

2.5. Hydrochemical Investigations

2.5.1 Aims

- To understand the depth profile of groundwater chemistry and geochemical processes in the sedimentary rocks and the upper part of the granite.
- To obtain information on the residence time of groundwater in the sedimentary rocks and the upper part of the granite.
- To determine the depth profile of redox properties and estimate the redox buffering capacity.
- To construct comprehensive geochemical model of the sedimentary rocks and the upper part of the granite.

2.5.2 Work performed

- Groundwater sampling was performed during hydraulic testing in the following intervals;
 - MSB-2: 79.0-130.5 mabh (main part, Toki Lignite-bearing Formation)
 - 132.0-154.0 mabh (basal conglomerate, Toki Lignite-bearing Formation)
 - 171.5-175.5 mabh (weathered zone, Toki Granite)
- MSB-4: 95.5-99.0 mabh (fresh granite, Toki Granite)
- Groundwater sampling was performed during pumping using the MP System™ in the following intervals by the end of February 2003 immediately before MIZ-1 drilling (planned drilling depth is 1350mabh) started in the MIU Construction Site;
 - MSB-4: 15.8-25.6 mabh (main part, Akeyo Formation)
 - 34.8-62.2 mabh (main part, Akeyo Formation)
- The water samples were analysed for physical and major chemical components and some isotopes.
- The planned groundwater sampling was cancelled in the main part of the Toki Lignite-bearing Formation in MSB-4 because of the low hydraulic head in the borehole.
- Additional groundwater sampling was done in the 79.0 to 130.5 mabh interval above the conglomerate in MSB-2 to better understand the distribution of the unexpected chemical composition of the groundwater in this borehole.
- Core logging and analysis of 60 core samples from MSB-1 to 4 were done to determine the depth profile in mineral, chemical and isotopic compositions.

2.5.3 Results

Groundwater chemistry and evolution:

- Si - Ca - Na - HCO₃ - SO₄ type groundwater occurs in the Akeyo Formation. Na - Cl type groundwater occurs in the Toki Lignite-bearing Formation and the upper part of the granite (Table 6, Figures 34 and 35, and Appendix III).

Table 6 pH, TDS and isotopic compositions of groundwater in MSB-2 and 4

MSB-2 79.0-130.5 mab Toki Lignite-bearing Formation Main part	MSB-2 132.0-154.0 mab Toki Lignite-bearing Formation Basal conglomerate	MSB-2 171.5-175.5 mab Toki Granite Weathered zone	MSB-4 15.8-25.6 mab Akeyo Formation Main part	MSB-4 34.8-62.1 mab Akeyo Formation Main part	MSB-4 95.5-99.0 mab Toki Granite Fresh granite
pH: 9.1 TDS*: 325 mg ^l ⁻¹ D: -57.8 ‰ ¹⁸ O: -9.1 ‰ ¹⁴ C: 58 pMC	pH: 8.8 TDS*: 417 mg ^l ⁻¹ D: -57.0 ‰ ¹⁸ O: -9.1 ‰ ¹⁴ C: 48 pMC	pH: 8.6 TDS*: 370 mg ^l ⁻¹ D: -61.0 ‰ ¹⁸ O: -8.9 ‰ ¹⁴ C: 33 pMC	pH: 7.5 TDS*: 415 mg ^l ⁻¹ D: Not measured ¹⁸ O: Not measured ¹⁴ C: Not measured	pH: 7.9 TDS*: 387 mg ^l ⁻¹ D: Not measured ¹⁸ O: Not measured ¹⁴ C: Not measured	pH: 8.8 TDS*: 248 mg ^l ⁻¹ D: -61.8 ‰ ¹⁸ O: -8.9 ‰ ¹⁴ C: 15 pMC

