Geochemistry, Origin and Balneological Properties of a Geothermal Brine at Hofsstadir near Stykkishólmur, Iceland

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Keywords: brine, low-temperature geothermal activity, stable isotopes, balneology

ABSTRACT

The geothermal field at Hofsstadir northern Snæfellsnes peninsula produces a low-temperature brine with about 5.4 ‰ salinity or about 15 % of sea water salinity. The fluid temperature is 86 °C, near to the resevoir temperatures of 90 °C as assessed from mineral solution/equilibrium conditions. The stable isotopic ratios δ^2H and $\delta^{18}O$ reveal that the water is significantly lighter than present day precipitation in the mountains of the Snæfellsnes peninsula. The water may either have its origin far north of the Bay of Breidafjörður in the highland of the western fjord-lands or dating back to a pre-Holocene age when local precipitation was considerably lighter due to the cold climate at that time. The water is used for heating of the small town Stykkishólmur by a central heat-exchanger plant due to high salinity of the water. The outbuilding of a health resort has been planned and the water has been used successfully for the treatment of psoriasis and is claimed to be appropriate for health cures by drinking as well as for bathing therapy for rheumatism.

1. INTRODUCTION

The Stykkishólmur geothermal field is located on a peninsula of low undulating relief marked by glacial scouring.

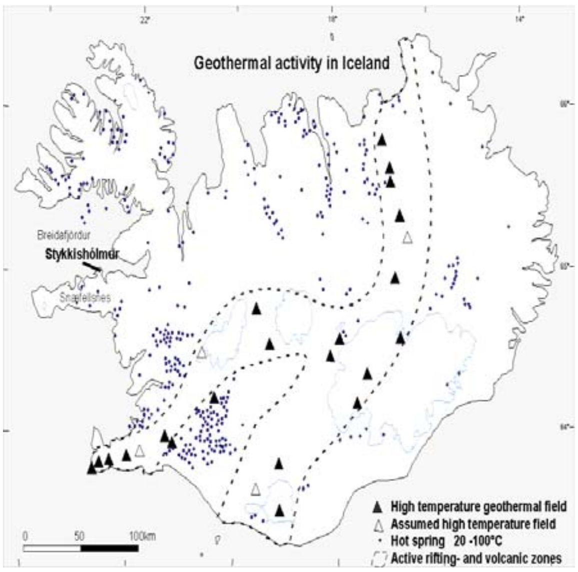

Figure 1. A geothermal map showing the location of Stykkishólmur. The geothermal field at Hofsstadir is about 10 km to the south of the town.

The peninsula is rather barren with low hills of rock and boggy depressions. Both landscape features are elongated NE-SW parallel with the regional strike of basalts and dykes. Narrow inlets form the sea cut into it from NE and SW. The geothermal field involves two subparallel fissures spaced 1200 m apart trending SSE to NNW. The eastern fissure closely approaches the sea shore at its NNW-end, and one of the inlets crosses the western one. The two fissures are only locally recognizable by surface criteria but they show up clearly in the thermal gradient of some 30 shallow (50 m deep) boreholes (Björnsson et al., 1997). The rocks of the peninsula are Miocene basalts and dykes of low primary permeability due to secondary mineralization. Permeability anomalies are fissure controlled, the one near Stykkisholmur being the largest traced so far in the surroundings. These provide the necessary pathways for sufficiently deep circulation of ground water down to at least 2000 m to sustain a geothermal system. There were no geothermal surface manifestations prior to drilling and the area had been defined as a “cold area”. The geothermal field was discovered during an extensive geoscientific exploration endeavour carried out in the period 1992 to 1997. The exploration covered the greater part of the coastline of Snæfellsnes. The above exploration lead to the discovery of a thermal anomaly located some 5 km south of the town of Stykkishólmur. The thermal anomaly has a Northwest Southeast direction (Fig. 1). The thermal gradient observed within the anomaly was well above the gradient values predominant in the region. A production well was drilled to 855 m depth yielding geothermal brine of 87°C. The main feed-zones were encountered between 175 and 820 m depth. The well started producing in 1999.

2. WATER GEOCHEMISTRY

The chemical composition of the geothermal water from the production well HO-01 is shown in Table 1. For comparison purposes the composition of cold potable water in the area is also given in Table 1. The concentration of all elements is in mg/l, except for the nutrient salts (NH_3, NO_3, NO_2, PO_4) which are in μmole/kg.

The water from well HO-01 is classified as calcium-sodium chloride water apparently in near chemical equilibrium with reservoir rocks (Kristmannsdóttir, 1996, Kristmannsdóttir and Hardardóttir, 1999). The concentration of chloride is 2.900 mg/l which is equivalent to a calculated salinity of 5.4 ‰ or 15 % of the salinity of seawater. The salinity value is indeed a very high value for Icelandic groundwater. It is furthermore the most saline geothermal water used for district heating purposes in Iceland so far. Therefore the system was designed in such a way that there is a central heat exchanger plant, with a closed water circulation loop. The heat-exchanger plant is located in the town in order to facilitate the use of effluent brine for balneological purposes and also for a more environmental discharge of excess water.

