Overview of R&D Activities at the Horonobe Underground Research Laboratory from FY2020

- Research Plans for the Next 9 Years -

2012年10月撮影

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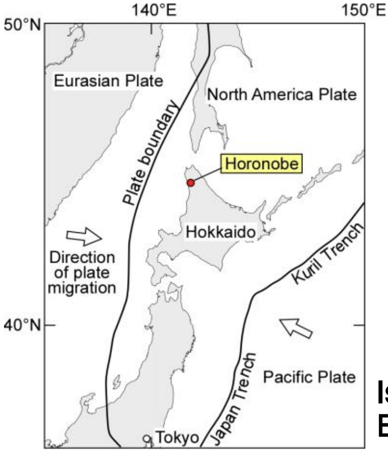
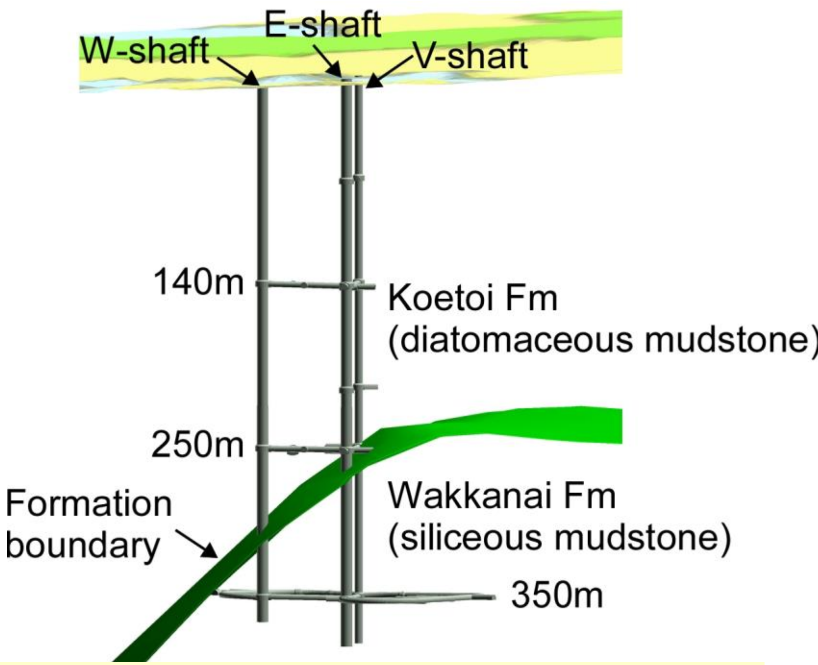
Recent R & D (FY2015-2019)



Ishii, E. (2015) JGR: Solid Earth120:2220-2241.



- Neogene argillaceous marine sedimentary rocks (Koetoi and Wakkanai Formations)
- Soft rock
- Saline groundwater with dissolved CH_4

Demonstration of EBS in geological environment

- ✓ Full-scale EBS (H12-V concept: vertical emplacement) test
- ✓ Overpack corrosion test
- ✓ In-situ mass transport test

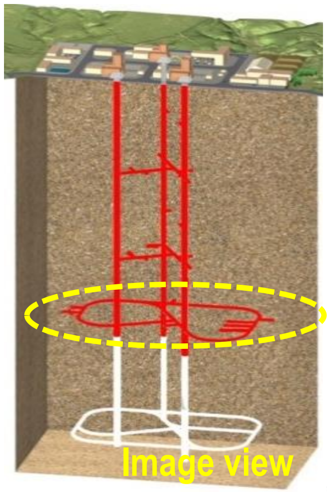
Demonstration of disposal concept

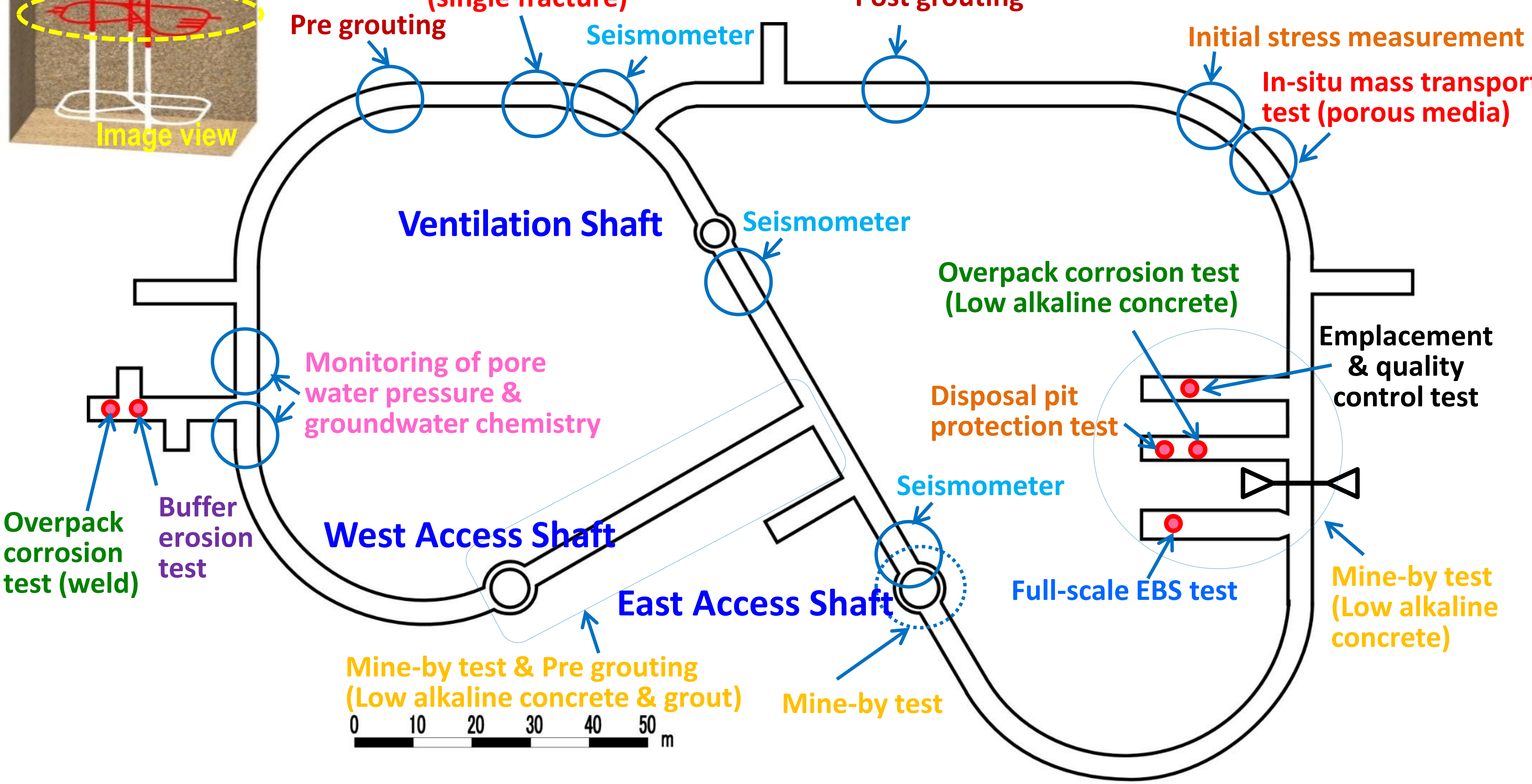
- ✓ Disposal pit protection test
- ✓ Emplacement & quality control test
- ✓ Higher temperature condition (e.g. >100 ˚C) test

Validation of buffer capacity of the sedimentary rock to tectonism

- ✓ Buffering capacity test
- ✓ Influence on EBS test

Field experiments (FY2015-2019)



