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GILMORE NO. 1

SPECIAL CORE ANALYSIS TESTS ON SAMPLES FROM THE DEVONIAN SANDSTONE GAS RESERVOIR

by

B.A. McKAY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

PETROLEUM TECHNOLOGY SECTION

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The Gilmore No. 1 well was drilled in 1964 on Authority to Prospect 84P, issued jointly to the Phillips Petroleum Company and Sunray DX Oil Company. The drilling operation was conducted by Phillips Petroleum on behalf of the two partners.

The well was drilled to a total depth of 14,260 feet. Casing was set to 13,504 feet and the hole plugged back to 12,900 feet. The casing was perforated over the interval 11,730 to 12,500 feet for a net of 347 feet, and the well was completed for gas production from the Etonvale Formation of Devonian age.

The drilling operation was approved for subsidy by the Commonwealth Government.

The Completion Report in respect of this drilling operation was submitted by Phillips Petroleum Company in 1965.

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INTRODUCTION

This report contains the results of a study comprising porosity, permeability, fluid imbibition and mercury injection capillary pressure tests conducted on samples from a gas producing Devonian reservoir sandstone in the Gilmore No. 1 well, Queensland. Pore size distribution values included in the report were calculated from the capillary pressure test data.

PROCEDURE AND APPARATUS

Two separate sets of samples were selected for test purposes; they included nineteen $\frac{3}{4}$ - inch diameter core plugs for mercury injection capillary pressure and imbibition tests (drainage and withdrawal), and nineteen 1 $\frac{1}{8}$ - inch core plugs for porosity, permeability and water imbibition tests. An additional complete set of nineteen $\frac{3}{4}$-inch samples was selected to re-check results obtained from mercury imbibition (withdrawal) tests. All plugs were diamond-drilled parallel to bedding and trimmed to approximately $1\frac{1}{4}$ inches in length.

Each sample was extracted with toluene in a Soxhlet-type apparatus for a 24 hour period, and oven-dried at 110°C for an additional period of 24 hours. Porosity and absolute permeability (using dry nitrogen) were then determined for each of the samples.

Capillary pressure (drainage) tests on the nineteen $\frac{3}{4}$-inch diameter plugs were carried out with Ruska-type mercury injection equipment using the Purcell (1) method whereby mercury

representing the saturating non-wetting phase, is injected into the samples at increasing pressure "steps". The mercury injected is recorded after volume stabilization at each step is reached; capillary pressure curves are then constructed from the completed test results after a maximum pressure (in these tests equal to 1400 psia) has been attained.

The with drawal, or mercury-imbibition (hysteresis) condition for each sample is obtained by reversing the process. Upon attaining the ultimate injection test pressure of 1400 psia, the system pressure is reduced in successive "steps", the last pressure step being approximately 20 microns.

Additional samples selected immediately adjacent to the above mercury injection plugs were used for the evaluation of water imbibition. These tests were conducted by placing the dry core plug in contact with water at its base, and allowing the water to climb up into the sample under the influence of capillarity. The residual non-wetting phase (air) saturation was calculated at the point of final (equilibrium or constant weight) wetting phase saturation. The results for each sample were compared with those determined by the mercury withdrawal method.

Finally, pore size values were calculated from the mercury injection capillary pressure data, using the formula :-

$$r = \frac{2\,\gamma\,\cos\theta}{\Delta P}$$

Average pore "throat" radii for the corresponding saturation - pressure intervals were calculated using values of 480 dynes / cm for mercury surface tension (γ), and 140° as the mercury rock contact angle (θ).

DISCUSSION OF RESULTS

Capillary pressure curves derived from the mercury injection tests are shown in Figures 1-19. Results of the two imbibition tests together with the porosity, permeability and mercury (non-wetting phase) saturation at ultimate test pressure are given in Table I. The position of the samples used in the tests is shown in Figure 30.

This (Devonian) sandstone reservoir has low porosity and permeability; sixty percent of the plugs tested were found to have a permeability less than 1 millidarcy, while the average porosity for all the samples was 7.8 percent.

These factors had a very significant effect on the capillary pressure results. All the samples displayed moderate to high threshold pressures and residual water saturations. In addition, the configuration of the capillary pressure curves generally indicate that the irreducible water saturation had not been obtained at the ultimate maximum test pressure of 1400 psia.

The results shown in Table I present an interesting picture of the saturations as they occur ahead of and behind an advancing water front. Other investigators (2, 3, 4) using various types of core material, have extensively studied saturation conditions behind an advancing front. They found that during the displacement of gas by water in the water-wet sandstones, residual gas saturations (after complete flood-out) behind the flood-front were independent of water injection rates and the final saturation distribution was essentially controlled by capillary forces. They have also shown that these saturations could be duplicated in the laboratory by the imbibition process.

Laboratory imbibition tests on Gilmore samples have shown the rock in this gas reservoir to be strongly water-wet. Therefore, the residual non-wetting phase saturation value determined by imbibition will be equal to the gas saturation behind an encroaching water front in this reservoir.

