International Review Workshop on JAEA's URL projects

Existing URL Programme Overview during the 2nd five-year Plan

Mizunami Underground Research Laboratory (MIU)

18th June 2014

Eiji SASAO

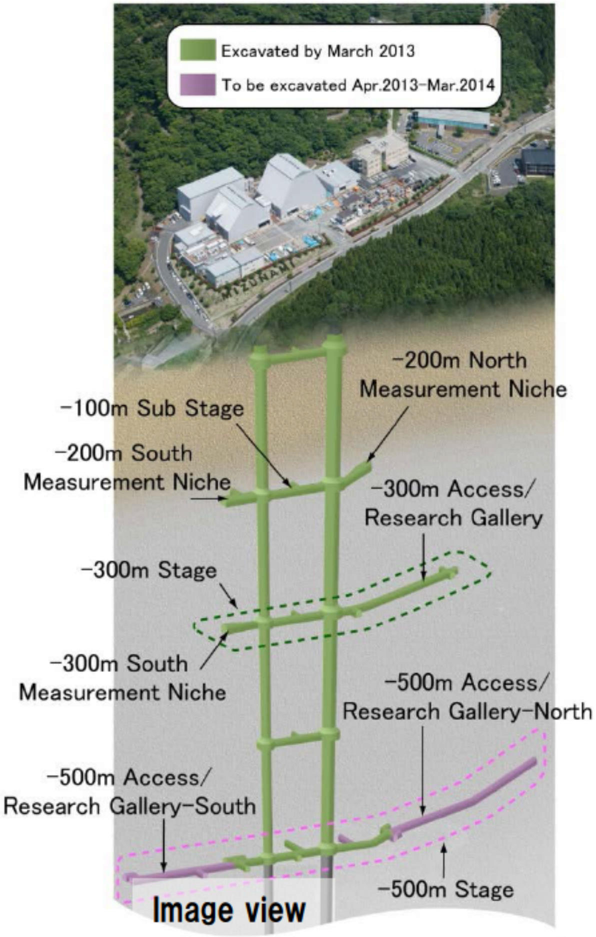
Japan Atomic Energy Agency

Sector of decommissioning and radioactive wastes management

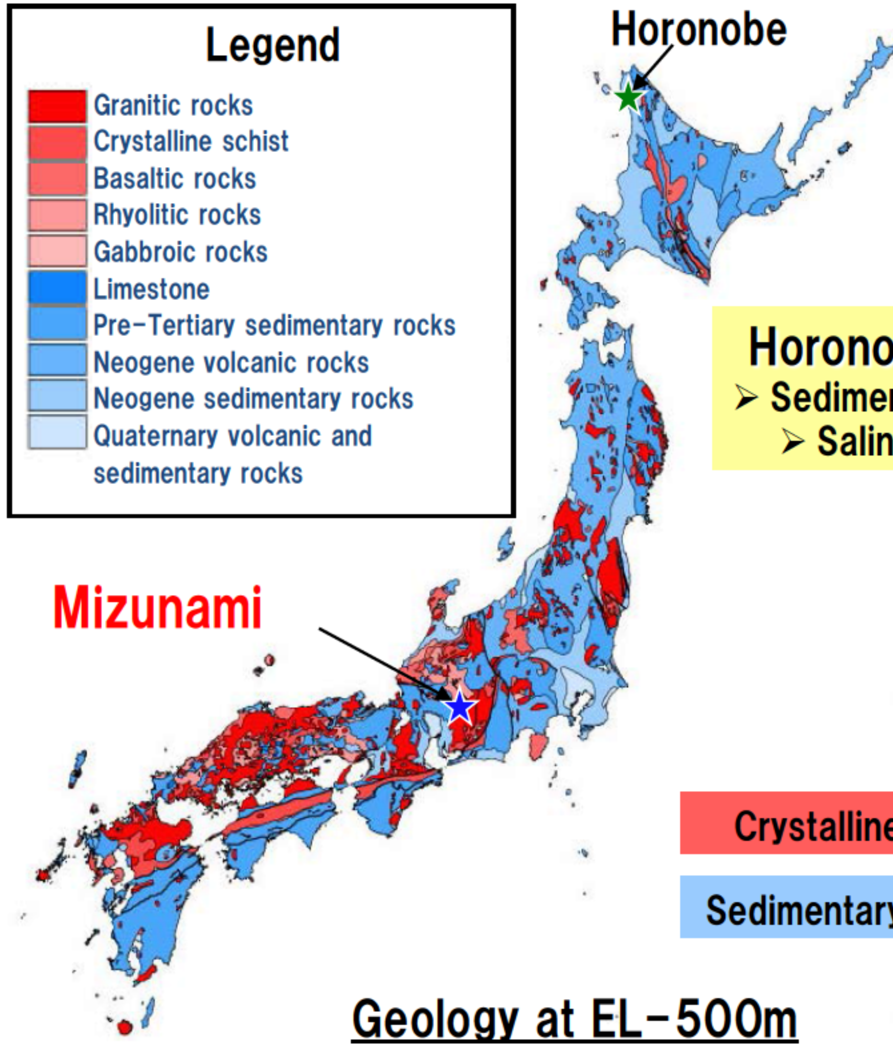
Tono Geoscience Center , Geoscientific Research Department,

Crystalline Environment Research Group

Mizunami Underground Research Laboratory (MIU)



Mizunami URL
- Crystalline rock
- Fresh water



Horonobe URL
- Sedimentary rock
- Saline water

Crystalline rocks

Sedimentary rocks

Geology at EL-500m

Why was Tono area selected for MIU site?

- Geological environment： granitic rock body exists in this area (Granite is one of representative rock in Japan)
- Central part of Japan： easy access by train and car

And,

- Existence of field exploration office in the vicinity since 1965 and accumulated geological information

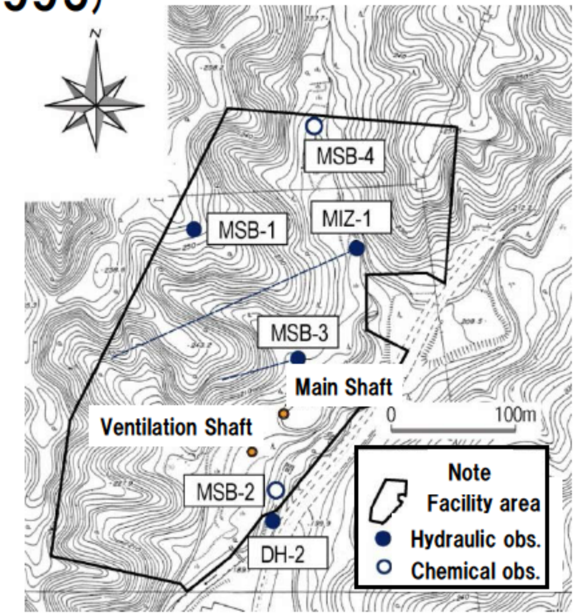
Therefore,

- Existence of knowledge and experience together with experts and technology in the field of earth sciences

MIU Project and Regional Situations

The MIU project has proceeded under three agreements with local governments on:

- ➢ Acceptance of MIU Project as about 20 years project (1995)
- ➢ Land lease from Mizunami city till 2021 (2002)
- ➢ Environmental protection (2005)



JAEA promises;

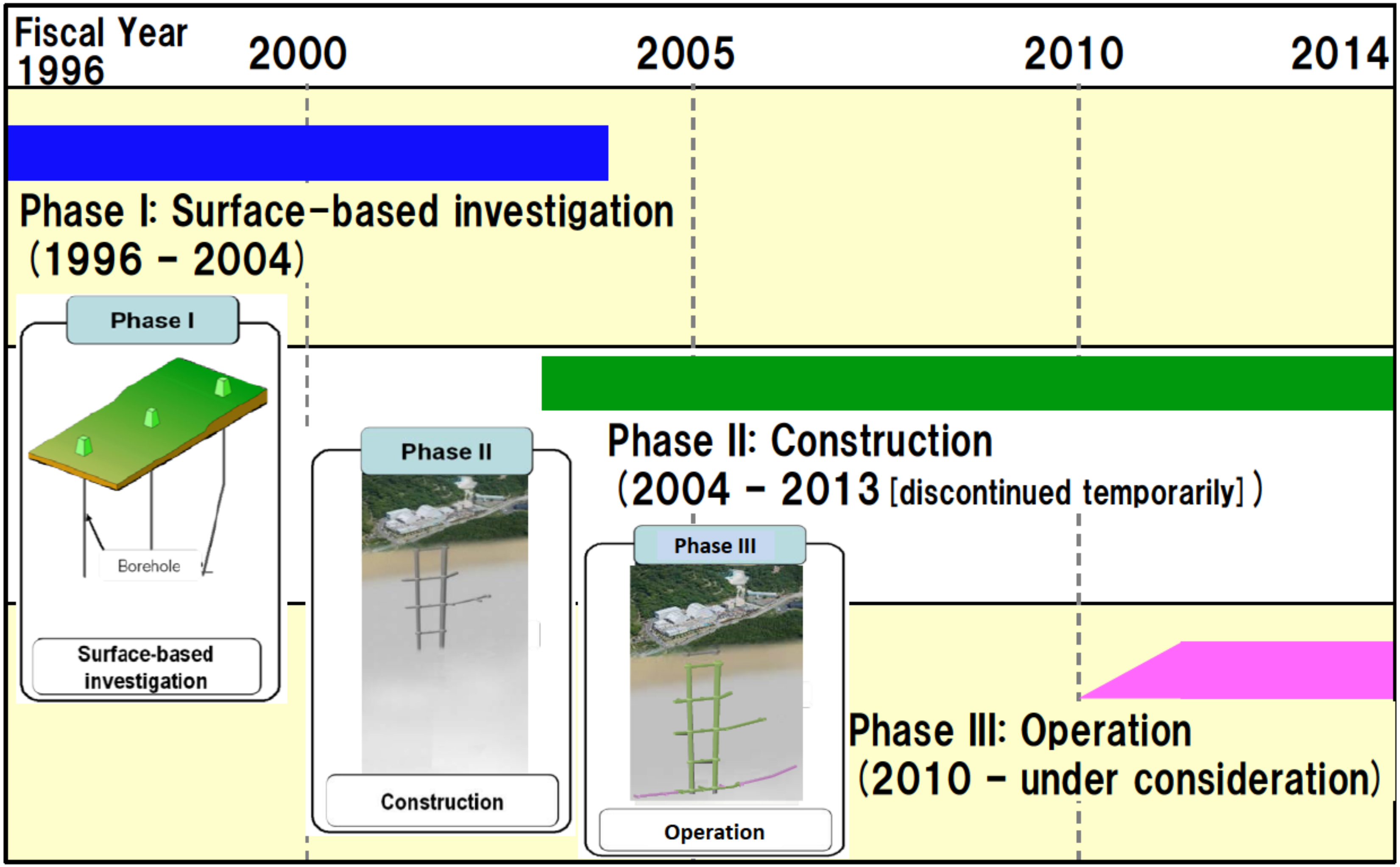
- Any radioactive wastes will not be brought nor used. The MIU will not be a repository in the future.
- The oversight committee with the local governments and residents will be set up, and the MIU site is open to academic research and education.