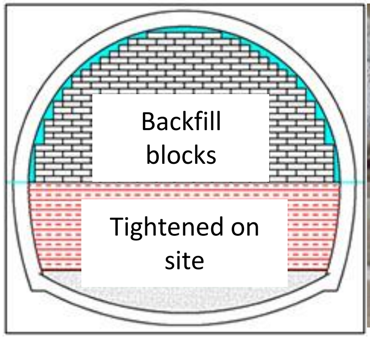


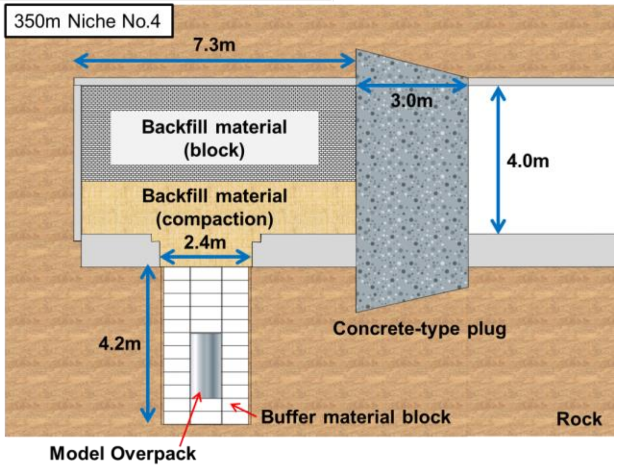
Full-scale EBS test

- Full-Scale EBS composed of overpack, buffer material was installed in a test pit and backfilled with the mixture of bentonite and excavated muck. Finally, the experimental area was isolated with a concrete plug.
- THMC behavior in and around the EBS were measured using monitoring sensors installed in the buffer material, backfill material and rock mass. The monitoring data was compared with the results of analysis by coupled THMC model.

【Outcome】

- Applicability of design technology, manufacturing / construction technology and quality control based on H12 report were evaluated for…
  - the engineered barrier (overpack/buffer material)
  - the closure technology (backfill material/plug)
- Observed near-field coupled THMC data and applicability evaluation of THM model of heating phase

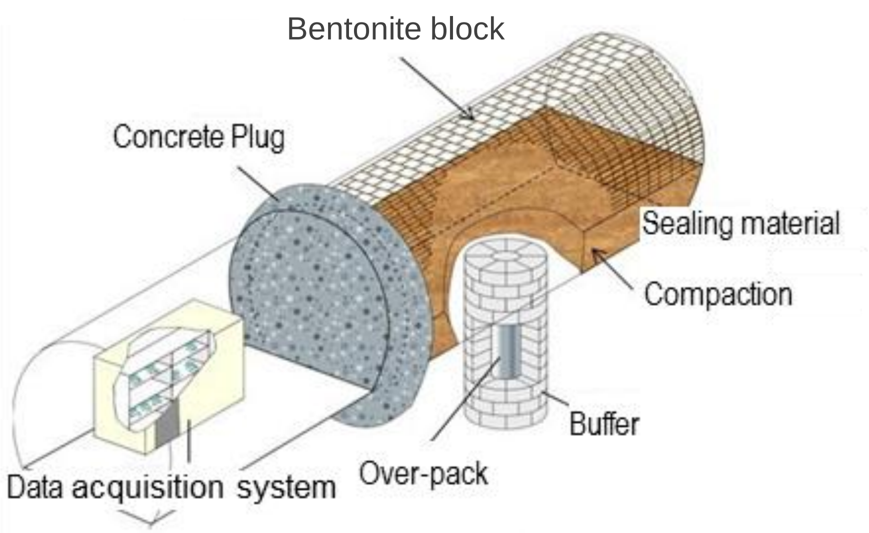




Full-scale EBS test

【Next】

- Obtaining verification data such as saturation through heat reduction tests and dismantling surveys, and confirming applicability of coupled THMC models
- Comparative verification, improvement and sophistication of simulation codes in international projects (**DECOVALEX-2023 Task D**, etc.)



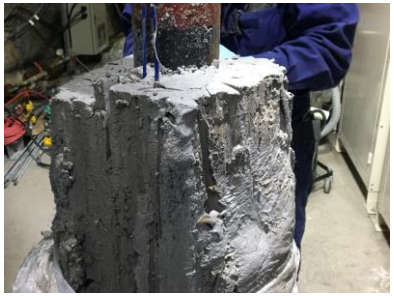


Image of dismantling investigation of EBS

Prior to dismantling the full-scale EBS, a trial of dismantling using a half-scale experimental EBS is planned.

Mass transport test

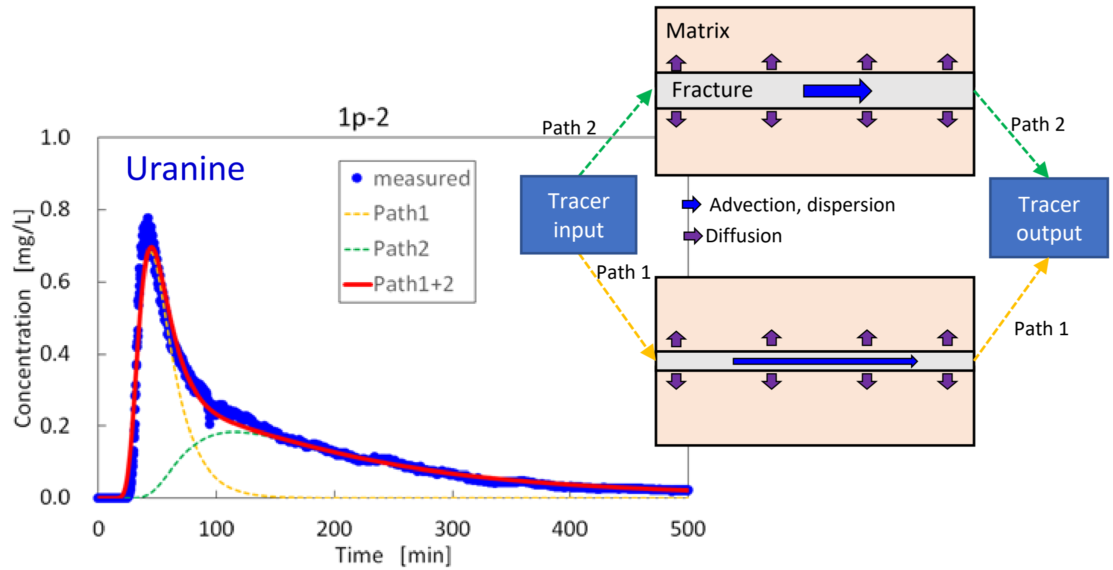
The tracer tests for intact rock and fracture were conducted to establish the concept of mass transport in the sedimentary rocks.

【Outcome】

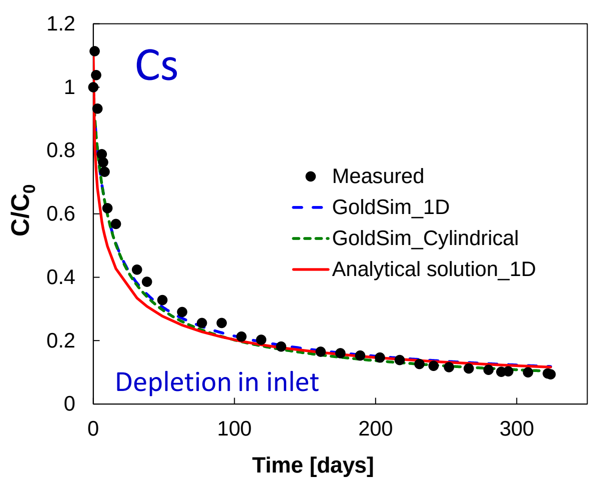
The tracer test methods were established for sedimentary rocks.