Laboratory tests by Gefen et al (4) have shown that residual gas saturation in a reservoir core sample is independent of fluid density, viscosity and interfacial tension between the displacing and displaced phases, provided the flooding fluids each wet the rock to the same extent. Two imbibition systems studied by Gefen and other (2) experimenters were air-water and mercury-air. They found that in both systems, quite comparable non-wetting phase saturations were obtained, and these agreed reasonably well with residual saturations evaluated by water flooding.

Similar imbibition tests were conducted on core material from the Gilmore No. 1 well, and the results are shown in Table I. Sixty percent of the samples tested by this technique gave results which were in close agreement with the imbibition test data of the adjacent sets of plugs. However, some marked saturation discrepancies were noted in the remaining forty percent of sample sets. These could not be resolved by additional drainage - imbibition testing.

Most of the discrepancies noted between the two imbibition methods were characterized by abnormally low residual mercury saturations; it appears that the source of error may lie with the mercury injection - withdrawal technique. However, this problem will require much additional investigation before the exact cause of error can be confidently identified.

CONCLUSIONS

A study of porosity, permeability, capillary pressure, imbibition and pore size distribution has been made on samples from the Gilmore No. 1 well. The investigation lead to the following conclusions :-

1. Porosity and permeability of this reservoir were found to be low; average values for the samples used in these tests were 7.8% and 1.3 md. respectively.
2. Mercury injection capillary pressure tests showed that the reservoir threshold pressures and irreducible water saturations were moderate to very high.
3. Imbibition tests revealed the formation to be strongly water-wet. Average residual gas saturation in the reservoir as determined by water displacing air was 26% of pore volume. Discrepancies were found in comparative tests between the mercury and water imbibition techniques. The exact cause of these discrepancies is not clear at this preliminary stage of our investigations.

REFERENCES

1. PURCELL, W.R. - "Capillary pressures, their measurement using mercury and the calculation of permeability therefrom". Petroleum Transactions, AIME, Febuary 1949.

2. PICKELL, J.J., SWANSON, B.F., HICKMAN, W.B. - "Application of air-mercury and oil-air capillary pressure data in the study of pore structure and fluid distribution". Journal of Petroleum Technology, March 1966.

3. KATZ, D.L. et al - "How water displaces gas from porous media". The Oil and Gas Journal, January 10, 1966.

4. GEFEN, T.M., PARRISH, D.R., HAYNES, G.W., MORSE, R.A. - "Efficiency of gas displacement from porous media by liquid flooding". Transactions, AIME, Volume 195, 1952.

Table 1

1 SAMPLE NUMBER	2 DEPTH (FEET)	3 POROSITY (% BULK) (VOLUME)	4 (DRY NOTROGEN) PERMEABILITY (Md.)	5 INITIAL GAS SATURATION BY MERCURY INJECTION (% PORE VOLUME)	6 RESIDUAL GAS SATURATION BY MERCURY IMBIBITION (% PORE VOLUME)	7 RESIDUAL GAS SATURATION BY WATER IMBIBITION (% PORE VOLUME)
1	11991	5.7	0.26	34.5	20	28
2	11995	5.2	1.2	36.5	20	20
3	11999	8.0	0.68	28.0	13	26
4	12003	9.8	0.14	34.0	27	29
5	12006	8.5	0.39	41.5	28	29
6	12010	8.2	1.8	56.0	38	39
7	12136	8.8	0.66	53.0	27	22
8	12138	8.9	0.34	32.0	22	21
9	12193	9.5	5.7	57.7	26	25
10	12195	10.9	1.8	48.0	24	15
11	12197	9.9	3.6	45.5	25	27
12	12401	5.4	1.4	42.5	19	31
13	12479	10.5	2.5	58.5	27	26
14	12483	8.8	0.58	32.5	26	30
15	12486	6.2	0.57	25.0	12	24
16	12490	10.8	1.4	28.0	17	18
17	12495	5.6	0.83	33.0	18	32
18	12840	3.9	0.52	35.0	19	22
19	12843	3.9	0.26	35.0	14	30
	AVERAGES	7.81	1.30	39.7	22.4	26.0

TABLE II

Average Pore Entry Radius (Microns)						Sample Depth (Feet)
	Saturation (% Pore Volume)					
	0-10	10-20	20-30	30-40	40-50	
		0.33	0.16			11991
	1.06	0.63	0.27			11995
	1.33	0.44				11999
	0.43	0.30	0.14			12003
	0.97	0.71	0.45	0.16		12006
	3.81	2.54	1.84	1.21	0.53	12010
		0.82	0.41	0.20	0.11	12137
	1.3	0.60	0.19			12138
	2.37	1.46	0.84	0.43	0.19	12193
		1.19	0.53	0.22		12195
		0.85	0.37	0.16		12197
	3.05	1.33	0.55	0.17		12401
		1.42	0.79	0.43	0.22	12479
	1.33	0.55	0.17			12483
		0.38				12486
		0.59				12490
	1.33	0.56	0.18			12495
	1.50	0.63	0.21			12840
		0.67	0.30			12843

