國立中央大學
應用地質研究所
National Central University
Graduate Institute of Applied Geology

Geothermal Resource Evaluation of the Tatun Volcano Group (TVG) Area, Northern Taiwan, inferred from multi-geophysical methods

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Date: 2023/04/28

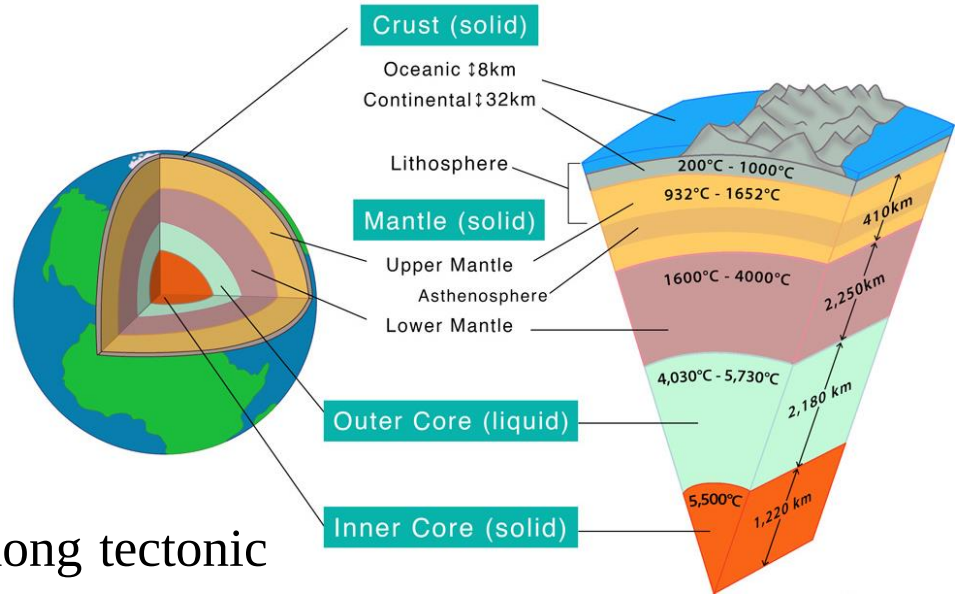
Outline

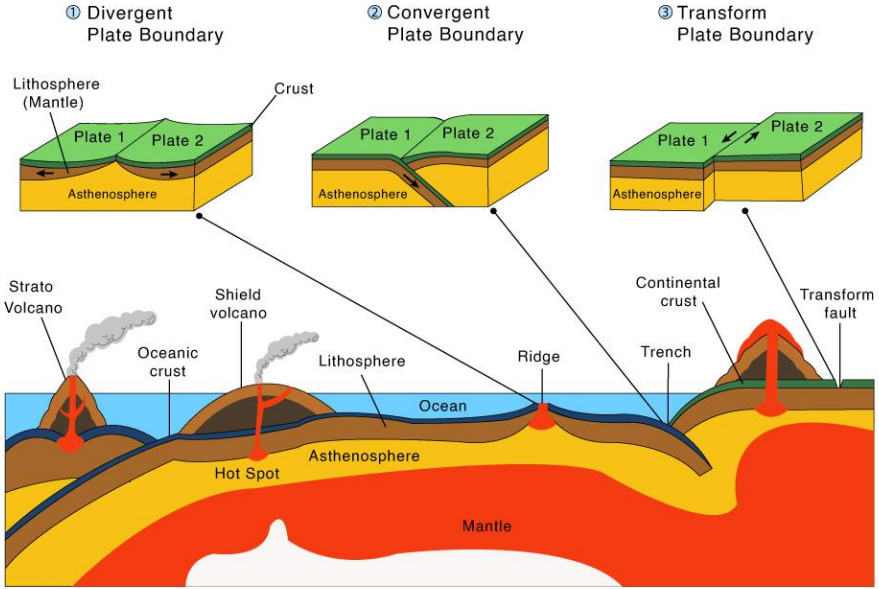
- Introduction
  - What is Geothermal?
  - Geological background: Tatun volcano group
- Methodologies
  - Geo-magnetic survey
  - Borehole data
- Results & Discussion
- Conclusions
- Future works

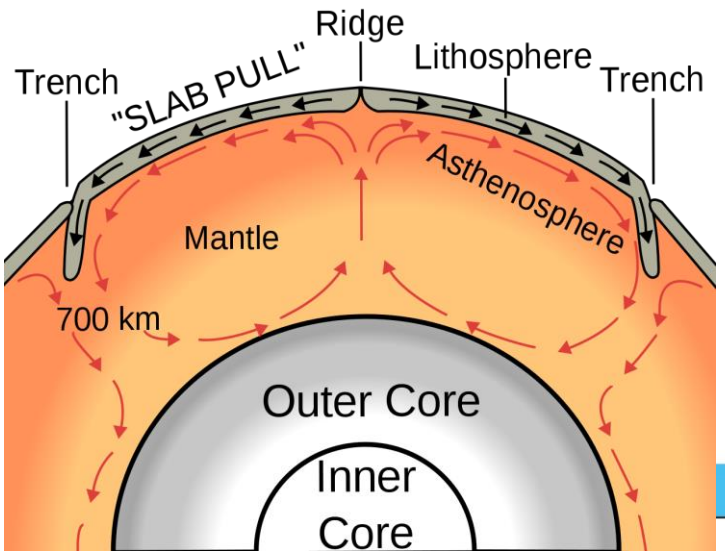
Introduction

What is geothermal energy?

- Geothermal energy is the heat from the earth
- The heat increase with depth
- Geothermal energy is exposed to the surface as a result of Earth's cooling mechanism (Convection process)
- The geothermal tends to be strongest along tectonic plate boundaries

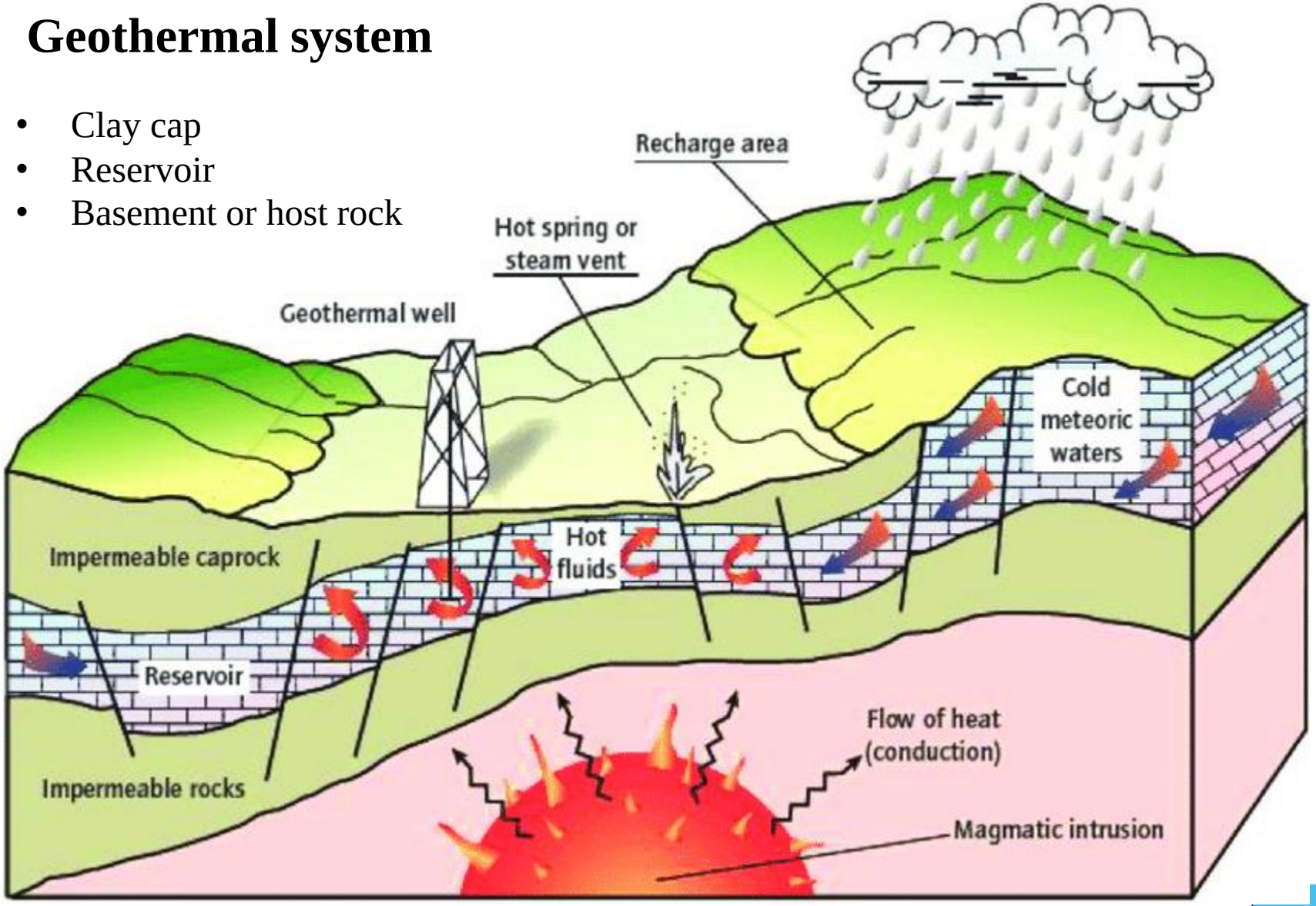




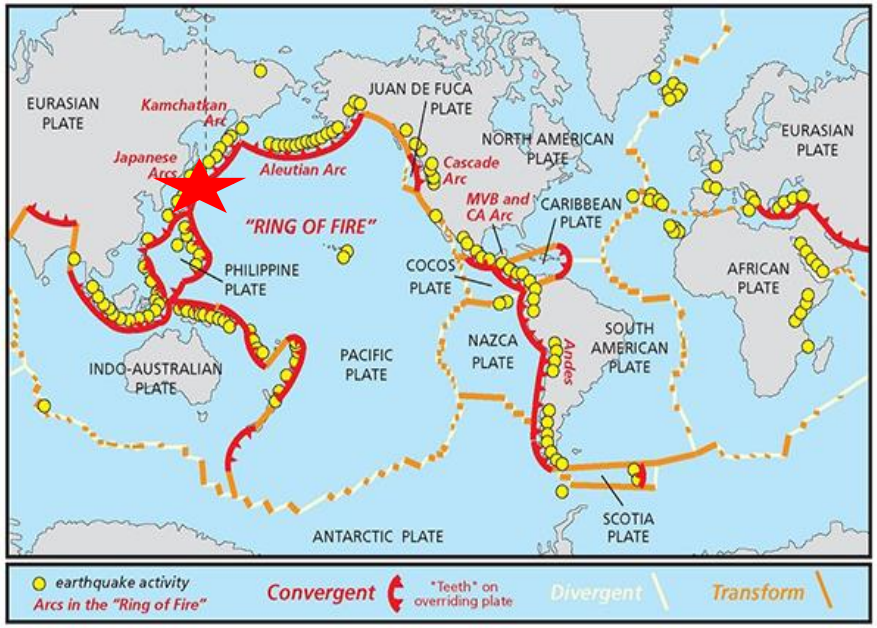


Geothermal system

- Clay cap
- Reservoir
- Basement or host rock



Geological background



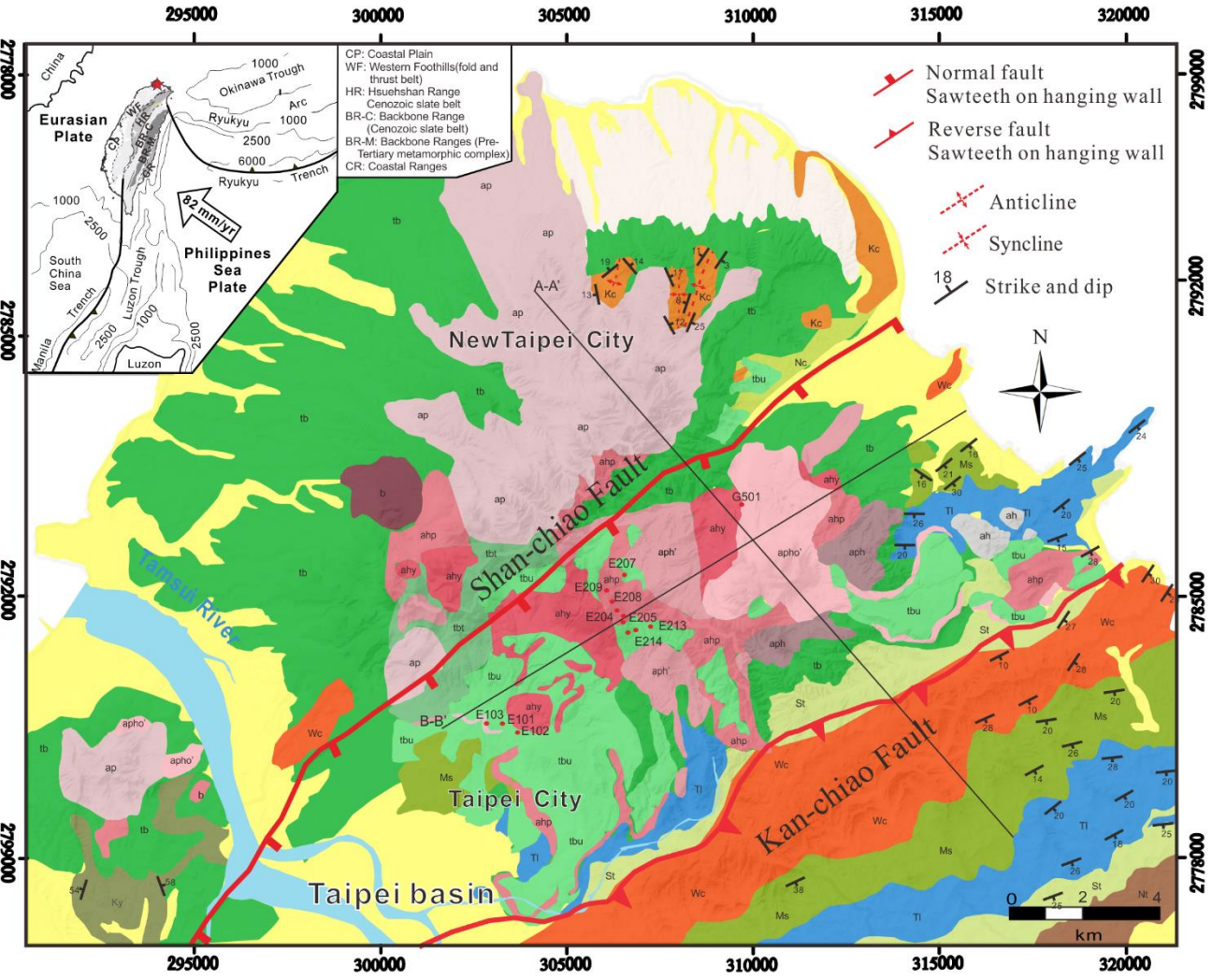
- Most of Taiwan is currently undergoing crustal shortening
- Northern Taiwan is experiencing extensional deformation.

