ORKUSTOFNUN

NATIONAL ENERGY AUTHORITY

HÚSATÓFTIR

HYDROLOGICAL INVESTIGATIONS
Prefeasibility report

Orkustofnun
Vatnaskil Consulting Engineers
Prepared for ELDI LTD.

OS-86006/JHD-01 B January 1986

ORKUSTOFNUN
Grensásvegi 9, 108 Reykjavík

Sverrir Þórhallsson

Bessi Aðalsteinsson
Freysteinn Sigurðsson
Hrefna Kristmannsdóttir
Kristján H. Sigurðsson
Sæþór L. Jónsson

Verkfræðistofan Vatnaskil hf.

HÚSATÓFTIR

HYDROLOGICAL INVESTIGATIONS
Prefeasibility report

Orkustofnun
Vatnaskil Consulting Engineers
Prepared for ELDI LTD.

OS-86006/JHD-01 B January 1986

CONTENTS

SUMMARY

This report describes the findings of the scientific investigations carried out for ELDI LTD. on the water supply for the aquaculture complex at Husatoftir. The investigations were carried out according to the proposal made by the National Energy Authority (Orkustofnun) and the Consulting Engineering firm Vatnaskil Ltd dated Oct 30, 1984, entitled: "Investigation on the water for the Aquaculture Complex at Husatoftir".

As part of this work three (3) observation wells were drilled. The locations of the wells and sites investigated are shown on fig. 1-3 (Location Map), production wells are numbered 3A1 to 3A5 and H-8.

Pumping tests were made, pumping from three (3) wells simultaneously with the same pump, and the suction pipes located at 7 m, 17 m and 27 m depths respectively. The seawater produced from 27 m was found to have extremely high concentration of iron (6-7 mg/kg) , and thus unsuitable for the intended purpose. The transition zone between freshwater and seawater disappeared after about one day of pumping from 17 m and 27 m depth.

This report focuses on the findings of the numerous measurements and observations made over a period of one month.

The main conslusions of the scientific investigations are as follows:

1) At Húsatóftir 100 l/s freshwater can be produced from five (5) wells spaced 5 m apart within the production area, without danger of seawater intrusion. The freshwater temperature that can be expected under these conditions is 9-10°C.
2) The seawater is unsuitable for the intended use because of iron contamination.
3) The transition zone cannot be used as a source of saline water because of its limited capacity.

1 HYDROGEOLOGY

The Reykjanes peninsula is of volcanic origin, the westernmost part is flat and largely covered by postglacial, basaltic lavas. Some hyaloclastite ridges or rows of hills run in SW-NE direction across the peninsula. The lava sequences between the ridges can reach a considerable thickness. The lavas are open and highly permeable, especially along the scoriaceous contacts and the belting planes in the lavas from the shield volcanoes. This structure causes a strong horizontal-vertical anisotropy. The numerous tectonic fissures running SW - NE cause a strong anisotropy in that direction. At Húsatóftir the lavas have flowed out into the sea. The permeability of the front of the lavas has probably been lessened by sediments and marine vegetation, that has been pressed into pores and fissures by the very strong surf at the coast.

The bedrock at Húsatóftir is thus highly permeable, with a SW - NE anisotropy as well as a very strong horizontal-vertical anisotropy. The latter one plays an important role in the layering of the groundwater. This can be seen clearly in the well-logs.

2 WELL LOGS, TEMPERATURE AND RESISTIVITY

In the westernmost part of Reykjanes peninsula the freshwater is floating on seawater. The thickness of the freshwater layer is greatest near the middle the peninsula, where it is near to 50 m. Near the coast in the Húsatóftir area it is about 20 m or somewhat less. Under natural conditions the fresh water part of it ($\leq$ 2 o/oo salinity) seems to be 16-17 m thick. Between it and the seawater is a transition layer (2-10 o/oo salinity), 4-7 m thick (Fig. 4).

The quality of the freshwater is influenced by the geothermal field at Svartsengi (fig. 5). The temperature of the freshwater at Húsatoftir is unusually high, 9-10°C. Similar temperatures are found in Grindavík. Farther east and west of Húsatóftir the temperatures are near to 7°C. At Húsatóftir the uppermost part of the seawater has a temperature of 11°C, decreasing to 9-10°C over a distance of 1 km to east and west, respectively. Below 70 m depth at Húsatóftir the temperature decreases to 9-9.5°C at 85-90 m depth. The relatively hot uppermost part of the seawater there may be indicative of the off-flow from the Svartsengi geothermal field.

3 CHEMICAL ANALYSES OF THE WATER

Table 1 contains all data of total chemical analyses of water from wells at Húsatóftir. Total chemical analysis means that all the main dissolved solids have been analysed plus pH and CO2. In a few analyses pH and CO2 are not analysed as they have not been sampled in an airtight tube (due to cost saving efforts by the contractors). Iron has not been analysed in all samples either since special on site treatment of the samples is required (filtering and acidifying). Oxygen has to be measured on the spot and when the sample is taken by someone other than the chemist it has accordingly not been measured.

For comparison the chemical analysis of sea-water just off shore nearby the village Grindavík is also given in table 1. The first columns of the table show the composition of water from three (3) different depths in drillhole 3A3 before the pumping tests. Then comes the composition of water from five (5) different depth levels in drillhole number 8. The freshwater layer has a chloride content of 500-900 mg/kg but at wellbottom the highest chloride concentration is 14000-15000 mg/kg. Six total analyses of water during the pumping test of well 3A3 are in table 1 and numerous analyses of 2-3 components in table 2. In table 2 are compiled the chemical analyses (with 2-3 components) of samples taken during pump tests at three (3) different depth levels.

An abrupt increase in salinity occurs in the pumping test at 7 m depth. During the pumptest at 17 m depth the transition zone vanishes as the freshwater is sucked down as expressed by the decrease in chloride concentration (table 2). A considerable concentration of iron is found in the saline water and precipitation of iron compounds occurs in stationary water in the wells. Such precipitation occurs also by surface aeration of the saline iron-rich groundwater.

Water pumped from the lower part of well 8 has almost the same salinity as seawater just off shore, but has an extremely high concentration of iron (6-7 mg/kg) as compared to seawater. Water from the well on the golf course and the one at the beach has very similar composition as in well 8.

As only a part of the samples in table 2 were filtrated and acidified when sampled the iron concentrations are not directly comparable. In the samples of stationary water from well 3A3 reported in table 1 the water was filtrated and acidified several hours after sampling. No dissolved iron was measured in the water but considerable quantities of rusty flakes were filtrated from the water.