FIGURE 1

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No. 1 SAMPLE DEPTH-11991

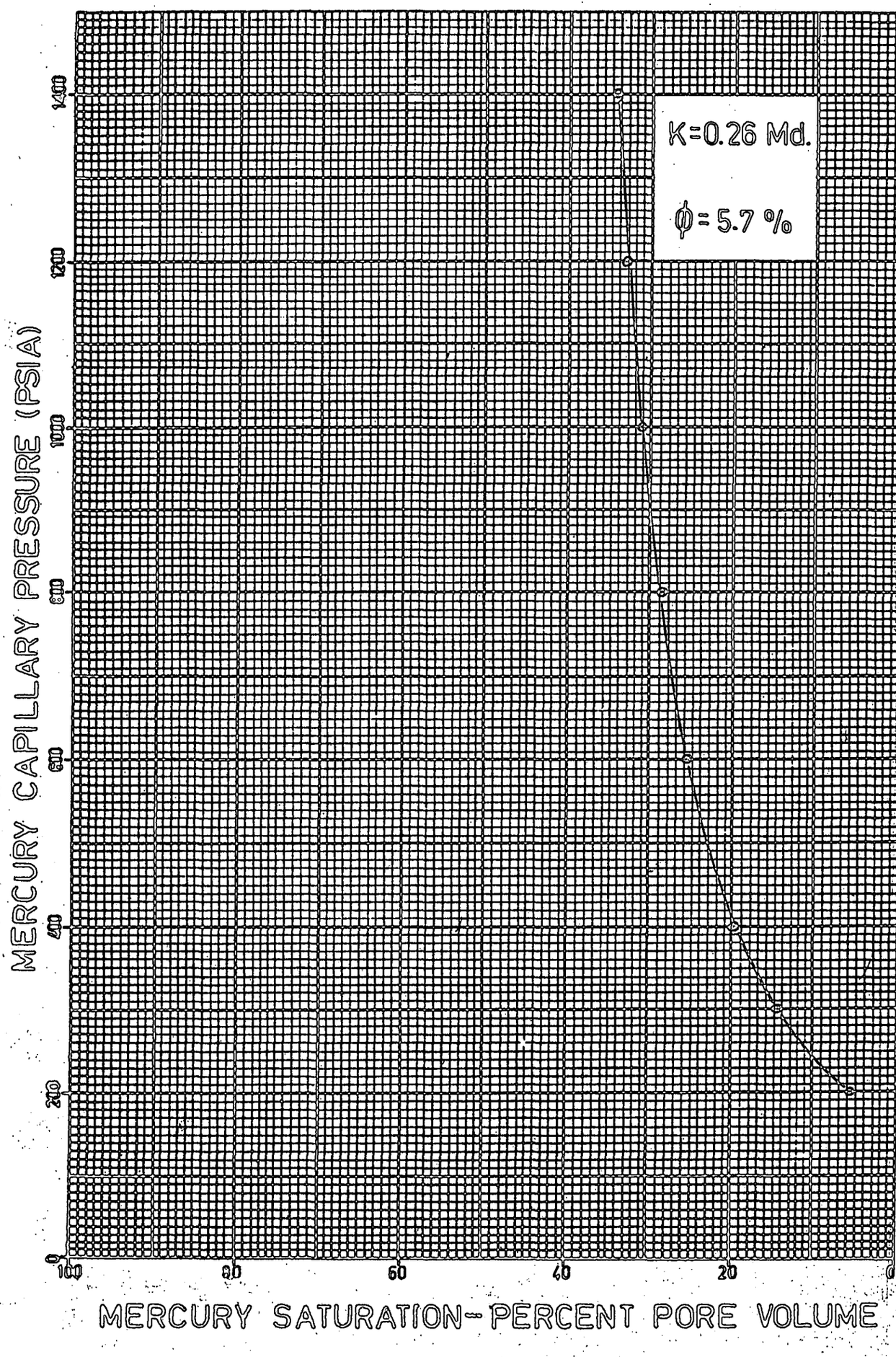
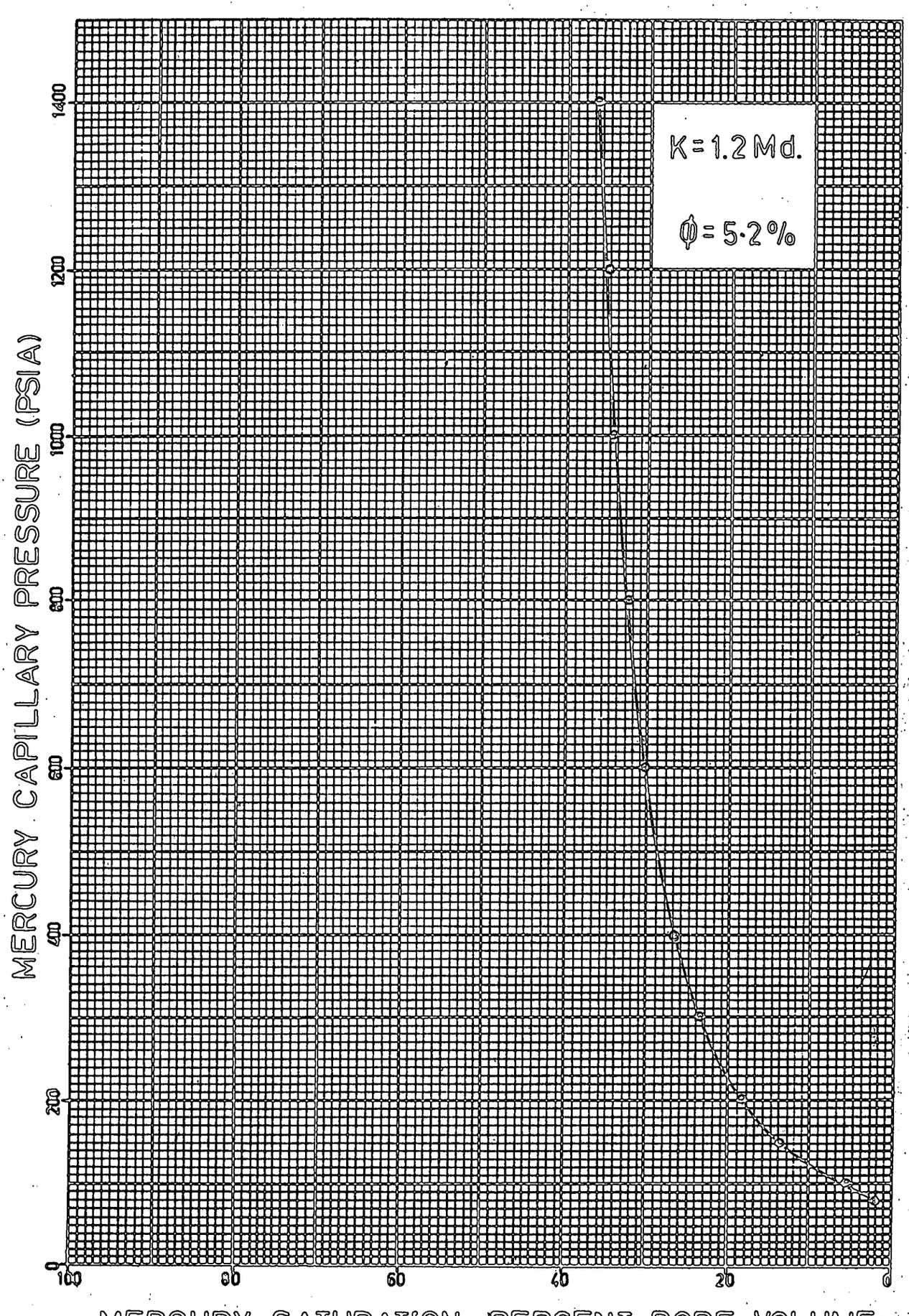


