Working Program for MIZ-1 Borehole Investigations

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1 INTRODUCTION

In the Mizunami Underground Research Laboratory (MIU) project, a wide range of geoscientific research and development activities are planned to be performed in three phases, Surface-based Investigations (Phase I), Construction (Phase II) and Operations (Phase III), over a period of 20 years. Surface-based investigations have been conducted at the Shobasama site since 1997, in accordance with the report “Master Plan of the MIU” (PNC, 1996). However, JNC could not obtain an agreement from the local community for beginning construction of the MIU facilities. Therefore, in July 2001, Mizunami City proposed lease of City land at a new site for construction of the MIU facility. JNC decided to accept the proposal and concluded an agreement with Mizunami City in January 2002 (Figure 1). Surface-based investigations at the new MIU construction site began in March 2002 (JNC, 2002).

Main goals of the MIU project are:

- To establish comprehensive techniques for investigating the geological environment, and
- To develop a range of engineering techniques for deep underground applications.

The specific goals of the surface-based investigations are,

- To construct geological models of the geological environment based on the surface-based investigations and develop an understanding of the deep geological environment (undisturbed, initial conditions) before excavation of the shaft and experimental drifts
- To formulate detailed design and plans for the construction of the shaft and experimental drifts, and
- To plan scientific investigations during the construction phase.

Figure 1 Location of the MIU construction and Shobasama sites

Three scales of surface investigation are considered for both the Regional Hydrogeological Study (RHS) project and the MIU Project. The RHS is a major geosciences project in the greater area around the MIU site. The three scales are:

- Regional scale (over 10-km square),
- Local scale (several km square), and
- Block scale (several 100-m square).

Investigations in the MIU project are mainly performed at the block scale while those in the RHS are related to the regional and local scales.

Field investigations during the surface-based investigations phase are planned for completion by the end of 2004, with excavation of the main shaft, Phase 2 construction, planned to start in December 2004 or January 2005. The diameter of the main shaft has provisionally been set at 6 meters and the proposed depth is 1,000 meters. Details of the geometry and depth of specific underground facilities, including the main shaft, the ventilation shaft and the drifts, will be defined using data on the geological environment obtained during the surface-based investigation phase.

As part of the surface-based investigations at the MIU construction site, outcrop geological mapping and a reflection seismic survey at and around the site were carried out. Shallow borehole investigations and hydrogeological investigations in the DH-2 borehole started in April 2002 in order to characterize the sedimentary cover rocks and the upper, approximately 332 meters of the crystalline basement respectively.

Taking into account the status of the investigations as of August 2002 and the remaining time (*i.e.,* two and a half years) for the surface-based investigations, an optimized program for MIZ-1 borehole investigations has been drawn-up. This program addresses the key issues (*e.g.,* identification and characterization of water-conducting features deep underground) and provides input to the subsequent investigation programs and design for the shaft and experimental drifts.

This document mainly describes the planned working program for the MIZ-1 borehole investigations including associated laboratory programs during and after drilling. The working program is divided into the following investigation fields: borehole drilling, geology, geophysics, hydrogeology, hydrochemistry and long-term monitoring. Post-MIZ-1 borehole investigations; a VSP (Vertical Seismic Profiling) survey, rock mechanical field investigations and laboratory tests, cross-hole seismic tomography and hydraulic testing between the MIZ-1 and DH-2 boreholes are planned in the surface-based investigations phase. An outline of these investigation programs is provided in the appendices to this document.

2 AIMS OF THE MIZ-1 BOREHOLE INVESTIGATIONS

Through consideration of the overall investigation program and the remaining key issues to be addressed in the surface-based investigations at and around the MIU construction site, including needed information on and hypotheses of the geological environment, the overall goals of the MIZ-1 borehole investigations were established as below:

- Characterization of the geological environment from the top to over 1,000m depth in the crystalline basement (Toki granite).
- Establishment of baseline conditions before excavation of the shaft and drifts.
- Provide a deep borehole for observation of hydrogeological responses during excavation of the shaft/drifts and experiments in the drifts during the construction and operation phases.

In particular, specific aims have been derived as follows:

- Identification and classification of potential water conducting features and detailed geological and hydrogeological characterization of water conducting features and rocks from the top to over 1,000m depth in the crystalline basement.
- Hydrochemical characterization of groundwater from the top to over 1,000m depth in the crystalline basement.
- Acquisition of rock mechanical data from the crystalline basement for supplementing the existing geotechnical data set.
- Establishment of the basis for design of the long-term hydraulic monitoring system in order to observe the undisturbed hydraulic head distributions before excavation of the shafts and drifts.
- Observation of hydrogeological responses in peripheral boreholes during MIZ-1 borehole investigations in order to assess hydraulic significance of water conducting features and potentially performance of cross hole hydraulic tests.
- Input to the development and assessment of techniques for predicting and modeling the geology, hydrogeology, hydrochemistry and geomechanical properties of the deep geological environment.
- Assessment of the applicability and effectiveness of a wide range of investigation techniques in addressing the key aspects of site characterization.

Details of the aims in each investigation field are discussed in Sections 5.1 to 5.6.

3 LOCATION AND LAYOUT OF THE MIZ-1 BOREHOLE

The MIZ-1 borehole will be drilled in an overall southwesterly direction (S46°W; azimuth 224°) from the northeast part of the MIU construction site (Figure 2 and 3). The inclination or plunge will vary with depth, based on the inclination control plan described below, which will enable the borehole investigation program to be optimized.

- Drill vertically from surface to approximately 250mabh. As discussed in Section 4, there is a good possibility of intersecting a zone in which major drilling fluid loss may occur at about ±30masl, in the UHFD. Drilling to 250mabh will ensure that if the zone is intersected, MIZ-1 will drill past the zone before starting the controlled directional drilling.
- From 250mabh to 460mabh, using controlled directional drilling, the borehole will curve in a southwesterly direction, with inclination decreasing from vertical in increments of 1.5 degrees every 30mabh. The inclination target is 12 degrees from vertical.
- From 460mabh to 1,350mabh, drill to southwest at 78 degrees inclination from horizontal.

This controlled directional drilling results in an offset from the borehole collar of about 207m at the bottom and a true vertical depth of about 1,329m.

The following restrictions and requirements were considered in planning the location and layout of the MIZ-1 borehole.

Restrictions:
- Borehole must be within the MIU construction site and cannot cross the site boundary at any depth.
- Obstruction to the MIU facility construction work should be avoided.

Requirements:
- Attempt to intersect inferred major faults considered to exist in the Toki granite at the MIU construction site and to study their geological properties.
- Less fractured, relatively hard granite is more amenable to controlled directional drilling than is highly fractured or soft rock. Therefore, for this technical reason, intersection of faults during the controlled directional drilling should be avoided.
- The true vertical depth must be over 1,000m to acquire information on the deep geological environment.

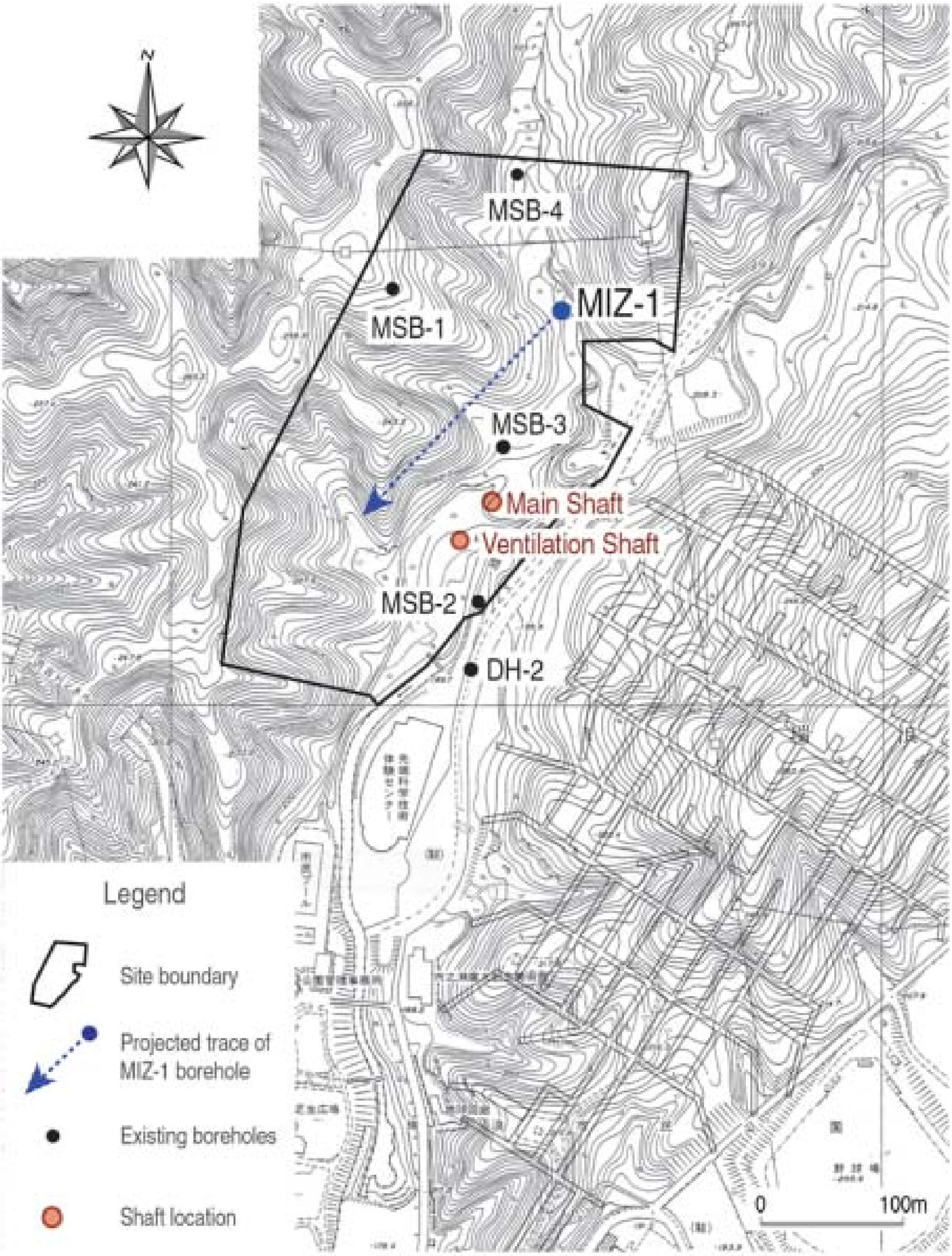


Figure 2 Location and projected trace of the planned MIZ-1 borehole

Figure 3 Location of the MIZ-1 and existing boreholes

Figure 4 View of the MIZ-1 drilling site

4 BACKGROUND INFORMATION AND PREDICTED CONDITIONS FOR PLANNING OF THE MIZ-1 BOREHOLE INVESTIGATIONS

JNC has obtained extensive information on the geology, hydrogeology, hydrochemistry and rock mechanical properties in the Tono area through the MIU project at the Shobasama site, at the MIU construction site, in the RHS project and from the Tono Mine studies. The information is useful in characterizing the geological environment, especially of the crystalline basement, in the MIU construction site. Based on compilation and interpretation of the data, summarized information related to the geological environment in the MIU construction site and predicted conditions in the MIZ-1 borehole are presented here:

Topography

- The overall topographic gradient across the MIU construction site is approximately 5% from NE to SW in the local-scale area (Figure 5).
- The main rivers at or near the site are the Toki, Hiyoshi and Garaishi Rivers, and together with their branches for the main drainage basins. The Toki River basin is the largest basin, the Garaishi River basin drains into the Hiyoshi River basin which in turn drains into the Toki River basin.
- The MIU construction site comprises small ridges and valleys derived by erosion of the main NNE-SSW trending ridge in the west, and a narrow fluvial plain along the Hazama River in the east.

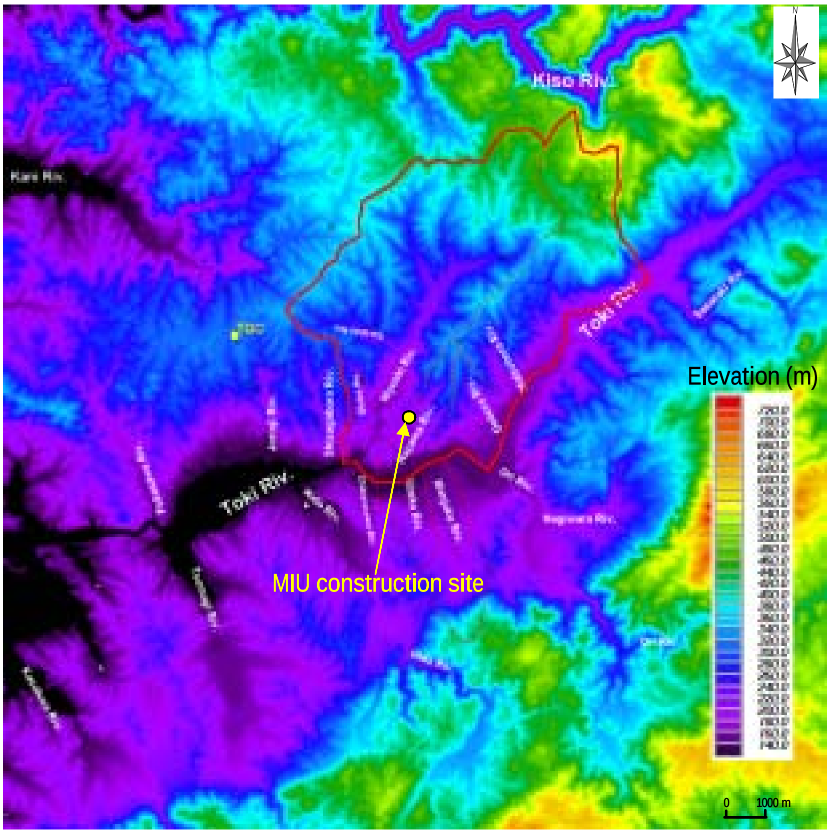


Figure 5 Topography around the MIU construction site

Geology

Sedimentary cover

- Tertiary sedimentary rocks (the Miocene Mizunami Group and the Pliocene Seto Group) unconformably overlie the eroded Cretaceous crystalline basement (the Toki granite) with varying thickness from 100 to 180m at the site (Figure 6) (JNC, 1999).
- The Mizunami Group is stratigraphically divided into the Toki Lignite-bearing Formation, the Akeyo Formation and the Oidawara Formation, in ascending order. Relatively low concentrations of uranium mineralization (0.01 to 0.05wt% of U_3O_8) are found in the basal conglomerate layer of the Toki Lignite-bearing Formation along the northwest trending paleochannel caused by erosion of the Toki granite (Figure 7) (PNC, 1988).

Basement granite

- The eroded surface of the Toki granite varies significantly in elevation from 25 to 200masl at the MIU construction site. West of the site, the channel is narrow and steep, possibly indicative of rapids or falls (Figure 8) with depth, except for the weathered zone at the top of the granite and two hydrothermal alteration zones. The weathered zone, which is about 1m thick, is characterized by overall argillic alteration and precipitation of iron oxyhydroxides. Two hydrothermal alteration zones suggest acid hydrothermal fluid circulation (*i.e.* sericite alteration) along major fault zones in past.
- Two structural domains, an upper highly fractured domain (UHFD) and a lower sparsely fractured domain (LSFD), have been distinguished in the Toki granite based on the fracture frequency data from boreholes at the Shobasama site (Figure 9) (JNC, 2001). Based on the consistency in thickness between the UHFD and the sedimentary cover observed in boreholes at the Shobasama site, the thickness of the UHFD expected at the MIU construction site is estimated to range from 270 to 349m (Figure 10).
- Two intensely fracture zones, named the jointed zone and characterized by a high frequency of low-angle fractures, have been identified in the UHFD intersected by the DH-2 borehole. Comparison of the borehole data with the seismic data shows there is a consistency in shape and distance between the jointed zones and the granite surface (Figure 11). This seems to indicate that the zone may extend across the site.

Major faults and water conducting features

- From the prior investigations (lineament analyses, reconnaissance survey, reflection seismic surveys, shallow borehole investigations, DH-2 borehole investigations), 12 inferred major faults (IMF) are believed to be present and cross the site (Figure 12).
- The 19 water inflow points identified by fluid logging in the DH-2 borehole investigations are considered to be water conducting feature (WCF). Of these, 84% of the water inflow points are related to major fracture zones, that is, related to the major faults and the jointed zones (Figure 13).

Prediction of the geology in the MIZ-1 borehole

- Based on the compilation and interpretation of the existing geological information, a predicted geological profile along the MIZ-1 borehole is produced (Figure 14 and Figure 15). The profile shows the major geological intersections expected such as the unconformity, the weathered zone, the jointed zone, two structural domains and three inferred major faults (IMF03, IMF10 and IMF11). Most of WCFs in the MIZ-1 borehole are expected to be related to the inferred major faults and the jointed zone.

