December 1982

RKER.82.243

INVESTIGATION OF CORES FROM WELL 31/2-4, NORWAY

- Petrophysical properties of core samples -

by

J.A. van Benten

KONINKLIJKE / SHELL EXPLORATIE EN PRODUKTIE LABORATORIUM
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Investigation 9.25.162

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CONTENTS

KEYWORDS

Well 31/2-4, Norway, porosity, formation-resistivity factor, in-situ porosity, cation-exchange capacity, mercury capillary pressure, compressibility, cementation factor.

INVESTIGATION OF CORES FROM WELL 31/2-4, NORWAY

- Petrophysical properties of core samples -

Ref.: Telex for 140822, dated 14-8-81, from Shell Forus, Norway,
to KSEPL, Rijswijk
Telex for 270507, dated 27-5-82, from Shell Forus, Norway,
to KSEPL, Rijswijk

INTRODUCTION

Petrophysical measurements were carried out on core samples from well 31/2-4, Norway.

The samples consisted of frozen core plugs and frozen core material. For drilling of the plugs, liquid nitrogen was used as coolant.

Formation-resistivity factor and corresponding porosity measurements were carried out at various isostatic pressures[1]. The pressures applied were based on the information given in telex for 121010 of 12.10.81.

Individual cementation factors were calculated from the results at in-situ stress to show the variation in porosity/formation-resistivity factor relationship for the different samples. An isostatic stress of 120 kg/cm^2 was used, which was assumed to be equivalent to an (estimated) initial effective grain pressure of 200 kg/cm^2 (Poisson's ratio 0.3).

The formation-resistivity relation may be expressed by:

$$FRF = 0.71\ \phi^{-1.92} \text{ (at 120 kg/cm}^2\text{, isostatic stress).}$$

The correlation coefficient of the linear regression line for log (FRF) versus log (ϕ) was: -0.99.

Cation-exchange capacity measurements were carried out as described in SMS 2285-1. The linear regression of Q_v versus $1/\phi$ showed (excluding samples 1 and 12) the correlation:

$$Q_v = (0.37 - \phi)/(3.63 \times \phi)$$

($r = 0.92$)

The clay corrected formation-resistivity factors and cementation factors as given in Table VI were calculated using actually measured Q_V values or the Q_V versus $1/\phi$ relation. The overall FRF^*/ϕ relation was found to be:

$FRF^* = 0.48\ \phi^{-2.25}$ (at 120 kg/cm^2, isostatic stress) (R = 0.99).

The R_W of the artificial formation water used was approximately 0.125 ohm metre at 22°C.

Table II gives porosities calculated from those measured at isostatic pressure (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 hydrostatic pressure is given in Table III. Pore compressibility as a function of uniaxial pressure is given in Table IV.

Mercury capillary pressure measurements were carried out in an automatic pore-injectivity apparatus (Autopore 9200). Owing to the low degree of cementation between the grains, samples B and C (depths 1574 and 1579 m, respectively) could not be cleaned with various solvents. These samples were dried in a vacuum oven for 4 hours at 100 °C, after which the capillary pressure curves were measured. 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 statistical approach from the shape of the capillary-pressure curves when plotted as log pressure versus log mercury saturation (% Vb).

The results of the analyses are given in Tables I-VII and Figures 1-15.

REFERENCES

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

OB/

OK [redacted]I - Formation-Resistivity Factor as a Function of Isostatic Pressure (First Loading Cycle) of Core Samples from Well 31/2-4

POR /FFH M

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Formation-resistivity factor, at ([redacted]/cm**2) /PNC						m-factor, at(kg/cm**2)
			50	75	100	120	150	200	120
1. SHELL	1423.30	9.95	70.9	73.5	76.5	78.0	80.9	85.2	1.83
2. SHELL	1451.15	34.79	5.5	5.6	5.6	5.6	5.6	5.6	1.58
3	1531.15	34.85	6.5	6.6	6.8	7.0	7.1	7.4	1.72
4	1569.01	33.81	5.9	6.1	6.2	6.3	6.4	6.6	1.60
7	1570.38	24.91	15.2	16.2	17.1	17.8	18.5	19.9	1.89
10	1574.28	33.88	6.6	6.8	6.9	7.0	7.1	7.3	1.68
14	1580.70	30.31	11.4	11.5	11.7	12.0	12.3	12.5	1.74
15	1581.03	32.85	6.1	6.1	6.2	6.2	6.2	6.3	1.55
16	1581.34	32.33	5.5	5.6	5.7	5.7	5.8	5.9	1.46
19	1610.20	34.02	6.4	6.5	6.5	6.6	6.6	6.7	1.69

[redacted]w approximately: [redacted]125 ohm metre at 22 degrees C.
Remark: For calculation of the m-factor in-situ porosity under isostatic loading conditions was used.

OB/

OK TABLE I a - Formation-Resistivity Factor as a Function of Isostatic Pressure (First Loading Cycle) of Core Samples from Well 31/2-4

POR /FF tt /PNC M

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Formation-resistivity factor, at (kg/cm**2)						m-factor, at(kg/cm**2)
			50	75	100	120	150	200	120
20	1624.12	23.99	17.1	17.6	18.1	18.4	18.8	19.3	1.96
21	1628.90	34.04	5.2	5.3	5.5	5.6	5.7	5.9	1.47
22	1633.45	1.93	1053.9	1206.2	1338.4	1434.6	1601.1	1882.8	1.81
23	1637.85	28.40	7.5	7.8	8.0	8.2	8.5	8.6	1.55
24	1639.24	29.24	7.0	7.3	7.3	7.3	7.4	7.6	1.53
25	1641.13	34.77	4.9	4.9	5.1	5.2	5.3	5.5	1.44
26	1645.40	25.93	11.0	11.3	11.5	11.6	11.8	12.1	1.75

Rw approximately: 0.125 ohm metre at 22 degrees C.
Remark: For calculation of the m-factor in-situ porosity under isostatic loading conditions was used.
Remark: For the samples given the FRF/in-situ porosity relation may be expressed by FRF = 0.71*PHI**-1.92 (r for log(FRF)/log(PHI) = 0.99)

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OK [illegible]BLE II - Porosity at Uniaxial Pressures * (First Loading Cycle) of Core Samples from Well 31/2-4

√ POR /PORU /PNC

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Porosity, % bv, at (kg/cm**2, uniaxial stress)						% bv poro*	φ200 / φatmos
			50	75	100	120	150	200	200	
1, SHELL	1423.30	9.95	9.77	9.66	9.60	9.54	9.47	9.35	9.41	.9457
2, SHELL	1451.15	34.79	34.49	34.35	34.22	34.12	33.99	33.79	34.13	.981
3	1531.15	34.85	34.19	33.82	33.53	33.29	32.92	32.34	.3317	.9518
4	1569.01	33.81	33.30	33.03	32.75	32.56	32.35	31.81	.3246	.9601
7	1570.38	24.91	23.99	23.57	23.19	23.00	22.70	22.31	.2291	9197
10	1574.28	33.88	33.22	32.94	32.64	32.43	32.15	31.72	.3242	.9569
14	1580.70	30.31	27.99	27.35	26.91	26.56	26.16	25.66	.2691	.8878
15	1581.03	32.85	32.11	31.90	31.76	31.65	31.51	31.32	.3181	.9683
16	1581.34	32.33	31.74	31.47	31.22	31.01	30.77	30.37	.3098	.9582
19	1610.20	34.02	33.65	33.49	33.36	33.26	33.13	32.94	.333	.9788

* The measurements were carried out under hydrostatic pressure conditions (first loading cycle). For conversion to uniaxial pressure conditions a Poisson ratio of .30 was assumed.

* regnet bare på φ reduksjon

OB/

OK TABLE II a - Porosity at Uniaxial Pressures * (First Loading Cycle) of Core Samples from Well 31/2-4

V POR /PORU /PNC

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Porosity, % bv, at (kg/cm**2, uniaxial stress)							
			50	75	100	120	150	200		
20	1624.12	23.99	23.49	23.33	23.20	23.12	23.00	22.82	.2309	9625
21	1628.90	34.04	33.31	32.91	32.62	32.35	31.97	31.41	.3226	.9477
22	1633.45	1.93	1.89	1.86	1.85	1.84	1.83	1.82	.0182	~~1.2~~ IKKE BRUKT
23	1637.85	28.40	27.63	27.33	26.97	26.72	26.41	25.92	.2658	.9359
24	1639.24	29.24	28.72	28.45	28.20	28.06	27.83	27.44	.2794	.9556
25	1641.13	34.77	34.02	33.62	33.30	33.07	32.71	32.19	.3304	.9503
26	1645.40	25.93	25.57	25.39	25.25	25.15	25.02	24.83	.2511	.9682

.952

* The measurements were carried out under hydrostatic pressure conditions (first loading cycle). For conversion to uniaxial pressure conditions a Poisson ratio of .30 was assumed.

