COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

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RECORD No. 1966/44

BARROW ISLAND NO. 1, CAPILLARY PRESSURE TESTS ON SAMPLES FROM THE WINDALIA (CRETACEOUS) AND JURASSIC RESERVOIR SANDSTONES

by

B.A. McKAY

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

PETROLEUM TECHNOLOGY LABORATORY

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INTRODUCTION

The following report presents results of mercury injection capillary pressure study performed on a number of samples from oil and gas producing zones of Barrow Island No. 1, in the Carnarvon Basin, Western Australia. Supplementary information, comprising pore size distribution, permeability versus water saturation and a single six-point average capillary pressure curve for the main Jurassic oil producing zone in the well based on test results is also presented.

PROCEDURE AND APPARATUS

The tests were carried out on 26 plugs, $\frac{3}{4}$ inch in diameter. The plugs were horizontally drilled-out from selected pieces of cores; they were trimmed with a diamond saw to a length of about $1\frac{3}{4}$ inches and extracted with toluene in a Soxhlet-type apparatus for 24 hours, then oven-dried at 110°C. Upon cooling, the effective porosity and absolute permeability values (using dry nitrogen) were determined on each of the plugs.

Next, capillary pressure tests were conducted on each plug in a "Ruska"-type mercury injection apparatus using the method described by Purcell*. Each sample placed in the mercury pump resevoir was subjected to a vacuum of 20 microns absolute pressure after which, using nitrogen gas, increasing pressure was applied to the mercury system at a number of pre-selected pressure "points". The volume of mercury injected into the sample at each pressure point was determined with the aid of the pump sight-glass and Vernier scale, after saturation equilibrium at each "point" had been established. The final pressure used throughout the test was 1500 PSIA.

The readings so obtained were then utilized in compiling capillary pressure curves for each of the plugs, after small volume corrections for pump expansion and sample surface-conformance to mercury were made.

The average capillary pressure curve (Figure 28) for the interval 6,750' - 6,886' was derived from the results of tests on all samples in this zone having permeability greater than 10 millidarcy. The method*, utilises the relationship between capillary pressure, water saturation and permeability (Figure 27) of all permeable samples in a particular zone of interest. Points for compilation of the average capillary pressure-pore volume saturation curve were then selected by reference to Figure 27 using an average nitrogen permeability value of 83 millidarcy.

Finally, pore size distribution of the samples was determined using the capillary pressure function $\Delta P = \frac{2\gamma \cos\theta}{r}$, and a value for the average pore entry radius over a particular saturation interval was calculated. The values γ and θ, respectively representing the inter-facial tension (480 dynes/cm) and the contact angle (140°) between mercury and the rock sample material were taken from Purcell's paper referred to above.

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* Petroleum Transactions, A.I.M.E., February, 1949

* "Practical Reservoir Engineering" by Guerrero & Stewart (The Oil & Gas Journal)

DISCUSSION

The test results, represented by the capillary curves of all the samples that were tested and the permeability - capillary pressure - fluid saturation combined relationship of these samples from the main Jurassic oil-producing sand are shown graphically in Figures 1-26. Pore size distribution results which were calculated from the above capillary pressure curves are presented in Tables I and II. Finally, porosity and permeability values of samples, and the copies of electrical log of the relevant section of the well samples are shown in Table III and Figures 29 and 30, respectively.

An examination of the capillary curves obtained from the tests reveales that only samples of a relatively high order of permeability attained equivalent irreducible water saturation. The curves of these samples showed a flat assymtotic character, while the capillary pressure curve form of the balance of samples tested is that of a continuous curvature from initial displacement (threshold) to ultimate test pressure, indicating that irreducible saturations had not been established.

The latter effect was displayed by both the shallow Windalia and the deeper Jurassic oil producing sandstone sections. The Windalia samples could be expected to show high residual water saturations because of their rather impermeable nature. As for the more permeable Jurassic sandstone, it has been shown in a previous report* that this material is strongly water-wet, and that it will imbibe water readily. Therefore, capillary characteristics of a high equilibrium pressure at irreducible water saturations would be quite normal for this type of material.

The average capillary pressure curve (Figure 28) for the section 6,750' - 6,886' was compiled from the data available at the time of writing this report, and consisted of 12 mercury injection capillary pressure curves and 19 horizontal air permeability values. In view of such limited data, this average curve should, at best, be considered only approximate in representing capillary conditions of the Jurassic oil sandstone section. Because of a greater dirth of core material for the Windalia and 6200-foot level gas sand, average capillary pressure curves for these two intervals could not be established.

In order to obtain average curves which would be truly valid for the particular zones of interest over the entire Barrow Island Field, a much greater number of samples should be tested from this and other wells in the field in order to obtain more accurate overall statistical average data. This is especially true for such factors as permeability and the permeability/water saturation relationship which are vital in picking the correct saturation and pressure values for the final capillary pressure curve.

CONCLUSIONS

A capillary pressure study of petroleum producing sands from the Barrow No. 1 well, by the mercury injection method, has resulted in the following information:

1. The average residual water saturation of the oil producing zone between 6,750' and 6,886' was found to be 37% of pore volume, while the lowest irreducible water saturation measured was 17.5% of pore volume.

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* B.A. McKay - "Barrow Island No. 1 Liquid Permeability and Wettability Tests on Samples of Cores from the Jurassic Reservoir Sandstone", February, 1966.

2. The maximum pore size as calculated from the capillary pressure data was 11.7 microns.

3. The nature of the capillary pressure curves obtained from the Jurassic oil sandstone interval of 6,750' - 6,886' suggests that a thick transition zone might be expected above the free water table in this reservoir. However, this could be restricted by a combination of high reservoir oil/water differential (capillary) pressures and the presence of impermeable vertical barriers to flow.

TABLE I

AVERAGE PORE ENTRY RADIUS (MICRONS)

SATURATION (% PORE VOLUME)								SAMPLE DEPTH (FEET)
0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	
0.81	0.39	0.22	0.13					2185
1.30	0.59	0.32	0.17	0.095				2189
1.4	0.71	0.37	0.20	0.10				2195
11.5	9.4	8.1	6.9	5.2	2.5	0.91	0.30	6204
8.7	8.3	7.6	6.6	5.4	3.0	1.2	0.36	6206
11.7	10.9	9.7	8.5	6.7	2.9	1.00	0.20	6213
5.1	2.6	1.6	0.96	0.61	0.20			6750
4.3	2.4	1.5	0.91	0.36	0.14			6758
7.0	6.3	5.6	4.7	2.7	0.57	0.12		6764
5.2	3.1	2.1	1.4	1.1	0.42			6770
	2.4	1.5	1.0	0.57	0.20			6774
3.6	3.3	2.3	0.71	0.19				6831
7.0	6.4	5.7	4.4	1.5	0.32	0.11		6837
	4.5	3.8	1.4	0.32	0.12			6845
5.0	4.5	3.8	1.8	0.48	0.14			6860
5.9	5.5	5.1	3.6	1.3	0.27			6866
5.3	5.0	4.4	2.5	0.74	0.19			6872
2.6	1.2	0.44	0.12					6880
5.1	4.7	4.2	2.6	1.0	0.30	0.10		6886
								6894

TABLE II

AVERAGE PORE ENTRY RADIUS (MICRONS)	SATURATION (% PORE VOLUME)							SAMPLE DEPTH (FEET)
	0–2	2–4	4–6	6–8	8–10	10–12	12–14	
	0.44	0.26	0.15					6693
	0.49	0.32	0.19	0.11				6699
	1.3	0.59	0.28	0.17	0.12			6781
	0.47	0.28	0.19	0.14	0.11			6797
	0.51	0.42	0.34	0.27	0.22	0.16	0.12	6822
		0.42	0.33	0.25	0.18	0.13	0.095	6851

TABLE III

SAMPLE DEPTH (FEET)	POROSITY (% BULK VOLUME)	DRY NITROGEN PERMEABILITY (MILLIDARCY)
2185	246	less than 0.5
2189	26.3	1.5
2195	26.5	2.0
6204	18.7	220
6206	21.8	204
6213	24.2	360
6693	16.8	less than 0.5
6699	16.8	less than 0.5
6750	28.6	91
6758	29.7	61
6764	29.5	179
6770	28.4	102
6774	28.4	68
6781	15.5	less than 0.5
6797	13.9	less than 0.5
6822	16.1	less than 0.5
6831	24.8	28
6837	29.8	165
6845	27.7	62
6851	19.7	less than 0.5
6860	26.8	52
6866	29.0	108
6872	28.5	87
6880	24.8	4.3
6886	27.9	72
6894	28.0	4.7

