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Working Programme for MIU-4 Borehole Investigations

August 1999

Tono Geoscience Center

Japan Nuclear Cycle Development Institute

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1 INTRODUCTION

Surface-based investigations have now been carried out since 1997 according to the Master Plan of the Mizunami Underground Research Laboratory (MIU) (PNC, 1996). The specific goals of the surface-based investigations are:

- To acquire information necessary for understanding the undisturbed deep geological environment as a background of the MIU and for predicting the effects of the construction of underground facilities.
- To establish methodologies for evaluating predictions.
- To formulate detailed design concepts for underground facilities and to plan scientific investigations during the construction of the MIU.

In addition, appropriate, systematic methodologies for investigating the deep subsurface should be developed through the surface-based investigations. It is expected that the surface-based investigations with further borehole investigations will last until March 2002. However, the construction of the MIU was provisionally planned to commence in the 2000 financial year.

JNC has drilled four 1,000m-deep boreholes and one 400m-deep borehole at the MIU site (JNC's land of about 140,000m^2) in Akeyo-cho, Mizunami City, Gifu Prefecture. In the surface-based investigations, specifically three 1,000m-deep boreholes, MIU-1, MIU-2 and MIU-3, have been drilled. Investigations in these boreholes have characterised mainly the geological structure and hydrogeological features of the deep geological environment. In addition, JNC has been developing investigation techniques and improving equipment for these investigations. At the time of writing, a series of borehole investigations are being carried out in the MIU-3 borehole. The MIU-3 borehole investigations aim mainly at characterising the Tsukiyoshi fault that intersects the crystalline basement in the site.

Ongoing surface-based investigations have provided a large amount of information on the characteristics of the deep geological environment. However, some key aspects (*eg* hydrochemistry, 3-D rock mechanics, *etc*) have not been addressed adequately yet and additional features to be evaluated (*eg* geometry of steeply dipping water-conducting fractures) have been identified during the previous investigations. Comprehensive techniques for planning, reliably investigating, predicting and modelling the deep geological environment, evaluating the predictions, reviewing the programme and transferring experiences to the next programmes have not been established yet.

Taking account of the present status and the remainder (*ie* two and a half years) of the surface-based investigations, an optimised programme for MIU-4 borehole investigations should be drawn-up. This programme should address the remaining key aspects mentioned above and provide promising results and inputs to the next or near-future investigation programmes. This document describes the planned working programme for the MIU-4 borehole investigations including associated laboratory programmes.

2 AIMS OF THE MIU-4 BOREHOLE INVESTIGATIONS

In the MIU-4 borehole investigation programme, higher priority should be given to addressing the remaining key aspects to be answered in the surface-based investigations as mentioned in the previous section. It is also important to control the quality of each aspect of the field/laboratory work throughout the MIU-4 borehole investigations. With these as the main elements of the programme, the specific aims of the MIU-4 borehole investigations can now be stated as:

- Geological and hydrogeological characterisation of potential water-conducting fractures and the Tsukiyoshi fault in the crystalline basement.
- Hydrochemical characterisation of groundwater in both sedimentary cover rocks and crystalline basement.
- Acquisition of rock mechanical data from the crystalline basement for supplementing the existing geotechnical data set.
- Development and assessment of techniques for predicting and modelling 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.

Details of the aims in each investigation field are discussed in Sections 5.1 to 5.7.

3 OVERVIEW OF THE DEEP GEOLOGICAL ENVIRONMENT

Two vertical boreholes, MIU-1 and MIU-2 (Figure 1), with a depth of about 1,000m have been extensively investigated to date (*see* Appendices I-1 and I-2). These borehole investigations allow the geological, hydrogeological and geomechanical characterisation of the crystalline basement, thereby advancing the understanding of the geological environment at the MIU site. Here, an overview of the current status of knowledge gained from the previous borehole investigations can be presented:

Geology

- Tertiary sedimentary rocks (*ie* the Mizunami Group) unconformably overlie the eroded Cretaceous crystalline basement (*ie* Toki granite, dated at about 60–70Ma) with a basal conglomerate. An unconformity and weathering surface occur horizontally between the two boreholes (Figure 2).
- The Mizunami Group is stratigraphically divided into the Toki lignite-bearing and Akeyo Formations in ascending order (Figure 2).
- The Toki granite can be divided lithologically into two main facies: biotite granite and felsic granite (Figure 2). They are subdivided into three types (*ie* coarse-, medium- and fine-grained) based upon the size of quartz phenocrysts. The felsic granite is highly fractured with fracture density over 1,000 fractures per 100m.
- Major water-conducting features were identified by fluid logging (temperature and flowmeter logging) and/or by a loss of fluid during drilling. These features are:
  - Strongly-weathered, permeable zones in the vicinity of the unconformity
  - Open fractures (201mbgl in the MIU-1 borehole and 223mbgl in the MIU-2 borehole)
  - Steeply dipping fractures in the felsic granite.
- A reverse fault, the Tsukiyoshi fault (inferred fault movements between about 5 and 15Ma), intersects the MIU site and is encountered in the MIU-2 borehole at a depth of 890.0 to 915.2mbgl. The fault is oriented E-W with a dip of 70° to 80°S (Figure 2).

Hydrogeology

- The mean hydraulic conductivity of the Toki granite is in the order of 10^{-7}m/s. The felsic granite close to the Tsukiyoshi fault is designated as a higher-permeability domain ($K \geq 10^{-6}$m/s). A lower-permeability domain ($K \leq 10^{-9}$m/s) is also identified in the interval of 400.7 to 503.0mbgl in the MIU-1 borehole on the basis of pumping tests, which correlates with a silica rich facies ($SiO_2 \geq 75$ wt %) in the biotite granite.
- The mean hydraulic conductivity of the major water-conducting features identified is in the order of 10^{-6}m/s ($T \approx 10^{-5}m^2/s$).
- The hydraulic conductivity of the Tsukiyoshi fault (or fault zone) is relatively low ($K=2x10^{-9}$m/s; $T=6x10^{-8}m^2/s$). In the footwall of the fault, hydraulic potentials are artesian.

Rock mechanics

- The Toki granite can be divided into three zones in terms of mechanical properties and *in situ* stress state, especially in the hanging wall of the Tsukiyoshi fault: 0 to 300mbgl, 300 to 700mbgl and 700 to 1,000mbgl.
- The direction of the maximum principal stress in a horizontal plane also changes at about 300mbgl from N-S (0 to 300mbgl) to NW-SE (300 to 1,000mbgl).