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OK [illegible]BLE III - [illegible]ractional Change in Pore Volume as a Function of Hydrostatic Pressure (First Loading Cycle) of Core Samples from Well 31/2-4

VPOR /PNC /DVPH

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	DVp/Vpo at (kg/cm**2)					
			50	75	100	120	150	200
1 SHELL	1423.30	9.95	.03327	.05161	.06359	.07442	.08642	.10741
2 SHELL	1451.15	34.79	.02119	.03108	.03998	.04725	.05659	.07006
3	1531.15	34.85	.04694	.07214	.09207	.10897	.13382	.17255
4	1569.01	33.81	.03657	.05548	.07474	.08837	.10315	.13966
7	1570.38	24.91	.07817	.11310	.14463	.16069	.18516	.21644
10	1574.28	33.88	.04672	.06667	.08764	.10197	.12132	.15070
14	1580.70	30.31	.17134	.21726	.24787	.27195	.29925	.33321
15	1581.03	32.85	.05390	.06834	.07834	.08618	.09597	.10985
16	1581.34	32.33	.04319	.06246	.08058	.09549	.11234	.14016
19	1610.20	34.02	.02670	.03758	.04726	.05404	.06330	.07645

03/

OK TABLE III a - Fractional Change in Pore Volume as a Function of Hydrostatic Pressure (First Loading Cycle) of Core Samples from Well 31/2-4

VPOR /PNC /DVPH

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	DVp/Vpo at (kg/cm**2)					
			50	75	100	120	150	200
20	1624.12	23.99	.04385	.05784	.06850	.07614	.08595	.10125
21	1628.90	34.04	.05237	.08010	.10024	.11876	.14437	.18192
22	1633.45	1.93	.03815	.06302	.06808	.07486	.08744	.09084
23	1637.85	28.40	.06045	.08357	.11148	.13091	.15388	.19068
24	1639.24	29.24	.04017	.06066	.07943	.08999	.10747	.13642
25	1641.13	34.77	.05306	.08065	.10235	.11770	.14194	.17681
26	1645.40	25.93	.03034	.04461	.05646	.06507	.07553	.09136

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ok [illegible]BLE IV. - Pore Compressibility as a Function of Uniaxial Pressure *
(First Loading Cycle) of Core Samples from Well 31/2-4

V POR /PNC2 /CPU

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Pore Compressibility x10**4/kg/cm**2 at Uniaxial Pressure of (kg/cm**2)					
			25	63	88	110	135	175
1 SHELL	1423.30	9.95	4.1	4.5	3.0	3.4	2.5	2.6
2 SHELL	1451.15	34.79	2.6	2.4	2.2	2.3	1.9	1.7
3	1531.15	34.85	5.8	6.2	4.9	5.2	5.1	4.8
4	1569.01	33.81	4.5	4.7	4.8	4.2	3.0	4.5
7	1570.38	24.91	9.7	8.6	7.8	5.0	5.0	3.9
10	1574.28	33.88	5.8	4.9	5.2	4.4	4.0	3.6
14	1580.70	30.31	21.	11.	7.6	7.5	5.6	4.2
15	1581.03	32.85	6.7	3.6	2.5	2.4	2.0	1.7
16	1581.34	32.33	5.3	4.8	4.5	4.6	3.5	3.4
19	1610.20	34.02	3.3	2.7	2.4	2.1	1.9	1.6

* The measurements were carried out under hydrostatic pressure conditions (first loading cycle). For conversion to uniaxial pressure conditions a Poisson ratio of .30 was assumed.

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OK. TABLE IV a - Pore Compressibility as a Function of Uniaxial Pressure * (First Loading Cycle) of Core Samples from Well 31/2-4

V POR PNC2 CPU

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Pore Compressibility x10**4/kg/cm**2 at Uniaxial Pressure of (kg/cm**2)					
			25	63	88	110	135	175
20	1624.12	23.99	5.4	3.5	2.6	2.4	2.0	1.9
21	1628.90	34.04	6.5	6.9	5.0	5.7	5.3	4.6
22	1633.45	1.93	4.7	6.2	1.3	2.1	2.6	0.42
23	1637.85	28.40	7.5	5.7	6.9	6.0	4.7	4.6
24	1639.24	29.24	5.0	5.1	4.6	3.3	3.6	3.6
25	1641.13	34.77	6.6	6.8	5.4	4.8	5.0	4.3
26	1645.40	25.93	3.8	3.5	2.9	2.7	2.2	2.0

* The measurements were carried out under hydrostatic pressure conditions (first loading cycle). For conversion to uniaxial pressure conditions a Poisson ratio of .30 was assumed.

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OK. TABLE V Cation-Exchange Capacity of Core Samples from Well 31/2-4

V POR GRDENS QV

Sample, No.	Depth, (m.)	Porosity, % bv (atm.)	Permea- bility, mD	Grain density, (g/ml) G/CC	Qv (m.eq/ml.pv) MEQ/CC
1 . SHELL	1423.30	9.9	--	2.69	0.08
2 . SHELL	1451.15	34.8	--	2.64	0.00
3	1531.15	34.9	--	2.78	0.03
4	1569.01	33.8	--	2.61	0.03
7	1570.54	24.9	--	2.60	0.10
10	1574.28	33.9	--	2.62	0.01
12	1576.10	--	--	--	0.31* CEC
14	1580.70	30.3	--	2.82	0.09
15	1581.03	32.8	--	2.65	0.02
16	1581.34	32.3	--	2.66	0.04
19	1610.20	34.0	--	2.63	0.04
20	1624.12	24.0	--	2.65	0.17

Remark: For the samples given the Qv / Porosity relation may be expressed by Qv = (0.372 - PHI)/(3.632 x PHI) (r for relation = 0.924)

* Units of meq/100 gram.

OK TABLE VI - FRF and FRF* at In-situ Isostatic Pressure of 120 (kg/cm**2) (First Loading Cycle) for Core Samples from Well 31/2-4

POROB FF M QV ~~FFSTAB~~ MSTAF

Sample, no.	Depth (m.)	Porosity, Isostatic % bv	✓ FRF	✓ m	Qv	FRF*	m*
1 SHELL	1423.30	9.28	78.0	1.83	0.080	80.5	1.85
2 SHELL	1451.15	33.70	5.6	1.58	0.004	5.6	1.58
3	1531.15	32.28	7.0	1.72	0.032	7.0	1.73
4	1569.01	31.77	6.3	1.60	0.027	6.4	1.61
7	1570.38	21.78	17.8	1.89	0.101	18.5	1.91
10	1574.28	31.51	7.0	1.68	0.012	7.0	1.68
14	1580.70	24.05	12.0	1.74	0.092	12.4	1.77
15	1581.03	30.89	6.2	1.55	0.021	6.2	1.56
16	1581.34	30.17	5.7	1.46	0.039	5.8	1.47
19	1610.20	32.78	6.6	1.69	0.041	6.7	1.70

Rw approximately: 0.125 ohm metre at 22 degrees C. (B = 3.13)

+ Calculated from Qv = (0.37-PHI)/(3.63*PHI)

OK TABLE VI a - FRF and FRF* at In-situ Isostatic Pressure of 120 (kg/cm**2) (First Loading Cycle) for Core Samples from Well 31/2-4

POROB QV FFSTAROB MSTAR

Sample, no.	Depth (m.)	Porosity, Isostatic % bv	√FRF	√ m	Qv	FRF*	m*
20	1624.12	22.57	18.4	1.96	0.174	19.7	2.00
21	1628.90	31.26	5.6	1.47	0.026+	5.6	1.48
22	1633.45	1.79	1434.6	1.81	5.029+	4256.8	2.08
23	1637.85	25.64	8.2	1.55	0.085+	8.5	1.57
24	1639.24	27.32	7.3	1.53	0.075+	7.5	1.56
25	1641.13	31.99	5.2	1.44	0.019+	5.2	1.45
26	1645.40	24.66	11.6	1.75	0.120+	12.2	1.79

Rw approximately: 0.125 ohm metre at 22 degrees C. (B = 3.13)
Remark: For these samples the FRF*/porosity relation may be expressed by FRF*= 0.48*PHI**-2.25 (r for log(FRF*)/log(PHI)= 0.99)
+ Calculated from Qv = (0.37-PHI)/(3.63*PHI)

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OK [illegible]BLE VII - Porosity at Isostatic Pressures (First Loading Cycle) of Core Samples from Well 31/2-4

V POR /PNC /POR H

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Porosity, % bv, at (kg/cm**2, isostatic stress)						%bvng*	ϕ_{200}/ϕ_{atmos}
			50	75	100	120	150	200	200	
1	1423.30	9.95	9.65	9.49	9.38	9.28	9.17	8.98	.0907	.912
2	1451.15	34.79	34.31	34.08	33.87	33.70	33.48	33.16	.3371	.9534
3	1531.15	34.85	33.77	33.17	32.69	32.28	31.67	30.69	.3202	.9189
4	1569.01	33.81	32.98	32.54	32.09	31.77	31.41	30.53	.3157	.9336
7	1570.38	24.91	23.42	22.73	22.10	21.78	21.28	20.63	.2165	.8652
10	1574.28	33.88	32.81	32.35	31.85	31.51	31.04	30.32	.3144	.9288
14	1580.70	30.31	26.49	25.40	24.65	24.05	23.36	22.48	.2439	.8047
15	1581.03	32.85	31.64	31.31	31.08	30.89	30.66	30.34	.3112	.9474
16	1581.34	32.33	31.37	30.93	30.52	30.17	29.78	29.12	.3019	.9306
19	1610.20	34.02	33.41	33.16	32.94	32.78	32.57	32.26	.3284	.9663

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OK TABLE VII a - Porosity at Isostatic Pressures (First Loading Cycle) of Core Samples from Well 31/2-4

√ POR /PMC /PORH

Sample, no.	Depth (m.)	Porosity, % bv (atm.)	Porosity, % bv, at (kg/cm**2, isostatic stress)						% bv my	
			50	75	100	120	150	200	200	200
20	1624.12	23.99	23.18	22.92	22.72	22.57	22.39	22.09	.2252	.9386
21	1628.90	34.04	32.85	32.19	31.71	31.26	30.63	29.69	.3104	.9119
22	1633.45	1.93	1.86	1.81	1.80	1.79	1.77	1.76	.0176	—
23	1637.85	28.40	27.15	26.66	26.06	25.64	25.13	24.30	.2534	.8922
24	1639.24	29.24	28.39	27.96	27.55	27.32	26.94	26.30	.271	.9267
25	1641.13	34.77	33.54	32.89	32.36	31.99	31.38	30.50	.3186	.9163
26	1645.40	25.93	25.34	25.06	24.83	24.66	24.45	24.13	.2457	.9476