Table 1. Chemical composition of geothermal water from well HO-01 and of cold potable water in Stykkishólmur.

Location	Well HO-01	Cold local water
Temperature °C	86.8	2.9
pH/°C	8.4/17	7.35/21
Total carb. (CO_2)	4.4	15.1
Hydr. Sulf. (H_2S)	0.07	-
Boron(B)	0.08	0.005
Cond. µS/cm (25°C)	8750	
Silica (SiO_2)	71.7	12.5
Tot. diss. solids	5430	38
Oxygen O_2	0	-
Sodium (Na)	740	5.6
Potassium (K)	14.5	0.66
Magnesium Mg)	0.5	1.83
Calcium (Ca)	1170	2.57
Strontium (Sr)	5.3	-
Fluoride (F)	1.23	0.06
Chloride (Cl)	2960	6.97
Bromide (Br)	9.7	0.025
Iodide (I)	0.6	0.001
Sulphate (SO_4)	315	1.63
Ammonium (NH_3) *	2.2	-
Nitrate (NO_3) *	<0.1	2.9
Nitrite (NO_2)*	0.04	0.03
Phosphate (PO_4)*	0.08	0.24
Aluminium (Al)	0.02	0.004
Arsenic (As)	0.0006	0.00005
Cadmium (Cd)	0.000003	<0.000002
Chromium (Cr)	0.000035	0.000024
Copper (Cu)	<0.000005	<0.000005
Mercury (Hg)	0.000007	<0.000002
Iron (Fe)	0.023	0.0005
Manganese (Mn)	0.023	<0.00003
Lead (Pb)	0.00005	<0.00001
Selen (Se)	0.00003	0.00018
Titanium (Ti)	0.00006	0.00002
Zinc (Zn)	0.005	0.00094
δ^2H ‰	-68.5	-60.9
$\delta^{18}O$ ‰	-11.1	9.0

The water is highly concentrated in calcium in comparison with seawater. The calcium concentration is also high relative to that of geothermal brines elsewhere (Kristmannsdóttir, 1991, Kristmannsdóttir and Ólafsson, 1989), which indicates intensive and prolonged water-rock interaction. As shown in a chloride, sulphate, bicarbonate ternary diagram (Fig. 2.) as designed by Giggenbach (1991) the waters plot close to the chloride corner and the field of mature geothermal waters. In Iceland the total carbonate is very low in the water and it contains no free CO_2. Since deep-seated intrusions emitting CO_2 are common in the Snæfellsnes peninsula and found to influence the chemical composition of the ground water, it was feared prior to drilling that the geothermal water might be affected by CO_2, which deteriorates its production characteristics. Water with such a high salinity would be considerably corrosive if also containing any free CO_2. Fortunately this was not found to be the case (Ólafsson and Kristmannsdóttir, 1997).

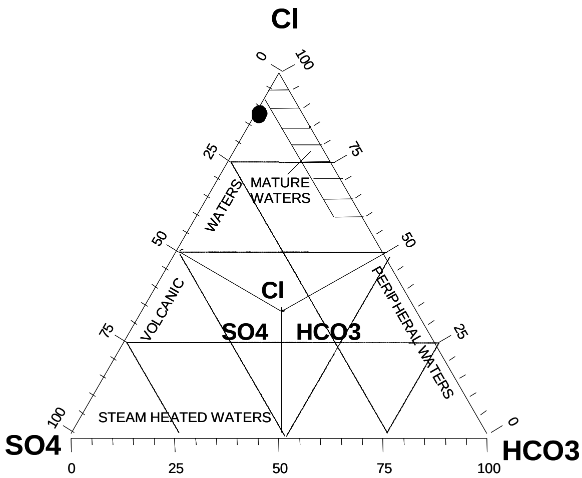

Figure 2: The classification of water from HO-01 according to Cl-SO_4-HCO_3 ternary diagram (Giggenbach 1991)

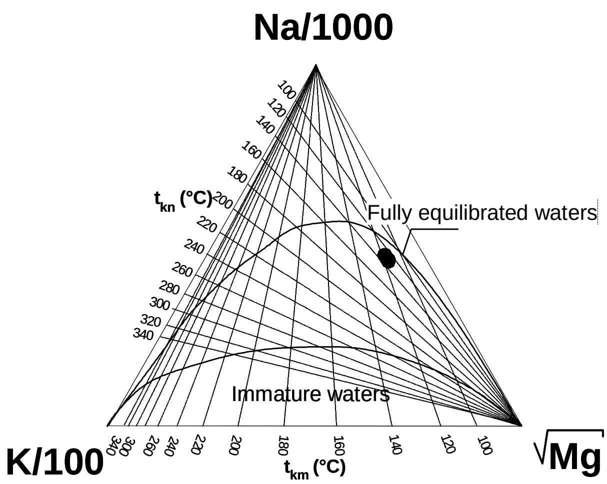

Figure 3: The composition of geothermal water from Hofsstadir plotted on Na-K-Mg ternary diagram (Giggenbach 1988).

