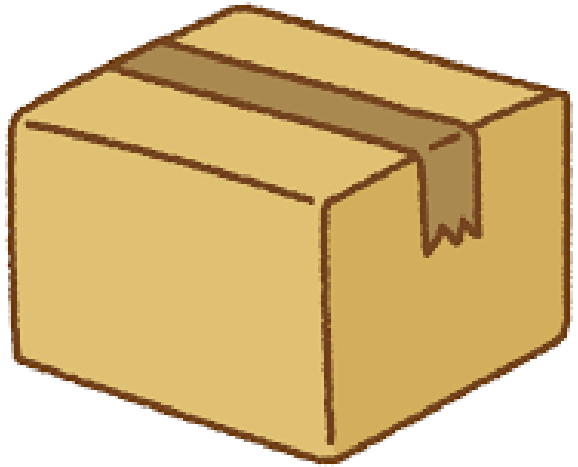
Practical training on geophysical investigation: -Seismic survey at the 140 m gallery -

Yusuke Ozaki

Geophysical exploration

What do you do when you want to know inside box?

- Shake the box
- Stick a needle
- Open the box
- Cut the box
- …

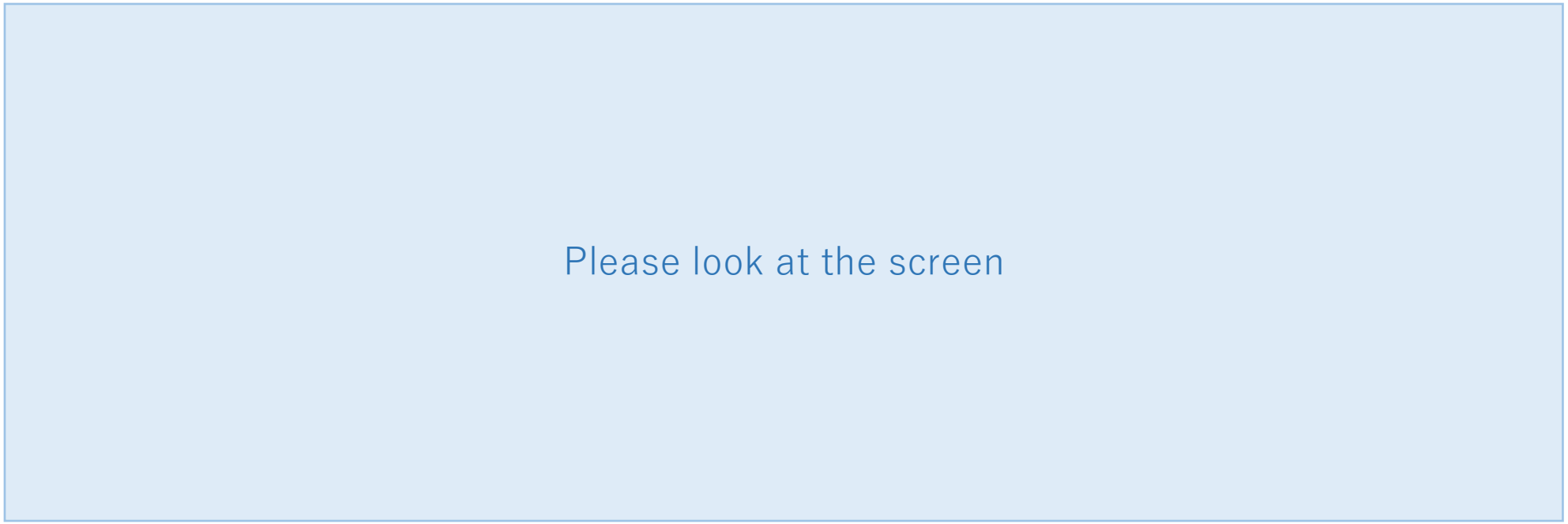


- How to investigate inside?
  - If we don’t want to destroy the target
  - When we cannot destroy the target

➡ Geophysical exploration is one of the solutions.

Geophysical exploration

- This may be more familiar for you…



Computed Tomography (CT) (X-ray tomography)
Similar technique is applicable to the earth.

Geophysical exploration

Most methods use phenomena that propagate subsurface.

- Seismic wave
  - Refraction survey (First-arrival traveltime tomography)
  - Reflection survey
  - …
- Electrical current (Direct current)
- Electromagnetic wave
  - Ground penetrating radar (GPR)
  - Time-domain electrical magnetic method
  - Magnetotelluric method
- Gravity
- Magnetic field
- …

Resolution and exploration depth are dependent on methods.

Geophysical exploration

What can we know from the results of geophysical exploration?

- A seismic method can estimate the velocity of seismic waves.

$$V_p = \sqrt{\frac{K + {}^4/_3\, G}{\rho}} \qquad V_s = \sqrt{\frac{G}{\rho}}$$ ➡ E.g., stiffness of rock

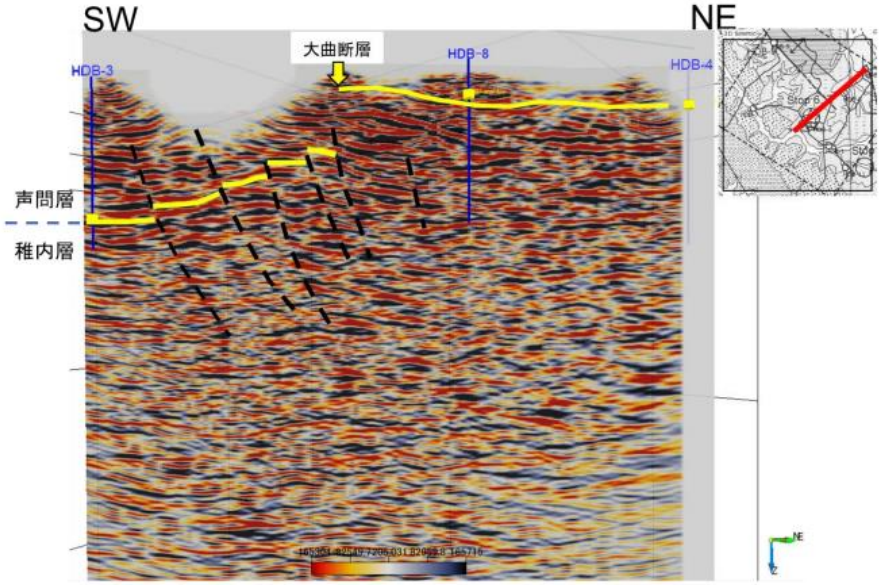
- Electrical-related methods can estimate the distribution of electrical resistivity.

$$\rho_R = a R_w \varphi^{-n} {S_w}^{-m}$$ ➡ E.g., water content in rock

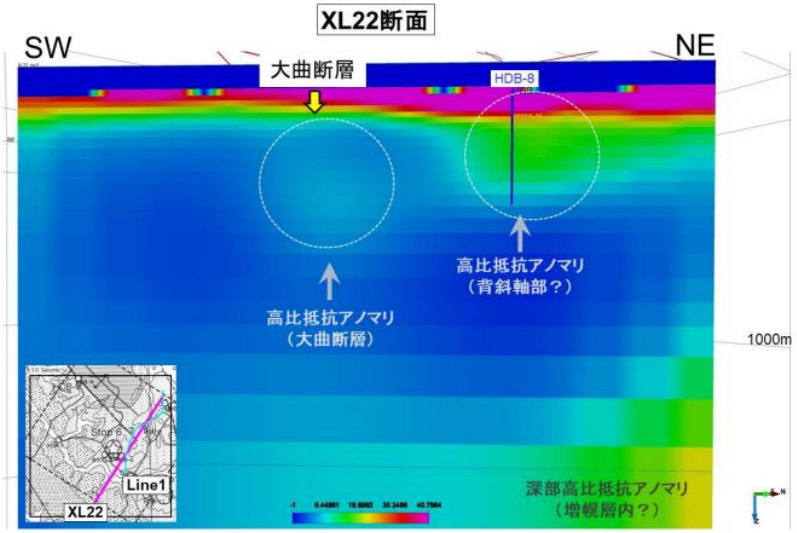
Example of large-scale survey around Horonobe URL