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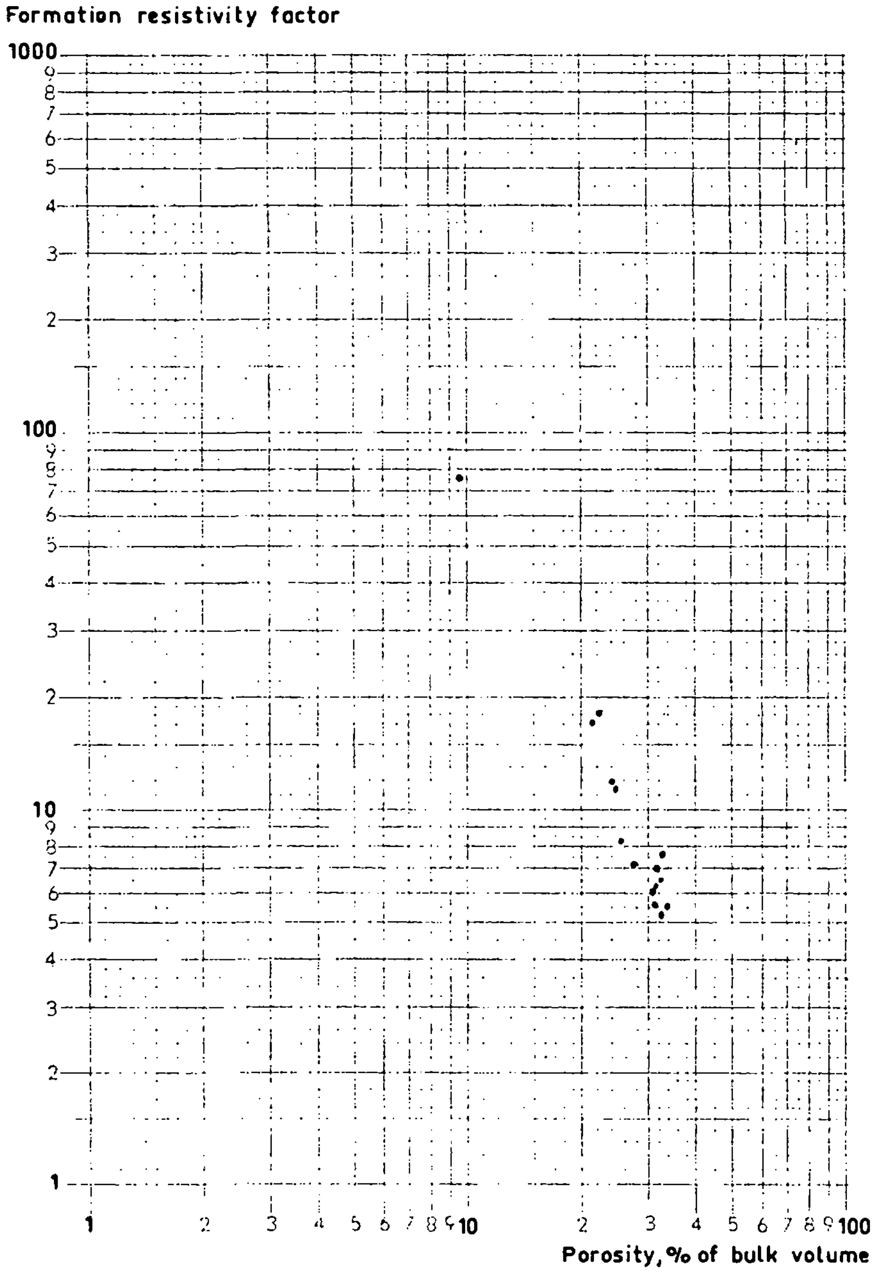


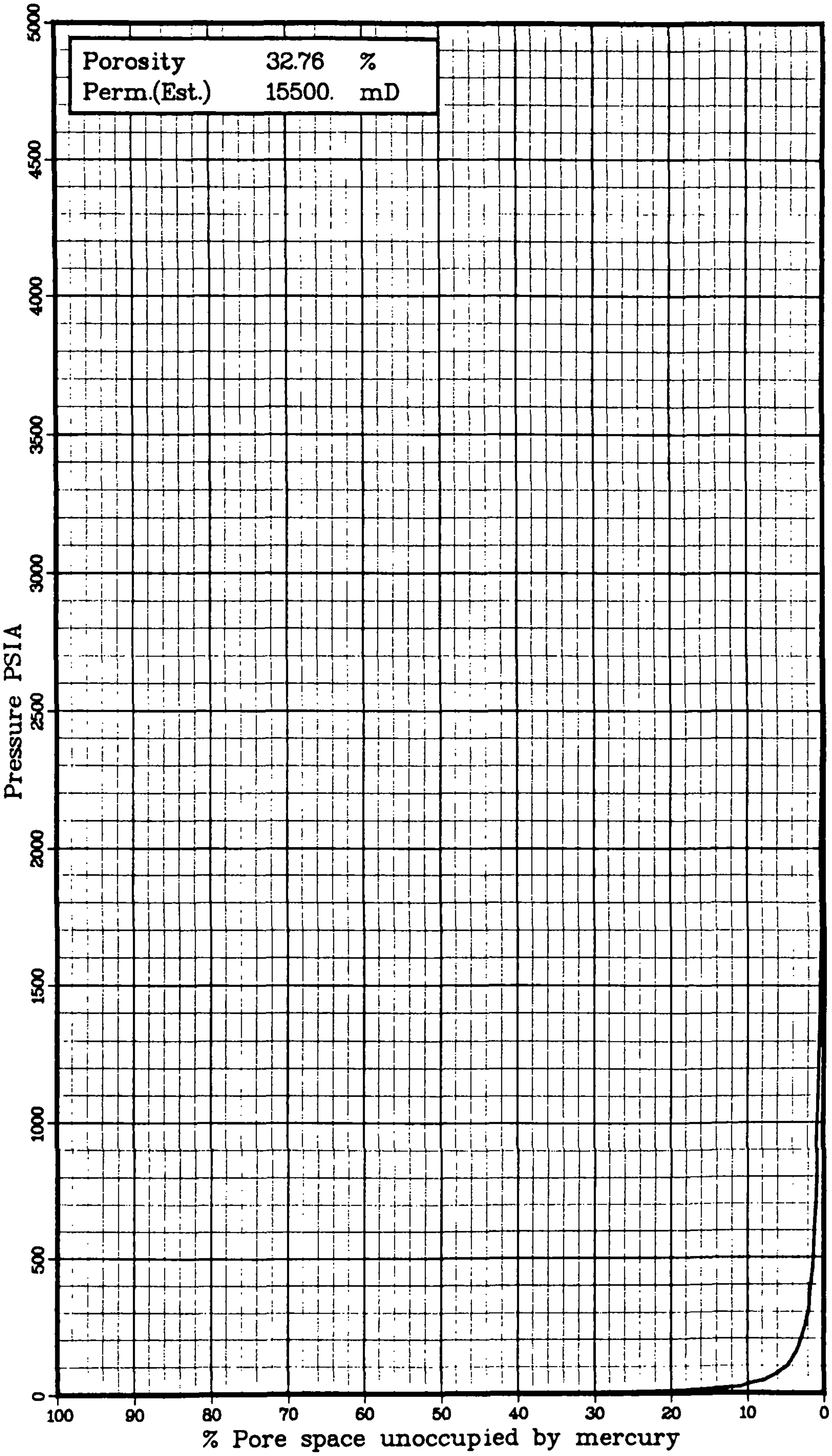
FORMATION-RESISTIVITY FACTOR VERSUS POROSITY AT AN ISOSTATIC PRESSURE OF 120 KG/CM^2 OF CORE SAMPLES FROM WELL 31/2-4

Fig.1

dr.no.

08 apr 82

displa version 8.2



Mercury capillary pressure curve

WELL 31/2-4 SAMPLE 2A DEPTH 1451.15 METER

RKER 82.243

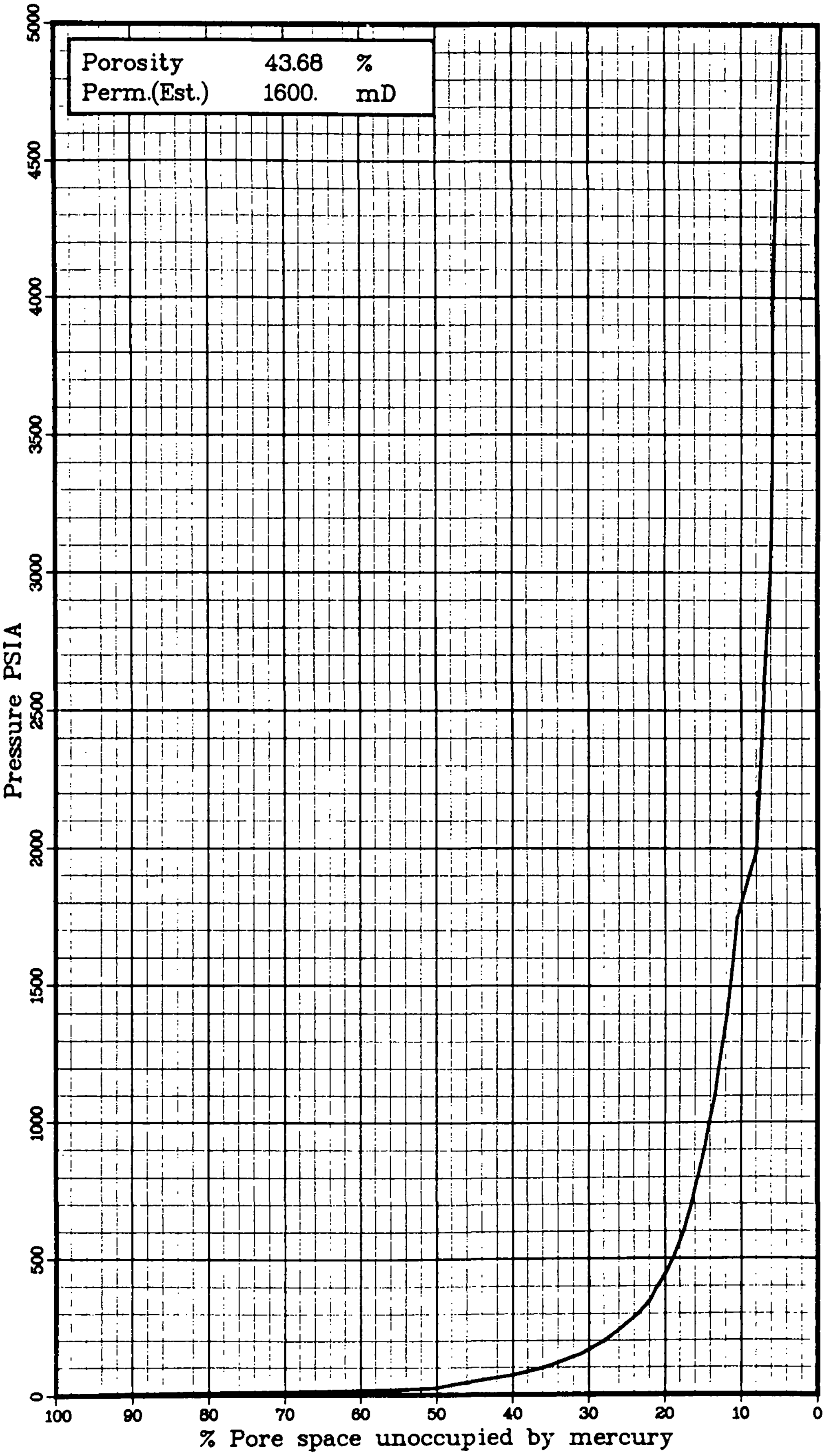
author: bur
design:

fig. 2

dr.no.

