# Directional Drilling Technology for HLW Disposal - Outline of System and its Application – 16078

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## ABSTRACT

During high-level waste (HLW) disposal site selection, borehole measurement and logging to investigate the hydro-geological and geo-mechanical conditions of the host rocks is a very important way to examine the potential of the disposal candidates. In Japan, attention is being given to Neogene soft sedimentary rock as the host rock for HLW disposal. In particular, the soft sedimentary rock in coastal areas is thought to be one of the best candidates, because there is little driving force from underground water.

Directional drilling is supposed to be efficient under limited topographic and geological conditions, and the Central Research Institute of Electric Power Industry (CRIEPI) has been conducting a project on directional drilling and logging/measurement technologies since 2000.

Basic directional drilling system was developed and the system was applied to the Neogene normal sedimentary rock at the Hokushin area of the Horonobe town in Hokkaido. The borehole was drilled to the 700 m long and the applicability of the system was confirmed until 2004.

A basic directional drilling system was developed, and the system was applied to the Neogene normal sedimentary rock in the Hokushin area, in the town of Horonobe in Hokkaido. A 700-m borehole was drilled, and the applicability of the system was confirmed in 2004.

After conducting a seismic reflection survey for the Omagari fault distribution at the Kami-Horonobe area in the town of Horonobe, a drilling site was selected, and a borehole trace was planned to perpendicularly intersect the fault zone in 2005. Considering the planned trace, a 1000-m-long borehole was drilled to a depth of 450 m. From 750 m to the bottom (1000 m), the borehole was horizontal. The total core recovery was 99.8%, even though it was drilled in the fault zone. The geological, hydrological, geo-mechanical, geophysical, and geochemical data were collected using borehole logging/measurement/survey and core logging/measurement/analysis, and the Omagari fault was characterized.

After conducting all the work in the borehole, a steel pipe was inserted into the borehole to case the wall. Open hole sections for monitoring were constructed considering the hydro-geological conditions throughout the hole. Then, the monitoring system was inserted and set up to obtain the initial conditions of the groundwater pressure and chemistry.

## INTRODUCTION

Neogene soft sedimentary rock is recognized as a potentially good host rock for high-level waste (HLW) disposal. This rock has the following characteristics:

- The geological structure is relatively simple, and a geological conceptual model can easily be constructed.

- There are few water conductive fractures in the rock mass, and water flow is reported to be directional based on the geological strata. Thus, it is easy to characterize the water flow in the rock mass.
- Fine-grained clastic rocks such as mudstone have been expected to have low permeability characteristics.

The coastal area is assumed to be a potential candidate area for the disposal of hazardous waste because little hydraulic driving force is expected as a result of the seawater level, and there is little human invasion.

Because of access and working site limitations in this coastal area, controlled, directional drilling methods with core sampling have been considered to provide more useful information compared to conventional vertical drilling methods. In order to develop a three-dimensional geological model, logging and measurement in the hole without disturbing the natural geological, hydrological, and geochemical conditions were essential [1]. From this viewpoint, the development of a directional drilling system that permitted loggings and measurements in the borehole was required, with an urgent need to systematize reasonable drilling and measuring methods.

The Central Research Institute of Electric Power Industry (CRIEPI) developed drilling technology that enabled various measurements and loggings in a borehole, in order to characterize the geology and hydrology of sedimentary rocks with reasonable confidence [2]. This was achieved in 1999. In 2000, CRIEPI started to develop their own core sampling, survey, and logging technology for directional drilling applications, following the guidance from previous work [3]. In this paper, we report the conceptual design and manufacture of a directional drilling system and in-hole logging, measuring, and monitoring systems, along with the results of their application to sites at Horonobe.

## TECHNOLOGY DEVELOPMENT

### Development Goal

The following development goals were established.

- To develop the technology for the directional drilling of 1000-m-long and 500-m-deep drill holes in the coastal Neogene soft sedimentary rocks;
- To collect a full core sample while drilling even in a fault zone (measurements from such core sample are considered very useful for this soft sedimentary rock);
- To make the hole as slim as possible considering the safety, handling, productivity, and cost performance; and
- To develop several logging, measurement, and monitoring routines during and post-drilling.

## Element Technologies for Development

This project comprised four basic technologies: (1) well bending technology; (2) rock core sampling technology; (3) locality detection technology; and (4) logging, measuring, and monitoring technology. CRIEPI reviewed the existing technologies and adapted their best principles for this project.

