Prospects in Balneology to Boost the Economy and Employment of Rural NE Iceland

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ABSTRACT

In NE Iceland there are ample geothermal resources both high temperature and low temperature geothermal fields as well as boiling low-temperature or medium enthalpy resources. It is of utmost importance not to waste the energy even where the resources are ample and cascade use of the energy is desirable. Many of the high-temperature fields in the area are now being harnessed for electricity production and balneological projects seem to be an ideal target to utilize the effluent water. High-temperature waters offer the possibility of the production of varied water types for bathing and treatment. Most of the water in the low-temperature fields in NE Iceland is fresh and not specified as any health water type. This kind of water still seems to be desirable for use in balneotherapy. Some of the low temperature geothermal waters in the area have similar chemical characteristics as waters in renowned foreign spas. Some of those waters have already proved to be effective in the treatment of skin diseases as psoriasis and also rheumatism. Besides the geothermal water in the area there can be pointed out many other fundamental attributes in the area for the building up of spas. some of which are also based on geothermal utilization:

- Potable water in ample quantities of good quality, but of varying chemical composition
- Fresh air
- Locally produced fresh food, fish, lamb and agricultural products
- Very good health service and a high tech hospital
- Long experience of using geothermal water for rehabilitation of invalid and elderly people
- Many municipal swimming pools
- Good general service and transport
- An international airport
- Multiform recreation and relaxation opportunities

The project is a part of a more general survey of new opportunities for increased employment in the area and diagnosis of market opportunities and possible business projects in connection with increased utilization of geothermal resources.

1. INTRODUCTION

Increased utilization of the vast geothermal resources in NE Iceland has been surveyed as a part of an innovation program aiming at the creation of new employment opportunities, especially in the rural areas. In the project the available resources were mapped, diagnoses were made of market opportunities and possible business projects were defined. The mapping of resources entails the classification of geothermal waters, checking the availability of mineral water, clay deposits and geothermal precipitates, the purity of the atmospheric air and potable water as well as the available medical and general services and recreation opportunities. The main aim of the project is to enhance the use of geothermal and other important resources in the area with special emphasis on environmental issues and cascade use of geothermal resources. A part of the resource definition as well as the definition of a business project is to designate the kind of balneoteraphy possible for the type of waters and other resources accessible. This requires a close cooperation of specialists from different fields, geoscientists, medical doctors and people educated in economics. The project was a cooperation project between University of Akureyri, the The National Institute of Regional Development, The Regional Development Agency for the Region of Thingeyjarsysla and The Health Center of Thingeyjarsyslur. In this paper the main emphasis is laid on the definition of available resources as the more business oriented results will be reported on elsewhere.

The tradition of using geothermal baths in Iceland spans from early settlement, some 1100 years ago. The Icelandic Sagas written in the thirteenth century report that bathing in geothermal pools was popular both for recreation and for balneotheraphy mostly to ease rheumatic pain. There is a long tradition for spas in Europe and Asia, but the traditions of geothermal bathing have developed differently in Iceland than most other places. In the last century it has become an everyday recreation and relaxation for most Icelanders to use outdoor swimming pools all year around. Icelanders are nowadays enjoying more numerous swimming pools per capita than in any other country, worldwide (Ragnarsson, 2005). The main balneological resorts in modern Iceland based on geothermal water are the Health and rehabilitation clinic in Hveragerði, SW Iceland and the Blue lagoon spa by the Svartsengi power plant, also in SW Iceland. The clinic in Hveragerdi serves mostly the domestic market for rehabilitation and for older people (Gunnarsson, 1998). It emphasizes on vegetarian diet. The Blue lagoon however is unique in the world and widely renowned and one of the main tourist attractions in Iceland (Blue lagoon committee, 1996). It is also visited by many Icelanders, both for recreation and treatment, especially for psoriasis (Ólafsson, 1996). Recently a health spa was opened in NE Iceland in the Myvatn area. Steam has been used for bathing in the area since the 13th century and in 1996 a steam bath in the spirit of former times was rebuilt and then in 2004 the present facilities were opened.

Outbuilding of health resorts and spas in Iceland has for a long time been suggested as viable new business opportunities (e.g. Checchi and Company, 1975. Kristmannsdóttir et al. 2000). In many of the rural areas where population is decreasing with an endangering speed and especially the young people are seeking better paid jobs elsewhere there appear to be good opportunities for such an outbuilding which will probably give a vast spinoff in food production and service.

In this context there may be considered different types of balneological prospects as:

1. Medical treatment of illnesses

2. Rehabilitation/treatment of disability or aging problems
3. Relaxation and resting
4. Amusement/recreation

In this project the main emphasis was placed on water, wellness and rehabilitation (items 2 and 3), not on direct medical treatment. Spa treatment is probably nowadays mainly aimed at treatment of "incurable" diseases where healing by traditional medical methods have failed and anyway the marketing of the concept water, wellness and rehabilitation was considered the most appealing and convenient.

