FEED ZONES IN GEOTHERMAL WELLBORES

A REPORT

SUBMITTED TO THE DEPARTMENT OF PETROLEUM ENGINEERING

OF STANFORD UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

MASTER OF SCIENCE

By

Mario Castaneda

march 1981

ACKNOWLEDGMENTS

I would like to express my gratitude to Dr. Roland Horne for his guidance as research advisor.

I would like also to thank Coordinadora Ejecutiva de Cerro Prieto, through its Department of Studies, who kindly contributed the field pressure and temperature logs used in this report.

I greatly appreciate the financial support for my graduate studies at Stanford University, from the Instituto de Investigaciones Electricas, Banco de Mexico and the Consejo Nacional de Ciencia y Tecnologia.

TABLE OF CONTENTS

INTRODUCTION ,

The location of feed zones or permeable levels in geothermal reservoirs is of great importance when a reinjection program is being planned in a geothermal field, mainly because it is desired to know where the injected water is going to go into the formation. The location of feed zones can also help us to have a better understanding in the interpretation of downhole measurements. It has been found that when separate feed zones are present in a wellbore, fluid movement results and wellbore pressure and temperature profiles are not those corresponding to reservoir.

This fluis movement is the result of two properties of geothermal reservoirs: one is the fractured nature of the reservoir and the other Is the non- static reservoir fluld state, Most geothermal fields consist of fractured rock. A well draws its fluid from one, or at most, a few fractures. Often, one dominates. It is only at the depth of the dominant fracture where the well contacts the the reservoir and truly reflects reservolr pressure. Pressure measurements taken elsewhere In the well reflect the only weight of the fluid column (water, two phase, steam) in the well.

Therefore, if reliable information about the reservoir is desired, a better understanding of the location of the feed zones in a wellbore is necessary.

II.- LITERATURE SURVEY .

The presence of fluid movement in shut-in oil wells has been recognized in the past in the petroleum literature. The need to understand this condition in the producing well was a factor that led to the development of more efficient production practices and to improvement in methods of completion of new wells. Dale[1] developed a velocity recorder that indirectly measured the flow of fluids in a well. He found that in some wells with long production intervals only a fraction of the formation in the upper part **of** the zone contributed any production. Thus, the migration of fluids and gas from one sand to another or from the producing interval into formations that were supposed to be excluded from the well was identified.

In geothermal wells, the appearence of this fluid movement presents a problem in the interpretation of downhole measurements, Only just a few technical papers have been appeared in the geothermal literature dealing with this fact. Recently, such internal flow was recognized by Grant[2,3]. He pointed out that the internal flow was due to the existence of major feed points at which the well was in equilibrium with the reservoir. When the pressure gradient exceeded the hydrostatic, the fluid moved within the well entering at one point and leaving at another. This phenomenon "masked" the true reservoir temperature and pressure. Thus, the well temperature profile is partially or wholly determined by fluid motion within the well and consequently those measurements cannot be literally interpreted as the reservoir temperature profile. Therefore, careful interpretation is needed in single phase systems and even more care in two phase systems. Several suggestions were given in order to find the permeable levels (feed points) under certain reservoir and well conditions.

Multiple feed points in a geothermal well can also cause instability in well performance. Bixley et al[4] pointed out that fluids of varying enthalpy enter and flow in the well. Fluid density and pressure difference between the two feed zones consequently vary and feedback between this pressure difference and the flow from each feed point causes sustained oscillation in pressure, enthalpy and mass flow at the wellhead. Also, they observed that downhole pressure and temperature measurements in these wells were strongly influenced by these flows. The downhole measurements over the section of the hole where flow occurs do not reflect reservoir values. Unless such internal flows in the well are recognized downhole pressure and temperature data will be wrongly interpreted.

In an attempt to identify the permeable levels or feed zones, Syms et al[5] used a flowmeter log in a geothermal wellbore. They pumped cold water down the bore from surface and determined from the flowmeter log where it went into the formation. A temperature log would usually give an idea of how far the injected water travel down the bore but unless the bore intersects only one loss zone, ambiguous interpretations of a temperature log can result. Therefore, the flowmeter log could help them to identify natural flows between the permeable levels.

Although flowmeter logs can identify such permeable levels, there are geothermal reservoirs with temperatures as high as 340 C (Bermejo et al[6]) in which we could have technical difficulties in running this log.

111.- STATEMENT OF THE PROBLEM ,

Feed zones causing internal flow. in wellbores have been found to be present in geothermal reservoirs. Unless such internal flows in the well are recognized, downhole pressure and temperature data will be wrongly interpreted. Some techniques for determining feed zones have been given recently in the literature but these techniques are qualitative and cannot be applied in all cases, A more general and systematic method would be of great use,

IV.- RESULTS .

A combination of pressure and temperature data gathered from respective logs is used here *to* locate the feed zones in a particular well. Pressure and temperature logs are run when the well is shut-l'n, The temperature log is used to calculate average density values using the steam tables and then the hydrostatic pressure gradients corresponding at specific depth intervals calculated and compared with pressure gradients obtained from the pressure log, looking for pressure gradients greater or less than hydrostatic within the well, Pressure gradients exceeding thy hydrostatic result from an upflow of fluid within the well. Pressure gradients less than hydrostatic indicate downflow of fluid due to the losses of pressure with the friction of fluid with the bore or pipe, Because the density values are taken from the steam tables for pure water, some correction may be applied when we are dealing with brine. This correction is made by superposing both graphs of pressure and density gradients vs depth.

In order to verify this approach field pressure and temperature data gathered from two wells of the Cerro Prieto Geothermal field (located approximately 35 km south of Mexicali B.C.Mexico) were used, WELL M-9.- The data analyzed using this method correspond to pressure and temperature logs run in this well by Lawrence Berkeley Laboratory (LBL) on Oct/26/1979 to test a combined function tool. Because of the reliability of the data, their surveys 10 and 11 were taken for this analysis only. This well was considered to be a good test example because the presence of a known perforated zone at 2348-2810 ft (720-860 m) depth interval gave a clear indication of a feed zone. A description of the completion of this well is presented in figure # 18. Pressure and temperature data for such surveys are presented in tabla 1, fig. 1 and table 2, fig. 2, respectively. Pressure and hydrostatic gradient values at specific depth intervals are presented in tables 3 and 4 and figures 3 and 4 for survey 10 and 11. Figure 5 presents the curves of figure 3 superposed taking into account any change in density for geothermal brines with respect to pure water, as explained before. On this figure it is clearly shown that the pressure gradient exceeds the hydrostatic at depth of 2800 ft to bottomhole, approximately, indicating an upflow of fluid within the well and a less well defined downflow (pressure gradient less than hydrostatic) at depth interval of 2600-2800 ft aproximately. Figure 6 presents the same behavior for survey 11. In this case tha data was not taken below 2600 ft but the graph shows a pressure gradient less than the hydrostatic at the same depth interval as survey 10. Figure 7 presents the difference in pressure and hydrostatic gradients for both surveys revealing the same results.

The same procedure was followed by converting the pressure and temperature data to an average density value for specific depth intervals resulting on the same conclusions as before (see tables 5 and 6, figures 8, 9, 10 and 11).

Although this was a demonstration of recognising fluid motion within this particular well and hence the feed zones, more test examples were examined. A particularity of this well was that the perforated interval was cemented in earlier years (June/1975) because of production problems. It was considered a good idea to look for temperature and pressure logs run during the time this interval was sealed in order to see any changes from the interpretation given before. One of the problems of getting the data was the lack of pressure and temperature logs run simultaneosly in this well. Fortunately, three sets of data were found that satisfied this requirement.

The first set of data was from logs run a few days after the cementing job was made (see figures 12a, 12b). This well was on small bleed. As before, the same technique was applied to these set of logs. Figure 12c presents the pressure and hydrostatic gradients vs depth. We can observe on this graph that there is no appreciable difference between them. Apparently, there is no indication here of any flow leaving or entering the perforated interval, as we should expect because of the cementing job. However, we find a more or less constant hydrostatic gradient below 800 m due to the constant temperature profile at this depth interval (see figure 12b). The interpretation here is that an amount of fluid is flowing from the bottom to approximately 800 m keeping the constant temperature on this interval but small enough that there is no appreciable difference on the pressure gradient from the hydrostatic. Since the well was bleeding this flow tended to rise to the surface flashing at few meters below the wellhead, as it can be seen on the boiling point profile plot for this well (figure 15).

The presence of this small flow capable of keeping constant temperature profile in a geothermal well has been discussed in the literature by some authors(2).

The second set of data was from logs run two months after the cementing job was made (figure 13a, 13b). The well was bleeding and the fluid was flashing at depth of 300-350 m, as it can be seen in the boiling point profile plot (figure 15). Figures 13c and 13d show the pressure and hydrostatic gradients as well as the difference between them vs depth, respectively. As we can observe, there was no difference in gradients around the perforated interval. Unfortunately, these logs were not run deep enough to notice any difference at the lower part of the well. The maximum gradient difference was at depth of 300-350 m, but because the fluid was boiling at this depth, we may consider that it is the boiling phenomenon that is causing this behavior.

The third set of data was from logs run after two years the cementing job was made (figure 14a, 14b). The well was on small bleed and the fluid was flashing at 300-350 m depth (see figure 15). Figure 14c, 14d and 14e show the pressure and hydrostatic gradients vs depth and the difference between them, respectively, As we can observe, there is not a definite trend on the pressure gradient at the perforated interval nor at bottomhole and it is not possible to have any interpretation as we did before. This could be a result of not allowing the pressure gage enough time to stabilize when the pressure measurements were taken (as it would suggest due to the shorter depth interval taken from station to station when the log was run). However, figure 14a suggests that the total bleeding is coming from the top of the perforated interval alone and that a colder region exists below this interval.

These obseryations suggest that at the time these logs were run, the perforated interval was no longer sealed. In fact, personnel from the production department [7] confirmed this suggestion because they were convinced that the cement was degradated and the seal was completely or at least partially lost. This could also contribute to support the argument of having a feed point at this depth when the LBL pressure and temperature logs were interpreted.

From the interpretation given before using the four set of logs we could characterize the well M-9 as that having three major feed zones: two within the perforated interval and the other near the bottom of the well.

The existence of pressure gradients less than hydrostatic at the perforated interval meaning downflow of fluid could be explained because the location of this well in the field. This well is situated at the periphery of the field and it was found that a possible cold-water inflow is taking place at this part of the field (Mañon <u>et al</u> [8])

<u>WELL M-42.-</u> The completion of this well is presented in figure 19. Two sets of pressure and temperature logs were used when applying the suggested method to this well. The first set of logs were run on Jan/14/1975 (see figures 16a and 16b). This well was completely shut-in at the wellhead. The pressure and hydrostatic gradients vs depth are presented in table 10 and figure 16c. Figure 16d presents both gradients superposed. As we can observe in this figure, there is a pressure gradient less than hydrostatic at 700-875 m depth interval and a pressure gradient greater than hydrostatic from 875 m to bottom-hole, approximately. Figure 16e presents the difference in pressure and

hydrostatic gradients and again we observe the same result as above. However, observing the completion in this well (figure 19) we see that the well is cased from surface to a depth of 1000 m approximately. One possible explanation would be a casing fracture at that particular depths but such casing fractures had not been detected before. It is difficult to confidently make such an assertion based on only two single data points.

The second set of logs were run on May/13/1976 (see figures 17a, 17b). This well was on small bleed and it was flashing at 350 m approximately. Table 11 and figure 17c present the pressure and hydrostatic gradients vs depth for this run. We can observe on this figure an appreciable deviation of pressure gradient from the hydrostatic at 900 m to bottomhole indicating a injection of fluid at this location (900 m). Also, in this figure we do not see any pressure gradient less than hydrostatic at 700-900 m depth interval as we did when analyzing the last set of logs for the completely shut- in well case. The likely reason for this may be that the magnitude of the bleed was such that water did not flow down the wellbore. Figure 17d presents the difference in pressure and hydrostatic gradients and we observe the same results. This well is located also at the periphery of the field but the same cold water inflow that is occuring in well M-9 is not apparent in this analysis.

It should be pointed out the need for sufficient and accurate information about well completion in order to make this kind of interpretation. Potentially the interpretation could lead us to detect any fracture or leaks on the production pipe or casing. Furthermore, it is believed that a careful logging procedure when taking pressure measurements would result In a more reliable pressure gradient data to be used for this Snterpretation technique. Needless to say it would be of great help **If** we had a device that could measure pressure difference instead **of** pressure at any specific depth within the wellbore. The use **of** such device could give us a quantitative value fot the magnitude **of** the flow. Such a device ***is*** not presently available commercially in the geothermal industry but efforts are being made to develop this type of differential pressure gauge (Kratz et al [9])

V.- CONCLUSIONS .

I.- Fluid movement within the well may be detected using data from pressure and temperature logs run simultaneosly in a geothermal wellbore.

11.- Pressure gradients different than hydrostatic have been found in the well by this method indicating the existence of fluid movement, even when the well is closed at wellhead.

111.- The need to have sufficient and accurate information about well completion as well as other kind of information related to the reservoir was helpful in interpreting the obtained results.

IV.- It is expected that the use of a differential pressure device would provide better pressure gradient data,

VI.- REFERENCES .

(1). Dale C.R., "Bottomhole Flow Survey For Determination of Fluid and Gas Movements in Wells", Trans AIME (1949) 186, 205-210.

(2). Grant A. M., "Interpretation of Downhole Measurements on Geothermal Wells", Applied Mathematics Division, Dept. of Scientific and Industrial Research, New Zealand (Dec 1979).

(3). Grant A.M., "Interpretation of Downhole Measurements at Baca Field", Proc. of Fifth Workshop on Geothermal Reservoir Engineering, Stanford University (Dec 1979).

(4). Bixley F.P., Grant M.A., Syms C.M., "Instability in Well Performance", Geothermal Resources Council (Transactions), 1979.

(5). Syms C.M., Bixley F.P., "The interpretation and Application of Flowmeter Logs in Geothermal Wellbores", Proceedings of The New Zealand Geothermal Workshop (Oct 1979).

(6). Bermejo F.J., Cortez A.C., Aragon A.A., "Physical and Thermodynamic Changes Observed in The Cerro Prieto Geothermal Field", First Symposium on The Cerro Prieto Geothermal Reservoir, San Diego Ca., (Sept 1978).

(7). Ing. Rafael Molinar (personal communication).

(8). Mañon M.A., Sanchez A.A., Fausto J.L., Jimenez S.M.E., "Preliminary Geochemical Model of The Cerro Prieto Geothermal Field", First Symposium on The Cerro Prieto Geothermal Reservoir, San Diego Cal., (Sept 1978).

(9). Kratz H.R., Day E.A., Ginn W.G., "Improved Geothermal Well Logging Tools Using No Downhole Electronics", Final Report, Systems Science and Software, La Jolla Ca., SAN-1315-1, (July 1979).

VII.- FIGURES

Table 1.- PRESSURE AND TEMPERATURE DATA FROM SURVEY # 10

DEPTH (ft)	PRESSURE (psia)	TEMPERATURE (°C)
100	153.4	138.2
200	195.0	138.2
300	237.1	139.0
400	279.6	139.0
500	323.4	138.2
1000	533.0	138.2
1500	744.6	138.2
2000	956.5	139.8
2500	1166.1	148.9
2560	1201.3	153.8
2570	1205.4	--
2580	1209.5	--
2590	1213.7	--
2600	1217.7	162.1
2700	1249.0	176.0
2800	1281.5	195.8
2900	1319.7	204.8
3000	1364.5	207.3
3100	1410.2	203.2
3200	1454.3	200.7
3300	1495.9	202.4
3400	1536.5	204.0
3500	1575.4	208.1
3600	1612.5	215.5
3675	1629.3	218.8

Table 2.- PRESSURE AND TEMPERATURE DATA FROM SURVEY # 11

DEPTH (ft)	PRESSURE (psia)	TEMPERATURE (°C)
0	130.0	125.3
100	197.1	146.4
200	232.8	146.3
300	272.8	146.1
400	313.5	145.8
500	355.7	145.4
1000	565.4	142.9
1500	776.4	141.0
2000	987.6	140.3
2100	1030.0	140.6
2200	1072.8	141.1
2300	1113.9	141.5
2400	1156.4	142.0
2500	1197.8	143.2
2520	1205.0	145.8
2540	1212.5	147.7
2560	1219.9	148.5
2580	1227.1	150.3
2600	1234.8	152.7

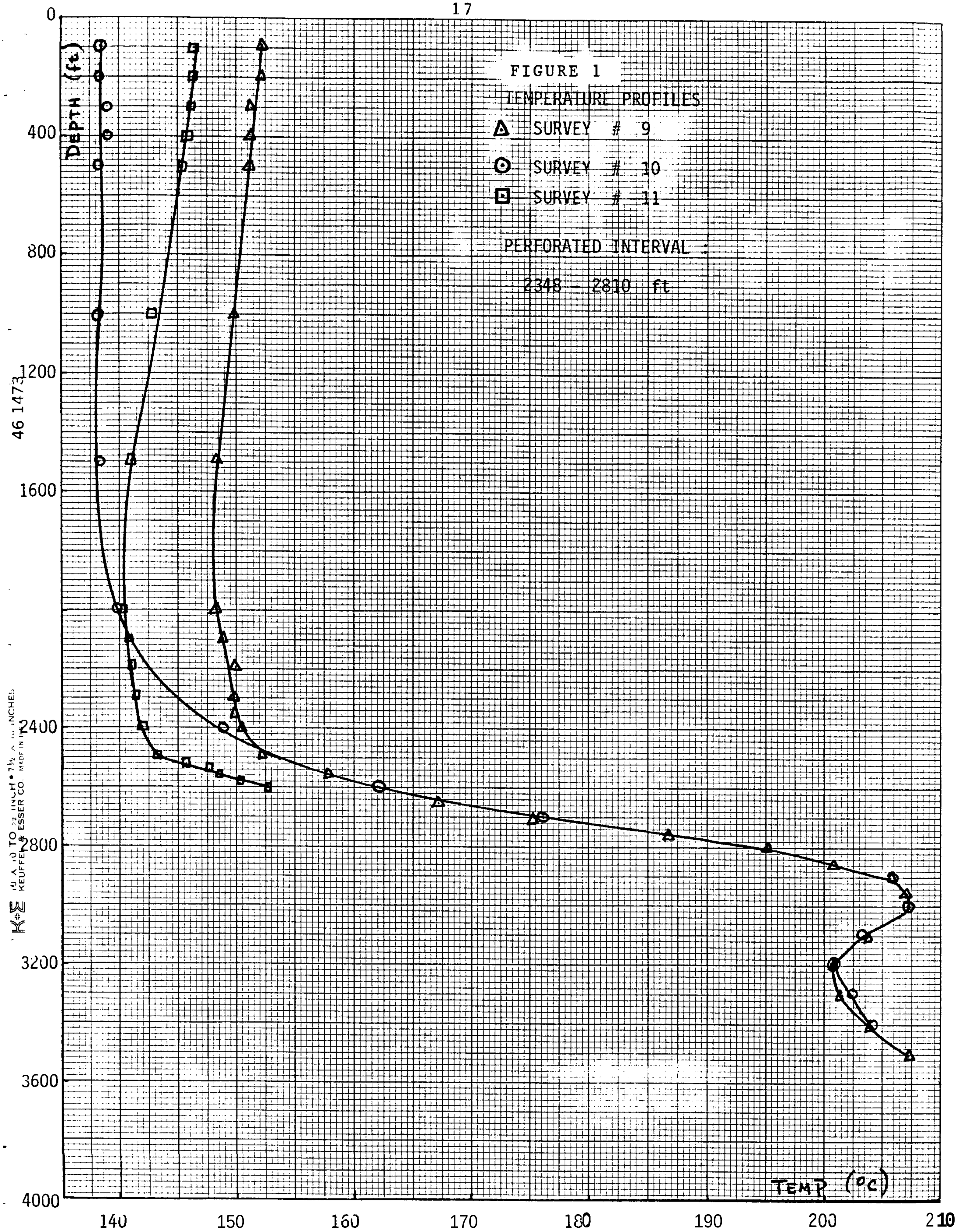


FIGURE 1
TEMPERATURE PROFILES
SURVEY # 9
SURVEY # 10
SURVEY # 11
PERFORATED INTERVAL :
2348 - 2810 ft
DEPTH (ft)
TEMP (°C)
0
400
800
1200
1600
2400
2800
3200
3600
4000
140
150
160
170
180
190
200
210
46 1473
K+E 10 X 10 TO 1/2 INCH • 7 1/2 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

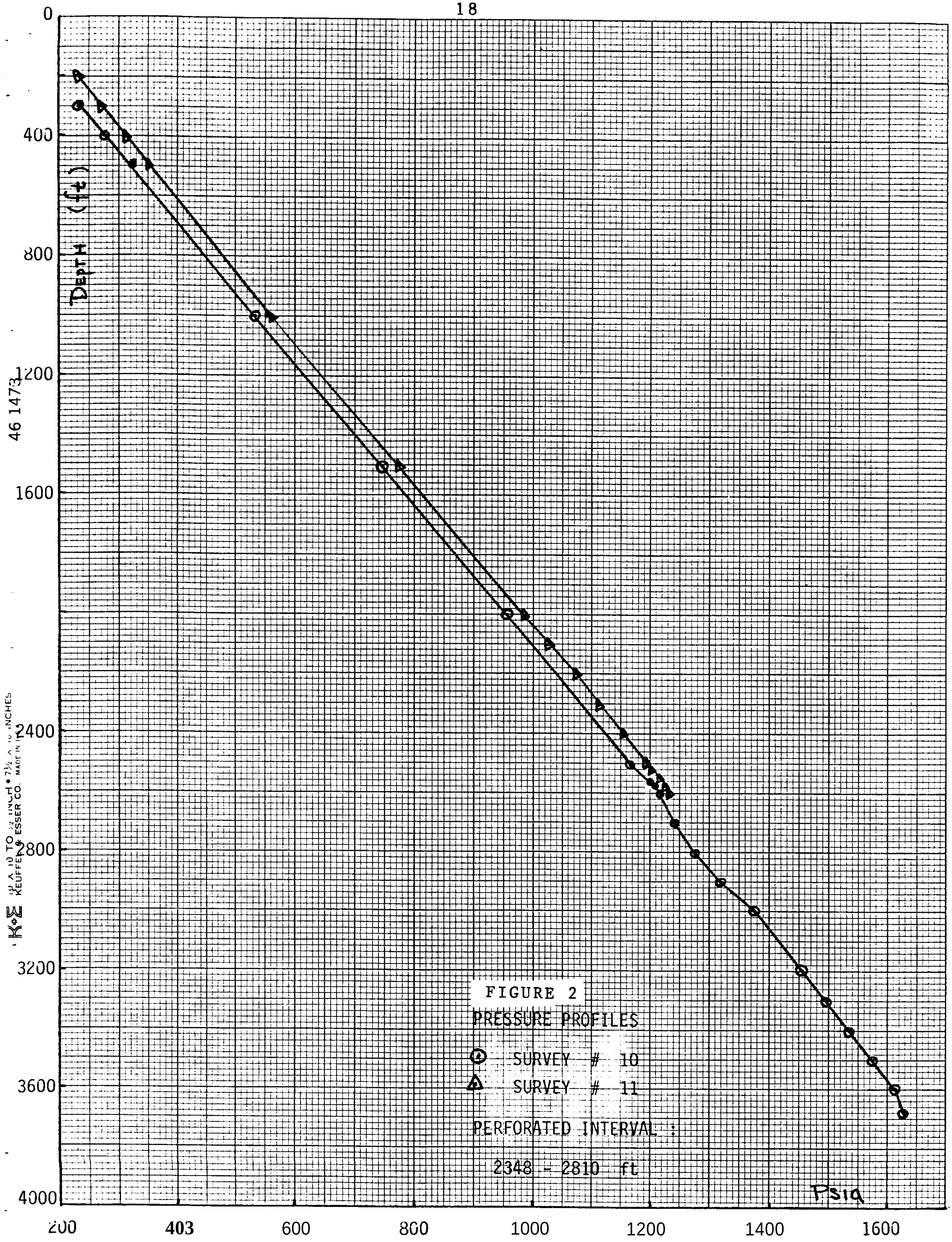


FIGURE 2

PRESSURE PROFILES

○ SURVEY # 10

△ SURVEY # 11

PERFORATED INTERVAL :

2348 - 2810 ft

Table # 3.- PRESSURE GRADIENT VS DEPTH. SURVEY # 10.