The freshwater does not contain excessive iron, but the saline water is highly contaminated due to processes effected by the geothermal effluent water.

By mixing of the oxygen-rich fresh water and the iron-rich and oxygen devoid saline water in the wells, precipitation of rust occurs.

The groundwater origin of the saline water is also demonstrated by the high silica concentration and the concentration of alkali and alkali earth metals as compared to seawater.

4 TIDAL RESPONSE

Tidal response has been recorded in several wells and fissures in the Húsatóftir area. Table 3 gives diffusivity values, T/S, obtained from amplitude ratio and timelag respectively. Location of the observation sites is shown on figs. 1, 2 and 3.

Table 3 Results from tidal analyses

Observation site	Amplitude ratio %	Timelag hours	T/S from amplit. ratio m2/s	T/S from timelag m2/s
3A5	18.0	2.12	6	15
2A2	18.3	1.82	4	13
1A1	18.5	1.73	4	14
H-9	18.0	1.85	4	13
HT-42	35.0	0.85	1	4
HT-43	8.1	2.20	6	27
HT-41	18.0	2.13	4	10
Baðstofugja	3.0			35
Miðgja	6.0	4.61	141	202
Hrafnagja	8.0	4.38	104	138

Figure 6 and 7 show examples of the tidal response

This result indicates tighter formation at the coast than further inland. Amplitude ratio of around 18 % is low compared to other areas close to the shore on the Reykjanes peninsula.

If we assume the storage value, S, to be about 5 %, the transmissivity, T, would be around 0.5 m2/s.

Calculations from tidal response measurements give an equivalent thickness of the freshwater lens of about 20 m, which is in accordance with observed well-logs, see chapter 2.

5 WELL TESTING

In order to investigate the supply of fresh and saline water from wells in the so-called east area, two (2) pump tests were carried out, one from the upper part of the freshwater layer and another from 17 m depth. A suction pump was used to pump from three (3) wells and the drawdown was measured in other three (3) wells, see figure 2. With the help of a datalogger flowrate, waterlevel, air and water temperature were measured and stored directly in a computer.

5.1 Pumping test from the freshwater layer

Pumping test from the freshwater layer was carried out during the period January 11-15, 1985. Pumping rate was 62 l/s and observed drawdown 3 cm in wells 3A5 and 3A2. No drawdown was observed in well 1A2 situated some 60 m away. Fig. 8 shows how the waterlevel varied with time. Average temperature of the pumped water was fairly constant about 9.5°C.

Calculations give values of transmissivity, T, in the range 0.6-0.8 m2/s which is in good agreement with the estimation of transmissivity from tidal response. The permeability is 0.032-0.042 m/s. Results from calculations are that 20 l/s can be pumped from a single well of 4" diameter penetrating 10 m into the freshwater layer. The target rate of 100 l/s of freshwater can thus be pumped from 5 such wells, provided they are spaced 5 m apart to avoid danger of seawater intrusion.

5.2 Pumping test from 17 m depth (the transition zone)

Pumping test from 17 m depth was carried out during the period January 17-22, 1985. The aim of the pumping test was to see if it was possible to pump ironfree water from the transition zone, which proved to be impossible. Calculated density profiles from well-logs are shown for well 3A2 on figure 7. The transition zone is seen to have disappeared after 1 day of pumping. The iron content of the pumped water was also much too high as can be seen from the tables in chapter 3.

It was also tried to pump water from the 27 m depth zone , but the result was the same as when pumping from the 17 m depth, as regards the iron content of the water, and the disappearance of the transition zone.

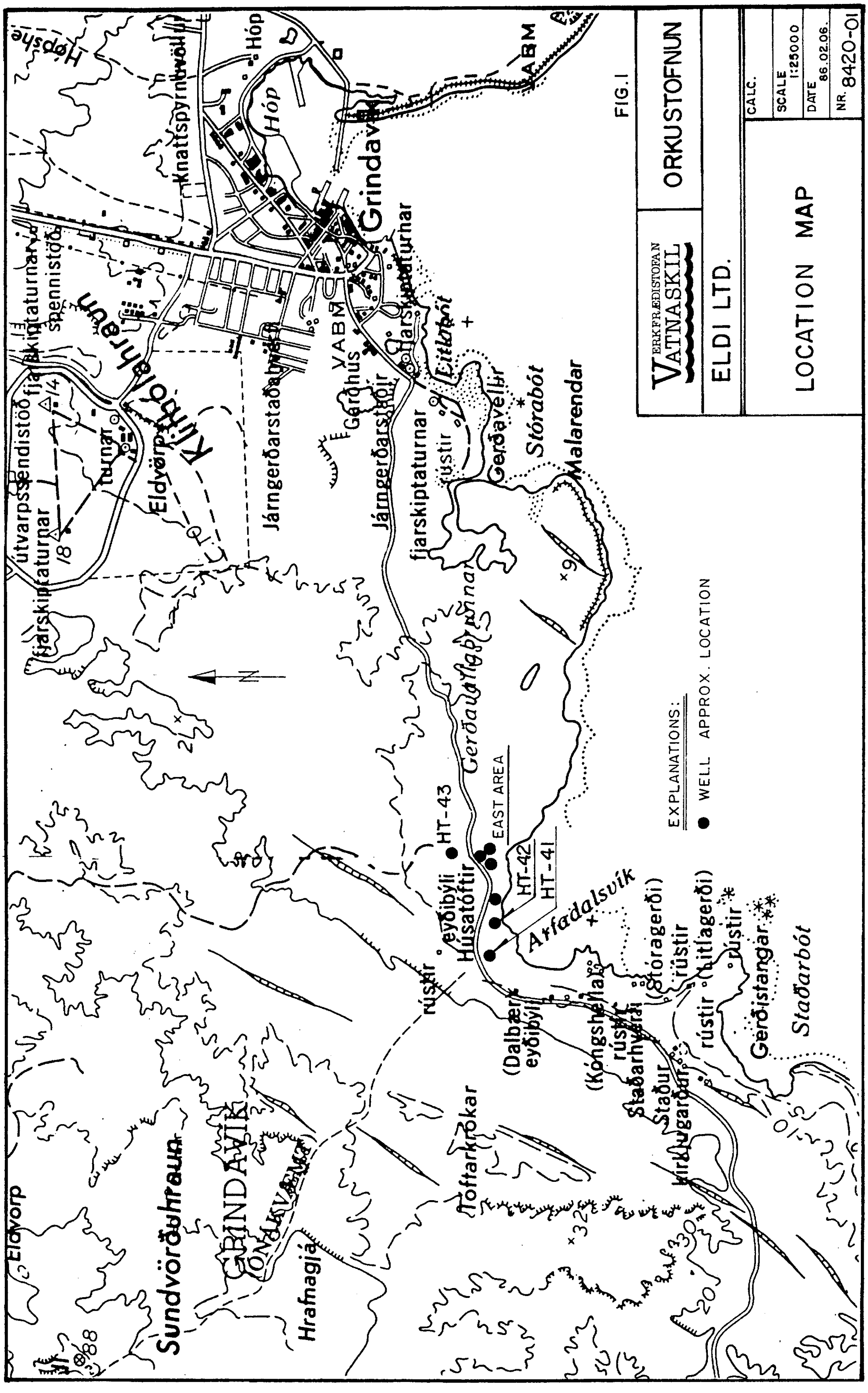
Table 1 Chemical analysis of water from Húsatóftir, Grindavík
(Concentration in mg/kg)

