

Exploration and Utilization of the Námafjall High Temperature Area in N-Iceland

Ásgrímur Gudmundsson, Anette K Mortensen, Arnar Hjartarson, Ragna Karlsdóttir and Halldór Ármannsson

Landsvirkjun Power, Háaleitisbraut 68, 103 Reykjavík, Iceland

asgrimurg@lvp.is

Keywords: Exploration, utilization, drilling, alteration, lithology, resistivity, conceptual model, reservoir modeling

ABSTRACT

The longest successful cascading operation of geothermal utilization in Iceland is in the Námafjall high temperature area, often recognized as the Bjarnarflag field (Fig. 1). Initially in the early 1950s, the purpose of utilization was to mine sulfur from the geothermal steam, however the product did not turn out to be economic. After a short investigation period in the early sixties, drilling activities started in 1962. In the next eight years, nine steam-wells were drilled to fulfill the needs of a diatomite plant and a 3 MW_e pilot power plant. The tenth and deepest well so far was drilled in the summer of 1975 down to 2000 m depth. Unfortunately an eruption event started in the Krafla central volcano at the end of the same year, which destroyed several wells in Bjarnarflag. This was followed by the successful drilling of two make up wells (BJ-11 and BJ-12) in the years 1979-80. In the early seventies, a central heating system for the Reykjavík village and nearby farms was constructed based on direct use, which turned out to be unfeasible because of a corrosive fluid. It was improved in 1984 by the installation of a heat exchanger. The utilization continued and in June 2004 the Mývatn Nature Baths opened. The warm geothermal waters of the Baths contain a unique blend of minerals, silicates and geothermal microorganisms, which are beneficial to the skin. According to new exploration program in NE- Iceland, three wells were directionally drilled in the years 2006-2008 to confirm the location of up-flow zones and improve the data input for the numerical model. Two of the wells appeared to be very powerful, 27 MWe in total, but the third one headed into colder environment. Further surface investigation of the Námafjall area and deep drilling exploration complemented the conceptual and natural state model of the area. Concurrently, a design for a 90 MW_e geothermal power plant was worked out and assessment of environmental impact was completed.

Landsvirkjun is the owner of the power plant in Bjarnarflag and got the privilege to exploit the area according to agreement with the state and landowners.

1. INTRODUCTION

The name Náma-fjall is composite of two Icelandic words, Náma = mine and fjall = mountain. In the Middle Ages in Europe, a sulfur mining operation in Iceland was developed for the Danish king. In those days sulfur was an important component in making gunpowder. The relation between sulfur and high temperature areas was well known with a few commentaries on it in old documents. A pioneer in utilization of geothermal in Iceland was the engineer Baldur Línal. He launched enhanced utilization of sulfur in the Námafjall area early in the 1950s by drilling shallow wells to increase the outflow of geothermal gas to the surface. The composition of the gas included H₂S up to 50 wt%. By

activating the gas outflow, it was a reasonable possibility to mine considerably more sulfur from the steam compared to the natural one. The project was not successful enough and was abandoned; nevertheless information about the area was obtained.

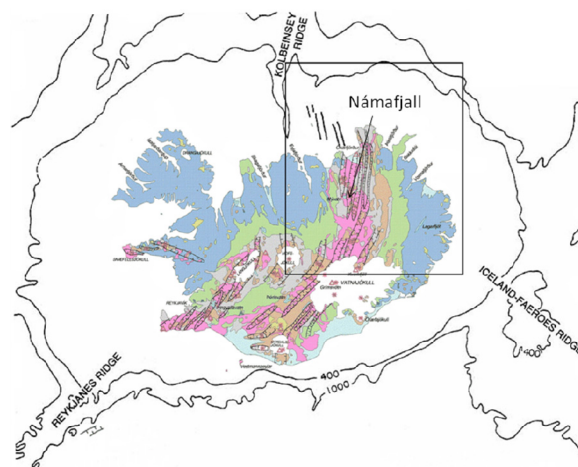


Figure 1. The location of the Námafjall high temperature area in NE-Iceland.

The high temperature area in Námafjall has a long research history. The first organized geothermal research program initiated in the 1960s. Exploration drillings commenced in the year 1963 to provide geothermal steam for a prospective diatomic factory. The drilling continued with the first scheduled geothermal research program in Námafjall and Krafla, which was based on Sveinbjörn Björnsson's ideas and was established in 1969. A detailed report, including an introduction of the first geothermal research conclusions was introduced in the year 1971 (Sæmundsson et.al. 1971), where the oldest reference is from the year 1886. The 1975-1984 volcanic episode at Krafla, the Krafla Fires, affected the Námafjall area, especially during two events in 1977 when magma intruded to the south along the fissure swarm (Brandsdóttir and Einarsson 1979). As a consequence, subsidence and expansion of the ground occurred between Grjótagjá to west and Krummaskarð to east (Fig. 6). In addition, transient pressure changes and a temperature increase in the upper part of groundwater system were observed. Constructions were seriously damaged, especially the facilities of the diatomite factory, including the slurry reservoirs, the office building and some of the production boreholes in Bjarnarflag. During the Krafla Fires, an extensive research program was carried out concerning the volcanism and geothermal areas and the relationship between them, followed by several reports and articles. Old documents, which describe the Mývatn Fires early in the eighteenth century, were taken into consideration.

In the high temperature area in Námafjall there remains great potential for exploiting the geothermal fields by generating electricity and concomitant cascading utilization. At the turn of the century, a research program was initiated

to reevaluate the area. Previous investigations, such as groundwater studies (chemical studies, mass and flow directions), were reviewed and as were the geophysical characteristics of the reservoir. A TEM-resistivity survey was carried out to map the low resistivity cover around the high resistivity core (Karlsdóttir 2002). The extension of the anomaly was estimated around 20 km² at 800 m depth according to this interpretation, compared to 8 km² based on previous Schlumberger-method measurements. The old reservoir assessment was revised and followed by a new conceptual model (Hjartarson et al. 2005). The model is 3-D and runs under the TOUGH2 code, which is widely used in geothermal industry and is supported by the inversion capabilities of iTOUGH2. During these years, an environmental impact assessment was processed. On February 26th 2004 the Icelandic Planning Agency commissioned 90 MWe power plant and 132 kV transmission lines with conditions.

