Japan Society Of Civil Engineers 2024 Japan-Taiwan Technology Exchange: International Symposium on Low-Level Radioactive Waste Disposal Technology

Validation of a natural barrier evaluation model

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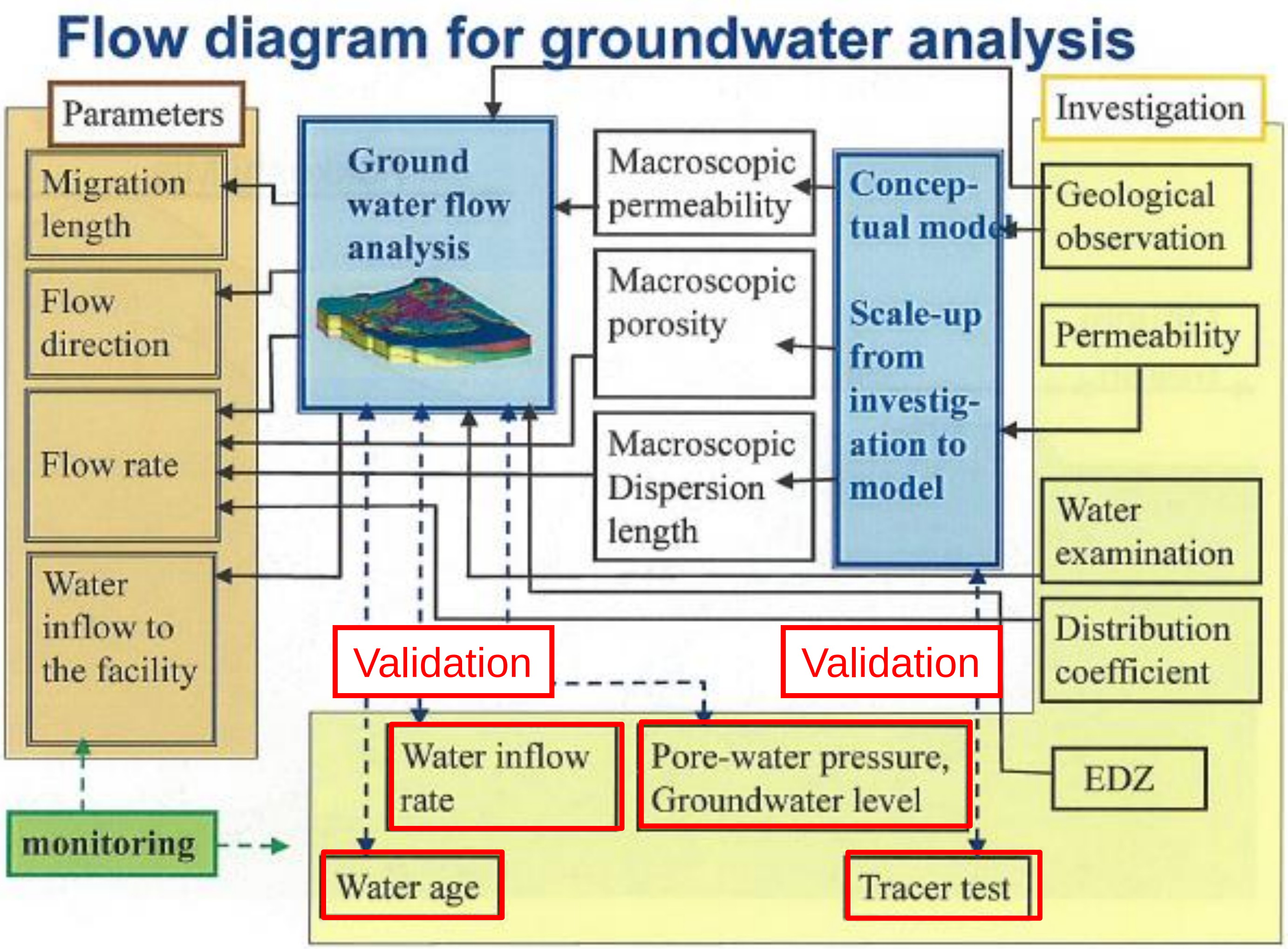
Japan Nuclear Fuel Limited

Contents

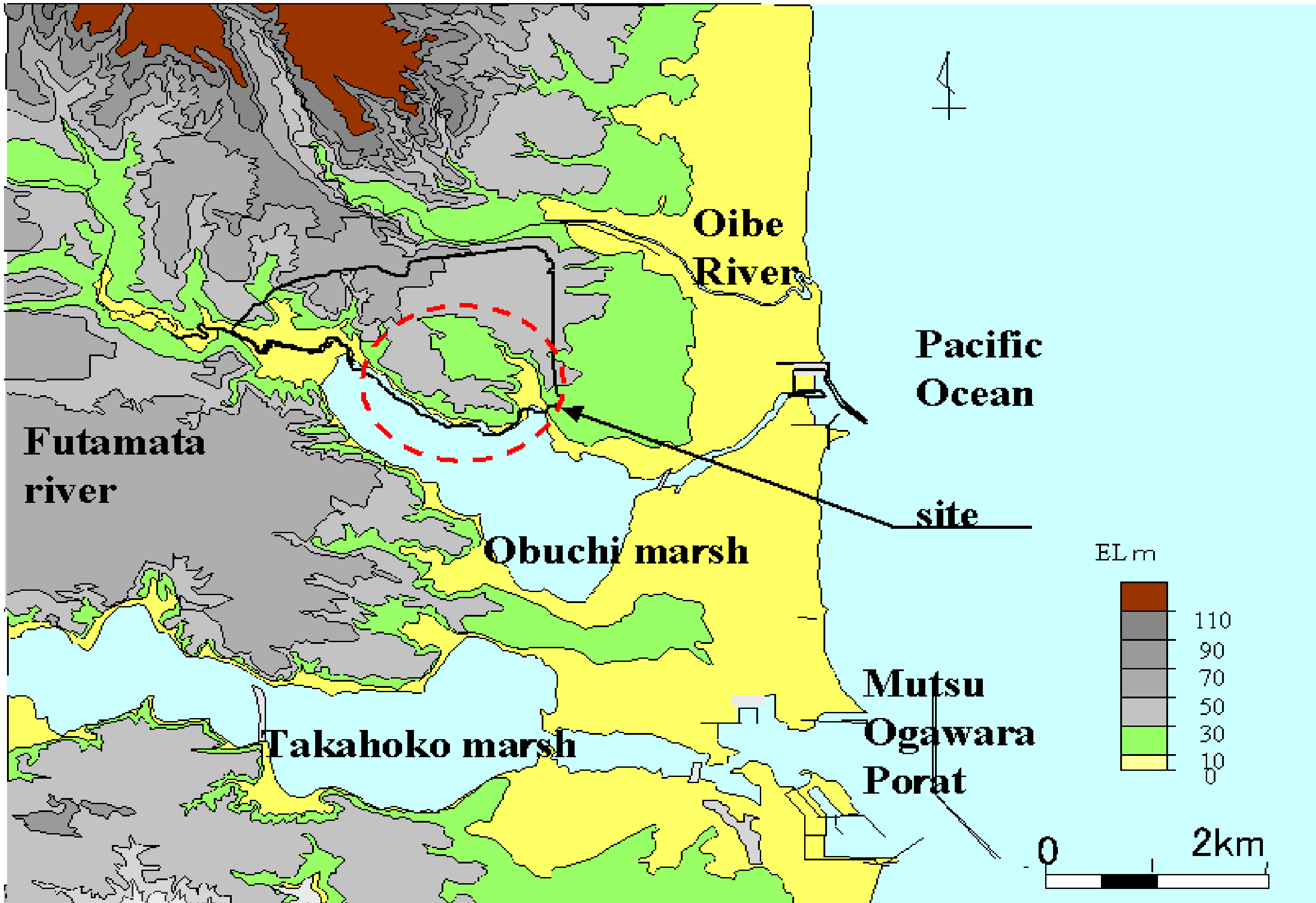
Analysis model creation and Model validation



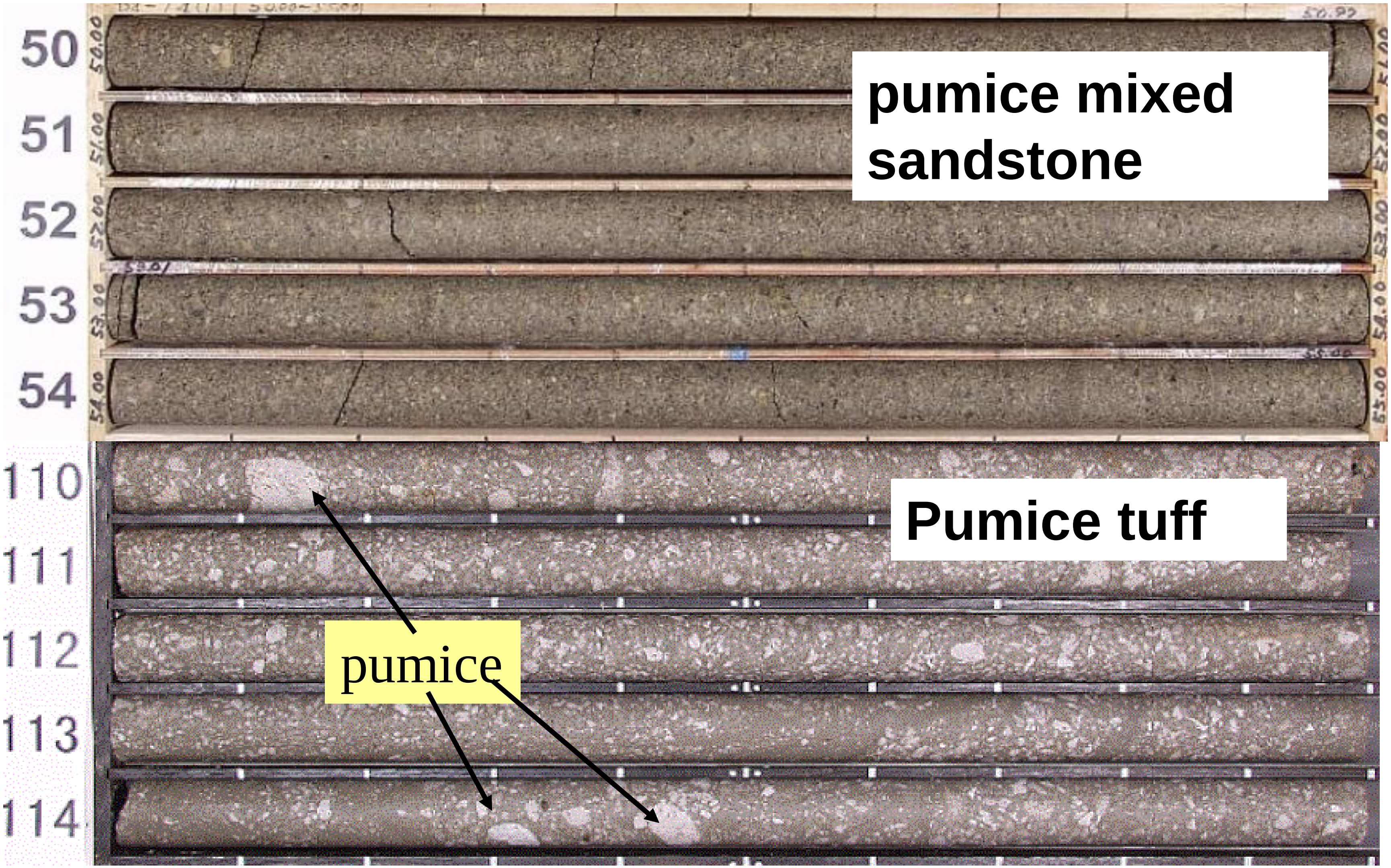
Background

- Shallow groundwater system (depth～300m)
- Soft rock(permeability:E-8～9m/s, porsity :50%)
- Groundwater age : ～30,000y
- Validation of analysis model

Topographic feature of the site



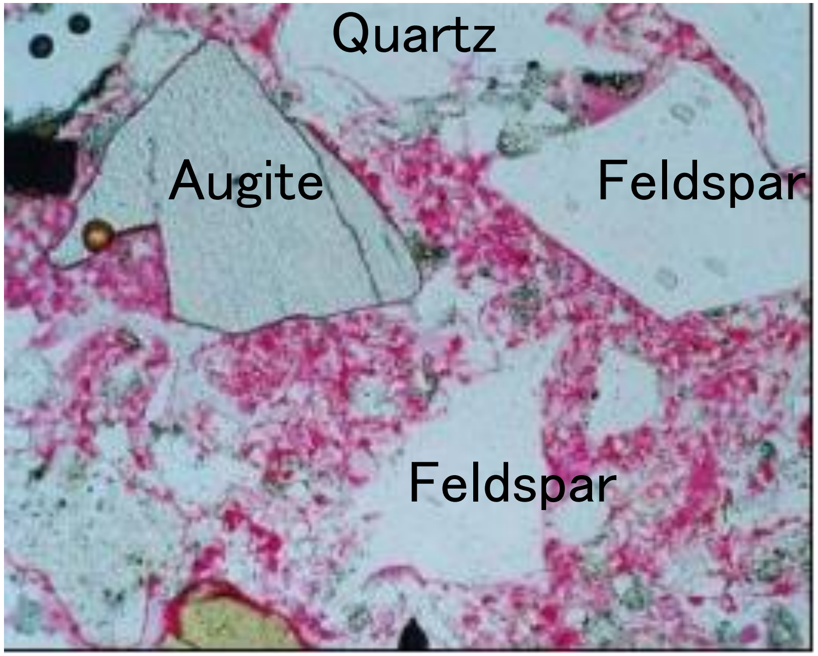
Host rock (Neogene period)



Observation of laminates

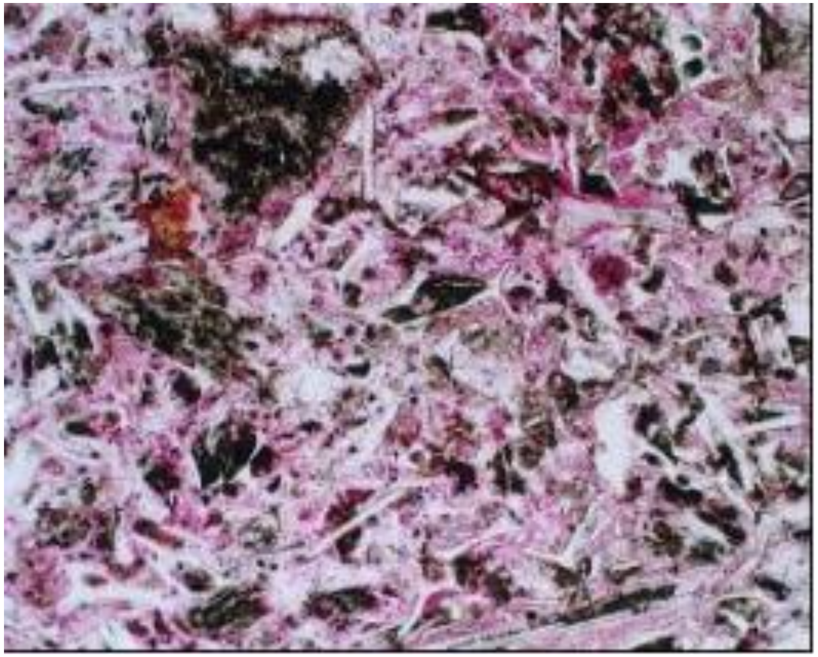
(Red color indicates permeable paths)

pumice mixed sandstone



(1mm)

Pumice tuff



(Needle-shaped parts are volcanic glasses)

Geological features

- **Distribution of Takahoko formation in the site**
  Sedimented it in the sea about 15 million years ago (Neogene period)

  It consists of mudstone, sandstone, pumice tuff, gravel-mixed sandstone, etc.

