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ABSTRACT

Recent progress in exploration, production and utilization of geothermal energy in Iceland is reviewed. Space heating still ranks foremost in utilization, but other uses such as electric power production and process heating are gaining in importance. Present projects include an extension of the Reykjavík Municipal District Heating Service to neighboring municipalities, a new district heating service from the Svartsengi high-temperature field to municipalities on the Reykjanes peninsula, and a 60 MW geothermal power station at the Krafla high-temperature field in northern Iceland.

In 1970 about 80,000 people enjoyed geothermal space heating. By the end of 1974 this figure had risen to 110,000 , or roughly 50% of the total population of Iceland. This will increase to about 60% in the next few years. With present prices of alternative energy sources, about 70% of the population is likely to enjoy geothermal space heating in the near future.

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INTRODUCTION

Geothermal developments in Iceland in 1960-1969 were reviewed in a paper at the U.N. Geothermal Symposium in Pisa (Pálmason and Zoëga, 1970). In 1970 about 80,000 people enjoyed geothermal space heating, most of which was in the capital Reykjavik. The diatomite plant at Mývatn (near Námafjall) had recently started operation, and a 3 MW geothermal power station had been built at Námafjall. About 120,000 m^2 of greenhouses were heated with natural hot water. Exploration of several high-temperature and low-temperature fields with geological, geophysical and geochemical methods and exploration drilling was in progress.

This development has continued at an increasing pace in the last five years. Present forecasts indicate that it will continue to do so in the next five years. The purpose of this paper is to review the main developments that are taking place in this field in Iceland.

EXPLORATION AND DRILLING

The 17 known high-temperature geothermal fields in Iceland are all located within the active zone of rifting and volcanism (Fig. 1), which forms the trace of the Mid-Atlantic Ridge through Iceland. The low-temperature fields are scattered over other parts of the country with a tendency to cluster along the flanks of the volcanic zone. The districution of geothermal fields in Iceland is, generally speaking, in good agreement with the concept of crustal accretion at diverging plate boundaries (Pálmason, 1974). The high-temperature areas are located where, according to the plate tectonics hypothesis, the crustal temperature is highest. Estimates, based on plate tectonics concepts, of the natural heat discharge by conduction and water convection in the volcanic zone indicate that this may amount to 10,000 MW (Pálmason, 1973). An independent estimate of the natural heat discharge of the high-temperature fields alone gives about 4000 MW (Bodvarsson, 1961).

Exploration of the high-temperature fields with geological, geochemical and geophysical methods and exploration drilling has been continued. The major part of the exploration effort has been confined to the fields which are best located with a view to a possible utilization, i.e. the Reykjanes, Svartsengi, Krísuvík and Hengill fields in southwest Iceland, and the Námafjall, Krafla and Theistareykir fields in northern Iceland. The Reykjanes work was completed in 1970 (Björnsson et al, 1970, 1972; Líndal, 1970). Abundant brine aquifers with temperature up to 290°C were found at 1000-1700 m depth in exploration drill-holes. The area was recommended for a sea-chemicals industry, but no decision has been made yet in the matter.

At Svartsengi, about 15 km northeast of the Reykjanes field, two exploration holes were drilled in 1971, yielding dilute brine (2/3 seawater) at 240°C. Natural manifestations of thermal activity in this area were only a weak steam emanation through a recent lava flow. A resistivity survey indicated the size of the field at less than 1000 m depth to be about 4 km^2. In 1974 two further test holes were drilled to a depth of 1400 and 1700 meters. The field is now considered for use in the Sudurnes district heating system on the Reykjanes peninsula.

In the Krísuvík field exploration work has been continued (Arnórsson et al., 1975b). Geological, geochemical and geophysical surveys have been completed, and exploration drilling to a depth of about 1000 m. A maximum temperature of 260°C has been found. Deeper holes are needed to test the permeability below 1000 m depth. The area of the field on the basis of resistivity surveys is about 40 km^2.

