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SURFACE EXPLORATION AND MONITORING OF GEOTHERMAL ACTIVITY IN THE KVERKFJÖLL GEOTHERMAL AREA, CENTRAL ICELAND

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ABSTRACT

The Kverkfjöll high-temperature area is situated within the Kverkfjöll central volcano, Central Iceland. The volcano consists of a mountain massif of hyaloclastic rocks, of evolved basaltic composition, and a fissure swarm comprising lava flows, rows of craters and hyaloclastic ridges. The thermal activity of the high-temperature area, is mainly confined to three fields, one in the western part of the Kverkfjöll mountain massif and two in the eastern part of the complex. Geothermal manifestations consist of fumaroles, mudpots and hot springs and cover some 25 km^2. Gas geothermometers indicate subsurface temperatures of about 300°C within the geothermal system. Mercury concentrations in steam range from 70 to 750 ng/kg indicating higher concentrations in fumaroles with higher gas content and higher gas geothermometer temperatures.The geothermal area has been monitored with respect to thermal activity and chemistry for about ten years. No major changes have been observed.

1. INTRODUCTION

The Kverkfjöll high-temperature geothermal area is a part of the Kverkfjöll central volcano which is located in a mountainous area on the northern edge of the Vatnajökull glacier, central Iceland (Figs. 1 and 2). Geothermal manifestations cover some 25 km^2 and consist of fumaroles, mudpots and hot springs at the edge of the ice sheet.

In 1992 Orkustofnun initiated an exploration program to study the geothermal activity of the Kverkfjöll high-temperature area. The main purpose is to establish subsurface temperatures and characteristics of the geothermal system as well as to monitor natural changes occuring within a unexploited geothermal area (Ármannsson et al., 2000). Production from the area is unlikely in the foreseeable future due to its poor accessability and remote location. The monitoring program consists mainly of mapping the geology and surface thermal manifestations and sampling fumaroles and hot springs for chemical analysis. In addition, the field has been scanned twice from air by infrared thermometry. Samples of fluid from fumaroles and hot springs were collected in 1992, 1993, 1994, 1997 and 1998. Concurrently, thermal activity was mapped with emphasis on short term (i.e. annual) changes in activity. In addition a geological map of the area is in preparation, as none was available prior to this investigation.

2. GEOLOGY

The Kverkfjöll volcano is located on the northern edge of the Vatnajökull glacier, Europe's largest glacier. The geology of the area has not been described and the only account of the geothermal activity is that of Thórarinsson (1953). The volcano is situated in the north-eastern volcanic zone where it crosses Central Iceland, close to the centre of the Icelandic hot spot (Wolfe, C.J. et al. 1997). The main volcanic massif rises to 1900 m altitude, approximately 1000 m above the surrounding area. A fissure swarm with lava flows and rows of craters and hyaloclastic ridges extends NE from Kverkfjöll forming the Kverkfjöll volcanic system in which the thermal area is centrally located. The southern part of the volcanic system is covered by the glacier. The volcanic massif consists mainly of hyaloclastic rocks dating from the last glacial period up to present. About seven fissure eruptions have taken place to the north of the mountains during Holocene, one of which extends southwards, just west of the most intense thermal area. Two subglacial caldera subsidences (Fig. 3) have been proposed within the complex (Thórarinsson et al., 1973) and the observed thermal activitiy is confined to the rim of the northern caldera. The main rock types of the area consist of different types of hyaloclastic rocks of evolved basaltic composition. Rhyolitic rocks have not been encountered so far, but a thick tephra layer of intermediate composition has been observed within the basaltic hyaloclastic formation in the eastern part of Kverkfjöll.

3. GEOTHERMAL ACTIVITIY

The area in Kverkfjöll, where surface geothermal activity is apparent, covers some 25 km^2. Inside this area the activity is discontinous and strongly controlled by fractures, faults and lithology. The thermal field is rather inaccessible in a very montainous area and is to a large extent covered by the glacier. Thermal manifestations include warm and hot springs, mudpots and fumaroles. A glacial river with unusually high temperature and chemical content runs from the central part of the area, draining subglacial thermal areas.