(1) Well bending while drilling
CRIEPI considered several techniques commonly used in directional drilling. These included the down-hole motor (DHM) technique, wedge technique, and a directional core barrel (DeviDrillTM) [4] as a bending tool for directional drilling. These systems were compared from the viewpoints of directional drilling, core sampling, locality detecting, and logging/measuring. The conclusion was that the DHM is the most practical for this directional drilling. Because the wall of the borehole in this soft sedimentary rock is unstable and collapses without support, a casing was used while drilling. The practicalities of developing the system were examined from the viewpoint of directional drilling, casing, core sampling, in-hole survey capability, and logging/measuring. This showed that the "Wellman" system [5] was the most practical for the casing and under-reamer.

(2)Core sampling technology
The core sampling technology was examined from the viewpoint of undisturbed core sampling recovery and quality. Considering the past results and effective sampling, a wire-line system using a triple core barrel with an acrylic tube was considered the most practical.

(3)Locality detecting technology
The measurement while drilling (MWD) and seismic while drilling (SWD) systems were compared and investigated as position detection systems. Considering the past results and locality detection resolution, the MWD was estimated to be more practical. Data transmission systems for MWD, such as the mud pulse and transmission cable, were compared and investigated from the viewpoints of the transmission speed and data volume. The transmission system was adopted because it can transmit a large volume of data at high speed, and it can also be used as another logging and measuring tool.
The MWD measurement items are the azimuth, inclination, weight on bit (WOB), torque, temperature, and inner and outer pressures. The azimuth is measured using a compass. The azimuth value can be affected by magnetic materials such as rods and other downhole tools. Thus, the azimuth value was corrected considering the magnetic effect. Additionally, in order to more accurately measure the azimuth value, a gyroscopic tool was developed and inserted into the hole at intervals of several tens of meters.

(4) Measuring, logging and monitoring technology
The element technologies for the development of logging and measurement systems were examined from the viewpoint that the geological, hydrological, geochemical, and mechanical measurements should be performed in the hole while drilling. There are a few past records of such technologies, and a few element technologies could be recognized. Logging, measurement, and monitoring systems such as a logging while drilling (LWD) system, permeability testing/water sampling system, pressure

meter, stress measurement system, and appropriate long-term monitoring system [6] for the drilling system were developed.

## SYSTEM OUTLINE

### Drilling System

This system was based on the wire line drilling principle, but conventional wire line tools cannot insert the drilling and measurement assembly in a gently sloping or horizontal drill hole. A water pressure insertion apparatus (so-called pump-in system) that can insert the downhole tools using the pressure of the drilling fluid was selected.

This drilling system comprised downhole tools, a casing pipe following the downhole tools to case the borehole wall and protect it from collapsing, and the armored cable with the insertion apparatus, which could easily push down and pull up the downhole tools and transmit their data using a telemetric line installed inside the armored cable (Fig. 1).

