地球観測実習
電磁気

遠藤　涼　　Wu Yifei　　B. Anselme
上嶋先生　　小山先生

目的

- To understand the basic theory about electromagnetic observation, especially MT method.(比抵抗探査）
- To learn about the equipment and process of field work.
- To analyze data and gain the structure of the measured place.

基礎方程式(Maxwell’s equations)

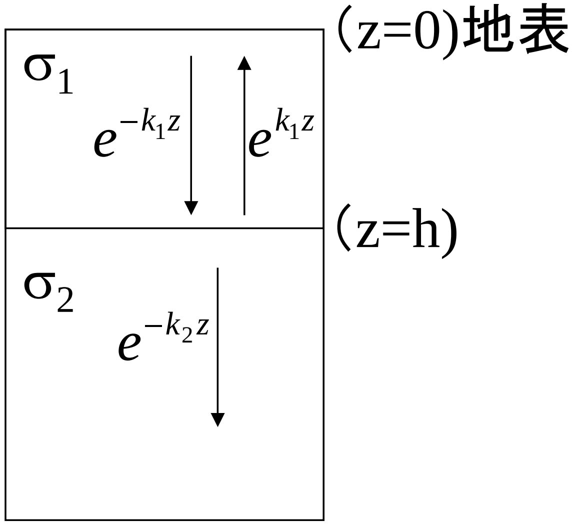
$$\nabla \times H = (i\omega\varepsilon + \sigma)E$$: Ampere法則

$$\nabla \times E = -i\omega\mu H$$: Faraday法則

σ : 電気伝導度[S/m] (1/σ = ρ : 比抵抗[Ωm])
ε : （真空）誘電率（8.854 × 10^{-12} [F/m])
μ : （真空）透磁率(4π × 10^{-7} [H/m])

MT法

- 地面で測定された電場/磁場の振幅比: impedance $Zxy(0) = \frac{Ex(0)}{Hy(0)}$
- →
- 構造：電気伝導度（比抵抗）、深さ



$$k_i = \sqrt{i\omega\mu\sigma_i}$$

$$\frac{E_x^{(2)}(h)}{H_y^{(2)}(h)} = Z_{xy}^{(2)}(h) = \frac{i\omega\mu}{k_2}$$

例えば
二層の場合

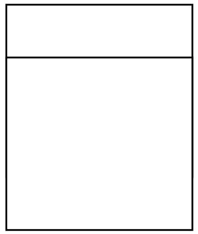
Forward
calculation

$$\frac{E_x^1(0)}{H_y^1(0)} = \frac{-i\omega\mu}{k_1}\frac{A_1 + B_1}{A_1 - B_1} = \frac{i\omega\mu}{k_1}\frac{1+\dfrac{Z_{xy}^{(2)}(h)-\dfrac{i\omega\mu}{k_1}}{Z_{xy}^{(2)}(h)+\dfrac{i\omega\mu}{k_1}}e^{-2k_1 h}}{1-\dfrac{Z_{xy}^{(2)}(h)-\dfrac{i\omega\mu}{k_1}}{Z_{xy}^{(2)}(h)+\dfrac{i\omega\mu}{k_1}}e^{-2k_1 h}}$$

apparent resistivity

$$\rho_a = \frac{|Zxy(0)|^2}{\omega\mu}$$

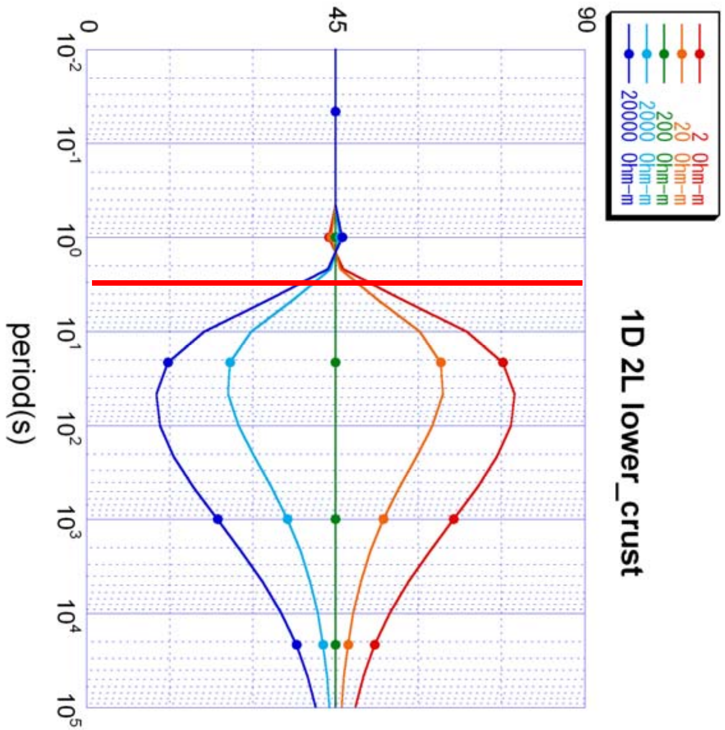
見かけ比抵抗



200Ωm, 15km(→4.5s）

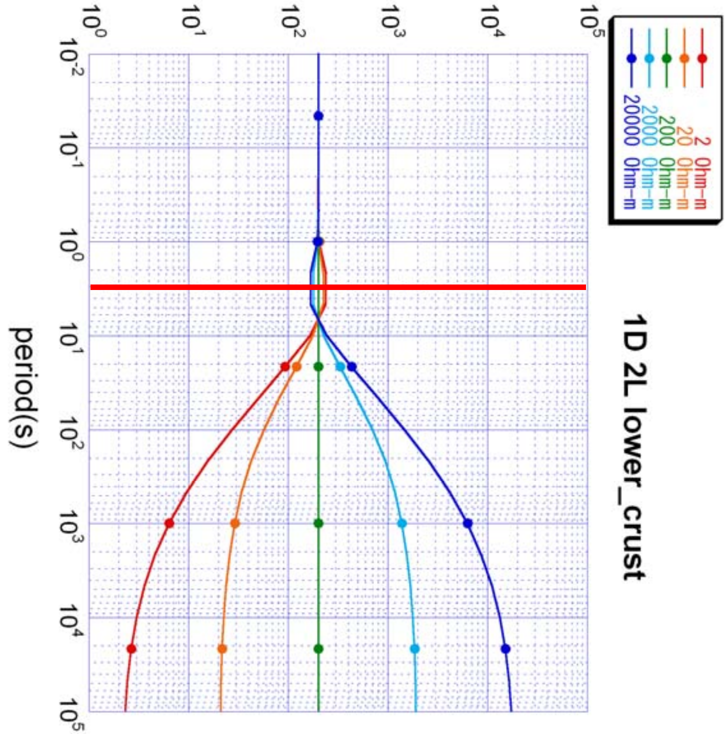
2, 20, 200, 2K, 20KΩm

phase [degree]



