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USE OF INJECTION PACKER FOR HYDROTHERMAL DRILLHOLE STIMULATION IN ICELAND.

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ABSTRACT

The method has been used in Iceland since 1968 to increase productivity of 30 hydrothermal drillholes, drilled in and near Reykjavík, for space heating purposes. The rotary drilled holes which range in depth from 800 to 2000 m and 22 to 31 cm in diameter, penetrate fresh and hydrothermally altered basalts and hyaloclastites of Quaternary age.

During stimulation, the inflatable packer is set between two or more producing horizons in the hole, and water in turn injected beneath and above the packer. The rate of pumping is from 30 to 100 l/s and varies according to the resistance of the producing horizons to flow. Well face pressures range from a few kg/cm^2 to 60-70 kg/cm^2 at 30 l/s in highly resistive horizons.

Tests have revealed three to four fold increases in the productivity by the process. At Reykir the production of one treated well has reached 81 l/s with a drawdown of 9 m, but usually it exceeds 40 l/s with drawdowns less than 50 m. This increase in productivity is predominantly attributable to the reopening of producing horizons clogged by drill cuttings and lost circulation materials during drilling, but also to the removal of zeolite and calcite vein deposits and by increasing the permeability of the hyaloclastic rocks in the immediate vicinity of the holes.

The injection packer has proved to be a valuable tool for determining the hydrologic characteristics of the hydrothermal systems. The fluctuation of water levels in observation drillholes of various depths reflect transmissitivities and impervious barriers of the various producing horizons of the hydrothermal systems.

INTRODUCTION

Inflatable open hole injection packers have been used for stimulation of hydrothermal drillholes in Iceland since 1967. The first packer experiment took place at Hlídardalur (Fig. 1) 50 km Southeast of Reykjavík, where production of a 1220 m deep narrow gage drillhole was increased from 1 l/s, 60°C, with a drawdown of 100 m, to 2-3 l/s, 110°C, by free flow. At the resumption of drilling in the Reykir hydrothermal area, 15-20 km northeast of Reykjavík, in 1970 (Fig. 1) the method became a routine stimulation procedure for the 29, 22 cm and 31 cm diam., drillholes completed there at depths of 800 to 2043 m by early 1975.

DESCRIPTION OF METHOD

The holes at Reykir are drilled by a rotary rig capable of drilling to 2050 m with a 22 cm drillbit and 11.4 cm O.D. drillpipe. Stimulation of the holes by the injection packer, which is either done immediately following the completion of drilling or after a short pumping period with compressed air, is performed by the aid of the rig´s pumps and its string of drillpipes. In Fig. 2 is shown schematically how mud tank is connected to the drillpipe and the packer. A 11.5 cm diam. steel pipe with flexible joints is substituted for the rig´s standpipe and Kelly and Kelly hosem in order to minimize frictional losses.

The packer consists of a 1.5 m long steel mesh reinforced rubber tubing fastened to a steel mandrel. It is lowered into the drillhole on the drillpipe to a predetermined depth, where it is inflated against the drillhole walls by water pressure through the pipe. Setting pressures are determined by the size of a brass shear pin and may range from 85 to 150 kg/cm^2. After the packer is set, water may be injected, either into the interval below the packer, through the drillpipe, or into the annulus above it, between packer and casing shoe, by injection through the blow out preventer, which is then closed against the drillpipe. Fig. 3 shows schematically the surface layout and the packer set in the hole.

Pumping is by three duplex reciprocating double-acting piston pumps with stroke lengths of 40.8, 38.5 and 30.5 cm respectively. The nominal displacement of the pumps, connected in parallel, at the maximum speed of 65 strokes per minute, is in excess of 100 l/s. However, with high frictional resistance in the drillpipe and ground, while injecting beneath the packer, volume is limited by the maximum working pressure of 85 kg/cm^2 of the pumps.

THE INJECTION TEST IN DRILLHOLE MG-25

In order to illustrate the packing method a short description of the injection process in drillhole MG-25 is given below.

Intervals to be treated by injection are selected from the records of zones of circulation water loss encountered during drilling and with aid of temperature logs. Packer seats are chosen in competant strata selected from the lithologic logs of the drillholes. Therefore these data must be at hand in advance of the injection tests. In Fig. 4 is a geological log of MG-25 worked out from the interpretation of drillcuttings with location and quantity of circulation water loss during drilling. In Fig. 5 is temperature logs from measurements during drilling and after the injection. The geological section is dominated by basalt and hyaloclastic rocks with minor amount of dolerite intrusion. These rock types are the most common quarternary rocks in Iceland and the section is typical for the Reykir area. Much of the aquifers (lost circulation zones) are small, near the detection limit of the measurements. The water used by drilling is much cooler than the rocks penetrated, therefore cooling is greatest where circulation losses are large. This helps to locate the lost circulation zones, Fig. 5. In MG-25 the total sum of lost circulating water was 13 l/s (Q_2) and the loss at the end of drilling was only 2 l/s (Q_1). The static water level is 20 m beneath the rig's flowline in both cases.

The first setting of the packer was at 758 m depth in dolerite. Dolerite intrusions are the most competent rocks for setting the packer. Most basalts are competent enough if they are not too heavily altered, but the hyaloclastics are avoided. The setting site of the packer separates the aquifers, the biggest aquifer is above the packer but many small aquifers beneath packer.

In Table 1 is a list of each injection run, the pumping rate, pressures and build up pressure. The build up pressure is pressure in the drillhole at the end of the injection. In Table 1 is the build up pressure register after 2 min. from stop of injection. The fall off rate of build up pressure after the injection is propositional to the permeability of the aquifers. In a good aquifer the build up pressure falls to zero within two minutes. In Fig. 6 is the injection rate and the measured pressure during the injection. In the first injection interval 758-2025 m the injection rate was constant through the entire run but the pressure was increasing step wise the first 5-6 hours but the last 4 hours the pressure increased only slightly. The falloff of pressure after the injection is shown in Fig. 7. This fall off curve is typical for an aquifer of low permeability. In good aquifer the fall off curve is straight down. In the next injection intervals (204-758) two runs were made with a short stop between them and the build up pressure did not fall off between the runs.