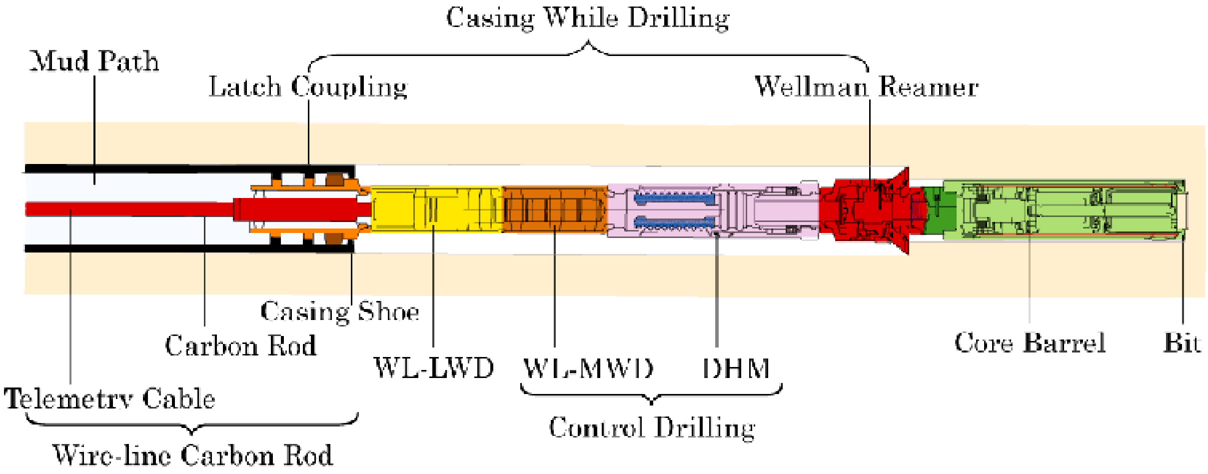

Figure 2 Conceptual design of downhole drilling tools

Figure 1 Conceptual design of drilling system

From the bottom, this system comprised a drilling bit and core barrel, reamer, DHM, MWD, and LWD. In addition, at the connection part between the downhole tools and casing pipe, there was a latch coupling to connect them and seal this joint to prevent the leakage of muddy water (Fig. 2).

The muddy fluid flows down inside the casing pipe and also inside the LWD and MWD, and provides the hydraulic pressure needed to rotate the DHM. Most of the fluid then flows up to the surface through the annulus, which is the aperture between the borehole wall and outside diameter of the casing pipe.

The tools for drilling can be pulled up to the surface using a wire-line cable in each 3-m core run; to collect a core sample, and if a test is deemed necessary, the drilling tools can be exchanged for the testing tools.

## In-situ Permeability Testing System

The in-situ permeability testing system (Fig. 3) was developed as one of the testing tools. This system had the following characteristics.

(1) The packer can be inflated using in-situ muddy water. A Mohno pump was adopted to supply muddy water to the packer. No tube to supply water/gas from the surface was necessary.

(2) Initially, the packer was installed in the pilot hole (diameter 98 mm), which was drilled using the coring bit, and a test was conducted at a short section between the packer and borehole bottom. Afterward, the packer was improved to allow it to be installed in the enlarged hole (diameter 152 mm), which was drilled using a wing bit, and the test could be conducted in a long section between the packer and borehole bottom. Finally, a double packer system was developed to conduct tests in an arbitrarily selected section.

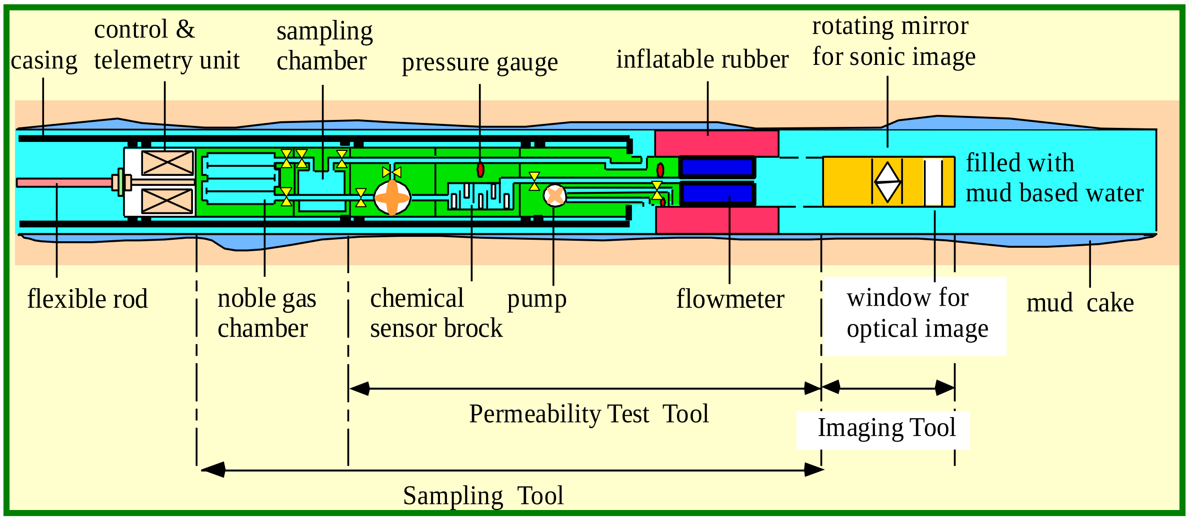

Figure 3 Conceptual design of permeability testing/water sampling tool

(3) The system utilized an acoustic imaging tool to observe the borehole wall condition where the packer was installed.

(4) The system had a water collection function. At an isolated section by the packer, the water was pumped out to change the fluid from muddy water to the in-situ groundwater. In order to check the fluid shift from the muddy water to in-situ groundwater, the system could monitor the turbidity and concentration of amino G acid mono-potassium salt, which was used to dope the muddy water as a tracer

material. If the fluid was judged to be in-situ groundwater, it was collected in a copper tube.