FIGURE 1

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-2185

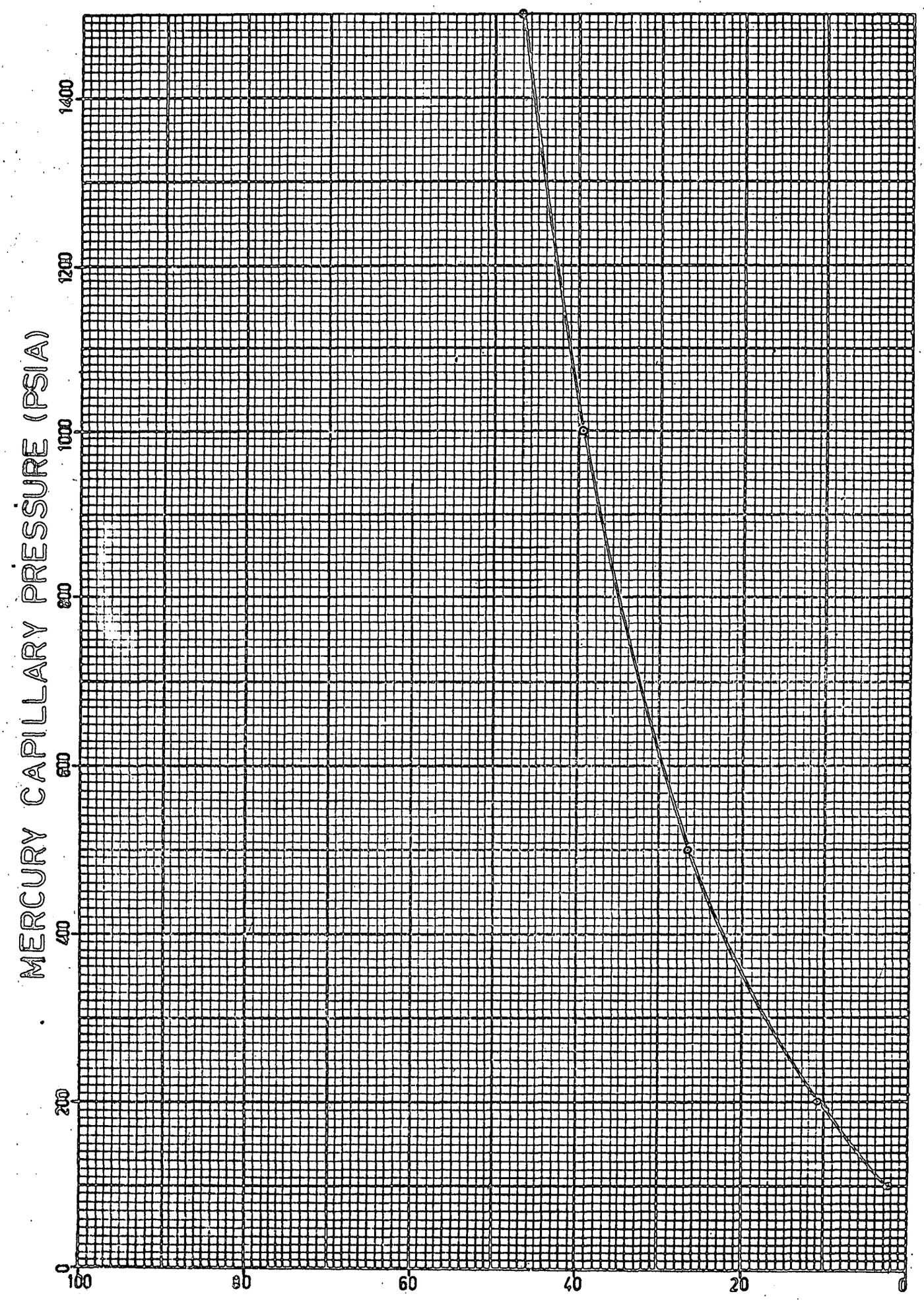


FIGURE 2

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-2189

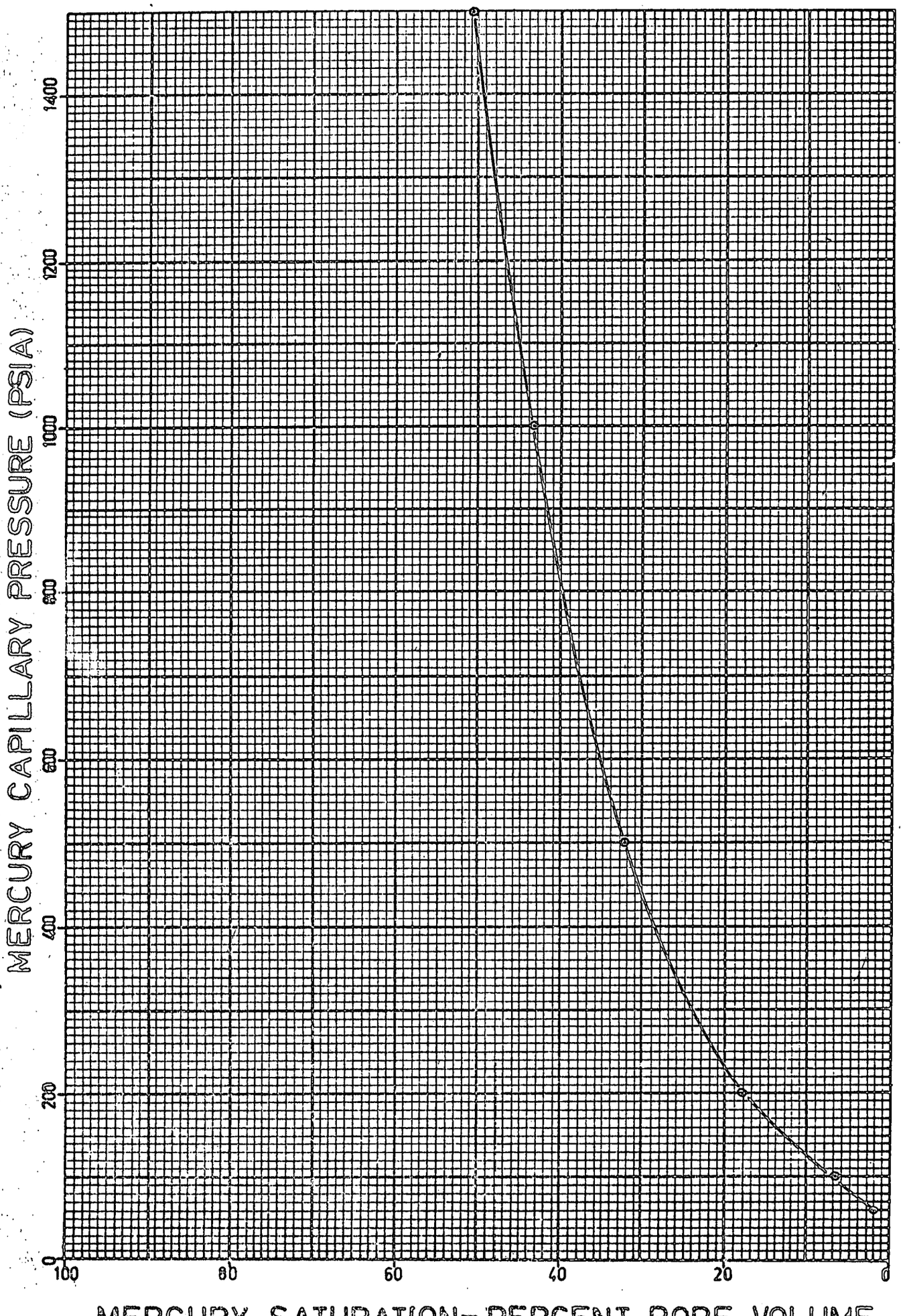


FIGURE 3

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-2195

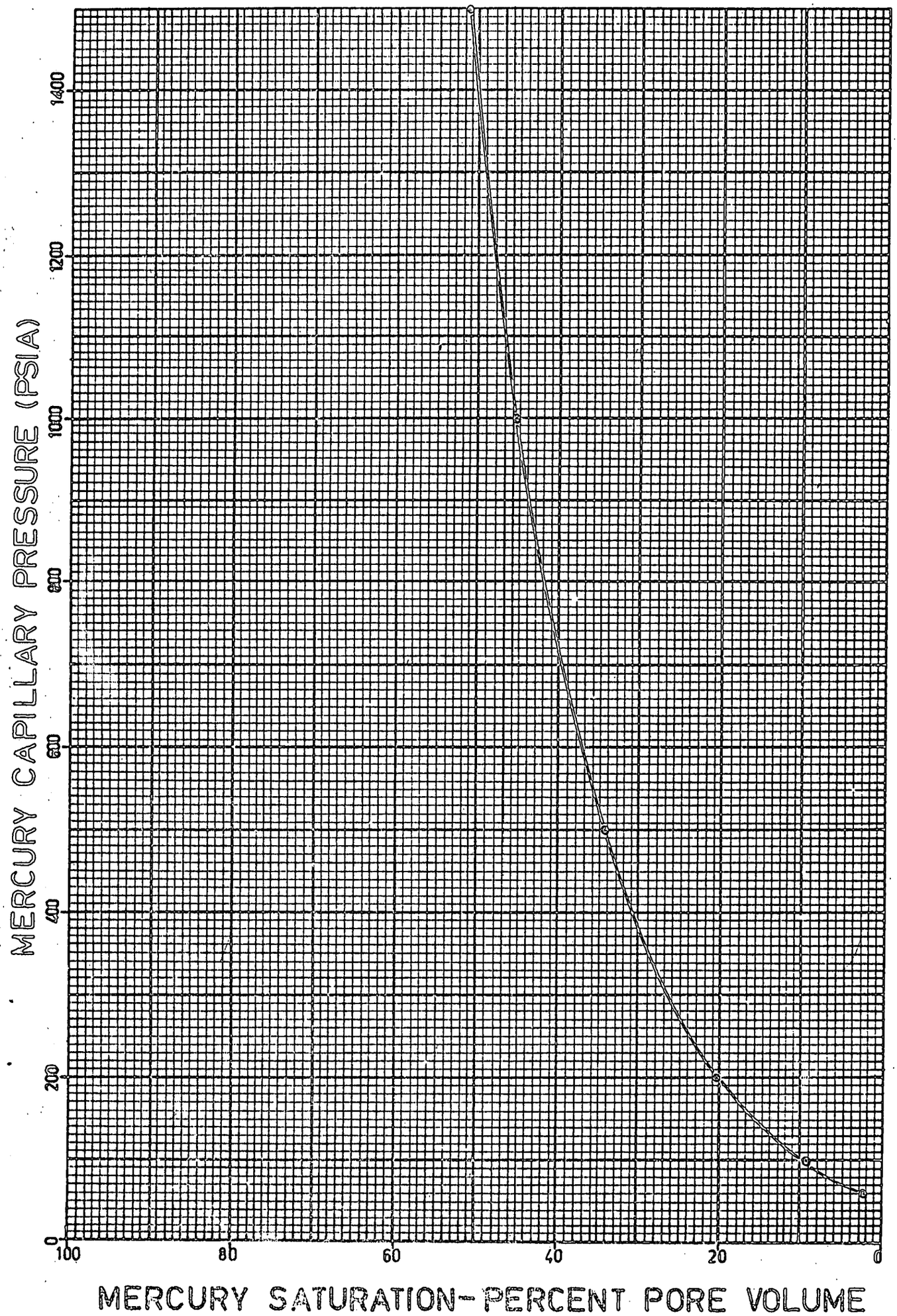


FIGURE 4

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6204