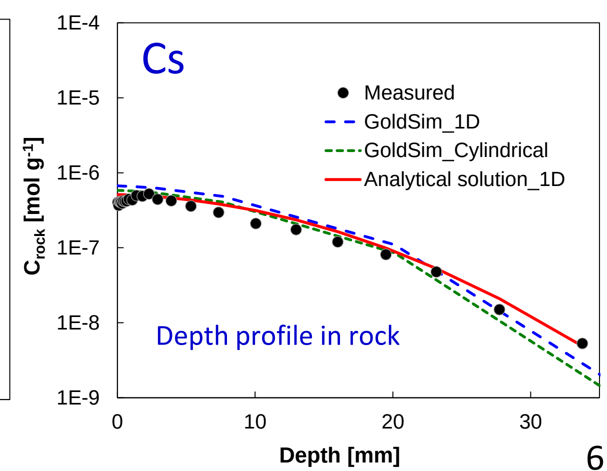
- It was confirmed that the 1-D analysis methods is possible to evaluate the mass transport parameters (i.e. dispersivity).
- Diffusion and sorption model, have been examined based on laboratory tests, is applicable to evaluate De and Kd for some tracers (i.e. Cs) *in-situ* condition.

In-situ dipole test (for fracture)

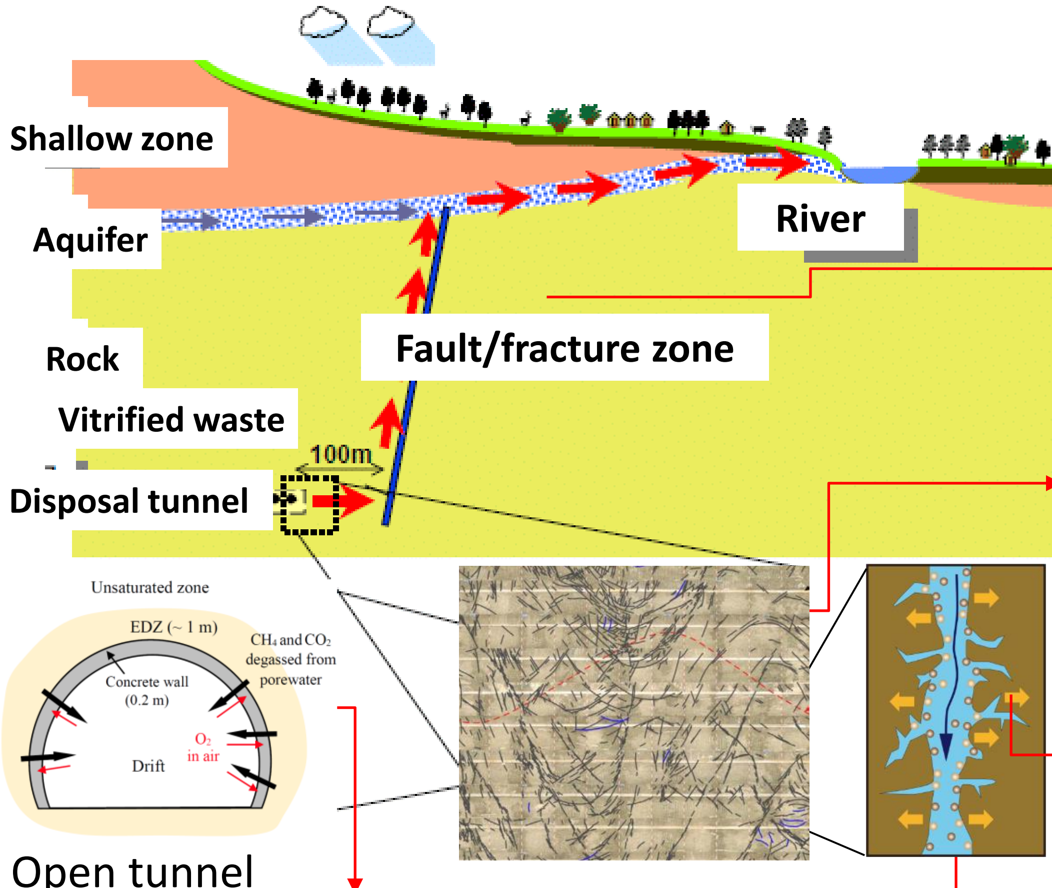


In-situ diffusion test (for matrix)





Mass transport in sedimentary rock



1) The fault/fracture connectivity in the deep part (ca. > 400 m) is limited.

2) The matrix diffusion could be predominant, and De and Kd obtained in lab. scale could be applicable to in situ scale.

3) The analogue elements have been preserved in matrix and faults.

4) There are many types of colloids in groundwater.

5) Neutral pH and reducing conditions are maintained around the tunnel.

Further understanding and modeling of mass transport from the near to far field is needed.

Demonstration of repository design options

ー Demonstration of remote emplacement and retrievable technology test ー

The machines and remote techniques were developed and demonstrated to improve the safety and efficiency of the operation.

【Outcome】

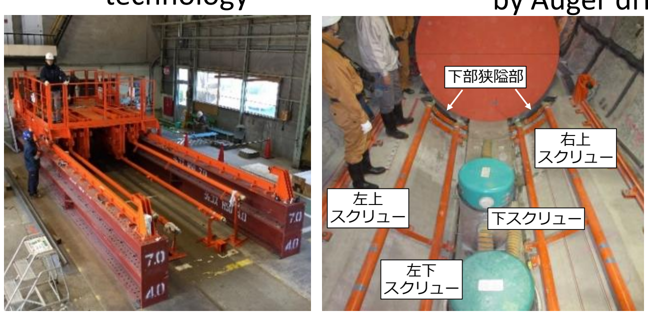
Following techniques were demonstrated;

- Excavation of disposal pit by the combination of casing and auger method
- Emplacement of buffer material for vertical system using vacuum holding device
- Emplacement of PEM by air bearing method and removal of buffer material by water jet and auger drilling for horizontal system
- Wireless transmission in bedrock of several meters for Full-scale EBS test

Buffer material removal technology

Removal of gap filling material by Auger drilling

Water jet removal test



Construction of backfill material by screw method

Notch drilling and plug construction

Demonstration of repository design options

ー Demonstration of remote emplacement ー

[The original version of this slide contains a video that shows the site activities of the remote emplacement experiment.]

Demonstration of repository design options

ーDemonstration of retrievable technologyー

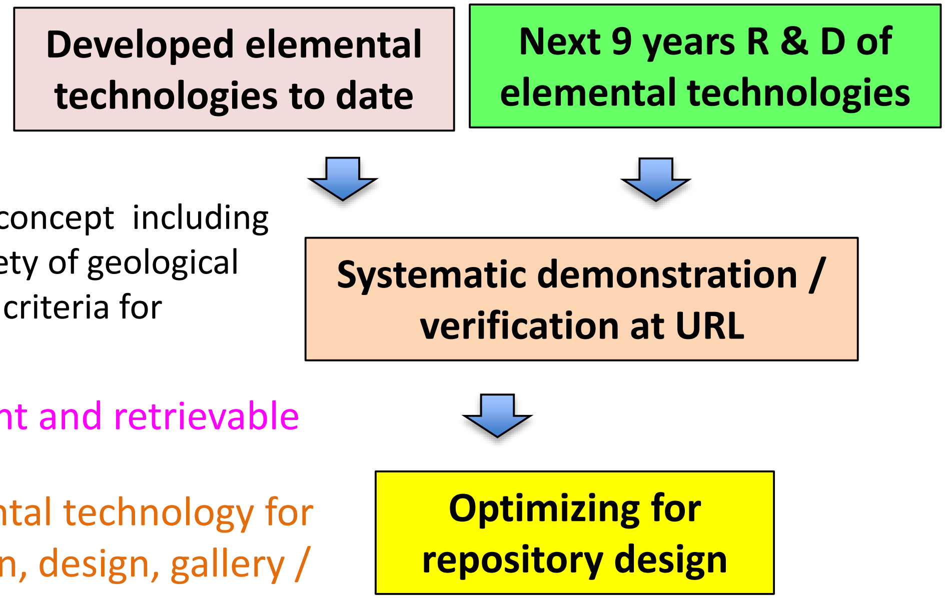
[The original version of this slide contains a video that shows the site activities of the retrievable technology experiment.]