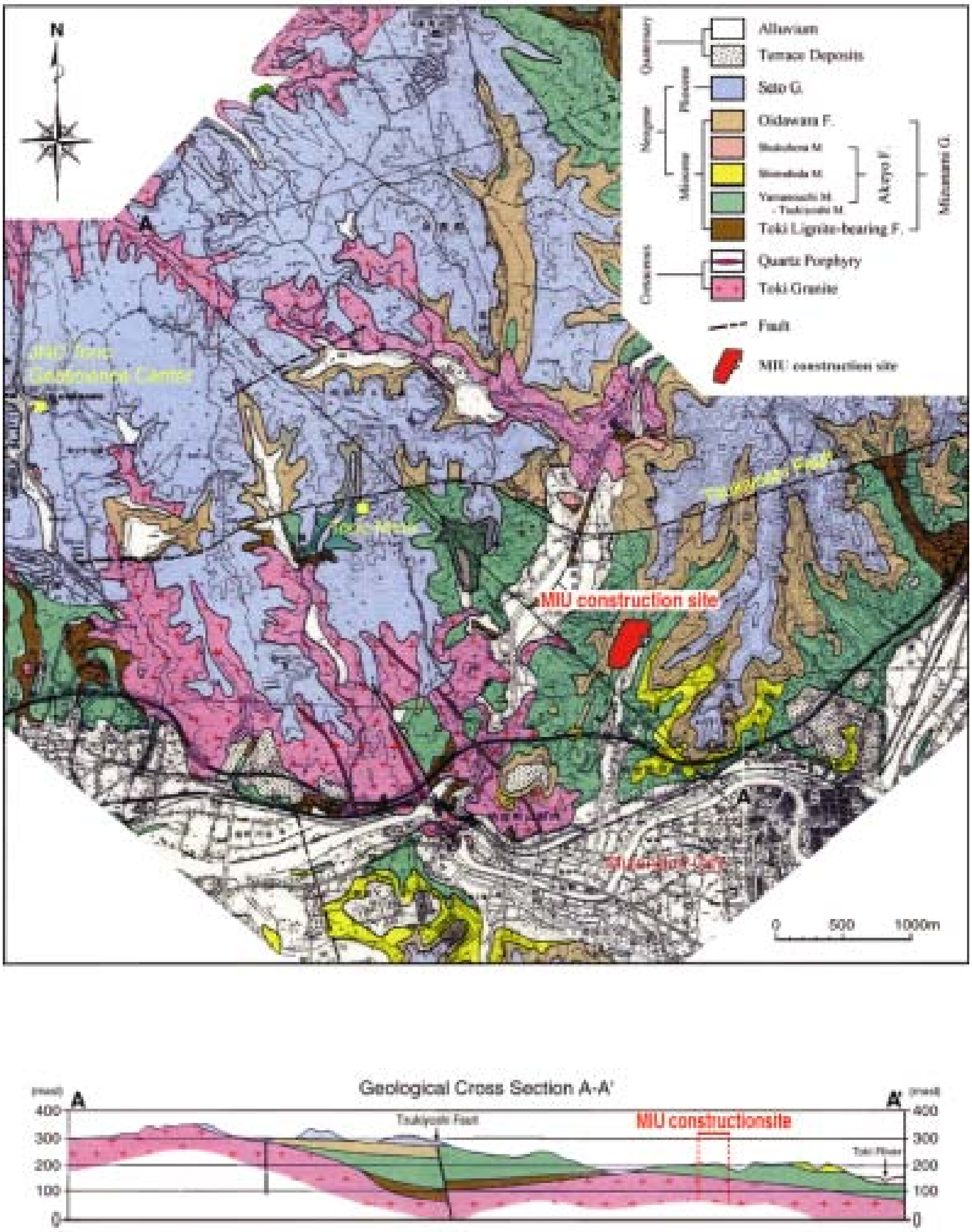


Figure 6 Geological map around the MIU construction site

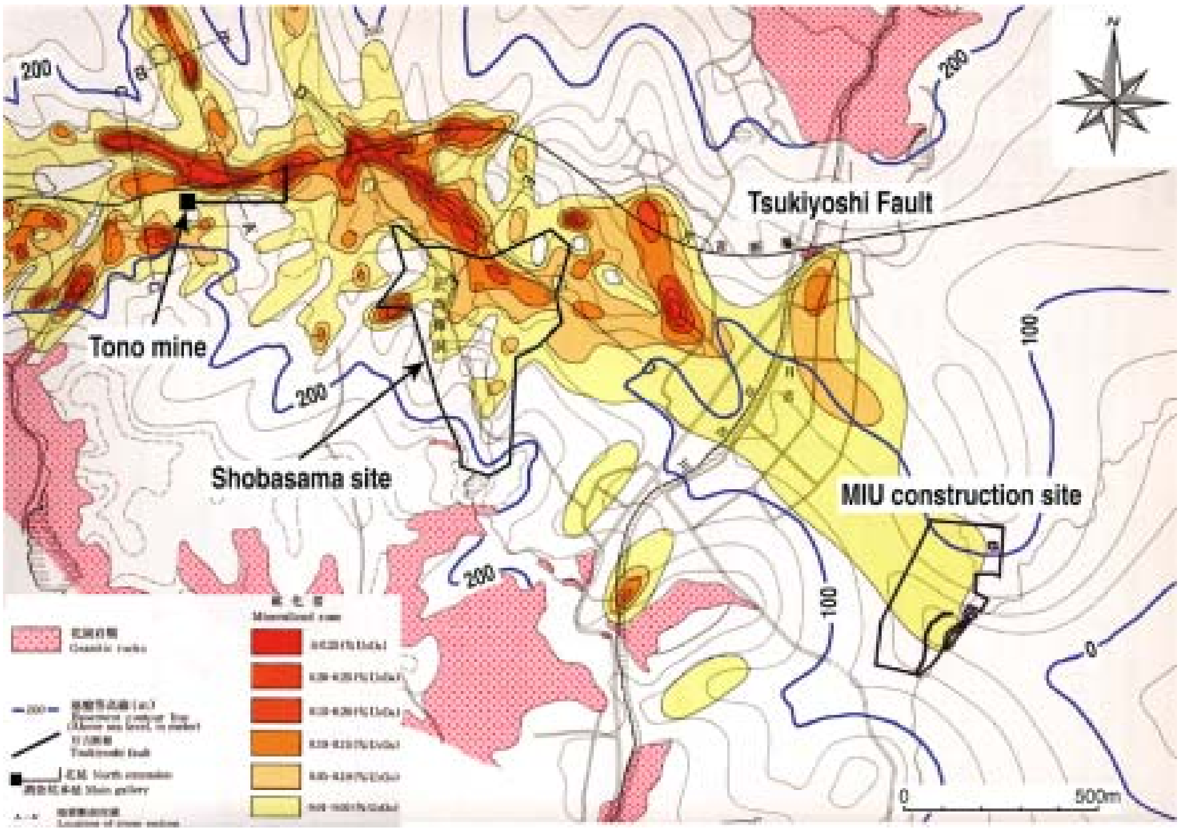


Figure 7Uranium occurrences around the MIU construction site

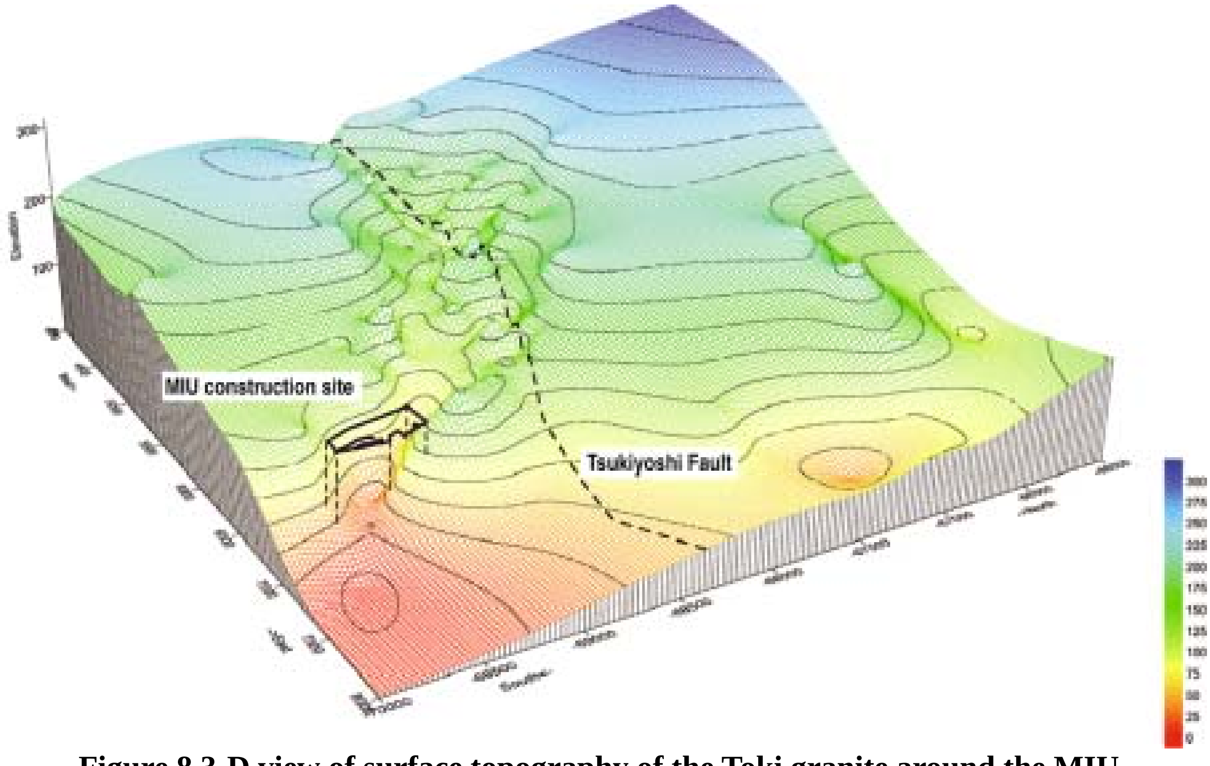


Figure 8 3-D view of surface topography of the Toki granite around the MIU construction site

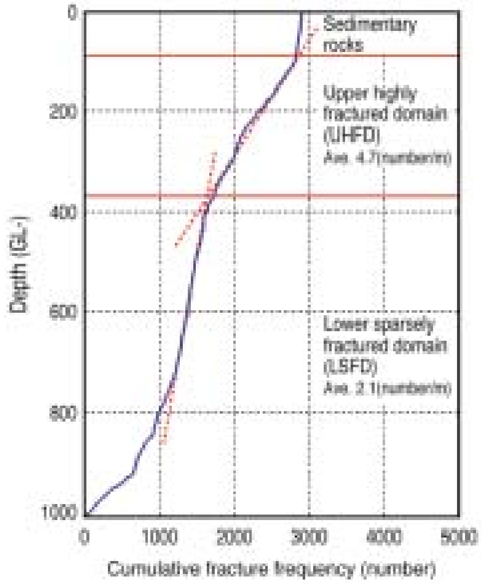


Figure 9 Cumulative fracture frequency in the MIU-2 borehole

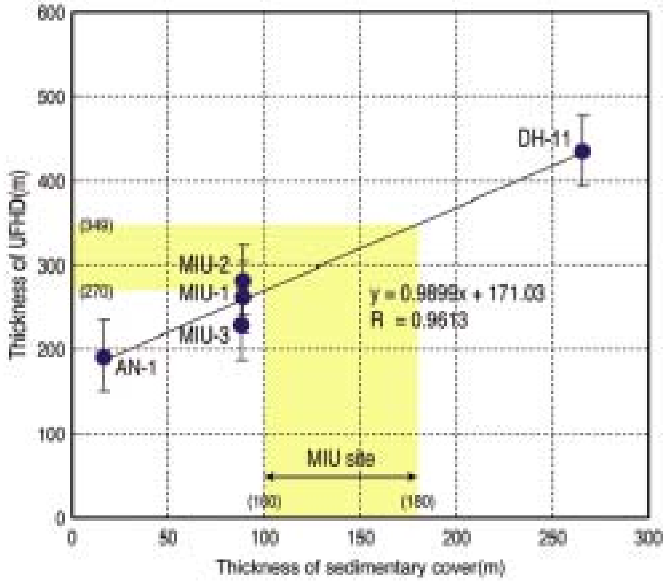


Figure 10 Relationship in thickness between UHFD and sedimentary cover

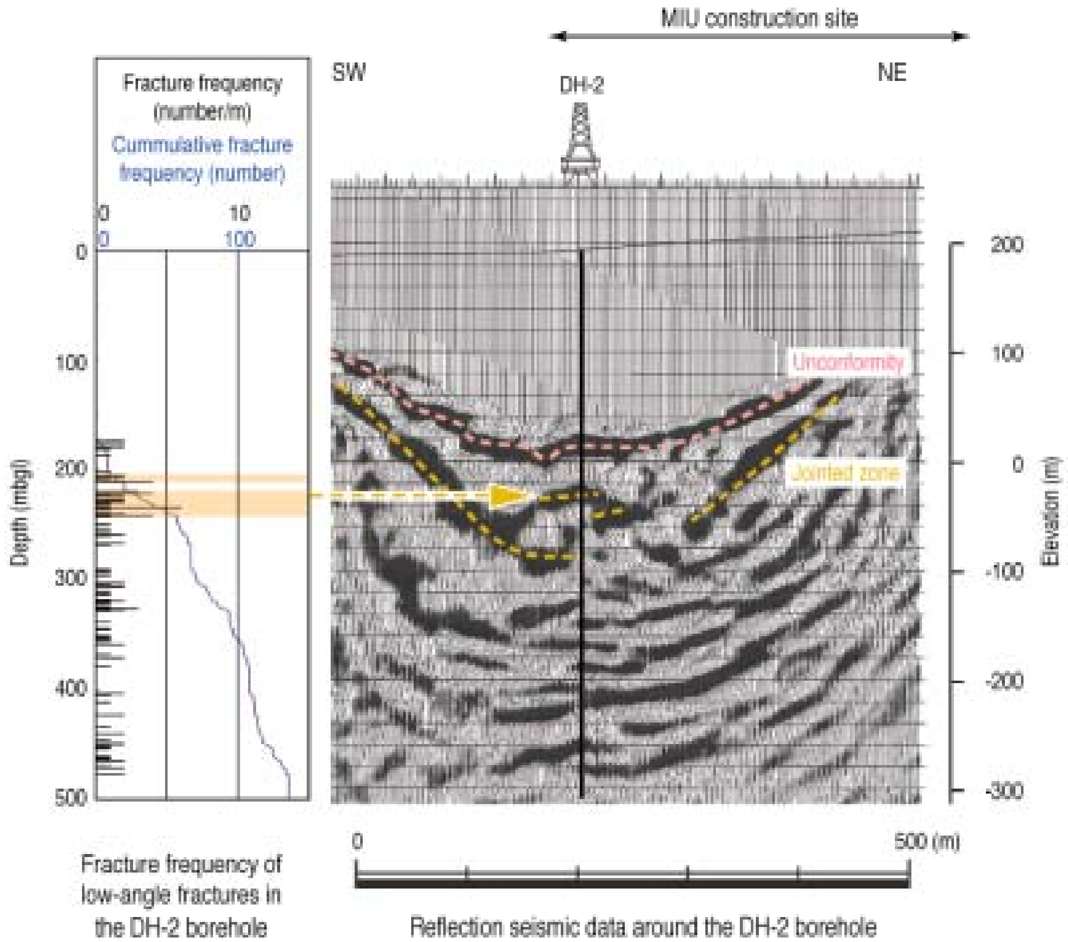


Figure 11 Comparison of fracture frequency of low-angle fractures in the DH-2 borehole and reflection seismic data around the DH-2 borehole (Matuoka et al.,2002)

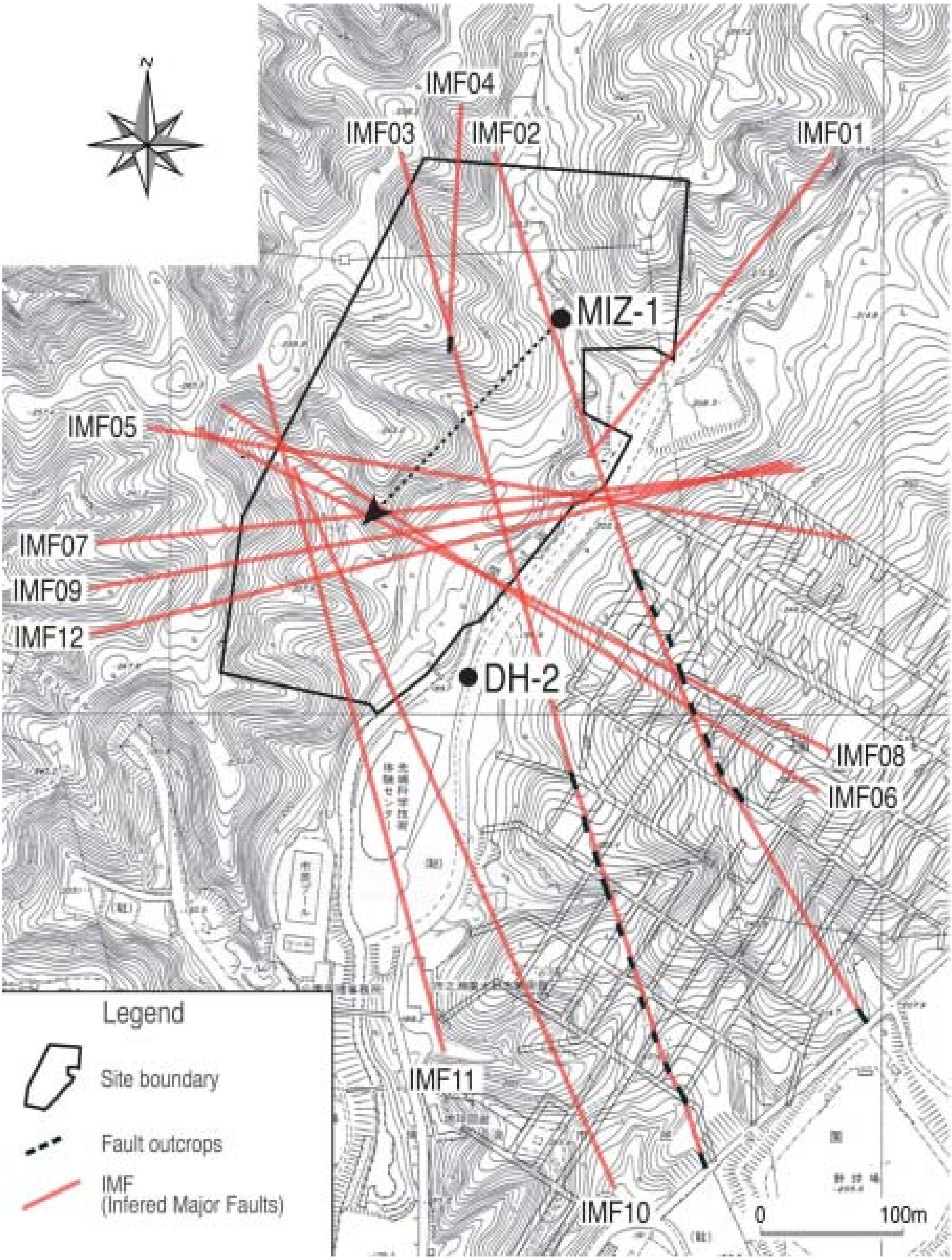
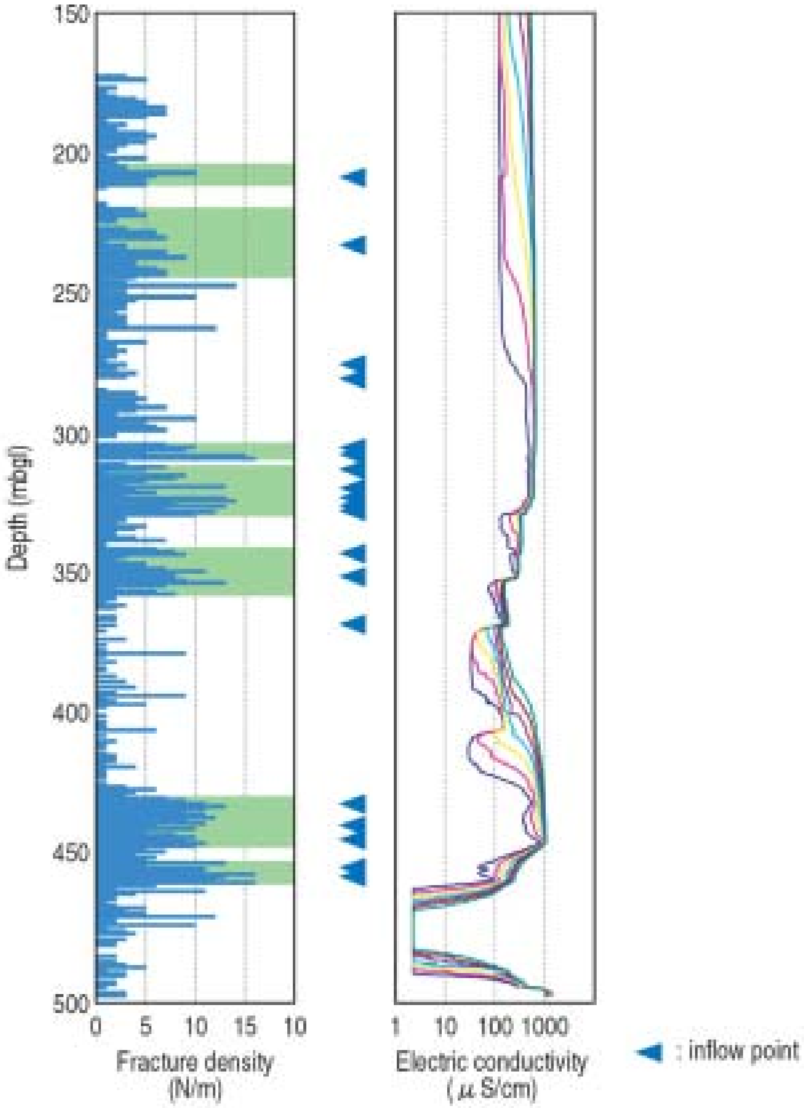
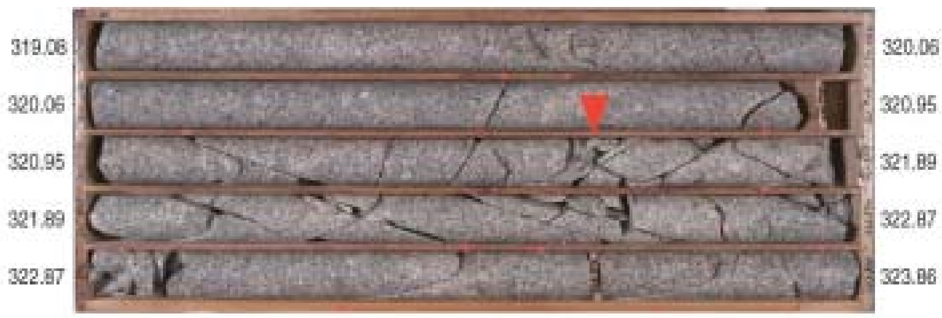


Figure 12 Distribution of known faults and inferred major faults (IMF) crossing the site around the MIU construction site



(b) Relationship in locations between major fracture zones and water inflow points



(a) Section of drillcore from a water inflow point (depth range 319.08 to 323.86 mbgl)

Figure 13 Water inflow points identified by fluid logging in the DH-2 borehole

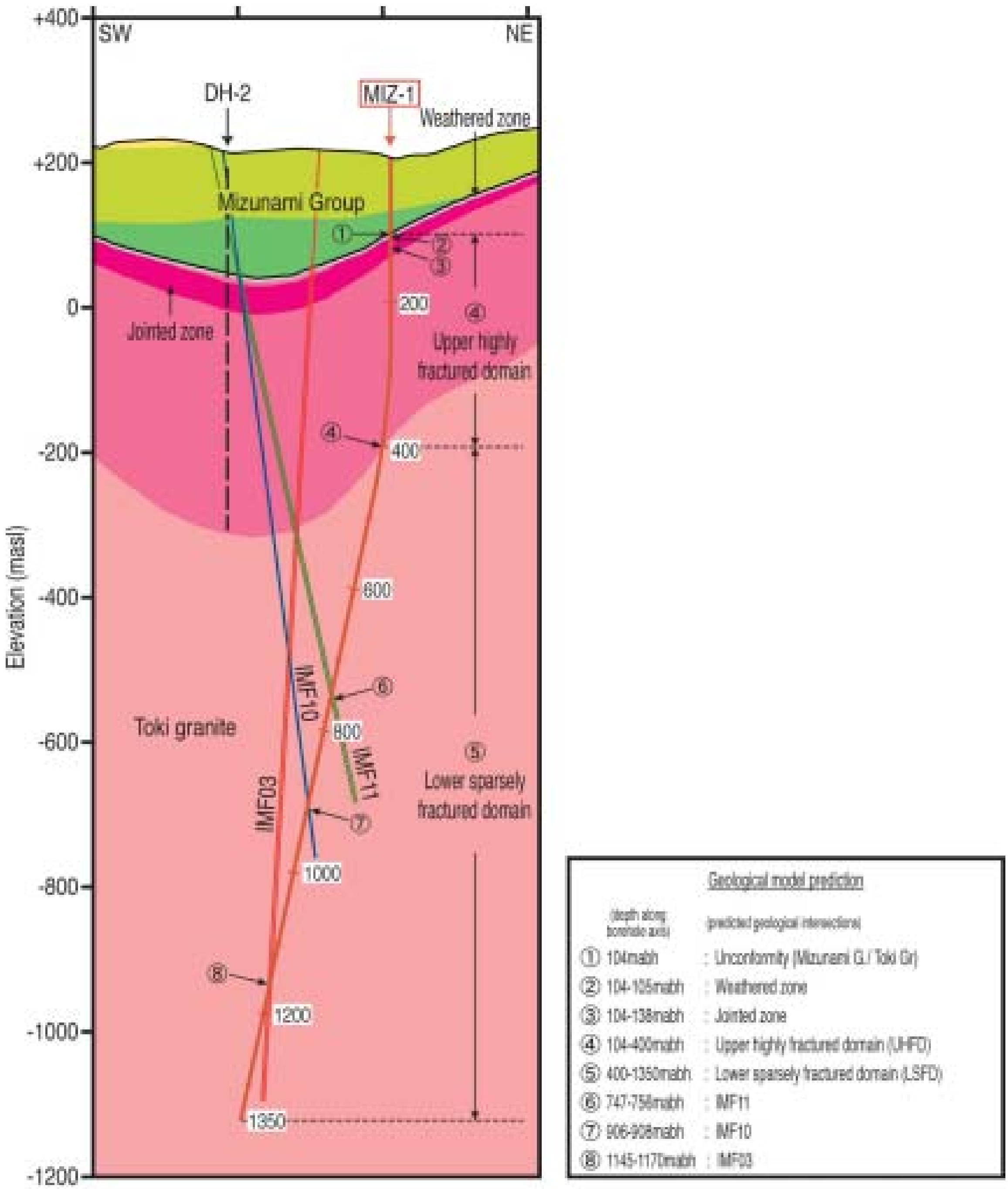


Figure 14 Predicted geological profiles along the MIZ-1 borehole (Representative model)

