電磁気観測

岡本篤郎　夏目祐紀　山河和也
上嶋誠　小山崇夫

Introduction 電磁気観測で分かること

- 電磁気観測→地盤の比抵抗を調べる！
- 地下構造に関する情報が得られる
  (比抵抗が下がる→地盤が水を含んでいる可能性がある、など)

Introduction 電磁気観測で分かること

- 電磁気観測→地盤の比抵抗を調べる！
- 地下構造に関する情報が得られる
  (比抵抗が下がる→地盤が水を含んでいる可能性がある、など)

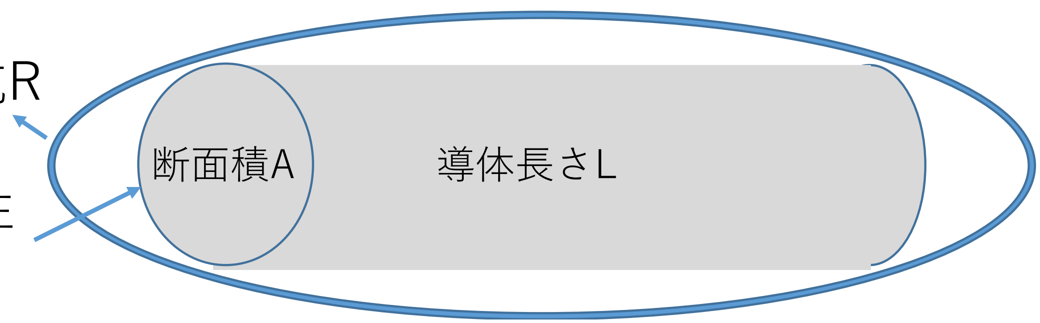
余談

・比抵抗と抵抗の関係　→　密度と質量の関係のようなもの

$$R = \rho \frac{L}{A}$$

全体の
電気抵抗R

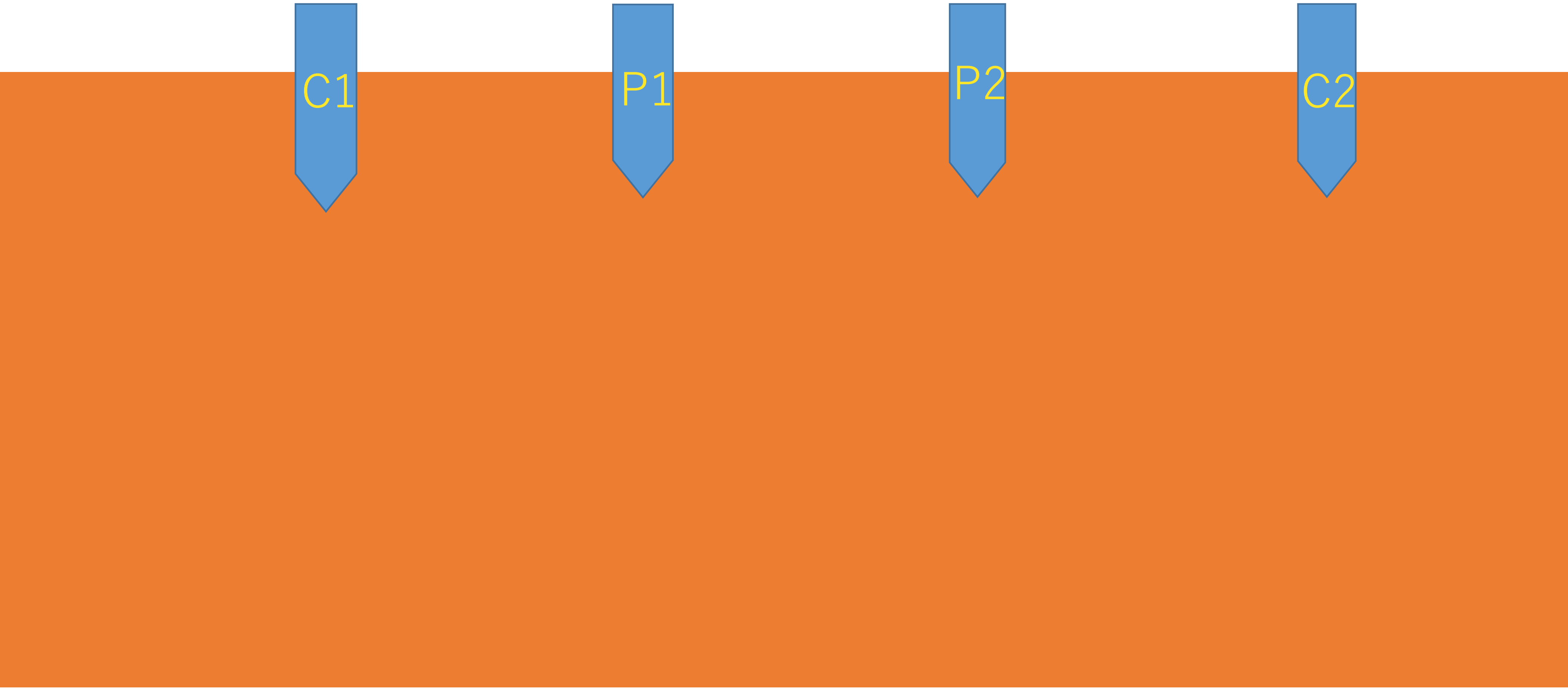
導体の物性
比抵抗ρ



電磁気観測の流れ

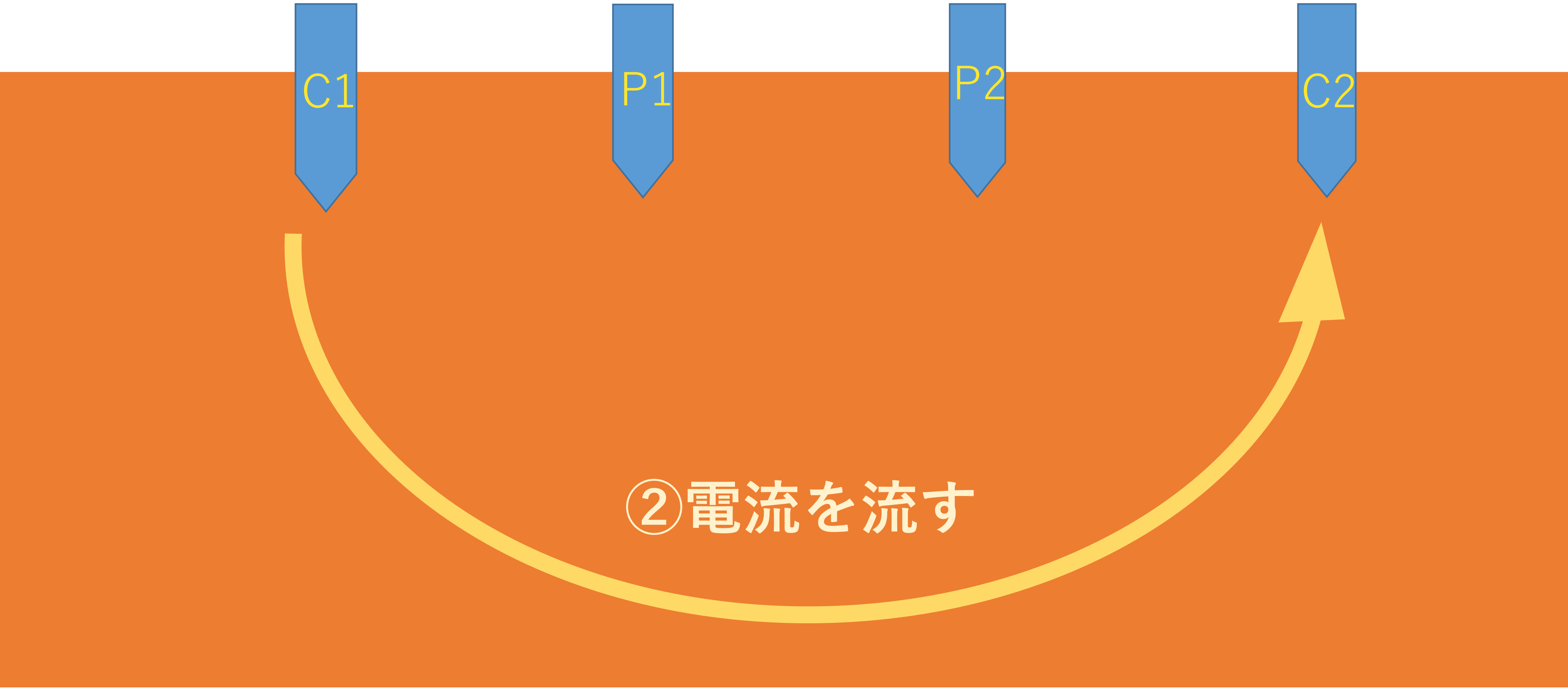
電磁気観測の流れ

①電極を刺す



電磁気観測の流れ

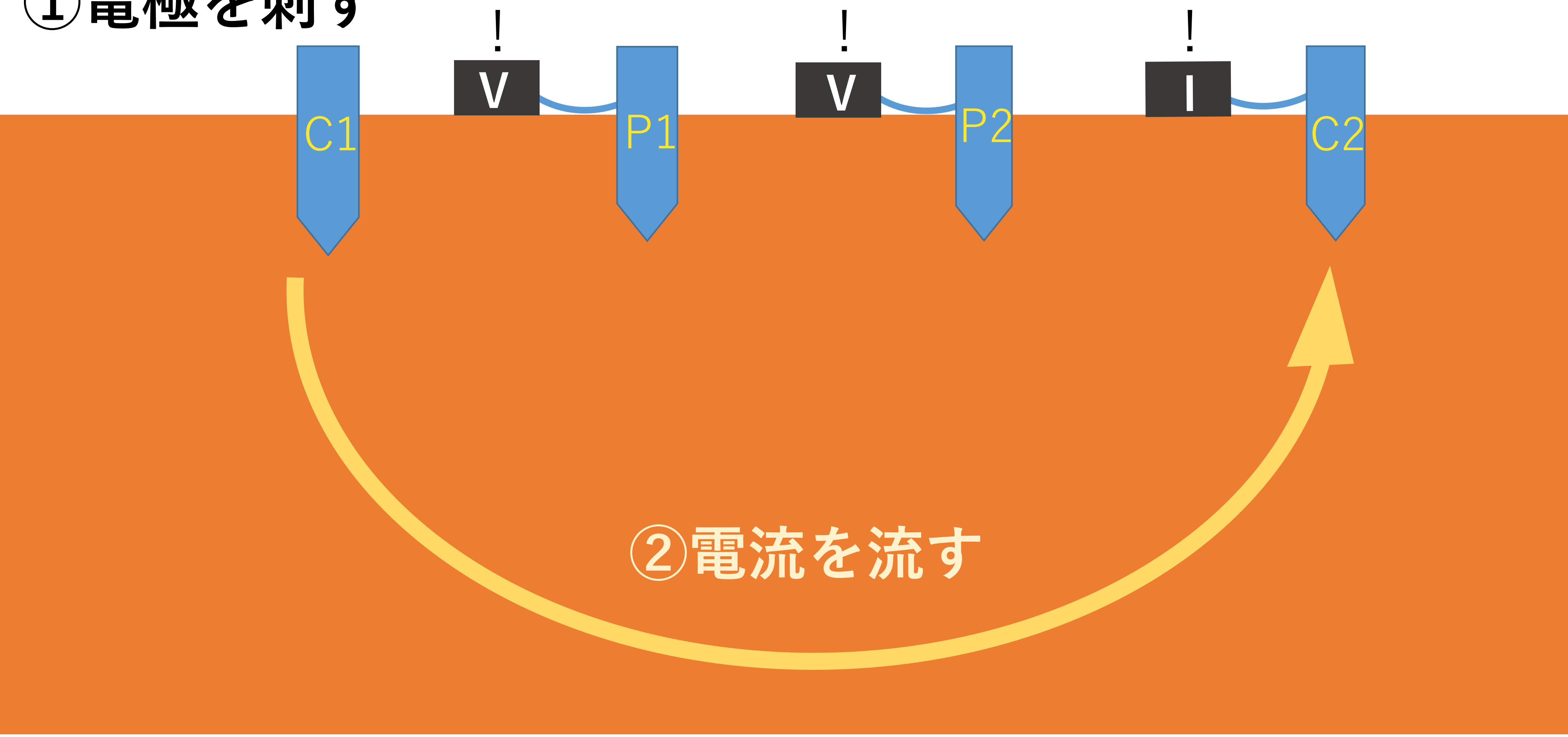
①電極を刺す



電磁気観測の流れ

