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The Reykholt and Húsafell Geothermal fields in Borgarfjördur- a Geochemical Study

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ABSTRACT

Several highly active geothermal fields are located in the Borgarfjördur region, W Iceland. Among them is the largest low-temperature field in Iceland, the Reykholt geothermal field yielding over 400 l/s of boiling water or at temperatures near to boiling. The reservoir temperatures at depth range up to 150 °C. The adjacent Húsafell geothermal field is cooler, with reservoir temperatures about 80 °C. Several geochemical exploration campaigns have been performed in the area during the last sixty years giving exellent opportunity to review changes in an area where the utilization has been exclusively from free flowing springs and wells. In the present campaign about 30 trace elements, stable isotopes, ^{14}C and Rn have been measured in addition to the main element concentration

1. INTRODUCTION

The Reykholt geothermal field which is located in western Iceland (Fig. 1) is believed to be the largest and most active low temperature geothermal field in Iceland covering an area of almost 300 km^2 (Georgsson et al., 1984). Iceland's biggest hot spring, Deildartunguhver, is one of the active geothermal manifestations, yielding about 200 l/s of boiling hot water.

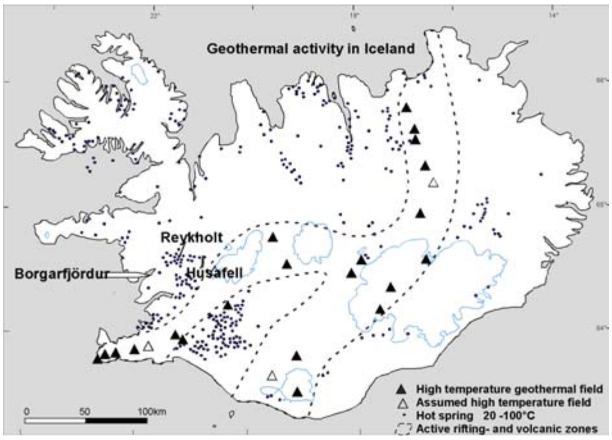

Figure 1: Location of the Reykholt and Húsafell geothermal fields. The map shows the main geothermal activity in Iceland.

The area has been studied by several scientists since the beginning of the 19th century (Thoroddsen, 1910, Thorkelsson, 1940, Jónsson, 1959, Sæmundsson, 1964, Sigvaldason, 1965, Sæmundsson et al., 1966, Arnórsson, 1969, Georgsson et al. 1978, 1984, 1985, Gunnlaugsson, 1980, Imitiaz, 1997).

The geological formations of the area consist of gently dipping lavas of late Tertiary age, Quaternary basalt floods, hyaloclastite breccias and tuffs (Arnórsson, 1968, Georgsson et al., 1978). The hills between the valleys are covered by ground morains. The Reykholtsdalur valley was transgressed by the sea after the last glaciation and the sediments in the lowlands are probably a mixture of fresh water and marine deposits. The tectonic systems are quite complicated and there has been an extensive earthquake activity in recent times (Einarsson et al. 1974). The western margin of the geothermal surface manifestations in Borgarfjördur appear to coincide with the Borgarnes anticline (Sæmundsson, 1979, Imitias, 1997). The hot springs in the Reykholtsdalur valley appear to occur at the intersection of northwesterly oriented young faults and northeasterly trending faults or dykes (Georgsson et al. 1984).

The Húsafell geothermal field is associated with an extinct central volcano (Sæmundsson and Noll, 1974, Georgsson et al., 1984) and the thermal manifestations occur along a layer of acidic tuff. There appears to be a different recharge to the two geothermal fields Reykholt and Húsafell and a mixing area between with lower temperatures.

The activity of the geothermal field in Reykholt varies with time and is believed to depend mostly on the tectonic activity and on how recently there has been movement on faults opening up the water channels and enhancing circulation and heat mining of the geothermal systems. No long term monitoring of the total yield has been made, but occasional observations show some changes with time (Georgsson et al. 1978, 1984).

In the Húsafell field there are no records available of possible changes in activity through time.

