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ANALYSIS OF WELLBORE TEMPERATURES AND PRESSURES IN THE MOMOTOMBO GEOTHERMAL FIELD, NICARAGUA

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ABSTRACT

This report is a study of changes in temperature, pressure and enthalpy in the Momotombo high temperature geothermal field, Nicaragua, Central America. The downhole data considered in this report was collected in 33 of the 39 wells in the field. A simple database was created on a PC personal computer for storing and processing the data, which consisted of 522 downhole temperature measurements and 45 pressure measurements. The measurements were carried out between 1975 and 1989. All these measurements are presented in supplementary appendix B of this report. A study of the reservoir temperature history shows that the northeast part of the well field has cooled down at a rate of up to 6°C/year. Other parts of the field remain unchanged or show a slight increase in temperature. Analysis of pressure data shows a minimum drawdown rate of 0.3 bars/year in the well field, and much higher drawdown rates in production wells. The production enthalpy of some wells that produce from shallow levels in the Momotombo reservoir, has changed from 1100 kJ/kg to almost a dry steam enthalpy, indicating that production from the field has reached peak capacity in some areas.

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1. INTRODUCTION

This work is the result of a 6 month training course in geothermal exploration and exploitation, given by The United Nations University (UNU) Geothermal Training Programme, Reykjavik, Iceland. The training, which ran from 30th April to 30th October 1990, was guided by the staff scientists of Orkustofnun (National Energy Authority); the UNU Geothermal Training Programme is operated within Orkustofnun.

This training started with a four week lecture course designed to give the Fellows insight into the various disciplines involved in the study of geothermal reservoirs and their utilization, such as: geology, geophysics, geochemistry, drilling technology, borehole geology, borehole geophysics, reservoir engineering, geothermal utilization and other related subjects.

An eight day field excursion was arranged to acquaint participants with (a few) low and high temperature geothermal fields in Iceland. This trip gave the author the opportunity to witness the various possible uses of these geothermal resources. The author also obtained training in the use of a PC personal computer installed at the UNU, practical field training in well testing, calibration of different borehole equipment and computer compilation of some geothermal data.

The project work of this report consists of analyzing wellbore temperature, pressure and enthalpy data from the Momotombo geothermal field in Nicaragua. Data from 33 wells has been considered. All available downhole pressure and temperature data has been collected and either presented in figures or tables. Since more than 560 measurements were available for the study, the author used a substantial fraction of the training time in ordering, computizing and plotting the data. However, there was time for analyzing the time behavior of pressure and temperature within the reservoir, giving some important information on the production responses of the field.

This work was performed in close cooperation with another UNU Fellow, Gonzalez Solorzano (1990). In his report, a careful study is done on the initial temperature distribution in the Momotombo field.

2. OUTLINE OF THE MOMOTOMBO GEOTHERMAL FIELD

The Momotombo geothermal field is located in the Nicaragua depression, a graben elongated in a SE-NW direction (Figure 1). This graben is filled mainly with volcanic products of pliocene-Quaternary age overlying Miocene tuffs and ignimbrites (Girelli et al., 1977).

The Momotombo geothermal field is situated 85 km NW of Managua City, the capital of Nicaragua, at the southern slope of the active Momotombo volcano. The volcano has an elevation of 1200 m a.s.l and covers a surface of 65 km^2. At present, there are two electrical power units of 35 MW each within the Momotombo geothermal field. The reservoir is both of low and high enthalpy origin and constitutes the first industrial development of a geothermal project in Nicaragua (Martinez Tiffer et al., 1988).

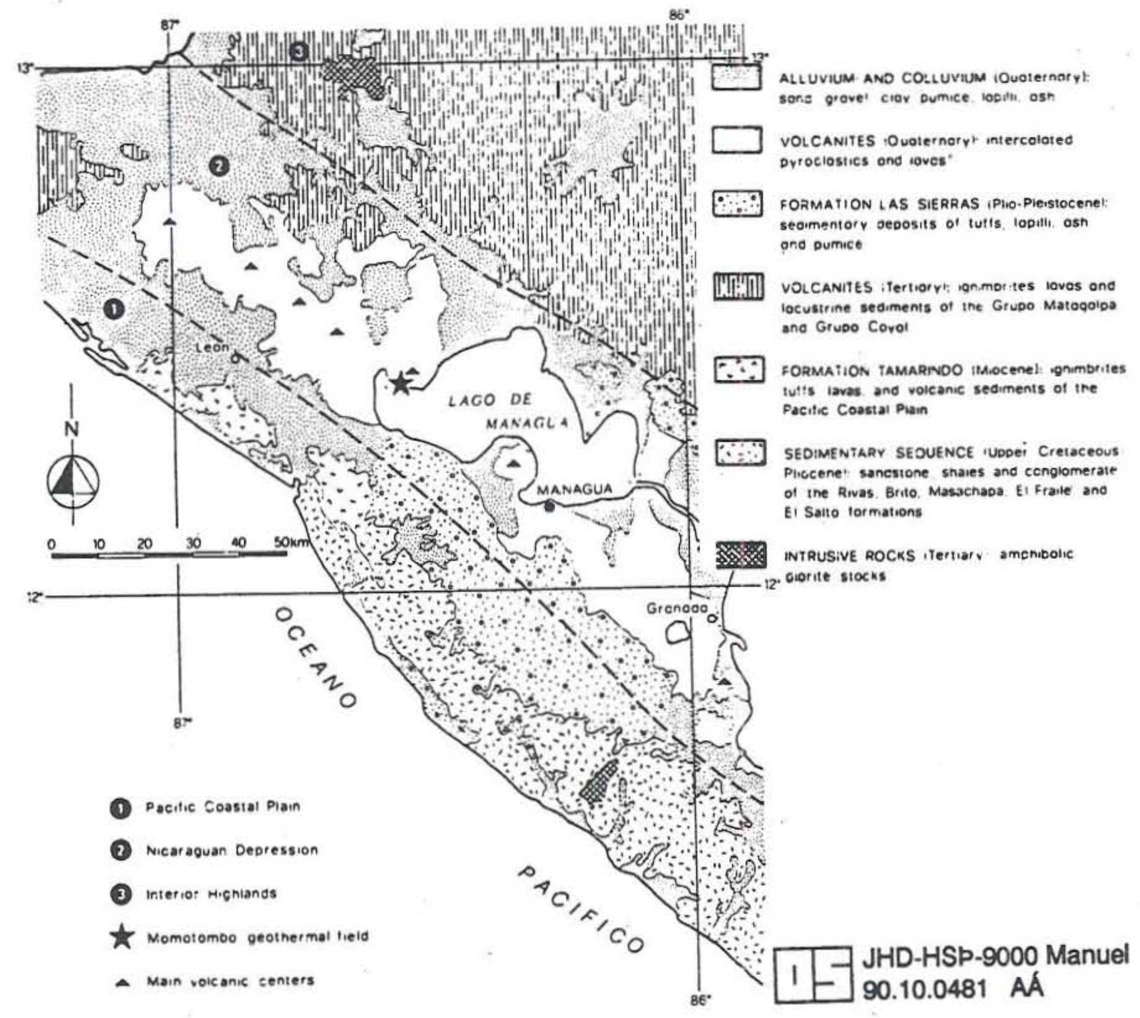

FIGURE 1: Geological map of Momotombo and surroundings (Girelly et al., 1987)

From 1974 to 1985, 39 wells were drilled between 310 and 2251 m in depth (Figure 2). At present, there are 23 production wells, 5 wells used for injection and 10 non-producing wells. The hydrothermal system of this field is characterized by infiltrated meteoric water, which is heated by a deep source that creates a convection cycle, complicated by the inflow of cold water from the east and south (Girelli et al., 1977).

The stratigraphy found in the wells at 0-300 m, shows the existence of alluvium and colluvial volcano-sedimentary deposits which fill the graben. A yellow palagonite tuff, alternated with lavic flows, occurs between 300 and 900 m depth. Volcanic agglomerates that contain intercalations of primary volcanic products, such as lava flows and tuff, occur between 900 and 2000 m. The lava flows contain basalt and andesite, poor in silica (Martinez Tiffer et al., 1988).

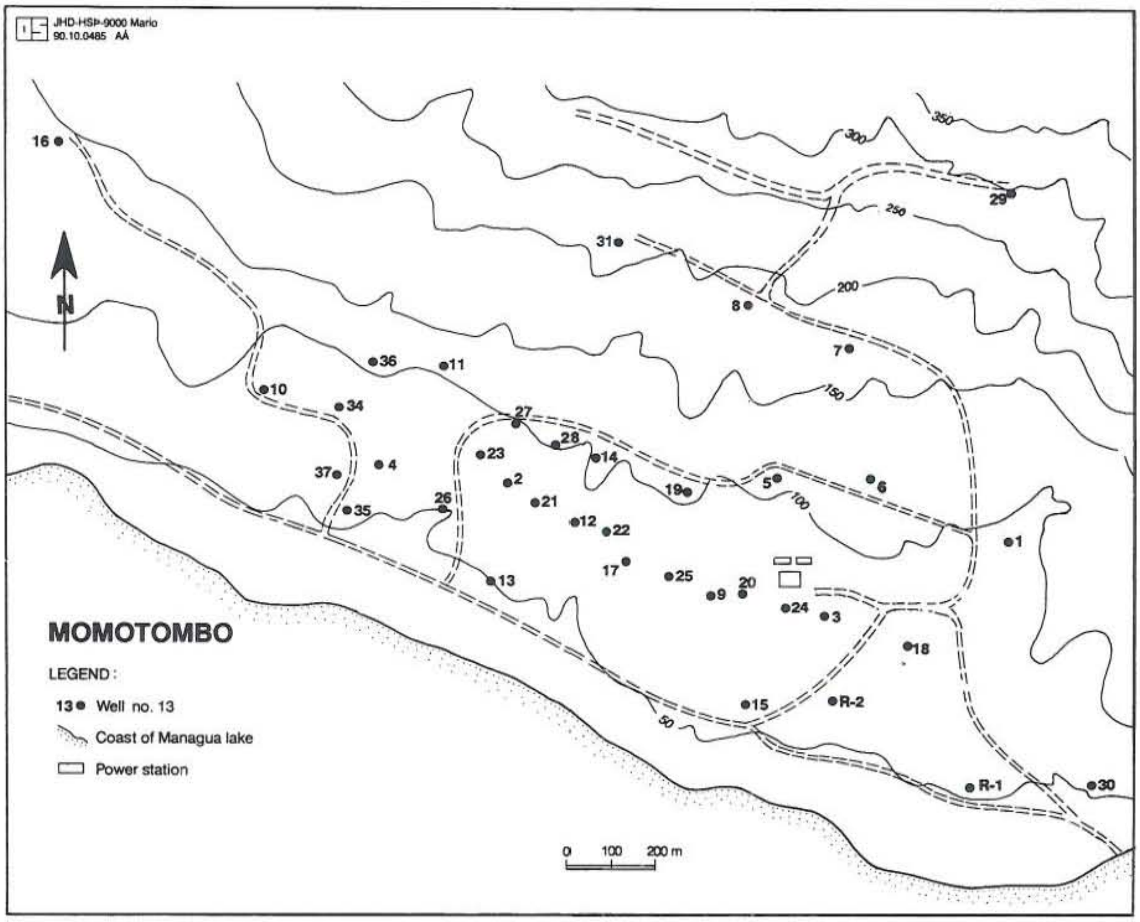

FIGURE 2: Areal map of the Momotombo geothermal field

3. DATA SOURCES

The downhole data considered in this report was collected in 33 wells at depths ranging down to 1990 m. Table 1 gives an overview of the Momotombo geothermal wells, including depths, drilling time and geometry. In Tables 2 and 3, a list of all temperature and pressure measurements is given. The oldest measurements are from 1975, when only 6 wells were present in the field. Since then, the amount of data has grown rapidly. The latest measurements presented here are from 1989.

All the downhole data presented here were collected by Recursos Geotermicos, which is part of Instituto Nicaraguense de Energia. The documents with the downhole data do not, however, include information on the conditions of the wells, prior and during the measurements. This is a serious drawback, since the downhole conditions of the individual wells can depend heavily on wellhead pressure, production rate or drilling operations.

Due to the high temperature and pressure environment found in the Momotombo wells, all the temperature and pressure measurements were carried out by using Amerada mechanical gauges. These gauges consist of three basic parts: the recording section, a clock and either a pressure sensor or a temperature sensor (Figure 3).

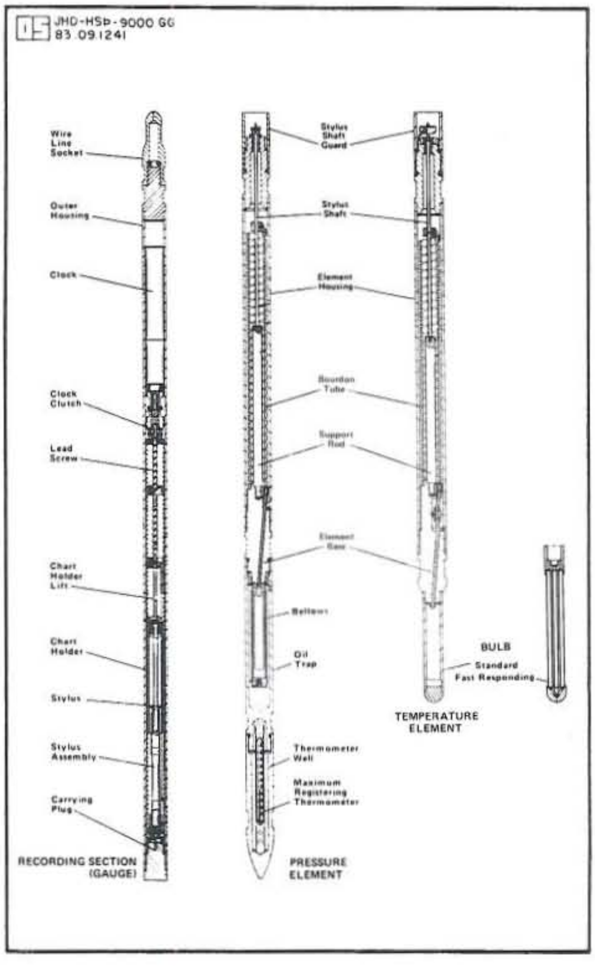

FIGURE 3: Cross-sections of Amerada pressure and temperature guages (Gebreigziabhier, 1983)

The basic part of the Amerada pressure element is a helical bourdon tube. The interior of this tube is exposed to the well pressure. A pressure change will result in rotation of the end of the bourdon tube which is transmitted directly to a recording stylus.

The stylus records on a metal chart made of thin metal, coated on one side with a special paint. A clock moves the chart down at a constant rate. The measurements will result in a curve on the metal chart that shows pressure with time. The logging people record the time and the depth of the gauge and are then able to transfer the pressure-time graph on the metal chart to a depth-pressure curve.

The basic part of an Amerada temperature element is a gas-filled bourdon tube (Figure 3), which is sealed in the element housing. A variation in temperature produces a different boiling pressure inside the bourdon tube. The vapour pressure of the enclosed liquid increases with temperature, producing rotation of the free end of the bourdon tube. This rotation is recorded by the recording stylus.

TABLE 1: Overview of the Momotombo geothermal wells

Well Name	Completion Time (dd,mm,yy)	Depth (m)	Casing Depth and Diam. (m & ")	Liner Length and Diam. (m & ")	Coordinate X (m)	Coordinate Y (m)	Elevation (m)	Status of the well M: Mononitoring P: Production R: Reinjection
MT-1	27-01-75	1885	425-9,5/8		2567	642	100	M
RMT-1	08-12-82	1564	562-9,5/8		2113	15	57	M
MT-2	06-05-75	488	366-9,5/8	122-7	1338	745	60	P
RMT-2	17-02-83	1170	592-9,5/8	579-7	2146	235	63	R
MT-3		310	282-9,5/8		2122	44	74	M
MT-4	25-05-76	1450	684-9,5/8	766-7	1023	787	74	P
MT-5	01-12-75	1124	377-9,5/8	747-7	2000	775	106	P
MT-6	28-12-75	580	548-9,5/8	32-7	2228	784	109	R
MT-7	01-03-76	1798	595-9,5/8	899-7	2163	1082	175	M
MT-8	19-04-76	1757	949-9,5/8	729-7	1913	1190	83	P
MT-9	29-05-76	616	232-13,3/8	411-8,5/8				
MT-10	14-08-76	2104	760-9,5/8	1092-7	730	960	100	R
MT-11	13-01-77	1885	915-9,5/8	915-7	1180	1031	112	P
MT-12	03-10-76	402	234-13,3/8	168-9,5/8	1504	655	67	P
MT-13	18-12-76	1824	260-9,5/8	1564-7	1311	520	49	P
MT-14	03-11-76	670	243-9,5/8	405-9,5/8	1555	810	102	P
MT-15	05-12-76	649	261-9,5/8	388-7	1936	220	66	R
MT-16	14-03-77	2251	827-9,5/8		50	1812	106	M
MT-17	10-06-77	328	285-9,5/8		1632	567	71	P
MT-18	10-07-77	1124	256-9,5/8	748-7	2332	375	75	R
MT-19	30-07-77	536	259-9,5/8	265-7	1780	736	99	P
MT-20	12-08-77	310	260-9,5/8		1922	490	80	P
MT-21	31-08-77	488	488-9,5/8	189-7	1413	702	71	P
MT-22	18-09-77	376	259-9,5/8	70-7	1582	635	70	P
MT-23	09-10-77	821	260-9,5/8	497-7	1274	815	71	P
MT-24	27-10-77	455	250-9,5/8	127-7	2025	460	83	P
MT-25	22-11-77	455	253-9,5/8	155-7	1734	530	73	P
MT-26	15-12-77	638	365-9,5/8	273-7	1179	680	49	P
MT-27	02-01-78	442	368-9,5/8		1365	896	87	P
MT-28	05-02-78	612	340-9,5/8	154-7	1458	840	93	P
MT-29	23-03-78	944	481-9,5/8	142-7	2578	1492	289	M
MT-30	17-05-78	1852	369-9,5/8		2785	27	52	M
MT-31	23-07-78	582	235-13,3/8		1602	1335	201	P
MT-32		934	234-13,3/8					
MT-34	30-05-83	985	516-9,5/8	469-7	923	925	86	M
MT-35	01-01-85	1300	603-9,5/8	160-7	932	932	56	P
MT-36	02-05-85	1653	650-9,5/8	250-7	1002	1033	97	P
MT-37		1650			916	758	71	P

4. A SIMPLE DATABASE AND DATA PROCESSING

The large amount of data, used in the study, required substantial base work in data storage and data processing. Although a sophisticated Oracle database was available on the Orkustofnun mainframe computer cluster, it was not used for the study, due to UNU requirements. A very primitive database was, therefore, designed by using a regular PC personal computer with 20 MB hard disk space. It is possible for the author to take this database with him to Nicaragua.

The basic structure of the database is depicted in Figure 4. A file tree was formed in the PC hard disk, where the top directory is simply called MOMOTOMB. This directory is then divided into 36 subdirectories, whereof 33 are used to store data for the 33 Momotombo wells which have been monitored frequently with downhole pressure and temperature measurements.

The well-subdirectories (MT-1 - MT-37) store downhole data for the individual wells. All the data files are of ASCII type. The majority of the data files contain two columns of either "depth (m), temperature (°C)" or "depth (m), pressure (kg/cm^2)". The names of the data files are simply YYMMDDP.DAT or YYMMDDT.DAT, where YY is a 2 digit number defining the year of measurement, MM is the month and DD is the day. The character T stands for temperature measurements and P for pressure measurement. The extension ".DAT" is necessary for the GRAPHER plotting package, which was used to plot the data.

In addition to the downhole data files, there are "depth, temperature" files called MINE.DAT and MINE1.DAT, where mine.dat is the minimum alteration temperature and mine1.dat is the maximum alteration temperature as defined by Manuel Gonzalez Solorzano (1990). The estimated initial temperature files are called INIT.DAT (Gonzalez Solorzano, 1990).

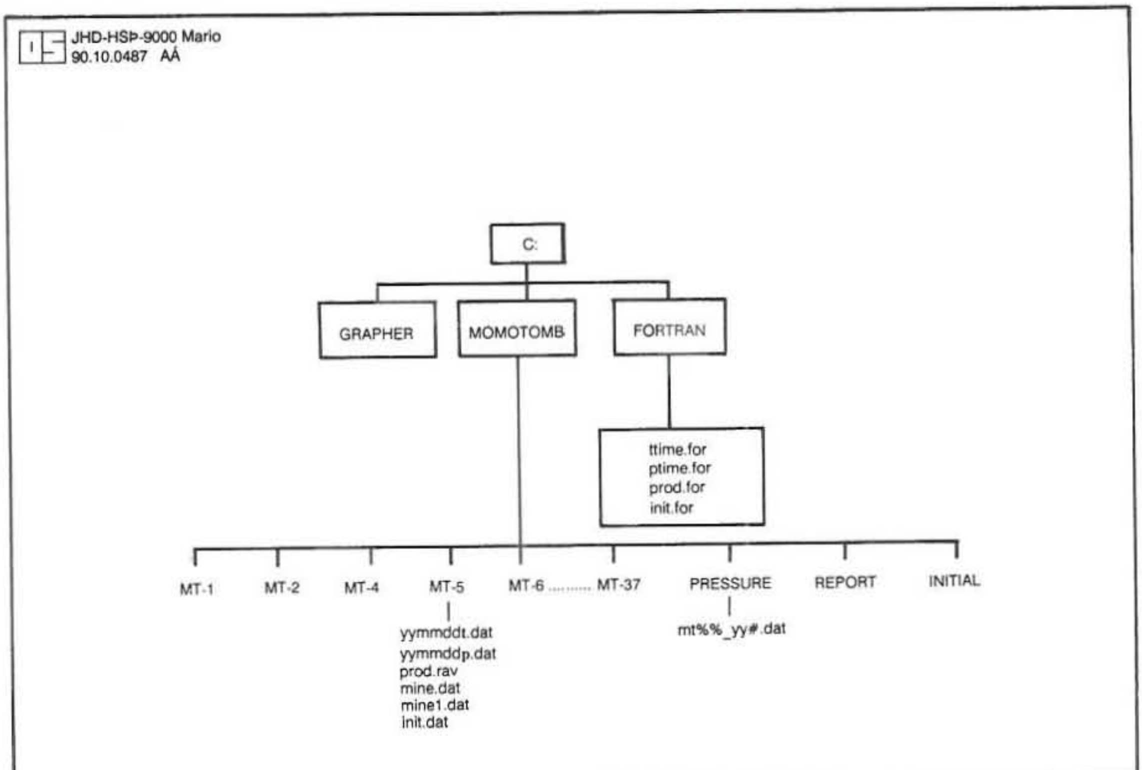

FIGURE 4: Basic structure of the Momotombo database

The subdirectory INITIAL contains initial temperature files for 33 Momotombo wells. Files with the extension "DIG" are digitized temperatures where the depth is given in meters under the wellhead, whereas files with the extension "DAT" store initial temperatures in m u.s.l.

A special subdirectory PRESSURE was made for analyzing pressure data (depth - m u.s.l., pressure - kg/cm^2). In this directory are files with names MT%%_YY#, where %% is the well number and YY is the year of measurement. The symbol # takes the value A,B,C,...etc, if there is more than 1 measurement in the year YY, otherwise it is omitted. All the files have the extension "DAT".

A special subdirectory "REPORT", was made to store the Word Perfect files used to write this report.

Since some of the data had to be processed for further analysis, a FORTRAN subdirectory was created for FORTRAN files and a FORTRAN compiler. In this directory are located 4 FORTRAN routines specially made for this study. The program TTIME reads in all temperature files in a well-subdirectory, and writes to an output file the temperature history at a depth given by the user. The time is counted in the number of days after January 1^{st}, 1975. A similar program, PROD.FOR was made to process production data. A file PROD.RAV is found in some of the well directories, storing a number of lines of the form dd,mm,yy,whp,flow,enth, where dd,mm,yy is the date of measurement as before, whp is the wellhead pressure in bar-g, flow is the flowrate in tons/h and enth is the total enthalpy in kcal/kg. The program PROD.FOR converts the values of flow and enthalpy into kg/s and kJ/kg respectively, and writes the output to a file PROD.DAT, where the time is now given in the number of days after January 1^{st} 1975.

A program INIT.FOR was made to change the depth value in YYMMDD(P or T).DAT files into depth in m u.s.l. Finally, a program PTIME.FOR was made for analyzing time behaviour of downhole pressure. The program works only in the PRESSURE subdirectory and gives, as output, a file with pressure, year of the measurements and the well number at a given depth in m u.s.l.

A listing of all these programs with a more detailed description is given in Appendix A. Appendices (A and B) of this study are published separately in a special report (see Gonzalez Barbosa, 1990).

5. ANALYSIS OF TEMPERATURE DATA

5.1 Presentation

Table 2 shows that there are presently 522 temperature measurements existing in our database. Appendix B shows all these measurements plotted with depth (for appendices see Gonzalez Barbosa, 1990). Manuel Gonzalez Solorzano (1990) used the figures in Appendix B for analyzing the initial temperature distribution in the Momotombo field. Here we will, therefore, concentrate on possible changes of reservoir temperature with time.

Figure 5 shows the temperature history of 29 Momotombo wells. The plotted curves were created by the program TTIME (Chapter 4). In the following pages we will analyze the temperature history of each well separately, and then finally combine the results of this analysis into a figure showing possible changes in the temperature of the Momotombo reservoir.

5.2 Temperature changes in wells

Well MT-1: This well is non-productive. Figure 5 shows that there is a slow warm up in the upper part of the well (1.4°C/year at 300-500 m) but a gradual cooling in the lower part (1-3°C/year at 900-1700 m). There are indications that some of the temperature gauges used went out of range when the cold section of the well was measured (element in 1987 measurement with 130°C baseline and element in 1989 measurement with 150°C baseline). It is, therefore, concluded that the well (and the reservoir) temperature has remained stable at 600-800 m.

Well MTR-1: This is a monitoring well, which shows stable temperature during the period, except at 800-1400 m, where a slow warm up occurs (0.5°C/year).

Well MT-2: This is a productive well, whose temperature is badly disturbed by production after 1976. Therefore, no conclusions can be made on the reservoir temperature history in the vicinity of the well.

Well MT-4: It is productive and the few measurements available are, therefore, disturbed. However, the temperature is stable at 600 m, indicating that at least the feedzone remains in stable condition.

Well MT-5: It is productive. Measurements show irregular temperature above 500 m, but there is a slow increase in wellbore temperature below 500 m (1°C/year). Since the production enthalpy of the well is not known, we cannot estimate the approximate depth of the boiling level during production. If this is a low enthalpy well, then the temperature increase under 500 m is real. Otherwise, it may be disturbed by boiling within the well.

Well MT-6: It has been used as an injection well since 1983. The temperature data in Figure 4 shows gradual cooling on the order of 1°C/year below 300 m depth.

