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TEMPERATURE DISTRIBUTION, PRODUCTIVITY AND UTILIZATION SCHEMES FOR THE EFRI-REYKIR GEOTHERMAL FIELD, S-ICELAND

Phan Van Tuyen
Hydrogeological Division No 8,
An Khanh - Thu Duc,
Ho Chi Minh City,
VIETNAM

ABSTRACT

The Efri-Reykir field is a low-temperature geothermal field located in the upper lowlands of South Iceland. Twenty-two shallow exploration wells and one production well (ER-23) have been drilled in the field. The formation temperature distribution of the geothermal system has been estimated on the basis of 80 temperature logs measured in the wells. The conceptual model of the Efri-Reykir geothermal field is based on the formation temperature distribution. It includes up-flow in a near-vertical fracture located between wells ER-23 and ER-21 intersected in well ER-23 at 700 m depth. This fracture is connected to a near-horizontal aquifer which is found at about 20 m depth below the now extinct hot springs, but dips towards the west and is found at a depth of 80 m in well ER-23. Analysis of production test data from well ER-23 shows that the well is highly productive. The reservoir appears to be single-phase liquid- dominated with a reservoir temperature of 145°C and enthalpy of about 610 kJ/kg. The maximum wellhead pressure of ER-23 is 4.3 bar-g and the maximum total flow 73.6 kg/s. If the wellhead pressure is lower than 3.1 bar-g some steam will be produced, the maximum being 6.3 kg/s. In spite of approximately 600,000 tons per year production during the last 8 years, very little pressure drop appears to have taken place in the reservoir. The permeability-thickness of the system is estimated to equal 200 Dm, which indicates a very high permeability. The geothermal energy at Efri-Reykir is currently used for space heating, greenhouses and a swimming pool. Some electricity production is possible. This would preferably be done with a binary cycle, which is efficient at the temperatures found at Efri-Reykir.

1. INTRODUCTION

Iceland is a part of the oceanic lithosphere extending above sea level. The Mid-Atlantic Ridge, an active spreading axis, crosses Iceland from southwest to northeast and appears as a zone of active rifting and volcanism (Flóvenz and Saemundsson, 1993). During the processes of rifting and volcanic activity, heat and energy is transported into the crust, creating high- and low-temperature geothermal systems.

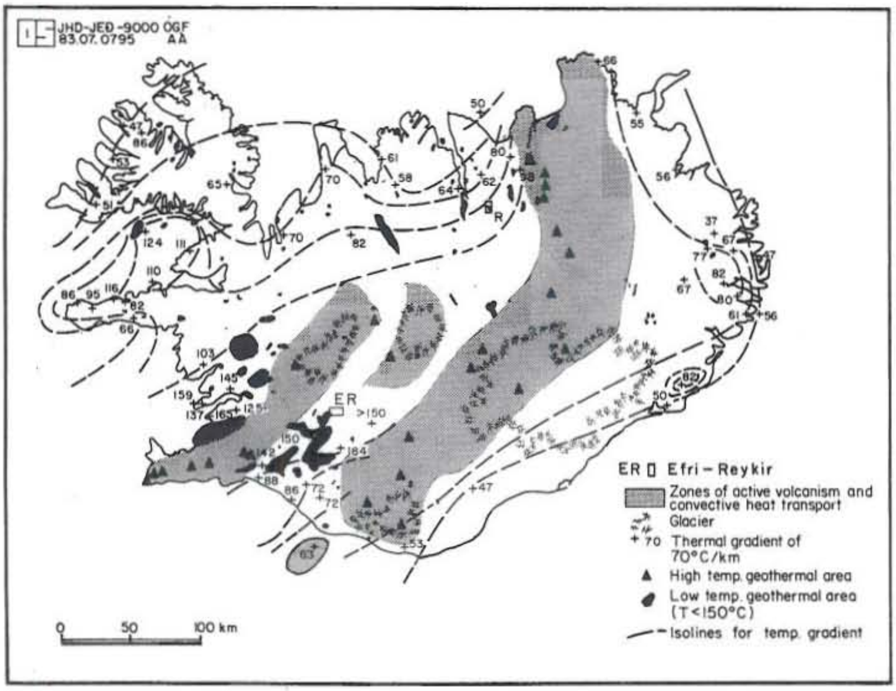

FIGURE 1: The regional temperature gradient and distribution of geothermal activity in Iceland (Flóvenz, 1985); the location of the Efri-Reykir geothermal field is inferred with the letters ER

Efri-Reykir is a small geothermal field in the Quaternary rocks of Central South Iceland (Figure 1). Since 1982 twenty two exploration wells (ER-01-ER-22) and one production well (ER-23) have been drilled in this field (Figure 2). The depth of the wells ranges from 18 to 722 m. Eighty temperature logs are available from these wells. Well ER-23 has been production tested on two occasions, first in August and September 1988 (Jónsson et al., 1988) and later in July 1996 (Björnsson and Steingrímsson, 1996). The geothermal energy is exploited for local greenhouses and space heating. This report presents an evaluation of temperature conditions, productivity and possible utilization schemes for the Efri-Reykir field. It describes work which was carried out as a part of the author's training at the UNU Geothermal Training Programme in Reykjavík in 1996.

Its purpose was, firstly, to define the temperature distribution, locate feed zones and outline the hot water upflow in the system. Secondly, the purpose was to analyse data from the two production tests. Thirdly, to review some possible utilization scheme for Efri-Reykir as well as utilization schemes which may be applicable in the author's home country, Vietnam.

2. THE EFRI-REYKIR GEOTHERMAL FIELD

2.1 Location and geological setting

The Efri-Reykir low-temperature geothermal field is located in the southern lowlands of Iceland (Figure 1), about 80 km east of Reykjavík and 4 km northeast of Lake Apavatn. The river Brúará, flowing southwards forms the western boundary of the geothermal area.

The active volcanic zone crossing Iceland represents a boundary where extension and accretion of the crust occurs. Faults, fractures and fissure swarms have been formed during the volcanic activity. Generally the dominant structures of the fissure swarms are volcanic fissures, noneruptive gaping cracks and faults or fault bundles with vertical and horizontal hades. Hot water flow comes up or down from these hades. These conditions are typical for the upper lowlands of South Iceland.

The lithology of the Efri-Reykir field is characterized by three layers, as follows: On top is an alluvium layer which covers the whole field, around 20 m in thickness (Saemundsson, pers. comm.). The second

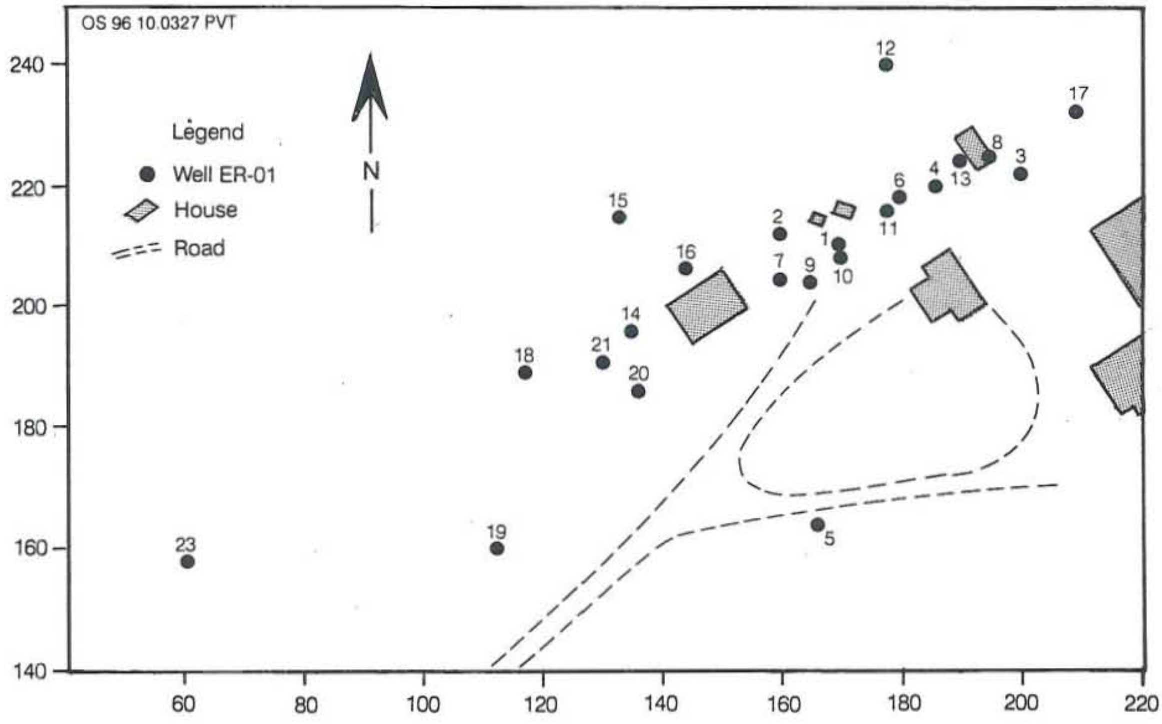

FIGURE 2: Location of wells in the Efri-Reykir area

layer is a part of the so-called upper Pleistocene series. It consists of different kinds of basaltic rocks, such as fresh basalt, altered basalt, basaltic breccia and tuff or hyaloclastites with ages ranging from 0.7 to 3.1 m.y. This includes thick files of breccia, a feature characteristic of the upper Pleistocene series in South Iceland. The breccia files are commonly several hundred m thick. The third layer is later Tertiary and Pleistocene hyaloclastites, around 700-800 m thick, with an age of 2 million years.

Several horizontal aquifers appear in the range 20-60 m depth. Of special note is an upflow at 720 m depth in the well ER-23.

2.2 Distribution of soil temperature

Measurements of soil temperature have proven to be a valuable geophysical method in prospecting for geothermal resources in Iceland. Measurements of soil temperature at for example 0.5 m depth in a field can give important structural information (Flóvenz, 1985). The results of soil temperature measurements in the Efri-Reykir field are shown in Figure 3. The northeastern part of the area is

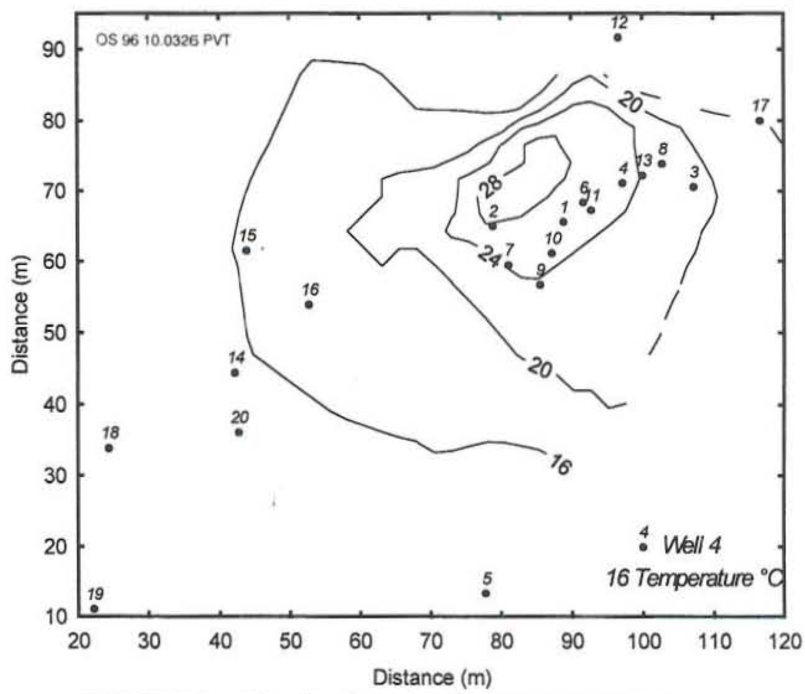

FIGURE 3: Distribution of soil temperature (°C)

characterized by an anomaly of 20-30°C. Wells ER-01, ER-02, ER-03, ER-04, ER-06 and ER-13 are located in this anomalous area. Outside it the soil temperature is in the range of 10-15°C, except near well ER-22 where the soil temperature is only 4°C, close to the average annual temperature in this area. Shallow flow of hot water (20-30 m depth) is responsible for the high soil temperature at Efri-Reykir.

2.3 Drilling history

Since 1982, twenty-three wells have been drilled in the Efri-Reykir area; all of them are exploration wells except one. The locations of the wells are shown in Figure 2. The wells are also listed in Table 1 along with information on their identification numbers in the Orkustofnun data-base (Oracle code number), their time of drilling, depth and casing. The first six wells (ER-01 - ER-06) were drilled in 1982, ranging in depth from 18 to 60 m. Seven wells (ER-07 - ER-13) were drilled in 1985, also ranging in depth from 18 to 60 m. Eight wells (ER-14 - ER-21) were drilled in 1986 with depths from 51 to 152 m. The last wells, ER-22 and ER-23, were completed in 1988 at 107 m and 722 m depth, respectively. Well ER-23 is free-flowing with a shut-in wellhead pressure of more than 4 bars.