- The TVG multi-vent volcano group covers an area of approximately 400 km^2 on the northern tip of Taiwan.
- The TVG is composed of more than 20 Quaternary-age volcanoes.

Taiwanese Ministry of Science and Technology
https://www.youtube.com/watch?v=M5rnPO1h-ro&t=1s&ab_channel=sunartscience

Regional geology

Tatun Volcano Group (TVG)



Legend

- Recent
  - Alluvium
- Pleitocene Pliocene
  - Tks — Hsiangshan Facies Toukoshan Formation
  - Kc — Kuechulin Formation
- Miocene
  - Nc — Shangfuchi Sandstone Nanchuang Formation
  - Nt — Nankang-Tsoho Formation
  - St — Shinti Formation
  - Tl — Taliao Formation
  - Ms — Mushan Formation
  - Wc — Wuchihshan Formation
- Pleitocene
  - Pyroclastic
  - Lava Flows
    - ah — Horblende andesite
    - ahy — Hypersthene hornblence andesite
    - ahp — Two-pyrocene hornblende Andesite
    - aph — Hornblende two-pyrocene andesite
    - aph' — Hornblende-bearing two-pyrocene andesite
    - ap — Two-pyrocene andesite
    - apho' — Olivine-bearing hornblende two-pyrocene andesite
    - b — Basal
  - Tuff Breccias
    - tbu — Upper tuff breccia
    - tb — Tatunshan tuff breccia
    - tbt — Lower tuff breccia

Purpose

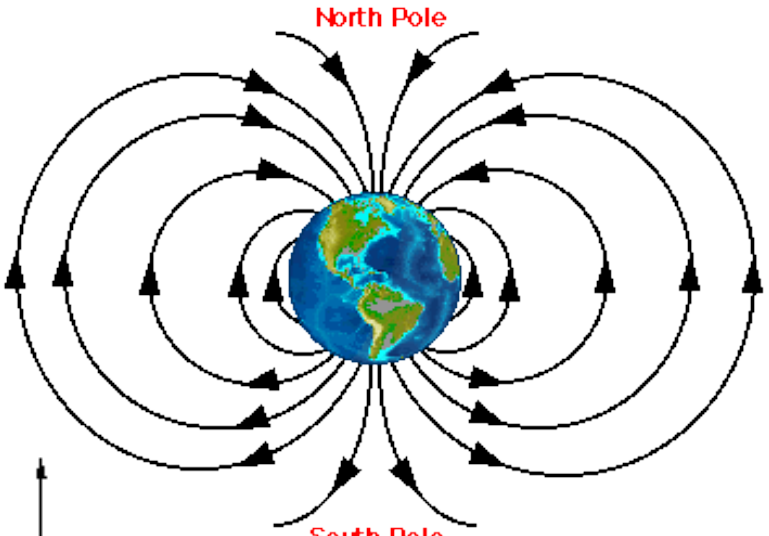
- Locating the heat source of the TGV geothermal system.
- Estimate the boundaries of the TGV geothermal system

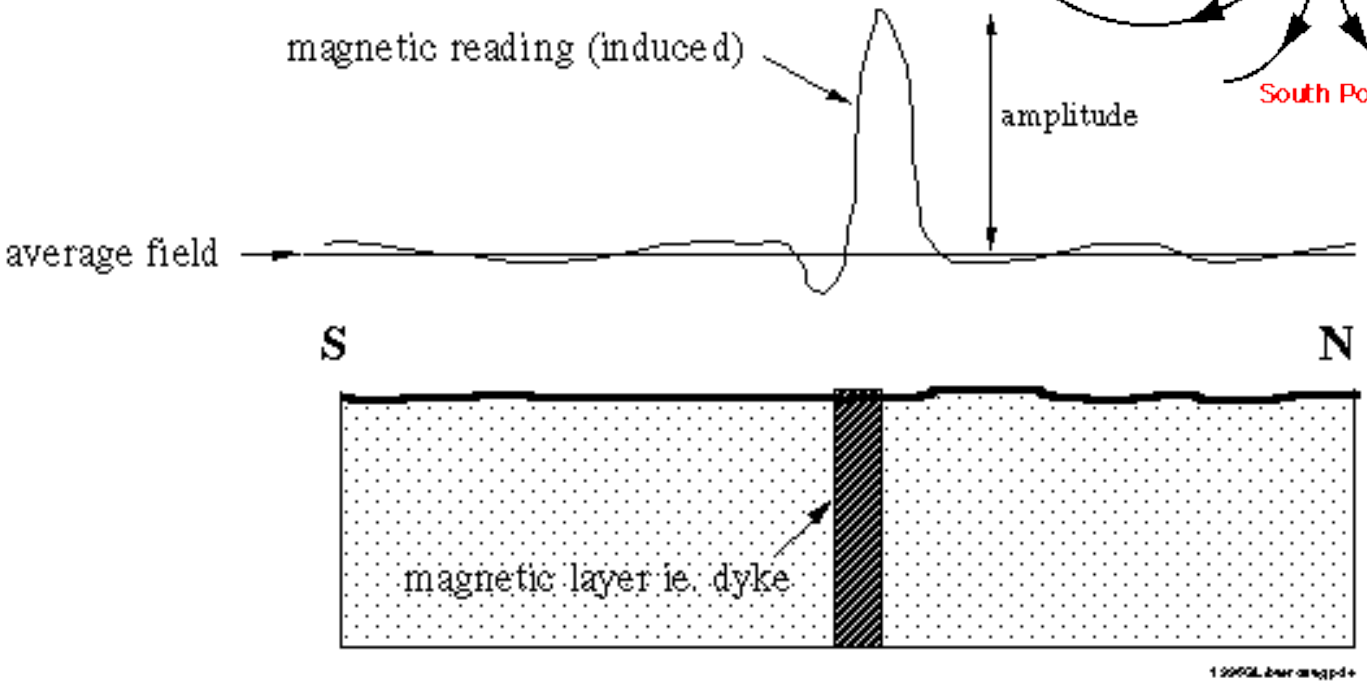
=> Create a design for a field survey/field investigation

- ❑ Reevaluate the viability of developing the TVG geothermal system.
- ❑ Provides an updated conceptual model of the TVG

The basic principle of Magnetic Survey

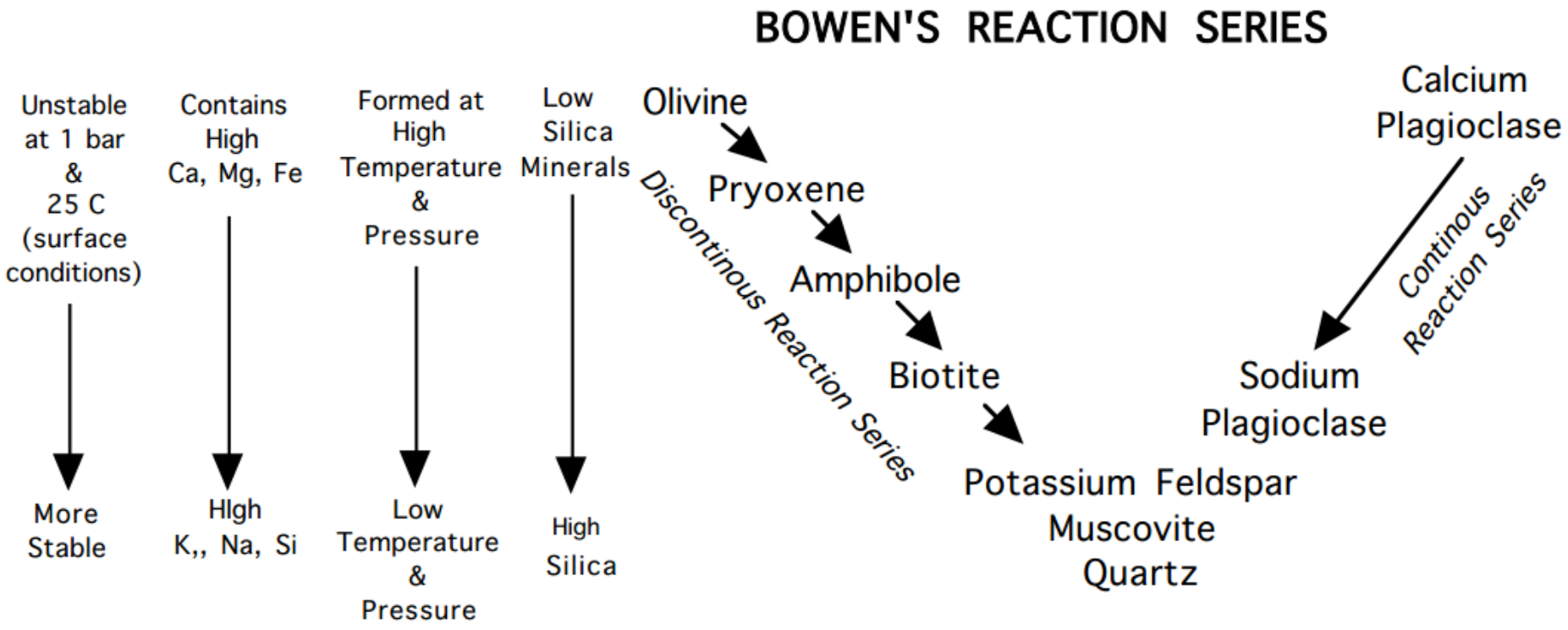
The magnetic survey is to investigate subsurface geology on the basis of the anomalies in the earth's magnetic field resulting from the magnetic properties of the underlying rocks





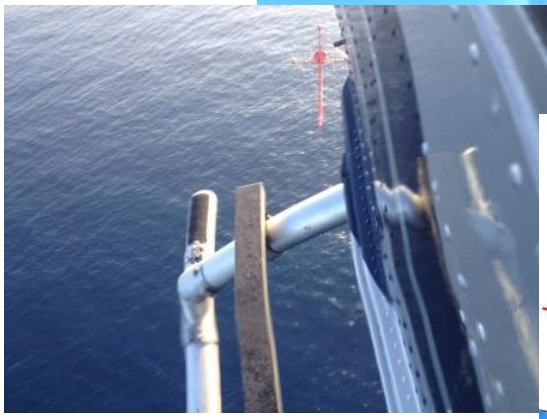
Mariita, 2007

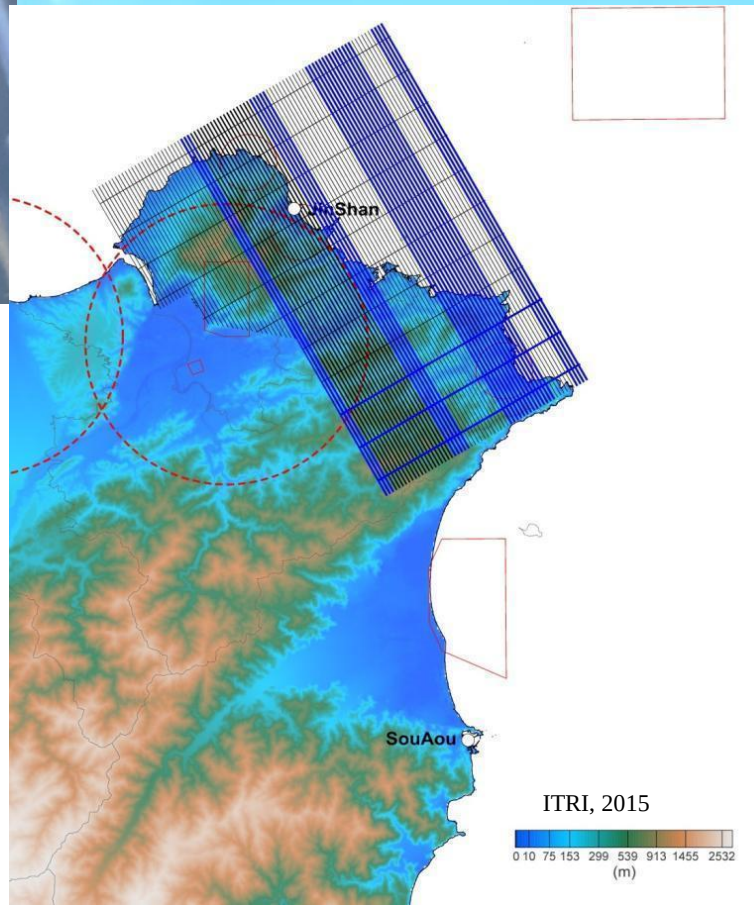
Physical Conditions and Bowen's Reaction Series