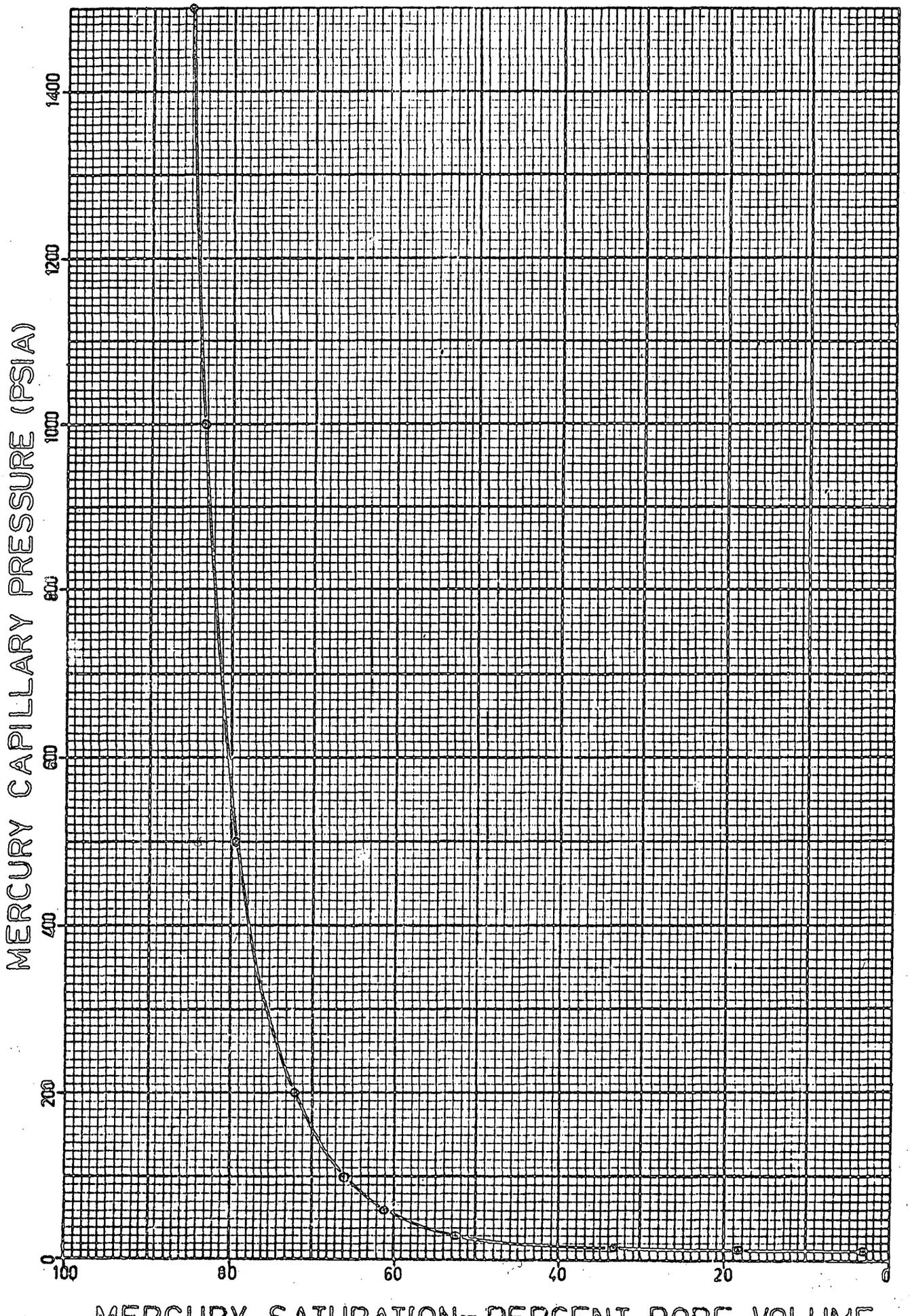


FIGURE 5

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6206

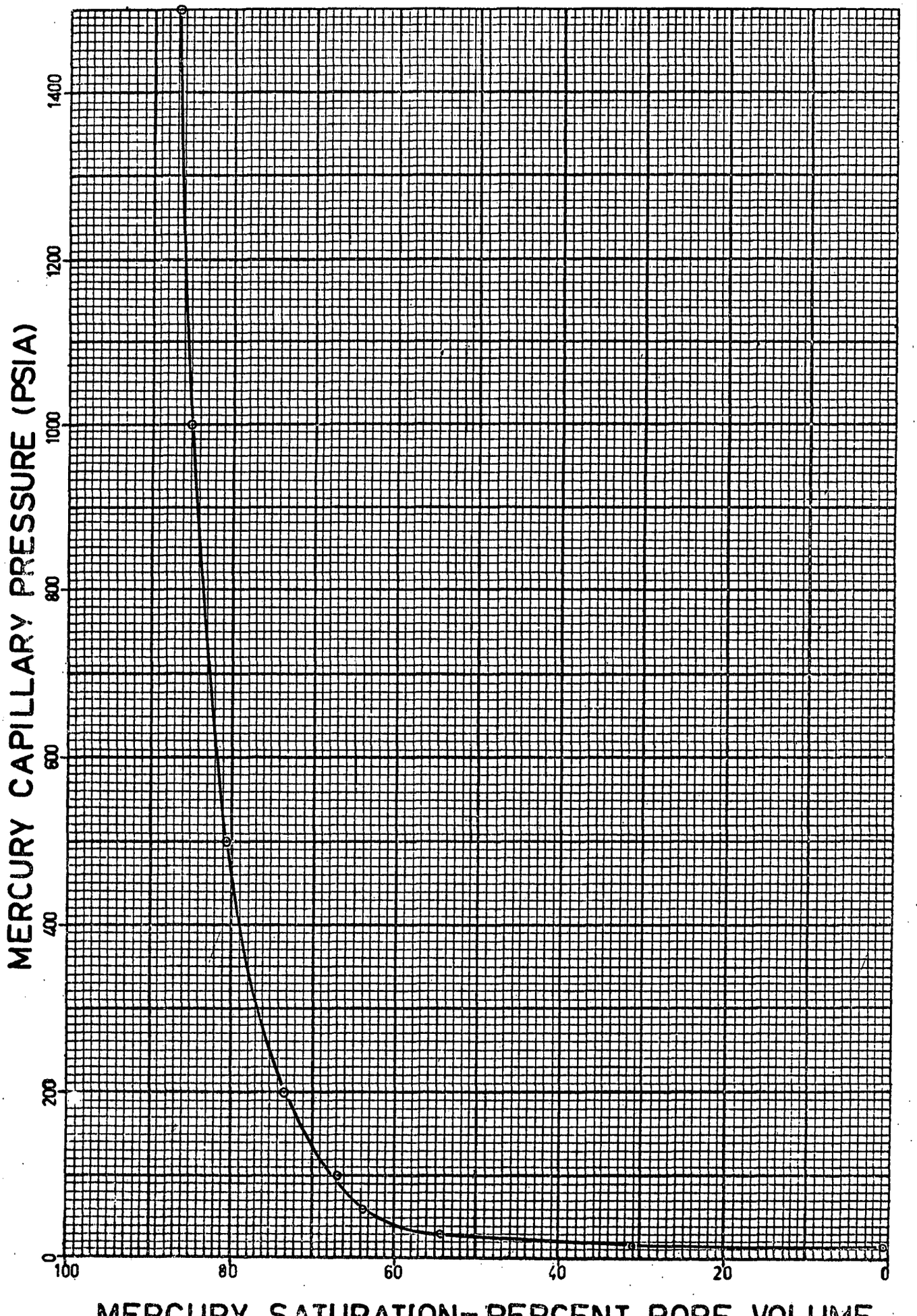


FIGURE 6

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6213

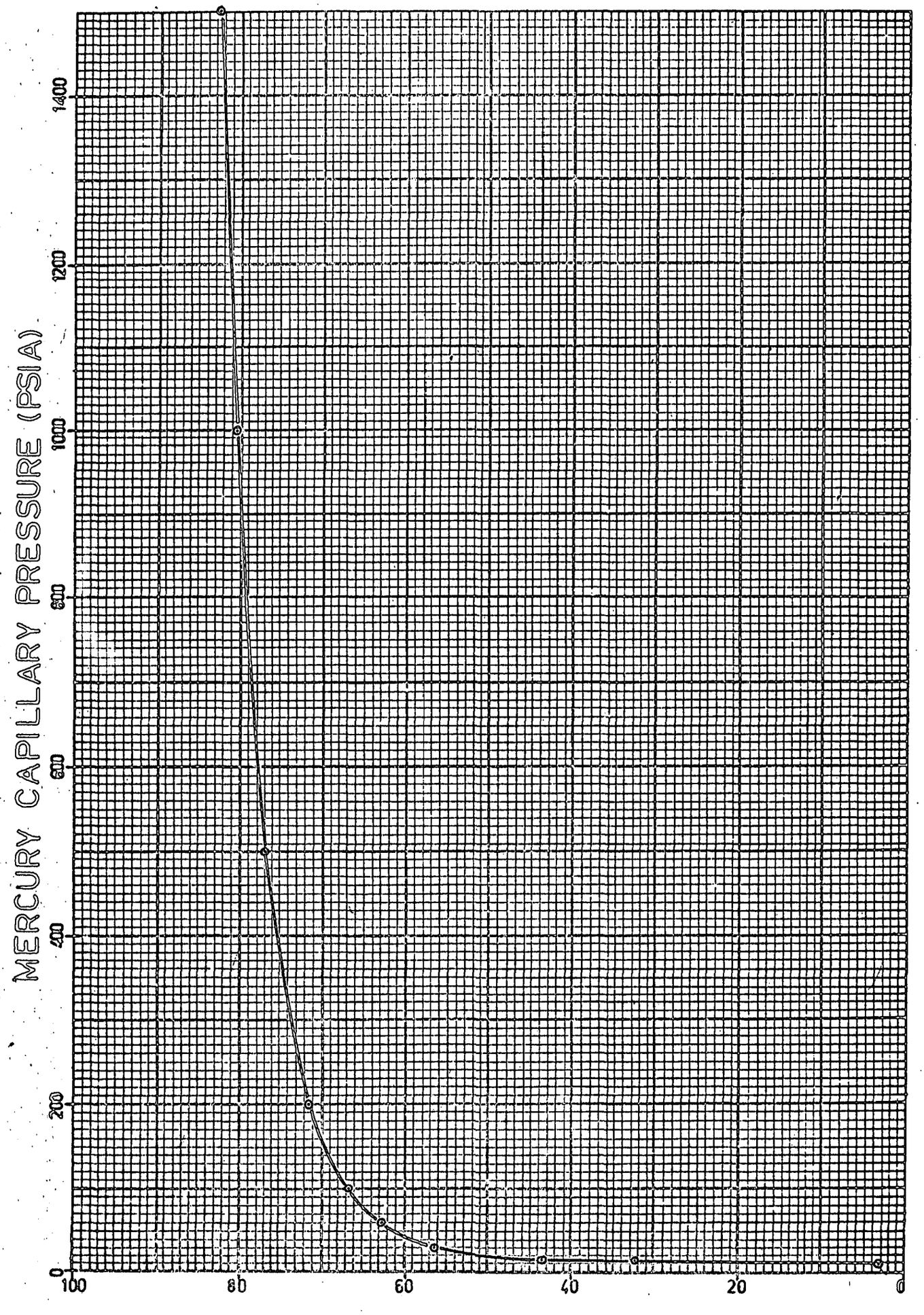


FIGURE 7

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6693

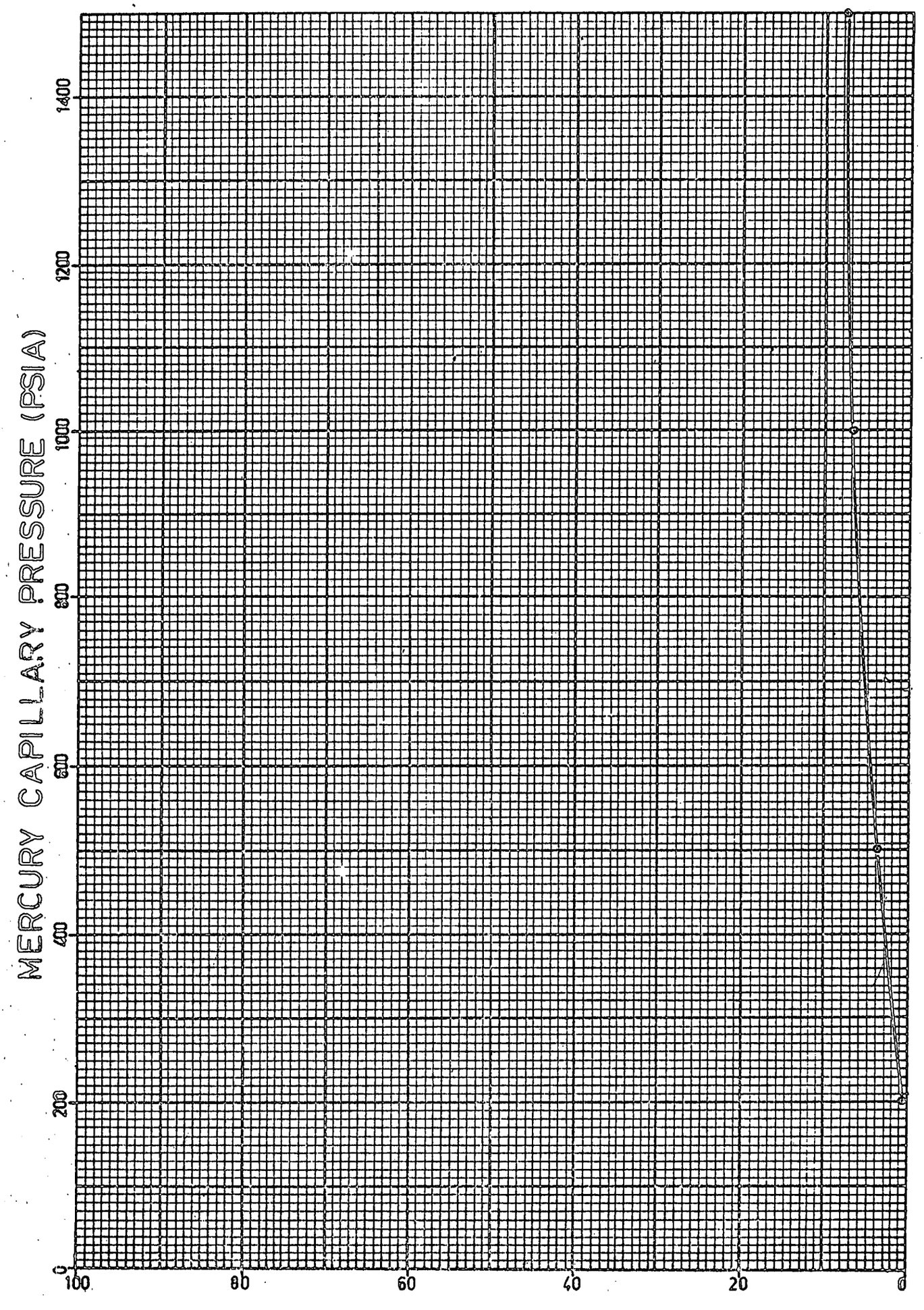


FIGURE 8

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6699

