NORDIC VOLCANOLOGICAL INSTITUTE 79 02
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VOLCANIC PREDICTION IN ICELAND

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CONTENT

INTRODUCTION

Volcanic eruptions occur in Iceland on the average every fifth year. This high frequency does, however, not give a direct indication of the volcanic hazard, since the country is sparsely populated and many eruptions occur without causing damage. In the past decades population has increased, and its density has shifted. Vulnerable technical installations have been built. In the perspective of a changing society and future resource utilization, the need for an evaluation of the volcanic hazard and eventual volcanic prediction has become evident. The goals to be achieved can be identified as:

(1) Long term hazard assessment providing reliable probability values for volcanic eruptions. This is particularily useful in new development areas, where plans are made for the construction of power plants, factories, etc. A typical question to be answered is: What is the probability (in figures) for an eruption in the area in the next 50 years?

(2) Short term hazard assessment, oriented towards the minimization of damage to already existing installations and human life. While the long term assessment is of immediate use to economic planners, the short term assessment provides guidelines for civil defence authorities.

Fig. 1 shows the zones of volcanic activity in Iceland. Eruptions can occur anywhere along the fissure systems, but recurrent activity at the same or closely spaced vents occurs in central volcanoes of each system.

Fig. 2 shows the distribution and density of population in Iceland. On the figure is also shown the principal highway around the country.

Fig. 3 shows main sites of present power production as well as the unused hydroelectric power potential.

Put together these three maps represent a preliminary evaluation of volcanic hazard in Iceland. Basic conclusions which can be drawn include:

(1) Volcanic hazard endangering human life is small, but by no means negligible.

(2) Technical installations, such as power plants, power lines and highways, are vulnerable to varying degree. Relatively long sections of highways and power lines can be destroyed at intervals of a few decades. Main hydroelectric power plants are relatively safe within any time period of interest (say 50 years), but some could be covered by tephra and/ or lava within centuries.

(3) Selection of future sites for any land based resource utilization should seriously consider eruption probability as an important guideline.

The geological record indicates that almost any known eruption type can occur in Iceland. Some eruption types, as f.i. catastrophic ash flows, are so infrequent that the probability of recurrence is beyond practical consideration.

Put together the active volcanic areas can be expected to give vent to different types of eruptions at different time intervals:

<u>Decades:</u> Small volume (<1 km^3) eruptions of chemically evolved[x)] basalts within central volcanoes.

[x)] Emphasis is put on the difference between evolved and primitive basalts rather than the absolute volume figures, which should be looked upon as maximum values. These two types of eruptions are usually referred to as fissure eruptions, and shield volcano eruptions respectively in the literature on Icelandic geology. The topographic form resulting from the volcanic construction is to a large degree a function of preexisting topography in the case of monogenetic structures and can therefore not be used in a meaningful classification.

<u>Centuries</u>: (1) Large volume (1-10 km^3) eruptions of chemically evolved basalts without predictable eruption site pattern on fissure systems.
(2) Plinian type explosive eruptions ($<$1 km^3) of silicic tephra from central volcanoes.

<u>Milennia</u>: (1) Very large volume (10-20 km^3) eruptions of primitive basalts without predictable eruption site pattern on fissure systems.
(2) Large volume ($>$1 km^3) plinian type explosive eruptions of silicic tephra from central volcanoes.

Superimposed upon this general scheme are particular effects resulting from (1) glacial cover of some volcanoes and (2) production of volatile constituents in amounts, which have adverse effect on vegetation and grazing animals. In rare cases it can result in pollution dangerous to humans.

Glacial cover of erupting volcanoes results in water floods, which can have catastrophic effects along their paths. The geographic distribution of such flood areas are shown in Fig. 1.

Poisonous effects by volatiles result mainly where tephra or dust particles, containing surface-adsorbed, water soluable fluorine components, are deposited in agricultural areas. The distribution of such adverse chemical pollutants is governed by the prevailing wind direction, and can therefore affect any part of the country.

<u>THE HISTORIC AND TEPHROCHRONOLOGICAL RECORD</u>

Written records on volcanic events in Iceland are available for the past 1100 years or since the settlement of the country, starting in 874 A.D. The records are of varying quality and sometimes rather sober. One of the most voluminous lava eruptions, which possibly produced close to 10 km^3 of lava, the Eldgjá eruption in the 10th century, is referred to with few words only in the Book of Settlement (Landnámabók) written in the 11th century (Larsen, 1979, in prep.). On the other hand another voluminous (12 km^3) eruption to occur in Iceland in historic times, the eruption of the Laki crater row in 1783, sparked the pastor Jón Steingrímsson to write a monograph, which is an internationally unknown classic in volcanology[x)]. The accuracy of the written records is variable. Thoroddsen (1925) based his history of the Icelandic volcanoes on a relatively uncritical study of the records, but in spite of this his large monograph remains the most complete overall review.

A combination of critical evaluation of the records and a study of the field evidence mainly by tephrochronology was initiated and carried to a high degree of perfection by Sigurdur Thorarinsson in a number of monographs on individual volcanoes (e.g. Thorarinsson, 1958, 1967a). On this basis it is now possible to give eruption probability values for those volcanoes, which display regular activity patterns, with repose periods much shorter than the length of the historic and tephrochronological record. Probability evaluation is much less accurate in those cases, where volcanoes or volcanic areas (fissure systems) erupted at irregular intervals or are known to have erupted only once or twice in historic times. In such cases continuous monitoring of the areas to detect changes in the level of activity is the only available approach to volcanic prediction. Examples of different types of prediction problems follow.

[x)] An English translation will be published on occasion of the 200 years anniversary of this eruption in 1983.

HEKLA

Hekla is a central volcano on a short fissure system in S-Iceland. It has erupted 15 times since the settlement of Iceland (Thorarinsson, 1967a). Each major eruption is initiated by a plinian phase producing dacitic tephra followed by effusion of icelandite lava. The volume of erupted material is typically 0.1 to 1 km^3, depending on the length of the preceding quiet period. Fig. 4 shows the distribution of tephra from major eruptions of Hekla. Lavas from the volcano are viscous and their distribution is restricted.

The frequency distribution of volcanic eruptions of Hekla, served Wickman (1966) as a basis for a statistical treatment to attempt to find the probability for a next eruption. In spite of good records over a long time period the statistical approach is limited due to low number of eruptions (or repose periods). Wickman (1966) calculated that Hekla would have a "loading time" of 20 years followed by a constant age dependent eruption rate of about 2-5 x 10^{-3} $months^{-1}$. A more realistic situation is that the eruption rate (eruption probability) increases continuously (Wickman, 1966, p. 340).

Volcanic hazard of Hekla eruptions is by tephra fall. Tephra has destroyed vegetation by (1) complete cover and (2) by adverse effect on grazing animals due to fluorine poisoning. There is no direct threat by explosions or lava flows to the present population or technical installation. Large amount of tephra might, however, cause temporary technical difficulties to a nearby hydroelectric power station.

The last eruptions of Hekla occurred in 1947 and in 1970. The next eruption is unlikely to occur until in the 21st century. Monitoring efforts are therefore at a minimum.

KATLA

Mýrdalsjökull (jökull = glacier) is a central volcano on the Eldgjá-Katla fissure system. Katla, a glacier filled caldera in this central volcano, has erupted at least 17 times since the settlement (Thorarinsson, 1975). Two additional eruptions may have occurred in the 10th century. The eruption products are basaltic, but due to the subglacial environment the products are all emitted as tephra. The volume of tephra produced in each eruption is in the order of 0.5 km^3 (Thorarinsson, pers. comm. 1979).

There is no indication of an eruption pattern, which might help to give an approximate indication of the length of a repose period. Since the beginning of reliable records on Katla (1580 A.D.) the repose periods have been of variable length, but always less than 70 years. The shortest repose, however, is 13 years.

Volcanic hazard by Katla eruptions is principally by a water flood resulting from the melting of huge amounts of glacier ice, but also by complete cover of tephra on farm land (Fig. 5). The water floods come swiftly, and erase everything in their path. Due to successive accumulation of flood deposits each flood tends to more lateral spreading than the previous one. Some communities are therefore in danger. A 25 km long section of the main highway around Iceland will be washed away (Fig. 1). Short term prediction of the eruption is therefore a necessity. The last eruption of Katla occurred in 1918. A period of 60 years is already among the longest reposes between eruptions and Katla is presently a potentially dangerous volcano.

Historic accounts indicate that Katla eruptions are preceded by strong earthquakes shortly (few hours) before the eruption. It is to be expected that sensitive seismometers can detect the unrest much before the earthquakes become strong enough to be felt by humans. The volcano is therefore surrounded by seismometers as shown in Fig. 6. Between 1970 and 1976 earthquake swarms have been recorded every year. Since then seismicity has been low. The earthquake swarm of December 1976 allowed the location of hypocenters (Fig. 6). The swarm originated in two areas beneath the glacier, both within the Katla caldera. The earthquakes come from variable depth with a fairly even distribution from the surface to 30 km depth (Björnsson & Einarsson, in prep.). Continuously recording tiltmeters and a geodimeter distance measurement net will be installed in 1979.

VESTMANNAEYJAR

The Vestmannaeyjar (ey = island; plural eyjar) is an example of a volcanic area, which was thought to be extinct. The present activity, which started in 1963, was preceded by a long repose period. There are no historic records of eruptions in the area and dating of the most recent visible products is in the order of 5000 years. Younger submarine eruptions may have occurred. The products are basaltic tephra and lava.

Within one decade two eruptions have occurred. The Surtsey eruption 1963-1967 and the Heimaey eruption 1973. A pattern of activity with two eruptions separated by 5 years after a repose of 5000 years demands a definition of the term "volcanic event". If the long repose period is numerically reduced to 50 years to compare with the nearby Katla volcano the proportional length of the shorter repose period is 18 days. Two outbreaks in the same volcanic system separated by 18 days would by most volcanologists be counted as the same volcanic event. The comparison helps to illustrate the point that a volcanic eruption may be but a slight surficial expression of a magmatic event. This will become strikingly evident in the following discussion on Krafla. In this perspective it seems well founded to speak of a magmatic event starting in the Vestmannaeyjar some time before the 1963 Surtsey eruption. There is at present no clear evidence to indicate that this event has come to an end.