Seismic reflection survey

Magnetotelluric survey



Target depth:
~km order



JAEA and CRIEPI (2021)

Example of survey in the Horonobe URL　Seismic refraction survey

At wall (Source & Receivers)

Receiver

In borehole (Source)

Source (air knocker)

Source (hit wall)

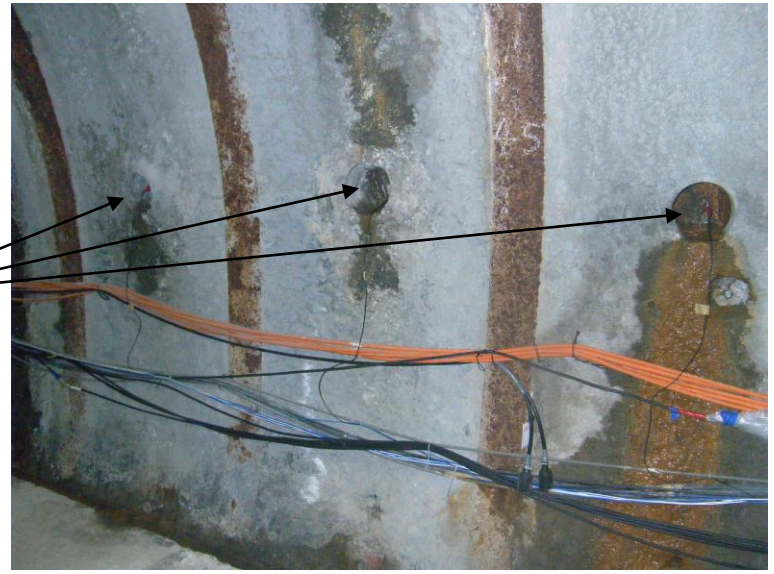
At wall (Receivers)

Receiver

Example of survey in the Horonobe URL　Electrical resistivity survey

At wall

Electrode



Electrode

In borehole

Electrode

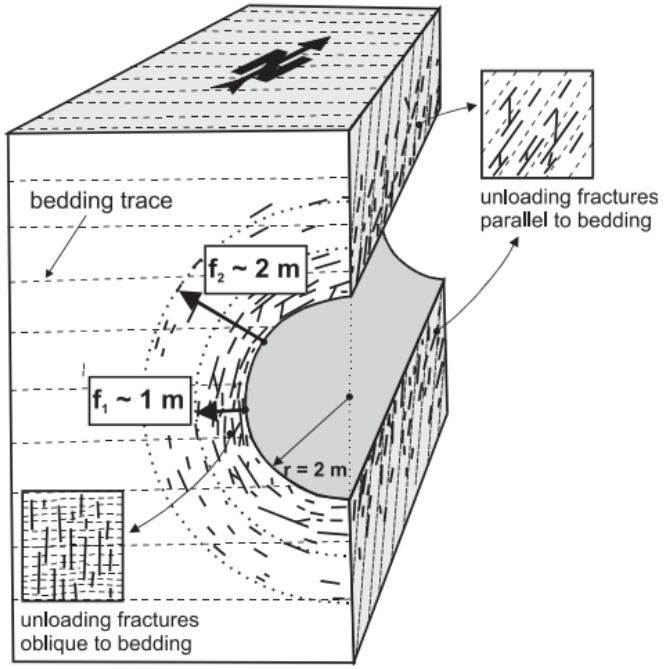
Switching box

Recorder

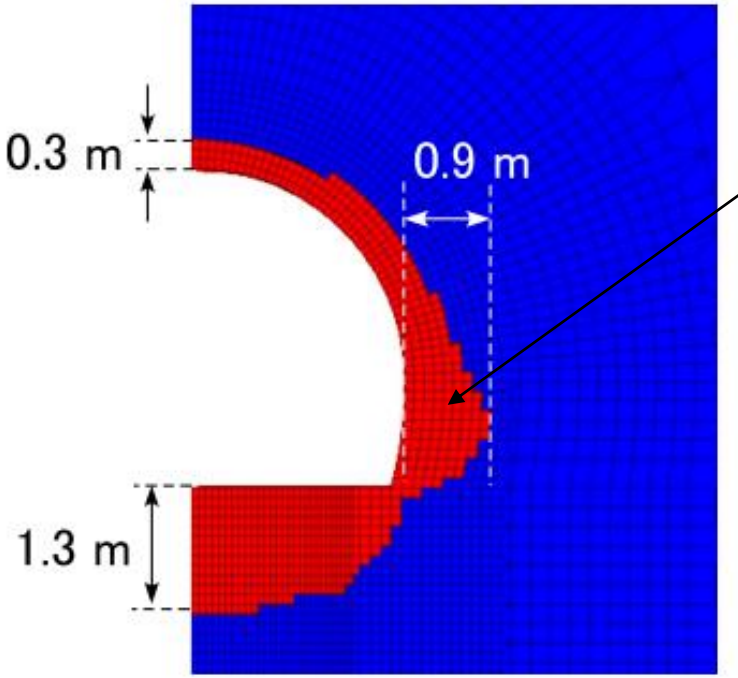
The target of geophysical exploration in URL

- Excavation of tunnel
  - Damage surrounding rock→Stiffness of rock decreases
  - Water drainage→Water content decreases

➡ Excavation damaged zone.