FIGURE 2

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No.1 SAMPLE DEPTH-11995



MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No. 1 SAMPLE DEPTH-11999

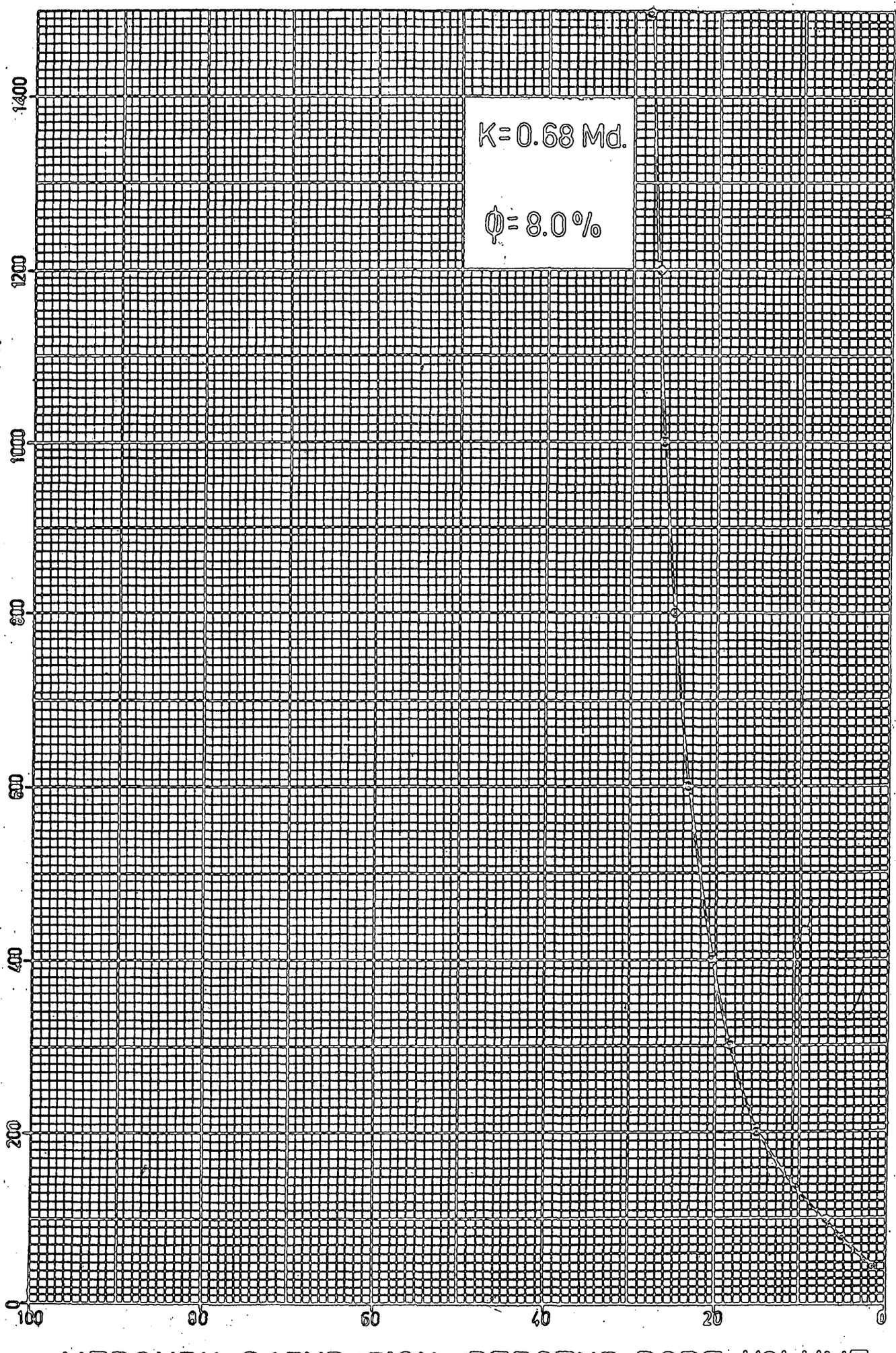


FIGURE 4

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No.1 SAMPLE DEPTH-12003

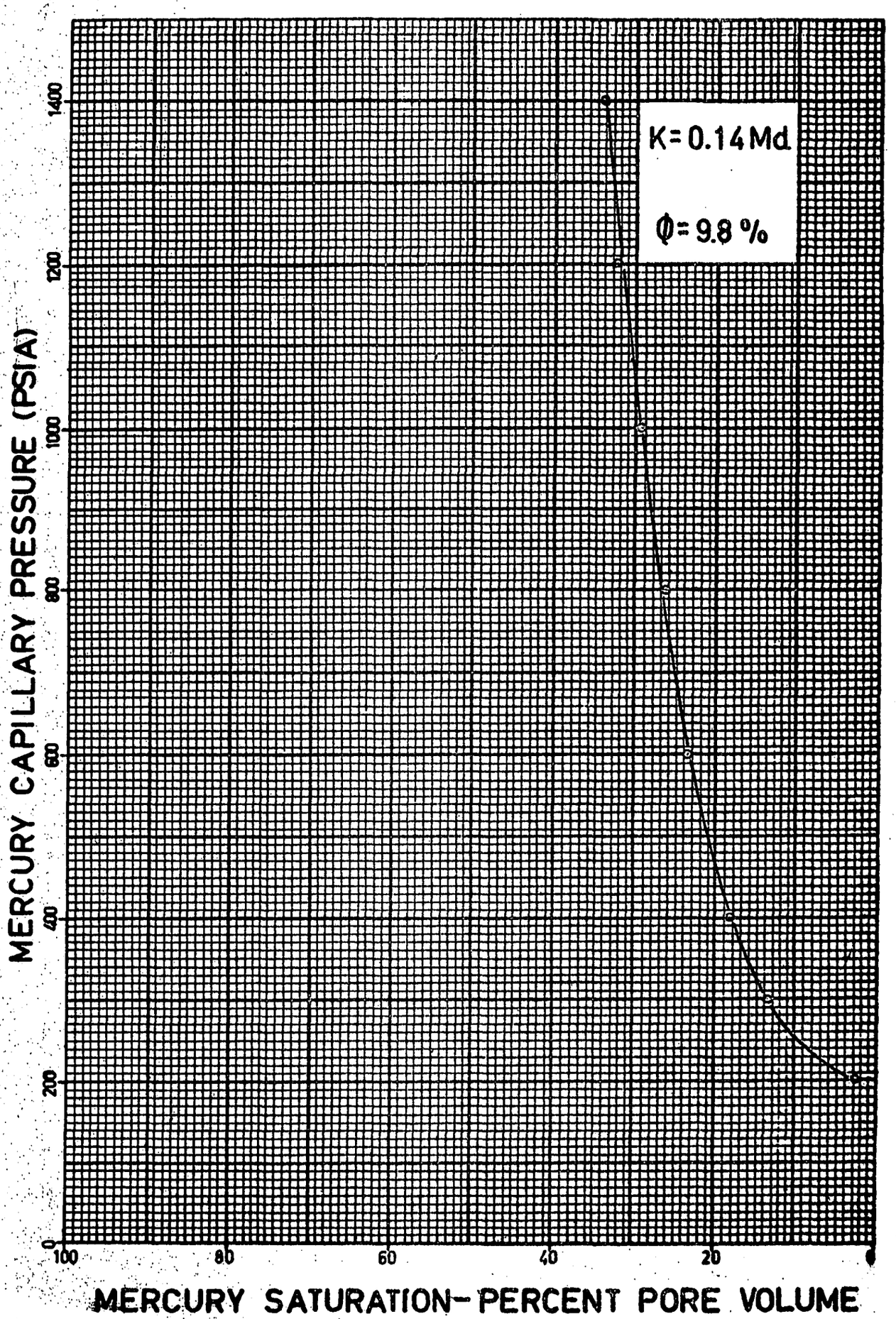


FIGURE 5

