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Geology and hydrogeology of Heidmörk area with regard to export of drinking water (Heidmörk)

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Report
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GEOLOGY AND HYDROGEOLOGY OF HEIDMÖRK AREA WITH REGARD TO EXPORT OF DRINKING WATER

Vatnsveita Reykjavíkur (Reykjavík Municipal Water Works) has asked Orkustofnun (National Energy Authority of Iceland) to evaluate the Heidmörk area with regard to export of drinking water. This report is written in order to meet the UK "Natural Mineral Water Regulations SI 1985 No.71" in accordance with "Guidelines for the recognition and Exploitation of Natural Mineral Waters, May 1989" prepared by the UK "Food Science Division, Ministry of Agriculture, Fisheries and Food".

The heading of each paragraph in the report refers to the numbers of the relevant sections in the Regulations (Schedule 1).

2(a)I Location of source

Myllulækur (Millbrook) springs are a copious spring area within a fault zone SE of Reykjavík. Boreholes have been drilled on a hillslope upwards of the springs to tap the spring water at depth. The water is extremely pure and fresh and no treatment of it is required. One of the boreholes defined as V-13 will be used as the source for the water bottling and is defined as follows:

The source identified as V-13 is a 50.5 m deep borehole. It is cased to 20 m depth. It is located at 86.2 m above sea level. Its static water level is at ~ 81 m. The main water bearing zone is at 36 m depth.

Fig. 1 shows the location of the borehole V-13 within Heidmörk area on a map with a scale 1:25.000. Fig. 2 is from the same map focussing on V-13. It shows the sources near Ellidavatn north of V-13 and other boreholes that now tap these sources a short distance upstream in the groundwater reservoir. The ground water level falls off to the northwest towards the lake. The Heidmörk area is part of a nature reserve which extends up to the Bláfjöll mountains in the SE. Heidmörk itself is a park reserved for reforestation and outdoor recreation. A 63 hectares area around Myllulækur is fenced off against unauthorized entry.

Drinking water for the Reykjavík area is supplied from boreholes within the Heidmörk park at a rate of about 1 m^3/s. Of this about 330 l/s are pumped from three boreholes in the Myllulækur area. One of those is V-13 which has a maximum yield of about 120 l/s at a drawdown of about 3 m.

2(a)II Geology and hydrogeology of the surrounding terrain

The bedrock of Heidmörk consists of interglacial and postglacial lava flows (Fig.3). The interglacial lavas are inferred to be of Eemian age, i.e. from the last interglaciation. These are fresh olivine rich basalts consisting of thin flow units with scoriaceous boundaries in between. Glacial mud has seeped into vugs, fractures and cavities and somewhat reduced the high primary permeability of the lava. The aquifers are located within the interglacial lava. Its permeability is greatly enhanced by extensional faults and fractures which lie across

Heidmörk from SW to NE.

The interglacial lavas carry some morainic deposits that are thickest in lows and on gentle slopes. They were smeared on the surface by a glacier that moved towards NW from the mountain range of the central Reykjanes peninsula. The morainic deposits date from the last glaciation. They are poorly permeable. From drilling it is known that layers of such deposits are interspersed with the subsurface strata. Locally they provide conditions for perched aquifers.

The Heidmörk area is located a few km NW of the zone of active volcanism. Piles of subglacially formed volcanic breccias occur in the higher ground to the SE (Fig. 3 and 4). During ice free periods lavas have spread over the area. Thus in postglacial time lavas have overflowed the southeastern part of Heidmörk. They have not reached the Myllulækur area and generally lie above the groundwater table as far as the area to the SE of V-13 is concerned. The postglacial lavas have an extremely rubbly surface and are highly permeable. The youngest lava flow was erupted some 1000 years ago. It has thin soil but a thick carpet of moss. The lava which extends up to Bláfjöll in the SE has an extremely rough surface and is therefore naturally protected from outside traffic. The lavas are very permeable and practically all the precipitation is infiltrated to the groundwater.

Heidmörk is traversed from NE to SW by an active fault swarm. The fault scarps are fresh with throws of up to 40 m. Extensional fissures with opening of up to 1/2-1 m are seen. The V-13 area lies near the middle of the fault swarm which is about 6 km wide (Fig. 3).

A continous core was obtained from a 100 m deep borehole which was drilled 200 m north of the nearest Myllulækur production borehole. It can be taken as representative for the subsurface geology of the area down to this depth (Fig.5). The stratigraphic log shows a sequence of 2-6 m thick lava flow units with porous tops grading into red stained, scoriacous partings. A sedimentary bed of conglomerate and claystone occurs at 60-64 m. The stratigraphic log suggests that at least two eruptive units are present in the 100 m section, separated by the sediment. Electric and natural gamma logs very clearly show dense lavas alternating with sedimentary or scoriaceous zones which do not exceed 4 m in thickness (Fig. 5). The geophysical logs indicate highly porous layers between 20 and 30 m depth. Most of the boreholes in the V-13 area were drilled by a hammer drill. Therefore no stratigraphic logs are available from the production boreholes. Geophysical logs show the same pattern as the cored well of Fig. 5.

A map showing the undisturbed groundwater level around V-13 is presented in Fig. 6. The water level is seen to drop by about 11 m over a distance of 0,5 km from the SE towards V-13 and the lake Ellidavatn in the NW where a number of springs emerge on the SE shore. Fig. 7 shows the effect of pumping at a rate of 330 l/s. Rather than tapping the springs directly the water is pumped from wells a short distance upstream from them. Pumping is kept at a rate lower than could possibly reverse the groundwater flow and cause ingress of lake water towards the wellfield.

The aquifers in the V-13 area occur at irregular intervals from 20 m down to 120 m depth. There is no indication that the aquifers terminate at this depth. The groundwater catchment is part of an extensive groundwater reservoir which depth is not known. Permeability is provided essentially by scoriaceous inter-lava partings and faults. Recharge is mainly from the lava covered high ground and mountains to the SE where precipitation is in the range 2000-3000 mm/y (Fig. 3).