The presently observed thermal activitiy of Kverkfjöll is mainly confined to three areas (Fig. 3). The most intense activity is in the western part of Kverkfjöll and consists of steaming fumaroles and mudpots with temperatures close to 100°C (Fig. 4). The western area, at an altitude of 1600 - 1700 m, is approximately 0.5 to 1 km wide and extends for some 3 km in the direction N30°. This area is sub-divided into three separated fields, which are from south to north;

Hveradalur, Hveraskál and Hveratagl. In addition to those three fields, active fumaroles and hot springs are found within a cauldron melted in the icecap to the south-east of Hveradalur. The big cauldron has been forming since before 1953, when it was only a depression in the ice with no steam visible (Thórarinsson 1953), but today one can walk to the bottom and sample the fumaroles and hot springs on the shore of a small lake.

The other thermal areas in Kverkfjöll are in the eastern part of the complex, between the Brúarjökull glacier and the Kverkfjöll mountains (Fig. 3), and extend to the highest peak of the mountains at more than 1900 m altitude (Thórarinsson 1953). The thermal activity of the two areas consists of hot springs in the Hveragil gorge with temperatures up to 62°C and some scattered steam outlets on the eastern flanks of Kverkfjöll, with temperature recorded as high as 84°C (Thórarinsson 1953). The flow of hot water from Hveragil has been estimated to amount to some 200 - 250 l/s with average temperature around 50°C. The water is carbonate rich and thick layers of calcite encrustations cover the bottom of the gully, as can be seen in Fig. 5.

4. GAS CHEMISTRY

A number of samples have been collected from 11 fumaroles (F-1 to F-11) in the thermal fields of the western part of Kverkfjöll as shown in Fig. 6. Several fumaroles have been sampled more than once in order to obtain information on natural changes in steam composition. Results are listed in Tables 1 and 2. Carbon dioxide is the dominant gas in all locations, amounting to 150 - 820 mmole/kg or 80 - 97% of the gas. Hydrogen and hydrogen sulphide account for 1 - 12% each. Methane concentrations are below 0.2%. Argon was measured in ten samples from 1997 and accounts for approximately 0.01% of the total gas. The amount of nitrogen and oxygen is variable, sometimes due to slight contamination by air, but in some cases due to different sampling and analytical techniques used in 1997, but not for the earlier ones. In general the concentration of gas is higher in the northern part of the thermal area than in the southern part.

Chloride and mercury concentrations have been measured in a number of steam samples from the fumaroles, as well as the stable isotopes of hydrogen and oxygen (Table 2). The chloride content is in the range 0.14 - 0.63 mg/kg and the mercury content in the range 70 - 750 ng/kg with a slight indication of increasing concentration of mercury from south to north, from Hveradalur through Hveraskál to Hveratagl. The results of determination of the stable isotopes of hydrogen and oxygen are presented in Fig. 7. The data points follow a relatively straight line off the meteoric line, indicating that the deep fluid has undergone some rather complex boiling, condensing and mixing processes.

Several gas geothermometers have been applied to the fumarole samples in order to estimate the subsurface temperature of the high-temperature system. Results are listed in Table 3. As shown in Table 3 seven gas geothermometers have been evaluated. Five are due to Arnórsson and Gunnlaugsson (1985), based on CO_2, H_2S and H_2 concentrations or their ratios, and calibrated with data from selected reservoirs that were belived to be one-phase systems. The sixth is from Arnórsson (1987), based on the CO_2/N_2 ratio of the gas and assuming that the geothermal fluid is derived from local groundwater in equilibrium with air at 5°C. The seventh gas geothermometer is from Giggenbach (1991), based on the CH_4/CO_2 ratio of the gas. The gas geothermometers show variations in temperature to some extent, but on the average the thermometers of Arnórsson and Gunnlaugsson (1985) and Arnórsson (1987), indicate a subsurface temperature of approximately 300°C for the geothermal system. On the other hand the geothermometer of Giggenbach (1991) indicates somewhat higher temperatures, approximately 350°C, reflecting the slow rate of methane equilibration and therefore preserving temperatures at greater depth within the geothermal system. These temperature estimates are in good agreement with those obtained from previous gas analysis by Óskarsson (1984) and Arnórsson (1991).

