JNC TN5400 2004-004

International Workshop on Horonobe Underground Research Laboratory Project

Abstracts

October, 2004

Horonobe Underground Research Center
Japan Nuclear Cycle Development Institute

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International Workshop on Horonobe Underground Research Laboratory Project

Abstract

(Research Document)

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Abstract

Japan Nuclear Cycle Development Institute (JNC) is pursuing two underground research laboratory (URL) projects to conduct a systematic research on geological disposal of high level radioactive wastes. The Tono Geoscience Center (TGC) has been carrying out research and development in crystalline rocks at Mizunami in central Japan and the Horonobe Underground Research Center in sedimentary rocks at Horonobe in northern Japan. Both projects are nearing termination of the first phase of surface-based investigation and is about to move on to the next phase of actually constructing the facilities underground. To mark this transition of phases, an international conference is organized to promote domestic and international recognition for the significance of constructing the URLs by disseminating research findings to a broad range of researchers and specialists from within and outside Japan as well as to the local community. Guest speakers from overseas organizations will also be invited to draw on their experiences and pave the way for an active discussion and exchange of opinion. It is hoped that the conference will bring out comments and further discussion on the two URL projects under way to be reflected in the subsequent phases.

The conference is divided into two parts, each to be held at the two proposed URL sites. Part 1 will be devoted to various findings in Mizunami URL (MIU), and the regional hydrogeological study. The second part will focus attention on the findings in the more recently commenced Horonobe URL project.

This report includes the abstracts for the international workshop on the Horonobe URL project.

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[3] Horonobe Underground Research Center Geoscience Facility Construction Group

Contents

An Introduction to
Horonobe Underground Research Laboratory Project

Shinichi YAMASAKI

Introduction

Two off-site (generic) underground research laboratory (URL) projects have been conducted by JNC, one for sedimentary rock (Horonobe, Hokkaido) and the other for crystalline rock (Mizunami, Gifu). These URLs are those that the Long-term Program for Research, Development and Utilization of Atomic Energy (Long-term Program) by Atomic Energy Commission of Japan states their technical and social importance and expectation of earlier execution.

The technical aims of the Horonobe URL project are presenting concrete geological environment as an example of sedimentary formation in Japan and confirming reliability of technologies for geological disposal of High-Level Radioactive Waste (HLW) by applying them to actual geological condition of sedimentary formation. Meanwhile, the social aim is providing opportunities for general public to experience the actual deep underground circumstance and R&D activities to be conducted there.

The project is composed of six technical subjects; 1) development of site characterization methodology, 2) development of monitoring techniques, 3) development of engineering techniques in deep underground and 4) study on neotectonics of the region/area, 5) development of engineering techniques for designing, construction and operation of a repository and 6) development of safety assessment methodology.

Research and development activities are planned over three phases that will span a total duration of about 20 years: the 1st surface-based investigation phase (6 years), the 2nd URL construction phase (8 years) and the 3rd operation phases (12 years). Phases are overlapped phase by phase.

The Horonobe URL project started its history with execution of an agreement by Hokkaido, Horonobe and JNC in November 2000.

JNC is bound by the agreement over to; 1) JNC will never bring nor use HLW in the area for the project, 2) JNC will never lend nor transfer the URL facilities to the implementing entity, Nuclear Waste Management Organization of Japan (NUMO), 3) JNC will close the facilities on the ground and refill the underground facility after completion of the project, 4) JNC never has the area be a site for repository for radioactive wastes nor introduces an interim storage of radioactive wastes in Horonobe.

Geology of the Area

Horonobe town is located in northernmost part of Hokkaido where northern latitude of 45 degree runs (Fig. 1). The gentle topography is thought to be periglacial landform. The area is located about 15km from the present coast line of the Japan Sea. The Teshio River, the 2nd longest river in Hokkaido, bounds southern margin of Horonobe town. There is a hot spring about 3km from the URL site in north neighboring Toyotomi town.

Horonobe town consists of Neogene sedimentary sequences (ascending orders; Souya coal-bearing Formation, Masuhoro Formation, Wakkanai Formation, Koetoi Formation and Yuchi Formation), which are underlain by igneous and Palaeogene to Cretaceous sedimentary basement. There are some faults called the Omagari Fault and Nukanan Fault zone in the area of interest within Horonobe town. The Wakkanai and Koetoi Formations, which are Neogene argillaceous sedimentary formations are selected for host geology for the URL.

The area is located in the tectonically active region. Microearthquake swarms have occasionally occurred in and around the Horonobe town and the Eastern margin of the Japan Sea is well defined as a seismic zone, especially microearthqukes. The Omagari Fault had been active until early Quaternary and thought to have a maximum vertical displacement of over 1000m in consideration of folding displacement. Present fault activities are thought to be occurred to the west of the Omagari Fault. Horonobe town is famous with a wetland located along the coast line where subsidence is predominated in Holocene. On the contrary, marine terrace deposits west to the wetland have been uplifted in Quaternary.

Horonobe town is located in a coal field and there used to be some coal mines in the Horonobe town. The area also located in the oil/gas field. The oil/gas exploration work including deep borehole investigations has been conducted in the region. The Toyotomi Hot Spring is a gift of the old exploration.

Surface-based Investigation Phase

After the inauguration of the project, surface-based investigations have been conducted since 2001. Along with the town-wide investigation, an area for intensive site investigation (URL area) was selected (Fig. 2) then land for facilities construction (URL site) was acquired in the area and the land preparation has started last year.

The investigations provided a lot of data which advanced our understanding on the geological environment of the area. Techniques and equipments which have been employed with improvements needed for the geological environment of the area have been confirmed their feasibility.

The main methods we employed are heli-borne electromagnetic, magnetic and gamma spectrometry surveys, ground geophysical survey (magnetotellulic methods (MT/AMT) in 2001, 2003, reflection seismic survey in 2002), geological mapping, shallow borehole investigation (including methane measurement), observation of precipitation, evapotranspiration and run-off (river flux) and deep borehole investigation. The town-wide area was the subject to the investigation of 2001, then the selected URL area has been the main subject to the following year's investigations. Deep boreholes drilled by the end of fiscal year 2003 total 8 holes and about 4,600m long.

Hydraulic monitoring system has been installed in deep boreholes drilled and is getting ready to start monitoring initial hydrological and hydrochemical conditions before URL construction. Seismic and electromagnetic active monitoring systems, called "ACROSS (Accurately Controlled Routinely Operated Signal System)" have been developed and installation of source and receiver systems is ready to start.

In order to understand present tectonic activities, a seismic observation system consists of one seismometer at the bottom of a borehole of about 140m deep and four seismometers on ground surface have been installed and more than 70 earthquakes were observed. A magnetotelluric observation system and a GPS system are also introduced. Apparent resistivity observed so far show static state. GPS data show a SE trended sharp horizontal movement of about 4cm of the observation point in the Tokachi Off-Shore Earthquake of September 26, 2003.

As the last campaign of the surface-based investigation, we plan to conduct detailed reflection seismic survey and 3 deep borehole investigations from this year to next year. The seismic survey is expected to reveal a clearer picture of the Omagari Fault. In the borehole investigation, in-situ measurement of pH/Eh and a task force for prior prediction are planned.

Modeling of geological environment of the area and prediction of the effect of shaft sinking have been done and they must be more confident before URL construction as they are going to be confirmed with data obtained during URL construction.

To confirm their feasibility, application of the geological disposal methods for repository and engineered barrier designing and performance assessment to the Horonobe case using the data obtained and the models made is in progress. In-situ experiments plan has been prepared for understanding the near-field system and application of disposal technologies. The former deals with experiments for THMC behavior, creep behavior, gas migration, overpack corrosion, cement effect and solute transport. The latter deals with transportation and emplacement of engineered barriers, low alkaline concrete performance and sealing of shaft and tunnel.

With the geological information obtained a detailed designing of URL is underway in parallel with planning of in-situ experiments in Phase 2 and 3 to give more detailed and concrete figure of URL in order to start its construction in 2005. The URL is planned to be composed of three shafts down to about 500m deep, two for access and one for ventilation and experimental tunnels to be developed at appropriate levels. The construction will start with the construction of shaft collar structures in 2005 and installation of a head frame in 2006 will be followed by full-scale shaft sinking to be completed in early 2010s.

Nature of the Geological Environment of the Area

The host argillaceous formations consist of diatomaceous mudstones. Mudstones are porous, especially that of Koetoi Formation is very porous with max. porosity of about 60% and even more compacted mudstone of the Wakkanai Formation have the porosity of 30 to 40%. Mudstones have fairly abundant fractures. The area has been thought to be cut by the Omagari Fault, but it is not yet well characterized by the surface-based investigation.

The mudstone is classified into soft rock; for instance, mudstone of the Koetoi Formation shows its average unconfined compressive strength of about 5MPa. On the other hand, that of the Wakkanai Formation varies from less then 10MPa to more than 30MPa and the average is about 15MPa. Some of the variety is possibly caused by its heterogeneous nature (Fig. 3). The direction of about EW of the horizontal maximum principal stress obtained by hydrofracturing done in boreholes in the area is concordant with the regional geotectonic setting.

Hydraulic conductivity of the mudstone is smaller than n*E-9m/sec. with some exceptional figures obtained from fracture zones in the Wakkanai Formation in shallower part. The vertical distribution of hydraulic conductivity shows fairly good depth dependency especially for fracture zone of the Wakkanai Formation (Fig. 4). Over pressure is observed in a deeper section of the Wakkanai Formation of a borehole, HDB-2 drilled in the south to the area. To meet existence of dissolved gas, we modified hydraulic testing equipment and testing procedure.

Groundwater samples are collected from packed-off sections in the boreholes and by squeezing of drill cores. Groundwater can be classified into three types, such as deep Na-Cl saline water, very shallow meteoric fresh water and mixture of these two. Salinity of the deep saline water looks inversely proportional to the degree of diagenesis of the host rock. In spite of the difference of the salinity, oxygen and hydrogen isotopic nature of saline water is much the same (Fig. 5). The oxygen and hydrogen isotopic data also support the mixing nature of the deep saline waters and shallow fresh waters. Methane is generally dissolved in groundwater.

Conclusion

After 4 years investigations, our understanding of the geological environment of the area has considerably advanced. One of the most important tasks still remained is to try to synthesize the data to make a comprehensive multi-disciplinary explanation (model) of the geological environment. Direct measurements of in-situ physicochemical properties, such as pH/Eh will help to make the explanation (model). On-going application of repository and engineered barrier designing and performance assessment methods to the data of the area as a case study will also helps to refine the explanation (model).

