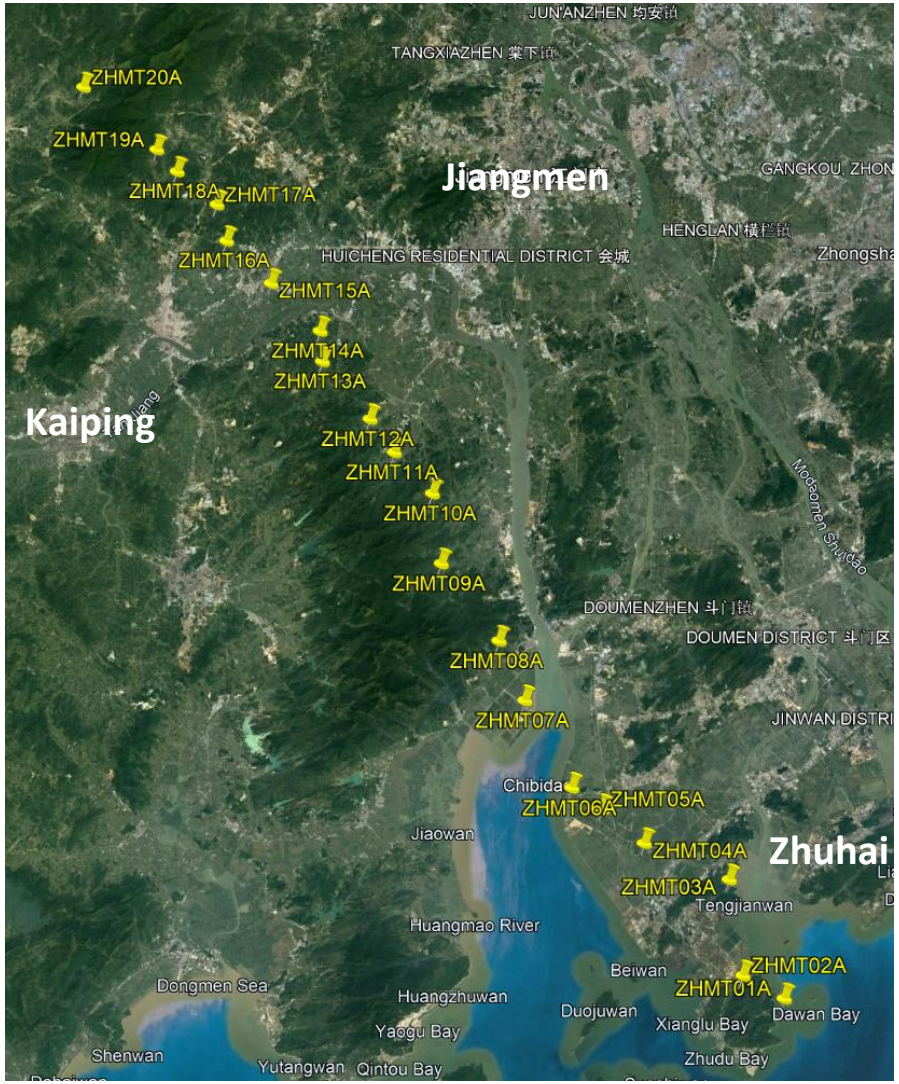


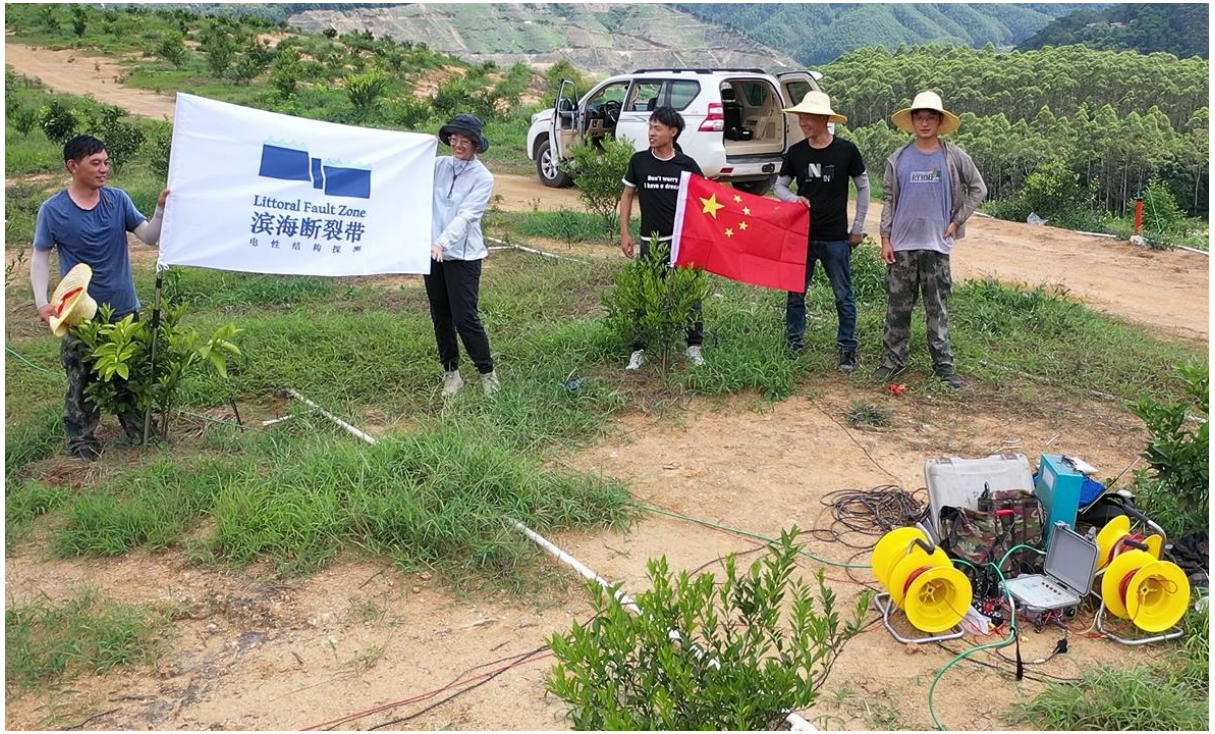


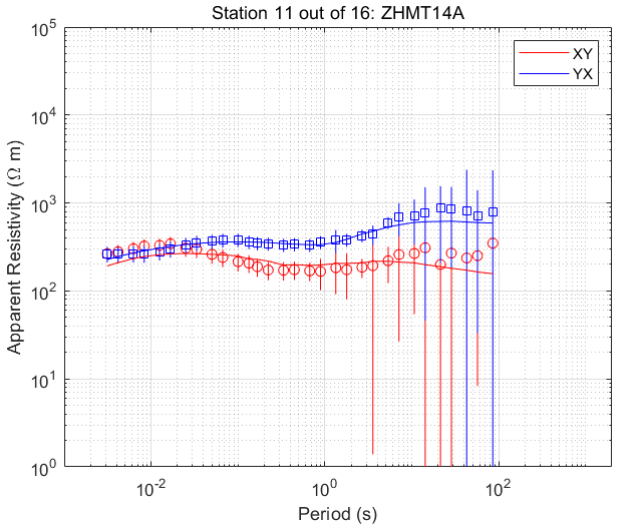


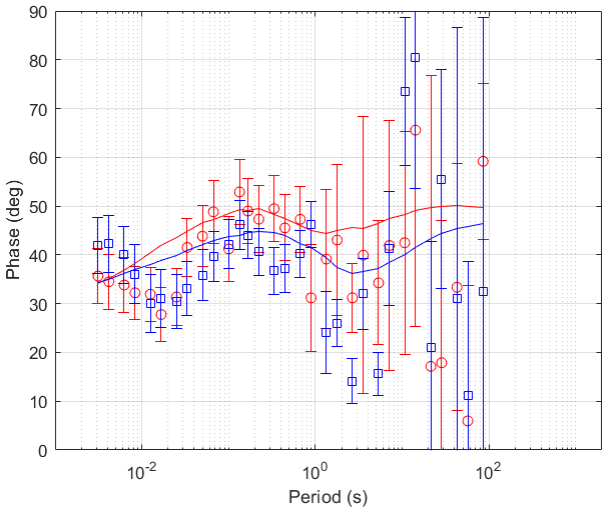
Tian, 2014

ZHMT Survey

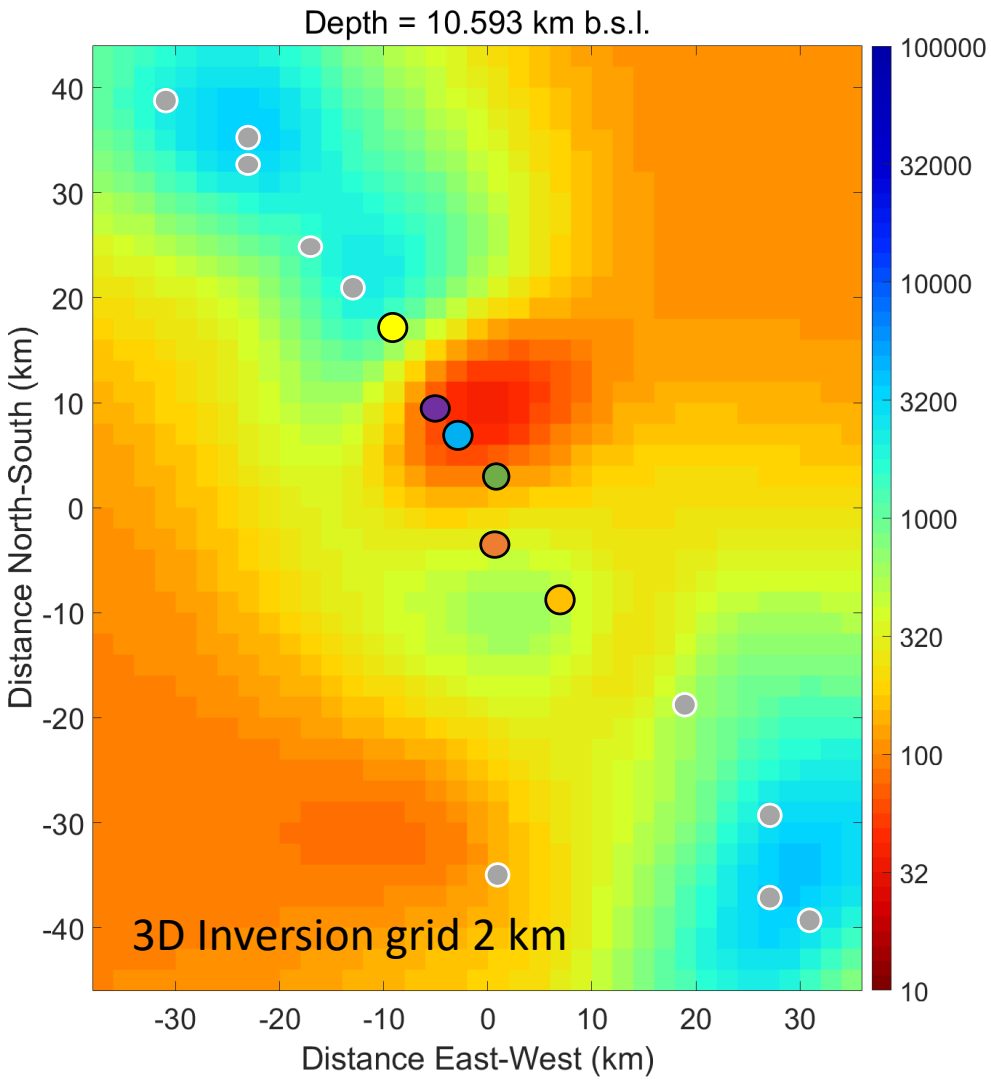

JUN'ANZHEN 均安镇
TANGXIAZHEN 棠下镇
ZHMT20A
ZHMT19A
ZHMT18A
ZHMT17A
Jiangmen
GANGKOU, ZHON
HENGLAN 横栏镇
ZHMT16A
HUICHENG RESIDENTIAL DISTRICT 会城
Zhongsha
ZHMT15A
ZHMT14A
ZHMT13A
Kaiping
ZHMT12A
ZHMT11A
ZHMT10A
Modaomen Shuidao
ZHMT09A
DOUMENZHEN 斗门镇
DOUMEN DISTRICT 斗门区
ZHMT08A
ZHMT07A
JINWAN DISTRI
Chibida
ZHMT06A
ZHMT05A
Jiaowan
ZHMT04A
Zhuhai
ZHMT03A
Tengjianwan
Huangmao River
Beiwan
ZHMT02A
ZHMT01A
Dongmen Sea
Huangzhuwan
Duojuwan
Dawan Bay
Xianglu Bay
Yaogu Bay
Shenwan
Zhudu Bay
Yutangwan
Qintou Bay