R & D plan (FY2020 – 2028)

1. Demonstration of EBS in geological environment

[Outline] Development of measurement and evaluation of T-H-M-C coupled behavior of EBS and mass transport in the EDZ and geological environment

- Full-scale EBS experiment (dismantling)
- Mass transport experiment



2. Demonstration of disposal concept

[Outline] Demonstration of engineering feasibility of disposal concept including emplacement, retrievable and closure techniques for a variety of geological environment. Demonstration of systemized techniques and criteria for determining disposal EBS setting and its interval.

- Demonstration of remote technique for emplacement and retrievable
- EBS behaviour over 100 degree C (overseas project)
- Systematic demonstration and verification of elemental technology for optimization of repository design (set of investigation, design, gallery / pit construction)

3. Validation of buffer capacity of the sedimentary rock to tectonism

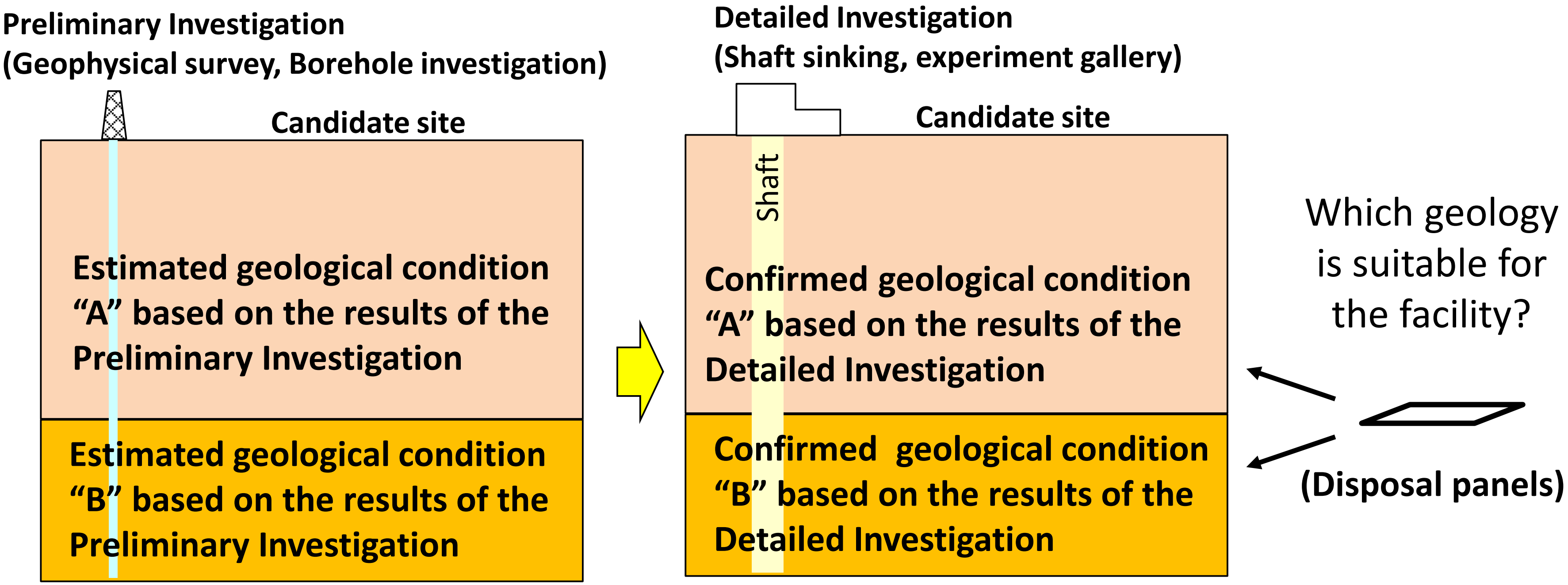
[Outline] Validation of hydro-mechanical stability against geological events. Measure to evaluate the groundwater retention area in order to select the site and repository design more scientific and rational.

- H-M buffering against long-term geological events such as fault reactivation / up-lift
- Self sealing behavior of EDZ around EBS after backfilling
- Evaluation techniques for groundwater retention area

Consideration of R&D on "Systematic demonstration/verification of elemental technology for optimizing repository design"

【Background】

- The geological condition is characterized by the **Preliminary Investigation** (borehole investigation, etc.), after the candidate site is selected.
- The estimated geological condition is confirmed by the **Detailed Investigation** (shaft sinking, experiment gallery, etc.).
- These investigations will be phased to select the suitable location for the repository (disposal panel).



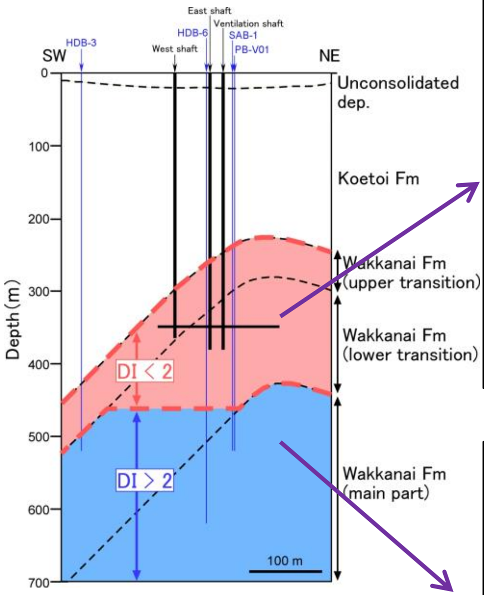
Consideration of R&D on "Systematic demonstration/verification of elemental technology for optimizing repository design"

View points to select preferable geological condition for the facility;

	Near field	Far field
View points	<u>**Mechanical stability**</u> - Strength of the rock mass - Principal Stress (anisotropy) - Fracture (size, density, distribution) - Fault (width, inclusion, seepage) <u>**Feasibility**</u> - Seepage (temporary/permanent) - Grout (material, injection volume and region) - Support (material, thickness) - Cost (Construction, operation, closure) <u>**Isolation**</u> - Critical path EDZ- (Fracture-Fault-Surface)	<u>**Isolation**</u> - Hydraulic connectivity Fracture (size, aperture) Fault (size, aperture) - Critical path (EDZ-) Fracture-Fault-Surface <u>**Geological stability**</u> - Uniformity - Thickness - Groundwater retention (fresh/saline) - Buffer/Recovery (reducing condition) etc. (H12 Report, JAEA)

Geological conditions of each domain in Horonobe URL

Water conducting features (= faults)

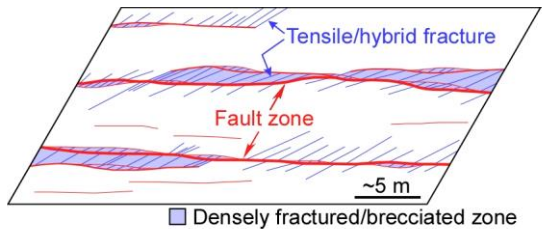


Geological section

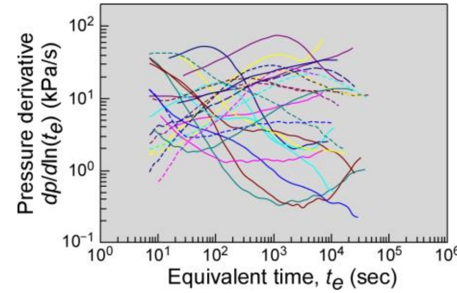
Wakkanai Fm is mechanically divided into two domain; the shallow domain preferable to tensile failure (DI<2) and the deep domain suitable to shear failure (DI>2)

Ductility Index (DI)
= Effective mean stress / Tensile strength

Shallow domain (DI < 2)



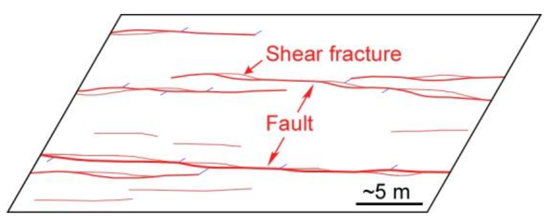
Fault connectivity based on outcrop & borehole data



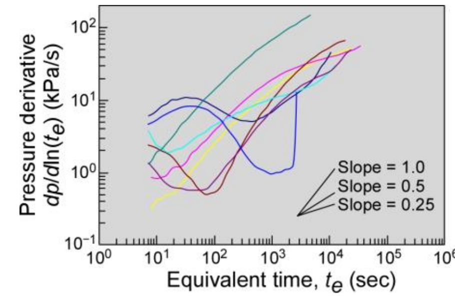
Pressure derivatives from packer tests for faults

- Faults are hydraulically connected by numerous dilational fractures along the faults.
- Derivatives during the hydraulic test indicate 2D to 3D flow, suggesting the faults are hydraulically connected.