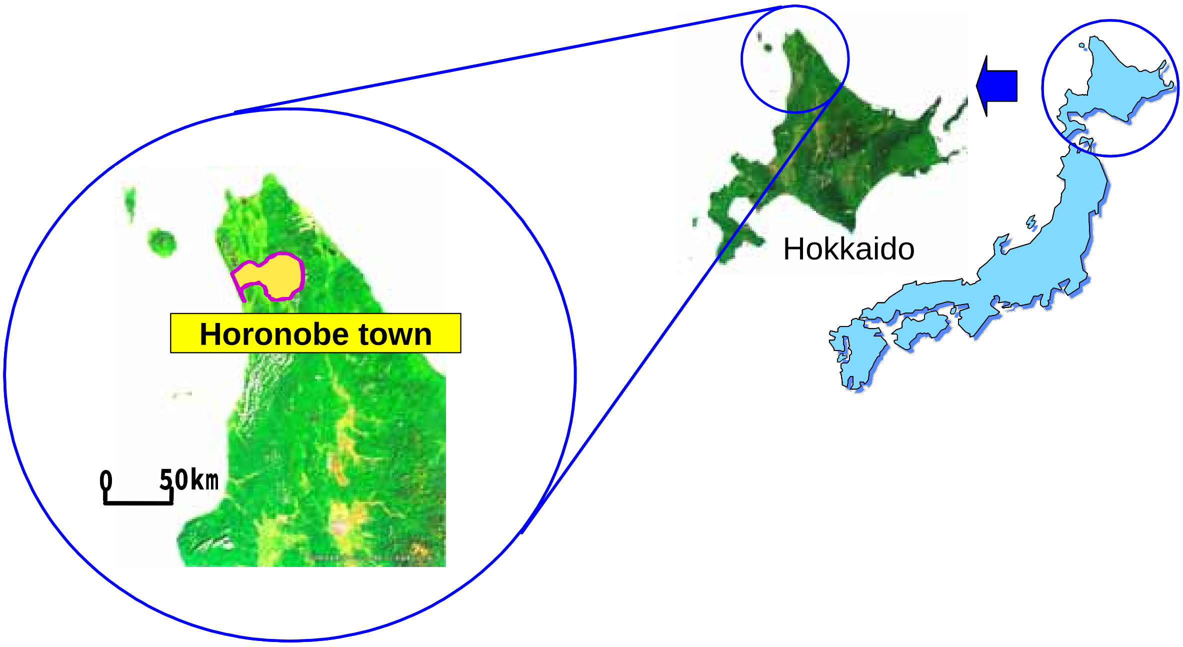

Fig.1 Location of the Horonobe town

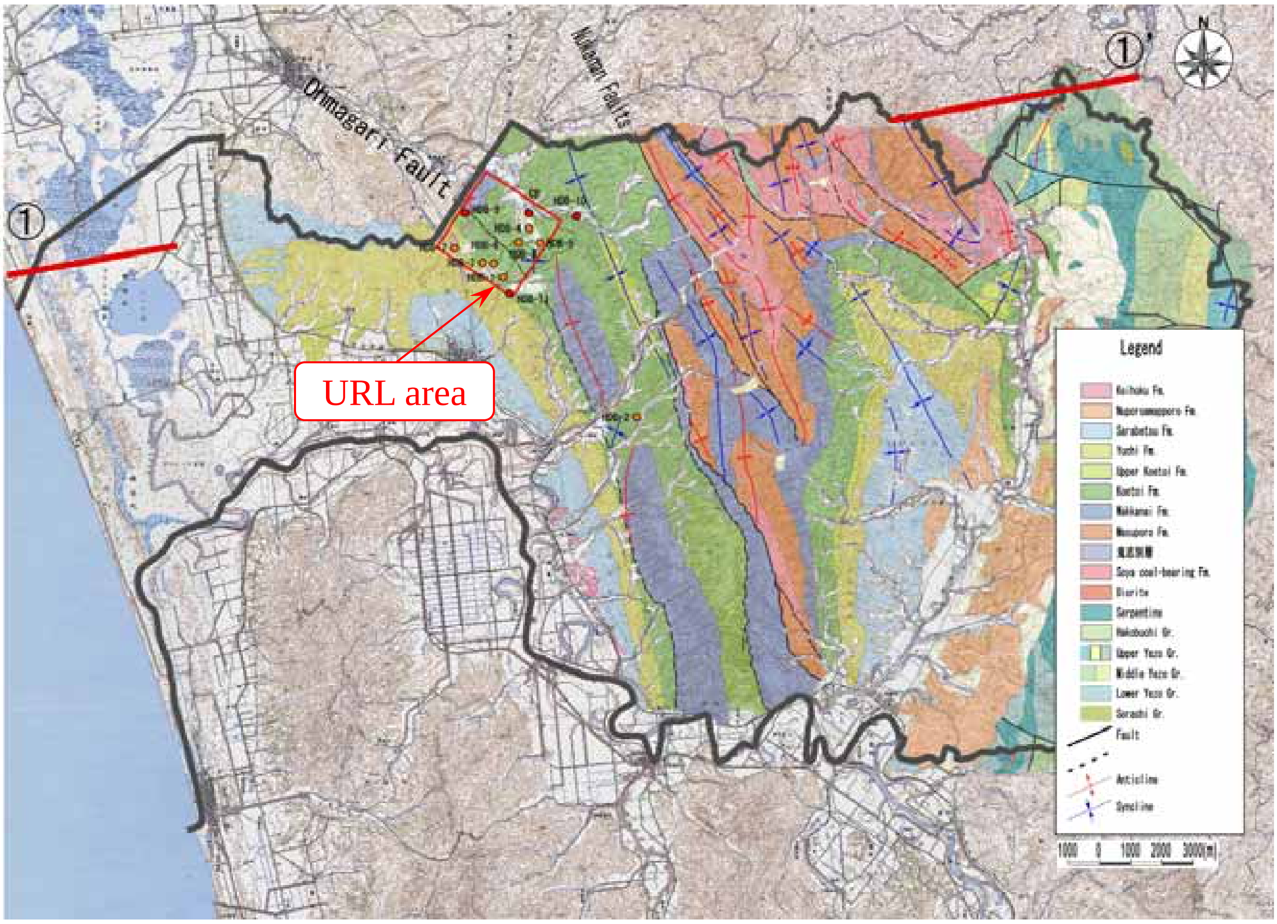

Fig.2 Location of the URL area

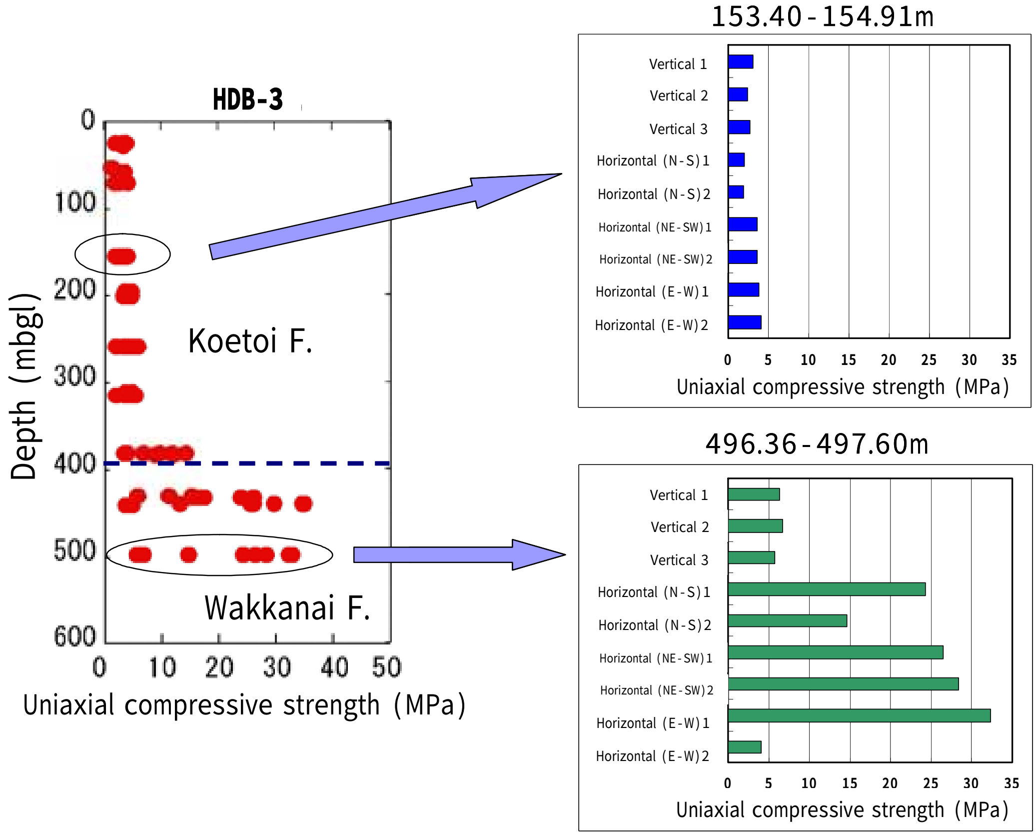

Fig.3 Heterogeneity of rock mechanical property

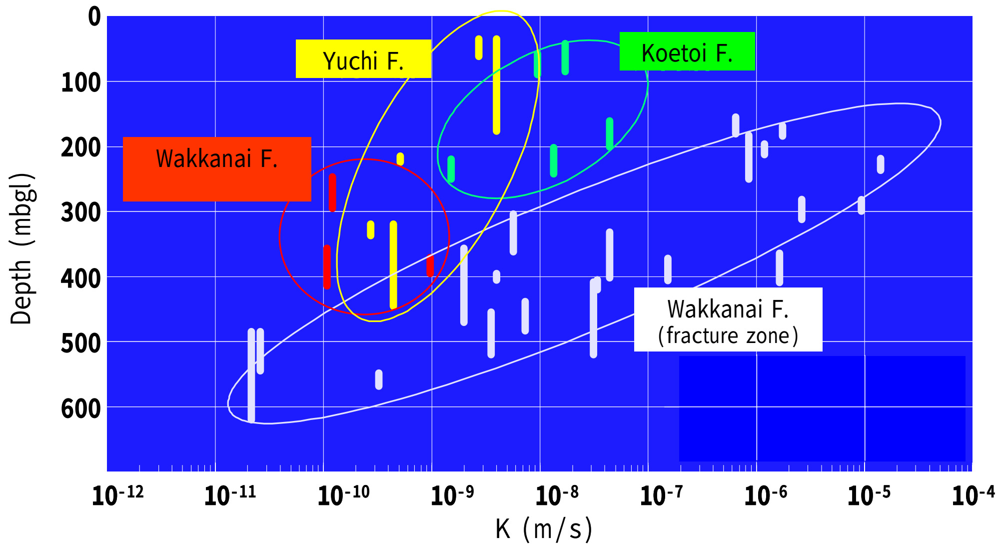

Fig.4 Depth profile of hydraulic conductivity by in-hole hydraulic test

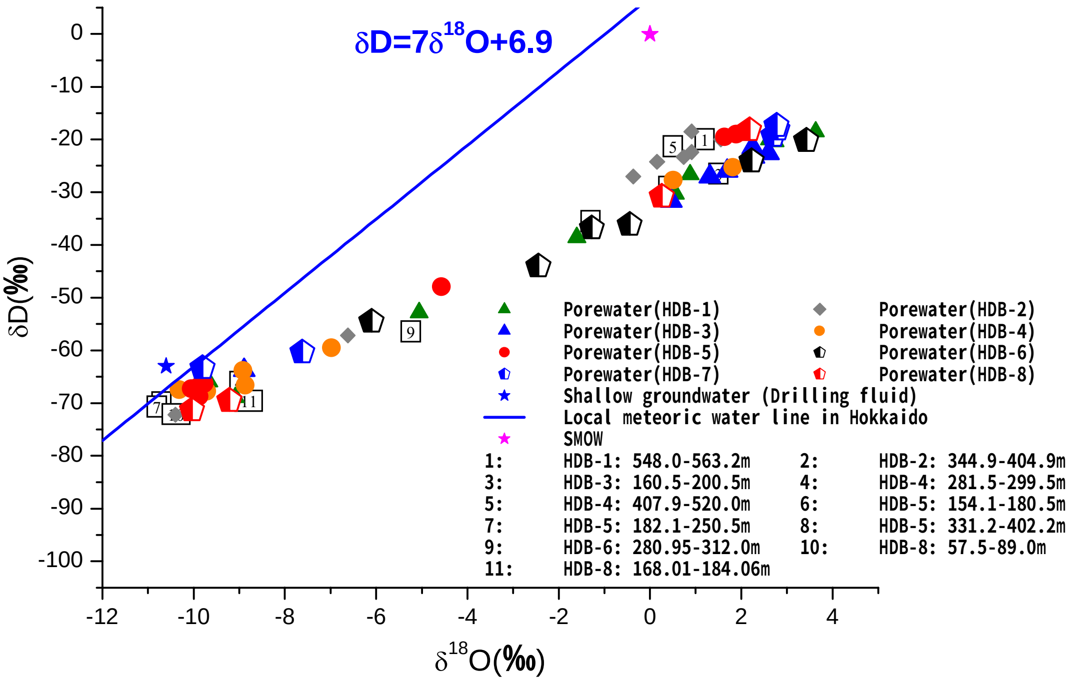

Fig. 5 δD-δ^{18}O diagram of groundwater

Horonobe Underground Research Laboratory Project
The Present Status in Investigation from the Surface
-Geology and Rock Mechanics-

Hiroya MATSUI

1. Objectives

Horonobe URL (Underground Research Laboratory) project in investigation from the surface (Phase I) pursued according to the following steps,

Step 1: Selection of a URL area in Horonobe-cho

Step 2: Selection of a URL site in the area

Step 3: Comprehensive investigation in and around URL in the area

The investigation programs were planned from 2001 in consideration of above steps. The main goals in geology and rock mechanical investigations in Phase I are to predict the geological environment of the area and the impact of constructing the URL facilities on geological environment. The predictions will be validated with the data acquired during the investigation during the construction of underground facility (Phase II). The objectives for geoscientific studies on the geology and rock mechanics are shown below.

Geology

To understand the geology and geological structure of the area.

To construct 3-D geological structural model for the basis of groundwater flow, rock mechanical and geochemical modeling.

Rock mechanics

To understand the mechanical properties distribution and in-situ stress state in the area for the selection of a URL site.

To provide the mechanical properties and in-situ stress for the URL design

2. Overview of the investigations from 2001 to 2003

In the project, the JNC's research area is limited within Horonobe-cho by the political reason. On the other hand, geological information of a regional scale is necessary for groundwater flow modeling. Therefore, collections of existing geological information in/around Horonobe-cho were carried out. Then, the information was confirmed its reliability by geological mapping, air-bone and ground geophysical survey. Secondly, borehole investigations of HDB-1 and HDB-2 were carried out to select the URL area in Horonobe-cho. As step 2, next borehole investigations (HDB-3,4,5) , seismic geophysical survey and geological survey in the URL area were carried out to select the URL site. In step 3, geological mapping, magnetotelluric geophysical survey and borehole investigations (HDB-6, HDB-7, HDB-8) performed in and around the URL area to collect data for design of URL and modeling of geological environment in the URL area.

At the beginning of the project, the data for mechanical properties of a borehole with about 1300m deep drilled in south to the URL site 18 years ago was available. However, there was no data for in-situ stress. In the boreholes HDB-1and HDB-2, in-situ stress measurements with hydraulic fracturing were performed. After the selection of the URL area, mechanical investigations were performed to confirm the constructability of URL and to provide mechanical information for URL design.

3. Main interests of the investigation

The investigation program on geology are focused following items to understand three dimensional geological structure of the URL area,

1) Lithology
2) Stratigraphy
3) Geological structure; Fault, fracture zone and fracture folding

A fault namely “Omagari” fault is thought to be run the URL area from SE to NW. Maximum vertical dislocation is said more than 1000m in its southern extension.

The investigation program on rock mechanics was planned to understand the following items in the URL area.

1) Three dimensional distributions of mechanical properties in the URL area.
2) In-situ stress condition in the URL area, more detailed near the URL site.