In the second run a great drop in pressure occurred but the pressure was built up again but not to the same hight as before and was almost constant 20 kg/cm^2 and did not change by change of the injection rate. After these runs the drillhole was injected in two injection intervals in several runs, the first interval again (758-2025 m) and by new setting of the packer at 552 m depth, the interval (552-2025 m). In both these intervals a drop of pressure occurred during the runs but pressure seemed to be built up again. The pressure drop probably means opening of an aquifer but gradually the pressure builds up again.

In Fig. 8 is a map of the Reykir area, showing the location of MG-25 and several observation drillholes equipped with automatic waterlevel recorders which record the change in water levels during the injection. In Fig. 9 are shown how the observation drillholes responded to the injection in MG-25. The nearest drillhole MG-16 is much affected by the injection in MG-25, MG-15 and MG-20 are only slightly affected but the drillholes MG-2 and MG-23 are not affected at all. This result will help us to interpret other hydrological data. The other features which are important is the great response in MG-16 to the injection interval 552-2025 m but not so great to the 204-758 m interval where the injection rate was 90% greater. This is explained in that way that the great part of the water in first case did go out just beneath the casing when the pressure rose up to 20 kg/cm^2. We have observed similar things in other drillholes in this area, i.e. when the pressure has reached certain maximum the increase in injection rate has little or no influence on the pressure. There seems to be a rule in the Reykir area that when the pressure in a vein is equal to the weight of the overlaying rocks the water goes out with very little resistance. The specific weight of the rocks is then assumed to be about 2. This water vein which is open beneath casing at certain pressure is not an aquifer. It is closed again when pressure is released and it has no influence on the yield of the drillhole.

After the injection the drillhole was tested with step draw-down test (Th. Thorsteinsson 1975). The test indicated a capacity of 40 l/s with 40 m drawdown. Before the test the drillhole was not useable, so if the test had not been performed the capital spent in the drilling of the hole would have been wasted. The 4 extra days which were spent in tests seem to be good investment and have given a rather good well for hot water production.

RESULTS AND CONCLUSIONS

Table 2 shows the improvement ratios I_1 and I_2 of the 27 drillholes treated by the injection packer method at Reykir. I_1 is the ratio of the specific capacity of a drillhole after injection, as computed from step drawdown tests, to the specific capacity of the hole at end of drilling, computed from the circulation loss Q_1 and the static water level in the hole during drilling, h. I_2 is the ratio of the specific capacity after injection to the specific capacity computed from the total sum of the circulation losses during drilling, Q_2, and the static water level h. The three specific capacity values are computed from a flow rate equal to the rate of the loss of circulation at the end of drilling, Q_1, and are therefore comparable.

$$I_1 = \frac{h}{CQ_1{}^2} \quad \text{and } I_2 = \frac{h}{CQ_2{}^2}$$

where C is the coefficient of head loss due to turbulence inside the drillhole and in its immediate vicinity, computed from step drawdown tests after the injection treatment.

Improvement ratio I_1 is high in drillholes such as MG-21 and MG-29, where large aquifers at shallow depths have been plugged by drill cuttings and lost circulation material from deeper drilling. I_1 is also high in holes MG-15 and MG-25 in which total loss of circulation is small, but is low in holes where large aquifers are near the bottom of the holes, like in MG-6 and MG-13.

Improvements ratio I_2 usually exceeds unity in drillholes of small total circulation loss but is less than unity in those of high total circulation loss. In table 2 I_2 is not computed for drillholes in which the total circulation loss, Q_2, exceeds 45 l/s. Values of the improvement ratios indicate that the greatest benefit from the injection packer method is by reopening of producing horizons clogged by lost circulation material and drill cuttings, during drilling, but also by removal of calcite and zeolite vein deposit and by increasing the permeability of hyaloclastic rocks in the immediate vicinity of the holes. Advantages of the method are summarized below:

1. Great increase in the production of the drillholes up to 3-4 times.
2. We can drill deeper drillholes than before because we need not stop drilling in good producing horizons, because we can open the clogged horizons again. We can drill through more aquifers and get better utilization of the geothermal systems.
3. The injection packer method has proved to be a valuable tool for determining hydrological characteristics of the hydrothermal systems. Fluctuation of water levels as recorded by automatic water stages recorders in observation holes of various depths reflect stransmissivities and impervious barriers of the various producing horizons of the hydrothermal systems.

FIGURE CAPTION

Fig. 1. Geological map of southwest Iceland with index map.

Fig. 2. Schematic picture of a packer and its connection with the mud tank and drillpipe.

Fig. 3. Schematic picture of injection in drillholes.

Fig. 4. Geological section of MG-25.

Fig. 5. Temperature logs during drilling and after injection showing cooling effects of drilling and injection water.

Fig. 6. Injection rate and measured pressure during the injection in MG-25.

Fig. 7. The fall-off pressure after first injection run in MG-25.

Fig. 8. Location of drillholes.

Fig. 9. Water level of several drillholes during injection in MG-25. (Location of the holes is shown in figure 8).

REFERENCES

Thorsteinsson, Th., 1975. Redevelopment of the Reykir Hydrothermal System in SW Iceland. U.N. Geothermal Symposium, San Francisco 1975.

TABLE 1

Drillhole nr. MG-25 Injection test 3-6 apr. Depth of packer 552m, 758m.