Place	Sea-water outside Grindavík	Húsat. Well 3A3 7 m d.	Húsat. Well 3A3 17 m d.	Húsat. Well 3A3 28 m d.	Húsat. Well 8 4 m d.	Húsat. Well 8 16,5 m d.	Húsat. Well 8 30 m d.	Húsat. Well 8 60 m d.	Húsat. Well 8 80 m d.	Húsat. Pumpt. 1 7 m d.	Húsat. Pumpt. 2 7 m d.	Húsat. Pumpt. 3 17 m d.	Húsat. Pumpt. 4 27 m d.	Húsat. Pumpt. 5 27 m d.	Húsat. Pumpt. 6 27 m d.	Húsat. Well 3A3 22 m d.	Húsat. Well 8 80 m d.	Húsat. HT-41 35 m d.	Húsat. HT-42 38 m d.	Húsat. Well 3A3 22 m d.	Húsat. Well 8 80 m d.
Date	25.11.84	18.12.84	18.12.84	18.12.84	18.12.84	18.12.84	18.12.84	18.12.84	18.12.84	11.01.85	16.01.85	19.01.85	25.01.85	31.01.85	02.02.85	25.02.85	25.02.85	01.03.85	01.03.85	01.03.85	01.03.85
Number	0102	0112	0113	0114	0115	0116	0117	0118	0119	0011	0013	0019	0021	0024	0025	0038	0039	0098	0099	0100	0101
t°C		9.8	10,4	10.4	7.9	8.9	10.2		9.8		9.8			10.1	10.2			9.0	9.4		
pH/°C	7.96/21.5	7.27/21.2	7.20/21.2	7.30/21.2	7.40/21.2	7.20/21.2	7.30/21.2		7.47/21.2	7.15/22	7.15/22	7.25/20.8	7.23/21	7.32/20.5	7.34/20.5						
Ohmm/°C	0.22/21.0	3.48/25.0	2.29/20.8	0.29/20.8	5.56/20.8	1.31/20.8	0.36/20.8	0.40/20.8	0.26/20.8	1.85/25	1.95/25	1.17/25	0.59/25	0.36/21.8	0.31/21.8			0.56/25	0.60/25	0.79/25	0.60/25
SiO2	1.5	19.6	21.3	40.6	17.1	23.3	35.7	31.4	33.6	21.7	21.4	23.7	30.3	32.8	35.1			38.0	35.3	25.5	42.2
Na	9717	467.6	749.2	7500	275.6	1425.6	6031.1	5175.9	8857.4	925.8	879.8	1602.0	3908.4	5559.6	6430.7	2208.3	9594.0	8992.5	9361.6	2121.0	9289.0
K	415.4	30.4	49.0	298.1	14.3	77.9	247.0	218.3	349.3	57.7	53.9	85.3	173.4	235.5	265.6	103.8	360.5	338.4	356.7	105.4	359.8
Ca	380.8	53.1	80.7	486.3	32.5	144.9	420.1	361.8	541.2	100.4	95.2	149.0	301.2	405.7	428.3	159.8	588.4	611.9	608.0	179.5	623.7
Mg	1222.8	43.8	69.0	898.0	30.4	140.0	710.7	611.2	1065.8	89.9	83.9	171.5	454.1	663.7	782.0	246.5	1184.5	1109.8	1160.6	236.5	1155.2
CO2	103.0	31.5	37.4	275.1	27.1	60.1	270.3		249.2	36.5	37.0	55.2	141.4	159.9	177.9						
SO4	2530.6	77.0	126.8	2032.6	49.8	269.1	1408.6	1212.7	2126.9	159.6	147.2	320.5	901.3	1324.2	1537.8	467.1	2300.1	2177.6	2281.2	445.8	2288.3
Cl	18037.0	853.2	1407.8	14271.0	515.3	2629.4	10867.0	9406.0	15661.0	1749.4	1671.8	3026.0	7320.3	10536.5	12221.8	4116.4	17971.0	17139.0	17768.0	4133.0	18029.0
F	0.57	0.06	0.06	0.11	0.07	0.07	0.1	0.12	0.19	0.05	0.05	0.07	0.08	0.11	0.11			0.11	0.13	0.07	0.14
Tot.dis.	35903.0	1832.2	2941.4	30700.8	1102.4	5515.6	23399.6	20283.2	34527.6	3415.8	3020.0	5956.4	14234.8	20698.8	24090.4	8109.0	36040.0	34781.0	35624.0	8089.0	35429.0
Fe	0.01									0.00	0.00	0.43	1.24	3.03	3.03		0.23	6.95	6.58	0.61	6.09
Li		0.024	0.04	0.13	0.001	0.047	0.123	0.096	0.143	0.05	0.045	0.062	0.104	0.119	0.125						
O2		9.0			9.0					5.5	9.0		4.5	4.5							
Br	67.9	3.06	5.23	51.8	1.85	11.4	38.3	33.02	58.91	7.07											
Al		0.034	0.044	0.02	0.02	0.022	0.018	0.016	0.016												

Pumptest 1-6 samples taken from well 3A3

Table 2 Chemical analyses of well water at Húsatóftir during pumptest, concentration in mg/kg