③電位と電流を測定する

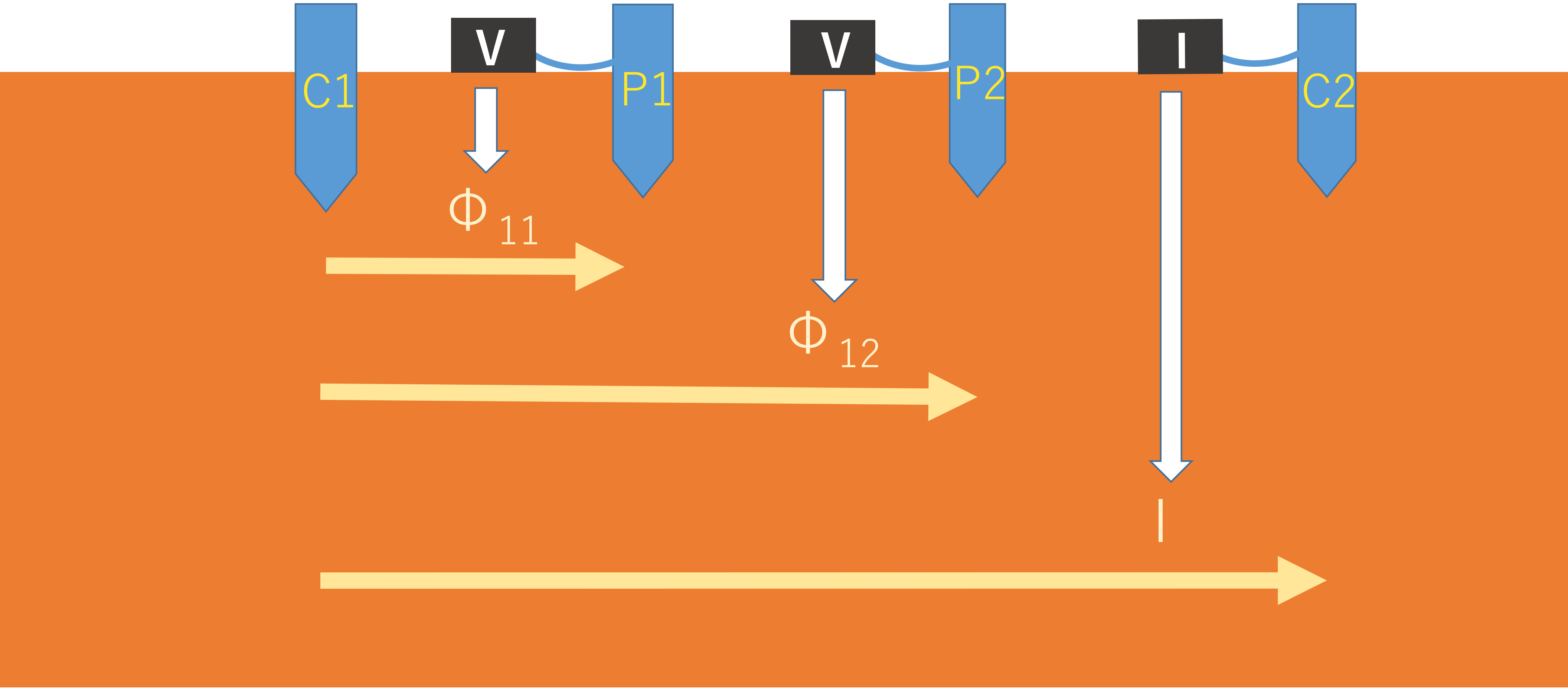
①電極を刺す



観測データ

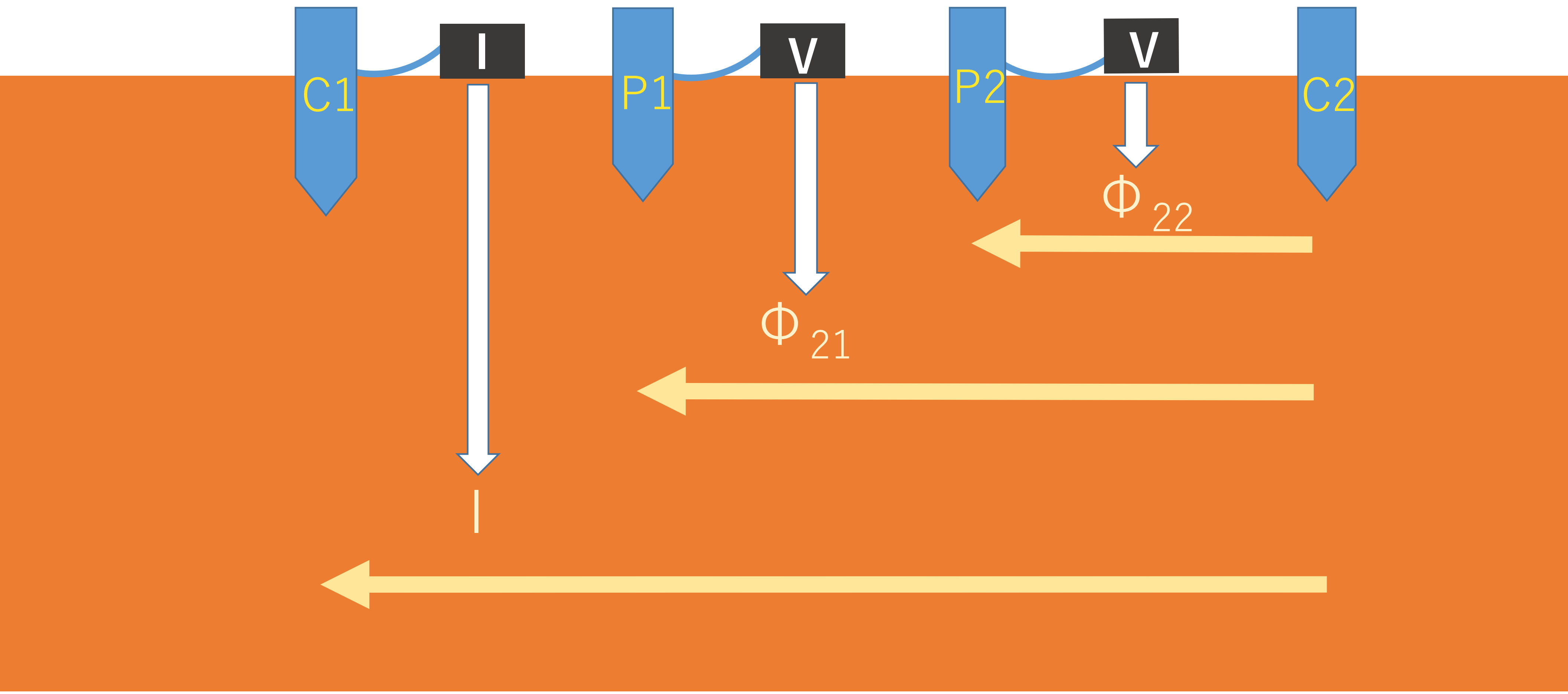
データ所得 Step1. C1から電流を流す

電流電極→C
電位電極→P　電位→Φ



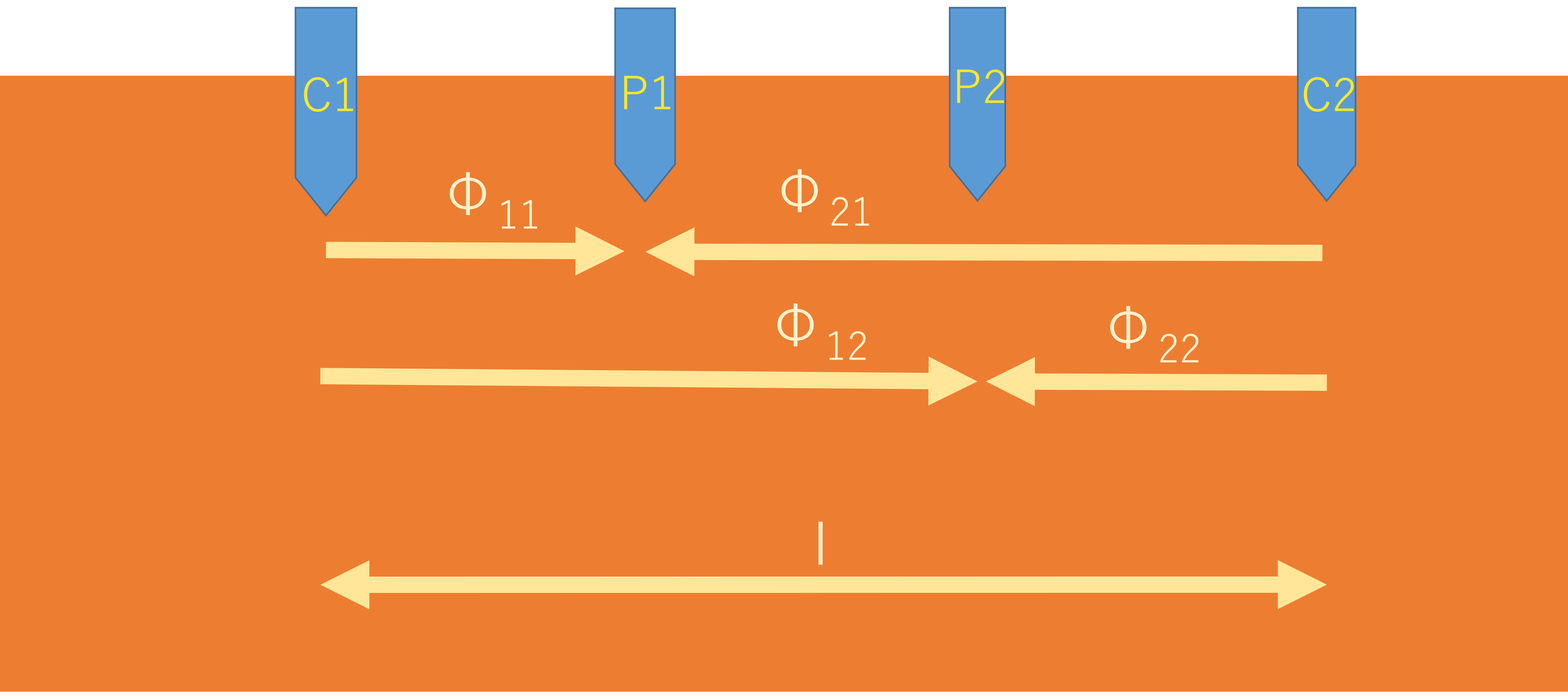
データ所得 Step2. C2から電流を流す

電流電極→C
電位電極→P　電位→Φ



データまとめ

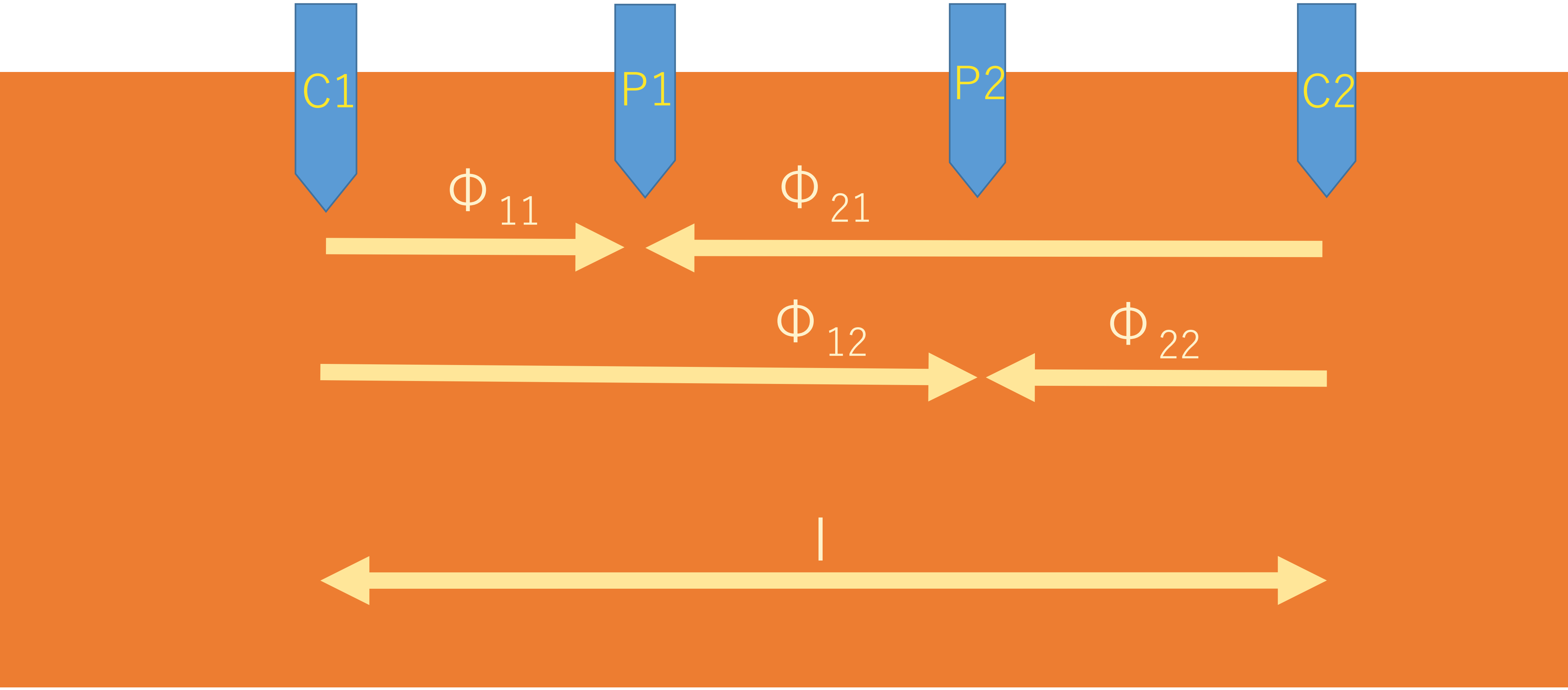
電流電極→C
電位電極→P　電位→Φ



データ処理

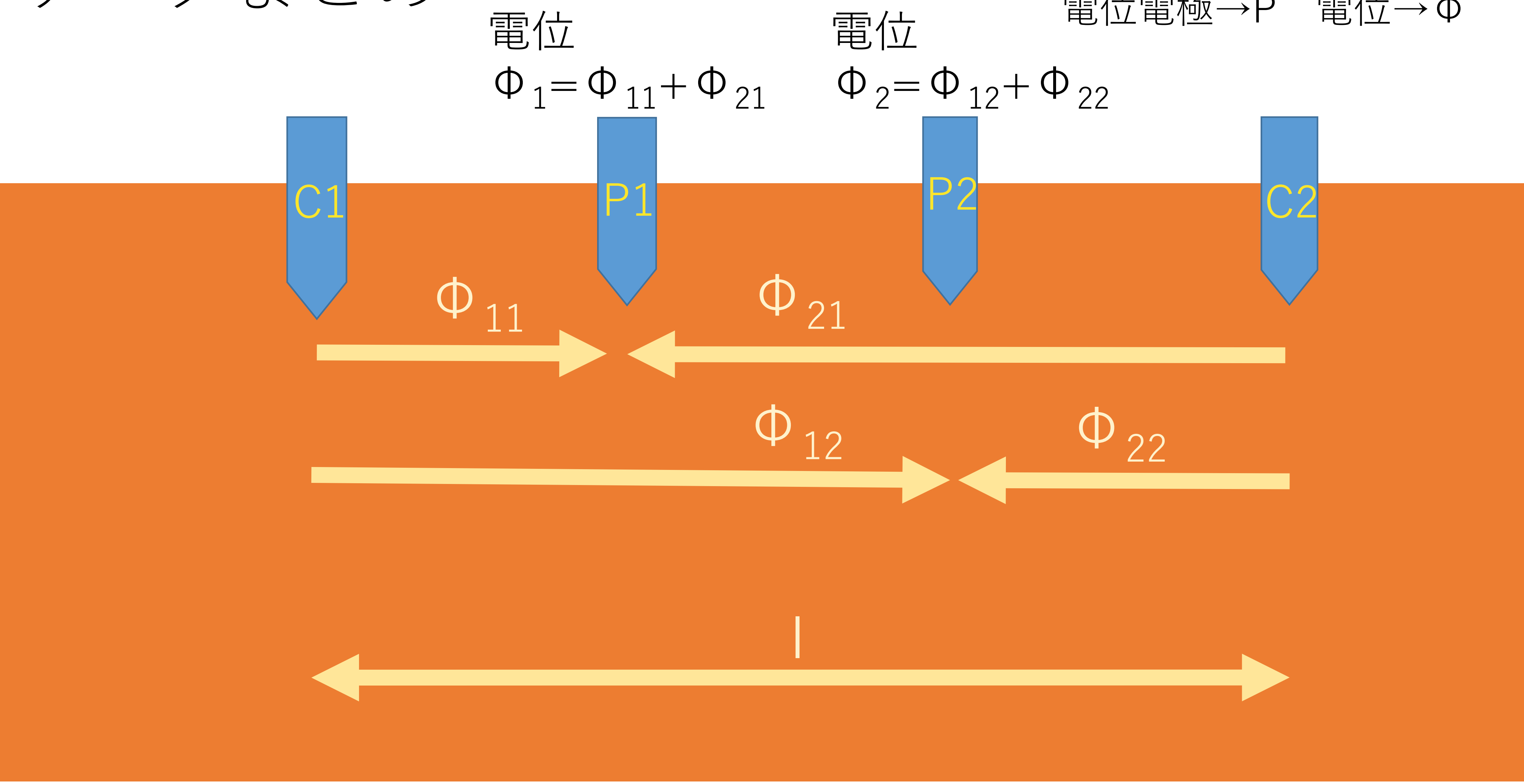
データまとめ

電流電極→C
電位電極→P　電位→Φ



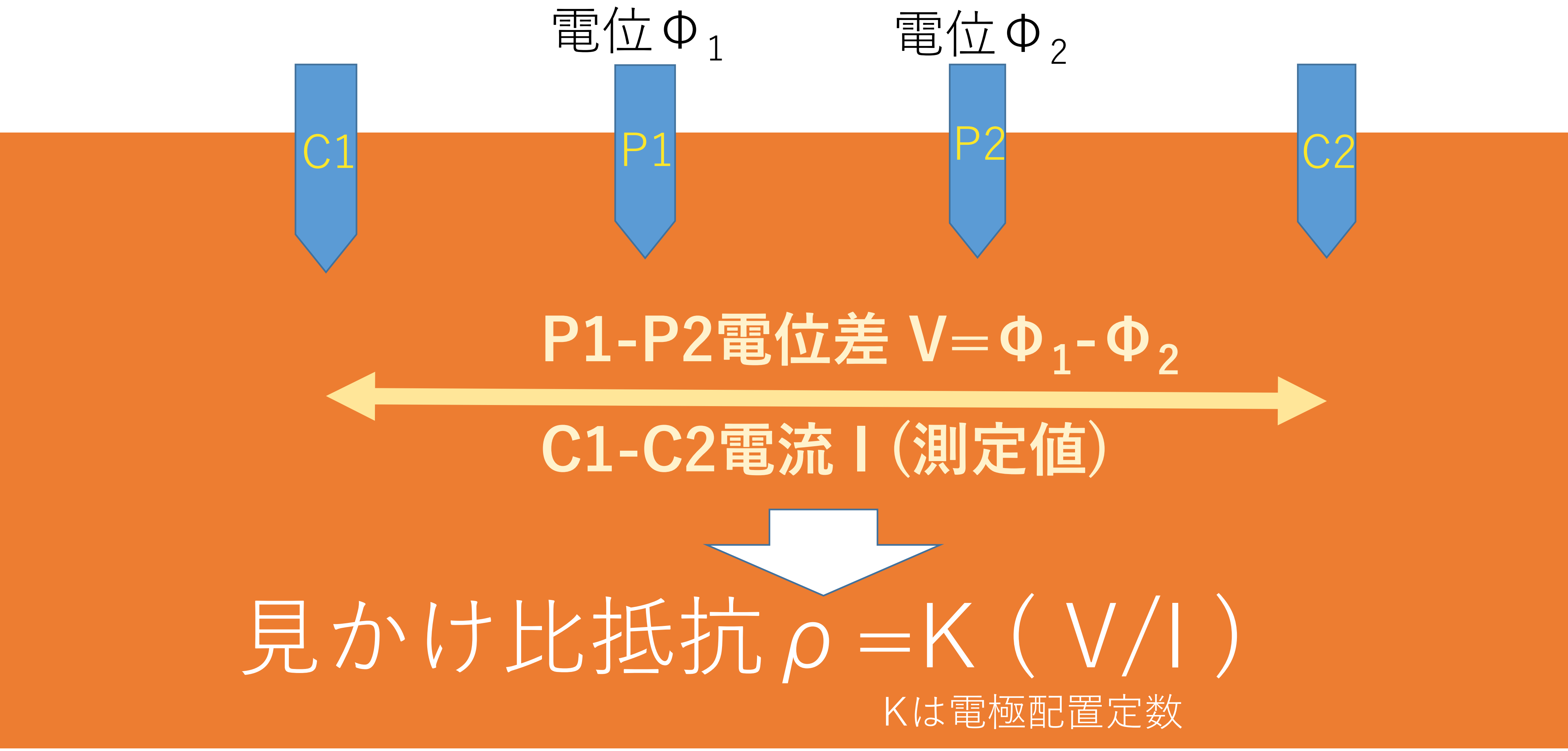
データまとめ

電流電極→C
電位電極→P　電位→Φ



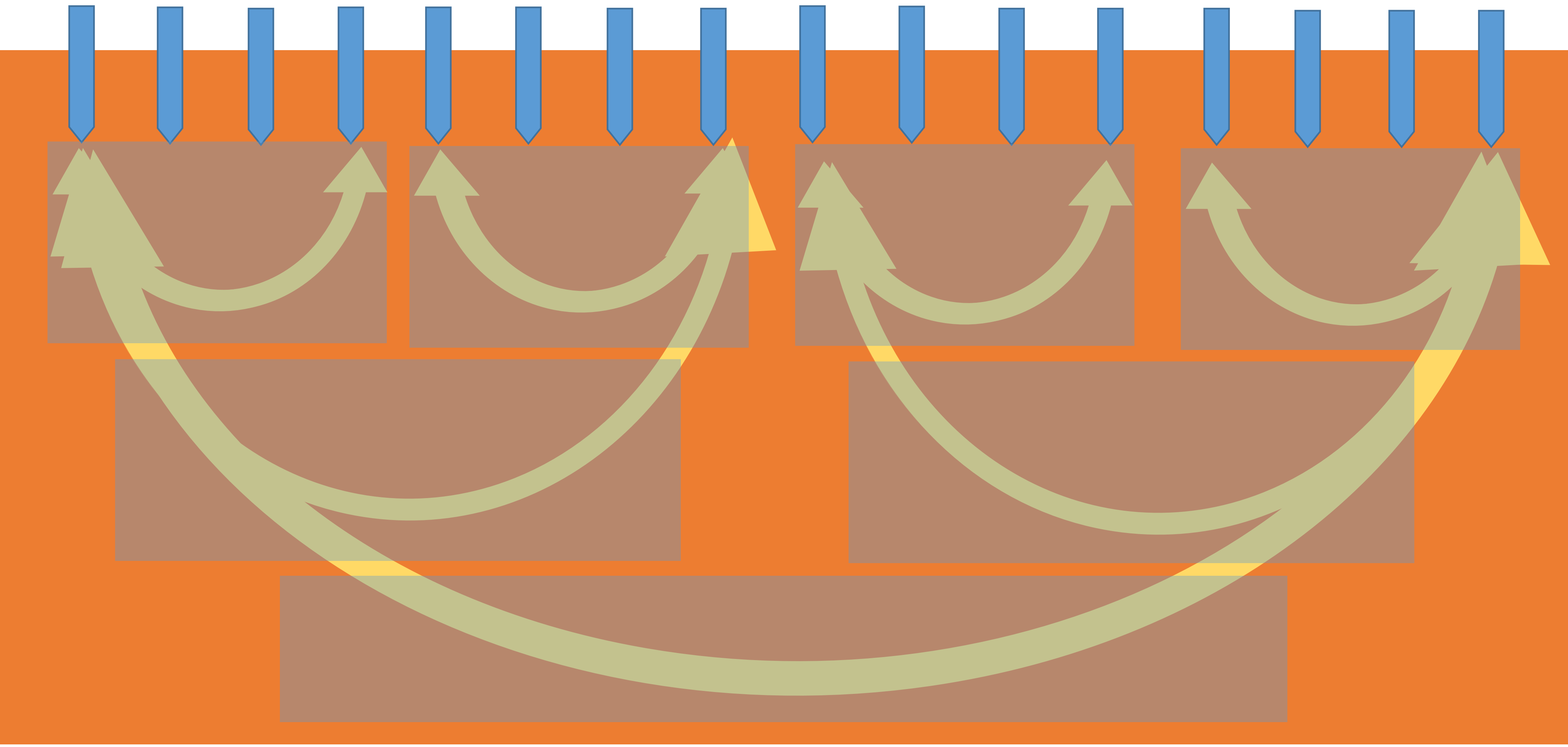
電位の計算

電流電極→C
電位電極→P　電位→Φ