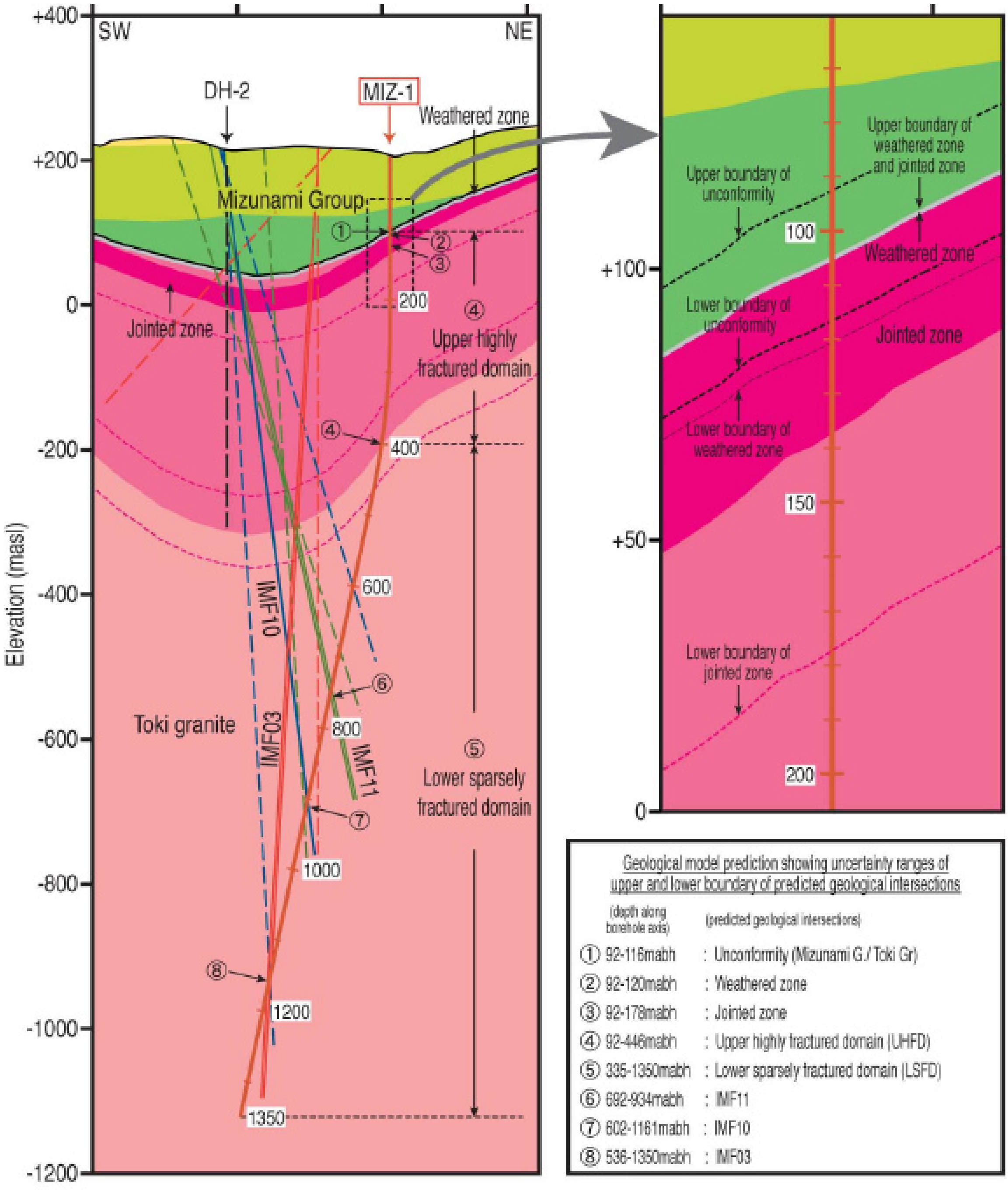


Figure 15 Predicted geological profiles along the MIZ-1 borehole (Uncertainty model)

Hydrogeology

Regional groundwater flow system

- The regional groundwater flow direction around the MIU construction site is estimated to be from NNE to SSW determined by groundwater flow simulations at three successively smaller scales: 115×115km, 70×70km and 35×35km (Figure 16). Calculated head distributions, to –2,000masl, are derived from the topography at the respective scale, including the MIU construction site (Figure 16) (Inaba et al., 2002).
- The groundwater flow simulations also suggest that the groundwater system recharges around the ridges south of the Kiso River at an altitude of 400 to 640masl, and flows downwards to the south (Figure 17). After recharge, the flow changes from downwards to horizontal as it moves SSW and eventually moves upwards in the discharge area, i.e. the Toki River at an altitude of 140 to 160masl (Figure 17) (Inaba et al., 2002).

Hydraulic properties in the Toki granite

- Previous experience in the RHS and MIU borehole investigations at the Shobasama site and around the MIU construction site indicated that major drilling fluid loss during drilling (in some instances more than 75%) tends to occur at specific depths in the upper part of the granite: most severe losses occurred at -28 to +20masl in DH-2; +20masl in MIU-1; and at -.25masl in MIU-2. Less severe losses were also intersected in the upper parts of the granite by other boreholes, but in a broader range from +34 to – 80masl. (Figure 18).
- In 1993 the transmissivity of the water inflow point intersected by the DH-2 borehole at 220-223.3mbgl was determined to be in the order of $10^{-5}m^2/sec$.
- Based on the results of the current DH-2 borehole investigations, major fracture zones (i.e., the jointed zone at 200-230 mabh, and the fault zones at 300-320 and 420-440mabh) have high transmissivities. Most of the WCFs identified from fluid logging are located in major fracture zones and have higher transmissivities in the range of 10^{-7} to $10^{-4}m^2/sec$ (Figure 19). The WCFs in the jointed zone are observed at the intersection with an E-W trending fault, and most of the WCFs in the fault zone have an E-W trend.
- Based on the hydraulic tests in the DH-2 borehole, hydraulic conductivities of IMF03, IMF10 and IMF11, all NNW-striking faults, are determined to be 10^{-6} to 10^{-7}m/sec.
- Hydraulic conductivity profiles for 11 RHS boreholes show decrease in conductivity with depth and the presence of a possible boundary at around 400mbgl, which is consistent with the boundary between the UHFD and LSFD defined from the geological information (Figure 20a). The mean hydraulic conductivity in the UHFD is in the order of 10^{-8}m/sec; in the LSFD, mean hydraulic conductivity is in the order of 10^{-9}m/sec (Figure 20b) (JNC, 2002).
- Head profiles for 11 RHS boreholes and 4 MIU boreholes indicate hydrostatistic conditions except for some boreholes drilled in the recharge area (DH-10 borehole), the discharge area (DH-12 borehole) and the footwall of the Tsukiyoshi fault (MIU-2, MIU-3 and MIU-4 boreholes). For the MIU construction site, a hydrostatistic condition with a head around 35mbgl is expected, based on data from the DH-2 borehole investigations.

Prediction of hydrogeology in the MIZ-1 borehole

- Based on the interpretation of existing information mainly described above, major drilling fluid loss in the upper part of the granite is predicted to occur in a broader range from –30 to +25masl, and hydraulic properties of the two structural domains (UHFD and LSFD) and three major faults (IMF 03, IMF 10 and IMF 11) are predicted as shown in Figure 21.

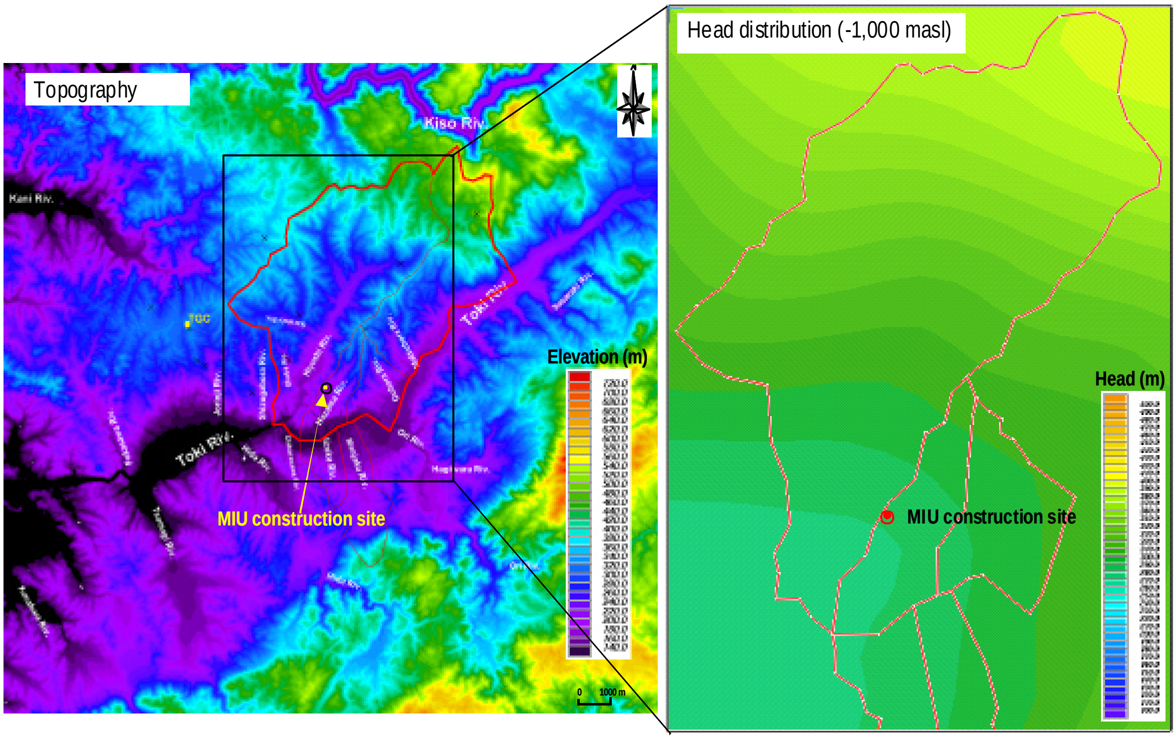


Figure 16 Topography and head distribution at -1,000masl

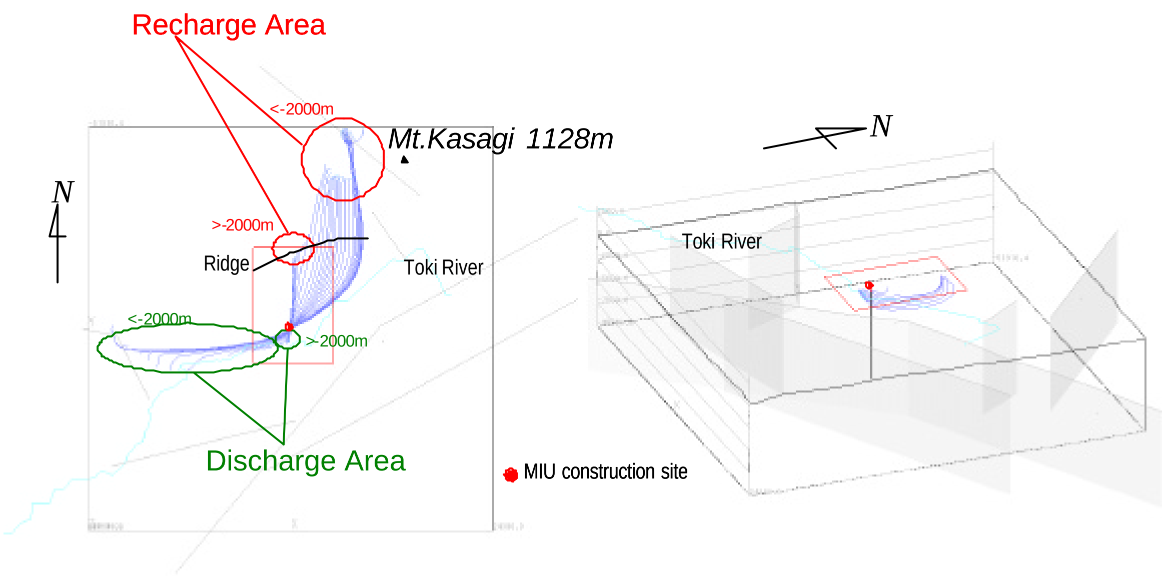


Figure 17 Groundwater flow lines through the deep underground below the MIU construction site, based on regional-scale groundwater flow models

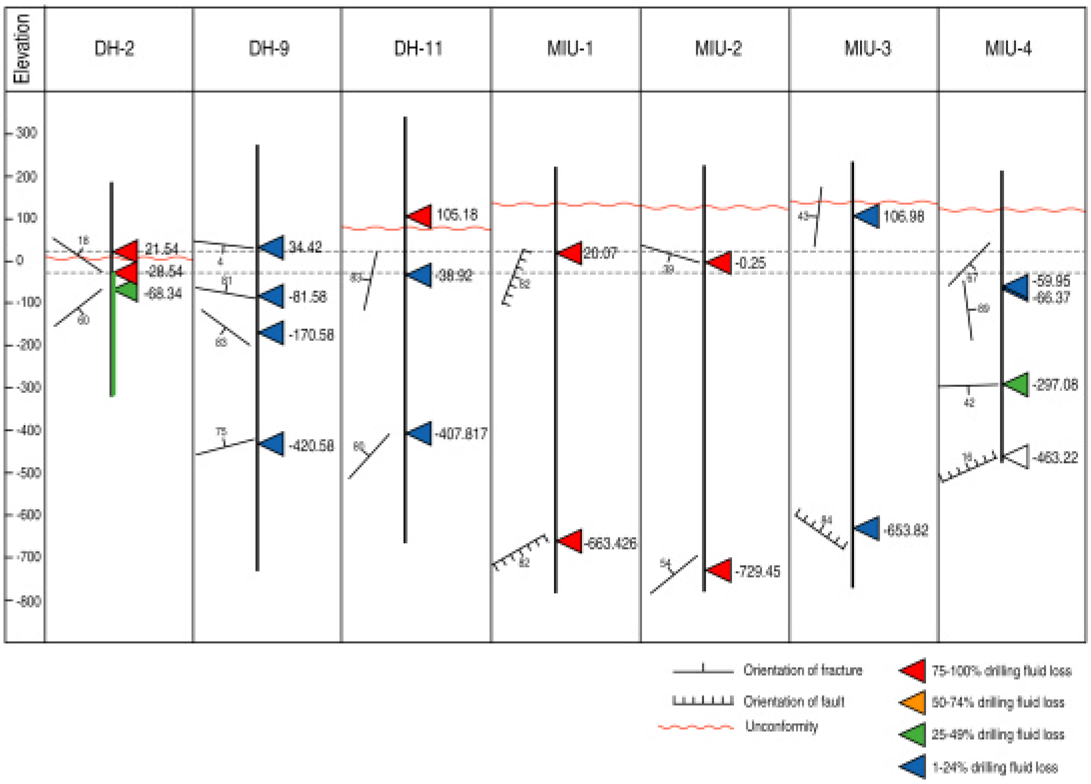


Figure 18 Location of major drilling fluid loss in UHFD

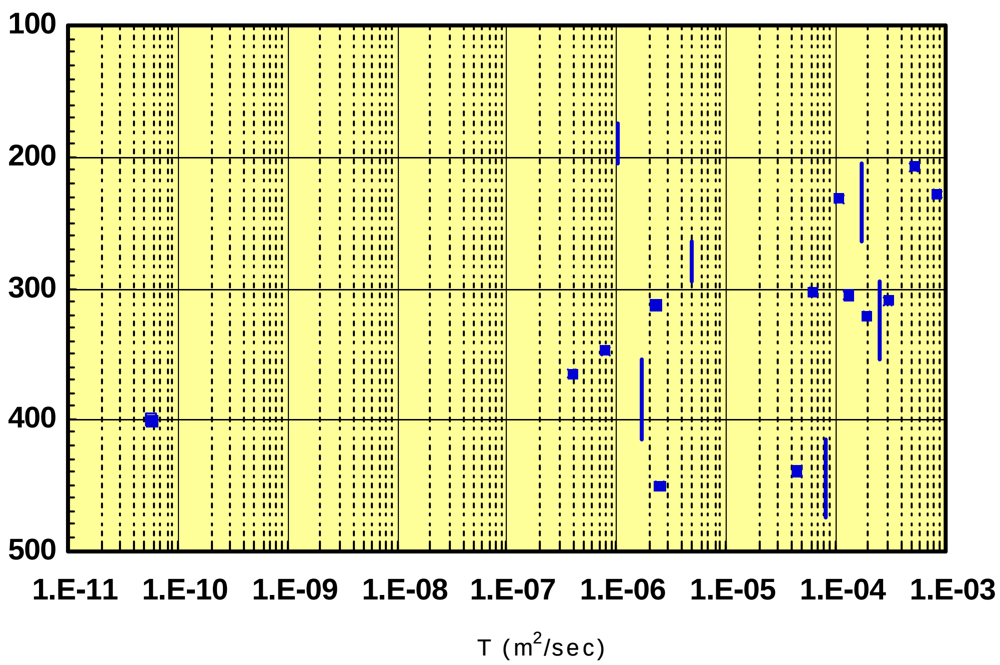
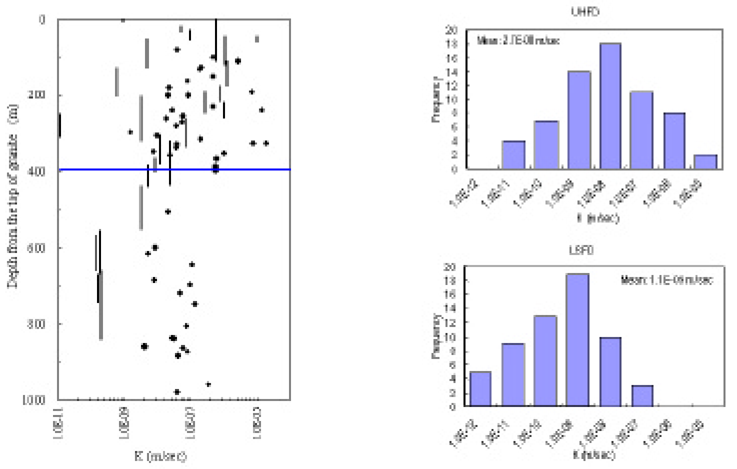


Figure 19 Transmissivity profile along the DH-2 borehole



(a) Hydraulic conductivity depth profile

(b) Distribution of hydraulic conductivities of the UHFD and LSFD

Figure 20 Hydraulic conductivities in the Toki granite

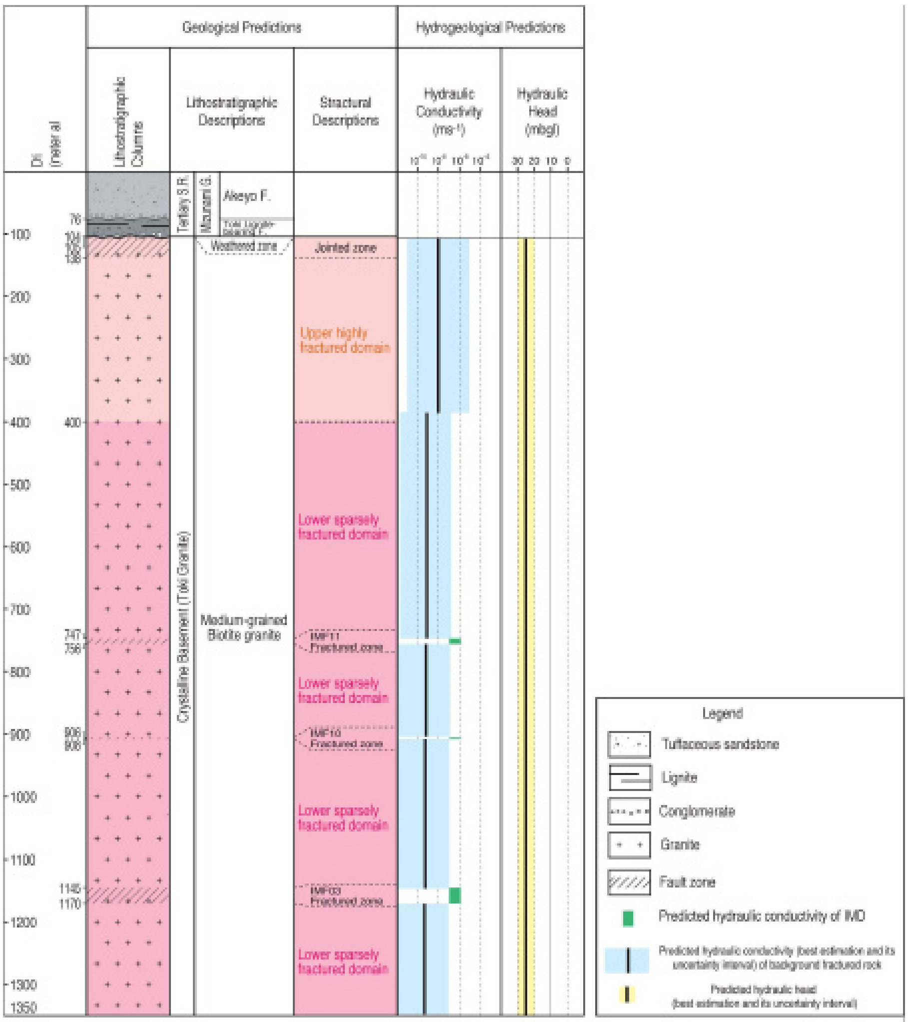


Figure 21 Predicted hydrogeological conditions along the MIZ-1 borehole

Hydrochemistry

Groundwater type and redox condition

- More than 250 water compositions of groundwater from the RHS, MIU and related boreholes north of the Toki River are all low mineral water (Total Dissolved Solids, TDS < 300mg/liter). On the other hand, more saline (up to 380mg/liter of TDS) waters are observed in the DH-12 borehole, which is located near the Toki River.
- Based on the hydrochemical data around the Tono Mine, the groundwater in the sedimentary rocks generally changes from Na-Ca-HCO3 type to Na-HCO3 type with increasing depth (Figure 22). The increases in Na^+ and alkalinity and the decrease in Ca^{2+} with depth are governed by water-rock interactions such as dissolution of calcite/feldspars and ion exchange between smectite and groundwater.
- The groundwater in the Toki granite also changes from Na-Ca-HCO3 type to Na-HCO3 type with increasing depth (Figure 23) indicated by data from several RHS boreholes north of the Toki River. Water-rock interactions including calcite, feldspars and clay minerals are expected to occur in the Toki granite, just as they occur in the sedimentary rocks indicated above.
- On the other hand, the groundwater collected from MSB boreholes and the DH-2 borehole at MIU construction site indicates that the groundwater is enriched in Na^+ and Cl^- in the lower parts of the sedimentary sequence and in the granite (approx. 80-180mbgl). Salinities of this groundwater are approximately. 1% of seawater. Chlorine contents in the drill core of MSB boreholes show that the fluvial deposits in the lower sedimentary sequences contain larger quantities of chlorine compared with the marine deposits in the upper sedimentary rocks (Figure 24). This may suggests chlorine in the rock formation is derived form groundwater. Although there are uncertainties in the groundwater sampling, the salinity of groundwater from DH-2 borehole tends to increase with depth.
- The unconformity between the sedimentary rocks and the Toki granite represents the approximate location of the redox front separating relatively oxidizing groundwater in the Toki granite from strongly reducing pore fluids in sedimentary rocks. In this geological situation, Eh values of groundwater in the Toki granite are relatively high (approx. 0mV) compared to that in sedimentary rocks, and they appear to be controlled by Fe (III)-oxyhydroxides-Fe^{2+} equilibrium (Figure 25). However, in the deeper parts of the granite, there is a possibility to encounter strongly reducing groundwater (to -380mV) by pyrite/Fe^{2+} and SO_4^{2-} /HS^- equilibrium. This is observed for several RHS boreholes that are not drilled through a sedimentary cover (Figure 25).