The reservoir data was restricted to relatively small drilling field compared to the size of the geothermal area therefore additional drilling were needed. Directional drilling was adopted for the first time in Námafjall during the spring 2006 and continued the following years.

Laxá Power Company built a geothermal power plant in 1969, and Landsvirkjun acquired it on 1 July 1983, when Laxá Power Company merged with Landsvirkjun. Furthermore, the steam supply system at Bjarnarflag was bought by Landsvirkjun from the State Geothermal Services; this system provides not only Bjarnarflag Geothermal Station with steam to produce electricity, but also supplies steam for example to the Diatomite Plant and the Mývatn district heating system.

The size of the power plant is 3 MWe and the energy generated by the Bjarnarflag station amounts to approximately 18 GWh per year.

Operation of the 3 MWe power plant in Bjarnarflag will continue until construction of the planned 90 MWe power plant is completed. Geothermal energy will be used in the future to heat up cold groundwater in heat exchangers for direct use in the central heating of the village Reykjahlid and neighborhood. Effluent water from the separation station will be utilized for the geothermal natural Mývatn baths.

2. THE GEOTHERMAL SYSTEM

The geothermal system at Krafla and Námafjall has been considered as two independent, discrete up-flows. Indication of interrelation was seen in the TEM-resistivity measurements through the main NNE-SSW trending fissure swarm. This also coincides with observations of seismicity and magma movements during the Krafla Fires in 1977 and 1980. Active geothermal manifestations are spread over an area of about 5 km² and warm water runoff to the lake Mývatn is at least 8 m³/s. The extent of the resistivity anomaly is about 20 km² down at 800-1000 m depth, which typically corresponds to the depth for the production casing shoe. White, gray and light yellow alteration colors cover most of the surface due to silica, gypsum, silica, iron-sulfides and sulfur, respectively. Visual appearance, including steam, clay and colorful surface, make the area outstanding. The elevation of the geothermal area is 340 m a.s.l. and higher, but the water table of the groundwater is at similar level as lake Mývatn, 278 m a.s.l.

Temperature logs and subsurface alteration reveal that the temperature has reached ca. 300 °C at 1000 m depth and increases slightly with depth (Hjartarson et al. 2005, Gudmundsson 1993). Chemical geothermometers strongly indicate rise in the reservoir temperature from west to east (Ármannsson, 1993).

The geology of the Námafjall area is characterized by an active rifting zone, forming a graben zone through its center, where volcanic craters, volcanic pyroclastics and lava flows, all of basaltic composition, dominate. The main fissure swarm is framed by Krummaskard at the western foothill of the hyaloclastite ridge (Mt. Námafjall) to the east and the Grjótagjá fissure in the lava plane to the west. The rift zone hosts the plate boundary where the American- and Euro-Asian plates drift apart. Significant lateral and horizontal movements occurred during the Krafla Fires, which damaged several boreholes. Through one of the boreholes, well B-4, magma erupted and left a few m³ of scoria surrounding the wellhead (Larsen et al. 1978). This will be remembered as a historical event, especially when it is considered that the particular well was still useable afterwards, and was producing until the year 2002 as a component of the heat exchanger unit for the central heating system.

To keep up with the demands of steam, two makeup wells, BJ-11 and BJ-12, were drilled east of the active tectonic area.

The key numbers for the utilization area are:

Geothermal anomaly 20 km²

Reservoir temperature ≥ 300 °C

Enthalpy of the borehole fluid 1600-2400 kJ/kg

Gas concentration < 1 wt%

TDS of the geothermal fluid ~1000 ppm

3 RESISTIVITY MEASUREMENTS

The most efficient geophysical surface research in Iceland to investigate geothermal areas has proved to be TEM (transient electric measurements). Two TEM-resistivity surveys was carried out in the Námafjall area by ÍSOR in the year 1992 and during the winter 2000/2001, and the final interpretation presented the year after (Karlsdóttir, 1993, 2002). The geothermal system in Námafjall appears to be distinct. Nevertheless, connection to the geothermal system at Krafla was observed along the NNE-SSW trending, active rift zone, which extends from the highland south of Námafjall north to the coast, crossing the Krafla caldera and Gjástykki geothermal area.

Resistivity measurements reflect the subsurface alteration down to ~1000 m depth and indicate the extent of the geothermal system. Most of the alteration minerals are temperature related. The main constituents of the alteration pattern are the clay minerals, due to the conductivity of their interlayer. The transition from smectite to chlorite indicates increasing temperatures above 100-240 °C. Chlorite becomes stable at 230-240 °C, but is less conductive than smectite and mixed layer clays. It appears in the TEM-measurements as high resistivity, and is usually declared as a high resistivity core compare to the low resistivity cover of the smectite-bearing formations. The previous conceptual model of the Námafjall area was based on all available data, and is presented in Figure 2. Two peaks indicate temperature increase and up-flow of the geothermal fluid toward the surface, below Mt. Námafjall and Jarðbadshólar. The second survey covered a more

extensive area, from Lake Mývatn to the east of Mt. Námafjall. With respect to the distribution of the secondary

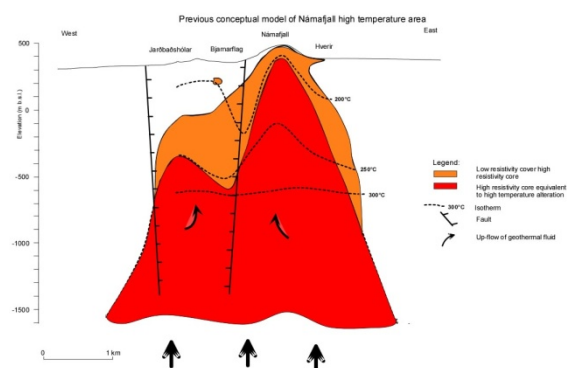


Figure 2. Previous conceptual model from 1992

minerals, the size of the area was reconsidered and has been estimated to be close to 20 km² (Fig. 3).

The resolution of the measurements is significant down to approximately 1000 m depth. It indicates that at 1000 m the low resistivity cover envelopes a more extensive area than in the previous model but does not affect the former concepts of up-flow zones.