電極間隔と比抵抗深さ

電極間隔を広げることで
深い位置の見掛比抵抗が分かる

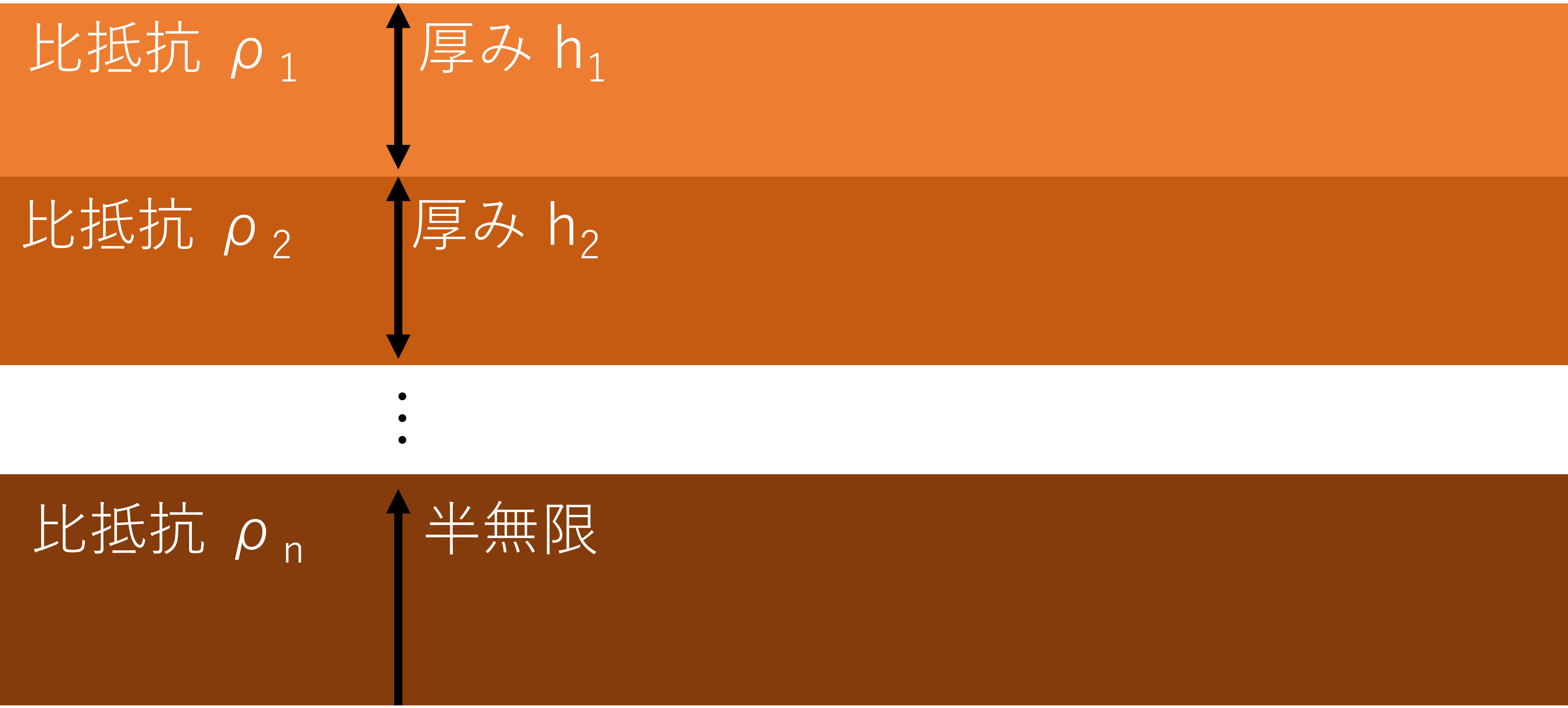


解析モデル
リニアフィルター法

１次元モデル

深さ方向に構造を与えて計算
水平構造なしと仮定

１次元多層モデル



1次元多層モデル

リニアフィルター法

比抵抗 ρ_1　厚み h_1

電流源に対して電位Φを求める式

比抵抗 ρ_2　厚み h_2

$$\phi = \frac{I}{2\pi}\int_0^\infty T(\lambda)J_0(\lambda r)\,d\lambda$$

⋮

Iは電流、J_0は0階のベッセル関数

Tは比抵抗変換と呼ばれ、以下の漸化式(n→1)より計算

比抵抗 ρ_n　半無限

$$\left.\begin{aligned} T(\lambda) &= T_1, \\ T_i &= \frac{T_{i+1}+\rho_i \tanh(\lambda h_i)}{1+T_{i+1}\tanh(\lambda h_i)/\rho_i}, \\ T_n &= \rho_n \end{aligned}\right\}$$