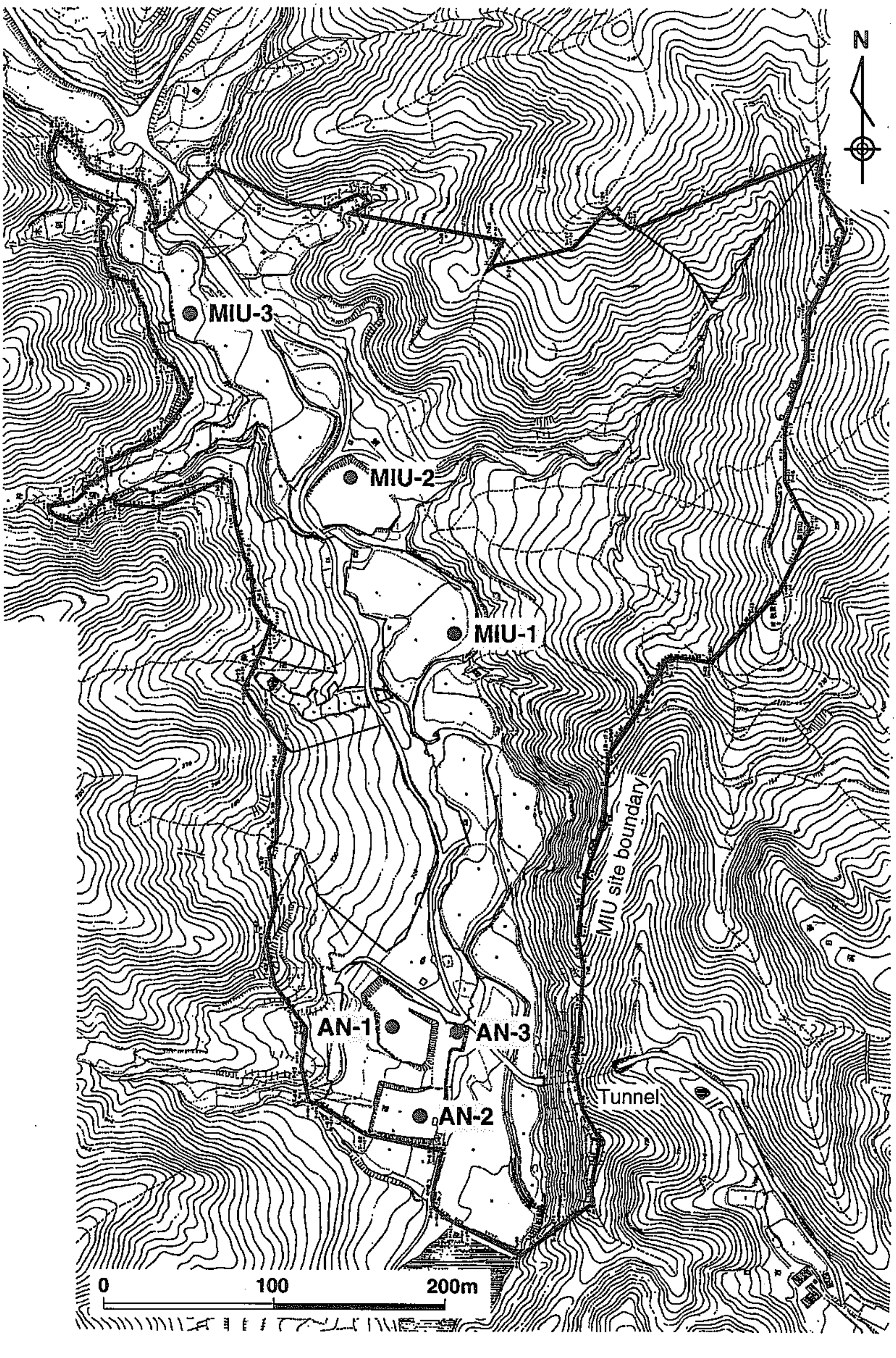


Figure 1 Location of existing boreholes at the MIU site

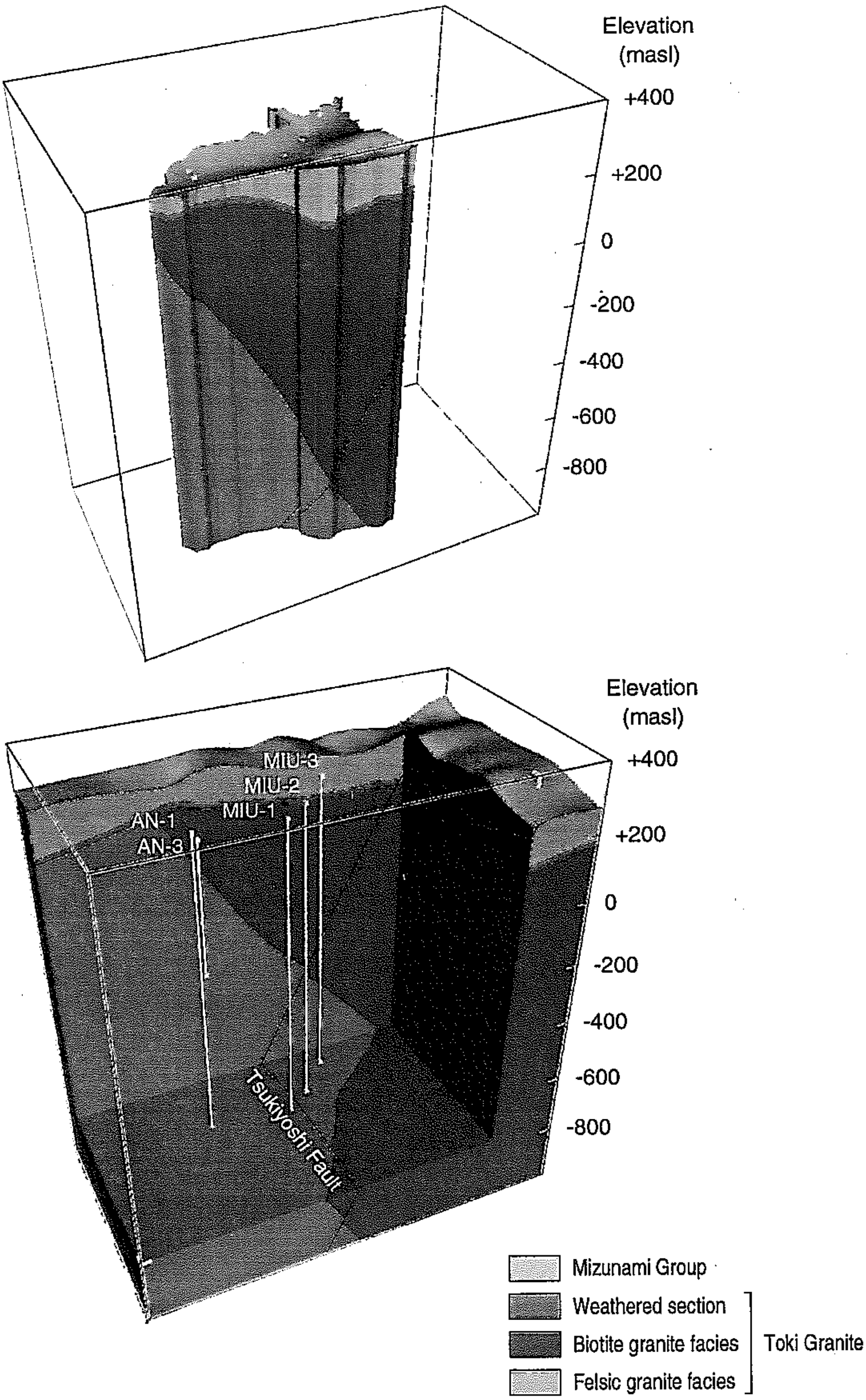


Figure 2 3-D conceptual geological model of the MIU site

4 LOCATION AND LAYOUT OF THE MIU-4 BOREHOLE

It is intended to drill an inclined borehole (MIU-4) at the MIU site, which will enable an optimised borehole investigation programme. The MIU-4 borehole will be drilled from the centre of the site in a north-easterly direction (N25°E) as shown in Figure 3. The planned inclination and drilling length of the MIU-4 borehole is 30° from vertical and 790m respectively (Figure 4). To decide the location and the layout of the MIU-4 borehole, the following constraints and requirements as well as the current knowledge described in the previous section have been taken into account:

- Borehole drilling in the north-eastern area of the MIU site has been prohibited to date for legal reasons.
- Borehole drilling beyond the boundaries of the MIU site, even underground, is prohibited.
- An inclined borehole will allow the geological and hydrogeological characterisation of steeply dipping features in the crystalline basement.
- It is necessary to confirm the applicability of different drilling techniques and the effectiveness of investigations in an inclined borehole for future investigation purposes.
- The geological model based upon data from vertical boreholes can be compared with data from an inclined borehole, which will enable an improved 3-D geological model to be developed.
- Since a MP (Multiple Piezometer) system has been installed in the AN-1 borehole and will be installed in the boreholes MIU-1, MIU-2 and AN-3, an inclined borehole will allow data to be obtained at varying depths with which to evaluate connectivity between boreholes during a hydraulic testing campaign.
- A rig should be located on the flat or gently sloped ground surface outside the prohibited area.

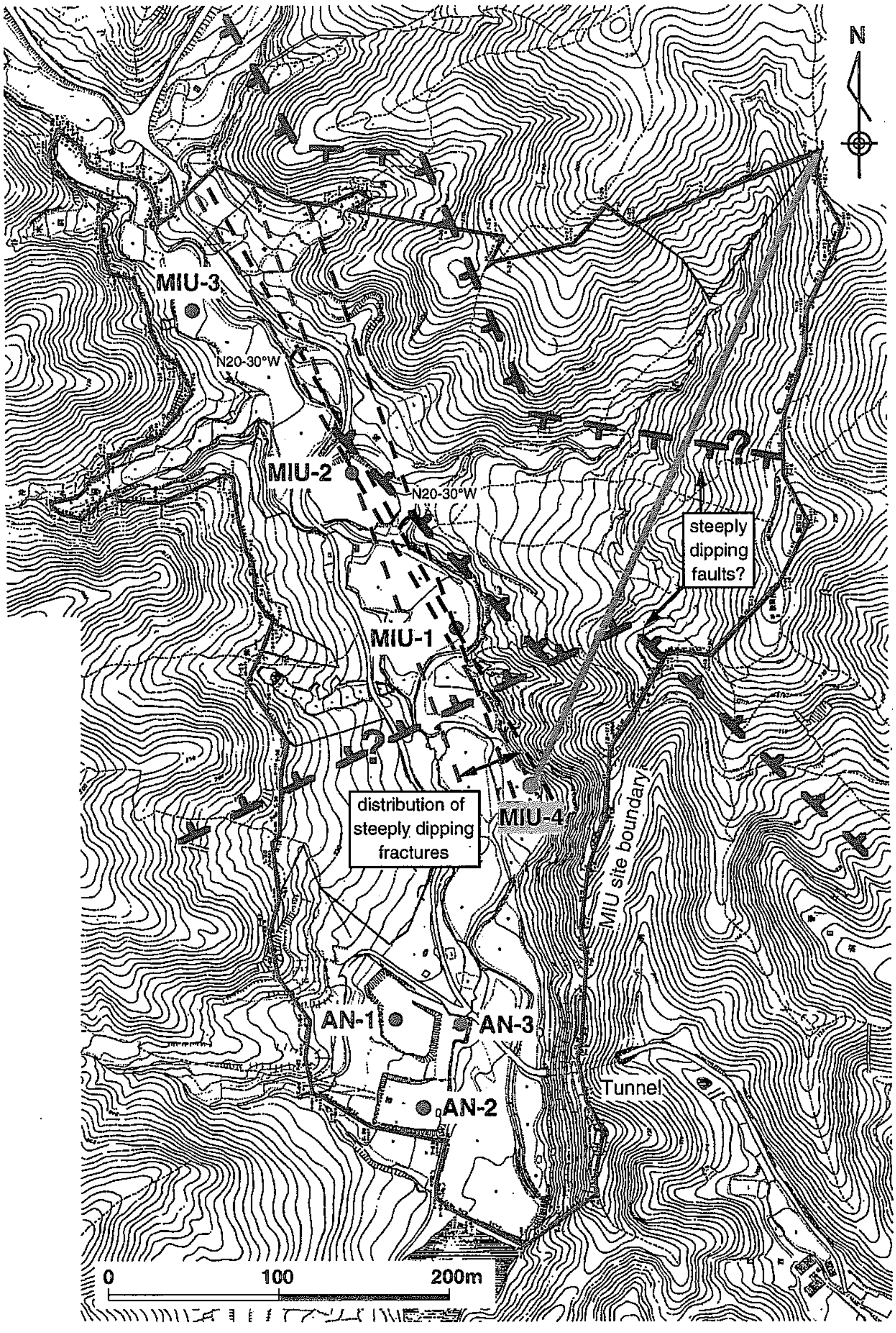


Figure 3 Location and projected trace of the planned MIU-4 borehole

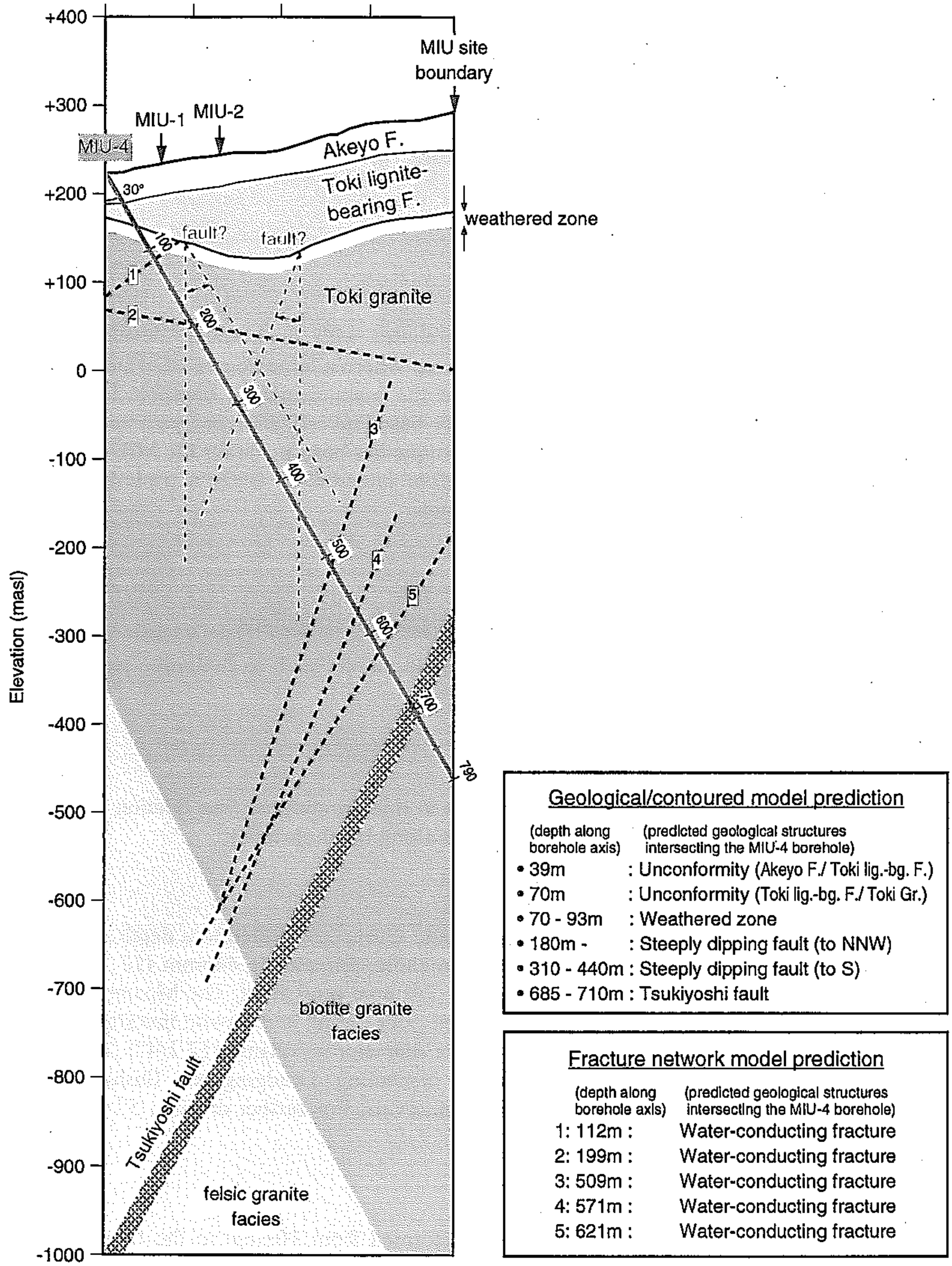


Figure 4 Predicted geological profile along the planned MIU-4 borehole

5 DETAILS OF THE MIU-4 BOREHOLE INVESTIGATIONS

In the MIU-4 borehole investigation programme, a wide range of investigations are planned. The following subsections (5.1 to 5.7) discuss the details of "base case" programme in each investigation field. The procedure for the "base case" investigation campaign is described in Section 6.1.1.

5.1 Borehole Drilling

Through the drilling of MIU-1 and MIU-2 boreholes with fresh water, development of drilling techniques has proven to be one of the areas where a large degree of effort has to be invested. This is because full core recovery and the maintenance of borehole integrity in highly fractured sections are required in the surface-based investigation programme. Although a certain modification to the existing drilling technique has been made for the MIU-3 drilling, it has not yet met the requirements. It is therefore intended to apply a triple-barrel core recovery technique in the MIU-4 drilling programme.

5.1.1 Aims

- Full core recovery for geological and hydrogeological investigations.
- To provide suitable locations for downhole investigations such as hydraulic packer tests, groundwater sampling and borehole logging.

5.1.2 Methodology

The MIU-4 drilling is performed over six phases in this programme (*see* Section 6.1.1) and the following on-site activities are planned (depths along borehole axis):

Casing and cementing

The surface soil and the friable top of the Mizunami Group are drilled to a depth of 10mbgl by using a tricorn bit or an air hammer. The borehole diameter is 445mm (17 1/2"). 14" casing pipes are installed to 10mbgl and fixed by full hole cementing. The Mizunami Group and the upper Toki granite to 100mbgl are reamed after coring and on-site investigations by using a tricorn bit or an air hammer. The borehole diameter is 311mm (12 1/4"). 10" casing pipes are then installed and fixed by full hole cementing. Dredging and flushing of the borehole are performed after cementing in both intervals. For further drilling, 5" temporary casing is installed to 100mbgl.

Coring

PQ wireline core drilling with fresh water is performed from 10mbgl to the final depth at 790mbgl. A triple-barrel corer with an acrylic innermost tube is employed for full core recovery. The borehole diameter is 123mm and the core diameter is about 80mm. Intact core is extracted from the acrylic tubes and orientated. The orientation is marked by drawing a reference line on the core. Friable core is consolidated, where necessary, with resin in the tube and removed from the tube after the resin has hardened.

