International Review Workshop on JAEA's URL projects

Existing URL programme overview during the 2^{nd} five-year plan

- Horonobe Underground Research Laboratory -

18th June 2014

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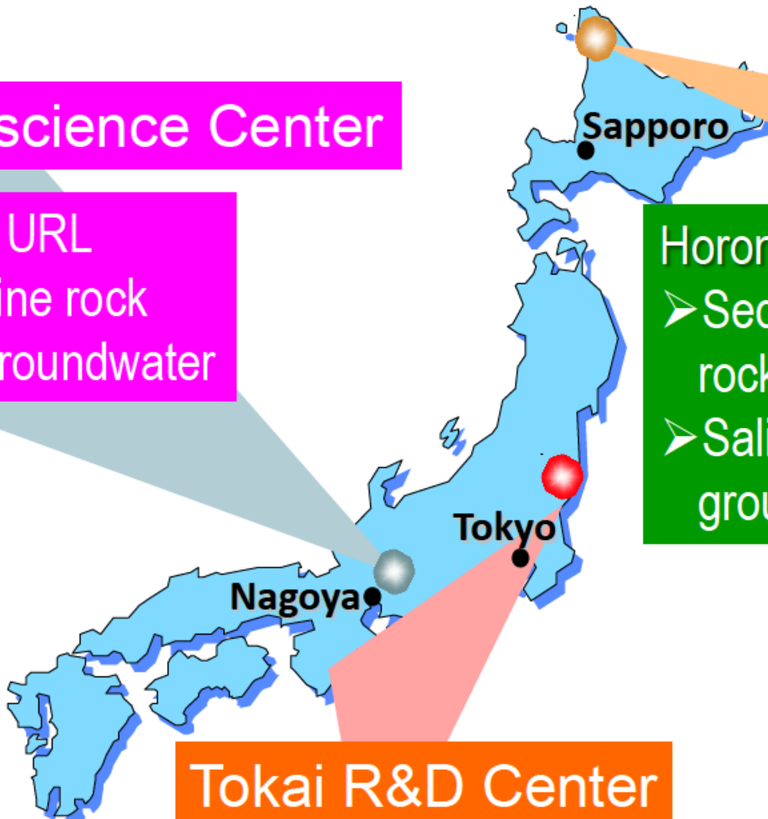
Rational of Horonobe URL in JAEA's R&D



Tono Geoscience Center

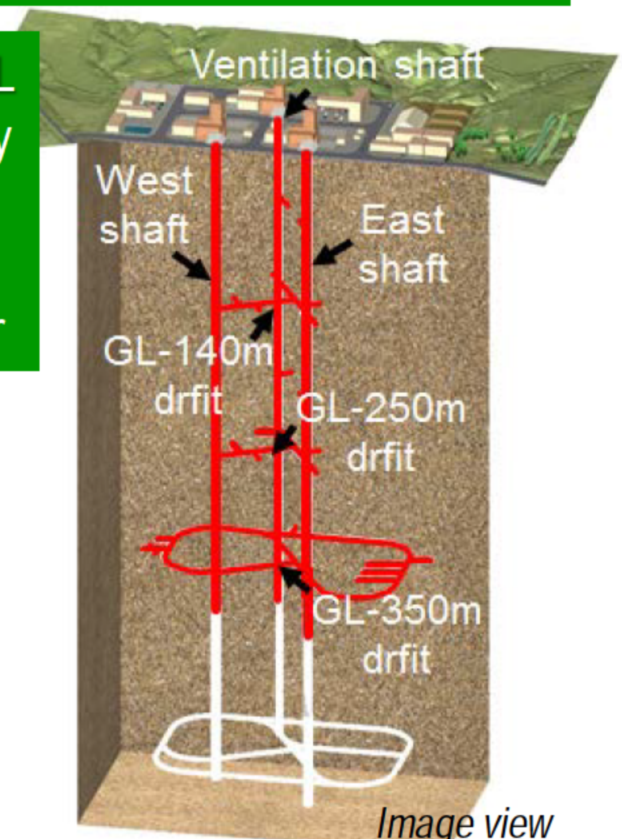
Mizunami URL
- ➢Crystalline rock
- ➢Fresh groundwater

Horonobe Underground Research Center

Horonobe URL
- ➢Sedimentary rock
- ➢Saline groundwater

Tokai R&D Center

ENTRY & QUALITY
- ➢Laboratory experiments (cold & hot)
- ➢Model development for performance assessment



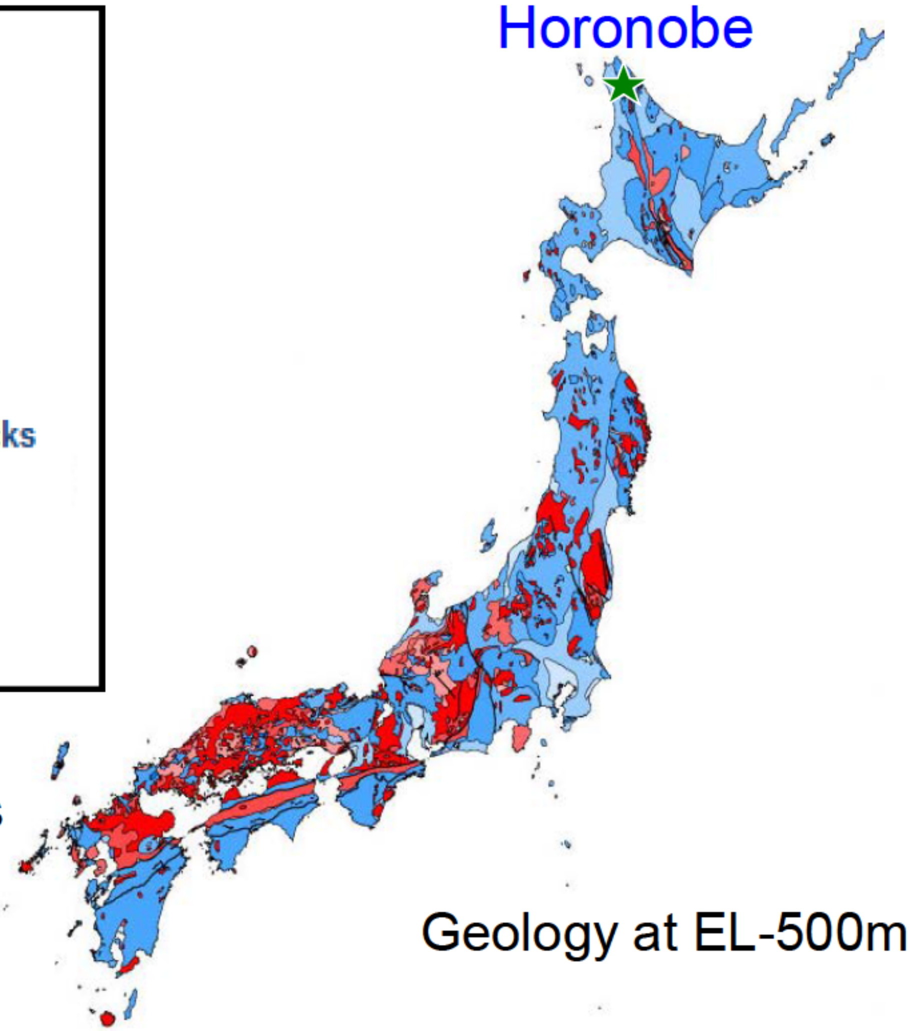
Red area: Excavation completed area
White area: Planed excavation area

➢ Generic URL for sedimentary rock in Japan

Geology in Japan & Locality of Horonobe

Legend

- Granitic rocks
- Crystalline schist
- Basaltic rocks
- Rhyolitic rocks
- Gabbroic rocks
- Limestone
- Pre-Tertiary sedimentary rocks
- Neogene volcanic rocks
- *Neogene sedimentary rocks*
- Quaternary volcanic and sedimentary rocks



Geology at EL-500m

BLUE: Sedimentary rocks
RED: Crystalline rocks

- Geology at Horonobe would be considered as an example for sedimentary rocks in Japan.

Main History of Horonobe URL Project

Nov. 2000: Agreement is signed by Hokkaido Prefecture, Horonobe Town & JAEA (JNC at that time)

Apr. 2001: Horonobe Underground Research Center opens

Jun. 2001: Field investigation starts followed by deep borehole investigations（HDBs-1 & 2）*

Jul. 2002: URL Area announcement

Dec. 2002: Announcement of the URL construction site

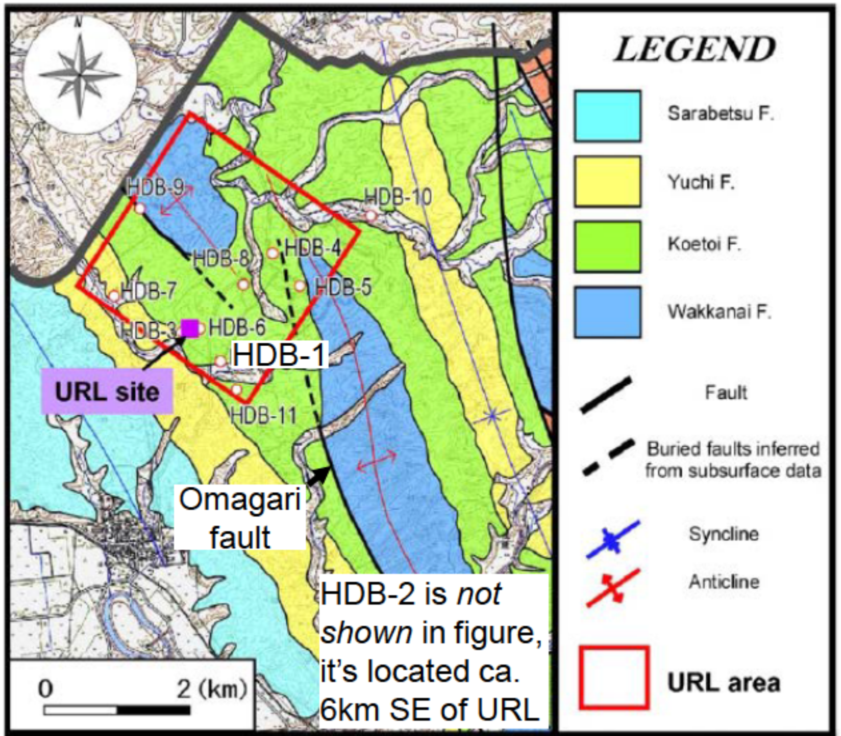
Jul. 2003: Site preparation starts

2004: Site preparation & surface building construction start.

Nov. 2005: Shaft construction starts

* HDB: Horonobe Deep Borehole（11 deep boreholes were drilled till 2005 for a depth range of 500 to 1000m）

Hama *et al.* (2007)



Topographic map is a part of 1:50,000 scale of "Toyotomi" and "Onoppunai" published by Geographical Survey Institute.

Selection Procedure for Horonobe URL Site #1

- General requirements

  Presence of suitable rock formation & groundwater (*i.e.*, geological environment criteria)

  - Distribution of sufficient volume of rock for safety construction of URL and execution of R&D activities

- Technical requirements
  - Max. depth of 500m, taking into account current engineering technology & rock properties investigated
  - Depth range of target formation range of 300 to 500m, considering Japanese legislation states of HLW disposal

- Social & environment requirements
  - Exclusion of special area such as national park & historic relics
  - Reduction of environmental impacts on flora & fauna, especially for rare plant & animal species

based on Ota *et al*. (2007)

Selection Procedure for Horonobe URL Site #2

- Stepwise selection process considering requirements
  - 4 candidate areas were selected
  - 1 URL site was selected comparing candidate areas in terms of technical, social & environmental requirements/conditions

Step	Process	Activities	Additional social consideration	Out-put
1st	Selection of potential URL areas	- Literature surveys	—	4 potential URL areas selected
2nd	Selection of URL area	- Aerial reconnaissance surveys - Geophysical surveys - Borehole investigations (HDB-1, 2)	Consideration of hot springs distribution	1 URL area selected
3rd	Selection of URL site	- Borehole investigations (HDB-3 to 5)	- No impact on Toyotomi hot springs - Existence of usable infrastructure (*e.g.*, road)	URL site defined (west side of Omagari fault)

based on Ota *et al.* (2007)

Policy for Social Concerns on Horonobe URL Project

JAEA promised with Hokkaido Prefecture and Horonobe Town;

- JAEA never brings nor uses any radioactive wastes in the area for the project during and after the project.
- JAEA never lends nor transfers the URL facilities to the implementing organization (Nuclear Waste Management Organization of Japan: NUMO) for the final disposal of HLW.
- JAEA closes the facilities on the ground and refill the underground facility after completion of the project.
- JAEA never has the area be a site for a repository for radioactive wastes nor introduces an interim storage for radioactive wastes in Horonobe.
- JAEA positively discloses information related to the project.
- JAEA positively cooperates in the regional developments such as preferential local employment with the project promoting.