方法　観測場所

浅間山黒豆河原

方法　観測機器設置

1.東西方向に電極（杭）を地面に固定

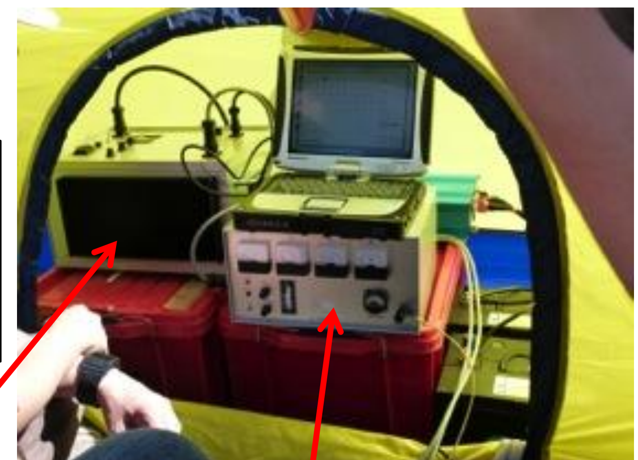
2.電極をリレーボックスにつなぎ、ボックス同士をケーブルで接合

電極

リレーボックス

ケーブル

3.テントの中に測定機器等を入れ、回路と接続

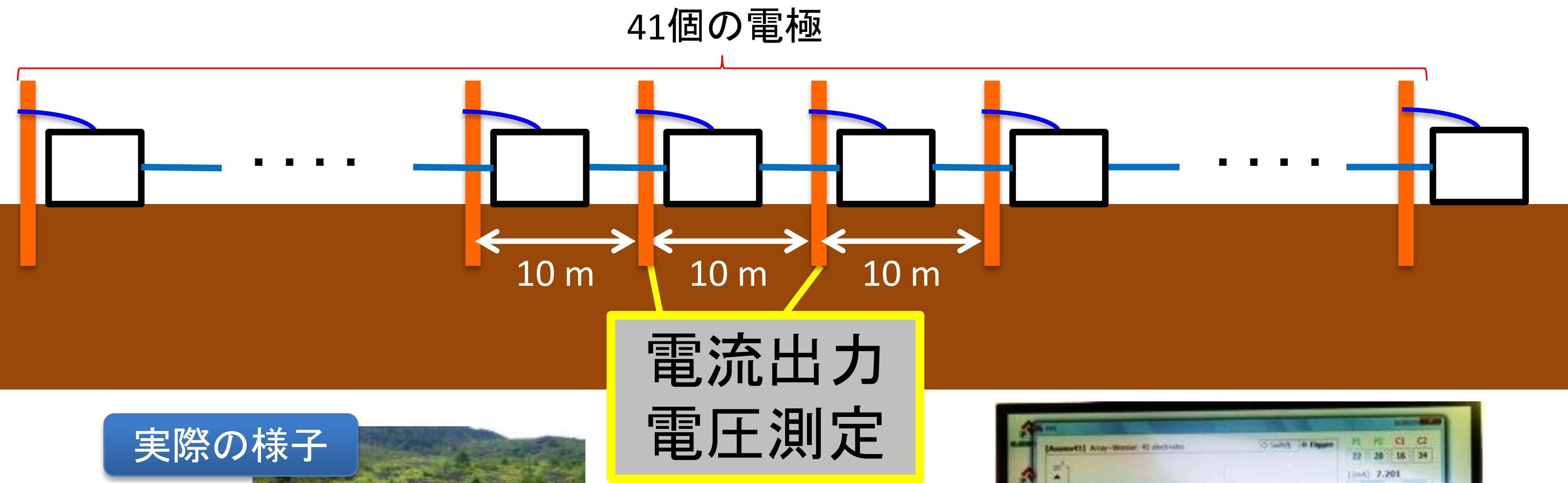


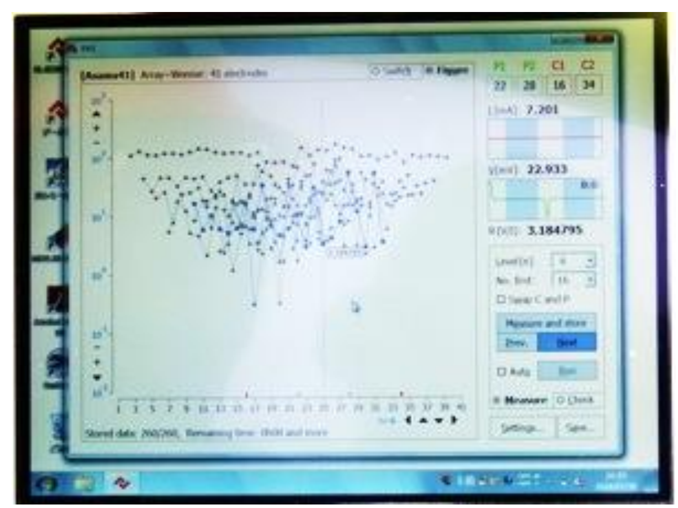
電流を流す機器

リレーボックスに指令を与える機器
電流・電圧を測定

方法　観測機器設置

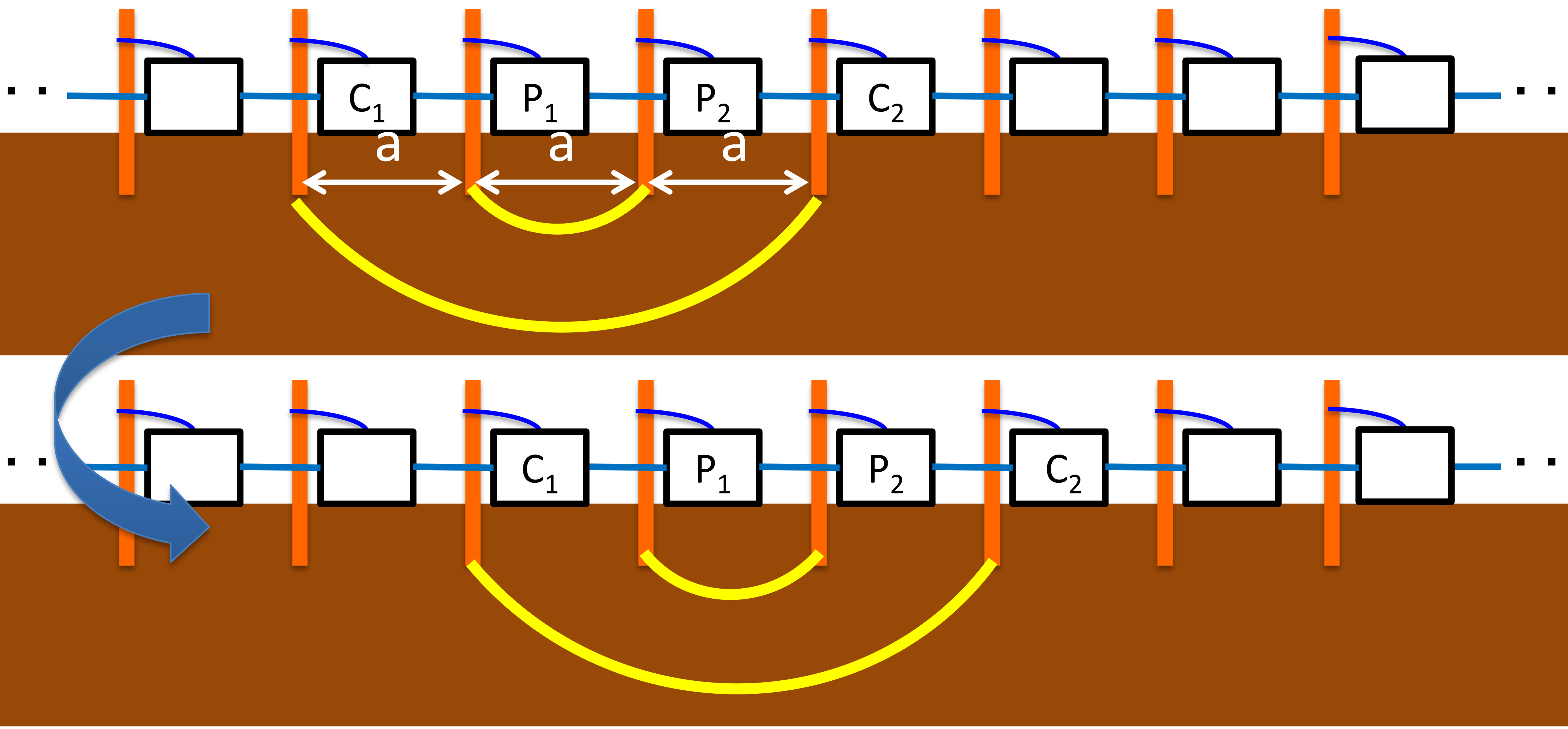
電極を全て等間隔に配列‥Wenner配置





使用する電極・測定時間等を制御

方法　Wenner配置 $a = 10$

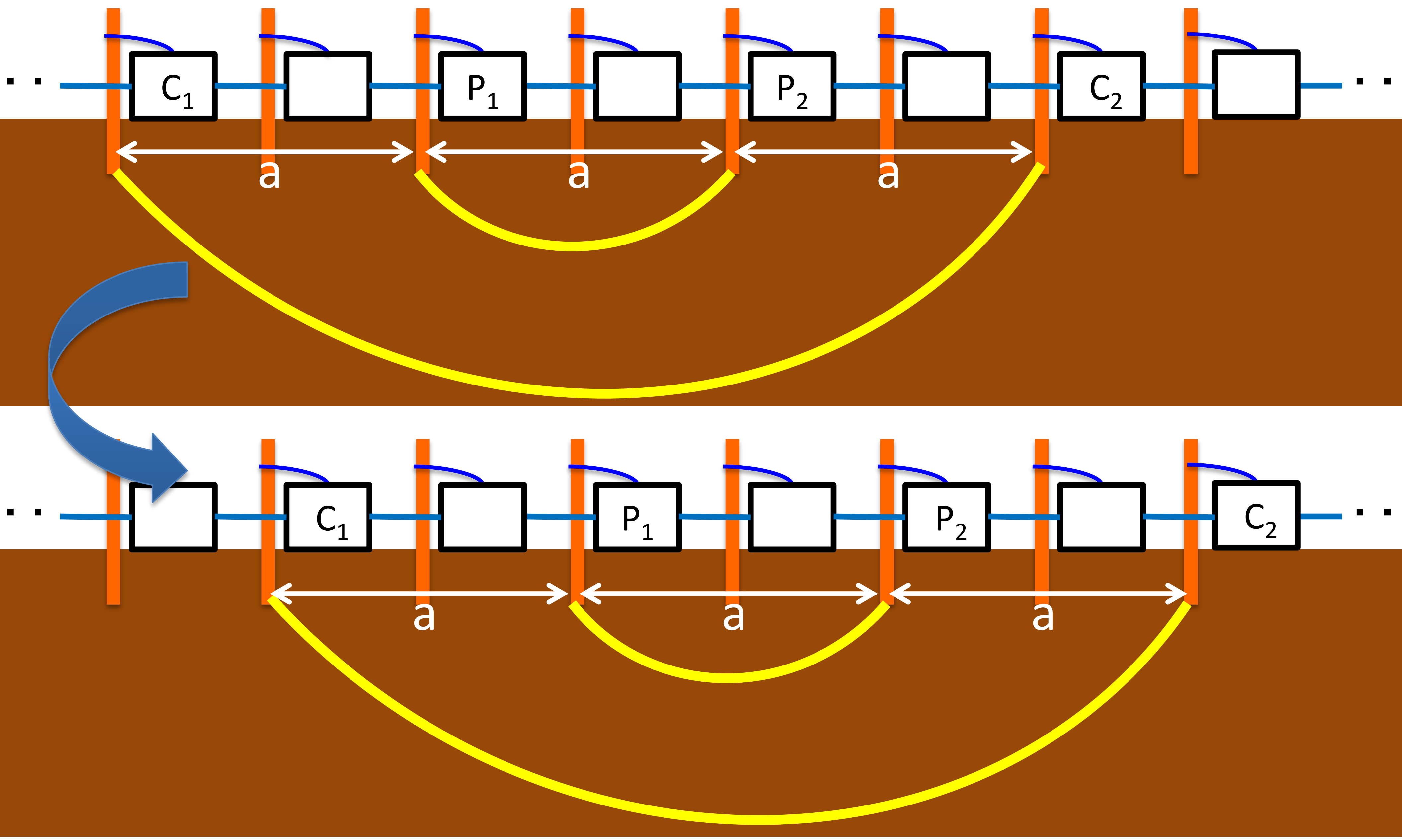


見かけ比抵抗
（Wenner配置の場合）

$$\rho = 2\pi a \frac{V}{I}$$

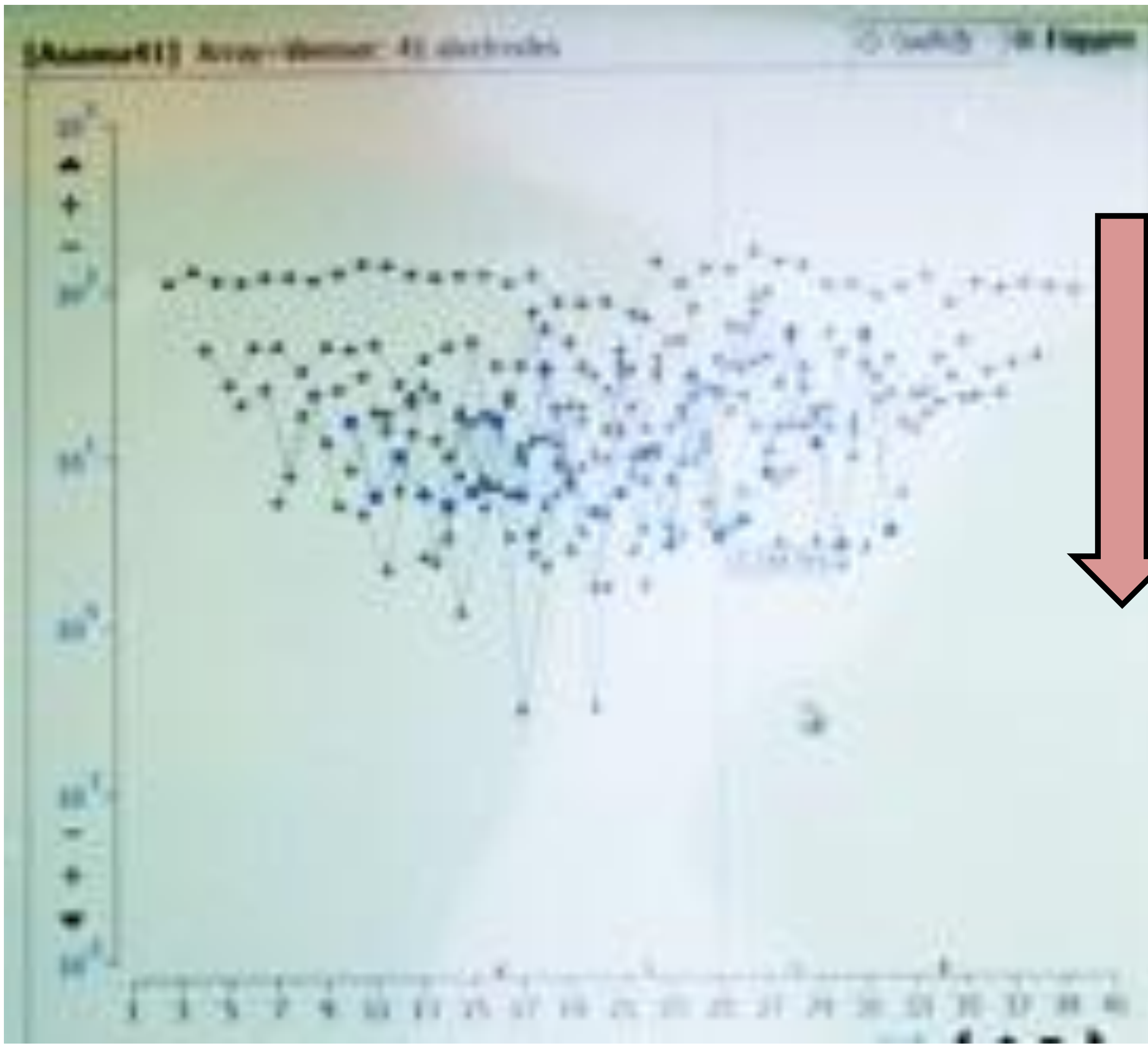
a : 電極の間隔（m）
V : 電圧（mV）
I : 電流（mA）

方法　Wenner配置 $a = 20$



方法　電極番号 vs 抵抗値

１組の配置での測定が終わるごとに抵抗値（V/I）が出現



間隔が広がると
抵抗値が減少

方法　観測地点

観測準備の様子

0番電極：北緯36度25分25.8秒，東経138度32分59.7秒, 標高1475 m
40番電極：北緯36度25分27.7秒，東経138度33分15.6秒, 標高1435 m

Results of 2016 Resistivity Survey of Mount Asama

Analytical Solution (2 Layer Model)