Origin and residence time of groundwater in the Toki granite

- All of the groundwater in the granite shows meteoric origin based on stable oxygen and hydrogen isotopes and that they were recharged in a colder climate than present. As the groundwater in the granite shows intermediate composition between surface water and sedimentary rocks in these isotopes, groundwater in the Toki granite can be younger, i.e. have shorter residence time, than the groundwater in sedimentary rocks. The residence time of the latter are between 13,000 and 15,000 years.
- From the relationship between $^{36}Cl/Cl$ and Cl for 7 groundwater samples and one river water sample, mixing between ‘old’ Cl and more recently recharged Cl water is considered as the main explanation for the pattern (Figure 26). This explanation also supports higher Cl content and longer residence time of groundwater in the DH-12 borehole, which lies further from the recharge area than do the more northerly

boreholes.

Prediction of hydrochemistry in the MIZ-1 borehole

- Based on the existing information, a conceptual model for groundwater chemistry in the area is presented in Figure 27. The groundwater evolution is possibly controlled by mixing process between low-salinity groundwater (Na-Ca-HCO3 and Na-HCO3 type) in the upper parts of the sedimentary rocks and higher-salinity groundwater (Na-Cl type) in deep granite. In the MIZ-1 borehole, groundwater chemistry is expected to evolve from low-salinity groundwater to relatively high-salinity groundwater with depth. The Eh values of groundwater are also expected to change from slightly (~0mV) to strongly reducing conditions (-300~-400mV) in the Toki granite with increasing depth.

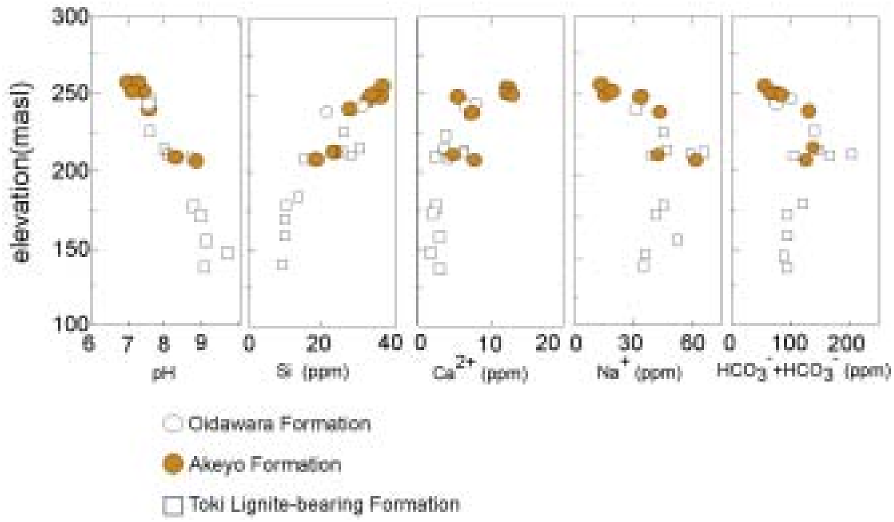


Figure 22 Depth profiles of hydrochemical data in sedimentary rocks

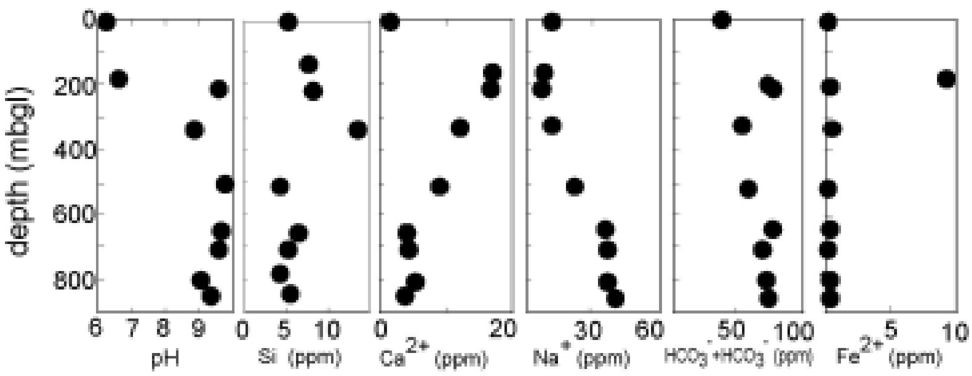


Figure 23 Depth profiles of hydrochemical data in the Toki granite

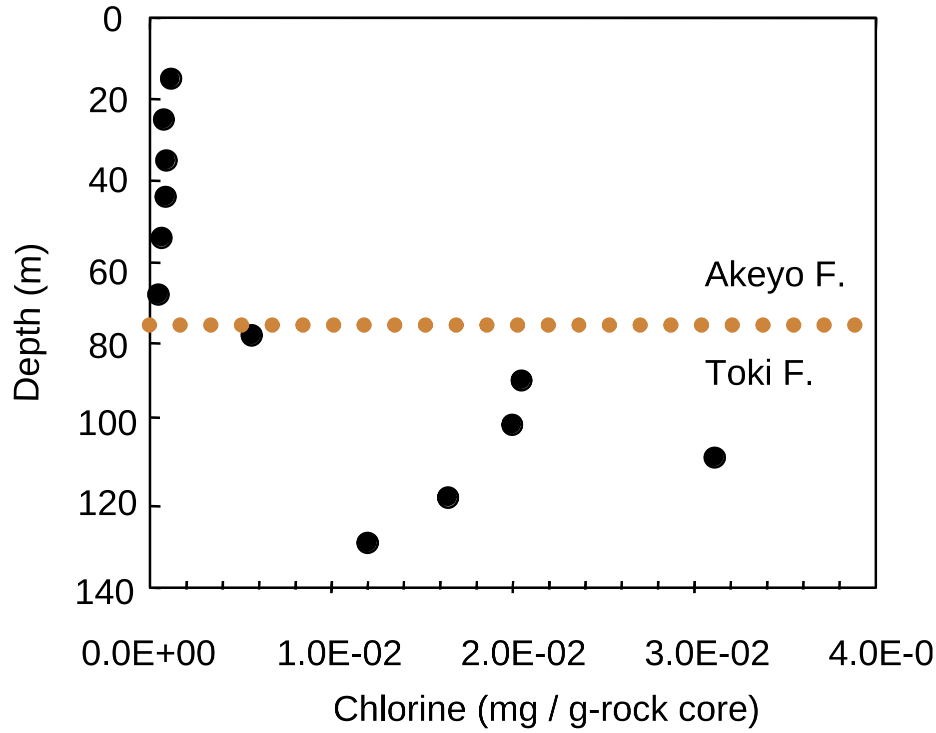


Figure 24 Chlorine content in rock core at MSB-2 borehole

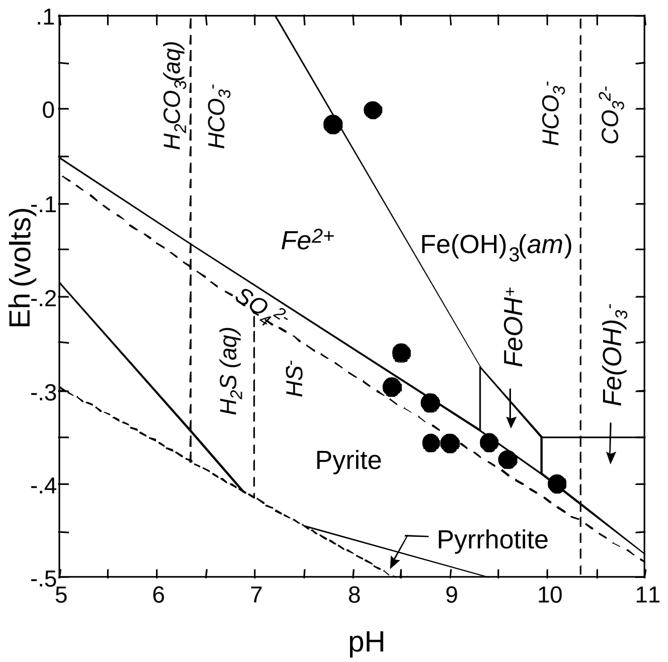


Figure 25 Eh-pH diagrams for the Fe-O_2-S-CO_2-H_2O system at 25°C and 1 bar (Activity of Fe species = 10^{-6}. Fugacity of CO_2 (*g*) = 10^{-5}. Activity of S species = 10^{-5}.)

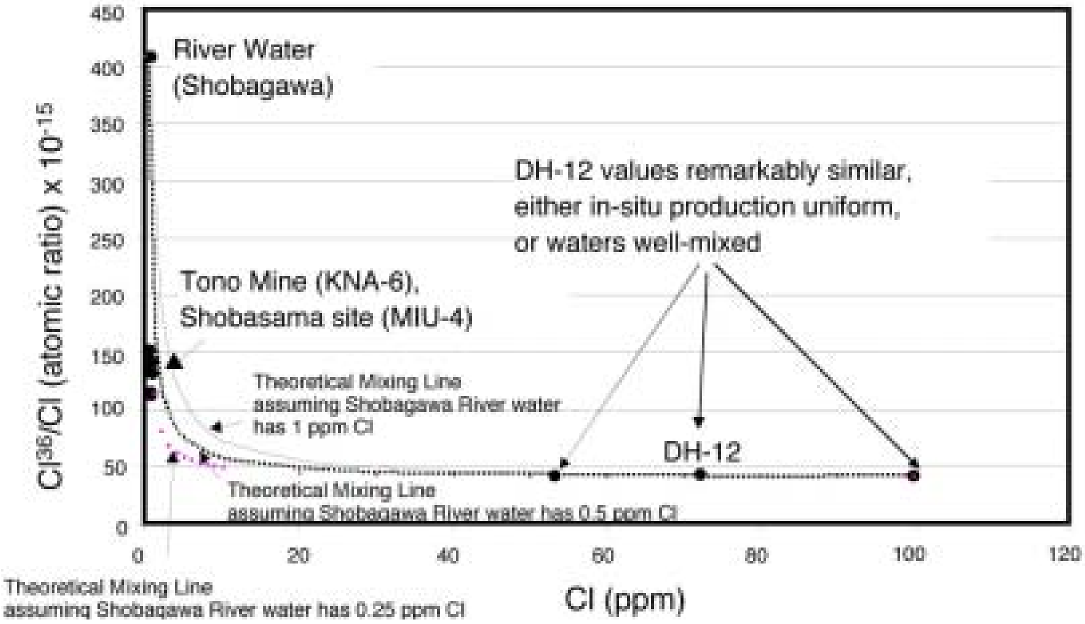


Figure 26 ^{36}Cl/Cl versus Cl concentrations for selected groundwater samples

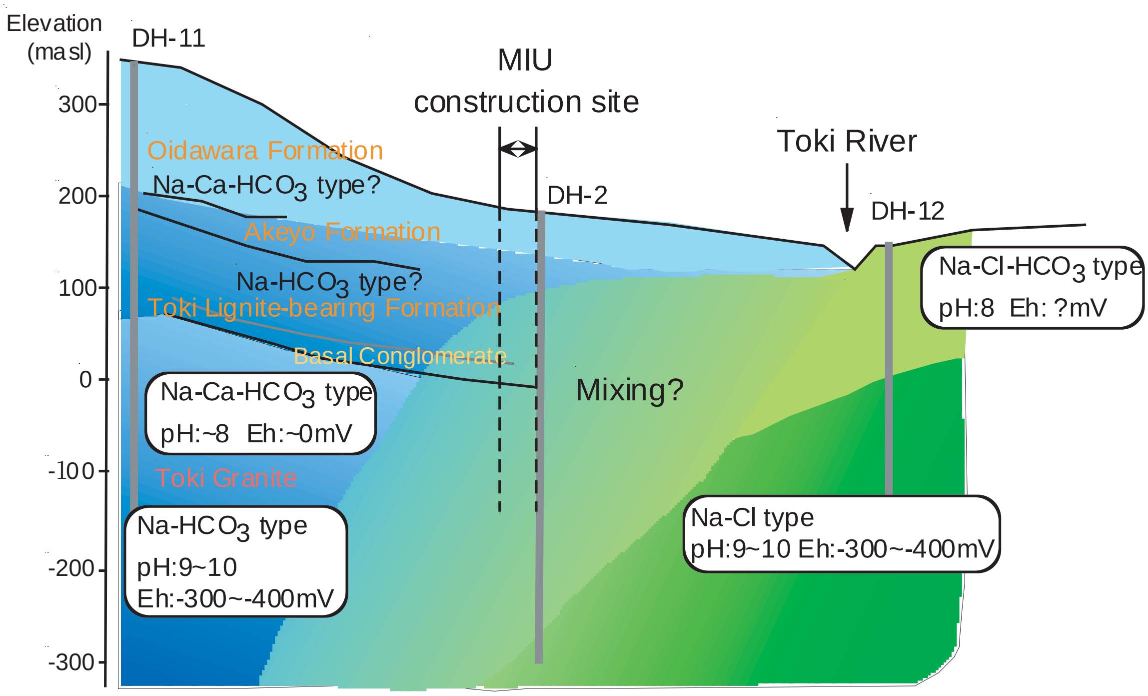


Figure 27 Conceptual hydrochemical model

Rock mechanics

In situ stress state

- The studies at the Shobasama site indicate that maximum principal stress is horizontal and the stresses increase with depth. It is considered that the stresses are affected by small structures in the hanging wall of the Tsukiyoshi fault (Figure 28(a)). Three zones are identified:

  0 to 300mbgl : $\sigma_H > \sigma_h > \sigma_v$

  300 to 700mbgl : $\sigma_H > \sigma_h = \sigma_v$

  300 to 1,000mbgl : $\sigma_H > \sigma_v > \sigma_h$

  In the footwall of the Tsukiyoshi fault the in situ stress state may be different compared to stress in the hanging wall of the fault. (Figure 28(a)).

  800 to 1,000mbgl : $\sigma_v > \sigma_H > \sigma_h$
- The direction of the maximum principal stress in the horizontal plane changes at about 300mbgl from N-S (0 to 300mbgl) to NW-SE (300 to 1,000mbgl) and is likely affected by local small structure present (Figure 28(a)).
- The Toki granite can be divided into three zones in terms of in situ stress state (stress decoupling) performed in the Shobasama site (Figure 28 and 29), especially in the hanging wall of the Tsukiyoshi fault: 0 to 300mbgl

  Zone 1 : ($\sigma_H > \sigma_h > \sigma_v$), 300 to 700mbgl

  Zone 2 : ($\sigma_H > \sigma_h = \sigma_v$), 700 to 1,000mbgl

  Zone 3 : ($\sigma_H > \sigma_v > \sigma_h$), and

  Zone 4 : ($\sigma_v > \sigma_H > \sigma_h$), footwall of Tsukiyoshi fault.

Mechanical properties

- The mechanical properties of intact rock are similar in each zone. Average values of mechanical properties determined from core samples obtained from the MIU-1, 2 and 3 boreholes are as follows; apparent specific gravity is 2.63, unconfined compressive strength is 165 MPa, Young modulus is 50 GPa, Poisson's ratio is 0.35, cohesion is 30 MPa, and angle of internal friction is 55 °.

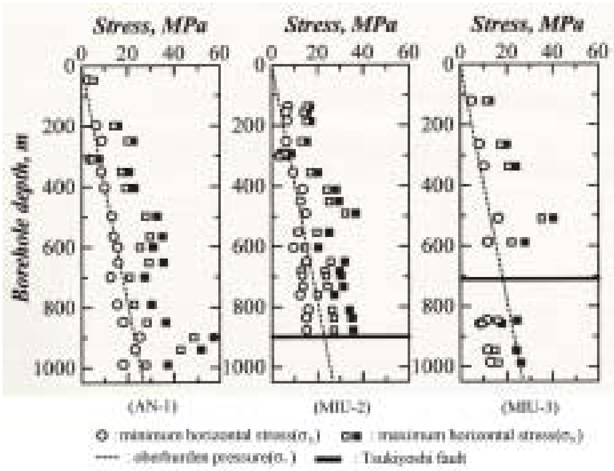
Prediction of rock mechanics in the MIZ-1 borehole

- The results of rock mechanical investigations at the Shobasama site showed that in-situ stress states are influenced by local geological conditions. The geomechanical conditions at the MIU construction site are predicted based on the expected geological conditions are as follows;

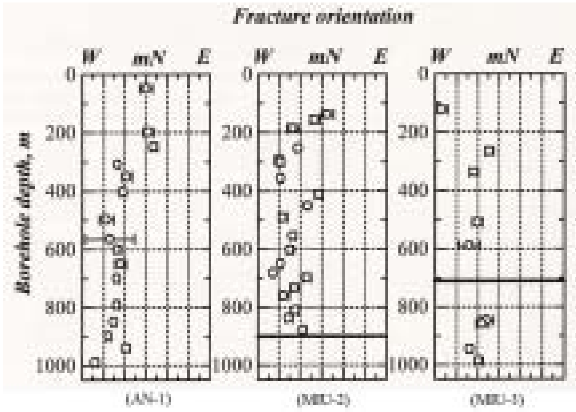
  Zone A (UHFD : 170~400mbgl) is predicted to be similar to the zone 1 at the Shobasama site ($\sigma_H > \sigma_v > \sigma_h$: direction of σ_H=N-S).

  Zone B (LSFD : 400~700mbgl) is predicted to be similar to zone 2 at the Shobasama site ($\sigma_H > \sigma_h = \sigma_v$: direction of σ_H=NW-SE).

  Zone C (LSFD influenced by IMF11, IMF10 and IMF03 : 700mbgl ~) is predicted to be similar to the part of zone 3 ($\sigma_H > \sigma_v > \sigma_h$: direction of σ_H=NW-SE) or zone 4 ($\sigma_v > \sigma_H > \sigma_h$: direction of σ_H=NW-SE).
- Mechanical properties of Zone A & B are predicted to be similar to the average values of mechanical properties of core samples obtained from MIU-1, 2 and 3 boreholes. Mechanical properties of Zone 3 are lower than that of Zone A & B.



(a) Horizontal principal stresses



(b) Direction of maximum horizontal stress

Figure 28 Profiles of in-situ stress state along boreholes at the Shobasama site

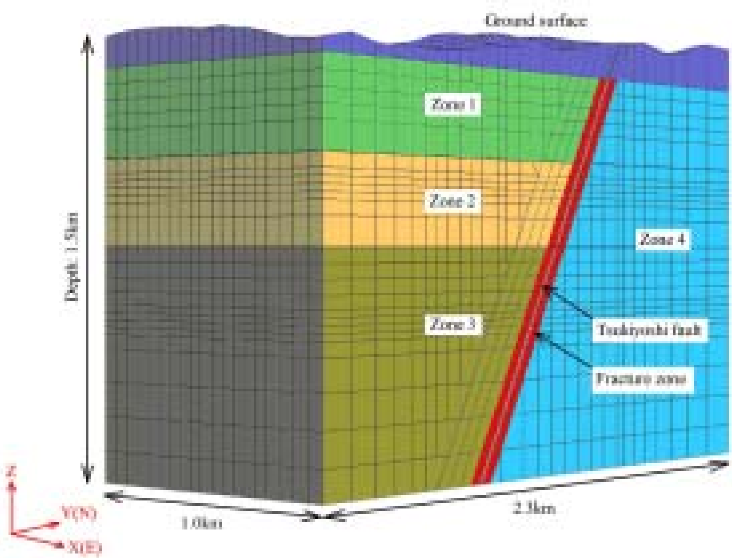


Figure 29 Conceptual geomechanical model at the Shobasama site

5 DETAILS OF THE MIZ-1 BOREHOLE INVESTIGATIONS

In the MIZ-1 borehole investigation program, a wide range of investigations are planned (Figure 30). The following subsections (5.1 to 5.6) provide the details of the "base case" program in each investigation field. The procedure and schedule for the "base case" investigation campaign is described in Section 6.1.1, and optional cases are discussed in Section 6.1.2.

5.1 Borehole Drilling

The MIZ-1 borehole investigations comprise the deep borehole program in the MIU construction site. The main objective is to intersect several defined targets, namely inferred major faults (IMF 03, IMF 10 and IMF 11) and to develop an understanding of the geological environment to approximately 1,330mbgl, in the Toki granite. Full core recovery and stable borehole conditions are required for the on-site geological, hydrogeological and hydrochemical investigations. A triple barrel-core recovery technique with an acrylic innermost core barrel was successfully employed in the MIU-4 borehole investigations to ensure high percentage core recovery and maintain borehole integrity. It is intended to apply this method to the MIZ-1 drilling program.

5.1.1 Aims

- Full core recovery for geological, hydrogeological, hydrochemical and geochemical investigations.
- Provide suitable locations for downhole investigations such as hydraulic tests, groundwater sampling and borehole logging.

5.1.2 Methodology

The MIZ-1 borehole will be drilled in six phases (see section 6.1.1). The following methodology will be used.

Casing and cementing

The surface soil and the friable top of the Mizunami Group will be drilled to a depth of 5mabh using a tricone bit. Borehole diameter will be 26 inches (660.4mm) with 20 inch (508.0mm) casing pipes installed to 5mabh and fixed by full hole cementing. Continuous core drilling will be done from 5mabh to about 114mabh that is through the Mizunami Group, the weathered zone and into the UHFD in Toki granite. Following borehole investigations in this interval, the interval from 5mabh to 106mabh will be reamed using a tricone bit or an air hammer to a diameter of 17- 1/2 inch (444.5mm). Then, either 14 inch (355.6mm) or 13-3/8 inch (339.7mm) casing pipes will be installed and fixed by full hole cementing. Dredging and flushing of the borehole are performed after cementing. The borehole is flushed with drilling fluid tagged with fluorescent dye (see *Drilling/flushing fluid* below). For further drilling, 6 inch (165.2mm) temporary casing is installed to 106mabh.

Coring

Wireline core drilling, 5-1/2 inch (136mm) diameter and using fresh water is performed from 5mabh to the final depth at 1,350mabh. A triple-barrel drilling method with an acrylic inner core barrel is employed for full or high percentage core recovery. The core diameter, except during the controlled directional drilling, is about 85mm. Intact core is extracted from the acrylic tubes and orientated. An orientation line is marked on the core.