(5) The permeability at the selected section was measured using a slug test and water pumping test. Several types of pumps such as a Mohno pump, plunger pump, and syringe pump could be attached, and the minimum rate of permeability at $10^{-11}$ m/s could be estimated.

## VERIFICATION OF APPLICABILITY

In 2003, a directional drilling system was constructed by integrating sub-tools that included the angle-capable drill rig, core barrel, winged bit, DHM, and MWD. Before applying this system to the site, we verified its performance by drilling an artificial rock mass made of mortar to a depth of 60 m. The directional drilling and measurement system was applied to sites at the town of Horonobe in Hokkaido, in the northern part of Japan, in order to verify the applicability of the systems as a collaboration between CRIEPI and the Japan Nuclear Cycle Development Institute (JNC). By 2005, CRIEPI had conducted the directional drilling of a 700-m-long and 500-m-deep drill hole in the mudstone of the Koetoi Formation and shale of the Wakkanai Formation of Neogene at the Hokushin site, which was located in the northern part of the town of Horonobe [7]. Following this drilling, another drilling was performed, targeting the Omagari fault, in order to verify the applicability for characterizing the fractured zone and in-situ measurements. This work was conducted at a Kami-Horonobe site, in the southern part of the town of Horonobe until 2013.

**Geological Conditions** The geology around the drilling site is mainly composed of the Koetoi and Wakkanai Formations of Neogene. The rock facies of these formations are mainly diatomaceous mudstone (Koetoi Formation) and hard shale (Wakkanai Formation). The thickness of each formation is more than several hundred meters [8]. The Horonobe area is characterized by the prevalence of a folded structure and the reverse Omagari fault. The axis of a fold has a north-northwest trend and dips to the north at the northern part of Horonobe. The Omagari fault has the same trend as the fold and a trace length of 25 km (Fig. 4). It intersects through the town center, and the outcrop of the fault is clearer in the southern part of town [9]. The porosities of the diatomaceous mudstone of the Koetoi and Wakkanai Formations are about 60% and 30% and their uni-axial compressive strengths are about 6 MPa and 15 MPa, respectively.