phase

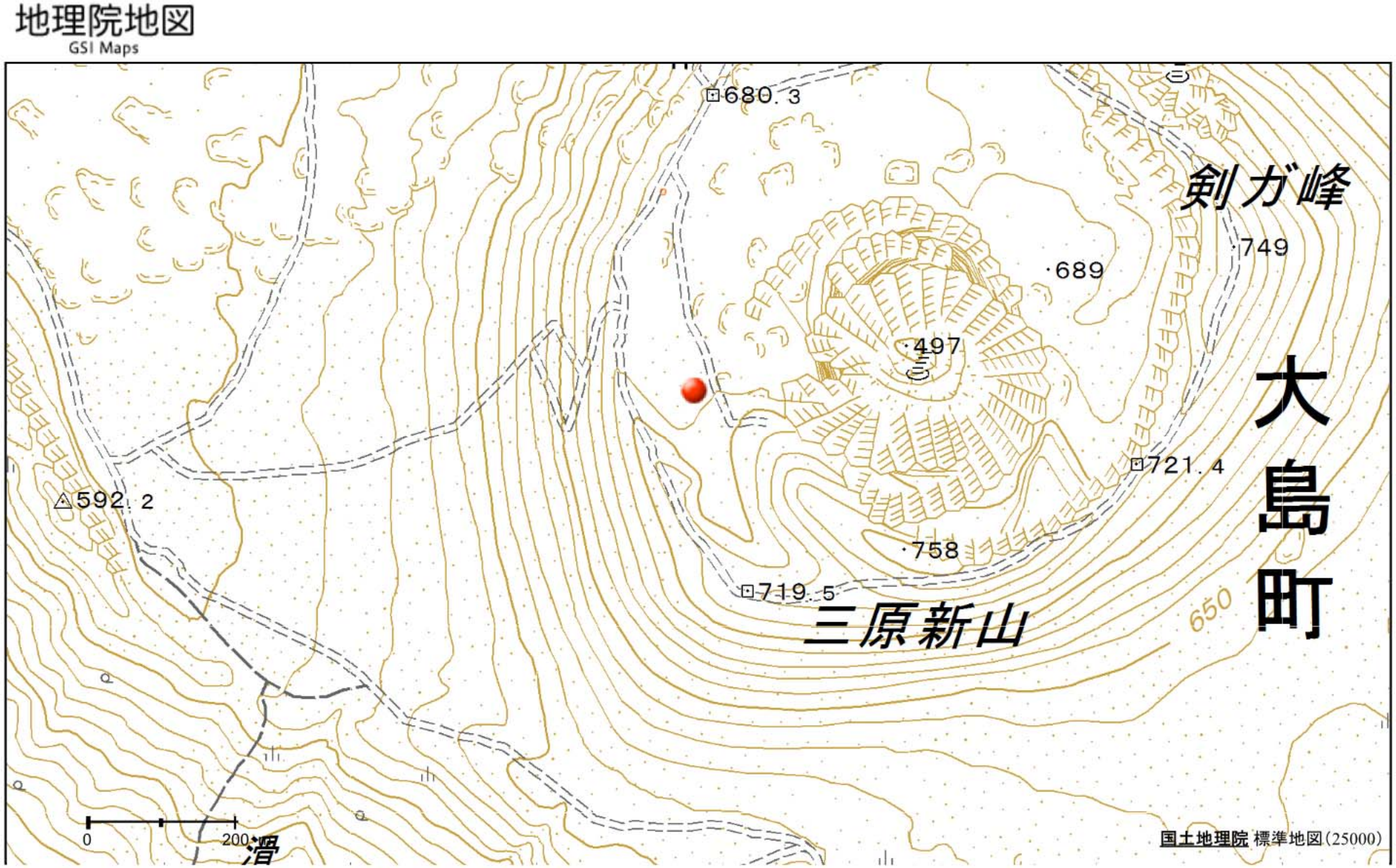
apparent resistivity [Ohm m]