08 apr 82

dispia version 8.2



Mercury capillary pressure curve

WELL 31/2-4 SAMPLE 6A DEPTH 1569.72 METER

RKER 82.243

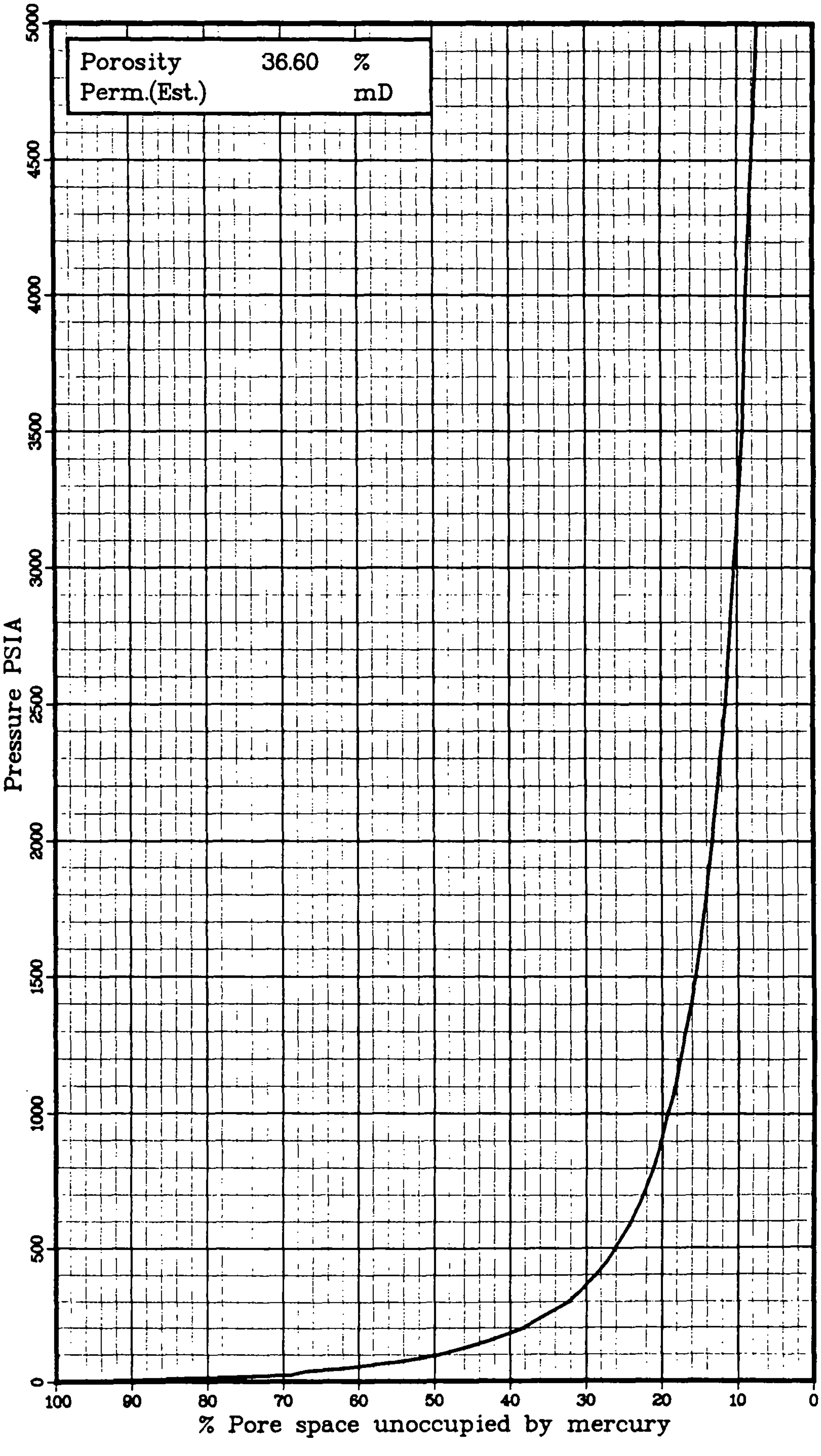
author: bur
design:

fig. 2

dr.no.

08 apr 82

displa version 8.2



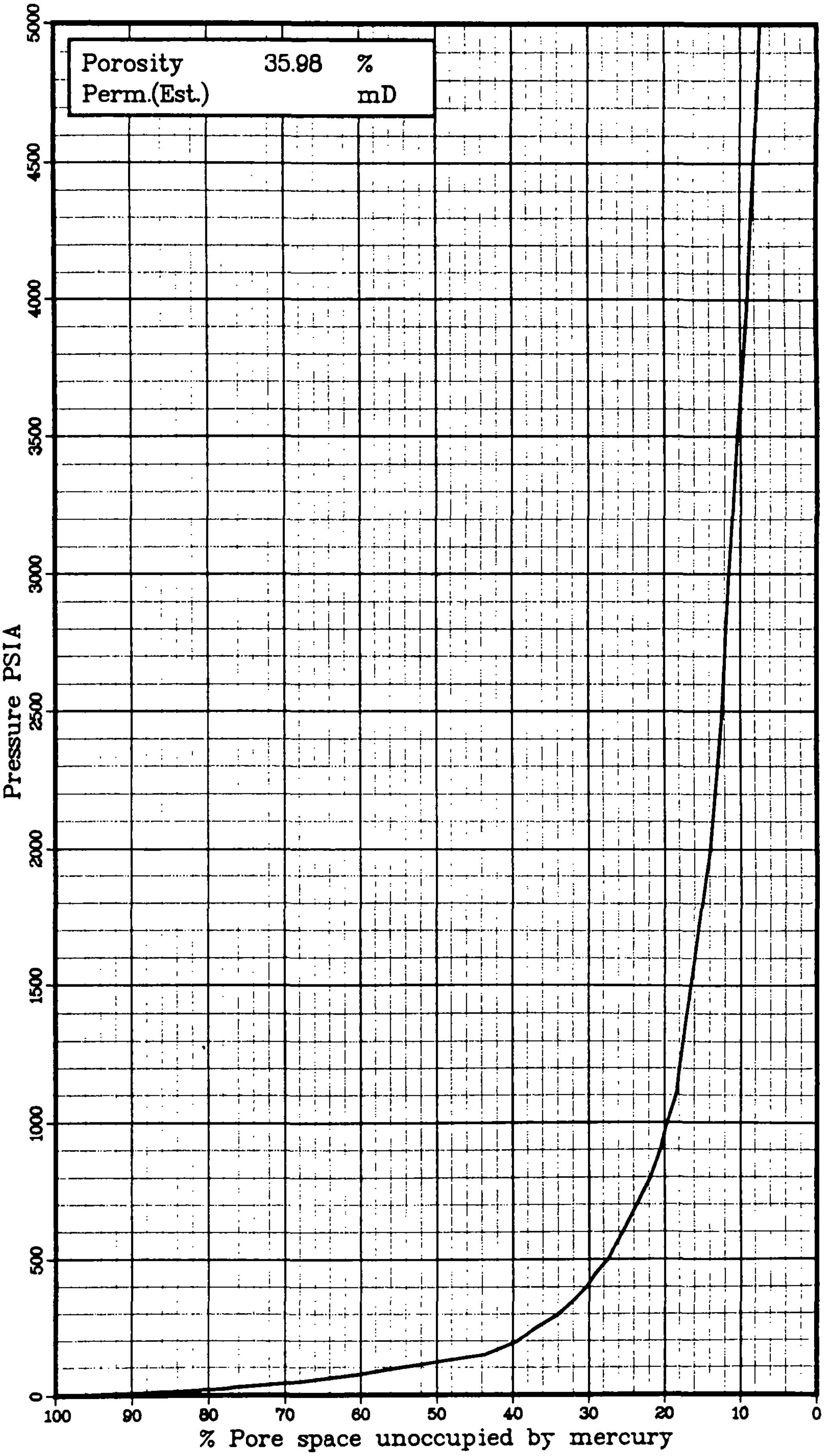
Mercury capillary pressure curve

WELL 31/2-4 SAMPLE 7A DEPTH 1570.38 METER

RKER 82.243

author: bur
design:

fig. 4



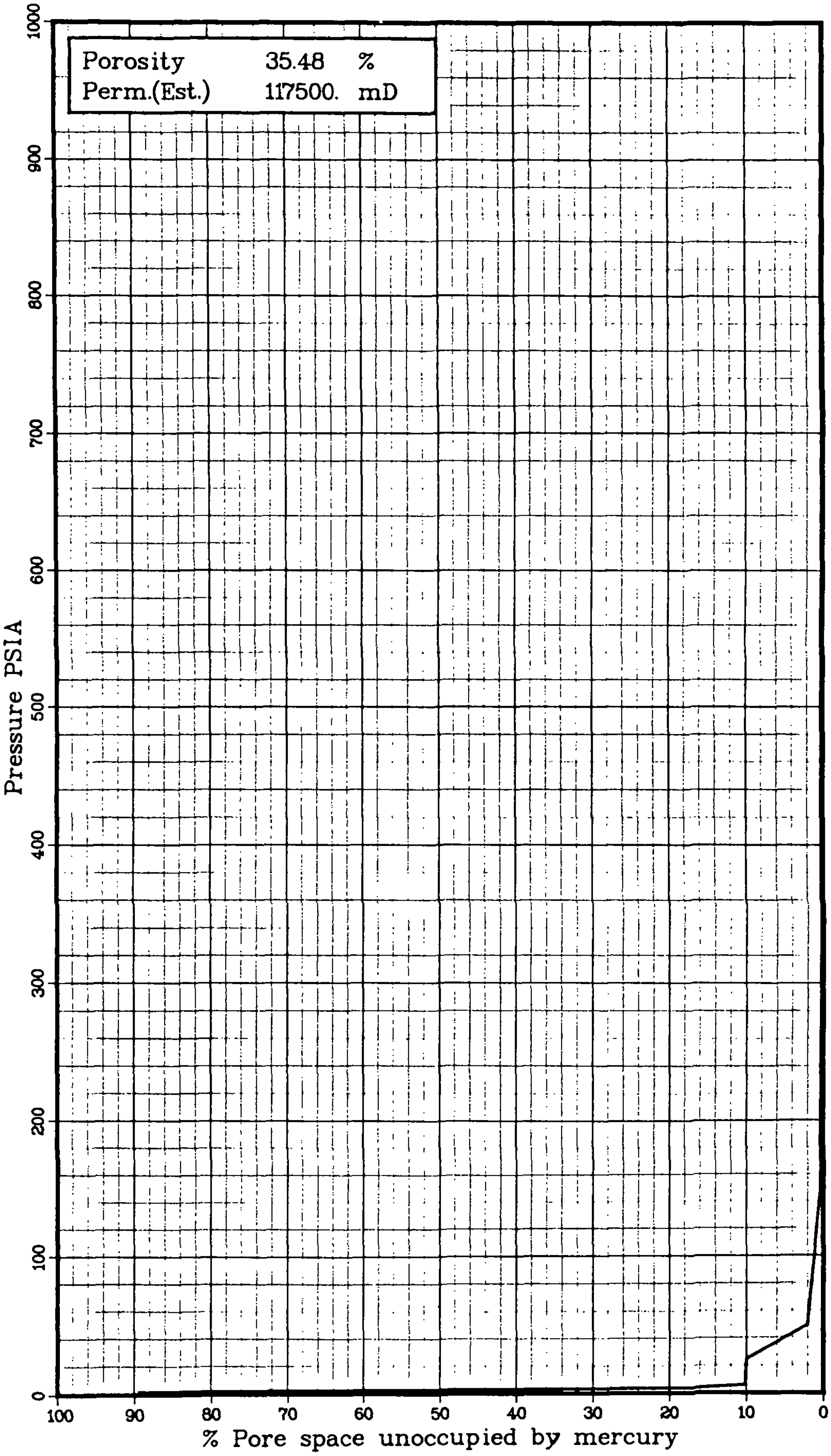
Mercury capillary pressure curve

WELL 31/2-4 SAMPLE 9A DEPTH 1571.31 METE

RKER 82.243

author: bur
design:

fi



Mercury capillary pressure curve

WELL 31/2-4 SAMPLE 8 DEPTH 1574.00 METER

RKER 82.243

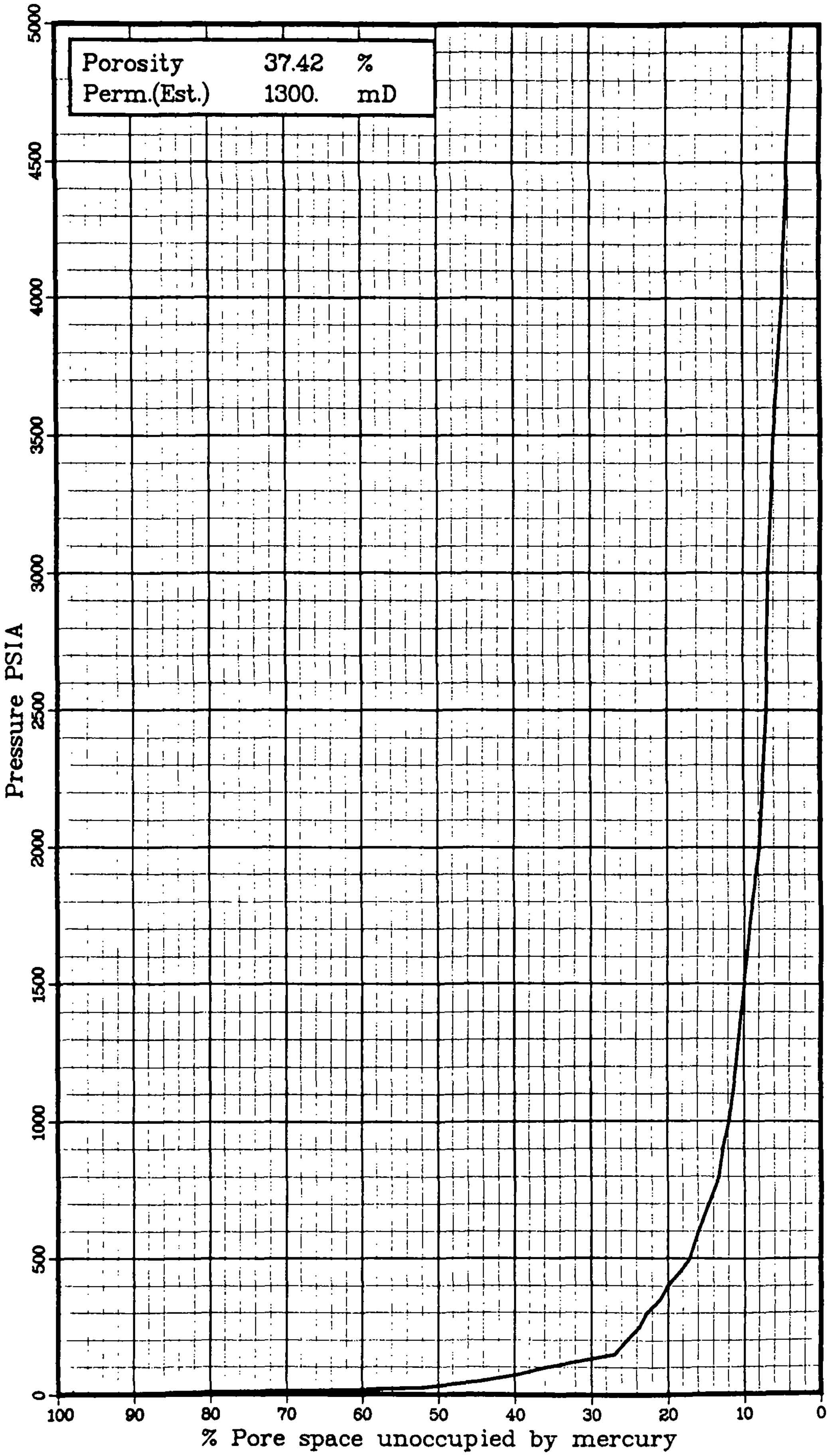
author: bur
design:

fig.6

dr.no.

08 apr 82

displa version 82



Mercury capillary pressure curve

WELL 31/2-4 RKER 82.243 **SAMPLE 13A** **DEPTH 1578.70 METER**

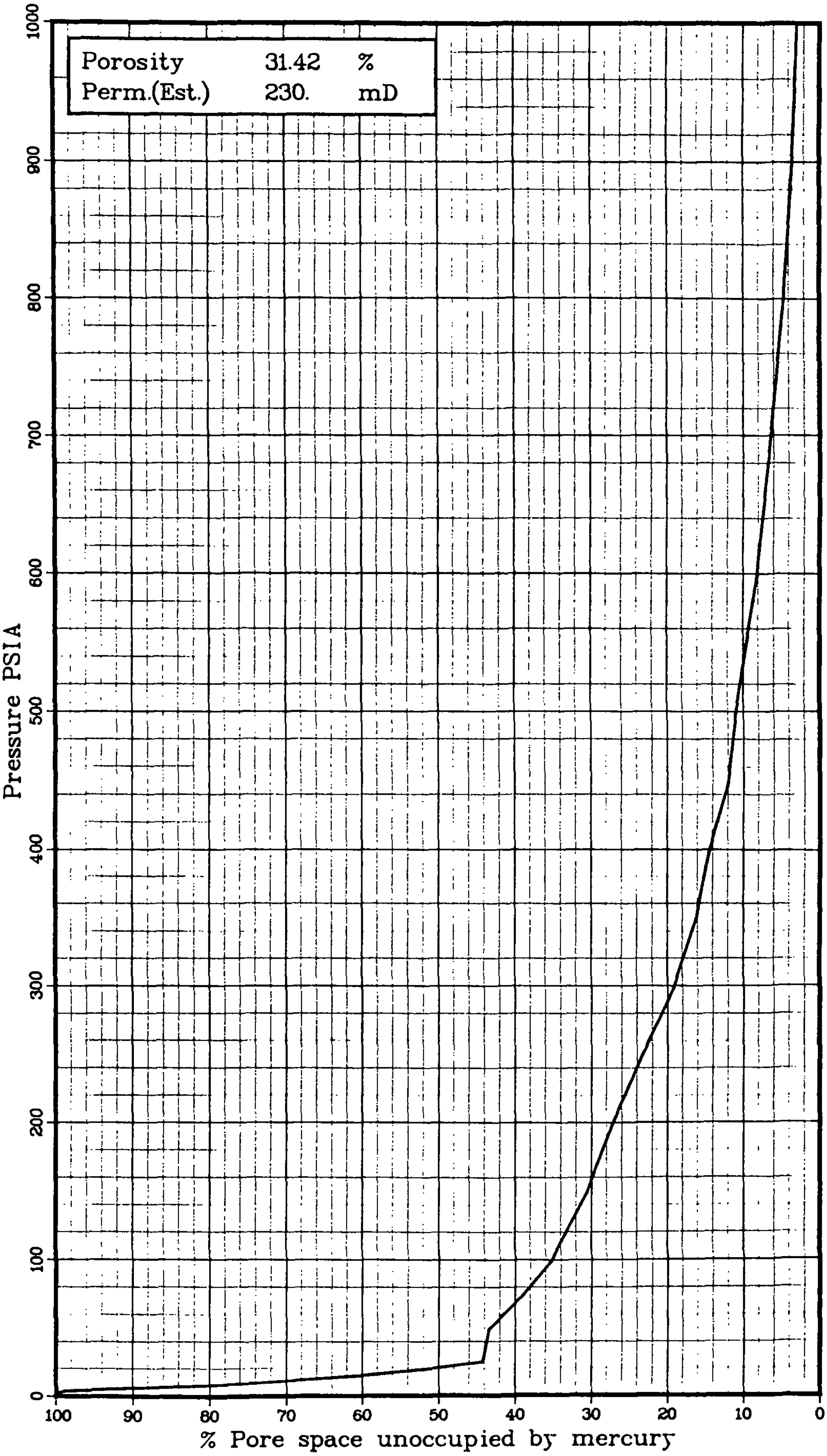
author: bur
design:

fig. 7

dr.no.