Place		Depth	Date	Time	Number	SO4	Cl	Br	Fe
Well	3A3	7m	85.01.11	10:34	0040	123.2	1360.9	5.28	
"	"	7m	85.01.11	11:55	0041	137.1	1510.7	5.58	
"	"	7m	85.01.11	13:50	0042	153.5	1689.1	6.48	
"	"	7m	85.01.12	16:30	0043	156.1	1703.1	6.18	
"	"	7m	85.01.12	21:00	0044	154.9	1686.1	6.48	
"	"	7m	85.01.13	14:45	0045	143.3	1581.3	6.48	
"	"	7m	85.01.13	16:30	0046	145.9	1626.4	6.18	
"	"	7m	85.01.13	19:30	0047	148.2	1643.4	6.48	
"	"	7m	85.01.14	13:10	0048	136.8	1513.1	5.88	
"	"	7m	85.01.14	15:40	0049	144.2	1586.2	5.88	
"	"	7m	85.01.14	18:00	0050	147.9	1674.9		
"	"	7m	85.01.15	14:30	0051	131.7	1459.2		
"	"	7m	85.01.16	10:50	0052	149.4	1670.8		
"	"	7m	85.01.16	13:10	0053	141.7	1571.6		
"	"	7m	85.01.16	15:10	0054	137.1	1527.8		
"	"	7m	85.01.16	17:45	0055	143.2	1599.7		
"	"	7m	85.01.17	13:30	0056	147.9	1649.3		
"	"	17m	85.01.18	11:45	0057	289.2	3052.6		2.95
"	"	17m	85.01.18	12:00	0058	256.8	2741.1		0.85
"	"	17m	85.01.18	12:40	0059	285.5	2918.2		1.15
"	"	17m	85.01.18	13:35	0060	322.0	3089.8		0.50
"	"	17m	85.01.18	15:00	0061	321.2	3080.1		0.45
"	"	17m	85.01.18	16:30	0062	290.2	2798.2		0.40
"	"	17m	85.01.18	17:10	0063	280.9	2740.5		0.40
"	"	17m	85.01.19	16:30	0064	274.7	2621.7		0.40
"	"	17m	85.01.19	18:00	0065	256.9	2459.8		0.40
"	"	17m	85.01.20	11:20	0066	175.5	1920.1		
"	"	17m	85.01.20	14:30	0067	186.3	2059.6		
"	"	17m	85.01.22	11:30	0068	192.5	2062.9		
"	"	27m	85.01.26	15:20	0069	903.6	7478.8		
"	"	27m	85.01.26	15:40	0070	1015.2	8427.4		
"	"	27m	85.01.27	13:40	0071	1212.1	9705.5		
"	"	27m	85.01.28	13:00	0072	1345.5	10694.9		
"	"	17m	85.01.23	08:30	0084				0.58
"	"	17m	85.01.23	19:30	0085				0.42
"	"	27m	85.01.25	15:30	0086				1.30
"	"	27m	85.01.27		0087				1.72


VERKFRÆÐISTOFAN VATNASKIL
ORKUSTOFNUN
ELDI LTD.
LOCATION MAP
CALC.
SCALE 1:25000
DATE 86.02.06.
NR. 8420-01
FIG. I
EXPLANATIONS:
● WELL APPROX. LOCATION
EAST AREA
HT-41
HT-42
HT-43
Grindavík
Hóp
Járngerðarstaðir
Gerðavellir
Stórabót
Malarendar
Arfadalsvík
Húsatóftir
Staðarbót
Gerðistangar
Hrafnagjá
Sundvörðuhraun
Eldvörp
Tóftarkrókar

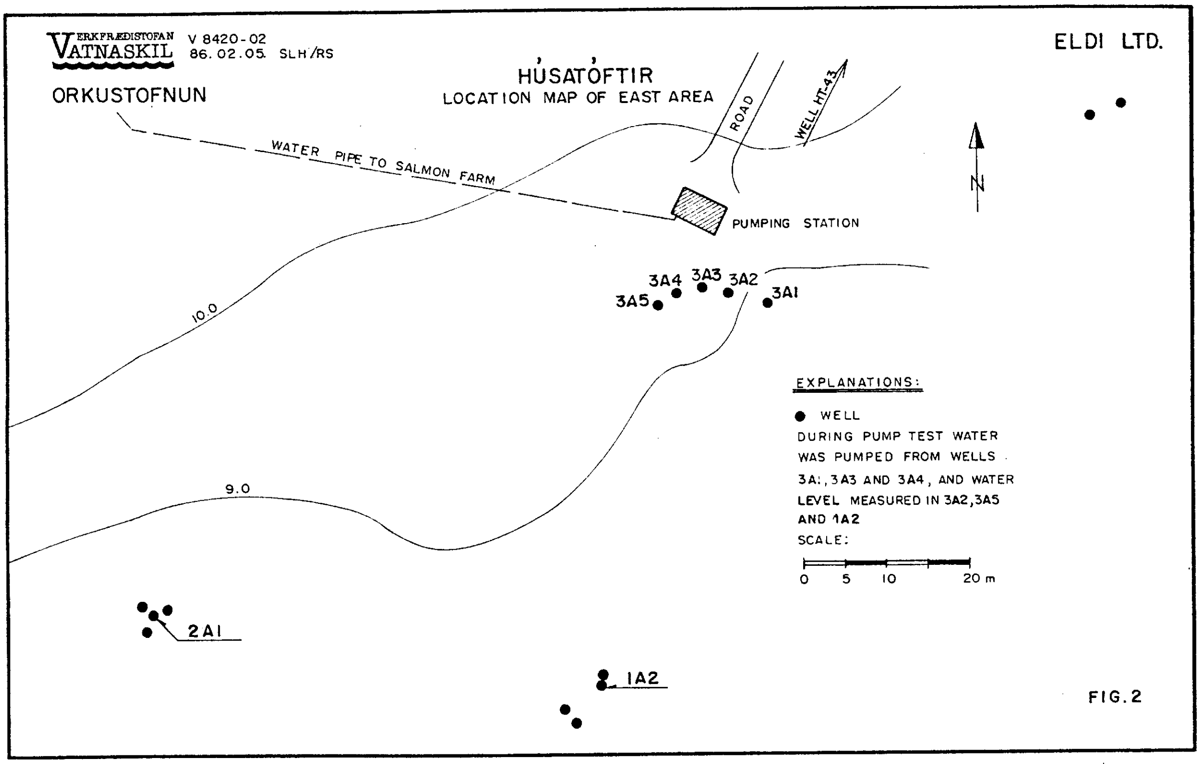

VERKFRÆDISTOFAN VATNASKIL
V 8420-02
86.02.05. SLH/RS
ORKUSTOFNUN
HÚSATÓFTIR
LOCATION MAP OF EAST AREA
ELDI LTD.
ROAD
WELL HT-43
WATER PIPE TO SALMON FARM
PUMPING STATION
N
10.0
9.0
3A4
3A3
3A2
3A5
3A1
2A1
1A2
EXPLANATIONS:
WELL
DURING PUMP TEST WATER WAS PUMPED FROM WELLS 3A1, 3A3 AND 3A4, AND WATER LEVEL MEASURED IN 3A2, 3A5 AND 1A2
SCALE:
0 5 10 20 m