Restrictions in Horonobe URL Project

- Necessity of water treatment

  Concentrations of some elements (*e.g.*, Se, F, B, NH_3) in groundwater are restricted when it drains to environment

  - Restriction by water pollution control law
  - Restriction by agreement with local fisher community

- Limit for amount of treated water drain

  Groundwaters are treated by water treatment plants to reduce concentrations below the restriction limits.

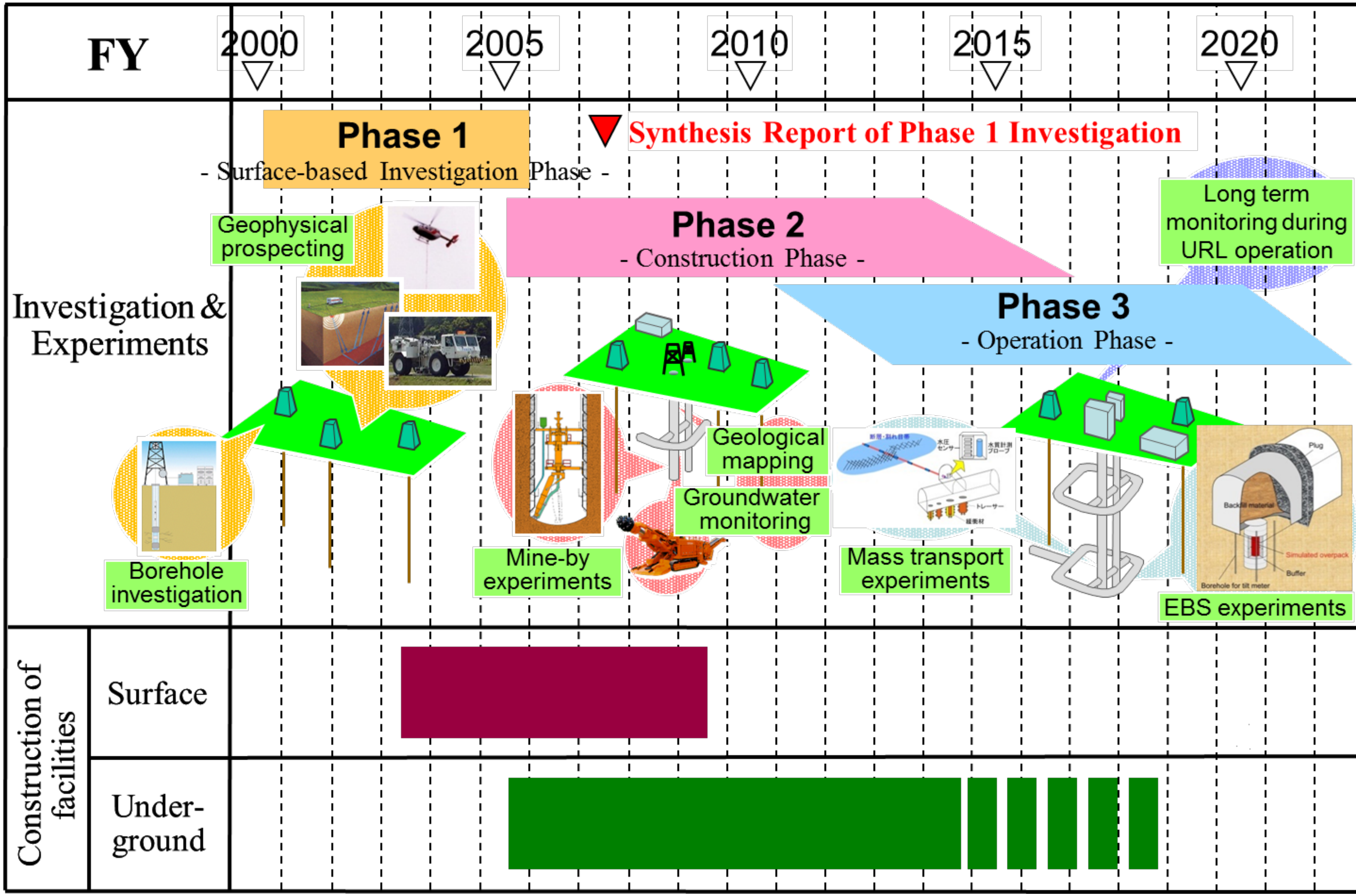
  - Amount of treated water drain is limited less than 750 m^3/day by agreement with local fisher community.

- Control of flammable gas (*i.e.*, CH_4(*g*))

  For safety measures, controlling system of flammable gas is necessary to avoid gas blowout.

  - Stationary gas sensors
  - Power shut down system

Main Schedule of Horonobe URL



Research Digest A1
Understanding of Initial Geo-environmental Conditions (GeC)

Over all objective: Development of generic techniques for surface-based investigation phase

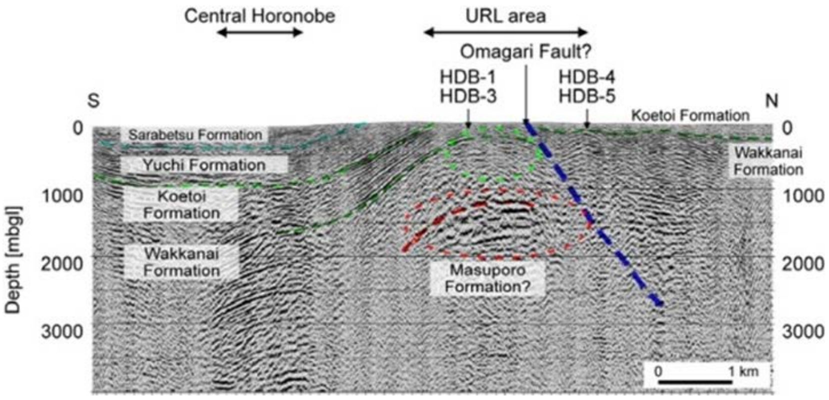
◆ *How should we identify appropriate area for URL construction ?*

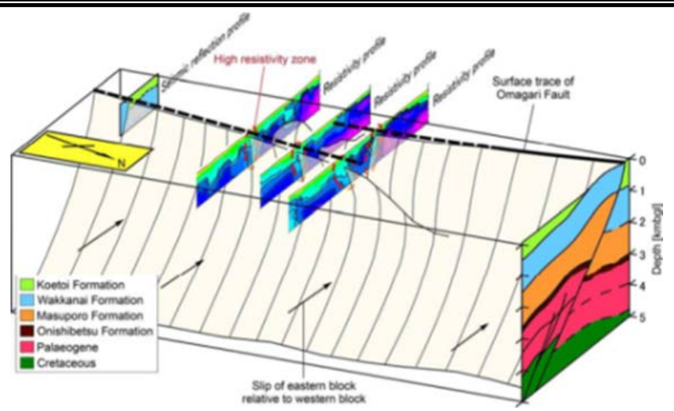
	Objectives	Focused feature and/or process, technology
Geology	Development of methods to identify appropriate rock mass & important fault (fracture) distribution	・Distribution of target rock mass ・Distribution of fault/fracture ・Heterogeneity of rock mass ・Important structure for migration path
Hydrology (see Appendix, Ap.1)	Development of methods to understand regional hydrology & to predict water inflow into shafts/drifts during construction/operation phases	・Regional hydrology around URL area ・Distribution of water flux ・Amount of water inflow into shaft/drifts
Rock mechanics (see Ap.2)	Development of methods to evaluate initial rock stress & property from surface	・Regional stress state around URL area ・Mechanical property of rock mass ・Status of temperature gradient ・Thermal property of rock mass
Geochemistry	Development of methods to identify spatial distribution of geochemical properties (*e.g.*, pH, Eh, salinity)	・Salinity distribution & evolution; water-rock interaction, mixing process ・pH/Eh distribution & evolution; water-rock-microbe interaction ・Residence time; piston-flow, mixing-flow, stagnant
Mass transport (see Ap.3)	Development of methods to identify mass transport property	・Sorption/diffusion properties on rock ・Identification of microbe/organic/colloid
Engineering technology (see Ap.4)	Application & confirmation of planning technology for URL design & construction	・Technology of support design for URL ・Technology for design of earthquake-resistance for URL

A1: Geology
Investigation method to understand regional geological structure

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

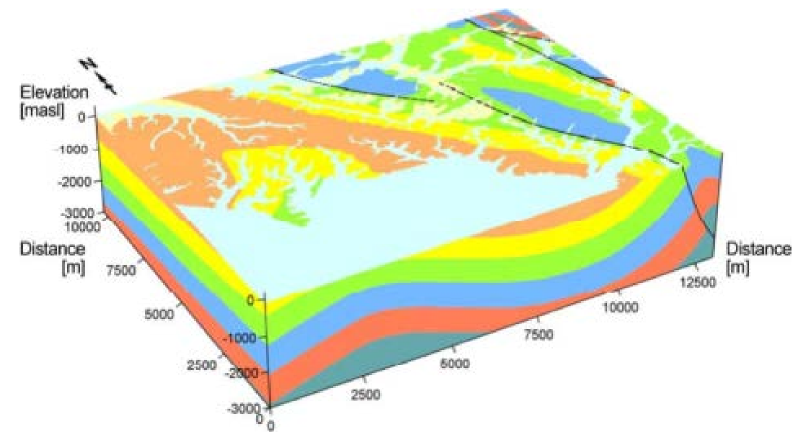
Combined results of reflection seismic survey and borehole investigations





Combined results of AMT geophysical survey and geological mapping

Integrated model of regional geological structure around Horonobe area



Ota *et al*. (2007)

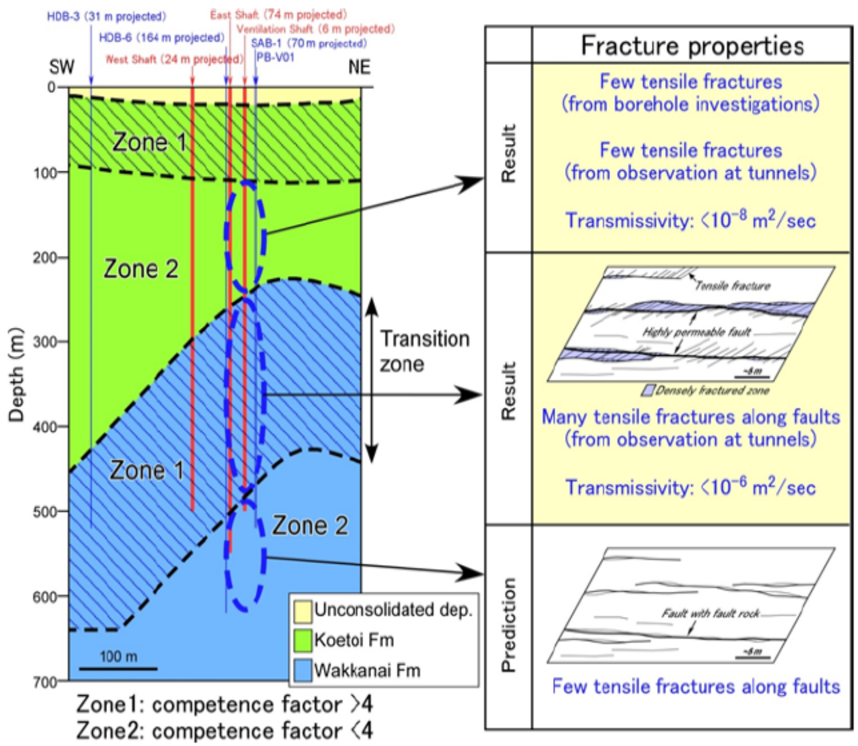
- Combination of multiple investigation methods (*e.g*., geological mapping, geophysical survey such as reflection seismic survey, surface-based boreholes) would be useful for development of confident geological model.