The volcanic hazard is serious, as shown by the eruption on Heimaey in 1973. The town on Heimaey, partly destroyed by the eruption, has been rebuilt and the population is now 4620 as compared to 5273 before the eruption.

The area is presently monitored by seismometers situated on the main land. Wave action on the coast of the islands prevents high sensitivity seismic recording on the islands. Continuously recording tiltmeters have been installed on Heimaey, and a net of geodimeter distance measurements have been measured (Fig. 7).

Seismometers have been operated since the eruption in 1973, showing sparse but regular earthquake activity with deep (about 20 km) hypocenters just north of Surtsey (Björnsson & Einarsson, in prep.).

KRAFLA

The three volcanoes or volcanic areas in the above examples are located on the eastern branch of the volcanic zones in S-Iceland. This volcanic zone is tectonically different from the principal rift zone of Iceland and the chemistry of volcanic products is different from the rift zone volcanic products (Imsland, 1978).

Volcanism on the rift zone occurs on fissure systems, which are variable in dimensions, but typically 20 by 100 km in the northern part of the zone where the Krafla-Mývatn fissure system is located (Fig. 8). Tensional stresses within the rift system arise as a consequence of crustal extension, which is considered to amount to 2 cm/year on the average. Rifting, however, is episodic (Björnsson et al., 1976, 1978). In Northern Iceland the crust seems to extend elastically over a period of approximately one century before rifting. Each rifting episode affects one fissure system only. The historic record is, however, too short to give a completely reliable support for this apparent pattern of behaviour. It is not possible from the historic eruption pattern to delineate a probable future pattern, useful for volcanic prediction.

The volcanic products of the rift zone range from tholeiitic basalts to dacitic and rhyolitic lavas and tephra. Due to sparse population of most of the northern rift zone volcanic hazard is small with the exception of the Krafla fissure system, where several hundred people are living and considerable technical installations have been built. The Krafla fissure system was last active in 1724-1729. No historic record of activity is known before this eruption and the repose may have been 1500-2000 years. An adjoining fissure system, the Askja system, was active in 1875.

The Krafla fissure system extends 100 km from the north coast inland. The fissure system has been volcanically active over most of its length. Productivity of different sections of the system is variable. The most productive part is in the Krafla area, where the fissure system cuts a caldera subsidence (Fig. 9). The caldera is of interglacial age and subsequently filled by volcanic material, mainly basaltic lava flows. Intense geothermal activity is continuous within the caldera, at Krafla, and on the fissure system to the south of the caldera at Námafjall.

Unusual seismic activity commenced in the Krafla fissure system in the summer of 1975. This was followed by a small basaltic eruption on December 20th that year. The eruption, which lasted only about 20 minutes, was followed by strong earthquake activity and extensional fissuring in an area 40 km to the north of the eruption site on the same fissure system. The earthquake activity continued until mid February 1976.

At the time of this event a geothermal power station was under construction at a distance of 2.5 km from the eruption site, employing several hundred workers in addition to the permanent population of the area. This together with eventual adverse effects of continued volcanic activity on the geothermal system resulted in an intense effort to monitor the area. At the time of this writing (February 1979) the following model has emerged:

Remeasuring of existing levelling lines in the Krafla caldera showed that the December event had resulted in a deflation of an area within the caldera amounting to 2.5 m maximum subsidence. When tiltmeters were installed in the area it became evident that the center of the caldera floor was inflating at a high rate, 7 mm/day. S-wave attenuation indicated the presence of a magma body at 3 km depth (Einarsson, 1978) and the inflation was assumed to result from continuous inflow of magma from depth at the rate of 5 m^3/sec (Tryggvason, 1978b). By September 29, 1976 the point of maximum inflation within the caldera had risen 1.3 m when deflation occurred again, lasting for a few days, immediately followed by inflation at the same rate as before.

The deflation events are now eleven (Table 1, Fig. 10). Three were accompanied by small basaltic eruptions (Grönvold & Mäkipää, 1978). The deflation results from subterraneous injection of magma from the shallow holding chamber beneath the Krafla caldera in either direction into the fissure system. The movement of the magma has been mapped with the help of migrating earthquakes (Fig. 11). Extensive fissuring and evolution of steam occurs where the magma comes to rest (Fig. 12). Basic information on magma movements and the volumes involved are given in Table 2 (Tryggvason, 1978c).

Since 1975 and to the present day the Krafla event has presented a problem of volcanic prediction unprecedented at least in Iceland. After two or three deflation events the tilt record suggested that the shallow magmatic holding chamber beneath the caldera is inflated only to a certain extent before magma has to be emptied into the adjoining fissure system. The flow of magma into the holding chamber seems to be constant and continuous and unaffected by inflation/deflation events in the shallow crust. It was therefore soon possible to calculate from the amount of deflation in each event when the next event could be expected. The average filling period of the holding chamber is 3 to 5 months.

Two most important predictions can, however, not be made. 1) It is not possible to tell into what part of the fissure system magma will intrude. Intrusion towards north affects both uninhabited areas and in its farthest reaches also an agricultural district and a fishing village on the north coast. A flow towards south causes earthquake activity (maximum 3.5 to 4 on Richter scale) in the Mývatn village, as well as serious rifting and disturbances in the geothermal field of the Mývatn area. 2) It is not possible to say if an event will result in a volcanic eruption. A third and important type of prediction, which appears still more remotely possible is to indicate when the magmatic event will come to an end.

Continuous monitoring of ground deformation and seismicity is useful for short term predictions. After each deflation event it is possible to say with a high degree of confidence, that a quiet period of some minimum length will follow. This serves to relief tension on the population, and has also given volcanologists the opportunity to study the effects of each event and reinforce their monitoring effort.

About two weeks before the next event is expected a 24 hour watch is set up in an observatory in the Mývatn village, where telemetered information from seismometers and tiltmeters is collected. (At other times unusual deflections on the seismometers activate a sound signal.)

The seismic array allows immediate location of epicenters, which are plotted on a map within two minutes after the earthquake occurred. The clustering of epicenters at the beginning of a deflation event forms a pattern, which gives a first indication of which direction, north or south, the magma may intrude. Tiltmeters give the first indication of the beginning of an event (Fig. 13). Some time after tilt direction has been definately reversed, the seismometers start to show volcanic tremor. The order in which volcanic tremor starts on the different seismometers gives an indication of direction of flow. The rate of deflation as read from the tiltmeters gives the rate of magma flow into the fissure system and experience has shown that the flow rate towards south is higher than towards north (Table 1). The speed of flow is also known from experience to be about 0.5 m/sec (Fig. 11) (Brandsdóttir & Einarsson, 1978). The distance from the holding chamber to the Mývatn area is about 10 km and this gives civil defence authorities nearly six hours to prepare for an eventual volcanic eruption in that area. Within one or two hours it is usually clear from the monitoring devices, which direction the magma flow has taken.

The monitoring of fumarole gases has been done by conventional gas sampling at intervals of varying length. Two levels of chemical changes have been observed (Óskarsson, 1978). (1) At the onset of magmatic activity the gas chemistry changed drastically in such way that carbon dioxide increased from 60 to 95 per cent in practically all fumaroles in the area. (2) Superimposed on this new composition is a slight but significant fluctuation in the hydrogen content of the gases. A few weeks before each deflation event hydrogen increases by a factor of 2 (from about 1 per cent) and falls back to the original value shortly after the event. In one instance when the deflation event resulted in a volcanic eruption, hydrogen increased to 20 per cent giving a sharp and short lived anomaly (Fig. 14). This observation has stimulated experiments with continuous chemical monitors.

DISCUSSION

The above examples of Icelandic volcanoes serve to illustrate the scope of volcanic prediction efforts in this country. The different types of volcanoes resulting from the complicated tectonic environment require different approaches. The statistical approach, based on the historic and tephrochronological record, serves a useful purpose in pinpointing areas of concern. With an indefinate number of potential eruption sites the mere selection of a site or sites where to concentrate the available scientific resources becomes the first and possibly fatal decision. A combined consideration of volcanic probability and volcanic hazard makes the selection easier, since volcanic hazard considerations are obviously given priority. It is, however, not forgotton that areas of high volcanic probability but no volcanic hazard can provide valuable scientific information, which in turn can help to considerably improve the service to society.

The monitoring approach appears to be the only available learning process, which eventually can lead to safe volcanic prediction. By using the term "learning process" I wish to emphasize the importance of monitoring all possible aspects of a volcanic system also in periods of apparent rest. It is not enough to rely on a single method of monitoring, e.g. seismic recording, with the intention of moving in additional sophisticated monitors, when unrest is already registered. If basic information on ground deformation, volatile chemistry, magnetics, gravity etc. is not available from the volcano while in a "normal" state, then a model of the changing situation will lack rigidity. A reliable model is a primary condition for an eventually successful prediction.

In Iceland the development of monitoring systems is slowly growing. Seismometers have been located at strategic points as shown in Fig. 15. The development and production of a new two-directional tiltmeter in Iceland (Sindrason & Ólafsson, 1978) has facilitated the continuous monitoring of ground movements. Geodimeter distance measurements are being preformed and new types of chemical monitors are under development. Experiments are conducted in energy provision for remote monitoring stations and telemetering of information to a computerized data center. At the same time the volcanic history of different areas is subjected to continued study and revision for improved hazard assessment.

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TABLE I

Magma movement during the Krafla subsidence events (Tryggvason, 1978c).

Beginning of event	Volume of moving magma (10^6 m^3)	Maximum rate of flow (m^3/sec)	Lava (10^6 m^3)	Direction of main flow
Dec. 20, 1975	150		0.4	north
Sept. 29, 1976	2	40	0	south
Oct. 1, 1976	8	45	0	north
Oct. 31, 1976	32	850	0	north
Jan. 20, 1977	21	800	0	north
April 27, 1977	46	2500	0.01	south
Sept. 8, 1977	20	2400	2	south
Nov. 2, 1977	2	520	0	north
Jan. 7, 1978	74	500	0	north
July 10, 1978	37	600	0	north
Nov. 10, 1978	44	750	0	north

TEXT TO FIGURES

Fig. 1. The active volcanic areas of Iceland (based on Sæmundsson, 1978).

