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Geothermal fluids in Iceland. Chemistry and places of special interest for balneological purpose.

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GEOTHERMAL FLUIDS IN ICELAND

Chemistry and places of special interest for balneological purpose

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INTRODUCTION

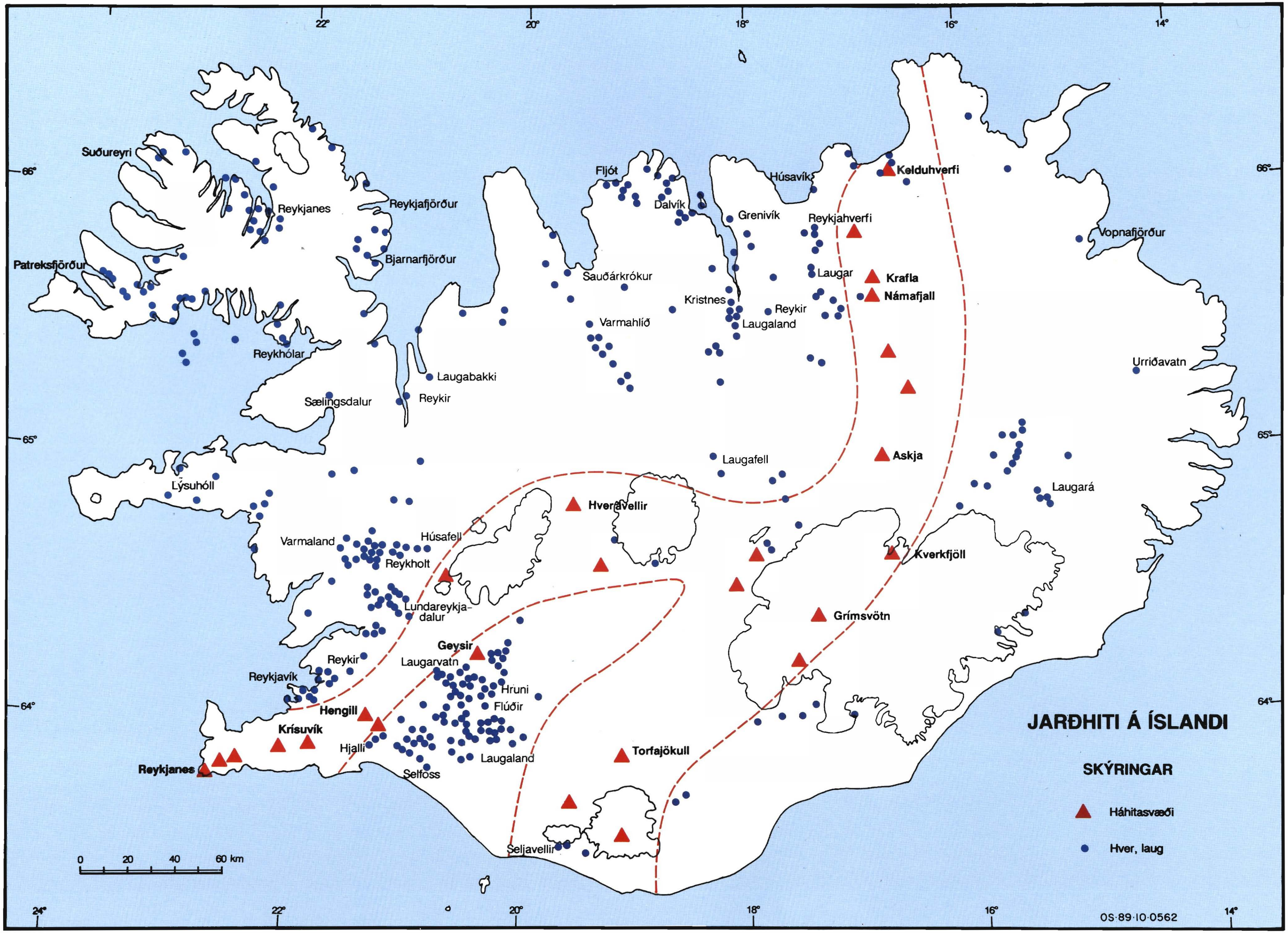
Geothermal activity is widespread in Iceland (Fig. 1). The geothermal fields are split into high-temperature geothermal fields and low-temperature geothermal fields. The high-temperature geothermal fields are all within the active volcanic zone and closely related to volcanic centers, whereas the low-temperature fields are found in older geologic settings (Fig.2). The definition used for a high-temperature geothermal field in Iceland is that the temperature at 1 km depth exceeds 200 °C, whereas fields with temperature less than 150 °C at 1 km depth are defined as low-temperature geothermal fields.