$$\rho_a = \rho_1 \left[1 + 4\Sigma_n \frac{\left(\frac{\rho_2/\rho_1 - 1}{\rho_2/\rho_1 + 1}\right)^n}{\sqrt{1 + 4n^2(d/r)^2}} - 2\Sigma_n \frac{\left(\frac{\rho_2/\rho_1 - 1}{\rho_2/\rho_1 + 1}\right)^n}{\sqrt{1 + n^2(d/r)^2}} \right]$$

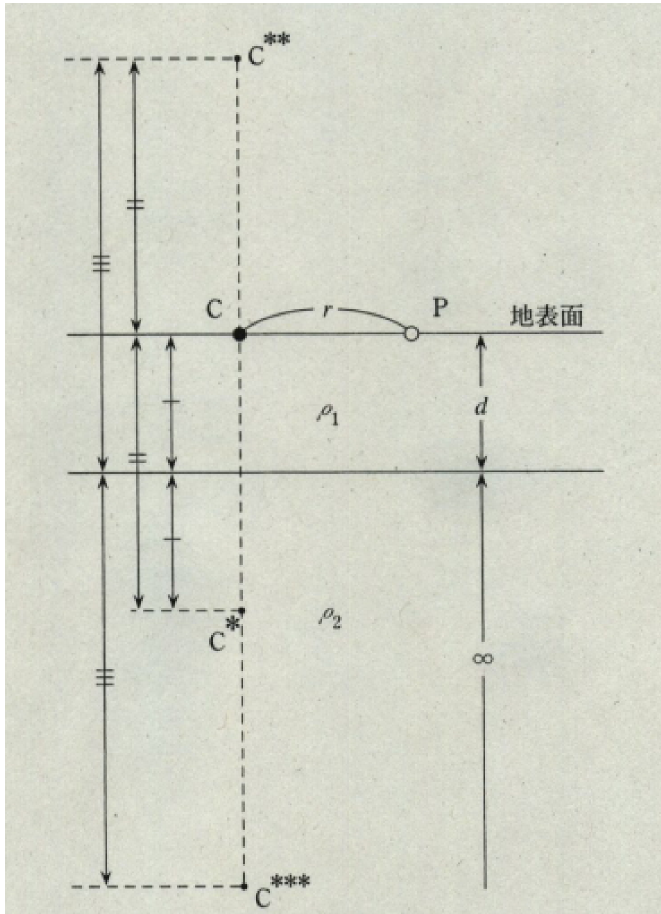


図 2.15 水平二層構造の仮想電流源分布

Digital Linear Filter Method (n layer model)

Given a Hankel transform $\phi = \frac{I}{2\pi} \int T(\lambda) J_0(\lambda r) d\lambda$

The kernel $T(\lambda)$ can obtained numerically though recursion

$$T(\lambda) = T_1, \, T_i = \frac{T_{i+1} + \rho_i \tanh(\lambda h_i)}{1 + T_{i+1} \tanh(\lambda h_i)/\rho_i}, \, T_n = \rho_n$$

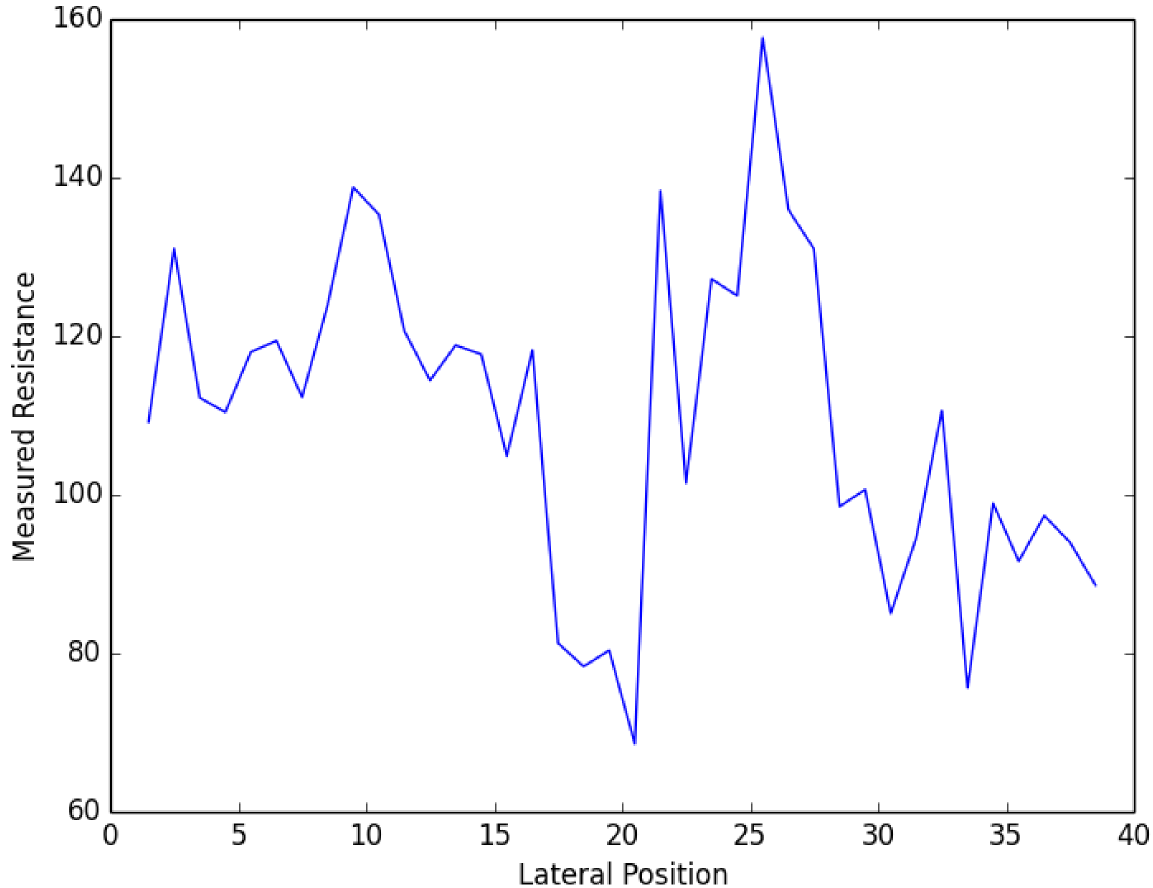
Using a set of n abscissae $\lambda_i = \frac{1}{r} 10^{a+(i-1)s}$, the Hankel transform can be discretized to

$$\phi = \frac{I}{2\pi r} \Sigma_i T(\lambda_i) W_i$$

where W_i are filter weights.