Bossart et al., 2022



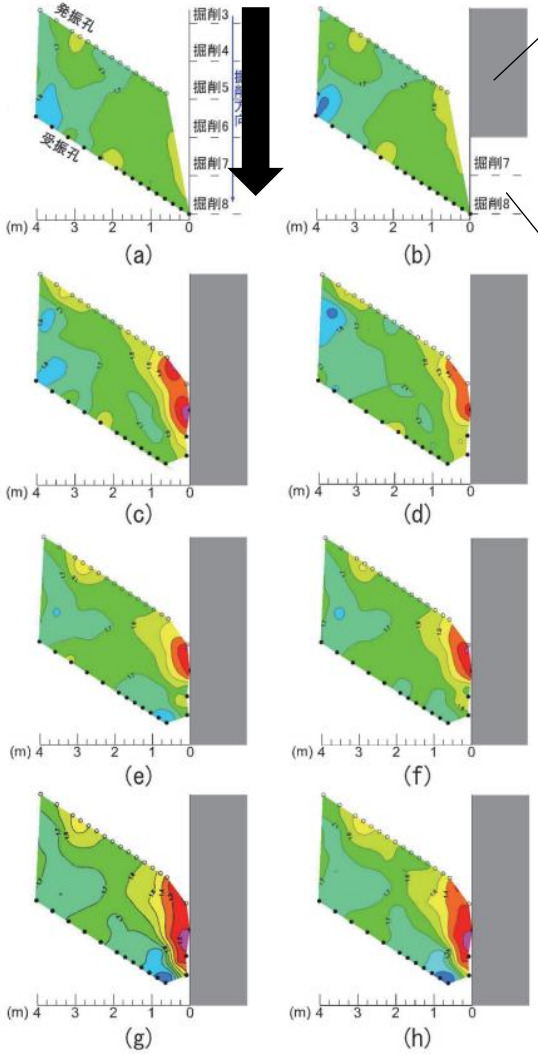
Target depth: several tenth cm

Example of survey results in the Horonobe URL

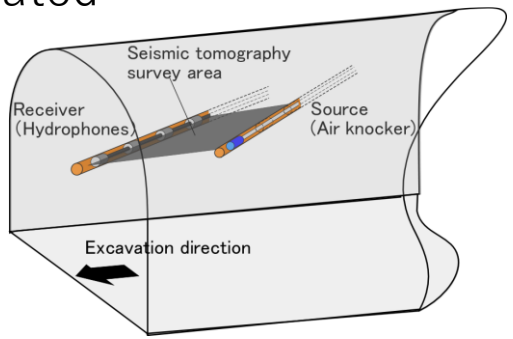
Results of refraction survey

Excavation direction

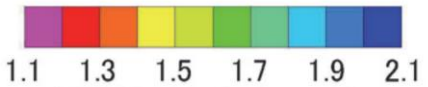
Excavated



Not excavated

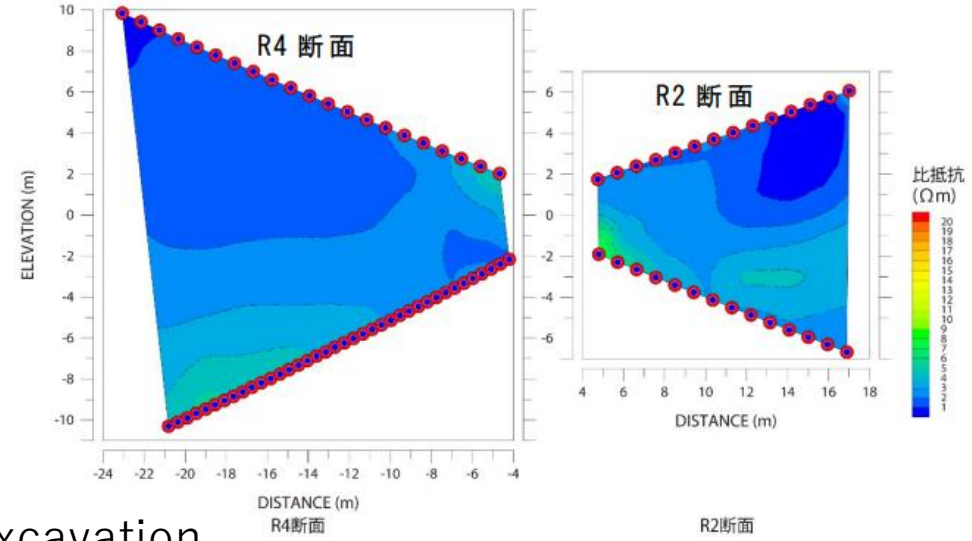


P-wave velocity [km/s]

