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RKER.83.133

INVESTIGATION OF CORES FROM WELL 31/2-6, NORWAY

Petrophysical properties of core samples

by

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Sponsor: Shell Forus Code: 774.20.100

Investigation 9.25.234

KONINKLIJKE/SHELL EXPLORATIE EN PRODUKTIE LABORATORIUM

RIJSWIJK, THE NETHERLANDS

(Shell Research B.V.)

CONTENTS

KEYWORDS

Well 31/2-6, Norway, porosity, formation-resistivity factor, in-situ porosity, cation-exchange capacity, mercury capillary pressure, compressibility, cementation factor, pore-size distribution.

The clay-corrected formation-resistivity factors and cementation factors as given in Table VI were calculated using actually measured Qv values. The FRF^*/ϕ relation was found to be

$$FRF^* = 1.00\ \phi^{-1.18} \text{ (at 200 kg/cm}^2\text{, isostatic stress)}$$

(r = 0.996).

The Rw of the artificial formation water used was approx. 0.122 ohm metre at 22°C.

The above FRF/FRF^* results differ considerably from those found for other 31/2 wells (e.g. 31/2-1, resulting $m^* = 2.01$ and 31/2-4, resulting $m^* = 1.69$).

As already mentioned, the poor condition of the core material did, however, not allow more measurements to be carried out. Moreover, for the same reason, measurements on the three samples could not be repeated. Therefore, although no obvious irregularities could be found in the measurements on the three samples, we are of opinion, that results should be considered with reserve.

Table II gives porosities calculated from those measured at isostatic stress (Table VII) by conversion according to Teeuw[1], assuming a Poisson ratio of 0.3. The fractional change in pore volume as a function of isostatic stress is given in Table III. Pore compressibility as a function of uniaxial stress is given in Table IV.

Mercury capillary-pressure measurements were carried out according to Shell Method Series 2165-1 in an automatic pore-injectivity apparatus (Autopore 9200). Owing to the low degree of cementation between the grains of the samples, cleaning with various solvents proved to be impossible. Hence, the frozen samples were only dried in a vacuum oven for 4 hours at 100°C, after which the capillary-pressure curves were determined. The porosity values in the curve plots were calculated on the assumption that at the highest pressure applied (60 000 psia) the pore volume was completely filled with mercury. Estimated permeabilities as given in the figures were derived by a statistical method from the shape of the capillary-pressure curves when plotted as log pressure versus log mercury saturation (% Vb).

However, for plotting of the mercury/air capillary-pressure curves it is essential to establish the packing correction for each sample. Unfortunately, owing to the rather poor condition of the samples, determination of the packing correction could not be carried out accurately. As a result, the degree of accuracy of the curve plots is less than usual and explains the missing (estimated) permeability results in Table VIII.

Pore-size distributions were determined by mercury injection, assuming 480 dynes per cm for the surface tension and 140^{o} for the contact angle of the air/mercury system used.

The results are given in Tables I - VIII and Figs 1 - 23.

<u>REFERENCE</u>

1. Teeuw, D., Prediction of formation compaction from laboratory compressibility data.
SPE Journal, September 1971, pp. 263-271.

[kg-force/cm²] * 0,980665 = [BAR]

OB/

OK TABLE I - Formation-Resistivity Factor as a Function of Isostatic Stress (First Loading Cycle) of Core Samples from Well 31/2-6

Sample no.	Depth (m.)	Porosity, % by (atm.) POR	Formation-resistivity factor, at (kg/cm**2) /PNC /PF H					m-factor, at (kg/cm**2) M
			50	100	150	200	250	200
✓ 2.SHELL	1538.00	22.26	5.9	6.5	7.2	7.714	8.2	1.11
✓ 3.SHELL	1552.10	35.53	2.7	3.0	3.4	3.815	4.2	1.06
✓ 5.SHELL	1580.10	24.53	6.0	6.3	6.5	~~6.7~~ 6.664	6.9	1.26

OK 60

Rw approximately: 0.122 ohm metres at 22 degrees C.

Remarks:-For calculation of the m-factor, in-situ porosity under isostatic loading conditions was used.

-For the samples given, the FRF/in-situ porosity relation may be expressed by FRF = 1.00*PHI**-1.15 [r for log(FRF)/log(PHI) = 0.9953]

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TABLE II - Porosity at Uniaxial Stress * (First Loading Cycle) of Core Samples from Well 31/2-6

Sample no.	Depth (m.)	VPorosity, % bv (atm.)	Porosity (% bv) at (kg/cm**2, Uniaxial Stress)				
			50	100	150	200	250
2	1538.00	√ 22.26	20.90	19.90	19.13	18.50	17.93
3	1552.10	√ 35.53	34.22	33.12	32.12	31.16	30.24
5	1580.10	√ 24.53	24.13	23.73	23.39	23.11	22.86

* The measurements were carried out under isostatic stress conditions (first loading cycle). For conversion to uniaxial stress conditions, a Poisson ratio of 0.30 was assumed.

TABLE III - Fractional Change in Pore Volume as a Function of Isostatic Stress (First Loading Cycle) of Core Samples from Well 31/2-6

Sample no.	Depth (m.)	Porosity, % bv (atm.)	DVp/Vpo at (kg/cm**2) 50	100	150	200	250
2	1538.00	22.26	.12479	.21360	.28029	.33448	.38289
3	1552.10	35.53	.09077	.16399	.22857	.28891	.34494
5	1580.10	24.53	.03478	.06904	.09814	.12186	.14301

TABLE IV - Pore Compressibility as a Function of Uniaxial Stress* (First Loading Cycle) of Core Samples from Well 31/2-6

Sample no.	Depth m.	Porosity, % bv (atm)	Pore Compressibility x10**4/kg/cm* at Uniaxial Stress of (kg/cm**2)				
			25	75	125	175	225
2	1538.00	22.26	16.1	12.3	9.8	8.3	7.7
3	1552.10	35.53	11.6	9.9	9.1	8.9	8.6
5	1580.10	24.53	4.4	4.4	3.8	3.2	2.9

* The measurements were carried out under isostatic stress conditions (first loading cycle). For conversion to uniaxial stress conditions, a Poisson ratio of 0.30 was assumed.

TABLE V   Cation-Exchange Capacity of Core Samples from Well 31/2-6

Sample, No.	Depth, (m.)	Porosity, % bv (atm.)	Permea-bility, mD	Grain density, g/ml	Qv m.eq/ml.pv
2	1538.00	22.3	--	2.66	0.142
3	1552.10	35.5	--	2.65	0.023
5	1580.10	24.5	--	2.66	0.058

Remark: For the samples given the Qv / Porosity relation may be expressed by Qv = (0.389 - PHI)/(6.403 x PHI) (r for relation = 0.870)

OK TABLE VI - FRF and FRF* at In-situ Isostatic Stress of 200 (kg/cm**2)
(First Loading Cycle) for Core Samples from Well 31/2-6

Sample no.	Depth (m.)	Porosity, Isostatic (% bv)	FRF ✓/200 bar	m	Qv	FRF*	m*
2	1538.00	16.00	7.714	1.11	0.213	8.346	1.16
3	1552.10	28.16	3.815	1.06	0.032	3.862	1.07
5	1580.10	22.21	6.664	1.26	0.065	6.831	1.28

Rw approximately: 0.122 ohm metres at 22 degrees C. (B = 3.13)

Remark: For these samples the FRF*/porosity relation may be expressed by FRF*= 1.00*PHI**-1.18 [r for log(FRF*)/log(PHI)= 0.9958]
The Qv values were corrected for the differences in porosities at atmospheric and reported stress.

TABLE VII - Porosity at Isostatic Stress (First Loading Cycle) of Core Samples from Well 31/2-6

Sample no.	Depth (m.)	Porosity, % bv (atm.)	Porosity (% bv) at (kg/cm**2, Isostatic Stress)				
			50	100	150	200	250
2	1538.00	22.26	20.03	18.38	17.08	16.00	15.01
3	1552.10	35.53	33.38	31.54	29.83	28.16	26.53
5	1580.10	24.53	23.88	23.23	22.67	22.21	21.79

TABLE VIII Mercury/Air Capillary Pressure Data from Well 31/2-6

Sample Number	Depth (m.)	Porosity (% BV)	Perm. (Est.) mD	Percent Pore Space Unoccupied by Mercury vs Pressure (PSIA)								
				10	20	30	40	50	60	70	80	90
1C	1538.00	32.8	--	1070.	286.	112.	54.	22.	15.	12.	11.	9.
2C	1552.10	6.8	--	48500.	34400.	7160.	937.	346.	182.	113.	74.	53.
3C	1570.00	14.0	--	39100.	19900.	2770.	23.	16.	13.	10.	8.	6.
4C	1580.10	15.9	--	1160.	250.	100.	49.	24.	15.	11.	8.	--
9C	1590.70	34.1	2600.	113.	22.	9.	5.	4.	4.	3.	3.	2.
10C	1593.00	25.5	11.	1990.	799.	418.	248.	153.	98.	69.	48.	29.
13C	1599.90	5.1	0.02	1960.	1110.	840.	687.	542.	432.	316.	207.	132.
8C	1600.00	4.7	0.01	1940.	1140.	892.	741.	585.	455.	324.	203.	120.
14C	1612.00	31.1	1900.	133.	32.	10.	6.	4.	4.	3.	3.	2.

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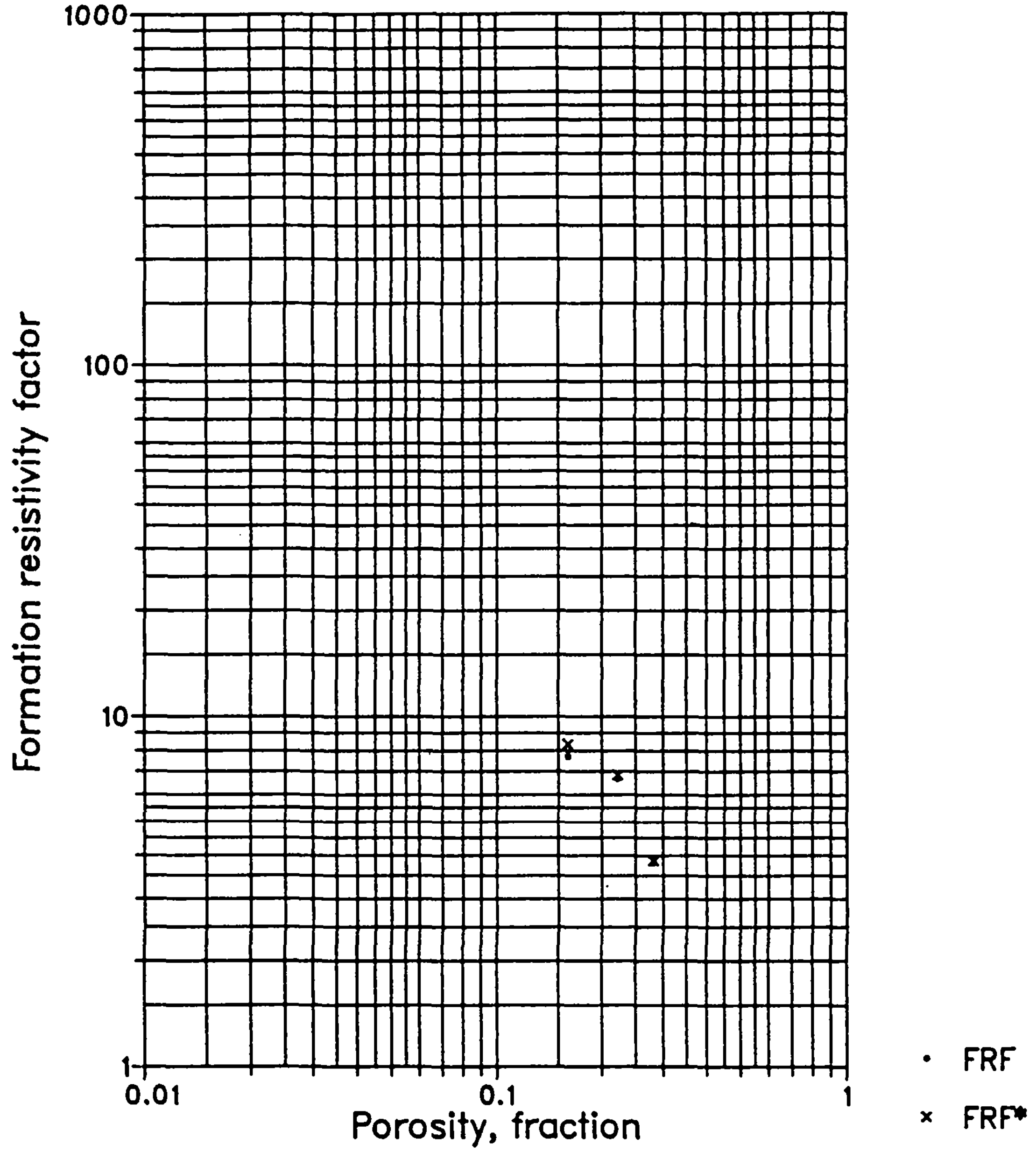
FRF and FRF* vs Porosity at In-Situ Stress Conditions