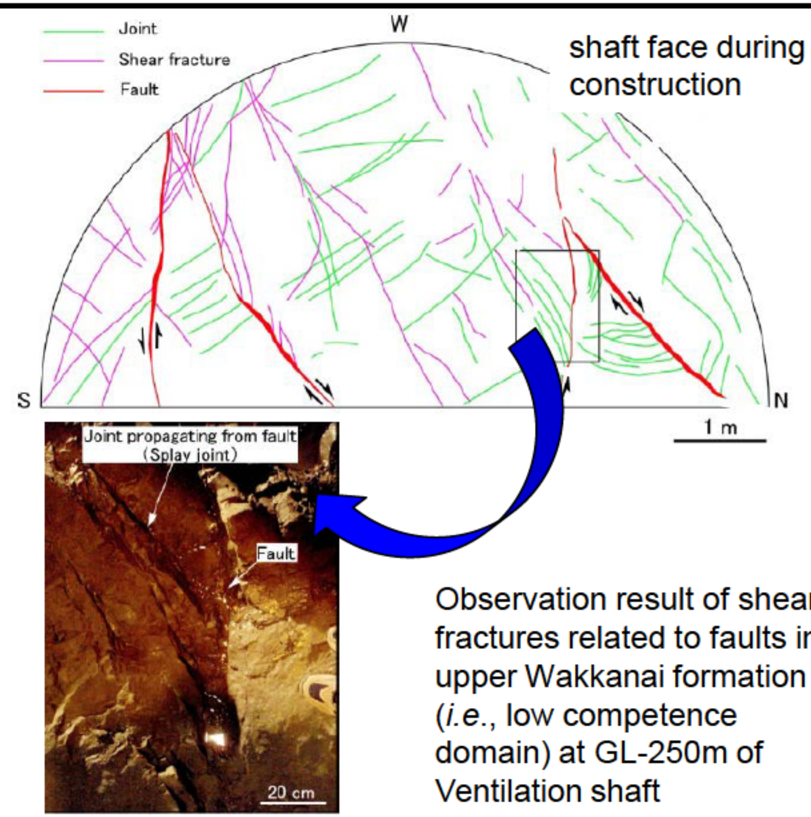
Understanding of heterogeneity and development process of fractures in sedimentary rock would be necessary for further detail consideration (*e.g*., panel layout).

A1: Geology
Investigation method to understand detail geological structure

Detail geological structure could be identified by borehole cores obtained in surface-based investigation phase and fracture observation on drift walls in construction phase.

Rock domain classified by competence factor, and geological & hydraulic properties of fractures in each domain





Observation result of shear fractures related to faults in upper Wakkanai formation (*i.e.*, low competence domain) at GL-250m of Ventilation shaft

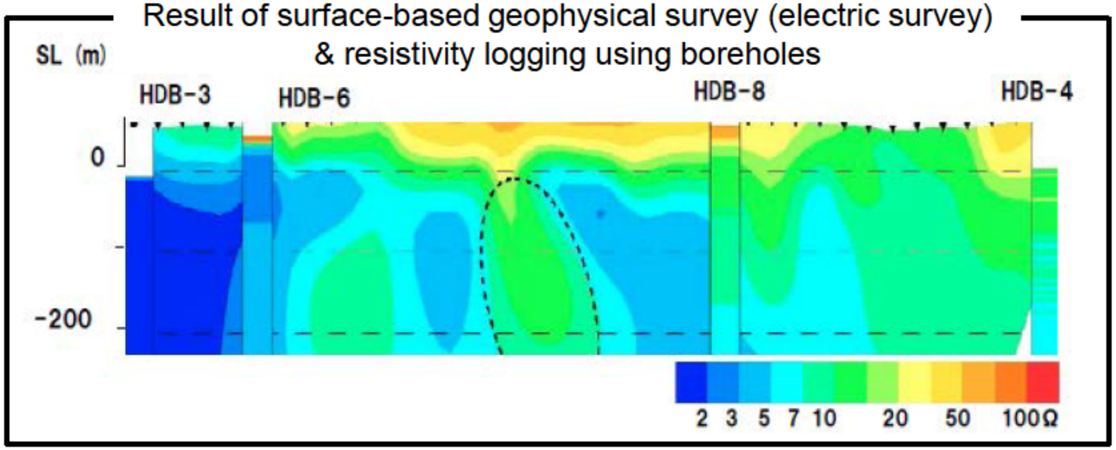
- Combined results for rock domain classification considering multiple features (*i.e.*, competence, geology, hydraulic property) based on surface-based investigation phase could be applicable to evaluate fault/fracture distribution observed in URL construction phase.

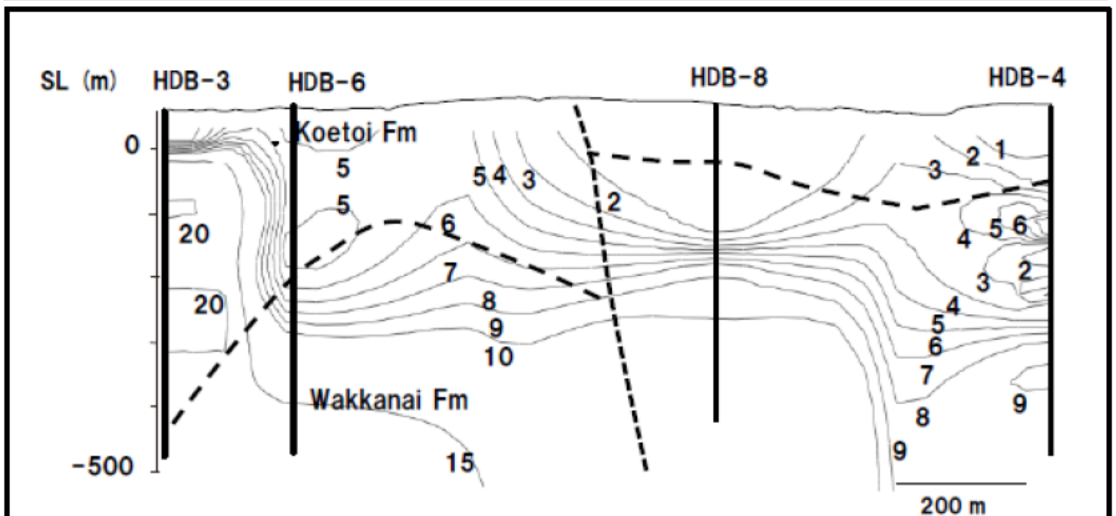
Understanding of heterogeneity and development process of fractures in sedimentary rock would be necessary for further detail consideration (*e.g.*, shaft/drift and pit layout).

A1: Geochemistry
Investigation method to understand spatial variability of GW chemistry

Appropriate combination of investigation methods (*e.g.*, 3 to 4 surface-based boreholes plus geophysical survey) would be applicable to evaluate spatial salinity distribution in sedimentary rock.

Result of surface-based geophysical survey (electric survey) & resistivity logging using boreholes





Extrapolation of Cl⁻ distribution based on GW obtained from boreholes

- Applicability of evaluation technique would depend on the following conditions;
  - ✓ frequency of major faults (less fault area is preferable)
  - ✓ homogeniety of rock mass
  - ✓ simple & clear distribution of different salinity GW
- Resistivity logging would be preferable technique for saline GW distribution area in sedimentary rock.

➢ Combination of multiple investigation methods (*e.g*., geophysical survey on ground, resistivity logging in surface-based boreholes, Cl⁻ measurement of GW) would be useful for confident understanding of spatial variability of GW chemistry.

Reduction of uncertainty for evaluation results of salinity distribution would be necessary for further better understanding.

Research Digest A2: Understanding of Short-term (ST) Changing/Recovering Behavior of GeC

Over all objective: Development of generic techniques for construction/operation phases

- *How should we design shaft/drift for URL construction ?*
- *How should we estimate environmental impact & recovery behavior during/after URL construction until closure ?*

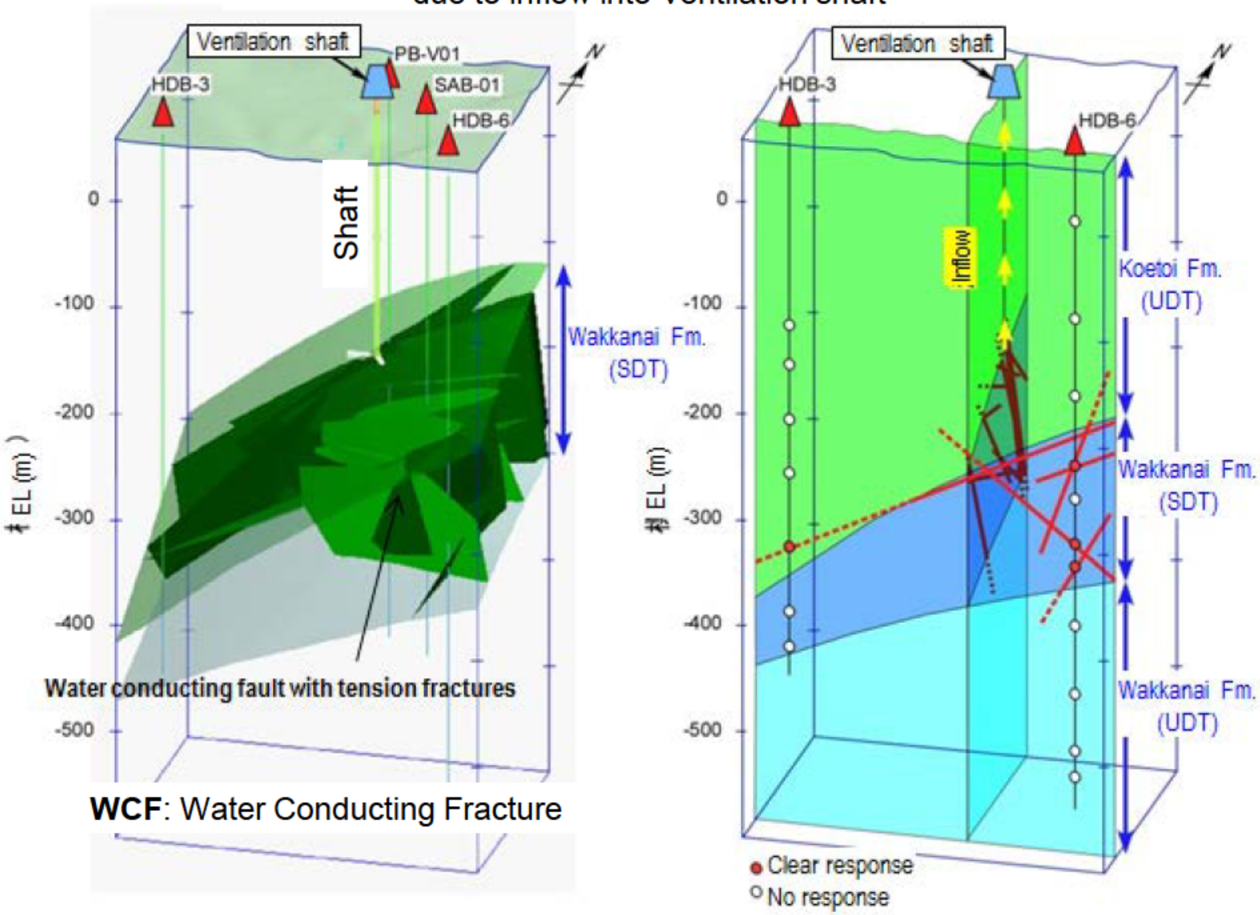
* EDZ: *Excavation Damaged Zone*, EdZ: *Excavation disturbed Zone*

	Objectives	Focused feature and/or process, technology
Geology (see Ap.5)	Development of methods to identify EDZ* caused by shaft/drift excavation	・Distribution of fractures in EDZ
Hydrology	Development of methods to monitor hydrological change in EdZ* by URL construction & to identify hydraulic property in EDZ	・Effect on water table & pressure ・Distribution of water flux ・Amount of water inflow into shaft/drifts
Rock mechanics	Development of methods to evaluate stress redistribution area in EDZ	・Extent of EDZ from view point of rock mechanics ・Mechanical property of rock mass in EDZ
Geochemistry (see Ap.6)	Development of methods to identify effects on GW chemistry in EdZ & EDZ	・Salinity distribution change; mixing caused by water pressure change ・pH/Eh distribution change including ST recovery behavior; water pressure change & oxygen diffusion
Mass transport (see Ap.7)	Development of advanced methods to identify mass transport property under URL construction/operation phases	・Sorption/diffusion properties on rock ・Identification of microbe/organic/colloid ・Estimation technique for mass transport path ・Evaluation technique for mass transport behavior
Engineering technology	Demonstration of URL construction technology	・Grouting technology considering countermeasure of exsolved gas ・Applicability of low-alkaline cement for support/grout materials under in-situ conditions

A2: Hydrology
Development of method to monitor impact on GW table & pressure

Appropriate monitoring intervals in boreholes considering regional hydrogeological structure would be important to identify heterogeneous hydraulic responses in fractured sedimentary rock.

