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KRÍSUVÍK - TRÖLLADYNGJA

Potential steam production and transmission to Energy Park, Straumsvík

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OS-94012/JHD-07 B March 1994

ORKUSTOFNUN - National Energy Authority
Geothermal Division

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1. INTRODUCTION

The use of geothermal steam for use in industry is hampered by the great distance of most high-temperature geothermal areas in Iceland from areas of population. One geothermal area of promise is Krísuvík, which includes the Krísuvík and Trölladyngja fields, located some 20 km to the south of Hafnafjörður and about 13 km away from the Straumsvík harbour. Interest has been shown in utilizing geothermal steam there and Orkustofnun was requested to prepare a short report on the prospects. The present schemes are for the use of 120 kg/s of steam at 7 bar a. This report will describe the present state of exploration and recommend what needs to be done in order to confirm the presence of an exploitable resource. The recommendations call for four (4) exploration wells to be drilled, two (2) in each field. The wells are designed as production wells and can serve as such if productive. The two wells at Trölladyngja have been sited so no further preparatory work is needed there but additional surveys are required for Krísuvík before new wells can be sited there. The total cost of this phase is estimated to be USD 6 million (6.8 MECU). If successful these wells could produce up to 1/3 of the steam that is required. A decision to proceed with the project can be made upon the successful completion of this phase. A rough estimate of the steam cost is presented. It is based on information from other areas in Iceland, as no production data is available on Krísuvík - Trölladyngja, and on the cost of piping the steam to Straumsvík. The net steam cost is USD 3.40 (3.8 ECU) per tonne. The total steam field development cost (incl. the exploration wells) is expected to be USD 80 million (91 MECU) and that of the pipeline to Straumsvík USD 33 million (37 MECU), adding up to a total investment cost of USD 113 million (128 MECU).

2. RESEARCH AND EXPLORATION TO DATE

Krísuvík is one of 27 known high temperature geothermal areas in Iceland (Fig.1). It lies to the south of Hafnarfjörður on the Reykjanes peninsula. The geothermal area can be divided into three separate fields: Krísuvík, Trölladyngja and Sandfell. In this report two of these, Krísuvík and Trölladyngja (Fig. 2) will be considered.

Before 1950 between fifteen and twenty shallow wells were drilled in the Krísuvík area in the first phase of an exploration that was undertaken by Hafnarfjörður to investigate its potential for the generation of electricity. After a large modern drilling rig had been acquired three 329 - 1270 m deep wells were drilled in 1959 and one 300 m deep in 1964. The third exploration effort, which included surface reconnaissance, was carried out from 1970 - 1973. Six slim exploration wells, 816 - 943 m deep, were drilled to obtain information on geology and temperature, but the wells were not designed for output tests (Arnórsson et al. 1975). Since then some research has been carried out but not as a part of any large exploration effort. Arnórsson and Gunnlaugsson (1985) reported on the results of gas temperatures over the area and Arnórsson (1987) made a wide ranging study of gas temperatures and the condensation of steam during upflow. A report was prepared for a private company assessing the potential for the exploitation of Trölladyngja for an aquaculture complex (Orkustofnun 1986). Orkustofnun personnel collected a few steam samples and inspected the area in the autumn of 1990 and came to the conclusion that little change had taken place in surface activity since