2. GEOTHERMAL WATER IN BALNEOTHERAPY

From many centuries back spas based on the use of geothermal water have been operated in Europe and Asia and later in America. Water of certain composition have been stated to be useful for the treatment of certain illnesses and ailments (Agishi et al., 1996, Fresenius and Kuβmaul, 1998, Björnsson, 2000, Kristmannsdóttir and Björnsson, 2003). Bathing in water certainly has detectable and easily measurable effect on the human body and the effects of both heat and pressure on the organs in the body can be monitored (Björnsson, 2000). As an example in a very hot bath, >42 °C, the heart beat is greatly increased and production of hormones like ß-endorphins is extremely enhanced. This hormone is addictive and has similar action as morphine (Björnsson, 2000). Effects due to heat and pressure of the water are noticed in the support system, heart and veins, kidneys, lungs, the neurological system and hormones (Björnsson, 2000). It can also be detected in blood cells, in coagulation of the blood and many other body functions. It is a well known fact that it is easier to move in water, especially saline water which is therefore used for rehabilitation after accidents and illness, aging problems and treatment for rheumatism.

The effect of chemical composition of the bath water is often more questionable and it is difficult to establish a correlation between chemical composition and balneological properties of the geothermal water. In many cases it seems more based on tradition than scientifically proven facts (Björnsson, 2000). Saline warm water stalls the symptoms of psoriasis, but ultra violet light is also one of the factors affecting symptoms of psoriasis. Sulfur rich water is effective to fight infections and disinfect wounds. Bathing in acidic hot water has proved to be effective to keep down certain types of eczema (Björnsson, 2000). It appears that different water types have been used in spas for the the treatment of many different illnesses (Agishi et al., 1996). A red thread seems to be that fresh geothermal water is useful for the treatment of very many different symptoms and ailments. Still the spa water is classified after concentration of certain elements and its usefulness for the treatment of certain ailments listed (Fresenius and Kuβmaul, 1998, Agishi et al., 1996, Björnsson, 2000). Regulations for spa water often claim that several trace elements are to be analyzed in spa water, a.o. bromide, boron, iron, manganese, lithium, arsenic, cadmium, chromium, mercury, nickel, lead, antimon, selenium, barium, copper, zinc, cobalt, molybdenum, vanadium, tin, silver, aluminum. Some elements are considered beneficial for balneological purpose, whereas others are not-the concentration probably plays a main role in this connection.

3. GEOTHERMAL RESOURCES IN NE ICELAND

In Iceland there are vast geothermal resources of varying type and potential. The extensive geothermal activity is due to the volcanic and seismic activity and high rate of precipitation. The geothermal heat is ultimately derived from volcanic activity, either directly or more indirectly. The high permeability, even in the older Tertiary reservoir rocks, is due to the seismic activity maintaining active circulation in the geothermal fields. Iceland has an European record in precipitation,>6000 m^3/s. A high proportion runs off, but still there is much more groundwater flow than in the neighboring countries (Jónsdóttir, 2006).

The distribution of the geothermal systems in Iceland is directly related to the geology of the country (Figure 1). The high-temperature geothermal areas are all located within the active zones of rifting and volcanism (younger than 0.8 My) and draw their heat directly from magma or cooling intrusions. Their reservoir temperatures exceed 200 °C at 1 km depth. The low-temperature geothermal areas occur in older geothermal formations of Quaternary and Tertiary age (0.8-16 My) and their heat is derived from fractured rock formations and the high geothermal gradient. Their reservoir temperatures are below 150 °C at 1 km depth. The geothermal resources in NE Iceland are ample and of varied nature and some of the most active are sub oceanic (Björnsson, 2007, Geptner et al, 2002). In Figure 2 the NE Iceland part of the map displayed in Figure 1 is enlarged, showing the many high-temperature geothermal fields, low-temperature geothermal fields as well as some boiling geothermal fields in NE Iceland.

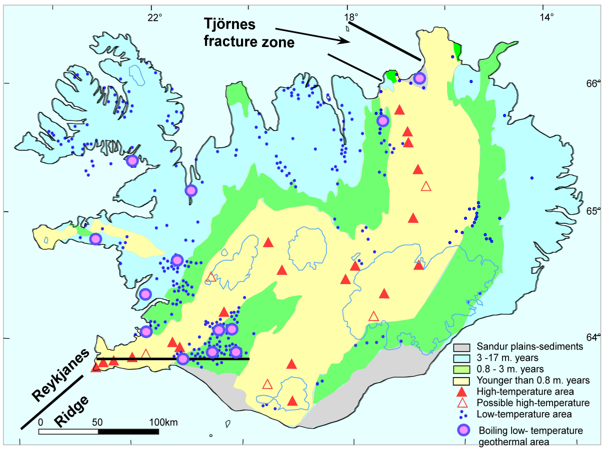

Figure 1: A simplified geological map of Iceland showing the location of geothermal fields in Iceland The figure is based on data from Saemundsson, (1979) and Björnsson et al., (1990).

The area of NE Iceland spans almost the whole geological history of Iceland from 10 My old Tertiery rocks to recent lavas as young as 25 years old (Björnsson et al., 2007). In the older western part of the area there are still numerous low-temperature geothermal fields owing their existence to the seismic activity of the Tjörnes transverse fracture zone to the north of the country (Figure 1 and 2). On the western flank of the active zone in quaternary and younger Tertiary rocks (0.8-3.1 My old) there are numerous very yielding low-temperature geothermal fields and also several within the active zone. A few boiling low-temperature geothermal fields with reservoir temperatures exceeding 100 °C also occur in those formations (Figures 1 and 2).