Controlled directional drilling

The MIZ-1 borehole will be drilled with careful control of drilling inclination and direction. Inclined drilling is done in order to intersect several IMFs in the MIU construction site. The borehole will be drilled in the overall southwesterly direction from the northeast part of the MIU construction site. The borehole will be drilled vertically from surface to 250mabh. In order to carry out the controlled directional drilling successfully, an interval of relatively intact, hard rock and little or no drilling fluid loss is best. Therefore, the controlled directional drilling will start below the highly fractured rock likely associated with the expected zone of major drilling fluid loss. This requirement will be met by extra drilling for confirmation of the stability of the rock at the predicted depth of 250mabh. The controlled, directional drilling will be done using a downhole-motor wireline coring system (core diameter is minimum 52.5mm) to change inclination and direction in the interval of 250– 460mabh. The inclination of the borehole will change several times in increments of 1.5 degrees every 30 metres, so that the borehole will curve in a southwesterly direction as inclination changes. The inclination target is 78 degrees from horizontal or 12 degrees from vertical. The drilling in the interval of 460– 1,350mabh will be done along the planned borehole trace (southwest direction and 78 degrees inclination) using 5 1/2 inch wireline core drilling tools. If it is necessary to adjust the borehole direction and inclination, controlled directional drilling using the downhole – motor will be done.

Drilling/flushing fluid

Fresh water tagged with fluorescent dye (type A) is used for drilling and flushing. Fluorescent dye (A) is Amino G. acid for the Mizunami Group and the upper granite. Fluorescent dye (B) is uranine for the Toki granite. No other chemicals/additives are planned to be used in the drilling fluid.

Monitoring of the drilling

Drilling data such as drilling rate, bit revolution, bit load, torque, pumping pressure, rate of water supply and return and any fluid volumes lost or gained are continuously monitored during borehole drilling to complement geological and hydrogeological investigations. Data are delivered on-line, in real-time, to the JNC office. As the MIZ-1 borehole is a controlled direction borehole, it will be important to perform a single shot hole deviation survey every 30m of drilling from top to final depth.

Borehole protection

In the event there is significant drilling fluid loss, plugging with LCM (Lost Circulation Material, e.g. cellulose) will be carried out. If successful, drilling will continue. However, if significant drilling fluid loss continues after plugging of the site, partial cementing of the drilling fluid loss location will be done. In case of significant borehole collapse, partial cementing will be carried out at the site where the collapse occurs. If collapse occurs even after the cementing of the location, drilling will be halted and borehole investigations (BTV/geophysics/hydraulic testing) will be performed. In all these situations, all possible on-site investigations to the site of collapse should be completed before borehole protection is implemented. After reaming with a tricon bit to the depth of collapse section is completed, casing pipes will be installed and fixed by full hole cementing to the depth of the collapse section. In the case of both drilling fluid loss and collapse occurring at same location, the borehole protection will be the same as for the borehole collapse case (see section 6.1.2).

5.1.3 Reporting

Daily report (daily at 8:20)

Status of the field work (drilling length, water level and tests performed, etc.) is reported by fax, by the on-site drilling inspector.

Daily report (to be supplied to JNC on the next morning)
Duration and time of drilling, personnel, activities undertaken, drilling length, tally list of drill strings and measurement or testing tools used, results of deviation surveys, bit life, details of machinery used, consumption of supplies and anything abnormal or unexpected are reported promptly.

Final report (by the end of the contract period)
A complete record of drilling is reported in detail with logs of drilling data.

5.2 Geological Investigations

The goals of geological investigations in the surface-based investigation program are to acquire geological and structural information, to identify geological structures related to higher or lower-permeability structures and to establish a systematic investigation technique for reliably and accurately characterizing the deep geological environment.

5.2.1 Aims

- To acquire geological and structural data on rocks, major faults and WCFs for the development of a geological model.
- To check and improve the existing geological model and acquire data for the development of a hydrogeological and geochemical model.
- To obtain data on geological, geochemical and geometrical properties of WCFs for understanding solute transport/retardation phenomena.
- To establish methodologies to relate geological characteristics including lithology, stratigraphy and faults to the hydrogeological regime.

5.2.2 Methods

A variety of geological investigations are planned on the MIU construction site and in the laboratory. The methods to be employed are as follows:

1. On the site

• Core description:	general geological information
• Core photographing:	visual geological information (*i.e.* core images)
• Core scanning:	digital data on geological structures
• Core sampling:	rock/mineral samples for laboratory work

2. In the laboratory

• Photo-processing:	grain size distribution and mineral composition
• Optical microscopy:	general petrological information
• Modal analysis:	mineral composition
• X-ray diffractometry:	mineral composition
• SEM examination:	microtexture and microscopic pore-space geometry
• EPMA analysis:	chemical composition of minerals
• Standard chemical analyses:	chemical composition
• Standard isotopic analyses:	isotopic composition
• CEC measurement:	cation exchange capacity
• Radiometric age determination:	K-Ar, ^{14}C, U-Th ages
• Hg injection porosimetry:	porosity, pore-space distribution and specific surface area
• Resin impregnation:	microscopic pore-space geometry and porosity

5.2.3 Planned field work

5.2.3.1 Work during drilling

On-site core description and photography (by contractor)
The cores are described completely at 1/20 scale by the contractor, using JNC’s core logging manual and data recorded on standardized logging forms to ensure accuracy and consistency. The following items are included in the description: drilling length along borehole axis, lithofacies (log), rock type, texture, phenocryst (mineral, diameter and shape), mafic mineral content, weathering, alteration, rock mass classification, RQD (Rock Quality Designation),

fracture density, location and dip of fracture (log), shape of fracture, structure on fracture plane, nature of alteration products along fracture, width of fracture and mineralogy of fracture filling materials including identification of potential flowing features. Depths where the core is cut for storage and good packer locations for hydraulic tests are also recorded. Borehole profiles, including all this information, will serve as a basis for other investigations.
Photographs of all cores are taken using a camera to preserve visual geological and structural information. All images include a scale and a color chart. Each image includes up to five, 1m long lengths of core.

Core scanning and sampling (in house)
Images of cores are taken with a digital scanning device using optical wavelengths for later numerical analysis of fractures. Samples for later laboratory work are then selected after the evaluation of information obtained during drilling.

5.2.3.2 Work after drilling

Core sampling (in house)
Samples for further laboratory work are selected based upon information obtained by previous investigations.

5.2.4 Planned laboratory work

The following laboratory work is planned. Details (*e.g.* constituents, methods and numbers of samples for analysis) are summarized in Table 1.

Petrological characterization (by contractor)
Standard optical microscopy is conducted on rock thin sections to clarify lithological characteristics of the Toki granite. Any correlation between such geological information and fracture density, hydraulic and physical properties is identified and discussed in the report.

Petrological characterization (in house)
Mineralogical and structural characteristics of fracture fillings and of altered wall rocks are described by means of microscopic examination of thin sections. Classification of WCFs is also made on the basis of microscopic examination and on-site core description. In addition, grain size distributions and mineral compositions of the granite matrix and of the fracture fillings are determined by the combined use of XRD (X-Ray Diffraction), XRF (X-Ray Fluorescence spectroscopy), and conventional modal analysis (*e.g.* point-counting).

Mineralogical characterization (in house)
Paragenesis of fracture fillings is investigated by detailed examination using optical microscopy and SEM (Scanning Electron Microscope). Chemical compositions of major fracture-filling minerals and of the constituent minerals of associated wall rocks are determined by EPMA (Electron Probe Micro-Analyzer) techniques.

Geochemical characterization (by individual contractor and in house)
Major components and trace elements including REEs (Rare Earth Elements) are analyzed on both granite samples and fracture fillings by XRF, IC (Ion Chromatography), ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) and by wet chemical methods. The aims of these analyses are to characterize the Toki granite at the MIU site as thoroughly as possible for geological modeling and to provide geochemical data on WCFs for interpreting water-rock interactions.
Stable isotope compositions (or isotopic ratios) are also determined on fracture fillings by various mass spectrometric techniques. Such isotopic data, together with data on geometry

and ages of WCFs, are used for understanding groundwater flow system and its evolution in the MIU construction site.

In addition, CEC (Cation Exchange Capacity) measurements and studies on ^{238}U-decay series disequilibrium across a profile from the fracture surface into the wall rocks are carried out. These may be of significance in the assessment of *in situ* solute transport/retardation behavior in the vicinity of the WCFs.

Radiometric age determination (by individual contractor and in house)

Radiometric age dating is performed on clay minerals and carbonates in the fracture fillings to understand the genesis and evolution of the WCFs.

Microscopic pore-space characterization (by individual contractor and in house)

To develop a conceptual model of the WCFs in the Toki granite, porosity is determined and microscopic pore-space geometry is characterized in detail on the fracture fillings and the wall rocks. These properties are relevant to solute transport/retardation phenomena. Hg injection porosimetry, which determines open or effective porosity (*i.e.* Hg-accessible porosity), is used for intact rock materials and a combined technique of resin impregnation and microscopic examination is applied for determining porosity of friable rock materials. The resin impregnation technique is also employed to characterize microscopic pore-space geometry.

5.2.5 Reporting

5.2.5.1 Field work reports

Quick look report (daily at 9:00 and 17:00)

Outline of lithofacies, weathering, alteration and geological structures observed on the core drilled since the last report is reported by telephone. Information on any anomalies and/or unexpected events encountered during drilling is also given.

Daily report (the morning following the day covered by the report)

A summary of lithofacies, weathering, alteration and geological structure based upon the on-site core description is reported with appended description sheets providing details on the previous day’s observations. Details of any anomalies and/or unexpected events encountered during drilling are described.

Summary report (within a week after each 50m of drilling has been completed)

A summary of lithofacies, weathering, alteration and geological structure including defined anomalies and/or events is reported with a geological log at 1/500 scale. All description sheets covering the interval are also submitted. Digitized numerical data (*e.g.* fracture density) are also supplied.

Final report (by the end of contract period)

A detailed geological description is reported with a full data set in a section of the final report. Full details of all methods employed, operating conditions of equipment, relevant detection limits and precision are described. Details are also given of anything unexpected that occurred during drilling.

5.2.5.2 Laboratory work reports

Prompt report (immediately after the investigation has been completed)

Raw data are reported immediately after each phase of the investigation has been completed. Data quality is then checked by JNC.

Final report (by the end of contract period)

All results are reported with full data sets. Full details of all methods employed, operating conditions of equipment, relevant detection limits and precision are described. Details are also given of anything unexpected that occurred during the laboratory work

Table 1 Planned laboratory work for geological investigations

Constituents	Methods*	Sample** Quantity			Laboratories
		GM	FF/AW	Remarks	
Petrological Characterization					
Petrography	Optical microscopy	25	30		JNC, Contractor
Mineral composition	XRD, XRF, Modal analysis, Photo-processing	25	30		JNC
Mineralogical Characterization					
Chemical composition	EPMA	–	30		JNC
Paragenesis	Optical microscopy, SEM	–	30		JNC
Geochemical Characterization					
Major components					
SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, H_2O+, H_2O-, CO_2	XRF, IC, ICP-MS, Wet chemical analysis	25	30		JNC, Contractor
Trace elements					
Li, Be, B, F, Cl, Br, S, Rb, Sr, Ba, Cs, Pb, Y, Zr, Hf, Nb, Ta, Th, U, Ni, Co, V, Cr, Sc	XRF, ICP-MS	15	30		Contractor
Rare earth elements					
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu	ICP-MS	15	30	Profile	Contractor
Stable isotopes					
D / H	GMS	–	20	Carbonates	JNC
^{13}C, ^{14}C	AMS	–	20	Carbonates	JNC
^{18}O / ^{16}O	GMS	–	20	Carbonates	JNC
^{87}Sr / ^{86}Sr	TIMS	–	20	Carbonates	Contractor
^{238}U-decay series	Alpha-, gamma-spectrometry	– –	30	Profile	JNC
Cation exchange capacity (CEC)	Schollenberger method	–	20		JNC
Radiometric Age Determination					
Clay minerals	K-Ar method	–	5	FF only	Contractor
Carbonates	^{14}C, U-Th methods	–	5	FF only	JNC, Contractor
Microscopic Pore-space Characterization					
Porosity	Hg injection porosimetry	15	–		Contractor
Geometry	Resin impregnation Microscopic examination	–	20		JNC

* Methods = XRD: X-Ray Diffractometry, XRF: X-Ray Fluorescence Spectroscopy, EPMA: Electron Probe Micro-Analyzer, SEM: Scanning Electron Microscope, IC: Ion Chromatography, ICP-MS: Inductively Coupled Plasma-Mass Spectrometry, TIMS: Thermal Ionization Mass Spectrometry, AMS: Accelerator Mass Spectrometry, GMS: Gas source Mass Spectrometry

** Sample = GM: Granite Matrix, FF/AW: Fracture Fillings and their Altered Wall Rocks

5.3 Geophysical Investigations

Geophysical logging and borehole TV (BTV) can provide basic information on the rock mass and structures necessary for hydrogeological and hydrochemical investigations which supplement the information from drilling reports and on-site core description. Therefore, in the MIZ-1 borehole investigation program, it is planned to conduct a series of geophysical investigations in support of the hydrogeological and hydrochemical investigations.

5.3.1 Aims

- To identify locations of potentially WCFs.
- To acquire information about the orientation and geometry of fractures and lithological boundaries.
- To acquire geophysical properties by continuous wireline logging to be used in the fracture characterization study and in the geological, hydrochemical and geomechanical modeling.
- To characterize *in situ* neutron flux production for hydrochemical interpretations.

5.3.2 Methods

A series of geophysical investigations are carried out by the following methods:

1. Petrophysical logging
   - Electrical: apparent resistivity of surrounding rock
   - Micro electrical: apparent resistivity of the borehole wall
   - Natural gamma: gamma rays from radioactive elements in the rocks
   - Spectral gamma: content of Potassium, Uranium and Thorium
   - Neutron: thermal neutron correlated with total porosity around the borehole
   - Density: decayed gamma rays correlated with apparent density
   - Acoustic: P-wave and S-wave velocity of surrounding rock
   - Borehole radar: location of electromagnetic reflectors in the borehole

2. Geotechnical logging
   - X-Y calliper: borehole diameters in orthogonal directions
   - Deviation: orientation and inclination of borehole

3. Borehole TV (BTV: digital scanning of the borehole wall)

5.3.3 Planned field work

Geophysical logging and BTV, to be performed basically in three phases, can provide information to determine test intervals for investigations such as hydraulic tests and groundwater sampling. The locations, orientations, widths, shapes and appearance of joints, faults and fractures, lithological boundaries and veins are identified as well as petrophysical properties of the rocks being characterized. The geometry of the structure system will be defined by data analysis, primarily from the digitized BTV data. Potentially WCFs may be identified by detecting anomalies on the geophysical logs and by comparing these logs with the geological and hydrogeological information.

Phase 1: 5 – 114mabh / Sedimentary rocks, weathered zone, jointed zone and UHFD in the Toki granite
- Geophysical logging (except for borehole radar) and BTV

Phase 2: 106 – 756mabh / weathered zone, jointed zone, UHFD and LSFD in the Toki granite (down to the fault zone below IMF11)

- Geophysical logging (except for borehole radar) and BTV

Phase 3: 106 – 1,350mabh / weathered zone, jointed zone, UHFD and LSFD in the Toki granite

- Geophysical logging (including borehole radar) and BTV

5.3.4 Reporting

5.3.4.1 Geophysical logging

Prompt report (1 day after the field investigation has been completed)
Each of the logs is submitted. Any anomalies and/or unexpected events encountered during the fieldwork are also reported.

Interim report (within 3 days after the field investigation has been completed)
Data records with all profiles at the same scale are submitted within 3 days of survey completion. Raw digital data in Microsoft Excel™ files are also submitted to JNC as soon as possible. Details of the anomalies and/or unexpected events are reported.

Final report (by the end of the contract period)
The report should include possible interpretations of results (including any anomalies and/or unexpected events) and the full data set. Data are in a format compatible with Land Mark™ software for modeling. Full details of all methods employed, operating conditions of equipment, relevant detection limits and precision are described.

5.3.4.2 Borehole TV

Prompt report (1 day after the field survey has been completed)
Pictures are submitted on videotape. Digitized images in BIPS™ image files to be used for analysis by computer (Borehole Image Processing System program) are also submitted to JNC as soon as possible. Details of any anomalies and/or unexpected events encountered during fieldwork are also given.

Interim report (within 1 week after the field survey has been completed)
The locations, orientations, widths, shapes and appearance of all fracture such as faults and joints, lithological boundaries and veins are identified. The structures can be compared with those identified on the core and the two sets of data should be matched as closely as possible. Results are submitted digitally in Microsoft Excel™ files.

Final report (by the end of the contract period)
Possible interpretations of results (*e.g.* details of identified faults) and full data sets are reported. Full details of all methods employed, operating conditions of equipment, relevant detection limits and precision are described.

5.4 Hydrogeological Investigations

The investigations performed in the DH-2 borehole in 1993 have provided the following indications on the hydrogeological characteristics of the Toki granite:
- Temperature anomalies were identified at three depths in the Toki granite, i.e. 212.6, 235.4 and 319.4mbgl.
- Remarkable drilling fluid loss during drilling was observed at 221.7 and 261.5mbgl.

In 2002, new DH-2 borehole investigations provided the following results:
- Major fracture zones; the jointed zone at 200-230mabh, and the fault zones at 300-320mabh and 420-440mabh have high transmissivities ($T \approx 10^{-4}$ m^2/sec).
- Most of the WCFs identified from fluid logging are in the major fracture zones and have high transmissivities ($T \approx 10^{-7}$ to 10^{-4} m^2/sec).
- The WCFs in the jointed zone are observed at the intersection with an E-W trending fault, and most of WCFs in the fault zone have E-W trend

5.4.1 Aims

- To obtain good quality data on the transmissivity, hydraulic conductivity, hydraulic head and flow model in the WCFs and the entire borehole section.
- To establish a methodology for estimating the connectivity of WCFs on a scale of several decameters to several hectometers based upon the pressure responses observed in the measurement intervals in the boreholes DH-2, MSB-1, MSB-2, MSB-3 and MSB-4 during the MIZ-1 drilling.

5.4.2 Methods

Fluid logging and hydraulic tests are planned. The methods to be employed are as follows:

1. Fluid logging (dynamic fluid logging, i.e. under pumping condition)
   - Spinner flowmeter logging: continuous measurement of flow velocity
   - Electro-magnetic flowmeter logging: continuous measurement of flow velocity
   - Heat pulse flowmeter logging: batch measurement of flow rate
   - Temperature logging (conventional): continuous measurement of temperature
   - Electric conductivity logging: continuous measurement of electric conductivity and flow rate
2. Hydraulic tests
   - Pulse test: low to very low transmissivity
   - Slug test: average to low transmissivity
   - Pumping test: average to high transmissivity

These tests will be conducted in a sequence of test events in every specified test interval.

5.4.3 Planned field work

5.4.3.1 Work during drilling

Fluid logging (by contractor)
Spinner flowmeter logging, electro-magnetic flowmeter logging and heat pulse flowmeter logging in undisturbed and pumping states are performed to identify inflow/outflow points and to provide a rough estimate of transmissivity. Temperature logging is performed in undisturbed and pumping-up state to determine the inflow/outflow points. Electric conductivity logging is performed using deionised water to identify inflow/outflow points and

to estimate transmissivity. These features are identified as anomalies on the profile, which in turn complement other geological and hydrogeological information, suggesting the locations of WCFs. Anomalies in spinner flow meter would indicate major WCFs, electro-magnetic flowmeter would show major to intermediate ones and electric conductivity logging would indicate intermediate to minor WCFs.

Hydraulic tests (by contractor)
A sequence of hydraulic test events during drilling is conducted for the purpose of obtaining hydraulic properties and sampling groundwater from WCFs.
Pulse, slug and pumping (*i.e.* constant pressure or constant flow rate) test techniques are employed for very low to low, low to intermediate and intermediate to high permeability rock respectively. The most suitable method for hydraulic testing is selected on the basis of the estimated transmissivity of the test interval, the time available for the test and the applicable equipment. There may be more than one kind of test in a given interval. The main contractor should inform JNC staff of all the relevant data continuously to decide the most appropriate interval for each test. These intervals are identified on the basis of the drilling fluid losses, rates of fluid loss and anomalies in the fluid logs and in other geophysical logs, and the core description.
Initially, pulse or slug tests are conducted to determine the most appropriate hydraulic testing method to be applied in each of the test intervals identified. It is necessary to observe and evaluate the rate of pressure recovery towards its initial state or to extrapolate to the initial state. In addition to this evaluation, a flow model and boundary condition should be estimated from the pressure derivative plot. When the permeability is low, a pulse test is carried out first. When the permeability is higher, slug tests are conducted first for deciding appropriate pumping flow rates precisely for the following diagnostic test, such as constant flow rate tests. After the slug test, constant flow rate tests and/or constant pressure tests are carried out. The subsequent pressure recovery is allowed to continue until the pressure in the test interval reaches the initial pressure or until the initial pressure can be reliably extrapolated from the recovery by the Horner plot method. Groundwater sampling takes place during the pumping test. Flow rates should be monitored continuously during groundwater sampling. Lastly, pulse tests should be conducted to check the test zone compressibility due to presence of free gas.
The planned hydraulic testing program is summarized in Table 2. The sequence of fieldwork during drilling is as follows:

- Hydraulic testing and groundwater sampling using a double or single packer assembly in the expected fluid loss section in the jointed zone in the UHFD (at the depth between of 106 and to 235mabh). (Table 2 – interval #1)

- Hydraulic testing and groundwater sampling using a double or single packer assembly in the IMF 11; in the expected interval from 747 to 756mabh. (Table 2 – interval #2)

1. - Fluid logging to identify WCFs in the Toki granite from 106 to 756mabh

- Hydraulic testing using double packers in five to six 100 m long intervals covering the entire borehole section from 106 to 756mabh. (Table 2 – intervals #3-8)

- Hydraulic testing and groundwater sampling using a double or single packer assembly in the IMF 03, in the expected interval from 1,145 to 1,170mabh). (Table 2 – interval #9)

- Hydraulic testing and groundwater sampling using a double or single packer assembly in drilling fluid loss sections (probable WCFs) (in the 2 intervals between 400 and 1,350mabh, if drilling fluid loss does occur). (Table 2 – intervals # 10-11)

2. - Fluid logging to identify WCFs in the Toki granite from 106 to 1,350mabh

Table 2 Planned hydraulic tests

No.	Test sections (mabh)	Geological Description	Drilling Phase	Packer Configuration	Water Sampling
1	1section between 106-235	UHFD (drilling fluid loss section)	During phase III	Double (or Single)	X
2	747-756	IMF 11	During phase IV	Double (or Single)	X
3 - 8	6 sections between 106 and 756 (covering whole section)	UHFD/LSFD	During phase IV	Double	
9	1145-1170	IMF 03	During phase V	Double (or Single)	X
(10 - 11)	2 sections between 400 and 1350 (focused on WCFs)	LSFD	During phase IV/VI	Double (or Single)	X X
12-17	6 sections between 756 and 1350 (covering whole section)	LSFD	After drilling	Double	
18	906-908	IMF 10	After drilling	Double	
19 - 39	21 sections between 106 and 1350 (focused on WCFs)	UHFD/LSFD	After drilling	Double	

5.4.3.2 Work after drilling

Hydraulic tests (by contractor)

A sequence of hydraulic tests after drilling is conducted for the purpose of obtaining hydraulic properties of entire borehole sections and in WCFs.