apparent resistivity

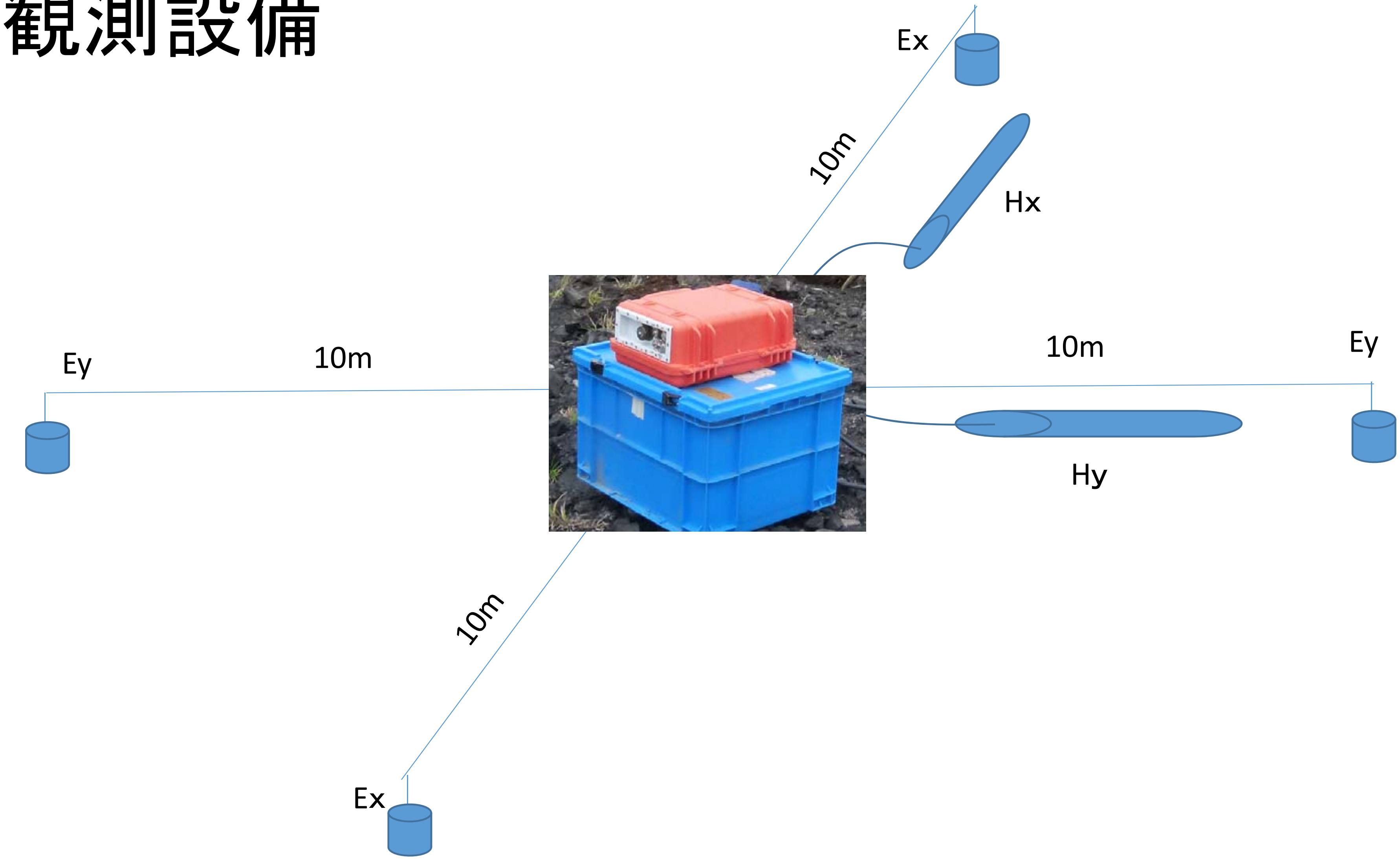
観測点

- 34°43’35”N
- 139°23’29”E



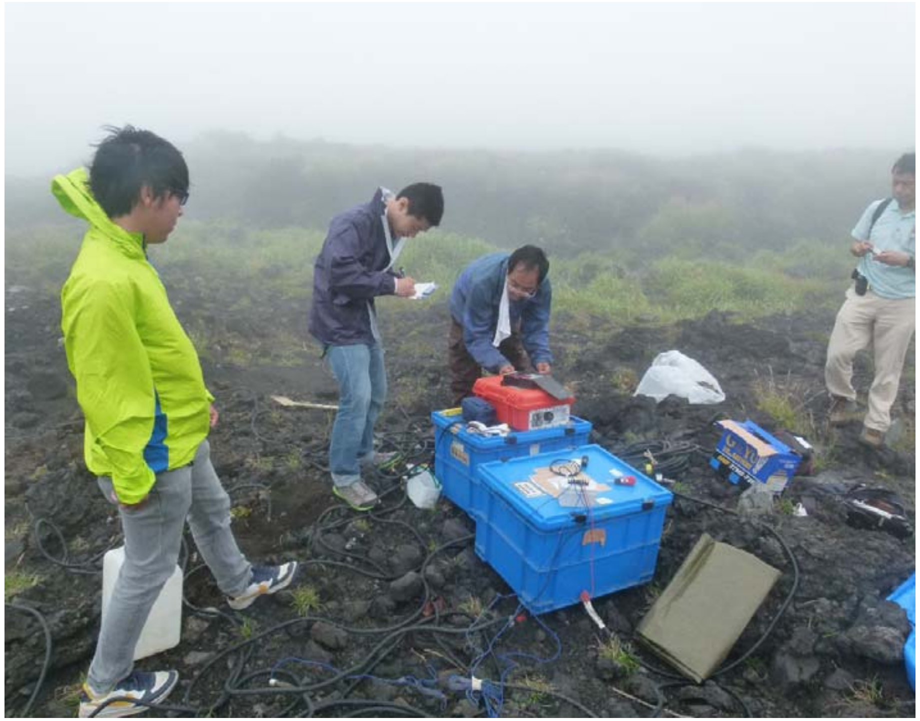
周りの様子

観測設備



コイルと電極

出来上がり

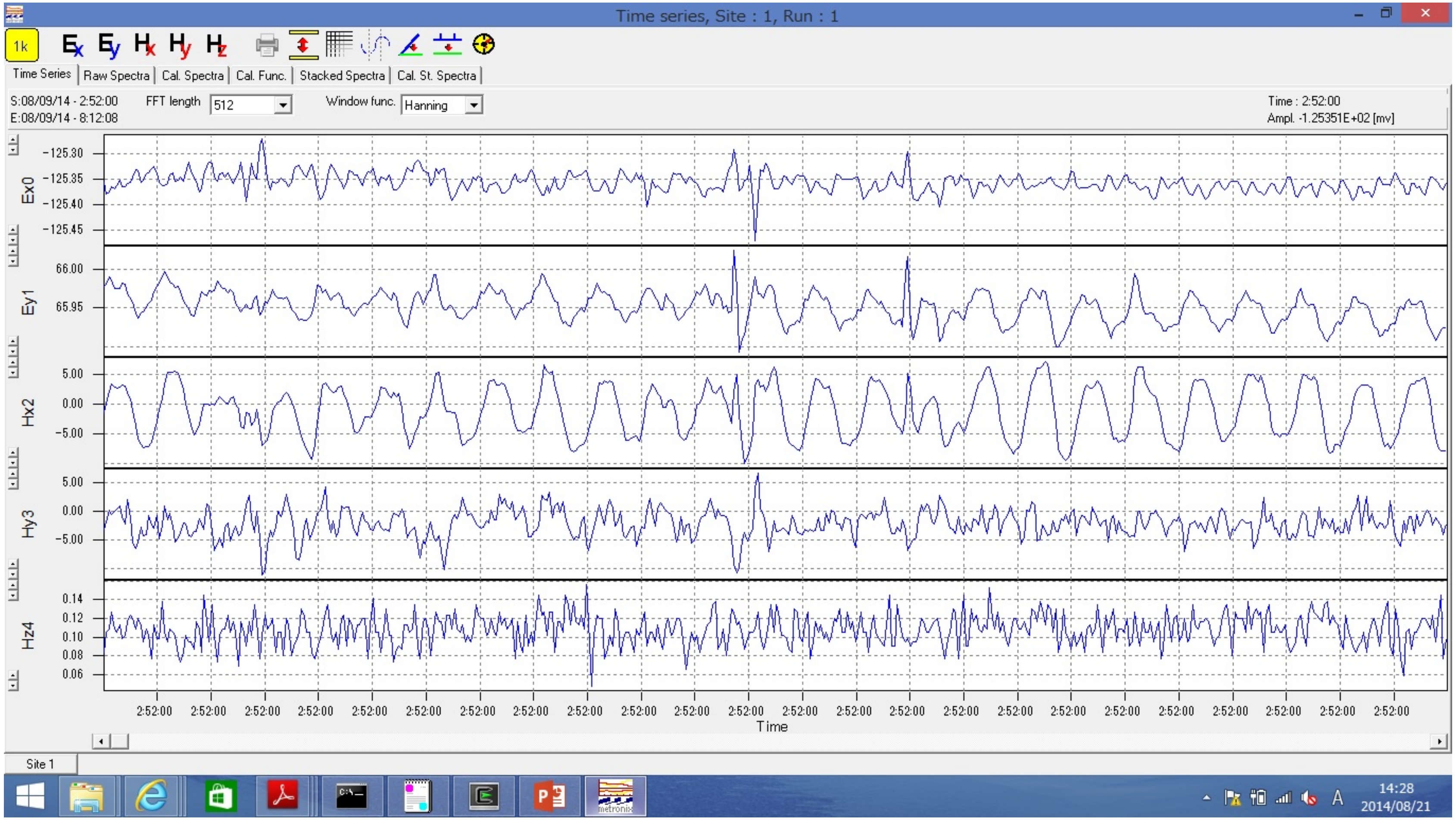


Data analysis

- What we measured: time series Ex(t), Ey(t), Hy(t), Hx(t)
- We use the program Mapros made by the instruments company
- FFT yields ex(f), ey(f), hx(f), hy(f)