TABLE 1: Basic information on the wells at Efri-Reykir

Well no.	Oracle code	End of drilling	Depth (m)	Casing length (m)
ER-01	91621	8.6.1982	74.5	31
ER-02	91622	11.6.1982	64	14.5
ER-03	91623	14.6.1982	31	10
ER-04	91624	15.6.1982	31	5.6
ER-05	91625	16.6.1982	30.5	1.7
ER-06	91626	19.6.1982	36.6	7.5
ER-07	91627	11.9.1985	60	
ER-08	91628	12.9.1985	30	
ER-09	91629	1.10.1985	62	
ER-10	91630	2.10.1985	46	
ER-11	91631	3.10.1985	20	
ER-12	91632	3.10.1985	18	
ER-12	91632	19.8.1986	40	
ER-13	91633	3.10.1985	18	
ER-14	91634	7.8.1986	51	
ER-15	91635	12.8.1986	60	7
ER-16	91636	12.8.1986	57	
ER-17	91637	13.8.1986	57	
ER-18	91638	18.8.1986	60	6
ER-19	91639	18.8.1986	60	8
ER-20	91640	19.8.1986	56	
ER-21	91641	29.11.1986	152	
ER-22	91642	18.4.1988	107.2	
ER-23	91643	1.6.1988	722.1	58

3. ANALYSIS AND INTERPRETATION OF TEMPERATURE DATA

3.1 Analysis of temperature logs and location of feed zones

Temperature logs are sets of temperature values recorded at different depths down a drillhole. The purpose of measuring temperature logs is to define the temperature distribution and outline of the hot water upflow in a system as well as to locate feed zones in wells.

During drilling, warm up and production, eighty temperature logs have been measured in the wells. The eight last temperature logs were carried out on 4th September 1996 by the author and his advisor. The temperature logs provide the basis for evaluation of the formation temperature in the geothermal system and location of feed zones. Information on the temperature logs from the twenty-three wells in the Efri-Reykir field is summarized in Table 2, and the logs are presented in Appendix I.

The formation temperature for a well is the true, or static, temperature in the formation around the well. Generally, formation temperature is based on the available temperature logs, but it is necessary to take into consideration some factors which disturb the logs. First, during the warm-up period the well has not reached equilibrium with the surrounding rock. Second, internal flow (up or down) will disturb temperature logs. The evaluation of formation temperature at Efri-Reykir was based on several principles:

a) Bottomhole temperatures, recorded during drilling;
b) Analysis of temperature disturbances in the well;
c) If temperature logs are available with the well in equilibrium and there is no flow in the well, then the log is assumed to represent the formation temperature.

According to the above, all temperature logs have been analysed one by one or in sets of similar logs and the formation temperature for each well estimated. The formation temperature profiles are presented in Figure 4. Most of the temperature logs show increasing temperature with depth down to where there is a maximum in temperature. Below that the temperature decreases again. This indicates a horizontal flow, probably along a fault or a fissure in the formation cut by the wells.

Well ER-01: The well is situated at the centre of the geothermal field. Altogether there are five temperature logs from this well. The first temperature log was taken on 8th June 1982, and the second temperature log two days later. It is about 12°C warmer than the first. The third temperature log was recorded on 16th June 1982 and its temperature reaches 110°C at 25 m depth and this log can be considered to show the formation temperature. The fourth and fifth temperature logs were similar to the third. All five temperature logs show two feed zones at 54 and 74.5 m depths and a horizontal flow at 20-30 m depth.

Well ER-02: Five temperature logs have been taken in the well. The first temperature log was recorded during drilling. Later temperature logs were similar and can be considered to show the formation temperature. All temperature logs show a horizontal flow at 20-40 m depth with temperature of 76-82°C. Water level on 10th June 1982 was 3.5 m and 6.0 m on 5th July 1982.

Well ER-03: Three temperature logs have been taken. All three temperature logs show a horizontal flow of 66-70°C at 20 m depth and the last one can be considered as showing the formation temperature. Water level was measured in a range from 6.0 to 8.5 m.

Well ER-04: Only one temperature log from the well exists taken on 16th June 1982, one day after the drilling stopped. There was free flow of 0.6 l/s at 111.4°C from the well. The temperature log also shows a horizontal flow at 18-22 m depth. Temperature below 20 m can be considered as the formation temperature but above that the log is disturbed.

TABLE 2: Temperature logs and water level at Efri-Reykir

Well no.	Temperature logging date	Water level (m)	Comment	Well no.	Temperature logging date	Water level (m)	Comment
ER-01	8.6.1982	6.5	31 m casing	ER-13	3.10.1985		
	10.6.1982				3.10.1985		
	16.6.1982	5.6			18.6.1986		
	5.7.1982	5.5			4.9.1996	2.07	
	7.7.1982	6.5		ER-14	7.8.1986	5.5	2 hours after drilling
ER-02	10.6.1982	3.5			8.8.1986	5.5	20 hours after drilling
	14.6.1982		Flowrate 0.5l/s		4.9.1996	5.7	
	16.6.1982	5.3		ER-15	13.8.1986		0.5 hour after drilling
	5.7.1982	6.0			4.9.1996	9.02	
	4.9.1996	7.3		ER-16	13.8.1986		Dry well
ER-03	16.6.1982	5.8			13.8.1986		
	5.7.1982	8.5		ER-17	14.8.1986		
	7.7.1982	6.0			14.8.1986		
	4.9.1996			ER-18	18.8.1986	5.0	
ER-04	16.6.1982		Flowrate 0.6 l/s		18.8.1986	5.0	
ER-05	16.6.1982				19.8.1986	5.0	
	5.7.1982	5.0		ER-19	18.8.1986	5.0	
	4.9.1996	4.9			19.8.1986	5.0	
ER-06	5.7.1982	4.5		ER-20	18.8.1986	10.0	0.5 hour after drilling
	4.9.1996	1.6			19.8.1986	10.0	6 hours after drilling
ER-07	11.9.1985				20.8.1986	10.0	20 hours after drilling
	11.9.1985			ER-21	28.11.1986	5.0	At the end of drilling
	18.6.1986				29.11.1986		Well closed over night, flowrate 1 l/s
ER-08	11.9.1985				7.12.1986		Disch. 1 l/s , well closed
	18.6.1986	3.0			4.1.1987		Disch. 1.5 l/s , well closed
	4.9.1996	2.47		ER-22	14.4.1988	6.1	At the end of drilling
ER-09	3.10.1985		36 hours after drilling		14.4.1988	34.4	Air-lift testing
	4.10.1985				15.4.1988	4.1	After 12 hr drill-break
	18.6.1986				18.4.1988	3.7	
ER-10	1.10.1985				21.4.1988	3.7	
	3.10.1985				26.5.1998		
	18.6.1986				4.9.1996	2.5	
ER-11	3.10.1985			ER-23	21.4.1988		At the end of drilling
	18.6.1986				22.4.1988	4.5	
	4.9.1996	3.54			23.4.1988	4.5	
ER-12	3.10.1985				25.4.1988	4.6	After a weekend break
	18.8.1986				29.4.1988		In drillstring,12 hrs. break
	19.8.1986				24.5.1988		In drillstring
	19.8.1986				24.5.1988	0.0	In drillstring
	4.9.1996	8.0			29.8.1988	3.5 bar	After a discharge test
					15.7.1996	3.5 bar	Flowing

Well ER-05: Three temperature logs have been taken. All temperature logs show a horizontal flow of 48-50°C at 20-30 m depth. Water level measured was 5.0 m. The second temperature log was probably taken when the well was in a stable condition and can be considered as the formation temperature. The last temperature log shows a slight cooling, probably due to the production from the field.

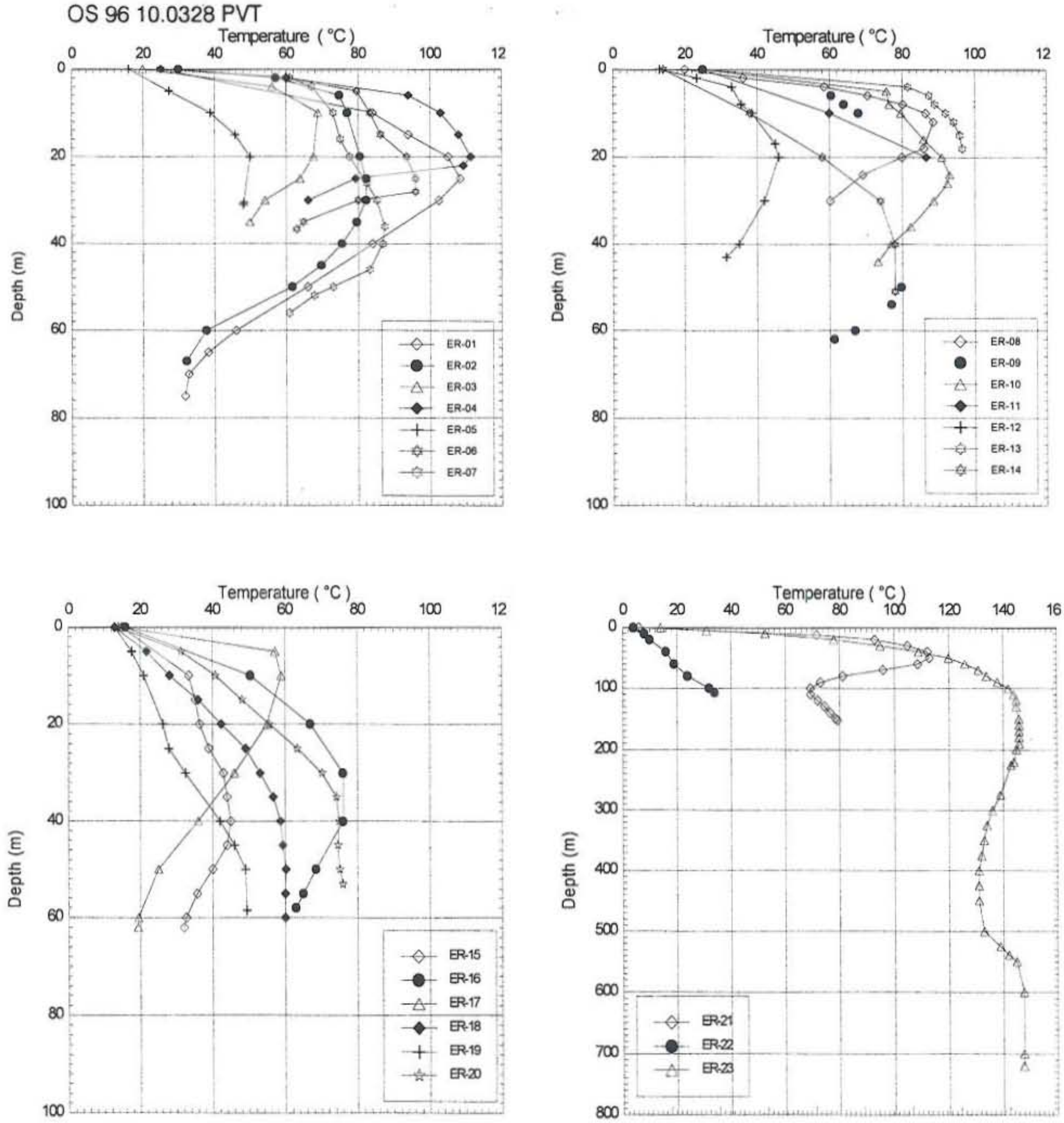

FIGURE 4: Formation temperature profiles from the Efri-Reykir wells

Well ER-06: Two temperature logs have been taken from the well. They were similar and can be considered as the formation temperature. The temperature logs show a horizontal flow of about 96°C at a depth of 24-30 m. This caused a negative geothermal gradient at greater depth. Water level measured was 4.5 m.

Well ER-07: Three temperature logs have been taken. The first two temperature logs were made during drilling and the third nine months later. All three temperature logs are similar and indicate a horizontal flow at 20-50 m depth. The first log below 20 m is considered as representing the formation temperature.

Well ER-08: Three temperature logs have been recorded in the well. The first was taken during drilling. The second is similar to the first. At a 10 m depth a horizontal flow of 100°C hot water can be seen in all the logs. The third temperature log shows higher temperatures than the others and was taken after eleven months of warm-up and can be considered to show the formation temperature.

Well ER-09: Three temperature logs have been recorded. The first temperature log was carried out at the end of drilling, the second two days later, and the third eight months later. All three temperature logs indicate three small aquifers, one shallow at 6 m another at 48 m and the deepest at 56 m depth. There is a down-flow between the two deeper ones. This well intersects the horizontal flow at above 60 m depth. The formation temperature is estimated at 10 m depth from the second log and at 50-62 m depth from the third log.

Well ER-10: Two temperature logs have been taken from the well. The first one was recorded one day after the end of drilling, but the second one few months later. They show a horizontal flow of 93°C at 20-30 m depth. The second log is considered to show formation temperature.

Well ER-11: Three temperature logs have been taken, the first one during drilling, the second a few months later and the third ten years later. An aquifer can be seen at the bottom of the well. The measured bottomhole temperature of 87°C can be considered the formation temperature.

Well ER-12: Five temperature logs have been taken from the well. The first two were recorded before the well was deepened. The second temperature log can be considered to show the formation temperature down to 20 m. Three logs have been taken since the well was deepened. An aquifer at the bottom of the well can be seen, with a flow between that aquifer and one at a shallow depth.

Well ER-13: There are three temperature logs from the well. The first two, measured at the end of drilling, show a feed zone of 97°C at 18 m depth. This is the maximum measured temperature at the bottom of the well. The last temperature log is colder than the others and shows the formation temperature after the well stabilized after drilling.

Well ER-14: Only one temperature log has been recorded in the well, during drilling. The temperature log is considered to show the formation temperature. A horizontal flow can be seen at around 40 m depth. Water level was at 5.5 m in the well.