In the late 1970's there was an enforcement of geothermal exploration all over Iceland in the wake of the oil crisis and an increased awareness of the need of alternative energy sources for house heating. Geothermal exploration in the Borgarfjördur area was aimed at the installation of heating systems in the local towns of Akranes and Borgarnes as well as the rural settlements of the region not already heated by geothermal power. As a result a decision was made to utilize the hot spring Deildartunguhver for the heating of the two towns Akranes and Borgarnes even though the water had to be piped for a distance of almost 70 km. Later improved exploration techniques revealed geothermal fields much closer to those towns, but then the distribution systems had already been installed.

In the Húsafell field geothermal water from two artesian wells and a hot spring is used for the heating of a holiday resort containing almost one hundred cottages, a swimming pool, numerous jaccussi pools, several farm houses and fish farming plant

All the water utilized in the Reykholt and Húsafell fields is from free flowing springs or artesian wells. The development of the fields has thus not induced any drawdown of the water level as commonly observed where the water is produced by downhole pumping from wells.

2. GEOCHEMISTRY OF THE WATERS

Several projects entailing geochemical studies of the geothermal fields in Borgarfjördur have been carried out since about 1940. The last compilation of geochemical data before the present project was in 1997 when a few of the locations were sampled and analyzed (Imtias, 1997). In the present study about twenty samples of geothermal water were taken in the area. Several cold springs were also sampled for trace element studies in the water.

The present study is the first comprehensive study of trace elements in geothermal waters from the Borgarfjördur region and is a part of a project aimed at the mapping of trace elements in Icelandic ground waters (Kristmannsdóttir et al. 2004) and to explain the environmental processes governing their concentration and stability in the different natural environments.

Table 1. Chemical composition, of waters in the Reykholt and Húsafell fields (main elements).

Location	Reykholt	Deildart.	Áslaugar	Húsafell
Temp.°C	100	100,2	73,8	76,7
pH°C	9,25/24	9,41/24	9,75/24	9,32/24
SiO_2 mg/l	171,9	122,6	100,2	79,8
B mg/l	0,29	0,24	<0.20	0,42
Na mg/l	81,78	75,83	49,28	87,97
K mg/l	3,60	2,04	0,99	1,58
Ca mg/l	2,16	3,06	1,71	4,69
Mg mg/l	<0.002	<0.002	0,0029	0,0020
Sr mg/l	0,009	0,011	0,003	0,029
CO_2 mg/l	30,4	21,9	24,9	23,3
H_2S mg/l	1,52	1,39	0,12	0,34
Cond. µS/cm 25°C	419	400	242	502
Rn Bq/l	5,9	2,4	4,8	3,0
δ^2H ‰	-72,5	-72	-74,1	-90,0
δ^{18}O ‰	-10,06	-10,23	-10,69	-12,23
d ‰	8	9,8	11,4	7,8
SO_4 mg/l	61,1	53,6	15,9	69,3
Cl mg/l	33,1	35,3	10,3	35,9
F mg/l	2,24	2,34	1,28	14,2
Tot. Diss. Sol. mg/l	382	316	195	308

Table 1 shows the main element composition of geothermal water from selected sites in the Reykholt and Húsafell geothermal fields and from a spring between those two fields. The Deildartunga hot spring (table 1) in the Reykholt area is the largest spring in Iceland. Most of the springs in the Reykholt area are boiling, whereas the Húsafell field is colder, with maximum temperature of 76 °C.

The geothermal water in the Borgarfjördur area has rather low mineralization, with maximum TDS of around 400 mg/l (Fig. 2). The pH of the waters is generally lower than common for Icelandic low temperature geothermal waters or 9.2-9.4 (Kristmannsdóttir, 2004).