Drilling/flushing fluid

Fresh water containing added tracers is used for drilling and flushing. There are no other chemicals/additives besides the tracers. Details of the tracers are described in Section 5.5.3.

Monitoring

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 to the JNC office. As the MIU-4 borehole is an inclined borehole, it will be important to perform a single shot hole deviation survey after every 50m of drilling.

Borehole protection

In the case of a significant loss of drilling fluid, cementing will be carried out at the site where the loss occurs. In the case of borehole collapse, 7" and, where necessary, 6" casing pipes will be installed to the depths of collapse after the drilled sections are reamed. If both occur at the same site, a cementing technique or, at worst, a combined technique of cementing and casing installation will be adopted. All possible on-site investigations from 100mbgl to the site of fluid loss and/or collapse should be completed before the appropriate borehole protection is made. Details of the borehole protection are described in Section 6.1.2.

5.1.3 Reporting

Daily report (to be supplied to JNC on the next morning)

Time of drilling during the day, personnel, activities undertaken, drilling length, lengths and dimensions of rods and casing pipes used, result of deviation survey, 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 programme are to acquire geological and structural information, to identify geological structures relating higher/lower-permeability structures and to establish a systematic investigation technique for reliably understanding the deep geological environment. Knowledge from previous investigations in the boreholes MIU-1 and MIU-2 is summarised in Section 3. In the ongoing MIU-3 borehole investigation programme, lithology, stratigraphy and geological discontinuities in the north-western domain of the MIU site and large-scale geometry of the Tsukiyoshi fault are investigated in detail.

5.2.1 Aims

- To check and improve the existing conceptual geological model.
- To acquire data for the development of a hydrogeological model.
- To obtain data on geological, geochemical and geometrical properties of water-conducting features for understanding solute transport/retardation phenomena.
- To characterise fractures and the Tsukiyoshi fault and to acquire details of their spatial distribution, geometry, mineralogy and microscopic pore-space geometry.
- To establish methodologies to relate geological structures including lithology, stratigraphy and discontinuities to the hydrogeological regime.

5.2.2 Methods

A variety of geological investigations are planned on the MIU 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 (*ie* 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, Rb-Sr, U-Th and Fission Track ages
• Hg injection porosimetry:	porosity, pore-space distribution, 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 photographing (by contractor)

The cores are described fully at a 1/20 scale by a contractor according to JNC's manual (*see* Appendix II). 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. Depths where the core is cut for storage are also recorded. Profiles including this information will serve as a basis for other investigations.

Images of all core sticks are taken using a camera to preserve visual geological and structural information. All images include a scale and a colour chart. Each image includes up to five, 1m long (or less) sticks 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 taken 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 taken based upon information obtained by previous investigations.

5.2.4 Planned laboratory work

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

Petrological characterisation (by contractor)

A standard microscopic observation 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.

Petrological characterisation (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 water-conducting features 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 Diffractometry), XRF (X-Ray Fluorescence spectroscopy), conventional modal analysis (*eg* point-counting) and photo-processing techniques.

Mineralogical characterisation (in house)

Parageneses of fracture fillings are investigated in detail by microscopic examination using an optical microscope 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-Analyser) techniques.

Geochemical characterisation (by individual contractor and in house)

Major components and trace elements including REEs (Rare Earth Elements) are analysed on both granite samples and fracture fillings by XRF, IC (Ion Chromatography), ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) and wet chemical methods. The aims of these analyses are to characterise the Toki granite in the north-eastern domain of the MIU site for geological modelling and to provide geochemical data on water-conducting features 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 water-conducting features, are used for understanding the evolution of water-conducting features.

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 behaviour in the vicinity of the water-conducting features.

Radiometric age determination (by individual contractor and in house)

Radiometric age dating is performed on clay minerals, carbonates, zircon and apatite in the fracture fillings to understand the genesis and evolution of the water-conducting features.

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

To develop a conceptual model of the water-conducting features in the Toki granite, porosity is determined and microscopic pore-space geometry is characterised in detail on the fracture fillings and the wall rocks. These properties are relevant to solute transport/retardation phenomena. Hg injection porosimetry 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. This resin impregnation technique is also employed to characterise microscopic pore-space geometry.

Table 1 Planned laboratory work for geological investigations

Constituents	Methods*	Sample** Quantity GM	FF/AW	Remarks	Laboratories
Petrological Characterisation					
Petrography	Optical microscopy	15	20		JNC, Contractor
Mineral composition	XRD, XRF, Modal analysis, Photo-processing	15	20		JNC
Grain size distribution	Photo-processing	15	–		JNC
Mineralogical Characterisation					
Chemical composition	EPMA	–	20		JNC
Paragenesis	Optical microscopy, SEM	–	20		JNC
Geochemical Characterisation					
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	15	20		JNC, Contractor, University
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	20		Contractor, University
Rare earth elements					
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu	ICP-MS	15	20	Profile	University
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	University
^{34}S / ^{32}S	GMS	–	20	Sulphides	JNC
^{238}U-decay series	Alpha-, gamma-spectrometry	–	20	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, Rb-Sr, U-Th methods	–	5	FF only	JNC, University
Zircon / Apatite	Fission track method	–	5	FF only	Contractor
Microscopic Pore-space Characterisation					
Porosity	Hg injection porosimetry	15	–		Contractor
Geometry	Resin impregnation Microscopic examination	–	20	Porosity also	JNC

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

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

5.2.5 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 structure on the cores 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 (on the next 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 filled in the previous day. Details of any anomalies and/or unexpected events encountered during drilling are described in the sheets.

Summary report (within a week after each 100m 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. Digitised numerical data (*eg* 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.

5.3 Geophysical Investigations

Some of the anomalies detected in geophysical logs in the boreholes MIU-1 and MIU-2 are comparable with major water-conducting features identified as listed in Appendix I-3. The other anomalies might indicate possible locations of smaller water-conducting features, which have not been investigated in detail. Geophysical logging and borehole TV (BTV) can provide basic information necessary for further investigations. In the MIU-4 borehole investigation programme, it is therefore planned to conduct a series of geophysical investigations.

5.3.1 Aims

- To identify locations of potentially water-conducting features.
- To acquire information about the orientation and geometry of geological discontinuities.
- To acquire geophysical properties continuously to be used in the fracture characterisation study and in the geological, hydrochemical and geomechanical modelling.
- To characterise *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
   - Neutron: thermal neutron correlated with total porosity around the borehole
   - Density: decayed gamma rays correlated with apparent density
   - Acoustic: P-wave velocity
2. Geotechnical logging
   - X-Y calliper: borehole diameters in two orthogonal directions
   - Deviation: orientation and inclination of borehole
3. Borehole TV (BTV: digital scanning of the borehole wall)

5.3.3 Planned investigations

Geophysical logging and BTV are performed in three phases, which can provide information to select test intervals for downhole investigations such as hydraulic packer tests and groundwater sampling. The locations, orientations, widths, shapes and appearance of geological discontinuities such as fractures, faults, flow structures, lithological boundaries and veins are identified as well as petrophysical properties of the background fractured rock being characterised. The geometry of the structure system is defined by data analysis. Potentially water-conducting features may be identified by detecting anomalies on the geophysical logs and by comparing these logs with other geological and hydrogeological information.

5.3.4 Reporting

5.3.4.1 Geophysical logging

Prompt report (within 1 day after the investigation has been completed)

Each of the logs is submitted. Any anomalies and/or unexpected events encountered during the field work are also given.

Interim report (within 3 days after the investigation has been completed)

A sheet with all profiles at the same scale is submitted. 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 (*eg* any anomalies and/or unexpected events) and the full data set. Data are in a format compatible with the Land Mark™ software for modelling. 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 (within 1 day after the investigation has been completed)

Pictures are submitted on a videotape. Digitised images in BIPS™ image files to be used for an 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 field work are also given.

Interim report (within 2 months after the investigation has been completed)

The locations, orientations, widths, shapes and appearance of geological discontinuities such as fractures, faults, flow structures, 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 (*eg* details of identified discontinuities) 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

Previous investigations performed in the boreholes MIU-1 and MIU-2 have provided the following information on the hydrogeological characteristics of the Toki granite:

- Some water-conducting features have been identified based upon the losses of fluid and anomalies in fluid logs (wireline logs) (*see* Appendices I-1, I-2 and I-3). The water-conducting features identified in a shallower part of the granite have sub-horizontal orientations whereas deeper ones have sub-vertical orientations.
- Hydraulic conductivity contrasts (*ie* higher/lower-permeability zones) have been identified from the results of the hydraulic packer tests.

To evaluate the connectivity of water-conducting features and to reliably simulate groundwater flow, further information should be obtained through investigations in the MIU-3 borehole. In addition, for these purposes it is also planned to monitor hydraulic pressure and take groundwater samples in the boreholes AN-1, AN-3, MIU-1 and MIU-2 during hydrogeological investigations in the MIU-4 borehole.

5.4.1 Aims

- To obtain good quality data on the transmissivity, hydraulic conductivity and hydraulic heads in the water-conducting features and the background fractured rock.
- To establish a methodology for predicting the connectivity of water-conducting features on a scale of several decametres to several hectometres based upon the pressure responses observed in the measurement intervals in the boreholes MIU-1, MIU-2, AN-1 and AN-3 during the MIU-4 drilling.

5.4.2 Methods

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

1. Fluid logging
   - Spinner flowmeter logging: continuous measurement of flow velocity
   - Heat pulse flowmeter logging: batch measurement of flow velocity
   - Temperature logging: continuous measurement of temperature
2. Hydraulic packer tests
   - Pulse test: low to very low transmissivity
   - Slug test: average to low transmissivity
   - Pumping test: average to high transmissivity

5.4.3 Planned field work

5.4.3.1 Work during drilling

Fluid logging (by contractor)

Three different techniques are employed to identify major water-conducting features. Spinner flowmeter logging in steady and pumping-up states and temperature logging are performed to identify inflow/outflow points. Heat pulse flowmeter logging is conducted to estimate flow velocity at each of the inflow/outflow points. These features are identified as anomalies on the profile, which in turn complement other geological and hydrogeological information, suggesting the locations of water-conducting features.

Hydraulic packer tests (by contractor)

Pulse, slug and pumping (*ie* constant pressure or constant flow rate) test techniques are employed for very low to low, low to average and average to high permeability rock respectively. The most suitable method for hydraulic packer tests is selected on the basis of the expected transmissivity of the rock, the time available for the test and the applicable equipment. There may be more than one kind of test in a given interval. The contractor should inform JNC staff of possible borehole intervals for hydraulic testing and also JNC staff with access to all the relevant data continuously evaluate the borehole. JNC then decides the most appropriate interval for each test. These intervals are identified on the basis of the losses and rates of losses of fluid and anomalies in fluid logs and in other geophysical logs. Anomalies in fluid logs and the locations of fluid losses would indicate major water-conducting features whereas those in other geophysical logs (*eg* neutron, calliper and density logs) might indicate smaller water-conducting features.

Firstly, pulse or slug tests are conducted by withdrawal to select the method to be applied to hydraulic packer tests in each of the test intervals identified. It will be necessary to check the pressure recovering towards its initial state or to extrapolate to the initial state. When a pumping test is used, step-drawdown tests are conducted first for deciding appropriate pumping flow rates precisely for the following constant flow rate tests. After the step-drawdown test, a recovery test is conducted until the pressure in the test interval reaches the initial pressure or until the initial pressure can be reliably extrapolated from the recovery. The constant flow rate tests and constant pressure tests are then carried out and the following recovery test is also conducted in the same way. Groundwater sampling takes place during the pumping test and it is desirable to maintain flow rates as low as practicable to minimise the chances of cross flow. In any case, flow rates should be monitored continuously during groundwater sampling. Lastly pulse tests should be conducted to check compressibility.

The planned hydraulic testing programme is summarised in Table 2. The sequence of field work during drilling is described as follows (depths along borehole axis):

1. Pumping test with water sampling using a single packer immediately above the unconformity (in the interval of 60 to 70mbgl).

2. Pumping test with water sampling using double packers between the unconformity and the base of weathered granite (in the interval of 70 to 93mbgl).

3. Fluid logging to identify water-conducting features especially in the basal conglomerate of the Akeyo Formation.
4. Pulse and slug tests with water sampling using double packers in the basal conglomerate of the Akeyo Formation (in the interval of 34 to 39mbgl).
5. Pumping test with water sampling using a single packer in the fractured zone above the Tsukiyoshi fault (provisionally planned in the interval of 655 to 685mbgl; as close to the fault zone as possible).
6. Fluid logging to identify water-conducting features between the casing shoe and the Tsukiyoshi fault.
7. Pumping test with water sampling using a single packer in the Tsukiyoshi fault (zone) (provisionally planned in the interval of 685 to 710mbgl).
8. Pumping test with water sampling using a single packer or double packers in the fractured zone below the Tsukiyoshi fault to the bottom of the borehole (in the intervals of 710 to 790mbgl).
9. Fluid logging to identify water-conducting features below the Tsukiyoshi fault.