Hydrogeological model & results of hydraulic responses due to inflow into Ventilation shaft



- ✓ UDT: unsuitable domain for pervasive tensile failure, which means favorable area for occurrence of tensile fractures.
- ✓ SDT: suitable domain for pervasive tensile failure, which shows unfavorable area for occurrence of tensile fractures

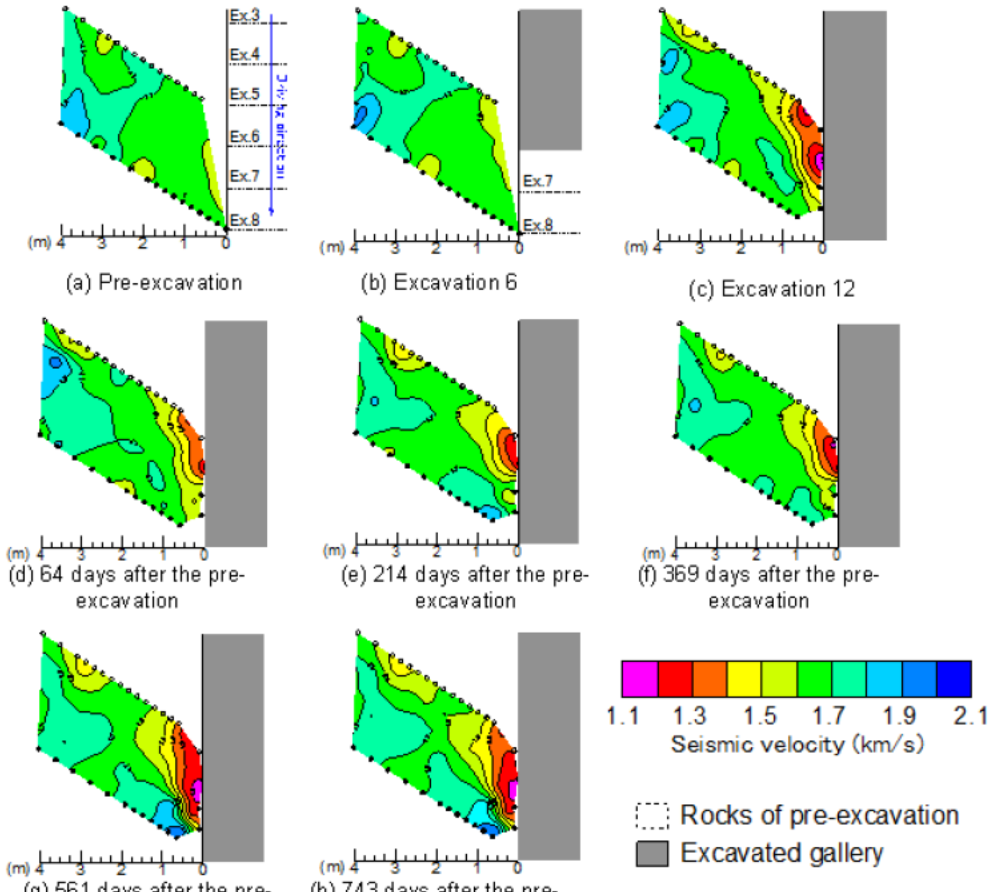
- Hydraulic responses are observed mainly in SDT through major WCFs, not observed in UDT.
- ➢ Multiple & continuous monitoring during construction/operation of URL would be useful to verify regional hydrogeological model developed at surface-based investigation phase.

Long-term monitoring technique would be necessary to identify recovery behavior of GW table & pressure during/after URL closure.

A2: Rock Mechanics
Development of method to monitor impact on rock mechanics

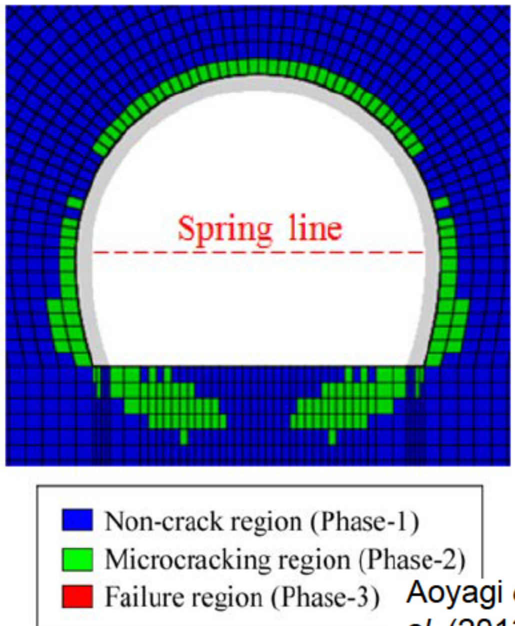
Extent of EDZ from view point of rock mechanics due to construction of URL could be estimated by multiple methods (*e.g.*, *in-situ* measurement, numerical simulation) consistently.

Results of seismic tomography survey at GL-250m drift



Aoyagi *et al.* in preparation

Result of stress analysis



Aoyagi *et al.* (2013)

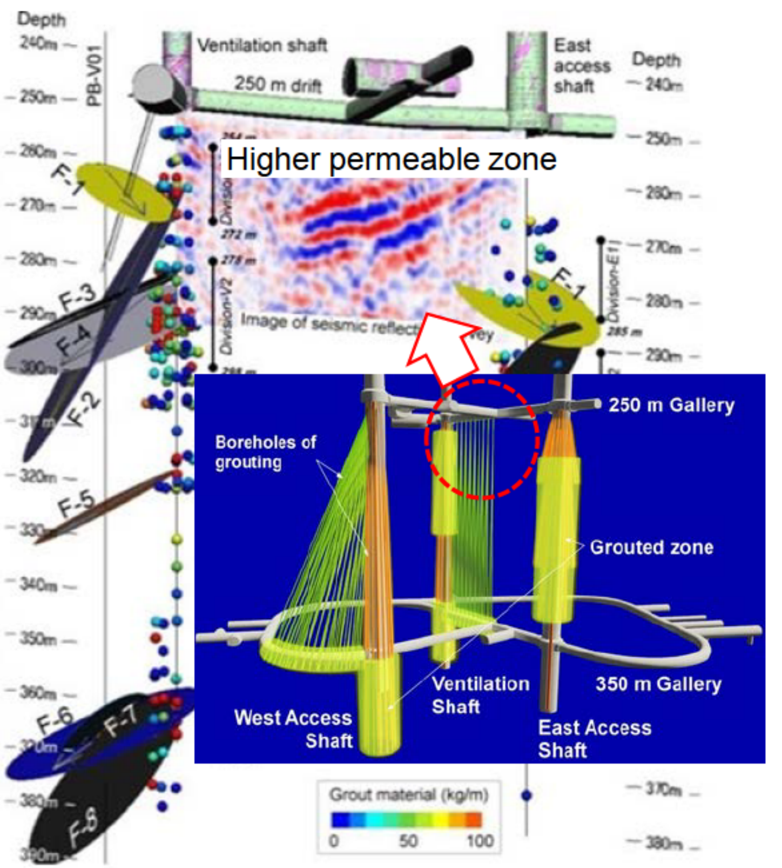
- Observed extent of seismic velocity decrease is limited within 1m from drift wall.
- Numerical simulation suggests microcracking occur 20cm from drift wall.

Method to reflect on design concept of drift closure considering mechanical properties in EDZ would be needed for future URL construction & performance assessment (PA).

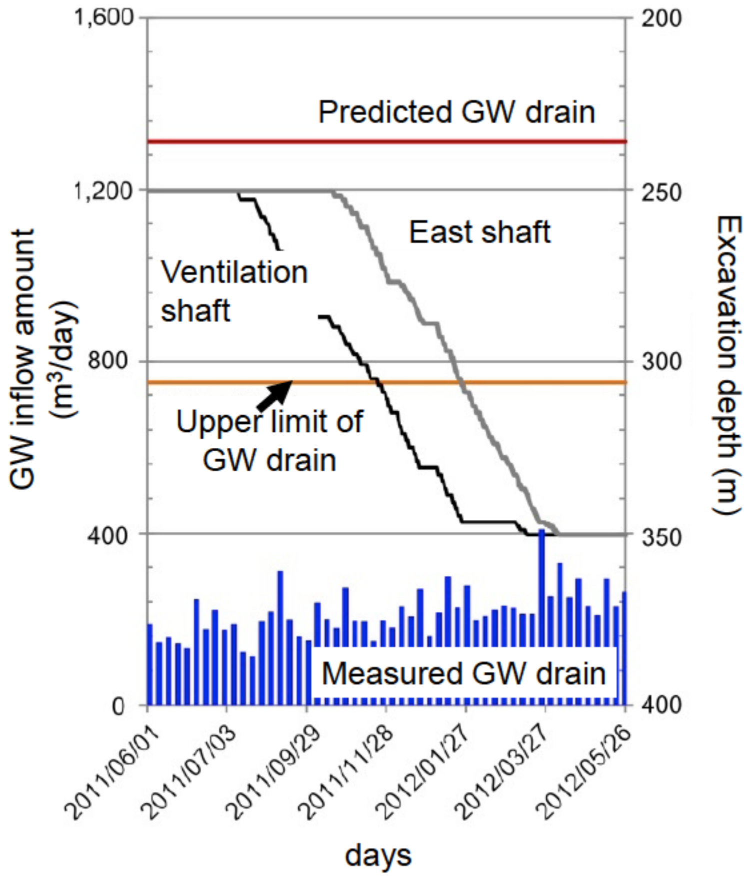
A2: Engineering Technology #1
Development of method to reduce GW inflow into shaft/drift

Conventional grouting techniques could be applicable to reduce GW inflow into shaft/drift against some difficulties (*e.g.*, blow-out of dissolved gases, pressuring of drilling bit).

Distribution of faults & amount of injected grout



Predicted & measured amount of GW inflow



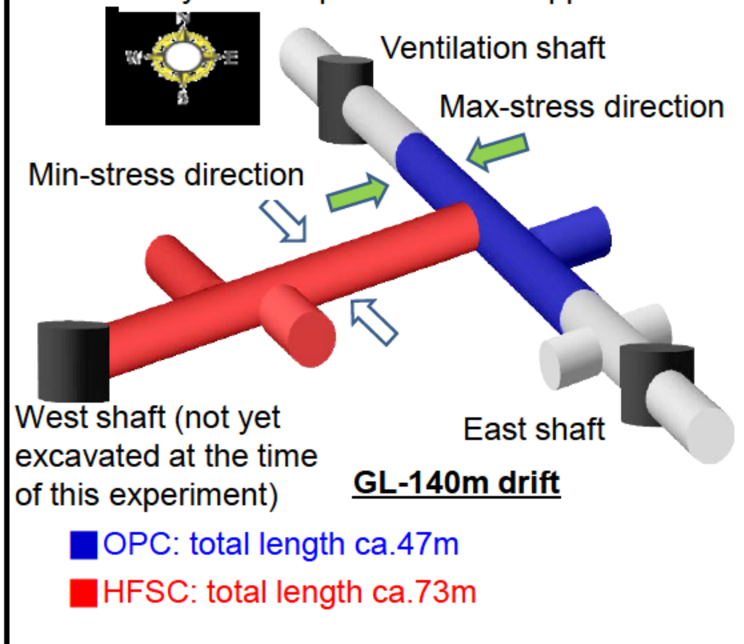
➢ Higher permeable zone in upper Wakkanai Fm. (*i.e.*, STD) could be improved by conventional OPC grout.

Improvement of grouting technology under difficult geological conditions might also be necessary for future potential URL construction/operation.

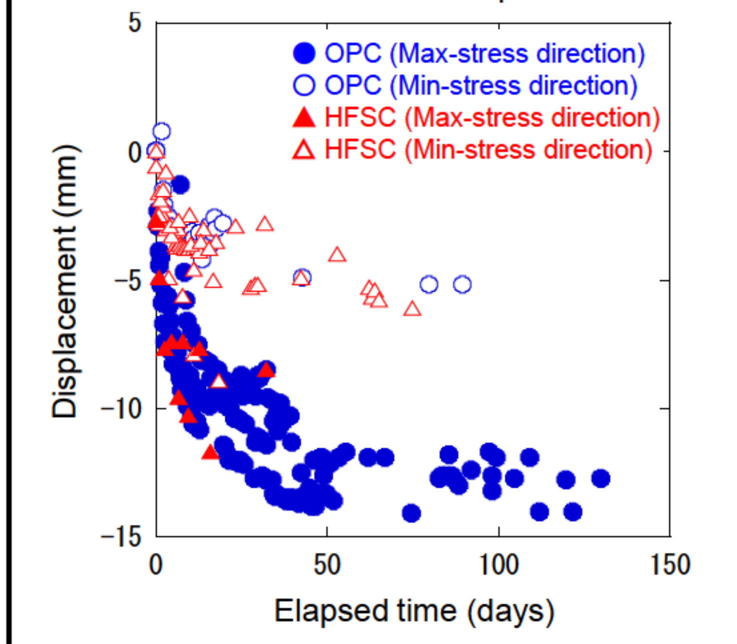
A2: Engineering Technology #2
Development of Low-Alkaline Cement (LoAC) material

Regarding to engineering point of view, LoAC material could be applicable for use of support & grout in URL construction as well as conventional cement material (*i.e.*, OPC).

Layout of experiments for support



Measurement results of displacement



Type of cement	Water-Binder Ratio (%)	Sand Ratio (%)	Unit weight (kg/m³)						
			Water	Binder			Fine Aggregate	Coarse Aggregate	Super Plasticizer
				OPC	SF	FA			
OPC	43.3	56.9	173	400	–	–	1068	806	2.00 (0.5%)
LoAC (HFSC)	30.0	59.7	150	200	100	200	974	638	3.25 (0.65%)

HFSC: Highly Fly-ash Contained Silica-fume Cement, OPC: Ordinary Portland Cement, SF: Silica-fume, FA: Fly-ash

- Basic engineering properties (*e.g.*, initial strength, workability, conductivity) of LoAC would be considered as equivalent with OPC.