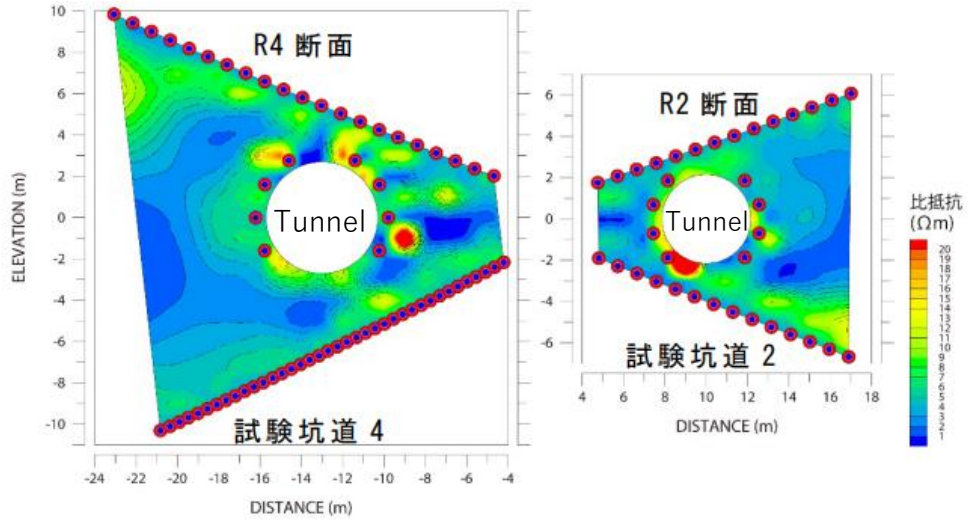


Results of electrical resistivity survey

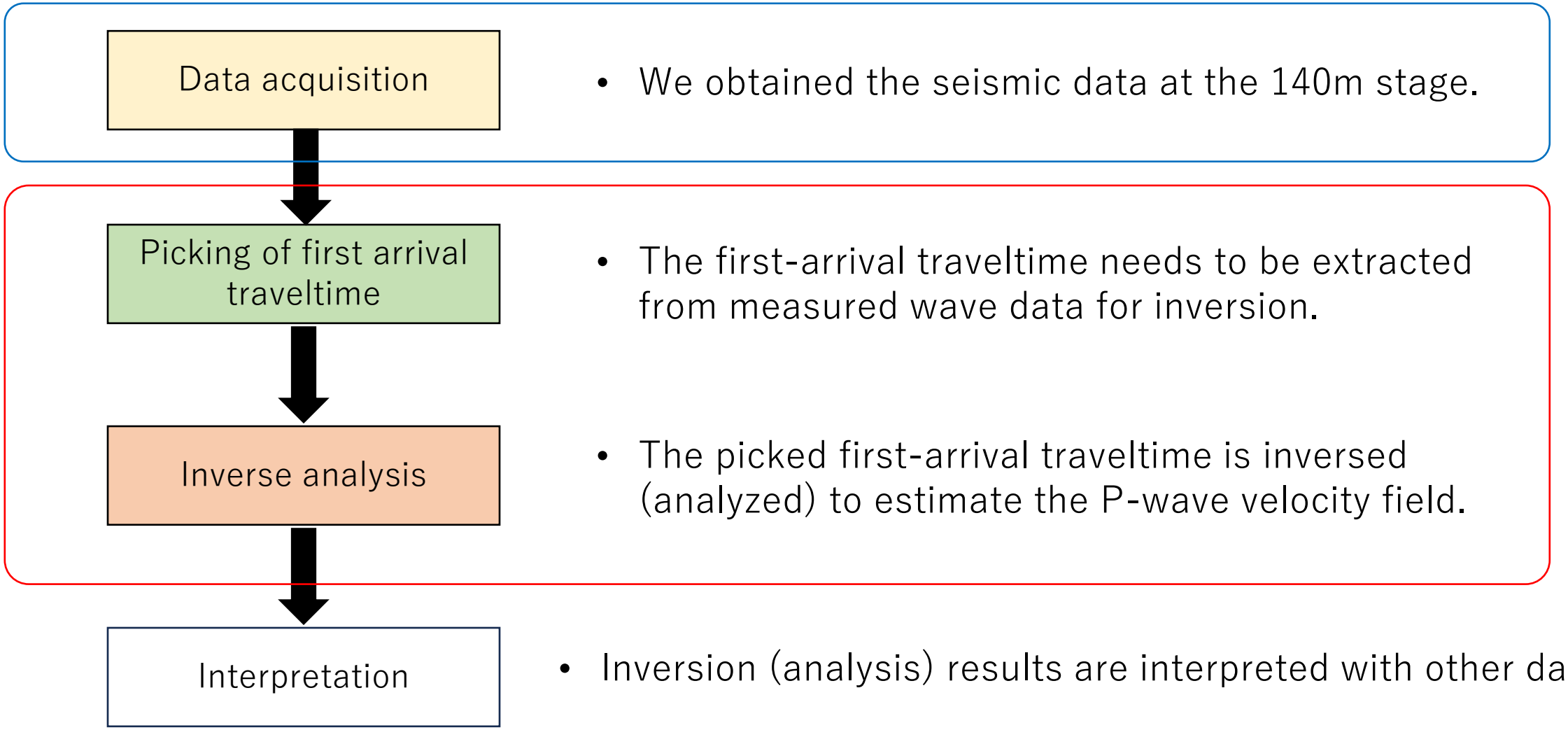
Before excavation



After excavation

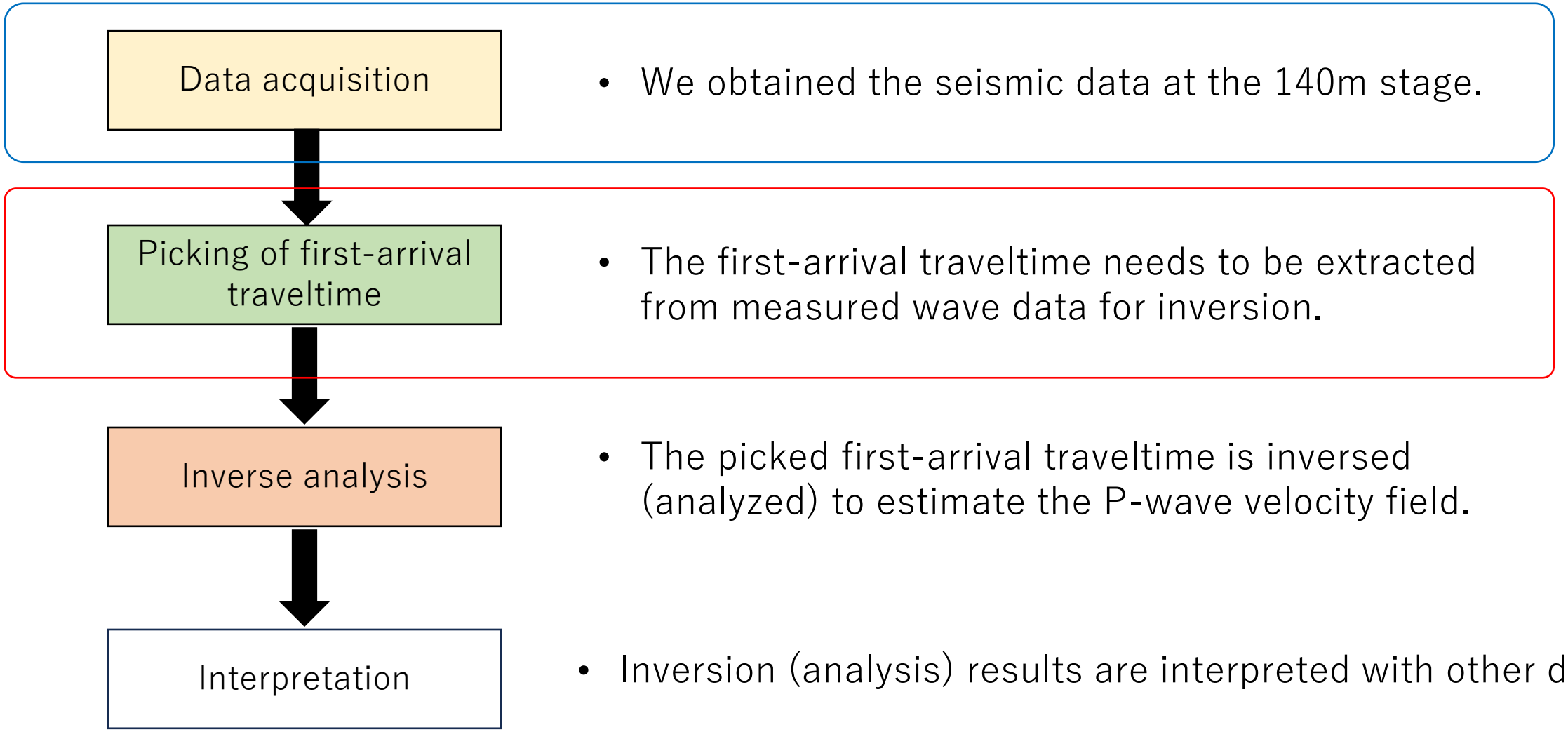


Step of data analysis



- We obtained the seismic data at the 140m stage.
- The first-arrival traveltime needs to be extracted from measured wave data for inversion.
- The picked first-arrival traveltime is inversed (analyzed) to estimate the P-wave velocity field.
- Inversion (analysis) results are interpreted with other data.

Step of data analysis



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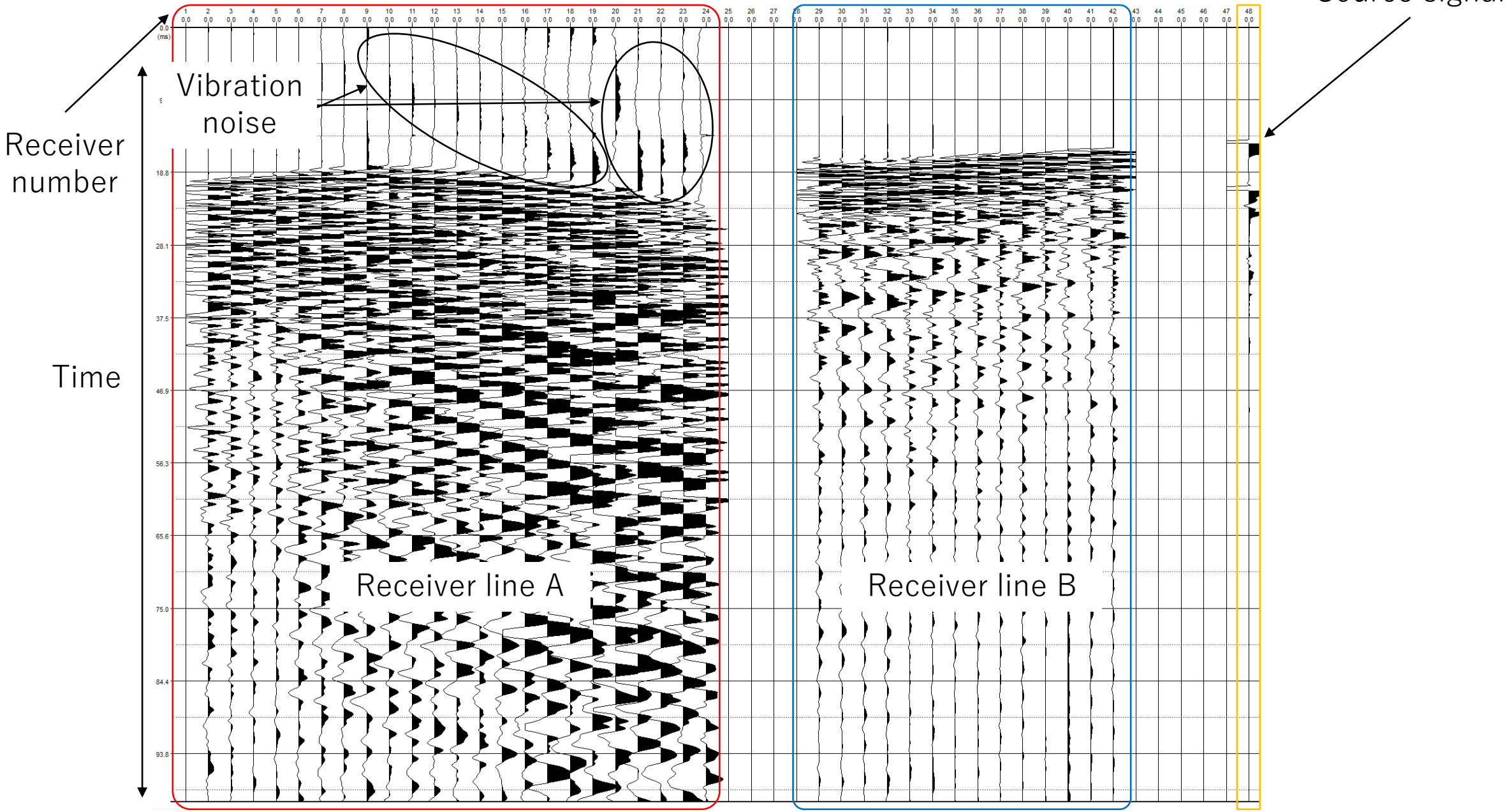
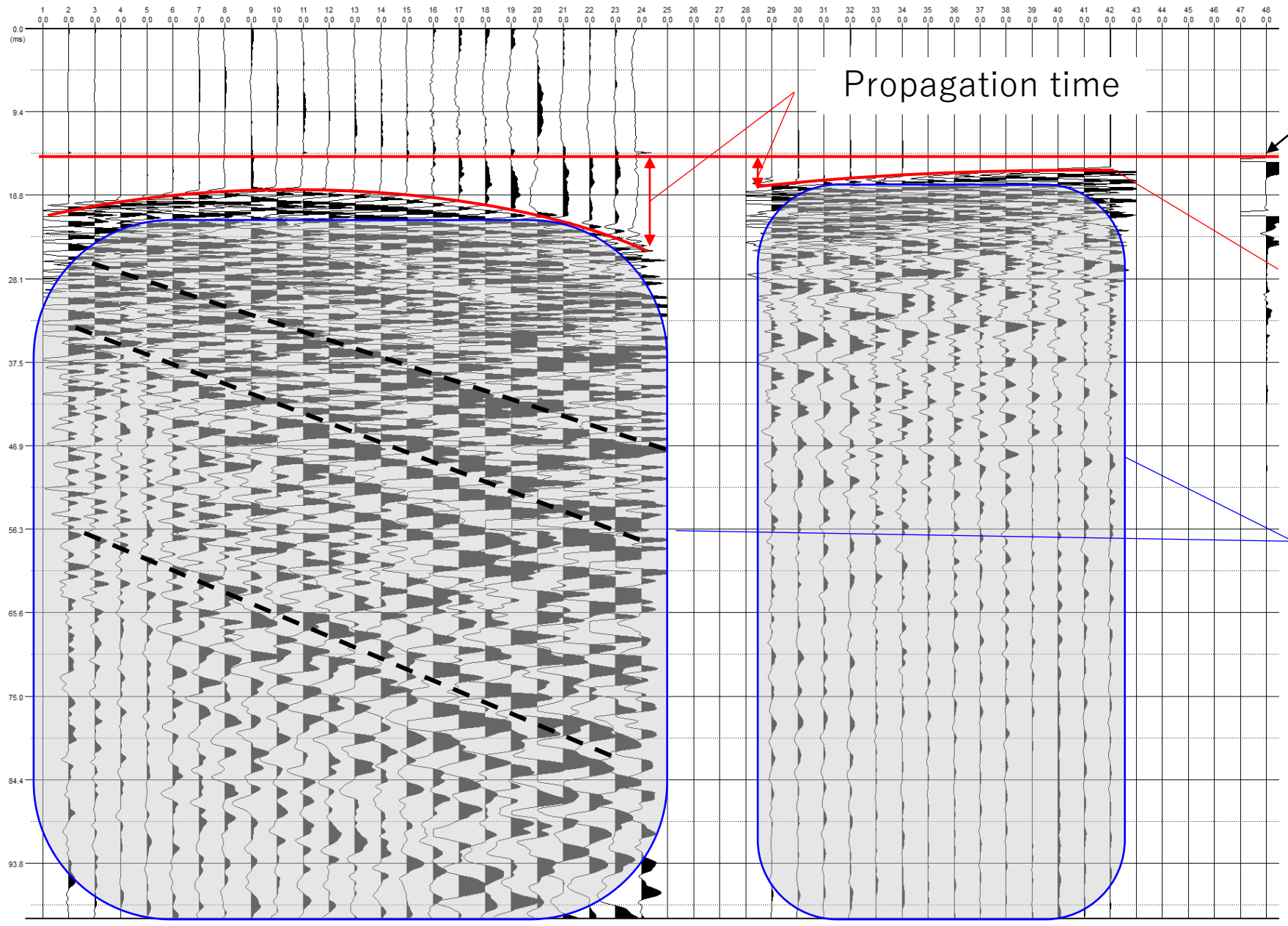
Picking of first-arrival time