DEPTH (ft)	PRESSURE GRADIENT (p/ft) × 100	HYDROSTATIC GRADIENT (p/ft) × 100
100	---	40.21
200	41.60	40.21
300	42.10	40.17
400	42.50	40.17
500	43.80	40.21
1000	41.92	40.21
1500	42.32	40.21
2000	42.38	40.17
2500	41.92	39.97
2560	---	39.74
2600	38.60	39.53
2700	38.00	38.95
2800	38.80	38.19
2900	38.00	37.50
3000	44.80	37.17
3100	45.70	37.23
3200	44.10	37.40
3300	41.60	37.40
3400	40.60	37.33
3500	38.90	37.17
3600	37.10	36.88
3675	22.40?	36.57

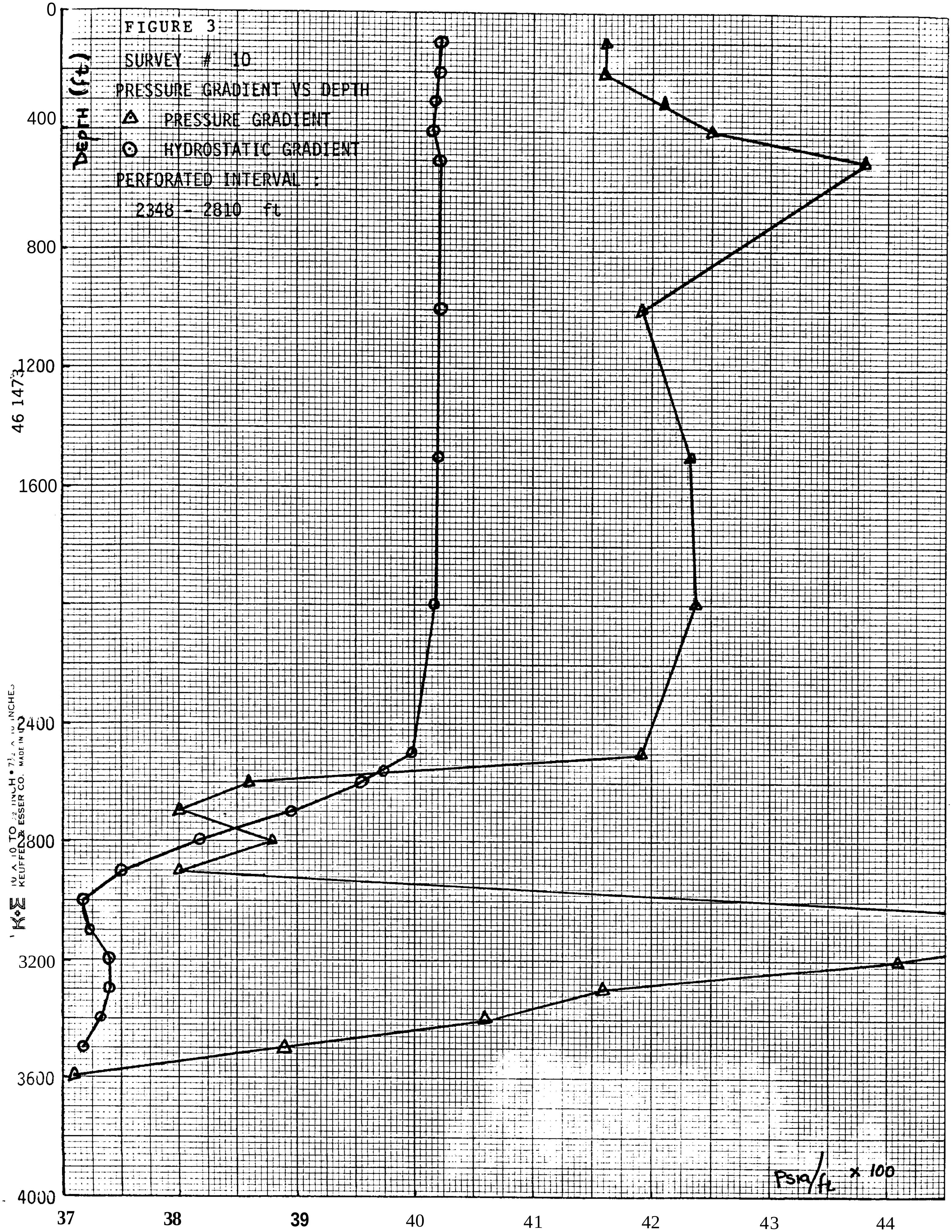
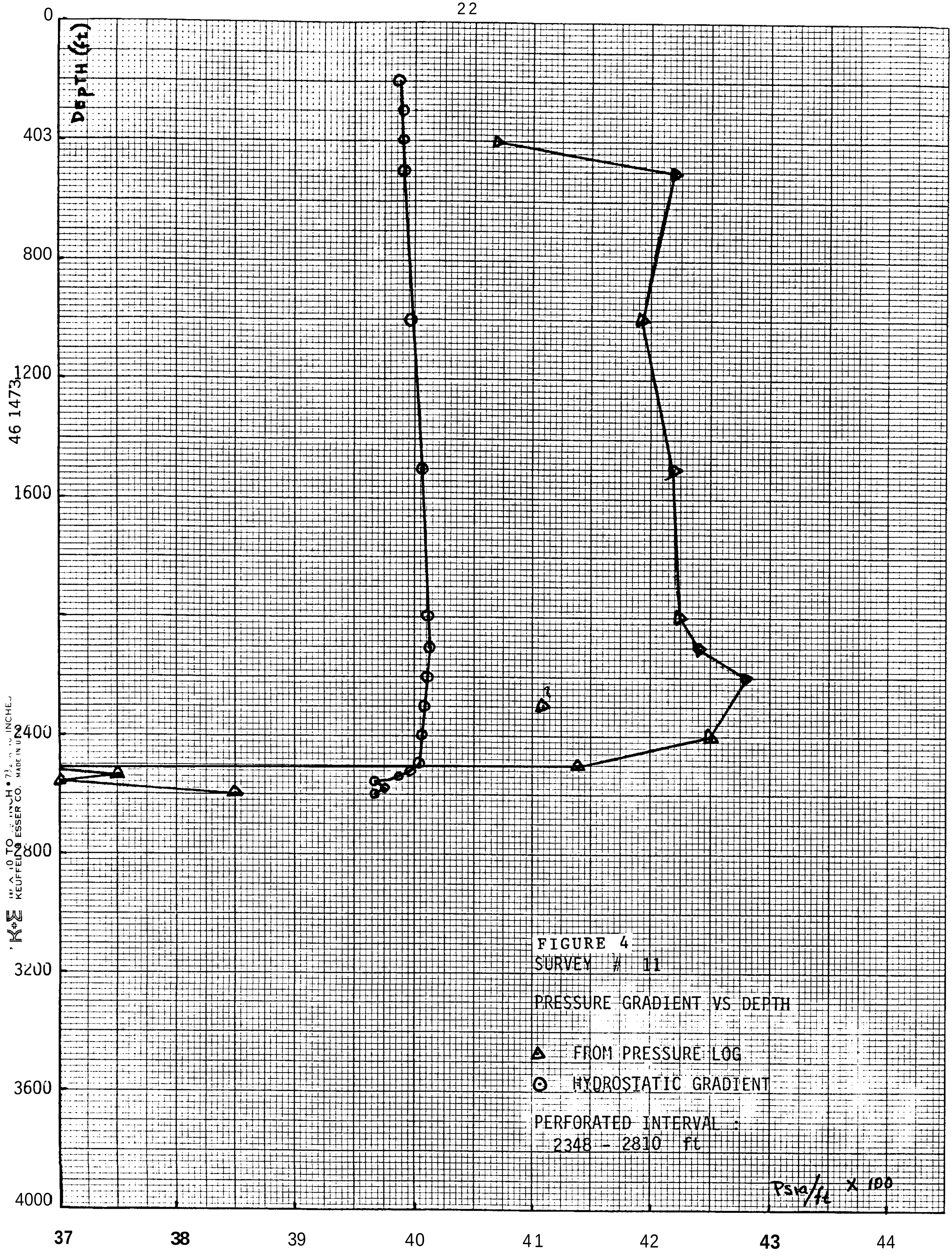


FIGURE 3
SURVEY # 10
PRESSURE GRADIENT VS DEPTH
PRESSURE GRADIENT
HYDROSTATIC GRADIENT
PERFORATED INTERVAL :
2348 - 2810 ft
DEPTH (ft)
0
400
800
1200
1600
2400
2800
3200
3600
4000
37
38
39
40
41
42
43
44
Psia/ft x 100
46 1473
KEUFFEL & ESSER CO. MADE IN U.S.A.

Table # 4.- PRESSURE GRADIENT VS DEPTH. SURVEY # 11.

DEPTH (ft)	PRESSURE GRADIENT (p/ft) x 100	HYDROSTATIC GRADIENT (p/ft) x 100
100	---	---
200	35.70	39.89
300	40.00	39.90
400	40.70	39.90
500	42.20	39.92
1000	41.94	39.98
1500	42.20	40.06
2000	42.24	40.11
2100	42.40	40.13
2200	42.80	40.11
2300	41.10	40.08
2400	42.50	40.07
2500	41.40	40.03
2520	36.00	39.96
2540	37.50	39.88
2560	37.00	39.68
2580	36.00	39.76
2600	38.50	39.68


DEPTH (ft)
0
403
800
1200
1600
2400
2800
3200
3600
4000
37
38
39
40
41
42
43
44
Psia/ft X 100
FIGURE 4
SURVEY # 11
PRESSURE GRADIENT VS DEPTH
FROM PRESSURE LOG
HYDROSTATIC GRADIENT
PERFORATED INTERVAL :
2348 - 2810 ft
46 1473

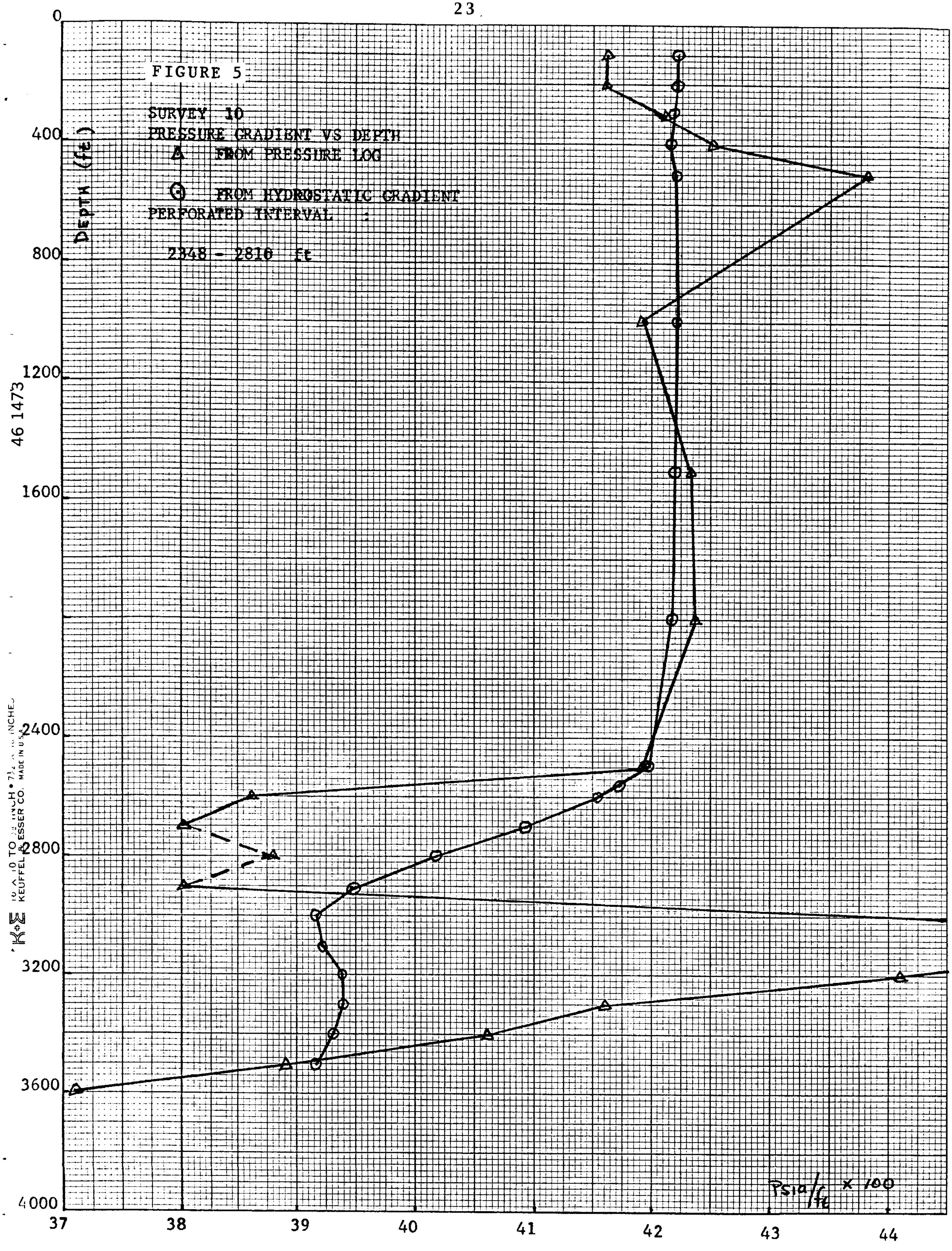


FIGURE 5
SURVEY 10
PRESSURE GRADIENT VS DEPTH
FROM PRESSURE LOG
FROM HYDROSTATIC GRADIENT
PERFORATED INTERVAL :
2348 - 2810 ft
DEPTH (ft)
Psia/ft x 100
0
400
800
1200
1600
2400
2800
3200
3600
4000
37
38
39
40
41
42
43
44
46 1473
KEUFFEL & ESSER CO. MADE IN U.S.A.

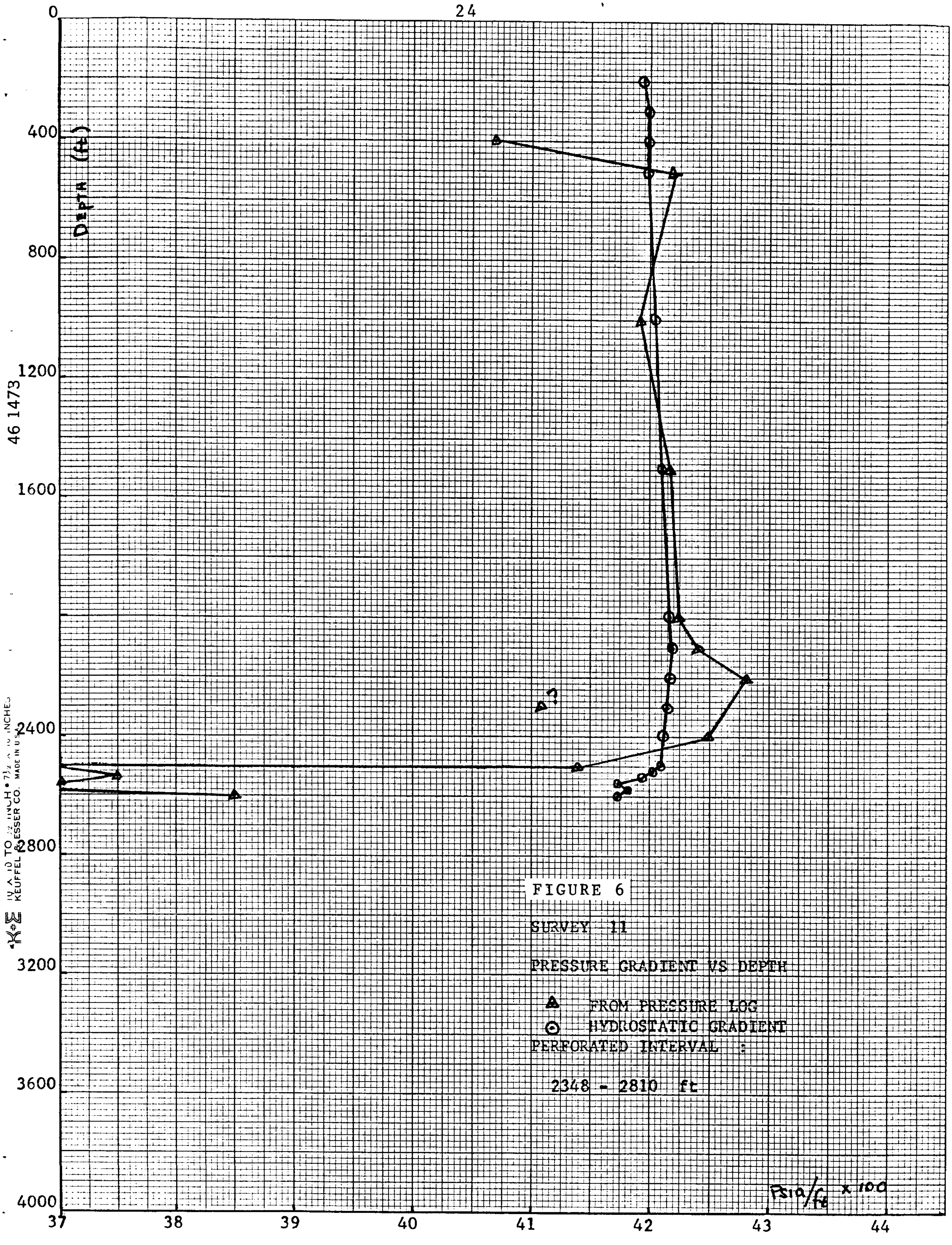


FIGURE 6

SURVEY 11

PRESSURE GRADIENT VS DEPTH

▲ FROM PRESSURE LOG

⊙ HYDROSTATIC GRADIENT

PERFORATED INTERVAL :

2348 - 2810 ft

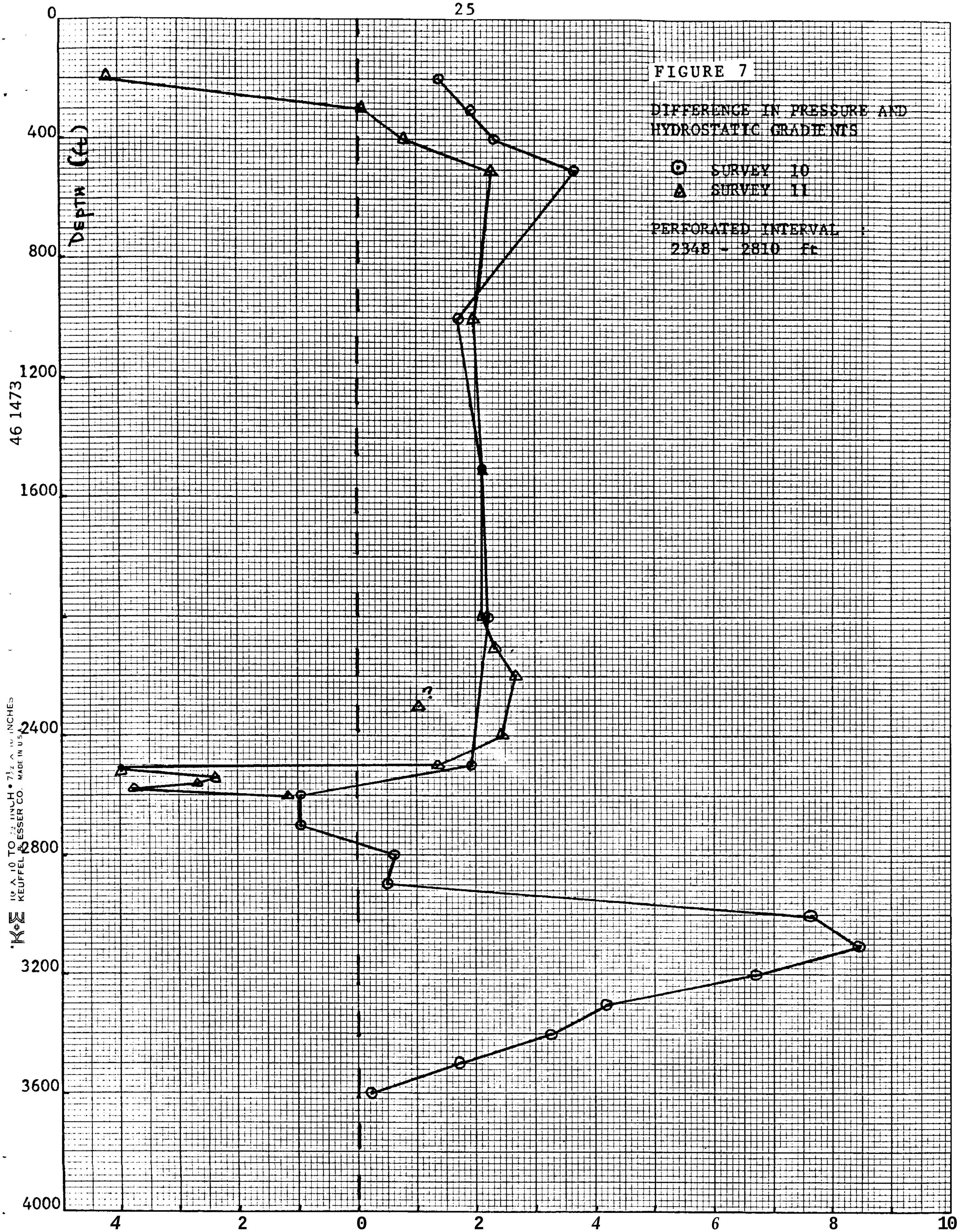


FIGURE 7
DIFFERENCE IN PRESSURE AND HYDROSTATIC GRADIENTS
SURVEY 10
SURVEY 11
PERFORATED INTERVAL :
2348 - 2810 ft
Depth (ft)
0
400
800
1200
1600
2400
2800
3200
3600
4000
4
2
0
2
4
6
8
10
?
46 1473
10 X 10 TO 1/2 INCH • 7 1/2 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

Table # **5.-** AVERAGE DENSITY VALUES FOR A GIVEN DEPTH.
SURVEY # 10.