***In-situ* field experiments for longer timescales using LoAC would be required for potential issues concerning chemical reactivity (*i.e.*, cement hydration, cement/rock reaction).**

Research Digest A3: Understanding of Long-term (LT) Changing/Recovering Behavior of GeC

Over all objective: Development of generic techniques for closure/post closure phases

- *How should we close URL and monitor mid/long-term change of geological environment ?*
- *How should we predict recovered stable environmental conditions post closure ?*
- *How should we develop scenario for PA on mid/long term ?*

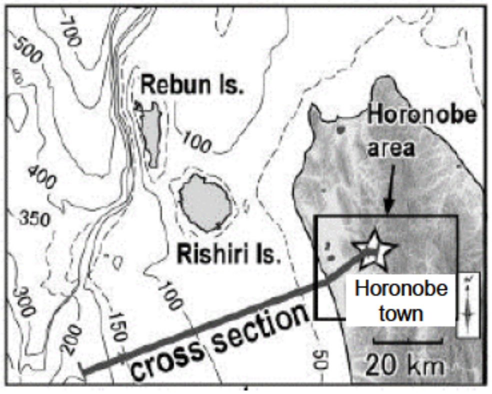
	Objectives	Focused feature and/or process
Geology	Development of methods to estimate LT evolution of geological structure	･Temporal evolution of topography & structure
Hydrology (Paleohydrology)	Development of methods to estimate LT variations of hydrological conditions	･LT evolution of hydrology ･LT evolution of water flux distribution
Rock mechanics (see Ap.8)	Development of methods to evaluate LT evolution of mechanical properties	･LT evolution of mechanical behavior (*e.g.*, creep)
Geochemistry	Development of methods to evaluate LT evolution of geochemical conditions	･Salinity distribution change; uplift/subsidence, flushing of saline water, earthquake ･pH/Eh buffering process; water-rock-microbe reactions ･Residence time; different waters exchange (*e.g.*, fresh *vs.* saline), stagnant
Mass transport (see Ap.9)	Development of methods to evaluate LT evolution of mass transport property	･Sorption/diffusion properties on rock ･Evaluation of evolution for mass transport path

A3: Hydrology (Paleohydrogeology)

Development of method to evaluate LT evolution of hydrogeological conditions

Integrated model to estimate paleohydrogeology could be constructed based on existing information related to geology, hydrology and (geochemistry) as example of coastal area at Horonobe.

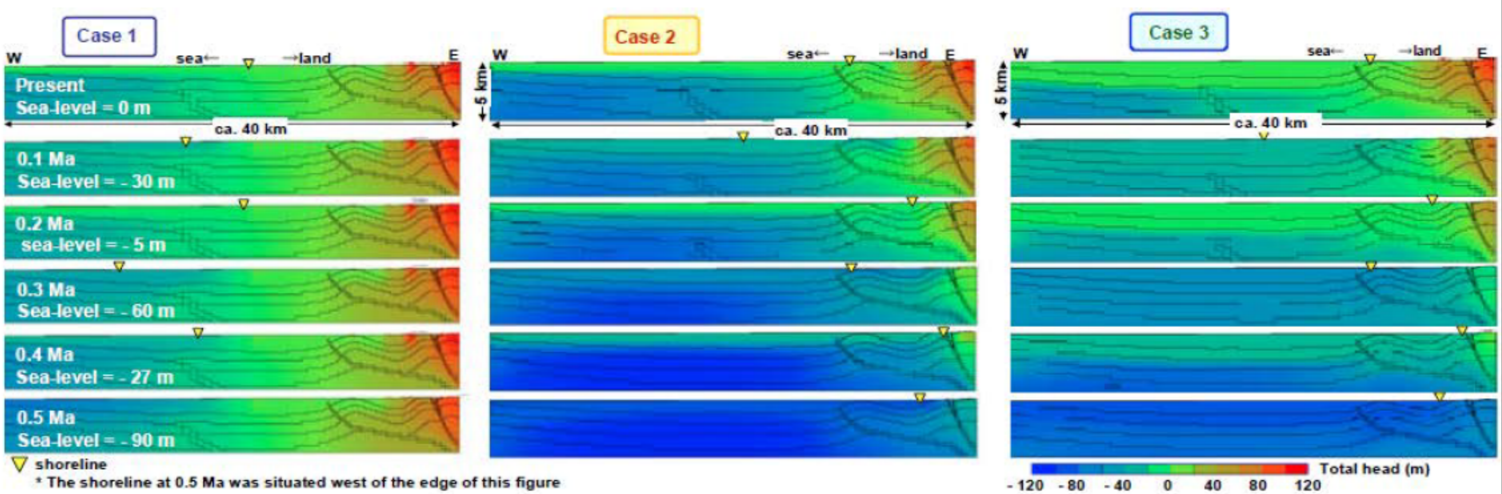
Simulation line (coastal area)



Simulation cases

Variant	Case1	Case2	Case3
Sea-level, groundwater recharge volume	○	○	○
Evolution of geological structures Uplift, subsidence, denudation, sedimentation, folding and faulting - 1.5 Ma to 1.2 Ma: no change - 1.2 Ma to 0.6 Ma: stepwise each 200 ka - 0.6 Ma or later: stepwise each 100 ka	×	○	○
Time-variation of hydraulic conductivity (assumed that hydraulic conductivity at 1.5 Ma is higher than at present)	×	×	○

·The period of simulation is from 1.5 Ma to the present.



Simulation results: time variation of distribution of hydraulic head from 0.5Ma to present

- With regard to LT variation of hydraulic distribution, impacts of tectonic such as uplift-subsidence plus change of hydraulic conductivity (Case 3) would give greater effects than only assumed sea-level & climate change alone (Case 1).

Niizato *et al.* (2009)

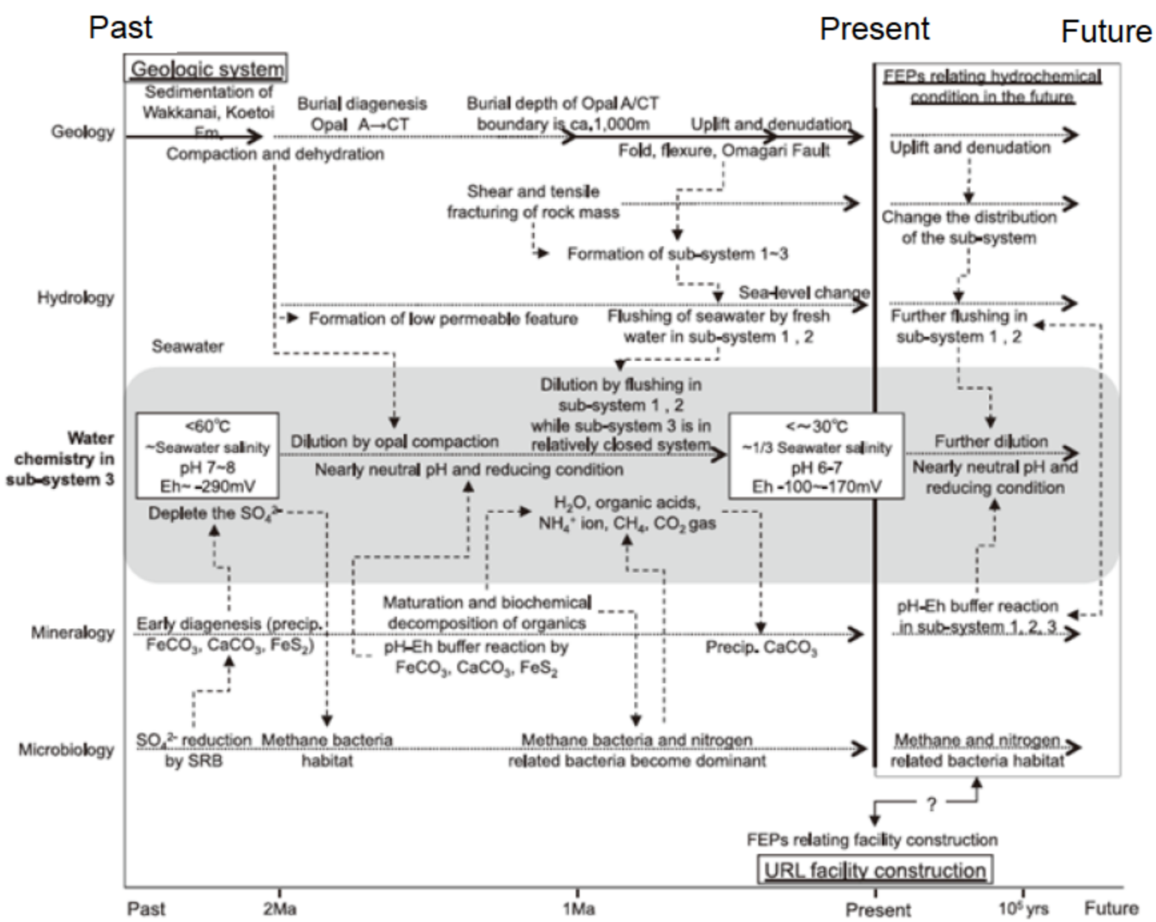
Improvement of integrated model considering uncertain parameters/phenomena would be necessary for reliable estimation of future LT hydrogeological conditions as methodology useful for PA.

A3: Geochemistry

Development of method to evaluate LT evolution of hydrochemical conditions

LT scenario including variations of important geochemical parameters (*e.g.*, pH, Eh, salinity) for PA could be constructed based on coupling information of geology, hydrology & geochemistry.

LT scenario related to hydrochemical evolution at Horonobe



- Constructed scenario could be useful tool for estimating LT evolution & variation of geochemical conditions which would be required for parameters setting (*e.g.*, solubility, Kd, De) of future PA for LT variation scenarios.

Iwatsuki *et al.* (2009)

Model development considering FEPs from past-to-present & testing reliability would be necessary to build confident predictive model from present-to-future.

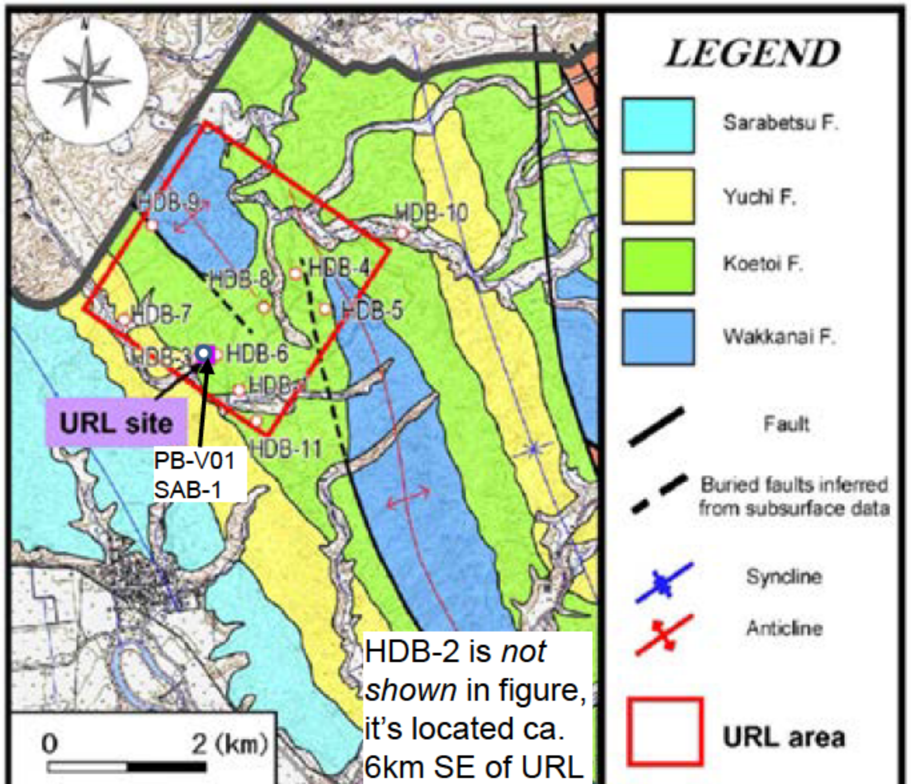
Conclusions & Next Plans

	Conclusions from Horonobe URL studies	Next Plans of Horonobe URL
A1: Understanding of Initial GeC	- Methods to identify appropriate area for URL construction for surface-based investigation phase have been developed & applied. - Initial GeC has been well characterized.	- Basically completed; data would be compared after obtaining data post closure of URL
A2: Understanding of ST Changing/Recovering Behavior of GeC	- Methods to design & construct URL using conventional technology have been confirmed. - Methods to identify EdZ & EDZ have been developed & tested. - Material to reduce environmental impact has been developed & applied.	- THMC experiment with model development (on-going) - Testing of solute migration models under *in-situ* conditions - Demonstration experiments of EBS considering disposal options
A3: Understanding of LT Changing/Recovering Behavior of GeC	- Methods to close URL have not yet tested. - Methods to evaluate LT evolution of GeC have been constructed and tested. - LT scenario of changing/recovering behavior useful for PA has been constructed.	- Development/testing of drift closure & retrieval technology - Development of LT monitoring technology for understanding of initial GeC post closure of URL - Testing of buffering/resilient potential in sedimentary rock

Appendix

A1: Hydrology
Investigation method to understand regional hydrology

Uncertain factors effectively affecting on GW hydrology should be identified and prioritized borehole investigation would give reasonable & cost-effective results in surface-based investigation phase.



