STRIPA PROJECT 90-08

Site Characterization and Validation – Hydrochemical Investigations Stage 3

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TECHNICAL REPORT

STRIPA PROJECT

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SITE CHARACTERIZATION AND VALIDATION -

HYDROCHEMICAL INVESTIGATIONS

STAGE 3

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ABSTRACT

The objective for the Stage III hydrochemical investigations was to classify groundwater and to determine the different flow paths within the investigated SCV-site by using water analyses from the C and D boreholes. The models for the hydrochemistry in the SCV-site have been compared with Stage 1 predictions framed by Wikberg et. al. (1988).

The water was divided into three classes shallow (A), mixed (B) and deep groundwater (C). This division was based on Cl and HCO_3 concentration.

The local geohydrological situation in the SCV-site can be divided into a disturbed situation and an undisturbed situation. The disturbed situation refers to the occasion when the boreholes are open for sampling. The undisturbed situation is the flow situation when the boreholes are sealed. This affects the flow paths and changes the flow direction.

Opening of the boreholes and sampling causes a disturbance of hydrochemical conditions. Three water types were found in the important water conductors, the GB and the GH zones. Shallow water (A-type) is flowing downwards while deep groundwater (C-type) is flowing upwards driven by the pumping of the mine. Where the two water types meet a zone of approximately 30 m thickness with mixed (B-type) water is formed. The flow situation is revealed by the geohydrological measurements

At undisturbed conditions shallow water (A-type) is flowing down in the investigated zones. The B and C water types are then found at a deeper level than during disturbed conditions.

A regional model can be constructed based on the described chemical and geohydrological investigations. Shallow water from the top and deep groundwater from below are drawn towards the mine by the pumping. Where these waters meet mixed water is formed.

Keywords: Crystalline bedrock, deep groundwater, mixed groundwater, shallow groundwater, multivariate analysis, flow paths, pressure head.

SUMMARY

The following conclusions of the hydrochemical investigation at the Stage III in the Stripa project can be made.

The water was divided into three classes shallow (A), mixed (B) and deep groundwater (C). This division was based on Cl and HCO_3 concentrations. A-type waters have low Cl (<70 mg/L) concentration but a high HCO_3 (>50 mg/L) concentration. In C-type waters the situation is reversed; high Cl (>150 mg/L) concentrations but low HCO_3 (<30 mg/L) concentrations. The B-type (Cl 70-150 mg/L) water is a result from mixing between A and C-type waters.

The local hydrochemical situation at the site can be divided into disturbed (sampling occasions) and undisturbed conditions (sealed boreholes). The flow directions are different at these two occasions. During disturbed conditions the three water types (A, B and C) are found at the site. The most important water conductors are the GB and GH zones. Shallow water is flowing downwards to the point where deep groundwater is flowing upwards, here mixed water is formed. The flow is driven by the pumping of the mine. Calculated and observed values showed calcite precipitation to occur as a result of mixing. This process can act as a retardation factor for the radionuclide transport.

At undisturbed conditions downward flowing shallow water is found in the fracture zones GB and GH. This is induced by the pumping of the mine and the sealed boreholes. Mixed and Deep water is found at a deeper level than during disturbed conditions. The geohydrological situation affects the groundwater composition. This interrelation can be used to derive the pressure head from genuine chemical data.

The regional groundwater situation is affected by the pumping of the mine. Shallow water from the top and deep groundwater from below is drawn towards the mine. Where these waters meet mixed water is formed.

The investigation was compared with Stage 1 modelling and predictions. The same water types and flow directions were found. The old models were adjusted according to the new findings.

CONTENTS

1 INTRODUCTION

The objective for the Stage III hydrochemical investigations was to classify groundwater and to determine the different flow paths within the investigated SCV-site by using water analyses from the C and D boreholes. The models for the hydrochemistry in the SCV-site has been compared with Stage 1 predictions framed by Wikberg et. al. (1988).

