The hydrogeochemical characterization of deep groundwaters in crystalline bedrock: investigations in boreholes with multipackers

P.H. Ruotsalainen *FINTACT, Hopeatie 1 B, 00440 Helsinki, Finland.*
M.V. Snellman *Imatran Voima Oy, Rajatorpantie 8, 01019 IVO, Finland*

Introduction

The Finnish nuclear power company, Teollisuuden Voima Oy (TVO) has been engaged for more than ten years in a survey of the Finnish bedrock aiming at the final disposal of spent nuclear fuel. The preliminary site investigations, including extensive hydrogeochemical studies (Lampen and Snellman, 1993), were performed at five sites during 1986-1992.

Detailed site investigations were started in 1993 at three of the above mentioned sites: Romuvaara (migmatite banded gneiss) in northeastern Finland, Kivetty (porphyritic granodiorite) in Central Finland and Olkiluoto (migmatized mica gneiss) on the southwestern coast. The aims of the detailed hydrogeochemical site investigations are to form an extensive database of the hydrogeochemical conditions before any actual test shafts will be construced at the sites, to characterize the local hydrogeochemical conditions and to produce reliable input data for the needs of geochemical modelling and the performance assessment. Instead of sampling from deep (500–1000 m), open boreholes, groundwater samples have now been pumped from borehole sections isolated with the help of multi-packer instruments. The boreholes (KR1-KR5) have been in hydrological equilibrium for 2–3 years before the groundwater sampling. To get an overall regional hydrochemical view, precipitation, surface waters and shallow groundwaters were also sampled. This paper will discuss the presently available hydrogeochemical results from Romuvaara and Kivetty.

Methods

The groundwater sampling from the deep boreholes was performed with a very slim membrane pump (Öhberg, 1991; Ruotsalainen *et al.*, 1994) at a rather slow and gentle (< 2 l/h) pumping rate. Quality of the groundwater was usually monitored for 3–6 weeks by continuous, on-line field measurements of pH, electrical conductivity, Eh, dissolved oxygen and temperature. When the field parameters had stabilized to an acceptable level, groundwater samples were taken for tritium and uranine or sodium fluorescein - a tracer used in the flushing water during drilling operations. If the groundwater passed through all these criteria for representativeness, the sampling campaign began.

The hydrogeochemical analysis programme (Teollisuuden Voima Oy, 1993) included field analyses for the most sensitive variables (alkalinity, acidity, Fe^{2+}, $Fe_{(tot)}$, HS^-, anions). Nearly all of the samples were filtered in the field laboratory, some in nitrogen atmosphere. The laboratory analyses include all of the most important physicochemical parameters, main components, evacuated gases and an extensive variety of isotopes.

Results and discussion

The groundwaters at Romuvaara are fresh with an average TDS of 200 mg/l. The dominating water types are Ca-(Na)-Mg-HCO_3 and Na-HCO_3. In general the chloride contents increase with depth to a local maximum of 60 mg/l. Specific to the groundwaters in the area are the large variations in pH values (6.5–10), reflecting the effects of different mineralogical surroundings, some of the waters being strongly basic due to mafic rocks present. The Romuvaara site is at an elevation of about + 220 m a.s.l. forming a local recharge area with relatively high hydraulic gradients (2–10 %). This is reflected by observations of iron oxide down to depths of 40–190 m. The few highly conducting fracture zones interpreted in the structural bedrock model (Saksa *et al.*, 1991) strongly influence the local groundwaters, seen e.g. in the high H-3 and C-14 contents. The C-14 results (local average 55 pmc, observed minimum 24.4 pmc) do not suggest very long mean residence times. At Romuvaara, all water samples, either from deep boreholes or shallow wells, have fairly similar stable isotope compositions. However, the groundwaters from borehole KR5 are generally the lightest ones with also the lowest C-14 and H-3 contents, apparently due to structural isolation from the other, more conducting fractures.

The groundwaters at Kivetty are also fresh with an average TDS of 150 mg/l. The local main water types are Ca-Mg-Na-HCO_3, and Mg-Ca-HCO_3 in the gabbro areas. Most of the Kivetty area is fairly flat with an average altitude of 180 m a.s.l. The bedrock of Kivetty is characterized by rather steep fractures with nearly similar hydrological conductivities compared with Romuvaara (Saksa *et al.*, 1992). Iron oxide has also been observed down to a depth of 60–200 m. The structural bedrock model created during the preliminary site investigations (1986–1992) is not in very good agreement with the isotopice results of the hydrogeochemical studies. The C-14 data refer to rather long residence times with a local average of 34 pmc and a minimum of 8.8 pmc. The tritium values are also very low, usually H-3 < 5 TU. At Kivetty variations in the stable isotope contents can be seen especially for borehole KR2 with lower overall H-2 and O-18 contents. This can be due to the isolating effects of some very dominating fracture zones. The low H-2 and O-18 values of the KR2 samples suggesting cooler recharge conditions and longer residence times are also confirmed by the low C-14 and H-3 data and the elevated Cl values, lower total uranium contents and moderately high U-234/U-238 ratios. The overall contents of U and Rn in the Kivetty groundwaters are higher compared with Romuvaara, reflecting the local geological surroundings.

The representativeness of the groundwater samples gathered from boreholes with the multi-packer equipment is much better compared with those taken from open boreholes. The quite long pumping periods before sampling have also reduced contamination of the remaining flushing water. The hydrogeochemical studies will be continued together with thorough mineralogical investigations in order to evaluate the water-rock interaction in more detail and to perform a site-specific 3D hydrogeochemical modelling.

References

Lampen, P.H. and Snellman, M.V. (1993) *Nuclear Waste Commission of the Finnish Power Companies. Report YJT-93-14.*

Ruotsalainen, P.H., Snellman, M.V., Helenius, J., Keinonen, M., Oksa, M.1(994) *The field guide for the hydrogeochemical studies of TVO* (in Finnish with an English abstract). In preparation.

Saksa, P. (ed.), Paananen, M., Paulamäki, S., Anttila, P., Ahokas, H., Pitkänen, P., Front., K., Vaittinen, T. (1991) *Nuclear Waste Commission of the Finnish Power Companies. Report YJT-91-55.*

Saksa, P. (ed.), Paulamäki, S., Paananen, M., Anttila, P., Ahokas, H., Front, K., Pitkänen, P., Korkealaakso, J., Okko, O. (1992) *Nuclear Waste Commission of the Finnish Power Companies. Report YJT-92-61.*

Teollisuuden Voima Oy (1993) *Report PATU-93-01E*

Öhberg, A. (1991) *Nuclear Waste Commission of the Finnish Power Companies. Report YJT-91-06.*