Well MT-7: It is a monitoring well. The well has an irregular temperature history in the uppermost 700 m. Below 700 m, however, there is gradual cooling in the well since 1978, when the well reached peak temperature. The cooling rate is 3°C/year at 800-1300 m, and more than 8°C/year at 1400-1700 m. This is a very high cooling rate. A possible explanation is the combined effects of slow internal flow and badly calibrated gauges. A real cooling of the reservoir rock, due to inward migration of a cooling front, is a more likely explanation, taking

TABLE 2: List of temperature measurements in the database

WELL	DATE OF MEASUREMENTS (YY,MM,DD)	DEPTH RANGE (METERS)
MT-1	76-04-03	0- 400
	77-02-01	50- 200
	77-02-04	0- 400
	77-02-07	0- 400
	77-02-16	0- 350
	78-06-21	450-1450
	78-09-07	0-1800
	80-08-09	0-1800
	80-08-11	0- 900
	81-03-24	0-1800
	82-11-23	700-1800
	86-04-22	0-1500
	87-03-09	0-1550
	89-05-26	0-1000
MTR-1	83-01-05	0-1500
	83-01-11	0-1500
	83-01-25	0-1500
	83-03-01	0-1500
	83-03-02	0-1450
	83-03-22	150-1450
MT-2	76-07-20	50- 450
	76-07-27	50- 450
	76-07-28	0- 450
	76-08-13	50- 450
	76-08-16	50- 450
	76-08-31	50- 450
	76-09-06	50- 450
	76-09-21	50- 450
	76-10-19	50- 450
	76-12-15	0- 450
	81-01-29	0- 450
	81-02-12	0- 450
	81-02-15	0- 450
	81-04-10	0- 450
	81-06-23	0- 450
	81-08-26	0- 450
	83-03-31	0- 450
	83-04-28	0- 450
	85-01-29	0- 200
	85-06-11	0- 500
	85-09-17	0- 400
	85-10-30	0- 450
	86-10-13	0- 300
	87-06-22	0- 400
	88-08-18	0- 350
	88-09-12	0- 350
RMT-2	83-02-16	0-1150
	83-02-07	0-1150
	83-02-08	0-1150
	83-03-16	0-1150
	83-03-17	0-1150
	83-04-13	0-1100
	84-03-16	0-1150
MT-4	84-06-26	0- 550
	84-10-15	0- 600
	85-01-30	0- 300
	85-07-30	0- 500
	89-04-19	0-1150
MT-5	76-01-17	0- 450
	76-02-19	50- 450
	76-04-19	0- 400
	76-04-28	0- 350
	76-04-29	0-1100
	76-05-11	100-1000
	76-05-26	100-1000
	76-05-27	100-1000
	76-05-29	200-1000
	76-05-31	100-1000
	76-06-01	100-1000
	76-06-08	100-1000
	76-06-11	100-1000
	76-06-16	100-1000
	76-06-18	100-1000
	76-06-22	100-1000
	76-06-26	100-1000
	76-06-30	50- 950
	76-07-17	50- 950
	76-09-29	0- 950
	76-10-01	250- 950
	76-10-29	0-1000
	76-12-05	50- 950
	77-02-19	0- 950
	77-08-06	50- 550
	77-09-12	50- 550
	77-09-24	100- 550
	77-10-13	150- 450
	77-11-12	100- 300
	77-12-14	0- 500
	80-10-17	100-1000
	81-03-26	100-1050
	81-06-10	0-1050
MT-5	81-06-24	0-1000
	81-06-30	100-1000
	81-07-03	100-1000
	81-07-23	0-1000
	81-08-07	50- 950
	81-07-28	50-1000
	81-08-13	0- 950
	81-08-20	0- 950
	81-09-07	0- 950
	81-09-08	100- 900
	83-01-0	0-1050
	84-06-22	0-1000
	84-10-26	0- 700
	85-04-03	0- 700
	85-05-23	0-1100
	85-07-31	0-1100
	86-04-14	0-1100
	86-06-09	0-1100
	86-07-10	0-1100
	86-09-24	0-1100
	87-03-10	0-1000
	87-08-19	0-1050
MT-6	76-01-07	0- 550
	76-01-17	0- 550
	76-02-23	0- 550
	76-05-08	100- 500
	76-06-01	100- 500
	76-06-03	100- 500
	76-06-07	100- 500
	76-06-11	100- 550
	76-06-14	100- 550
	76-06-16	100- 550
	76-06-18	100- 500
	76-06-23	100- 500
	76-06-26	100- 550
	76-06-30	100- 550
	76-07-13	100- 450
	83-01-11	0- 450
	83-04-07	0- 450
	87-03-04	0- 450
MT-7	76-03-11	0-1700
	76-03-27	0-1700
	76-04-02	0-1700
	76-05-04	0-1700
	76-06-15	200-1700
	76-06-17	200-1700
	76-06-22	100-1700
	76-07-06	200-1700
	76-07-15	200-1700
	76-07-20	200-1700
	76-08-16	200-1700
	76-09-01	200-1700
	76-09-23	200-1400
	76-10-04	400-1700
	76-10-06	200-1500
	76-12-09	700-1200
	76-01-21	0- 550
	76-03-02	0-1700
	76-03-05	0-1700
	76-01-18	0- 250
	76-07-27	200-1700
	76-07-28	200-1700
	76-08-13	200-1700
	81-03-27	200- 450
	81-05-29	100- 450
	81-07-01	0- 450
	81-08-06	100- 450
	81-08-14	0- 450
MT-8	76-08-14	0-1700
	76-09-01	100-1750
	76-09-23	100-1750
	76-10-20	100-1750
	76-12-09	100-1600
	76-04-19	0-1700
	76-04-27	0-1700
	76-05-04	0-1700
	76-05-15	0-1750
	76-06-05	0-1700
	76-06-15	200-1700
	76-06-17	200-1700
	76-07-31	0-1750
	77-01-25	100-1750
	77-01-31	100-1750
	77-07-05	100- 850
	78-02-25	50-1750
	78-05-31	50-160
MT-8	84-01-02	0-1700
	84-10-31	0- 600
	85-03-13	0- 400
	85-04-08	0- 800
	85-11-05	0- 800
	86-02-10	0- 800
	86-02-11	0- 800
	87-03-11	0- 800
	89-05-23	0- 800
MT-9	87-03-17	0- 200
	88-05-25	0- 150
MT-10	76-08-11	400-1900
	76-08-12	800-2000
	76-08-26	400-1800
	76-08-31	500-1800
	76-09-16	100-1400
	76-09-27	600-1800
	76-10-26	100-1800
	77-11-24	100- 900
	77-11-31	100- 900
	81-11-07	50-1100
	81-11-08	50- 950
	82-01-07	0- 700
	82-01-13	50- 700
	82-03-05	0- 750
	82-03-12	0- 750
	82-03-15	0- 750
	82-03-19	0- 750
	82-03-23	0- 750
	82-03-26	0- 750
	82-03-30	0- 750
MT-11	76-09-16	250- 900
	76-09-17	250- 850
	76-09-22	50- 800
	76-09-27	50- 800
	76-10-18	50- 800
	76-12-09	50- 850
	77-02-17	0-1200
	77-03-29	300-1900
	77-05-09	100-1900
	77-07-05	50- 850
	83-04-05	0- 800
	84-02-07	0- 850
	84-08-29	0- 900
MT-11	84-11-06	0- 800
	85-02-06	0- 500
	85-03-06	0- 800
	85-03-30	0- 900
	85-07-16	0- 900
	86-05-14	0- 900
	86-07-02	0- 900
	86-08-08	0- 900
	86-09-15	0- 800
	87-06-25	0- 850
MT-12	83-02-02	0- 350
	88-06-03	0- 400
MT-13	76-10-28	0- 250
	77-04-11	300-1800
	77-04-14	300-1700
	77-05-23	0-1700
	77-07-28	50- 700
	80-09-03	100-1600
	81-07-09	0-1600
	81-08-10	0-1050
	81-09-10	200-1050
	81-10-06	100-1050
	81-10-29	0-1050
	81-10-30	50-1050
	81-11-11	50-1050
	82-10-04	0-1450
	84-09-03	0- 950
	84-01-24	100-1000
	84-11-07	0-1000
	85-06-08	0-1600
	85-09-18	0-1050
	86-01-29	0-1600
	86-02-26	0-1600
	86-07-07	0- 800
	86-07-28	0-1500
	86-08-06	0-1700
	86-10-01	0-1500
	86-10-14	0-1500
	86-10-15	0-1700
	89-06-01	0-1000
MT-14	76-12-05	0- 400
	76-12-07	0- 350
	76-12-12	0- 400
	76-12-16	0- 400
	76-12-21	0- 400
	77-01-04	0- 400
MT-14	77-01-20	0- 400
	77-02-04	0- 209
	77-07-02	0- 750
	77-07-18	0- 650
	80-08-14	0- 400
	81-04-07	0- 400
	81-06-23	0- 600
	81-06-25	0- 650
	81-08-21	0- 550
	81-09-19	0- 650
	81-09-30	0- 550
	81-10-05	0- 650
	81-10-14	0- 650
	81-11-04	0- 650
	81-11-15	0- 233
	81-11-19	0- 650
	82-05-05	0- 400
	83-04-21	0- 400
	84-01-26	0- 400
	84-05-24	0- 600
	84-09-04	0- 400
	84-11-13	0- 400
	85-11-22	0- 400
	85-09-04	0- 450
	85-10-29	0- 650
	86-06-19	0- 650
	86-07-24	0- 650
	86-08-25	0- 600
MT-15	76-12-10	50- 600
	76-01-14	50- 600
	76-12-23	300- 600
	77-01-10	250- 600
	77-01-18	100- 600
	77-02-09	150- 600
	77-07-07	50- 600
	81-07-29	50- 600
	81-09-11	0- 600
	81-10-01	50- 450
	81-10-07	200- 450
	81-10-08	100- 450
	81-11-10	50- 450
MT-15	82-01-28	50- 450
	82-02-04	50- 450
	82-02-07	50- 450
	82-02-10	50- 450
	82-02-13	50- 450
	82-02-16	50- 450
	82-02-28	50- 450
	82-11-16	0- 600
MT-16	77-03-08	900-2000
	77-03-09	900-2000
	77-03-10	900-2000
MT-17	77-07-28	0- 300
	80-06-20	0- 300
	80-06-21	50- 300
	80-06-22	0- 300
	80-10-24	150- 300
	80-11-18	0- 300
	81-01-08	0- 300
	81-04-08	0- 300
	81-08-25	0- 300
	82-01-21	0- 300
	82-04-22	0- 300
	82-10-12	0- 300
	84-05-16	0- 300
	84-09-17	0- 250
	84-11-14	0- 250
	85-01-17	0- 250
	85-06-12	0- 300
	85-08-20	0- 300
	85-10-16	0- 300
	85-10-18	0- 300
	85-12-03	0- 300
	86-01-22	0- 250
	86-05-08	0- 350
	86-06-24	0- 300
	86-08-19	0- 300
	86-10-22	0- 300
	86-10-27	0- 300
	87-12-15	0- 350
	88-01-19	0- 350
	88-01-26	0- 350
MT-18	77-07-06	00-1050
	77-07-07	300- 800
	77-08-02	50-1100
	81-04-09	50- 200
	81-08-25	0- 200

TABLE 2: List of temperature measurements in the database (cont.)

WELL	DATE OF MEASUREMENTS (YY,MM,DD)	DEPTH RANGE (METERS)
MT-18	81-09-12	0- 250
	81-09-25	0- 250
	81-10-13	0- 250
	81-10-15	0- 650
	81-11-02	0- 650
	81-11-12	100- 650
	81-11-20	0- 650
	82-11-17	0- 650
	83-04-12	0- 650
	83-05-05	0- 650
	88-03-29	0- 700
	89-07-05	0- 700
MT-19	77-10-20	50- 500
	80-09-04	0- 500
	83-03-3	0- 500
	84-01-20	50- 500
	84-09-06	0- 500
	84-11-29	0- 500
	85-01-17	0- 350
	85-06-13	0- 500
	85-08-14	0- 500
	86-10-19	0- 500
	87-08-21	0- 550
	88-01-18	0- 550
	89-05-16	0- 500
MT-20	83-01-13	0- 300
	88-06-09	0- 300
MT-21	77-10-21	0- 450
	77-10-28	0- 450
	80-11-19	100- 450
	81-01-07	0- 450
	81-04-21	0- 400
	81-09-18	0- 450
	81-09-29	0- 450
	81-09-30	0- 450
	81-10-13	0- 450
	81-10-14	0- 400
	81-11-03	0- 450
	81-11-19	50- 450
	82-05-04	0- 450
	82-10-14	0- 450
	84-05-10	0- 450
	84-09-12	0- 450
	84-12-03	0- 450
	86-01-30	0- 450
MT-21	86-03-24	0- 400
	86-03-25	0- 400
	86-04-03	0- 450
	86-06-04	0- 450
	86-07-09	0- 450
	86-07-25	0- 450
MT-22	85-06-18	0- 350
	85-08-29	0- 350
	85-10-15	0- 350
	85-12-18	0- 350
	86-01-21	0- 350
	86-02-25	0- 350
	86-05-15	0- 350
	86-06-23	0- 350
	86-07-27	0- 350
	86-08-05	0- 350
	86-11-10	0- 350
	86-11-11	0- 350
	88-03-14	0- 300
	88-05-23	0- 350
MT-23	83-01-13	0- 800
	87-12-16	0- 800
	89-01-21	0- 800
MT-24	85-01-14	0- 400
	85-06-06	0- 450
	85-08-06	0- 450
	85-10-10	0- 450
	85-11-12	0- 450
	86-09-10	0- 450
	86-05-15	0- 450
	86-07-14	50- 400
	86-04-10	0- 400
MT-25	84-09-20	0- 400
	84-12-05	0- 400
	85-01-15	0- 400
	85-06-06	0- 450
	85-08-07	0- 450
	85-10-11	0- 450
	85-11-11	0- 450
	86-04-11	0- 450
	86-04-15	0- 450
	86-07-15	0- 450
	86-08-20	0- 450
MT-25	86-09-18	0- 450
	86-10-23	0- 450
	87-07-08	0- 450
	88-08-15	0- 450
	89-07-12	0- 450
MT-26	86-04-16	0- 450
	86-05-20	0- 600
	86-06-11	0- 600
	86-07-04	0- 600
	86-08-21	0- 600
	86-09-17	0- 600
	86-11-20	0- 600
	87-03-06	0- 600
	87-08-12	0- 600
	87-10-23	0- 600
	87-11-13	0- 600
	87-11-23	0- 600
MT-27	83-01-12	0- 400
	83-02-16	0- 400
	83-03-29	0- 400
	83-04-27	0- 400
	88-08-05	0- 400
	89-05-04	0- 450
MT-28	86-06-10	0- 600
	86-07-08	0- 600
	86-08-22	0- 600
	86-10-28	0- 600
	89-05-15	0- 600
	89-11-23	0- 600
MT-29	86-07-01	0- 550
MT-30	83-04-13	0- 550
	84-01-19	0- 800
	84-06-11	0- 800
	84-06-12	0- 800
	84-06-13	0- 800
	84-06-14	0- 800
	84-10-02	50- 800
	84-12-10	0- 800
MT-31	78-07-17	250- 550
	78-07-18	250- 550
	78-08-01	100- 550
	78-08-04	100- 550
MT-31	78-08-24	50- 550
	80-07-01	50- 550
	80-07-08	0- 550
	80-07-31	0- 550
	80-09-12	0- 550
	81-09-18	0- 550
	81-09-27	0- 550
	81-10-20	0- 550
	81-10-21	0- 550
	81-10-22	0- 550
	81-11-10	0- 550
	85-01-22	0- 400
	85-06-19	0- 500
	85-10-23	0- 450
	86-01-27	0- 550
	86-04-24	0- 550
	86-05-21	0- 550
	86-07-30	0- 550
	87-07-30	0- 550
	87-08-06	0- 550
	88-08-17	0- 550
MT-35	86-01-28	0-1300
	86-04-25	0-1000
	86-04-29	0-1100
	86-04-30	0-1100
	86-05-26	0- 800
	86-06-25	0-1300
	86-11-25	200-1300
	87-12-28	0-1300
	88-03-01	0-1300
	88-03-10	0-1300
	88-08-10	150- 500
MT-36	86-02-12	0- 700
	86-04-23	0- 600
	86-05-22	0- 700
	86-06-27	0- 700
	86-12-03	0-1000
	88-08-01	0-1000
MT-37	85-11-19	600-1500
	85-11-20	600-1500
	85-11-21	600-1500
	85-11-25	600-1500
	85-11-27	600-1500
	85-11-28	600-1500
	85-11-29	600-1500
	85-12-19	0-1500

TABLE 3: List of pressure measurements in the database

WELL	DATE OF MEASUREMENTS (YY,MM,DD)	DEPTH RANGE (METERS)
MT-1	75-03-05	0-50
	89-05-24	100-1000
MT-2	88-09-12	0-350
MT-4	89-04-19	0-1100
MT-5	87-08-19	0-1100
MT-6	87-03-04	0-550
MT-8	89-05-23	200-800
MT-9	88-12-25	0-250
MT-11	89-06-02	100-800
MT-13	89-06-01	0-1000
MT-14	89-05-11	0-650
MT-15	88-02-24	0-600
MT-17	82-10-12	50-300
	87-15-12	0-320
	88-01-20	0-320
	88-01-26	0-320
MT-18	89-07-04	0-700
MT-19	89-05-15	0-500
MT-20	83-01-13	0-300
	88-06-09	0-300
MT-21	86-10-21	0-550
MT-22	83-04-20	0-350
	88-03-14	0-370
	88-05-23	0-400
MT-23	89-01-21	0-800
MT-24	89-07-24	0-500
MT-25	89-07-11	0-500
MT-26	83-01-06	0-480
	87-10-23	0-600
	87-11-11	0-600
	87-11-23	0-700
MT-27	83-04-27	0-400
	88-08-08	0-450
	89-11-09	0-400
MT-28	89-11-23	0-600
MT-29	86-07-01	0-550
MT-30	84-12-10	100-800
MT-31	86-06-30	0-550
	86-07-30	0-550
	87-08-06	0-550
	88-08-17	0-550
MT-35	87-12-23	0-1300
	88-03-01	0-500
	88-03-09	0-1300
MT-36	89-05-11	0-1000