Pulse, slug and pumping tests in the most appropriate test intervals selected as mentioned above. The sequence of hydraulic tests after drilling is described as follows (also shown in Table 2 for the whole program):

- Hydraulic testing using double packers in 6 approximately 100 m long intervals covering the entire section from 756 to 1,350mabh. (Table 2 – intervals # 12-17)
- Hydraulic tests using double packers in the IMF 10 (in the interval of 906 to 908mabh). (Table 2 – intervals # 18)

1. - Hydraulic testing using double packers in the WCFs at 21 sections selected on the basis of core observation and geological/fluid logging in the interval of 106 to 1,350mabh. (Table 2 – intervals # 19-39)

5.4.4 Reporting

Prompt reports

1. Fluid logging (within 24 hours after the field investigation has been completed)
   Results of the fluid logging are reported together with the geophysical and geological logs. Information on any anomalies and/or unexpected events along the borehole is also reported.

2. Hydraulic tests
   Before starting any hydraulic test, check sheets for the test equipment and a tally list of any equipment to be used in boreholes should be submitted to JNC staff.
   The progress of the test should be reported daily by fax or email. It should include graph plots such as pressure plots and pressure derivative vs. time, and derived values of transmissivity, hydraulic conductivity, and hydraulic head with analytical methods employed etc. Test event log should also be included.

Summary report (within a week after each campaign has been completed)

A summary of the hydraulic tests performed including transmissivity and/or hydraulic conductivity and hydraulic head with depth is reported together with the geological log. Results of the hydraulic tests are reported with the following information:

- Objectives and techniques employed
- Geology of test intervals
- Test event log
- Test interval (upper/lower/midpoint depths, length and volume of packed-off interval, pumping rate, *etc*)
- Borehole and tubing radius
- Water level in annulus (in mbgl)
- Inflation pressure of packers
- Time of test start and end
- Test results with detection limits and precision (pressure history, final pressure plots and it's derivative of each test event, hydraulic head, data plots, analytical method used, result of curve matching, transmissivity and hydraulic conductivity taking account of the well-bore storage and skin effects etc.)
- Short comments on the tests, including duration of pumping, rate of pressure recovery, rational for selection of diagnostic test and details of anything abnormal or unexpected

JNC staff will check the quality of the data together with the test techniques selected.

Final report (by the end of contract period)

All results are reported with full data sets. Full details of all analytical methods employed, operating conditions of equipment, relevant detection limits and precision are described. Details are also given of anything unexpected that occurred during the investigations.

5.5 Hydrochemical Investigations

The method and procedure for groundwater sampling, combined with hydraulic testing, was successfully employed in the MIU-4 borehole investigations to ensure high quality hydrochemistry data (Ota et al., 2001and Kumazaki et al., 2002) .It is intended to apply these method and procedure to the MIZ-1 investigation program.

From investigations at the Shobasama site and in the RHS project so far, it is known that Na-Ca-HCO_3 and/or Na-HCO_3 type groundwater occurs in the crystalline basement north of the Toki River. The shallow borehole investigations at MIU construction site has shown that Na-Cl type groundwater (about 1% salinity of seawater) occurs in the sedimentary rocks. Based on the above mentioned and previous knowledge and predictions as described in Section 2, the following hydrochemical investigations are planned.

5.5.1 Aims

- To determine the groundwater hydrochemical profile from the top to over 1,000m depth in the crystalline basement.
- To obtain basic information for the identification of the dominant geochemical process (e.g. water-rock-microbe interaction, mixing between saline and fresh water) and chemical buffer capacities.
- To determine the hydrochemical properties and residence time of groundwater within major fracture zones.

5.5.2 Methods

Groundwater sampling and subsequent analytical work will be performed at the MIU construction site and in the laboratory. The methods and objectives are as follows:

1. At the field site
   - Drilling fluid preparation: drilling fluid added fluorescent dye for quantitative hydrochemical investigations
   - Fluorescent dye analyses (during drilling): maintenance of fluorescent dye concentration in drilling fluid
   - Fluorescent dye analyses (during pumping): to monitor degree of groundwater contamination
   - Standard chemical analyses: chemistry of drilling fluid and groundwater

2. In the laboratory
   - Comprehensive chemical analyses: chemistry of drilling fluid and groundwater
   - Standard isotopic analyses: isotopic composition, origin and residence time of groundwater
   - Gas analyses: redox condition, recharge temperature, origin and residence time of groundwater
   - Organics/microbes studies: role and influence on groundwater chemistry

5.5.3 Planned field work

Drilling fluid preparation (in house)

Fluorescent dyes are added to the drilling fluid to allow the degree of contamination of groundwater samples by the drilling fluid to be determined quantitatively. The drilling fluid is mixed in a separate tank from an in-line fluid reservoir. After mixing, a reference sample of drilling fluid is stored. The fluorescent compounds to be used are Amino G. acid in sedimentary rocks and uranine in granite. The concentrations are calculated by considering the detection limits of the fluorescent dyes and the need to identify drilling fluid contamination as low as 1%.

Monitoring of drilling fluid during drilling (by contractor)
The general analytical program is shown in Table 3. Physico-chemical parameters, major chemical constituents, isotopic compositions and fluorescent dye concentrations are analyzed regularly. Fluorescent dye concentrations may need to be adjusted periodically to keep the concentrations as constant as practicable. Physico-chemical parameters are continuously measured on-site. Major chemical constituents, isotopic compositions and fluorescent dye concentrations are determined at the site or in the off-site laboratory. Major chemical constituents and isotopic compositions in the original river water are also analyzed periodically in house.

Groundwater sampling combined with hydraulic tests (by contractor)
It is planned to collect groundwater during each hydraulic testing period (*see* Section 5.4.3) in structures or features predicted in the following locations:

- Drilling fluid loss section in the UHFD (predicted at about 106 - 235mabh)
- Fracture zone along the IMF 11 (predicted at about 747-756mabh)
- Fracture zone along the IMF 03 (predicted at about 1,145-1,170mabh)
- Drilling fluid loss sections in the LSFD (2 intervals within 400-1,350mabh)

The interval to be sampled is sealed off with a single or double packer assembly. Once the packers have been inflated, the drilling fluid should be removed, generally using a submersible pump, from the packed-off interval and tubing and replaced naturally by in situ groundwater.
Preparation of the drilling fluid with fluorescent dyes allows contamination of the groundwater by the drilling fluid to be estimated quantitatively. During pumping, before any groundwater samples are taken, the fluorescent dye concentration is determined regularly on the site. Several physical and chemical parameters are also measured simultaneously by JNC. As stated in the previous section, measurements are aimed at testing the applicability of mixing calculations for the estimation of groundwater chemistry. Groundwater sampling takes place when the fluorescent dye concentration is sufficiently low (*i.e.* generally below 1%). In case the fluorescent dye concentration in the isolated section does not decrease sufficiently within the time available for groundwater sampling due to large contamination of the groundwater with drilling fluid and it is judged that continued pumping will not remove sufficient drilling fluid, pumping will cease. Groundwater samples will then be taken and analyzed for major components and selected isotopes. Based on estimates of drilling fluid contamination from the tracer concentration in the samples together with the rate of tracer decrease with pumping, the in situ or initial groundwater composition will be back calculated.

5.5.4 Planned laboratory work

Some hydrochemical parameters of the drilling fluid and groundwater samples will be measured at the site. In addition, comprehensive chemical and isotopic analyses of the groundwater samples are carried out in specialized laboratories (contractor, university and in house) as shown in Table 3. Reference samples of drilling fluid, river water and groundwater are suitably pre-treated and preserved according to standard protocols, i.e., by refrigeration.

Table 3 Planned analytical work for hydrochemical investigations

Constituents	Sampling / Analysis Combinations*				Laboratories	Remarks
	A	B	C	D		
Physico-chemical Parameters						
pH	3S	1S	1S	1S	–	**C/D** by JNC
Electrical conductivity (EC)	3S	1S	1S	1S	–	**C/D** by JNC
Eh	–	–	1S	1S	–	**C/D** by JNC
Dissolved Oxygen (DO)	3S	–	1S	1S	–	**C/D** by JNC
Temperature (T)	3S	1S	1S	1S	–	**C/D** by JNC
Major Components						
Sodium (Na^+)	3S	3S	4S	6S	Contractor	
Potassium (K^+)	3S	3S	4S	6S	Contractor	
Ammonium (NH_4^+)	–	–	–	6S	Contractor	
Magnesium (Mg^{2+})	3S	3S	4S	6S	Contractor	
Calcium (Ca^{2+})	3S	3S	4S	6S	Contractor	
Strontium (Sr^{2+})	3S	3S	–	6S	Contractor	
Manganese (Mn^{2+})	–	–	–	6S	Contractor	
Iron (total Fe)	3S	3S	–	6S	Contractor	
Iron (Fe^{2+})	–	–	–	6S	Contractor	
Aluminium (Al)	3S	3S	–	6S	Contractor	
Rare earth elements (REEs)	–	–	–	6L	Contractor	
Fluoride (F^-)	3S	3S	4S	6S	Contractor	
Chloride (Cl^-)	3S	3S	4S	6S	Contractor	
Bromide (Br^-)	3S	3S	4S	6S	Contractor	
Iodine (I^-)	3S	3S	4S	6S	Contractor	
Nitrate (NO_3^-)	3S	3S	4S	6S	Contractor	
Nitrite (NO_2^-)	–	–	–	6S	Contractor	
Sulphate (SO_4^{2-})	3S	3S	4S	6S	Contractor	
Sulphide (total H_2S)	–	–	–	6S	Contractor	
Silica (H_2SiO_3)	3S	3S	4S	6S	Contractor	
Alkalinity	3S	3S	4S	6S	Contractor	
Total inorganic carbon (TIC)	3S	3S	4S	6S	Contractor	
Total organic carbon (TOC)	–	–	–	6S	Contractor	
Isotopes						
Deuterium (^2H)	4L	5L	4L	6L	JNC	
Tritium (^3H)	4L	5L	4L	6L	Contractor	
Oxygen-18 (^{18}O)	4L	5L	4L	6L	JNC	
Carbon-13 (^{13}C)	4L	5L	–	6L	JNC	CH_4 and C_2H_6 are option
Carbon-14 (^{14}C)	4L	5L	–	6L	JNC	
Sulphur-34 (^{34}S)		–	–	6L	JNC	SO_4^{2-} and H_2S are option
Chlorine-36 (^{36}Cl)	4L	–	–	6L	Contractor	
He isotopic ratio (^3He / ^4He)	–	–	–	6L	University/Contractor	
Cl isotopic ratio (^{37}Cl / ^{35}Cl)	–	–	–	6L	Contractor	
^{238}U-decay series	–	–	–	6L	Contractor	Including total U
^{232}Th-decay series	–	–	–	6L	Contractor	
Dissolved Gas						
H_2, N_2, CH_4, CO_2, He, Ar, H_2S	–	–	–	6L	Contractor	
Others						
Organics / Microbes	–	–	–	6L	JNC/University	
Fluorescent dyes						
	–	2S	2S	6L	Contractor	
Samples for analyses	5 litres	3 litres	3 litres	20 litres	–	
Samples for storage	0.1 litre	0.1 litre	–	20 litres	–	

* Sampling/analysis combinations = A: Monitoring of river water for drilling fluid
B: Monitoring of drilling fluid during drilling
C: Monitoring of outflow during pumping test
D: Groundwater (formation water) sampling
1: Continuously, 2: Hourly, 3: Daily, 4: A few times a campaign, 5: For each 100m drilled,
6: At the end of hydraulic testing
S: On the site, L: In the laboratory

5.5.5 Reporting

5.5.5.1 Field work reports

Prompt report (within 24 hours after the field investigation has been completed)
A report to be submitted by contractors includes raw data and the following information:

1. Drilling fluid monitoring
   - Analyzed values with errors and detection limits
   - Method used, including details of equipment employed and operating conditions
   - Anything abnormal during monitoring/sampling or analysis
2. Groundwater sampling
   - pH, Eh, electrical conductivity, oxygen content and temperature during sampling
   - Any observations of color changes in water, gas bubbles, precipitation and smell
   - Amount of water sampled
   - Details of characteristics of storage containers used
   - Fluorescent dye contents
   - Alkalinity
   - Anything abnormal during sampling or analysis

Final report (by the end of contract period)
All results are compiled and reported with full data sets. The report should include analyzed values with errors and detection limits, details of method used, details of equipment employed and its operating conditions and details of anything unexpected that occurred during the monitoring/sampling and analyses.

5.5.5.2 Laboratory work report

Final report (by the end of contract period)
All results are compiled and reported with full data sets. The report should include analyzed values with errors and detection limits, details of analytical method used and its conditions and details of anything unexpected that occurred during the analyses.

5.6 Long-term monitoring

Long-term hydraulic monitoring systems will be installed in the boreholes DH-2, MSB-1, MSB-2, MSB-3 and MSB-4 (Figure 2 and 3) prior to the MIZ-1 drilling. This will provide the opportunity to carry out additional investigations i.e. monitoring pressures in these boreholes before, during and after drilling the MIZ-1 borehole. These investigations are intended to provide data to evaluate connectivity between boreholes. After the MIZ-1 campaign has been completed, a multi-packer system will be installed in the MIZ-1 borehole for long-term monitoring before, during and after excavation of the shaft/drift.

5.6.1 Aims

- To evaluate the connectivity of the WCFs between the MIZ-1 borehole and the boreholes DH-2, MSB-1, MSB-2, MSB-3 and MSB-4.
- To determine the spatial distribution and variations in hydraulic heads before the construction of the MIU.
- To obtain hydraulic information necessary for evaluating the groundwater flow system through the iterative process of groundwater flow simulations and refinement of concepts.

5.6.2 Methods

Pressure responses observed in the selected intervals in the DH-2, MSB-1, MSB-2, MSB-3 and MSB-4 boreholes with the multi-packer system will be recorded systematically before and during the MIZ-1 drilling. Long-term hydraulic monitoring in all boreholes, including MIZ-1 borehole are planned. The long-term monitoring includes monitoring of hydraulic heads.

5.6.3 Planned field work

5.6.3.1 Pressure response observation (by JNC)

Hydraulic pressure responses are recorded in selected measurement intervals in the boreholes DH-2, MSB-1, MSB-2, MSB-3 and MSB-4 before MIZ-1 drilling every 30 to 60 minutes and during drilling every 10 to 30 minutes.

5.6.3.2 Long-term hydraulic monitoring (by contractor)

After the MIZ-1 borehole investigations have been completed, a multi-packer system that contains up to 10 packed-off intervals will be installed in the MIZ-1 borehole. Suitable packed-off intervals for the hydraulic monitoring are selected on the basis of the geological, hydrogeological and hydrochemical investigations in the MIZ-1 borehole investigations. Hydraulic heads are monitored in the intervals in the MIZ-1 borehole as well as in the boreholes DH-2, MSB-1, MSB-2, MSB-3 and MSB-4. Data on hydraulic heads are acquired hourly throughout the excavation of the shaft/drift. Information on the spatial distribution and variations in hydraulic heads with time, provided by the long-term hydraulic monitoring, is needed for evaluation of the groundwater flow system. The individual contractors will carry out all the work mentioned above except for data acquisition.

5.6.4 Reporting

5.6.4.1 Pressure response observation

A prompt report should be provided every week before MIZ-1 drilling and everyday or for each anomalous pressure event during the MIZ-1 drilling. The prompt report contains raw and plotted data with time, relevant detection limits and precision, comments on the measurements and details of anything abnormal or unexpected. This report will be prepared by JNC.

5.6.4.2 Long-term hydraulic monitoring

Prompt reports

1. Installation of a multi-packer system
   The progress of the installation work should be reported every day.

2. Hydraulic monitoring (every month)
   Raw and plotted data (pressure-time), relevant detection limits and precision, details of the system set-up, measurement method employed, comments on the measurements and details of anything abnormal or unexpected are reported. Data will be provided by JNC.

Final reports (by the end of contract period)

1. Installation of a multi-packer system
   The report should clearly and accurately show packed-off intervals, inflation pressure of packers, hydraulic heads and anything abnormal that occurred during the installation of the multi-packer system. Drawings of the multi-packer system and its set-up are appended.

2. Hydraulic monitoring
   All results are compiled and reported with full data sets based on the data provided by JNC. The report should contain the interpretation of the results and comments on the spatial distribution and variations in hydraulic heads with time prior to and in response to excavation of the shaft/drift.

6 INVESTIGATION PROCEDURE AND SCHEDULE

This section describes the procedure and schedule for the “base case” investigation campaign to be executed in the MIZ-1 borehole. These are summarized in Figures 30 and 31 respectively. In addition, a couple of alternative programs (optional cases) are also discussed.

6.1 Investigation Procedure

The investigation campaign will be performed in six phases during drilling and one phase after drilling. The campaign has been defined on the basis of geological, hydrogeological and hydrochemical prediction, the priority of planned investigations and the time available for the investigations.

All depths are given as depth in meters along the borehole (mabh). The actual depths at which the target features are intersected may be different from the predicted depths given below. Similarly, the proposed depths of testing and the sampling intervals are approximate and may change in light of actual geological and geophysical observations during the field investigations.

6.1.1 Base case

The following investigation procedures are described for each of the drilling phases.

During drilling

Phase I 0 – 5mabh / Surface soil and sedimentary rocks (Akeyo Formation)

1. Drilling with either a tricone bit or an air hammer; borehole diameter 26 inch (660.4mm). Drilling fluid - fresh water tagged with fluorescent Amino G. acid dye (drilling fluid I) from the surface to 5mabh.
2. Installation of 20 inch (508mm) casing pipes to 5mabh and fixing by full hole cementing. Flushing the borehole to extract cuttings with drilling fluid I after dredging cement.
3. Installation of 6 inch temporary casing pipes to 5mabh.

Phase II 5 – 114mabh / Sedimentary rocks (Mizunami Group) – Weathered zone and UHFD in the Toki granite

1. Begin 5 1/2 inch wireline, triple-tube, core drilling to 114mabh with drilling fluid I. Drilling will halt after penetrating the bottom of the weathered zone (predicted depth: about 105mabh) and allowing for a surplus drilling length of approximately 9m. The boundaries of the weathered zone will be determined by JNC staff based upon the lithological and geometrical information observed in the core. Core recovery is done using the inner core barrel on wireline. The borehole diameter is approximately 136mm and the core diameter is approximately 85mm. Continuous monitoring of drilling parameters such as drilling rate, bit revolution, bit load, torque, pumping pressure, rate of drilling water supply and return, using a suitable monitoring device, will be done to the final depth at 1,350mabh. Borehole orientation will be checked every 30m drilling from the top to the final depth of the borehole.
2. Flushing the borehole to extract cuttings with drilling fluid I.
3. Extraction of 5 1/2 inch wireline tools, and drilling pipes.
4. Borehole TV and geophysical logging from 5 to 114mabh.

5. Extraction of 6 inch temporary casing.

6. Reaming by either a tricone bit or air hammer (17-1/2 inch, 444.5mm diameter) with drilling fluid I from 5mabh to 106mabh.

7. Installation of 14 inch (355.6mm) or 13-3/8 inch (339.7mm) casing pipes below the expected bottom of the weathered zone to approximately 106mabh and full hole cementing. Flushing the borehole to remove drilling fluid I and replace it with drilling fluid II, fresh water tagged with fluorescent uranine dye (drilling fluid II) until the concentrations of drilling fluid I decrease below 1%, and to extract cuttings after dredging cement.

8. Reinstallation of 6 inch temporary casing pipes to 106mabh.

Phase III 114 – 250mabh / UHFD in the Toki granite

1. Continue 5 1/2 inch wireline core drilling to 250mabh with drill fluid II. Drilling will halt after intersecting the bottom of the predicted major drilling fluid loss section in the UHFD and confirmation of the stability of the rock at the predicted depth of 250mabh. This plan takes account of the need for surplus drilling length (approximately 15m) in order to confirm the stability of the rock and to completely pass the predicted, major drilling fluid loss section. The top and bottom of the fluid loss section will be determined by JNC staff based upon the joint frequencies and structural features of fractures observed in the core. Flushing the borehole with drilling fluid II will be done to extract cuttings after drilling.

2. Extraction of 5 1/2 inch wireline tools, drilling pipes and 6 inch temporary casing

3. Hydraulic testing and water sampling using a single or double packer assembly in the predicted drilling fluid loss section at the jointed zone in the UHFD (at the depth between of 106 to 235mabh. (Table 2 – interval # 1)

   • Aims: transmissivity (T), hydraulic head (H), flow model (M) and water sample (W)
   • Methods: Slug, pulse and pumping
   • Structure/Lithology: Drilling fluid loss section of UHFD in the Toki granite.

4. Borehole protection using lost circulation materials (LCM) in the drilling fluid loss section. Flush the borehole with drilling fluid II after borehole protection.

Phase IV 250 – 756mabh / UHFD and LSFD above the IMF11 in the Toki granite

1. Start 5 1/2 inch wireline core drilling from approximately 250mabh, using controlled directional drilling to 460mabh using drilling fluid II. For controlled directional drilling, a downhole-motor coring system is employed. When the downhole-motor coring system is used, the core diameter is reduced to approximately 52.5mm. The borehole inclination is changed 8 times (1.5 degrees every 30mabh) in the interval from 250 – 460mabh. Flushing the borehole to extract cuttings is done with drilling fluid II after drilling.

2. Extraction of 5 1/2 inch directional control drilling tools.

3. Resume 5 1/2 inch conventional wireline, triple-tube core drilling using drilling fluid II until the expected fracture zone IMF11 is penetrated. Drilling will halt immediately after intersecting the bottom of IMF11 (predicted depth: about 756mabh). The top and bottom of the fracture zone will be determined by JNC staff based upon the frequencies and structural features of fractures observed in the core. The borehole diameter is approximately 136mm and the core diameter is approximately 85mm. Flushing the

borehole to extract cuttings is done with drilling fluid II after drilling.

