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Working Programme for MIZ-1 Borehole Investigations

Revision of work procedures after Phase Ⅳ

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1 INTRODUCTION

1.1 Background to MIZ-1 Borehole Investigations

The Mizunami Underground Research Laboratory (MIU) Project proceeds in three overlapping phases, Surface-based Investigation (Phase I), Construction (Phase II) and Operation (Phase III), over a period of 20 years [1]. A wide range of geoscientific research and development activities is planned to be performed in each phase. Surface-based investigations have now been carried out at the MIU Construction Site (MIU Site) since January 2002. The main aims of these investigations are the development of conceptual models of the geological environment and the enhancement of the understanding of the undisturbed deep geological environment before excavation of the shafts and research galleries. The approach adopted for the investigations has involved the iteration of the following steps [2]:

- development of an investigation concept
- planning of investigations
- performance of the planned investigations
- interpretation of investigation results
- modelling and simulations of investigation results
- assessment of the outcomes of modelling and simulations
- evaluation of uncertainties within the consequences
- specification of the main items for further investigations

Through these steps, it is intended that the key aspects defined for characterising the deep subsurface should be addressed adequately. Consequently the relationship between the adequacy of investigation technology, the advancement of geological understanding and the degree of uncertainty could be established.

Field investigations began with fault mapping at and around the MIU Site, following a literature survey (Figure 1.1). Work continued with geophysical investigations consisting of 9.0 km of reflection seismic survey [3, 4], vertical seismic profile survey [5] and geological and hydrogeological investigations in the existing borehole (DH-2) [5, 6]. In addition, four shallow boreholes (MSB-1, MSB-2, MSB-3 and MSB-4), with depths ranging from 99 to 201 mabh (metre along borehole), were newly drilled at the MIU Site and extensive borehole investigations were performed [4, 7]. The outcome of the investigations, modelling and simulations in each step was evaluated in the subsequent step with new information, and the investigation techniques were improved in a step-wise manner. These investigations have to date provided a wealth of information on the characteristics of the geological environment at and around the MIU Site. Specifically, geological understanding has progressively advanced for geological structures and hydraulic properties of the sedimentary formations, chemistry of shallow groundwaters and the geological and hydrogeological properties of water-conducting features (WCFs) in the upper part of the Toki granite. In addition, a couple of main items (or, in general, key issues) that need to be further characterised have been newly identified.

The MIZ-1 borehole investigation programme is thus dedicated to addressing the key issues in order to achieve the main aims of the surface-based investigations at the MIU Site.

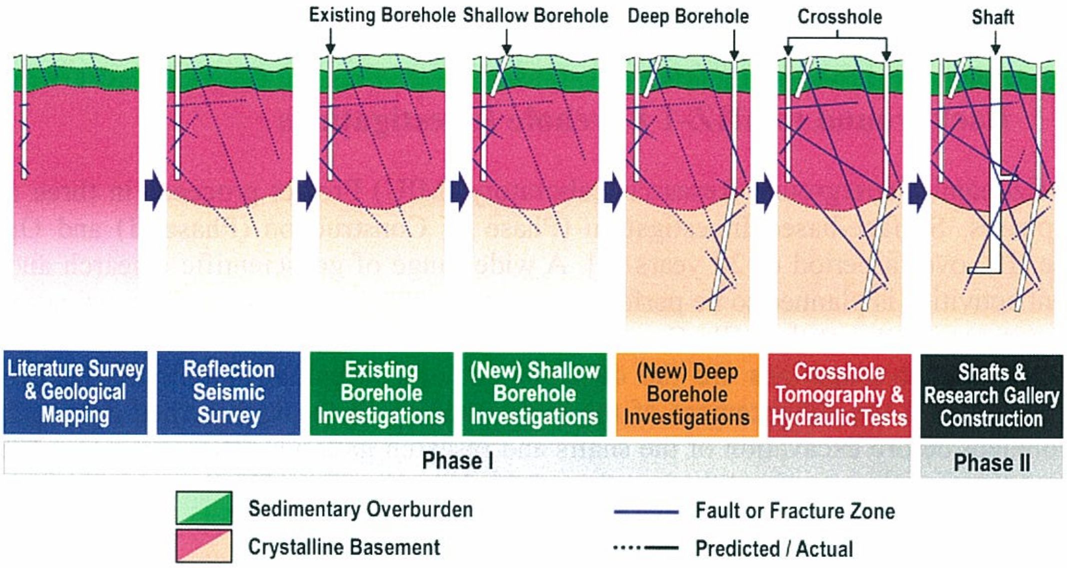

Figure 1.1: Illustration of the MIU surface-based investigation concept; Literature survey to reflection seismic survey as Step 1; Existing borehole investigations to shallow borehole investigations as Step 2; Deep borehole investigations as Step 3; Cross-hole tomography and hydraulic tests as Step 4

1.2 MIZ-1 Borehole Investigation Programme

The MIZ-1 borehole investigation programme has been running, as a subsequent step of the field investigations at the MIU Site, since December 2002 in accordance with the "Working Program for MIZ-1 Borehole Investigations" [8]. The programme was optimised on the basis of the status of the surface-based investigations as well as the time constraints for the investigations. The overall goals of the MIZ-1 borehole investigations are:

- the characterisation of the geological environment from the surface to over 1,000 m depth in the crystalline basement,
- the establishment of baseline conditions before excavation of the shafts and research galleries,
- the provision of a deep borehole for observing hydraulic responses during excavation of the shafts and research galleries and experiments in the research galleries during the Construction and the Operation Phases.

The MIZ-1 borehole investigations should, in particular, involve the following key issues:

- the identification and classification of potential WCFs and detailed geological and hydrogeological characterisation of WCFs and background fractured rocks (BFRs) from the surface to over 1,000 m depth in the crystalline basement,
- the hydrochemical characterisation of groundwater from the surface to over 1,000 m depth in the crystalline basement,
- the acquisition of rock mechanical data from the crystalline basement for supplementing the existing geotechnical dataset,

- the establishment of the basis for designing of the long-term hydraulic monitoring system in order to observe the hydraulic head distributions before excavation of the shafts and research galleries,
- the observation of hydraulic responses in peripheral boreholes during the MIZ-1 borehole investigations in order to assess hydraulic significance of WCFs and potential performance of cross-hole hydraulic tests,
- input to the development and assessment of techniques for predicting and modelling the geology, hydrogeology, hydrochemistry and geomechanical properties of the deep geological environment,
- the assessment of the applicability and effectiveness of a wide range of investigation techniques in addressing the key aspects of site characterisation.

The MIZ-1 borehole is located in the north-eastern area of the MIU Site (Figure 1.2). The inclination or plunge of the borehole would vary with depth, based on the directional control plan as shown in Figure 1.3. The borehole was planned to be drilled vertically from the surface down to 250 mabh (metre along borehole). From 250 to 460 mabh, it was intended to apply controlled directional drilling, which would result in the borehole deviating in a south-westerly direction (S46°W) with inclination increasing from 0°, in increments of 0.67° every 12 mabh (and 0.61° in the 454–460 mabh section), to 12° from vertical. From 460 mabh to the final depth at 1,350 mabh, the drilling could proceed in a south-westerly direction with inclination of 12° from vertical. The MIZ-1 borehole would eventually have had a vertical depth of 1,328.96 mbgl (metre below ground level) and an offset from the borehole collar of 207.68 m at the bottom.

The MIZ-1 borehole drilling commenced on 12th March 2003. In MIZ-1 Phases I to III, the borehole was drilled from the surface down to 250.00 mabh and a series of field investigations was performed according to the working programme [8]. In MIZ-1 Phase IV, however, controlled directional drilling downwards from 250.00 mabh was not successful and the borehole considerably deviated (in a south-south-easterly direction) from the planned trace (Figures 1.2 and 1.3). It was therefore decided to terminate the drilling at 502.84 mabh, taking into account the boundary conditions and technical difficulties in the controlled directional drilling, and most of the planned investigations and some additional field-work were carried out down to that depth. Throughout the MIZ-1 Phase I–IV investigations, quality-controlled data on geology, hydrogeology, hydrochemistry and rock mechanics had been acquired, thereby advancing the understanding of the geological environment at the MIU Site. In addition, information on the investigation techniques relevant to site characterisation had also been obtained. The MIZ-1 Phase I–IV investigations, however, spanned about 11 months, consequently bringing an unrecoverable delay of more than 6 months.

Taking into account the status of the MIZ-1 borehole investigations at the end of Phase IV (mid February 2004), the additional field-work preformed and the remainder of the planned investigations as well as the time available for them, the layout of the MIZ-1 borehole and the methodologies and timetable for the investigations in the following phases were revised and optimised. This changed neither the overall concept nor the significance of the MIZ-1 borehole investigations but was considered to be crucial for addressing all the key issues mentioned above and eventually achieving the goals of the MIZ-1 borehole investigations.