Picking of first-arrival time



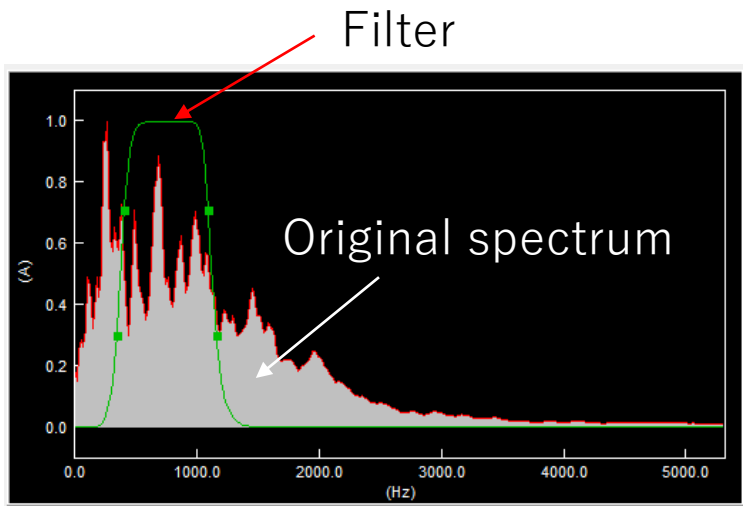
- Pick the starting time of wave

- Information from these waves is not used by first-arrival traveltime tomography. (although some seemingly informative traces are seen.)

Picking of first-arrival time

Processing for picking

- If highly frequent noise is an obstacle, filtering is applied.



- If the signal is small, the signal is amplified.

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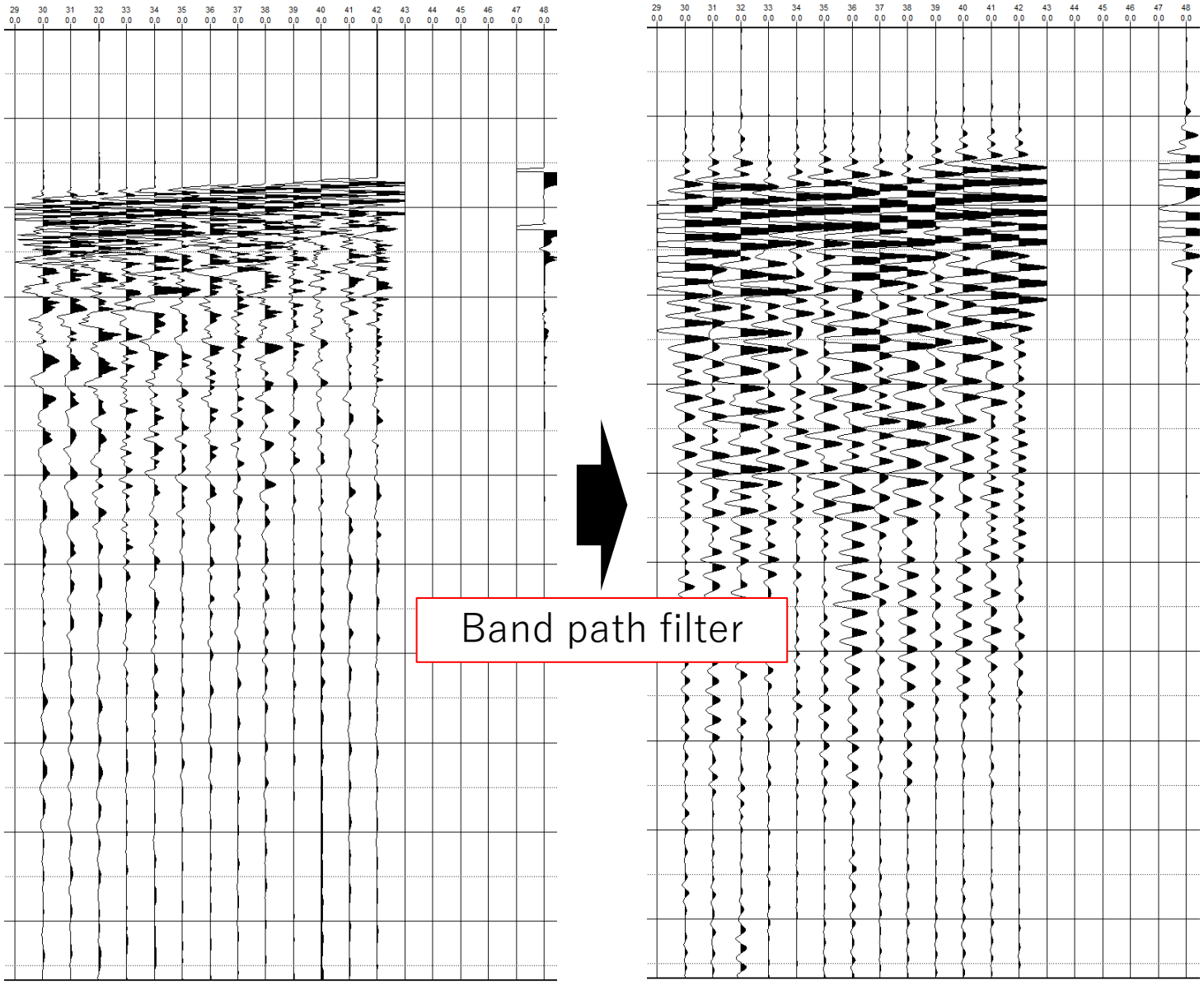
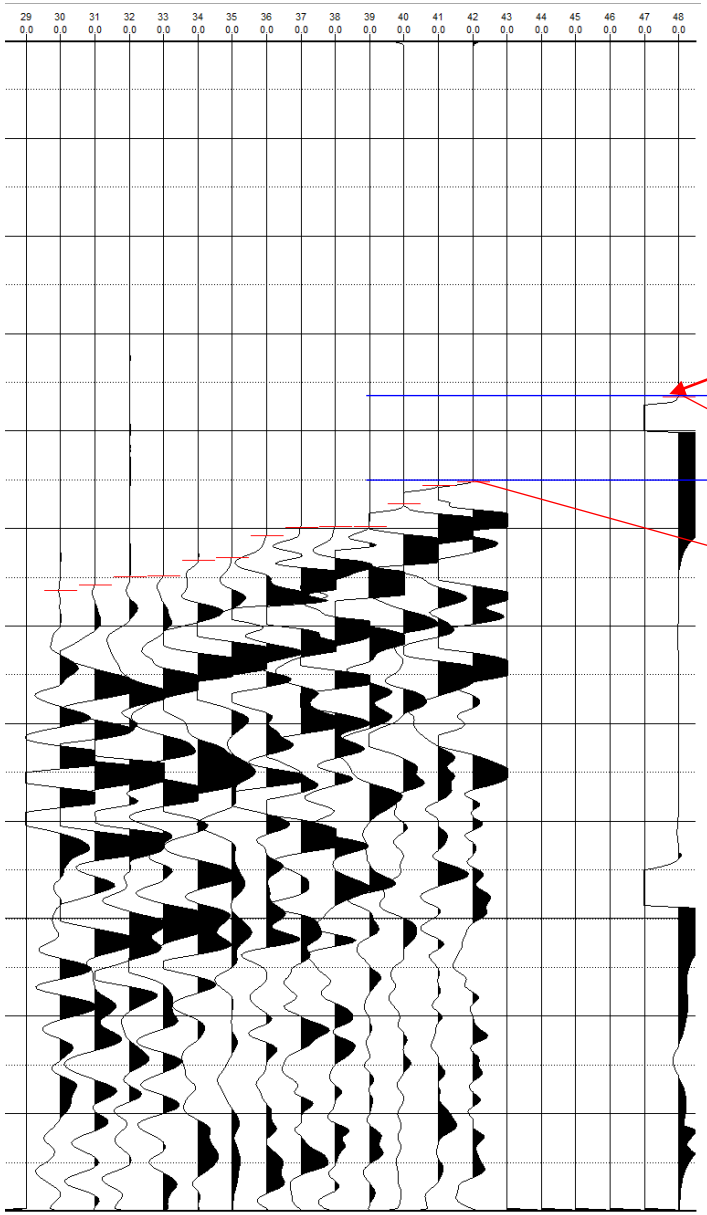
➡ Get easy-to-read data for picking.