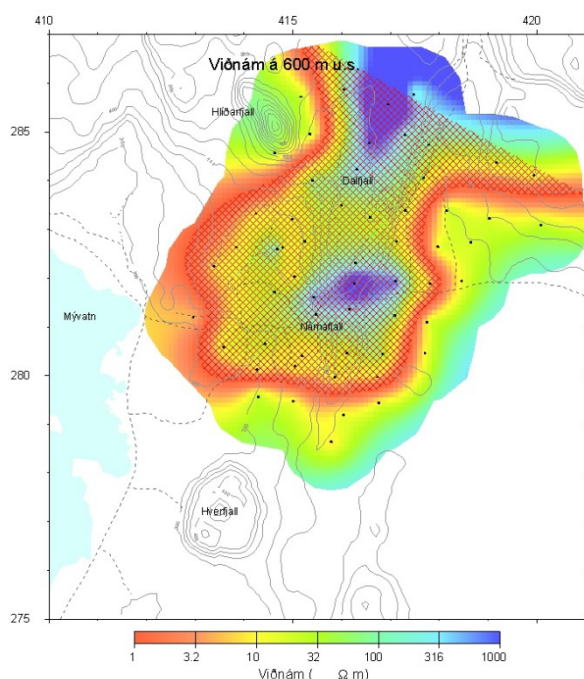


Figure 3. The extension of the Námafjall high temperature area according to TEM-measurements.

4 CHEMISTRY OF THE GEOTHERMAL FLUID

Investigations of geothermal fluid date back to 1950 and are still ongoing. Gas geothermometers reveal prograding temperature in the natural outflow from west to east in the Námafjall area. The maximum temperature, >300 °C, is observed east of Mt. Námafjall at Hverir (Fig. 4). In accordance, sulfur is prominent in Mt. Námafjall and the surrounding area, and to east of Hverir, the sulfur vents are eye-catching in the sand-bearing lava. Furthermore, high temperatures extends to the north and east side of the main rifting zone (Fig. 4).

The borehole fluid is dilute, the TDS (total dissolved solids) in the deep reservoir is around 0.1 % (1 g/kg), and pH is 7-8. Chloride and sulfate are the main anion constituents, but

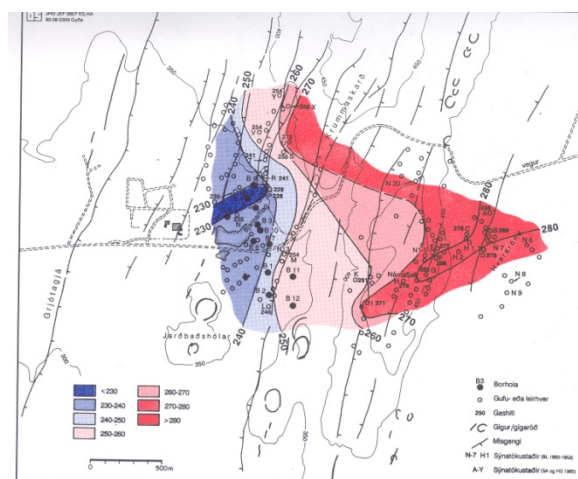


Figure 4. Distribution of gasgeothermometer temperatures.

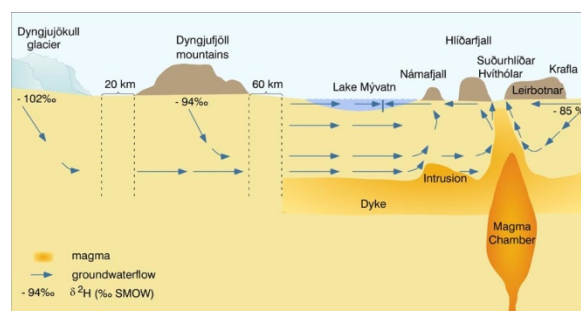


Figure 5. Possible groundwater flow to Námafjall and Krafla.

their concentration varies episodically. The gas in the steam is generally low, 0.3 – 0.5 wt%. Transient pulses, like during the Krafla Fires, can double or even triple the value with an increase in CO₂. About 50% of the gas is H₂S, and H₂ is substantial. This is an extremely high percentage of H₂S in comparison with the reservoir in Krafla, where CO₂ is around 90%.

Based on the value of deuterium isotopes, the origin of the geothermal fluid is considered to be precipitation at high elevation, probably in the vicinity of the Vatnajökull glacier to the south (Dyngjujökull glacier in Fig 5). The δD ≈ -100‰ SMOW, compared to δD ≈ -88‰ SMOW of the local groundwater (Fig. 5) (Ármannsson 2005).

5 DRILLING EXPLORATION

The first drilling activities in the Námafjall area commenced in the Hverir field east of Mt. Námafjall in the years 1951-1953. Their purpose was to mine sulfur by enhancing the steam and H₂S rich-gas outflow through shallow boreholes. Hammer rigs drilled 16 wells down to 11-227 m depth directly into the hottest part of the area without any safety equipment (Fig. 5). Some of the wells are still blowing but are covered with stones of lava. In that case, some of the geothermal manifestations are, in a manner of speaking, manmade. Furthermore, some scaled wellheads are seen in the eastern slopes of the mountain.

The second drilling phase was started in the year 1963 by exploration drilling in the Bjarnarflag field and lasted until 1980. The drilling was supposed to be completed in the

summer of 1975, when the borehole B-10 was successfully completed. Unfortunately a volcanic period commenced in the end of the year and lasted to 1984. Catastrophic events occurred two times in 1977 in the Bjarnarflag rifting zone. Several boreholes were damaged (Table 1). Some of the Diatomite factory's constructions were destroyed or damaged. The slurry reservoirs drained into the ground through new fractures and another fracture crossed the office building. One historical event happened during this hazard period, when magma erupted through a fracture in borehole B-4, probably close to the bottom at 1300 m. A few cubic meters of scoria was erupted and surrounded the wellhead. The volcanic material only blocked the deeper part of the well since fluid from an aquifer at 630 m depth kept it open and the well was in use for central heating in the area until 2002.

Boreholes 11 and 12 in Bjarnarflag were drilled in the year 1979 and 1980 in the foothills of Mt. Námafjall, east of Krummaskarð (fault) and the active rifting zone. Both were successfully completed and are still good producers thirty years later. Thus far all these boreholes were vertically drilled.