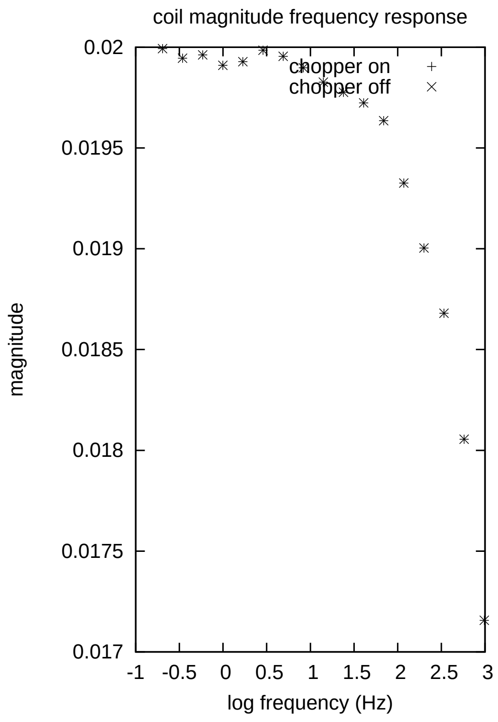
- Filter to eliminate the coils frequency response of h(f)

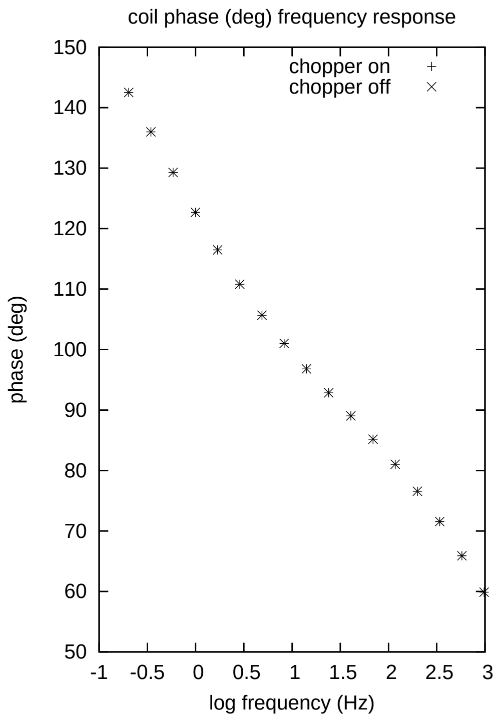
Time series



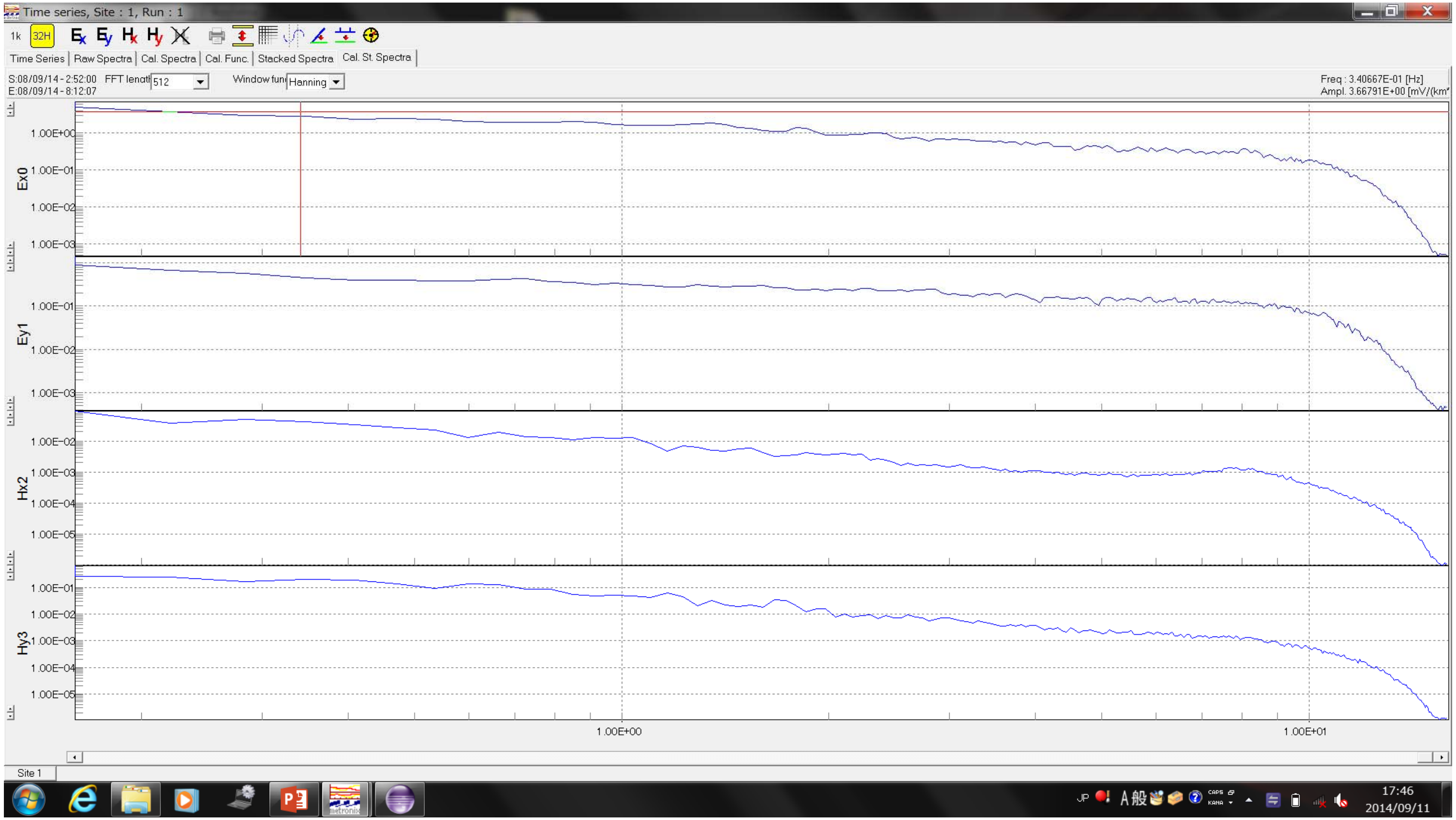
Time series, Site : 1, Run : 1
1k
Time Series
Raw Spectra
Cal. Spectra
Cal. Func.
Stacked Spectra
Cal. St. Spectra
S:08/09/14 - 2:52:00
E:08/09/14 - 8:12:08
FFT length
512
Window func.
Hanning
Time : 2:52:00
Ampl. -1.25351E+02 [mv]
Ex0
Ey1
Hx2
Hy3
Hz4
Time
Site 1
14:28
2014/08/21

Calibration curves





Frequency domain



Impedances

- We assume:
- ex = Zxx*hx+Zxy*hy
- ey = Zyx*hx+Zyy*hy

- We neglect Zyy, Zxx hence
- ex/hy = Zxy(f), ey/hx = Zyx(f)
- (Zxy and Zyx both complex numbers)

