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NATURAL CHANGES IN UNEXPLOITED HIGH-TEMPERATURE GEOTHERMAL AREAS IN ICELAND

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ABSTRACT

Geothermal areas differ and the effects of exploitation on their environment are also very variable. According to Icelandic law an environmental impact assessment is required for a planned power plant, as well as a comparison of alternative power production possibilities for the selection of the environmentally most favourable one. To be able to forecast possible changes following the exploitation of a geothermal field the extent of natural changes occuring within the area with time needs to be known. Monitoring of the field in question is thus needed for several years prior to exploitation. One task of an Icelandic enforcement project on environmental effects of geothermal exploitation has been dedicated to the study of unexploited geothermal areas. The first part of the project was a survey of the status of environmental research in the areas, and as such disclosed an urgent need for increased research. This was followed by the initiation of a monitoring program in selected unexploited geothermal areas. Four areas at different stages of development, Krýsuvík, Theistareykir, Torfajökull and Kverkfjöll, have been chosen for monitoring and it is clear that natural changes are quite extensive and depend on factors such as hydrothermal sealing, earthquakes, volcanic activity and hydrological conditions.

1. INTRODUCTION

Due to the increased emphasis on the environmental viability of energy production it is now required by Icelandic law to assess the environmental impact of energy production and select the most favourable option concerning environmental effects.

The most important environmental changes brought about by geothermal utilization are: *Surface disturbances*, *physical effects due to fluid withdrawal, noise, thermal effects and emission of chemicals, both, gas emissions and liquid discharge* (Ármannsson and Kristmannsdóttir, 1992). As many geothermal areas are of unique beauty, of historical interest or are popular tourist attractions, their *protection* must be considered. Most of these effects vary considerably from one geothermal site to another and as well as by the type of utilization. The variability of the environmental effects from one field to another depends on the special characteristics of the field in question. In this respect the geology and the subsurface structure, as well as the type of reservoir, play a major role. Geothermal areas are dynamic features and changes occur even though they are not exploited. Surface expressions and activity of geothermal fields are quite changeable. It also varies from one field to another how frequently and how dramatically changes occur. Within the same field changes are variable from one time to another. It is thus necessary to know probable natural changes with time in the unexploited geothermal areas. Well known examples involve geysers such as Geysir in Haukadalur, South Iceland, which tends to become active after earthquakes but deposits are formed around the basin that raise its water level until it ceases to erupt. In the past human intervention has changed the character of geothermal fields leaving features that are now considered part of nature. An example of this are several wells drilled in the Hveraröndpart of the Námafjall area, North-Iceland, where several wells were drilled for a proposed sulphur plant during the 1950's but were abandoned when the project was. These are now wonderful springs and fumaroles that attract thousands of tourists every year and their possible disappearance has recently been cited as a reason for not building a power station at Námafjall. To be able to forecast possible changes in the wake of exploitation and to distinguish natural changes from changes due to exploitation, the nature of each field has to be well studied prior to exploitation and monitored over a long period. Only by long term monitoring and studies of the physical and chemical features of the field may the nature of the apparent changes be explained. Such studies are the basis for making the most environmentally viable choice of geothermal area to develop. The problem is that research is costly and money for this kind of research is rarely available until there is an urgent need for the exploitation of the energy source in question.

In 1991 when new environmental legislation for Iceland was in preparation, Orkustofnun initiated an enforcement project in Iceland to study the environmental impact of geothermal exploitation. For funding Orkustofnun requested the co-operation of the main exploiters of high-temperature geothermal energy in Iceland (Fig. 1). This co-operative project of Orkustofnun and major high-temperature geothermal energy exploiters in Iceland (exploiting the Reykjanes, Svartsengi, Nesjavellir, Námafjall and Krafla areas) was initiated in 1991 and concluded in 1997 (Kristmannsdóttir, 1997, Kristmannsdóttir et al., 2000) Several sub-projects are still in progress. The aim was to establish and predict environmental impact of geothermal utilization, and to suggest remedies. It entailed firstly an assessment of the present status at the five main sites of high-temperature geothermal production in Iceland and secondly the definition of several priority projects (Kristmannsdóttir and Ármannsson, 1995) to be carried out within the scope of the project. One priority project was aimed at the exploration of unexploited geothermal areas.

2. SCOPE OF THE NATURAL CHANGES PROJECT

The main aim of the project was to define and initiate monitoring schemes for natural features in unexploited geothermal areas and to develop research methods for that purpose.