Fig. 2. The distribution and density of population in Iceland and the main highway connection around the country.

Fig. 3. Presently installed power plants and unused hydroelectric power potential. For possible sites of geothermal power plants see Fig. 1.

Fig. 4. Distribution of tephra in historic eruptions of Hekla (Thorarinsson, 1974).

Fig. 5. Distribution of tephra in some historic Katla eruptions (Thorarinsson, 1975).

Fig. 6. Earthquake epicenters in Mýrdalsjökull during an earthquake swarm in 1976. Circles around the glacier indicate location of seismometers. Björnsson & Einarsson, in prep.).

Fig. 7. The geodimeter lines in Vestmannaeyjar and the location of tiltmeters (Tryggvason, 1978a).

Fig. 8. The fissure systems in the rift zone in N-Iceland (Björnsson et al., 1978).

Fig. 9. The Krafla caldera and associated fissure system (Björnsson et al., 1978).

Fig. 10. The upper graph is the north component of tilt measured by a water tube tiltmeter at Krafla. The lower trace shows the rate of tilt converted to rate of volume increase (inflow) of the magma chamber (Tryggvason, 1978c).

Fig. 11. The propagation of earthquake activity in the deflation event of Sept. 1977. The latitude of the epicenter is plotted as a function of time of occurrence. The activity begins within the caldera and propagates south along the Krafla fault swarm with a speed of about 0.5 m/sec (Brandsdóttir & Einarsson, 1978).

Fig. 12. Areas of maximum ground deformation and rifting outside the Krafla caldera during different deflation events. (Björnsson et al., 1978).

Fig. 13. Trace of the electronic tiltmeter (north-south component) at the beginning of the deflation event of Sept. 8th 1977 (Sindrason & Ólafsson, 1978).

Fig. 14. Variation in the CO_2/H_2 ratio of gases from two fumaroles (filled and open circles respectively) within the Krafla caldera. Vertical lines show time of deflation events, broken and solid lines indicate deflation respectively without and with simultaneous volcanic eruption (Óskarsson, 1978).

Fig. 15. The net of seismometers in Iceland (Björnsson & Einarsson, in prep.).

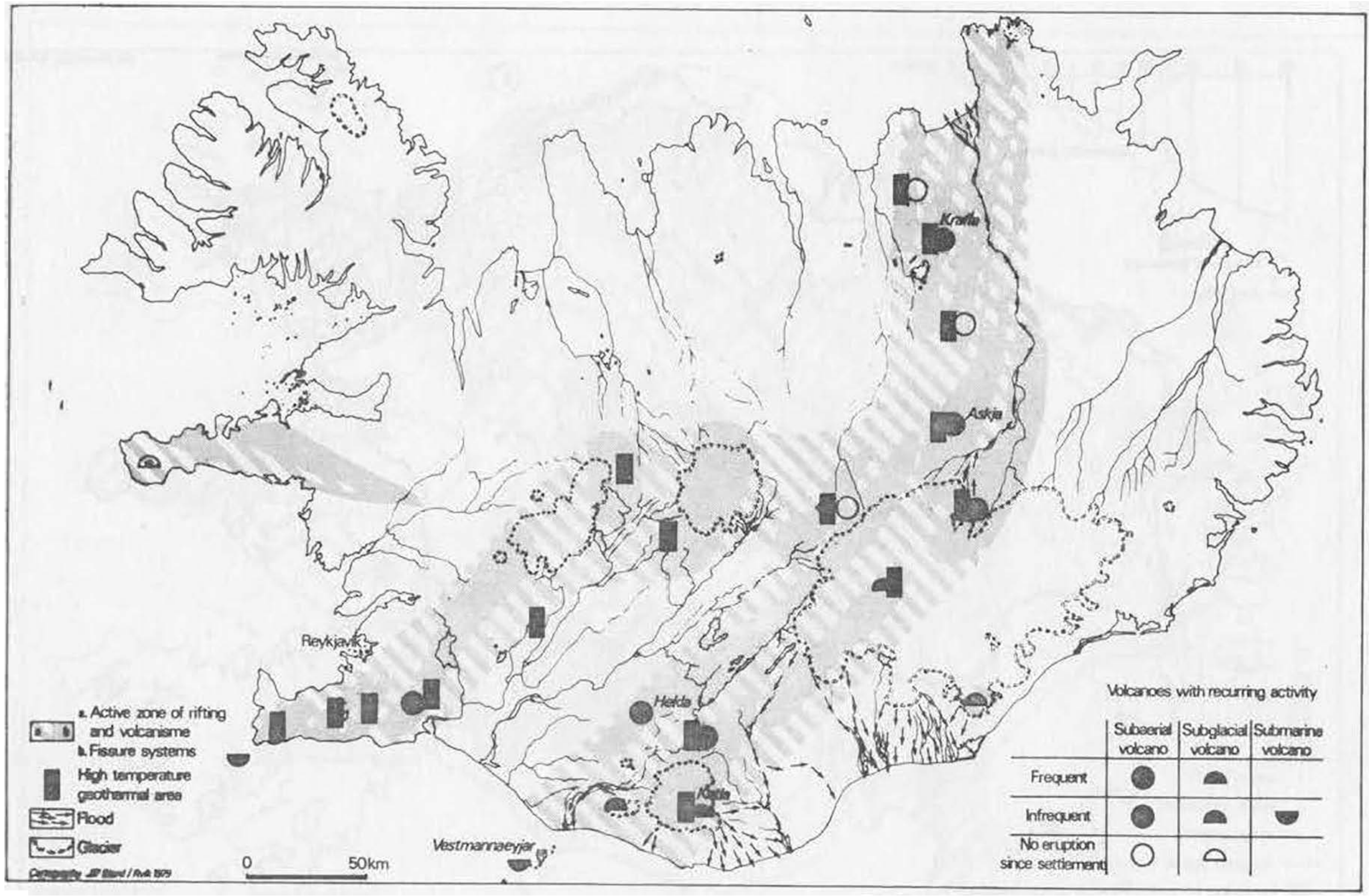

Krafla
Askja
Hekla
Katla
Reykjavik
Vestmannaeyjar
a. Active zone of rifting and volcanisme
b. Fissure systems
High temperature geothermal area
Flood
Glacier
0
50km
Volcanoes with recurring activity
Subaerial volcano
Subglacial volcano
Submarine volcano
Frequent
Infrequent
No eruption since settlement

Fig. 1.

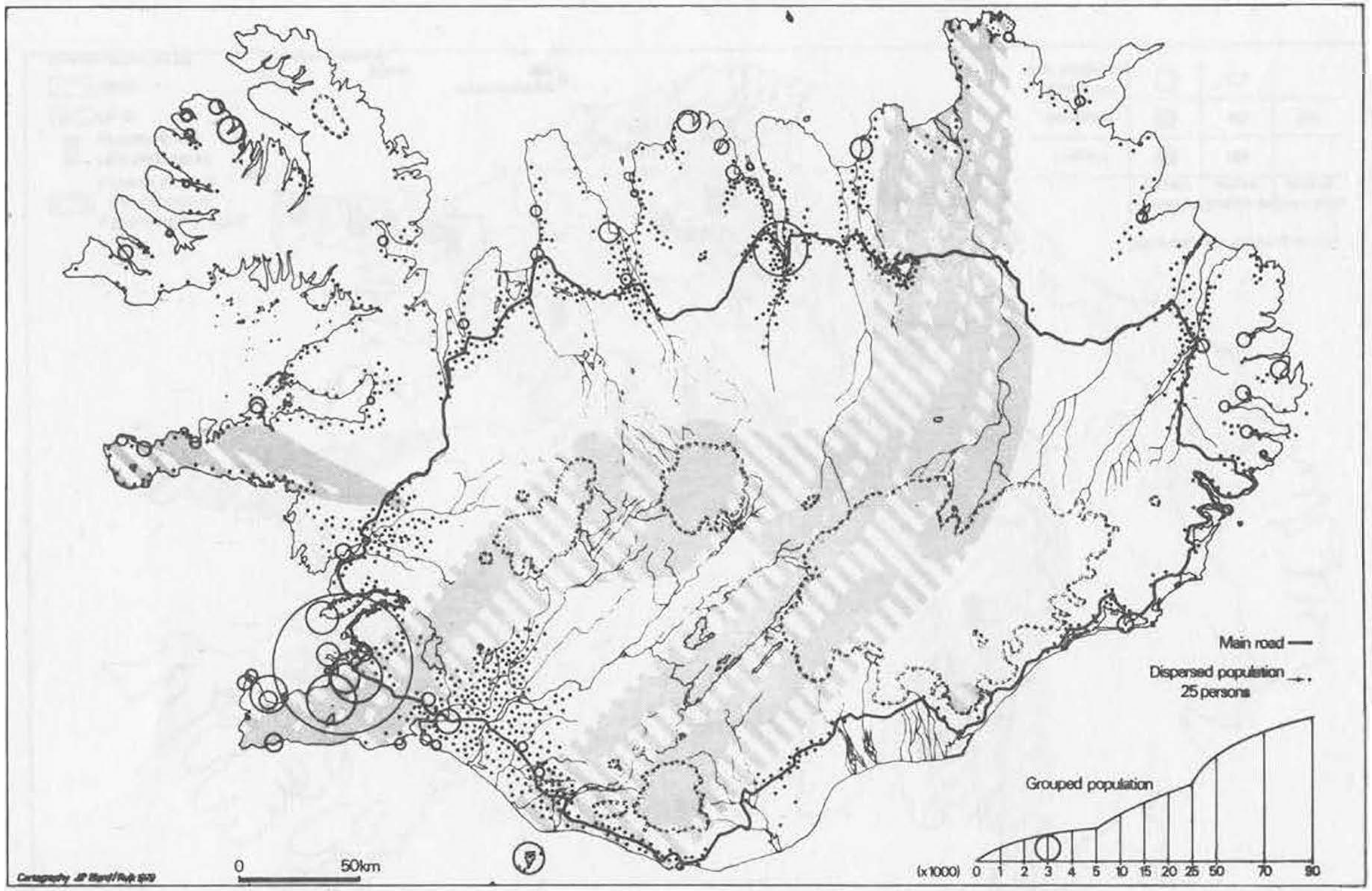

Main road
Dispersed population
25 persons
Grouped population
(x1000) 0 1 2 3 4 5 10 15 20 25 50 70 90
0 50km

Fig. 2.