Deep domain (DI > 2)



Fault connectivity inferred from borehole data

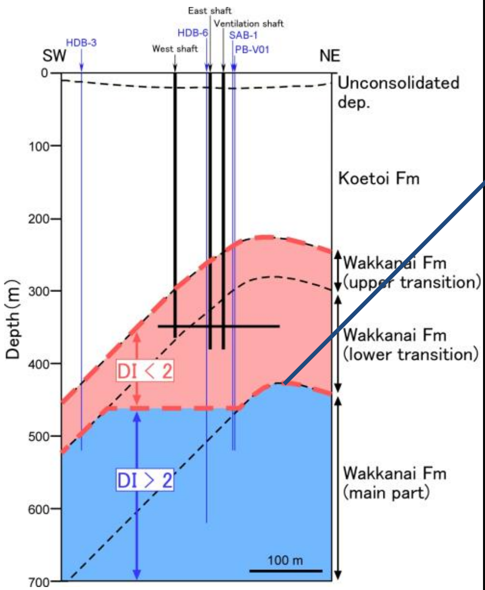


Pressure derivatives from packer tests for faults

- Faults are estimated to be hydraulically less connected by a few dilational fractures along the faults.
- Derivatives during the hydraulic test indicate 1D flow to no flow, suggesting the hydraulic connectivity of faults is limited.

Geological conditions of each domain in Horonobe URL

Water pressure and chemistry



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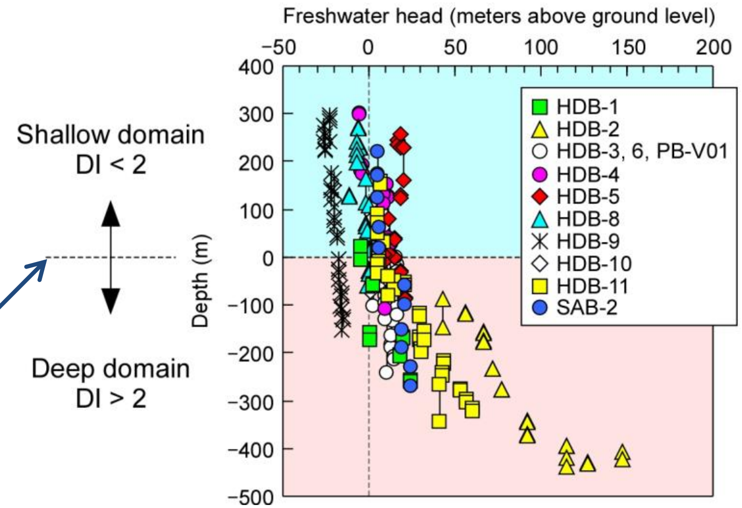
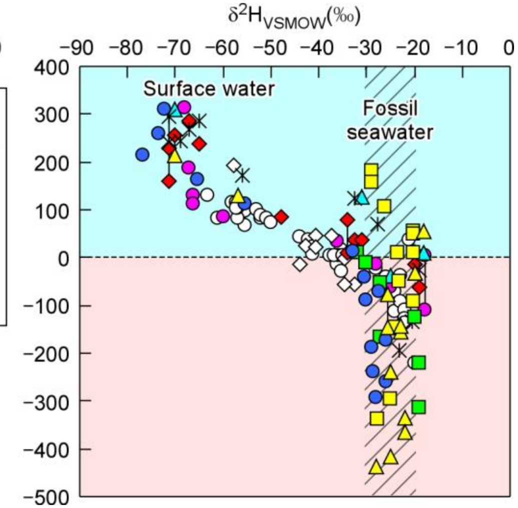


Freshwater head from long-term monitoring and packer tests



Stable isotope composition of groundwater/porewater

Shallow domain (DI < 2)

- Water pressure: Generally hydrostatic
- Water chemistry: Young surface water (^{14}C contains) mix to fossil seawater to depths of hundreds meters
- Flow system: Advection-dominant through fault network

Deep domain (DI > 2)

- Water pressure: Increasing with depth, indicating low effective *K*
- Water chemistry: Fossil seawater that has reached isotope equilibrium with the surrounding rock (clay/silica minerals) without mixing with young surface water; ^{36}Cl and ^{4}He age >1 Ma
- Flow system: Hydraulically closed due to the limited fault connectivity

Systematic demonstration/verification of elemental technology for optimization of underground facility design taking Horonobe URL as an example

	Wakkanai Formation (Shallow domain)	Wakkanai Formation (Deep domain)
Estimation based on the Preliminary Investigation	Engineering countermeasures are required for; - Fracturing structure - Possible hydraulic connectivity - Continuous seepage during and after gallery excavation (grouting all over gallery)	Engineering countermeasures are expected to be less. - Hydraulic isolation - Limited seepage during only gallery excavation (non-grout)
Confirmation based on the Detailed Investigation	Done at 350m gallery Estimation by Preliminary Investigation was verified.	Not yet
R & D of the elemental technology	Done at 350m gallery Design and construction of gallery Grouting technology Characterization of the EDZ (mechanical, hydraulic) Characterization of the principal stress etc.	Only preliminary design of gallery was done.
Optimizing underground facility design	Not yet	Not yet

The Horonobe URL has a large advantage in optimizing underground facility design in the Wakkanai formation (both shallow and deep domains).

Systematic demonstration/verification of elemental technology for optimization of repository design taking Horonobe URL as an example