The active volcanic zone ends at the shore of the Öxarfjördur bay where the transverse fault zone of Öxarfjördur jumps it towards the Kolbeinsey Ridge in west (Figure 1). A boiling low-temperature geothermal area occurs on the edges of the zone and is probably a cooling high-temperature area. The volcanic zone in NE-Iceland is segmented into five major discrete volcanic systems (Björnsson, 2007).

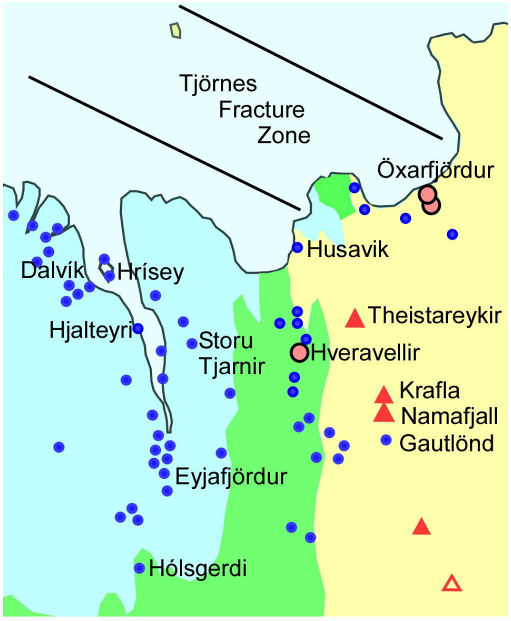

Figure 2. The study area in NE Iceland enlarged from the map in Figure 1. The legend is the same as in Figure 1, except for the boiling geothermal fields which here are red dots with a black circle around.

Several high-temperature geothermal fields are found within the active zone, each connected to a fissure swarm within the zone (Figure 3).The fissure swarm connected to the Krafla central volcano has been the most active during the last century (Björnsson et al., 2007). The high-temperature geothermal fields of Krafla. Námafjall (B on map) and the assumed high-temperature geothermal field at Gjástykki (G on map) are within this swarm. The Theistareykir high-temperature geothermal field is connected to the Theistareykir fissure swarm and the Fremrinámur and Askja high-temperature geothermal fields to each their fissure swarm. The high-temperature geothermal field in Krafla is used for electricity generation in the 60 MW Krafla power plant and a small power plant is also operated in the Námafjall geothermal field, where there are plans for a larger plant to be built. The Theistareykir field is being harnessed and the Gjástykki field is also under exploration. The outbuilding of those enterprises gives potential for the outbuilding of balneological projects based on the use of waste water and excess energy from the power plants. The health spa in the Myvatn area (near Námafjall) uses at present water and steam from production boreholes intended for the operation of a new electrical power plant.

Some of the low-temperature geothermal fields in the area are used for heating of both the small towns and the rural areas. The largest municipal heating system is for the town of Akureyri with about 17 thousand inhabitants (see Figure 3 for location).

That system utilizes six different geothermal fields for its operation as the town is located in the geologically oldest part of the NE Iceland region where the permeability of rocks is low and the fields normally not very yielding (Axelsson, 1998). An exception being some few fields located within the crossing of major fault zones in the northern part of Eyjafjördur (Marteinsson et al., 2001. Pálmason, 2005). For the town of Húsavík with about 2.500 inhabitants a geothermal district heating system has been in operation since 1970 (Hjartarson et al., 2002). The 125°C water comes from the Hveravellir boiling low-temperature geothermal area south of the town.

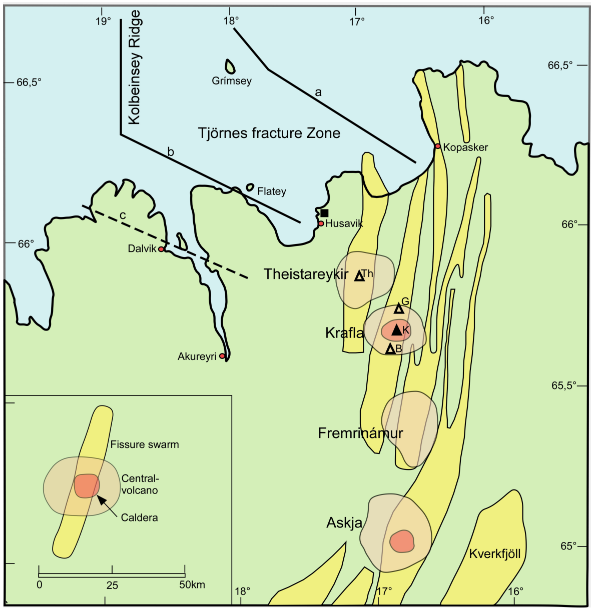

Figure 3. The active fissure swarm within the volcanic zone in NE Iceland (Björnsson, 2007).

Until a few years ago the water flowed through a 18 km long eternite (asbestos) pipe to the town and lost some 15°C on the way to town. Now it has been replaced with a preinsulated steel pipe transporting the water under pressure to the town with only about 2°C temperature loss. In the new system there is combined in one system the generation of electricity by a Kalina Binary system and hot water supply for different direct uses, mainly heating purposes. The integrated system improves considerably the efficiency in the geothermal utilization (Hjartarson et al., 2002). The boiling geothermal field at the shore of the Öxarfjördur bay is used for the heating of the village of Kópasker (See figure 3 for location). There one has to cool the water to avoid calcite scaling and the water is also much too hot for consumption, thereby wasting a considerable part of the energy. Unfortunately the economical situation of the area does not allow a more elaborate system to be installed. By the building of a similar system as in Húsavik almost double of all the electricity used now in the area could be produced by cooling the water down to a proper temperature for use in the heating system. By producing still more electricity the fish farming firms in the area or some new enterprises could use some of the effluent water not needed for heating. Most of the wast low-temperature geothermal resources in the area are not utilized or only a small fraction of them. Due to the sparse population it is difficult to get funds to harness the resources and some places people are paying fortunes for oil or electricity for heating where there are proven geothermal resources and even tens of liters of hot water flowing into the river within a short distance.