*TDS: Total Dissolved Solids

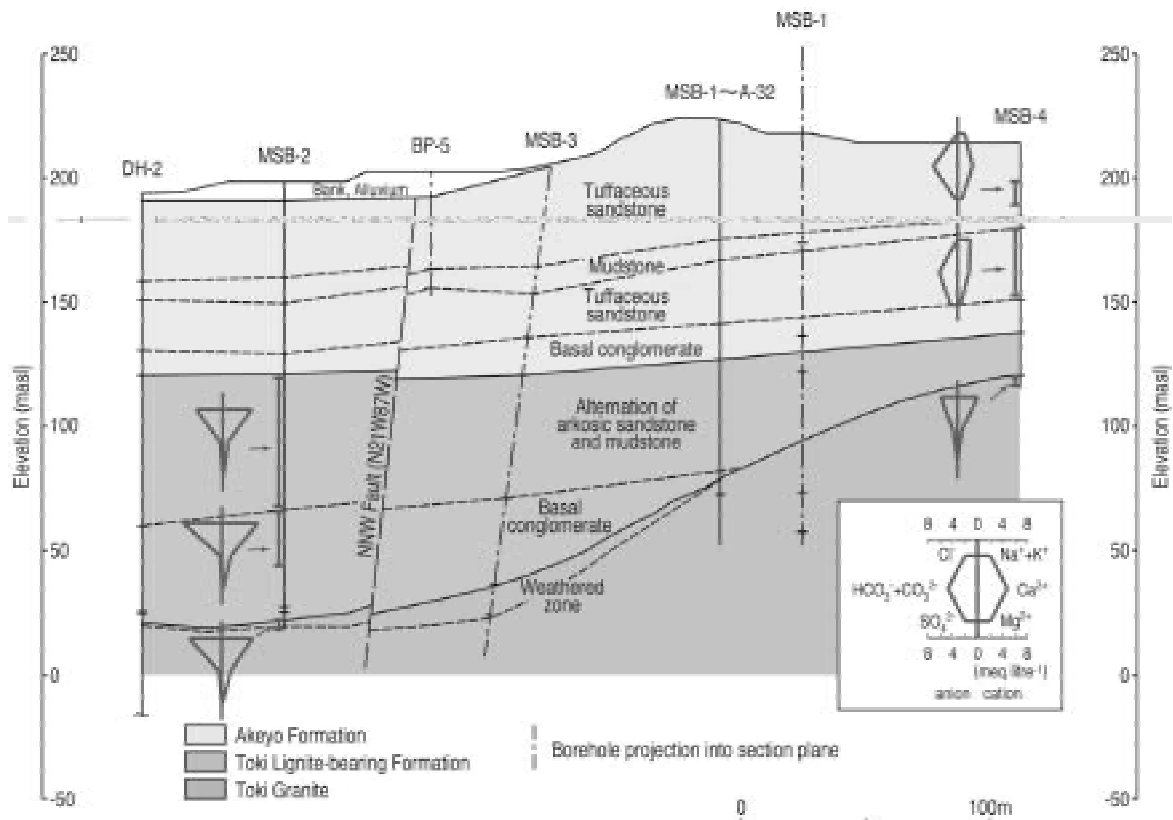


Figure 34 Chemical composition of groundwater in MSB-2 and 4

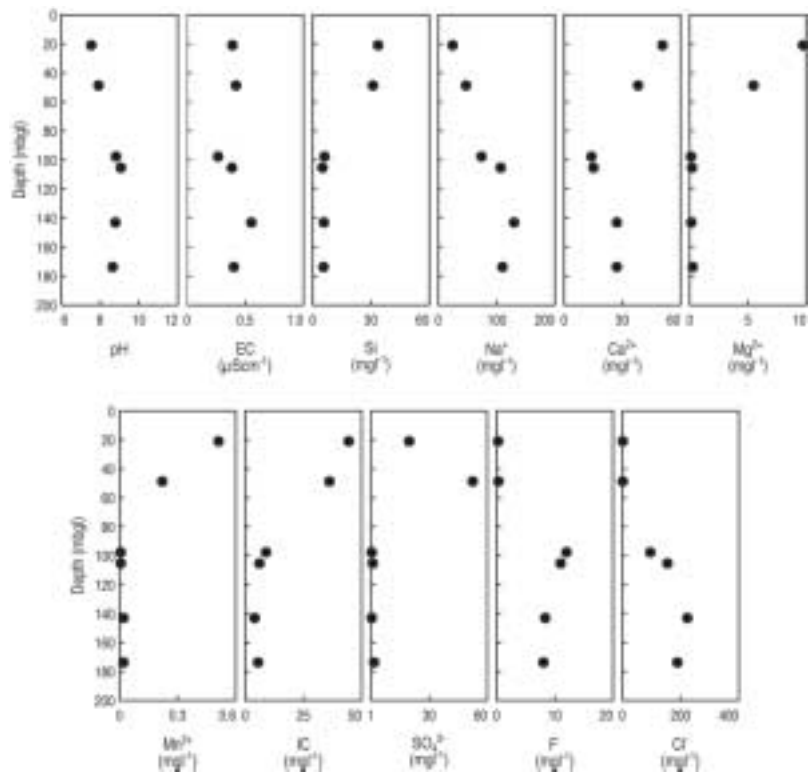


Figure 35 Depth profile of chemical composition of groundwater from MSB-2 and 4

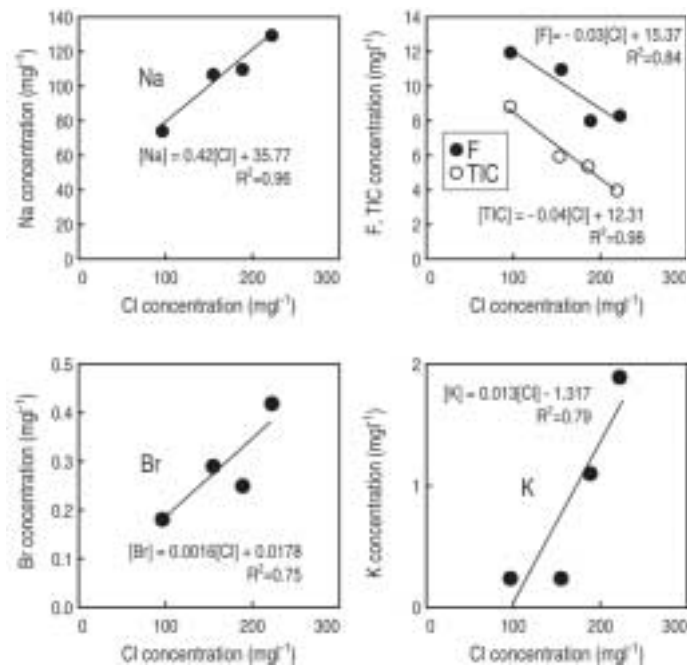


Figure 36 Relationships between chlorine and other chemical components in groundwater from Toki Lignite-bearing Formation and upper part of Toki Granite

- The salinity of groundwater from the Toki Lignite-bearing Formation and the upper part of the granite are less than 1% of seawater. Calcium, magnesium, manganese, silica, inorganic carbon and sulphate ion concentrations decrease with depth in the sedimentary rocks; Fluorine, chlorine and sodium concentrations increase with depth (Figure 35). Moreover sodium, fluorine, inorganic carbon, bromine and potassium ion concentrations have linear relationships with chlorine concentration (Figure 36).
- Chlorine content in core samples from the Toki Lignite-bearing Formation (fluvial sediments) is higher than in the Akeyo Formation (marine sediments), down to the basal conglomerate of the Akeyo Formation (Figure 37). This relationship between the distinctive Cl distributions in the two formations and the hydraulic head boundary in the basal conglomerate of the Akeyo Formation is being investigated.

