Mizunami Underground Research Laboratory Project
- Achievment during Phase I/II and Important Issues for Phase III -

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Abstract

The Mizunami Underground Research Laboratory (MIU) project is being pursued by the Japan Atomic Energy Agency (JAEA) to enhance the reliability of geological disposal technologies in the crystalline host rock (granite) at Mizunami City in Gifu Prefecture, central Japan. The project proceeds in three overlapping phases, Surface-based investigation Phase (Phase I), Construction Phase (Phase II) and Operation Phase (Phase III). The MIU Project has been ongoing the Phase III. During Phase I, a step-wise investigation was conducted by iterating investigation, interpretation, and assessment, thereby understanding of geologic environment was progressively and effectively improved with progress of investigation. An optimal procedure from investigation to assessment was compiled as a set of geosynthesis data flow diagram for each investigation step. During Phase II, we have evaluated adequacy of techniques for investigation, analysis and assessment of the deep geological environment established in the Phase I. For Phase III, three important issues were identified based on the latest results.

(1) Development of countermeasure technologies for reducing groundwater inflow,
(2) Development of modeling technologies for mass transport,
(3) Development of drift backfilling technologies.

For the issue (1), post-grouting works have been applied to a gallery at 500 m depth. Three grouting concepts were applied to the post-grouting works; a new grout material, a new injection system, and a new post-grouting zone. For the issue (2), in-situ and laboratory mass transport experiments have been carried out. The macroscopic and microscopic observations were carried out to understand the distribution of tracer (uranine) after the laboratory diffusion experiment. For the issue (3), with a focus on hydraulic pressure and hydrochemical recovery processes around underground galleries in fractured crystalline rock, the groundwater recovery experiment has been conducted to evaluate the natural groundwater and hydrochemical recovery of the rock mass.

1. Introduction

The Mizunami Underground Research Laboratory (MIU) project is being pursued by the Japan Atomic Energy Agency (JAEA) to enhance the reliability of geological disposal technologies in the crystalline host rock (granite) at Mizunami City in Gifu Prefecture, central Japan. The project proceeds in three overlapping phases, Surface-based investigation Phase (Phase I), Construction Phase (Phase II) and Operation Phase (III). The MIU Project has been ongoing the Phase III. During Phase I, a step-wise investigation was conducted by iterating investigation, interpretation, and assessment, thereby understanding of geologic environment was progressively and effectively improved with progress of investigation. An optimal procedure from investigation to assessment was compiled as a set of geosynthesis data flow diagram for each investigation step. During Phase II, we have evaluated adequacy of techniques for investigation, analysis and assessment of the deep geological environment established in the Phase I. For Phase III, three important issues were identified based on the latest results.

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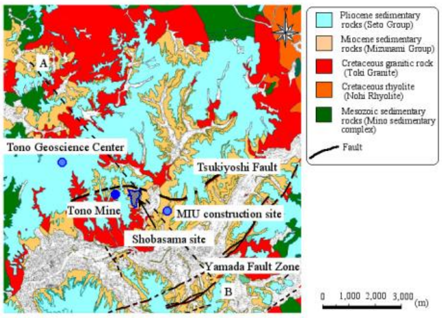
This paper summarizes the achievment during Phase I/II and important issues for Phase III

2. Mizunami Underground Research Laboratory
2. 1 Location

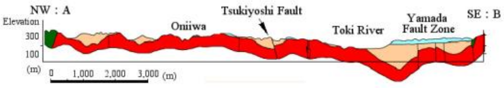
The MIU is located in Mizunami City, Gifu Prefecture, in the central part of Honshu, the main island of Japan. The MIU facility and related surface plant have been constructed on land in Akiyo-cho leased from Mizunami City.

2. 2 Geology, Mechanical and Hydraulic Properties of Rock Mass

The shafts and galleries have been excavated through an overlying sequence of Miocene sedimentary rock (Mizunami Group) and into the late Cretaceous Toki Granite. The Toki Granite has been faulted and has undergone several episodes of uplift and subsidence from the Miocene to the Pliocene, indicated by the presence of lacustrine and marine sedimentary formations unconformably overlying the granite (Fig.1).



i) Geological map



ii) Cross section of the line A-B in the geological map

Fig.1 Geological map and geological section around MIU

The maximum thickness of the sedimentary formations in this area is about 170 m. The average P-wave velocity, unconfined compressive strength and Young's modulus of intact granite are 5.5 km/sec, 150 MPa and 50 GPa, respectively. Table 1 shows hydraulic conductivities of the main rock units and several structural elements based on hydraulic tests in deep boreholes drilled from the surface in and around the MIU site.