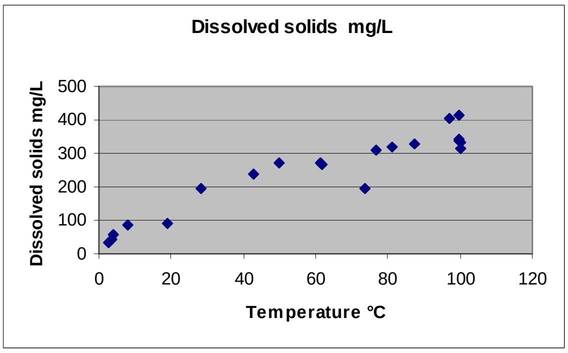

Figure 2. TDS (total dissolved solids) plotted against measured temperature at outflow for geothermal and cold water springs in the Borgarfjördur area.

The water in the area is nearly all classified as sulfate water with a few samples falling on the border line to bicarbonate water (Fig. 3). The geothermal water at Reykholt has high silica concentration and calculated silica geothermometer temperatures are about 140°C for the chalcedony geothermometer and around 160°C according to the quartz geothermometer. Alkali-feldspar geothermometers indicate reservoir temperatures of about 130-140°C. In the Húsafell geothermal field silica and alkali geothermometers indicate reservoir temperatures of 80-85 °C, which is less than 10 °C higher than obtained by drilling sofar.

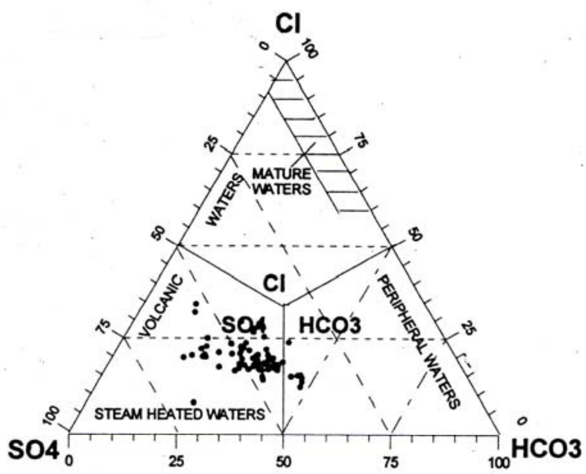

Figure 3: The classification of water from the Borgarfjördur area according to the Cl-SO_4-HCO_3 ternary diagram of Giggenbach (1991).

On a Giggenbach (1988) Na-K-Mg ternary diagram (Fig. 4) samples from Húsafell and Reykholt fall near the line for fully equilibrated waters (Imtiaz, 1997) and most other samples fall within the zone of partially equilibrated waters, indicating mixing with cold groundwater during upflow as is to be expected for samples from natural springs in a very permeable area with an active tectonism.

The recharge areas of the two geothermal fields are clearly differentiated by the stable isotope ratios (Fig. 5). The waters from the Reykholt geothermal field have δ^2H of about -72,5 and δ^{18}O of about -10, whereas the water at Húsafell is much lighter with δ^2H of about -90 and δ^{18}O of about -12.

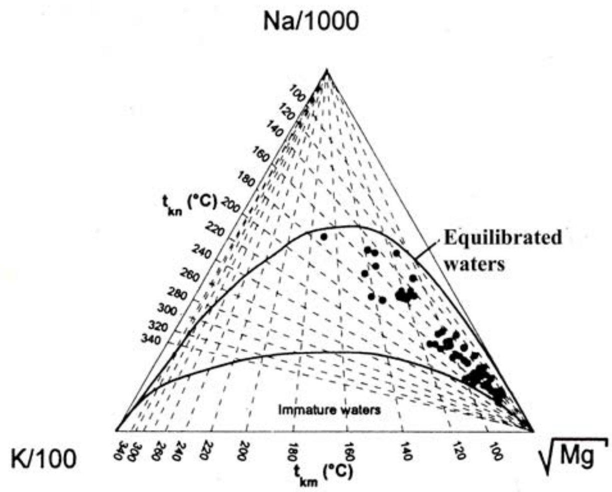

Figure 4: The composition of geothermal water from Borgarfjördur area plotted on Na-K-Mg ternary diagram (Giggenbach 1988).

There are a few springs between the fields with waters of somewhat mixed character, but still there is a distinct gap between the stable isotopic ratio of springs from the two different fields. There is observed a slight oxygen shift both for the Húsafell water and some of the hottest waters from Reykholt geothermal field. One would however not expect a distinct oxygen shift in water from the Húsafell due to the relatively low reservoir temperature.

