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THE INFLUENCE OF EFFLUENT WATER DISCHARGED FROM THE NÁMAFJALL GEOTHERMAL FIELD ON LOCAL GROUNDWATER

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ABSTRACT

The Námafjall geothermal field has been produced for the last thirty years. The effluent water has been discharged at the surface and there is concern about the possible effect on the extraordinary nature in and around Lake Mývatn only two km away. Tracer tests made in the early 1980's indicated a relatively slow groundwater flow from the site of the geothermal field towards Lake Mývatn. On the other hand there is a rapid surface flow observed in open fissures in the area to the south and west. Recent tracer tests using potassium iodide and fluorescent dyes support this indicating that the effluent flow is partly along fissures and partly a slower groundwater flow system. Up to ¼ of injected iodide tracer had been recovered within two weeks. The iodide tracer test reults point to an extended dilution and mixing within the groundwater system.

1. INTRODUCTION

Námafjall geothermal area is located about two km east of Lake Mývatn and has been in production for the last 30 years (Fig. 1). Steam from the production wells has been used for drying purposes in a diatomite factory as well as production of 3 MW of electricity and heating of the small village, Reykjahlíð. Within the Mývatn area nature is extraordinary, with flourishingbird and other wildlife, and it has been one of the most visited tourist attractions in Iceland for years. The life in Lake Mývatn has adapted to the warm spring water flowing naturally into the lake from the east. It is important to obtain information about the flow path of the effluent water discharged from the Námafjall geothermal area in order to evaluate its effect on the biology of the lake. Plans for building a new power plant have put increased emphasis on research on groundwater in the area and specially on the possibility of effluent water reaching Lake Mývatn, the time it takes and the extent of dilution underway. At present, the discharge pond by the production wells in Námafjall drains into a NA-SW fissure, which then extends to the south towards Grjótagjá.

1.1 Groundwater hydrology of the area

Groundwater in the Mývatn region has been divided into five groups based on chemical and isotope concentrations (Ármannsson *et al*., 1998). Figure 1 shows the basic trends of the flow pattern where the warm groundwater flow is confined to the Ytriflói part of the lake (Ólafsson, 1979b). The five groundwater groups are traced to three main streams of cold groundwater. They all show signs of geothermal impact to a different extent. These include cooling geothermal water and different mixtures of effluent water and cold groundwater. The groundwater flow rates from the east coast of Lake Mývatn to the Ytriflói is estimated to be around 7 m^3/s and to the Syðriflói it is around 21 m^3/s (Ólafsson, 1979b) Measurements of the flow velocity in Grjótagjá fissure (Fig 1.) suggest that the surface flow in the top layer of the groundwater in the fissures is very fast, up to 3,5 m/s, but at a depth of 2-4 m the flow becomes disturbed and obvious mixing occurs (Thóroddsson and Sigbjarnarson, 1983).

1.2 Volcanic influence on groundwater geochemistry

The Mývatn area has experienced several volcanic episodes since the end of the last glaciation period. The oldest lava flows are dated at 6400-7000 BP and the most recent flows were formed during the Mývatn fires in 1724-1729 (Thórarinsson, 1979, Sæmundsson, 1991). In 1975 volcanic activity started in the Krafla volcanic centre located some 10 km to the north of the Námafjall geothermal area. The volcanic impact during the volcanic activity did greatly overshadow the effect of any effluent water from the producing wells in the field (Zeeuw and Gíslason, 1988). This was most obvious in Grjótagjá, which is located at the centre of the groundwater system, and experienced a temperature increase of 15°C (Ólafsson and Kristmannsdóttir, 1989).

2. TRACER TESTS

2.1 Earlier tracer tests

In 1981 and 1982 two tracer test were carried out using Na-fluoreschein as tracer. The main purpose of these tests was to follow the flow path of the discharge from the diatomite plant. Figure 1 shows where Na-fluoreschein was injected in two places; into the discharge water about 1 km east of the lake shore (A in Fig.1) and into the diatomite slurry reservoir just north from the plant (B). In general the results confirmed the previous flow paths suggested by Ólafsson (1979b) where the fluoreschein was recovered in springs in Ytriflói west from the plant. The travel time of the fluoreschein from the diatomite plant to the lake was around two weeks.