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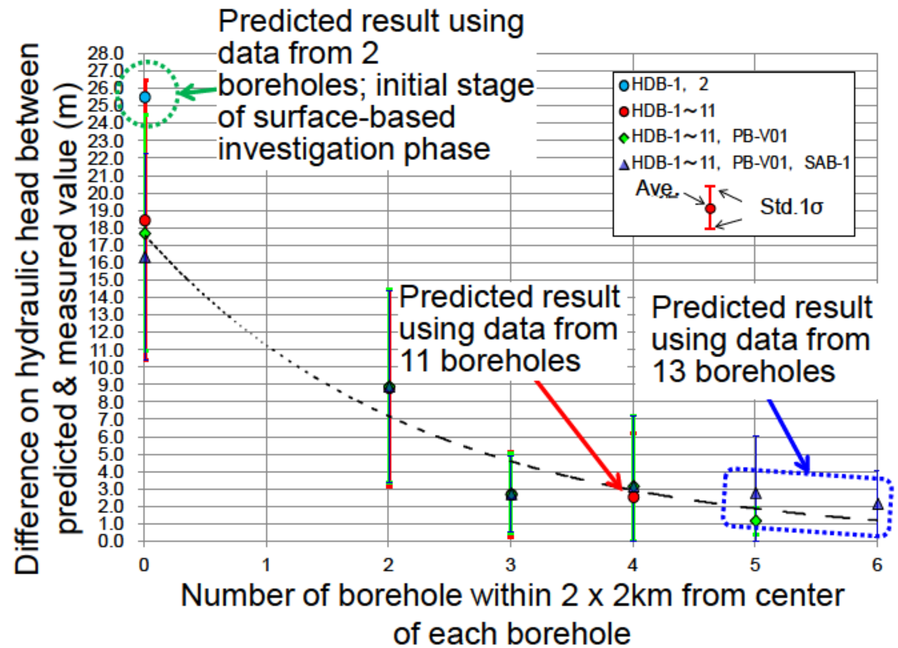


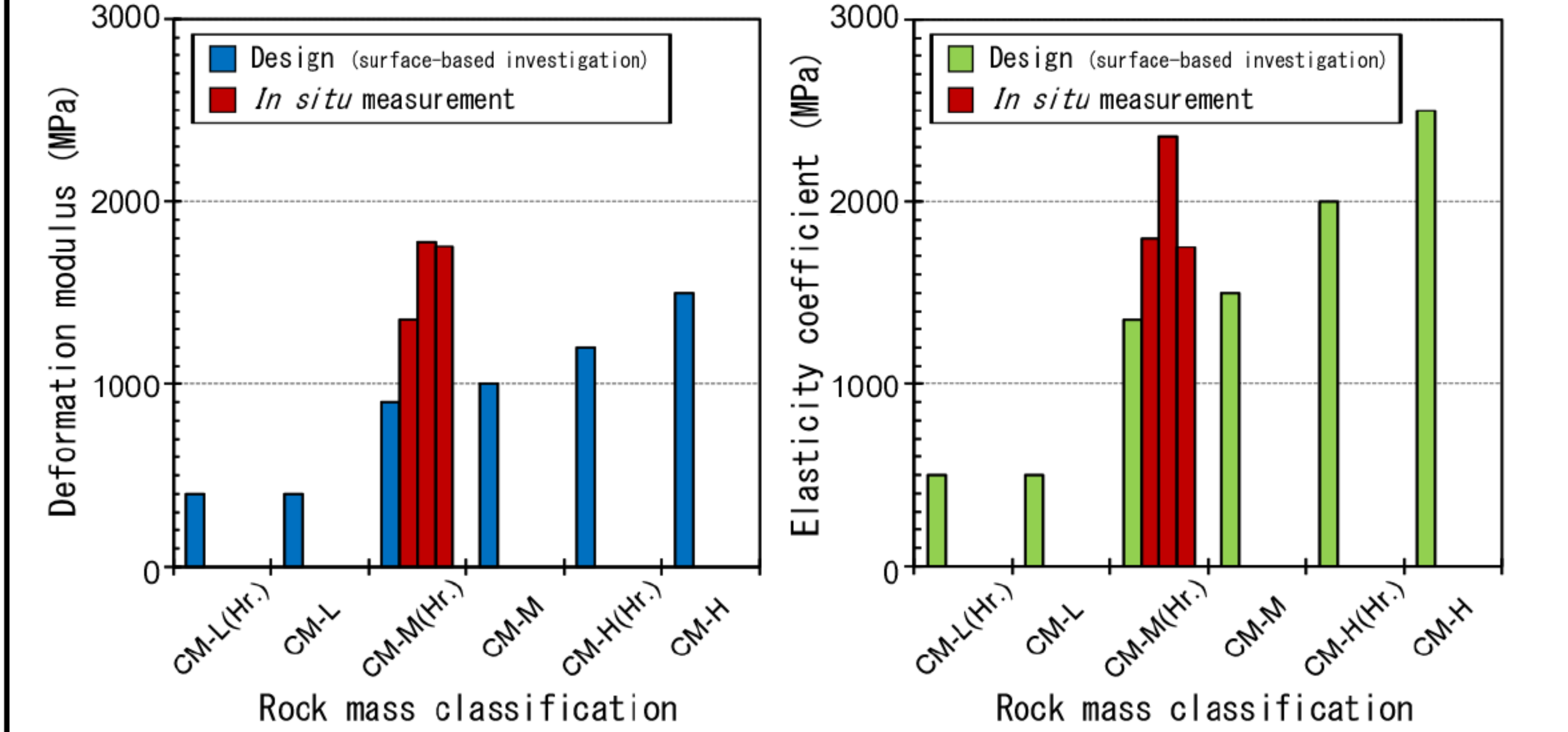
- Difference on hydraulic head between predicted & measured value decreases with number of borehole considered in hydrological simulation, the uncertainty in difference would not decrease significantly if appropriate number of borehole (*e.g.*, more than 5 boreholes in this case) has been considered, however.

Experiences to confirm appropriateness for up-date of hydrogeological model based on on-going short-term variant data would be necessary to increase confidence as methodology.

A1: Rock mechanics
Investigation method to understand initial mechanical property

Initial mechanical property (*i.e.*, designed value) of rock in URL scale could be estimated reasonably by data obtained in surface-based investigation phase.

Comparison between designed (estimated) parameters and results of *in-situ* plate loading tests conducted at GL-350m drift (after Tsusaka et al., 2014)



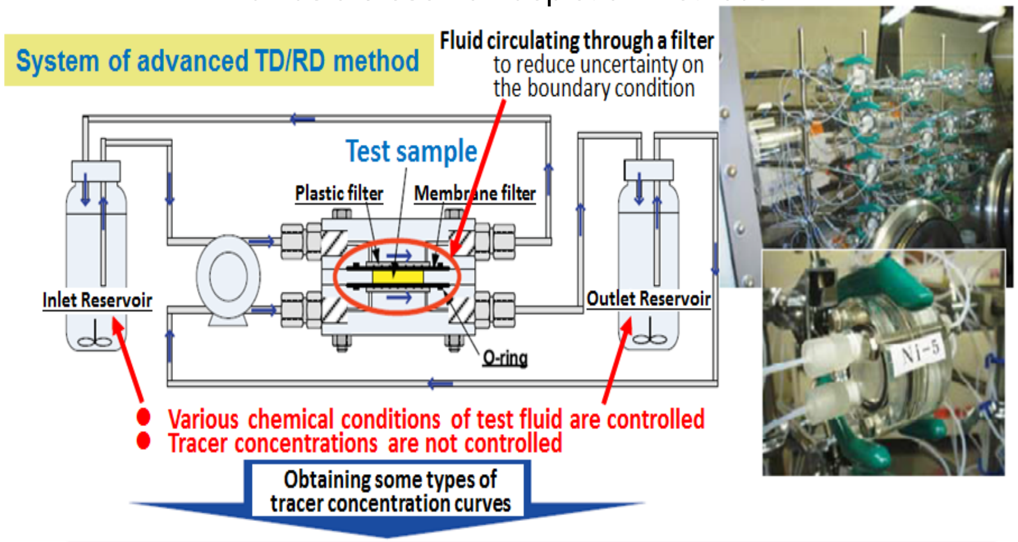
- Designed parameters of rock mechanics (*e.g.*, deformation modulus, elasticity coefficient) would be predicted within reasonable range (somewhat larger than *in-situ* measurements, however) from view point of URL design at surface-based investigation phase.

Know-how for *in-situ* measurements & estimation method based on data obtained in surface-based investigation phase should be summarized for later detail design of URL construction.

A1: Mass transport
Investigation method to understand mass transport property

Through-diffusion experiments with variable concentrations & multiple curve analyses including depth profiles, could be evaluated as useful method to understand complex diffusion and sorption mechanisms.

Illustration of approach for advanced through-diffusion/reservoir-depletion methods



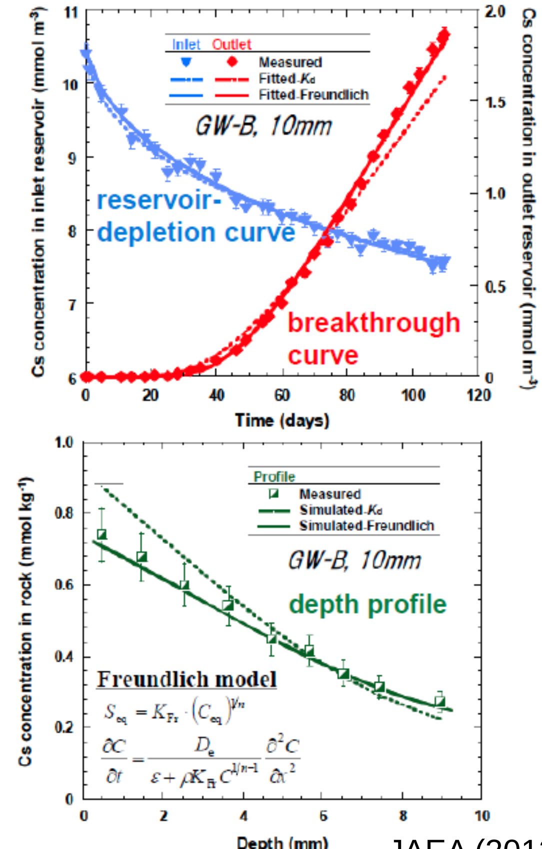
3 curves (3 phases: Reservoir-depletion curve + Breakthrough curve + Depth profile)
2 curves (2 phases: Reservoir-depletion curve + Depth profile)

➡ Coupled fitting ➡ Effective diffusion coefficient (D_e) / Distribution coefficient (K_d)

$$c(x,t)=\frac{c_1(0)}{\delta+\gamma+1}-2c_1(0)\sum_{m=1}^{\infty}\frac{\exp\left(-\frac{De\cdot\varepsilon_m^2}{\alpha\cdot L^2}\cdot t\right)\cdot\left[\delta\cdot\cos\left(\varepsilon_m^2\cdot\frac{L-x}{L}\right)-\gamma\cdot\varepsilon_m\cdot\sin\left(\varepsilon_m\cdot\frac{L-x}{L}\right)\right]}{\left[\gamma\cdot\varepsilon_m^2-\delta\left(\delta+\gamma+1\right)\right]\cdot\cos(\varepsilon_m)+\left[\delta\cdot\gamma+\delta+2\gamma\right]\cdot\sin(\varepsilon_m)}$$

Zhang et al.(2006); MRS Symp. Proc.