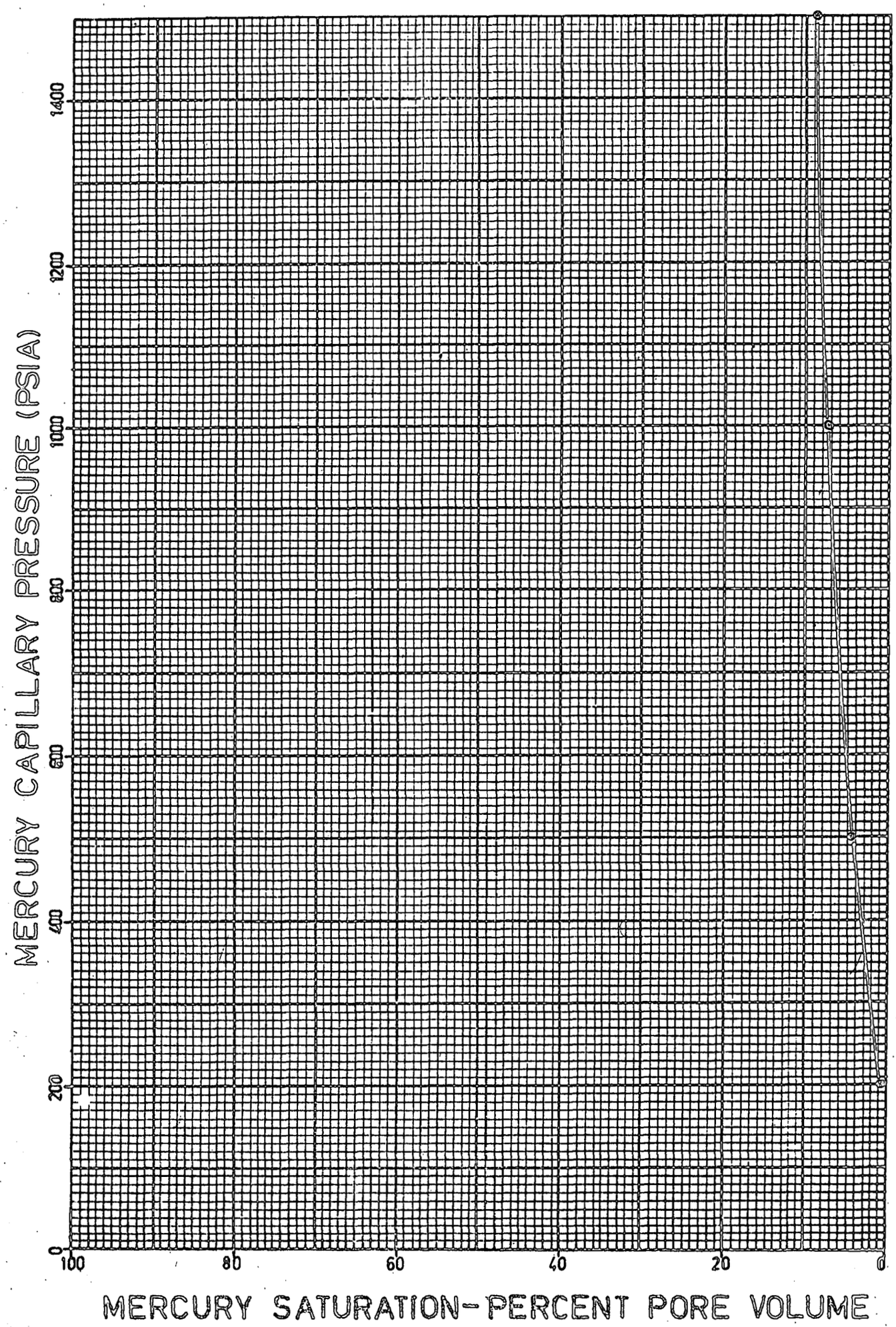


FIGURE 9

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6750

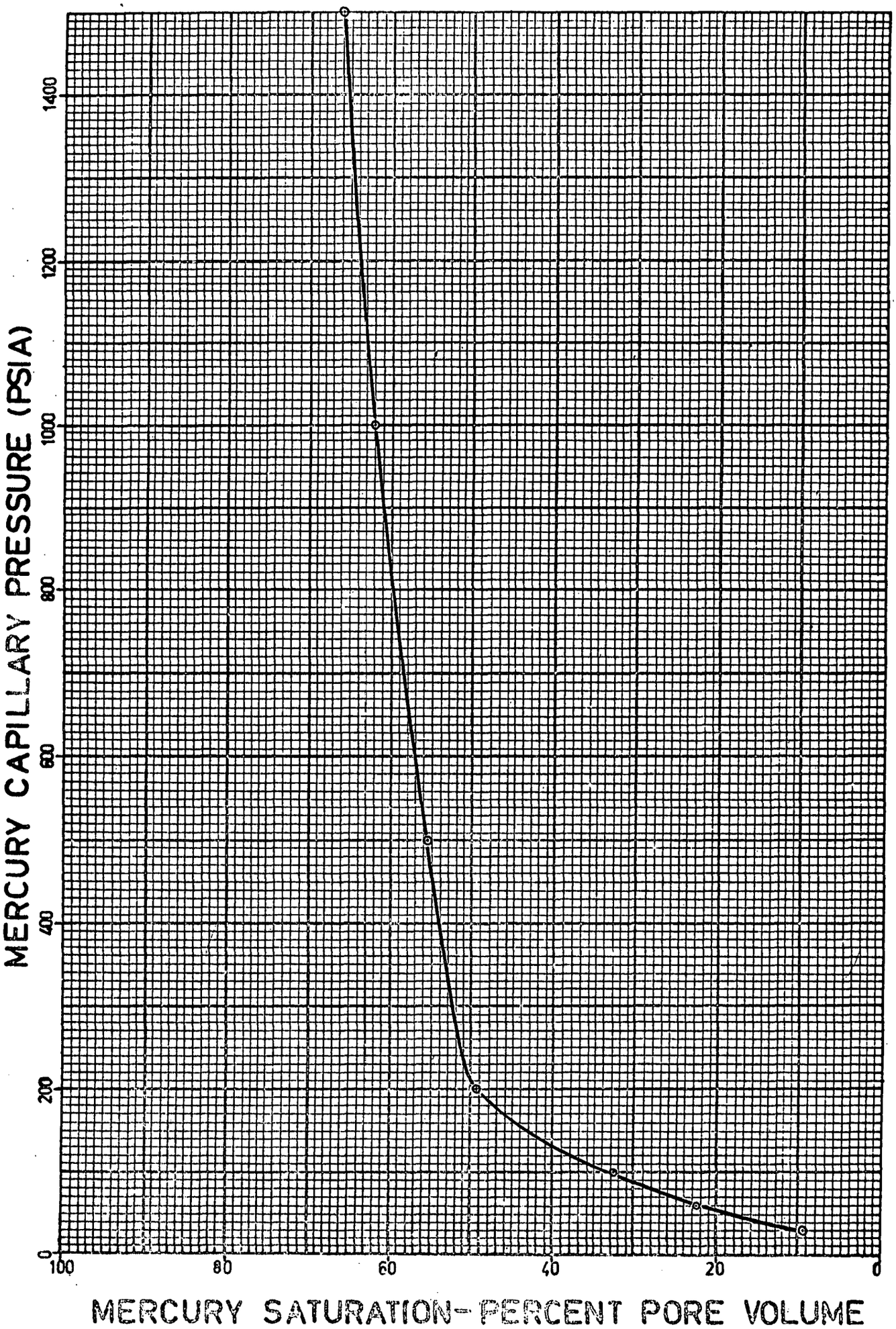


FIGURE 10

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6758

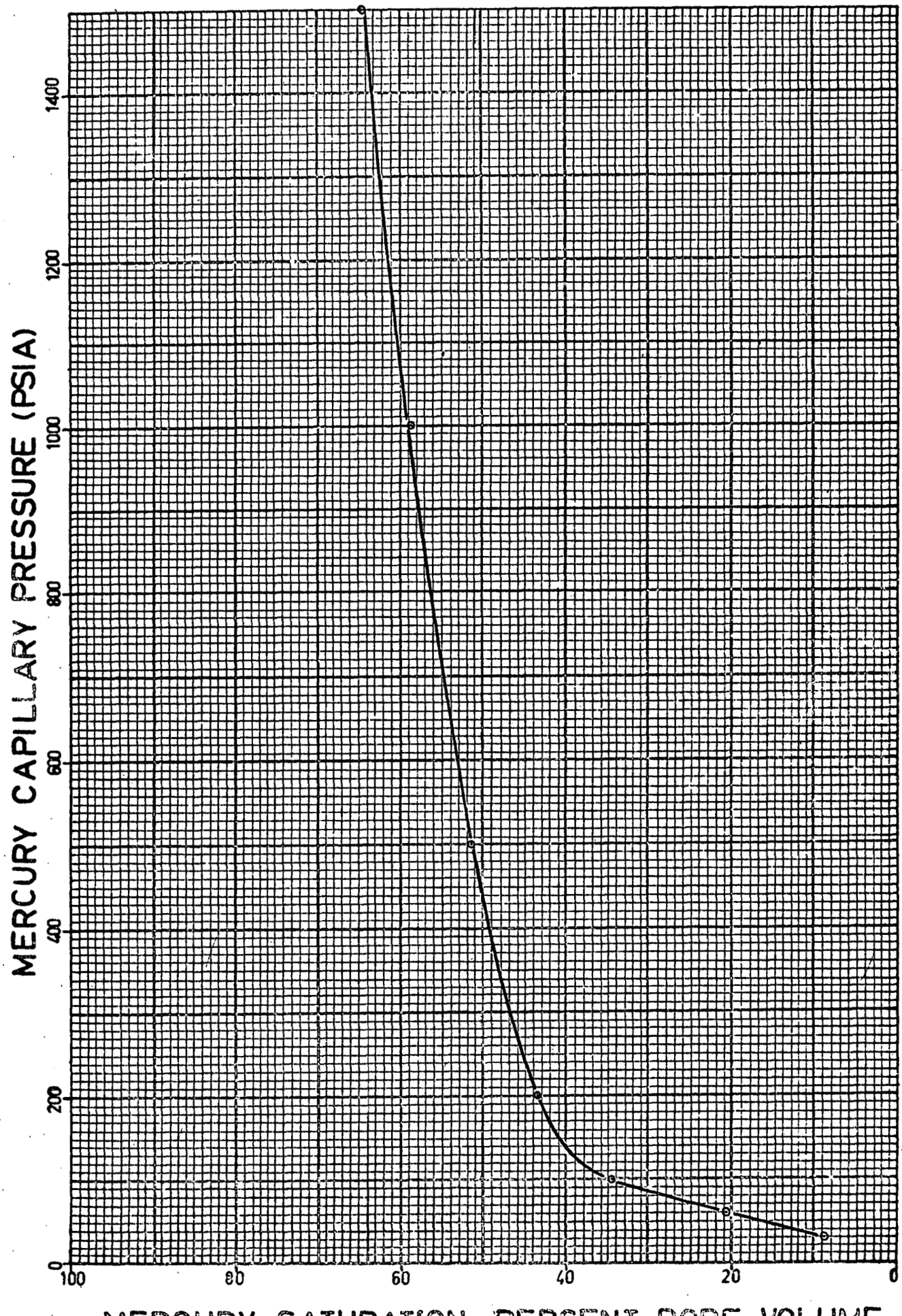


FIGURE 11

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6764

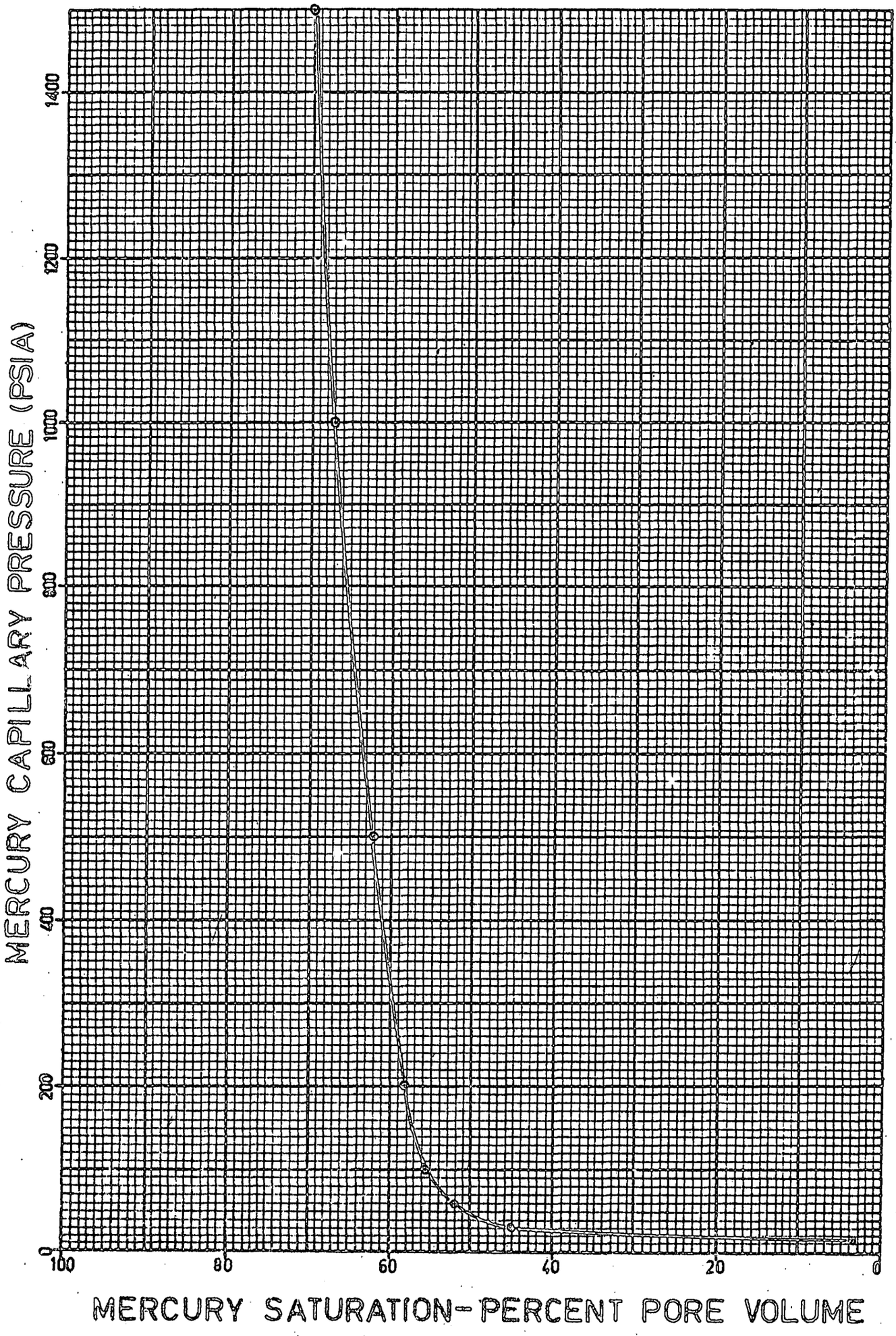