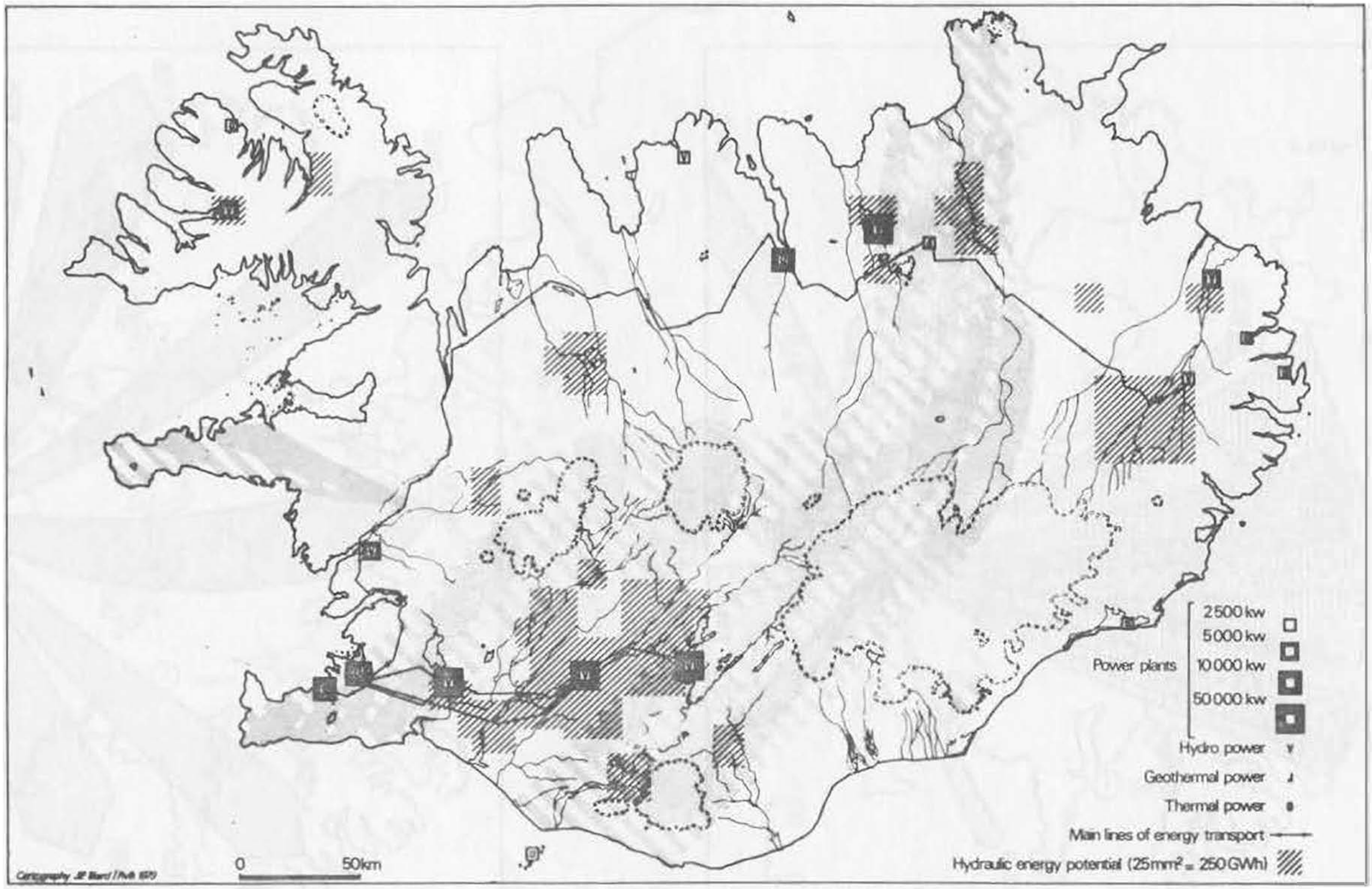

2500 kw
5000 kw
Power plants
10000 kw
50000 kw
Hydro power
Geothermal power
Thermal power
Main lines of energy transport
Hydraulic energy potential (25mm² = 250 GWh)
0
50km

Fig. 3.

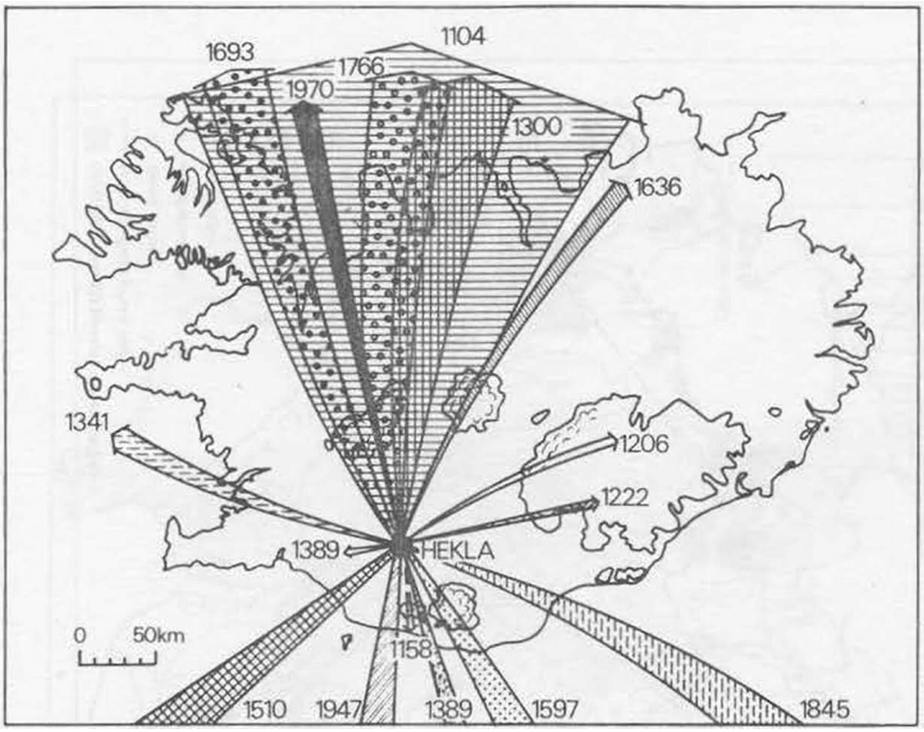

1104
1693
1766
1970
1300
1636
1341
1206
1222
1389
HEKLA
0 50km
1158
1510
1947
1389
1597
1845

Fig.

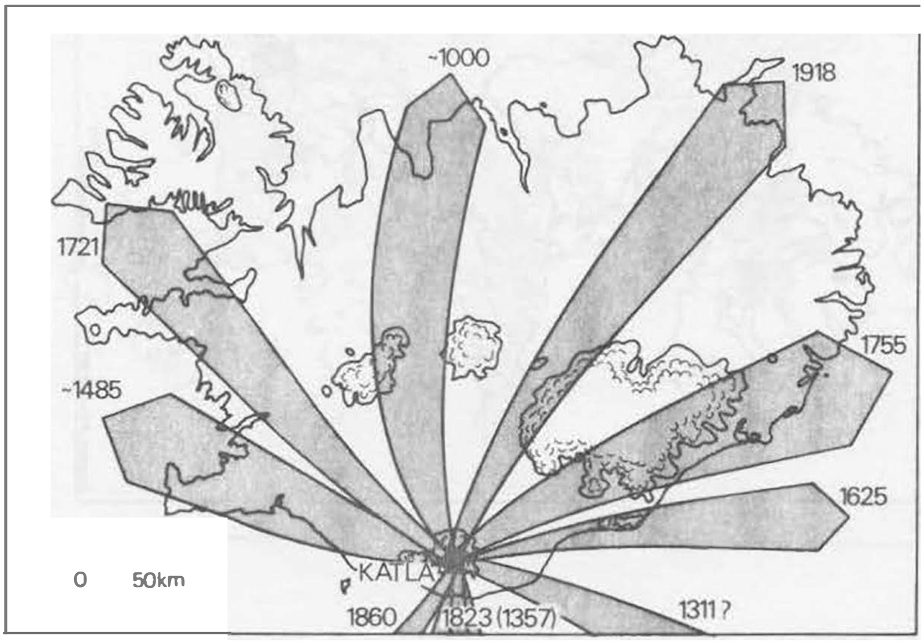

~1000
1918
1721
1755
~1485
1625
0 50km
KATLA
1860
1823 (1357)
1311 ?