- **The quaternary formation is thinly distributed near the surface**
  120 thousand-years-old marine terrace

Result of main investigation for next phase LLW facility 2006.9.1 JNFL (in Japanese)

Geological conditions

- **Sedimentary soft rock**

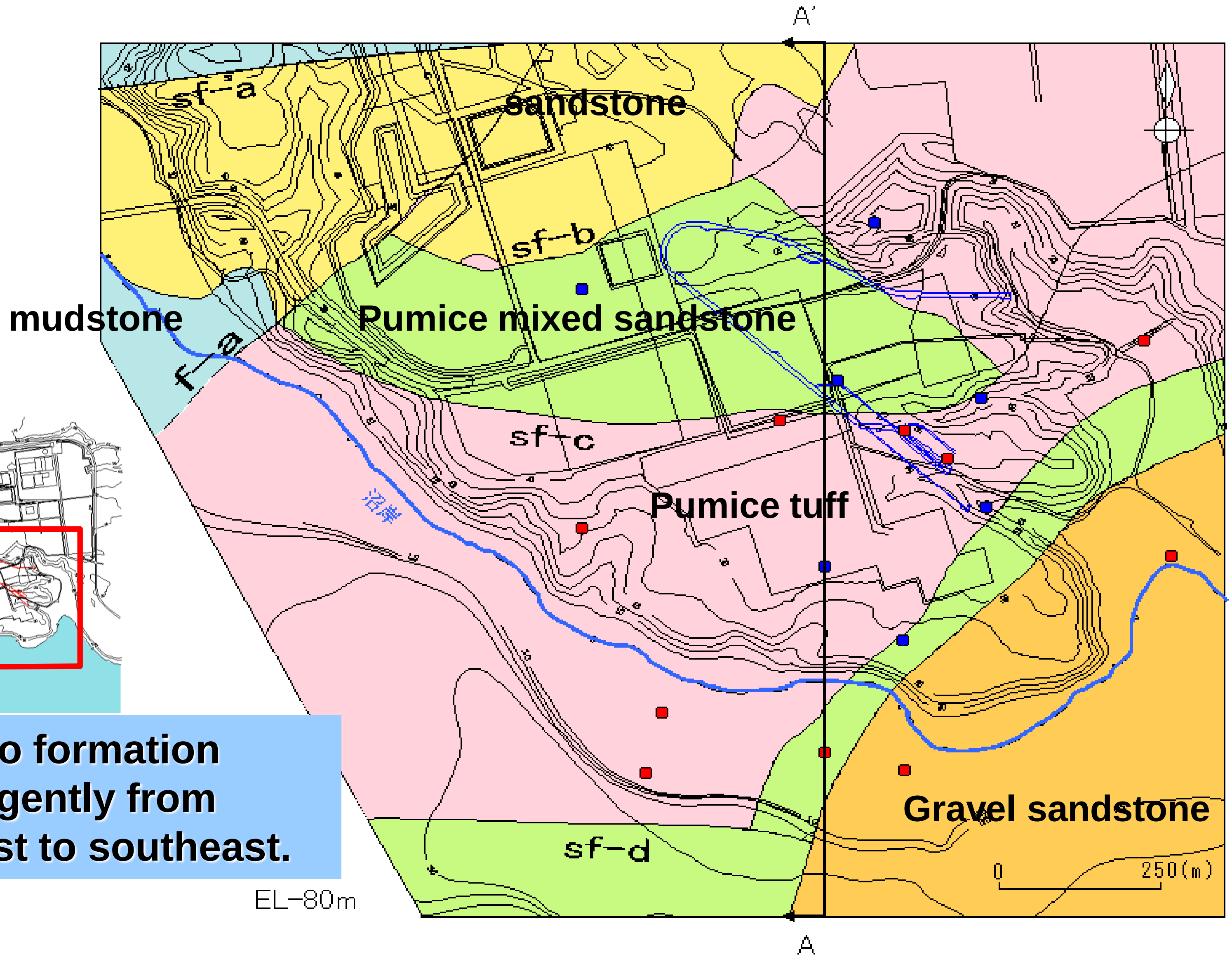
  Uniaxial compressive strength =<10Mpa (2 - 6 MPa)

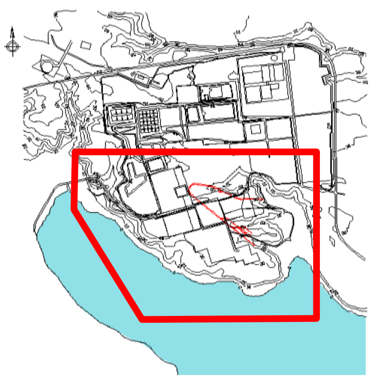
- **Porous rock**

  Porosity 40 - 60 %, according to physical tests and tracer tests

Journal of MMIJ Vol. 125 P. 347－357 (in Japanese)

Geology of horizontal section (EL-80m)





- **Takahoko formation inclines gently from northwest to southeast.**

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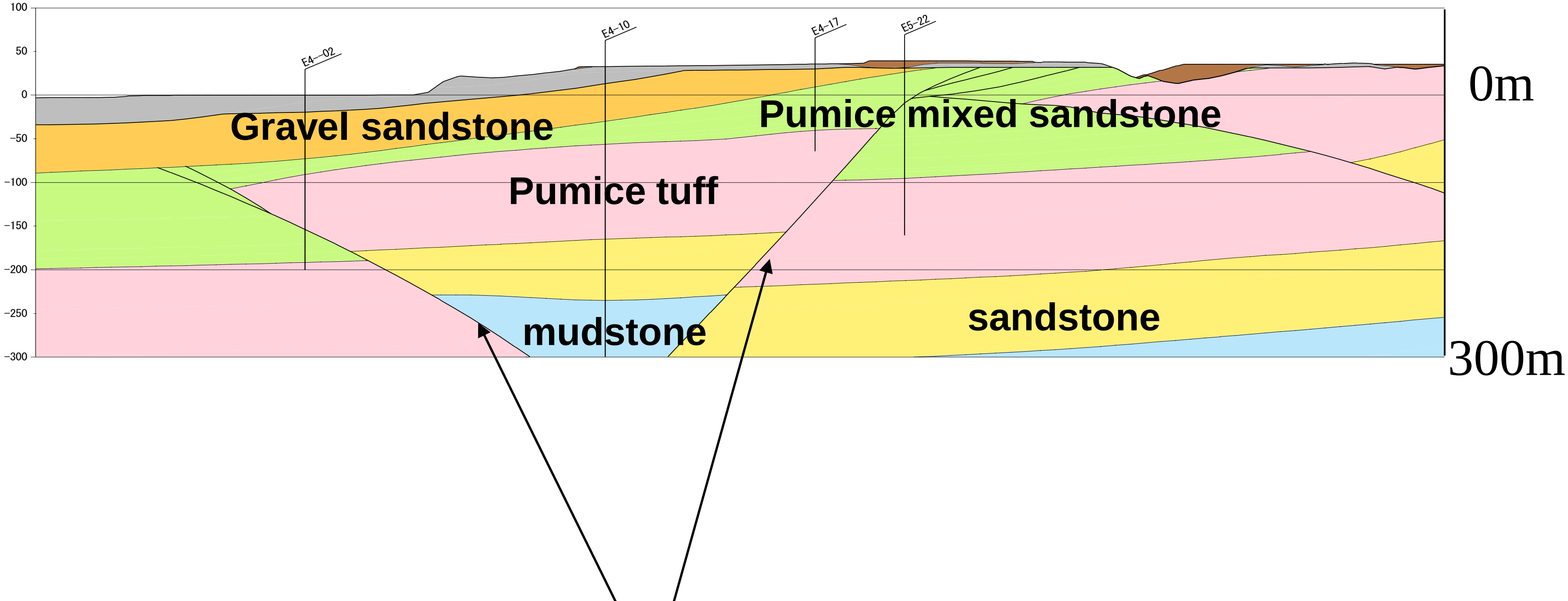
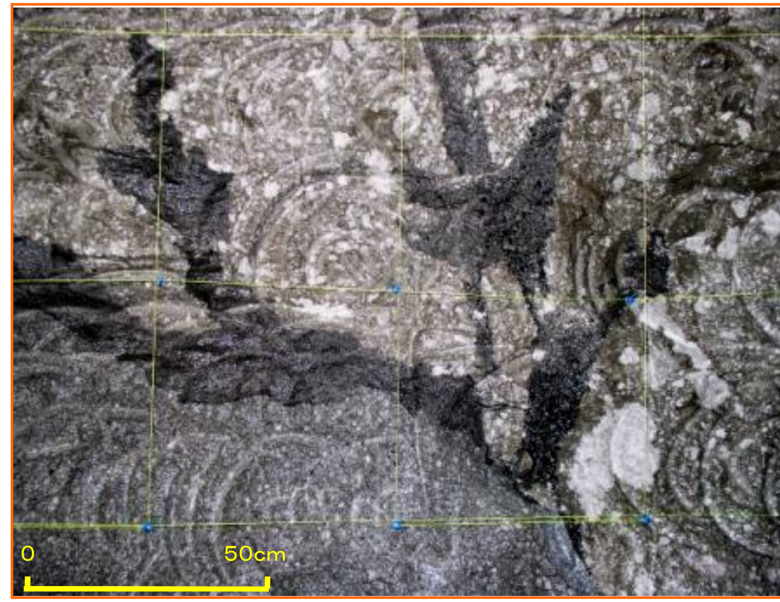
Geological section

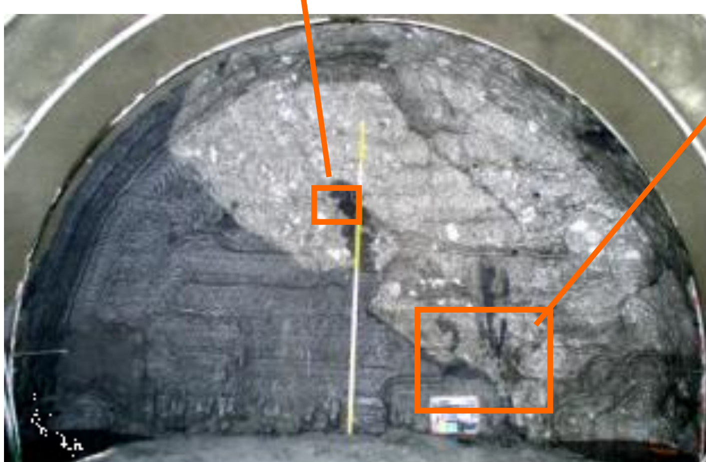


- **several faults (gap 50-100m) divide the site into several blocks.**

Result of main investigation for next phase LLW facility 2006.9.1 JNFL (in Japanese)