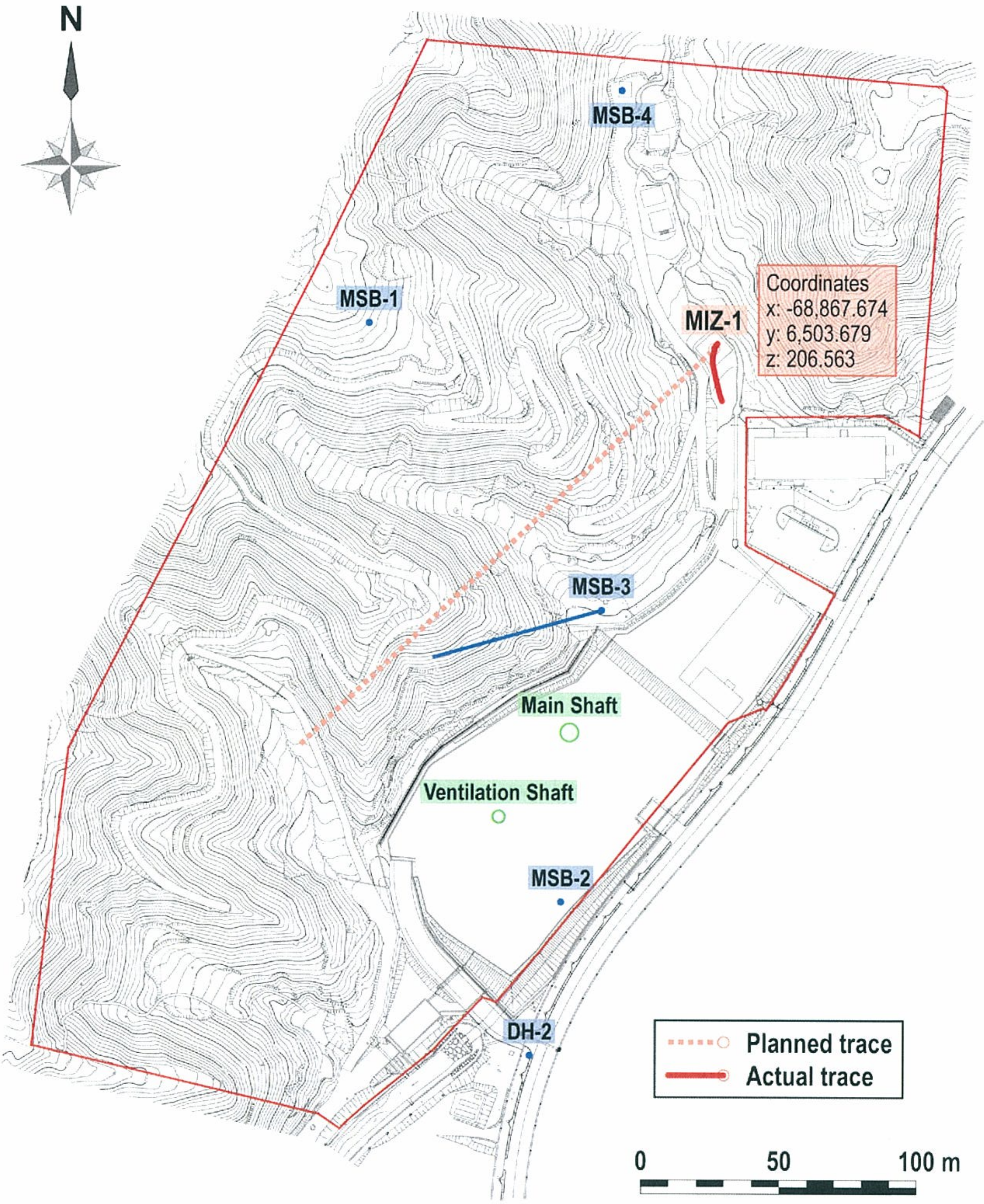

Figure 1.2: Location and projected trace of the MIZ-1 borehole at the MIU Site; Actual borehole trace down to 502.84 mabh

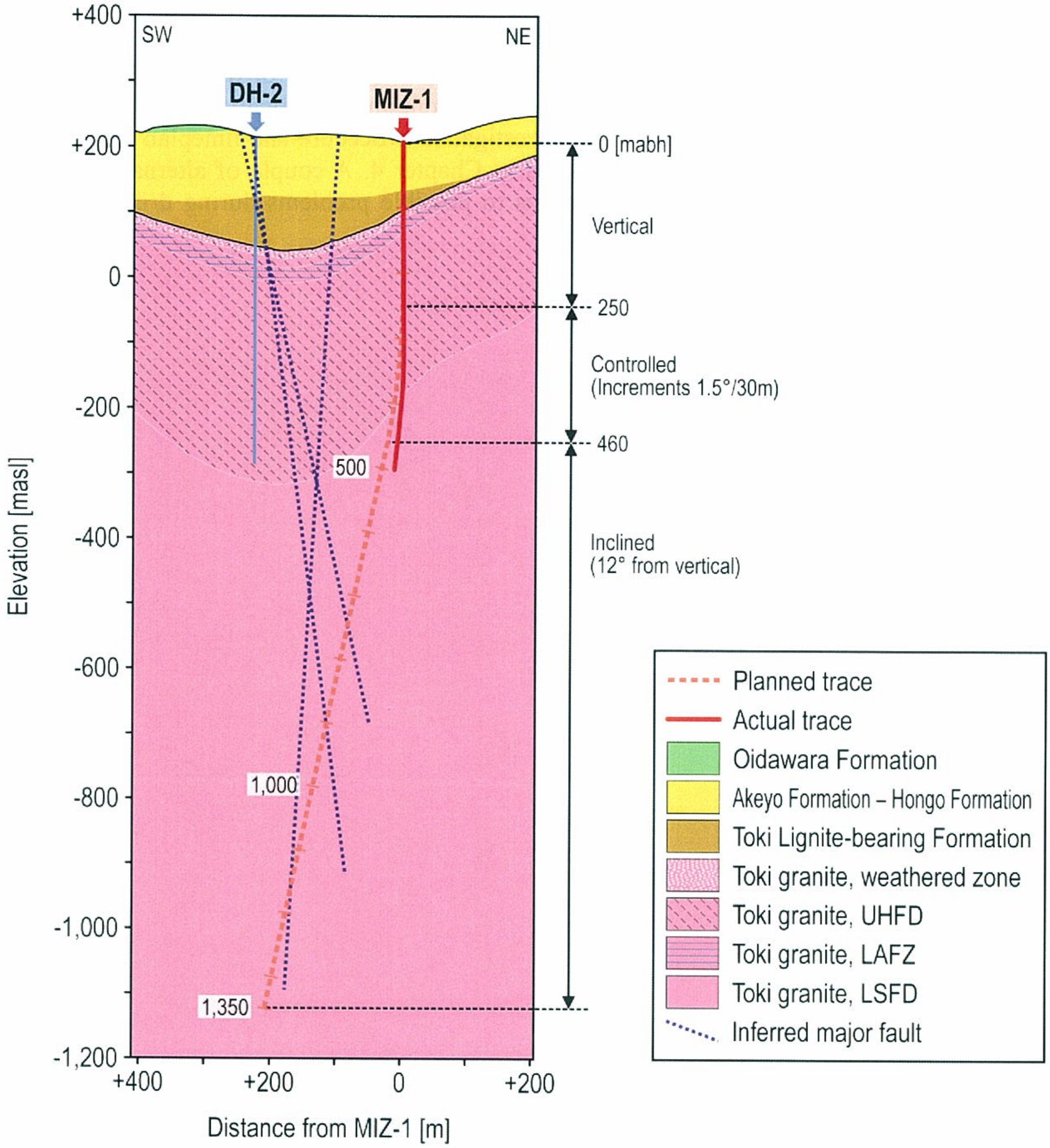

Figure 1.3: Planned trace of the MIZ-1 borehole in a S46°W direction and the predicted geological profiles; Actual borehole trace down to 502.84 mabh

This document describes the rationale behind the optimisation of the MIZ-1 borehole investigation programme and the revised working programme for continuing the borehole investigations after MIZ-1 Phase IV. Following a summary of the progress of the MIZ-1 Phase I–IV investigations (Chapter 2), the optimised borehole layout and investigation methodologies are detailed in Chapter 3. Finally, the revised investigation procedure and timeplan for the "base case" investigation programme are described in Chapter 4. A couple of alternative (*ie* "optional case") programmes providing solutions to possible problems during drilling are also discussed.

2 PROGRESS OF MIZ-1 BOREHOLE INVESTIGATIONS

2.1 Overview of MIZ-1 Phase I–IV Investigations

Drilling of the MIZ-1 borehole, with the introduction of the new method of wireline core drilling with a downhole motor (152 SDS drilling system; see [9] for further details), commenced on 12th March 2003 following the site preparation. The borehole was drilled vertically from the surface through the entire sedimentary section (*ie* the Mizunami Group) down to 123.00 mabh in the uppermost part of the Toki granite, in MIZ-1 Phases I and II from March to May 2003 [9], and further down to 250.00 mabh in the upper highly fractured domain (UHFD) of the Toki granite, in MIZ-1 Phase III from May to July 2003 [10]. In these phases, a series of geological, geophysical, hydrogeological and hydrochemical investigations were performed basically according to the work procedures defined previously [8], as seen in Figure 2.1, with complementary long-term monitoring.

In MIZ-1 Phase IV from July 2003 to February 2004, controlled directional drilling with the 152 SDS drilling system was attempted in a south-westerly direction (S46°W) downwards from 250.00 mabh. A variety of efforts had continuously been made to maintain the directional control (*eg* application of a conventional drilling method with a down-hole motor or a retrievable wedge, use of stiff drilling rods, CHD134, instead of NL140 *etc*) but the fact remained that, owing to the system and work management inadequacies, the drilling direction incrementally deviated with depth from the planned trace (Figure 1.2). Eventually the borehole headed in a south-south-easterly direction (S21°42'E; sub-parallel to the trends of the targeted major faults, N15–25°W) at a depth of 502.70 mabh in the lower sparsely fractured domain (LSFD) of the Toki granite, although the planned inclination (12° from vertical) was attained. This indicates a considerable borehole deviation of approximately 70° from the planned trace. Although a couple of possible measures to adjust the drilling direction were discussed, it was decided to terminate the drilling at 502.84 mabh[1)], backfill the borehole up to the most appropriate depth with cement and retry the control directional drilling from that depth. The rationale behind this decision is that:

- the continuation of the controlled directional drilling to adjust the drilling direction with the 152 SDS drilling system would be associated with a large degree of uncertainty as the technical reasons for this incident has not been convincingly explained; even if the adjustment was possible, this would inevitably need long duration,
- the continuation of the controlled directional drilling in the current direction, even though the drilling direction was slightly adjusted, would evidently enhance the degree of risk that the borehole would cross the boundary of the MIU Site and further obstruct the construction of the MIU research galleries,
- more than 6 month's delay produced significant time constraints for the remainder of the planned field investigations, which would minimise chance that the borehole would intersect by the targeted major faults (in particular, IMF03 fault, predicted to occur between 1,145 and 1,170 mabh) and that all the investigations could be performed.

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1) The MIZ-1 Phase IV drilling was planned to halt at a depth of 756 mabh intersecting the bottom of a major fault [8].