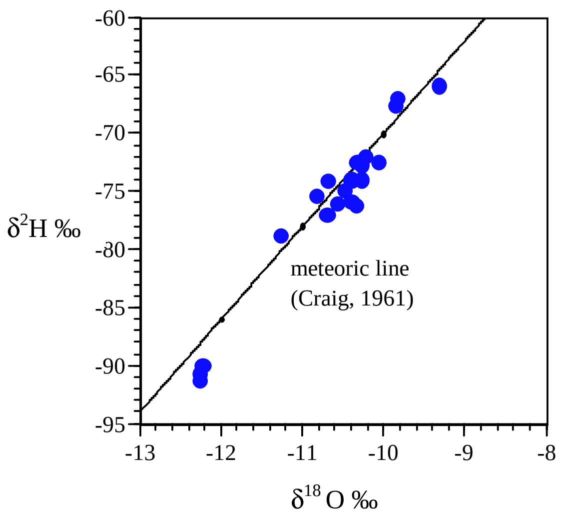

Figure 5. δ^2H plotted against δ^{18}O for the geothermal water in Reykholt and Húsafell. The location of the world meteoric line (Craig, 1961) is shown for comparison.

The radon (Rn) concentration of all the geothermal waters is low as compared to water in most other places of the world, but is similar or even rather high as compared to radon concentration commonly encountered in Icelandic waters. There appears not to be any direct correlation between temperature and radon concentration of the waters (Fig. 6). Radon concentration is believed to be in relation to seismic activity and has been used to predict larger earth-quakes (Hauksson and Goddard, 1981, Theodórsson et al., 2002). Sofar there has not been any monitoring of radon concentration through longer time in those areas. The data for radon concentration are only point measurements so any clear correlation with the most active tectonic zones in the area is not to be expected.

The geothermal water from Húsafell is somewhat different from water in the Reykholt field, due to different resource regions and the close association with an extinct central volcano. Besides the above mentioned difference in stable isotope ratio the most distinct difference is the very high concentration of fluoride (Table 1), rather high boron concentration and higher concentration of special metals as copper, zink, molybdenium, strontium, wolfram as well as higher concentration of antimony (Tables 1 and 2). The concentration of fluoride is considerably higher in the Húsafell geothermal field than encountered in any other low-temperature geothermal field in Iceland. In a few Icelandic high-temperature geothermal fields similar concentrations have been encountered (Kristmannsdóttir, 2004, Pasvanoglu et al. 2000).

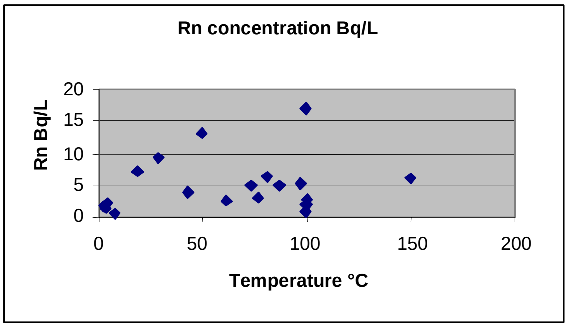

Figure 6. Concentation of Radon in geothermal water and cold water in Borgarfjördur.

In general the trace element concentration of geothermal waters from both the Reykholt and Húsafell geothermal fields (Table 2) is quite low and for many elements below the detection limit for the elements when anlysed by ICP-MS high resolution methods.

3. CHANGES BY TIME

The Reykholt and Húsafell geothermal fields are among the few places where chemical data are available over tens of years and where the utilization has not created substantial drawdown. Any change in chemistry of the waters would thus be expected to occur due to natural processes in the fields as change in tectonic activity.

No older data for most of the trace elements recorded in table 2 are available. Thus, changes by time can only be observed for the main elements.