Injection interval m - m	Run number	Injection time	Injection rate l/s	Measured pressure Kg/cm^2	Calculated pressure Kg/cm^2	Built up pressure a. two min. Kg/cm^2	Quantity in tons
758-2025	1	10.35	34	56-63	34-41	30	1290
204-758	2	3.00	87	17-21		6	940
"	3	9.55	83	21-13-20		5	2960
Total		12.55					3900
758-2025	4	2.55	38	58-65-60-61	36-43-38-39	35	334
"	5	2.55	37	61-67	41-51		390
"	6	2.08	37	65-69	45-49		282
Total		7.28					1006
552-2025	7	4.54	45	60-61	39-40	24	794
	8	15.10	46	58-56-58	36-34-36	18	2500
Total		20.04					3294
Total in hole		50.02					9490

TABLE 2

Drillholes in Reykir	Year of Drilling	Depth m	Depth of casing m	Depth to water m	Q2 Total circulation loss l/s	Q1 Circulation loss at end l/s	C $m/(l/s)^2$	Improvement Ratio	
								I_1	I_2
MG- 3	1970	1414	116	- 5.00	29	9	0.019	3.2	0.31
MG- 4	1970	1334	129	-14.60	16	7	0.035	8.5	1.63
MG- 5	1970	1592	136	- 4.45	13	4	0.039	7.1	0.6
MG- 6	1970	1416	136	- 9.30	21	19	0.016	1.6	1.3
MG- 7	1970-71	1484	135	- 9.70	> 66	11	0.0035	22.9	
MG- 8	1971	1562	136	-38.10	> 42	23	0.026	2.7	0.84
MG- 9	1971	1803	158	-11.54	11	6	0.052	6.2	1.8
MG-10	1971	1044	159	-13.85	> 51	9	0.005	34.2	
MG-11	1971	1235	170	-25.0	21	4	0.025	62.5	2.2
MG-12	1972	800	195	-28.86	> 49	6	0.018	44.5	
MG-13	1972	1905	185	-28.0	> 51	> 40	0.009	1.9	
MG-14	1972	2035	214	- 7.37	5	1	0.1	73.7	2.9
MG-15	1972-73	1988	214	-25.61	15	1	0.1	256.1	1.1
MG-16	1973	2033	215	-22.7	50	5	0.022	41.3	
MG-17	1973	1766	390	-50.59	> 93	> 40	0.004	7.9	
MG-18	1973	2043	187	-23.10	27	9	0.018	15.8	1.7
MG-19	1973	1766	183	-21.70	103	30	0.011	2.2	
MG-20	1973	2036	202	-38.90	82	6	0.035	30.9	
MG-21	1973	1768	146	-30.0	>231	3	0.008	416.6	
MG-22	1973	1582	200	-41.7	>146	33	0.002	19.1	
MG-23	1973-74	1203	207	-28.51	>125	10	0.004	71.3	
MG-24	1974	1950	203	-44.96	> 82	> 40	0.005	5.6	
MG-25	1974	2025	203	-20.0	13	2	0.025	200.0	4.7
MG-26	1974	867	200	-40.0	> 63	34	0.008	4.3	
MG-27	1974	2004	196	-43.0	42	10	0.025	17.2	0.9
MG-28	1974	2040	190	- 6.62	17	5	0.01	26.5	2.2
MG-29	1974	1354	273	-35.15	>106	10	0.003	117.2	
MG-30	1975	1600	200	-56.05	>104	22	0.005		
MG-31	1975	1476	200	-60.90	> 63	11	0.005		

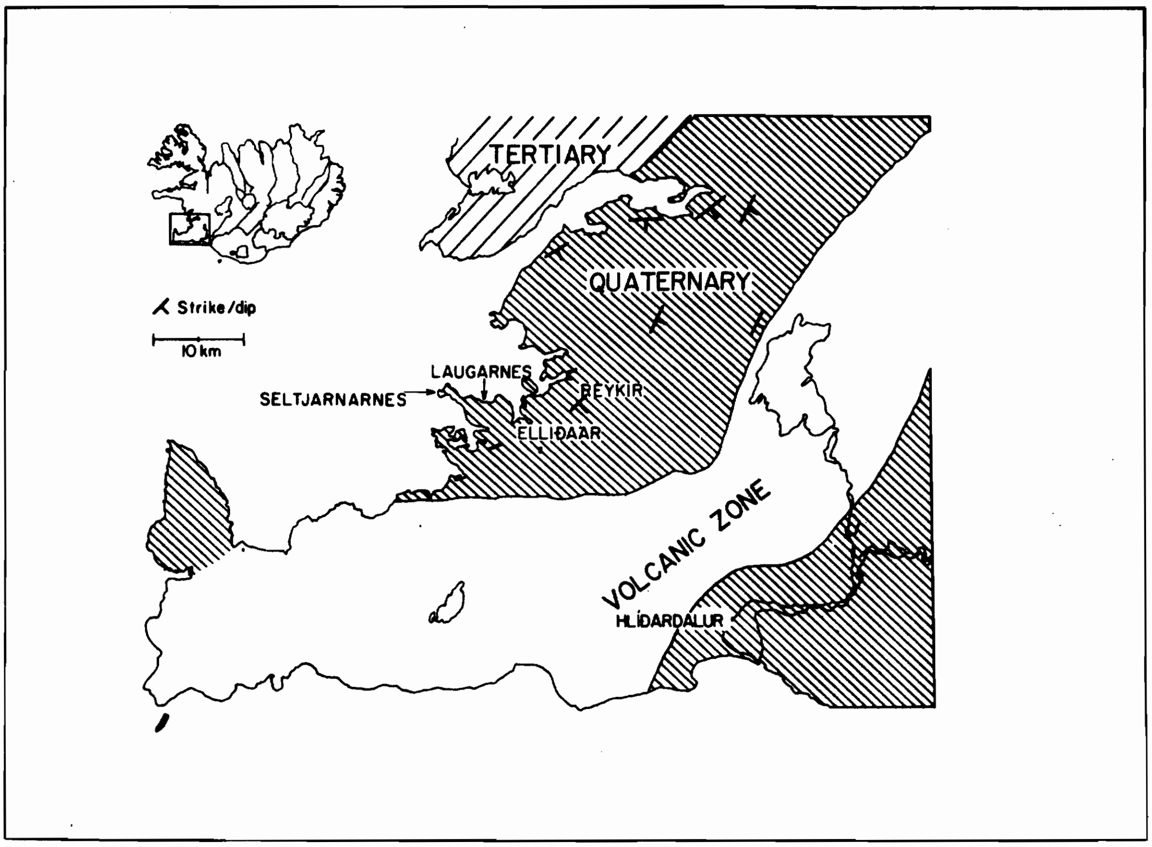
TERTIARY
QUATERNARY
Strike/dip
10 km
LAUGARNES
SELTJARNARNES
REYKIR
ELLIÐAÁR
VOLCANIC ZONE
HLÍÐARDALUR