4. CHEMISTRY OF THE WATERS

The chemistry of all the geothermal waters is governed by equilibrium with silica minerals, alkali-. iron- magnesium and aluminum silicates, calcium carbonate and metal sulfides and oxides (Arnórsson et al.. 1983, Kristmanns-dóttir. 2004). The silica concentration of the waters is in direct relation with increasing temperature. The waters are highly depleted in magnesium. even at moderate temperatures.

4.1 High-temperature waters

The high temperature waters in the area have a relatively low mineralization even though their mineral concentration is considerably higher than in the low-temperature waters (Table 1).

The high-temperature waters contain acid gases which mostly follow the steam phase by boiling. Normally carbon dioxide is the gas type in highest concentrations in the gas phase, but the concentration of hydrogen sulphide, hydrogen and methane may be considerable in some areas (Table 1). Trace concentrations of ammonia, mercury, boron and other substances are also encountered. The boiled high-temperature water is alkaline, whereas the condensed steam is acidic due to high gas concentration.

In Table 1 there are shown examples of the chemical composition of fluids from the three high-temperature geothermal fields which have been drilled into, Krafla, Námafjall and Theistareykir. All samples are displayed after boiling at 180 °C and the water and steam phase at that temperature are shown separately in the table. As shown in the table water from the Krafla field has the highest percentage of gases, whereas H_2S as well as H_2 is in relatively highest concentration in the geothermal steam in the Námafjall area. The highest concentration of chloride in water is encountered in the deep water system in Krafla, whereas sulphate concentration is highest in the water from the shallower resource in Krafla. Total dissolved solids (TDS) are relatively low in all geothermal systems and not always exceeding the 1000 mg/L limit to be classified as highly mineralized waters. As and Cd concentrations are highest in the deep water system of Krafla and mercury is highest in Theistareykir and Krafla fields. Mercury is concentrated in the steam, but reliable analysis were not available. The analytical process for mercury analysis and sampling is very difficult and faulty results are common (Edner et al., 1991).

4.2 Low temperature waters

The low temperature waters in the area vary mainly after the type of recharge water (meteoric or seawater) and geological settings (Table 2 and 3). Most of the water is of meteoric origin, but seawater originated water is also encountered near the sea shore, especially in the fissure swarms within the acticve volcanic zone. Typical for the low-temperature waters in the western part reacting with older Tertiary rocks are high pH values, typically 9-10 (Table 2). Waters with extremely high pH, up to 11, are encountered in the eastern part, especially on the border of the active volcanic zone where young, glassy, basalt lavas are common in the underground reservoir rocks (Table 3). Total carbonate concentration in the low- temperature waters is in inverse relation to increasing temperature. They are devoid of dissolved oxygen and the gas phase is mainly constituted of nitrogen and minor argon, as well as traces of carbon dioxide and hydrogen sulfide. Hydrogensulfide is in higher concentration in waters reacting with the younger reservoir rocks (Table 3). Waters reacting with acidic rocks as within central volcanoes contain somewhat higher chloride concentrations than those reacting with basaltic rocks. They also have higher concentrations of fluoride, boron, lithium and many other trace elements. The water at Hólsgerdi (Figure 2) is typical for such waters (Table 2). In the western part of the area saline waters are not common, but in table 2 is shown one example of slightly saline water occurring on the Hrísey island in the fjord of Eyjafjördur (Figure 2). Most of the other geothermal waters in the western area are fresh waters with very low mineralization, with TDS in the range of 150-350 mg/L. In the eastern part of the area the waters are more varied and saline waters are more common (Kristmannsdóttir et al., 2007). Boiling low-temperature areas with both fresh (Hveravellir) and saline waters (Öxarfjördur) are encountered in this part of the area adding to the variety of geothermal water types (Figure 2, Table 3).

Within the limits of the small town of Húsavík (Figure 2) saline water has been obtained by drilling (Table 3).This water is one of the lightest water ever found in Iceland according to δ^2H analysis and also very old according to ^{14}C dating (Kristmannsdóttir et al. 2007). The reservoir rocks in the geothermal field are partly seawater sediments. The concentration of trace elements is generally very low in the low-temperature waters. Aluminium concentration is highest in the warmest non-saline waters and the most alkaline, but low in the saline waters.

Table 1. Analysis of typical high-temperature water from NE-Iceland. Data from Orkustofnun database.