5. WATER CHEMISTRY

In 1998 water samples for chemical analysis (H-1 to H-4) were collected from hot springs in the eastern part of the Kverkfjöll area (Fig. 6). The analyses of representative samples are shown in Table 4.

The hot water in Hveragil is carbonate rich, with the amount of CO_2(t) in the range 500 - 600 mg/l, which is often the case for runoff waters from high-temperature areas. The pH is approximately neutral and the silica and chloride content as high as 150 and 50 mg/l respectively for the springs where temperatures are above 50°C. The amount of mercury was below our detection limits, 5 ng/l. The analyses for the stable isotopes of hydrogen and oxygen from the hot water samples fall on the meteoric line (Fig. 7). This indicates that the water originates from present day precipitation.

Geothermometry calculations based on silica and alkali metal content for the two Hveragil samples are shown in Table 4. They indicate that subsurface temperatures for this water could be as high as 160 - 165°C based on the quartz geothermometer of Fournier and Potter (1982) and the Na/K ratio (Arnórsson et al., 1998) or as low as 120 - 135 based on the Na/Li ratio (Kharaka et al., 1982) and chalcedony geothermometer of Fournier (1977) respectively.

A glacial river called Volga, often with unusually high temperature, runs northwards from the Kverkárjökull glacier (Fig. 3) indicating its origin to be subglacial and within the center of the Kverkfjöll high-temperature area. A sample for chemical analysis was collected from the river on 17th August 1998. At that time the temperature of the river was only 4.5°C, but temperatures of 26°C were observed in the river on 3rd July 1979 and depend on the weather and the amount of melt-water from the ice. Results of the chemical analysis are shown in Table 4. The data shows that a geothermal water component is present in the river in addition to the melt-water from the glacier. This is demonstrated by the low pH of the river water as well as its relatively high silica and sulphate content. The water has an isotopic signature indicating its origin in recent precipitation on the Vatnajökull glacier (Fig. 7).

6. MONITORING

Based on the present data no major changes in the geothermal activity within the Kverkfjöll high-temperature system have been observed between the years 1992 until 1997. During this period, other volcanic systems within the Vatnajökull glacier have been very active, e.g. eruptions in Gjálp 1996 and Grímsvötn 1998. Chemical changes have not been observed in gases emitted from fumaroles in Kverkfjöll as can been seen in Fig. 8, which shows gas geothermometer temperatures based on the concentrations of CO_2 and H_2S in steam from fumaroles which have been sampled on several occasions. However, some changes in the thermal manifestations of the area have taken place during the last 50-60 years with reference to the descriptions of Thórarinsson (1953).

7. CONCLUSIONS

The Kverkfjöll central volcano consists of hyaloclastic rocks of evolved basaltic composition. The main volcanic massif rises about 1000 m above the surrounding area and a fissure swarm with lava flows and rows of craters and hyaloclastic ridges extends to the NE from Kverkfjöll, whereas the southern part of the system is covered by the Vatnajökull glacier. The Kverkfjöll high-temperature area is located in the mountain complex. At present, the observed geothermal activity is confined to the western and eastern part of the complex, covering some 25 km^2. The geothermal area has been monitored for changes in thermal activity and chemistry during a period of approximately ten years. Calculations based on gas geothermometers indicate subsurface temperatures of the thermal system to be about 300°C. In spite of significantly increased volcanic activity in other volcanic systems in the Vatnajökull glacier, no major changes in thermal activity nor chemistry of fumarole steam have been observed during the present monitoring period.