→Borehole investigation from gallery is limited in a domain of leased land (approx. 200 m x 450 m).

→ R & D is limited in the field of geoscience, engineering for underground facility. We don't study Engineering Barrier System nor use radioactive tracer in MIU.

→ Single fiscal year budget is given by government (MEXT) for MIU operation and R & D every year. Their feel that cannot ignore the public opinion cannot be ignored and this is reflected in an annual budget. The budget has decreased since the Fukushima accident.

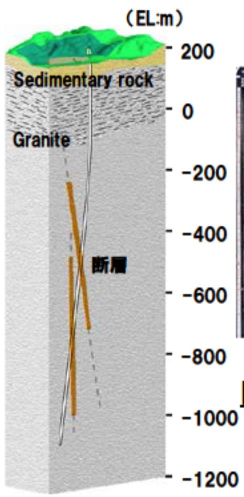
Progress of MIU Project

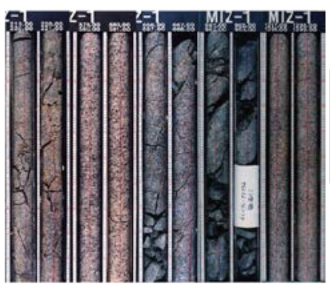


Step-wise investigations in MIU project

A1

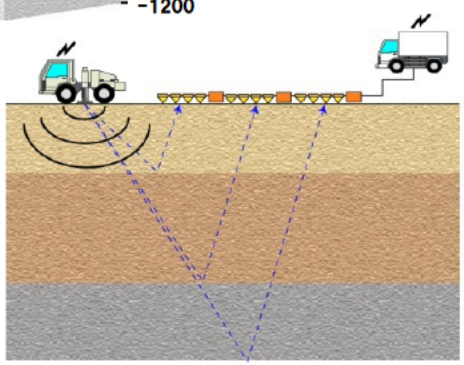
[Surface-based investigation]





Core

Borehole investigation

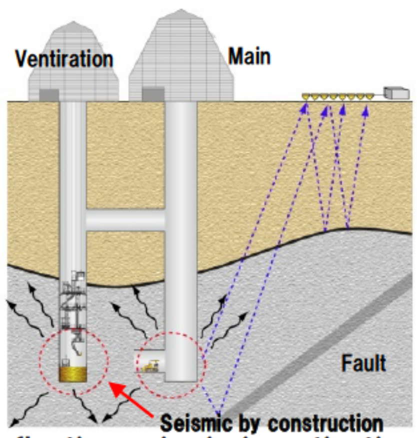


Reflection seismic investigation

A2

[Construction]

Geological mapping/sampling

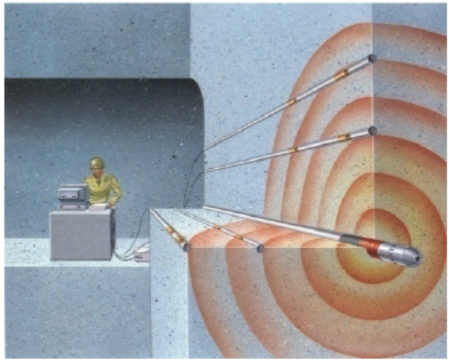


Reflection seismic investigation using the construction effect

A2, A3

[Operation]

Monitoring in boreholes



Monitoring by geophysical methods

Research digests on facility construction and operation (A2)

Aims: Development of generic technique for Construction/Operation phase:

- How to design the shaft and gallery taking hydrogeological structure and rock mechanics into account.
- How to estimate the environmental impact and recovery during/after facility construction – closure.

Event

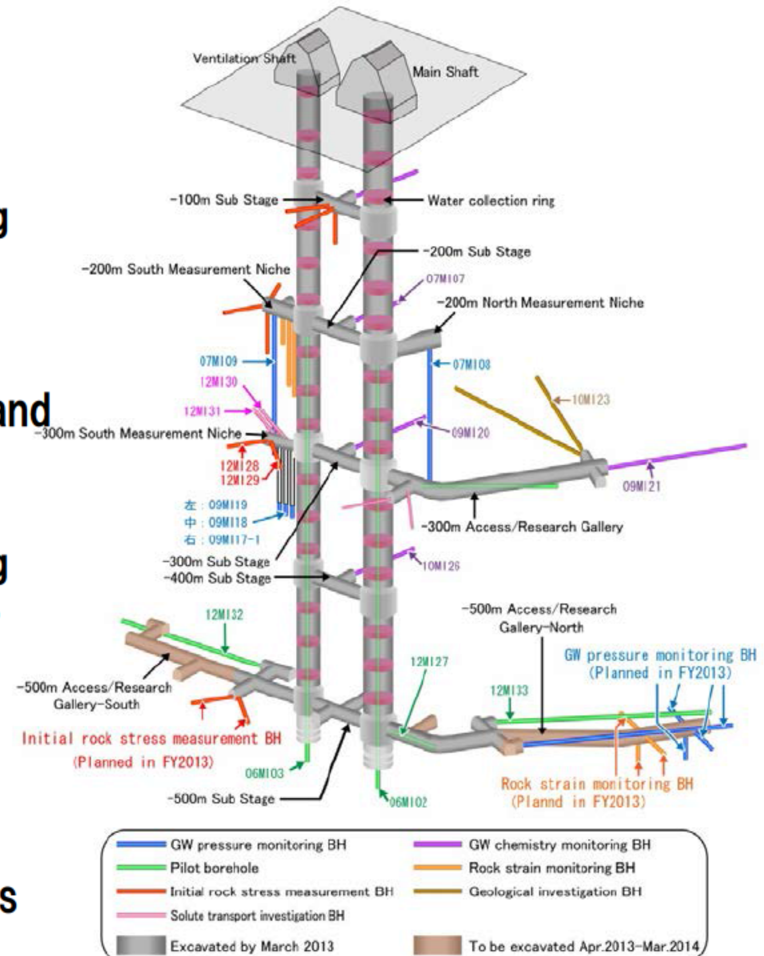
- Facility construction: grouting, shotcrete, rock mechanical damage (fracturing), long-term opening of gallery and pump up of GW

Focused Process

- EDZ: Change of rock mechanical, hydrogeological and chemical property, GW alkalization and sealing of fracture by water-cement interaction, etc.
- EdZ: GW drawdown and/or upconing, mixing among chemically-distinct waters and buffering by water-rock interaction

Focused Feature

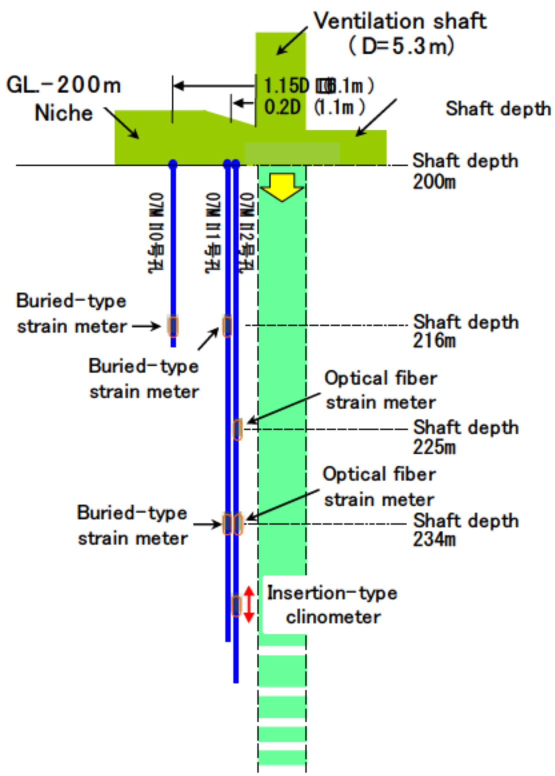
- Deformation of rock, permeability, GW chemistry around gallery (EDZ)
- GW pressure, chemistry around facility and relations to hydrogeological structures (EdZ)



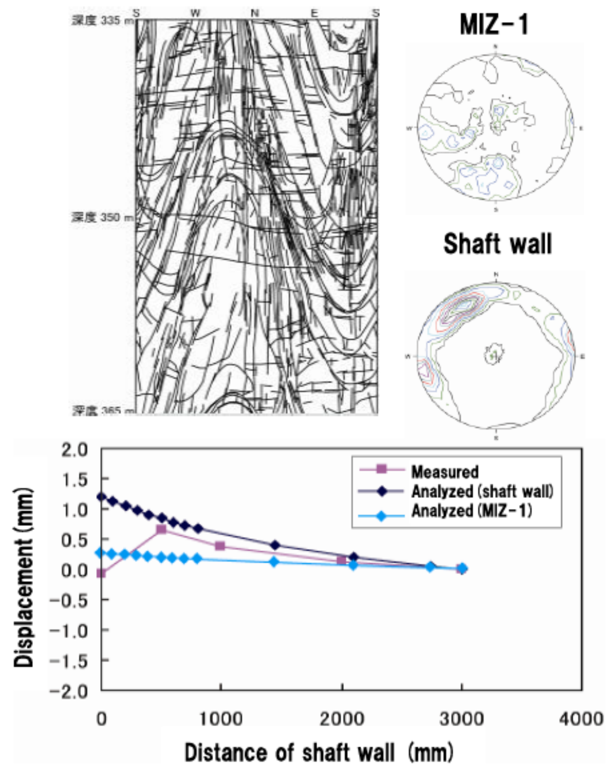
A2) Understanding of short-term evolution/recovery behavior of geological environments

- Development of method to monitor impact on rock mechanical property -

Estimation of EDZ due to construction of underground facility and operation is possible by in-situ measurement and numerical analysis.