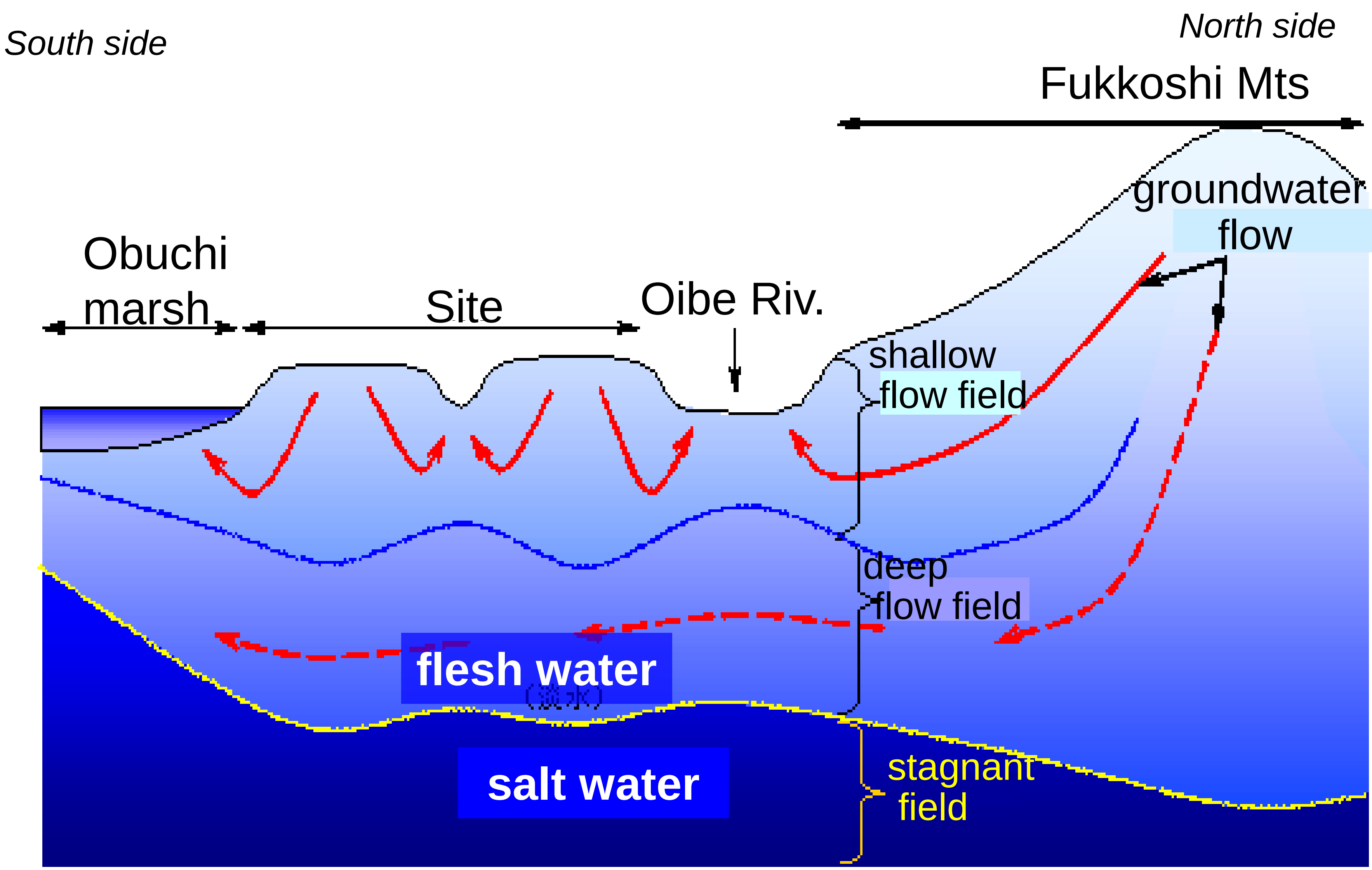
Fault



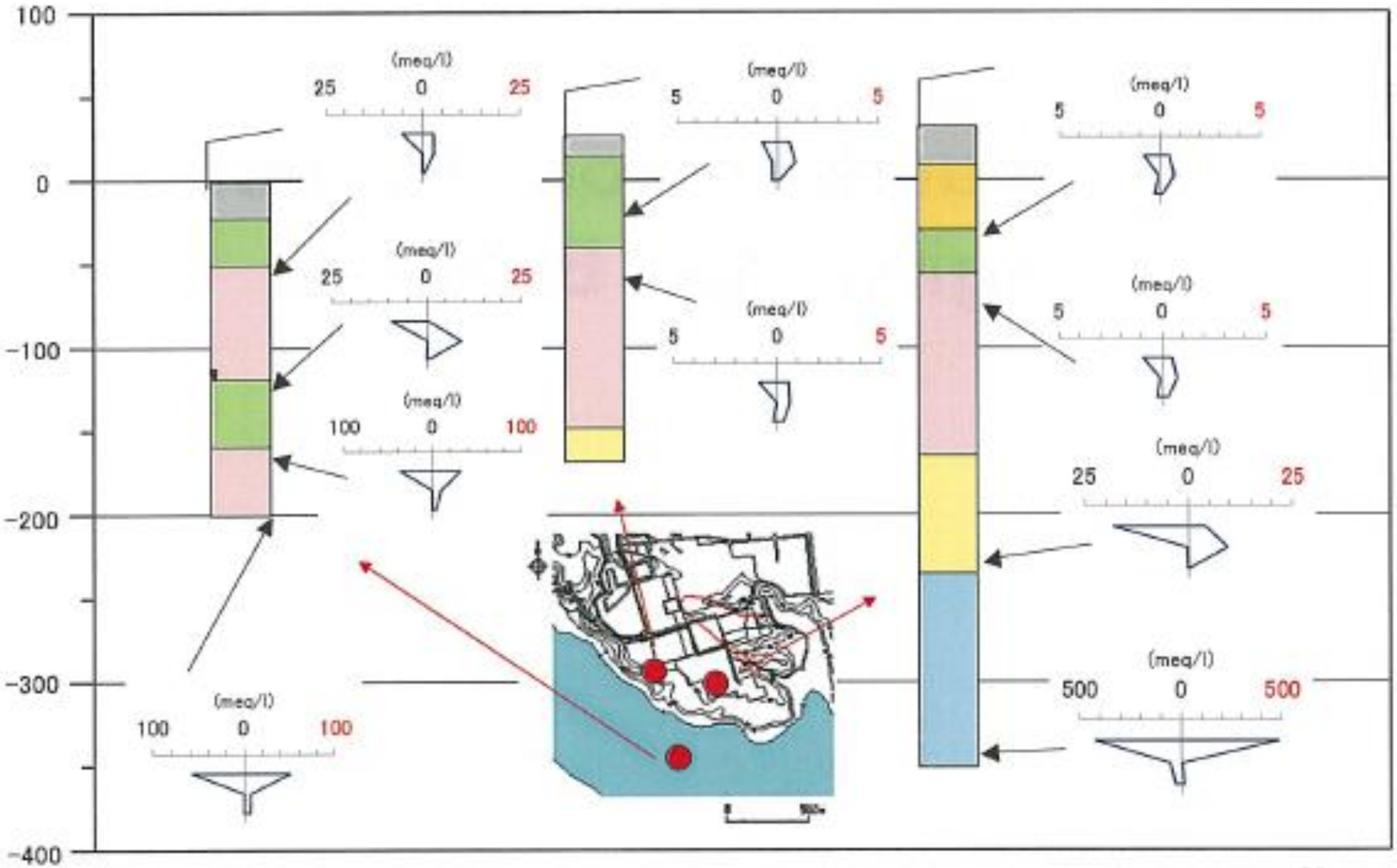


- The faults are formed by submarine landslide at time of deposition.
- The fault planes adhere each other.

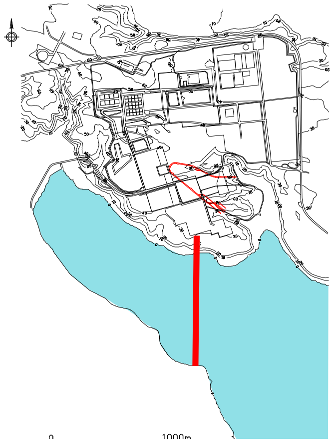
regional groundwater flows

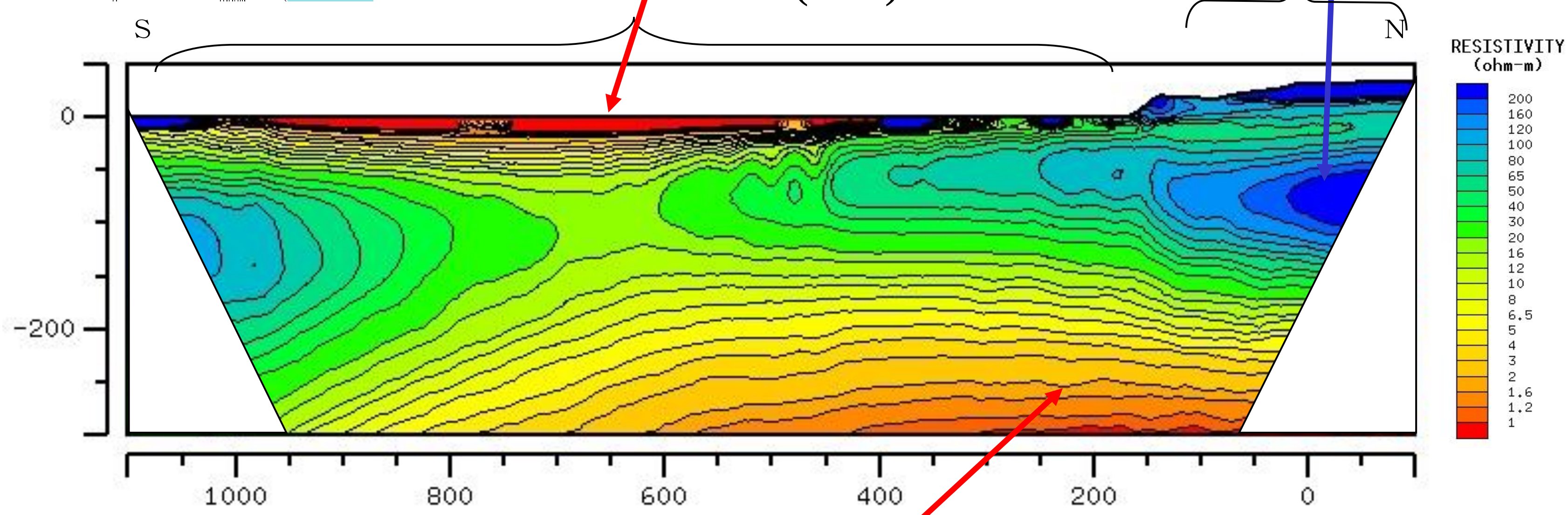


Measurement results -Distribution of water compositions



Resistivity test

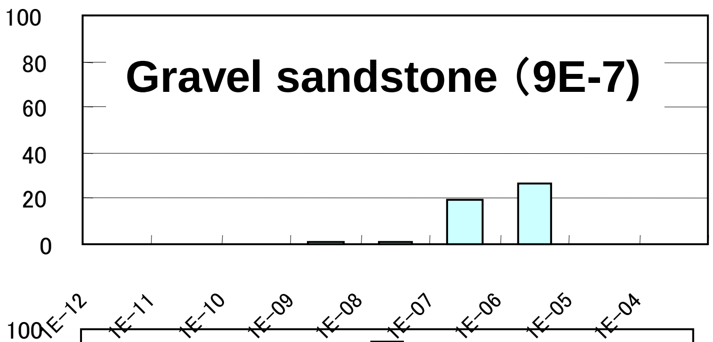


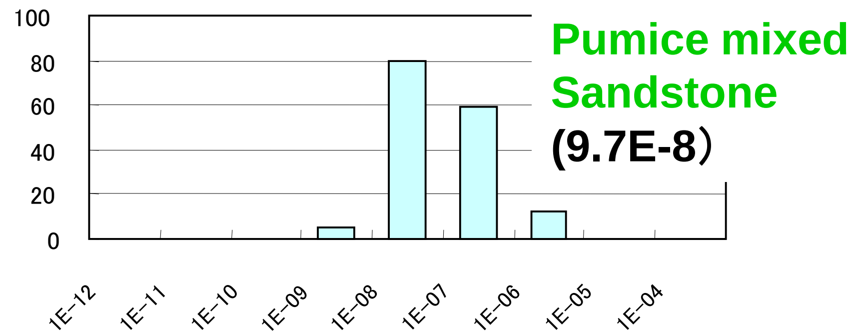


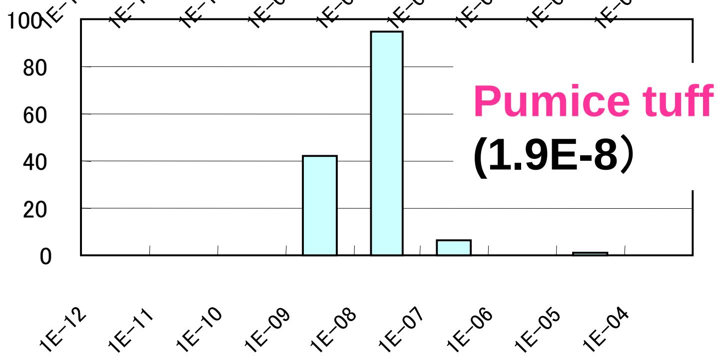
Result of main investigation for next phase LLW facility 2006.9.1 JNFL (in Japanese)