At Orkustofnun there has been a continous collection of data for over twenty years about all existing natural geothermal activity in Iceland, but there is no recent publication summarizing all those data. Orkustofnun keeps files of all geothermal drillings in Iceland and almost all geothermal research in the country has been performed by the Institute or in cooperation with it. Data of chemical compostion of spring water, gas and steam from fumaroles and fluids from wells from most of the geothermal fields in the country are also filed at Orkustofnun. The data span over long time interval and are of different quality. For most utilized fields there have been a more or less continous chemical monitoring of the fluid composition throughout the production time, as chemical changes are often precursors of cooling and may give a warning for preventive action (Kristmannsdóttir and Ármannsson, 1992) Those data have been published in a number of publications, but again there does not exist a single one summarizing the data. In connection with the plans to build up a major aquacultural industry in Iceland, there were carried out many research projects which did increase our knowledge about Icelands resources of cold, tepid and hot groundwater all over the country.

CHEMISTRY OF WATERS

Geothermal water in Iceland is in most cases of meteoric origin and only in a few places originated from sea-water. The waters in the low-temperature geothermal fields have mostly very low concentrations, typically 200-400 mg/l, of dissolved solids and gases, but the mineralization increases by increased reservoir temperature of the geothermal fields. In the non-saline high-temperature geothermal waters thetotal concentration of dissolved solids will exceed 1000 mg/l. There do exist a few sea-water contaminated fields with subsequently higher concentration of dissolved solids. The salinity of those waters is mostly less than 10 % of sea-water, but on the Reykjanes peninsula in SW Iceland and in Öxarfjördur in NE Iceland there are found waters with much higher salinity, even up to that of sea-water (Kristmannsdóttir and Ólafsson, 1989).

The dominant reservoir rocks in the Icelandic geothermal fields are basaltic lavas and hyaloclastites and the fluids evolved by reacton with such rocks at elevated temperatures have high pH values. Acidic igneous rocks are encountered within the central volcanoes, past and present, but they account to not more than about 10 % of the total volume of rock formations in Iceland.


JARÐHITI Á ÍSLANDI
SKÝRINGAR
Háhitasvæði
Hver, laug
Suðureyri
Reykjanes
Reykjafjörður
Bjarnarfjörður
Patreksfjörður
Reykhólar
Laugabakki
Reykir
Sælingsdalur
Lýsuhóll
Varmaland
Húsafell
Reykholt
Lundareykja-
dalur
Reykir
Reykjavík
Hengill
Krísuvík
Hjalli
Reykjanes
Geysir
Laugarvatn
Hruni
Flúðir
Laugaland
Selfoss
Torfajökull
Seljavellir
Hveravellir
Fljót
Dalvík
Sauðárkrókur
Varmahlíð
Kristnes
Reykir
Laugaland
Grenivík
Húsavík
Reykjahverfi
Laugar
Krafla
Námafjall
Kelduhverfi
Askja
Laugafell
Kverkfjöll
Grímsvötn
Vopnafjörður
Urriðavatn
Laugará
0 20 40 60 km
24° 22° 20° 18° 16° 14°
66° 65° 64°
OS-89-10-0562

The pH is typically 9-10 for the low-temperature waters, but lower for the high-temperature geothermal waters due to their higher concentrations of acidic gases. The waters are in equilibrium with silica minerals, several alkali-, iron- and aluminium silicates, calcium carbonate and metal sulfides and oxydes (Arnórsson et al., 1983). The silica composition of the waters rises in direct relation with temperature, carbonate concentration declines by increasing temperature, they are devoid of oxygen, contain hydrogen sulfide and are highly depleted in magnesium, even at moderate temperatures.