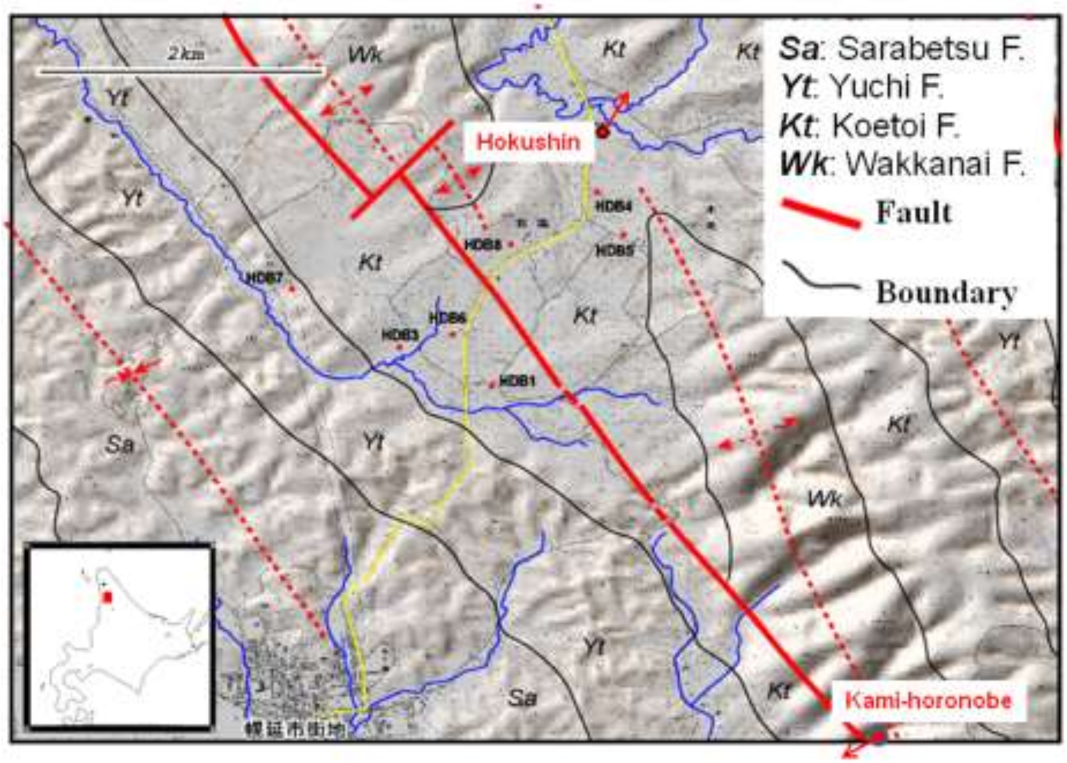

Figure 4 Geological map and drilling sites

## Drilling Results

(1) Hokushin site

CRIEPI started the drilling project to verify the applicability of the directional drilling and survey/measurement technology at the Hokushin site (Fig. 4) in 2003. The target geology was the Koetoi and Wakkanai Formations. For 3 years, from 2003 to 2005, we planned to drill a 700-m-long borehole. The direction of the borehole was kept at N30E, and the inclination was changed from a high dip to low dip. At the mouth of the borehole, the inclination was set to 30°, and at the bottom of the borehole, the inclination was expected to be about 70° (Fig. 5).

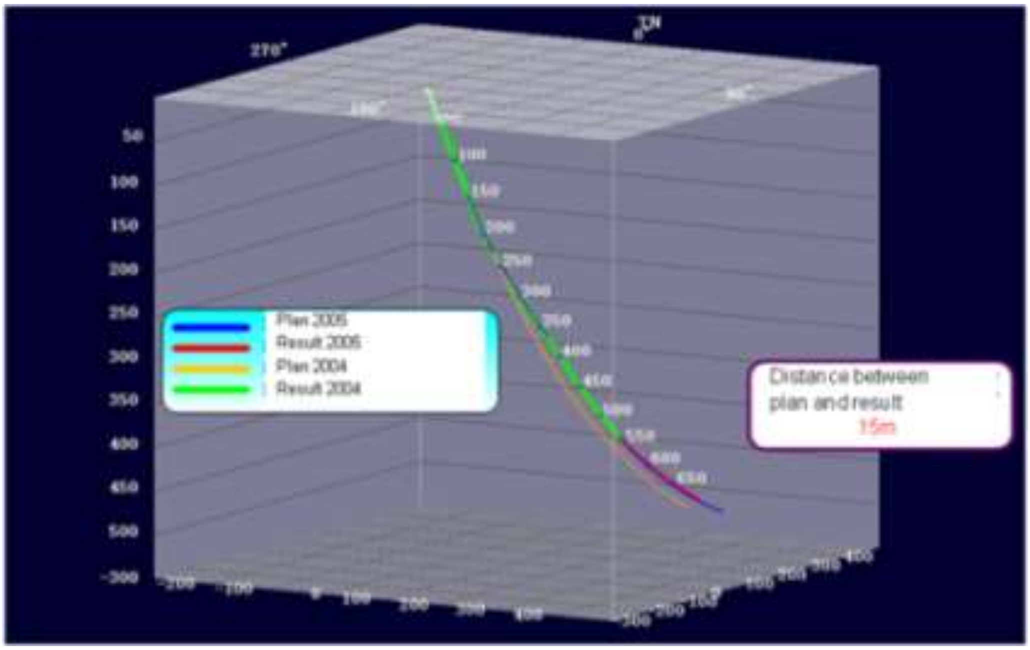

Figure 5 Results of directional drilling at Hokushin site

In 2003, we started drilling a 150-m-long pilot hole with a stable inclination of 30°, after which controlled drilling was performed to produce a 290.3-m-long hole. In 2004, we continued to drill to a length of 547 m, with an inclination change from 30° to 55°. In 2005, we drilled to a length of 706 m, with a bottom inclination of 68°.

From 0 to 150 m in length, conventional drilling without coring was performed, and a casing pipe with an inner diameter of 157.8 mm was finally inserted. From 150 m to 706 m in length, we tried to collect core samples, except for the 352–390-m section, where the core drilling could not be done because of a large water loss. At the core drilling section, the core recovery was almost 100%.

The borehole was drilled with a stable inclination of 30° from 0 m to a length of 150 m. From 150 m to 290 m, directional drilling was carried out to change the inclination with a change rate of 1° per 10 m. The inclination was not changed to 250 m, because we attempted to determine the best combination of bent angle of the kick-off sub and barrel length to change the inclination. We could successfully change the inclination from 250 m to 547 m using the new combination of a bent angle of 0.78° and barrel length of 1.5 m.