The third drilling phase started in the spring of 2006. Directional drilling technique was applied. Boreholes 13

and 14 were situated next to well 12 and drilled in opposite directions (Fig. 6). Well BJ-13 was directed to ENE beneath Mt. Námafjall, which is considered to be the strongest up-flow zone in the area. The horizontal section is around 980 m in $\sim 60^\circ$ azimuth direction from the wellhead down to 2174 m depth (MD, 1810 TVD). Well BJ-14 was directed WNW beneath Jarðbadshólar, considered the second largest up-flow zone. The horizontal section is around 1035 m in the 284° azimuth direction from the well head down to 2506 m depth (MD, 2215 TVD). Both the wells appeared to be good producers in accordance to the existing conceptual model of the area. Well BJ-15 was located 750 m north of the BJ-12 wellpad and directional drilled to NW into the north-east part of the rifting zone. The horizontal section is around 724 m in the 320° azimuth direction from the well head down to 2690 m depth (MD, 2485 TVD). During the warming up period after drilling completion, a sudden cooling beneath 1700 m was observed, which indicate a temperature barrier between the well paths of wells BJ-15 and BJ-14.

Referring to the drilling data, the well design program has been under development during the exploration time. In the third drilling phase the production casings were down to ~ 850 m to avoid inflow of cooler fluid from above formations.

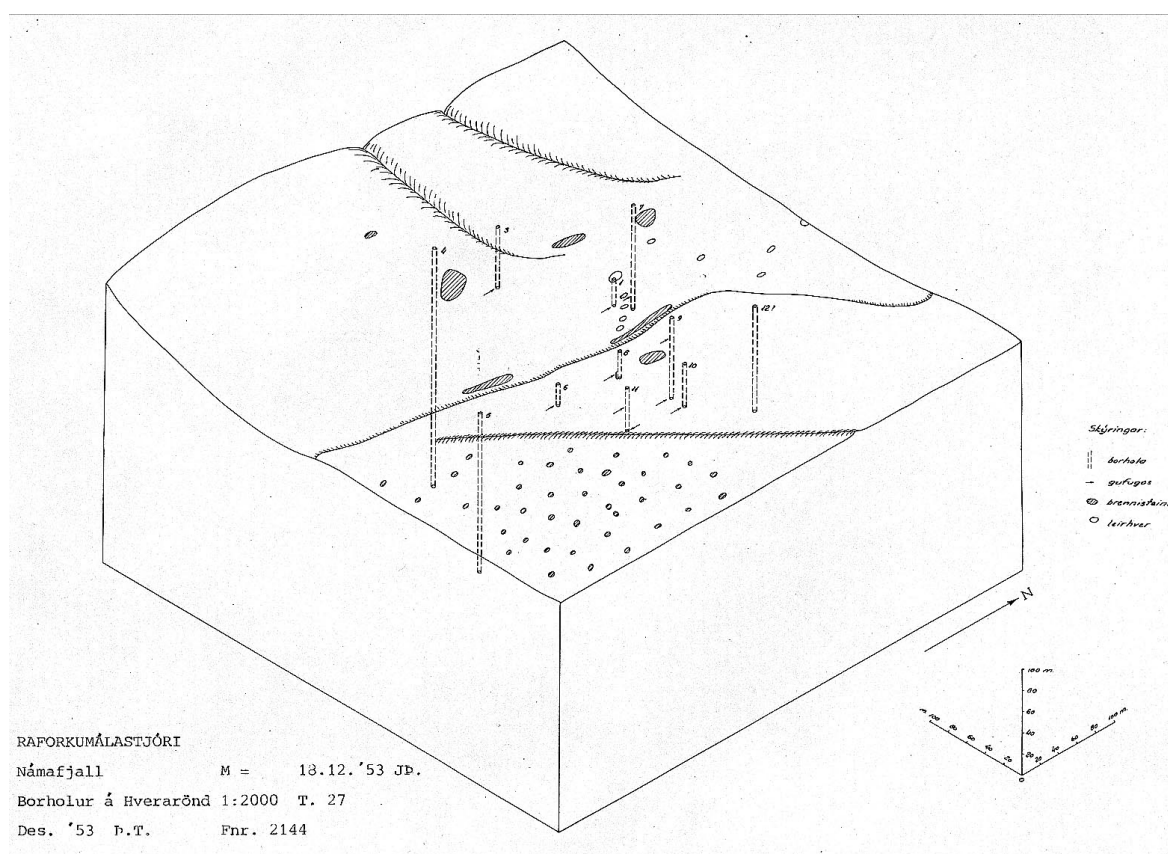


Figure 5. Location of boreholes in Hverir field, drilled 1951-1953.