Thus a series of the planned geological, geophysical, hydrogeological, hydrochemical and rock mechanical investigations was carried out, as shown in Figure 2.2, down to 502.84 mabh according to the work procedures [8] and the complementary long-term monitoring was continued. In addition, in order to check the borehole direction and condition and to eliminate iron compounds precipitated on the borehole wall, borehole deviation survey, calliper logging and borehole wall cleaning were made.

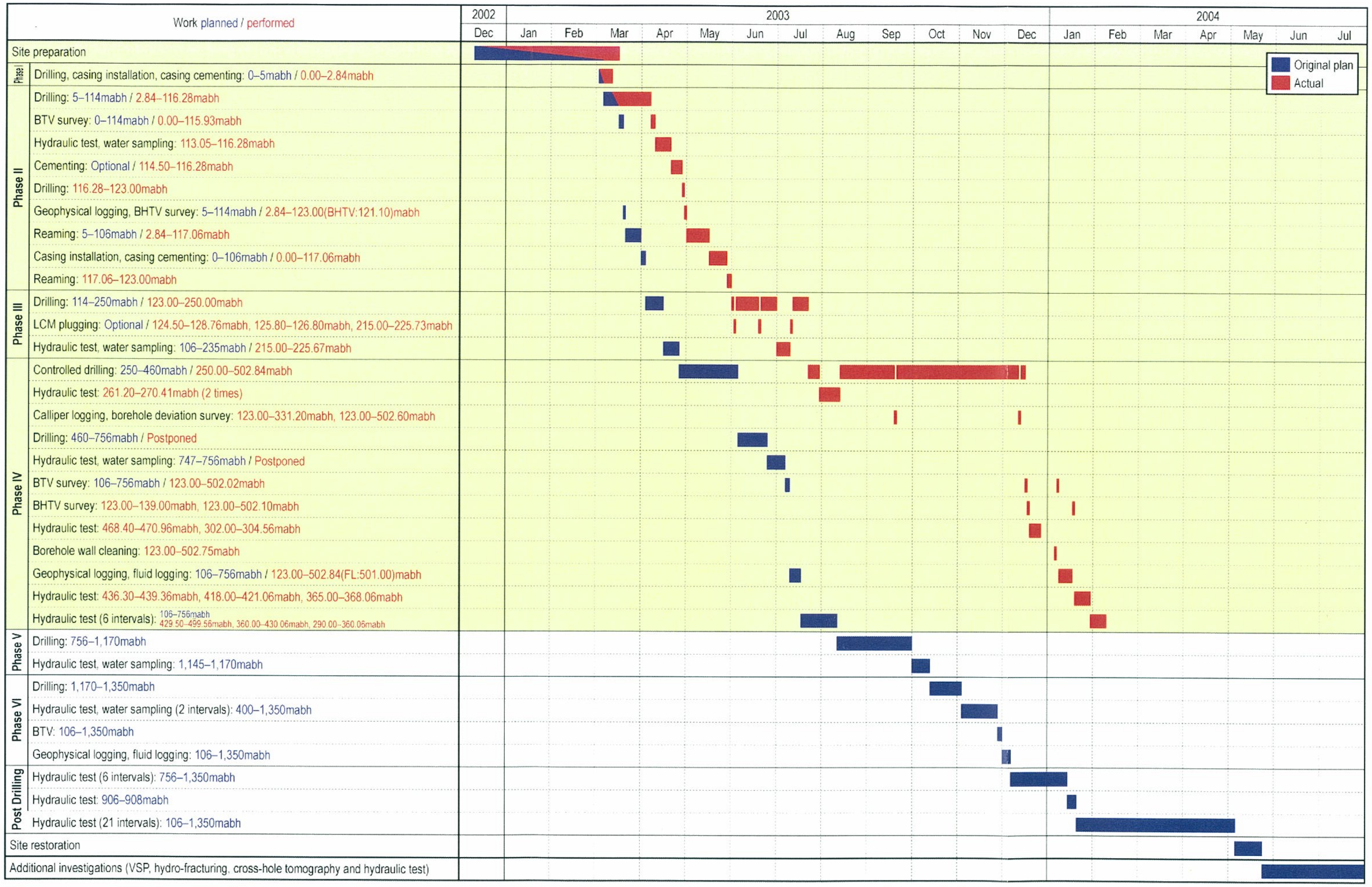


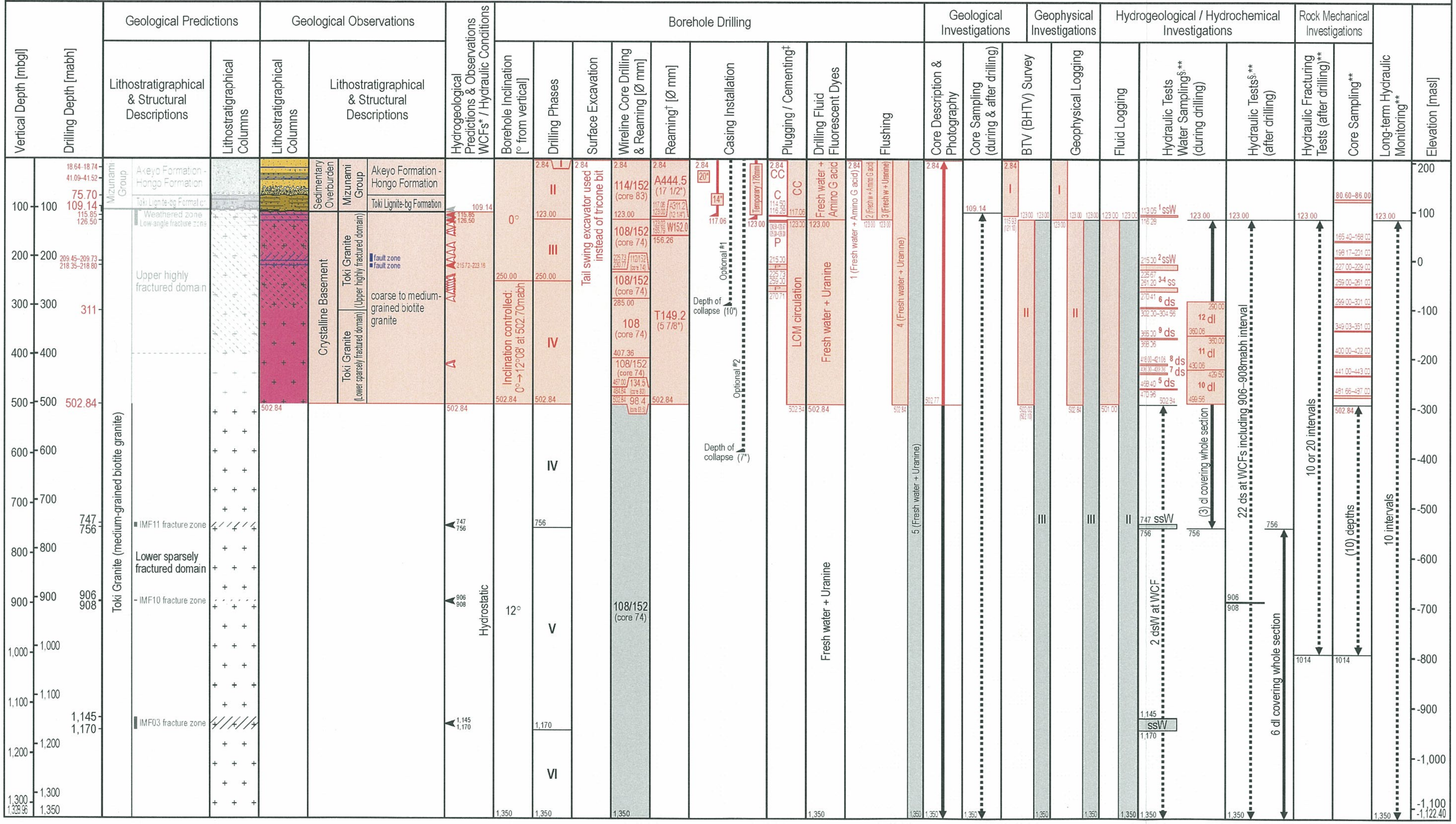
Figure 2.1: Timetable of the planned and performed MIZ-1 borehole investigations

Figure 2.2: Overview of the MIZ-1 borehole investigations during Phases I to IV ➡

Overview of the MIZ-1 Borehole Investigations (Phases I – IV, down to 502.84mabh)

Coordinates x: -68.867.674, y: 6,503.6791, z: 206.563
Borehole Inclination & Direction: 0°→12°08' to S8°35'E

Original: 28 May 2004 / K Ota
Finalisation: 7 July 2004 / K Ota



* WCFs: (WCF, depth defined), (inflow point, depth not yet defined precisely)
† Reaming: A (air hammer bit), W (water hammer bit), T (tricone bit)
‡ Plugging / Cementing: C (cementing), CC (casing cementing), P (plugging with LCM)

§ Hydraulic Tests & Water Sampling: ss (single packer, short straddle), ds (double packers, short straddle), dl (double packers, long straddle), W (water sampling)
** The number representing the number of tests or depths originally planned; the number in parentheses representing the number of tests or depths remaining.

abc Work performed
abc Work planned

2.2 Results of MIZ-1 Phase I–IV Investigations

Throughout the investigation programme, as shown in Figure 2.2, with a series of the planned and some optional investigations from the surface down to some 500 m depth in the Toki granite at the MIU Site, relevant information on the characteristics of the geological environment was obtained (Figure 2.3) and, from technical and QC viewpoints, both successes and set-backs were encountered. This could consequently allow not only the understanding of the geological environment to be advanced, but also a variety of lessons on the investigation techniques to be learnt. Here, the results of the investigations are briefly overviewed and the current status of knowledge gained from these is presented.