Strain measurement during shaft sinking

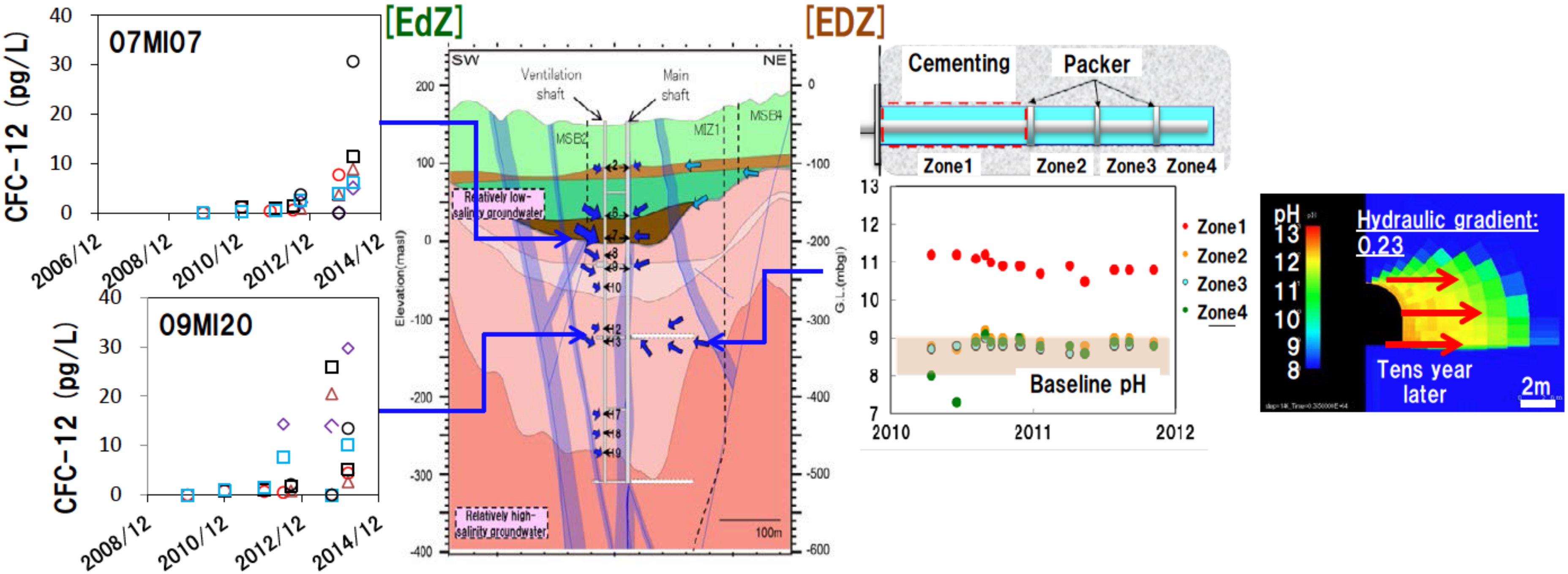


Comparison of measured and analyzed value

- Strain due to shaft sinking was same order of magnitude of elastic analysis. Width of EDZ would be within 1m from shaft wall.
- Rock stress and strain would be underestimated in the equivalent continuum analysis using crack tensor due to difficulty of high angle fractures at the surface-based investigation.

A2) Understanding of short-term evolution/recovery behavior of geological environments
- Development of method to monitor impact on GW chemistry -

Generic process and feature on GW chemistry in EDZ/EdZ during facility construction/operation can be identified by monitoring and PCA analysis.



Hydrochemical observation such as ^3H, CFCs and multivariate analysis suggest that the GW to the depths of 400 m is replacing by shallow water due to 10 years drainage (hundreds ton/day), and alkalization around drift occurs heterogeneously according to water inflow (flushing) condition.

A2) Summary on short-term evolution/recovery behavior of geological environments during facility construction/operation

Important geological features during facility construction/operation:

- Width of rock mechanical EDZ would be within 1m from shaft wall (study of EDZ around gallery is ongoing).
- Hydraulic responses differ with each hydraulic compartment which are formed with low permeability structures.
- The GW around facility in fractured rocks is replaced by shallow GW when large amount GW inflow (hundreds ton/day) occurred.

Technical findings:

- Estimation of rock mechanical EDZ due to facility construction/operation is possible by in-situ measurement and numerical analysis.
- Assignment of monitoring intervals taking into account hydrogeological heterogeneity including hydrogeological compartment is essential to estimate the hydraulic characteristics.
- Generic process and feature on GW chemistry in EDZ/EdZ during facility construction/operation can be identified by monitoring and PCA analysis.

Research digest on long-term behavior (A3)

Aims: Development of generic technique for facility closure/post closure phase:

- How to close the gallery and to monitor the mid-term change of geological environment.
- How to predict the recovered stable condition after closure.
- How to develop the scenario on mid-term artificial and long-term natural processes.

Event

- Facility closure: grouting, shotcrete, plug and backfilling
- Geological events: marine regression/transgression, uplift/erosion, earthquake, etc.

Focused Process

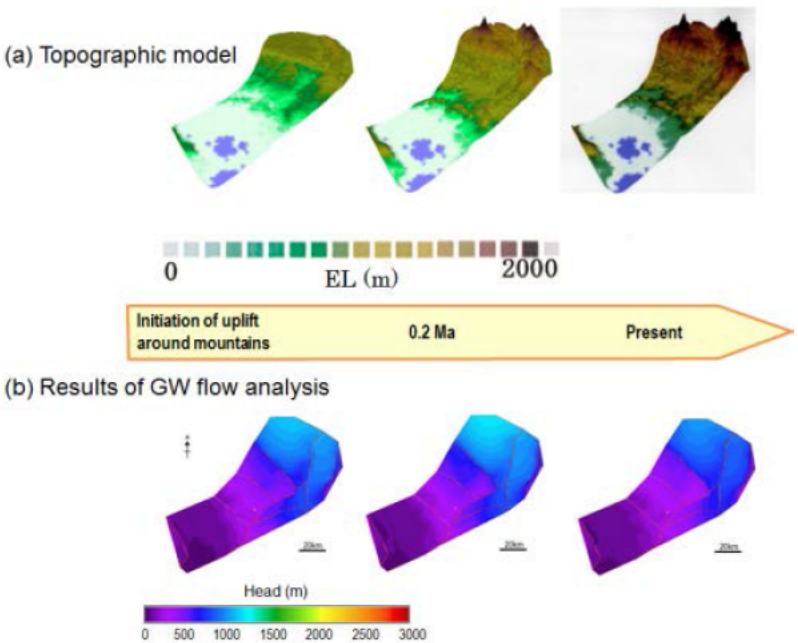
- EDZ: water-cement-backfilling interaction, seal the fracture, colloid formation…
- EdZ: groundwater recovery (flushing/replacement), chemical reduction of infiltrated shallow water?, change of GW pressure and mixing condition by earthquake, etc.

Focused Feature

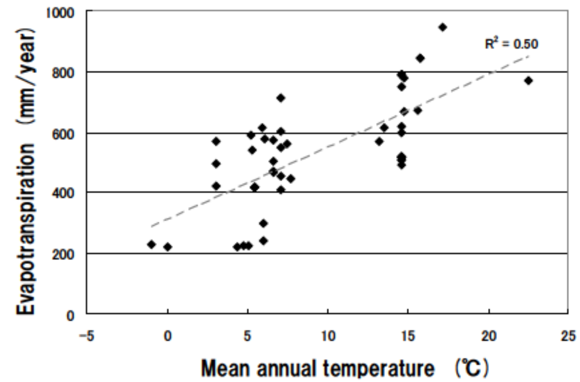
- Permeability of sealed fracture, GW pressure and chemistry around facility
- Respond of GW pressure and chemistry on earthquake, the other geological events

A3) Understanding of long-term evolution/recovery behavior of geological environments
-Techniques to estimate long-term evolution of geological structure-

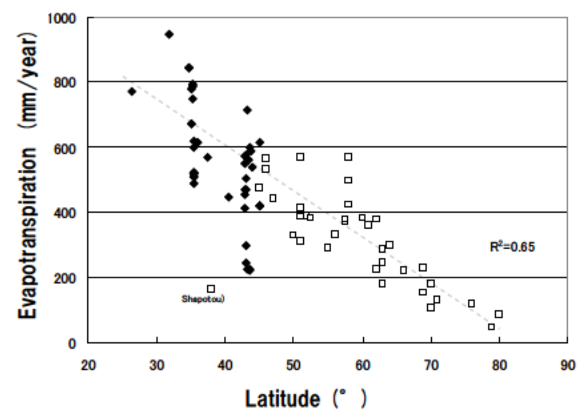
A series of synthesized investigation, analysis and modeling techniques taking into account uplift and subsidence, erosion, sedimentation, climatic perturbation etc. could be developed.