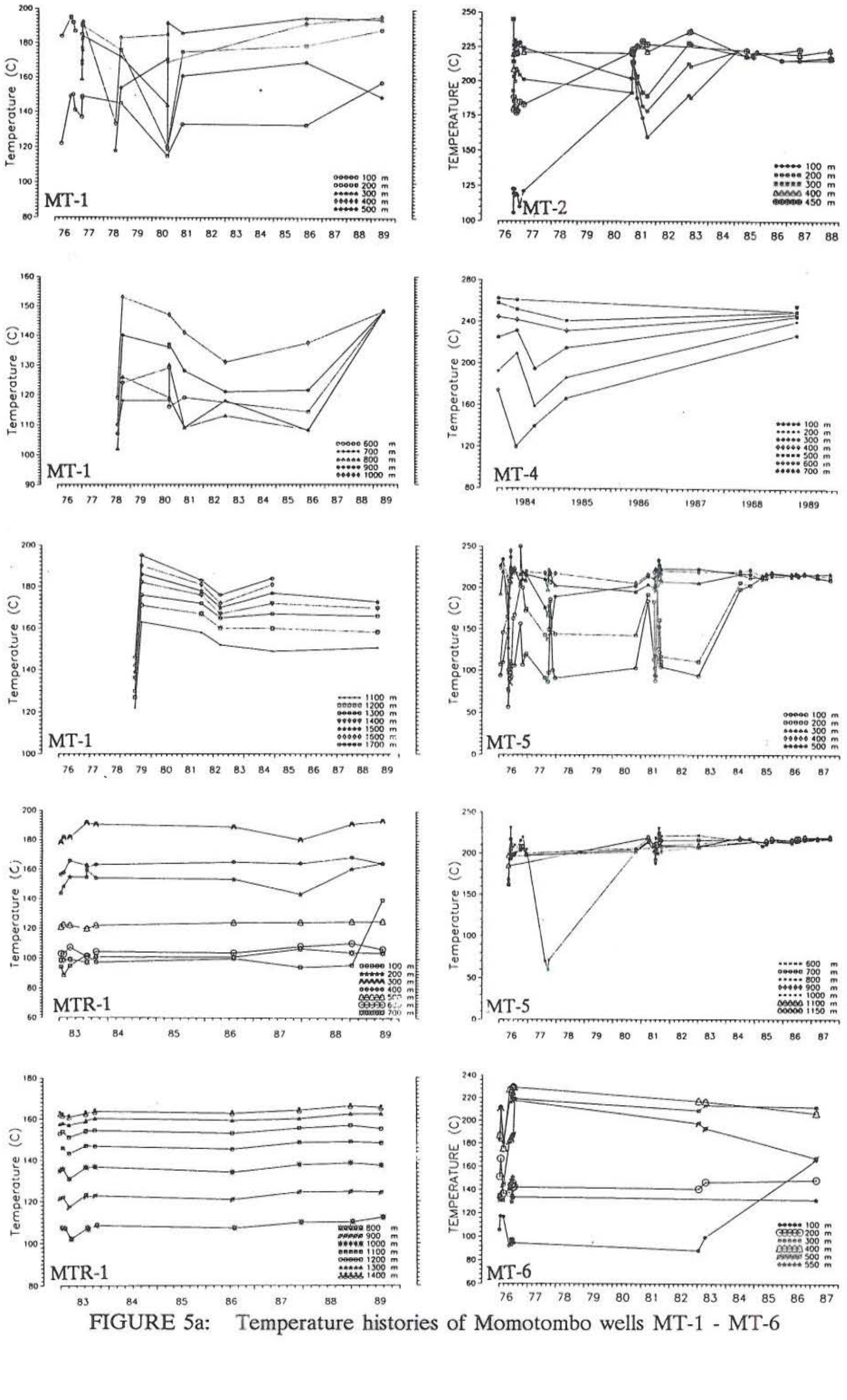

FIGURE 5a: Temperature histories of Momotombo wells MT-1 - MT-6

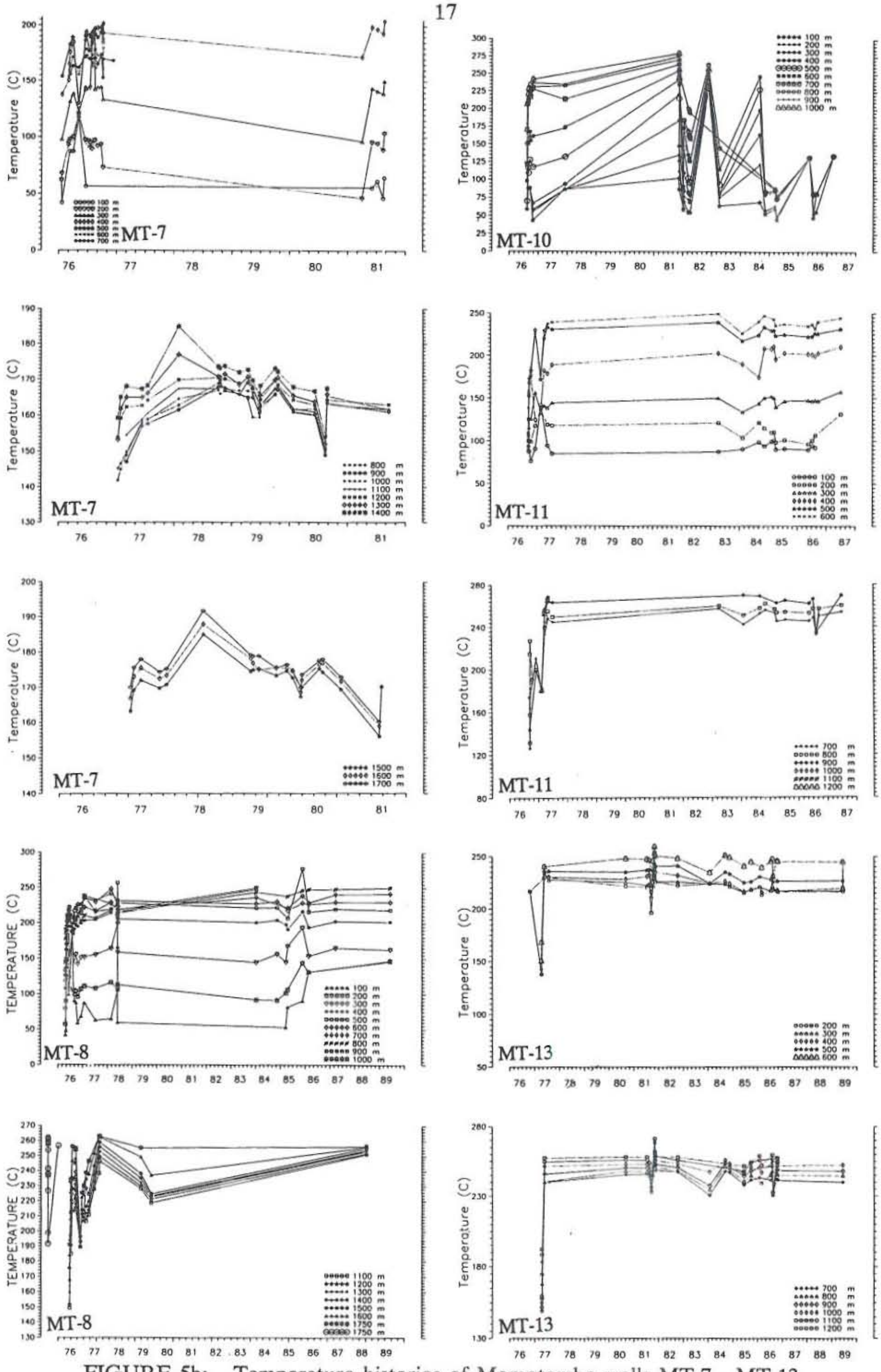

FIGURE 5b: Temperature histories of Momotombo wells MT-7 - MT-13

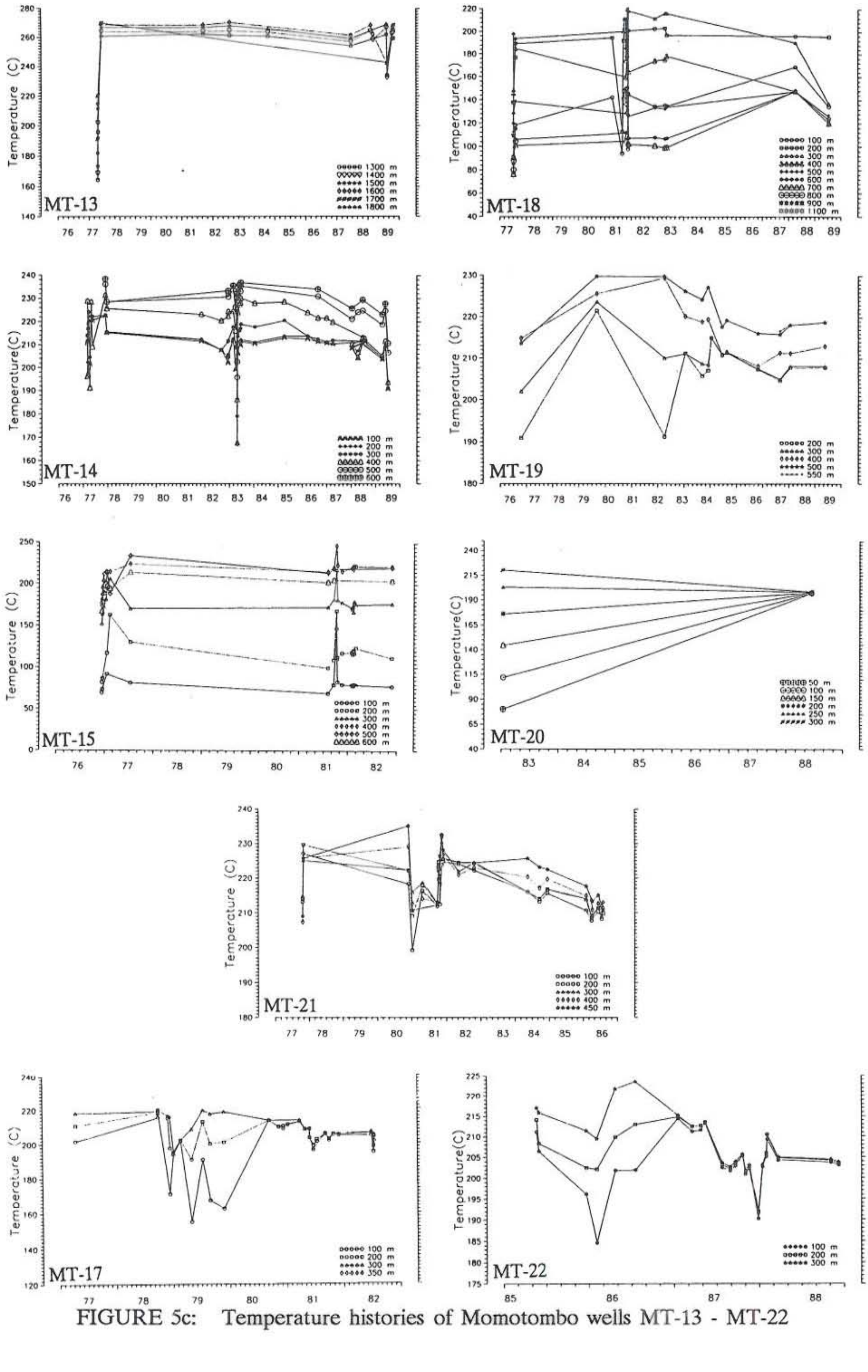

FIGURE 5c: Temperature histories of Momotombo wells MT-13 - MT-22

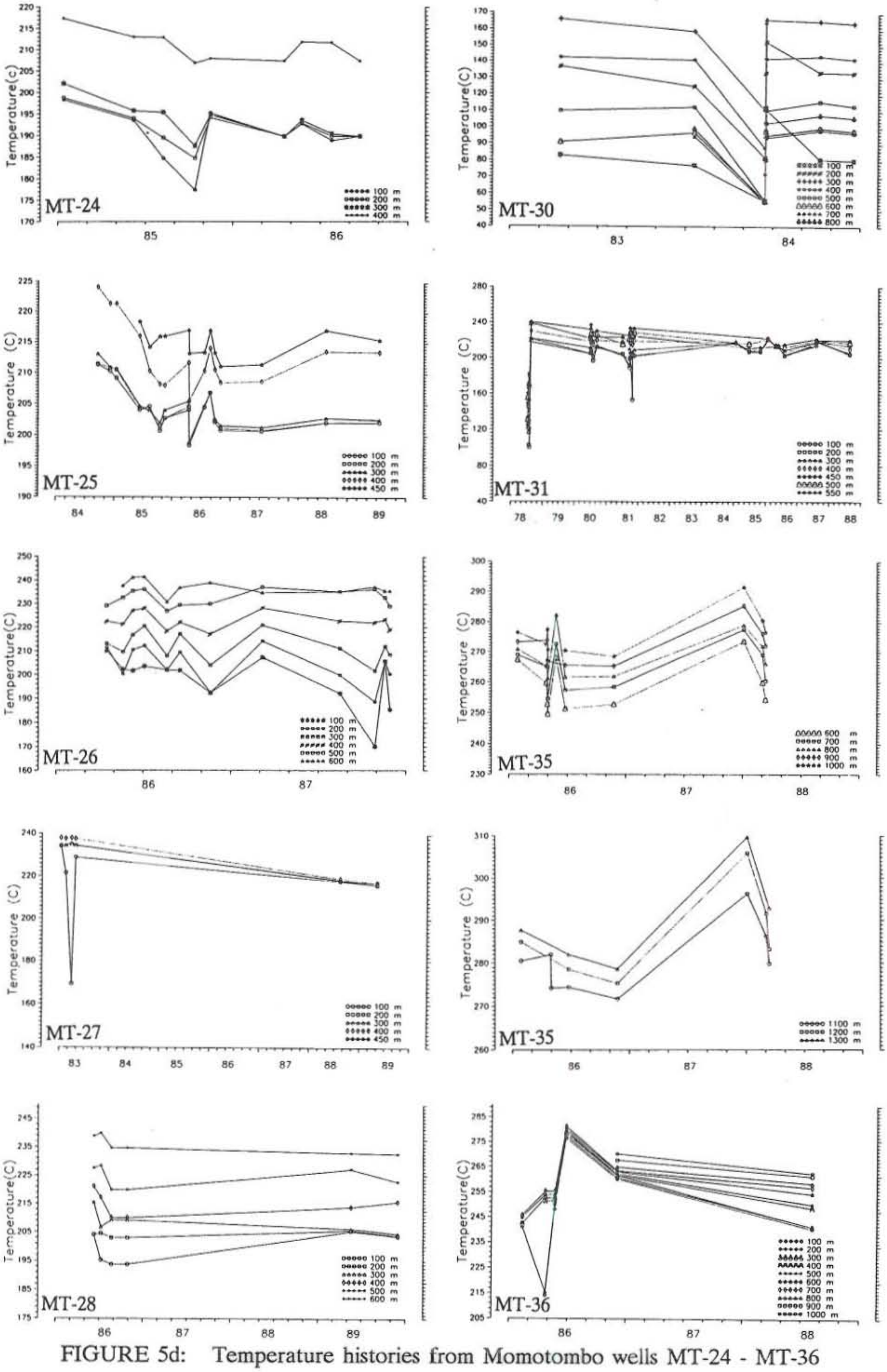

FIGURE 5d: Temperature histories from Momotombo wells MT-24 - MT-36

into account the abnormally high lateral temperature gradient between wells 7 and 8 (Gonzalez Solorzano, 1990).

Well MT-8: It is a productive well. The temperature history at different elevations is irregular and no conclusion can be made due to production distortion of the wellbore temperature.

Well MT-10: It is an injection well and shows irregular temperature history with time (Figure 4). Therefore, no conclusions on possible warming or cooling rates are made.

Well MT-11: It is productive and shows relatively stable temperatures with time at the different elevations considered. If a conclusion can be made, then we will say that a slow warm up is taking place with time.

Well MT-13: It is productive with a stable bottomhole temperature.

Well MT-14: It is a productive well. A high cooling rate is observed in Figure 4 after 1983, on the order of 1-6°C/year.

Well MT-15: It is an injection well and shows stable temperatures during the history of measurements.

Well MT-16: There is insufficient data for predicting possible temperature changes in its vicinity. The three measurements available show a fast warm-up after drilling, indicating a bottomhole temperature well above 240°C (Appendix B).

Well MT-17: It is productive and with an irregular temperature history at all depths examined, due to production.

Well MT-18: It is an injection well with a very irregular temperature history. At least one of the measurements is made by a temperature gauge which has the baseline higher than the wellbore temperature (88-03-29 in Appendix B). Injection was started in 1983. No conclusions will be made on the temperature history of this well.

Well MT-19: It is productive and shows a gradual cooling of 1.5°C/year since 1982. This cooling may only be due to boiling in the well during production. Therefore, no statements will be made.

Well MT-20: It is productive with only 2 measurements available, too few for making any conclusions.

Well MT-21: It is productive and shows a gradual cooling rate of 2°C/year at 0-450 m depth. This may be caused by production boiling only, so the temperature history of the well surroundings remains unknown.

Well MT-22: It is productive with temperature measurements in accordance with that; therefore, there are no conclusions.

Well MT-24: It is productive and shows a steady cooling rate of 6°C/year. Two years of measurements are available for the well. Since the characteristics of the temperature history at 400 m depth is very different from the upper levels, it is concluded that the measurements are made within a liquid column, showing a gradual cooling of the bottom hole feedzone.

Well MT-25, MT-26 and MT-27: These are productive, with temperature histories dominated by production.

Well MT-28: It is a productive well showing a slow increase in reservoir temperature with time (< 1°C at 300-500 m).

Well MT-30: It is a monitoring well with a distorted temperature history, due to boiling in the well.

Well MT-31: It is productive, and shows a gradual cooling of more than 1°C/year at 400-500 m depth.

Well MT-35: It is productive and shows a temperature increase with time. This is a high enthalpy well which probably boils all the way to the bottom during production. The wellbore temperature is, therefore, very sensitive for the time that passed between well shutdown and the measurement time. Therefore, there are no conclusions on reservoir temperature history.

Well MT-36: It is productive and disturbed by production in the temperature measurements considered.

5.3 Production induced cooling in the field

In Figure 6, an attempt is made to unite the cooling and the warm-up rates discussed above. Shown are warm-up and cooling rates in °C/year. Also shown with capital letters is the status of the wells used for the analysis. The main result of this analysis is that an area of cooling, due to production, is forming in the eastern part of the well field. The data used is incomplete and the exact shape of the area is, therefore, inaccurate. However, considerable cooling has occurred in some of the wells, indicating that influx of colder, peripheral water is now taking place in the Momotombo reservoir.

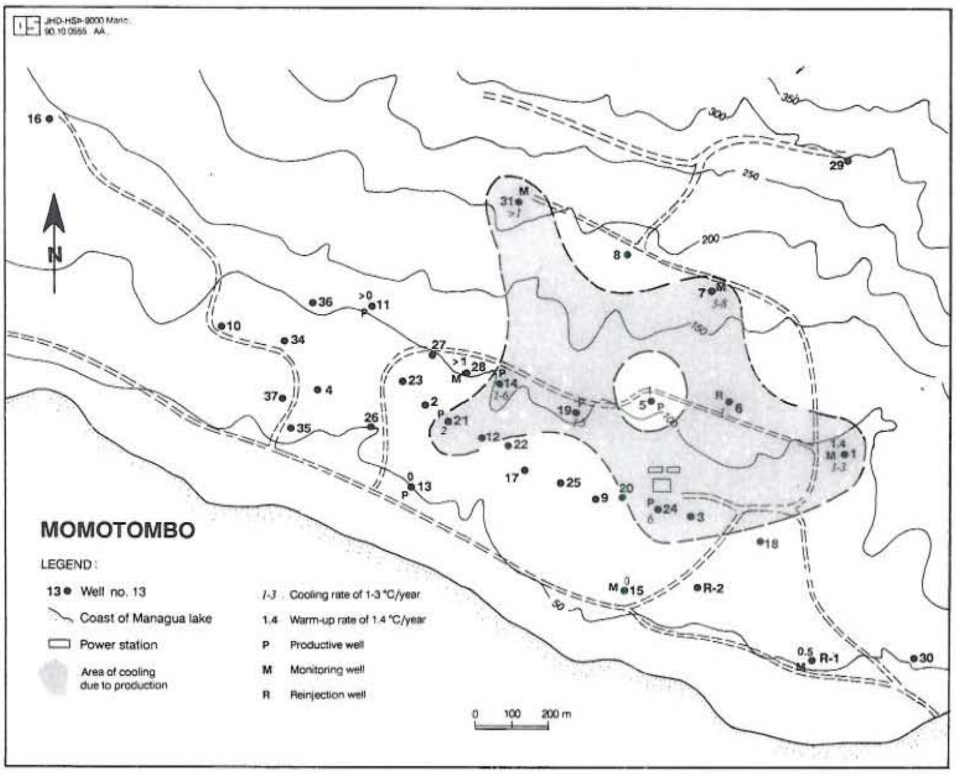

FIGURE 6: Estimated cooling and warming rates in the Momotombo reservoir

6. ANALYSIS OF PRESSURE DATA

6.1 Presentation

Table 3 shows that there are 45 pressure measurements available in the database. The pressure profiles for the individual wells are presented in Appendix B (for appendices, see Gonzalez Barbosa, 1990). In the following, we will analyze the pressure history of the field.

6.2 Reservoir pressure changes

Careful monitoring of wellbore pressures is one of the most critical parts of good reservoir monitoring. The wells chosen for such a monitoring task should be:

a) nonproducing or suffering little drawdown during production.
b) cased deep into the productive reservoir.
c) monitored at regular time intervals.

The pressure data existing in the Momotombo wells does not, in most cases, fullfill the above criteria.

The following analysis of reservoir pressure changes will, therefore, be incomplete. Figures 7-10 show measured pressures for several Momotombo wells at 200-800 m u.s.l. This unusual method of presentation was chosen, as the pressure measurements were made very irregularly in the individual wells. The disadvantage of this presentation is that lateral pressure changes in the reservoir will widen the range of datapoints on the figures, making the estimation of drawdown with time more inaccurate. The lateral pressure gradient in the field, prior to production, is on the order of 10 bars, descending to the east (Girelli et al., 1977).

The main conclusions drawn from Figures 7-10 are:

a) A minimun drawdown rate of 0.3 bars/year is taking place in the reservoir. This is even valid for wells in the southeast part of the well field which are furthest away and downstream from the main production zone.

b) Drawdown rates in productive wells are up to 20 bars for the 8 years that have passed since the installation of the first 35 MW unit in 1983. These values are overestimated, since a local drawdown close to productive wells is probably affecting the wells during the time of measurements.

It should be kept in mind that this kind of analysis is very primitive, since both initial pressures and the status of the wells during the measurements remain unknown.

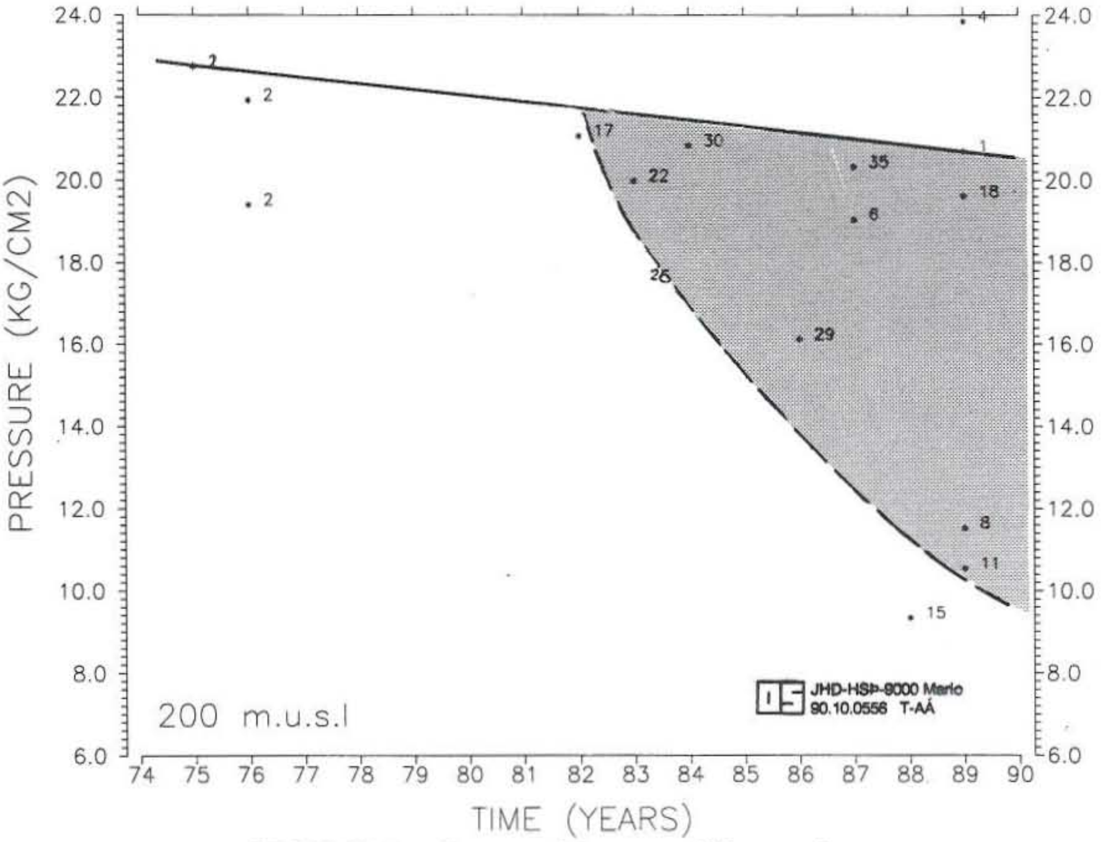

FIGURE 7: Pressure history at 200 m u.s.l.

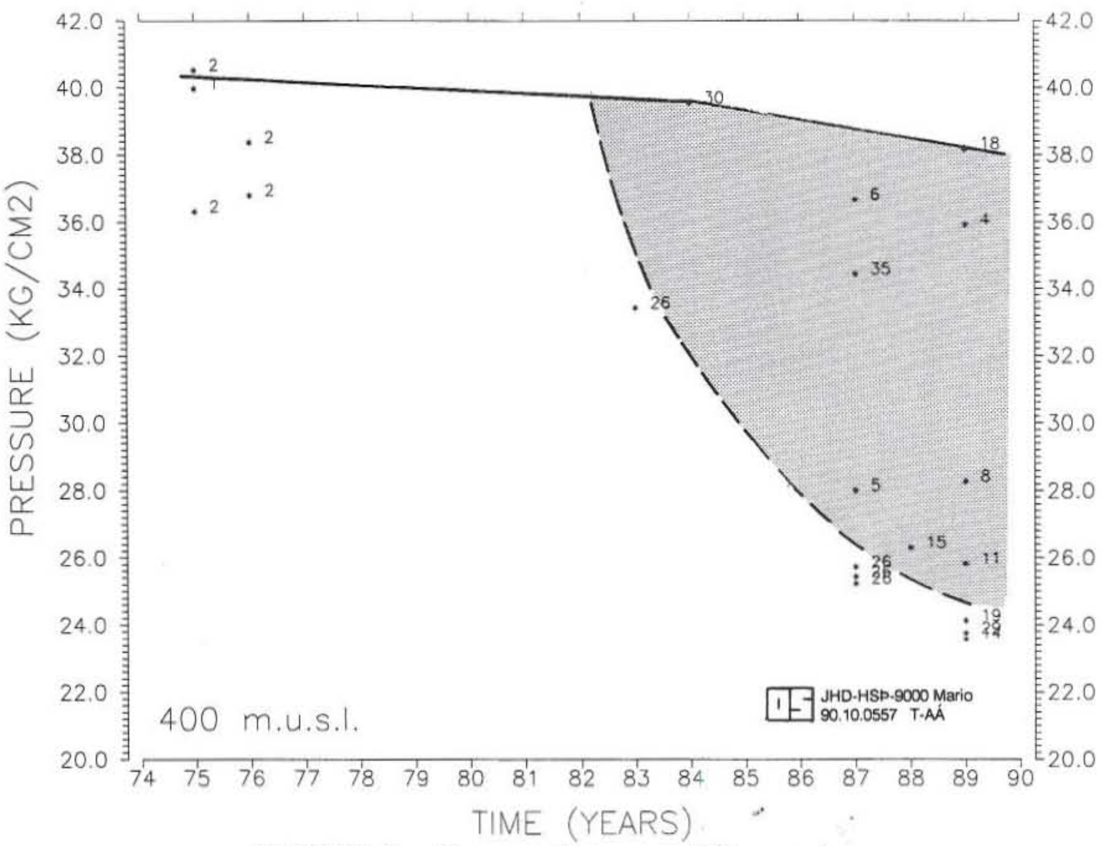

FIGURE 8: Pressure history at 400 m u.s.l.

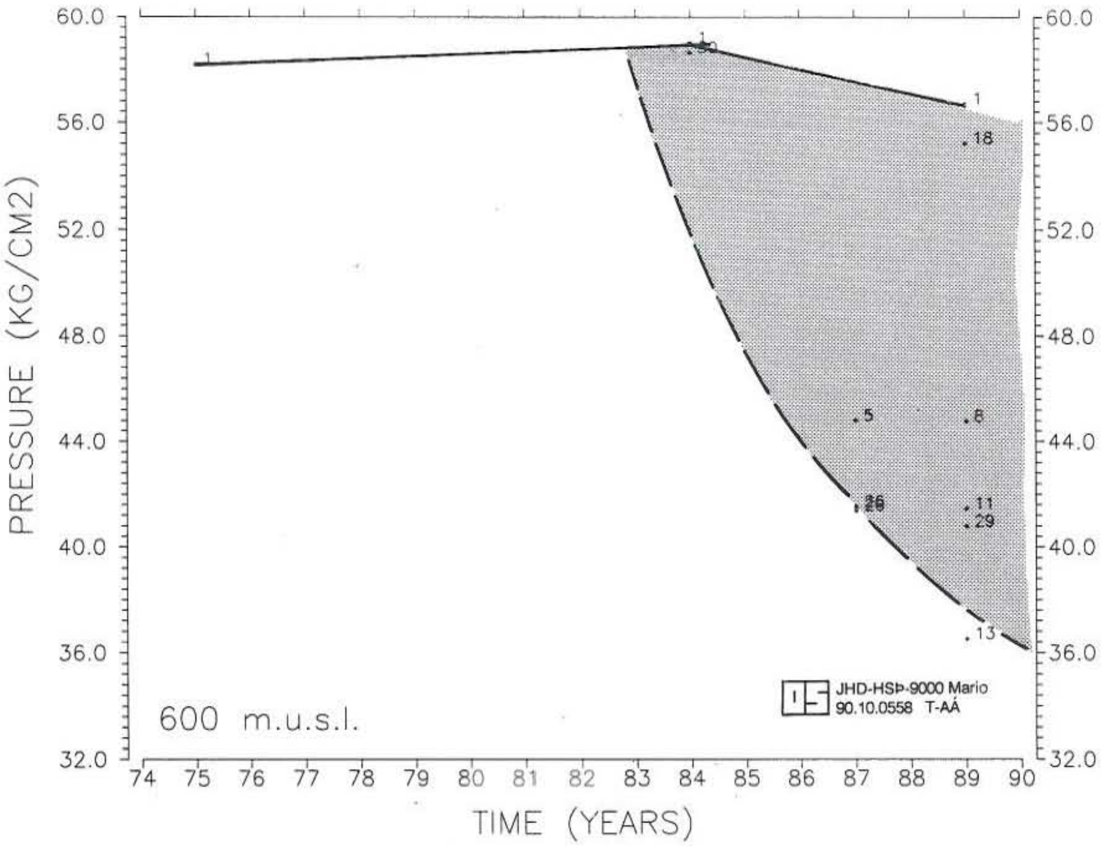

FIGURE 9: Pressure history at 600 m u.s.l.

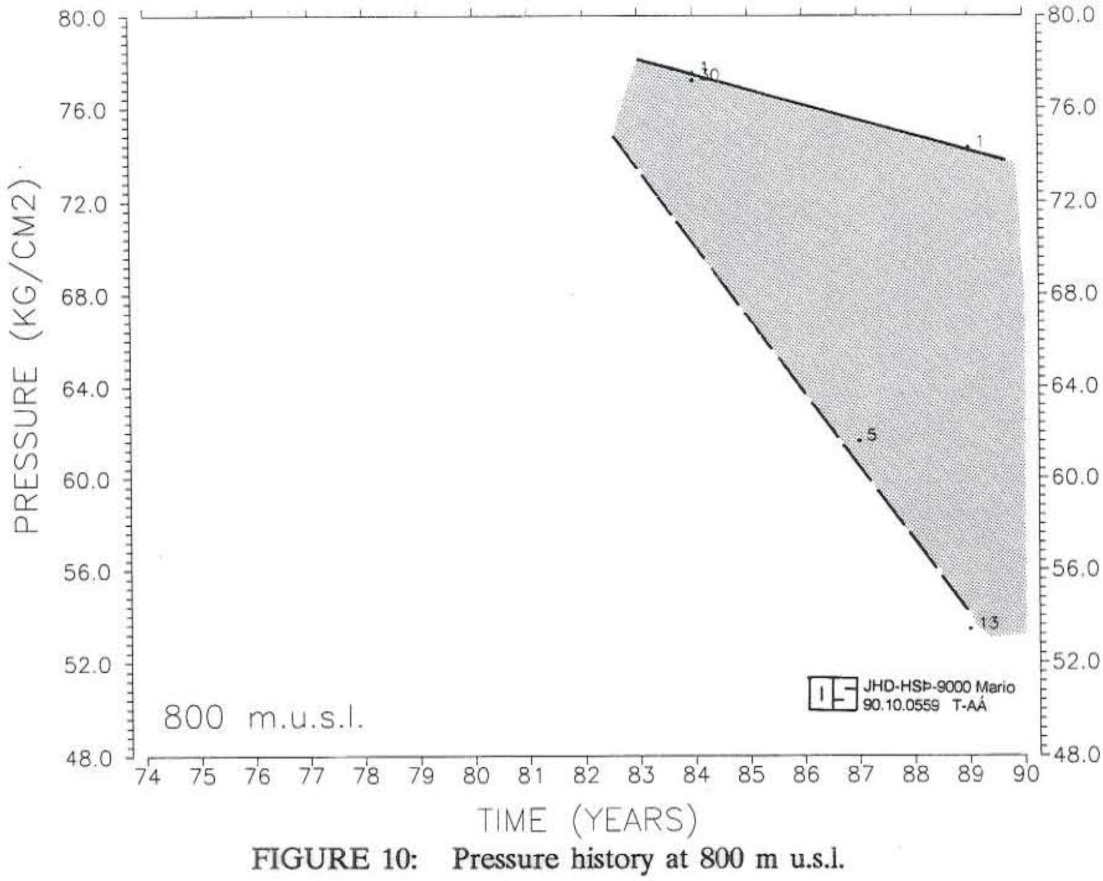

FIGURE 10: Pressure history at 800 m u.s.l.

7. ANALYSIS OF ENTHALPY CHANGES

Table 4 shows production data for some of the Momotombo wells (INE, 1984). In Figure 11, this data is plotted on an areal map of the well field. The Momotombo reservoir can be divided into a deep and a shallow reservoir (Gonzalez Solorzano, 1990). These two reservoirs are seen clearly in the produced enthalpy, where wells in the shallow reservoir are of low enthalpy origin and wells in the deep reservoir of high enthalpy origin. The more than 7 year history of intensive production has changed some of the shallow reservoir wells into almost dry steam wells. This indicates serious drawdown close to the wells, resulting in an increased steam fraction of the flow. This is a sign of maximum production from wells in a reservoir which was initially at liquid dominated condition. Therefore, a reduced flowrate should be expected in the near future in the shallow reservoir wells.

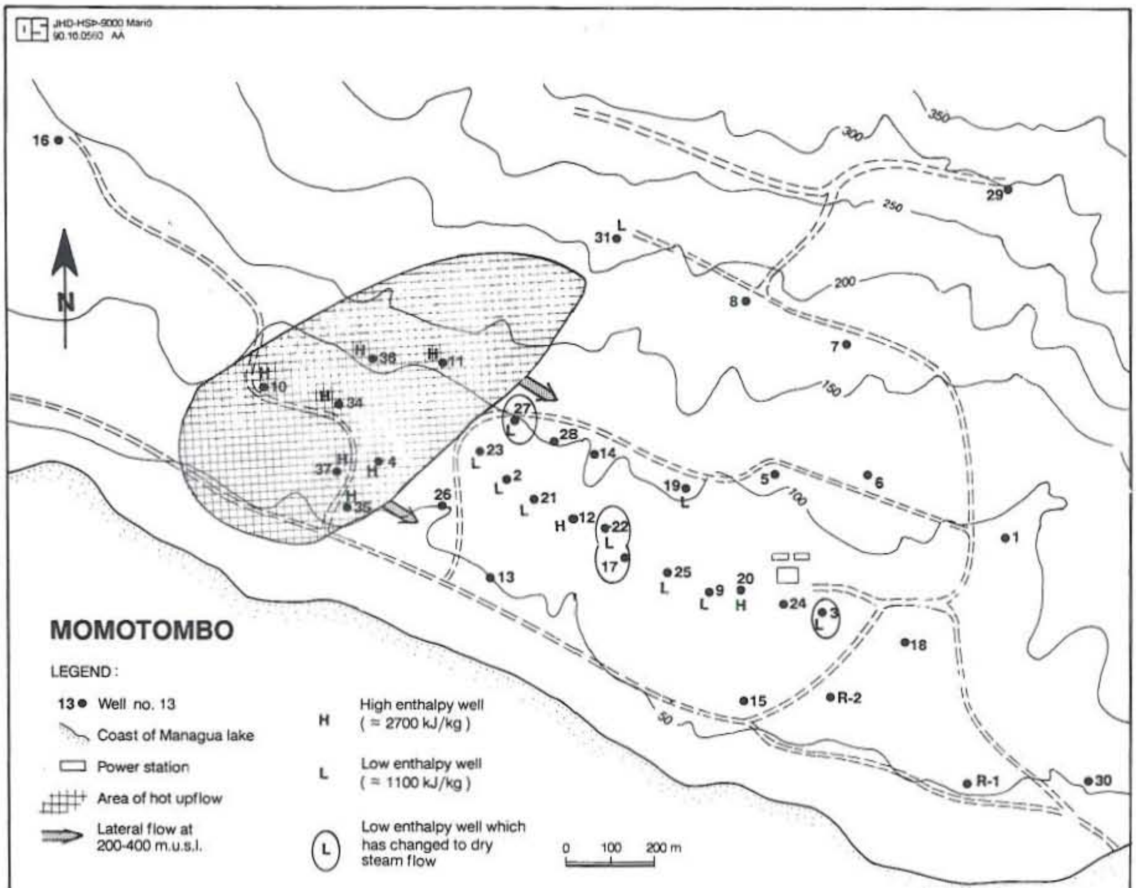

FIGURE 11: Enthalpy changes in Momotombo wells

TABLE 4: Production data for some Momotombo wells

Wells	Total flow rate (kg/s)	Steam flow rate (kg/s)	Enthalpy (kg/s)
MT-2	60	12	1100
MT-3	95	18	1100 (*)
MT-4	8	8	2700
MT-9	70	13	1100
MT-10	7	7	2700
MT-12	20	20	2700
MT-17	40	8	1100 (*)
MT-19	20	4	1100
MT-20	32	32	2700
MT-21	34	6	1100
MT-22	60	11	1100 (*)
MT-23	85	16	1100
MT-25	55	10	1100
MT-26	90	17	1100
MT-27	140	26	1100 (*)
MT-31	110	12	950
MT-35	60	38	2021

(*) Wells which have been producing dry steam from 1983.