5.4.3.2 Work after drilling

Hydraulic packer tests (by contractor)

Pulse and slug tests and pumping tests with groundwater sampling also take place in the most appropriate test intervals that are selected as mentioned above. The sequence of hydraulic packer tests after drilling is described as follows (also shown in Table 2 for the whole programme):

1. Pumping tests with water sampling using double packers between the casing shoe and the Tsukiyoshi fault (at 2 intervals if there are water-conducting features of which pressure responses are not observed in the MIU-1 and MIU-2 boreholes).
2. Long-interval pumping tests using double packers at 7 intervals below the casing shoe.
3. Short-interval pulse and slug tests using double packers at 5 intervals below the casing shoe.

Table 2 Planned hydraulic packer tests

No.	Test Intervals (mbgl along borehole axis)	Geological Descriptions	Test Phases*	Packer Configuration**	Test Methods***
1	60-70	Basal conglomerate of the Toki lignite-bearing Formation	During phase II	s	PP, WS
2	70-93	Weathered granite	During phase III	d	PP, WS
3	34-39	Basal conglomerate of the Akeyo Formation	During phase III	d	SP, WS
4	655-685	Fractured zone above the Tsukiyoshi fault (Toki granite)	During phase IV	s	PP, WS
5	685-710	Tsukiyoshi fault (zone)	During phase V	s	PP, WS
6	710-790	Fractured zone below the Tsukiyoshi fault (Toki granite)	During phase VI	s or d	PP, WS
7-8	2 intervals between 100 and 685	WCF in the Toki granite	After drilling	d	PP, WS
9-15	7 intervals between 100 and 790	Toki granite	After drilling	d	PP
16-20	5 intervals between 100 and 790	WCF in the Toki granite	After drilling	d	SP

* Test Phases = *see* Section 6.1.1
** Packer Configuration = s: single packer, d: double packers
*** Test Methods = PP: PumPing test, SP: Slug and Pulse tests, WS: Water Sampling

5.4.4 Reporting

Prompt reports

1. Fluid logging (immediately after the 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 packer tests (immediately after each investigation has been completed)

   Results of the hydraulic packer tests are reported with the following information:
   - Objectives and employed techniques
   - Geology of test intervals
   - 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/end
   - Test results with detection limits and precision (hydraulic head, plotted data, analytical method used, result of matching and transmissivity and hydraulic conductivity)
   - Short comments on the tests (including details of anything abnormal or unexpected)

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

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

A summary of the hydraulic packer tests performed including transmissivity and/or hydraulic conductivity and hydraulic head with depth is reported together with the geological log. Comments on the hydraulic characteristics of the test intervals are also reported.

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 investigations.

5.5 Hydrochemical Investigations

As stated in Section 2, the highest priority has to be given to hydrochemical investigations in this programme. In addition, since hydrochemical investigations have not been made to date in the MIU site, groundwater sampling from the boreholes MIU-1 and MIU-2 will be also carried out in the 1999 financial year after cross-hole interference pumping tests are completed.

5.5.1 Aims

- To determine the depth profile of hydrochemical properties of groundwater.
- To obtain basic information for the characterisation of water-rock interactions (*eg* redox reactions, correction of ^{14}C ages of groundwater, *etc*).
- To determine the hydrochemical properties and residence time of groundwater within fractured zones.
- To obtain information for evaluating uncertainties in the geochemical interpretation of the MIU site (*eg* representativity of obtained hydrochemical data).
- To refine the procedure for groundwater sampling.

5.5.2 Methods

Groundwater sampling and subsequent analytical work are planned on the MIU site and in the laboratory respectively. The methods to be employed are as follows:

1. On the site

• Drilling fluid preparation:	drilling fluid for quantitative hydrochemical investigations
• Tracer analyses (during drilling):	maintenance of tracer concentration in drilling fluid
(during pumping):	groundwater contamination
• Uranine, LiCl analyses:	groundwater mixing (*eg* fracture connectivity)
• Standard chemical analyses:	drilling fluid and groundwater chemistries

2. In the laboratory

• Comprehensive chemical analyses:	drilling fluid and groundwater chemistries
• Standard isotopic analyses:	isotopic composition, origin and residence time of groundwater
• Gas analyses:	redox conditions, recharge temperature, origin and residence time of groundwater
• Colloids/organics/microbes studies:	population and role

5.5.3 Planned field work

5.5.3.1 Work during drilling

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. Since uranine has been used during the drilling of MIU-1 and MIU-2 boreholes, another kind of fluorescent dye should be used as a tracer for the MIU-4 drilling. The most useful fluorescent dyes (or combination of different dyes) are selected on the basis of the laboratory tests to be carried out before the drilling. Possible fluorescent compounds are eosin, rhodamine B, sulphorhodamine B, amidorhodamine G, Na-naphtionate, rhodamine WT, rhodamine 6G, lissamine, erythrosine, lanaperl fast yellow, bengal rose and pyranine. The actual concentrations of the tracers in the drilling fluid depend on the tracer selected. The concentrations are calculated by giving consideration to the detection limits of the tracers and the need to identify drilling fluid contamination of only 1%.

Monitoring of drilling fluid during drilling (by contractor)

The general analytical programme is shown in Table 3. Physico-chemical parameters, major chemical constituents, isotopic compositions and tracers are analysed and adjusted periodically to keep the concentrations as similar as practicable. Physico-chemical parameters are continuously measured on-site. Major chemical constituents, isotopic compositions and tracer concentrations are determined at the site or in the off-site laboratory. Since uranine has been used during the drilling of MIU-1 and MIU-2 boreholes, the uranine concentrations in the drilling fluids should be checked simultaneously with the other monitoring parameters, providing information on the connectivity of water-conducting features between the boreholes. Major chemical constituents and isotopic compositions in the original river water are also analysed periodically in house.

Groundwater sampling combined with hydraulic packer tests (by contractor)

It is planned to collect groundwater during hydraulic testing period (*see* Section 5.4.3) in the following areas (depths along borehole axis):

1. Sedimentary formation: 2 intervals
   - Basal conglomerate of the Akeyo Formation (in the interval of 34 to 39mbgl)
   - Immediately above the unconformity (in the interval of 60 to 70mbgl)
2. Toki granite: 4 intervals
   - Weathered section (in the interval of 70 to 93mbgl)
   - Fractured zone within the hanging wall above the Tsukiyoshi fault (provisionally planned in the interval of 655 to 685mbgl; as close to the fault zone as possible)
   - In the Tsukiyoshi fault (zone) (provisionally planned in the interval of 685 to 710mbgl)
   - Fractured zone within the footwall below the Tsukiyoshi fault (in the interval of 710 to 790mbgl)

The interval to be sampled (encompassing one or more water-conducting features) is sealed off with a single or double packer assembly. Once the packers have been inflated, the drilling fluid should be removed from the packed-off interval and tubing and replaced by flowing groundwater with a submersible pump.

Preparation of the drilling fluid with tracers allows the contamination of the groundwater by the drilling fluid to be estimated quantitatively. During pumping before groundwater sampling, the tracer concentration is determined periodically on the site. Several physical and chemical parameters are measured simultaneously by JNC. The measurements are aimed at testing the applicability of mixing calculations for the estimation of groundwater chemistry. Groundwater sampling takes place when the tracer concentration is sufficiently low (*ie* generally below 1%). In case the tracer concentration does not decrease sufficiently within the time available for groundwater sampling due to the heavy contamination of the groundwater, such sections are only sampled for the analyses of major components and some isotopes.

5.5.3.2 Work after drilling

Groundwater sampling (by contractor)

Additional groundwater sampling (maximum 2 intervals) is planned between the casing shoe and the Tsukiyoshi fault. Suitable intervals to be sampled are selected on the basis of the fluid logging and the orientation of the water-conducting features. The criteria to be used for the selection of test intervals are:

- Inflow or outflow is observed.
- There are water-conducting features which do not transmit pressure responses detectable to the MIU-1 and MIU-2 boreholes.

Groundwater sampling should not be carried out in the sections where there is:

- No water-conducting feature.
- Any water-conducting feature transmitting pressure responses to other boreholes.

5.5.4 Planned laboratory work

Some hydrochemical parameters of the drilling fluid and groundwater samples are measured at the site. Comprehensive chemical and isotopic analyses of the groundwater samples are carried out in specialised laboratories (*ie* by contractor and university and in house) as shown in Table 3. The reference samples of drilling fluid, river water and groundwater, which have been suitably pre-treated, should be preserved under 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, 7S	–	C/D by JNC
Electrical conductivity (EC)	3S	1S	1S	1S, 7S	–	C/D by JNC
Eh	–	–	1S	1S, 7S	–	C/D by JNC
Dissolved Oxygen (DO)	3S	–	1S	1S, 7S	–	C/D by JNC
Temperature (T)	3S	1S	1S	1S, 7S	–	C/D by JNC
Major Components						
Sodium (Na^+)	3S	3S	4S	6L, 7L	Contractor	
Potassium (K^+)	3S	3S	4S	6L, 7L	Contractor	
Ammonium (NH_4^+)	–	–	–	6L, 7L	Contractor	
Magnesium (Mg^{2+})	3S	3S	4S	6L, 7L	Contractor	
Calcium (Ca^{2+})	3S	3S	4S	6L, 7L	Contractor	
Strontium (Sr^{2+})	3S	3S	–	6L, 7L	Contractor	
Manganese (Mn^{2+})	–	–	–	6L, 7L	Contractor	
Iron (total Fe)	3S	3S	–	6L, 7L	Contractor	
Iron (Fe^{2+})	–	–	–	6L, 7L	Contractor	
Aluminium (Al)	3S	3S	–	6L, 7L	Contractor	
Rare earth elements (REEs)	–	–	–	6L, 7L	University	
Fluoride (F^-)	3S	3S	4S	6L, 7L	Contractor	
Chloride (Cl^-)	3S	3S	4S	6L, 7L	Contractor	
Bromide (Br^-)	3S	3S	4S	6L, 7L	Contractor	
Nitrate (NO_3^-)	3S	3S	4S	6L, 7L	Contractor	
Nitrite (NO_2^-)	–	–	–	6L, 7L	Contractor	
Sulphate (SO_4^{2-})	3S	3S	4S	6L, 7L	Contractor	
Sulphide (total H_2S)	–	–	–	6L, 7L	Contractor	
Silica (H_2SiO_3)	3S	3S	4S	6L, 7L	Contractor	
Alkalinity	3S	3S	4S	6L, 7L	Contractor	
Total inorganic carbon (TIC)	3S	3S	4S	6L, 7L	Contractor	
Total organic carbon (TOC)	–	–	–	6L, 7L	Contractor	
Isotopes						
Deuterium (^2H)	4L	5L	4L	6L, 7L	JNC	
Tritium (^3H)	4L	5L	4L	6L, 7L	Contractor	
Oxygen-18 (^{18}O)	4L	5L	4L	6L, 7L	JNC	
Carbon-13 (^{13}C)	4L	5L	–	6L, 7L	JNC	
Carbon-14 (^{14}C)	4L	5L	–	6L, 7L	JNC	
Sulphur-34 (^{34}S)		–	–	6L, 7L	JNC	
Chlorine-36 (^{36}Cl)	4L	–	–	6L, 7L	Contractor	
He isotopic ratio (^3He / ^4He)	–	–	–	6L, 7L	JNC	
Sr isotopic ratio (^{87}Sr / ^{86}Sr)	4L		–	6L, 7L	University	
Cl isotopic ratio (^{37}Cl / ^{35}Cl)	–	–	–	7L	Contractor	Depending on total Cl
^{238}U-decay series	–	–	–	6L, 7L	University	Including total U
^{232}Th-decay series	–	–	–	6L, 7L	University	
Dissolved Gas						
H_2, N_2, CH_4, CO_2, He, Ar	–	–	–	6L, 7L	Contractor	
Others						
Colloids	–	–	–	7L	JNC, Contractor	
Organics	–	–	–	7L	JNC, Contractor	
Microbes	–	–	–	7L	University	
Tracers						
Uranine (for MIU-1/2 drilling)	–	–	4S	6L, 7L	Contractor	
Lithium (for MIU-3 drilling)	3S	–	4S	6L, 7L	Contractor	
X (for MIU-4 drilling)	–	2S	2S	6L, 7L	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: At each 100m drilling,
6: At the end of hydraulic testing, 7: During long-term monitoring (when needed),
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 investigation has been completed)

A report to be submitted by contractors includes raw data and the following information:

1. Drilling fluid monitoring
   - Analysed values with errors and detection limits
   - Method used, including details of equipment employed and its 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 colour changes in water, gas bubbles, precipitation and smell
   - Amount of water sampled
   - Details of characteristics of storage containers used
   - Tracer 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 analysed 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 analysed 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 Rock Mechanical Investigations

The goals of rock mechanical investigations in the surface-based investigation programme are to develop a methodology and conceptual model for rock mechanics on a scale of several decametres to a hectometre and to define mechanical properties and *in situ* stress state up to 1,000m depth in the Toki granite for the design of underground facilities. Knowledge from previous investigations in the boreholes MIU-1 and AN-1 is summarised in Section 3. Additional investigations will be carried out in the boreholes MIU-2 and MIU-3 in 1999, which will provide the geotechnical data for the footwall of the Tsukiyoshi fault and information on the influences of fault movements on rock mechanics.