Well ER-15: A temperature log was taken at the end of drilling and shows a flow between aquifers at 25 m and 50 m depths. The second log was taken ten years later and generally shows lower temperature than the first one. The temperature from 56 m down to the bottom of the well in the first log is considered to show the formation temperature .

Well ER-16: Two temperature logs have been taken, both one day after the drilling stopped. Both temperature logs show a horizontal flow at around 35 m depth. The second one is considered as giving the formation temperature of the well.

Well ER-17: Two temperature logs were taken on the same day (14th August 1986). Both temperature logs show flow between a shallow aquifer and one at 48 m depth. The formation temperature is estimated at 10, 60 and 62 m depth from the second log.

Well ER-18 : Three temperature logs have been recorded in the well, the first two were taken at the end of drilling and the third a day later. All the logs show a horizontal flow at 50-60 m depth. The last log is considered showing the formation temperature.

Well ER-19: Two temperature logs have been taken. The first log was obtained during drilling, the second was taken a day later. Both temperature logs show a feed zone at 25-30 m depth. The bottomhole temperature is considered the formation temperature.

Well ER-20: Altogether there are three temperature logs from the well. The first two were taken during drilling, but the third was recorded one day after the drilling stopped. All three logs are similar and show horizontal flow at 40-56 m depth. The last log shows higher temperature than the other and is considered to show formation temperature. Water level was at 10 m in the well.

Well ER-21: Four temperature logs have been taken from the well. All the logs indicated a horizontal flow and a feed zone at 58-60 m depth. The maximum measured temperature is 116°C at 58 m depth and the bottomhole temperature is 80°C; the temperatures below 58 m in the last two logs are considered formation temperature.

Well ER-22: It is located outside the geothermal field. Altogether there are seven temperature logs from the well. The first two were taken at the end of drilling. All the temperature logs show a downflow of cold water in the well and it is considerable colder than the other wells.

Well ER-23: Nine temperature logs have been taken from the well. The first four were recorded to a depth of 60 m. The logs on 24th May 1988 show the horizontal flow below 120 m depth. The last five temperature logs indicate a feed zone of 148°C at 720 m depth. The temperature measured on 24th May 1988 is considered the formation temperature and the bottomhole temperature comes from the last logs.

TABLE 3: Location and temperature of feed-zones in the Efri-Reykir wells

Well no.	Location (m)	Max. temperature (m, °C)
ER-01	20-30, 54, 75	25, 110
ER-02	25, 30	30, 82
ER-03	30-35	15-20, 68
ER-04	18-22	20, 111
ER-05	20-25	25, 50
ER-06	24-30	28, 96
ER-07	30-40	34, 89
ER-08	8-12	10, 100
ER-09	6, 48, 56	52, 80
ER-10	20-26	24, 95
ER-11	18-20	20, 87
ER-12	2, 42	40, 38
ER-13	8, 18	16, 98
ER-14	36, 51	40, 79
ER-15	25, 50	40, 40
ER-16	35	35, 75
ER-17	6, 60	10, 61
ER-18	44, 60	55, 61
ER-19	10-30, 59	59, 49
ER-20	40, 54	53, 76
ER-21	58-60, 100-152	58, 116
ER-22		no feedzone
ER-23	120-130, 700	720, 147

Location and temperature of the minor feed zones in the Efri-Reykir wells are listed in Table 3. Generally in the Efri-Reykir geothermal field, there is a horizontal shallow aquifer with feed zones in some of the wells and one deep aquifer (720 m) in well ER-23.

3.2 Formation temperature distribution

The temperature measurements in the wells has been used to estimated the formation temperature around the wells. In general, the formation temperature increases fast at shallow depths (0-20 m). The temperature gradient at shallow depth is higher than at greater depth. In most of the wells there is a negative temperature gradient below 20-60 m depth caused by horizontal flow.

Two cross-sections, A-A′ trending W-E along the anomalous area (Figure 5) and B-B′ trending N-S (Figure 6), were made of the formation temperature to better understand the flow pattern of the hot water in the field. The temperature anomalies give indications of the heat flow patterns (dykes and features) in the geothermal field. There is a high temperature anomaly that shows a horizontal aquifer at 20-60 m depth (Figure 5) in the eastern part of the well field that dips to the west. Another aquifer is intersected by well ER-23 at about 700 m depth. This aquifer probably dips to the west and intersects the other aquifer at shallow depth.

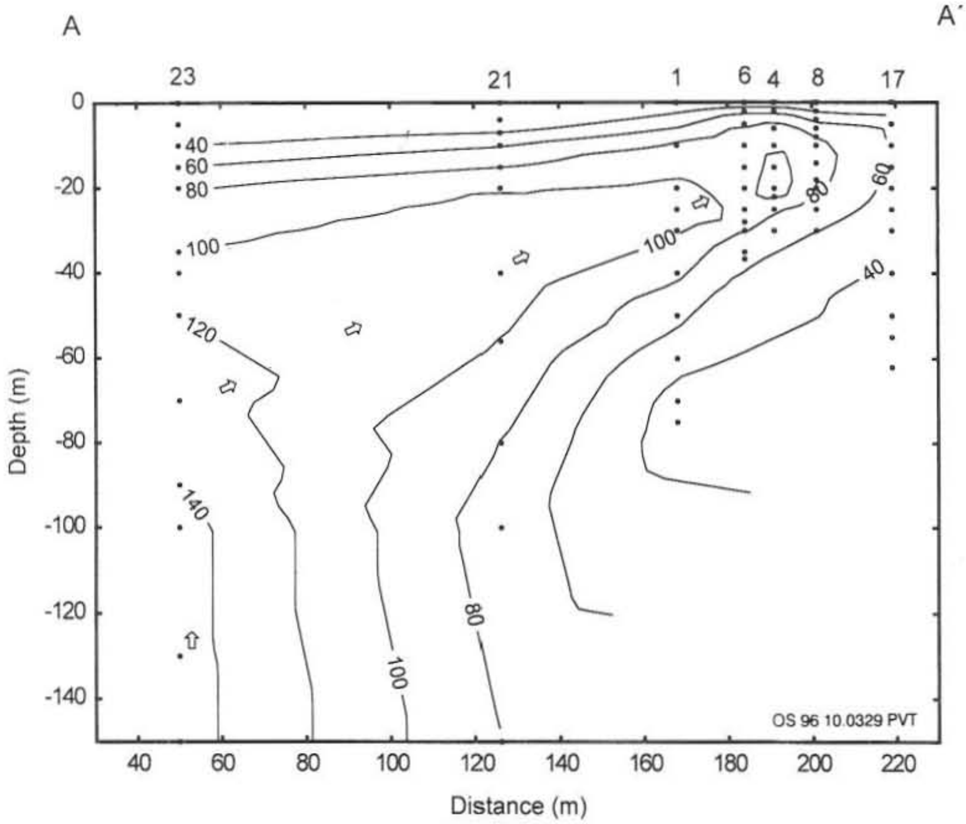

FIGURE 5: Temperature cross-section A-A', along the Efri-Reykir anomaly

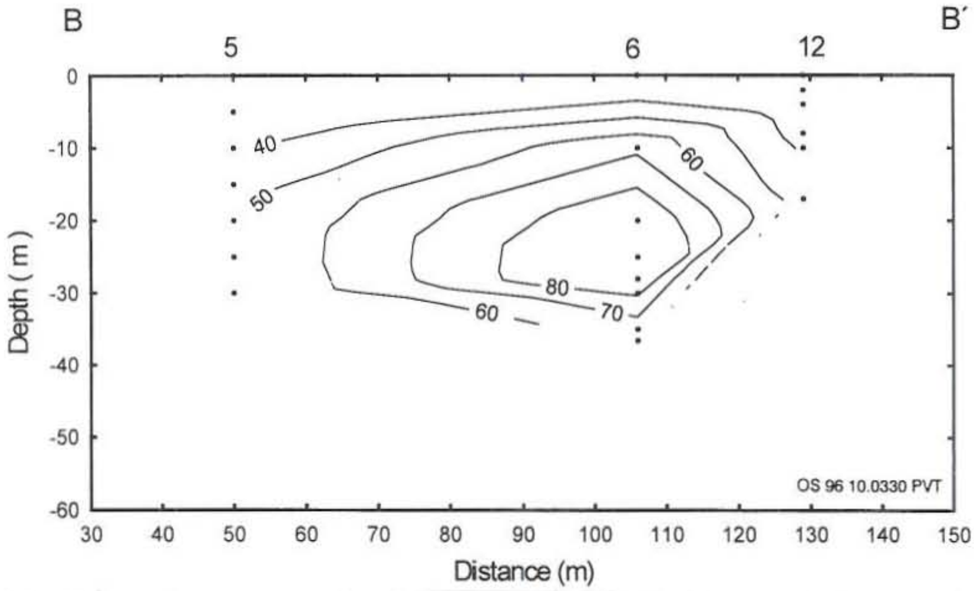

FIGURE 6: Temperature cross-section B-B', across the Efri-Reykir anomaly from south to north

The formation temperature distribution was also plotted at different depths. At 20 m depth, (Figure 7) the isotherms illustrate that there is an area of anomalously high temperature striking northeast. At 60 m depth (Figure 8), the isotherms also illustrate an area of anomalously high temperature striking northeast, but the highest temperatures are found more to the west at 60 m depth.

In summary, the Efri-Reykir low geothermal field is a fracture-dominated system which derives its heat from the hot crust by active and localized convection in near-vertical and horizontal fractures. At

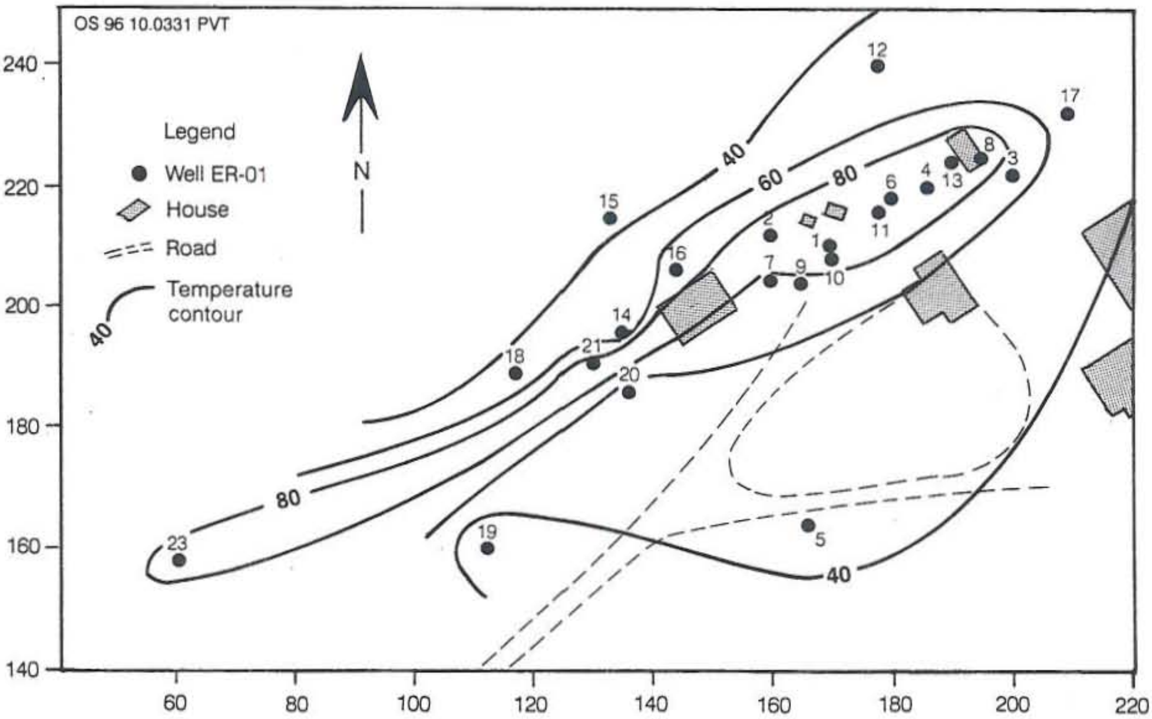

FIGURE 7: An isothermal map of the Efri-Reykir area at 20 m depth

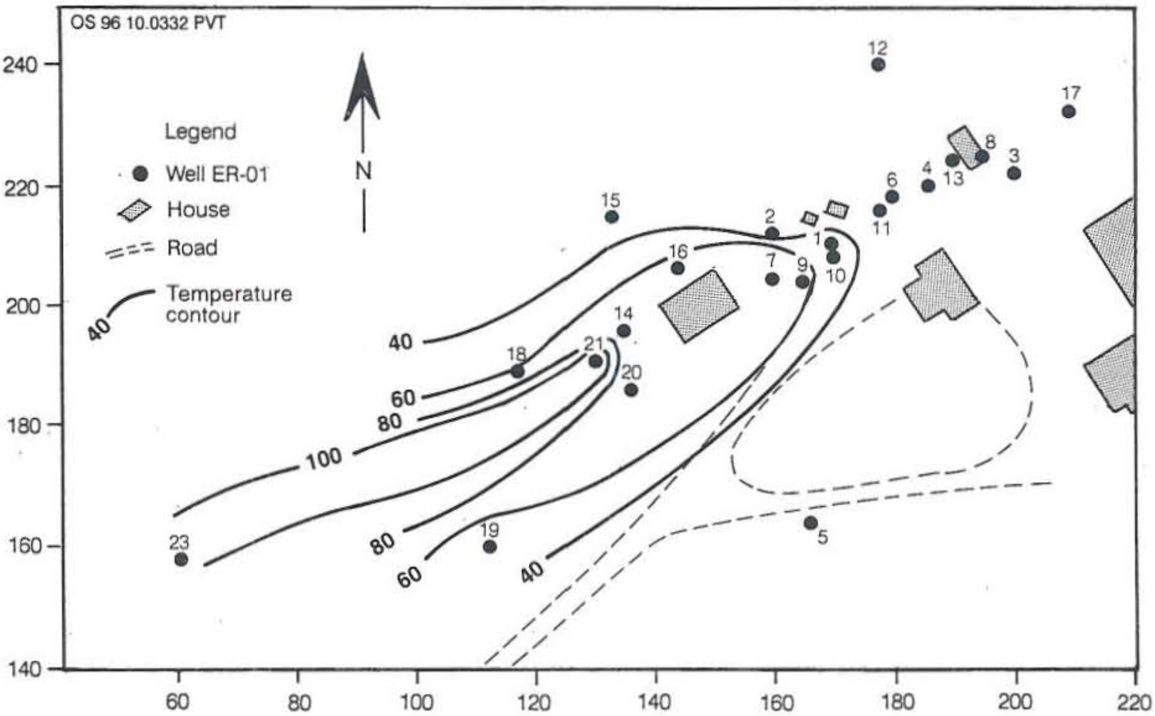

FIGURE 8: An isothermal map of the Efri-Reykir area at 60 m depth

shallow depth (in the range of 20-40 m) in the eastern part of the field, the temperature is much higher than at greater depth (see Table 3). This implies that at shallow depth there is a recharge of horizontal hot water with temperature over 100°C. That is due to the active convection occurring within the geothermal system, whereby the heat is transferred from the deeper part of the system to the shallower part through near-vertical faults or fissures probably located between wells ER-23 and ER-21 and which intersect the horizontal fractures at about 60 m depth.