Long-term hydrology was roughly evaluated by numerical analysis taking into account paleogeography (from kiso mountain to Ise-bay), recharge rate and hydraulic properties of faults.



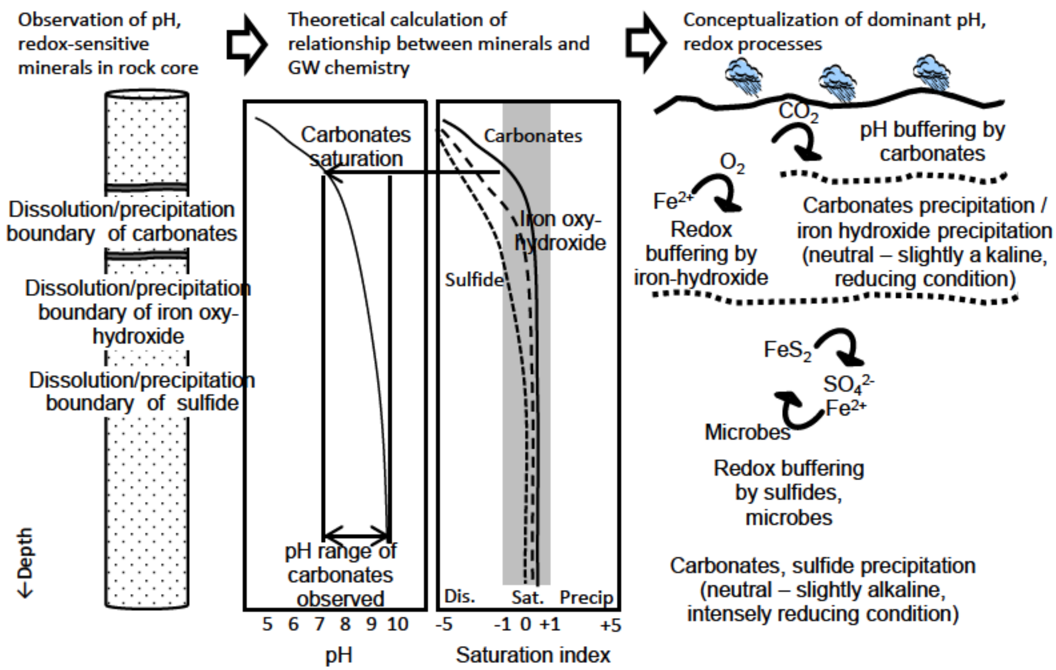
Relationship between mean annual temperature and evapotranspiration in Japan

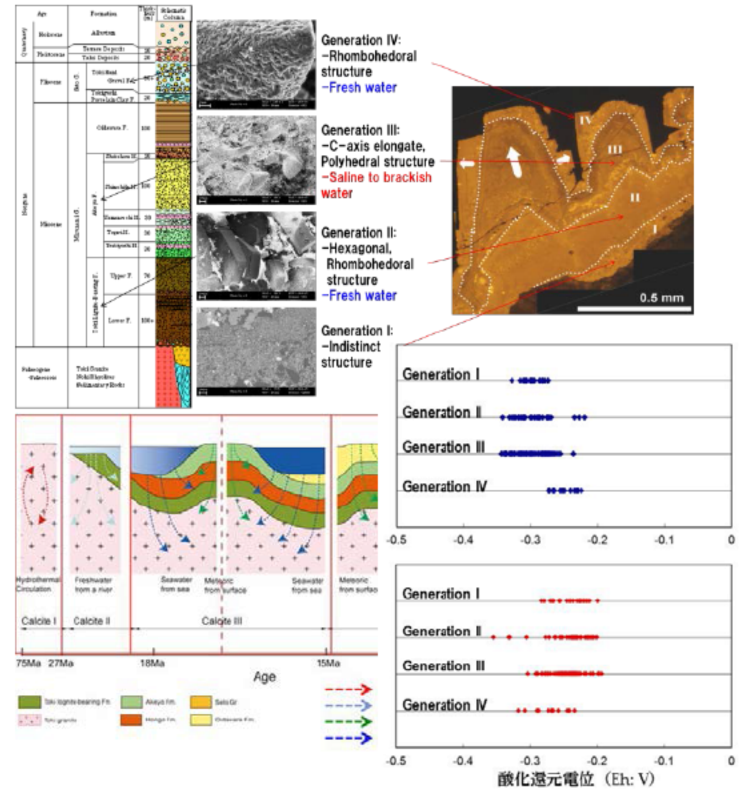


Relationship between latitude and evapotranspiration in Japan

A3) Understanding of long-term evolution/recovery behavior of geological environments

- Techniques to estimate long-term evolution of GW chemistry -

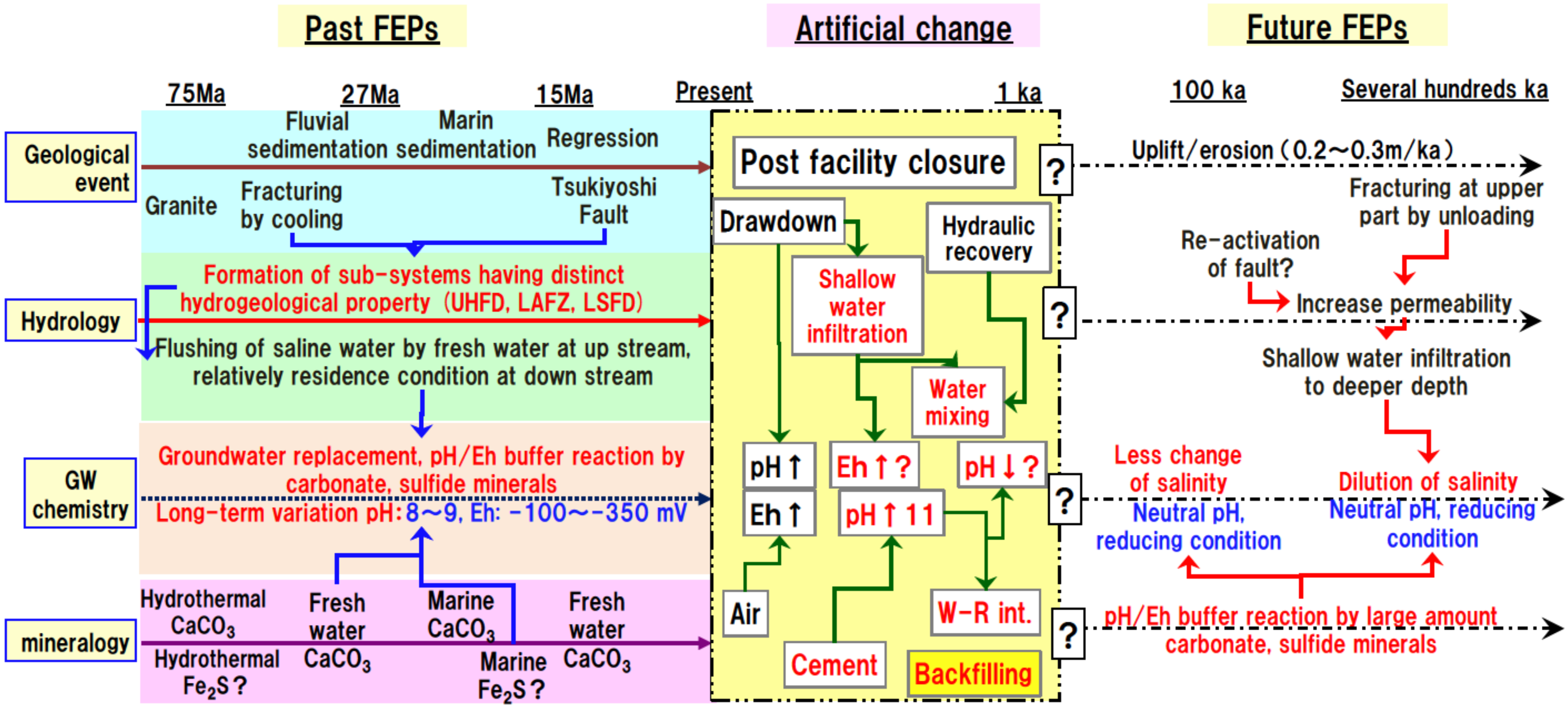




As an example, the long-term "chemically favorable" domain in Japanese geological environment are estimated by morphology, isotopic and chemical characteristics of secondary minerals:

- medium pH : deeper than 200 m in granite / deeper than several tens m in sedimentary rock
- reducing ORP: deeper than 200 m in granite / deeper than 30 m in sedimentary rock

A3) Understanding of long-term evolution/recovery behavior of geological environments
- Next challenge to estimate long-term evolution of geological environment -



- "Scenario" on long-term variation up to present has been inferred by natural FEP analysis.
- Artificial changes (facility impact) such as GW drawdown by facility operation were demonstrated.

Next steps are
- to demonstrate the scenario analysis integrating natural and artificial FEPs as a Japanese example
- to demonstrate the real process and feature (stable condition) after facility closure in Japanese granite (fracture system in Neotectonic zone)

A3) Summary on long-term evolution and recovery behavior of geological environments after facility closure

Technical findings:

- A series of synthesized investigation, analysis and modeling techniques taking into account uplift and subsidence, erosion, sedimentation, climatic perturbation etc. could be developed.
- GW pressure changed immediately after the earthquake, and it recovered within two years. Changes in hydraulic gradient by earthquake was negligible small. The variation of GW chemistry is caused by mixing of existing GW within the chemistry of end-member GWs.
- Long-term pH/redox condition can be estimated by mineralogical methods.
- “Scenario” on long-term natural variation to present was inferred. The demonstrations of short, mid-term artificial change and stabilized condition around the facility after the closure are next issues.