Fig. 1

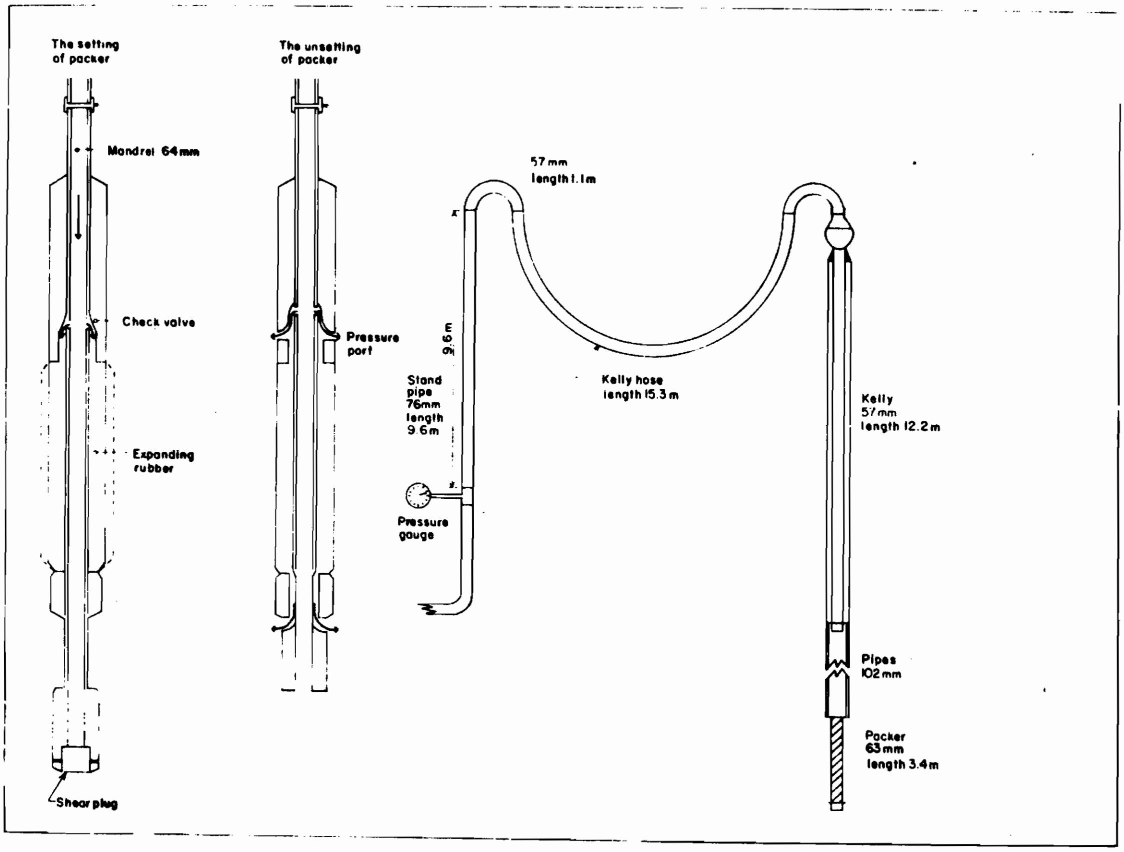
The setting of packer
Mandrel 64mm
Check valve
Expanding rubber
Shear plug
The unsetting of packer
Pressure port
57mm length 1.1m
9.6m
Stand pipe 76mm length 9.6m
Pressure gauge
Kelly hose length 15.3m
Kelly 57mm length 12.2m
Pipes 102mm
Packer 63mm length 3.4m

Fig. 2

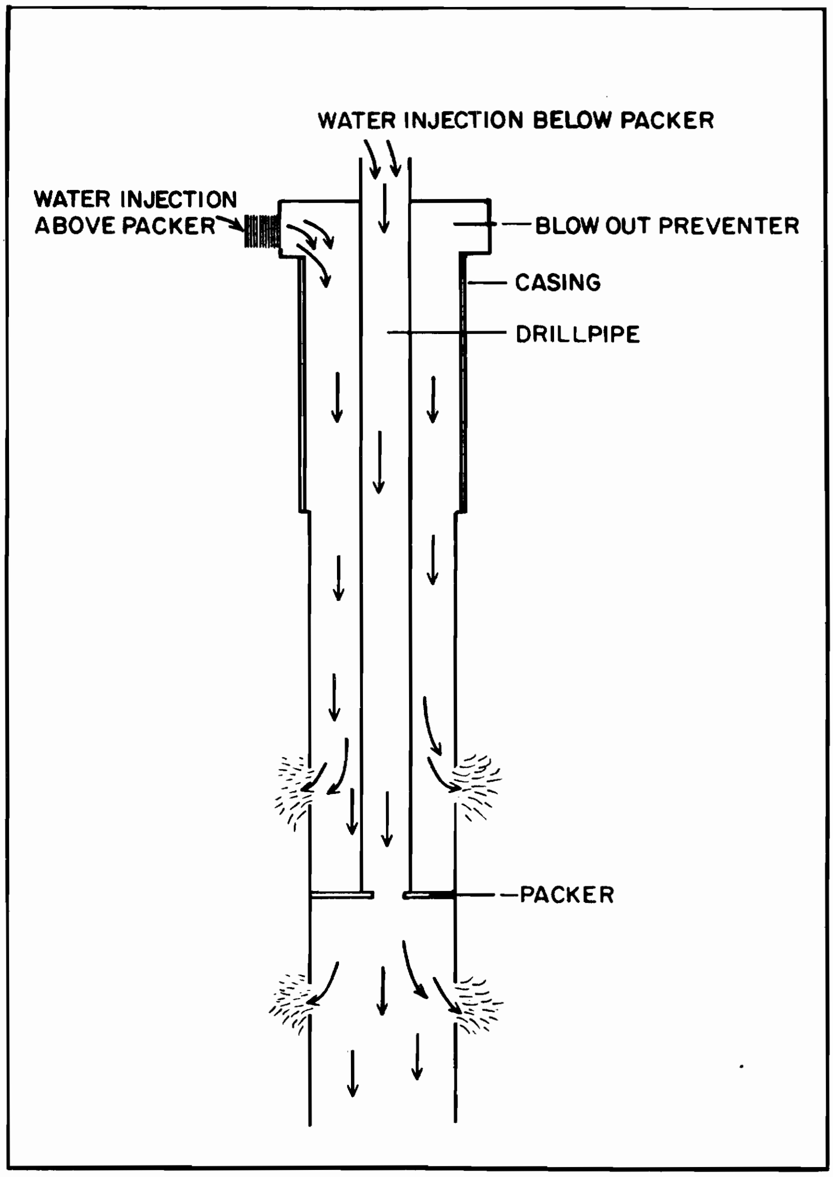
WATER INJECTION BELOW PACKER
WATER INJECTION ABOVE PACKER
BLOW OUT PREVENTER
CASING
DRILLPIPE
PACKER