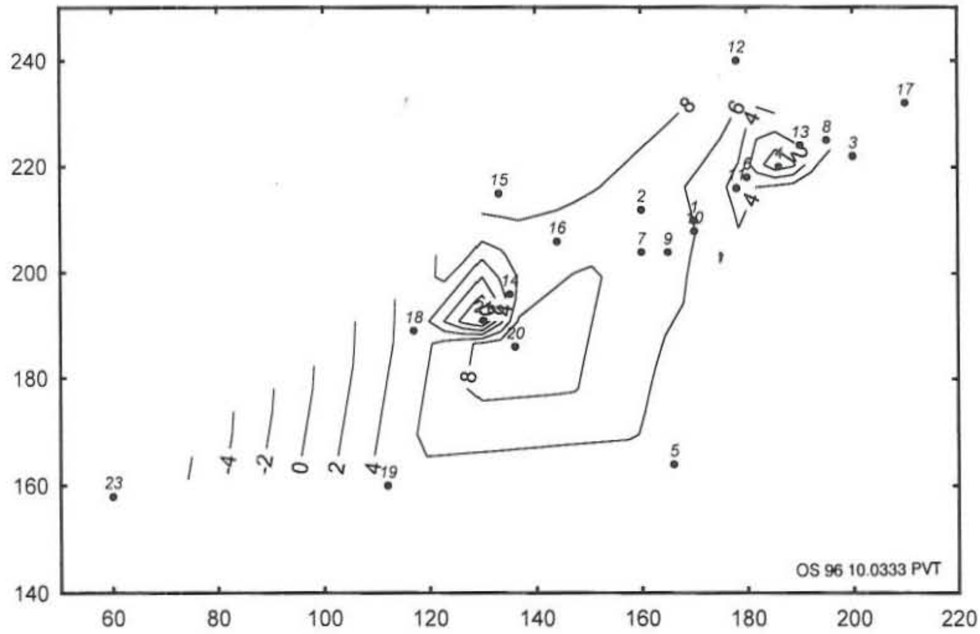

FIGURE 9: Contour map showing the water level in the Efri-Reykir wells

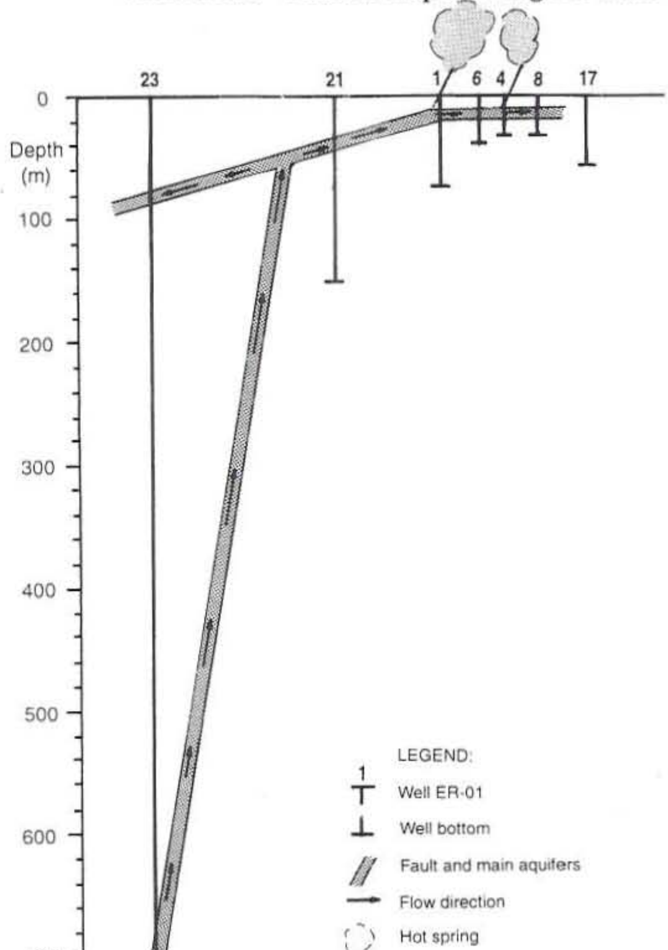

FIGURE 10: A conceptual model of the Efri-Reykir geothermal field

It is necessary to emphasize that temperature logging is a powerful method for obtaining infomation on the thermal state of a reservoir and it is successfully applied in Iceland and other countries around the world. In Figure 9 the water level in the wells is shown. From the contour lines, it can be seen that the water is generally flowing from west to east.

3.3 Conceptual model of the Efri-Reykir geothermal field

The general characteristics of the Efri-Reykir geothermal field are represented as follows and are summarized in Figure 10:

1. There is an anomaly in the soil temperature in the northeastern part of this field, around the hot springs;
2. Some faults or fractures chiefly striking SW-NE were found by surface geological investigation and exploration in 1982;
3. The distribution of the formation temperatures drawn in two cross-sections (Figures 5 and 6) and two temperature contour maps at 20

and 60 m depths (Figures 7 and 8) show that the direction of the hot flow is from southwest to northeast, that there is a horizontal flow at 20-60 m depth, and a vertical up-flow appeared in well ER-23 at 700 m depth;

4. The map of the water level (Figure 9) shows that direction of fluid movement is from southwest (ER-23) to northeast. In addition, wells ER-23, ER-21 and ER-04 have a free flow with gradually decreasing flow rate.

All the above features can be explained by supposing a near-vertical permeable fracture or fault striking southwest located between wells ER-23 and ER-21. A conceptual model of the Efri-Reykir geothermal field is shown in Figure 10. Well ER-23 cuts this fracture or fault close to the bottom of the well at around 700 m depth. The fracture then intercepts at shallower depth another fracture that is nearly horizontal and also striking southwest. This fracture is very shallow in the eastern part of field, where the hot springs are, but in well ER-23 it is intersected at 60 m depth.

4. ANALYSIS OF PRODUCTION DATA

4.1 Production testing of geothermal wells

During the warm-up period, the water level in a geothermal well will gradually rise and eventually build a wellhead pressure above atmospheric pressure if the well is artesian. When the wellhead pressure has built up sufficiently, a production test can be conducted by flowing the well through an orifice. To quantify a well's output and obtain data suitable for reservoir analysis and surface plant design, the following information must be obtained during the test: 1) the total mass flow, 2) the discharge enthalpy of temperature, 3) the noncondensible gas content, and 4) the total dissolved solid. The latter two are naturally only required if the chemical quantities are significant.

Several different methods are available for estimating the first two parameters (flow and enthalpy), depending on the conditions during a given test. One method involves using a separator and measuring the water and the steam flow rate separately. Another method is the Russel-James method where the total flow is given by the so-called lip pressure and the enthalpy of two-phase mixture (Grant el al.,1982).

During a successful output test the stable or quasi-stable flow can be measured at different wellhead pressures. From the manner in which the mass flow and enthalpy vary with wellhead pressure some deductions can be made about the reservoir in question. For example, in a reservoir of liquid water of constant temperature, such as at Efri-Reykir, variations in output are controlled solely by variations in pressure at the wellhead and in the reservoir.

According to the above, well ER-23 has been production tested on two occasions. First in August/September 1988 and later in July 1996. The analysis of the data collected during these tests is discussed in the following.

4.2 Data from the 1988 test

The first test, in 1988, lasted 21 days. During the first few hours the flow rate was increased in steps. Following that the well discharge remained relatively stable throughout the test. A separator was used during this test and a weir box with a sharp edge rectangular V-notch, to measure the separated water flow rate. This is given by a formula of the type:

$$m_w = K \rho \Delta h^m \tag{1}$$

where ρ and Δh are the water density and the water head in the weir box measured from the tip of the V-notch, respectively. The exponent m is ≤2.5 and for SI-units K = 1.3-1.4 is constant.

For a liquid-dominated reservoir such as Efri-Reykir the discharge enthalpy will be that of liquid water at the presumed reservoir temperature, i.e. the temperature of the well's major feed. Consequently the total flow rate is determined by using the following formula:

$$m_t = \frac{m_w}{1-X} \tag{2}$$

where m_t and m_w are the total and water flow, respectively, in kg/s and X the mass ratio of steam, given by

$$X = \frac{h_t-h_w}{h_s-h_w} \tag{3}$$

where h_t is the discharge enthalpy (two-phase) and h_w, h_s are the enthalpies of water and steam at the wellhead pressure (steam tables or the program TAFLA).

The steam flow (kg/s) is then given by

$$m_s = Xm_t \tag{4}$$

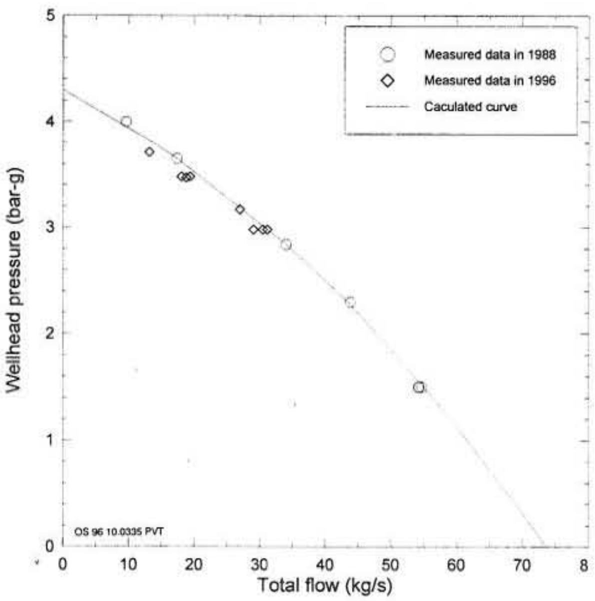

FIGURE 11: The plot of wellhead pressure vs. total flow

The data, measured and calculated, from the production testing of ER-23 are listed in Table 4. According to a temperature-log from 19th August 1988, the feed zone temperature is 146°C and the corresponding enthalpy 616 kJ/kg.