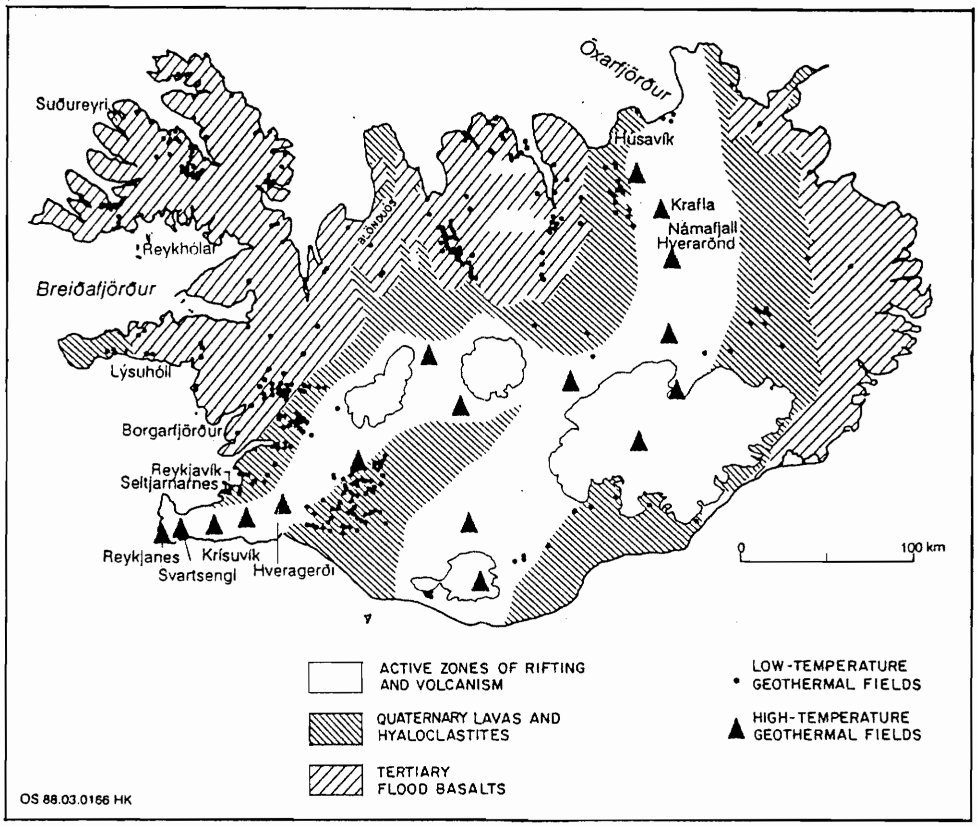


Fig. 2. The relation of geothermal activity in Iceland to geologic formations.

Carbon dioxide waters, both thermal and cold waters, occur in Iceland and are most common in the Snæfellsnes peninsula (Arnórsson and Barnes, 1983). The chemistry of geothermal water of this type differs significally from other geothermal water in Iceland.

The radioactivity of the thermal waters has not been studied in any detail. In light of the low content of radioactive elements in Icelandic rocks (Poliackov and Sobornov, 1975, Stefánsson, Gudmundsson and Emmermann, 1982 b) and in precipitation (Jónsson, Árnason and Theodórsson, 1968) the radioactivity of the waters is believed to be diminutive. There have been some research programs concerning radon in Icelandic geothermal waters in the aim to forecast earthquakes (Hauksson and Goddard, 1981) and to map the flow pattern in geothermal fields (Ármannsson et al., 1982).

As compared to geothermal waters in other countries the waters in Iceland have generally much lower concentrations of dissolved solids although there are also found geothermal brines in a few places. The thermal waters in central Europa are much more highly mineralized than typical low-temperature geothermal waters in Iceland. Geothermal waters in Japan are varied in composition and many are quite comparable in composition to waters in Iceland. Especially would the conditions in the high-temperature geothermal fields be rather similar in Japan and Iceland.

Low-temperature geothermal waters

In table 1 is shown the range of chemical compostion of low-temperature geothermal waters from well bores around in Iceland, mostly ones used in district heating systems. Spring water is more or less within the same concentration range as water from wells, but is more varied due to reactions occurring during upflow and mixing with cold water near the surface. The reason for choosing exclusively water from well bores is that for any major utilization drilling would be neccessary to obtain enough water.