5.6.1 Aims

- To estimate the extent and degree of changes in rock mechanical properties and *in situ* stress caused by past fault movements.
- To evaluate the 3-D *in situ* stress state in the hanging wall of the Tsukiyoshi fault from the ground surface to 1,000mbgl.

5.6.2 Methods

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

1. On the site
   - Hydraulic fracturing: *in situ* stress magnitude and direction
2. In the laboratory
   - DSCA: microcrack distribution and anisotropy of elastic modulus
   - AE: AE activity under the compressive stress

5.6.3 Planned field work

In situ stress measurement (by individual contractor)

Stress measurements are conducted *in situ* at 6 intervals (about 115.5m (*ie* 100m measured vertically) each) by the hydraulic fracturing method, which provides stress components perpendicular to the borehole axis.

5.6.4 Planned laboratory work

The following laboratory tests on core samples are planned.

Testing the anisotropy of the Toki granite (by individual contractor)

The distribution of microcracks and anisotropy of elastic modulus in three dimensions are estimated on rock samples with the DSCA (Differential Strain Curve Analysis) method, which is normally used for stress measurements in Japan. This method works by comparing the stress-strain curve of the rock sample with that of a completely elastic material (quartz cube) under the same hydrostatic stress condition.
Samples are taken from the rock matrix at varying distances from the Tsukiyoshi fault in the MIU-4 borehole. In addition, the core samples of the Toki granite matrix are also taken from the existing boreholes, not from the MIU-4 borehole, as a lapse after the recovery of cores does not have any effect on the testings.

- MIU-4 borehole: 10 samples at varying distances from the Tsukiyoshi fault in each of the wall rocks. The locations of the samples are selected after the location of the Tsukiyoshi fault has been determined.
- Existing boreholes: 3 to 5 samples in each of the different mechanical zones identified in the Toki granite.

The DSCA data can be used, where necessary, to estimate the 3-D stress state, assuming the magnitude of vertical stress to be equal to overburden pressure. It is necessary to check the validity of this approach by comparing the estimates with the results of stress measurements carried out in the existing boreholes.

Stress measurement (by individual contractor)

Stress measurements are conducted by the AE (Acoustic Emission) method on core samples collected from the intervals where *in situ* stress measurements are carried out as mentioned above. *In situ* stress can be estimated by determining the reloading stress at which AE activity begins to increase continuously under the uniaxial compressive stress condition, as the activity does not increase until the reloading stress level exceeds the historical maximum stress (*ie* a phenomenon called the Kaiser effect). The results of *in situ* and laboratory stress measurements supplement the existing geotechnical data set, which allows the characterisation of the recent stress field (*ie* the direction and the size of stress components) in the Toki granite.

5.6.5 Reporting

5.6.5.1 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 curve 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, the interpretation of the 3-D stress state from the surface to 800mbgl and the effect of fault activities on the 3-D stress field are reported.

5.6.5.2 Laboratory work reports

Prompt report (immediately after the testing and measurement have been completed)

The stress-strain curve and the preliminary interpreted results are reported for testing the anisotropy of the Toki granite. The measured stress and the raw data for AE activities during the testing are reported for the stress measurements by the AE method.

Final report (by the end of contract period)

All results are reported with a full data set. The possible interpretations are discussed, including considerations of the following issues:

- The degree of anisotropy of elastic modulus and crack porosity of rock matrix in the Toki granite
- The extent and degree of rock mechanical property changes caused by fault activities
- The calculated 3-D stress state based upon the above results and the confidence in the results evaluated by comparison with the results of other stress measurements

5.7 Additional Investigations

The MP system has been installed in the AN-1 borehole and will be installed in the boreholes MIU-1, MIU-2 and AN-3 prior to the MIU-4 drilling. It is thus worthwhile carrying out additional investigations in these boreholes before and during a series of investigations in the MIU-4 borehole, which may provide data to evaluate connectivity between boreholes. After the MIU-4 campaign has been completed, a multipacker system should be installed in the MIU-4 borehole for long-term monitoring before and during the construction of the MIU.

5.7.1 Aims

- To evaluate the connectivity of the water-conducting features between the MIU-4 borehole and the boreholes MIU-1, MIU-2, AN-1 and AN-3.
- To determine the spatial distribution and variations in hydraulic heads before the construction of the MIU.
- To obtain hydraulic and hydrochemical information necessary for evaluating the groundwater flow system through the iterative process of simulation of groundwater flow and refinement of concepts.

5.7.2 Methods

Observation of pressure responses in the boreholes MIU-1, MIU-2, AN-1 and AN-3 before and during the MIU-4 drilling and long-term hydraulic/hydrochemical monitoring in the MIU-4 borehole are planned. The long-term monitoring includes monitoring of hydraulic heads and groundwater sampling.

5.7.3 Planned field work

5.7.3.1 Pressure response observation

Hydraulic pressure responses are observed every 1 minute in the measurement intervals in the boreholes MIU-1, MIU-2, AN-1 and AN-3 before and during the MIU-4 drilling by a contractor. Data are used in the geological, hydrogeological and hydrochemical investigations.

5.7.3.2 Long-term hydraulic/hydrochemical monitoring

After a series of the MIU-4 borehole investigations have been completed, a multipacker system that contains up to 10 packed-off intervals is installed in the MIU-4 borehole. Suitable packed-off intervals for the hydraulic/hydrochemical monitoring are selected on the basis of the geological, hydrogeological and hydrochemical investigations. Hydraulic heads are monitored in the intervals in the MIU-4 borehole as well as in the boreholes MIU-1, MIU-2, AN-1 and AN-3. Data on hydraulic heads are acquired hourly throughout the construction of the MIU. Information on the spatial distribution and variations in hydraulic heads with time, provided by the long-term hydraulic monitoring, is needed for the evaluation of the groundwater flow system.

On the other hand, groundwater sampling and subsequent analytical work specified in Table 3 are carried out. Hydrochemical information serves as a check on the reasonableness of descriptions of the groundwater flow system. All the work mentioned above is carried out by an individual contractor.

5.7.4 Reporting

5.7.4.1 Pressure response observation

A prompt report should be submitted within 24 hours after each drilling campaign has been completed, which contains raw and plotted data with time, relevant detection limits and precision, comments on the measurements and details of anything abnormal or unexpected.

5.7.4.2 Long-term hydraulic/hydrochemical monitoring

Prompt reports

1. Hydraulic monitoring (every week)

   Raw and plotted data with 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.

2. Groundwater sampling (within 24 hours after the investigation has been completed)

   Raw data, hydraulic head, pH, electrical conductivity and temperature of groundwater, any observation of colour changes in water, gas bubbles, precipitation, smell, amount of water sampled, details of the system set-up, sampling method used and anything abnormal during the sampling or analyses are included in a report.

Final reports (by the end of contract period)

1. Installation of a multipacker system

   The report should clearly show accurate packed-off intervals, inflation pressure of packers, hydraulic heads and anything abnormal during the installation of the multipacker system. Drawings of the multipacker system and its set-up are appended.

2. Hydraulic monitoring

   All results are compiled and reported with full data sets and relevant information described above. The report should contain the interpretation of the results and comments on the spatial distribution and variations in hydraulic heads with time due to the construction of the MIU.

3. Groundwater sampling

   All results are compiled and reported with full data sets. The report should include analysed values with errors and detection limits, details of the system set-up, details of sampling and analytical methods employed and their conditions and details of anything unexpected that occurred during the sampling and analyses.

6 INVESTIGATION PROCEDURE AND TIMEPLAN

This section describes the procedure and timeplan for the "base case" investigation campaign to be executed in the MIU-4 borehole, which are summarised in Figures 5 and 6 respectively. In addition, a couple of alternative programmes (*ie* optional cases) are also discussed.

6.1 Investigation Procedure

Investigation campaigns during drilling over six phases and after drilling have been defined on the basis of geological and hydrogeological prediction, the priority of planned investigations and the time available for the investigations.

Here all depths are given along the borehole axis and are approximately determined based upon existing geological and hydrogeological knowledge. The actual depths at which these features are encountered may be different from the depths given below. Similarly, the depths of testing and sampling intervals are approximate and may change from the proposed depth in the light of actual geological and geophysical investigations.

6.1.1 Base case

During drilling

Phase I 0 – 10mbgl / Surface soil and sedimentary rocks (Akeyo Formation)

1. Drilling by a tricone bit with fresh water containing added tracers (I)† or an air hammer from the surface to 10mbgl at 445mm (17 1/2") in diameter.
2. Installation of 14" casing pipes to 10mbgl and fixing by full hole cementing. Flushing the borehole to extract cuttings with fresh water containing added tracers (I) after dredging cement.
3. Installation of 5" temporary casing pipes to 10mbgl.

Phase II 10 – 70mbgl / Sedimentary rocks (Mizunami Group)

4. PQ wireline core drilling to 70mbgl (*ie* immediately above the unconformity) with fresh water containing added tracers (I). Core recovery using a triple-barrel corer. The borehole diameter is 123mm and the core diameter is about 80mm. Continuous monitoring of drilling parameters such as drilling rate, bit revolution, bit load, torque, pumping pressure, rate of water supply and return using a suitable monitoring device to the final depth at 790mbgl. Flushing the borehole to extract cuttings with fresh water containing added tracers (I) after dredging cement.
5. Extraction of PQ wireline tools, PQ rods and 5" temporary casing.
6. Pumping test and water sampling using a single packer in the interval of 60 to 70mbgl.
   - Aims: transmissivity (T), hydraulic head (H) and water sample (W)
   - Lithology: basal conglomerate of the Toki lignite-bearing Formation

† Three groups of tracers, here denoted I, II and III (see Section 5.5.3.1 for details), are used. The identities of these tracers have yet to be decided. This footnote continues onto the next two pages.

7. Reinstallation of 5" temporary casing pipes to 10mbgl.

8. Flushing the borehole to exchange tracers with fresh water containing new tracers (II) until the concentrations of previous tracers (I) decrease below 1%.

Phase III 70 – 100mbgl / Weathered and intact Toki granite

9. PQ wireline core drilling to 100mbgl (*ie* the base of weathered granite) with fresh water containing added tracers (II). Core recovery using a triple-barrel corer. The borehole diameter is 123mm and the core diameter is about 80mm. Flushing the borehole to extract cuttings with fresh water containing added tracers (II) after drilling.

10. Extraction of PQ wireline tools, PQ rods and 5" temporary casing.

11. Pumping test and water sampling using double packers in the interval of 70 to 93mbgl.

    - Aims: T, H, W
    - Lithology: weathered section of the Toki granite

12. Borehole TV, geophysical and fluid logging from 10 to 100mbgl.

13. Pulse and slug tests using double packers and water sampling with the same test device in the interval of 34 to 39mbgl.

    - Aims: T, H, W
    - Lithology: basal conglomerate of the Akeyo Formation

14. Reaming by a tricone bit with fresh water or an air hammer at 311mm (12 1/4") in diameter.

15. Installation of 10" casing pipes to 100mbgl and full hole cementing. Flushing the borehole to extract cuttings with fresh water containing added tracers (II) after dredging cement.

16. Reinstallation of 5" temporary casing pipes to 100m.

Phase IV 100 – 685mbgl / Hanging wall of the Tsukiyoshi fault in the Toki granite.

17. PQ wireline core drilling with fresh water containing added tracers (II) until the fractured zone (about 30m above the Tsukiyoshi fault) is encountered. The top depth of the fractured zone above the fault zone is 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 123mm and the core diameter is about 80mm. Drilling is stopped when encountering fractures that support sufficient groundwater flow to allow a pumping test and water sampling in the fracture zone. Flushing the borehole to extract cuttings with fresh water containing added tracers (II) after drilling.

18. Extraction of PQ wireline tools, PQ rods and 5" temporary casing.

19. Pumping test and water sampling using a single packer in the interval of 655 to 685mbgl.

    - Aims: T, H, W
    - Lithology: fractured zone enveloping the Tsukiyoshi fault in the Toki granite

20. Reinstallation of 5" temporary casing pipes to 100mbgl.

21. Borehole TV, geophysical and fluid logging from 100 to 685mbgl.

22. Flushing the borehole to exchange tracers with fresh water containing new tracers (III) until the concentrations of previous tracers (II) decrease below 1%.