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Figure 1. A photograph of the Kverkfjöll volcanic complex, viewed from north to south (Photo; Oddur Sigurdsson).

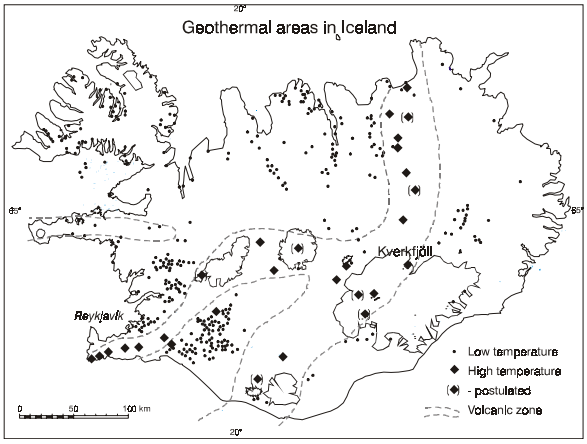

Figure 2. Location of the Kverkfjöll high-temperature area.

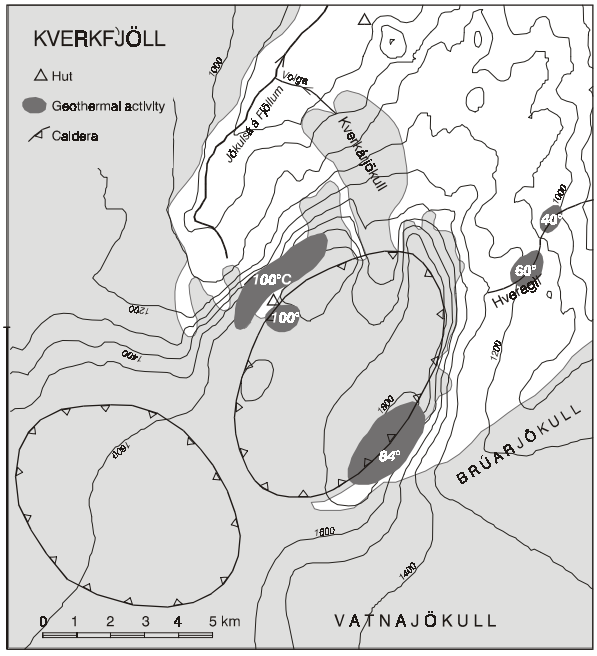

Figure 3. Geothermal activity of the Kverkfjöll high-temperature area.



Figure 4. Geothermal activity in the western part of Kverkfjöll.



Figure 5. Calcite encrustations in Hveragil.

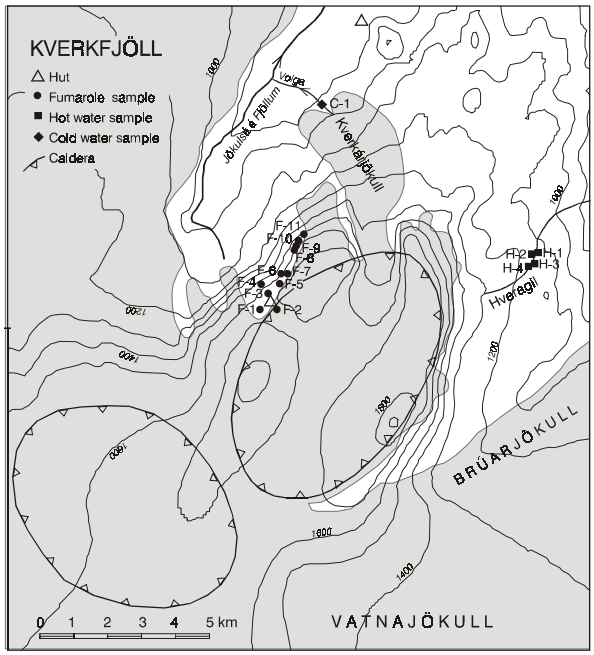

Figure 6. Location of fumarole and hot spring samples.