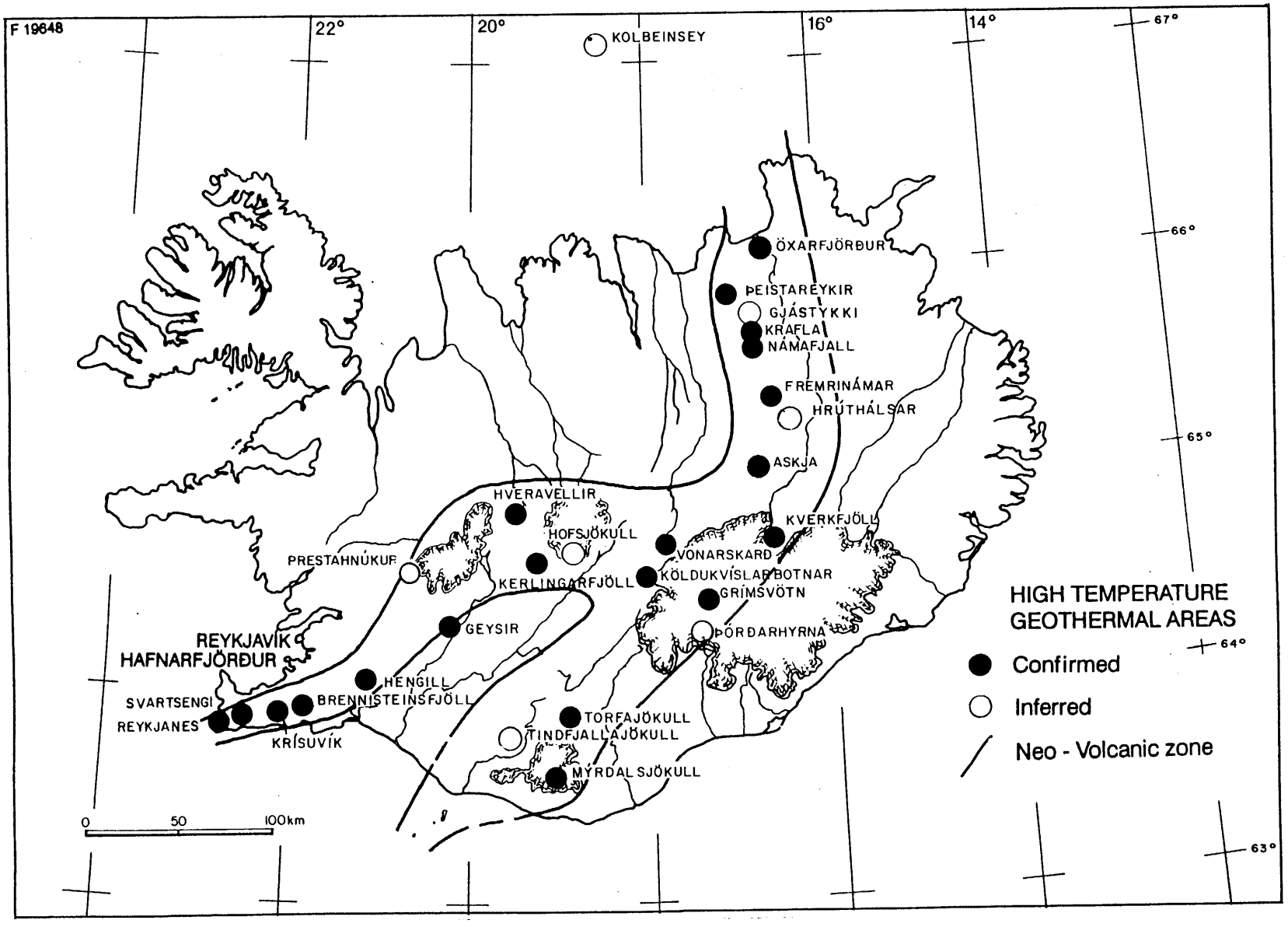


Figure 1. High - temperature geothermal areas in Iceland

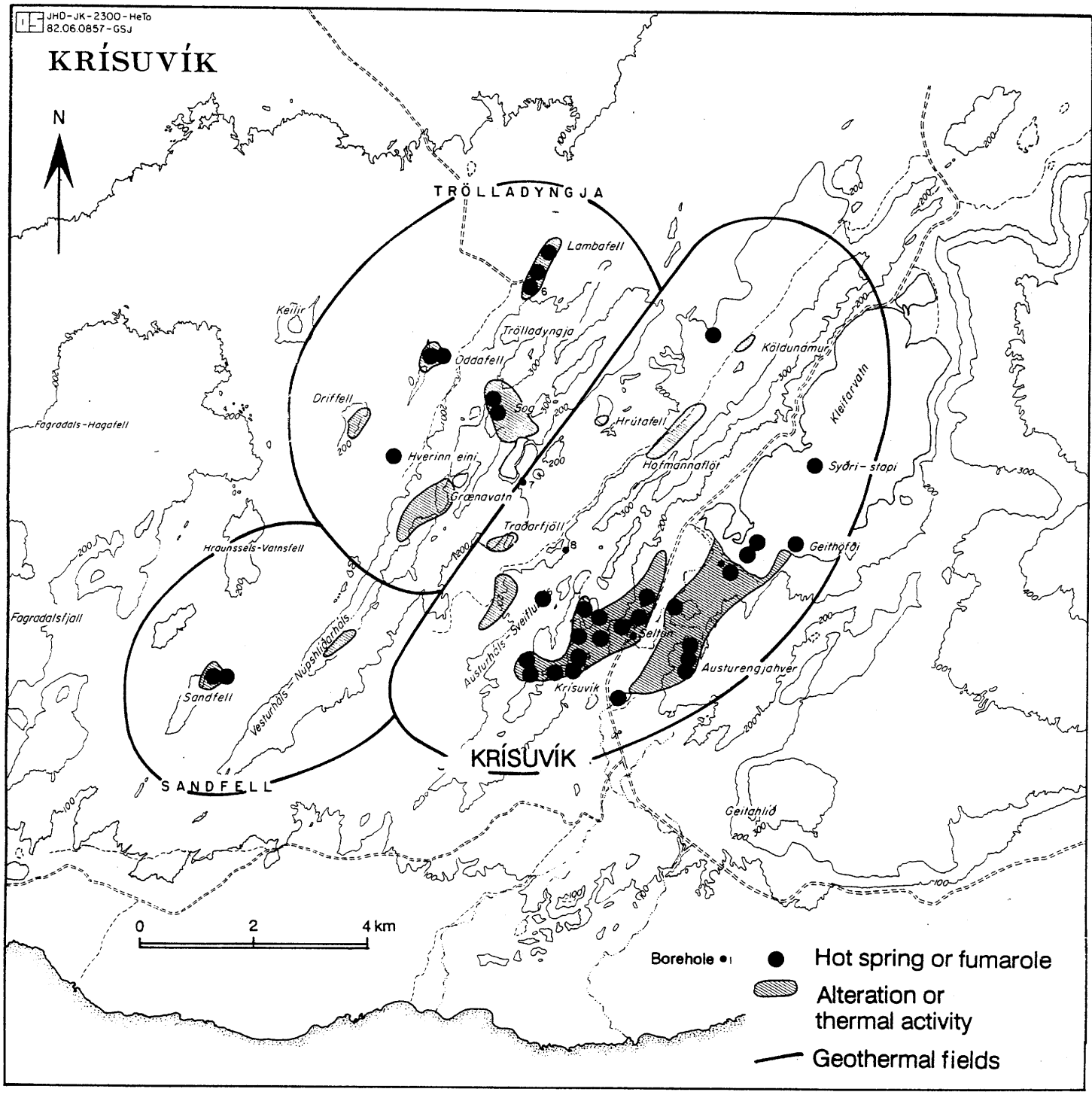


Figure 2. The Krísuvík geothermal fields. Boreholes and surface geothermal manifestations (Arnórsson et al. 1975, Jónsson 1978)

1983 (Ólafsson et al. 1991). Additional geological (Vargas 1992) and geophysical studies (Kanyanjua 1987, Mariita 1986) have been carried out on parts of the field by fellows of the United Nations University Geothermal Training Programme at Orkustofnun in recent years. A geological map by Jónsson (1978) has been published and Pálmason et al. (1985) have assessed the areal extent and heat content of the area.

3. THE EXTENT OF THE GEOTHERMAL AREA

The total surface area of the geothermal fields of Krísuvík-Trölladyngja-Sandfell is estimated to be approximately 60 km^2 (Pálmason et al. 1985), Trölladyngja covering 15 - 20 km^2 but Krísuvík 30 - 35 km^2. A resistivity survey carried out in 1970 - 1973 revealed a 25 km^2 area of < 10 Ωm resistivity, about the same as the areal extent over which geothermal surface manifestations are found. The surface manifestations are shown in Figs. 2 and 3. (Jónsson 1978, Arnórsson 1987).

4. TEMPERATURE

Several measurements have been made to find out what the reservoir temperature is in different parts of the fields. The most important results of temperature logging and chemical geothermometry are shown in Table 1. A significant feature of the temperature logging results is that inverted profiles were recorded for most of the wells with maximum temperatures at 300 - 600 m depth. This suggests that the main upflow zone has not yet been located.

Table 1. Krísuvík and Trölladyngja. Maximum temperatures obtained by logging and chemical geothermometry (°C)

Field	Max. logged temperature (Arnórsson et al. 1975)	Max. quartz temperature (Fournier and Potter 1982)	Max. Na/K-temperature (Arnórsson et al. 1983)	Max. gas temperature (Arnórsson 1987)
Krísuvík	220	243	221	296
Trölladyngja	262	261	261	285

5. FLOW

The only borehole at Krísuvík on which flow measurements are known to have been carried out is well No. 14 (230 m), drilled in the original series before 1950. Jónsson (1960) carried out extensive flow measurements from 1957 - 1959 using two widths of pipes (6" and 8") and two orifice diameters (110 and 150 mm). The flow through the two pipes was varied with the orifice in the 8" pipe. A summary of the steam flow results is shown in Table 2. These early measurements were made with primitive equipment and the results are not considered accurate.