Phase V 685 – 710mbgl / Tsukiyoshi fault (zone) in the Toki granite.

23. PQ wireline core drilling penetrating the fault (zone) with fresh water containing added tracers (III). Core recovery using a triple-barrel corer. The borehole diameter is 123mm and the core diameter is about 80mm. Drilling is stopped when encountering the bottom of the fault (zone). The bottom depth of the fault (zone) is determined by JNC staff based upon the termination of highly crushed and deformed textures observed on the core. Flushing the borehole to extract cuttings with fresh water containing added tracers (III) after drilling.

24. Extraction of PQ wireline tools, PQ rods and 5" temporary casing.

25. Pumping test and water sampling using a single packer in the interval of 685 to 710mbgl.

- Aims: T, H, W
- Lithology: Tsukiyoshi fault (zone) in the Toki granite

26. Reinstallation of 5" temporary casing pipes to 100mbgl.

Phase VI 710 – 790mbgl / Footwall of the Tsukiyoshi fault in the Toki granite.

27. PQ wireline core drilling to the final depth at 790mbgl with fresh water containing added tracers (III). Core recovery using a triple-barrel corer. The borehole diameter is 123mm and the core diameter is about 80mm. Flushing the borehole to extract cuttings with fresh water containing added tracers (III) after drilling.

28. Extraction of PQ wireline tools, PQ rods and 5" temporary casing.

29. Pumping test and water sampling using a single or double packer assembly in the interval of 710 to 790mbgl.

- Aims: T, H, W
- Lithology: fractured zone in the Toki granite below the Tsukiyoshi fault

30. Borehole TV, geophysical and fluid logging from 685 to 790mbgl.

After drilling

31. Pumping tests using double packers over 2 intervals selected on the basis of core observation and borehole logging in the intervals of 100 to 685mbgl. Water sampling with pumping test device if there are water-conducting features of which pressure responses are not observed in other boreholes.

- Aims: T, H, W
- Lithology: Toki granite (*ie* hanging wall of the Tsukiyoshi fault)

32. Pumping tests using double packers at 7 intervals covering the whole drilling section from 100 to 790mbgl except the fault (zone).

- Aims: T, H, (W; if possible)
- Lithology: Toki granite

33. Pulse and slug tests with double packers at 5 intervals selected on the basis of core observation and borehole logging in the interval of 100 to 790mbgl.

    - Aims: T, H
    - Lithology: Toki granite

34. Reinstallation of 5" temporary casing pipes to 100mbgl and PQ wireline tools to the bottom. Flushing the borehole with fresh water.

35. Extraction of PQ wireline tools and emplacement of flange on the top of 10" casing pipes. Dismantlement of any equipment used and restoration of the site.

36. *In situ* stress measurements at 6 intervals between 100 and 790mbgl by the hydraulic fracturing method after the dismantlement and restoration.

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

37. Installation of a multipacker system containing up to 10 packed-off intervals for long-term hydraulic/hydrochemical monitoring.

6.1.2 Optional cases

Optional case #1: Loss of drilling fluid during drilling

If a loss of drilling fluid occurs, transmitting pressure responses to other MIU boreholes, or if there are no responses but 100% fluid loss, all planned investigations that are practicable during and after drilling from 100mbgl to the depth of the fluid loss are executed: pumping test and water sampling with a single packer and with double packers, pulse and slug tests with double packers, borehole TV, geophysical and fluid logging. After these investigations have been completed, cementing is carried out at the site where the loss occurs and drilling is carried on. An appropriate tracer 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/hydrochemical monitoring to be carried out.

Optional case #2: Borehole collapse

If it is necessary to stabilise the borehole wall where collapse occurs, all planned investigations from 100mbgl to the depth of the collapse are executed. This section is reamed at 216mm (8 1/2") in diameter and 7" casing installed at 100mbgl is pushed fully to the depth of the collapse. Drilling is then carried on.

In the case of further borehole collapse, all possible on-site investigations are performed in the section below the shoe of the 7" casing down to the site of the collapse. Then the following steps to carry on drilling and the remainder of on-site investigations will be taken.

- Unless it is impossible to retrieve the 7" casing installed, the section is reamed at 216mm (8 1/2") in diameter after the extraction of the 7" casing. 7" casing pipes are then reinstalled fully to the depth of the collapse.

- If it is impossible to retrieve the 7" casing installed, the section is reamed at 171mm (6

3/4") in diameter. 6" casing pipes are then installed fully to the depth of the collapse and are fixed by full hole cementing. If further borehole collapse occurs below the shoe of the 6" casing, cementing will be carried out at the site of the collapse.

- If it is impossible to protect the borehole where collapse occurs by further installation of casing (*ie* 7" or 6" pipes), cementing is carried out at the site of the collapse.

To enable hydraulic/hydrochemical 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, cut and retrieved or the interval is, where necessary, perforated.

Optional case #3: ***Fluid loss and borehole collapse at the same location***

In that case all planned investigations from 100mbgl to the location where 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 tracer is added to the cement to allow the degree of contamination of groundwater by cement dissolution to be quantified.

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

- It is intended to conduct underreaming and cementing at the location.
- Alternatively the section from 100mbgl to the depth of the fluid loss and/or collapse is reamed at 216mm (8 1/2") in diameter. 7" casing pipes are then installed and fixed by full hole cementing.
- If 7" casing pipes have been already installed in the borehole and are not retrievable, the section below the shoe of the 7" casing down to the location is reamed at 171mm (6 3/4") in diameter. 6" casing pipes are then installed and fixed by full hole cementing.

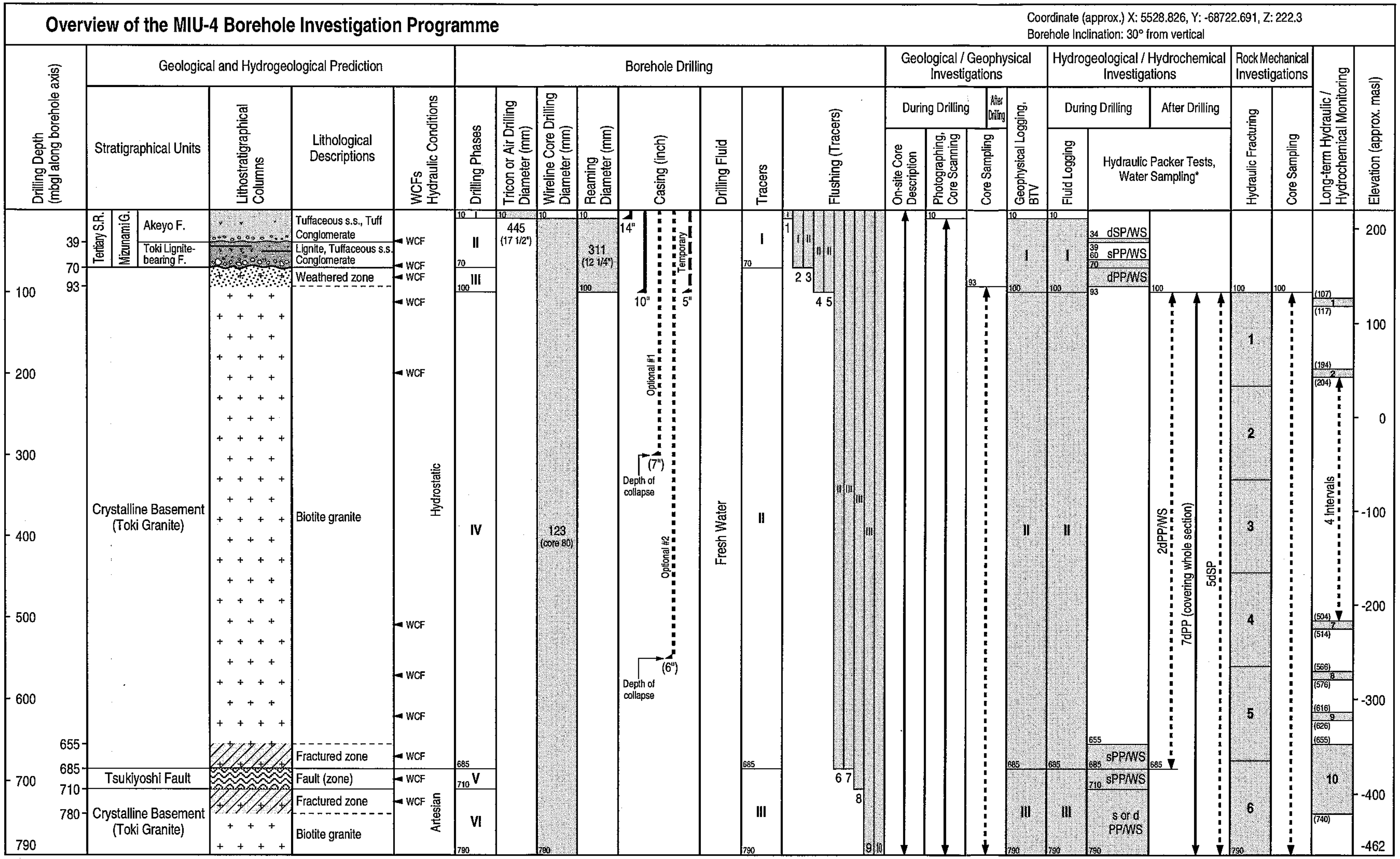
To enable hydraulic/hydrochemical monitoring to be carried out after all planned on-site investigations have been completed, the location of the fluid loss and/or collapse is, where necessary, perforated or the casing pipes in the interval spanning the location are, if possible, cut and retrieved.

Optional case #4: ***No occurrence of the Tsukiyoshi fault at the predicted depth***

Drilling is carried on to the final depth at 790mbgl and all planned investigations except for those in phases V and VI are executed. In that case additional hydraulic packer tests and groundwater sampling during the Step 31 are conducted.

Optional case #5: ***Insufficient groundwater flow at planned test/sampling intervals in the Tsukiyoshi fault and/or in the footwall***

Additional hydraulic packer tests and groundwater sampling during the Step 31 are conducted.



* Hydraulic Packer Tests / Water Sampling = s: single packer, d: double packers
PP: PumPing test, SP: Slug and Pulse tests,
WS: Water Sampling

Figure 5 Overview of the MIU-4 borehole investigation programme

6.2 Timeplan

The programme is planned to launch in December 1999 and take 19 months as shown in Figure 6. Minimum time requirements for the planned field and laboratory work excluding the long-term hydraulic/hydrochemical monitoring are as follows:

- Site preparation: 1.5 months
- Drilling/on-site investigations: 13.0 months
- Site restoration: 0.5 months
- Laboratory work: 9.0 months
- Reporting 6.0 months