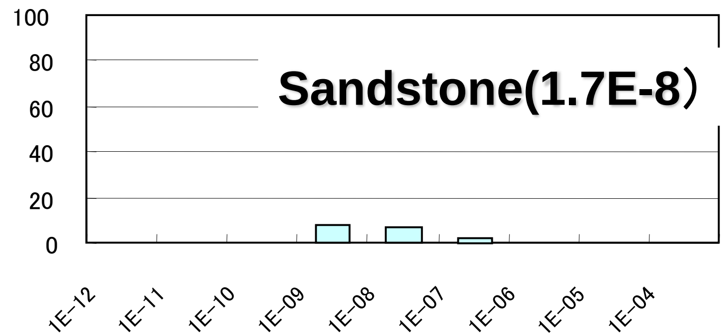
Histogram of hydraulic conductivity

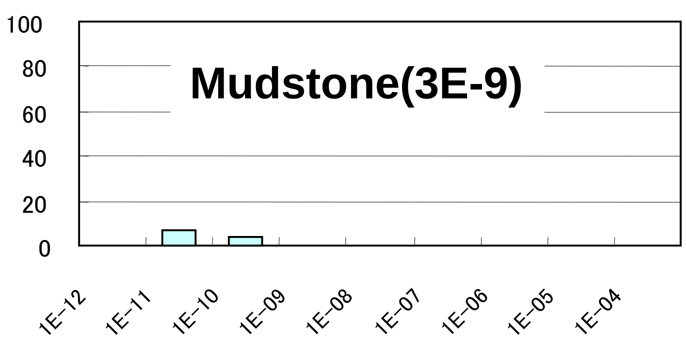
Unit:m/s







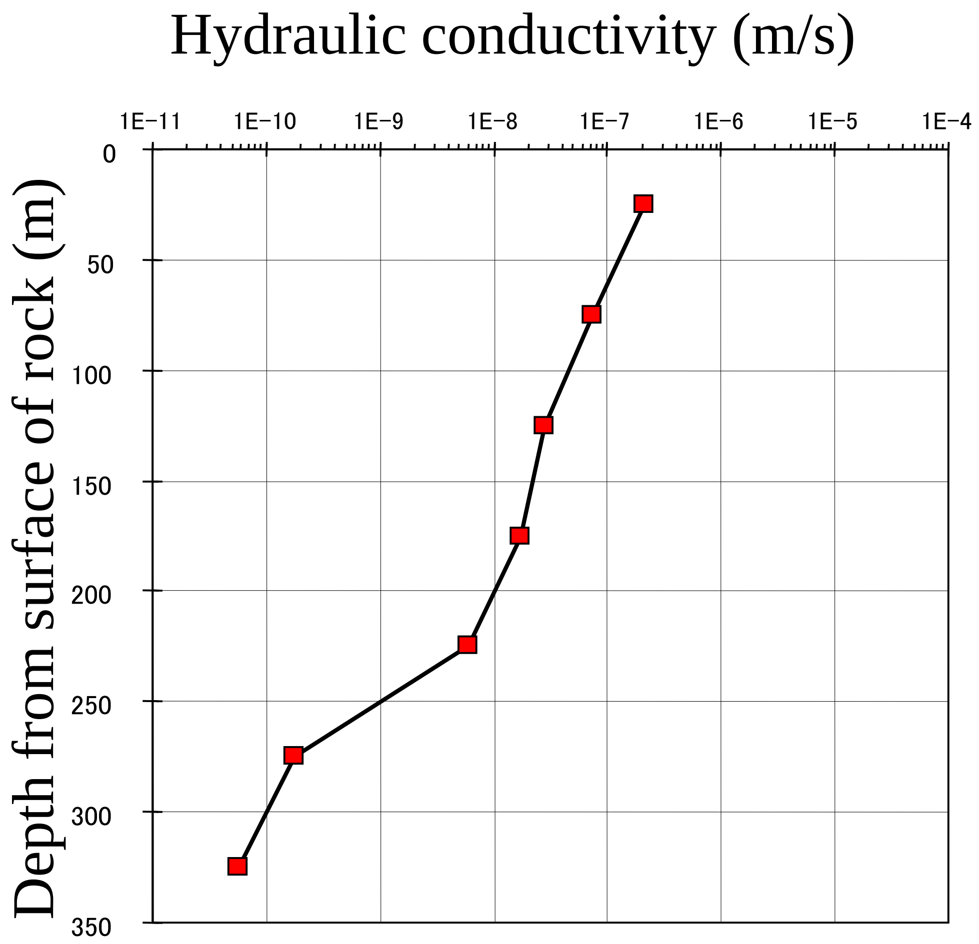




According to the logarithmic mean of hydraulic conductivity estimated by the injection test, each stratum have different hydraulic conductivity.

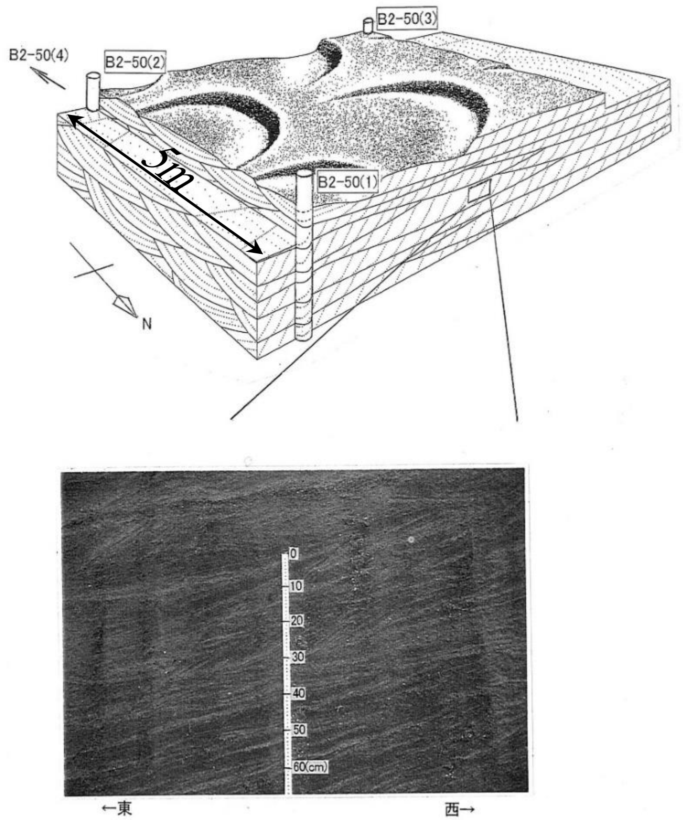
Result of main investigation for next phase LLW facility 2006.9.1 JNFL (in Japanese)

Hydraulic conductivity versus depth

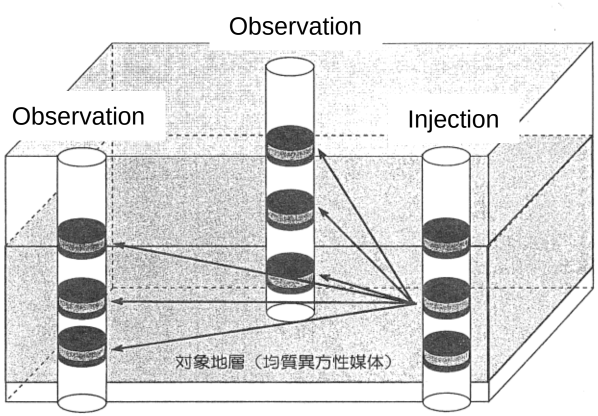


Result of main investigation for next phase LLW facility 2006.9.1 JNFL (in Japanese)

Hydraulic conductivity (Anisotropy)



Cross laminae structures (Sandstone)

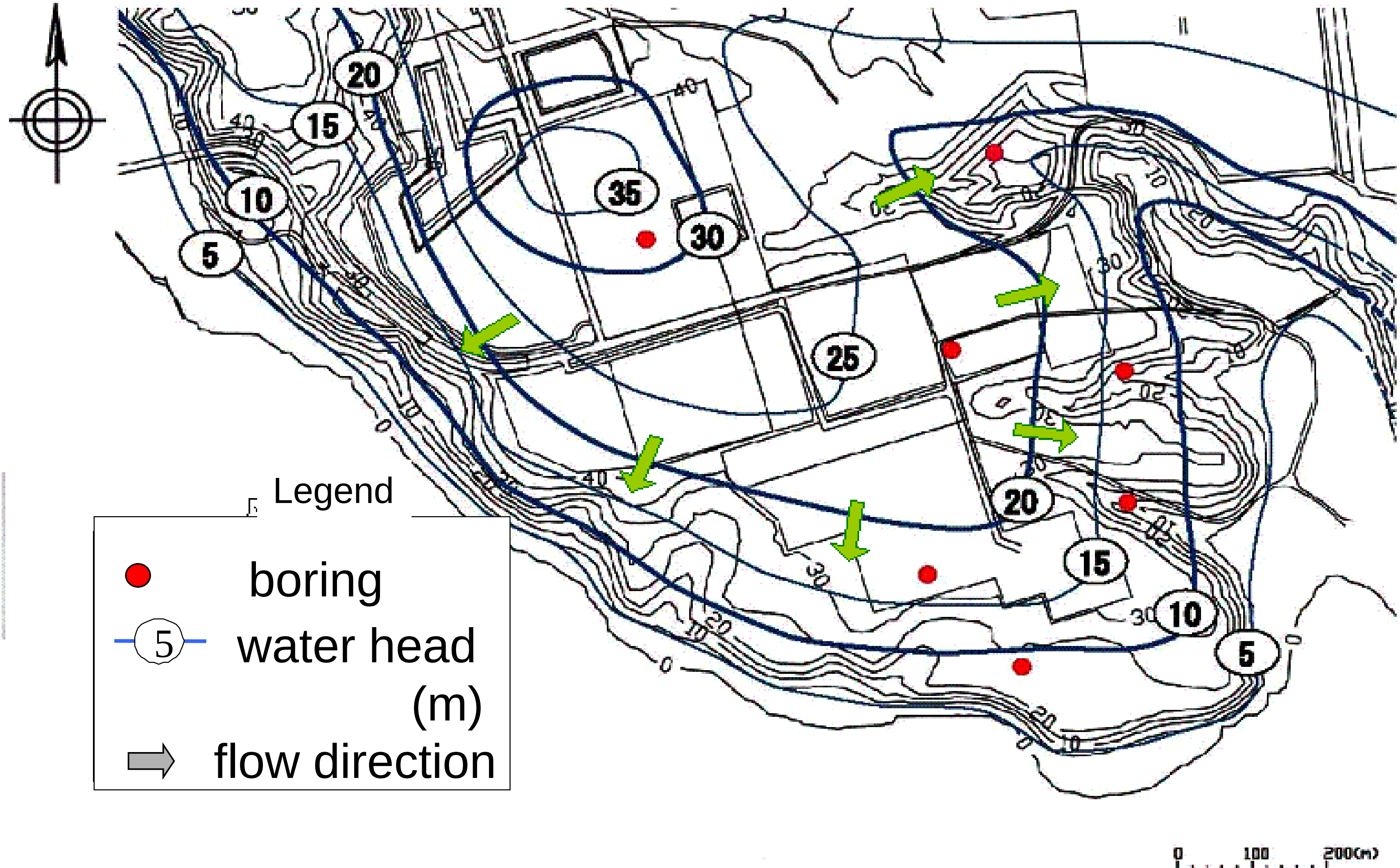


	Permeability (K; m/s)
Horizontal (E-W)	6.9E-7
Horizontal (N-S)	9.0E-8
Vertical	1.6E-8
Horizontal / Vertical	43〜6

Crosshole test

Rocks having layer structures or alternates have anisotropy in hydraulic conductivity.

Hydraulic head (observation) EL-80m

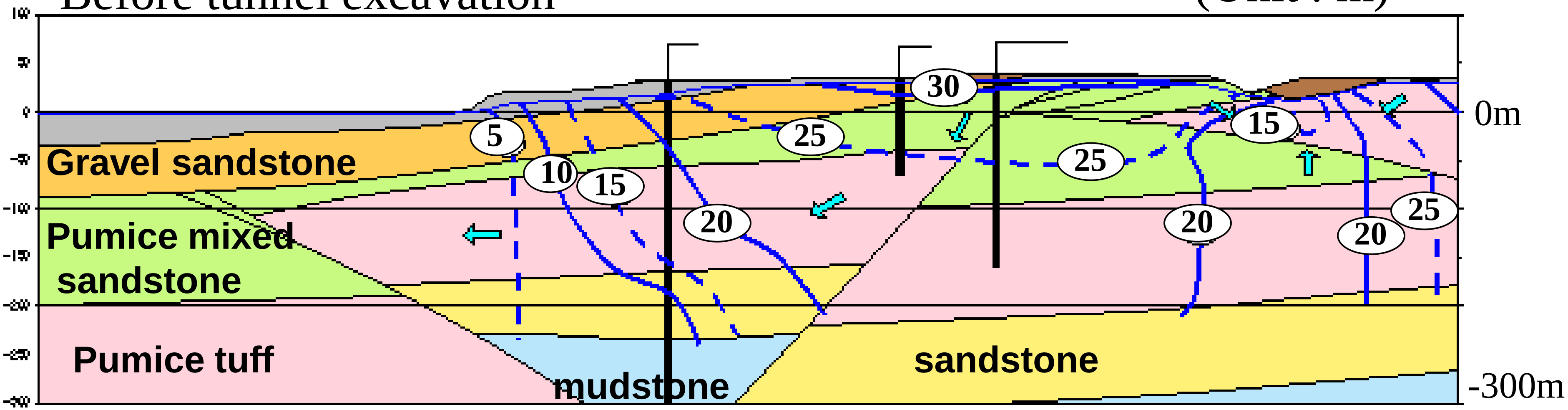


Result of main investigation for next phase LLW facility 2006.9.1 JNFL (in Japanese)

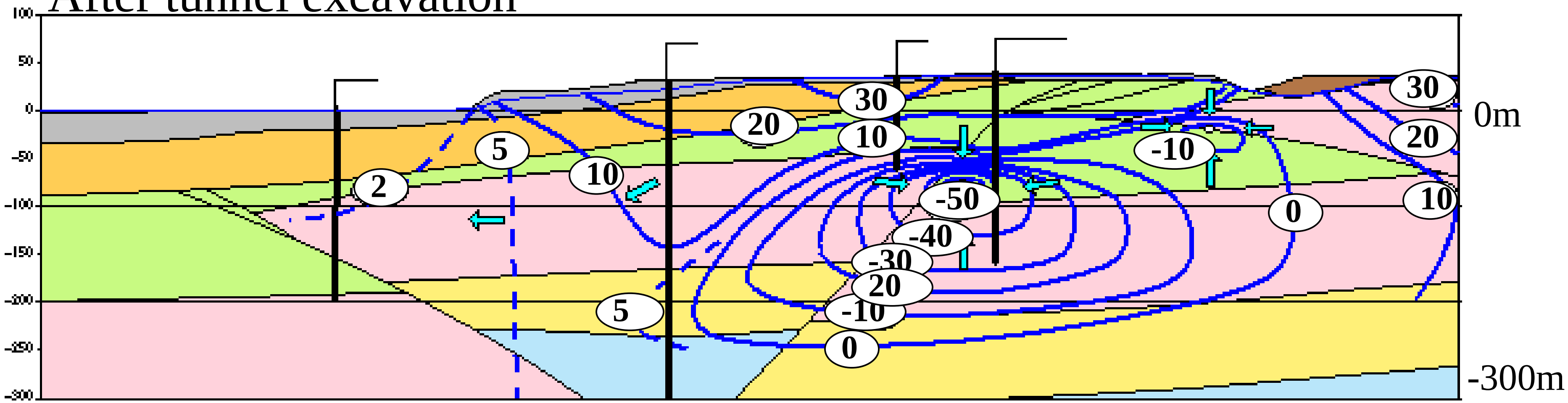
Hydraulic head (observation)