The Hengill field is the largest one in southwest Iceland, about 50 km^2. Two border areas of the field have been explored by drilling, Hveragerdi in the south and Nesjavellir in the north. Recent drillings to 1800 meters at Nesjavellir have encountered a maximum temperature of 286°C. The Nesjavellir area has been under exploration with a view to a possible use for district heating for Reykjavík, but plans for this project have been postponed because abundant supplies of low-temperature water have been found in the Reykir low-temperature field. In the Hengill area geophysical surveys are being continued. Tentative plans have been put forward for a geothermal power station to be build there possibly around 1982.

In northeastern Iceland the main emphasis has been on exploration of the Krafla field. It is situated at the southern border of a caldera structure (Saemundsson, 1975) about 8 km northeast of the Námafjall field. Geological, geochemical and geophysical surveys have been completed, and two exploration holes were drilled in 1974 to about 1100 m depth. The maximum temperature found was 298°C. A decision has been made to build a 60 MW geothermal power station at the Krafla field if production drillings, which will start in 1975, prove successful.

In the low-temperature areas considerable exploration work is carried out every year, mainly for the purpose of guiding drillings for hot water for space heating. In some areas, e.g. the southern lowlands and the Reykjavík-Reykir area, systematic regional resistivity surveys to a depth of approximately 1000 m have outlined the general pattern of hot-water movement (Stefánsson and Arnórsson, 1975; Tómasson et al., 1975), and indicated its relationship to the adjacent volcanic zone with its high-temperature fields.

The Reykir low-temperature field, about 15 km northeast of Reykjavík, has been producing by free flow from relatively shallow holes about 330 l/sec of water for the Reykjavík district heating system. New deeper drillings since 1970 have revealed highly permeable aquifers to a depth of at least 2000 meters, with water temperatures of 90-100°C. Injection packers are used routinely to increase water production from the wells (Tómasson and Thorsteinsson, 1975). Pumping tests have indicated that the Reykir hydrothermal systems can produce at least 1700 l/sec with a water level decline of 60 meters (Thorsteinsson, 1975). The additional water produced will be used in an extension of the Reykjavík Municipal District Heating Service to the neighboring municipalities (pop. 25,000).

Two other main low-temperature exploration projects are in progress, with the objective of locating hot-water sources for space heating of Akranes (pop. 4,500) and Akureyri (pop. 12,000). At Leirá, about 15 km northeast of Akranes, drillings to a depth up to 2000 m will be carried out in 1975.

Drillings in recent years in the Reykjanes and Svartsengi high-temperature fields and the Reykir low-temperature field have shown clearly that highly productive aquifers occur at depths to at least 2000 m. This has been, until this year, the depth capacity of present drilling equipment in Iceland. With the purchase in 1975 of a new drilling rig with a depth capacity of 3600 m new possibilities have been opened to investigate the deeper parts of hydrothermal systems and production characteristics of aquifers below 2000 m. The first drillings of this kind are planned in the Reykir low-temperature field.

Fig. 2 shows the total cumulative depth of geothermal drillholes in Iceland in the period 1960-1974. The extrapolation to 1980 is based on current demand for new holes and the capacity of available drilling equipment. The approximately exponential rate of increase of 9.5 percent per year over a period of 20 years is noteworthy. This corresponds to a doubling period of 7.3 years.

UTILIZATION

The use of geothermal energy in Iceland is steadily growing. Fig. 3 shows the geographical distribution of the main sites of utilization in 1975.

Space heating continues to be the most important utilization. By the end of 1974 about 110,000 people, or roughly 50% of the population, enjoyed geothermal space heating. Two main projects are underway in this field. One is an extension of the Reykjavík district heating system (pop. 85,000)[x] to neighboring municipalities (pop. 25,000). This project is to be completed in 1976. The other project is the Sudurnes district

[x] (Zoëga, 1974)

heating system from the high-temperature area at Svartsengi, which will serve several municipalities (pop. 11,000) on the Reykjanes peninsula, and the international airport at Keflavík. This will take an estimated 3-4 years to complete. When these projects as well as a few smaller ones have been completed an estimated 60% of the population of Iceland will enjoy geothermal space heating. It is estimated that with the present price of alternative energy resources, this figure will rise to about 70% in the near future. For the remaining 30%, electrical heating will be more economical because of the distance of the populated areas from the geothermal resources.