DEPTH (ft)	DENSITY (1) lb/ft	DENSITY *(2)* lb/ft
100	----	57.90
200	59.90	57.90
300	60.62	57.85
400	61.20	57.85
500	63.07	57.90
1000	60.36	57.55
1500	60.94	57.90
2000	61.03	57.85
2500	60.36	57.55
2600	55.58	56.92
2700	54.72	56.09
2800	55.87	54.99
2900	54.72	54.00
3000	64.51	53.53
3100	65.80	53.61
3200	63.50	53.85
3300	59.90	53.86
3400	58.46	53.76
3500	56.02	53.53
3600	53.43	53.10
3675	32.26?	52.66

(1) FROM PRESSURE DATA
(2) FROM TEMPERATURE DATA

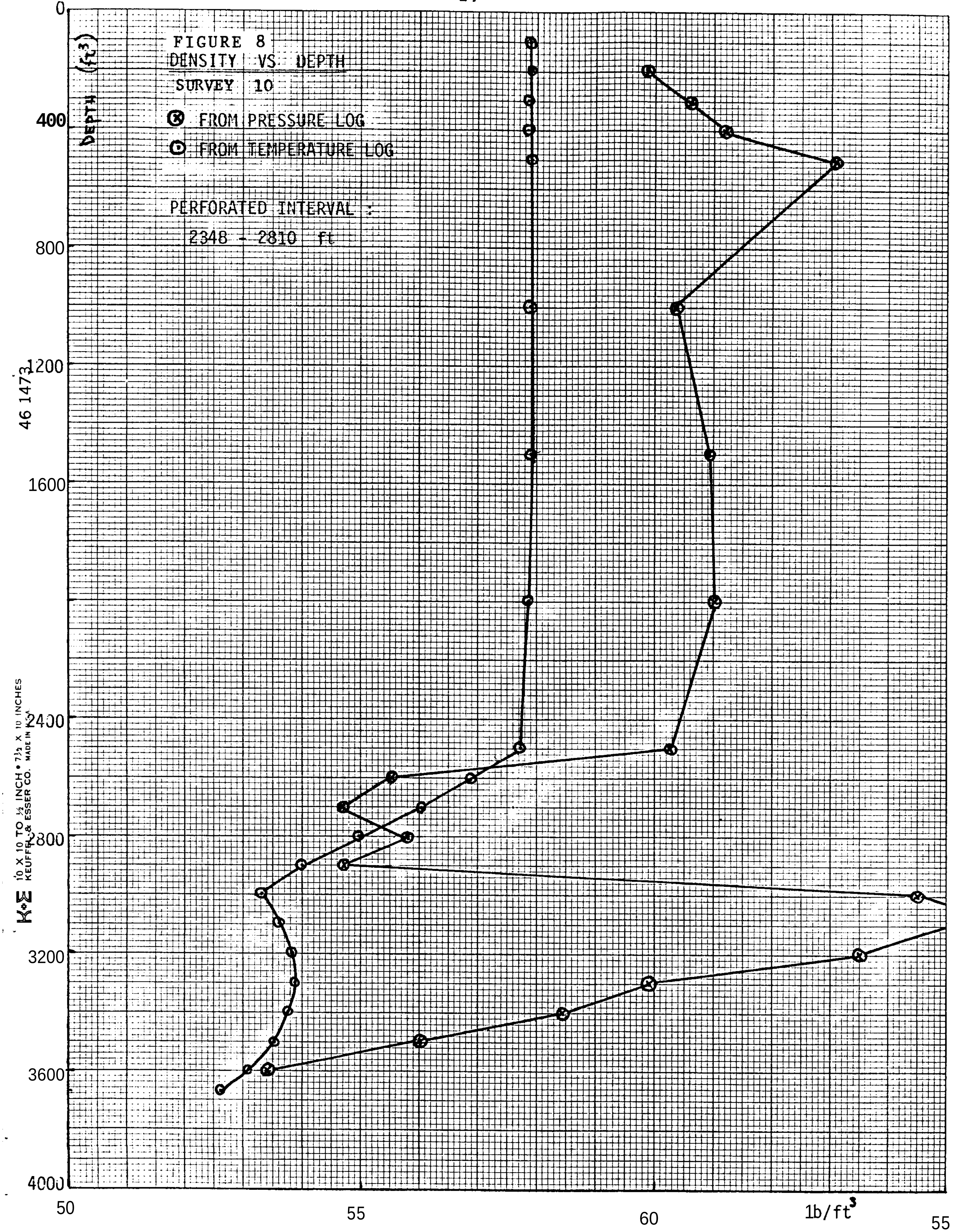


FIGURE 8
DENSITY VS DEPTH
SURVEY 10
FROM PRESSURE LOG
FROM TEMPERATURE LOG
PERFORATED INTERVAL :
2348 - 2810 ft
DEPTH (ft)
0
400
800
1200
1600
2400
2800
3200
3600
4000
50
55
60
55
lb/ft^3
46 1473
K+E 10 X 10 TO ½ INCH • 7½ X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

Table # 6.- AVERAGE DENSITY VALUES FOR A GIVEN DEPTH.
SURVEY # 11

DEPTH (ft)	DENSITY (1) lb/ft	DENSITY (2) lb/ft
100	----	----
200	51.41	57.44
300	57.60	57.45
400	58.61	57.46
500	60.76	57.48
1000	60.39	57.57
1500	60.83	57.69
2000	60.77	57.76
2100	61.06	57.78
2200	61.53	57.76
2300	59.18	57.72
2400	61.20	57.70
2500	59.61	57.65
2520	51.84	57.54
2540	54.00	57.42
2560	53.28	57.14
2580	51.84	57.26
2600	55.44	57.14

(1) FROM PRESSURE DATA

(2) FROM TEMPERATURE DATA

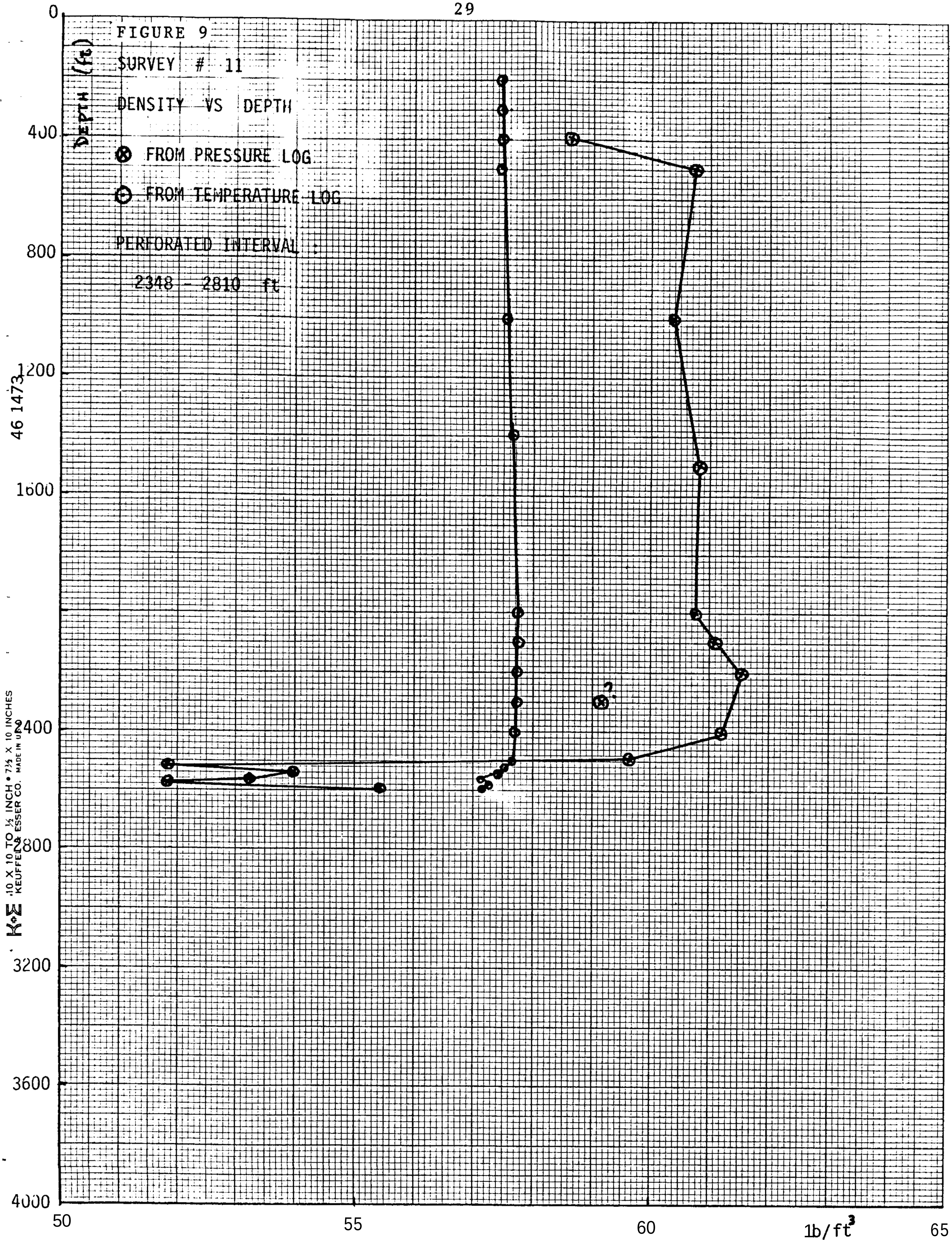


FIGURE 9
SURVEY # 11
DENSITY VS DEPTH
⊗ FROM PRESSURE LOG
⊕ FROM TEMPERATURE LOG
PERFORATED INTERVAL :
2348 - 2810 ft
DEPTH (ft)
0
400
800
1200
1600
2400
2800
3200
3600
4000
50
55
60
65
lb/ft³
?

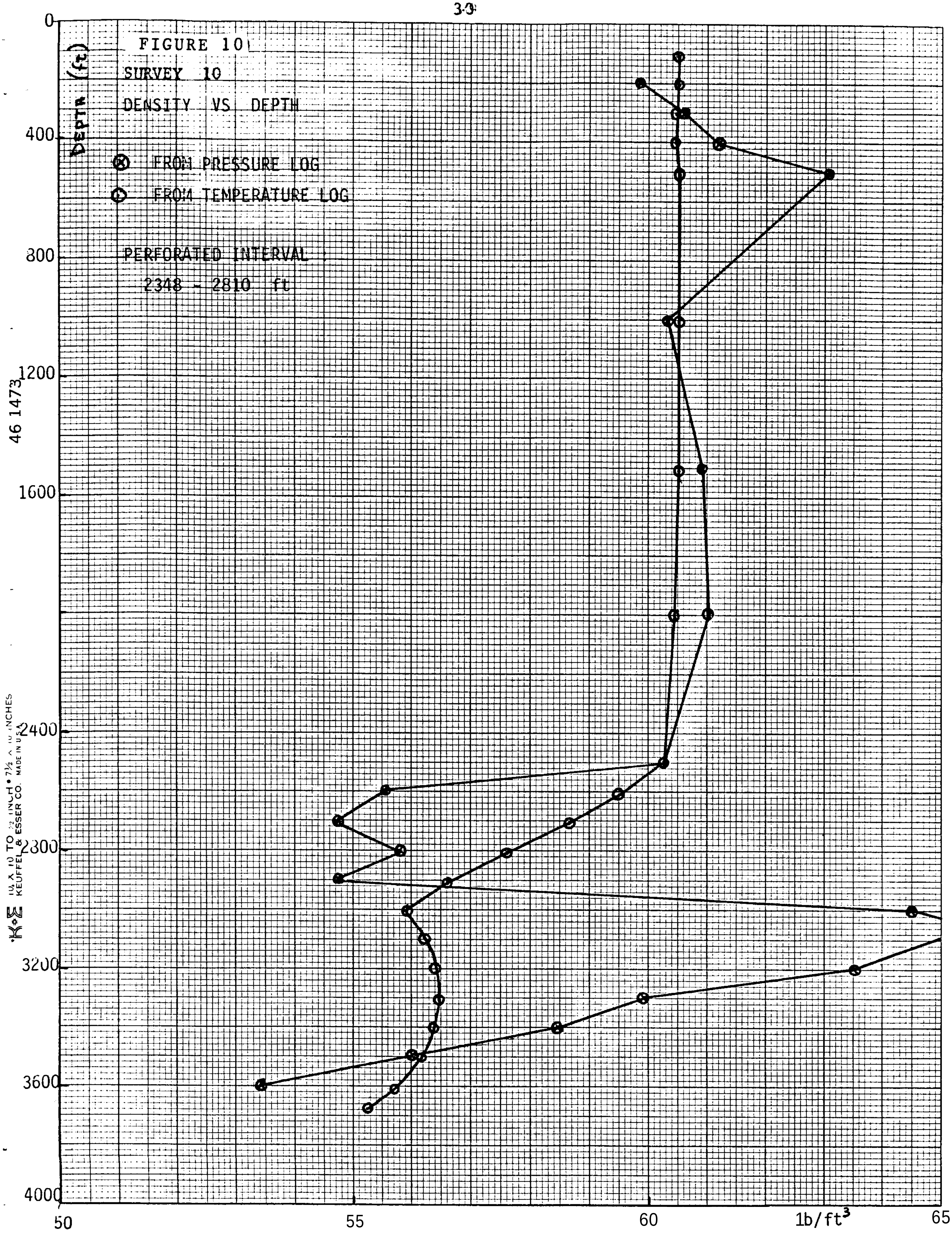


FIGURE 10
SURVEY 10
DENSITY VS DEPTH
FROM PRESSURE LOG
FROM TEMPERATURE LOG
PERFORATED INTERVAL :
2348 - 2810 ft
DEPTH (ft)
0
400
800
1200
1600
2400
2800
3200
3600
4000
50
55
60
65
lb/ft³
46 1473
K&E 10 X 10 TO 1/2 INCH • 7 1/2 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

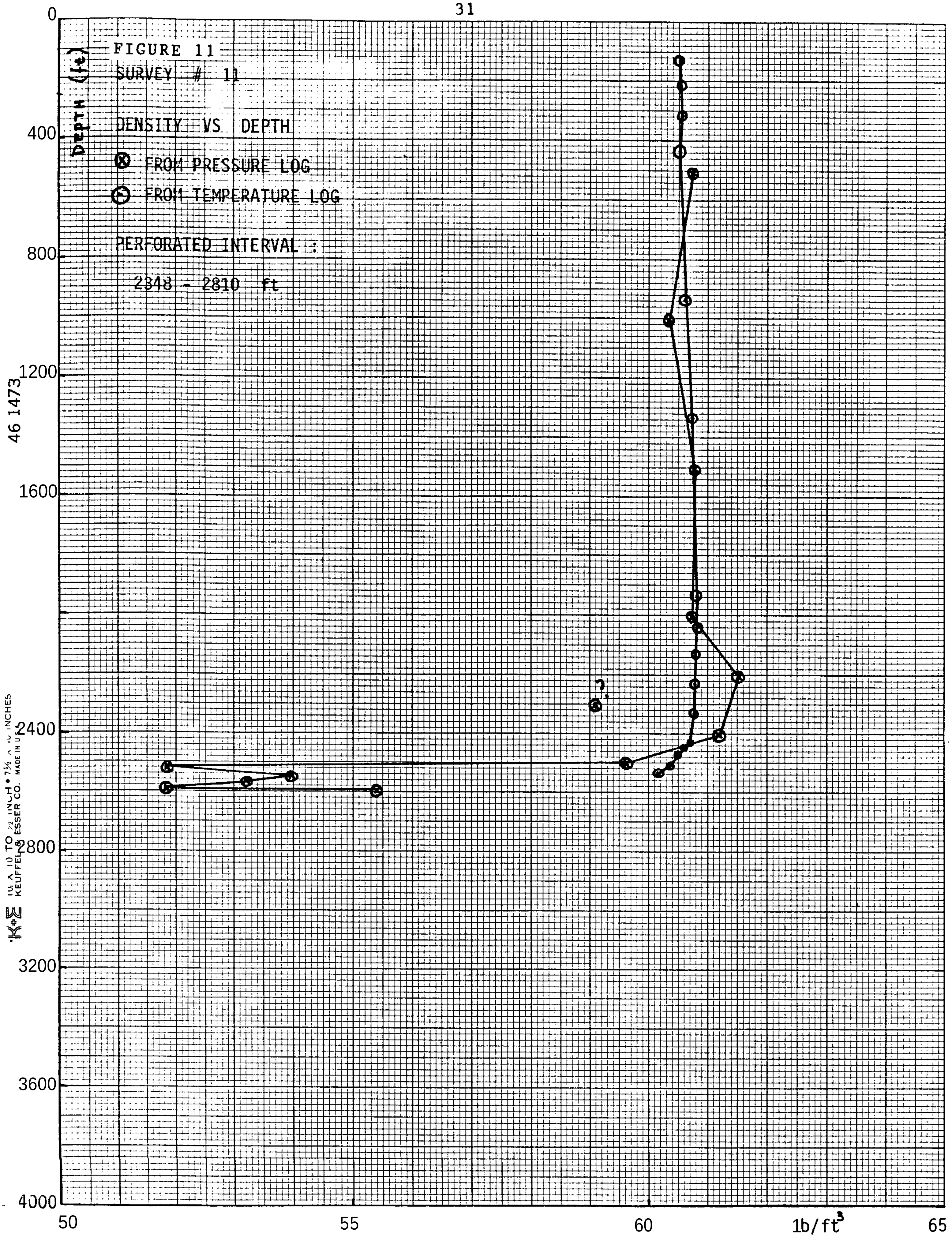


FIGURE 11
SURVEY # 11
DENSITY VS DEPTH
FROM PRESSURE LOG
FROM TEMPERATURE LOG
PERFORATED INTERVAL :
2348 - 2810 ft
DEPTH (ft)
0
400
800
1200
1600
2400
2800
3200
3600
4000
50
55
60
65
1b/ft3
?
46 1473
10 X 10 TO 1/2 INCH • 7 1/2 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

P-3 / M-9

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE PRESION DE FONDO

POZO M- 9 FECHA JUNIO 2 DE 1975.

CONDICIONES EN EL POZO FLUYE POR PURGA DE 1" DE DIAMETRO CON VALVULA REGULADA.