【Subject】

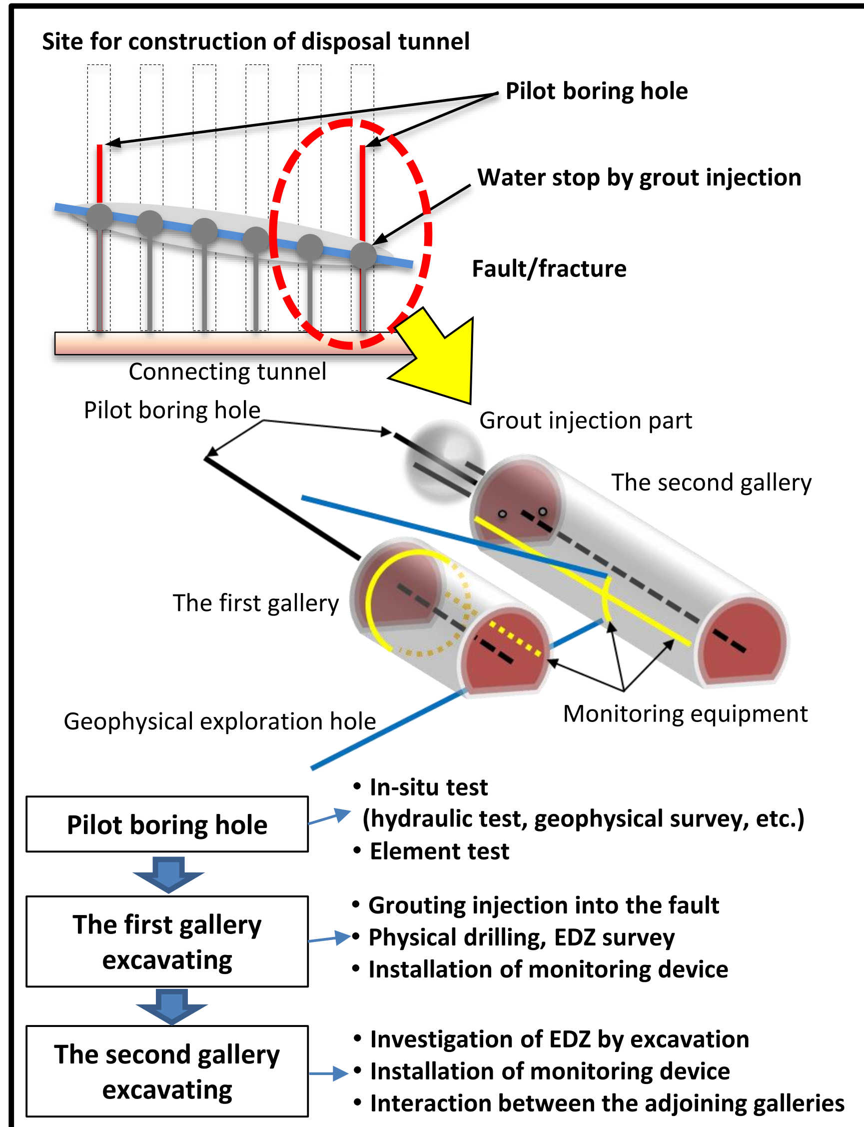
Systematic examination of the elemental technologies such as the geological surveys and tunnel layout design for disposal panel including excavation of the disposal pit (distance between disposal tunnels, waste package pitch, etc.).

【Work】

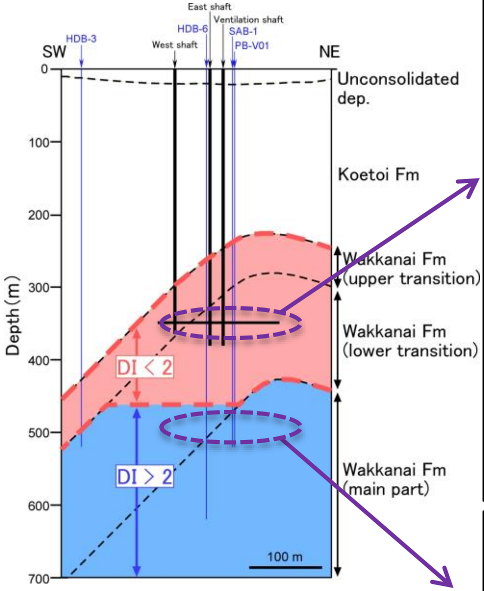
- ➢ Demonstration of the techniques concerning the multiple parallel galleries design and layout considering the hydrogeological and mechanical condition
- ➢ Evaluation of the buffer material loss by groundwater flow and the mass transport
- ➢ Evaluation of the process and post-closure initial condition if the repository maintained a retrievability

Discussion : What is the favorable geological condition for these R&D?

Shallow or deep domain?



From the R & D perspective of elemental technology...



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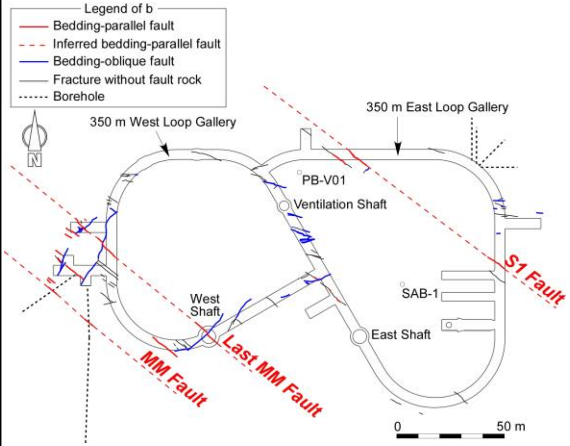
Shallow domain

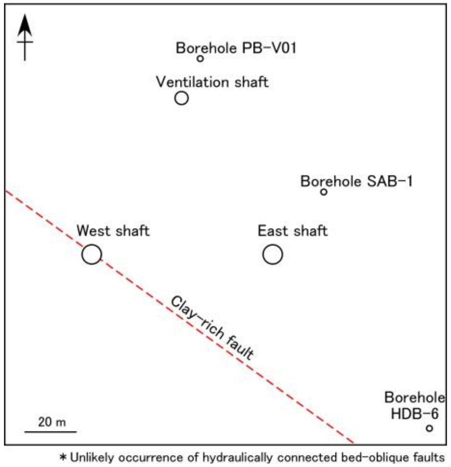


Occurrence of faults at 350 m level

- Mass transport in the area where fractures are connected over hundreds meters (**severe geological feature case**).
- Dismantling the current EBS
- Demonstration of robotic systems for remote operation
- Evaluation of an initial environments if repository maintained for retrievability

Longer research period

Deep domain



Occurrence of fault at 500 m level

- Mass transport in regions where small-scale faults exist, but with limited hydraulic connectivity and relatively closed migration paths (**preferable geological feature case**).
- Demonstrate the construction technology of a repository tunnel for sedimentary rocks under higher rock stress
- Differences in geological characteristics and engineering know-how can be compared between two depths.

Shorter research period

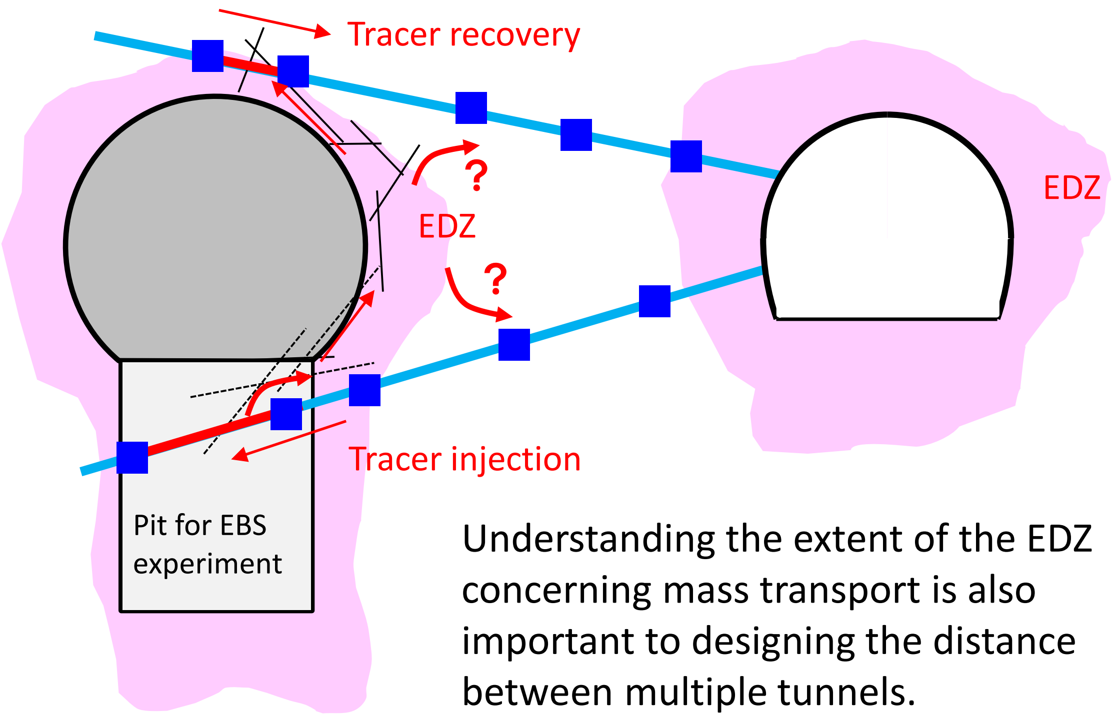
Mass transport experiment

【Background】

POSIVA safety case, STUK requirement: Transport properties in EDZ; verification of DFN model, based on the information from tunnels and by comparing the hydrogeological model with alternative modelling methods involving depth-dependent channeling within fractures.