4.3 Analysis of step rate test

Based on the data in Table 4 the characteristic curve for well ER-23 is plotted in Figure 11. It shows the variations in mass flow versus wellhead pressure, i.e. the so-called output curve. As wellhead pressure reduces the total flow increases. The extrapolation of the curve indicates the maximum pressure of 4.3 bar-g as the discharge approaches zero. The data in Figure 11, i.e. wellhead pressure versus total flow, may be simulated by a second order equation as follows:

TABLE 4: Well test data from well ER-23 in 1988

Date	**Time**	**Measured values**			**Caculated values ***		**Step**
		Wellhead pressure ER-23 (bar-g)	**Water flow rate ER-23 (kg/s)**	**Wellhead pressure ER-21 (bar-g)**	**Total flow rate ER-23 (kg/s)**	**Steam flow rate ER-23 (kg/s)**	
88.08.12	11:00	3.90	0.0	0.65	0.0	0.0	
88.08.12	11:15	4.00	0.0		0.0	0.0	
88.08.12	11:20	4.00	11.0		12.0	0.7	
88.08.12	11:25	4.00	8.9		9.7	0.6	1
88.08.12	11:30	4.00	8.7	0.52	9.6	0.6	
88.08.12	11:40	4.00	8.6	0.51	9.4	0.6	
88.08.12	11:45	4.00	8.4	0.5	9.2	0.6	
88.08.12	11:50	3.72	18.2		19.9	1.2	
88.08.12	11:55	3.72	18.0	0.48	19.7	1.2	
88.08.12	12:00	3.68	17.2		18.8	1.2	2
88.08.12	12:05	3.66	17.2	0.55	18.8	1.2	
88.08.12	12:10	3.65	17.2		18.8	1.2	
88.08.12	12:15	3.65	15.8		17.3	1.1	
88.08.12	12:20	2.93	33.5		36.7	2.3	
88.08.12	12:25	2.90	32.8	0.48	35.9	2.2	3
88.08.12	12:35	2.86	32.1	0.52	35.1	2.2	
88.08.12	13:00	2.84	31.0		34.0	2.1	
88.08.12	13:10	2.30	40.4		44.3	2.7	
88.08.12	13:20	2.30	40.0	0.47	43.8	2.7	4
88.08.12	13:30	2.30	40.0		43.8	2.7	
88.08.12	13:40	1.50	50.9		55.7	3.4	
88.08.12	13:50	1.50	50.9		55.7	3.4	
88.08.12	14:00	1.50	50.0	0.28	54.7	3.4	
88.08.12	14:30	1.50	49.5		54.2	3.3	
88.08.12	15:20	1.50	48.6	0.2	53.2	3.3	
88.08.12	20:00	1.45	47.2	0.2	51.7	3.2	
88.08.13	08:00	1.45	47.2	0.2	51.7	3.2	
88.08.13	20:00	1.45	45.5	0.2	49.8	3.1	
88.08.14	08:00	1.45	45.5	0.2	49.8	3.1	
88.08.14	20:00	1.45	45.5	0.2	49.8	3.1	
88.08.15	08:00	1.45	45.5	0.2	49.8	3.1	
88.08.15	20:00	1.45	45.5	0.2	49.8	3.1	
88.08.16	08:00	1.45	45.5	0.18	49.8	3.1	
88.08.16	20:00	1.45	45.5	0.16	49.8	3.1	5
88.08.17	08:00	1.45	45.5	0.16	49.8	3.1	
88.08.17	20:00	1.45	45.5	0.15	49.3	3.1	
88.08.18	08:00	1.45	45.0	0.15	49.3	3.0	
88.08.18	20:00	1.45	45.0	0.15	49.3	3.0	
88.08.19	08:00	1.45	45.0	0.15	49.3	3.0	
88.08.19	20:00	1.45	45.0	0.15	49.3	3.0	
88.08.20	08:00	1.45	45.0	0.15	49.3	3.0	
88.08.20	20:00	1.45	45.0	0.15	49.3	3.0	
88.08.21	08:00	1.45	45.0	0.15	49.3	3.0	
88.08.21	20:00	1.45	45.0	0.15	49.3	3.0	
88.08.22	08:00	1.45	45.0	0.15	49.3	3.0	
88.08.22	20:00	1.45	45.0	0.15	49.3	3.0	
88.08.23	08:00	1.45	45.0	0.15	49.3	3.0	
88.08.23	20:00	1.45	45.0	0.15	49.3	3.0	

TABLE 4: Well test data from well ER-23 in 1988, continued

Date	Time	Measured values			Caculated values *		Step
		Wellhead pressure ER-23 (bar-g)	Water flow rate ER-23 (kg/s)	Wellhead pressure ER-21 (bar-g)	Total flow rate ER-23 (kg/s)	Steam flow rate ER-23 (kg/s)	
88.08.24	08:00	1.45	45.0	0.13	49.3	3.0	
88.08.24	20:00	1.45	45.0	0.13	49.3	3.0	
88.08.25	08:00	1.45	45.0	0.13	49.3	3.0	
88.08.25	20:00	1.45	45.0	0.13	49.3	3.0	
88.08.26	08:00	1.45	45.0	0.12	49.3	3.0	
88.08.26	20:00	1.45	45.0	0.12	49.3	3.0	
88.08.27	08:00	1.45	45.0	0.12	49.3	3.0	
88.08.27	20:00	1.45	45.0	0.12	49.3	3.0	
88.08.28	08:00	1.45	45.0	0.12	49.3	3.0	5
88.08.28	20:00	1.45	45.0	0.12	49.3	3.0	
88.08.29	08:00	1.45	45.0	0.12	49.3	3.0	
88.08.29	20:00	1.45	45.0	0.12	49.3	3.0	
88.08.30	08:00	1.45	45.0	0.12	49.3	3.0	
88.08.30	20:00	1.45	45.0	0.12	49.3	3.0	
88.08.31	08:00	1.45	45.0	0.12	49.3	3.0	
88.08.31	20:00	1.45	45.0	0.12	49.3	3.0	
88.09.02	11:50	1.45	45.0	0.16	49.3	3.0	
88.09.02	12:00	2.10	32.4	0.27	35.5	2.2	
88.09.02	12:10	2.10	31.7	0.28	34.7	2.1	
88.09.02	12:50	2.10	31.7	0.32	34.7	2.1	6
88.09.02	13:50	2.65	22.8	0.45	25.0	1.5	
88.09.02	14:15	3.30	0.0	0.52	0.0	0.0	

* Using h_t = 616 kJ/kg at T_{res} = 146°C

$$P = 4.3 - 0.0004\,q^2 - 0.029\,q \tag{5}$$

where P is the wellhead pressure and q the total flow.

Based on Equation 5 we calculate that q_{max} = 73.6 kg/s when P = 0. Thus, a relationship between total flow and wellhead pressure was also established as follows:

$$q = 73.6 - 8.8\,P - 0.61\,P^2 \tag{6}$$

4.4 Long-term test

A long-term test is necessary to estimate the long term variations in the reservoir, i.e. whether stable flow conditions are attained or whether a continuous decline in output may be expected. The long-term part of the production test of ER-23 lasted about twenty one days with a stable total flow of 49.3 kg/s and wellhead pressure of 1.45 bar-g. A pressure drop in the reservoir was observed in well ER-21 which is 76 m away from well ER-23 (see Figure 12). The data is of rather poor quality because the sensitivity of the sensor used was only 0.01 bar.

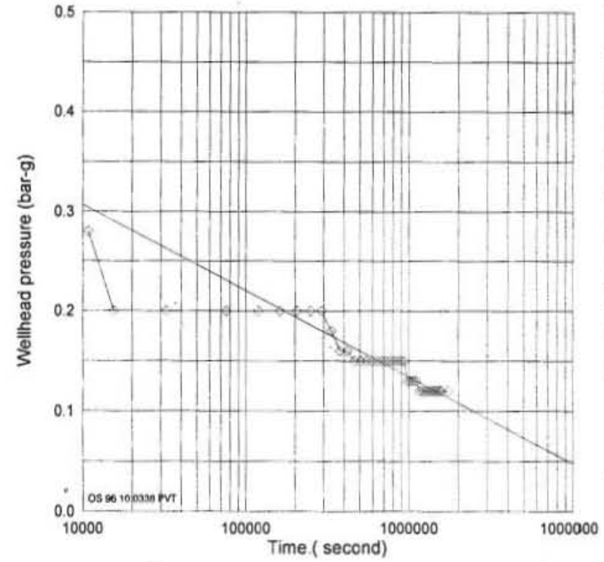

FIGURE 12: Wellhead pressure in ER-21 vs. logarithm of time

During the first 13 days of the test the wellhead pressure of ER-21 fell by 0.53 bar, from 0.65 to 0.12 bar (Table 4). This corresponds to a water-level drop of about 5.5 m. By plotting the wellhead pressure versus the logarithm of time, the transmissibility, kh/ν, may be estimated. This is done in Figure 12, yielding a slop of m = 0.09 bar/cycle and a transmissibility of $kh/\nu = 10^{-3}$ kg/Pa.s. This corresponds to a permeability-thickness of about 200 Dm, indicating a very high permeability.

4.5 Data from the 1996 test

Well ER-23 was production tested again on 15th July 1996. Prior to the actual test, a temperature and a pressure log were measured in the well. The temperature log is presented in Figure 13 along with a log from 29th August 1988. These logs are very similar. The main feed zone is at a depth of about 700 m with a temperature of 147.5°C. The temperature at the top of the well is 145°C with the specific enthalpy of 610 kJ/k.

The pressure log is presented in Figure 14. It shows that the pressure increases linearly with depth. The gradient is about 9300 Pa/m, indicating an average fluid density of 960 kg/m^3. This shows that no boiling occurs in the well, at a wellhead pressure of 3.45 bar-g.

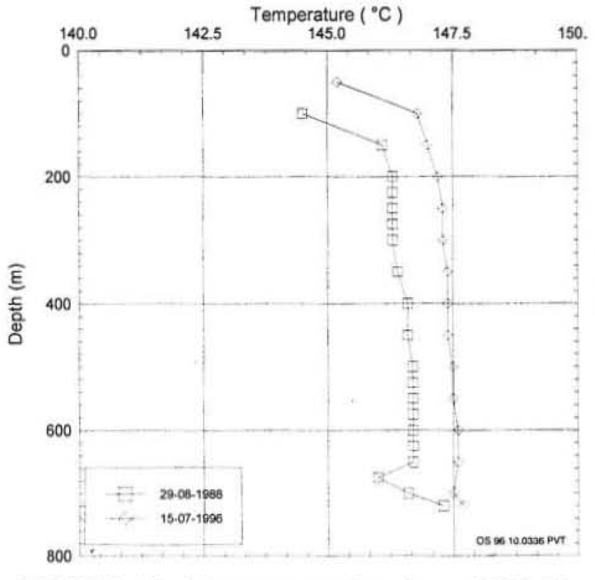

FIGURE 13: Temperature logs in well ER-23

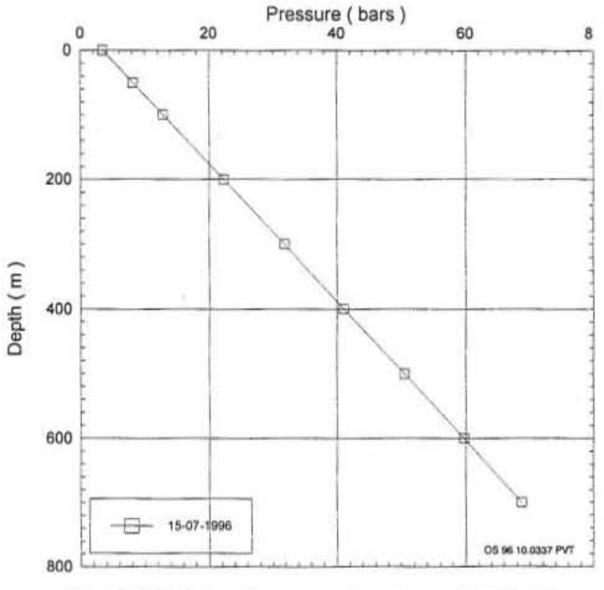

FIGURE 14: Pressure log in well ER-23

The second production test, which only lasted 2-3 hours, involved increasing the discharge from well ER-23 in two steps. The data collected during the test is presented in Table 5. Prior to the test the well was flowing at a rate of about 19 kg/s. During this test the water flow rate was measured while the total (steam + water) flow rate is calculated (Equations 2 and 3). The mass flow of steam is estimated to be about 8.5% (h_t = 610 kJ/kg at wellhead pressure of 3.2 bar-g and 145°C temperature and h_w = 419 kJ/kg, h_s = 2672 kJ/kg at atmospheric pressure and 100°C).

Initially the wellhead pressure varied from 3.4 to 3.6 bar-g, corresponding to a total flow of 18 to 19 kg/s. When the wellhead pressure was reduced to 3.17 bar-g the total flow was calculated to be 27 kg/s. The maximum total flow is 30.4 kg/s at 2.98 bar-g wellhead pressure. At the end of the test the wellhead pressure was raised to 3.7 bar-g and the total flow decreased to 13.1 kg/s.

If the average production from well ER-23 is assumed to equal the production prior to the test, 19 kg/s, the amount produced each year has been around 600,000 tonnes. The rate of heat production is then given by $Q = m \times h$ = 610 x 19 = 10600 kJ/s, which equals 10.6 MW, corresponding to an energy production of 370 x 10^{12} J (370TJ) per year.

TABLE 5: Well test data from well ER-23 in 1996

Time	Measured values		Calculated values*		Step
	Wellhead pressure (bar-g)	Water flow rate (kg/s)	Total flow rate (kg/s)	Steam flow rate (kg/s)	
13:43	3.58	16.5	18.0	1.4	
14:26	3.52	17.1	18.6	1.5	1
15:23	3.43	17.5	19.0	1.5	
15:59	3.55				
16:03	3.48	16.5	18.0	1.4	2
16:05	3.48	17.7	19.3	1.5	
16:08	3.47	17.1	18.7	1.5	
16:10	3.45				
16:17	3.16				3
16:20		24.6	26.9	2.3	
16:28	3.17	24.6	26.9	2.3	
16:30	2.98	26.5	29.0	2.5	
16:35	2.98	28.5	31.1	2.6	4
16:38		27.8	30.4	2.6	
16:42	3.71	12.1	13.1	1.0	
16:45	3.62				
16:47	3.65				5
16:48	3.67				
16:50	3.68				

* Using h_t = 610 kJ/kg at T_{res} = 145°C

4.6 Comparison between 1988 and 1996 step rate data

The 1988 production test was a long-term test. Its purpose was to estimate changes in the pressure conditions of well ER-23 and in the geothermal reservoir. This was done before long-term production from the well started. The test was carried out for three weeks. The test in 1996 lasted only for a period of three hours. Its purpose was to review the temperature and pressure conditions of the well, as well as conditions in the reservoir.