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12006

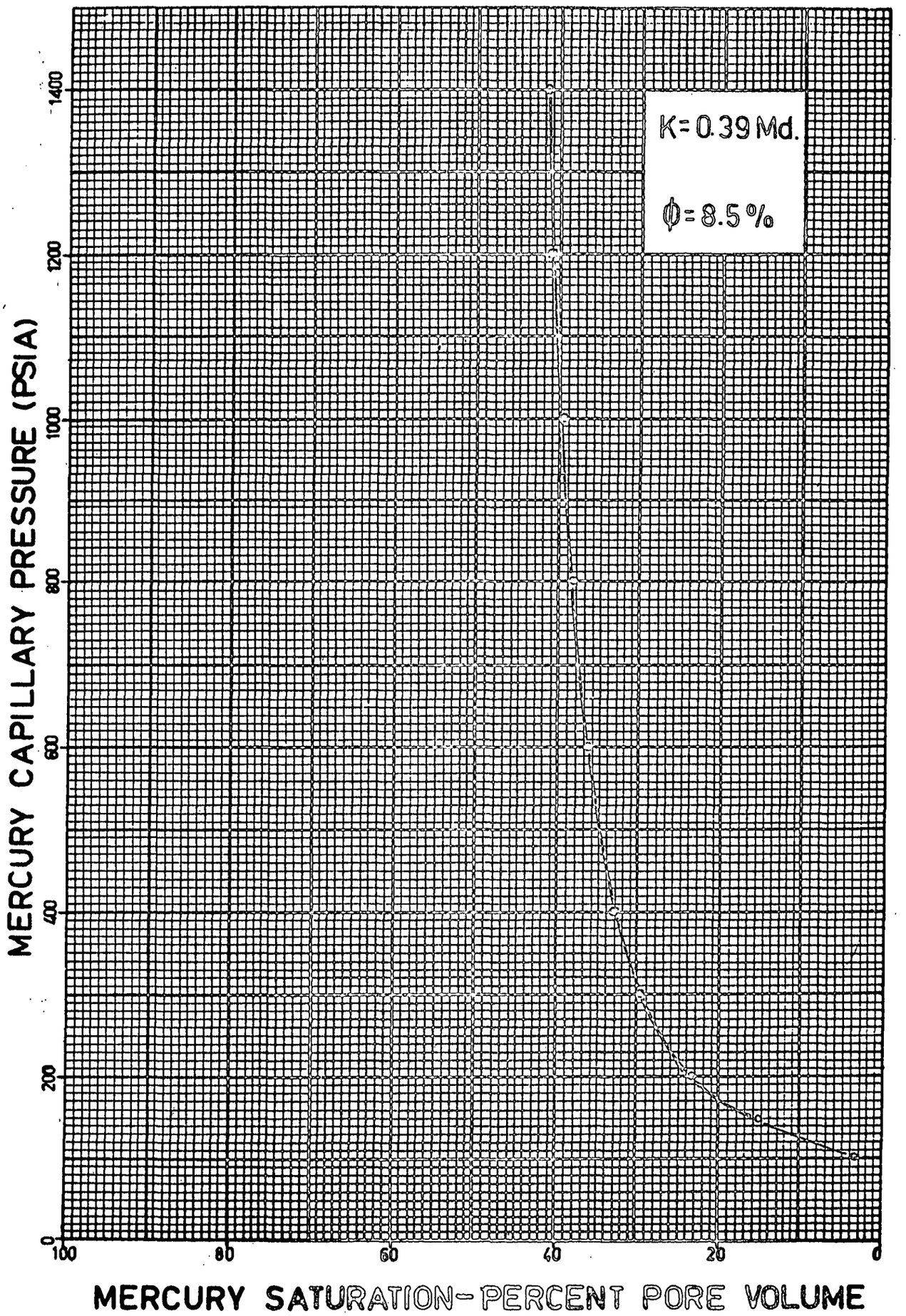


FIGURE 6

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12010