Raw Data

Raw data is resistance as a function of electrode position.

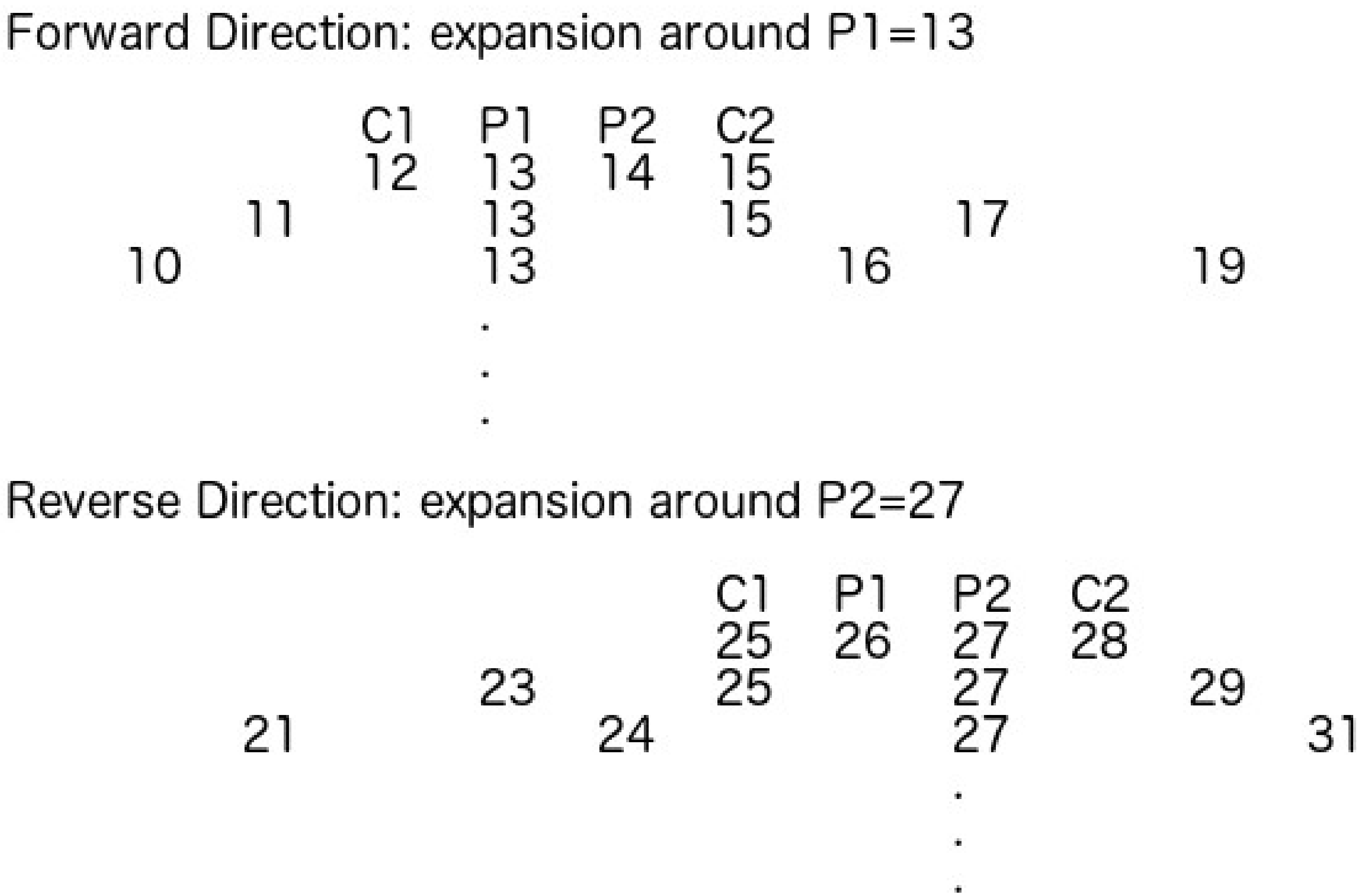


Multiple sets of such data was extracted for a set of different electrode spacings.

Results 1a

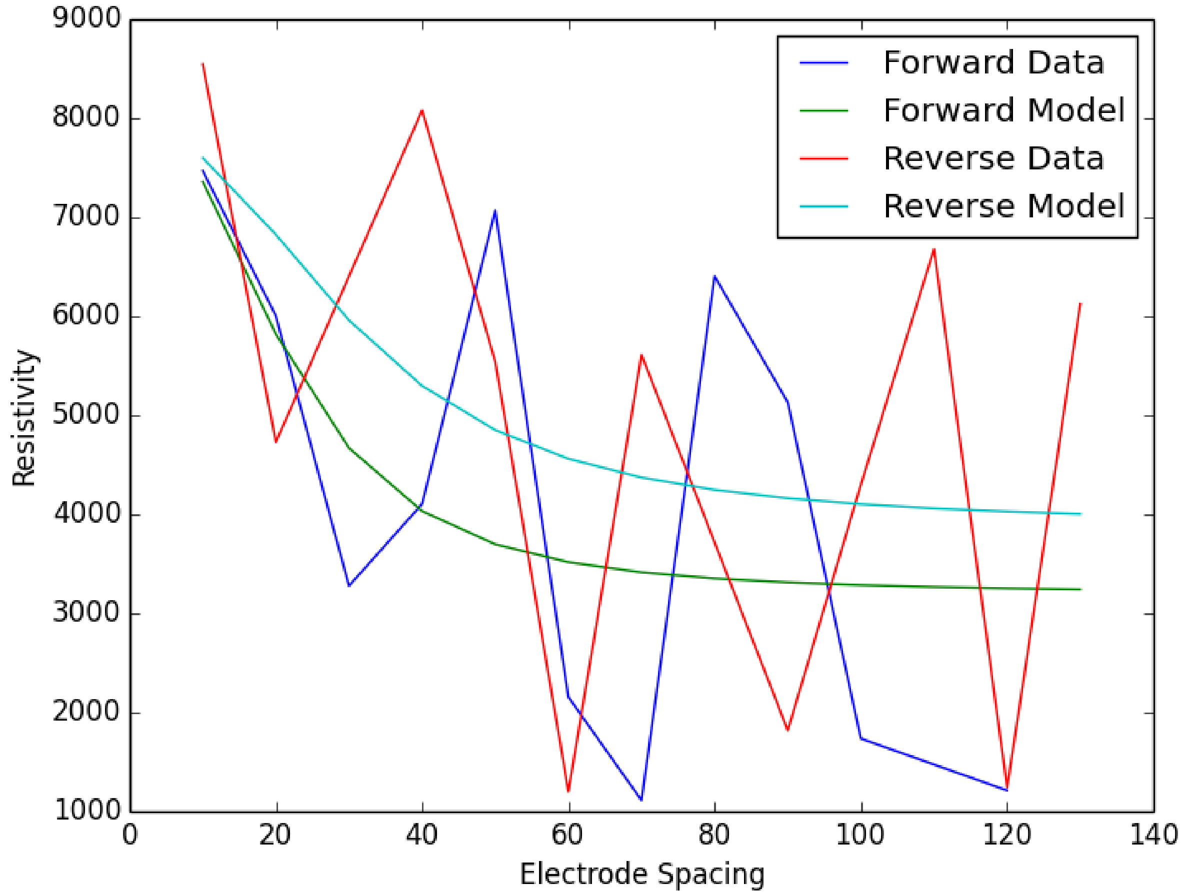
Fix position of one potential electrode and expand along the array.

Plot the measured resistivity as a function of electrode spacing.



Results 1b

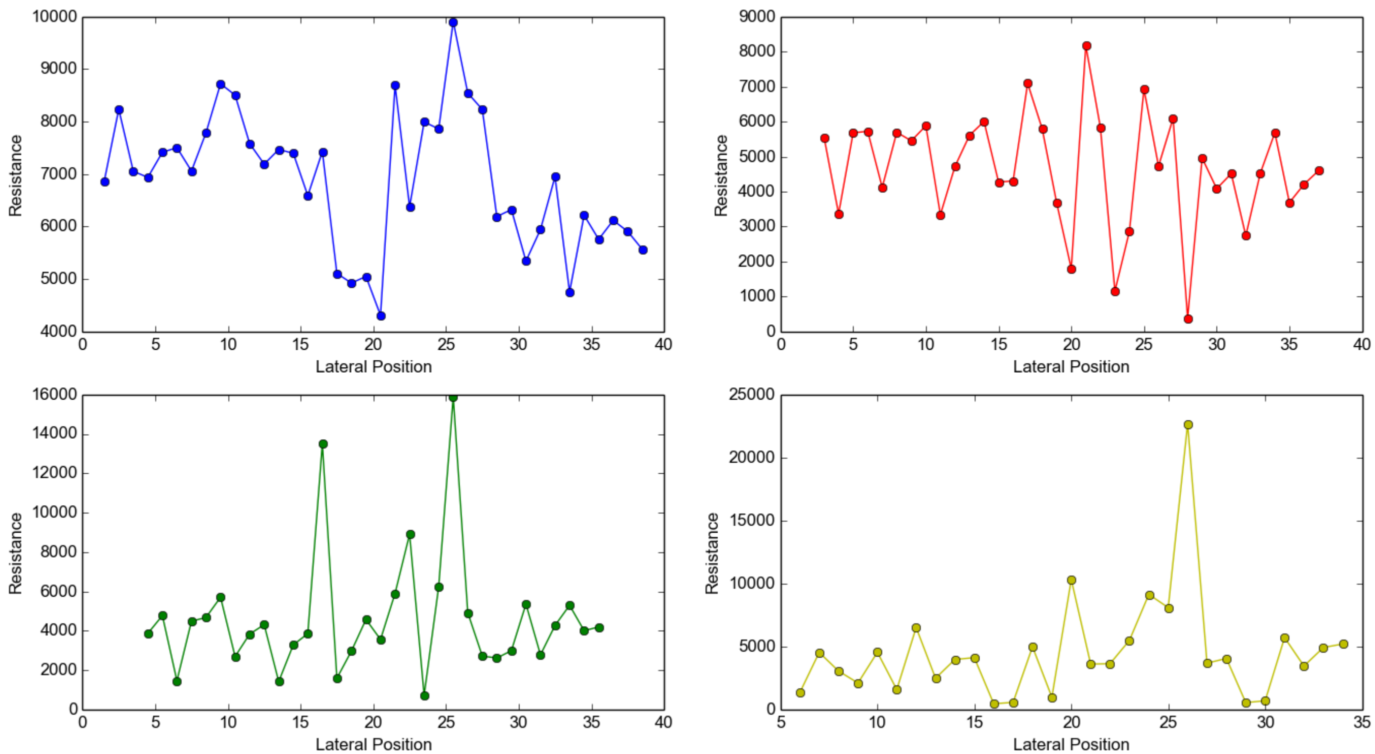
2 layer model non linear inversion using Python.



Forward: $\rho_1 = 7960\Omega\text{m}$, $\rho_2 = 3190\Omega\text{m}$, $d = 14\text{m}$.
Reverse: $\rho_1 = 7800\Omega\text{m}$, $\rho_2 = 3880\Omega\text{m}$, $d = 19\text{m}$.