Fig. 3

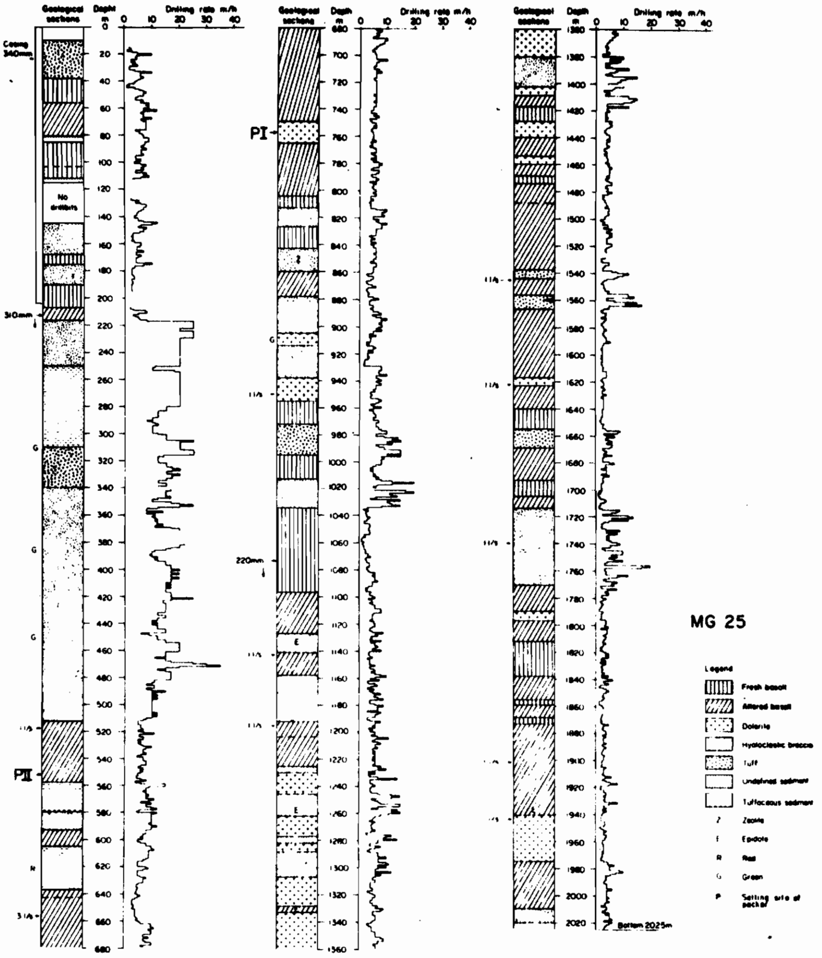
Geological sections
Depth m
Drilling rate m/h
0 10 20 30 40
Casing 340mm
No drillbits
310mm
220mm
PI
PII
G
R
Z
E
Bottom 2025m
MG 25
Legend
Fresh basalt
Altered basalt
Dolerite
Hyaloclastic breccia
Tuff
Undefined sediment
Tuffaceous sediment
Z Zeolite
E Epidote
R Red
G Green
P Setting site of packer
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680
680 700 720 740 760 780 800 820 840 860 880 900 920 940 960 980 1000 1020 1040 1060 1080 1100 1120 1140 1160 1180 1200 1220 1240 1260 1280 1300 1320 1340 1360
1360 1380 1400 1420 1440 1460 1480 1500 1520 1540 1560 1580 1600 1620 1640 1660 1680 1700 1720 1740 1760 1780 1800 1820 1840 1860 1880 1900 1920 1940 1960 1980 2000 2020