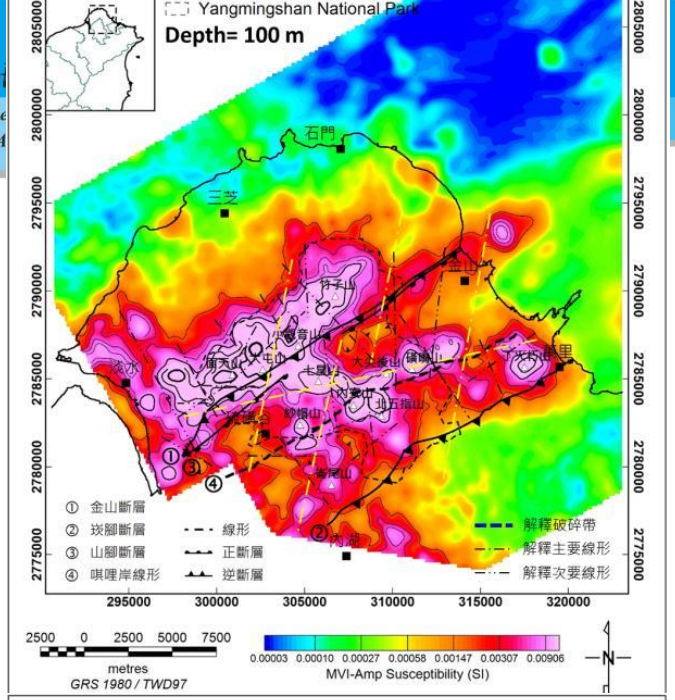
Airborne Magnetic Survey

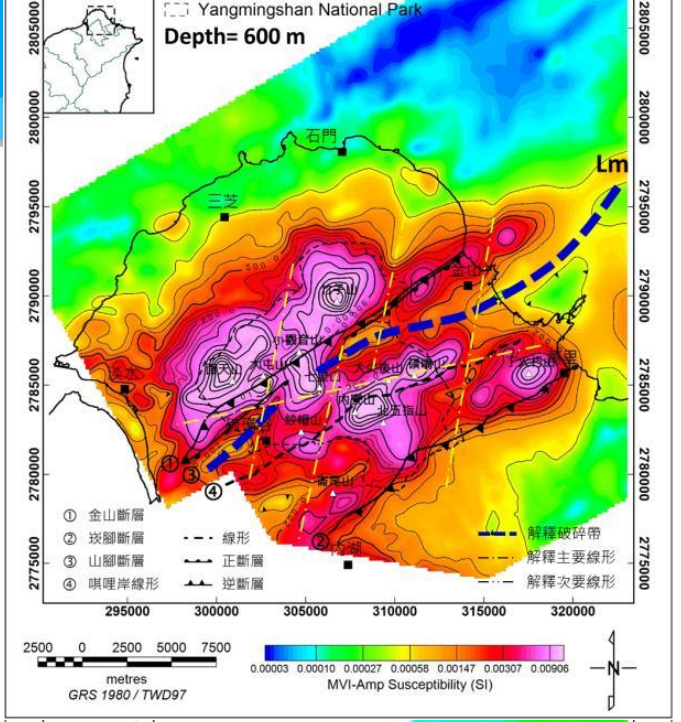
The field survey was completed in 2013

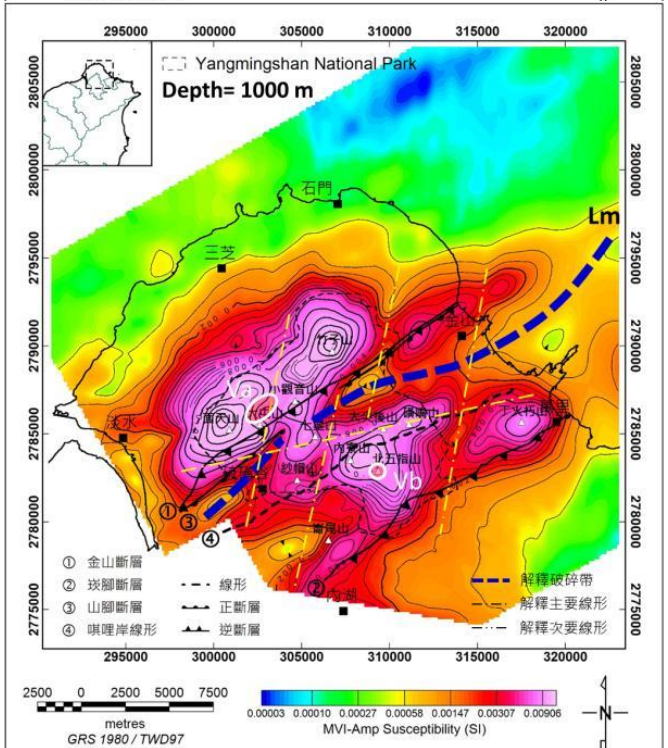


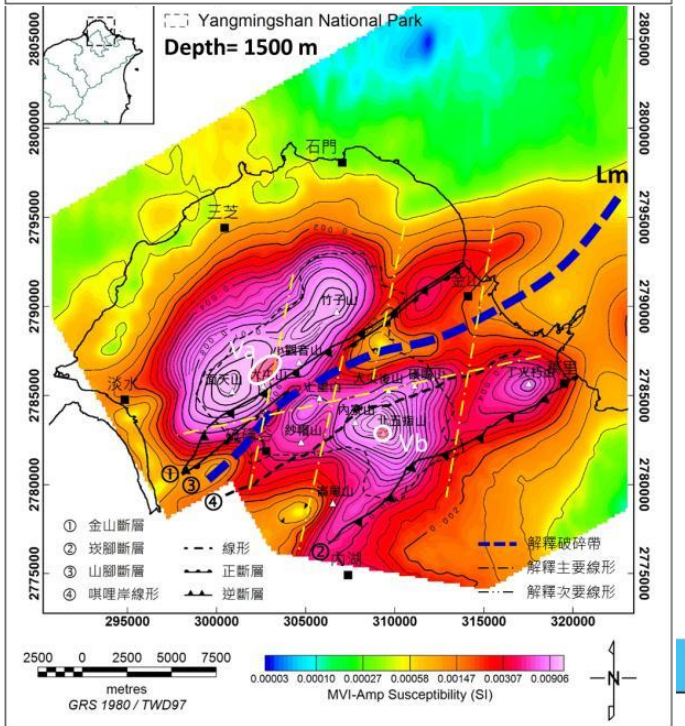


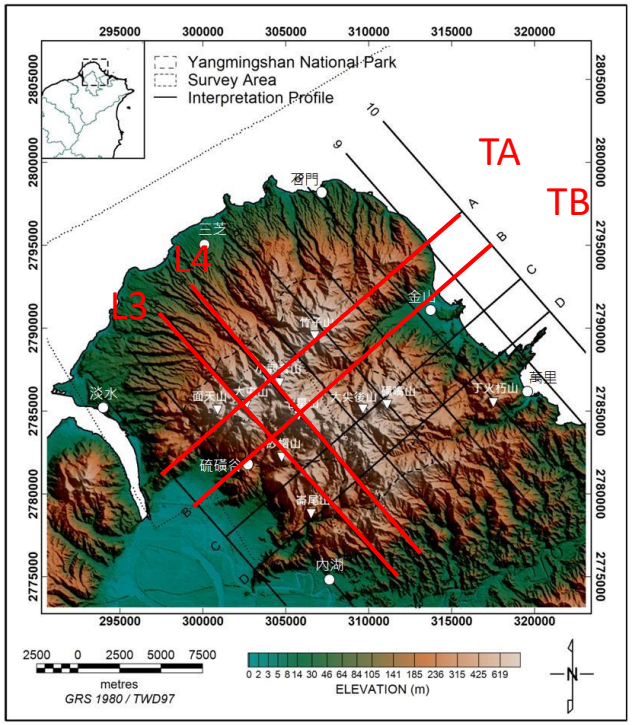
Results & Discussion

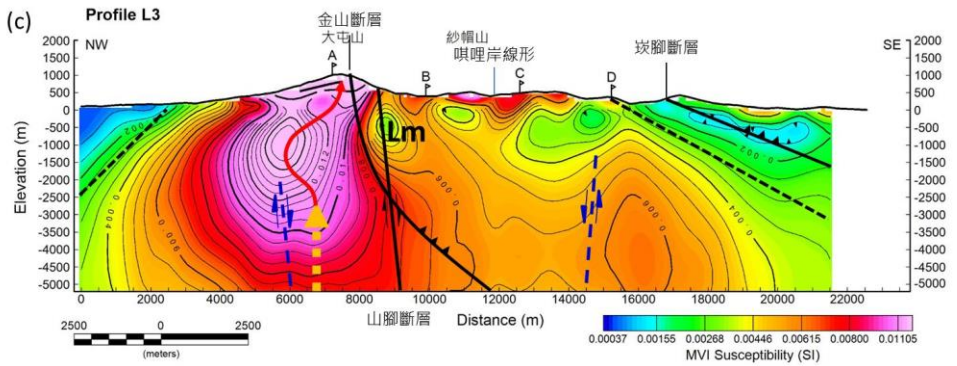


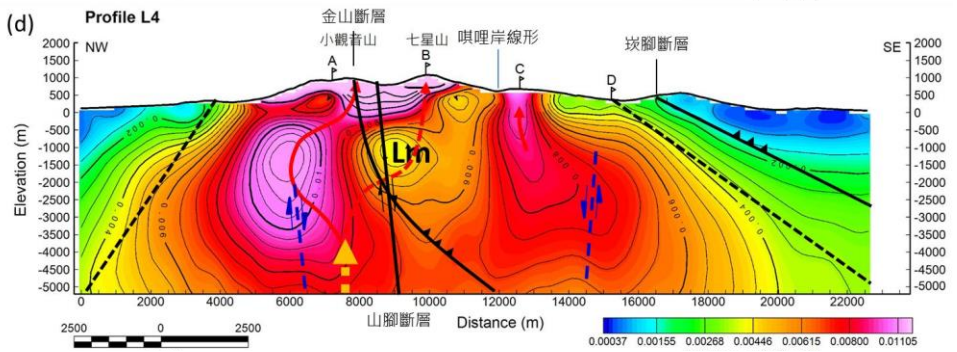


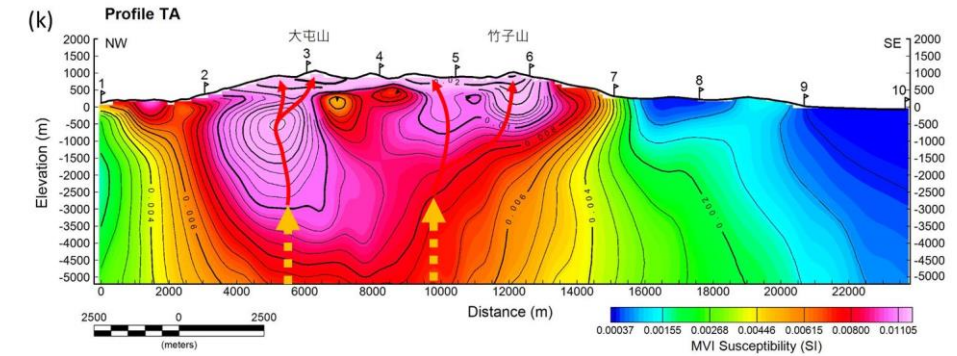


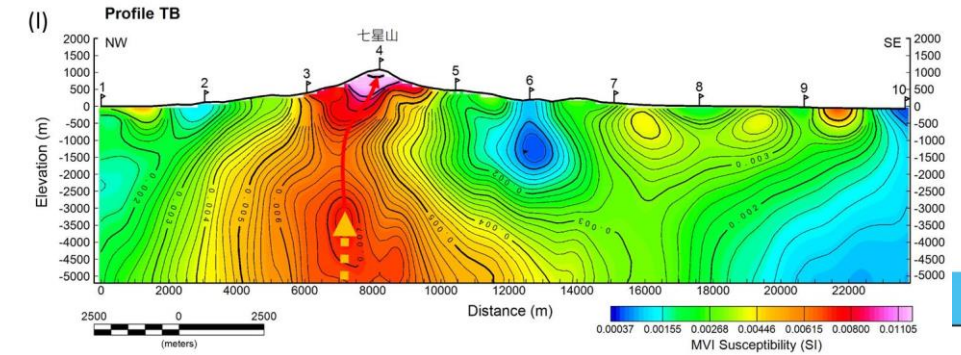



Yangmingshan National Park
Survey Area
Interpretation Profile
TA
TB
L3
L4
A
B
C
D
9
10
淡水
三芝
金山
萬里
硫磺谷
內湖
295000
300000
305000
310000
315000
320000
2805000
2800000
2795000
2790000
2785000
2780000
2775000
2500 0 2500 5000 7500
metres
GRS 1980 / TWD97
0 2 3 5 8 14 30 46 64 84 105 141 185 236 315 425 619
ELEVATION (m)
N