In 2004, we experienced a large water loss at several sections while drilling. At these sections, we performed cementing to reduce the water loss, but these procedures took much time, and the schedule was delayed. The causes of the water loss were assumed to be as follows.

(i) There were many water conductive fractures leading to the water loss.
(ii) The highly pressurized water used to move the down-hole motor caused the water loss.

To prevent water loss, the system was improved to reduce the water pressure in the borehole.

In 2005, we identified the section with the large water loss from 482.5 m to 488.5 m and attempted to perform cementing at this section to reduce the water loss.
From 547 m to 598.7 m, using the combination of a bent angle of 0.78° and barrel lengths of 2.5 m and 3.5 m, the borehole could be drilled with an inclination change of 1.46° per 10 m, and from 598.7 m to 706.0 m, using the combination of a bent angle of 0.39° and barrel lengths of 2.5 m and 3.5 m, the borehole could be drilled with an inclination change of 0.51° per 10 m.

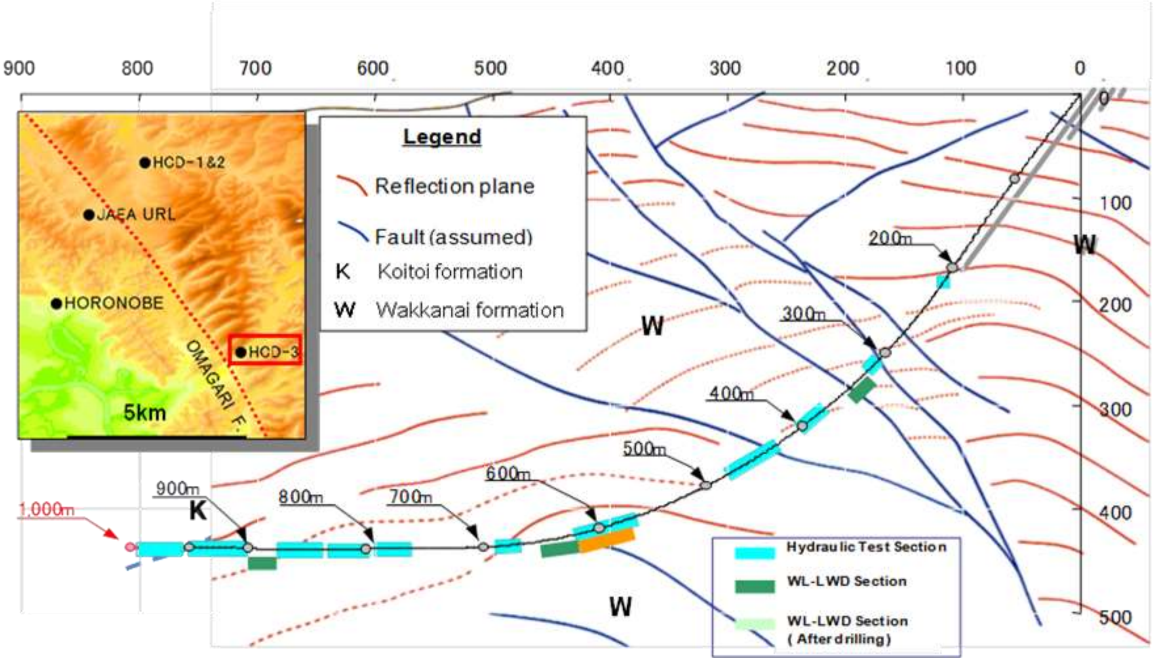

Figure 6 Results of directional drilling at Kami-Horonobe site

(2) Kami-Horonobe site

In 2005, the seismic reflection method was used at the Kami-Horonobe site (Fig. 4) where the outcrop of the Omagari fault is located, and the fault lineament is well defined. Taking into consideration the fault profile deduced from the results of seismic reflection, a borehole trace was proposed to intersect the fault. In 2006, directional drilling was started to verify the applicability of the drilling and measuring system. The borehole was drilled on a bearing of S40W, with a stable inclination of 35° from 0 m to a length of 200 m. From 200 m onward, the directional drilling was relaxed to a shallower inclination of 3° per 30 m, and the borehole reached a horizontal attitude at a length of 720 m. Drilling was terminated at a length of 1000 m after horizontal drilling for 280 m, as of 2011 (Fig. 6). From 0 m to 200 m, drilling was conducted without coring, and from 200 m, cored drilling was performed, and the core recovery was almost 98% as of 2011, even in the fractured zone.