4. Preliminary Results

4.1 Geology

The resistivity distribution in Horonobe-cho obtained by air-bone magnetotelluric survey was consistent with the existing surface geology (Yamasaki et.al. 2000). Based on the results, we made the first 3-D geological structural model. In the model, major faults were considered based on the existing geological information.

The borehole investigations of HDB-1, HDB-3, HDB-4, HDB-5, HDB-6, HDB-7 and HDB-8 provided the data to establish the present lithostratigraphic definition that upper Koetoi Formation consists of diatomaceous mudstone and lower Wakkanai Formation consists of more tight, slightly harder shale. The difference is thought to be caused by the difference of degree of diagenesis. Upper most part of the Wakkanai Formation forms transition zone between upper Opal-A and lower Opal-CT zones.

The Omagari fault is inferred to located between HDB-6 and HDB-8 and close to HDB-4 by the results of the seismic reflection survey, audio-frequency magnetotelluric survey and borehole investigations. Lithostratigraphic correlation by shallow boreholes data drilled between HDB-6 and HDB-8 was found only little vertical stratigraphic difference between the HDB-6 and HDB-8. The methane with high concentration was detected in the measurement in the shallow boreholes and the result may suggest that the passes for methane to more upward from deeper part exist. On the other hand, based on the detailed interpretation of the reflection seismic survey, the gap's of the Wakkanai/Koetoi Formation boundary were detected clearly between HDB-6 and HDB-8. The gaps location is corresponding to one of the two high-resistivity areas found by audio-frequency magnetotelluric survey, and the other is close to HDB-4.

Core observations indicate that the fractures can be classified into two types (figure.1). One is the fractures crossing bedding planes at a high angle, frequently with fault rock/striation/slickenside. The other is the fractures parallel to bedding planes, rarely with fault rock/striation/slickenside. The former forms the fracture zones which are considered to be water conductive feature in the URL area (figure.1).

4.2 Investigation on Rock mechanics

Several kinds of laboratory tests were conducted based on the assumption of the rock characteristics in the area to be porous, continuum and soft materials and small influence of fractures to rock mass properties. They include physical properties measurements, seismic velocity measurement, uniaxial compressive tests, triaxial compressive tests with different drain condition (CU, CD tests), slaking test on cores. In-situ stress measurements with hydraulic fracturing were also carried out in several boreholes.

As common feature derived from all results of laboratory tests and geophysical logging in HDB-1 to HDB-8, the rock properties were changed more or less with depth. Diatomaceous mudstone has large effective porosity (50 to 65 %), below 1 GPa of elastic modulus and 5MPa of σ_c. The properties except porosity indicate the typical Neogene sedimentary rock distributed in Japan as described in second progress report (JNC, 2000). The porosity of hard shale is around 30% and elastic modulus and σ_c distribute 1 to 3GPa, 5 to 20MPa, respectively. The transition zone where shows sudden and continuous properties change is considered a specific feature at Horonobe. The anisotropy on mechanical properties was also found. Generally, the deformability and strength of rock in horizontal are higher than those of vertical direction. The above zones with different mechanical properties are almost agreeable to lithostratigraphic units in the URL area.

The P-wave velocities on cores were concordance with P-wave velocity measured by sonic logging. The range of the variation with depth of seismic velocity seems to be small compared to crystalline rock. The dynamic elastic modulus(E_d) can be calculated by V_p, V_s and density was measured by geophysical logging. The range of the variations is estimated within approximately ±10% of averaged E_d in each rock. These results suggest that the influence of fractures on mechanical properties of in-situ rock mass is small. Furthermore, the distributions of the rock properties can be interpreted as uniform at any given point in the URL area (Fig.2)

Magnitudes of the measured maximum horizontal principal stresses (σ_H) in HDB-1, HDB-3, HDB-4, HDB-5 and HDB-6 do not exceed 1.5 times that of minimum horizontal principal stresses (σ_h). σ_h are almost equal with overburden pressure (σ_v). The results of in-situ stress measurements and the direction of observed borehole breakout show the directions of σH to be almost E-W down to 700m deep close to the URL site.

Above understandings are summarized in the present conceptual model shown in Fig.3

5. Concluding remarks

Borehole investigations are still on going and the final conclusions of our research can not be made at this time. However, the current findings on geology and rock mechanics were summarized as follows,

Geology

Lithology in main study area can be characterized by three types of rocks, which are diatomaceous mudstone, hard shale and a transition zone.

The position of Omagari fault in the URL area is inferred to be between HDB-6 and HDB-8 and close to HDB-4.

Fractures found in the URL area can be divided into two types. One is the fracture crossing a bedding plane at a high angle. The other is the fracture parallel to a bedding plane. The former forms fracture zones which are considered to be water conductive feature in the URL area.

Rock mechanics

The distribution of the mechanical properties in main study area can be described by the model consist of three zones from mechanical point of view.

The fractures in rock mass in the URL area seem to have small influence on mechanical properties of in-situ rock mass.

The magnitudes of the maximum horizontal principal stresses are within 1.5 times of minimum horizontal principal stresses and the directions is almost E-W from near surface to 700m depth close to the URL site. The magnitudes of the minimum horizontal principal stresses are almost equal overburden pressure.

The remaining tasks on geological and rock mechanical investigation are summarized below,

Geology

To identify a position, distribution and feature of major fracture zones including Omagari fault. For this purpose, shallow borehole investigation and detailed seismic reflection survey including VSP survey will be performed.

Rock mechanics

Quantitative estimation of the stress dependency of the mechanical properties of rock

Modeling for the prediction of mechanical behavior include EDZ during URL construction.

6. Reference

Shigeta, N., Takeda, S., Matsui, H. and Yamasaki, S. (2003): UNDERGROUND RESEARCH LABORATORIES FOR CRYSTALLINE ROCK AND SEDIMENTARY ROCK IN JAPAN, Waste Management 03 conference, Tuscon, AZ

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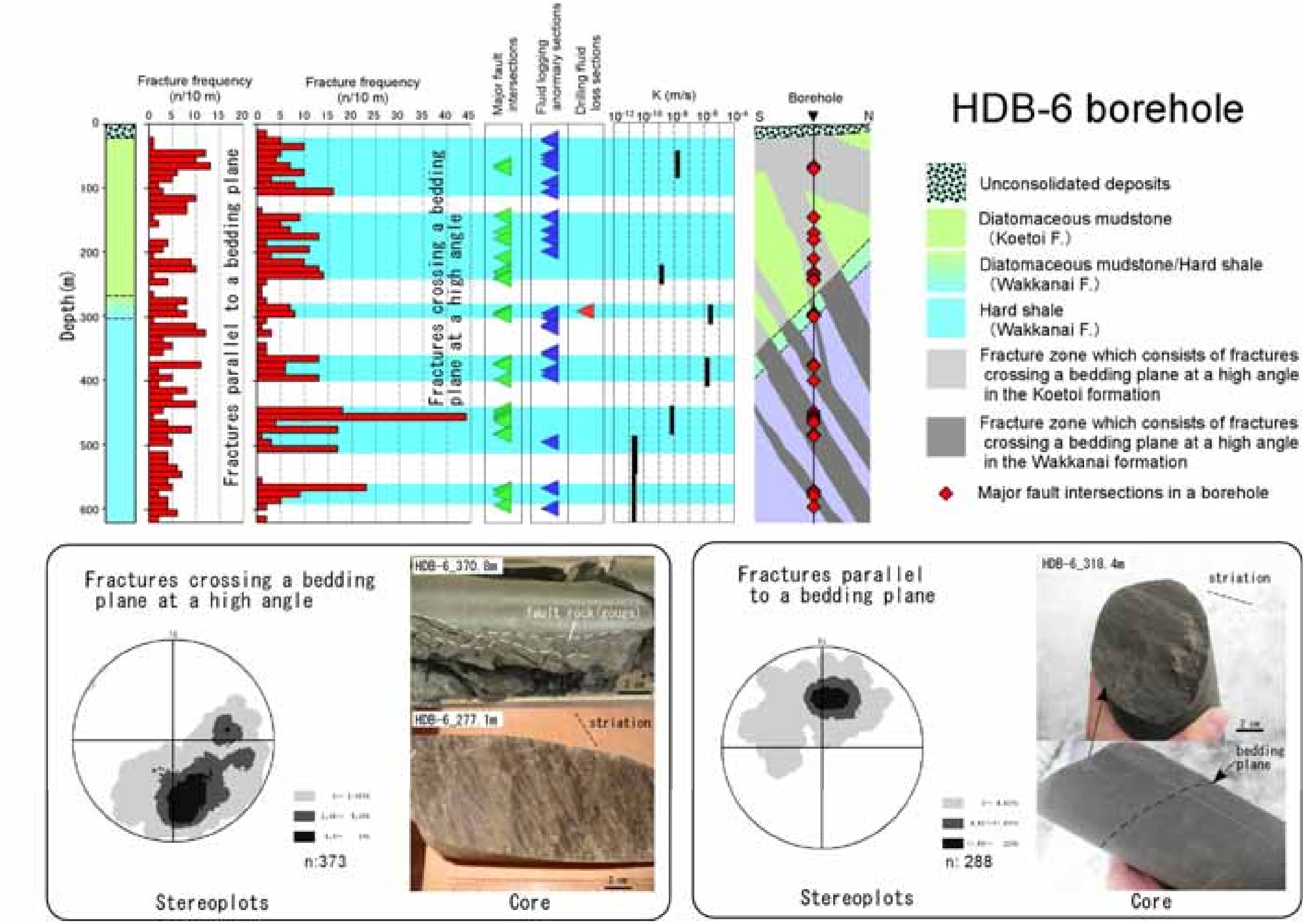

Figure.1 Typical geological features found in main study area

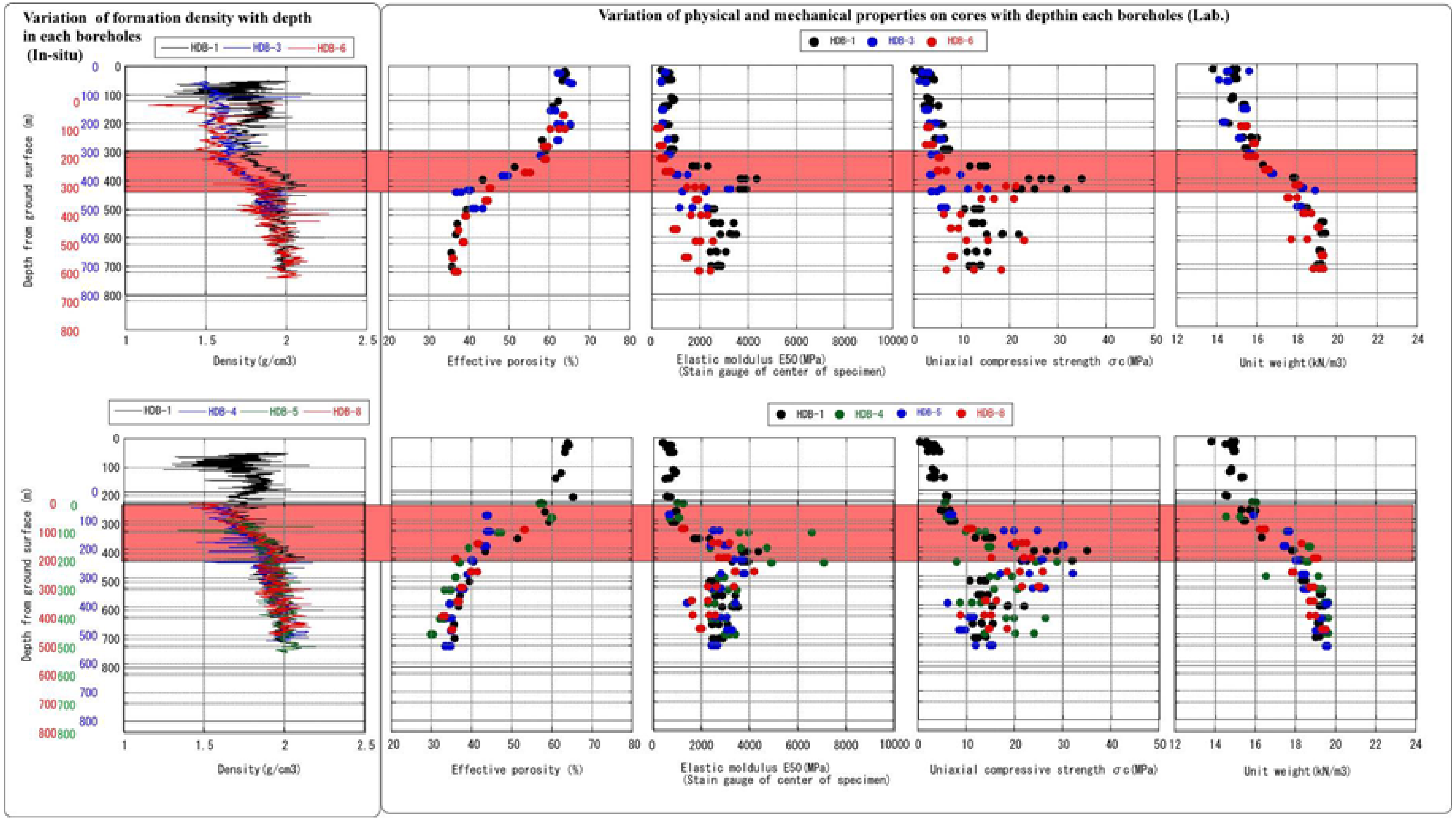

Figure.2 Example of the comparison with the results of laboratory testing and geophysical logging in boreholes