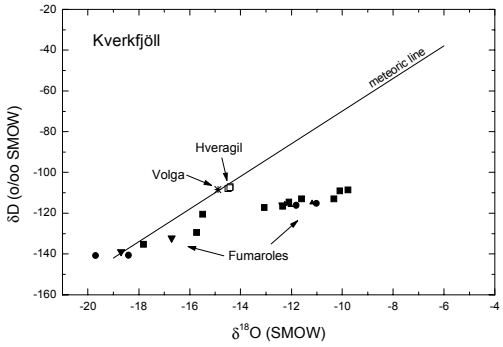

Figure 7. The stable isotopes of hydrogen and oxygen in fumarole and water samples from Kverkfjöll.

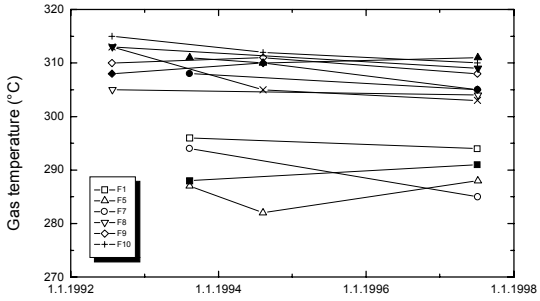

Figure 8. CO_2 (open signs) and H_2S (solid signs) gas geothermometer temperatures for several fumaroles, 1992 - 1997.

Table 1. Composition of fumarole discharge in Kverkfjöll (mmole/kg)

Sample #	Location	CO_2	H_2S	H_2	CH_4	N_2	O_2 [1)]	Ar	Total gas
1993-0123	F-1	301	8.30	6.74	0.396	0.399	8.721	-	326
1997-0414	F-1	282	9.52	5.68	0.319	0.664	0	0.013	298
1997-0418	F-2	506	5.17	5.43	0.667	1.92	0	0.036	519
1997-0422	F-3	174	6.21	12.3	0.232	0.576	0	0.011	193
1997-0421	F-4	159	10.6	18.1	0.248	0.503	0	0.010	188
1993-0124	F-5	286	27.5	40.2	0.652	2.03	0.274	-	357
1994-0151	F-5	183	26.4	17.3	0.387	0.841	0.086	-	228
1997-0419	F-5	226	26.7	29.2	0.367	0.897	0	0.017	283
1994-0150	F-6	263	22.9	15.2	0.549	1.423	0.082	-	303
1993-0125	F-7	337	22.8	40.5	0.828	1.66	0	-	403
1997-0420	F-7	207	20.4	25.5	0.308	1.09	0	0.018	254
1992-0164	F-8	411	29.6	12.1	0.307	1.20	0.044	-	454
1997-0423	F-8	404	24.1	13.4	0.210	0.790	0	0.013	443
1992-0162	F-9	495	23.8	35.6	0.375	1.51	0.054	-	556
1994-0152	F-9	516	26.4	34.4	0.391	1.609	0.167	-	579
1997-0416	F-9	462	17.9	29.9	0.287	19.3	0	0.234	529
1992-0161	F-10	820	30.2	13.9	0.765	2.88	0.255	-	868
1994-0153	F-10	533	20.0	10.1	0.220	1.45	0.055	-	565
1997-0415	F-10	497	17.6	8.48	0.222	0.867	0	0.014	524
1997-0417	F-11	494	15.6	22.7	0.191	0.897	0	0.014	533
Average gas composition		378	19.6	19.8	0.396	2.125	-	-	