Place	Þeista-reykir ÞG-1	Krafla KG-5 Shallow	Krafla KJ-20 Deep	Náma-fjall BJ-11
Deep temp.°C	280	205	280	270
Vater phase				
pH/°180	8.0	7.97	7.48	7.82
SiO_2 mg/L	754	324	817	702
B mg/L	1.7	0.5	2.4	2.4
Na mg/L	118	175	244	113
K mg/L	24	16	51	18
Ca mg/L	0.5	3.6	2.0	0.6
Mg mg/L	0.004	0.009	0.01	0.01
Tot. Carb (CO_2) mg/L	27	36	194	37
H_2S mg/L	22	32	44	70
SO_4 mg/L	9.3	228	17	25
Cl mg/L	106	40	219	45
F mg/L	1.0	1.0	1.5	3.4
TDS mg/L	1185	778	1580	1060
Al µg/L	2040	797	1002	1850
As µg/L	7.19	2.24	25.8	22.4
Cd µg/L	<0.005	0.0067	0.0026	<0.002
Fe µg/L	7.0	129	42.5	6.4
Hg µg/L	0.0499	0.062	<0.02	<0.02
Mn µg/L	1.81	-	-	-
Pb µg/L	0.0420	0.0541	0.0222	0.0394
Steam phase				
CO_2 mg/L	1279	1749	24948	2521
H_2S mg/L	238	367	1400	1161
H_2 mg/L	22	2.29	50	88
CH_4 mg/L	0	3.6	3.3	8.7

Table 2. Analysis of typical low-temperature geothermal water from NE Iceland. The places are from the western part of the study area. in Tertiary reservoir rocks. Data from Kristmannsdóttir et al., 2005).

Place	**Dalvík**	**Hrísey**	**Hjalt-eyri**	**Hóls-gerði**	**Eyjafj.**
Temp. °C	64.5	77	86	41	94
pH/°C	10.17 / 23	9.26 / 23	10.07 / 20	9.63 / 24	9.72 / 20
SiO_2 mg/L	85.8	58.9	114.2	81.6	97.4
B mg/L	0.08	0.10	0.19	0.28	0.16
Na mg/L	49	236	56	81	52
K mg/L	0.81	4.53	0.92	1.49	1.19
Ca mg/L	1.93	86.15	1.79	5.76	2.85
Mg mg/L	<0.002	0.0438	<0.002	0.0355	<0.002
Tot. Carb (CO_2) mg/L	14	3.2	13	22	17
H_2S mg/L	0.06	0.04	0.289	0.015	0.066
Rn Bq/L	-	-	2.6	4.5	2.6
SO_4 mg/L	13.2	60	17.6	75	40
Cl mg/L	9.26	500	10.9	38.8	12.5
F mg/L	0.50	0.26	1.77	4.25	0.38
TDS mg/L	167	952	214	344	216
Al µg/L	78	15	129	56	131
As µg/L	2.8	2.5	13	6.1	5.4
Cd µg/L	<0.002	0.006	<0.002	<0.002	<0.002
Fe µg/L	0.7	1.0	3.0	1.1	1.7
Hg µg/L	<0.002	0.01	<0.002	0.025	<0.002
Mn µg/L	<0.03	0.4	<0.03	0.08	0.07

As concentration is very low, but highest in the warmest waters. Cadmium (Cd) concentration is below detection in most of the waters as well as mercury (Hg), which is mostly detected in the waters of highest temperature. Manganese (Mn) is highest in the most saline thermal waters and actually it has been reported to be highest in tepid saline waters in the area (Kristmanndóttir and Ólafsson, 1989). Other trace elements are also very low in concentration.

5. BALNEOLOGICAL CLASSIFICATION

For the classification of Icelandic geothermal waters there has formerly been used a classification according to chemical character and balneological properties, slightly adapted for Icelandic conditions, but based on both German and Japanese classifications for health resort water (Kristmannsdóttir et al., 2000. Agishi et al., 1996. Fresnius and Kuβmaul, 1998).

Table 3. Analysis of typical low-temperature geothermal water from NE Iceland. The places are from the eastern part of the study area. in Quaternary and recent reservoir rocks. Data from Kristmannsdóttir et al., 2005).

Place	Stóru Tjarnir	Gaut-lönd	Hvera-vellir	Húsa-vík	Öxar-fjördur
Temp. °C	66	66	128	70	116
pH/°C	9.70/ 21	10.44/ 20	9.32/ 23	8.88/23	6.9/22
SiO_2 mg/L	102.5	77.4	173.5	84.8	172.0
B mg/L	0.113	0.05	0.07	0.14	1.26
Na mg/L	54	56	58	827	949
K mg/L	0.87	0.62	2.27	26.2	46.0
Ca mg/L	2.4	1.9	1.7	237	178
Mg mg/L	0.002	0.001	0.002	0.015	0.311
Tot. Carb mg/L CO_2	20	20	36	2.1	23
H_2S mg/L	1.04	0.01	1.42	0.1	0.24
Rn Bq/L	2.0	1.7	-	3.1	16.9
SO_4 mg/L	29.0	14.4	30.7	83	99.0
Cl mg/L	15.7	8.8	11.3	1760	1671
F mg/l	0.80	1.04	0.95	0.15	0.28
TDS mg/L	205	160	303	3020	3136
Al µg/L	27	236	205	48	26
As µg/L	6.97	0.47	1.14	13.2	12.0
Cd µg/L	<0.002	<0.002	<0.002	0.033	<0.05
Fe µg/L	<0.001	<0.001	0.008	0.9	44.8
Hg µg/L	<0.002	<0.002	0.584	0.017	0.14
Mn µg/L	0.15	0.17	0.10	1.41	23.0

The classification groups defined are:

1. Carbonate water containing total carbonate (calculated as CO_2) in excess of 300 mg/L.
2. Sulfide water containing H_2S in excess of 1 mg/L and of temperature exceeding 40 °C.
3. Highly mineralized warm (>40 °C) waters with TDS (total dissolved solids) exceeding 1000 mg/L.
4. Iron rich water containing iron in excess of 20 mg/L and of temperature exceeding 40 °C.
5. Fluoride water containing fluoride in excess of 2 mg/L and of temperature exceeding 40 °C.