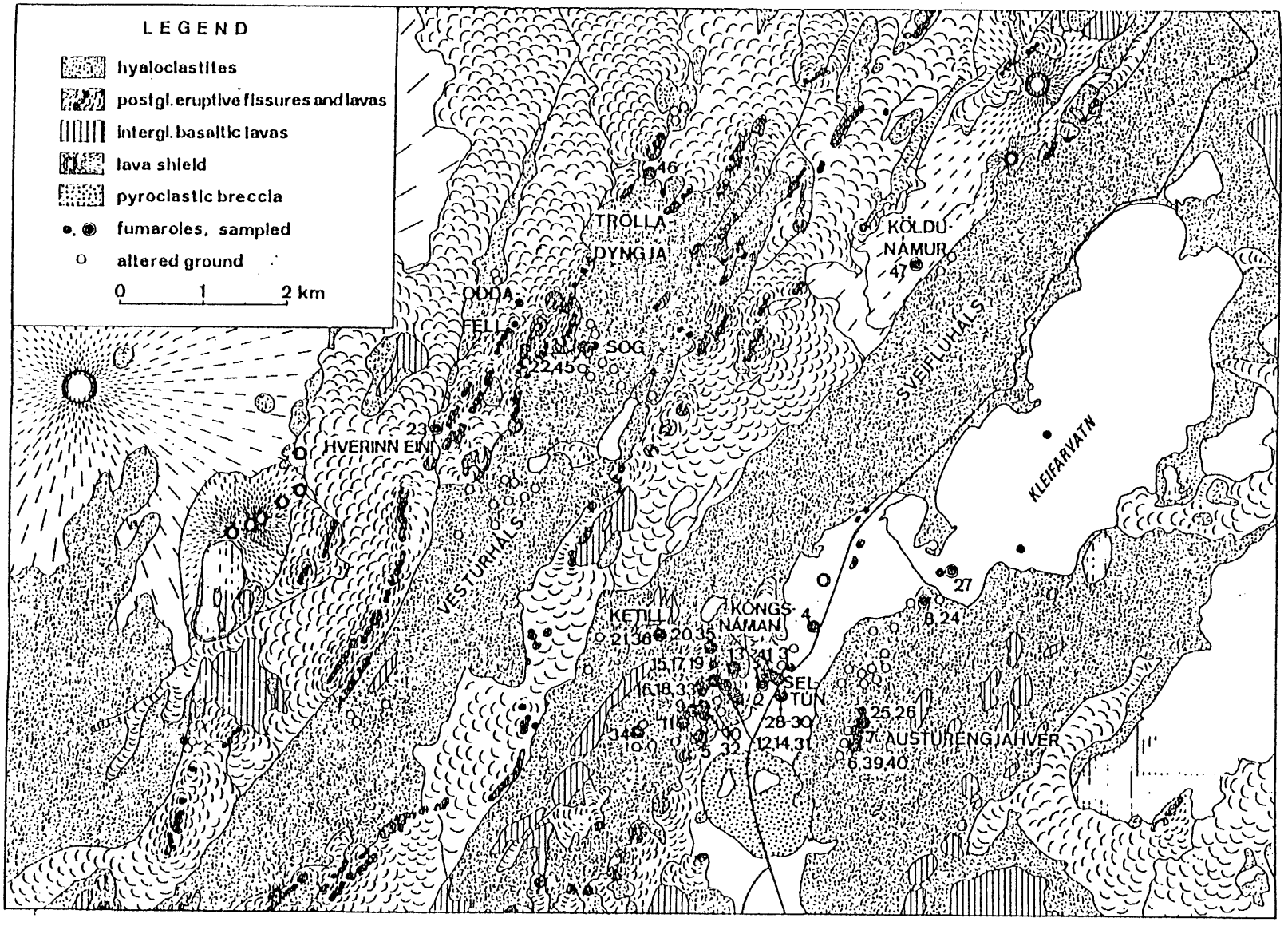


Figure 3. Krísuvík and Trölladyngja fields. Geological map (Jónsson 1978, Arnórsson 1987)

Table 2. Well 14, Krísuvík. Summary of results of steam flow measurements 1957 - 1959

Orifice diameter	Wellhead pressure, P_0, bar a	Steam flow kg/s
150 mm	2.1 - 3.6	6.7 - 10.4
110 mm	3.5 - 6.0	4.2 - 6.5

The steam fraction was fairly constant at 0.25 - 0.30 when the 150 mm orifice was used. If one phase flow is assumed this corresponds to an enthalpy of about 1130 kJ/kg or an inflow temperature of about 260°C. The steam fraction increased to about 0.5 when the 110 mm orifice was used and this suggests either that the liquid flow has been hampered or what is less likely that the well started tapping a two-phase reservoir only.

There were significant circulation losses during drilling in the 1970 - 1973 exploration wells (> 50 l/s, Arnórsson etal. 1975). The aquifers are thought to reside in fissures but a mean of 11% porosity was found in a study of several core samples. Thus there are strong indications that the area is potentially a productive one.