Fig. 8 shows the result of a resistivity survey of Reykjavík and surroundings. A zone of high resistivity lies east of Reykjavík, in the area of young open fractures. The high resistivity zone

reaches at least 750 m below sea level and correlates with an area of near zero geothermal gradient (Fig.9). Both is taken to indicate the existence of an extensive cold aquifer. A borehole 7 km SW of V-13 has confirmed 5°C to about 650 m below sea level.

2(a)IV Description of the Myllulækur wellfield

The Myllulækur area is situated at 80-90 m above sea level 300-800 m SE of Lake Ellidavatn (75,5 m above sea level). The ground is moraine covered interglacial basalt cut by several faults with SW-NE trend. The soil is thin and discontinuous and the vegetation is mainly of heath and shrub type. Roads and walking paths pass southeast of the wellfield. They are used mainly during the summer by people enjoying the nature of the park. The nearest permanent dwellings are at Ellidavatn (residence of park warden) 1.2 km north of the wellfield and the farm Vatnsendi northwest of Lake Ellidavatn about 2 km distant, both downslope from V-13 with regard to groundwater flow. Highway 1 passes about 3 km NE of V-13, also outside the groundwater catchment of this well. The well field around V-13 is fenced off and proof against unauthorized entry. Also the park as a whole is fenced off to keep out domestic animals. Well V-13 is farthest to the south among the production wells, and therefore also farthest upstream with regard to groundwater flow.

The Heidmörk park is reserved for outdoor life, reforestation and last but not least as a supplier of abundant ground water for Reykjavík and the neighbouring communities. Apart from a skiing area on the NW-slope of Bláfjöll 12 km to the SE, there is no landuse at present upstream from V-13 that could contaminate the groundwater. No land use is planned either in the future. During times of rapid snow melting water may accumulate temporarily in ponds and seep into the permeable ground to mix with the groundwater at near surface level.

2(b)I Rate of flow

The rate of flow from the spring area north of V-13 has not been measured. Some of the largest springs emerge at or below lake level. Evidently the flow fluctuated. The flow has been estimated in the range of hundreds of l/s. These springs have only partly dried up (i.e. the highest springs) as a result of pumping from the production boreholes north of V-13. A pumping test of V-13 yielded ~ 20 l/s at a drawdown of the water level in the borehole from ~ 85 m to ~ 78 m a.s.l. For bottling the normal yield from the borehole will not exceed 5 l/s.

2(b)II Temperature of the aquifer.

Temperature measurements of well V-13 show a constant downhole temperature of the aquifers of about 3°C.

2(b)III Water chemistry and hydrogeology and the nature of the terrain

The surroundings of Reykjavík can be roughly divided in three hydrogeologically different regions:

1) Esja - Mosfellssveit area: Pliocene - Pleistocene rocks with a rather low permeability and not very much affected by recent fissure zones. A high rate of surface off-flow and a low discharge of perennial springs (of the order 1 - 10 l/s). Numerous small groundwater basins, with marked seasonal variations. Mostly unconfined aquifers. Precipitation

probably 1,000 - 2,500 mm/a but the infiltration ratio is low.

2) Reykjavík border area, stretching from Mosfellssveit to Hafnarfjördur: Pliocene rocks with a rather low permeability, covered by relatively thin Pleistocene rocks with a markedly higher permeability. Strongly fissured in SW - NE direction. Surface runoff restricted and infiltration considerable. Few springs but some in excess of 10 l/s. Seasonal variations probably less marked. A composite groundwater basin with some subbasins. Mostly confined aquifers. Precipitation near to or less than 1,000 mm/a.

3) The Reykjanes peninsula: Pleistocene rocks with a very high permeability, strongly fissured. Hardly any surficial runoff. Discharge in many marginal and seashore springs in excess of 100 l/s. A continous groundwater basin although divided in subbasins. Semi-confined aquifers. Two main outlet areas, one in Heidmörk and the other at Straumsvík, both with a total discharge of near to 5,000 l/s or more. Seasonal variations observed on some surficial springs, as well in discharge as temperature. Precipitation probably 1,000 - 4,000 mm/a, with a very high ratio of infiltration.

The groundwater in any distinct area has its own chemical characteristics, so far as can be concluded from the few and diverse analyses available. A considerable part of the chemical contents is of marine origin, from seaspray and salt particles, carried to the groundwater with the precipitation. Most chemical components show a clear correlation to the chloride content. The concentration values can therefore be corrected for the marine component with a simple subtraction. The remaining concentrations are then the result of the reactions between the groundwater and the rocks in the aquifers under the prevailing hydrogeological conditions. The corrected chemistry is thus indicative of the hydrogeological nature of the aquifers. In deep and confined aquifers the water is undersaturated with regard to carbon dioxide (total dissolved carbon), due to reactions with the rocks, and the pH is correspondingly high (near to ~9). In equilibrium with the atmosphere, the water usually acquires <pH near to 7.5. The groundwater in the Reykjavík border zone is rather typical for water from deeply fissured, not very permeable basaltic rocks in Iceland: A high pH (>9), Magnesium and potassium, when corrected for the marine component in the precipitation, are virtually depleted, the corrected contents of sodium and calcium are rather high (5-10 ppm). In the Esja - Mosfellssveit area the water is typical for rather shallow aquifers with a considerable constituent from high mountains: A rather low pH (7-7.5), low overall chemistry (calcium (corrected) near to 4 ppm, sodium (corrected) 1 - 4 ppm) but yet the corrected values for magnesium and potassium are higher than in the fissured area (0.3-1 ppm resp. 0-0.2 ppm).

With the same corrections, the chemistry in the Reykjanes peninsula area, inclusive the Heidmörk area around V-13, can be interpreted as typical for deep, semiconfined aquifers, the pH being rather high (up to 9), magnesium low (0.2-0.6 ppm), sodium and calcium not very high (2 - 5 ppm resp. 2.5-4 ppm) and potassium rather low (0.2 ppm). In Heidmörk the sodium content is relatively high (near to 5 ppm) and the magnesium content relatively low (0.2-0.3 ppm) indicating a relatively great depth of circulation and a high degree of confinity.