Fig. 5

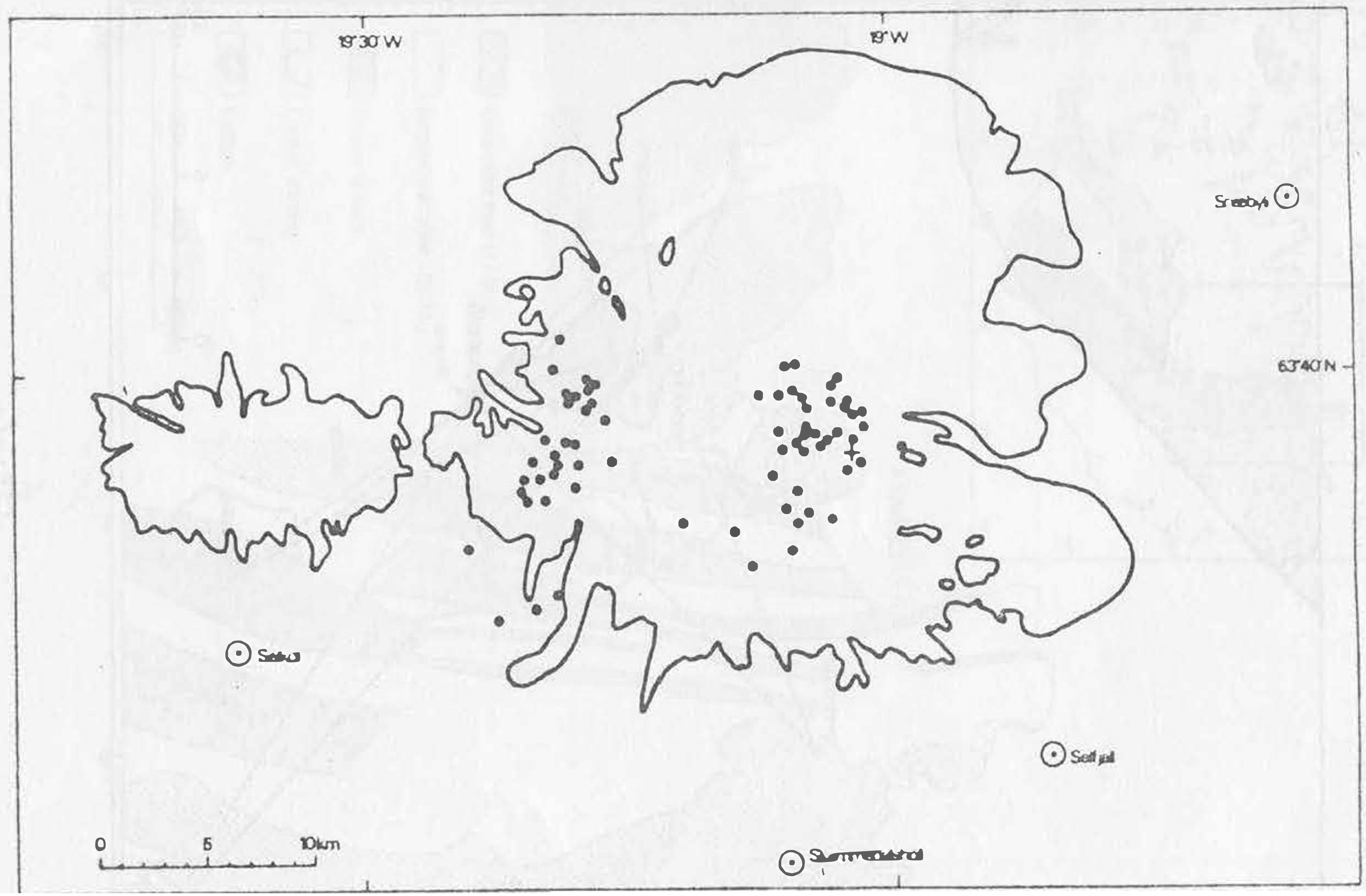


Fig. 6.

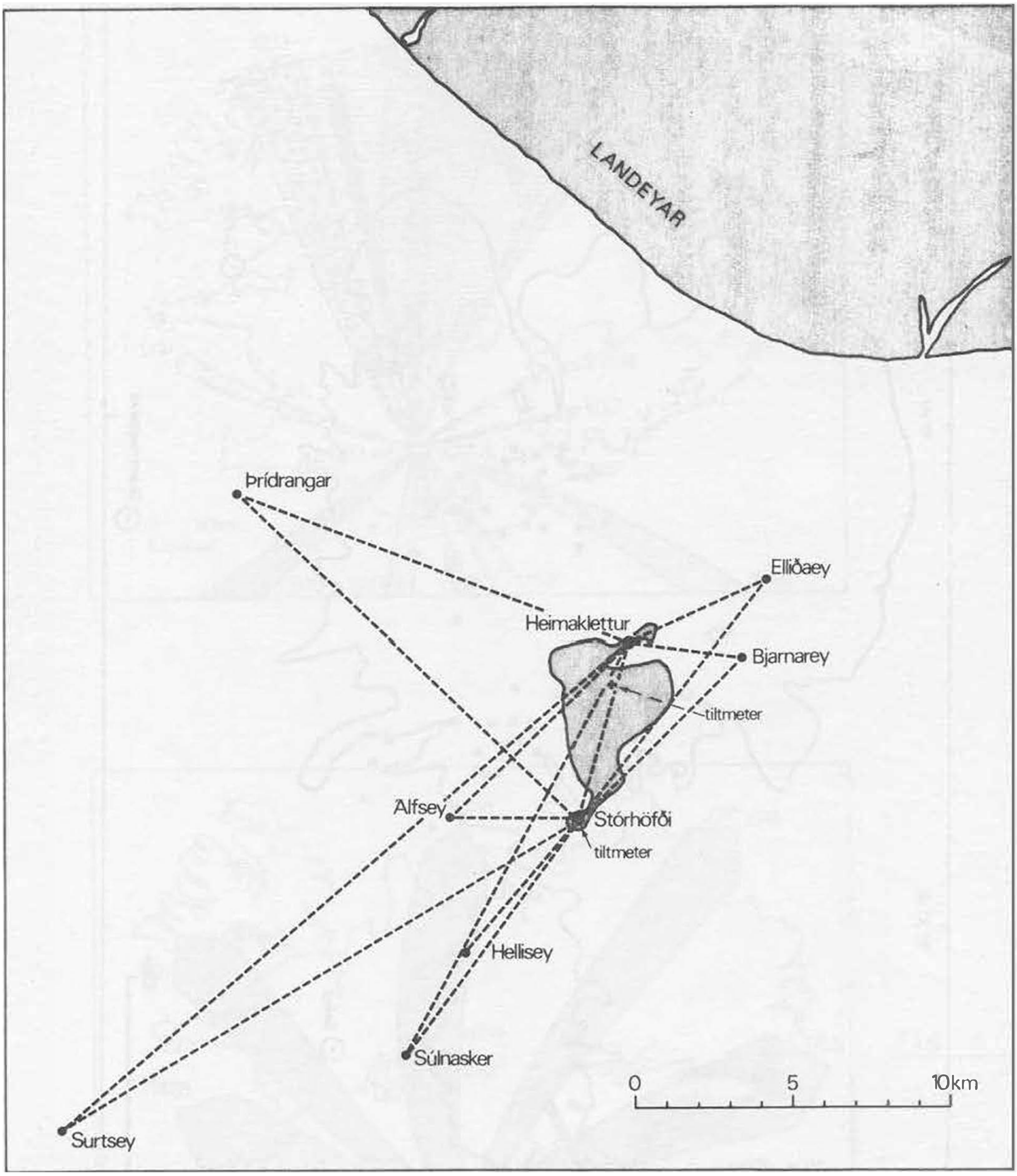
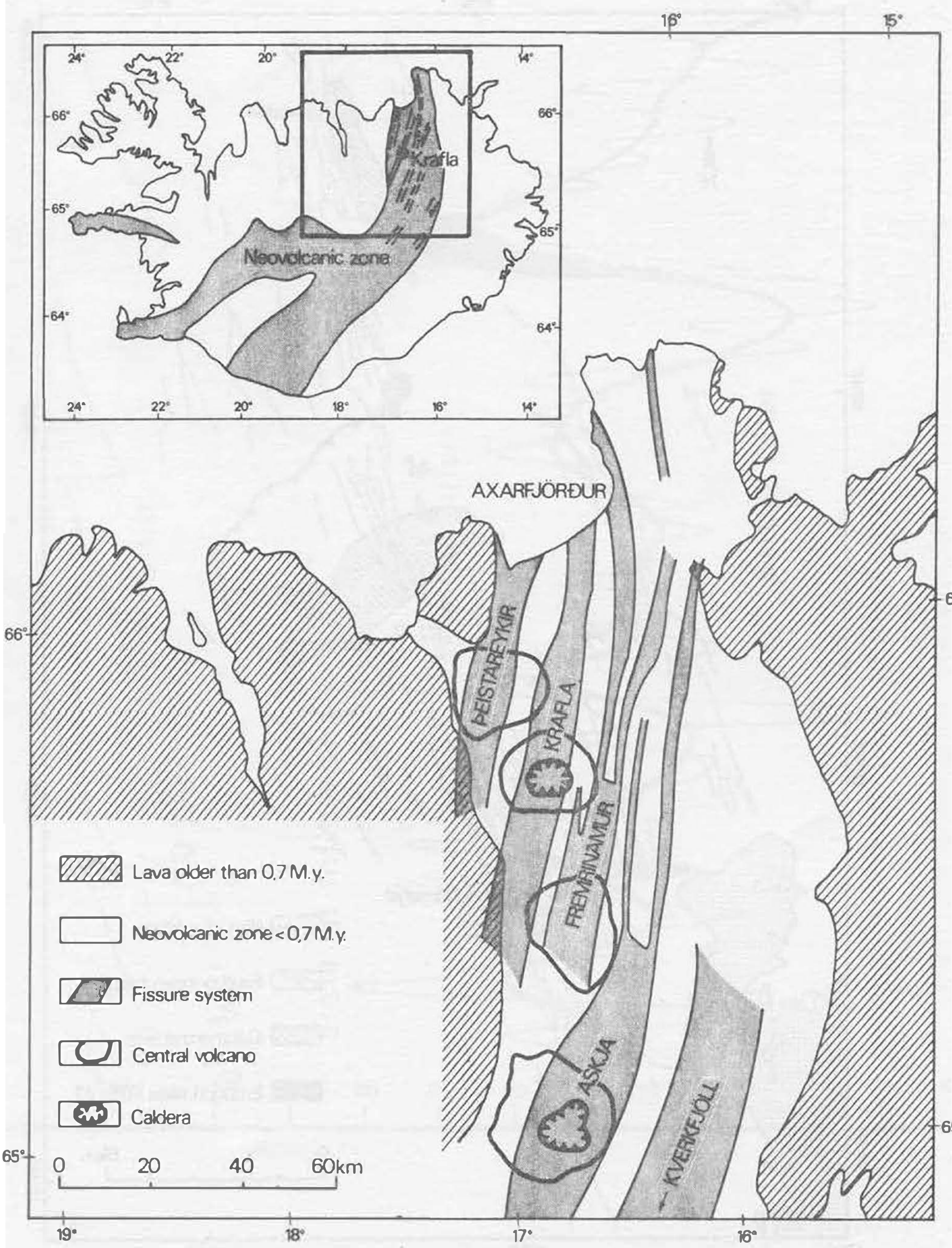

LANDEYAR
Þrídrangar
Elliðaey
Heimaklettur
Bjarnarey
tiltmeter
Álfsey
Stórhöfði
tiltmeter
Hellisey
Súlnasker
Surtsey
0
5
10km

Fig. 7.