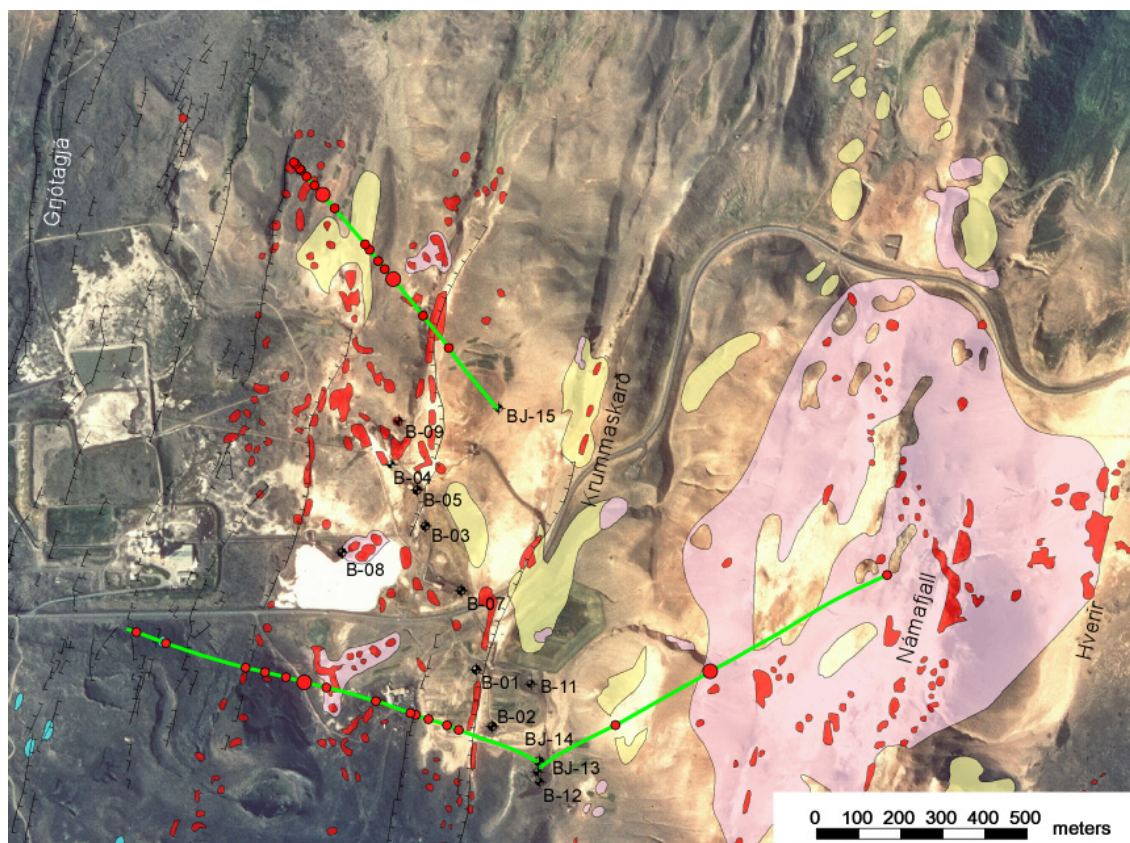


Figure 6. Bjarnarflag – location of boreholes, well paths and feed zones.

Table 1. Boreholes in Bjarnarflag field.

Well no.	Drilling year	Prod. c. shoe	Liner	Dia.	Depth
B-1	1963-1965	107	-	4 3/4	342*
B-2	1963-1965	207	-	4 3/4	492**
B-3	1966-1968	596	-	4 3/4	683
B-4	1968	625		6 1/4	630 (1138)***
B-5	1968-1969	478		8 3/4	638**
B-6	1969	577	550-953	6 1/4	1193*
B-7	1969	582		6 1/4	1206*
B-8	1970	537.5		6 1/4	1312*
B-9	1970	600	570-819****	6 1/4	843 (1311)
B-10	1975	598	558-1780	8 3/4	1809*
BJ-11	1979	619.6	604-1915	8 1/2	1923
BJ-12	1980	686	631-1955	8 1/2	1999
BJ-13	2006	851.7	816-2155	8 1/2	2174 *****
BJ-14	2008	840.5	801.7-2479	8 1/2	2506 *****
BJ-15	2008	846	806.9-2655.6	8 1/2	2690 *****

*Collapsed 1977

**Monitoring well

***Lava intruded through the bottom aquifer

****Slotted linear 621-641 m

*****Directionally drilled

6 SUBSURFACE GEOLOGY AND ALTERATION

Mapping the subsurface stratigraphy is a direct continuation of surface geology mapping. The first exploration well shows the main formation penetrated to some depth and extends the first model into the geothermal reservoir, including porosity, permeable zones and chemical composition of the rock. The first wells were located to confirm the geological and geochemical interpretation of the surface exploration. Furthermore, drill cuttings together with geophysical logs allow extrapolation of tectonic features to some depth with more confidence and evaluation of the frequency of intrusions (Gudmundsson 2005). The subsurface geology in the Námafjall area is based on analysis of cuttings, geophysical logs and related drilling data. The quality of the data of the first 9 boreholes differs and is difficult to compare to the last 6 holes. Nevertheless the same general stratigraphy appears in all the lithological logs. Two logs from wells BJ-11 and BJ-12 were selected to illustrate the general stratigraphy of the formations in the reservoir of the Bjarnarflag field (Fig. 7). Sequences of lavas and hyaloclastites of basaltic composition characterize the reservoir formations. It reflects the environment during their formation. The hyaloclastites are accumulated volcanic glassy products, which have formed below the water table, most commonly in glaciers, and build up ridges and table-mountains. These features are dominant influences on the topography and indicate glacial periods. On the other hand, the lava flows formed during interglacial time or shorter periods with ice-free conditions. The physical properties of lava and hyaloclastites vary a lot. Hyaloclastite is a heterogeneous material, with a high porosity but variable permeability. The basaltic lavas are more homogeneous. The porosity is in the range of 5-15% and the permeability is rather high through the top and bottom scoria as well as through the columnar jointing.

Intrusion frequency is low, especially down to 1400-1700 m. Observations in Icelandic geothermal systems have revealed that fractures and intrusions are the main conductors of the geothermal fluid and generally the matrix permeability is low, but on the other hand, the porosity appears to be high (5-30%). The permeability is fracture dominated. Figure 7 demonstrates the main character of the reservoir, which reveals a high content of pyrite in the upper part as well as around feed zones indicating higher permeability. Siliceous rocks are scattered below 1800 m depth.

Specific secondary temperature dependent minerals known as index minerals are listed in Table 2, but the list is not exhaustive. The temperature values are mostly based on geothermal empirical work in Iceland from 1970 up to the present (Kristmannsdottir 1979; Franzson 1998). The minerals anomalies, where low- or medium temperature minerals appear with minerals that are stable at high temperatures, are sometimes observed in mineral assemblages. This can be evidence of cooling in the geothermal reservoir on either transient or long term. Overprinting of calcite is the most common indication of a cooling event. On the other hand, if calcite disappears it is evidence of temperatures close to the boiling point depth curve. The relative high quantity of fracture fillings is a good indicator of past or present permeability. A high abundance of the secondary mineral pyrite is evidence of good permeability. Pyrite is more abundant in the uppermost 1000 m where the variance in temperature is from 100–300 °C, but its relative abundance, where temperature is above 300 °C, shows a good correlation with aquifers (Gudmundsson 1993). The appearance of certain secondary minerals is due to their temperature stability in

the reservoir often the main criterion in deciding casing and final depths of wells. The distribution of secondary minerals in the Bjarnarflag reservoir present existing temperature conditions that agree reasonably with measured temperatures.