The chloride values decrease from the coast (13 - 18 ppm in groundwater) and are as low as 10 ppm on the borders of the interglacial Mosfellsheidi shield volcano. On the other side of the Reykjanes peninsula, in Ölfus, springs with contents of only 8 ppm chloride are found, which drain the higher central parts of the peninsula. The chloride content in the Heidmörk area is close to 10 ppm, which indicates that a considerable part of the water must be drawn from the central parts of the Reykjanes peninsula, the drainage basin probably stretching up to the mountain cluster of Bláfjöll.

A similar conclusion can be drawn from the sulphate contents, when corrigated for the marine factor. It is around 3 ppm in the fissured border zone, near to Reykjavík, but around 2.5 ppm in the Esja area. In the Heidmörk area it is still lower or around 2.0 ppm. These low values can be explained by a relatively high altitude for the place of precipitation, in view of the country-wide distribution of sulphate in groundwater. The most probably area would again be the Bláfjöll mountain cluster.

Summarily, the available chemical and hydrogeological evidence indicates, that the groundwater present in the V-13 area - and for that purpose in the whole Heidmörk area - is from a deep, semiconfined aquifer with an extension far into the uninhabitated, mountainous Reykjanes peninsula, eventually as far as to the mountains of Bláfjöll.

List of Figures

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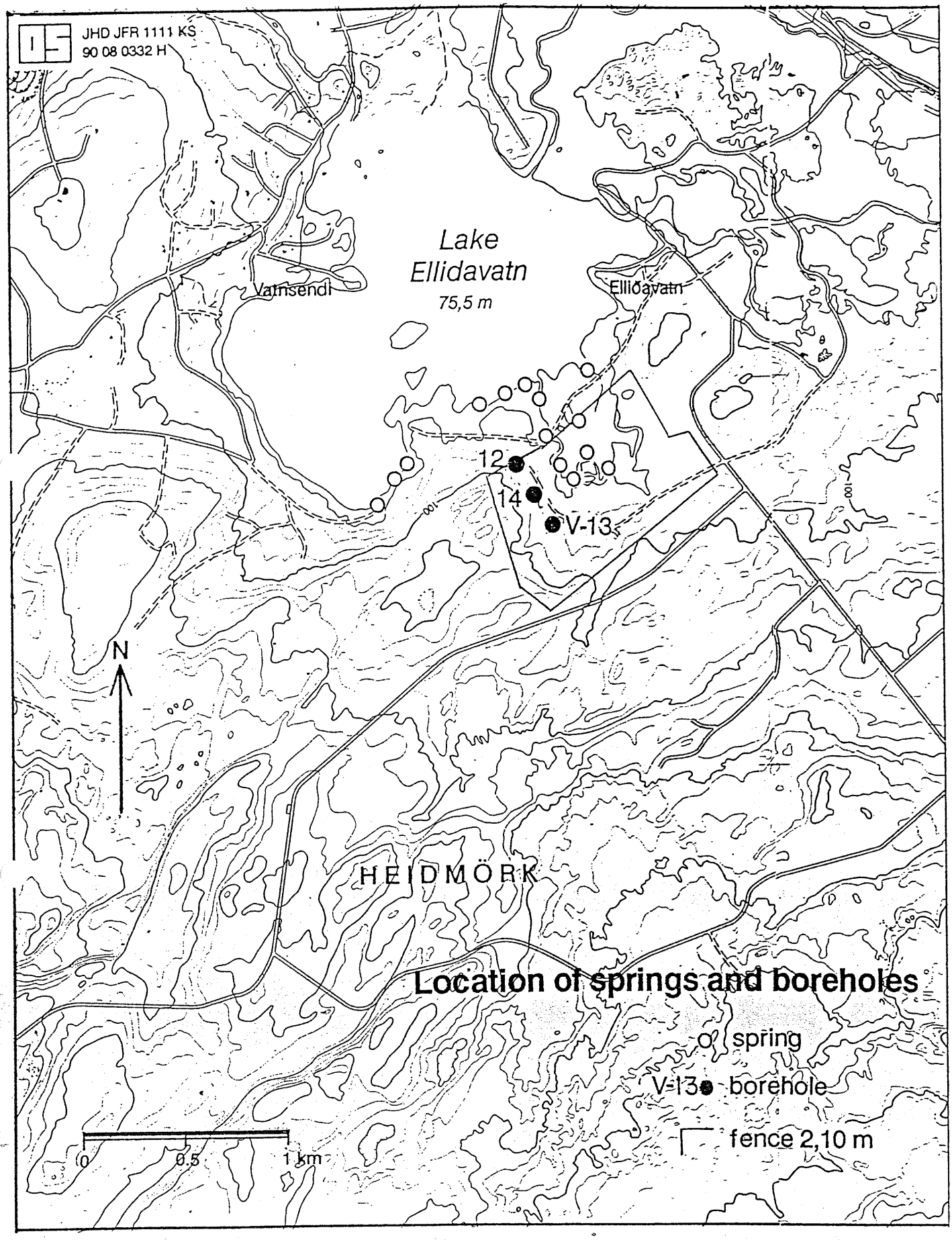
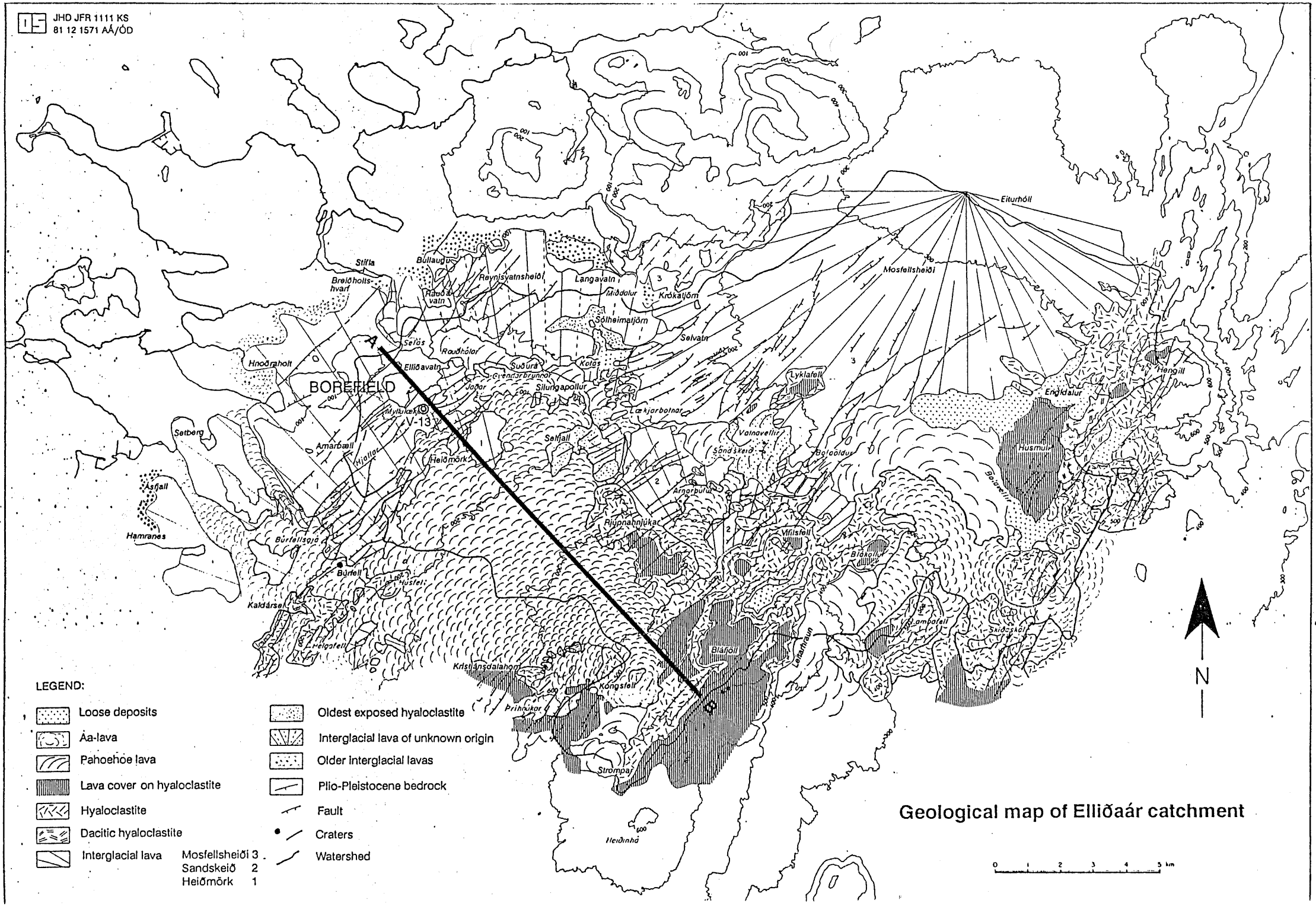