Table 1. Typical composition of low-temperature geothermal waters in Iceland. Concentration in mg/l.

	Fresh water					Slightly saline geothermal water			Saline geothermal water
Place	H-Rey	H-Gnúp G-5	H-Ak h-1	H-Ól LJ-5	H-Reykh h-4	H-Selt h-5	H-S.Skeið h-6	H-Hrís h-2	Staóur Reykjanes h-10
Number	820070	820097	890061	880182	910174	880004	870191	880020	880049
Temp.°C	130	67	93	60	112	117	75	79	71
pH/°C	9.3/23	9.9/22	9.8/23	10.1/20	9.7/23	8.4/22	9.7/21	9.6/22	7.3/22
Silica (SiO_2)	146.2	70.8	98.2	71.7	126	122.9	69.0	69.2	69.0
Sodium (Na)	62.2	54.8	53.0	35.1	61	597	344	224	11041
Potassium (K)	2.9	0.8	1.2	0.5	2.0	14.0	4.7	4.4	399
Calcium (Ca)	3.1	2.3	3.0	2.4	3.1	522.9	35.6	56.9	1915
Magnesium (Mg)	0.007	0.012	0.003	0.007	0.003	0.380	0.001	0.007	109.2
Tot.carb. (CO_2)	20	15	21	13	18	9.8	6.4	6.0	40
Sulfate (SO_4)	28.6	39.4	40.8	5.4	28.9	304.4	117.5	47.8	1534
Hydrogen sulfide (H_2S)	0.22	0	0.07	<0.03	0.21	0.10	0	0	0
Chloride (Cl)	46.3	24.9	13.5	7.9	28.9	1617	501.4	388.8	19950
Fluoride (F)	1.13	1.52	0.364	0.150	0.47	0.667	1.29	0.279	0.039
Tot.diss.solids (TDS)	331	239	256	183	288	3484	1113	804	36690
Iron (Fe)	<0025	-	<0.025	<0.025	<0.025	0.025	<0.025	<0.025	1.1
Manganese (Mn)	-	-	-	-	<0.005	-	0	-	1.8
Oxygen (O_2)	0	<0.005	0	0.200	0	0	0.020	0.005	-
Aluminium (Al)	-	-	0.132	-	0.141	0.025	-	-	-

As pointed out in the general description of the nature of geothermal fluids the table shows that mineralization is very low in the waters. In some waters there is an increased salinity due to sea-water infiltration or seepage through sediments containing sea salt. Waters reacting with acidic rocks will also contain somewhat more chloride than those reacting with basaltic rocks. Such waters will also have higher concentrations of fluoride, boron, lithium and radioactive elements. In general all the elements, which are not bound in the minerals of the basaltic rocks, will be concentrated in the acidic rocks. Other elements as iron, manganese, copper, cobolt and zink will be more enriched in the basalts and therefore also in the waters reacting with such rocks. The mineral concentrations of the waters will also be highly dependent on the age and weathering and alteration state of the rocks. The recent, glassy basalts will be the more reactive than older and more altered basalts and would be expected to contain the highest concentrations of heavy metals and other trace elements. This has not been studied very much sofar. The main variation in the low temperature waters, besides differences in salinity, is encountered in the fluoride concentration, which is normally 0,5-1,5 mg/l, but may locally be much higher (5-15 mg/l). Waters with extreme high pH, 10-11, are also encountered, especially on the boarders of the active volcanic zones in SW and NE Iceland.

High-temperature waters

The high temperature geothermal waters are much more mineralized due to increasing solubility by increased temperature of most of the minerals determining the water-rock equilibrium in the geothermal systems. In table 2 is shown typical composition of some high temperature geothermal fluids. Again there are chosen samples from well bores only by the same reasons as for the low-temperature waters. In the table are shown firstly concentration of the total flow from the wells and

Table 2. Chemical composition of selected high-temperature geothermal waters. Concentration in mg/l.