The chemical analyses include pH, Na, Ca, K, Mg, Si, Cl, Br, SO_4 and HCO_3. These elements describe the groundwater composition and can therefore be used as an indication for the flow paths. This understanding can be used in the safety evaluation of spent nuclear fuel repositories in hard bedrock. Water composition and flow can influence such safety related processes as corrosion, waste form dissolution, near-field chemical stability and radionuclide migration.

In the modelling a statistical method called multivariate analysis (MV-analysis) was performed by using the computer code PARVUS (Fiorina et al., 1988). Several or all of the chemical variables in the data matrix are simultaneously examined with this method. Data can be explored, minimized, structured, correlated and classified.

2 RESULTS AND QUALITY OF THE SAMPLES

The most conductive sections in the C and D boreholes, inflow 1 - 510 ml/min, were sampled. The chemical components were analysed using ICP, ion chromatography, titrimetric and spectrophotometric methods. The results of the analyses are summarized in Appendix 1.

The aim was to classify the water into different water types so that a comparison with earlier investgations could be made, not to do a complete chemical characterisation. Hence, only a few major components were analysed. The sampling was performed in connection with other types of measurements in the site. Ordinary routines such as filtration or in situ analyses of the waters were therefore not practically to do. This was instead made when the samples arrived to the laboratory.

As a quality criterion for chemical analyses we used the ion balance which should be within +/- 10% for acceptability. The ion balance calculations showed the ratio between anions and cations to be erroneous for the C1:1, C3:2 and C4:1 samples (A-C Nilsson pers. comm.). The results from the analyses of these samples are marked in appendix 1 and should be used with care. Earlier water data from the area was used to construct a water composition model. MV-analysis (principal component analysis) was then used to suggest the reason for the deviation between the model and measured values. The errors were indicated in the sulphate values for these samples.

The transportation of the samples affects the reliability of the pH value. The waters have a low buffer capacity causing the pH to decrease if carbon dioxide from the air affects the samples. Therefore, measured pH values are uncertain and PHREEQE (Parkhurst et. al. 1988) calculations indicate the pH to be 0.4

to 1.2 units higher for the samples from the D boreholes. The measured pH values have therefore been corrected with these quantities in the mixing modelling in section 4.1.

3 WATER CLASSIFICATION

The MV-analyse showed that Cl and HCO_3 are the only variables needed to classify the waters from the site into three categories suggested by Wikberg et. al. (1988). The probability is lower than 1% to classify the samples erroneously by using these two variables. The categories are; shallow (A), mixed (B) and deep groundwater (C) according to table 1.

Table 1. Water classification

Water type	Cl(mg/L)	HCO_3(mg/L)
A (shallow)	<70	>50
B (mixed)	70-150	30-50
C (deep)	>150	<30

A-type waters have low Cl concentration but a high HCO_3 concentration. In C-type waters the situation is reversed, high Cl concentrations but low HCO_3 concentrations. The B-type water is a result from mixing between A and C-type waters. The samples are divided into these classes in appendix 1.

4 LOCAL HYDROCHEMICAL MODEL

4.1 Disturbed conditions

The local geohydrological situation in the SCV-site can be divided into a disturbed situation and an undisturbed situation. Disturbed situation refers to the occasion when the boreholes are open for sampling. The undisturbed situation is the flow situation when the boreholes are sealed. This affects the flow paths and changes the flow direction.

Opening of the boreholes and sampling causes a disturbance of the hydrochemical conditions. The three water types were found in the important water conductors, the GB and the GH zones. Shallow water (A-type) is flowing downwards while deep groundwater (C-type) is flowing upwards driven by the pumping of the mine. Where the two water types meet a zone of approximately 30 m thickness with mixed (B-type) water is formed. The flow situation is revealed by the geohydrological measurements (David Holmes pers. comm.). The flow directions and water types are presented graphically in figure 1.