(Unit : m)

Before tunnel excavation



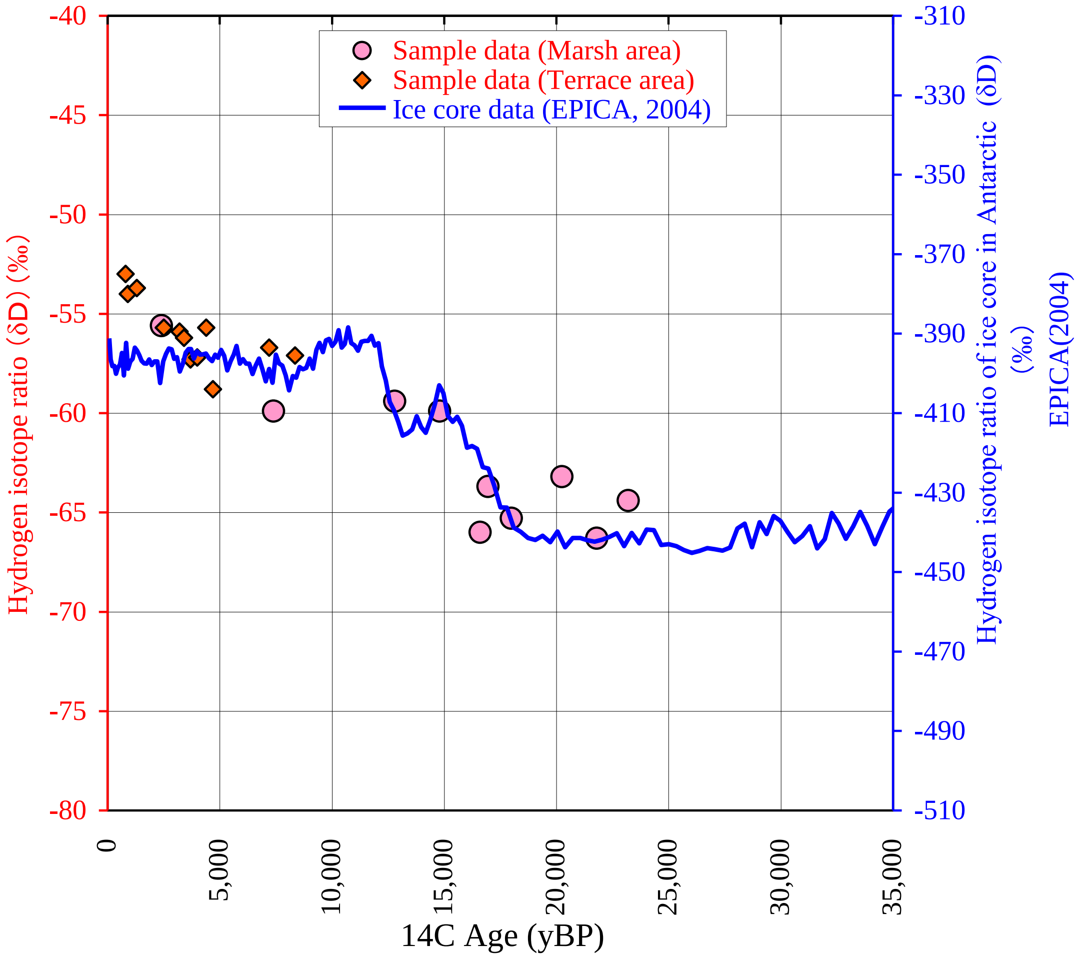
After tunnel excavation



Result of main investigation for next phase LLW facility 2006.9.1 JNFL (in Japanese)

Groundwater age

Groundwater age by ^{14}C and Hydrogen isotope ratio

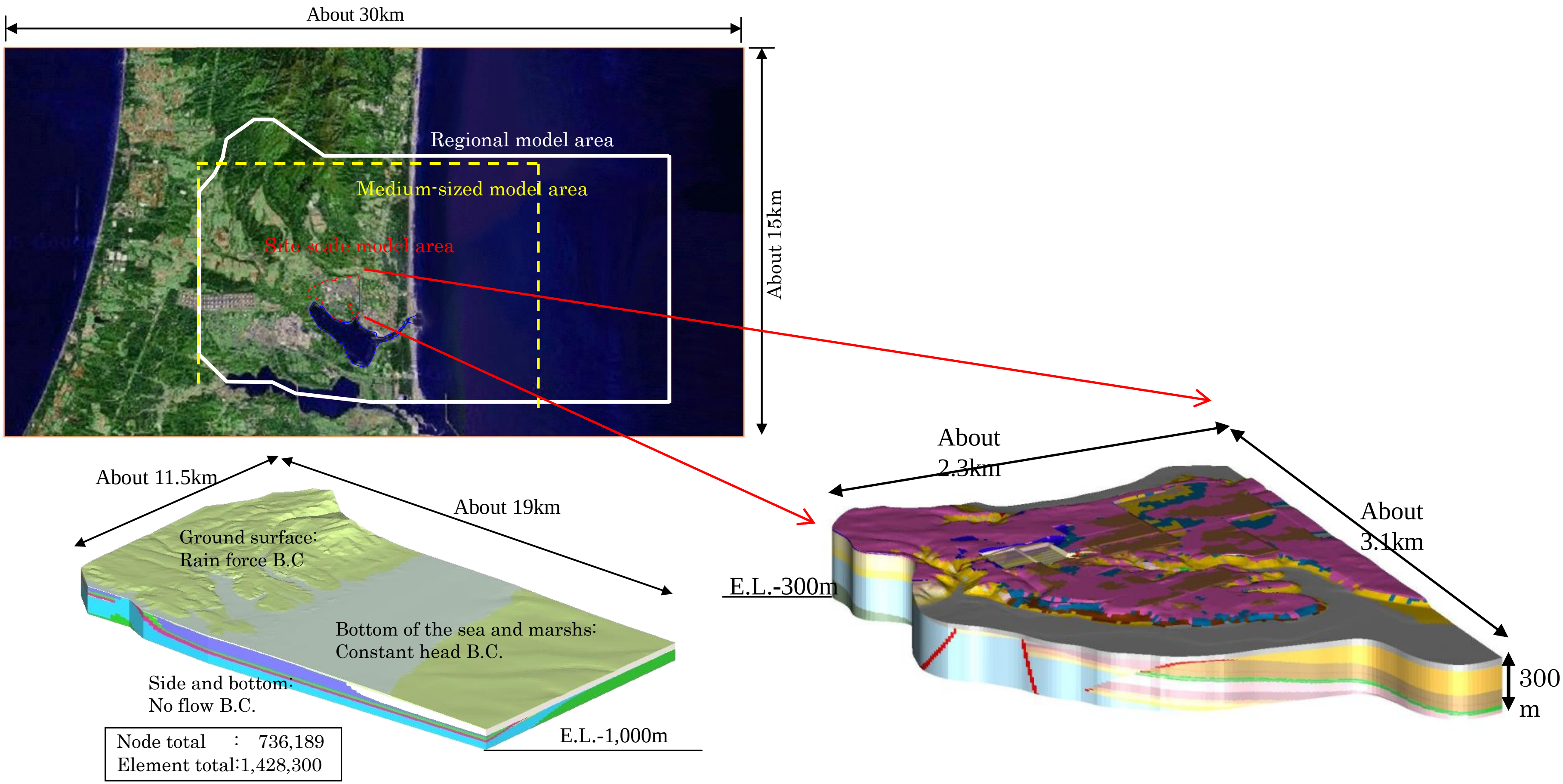


The relationship between groundwater ages based on C-14 and δD (deuterium) concentrations is consistent with the relationship between Antarctic ice ages and δD. Groundwater ages on the plateau are less than 10,000 years old, whereas groundwater ages below the downstream swamps range from 10,000 to 25,000 years old

EPICA Community Members (2004):Nature, 429, 10, pp.623-628.

δD data: NOAA database; http://www.ncdc.noaa.gov/paleo/icecore/antarctica/domec/domec_epica_data.html

2. Groundwater flow analysis model



Wide-area model

Site Model

3. Validation of analysis model

3.1 Validation of analysis model by the groundwater table level

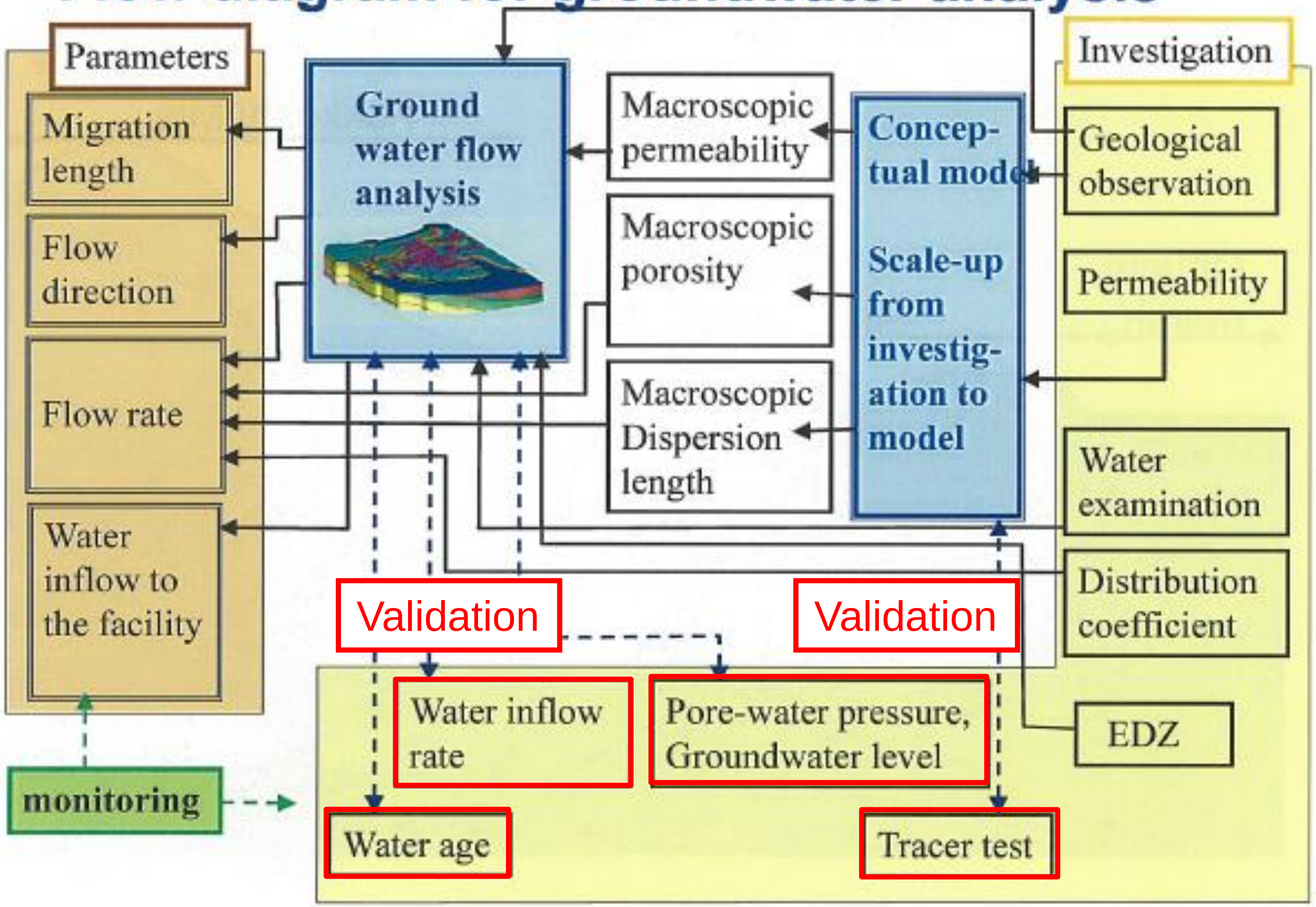
3.2 Validation of analysis model by the pore water pressure

3.3 Validation of hydraulic conductivity
by the discharge from exploratory drifts

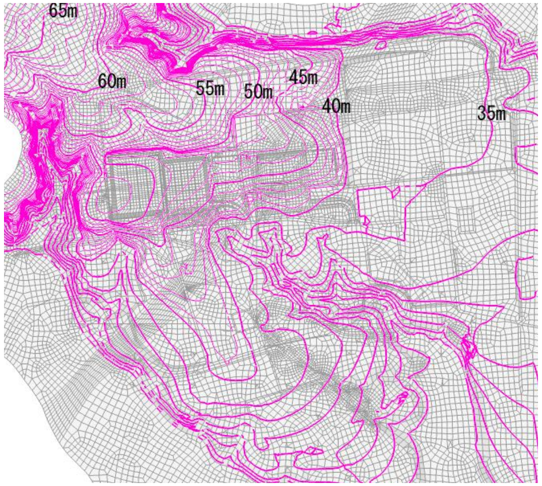
3.4 Validation of flow porosity by the analysis transition time