【Aim and Work】

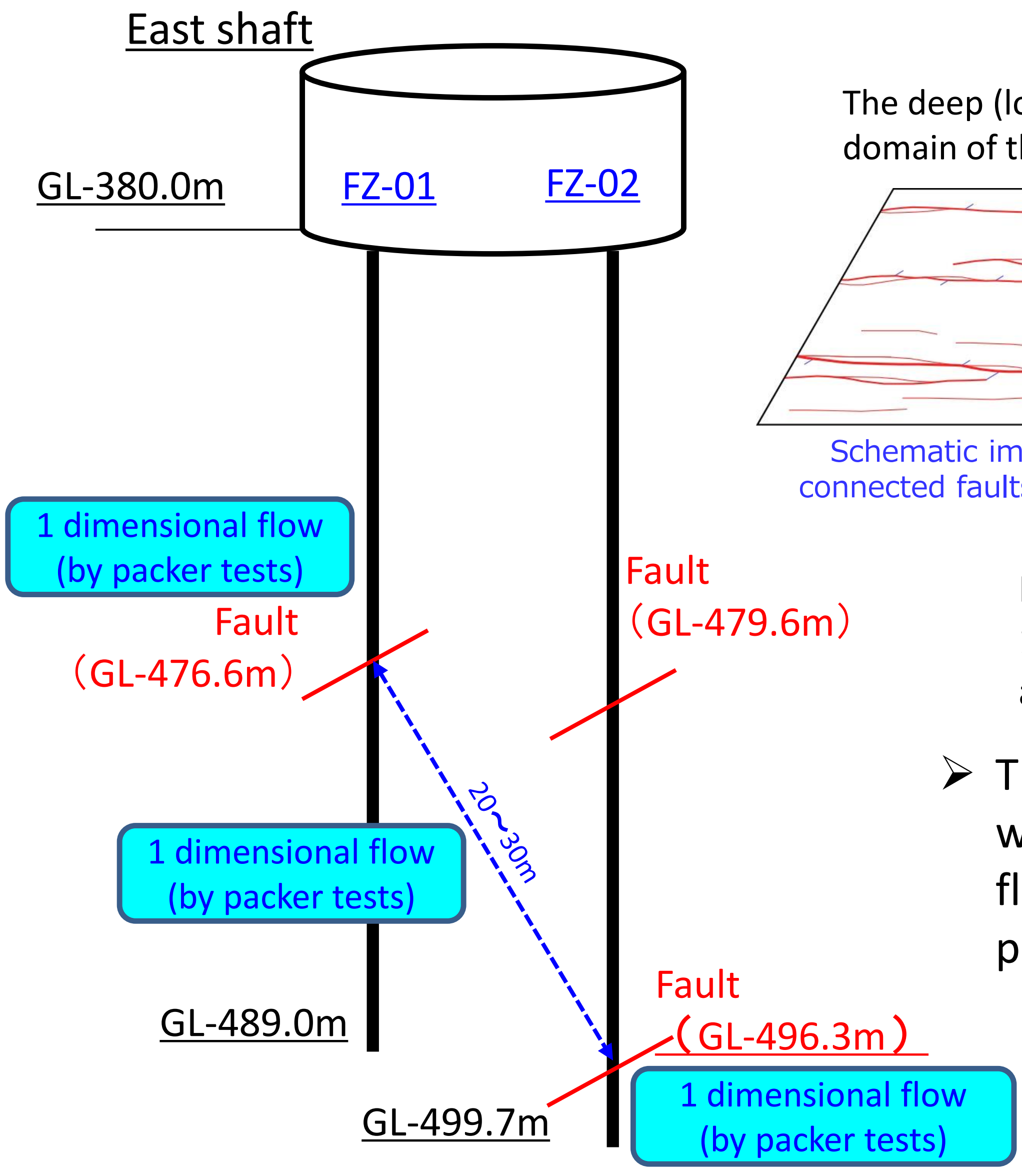
- Transport test for EDZ under saturated condition using the filled & injected tunnel
- Transport test for fractures in which flow is 1D (channeled) in the deep (low permeability) domain of the Wakkanai Fm.
- Development of mass transport evaluation method for near field including EDZ for sedimentary rocks



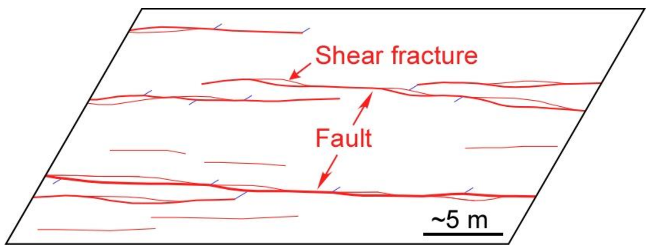
Understanding the extent of the EDZ concerning mass transport is also important to designing the distance between multiple tunnels.

Mass transport experiment focused on channeling within fracture

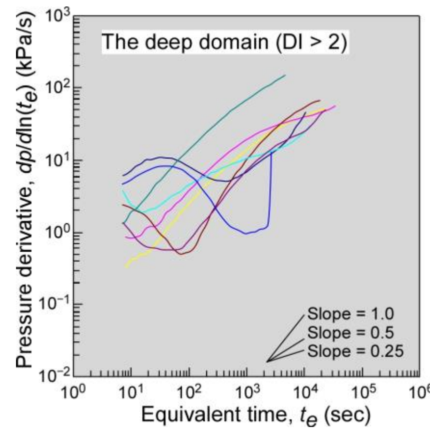
Development and verification of mass transport model considering fractures within channeling



The deep (low permeability) domain of the Wakkanai Fm.



Schematic image depicting poorly connected faults (from borehole data)



Results from packer tests

Derivatives during the hydraulic test indicate 1D flow to no flow, suggesting channel flows and poorly connected flow paths

- The tracer test is planned for the fracture, which is the one-dimensional (channel) flow path previously identified in the packer test.

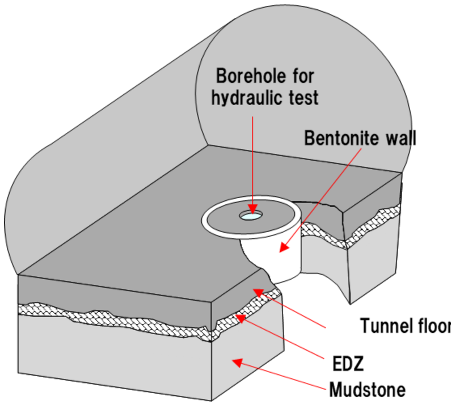
Sealing of EDZ around Horizontal Tunnel and shaft

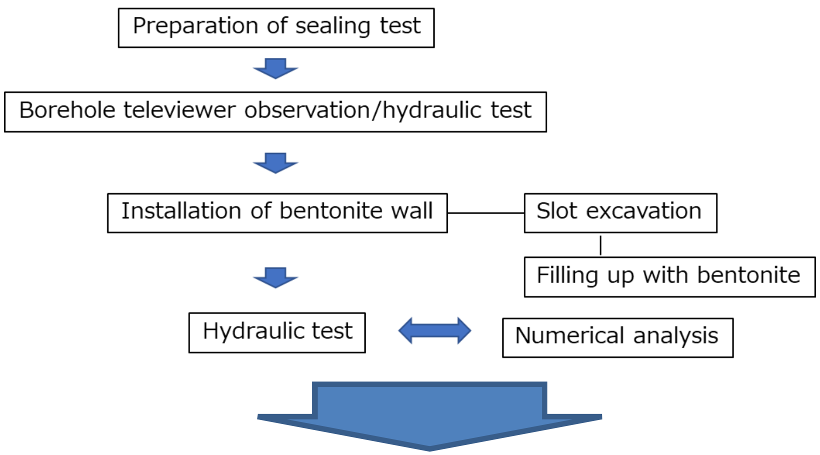
【Background】
The EDZ is one of the possible mass transport paths and demonstrating its closure is an important research topic.