Experimental results for Cs diffusion



JAEA (2013)

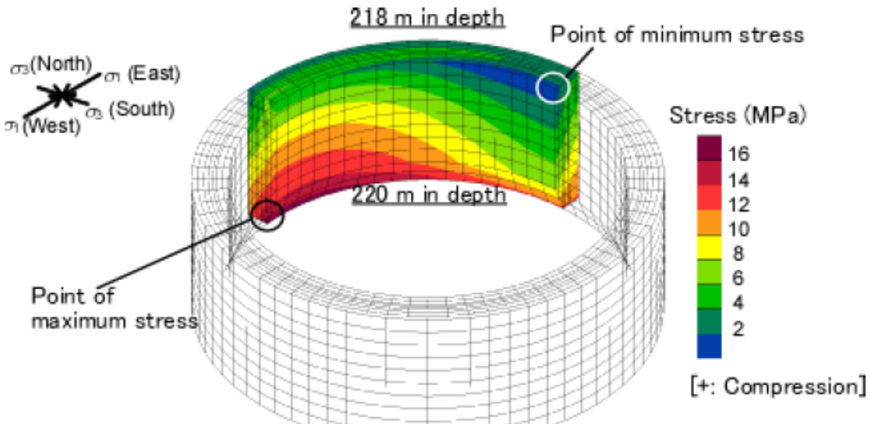
■ Multiple curve fitting method could reproduce the experimental data satisfactorily.

Test applicability of experimental method for more complex chemical species and other type of sedimentary rock would be necessary in future.

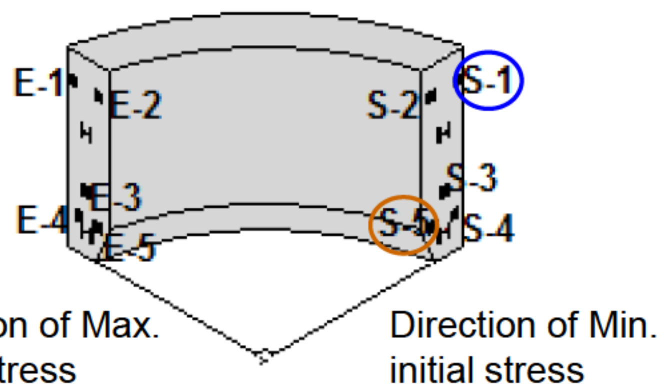
A1: Engineering technology
Development method for planning technology of URL

Planning technology including feed-back from observed differences between simulated & measured of stress on support have been developed & applied on soft sedimentary rock.

Numerical simulation of stress distribution on support

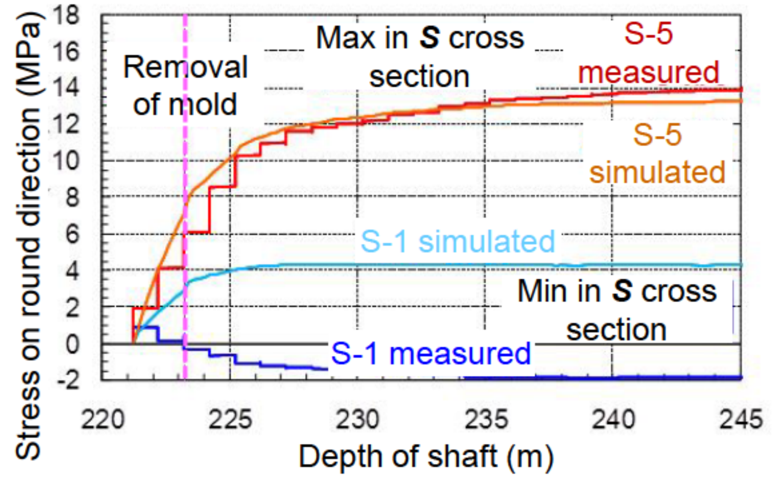


Tsusaka *et al.* (2012)



Stress measurement points on concrete support

Comparison of stress on concrete support between measurement & simulation



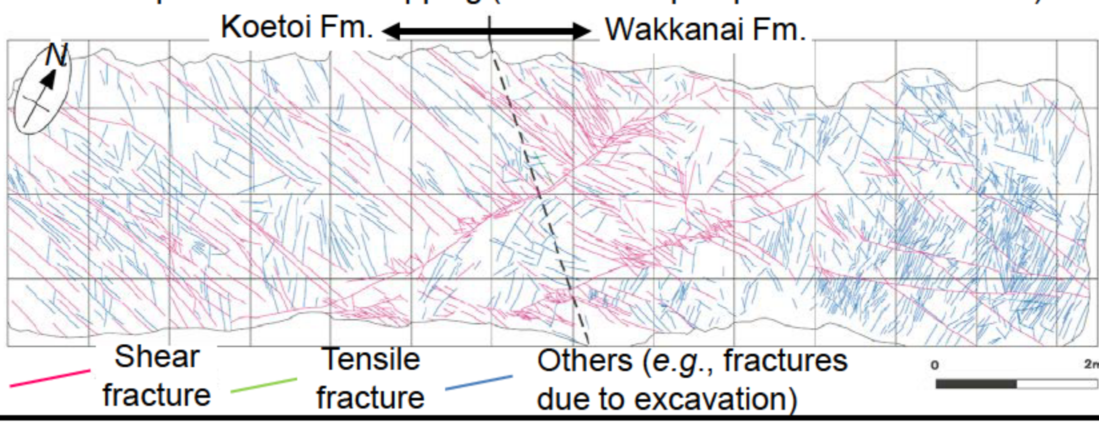
- There would be significant differences on stress distribution in concrete support when short-step method was applied for soft sedimentary rock.
- It would be necessary to allocate stress measuring points considering distribution of initial stress & construction procedure of support.

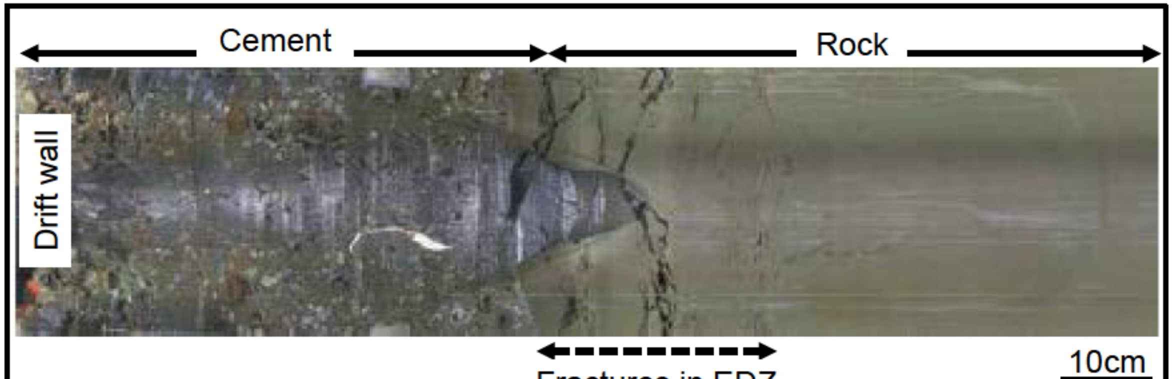
Know-how of planning technology for future construction would be summarized considering experiences obtained through Horonobe URL planning.

A2: Geology
Development of method to identify EDZ by fracture observation

Identification of EDZ around drift would be possible by detail fracture observation comparing with features of natural fractures & artificial fractures due to excavation.

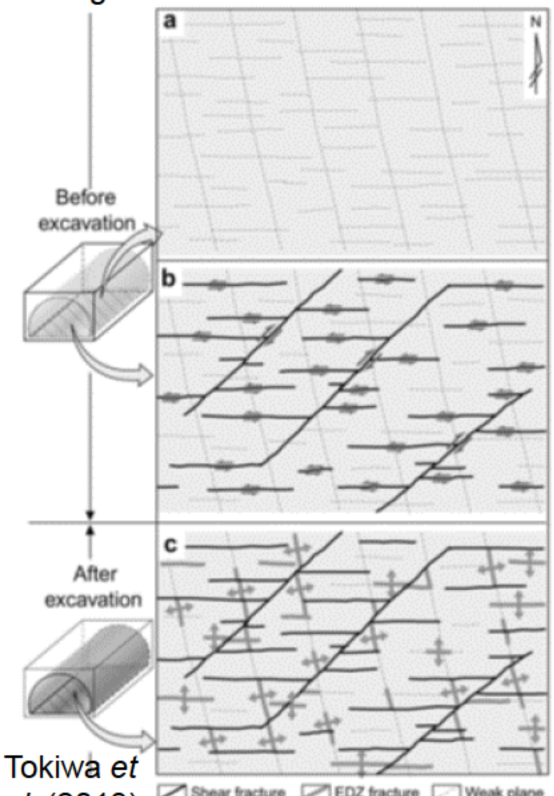
Example of fracture mapping (drift floor of pump-station at GL-250m)





Example of facture in EDZ observed in borehole core of Wakkanai Fm. (GL-350m drift)

Conceptual model for generation of fracture in EDZ



Tokiwa *et al.* (2013)

- Fracture generation by excavation would be related to stress record from past-to-present.

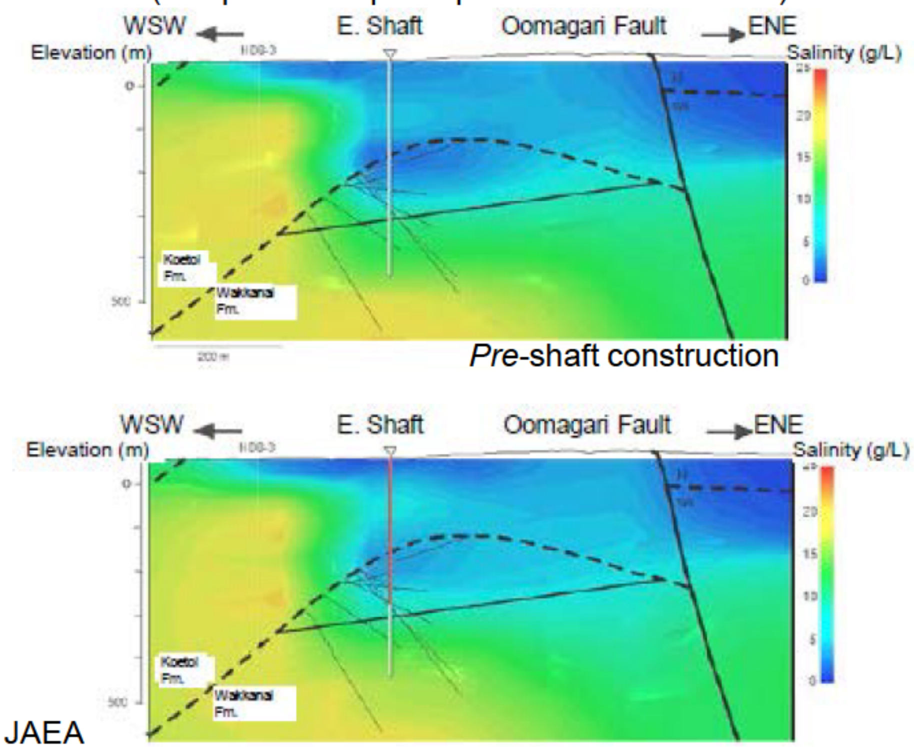
Method to monitor change of fracture distribution during construction/operation of URL & information related to LT behavior of fractures in EDZ (*e.g.*, self-sealing) would be necessary.

A2: Gechemistry

Development of method to identify effects on GW chemistry in EdZ & EDZ

Methods to monitor effects on GW chemistry in EdZ & EDZ would be applicable for during URL construction/operation phases.

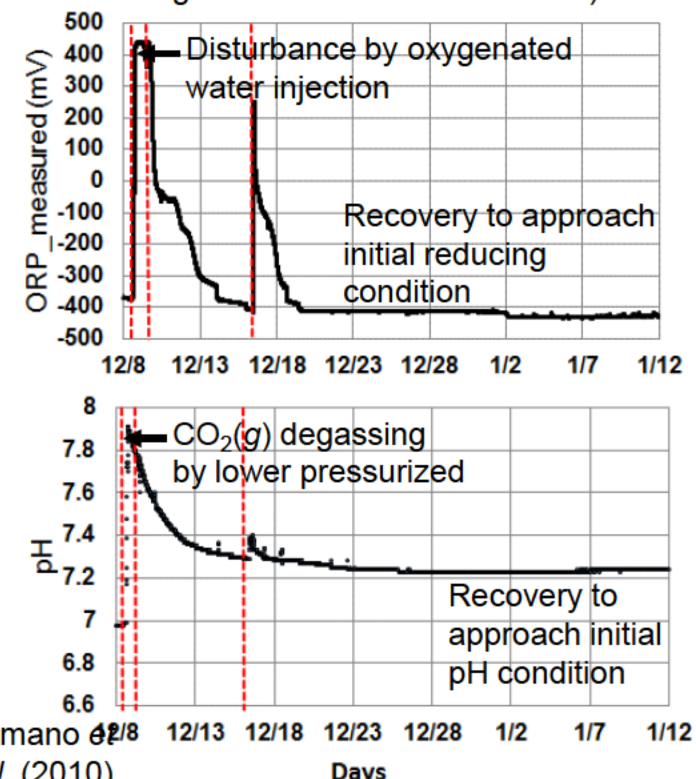
Evaluation result of salinity distribution change in EdZ (comparison of pre & post-shaft construction)



Post-shaft construction (ca. 7 years later)

JAEA (2013)

Eh & pH recovery in EDZ (20m length borehole at GL-140m drift)



Amano *et al*. (2010)

- No significant change of salinity around URL area has not been estimated, small change would be inferred close to excavated shaft, however.
- Chemical buffering would be expected by combined reactions of mineral-gas-water-microbe.