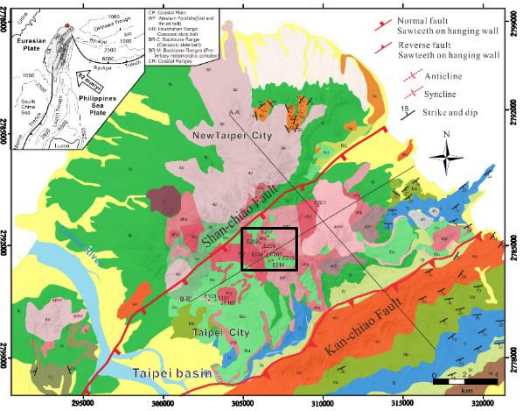

(c)
Profile L3
金山斷層
大屯山
紗帽山
淇哩岸線形
崁腳斷層
NW
SE
A
B
C
D
Lm
Elevation (m)
山腳斷層
Distance (m)
2500 0 2500
(meters)
0.00037 0.00155 0.00268 0.00446 0.00615 0.00800 0.01105
MVI Susceptibility (SI)


(d)
Profile L4
金山斷層
小觀音山
七星山
淇哩岸線形
崁腳斷層
NW
SE
A
B
C
D
Lm
Elevation (m)
山腳斷層
Distance (m)
2500 0 2500
0.00037 0.00155 0.00268 0.00446 0.00615 0.00800 0.01105

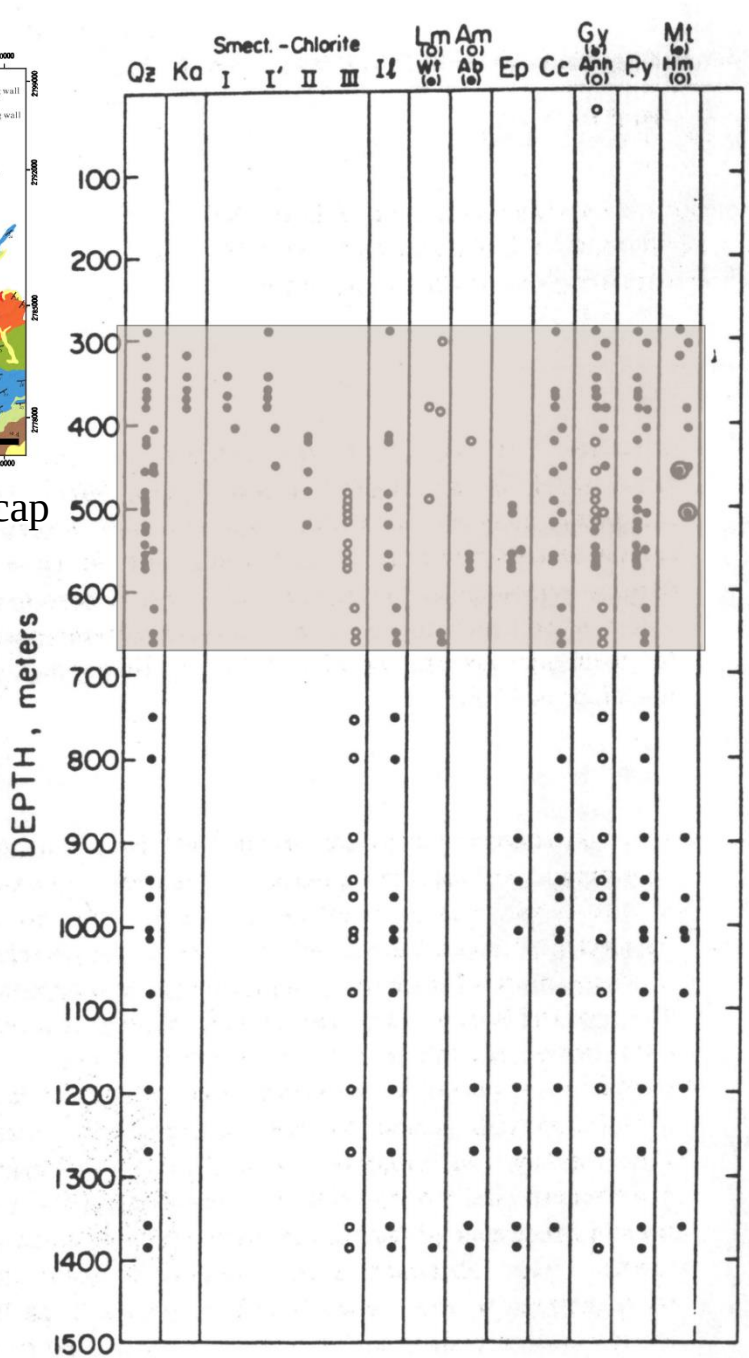

(k)
Profile TA
大屯山
竹子山
NW
SE
Elevation (m)
Distance (m)
2500 0 2500
(meters)
0.00037 0.00155 0.00268 0.00446 0.00615 0.00800 0.01105
MVI Susceptibility (SI)

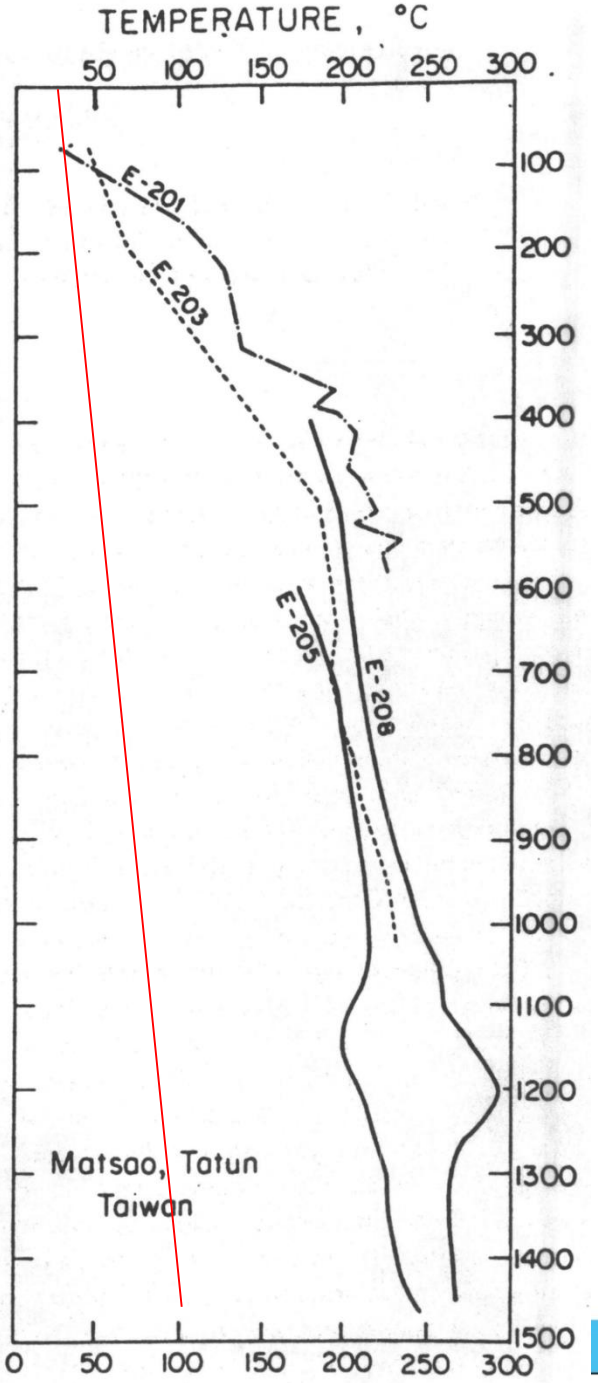

(l)
Profile TB
七星山
NW
SE
Elevation (m)
Distance (m)
2500 0 2500
(meters)
0.00037 0.00155 0.00268 0.00446 0.00615 0.00800 0.01105
MVI Susceptibility (SI)