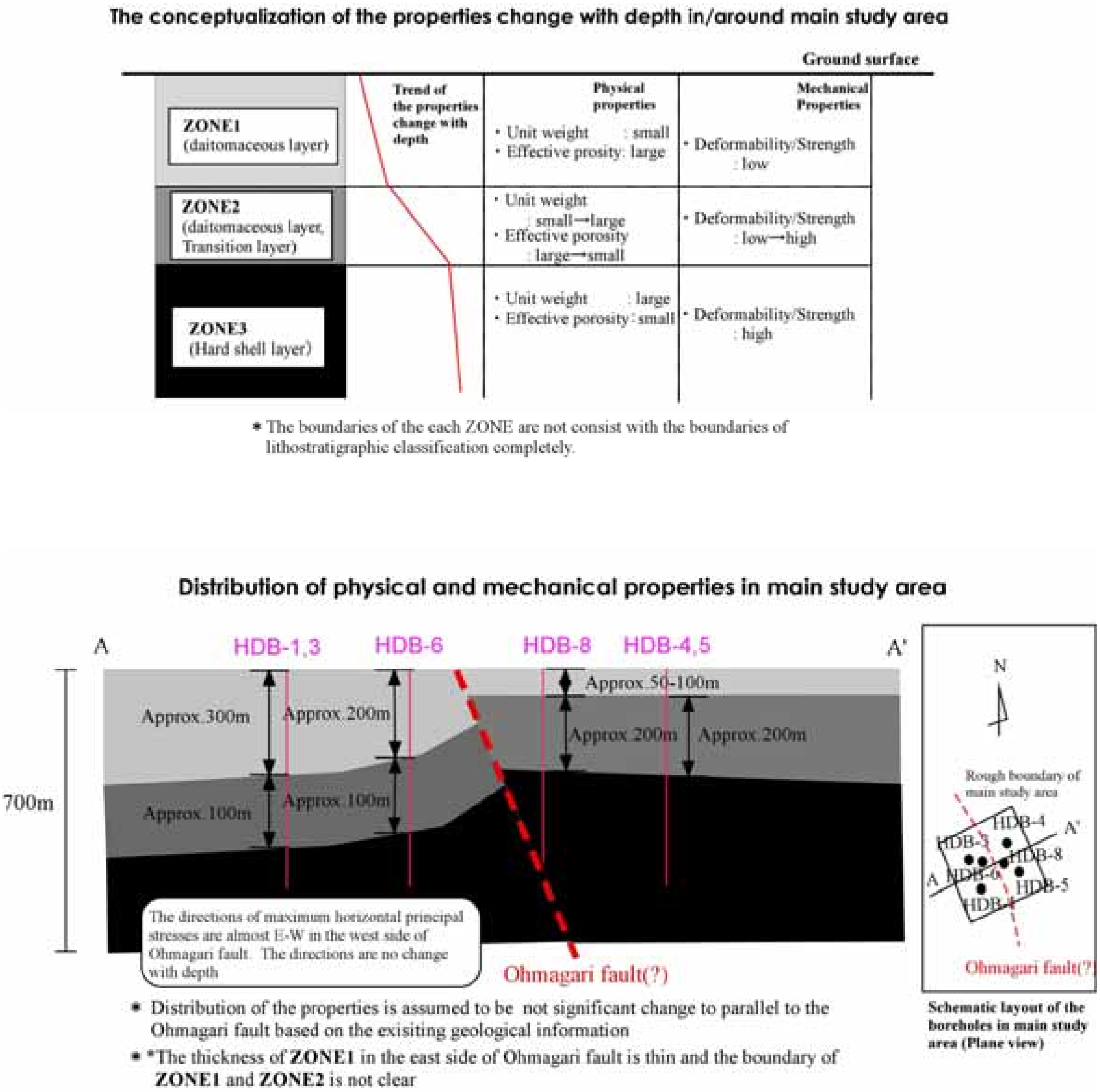

Figure.3 Present Geotechnical conceptual model in main study area

Horonobe Underground Research Laboratory Project
The Present Status in Surface Based Investigation
-Hydrogeological and Hydro-geochemical Investigations-

Katsuhiro Hama

1. INTRODUCTION

Hydrogeological and hydro-geochemical investigations are the important items for the Horonobe URL project. To understand hydrogeological and hydro-geochemical characteristics, various kinds of in-situ tests and laboratory experiments have been carried out. In this report, the status of each investigation is presented.

2. HYDROGEOLOGICAL INVESTIGATIONS

(1)OBJECTIVES

One of the important objectives of the hydrogeological investigations is to construct hydrogeological model. And based on the hydrogeological model, the groundwater flow around the URL construction area is simulated and the change of the groundwater flow caused by the shaft sinking is predicted.

(2)METHODS

[Surface hydrogeological investigations]

Surface hydrogeological investigations have been carrying out in the URL area. Three basins have been selected for the measurement of run off (river flux). And meteorological data of the area such as precipitation, temperature, humidity, wind velocity and direction, evapotranspiration rate are measured (Figure 1).

[Deep borehole investigations]

Seven deep boreholes (HDB-1,3,4,5,6,7,8: 470-620 mbgl) have been drilled in the URL area. Geophysical loggings, fluid loggings and hydraulic packer tests have been carried out to obtain the hydraulic parameters such as head, transmissivity and hydraulic conductivity. Laboratory tests have also been tried to understand the hydraulic conductivity of the host rock and its heterogeneity. The long-term monitoring equipments have been installed in the boreholes after the drilling campaign to understand the initial head distribution before shaft excavations.

[Hydrogeological modelling]

Geological and hydrogeological models were constructed based on the field data as well as the data from literatures. The groundwater flow was simulated by the computer program (DTRANSU). The DTRANSU can treat saturated/unsaturated groundwater flow. An example of the modelled domain is shown in Figure 2.

(3)RESULTS

[Surface hydrogeological investigations]

The data acquisition has been continued for about two years. To obtain reliable recharge rate (especially in winter), the measurements should be continued. And additional measurements such as water table in the shallow borehole are planned.

[Deep borehole investigations]

An example of the result of the fluid loggings and the hydraulic packer tests is shown in Figure 3. Relatively higher conductivities are observed at 300-400 mbgl and water inflow is also observed at the same depth. The fact that some fractures are observed at this depth implies that the fracture distribution might control the groundwater flow in the sedimentary rocks.

The depth profile of the hydraulic conductivity is shown in Figure 4. Roughly speaking, hydraulic conductivity decreases with depth. That suggests slower groundwater flow in the deeper zone.

[Hydrogeological modelling]

The hydrogeological modelling work has started using the newest data. So, only tentative results are obtained.

3. HYDRO-GEOCHEMICAL INVESTIGATIONS

(1)OBJECTIVES

The objective of the hydro-geochemical investigations is to understand 3-D distribution of the hydrochemistry of groundwater and groundwater evolution process. Establishment of groundwater sampling methodology is also important objective.

(2)METHODS

[Groundwater sampling during hydraulic packer tests]

Groundwater samples are collected during pumping test. Groundwater sampling was executed when the tracer content was below 1%. In some cases, tracer content was higher than 1% due to the lower flow rate and restriction of the time. Physico-chemical parameters were continuously measured on-site and comprehensive analyses of the groundwater samples were carried out in laboratories.

[Porewater squeezing]

Porewater squeezing was carried out in the laboratory by the squeezing equipment (max. stress: 70MPa) under aerobic condition. The porewater samples were subjected to the chemical analyses.

(3)RESULTS

The depth profile of the groundwater chemistry is shown in Figure 5. Na-HCO_3 dominated groundwater is distributed in the shallower zone. Na-Cl type groundwater is observed in the deeper zone. One possibility is that the groundwater solutes could be explained by the diagenetic modification of depositional marine pore water. The ^{18}O-enriched stable isotopic compositions (Figure 6) could also be explained by diagenesis.

The lateral spatial variation in groundwater salinity implies significant groundwater flow in the shallower zone. It is anticipated that future investigations will clarify the timing of flow, the flow directions and the characteristics of the flow paths.

4. ISSUES TO BE SOLVED

We still have a lot of issues to be solved by the end of Phase 1. The urgent issues are as follows.

[To construct the groundwater flow concept in the Horonobe sedimentary rocks]

The sedimentary rocks can generally be considered as a porous media for the groundwater flow. The results from the deep borehole investigations show the possibility of the fracture flow.

How should we decide the modelling concept for the groundwater flow?

[To measure in-situ pH/Eh in deep boreholes]

The pH/Eh values are often measured on the surface because of time restriction. But, the surface measurement always suffers the degassing of dissolved gases and oxidation of groundwater. For in-situ pH/Eh measurement, specially-designed equipment and enough time are required. We will try to measure in-situ pH/Eh in one of deep boreholes in this year.

Should we measure in-situ pH/Eh in all deep boreholes?

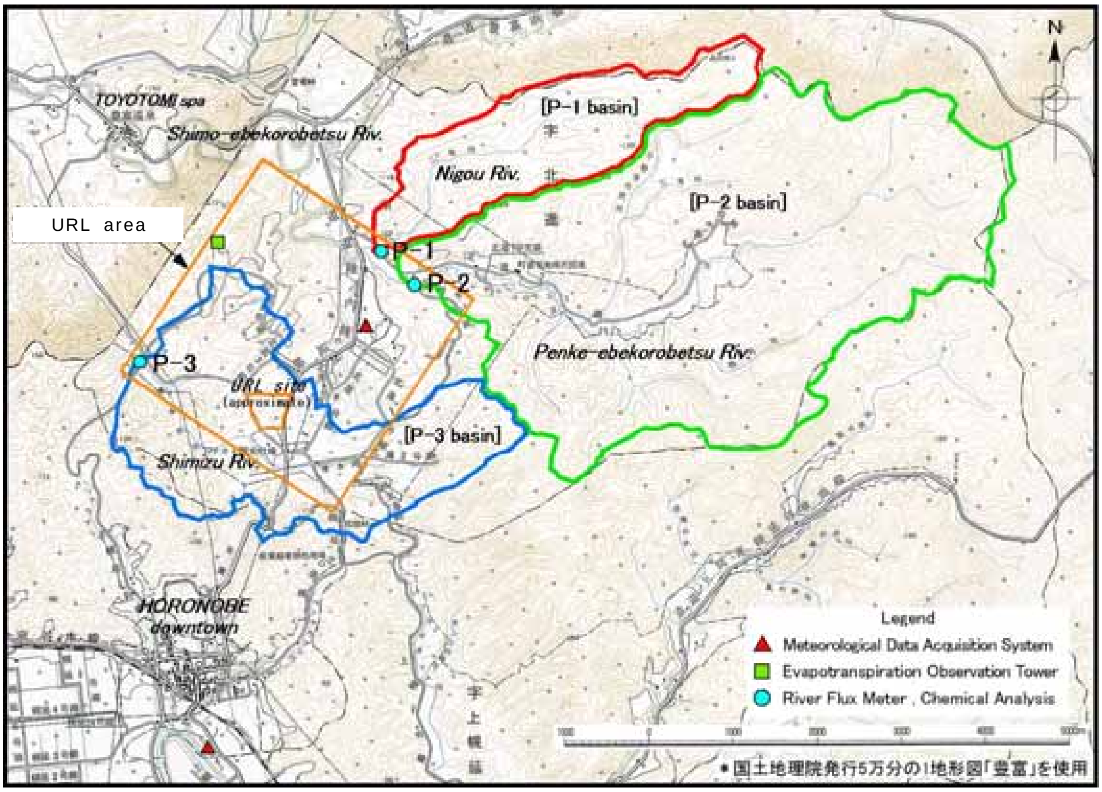

Figure 1 Location of the equipment for the surface hydrogeological investigations.

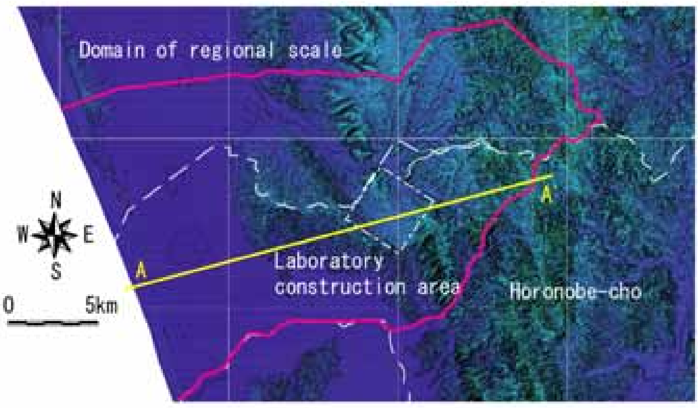

Figure 2 Location of the modelled area.