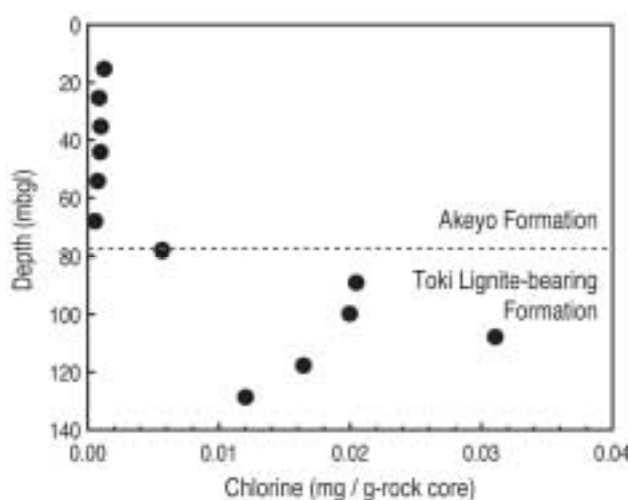


Figure 37 Chlorine content in core from MSB-2

- Lithofacies at the groundwater sampling points in the Akeyo Formation are highly weathered due to their proximity to ground surface. The precipitation of iron oxyhydroxides and dissolution textures of carbonate minerals in fossil shells in core suggest that oxidizing and low pH conditions occur in the shallow part of the Akeyo Formation. Taking these observations into consideration, weathering of constituent minerals such as quartz and feldspars, and dissolution of marine sulphate/sulphide and of carbonate minerals probably controls chemical composition of groundwater.
- Alternative explanations for the evolutionary process regarding the Na-Cl type groundwater in the Toki Lignite-bearing Formation and the upper part of the granite are: 1) brine generation caused by long-term water-rock interactions in closed system; 2) mixing process between low and high salinity groundwater.
- However, ^{14}C concentration suggests that the groundwater residence time is not long enough to generate brine. The Na/Cl and Br/Cl ratios roughly agree with those of seawater. Thus the chemical compositions of groundwater are deduced to be controlled by mixing process between high and low salinity groundwater. Such high-salinity groundwater might be derived from fossil seawater or brine that may be distributed in the deeper parts of the granite around the Toki River.

Groundwater origin and residence time:

- Hydrogen and oxygen stable isotopes plot in the range of the meteoric water lines for this area (Figure 38). Groundwater is mainly of meteoric origin.
- Tritium concentrations indicate that the groundwater residence time is, at least, longer than 50 years.

Redox profile and buffer capacity:

- Redox conditions are inferred based on the occurrence of redox sensitive minerals. Iron oxy-hydroxide and pyrite precipitates are observed at depths shallower than approximately 10 to 20 m and deeper than 40 to 60 m, respectively.
- The pyrite precipitates with carbonate minerals around organic materials in the Toki Lignite-bearing Formation. Such co-precipitation probably implies microbial controlled redox processes; sulphate ion is reduced by sulphate-reducing bacteria via the organics.
- Groundwater contains abundant sulphate in the shallow parts of the Akeyo Formation and hydrogen sulphide in the Toki Lignite-bearing Formation and the upper part of the granite (Appendix III). This suggests that the groundwater is oxidizing in the shallow parts of the Akeyo Formation and reducing conditions prevail in the Toki Lignite-bearing Formation and the upper part of the granite, with respect to sulphate/sulphide redox couples.
- Taking these mineralogical and chemical signatures into consideration, oxidation of iron and sulphate reduction are surmised to be the dominant redox processes in the sedimentary rocks.

Geochemical modelling at the MIU Construction Site:

- The hydrogeochemical conditions and processes operating in the sedimentary rocks and the upper part of the granite elucidated by the shallow borehole investigations are summarised in Figure 39.

2.5.4 Evaluations

- Groundwater evolution with depth and the processes at work in the sedimentary rocks and the upper part of the granite were determined.
- Origins and residence times of groundwater were elucidated.
- Redox condition and the dominant processes were preliminarily evaluated.
- Geochemical model of the sedimentary rocks and the upper part of the granite was constructed.