Impedances Zxy, Zyx

Data for inversion

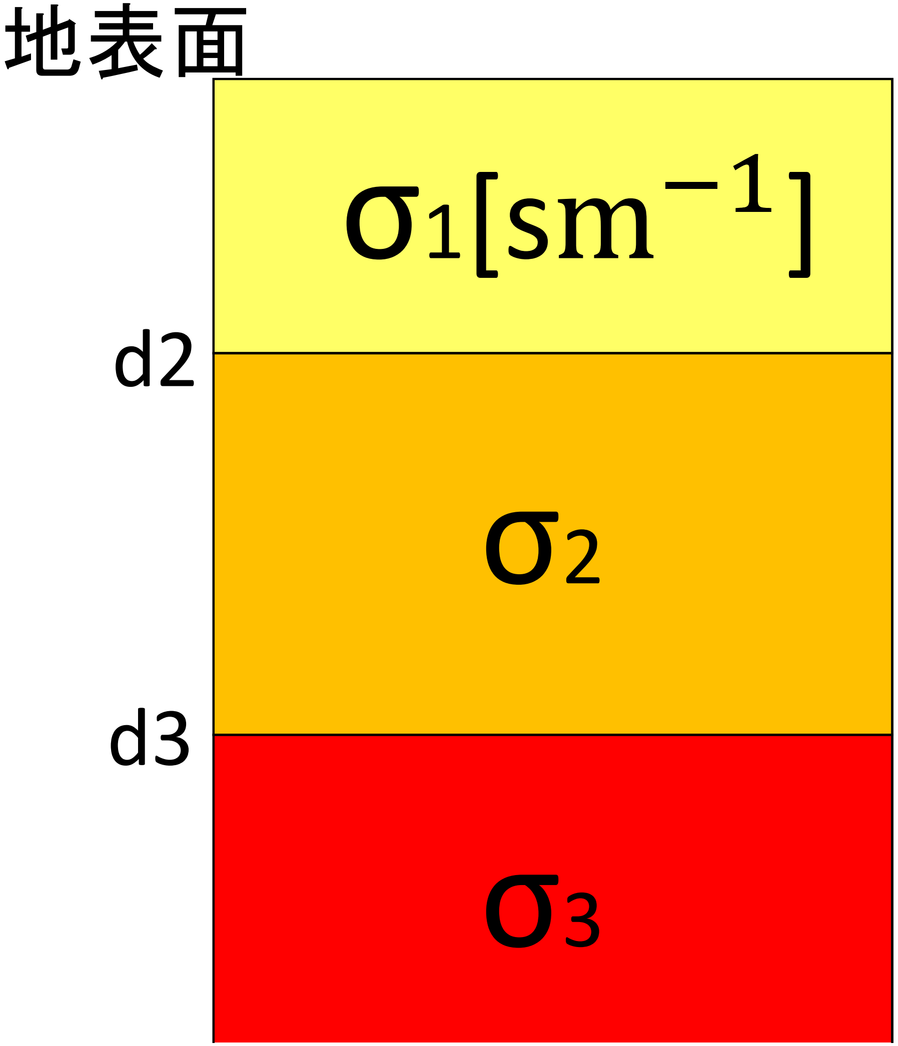
- In 1D, it should be Zxy = -Zyx. Hence take
  - $Z = (Zxy - Zyx)/2$
- Get the phase and amplitude of Z
- Compute apparent resistivity $\rho = |Z|^2/(\omega\mu)$
- Make a code to compute ρ(f) for a given 1D layered structure: input are the thickness and conductivity of the layers
- Inversion to find the structure that best fits the data ρ(f)

Inversion

- Compute many Zyx for 3 layers, σ in $[10^{-4}$-$100]sm^{-1}$, d in [10-500]m. Choose to minimize $\Sigma(Z\text{-}Zyx)^2$
- Frequency f in [1-250]Hz

- How to choose σ range?
- → Estimated from the apparent resistivity curve and typical range in the crust
- How to choose d range?
- → length scale is d_skin = sqrt(2/ σ/μ/ω)
- Using 10(Ωm) and 1Hz, max d_skin is 1.59km

地下構造の推定



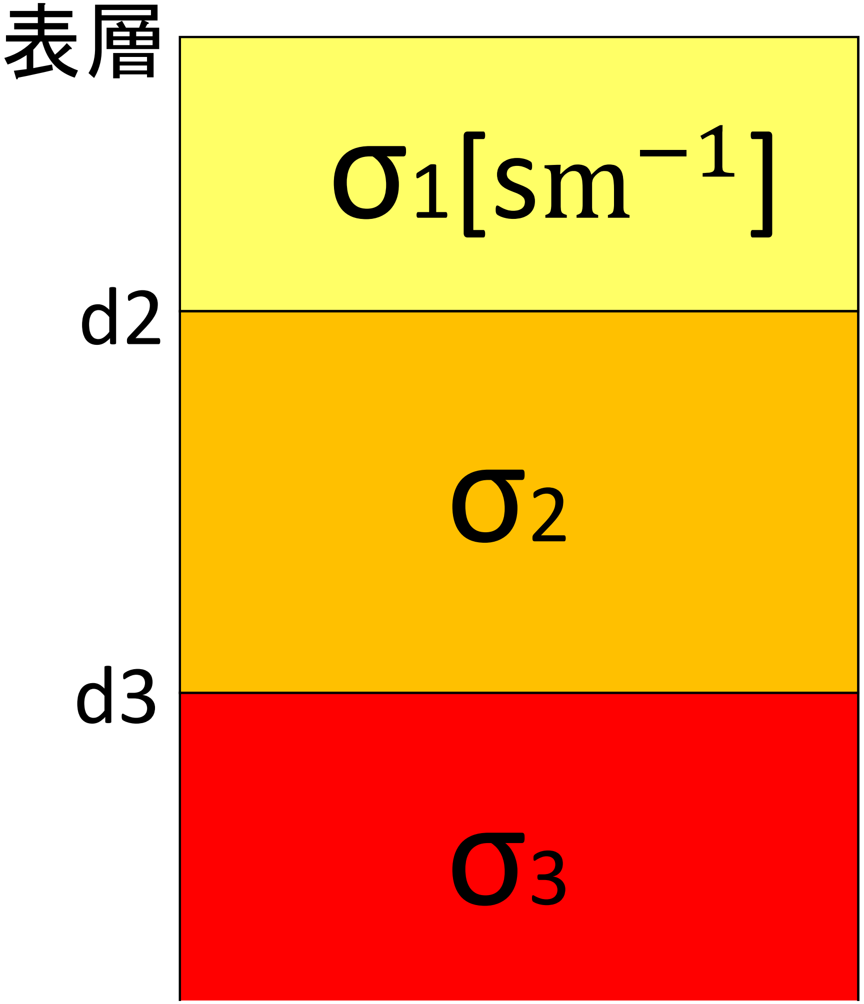
地下構造の
- ・層数(j=2, 3)
- ・境界の深度(d(j))
- ・各層の電気伝導度(σ(j))
  （＝1/（比抵抗ρ_a））