[1)] : $O_2 = O_2$ + Ar if Ar not reported

Table 2. Chemical composition of steam samples

Sample #	Cl (mg/kg)	Hg (ng/kg)	δD ‰SMOW	$\delta^{18}O$ ‰SMOW
1993-0123	-	-	-115.5	-12.25
1997-0414	0.47	300	-116.5	-12.35
1997-0418	0.31	150	-120.5	-15.49
1997-0422	0.15	550	-117.2	-13.07
1997-0421	0.14	230	-112.9	-11.60
1993-0124	-	-	-114.8	-11.19
1994-0151	0.26	320	-115.2	-11.02
1997-0419	0.14	70	-108.5	-9.78
1994-0150	0.25	130	-140.8	-19.7
1993-0125	-	-	-116.0	-12.04
1997-0420	0.28	150	-109.0	-10.10
1992-0164	0.26	-	-132.2	-16.71
1997-0423	0.14	460	-129.4	-15.73
1992-0162	0.20	-	-116.0	-12.36
1994-0152	0.55	610	-116.2	-11.81
1997-0416	0.63	320	-114.5	-12.1
1992-0161	0.27	-	-138.9	-18.7
1994-0153	0.16	670	-140.7	-18.40
1997-0415	0.45	750	-135.2	-17.82
1997-0417	0.42	270	-112.9	-10.33

Table 3. Chemical composition of water samples (mg/l and ‰SMOW)

Location	Hveragil H-1	Hveragil H-4	Volga C-1
Sample #	1998-0427	1998-0430	1998-0431
Temp (°C)	53.2	61.5	4.5
Flow (l/s)	0.3	0.1	-
pH/°C	7.32/21	7.18/23	6.98/24
CO_2 (t)	553	583	77.1
H_2S	<0.03	<0.03	<0.03
B	0.21	0.21	0.10
SiO_2	149.3	147.8	27.8
Li	0.062	0.071	0.006
Na	107	114	10.4
K	8.05	10.7	0.98
Mg	37.5	31.3	4.18
Ca	18.5	20.4	17.7
F	0.82	0.83	0.13
Cl	44.5	49.8	7.44
SO_4	42.1	39.9	25.7
Al	0.016	0.009	0.096
Mn	0.0131	0.125	0.16
Fe	0.33	0.006	0.37
TDS	820	978	164
δD	-107.8	-107.4	-108.4
$\delta^{18}O$	-14.48	-14.42	-14.89
$T_{chalsed.}$	137	136	
T_{quartz}	161	160	
$T_{Na/K}$	165	182	
$T_{Na/Li}$	123	126	

Table 4. Gas geothermometer temperature for fumaroles (°C)

Sample #	Location	CO_2 [1)]	H_2S[1)]	H_2[1)]	CO_2/H_2[1)]	H_2S/H_2[1)]	CO_2/N_2[2)]	CH_4/CO_2[3)]
1993-0123	F-1	296	288	295	295	301	298	342
1997-0414	F-1	294	291	293	293	295	321	348
1997-0418	F-2	310	279	293	285	305	309	342
1997-0422	F-3	280	282	300	309	316	313	342
1997-0421	F-4	278	293	304	315	313	314	337
1993-0124	F-5	295	311	311	317	311	292	323
1994-0151	F-5	282	310	303	313	297	304	326
1997-0419	F-5	288	311	308	316	306	308	335
1994-0150	F-6	292	308	302	306	297	300	326
1993-0125	F-7	299	308	311	315	314	303	321
1997-0420	F-7	285	305	307	316	308	301	338
1992-0164	F-8	305	313	300	298	289	315	363
1997-0423	F-8	304	309	301	299	294	325	377
1992-0162	F-9	310	308	309	309	311	314	362
1994-0152	F-9	311	310	310	308	309	314	362
1997-0416	F-9	308	303	308	308	313	243	370
1992-0161	F-10	323	313	301	291	291	311	355
1994-0153	F-10	312	305	298	293	293	317	386
1997-0415	F-10	310	303	297	291	291	327	383
1997-0417	F-11	309	300	306	303	310	327	389

[1)] : Arnórsson and Gunnlaugsson, 1985; [2)] : Arnórsson, 1987; [3)] : Giggenbach, 1991