The output curve for well ER-23 in 1996 is plotted in Figure 11 along with the earlier results. The output curves for 1988 and 1996 are quite similar, in spite of a continuous production of 19 kg/s (estimated)for 8 years. This shows that the long-term pressure drop in the Efri-Reykir reservoir is very small, and that it will be able to sustain this production in the future. Considerably greater production will most likely be possible.

4.7 Steam production

If the wellhead or separator pressure is lower than 3.1 bar-g some steam will be produced from well ER-23. Based on Equation 6 above, the steam fraction and steam flow may be calculated as functions of pressure. Figure 15 shows that the steam flow and fraction will decrease as wellhead pressure increases. At 2 bar-g wellhead pressure the steam flow is about 1 kg/s and at 3 bar-g it is negligible. The maximum steam flow will be about 6.3 kg/s at 1 bar-a (corresponding to atmospheric pressure). This steam may be used to generate electricity.

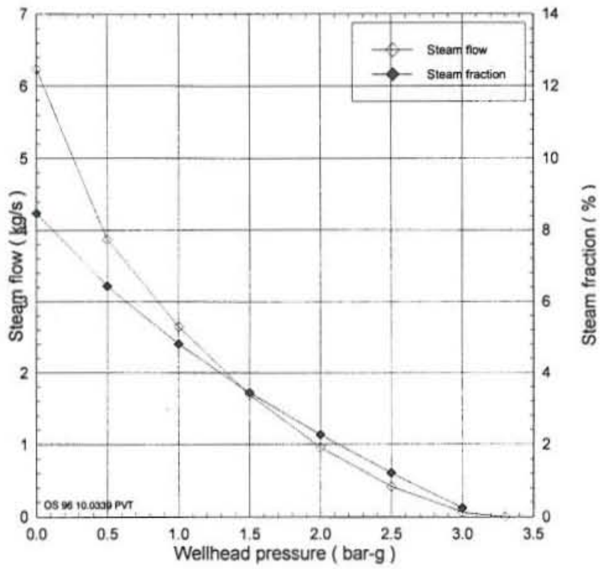

FIGURE 15: Steam flow in ER-23 vs. wellhead pressure

5. UTILIZATION SCHEMES

5.1 Introduction

Man has utilized geothermal energy for centuries. Historically its use was limited to washing, bathing and balneology. Currently, in addition to the above, the major fields of geothermal utilization are: electrical generation, space heating, agriculture, aquaculture and industrial applications. The Lindal diagram (Figure 16) gives an overview of the different models of utilization, for the different temperatures of geothermal resources. Many countries utilize geothermal energy, because it is economically competitive with other forms of energy. The two main categories of geothermal utilization are electrical power generation and the other is direct utilization. These will be discussed in the following, with special reference to utilization at Efri-Reykir and in Vietnam.

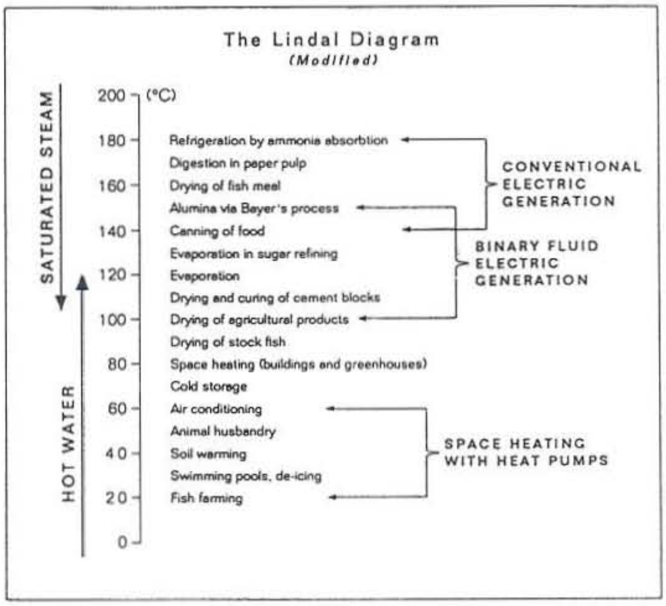

FIGURE 16: The Lindal diagram

5.2 Electricity generation

Geothermal electricity production is equally common in the industrialized and developing countries, but plays a more important role in the developing countries. Some of the countries which utilize geothermal energy to generate electricity are (numbers for 1994): USA (16,491 MWh); Philippines (5,470 MWh); New Zealand (2,193 MWh); Iceland (265 MWh) (Fridleifsson and Freeston, 1994). The high-temperature geothermal systems (>200°C) are most suitable for generating electricity. But in this section we will only consider the utilization of low-temperature geothermal energy to generate electricity. Geothermal binary fluid technology has been developed primarily to generate electricity from low- to medium-temperature geothermal systems and to improve the efficiency of utilization of geothermal resources by recovering waste heat. An obvious source of waste heat in a geothermal field is the separated water from the flash separators.

A binary plant can be designed to operate with temperatures in the range 85-170°C, through a conventional Rankine cycle. Net generated electric power can be calculated in the following formula:

$$NEP = \frac{(0.18T-10)ATP}{278} \tag{7}$$

where T is the temperature (°C); NEP the net electric power (KW); ATP the available thermal power (KW).

The binary cycle technique was developed by ORMAT (Dickson and Fanelli, 1990). Ormat modular power plants are available in a range from 200 kW to over 120 MW. Figure 17 shows a simplified diagram of a binary system.

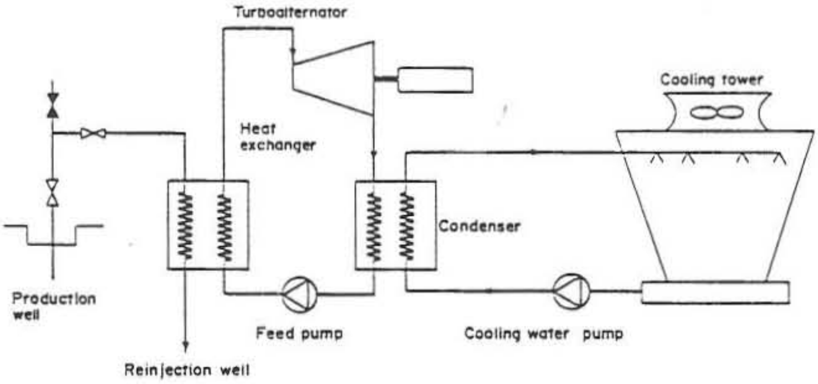

FIGURE 17: Binary cycle system simplified diagram (Hudson, 1995)

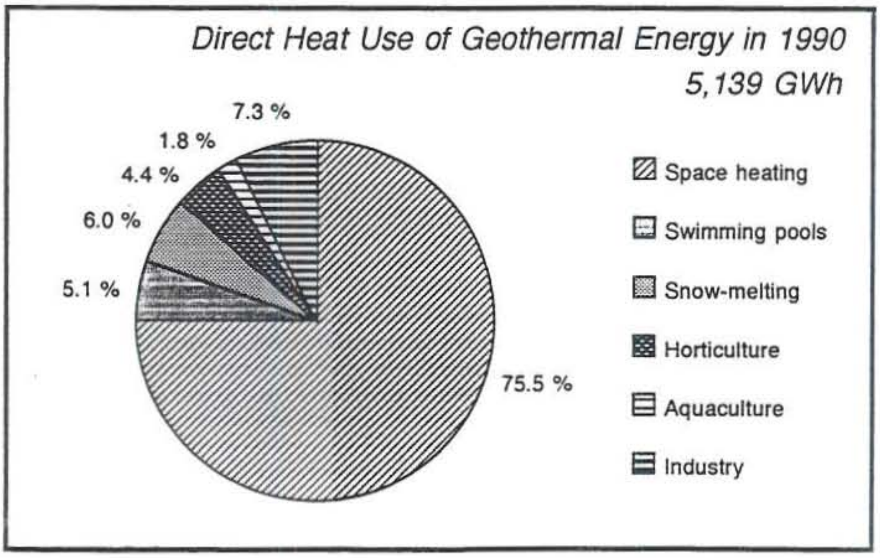

FIGURE 18: Non-electrical uses of geothermal energy in 1990, by sectors (Pálmason, 1992)

5.3 Direct utilization

The major fields of direct utilization are: space heating, agricultural applications, aquaculture, various industrial applications as well as in swimming pools, bathing and balneology.

In Iceland geothermal energy has been used for multiple purposes, thereby highly benefitting the economic development of the country. According to Pálmason (1992) the direct geothermal energy utilization can be divided as follows: Space heating 75.5%, swimming pools 5.1%, horticulture 4.4%, snow-melting 6.0%, aquaculture 1.8% and industrial applications 7.3% (Figure 18). In the following subchapters, the direct use of geothermal energy is discussed.

5.3.1 Space heating

Space conditioning includes both heating and cooling. Space heating with geothermal energy has widespread applications. Iceland is a good example where more than 85% of all houses are heated by geothermal energy. Individual buildings are heated by hot water which is pumped to them. The geothermal water is either used directly, or indirectly with the aid of heat exchangers. The latter is the case when the temperature of the geothermal fluid is too high (high-temperature system), or its chemical composition is not favourable. For space heating systems, as in Iceland, the optimum water temperature is 80°C and the return temperature, after passing through radiators is commonly in the range of 30-40°C. The low limit for district heating is 50-60°C.

5.3.2 Greenhouses

Typically, agricultural use of geothermal energy (including greenhouses) requires lower temperatures than space heating, or temperature of 25-90°C. Numerous commercially marketable crops have been raised in geothermally-heated greenhouses. In Iceland these include vegetables such as cucumbers and tomatoes as well as cut flowers and house plants. Using geothermal energy for heating reduces operating costs, which can account for 35% of product costs. The optimum growth temperatures of some vegetables are as follows: Cucumbers in the range 25-30°C, tomatoes near 20°C and lettuce at 15°C. The general design criteria for greenhouses can be found in Lund (1996).

5.3.3 Swimming pools

Low-temperature geothermal energy is well suited for use in swimming pools. The conventional water temperature in swimming pools varies from one country to another. In Iceland the pool water temperature tends to be kept at 30°C in outdoor pools.

5.3.4 Agricultural drying

Many industries utilize heat at temperatures under 150°C for evaporating water or to dry different products. The largest consumers are pulp and paper drying, as well as textile product drying, most in the 90-150°C range. Smaller industries with drying applications include sugar, furniture, rubber, leather, copper, concentrate, potash, soybean meal and tobacco.

Small fruit driers are feasible to dry fruit with geothermal heat. An example is a pilot drier in Mexico, which will be enclosed in a small building with room for trucks (hand carts) each holding 30 one-square-metre trays with a total capacity of approximately one tonne of wet fruit (Lund, 1996).

A rice drying plant can be operated with geothermal water of about 75°C temperature. Temperature of outflow fluid will be sufficiently high to feed drying plants for cereal, fodder, timber, etc. (60-80°C). In this plant, thermal exchange occurs between the fluid and airflow whose temperature must be constantly 2-3 to 10-20°C higher than the ambient temperature. Technical data and layout of a rice drying plant (Kotchni - Macedoria) are as follows: The geothermal water inlet temperature is 75°C; the geothermal water outlet temperature is 50°C; the production capacity is 10 tons/hr. of milled rice; the inlet moisture content is 20%, the outlet moisture content is 14% and the installed electric power 45 kW.

5.4 Geothermal energy utilization at Efri-Reykir

Well ER-23 at Efri-Reykir has been exploited for eight years. The hot water has mainly been used for space heating of farms and summerhouses in the neighbourhood. It is also used as hot tap water (washing and bathing), in a swimming pool and for heating greenhouses. The geothermal fluid from the well may also be used for generating electricity. A binary cycle would be most efficient. Using Equation 7 and ATP = 1590 kW, the NEP is calculated to equal 619 kW.

5.5 Possibilities of geothermal utilization in Vietnam

Many low-temperature geothermal fields in Vietnam are similar to the Efri-Reykir field in Iceland. At present, the use of geothermal water in Vietnam is limited to bathing, medical purposes, and mineral water production. General information about geothermal activity in Vietnam is listed in Table 6. Surface temperatures of the hot water springs are in the range 40-100°C. An example is the Binh Chau hot spring with a temperature of 80°C, which is used for a swimming pool and medical treatment.

The possible uses for the hot water from geothermal areas in Vietnam include:

- Drying of agricultural products;

- Drying of stock fish;
- Swimming pools;
- Electricity generation (if sub-surface temperatures turn out higher than listed in Table 6).

TABLE 6: Temperature and locations of hot water springs in Vietnam

Location	Temperature (°C)	Location	Temperature (°C)
Ta Vi	63	Dak Puong	53
Dan Thanh	70	Kon Br	60
Tan My	48	Nghia Ky	67
Hoi Van	84	Phouc Long	53
Vinh Thinh	71	Ninh Hoa	66
Lac Xanh	58	Xa Dieu	62
Mo Duc	76	Triem Duc	76
Binh Chau	80	Tac To	67
Mo Ray	53	Le Thuy	100
Hanh Dung	56	Phouc Tho	68
Rang Ria	63	Kon Du	60
Dak Ro Man	46		

6. DISCUSSION AND CONCLUSIONS

1. Twenty three-wells have been drilled, to date, in the Efri-Reykir geothermal field, all of them relatively shallow exploration wells, except the production well ER-23. From 1982 to 1996, eighty temperature logs were measured in the wells. Well ER-23 was production tested on two occasions, first for three weeks in 1988 and later for a few hours in 1996. An estimated 600,000 tonnes per year, or 19 kg/s, have been produced from well ER-23 during the last eight years.