Results 2a

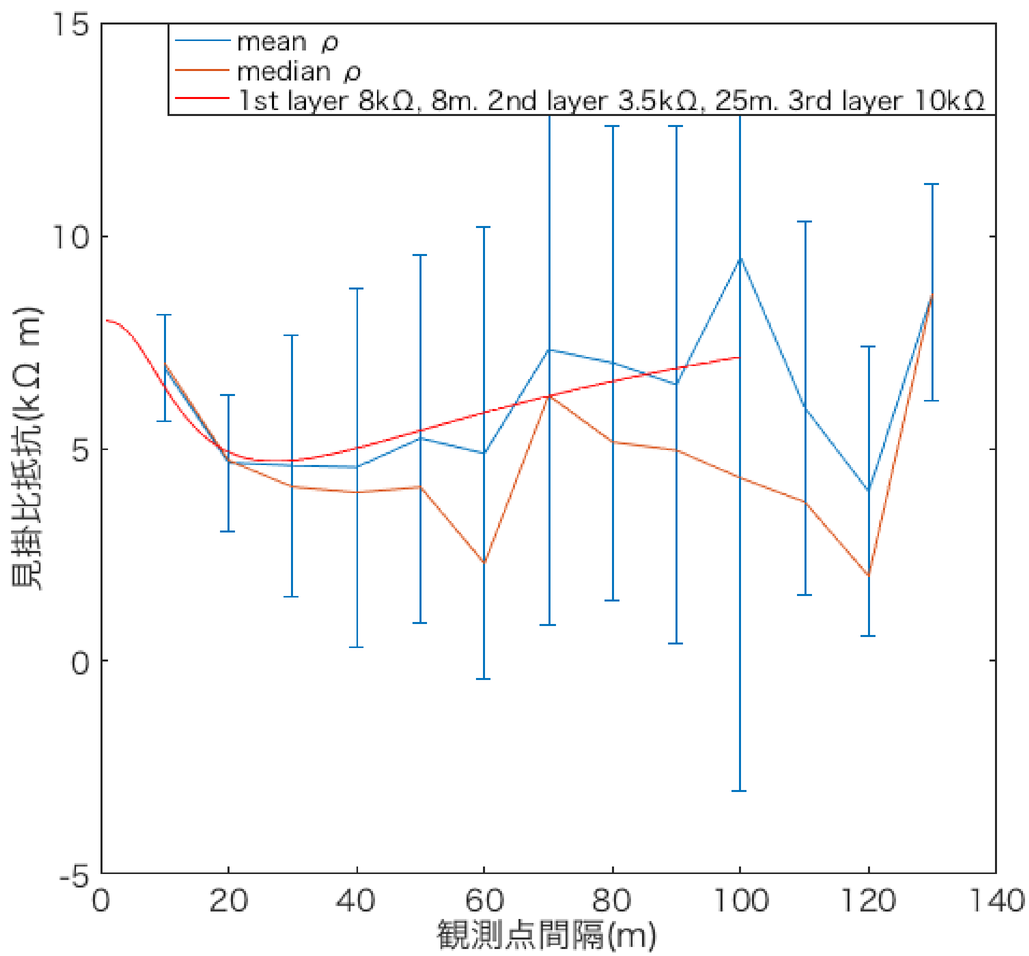
For each set of data corresponding to one electrode spacing, find the average/median resistivity.



Plot the average/median resistivity as a function of electrode spacing.

Results 2b

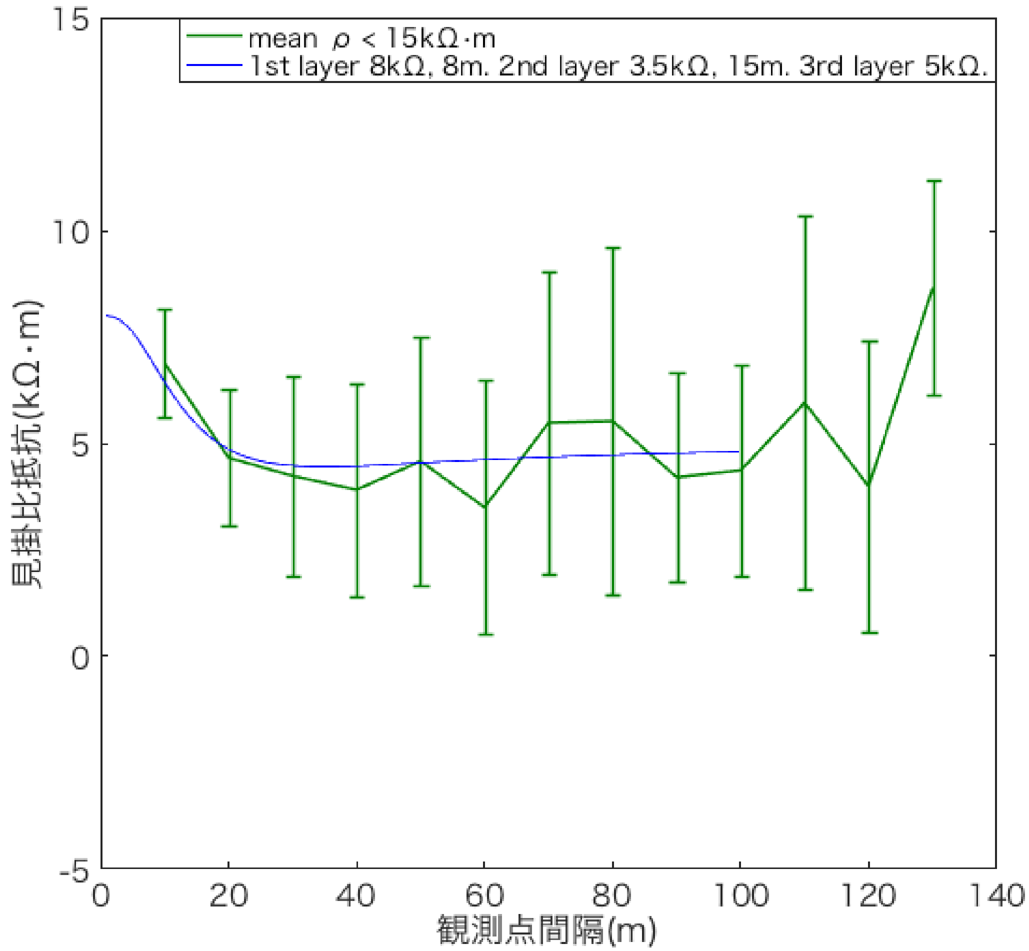
Using all 260 data points, fitting through trial and error.



Model parameters: $\rho_1 = 8000\Omega\text{m}$, $\rho_2 = 3500\Omega\text{m}$, $\rho_3 = 10000\Omega\text{m}, d_1 = 8\text{m}$, $d_2 = 25\text{m}$.

Results 2c

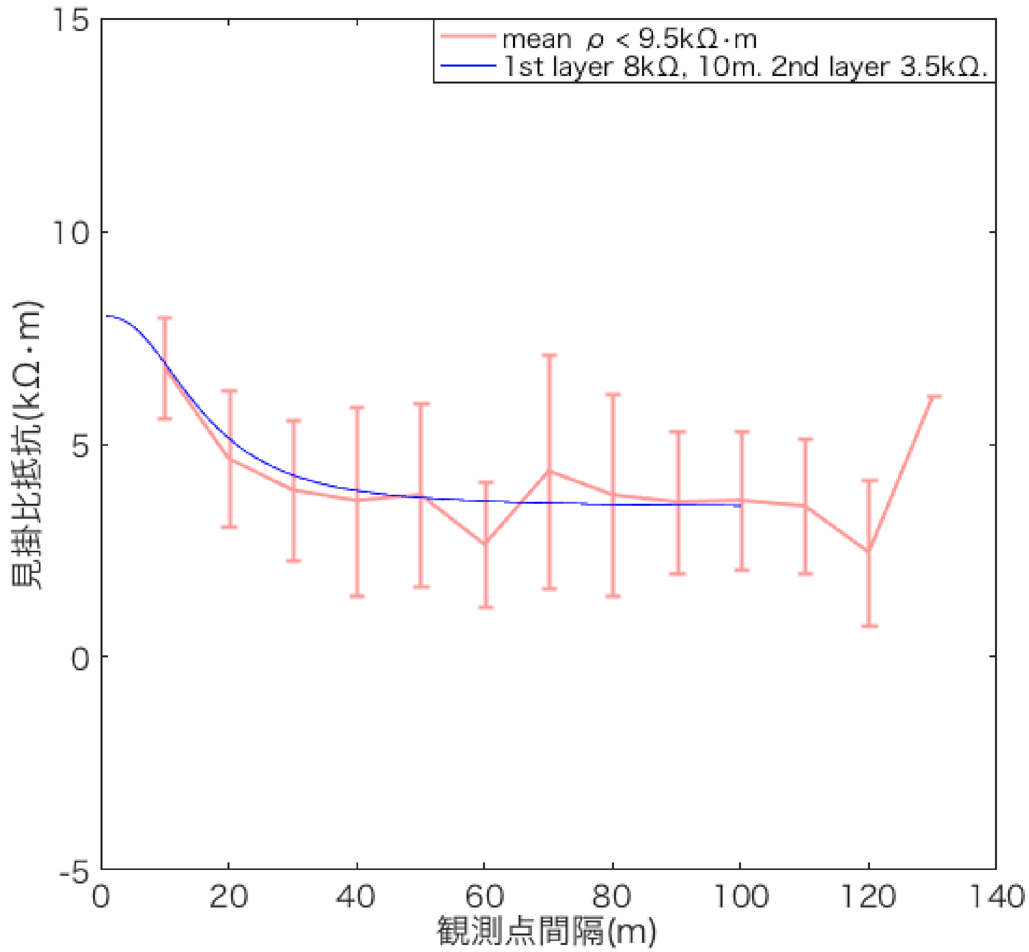
Excluding data points larger than 15 kΩm.



Model parameters: $\rho_1 = 8000\Omega\text{m}$, $\rho_2 = 3500\Omega\text{m}$, $\rho_3 = 5000\Omega\text{m}, d_1 = 8\text{m}$, $d_2 = 15\text{m}$.

Results 2d

Exluding data points larger than 9.5 kΩm.

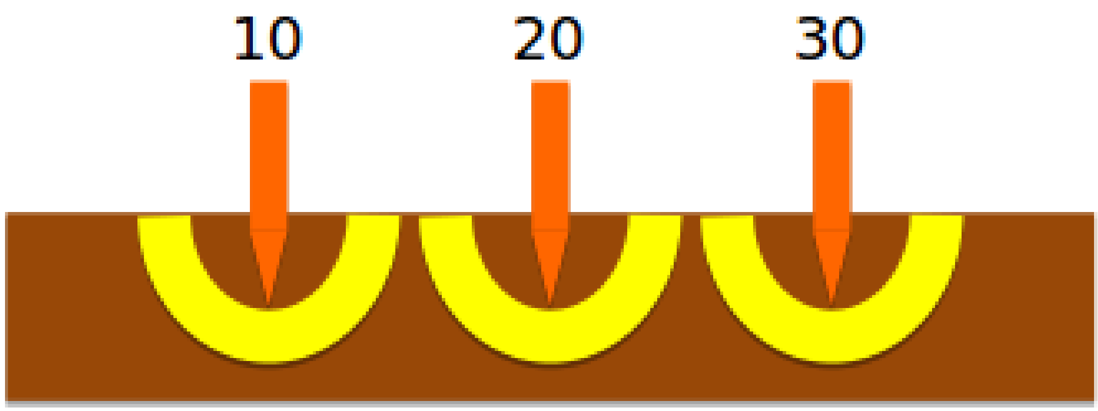


Model parameters: $\rho_1 = 8000\Omega\text{m}$, $\rho_2 = 3500\Omega\text{m}$, $d = 10\text{m}$.

Results 3a

Select for analysis only the electrodes 10, 20, 30.