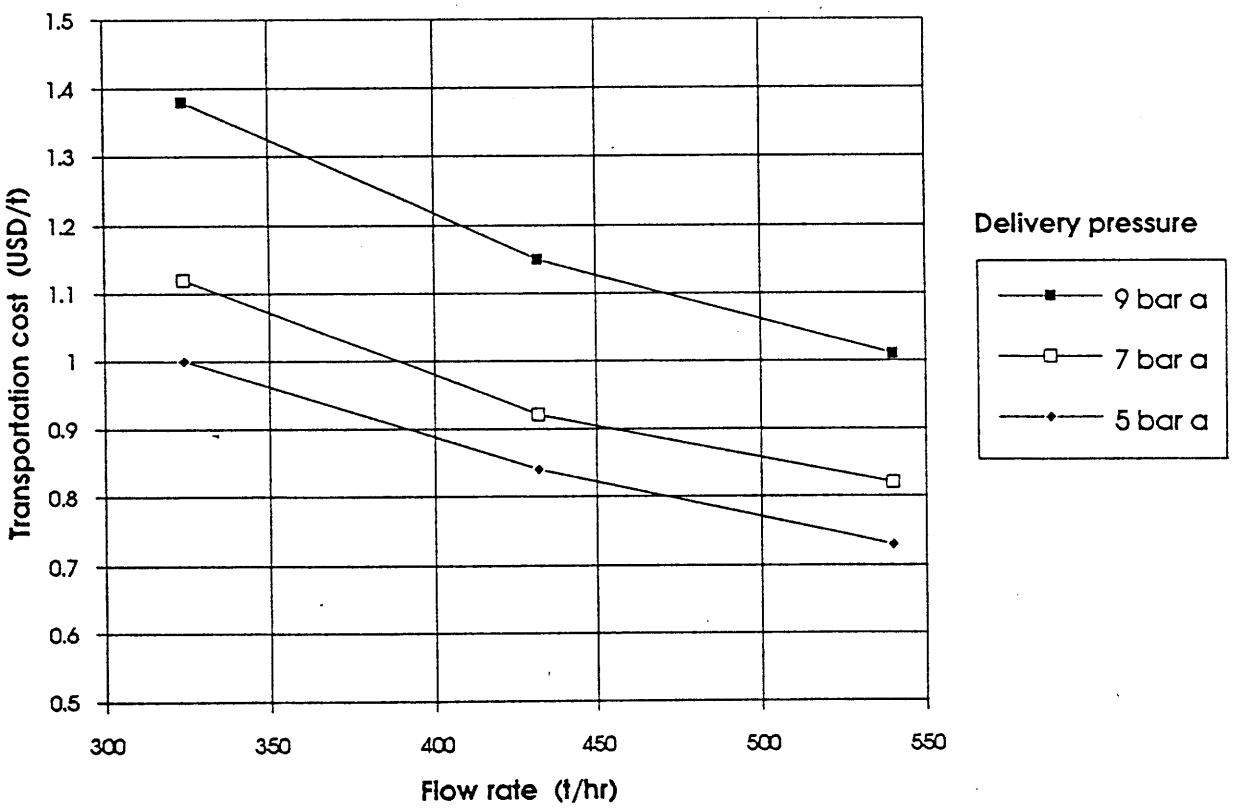


Figure 4. The effect of flow and delivery pressure on transportation cost

No reliable estimate of the reservoir potential can be given at this time. In the past Pálmason et al. (1985) estimated the electrical potential for the field as at least 300 MW_e for 50 years, i.e. 600 kg/s at 10 bar abs. This estimate is based on the volumetric method which assumes the reservoir to have a certain volume of set properties. This method has been found to give too optimistic estimates. The production characteristics need be confirmed by further exploration drilling and reservoir modelling to obtain a reliable estimate.

6. STEAM COST

Since so little data is available at this time for Krísuvík-Trölladyngja, estimates of steam production cost cannot be made for these particular fields. Steam cost estimates have, however, been made based on a generalized model (Thórhallsson and Ragnarsson 1992). This steam cost will be presented here and a rough cost estimate for transmitting the steam to Straumsvík, based on a steam flow of 120 kg/s and steam pressure requirements of the industrial consumer of 7 bar a. A digram showing the effect of other flow or pressure requirements on steam tranportation cost is apresented (Fig. 4).

Table 3. Production cost of geothermal steam (Not including exploration cost, general and administration, profit, land acquisition, royalties or taxes)

	Basis for Cost Calc.	Cost Estimate
Well cost (US$/m)	1,000	
Average well depth (m)	1,800	
Number of production wells	3	
Number of reinjection wells	2	
Unsuccessful wells	2	
Total drilling cost (US$)		12,600,000
Surface installations:		
Housing, infrastructure (US$)	2,500,000	
Separators, pipelines (US$)	3,500,000	
Total surface installation		6,000,000
Total investment (US$)		18,600,000
COST ANALYSIS		
Lifetime (y)	20	
Interest (%)	6.0	
Annuity (US$)		1,621,632
Operation and maint. (2.5%)		465,000
Total annual cost (US$)		2,086,632
STEAM COST (US$/t)	2.48	

Thórhallsson (1991) reported 11.2 kg/s at 7 bar abs. as the average steam flow from high temperature wells in Iceland corresponding to the production of 5 MW_e of electricity, or about 10 kg/s at 10 bar abs., assuming that the temperature of the geothermal system is 260°C. Stefánsson (1992) states that the average steam flow from geothermal wells worldwide is 4.17 MW_e corresponding to 8.3 kg/s of steam at 10 bar abs. pressure.

Estimates of geothermal steam cost were presented by Thórhallsson and Ragnarsson (1992). The net cost of the steam that can be piped to the final consumer was found to be 2.48 USD/tonne (2.80 ECU/tonne) (Table 3).