Borehole Drilling

- Controlled directional drilling was attempted from 250.00 to 502.84 mabh by a newly introduced drilling method using the 152 SDS drilling system and a conventional drilling method with a down-hole motor or a retrievable wedge, but was not successful. Although the drilling was able to attain the borehole inclination of 12° from vertical at a depth of about 455 mabh (and finally, 12°08' from vertical at 502.70 mabh), the borehole considerably deviated in direction (S21°42'E or azimuth 291°42' at 502.70 mabh) from the planned trace (S46°W or azimuth 224°) as shown in Figure 1.1.
- The average rate of core recovery was 98.7 % throughout the drilled section from 2.84 to 502.84 mabh. Specifically, the core recovery rates were about 95.1 % and 99.6 % in the entire sedimentary section and in the Toki granite respectively. Poor core recovery (<90 %) partly occurred in the Toki granite; this was not due to drilling through a fault (zone) of friable nature, rather occasionally cores remained in the bottom of the borehole and were subsequently crushed and ground down when the drilling resumed.
- The wireline core drilling from 123.00 to 502.84 mabh provided an average borehole diameter of 149.8 mm (doubled standard deviation of 3.2 mm), which enabled the installation of downhole equipment for the planned geological, geophysical and hydrogeological investigations. The occurrence of a continuous fluid loss below 270 mabh, however, hampered groundwater sampling.
- Although the optimum drilling parameters and appropriate coring and reaming bits were defined in advance, technical difficulties in performing the requisite drilling by the 152 SDS drilling system were demonstrated. This was due to the structural/mechanical inadequacies of the system and partly the insufficient management on the drilling work.

Geological Investigations

- On-site description and photography of the recovered cores were synchronised with each drilling run. As a sedimentary overburden, the Mizunami Group occurs above 109.14 mabh, which is stratigraphically divided into the Toki Lignite-bearing Formation, the Hongo Formation and the Akeyo Formation, in ascending order [9]. The Toki Lignite-bearing Formation unconformably overlies the Toki granite without a basal conglomerate layer. The profile of core recovered from the Toki granite (from 109.14 to 502.84 mabh) comprises a coarse- to medium-grained biotite granite with little textural heterogeneity. A weathered section is not distinct in the uppermost part of the Toki granite (Figure 2.3).

- The Toki granite is structurally subdivided into an upper highly fractured domain and a lower sparsely fractured domain at a depth of 311 mabh based on the fracture frequency data derived from the borehole TV (BTV) image analysis, as shown in Figure 2.3. A total of 421 fractures were identified in the 109.14–502.84 mabh section: low-angle fractures, striking roughly E-W and dipping up to 30° southward, are prominent in UHFD, whereas E-W- and NNW-SSE-trending steeply dipping fracture sets are distinguishable in LSFD.
- Two fault zones were identified at 195.27–211.98 mabh (fault core at 209.45–209.73 mabh) and 215.71–223.16 mabh (fault core at 218.35–218.80 mabh) in the Toki granite (Figure 2.3). The fault cores of both fault zones trend NNW-SSE and dip approximately 70°E.
- There is a good agreement in the depths of lithostratigraphical boundaries (*eg* unconformities) between the geological predictions and the actual geological intersection, taking account of the estimated uncertainties of the predictions, which ensures that the geological structure was modelled appropriately. However, the difficulty in modelling the heterogeneous distribution of fractures and faults is also demonstrated.

Geophysical Investigations

- A suite of geophysical logging (electrical, micro electrical, natural gamma, spectral gamma, neutron, density, acoustic, temperature, X-Y calliper and deviation logging) was carried out in the whole drilled section. Lithological boundaries within the sedimentary formations and the unconformity with the Toki granite were identified as anomalies on the geophysical logs. In the Toki granite (below 123.00 mabh), anomalies detected in the electrical, micro-electrical and acoustic logging almost coincide in location with fluid logging anomalies, as shown in Figure 2.3.
- Both BTV and borehole televiewer (BHTV) surveys were also carried out as part of the geophysical investigations. Comparison of the results of BTV survey, BHTV survey and core logging shows slight differences in the number, depth and orientation of fractures. This discrepancy is to be analysed in detail and interpreted in order to eventually establish a reliable technique for the characterisation of fracture system in the host rock.

Hydrogeological Investigations

- A series of fluid logging (temperature, spinner flowmeter, electro-magnetic flowmeter, heat pulse flowmeter and fluid electrical conductivity (FEC) logging) was performed in the whole granite section. More than 20 inflow points were identified, as the fluid logging anomalies, mainly in UHFD (Figure 2.3). Combined with relevant geological, geophysical and drilling information (*eg* fracture distribution, geophysical logging anomaly, fluid loss), this evidence enabled potential WCFs to be accurately localised in the Toki granite.
- A total of 12 (9 short-straddle and 3 long-straddle) hydraulic test campaigns were performed. The transmissivities of the potential WCFs are high, ranging from 10^{-5} to 10^{-3} m^2s^{-1}, whereas other fractures (*ie* non-WCFs) give rather low transmissivity values in the range of 10^{-11} to 10^{-7} m^2s^{-1}, as shown in Figure 2.3. In addition, the hydraulic conductivity of BFR is generally smaller than 10^{-8} ms^{-1}.

- Hydraulic pressure changes, responding to fluid loss during drilling, cementing of the location of fluid loss, hydraulic packer tests *etc* in the MIZ-1 borehole, were often observed in the measurement intervals, located deeper than the basal conglomerate layer of the Hongo Formation, in the surrounding monitoring boreholes (*eg* [9]). The MIZ-1 borehole and the monitoring boreholes are hence hydraulically connected through the fracture systems involving the WCFs and the basal conglomerate layers of the sedimentary formations. In addition, the IMF03 fault that intersects the MSB-3 borehole [7] is considered to function as a hydraulic barrier within the sedimentary overburden.
- It is demonstrated that the current fluid logging technique is applicable to the detection of inflow points, transmissivity of which is higher than 10^{-8} m^2s^{-1}, in borehole sections. This would contribute to the definition of borehole set-up for hydraulic tests.

Hydrochemical Investigations

- Groundwaters in UHFD, sampled from the intervals of 113.05–116.28 mabh and 215.00–225.67 mabh, were classified as an Na-Cl dominated fresh water [9, 10], as shown in Figure 2.3. As predicted, the salinity of groundwater increases with depth: total dissolved solids (TDS) concentrations of 175 mgl^{-1} and 243 mgl^{-1} at shallower and deeper intervals respectively.
- Chemistry of the MIZ-1 groundwater in UHFD is consistent with that observed in the MSB-2 and MSB-4 boreholes [7]. The evolution of groundwaters occurring at the MIU Site could be explained as a mixing of low Cl groundwaters (Na-HCO_3 to Na-Ca-HCO_3 type) found over a considerable area north of the MIU Site and a high Cl groundwater (Na-Cl type) occurring in an area south of the MIU Site. An increase of the salinity of groundwater indicates that the mixing proportion of a high Cl groundwater with a low Cl groundwater becomes larger with depth [11].
- It was ensured that, even though the fluid tracer concentration in the interval did not decrease sufficiently (below 1 %) within the time available, the chemical composition of *in situ* (or uncontaminated) groundwater was able to be reliably back calculated by establishing a linear correlation between the concentrations of major chemical components and the fluid tracer. For this, effort is required to keep the fluid tracer concentrations as constant as practicable and conduct frequent sampling of water contaminated with the drilling fluid.

Rock Mechanical Investigations

- A range of laboratory tests was carried out to understand the rock mechanical properties and *in situ* stress state at the MIU Site. Crack parameters determined by the DSCA (Differential Strain Curve Analysis) method suggest that the maximum principal stress in the MIZ-1 borehole trends between N-S and NW-SE. This is consistent with the investigation results from the DH-2 borehole and the Shobasama Site [12]. In line with this evidence, the mechanical properties (*eg* apparent density, Young's modulus, Poisson's ratio) of the Toki granite, defined in the MIZ-1 borehole, are very similar to those characterised in the DH-2 borehole and the Shobasama Site.
- The Toki granite in UHFD (except the fracture zone) has unconfined compressive strength values between 168 and 207 MPa, which shows no depth dependency. It is noteworthy that the values obtained in the MIZ-1 borehole are up to 2 times higher than those measured in the DH-2 borehole.

Quality Control

- The QC system (*eg* work protocol, daily report, check sheet) established at the beginning of the MIZ-1 borehole investigations certainly helped in maintaining the traceability of field-work and investigations and reformulating the standard of them, although further refinement of the system was still required. The QC system should continue to govern all activities during the later phases, but, in order for them to proceed more efficiently and practically, further refinement of the system should be made step by step.