Table 1 Hydraulic conductivities of main lithologies and structural elements in and around MIU[1),2)]

Stratigraphy and structural elements			Hydraulic conductivity
			Log [k (m/s)]
Sedimentary rock	Seto Group		-5
	Mizunami Group		-8.5 to -4.0
Toki granite		Upper highly fractured domain	-6.7
		Low angle fracture zone	-5.4
		Lower sparsely fractured domain	-7.7
Highly fractured zone along the Tsukiyoshi fault			-6.4
Fault	Main part of Tsukiyoshi fault		-11
	Other faults	Parallel to fault	-9.0 to -4.0
		Normal to fault	-11

2. 3 Shaft and Galleries

Foundations for the shaft head frames are anchored on bedrock of the upper part of the Mizunami Group. Depth to bedrock at the Main and Ventilation shafts is around GL-10m. By July 2003, the shaft entrances had been excavated. Excavation of the upper, approximately 50m of the shafts started in March 2004, and was followed by installation of shaft-sinking equipment, including the mobile scaffolding, for excavating below 50m depth. In March 2006, shaft excavation started using all of the equipment for shaft sinking. By 2012, excavation of the Main and Ventilation Shaft had reached 500 m depth (Fig.2).

Current design for the MIU is as follows:

- Two shafts, the Main Shaft (6.5m ϕ) and the Ventilation Shaft (4.5m ϕ); and
- Two experimental levels, at the 300 m level and the 500 m level.
- Sub stages, at the 100m, 200m and 400m levels

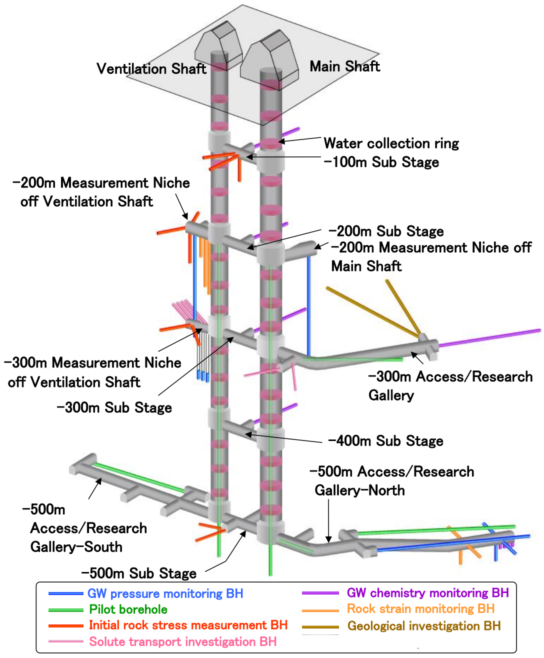


Fig.2 Layout of MIU

3. Summary of the Phase I and Phase II investigations

The investigations during Phase I followed the sequence of overall characterization of the regional geological environment, identifying investigation items requiring more detailed information and borehole investigations addressing the investigation items. Investigations were scheduled so that interactions among excavations or borehole tests due to simultaneous implementation of several borehole investigations could be avoided. More specifically, investigations were categorized into six groups as shown in Fig. 3: surveys of existing information and five investigation steps moving from surface reconnaissance to crosshole tomography surveys and crosshole hydrological tests.

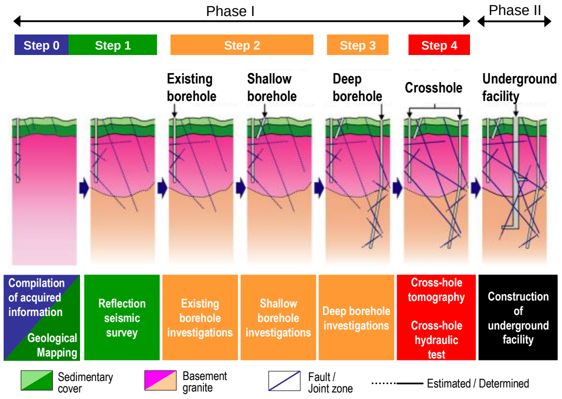


Fig. 3 Concept of Phase I/II investigations

In the following chapter, detailed results of hydrochemical investigations are described as an example. Step-wise approach was applied for hydrochemical investigation in and around the MIU construction site. Hydrochemical investigations are carried out in step 0 (surveys of existing information), in step 2 (surveys in existing boreholes and new shallow borehole investigations) and also in step 3 (new deep borehole investigations).