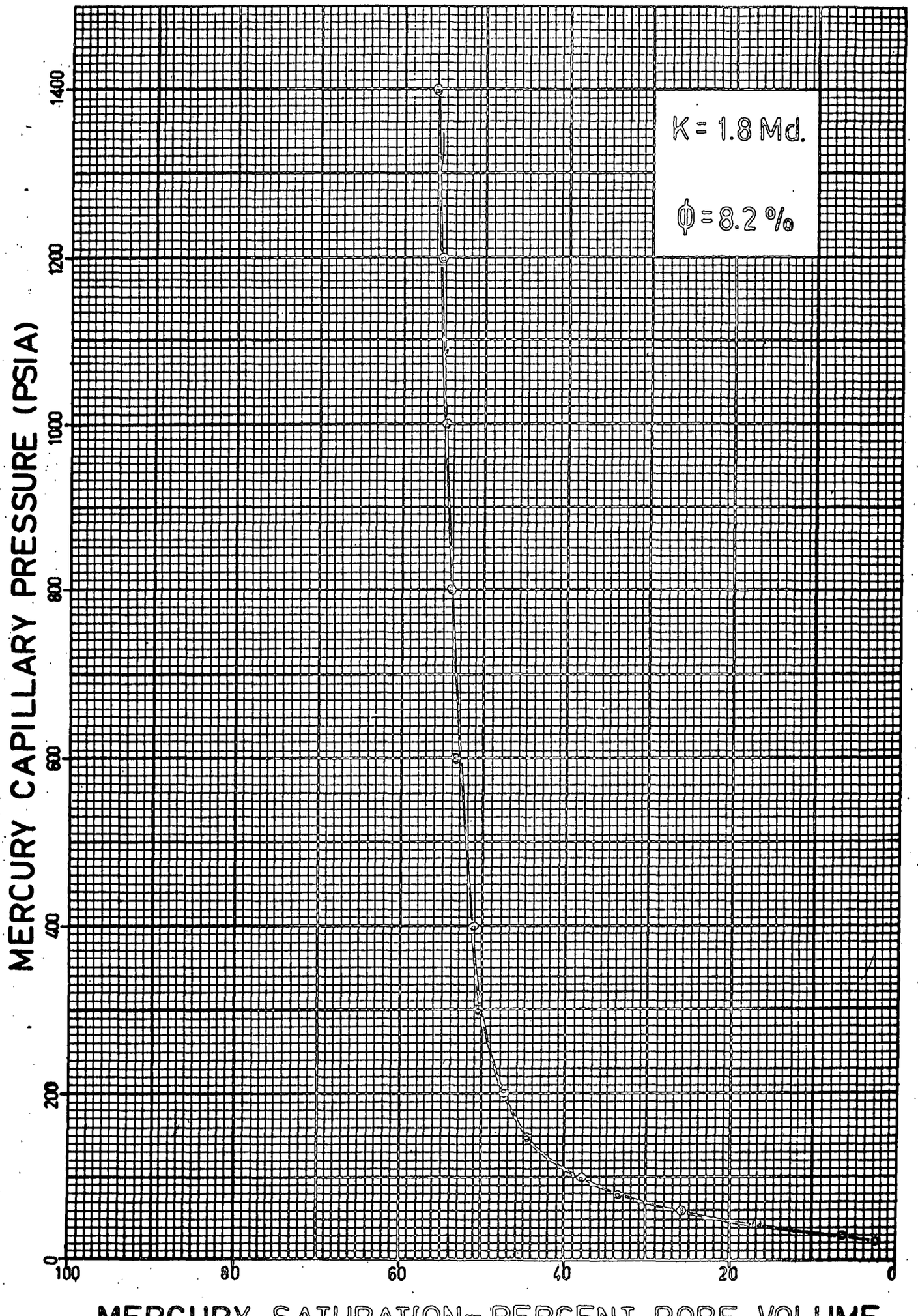


FIGURE 7

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12136

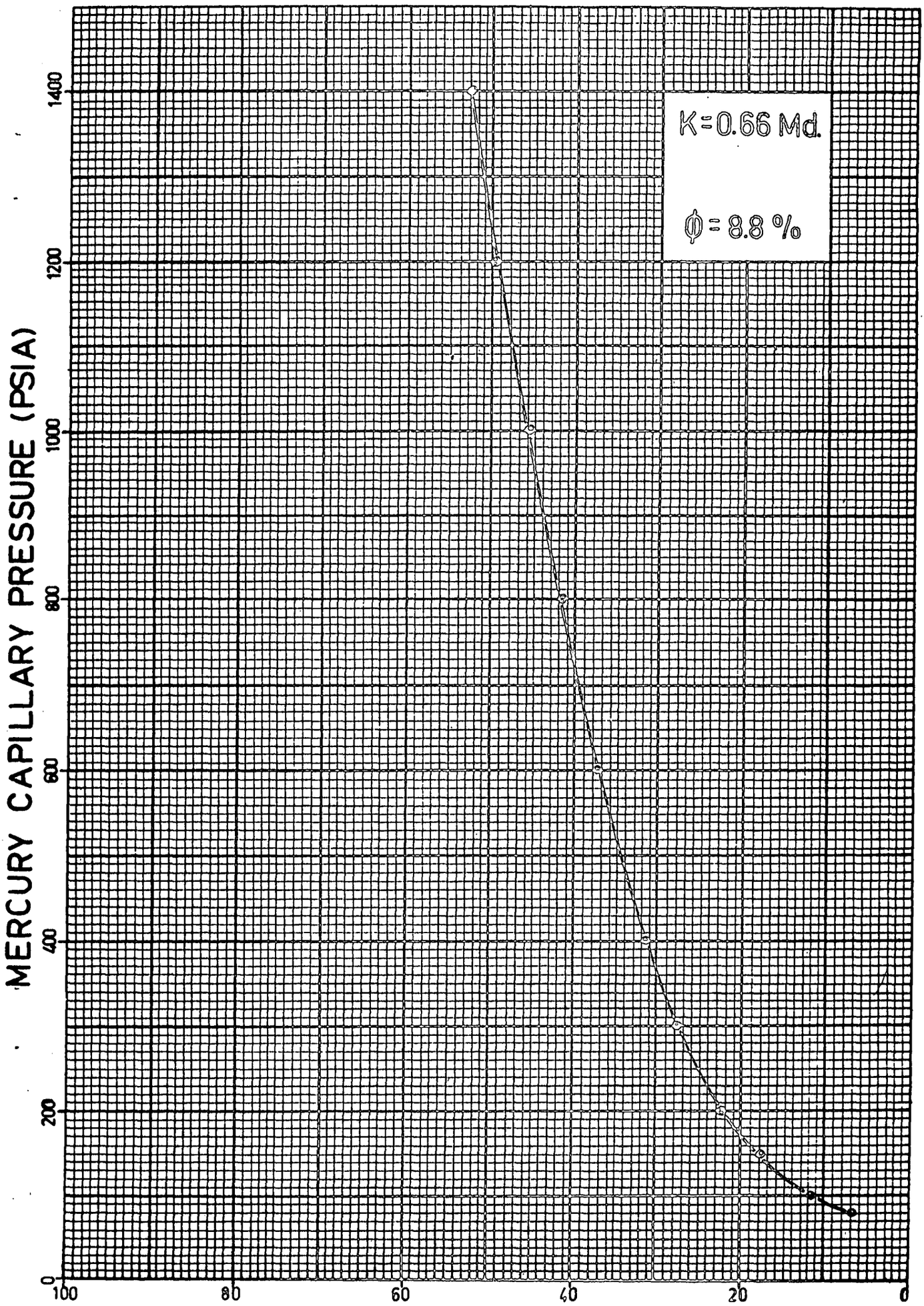


FIGURE 8