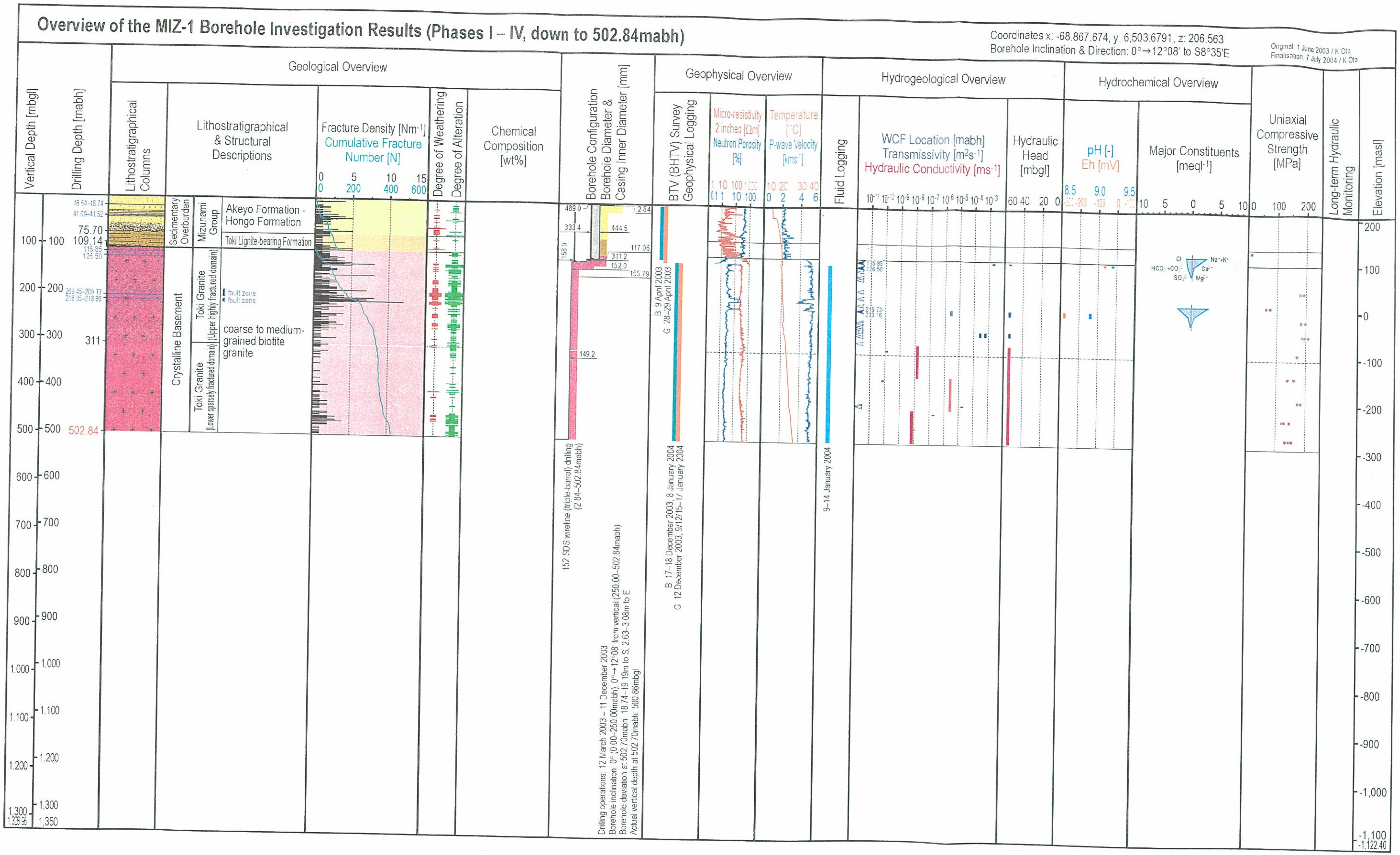


Figure 2.3: Overview of the results of the MIZ-1 borehole investigations in Phases I to IV

3 OPTIMISATION OF INVESTIGATION PROGRAMME AFTER MIZ-1 PHASE IV

3.1 Rationale behind Optimisation

The MIZ-1 Phase I–IV investigations provided a wealth of information on the characteristics of the geological environment down to about 500 m depth at the MIU Site, as described in Section 2.2, and input to the improvement of a wide range of investigation techniques. This progress resulted in enhancing the significance of the MIZ-1 borehole investigations and thus further underlined the necessity to achieve the overall goals and specific aims of the investigations, eventually providing the promising results for the MIU surface-based investigations. In this context, it is essential to perform the planned investigations down to 1,350 mabh without changing the overall concept of the MIZ-1 borehole investigations. The investigations thus need to address all the key issues defined previously. Specifically, the highest priority should be given to characterising the deepest targeted fault (IF_SB1_004[2)]) and/or its footwall (or LSFD of the Toki granite below 1,000 mbgl) from the standpoint of geology, hydrogeology and hydrochemistry. Since this fault was shown to have hydraulic significance at the MIU Site and predicted to intersect the MIU shafts very widely (*ie* appear in a wide section in the MIU shafts), the importance of the fault characterisation was greatly enhanced.

The MIZ-1 borehole investigations were, however, terminated at 502.84 mabh owing to some technical and practical reasons, as described in Section 2.1. In the next phase from mid February 2004, the borehole needs to be backfilled up to the most appropriate depth with cement and subsequently re-drilled along the re-planned trace from that depth. Here it is noted that the MIZ-1 Phase I–IV investigations have brought a likely unrecoverable delay of more than 6 months. This delay should not allow the quality and quantity of the investigations to be decreased but necessitate optimising, where necessary, the investigation methodology. More importantly, the amount of time available for the additional field-work (*ie* full-hole cementing and re-drilling) and the remainder of the planned investigations in the following phases should be maximised: the postponement of the planned post-MIZ-1 borehole investigations (cross-hole tomography survey, multi-offset VSP survey, hydraulic fracturing test and cross-hole hydraulic test; see [8] for details) until the beginning of September 2004 would enable the time for the field-work and investigations to be extended, at maximum, for 3.5 months. This would provide 6.5 months in total to complete the MIZ-1 borehole investigations.

Consideration was concentrated on the requisite optimisation of the MIZ-1 borehole layout and the investigation methodologies. In the following Sections, 3.2 and 3.3, the optimised borehole layout and the refined methodologies are discussed in detail. The revision of the investigation procedure and timeplan, according to this optimisation, is described in Chapter 4.

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2) Previously this fault was labelled IMF03 [8]. The geological predictions of the major fault distribution were revised based on the geological model improved with newly available information. Accordingly the new number (*ie* IF_SB1_XXX) was given to each fault.

3.2 Optimisation of Borehole Layout

In the optimisation of the MIZ-1 borehole layout, the following restrictions and requirements were taken into account:

- The borehole is prohibited to cross the boundary of the MIU Site at any depth.
- The borehole should penetrate through the IF_SB1_004 fault, which is predicted to dip 87.6±2.0°W, and is desired to be drilled in the footwall to a depth of, at least, 100 m below the bottom of the fault.
- The borehole should meet the IF_SB1_004 fault as early as (*ie* at as shallow a depth as) practicable.
- The borehole should have a drilling length of 1,350 m and an actual vertical depth of over 1,000 m.
- The inclination-controlled section of the borehole should allow downhole equipment and drilling rods to descend smoothly.

A decision was thus made to re-drill the borehole in a west-south-westerly direction (S66°W or azimuth 204°; almost perpendicular to the estimated trend of the IF_SB1_004 fault, N19.3°W) with inclination increasing to 14° from vertical, as shown in Figures 3.1 and 3.2. The depth where controlled directional drilling should start was determined. Since the difference between the measured and the re-planned borehole direction would become the smallest at 356 mabh (S58°32'W measured while S66°W re-planned) when the borehole inclination was over 1°, controlled directional drilling in a S66°W direction was decided to start at this depth. The borehole inclination would subsequently attain 14° from vertical at a depth of 485 mabh. Eventually, the MIZ-1 borehole would have a vertical depth of 1,322.99 mbgl and an offset from the borehole collar of 224.02 m at the bottom, which is expected to be intersected by the IF_SB1_004 fault in the section from 1,005.5 to 1,030.5 mabh (*cf* IMF03 between 1,145 and 1,170 mabh).

3.3 Optimisation of Investigation Methodology

Since controlled directional drilling from 356 to 485 mabh following full-hole cementing is to be performed, certain modifications of the methods and planned field-work is also required. For the most part, however, the field investigations in the following phases will be performed according to the original working programme [8]. All the work and investigations should proceed as efficiently as possible so that these could be completed within 6.5 months currently available; no further delay is allowed. The optimised investigation methodology in each discipline is presented as follows:

Borehole Drilling

Because the original section from 356 to 502.84 mabh was fully cored, it is intended to adopt non-core drilling for the new controlled directional drilling section from 356 to 485 mabh. Work will begin with backfilling the borehole section to be abandoned with cement up to the depth for setting a non-retrieval whipstock as required by the standard whipstock installation procedure. Uranine will be added to the cement as a tracer. The controlled directional drilling will then start with sidetrack drilling through the whipstock placed on the top of the cemented section. The whipstock should be oriented in a particular direction, which can force the drilling bit to start drilling in a S66°W direction away from the borehole axis. The drilling will continue down to 485 mabh using the MWD (measurements-while-drilling) system (see [13] for details). The borehole would be deviating with inclination increasing from 1°22', in increments of 1° every 9 mabh (and 0–0.5° in the 386–404 mabh section), to 14° from vertical. From 485 mabh to the final depth at 1,350 mabh, along-the-trace core drilling will be performed by the conventional wireline method with CHD134 drilling rods. The borehole direction (S66°W or azimuth 204°) and inclination (14° from vertical) could be maintained.

Geological Investigations

On-site core description and photography, which should be synchronised with each drilling run, will be performed on the recovered cores from the Toki granite from 485 to 1,350 mabh. The characterisation of the IF_SB1_004 fault and, secondly, LSFD of the Toki granite below 1,000 mbgl takes priority over other geological investigations.

Geophysical Investigations

A suite of geophysical logging and BTV survey will be performed in the interval of 123.00 to 1,350 mabh, covering the non-core drilling section. BHTV survey will be performed alternatively to obtain supplementary information in case BTV images are not sufficiently clear.

Hydrogeological Investigations

A total of 16 short-straddle and 11 long-straddle hydraulic tests are planned for the potential WCFs and BFRs respectively (Table 3.1). The intervals for testing the potential WCFs will be selected mainly on the basis of the fluid losses during drilling, the rate of fluid loss, anomalies in the FEC logs and the core descriptions. Although the section from 356 to 502.84 mabh was hydrogeologically characterised, a short-straddle test will be performed also in the newly drilled section from 356 to around 500 mabh in case a major potential WCF that was not identified in the previously drilled section is encountered. Priority is given to performing the short-straddle tests at the major faults (IF_SB1_004 and IF_SB1_005[3)]) and fluid logging in the interval of 123.00 to 1,350 mabh.

Table 3.1: Planned hydraulic tests after MIZ-1 Phase IV

Number	Test interval [mabh]	Geo-structural description	Phase	Packer configuration*	Water sampling
13	750 – 759	IF_SB1_005 fault	V	ss	Yes
14–16	3 intervals between 499.56 and 759 (covering whole section)	BFRs (LSFD)	V	dl	No
17	1,005.5 – 1,030.5	IF_SB1_004 fault	VI	ss	Yes
18	1 interval between 502.84 and 1,350	WCF	V–VII	ds	Yes
19–24	6 intervals between 759 and 1,350 (covering whole section)	BFRs (LSFD)	Post Drilling	dl	No
25–26	2 intervals between 123.00 and 290.00 (covering whole section)	BFRs (UHFD)	Post Drilling	dl	No
27–39	13 intervals between 123.00 and 1,350	WCFs	Post Drilling	ds	No

* Packer configuration: ss (single packer, short straddle), ds (double packers, short straddle), dl (double packers, long straddle)

3) Previously this fault was labelled IMF11 [8].