を変化させ、見かけ比抵抗の理論値を計算

⇓

見かけ比抵抗の観測値と理論値の差分の最小2乗和を計算

地下構造の推定



＜手法＞

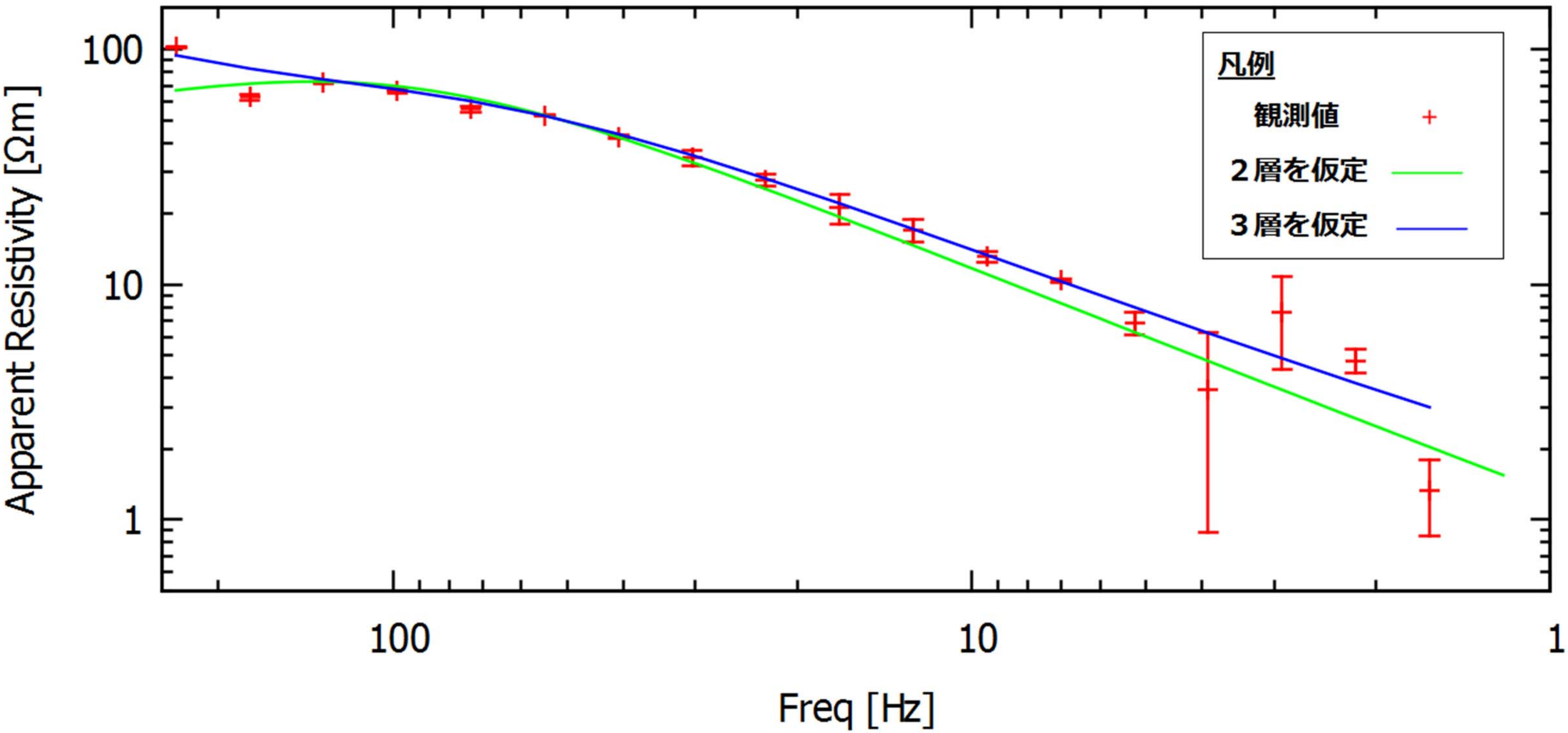
$$\sum_{j}\left(\frac{\rho_{a\_}\mathrm{the}(\omega_j)-\rho_{a\_}\mathrm{obs}(\omega_j)}{\varepsilon_j}\right)^2$$

※ $\varepsilon_j = \frac{2\,|Z_{yx}|\Delta Z_{yx}}{\mu\omega_j}$

σ : 10^{-4}～10^{2} $[sm^{-1}]$

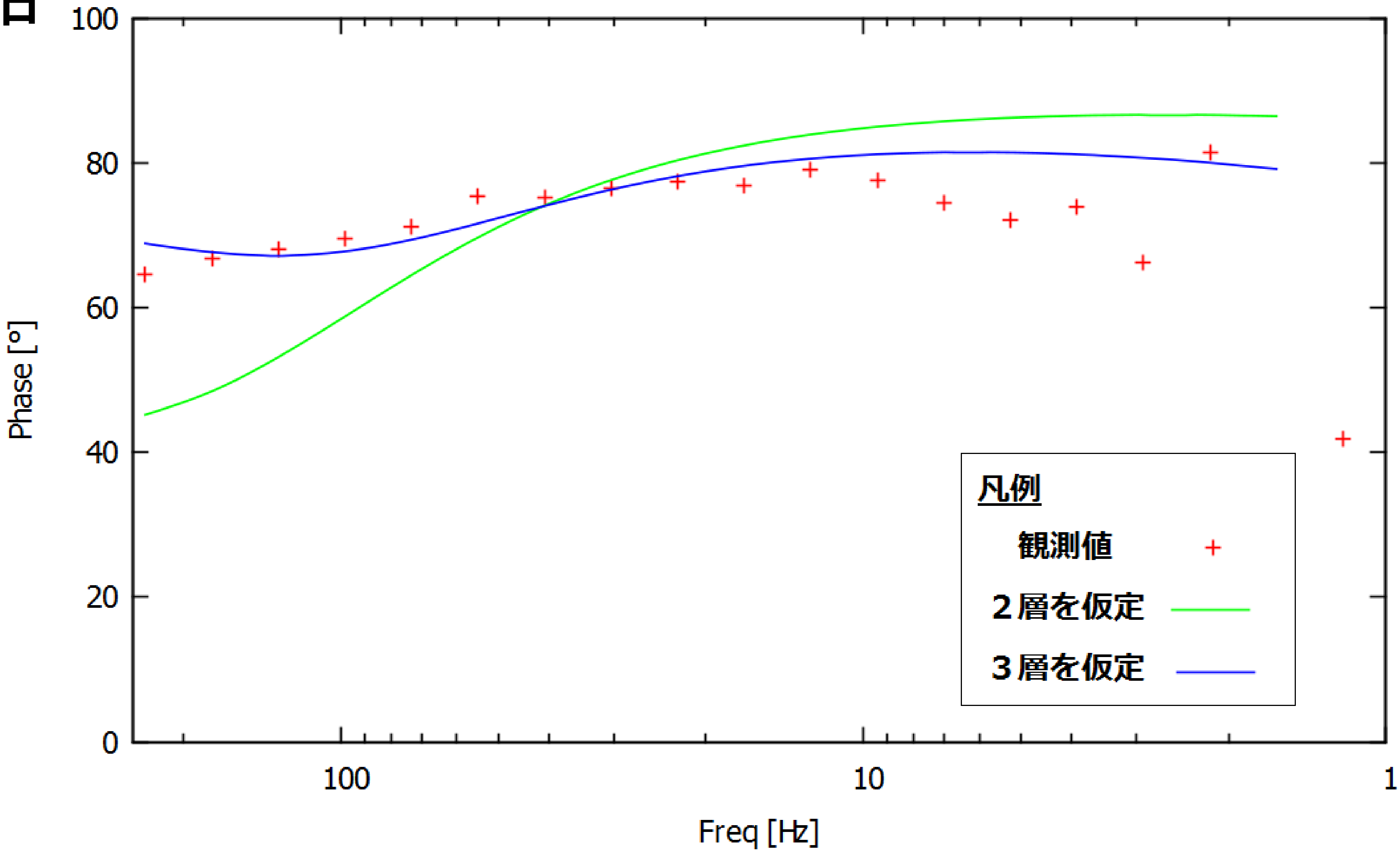
d : 10～500 [m]