Conclusion and vision for future

A1) Identify the initial condition (for siting) :

- Complete R&D on surface-based investigation by feedback of knowledge on facility closure

A2) Estimate the short-term changing/recovering behavior of environmental conditions (for isolation and final closure) :

- Demonstrate the long-term monitoring techniques and recovering process to the baseline (or stable) condition in intensely impacted environment where large water inflow occurred
- Simulation on environmental changes eg. GW replacement in facility scale (EdZ) and rock mechanical-hydraulic-chemical process in drift scale (EDZ)
- Propose an appropriate drift/facility closure methods, procedures based on the observations in drift closure

A3) Estimate the long-term changing/recovering behavior of environmental conditions (for isolation and additional counterplan) :

- Develop the possible long-term scenarios by integration of FEPs on post facility closure and on geological environment in more longer time scale
- Demonstrate the change of geological environment by earthquake for Public Acceptance

Appendix

Research digest of A1

Aims: Development of generic technique for Surface-based investigation phase: How to identify the favorable* domain for facility construction.

*: good rock condition, hydrogeological structure (low-permeable mass), reducing condition, GW/rock chemistry below the environmental standard, etc.

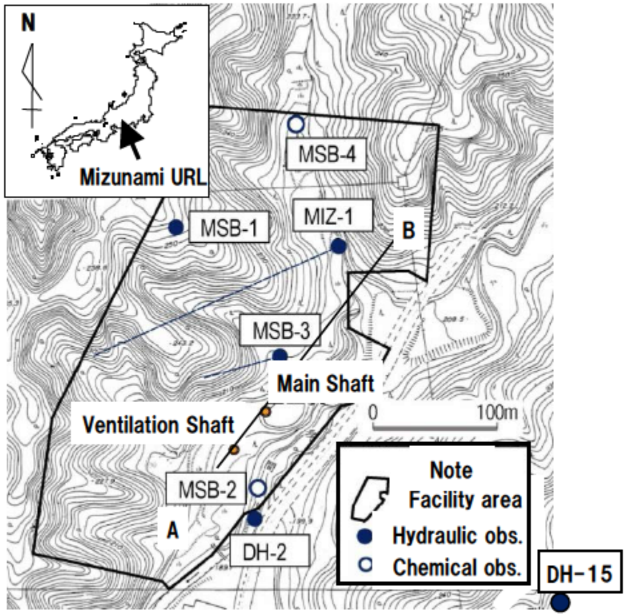
Focused Feature

- Rock mechanical property
- Geological / hydrogeological structure (fault, fracture, permeability…)
- GW chemistry and residence time

Focused Process

- Regional rock stress condition
- Chemical evolution: water-mineral interaction, mixing, redox reaction, fossil water retention, etc.

Event



-Compilation of existing information
-Geological and geophysical surveys
-Borehole investigations including hydraulic tests, groundwater sampling (MSB1～4 to 200 m; MIZ1 to 1200 m).

A1) Summary on surface-based investigation

<u>Methodologies in Surface-based investigation phase:</u>

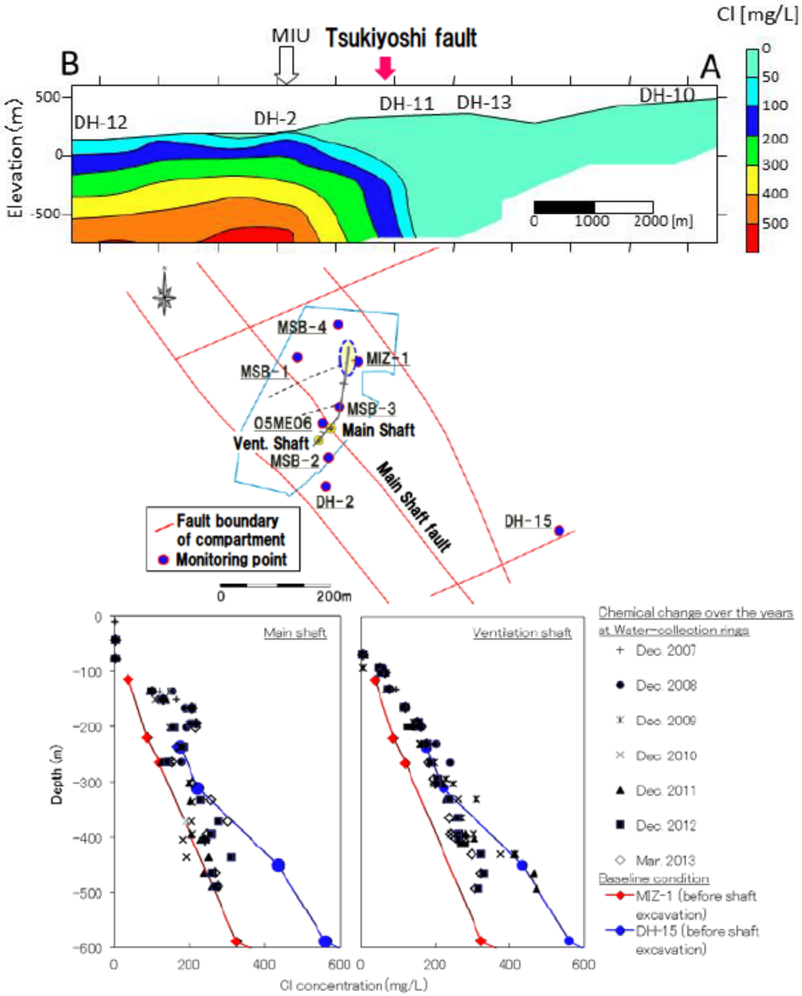
- Estimation of in-situ stress state and rock mass property in facility scale using combination of in-situ and lab. test, and numerical analysis is possible in the Surface-based investigation phase and Construction phase.
- Geological classification taking into account fault distribution and fracture frequency is possible by integrated interpretation of geological mapping, geophysical surveys and borehole investigation data.
- Borehole investigation and monitoring taking hydrogeological structure into consideration are necessary to estimate distribution of GW chemistry.

<u>Technical findings for fractured rock:</u>

- Fluid electrical conductivity logging is capable to detect water conducting feature with a transmissivity two orders of magnitude lower than that detected by flow-meter logging method using impeller or electric-magnetic flow-meter etc.

A1) Understanding of initial condition of geological environments
- Investigation method to understand GW chemistry -

Borehole investigation and monitoring taking hydrogeological structure into consideration are necessary to estimate distribution of GW chemistry in crystalline rock.



● Important features observed

- GW chemistry is different at both sides of fault (eg. Tsukiyoshi Fault).
- The geological structure that can affect the distribution of GW chemistry is conglomerate, fault, unconformity and fractured zone of granite.

● Technical finding

✓ Investigate GW at both sides of the geological structure. Use the borehole as a monitoring borehole. Monitor at the potential permeable zone reach to underground facility.

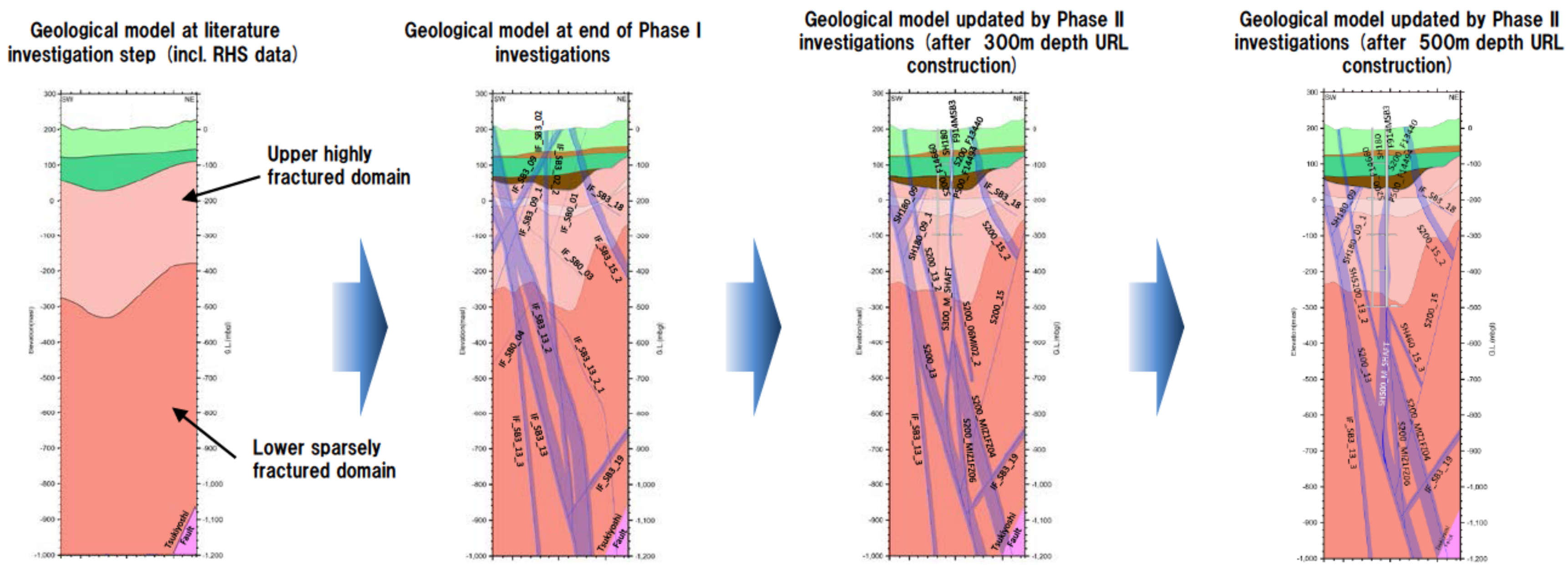
✓ Drill at least one borehole in each hydrogeological compartment and enforcement of a cross-hole hydraulic test with long-term pumping is desirable to infer hydrochemical disturbance during facility construction.