3.1 Phase I Investigations

(1) Step 0 (Surveys of existing information)

For the local-scale area, data on groundwater chemistry, pH and redox conditions had been obtained mainly from borehole investigations carried out as part of the regional hydrogeological study. Using these data, the spatial distribution of the hydrochemical characteristics of the groundwater between the boreholes were estimated using the kriging method. It was indicated that the groundwater in the granite was Na-Cl type, the concentration of chloride ions increases with depth, the pH of the groundwater was mildly alkaline and the redox conditions were estimated to be weakly to strongly reducing. Mass balance analysis and multivariate analysis indicate that the chemistry of the groundwater could be explained by the mixing of several groundwaters with different salinities. One of the main processes determining groundwater chemistry was thus identified as being the mixing of groundwaters with different salinities

(2) Step 2 (shallow borehole investigations)

One of the goals of the investigations in this step is to validate and update the hydrochemical model and to determine the geological environment prior to the construction of the URL. In this step, groundwater and rock samples were collected and analyzed for hydrochemical analysis and for updating the model, by conducting borehole investigations for the Mizunami Group with a thickness of a few tens of meters to approximately 200 meters, covering the Toki Granite.

The results of the investigations indicated that the groundwater in the sedimentary rocks is Na-Ca-HCO_3 type, rich in silicon and sulphate ions in the shallower part and Na-Cl type in the deeper part of the Mizunami Group and the upper part of the Toki Granite. It was also found that the salinity of the groundwater generally increases with increasing depth. A low permeability formation was found at the depth where the boundary occurs between the Na-Ca-HCO_3 type and the Na-Cl type groundwater in the Mizunami Group, below which a significant decrease in hydraulic head was observed. This was considered to be due to the existence of the low permeability formation and due to the fact that the distribution of the characteristics of the groundwater chemistry may be governed by the hydrogeological structure. In the shallower part of the Mizunami Group, the hydrogen/oxygen isotope ratio in the groundwater varies within the range of fluctuation of that in the precipitation water sampled around the URL construction site and tritium was also detected. Thus, the origin of the groundwater in the shallower part of the Mizunami Group is considered to be recent precipitation, with a faster recharge rate compared to the groundwater in the deeper part of the Mizunami Group3).

(3) Step 3 (deep borehole investigations)

The objectives of the deep borehole investigations include determining the hydrochemical property of the groundwater in the granite to a depth of approximately 1,000 meters before construction of the URL. A further objective is to determine hydrochemical property of the groundwater encountered in the URL as input for planning the investigations in Phase II. Groundwater and rock samples were collected and analyzed and the hydrochemical model based on the investigation results from Step 2 and preceeding steps was updated.

Na-Ca-Cl type groundwater with a salinity of approximately 2,500 mg 1^{-1} (one tenth of the salinity of seawater) was found in the granite at a depth of approximately 1,000 meters. The quantitative hydrochemical model with the 3D distribution of the groundwater chemistry was updated by repeating the multivariate analysis, with more reliable data on the water chemistry obtained during step 3. The pH of the groundwater was in the range of 8 - 9 and this was consistent with the result predicted in Step 0. From the thermodynamic analysis for the equilibrium condition of the water-rock reaction and microscopic observation of rock alteration, the water has a major pH buffering capacity due to dissolution/precipitation reactions with carbonate minerals3). Although there is no measured value for the redox potential in situ, based on mineral observations and the results of dissolved gas analysis, possible occurrence of redox reactions involving iron minerals, sulphur minerals and hydrogen sulphide gas was indicated. With regard to the origin and residence time of the Na-Ca-Cl type groundwater, it was concluded from the isotopic composition and the ratio of the dissolved chemical components that the groundwater was diluted from saline water that either originated from fossil seawater or from long-term water-rock reactions. The hydrochemical model of the distribution of groundwater chemistry on the site scale that was constructed in Step 0 was updated using the results from this step (Fig. 4) 3).

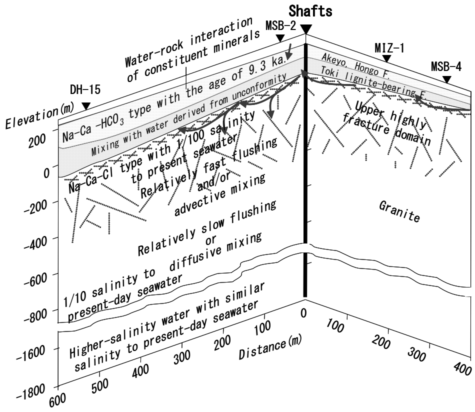


Fig. 4 Hydrochemical conceptual model around URL

3.2 Phase II investigations

During Phase II investigations, the changes in groundwater salinity and pH/redox conditions have evaluated. In this section, the results concerning changes in salinity have been summarized.