JHD JFR 1111 KS
90 08 0332 H
Lake
Ellidavatn
75,5 m
Vatnsendi
Ellidavatn
12
14
V-13
100
N
HEIÐMÖRK
Location of springs and boreholes
spring
V-13 borehole
fence 2,10 m
0
0.5
1 km

Fig. 2

JHD JFR 1111 KS
81 12 1571 AÁ/ÓD

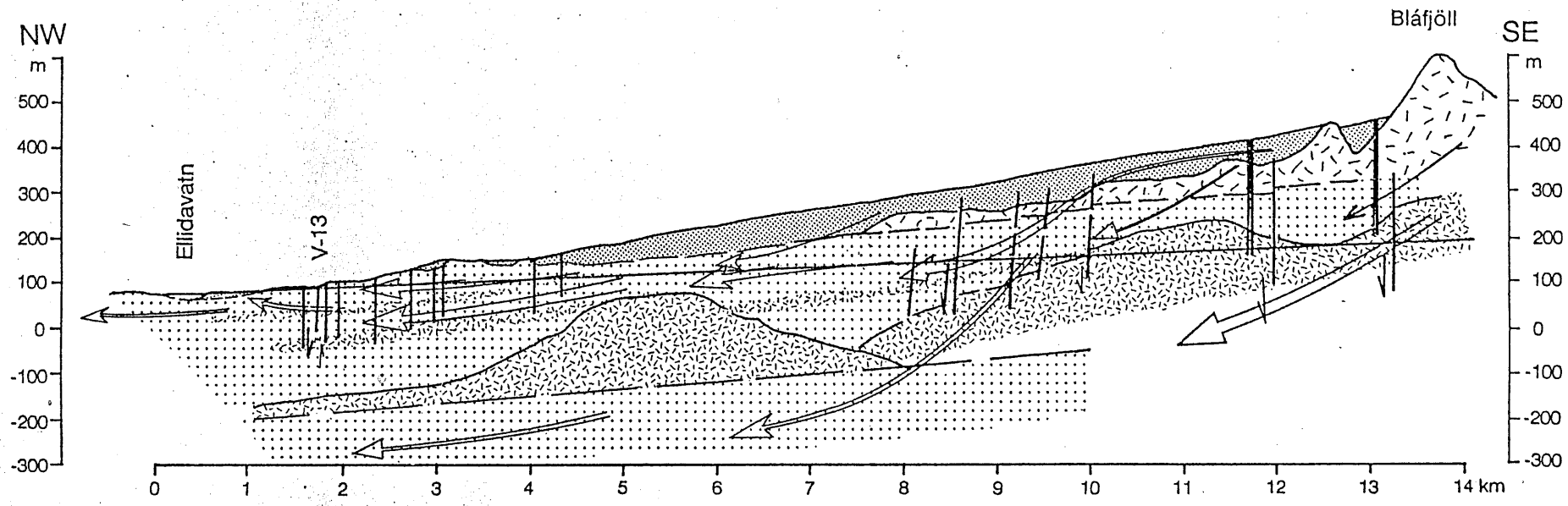


LEGEND:

- Loose deposits
- Aa-lava
- Pahoehoe lava
- Lava cover on hyaloclastite
- Hyaloclastite
- Dacitic hyaloclastite
- Interglacial lava — Mosfellsheiði 3, Sandskeið 2, Heiðmörk 1
- Oldest exposed hyaloclastite
- Interglacial lava of unknown origin
- Older interglacial lavas
- Plio-Pleistocene bedrock
- Fault
- Craters
- Watershed

Geological map of Elliðaár catchment

Geological section across Heidmörk



Groundwater flow
Postglacial lava
Volcanic breccia (subglacial)
Interglacial lava
Volcanic breccia and detrital beds
Geological boundary
Fault
Eruptive fissure
Groundwater level

JHD JFR 1111 KS
90 08 0331

GEOLOGICAL SECTION AND LOGS
Myllulækur borehole 81-1

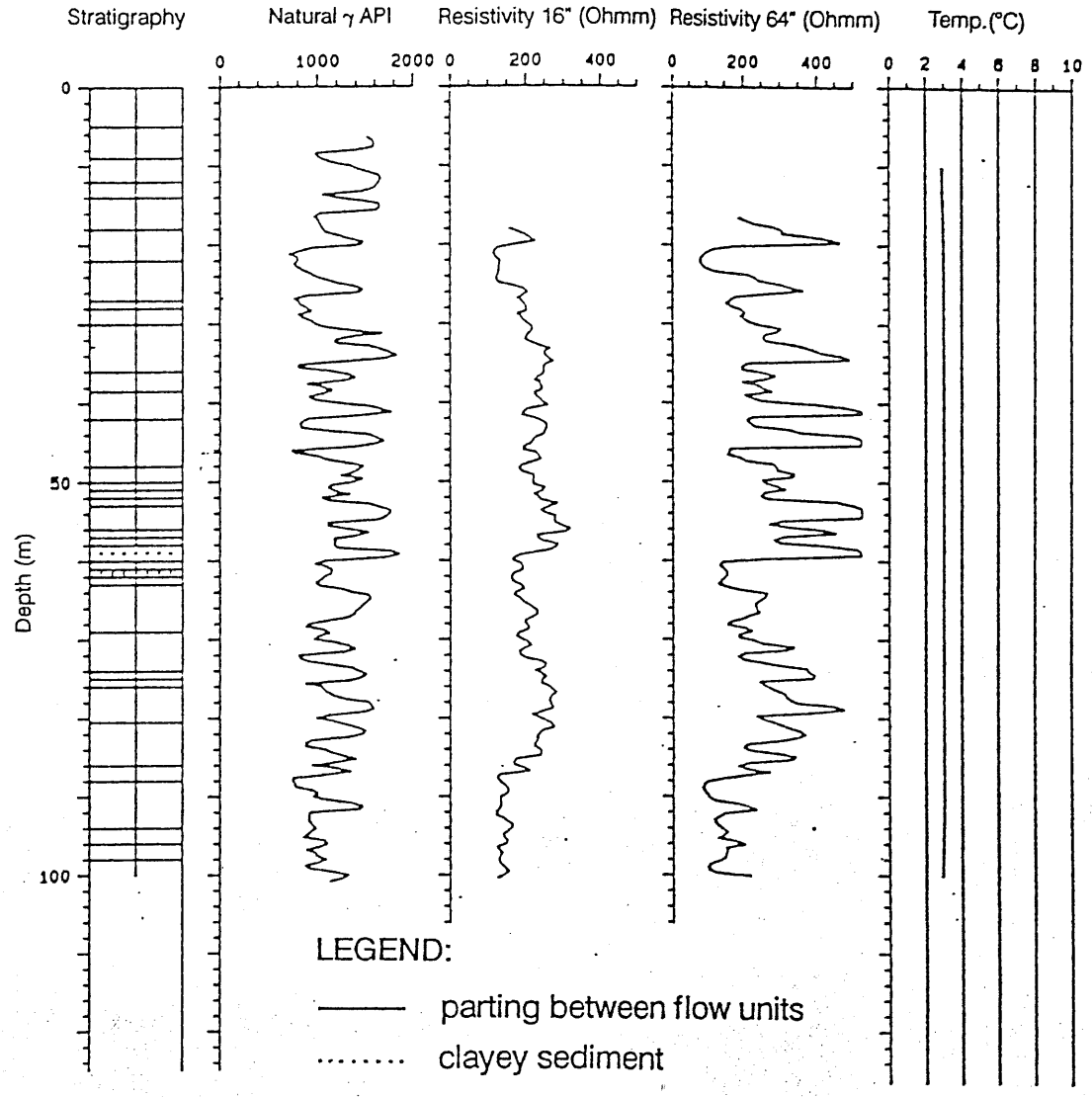
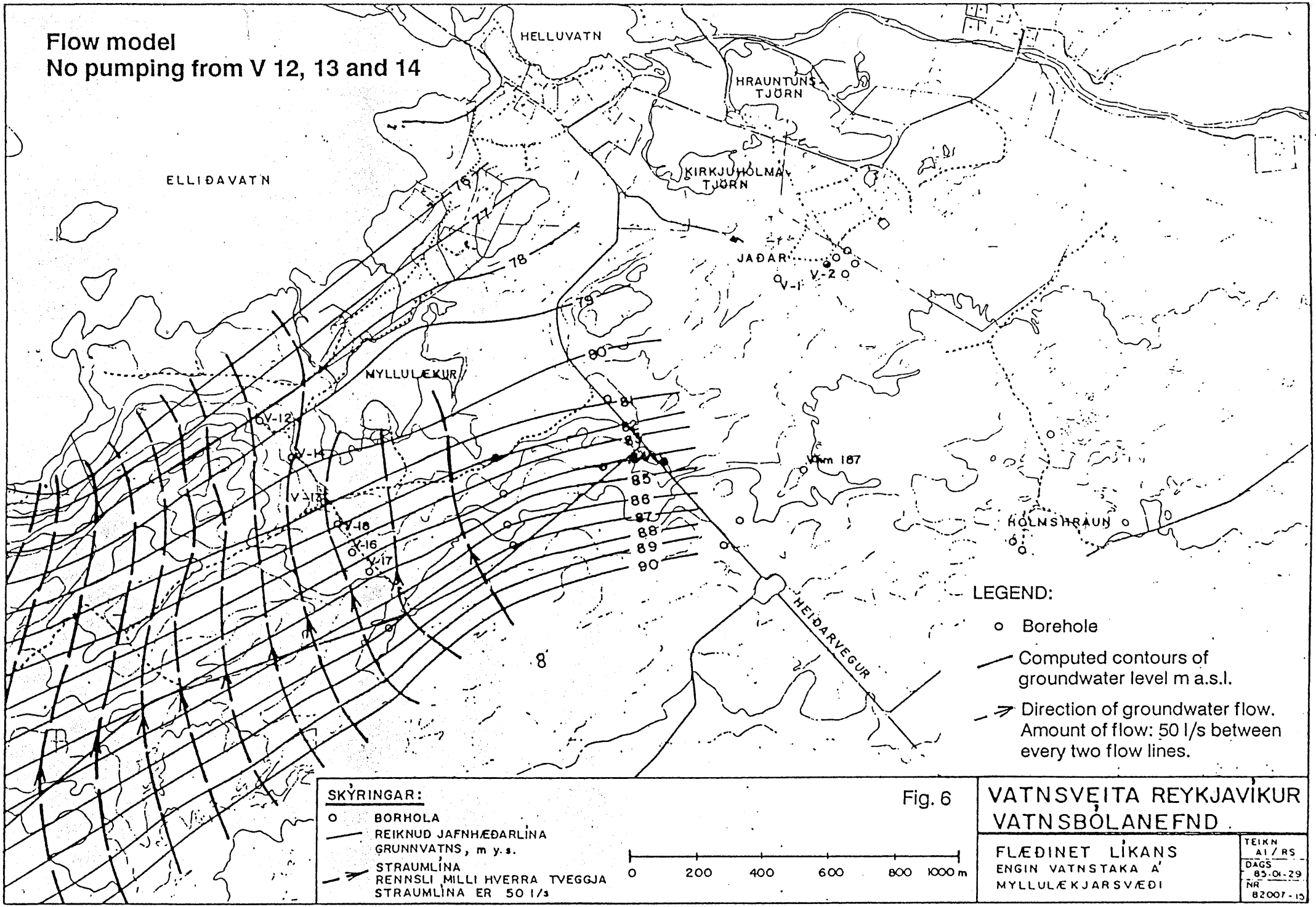
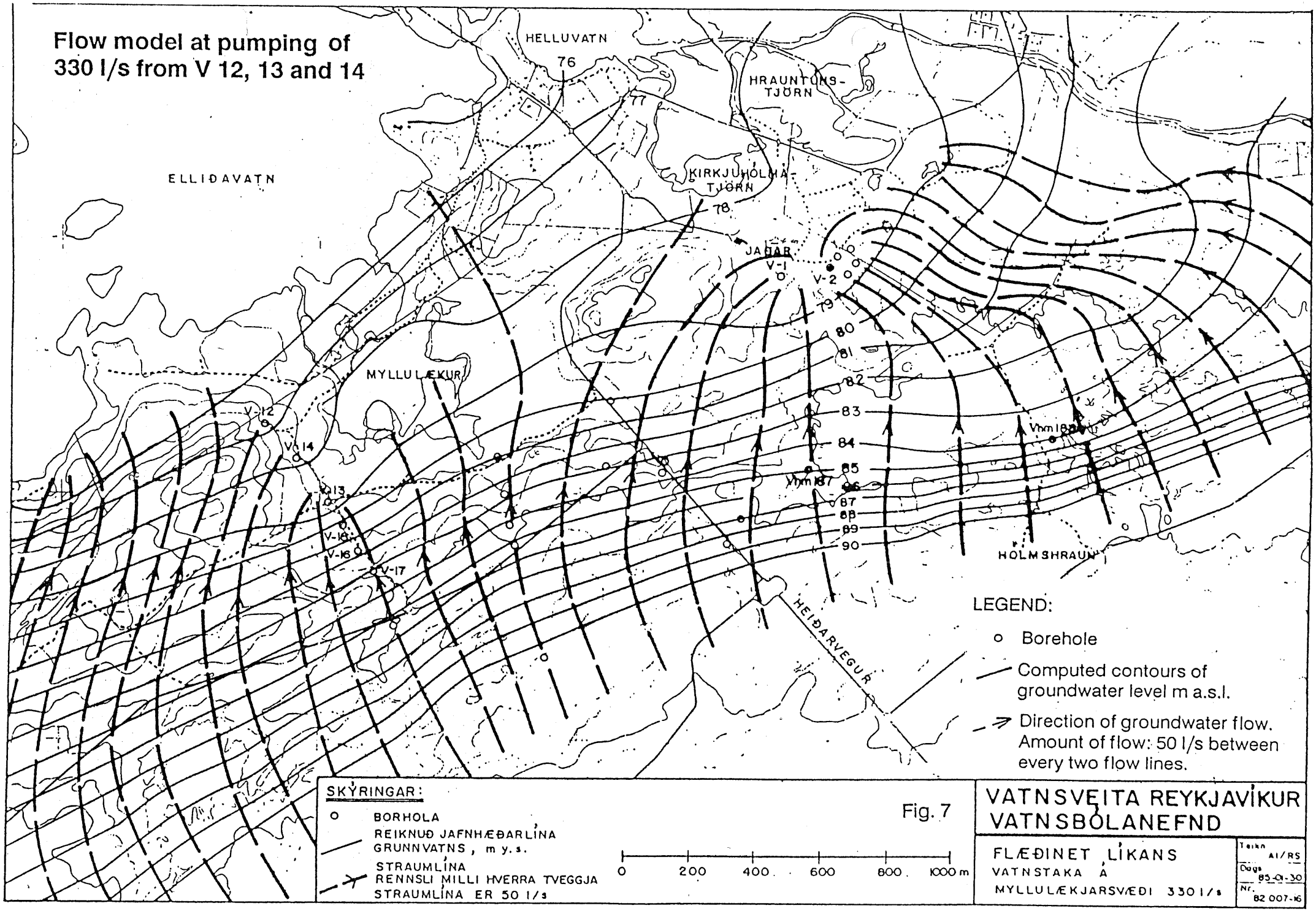
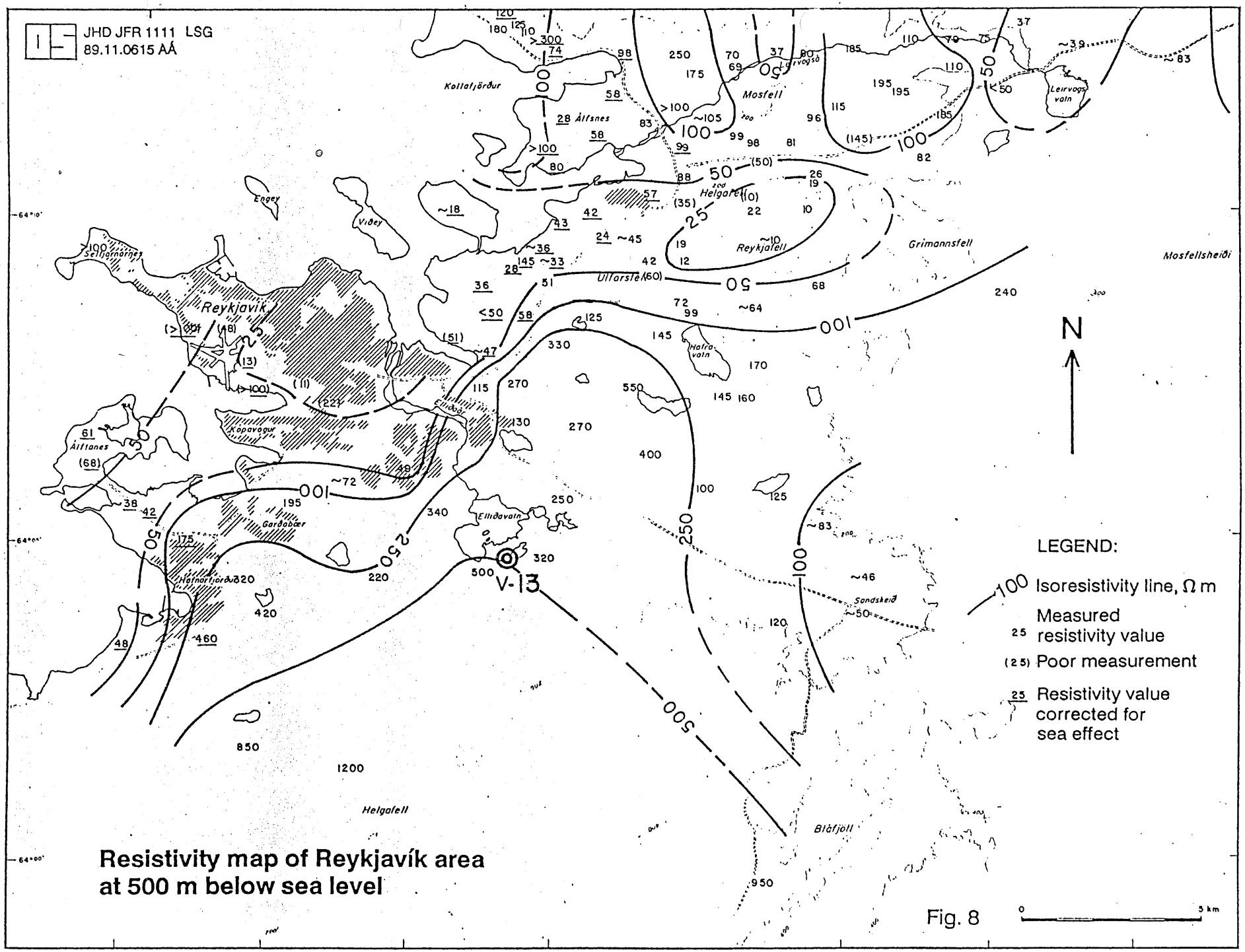