The water is somewhat depleted in sulphate concentration relative to that of seawater. It is highly depleted in magnesium as all geothermal waters, but the magnesium content is two orders of magnitude higher than in nonsaline geothermal waters of similar temperature. The pH of the water is 8.35-8.45 that is quite normal and as to be expected regarding the salinity and the low carbonate concentration of the water.

Analysis of the dissolved gas in the water sampled at wellhead reveals it to be 98.4 % nitrogen and contain less than 0.01% CO_2. This is in accordance with Icelandic experience from other low-temperature geothermal fields where the dissolved gas accompanying such waters is found to be almost exclusively of atmospheric origin.

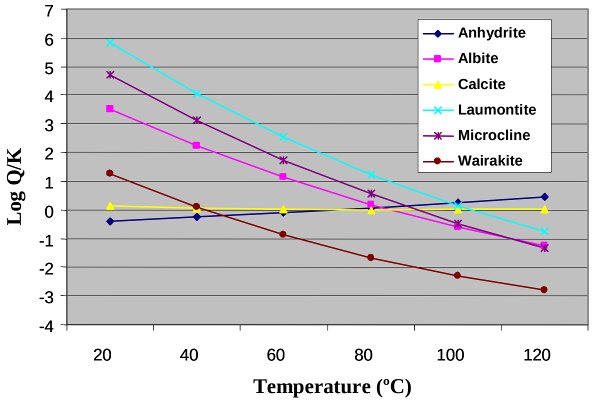

Figure 4. The relation between calculated activity products in the water from well HO-01 at Hofstadir, the productions well for Stykkishólmur and corresponding equilibrium constant for the formation of selected alteration minerals (log Q/K) against temperature.

The water appears to be in equilibrium at temperatures of 120-130°C and 100-110°C respectively according to the Na-K-Mg ternary plots (Fig. 3) of Giggenbach, (1988) and Arnórsson (1991). The reservoir temperature indicated by the calculated chalcedony geothermometer is 90°C, which is close to the actual production temperature of the water. The calculated sodium-potassium geothermometer gives considerably lower values, as is often the case with somewhat saline geothermal waters. Calculated mineral equilibrium for many common alteration minerals in basaltic rocks indicates reservoir temperature of 80-90°C, but there is considerable scatter in the results (Fig. 4).

The concentration of iron is higher than that generally observed in Icelandic geothermal water, but not exceedingly so. The concentration of manganese is also rather high, but that of other heavy metals as copper, zinc, lead and mercury is relatively low. The concentration of aluminium is very low as common in geothermal brines.

Microorganisms encountered in the water are of types similar to those most commonly found in geothermal water of this temperature (Pétursdóttir and Kristjánsson, 1997) and fairly uniform.

The radioactivity of the water due to concentration of Radon is 0.026 Bq/l.

3. ORIGIN

The stable isotopic ratios δD and $\delta^{18}O$ (Fig. 5) show the water to be significantly lighter than water originating from the mountains in the southern part of the Snæfellsnes peninsula (Árnason, 1976). The water must either have its origin far north in the western fjord-lands peninsula, or dating back to a pre Holocene age. The deuterium excess value ($d=\delta^2H-8*\delta^{18}O$) of the water is 22 ‰ as demonstrated in Figure 5, which is considerably higher than found in the present day precipitation (around 10 ‰) and may suggest that the water was originated as precipitation from a different climate regime (Johnsen et al. 1989). This high deuterium excess value supports the hypotheses that the water is pre-Holocene, which also agrees with the excessive water-rock reaction as deduced from the water chemistry and the classification of the water as "mature geothermal water". One may expect a change to occur in the isotopic ratio with time and increased development of the geothermal field when the pressure declines and a more local recharge of water can be to be expected.