2.2 Recent tracer tests

When choosing a tracer for the project the results of the 1981 and 1982 tests were taken into consideration. The tracer needs to be readily soluble in water and should be easy to measure at low concentrations. It should not be expensive, analyses should be simple and it has to be harmless to the environment. Both Na-fluoreschein and Rhodamine WT fluorescent dyes satisfy the demands made. Potassium iodide has also been used as an efficient tracer (Gaspar, 1987).

Rhodamine WT tracer test

In the summer of 1998 3 l of 20% Rhodamine WT solution were released into the discharge pond of Námafjall geothermal plant (C) to trace the effluent water discharged from the geothermal power plant. The discharge pond drains into a NE-SW trending fissure which is suspected to extend to or be a part of the same fissure as Grjótagjá (14). Samples were collected in 14 places either from the open fissures or springs along the east coast of the lake (Fig. 1, Table 1).

The Rhodamine WT was not recovered with certainty at any of the locations sampled during the following two months. The lack of recovery can be partly explained by the high concentrations of diatomite slurry and residual silica in the lava flows around the effluent discharge pond. Rhodamine WT is known to be readily adsorbed to clays (Smart and Laidlaw, 1977) and high concentrations of silica have been shown to greatly affect the stability of the tracer (Hauksson, 1981). Some 20 years ago there were reports of diatomite pollution in groundwater in the Mývatn area (Ólafsson, 1979a). This together with the effluent water from the geothermal power plant which contains very high concentrations of silica is most likely responsible for Rhodamine WT not being recovered.

Potassium iodide tracer test

In September 1998 some 100 kg of potassium iodide were mixed into the effluent water pond at the same location as the Rhodamine WT some months earlier. Samples were collected at the same 14 locations as described before (Fig. 1), and sampling started two days after injection. This was assumed to be sufficient with regard to results of earlier tracer tests but by the time the first samples were analysed it was clear that the iodide had travelled fast through the groundwater system (Fig. 2). Figures 2a-d show the concentration of the iodide recovered from four of the sample locations. The results have been recalculated to eliminate the natural water concentrations found in . The recovery was very low for Grjótagjá but early samples from Hverfjall, in the southern part of the same fissure, contained iodide in significant amounts. Such early recovery was also observed for the locations Helgavogur (11) and Vogaflói (20) (Figs. 2c, 2d).

Na-fluoreschein tracer test

An effort was made to fill into the gap left out in the two first days of the iodide tracer test. Na-fluoreschein was used as a tracer as it had not been used in the previous tests and there was no danger of overlap from earlier tests. This is important as it was observed during this test that iodide was still being recovered after four months. The Na-fluoreschein tracer was injected into the effluent water in January 1999 and samples collected from six locations; Langivogur (10), Grjótagjá (14), Bjarg (18), Hverfjall (19), Strandarvogur (20) and Garðslind (22). Figures 3a and 3b show the recovery at two locations, Grjótagjá and Bjarg. The maximum concentration detected is not enough for recovery and flow rate calculations. Na-fluoreschein has a complicated molecular structure and adsorption to aquifer material has to be expected (Smart and Laidlaw, 1977, Sabatimi and Austin 1991). It is obvious from this data that the tracer is detected very soon after injection from Grjótagjá, but considerably later at Bjarg. The distance of these locations from the effluent water pond is similar, 2,5 km for the former and 3,0 km for the latter.

2.3 Interpretations of tracer test results

The Rhodamine WT and Na-fluoreschein dyes were not recovered in concentrations high enough for numeric interpretation. This is thought to be due to adsorption of the compounds to clays, diatomite slurry and silica polymers (Smart and Laidlaw, 1977). From the limited data recovered in the Na-fluoreschein test there is an obvious difference in the residence time of the tracer in Grjótagjá and Bjarg (Fig. 3). The maximum amount is recovered quickly in the SW-NE trending fissure of Grjótagjá but the groundwater flow is much slower towards Bjarg, east of the effluent pond at Námafjall.