For health resort water iodide (I) and radioactive waters are commonly encountered, but such waters are not found in Iceland.

Most of the high-temperature geothermal fields in NE Iceland have waters which fall in group 2 and 3. Some will be classified in group 5, fluoride water. On the borders of the high temperature fields there may be found carbonate waters formed by percolation of geothermal gases through groundwater and even iron rich water. After boiling of a high-temperature geothermal fluid the water will normally not be characterized as carbonate water as most of the carbon dioxide will follow the gas phase. The availability of high-temperature geothermal waters however offers the possibility of the production of varied types of geothermal baths. The boiled water is alkaline, sulfur rich and highly mineralized whereas by percolation of the geothermal steam through cold water there may be obtained acidic, sulfur and sulfate rich waters for health baths.

In the western part of the area there are occasional low-temperature waters classified in group 3, highly mineralized water and several waters classified as group 5, fluoride rich water. Most of the waters are fresh geothermal water and cannot be classified into any of those groups. Low temperature waters in the eastern part of the area are classified as groups 1. 2. 3 and 5 although there are also ample resources of fresh geothermal water not falling into any of the classification groups for health resort water. Highly mineralized saline waters are most common in the Öxarfjördur area in the far eastern part of the study area.

Some of the saline low-temperature waters in NE Iceland as the water in Húsavík are rather similar to waters in renowned European health resorts like Baden (Table 4). The fresh geothermal water bears some likenesses to water from resorts elsewhere in the world as compared in table 4, but the alkaline character and low hardness are special properties for waters reacting with basaltic reservoir rocks.

Table 4. Comparison of chemical composition of water from some low-temperature geothermal fields in NE Iceland and the health resort of Baden-Baden and Hot Spring in Arkasaw USA.

“Kristmannsdóttir et al., 2005, # Björnsson, 2000 , □ Lund, 1996.

Place	Öxar-fjord”	Húsa-vík “	Bad.Bad #	Eyjafj”	Ark-ansaw□
Temp. °C	116	70	56	61	61
pH/°C	6.9/ 22	8.88/23	8.2/ 20	9.87/21	-
Tot.carb. (CO_2) mg/L	23.2	2.1	20.4	16.4	119
H_2S mg/L	0.24	0.1	-	0.05	-
SiO_2 mg/L	172	85	167	76	42
TDS mg/L	3.081	3.020	3.115	178	167
Na mg/L	949	827	851	46.0	4.0
K mg/L	46	26.2	32.9	0.52	1.5
Mg mg/L	0.31	0.015	58	0.001	4.8
Ca mg/L	178	237	144	2.45	45
Sr mg/L	7.3	0.85	4.3	0.01	-
F mg/L	0.28	0.15	0.6	0.6	0.2
Cl mg/L	1.671	1.761	1.442	11	1.8
Br mg/L	5.4	6.15	1.6	0.04	-
SO_4 mg/L	99	83	209	33	8
Rn Bq/L	16.9	3.1	26	2.6	-

6. OTHER RESOURCES

The main survey was aimed at the geothermal water sources, but other resources have also been looked into, but in much less detail.

6.1 Clay deposits

Clay deposits were originally mapped in this area in the early 1970´ties for the purpose to find mineable clay for pottery (Kjartansson, 1972). Few years ago a research project aimed at investigation of the properties of clay deposits in the area was conducted by the Russian scientist Alfred Gepthner (Geptner, 2004, 2005). The full results of that project are not yet being published, but from the results of those two projects it seems clear that it is difficult to find mineable clay in the Krafla and Námafjall fields. At the Theistareykir field there are more possibilities as the clay there is partly reworked and thus more homogeous in places. The clay in Theistareykir field appears to have similar mineralogical and chemical composition as clay from Hveragerdi SV Iceland which has been used for balneotheraphy for tens of years (Geptner, pers. comm., Geptner and Kristmannsdóttir, 2008). The trace element composition is also very similar. The concentration of silver, which is considered beneficial for skin treatment, was found to be the highest one found in both Icelandic and foreign spa clays investigated in the project. Possibly permission to mine the clay at the Theistareykir field may be difficult to obtain though due to environmental considerations as there is great concern at present not to disturb or destroy beautiful natural formations.

6.2 Silica and other precipitates

As in the Blue lagoon in SW Iceland, in Japan and many other places silica and other precipates formed by geothermal fluids are commonly used in balneotherapy. In all the high-temperature geothermal fields of NE Iceland such precipitates could be produced and utilized. As the water is non saline in the high-temperature geothermal fields in NE Iceland the texture and composition of silica precipitates differ considerably from that of the renowed Blue lagoon silica. The precipitates are more fine grained and show almost no crystal structure as the Blue lagoon silica does and their concentration of heavy metals appear to be lower. There also appears to be another difference as in the Blue lagoon almost no microorganisms do thrive in the water nor silica mud. This appears not to be the case in silica mud from the Námafjall field. There is at present no apparent explanation of this difference but a suggestion may be that due to the special clay-like structure of the Blue lagoon silica and its contents of heavy metals (Kristmannsdóttir et al., 1996) it may act as some kind of a killer clay (Williams et al., 2004). This is however just a hypothesis, which has to be tested and proved.