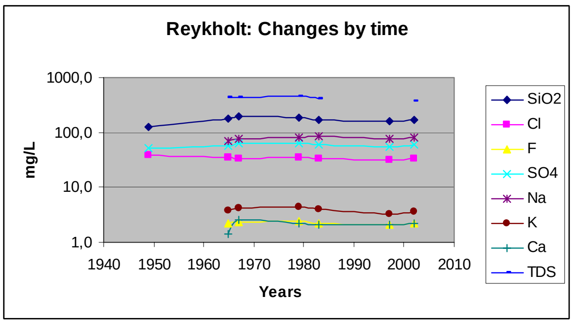

Figure 7. Concentation of selected components in geothermal water at Reykholt farm in the Reykholt field. The first 4 samples are from a spring and the later ones from a shallow well at the same site.

There exist chemical analysis from springs in Borgarfjördur from early last century, but the first analysis of a comparable quality to present day analyses are from 1949 for the Reykholt field and from 1967 for the Húsafell field.

The first well in Húsafell was drilled in 1986 so comparison is made between samples from springs before that time and after that from samples from the well. For Reykholt all samples from after 1967 are from wells, but the first sample from 1949 is from the main spring at Reykholt. In figure 7 there are shown concentration of several main components by time from Reykholt itself. In figure 8 there are shown concentration of several main components by time from the biggest spring in the field, Deildartunga. In figure 9 changes by time of the same elements as in figures 7 and 8 are shown for the Húsafell field.

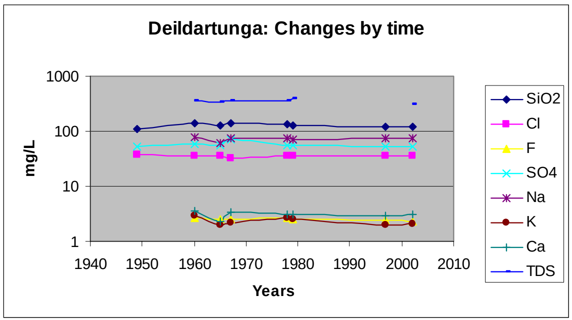

Figure 8. Concentation of selected components in geothermal water in the Deildartunga hot spring in the Reykholt field.

For all the sites it can be stated that there are very little changes to be observed by time. In both Reykholt and Deildartunga sites there may be detected some slight changes between 1960 and 1980 for some components. There appear first to be some drop in concentration followed by a general increase. Since 1979 there may be detected a slight trend of decrease of concentration of most elements. Those changes are however very slight and the samples too few to draw too many and too distinctive conclusions. The trend observed could be in accordance with the history of tectonic activity. There was reported increased tectonic activity in the area during the early seventies (Einarsson et al., 1974), but since then there has not been much tectonic activity.

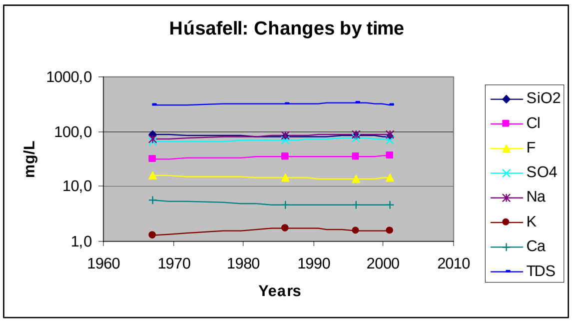

Figure 9. Concentation of selected components in geothermal water in Húsafell.

One might expect that there would be an increase of most dissolved solids in the wake of increased tectonic activity with a consequent decrease during times of little activity. The data are too scanty though too draw definite conclusions, but it would be very interesting to follow the future development in the region.

For the Húsafell field there are no significant changes in concentration by time and the chemical concentration of the water is remarkable similar in all samples from the oldest well and the chemical composition of water from the older sample from the nearby spring is also very similar.

Table 2. Trace elements composition, of waters from the same selected locations in Reykholtsdalur as in table 1 and from Húsafell.