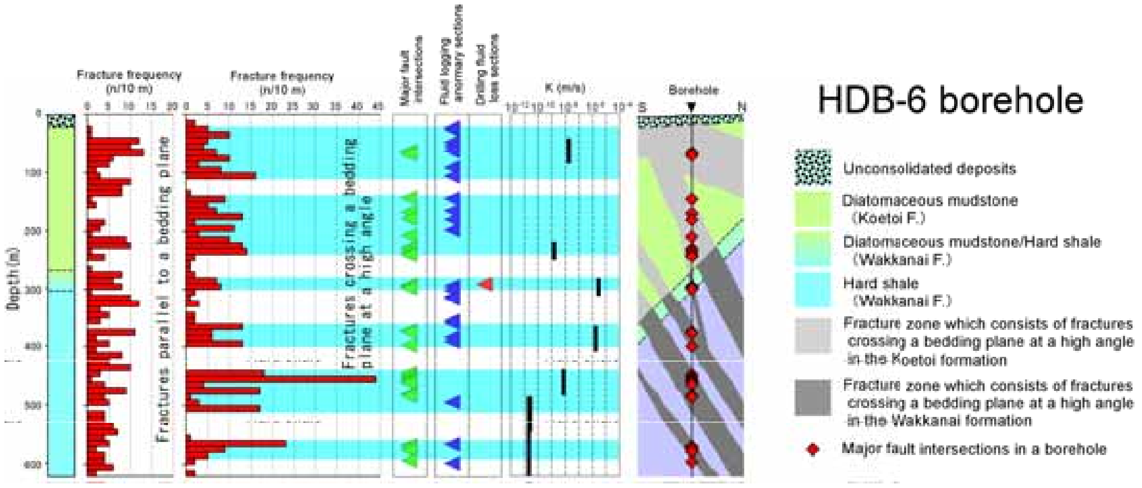

Figure 3 Result of the borehole investigations

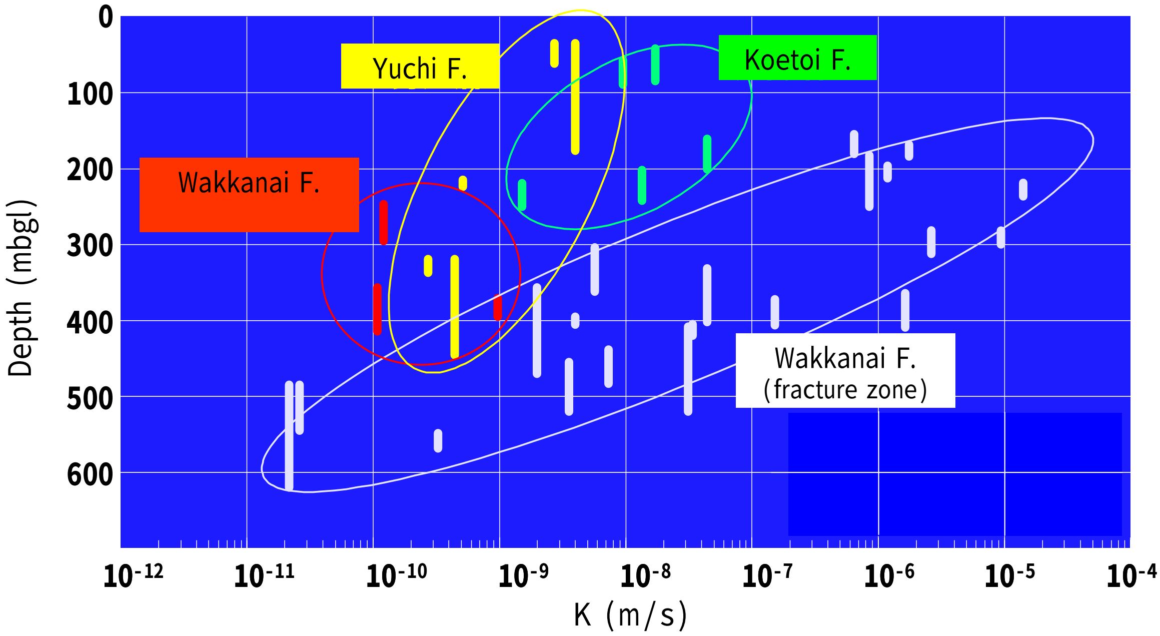

Figure 4 Depth profile of hydraulic conductivity

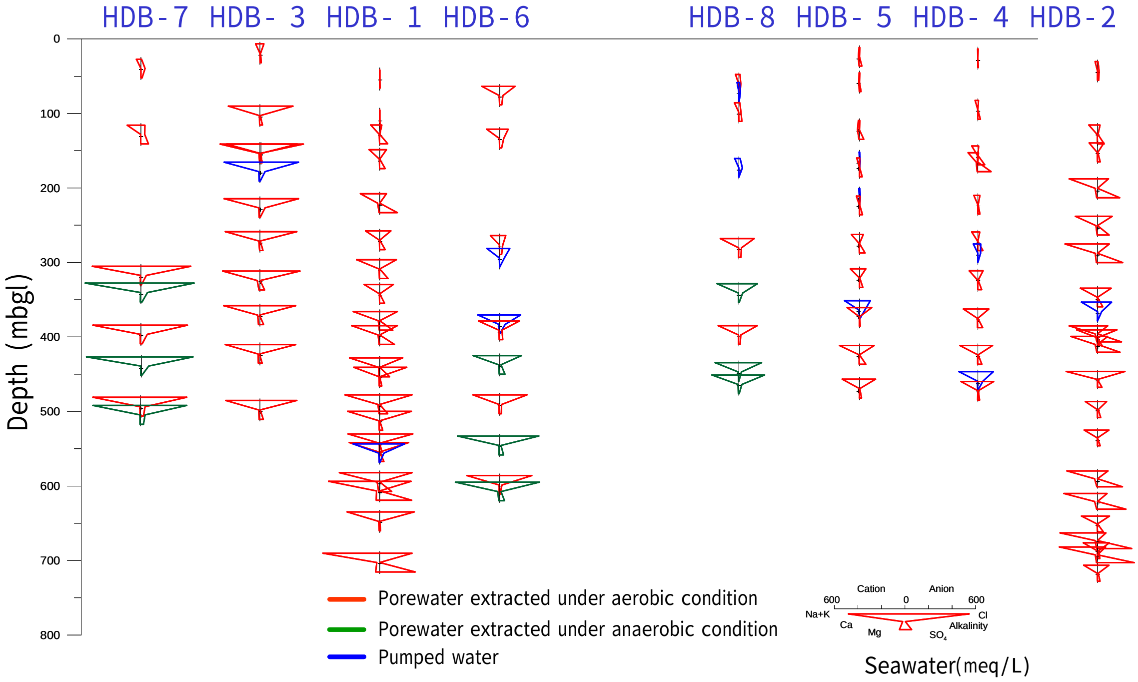

Figure 5 Depth profile of hydrochemistry of groundwater

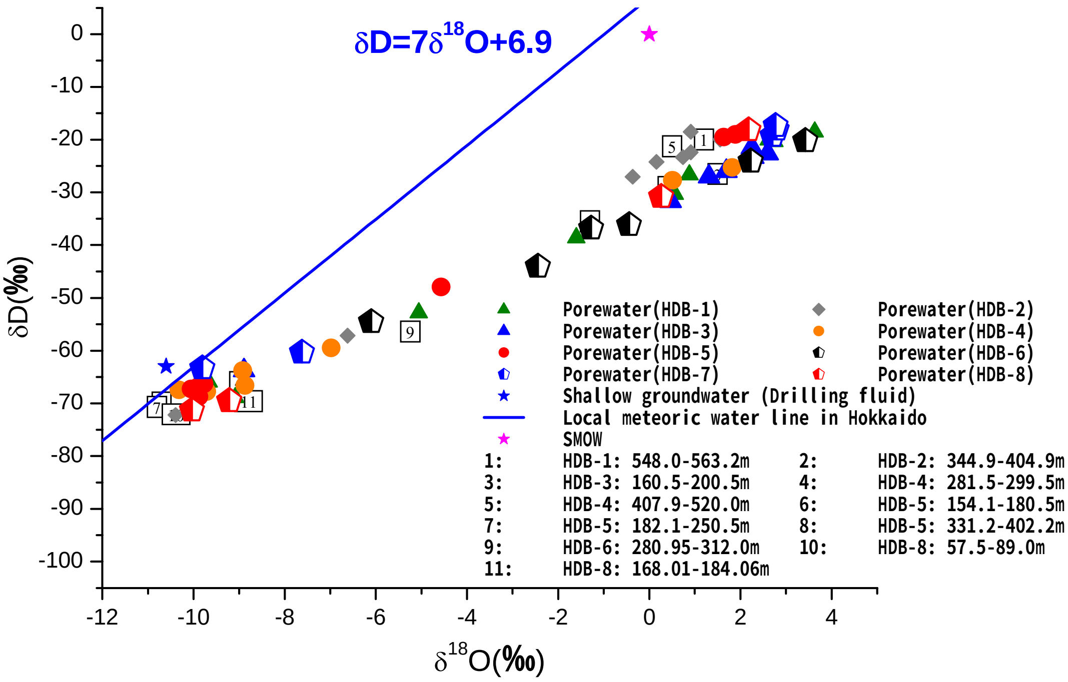

Figure 6 δD-δ^{18}O diagram of groundwater

Horonobe Underground Research Laboratory Project
The Present Status in the Designing of Horonobe URL Facilities

Hiroshi MORIOKA

1. Introduction

The Horonobe Underground Research Laboratory (hereafter abbreviated as Hnb-URL) at present is planned at the depth of about 500m from engineering point of view. Basic requirements for the site are as follows:

- Geological formations to be investigated lie at about 500m depth in sufficient extent and thickness.
- Underground facilities can be safely constructed.

The facilities also take into account the need to provide opportunities for the public to experience the deep underground as well. The highest priority is given to safely construct and research in the facilities. Therefore, evaluation of stability of caverns with complexity of rock property and plan of disaster prevention against such as tunnel fire are fully considered in the designing.

2. Geology and physical properties

The geology consists of Tertiary sedimentary rocks. The regional geology of Horonobe consists of Neogene sedimentary sequences, which are underlain by igneous Palaeogene to Cretaceous sedimentary basement. The shafts and drifts of the Hnb-URL will be excavated in Neogene sedimentary sequences (Koetoi and Wakkanai Formations).

Table 1. Physical properties and representative environmental conditions.

Items	Value
Natural water contents	40-60(%)
Unit weight	15-19(kN/mm^3)
Uniaxial compressive strength	3-30(MPa)
Hydraulic conductivity	10^{-12}-10^{-9}(m/s)
Swelling factor	<0.04(%)
Durability factor	>90(%)
Dissolved gas	Methane
Groundwater	Saline water

These formations consist of diatomaceous mudstone. Their physical properties and representative environmental conditions are shown in Table 1. The rocks of these formations are classified as “soft rock”.

3. Conceptual design of facilities

The present conceptual design for the Hnb-URL consists of two 500m access shafts (6.5 mϕ), a ventilation shaft (4.5 mϕ), and two levels experimental drifts, the main level at 500m and the middle level at 250 m depth (Fig.1). The cross section of the drifts is in the form of a three-centered arch with a width and height of about 4.0 m. To safely excavate shafts and drifts under the condition of methane gas inflow, it is necessary to maintain a sufficient supply of fresh air combined with gas drainage using short borehole drilling. Application of remote controlled drill jumbos and other mining equipment will also be implemented as additional safeguards.

4. Schedule of construction

The results of the geoscience research carried out in the Hnb-URL project will be applied as the technological basis for safety regulations by the government and for the HLW disposal program to be carried out by the Nuclear Waste Management Organization of Japan (NUMO). Fig. 2 shows the construction schedule. At this time in 2004, ground preparation and construction of surface facilities are underway and the detailed design of the underground facilities is under examination.

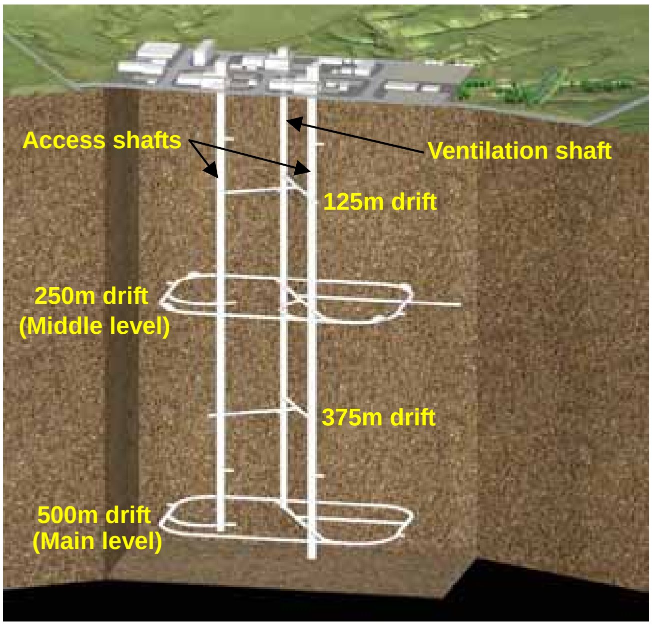

Figure 1. Conceptual design of Hnb-URL facilities.