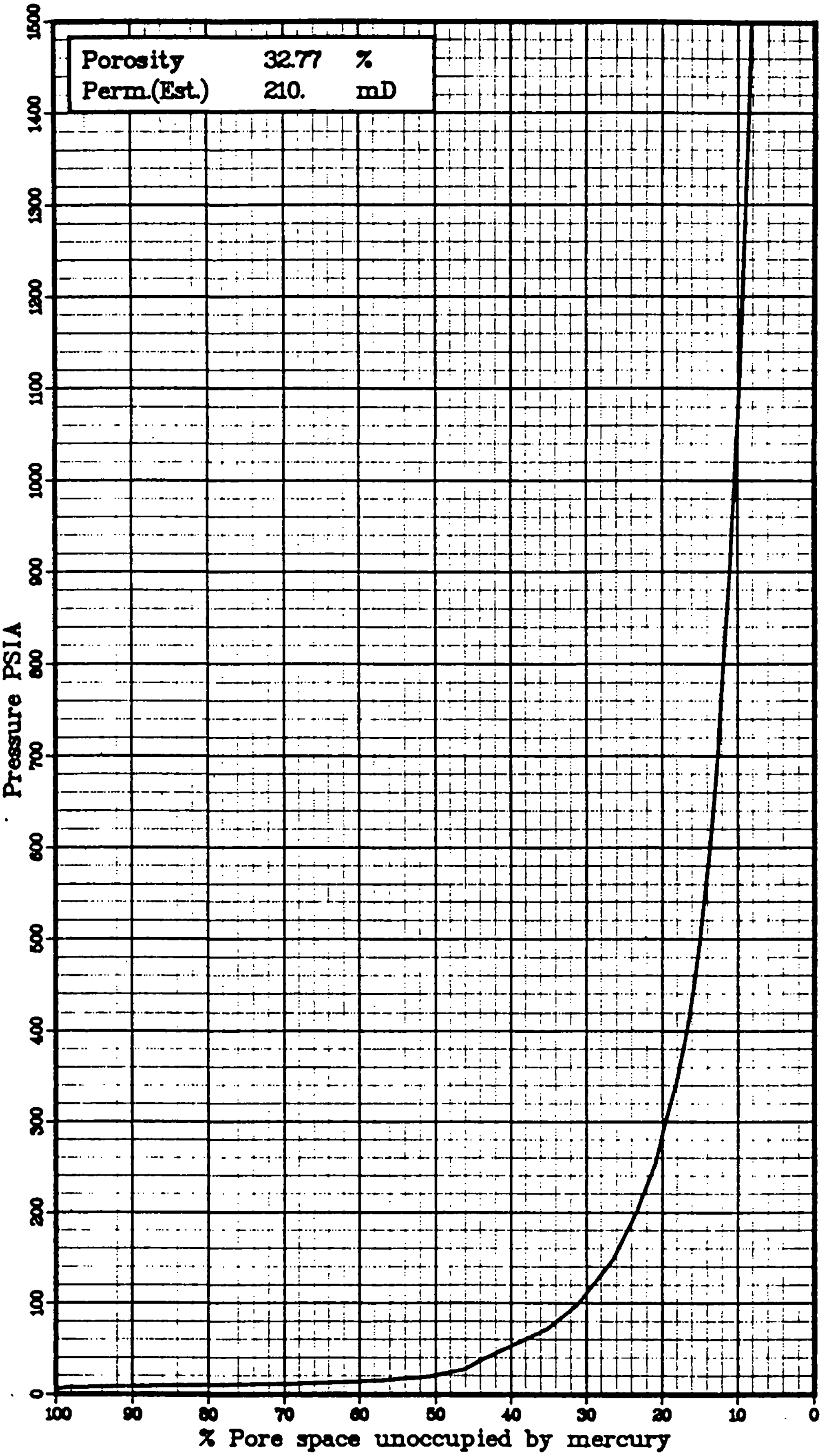


Well name: 31/2-6

Linear Regression:
FRF = 0.93*phi**-1.20 (r = 0.9140)
FRF* = 0.80*phi**-1.32 (r = 0.9350)

Forced Linear Regression:
FRF = 1.00*phi**-1.15 (r = 0.9953)
FRF* = 1.00*phi**-1.18 (r = 0.9958)

FIG. 1



Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 1C DEPTH 1538.00 METER

author: bur
design:

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fig. 2

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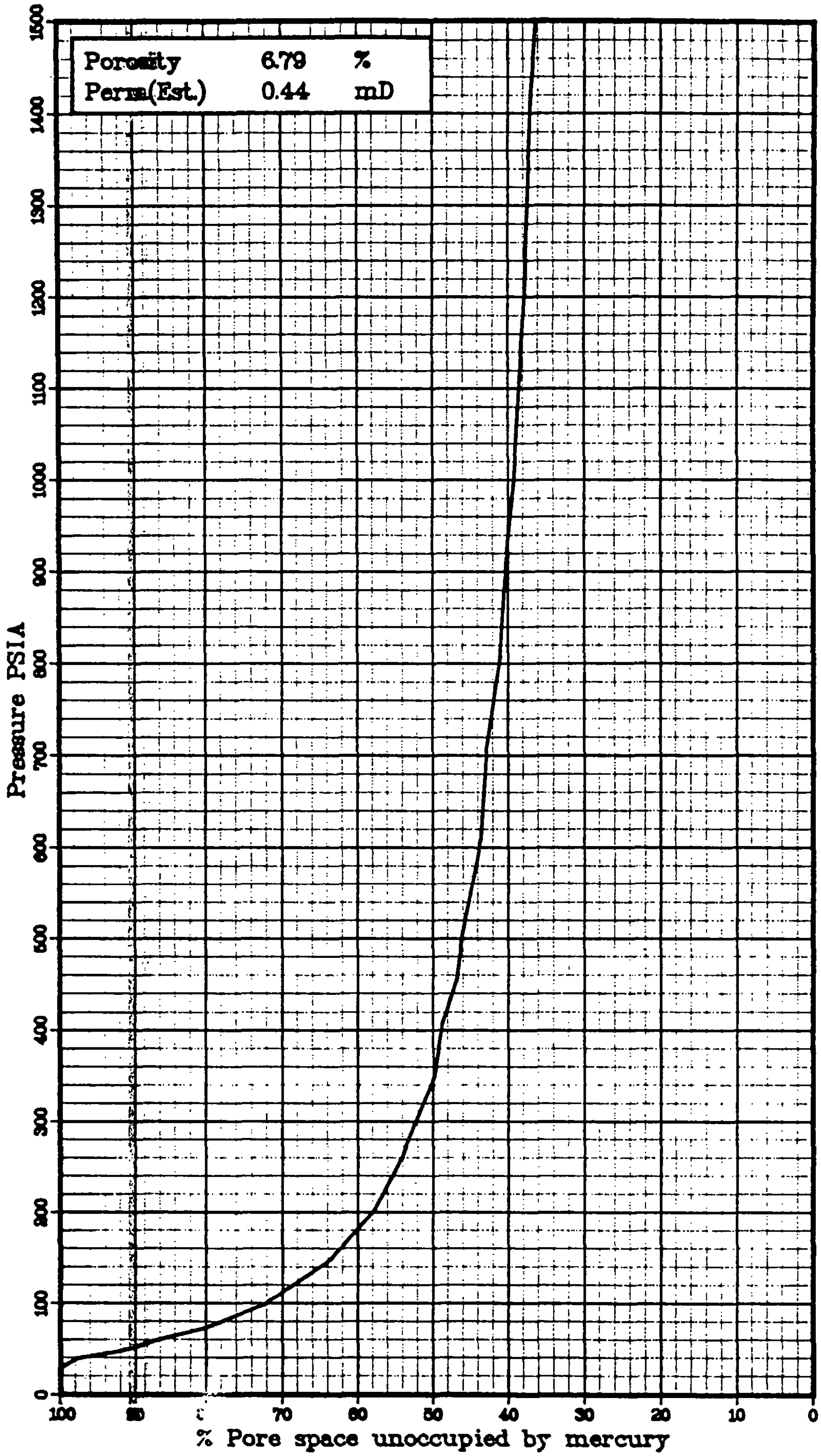

Mercury capillary pressure curve

WELL 31/2-3 SAMPLE 2C DEPTH 1552.10 METER

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fig. 3

author: bur
design:

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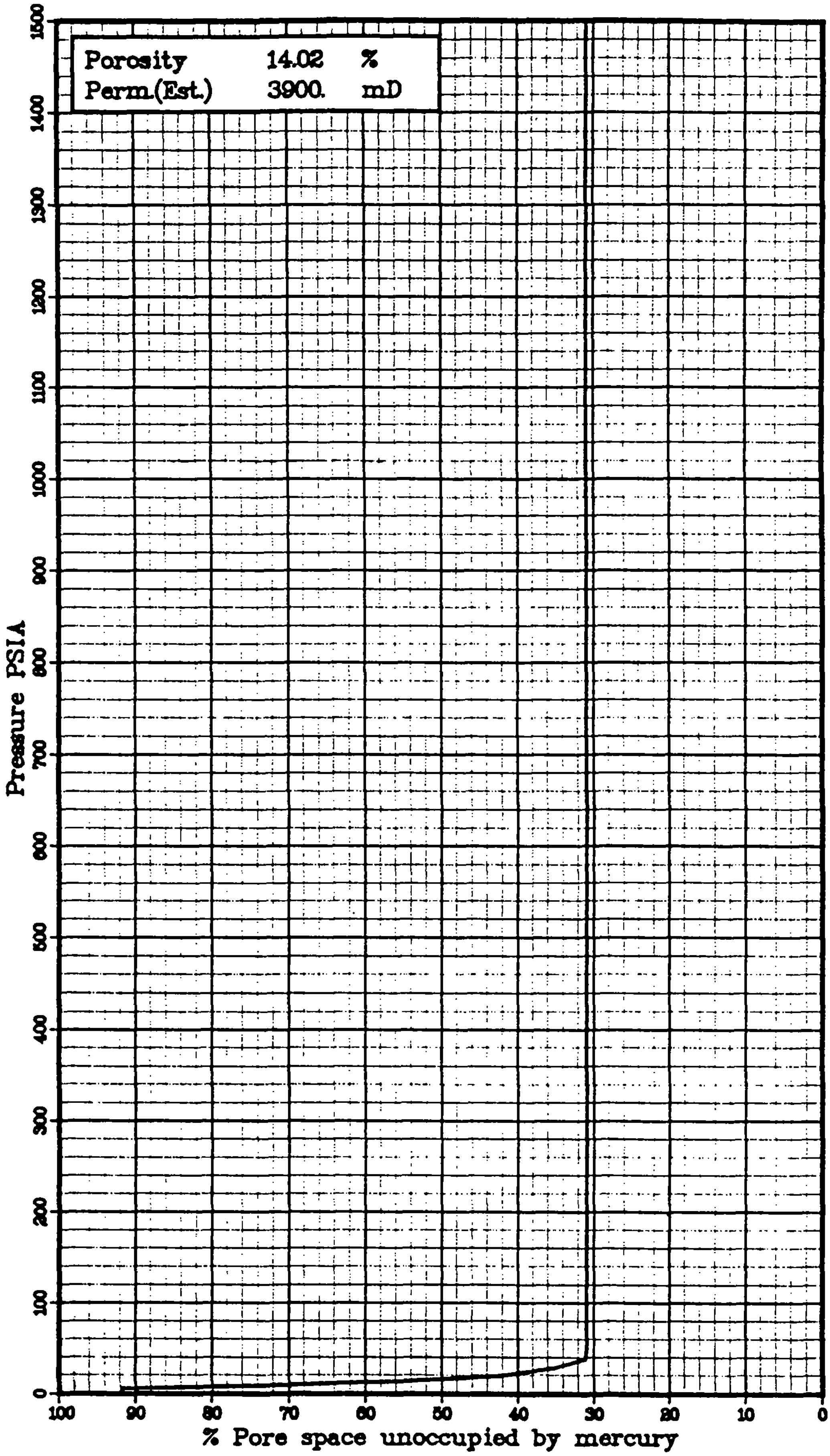

Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 3C DEPTH 1570.00 METER

author: bur
design:

RKER 83.133

fig. 4

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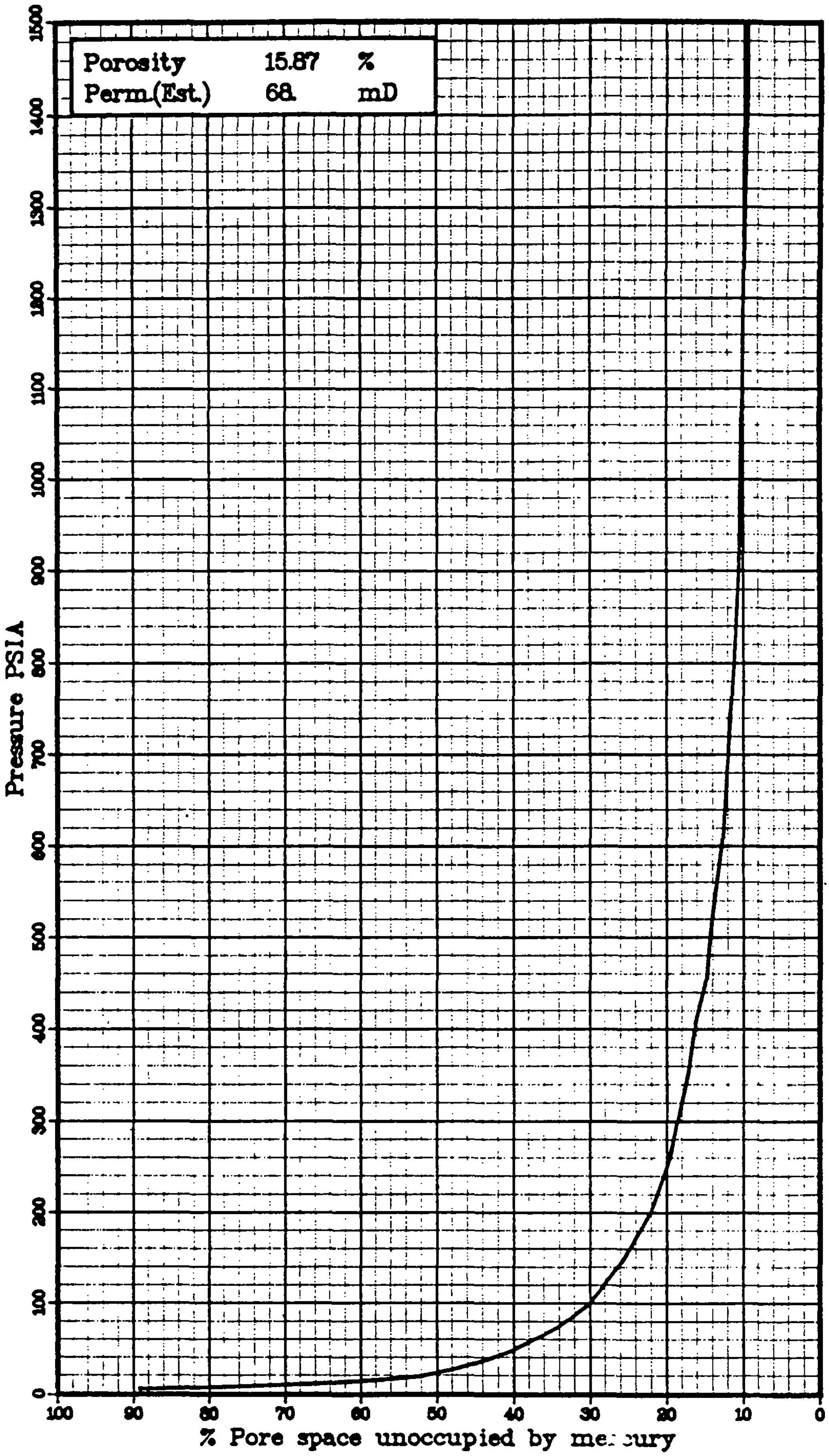


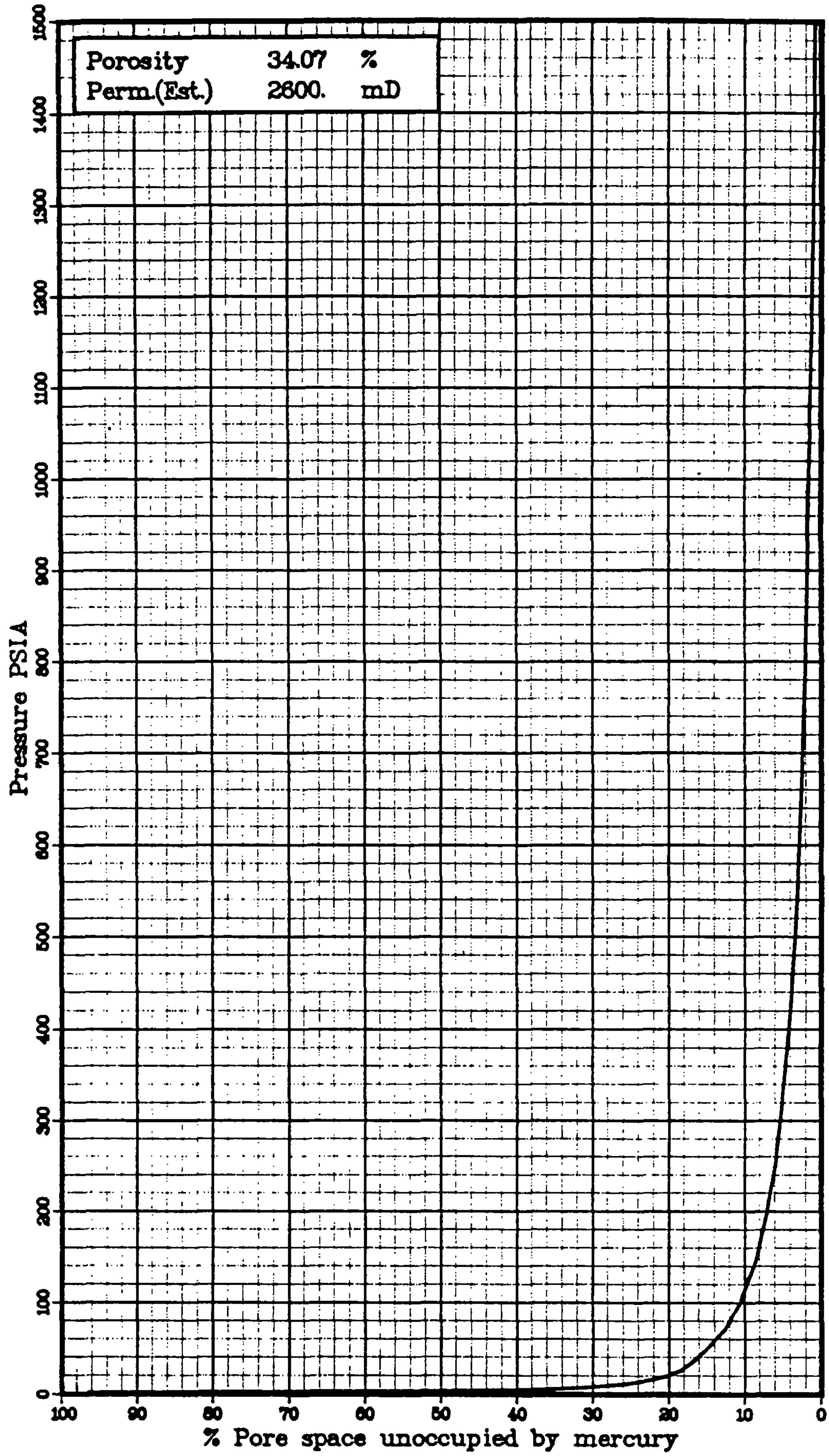
Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 4C DEPTH 1580.10 METER

RKER 83.133

author: bur
design:

fig. 5



Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 9C DEPTH 1590.70 METER

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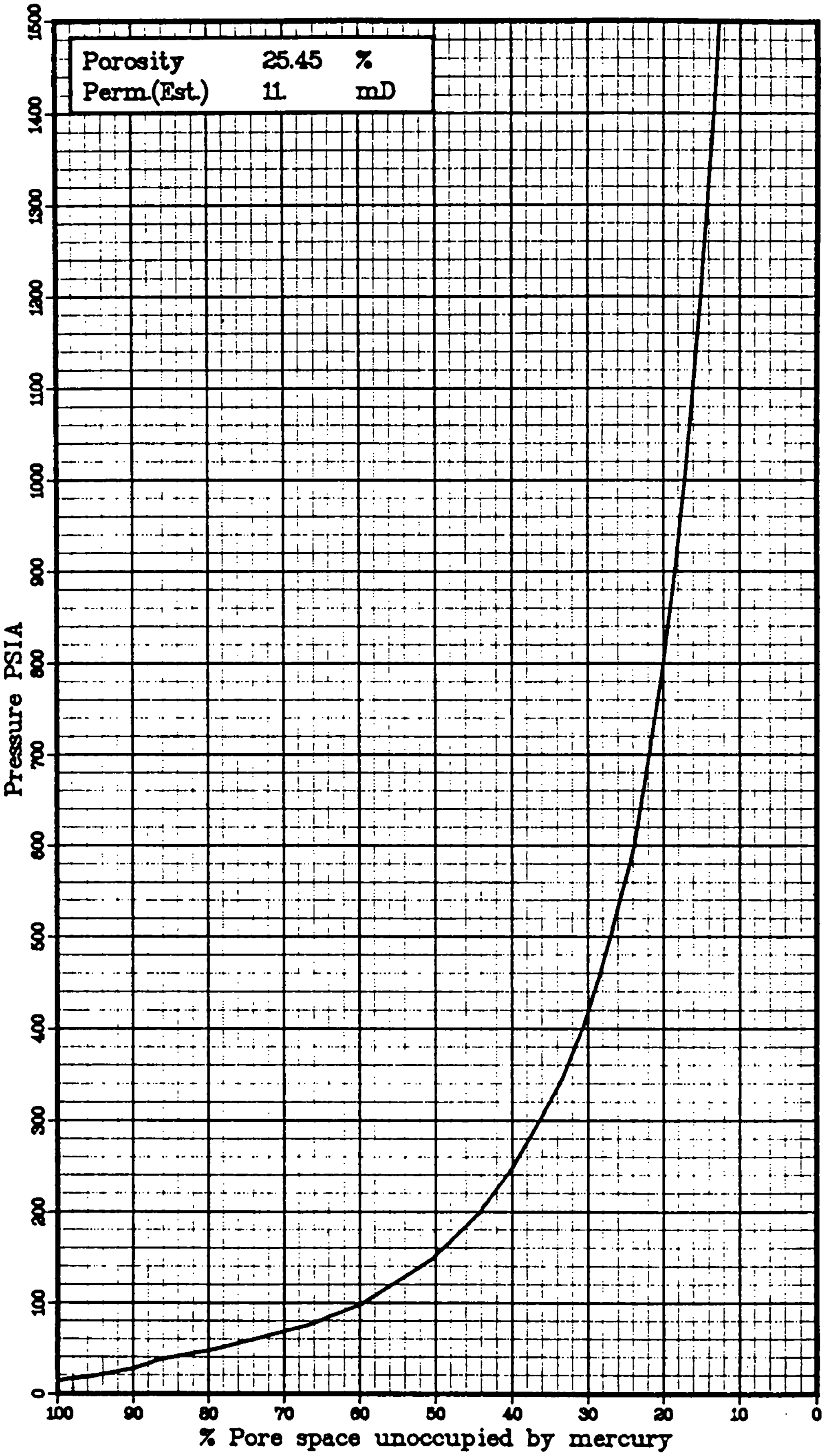
author: bur
design:

fig. 6



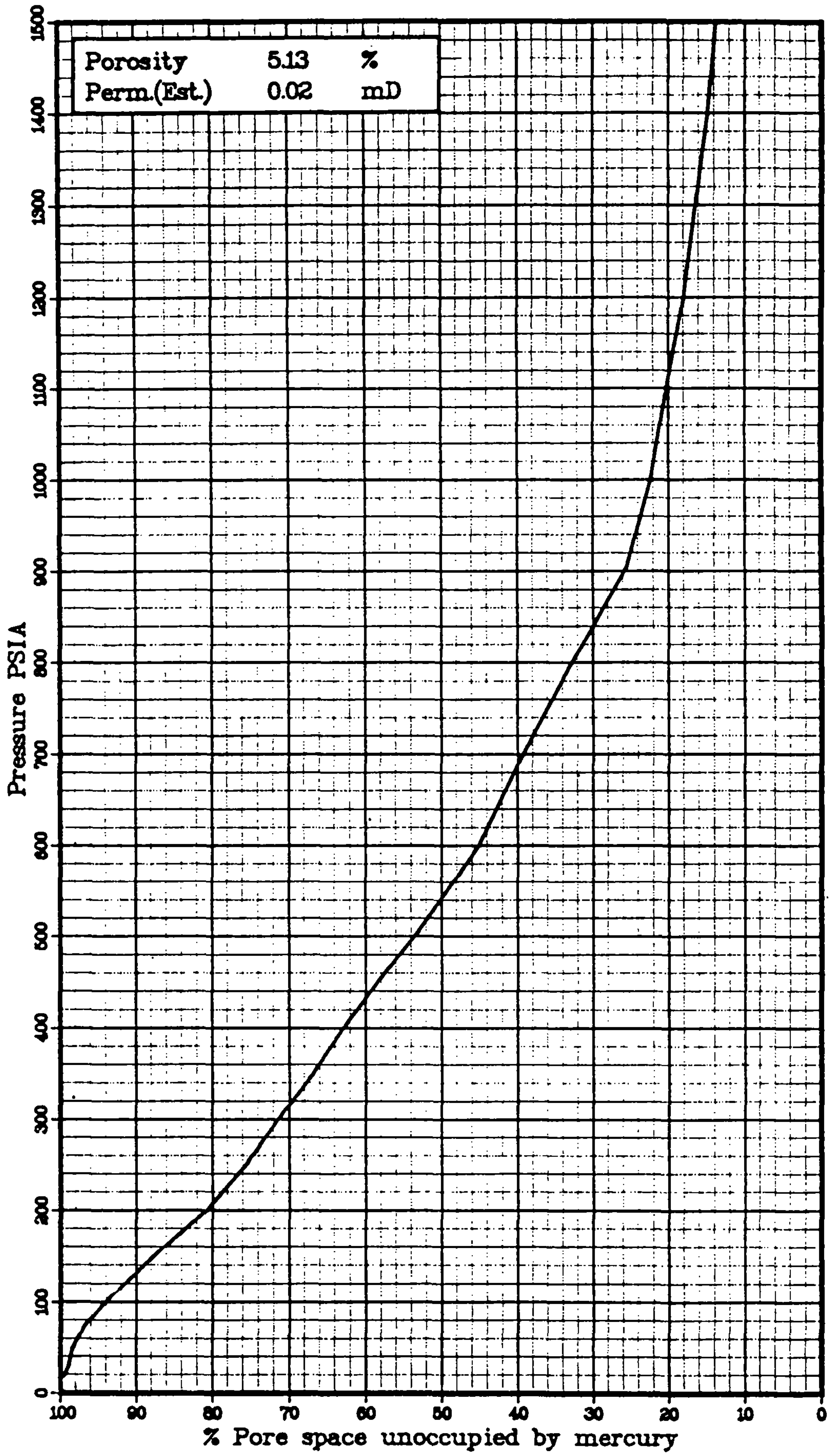
Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 10C DEPTH 1593.00 METER

author: bur
design:

RKER 83.133

fig. 7



Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 13C DEPTH 1599.90 METER

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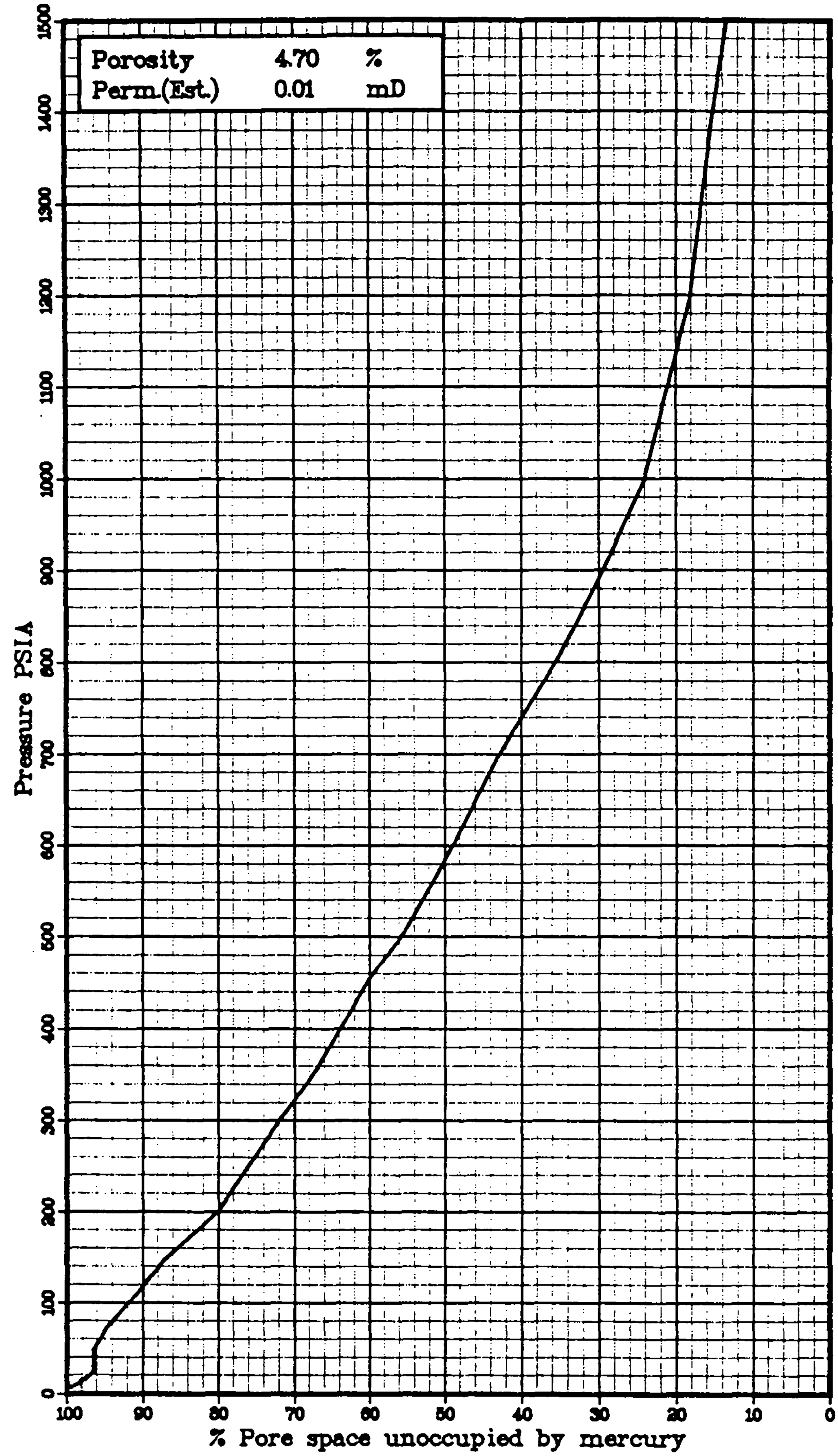
author: bur
design:

fig. 8



Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 8C DEPTH 1600.00 METER

author: bur
design:

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fig. 9

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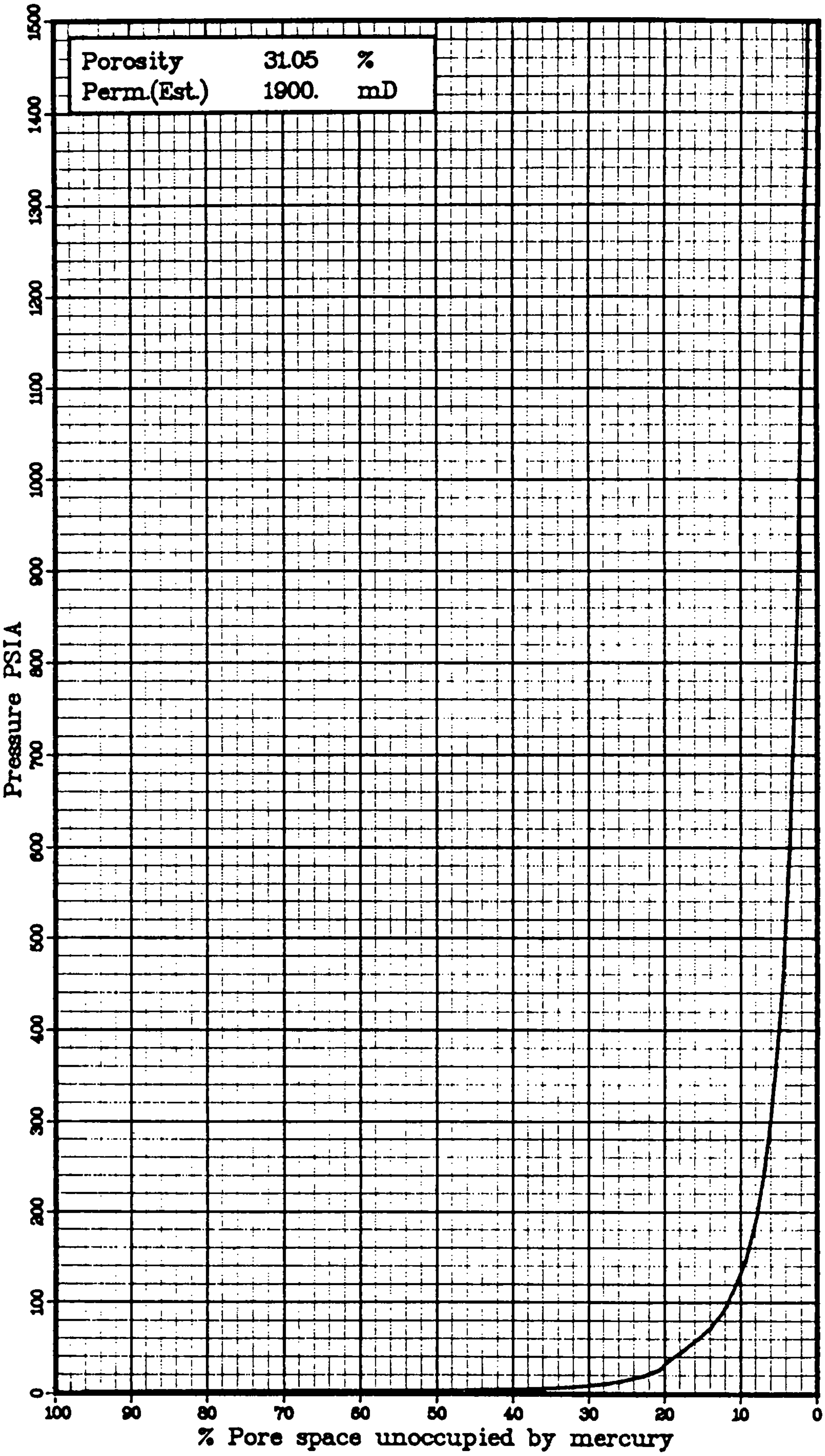

Mercury capillary pressure curve

WELL 31/2-6 SAMPLE 14 C DEPTH 1612.00 METER

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author: bur
design:

fig. 10

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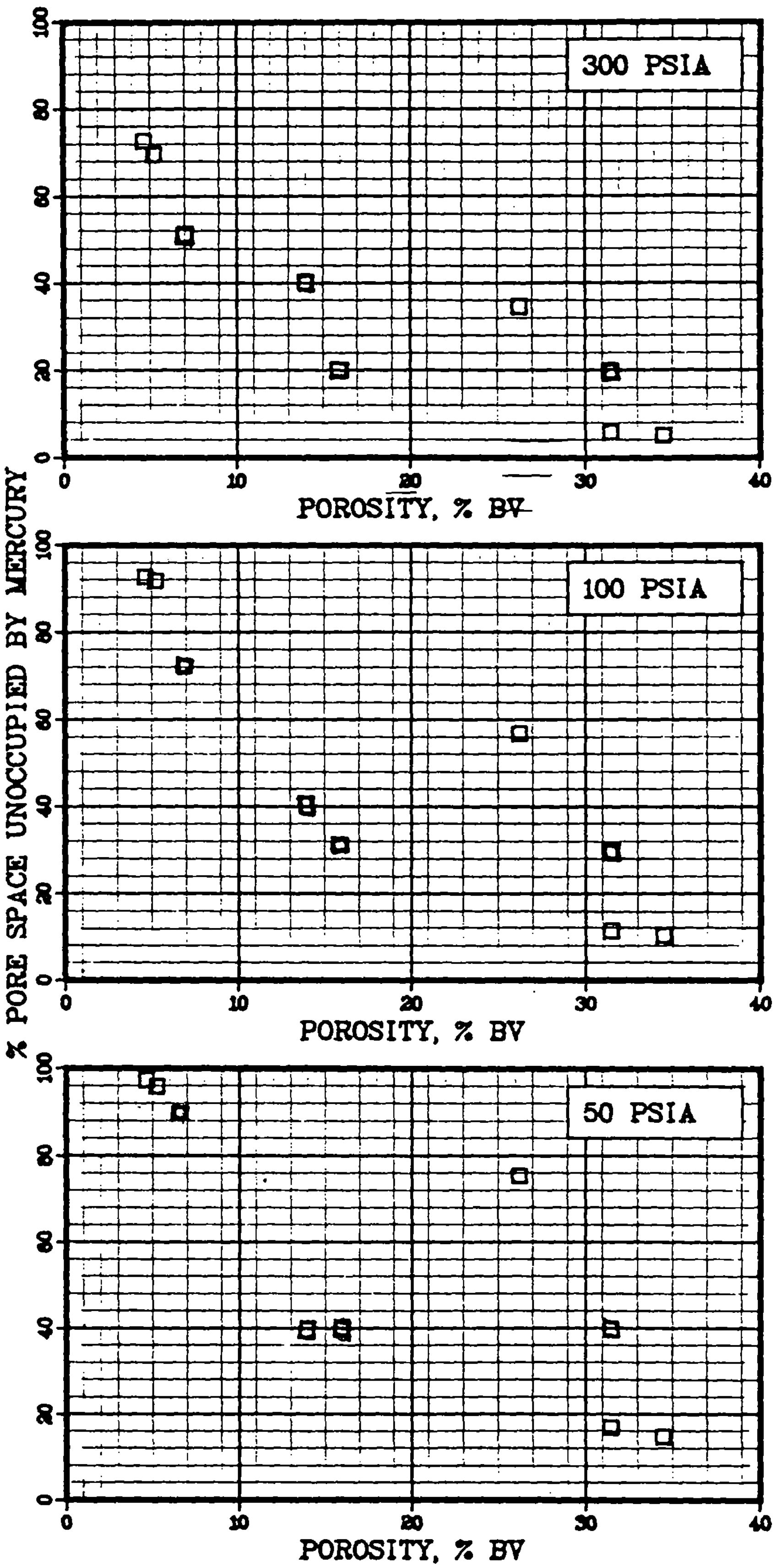