FIG. 2

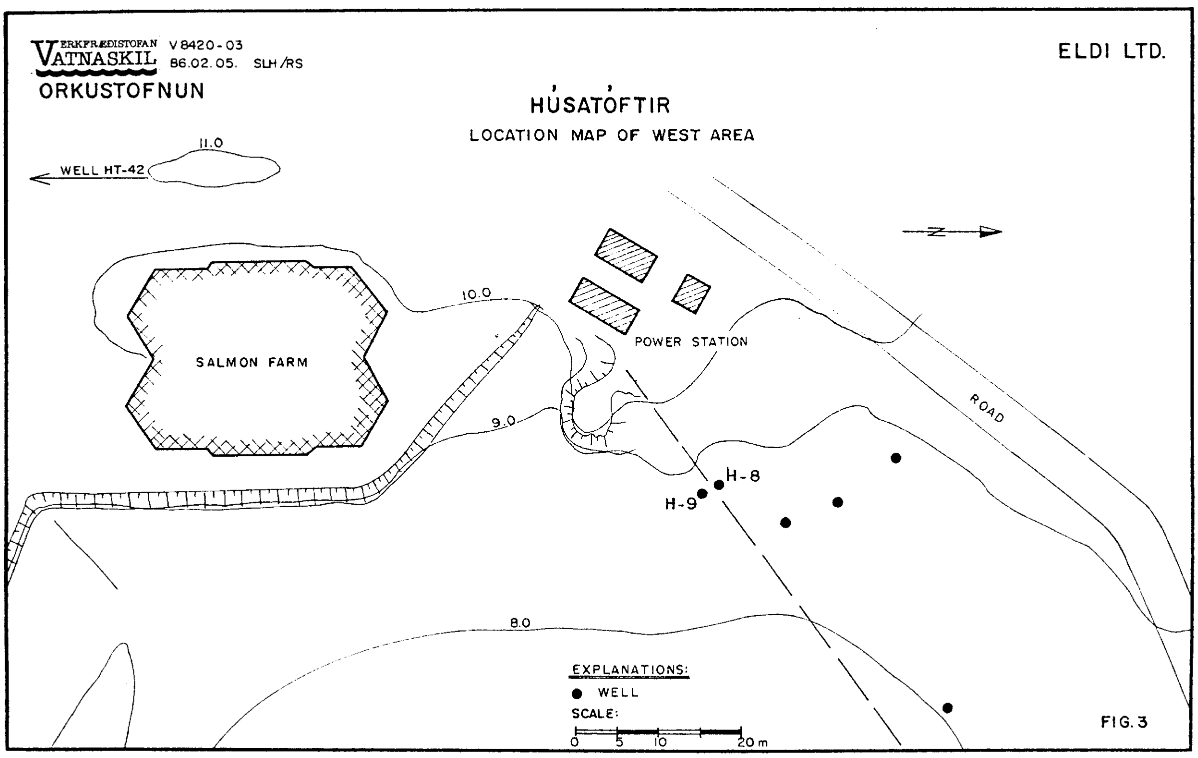
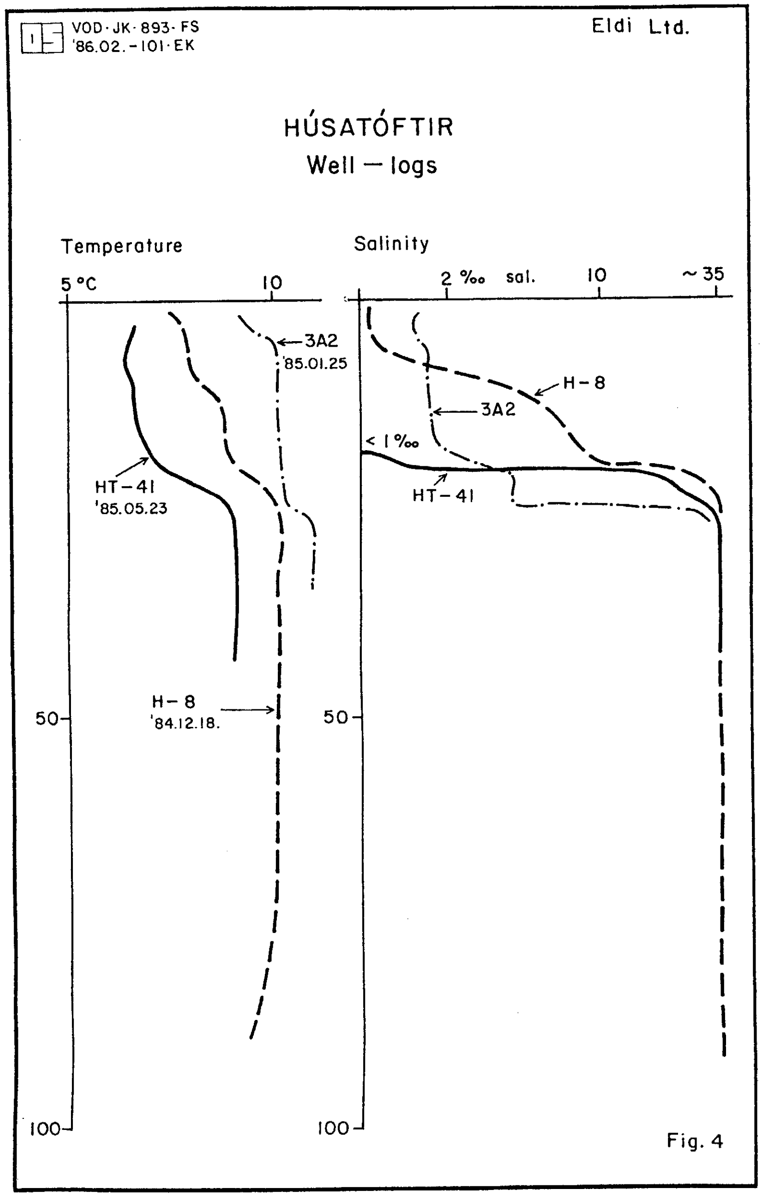
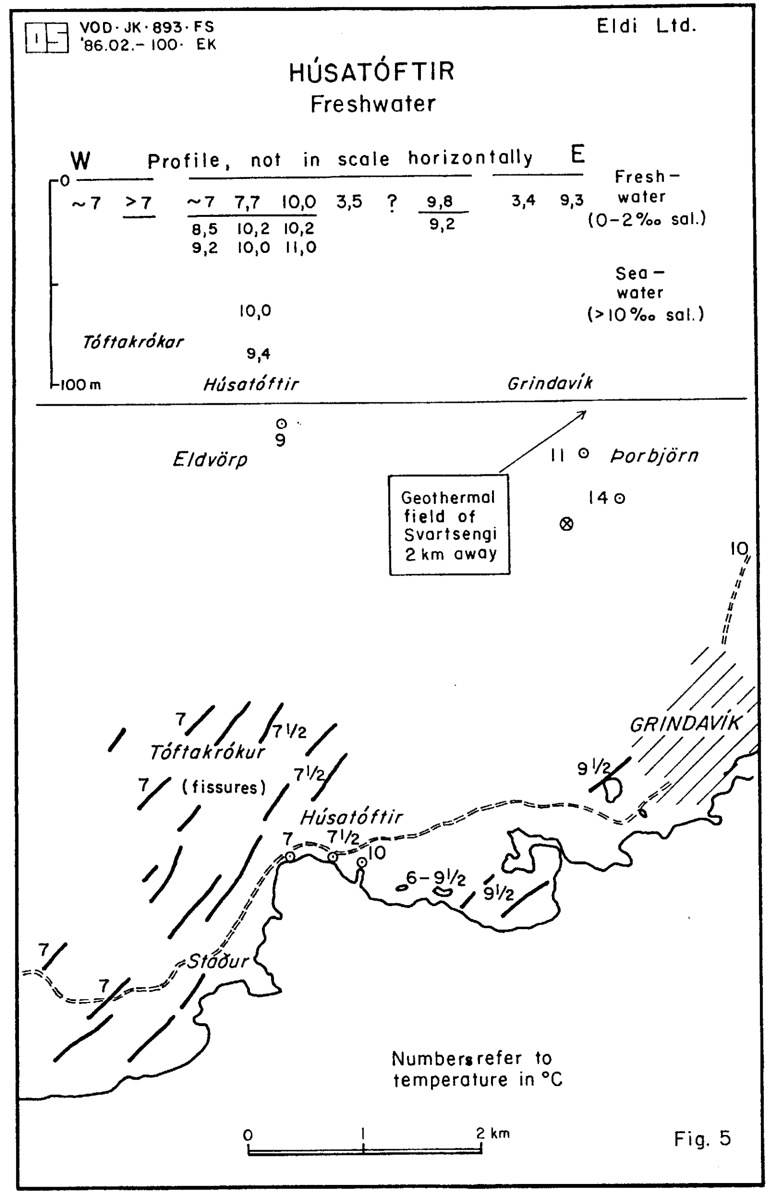

