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GEOTHERMAL INFLUENCE ON GROUNDWATER IN THE LAKE MÝVATN AREA, NORTH ICELAND

Halldór Ármannsson, Hrefna Kristmannsdóttir and Magnús Ólafsson
Orkustofnun, Grensásvegur 9, IS-108, Reykjavík, Iceland

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ABSTRACT

Cold groundwater and geothermal effluent in the Lake Mývatn area has been divided into six distinct groups according to origin and geothermal influence. This division is based on stable isotope ratios, chemical composition and geographical positions. The groundwater has apparently two basically separate origins, i.e. the local high ground north of Lake Mývatn and the highlands far to the south, possibly as far south as the glacier Vatnajökull. No traces of seawater are observed and the concentrations of conservative constituents suggest extensive water-rock interaction. The waters are to a different extent affected by geothermal activity and effects of volcanic activity were noted during the Krafla fires 1975-1984. These have diminished but not disappeared completely.
The effluent from the Krafla geothermal power plant seems to travel to the east of Lake Mývatn and traces of it have not been found to enter the lake. The Námafjall diatomite plant effluent on the other hand travels along fissures to the lake. An attempt at simulating the composition of Krafla and Námafjall geothermal water by titrating local groundwater with rock at 205°C and adding volcanic gas seems promising.

1. INTRODUCTION

Drilling was started in Námafjall in 1963 and the geothermal fluid has been exploited for a diatomite plant, a district heating service and a small power plant since 1966. Drilling started in Krafla in 1974 and a power plant has been in operation there since 1978. Both areas are close to the ecologically sensitive Lake Mývatn and therefore good reasons to monitor the fate of effluent from these geothermal areas. Original plans for a dam, creating a pond in Krafla, were abandoned after production drilling due to the high enthalpy of the fluid and the consequent small liquid fraction of the effluent. Since the initiation of the power plant the effluent liquid has been discharged into a small stream which eventually flows down into the Búrfellshraun lava field (Fig. 1). In 1998 the production of the power plant was increased from 30 to 60 MW and the additional drilling caused increased unacceptable flow to the pond and reinjection of spent fluids is planned.

In Námafjall the effluent is discharged into a pond but then seeps into the lava field. In 1978 well AB-02 was drilled in Búrfellshraun close to where the Krafla effluent stream disappeared on the surface with the aim of monitoring the underground flow and possible contamination by the geothermal effluent It was monitored until 1982 and was sampled again in 1994 and has been sampled regularly during the present project. Two fissures in the Námafjall area have been monitored and also three groundwater wells until 1985 after which the wells were not accessible. Thóroddsson and Sigbjarnarson (1983) published a treatise on the groundwater in the vicinity of the Námafjall diatomite plant in which they derived flow paths for the groundwater and de Zeeuw and Gíslason (1987) carried out a survey of warm springs in the Lake Mývatn area. Darling and Ármannsson (1989) studied the stable isotope patterns in the geothermal systems and suggested flow patterns for them. Ólafsson and Kristmannsdóttir (1989) have studied the effects of the magmatic events in Krafla 1975-1984 on the Námafjall groundwater system and Tole et al. (1993) its effect on the Námafjall geothermal system. The National Power Company in Iceland is now responsible for the management of both geothermal areas and following some preliminary work carried out during an enforcement project in Iceland to study the environmental impact of geothermal exploitation (Kristmannsdóttir et al. 2000) it joined Orkustofnun in two projects aimed at establishing the flow patterns in the area. The project described in this paper involves reviewing all old data, sampling 22 locations for total chemical analysis once a year but for analysis of selected constituents every two months. The second project involves the injection of tracers into the downflows from the Krafla effluent stream and the Námafjall effluent pond and trace them to Lake Mývatn if possible (Hauksdóttir et al. 2000).

2. SAMPLING AND ANALYTICAL METHODS

Water was pumped from wells springs, and open fissures (at least 30 cm below surface), except from well AB-02 where a downhole sampler was employed, filtered through 0.22µ membrane filter, portions for metal analysis acidified with Suprapur HNO_3, H_2S determined immediately by titration but samples for the determination of pH and CO_2 preserved in air-tight glass tubes and analysed within 24 hours. AAS was used for the determination of metals, spectrophotometry for SiO_2 and B, titration with acid for CO_2, pH meter for pH, selective electrode for F and ion chromatography for the rest of the anions.