FIGURE 12

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6770

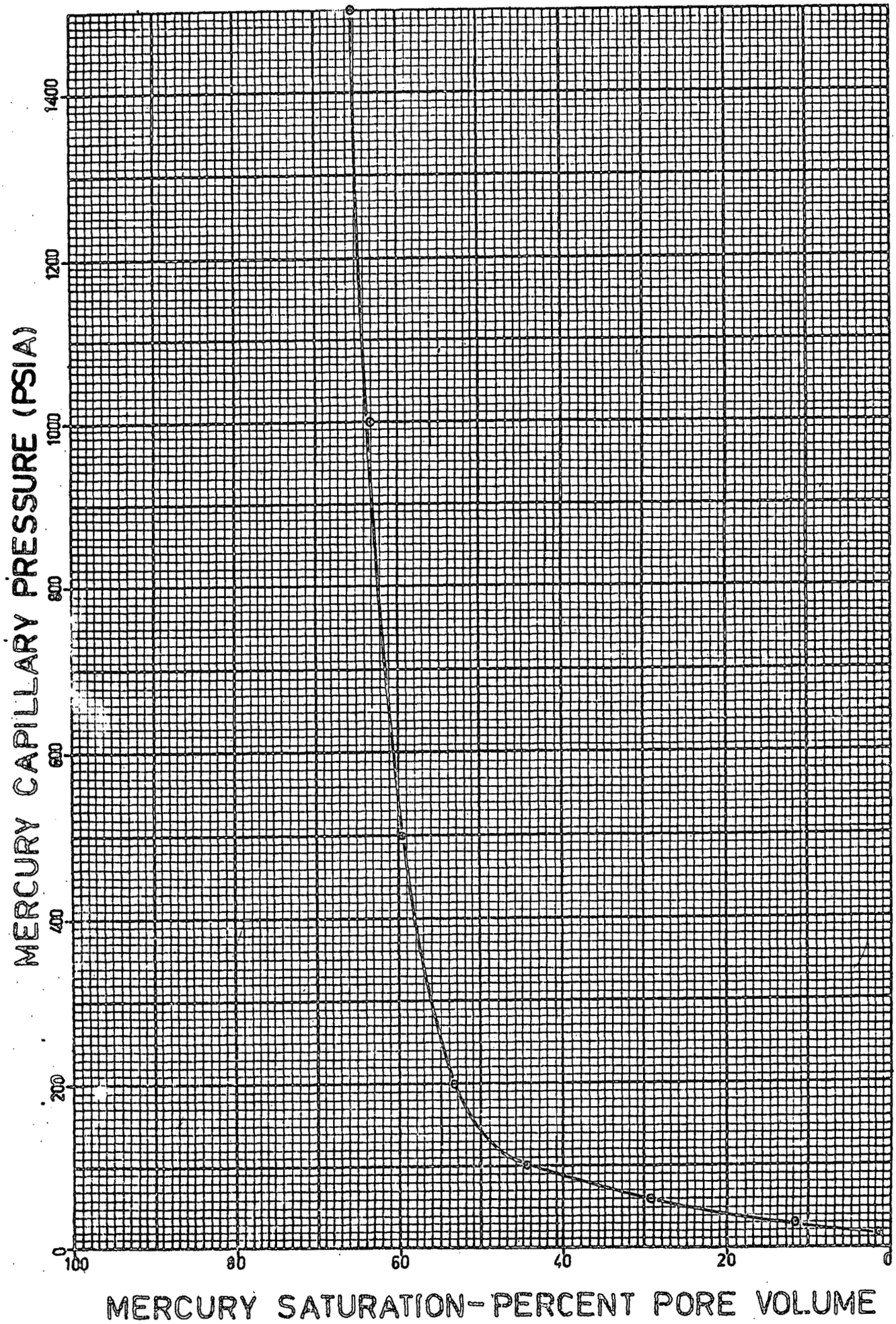


FIGURE 13

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6774

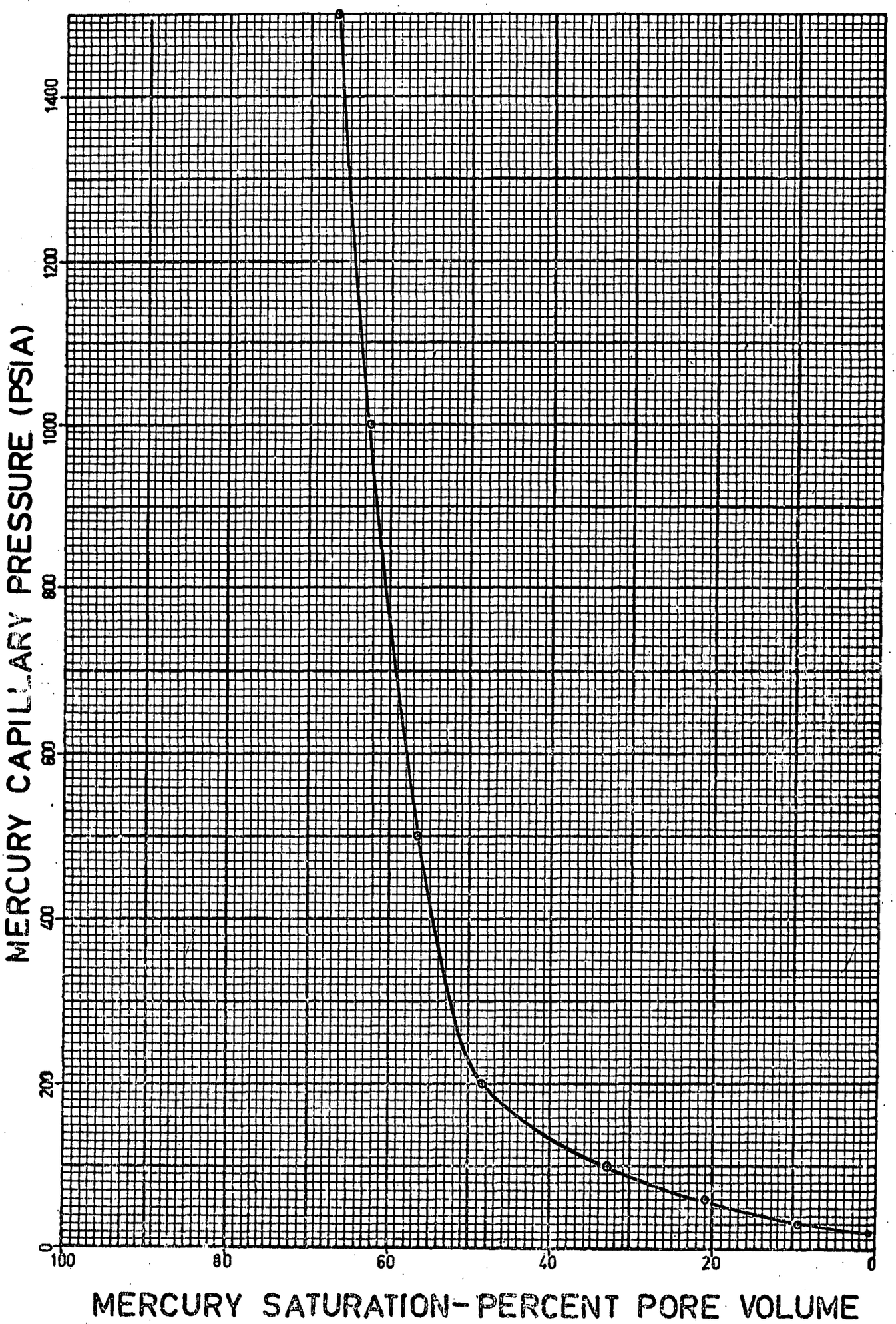


FIGURE 16

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6781

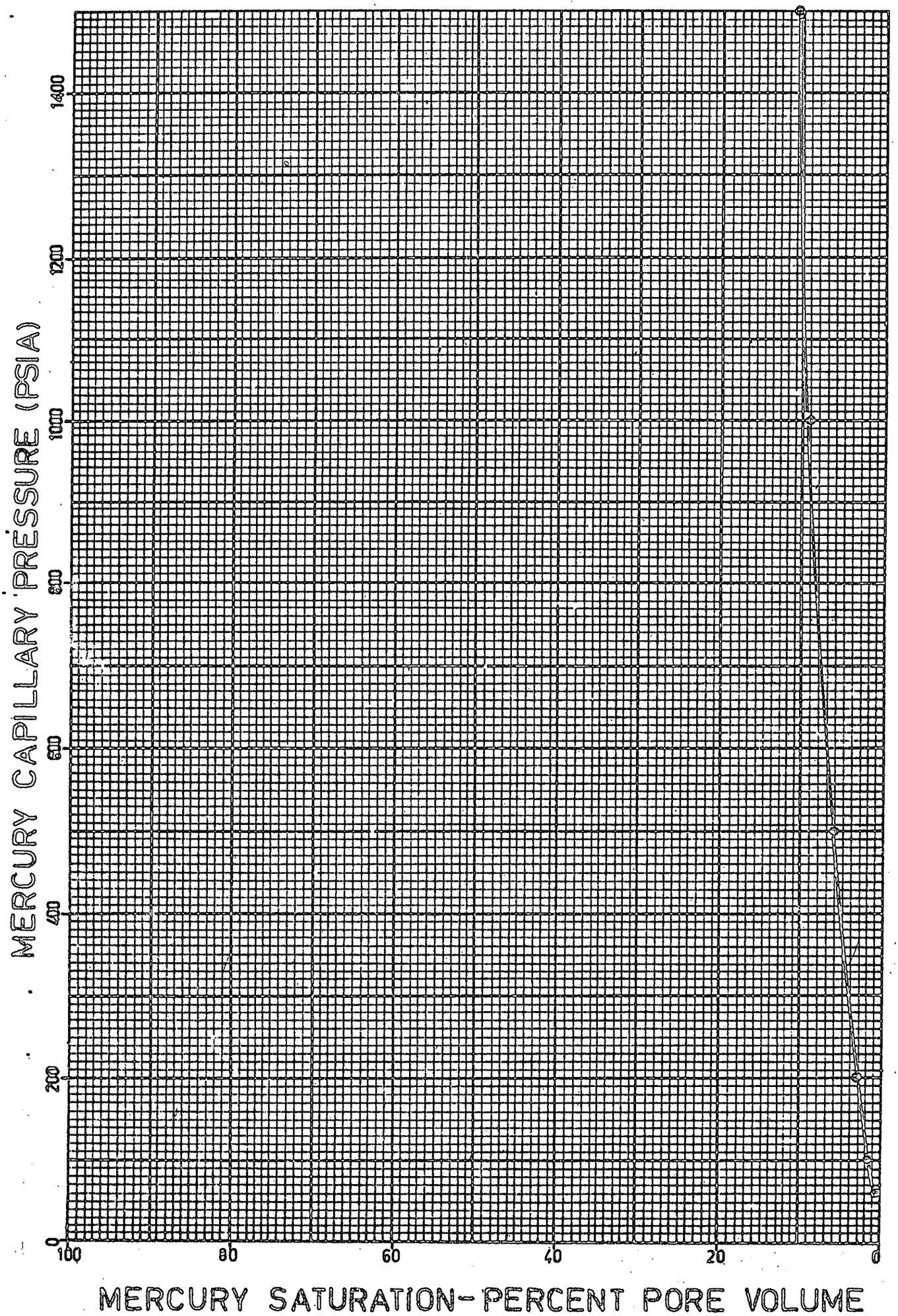


FIGURE 15

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6797