VERKFRÆDISTOFAN VATNASKIL
V 8420-03
86.02.05. SLH/RS
ORKUSTOFNUN
ELDI LTD.
HÚSATÓFTIR
LOCATION MAP OF WEST AREA
WELL HT-42
11.0
N
SALMON FARM
10.0
POWER STATION
ROAD
9.0
H-8
H-9
8.0
EXPLANATIONS:
WELL
SCALE:
0 5 10 20 m

FIG. 3


VOD-JK-893-FS
'86.02.-101-EK
Eldi Ltd.
HÚSATÓFTIR
Well — logs
Temperature
5 °C
10
50
100
Salinity
2 ‰ sal.
10
~35
50
100
3A2
'85.01.25
HT-41
'85.05.23
H-8
'84.12.18.
H-8
3A2
< 1 ‰
HT-41
Fig. 4


VOD-JK-893-FS
'86.02.-100-EK
Eldi Ltd.
HÚSATÓFTIR
Freshwater
W
Profile, not in scale horizontally
E
0
~7 >7 ~7 7,7 10,0 3,5 ? 9,8 3,4 9,3
8,5 10,2 10,2
9,2 10,0 11,0
9,2
Fresh-
water
(0-2‰ sal.)
Sea-
water
(>10‰ sal.)
10,0
Tóftakrókar
9,4
100 m
Húsatóftir
Grindavík
9
Eldvörp
11 Þorbjörn
14
Geothermal
field of
Svartsengi
2 km away
10
GRINDAVÍK
9 1/2
7
7 1/2
Tóftakrókur
7 1/2
7
(fissures)
Húsatóftir
7
7 1/2
10
6-9 1/2
9 1/2
7
Staður
7
Numbers refer to
temperature in °C
0
1
2 km
Fig. 5