Figure 8 is of data from well BJ-11 and reveals an example of how analysis of alteration minerals are presented. The first appearance of secondary mineral or the depth, where it is continuously identified is matched as index temperature value. To evaluate the data it is compared to T-logs and calculated formation temperature distribution. Commensurate work was done for wells B-2, B-6, B-9, BG-10, BJ-11 and BJ-12 (Gudmundsson, 1993). Furthermore, the analysis of wells 13-15 shows good agreement with previous interpretation.

A north-south cross-section of subsurface alteration in Bjarnarflag is presented in figure 9. The alteration minerals are arranged into zones with the name of characterizing minerals. Beyond the alteration zones, aquifers are presented and are located by circulation losses, P- and T-logs, as well as tectonics. To summarize interpretation of the subsurface alteration in figure 9:

- Reasonable consistency between alteration temperature distribution and the measured one.
- Evidence of heating is observed and therefore identification of temperature dependant minerals is significant in the area.
- The maximum rise in temperature appears in the northern part, but at 900 m depth the isotherms are almost horizontal.

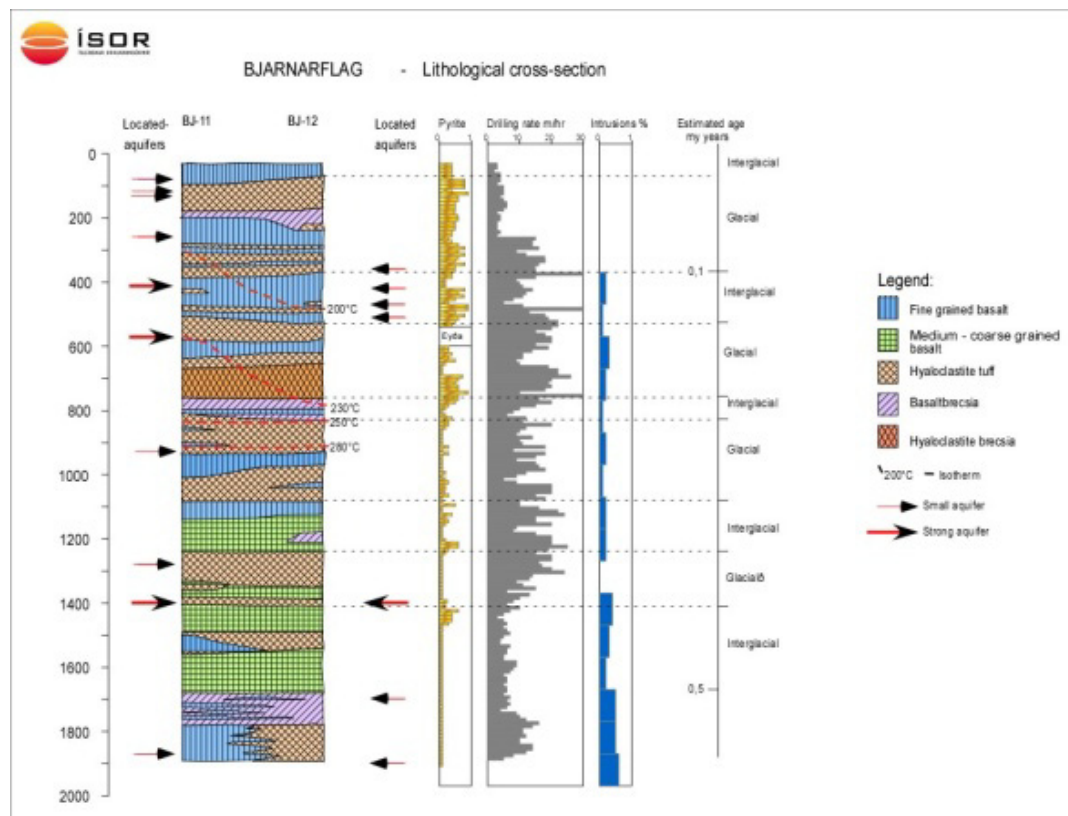


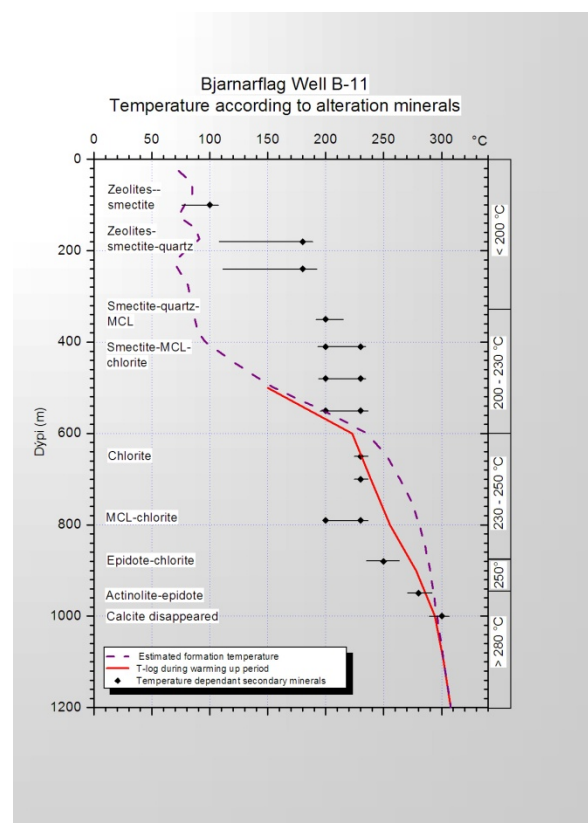
Figure 7. Lithological cross-section through wells BJ-11 and BJ-12.

Table 2. Some temperature dependant minerals in high temperature areas in Iceland.

Minerals	Min. temp. °C	Max. temp. °C
zeolites	40	120
*laumontite	120	180
quartz	180	>300
*wairakite	200	
smectite		<200
**MLC	200	230
chlorite	230	>300
calcite	50-100	280-300
prehnite	240	>300
epidote	230-250	>300
wollastonite	260	>300
actinolite	280	>300

*Belong to the zeolite group.