R & D is completed by doing feedback of knowledge relevant to the hydrochemical condition after facility closure into surface-based investigations in future.

A1) Understanding of initial condition of geological environments

-Investigation method to understand geological/hydrogeological structure-

Geological classification taking into account fault distributions and fracture frequency is possible by integrated interpretation of geological mapping, geophysical surveys and borehole investigation data.



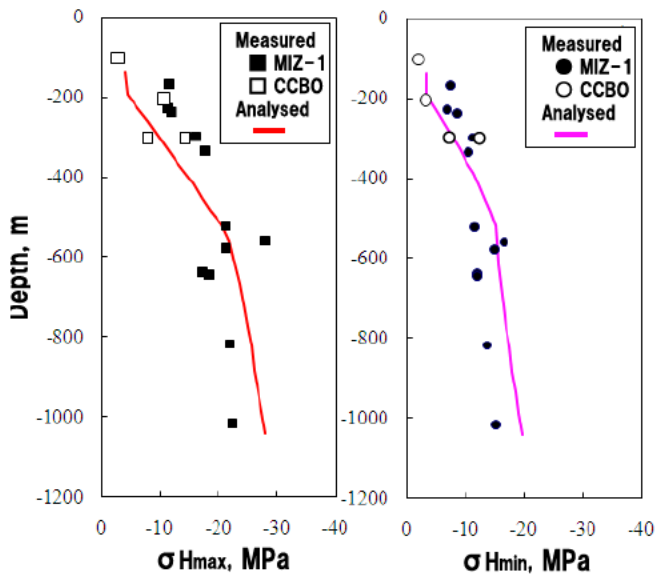
- 3 dimensional distributions of host rock (granite), surrounding sedimentary rocks and faults can be estimated by integrated investigation and interpretation using geological mapping, geophysical surveys and borehole investigation.
- Error of boundary of these fracture frequency domain between phase I and phase II models was less than several meter.

Understanding of heterogeneity and development process of fractures is needed for consideration of panel layout, because the depth of low fracture frequency domain seems to horizontal change.

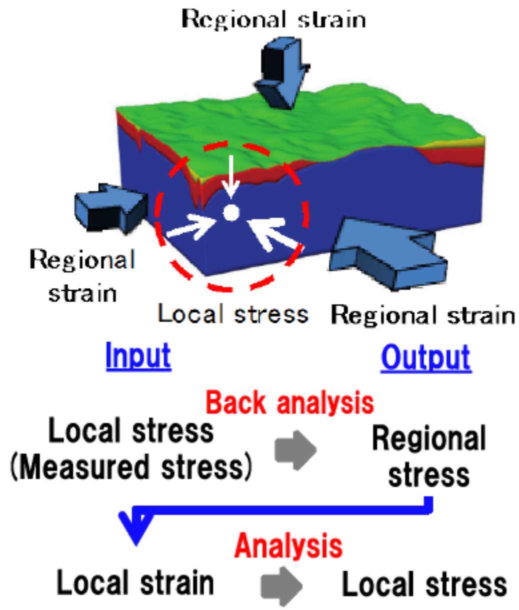
A1) Understanding of initial condition of geological environments

- Investigation method to understand rock mechanical property -

Estimation of in-situ stress state and rock mass property in facility scale using combination of in-situ and lab. test, and numerical analysis is possible in the Surface-based investigation phase and Facility construction phase.



Comparison of measured and analyzed stress



Estimation of regional stress

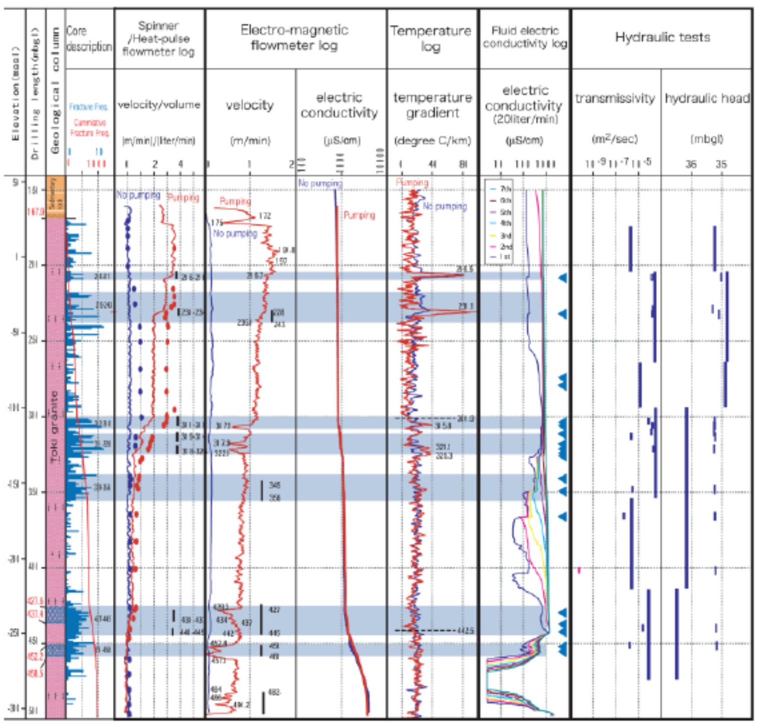
- It is possible to estimate deep underground in-situ stress state using hydraulic fracturing test and core method (DSCA etc.) for design underground facility and assessment of EDZ.
- It is important to estimate re-opening pressure using high compliance system of hydraulic fracturing test.
- Estimation of regional stress using back analysis based on three-dimensional finite element analys is and the boundary element method were developed.

Accumulation of information for knowledge of in-situ stress and property of rock mass would be arranged for design of disposal facility in the detailed investigations by NUMO.

A1) Understanding of initial condition of geological environments

-Investigation method to understand spatial variability of GW flux-

Fluid electrical conductivity logging is capable to detect water conducting feature with a transmissivity two orders of magnitude lower than that detected by flow-meter logging method using impeller or electric-magnetic flow-meter etc.



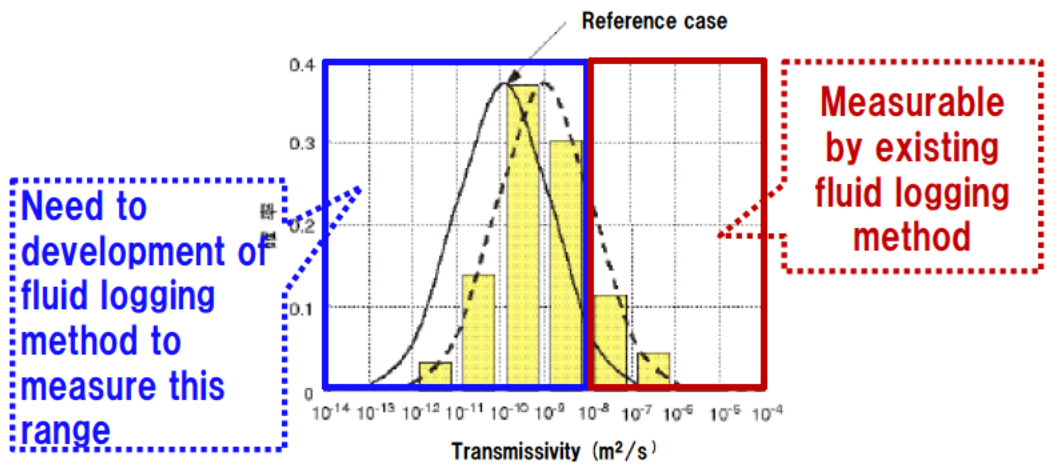
Results of fluid logging and hydraulic test in 500m borehole

● Technical finding

It was confirmed that water conducting features with a transmissivity higher than 10^{-8} – 10^{-9} m^2/s could be detected by the fluid electrical conductivity logging.

● Remaining issue

Development of effective investigation technique for data acquisition of fracture with a wide range of hydraulic characteristics in a continuous manner.

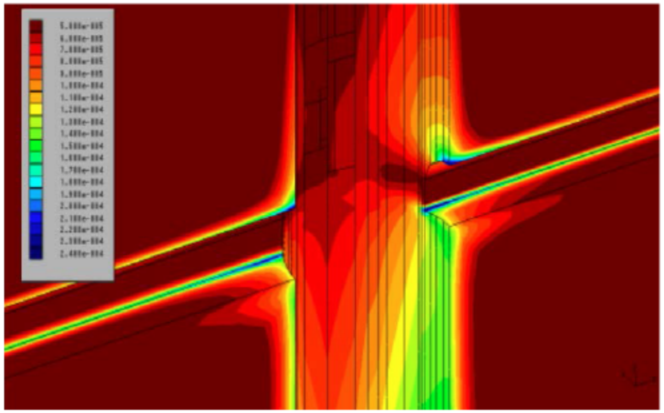


Development of effective investigation technique for data acquisition of fracture with a wide range of hydraulic characteristics in a continuous manner will be done in A2 and feed backed to A1.