Picking of first-arrival time



Pick the time

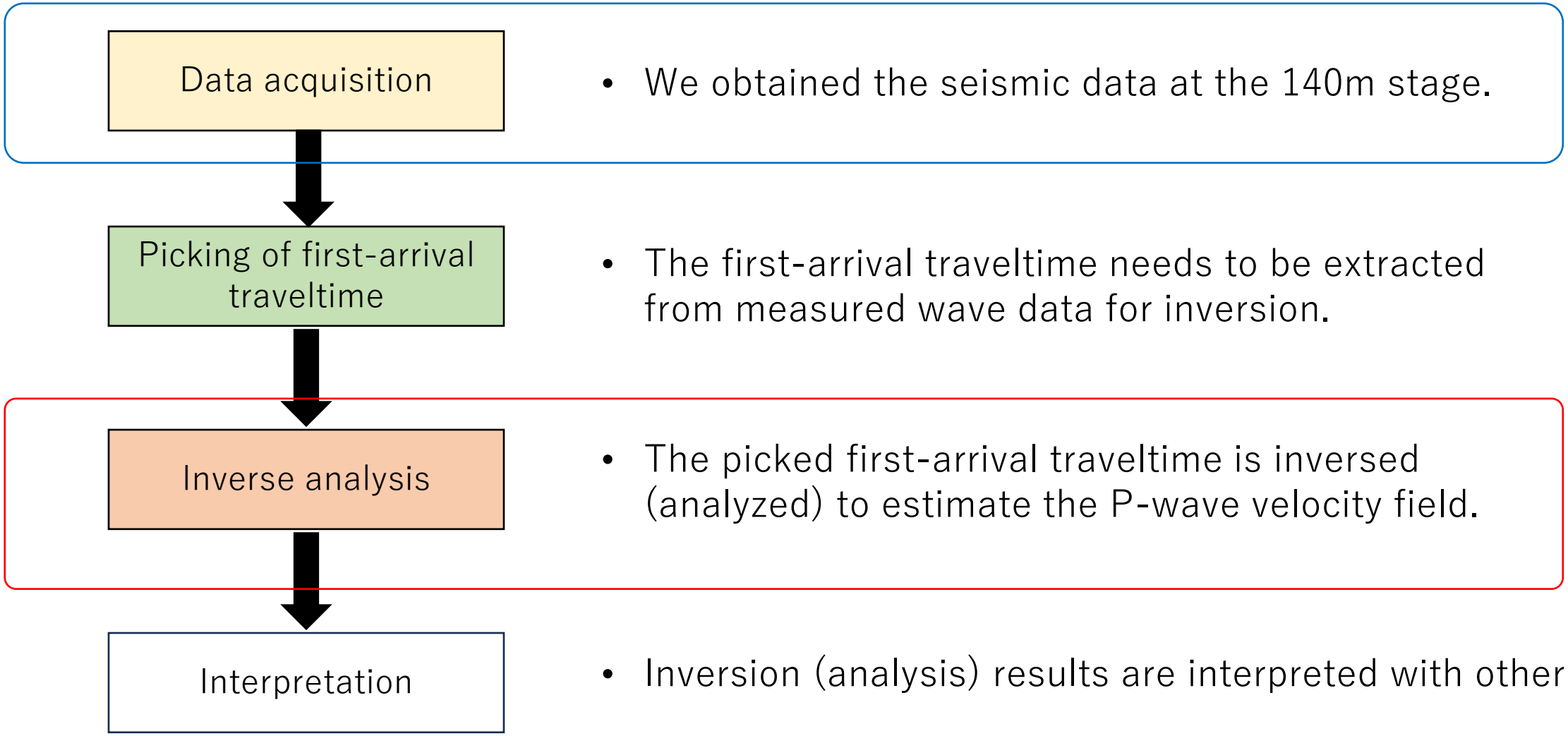
No. (Receiver)	Arrival time	Propagation time
30	0.007044	0.002481
31	0.006973	0.00241
32	0.006868	0.002305
33	0.006856	0.002293
34	0.006658	0.002095
35	0.006622	0.002059
36	0.006342	0.001779
37	0.006236	0.001673
38	0.006225	0.001662
39	0.006225	0.001662
40	0.005932	0.001369
41	0.005698	0.001135
42	0.005651	0.001088
48	0.004563	0

Input data

Data of source

- For all source and receiver pairs, the same processes are done to obtain input data.