【Aim】
Validate the sealing method of the EDZ around the horizontal tunnel and shaft.

【Work】
- Investigate the erosion of the clay material in EDZ with groundwater flow
- Evaluation of the sealing performance for long-term
- Tracer tests in and around the bentonite wall

Niche at Horonobe URL
（depth of 350m）





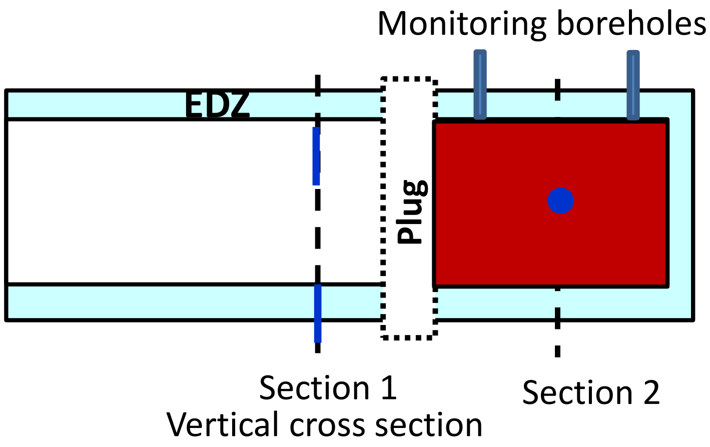
Preliminary tests were carried out to validate the potential for sealing of EDZ of the clay material under in-situ conditions.

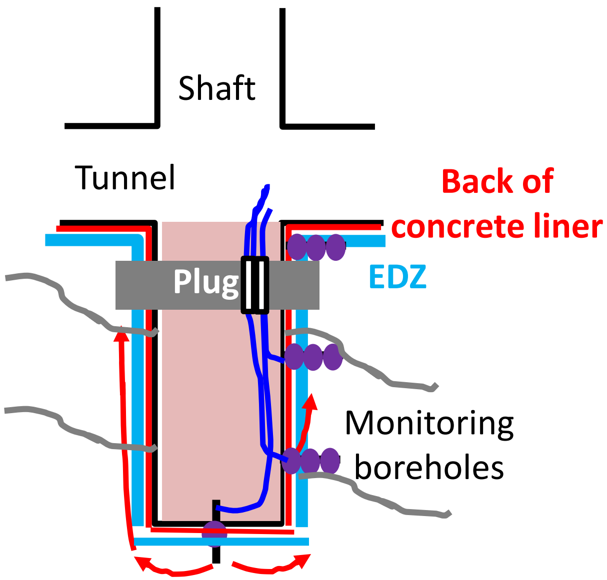
These are on going as a part of R&D program by METI in FY2020 (RWMC/JAEA joint project)

Sealing of EDZ around Horizontal Tunnel and shaft

【Work】

- Full-scale experiment of watertight clay plug
- Design the clay plug considered fractures and EDZ in the bedrock
- Evaluation of the installing method for interface between a tunnel wall and a clay plug
- Collecting leakage-water from the clay plug into the weir to measure the flow rate of the leakage-water and the amount of bentonite
- After backfilling the tunnel and installing of the clay plug, tracer tests (natural gradient test or radially divergent test) will be carried out to evaluate the function of plug cut off flow paths in EDZ





Demonstration of robotic systems for remote operation

【Background】

Further R & D on remote emplacement and retrievable technologies, including those demonstrated in recent research, can contribute to international project on remote robotic systems (RRS), eg. OECD / NEA WG-RSS project (Initiative on Application of Remote and Robotic Systems in Nuclear Back-end Activities).

【Aim】

Demonstrate an option of the engineering technology on retrievability and emplacement

【Subject】

- Establishment of the quality assurance methodology for engineered barrier system

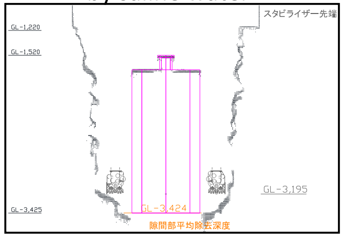
【Work】

- Improvement of the developed engineering technology
- Examination of the design option for retrievability (considering in the view of thermal influence)

Vertical deposition case

Developed prototype

Removal of the buffer material by saline water



Example of a preliminary test (Shape of removed area)

Horizontal deposition case

Emplaced dummy PEM In Horonobe URL

Removal using of a machine

Removal by water jet

Retrieving of dummy PEM by air bearing

These are on going as a part of R&D program by METI in FY2020 (RWMC/JAEA joint project)

R&D on retrievability and environment

【Background】

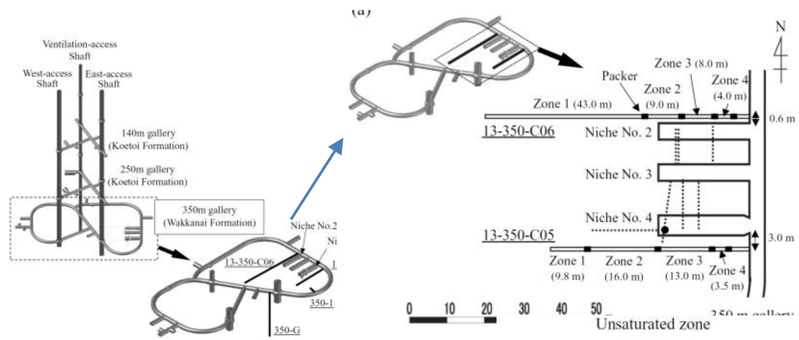
There is little international knowledge and actual experiences on the phenomenon from the opening of the tunnel to the post-closure, and initial conditions in the context of safety assessment for the retrievable geological disposal system.

【Aim】

- Estimation of the initial condition and relating process if the repository maintained retrievability
- Understanding the impact on the safety function of natural barriers due to the existence of open tunnels during the retrievability period

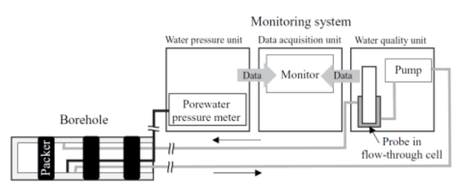
【Subject】

- Evaluate the hydraulic and chemical EdZ around the tunnel
- Estimate the environmental buffer capacity such as the recovery process and rate against the artificial impact

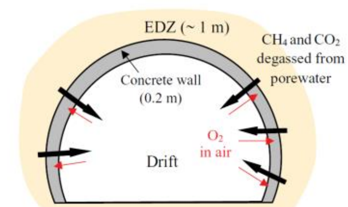


【Work】

- Examine the change in properties for concrete lining in geological environment
- Modelling of the long-term change in geological environment around a drift



Installed monitoring system



An example of developed conceptual model around a drift

Domestic/international cooperation

Domestic cooperation

Tohoku Univ., Univ. of Tokyo, Nagoya Univ. Kyoto Univ., CRIEPI, AIST, RWMC, NIES, etc.

International cooperation

DECOVALEX-2023: Development of modelling and simulation technique of T-H-M process in the EBS (JAEA, KAERI, TaiPower, CAS, BGR)

Mont Terri Project: FS-B, Imaging the long-term loss of faulted host rock integrity

Clay Club: Information exchange regarding clay property, etc.

Pacific Rim Partnership: Under consideration to produce a charter for the URL Working Group (JAEA, CRISO, Sandia, KAERI, TaiPower….)

Horonobe URL has been aiming to become an international research center.
The 25th Technical Committee Meeting on JAEA's URL Projects also recommended to enhance the international cooperation using the Horonobe Center.

Any suggestions?