The recovery of iodide was estimated by integration of graphs as shown in Figure 2 for all the springs along the east shore of the lake. This gave r/q where r is recovery and q is the mass flow rate (Table 2). As the flow rate (q) at each of the locations is unknown, the flow rate was estimated by calculating the velocity of the groundwater flow from Námafjall by recording for the breakthrough curve at each location. This is listed in table 2 along with estimated flow velocity and temperature. The mean recovery for the locations where the groundwater flows into the Ytriflói part of the lake is 0,0034 kg.s/kg and the mean velocity is 0,012 m/s. For the springs sampled in the Syðriflói part the mean recovery rate is 0,0015 kg.s/kg and the mean groundwater flow velocity is 0,022 m/min. Based on flow rate estimates by Ólafsson (1979b) the groundwater flow rate for the springs sampled in Ytriflói is estimated at 3,5 m^3/s and 7 m^3/s for the springs in Syðriflói.

There is a strong correlation between temperature and distance from the Námafjall geothermal area (Table 2). The water cools with distance from the place where the effluent water is discharged as it mixes with cold groundwater from the south. There also seems to be a correlation between the groundwater velocity, calculated from the recovery of the iodide tracer, and temperature. This indicates that the velocity of the groundwater increases as the water is colder and further away from the Námafjall area. It is therefore suggested that the velocity of the cold groundwater flow is faster than that of the warm groundwater flow.

According to the estimates of flow rates and velocities from the maximum recovery of iodide tracer, the amount of recovered iodide the first two weeks was app. 20 kg which is ¼ of the iodide used. The maximum concentration analysed was significantly lower than what would be expected from the estimates of the flow rate in the area and the observed flow velocity in the fissures. The tracer seems to have been significantly diluted and well mixed within the groundwater system.

Samples were collected for a longer period from the Grjótagjá sample location (14). There a second maximum recovery was observed some 3-4 months after the tracer was injected. This result strongly supports the conclusion that there exist two groundwater flows at different flow rates.

3. CONCLUSIONS

Rhodamine WT and Na-fluoreschein fluorescent dyes can not be used as tracers in this area because of adsorption to clays, diatomite slurry and silica polymers.

The results of the iodide tracer test suggest that the velocity of a part of the groundwater flow is high but also that the tracer has been dispersed widely through the system. This is supported by low concentrations at the maximum breakthrough point and that the iodide was recovered at widely distributed sample locations.

The groundwater flow is divided into a cold and warm part, the velocity of the cold appears to be significantly higher than the warm.

The groundwater flow from Námafjall geothermal field is fast along the open fissures SW from the discharge pond. The flow seems to be considerably slower to the west towards the lake, at right angles to the direction of fissures in the area.

The results of this project also indicates that a fair increase in the amount of effluent water from Námafjall geothermal field discharged into the groundwater system will probably not prove disastrous.