2.5.5 Lessons learned

- Groundwater samples could not be collected as planned from the main part of the Toki Lignite-bearing Formation of MSB-4. The hydraulic conductivity and head in this part of the formation are too low for the performance of pumping test to obtain groundwater samples. If pumping test is not done, the groundwater sampling initially planned will not be possible. It is required to have a contingency plan based on the expectation that sampling intervals having low hydraulic conductivity and head can be encountered.

- In addition, an optional plan including alternative sampling locations for hydraulic testing and groundwater sampling is also necessary.

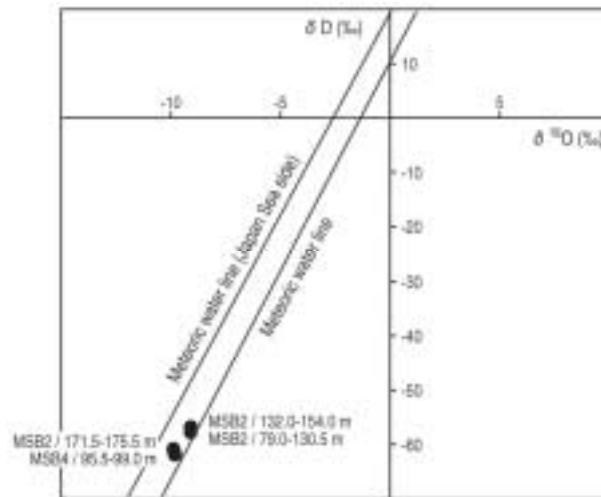


Figure 38 Oxygen and hydrogen isotopes in groundwater from MSB-2 and 4

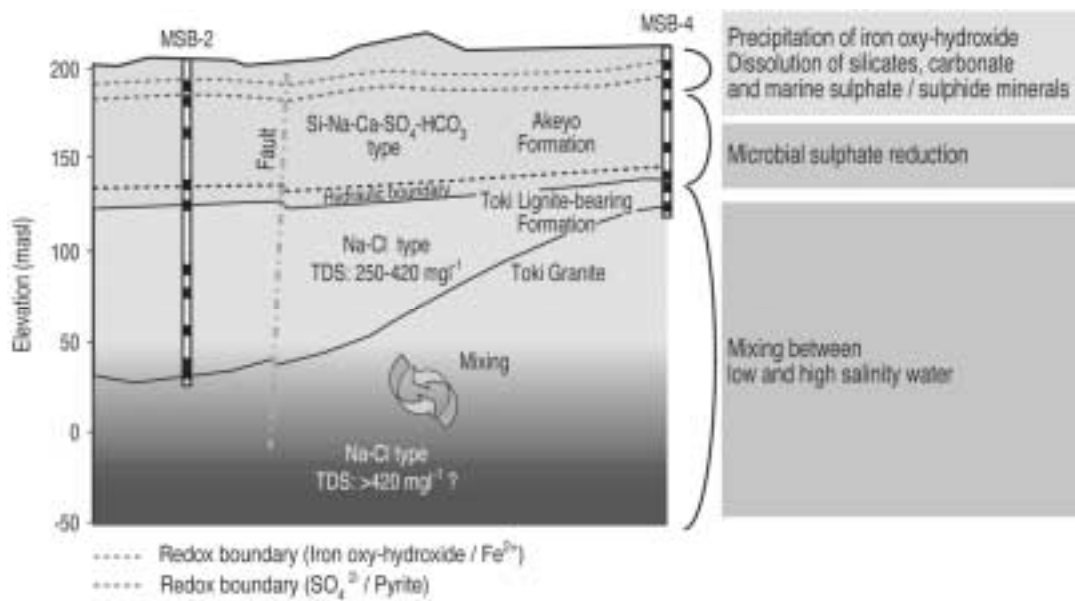


Figure 39 Conceptual model of geochemical condition at the MIU Construction Site