2. The formation temperature distribution has been estimated on the basis of the temperature logs. Temperature anomalies at different depths delineate clearly the hot water upflow in the system. The conceptual model of the Efri-Reykir geothermal field is based on the formation temperature distribution. It includes a near-vertical up-flow in a fracture located between wells ER-23 and ER-21 intersected by ER-23 at 700 m depth. This fracture is connected to a near-horizontal aquifer which is found at a depth of about 20 m below the now extinct hot springs, but dips towards the west and is found at a depth of 60 m in well ER-23.

3. Analysis of the production test data from well ER-23 shows that the well is highly productive. The Efri-Reykir reservoir appears to be a single-phase, liquid-dominated system with a discharge temperature of 145°C and an enthalpy of about 610 kJ/kg. The maximum wellhead pressure is 4.3 bar-g and the maximum total flow 73.6 kg/s. At a wellhead pressure of 1.4 bar-g, the water and steam flow rate are 45 kg/s and 3.0 kg/s, respectively. At a wellhead pressure of 2.3 bar-g, the water and steam flow rate are 40 kg/s and 2.7 kg/s and at a wellhead pressure of 3 bar-g, the water and steam flow rate are 26.5 kg/s and 2.3 kg/s, respectively. In spite of approximately 600

thousand tonnes per year production, very little pressure drop appears to have taken place in the reservoir. Based on the interference in well ER-21 during the 1988 test, the permeability-thickness of the system is estimated to equal 200 Dm, which is a very high value.

4. The geothermal energy at Efri-Reykir is currently used for space heating, greenhouses and a swimming pool. Some electricity production is possible at Efri-Reykir. This would preferably be done with a binary cycle, which is more efficient at the temperatures at Efri-Reykir.

5. If the production is increased in the future, careful monitoring will become essential. The following should be monitored: Production, wellhead pressure and enthalpy for ER-2, wellhead pressure for ER-21 as well as chemical content of the fluid produced.

6. The possibilities of geothermal utilization in Vietnam are drying of agriculture products, drying of stock fish, swimming pools and electricity production by binary cycle.

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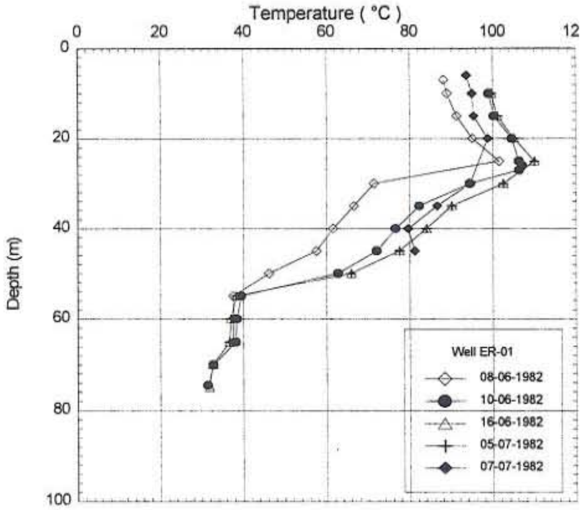
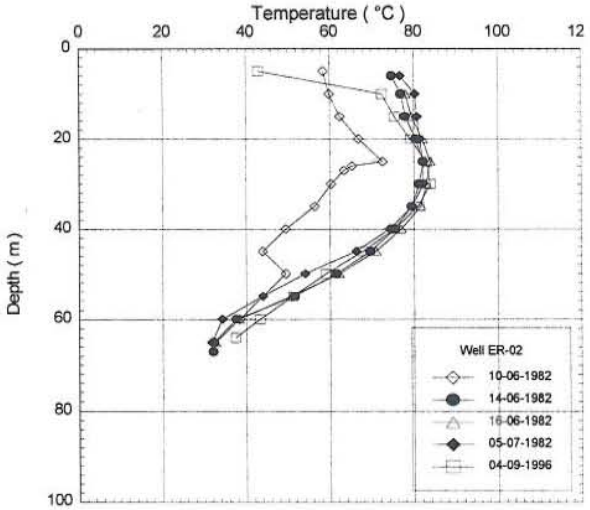
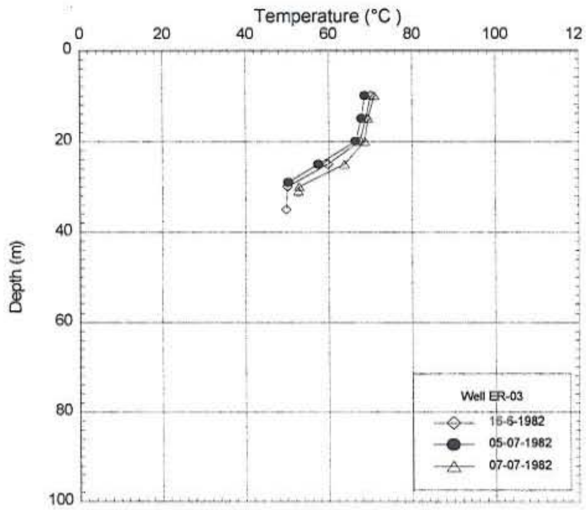
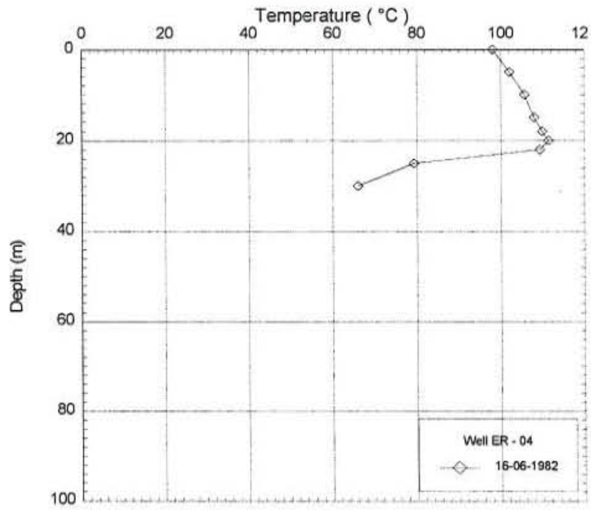
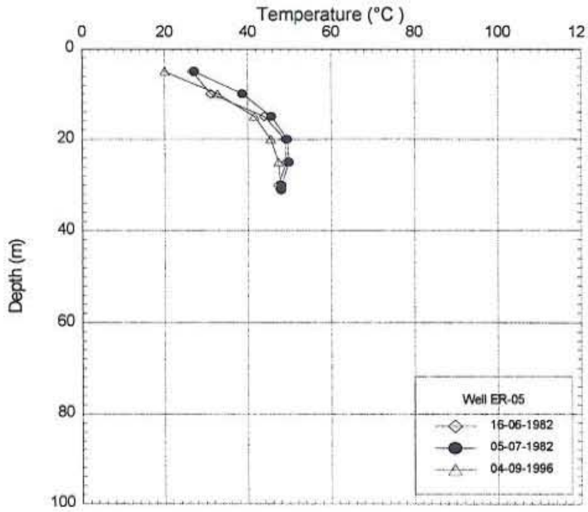
APPENDIX I: Temperature logs in the wells in the Efri-Reykir area