Fig. 4

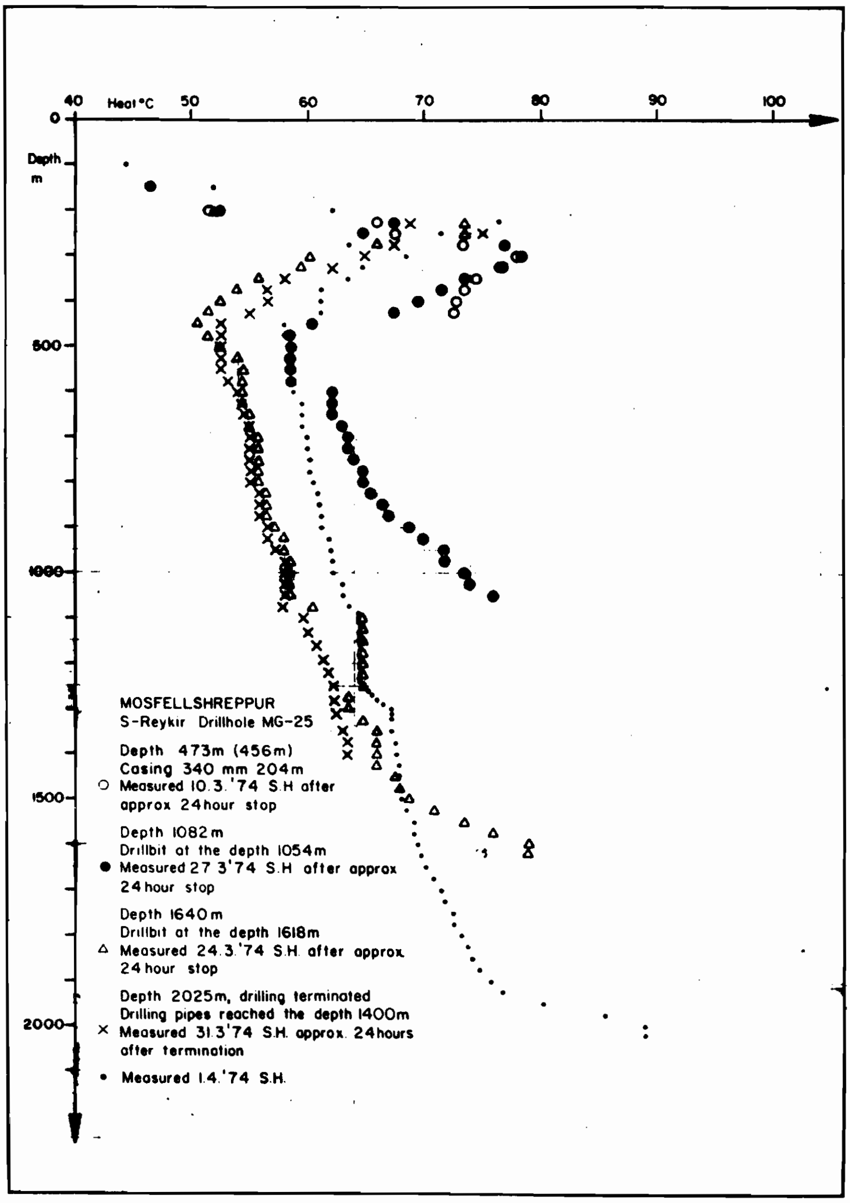
40
Heat °C
50
60
70
80
90
100
0
Depth
m
500
1000
1500
2000
MOSFELLSHREPPUR
S-Reykir Drillhole MG-25
Depth 473m (456m)
Casing 340 mm 204m
○ Measured 10.3.'74 S.H after approx 24hour stop
Depth 1082m
Drillbit at the depth 1054m
● Measured 27.3.'74 S.H after approx 24hour stop
Depth 1640m
Drillbit at the depth 1618m
△ Measured 24.3.'74 S.H. after approx. 24hour stop
Depth 2025m, drilling terminated
Drilling pipes reached the depth 1400m
× Measured 31.3.'74 S.H. approx. 24hours after termination
• Measured 1.4.'74 S.H.

Fig. 5

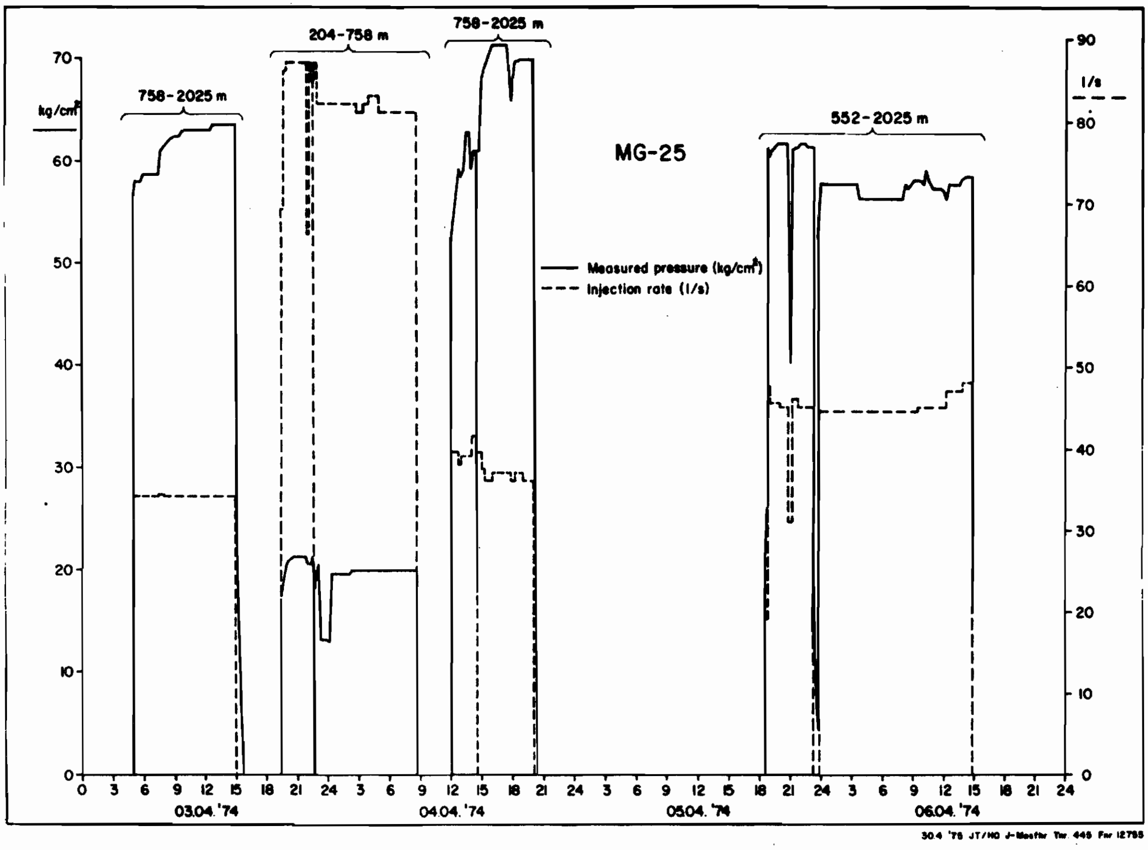
MG-25
758-2025 m
204-758 m
758-2025 m
552-2025 m
kg/cm²
l/s
Measured pressure (kg/cm²)
Injection rate (l/s)
0
10
20
30
40
50
60
70
80
90
0 3 6 9 12 15 18 21 24 3 6 9 12 15 18 21 24 3 6 9 12 15 18 21 24 3 6 9 12 15 18 21 24
03.04.'74
04.04.'74
05.04.'74
06.04.'74
30.4 '75 JT/HO J-Mostfr Tw 445 Fnr 12795