Water mixed from different aquifers can result in a nonlinear over or undersaturation (Runnells, 1969). Granitic waters which are in equilibrium with respect to the fracture mineral calcite result in oversaturation if mixed (Puigdomènech and Nordstrom, 1987). This causes precipitation of the mineral from the water. Precipitation of calcite is important as a retardation factor for the radionuclide transport because of co-precipitation (Bruno and Sandino, 1987).

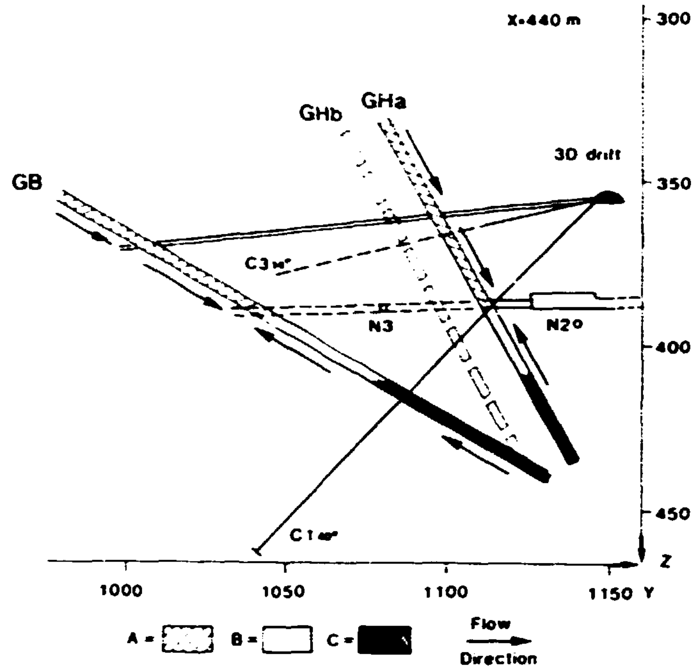

Figure 1. The local hydrochemical model with the water types (A, B and C) and the flow directions at disturbed conditions.

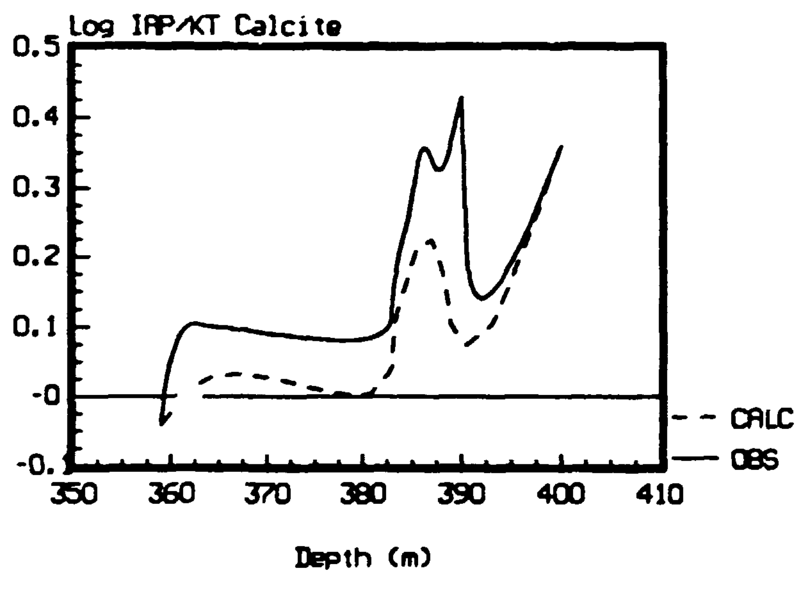

Figure 2. Mixing in the GH zone has been simulated. The calculated (CALC) saturation indexes for calcite have been compared with values based on observed (OBS) water composition.

Shallow water (W1-borehole) and deep groundwater (N2-borehole) from the GH zone were mixed in proportions (3% - 55% of deep groundwater) using the PHREEQE code. The objective was to simulate the original water composition in the mixed zone (D boreholes). The saturation index (Log IAP/KT) for calcite was then calculated for these simulated waters. The calculated indexes have been compared with indexes calculated for the real water samples from the D boreholes (see figure 2). The pH values have been adjusted according to the discussion in section 2.