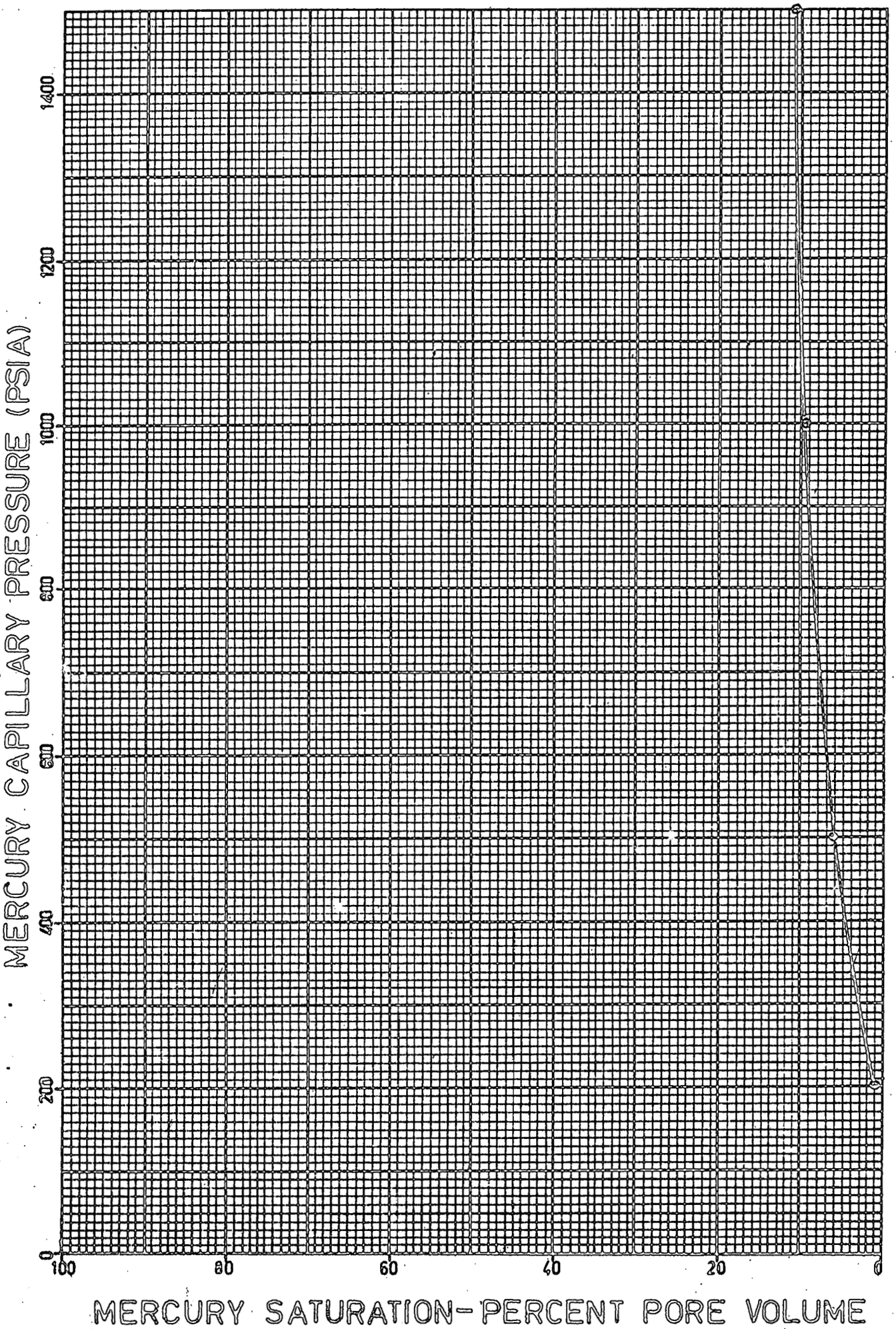


FIGURE 16

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6822

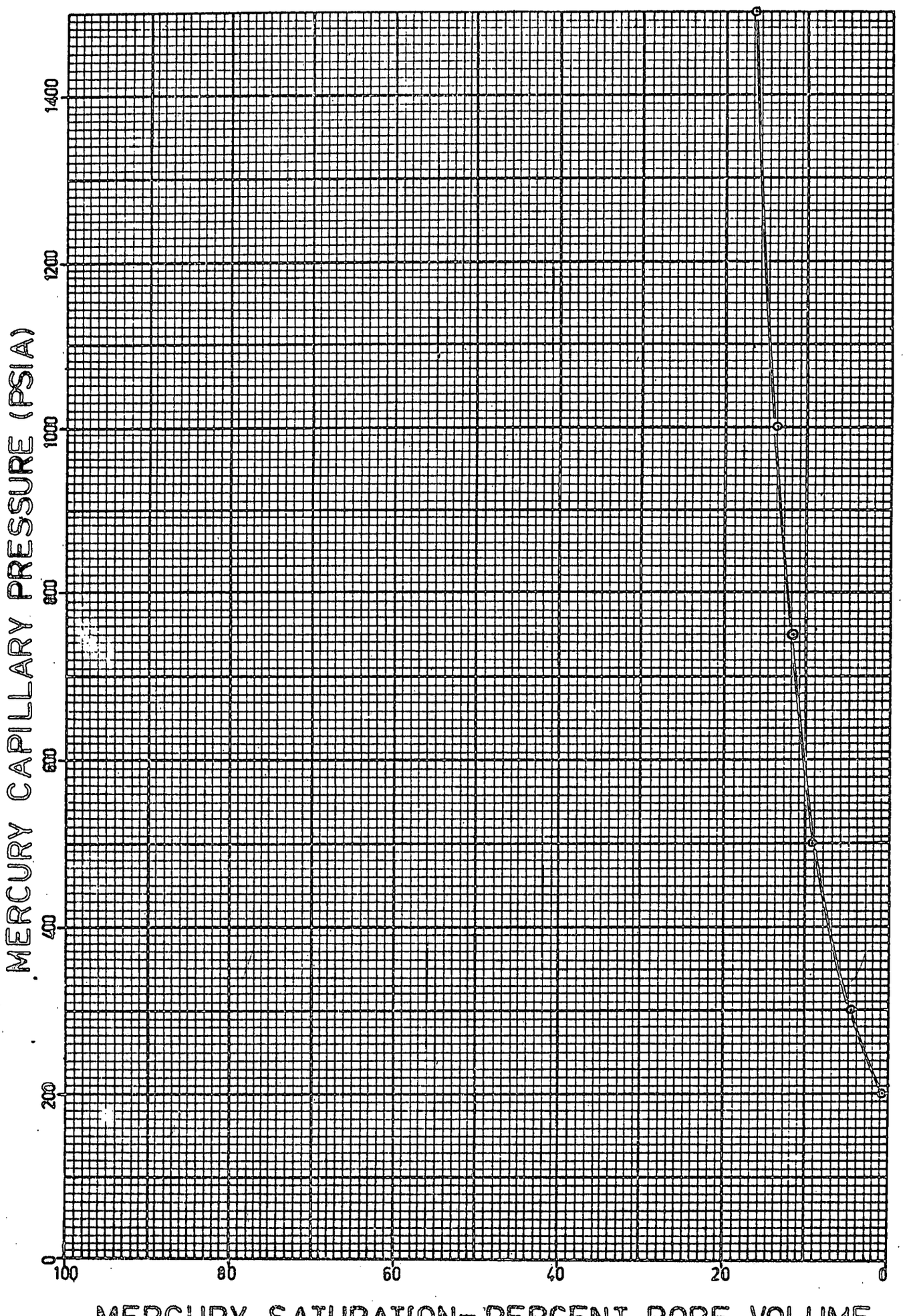


FIGURE 17

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6831

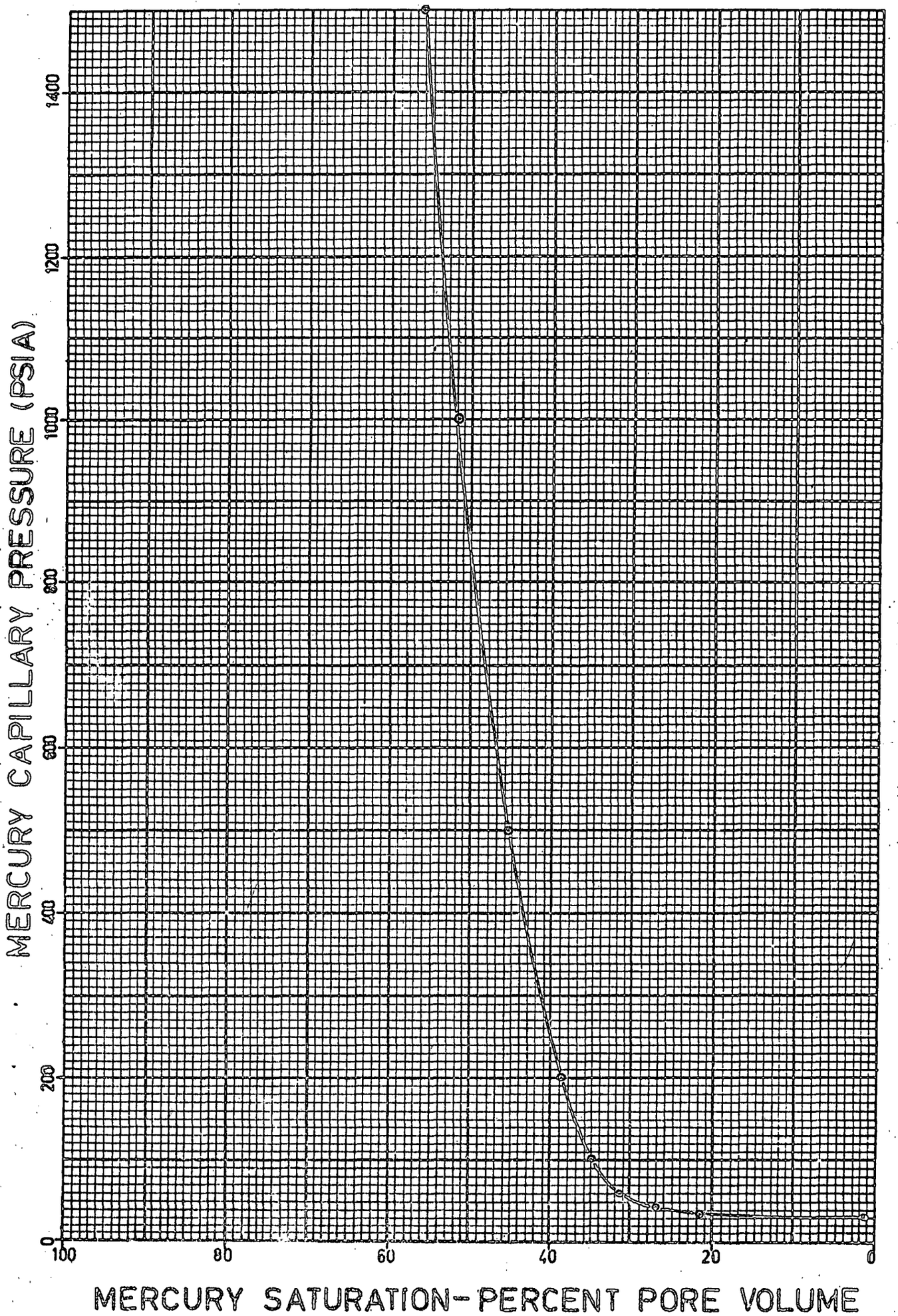


FIGURE 18

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6837

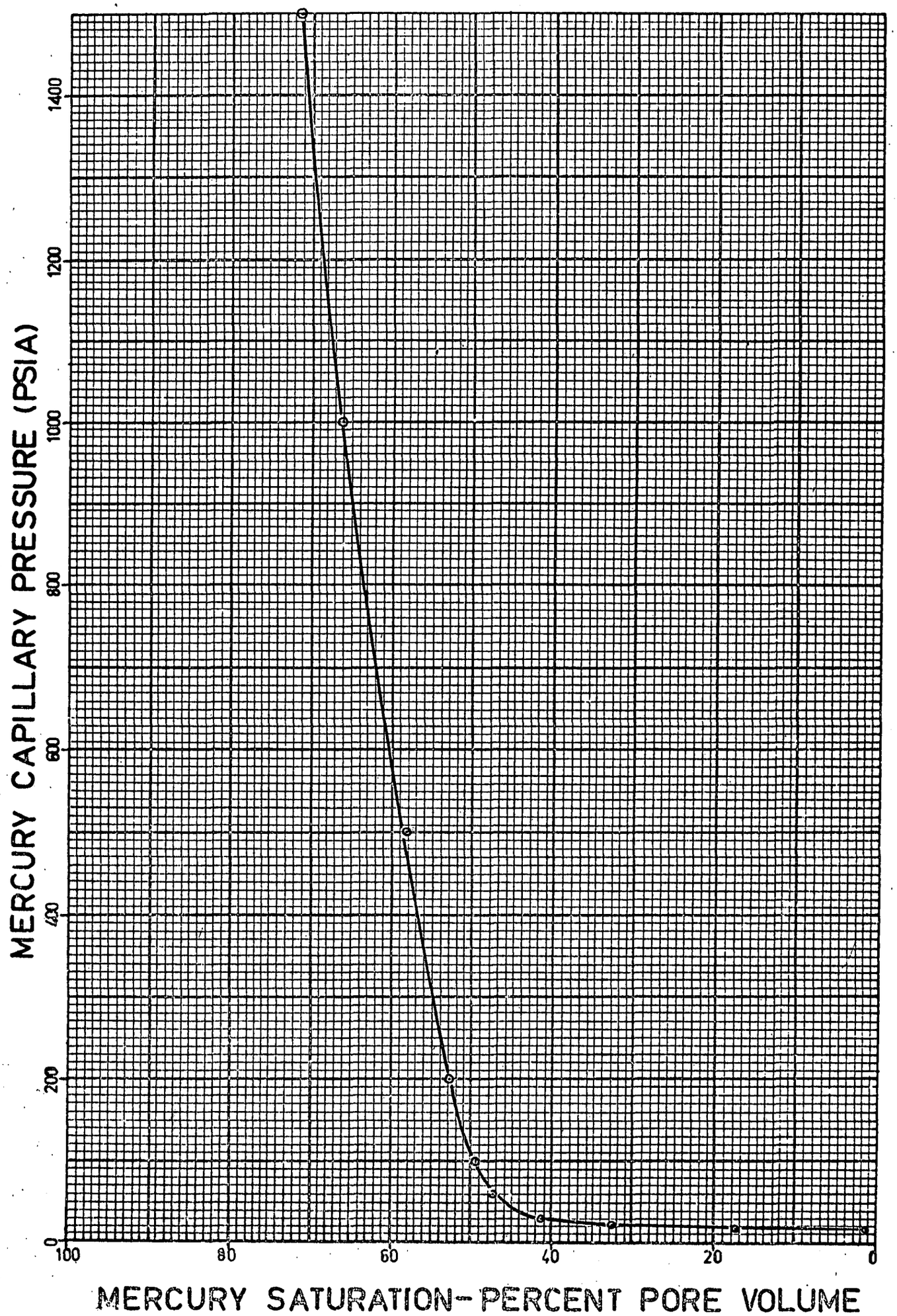
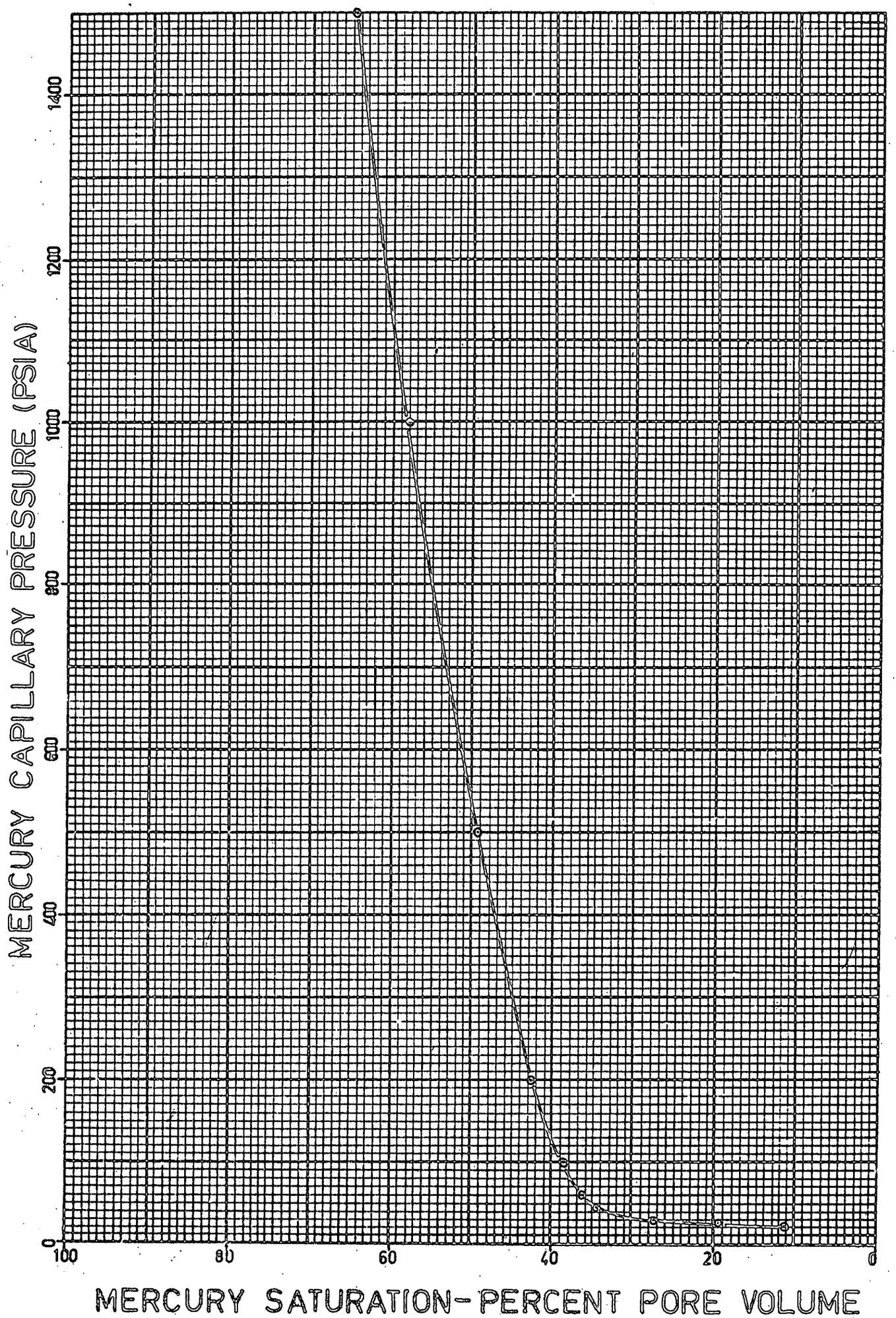