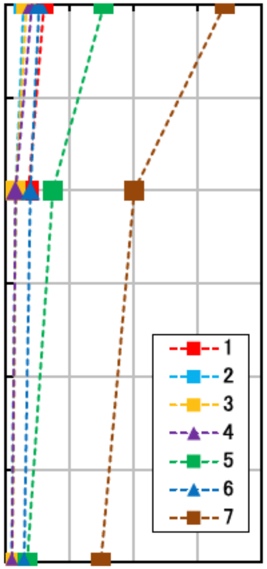
A1) Understanding of initial state of geological environment
- Technology for design and construction planning of underground facility-

Confirmation of effectiveness of technology for feedback system and earthquake-resistance design

(1) Mechanical stability, support design
(2) Feedback of measurement results to next excavation
(3) Earthquake-resistance design



Result of 3D FEM (Distribution of max. shear strain)



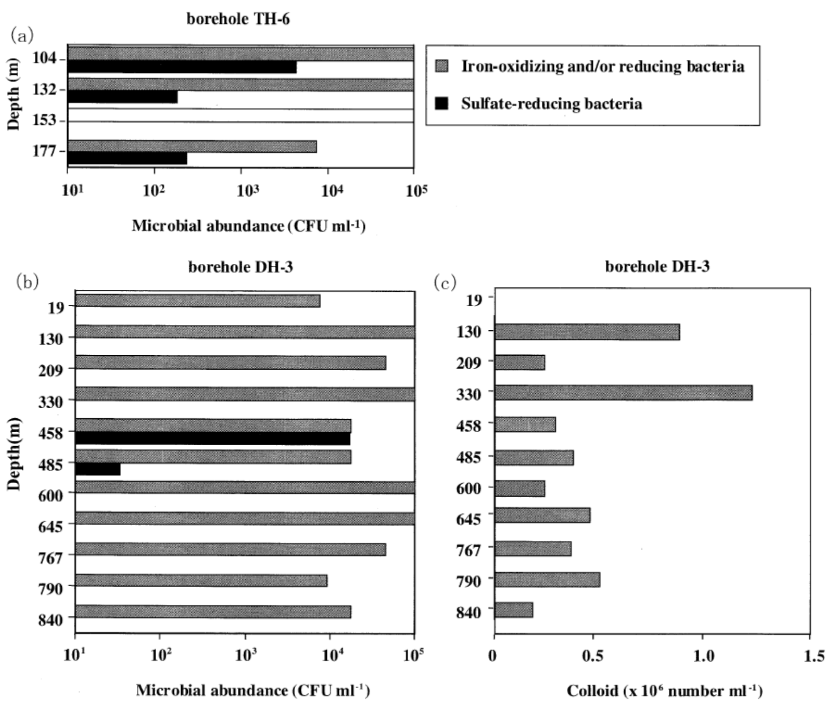
Max. acceleration of earthquake

- Support system design depending on rock mass classification was checked based on 2D and 3D FEM analysis.
- Seismic wave assumed historical earthquake, active fault and Tokai-Tonankai Consolidated Type Earthquake was calculated. Allowable stress of lining concrete was more than the stress due to these waves.

Demonstration of technology for designing of disposal facility

A1) Understanding of initial state of geological environment
- Characterization methodology for the colloid/organics/microbe in GW-

Understanding microbial community in GW



(Murakami, 2003)

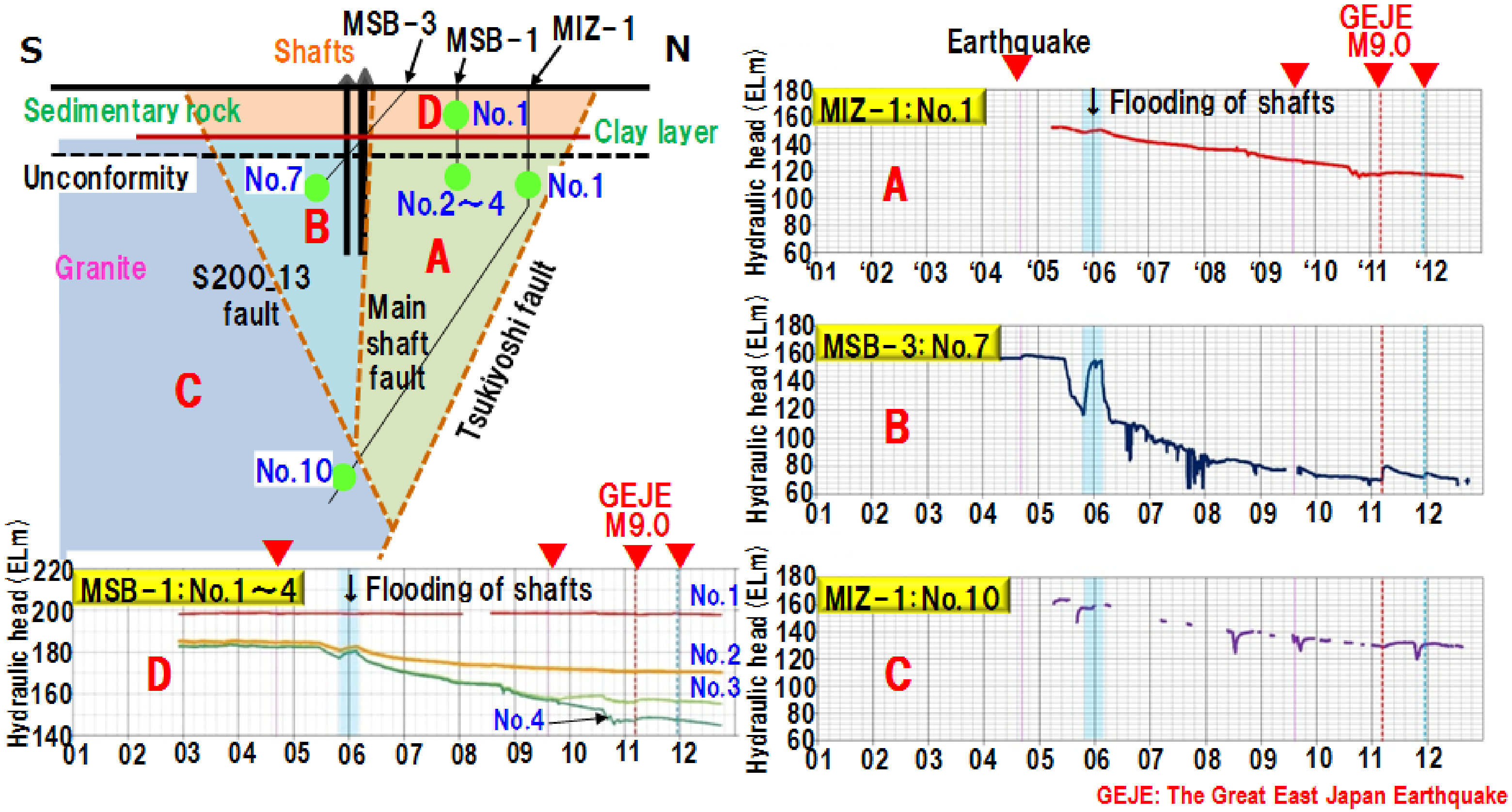
- Existence of sulfate-reducing bacteria and iron-relating bacteria in the granitic GW
- Microbial population could be related to the geochemical environment

Accumulation of data and evaluation of the effect on solute transport

A2) Understanding of short-term evolution/recovery behavior of geological environments

- Development of method to monitor impact on GW table and pressure -

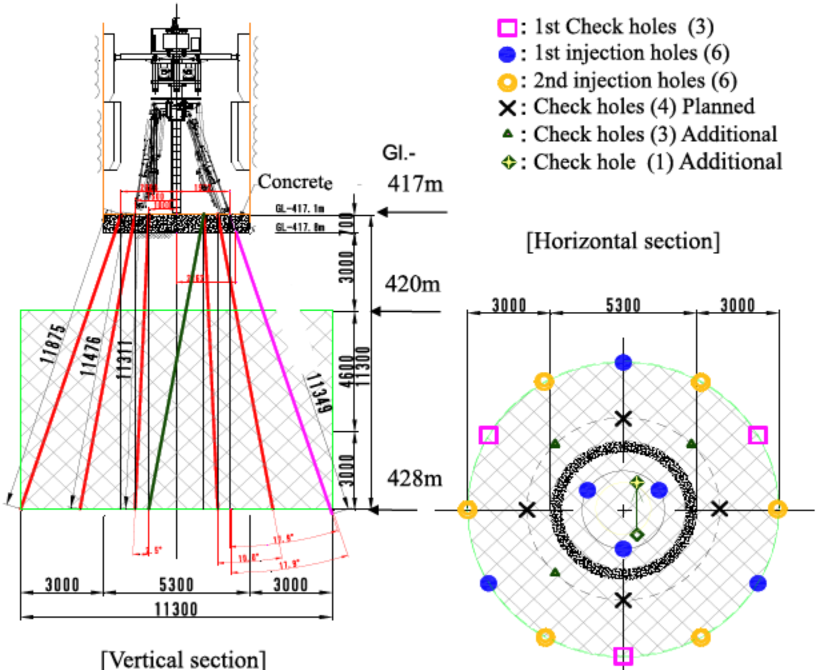
Assignment of monitoring intervals taking into account hydrogeological heterogeneity including hydrogeological compartment is essential to estimate the hydraulic characteristics



Hydraulic monitoring during MIU construction

- Hydraulic responses differ with each hydraulic compartment which are formed with low permeability structures.