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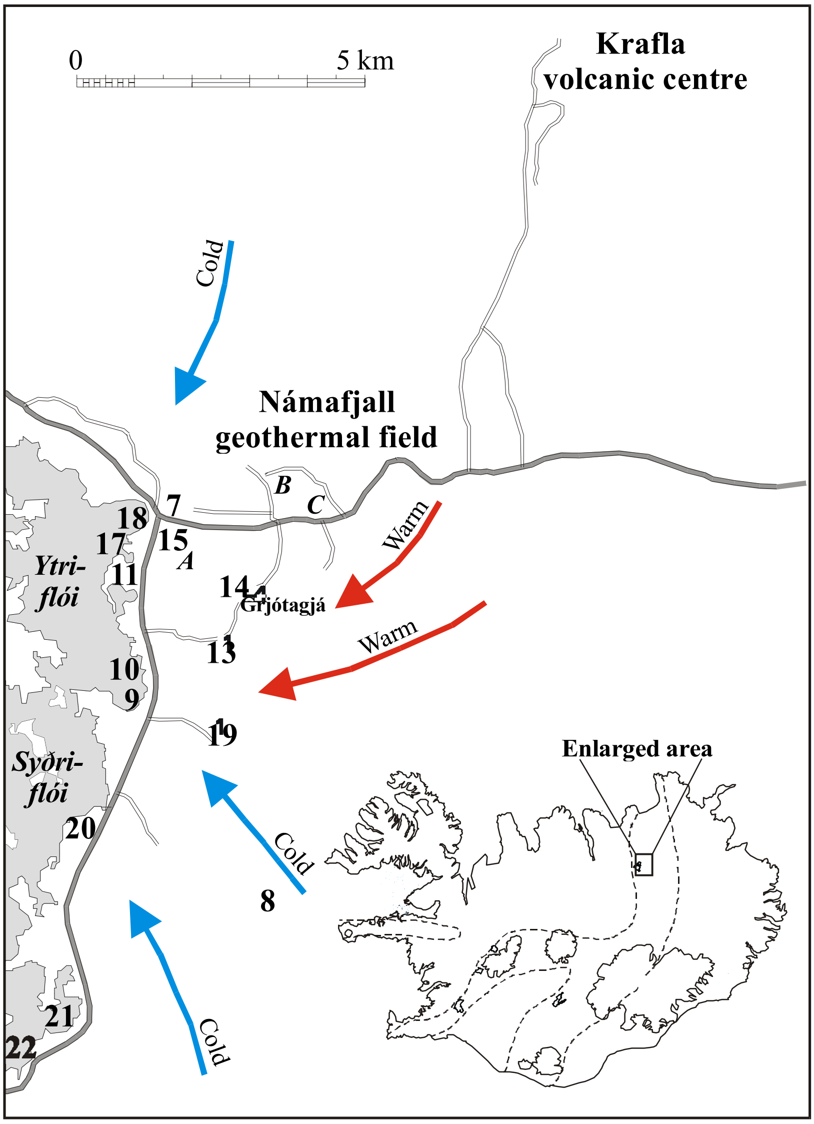

Figure 1. Map showing the easten part of Lake Mývatn, the sampling locations for the tracer tests and suggested flow pattern for the groundwater flow (Ólafsson, 1979b, Thóroddsson and Sigurbjarnarson, 1983).