8. CONCLUSIONS AND RECOMMENDATIONS

The main conclusions of the study are:

a) A simple PC database is available with most of the downhole temperature and pressure measurements made in Momotombo.

b) Temperature changes with time are minimal in most of the wells. However, there is production induced cooling at rates of up to 6°C/year in the northeast part of the well field.

c) A minimum drawdown rate is 0.3 bars/year in the reservoir and the drawdown rates in productive wells are up to 20 bars for the 8 years of exploitation.

d) Pressure drawdown close to the production wells has changed the flow of some wells into almost dry steam flow. This indicates that production has reached maximum capacity in that part of the well field.

The study of time dependent changes shows, therefore, that the natural state of the Momotombo reservoir is already being changed by production, especially at shallow levels. These changes should be monitored in order to gain data for a future production scheme for the field. The most important factors for such a scheme are:

a) Monitor pressure in non-producing wells, or in productive wells which suffer little drawdown during production.

b) Register wellhead conditions when pressure and temperature measurements are made and store with the downhole data.

c) Organize available data on production and injection rates and store it in some kind of computer database.

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Report 5 appendices, 1990

APPENDICES TO THE REPORT:
ANALYSIS OF WELLBORE TEMPERATURES AND PRESSURES IN THE MOMOTOMBO GEOTHERMAL FIELD, NICARAGUA

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These are the appendices to the report: Analysis of wellbore temperatures and pressures in the Momotombo geothermal field, Nicaragua. It was written by Mario Gonzalez Barbosa at the UNU Geothermal Training Programme in 1990. It is divided into two parts. Appendix A shows a list of all the FORTRAN routines used for the MOMOTOMB database with a detailed description. Appendix B shows all 522 temperature measurements and all 45 pressure measurements for wells in the Momotombo geothermal field available in the database.

APPENDIX A:

FORTRAN routines used in the database MOMOTOMB

```
c***********************************************************************
c                         PROGRAM TTIME.FOR
c
c  This program reads in temperature data files for the MOMOTOMBO
c  geothermal field.  The temperature files are stored on separate
c  subdirectories for the individual wells.  On each of these sub-
c  directories is also stored a file with the name "FILES.TEM", which
c  containes the names of the temperature data files.  The program askes
c  for the depth of interst in the well and creates a file with the
c  temperature history at that depth.  The time skale is in number of
c  days after some initial date (supplied by user).  The output file
c  is applicable for the GRAPHER.
c
c  The character vector FILES stores the names of the temperature data
c  files, and NUM is the number of files.  DMAX is the maximum distance
c  used to extrapolate temperature values into some depth.  The vector
c  days stores the number of days passed from some initial date for
c  all the temperature data files.
c
c                         Reykjavik august 1990, Grimur Bjornsson
c***********************************************************************
c
      program ttime
      real t,d,dmax
      real depth(200),temp(200)
      integer yy,mm,dd,y0,m0,d0,inyear
      integer days(100)
      character*50 inname,outname
      character*50 files(200)
c
c-----------------------------------------------------------------------
c  Reading in data, converting it to the right units and writing it to
c  the output file
c-----------------------------------------------------------------------
c
25    write (6,'('' Initial date (yymmdd, -99=770101 ) : '',$)')
      read (5,'(i6)',err=25) inyear
      if ( inyear .lt. 0 ) then
        y0 = 77
        m0 = 1
        d0 = 1
      else
        y0 = int( inyear/10000 )
        m0 = int( (inyear-y0*10000)/100 )
        d0 = inyear-y0*10000-m0*100
        if ( m0 .gt. 12 .or. d0 .gt. 31 ) then
          write (6,'(''** error in date '',i7)') inyear
          close (unit=1)
          close (unit=2)
          stop
        endif
      endif
c
c-----------------------------------------------------------------------
c  Asked for name of output file and files opened
c-----------------------------------------------------------------------
c
5     open (unit=1,file='files.tem',status='old')
20    write (6,'('' Name of output file : '',$)')
      read (5,'(a)') outname

      open (unit=2,file=outname,status='unknown',err=20)
26    write (6,'('' Depth in well (m)                    : '',$)')
      read (5,'(f10.2)',err=26) d
27    write (6,'('' Max. interpol. distance (m)          : '',$)')
      read (5,'(f10.2)',err=27) dmax
c
c-----------------------------------------------------------------------
c  Reading in names of data files, maximium of 200 files
c-----------------------------------------------------------------------
c
      do 28 i=1,200
        num = i
        read (1,'(a)',end=29 ) files(i)
        call transf (files(i)(1:2),yy)
        call transf (files(i)(3:4),mm)
        call transf (files(i)(5:6),dd)
        if ( mm .gt. 12 .or. dd .gt. 31 ) then
          write (6,'(''** error in file name '',i7)') inyear
          close (unit=1)
          close (unit=2)
          stop
        endif
        if ( yy .gt. y0 ) then
          days(i) = (12-m0)*30.4 + 31-d0
          days(i) = days(i) + (yy-y0-1)*365.25 + (mm-1)*31 + dd
        elseif ( yy .eq. y0 .and. mm .ge. m0 ) then
          if ( mm .eq. m0 .and. dd .ge. d0 ) then
            days(i) = dd-d0
          elseif ( mm .eq. m0 .and. dd .lt. d0 ) then
            days(i) = -99
          else
            days(i) = (mm-m0-1)*30.4 + 31.4-d0 + dd
          endif
        else
          days(i) = -99
        endif
28    continue
29    num = num-1
c
c-----------------------------------------------------------------------
c  Reading in temperature data files and writing the temperature values
c  into a file.
c-----------------------------------------------------------------------
c
      do 50 i = 1,num
        open (unit=1,file=files(i),status='old')
        do 60 j = 1,1000
          read (1,*,end=77) depth(j),temp(j)
          nn = j
          if ( depth(j) .ge. d ) goto 77
60      continue
77      close (unit=1)
        if ( abs(depth(nn)-d) .lt. 1. ) then
          write (2,1000) days(i),temp(nn)
1000      format ( i6,f10.2 )
        elseif ( depth(1) .gt. d .and. abs(depth(1)-d) .lt. dmax ) then
          a = (30.-temp(1)) / depth(1)
          b = temp(1) - a*depth(1)
          t = a*d + b
          write (2,1000) days(i),t
        elseif (depth(nn) .lt. d .and. abs(depth(nn)-d) .lt. dmax) then
          a = (temp(nn-1)-temp(nn)) / (depth(nn-1)-depth(nn))
          b = temp(nn) - a*depth(nn)
          t = a*d + b
          write (2,1000) days(i),t
        elseif ( abs(depth(nn)-d) .lt. dmax .or.
     1  abs(depth(nn-1)-d) .lt. dmax ) then
          a = (temp(nn-1)-temp(nn)) / (depth(nn-1)-depth(nn))
          b = temp(nn) - a*depth(nn)
          t = a*d + b
          write (2,1000) days(i),t
        endif
50    continue
      close ( unit=1 )
      close ( unit=2 )
      write ( 6,'('' More depths to create ( yes= 1 ) : '',$)')
      read (5,'(i4)' ) ians
      if ( ians .eq. 1 ) goto 5
      stop
      end
c
c-----------------------------------------------------------------------
c                         SUBROUTINE TRANSF
c
c  This subroutine transfers two digit character number into
c  two digit integer
c-----------------------------------------------------------------------
c
      subroutine transf(kar,nn)
      character*50 kar
      integer i1,i2,nn
      i1=0
      i2=0
      if ( kar(1:1) .eq. '1' ) then
        i1=1
      elseif ( kar(1:1) .eq. '2' ) then
        i1=2
      elseif ( kar(1:1) .eq. '3' ) then
        i1=3
      elseif ( kar(1:1) .eq. '4' ) then
        i1=4
      elseif ( kar(1:1) .eq. '5' ) then
        i1=5
      elseif ( kar(1:1) .eq. '6' ) then
        i1=6
      elseif ( kar(1:1) .eq. '7' ) then
        i1=7
      elseif ( kar(1:1) .eq. '8' ) then
        i1=8
      elseif ( kar(1:1) .eq. '9' ) then
        i1=9
      endif
      if ( kar(2:2) .eq. '1' ) then
        i2=1
      elseif ( kar(2:2) .eq. '2' ) then
        i2=2
      elseif ( kar(2:2) .eq. '3' ) then
        i2=3
      elseif ( kar(2:2) .eq. '4' ) then
        i2=4
      elseif ( kar(2:2) .eq. '5' ) then
        i2=5
      elseif ( kar(2:2) .eq. '6' ) then
        i2=6
      elseif ( kar(2:2) .eq. '7' ) then
        i2=7
      elseif ( kar(2:2) .eq. '8' ) then
        i2=8
      elseif ( kar(2:2) .eq. '9' ) then
        i2=9
      endif
      nn = i1*10 + i2
      return
      end
```

```
c***********************************************************************
c                         PROGRAM PTIME.FOR
c
c  This program reads in pressure data files for the MOMOTOMBO
c  geothermal field.  The files are stored in the same subdirectory
c  and have the names MT#_YY.DAT where # is the well number and
c  YY is the year of measurement.  In most cases, there is only
c  one measurement/year in each well, but in few cases, there are
c  well names of the type MT#_YYa.dat etc.  On the directory is
c  also a file with the name "FILES.TEM", which
c  containes the names of the pressure data files.  The program askes
c  for the depth of interst in the well and creates a file with the
c  pressure history at that depth for all the wells.  The time skale
c  is the year of measurement + 0.5.  The output file
c  is applicable for the GRAPHER.
c
c  The character vector FILES stores the names of the pressure data
c  files, and NUM is the number of files.  DMAX is the maximum distance
c  used to extrapolate pressure values into some depth.
c
c                         Reykjavik october 1990, Grimur Bjornsson
c***********************************************************************
c
      program ptime
      real p,d,dmax
      real depth(200),press(200)
      integer yy,mm,dd,y0,m0,d0,inyear
      integer years(100),well(100)
      character*50 inname,outname
      character*50 files(200)
c
c-----------------------------------------------------------------------
c  Asked for name of output file and files opened
c-----------------------------------------------------------------------
c
5     open (unit=1,file='files.tem',status='old')
20    write (6,'('' Name of output file : '',$)')
      read (5,'(a)') outname
      open (unit=2,file=outname,status='unknown',err=20)
26    write (6,'('' Depth in well (m.u.s.l.)             : '',$)')
      read (5,'(f10.2)',err=26) d
27    write (6,'('' Max. interpol. distance (m)          : '',$)')
      read (5,'(f10.2)',err=27) dmax
c
c-----------------------------------------------------------------------
c  Reading in names of data files, maximium of 200 files
c-----------------------------------------------------------------------
c
      do 28 i=1,200
        num = i
        read (1,'(a)',end=29 ) files(i)
        call transf (files(i),years(i),well(i))
28    continue
29    num = num-1
c
c-----------------------------------------------------------------------
c  Reading in pressure data files and writing the pressure values
c  into a file.
c-----------------------------------------------------------------------
```

```
      do 50 i = 1,num
        open (unit=1,file=files(i),status='old')
        do 60 j = 1,1000
          read (1,*,end=77) depth(j),press(j)
          nn = j
          if ( depth(j) .ge. d ) goto 77
60      continue
77      close (unit=1)
        if ( abs(depth(nn)-d) .lt. 1. ) then
          write (2,1000) years(i), press(nn), well(i)
1000      format ( i6,f10.2,i6,f8.5 )
        elseif ( depth(1) .gt. d .and. abs(depth(1)-d) .lt. dmax ) then
          a = (1.-press(1)) / depth(1)
          b = press(1) - a*depth(1)
          p = a*d + b
          write (2,1000) years(i), p, well(i), abs(a)
        elseif (depth(nn) .lt. d .and. abs(depth(nn)-d) .lt. dmax) then
          a = (press(nn-1)-press(nn)) / (depth(nn-1)-depth(nn))
          b = press(nn) - a*depth(nn)
          p = a*d + b
          write (2,1000) years(i), p, well(i), abs(a)
        elseif ( abs(depth(nn)-d) .lt. dmax .or.
     1  abs(depth(nn-1)-d) .lt. dmax ) then
          a = (press(nn-1)-press(nn)) / (depth(nn-1)-depth(nn))
          b = press(nn) - a*depth(nn)
          p = a*d + b
          write (2,1000) years(i), p, well(i), abs(a)
        endif
50    continue
      close ( unit=1 )
      close ( unit=2 )
      write ( 6,'('' More depths to create ( yes= 1 ) : '',$)')
      read (5,'(i4)' ) ians
      if ( ians .eq. 1 ) goto 5
      stop
      end
c
c-----------------------------------------------------------------------
c                          SUBROUTINE TRANSF
C
C  This routine finds well number and year of measurement from a
c  file name of the form MT#_YY
c-----------------------------------------------------------------------
c
      subroutine transf(file,yy,nn)
      character*50 file
      integer yy,nn
c
      i3 = 5
      call number(file(3:3),i1)
      nn = i1
      if ( file(4:4) .ne. '_' ) then
        call number(file(4:4),i2)
        nn = 10*i1 + i2
        i3 = 6
      endif
      call number(file(i3:i3),i4)
      call number(file(i3+1:i3+1),i5)
      yy = i4*10 + i5 + 0.5
      return
c***********************************************************************
c                          PROGRAM PROD.FOR
c
c  This program converts productiond data files for the MOMOTOMBO
c  geothermal field into file that is applicable for the GRAPHER.
c  Input for the program is a rav data file (often called PROD.RAV)
c  whith data lines of the form:
c         yymmdd,whp,flow,ent
c  where 'whp' is wellhead pressure in bar-g, 'flow' is the total wellhead
c  flow in tonnes/hour and 'ent' is the wellhead enthalpy in kcal/kg.
c  The output file has the same form, except that the data (yymmdd) is
c  now given in number of days from some initial date, provided by the
c  user.
c                         Reykjavik august 1990, Grimur Bjornsson
c***********************************************************************
c
      program prod
      real whp,flow,ent
      integer yy,mm,dd,y0,m0,d0,inyear,days
      character*50 inname,outname
c
c-----------------------------------------------------------------------
c  Asked for names of input and output files and they opened
c-----------------------------------------------------------------------
c
10    write (6,'('' Name of input  file : '',$)')
      read (5,'(a)') inname
      open (unit=1,file=inname,status='old',err=10)
20    write (6,'('' Name of output file : '',$)')
      read (5,'(a)') outname
      open (unit=2,file=outname,status='new',err=20)
c
c-----------------------------------------------------------------------
c  Reading in data, converting it to the right units and writing it to
c  the output file
c-----------------------------------------------------------------------
c
25    write (6,'('' Initial date (yymmdd, -99=770101 ) : '',$)')
      read (5,'(i6)',err=25) inyear
      if ( inyear .lt. 0 ) then
        y0 = 77
        m0 = 1
        d0 = 1
      else
        y0 = int( inyear/10000 )
        m0 = int( (inyear-y0*10000)/100 )
        if ( m0 .gt. 12 ) then
          write (6,'(''** error in month '',i7)') inyear
          close (unit=1)
          close (unit=2)
          stop
        endif
        d0 = inyear-y0*10000-m0*100
        if ( d0 .gt. 31 ) then
          write (6,'(''** error in date '',i7)') inyear
          close (unit=1)
          close (unit=2)
          stop
        endif
      endif
       end
c
```

```
c-----------------------------------------------------------------
c                          SUBROUTINE NUMBER
c
c  This subroutine transfers one digit character number into
c  one digit integer
c-----------------------------------------------------------------
c
      subroutine number(kar,i1)
      character*1 kar
      integer i1,i2,nn
      i1=0
      i2=0
      if ( kar(1:1) .eq. '1' ) then
        i1=1
      elseif ( kar(1:1) .eq. '2' ) then
        i1=2
      elseif ( kar(1:1) .eq. '3' ) then
        i1=3
      elseif ( kar(1:1) .eq. '4' ) then
        i1=4
      elseif ( kar(1:1) .eq. '5' ) then
        i1=5
      elseif ( kar(1:1) .eq. '6' ) then
        i1=6
      elseif ( kar(1:1) .eq. '7' ) then
        i1=7
      elseif ( kar(1:1) .eq. '8' ) then
        i1=8
      elseif ( kar(1:1) .eq. '9' ) then
        i1=9
      else
        i1=0
      endif
      return
      end
c-------------------------------------------------------------------
c  Reading in data, converting it to the right units and writing
c  the output file
c-------------------------------------------------------------------
c
30    read (1,*,end=999) dd,mm,yy,whp,flow,ent
      flow = flow * 1000/3600
      ent = ent * 4.2
      if ( mm .gt. 12 ) then
        write (6,'(''** error in month '',i7)') inyear
        close (unit=1)
        close (unit=2)
        stop
      endif
      if ( dd .gt. 31 ) then
        write (6,'(''** error in date '',i7)') inyear
        close (unit=1)
        close (unit=2)
        stop
      endif
      if ( yy .gt. y0 ) then
        days = (12-m0)*30.4 + 31-d0
        days = days + (yy-y0-1)*365.25 + (mm-1)*31 + dd
        write ( 2,'(i5,3f8.2)') days,whp,flow,ent
      elseif ( yy .eq. y0 .and. mm .ge. m0 ) then
        if ( mm .eq. m0 .and. dd .ge. d0 ) then
          days = dd-d0
        elseif ( mm .eq. m0 .and. dd .lt. d0 ) then
          goto 30
        else
          days = (mm-m0-1)*30.4 + 31.4-d0 + dd
        endif
        write ( 2,'(i5,3f8.2)') days,whp,flow,ent
      endif
      goto 30
999   stop
      end
```

```
c*******************************************************************
c                  PROGRAM INIT.FOR
c
c  A program which reads in a file with digitized temperature
c  curve from Momotombo, and the elevation of the well in m.a.s.l.
c  The output file will contain 3 columns, 1st. column is
c  the depth in well coordinates, 2nd. column is the depth
c  relative to sealevel and the 3rd. column is the temperature.
c
c         Reykjavik August 1990, Grimur Bjornsson
c*******************************************************************
c
      program init
      character*50 in, out
      real elev,d,t
      write (6,'(''  Name of input file ......: '',$)')
      read (5,'(a)') in
      write (6,'(''  Name of output file .....: '',$)')
      read (5,'(a)') out
      write (6,'(''  Elevation (m.a.s.l.) ....: '',$)')
      read (5,'(f10.1)') elev
      open (unit=1,file=in,status='old')
      open (unit=2,file=out,status='unknown')
c
      do 10 i=1,1000
        read (1,*,end=99) d,t
        write (2,'(3f10.1)') d-elev,t,d
10    continue
99    close (unit=1)
      close (unit=2)
      stop
      end
```

APPENDIX B:

Temperature and pressure measurements available in the MOMOTOMB database

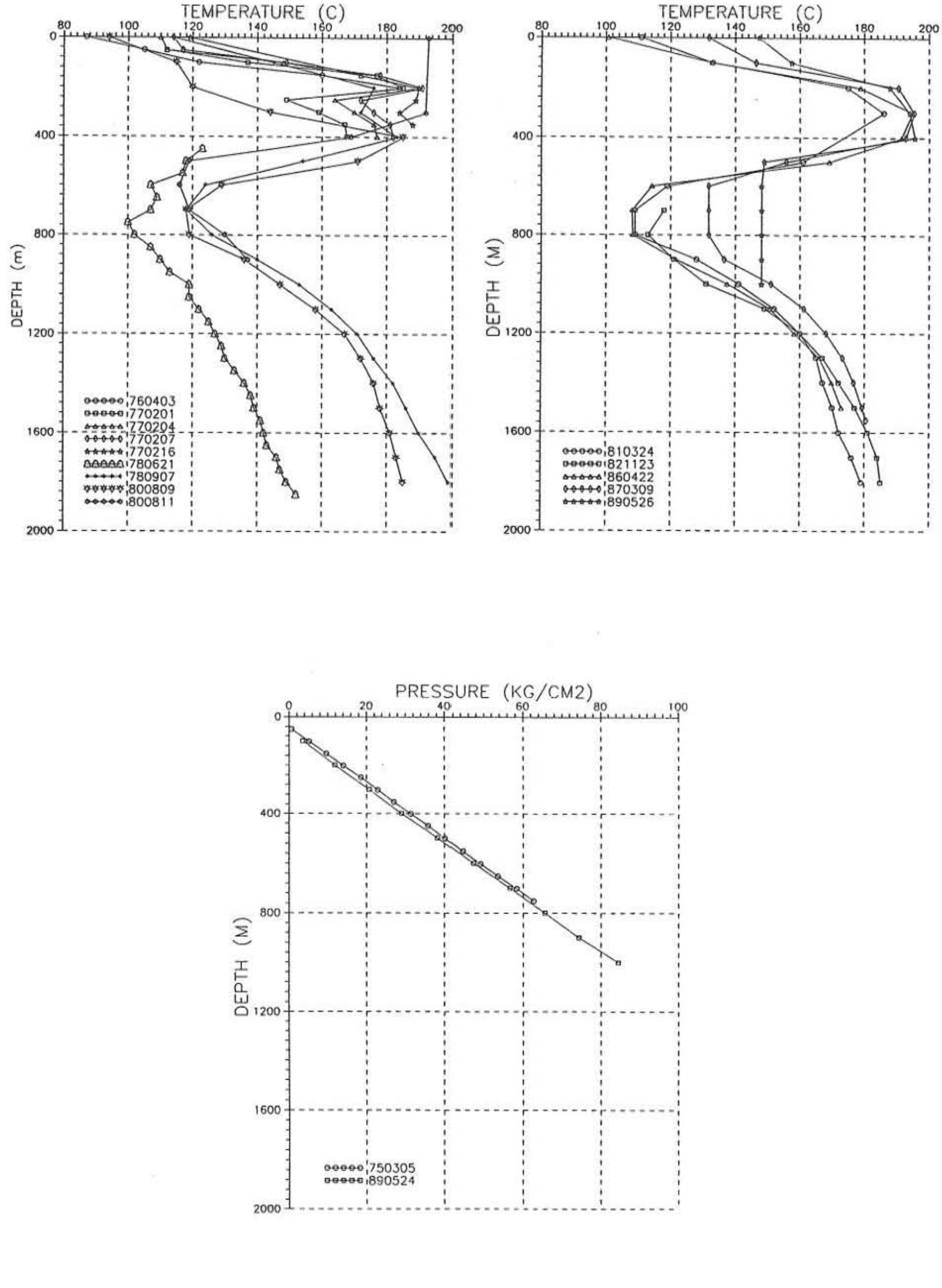


Figure A1: Temperature and pressure measurements in well MT-1

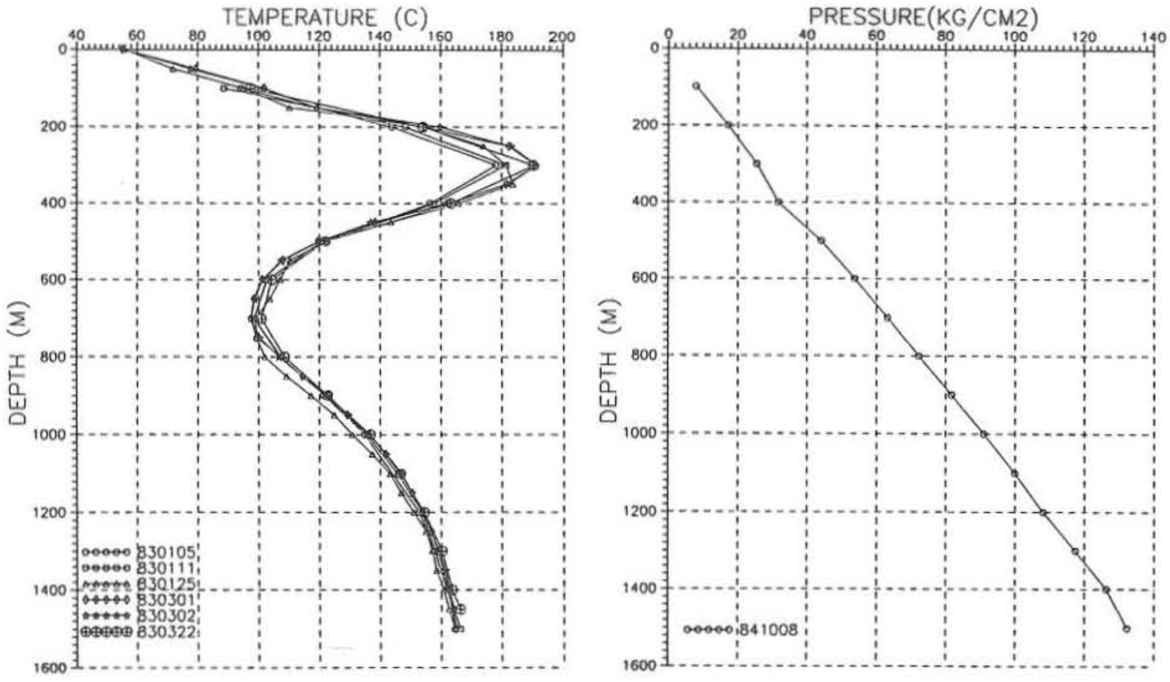


Figure A2: Temperature and pressure measurements in well MTR-1

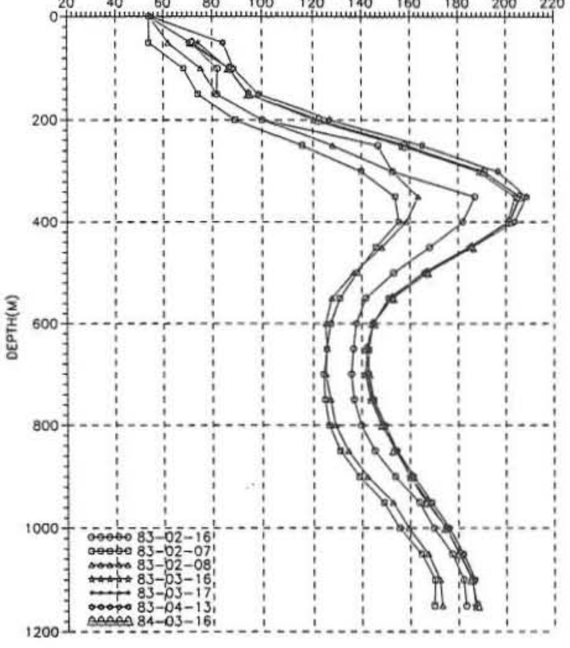


Figure A3: Temperature measurements in well MTR-2

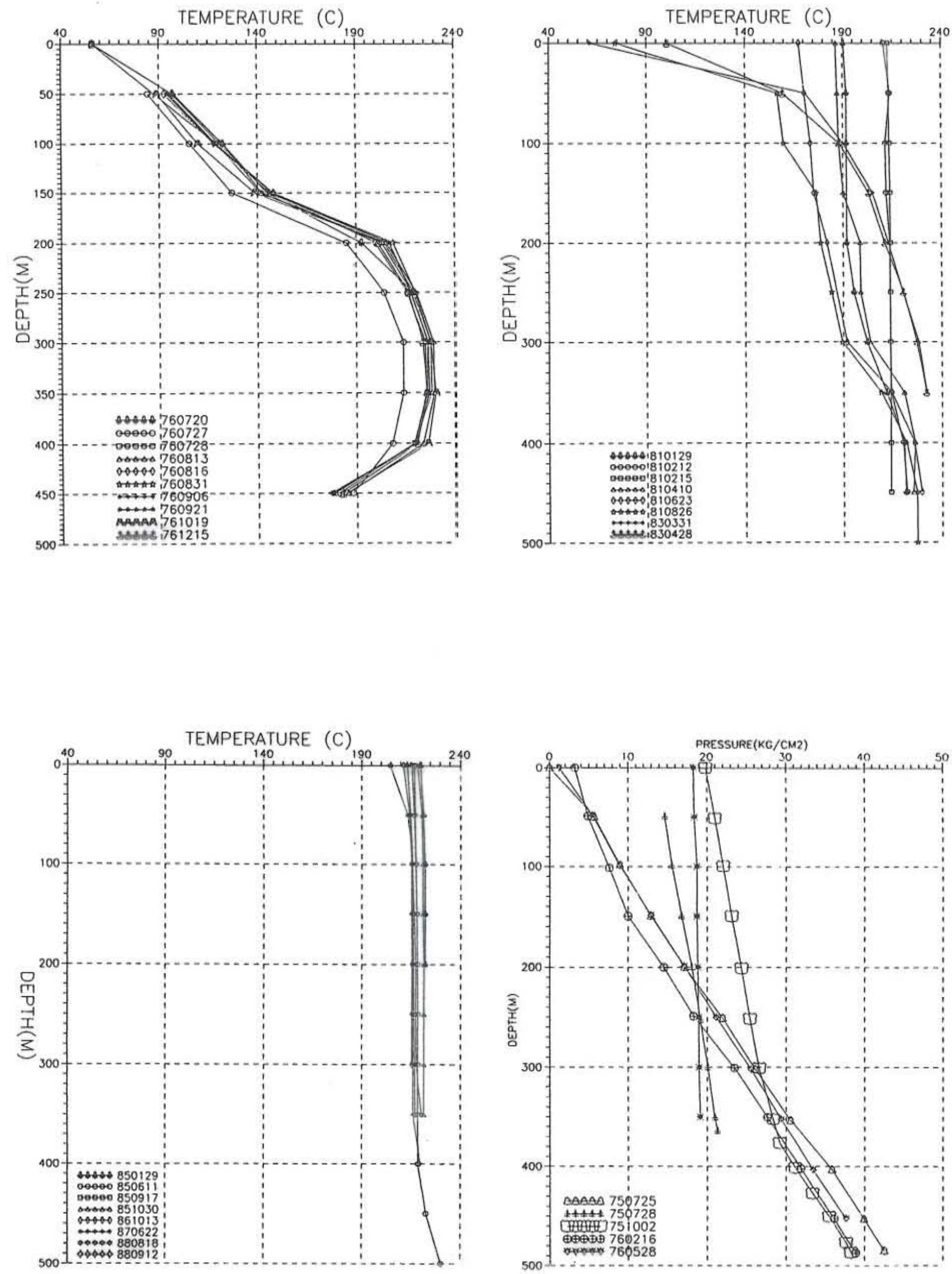


Figure A4: Temperature and pressure measurements in well MT-2

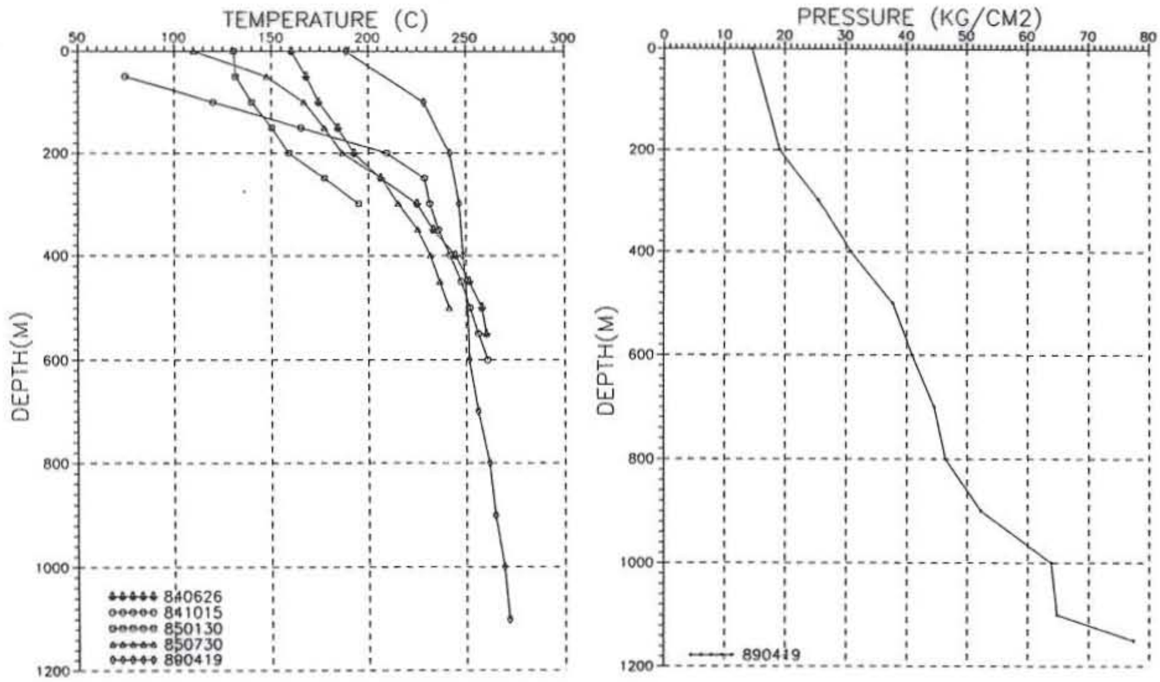


Figure A5: Temperature and pressure measurements in well MT-4

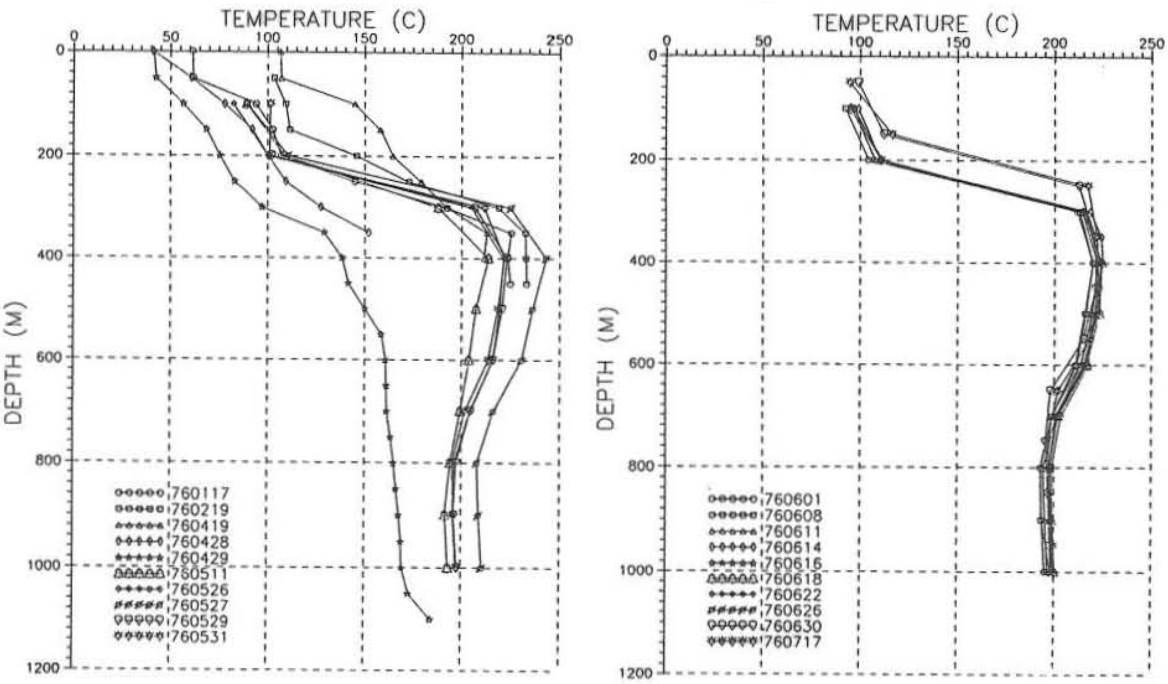


Figure A6: Temperature measurements in well MT-5

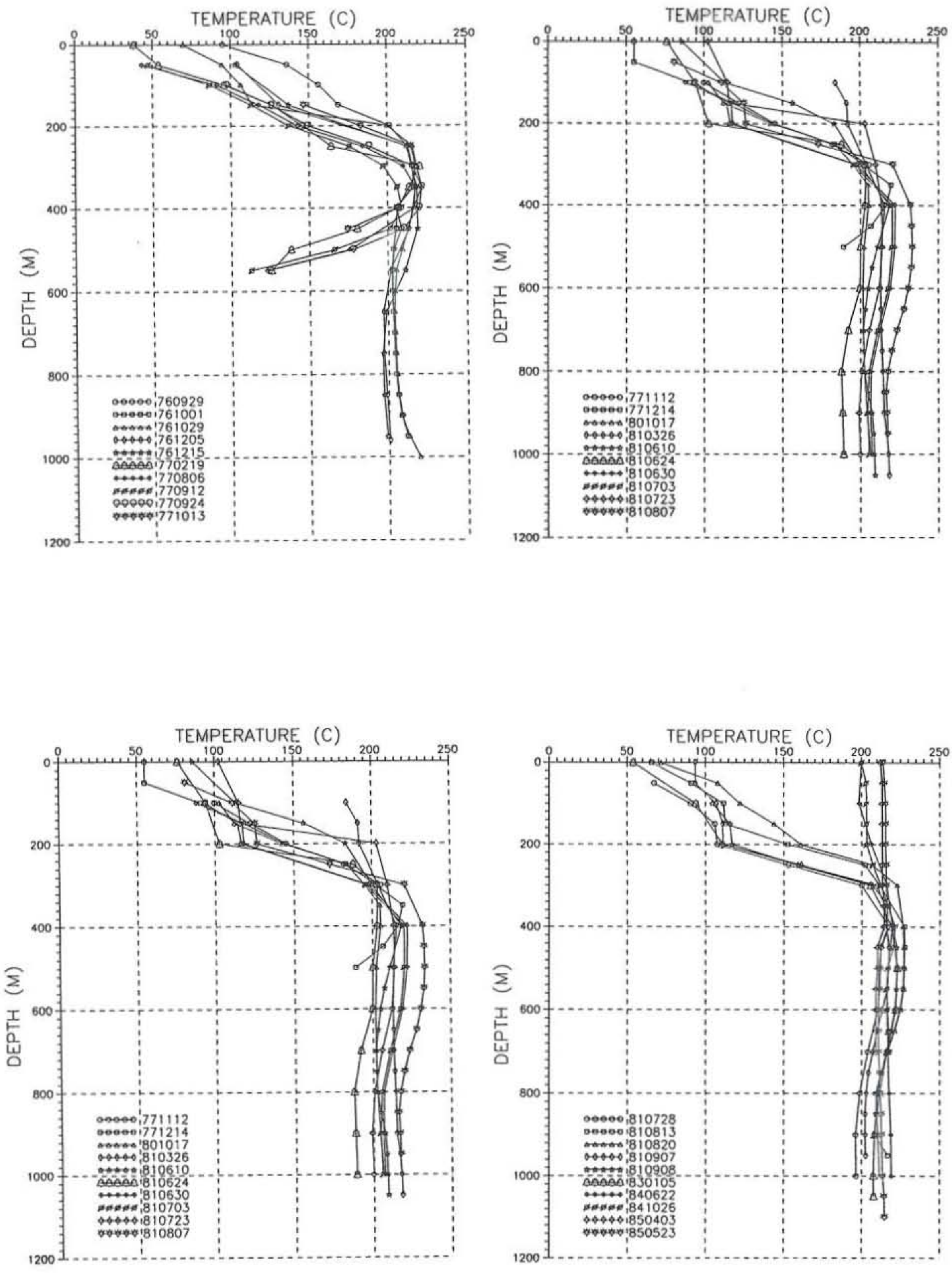


Figure A7: Temperature measurements in well MT-5

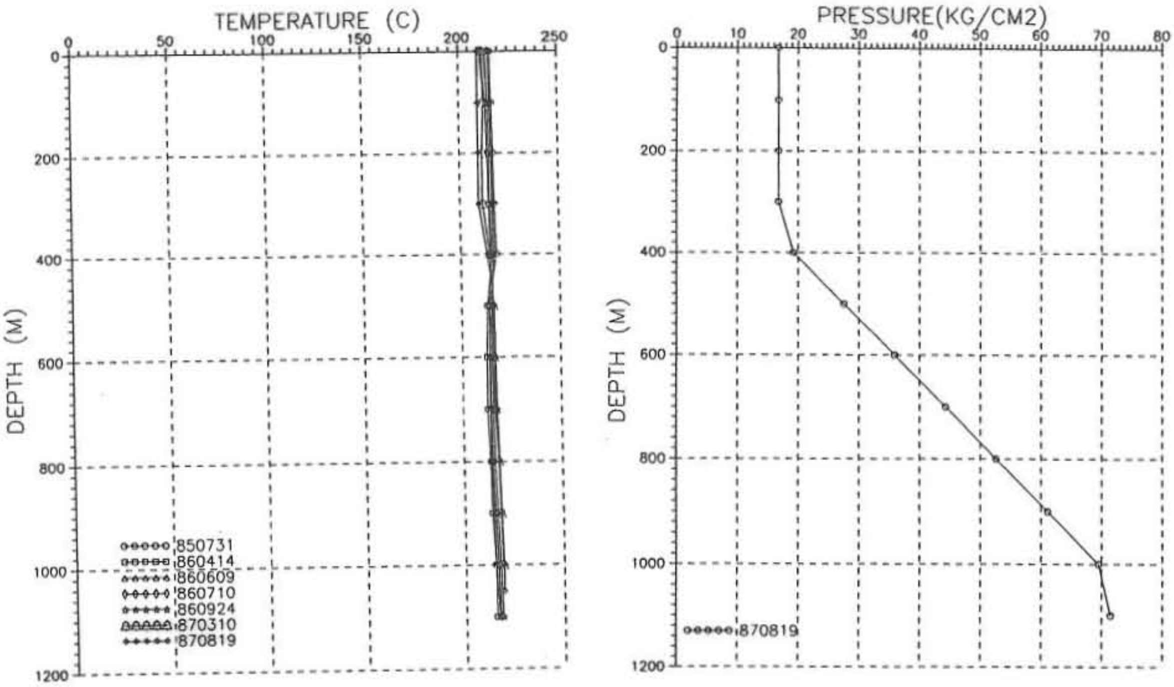


Figure A8: Temperature and pressure measurements in well MT-5

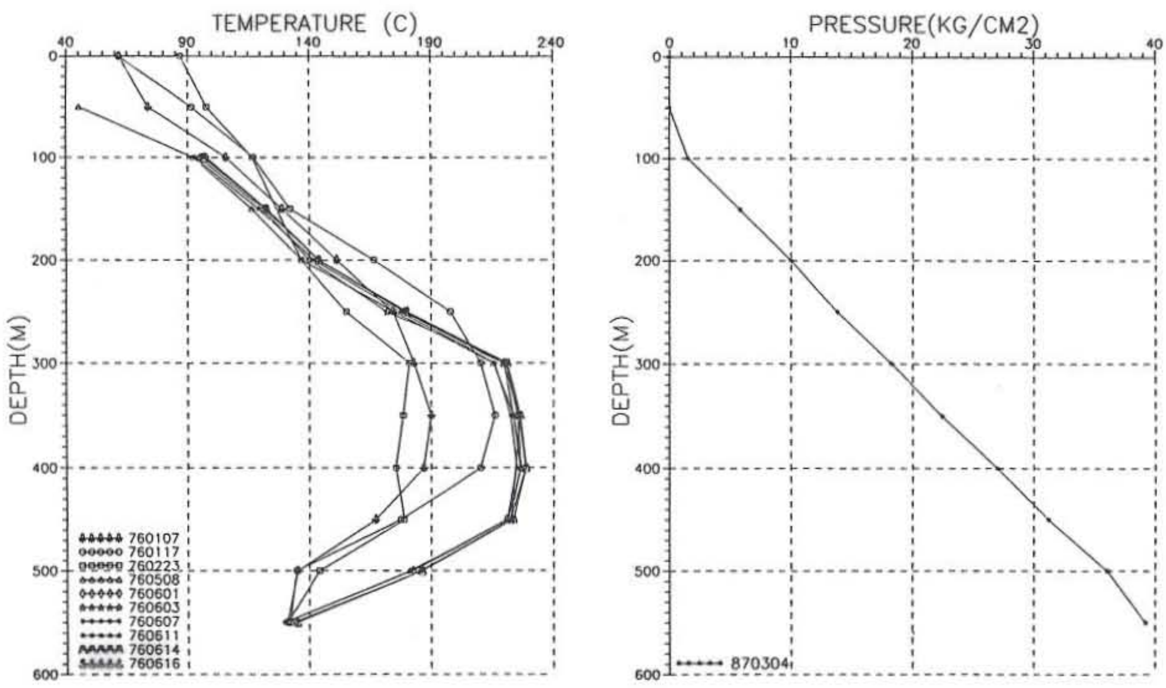


Figure A9: Temperature and pressure measurements in well MT-6

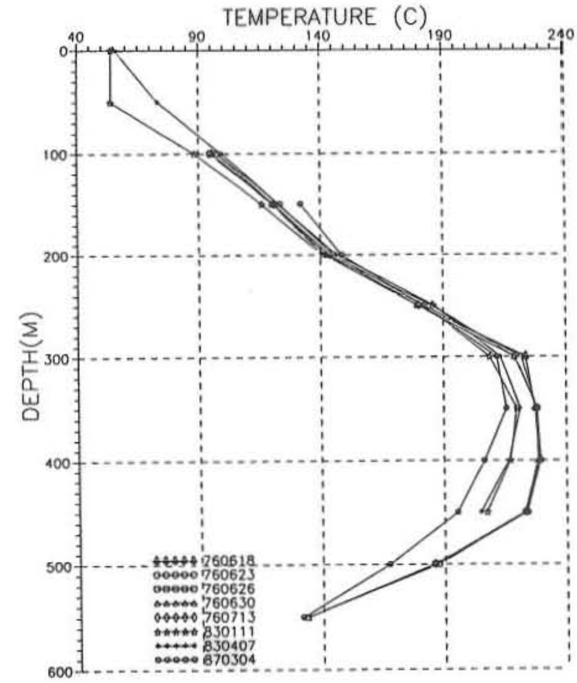


Figure A10: Temperature measurements in well MT-6

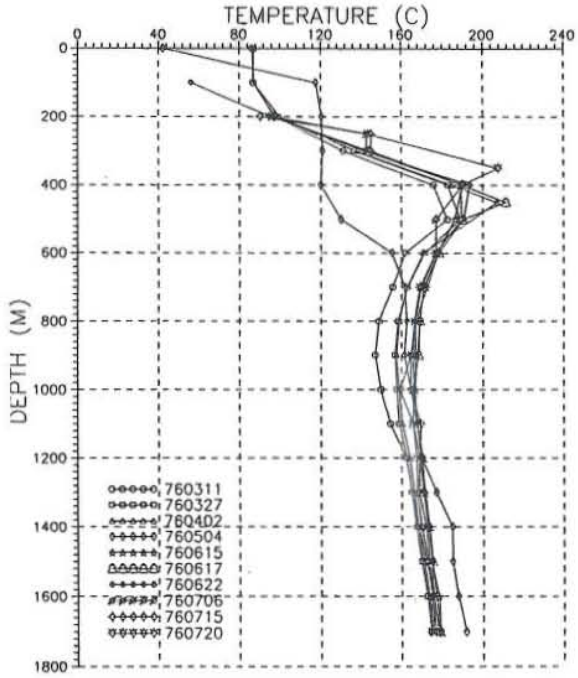


Figure A11: Temperature measurements in well MT-7

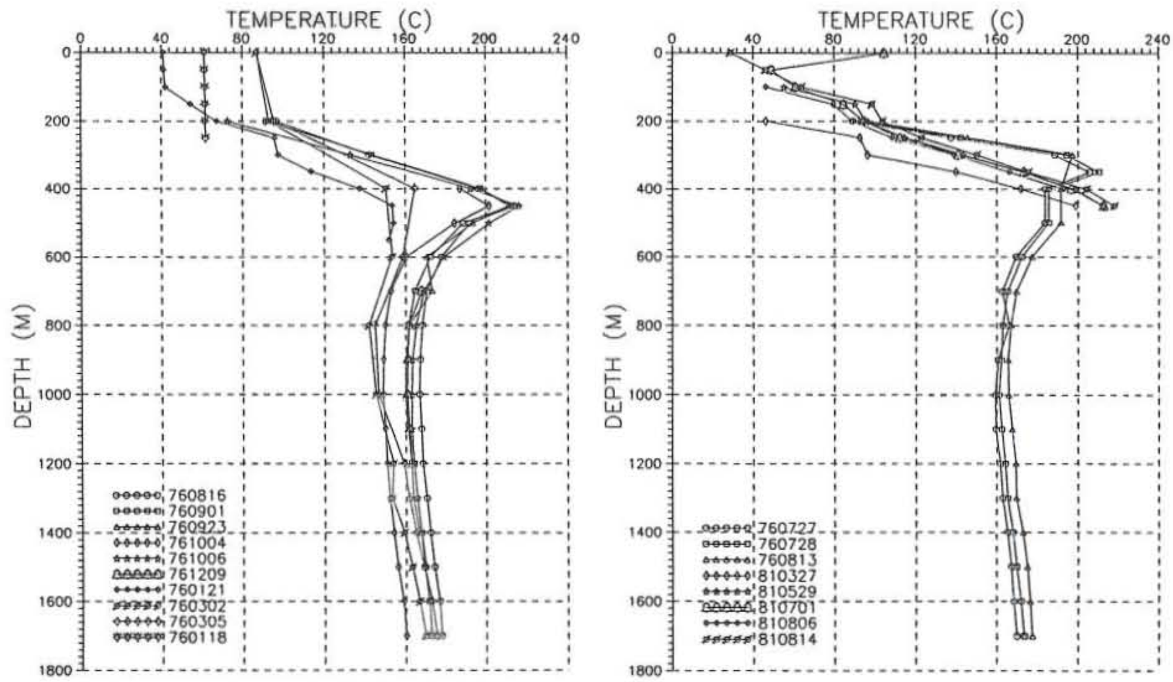


Figure A12: Temperature measurements in well MT-7

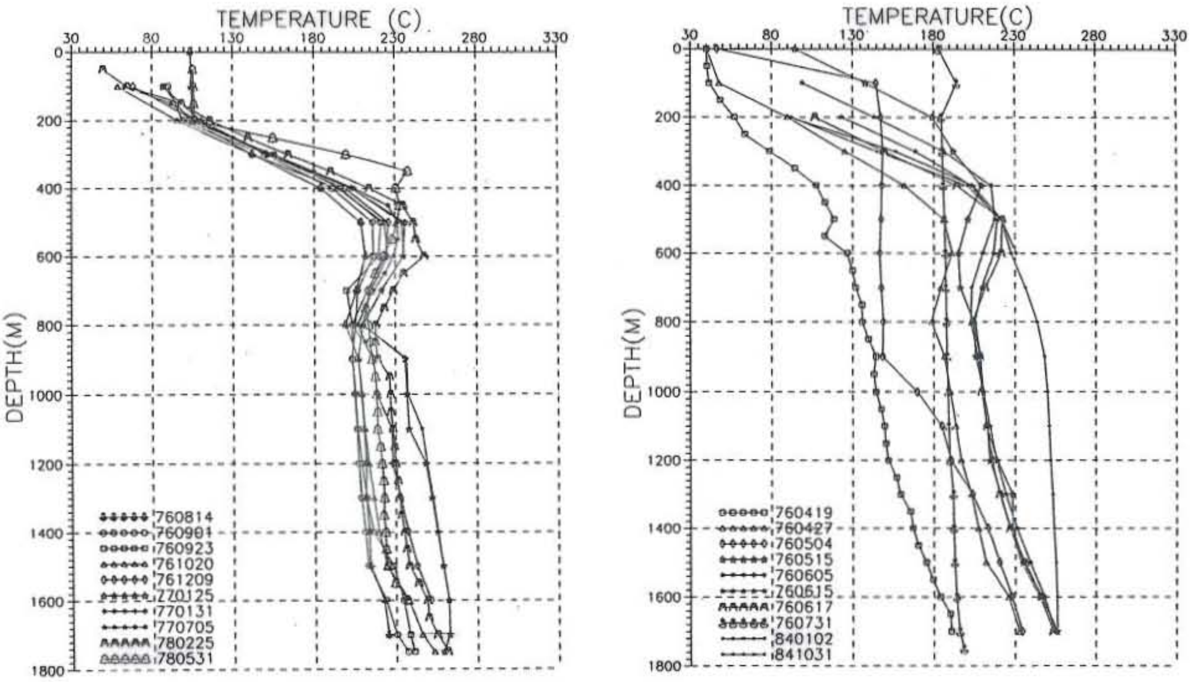


Figure A13: Temperature measurements in well MT-8