PRESION CABEZA 69 PSI (4.9 Kg/cm²)

PRESION MAXIMA 1786 PSI (125.5 Kg/cm²)

PROFUNDIDAD MAXIMA DEL REGISTRO 1339 m. ELEMENTO KP.-9126

PROFUNDIDAD M	lb/in²	kg/cm²
0	69	4.9
50	124	8.7
100	191	13.4
150	260	18.3
200	326	22.9
250	393	27.6
300	460	32.3
50	525	36.9
00	591	41.6
450	656	46.1
500	721	50.7
550	785	55.2
600	850	59.8
650	914	64.3
00	978	68.7
750	1042	73.2
800	1104	77.6
50	1167	82.0
900	1231	86.5
50	1294	91.0
00	1358	95.5
050	1423	100
00	1487	105
150	1551	109
200	1614	114
50	1677	118
300	1740	122
339	1786	126

OBSERVACIONES

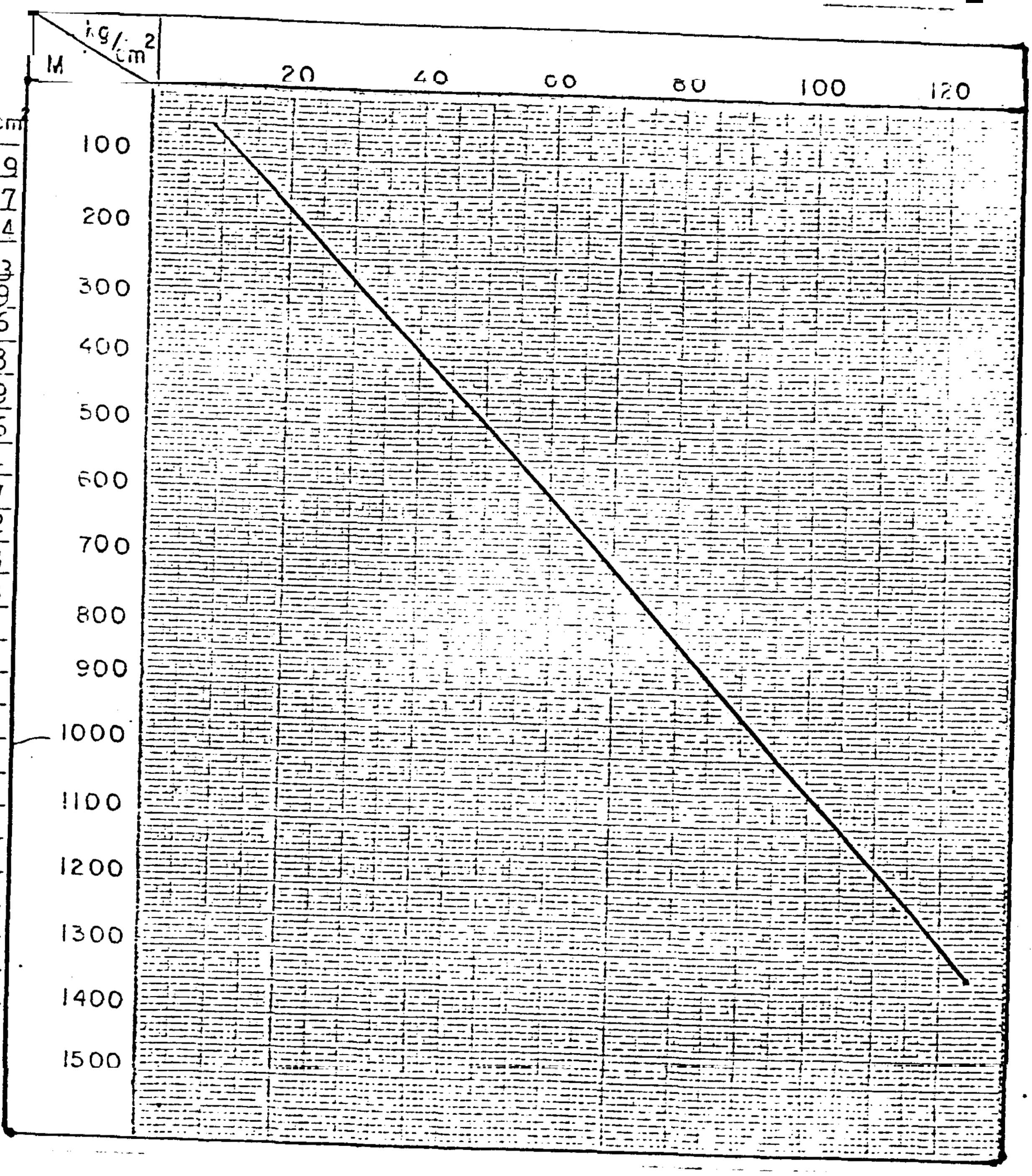


FIGURE 12a.- Pressure profile for well M-9 (June61975)

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE TEMPERATURA DE FONDO

POZO M- 9 FECHA JUNIO 2 DE 1975.

CONDICIONES EN EL POZO FLUYE POR PURGA DE 1" DE DIAMETRO CON VALVULA REGULADA.

PRESION CABEZA (P.S.I.) 69 PSI (4.9 Kg/cm^2) ELEMENTO ET-B.-10027

TEMP. MAXIMA 471°F (244°C).

PROFUNDIDAD MAXIMA DEL REGISTRO 1339 m.

PROFUNDIDAD M	°C	°F
50	150	302
100	159	319
150	170	338
200	[illegible]	[illegible]
250	184	363
300	192	378
350	203	398
400	211	412
450	218	424
500	225	437
550	232	449
600	235	454
650	238	461
700	241	466
750	243	469
	244	471
800	237	458
850	235	455
900	234	453
950	234	453
1000	234	453
1050	234	453
1100	233	451
1150	233	451
1200	232	450
1250	232	450
1300	220	428
1339	215	419

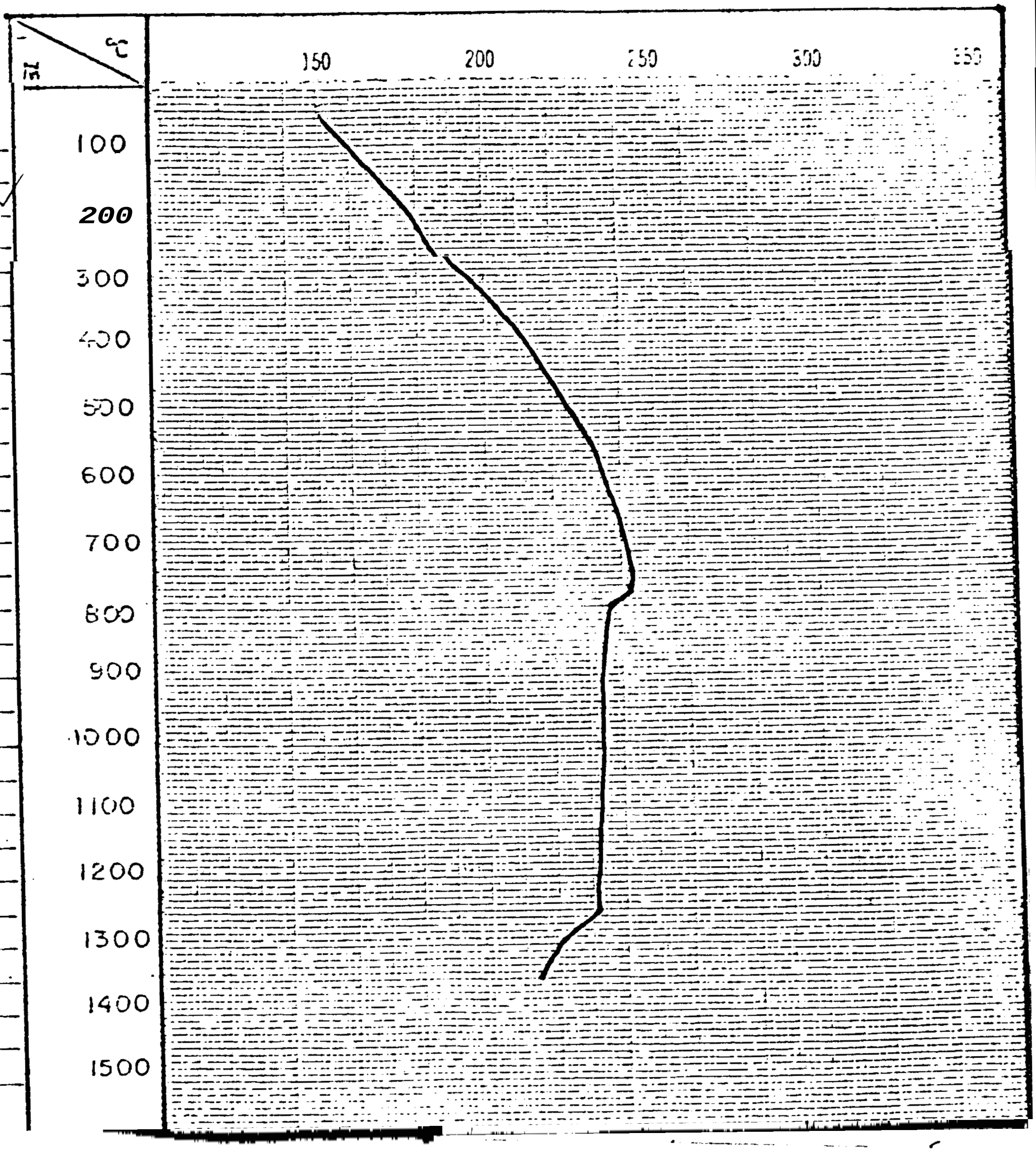


FIGURE 12b.- Temperature profile for well M-9 (June61975).

Table 7.- Pressure and hydrostatic gradients taken from pressure and temperature logs run on July/2/1975 . Well M-9 .

DEPTH (m)	PRESSURE GRADIENT (ΔP/ft) × 100	HYDROSTATIC GRADIENT (ΔP/ft) × 100
100	40.8	39.6
150	42.1	39.1
200	40.2	38.7
250	40.8	38.4
300	40.8	38.1
350	39.6	37.6
400	40.2	37.1
450	39.6	36.8
500	39.6	36.3
550	39.0	36.0
600	39.6	35.6
650	39.0	35.5
700	39.0	35.3
750	39.0	35.2
800	37.8	35.1
850	38.4	35.3
900	39.0	35.6
950	38.4	35.6
1000	39.0	35.6
1050	39.6	35.6
1100	39.0	35.6
1150	39.0	35.6
1200	38.4	35.8
1250	38.4	35.8

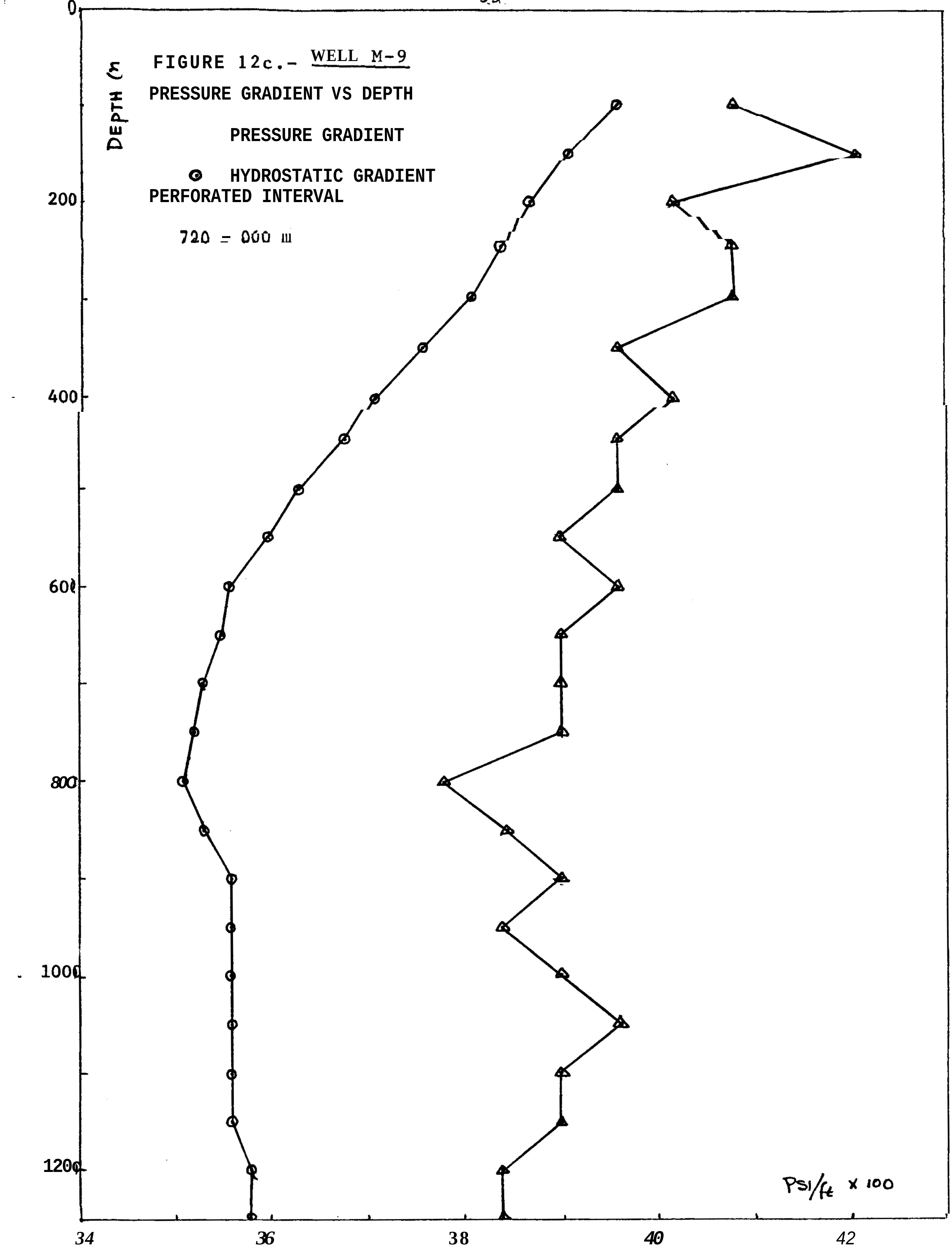


FIGURE 12c.- WELL M-9
PRESSURE GRADIENT VS DEPTH
PRESSURE GRADIENT
HYDROSTATIC GRADIENT
PERFORATED INTERVAL
720 = 000 m
DEPTH (m
0
200
400
600
800
1000
1200
34
36
38
40
42
PSI/ft x 100

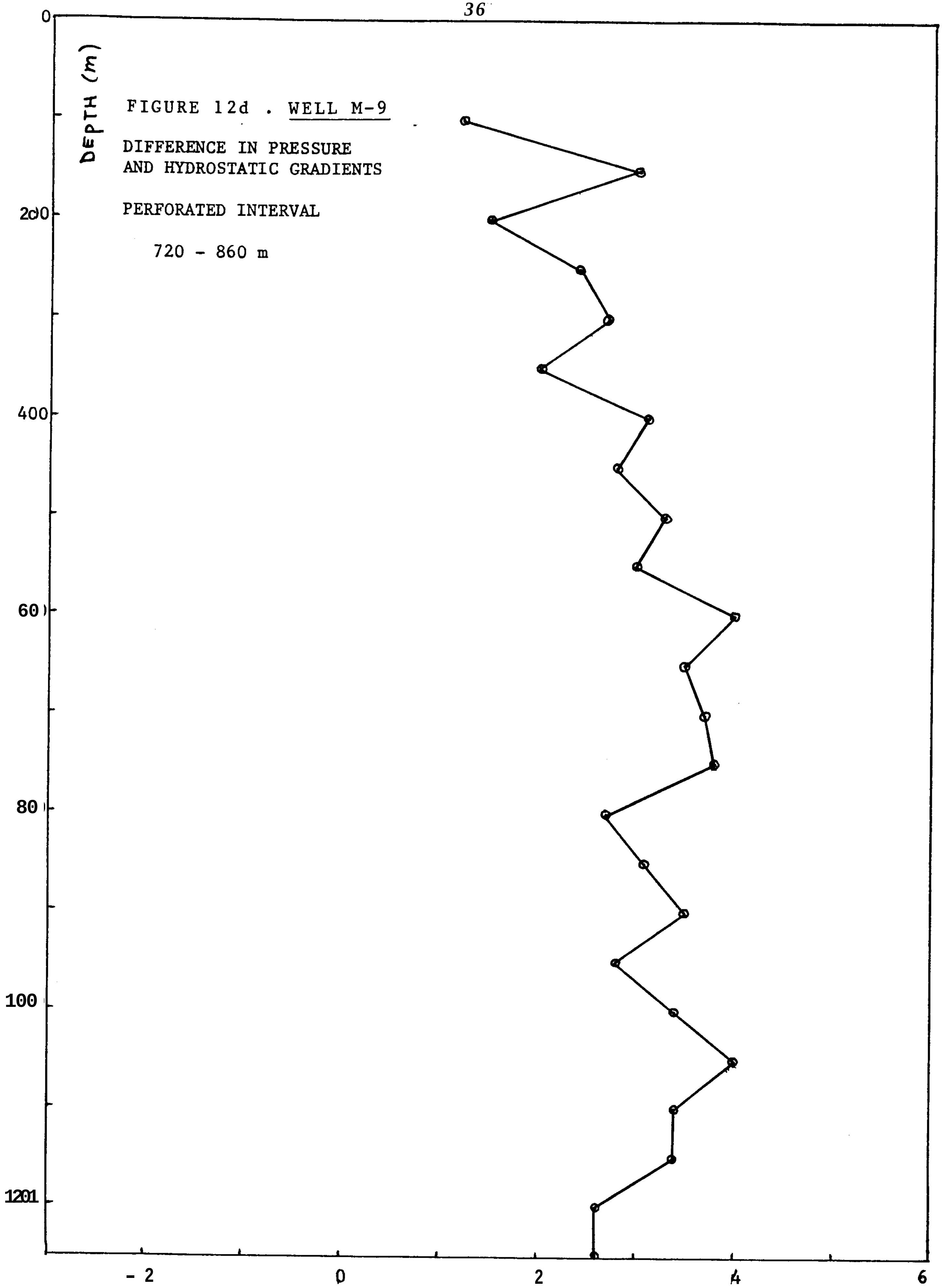


FIGURE 12d . WELL M-9
DIFFERENCE IN PRESSURE
AND HYDROSTATIC GRADIENTS
PERFORATED INTERVAL
720 - 860 m
DEPTH (m)
0
200
400
600
800
1000
1200
- 2
0
2
4
6

P-7/M-9

COMISION FEDERAL DE ELECTRICIDAD
OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO
REGISTROS DE PRESION DE FONDO

POZO M- 9 FECHA AGOSTO 25 DE 1975.

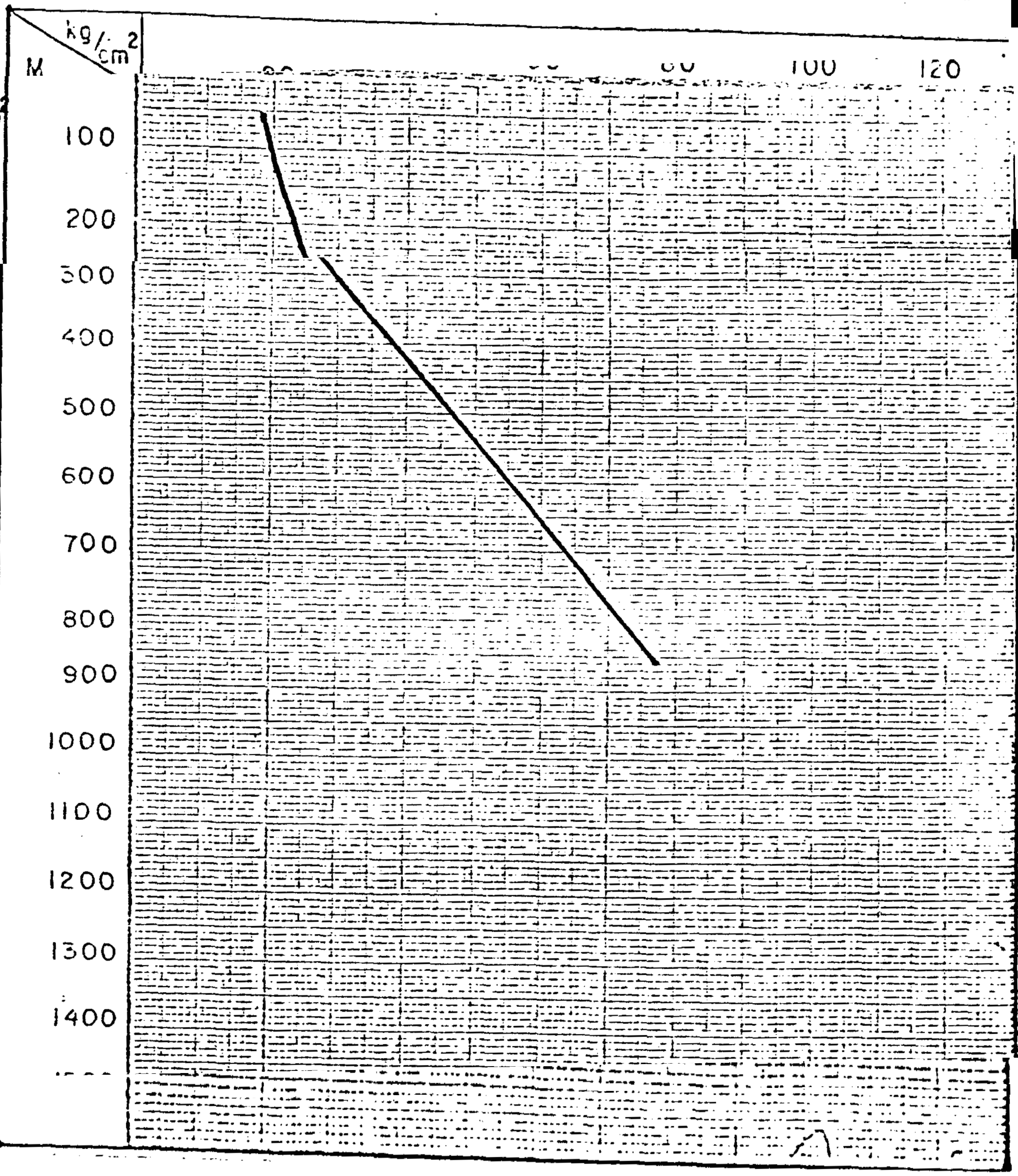
CONDICIONES EN EL POZO FLUYE POR LINEA DE 6" CON VALVULA REGULADA PARA TENER PRESION MAXIMA.

(17.7 Kg/cm²).

PRESION MAXIMA 1088 PSI (76.5 Kg/cm²) ELEMENTO EMPLEADO KPG.-6122

PROFUNDIDAD MAXIMA DEL REGISTRO 850 m.

PROFUNDIDAD M	lb/in²	kg/cm²
50	257	18.1
100	276	19.4
150	299	21.0
200	[illegible]	[illegible]
250	366	25.7
300	425	29.9
350	489	34.4
00	550	38.7
450	610	42.9
500	669	47.0
550	729	51.2
600	789	55.5
650	849	59.7
700	909	63.9
725	939	66.0
750	969	68.1
775	999	70.2
800	1029	72.3
825	1059	74.4
50	1088	76.5



OBSERVACIONES

FIGURE 13a.- Pressure profile for well M-9 (Aug./25/1975).