A study was made by Orkustofnun (1993) on the cost of steam transmission from the geothermal fields of Krísuvík and Trölladyngja to Straumsvík on the coast employing the projected pipe location shown in Fig. 5. The results based on the following assumptions are presented in Table 4.

Steam production	3.46 million tonne/year
Running time	8000 hr/year
Maximum flow rate	120 kg/s
Steam delivery temperature	165°C
Steam delivery pressure	7 bar a
Well life	25 years
Interest rate	6%
Operation and maint. cost	2%/year

Table 4. Cost estimate for steam transmission from the Krísuvík and Trölladyngja fields to Straumsvík harbour.

Steam production: Krísuvík and Trölladyngja Steam utilization: Straumsvík							
	Pipe length km	Pipe diameter mm	Pipe inlet flow rate kg/s	Pipe outlet flow rate kg/s	Pipe inlet pressure bar a	Pipe outlet pressure bar a	Pipe cost estimate mill. USD
Krísuvík branch	8.2	1000	61.5	60.5	9.3	8.5	11.6
Trölladyngja branch	3.2	900	60.8	60.5	9.0	8.5	4.1
Pipeline to Straumsvík	9.5	1200	121.0	120.0	8.5	7.0	16.8
Total	20.9						32.5

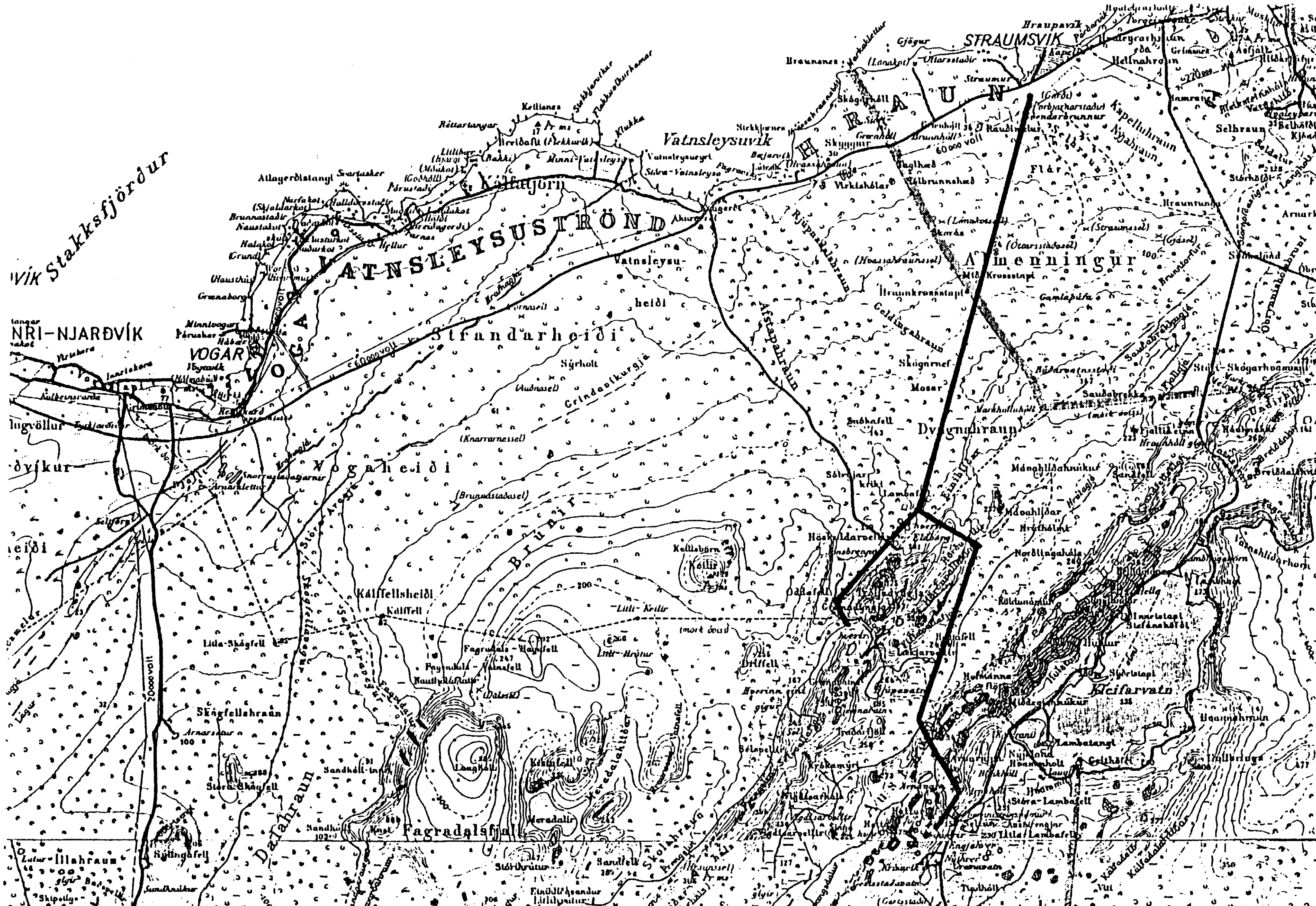


Figure 5. Location of proposed pipeline from Krísuvík and Trölladyngja to Straumsvík

Cost analysis:

Steam production:	Krísuvík and Trölladyngja
Utilization:	Straumsvík
Capital cost of transmission pipelines:	32.5 million USD (36.7 MECU)
Steam transportation cost:	0.92 USD/t (1.04 ECU/t)

The cost of steam delivered to Straumsvík is thus USD 2.48 + 0.92 = 3.40 per tonne (3.80 ECU/tonne) based on the above assumptions.