Step of data analysis



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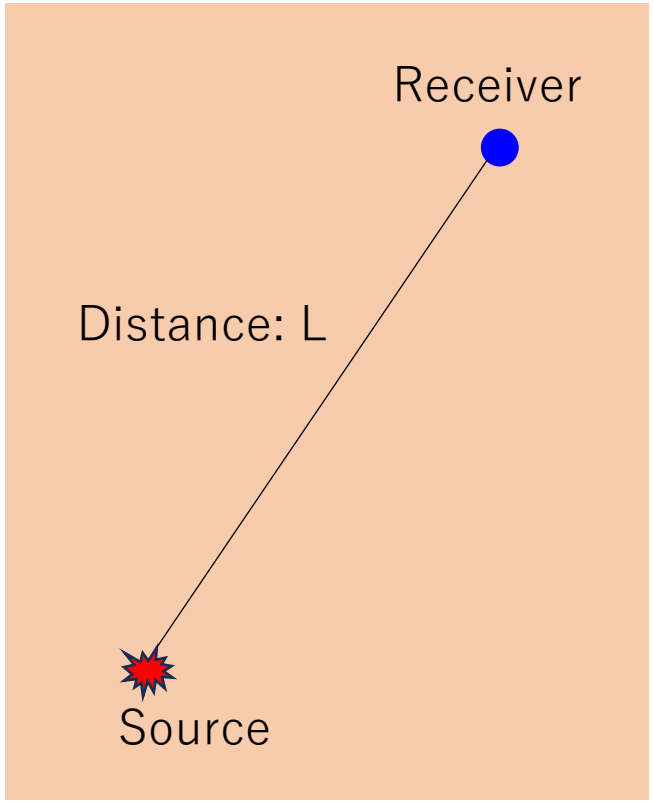
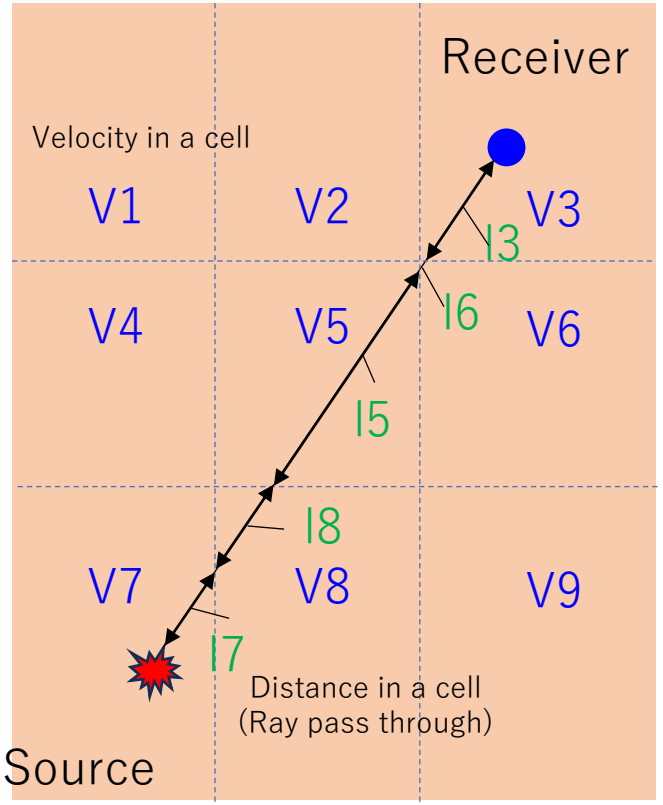
Data analysis

- Eikonal equation-based method. (Based on the governing equation of ray path)
- Ray-based method.



- Distance=L
- Traveltime=T
- Vp=L/t



To consider heterogeneity, discretize the domain.

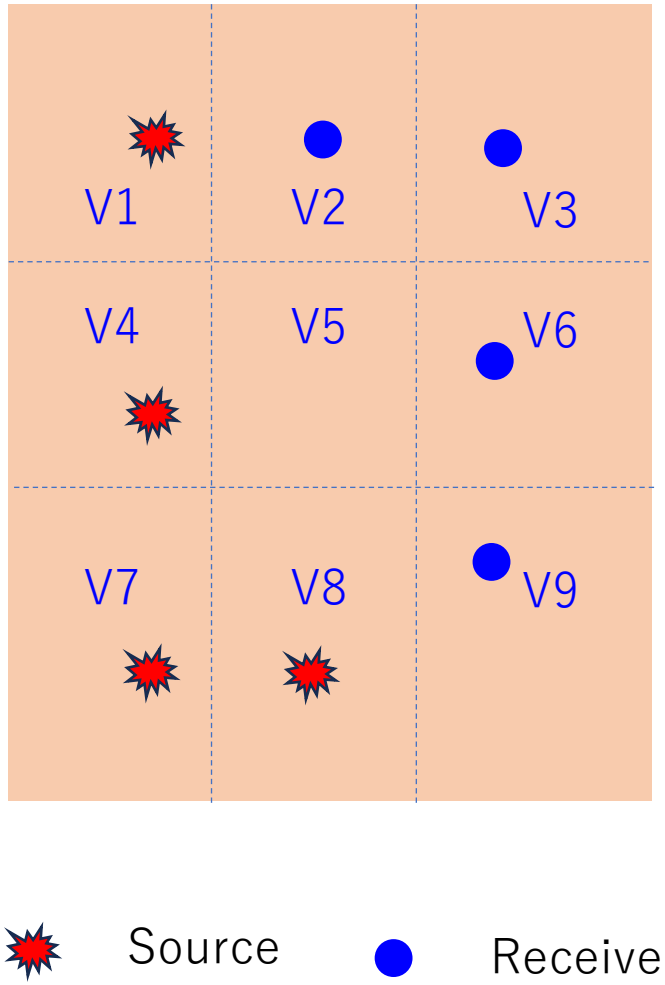
- Measured time between source and receiver (T1) is described as:

$$T_1 = \frac{l_3}{V_3} + \frac{l_5}{V_5} + \frac{l_6}{V_6} + \frac{l_7}{V_7} + \frac{l_8}{V_8}$$

- Rewrite 1/V=S (Slowness)

$$T_1 = l_3 S_3 + l_5 S_5 + l_6 S_6 + l_7 S_7 + l_8 S_8$$

Data analysis



- The data of traveltime between multi-source and receiver pairs are obtained.
- A measured data is described as:

$$T_i = \sum_{j=1,N_e} l_j S_j \qquad \text{i=1, } N_d$$

N_d : Number of data

N_e : Number of cell

After all data is gathered…

$$\begin{pmatrix} T_1 \\ T_2 \\ \vdots \end{pmatrix} = \begin{pmatrix} l_1 & l_2 & \cdots \\ l_1 & l_2 & \cdots \\ \vdots & \vdots & \ddots \end{pmatrix} \begin{pmatrix} S_1 \\ S_2 \\ \vdots \end{pmatrix}$$

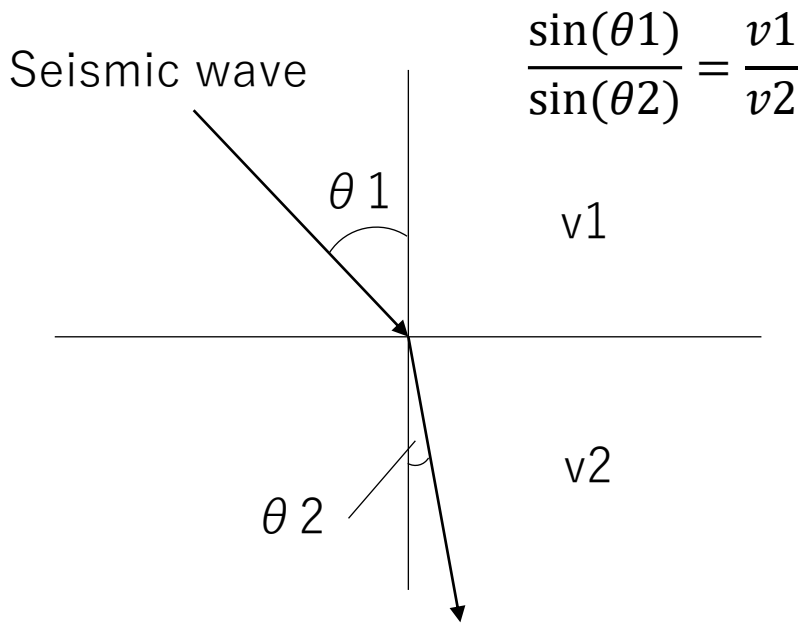
Solve matrix

P-wave velocity field?