F.J.F. No.-1. /75

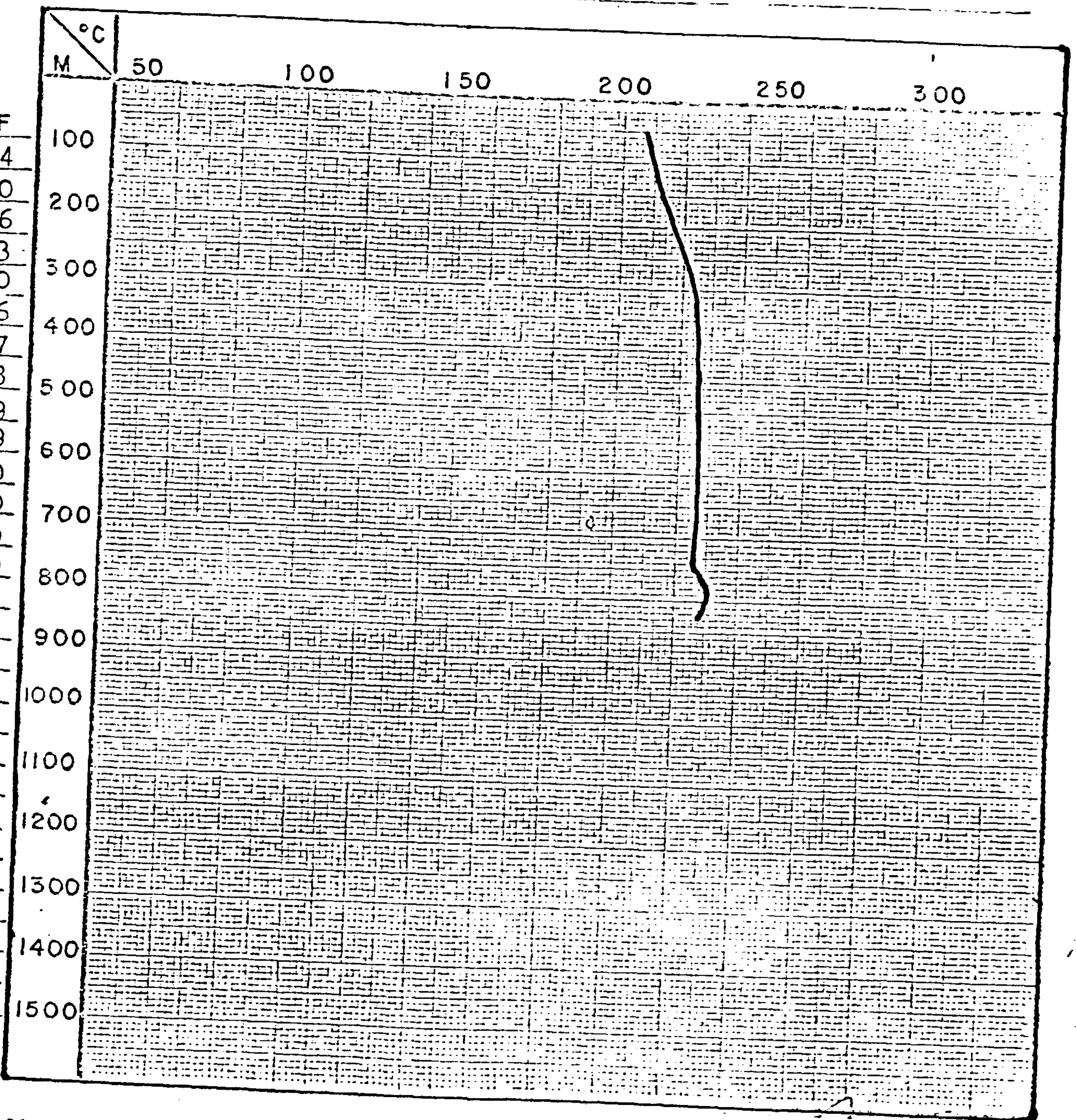
T-20/M-9

COMISION FEDERAL DE ELECTRICIDAD
OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO
REGISTROS DE TEMPERATURA DE FONDO

(3)

POZO M- 9 FECHA AGOSTO 25 DE 1975
CONDICIONES EN EL POZO FLUYE POR LINEA DE 6" CON VALVULA REGULADA PARA TENER PRESION MAXIMA.
PRESION CABEZA 252 PSI (17.7 Kg/cm²).
TEMP. MAXIMA 447°F 231°C
PROFUNDIDAD MAXIMA DEL REGISTRO DEL REGISTRO 825 m. ELEMENTO EMPLEADO KT-B 10065

PROF.	°C	°F
50	207	404
100	210	410
50	213	416
200	217	423
250	221	430
300	224	436
350	225	437
00	226	438
50	226	439
500	226	439
50	227	440
00	227	440
650	227	440
0	227	440
5	227	440
750	227	440
75	231	447
00	231	447
825	228	443



OBSERVACIONES

FIGURE 13b.- Temperature profile for well M-9 (Aug./25/1975).

Table 8.– Pressure and hydrostatic-gradients taken from pressure and temperature **logs** run on Aug/25/1975. Well M-9 .

DEPTH (m)	PRESSURE GRADIENT ($\Delta P/ft$) x 100	HYDROSTATIC GRADIENT ($\Delta P/ft$) x 100
100	11.6	37.1
150	14.0	36.9
200	17.1	36.7
250	23.8	36.5
300	36.0	36.3
350	39.0	36.2
400	37.2	36.2
450	36.6	36.1
500	36.0	36.1
550	36.6	36.1
600	36.6	36.1
650	36.6	36.1
700	36.6	36.1
725	36.6	36.1
750	36.6	36.1
775	36.6	35.9
800	36.0	35.7
825	36.6	35.9

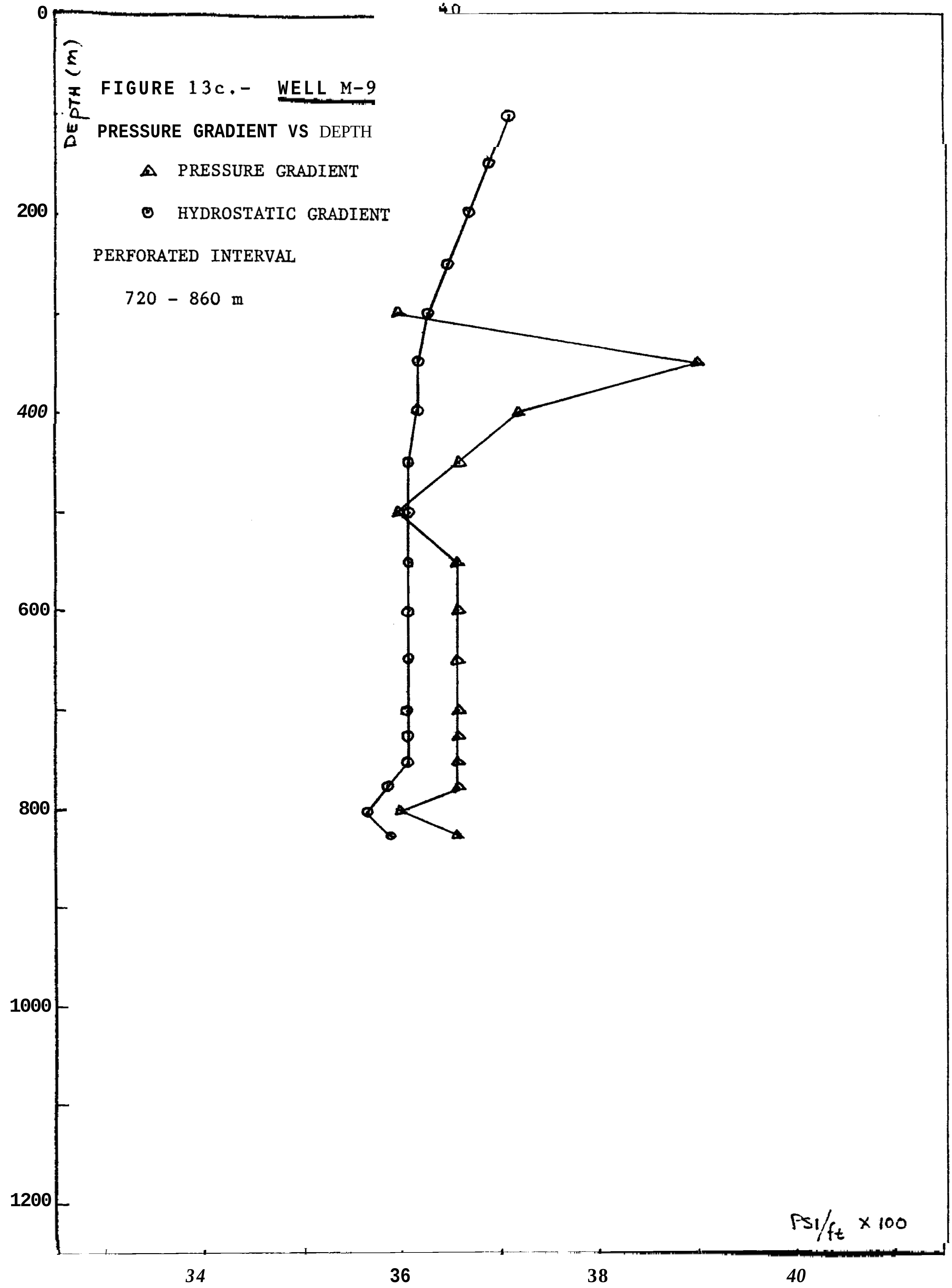
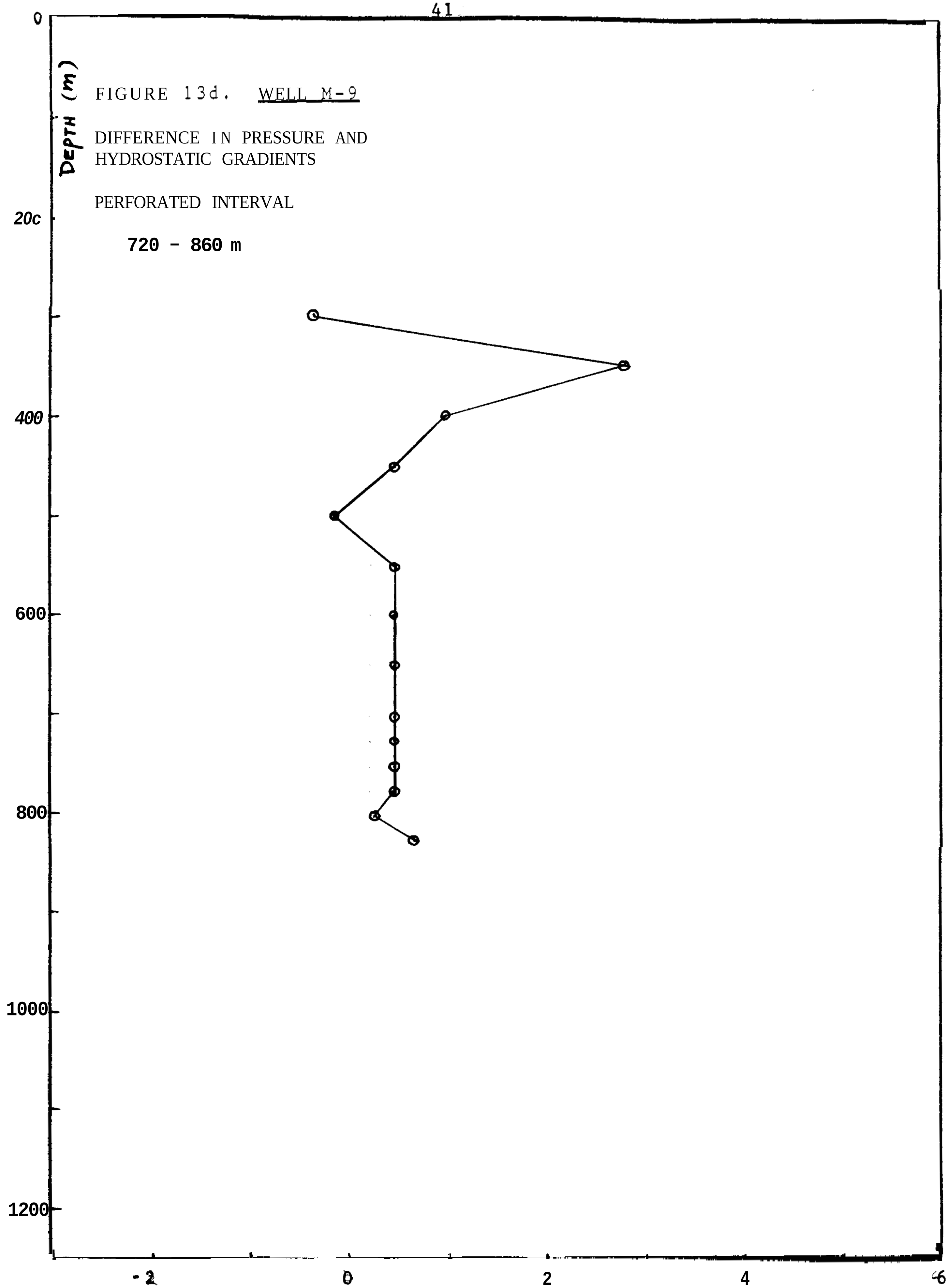


FIGURE 13c.- WELL M-9
PRESSURE GRADIENT VS DEPTH
PRESSURE GRADIENT
HYDROSTATIC GRADIENT
PERFORATED INTERVAL
720 - 860 m
DEPTH (m)
0
200
400
600
800
1000
1200
34
36
38
40
PSI/ft x 100



DEPTH (m)
FIGURE 13d. WELL M-9
DIFFERENCE IN PRESSURE AND HYDROSTATIC GRADIENTS
PERFORATED INTERVAL
720 - 860 m
0
20c
400
600
800
1000
1200
-2
0
2
4
6

M-9 / T-27

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE TEMPERATURA DE FONDO

POZO M- 9 FECHA 18 DE JUNIO DE 1977

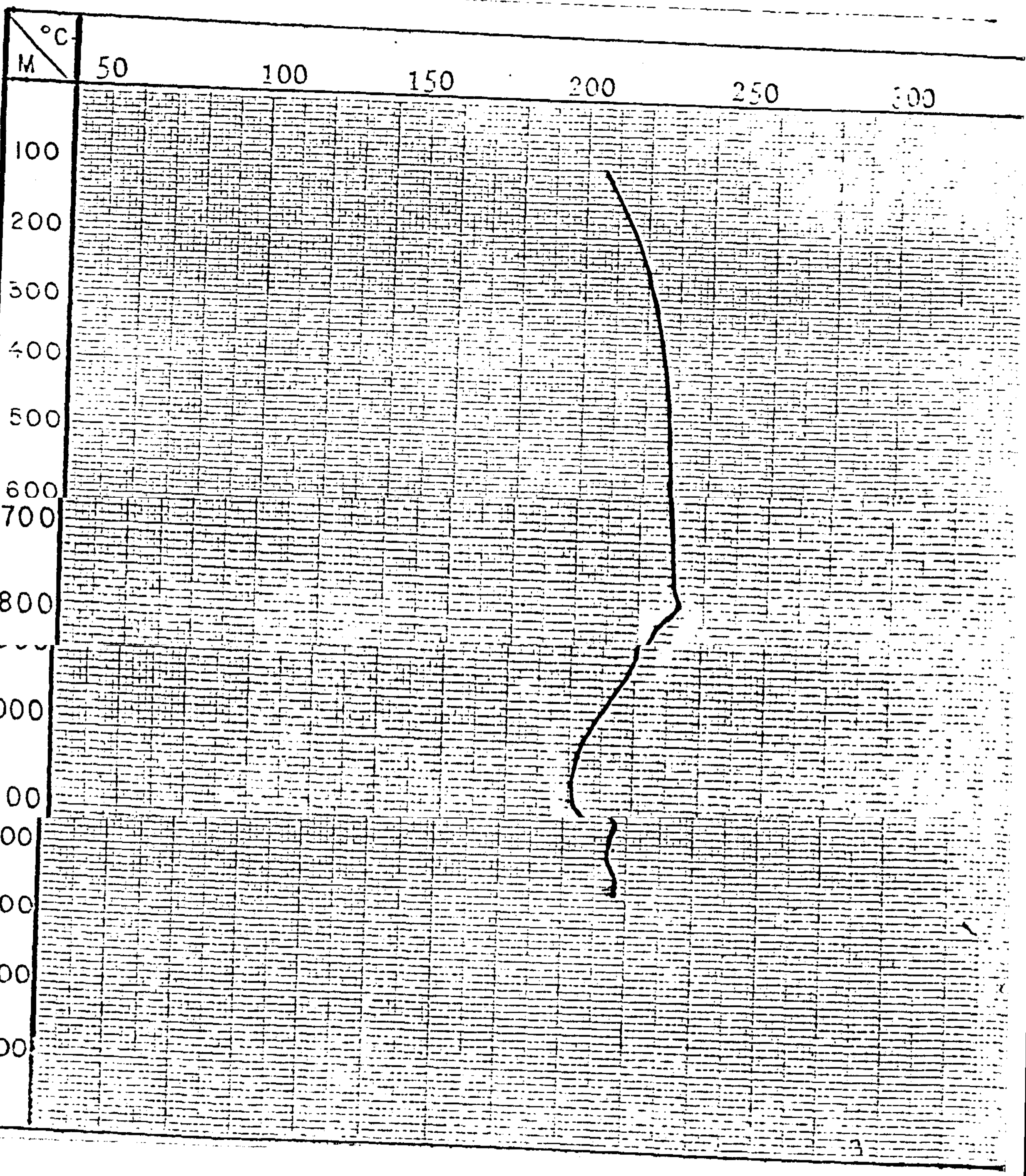
CONDICIONES EN EL POZO FLUYE POR PURGA DE 2"Ø V.R.
CALENTAMIENTO

PRESION CABEZA 13.35 Kg/cm^2 190 psig.

TEMP. MAXIMA 217°C 422°F

PROFUNDIDAD MAXIMA DEL REGISTRO 1253 mts. ELEMENTO EMPLEADO KTC-10027

PROF. M	°C	°F
100	206	402
200	217	423
300	223	433
400	226	439
500	228	443
600	229	445
700	231	447
725	231	447
750	231	447
775	233	452
800	233	434
850	222	432
900	220	428
1000	204	399
1050	201	394
1075	202	396
1100	208	406
1125	212	413
1150	216	420
1200	214	417
1225	217	422
1253	216	420



OBSERVACIONES

P-11 / M-9

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE PRESION DE FONDO

POZO M- M-9 FECHA 18 DE JUNIO DE 1977

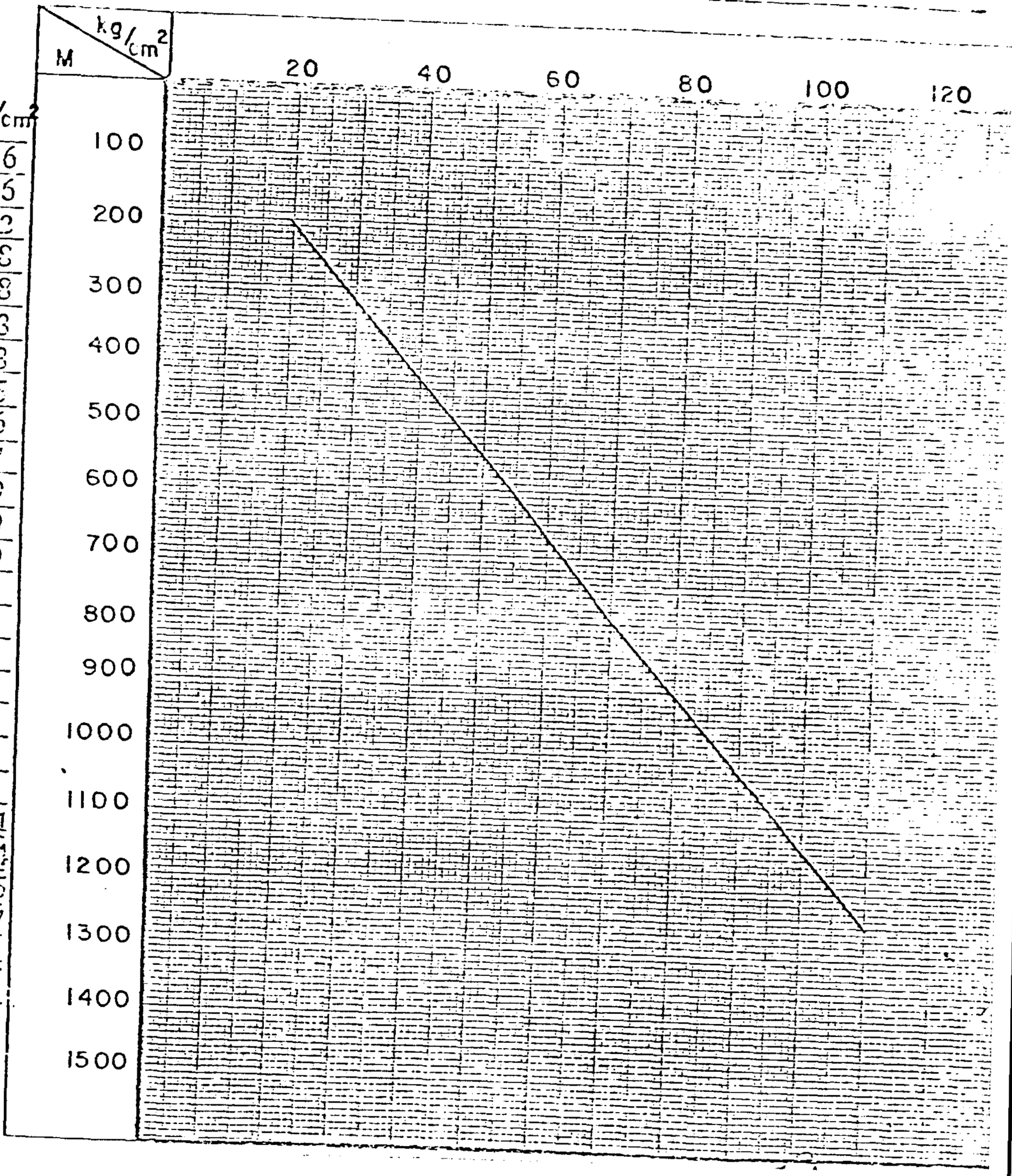
CONDICIONES EN EL POZO FLUYE POR PURGA DE 2"Ø V.R. CALENTAMIENTO

PRESION CABEZA 13.36 Kg/cm^2 190 PSI.