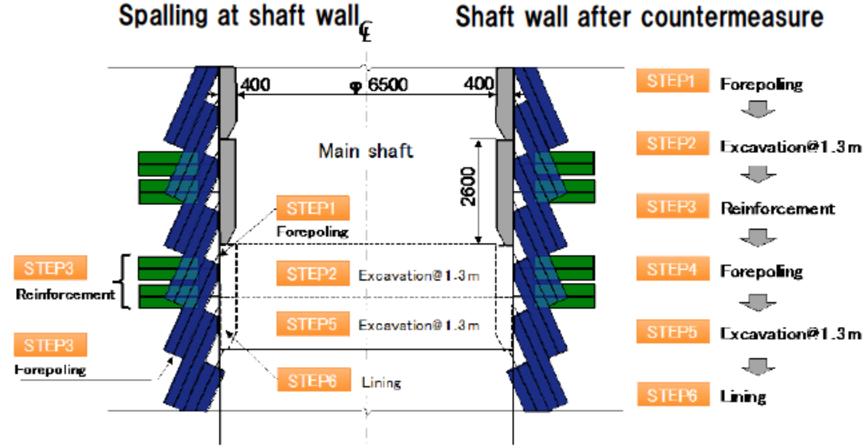
Confirmation of effectiveness of countermeasure technology for water inflow (grouting) and spalling during excavation



Layout of grouting injection holes at Ventilation shaft

Spalling at shaft wall

Shaft wall after countermeasure

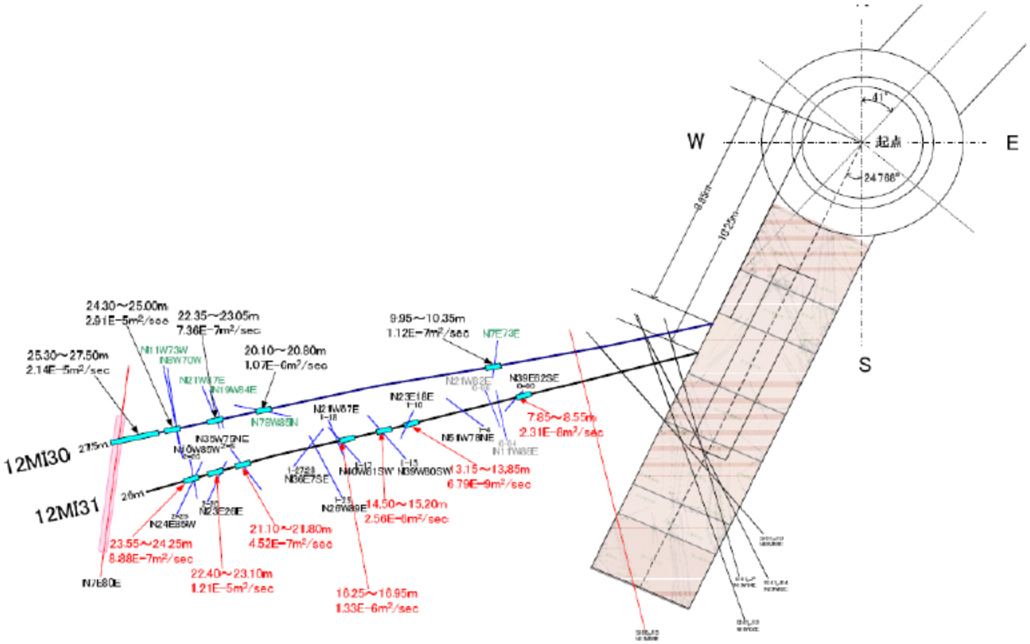


Layout of countermeasure for spalling at shaft wall

- All the Lugeon values at the check holes and 2nd injection holes were below 2 Lugeon at the GL.-400m. The results showed that pre-excavation grouting attained the target hydraulic conductivity.
- Applicability of countermeasure for spalling at shaft wall was tested.

Demonstration of countermeasure technology for water inflow during construction and operation of disposal facility

Equipment and procedure for the in-situ experiment have been developed and applied.



Borehole investigation for geological/hydrogeological characterization

Newly developed tracer test equipment (Packer-combined type)

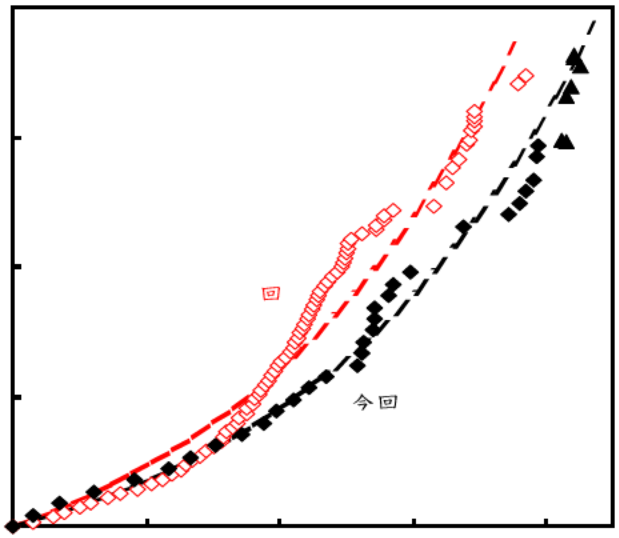
- Newly developed equipment has been applied.
- Geological and hydrogeological characterization has been started to evaluate the fracture distribution and connectivity.

Application of the equipment/procedure and improvement

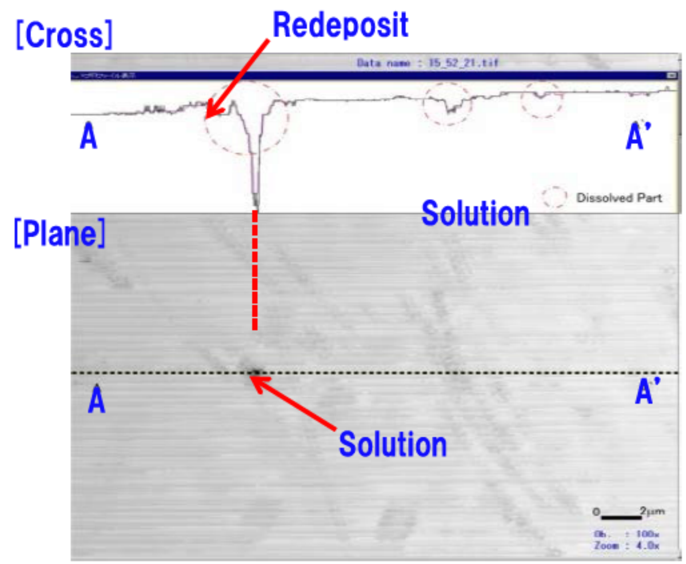
A3) Understanding of long-term evolution/recovery behavior of geological environments

- Techniques to estimate long-term evolution of rock mechanical property -

Estimation of rock mass behavior in long-term intended implementation of disposal



Long-term creep test of Tuff.



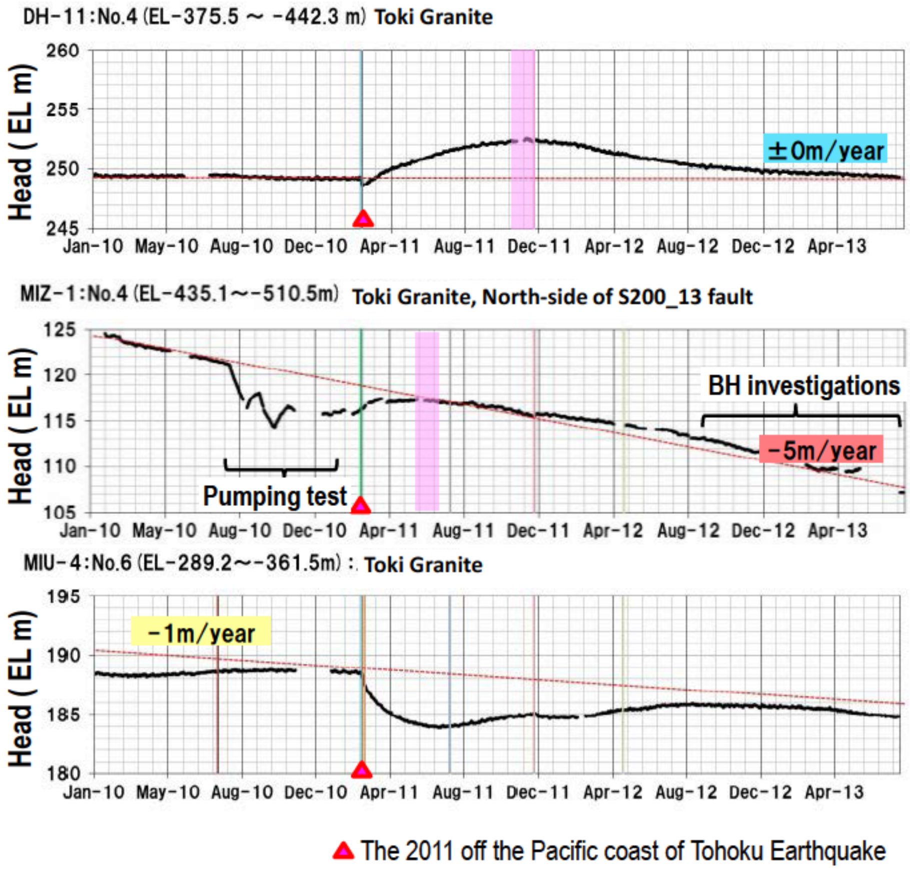
Pressure solution test of quartz

- Long-term creep test over 10 years for Tuff has been performed. Basic information for estimation of long-term rock mass behavior by numerical analysis has been obtained.
- Estimation of micro crack propagation based on the results of unconfined compressive test, microscope observation and chemical analysis for understanding of pressure solution of quartz have been performed.
- Prediction of long-term behavior of EDZ in Toki granite.

A3) Understanding of long-term evolution/recovery behavior of geological environments

- Techniques to estimate long-term evolution of spatial variability of GW flux -

GW pressure changed immediately after the earthquake, and it recovered within two years. Changes in hydraulic gradient by earthquake was negligible small. The variation of GW chemistry is caused by mixing of existing GWs and is within the chemistry of end-member GWs.



GW pressure monitoring data

- GW pressure changed shortly after the earthquake were caused by volumetric strain induced by the earthquake.
- Changes in the vertical and horizontal hydraulic gradient after the earthquake was negligible small.
- Different trends of changes in GW pressure indicate that faults are likely boundaries of GW flow zone.
- The changes of GW chemistry resulting from earthquake are stabilizing in several months after earthquake. It occurs by the change of mixing ratio among chemically-distinct waters.

It is required to understand detail process and accumulate the observation of hydraulic and hydrochemical change induced by earthquake by long-term monitoring.