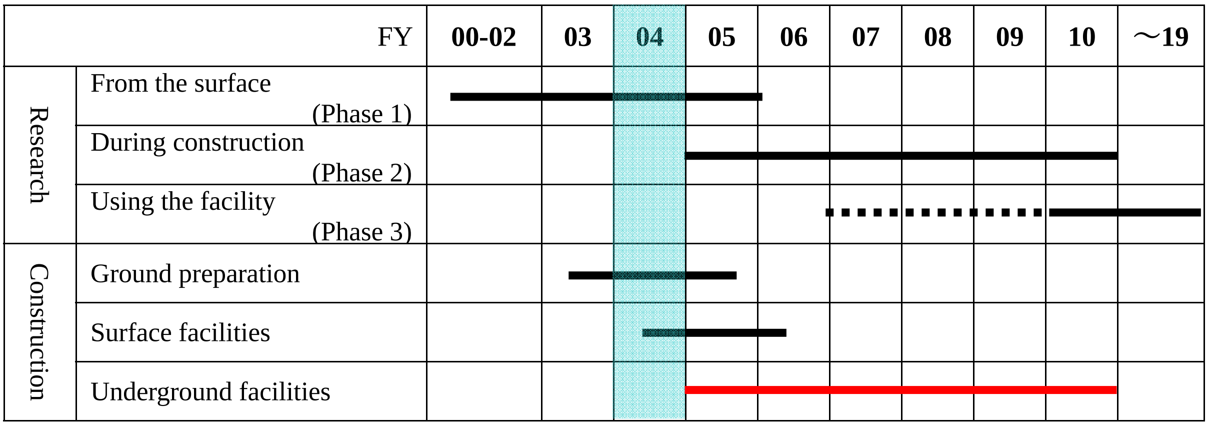

Figure 2. Construction schedule of the Hnb-URL facilities.

5. Estimation for mechanical stability of the underground cavern

Mechanical stability of the caverns is an important factor relevant to the design and construction of deep underground facilities. In the Hnb-URL, mechanical stability of the drift is especially an important issue for design and construction because rock competence factor which is defined as the ratio of rock (uniaxial compressive) strength to overburden pressure is comparatively small. In order to evaluate mechanical stability of shafts and drifts of the URL and to design the support, calculations are performed using mainly the 2-Dimensional FEM (Finite Element Method).

5.1 Rock classification and its mechanical properties

Diatomaceous mudstone layers in Hnb-URL site are divided into 12 zones based on rock classification determined by mechanical properties (RQD, crack density, uniaxial compressive strength etc.) of core samples from boreholes near the construction site. The input parameters of the rock for analyses are given in Table 2.

Rock stresses for boundary condition analyses are determined based on the results of in-situ stress measurements by the hydraulic fracturing method performed in the boreholes. Overburden pressure is calculated based on rock density. The coefficient of lateral pressure, which is defined as maximum horizontal stress to minimum horizontal stress, is set at 1.5.

Table 2. Mechanical properties and input parameters of rock.

Zone	Layer	Depth(m)	Unit weight (kN/mm³)	Cohesion (MPa)	Friction angle (degree)	Elastic modulus (MPa)	Poisson's ratio	Uniaxial compressive strength (MPa)	Tensile strength (MPa)
1	Koetoi	25	14.8	0.1	24.1	8.3	0.30	0.2	0.02
2-1	Koetoi	80	14.9	0.3	8.1	223.2	0.18	0.7	0.07
2-2	Koetoi	139	14.9	0.9	8.1	337.3	0.18	2.1	0.21
3	Koetoi	219	14.4	1.0	16.5	365.5	0.12	2.8	0.28
4	Koetoi	299	15.4	1.3	19.6	626.0	0.13	3.7	0.37
5	Koetoi	339	14.9	0.9	16.3	449.5	0.14	2.5	0.25
6	Koetoi	360	14.9	1.2	18.2	522.2	0.14	3.2	0.32
7	Wakkanai	399	16.8	1.1	16.0	845.6	0.10	2.9	0.29
8	Wakkanai	429	18.6	1.1	16.5	1032.4	0.11	3.0	0.30
9	Wakkanai	449	18.0	1.9	20.5	1177.0	0.11	5.5	0.55
10	Wakkanai	479	18.1	2.0	20.8	1153.0	0.12	5.7	0.57
11	Wakkanai	534	18.0	1.7	19.5	1116.2	0.11	4.8	0.48

5.2 Support design

Support systems for Hnb-URL caverns are designed by using allowable stress method. The 2-D FEM (elastic, perfectly plastic model) analyses using Mohr-Coulomb's failure criterion are performed to understand mechanical stability of the rock and the support. The main support members of the caverns consist of shotcrete, concrete liner and H-section steel (Table 3). For analyses, significant factors such as drift cross-section geometry, excavation procedure, the effect of supports are considered. Stress intensity of all support members and thickness of the plastic zone around the caverns are judgment indicators used in this analysis. Detailed support members of each zone are determined based on this numerical analysis. Two samples (shaft and drift) of the results of numerical analysis and these support patterns are shown in Fig. 3 and Fig. 4. Rockbolts are added in the standard support in the shafts and drifts to resist falling loosened rock masses.

Table 3. Allowable stress of support materials.

Support material	Design strength (MPa)	Allowable stress (MPa)
Shotcrete (normal)	18	4.5
(high strength)	36	9.0
Concrete liner	18	4.5
	24	6.0
	30	7.5
	40	10.0
H-section steel (normal)	400	160
(high strength)	590	236

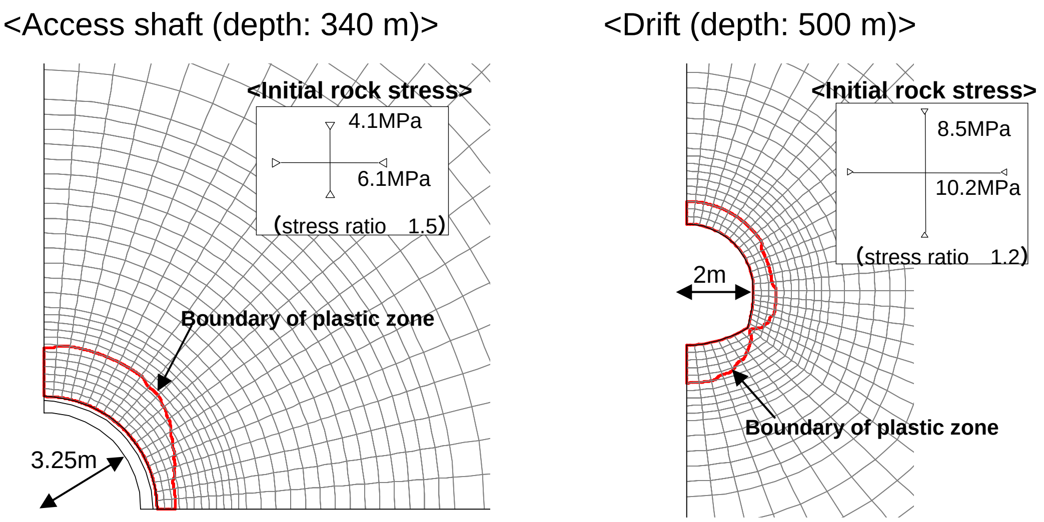

Figure 3. Results of analyses (Boundary of plastic zone).

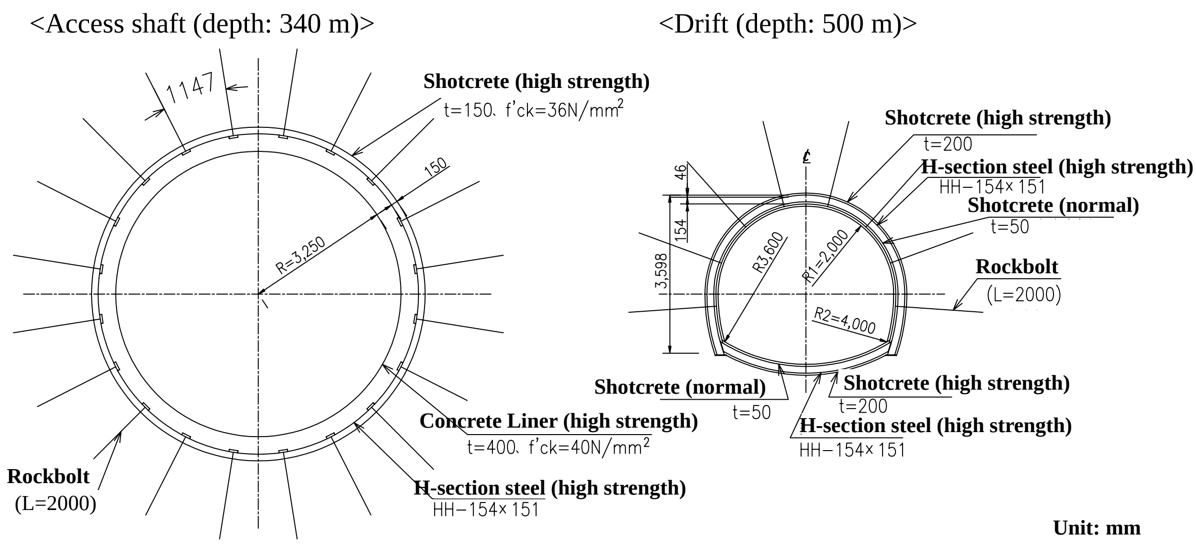

Figure 4. Standard support patterns (Samples).

6. Construction plan

Shafts are to be excavated by blasting or mechanical method. As the rock in the area is classified as “soft rock,” it can easily be excavated by mechanical method. However, application of its technology needs to be confirmed because a deep shaft has never been excavated by mechanical method. Blasting is also planned to be introduced to one access shaft excavation. For reasons of rapid excavation and actual, proven applications, the short-step method is to be selected. This method performs excavation in a single step, with length ranging approximately from 1.0 to 2.0 m, and excavating, mucking, and shaft-lining are carried out in every cycle. Drifts are to be excavated by mechanical method (road header). As a support method, NATM (New Austrian Tunneling Method) is to be selected.

7. Disaster prevention plan

As countermeasures to prevent disasters in underground caverns, a refuge route, on which any people in the cavern can safely evacuate from fire and gas, must be secured. To prevent spread of damage by fire and gas, ventilation plan of the cavern is studied using a mine ventilation network analysis.

The analyses of supposed fire conditions at each construction step indicate that the risk of contamination by smoke-filled air (carbon monoxide, carbon dioxide, etc.) can be minimized by appropriately and promptly controlling the ventilation system, for example, the operation of ventilation fans and ventilation doors, etc.

The results show that during operation phase (Phase 3) and even for a part of URL construction phase (Phase 2), an uncontaminated refuge route for evacuation to surface can be secured.

Fig. 5 shows an example of ventilation network analysis under fire conditions.

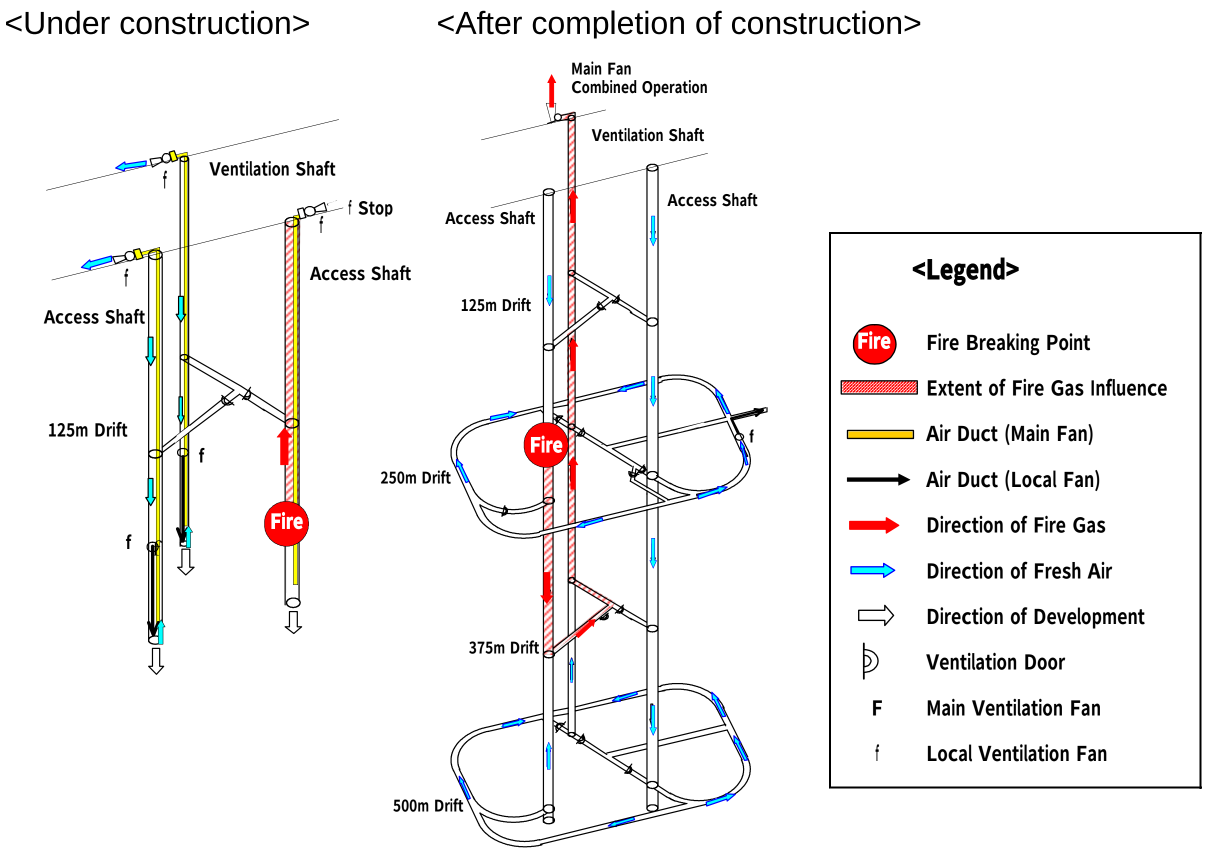

Figure 5. Results of ventilation network analysis under fire condition.