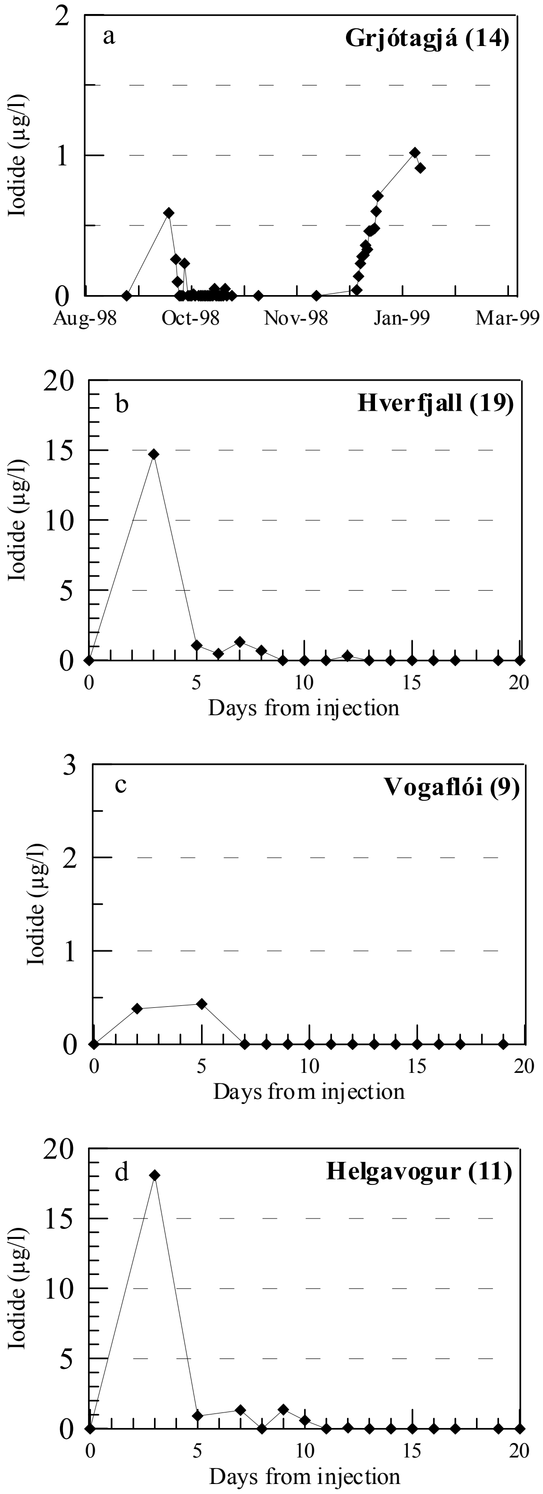

Figure 2a-d. Recovery of iodide at Grjótagjá, Hverfjall, Vogaflói and Helgavogur sample locations.

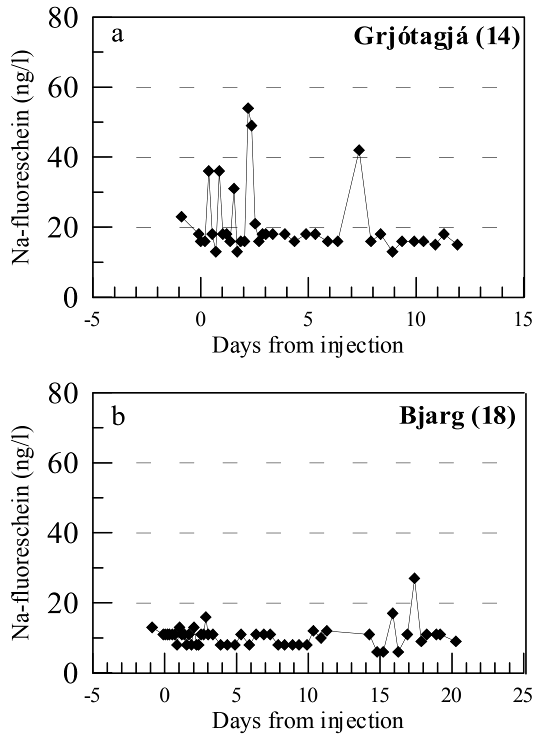

Figure 3a-b. Recovery of Na-fluoreschein at sample locations Grjótagjá and Bjarg.

Table1. Sampling locations for tracer tests in 1998-1999. Numbers refer to Figure 1.

Sampling location	Number
Egilshola, borehole	7
Helgagjá, fissure	8
Vogaflói, spring	9
Langivogur, spring	10
Helgavogur, spring	11
Vogagjá, fissure	13
Grjótagjá, fissure	14
Stóragjá, fissure	15
Helgavogur, borehole	17
Bjarg, spring	18
Hverfjallsgjá, fissure	19
Strandarvogur, spring	20
Grjótavogur, spring	21
Garður, spring	22

Table 2. Results from the interpretation of the iodide tracer test.

Loc. (nr.)	days	dist. (km)	r/q (kg.s/kg)	max. (days)	veloc. (m/min)	temp (°C)
14	27	2,5	0,000462	4,5	0,39	47
13	27	3,0	0,00303	5,0	0,42	42
19	20	4,5	0,00397	3,0	1,0	6
8	19	7,0	0,000207	8	0,61	7
22	19	11,5	0,00246	4,0	2,0	6
21	19	10	0,000664	5,5	1,3	5
20	19	6,5	0,00140	3,0	1,5	7
9	19	5,0	0,000413	3,5	1,0	6
10	19	4,0	0,00130	6,5	0,43	23
11	19	3,5	0,00476	3,0	0,81	26
17	19	3,5	0,000150	7	0,33	27
18	27	3,0	0,00355	3,0	0,69	20
7	27	2,5	0,00199	4,5	0,39	31
15	27	2,5	0,00224	3,0	0,58	29