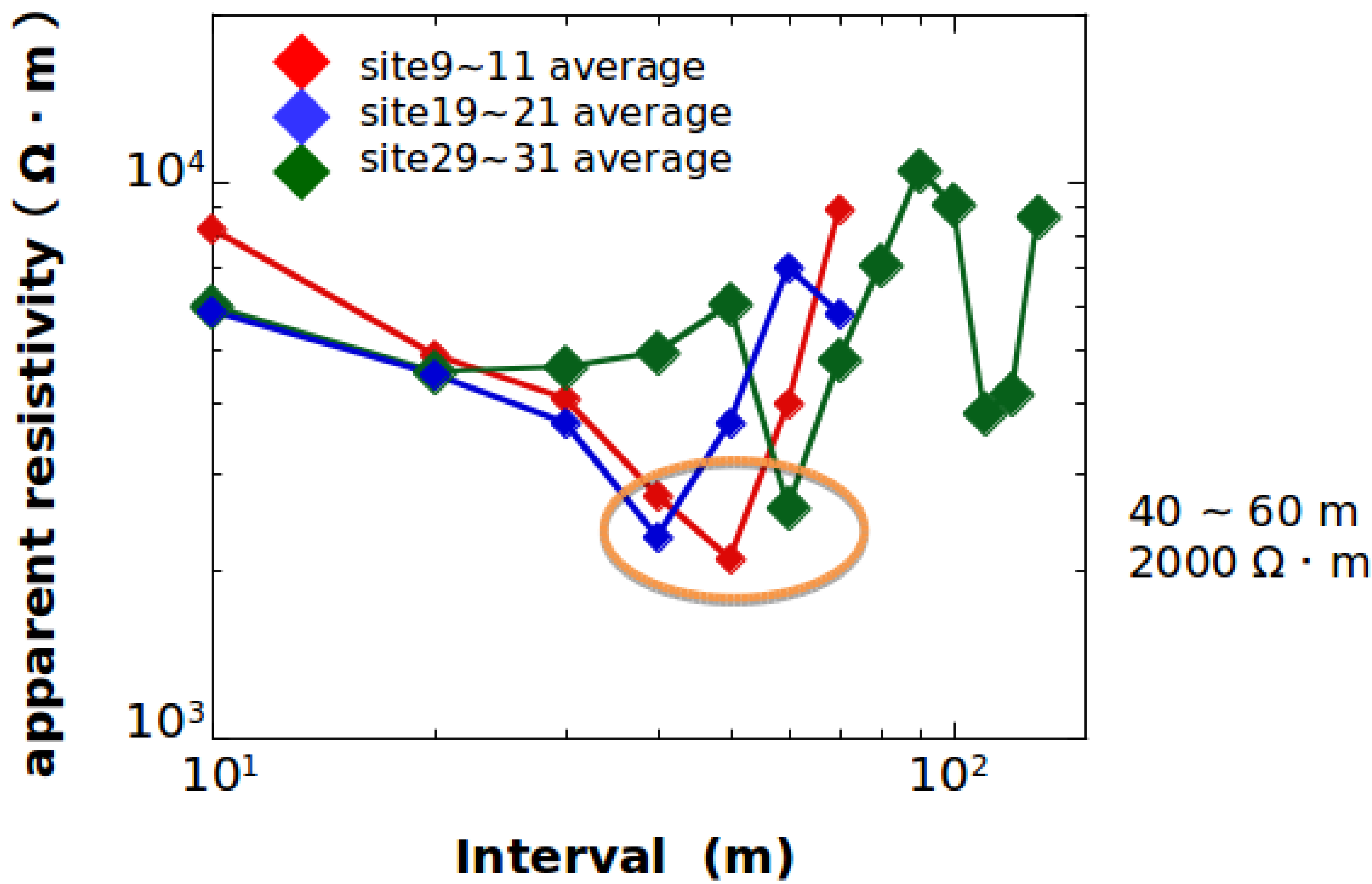
Calculate average measured values of the selected electrodes and the electrodes next to them.



Results 3b

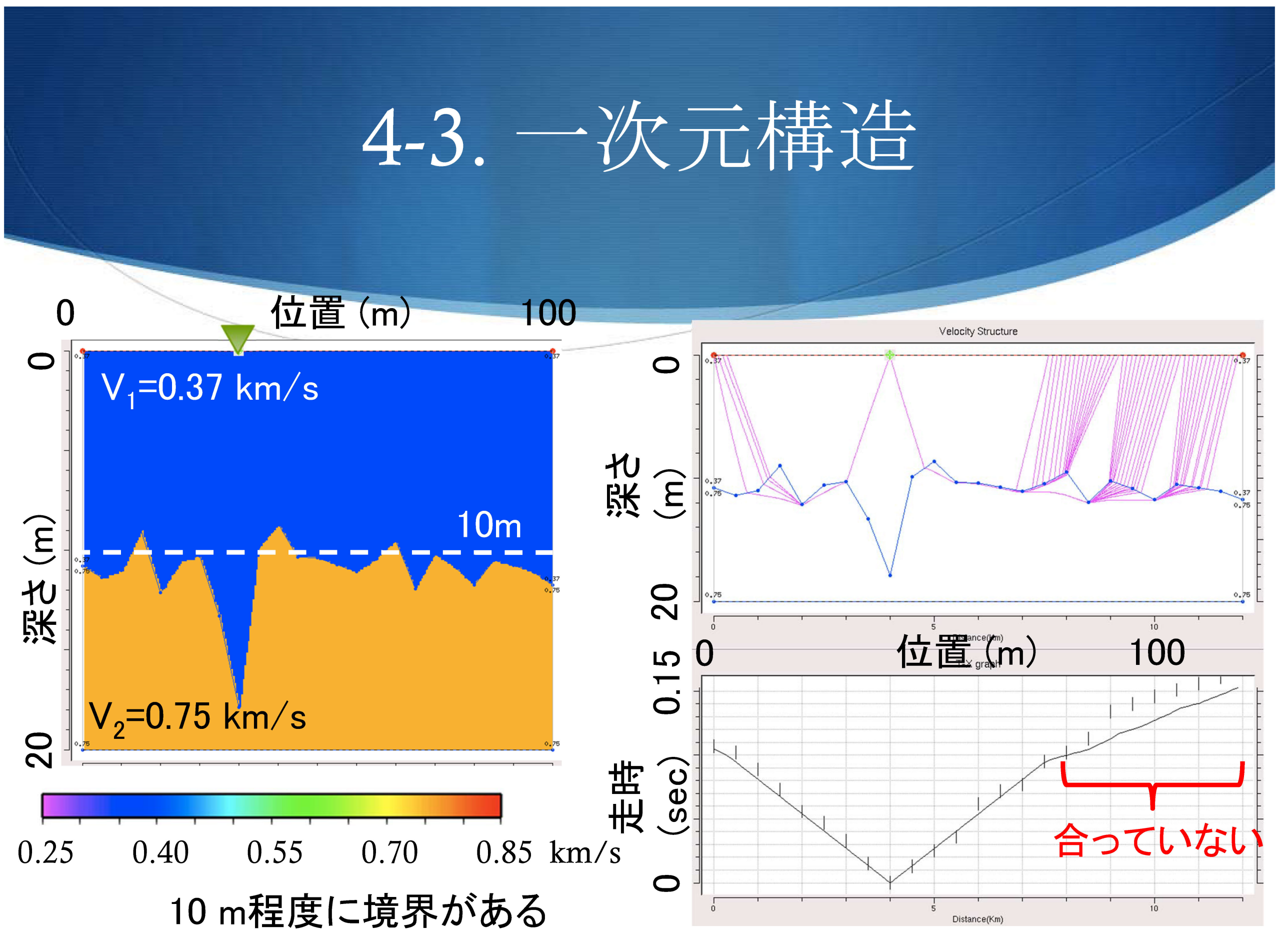
Turning point observed in graph at 40 - 60 m bsl, with minimum resistance of 2000 Ωm.

Might indicate a boundary between two layers.



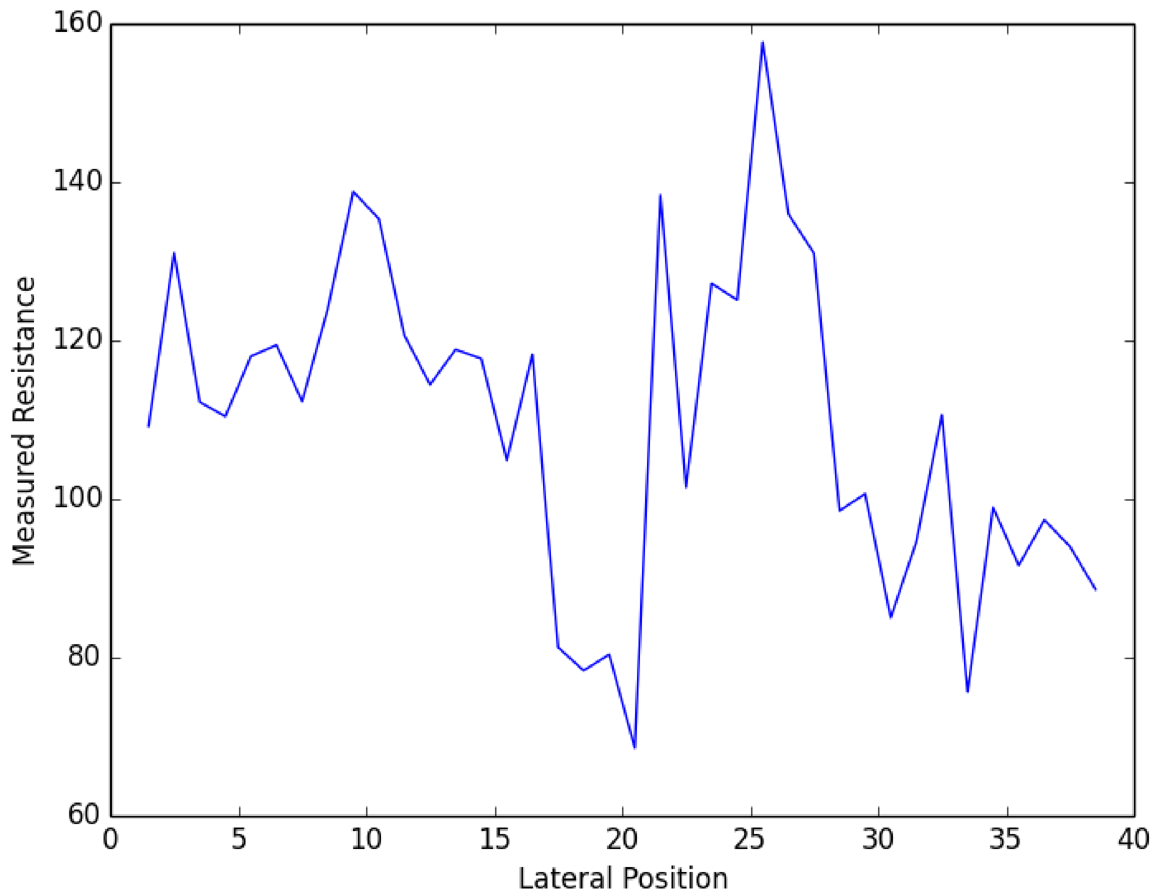
Comparison with Seismic Wave Group of 2013

Modelled 2 layer model with thickness of order 10 m agrees well with values obtained by Seismic Wave Group (Okano, Yabe, Nishikawa and Profs. Shiobara, Mochizuki and Miyake, 2013)



Other Possible Analyses

Lateral electrical profiling can be done using the same data.



However, lateral electrical profiling is still limited to 1 dimension. Electrical imaging should be used to obtain a 2 dimensional pseudosection.

Prospects

Minimum electrode spacing of 10 m, maximum electrode spacing of 130 m.

Corresponding penetration depths of 5 m and 65 m respectively.

Prospects

Very noisy data with extremely large measured values in excess of 10000 Ωm due to small (mA) currents and large contact resistances.

Model solutions are non-unique due to current refraction. Need to compare results with other measurements e.g. borehole drilling.

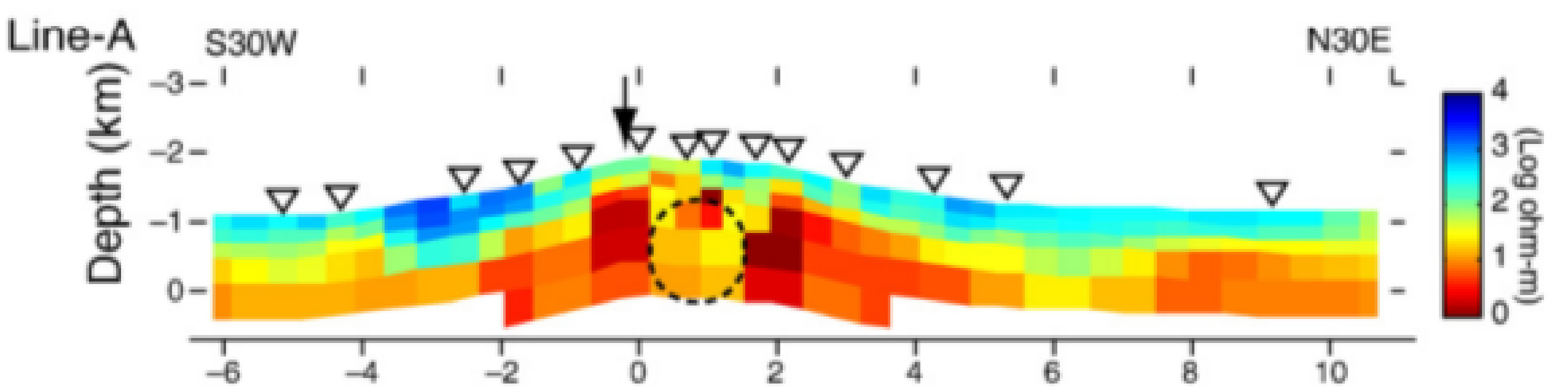


Figure : N-S resistivity profile of Mount Asama [1]

[1] K. Aizawa et al. Journal of Volcanology and Geothermal Research 173 (2008) 165-177