8. Summary

This paper describes the outline of the design contents, the layout and design of the shafts and drifts of the Hnb-URL, and the results of mechanical stability and ventilation analyses. Details of the design of shafts and drifts will be determined in FY2004.

Horonobe Underground Research Laboratory Project Key Issues for Disposal Technologies at the Surface-based Investigations (Phase 1)

Koichiro HATANAKA

Introduction

The specific characteristics of geological environment, e.g., sedimentary soft rock, saline type of groundwater, dissolved methane gas in groundwater, etc. in Horonobe, are important for confirming the reliability of disposal technologies in the application. These specific characteristics are not only necessary for designing underground facilities and engineered barrier system but also for designing in-situ experiments planned to be conducted at the underground facility in Phase 2 and 3. In this report, the progresses of research and development on disposal technologies during Phase 1 in Horonobe are summarized under considerations of these specific characteristics. By taking these specific characteristics of geological environment in Horonobe into consideration, we discussed and identified key issues related to disposal technologies such as designs of EBS and underground facilities, integrity of the EBS, technologies for construction, operation and sealing of underground facilities. Based on the discussion, we summarized the concepts and preliminary plans for the following in-situ experiments to resolve the key issues; thermal-hydrological-mechanical-chemical (THMC) coupling processes, creep on buffer material and sedimentary rock, overpack corrosion, effect of normal cement (used for tunnel support) to buffer material and sedimentary rock, low alkaline concrete construction, emplacement technology, sealing technology. This work has been continued in collaboration with Tokai (laboratory and modeling side) and Horonobe (URL side) by organizing the disposal technology working group since 2001 when Horonobe URL project started.

Characteristics of geological environment in Horonobe

Based on the information obtained from surface investigations, borehole investigations and laboratory experiments using samples of the drilled rock core and the natural groundwater during Phase 1, geological environment in Horonobe URL area was roughly characterized. The Miocene-Pliocene sediment which is composed of Soya coal-bearing Formation, Masuhoro Formation, Wakkanai Formation, Koetoi Formation, Yuchi Formation and Sarabetsu Formation in this sequence overlies the Cretaceous-Paleogene basement. The Wakkanai Formation and the Koetoi Formation which are diatomaceous siliceous sediments with thickness over 500 m are mainly distributed around the URL area. The Wakkanai Formation is composed of hard shale containing Opal-CT and the Koetoi Formation is composed of diatomaceous mudstone containing Opal-A. The Koetoi Formation has been indurated to the Wakkanai Formation due to progressive burial diagenesis of silica minerals. Since the uniaxial compressive strengths of the Koetoi Formation and the Wakkanai Formation are less than 10 MPa and 20 MPa, respectively, the rocks in these formations are both classified as soft rock. According to the chemical analysis of groundwater sampled from drilled boreholes, fresh groundwater is distributed in shallower part (100 – 300 m below ground level (mbgl)) of the sedimentary rock formations and saline groundwater is distributed in deeper part (300 – 500 mbgl) of the formations. Fractures are observed by geophysical logging and rock core observation in both Koetoi Formation and Wakkanai Formation. And the hydraulic conductivities obtained by in-situ hydraulic tests are ranging from 10^{-9} to 10^{-7} m/s in the Koetoi Formation and from 10^{-11} to 10^{-5} m/s in the Wakkanai Formation. In addition, methane generation from the groundwater was observed in the Horonobe URL area. Therefore, the specific characteristics of the geological environment in Horonobe are briefly summarized as follows.

- Sedimentary soft rock
- Many fractures
- Saline type of groundwater in deep underground
- Methane gas generation

Classification of key issues on disposal technologies

By taking the specific characteristics of the geological environment in Horonobe into consideration, we discussed and identified key issues by classifying disposal technologies into following categories; design of EBS, design of underground facility, integrity of EBS, technologies for construction, operation, sealing and monitoring (Kurihara et al., 2004).

Design of EBS

According to H12 report, design requirements for overpack and buffer material as components of EBS are summarized as follows.

Overpack : containment of radionuclides, corrosion resistance, pressure resistance, etc.
Buffer Material : low hydraulic conductivity, radionuclide sorption, colloid filtration, chemical buffering, etc.

A key issue for the EBS design is to confirm if the design requirements are maintained for a long time or not. The key issue for the EBS design is closely related to the integrity of EBS. Therefore, we considered that the key issue of EBS design can be replaced by these for the integrity of EBS.

Design of underground facility

Since underground facility is planned to be constructed in deep underground formed by sedimentary soft rock in Horonobe, the most important issue for the design of the underground facility is the mechanical stability of tunnel. Therefore, 1) procedure for data acquisition, data evaluation and input data setting for the analysis of the mechanical stability of tunnel, 2) procedure for the selection of the analysis model, 3) procedure for setting safety criteria and determining tunnel specification including tunnel support, have to be summarized as a case study on design of underground facility. The applicability of the case study will be evaluated through measurements for mechanical stability in Phase 2 and 3.

Integrity of EBS

In H12 report, 1) behavior of EBS during re-saturation process, 2) long-term mechanical stability of EBS settling, 3) seismic stability, 4) effect of hydrogen gas generation, and 5) extrusion of buffer materials into rock mass, are described as important study items for the integrity of EBS in generic point of view. So, concepts and models adopted in H12 report are necessary to be applied to the realistic geological environment in Horonobe to confirm their reliabilities. In addition to 1) – 5), 6) degradation/alteration of EBS due to high-pH plume generated from normal cement is an additional important study item to be evaluated for the integrity of EBS. Key issues for item 1) -6) are summarized in Table 1.

Construction technology

Construction technology is classified into the following three categories; 1) technology for tunnel excavation and countermeasure, 2) technology for disposal pit excavation, and 3) technology for tunnel supporting by using low alkaline concrete. Key issue for 1) is to apply present technologies such as several excavation methods, tunnel supporting technology and countermeasure technology, to the realistic geological environment in Horonobe. Key issue for 2) is to confirm the possibility for constructing the disposal pit by existing boring machine or its improvement. Key issue for 3) is to understand performance of low alkaline concrete in laboratory experiments and to show the demonstration of the applicability by the construction.

Operation technology

In operation technology, many issues such as inspection of overpack, welding of overpack, fabrication and storage of buffer material, transportation, emplacement, etc. are to be considered and resolved. Among issues mentioned above, a key issue related to the long-term safety in operation technology is emplacement of engineered barrier system into a disposal pit/tunnel. Therefore, degree of accuracy for emplacement has to be clarified under the realistic geological environment in Horonobe.

Sealing technology

A key issue for sealing technology in the caverns such as shaft, tunnel and disposal pit is to confirm performance of plug and backfill and to understand properties of sealing materials through laboratory and in-situ experiments.

Monitoring technology

A key issue for the monitoring technology related to the disposal technology is to consider following items; determination of monitoring items, long-term durability of measurement instruments, effect of measurement system installation to EBS.

Conclusion

Key issues related to the disposal technologies in case of these applications to specific geological environment in Horonobe were discussed and identified. In the examination of the key issues, we referred to the disposal concepts described in H12 report and existing data obtained from laboratory and in-situ experiments conducted in Phase 1 of the Horonobe URL project. In order to resolve the key issues, concepts and preliminary plans of in-situ experiments related to the disposal technologies were developed by taking the schedule for the construction of the underground facilities into consideration. Based on the achievements obtained in planning effort, we will make effective plans for the design of underground facility, design of EBS and in-situ experiments in the Phase 2 & 3 of Horonobe URL project.

Reference

Kurihara Y., Yui, M., Tanai, K., Kawakami, S., Sugita, Y., Taniguchi, N., Hirai, T., Ogawa, T., Mihara, M., Matsui, H., Fujishima, A. (2004): Studies on In-situ Experiments with respect to Deposal Engineering in Horonobe Underground Research Laboratory,, JNC Technical Report, JNC TN8400 2004-002 (in Japanese).

Table 1 Key issue for the integrity of EBS

	Items	Key issues
1)	Behavior of EBS during resaturation process	Modeling and data acquisition for THMC coupled processes under conditions of saline water and deep underground environment Apply model to realistic geological environment condition
2)	Long-term mechanical stability	Reliable modeling Synthetic evaluation considering overpack, buffer material and surrounding rock Data acquisition under conditions of saline water and deep underground environment (overpack corrosion, swelling and sealing of buffer material)
3)	Seismic stability	Quantitative evaluation of critical condition Data acquisition to understand long-tem stability (displacement, displacement rate, acceleration)
4)	Effect of hydrogen gas generation	Data acquisition on gas permeability of buffer material in realistic geological environment condition Reliable modeling of gas transport
5)	Extrusion of buffer materials into rock mass	Data acquisition for extrusion of buffer material in realistic geological environment condition Understand threshold of initiation of extrusion Understand relationship between geological environment and extrusion
6)	Degradation/alteration of EBS	Reliable modeling alteration of buffer material due to high pH plume generated from normal cement Data acquisition

Horonobe Underground Research Laboratory Project
Modeling Study and Data Acquisition
for Safety Assessment Methodology

Koichiro HATANAKA

Introduction

The Horonobe Underground Research Laboratory (URL) Project is at present nearing termination of the surface-based investigation phase (Phase 1) and shaft excavation is planned to start in the middle of July 2005. JNC has been conducting surface investigations and borehole investigations (HDB-1 – 8) since the initiation of the Horonobe URL project in 2001. Data on geology, hydrogeology, geochemistry and rock mechanics have been collected to understand the characteristics of the geological environment of Horonobe. The findings so far indicate that sedimentary rock formations are widely distributed in the URL area in Horonobe; the host rocks are mechanically regarded as soft rock; the groundwater distributed in the deep underground is of saline type; and the methane gas dissolved in groundwater is observed during borehole investigations. Based on these characteristics, the geological features were conceptualized and the properties of flow and transport were evaluated. The next step of the modeling study is to evaluate the safety assessment methodology as applied to the geological environment in Horonobe.

Geological Features of the Horonobe URL area

The URL area is composed mainly of the Wakkanai Formation and the Koetoi Formation which are diatomaceous siliceous sediments with thickness over 500 m. The Koetoi Formation has been indurated to the Wakkanai Formation due to progressive burial diagenesis of silica minerals. The Wakkanai Formation is characterized by hard shale and the Koetoi Formation is characterized by diatomaceous mudstone. The Omagari Fault as a possible major water-conducting feature is inferred to exist within the URL area. In addition, many fractures are found to be distributed in the Koetoi Formation and the Wakkanai Formation by outcrop observations and borehole investigations. Saline type of groundwater is observed in the deep underground of the URL area. Taking these geological features into consideration, a geological structure model was constructed. The hypothetical characteristics of the Omagari Fault and fractures as possible water-conductive features are described below.

Omagari Fault

The location of the Omagari Fault can be confirmed by outcrop observations in several places in Horonobe other than the designated URL area. However, based on the information obtained from reflection seismic survey, audio-frequency magnetotelluric survey and borehole investigations, the existence of the Omagari Fault is also inferred to be within the URL area. The Omagari Fault is a reverse fault with strike-slip components around which are fracture zones with a thickness of more than 300 m. The strike of the Omagari fault is NNW-SSE and the length is estimated at more than 25km. In addition, the east side of the Omagari Fault is uplifted. According to the analysis of the resistivity section map obtained from the audio-frequency magnetotelluric survey, high resistivity region is distributed around the estimated location of the fault which can be thought a result of freshwater invasion from the surface. On the other hand, low resistivity region is distributed in other parts of the resistivity section map due to existence of the saline type groundwater. This means that the Omagari Fault can be more water-conductive compared to the other regions and regarded as a major water-conducting feature.

Fractures

Fractures found in the Koetoi Formation and the Wakkanai Formation in the URL area can be divided into two types (Type 1 & Type 2). Type 1 fractures cross a bedding plane at a high angle. Type 2 fractures are parallel to the bedding plane. Type 1 & Type 2 were considered to be generated respectively by strike-slip faulting and flexural slip folding. These two types of fractures are observed not only in outcrop investigations but also in borehole investigations. According to borehole investigations, Type 1 fractures are observed to be closely distributed and form fractured zones. These fracture zones have a width ranging from several meters to several hundred meters, a length of 0.1 km to 2.0 km, a NS - NE – EW strike and a dip of 45 to 90 degrees. The length of the fracture zone was estimated by the empirical relationship between the length and the width of the fracture zone proposed by Vermilye and Scholz, 1998. Type 2 fractures, on the other hand, are uniformly distributed along the borehole.

Properties of Flow and Transport

Flow Property

Hydraulic conductivities obtained by in-situ hydraulic tests range from 10^{-9} to 10^{-7} m/s in the Koetoi Formation and from 10^{-11} to 10^{-5} m/s in the Wakkanai Formation. However, the hydraulic conductivities obtained by laboratory tests using intact rock core samples range from 10^{-11} to 10^{-10} in the Koetoi Formation and from 10^{-12} to 10^{-11} m/s in the Wakkanai Formation. The hydraulic conductivities of the fracture zones as water-conductive features were determined by considering the observed distribution of Type 1 fractures along the boreholes and the results of flow loggings and in-situ hydraulic tests.