PRESION MAXIMA 110.2 Kg/cm^2 ELEMENTO - 7077

PROFUNDIDAD MAXIMA 1253 m.

PROFUNDIDAD M	lb/in^2	kg/cm^2
100	222	15,6
200	279	19.5
300	401	28.2
400	524	36.8
500	651	45.8
600	772	54.3
700	887	62.3
725	917	64.5
750	947	66.6
775	976	68.7
800	1008	70.9
825	1036	72.9
850	1067	75.0
900	1128	79.3
1000	1252	88.1
1025	1280	90.0
1050	1315	92.5
1075	1346	94.7
1100	1375	96.8
1125	1408	99.6
1150	1438	101.1
1175	1471	103.4
1200	1500	105.5
1225	1532	107.7
1253	1566	110.1



OBSERVACIONES

FIGURE 14b.- Pressure profile for well M-9 (June/18/1977).

Table 9.- Pressure and hydrostatic gradients taken from pressure and temperature logs run on June/18/1977. Well M-9 .

DEPTH (m)	PRESSURE GRADIENT (ΔP/ft) x 100	HYDROSTATIC GRADIENT (ΔP/ft) x 100
100	9.8	36.9
200	17.4	36.4
300	37.2	36.2
400	37.5	36.0
500	38.7	35.9
600	36.9	35.9
700	35.1	35.8
725	36.6	35.8
750	36.6	35.8
775	35.4	35.8
800	39.0	35.8
825	34.1	36.2
850	37.8	36.3
900	37.2	36.3
1000	37.8	36.9
1025	38.5	37.3
1050	42.7	37.4
1075	37.8	37.4
1100	36.6	37.2
1125	39.0	37.0
1150	36.6	36.8
1175	40.2	36.6
1200	35.4	36.8
1225	39.0	36.7
1253	37.0	36.6

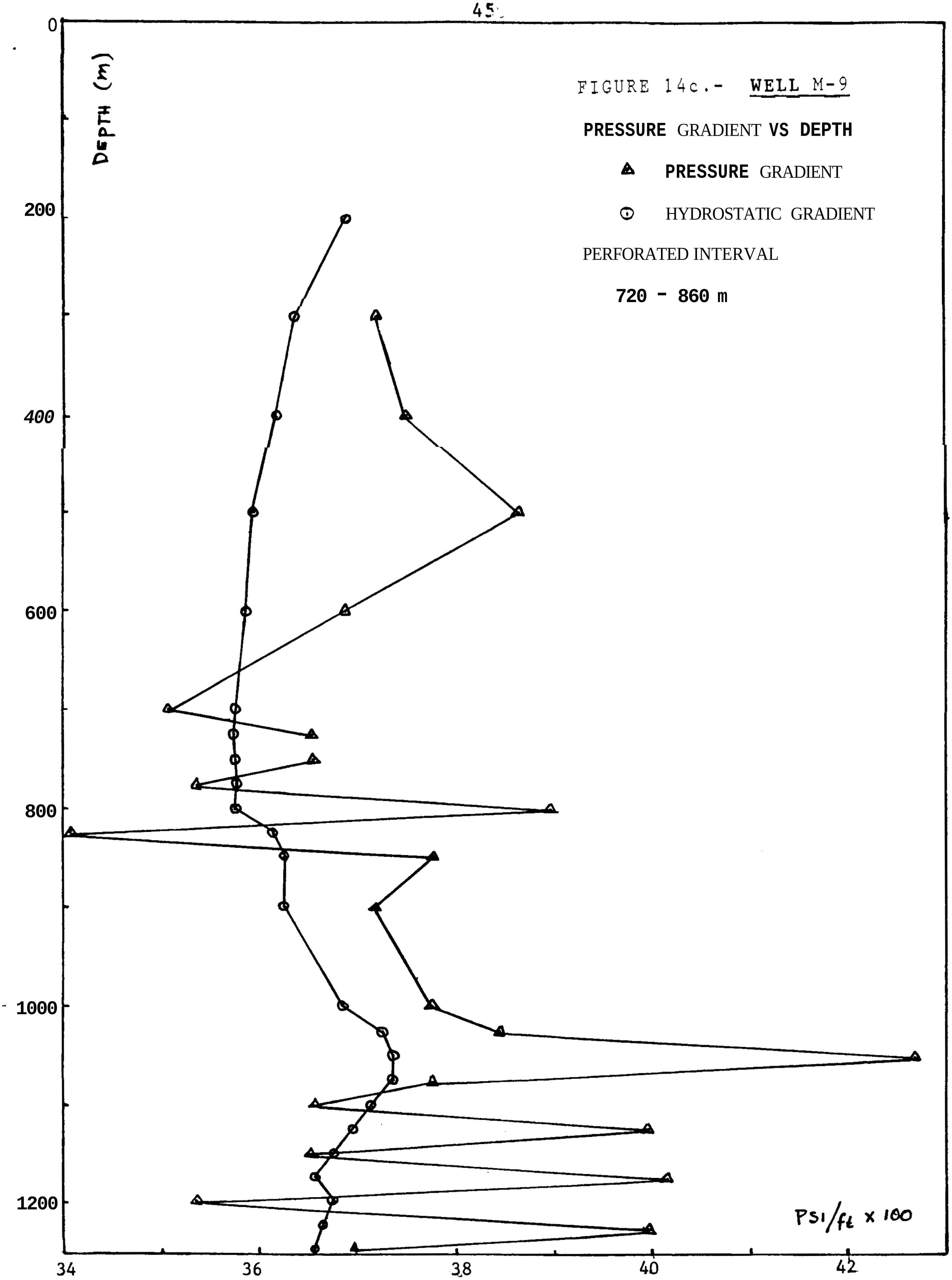


FIGURE 14c.- WELL M-9
PRESSURE GRADIENT VS DEPTH
PRESSURE GRADIENT
HYDROSTATIC GRADIENT
PERFORATED INTERVAL
720 - 860 m
DEPTH (m)
0
200
400
600
800
1000
1200
34
36
38
40
42
PSI/ft x 100

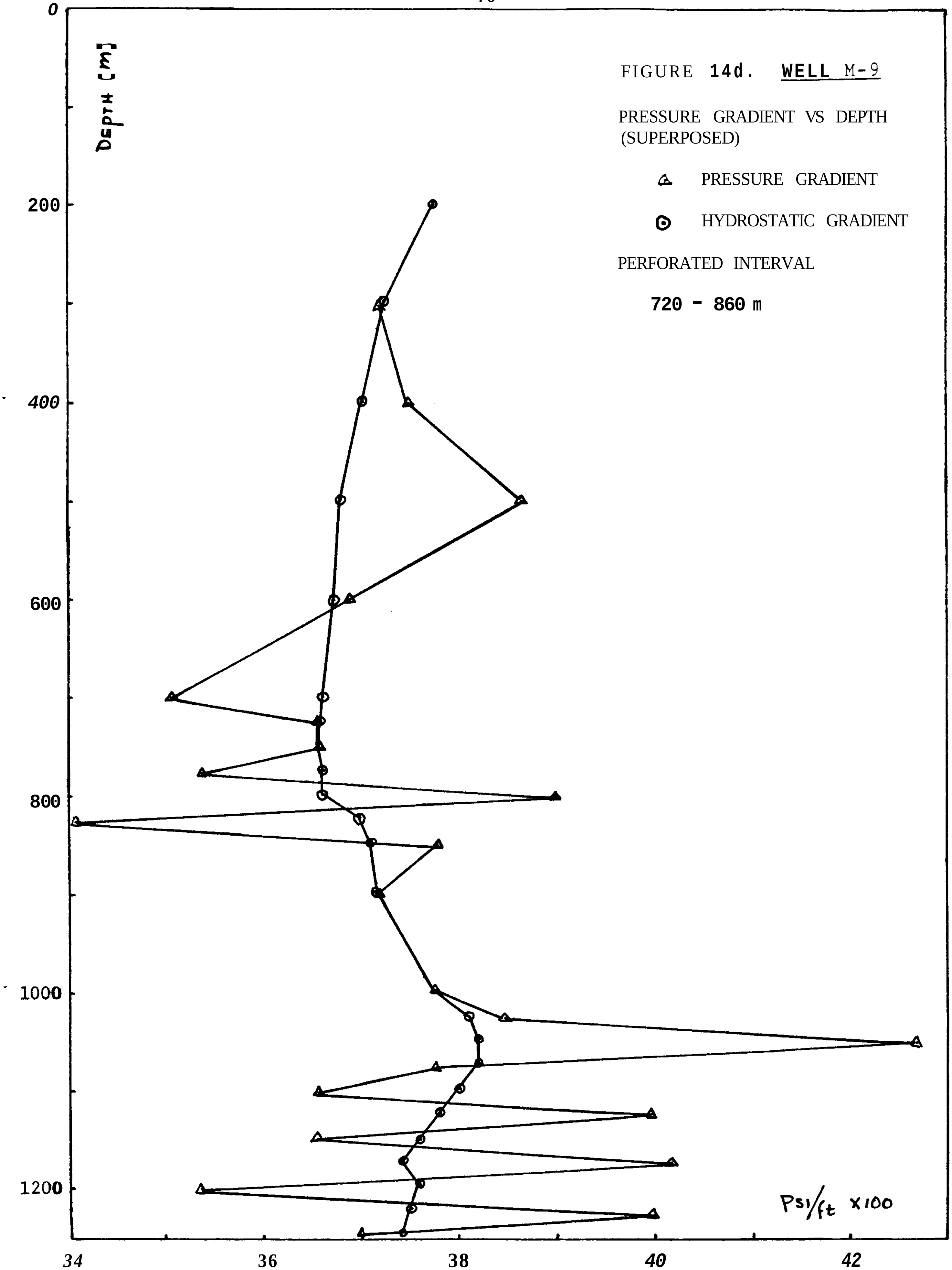


FIGURE 14d. WELL M-9
PRESSURE GRADIENT VS DEPTH (SUPERPOSED)
PRESSURE GRADIENT
HYDROSTATIC GRADIENT
PERFORATED INTERVAL
720 - 860 m
DEPTH [m]
0
200
400
600
800
1000
1200
34
36
38
40
42
Psi/ft x100

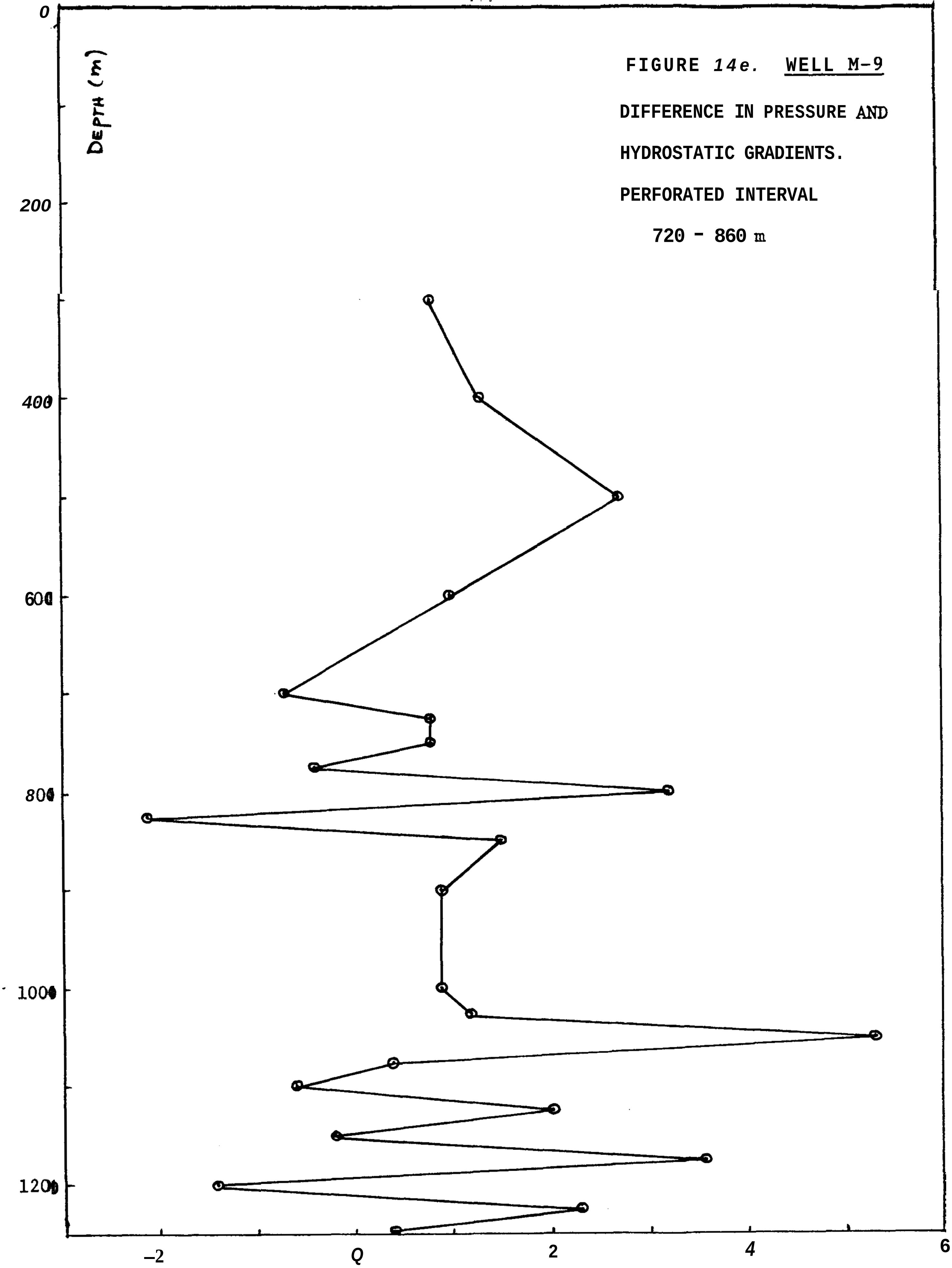


FIGURE 14e. WELL M-9

DIFFERENCE IN PRESSURE AND HYDROSTATIC GRADIENTS.

PERFORATED INTERVAL

720 - 860 m

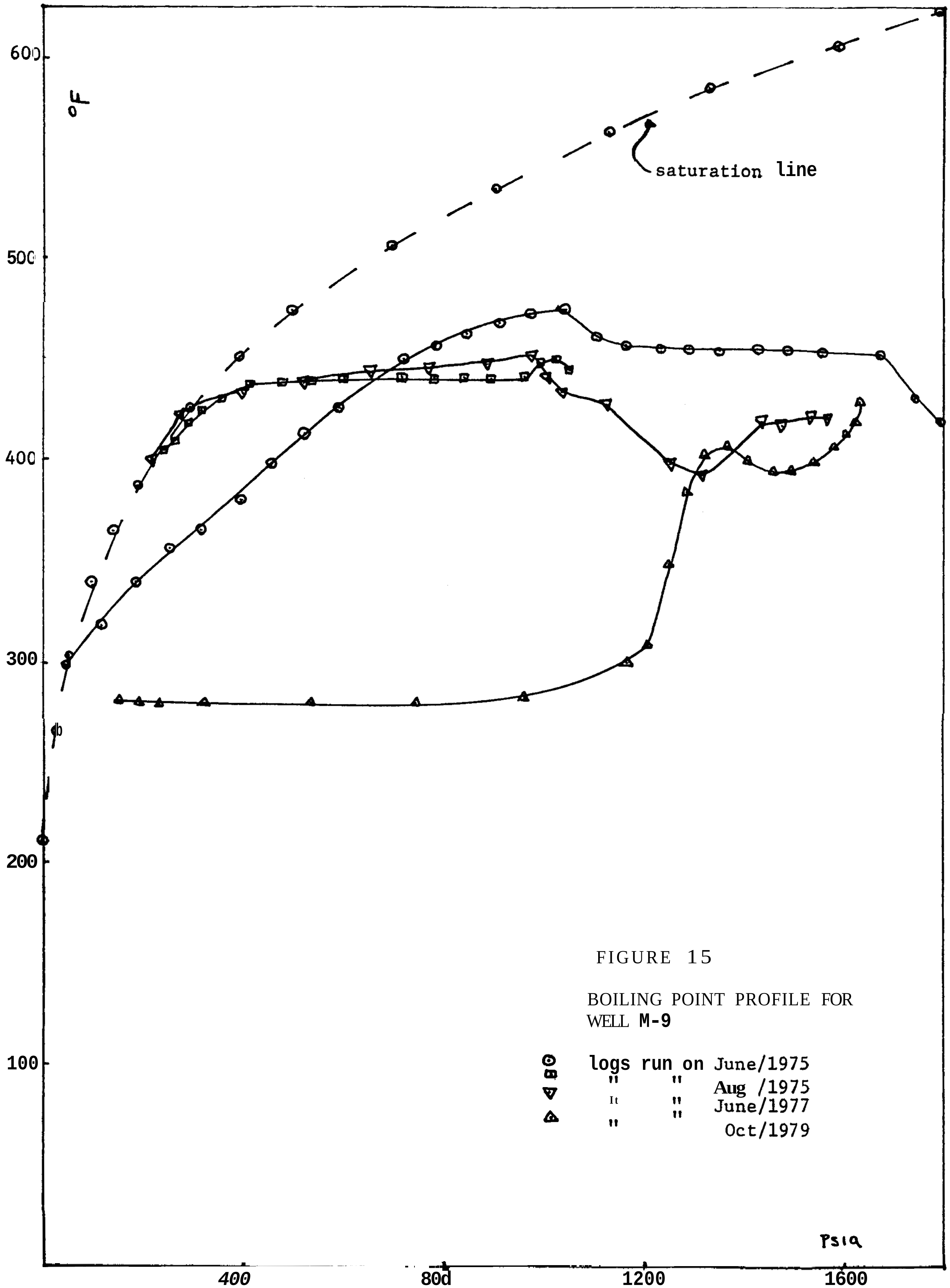


FIGURE 15

BOILING POINT PROFILE FOR WELL M-9

P-2 / M-42

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE PRESION DE FONDO

POZO M- 42 FECHA JUNIO 3 DE 1975.

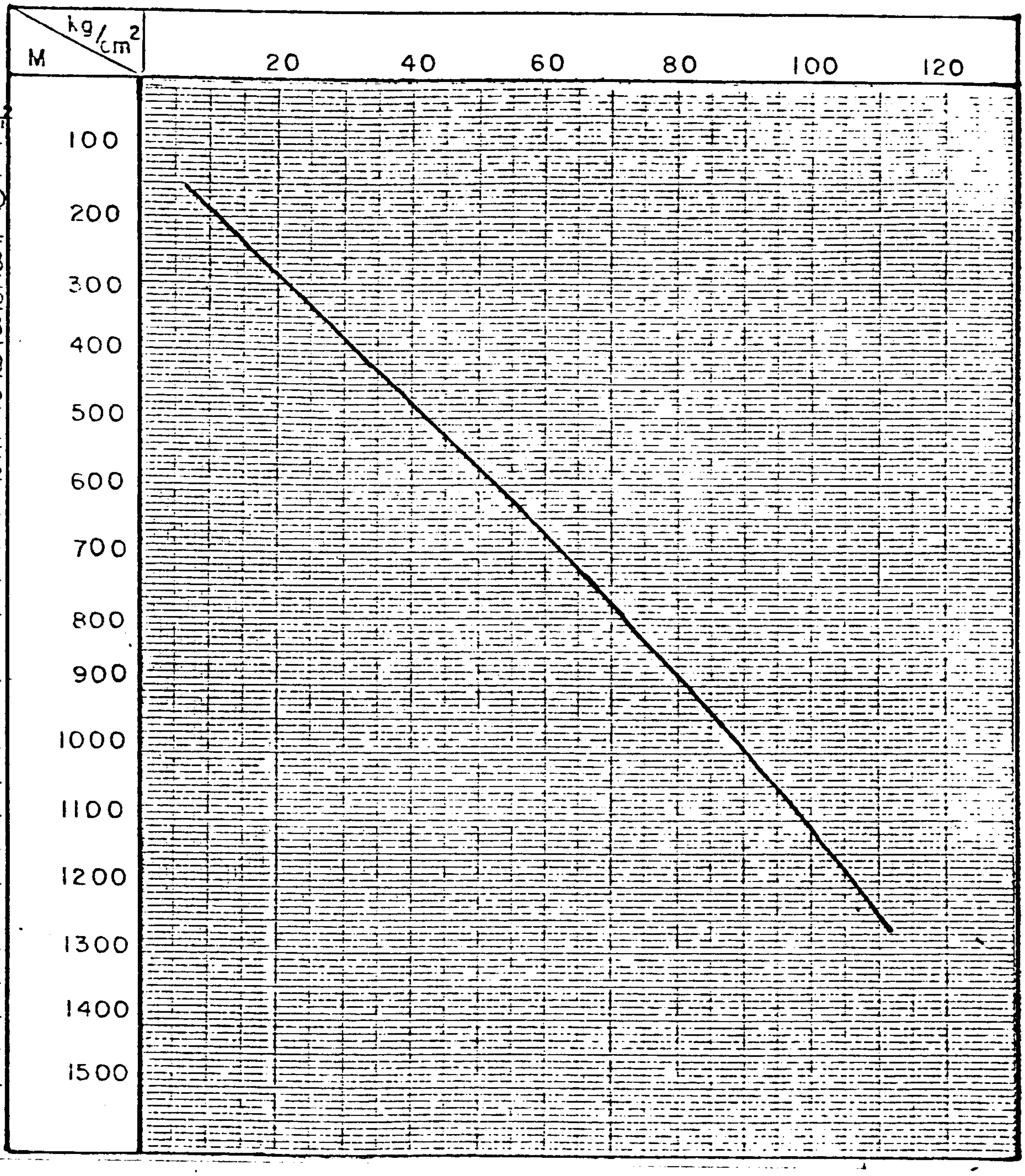
CONDICIONES EN EL POZO CERRADO, SIN FLUIR, CON AGUA EN REPOSO DESDE EL 27 DE AGOSTO DE 1973.- ESPEJO DE AGUA A 82.22 m.