The hot-water for the extension of the Reykjavík system in produced from drillholes is the Reykir field, 15 km northeast of Reykjavík. A new pipeline (Φ 700 mm) was completed in 1973 to accommodate the added volume of water.

The Sudurnes system will be the first major use of high-temperature water in a district heating system. Experiments have been carried out to test various methods of transferring the heat of the geothermal fluid to fresh water obtained from shallow drillholes in the surrounding field of recent lava flows (Arnórsson et al., 1975a). Direct mixing of steam with the fresh water is an efficient method and appears to produce hot-water that can be used directly in the distribution system. The heat exchanger plant will be located near the geothermal field.

The use of geothermal energy for electric power production has been on a very small scale so far, despite an abundance of high-temperature fields that could be used for this purpose. The reason is that sufficient hydropower resources have been available at a comparable cost, and with a better known harnessing technology. A 3 MW geothermal power station has been in operation at Námafjall since 1970. A decision has now been taken to build a 60 MW power station at the Krafla field about 8 km northeast of Námafjall. Production drillings will start in 1975, and it is expected that the first 30 MW unit will be in operation in 1977. The plant will consist of two double entry turbine driven 30 MW electric generating units and ancillary equipment, enclosed in a steel reinforced concrete power plant building. Cooling towers will be provided for rejection of the latent heat from the turbine exhaust steam condensed in low level direct contact condensers.

Greenhouse farming has been a steadily growing industry. In 1970 some 120,000 m^2 of greenhouses were in use. By the end of 1974 this had risen to about 140,000 m^2. A feasibility study has been made of a large-scale production of flowers in greenhouses heated with geothermal water and lighted artifically (Lúdvíksson, 1975).

At Reykhólar in northwest Iceland a small plant for the drying of seaweed for alginate production is under construction. It will use 50 kg/sec of geothermal water at 100°C for drying. Operation will begin in 1975.

Table I shows the gross production of geothermal energy for various purposes in 1970-1974, and predictions for the period 1975-1980. The predictions are based primarily on projects that have already been firmly decided on, and they are thus fairly reliable. Two efficiency factors are given for each utilization. They should enable an estimate to be made of the useful and wasted energy in each case. The wellhead efficiency gives the part of the total energy which is transported from drillholes to the plant. In the case of power production it represents the energy in the steam phase from the separators. The plant efficiency denotes the efficiency at the plant. Small losses in transmission and distribution have been ignored.

The diagram in Fig. 4 shows graphically the trend in the production and use of geothermal energy in Iceland in the period 1960-1980. During the first half of this period, when production was mainly from low-temperature fields for space heating, relatively little heat was wasted. With the growing production from high-temperature fields in the second half of this period the wasted heat increases drastically. The overall efficiency of utilization drops from 90% in 1960 to an estimated 45% in 1980. This reflects the poorer efficiency of utilization in electric power plants as compared with heating or drying applications. It is likely that future developments will see an increased effort to improve the efficiency of utilization, either through multipurpose projects, or reinjection of the waste heat into the hydrothermal reservoir.

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Table I

GROSS ANNUAL PRODUCTION OF GEOTHERMAL ENERGY (ABOVE 40°C)

1970-74, AND 1975-80 (PREDICTED)

GWH

Year	70	71	72	73	74	75	76	77	78	79	80	Wellhead eff. %	Plant eff.%
Reykjavík District Heating	1210	1270	1330	1490	1550	1750	1900	2070	2150	2220	2300	100	90
Sudurnes District Heating							140	230	240	250	260	90	45
Other district heating serv.	189	190	210	220	240	250	290	300	400	470	730	100	90
Greenhouse farming	130	140	150	150	150	160	170	170	180	180	190	100	70
Námafjall Diatomite Plant	520	630	690	640	620	620	620	620	620	620	620	40	70
Námafjall Power Plant	440	440	800	900	870	850	850	850	850	850	850	40	6.7
Krafla Power Plant								990	1240	1960	2480	57	17
Reykhólar Seaweed Drying						30	40	40	40	40	40	90	71
Total	2480	2670	3180	3400	3430	3660	4010	5270	5720	6590	7470		