3. Analysis model creation and Model validation

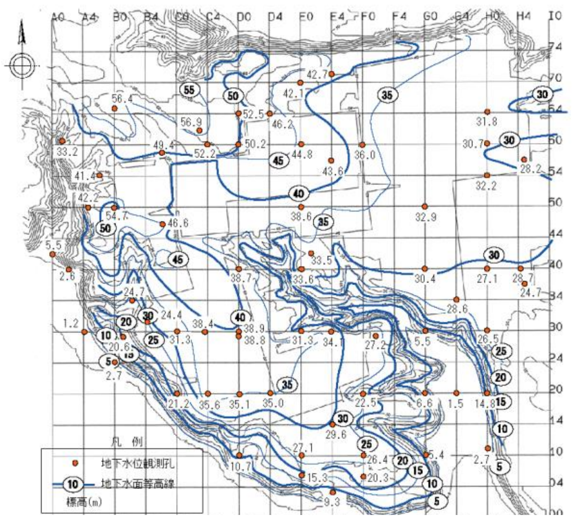
Flow diagram for groundwater analysis



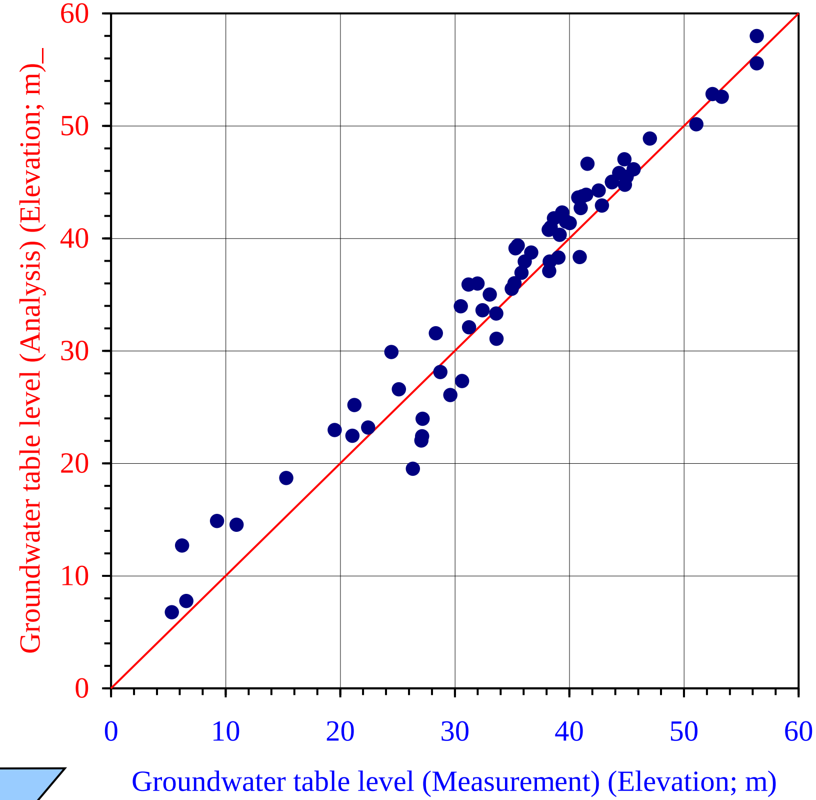
3.1 Validation of analysis model by the groundwater table level



Groundwater table level (Analysis) (Elevation; m)

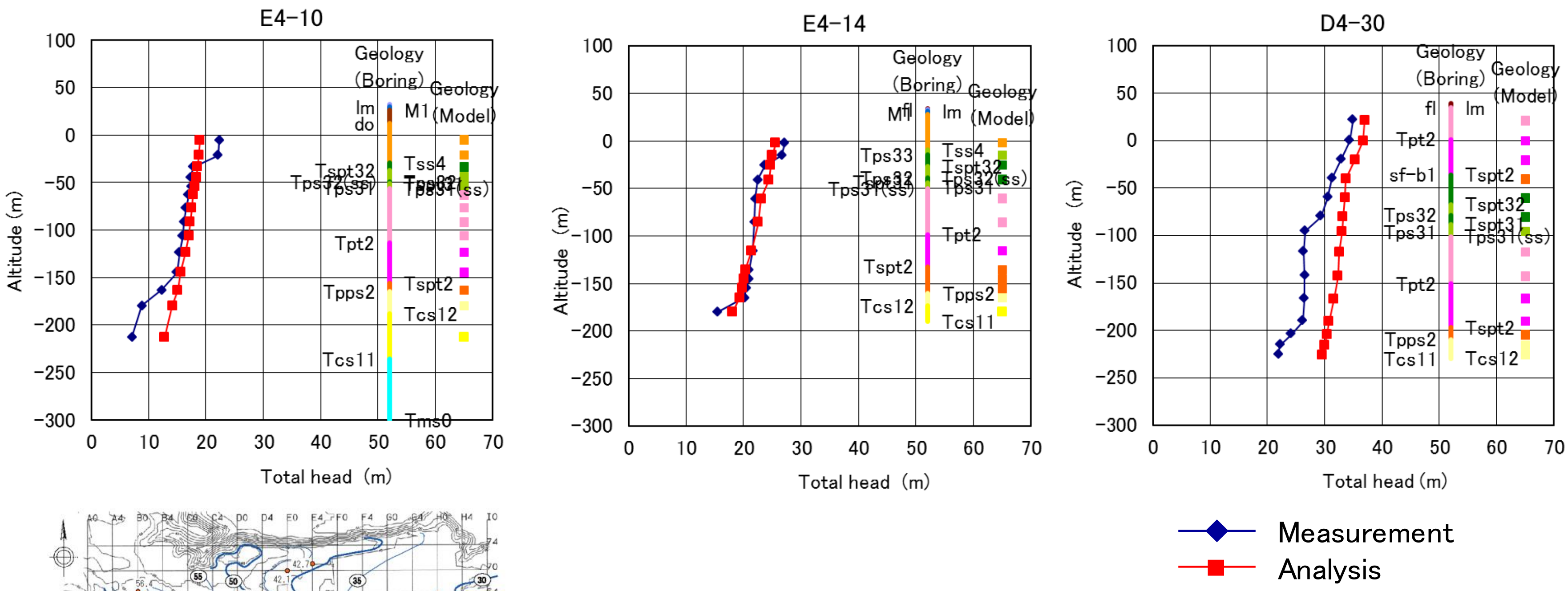


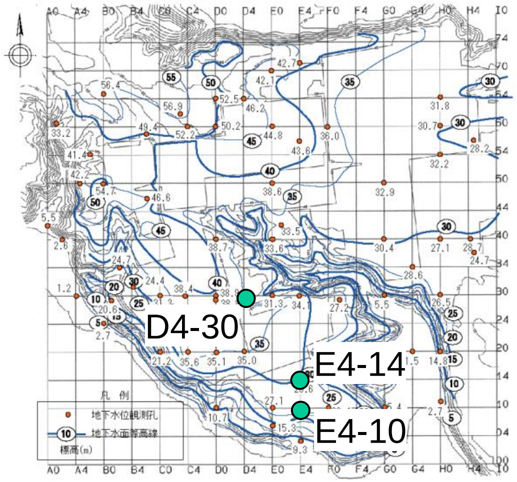
Groundwater table level (Measurement) (Elevation; m)



Groundwater levels in the analysis and measured groundwater levels are generally consistent.

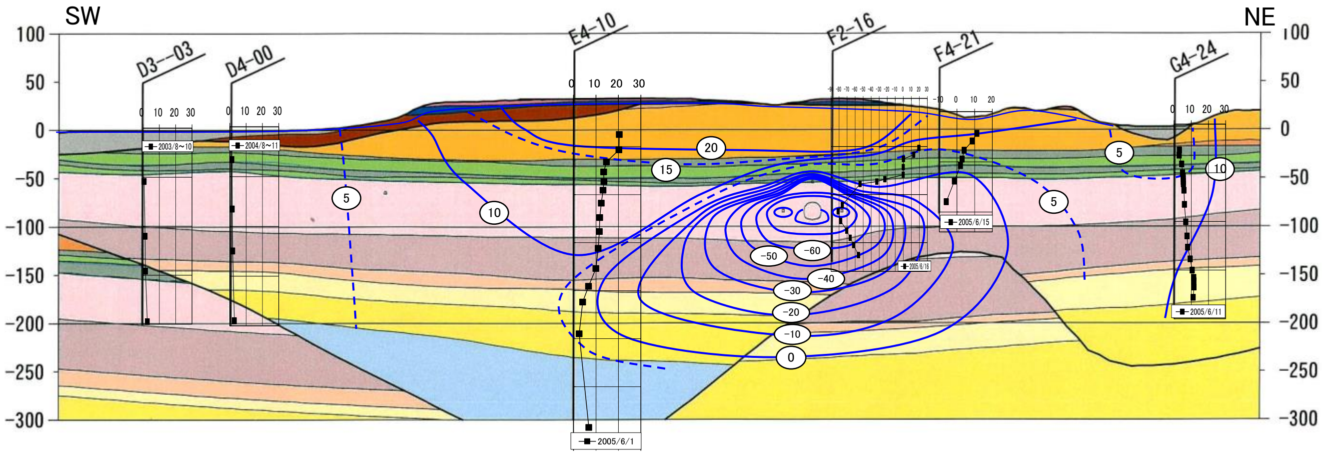
3.2 Validation of analysis model by the pore water pressure



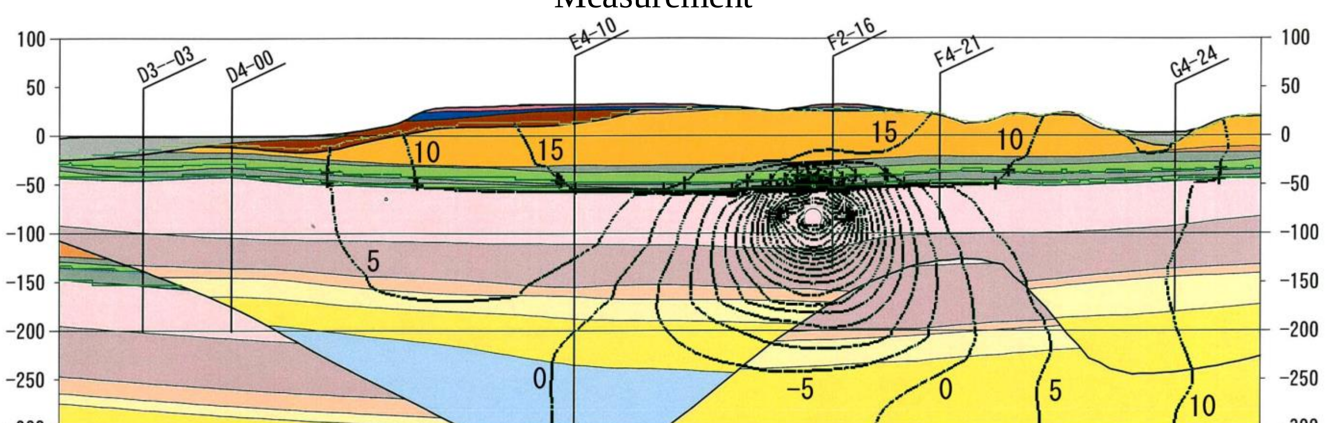


The analytical hydraulic head distribution is generally consistent with the measured hydraulic head distribution.

3.2 Validation of analysis model by the pore water pressure



Measurement

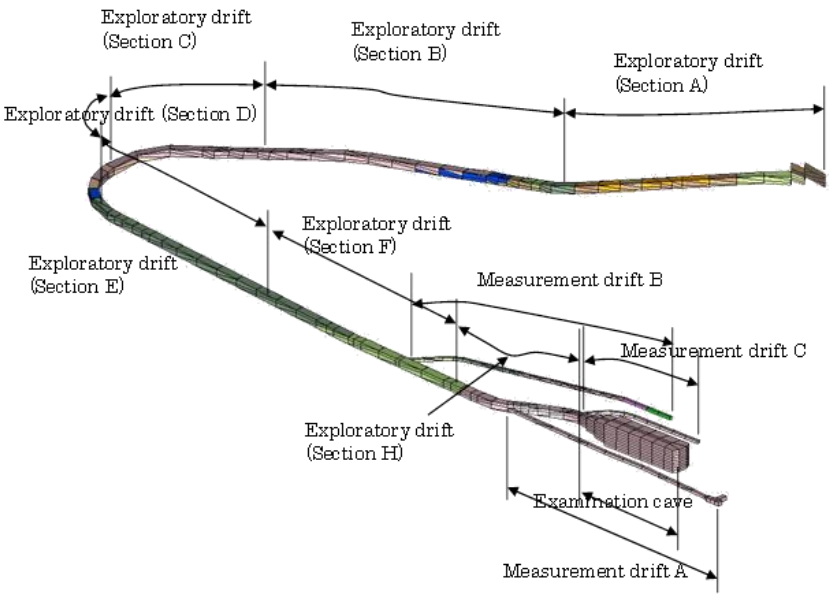


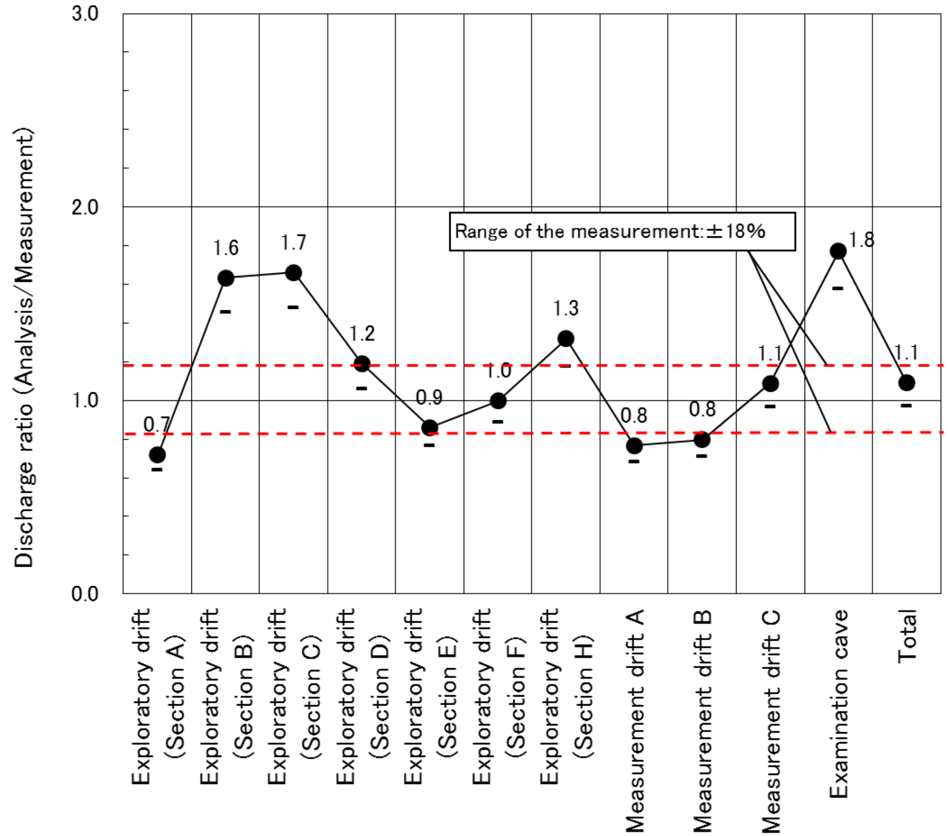
Analytical

The analytical hydraulic head distribution is generally consistent with the measured hydraulic head distribution.