見かけ比抵抗

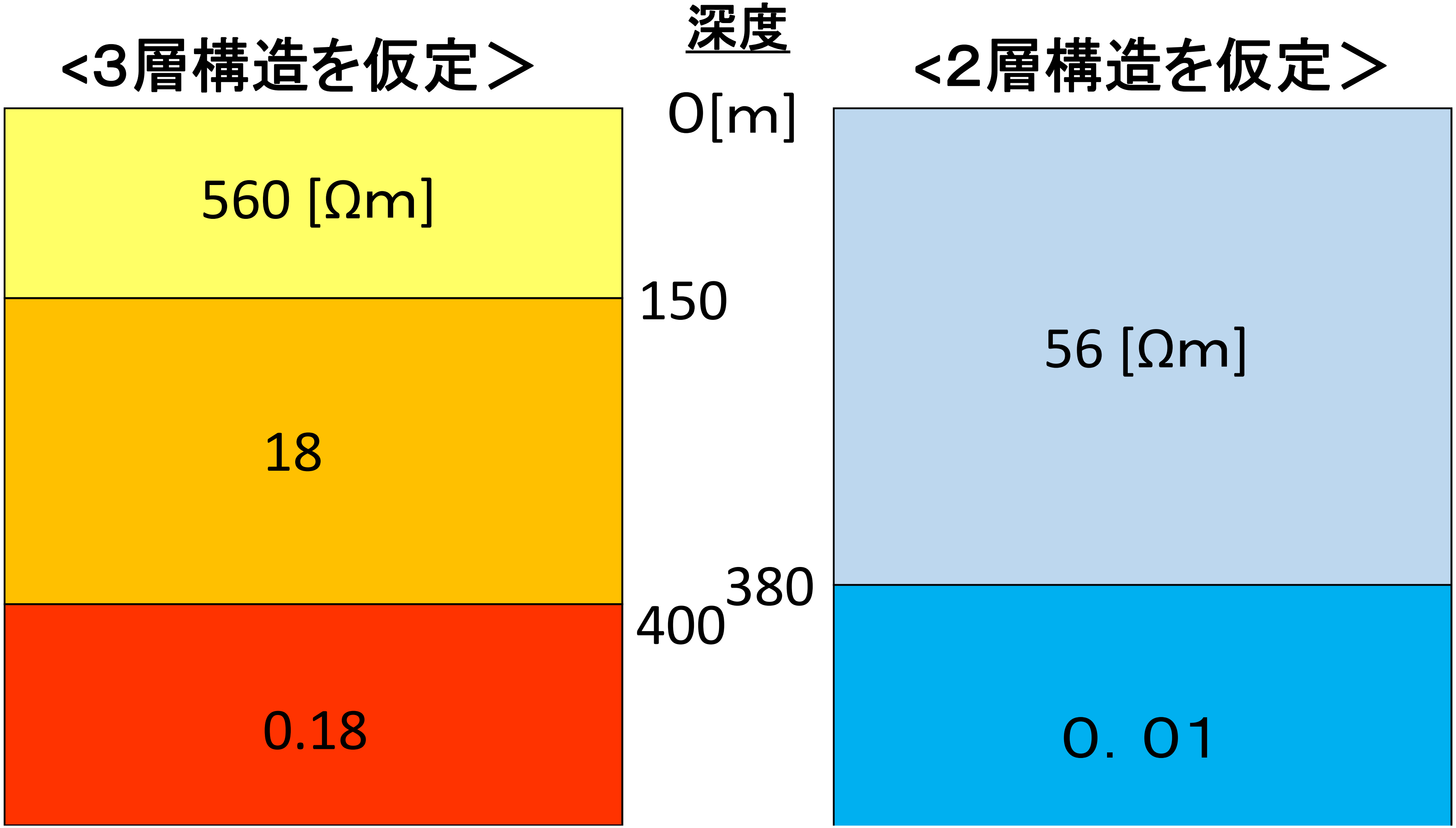


凡例
観測値
2層を仮定
3層を仮定
Apparent Resistivity [Ωm]
100
10
1
100
10
1
Freq [Hz]