4. Extraction of 5 1/2 inch wireline tools, drilling pipes and 6 inch temporary casing
5. Hydraulic testing and groundwater sampling using double packers in the 747 to 756mabh interval. (Table 2 – interval # 2)
   - Aims: T, H, M and W
   - Methods: Slug, pulse and pumping
   - Structure/Lithology: Fracture zone of the IMF11 in the Toki granite.
6. Continuous borehole TV, geophysical and fluid logging from 106 to 756mabh.
7. Hydraulic testing using double packers in 6 approximately 100m long intervals selected on the basis of core observation, geophysical and fluid logging in the interval of 106 to 756mabh (just below the fracture zone of IMF11). (Table 2 – intervals # 3~8)
   - Aims: T, H and M
   - Methods: Slug, pulse and/or pumping
   - Structure/Lithology: UHFD and LSFD above the fracture zone of IMF11.
8. Reinstallation of 6 inch temporary casing pipes to 106mabh

Phase V 756 – 1,170mabh / LSFD below the IMF11 in the Toki granite

1. Continue 5 1/2 inch wireline core drilling with drilling fluid II until the fracture zone of IMF03 is penetrated. Drilling will halt immediately after intersecting the bottom of the fracture zone (predicted depth: about 1,170mabh). The top and bottom of the fracture zone will be determined by JNC staff based upon the frequencies and structural features of fractures observed on the core. Core recovery using a triple-barrel corer. The borehole diameter is approximately 136mm and the core diameter is approximately 85mm. Flushing the borehole to extract cuttings is done with drilling fluid II after drilling.
2. Extraction of 5 1/2 inch wireline tools, drilling pipes and 6 inch temporary casing.
3. Hydraulic testing and groundwater sampling using double packers in the 1,145 to 1,170mabh interval. (Table 2 – interval # 9)
   - Aims: T, H, M and W
   - Methods: Slug, pulse and pumping
   - Structure/Lithology: Fracture zone of the IMF03 in the Toki granite.
4. Reinstallation of 6 inch temporary casing pipes to 106mabh.

Phase VI 1,170 – 1,350mabh / LSFD below the IMF 03 in the Toki granite

1. Continue 5 1/2 inch wireline core drilling from approximately 1,170mabh to 1,350mabh with drilling fluid II. Core recovery using a triple-barrel corer. The borehole diameter is approximately 136mm and the core diameter is approximately 85mm. Flushing the borehole to extract cuttings is done with drilling fluid II after drilling.
2. Extraction of 5 1/2 inch wireline tools, drilling pipes and 6 inch temporary casing.
3. Hydraulic testing and groundwater sampling using double packers in two (2) intervals in the expected drilling fluid loss section (WCF), if it happens during the drilling from 400 to 1,350mabh interval; except for the planned test intervals such as the fracture zones IMF03, IMF10 and IMF11. (Table 2 – intervals # 10 and 11)

4. Continuous borehole TV, geophysical and fluid logging from 106 to 1,350mabh.

After drilling

1. Hydraulic testing using double packers in 6, approximately 100m long intervals selected on the basis of core observation, geophysical and fluid logging in the interval from 756 to 1,350mabh. (Table 2 – intervals # 12~17)

   • Aims: T, H and M
   • Methods: Slug, pulse and/or pumping
   • Structure/Lithology: LSFD below the fracture zone of IMF11.

2. Hydraulic testing using double packers in the 906 to 908mabh interval. (Table 2 – interval # 18)

   • Aims: T, H ands M
   • Methods: Slug, pulse and pumping
   • Structure/Lithology: Fracture zone of the IMF10 in the Toki granite.

3. Hydraulic testing using double packers in 21 intervals selected on the basis of core observation, BTV and geophysical/fluid logging in the 106 to 1,350mabh interval (Table 2 – intervals # 19~39)

   • Aims: T, H and M
   • Methods: Slug, pulse and/or pumping
   • Structure/Lithology: Fracture zone in the Toki granite

4. Reinstallation of 6 inch temporary casing pipes to 106mabh, and flushing the borehole with fresh water.

5. Extraction of 5 1/2 inch wireline tools and emplacement of flange on the top of 14 inch casing pipes. Dismantle drilling equipment and drill rig and restoration of the site.

Post-MIZ-1 Drilling Geophysics and Rock Mechanics Investigations

1. VSP (Vertical Seismic Profiling) survey covering the entire section from 106 to 1,350mabh by Multi-offset methods. (See Appendix II-1)

   • Aims: Location of geological structures and identification of structure geometry
   • Lithology: Toki granite

2. Hydraulic fracturing to obtain in situ stress measurements at 10 or more intervals between 106 and 1,000mabh by method. (See Appendix II-2)

   • Aims: *in situ* stress magnitude and direction
   • Lithology: Toki granite

3. Cross-hole tomography between MIZ-1 and DH-2 using either resistivity or seismic methods. (See Appendix II-3)

   • Aims: Location of geological structures, determination of their geometry and rock mass properties
   • Lithology: Toki granite

Post-MIZ-1 Drilling Cross-hole Hydraulic Interfernce Tests

1. Installation of a multi-packer system containing up to 10 packed-off intervals for long-term hydraulic monitoring.

2. Cross-hole hydraulic test between MIZ-1 and DH-2 by pumping and other methods. (See Appendix II-4)
   • Aims: Assessment of hydraulic significance and role of water conducting features, T, H and M in selected test intervals.
   • Lithology: Toki granite

6.1.2 Optional cases

Optional case #1: Loss of drilling fluid during drilling
If loss of drilling fluid occurs, transmitting pressure responses to DH-2 borehole, or if there are no pressure responses but 100% drilling fluid loss occurs, all planned investigations that would have been performed during and after drilling, from 106mabh to the depth of the drilling fluid loss, will be executed: hydraulic testing and water sampling with a single or double packer configuration, borehole TV, geophysical and fluid logging. After these investigations have been completed, plugging or cementing is carried out at the site where the loss occurs, to reduce drilling fluid loss to the formation and drilling is resumed
If drilling fluid loss of less than 100% occurs and there are no pressure responses in other boreholes, the following steps prior to resumption of drilling and performing the remainder of on-site investigations will be taken.

- Plugging with an appropriate material (*e.g.* cellulose) will be carried out in the interval encompassing the site where the loss occurs. The interval should be sealed off with a single or double packer assembly, as necessary.
- If drilling fluid loss continues after plugging of the site, partial cementing of the drilling fluid loss location will be done.

When using cement, an appropriate fluorescent dye is added to the cement to allow the degree of contamination of groundwater by cement dissolution to be quantified. After all planned on-site investigations have been completed, the cemented interval is, where necessary, perforated to enable hydraulic monitoring to be carried out.

Optional case #2: Borehole collapse
If it is necessary to stabilize the borehole wall where collapse occurs, all planned and feasible investigations, including all hydraulic tests, from 106mabh to the depth of the collapse will be executed. This section will then be partially cemented. In this case, the interval should be isolated with a single or double packer assembly, as necessary.
If collapse occurs even after the cementing of the location, the following steps to carry on drilling and the remainder of on-site investigations will be taken.

- The section from 106mabh to the depth of the collapse will be reamed to 12-inch (311.2mm) diameter and 10-inch casing pipes installed to the depth of the collapse and fixed by full hole cementing.
- If 10 inch casing pipes have already been installed and fixed by full hole cementing in a previous collapse zone, the section below the shoe of the existing 10 inch casing down to the collapsed zone will be reamed to 8 inch (215.9mm) diameter, and 7 inch casing pipes installed and fixed by full hole cementing.

To enable hydraulic monitoring to be carried out after all planned on-site investigations have been completed, the casing pipes in the interval spanning the site of the collapse are, where necessary perforated.

Optional case #3: Drilling fluid loss and borehole collapse at the same location

In this case, all planned investigations from 106mabh to the location where drilling fluid loss and collapse occur are executed. After these investigations have been completed, cementing is carried out at the location and drilling is carried on. An appropriate fluorescent dye is added to the cement to allow the degree of contamination of groundwater by cement dissolution to be quantified.

If drilling fluid loss and/or borehole collapse occurs even after the cementing of the location, the following steps to carry on drilling and the remainder of on-site investigations will be taken.

- The section from 106mabh to the depth of the collapse is reamed to 12-inch (311.2mm) diameter and 10 inch casing pipes are installed and fixed by full hole cementing.
- If 10 inch casing pipes have already been installed and fixed by full hole cementing, the section below the shoe of the 10 inch casing down to the location is reamed to 8 inch (215.9mm) in diameter and 7 inch casing pipes are installed and fixed by full hole cementing.

To enable hydraulic monitoring to be carried out after all planned on-site investigations have been completed, the location of the drilling fluid loss and/or collapse is, where necessary perforated.

Optional case #4: IMF 11 not intersected

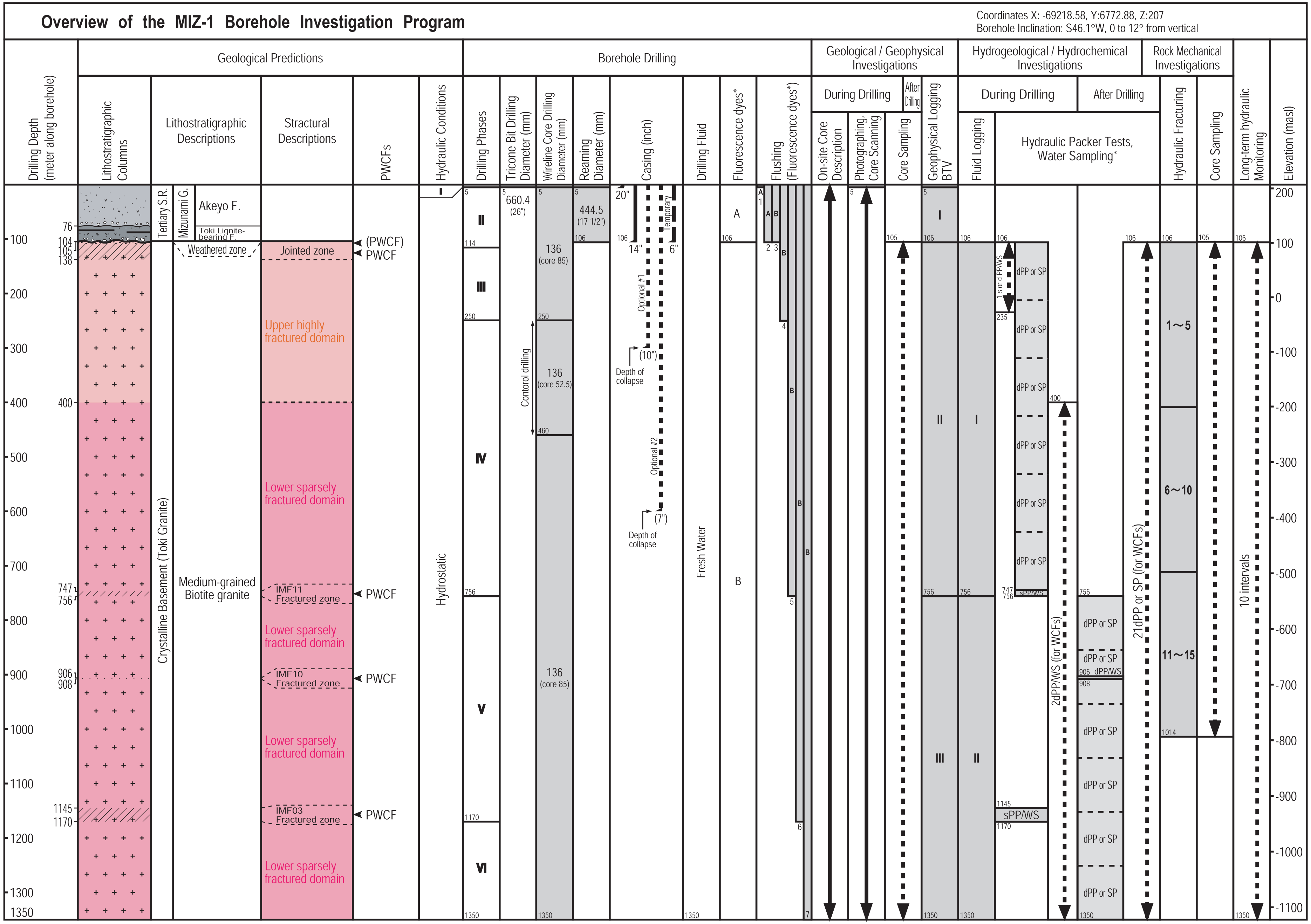
If IMF11is not intersected in the expected interval, the drilling will continue until the next fracture zone, IMF 10 or a significant drilling fluid loss occurs. Drilling will halt immediately after intersecting either of the above, and planned investigations (PhaseIV-5 to Phase IV-7) are executed: hydraulic testing and groundwater sampling in the fracture zone of IMF 10 or drilling fluid loss section, borehole TV geophysical and fluid logging from 106mabh to the bottom of borehole and hydraulic testing using double packers in approximately 100m long intervals from 106mabh to the bottom of borehole.

Optional case #5: IMF 10 and IMF11 not intersected and major drilling fluid loss not occur

If IMF 11 and IMF 10 are not intersected and there is no significant drilling fluid loss in the interval from about 700 to 1,000mabh, drilling will halt at approximately 1,000mabh. The following investigations are then executed: borehole TV geophysical and fluid logging (IV-6) and hydraulic testing using double packers by approximately 100m long interval (IV-7) from 106mabh to bottom of borehole.

Optional case #6: IMF 3 not intersected

If the expected intersection of IMF03 does not occur, the drilling will continue until a significant drilling fluid loss section is penetrated or the planned depth is reached. If significant drilling fluid loss occurs, drilling will halt immediately after intersecting bottom of drilling fluid loss section. Hydraulic testing and groundwater sampling in the drilling fluid loss section are executed.



*Hydraulic Packer Tests / Water Sampling = s: Single packer, d: Double packers, PP: Pumping Test, SP: Slug and pulse tests, WS: Water sampling
*Fluorescence dyes = A: Sodium naphthionate, B: Uranine

Figure 30 Overview of the MIZ-1 borehole investigation program

6.2 Schedule

The program is planned to start in December 2002 and take 25 months, as shown in Figure 31. Minimum time requirements for the planned field and laboratory work excluding the post MIZ-1 borehole investigations such as VSP survey, cross hole tomography and hydraulic test and long-term hydraulic monitoring are as follows:

- Site preparation: 2.0 months
- Drilling/on-site investigations: 17.5 months
- Site restoration: 1.0 month
- Laboratory work: 14.0 months
- Reporting 11.0 months

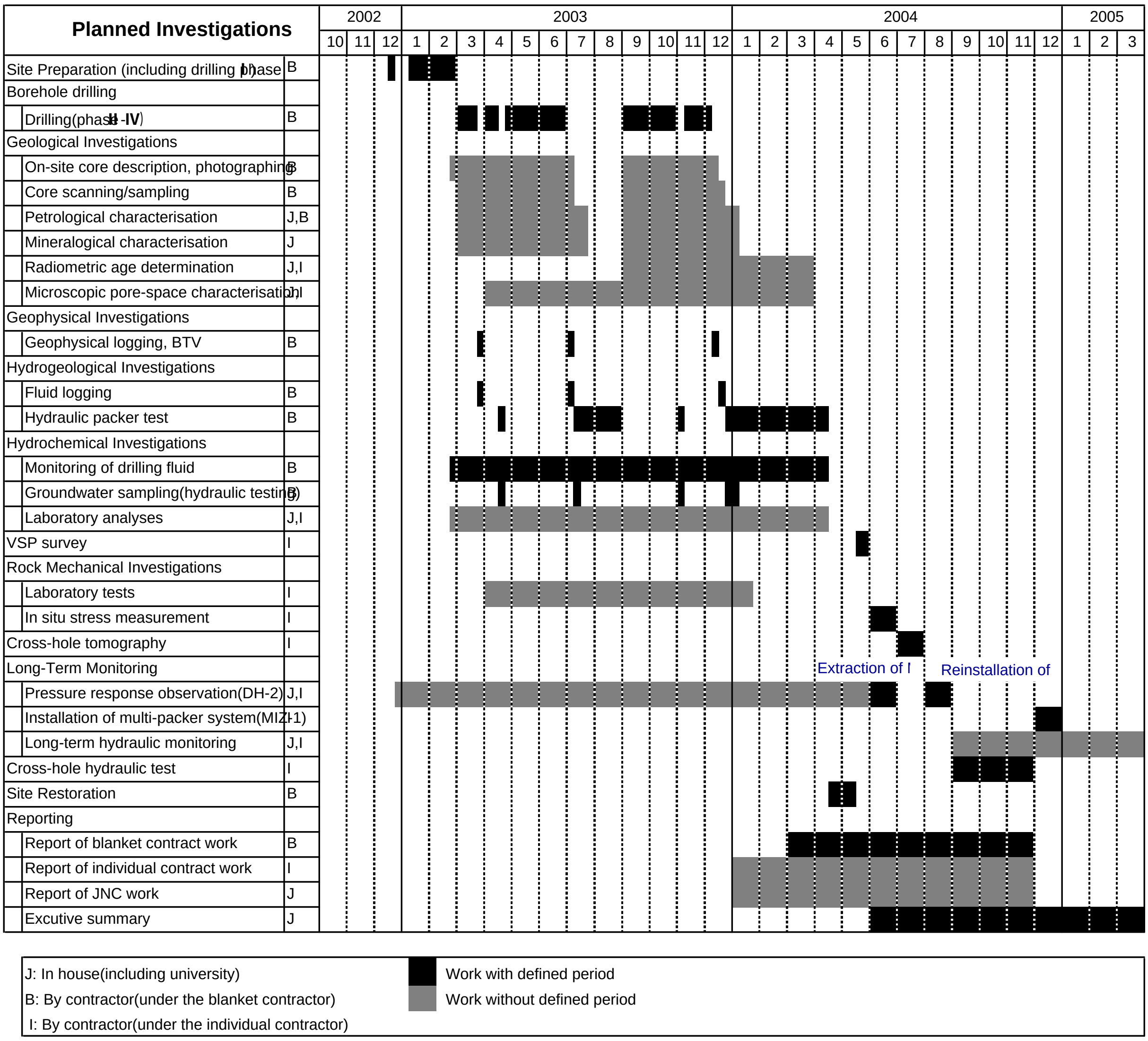


Figure 31 Schedule of the MIZ-1 borehole investigation program

7 QUALITY ASSURANCE/CONTROL AND REPORTING

It is required that a quality assurance (QA) system be applied to all activities and operations carried out by contractors, which meets at least national standards.

In addition, JNC has a responsibility for the quality control (QC) of each aspect throughout the contract work and for the careful review of their deliverables as described in the preceding sections. JNC's QC system is employed to ensure that the purpose for which the work is carried out is likely to be successfully achieved. It is also intended, for the QC purpose, to have external review by experts (*e.g.* under international collaboration studies) in the particular field during the MIZ-1 borehole investigations.

The final report of the MIZ-1 borehole investigations, written both in Japanese and in English, is produced in the form of an executive summary within a few months after all the reports are submitted. All field and laboratory data are compiled and achievements corresponding to the aims stated in Section 2 are evaluated, which should be brought into a broader context in the executive summary. The report also discusses the remaining key issues to be answered in the surface-based investigations (*e.g.* establishment of comprehensive investigation techniques) and their contributions to the next or near-future programs (*e.g.* planning of scientific investigations during construction phase and detailed design of the shaft and experimental drifts).

8 BUDGET FOR THE MIZ-1 BOREHOLE INVESTIGATIONS

JNC plans to contract with a main contractor for the MIZ-1 borehole investigations, which will cover all of the planned fieldwork except for the VSP survey, *in situ* stress measurements, cross-hole tomography, cross-hole hydraulic test and long-term hydraulic monitoring. About 694 million yen has been budgeted for this blanket contract. Individual contractors perform some of the field and laboratory programs. About 52 million yen is now requested for laboratory analytical work and up to 215 million yen is now planned for the VSP survey, the *in situ* stress measurements, the cross-hole tomography, cross-hole hydraulic test and installation of multi-packer system with long-term hydraulic monitoring. Details of the budget are listed in Table 4.

Table 4 Budget for the planned MIZ-1 borehole investigation program

Constituents	Budget (kYen)	Status (in financial year)
Blanket Contract	694,453	
Borehole drilling	362,127	Defined (2002)
On-site core description, photography	16,961	Defined (2002)
Geophysical logging, BTV	72,450	Defined (2002)
Hydraulic packer tests, groundwater sampling	111,257	Defined (2002)
Monitoring and laboratory analysis of drilling fluid	107,608	Defined (2002)
Drill core testing *etc*	24,050	Defined (2002)
Individual Contract	326,350	
Laboratory chemical analysis of rock / water samples	4,650	Planned (2002), not yet defined
VSP survey	25,000	Planned (2002), not yet defined
In situ / laboratory stress measurements	56,700	Planned (2002), not yet defined
Cross-hole tomography	20,000	Planned (2002), not yet defined
Cross-hole hydraulic test	50,000	Planned (2002), not yet defined
Installation of multi-packer system/long-term monitoring	170,000	Planned (2002), not yet defined
Total budget	1,020,803	

ACKNOWLEDGEMENT

We gratefully acknowledge Drs Stratis Vomvoris and Bernhard Frieg of Nagra (National Cooperative for the Disposal of Radioactive Waste), Switzerland, Dr Glen McCrank of AECL (Atomic Energy of Canada Limited), Canada, Professor Komatu, University of Ehime and Professor Nishigaki, University of Okayama for support and review during the drawing up of this working program.

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On-site Core Description Manual

Version: July 2002

Geoscience Research Execution Group
Tono Geoscience Centre

CONTENTS

1 Depth

Fill in the depth along the borehole axis per 1 m.

2 Lightfaces

Paste digital core photographs with Adobe Illustrator. Digital core photographs should be processed well with Adobe Photoshop.

3 Rock name

Assign rocks (or unconsolidated materials) recovered to one of the following units: the Seto Group, the Mizunami Group, the Toki granite and dykes. Sedimentary rocks are divided into sandstone, mudstone, tuff and conglomerate. Granitic rocks are classified into 3 groups in terms of an average diameter of quartz phenocrysts: fine-grained (Ø≤1mm), medium-grained (1mm≤Ø≤5mm) and coarse-grained (5mm≤Ø). Refer to a scale.

4 Texture

Describe texture such as porphyritic, equigranular and so on in granite.