3.3 Validation of hydraulic conductivity by the discharge from exploratory drifts

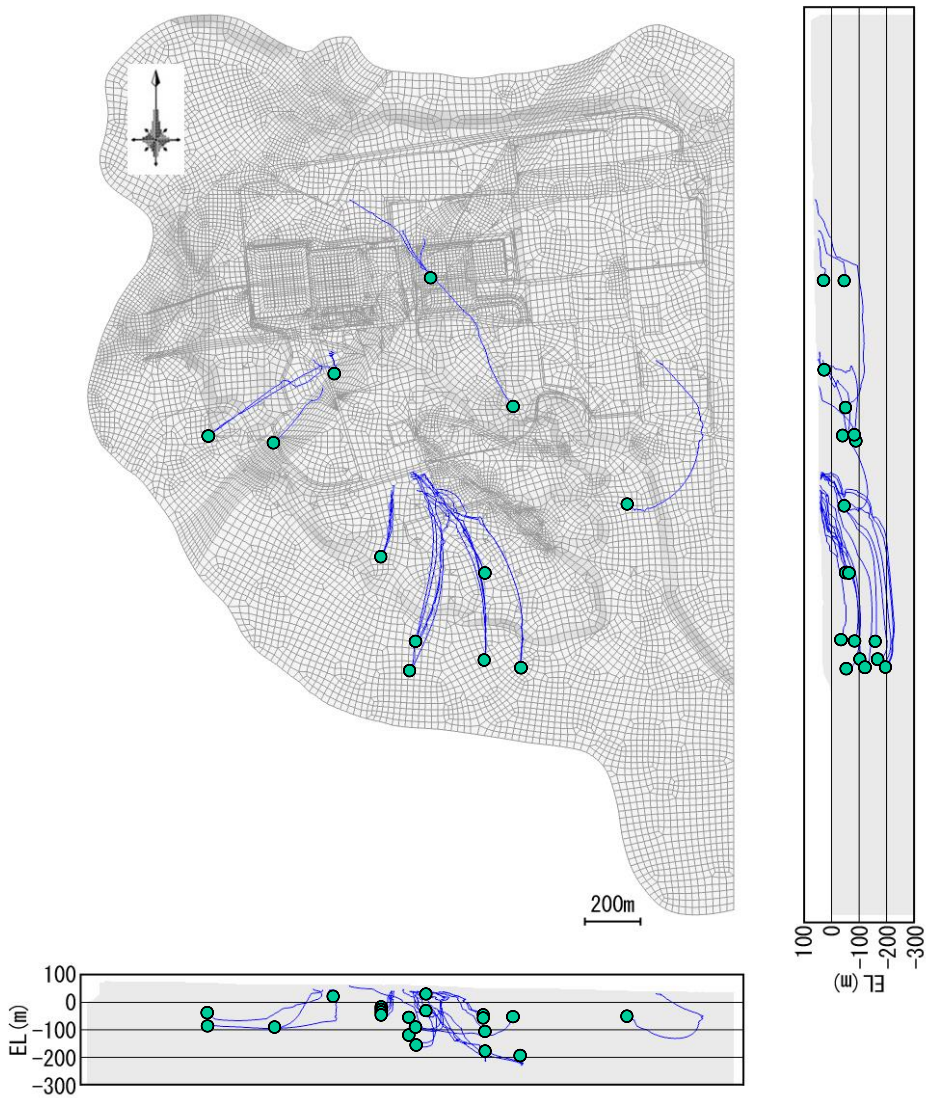
JNFL





Compared the results of the analysis of tunnel water inflow using the average hydraulic conductivity obtained from permeability tests using boreholes with the measured water inflow for each geological section of the tunnel.The two are generally consistent, but the analysis exceeds 1.5 times the actual measurement in some sections.Also, on average, the flow rate of the analysis was 1.1 times that of the actual measurement

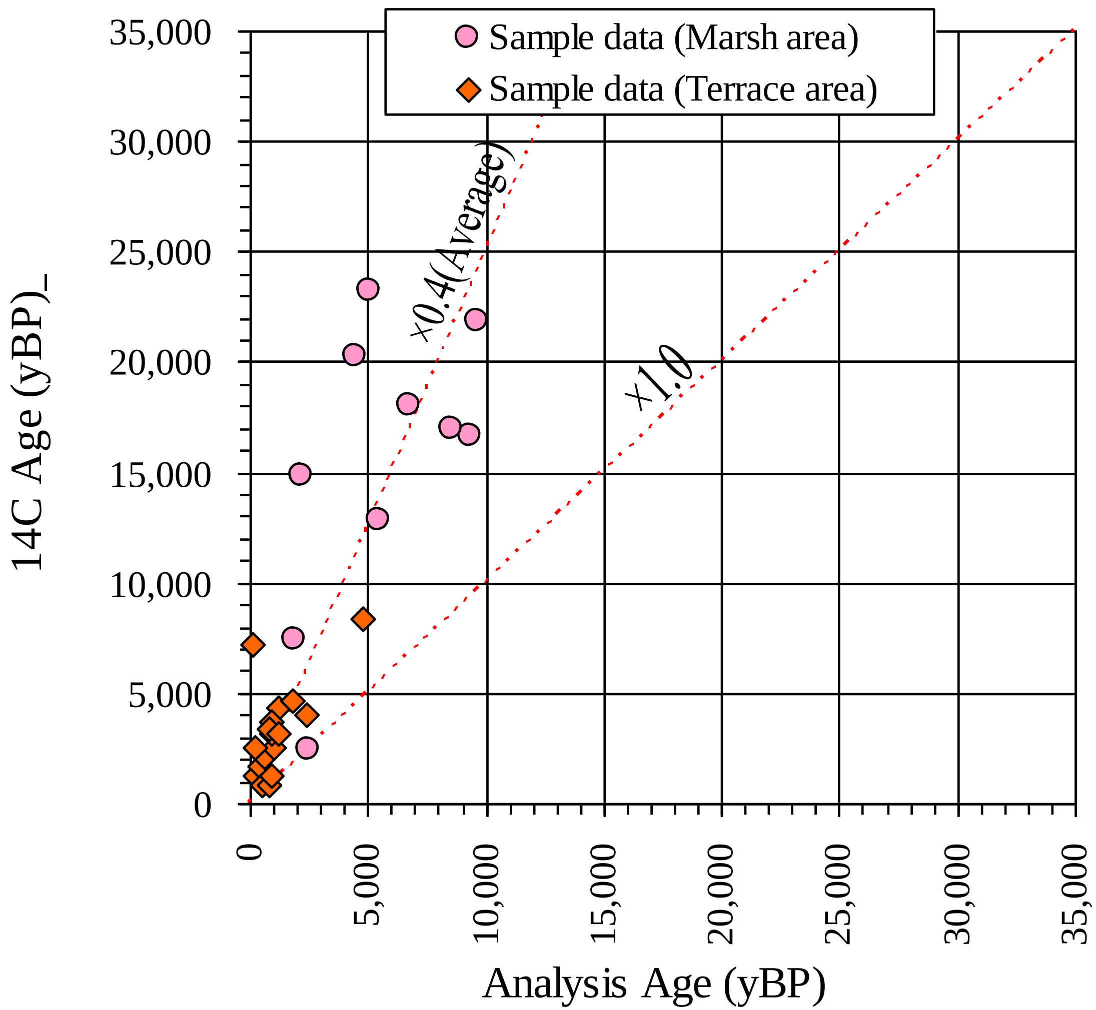
3.4 Validation of flow porosity by the analysis residence time (Groundwater age)



Particle trace lines
Sampling points (in borehole)

To compare the analytical groundwater age with the measured groundwater age, the stream trace line from the point where rainfall infiltrated into the ground to the point where groundwater sampling was conducted was determined by analysis, and the travel time was calculated.

3.4 Validation of flow porosity by the analysis residence time (^{14}C)



Measured and analyzed groundwater ages were compared. Analytical groundwater ages averaged 0.4 to 0.6 times (younger) than measured

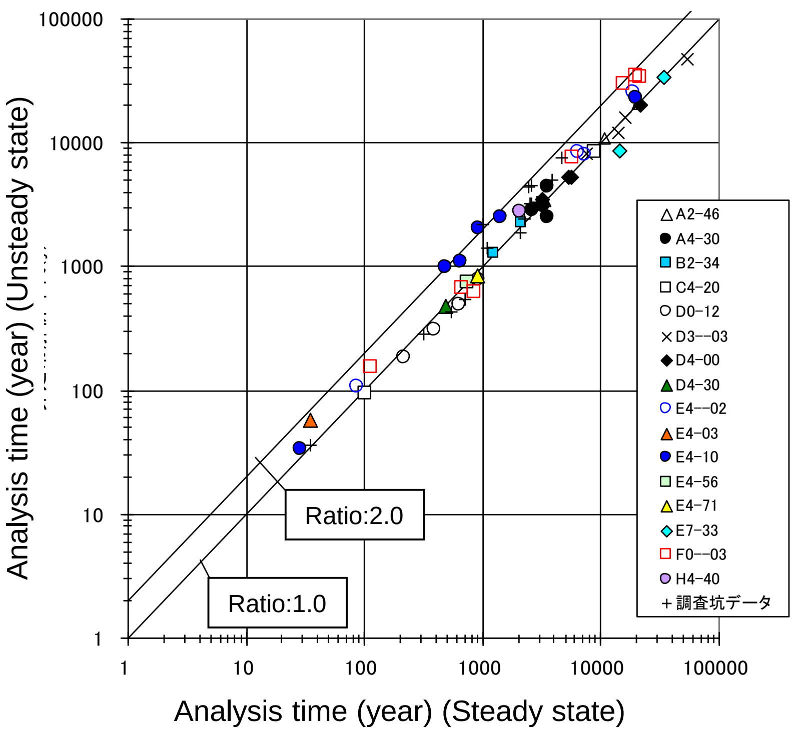
4. 1 Discussion

The analysis groundwater age is 0.4 - 0.6 times younger than measured groundwater age　why ?

4. 2 Discussion (Unsteady state)

Steady state analysis, we could not consider past climate change influence and unsteady state behavior.

Comparison of groundwater ages based on steady-state and un-steady-state considering past climate change



Groundwater age from steady-state analysis x 1.2 times = groundwater age from un-steady-state analysis

4. 3 Discussion (Viscosity)

Viscosity change of past groundwater

Twenty thousand years ago, temperatures were 10 degrees Celsius lower than today. Groundwater temperature affects viscosity, and viscosity affects hydraulic conductivity.

$$K = k\frac{\rho g}{\mu}$$

K is hydraulic conductivity (m/s), k is intrinsic permeability (m2), ρ is density (kg/m3), g is gravitational acceleration 9.81 m/s2, μ is viscosity (Pa-s)The ratio of the permeability K5 at a water temperature of 10° C to the permeability K10 at a water temperature of 5° C is

$$\frac{K5}{K_{10}} = \frac{\rho 5}{\rho_{10}} \times \frac{\mu_{10}}{\mu 5} = \frac{0.99996}{0.99970} \times \frac{1.307}{1.520} \cong 0.86$$

Assuming that the average temperature over the past 20,000 years was 5 degrees Celsius lower than today, the age of the analysis must be multiplied by 1.2 to account for the effect of reduced groundwater viscosity during cold weather on hydraulic conductivity and groundwater age

4. 4 Discussion (hydraulic conductivity test)

Effect of scale on permeability testing

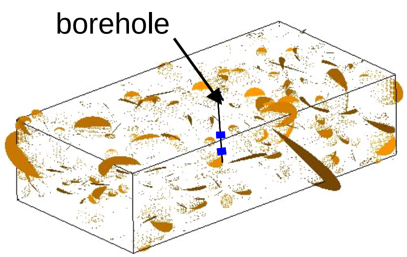
- Comparing the measured inflow into the tunnel with the inflow into the tunnel from groundwater flow analysis using hydraulic conductivity based on borehole measurements, the hydraulic conductivity in the analysis is on average 1.1 times the measured inflow, the hydraulic conductivity used in the analysis is slightly larger, and the analysis may have shortened the age of the groundwater.
- There is a possibility that the analysis may have shortened the age of the groundwater. To account for the effect of the scale at which permeability is evaluated, the age of the analysis should be multiplied by 1.1Translated with DeepL.com (free version)