位相

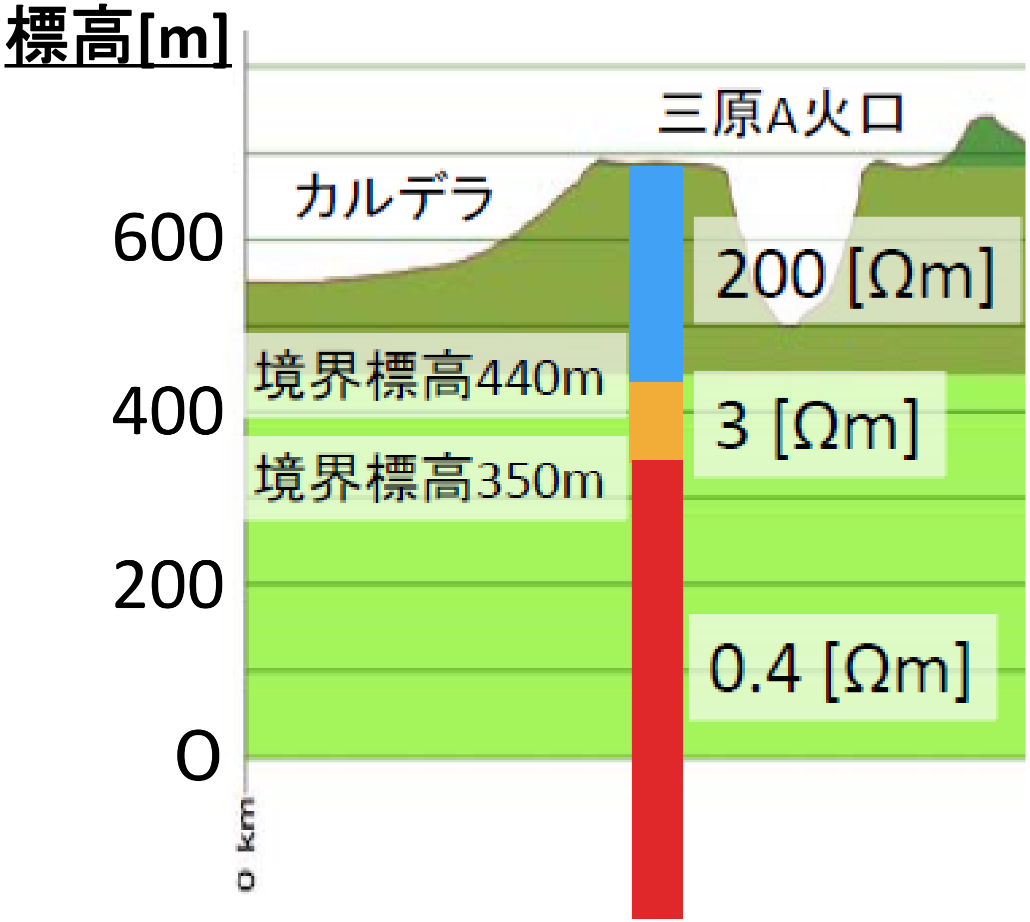


推定した地下構造

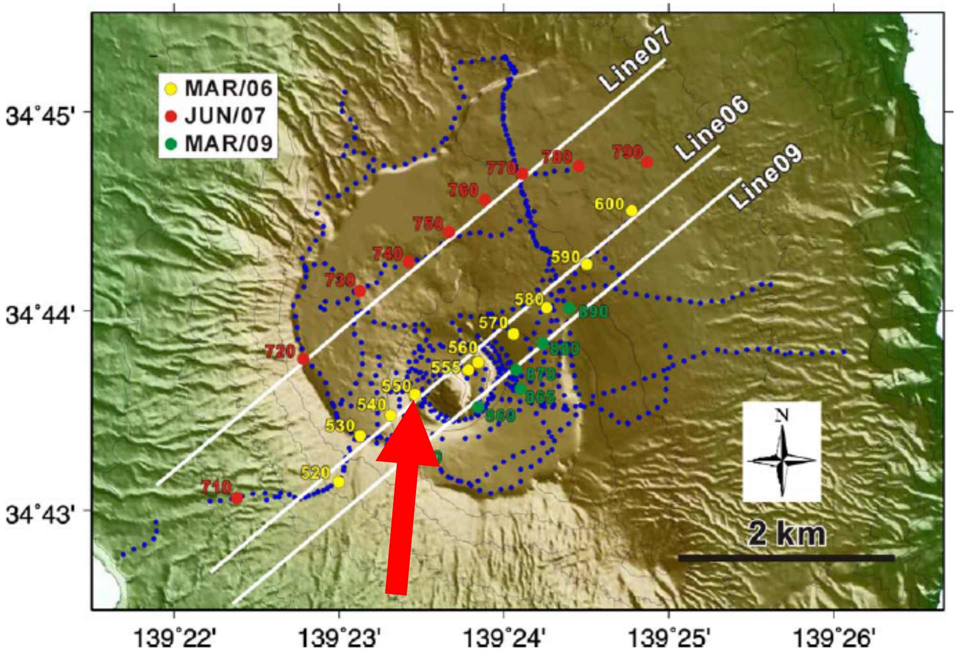


地下構造の解釈①

- 2011年度の伊豆大島実習との比較

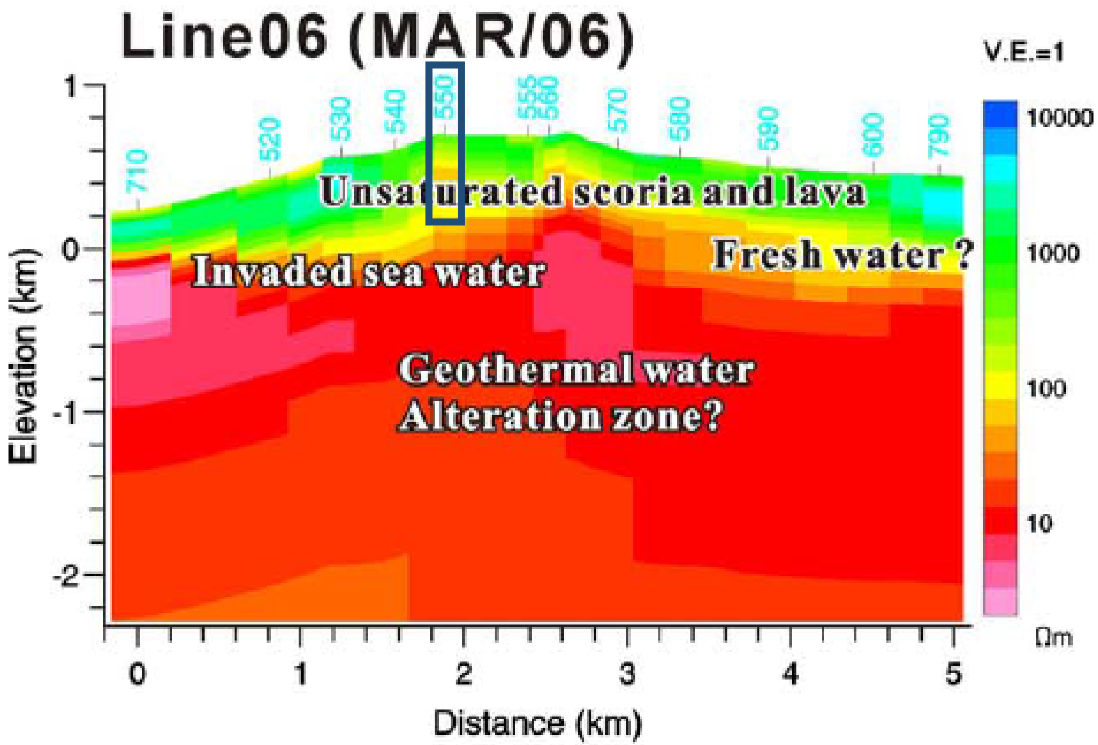


地下構造の解釈②



第 1 図　伊豆大島火山の AMT 法測点位置。
Fig.1 Location map of Izu-Oshima Volcano showing the AMT survey sites.

高倉ほか(2007)との比較



今回の観測との数値の違いの原因

⇒観測時間が短く、長周期の観測記録に問題
⇒昼間のみの観測であり、ノイズが大きい

まとめ

- 伊豆大島三原山山頂において、比抵抗探査を行った
- 得られたデータの周波数解析を行い、見かけ比抵抗、位相を求めた。
- 地下内部に複数の層の存在を仮定し、理論値と観測値から、１次元地下構造を推定した
- 推定された1次元地下構造と、先行研究・実習において推定された地下構造との比較を行った。