18 jun 82

displa version 8.2



Mercury capillary pressure curve

WELL 31/2-4 SAMPLE C DEPTH 1579.00 METER

RKER 82.243

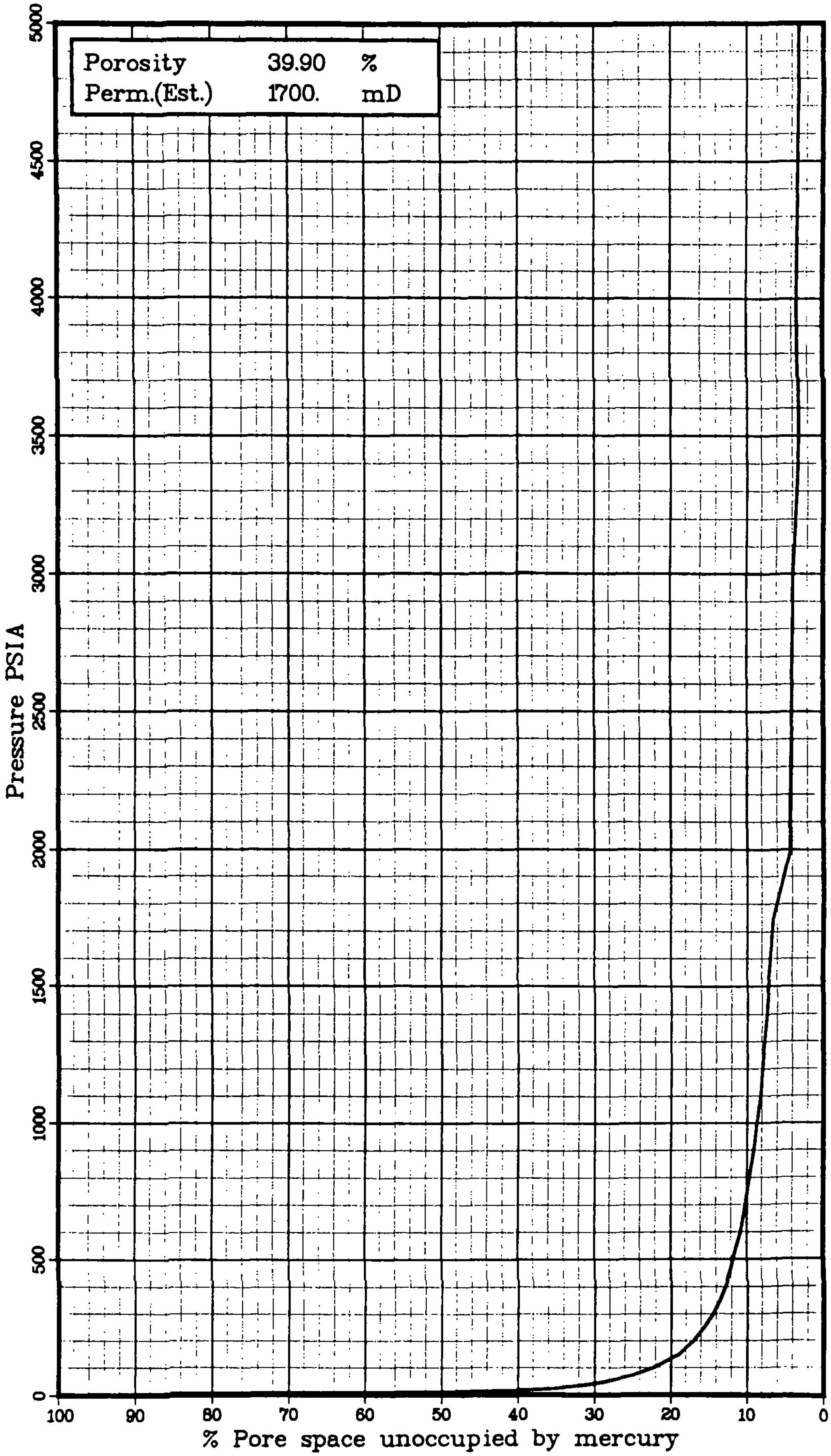
author: bur
design:

fig. 8

dimpla version 8.2

08 apr 82

dr.no.



Mercury capillary pressure curve

WELL 31/2–4 **SAMPLE 16A** **DEPTH 1581.34 METER**

RKER 82.243

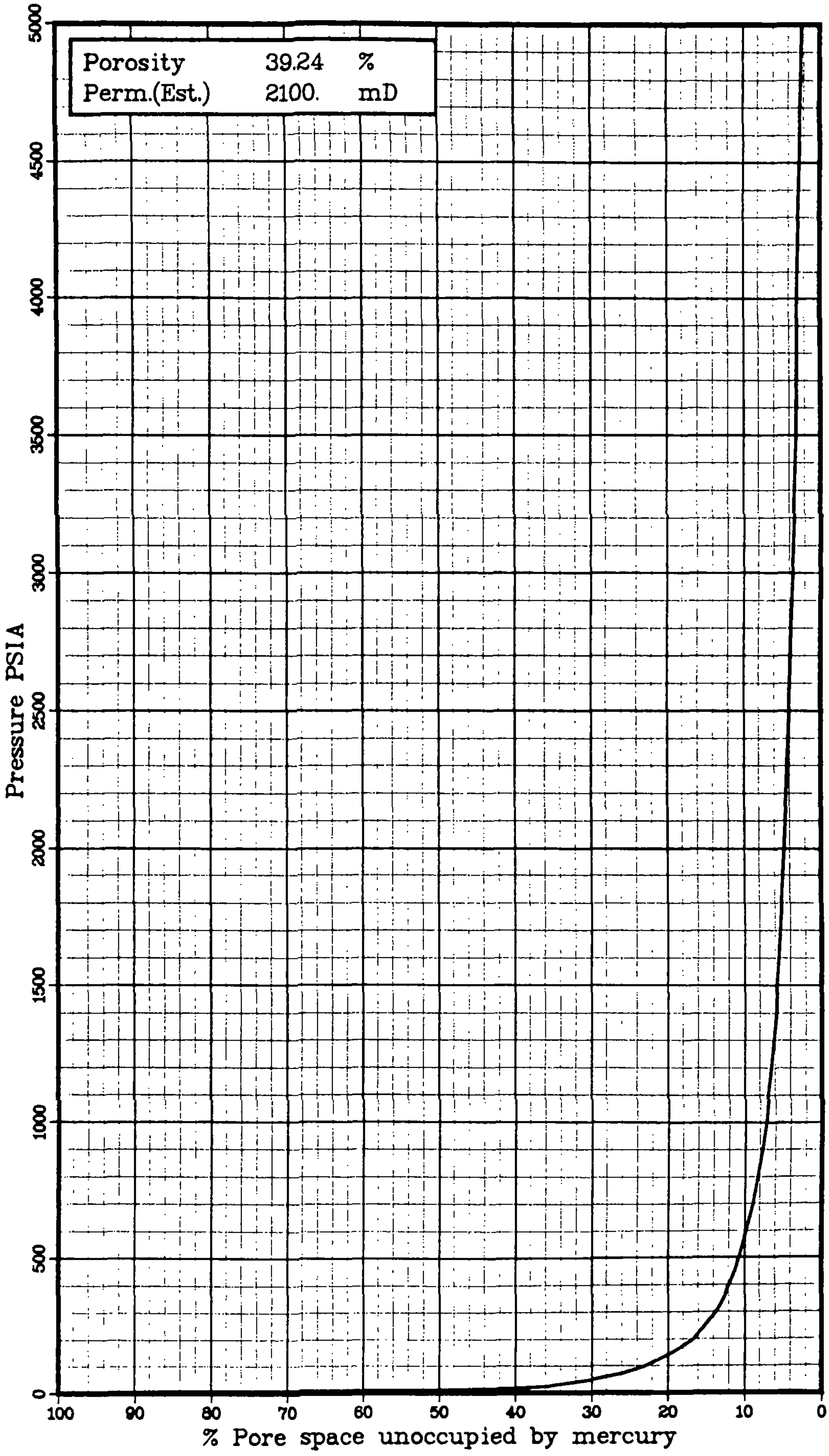
author: bur
design:

fig. 9

dr.no.