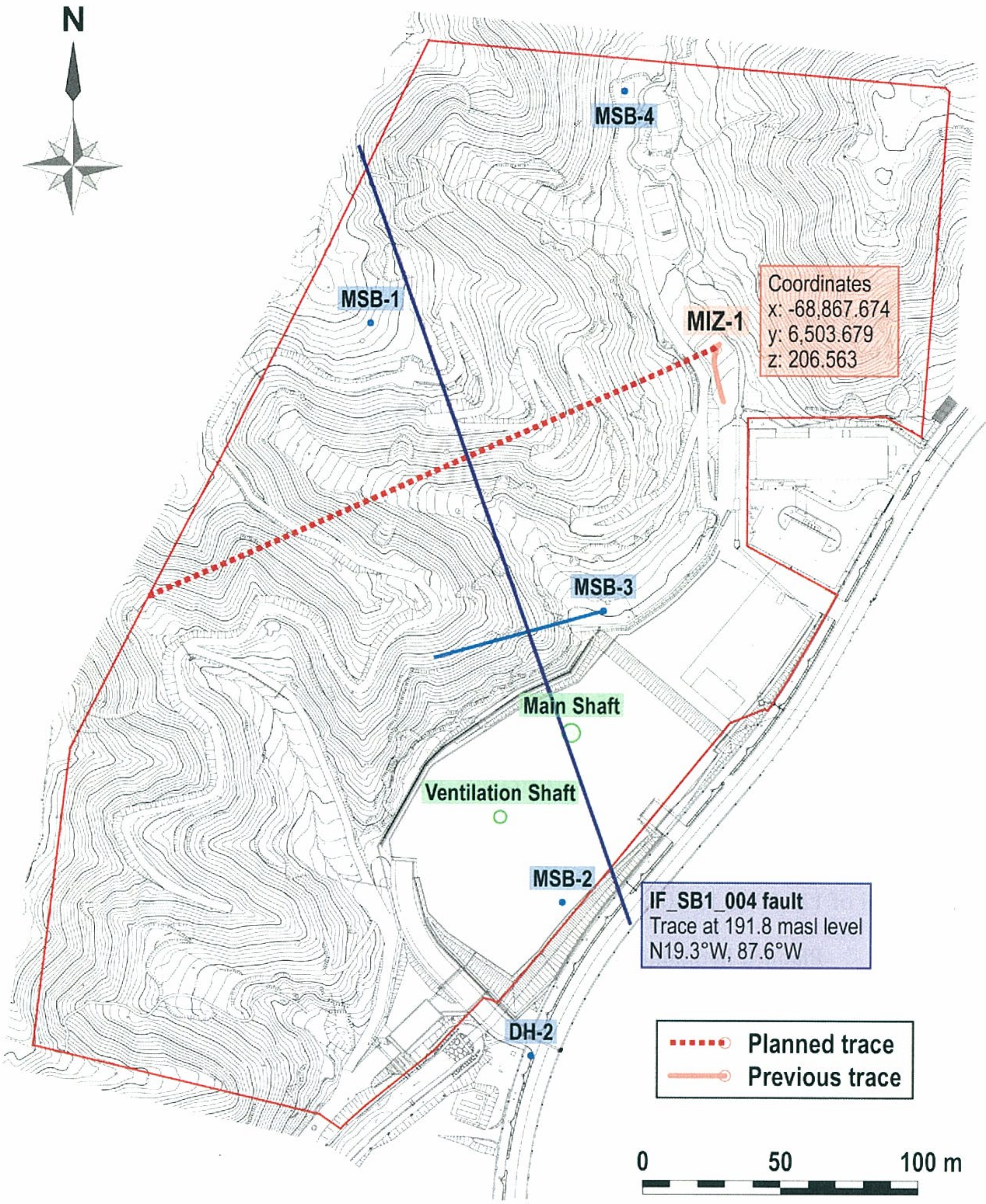

Figure 3.1: Projected trace of the re-planned MIZ-1 borehole from 356 to 1,350 mabh and the inferred IF_SB1_004 fault at the MIU Site

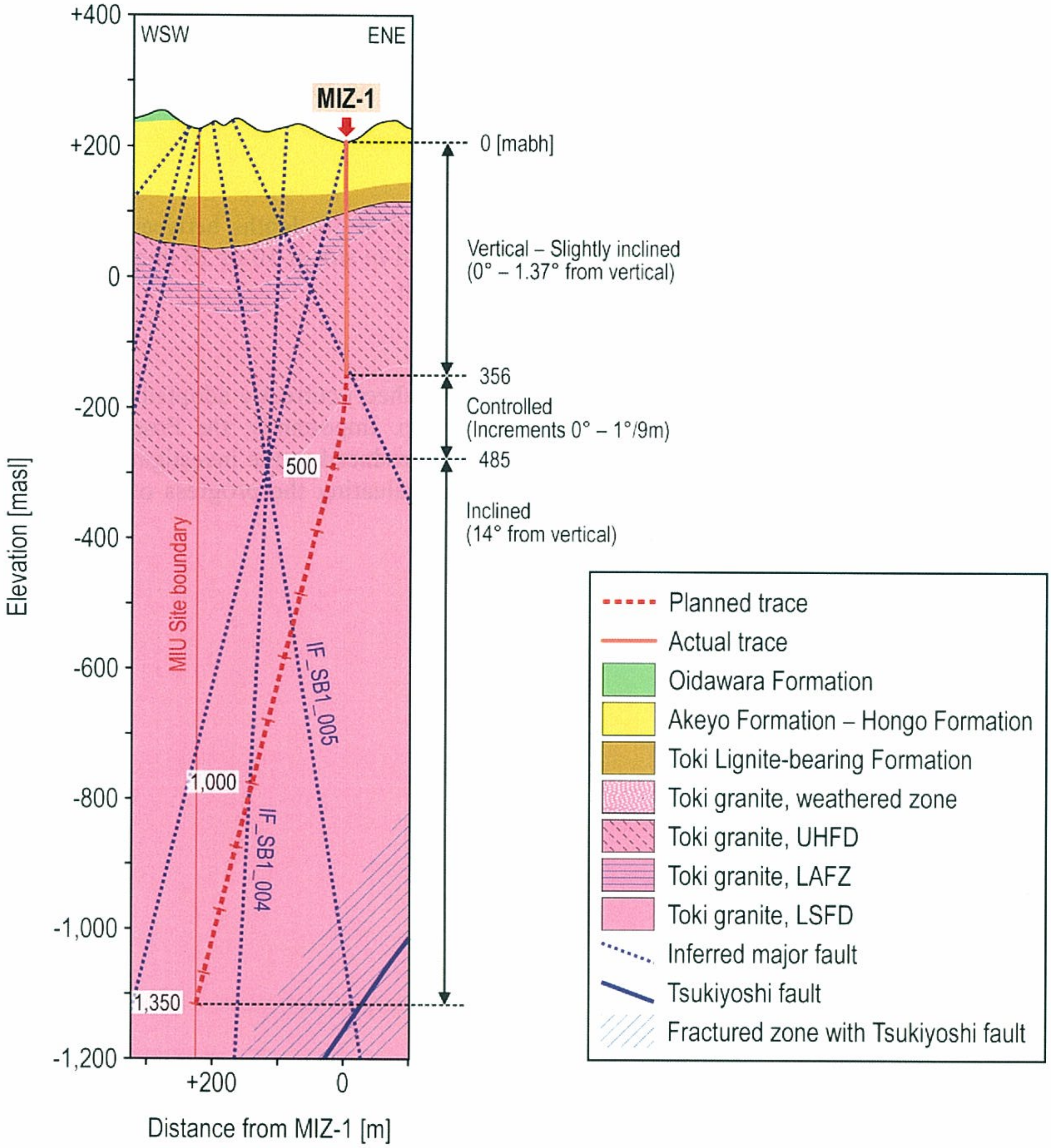

Figure 3.2: Re-planned trace of the MIZ-1 borehole in a S66°W direction and the predicted geological profiles; Actual borehole trace down to 356 mabh

Hydrochemical Investigations

Groundwater sampling will take place in 3 intervals, which is combined with the hydraulic test campaign as shown in Table 3.1. The first priority is to collect a quality-controlled groundwater sample below a depth of 1,000 mbgl.

Rock Mechanical Investigations

Core materials for laboratory tests will be sub-sampled at 10 depths between 502.84 and 1,017 mabh. Hydraulic fracturing tests will be performed *in situ* at 10 or 20 intervals close to the sub-sampling depths between 123.00 and 1,017 mabh.

Quality Control

The QC system (*eg* work protocol, daily report, check sheet) currently adopted to the MIZ-1 borehole investigations should be refined step by step. Importantly, the Process Decision Program Chart (PDPC; for details, see [14]) will be introduced to the investigations in order to identify both risks and countermeasures through evaluating the progress of work and a variety of conceivable outcomes.

4 REVISION OF INVESTIGATION PROCEDURE AND TIME-PLAN AFTER MIZ-1 PHASE IV

This section describes the procedure and timeplan for the "base case" investigation campaign to be performed in the MIZ-1 borehole after Phase IV. These are summarised in Figure 4.1 and Figure 4.2 respectively. In addition, a couple of alternative programmes (*ie* optional cases) for solutions to possible problems during drilling are also discussed.

4.1 Revised Investigation Procedure

The investigation campaign will be performed, in the Toki granite, in three phases during drilling (from MIZ-1 Phases V to VII) and one Post Drilling Phase. The original plans for the investigation campaign [8] have been revised based on the optimisation of the MIZ-1 borehole investigation programme as described in Chapter 3. Specifically, the time available for the planned investigations and the priority of the investigations in each discipline are taken into account for the revision.

The actual depths at which the targeted features occur may be different from the predicted depths given below (see also Figure 4.1), as small changes in fault dip may result in significant changes in the predicted intersection depth. Similarly, the proposed depths of testing and sampling intervals are approximate and may change in the light of actual geological, geophysical and hydraulic observations during the field investigations.