6.3 Potable water

There are ample resources of fresh groundwater in the area, especially in the eastern part. The chemical composition is variable after age and type of reservoir rocks and most types of Icelandic groundwater are encountered in the area (Kristmannsdóttir, 2004). All the waters have low mineralization, with total dissolved solids (TDS) 30-120 mg/L. In the western part of the area there is groundwater typical for water emerging from the old Tertiary rock formations, with pH 8.5-8.8, and normally higher TDS than water emerging from the younger rock formations. Water from the youngest rock formations normally has pH in the range 8.9-9.2, but ultra alkaline waters with pH of 9.5 or higher are also found.

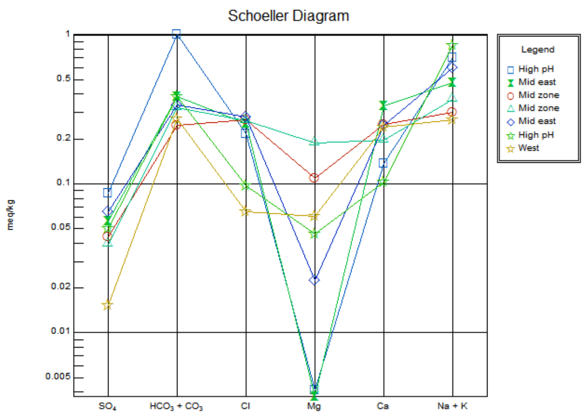

Figure 4. Schoeller diagram of the main types of fresh groundwaters in the area.

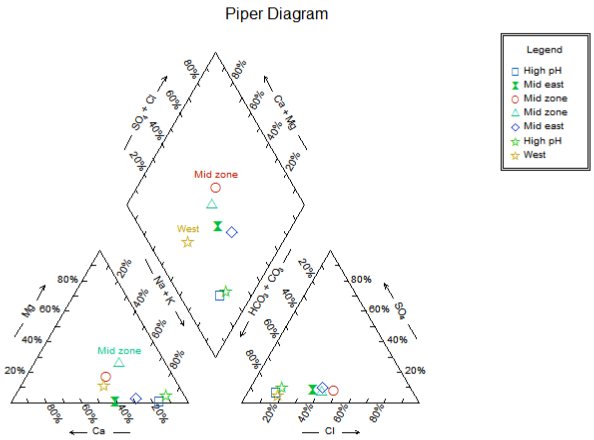

Figure 5. Piper diagram of the main types of fresh groundwaters in the area.

The ultra alkaline waters all emerge from rather unaltered hyaloclastite bedrock. In a few cases geothermal influence may result in carbonated cold water with a lower pH and higher TDS. A Schoeller diagram of typical potable water types in the area is shown in figure 4 and a Piper diagram for the same types of water in figure 5. All the waters are classified as alkali-bicarbonate waters, but show varying individual character, the main variation displayed in magnesium concentration. The concentration of other elements also varies, mainly the bicarbonate concentration.

On the Piper diagrams the waters fall typically in different groups after type of water; waters from the geologically older western part, waters from the mid zone of Quaternary rocks, waters from the geologically young zone in the east. Finally the high pH waters, which all occur in the youngest part where the rocks are dominantly slightly altered hyaloclastites.

All the ground waters in the area are fresh, uncontaminated and good potable water, but the taste is different and that attribute may offer certain possibilities in marketing of health resorts.

6.4 Atmospheric air

There is not much industry in the area and pollution of the atmospheric air is probably insignificant. Air quality monitoring has not been conducted though except within the town of Akureyri, so proofs of the air being fresh and unpolluted are not available at present.

6.5 Sustainable food production

In the area there are produced a selection of food, which can be designed as organic and sustainable produce. There is a thriving fish farming industry in both the western and the eastern part of the area, partly by the use of geothermal heat and ample opportunities for substantial increase. There have been built up greenhouses in the eastern part of the area, which now more than fulfill the needs of this part of the country for vegetables as tomatoes and cucumbers. There are good possibilities to build out this industry if there are available local markets. Organic growth of vegetables, mainly carrots has been developed in the last years in the eastern part of the area (Aðalbjarnardóttir, 2004, Kristmannsdóttir et al., 2006). Last but not least the sheep farming produces lamb meat that is healthy and tastes like wild animal as the lambs graze freely with their mothers in the wilderness during the summer before being slaughtered.

6.6 Medical services

In the town of Akureyri there is a high-tech hospital with highly qualified personal and all modern technical aid.

Rehabilitation and treatment of elderly people by the use of balneotherapy has been used for a long time in cooperation with the hospital and health care center in the town. In Húsavík there is also a health care center capable of rending all kinds of medical assistance and services.

6.7 Tourist attractions

Some of the most beautiful sights in the country are located in this area, like Lake Mývatn and surroundings, many beautiful waterfalls as Godafoss, Aldeyjarfoss and Dettifoss. Catastrophic floods in the glacial rivers at older times have left magnificent remnants in the form of majestetic landscape, the most famous being the Ásbyrgi cliff formation. The island Grimsey touches the Arctic Circle and the midnight sun is to be enjoyed in the area during mid summer. The geothermal fields are spectacular and so are the volcanoes. The barren highlands and the arctic shore lines are also unforgettable. There are many historical places and trails to visit. Even though there are much more tourists visiting in the summer, winter tourism could also offer many special activities and enjoyable experiences. Bathing in a hot tub outside in a clear cold winter night with the northern lights flaming and the stars shining is something spectacular and unforgettable!