08 apr 82

displa version 8.2



Mercury capillary pressure curve

WELL 31/2-4 RKER 82.243 SAMPLE 19A DEPTH 1610.20 METER

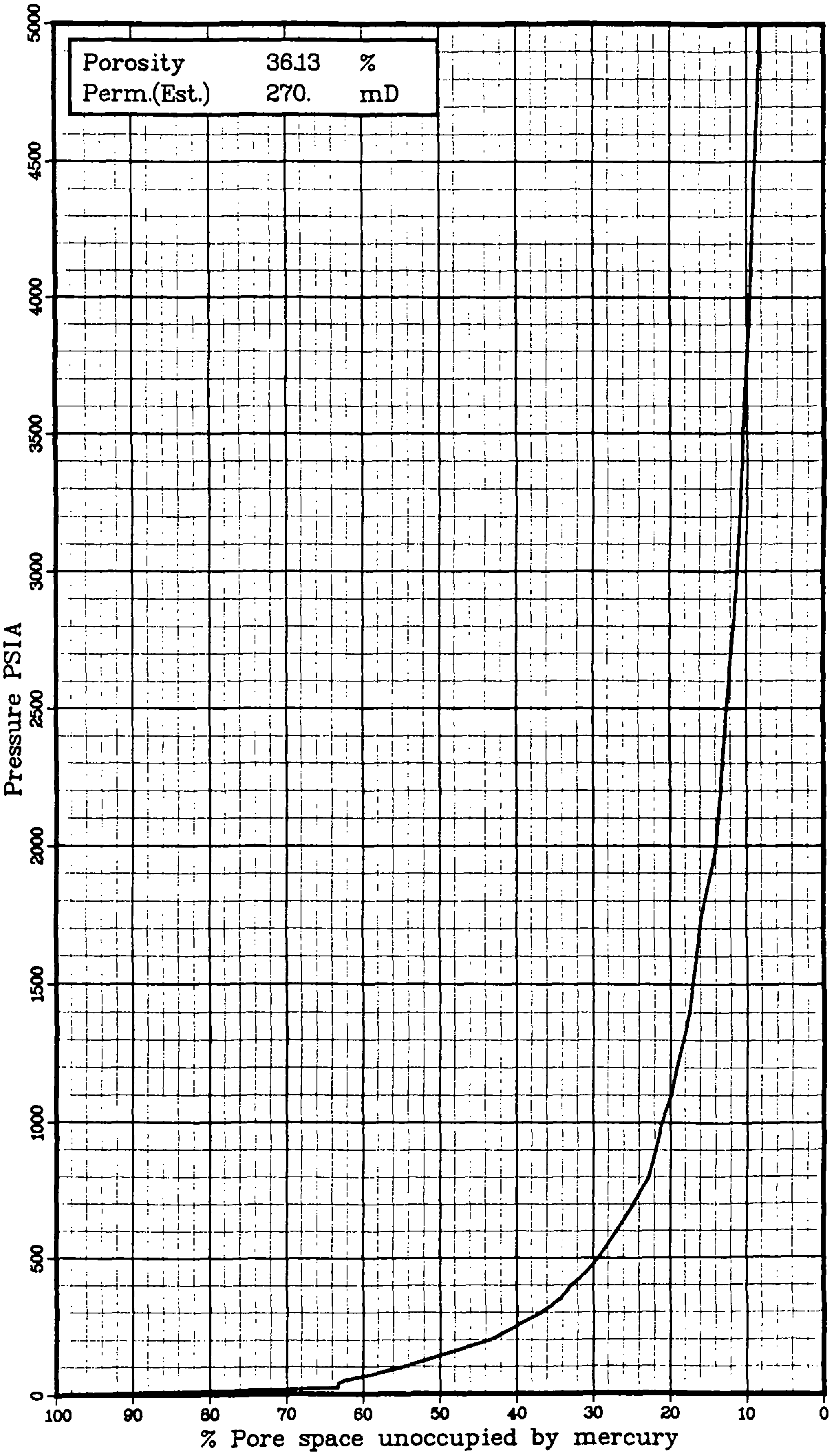
author: bur
design:

fig. 10

dr.no.

08 apr 82

displa version 8.2



Mercury capillary pressure curve

WELL 31/2-4 **SAMPLE** 20A **DEPTH** 1624.12 **METER**

RKER 82.243

author: bur
design:

fig. 11

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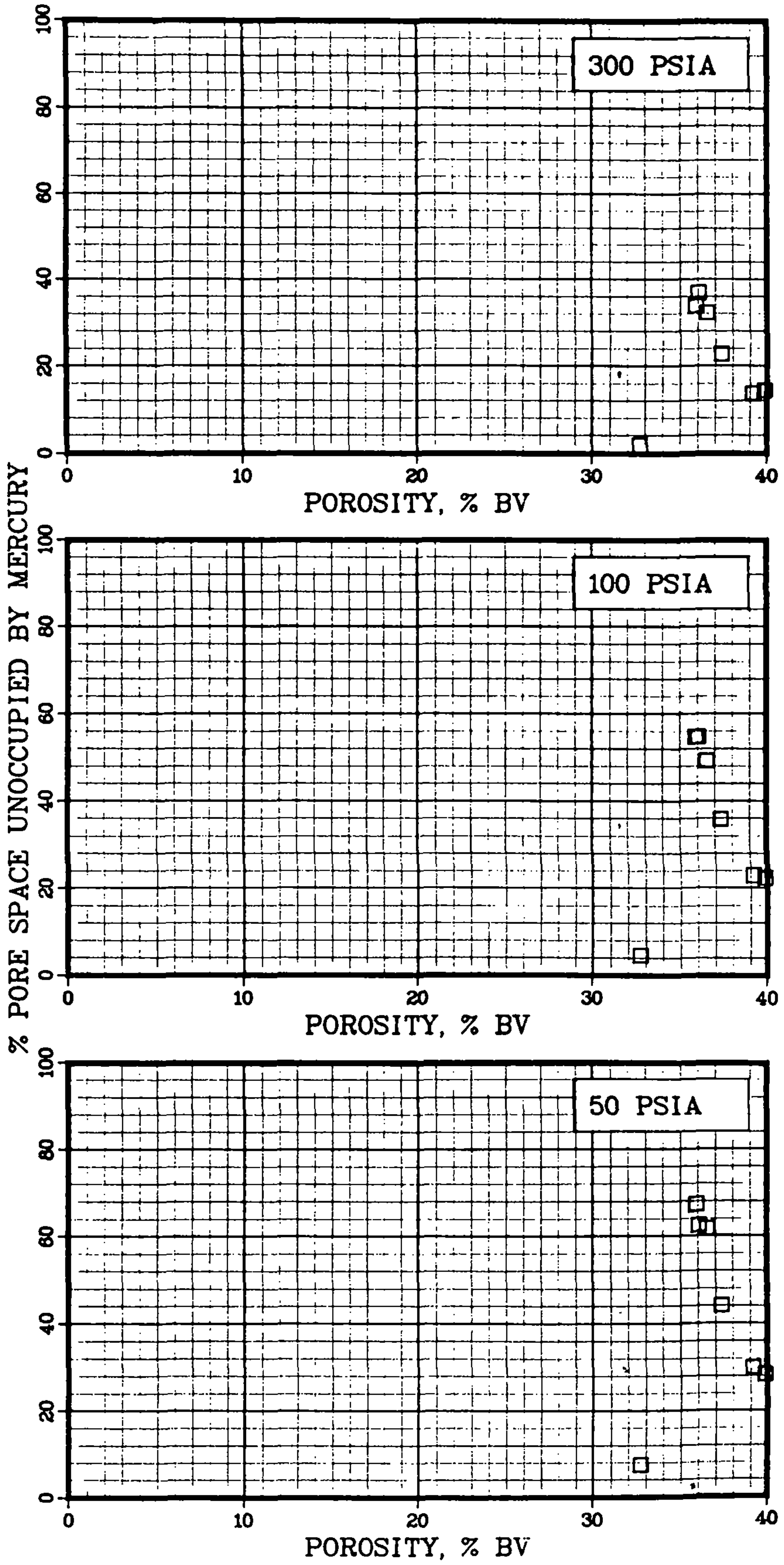
DISSPLA VERSION 8.2



PERCENTAGE OF PORE SPACE UNOCCUPIED BY MERCURY VERSUS, POROSITY AT CAPILLARY PRESSURES OF 50, 100 AND 300 PSIA FOR CORE SAMPLES FROM WELL 31/2-4

AUTHOR: BUR
DESIGN:

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FIG.12

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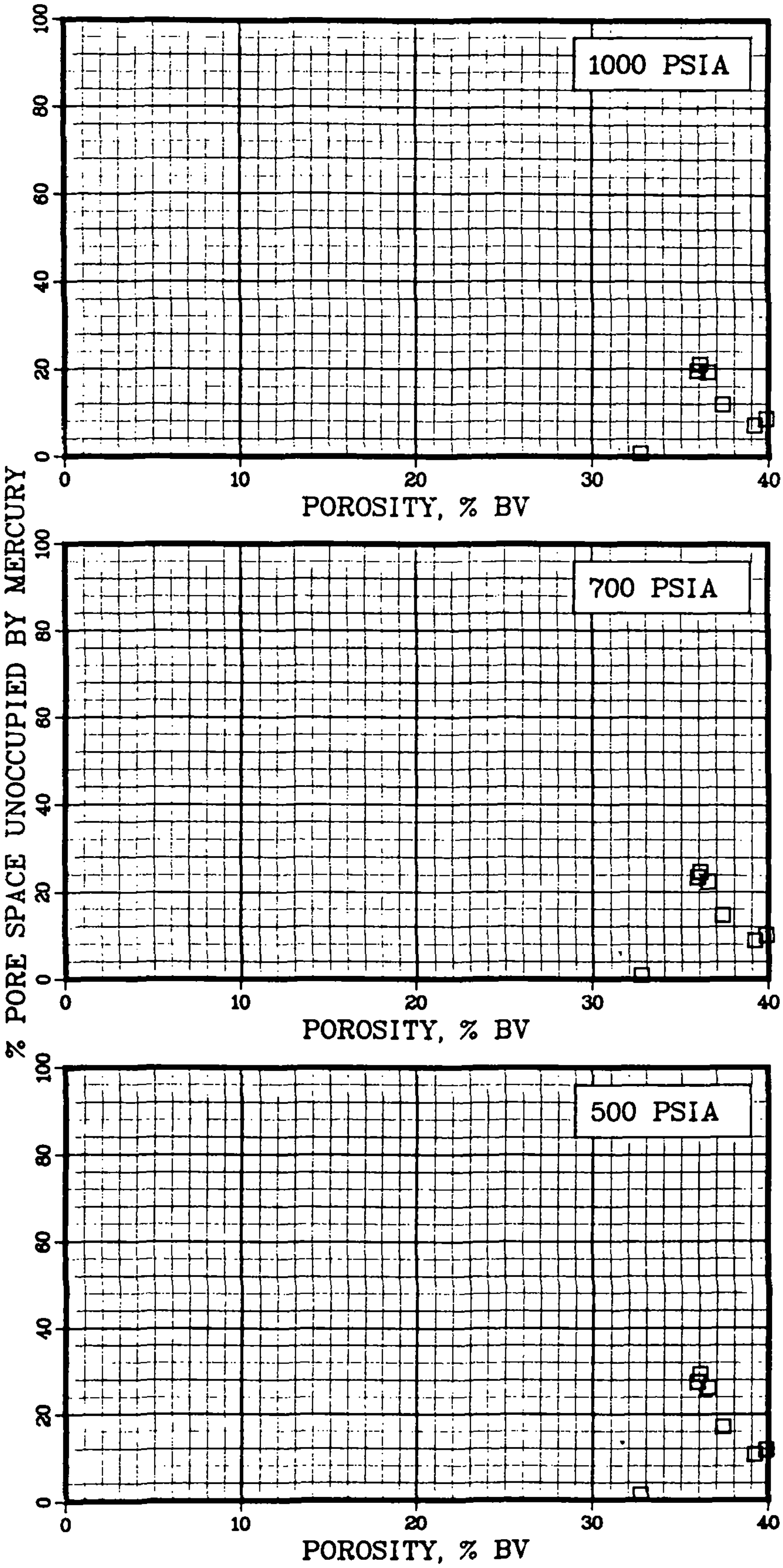
DISSPLA VERSION 8.2