Transport Property

Laboratory tracer experiments using intact rock core samples and rock core samples with single Type 2 fracture led to the following transport properties (Shimo et al., 2003): effective diffusion coefficient of intact rock (8.16×10^{-12} - 2.55×10^{-11} (m^2/s)), transmissivity of Type 2 fracture (1.12×10^{-9} - 1.02×10^{-8} (m/s)), dispersivity in Type 2 fracture (0.0015(m)), hydraulic aperture (3.93×10^{-6} - 8.19×10^{-6} (m)), and transport aperture (7.00×10^{-6} - 1.40×10^{-5}(m)). According to the results from laboratory experiments, a transport model in a single fracture used in the H12 report can be applicable to the sedimentary rock with a single Type 2 fracture sampled from the URL area in Horonobe.

In addition, experiments on sorption of Cs onto the sedimentary rock sampled from the URL area in Horonobe were also conducted under conditions of N_2 atmosphere glove boxes with O_2 less than 1ppm by changing initial concentration of Cs (Xia et al., 2004). Three kinds of water such as deionized water, synthesized saline groundwater, natural groundwater were used in the experiments. As a result, the distribution coefficients were obtained in the range of 0.1 – 12m^3/kg for deionized water and 0.01 – 0.55 m^3/kg for synthesized saline groundwater and natural groundwater. The distribution coefficients using deionized water are one order of magnitude larger than those using synthesized saline groundwater and natural groundwater.

Discussion and Conclusion

Based on information from the surface-based investigations in Phase 1, the Omagari Fault, fracture zones, and individual fractures as water-conductive features and stratigraphy in the URL area in Horonobe were characterized and described. The characteristics were used for constructing a geological structure model. In addition, properties for flow and transport were obtained by conducting in-situ and laboratory experiments. The achievement of current stage will be used for constructing the numerical models for groundwater flow and radionuclide transport, and then for confirming the applicability of safety assessment methodology. The studies mentioned in this report are still going on and the final achievement of Phase 1 will be summarized as a progress report (H17 report) by the end of 2005.

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Horonobe Underground Research Laboratory Project
The plan for the in-situ experiments in Phase 2 and Phase 3

Tatsuo FUKUSHIMA

The Horonobe Underground Research Laboratory Project is an investigation project which is planned over 20 years. The investigations are conducted in three phases: investigations from the surface (Phase 1), investigations during construction of the underground facility (Phase 2) and investigations using the facility (Phase 3). The construction of the underground facility is planned to start in 2005. In concert with the start of construction, the Phase 2 will start in the same year.

The program for the in-situ experiments in the Phase 2 and 3 is under study, in parallel with the consideration of the design and the construction schedule of the underground facility.

The items of in-situ experiments which we are studying are as follows;

Phase 2

1. In-situ experiments for understanding of geological environment

1) Geological survey at drift face
2) Inflow measurement in three shafts
3) Water pressure monitoring and groundwater sampling around a shaft during excavation of URL
4) Investigation for EDZ around a shaft
5) Stress measurement on support
6) Detail investigations for geological environment around 250m drift and 500m drift
7) Excavation disturbance experiment in a drift
8) Investigation for desaturation zone and redox condition around a shaft

2. Engineered barrier system

1) In-situ experiment on low-alkaline concrete
2) In-situ experiment for gas migration in engineering barrier system

Phase 3

1. In-situ experiments for understanding of geological environment

1) EDZ experiment for stress interference
2) Investigation of long-term behavior of EDZ around a drift
3) Detail investigation on fault/fracture zone
4) Monitoring for the change of geological environment at earthquake

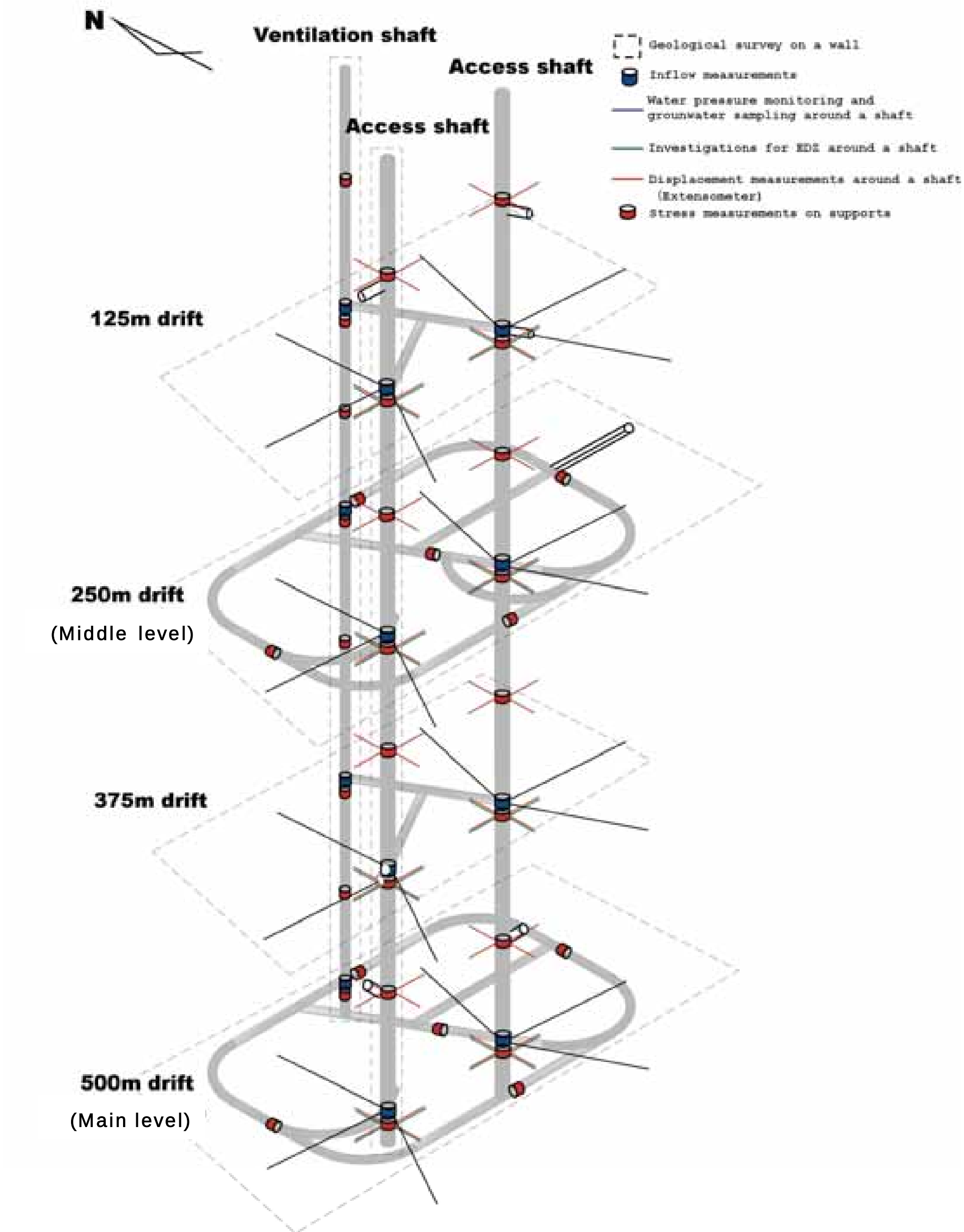
5) Backfill test in borehole

2. Engineered barrier system

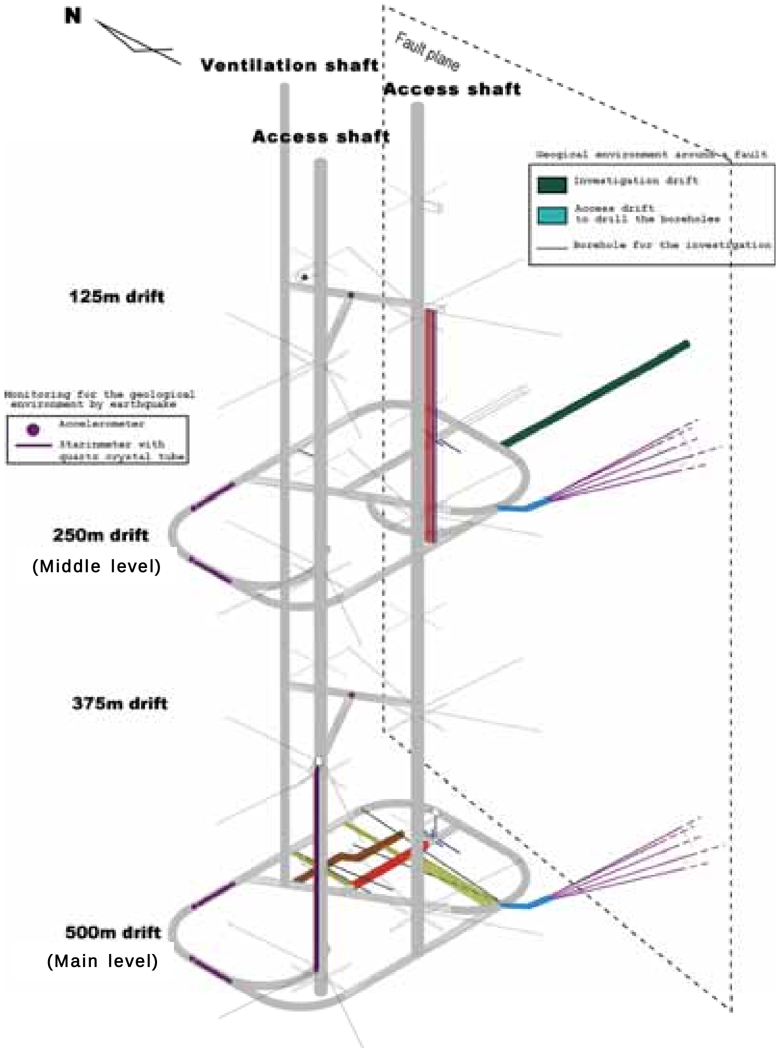
1) T-H-M-C experiment
2) In-situ experiment for corrosion of overpack
3) Investigation of the influence of a concrete to engineering barrier system and geological environment
4) In-situ experiment for interference between backfill material and geological environment
5) Backfill test in drift and shaft

3. Safety assessment

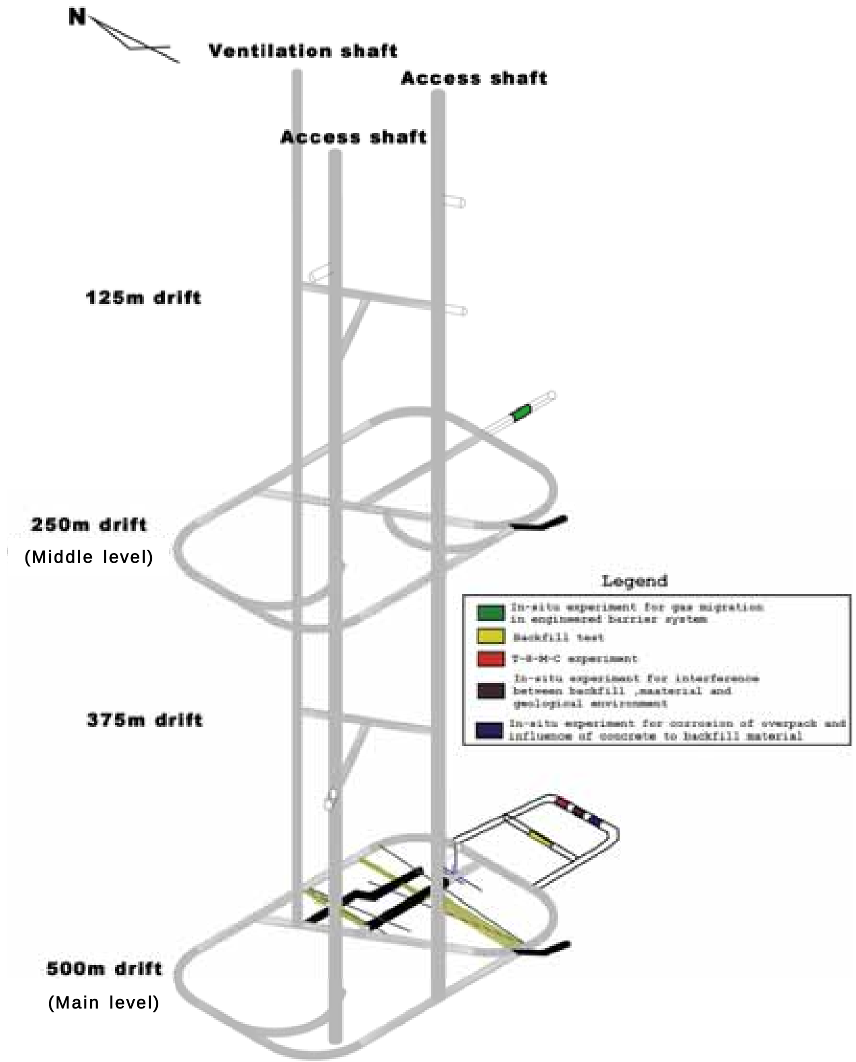
1) Tracer tests in engineering barrier system, natural barrier and fault/fracture zone



a) Preliminary plan for each investigations around a shaft in Phase2



b) Preliminary plan for geoscientfic study in Phase 3



c) Preliminary plan for engineered barrier system in Phase 3