Geothermal area	Námafjall	BJ-12	Krafla	KJ-7	Svartsengi	SG-6	Reykjanes	Rn-9	Hveragerði	NLF-2
	a	b	a	b	a	b	a	b	a	b
Date	830525		771029		810220		831024		820618	
Enthalpy H_o kJ/kg	2248		1973		1029		1317		850	
Silica (SiO_2)	162	619	313	787	437	504	587	812	242	254
Sodium (Na)	35	135	83	209	6478	7468	9079	12564	149	156
Potassium (K)	5.0	19.0	14.2	35.8	935	1078	1388	1920	11.4	11.9
Calcium (Ca)	0.1	0.4	1.4	3.5	938	1082	1526	2112	1.7	1.8
Magnesium (Mg)	0.0	0.01	0.01	0.13	0.57	0.66	0.93	1.28	0.0	0.003
Carbon dioxide (CO_2)	815	22.2	48597	255	662	16.5	1523	14.2	448	71
Sulfate (SO_4)	1.7	6.5	55.5	139	28.1	32.4	16.2	22.4	39.4	41.2
Hydrogen sulfide (H_2S)	975	108	478	9.4	6.2	0.3	48	1.0	46	20
Hydrogen (H_2)	62	0.02	40	0.01	0.0	0.0	0.10		0.3	0.0
Chloride (Cl)	9	34	38	95	13925	16052	17749	24558	126	132
Fluoride (F)	0.19	0.73	0.31	0.78	0.19	0.22	0.15	0.21	1.62	1.69
Tot.diss.solids (TDS)	229	862	489	1229	21404	24675	30927	42797	701	734
Iron (Fe)	<0.025	<0.025	0.01	0.02	0.13	0.15	0.7	0.9	<0.025	<0.025
Aluminium (Al)	0.4	1.47	0.5	1.23	0.50	0.62	0.80	1.2	0.50	0.51
Methan (CH_4)	1.38	0.0	42	0.01	0.09	0.0	0.05		0.33	0.0
Nitrogen (N_2)	12.3	0.0	0.0	0.0	2.8	0.01	3.9		11.5	0.02
Coll.press. P_s bars	19.2		12.4		14		43		7.1	

a: total flow
b: water boiled at 180°C

secondly the composition of waters boiled at 180 °C. Boiling at still lower temperature would yield still more highly concentrated waters. As in the case of the low-temperature waters there do exist geothermal brines on the Reykjanes peninsula and in Öxarfjörður NE Iceland. The same reasons hold for the high-temperature geothermal waters and reaction with basaltic and acidic rocks. The high-temperature geothermal fluids offer a great variability in water composition by the addition of steam to either the boiled and cooled geothermal water or to cold water. By varying those components waters with a range of pH and mineral concentration can be created. At the sites of high-temperture geothermal fields there is usually also readily available geothemal clay, silica precipates and steam sublimates, which are of importance for balneological uses.

Carbon dioxide waters

As pointed out in the Introduction carbon dioxide waters are found quite a few places in Iceland (Arnórsson, 1982), both the thermal and cold waters. The carbon dioxide of both the thermal and cold waters is believed to have a different origin from the waters and be derived from deep seated intrusions or the mantle. This ascending gas has then been mixed with the waters, either close to the surface to produce the cold carbon dioxide waters or at considerable depth in the case of the geothermal waters. The carbon dioxide waters are of mainly four different types (Arnórsson and Barnes, 1983) :

1. Cold water with seasonal variation in temperature

2. Cold groundwater with a constant yearly temperature

3. Low-temperature geothermal water

4. Mixture of cold water and high-temperature geothermal water or steam

In table 3 are shown exemples of all the three types of carbon dioxide waters in Iceland. Common for all the waters is a low pH and a high concentration of total carbonate, but other factors are quite different. The first group is surface water, wich has been mixed at shallow depths with carbon dioxide gas ascending from great depths in the earth and shows seasonal variations in temperature and chemical composition.

Table 3. Chemical composition of carbon dioxide waters (mg/l) (Arnórsson, 1983).