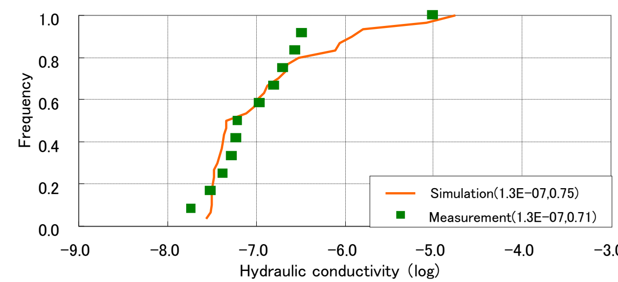
4. 5 Discussion (Macroscopic Hydraulic conductivity)

Fracture data
- Orientation
- Density
- Radius distribution

Hydraulic conductivity data (In-situ)
- including fractures
- without fractures (Matrix)

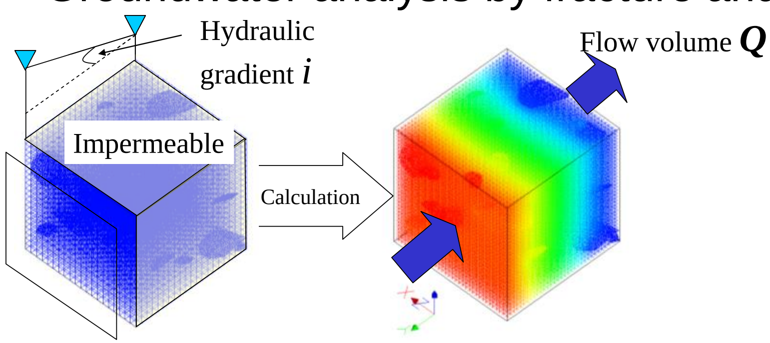
In-situ test simulation by fracture and matrix complex model





Transmissibility of fracture

Groundwater analysis by fracture and matrix complex model

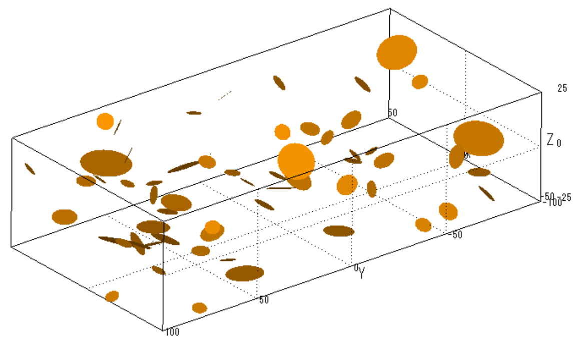


Used Code : Don-Chan
(Developed by Prof.Watanabe, Saitama univ.)

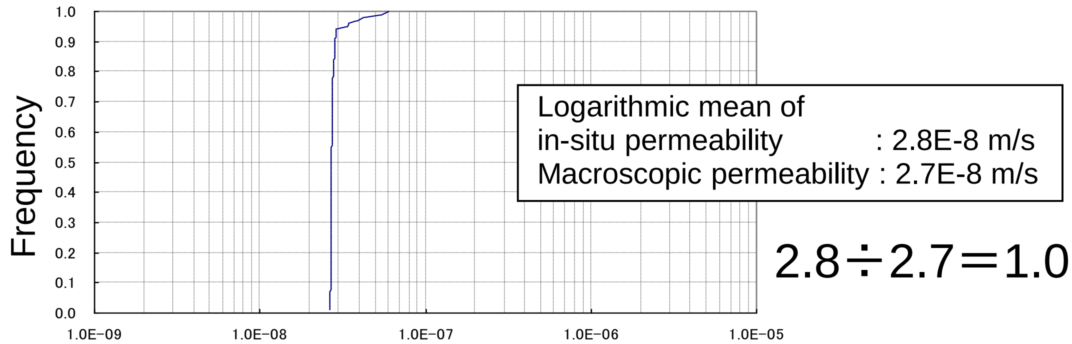
Macroscopic permeability

$$k = \frac{Q}{A \times i}$$

4. 5 Discussion (Macroscopic Hydraulic conductivity)

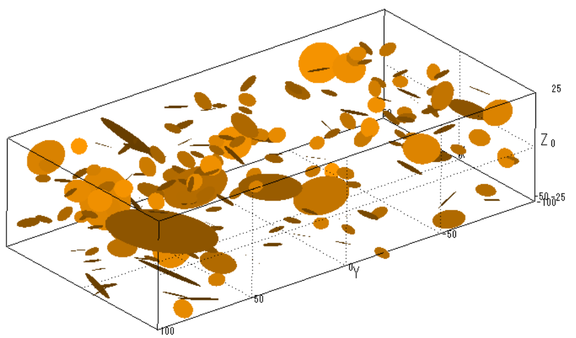


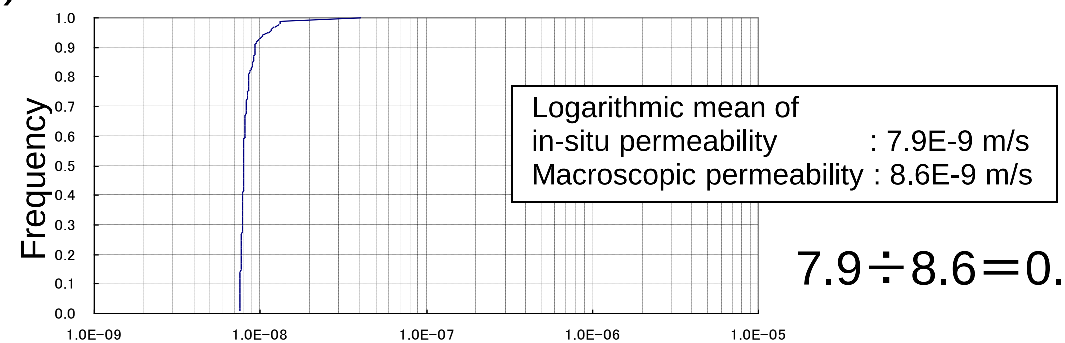
Fracture distribution (Pumice tuff)



Macroscopic permeability (100 realization)

2.8÷2.7＝1.0





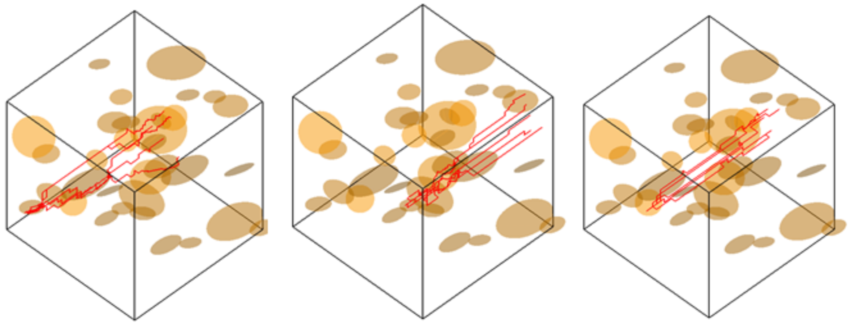
7.9÷8.6＝0.9

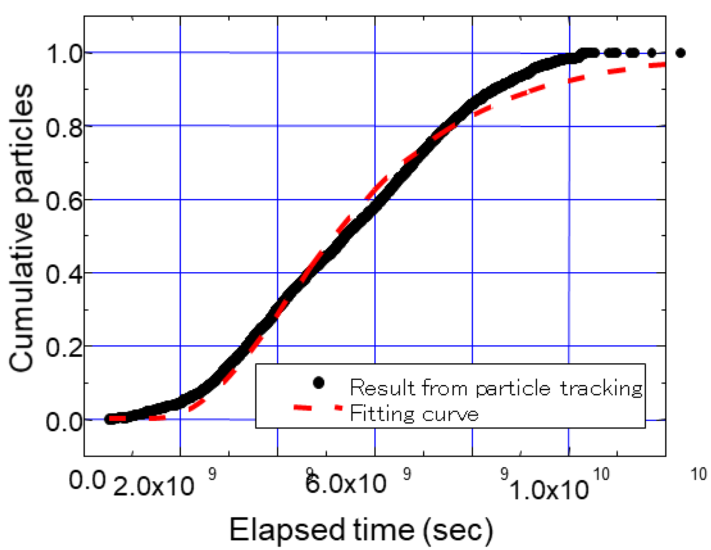
Macroscopic permeability (100 realization)

Fracture distribution (Sandy pumice tuff)

Influence of macroscopic permeability is 0.9 to 1.0 times, and the influence is small

4.6 Flow porosity (Macroscopic effective porosity)





Input large number of the particles and calculate the distribution of migration time

Fitting to one dimensional theoretical solution to calculate the mean actual velocity and dispersion length

Porosity (matrix; laboratory test): 0.50
Macroscopic effective porosity(calculation）: 0.46 ～ 0.49 (average 0.475)

The macroscopic effective porosity including cracks is slightly smaller than the porosity of the substrate (0.475 / 0.5 = 0.95)

Influence of macroscopic effective porosity is small

4. 7 Discussion (Conclution)

The analysis groundwater age is 0.4 - 0.6 times younger than measured groundwater age

Items not considered in the analysis	Magnification that needs to be corrected for age of analysis
Unsteady impacts of climate change	× 1.2
Decrease in viscosity due to climate change	×1.2
Scale effects of permeability tests (borings and tunnels)	× 1.1
macroscopic hydraulic conductivity	Influence is small
macroscopic effective porosity	Influence is small

$1.2 \times 1.2 \times 1.1 = 1.6$

Considering the above, magnification that needs to be corrected for age of analysis is

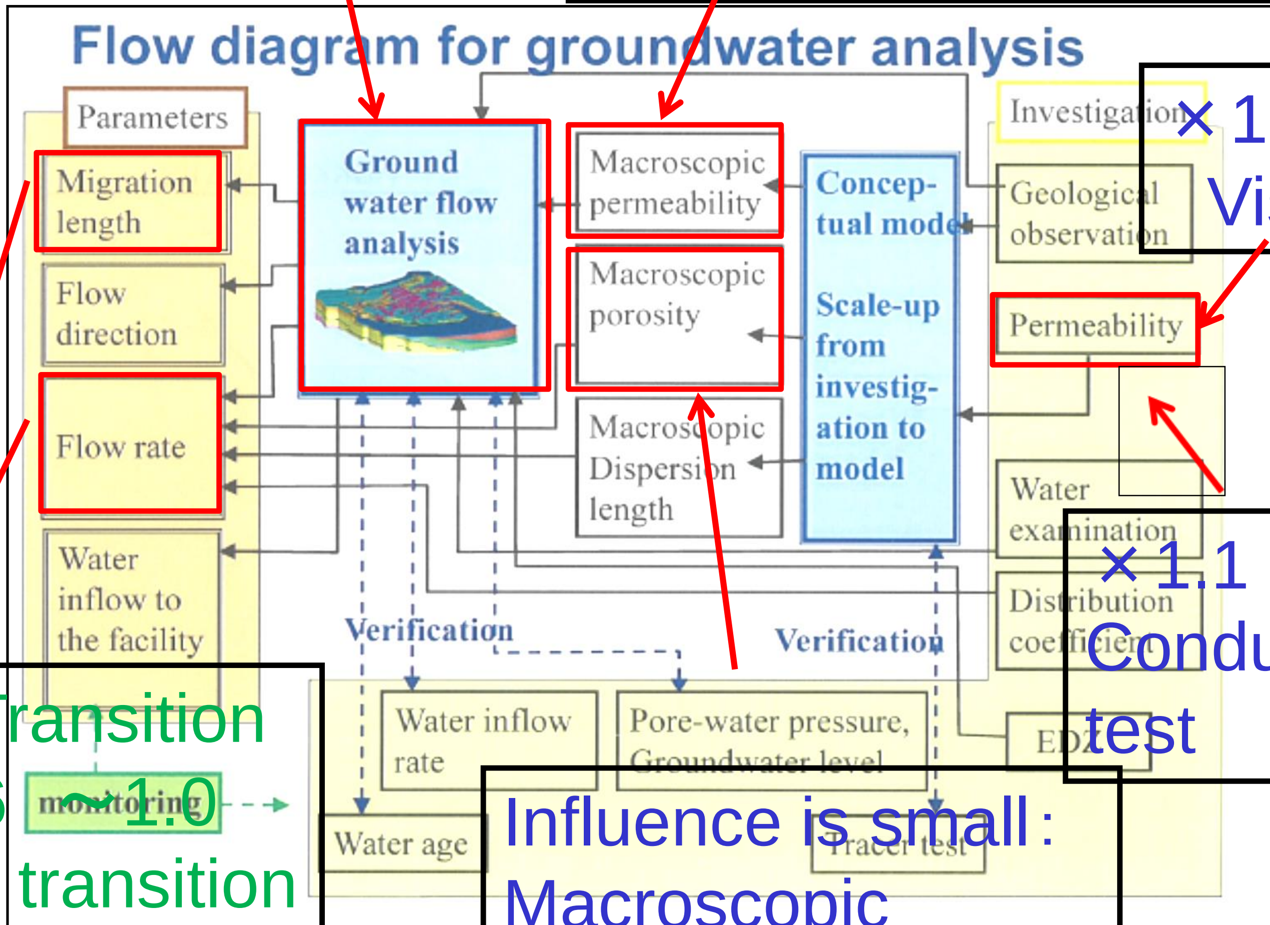
$0.4 \sim 0.6 \times 1.6 = 0.6 \sim 1.0$

The analytical model can be evaluated for certainty using the fact that the analytical groundwater ages are 0.6 to 1.0 times greater than the measured groundwater ages.

4. 7 Discussion (Conclution)

×1.2 : Unsteady state

Influence is small : Macroscopic conductivity



×1.2 : Viscosity

×1.1 Conductivity test

Analysis Transition Time×0.6 ~1.0 Measured transition time

Influence is small : Macroscopic porosity

5. Summary

- Groundwater age data is useful to validate the groundwater flow model
- We can treat uncertainty quantitatively by using Groundwater age data.

Note: Please note that this discussion represents a possible method of model validation and the results of the quantitative evaluation may change in future studies.