3. SAMPLING SITES

The sites are chosen to reflect on groundwater in the area so that use of the composition of the effluent discharged into it can be discerned, and thus set up a baseline against which any future contamination can be judged. The sampling sites are shown in Fig. 1 and described in Table 1.

4. ISOTOPE AND CHEMICAL COMPOSITION

The water is mostly bicarbonate water as is to be expected for groundwater in this terrain although significant sulphate contributions are observed especially in the geothermal effluent waters.

Using δD an $\delta^{18}O$ values (Fig. 2) the waters have been divided into 6 distinct groups which can also be distinguished geographically (Fig. 1). This grouping is confirmed by a Cl vs. B diagram (Fig. 3) which also shows that there is no sea water component and the B is mostly leached from rock but to a different extent.

Geothermometer temperatures are generally much higher than measured ones (Table 1), probably reflecting admixture of geothermal water. This is confirmed by a Na-K-Mg diagram which suggests immature to partially mature (or mixed) water with Na/K temperatures of 180-220°C. The pH is in the range 7 to 9.4, significantly lowest in the two springs of group II, which are the coldest springs and probably least affected by geothermal water. The pH of the water from the one well of group II is relatively high as are its geothermometer temperatures, suggesting significant admixture of geothermal water.

Several of the springs sampled during this project were sampled by De Zeeuw and Gíslason (1988) in 1983. Temperatures are significantly lower now in all the thermal springs sampled except No. 9 and 10, reflecting the gradual cooling following the heating of the groundwater system caused by the “Krafla fires” (Ólafsson and Kristmannsdóttir 1989). Their chemistry also reflects less geothermal influence now (Table 2).

5. SEASONAL VARIATIONS

Isotopic composition of the River Laxá (the outflow from Lake Mývatn) and some nearby springs obtained by Friedman et al. (1963) and Árnason (1976) and temperature measurements in the fissures in the area by Orkustofnun suggest that there might be a seasonal variation in the temperature and composition of groundwater in the area. To verify this temperature monitors were placed in the fissures Grjótagjá (location No. 14) and Stóragjá (location No. 15) but due to operational difficulties continuous records wee not obtained for the whole period. The patterns obtained suggest that there is a seasonal temperature variation of about 1°C in Grjótagjá and 0.5°C in Stóragjá with the lowest values in late winter and early spring but the highest ones in late summer, probably reflecting the effect of spring meltwater.

6. PRECIPITATION AND FLOW PATTERNS

The calculated mean annual precipitation predicted for the area based on the precipitation at nearby weather stations 1931-1960 (A.B. Sigfúsdóttir, pers. comm.) and data for more stations for the period 1961-1990 (Th. Pálsdóttir, pers. comm.) suggest that the precipitation in the high ground in the Krafla area is about 800 mm but in the low ground in the Lake Mývatn area about 400 mm and some flow from high to low ground in that direction would be expected.

A combination of the available data on groundwater table and from isotope composition over the last twentyfiveyears both from direct observation and resistivity mapping (Sigbjarnarson et al. 1974, Arnórsson and Gunnlaugsson 1976, Ingimarsson et al. 1976, Thórarinsson and Björgvinsdóttir 1980, Thóroddsson and Sigbjarnarson 1983, de Zeeuw and Gíslason 1988, Sæmundsson, pers. comm., Friedman et al. 1963, Árnason 1976, Darling and Ármannsson 1989) has led to the construction of a map showing the relative water table and thus the probable flow patterns in the area (Fig. 4), suggesting a barrier to westward flow towards Lake Mývatn from Krafla, i.e. water from Krafla seems to flow quite far south before it can turn toward Lake Mývatn. This could explain the absence of changes that could be due to geothermal influence in well AB-02 (location No. 5) which is quite close to the location where the effluent stream from Krafla disappears into the lava.