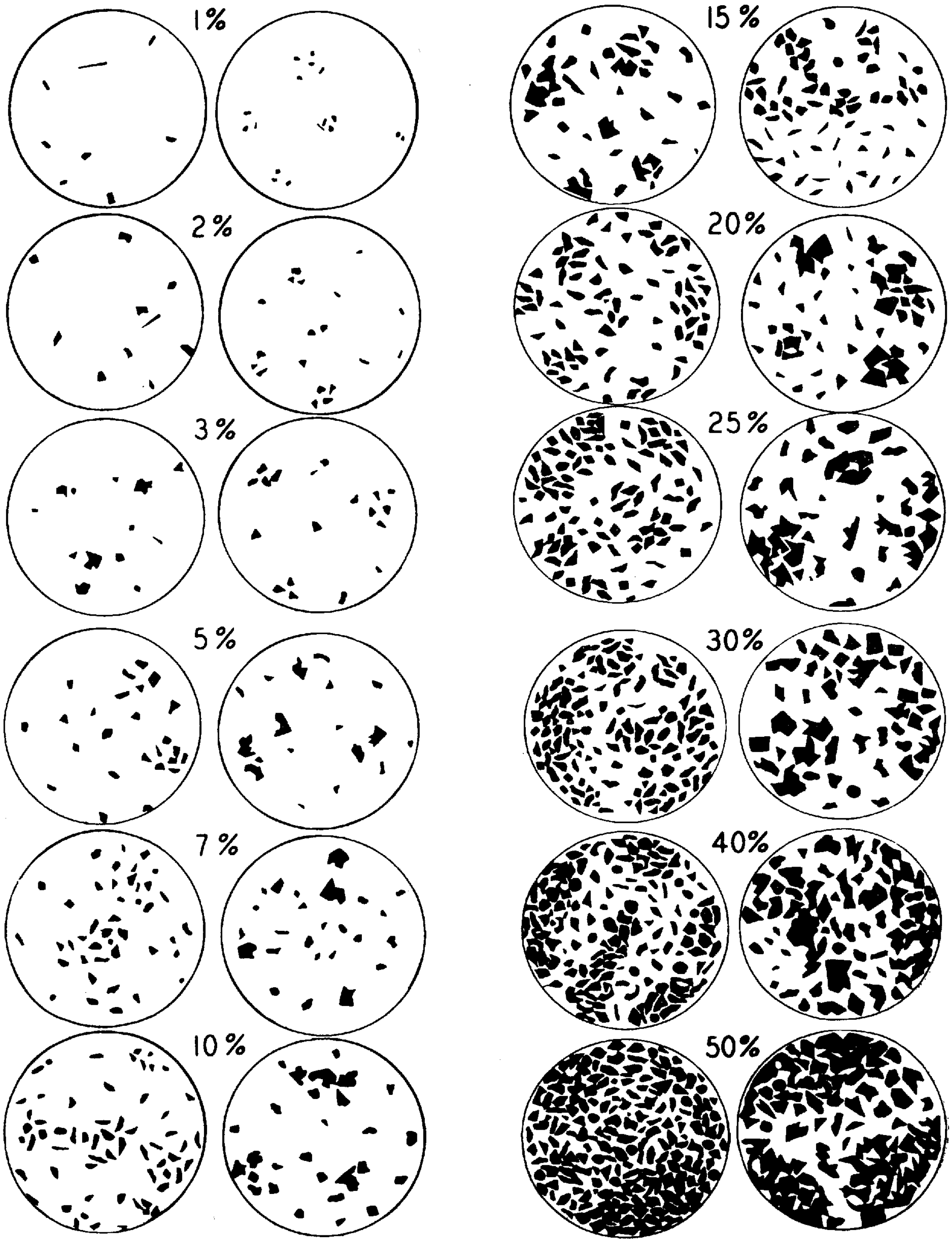
5 Mineralogy

Describe constituent minerals in the Toki granite and dykes, their diameter (or size) and shapes.

6 Color

Describe the content of mineral in dark color in granite (according to following figure).

DIAGRAMS REPRESENTING VARIOUS PERCENTAGES OF GRAINS



Terry, R.D. and Chilingar, G.V. (1955)

7 Weathering

Classify the degree of weathering by atmospheric oxygen or surface waters, according to the following definitions:

Class	Definition	
□	Fresh. No discoloration, no oxidation (limonite), but coatings of chlorite, quartz, biotite, calcite, sulphides or clay on fractures are common.	No leaching.
□	Slightly weathered. Discoloration or oxidation (limonite) limited to surface of, or short distance from, fractures; some feldspar crystals are dull.	Minor leaching of some soluble minerals may be noted.
□	Moderately weathered. Discoloration or oxidation (limonite) extends from fractures, usually throughout; Fe-Mg minerals are "rusty," feldspar crystals are "cloudy."	Soluble minerals may be mostly leached.
□	Highly weathered. Discoloration or oxidation (limonite) throughout; all feldspars and Fe-Mg minerals are altered to clay minerals (kaolinite)to some extent.	Leaching of soluble minerals may be complete.
□	Extremely weathered. Discoloration or oxidation (limonite) throughout, but resistant minerals such as quartz may be unaltered; all feldspars and Fe-Mg minerals are completely altered to clay minerals (kaolinite).	Leaching of soluble minerals usually complete.

(modified from "Engineering geology field manual" by USBR(2000))

8 Rock mass classification

Classify rocks in the degree of physical disintegration by weathering/alteration according to the following definitions:

Class	Definition
A	Very fresh. Not weathered/altered. Clear sound when hit with a hammer.
B	Slightly weathered/altered. Clear sound when hit with a hammer.
CH	Weathered/altered except quartz. Dull sound when hit with a hammer and fractured by hitting hardly.
CM	Moderately weathered/altered. Dull sound by hitting with a hammer and fractured when hit hardly.
CL	Highly weathered/altered. Dull sound and fractured when hit with a hammer. Clay minerals on a fracture plane.
D	Extremely weathered/altered. Very dull sound when hit with a hammer and easily fractured. Clay minerals on a fracture plane.

9 RQD and Core recovery

- RQD(Rock quality designation) is defined by the percentage of the sum of lengths of cores longer than 10cm in the whole core length in 1m drilling.

  RQD = (sum of length of cores over 10cm) / (whole core length) x *100* [%]

- Core recovery is defined by the percentage of cored length in 1m drilling. The core length is measured at the center of the core.

  Core recovery = (whole core length in 1m drilling) / (1m) x *100* [%]

10 Fracture density

Fill in the number of fractures per 1m core.

11 Location of fracture

Fill in the upper and lower depths of fracture on both sides of the column.

12 FRACTURE NUMBER

Describe the cumulative number of fracture in 10 m such as M-N. If a fracture is 12th in 230-240 m, M and N denotes 23 and 12 respectively.

13 Depth of fracture

Describe the depth intersection between fracture and core axis.

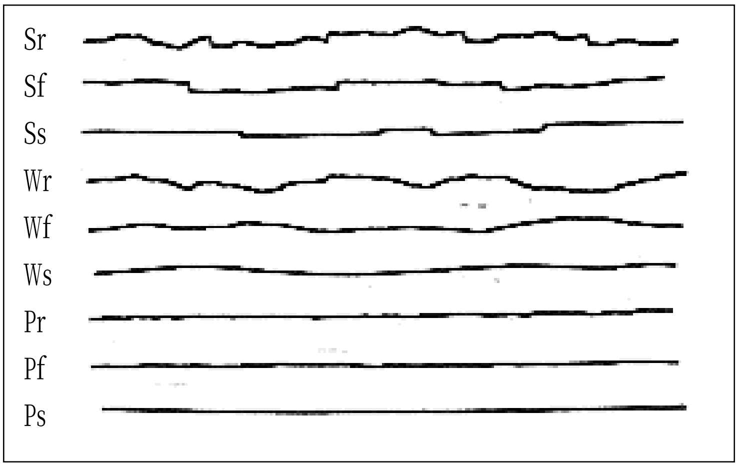
14 Dip of fracture

Describe the angle of fracture with a vertical plane to core axis.

15 Type of fracture

Classify fractures according to the following definitions:

Type	Definition
Sr (stepped rough)	Stepped shaped with rough fracture plane.
Sf (stepped flat)	Stepped shaped with flat fracture plane.
Ss(stepped slickenside)	Stepped shaped. Striation on a slickensided surface.
Wr (wavy rough)	Wavy shaped with rough fracture plane.
Wf (wavy flat)	Wavy shaped with flat fracture plane.
Ws (wavy slickenside)	Wavy shaped. Striation on a slickensided surface.
Pr (planar rough)	Planar shaped with rough fracture plane.
Pf (planar flat)	Planar shaped with flat fracture plane.
Ps (planar slickenside)	Planar shaped. Striation on a slickensided surface.



Martin Mazurek et al., (1996)

16 Striation on fracture

Classify striation on fractures according to the following definitions:

Type	Definition
SL (slickenline)	Slicken line
ST (slickenstep)	Slicken step
-	No striation

Describe the rake on SL and/or ST, such as the angle of direction of SL and/or ST with dip direction of fracture.

17 Occurrence of fracture

Classify fractures occurrence according to the following definitions:

Group	Definition
S	Shear fault/fracture
T	Tension fault/fracture
S or T	Unknown
D	Drilling damage

18 Fault rock classification

Classify fault rock according to the following definitions:

		Random fabric	*Foliated*	*Fine matrix*
INCOHE-SIVE		Fault breccia	Foliated fault breccia	<30%
		Fault gouge	Foliated fault gouge	>30%
COHESIVE	*Cataclasite Series*	Cataclastic breccia	Foliated cataclastic breccia	0-10%
		Protocataclasite	Foliated protocataclasite	10-50%
		Cataclasite	Foliated cataclasite	50-90%
		Ultracataclasite	Foliated ultracataclasite	90-100%
	Mylonite Series	?	Protomylonite	10-50%
		?	Mylonite	50-90%
		?	Ultramylonite	90-100%
		?	Blastomyronite (Grain growth pronounced)	

After Shimamoto et al.,(1996)

19 Thickness range of the fault

Describe the width the zone containing the master faults and/or the width of the zone affected by intense fracturing.

20 Width and coloration of altered zone along fracture

Describe the width of altered zone along fractures.

21 Alteration materials along fracture

Define the degree of alteration according to the following definitions:

Class	Degree
1 (fresh)	Unaffected by alteration.
2 (weak)	Rock fabric completely preserved. Unaltered volume over 50%.
3 (moderate)	Original rock texture recognizable. Some unaltered volume.
4 (strong)	Minerals and fragments altered to clay minerals. Original rock texture no longer recognizable.

22 Width of filling materials in fracture

Describe the width of filling materials in fractures.

23 Fracture filling materials

Describe materials filling fracture in the order of relative age, using the following letter symbols:

qtz: quartz ***Fe***: Fe-oxyhydroxide/hydroxide ***chl***: chlorite ***hem***: hematite ***ep***: epidote ***py***: pyrite ***cal***: calcite ***cly***: clay minerals ***zeo***: zeolite ***gyp***: gypsum
Ser: sericite

24 Remarks

Any finding such as characteristic minerals and the change of mineral compositions should be described in detail. The depth should be recorded on the left side of the lithostratigraphical column.

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PROVISIONAL PROGRAM FOR VERTICAL SEISMIC PROFILING SURVEY IN MIZ-1 BOREHOLE

A Vertical Seismic Profiling (VSP) survey is planned to follow the MIZ-1 drilling and the series of investigations in the MIZ-1 borehole.

Aims

- To acquire information about the orientation, geometry and possibly extent of fractures such as joints and faults in the rock volume around the borehole, including any WCFs.
- To detect and locate inclined reflectors in the vicinity but not intersected by the borehole.

Methods

Data acquisition is carried out using several sources on the ground and a receiver string in the borehole (Multi-offset VSP survey). Seismic reflectors will be imaged by VSP data processing.

Planned field work

A multi-offset VSP survey is planned to be performed after the MIZ-1 drilling and the series of investigations in the MIZ-1 borehole are completed. A vibrator is used as a source that will be located along the projected surface trace of the MIZ-1 borehole. Receivers will cover the entire MIZ-1 borehole section in the Toki granite. VSP surveying has the advantage and provides the opportunity to locate both sub-horizontal and inclined reflectors in the rock volume around the MIZ-1 borehole. Existing information and the geological model suggest that some major faults have steep dips, which are difficult to recognize as reflectors by VSP data processing, even though MIZ-1 is designed as a curved and inclined borehole. Modeling will be attempted to image both steeply dipping reflectors and the reflectors not intersected by the MIZ-1 borehole. It will be accomplished by making a reflector model, calculating synthetic VSP data based on the model and comparing the field data and the synthetic data.

Reporting

Daily report (during the field work)
A work sheet on data acquisition is submitted. Details of any anomalies and/or unexpected events encountered during field work are also reported.

Interim report (within 2 months after the field work has been completed)
A series of VSP data processing results, spectrum analysis, travel-time analysis, velocity function, and seismic profiles of multi-offset VSP data are submitted. Basic geological interpretations with other investigations are reported.

Final report (by the end of the contract period)
Possible interpretations of results (*e.g.* details of identified fractures such as joints and faults), data processing results including modeling analysis and full data sets are reported. Full details of all methods employed, operating conditions of equipment, relevant detection limits and precision are described. A series of VSP data sets (both pre- and post-processing) are also submitted digitally in SEG-Y format.

PROVISIONAL PROGRAM FOR ROCK MECHANICAL INVESTIGATIONS IN MIZ-1 BOREHOLE

The goals of the rock mechanical investigations in the surface-based investigation program are to develop a methodology and conceptual model for rock mechanics on a scale of several decameters to a hectometer and to define mechanical properties and *in situ* stress state up to approximately 1,000m depth in the Toki granite for input to the design of underground facilities. Knowledge from previous investigations in the boreholes at Shobasama area is summarized in Section 4. Rock mechanical investigations planned for the new site are based on the assumption that the preliminary rock mechanical conceptual model of the new site is similar to that of the Shobasama model. Investigations are performed to confirm that the granitic rock mass properties are heterogeneous at the MIU construction site and that they occur in three zones in terms of *in situ* stress state and mechanical properties.

Aims

- To determine and understand rock mechanical properties and *in situ* stress state at the MIU construction site.
- To develop a conceptual geomechanical model at the MIU construction site and compare it with the model developed at the Shobasama site.

Methods

The following stress measurement techniques and laboratory tests are employed on the site and in the laboratory:

1. Field investigation
   - Hydraulic fracturing test
2. Laboratory tests
   - AE (Acoustic Emission) / DRA (Deformation Rate Analysis), DSCA (Differential Strain Curve Analysis), ASR (Anelastic Strain Recovery Method)
   - Density measurement, ultrasonic velocity measurement, unconfined compressive test, confined compressive test, Brazilian test, shearing test, etc.
   - Core disking analysis

Planned field work

In situ stress measurement
Hydraulic fracturing test will be conducted *in situ* at 10 to 15 points from surface to a depth of about 1,000 m to provide estimates of stress components perpendicular to the borehole axis.

Planned laboratory work

The following laboratory tests on core samples are planned.

Determination of in situ stress and testing the anisotropy of the Toki granite
AE/DRA, DSCA and ASR are performed using core samples obtained from 10 to 15 points from surface to a depth of about 1,000m. The distribution of microcracks and anisotropy of elastic modulus in three dimensions are estimated on rock samples with the DSCA method. This method works by comparing the stress-strain curve of the rock sample with that of a completely elastic material (quartz cube) subjected to the same in situ stress condition.

Mechanical property measurements
Density measurement, ultrasonic velocity measurement, unconfined compressive tests,

confined compressive tests, Brazilian tests and shearing tests on core samples obtained from the 10 to 15 locations from surface to depth of about 1,000 m where the *in situ* stress measurements will have been carried out by hydraulic fracturing.

Reporting

Field work reports

Interim report (after measurements have been completed)
All raw data and the results of preliminary analysis (the magnitude and direction of principal stresses) are reported. The quality of the following data should be checked during the *in situ* stress measurements: the fracture distribution near the measurement depth before the measurement, the pressure-time curves during the measurement and the orientations of induced fractures after the measurement.

Final report (by the end of contract period)
The magnitudes and the directions of principal stresses in the plane perpendicular to the borehole axis from surface to depth of about 1,000 m are compared with the results of laboratory tests including core disking analysis.

Laboratory work reports

Prompt report (immediately after the testing and measurement have been completed)
Preliminary interpretation of results, for example, stress-strain curve, AE activity, elastic wave form and so on, are reported for stress measurements and mechanical property measurements obtained on core samples.

Final report (by the end of contract period)
The results of AE/DRA, DSCA, ASR and core disking analysis will be compared with the result of hydraulic fracturing tests. All results of laboratory test on mechanical properties are reported with a full data set for numerical analysis and prediction of rock mass response to shaft and drift excavation.

PROVISIONAL PROGRAM FOR CROSS-HOLE TOMOGRAPHY SURVEY BETWEEN MIZ-1 AND DH-2 BOREHOLES

Cross-hole tomography surveying is planned to follow the MIZ-1 drilling and the series of investigations in the MIZ-1 borehole. There are two effective methods possible, i.e. seismic and resistivity. To achieve the aims of the tomography survey described below and as an investigation method to complement the reflection seismic and VSP (both DH-2 and MIZ-1) surveys, the seismic method will be used; the resistivity method would be the alternative if there is a problem.

Aims

- To acquire information about the extent of geological structures in the granite such as joints, faults, UHFD and LSFD between the MIZ-1 and DH-2 boreholes.
- To acquire information about the rock mass properties in the granite between the MIZ-1 and DH-2 boreholes.
- To contribute the information acquired to make the geological model more reliable and reduce the uncertainty and for the construction work of the main and ventilation shaft.

Methods

For the seismic method, a seismic source is placed in one borehole and a receiver string in the other borehole. Seismic velocity distribution between the two boreholes will be reconstructed by an inversion analysis of the field data.

Planned field work

Data acquisition for the seismic tomography survey may be performed together with the VSP survey in the MIZ-1 borehole, if a seismic source under a diameter of about 98mm can be utilized in the DH-2 borehole, i.e. receivers will be shared in the MIZ-1 borehole. If not, the tomography survey will be carried out after the VSP survey with the seismic source placed in the MIZ-1 borehole. A piezoelectric transducer is used as a source and it will be placed in the borehole moving up or down at a fixed interval of depth. Receivers will be placed in the other borehole at a fixed interval of depth Seismic velocity distribution between the two boreholes will be imaged by an inversion analysis of the travel time data. It is expected that a velocity contrast between the UHFD and the LSFD will be detected.
Resistivity tomography would be an alternative method if the seismic method is not applicable for some reason, for example, if there is a reduced output from the seismic source due to noise or complete or near complete attenuation of the seismic signal due to the presence of highly fractured rock.

Reporting

Daily report (during the field work)
A work sheet on the data acquired is submitted. Details of any anomalies and/or unexpected events encountered during field work are also reported.

Interim report (within 2 months after the field work has been completed)
All of the observed waveform data and traveltime data are submitted. The method employed, the seismic velocity data and imagery and the analytical method used for developing the tomographic profiles are reported.

Final report (by the end of the contract period)

Possible interpretations (*e.g.* details of each identified geological structure in the granite), data processing results including a seismic velocity image and data sets employed for an inversion analysis are reported. Full details of all methods employed, operating conditions of equipment, relevant resolution and precision are described. A series of seismic data sets (both pre- and post-processing) are also submitted digitally in SEG-Y format.

PROVISIONAL PROGRAM FOR CROSS-HOLE HYDRAULIC TESTING BETWEEN MIZ-1 AND DH-2 BOREHOLES

In the cross-hole hydraulic testing performed at the Shobasama site borehole spacing was greater than 100 m. The testing showed that major fracture zone (e.g. the fracture zone along the Tsukiyoshi fault) and conductive zones (e.g. UHFD) can be significant hydraulic conductors. This indicates the likelihood that small scale WCFs are well-connected structures. As the distance between MIZ-1 and DH-2 boreholes is over 100 m, cross-hole hydraulic testing in the MIU construction site should focus on the connectivity of the major fracture zone such as faults, joints and the conductive zone between the boreholes. The test results should be very useful for predicting the location of the WCFs that might be intersected by the MIU shaft, which will be located between the two boreholes.

Aims

- To predict connectivity of the WCF between the MIZ-1 and DH-2 boreholes.
- To obtain average values of transmissivity and hydraulic conductivity of rock volume between MIZ-1 and DH-2 boreholes.
- To predict WCF along the shaft before it is constructed.

Methods

A long term pumping test is planned from specific sections in the MIZ-1 borehole and the pressure response will be monitored and measured in the DH-2 borehole. The pumping would be performed using either a hydro-testing tool or the long-term monitoring system. Some tracer might be used during the test for estimation porosity of the WCF. However, details for the test specification, condition, procedure and evaluation for the result etc must be discussed before the planning for the cross-hole testing.

Planned field work

Several pumping tests would be carried out. The pumping sections will be decided based on the response to MIZ-1 drilling observed in the DH-2 borehole, the VSP survey and MIZ-1 investigations etc. The pumping rate should be decided based on the transmissivity of each test section. The pumping duration should be as long as possible so that the pressure response reaches the observation sections considering time available and the drawdown is sufficient for analytical purposes. Pressure recovery in the pumping and observation sections should be observed and analyzed carefully, based on the pressure derivative curves etc.

Reporting

Prompt reports

Before starting the pumping tests, check sheets for the test equipment and tally lists of all equipment to be installed should be submitted to JNC staff.

The progress of the test should be reported daily by fax or email. It should include measured head response, graphs of pressure plots vs time and its derivative, derived values of transmissivity and analytical methods employed etc. The test event log should also be provided.

Summary report (within a week after each campaign has been completed)

A summary of the cross-hole hydraulic tests including transmissivity, changes in hydraulic head and connectivity in each test section is reported together with the geological log.

Results of the hydraulic tests are reported with the following information:

- Objectives and techniques employed
- Geology of test intervals
- Test event log
- Test interval (upper/lower/midpoint depths, length and volume of packed-off interval, pumping rate, *etc*)
- Borehole and tubing radius
- Water level in annulus (in mbgl) (if the hydro-testing tool is used)
- Inflation pressure of packers
- Time of test start and end
- Test results (pressure history, final pressure/time plots and derivative plots of each test event, hydraulic head, data plots, analytical method used, result of curve matching, transmissivity and flow model taking account of the well-bore storage and skin effects etc.
- Short comments on the tests, including duration of pumping, rate of pressure recovery, rational for selection of diagnostic test and details of anything abnormal or unexpected

JNC staff will check the quality of the data together with the test techniques selected.

Final report (by the end of contract period)
All results are reported with full data sets. Full details of all analytical methods employed, operating conditions of equipment, relevant detection limits and accuracy, and QA/QC method adopted for data acquisition should described. Details are also given of anything unexpected that occurred during the investigations.