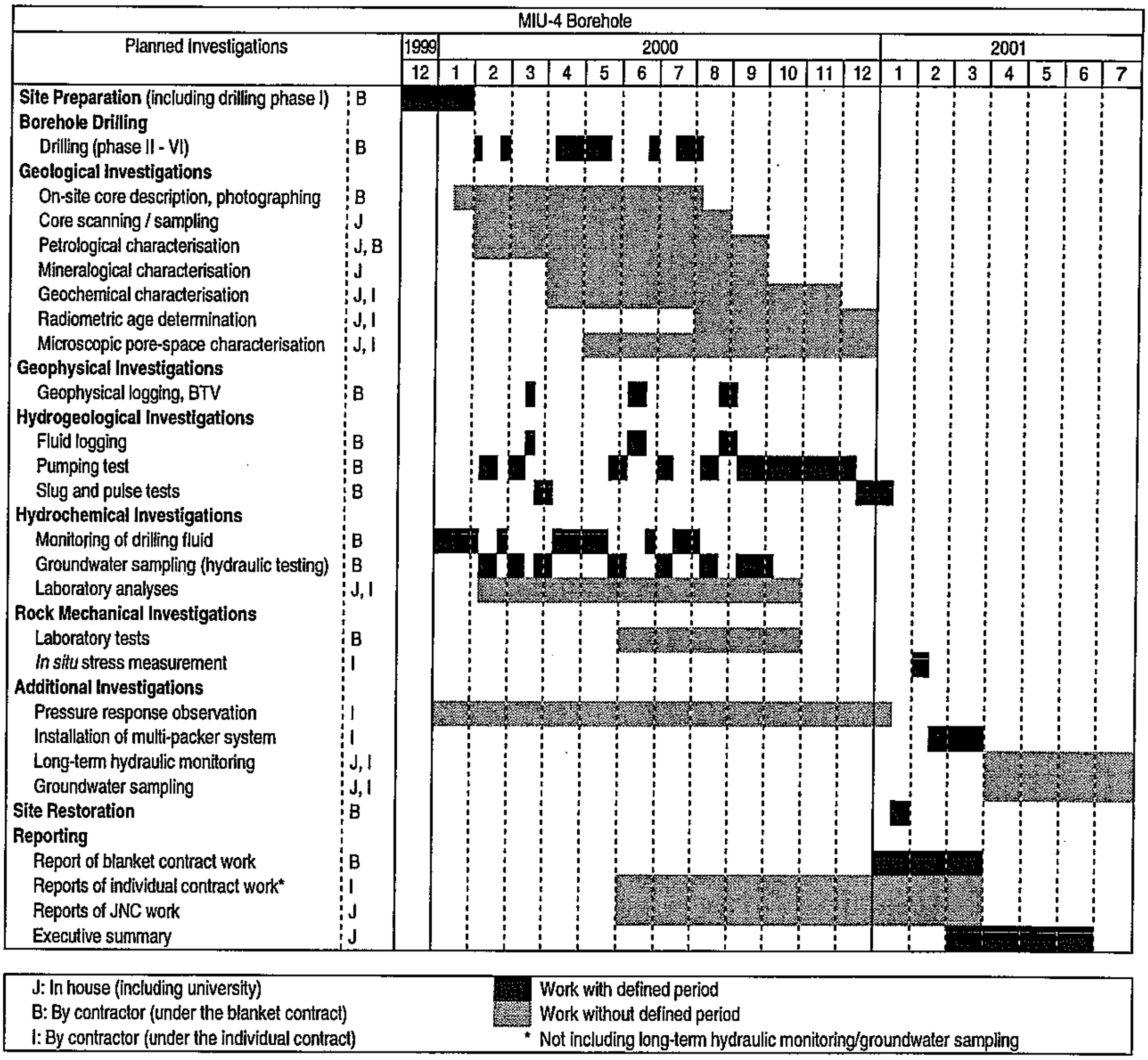


Figure 6 Timeplan of the MIU-4 borehole investigation programme

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. 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. The JNC's QA/QC system is employed to ensure that the purpose for which the work is carried out is most likely to be successfully achieved. It is also intended, for the QC purpose, to have external review by experts (*eg* under international collaboration studies) in the particular field during the MIU-4 borehole investigations.

The final report of the MIU-4 borehole investigations, written both in Japanese and in English, is produced in the form of an executive summary within three 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 aspects to be answered in the surface-based investigations (*eg* establishment of comprehensive investigation techniques) and their contributions to the next or near-future programmes (*eg* geotechnical data set for the construction of the MIU).

8 BUDGET FOR THE MIU-4 BOREHOLE INVESTIGATIONS

JNC plans to contract with a main contractor for the MIU-4 borehole investigations, which covers all of the planned field work except for *in situ* stress measurements and long-term hydraulic/hydrochemical monitoring. About 360 million yen has been budgeted for this blanket contract. Some of the field and laboratory programmes in the particular field are, however, performed by individual contractors. About 22 million yen has been budgeted for laboratory analytical work and up to 96 million yen is now requested for the *in situ* stress measurements and the long-term hydraulic/hydrochemical monitoring. Details of the budget are listed in Table 4.

Table 4 Budget for the planned MIU-4 borehole investigation programme

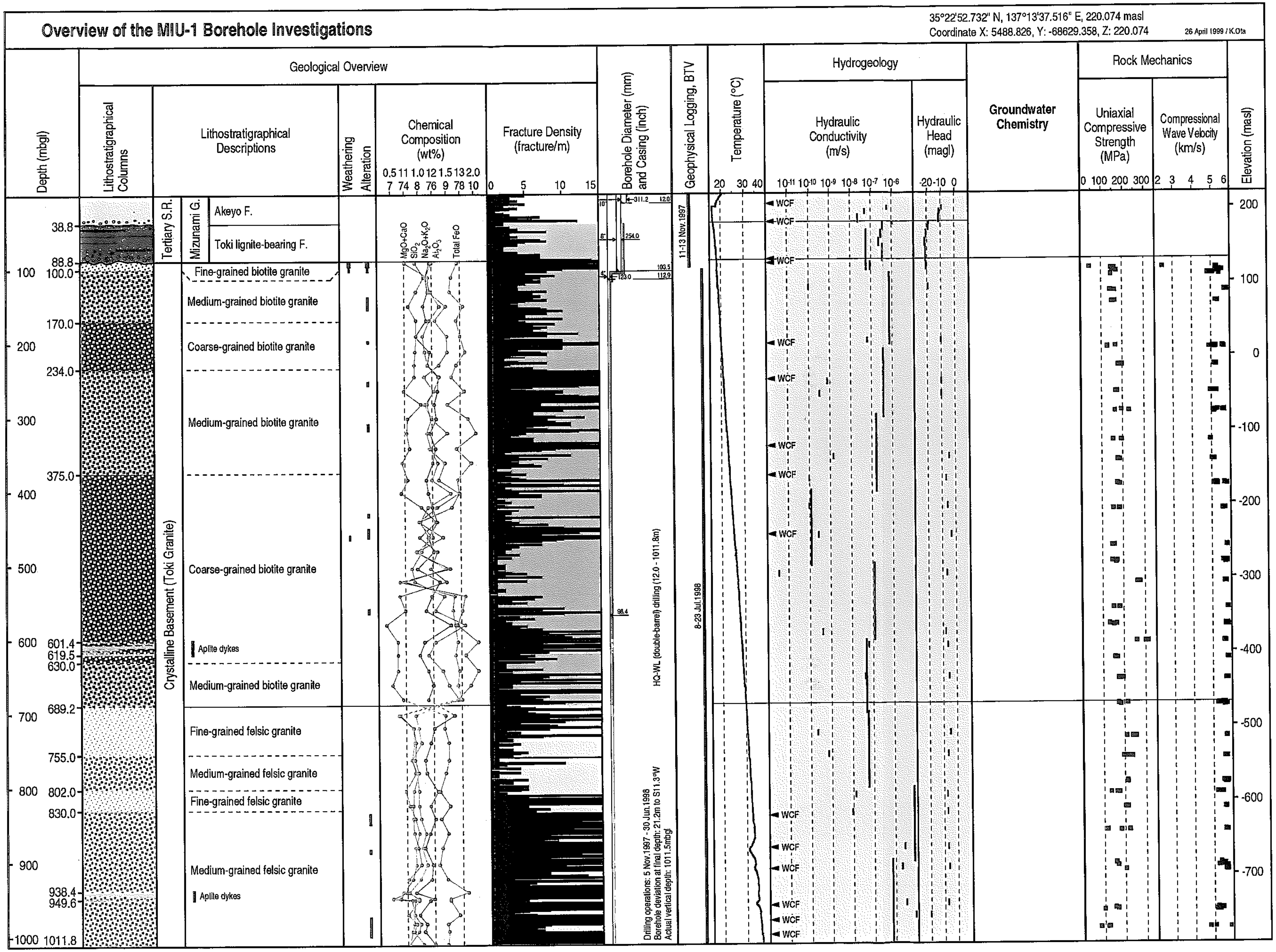
Constituents	Budget (kYen)	Status (in financial year)
Blanket Contract	359,900	
Borehole drilling	166,000	Defined (1999)
On-site core description, photographing	5,300	Defined (1999)
Geophysical logging, BTV	39,200	Defined (1999)
Hydraulic packer tests, groundwater sampling	66,000	Defined (1999)
Monitoring of drilling fluid	55,400	Defined (1999)
Drill core testing (petrological, rock mechanical, *etc*)	28,000	Defined (1999)
Individual Contract	118,660	
Laboratory chemical analysis of rock / water samples	22,200	Defined (1999)
In situ / laboratory stress measurements	11,550	Requested (2000), not yet defined
Long-term monitoring	84,890	Requested (2000), not yet defined
Total budget	478,560	

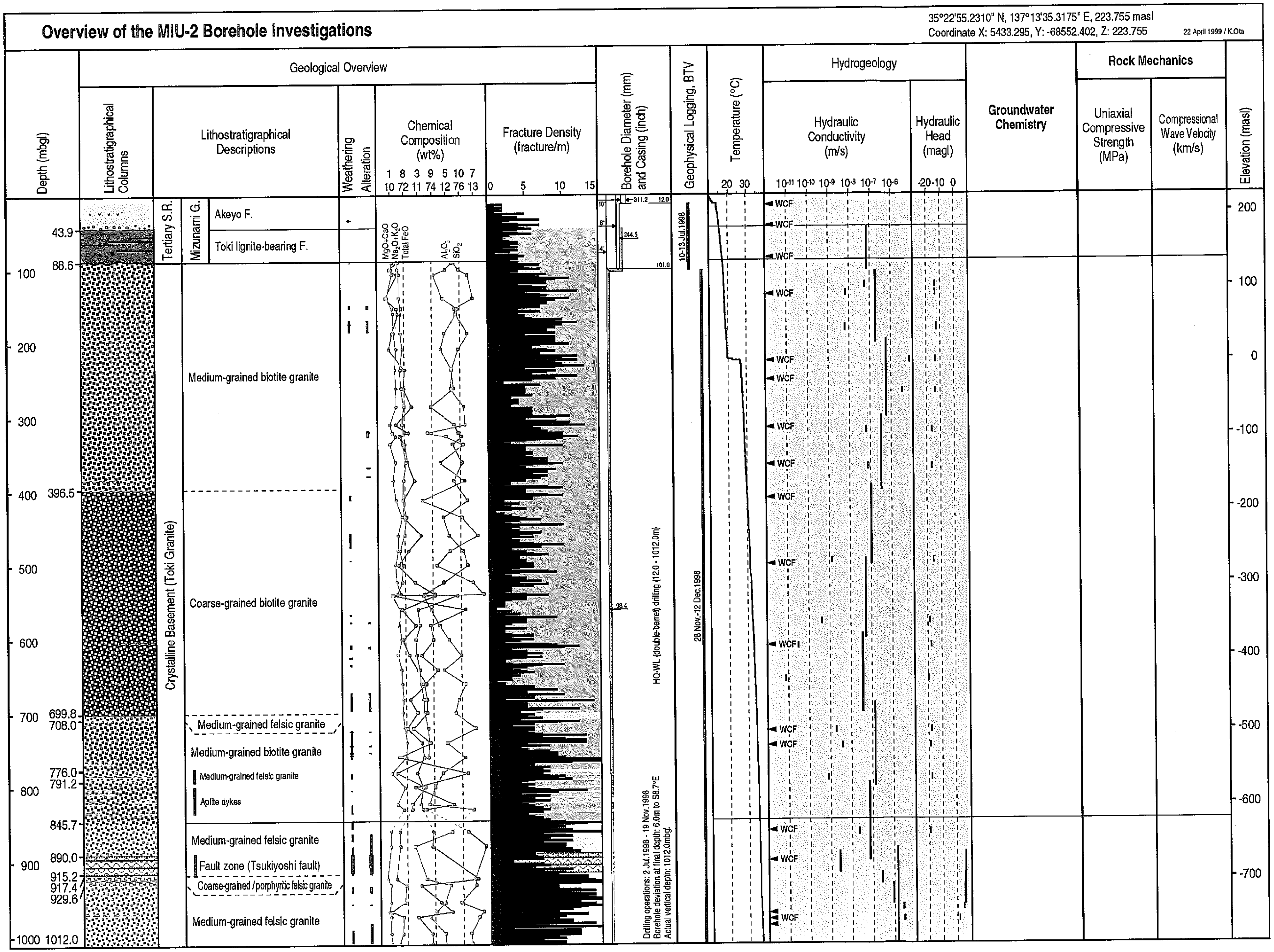
ACKNOWLEDGEMENT

We gratefully acknowledge Drs Stratis Vomvoris and Bernhard Frieg of Nagra (National Cooperative for the Disposal of Radioactive Waste), Switzerland and Dr H Niklaus Waber of GGWW (Rock-Water Interaction Group), University of Berne, Switzerland for reviewing and discussing during drawing up this working programme.