The data available on the water table in well AB-02 suggest a considerable variation but the data is too infrequent and unevenly distributed to say whether there is a seasonal variation.

7. UPTAKE OF CHEMICALS IN GROUNDWATER

The chemical composition of groundwater changes either due to water –rock interaction or mixing with different waters. To follow the whole process from original groundwater to geothermal water and then back to mixing of the geothermal water with the original groundwater involves quite complex thermodynamic calculations with assumptions about thermodynamic data and underground conditions. Some preliminary calculations have been carried out using water from Austaraselslindir (location No. 2) (Table 3) titrated with rock from Krafla (Swanteson and Kristmannsdóttir 1978, N. Óskarsson, pers. comm.) (Table 4). As it was clear that the composition of the geothermal fluid could not be due to the interaction this water and rock only, attempts were made to add volcanic gas of basic composition like that of Surtsey gas (Gerlach 1980) with additional information on the Cl_2 and F content of gas from the Krafla area from N. Óskarsson (pers. comm.) (Table 5). The calculations were done for 205°C which is considered a likely base temperature for the upper part of the Leirbotnar field in Krafla. The speciation programme SOLVEQ and the reaction path programme CHILLER (Reed and Spycher 1984, Spycher and Reed 1989a, b) were used for the calculations. Preliminary results seemed to give best fit with observed values in Krafla and Námafjall at water-rock ratio of about 10 and addition of about 20% volcanic steam. Preliminary results at these conditions are compared with the composition of one well in Krafla and one in Námafjall calculated at 205°C using the speciaton programme WATCH (Arnórsson et al. 1982, Bjarnason 1994) in Table 6. There are some differences although in most cases the degree of magnitude is the same. The use of different temperatures, finer tuning of the water-rock ratio, and addition of gas after such changes, as well as attempts at a finer variation in gas proportions should all be addressed. In the present calculation H_2 gas was assumed to be unreactive but this need not be so especially if higher temperatures are considered.

8. TRACER TESTS

The tracer test project is described in detail by Hauksdóttir et al. (2000). Tracers were injected at the points where the Krafla and Námafjall effluents are seen disappearing into the lava (Fig. 1, points A and B)) and samples collected from 14 of the chemical sampling points (locations No. 7-11; 13-15; 17-22). No tracers were recovered from the Krafla effluent injection (point B). This is consistent with the pattern shown in Fig. 4 which suggests that one needs look further east and south to trace that flow. The results for injections into the Námafjall effluent (point A) suggest that a substantial part of the effluent travels fast to the lake (2-4 days) In Grjótagjá (location No. 14) a peak was observed after 2 days and another after 4 months so there are at least two pathways by which the effluent travels at very different rates.

9. CONCLUSIONS

The groundwater in the Lake Mývatn area is to a differing extent mixed with geothermal water, mostly from natural sources. The water in most warm springs has cooled since the end of the Krafla fires with attendant changes in chemistry. Signs of effluent from the Krafla power plant have not been detected in the groundwater in the area and it seems that this probably travels underground to the east of the lake. Effluent from the Námafjall plant on the other hand travels along fissures directly to Lake Mývatn.

An attempt at modelling the change in chemistry when groundwater is heated up with rock and volcanic gas shows promise.

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Table 1. Water groups, sampling locations, measured and geothermometer temperatures for groundwater in Lake Mývatn area

Group No.	Location No.	Description	Measured temperature °C	Chalcedony temperature °C	Na/K temperature °C
I	3	Krafla efflent stream, Skarðssel	13.6	138	215
I	6	Krafla effluent stream near AB-02	9.5	125	229
II	1	Sandabotnar, spring	13.2	47	221
II	2	Krafla, old cold water well	26.5	113	245
II	4	Austarasel, spring	4.1	44	232
III	5	Búrfellshraun, lava field. Well AB-02	2.3	47	231
III	7	Reykjahlíð, well AF-01	30.8	105	208
III	11	Helgavogur south, spring	26.2	94	208
III	12	Helgavogur, north, spring	26.3	102	205
III	15	Stóragjá, fissure	29.7	102	210
III	17	Helgavogur, shallow well	27.2	96	206
III	18	Bjarg, spring	20.3	84	202
IV	8	Helgagjá, fissure	6.5	32	196
IV	9	Vogaflói, spring	5.7	32	197
IV	19	Hverfjallsgjá, fissure	5.8	43	204
IV	20	Strandarvogur, spring	6.7	39	178
IV	21	Grjótavogur, spring	5.3	34	167
IV	22	Garður, spring	5.9	34	193
V	10	Langivogur, spring	24.8	110	189
V	13	Vogagjá, fissure	42.8	133	201
V	14	Grjótagjá, fissure	47.9	138	214
VI	16	Námafjall, effluent lake	35.7	187	240