Fig. 4 shows the transportation cost for delivery pressures and steam flows other than that calculated above but steam production is relatively unaffected.

7. FUTURE EXPLORATION

Two wells have been sited at Trölladyngja and can be drilled without much further work. A resistivity profile at 300 m depth below sea level with the locations of the sited wells is shown in Fig. 6. There is no freshwater available for drilling fluid and a well has to be drilled for that purpose. A typical casing profile for a 1700 m deep hole is shown in Fig. 7. The estimated cost for one high-temperature geothermal well, 1700 m deep, is:

		Million ISK
1.	Drill site preparation and road	3.9
2.	Pre-drilling to 50 m (cable tool rig)	3.3
3.	Rig and equipment transport roundtrip. Rig-up and tear-down	7.2
4.	Material transport	1.0
5.	Rig rental and crew	29.0
6.	Materials: casings, cement, mud, drill bits, wellhead	24.3
7.	Well logging services during drilling	2.6
8.	Engineering, supervision and geological services (8%)	5.7
9.	Contingencies (15%)	11.6
10.	Value added tax (24.5%)	21.7
	Total estimated cost: (Million ISK)	110.3

Additional geophysical measurements have to be made at Krísuvík in order to site the two exploration wells. The actual cost of drilling is in accordance with the information in Table 3. The total acost of drilling the four (4) wells, including the cost of additional surveys and supervision of the project is thus roughly estimated to be 440 million ISK or USD 6 million.