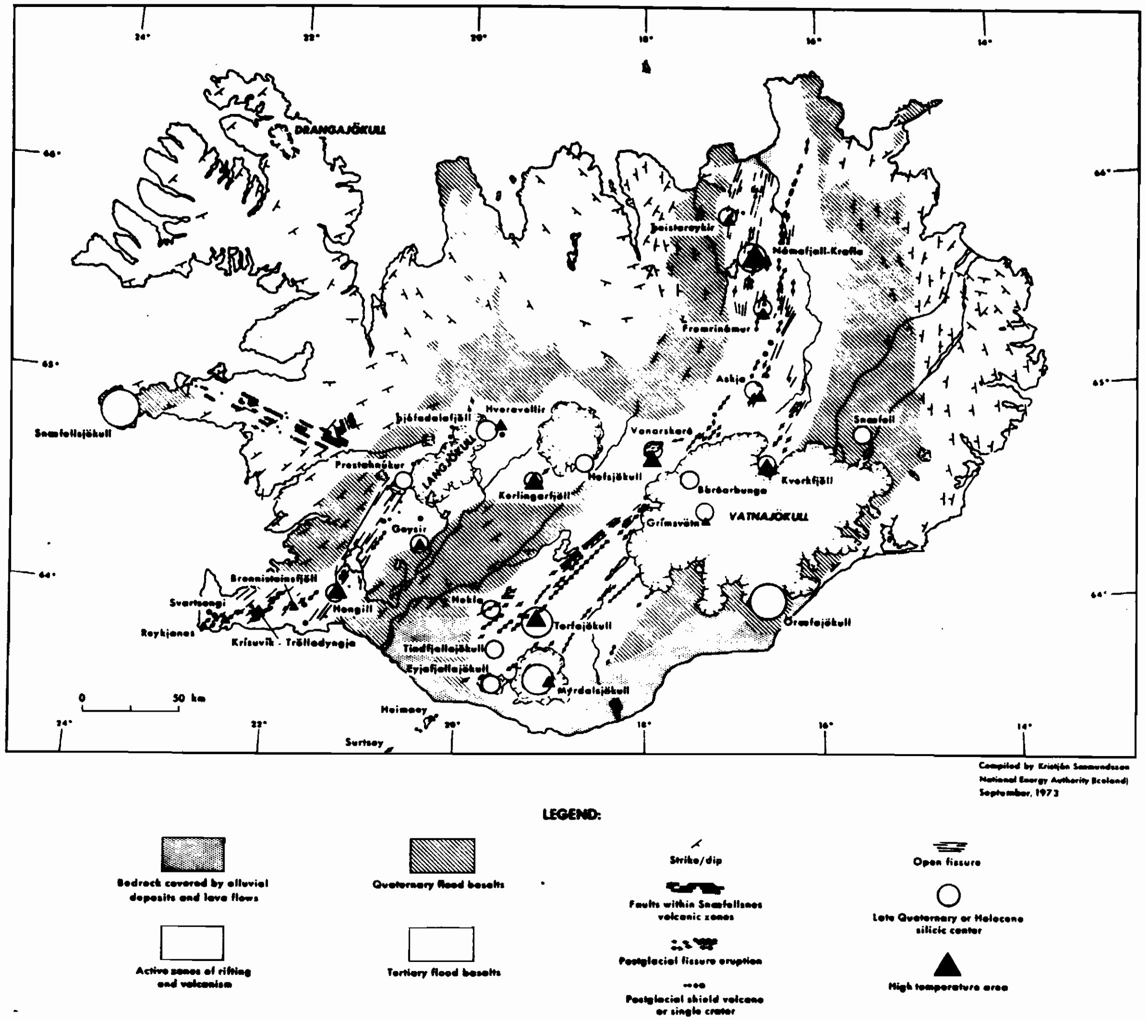

Figure 1. Geological features of Iceland and the distribution of high-temperature fields in the volcanic zone.