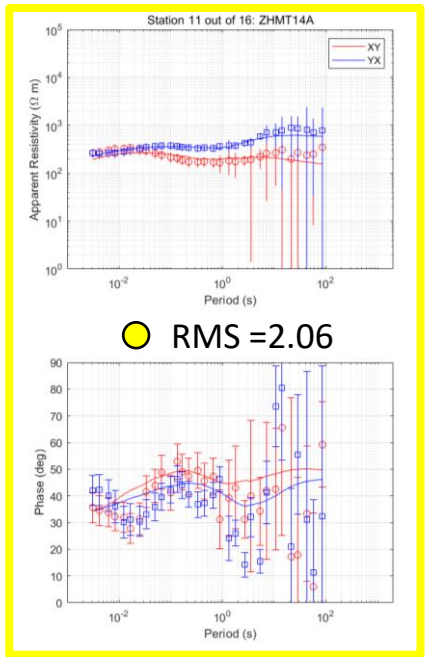

Littoral Fault Zone
滨海断裂带

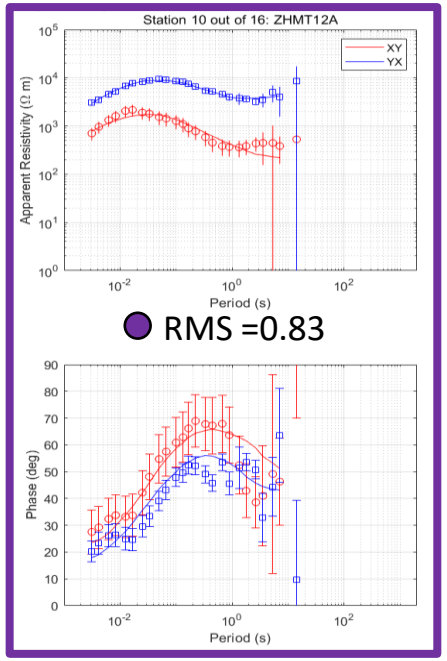

Station 11 out of 16: ZHMT14A
XY
YX
Apparent Resistivity (Ω m)
Period (s)

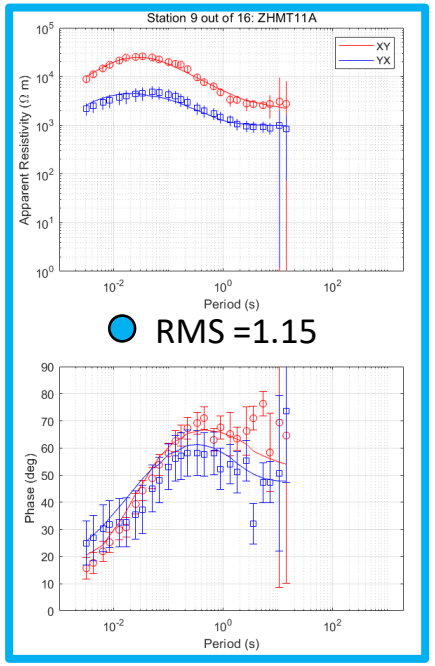

Phase (deg)
Period (s)