Hydrochemical monitoring was conducted in and around the MIU during the shaft construction down to G.L. −500 m depth (Fig. 5).

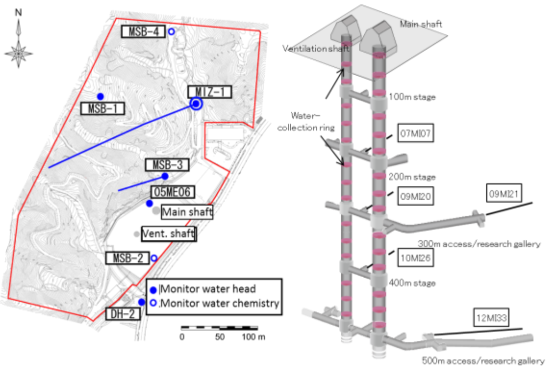


Fig. 5 Hydrochemical monitoring boreholes in and around the MIU

Water-collection rings (WR) were placed every 25 m in the shafts to direct the water inflow and reduce the water pressure on the concrete lining. The inflow rate was measured at each WR in the shafts. The highest water inflow occurred from the conglomerate layer; this is probably the dominant groundwater flow path in the sedimentary rock.

The groundwater chemistry in the WRs is possibly affected by water–cement interactions caused by contact with the concrete liner. Incidentally, Cl is not susceptible to water–mineral interactions. The Cl concentrations in the WRs and boreholes increased during the initial observation period but subsequently decreased with time. The groundwater chemistry at depth was affected by the upconing in the initial period. After the excavation of the shaft had advanced to deeper depths, the upconing point also moved to a greater depth. In the upper depths, upconing was reduced and the impact of shallower groundwater infiltration increased with time4). To assess shallow water infiltration, stable isotopes, tritium (^{3}H), and chlorofluorocarbons (CFCs) as tracers of shallow groundwater were monitored in granitic rock for 5 years. The results showed that the shallow groundwater infiltrates into the groundwater at depths of 200–400 m after 10 years of drainage (hundreds ton/day). The mixing ratio of surface water in deep groundwater can be approximately estimated using CFC-12 data. The hydrochemical changes in groundwater were estimated by principal components analysis (PCA) 4). It is presumed that deep groundwater will be replaced by shallow groundwater in the future.

The groundwater in 07MI07, 09MI20, and 10MI26 initially had relatively high Na, Ca, and Cl and low DIC and SO_4 concentrations, which subsequently changed to relatively low Na, Ca, and Cl and high DIC and SO_4 concentrations. This tendency was clearly observed near the borehole collars in the excavations (e.g., zones 5 and 6). Horizontal monitoring boreholes were drilled sequentially in the deepest gallery during excavation. Therefore, the observations at each borehole were affected by upconing during the initial period. In boreholes 07MI07, 09MI20, and 10MI26 on the south side of the Main Shaft fault, groundwater with relatively high levels of Na, Ca, and Cl and low DIC and SO4 concentrations during early observations was representative of the upconed-water around the Ventilation Shaft. Since then, relatively shallow groundwater has infiltrated to the area around the Ventilation Shaft and is characterized by low levels of Na, Ca, and Cl, and high DIC and SO_4 concentrations. This process of groundwater replacement is most likely occurring at a faster rate on the south side of the Main Shaft fault than on the north side of the fault, reflecting the extent of hydraulic impact. However, such trends were not observed in borehole 09MI21 on the north side of the Main Shaft fault. Borehole 09MI21 is located approximately 100 m north of the Main Shaft fault and was drilled into LSFD. Hydrochemical changes in the groundwater here were most likely caused by mixing with groundwater at 300 m depth without having been influenced by the upconing along the shaft. In general, mixing with shallower groundwater became the dominant process on the south side of the Main Shaft fault whereas mixing with deeper groundwater dominated groundwater chemistry on the north side of the fault[3].

To infer the infiltration of shallow groundwater as a result of the long-term drawdown into the shafts, measurements of tritium and chlorofluorocarbon (CFC) concentrations were used as an index of surface water infiltration. Tritium was detected at several monitoring zones even though the concentrations dropped to zero at around 200 m depth prior to shaft excavations[3]. CFC-12 was first detected in 2010, and the concentrations gradually increased with time as observed in boreholes 07MI07 (200 m depth), 09MI20 and 09MI21 (300 m depth), and 10MI26 (400 m depth). This implies that surface water containing CFC-12 penetrated up to 400 m depth within a few years.