The status of environmental knowledge for the unexploited high-temperature geothermal areas in Iceland was defined in the beginning. Concurrently background data on some unexploited areas was collected and monitoring schemes initiated in a few selected areas.

A schedule of the work needed to carry out an environmental impact assessment for a 20 MW power plant in each of the unexploited Icelandic geothermal areas was prepared together with an estimate of the cost.

Methods were developed to measure the mass flow of steam in fumarole outlets (Gíslason, 1997) and for the monitoring of geothermal areas by aerial thermography remote sensing methods (Árnason, 1997 a).

The concentration of sulphur gases and mercury in atmospheric air was measured in four unexploited geothermal areas (Ívarsson *et al*., 1993).

3. PRESENT STATUS OF NON EXPLOITED GEOTHERMAL AREAS

The status of environmental investigation in 28 high-temperature geothermal areas in Iceland (Fig. 1) was examined and the results compiled (Ármannsson et al, 1997). The main emphasis was on non-biological work, but publications on biological material such as vegetation and wild life were also compiled. Environmental exploration status is defined as the present condition of the area, the basis needed to evaluate against the possible changes following the development of the area, and the necessary data to conduct an environmental impact assessment for a 20 MW power plant. The reason for selecting the 20 MW size for the assessment is because this is a standard size for steam turbines and a minimum size for the initiation of a geothermal power plant. It is often considered practical to build up steam power plants in steps of 20 MW units and expand them as results are obtained for the area´s exploitation. The results of examination of the present status (non-biological material) of environmental investigation in the areas are summarized in Table 1.

Of the 28 high-temperature areas, 7 are developed to some degree, 3 are ready for production drilling, 8 are at the stage that research drilling is due to commence, 4 are in the first stages of surface exploration and 6 have not been explored at all.

The status of biological work is in most cases insignificant but recommendations were made.

4. STUDIES OF SELECTED UNEXPLOITED GEOTHERMAL AREAS

4.1 Areas chosen

Four unexploited areas were selected as type localities for the project: Krýsuvík, Theistareykir, Torfajökull and Kverkfjöll (Fig. 1). Krýsuvík had been explored and drilled. In Theistareykir surface exploration had taken place. Surface exploration in Torfajökull was just starting but Kverkfjöll is a remote area, not likely to be exploited in the near future. According to the project plan the surface manifestations in the areas were to be mapped every year, the steam flow evaluated and samples for chemical analysis collected from at least 2-4 fumaroles in each area.

4.2 Krýsuvík

In the Krýsuvík area (Fig. 2) surface exploration and exploratory drilling was carried out in the early 1970s and in 1981-1985 samples for chemical analysis were collected from fumaroles from all sites of surface expression and changes noted. The gas chemistry of the field based on samples from these investigations was described by Arnórsson (1987). In 1991–1995 the area was visited several times and a few fumaroles sampled repeatedly. The area was photographed by infrared thermometry three times during these years. Both the remote sensing methods and the surface studies showed extensive changes in surface expressions even during the six years the enforcement program lasted. These are to a large extent connected to a considerable variation in the groundwater table in the area. The water level of Lake Kleifarvatn is a manifestation of this water table and is regularly monitored by the Hydrometry Division of Orkustofnun. The fluctuations from 1964 to 1999 are shown in Fig. 3 (Áráttan 1999). At the same time gas geothermometer temperatures in the area have not changed. (Table 2). The first signs of changes in geothermal manifestations suggesting rising temperatures were noted in 1994 with a steady increase until 1995 when temperature measurements in the area revealed new hotsprings with temperature < 99°C and the mossy soil with 50-60°C (Torfason 1995). These changes were clearly revealed by remote sensing which was clear from the differential image of the area for temperatures in 1994 and 1995 (Fig. 4) (Ko. Árnason, pers. comm.). Concentration of sulphur gases and mercury in atmospheric air was measured at two points within the geothermal area (Ívarsson *et al*., 1993) and point measurements of H_2S in the atmosphere made over parts of the area.

4..3 Theistareykir

The Theistareykir area represented a good basis for the investigation. A preliminary exploration of the area had been carried out in the seventies and a comprehensive surface exploraton in 1981-1983. During 1991-1997 the area has been visited five times, surface expressions mapped and samples for chemical analysis collected from selected fumaroles. Extensive changes in surface expressions were confirmed between 1983 and 1991, gas geothermometers showed substantial cooling in parts of the area but possible heating in others. After 1991, however, changes have been insignificant (Fig. 4, Table 3). Remote sensing methods have also been used for the observation, but the interpretation has not been completed (Árnason, 1997b). Concentration of sulphur gasses and mercury in atmospheric air was measured at two points near the center of the geothermal area and point measurements of H_2S made over the entire area (Ívarsson *et al.* 1993).