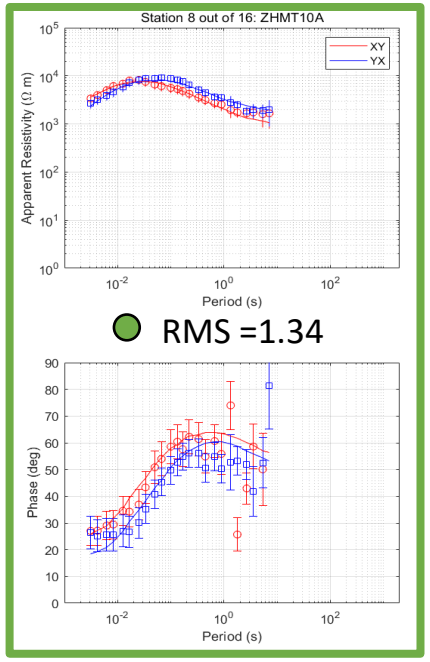
ZHMT 3D Inversion

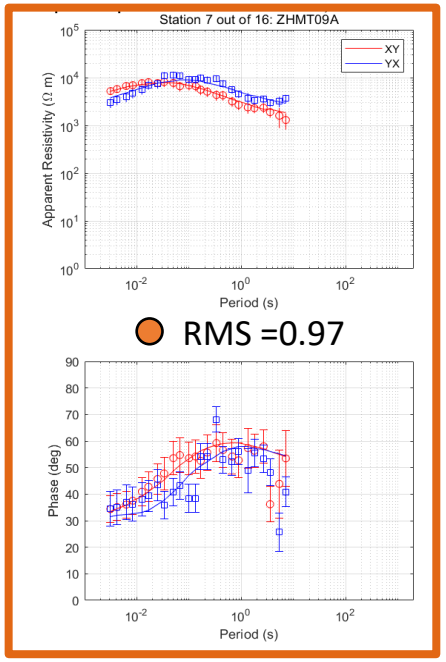


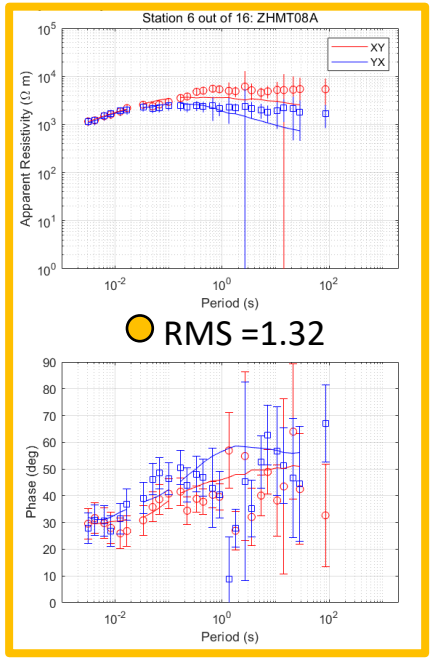




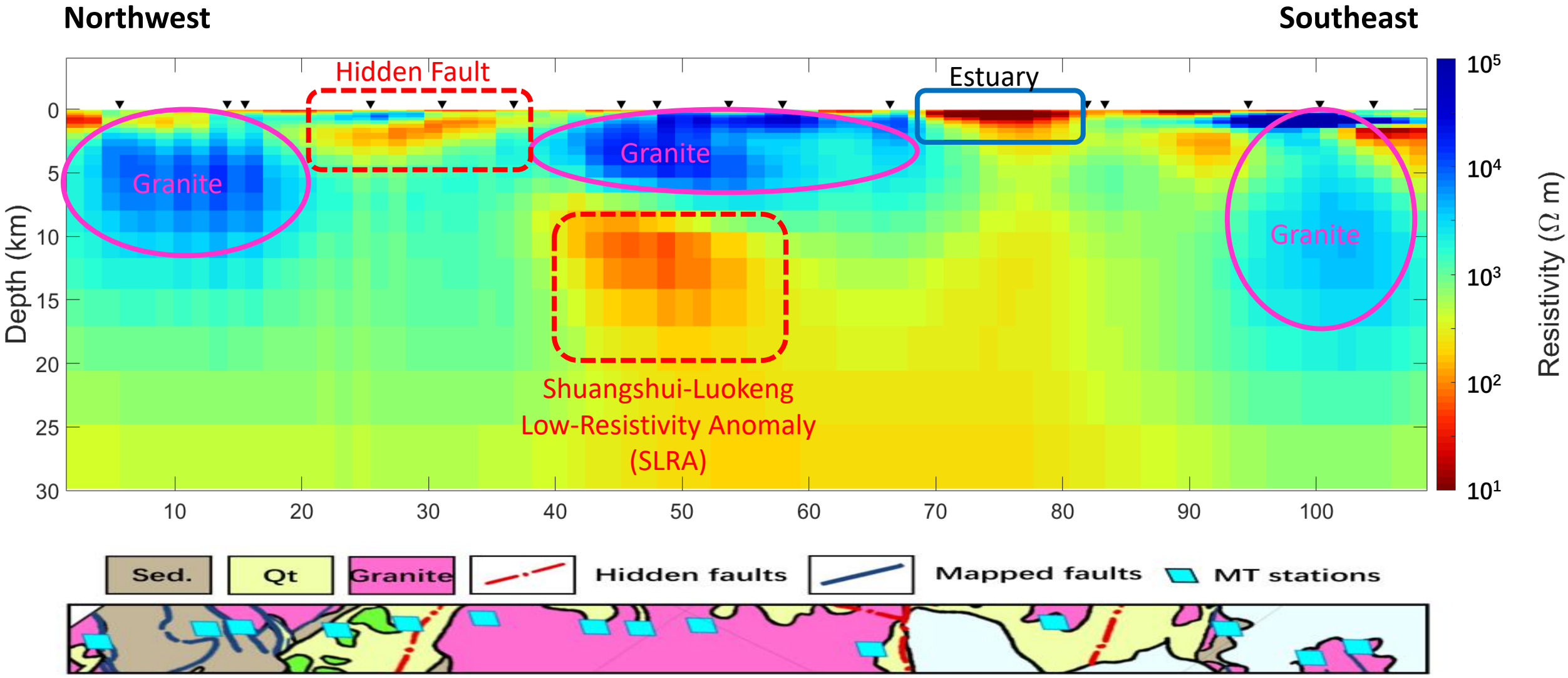




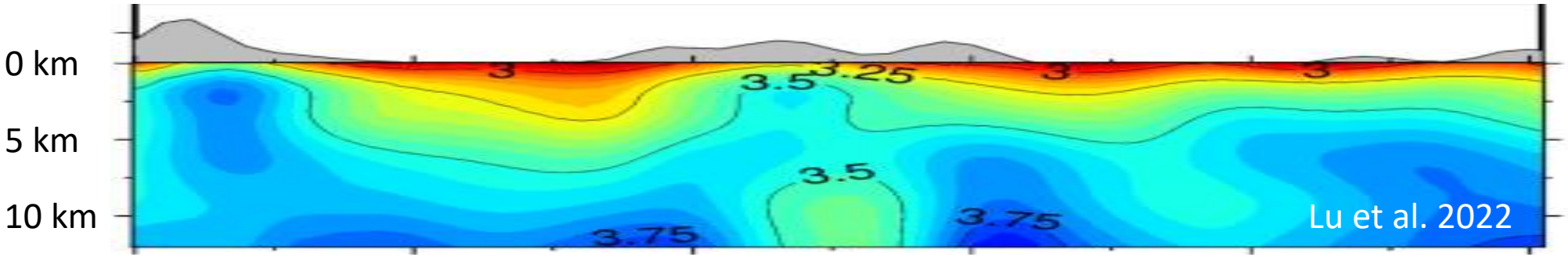




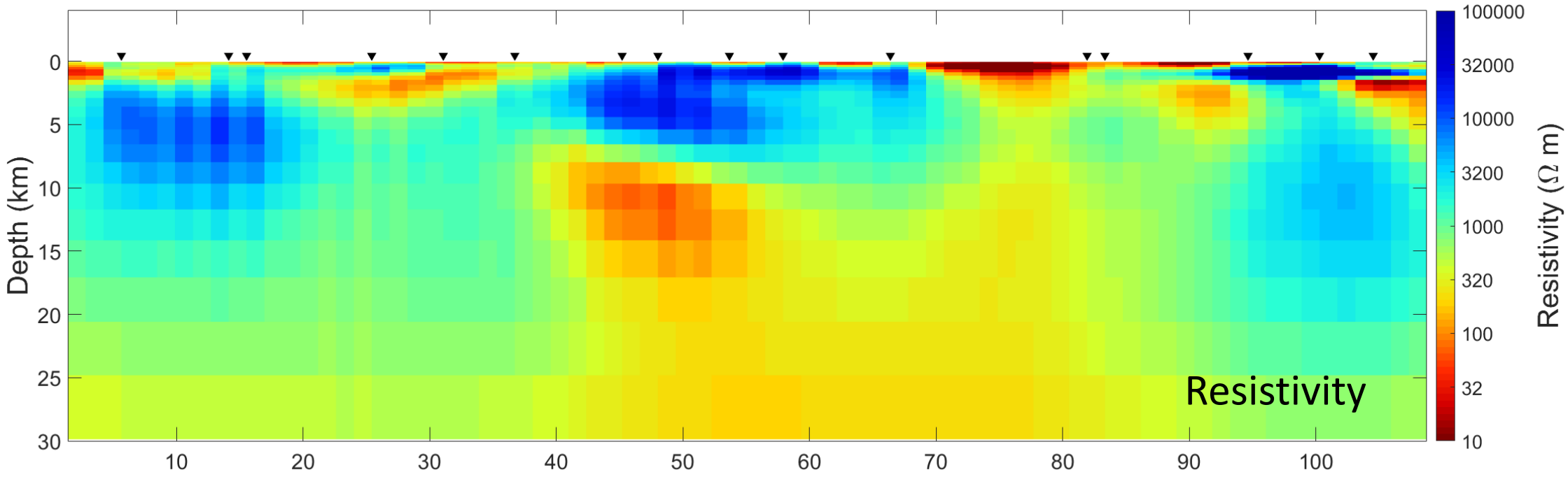
ZHMT Model


Northwest
Southeast
Hidden Fault
Estuary
Granite
Granite
Granite
Shuangshui-Luokeng
Low-Resistivity Anomaly
(SLRA)
Depth (km)
0
5
10
15
20
25
30
10
20
30
40
50
60
70
80
90
100
10^5
10^4
10^3
10^2
10^1
Resistivity (Ω m)