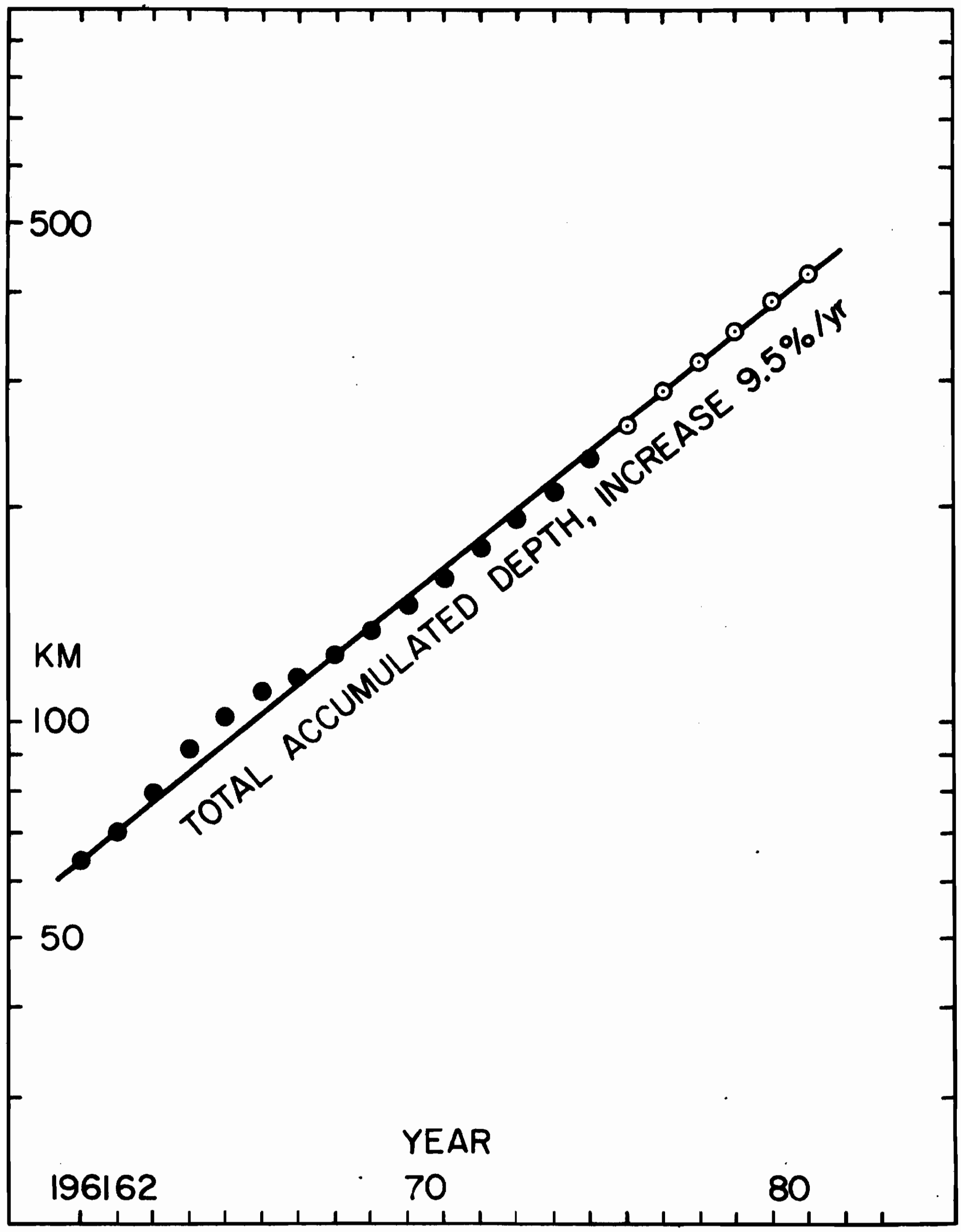

Figure 2. Drilling for geothermal energy in Iceland 1960-1980.