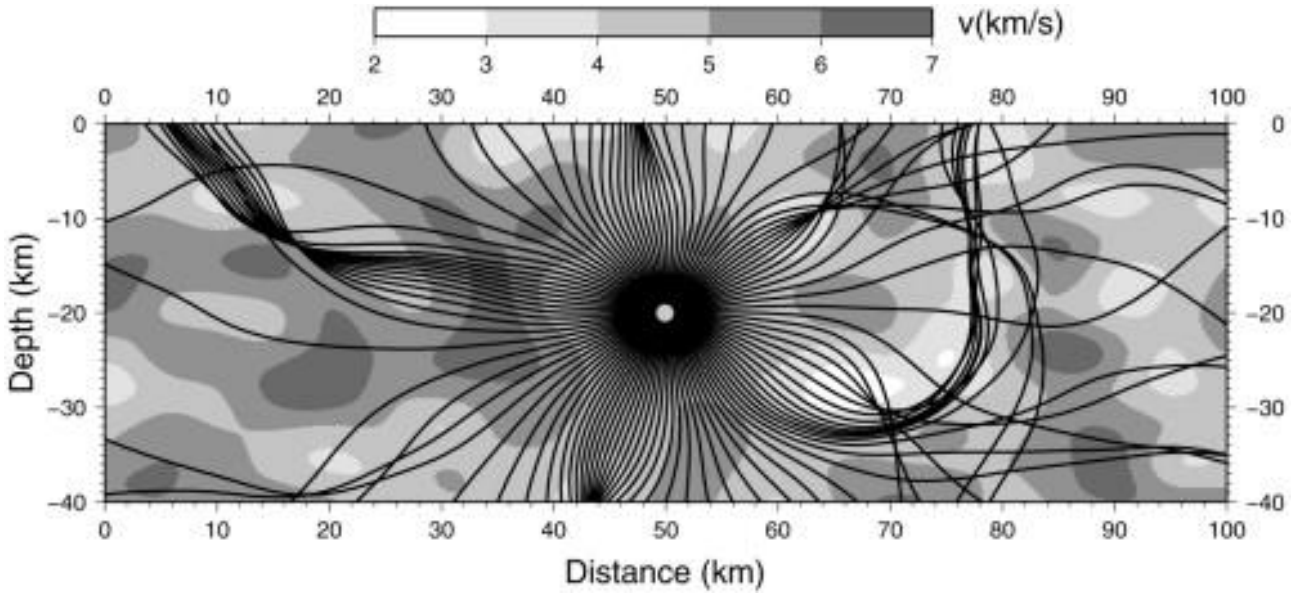
Ray tracing

- Ray path (path of first-arrival time) bends through the heterogeneity of velocity.
- Refraction is controlled by Snell's law.
- Refraction (bending of ray path) is needed to be considered for analysis.

Snell's law



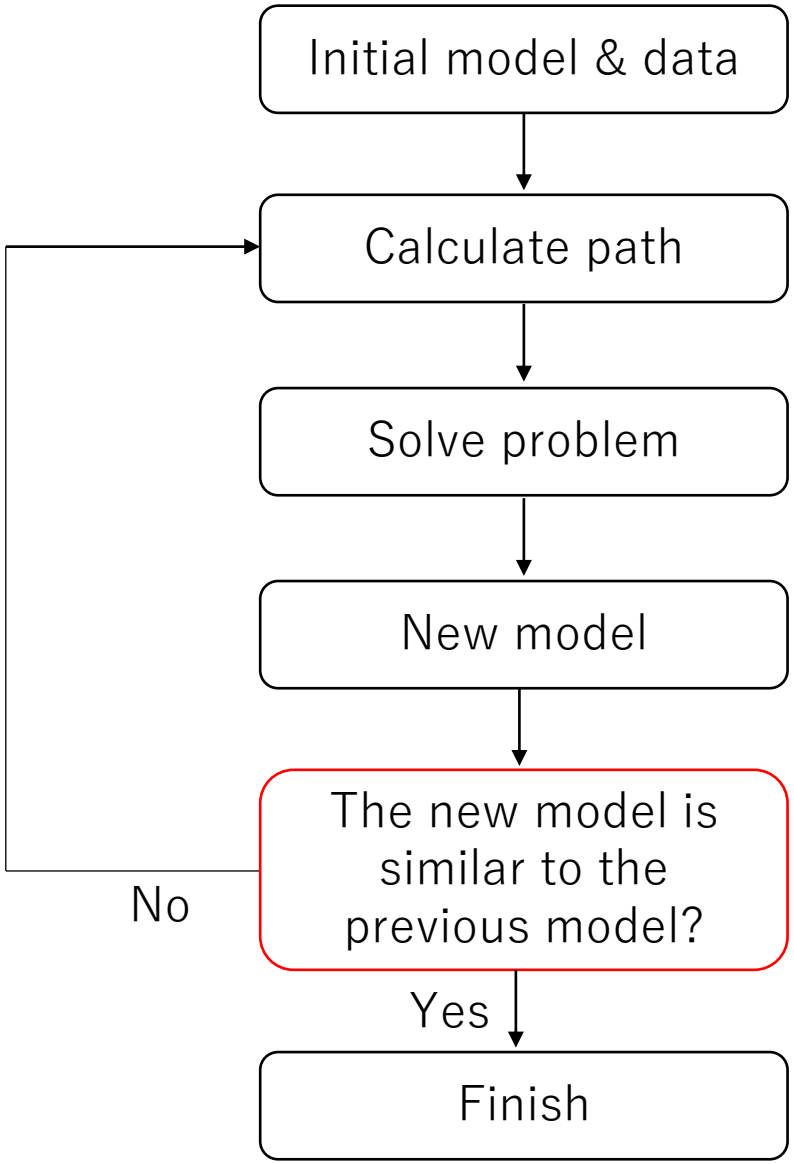
$$\frac{\sin(\theta 1)}{\sin(\theta 2)} = \frac{v1}{v2}$$



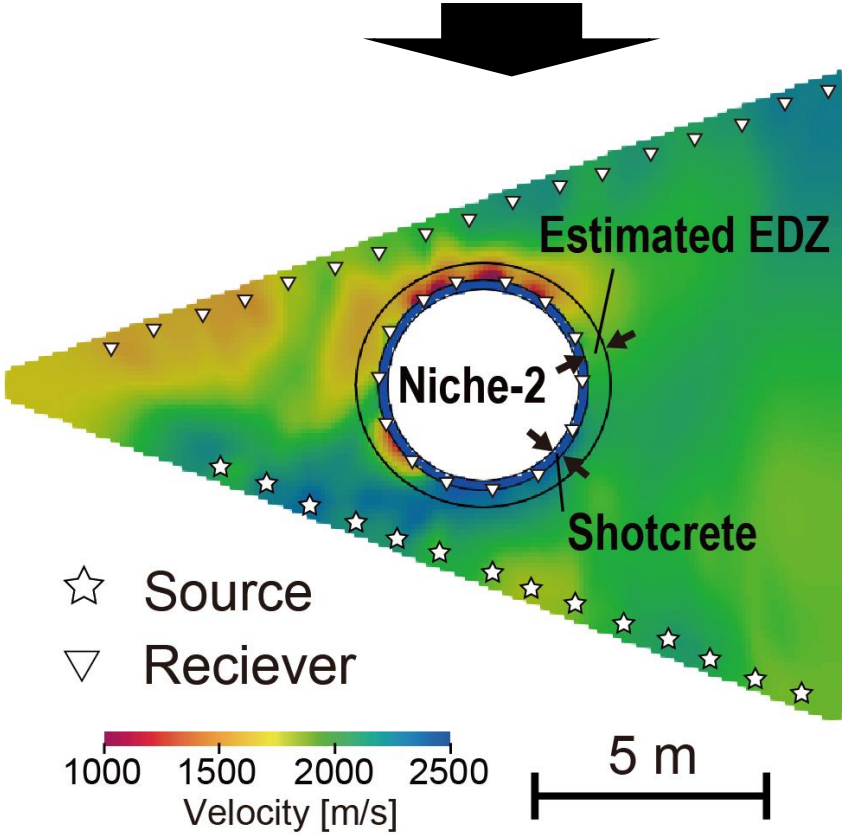
Rawlinson et al., 2008

Ray tracing

Data analysis



- Model update is repeated iteratively.



Get image
(example of the result at the 350m stage)

Question?