Krafla
Neovolcanic zone
AXARFJÖRÐUR
ÞEISTAREYKIR
KRAFLA
FREMRINÁMUR
ASKJA
KVERKFJÖLL
Lava older than 0,7 M.y.
Neovolcanic zone < 0,7 M.y.
Fissure system
Central volcano
Caldera
0 20 40 60km

Fig. 8.

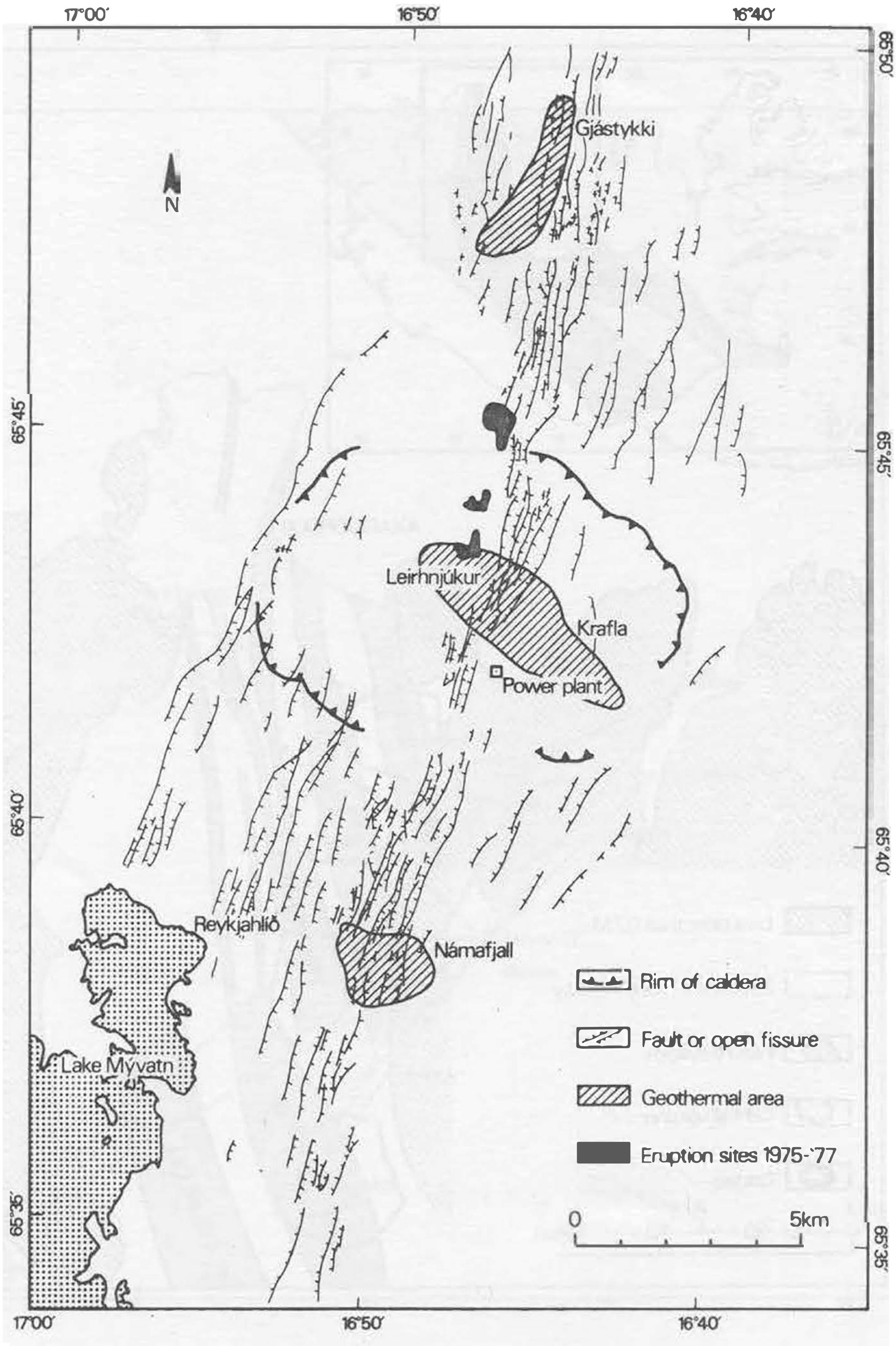

17°00'
16°50'
16°40'
65°50'
N
Gjástykki
65°45'
65°45'
Leirhnjúkur
Krafla
Power plant
65°40'
65°40'
Reykjahlíð
Námafjall
Lake Mývatn
Rim of caldera
Fault or open fissure
Geothermal area
Eruption sites 1975-'77
0
5km
65°35'
65°35'
17°00'
16°50'
16°40'

Fig. 9.

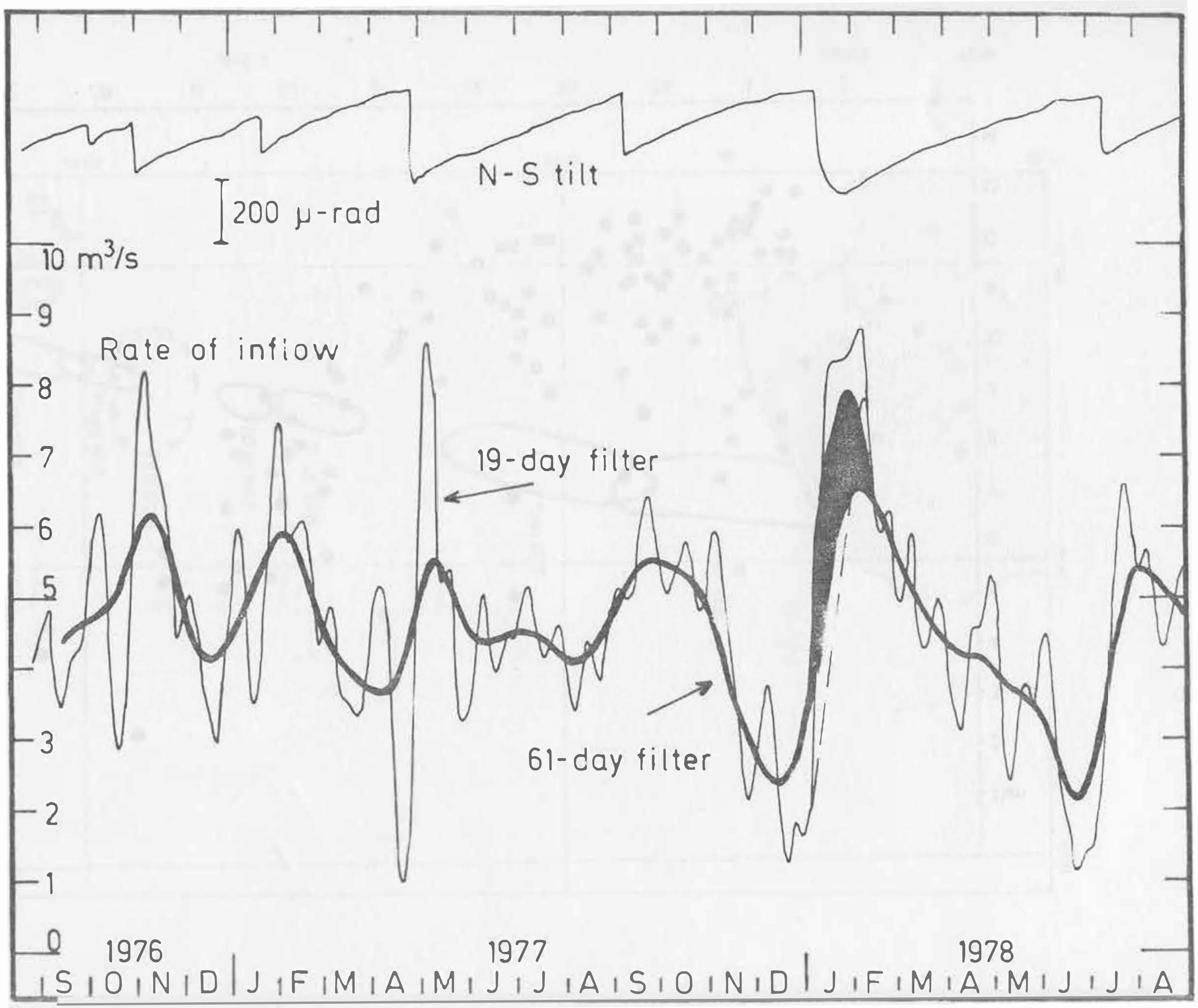

N-S tilt
200 μ-rad
10 m³/s
9
8
7
6
5
3
2
1
0
Rate of inflow
19-day filter
61-day filter
1976
1977
1978
S O N D J F M A M J J A S O N D J F M A M J J A

Fig. 10.