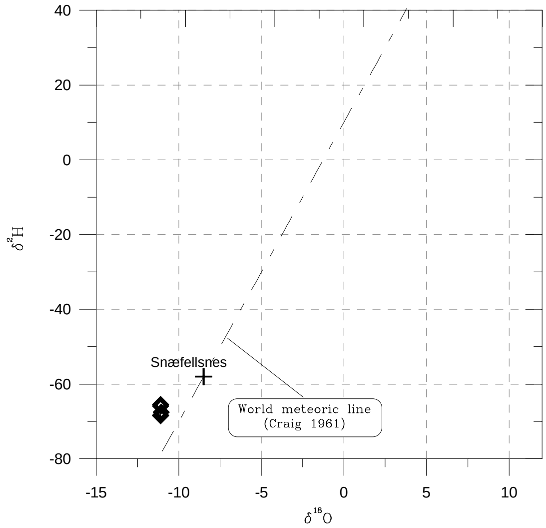

Figure 5. δ^2H plotted against $\delta^{18}O$ for the geothermal water at Hofsstadir. The values of the local precipitation as well as the location of the world meteoric line (Craig, 1961) are shown for comparison.

4. PRODUCTION PROPERTIES

The high salinity of the water renders it unfit for direct heating purposes and for consumption. The water salinity catalyses all possible chemical reactions and the uptake of even a trace of oxygen causes the corrosion rate of steel to become very rapid. There is however a trace concentration of hydrogen sulphide in the water, which acts as a built-in corrosion inhibitor by reacting with and scavenging the oxygen in the water. Calculation reveals the water to be considerably supersaturated with respect to calcium carbonate (calcite) contrary to most Icelandic geothermal waters, which are in exact mineral equilibrium with respect to calcite. This may be due to the very high calcium concentration and is probably mostly governed by equilibrium with calcium silicates. The water is supersaturated with respect to calcium carbonate and even though no scaling was observed during production tests (Björnsson et al., 1997, Salinegeoheat, 2001) small changes in pH or flow pattern might trigger off precipitation. The high salinity provides a reason for being more aware of potential scaling problems in the production monitoring.

The water is very little corrosive for stainless steel (SS 304) and "casing" steel (API K 55), except when substantial concentrations (>100 µg/l) of oxygen are introduced. The same results were observed in the case of aluminium and also copper which is not substantially corroded either, except when oxygen is introduced (Salinegeoheat, 2001).

All the measured heavy metals are far below the maximum allowed limit for drinking water. The concentration of fluoride is close to the upper limits allowed for drinking water. The water contains no constituents dangerous to health and is considered safe for consumption and food processing. The high calcium concentration relative to sodium may even make it rather wholesome for consumption. The water is considered to be poorly suitable as hot tap water, even though it is not dangerous, because salt and silica will precipitate in sinks and bathtubs and may clog or ruin faucets and pipe connections.

Figure 6. In the early days of balneologcal outbuilding in Stykkishólmur town.

5. BALNEOLOGICAL PROPERTIES

The water may have a special balneological potential due to its mineral content. It falls into the high mineral and high fluorine water classification according to the German classification scheme for health spa waters. The pH of the water is lower than common in Icelandic geothermal water as well as being much more mineralised. Together this prevents drying out of the body's skin, which is often experienced bathing in Icelandic geothermal water.

The water has been used successfully for the treatment of psoriasis from the early days of exploration (Fig. 6). Just after the first aquifer started yielding locals started to bathe in fishboxes at the location. The water has later been attested by Institut Fresnius in Germany as "Heilwasser". It is claimed to be appropriate for health cures by drinking as well as for bathing therapy for rheumatism. A new swimming pool was buildt in Stykkishólmur soon after production from the geothermal field started and a treatment pool with no added chlorine was also installed (Fig. 7). The outbuilding of a health resort in cooperation with the local hotel as well as the hospital has been planned, but is awaiting a suitable financing body to undertake the project.

6. CONCLUSION

The geothermal exploration of northern Snæfellsnes peninsula Iceland revealed a unique geothermal field at Hofsstadir close to Stykkishólmur town producing almost 90 °C hot brine of higher salinity than used for district heating elsewhere in the country (5.4 ‰). The measured temperature is near resevoir temperatures assessed from mineral equilibrium conditions. The water is significantly lighter than present day precipitation in the mountains of the Snæfellsnes peninsula as demonstrated by isotopic ratios for δ^2H and δ^{18}O. Its origin probably dates back to an age prior to the latest glaciation period some ten thousand years ago. The water is presently used for heating of the small town Stykkishólmur by a central heat-exchanger plant and a closed water circuit, which is a also unique design for district heating systems in Iceland where the geothermal water is mostly used directly and the water only partly reused in a some larger systems due to high salinity of the water. The water is classified as high mineral and high fluorine water health spa water according to the German classification scheme. Its pH is lower than common in Icelandic geothermal water. The water has been used successfully for the treatment of psoriasis and has been attested as health water appropriate for both for drinking and for bathing therapy use. An outbuilding of health tourism based on balneological properties of the water is expected to take place in the near future within Stykkishólmur town and the area around.

Figure 7. A treatment pool for psoriasis in the new swimming pool consortium in Stykkishólmur town.

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