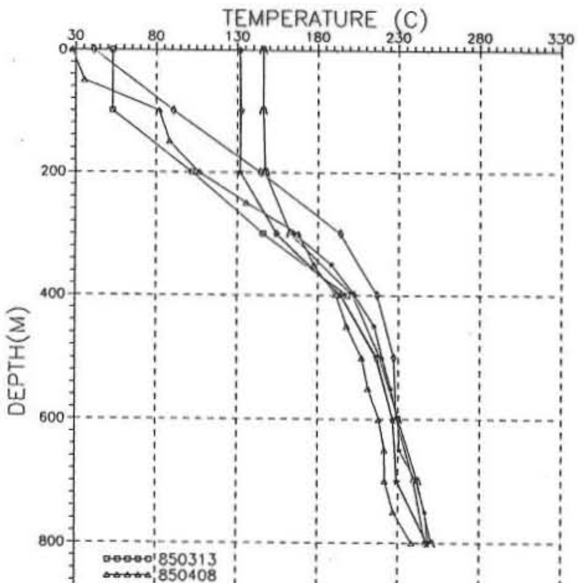


Figure A14: Temperature measurements in well MT-8

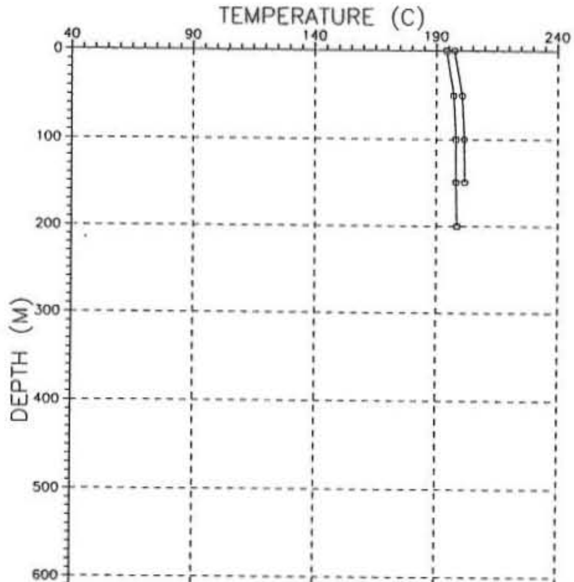


Figure A15: Temperature measurements in well MT-9

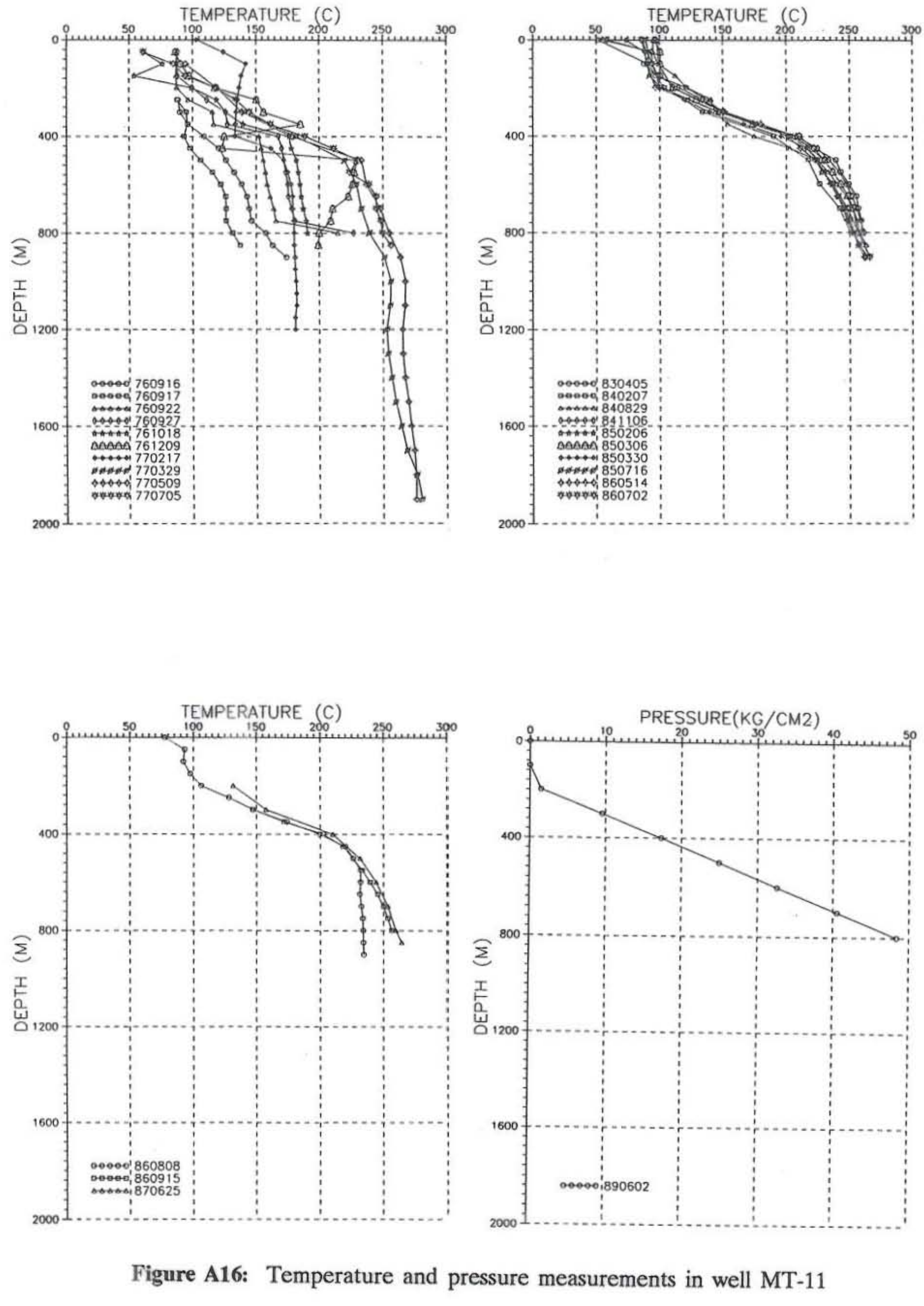


Figure A16: Temperature and pressure measurements in well MT-11

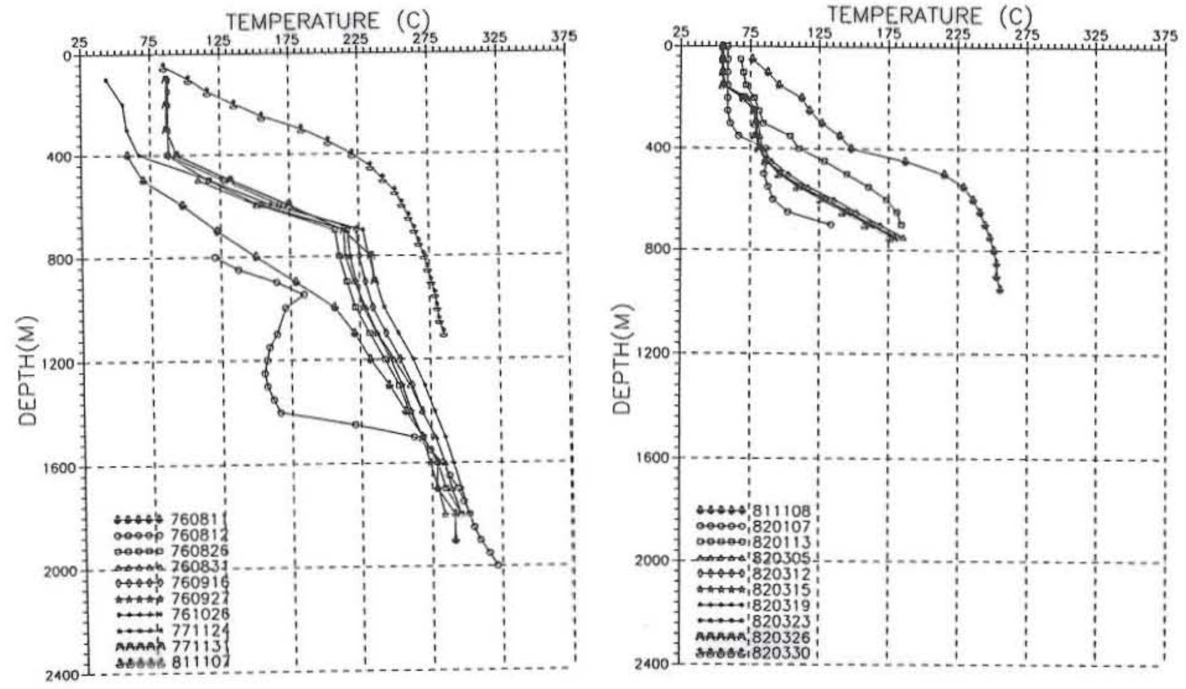


Figure A17: Temperature measurements in well MT-10

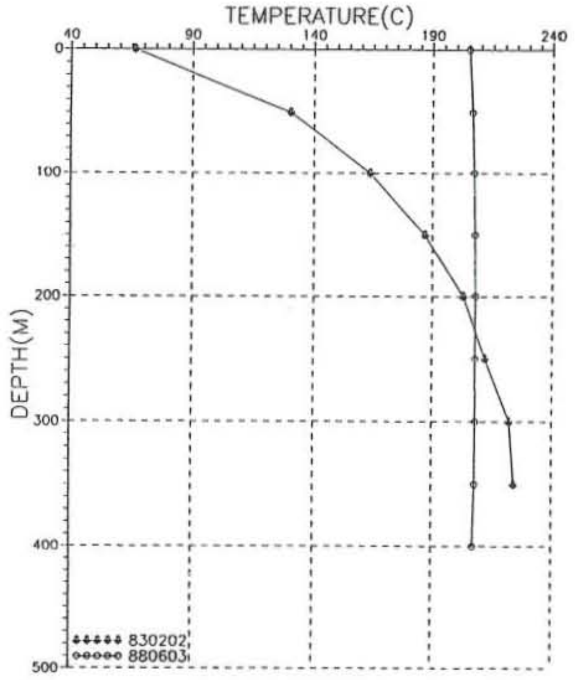


Figure A18: Temperature measurements in well MT-12

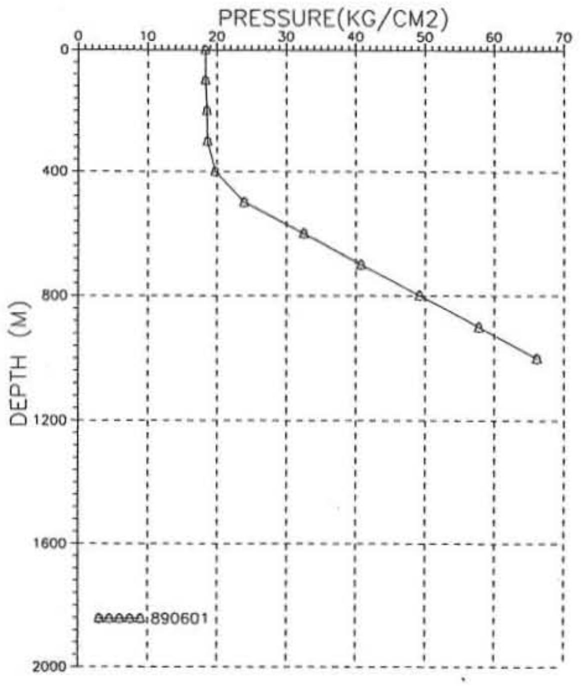


Figure A19: Pressure measurements in well MT-13

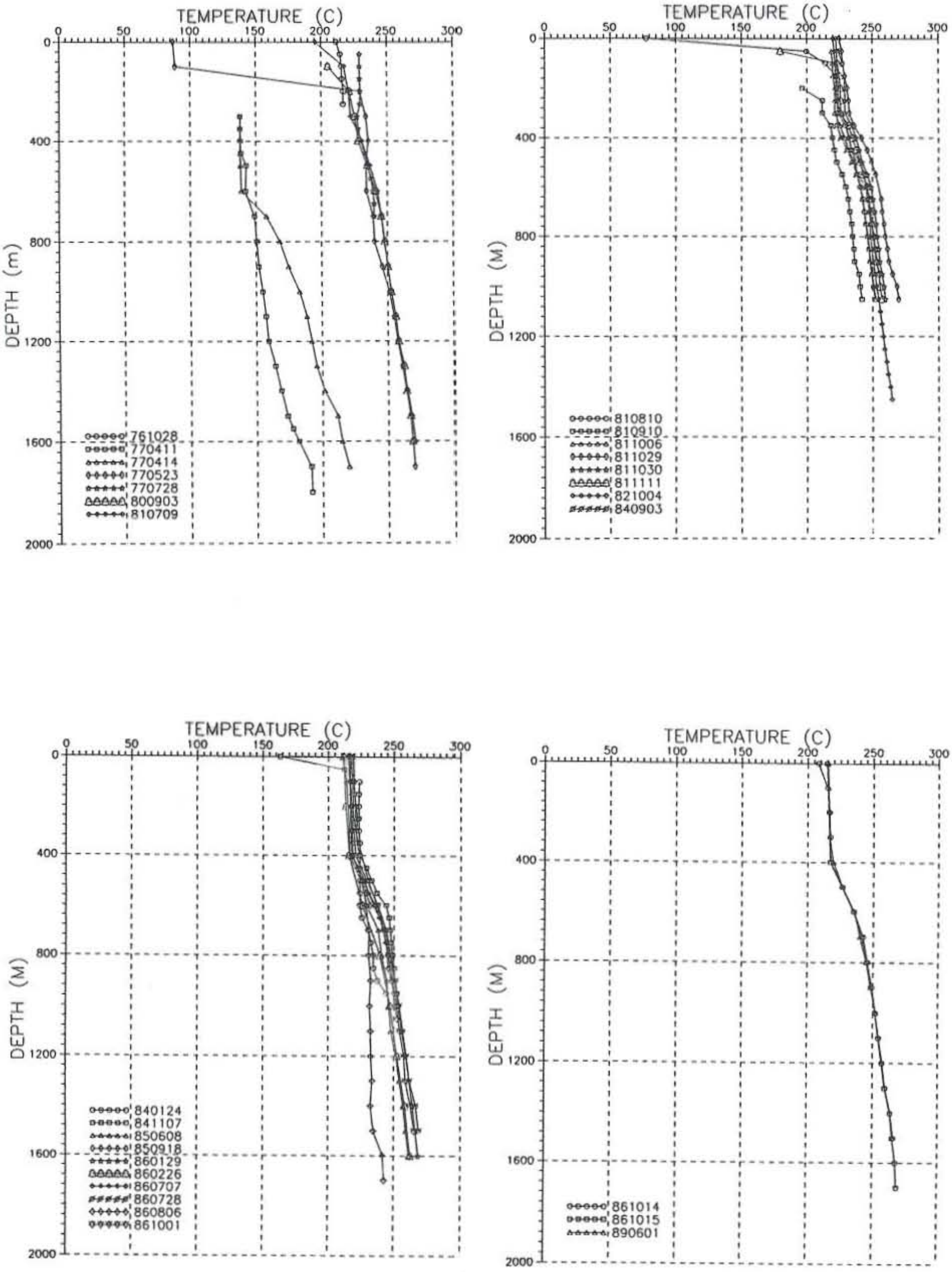


Figure A20: Temperature measurements in well MT-13

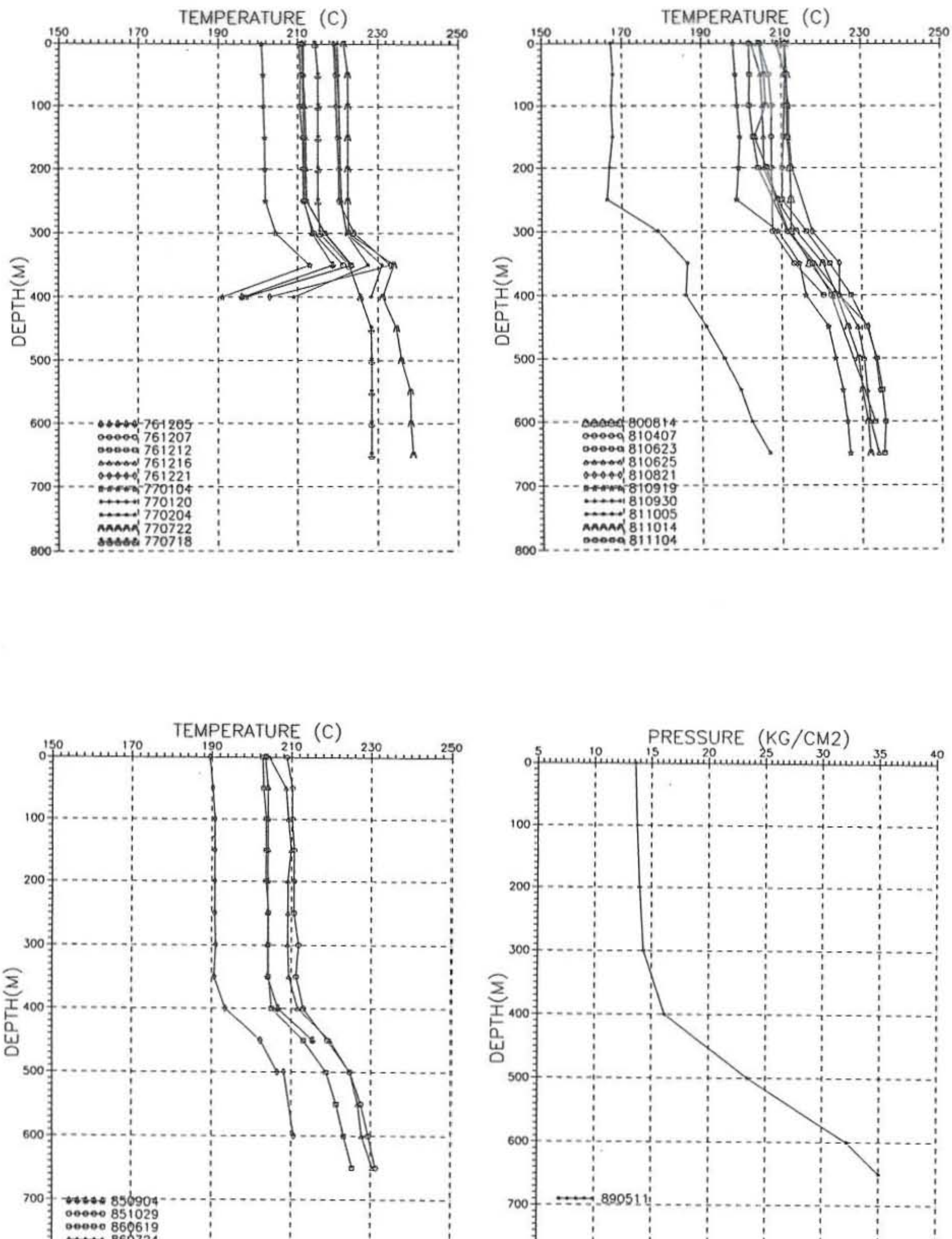


Figure A21: Temperature and pressure measurements in well MT-14

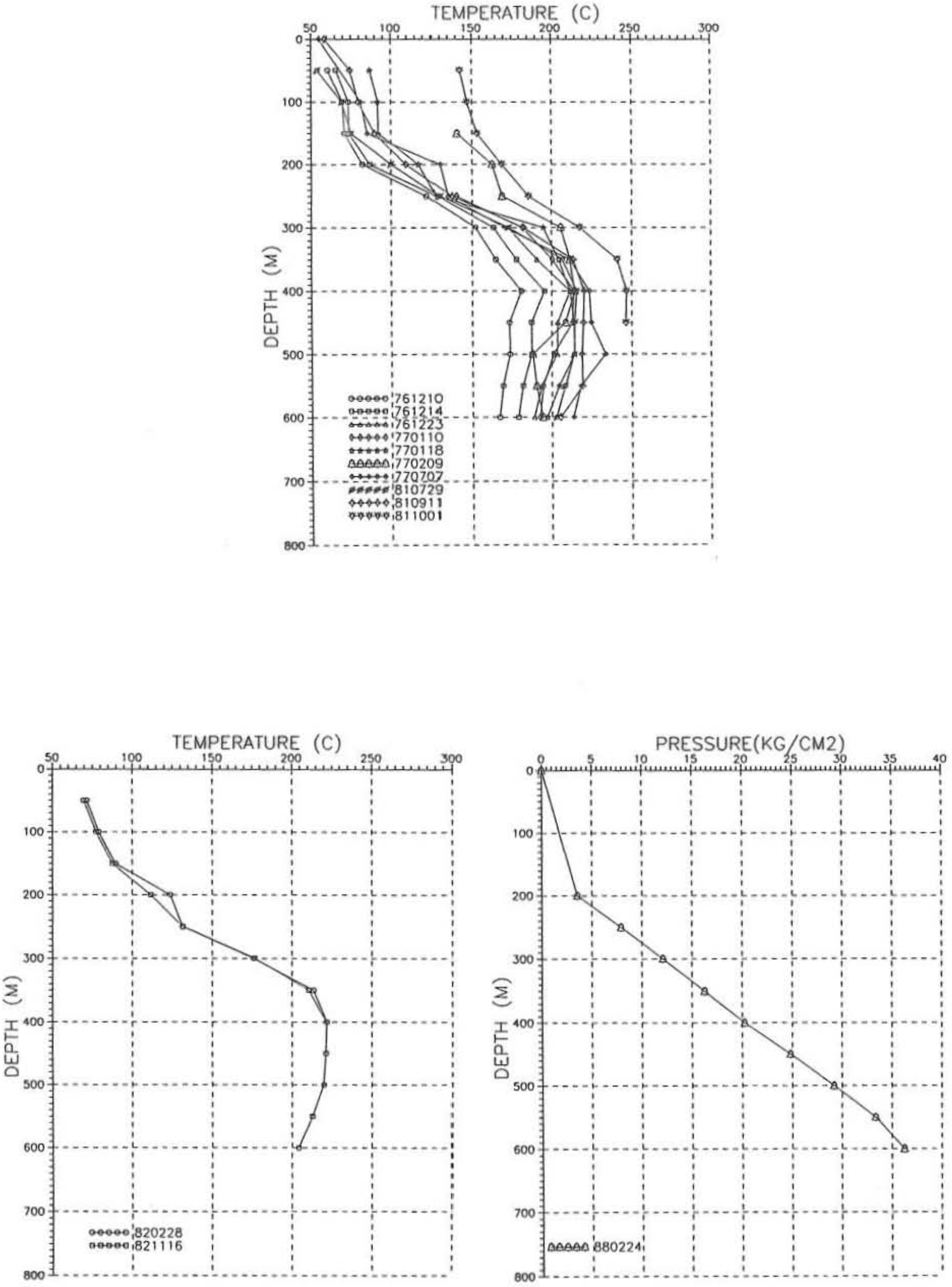


Figure A22: Temperature and pressure measurements in well MT-15

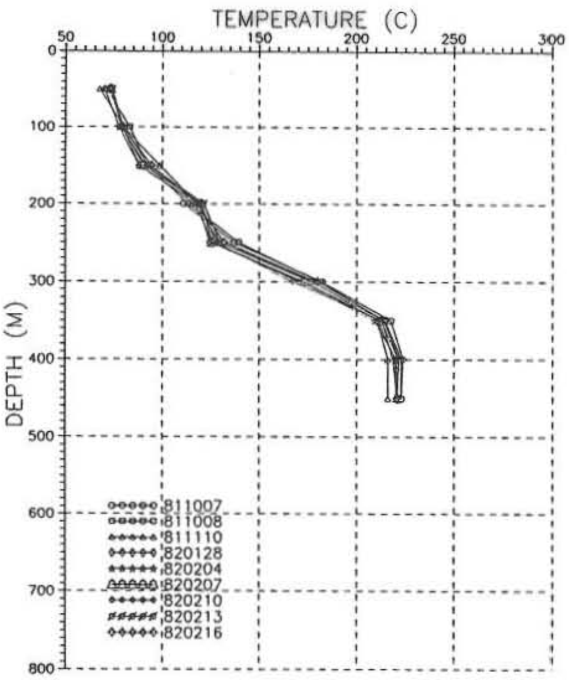


Figure A23: Temperature measurements in well MT-15

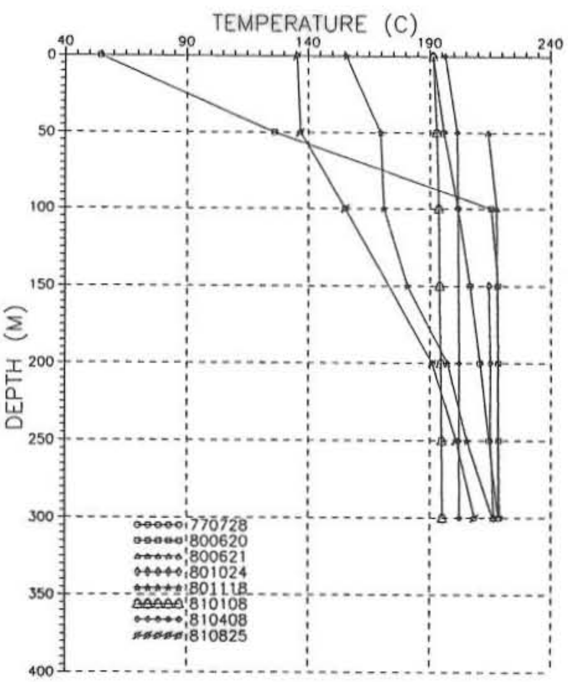


Figure A24: Temperature measurements in well MT-17

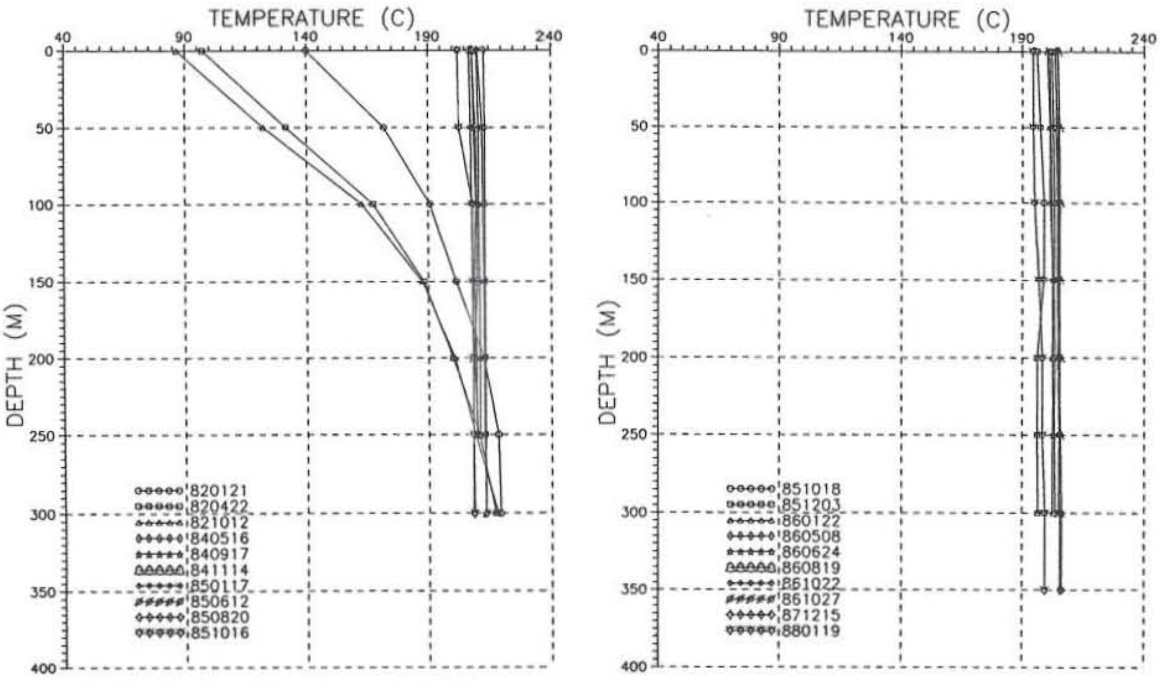


Figure A25: Temperature measurements in well MT-17

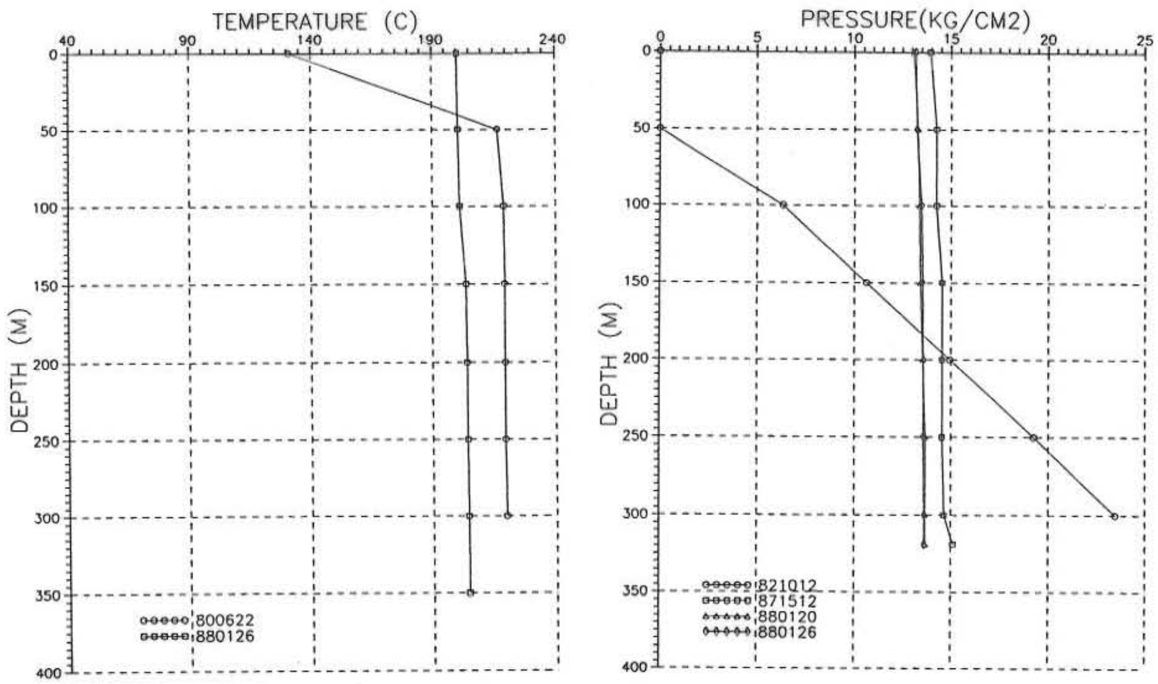


Figure A26: Temperature and pressure measurements in well MT-17

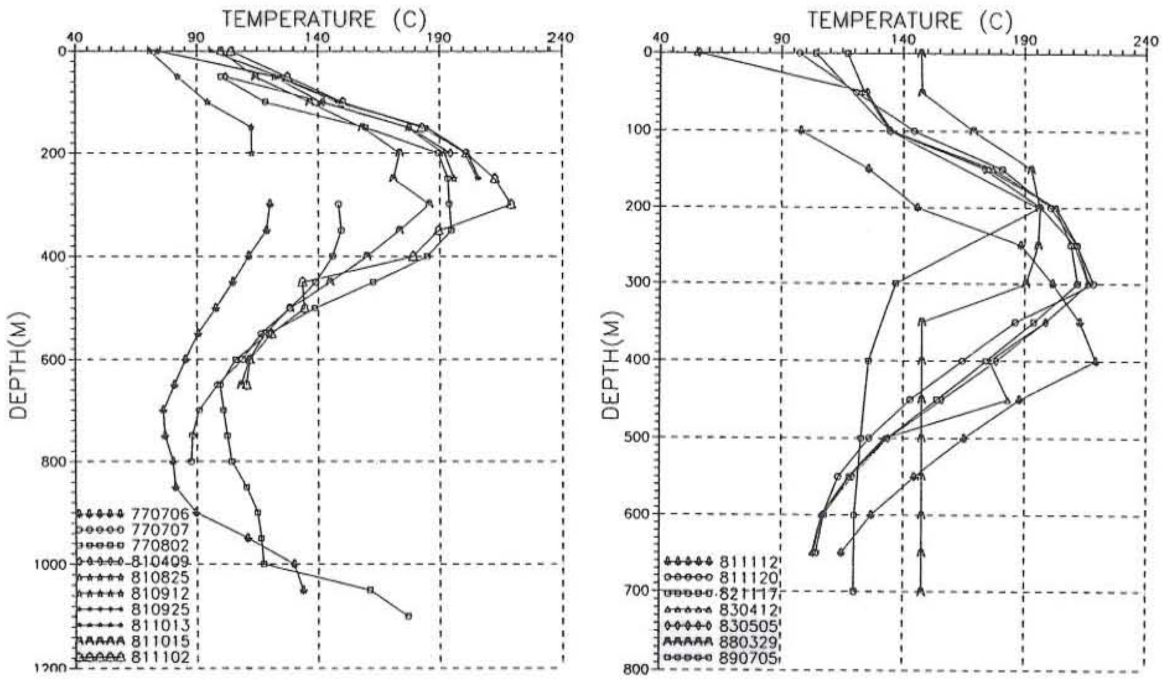