Fig. 6

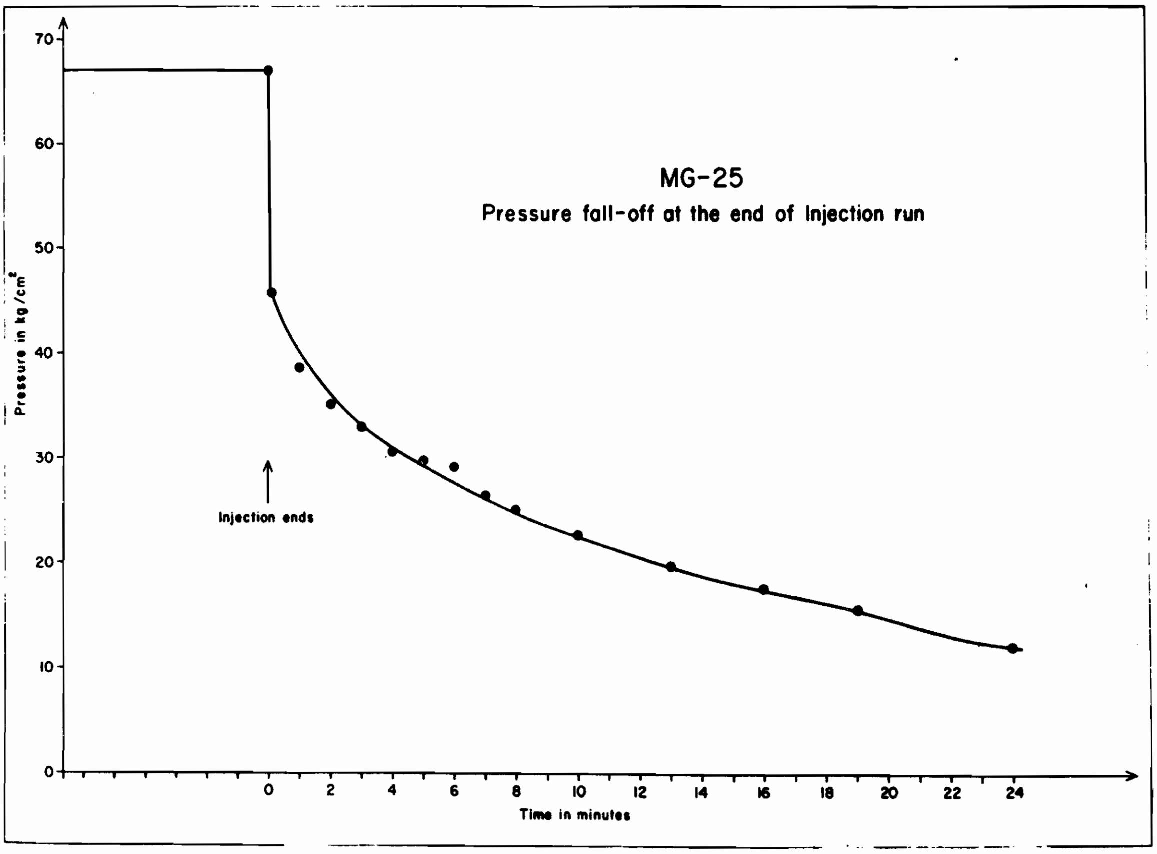
MG-25
Pressure fall-off at the end of injection run
Pressure in kg/cm²
0
10
20
30
40
50
60
70
Injection ends
0 2 4 6 8 10 12 14 16 18 20 22 24
Time in minutes