PRESION CABEZA CERO

PRESION MAXIMA 1593.5 PSI (112.0 Kg/cm²) ELEMENTO KP.-9126

PROFUNDIDAD MAXIMA DEL REGISTRO 1263 m.

PROFUNDIDAD M	lb/in²	kg/cm²
50	–	–
100	14.4	1.0
150	86.2	6.1
200	161	11.3
250	235	16.5
300	311	21.8
350	384	26.9
400	458	32.2
450	533	37.4
500	605	42.6
550	678	47.7
600	751	52.8
650	823	57.8
700	895	63.0
750	964	67.7
800	1025	72.0
850	1089	75.5
900	1156	81.3
950	1231	86.5
1000	1290	90.7
1050	1340	94.8
1100	1408	99.0
1150	1464	103
1200	1522	107
1250	1570	111
1263	1594	112



OBSERVACIONES

FIGURE 16a.- Pressure profile for well *M-42* (June/1975).

T-4 / M-42

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE TEMPERATURA DE FONDO

POZO M- 42 FECHA 14 DE ENERO DE 1975.

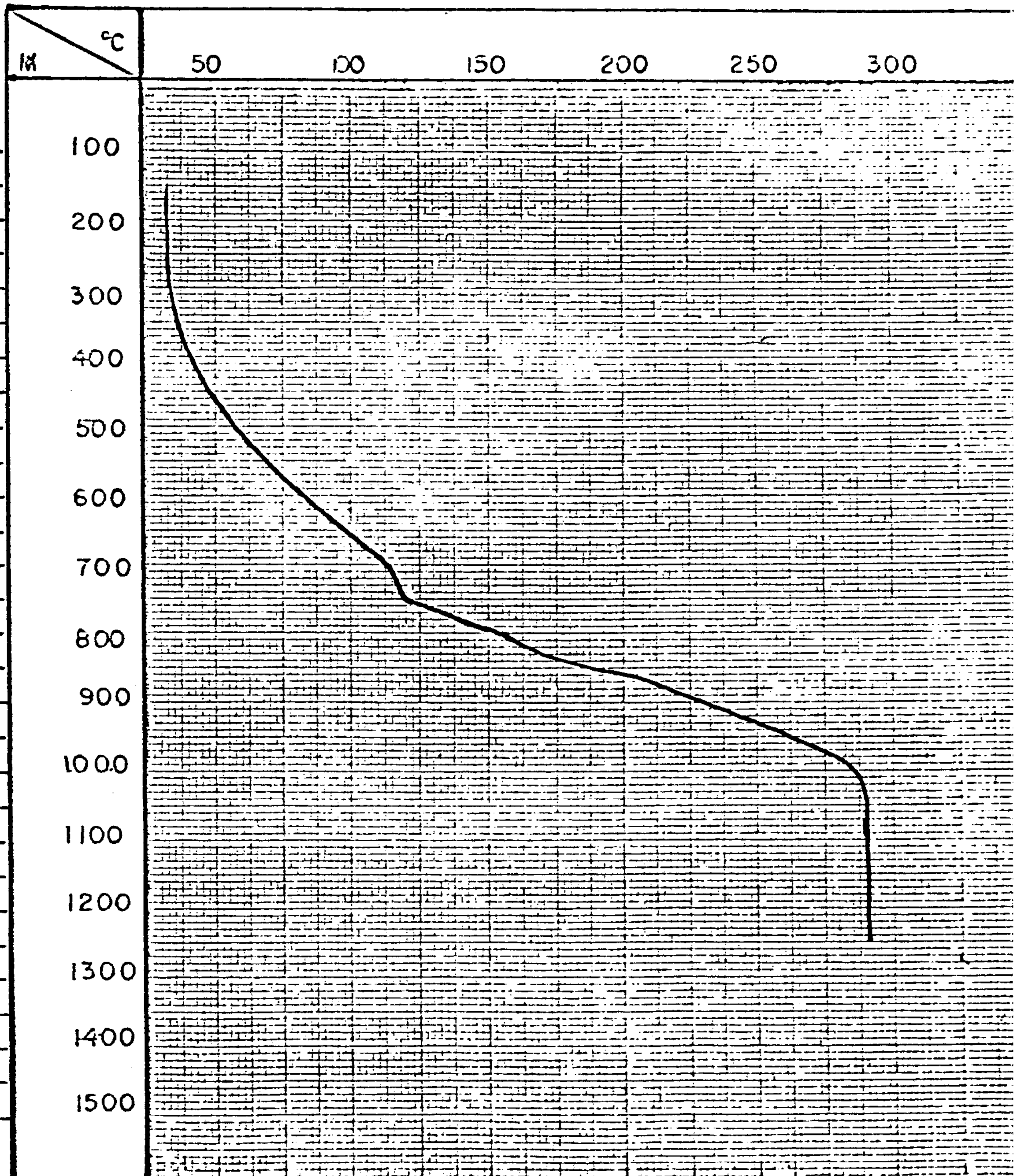
CONDICIONES EN EL POZO SIN FLUIR CERRADO, CON AGUA EN REPOSO DESDE EL 27 DE AGOSTO DE 1973.

PRESION CABEZA (P.S.I.) 0 (CERO)

TEMP. MAXIMA REBASO EL RANGO DEL ELEMENTO.

PROFUNDIDAD MAXIMA 1250 MTS. ELEMENTO EMPLEADO KT.B 100/1.

PROFUNDIDAD M	°C	°F
50	–	–
100	–	–
150	32	90
200	32	91
250	33	91
300	34	93
350	36	97
400	41	106
450	48	118
500	56	135
550	69	156
600	83	181
650	98	208
700	114	237
750	120	248
800	157	314



OBSERVACIONES

FIGURE 16b.- Temperature profile for well *M-42* (Jan./1975).

Table 10.- Pressure and hydrostatic gradients taken from pressure and temperature logs run on Jan/14/1974. Well M-42 .

DEPTH (m)	PRESSURE GRADIENT (ΔP/ft) x 100	HYDROSTATIC GRADIENT (ΔP/ft) x 100
200	45.6	43.1
250	45.1	43.1
300	46.3	43.1
350	44.5	43.1
400	45.1	43.0
450	45.7	42.9
500	43.9	42.7
550	44.5	42.4
600	44.5	42.1
650	43.9	41.6
700	43.9	41.4
750	42.1	40.9
800	37.2	40.2
850	39.0	38.7
900	40.8	36.4
950	45.7	34.4
1000	36.0	32.5
1050	36.0	31.9
1100	36.0	31.9
1150	34.1	31.9
1200	35.4	31.9
1250	34.7	31.8
1263	35.2	31.8

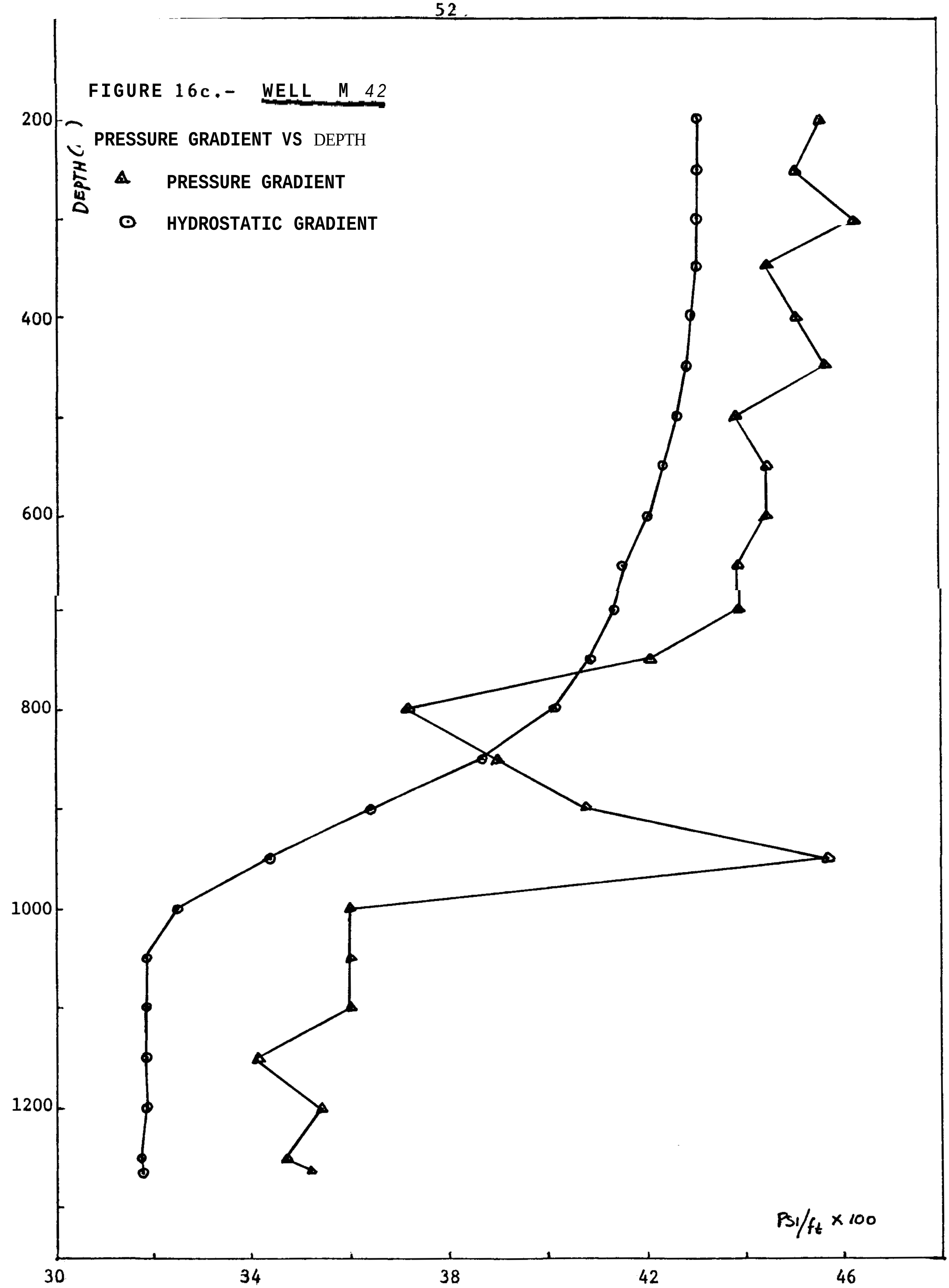
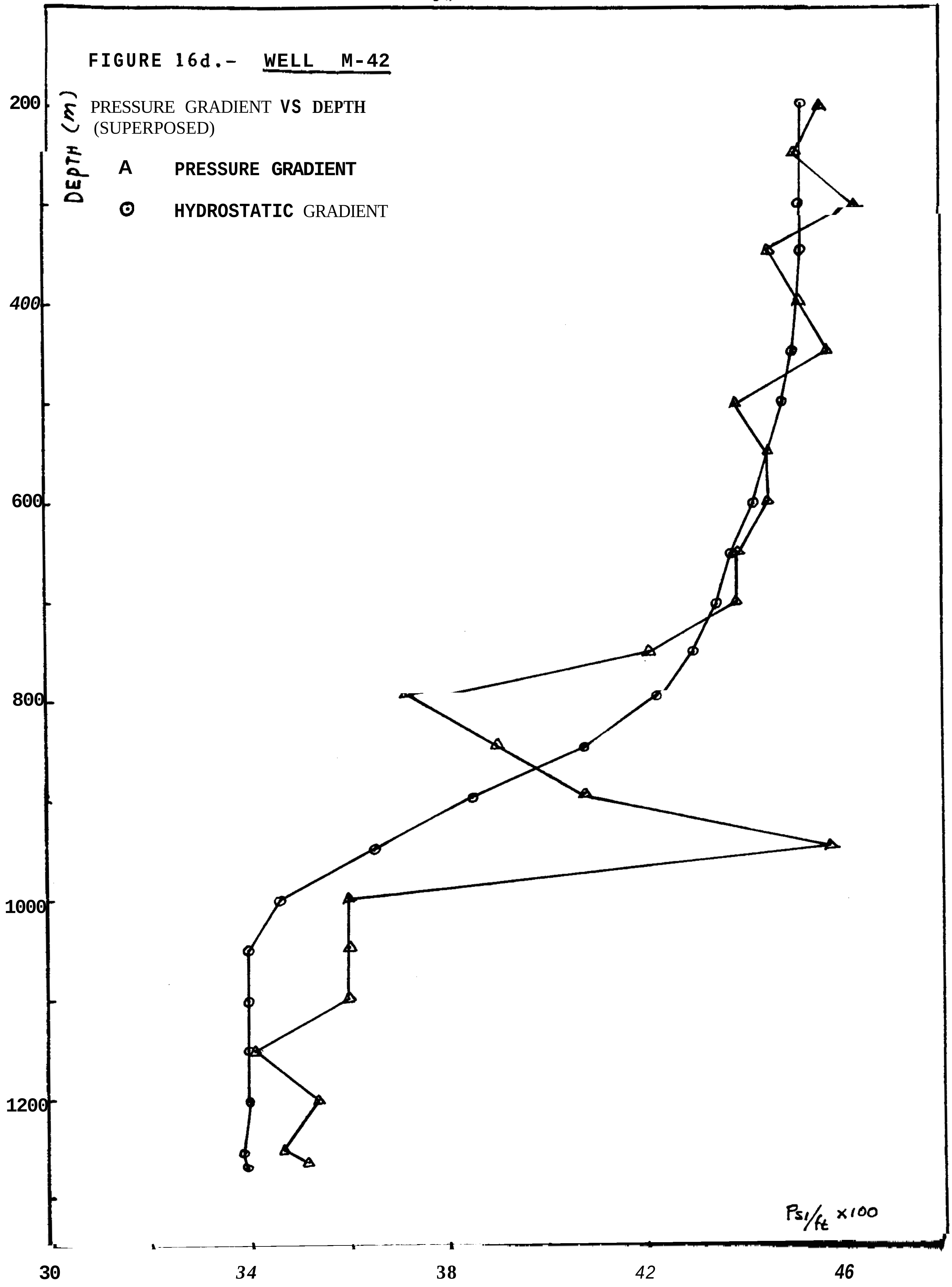


FIGURE 16c.- WELL M 42
PRESSURE GRADIENT VS DEPTH
PRESSURE GRADIENT
HYDROSTATIC GRADIENT
DEPTH
200
400
600
800
1000
1200
30
34
38
42
46
PSI/ft x 100

FIGURE 16d.- WELL M-42



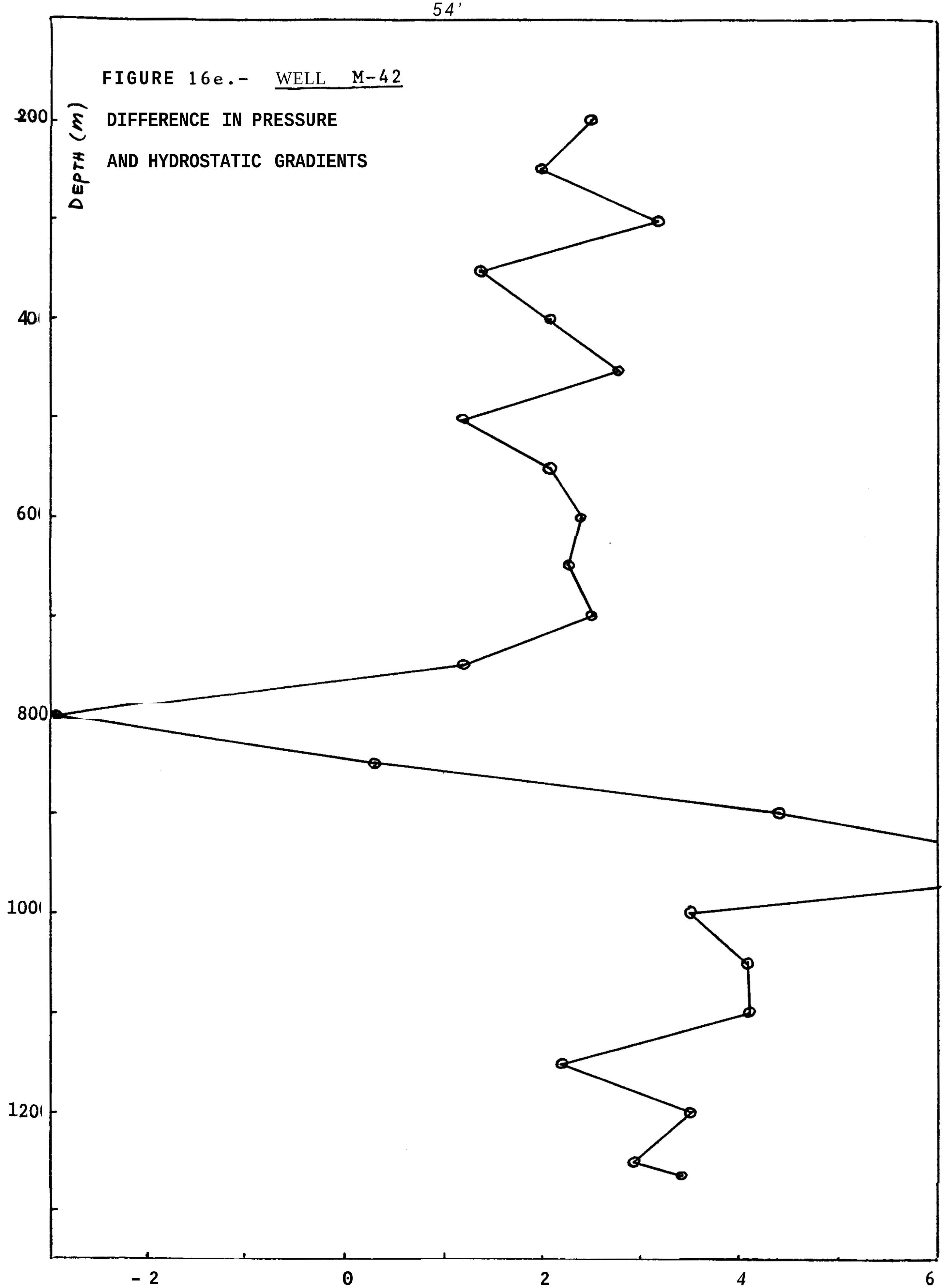


FIGURE 16e.- WELL M-42
DIFFERENCE IN PRESSURE
AND HYDROSTATIC GRADIENTS
DEPTH (m)
200
400
600
800
1000
1200
- 2
0
2
4
6

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE PRESION DE FONDO

POZO M-42 FECHA MAYO 13 DE 1976

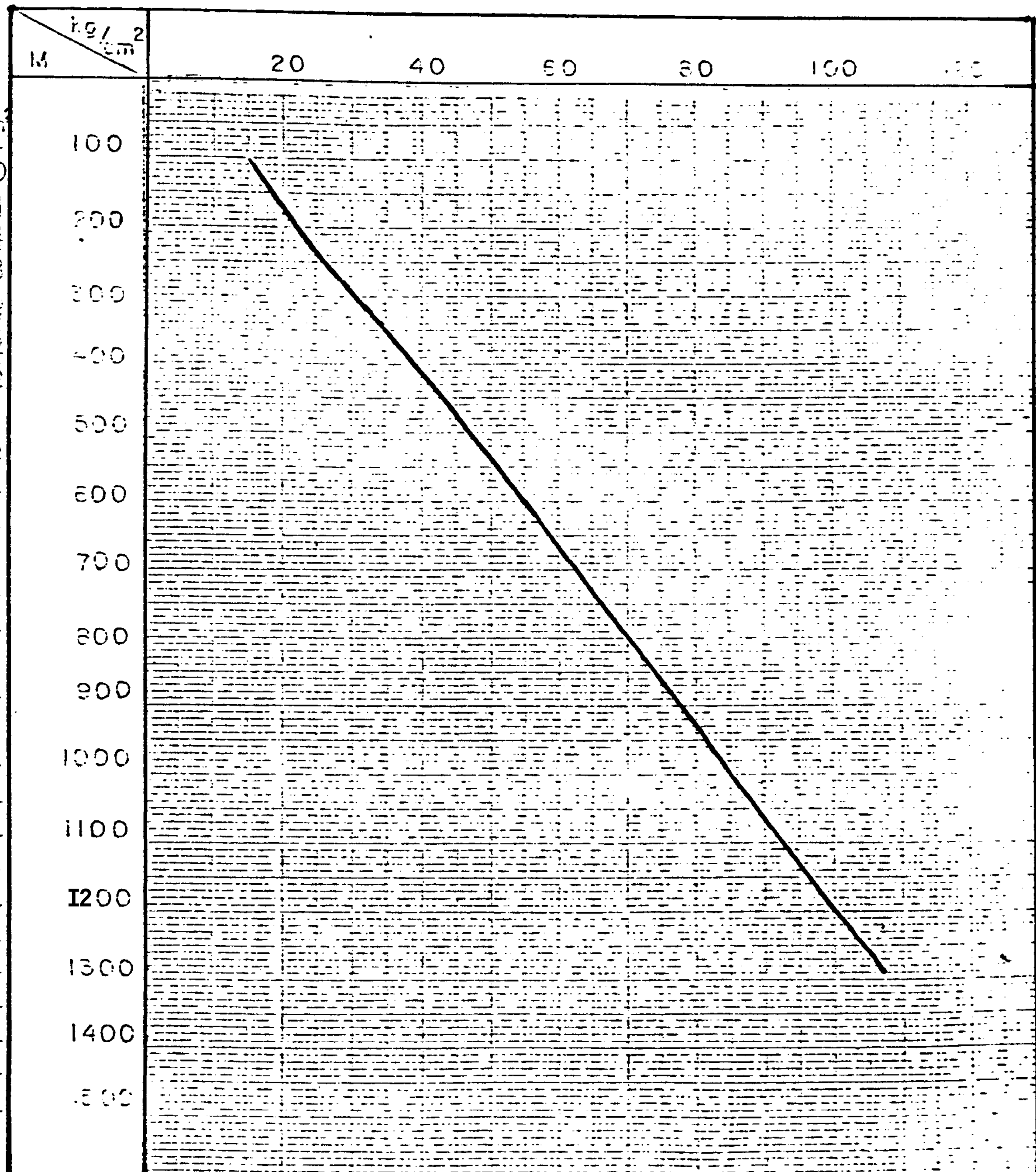
CONDICIONES EN EL POZO FLUYE POR PURGA DE (1"Ø) 25 mm. CON VALVULA REGULADA POZO EN CALENTAMIENTO.