The calculated and measured positive values confirm that calcite precipitates because of mixing. Calcite is also found as a fracture mineral in the geological investigations in the Stripa mine.

Calcite precipitation might therefore act as an important barrier for the radionuclide transport to the biosphere.

4.2 Undisturbed conditions

The pressure head values give the potential for water movement in the rock. Measured geohydrological data during undisturbed condition (sealed boreholes) show decreasing pressure heads with depth and therefore a downward water flow at the site (David Holmes pers. comm).

By using groundwater data the differences of the prevailing pressure heads can be calculated. The obtained values are close to the values observed in the field. The chemical data have been collected during disturbed conditions. However, the undisturbed situation can be reconstructed if the water flow direction during sampling is known. The pressure condition affects the mixing situation and thus the solute concentration of the water, as has been obtained with MV-analysis in other studies in granitic bedrock (Laaksoharju 1989).

A high groundwater table results in high pressure and dilute water while a low groundwater table gives low pressure but groundwater with high solute concentration at the measuring point. This is valid in a downward water flow situation. In an area with upward water flow, the situation is reversed. This relationship is described in equation 1.

$$1: \quad p = (+/-)\ \frac{x - a\,(y + b)}{1245}$$

Where p is pressure head (m), (+) downward flow and (-) upward flow, x is the point of measurement below the groundwater table (m), y is the chloride concentration (mg/L), a and b are coefficients (here 3.36 and 0) for the mixing line between the most and least saline water type in the area. The constant (1245) is from the Ghyben - Herzberg relation (Freeze et al., 1979). The calculations indicate a low pressure head difference (maximum 1 m or 0.1 bar) at the site. The measured pressure head values gave low pressure head difference (maximum. 4 m or 0.4 bar) (David Holmes pers. comm.) and thus show a qualitative agreement with the calculated values.

During undisturbed conditions shallow water (A-type) is flowing down. The B and C water types are then found at a deeper level than during disturbed conditions (see figure 3).

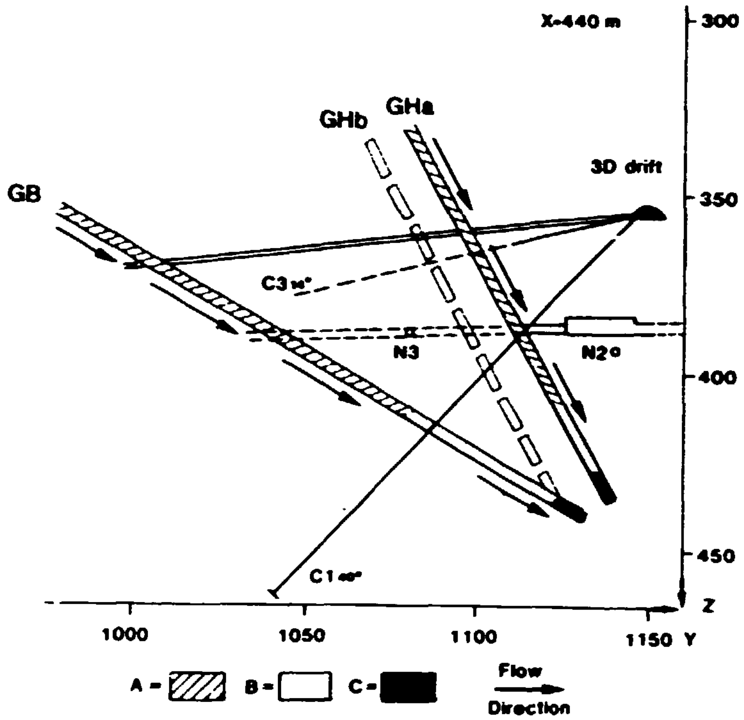

Figure 3. The local hydrochemical model with the water types (A, B and C) and the flow directions at undisturbed conditions (sealed boreholes).