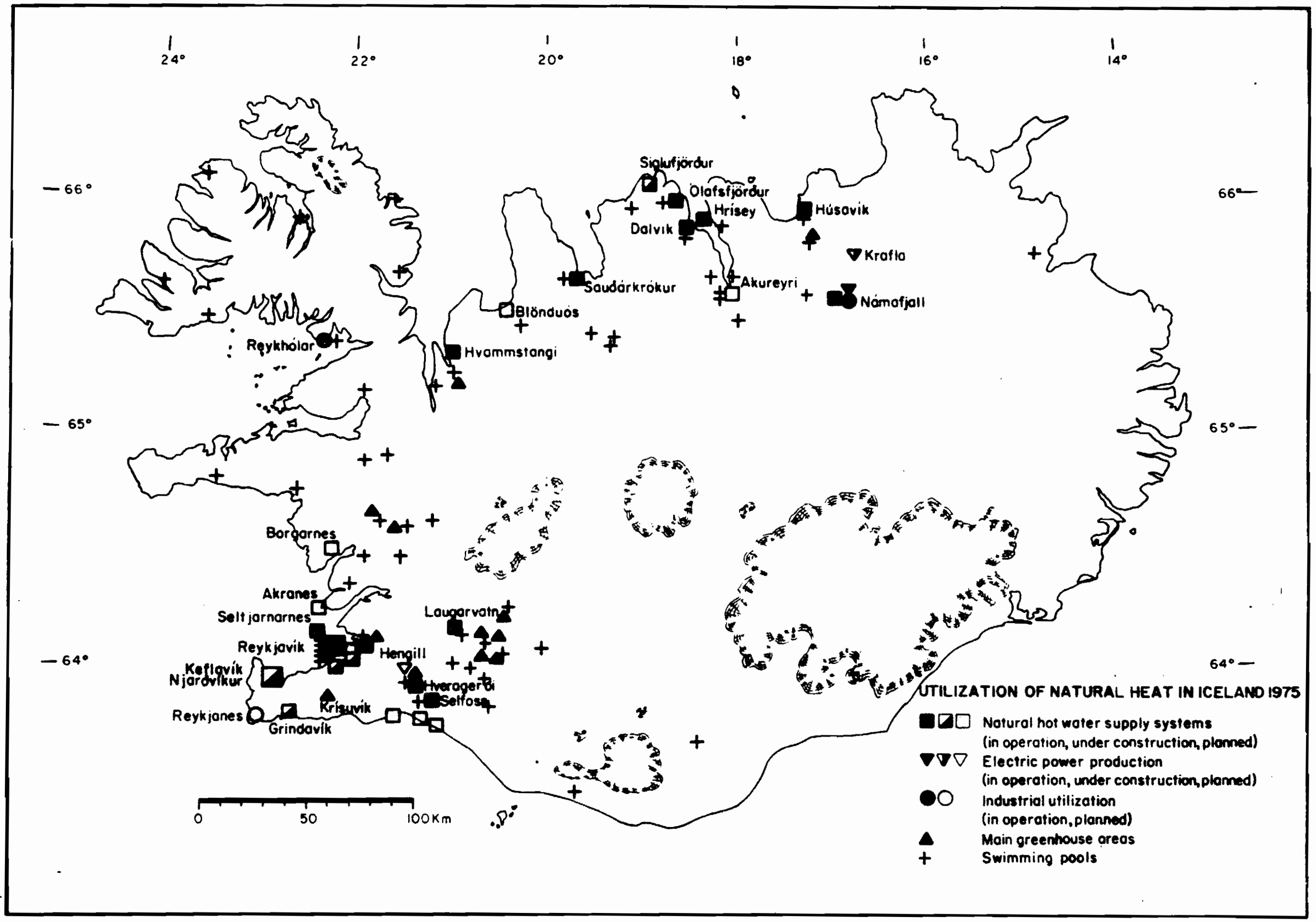

Figure 3. Main sites of utilization of geothermal energy in 1975.