FIGURE 18

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6845



MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6851

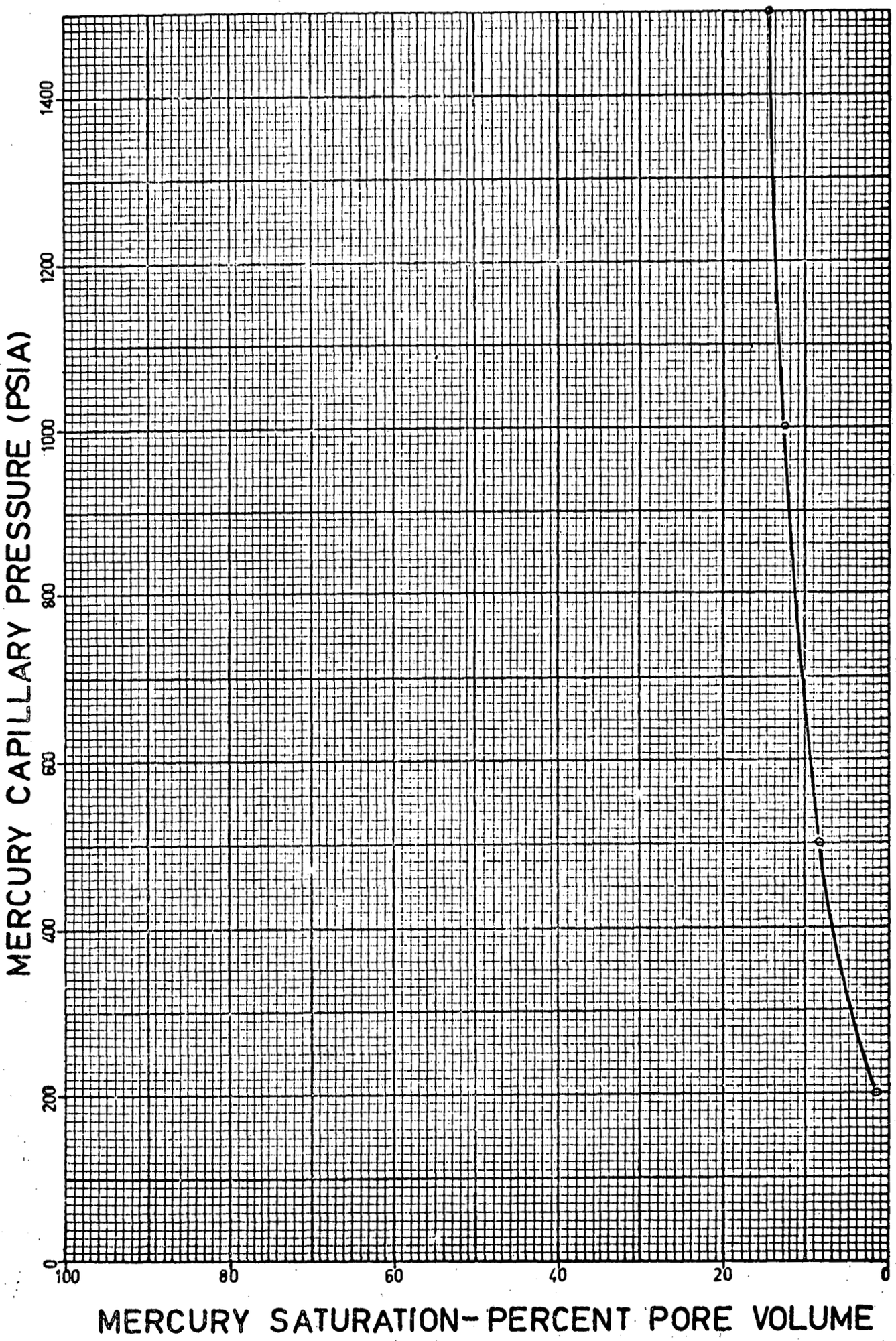


FIGURE 21

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6860

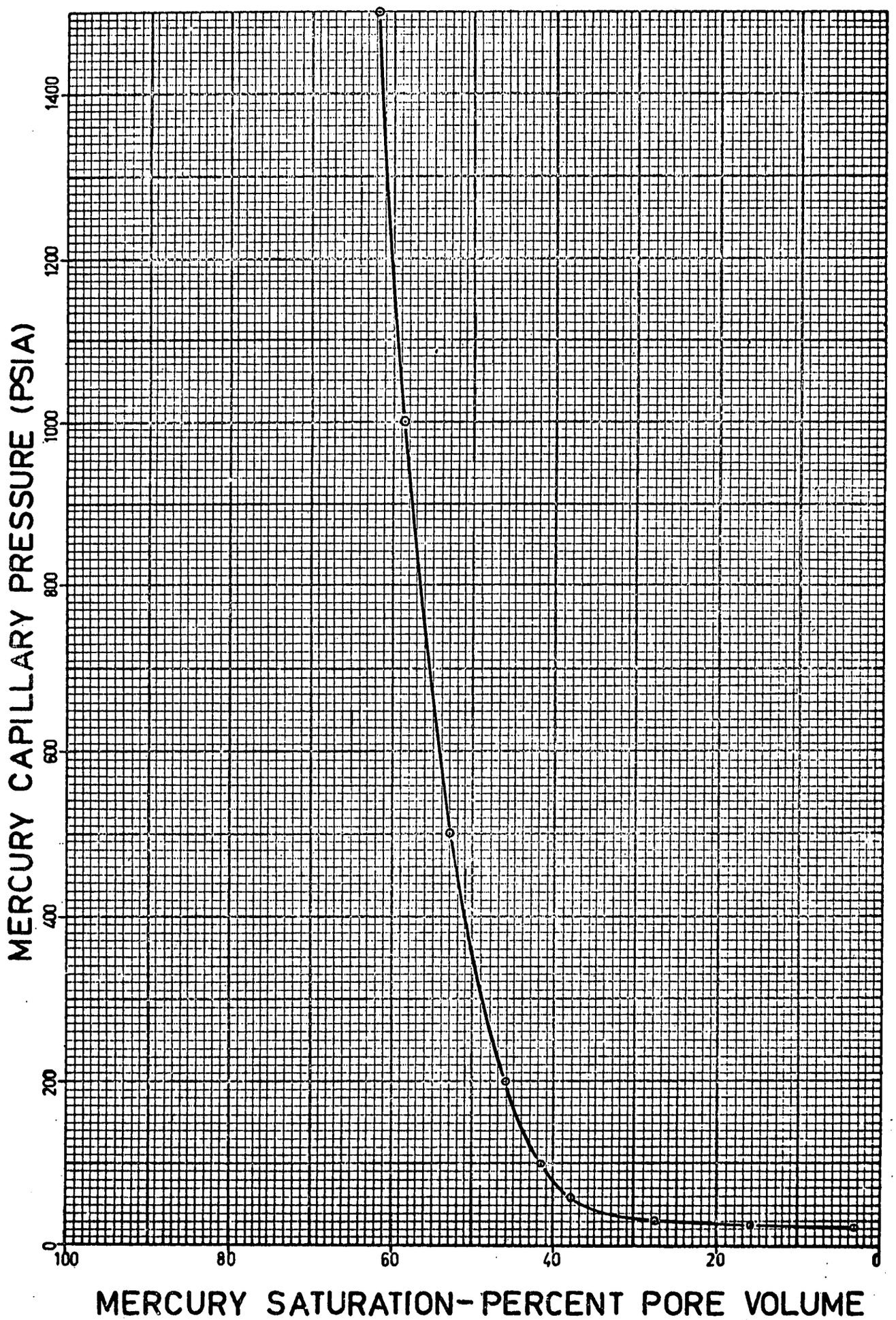


FIGURE 22

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6866

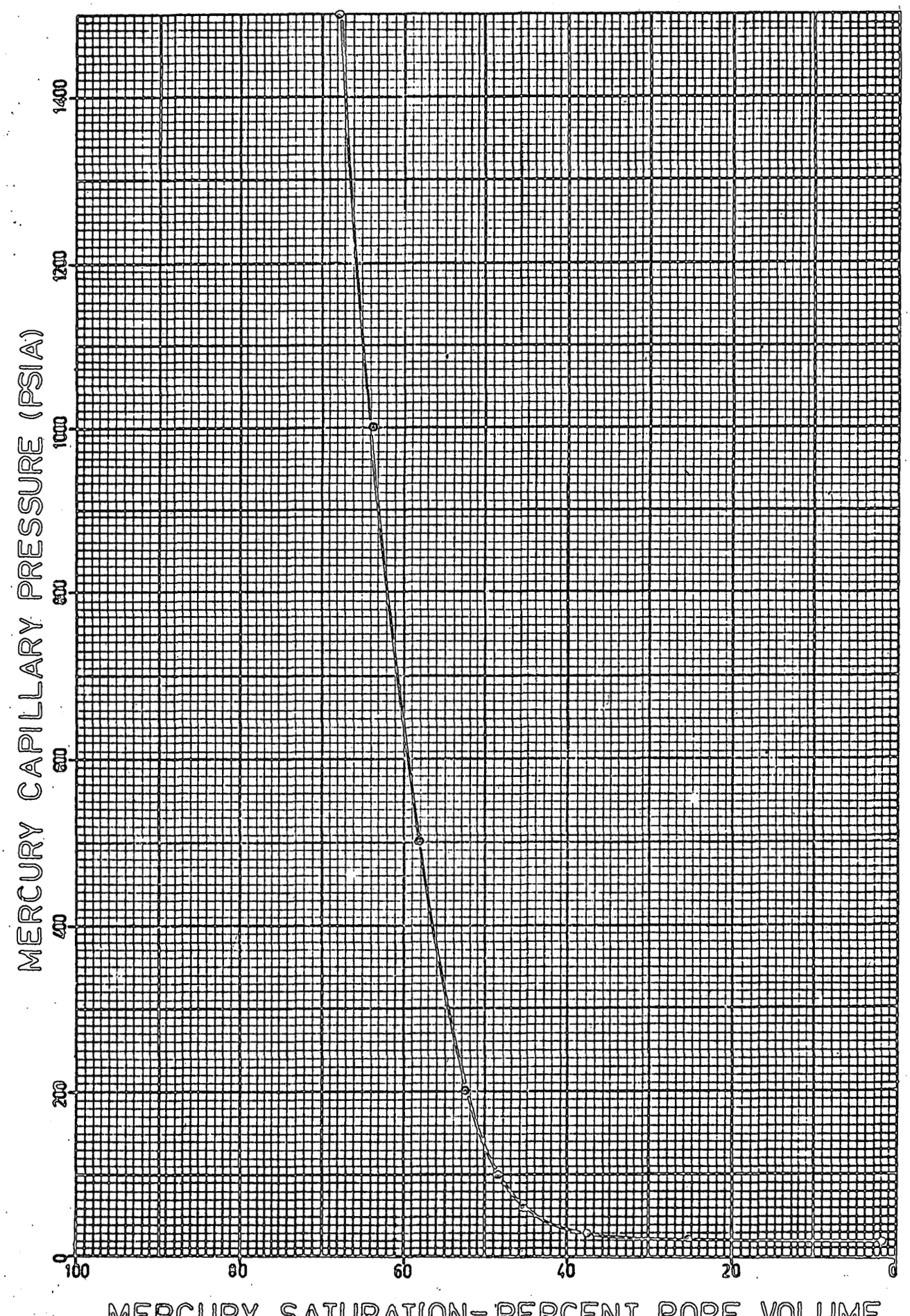


FIGURE 23

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6872

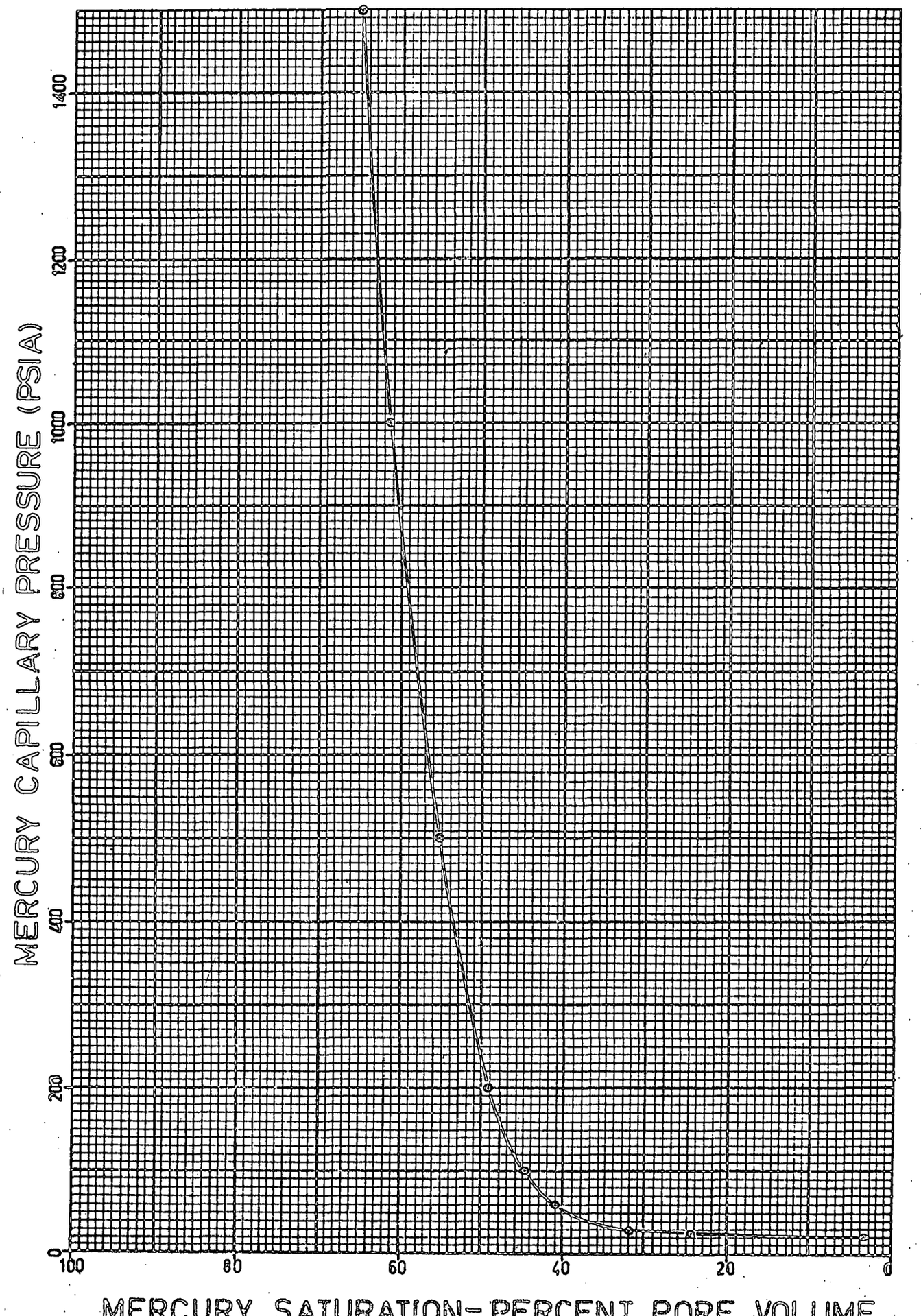


FIGURE 24

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6880

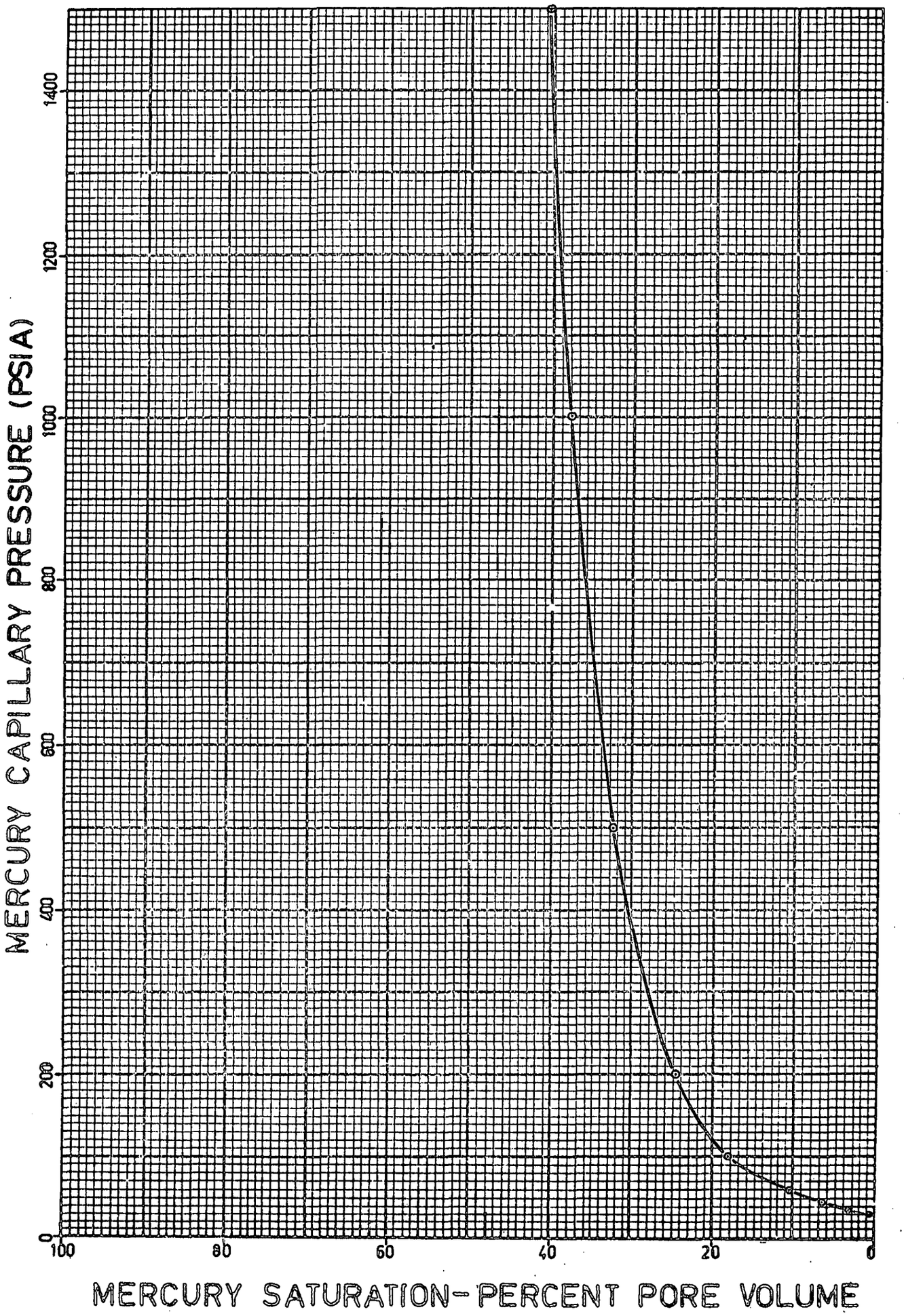


FIGURE 25