4.1.1 Base Case

Phase V 356 – 759 mabh / LSFD above the IF_SB1_005 fault

1 Full-hole cementing from 502.84 up to approximately 374 mabh. Dredging of cement down to an appropriate depth, where necessary.

2 Emplacement of a non-retrieval whipstock on the top of cemented section and fixation of the top of the whipstock with cement at a depth of 356 mabh. The whipstock is oriented so that a drilling bit is able to head in a S66°W direction away from the borehole axis.

3 Controlled directional drilling from approximately 356 to 485 mabh by the non-core method using a 5 7/8" tricone bit with fresh water labelled with uranine. Drilling begins with sidetracking through the whipstock and continues using the MWD system. The borehole inclination increases from 1°22', in increments of 1° every 9 mabh (and 0–0.5° in the 386–404 mabh section), to 14° from vertical. The borehole diameter is 149.2 mm.

4 Extraction of the 5 7/8" wireline tools for controlled directional drilling.

5 Start of 5 1/4" wireline core drilling at 485 mabh with fresh water labelled with uranine. Core recovery using a triple-barrel corer. The direction and inclination of the borehole is maintained to be S66°W and 14° respectively. The borehole diameter is 134.5 mm and the core diameter is approximately 83 mm. Drilling halts immediately after penetrating the bottom of the IF_SB1_005 fault (predicted at 759 mabh). The top and bottom depths of the fault are determined by JNC staff based on the frequencies and structural features of fractures observed on the core.

6 Extraction of 5 1/4" wireline tools and drilling pipes.

7 Hydraulic test and groundwater sampling with a single packer configuration in the interval of 750–759 mabh (No 13 in Table 3.1).

- Aims[4]: T, H, M, W
- Methods: slug, pulse and pumping
- Structure/lithology: IF_SB1_005 fault

8 Hydraulic tests with a double packer configuration in three approximately 90 m-long intervals covering the 499.56–759 mabh section (between the bottom of No 10 test interval and the bottom of the IF_SB1_005 fault). The test intervals (Nos 14 to 16 in Table 3.1) are selected on the basis of the fluid loss during drilling and core observation.

- Aims: T, H, M
- Methods: slug, pulse and/or pumping
- Structure/lithology: LSFD (BFRs)

Phase VI 759 – 1,030.5 mabh / LSFD between the IF_SB1_004 fault and the IF_SB1_005 fault

1 Resumption of 5 1/4" wireline core drilling at 759 mabh with fresh water labelled with uranine. Core recovery using a triple-barrel corer. The direction and inclination of the borehole is maintained to be S66°W and 14° respectively. The borehole diameter is 134.5 mm and the core diameter is approximately 83 mm. Drilling halts immediately after penetrating the bottom of the IF_SB1_004 fault (predicted at 1,030.5 mabh). The top and bottom depths of the fault are determined by JNC staff based on the frequencies and structural features of fractures observed on the core.

2 Extraction of 5 1/4" wireline tools and drilling pipes.

3 Hydraulic test and groundwater sampling with a single packer configuration in the interval of 1,005.5–1,030.5 mabh (No 17 in Table 3.1).

- Aims: T, H, M, W
- Methods: slug, pulse and pumping
- Structure/lithology: IF_SB1_004 fault

Phase VII 1,030.5 – 1,350 mabh / LSFD below the IF_SB1_004 fault

1 Resumption of 5 1/4" wireline core drilling at 1,030.5 mabh with fresh water labelled with uranine. Core recovery using a triple-barrel corer. The direction and inclination of the borehole is maintained to be S66°W and 14° respectively. The borehole diameter is 134.5 mm and the core diameter is approximately 83 mm. Drilling ends at a depth of 1,350 mabh.

2 Borehole flushing to extract cuttings with fresh water labelled with uranine.

3 Extraction of 5 1/4" wireline tools and drilling pipes.

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[4] Abbreviations used for the aims of hydraulic tests and groundwater sampling are listed below:
H Hydraulic head M Flow model T Transmissivity W Water sample

4 Hydraulic tests and groundwater sampling with a double packer configuration in one short interval where a fluid loss has occurred (at a potential WCF; No 18 in Table 3.1), if it happens during drilling from 502.84 to 1,350 mabh.

- Aims: T, H, M, W
- Methods: slug, pulse and pumping
- Structure/lithology: WCF

5 Borehole flushing with fresh water.

6 Continuous BTV survey, geophysical and fluid logging from 123.00 to 1,350 mabh.

Post Drilling Phase

1 Hydraulic tests with a double packer configuration in six approximately 100 m-long intervals covering the 759–1,350 mabh section (below the bottom of the IF_SB1_005 fault). The test intervals (Nos 19 to 24 in Table 3.1) are selected on the basis of core observation and the results of BTV survey and geophysical and fluid logging.

- Aims: T, H, M
- Methods: slug, pulse and/or pumping
- Structure/lithology: LSFD (BFRs)

2 Hydraulic tests with a double packer configuration in two approximately 90 m-long intervals covering the 123.00–290.00 mabh section (between the bottom of the temporary casing and the top of No 12 test interval). The test intervals (Nos 25 and 26 in Table 3.1) are selected on the basis of core observation and the results of BTV survey and geophysical and fluid logging.

- Aims: T, H, M
- Methods: slug, pulse and/or pumping
- Structure/lithology: UHFD (BFRs)

3 Hydraulic tests with a double packer configuration in 13 intervals (at potential WCFs) between 123.00 and 1,350 mabh. In case a major potential WCF not identified in the previously drilled borehole is encountered in the newly drilled section from 356 to 502.84 mabh, a short-straddle test is also to be performed. The test intervals (Nos 27 to 39 in Table 3.1) are selected on the basis of core observation and the results of BTV survey and geophysical and fluid logging.

- Aims: T, H, M
- Methods: slug, pulse and/or pumping
- Structure/lithology: WCFs

4 Borehole flushing with fresh water.

5 Extraction of 5 1/4” wireline tools and drilling pipes.

6 Emplacement of a bit guide between 116.5 and 123.0 mabh and a flange on the top of 14” casing pipes.

7 Additional field investigations[5] (for details, see Appendices II-1 to II-4 to the original working programme [8]).

- Multi-offset VSP survey in the entire drilled section (Step 3)
- Cross-hole tomography survey between the MIZ-1 and DH-2 boreholes (Step 4)
- Hydraulic fracturing tests at 10 or 20 intervals between 117.06 and 1,017 mabh (Step 3)
- Cross-hole hydraulic test between the MIZ-1 and DH-2 boreholes (Step 4)

8 Installation of a long-term monitoring system.

9 Dismantlement of drilling equipment and drill rig and final restoration of the site.

4.1.2 Optional Cases

Optional Case No 1: Loss of drilling fluid during drilling

If a loss of drilling fluid occurs, which transmits pressure responses to DH-2 borehole, or if there are no pressure responses but a 100% drilling fluid loss occurs, all planned investigations that would have been performed during and after drilling from 117.06 mabh to the depth of the drilling fluid loss are performed: hydraulic tests and water sampling with a single or double packer configuration, BTV survey, geophysical and fluid logging. After these investigations have been completed, plugging with a lost circulation material (LCM) or cementing is carried out at the site where the drilling fluid loss occurs, in order to prevent any further loss of drilling fluid, and drilling is resumed.

If a drilling fluid loss of less than 100 % occurs and there are no pressure responses in other monitoring boreholes, the following steps to resume drilling and perform the remainder of on-site investigations will be taken.

- Plugging with LCM is carried out in the interval encompassing the borehole section where the drilling fluid loss occurs. The interval could be sealed off, where necessary, with a single or double packer assembly.
- If the drilling fluid loss continues after plugging of the section where the drilling fluid loss occurs, partial cementing of the section is done.

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

Optional Case No 2: Borehole collapse

If it is necessary to stabilise the borehole wall where collapse occurs, all planned and feasible investigations, including all the hydraulic tests, from 117.06 mabh to the depth of the collapse are performed. The section is then partially cemented.

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[5] Although the additional field investigations (multi-offset VSP survey, cross-hole tomography survey, hydraulic fracturing tests and cross-hole hydraulic tests) are not involved in the MIZ-1 borehole investigation programme, these investigations need to be performed during the Post Drilling Phase in order to have the planned field work at the MIZ-1 borehole proceeding more efficiently and practically.

If collapse recurs even after the cementing of the site, the following steps to resume drilling and perform the remainder of on-site investigations will be taken.

- The section from 117.06 mabh to the depth of the collapse is reamed to 311.2 mm (12 1/4") in diameter. Ten inches casing pipes are then installed to the depth of the collapse and fixed by cementing.
- If 10" casing pipes have already been installed and fixed by cementing in a zone previously collapsed, the section below the shoe of the existing 10" casing down to the site of collapse is reamed to 215.9 mm (8 1/2") in diameter. Seven inches' casing pipes are then installed and fixed by cementing.

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

Optional Case No 3: Drilling fluid loss and borehole collapse at the same location

In that case all planned investigations from 117.06 mabh to the location where drilling fluid loss and collapse occur are performed. After these investigations have been completed, cementing is carried out at the location and drilling is carried on. An appropriate fluorescent dye is added to the cement to allow the degree of contamination of groundwater by cement dissolution to be quantified.

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

- The section from 117.06 mabh to the depth of the collapse is reamed to 311.2 mm (12 1/4") in diameter. Ten inches casing pipes are then installed to the depth of the collapse and fixed by cementing.
- If 10" casing pipes have already been installed and fixed by cementing in a zone previously collapsed, the section below the shoe of the existing 10" casing down to the location is reamed to 215.9 mm (8 1/2") in diameter. Seven inches' casing pipes are then installed and fixed by cementing.

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

Optional Case No 4: No occurrence of IF_SB1_005 fault

Drilling continues until the next targeted major fault, IF_SB1_004, or a significant drilling fluid loss occurs. Drilling halts immediately after penetrating either of the above and planned investigations are performed: hydraulic tests and groundwater sampling with a single packer configuration at the IF_SB1_004 fault or the fluid-losing fracture (or a potential WCF) and hydraulic tests with a double packer configuration in long (approximately 70 to 100 m) intervals covering the section from 499.56 mabh to the bottom of the borehole.