6.8 Available services

There is an international airport in the town of Akureyri with overseas services in the summertime. The airport at Húsavík is very well located and could also be a possible port for charter flights if the market requires. There are available overnight opportunities in the area in all price classes from youth hostels to four star hotels. There are all categories of restaurants in the town of Akureyri, from first class gourmet establishments to simple breakfast joints. In Húsavík there are also a few restaurants. Sightseeing opportunities are varied and observing of special natural rarities as whale watching outside Húsavík and observation of European and American bird species side by side at Lake Myvatn. There are also a variety of museums of any kind in the area. There are many public outdoor swimming pools, some of them have been built out to a kind of a bathing wonderland for kids, but others are simple and all use the local natural geothermal water.

7. DISCUSSION

The main purpose of the project was to collect and process information and data for the tourist industry to the use in development and marketing of health tourism and balneology. The part reported on in this paper focuses mainly on the research of compiling and mapping of data concerning available natural resources and evaluation of the data necessary for marketing. Comparison and diagnosis of market opportunities and possible business projects have also been reviewed in the project, but need to be further elaborated. The medical approach has been looked into for the use of the waters in balneotheraphy, but the main emphasis is on water and wellness, rehabilitation and recreation. The reason is mainly that in a former project where medical literature on balneotherpy was reviewed it was concluded that the scientific basis for the medical effect of geothermal water of different chemical composition in treating different illnesses was in most cases rather poorly defined (Björnsson, 2000, Kristmannsdóttir et al., 2000).

The characteristic composition of the Icelandic geothermal waters in Iceland is due to the basaltic basement reacting with the waters and also the very high permeability, resulting in highly alkaline waters with low mineralization. The Icelandic waters are thus rather special in composition as compared to geothermal waters elsewhere. As compared to geothermal waters in other countries the waters in NE Iceland are generally much less mineralized although there occur saline geothermal waters and highly mineralized waters in a few places, like near the town of Húsavík and in Öxarfjördur. The thermal waters in central Europe are much more highly mineralized than typical low- temperature geothermal waters in Iceland. Waters in some American health resorts are somewhat similar to the Icelandic waters. There are known geothermal waters in Japan which are quite comparable in composition to geothermal waters in Iceland as the reservoir rocks are comparable in places. The high-temperature waters are more similar in composition to high-temperature geothermal waters elsewhere in the world. Even though the chemical characteristics of geothermal waters are probably not the main deciding factor for their usefulness in balneotheraphy is is important for marketing purposes to classify the waters according to health resort standards-which was accordingly done in the project. The compilation of other important factors for the definition and valuation of possible projects and business ideas, like potable water, air freshness data, availability of organic and sustainable produced food, tourist attractions and available medical and general services was conducted within the project and several different possible business projects were suggested. Those projects are now being processed by specialists in business and marketing and the first feasibility studies are being conducted.

8. CONCLUSION

There are ample geothermal resources in NE Iceland both high temperature and low temperature geothermal fields as well as boiling low-temperature or medium enthalpy resources. One of the aims of this project was to define possible cascade uses of the geothermal energy as it is of utmost importance not to waste energy even though the resources are ample. Many of the high-temperature fields in the area are now being harnessed for electricity production and balneological projects seem to be an ideal target to utilize the effluent water. The high-temperature water offers the possibility of the production of varied water types for bathing and treatment by boiling of the fluid and mixing of geothermal steam with fresh water. There are possibilities for production of silica and other geothermal precipitations and possibly mining of clay in the Theistareykir field. The properties of the silica are different though from that of the Blue lagoon in SW Iceland.

The boiling low-temperature geothermal fields near Húsavík and in Öxarfjördur offer unique opportunities for projects based on cascade use of the geothermal power. In the town of Húsavík there has already been built such a unit, with a binary Kalina power plant, heating system, fish farming and possibility for balneological projects and instrial use. In Öxarfjördur the need for heating is less due to sparse population, but it would be beneficial for the existing heating plant if a binary plant was installed to cool down the water and the effluent water could be used to enforce the already rather strong fish farming industry in the area and to build up greenhouse farming and for balneological projects. Most of the water in the low-temperature fields in NE Iceland is fresh and not specified as any health water type, but such water still seems to be desirable for balneotherapheutic use. Some of the low temperature geothermal waters in the area have similar chemical characteristics as waters in renowned foreign spas and have already proved to be effective in the treatment of skin diseases as psoriasis as well as rheumatism. There is good basis for the outbuilding of spas both in the western part of the area and in the mid and eastern parts. In all the area there is access to good unpolluted potable water in ample quantities. The water is of varied types and the taste differs, which may offer opportunities for marketing of the spas.

Besides the geothermal and fresh water resources in the area there can be pointed out many other fundamental attributes for the building up of spas, some of which are also based on geothermal utilization. The conclusion of this survey is that there are numerous opportunities to develop balneological projects in the area. Now there need to be conducted market analysis and feasibility studies on the business ideas which have been defined and also to define other viable business ideas to develop and carry further towards realization.

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