PERCENTAGE OF PORE SPACE UNOCCUPIED BY MERCURY VERSUS POROSITY AT CAPILLARY PRESSURES OF 50, 100 AND 300 PSIA FOR CORE SAMPLES FROM WELL 31/2-6

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FIG. 11

AUTHOR: BUR
DESIGN:

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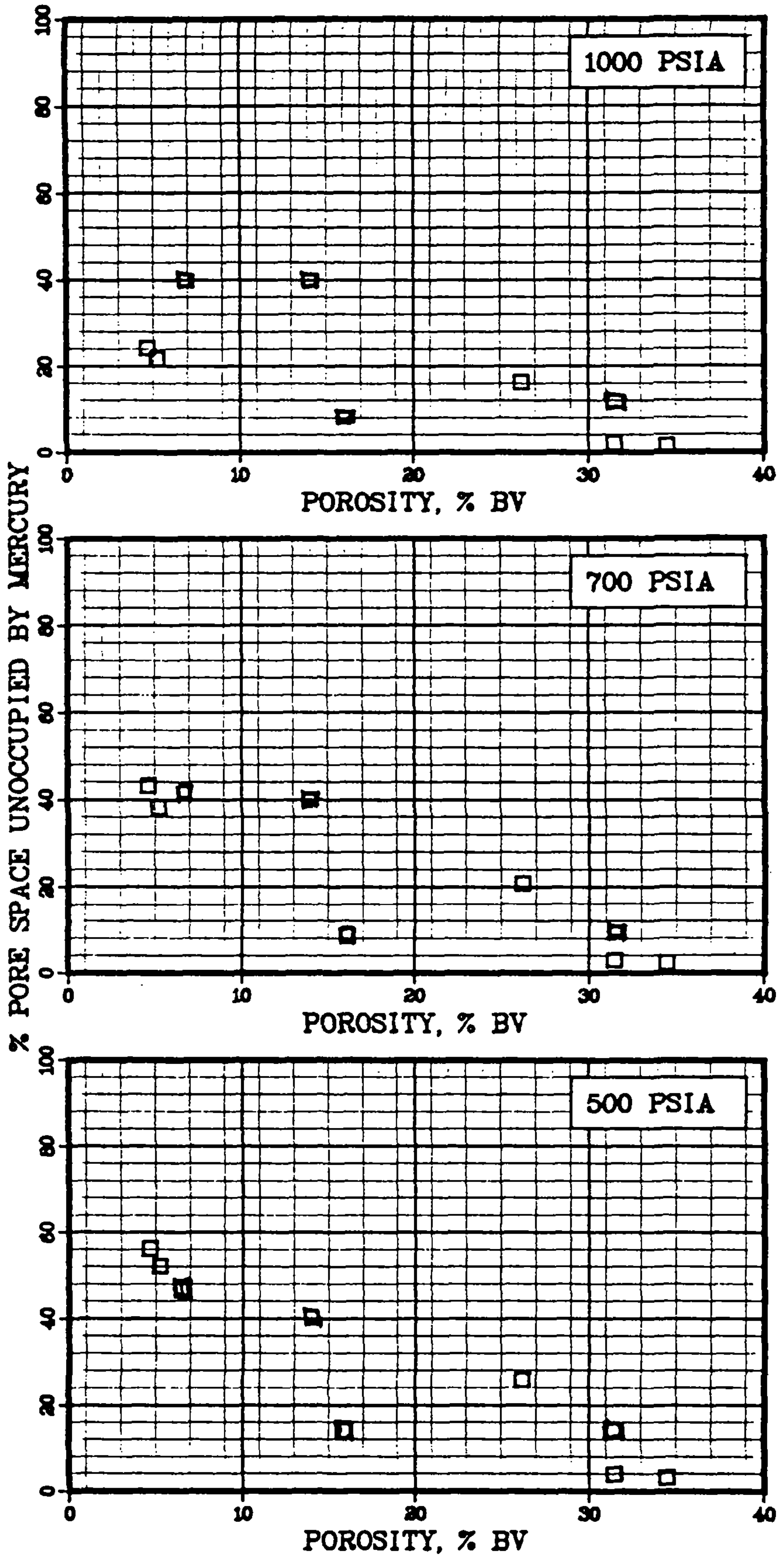

PERCENTAGE OF PORE SPACE UNOCCUPIED BY MERCURY VERSUS, POROSITY AT CAPILLARY PRESSURES OF 500, 700 AND 1000 PSIA FOR CORE SAMPLES FROM WELL 31/2-6

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AUTHOR: BUR
DESIGN:

FIG.11

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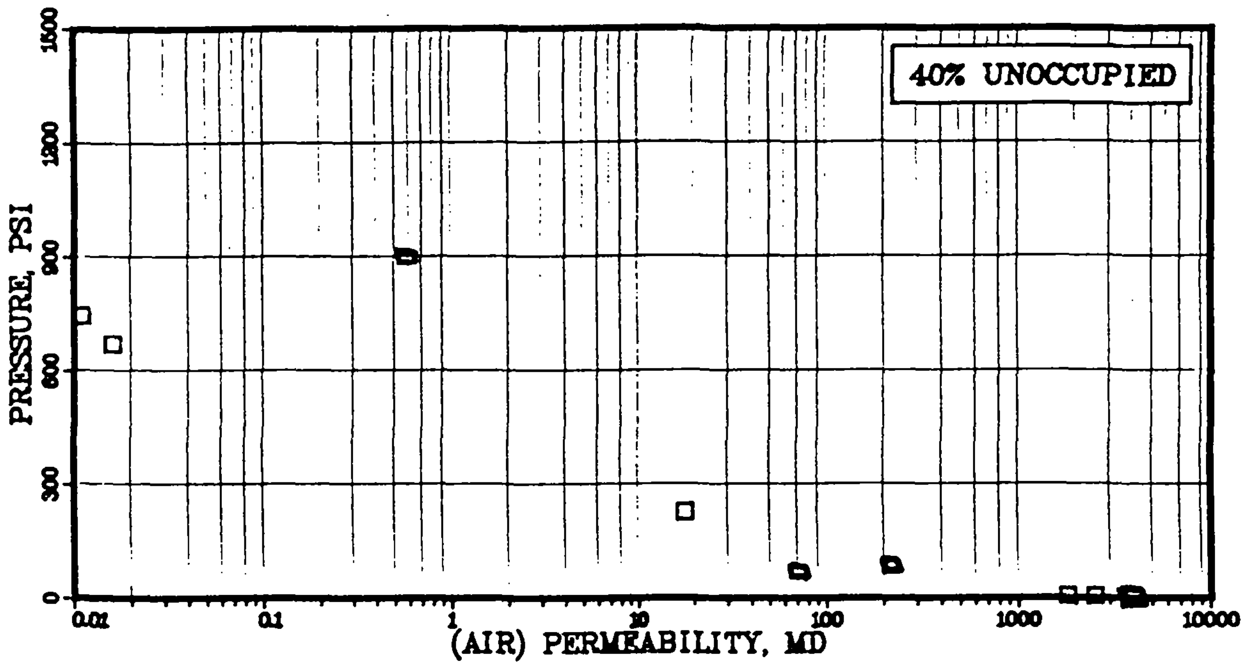

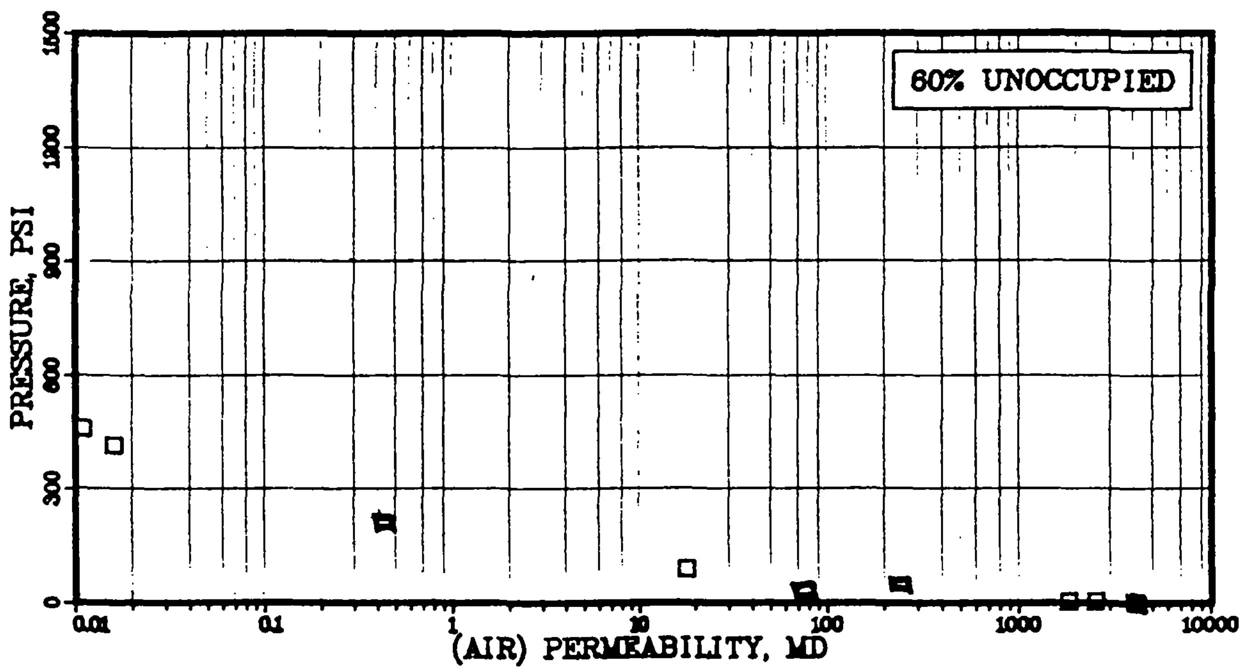

MERCURY/AIR CAPILLARY PRESSURE VERSUS (AIR) PERMEABILITY AT 60% AND 40% OF PORE SPACE UNOCCUPIED BY MERCURY FOR WELL 31/2-6

RKER 83.133

AUTHOR: BUR
DESIGN:

DR.NO.
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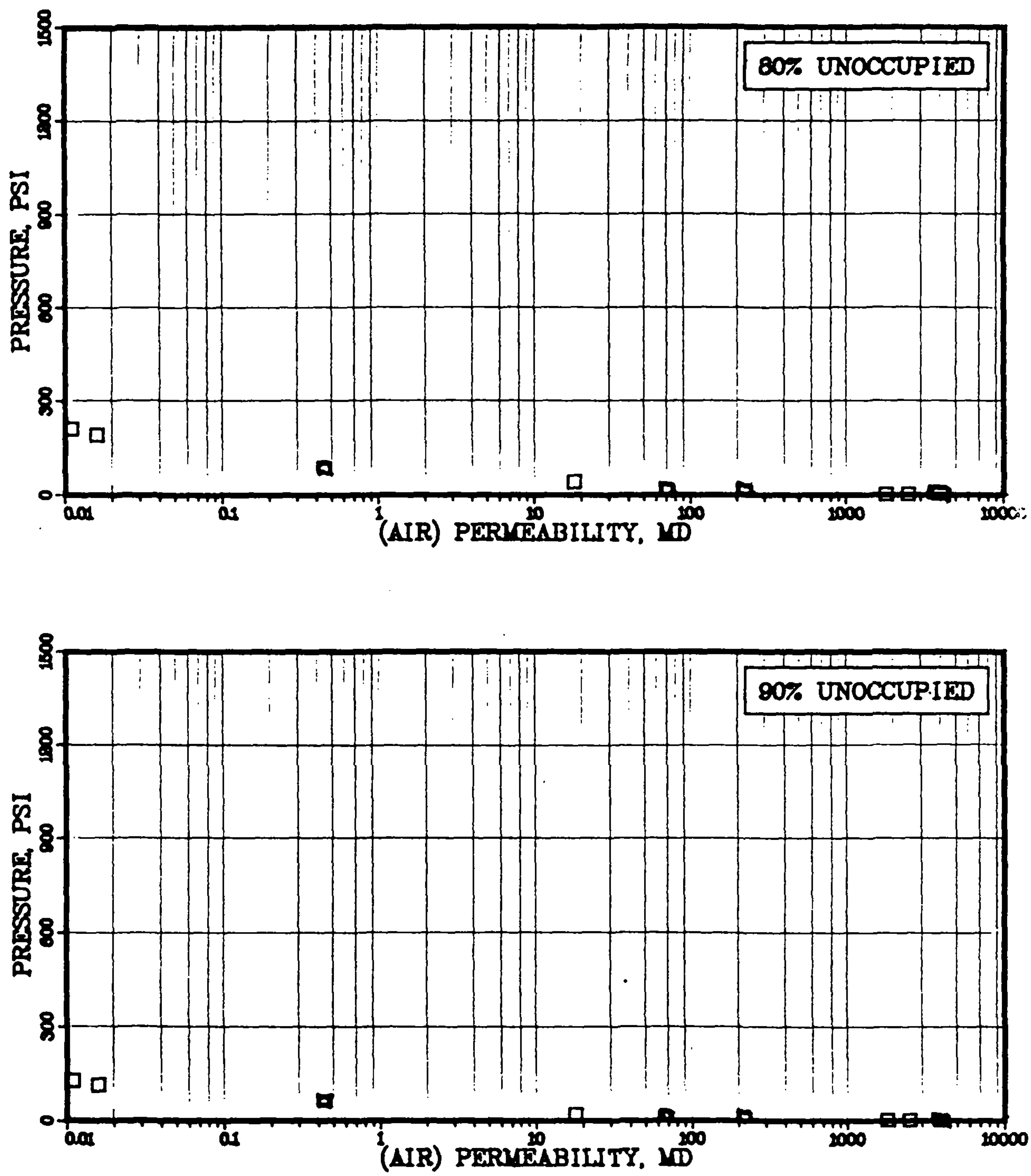
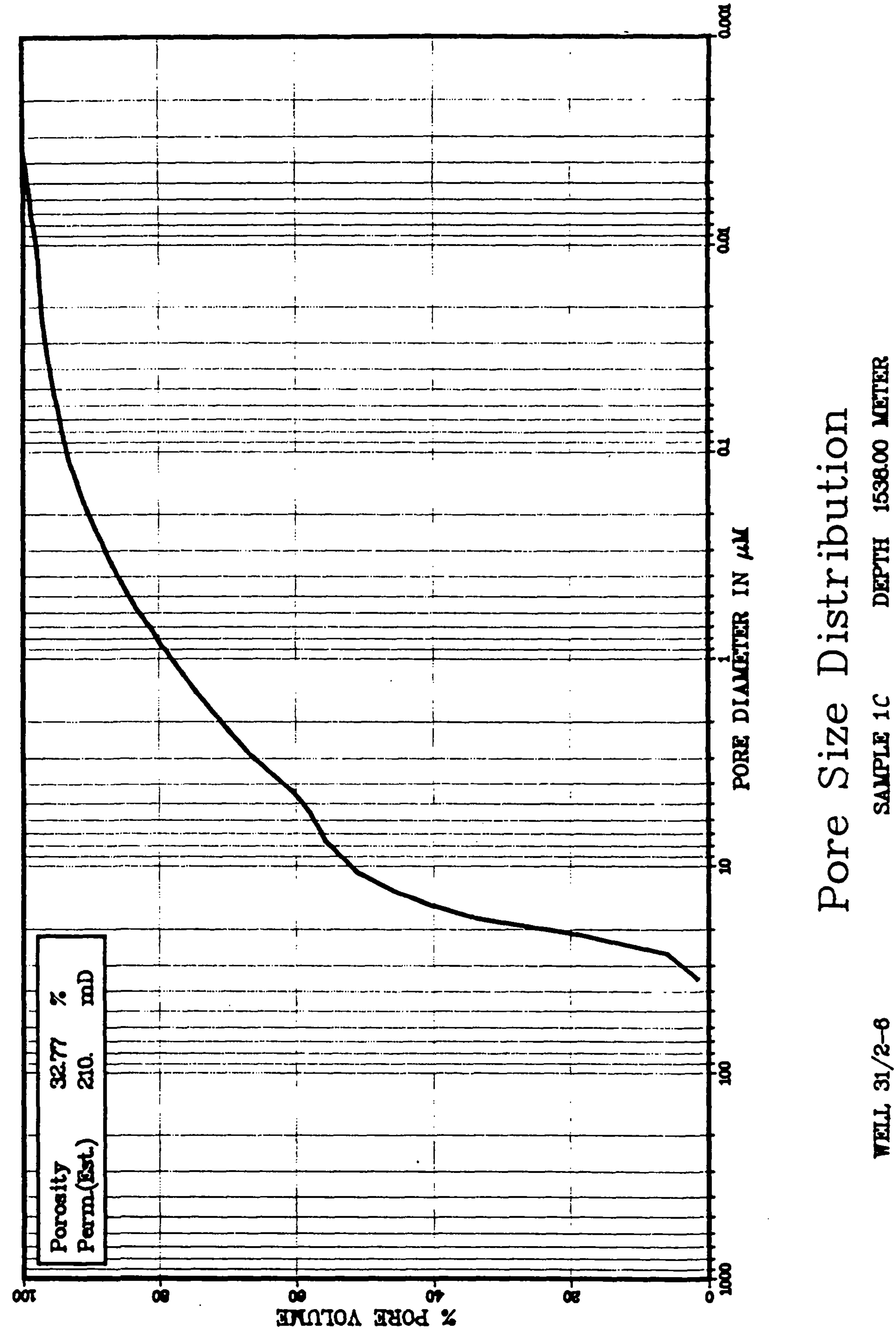
FIG. 13



MERCURY/AIR CAPILLARY PRESSURE VERSUS
(AIR) PERMEABILITY AT 90% AND 80% OF PORE SPACE
UNOCCUPIED BY MERCURY FOR WELL 31/2-6

AUTHOR: BUR
DESIGN:

FIG. 14



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design:

fig. 15

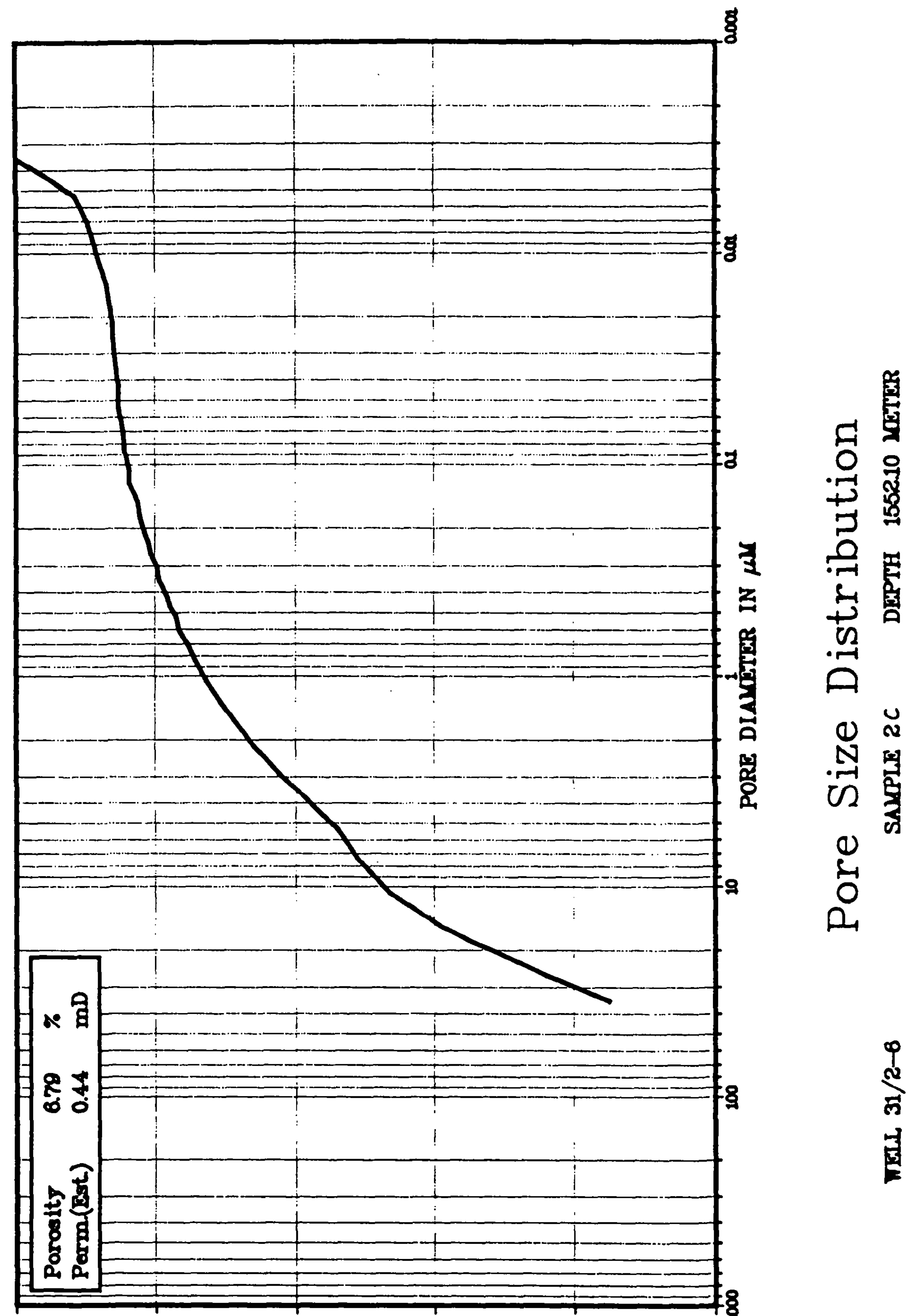

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fig. 16

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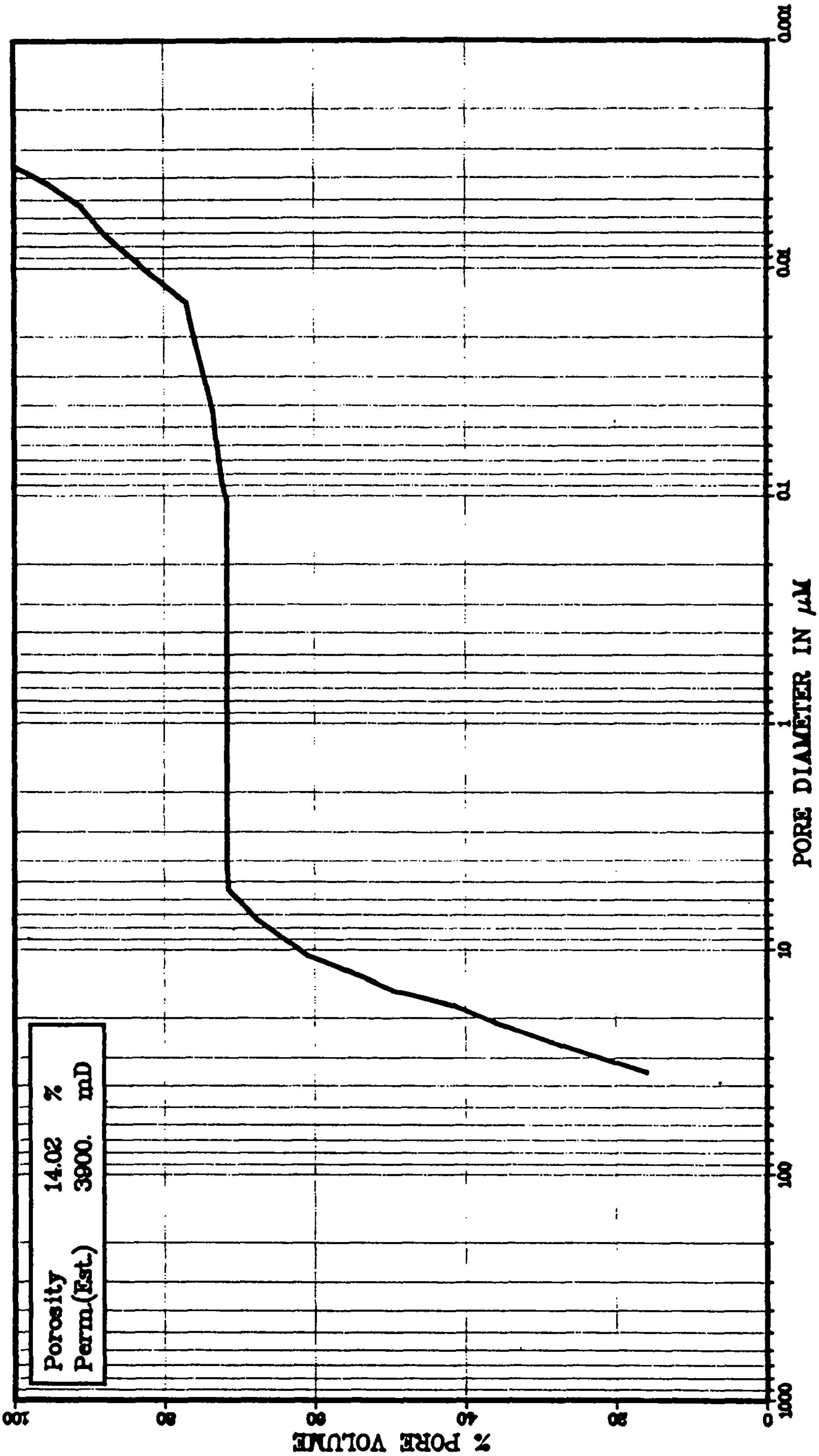

Pore Size Distribution

WELL 31/2-6 SAMPLE 3C DEPTH 1570.00 METER

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author: bur
design:—

fig. 17

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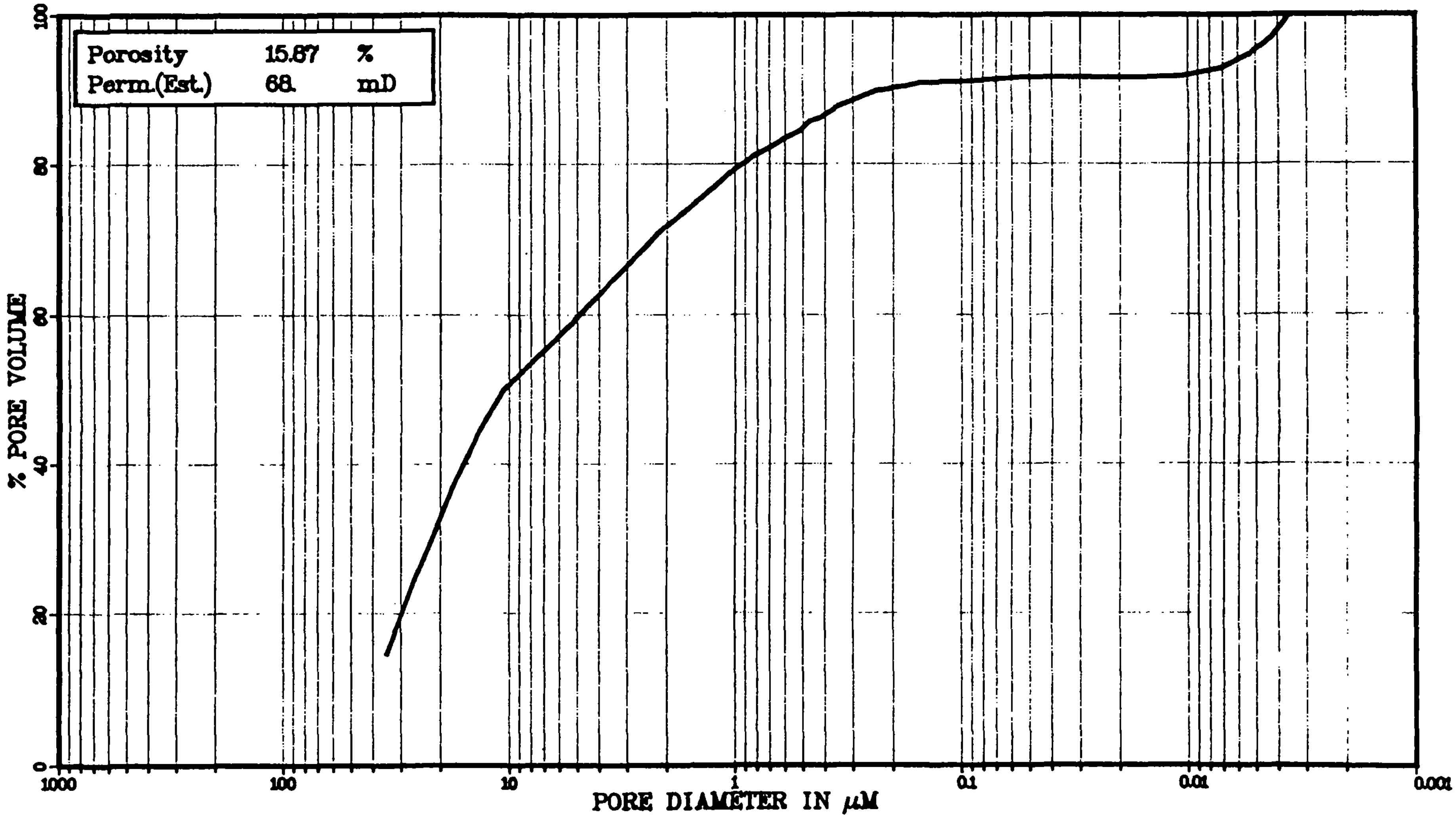

Pore Size Distribution

WELL 31/2-6 SAMPLE 4C DEPTH 1580.10 METER

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design:

fig. 18

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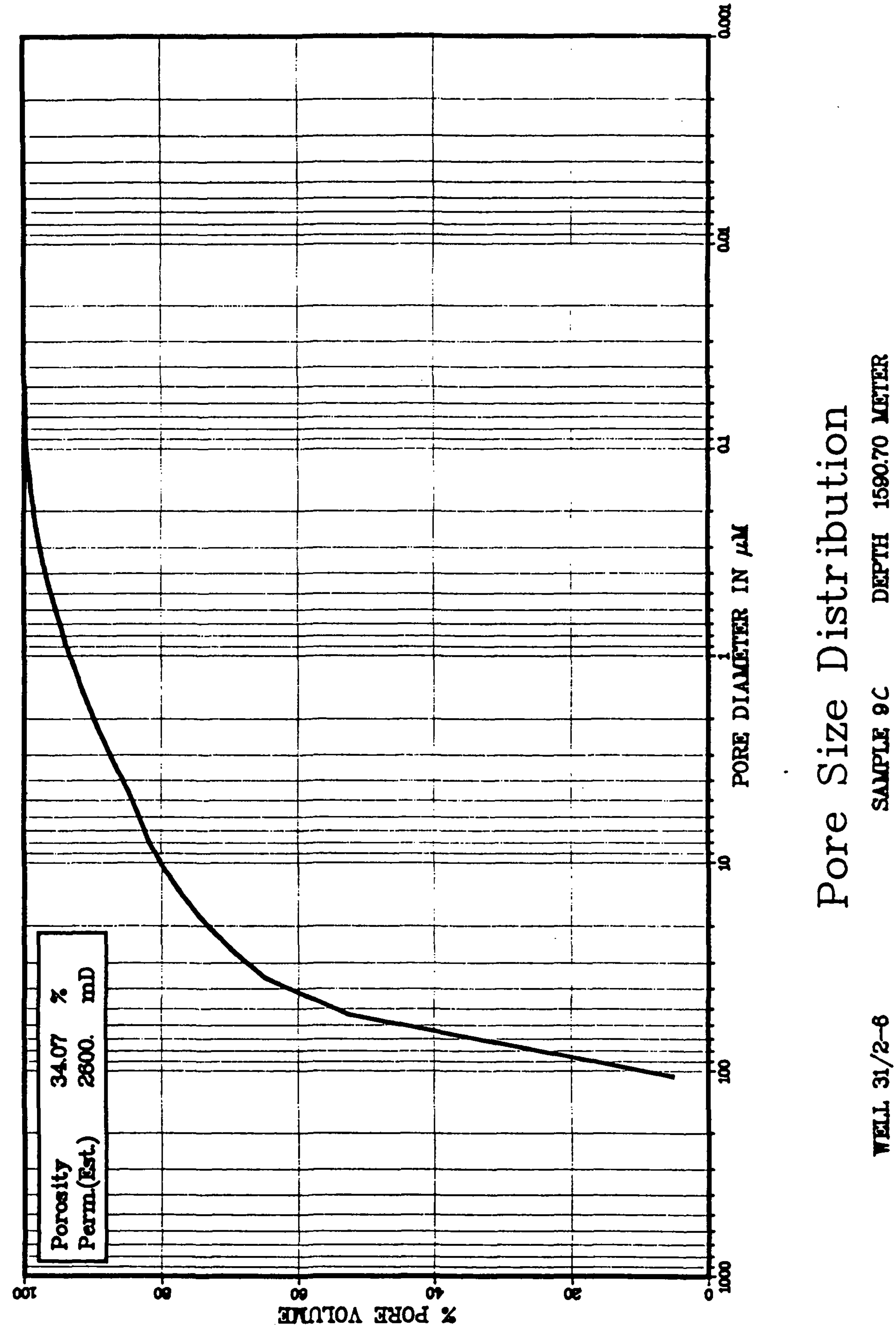

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fig. 16

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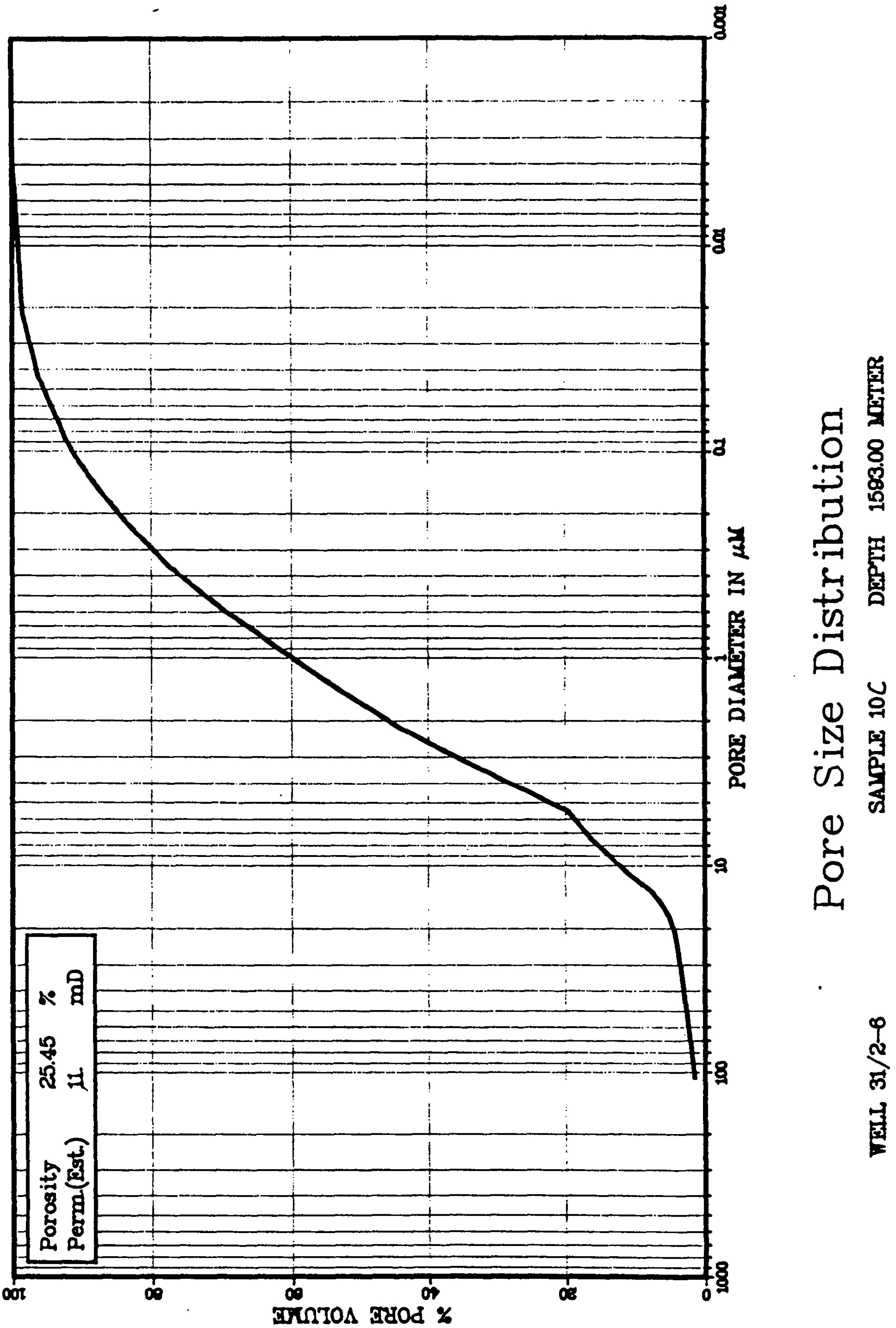