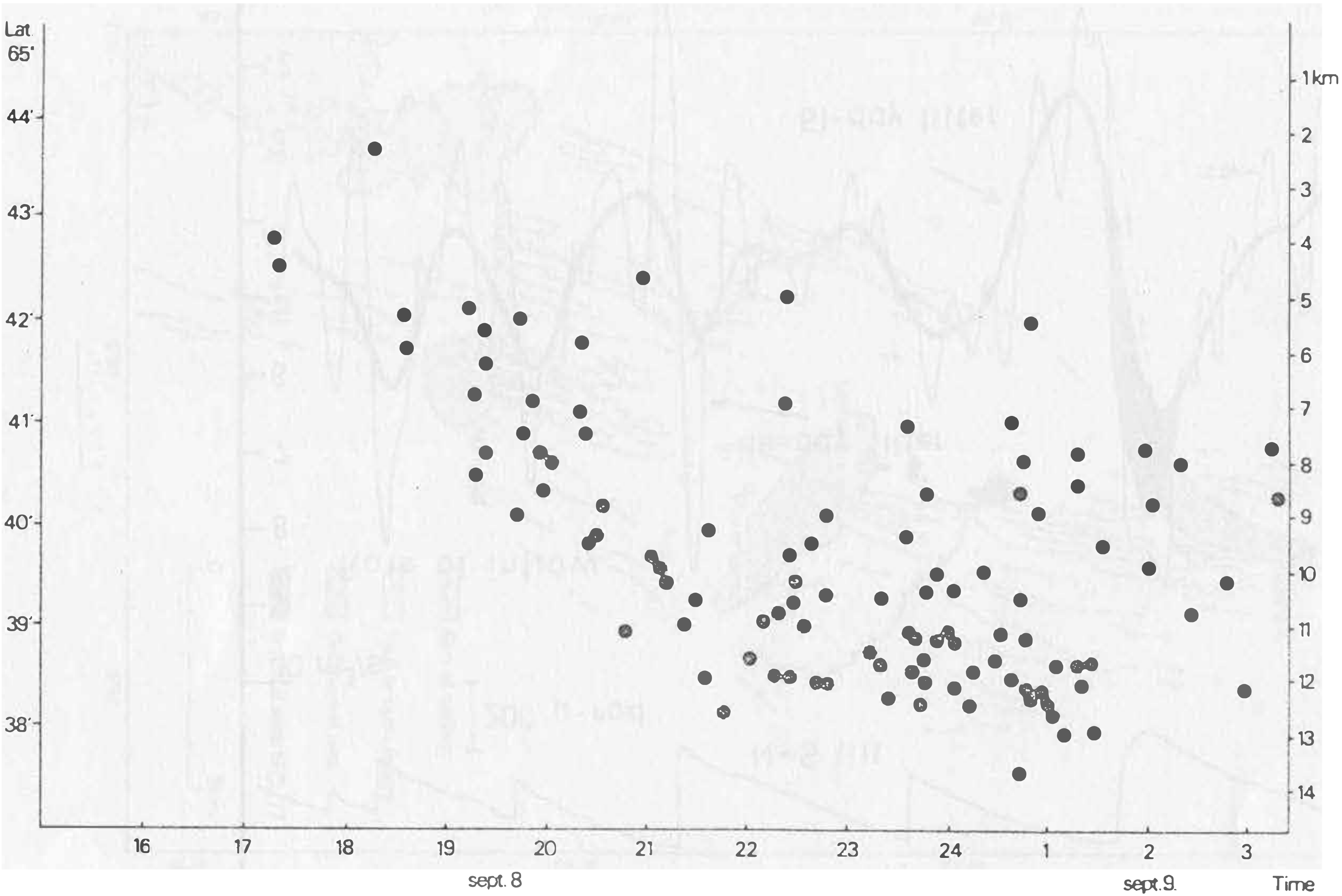

Lat.
65'
44'
43'
42'
41'
40'
39'
38'
1km
2
3
4
5
6
7
8
9
10
11
12
13
14
16
17
18
19
20
21
22
23
24
1
2
3
sept. 8
sept. 9.
Time

Fig. 11.

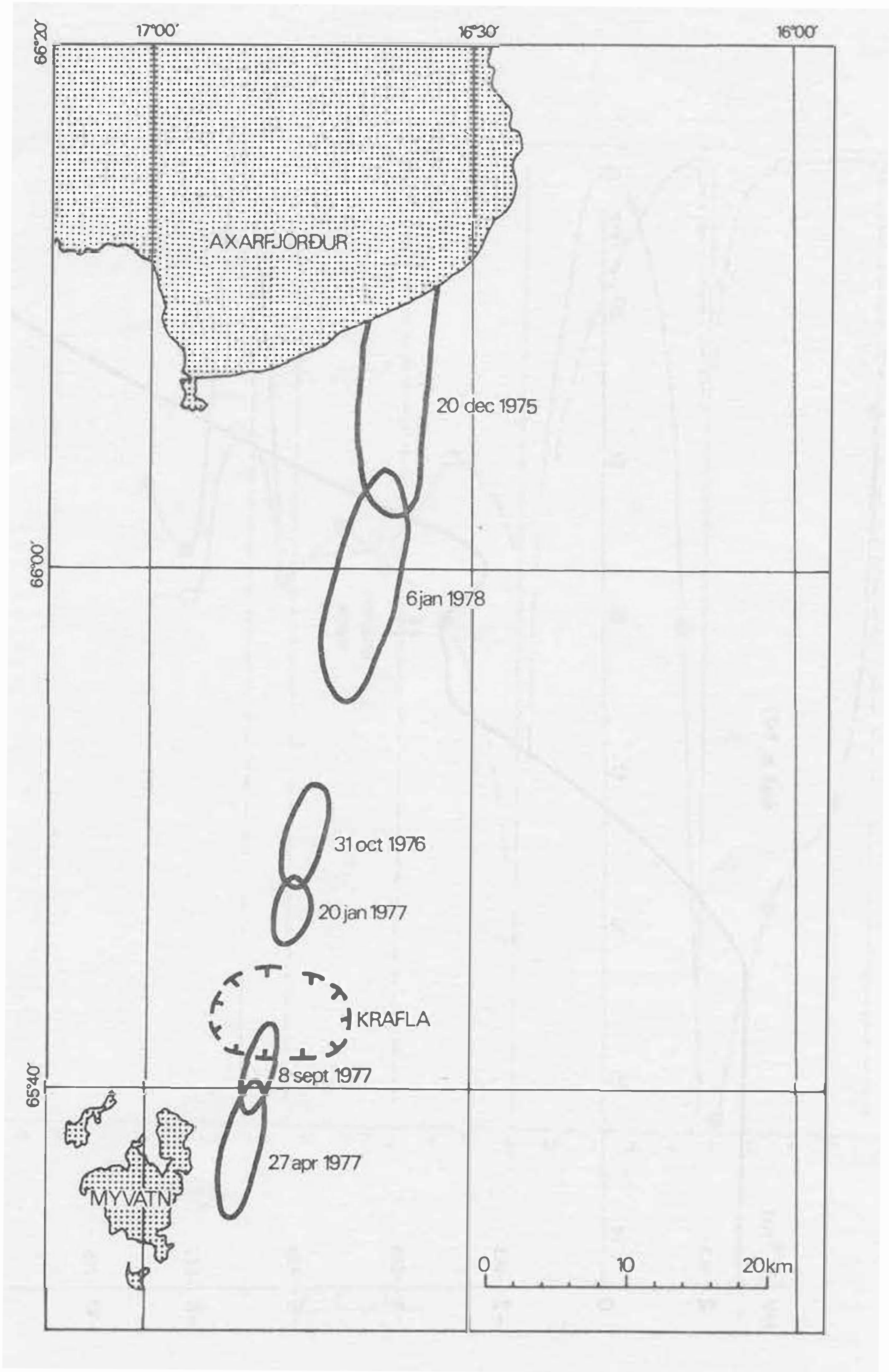
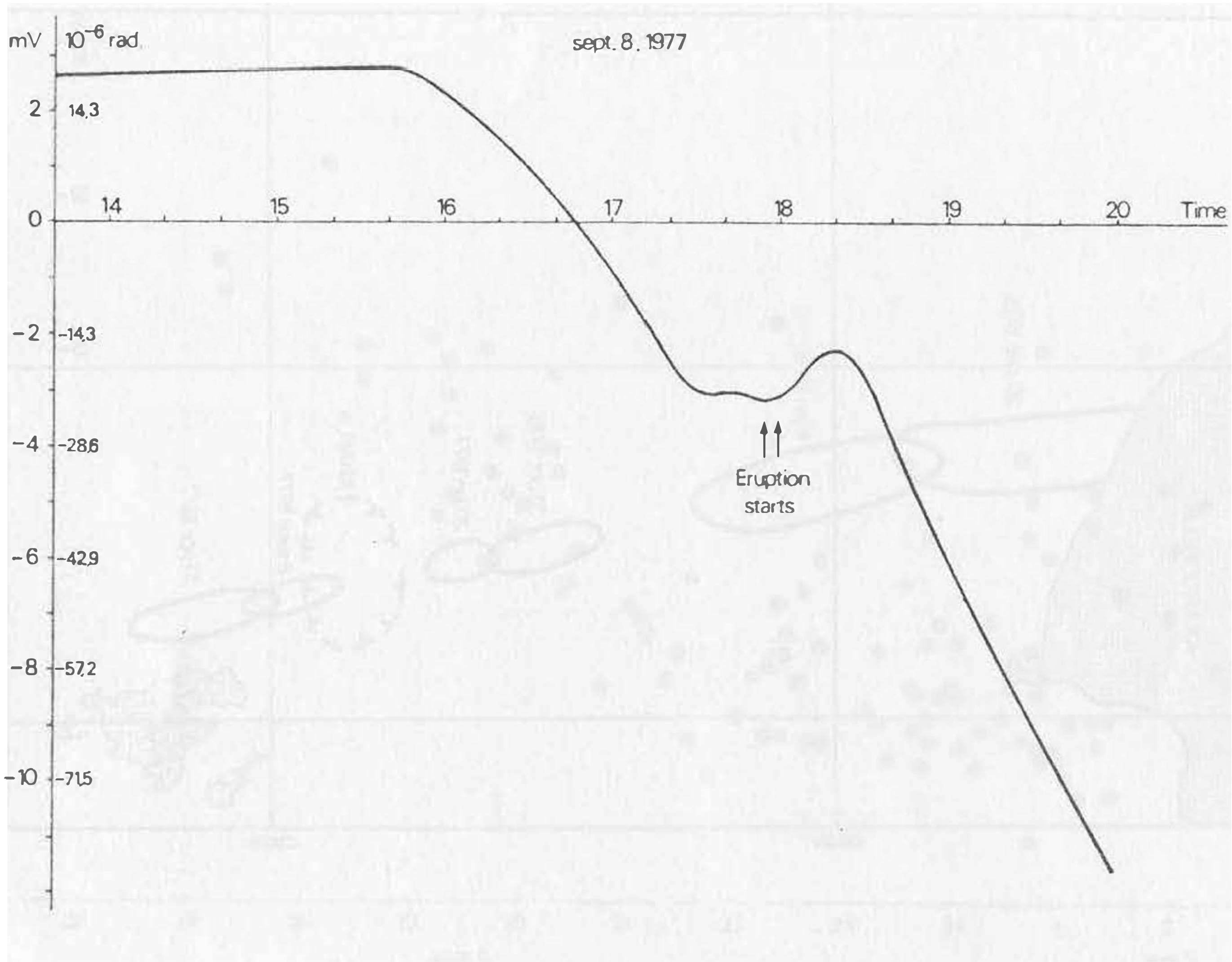