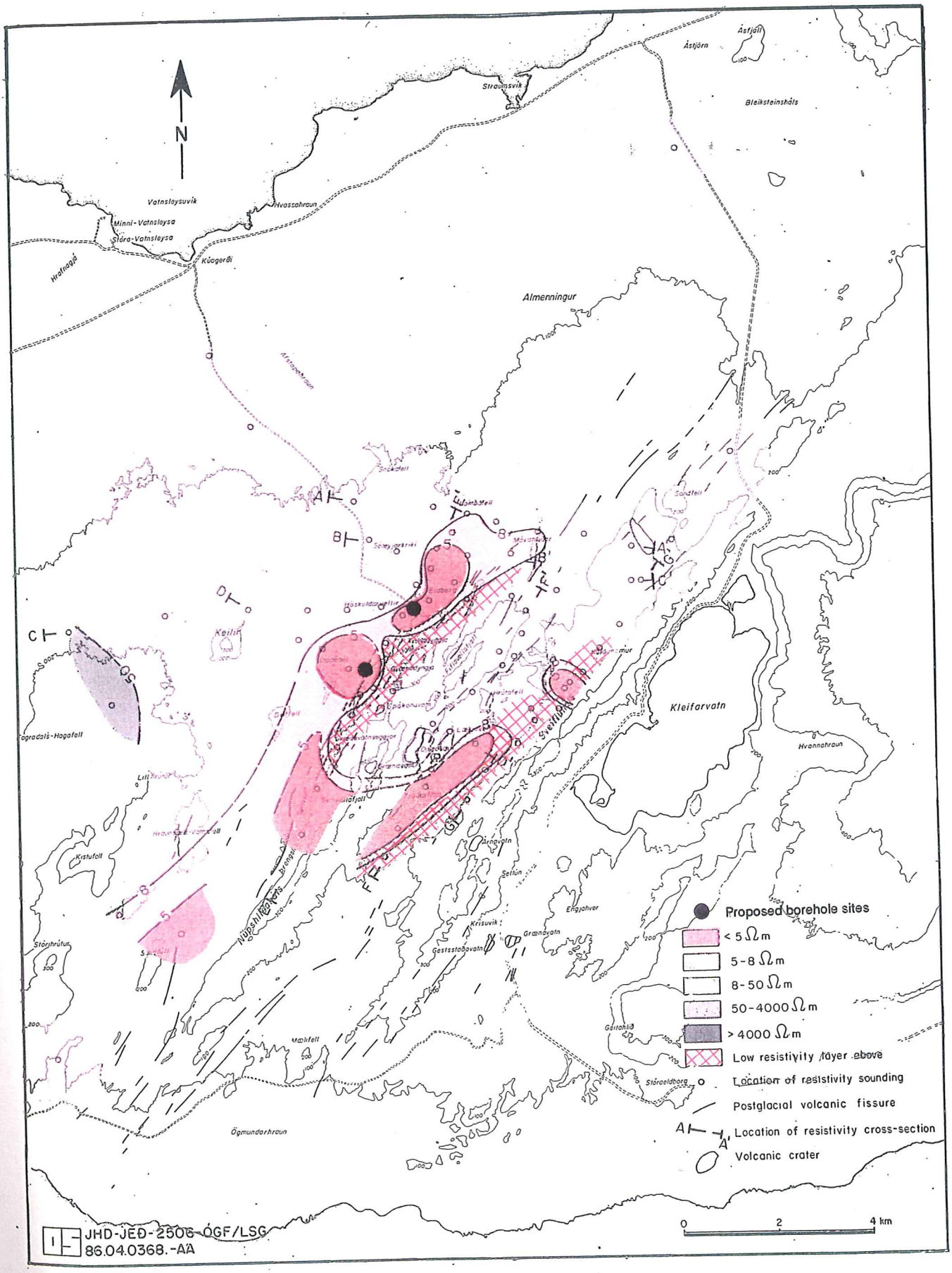
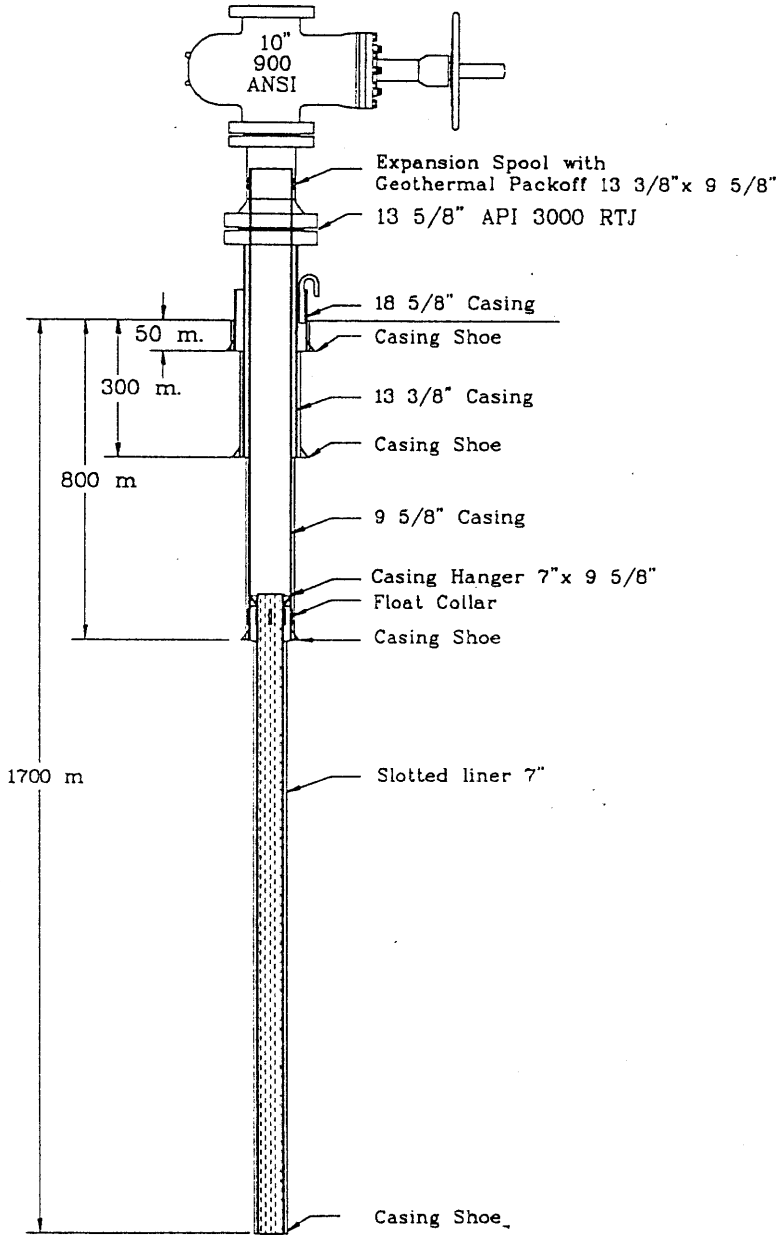


Figure 6. The resistivity of the Trölladyngja area at 300 m depth below sea level and sites for proposed geothermal wells



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	ORKUSTOFNUN Grensásvegi 9 108 Reykjavik Telf. 91-696000		Krísuvik - Trölladyngja Casing program and Wellhead of a 1700 m Geothermal Well for cost estimate	
Mkv.:	Hannað: SÞ / SLJ	Dags.: 01.03.1994	Teikning nr.: JHD-VFR-2500-SLJ 94.03.0093.ACAD.T	Blað nr.:

Figure 7. Casing profile for a 1700 m deep geothermal well

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