Figure A27: Temperature measurements in well MT-18

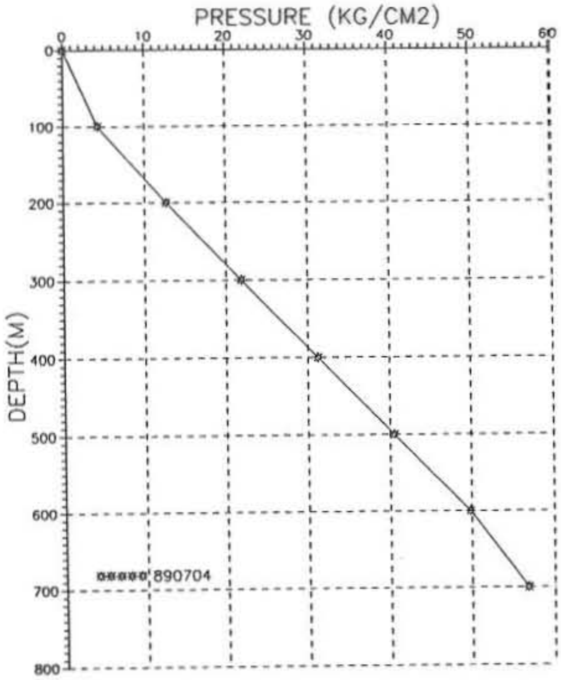


Figure A28: Pressure measurements in well MT-18

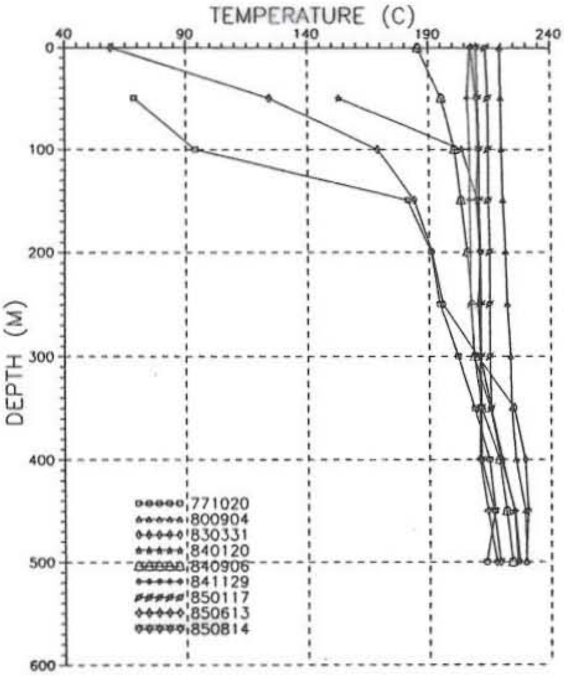
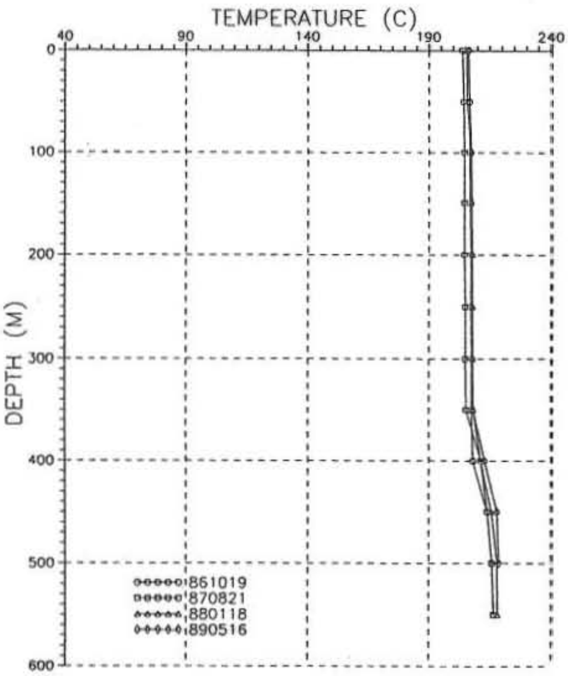


Figure A29: Temperature measurements in well Mt-19



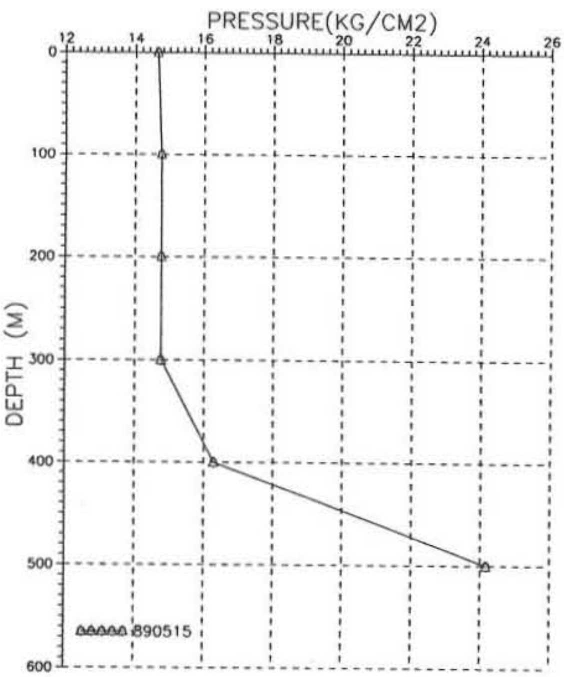


Figure A30: Temperature and pressure measurements in well MT-19

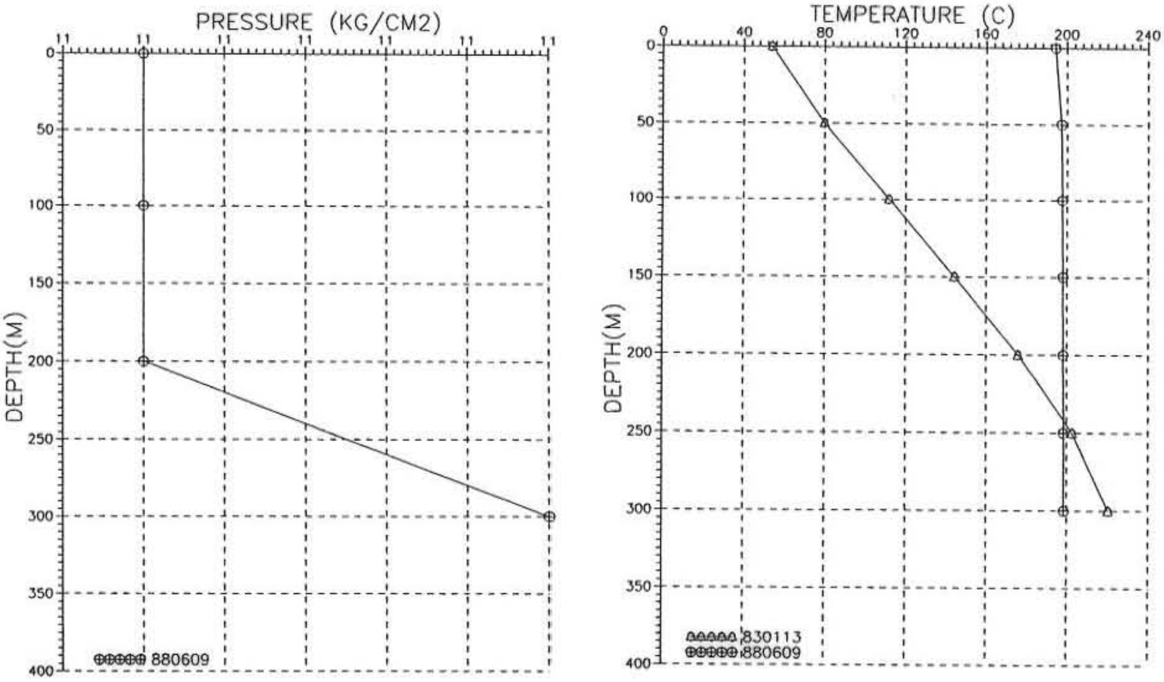


Figure A31: Pressure and Temperature measurements in well MT-20

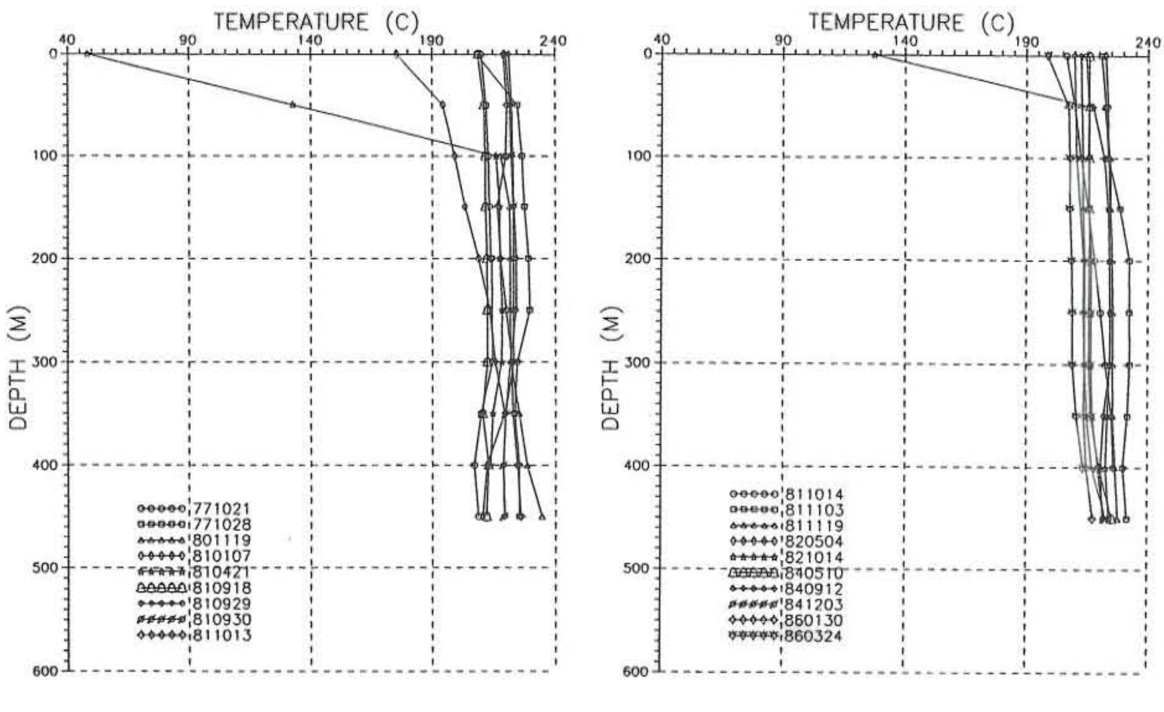


Figure A32: Temperature measurements in well MT-21

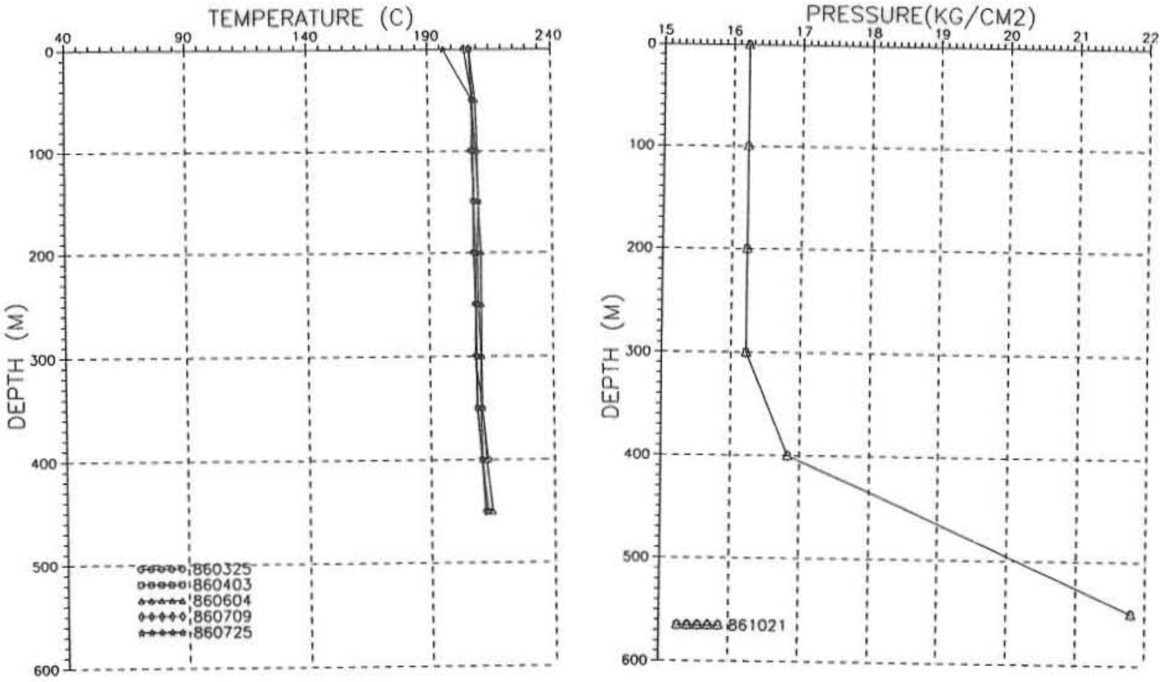


Figure A33: Temperature and pressure measurements in well MT-21

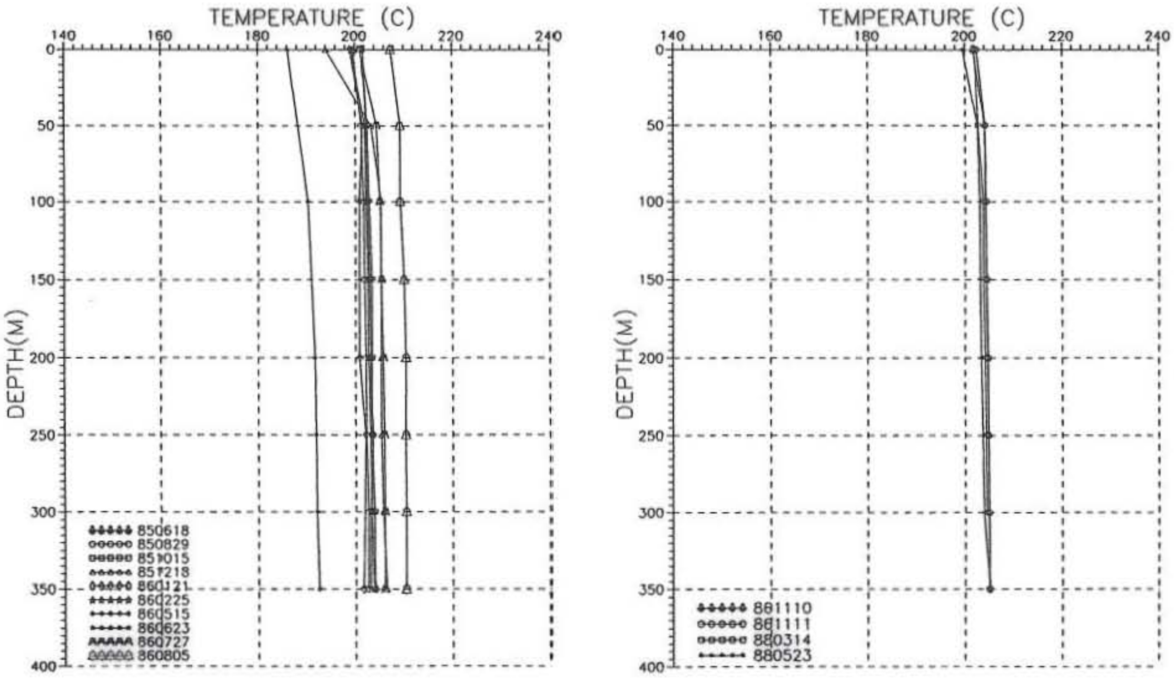


Figure A34: Temperature measurements in well MT-22

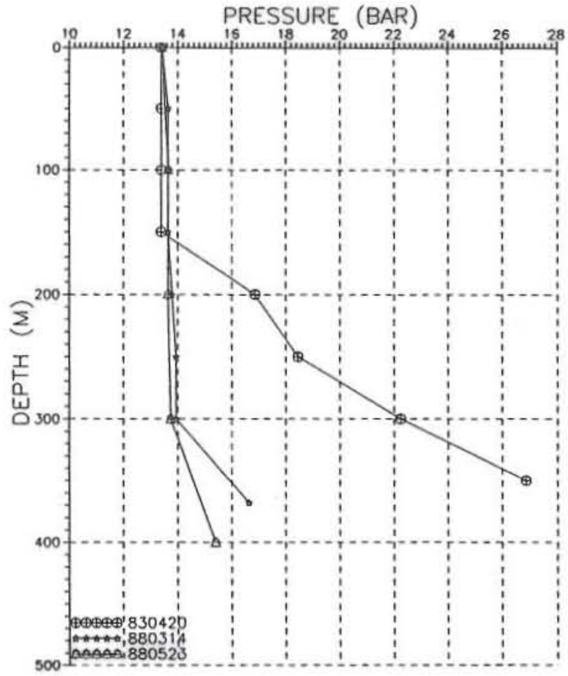


Figure A35: Pressure measurements in well MT-22

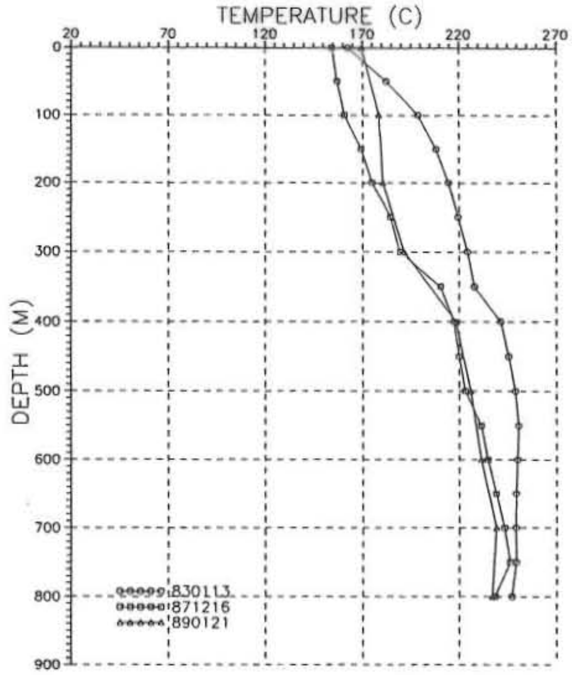


Figure A36: Temperature measurements in well MT-23

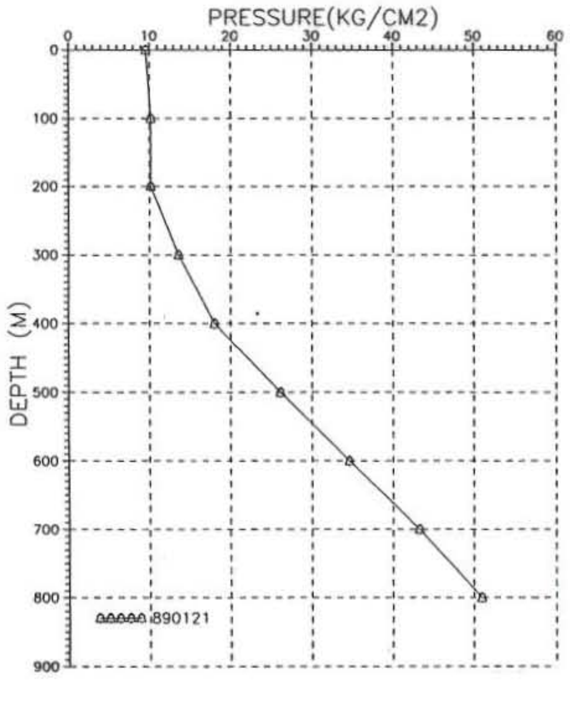


Figure A37: Pressure measurements in well MT-23

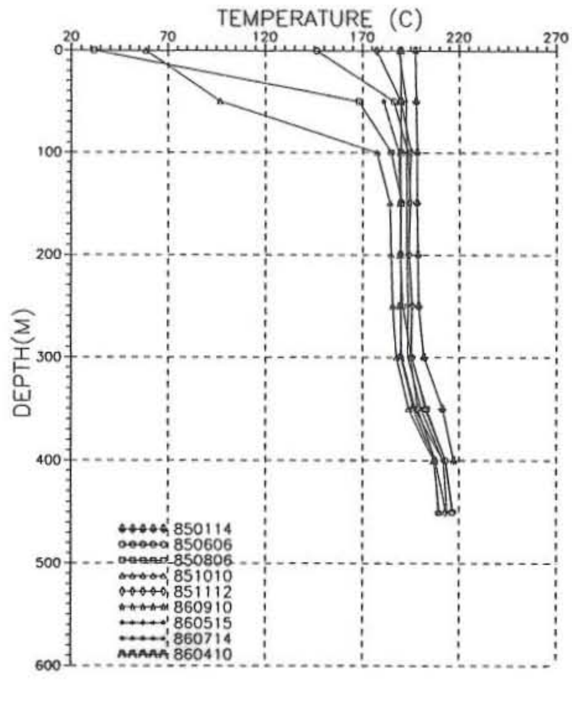


Figure A38: Temperature measurements in well MT-24

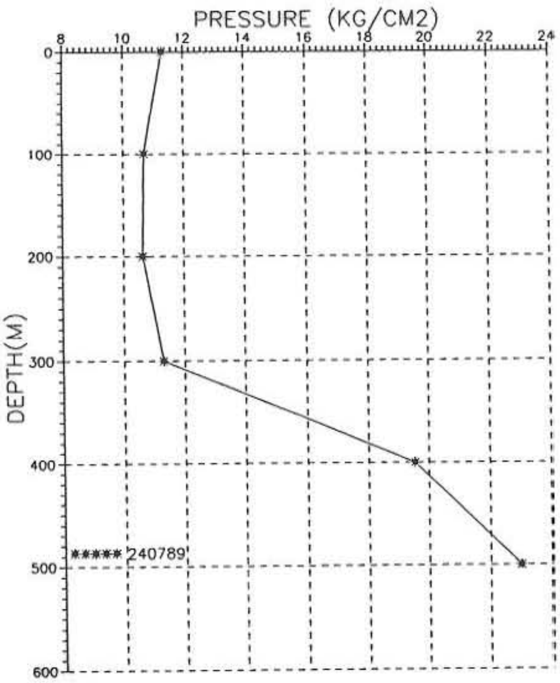


Figure A39: Pressure measurements in well MT-24

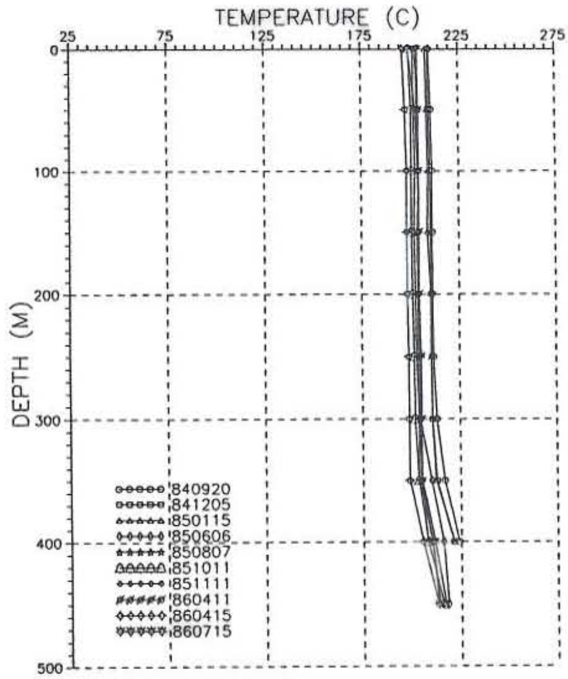
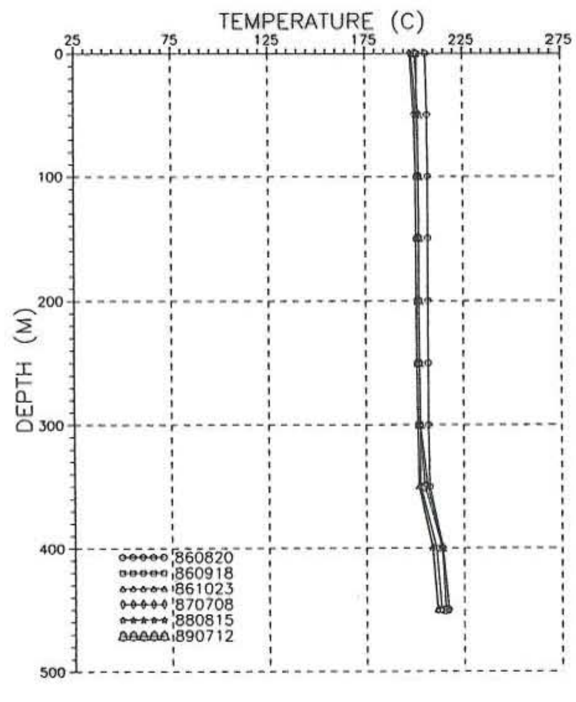