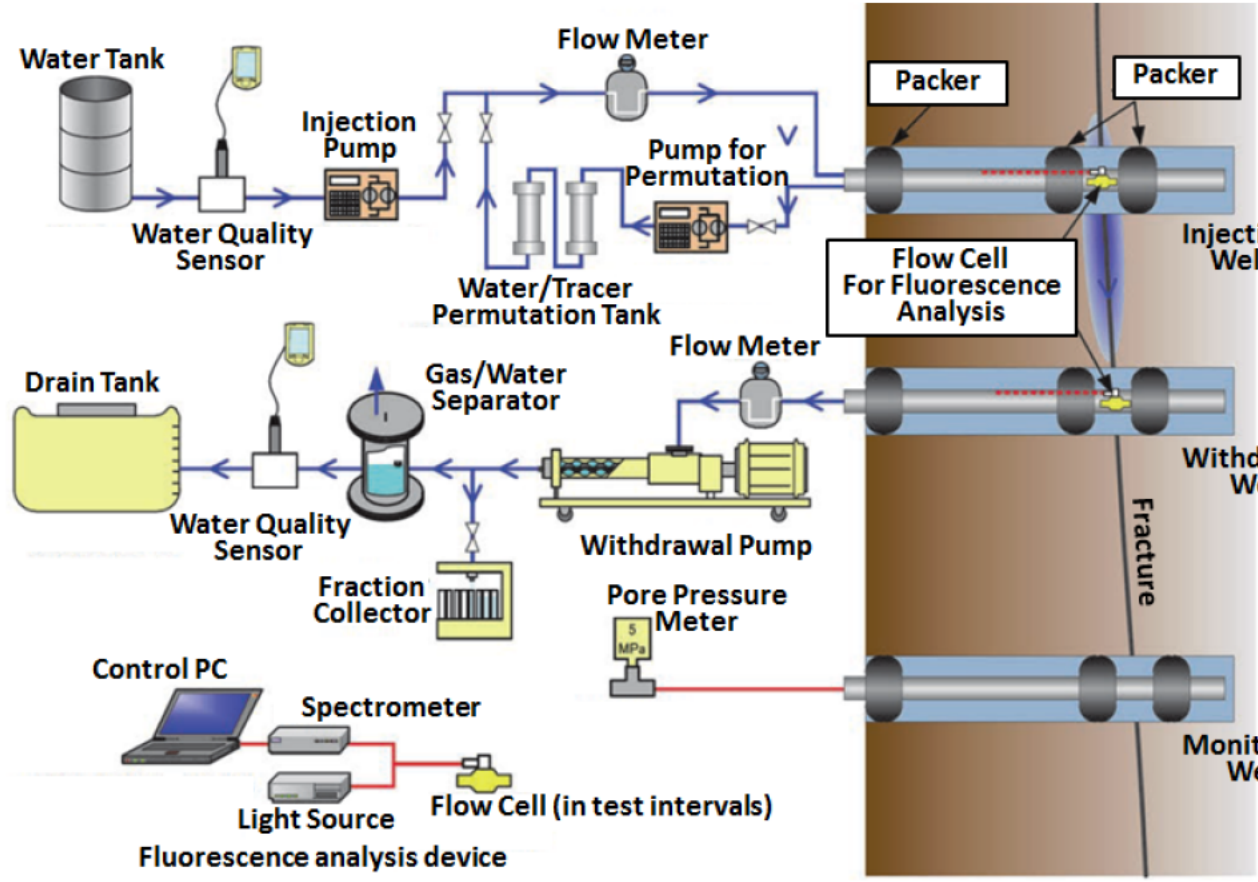
Model development to interpret ST impact & recovery behavior would be necessary to estimate potential impacts on URL construction until closure in future.

A2: Mass transport

Development of advanced method to identify mass transport property

Advanced methods to obtain relevant parameters required for mass transport evaluation have been constructed & tested with reducing troubles on experiment by high dissolved gases.

Schematic illustration of dipole tracer migration experiment reducing effects by high dissolved gases



Nakayama ed. (2012)

- Equipment & apparatus necessary for mass transport experiment have been tested by *in-situ* experiments.

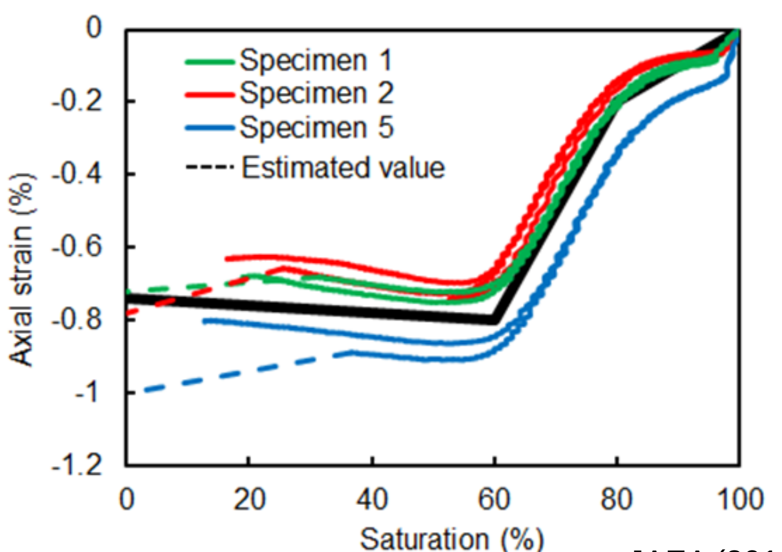
Accumulation of experiences & know-how for *in-situ* mass transport experiment would be required for different types/conditions of sedimentary rocks.

A3: Rock mechanics

Development of method to evaluate LT evolution of mechanical property

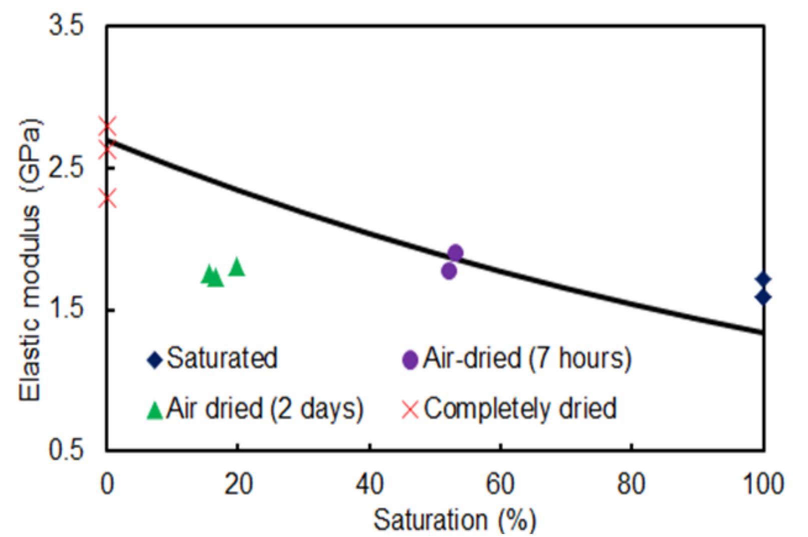
Consideration to evaluate LT evolution of mechanical property has been initiated based on relevant experiments under conditions expected in LT time-scale.

Results of drying-induced deformation test



JAEA (2013)

Relationship between saturation & elastic modulus



JAEA (2013)

- Result of drying-induced deformation test could be interpreted by model estimation.
- Relationship between saturation & elastic modulus could be interpreted by exponential function based on experimental data.

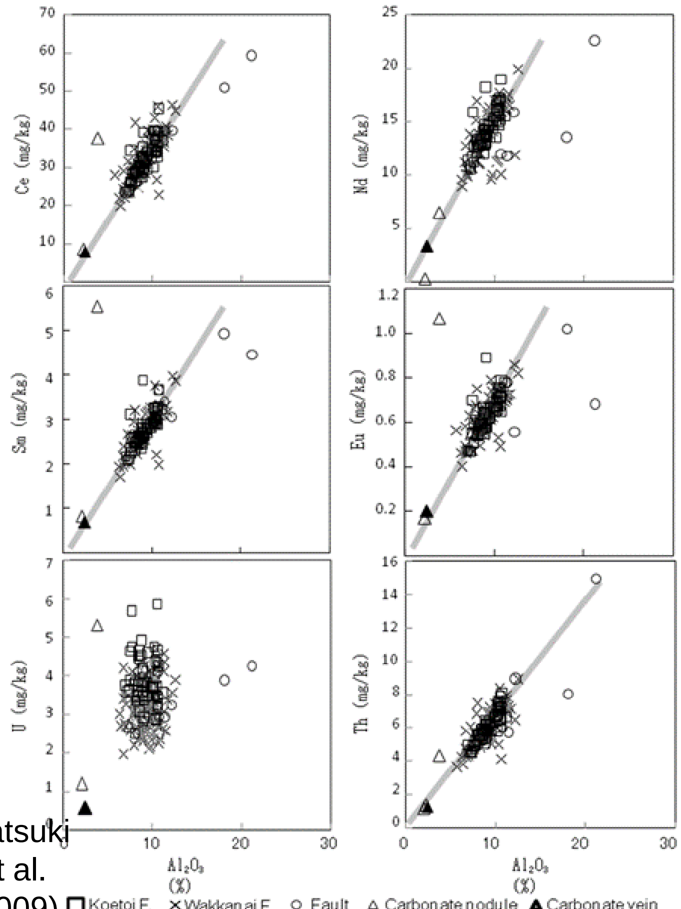
Accumulation of data & experiences for understanding of LT evolution of mechanical property would be necessary to construct reliable model to predict LT evolution.

A3: Mass transport

Development of method to evaluate LT evolution of mass transport property

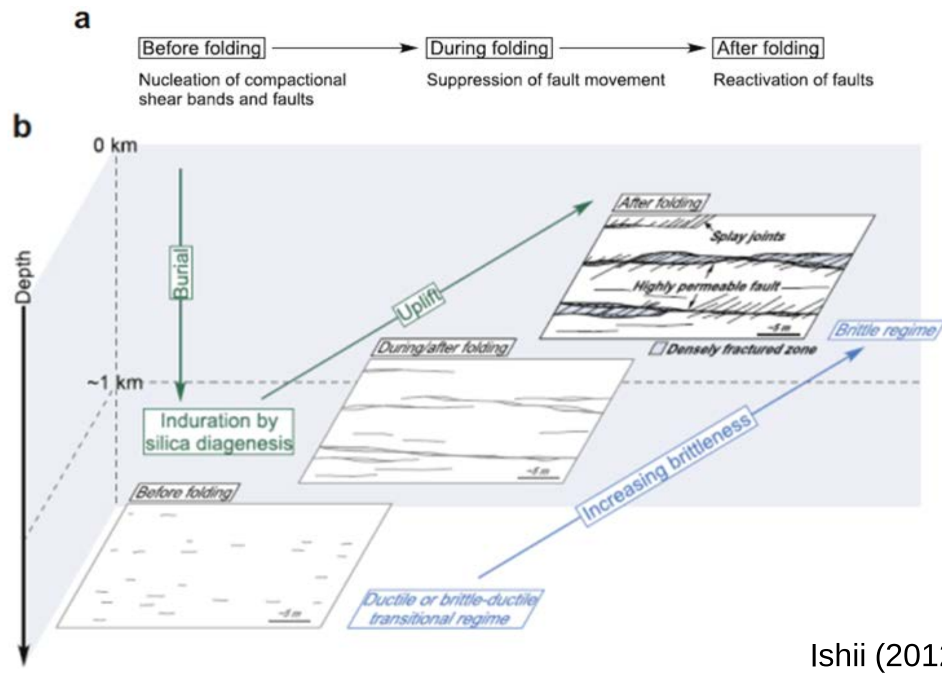
Consideration to evaluate LT evolution of mass transport property has been initiated based on relevant information of geochemical & hydrogeological trends from past-to-present .

Correlation between rare earth elements & Al oxide concentration.



Iwatsuki et al. (2009)

Schematic image for evolution of geological structure related to hydraulic property



Ishii (2012)

- Preliminary results suggest no significant migration may occur in LT except for some fault zones.
- Concept for LT evolution of hydraulic property integrated with competence of rock & natural events (uplift-subsidence).

Development of conceptual model for understanding of LT evolution of mass transport property would be necessary based on natural analogue study for relevant elements considering geological evolution.