## Measurement Results

From 2006 to 2013, measurement and logging were conducted in the borehole, including LWD, water sampling, and permeability tests. Core logging, measurement, and analyses were also carried out. The LWD was conducted at selected intervals, and permeability tests were attempted at the same sections at 11 different depths.

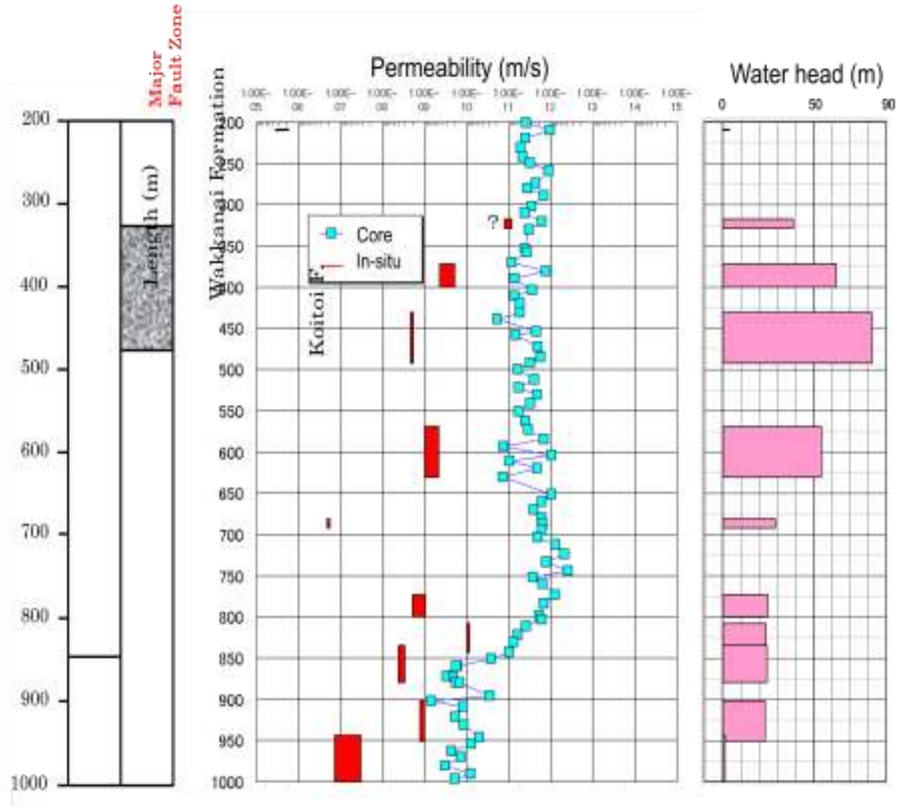

Figure 7 Hydrological characteristics

The color, hardness, and susceptibility of the core samples were measured in-situ every 50 cm, and the rock core was sampled every 10 m for a mineral analysis, water chemistry analysis, permeability test, uni-axial compressive strength test, and physical property test.