Table 2. Temperature and selected component concentrations (mg/kg) at locations sampled in 1983 and 1997

Location No.	Year	Temperature °C	pH/°C	CO_2	SiO_2	Na	K	Mg	Ca	Cl	SO_4
7	1983	37.0	8.5/22	82	129	85	8.8	2.8	17	37	113
	1997	30.8	8.1/28	113	94	67	6.0	5.2	26	14	92
9	1983	6.0	8.5/23	75	24	21	1.9	6.6	12	5.6	22
	1997	5.7	8.7/23	64	21	22	1.7	6.2	11	4.7	20
10	1983	26.5	8.6/23	104	123	80	8.0	3.7	14	25	73
	1997	24.8	8.6/23	70	103	68	4.8	3.0	11	14	85
12	1983	32.5	8.4/23	77	119	80	8.6	3.3	17	34	108
	1997	26.3	8.2/23	108	89	65	5.6	5.2	25	13	89
14	1983	53.0	8.2/20	73	178	97	12.3	2.5	15	29	54
	1997	47.9	8.2/24	116	156	76	7.4	2.9	13	18	63
15	1983	36.0	8.4/20	76	121	84	8.7	3.0	17	39	112
	1997	29.7	8.2/24	118	89	65	5.9	5.5	27	12	89

Table 3. Chemical composition (in mg/kg) of Austarasel spring water used for titration with rock and volcanic gas

pH/°C	SiO_2	Na	K	Ca	Mg	CO_2	SO_4	H_2S	Cl	F	TDS [1)]
7.62/23	26.4	7.8	1.1	8.7	5.0	40.0	5.7	0.00	2.9	0.05	164

[1)] TDS: Total dissolved solids

Table 4. Chemical composition of rock used for the titration (%)

SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	$CaCl_2$	CaF_2
50.0	13.7	5.0	7.0	0.1	6.0	10.0	3.0	0.15	3.0	0.005	0.006

Table 5. Chemical composition of gas (mole %) used for the titration

CO	CO_2	HCl	H_2	H_2O	H_2S	SO_2	S_2	HF
0.70	9.54	0.10	2.78	81.56	0.76	3.64	0.19	0.05

Table 6. Calculated composition of groundwater from Austarasel (location No.2) titrated with rock from the Krafla area at water-rock ratio 10 and temperature 205°C, with and without 22% volcanic gas added, compared to the composition of samples from wells Krafla KG-8 and Námafjall B-04 calculated at 205°C (Concentrations in mg/kg)

Component	Rock, no gas	Rock + gas	Krafla KG-8	Námafjall B-04-
pH	6.85	7.48	7.17	7.71
Cl	6.06	19.89	26.35	8.08
SO_4	0	208.5	194.1	65.43
HCO_3	55.43	700	327.6	70.16
HS	2.03	5.39	58.4	106.6
SiO_2	302.4	251.5	383.6	621.0
Al	1.22	0.38	1.15	1.18
Ca	0.02	0.41	1.42	1.33
Mg	0.0001	0.0003	0.027	0.038
Fe	0.0004	0.0001	0.024	0.008
K	5.80	24.51	20.03	23.78
Na	74.64	299.9	193.25	152.17
F	2.94	6.25	0.95	1.71