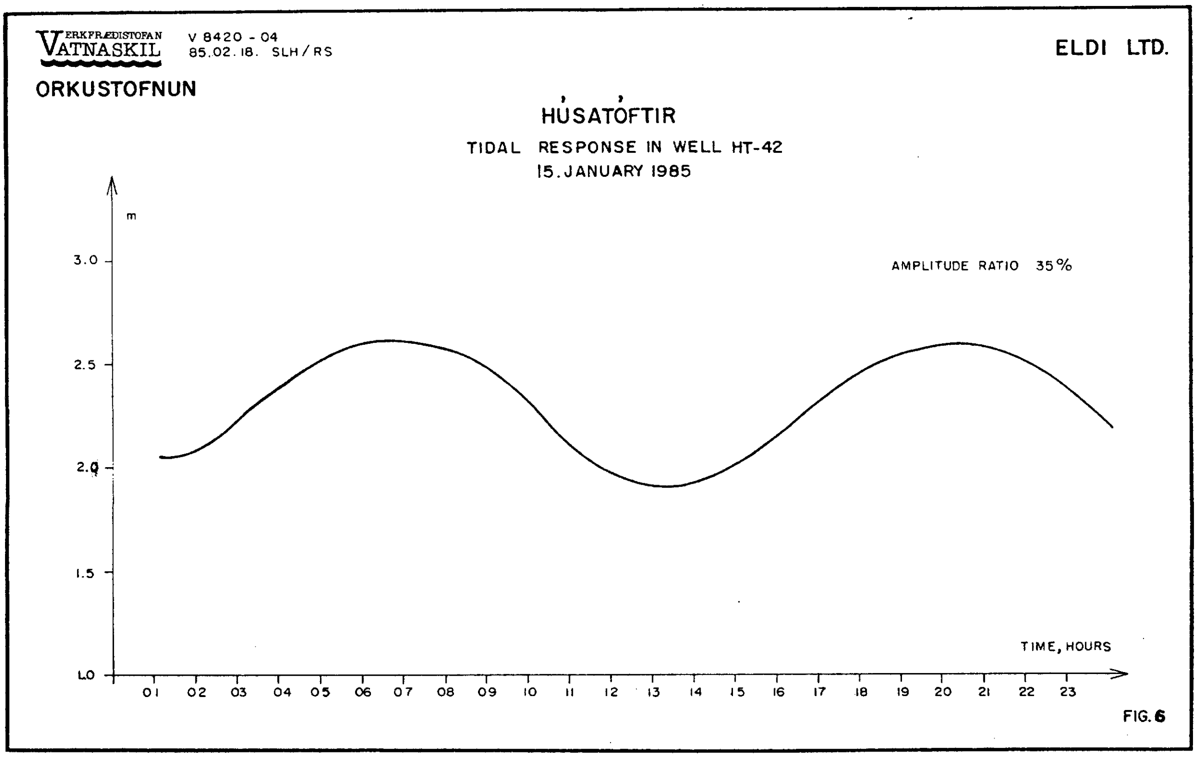

VERKFRÆÐISTOFAN VATNASKIL
V 8420 - 04
85.02.18. SLH/RS
ELDI LTD.
ORKUSTOFNUN
HÚSATÓFTIR
TIDAL RESPONSE IN WELL HT-42
15.JANUARY 1985
m
3.0
2.5
2.0
1.5
1.0
AMPLITUDE RATIO 35%
TIME, HOURS
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23

FIG. 6

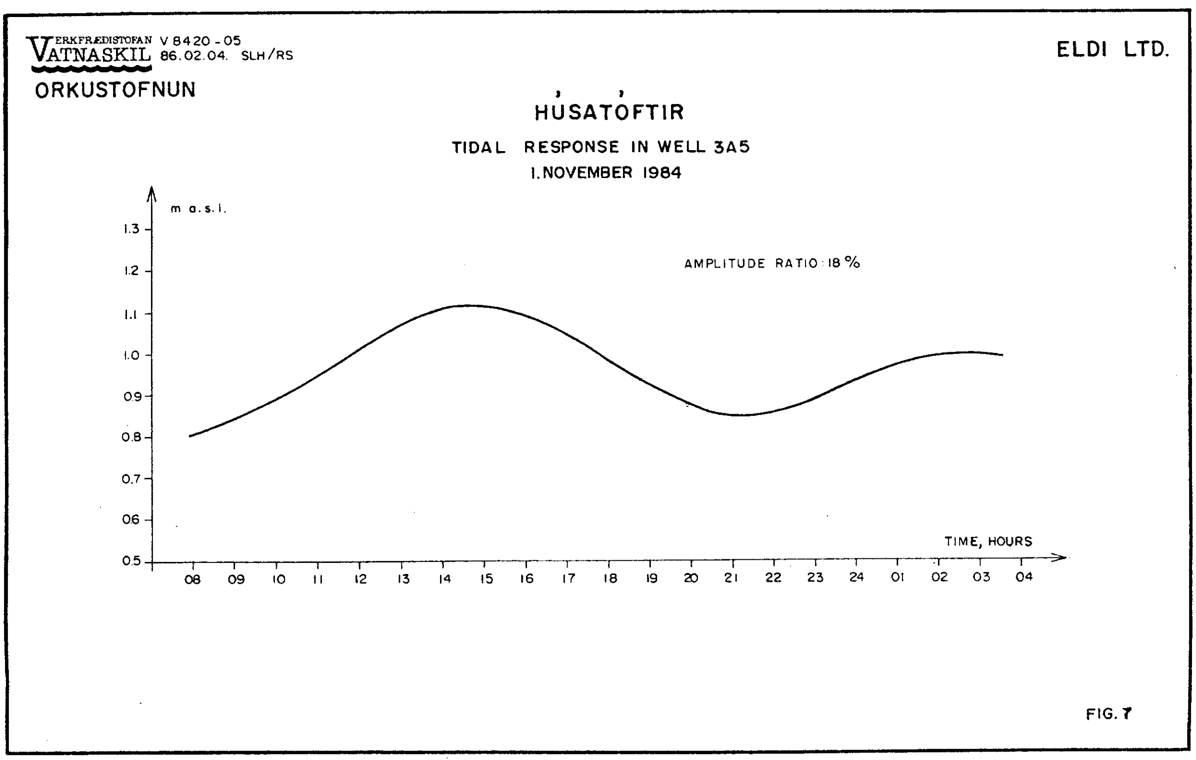

VERKFRÆÐISTOFAN VATNASKIL
V 8420 - 05
86.02.04. SLH/RS
ELDI LTD.
ORKUSTOFNUN
HÚSATÓFTIR
TIDAL RESPONSE IN WELL 3A5
1.NOVEMBER 1984
m a.s.l.
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
AMPLITUDE RATIO 18%
TIME, HOURS
08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 01 02 03 04