ITRI, 2015

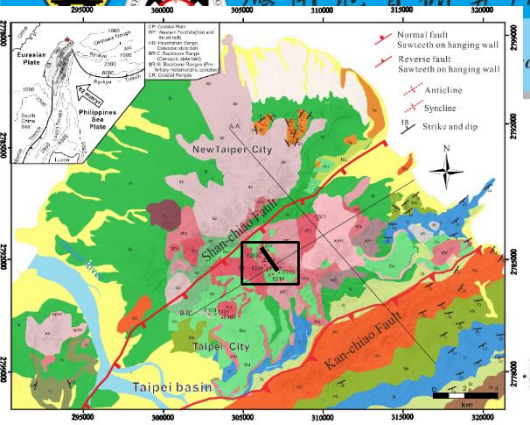


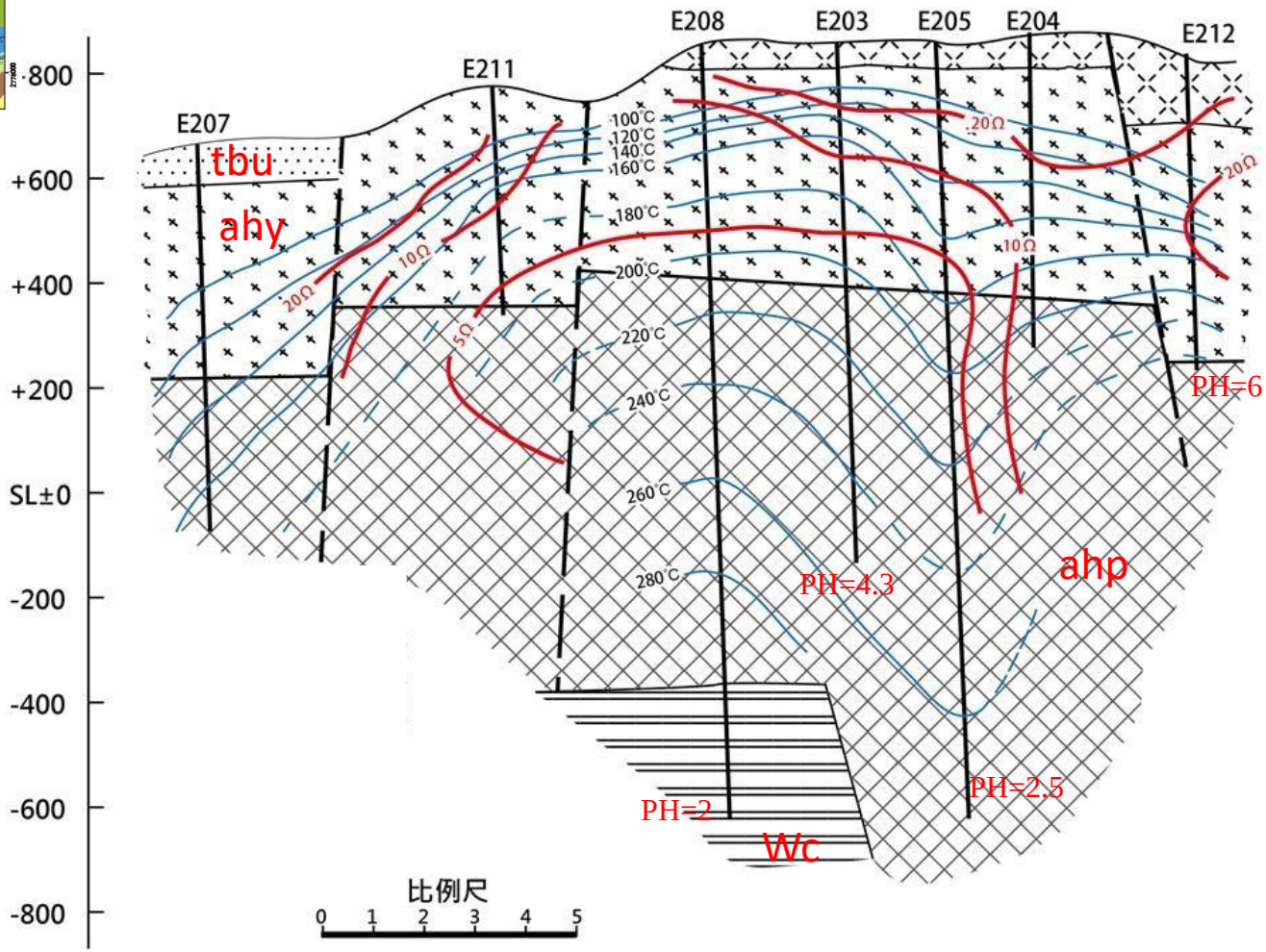
Clay cap

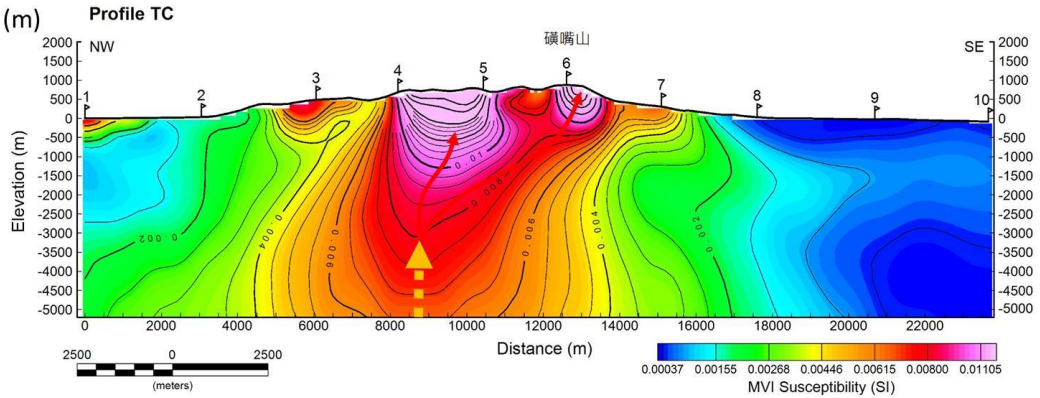


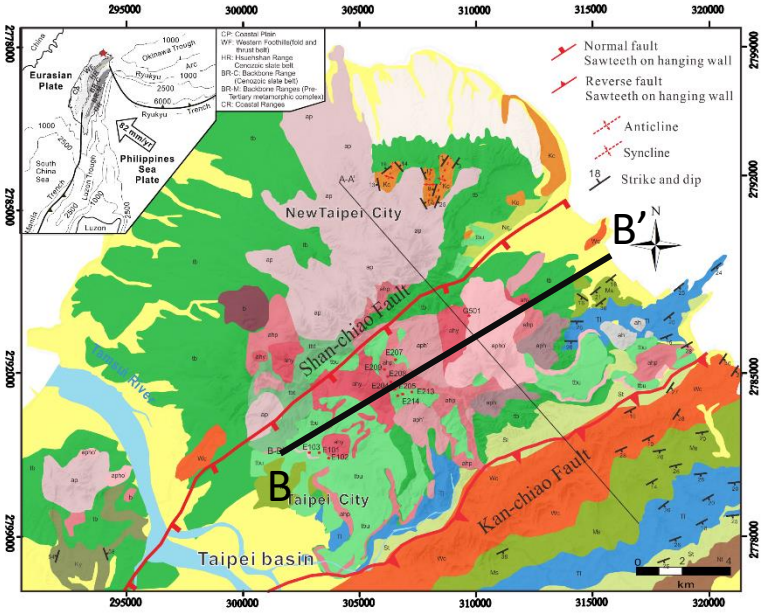


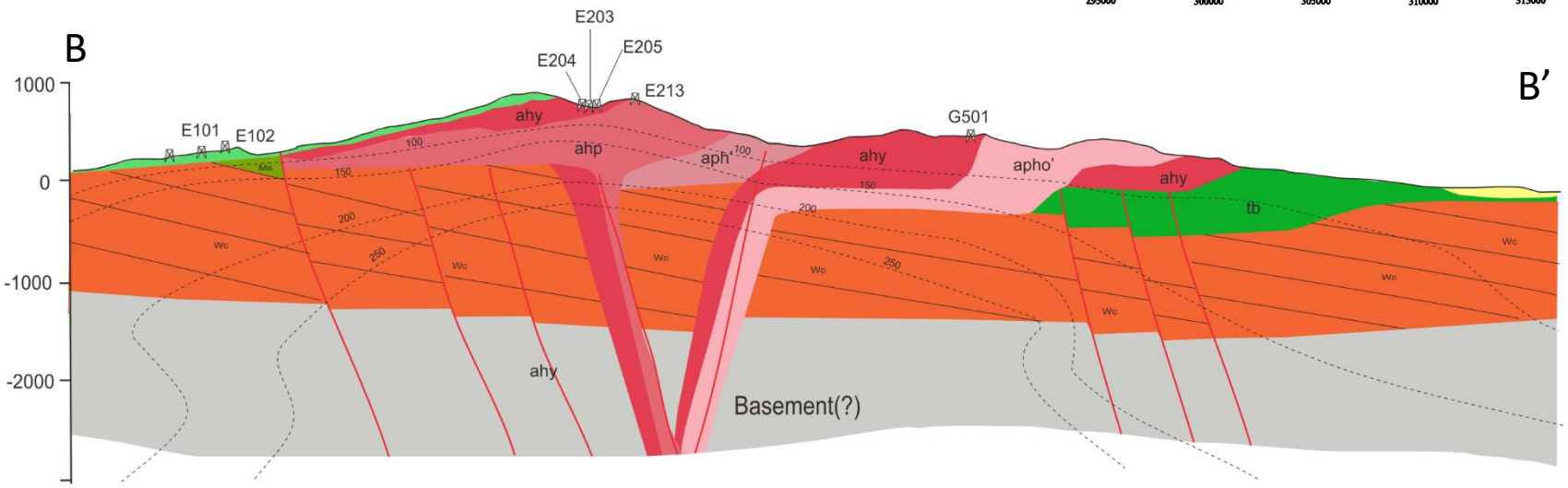
I: alkaline montmorillonite
I': Smectite (with mordenite and clinoptilolite)
II: Smectite-chlorite with laumotite
III: wairakite
Qz: Quartz
Ka: Kaolinite
Il: Illite
Lm: Laumotite, Wt: wairakite, Am: Analcime, Ab: Albite, Ep: Epidote, Cc: Calcite, Gy: Gypsum, Anh: anhudrite, Py: Pyrite, Mt: Magnetite, Hm: Hemaite

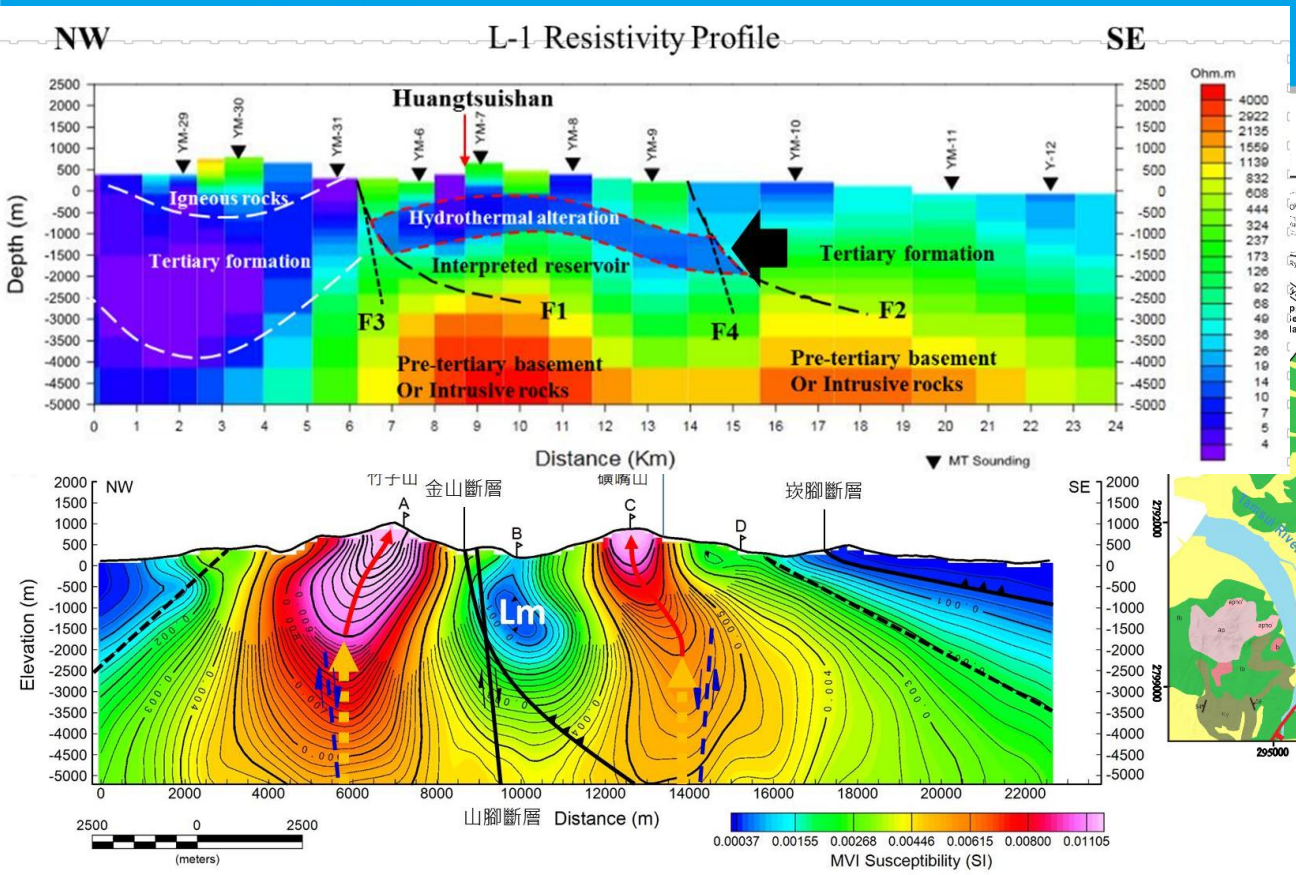

Normal fault
Sawteeth on hanging wall
Reverse fault
Sawteeth on hanging wall
Anticline
Syncline
Strike and dip
New Taipei City
Shan-chiao Fault
Kan-chiao Fault
Taipei City
Taipei basin
Eurasian Plate
Philippines Sea Plate


E207
E211
E208
E203
E205
E204
E212
tbu
ahy
ahp
Wc
PH=6
PH=4.3
PH=2.5
PH=2
100°C
120°C
140°C
160°C
180°C
200°C
220°C
240°C
260°C
280°C
20Ω
10Ω
5Ω
+800
+600
+400
+200
SL±0
-200
-400
-600
-800
比例尺
0 1 2 3 4 5

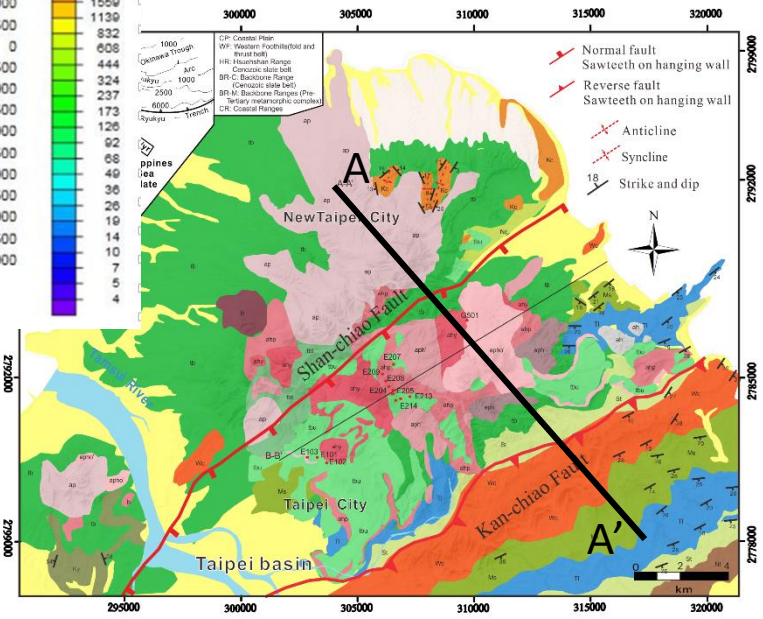

(m)
Profile TC
NW
SE
磺嘴山
Elevation (m)
Distance (m)
(meters)
MVI Susceptibility (SI)
0.00037 0.00155 0.00268 0.00446 0.00615 0.00800 0.01105

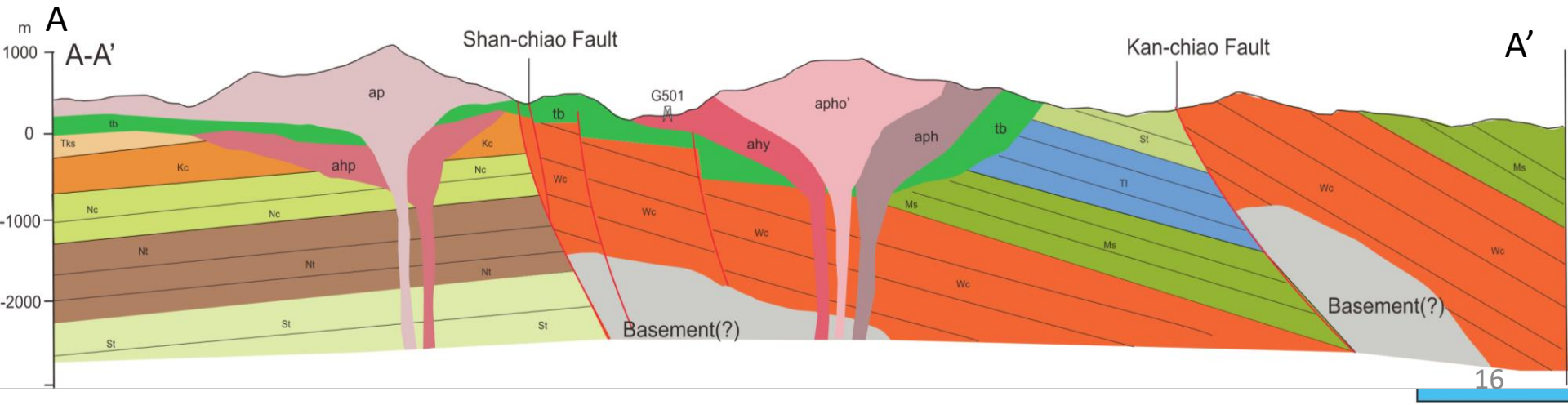

Eurasian Plate
Philippines Sea Plate
Normal fault
Sawteeth on hanging wall
Reverse fault
Sawteeth on hanging wall
Anticline
Syncline
Strike and dip
NewTaipei City
Shan-chiao Fault
Kan-chiao Fault
Taipei City
Taipei basin
B
B'
km


B
B'
E101
E102
E203
E204
E205
E213
G501
ahy
ahp
aph'
apho'
tb
Wc
Basement(?)