REFERENCE

Power Reactor and Nuclear Fuel Development Corporation (PNC), 1996: Master plan of Mizunami underground research laboratory. *PNC Technical Report*, **PNC TN7070 96-002**, PNC Tono Geoscience Centre, Toki, Japan. *(in Japanese; also available in English, JNC TN7410 99-008)*


Overview of the MIU-1 Borehole Investigations
35°22'52.732" N, 137°13'37.516" E, 220.074 masl
Coordinate X: 5488.826, Y: -68629.358, Z: 220.074
26 April 1999 / K.Ota
Depth (mbgl)
Geological Overview
Lithostratigraphical Columns
Lithostratigraphical Descriptions
Weathering
Alteration
Chemical Composition (wt%)
MgO+CaO
SiO2
Na2O+K2O
Al2O3
Total FeO
Fracture Density (fracture/m)
Borehole Diameter (mm) and Casing (inch)
Geophysical Logging, BTV
Temperature (°C)
Hydrogeology
Hydraulic Conductivity (m/s)
Hydraulic Head (magl)
Groundwater Chemistry
Rock Mechanics
Uniaxial Compressive Strength (MPa)
Compressional Wave Velocity (km/s)
Elevation (masl)
38.8
88.8
100.0
170.0
234.0
375.0
601.4
619.5
630.0
689.2
755.0
802.0
830.0
938.4
949.6
1011.8
Tertiary S.R.
Mizunami G.
Akeyo F.
Toki lignite-bearing F.
Crystalline Basement (Toki Granite)
Fine-grained biotite granite
Medium-grained biotite granite
Coarse-grained biotite granite
Medium-grained biotite granite
Coarse-grained biotite granite
Aplite dykes
Medium-grained biotite granite
Fine-grained felsic granite
Medium-grained felsic granite
Fine-grained felsic granite
Medium-grained felsic granite
Aplite dykes
11-13 Nov.1997
8-23 Jul.1998
HQ-WL (double-barrel) drilling (12.0 - 1011.8m)
Drilling operations: 5 Nov.1997 - 30 Jun.1998
Borehole deviation at final depth: 21.2m to S11.3°W
Actual vertical depth: 1011.5mbgl
WCF


Overview of the MIU-2 Borehole Investigations
35°22'55.2310" N, 137°13'35.3175" E, 223.755 masl
Coordinate X: 5433.295, Y: -68552.402, Z: 223.755
22 April 1999 / K.Ota
Depth (mbgl)
Geological Overview
Lithostratigraphical Columns
Lithostratigraphical Descriptions
Weathering
Alteration
Chemical Composition (wt%)
Fracture Density (fracture/m)
Borehole Diameter (mm) and Casing (inch)
Geophysical Logging, BTV
Temperature (°C)
Hydrogeology
Hydraulic Conductivity (m/s)
Hydraulic Head (magl)
Groundwater Chemistry
Rock Mechanics
Uniaxial Compressive Strength (MPa)
Compressional Wave Velocity (km/s)
Elevation (masl)
Tertiary S.R.
Mizunami G.
Akeyo F.
Toki lignite-bearing F.
Crystalline Basement (Toki Granite)
Medium-grained biotite granite
Coarse-grained biotite granite
Medium-grained felsic granite
Medium-grained biotite granite
Medium-grained felsic granite
Aplite dykes
Medium-grained felsic granite
Fault zone (Tsukiyoshi fault)
Coarse-grained / porphyritic felsic granite
Medium-grained felsic granite
43.9
88.6
396.5
699.8
708.0
776.0
791.2
845.7
890.0
915.2
917.4
929.6
1012.0
MgO-CaO
Na2O+K2O
Total FeO
Al2O3
SiO2
10-13 Jul.1998
28 Nov.-12 Dec.1998
HQ-WL (double-barrel) drilling (12.0 - 1012.0m)
Drilling operations: 2 Jul.1998 - 19 Nov.1998
Borehole deviation at final depth: 6.0m to S8.7°E
Actual vertical depth: 1012.0mbgl
WCF

Water-Conducting Features Identified in the MIU-1/MIU-2 Boreholes

Borehole	Lithostratigraphy		Depth (mbgl)	Drilling: Loss of Fluid (%)	Fluid Logging: Temperature	Fluid Logging: Flowmeter	Geophysical Logging: Neutron	Geophysical Logging: Density	Geophysical Logging: Calliper	Geophysical Logging: Resistivity	Geophysical Logging: Micro Resistivity	Geophysical Logging: Natural Gamma	Hydraulic Testing: K (m/s)
MIU-1 Borehole	Akeyo Formation		11.4-16			+*						+	nd
MIU-1 Borehole	Akeyo Formation		38			+					+		2.2×10^{-8}
MIU-1 Borehole	Toki Lignite-bg. F.		89			+			+	+	+	+	3.3×10^{-7}
MIU-1 Borehole	Toki Granite	Biotite Granite	93.5			+				+	+		1.8×10^{-7}
MIU-1 Borehole	Toki Granite	Biotite Granite	201	80			+	+	+	+	+	+	6.2×10^{-8}
MIU-1 Borehole	Toki Granite	Biotite Granite	250				+	+	+	+			nd
MIU-1 Borehole	Toki Granite	Biotite Granite	340				+	+	+	+	+		nd
MIU-1 Borehole	Toki Granite	Biotite Granite	380				+	+	+				nd
MIU-1 Borehole	Toki Granite	Biotite Granite	460				+	+	+	+	+		2.5×10^{-10}
MIU-1 Borehole	Toki Granite	Felsic Granite	840				+	+	+	+	+		8.7×10^{-9}
MIU-1 Borehole	Toki Granite	Felsic Granite	882		+	+	+	+	+	+	+		2.6×10^{-6}
MIU-1 Borehole	Toki Granite	Felsic Granite	910		+	+	+	+		+	+		1.9×10^{-6}
MIU-1 Borehole	Toki Granite	Felsic Granite	960		+	+	+	+		+	+		2.9×10^{-6}
MIU-1 Borehole	Toki Granite	Felsic Granite	980	100			+	+		+			7.6×10^{-6}
MIU-1 Borehole	Toki Granite	Felsic Granite	1000				+	+	+	+	+		nd
MIU-2 Borehole	Akeyo Formation		14		+					+			nd
MIU-2 Borehole	Akeyo Formation		42		+					+			nd
MIU-2 Borehole	Toki Lignite-bg. F.		85		+			+			+		nd
MIU-2 Borehole	Toki Granite	Biotite Granite	135				+	+	+	+		+	6.5×10^{-9}
MIU-2 Borehole	Toki Granite	Biotite Granite	223	100	+	+	+	+	+	+	+	+	6.7×10^{-6}
MIU-2 Borehole	Toki Granite	Biotite Granite	250			+	+	+	+	+			nd
MIU-2 Borehole	Toki Granite	Biotite Granite	315				+	+	+	+	+	+	6.0×10^{-8}
MIU-2 Borehole	Toki Granite	Biotite Granite	365				+	+	+	+	+	+	7.2×10^{-8}
MIU-2 Borehole	Toki Granite	Biotite Granite	410				+	+	+		+	+	nd
MIU-2 Borehole	Toki Granite	Biotite Granite	500				+	+	+		+	+	nd
MIU-2 Borehole	Toki Granite	Biotite Granite	610				+	+	+	+		+	3.0×10^{-11}
MIU-2 Borehole	Toki Granite	Biotite Granite	725				+	+	+			+	1.8×10^{-9}
MIU-2 Borehole	Toki Granite	Biotite Granite	745				+	+	+			+	3.6×10^{-9}
MIU-2 Borehole	Toki Granite	Felsic Granite	860				+	+	+			+	2.1×10^{-8}
MIU-2 Borehole	Tsukiyoshi Fault		900				+	+	+	+		+	2.4×10^{-9}
MIU-2 Borehole	Toki Gr.	Felsic Granite	970		+		+	+		+	+		2.5×10^{-6}
MIU-2 Borehole	Toki Gr.	Felsic Granite	980		+		+	+					2.5×10^{-6}
MIU-2 Borehole	Toki Gr.	Felsic Granite	987		+		+	+	+	+			2.7×10^{-6}

*+: Indication of water-conducting feature

On-site Core Description Manual

Version: December 1998

Geoscience Research Execution Group
Tono Geoscience Centre

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1 Scale
2 Altitude
3 Depth
4 Lithofacies
5 Rock Name
6 Mineralogy
7 Colour
8 Hardness
9 Shape
10 RQD and Core Recovery
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12 Rock Mass Classification
13 Weathering
14 Alteration
15 Location of Fracture
16 Shape of Fracture
17 Type of Fracture
18 Fracture Filling Materials
19 Remarks

1 Scale

Mark a scale in metres (*ie* at every 5cm of column on the sheet).

2 Altitude

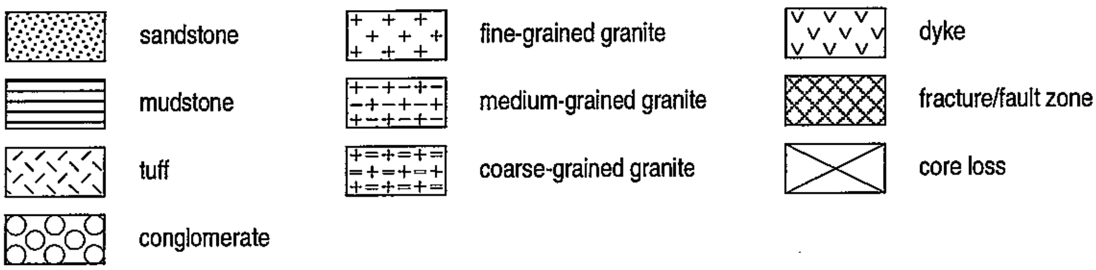
Fill in the altitude of the well head.

3 Depth

Fill in the depth along the borehole axis.

4 Lithofacies

Use the following patterns for lithostratigraphical columns:



5 Rock Name

Assign rocks (or unconsolidated materials) recovered to one of the following units: the Seto Group, the Mizunami Group, the Toki granite, the Mesozoic sedimentary rocks of the Mino Belt 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.

6 Mineralogy

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

7 Colour

Describe the colour of wet core under the sunlight using the following colours:

white, grey, black, purple, blue, green, yellow, brown, orange and *red.*

A combination of two colours mentioned above is available. The principal colour is followed by accessory colour. *Dark* can be used for blackish colour and *pale* for very weak accessory colour.

8 Hardness

Classify cores in hardness according to the following definitions:

Class	Definition
A	Very hard, hardly broken using a rock hammer.
B	Hard, clean sound when hit.
C	Medium, easily broken using a rock hammer.
D	Soft, easily broken into pieces using a rock hammer.
E	Very soft, clayey.

9 Shape

Classify cores in shapes according to the following definitions:

Class	Definition
I	Length over 50cm, columnar.
II	Length between 50 and 15cm, columnar.
III	Length between 15 and 5cm, columnar or blocky.
IV	Length below 5cm, columnar or blocky, core surface recognisable.
V	Mainly rubbly.
VI	Mainly sandy.
VII	Mainly clayey.
VIII	No core formed, including slime.

10 RQD (Rock Quality Designation) and Core Recovery

- RQD 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 centre of the core.

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

11 Fracture Density

Fill in the number of fractures per 1m core.

12 Rock Mass Classification

Classify rocks in the degree of weathering and alteration according to the following definitions:

Class	Definition
A	Very fresh. Not weathered/altered. Little open fracture. Clear sound when hit with a hammer.
B	Slightly weathered/altered. Little open fracture. Clear sound when hit with a hammer.
CH	Weathered/altered except quartz. Relatively hard. Dull sound when hit with a hammer and fractured by hitting hardly. Partially stained/discoloured by limonite. Clay minerals on a fracture plane.
CM	Moderately weathered/altered. Strength decreased. Dull sound by hitting with a hammer and fractured when hit hardly. Clay minerals on a fracture plane.
CL	Highly weathered/altered. Relatively soft. Dull sound and fractured when hit with a hammer. Clay minerals on a fracture plane.
D	Extremely weathered/altered. Soft. Very dull sound when hit with a hammer and easily fractured. Clay minerals on a fracture plane.

13 Weathering

Define the degree of weathering according to the following definitions:

Class	Definition
α	Very fresh.
β	Fresh. Colour changed partially. Easily broken.
γ	Weathered along schistosity or on bedding plane.
δ	Weathered entirely.
ε	Highly weathered to yellow-brown colour by limonite staining/bleaching. Easily crumbled.

14 Alteration

Define the degree of alteration according to the following definitions:

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

15 Location of Fracture

Fill in the upper and lower depths of fracture on both sides of the column. Measure apparent dip to the core axis.

16 Shape of Fracture

Classify fractures in shapes according to the following definitions:

Group	Definition
a	Tectonic fault/fracture.
b	Minor fault/fracture.
c	Derived from *in situ* stress release.
d	Derived from alteration.
e	Derived from drilling.
f	Unknown.

17 Type of Fracture

Classify fractures according to the following definitions:

Type	Definition
P (planer)	Planar shaped. Striation on a slickensided surface.
I (irregular)	Irregular shaped. Easily restored in original state. No striation on a rough fracture plane.
C (curved)	Curved shaped.
S (stepped)	Stepped shaped.

18 Fracture Filling Materials

Use the following letter symbols for the description of fracture filling materials:

qtz: quartz
chl: chlorite
ep: epidote
carb: carbonates
cl: clay minerals (including colour description)

lim: limonite
hem: haematite
py: pyrite
Fe: Fe-oxides

19 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.