66°20'
17°00'
16°30'
16°00'
AXARFJORÐUR
20 dec 1975
66°00'
6 jan 1978
31 oct 1976
20 jan 1977
KRAFLA
8 sept 1977
65°40'
27 apr 1977
MYVATN
0
10
20km

Fig. 12.



mV
10^{-6} rad
sept. 8. 1977
2
14,3
0
-2
-14,3
-4
-28,6
-6
-42,9
-8
-57,2
-10
-71,5
14
15
16
17
18
19
20
Time
Eruption
starts

Fig. 13.

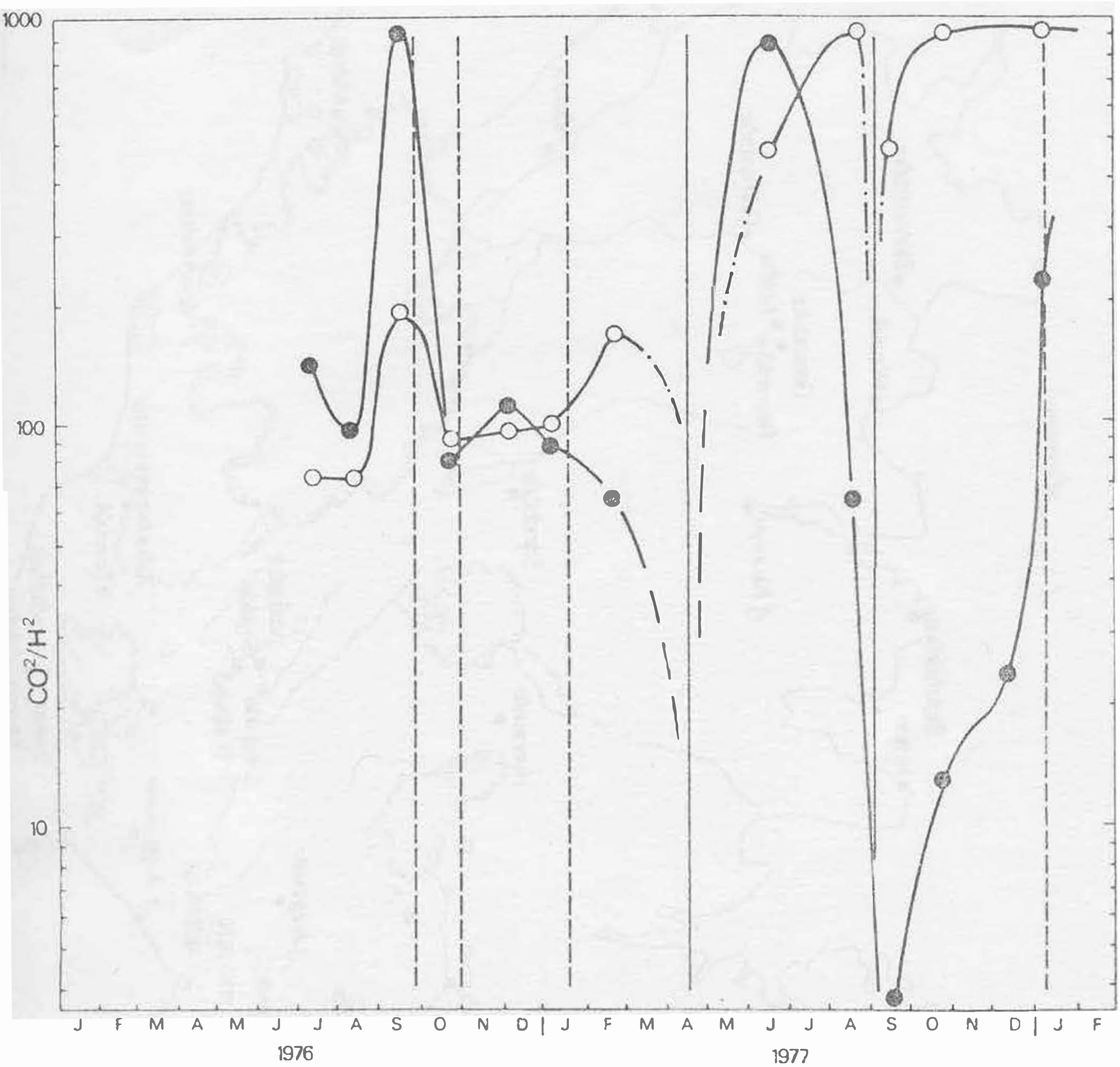


Fig. 14.

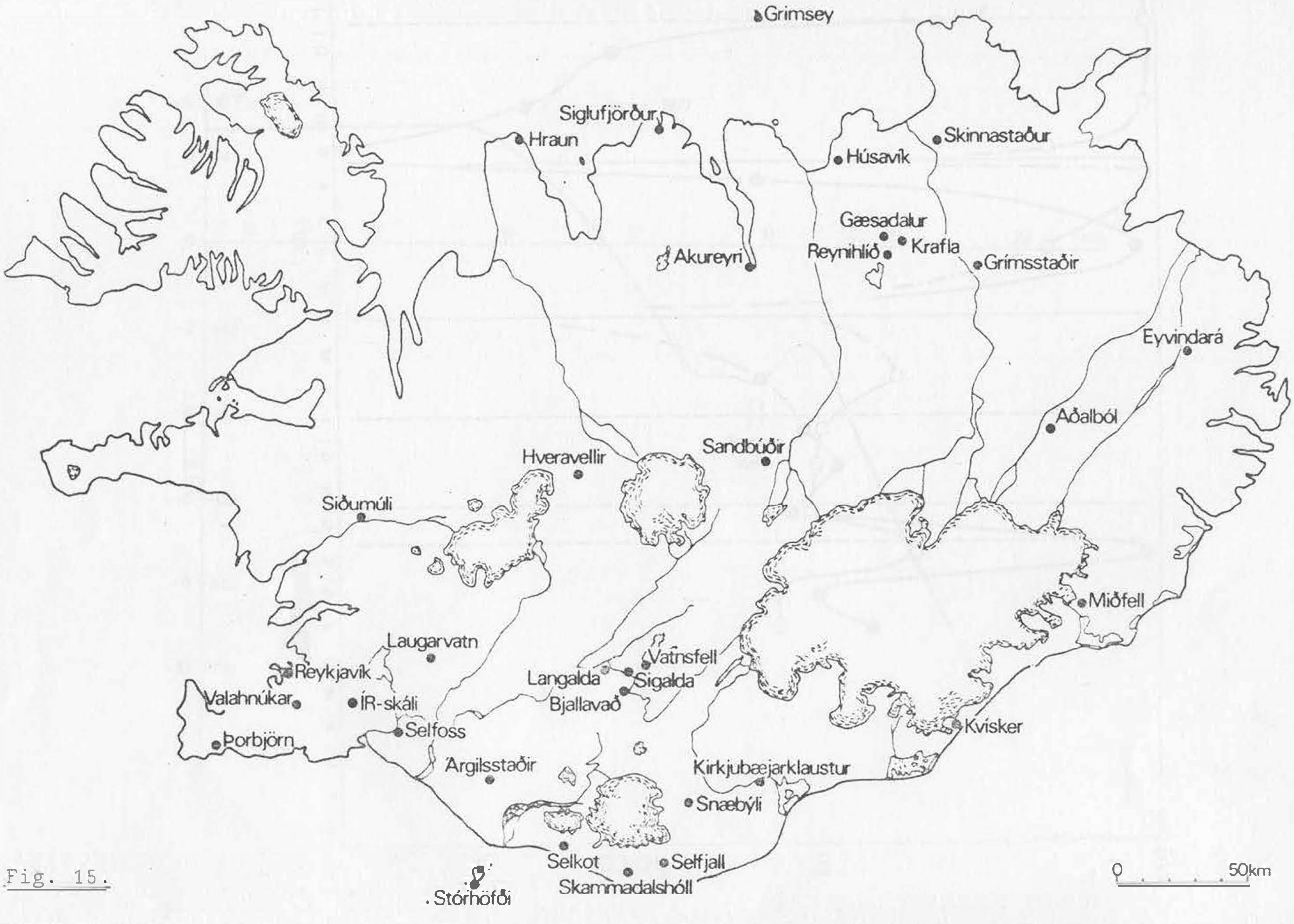

Grimsey
Siglufjörður
Hraun
Húsavík
Skinnastaður
Gæsadalur
Krafla
Reynihlíð
Akureyri
Grímsstaðir
Eyvindará
Aðalból
Sandbúðir
Hveravellir
Siðumúli
Miðfell
Laugarvatn
Vatnsfell
Reykjavík
Langalda
Sigalda
Valahnúkar
ÍR-skáli
Bjallavað
Kvísker
Selfoss
Þorbjörn
Árgilsstaðir
Kirkjubæjarklaustur
Snæbýli
Selkot
Selfjall
Skammadalshóll
Stórhöfði
0
50km

Fig. 15.