Location	Reykholt	Deildart.	Áslaugar	Húsafell
Ag µg/l	<0.002	<0.002	<0.002	<0.002
Al µg/l	276,0	129,0	93,2	58,9
As µg/l	14,30	7,96	8,56	5,14
Au µg/l	<0.0005	<0.0005	<0.0005	<0.0005
B µg/l	278,0	245,0	101,0	402,0
Ba µg/l	0,46	0,29	0,29	0,19
Br µg/l	101,0	109,0	52,3	106,0
Cd µg/l	<0.002	<0.002	<0.002	<0.002
Co µg/l	<0.005	<0.005	<0.005	<0.005
Cr µg/l	0,018	<0.01	<0.01	<0.01
Cs µg/l	2,010	0,760	0,080	1,130
Cu µg/l	0,124	0,036	0,219	2,310
Fe µg/l	7,0	1,8	1,5	5,0
Ga µg/l	6,71	4,60	7,40	3,67
Ge µg/l	2,83	3,08	1,41	11,90
Hg µg/l	0,00	0,00	<0.002	<0.002
I µg/l	8,71	10,20	2,50	6,76
Li µg/l	45,0	26,6	5,7	25,0
Mn µg/l	1,320	0,210	0,174	0,303
Mo µg/l	23,50	19,40	13,10	64,6
Ni µg/l	<0.02	<0.02	0,024	0,410
P µg/l	0,95	0,44	0,56	0,44
Pb µg/l	0,041	<0.010	<0.010	0,018
Rb µg/l	17,50	8,33	1,69	7,23
Sb µg/l	0,0660	0,0650	0,0220	0,2810
Sn µg/l	0,379	<0.020	<0.020	<0.020
Sr µg/l	7,5	10,5	2,9	28,6
Th µg/l	<0.0020	<0.0020	<0.0020	0,0075
Ti µg/l	0,06	<0.02	0,13	0,29
Tl µg/l	0,011	0,010	0,004	0,008
U µg/l	<0.0005	<0.0005	<0,0005	<0,0005
V µg/l	0,950	0,348	0,840	1,860
W µg/l	5,000	4,680	1,880	20,400
Zn µg/l	1,10	0,15	0,25	3,33
Se µg/l	0,016	<0.008	0,017	<0.008

4. CONCLUSION

The Reykholt and the adjacent Húsafell geothermal fields in Borgarfjördur West Iceland have different recharge areas as demonstrated by a distinct difference in the stable isotope ratios of the waters. The geothermal water from Húsafell is somewhat different from water in the Reykholt field, due to different resource regions and the close association with an extinct central volcano. There are found a few springs between the fields with waters of somewhat mixed character.

The water in both fields is classified as sulfate water with a few samples falling on the border line to bicarbonate water. The waters from the central part of the fields are classified as fully equilibrated waters on a Giggenbach Na-K-Mg ternary diagram.

The reservoir temperatures range up to 150 °C in the Reykholt field, but Húsfell field is cooler with reservoir temperatures about 80 °C.

There is observed a slight oxygen shift for the hottest waters from Reykholt and also for the Húsafell water in spite of its relatively low reservoir temperature.

Geochemical data of the main comonents of the geothermal waters exist from over sixty years back giving exellent opportunity to review changes in geothermal fields where utilization has only been from free flowing springs and wells. In the present project there have in addition to main elements in the water been measured about 30 trace elements, stable isotopes, ^{14}C and Rn.

The radon (Rn) concentration of the geothermal waters in both fields is low as compared to water most other places in the world, but rather high as compared to radon concentration commonly encountered in Icelandic groundwaters.

The trace element concentration of geothermal waters from both the Reykholt and Húsafell geothermal fields is generally quite low. The Húsafell water contains higher concentration of special metals as copper, zink, molybdenium, strontium, wolfram than in the Reykholt field. The concentration of boron and as well as antimony is also higher. The concentration of fluoride is considerably higher in the Húsafell geothermal field than encountered in any other low-temperature geothermal field in Iceland.

For both the geothermal fields there are observed very slight changes in water chemistry by time. Slight changes are indicated between 1960 and 1980 for some of the main chemical components in waters from the Reykholt field. The changes may correlate with an increased tectonic activity in the area during the early seventies.

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