4. Important issues for Phase III

The R&D results during Phase I/II investigations have summarized in a synthesized research report[5]. For the Phase III investigations, the following three important issues were identified in the this five years (2015-2020) based on the latest results.

(1) Development of countermeasure technology for deep underground application to mitigate problems/issues

・Water-tight grouting technology

(2) Development of modelling technology for mass transport

・Fracture network modelling technology for heterogeneous fracture networks

・Technology for analysis and evaluation of long-term changes of the geological environment

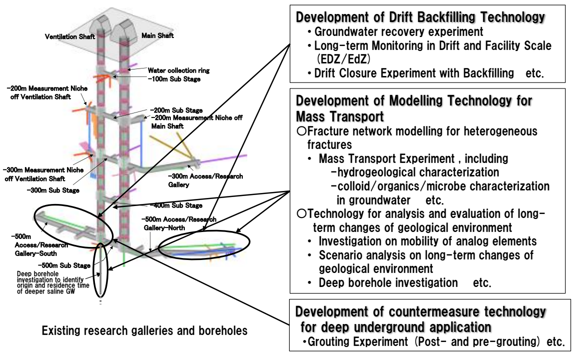
(3) Development of Drift Backfilling Technology

・Long-term monitoring technology

・Environment recovery technology with sealing of tunnels and the facility

Experiments into each research topic will be mainly carried out at the 500-m depth research gallery (Fig. 6).

For the issue (1), post-grouting works have been applied to a gallery at 500 m depth. Three grouting concepts were applied to the post-grouting works; a new grout material, a new injection system, and a new post-grouting zone. For the issue (2), in-situ and laboratory mass transport experiments have been carried out. The macroscopic and microscopic observations were carried out to understand the distribution of tracer (uranine) after the laboratory diffusion experiment. For the issue (3), we have already started a groundwater recovery experiment as part of the research into development of drift backfilling technology. The main objective of this experiment is to observe any changes of hydraulic and hydrochemical conditions and the recovery process during flooding of a gallery to develop monitoring technology and to acquire the requisite knowledge and develop the methodology for appropriate facility closure before performing a partial backfilling experiment at the drift scale[6].



Development of Drift Backfilling Technology
・Groundwater recovery experiment
・Long-term Monitoring in Drift and Facility Scale (EDZ/EdZ)
・Drift Closure Experiment with Backfilling etc.

Development of Modelling Technology for Mass Transport
○Fracture network modelling for heterogeneous fractures
・ Mass Transport Experiment , including
-hydrogeological characterization
-colloid/organics/microbe characterization in groundwater etc.
○Technology for analysis and evaluation of long-term changes of geological environment
・ Investigation on mobility of analog elements
・ Scenario analysis on long-term changes of geological environment
・ Deep borehole investigation etc.

Development of countermeasure technology for deep underground application
・Grouting Experiment (Post- and pre-grouting) etc.

Fig.6 Location of planned experiments

Prior to construction of the experiment gallery, a pilot borehole, adjacent and parallel to the gallery, was drilled to estimate baseline hydraulic and hydrochemical conditions.

Hydraulic and hydrochemical conditions and any changes during gallery construction have been monitored in the borehole. Geological mapping on the gallery was done to determine the fracture distribution. In additional monitoring boreholes drilled after construction of the gallery, hydraulic and hydrochemical conditions have been monitored. And, in addition, a backfill material test was started using a pit bored into the experiment gallery floor in order to acquire data on saturation phenomena in the backfill material and assess its influence on the hydrochemical environment in the rock mass. A plug will be installed at the entrance to the experiment gallery in order to understand and assess the recovery process in terms of hydraulic pressure changes, changes in hydrochemical conditions and in rock stress distribution around the gallery during flooding and draining events. Applicability of monitoring techniques and plug performance during a facility closure phase can then be validated based on the results.

5. Summary

This paper summarizes the results of investigations, providing an example of stepwise investigation /evaluation of the geological environment relevant to geological disposal using surface-based investigations and investigations during shaft construction in the crystalline rock in the Tono area as a case study. And know-how for the execution of investigation/modeling can be obtained through the Phase 1/II investigation.

Techniques for investigations and analyses and technical findings established or obtained in Phase I and II could be applied widely with appropriate consideration of the differences in the characteristics of the geological environment of interest and making appropriate modifications. The R&D activities planned for this five years (2015-2020) also has presented. JAEA will execute the R&D plan and promote the R&D activities in Phase III at the MIU with the objective of building technical confidence.

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