4.4 Torfajökull

Surface exploration of the Torfajökull area (Fig. 5) has been in progress since 1992 and a basis for a future environmental monitoring has been laid. Earlier some geological and geochemical studies had been reported by Arnórsson (1985) and Arnórsson *et al.* (1987). The results of the chemical studies are described by Ólafsson and Bjarnason (2000). Their conclusion is that the geothermal manifestations are quite transient and there is support for this opinion in that results for deuterium and oxygen-18 ratios in the fumarole steam are quite variable. The reasons for this variability are likely to be the large amount of precipitation in the area, the large amount of snow that melts during the summer or possibly condensation of steam during upflow. The area may be developed in the not too distant future. Very few studies of the geothermal system had been carried out in the area previously and thus no changes could be reported. There was, however, considerable knowledge available of the geology of the area.

4.5 Kverkfjöll

In the Kverkfjöll area (Fig. 6) no previous surface exploration had been carried out as this area is very remote and partly within the Vatnajökull glacier and thus not likely to be developed in the foreseeable future. Mapping of surface expressions has been in process from 1992 and samples for chemical analysis collected from fumaroles and particular fumaroles selected for monitoring (Ólafsson *et al*. 2000). The area was photographed by infrared thermometry twice during these years.

5. CONCLUSIONS

Several factors influence changes in geothermal areas. The formation of deposits in fissures will stop water flow to the surface, and earthquakes may reopen such fissures. Volcanic activity will enhance geothermal activity and surface manifestations depend on the hydrological conditions, particularly if the water table is at a shallow depth. There are great differences between geothermal fields in this respect. To be able to foresee changes in a specific field upon exploitation it has thus to be monitored for several years prior to exploitation.

A rough project schedule and a cost estimate were made within the enforcement program for work necessary for an environmental impact assessment of a 20 MW power plant in all unexploited Icelandic geothermal areas (Kristmannsdóttir *et al.*, 1995). A five year plan to accquire necessary background data on six selected areas and the start of environmental monitoring in these is more realistic (Kristmannsdóttir, 1997).

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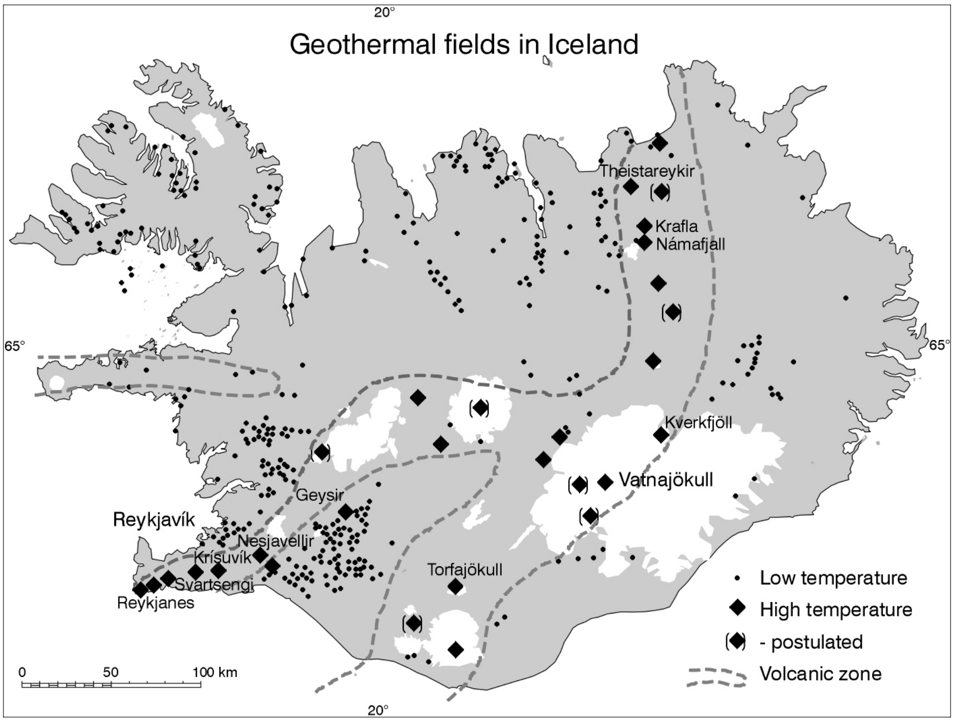

Figure 1. Geothermal areas in Iceland. The five main exploited high-temperature areas, Svartsengi, Reykjanes, Nesjavellir, Krafla and Námafjall are shown as well as the four unexploited high-temperature geothermal areas selected for study of natural changes, Krýsuvík, Theistareykir, Torfajökull and Kverkfjöll areas.