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH-6886

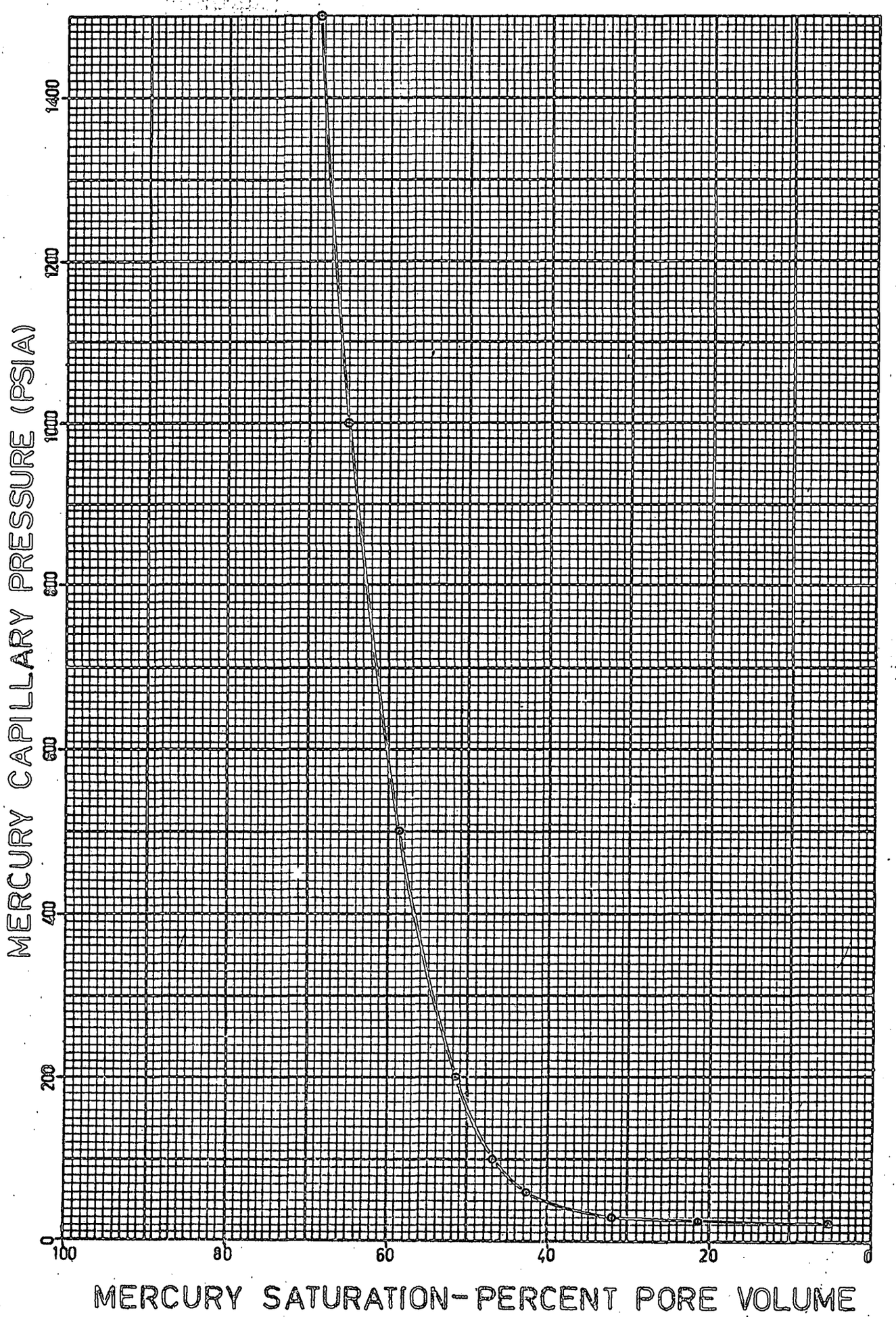


FIGURE 26

MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No.1 SAMPLE DEPTH-6894

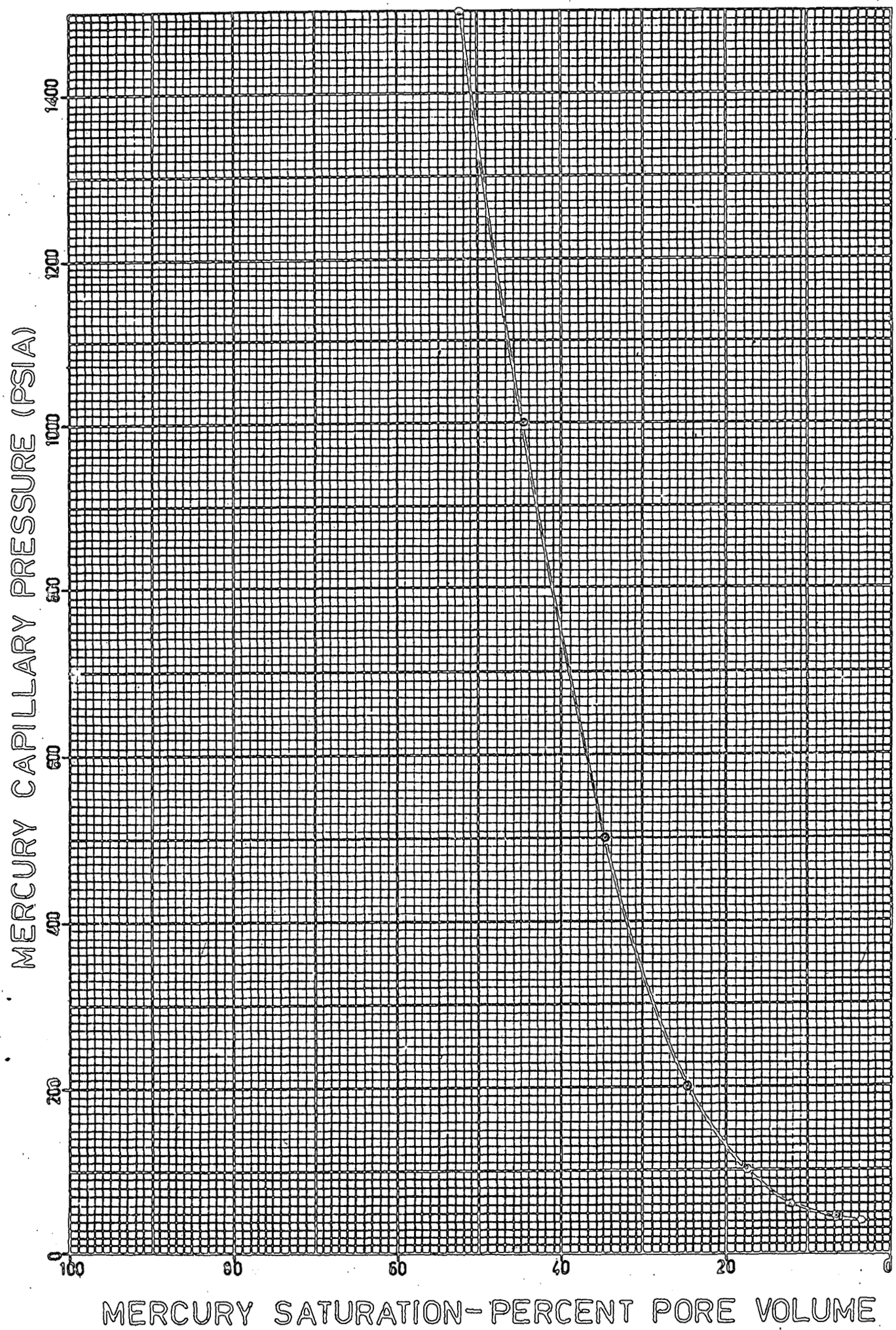
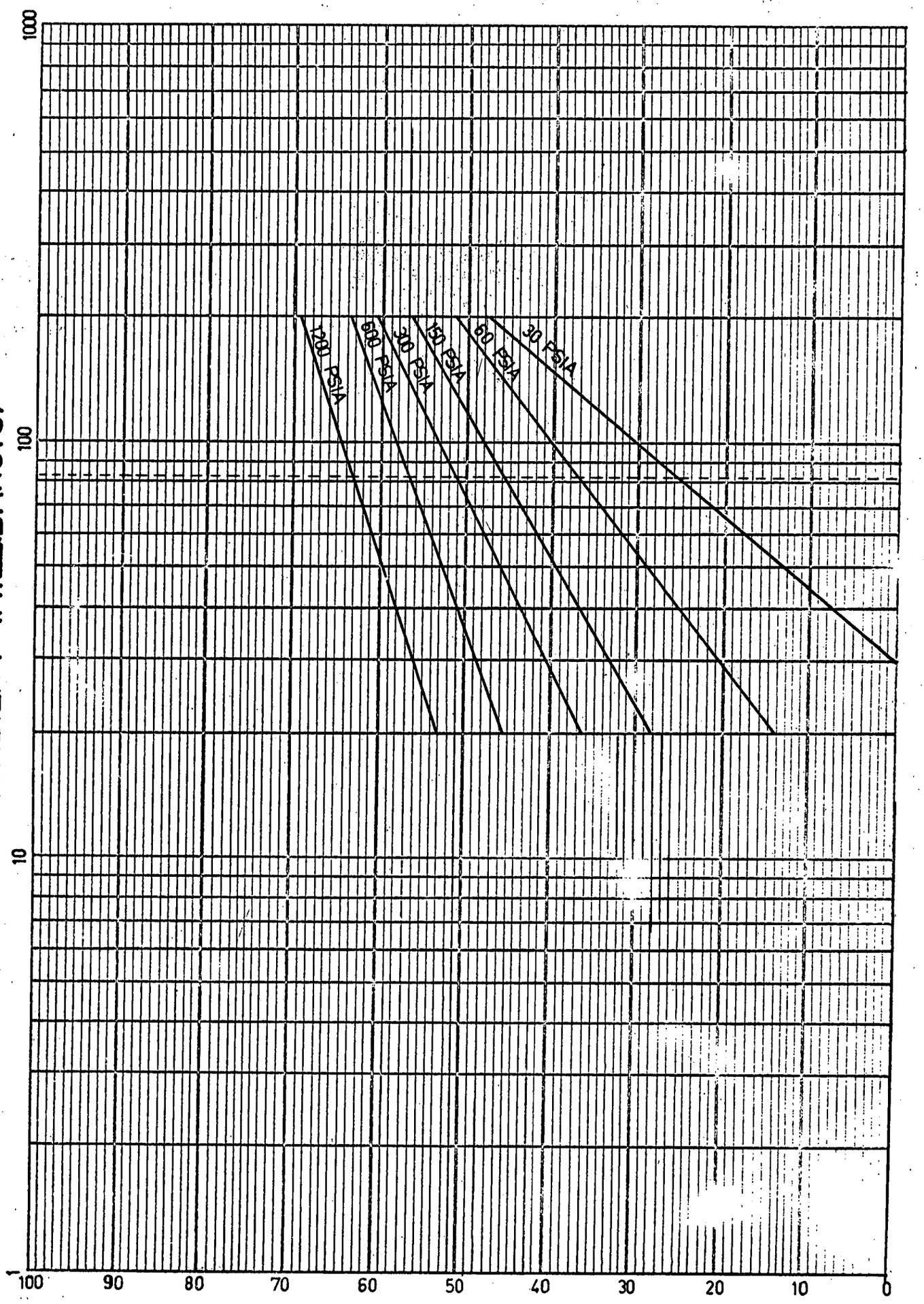


FIGURE 27

RELATION BETWEEN PERMEABILITY SATURATION AND CAPILLARY PRESSURE

BARROW No 1 6750' to 6886'



AVERAGE
MERCURY CAPILLARY PRESSURE

WELL NAME-BARROW No 1 SAMPLE DEPTH – 6750 to 6886

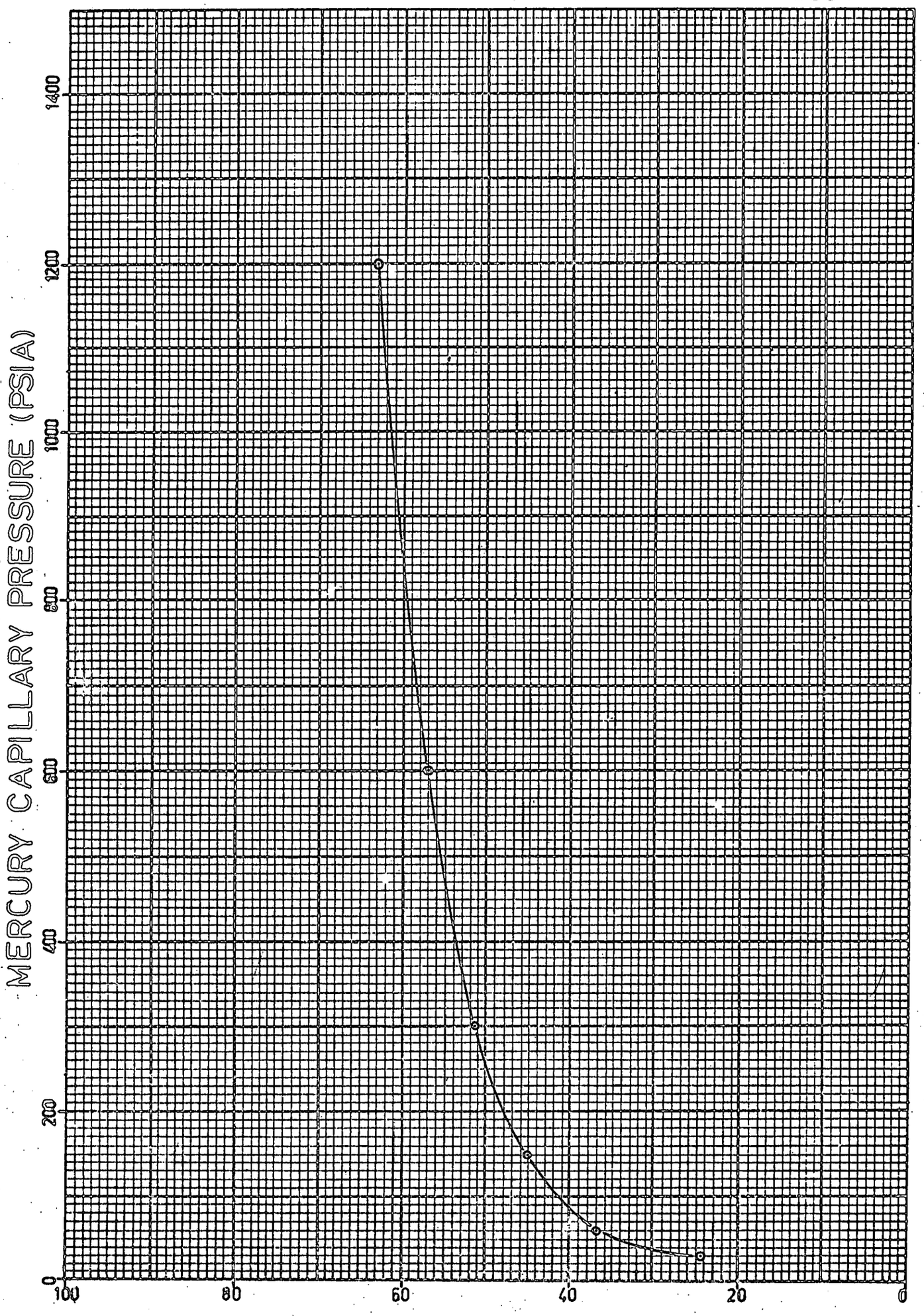


FIGURE 28

FIGURE 29

INDUCTION ELECTRICAL LOG BARROW No 1

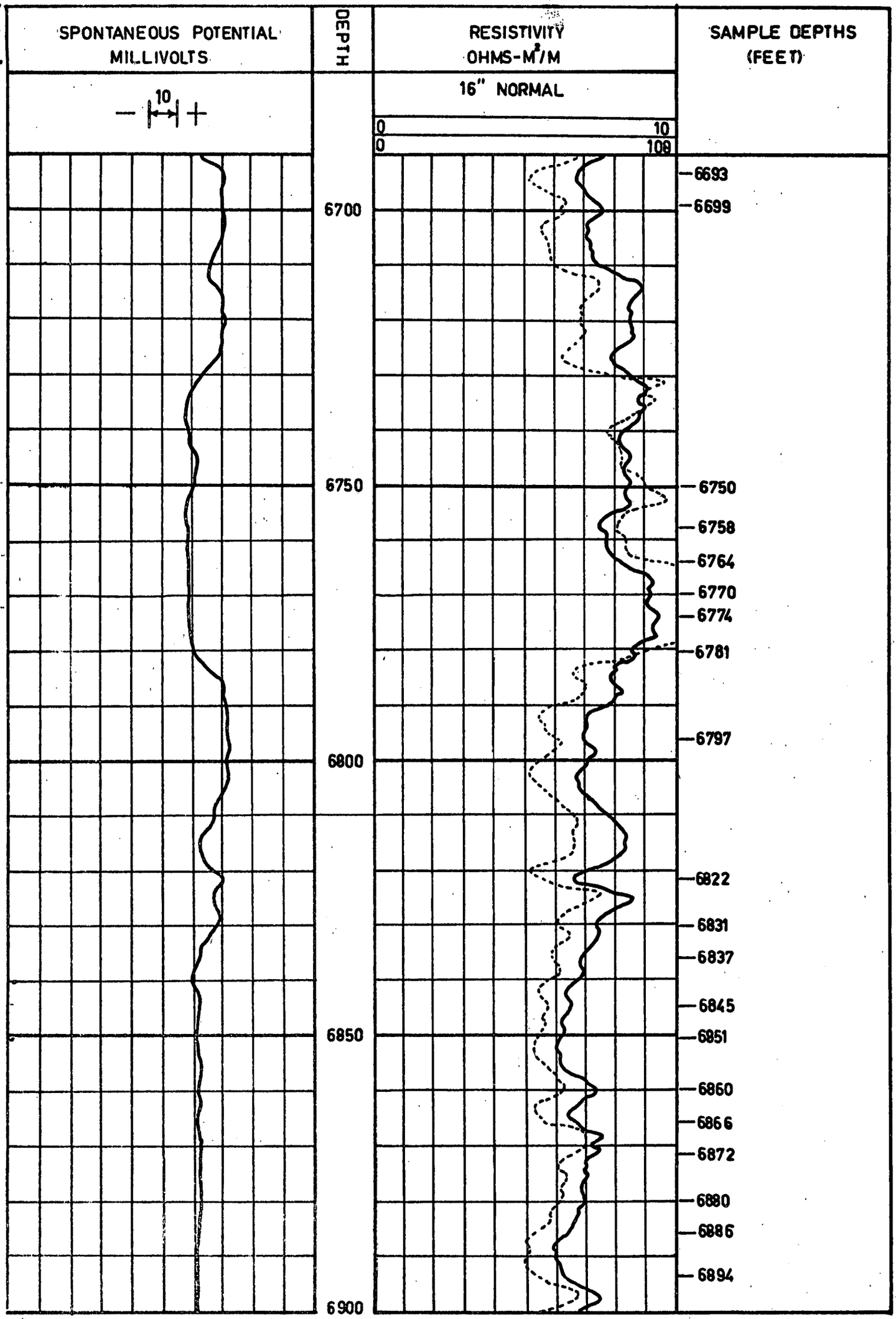


FIGURE 30

INDUCTION ELECTRICAL LOG BARROW No 1