PRESION CABEZA (142 PSI) 10.0 Kg/cm²

PRESION MAXIMA (1524 PSI) 107.1 Kg/cm² ELEMENTO Y RELOJ No. 8122

PROFUNDIDAD MAXIMA 1291 m.

PROFUNDIDAD M	lb/in²	kg/cm²
100	213	15.0
200	315	22.1
300	432	30.4
400	552	38.8
500	667	46.9
600	780	54.8
700	889	62.5
800	997	70.1
900	1103	77.5
1000	1211	85.1
1050	1265	88.9
1100	1319	92.7
1150	1371	96.4
1200	1425	100
1250	1480	104
1292	1524	107



OBSERVACIONES

FIGURE 17a.- Pressure profile for well M-42 (May/13/1976).

COMISION FEDERAL DE ELECTRICIDAD

OBRAS GEOTERMICAS CAMPO DE CERRO PRIETO

REGISTROS DE TEMPERATURA DE FONDO

POZO M- 42 FECHA MAYO 13 DE 1976

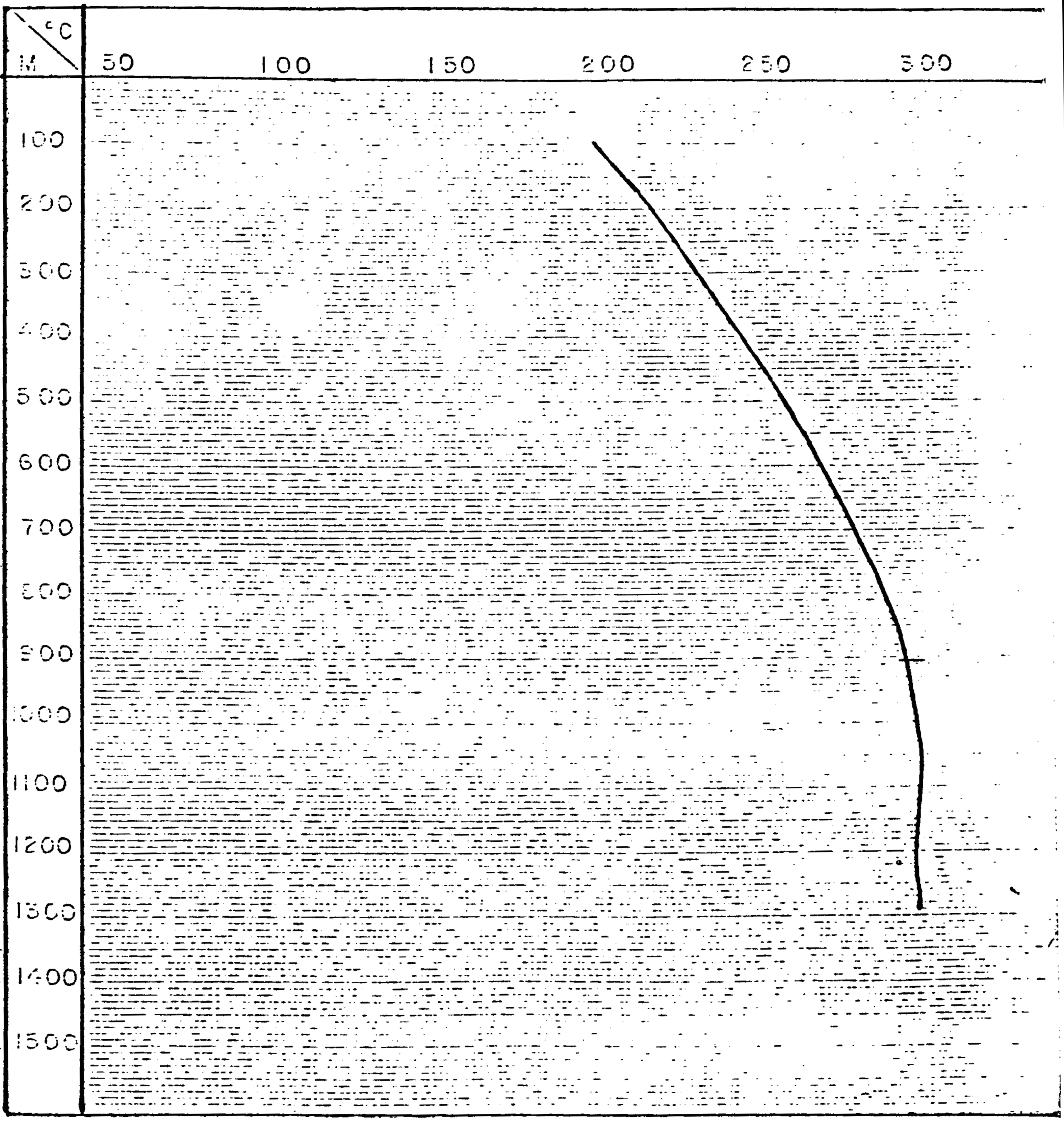
CONDICIONES EN EL POZO FLUYE POR PURGA DE (1"Ø) 25 mm. CON VALVULA [illegible] POZO EN CALENTAMIENTO.

PRESION CABEZA (142 PSI) 10.0 Kg/cm²

TEMP. MAXIMA (567°F) 297°C ELEMENTO EMPLEADO [illegible]

PROFUNDIDAD MAXIMA DEL REGISTRO 1292 m.

PROF. M	°C	°F
100	195	383
200	214	418
300	228	443
400	242	468
500	255	491
600	266	511
700	277	530
[illegible]	286	546
[illegible]	291	556
1000	296	565
1050	297	567
1100	297	566
1150	296	564
1200	295	563
1250	296	564
1292	296	564



OBSERVACIONES

FIGURE 17b.- Temperature profile for well *M-42* (May/13/1976).

Table 11.- Pressure and hydrostatic gradients taken from pressure and temperature logs run on May/13/1976. Well M-42 .

DEPTH (m)	PRESSURE GRADIENT (P/ft) 100	HYDROSTATIC GRADIENT (P/ft) 100
200	31.1	37.2
300	35.7	36.3
400	36.6	35.6
500	35.1	34.7
600	34.4	33.9
700	33.2	33.2
800	32.9	32.5
900	32.3	31.8
1000	32,9	31.4
1050	32.9	31.2
1100	32.9	31.3
1150	31.7	31.2
1200	32.9	31.3
1250	33.5	31.3
1292	31.9	31.3

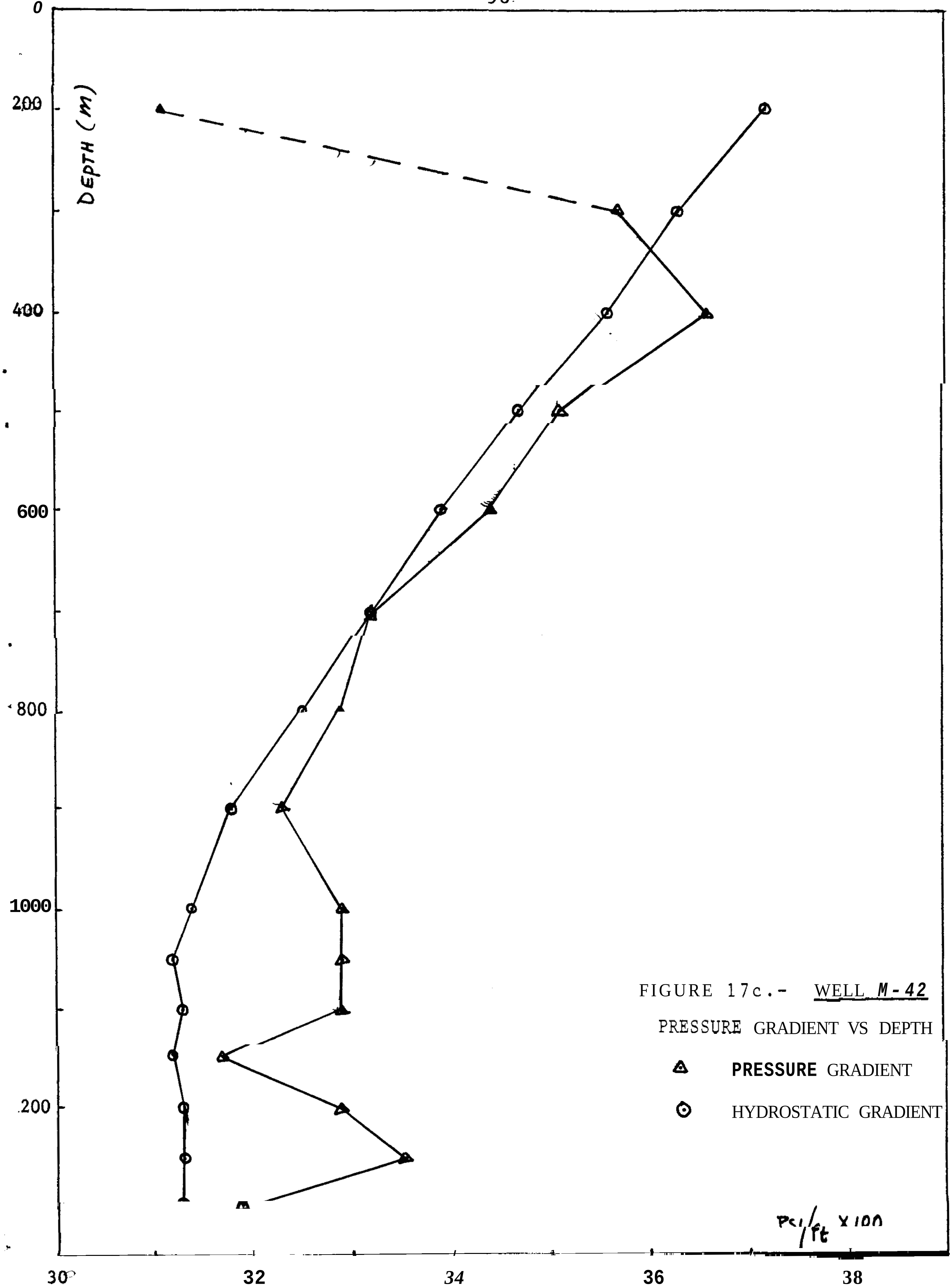


FIGURE 17c.- WELL M-42

PRESSURE GRADIENT VS DEPTH

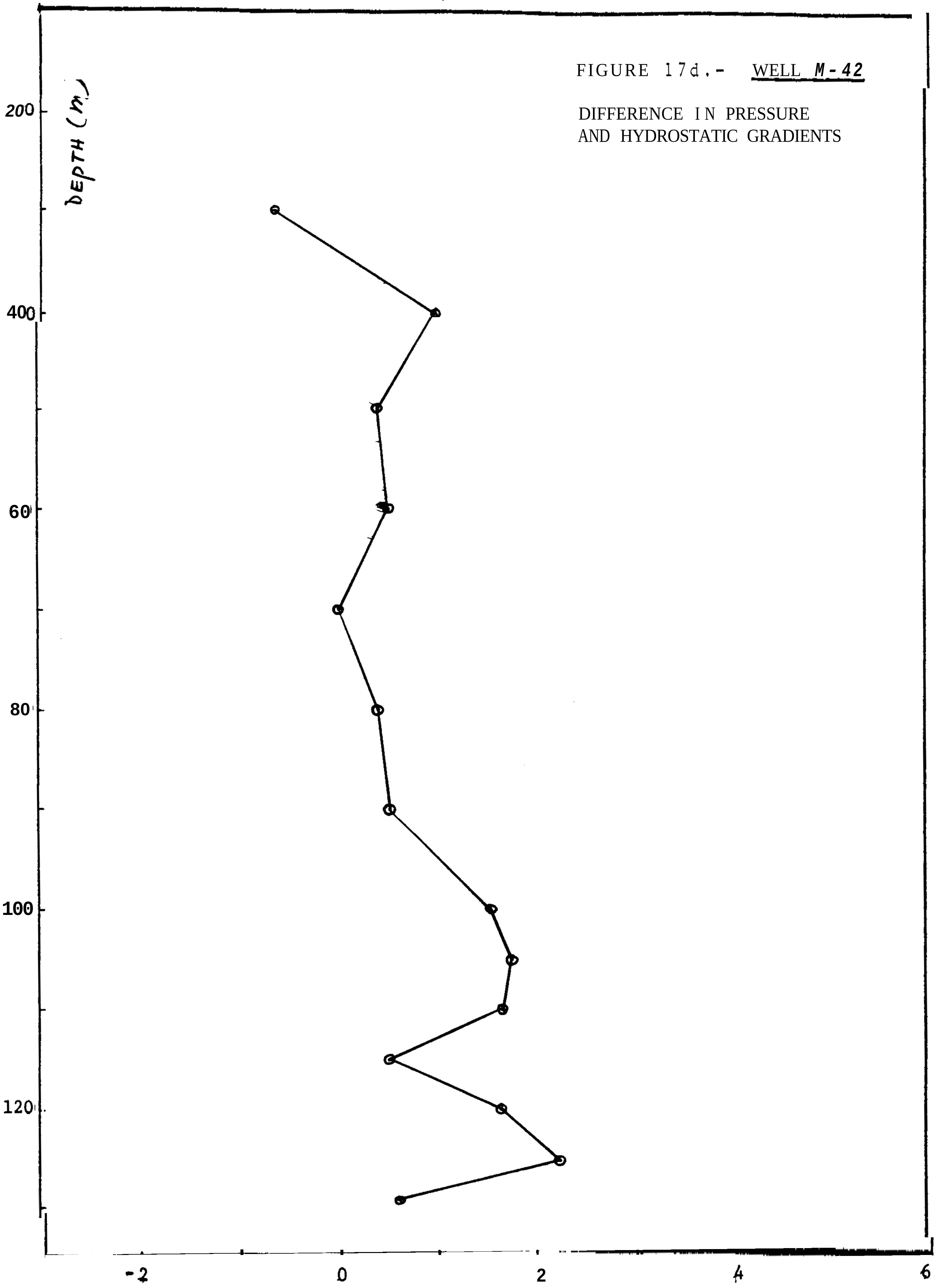


FIGURE 17d.- WELL *M-42*

DIFFERENCE IN PRESSURE AND HYDROSTATIC GRADIENTS

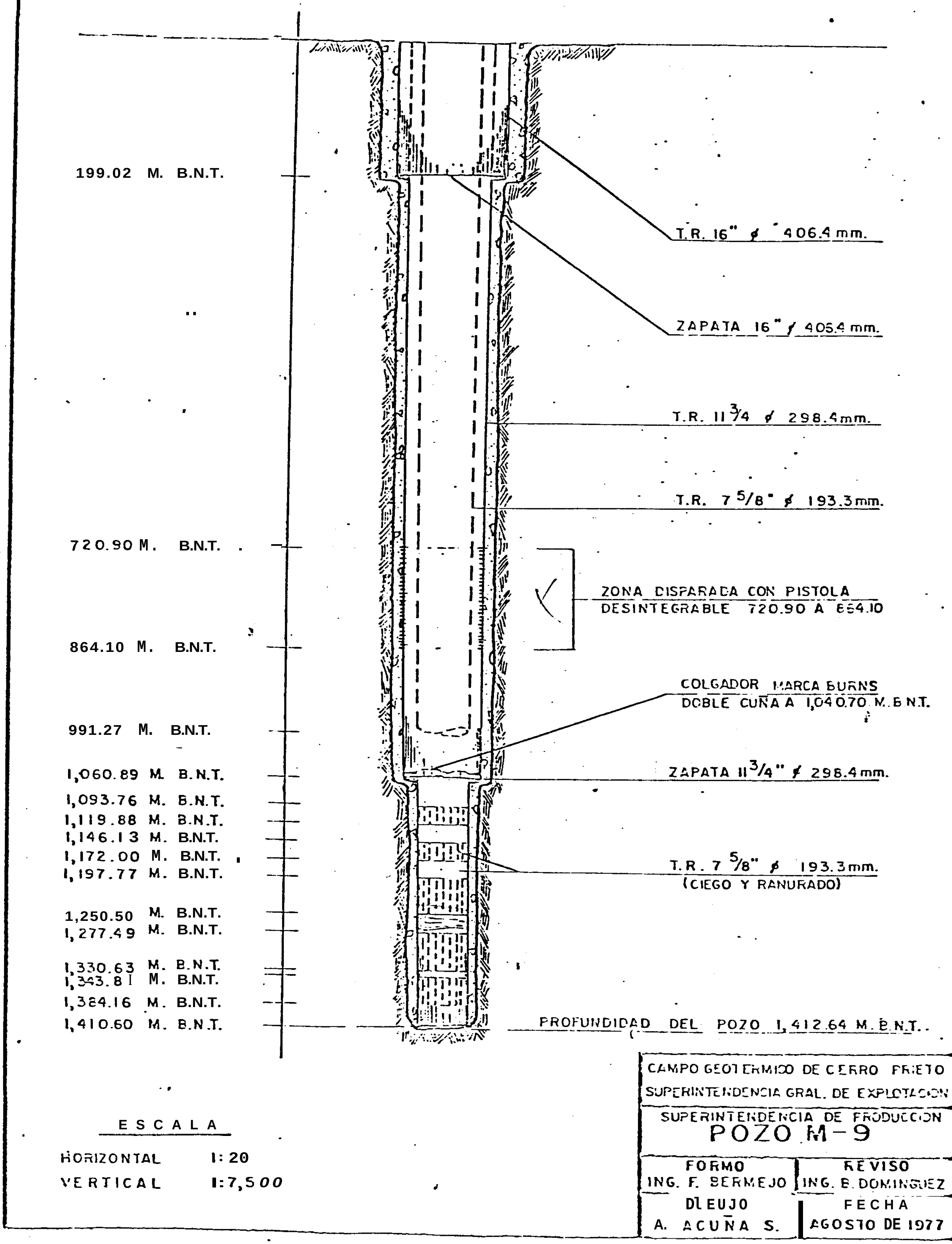


FIGURE 18.- Well completion scheme for well M-9 ,

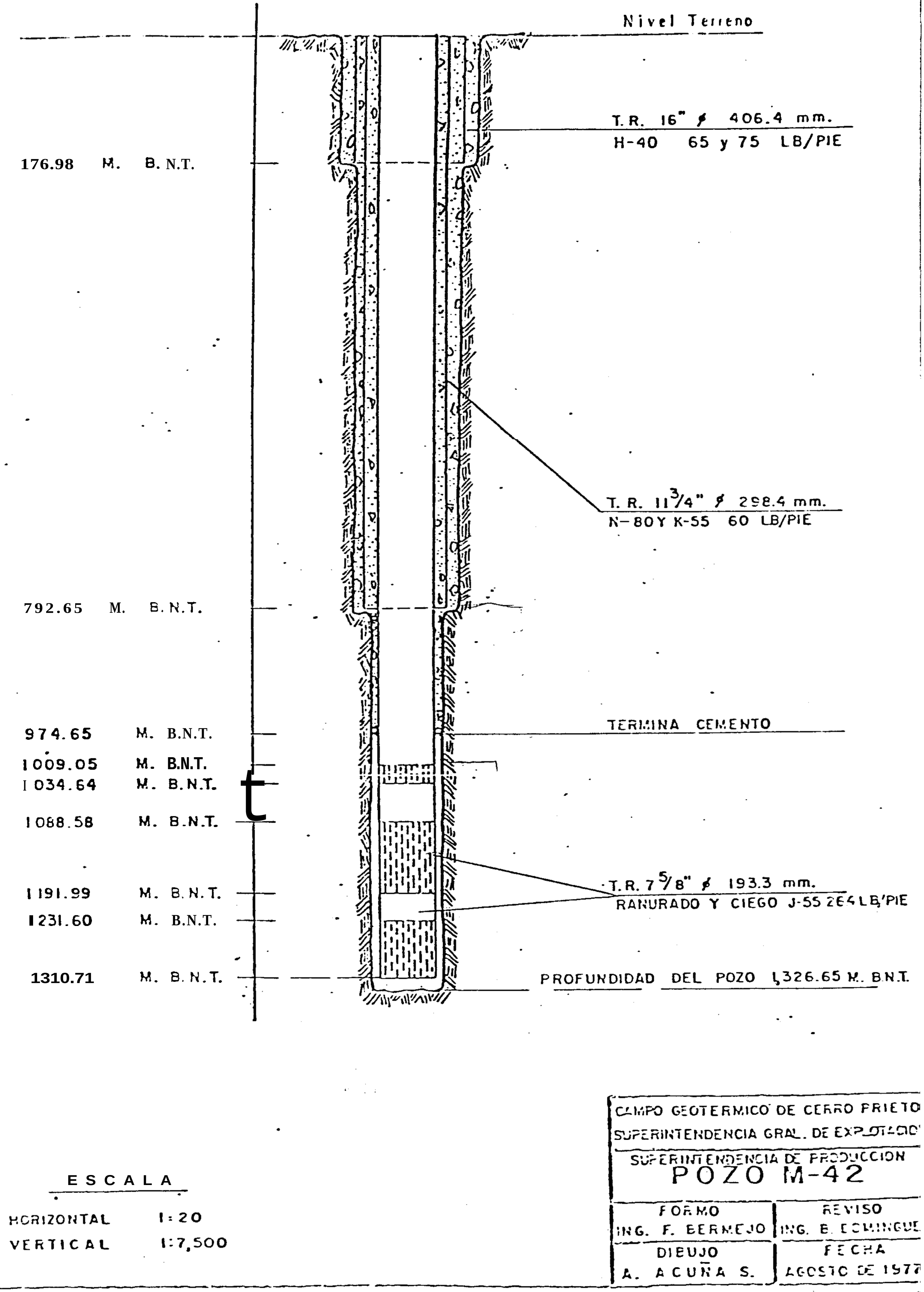


FIGURE 19.- Well completion scheme for well *M-42* .