Table 1. The status of environmental research in 28 geothermal areas in Iceland. The number refers to how many areas are at a specific stage regarding specific research methods.

Stage	Reference list	Preliminary EIA [1)]	Geothermal map	Natural steam flow	Gas % in steam	Gas % in atmosphere	Groundwater map	Gravity measurements	Changes in natural activity
Ready	15	8	17	10	11	10	15	14	9
Partly	0	0	5	6	9	3	2	2	8
Missing	13	20	6	12	8	15	11	12	11

[1)] EIA: Environmental Impact Assessment

Table 2. Krýsuvík. Gas geothermometer temperatures 1983 -1992

Location	Gas temp.°C 1983	Gas temp.°C 1990-92
Seltún	259	259
Hveradalur	256	259

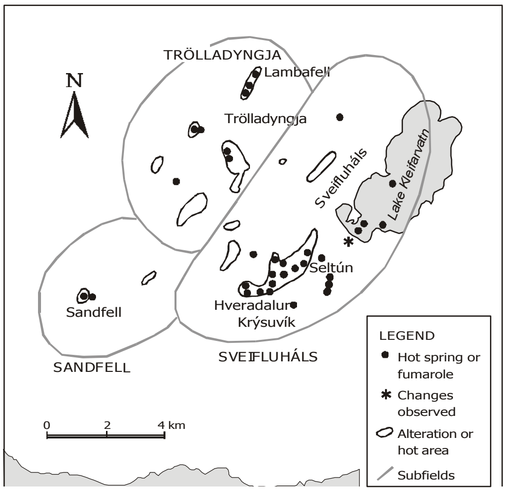

Figure 2. Map of the Krýsuvík area, showing the two fumarole sampling locations

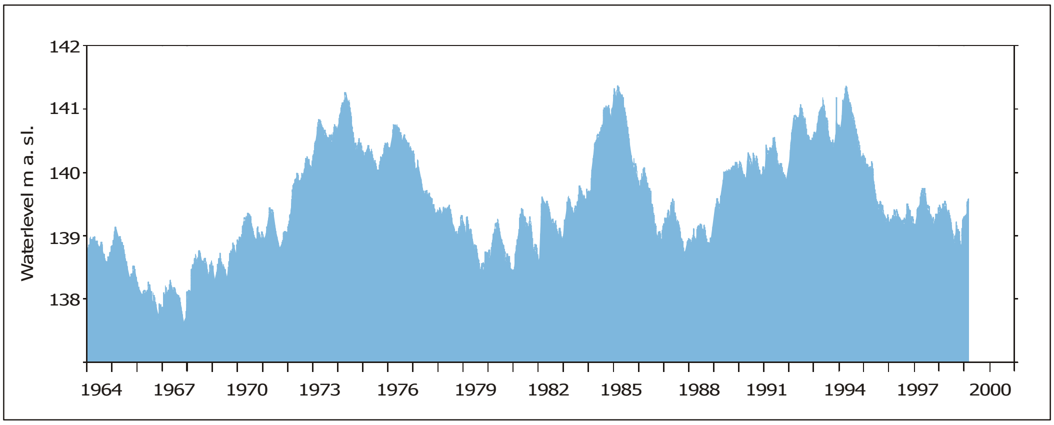

Figure 3. Kleifarvatn. Water level 1964 – 1999

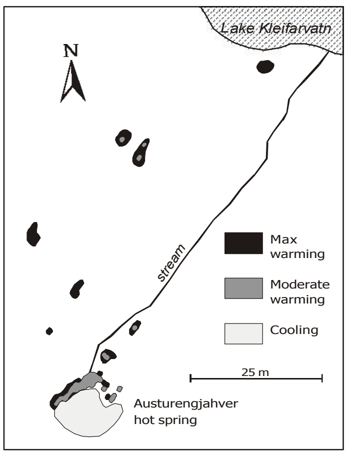

Figure 4. Krýsuvík. Differential thermal image between September 1995 and November 1994