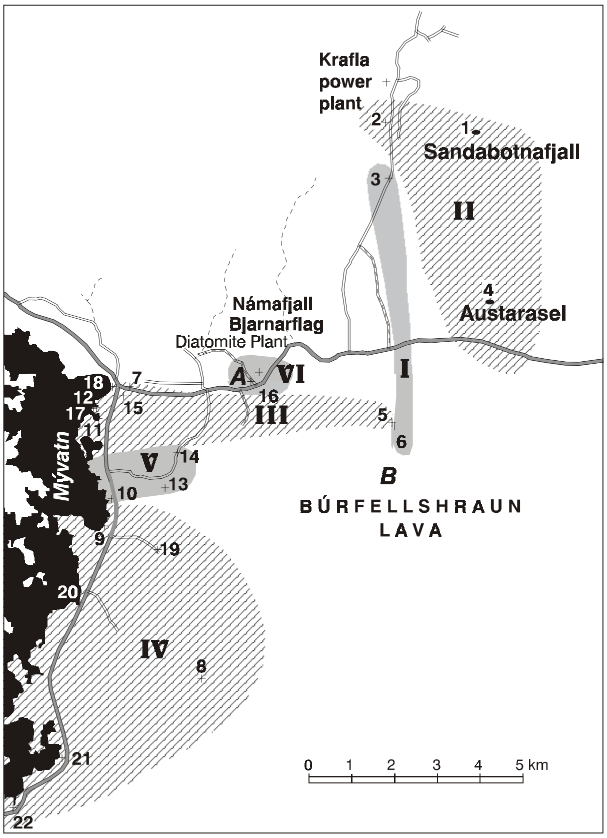

Figure 1. Map of area, showing division into groups (I-VI), sampling locations (1-22) and injection locations (A and B)

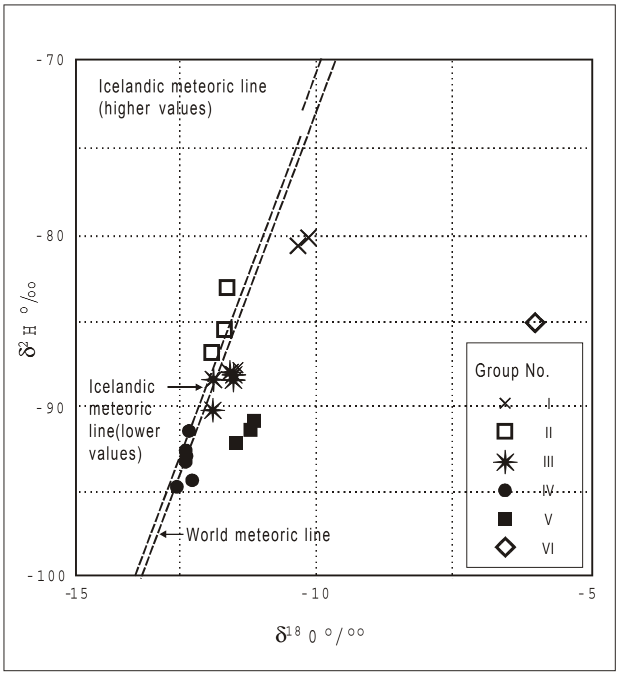

Figure 2. δD vs. $\delta^{18}O$, showing World and Icelandic meteoric lines and division into groups of the Lake Mývatn area groundwater

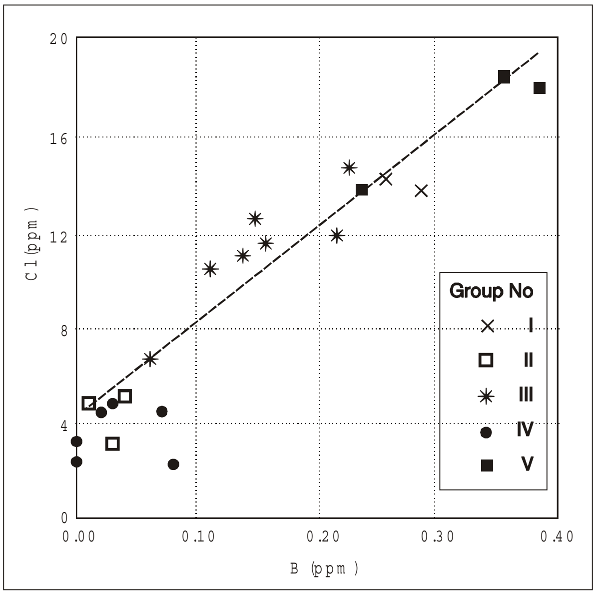

Figure 3. Cl-B diagram, showing alignment of groups. Cl in rainwater from the arae is 3-4 mg/l (Sigurðsson 1990). Hence it is deduced that there is no seawater component.