Sed.
Qt
Granite
Hidden faults
Mapped faults
MT stations

Resistivity and seismic velocity

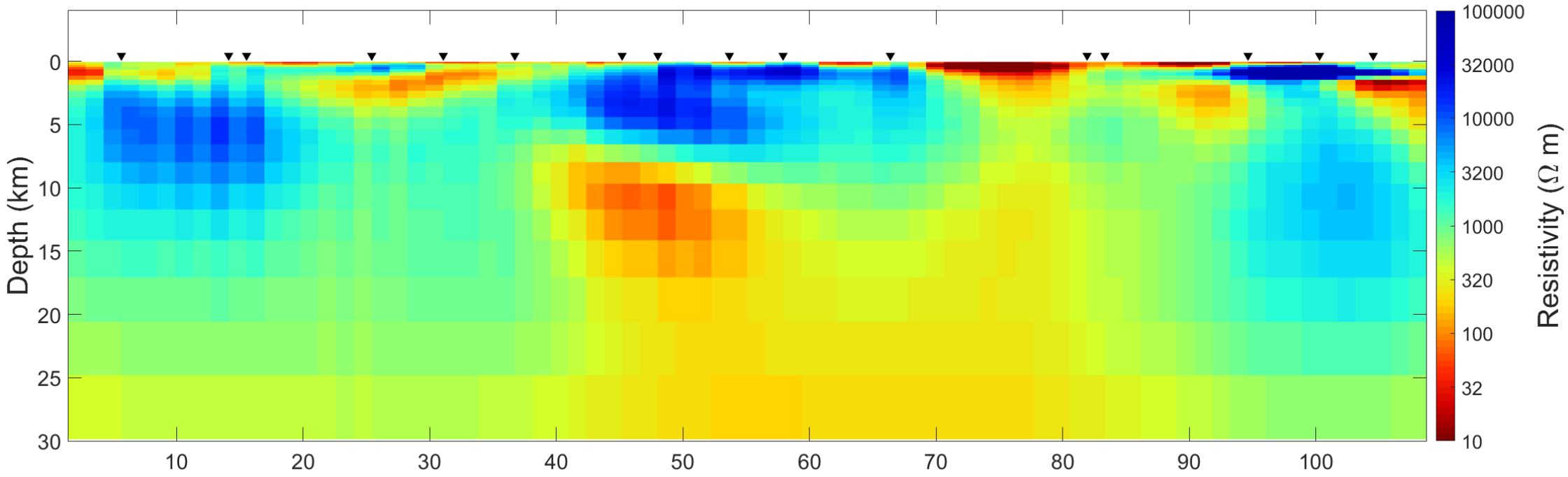


Seismic velocity (Vs)



Resistivity and gravity

Gravity data



Conclusions

1. Local crustal modeling is crucial for accurate calculation of geoneutrino
2. Geochemical data only available on the surface, but geophysical data can reach deep
3. Geophysics can provide crustal structure and help identify rock types in 3D
4. Intrinsic non-uniqueness and ambiguity in geophysics:
   - **Multi-physical approach and data/model integration for high-resolution structure and UQ**
   - More MT data and seismic dense array data
   - Extensive laboratory tests for reliable mapping from (3) physical models to rock types
   - More geochemical sampling for U/Th abundance at more locations

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GMES group members of SUSTech

GMES

Geophysical Multimodal Exploration @ SUSTech

THANK YOU

谢 谢！

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