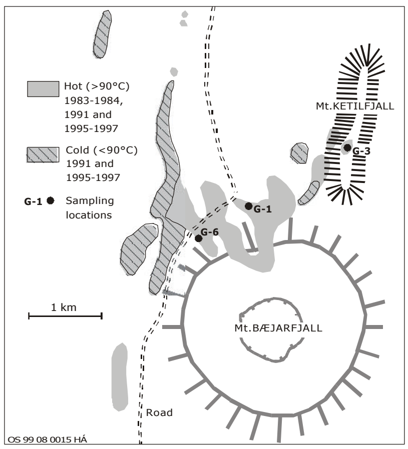

Figure 5. Theistareykir. Changes in surface manifestations 1983-1997. Fumarole sampling locations are shown.

Table 3. Theistareykir gas geothermometer temperatures. 1981-1997

Location	Gas temp. °C 1981	Gas temp.°C 1991-97
G-1	271	277
G-3	272	288
G-6	309	271

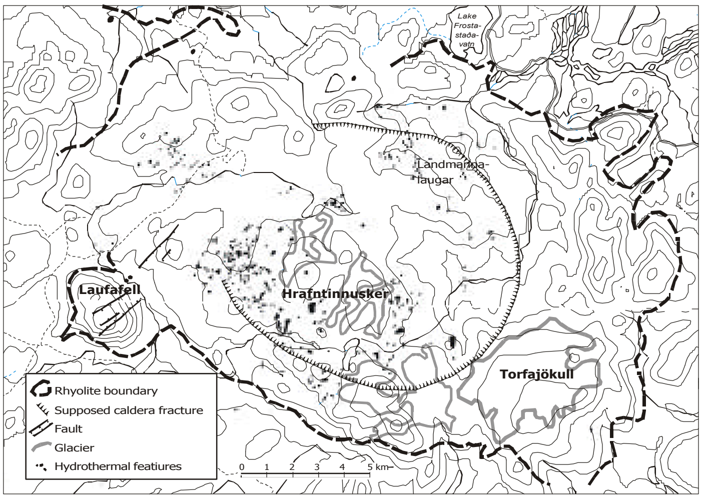

Figure 6. Torfajökull. Geothermal manifestations (Arnórsson et al. 1987)

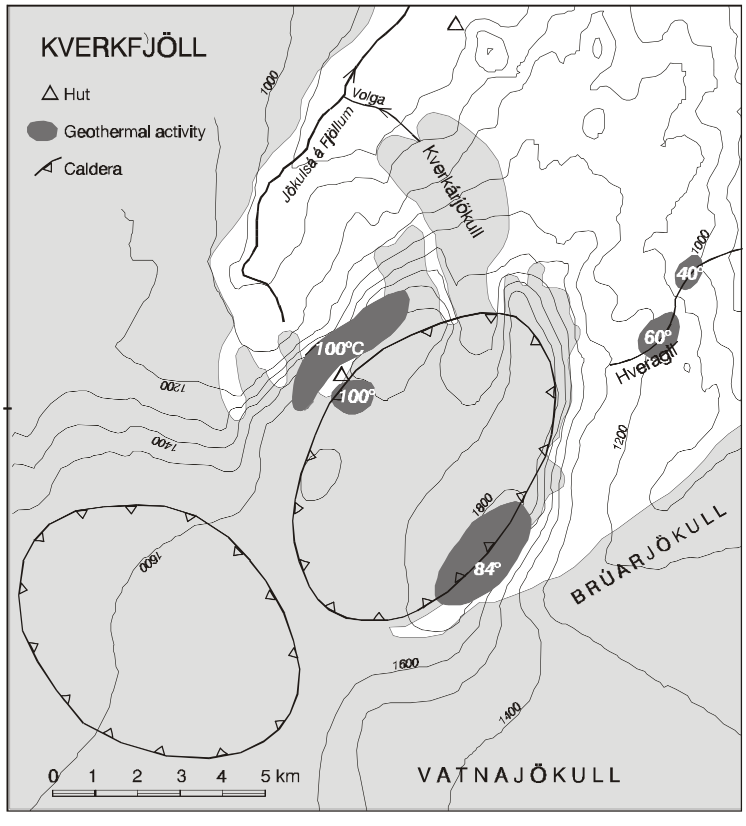

Figure 7. Kverkfjöll. Geothermal manifestations. Surface temperature distribution