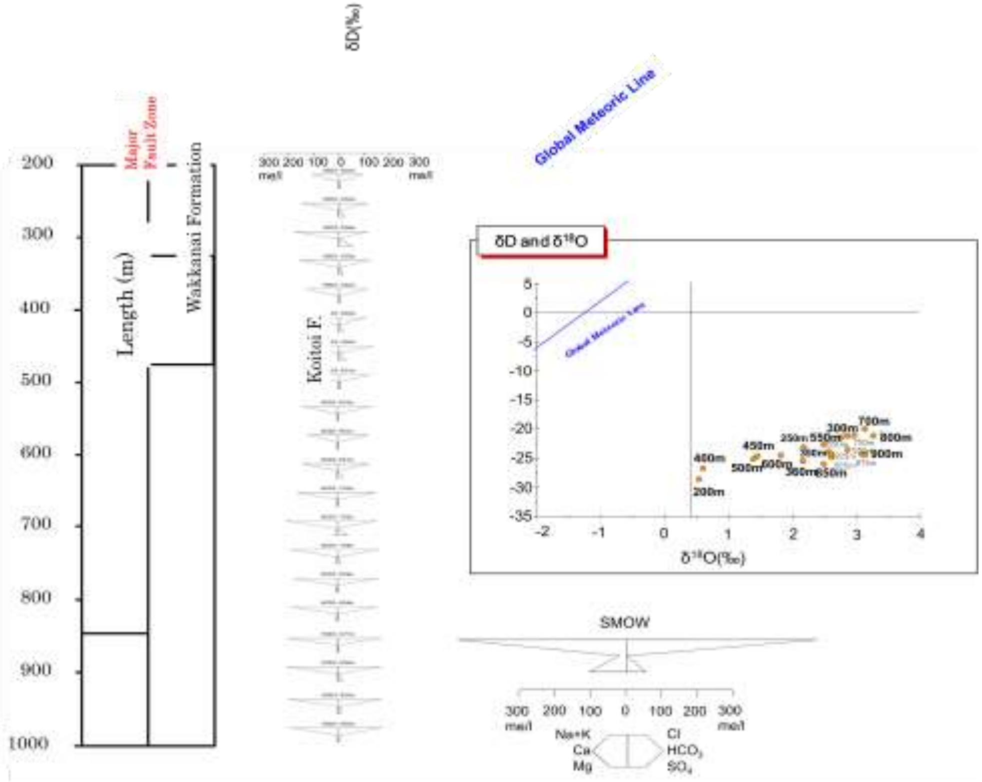

Figure 8 Geochemical characteristics

The Omagari fault was characterized using the logging and measurement results in the borehole, along with the core logging and measurement results. The fault zone (f) was defined as a zone that had a fault rock (fault gauge, fault breccias, and cataclasite) with a thickness of more than 10 cm, along with micro-faults and the same trend fractures distributed around the fault rock. Based on the core logging, twenty-four fault zones (f1–f24) were recognized at different depths. The fault profile deduced from seismic reflection methods coincided with the zone from f3 to f14 (major fault zone). The geological structure differed at f8, which was assumed to coincide with the main fault of the Omagari fault. The permeability within the fault was a little lower than that around the fault (Fig. 7), and the water chemistry did not change between the inside and outside of the fault (Fig. 8). The hydraulic head pressure at the foot wall side of the fault was about 80 m, and it was recognized to be relatively large compared with that at the hang wall side of the fault. From these results, it was assumed that the fault cannot control the underground water flow, but has the ability to maintain the hydraulic pressure.

## CHARACTERISTICS

CRIEPI's directional drilling system has the following characteristics.

(1) Applicable to soft rock: This directional drilling system can drill even in soft rock, because the DHM is attached at the wire-line downhole assembly, and the casing rod can follow the downhole tools to case the borehole.

(2) High core recovery: The rotational driving force is located just above the core barrel. Thus, the wobbling of the core bit must be less than that of a conventional drilling system. The MWD that is attached to the drilling assembly can monitor real-time drilling information such as the WOB, torque, and pressure, and this information is very useful for drilling.

(3) Exhaustive survey: Survey and logging technologies such as LWD, a hydraulic testing and water sampling tool, an in-situ rock stress measuring tool, a pressure meter, and a long-term monitoring system in a borehole drilled by the directional drilling system have been developed, and these surveys can cover most of the necessary geological characteristics for HLW disposal site selection.

## CONCLUSION

CRIEPI has been conducting directional drilling projects with associated in-borehole logging/measurement/monitoring technologies to verify the hydro-geological and geo-mechanical conditions of the host rock at potential waste disposal candidate sites. In 2000, at the beginning of this project, we designed the concepts of the drilling and measurement systems, and manufactured key tools for each technology. The element technologies were selected based on the following four key technologies.

(i) Technology for well bending while drilling: DHM and casing following system
(ii) Core sampling technology: Triple tube core barrel
(iii) Locality detection technology: Wire-line MWD
(iv) Logging and measurement technology: Wire-line LWD, in-situ permeability test with geochemical water sampling and imaging, pressure meter, in-situ stress measurement, and hydraulic pressure monitoring

Based on the conceptual design, sub-tools were manufactured, and the drilling system was constructed by integrating these sub-tools. Before implementing the drilling system in the field, a test of the drilling system was carried out by drilling in artificial rock made of mortar at the beginning of 2003.

Since late in 2003, CRIEPI has been conducting in-situ directional drilling to verify the applicability of the drilling, logging, and measurement system at the town of Horonobe. Since 2006, we have been drilling the Omagari fault to estimate the fault characteristics with an inclination change of 3° per 30 m to the horizontal. During and after drilling, measurements and logging were carried out, and the geological, hydrological, geochemical, and geo-mechanical characteristics of the fault were accurately determined.

## ACKNOWLEDGEMENTS

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