Place	Rauðamels-ölkelda[a]	Ólafsvík[a]	Ölkelda[b]	Bjarnar-fosskot[b]	Lýsuhóll[c]	Leirá[c]	Landmanna-laugar[d]	Strútslaug Torfajökull[d]
Temp.°C	4	4	5	6	60	128	82	67
(pH)	4.66	4.54	6.21	6.22	6.88	6.94	6.10	6.60
Silica (SiO_2)	5	10	77	77	178	237	258	138
Sodium (Na)	5.1	12.2	660	171	486	244	253	318
Potassium (K)	0.4	2.2	26.8	9.7	36.5	27.6	35.3	41.0
Calcium (Ca)	1.6	3.9	256.1	216.8	79.9	15.4	10.9	4.2
Magnesium (Mg)	0.95	4.2	60.5	177.8	20.8	0.66	2.28	7.3
Tot.carb. (CO_2)	616	1356	4100	2846	1358	157	280	449
Sulfate (SO_4)	3.0	5.8	125.4	3.0	43.1	55.3	70.0	40.9
Hydrogen sulfide (H_2S)	0.1	0.1	0.1	0.1	0.02	5.40	0.07	0.10
Cloride (Cl)	7.7	22.3	239.0	29.5	69.5	264	307	30.2
Fluoride (F)	0.03	0.06	0.61	0.08	4.79	2.97	7.15	2.00
Tot.diss.solids (TDS)	21	53	2584	1124	1412	971	1031	1223
Iron (Fe)			3.3		0.83	0.27	0.04	0.66
Boron (B)			0.90		0.48	0.21	1.72	1.41

[a] Cold springs with seasonally varying water temperature. [b] Cold springs with constant yearly temperature.
[c] Low-temperature geothermal spring water. [d] Springs occuring at the outskirts of high-temperature geotermal fields.

The second group is cold groundwaters, which has partly equilibrated with the underground rocks before mixing with the carbon dioxide gas and does not show seasonal changes neither in temperature nor chemical composition.

The third group is low-temperature geothermal water, which has been mixed with carbon dioxide gas at deeper levels than the others and then reacted with the underground rocks and attained equilibrium with minerals at the prevailing temperatures. As a consequence those waters have much higher concentrations of silica, magnesium, calcium and other metals than usual for low-temperature waters.

The carbon dioxide springs of group 4 occur on the outskirts of many high-temperature geothermal fields and are formed by either mixing of hot and cold water or by steam heating of shallow cold groundwater.

PLACES OF SPECIAL INTEREST

When selecting places of special interest for health spas there are several factors to be considered. The main factors appear to be the type and availability of water and the cost aquiring it as well as availability and cost of other desirable raw materials for health cure as mineral water for drinking, mud, silica and clay deposits.

High-temperture gives much more variability in the possible water/bath composition as steam or condensate addition to the hot water or even cold water will give a broad spectrum of different water composition. At high-temperature geothermal sites there will generally be ample deposits of geothermal mud, clay an silica deposits.

The main fields of interest near densely populated areas are the Krísuvík and Reykjanes fields, besides the Svartsengi field where a small project of this kind has already been started.

The Reykjanes and Svartsengi are brine fields and there have already been drilled for ample water, which in the case of the Reykjanes field is only utilized to a small extent.

In the Krísuvík field the water is not very saline. Addtional research is needed and water and steam would have to be drilled for. The field has however all the advantages mentioned for high-temperature fields and is also quite big.

Other interesting high-temperature geothermal fields are the Námafjall/Hveraröndd and Hveragerði fields, which are accessible, near great turist attractions, are well known and studied and some water and steam already available. In Hveragerði there is already long tradition for the running of a sanatorium and use of mud and hot water baths for health purposes. The water in both those fields is non-saline.

Places with low-temperature brines are known especially on the Reykjanes peninsula and in Öxarfjördur NE Iceland. Near Húsavík in NE Iceland salty low-temperature water has been used experimentally for health baths for psoriasis patients. An interesting location within an urban area is the town of Seltjarnarnes, one of the suburbs of the capital city Reykjavík, where ample sources of salty water are available.

There are several places with eccessive water and special other attractions, like the Reykhólar field in western Iceland. There the water is fresh, just over 100 °C and available in ample quantities. The largest known sedimentary mud deposits in Iceland are found nearby. There are several turist attractions in the area, which is also very scenic. In several of the islands in the bay of Breidafjördur south of the area there are springs with hot water of varying salinity.

Places with carbon dioxide water and geothermal water available at the same site are not common. The Lýsuhóll field on Snæfellsnes is one of the few known places.

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