Fig. 7

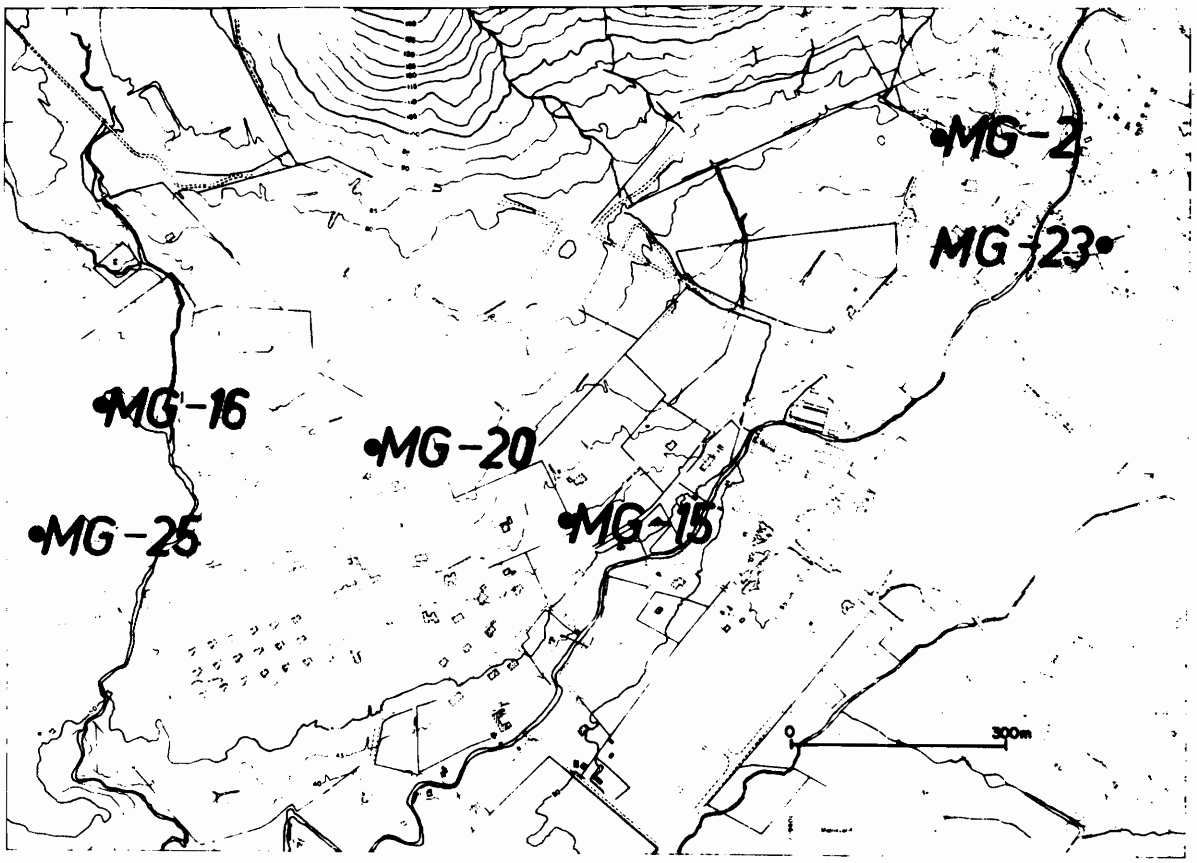

Fig. 8

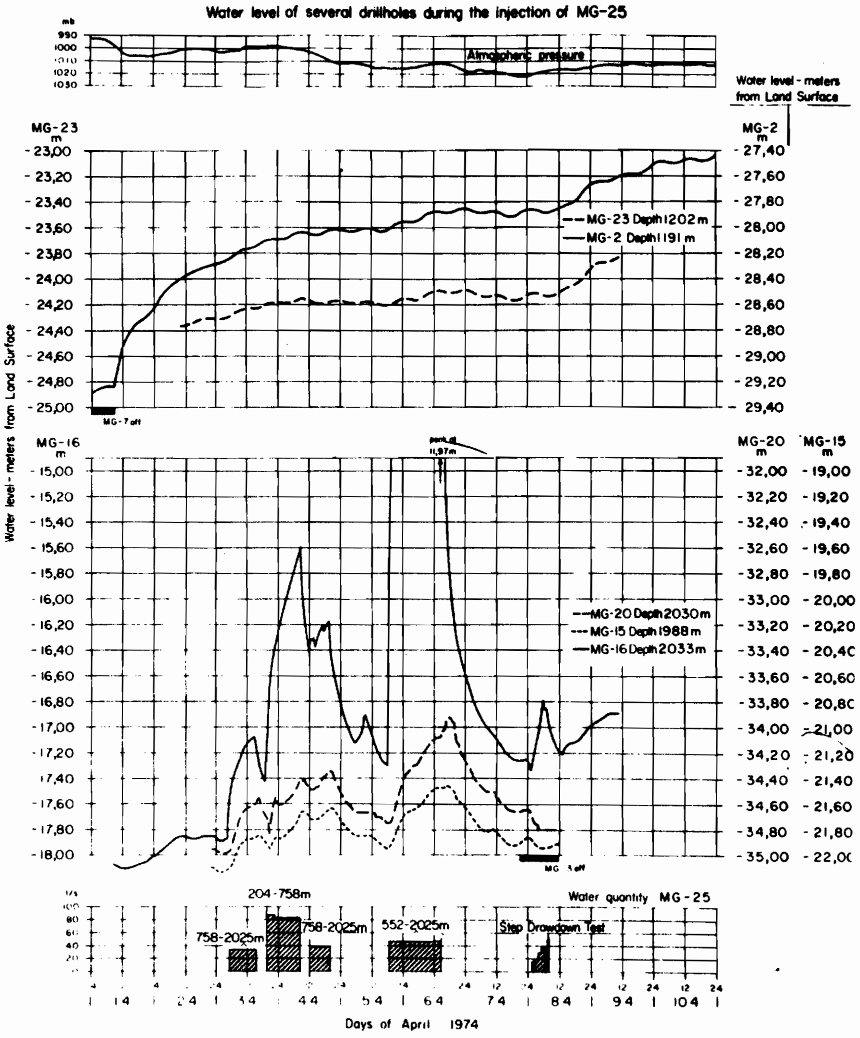
Water level of several drillholes during the injection of MG-25
mb
990
1000
1010
1020
1030
Atmospheric pressure
Water level - meters from Land Surface
MG-23 m
MG-2 m
-23,00
-23,20
-23,40
-23,60
-23,80
-24,00
-24,20
-24,40
-24,60
-24,80
-25,00
-27,40
-27,60
-27,80
-28,00
-28,20
-28,40
-28,60
-28,80
-29,00
-29,20
29,40
MG-23 Depth 1202 m
MG-2 Depth 1191 m
MG-7 off
Water level - meters from Land Surface
MG-16 m
MG-20 m
MG-15 m
peak at 11,97m
-15,00
-15,20
-15,40
-15,60
-15,80
-16,00
-16,20
-16,40
-16,60
-16,80
-17,00
-17,20
-17,40
-17,60
-17,80
-18,00
-32,00
-32,20
-32,40
-32,60
-32,80
-33,00
-33,20
-33,40
-33,60
-33,80
-34,00
-34,20
-34,40
-34,60
-34,80
-35,00
-19,00
-19,20
-19,40
-19,60
-19,80
-20,00
-20,20
-20,40
-20,60
-20,80
-21,00
-21,20
-21,40
-21,60
-21,80
-22,00
MG-20 Depth 2030 m
MG-15 Depth 1988 m
MG-16 Depth 2033 m
MG-3 off
l/s
100
80
60
40
20
0
204-758m
758-2025m
758-2025m
552-2025m
Step Drawdown Test
Water quantity MG-25
14
24
34
44
54
64
74
84
94
104
Days of April 1974

Fig. 9