Relatively small fluctuations in the groundwater level change the interface between the shallow and deep groundwater significantly. Accordingly changes in the groundwater chemistry can be understood better if geohydrology is taken into account to describe the mixing processes.

5 REGIONAL HYDROCHEMICAL MODEL

A regional model can be constructed based on the described chemical and geohydrological investigations. Shallow water from the top and deep groundwater from below are drawn towards the mine by the pumping. Where these waters meet mixed water is formed. The regional groundwater situation is presented in figure 4.

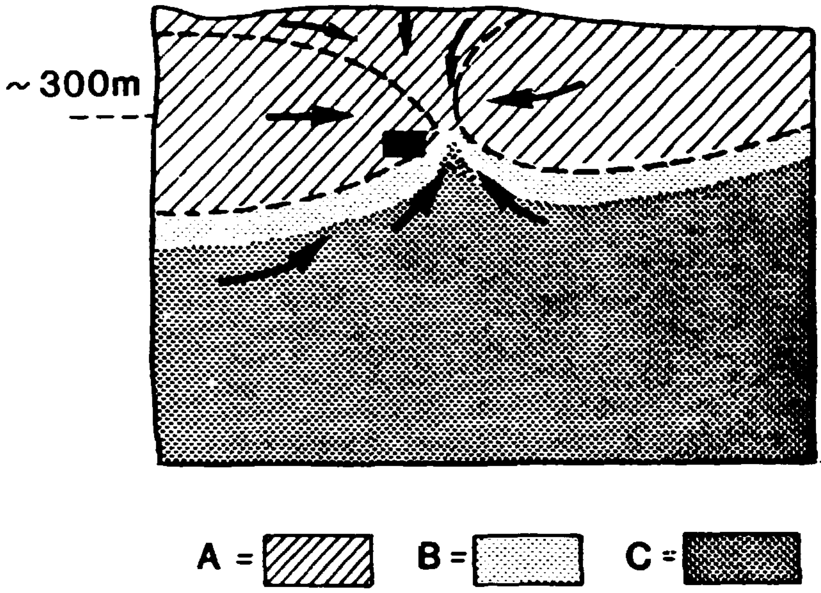

Figure 4. The regional model for the hydrochemical situation in the Stripa mine. Shallow water (A) and deep groundwater (C) is drawn to the mine because of the pumping. The mixed water (B) is formed. (Based on picture 2.10 from Olsson et. al. 1989).

6 EARLIER INVESTIGATIONS

In connection with stage 1 investigations of the SCV-site a hydrochemical investigation and modelling was performed by Wikberg et. al. (1988). The following aspects were discussed:

A) The water can be roughly divided into saline (Cl > 120 mg/L) and nonsaline (Cl < 60 mg/L). The water at the site can be divided more accurately into 3 categories; a shallow, deep and mixed water type. The elevated tritium values of some samples indicates portions of young water. High total organic carbon values are from the plastic tubing, not from the biosphere. The redox chemistry of the groundwater is determined by the Fe(II) / Fe(III) and SO_4^{2-} / S^{2-} couples and is also reflected in the behaviour of uranium. The reducing state of the water is documented by the presence of ferrous iron and sulphides. Also calculated Eh values (-270 to -370 mV) indicated these waters to be reducing.

B) The local hydrochemical model of the SCV site demonstrates GH and GB zones to be the most important water conductors. The saline water is flowing upwards in the vertical fracture zone GH driven by the drainage of the mine. In the subhorizontal fracture zone GB the saline water is mixed with the nonsaline water. This results in the mixed water type.

C) The regional hydrochemical model shows that shallow and deep groundwater are transported and form mixed water because of heavy pumping in the mine.

Our investigation confirms these earlier predictions. The same water types and flow directions have been detected. No redox couples were analysed, verification of the redox conditions were therefore not made. The local and regional models have been established by using more measured and calculated chemical and geohydrological data.