PERCENTAGE OF PORE SPACE UNOCCUPIED BY MERCURY VERSUS POROSITY AT CAPILLARY PRESSURES OF 500, 700 AND 1000 PSIA FOR CORE SAMPLES FROM WELL 31/2-4

RKER 82.243

AUTHOR: BUR
DESIGN:

FIG.13

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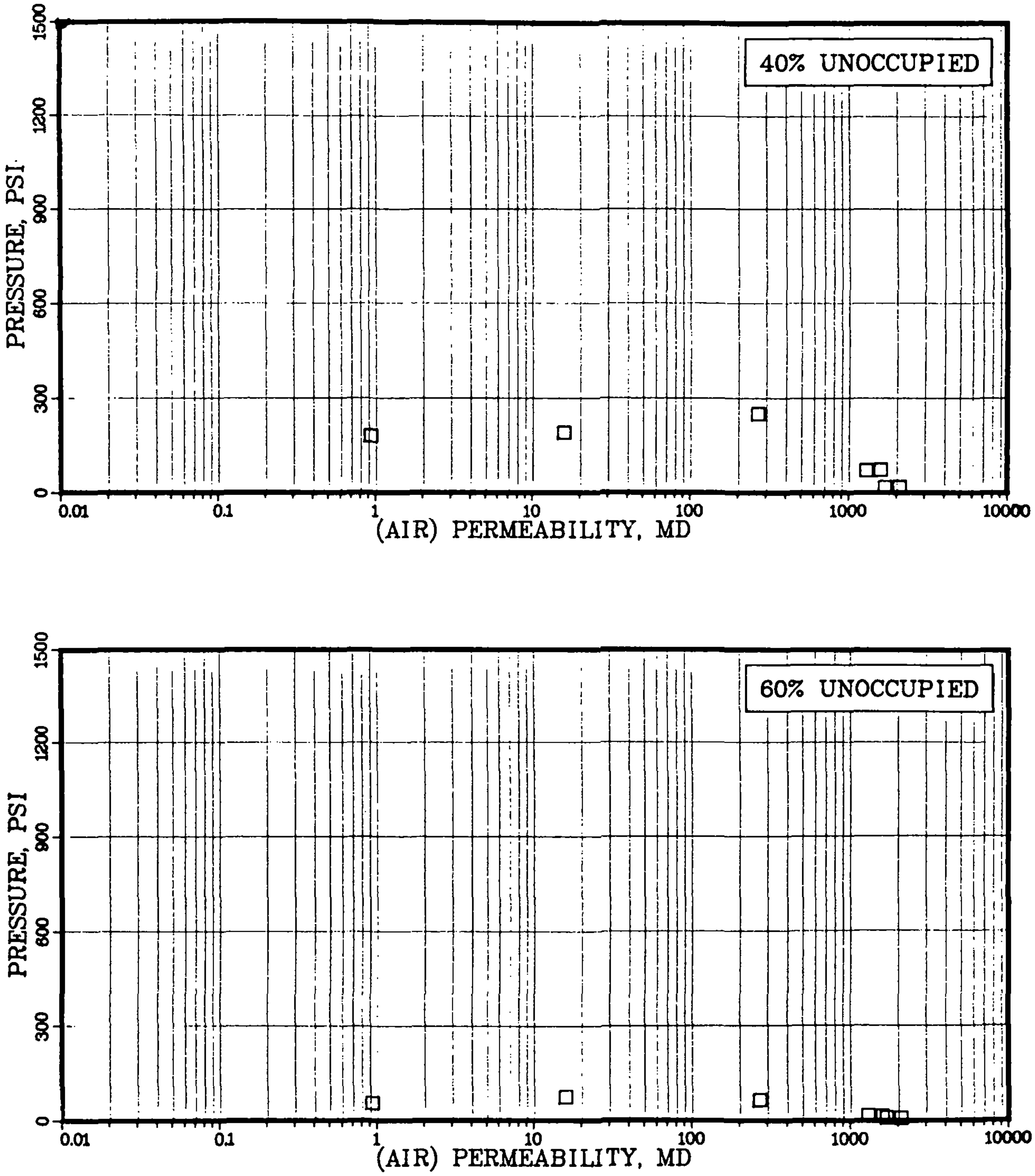
DISSPLA VERSION 8.2



MERCURY/AIR CAPILLARY PRESSURE VERSUS
(AIR) PERMEABILITY AT 60% AND 40% OF PORE SPACE
UNOCCUPIED BY MERCURY FOR WELL 31/2-4

RKER 82.243

AUTHOR: BUR
DESIGN:

FIG. 14

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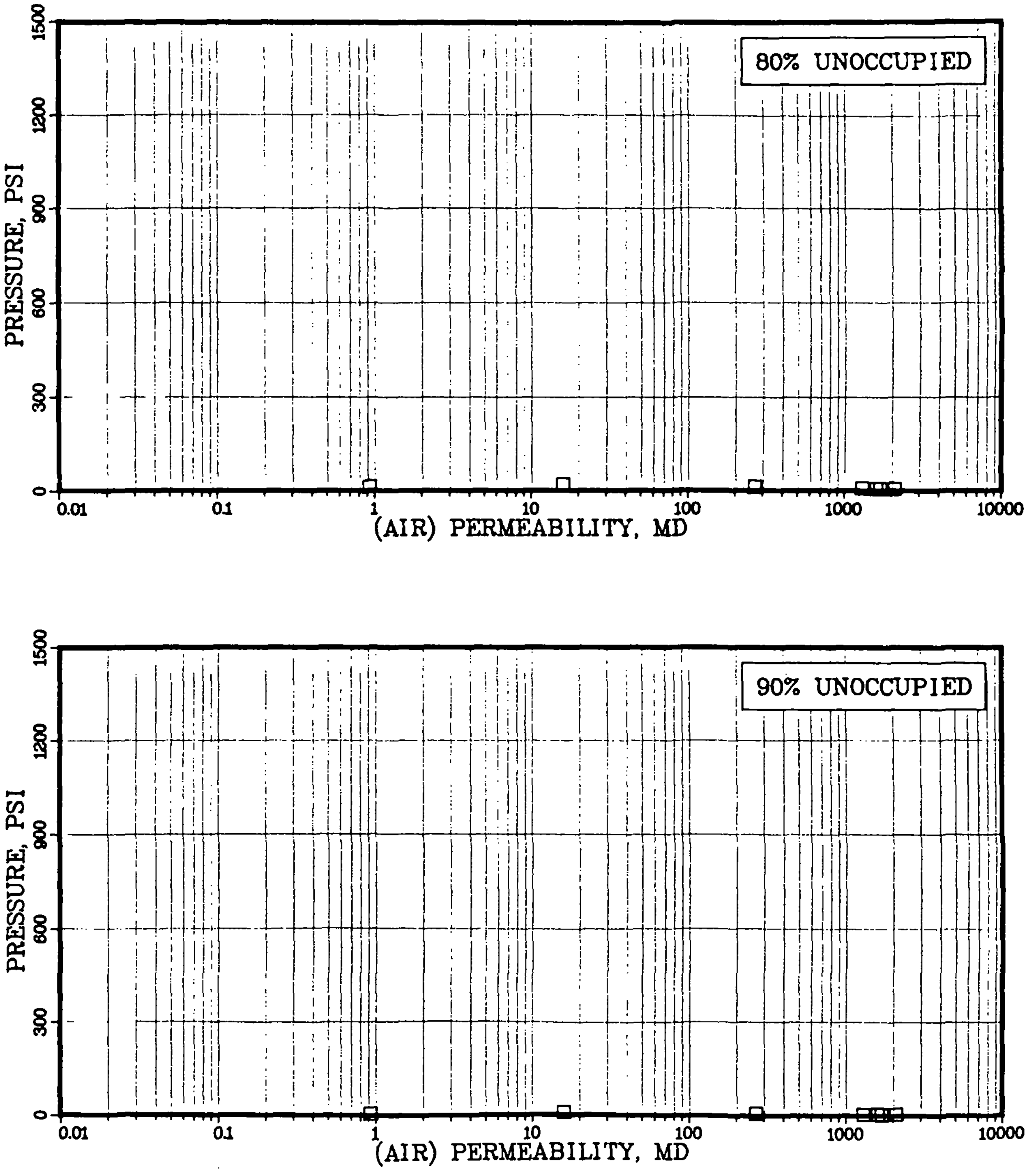
DISSPLA VERSION 8.2



MERCURY/AIR CAPILLARY PRESSURE VERSUS
(AIR) PERMEABILITY AT 90% AND 80% OF PORE SPACE
UNOCCUPIED BY MERCURY FOR WELL 31/2-4

RKER 82.243

AUTHOR: BUR
DESIGN:

FIG.15