Fig. 5


Flow model
No pumping from V 12, 13 and 14
HELLUVATN
HRAUNTÚNS-TJÖRN
KIRKJUHÓLMA-TJÖRN
ELLIÐAVATN
JAÐAR
V-1
V-2
NYLLULÆKUR
V-12
V-14
V-15
V-16
V-17
V-18
Vm 187
HOLMSHRAUN
HEIÐARVEGUR
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
LEGEND:
Borehole
Computed contours of groundwater level m a.s.l.
Direction of groundwater flow. Amount of flow: 50 l/s between every two flow lines.
SKÝRINGAR:
BORHOLA
REIKNUD JAFNHÆÐARLÍNA GRUNNVATNS, m y.s.
STRAUMLÍNA
RENNSLI MILLI HVERRA TVEGGJA STRAUMLÍNA ER 50 l/s
0 200 400 600 800 1000 m
Fig. 6
VATNSVEITA REYKJAVÍKUR
VATNSBÓLANEFND
FLÆÐINET LÍKANS
ENGIN VATNSTAKA Á MYLLULÆKJARSVÆÐI
TEIKN AI / RS
DAGS 85-01-29
NR 82007-15


Flow model at pumping of
330 l/s from V 12, 13 and 14
HELLUVATN
76
77
HRAUNTÚNS-
TJÖRN
ELLIÐAVATN
KIRKJUHÓLMA-
TJÖRN
78
JAÐAR
V-1
V-2
79
80
81
82
83
84
85
86
87
88
89
90
MYLLULÆKUR
V-12
V-14
V-13
V-15
V-16
V-17
Vm 87
HOLMSHRAUN
HEIÐARVEGUR
LEGEND:
Borehole
Computed contours of groundwater level m a.s.l.
Direction of groundwater flow. Amount of flow: 50 l/s between every two flow lines.
SKÝRINGAR:
BORHOLA
REIKNUÐ JAFNHÆÐARLÍNA GRUNNVATNS, m y.s.
STRAUMLÍNA
RENNSLI MILLI HVERRA TVEGGJA STRAUMLÍNA ER 50 l/s
0
200
400
600
800
1000 m
Fig. 7
VATNSVEITA REYKJAVÍKUR
VATNSBÓLANEFND
FLÆÐINET LÍKANS
VATNSTAKA Á
MYLLULÆKJARSVÆÐI 330 l/s
Teikn. AI/RS
Dags. 85-01-30
Nr. 82 007-16


JHD JFR 1111 LSG
89.11.0615 ÁÁ
Kollafjörður
Mosfell
Leirvogsvatn
Engey
Viðey
Reykjavík
Selfjarnarnes
Álftanes
Kópavogur
Elliðaár
Elliðavatn
Garðabær
Hafnarfjörður
Ullarstell
Helgafell
Reykjafell
Grimannsfell
Mosfellsheiði
Hafravatn
Sandskeið
Bláfjöll
V-13
N
LEGEND:
100 Isoresistivity line, Ω m
25 Measured resistivity value
(25) Poor measurement
25 Resistivity value corrected for sea effect
Resistivity map of Reykjavík area at 500 m below sea level
Fig. 8
0
5 km

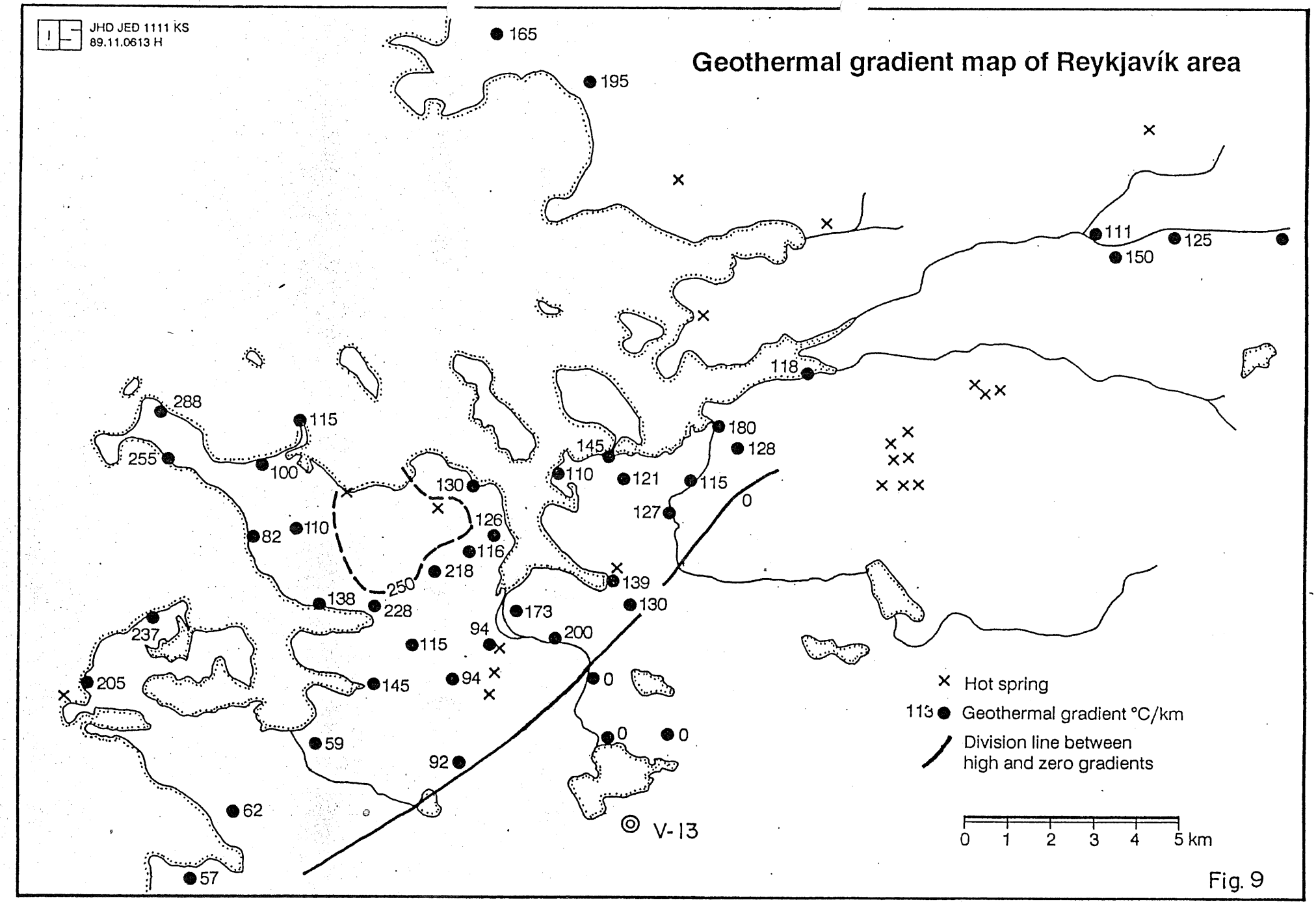

JHD JED 1111 KS
89.11.0613 H
Geothermal gradient map of Reykjavík area
165
195
111
125
150
118
288
115
255
100
130
126
82
110
116
218
250
138
228
237
115
205
145
94
59
92
62
57
180
128
145
110
121
115
127
0
139
130
173
200
94
0
0
0
V-13
Hot spring
113 Geothermal gradient °C/km
Division line between high and zero gradients
0 1 2 3 4 5 km

Fig. 9