7 ACKNOWLEDGEMENTS

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APPENDIX 1

The results of the chemical analyses

Bore-hole	Level m	Water Type	pH	Na (mg/l)	Ca (mg/l)	K (mg/l)	Mg (mg/l)	Si (mg/l)	F (mg/l)	Cl (mg/l)	Br (mg/l)	SO4 (mg/l)	HCO3 (mg/l)	Ion bal %	Flow ml/min	Sampled Zone
D2:1	24.87	B	7.8	71.8	36.6	0.5	0.44	6.0	3.4	143	1.2	1.3	56	-1.70	42	GH
D2:2	25.82	B	7.6	66.7	35.7	0.5	0.53	6.0	3.6	126	1.2	1.3	55	0.53	25	GH
D3:1	26.00	B	7.9	54.8	26.0	0.4	0.27	6.0	3.8	84	0.7	1.4	68	-0.34	34	GH
D3:2	90.51	B	7.6	59.3	25.7	0.3	0.31	5.9	4.3	72	0.6	4.3	79	3.09	22	GB
D4:1	27.02	A	8.2	46.4	20.1	0.6	0.38	6.2	4.2	46	0.4	2.3	85	1.73	43	GH
D4:2	89.77	A	8.5	48.5	13.1	0.3	0.21	6.1	5.1	26	0.2	4.4	101	0.97	43	GB
D5:1	81.75	A	8.4	54.9	17.8	0.2	0.17	6.1	5.0	59	0.5	2.7	78	0.49	17	GB
D5:2	87.13	A	8.7	47.8	14.4	0.3	0.19	6.2	4.9	30	0.3	3.5	97	0.91	45	GB
D6:1	25.98	B	8.0	66.6	32.7	0.6	0.36	6.1	3.4	118	1.0	1.3	60	0.37	31	GH
D6:2	81.04	A	8.5	55.4	18.1	0.4	0.16	6.2	4.7	59	0.6	2.6	77	1.60	40	GB
D6:3	86.59	A	8.4	49.3	15.5	0.4	0.26	6.2	5.7	38	0.4	4.0	92	-0.47	51	GB
C1:1*	1-39	A	7.8	53.8	5.0	0.3	0.13	0.4		29		17.4	36	19.09	1	GC
C1:2	40-70	A	8.2	51.5	21.4	0.4	0.34	6.0		67		2.7	80	1.27	510	GH
C1:3	71-105	C	7.1	70.3	37.6	0.4	0.22	2.3		168		6.8	17	-1.89	31	GB
C1:4	106-15	C	7.2	71.6	54.8	0.4	0.12	5.5		203		5.2	18	-2.13	11	GI
C2:1	1-70	A	8.1	44.7	17.8	0.3	0.23	5.4		48		1.7	83	2.14	348	GH
C2:2	71-86	C	7.3	74.0	36.5	0.3	0.29	3.5		173		5.0	24	-2.97	50	GB
C2:3	87-124	C	7.1	76.4	36.1	0.6	0.31	1.1		178		5.3	14	-1.84	5	GA
C2:4	125-14	C	6.1	74.4	40.8	0.3	0.27	5.1		188		31.6	29	-9.64	1	GA
C3:1	1-70	A	7.0	40.5	13.8	1.1	1.20	0.3		60		21.2	44	-4.90	39	GH
C3:2*	71-100	A	7.6	38.1	13.2	2.2	1.20	5.0		29		32.3	125	-17.80	13	GH
C4:1*	2-61	A	7.8	41.7	22.1	0.9	2.10	2.4		44		6.6	30	24.97	2	GH
C5:1	1-70	A	8.1	28.4	38.2	2.2	5.90	4.3		49		18.9	113	0.79	14	GH
C5:2	71-140	B	8.1	51.1	39.7	1.5	3.80	4.9		108		11.4	78	-0.23	47	GH

* = poor quality

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