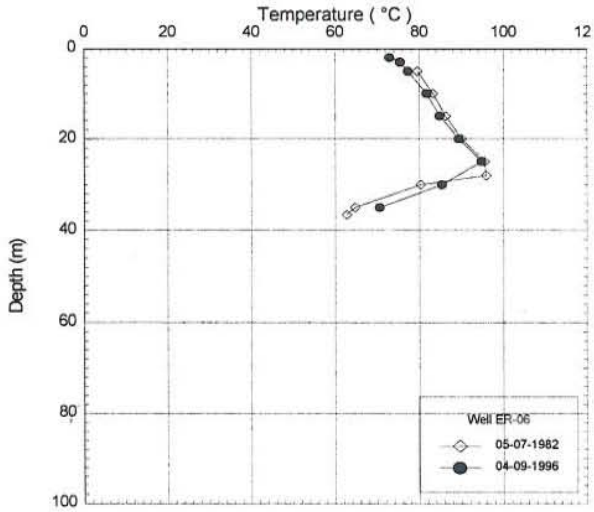


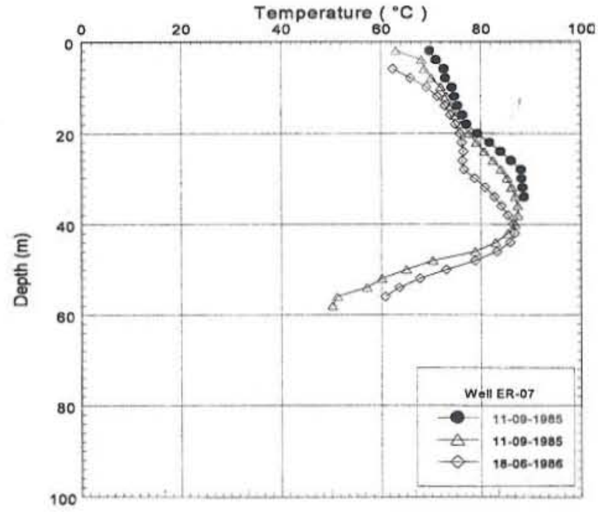


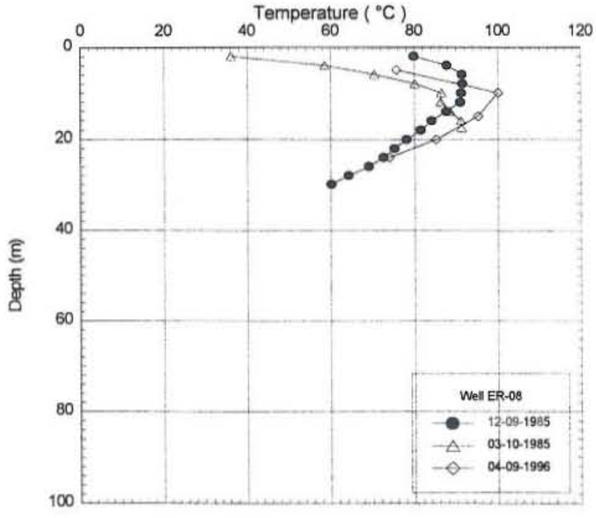









Temperature (°C)
Depth (m)
Well ER-07
11-09-1985
11-09-1985
18-06-1986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Well ER-08
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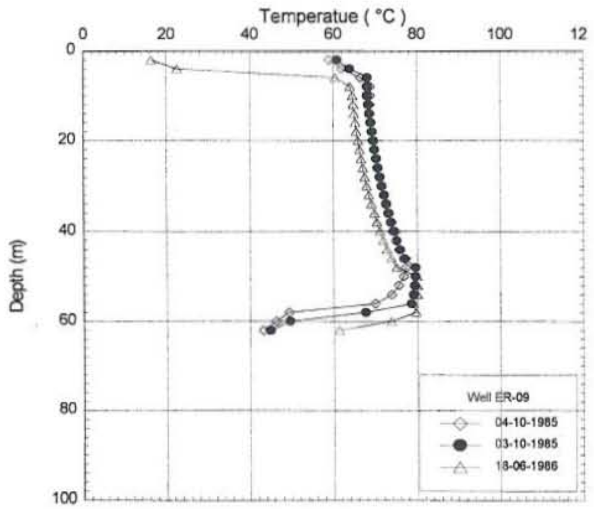
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Depth (m)
Well ER-09
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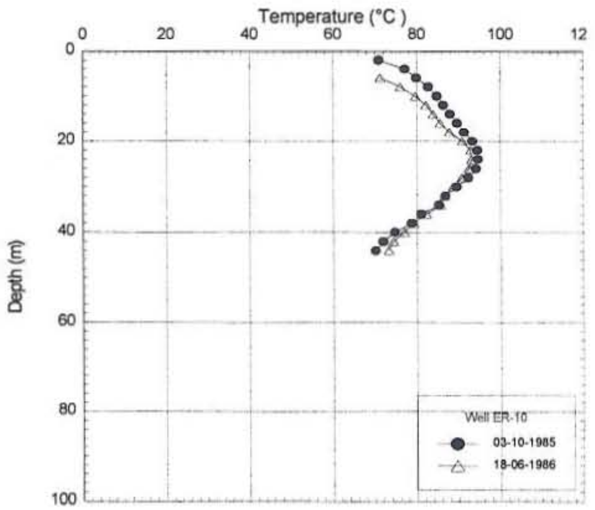
03-10-1985
18-06-1986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Depth (m)
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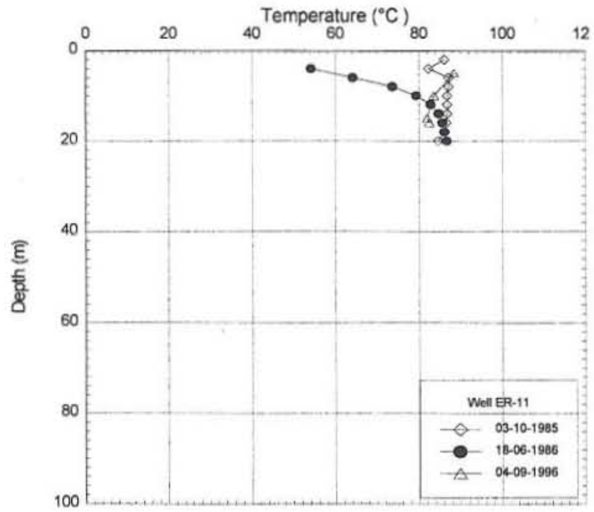
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Depth (m)
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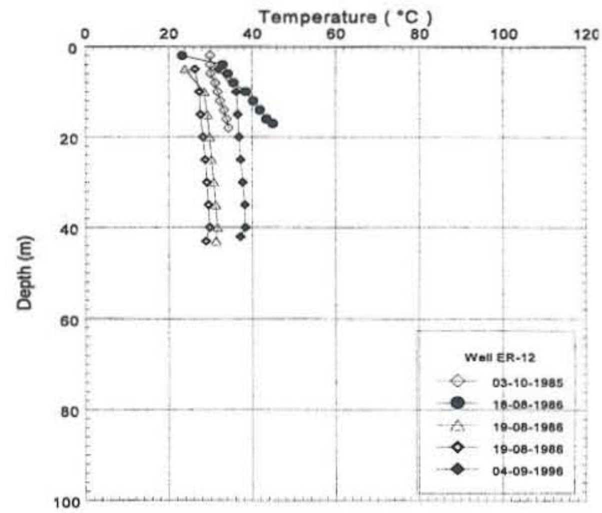
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Depth (m)
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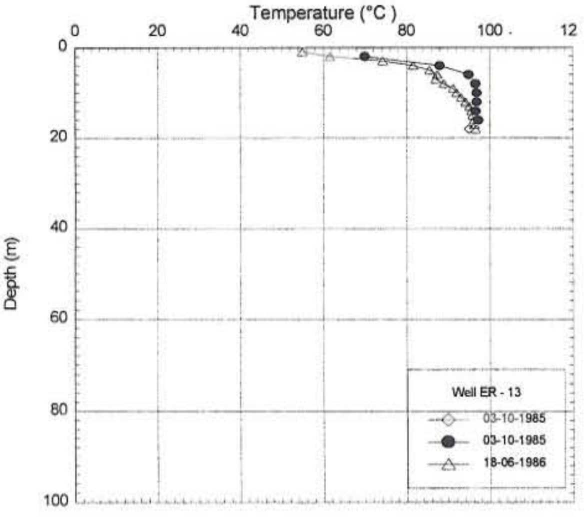
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Depth (m)
Well ER - 13
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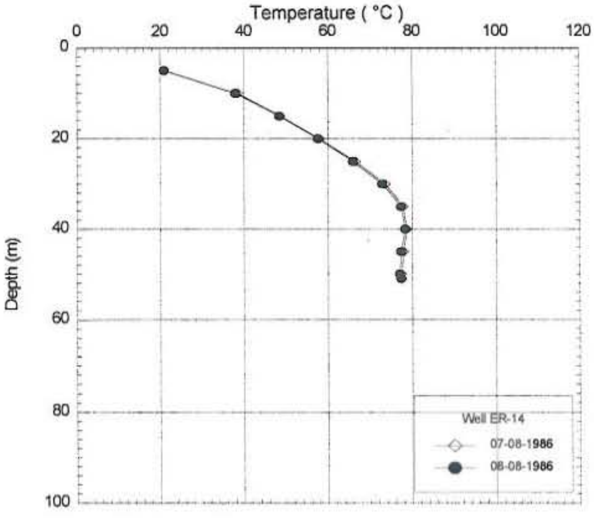
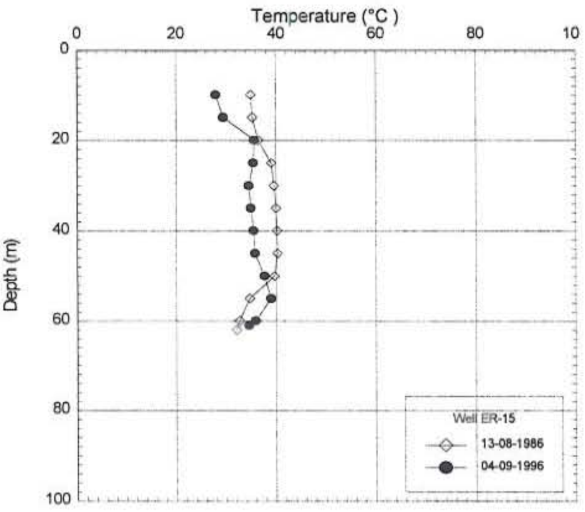

Temperature (°C)
Depth (m)
Well ER-14
07-08-1986
08-08-1986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Depth (m)
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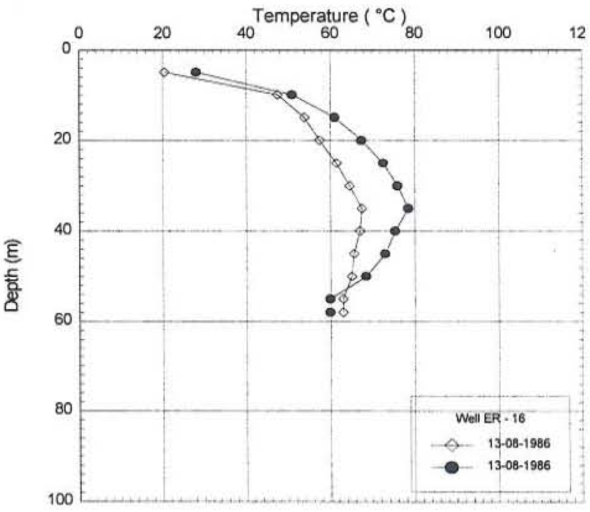
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Depth (m)
Well ER - 16
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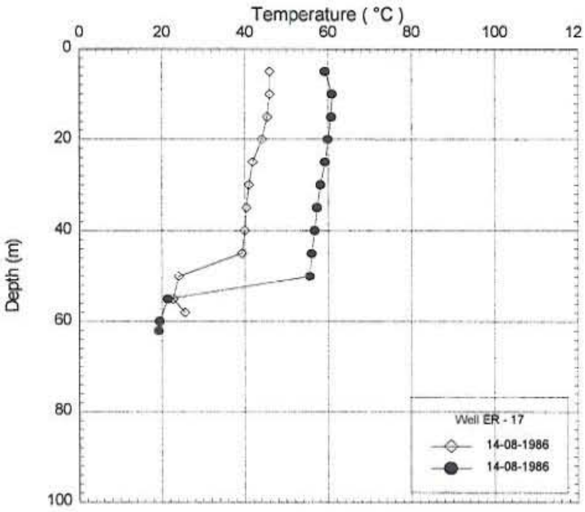
13-08-1986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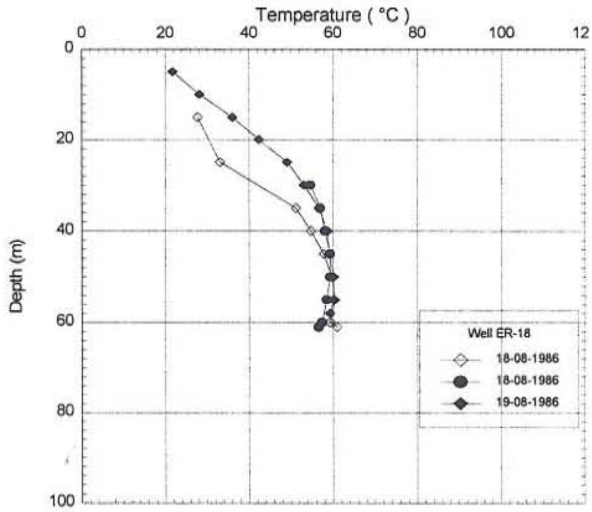
Depth (m)
Well ER - 17
14-08-1986
14-08-1986


Temperature (°C)
Depth (m)
Well ER-18
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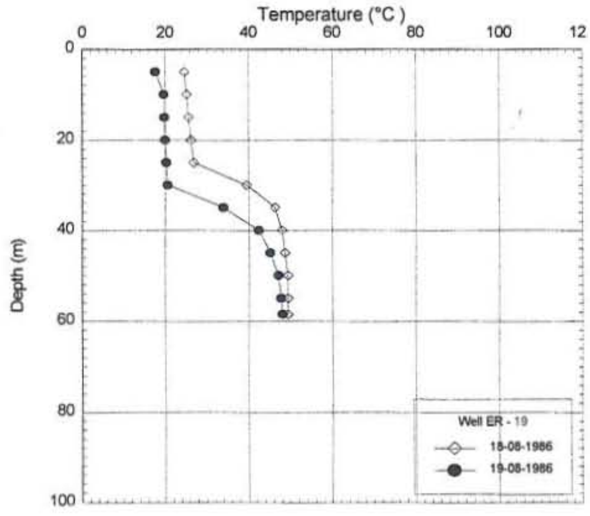
19-08-1986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Depth (m)
0 20 40 60 80 100
Well ER - 19
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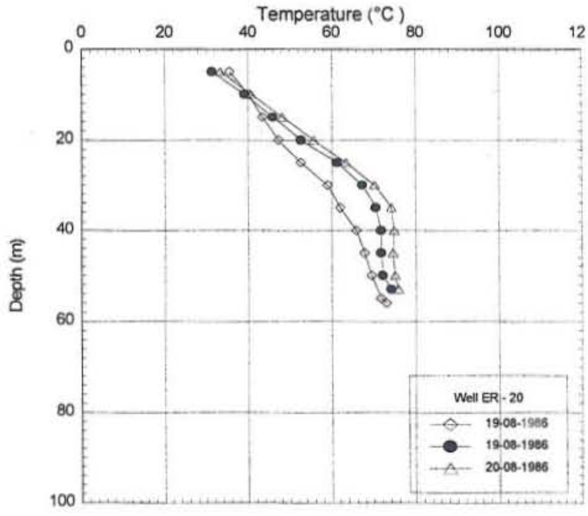
19-08-1986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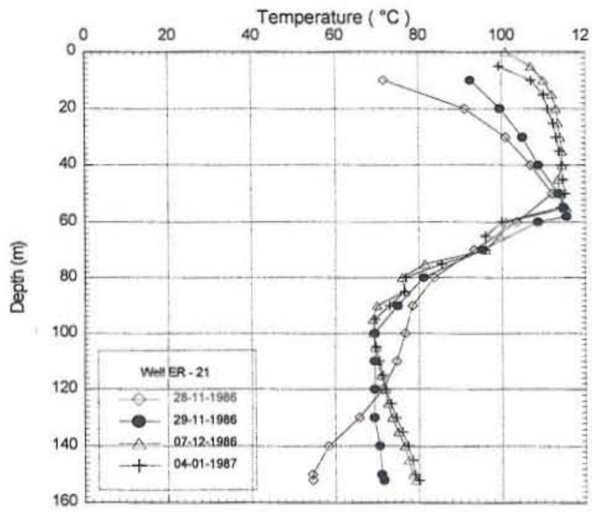
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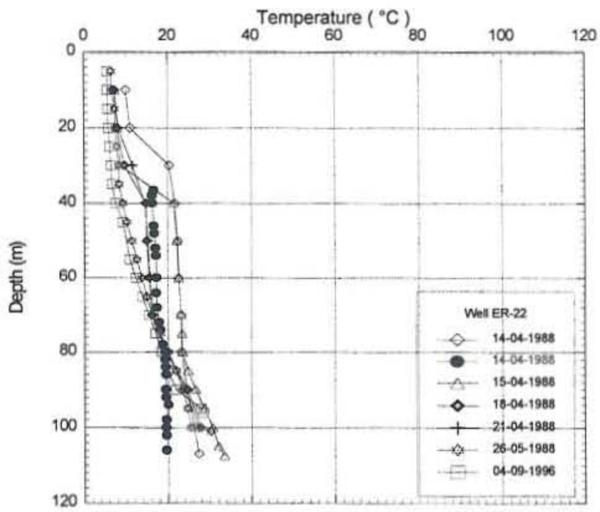
04-01-1987


Temperature (°C)
0 20 40 60 80 100 120
Depth (m)
0 20 40 60 80 100 120
Well ER-22
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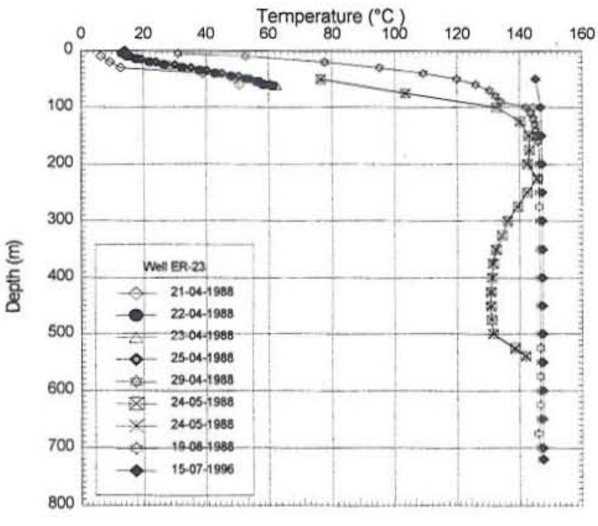
26-05-1988
04-09-1996


Temperature (°C)
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Depth (m)
0 100 200 300 400 500 600 700 800
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22-04-1988
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25-04-1988
29-04-1988
24-05-1988
24-05-1988
19-08-1988
15-07-1996