NW
L-1 Resistivity Profile
SE
Huangtsuishan
YM-29
YM-30
YM-31
YM-6
YM-7
YM-8
YM-9
YM-10
YM-11
Y-12
Igneous rocks
Tertiary formation
Hydrothermal alteration
Interpreted reservoir
F1
F2
F3
F4
Tertiary formation
Pre-tertiary basement
Or Intrusive rocks
Pre-tertiary basement
Or Intrusive rocks
Depth (m)
Distance (Km)
Ohm.m
4000
2922
2135
1559
1139
832
608
444
324
237
173
126
92
68
49
36
26
19
14
10
7
5
4
MT Sounding

NW
竹子山
金山斷層
噴嘴山
崁腳斷層
SE
A
B
C
D
Lm
Elevation (m)
山腳斷層
Distance (m)
2500
0
2500
(meters)
0.00037
0.00155
0.00268
0.00446
0.00615
0.00800
0.01105
MVI Susceptibility (SI)

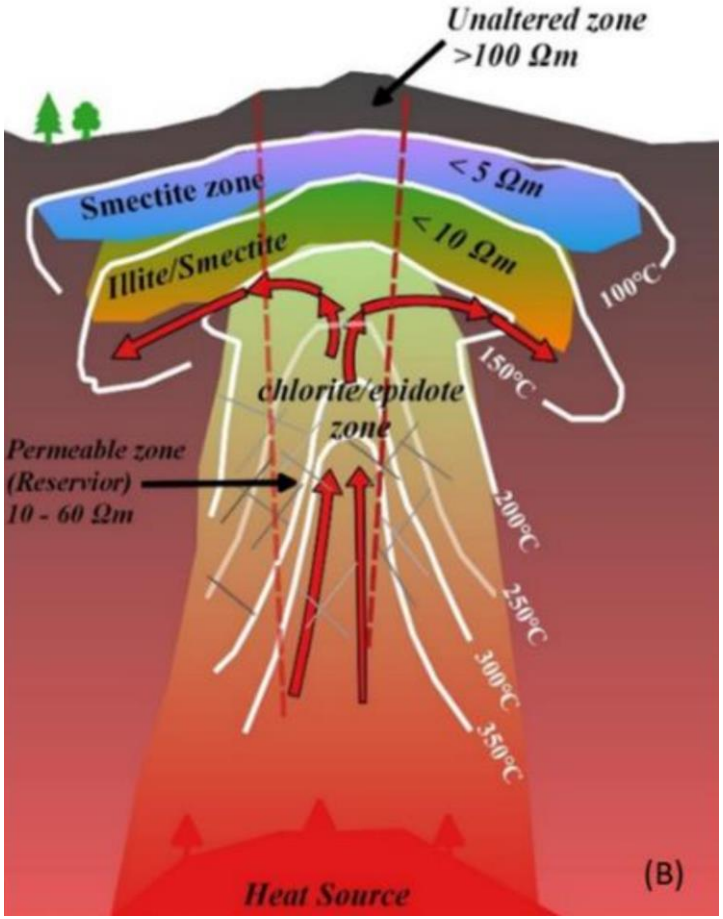

Normal fault
Sawteeth on hanging wall
Reverse fault
Sawteeth on hanging wall
Anticline
Syncline
Strike and dip
A
A'
NewTaipei City
Taipei City
Taipei basin
Shan-chiao Fault
Kan-chiao Fault
Tamsui River
km


m
A
A-A'
Shan-chiao Fault
Kan-chiao Fault
A'
ap
tb
G501
apho'
ahy
aph
ahp
Tks
Kc
Nc
Nt
St
Wc
Ms
Tl
Basement(?)
Basement(?)

Conclusions

- NE-SW trending faults define the major trend of recent volcanic activity and the extent of the geothermal system
- Kan-Chiao Fault is the boundary of TVG in the South-East
- Clay-cap located at 300-700m depth within Matsao area.
- Provide 2 cross-sections using borehole data and magnetic data

Geothermal system (volcanic type conceptual model)



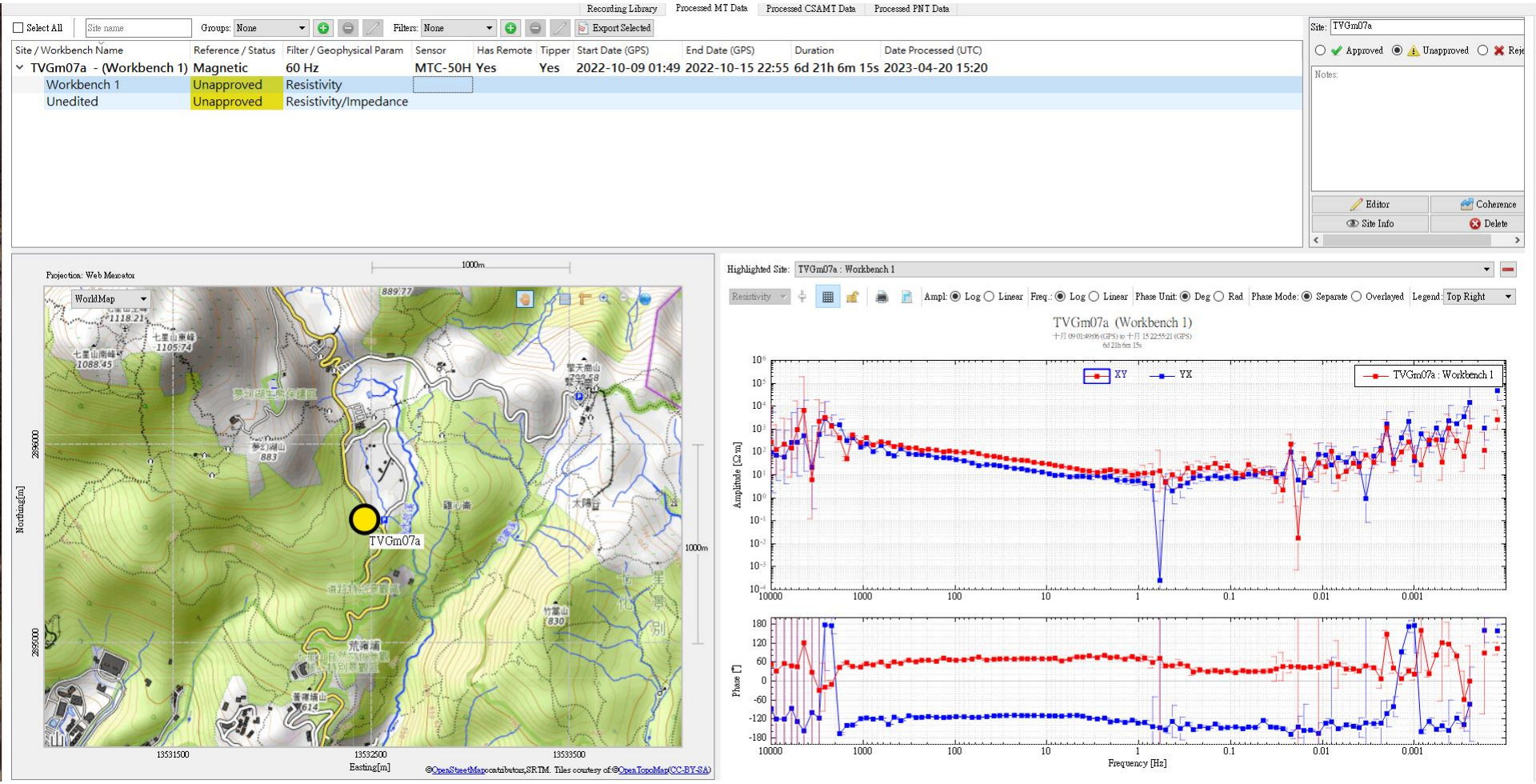
Johnston et al. (1992) and Cumming (2009)

- **Clay cap**: Low permeability (smectite and illite zone) low resistivity (<10 Ωm)
- **Reservoir**: High permeability zone consists of fluid (related to high-temperature mineral low resistivity but slightly higher than clay cap (10-60 Ωm)
- **Basement or host rock:** higher resistivity (>100 Ωm)

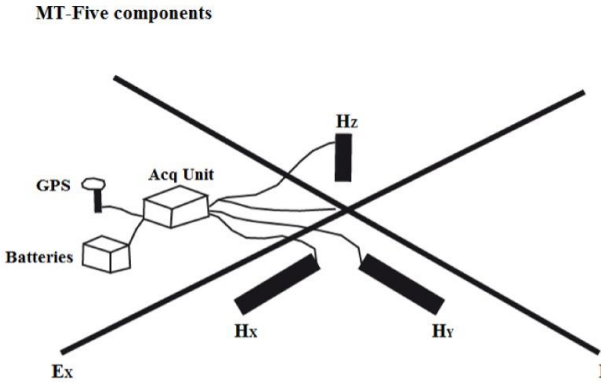
The main target for MT (Magnetotelluric) investigation

Proper MT can delineate the geothermal system model and guide well target zone.