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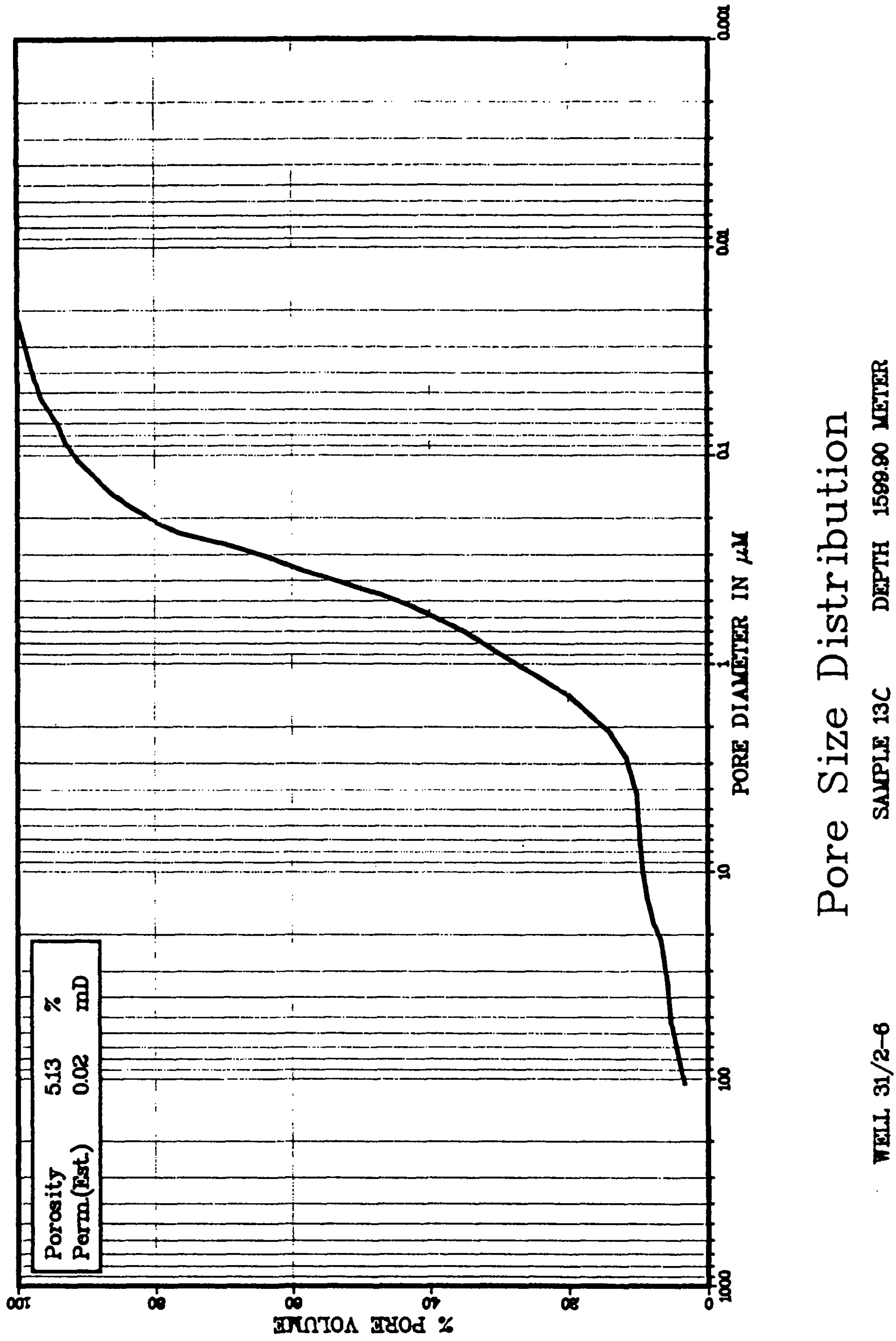
fig. 20



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design:

fig. 21

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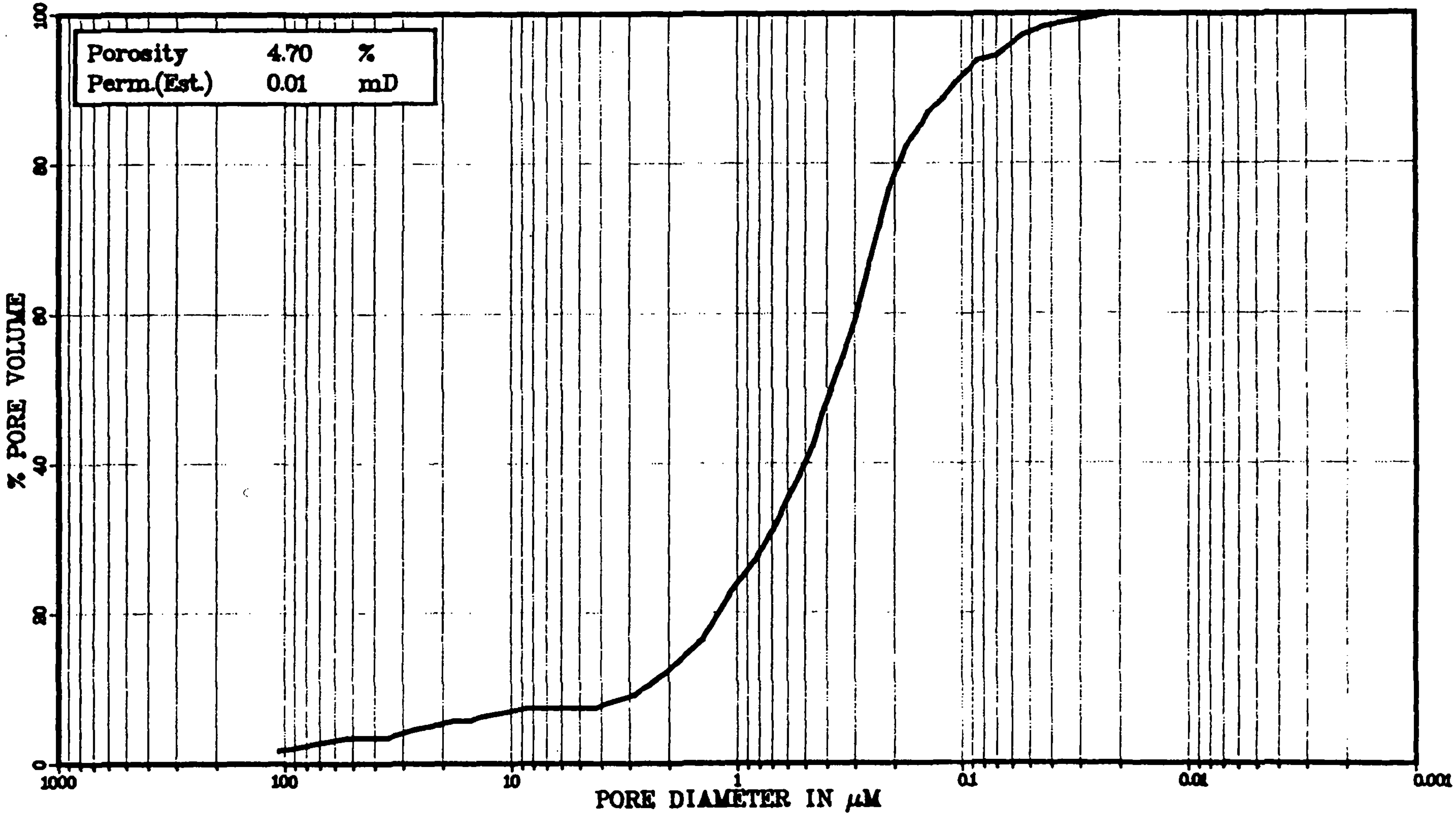

Pore Size Distribution

WELL 31/2-6 SAMPLE 8C DEPTH 1600.00 METER

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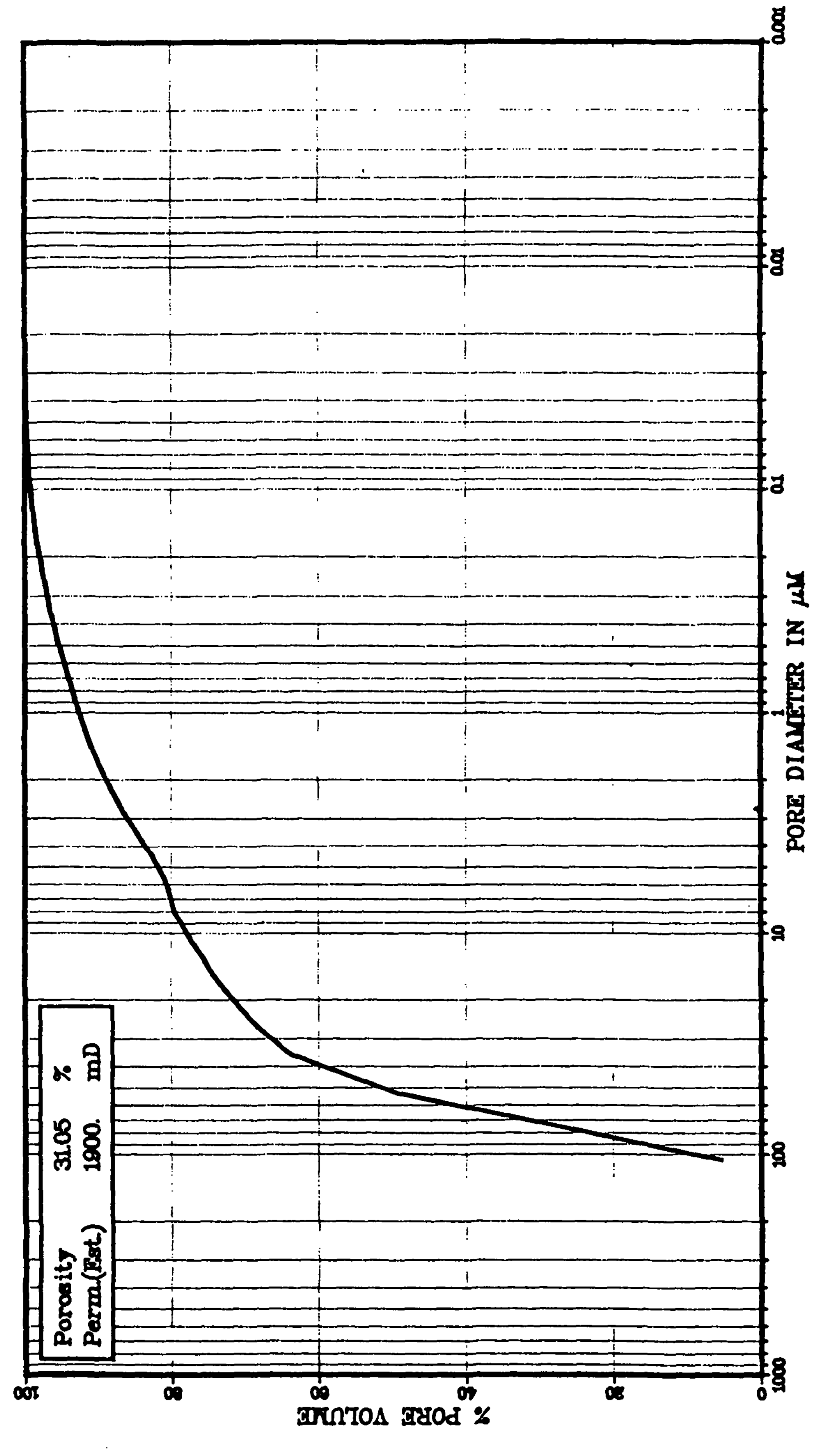
author: bur
design:

fig. 11



Pore Size Distribution

WELL 31/2-6 SAMPLE 14C DEPTH 1612.00 METER

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fig. 23

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