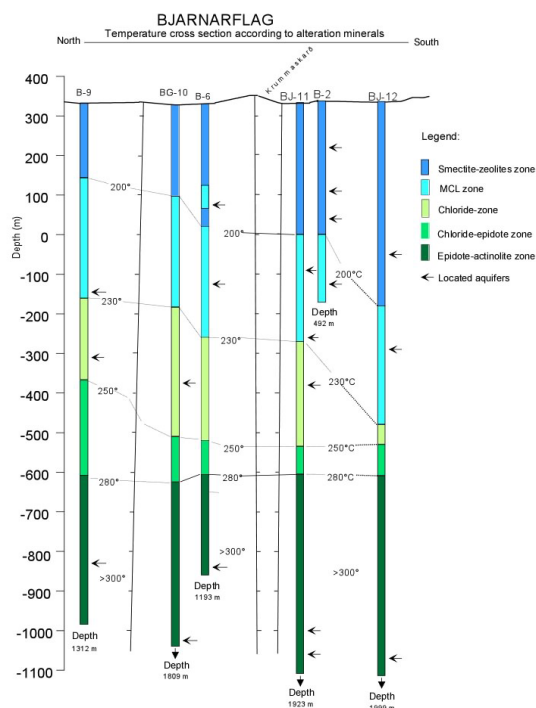
**Mixed layer clay.

**Figure 8. Temperature according to alteration minerals in well BJ-11.**

7 TEMPERATURE AND PRESSURE

The geothermal wells are located in a rather restricted part of the geothermal area. Therefore it can be questionable to extrapolate temperature and pressure values over long distances. Nevertheless, good monitoring data exist from the year 1990 from shallow boreholes and as does initial pressure from other boreholes and as temperature from warming up periods following drilling completion. To demonstrate the temperature, data from well BJ-13, which was drilled in 2006, was chosen (Fig. 10). This particular well was selected since it has a short discharge time and represents more or less undisturbed data due to wellbore influences. The older production boreholes like BJ-11 and BJ-12, drilled in 1979 and 1980, respectively, have been in

almost continuous production since. The temperature is close to the boiling curve, so boiling has moved from the wellbore into the formation.

**Figure 9. Temperature cross-section in Bjarnarflag according to alteration minerals.**

Physical properties under such influences cause a pressure drawdown in the vicinity to the well, which does not correspond to the characteristics of the geothermal area or drilling field. Figure 11 presents pressure data from drilling completion for boreholes BJ-11, BJ-12 and BJ-13. Significant pressure drawdown is measured during the production time of BJ-11 and BJ-12. In the year 2005, a recovery is measured in BJ-11 and shows a slowly pressure build-up trend pointing at the initial pressure of BJ-13. The recovery data of such a long production time indicates slow recovery with a trend to the initial state. With such philosophy it may be argued that the utilization in the Námafjall area is sustainable.

8 NUMERICAL MODELING

In the year 2005, a comprehensive conceptual model and numerical calculations of the Námafjall high temperature area were performed and published (Hjartarson et.al 2005). The model is 3-D and runs under the TOUGH2 code, which is widely used in geothermal industry and is supported by the inversion capabilities of iTOUGH2. Since geothermal systems are generally quite complicated phenomena, it is important to emphasise the scope of the work:

- Constructed a simple mathematical model to aid understanding
- The models were used to simulate the nature of the systems, mostly based on the production and monitoring histories
- The models were used to make future forecasts and therefore assess the production potential
- Simple and numerical models were used

The construction of the Námafjall model is presented in figure 12.

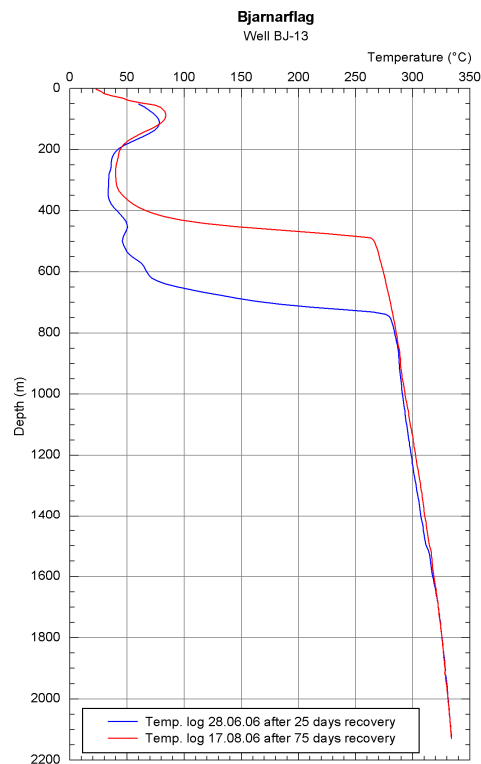


Figure 10. Warming up measurements in borehole BJ-13 after drilling completion.

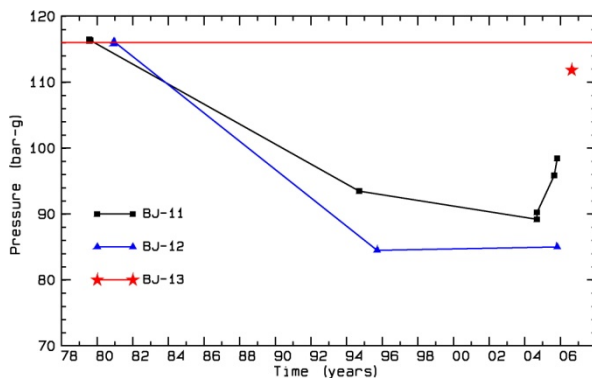


Figure 11. Initial pressure and recovery of well BJ-11 and BJ-12 in comparison with initial pressure of well BJ-13.