Current work



Future work



+ geology
+geochemistry

Raw MT data

Advanced processing

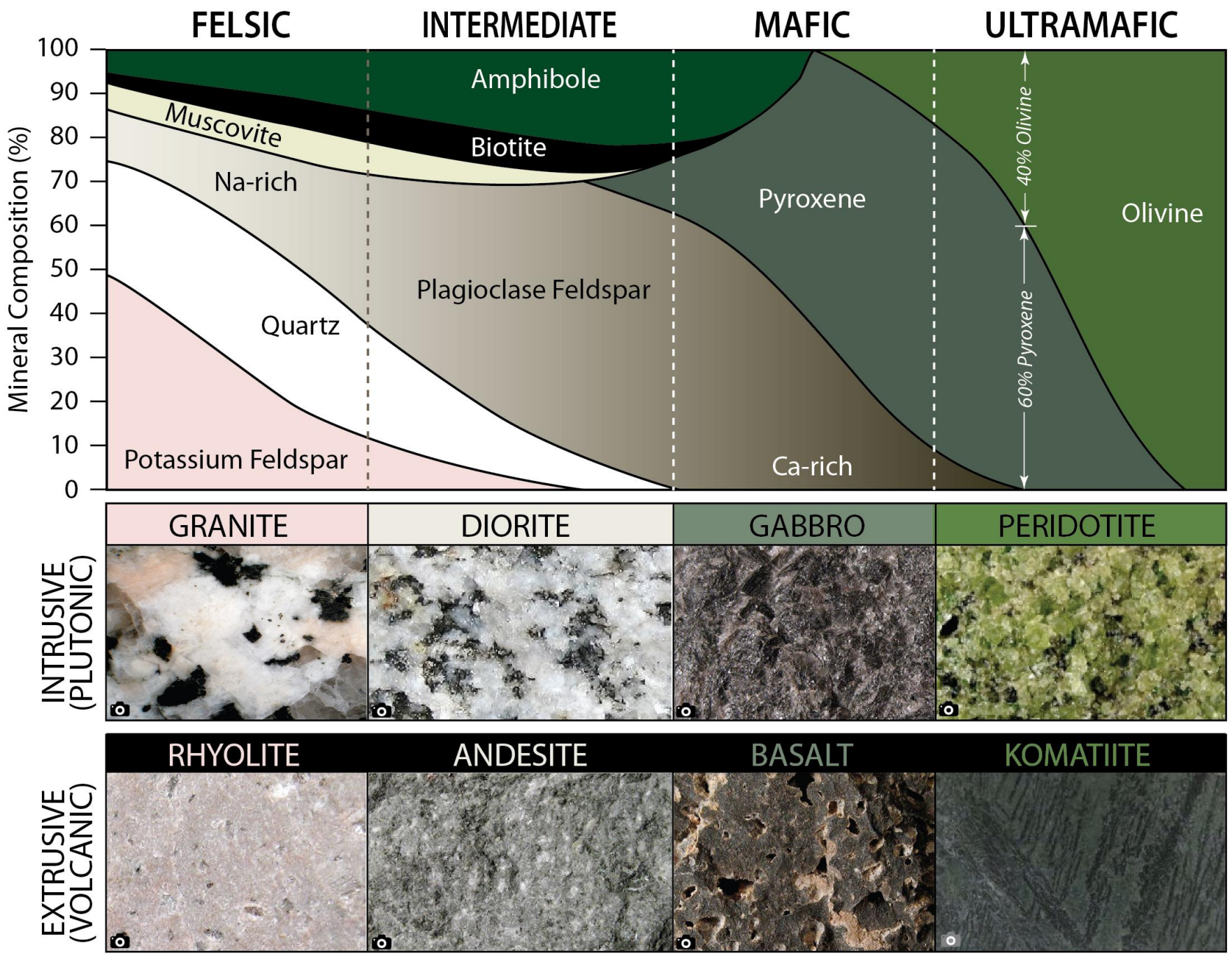
Geophys. Assessment

Resource Assessment & Well targeting

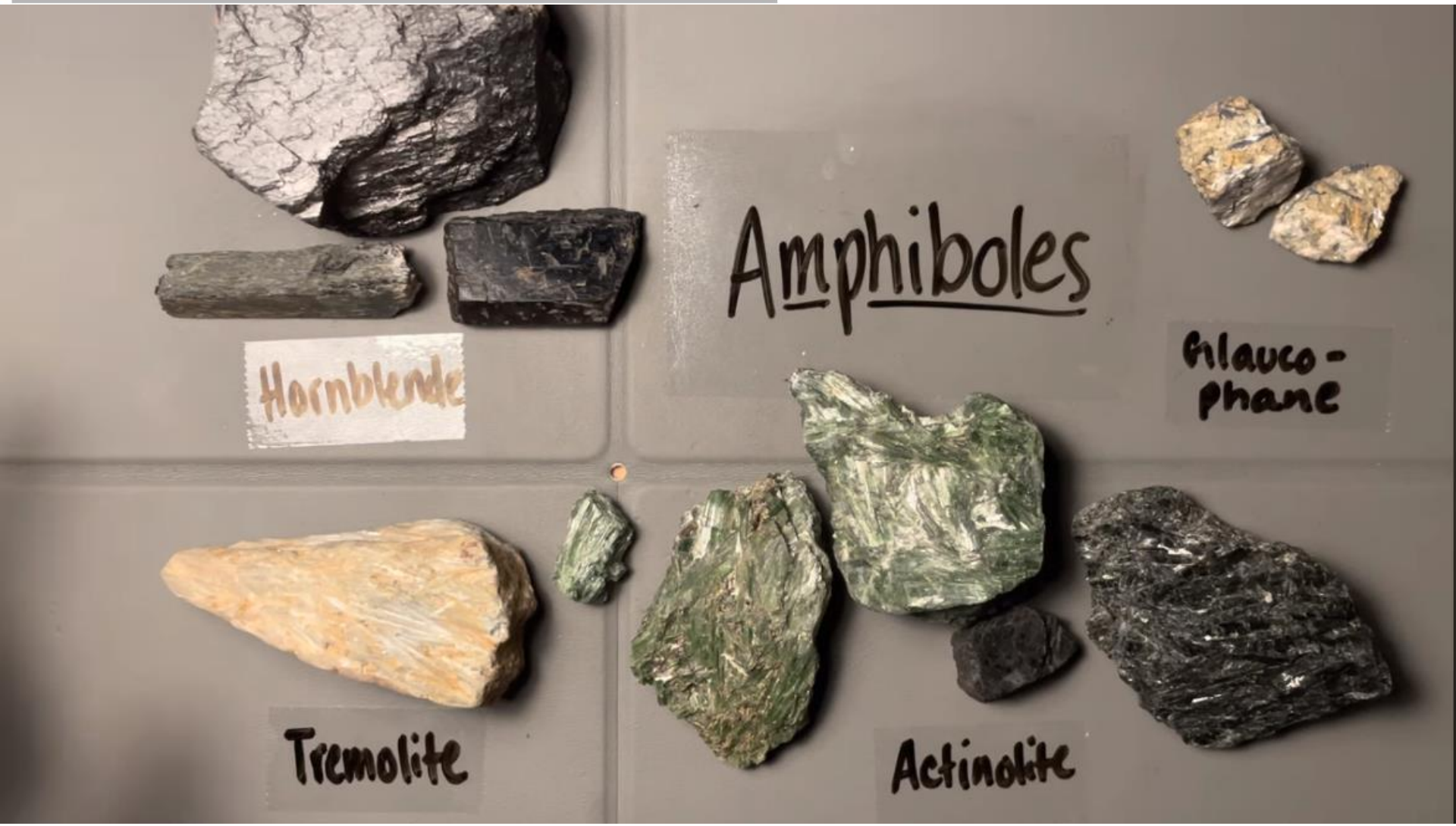
- Time-series analysis
- Static-shift correction (TEM/TDEM)
- 1D, 2D, 3D modeling. Inversion

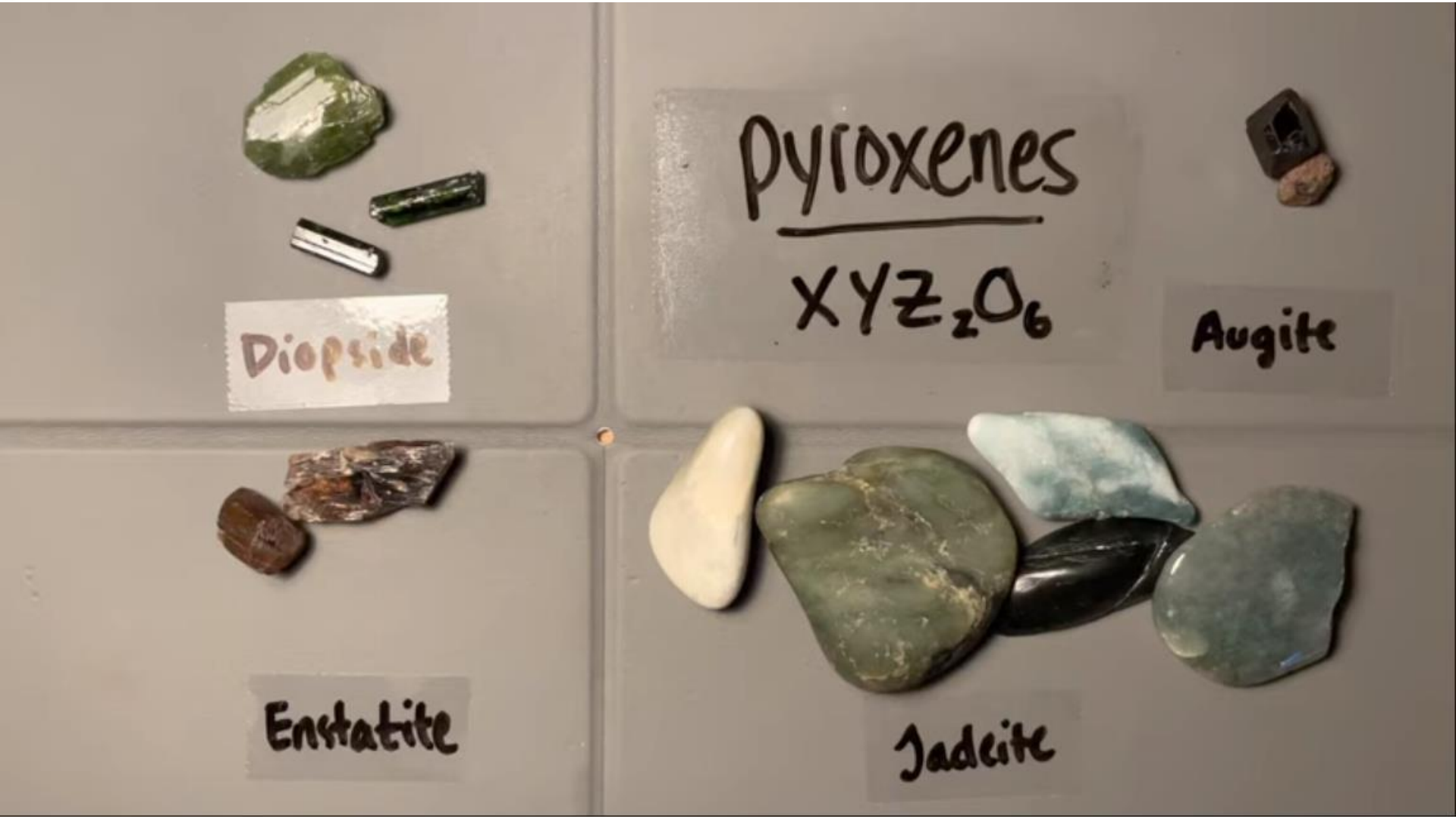
- Conductive clay cap
- Boundary of the reservoir
- Top of the reservoir
- Analysis of geological structure, fracture/permeable zone

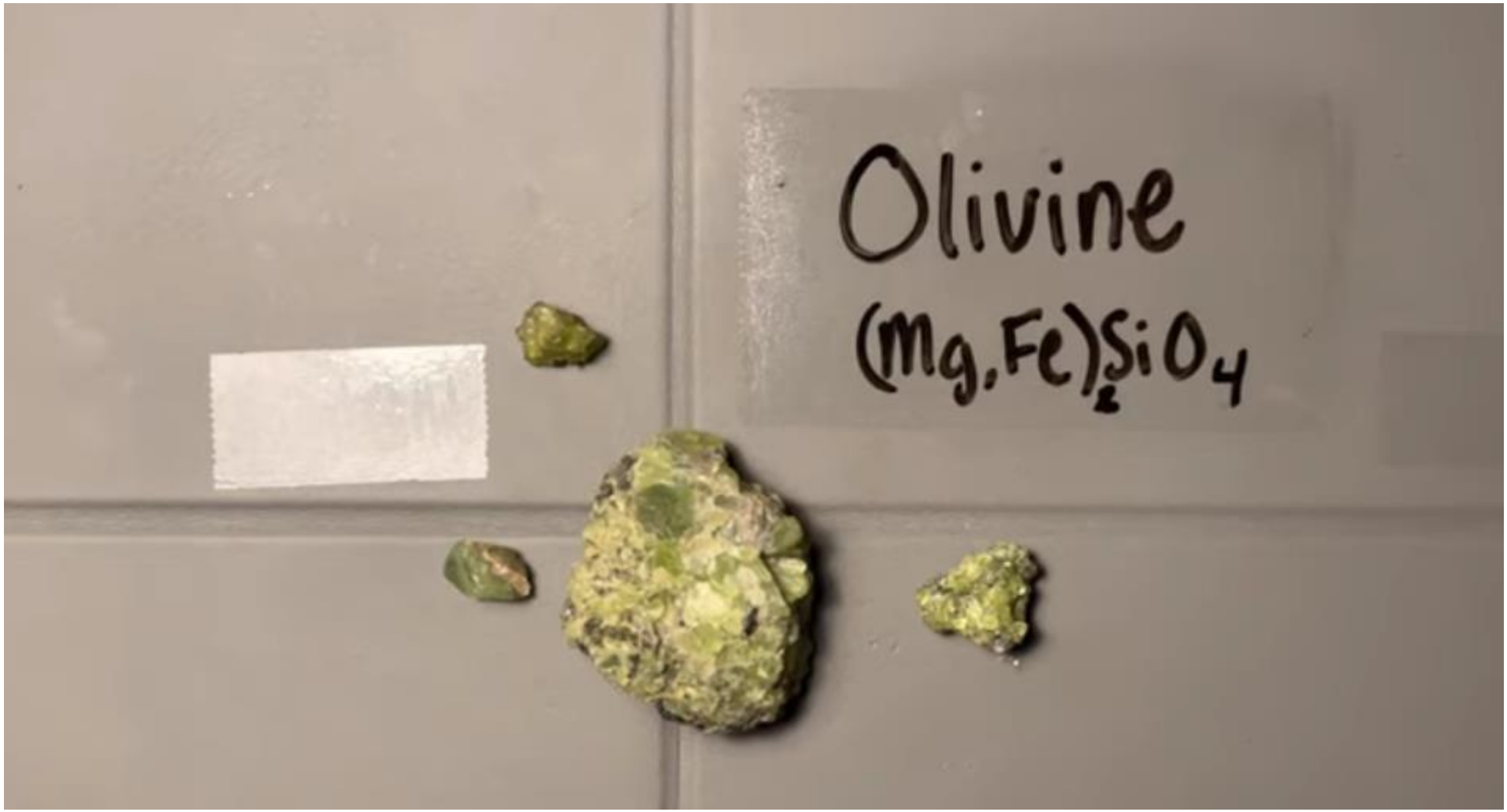

Thanks for your attention!