FIG. 7

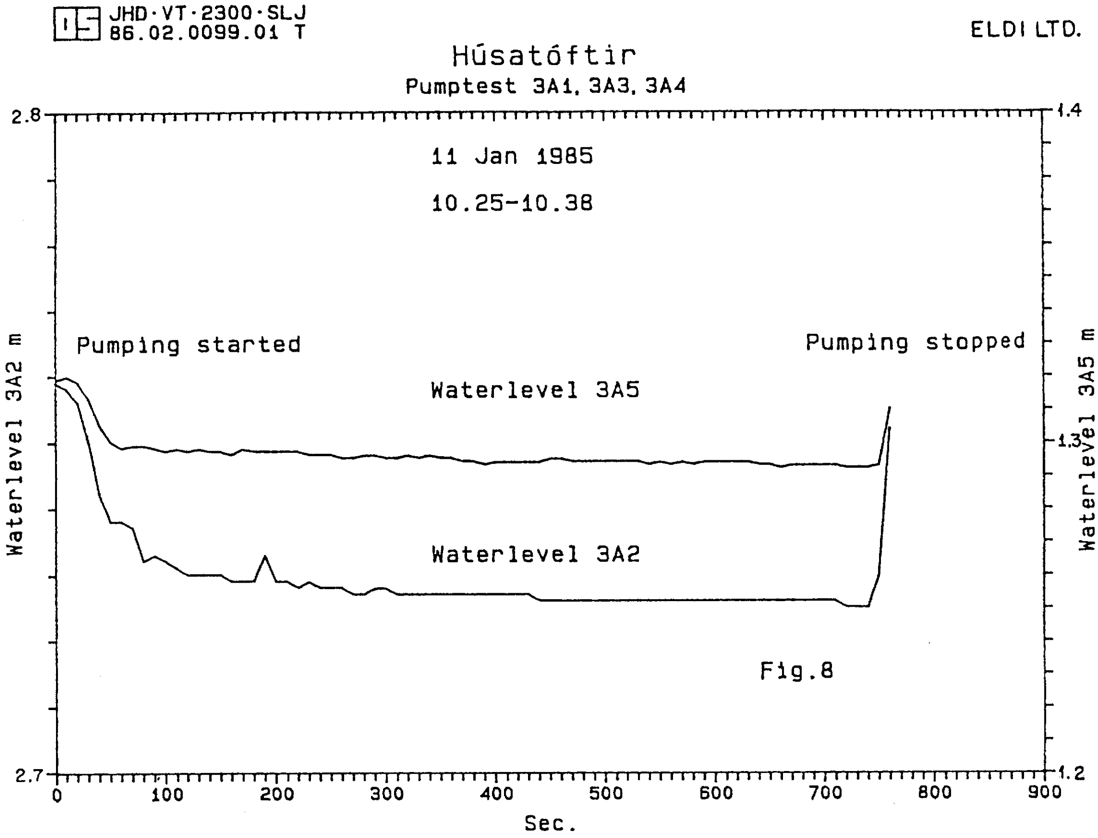

JHD·VT·2300·SLJ
86.02.0099.01 T
ELDI LTD.
Húsatóftir
Pumptest 3A1, 3A3, 3A4
11 Jan 1985
10.25-10.38
Pumping started
Pumping stopped
Waterlevel 3A5
Waterlevel 3A2
Waterlevel 3A2 m
Waterlevel 3A5 m
2.8
2.7
1.4
1.3
1.2
0
100
200
300
400
500
600
700
800
900
Sec.

Fig.8

VERKFRÆDISTOFAN VATNASKIL V8420-06
86.02.06. SLH/RS

ORKUSTOFNUN

ELDI LTD.

HÚSATÓFTIR

CALCULATED DENSITY PROFILE IN WELL 3A2

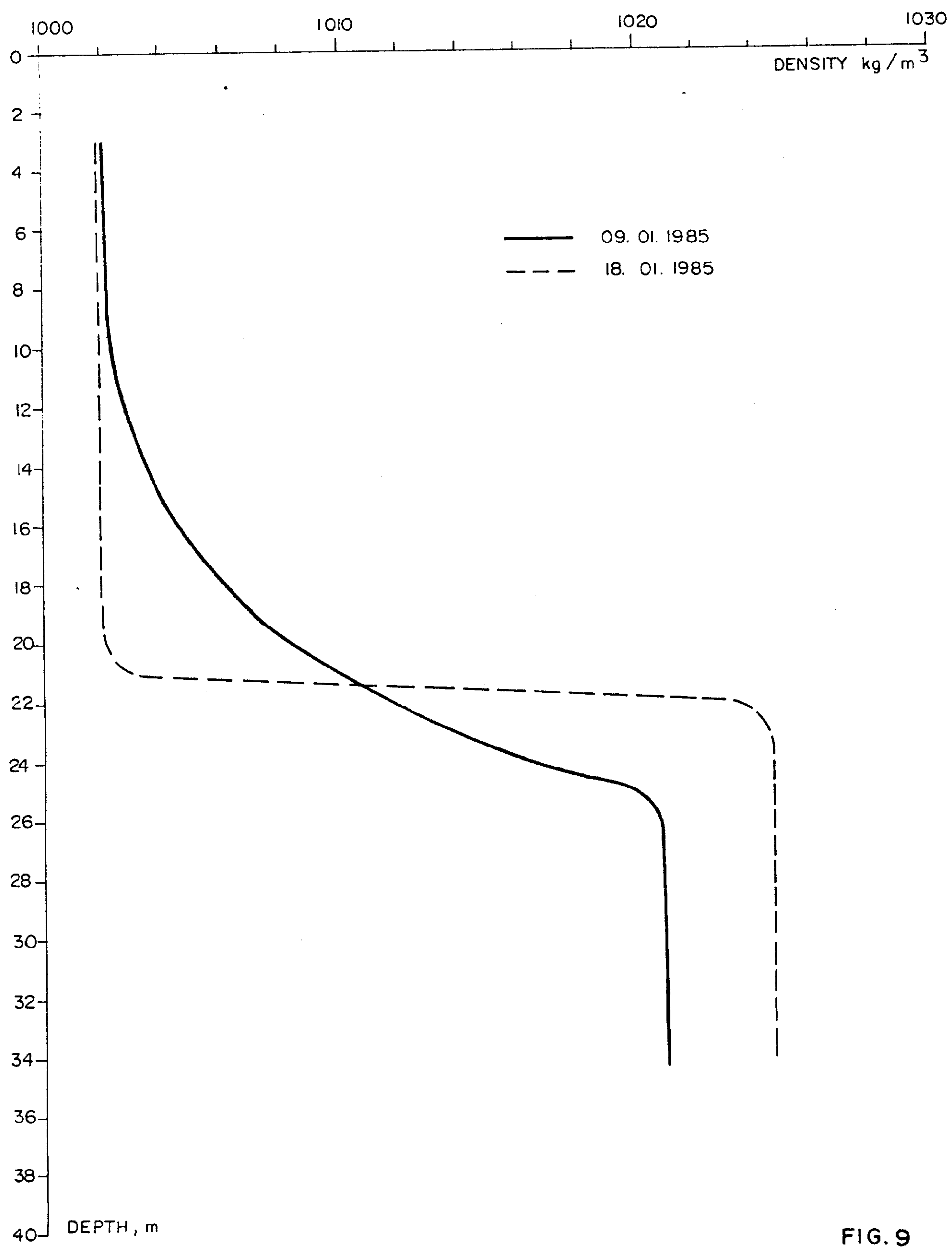


FIG. 9