Figure A40: Temperature measurements in well MT-25



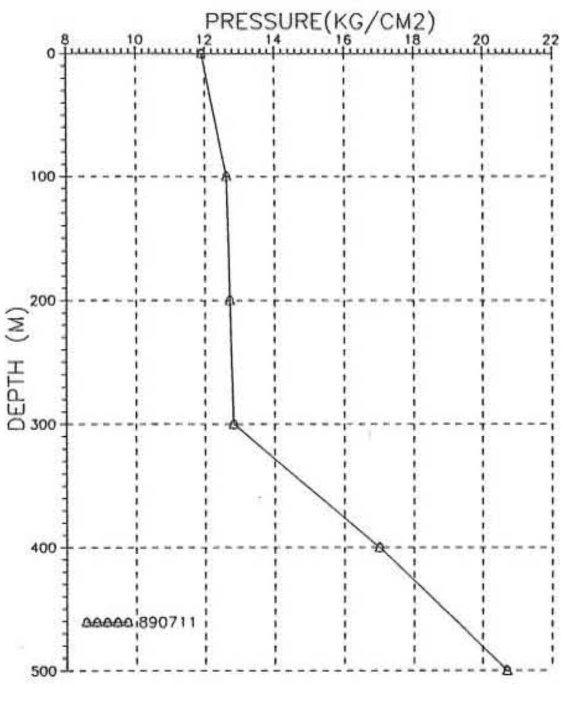


Figure A41: Temperature and pressure measurements in well MT-25

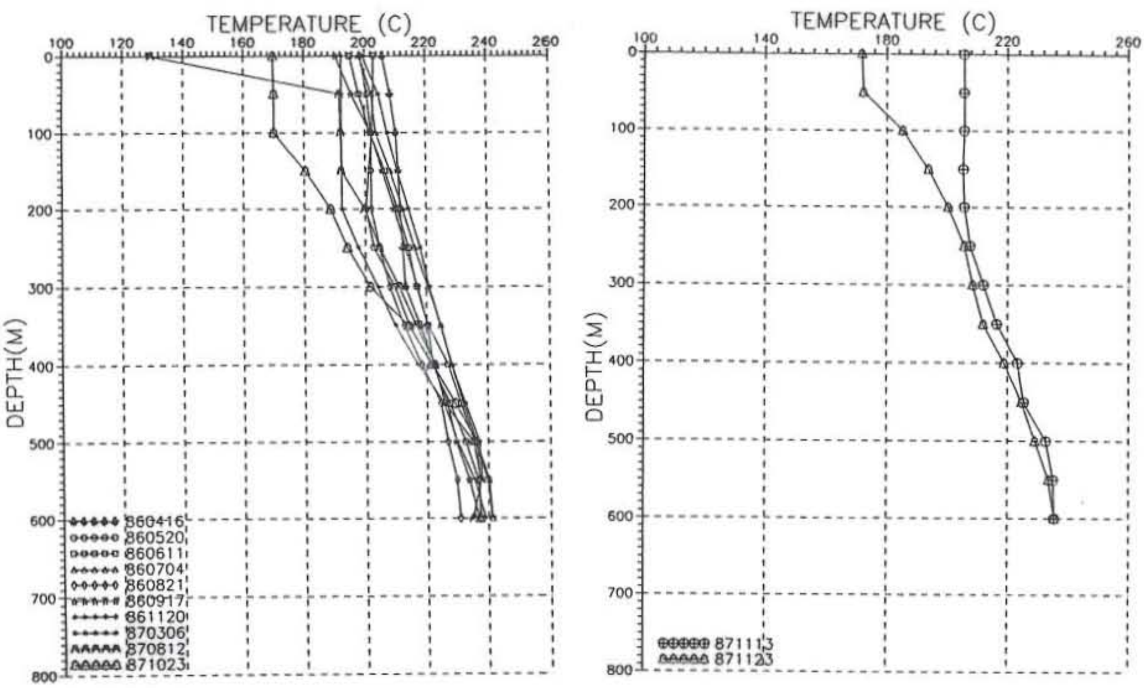


Figure A42: Temperature measurements in well MT-26

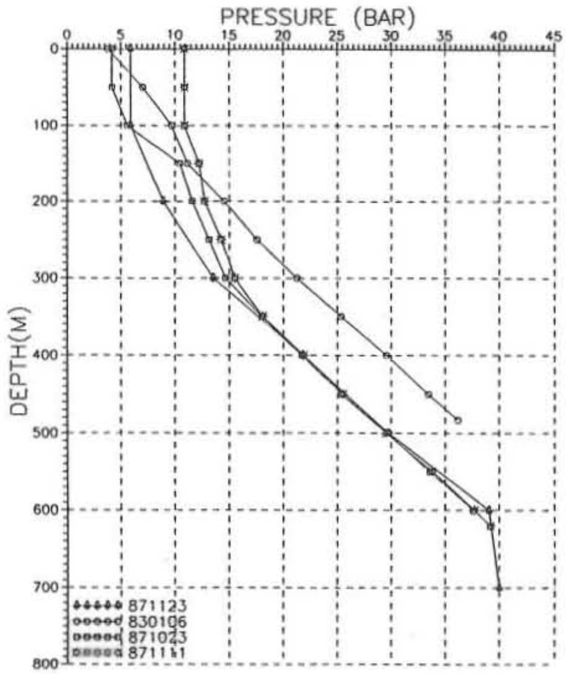


Figure A43: Pressure measurements in well MT-26

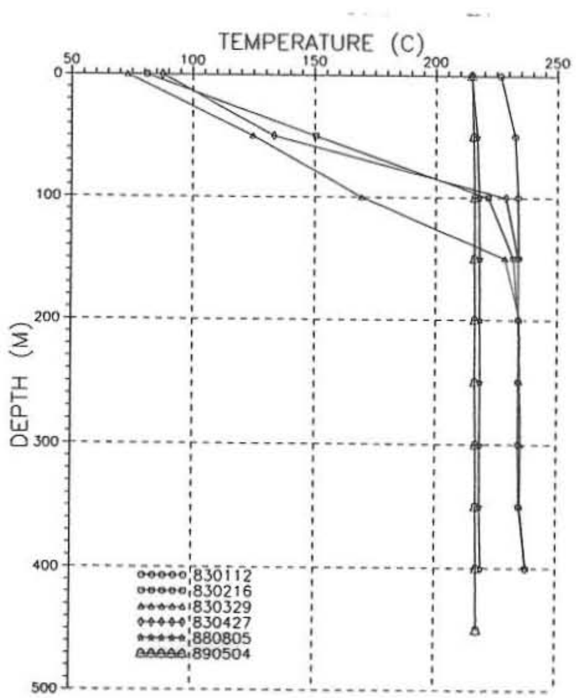


Figure A44: Temperature measurements in well MT-27

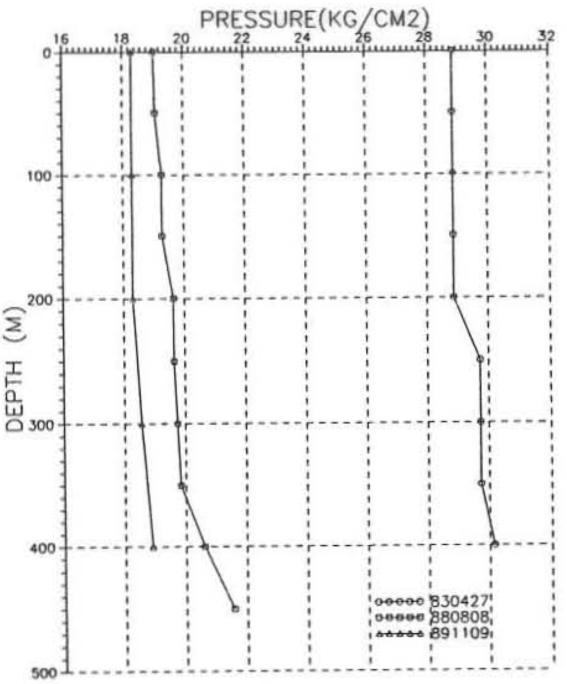


Figure A45: Pressure measurements in well MT-27

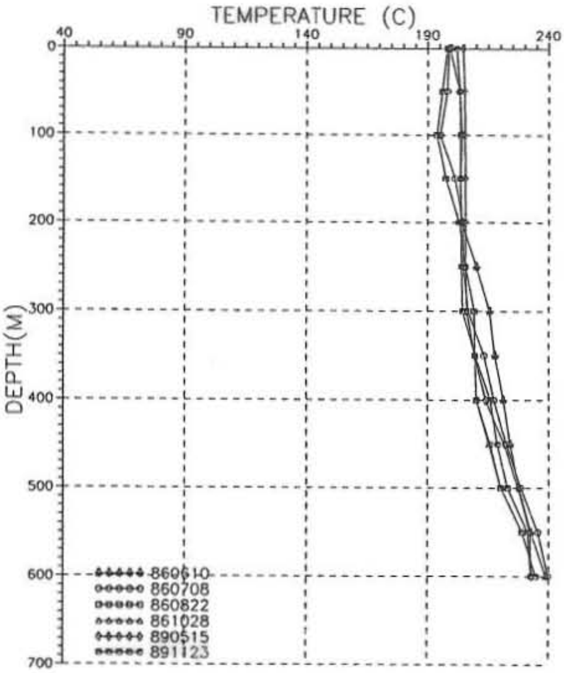


Figure A46: Temperature measurements in well MT-28

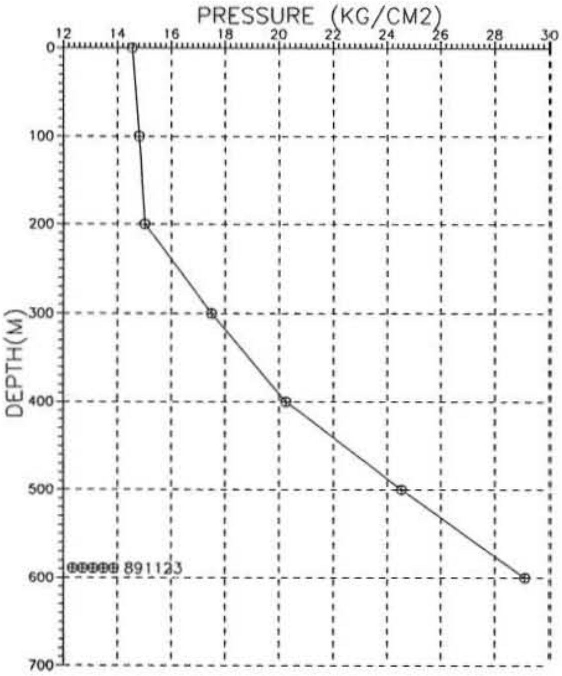


Figure A47: Pressure measurements in well MT-28

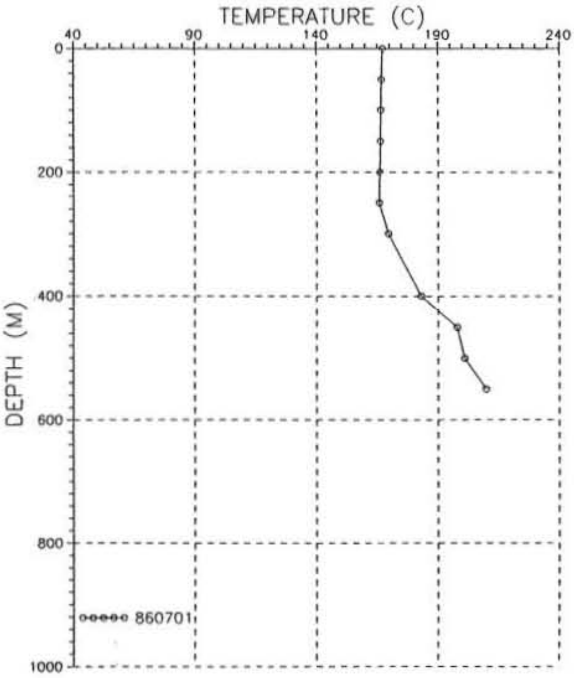


Figure A48: Temperature measurements in well MT-29

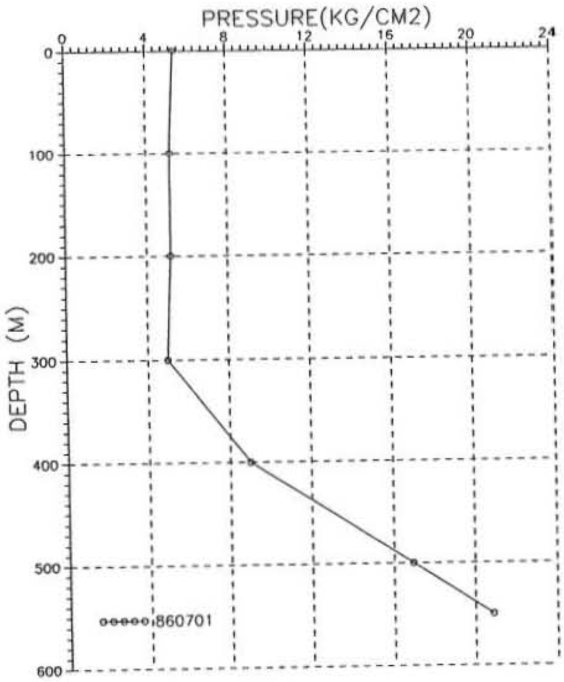


Figure A49: Pressure measurements in well MT-29

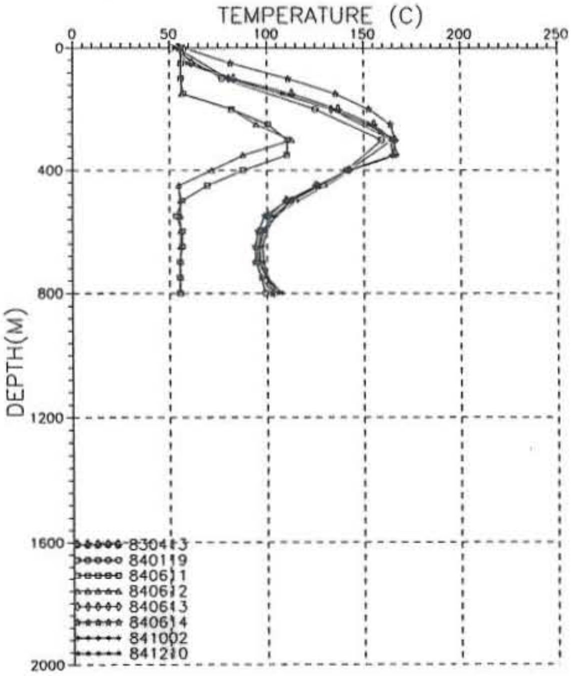


Figure A50: Temperature measurements in well MT-30

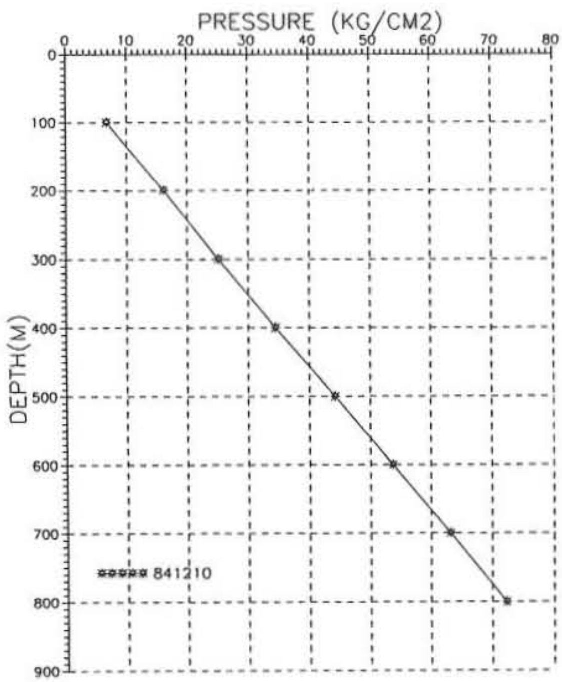


Figure A51: Pressure measurements in well MT-30

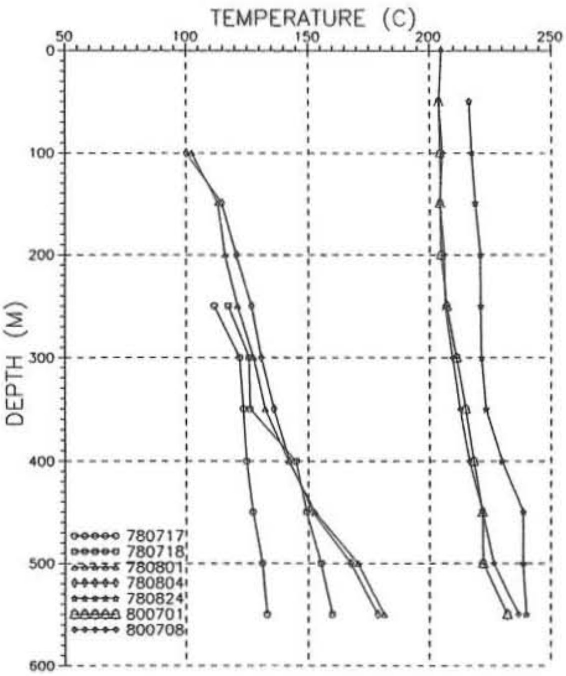


Figure A52: Temperature measurements in well MT-31

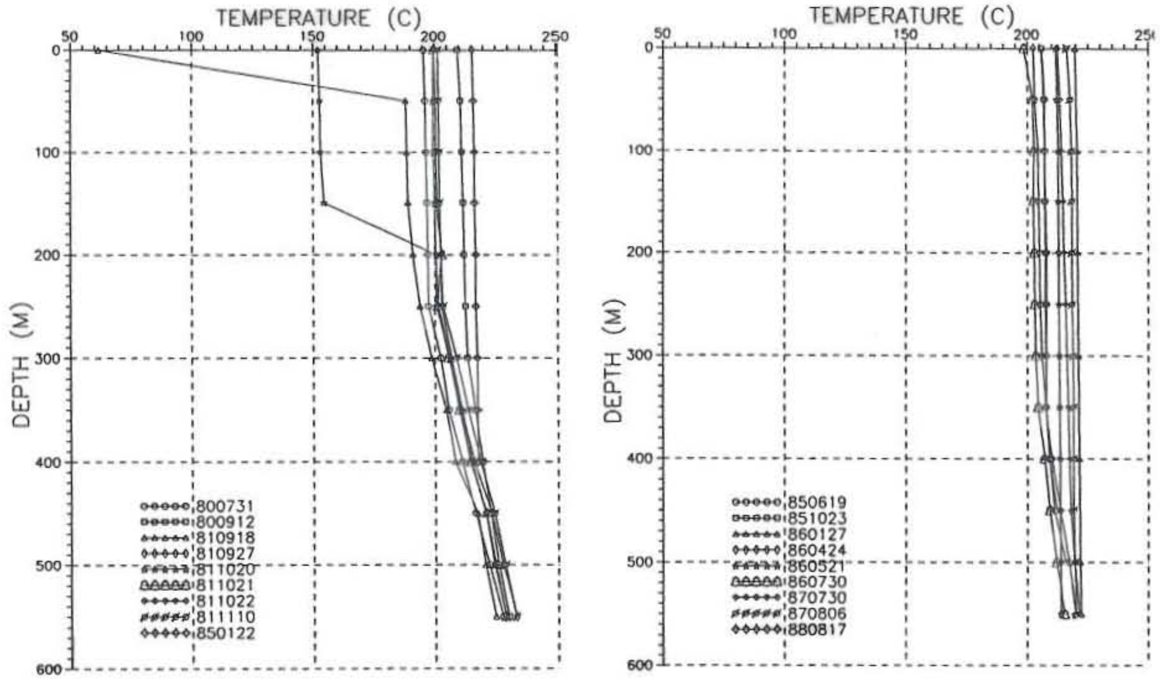


Figure A53: Temperature measurements in well MT-31

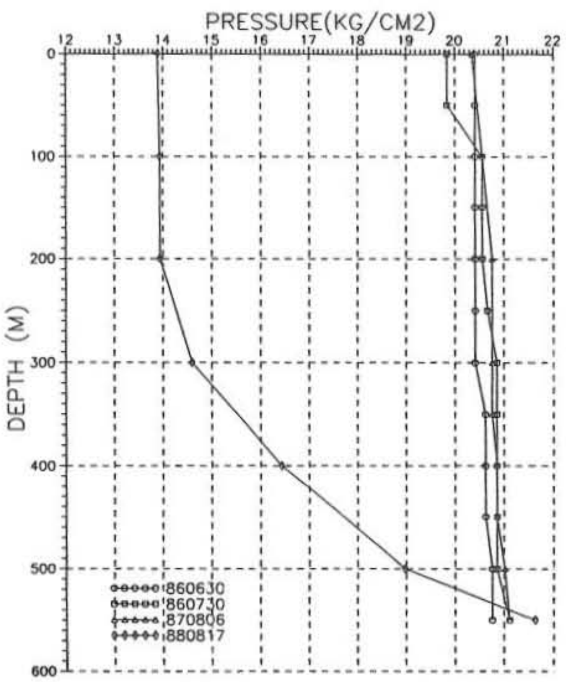


Figure A54: Pressure measurements in well MT-31

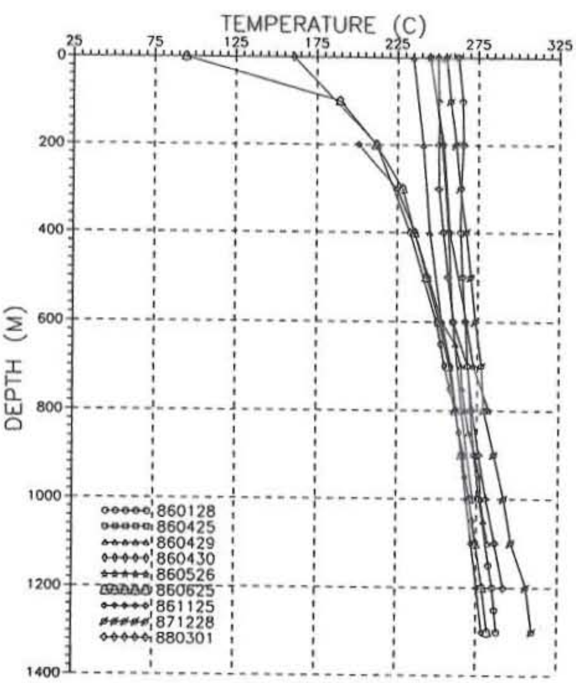


Figure A55: Temperature measurements in well Mt-35

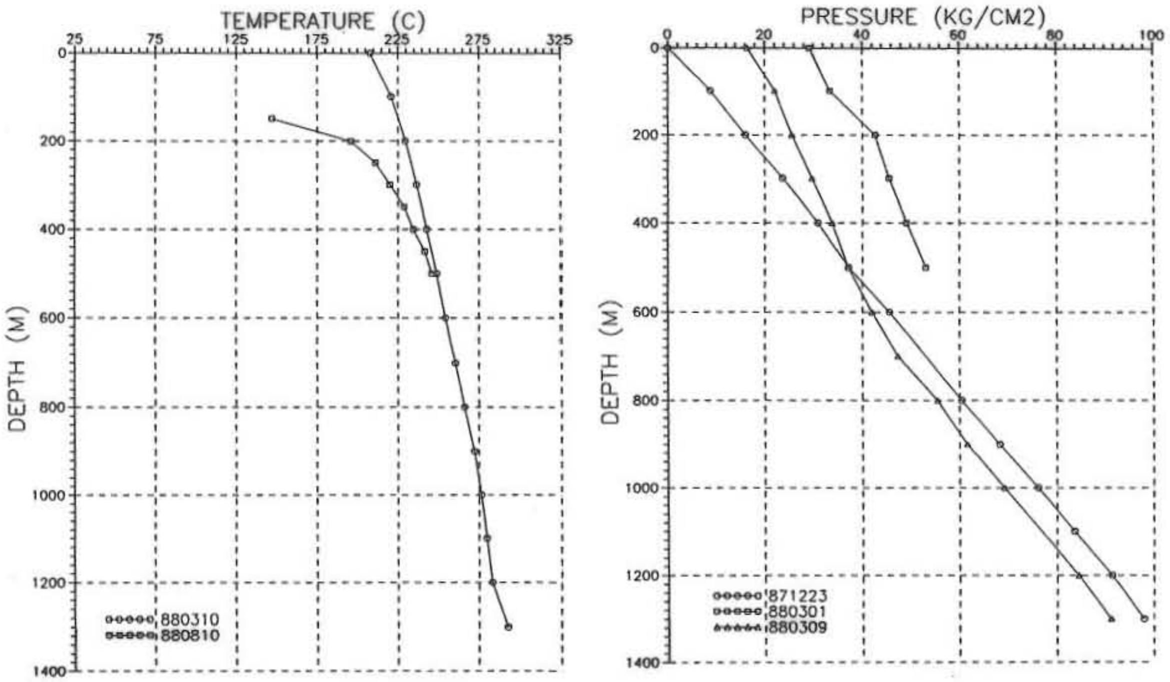


Figure A56: Temperature and pressure measurements in well MT-35

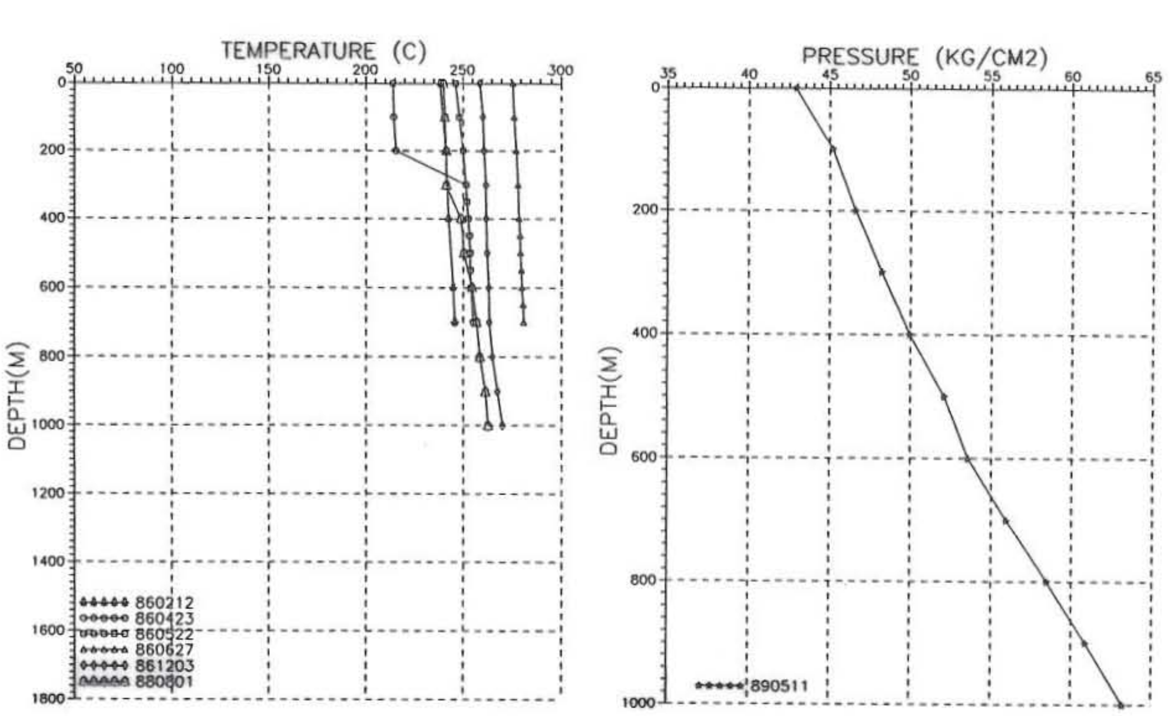


Figure A57: Temperature and pressure measurements in well MT-36