Optional Case No 5:   No occurrence of IF_SB1_005 fault or drilling fluid loss

If neither the IF_SB1_005 fault nor a significant drilling fluid loss occurs in the section from 499.56 to 1,005.5 mabh, drilling halts at 1,005.5mabh (*ie* before meeting the IF_SB1_004 fault). Hydraulic tests with a double packer configuration in long (approximately 70 to 100 m) intervals covering the section from 499.56 mabh to the bottom of the borehole are performed.

Optional Case No 6:   No occurrence of IF_SB1_004 fault

Drilling continues until a significant drilling fluid loss occurs or the planned final depth is reached. In the case of drilling fluid loss, drilling halts immediately after penetrating the bottom of the drilling fluid loss section. Hydraulic tests and groundwater sampling are then performed in this section.

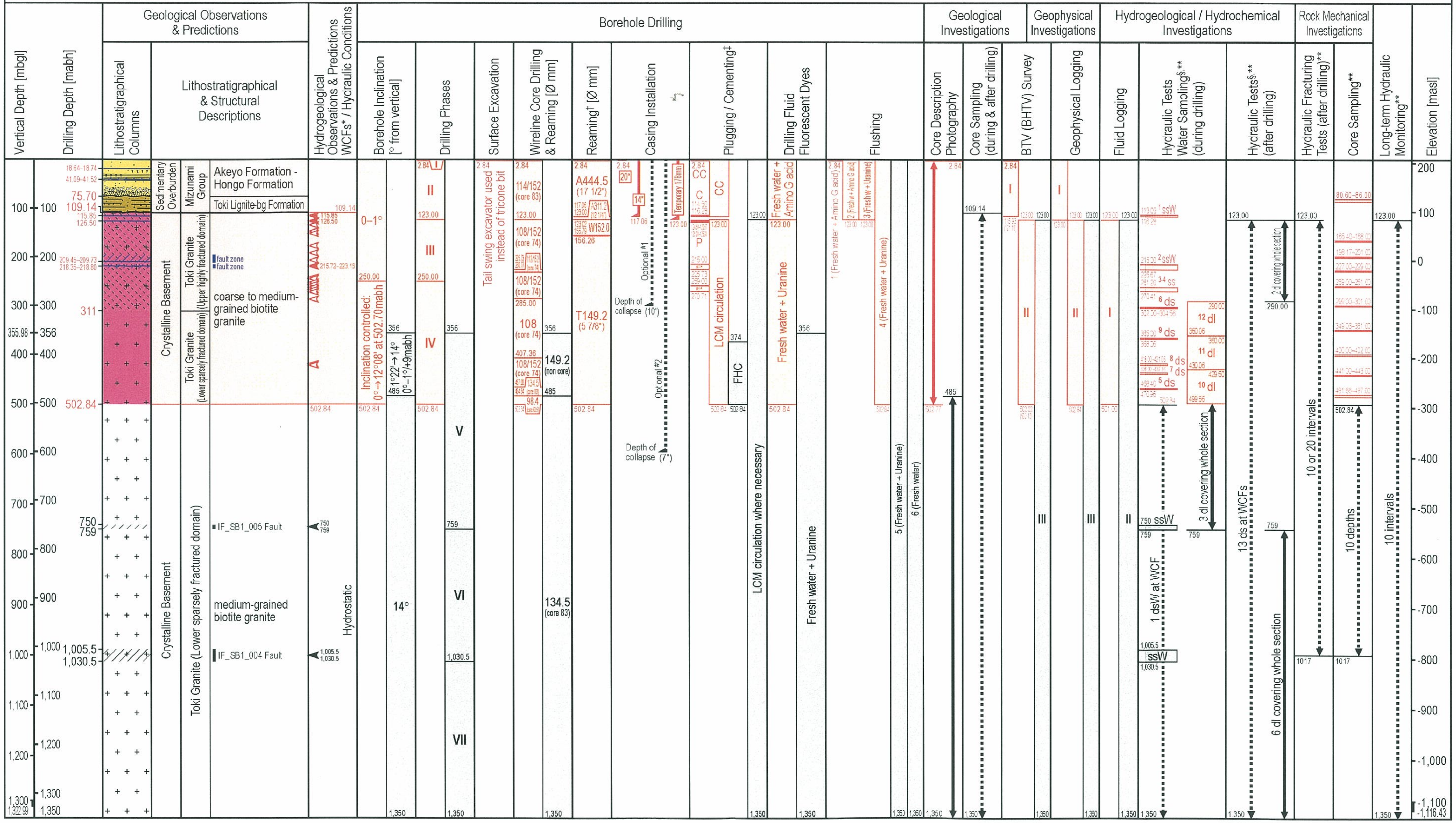
Figure 4.1: Overview of the revised programme for the MIZ-1 borehole investigations after Phase IV

➡

Overview of the Revised MIZ-1 Borehole Investigation Programme (Phases V – VII, from 356mabh)

Coordinates x: -68.867.674, y: 6,503.6791, z: 206.563
Borehole Inclination & Direction: 1°22'→14° to S66°W

Original: 28 May 2004 / K Ota
Finalisation: 7 July 2004 / K Ota



* WCFs: (WCF, depth defined), (inflow point, depth not yet defined precisely)
† Reaming: A (air hammer bit), W (water hammer bit), T (tricone bit)
‡ Plugging / Cementing: C (cementing), CC (casing cementing), P (plugging with LCM)

§ Hydraulic Tests & Water Sampling: ss (single packer, short straddle), ds (double packers, short straddle), dl (double packers, long straddle), W (water sampling)
** The number representing the number of tests or depths planned after the revision.

abc Work performed
abc Work planned

4.2 Timeplan

This revised programme is planned to start in mid February 2004 and take about 14 months, as shown in Figure 4.2. Minimum time requirements for the planned drilling work with the following on-site investigations, site restoration and laboratory work after MIZ-1 Phase IV are 6.5 months, 0.5 months and 10.0 months respectively.

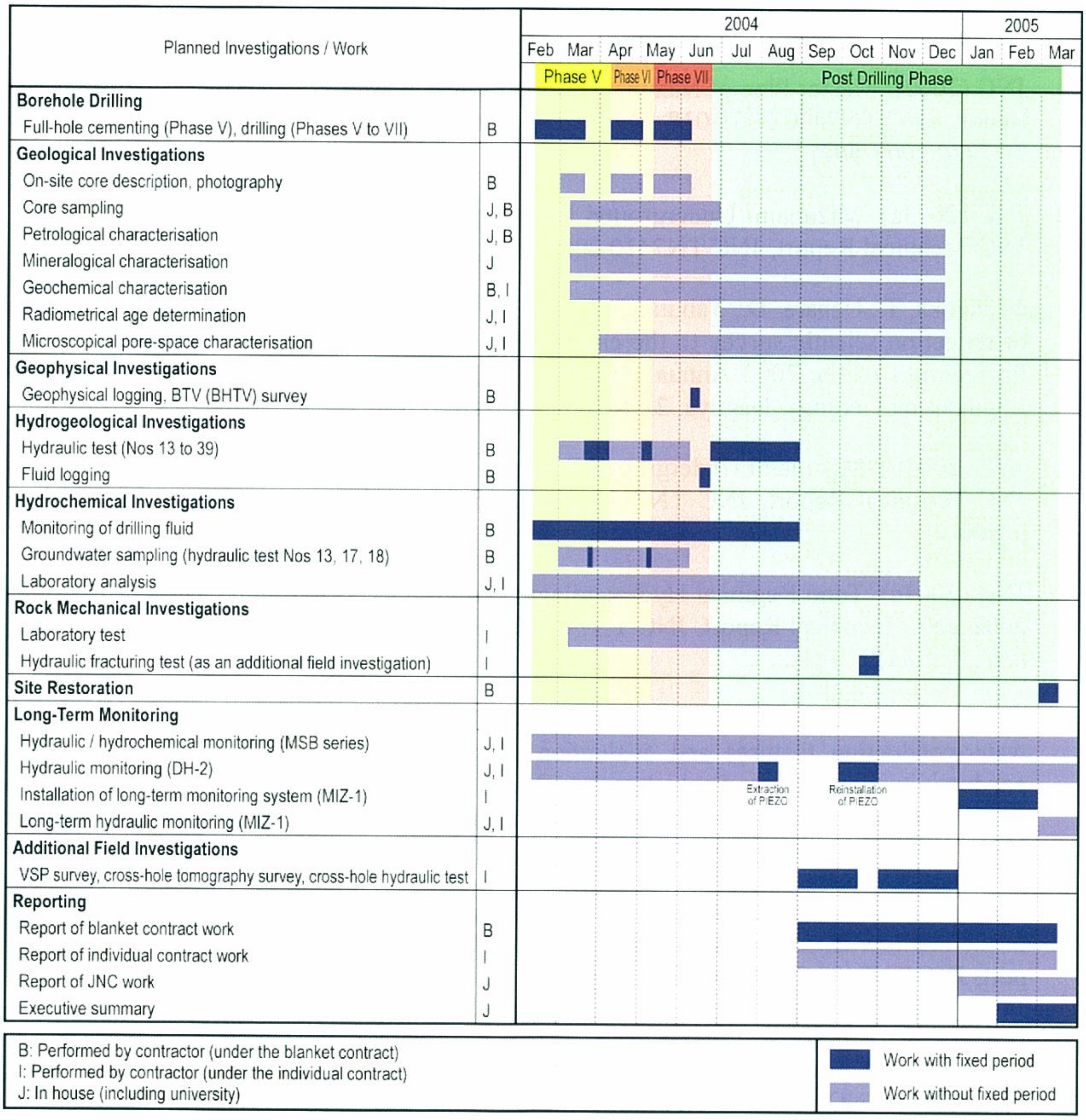


Figure 4.2: Timetable of the planned MIZ-1 borehole investigations after Phase IV

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