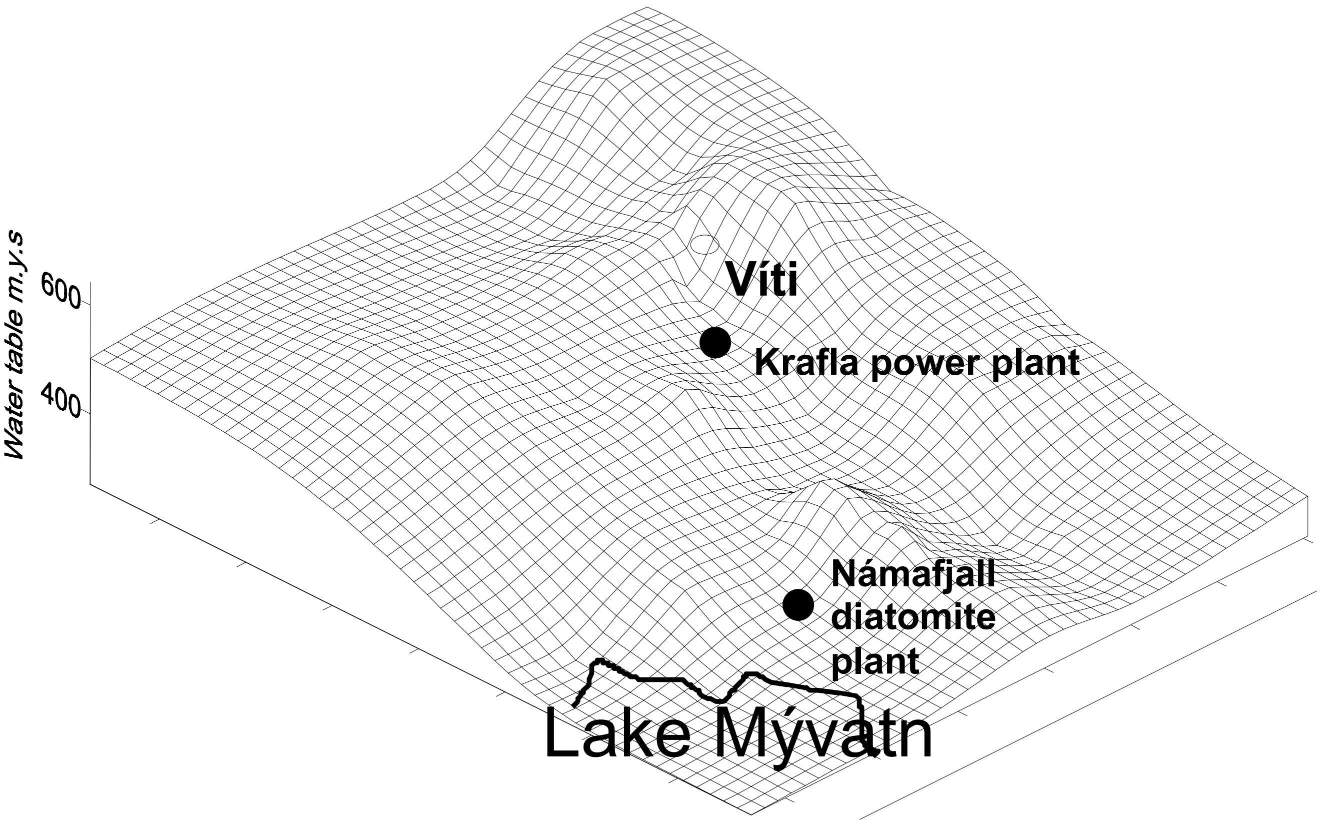

Figure 4. Water level in Lake Mývatn area