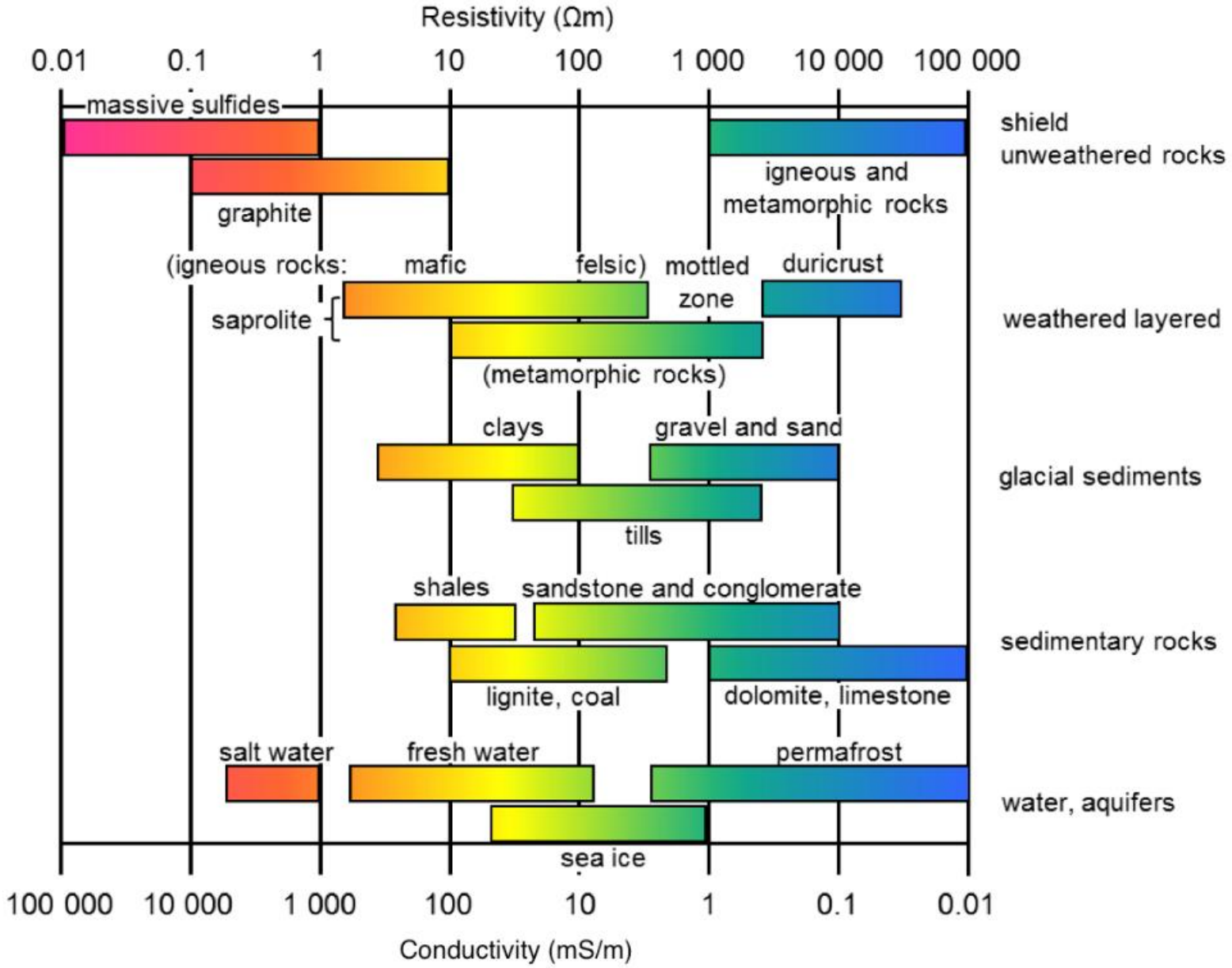
R. Weller/ Cochise College
K. Panchuk


Amphiboles
Hornblende
Glauco-
phane
Tremolite
Actinolite

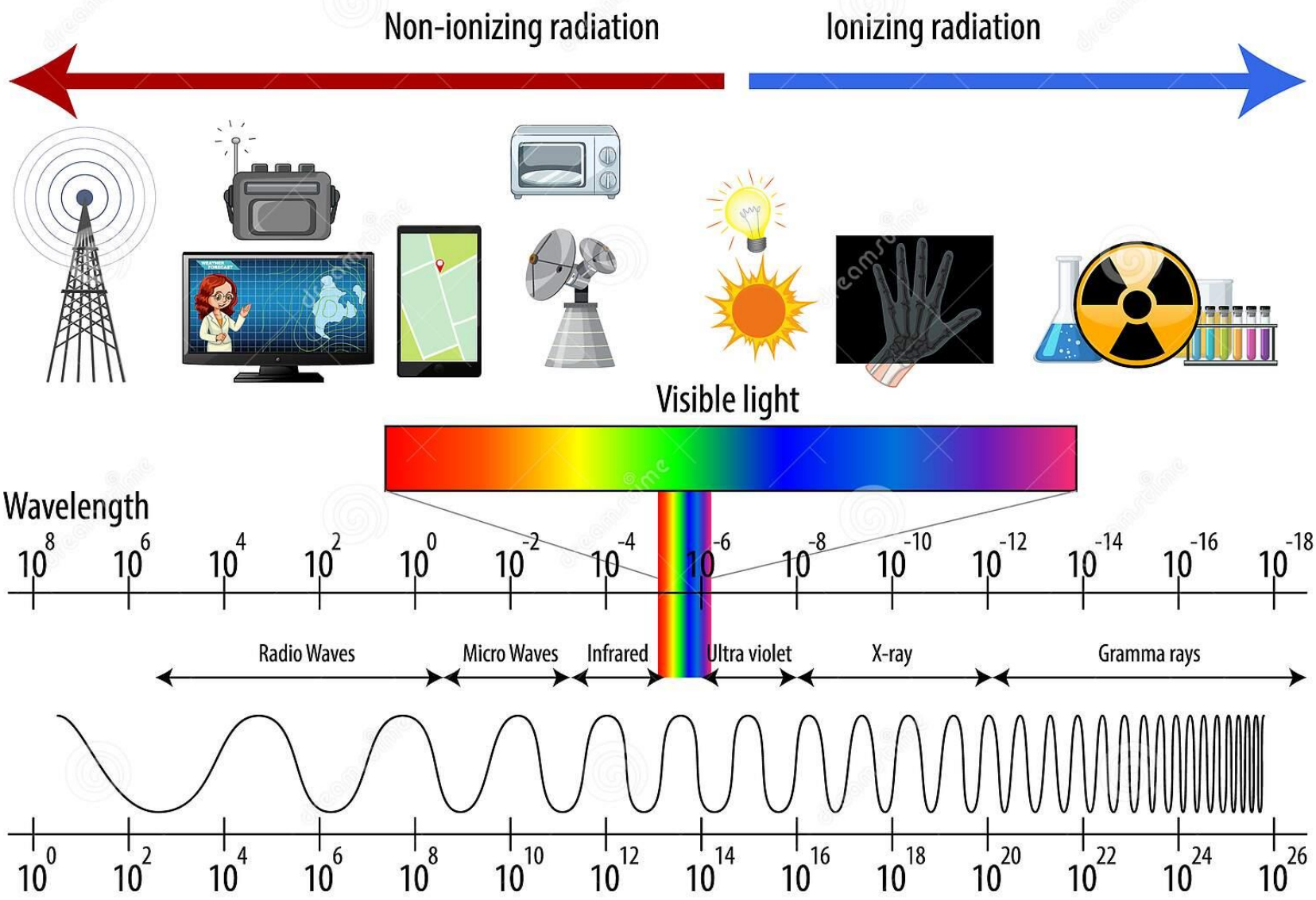

Pyroxenes
XYZ_2O_6
Diopside
Augite
Enstatite
Jadeite


Olivine
(Mg,Fe)2SiO4

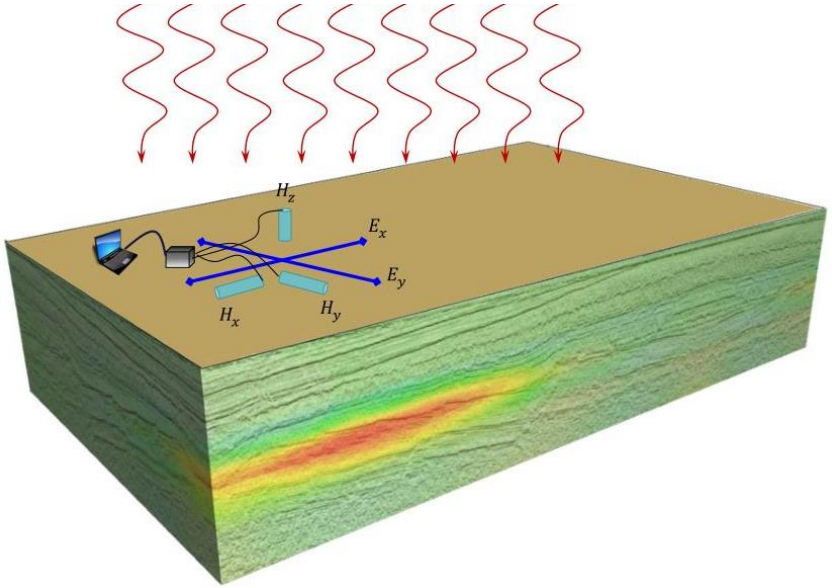

TikTok
@1day50videos


Resistivity (Ωm)
0.01
0.1
1
10
100
1 000
10 000
100 000
massive sulfides
graphite
(igneous rocks:
mafic
felsic)
mottled zone
duricrust
saprolite
(metamorphic rocks)
igneous and metamorphic rocks
shield unweathered rocks
weathered layered
clays
gravel and sand
tills
glacial sediments
shales
sandstone and conglomerate
lignite, coal
dolomite, limestone
sedimentary rocks
salt water
fresh water
permafrost
sea ice
water, aquifers
100 000
10 000
1 000
100
10
1
0.1
0.01
Conductivity (mS/m)

THE ELECTROMAGNETIC SPECTRUM



How to measure the resistivity of the Earth with MT



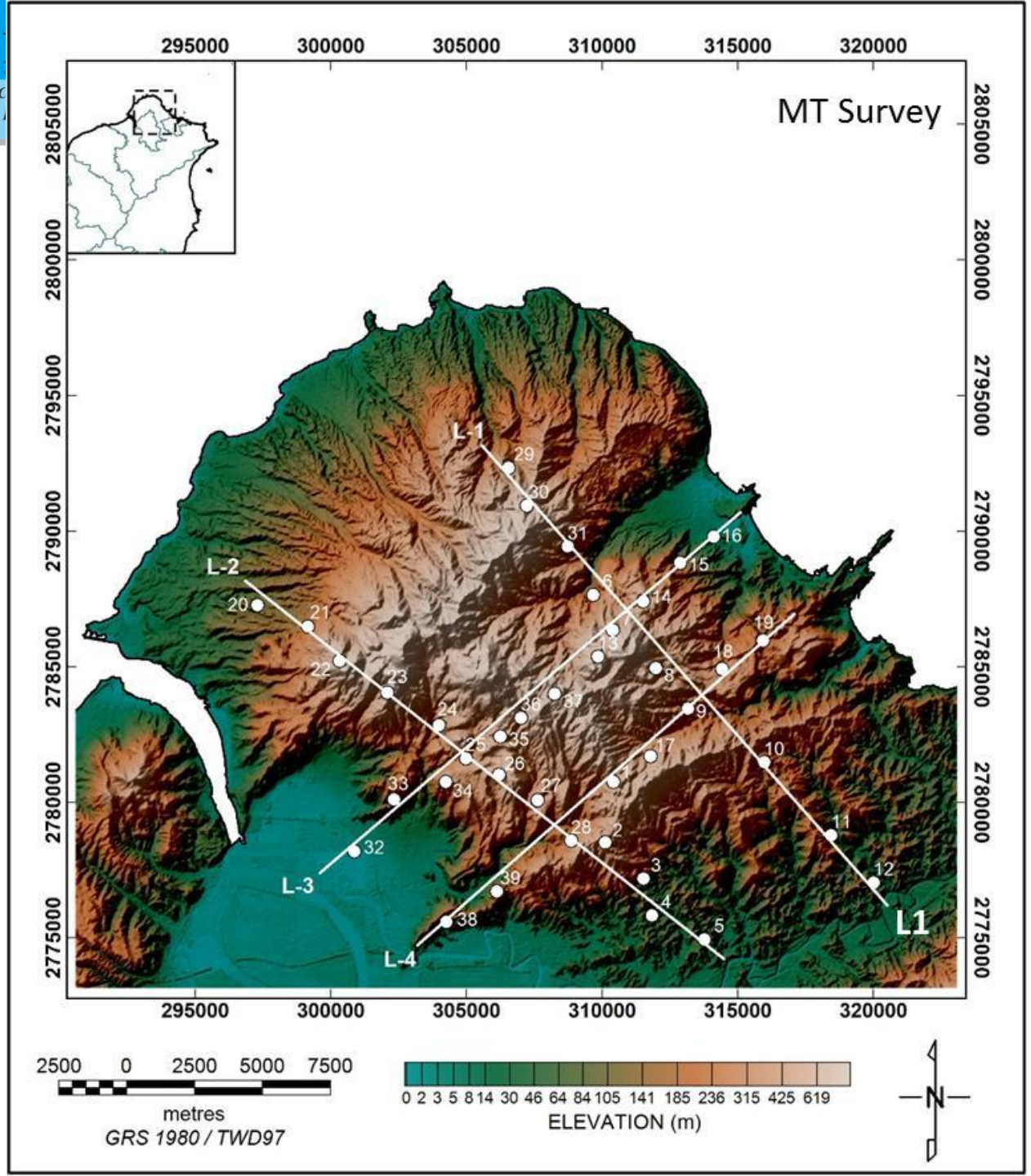
ρ_a → Apparent Resistivity (Ω.m)
δ → depth of penetration (m)
E_x → electric field component (V/m)
H_y → magnetic field components (A/m)
μ → magnetic permeability of the medium (H/m)
f → frequency (Hz)
ω → angular frequency (rad/s)

$$\rho_a = \frac{1}{\omega\mu_0}\left|\frac{E_x}{H_y}\right|^2$$

μ_r = Relative Permeability (usually 1)

μ_o = Permeability Constant = $4\pi \times 10^{-7}$

$$Skin\ Depth = \delta = \sqrt{\frac{\rho_a}{\pi f \mu}} = \sqrt{\frac{\rho_a}{\pi f \mu_r \mu_o}} = 500 * \sqrt{\rho_a / f}$$


MT Survey
295000
300000
305000
310000
315000
320000
2805000
2800000
2795000
2790000
2785000
2780000
2775000
L-1
L-2
L-3
L-4
L1
2500 0 2500 5000 7500
metres
GRS 1980 / TWD97
0 2 3 5 8 14 30 46 64 84 105 141 185 236 315 425 619
ELEVATION (m)
N