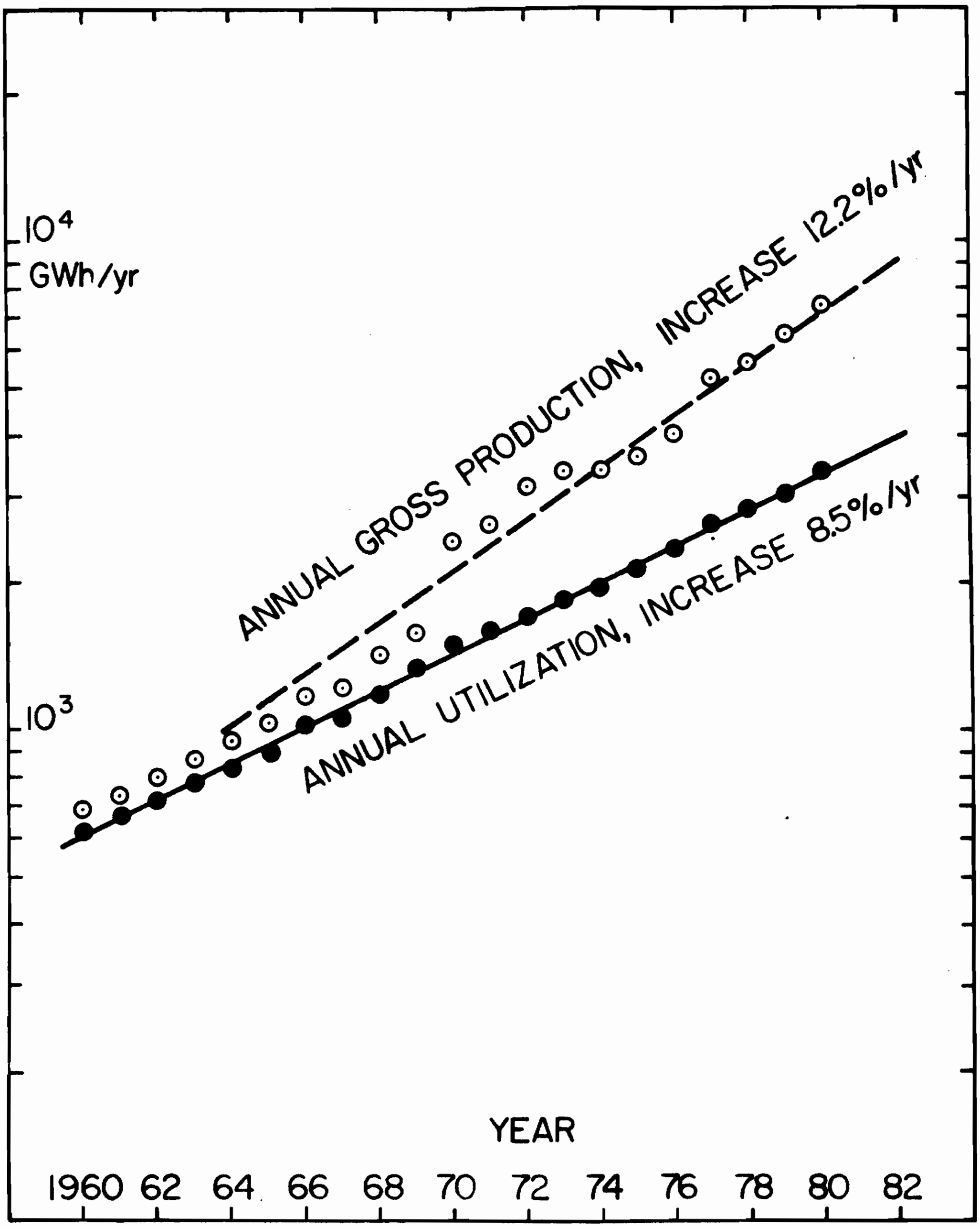

Figure 4. Production and use of geothermal energy in Iceland 1960-1980.