The software helps identifying model parameters like:

- Permeability, production indexes, mass and enthalpy of inflow.
- Parallel computations – multi processor Linux cluster.
- All relevant data can be input with different weight factors.
- 137 dataset and series simulated at the same time.
- T and P profiles, flow rates, pressure drawdown, and enthalpy.
- Wells produce on deliverability.
- Results in well output decline due to reservoir pressure drawdown
- Estimate of number of future makeup wells

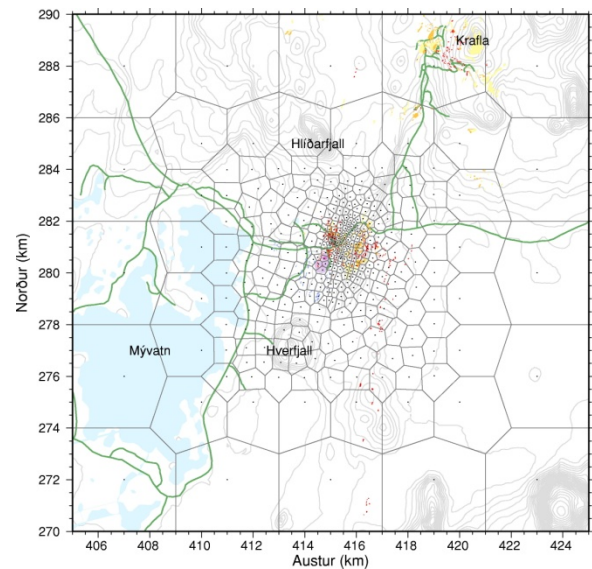


Figure 12. The basic grid of the Námafjall Model.

The main components of the model are as follows: 3100 elements, a well to well grid, area covers 400 km², 10 identical layers, a source of 15 kg/s, enthalpy of 2160 kJ/kg and recharge from the sides. The first product is a Natural State Model, which simulates the model to natural conditions, as the name implies. The subsurface formation is divided in layers with depth by alphabetical order. In Figure 13 is an example of the natural state as it appears at 925 m depth, layer E.

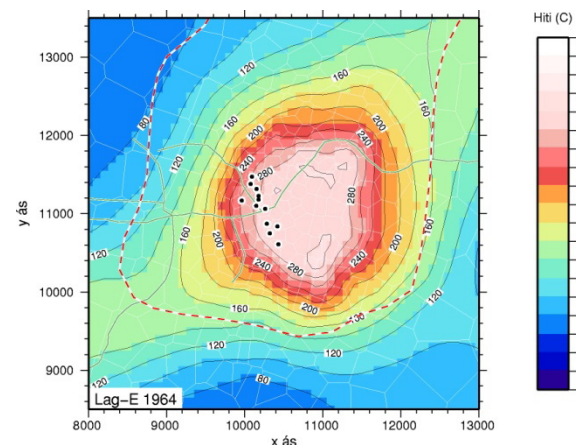


Figure 13. Layer-E at 925 m depth.

The Námafjall reservoir assessment 2005 has been revised and improved. In the future it will be a dynamic tool to monitor the main parameters in the utilization of the geothermal area.

7. DISCUSSION

The Námafjall geothermal area has been developed for several decades and is still under study. The geothermal potential is promising. Strong groundwater flow from the highland in the south exists and cools the subsurface deep into the ground through fractures. The resolution of TEM-resistivity measurements allows a maximum interpretation down to 1000 m depth. Therefore, it will be interesting to emphasize further investigations to the south with the aid of MT-measurements. Strong indications of further potential to the south are volcanic surface manifestations, such as eruption fissures with crater rows and huge explosion craters.

On 26th of February 2005 a 90 MWe Power Plant and 132 kW transmission lines passed the Environmental Impact Assessment, with preconditions.

8. CONCLUSIONS

The Námafjall area is unique for several geothermal utilities. Previously exist electrical power generation, heat exchanger for house heating, SPA facilities and other local domestic use. It has great potential and future prospects.

ACKNOWLEDGEMENTS

The authors would like to thank Landsvirkjun (The National Power Company) for permission for use of data.

REFERENCES

- Ármannsson, H., 2005. Monitoring the Effect of Geothermal Effluent from the Krafla and Bjarnarflag Power Plants on Groundwater in the Lake Mývatn Area, Iceland, with Particular Reference to Natural. Proceedings World Geothermal Congress 2005 Antalya, Turkey, 24-29 April 2005, 8p.
- Ármannsson, H. 1993. The Geothermal System in Námafjall – Chemical Compilation. Collaboration Project of Landsvirkjunar and Orkustofnunar, OS-93053/JHD-29 B, 30p (in Icelandic).
- Brandsdóttir, B. and Einarsson, P. 1979. Seismic activity associated with September 1977 deflation of the Krafla central volcano in NE Iceland. J. Volcanol. Geotherm. Res., 6, 197212, 1979.
- Franzson, H. 1998: Reservoir Geology of the Nesjavellir High-Temperature Field in SW-Iceland, Proceedings 19th Annual PNOC-EDC Geothermal Conference, Manila, Philippines, March 5-6th 1998 13-20.
- Gudmundsson, Á. 1993: Lithology cross section through wells BJ-11 og BJ-12 in Bjarnarflag. OS-93071/JHD-35 B 46p (in Icelandic)
- Gudmundsson, Á. 1993: The alteration formation temperature in the geothermal system in Bjarnarflag. OS-93065/JHD-31 B 21p (in Icelandic).
- Gudmundsson, Á 2005. Geothermal Data Collection and Consultancy at Drill Site. Proceedings World Geothermal Congress 2005 Antalya, Turkey, 24-29 April 2005, 6p
- Hjartarson, A., Sigurðsson Ó., Guðmundsson Á., Ármannsson, H., Karlsdóttir R., 2005. Numerical Modeling of the Geothermal System in Námafjall and Response Prediction of 30-90 MW electrical generation in Bjarnarflag. Íslenskar orkurannsóknir, ÍSOR 2004/009, 123p (in Icelandic).
- Karlsdóttir, Ragna. 1993. Námafjall. TEM-resistivity measurements 1992. Orkustofnun, OS-93022/JHD-12: 34 p
- Karlsdóttir, Ragna, 2002: Námafjall. TEM-resistivity measurements 2001. Orkustofnun, OS-2002/057, 68p (in Icelandic).
- Larsen, G., Grönvold, K. and Thórarinnsson, S. 1978 : Volcanic eruption through a geothermal borehole at Námafjall Iceland. Nature 278: 707-710.
- Kristmannsdóttir, H. 1979: Alteration of basaltic rocks by hydrothermal activity at 100-300°C. In: Development of sedimentology (eds Mortland, M & Farmer, V.), pp. 359-367. Elsevier, Amsterdam.
- Sæmundsson, K., Gudmundsson, G.;Pálmason, G., Grönvold, K., Ragnars, K. and Arnórsson S. 1971. Námafjall – Krafla, preliminary investigations of the high temperature areas. Orkustofnun June 1971, 121p (in Icelandic).