MERCURY-CAPILLARY PRESSURE

WELL NAME-GILMORE No. 1 SAMPLE DEPTH-12138

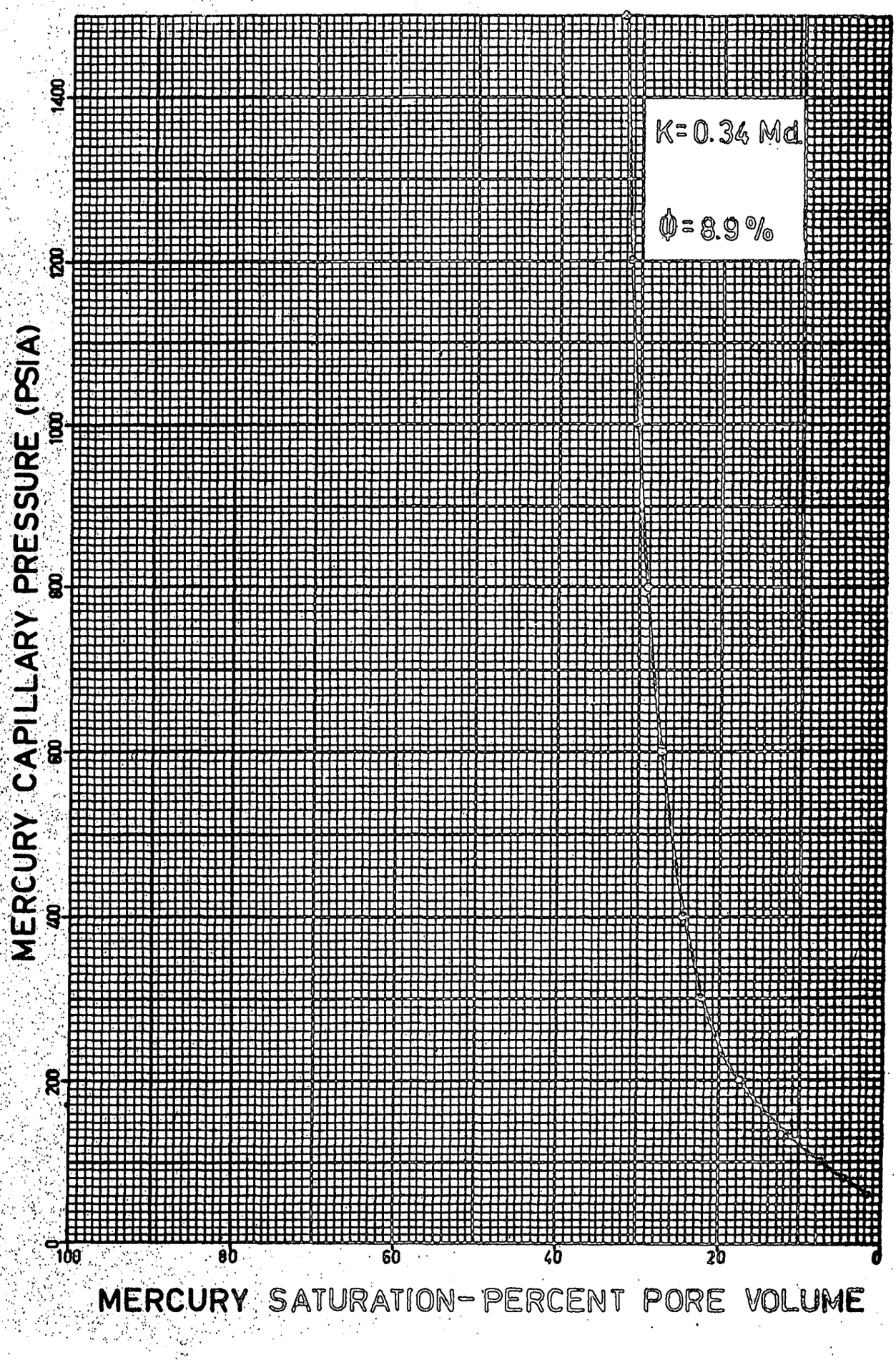


FIGURE 9

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12193

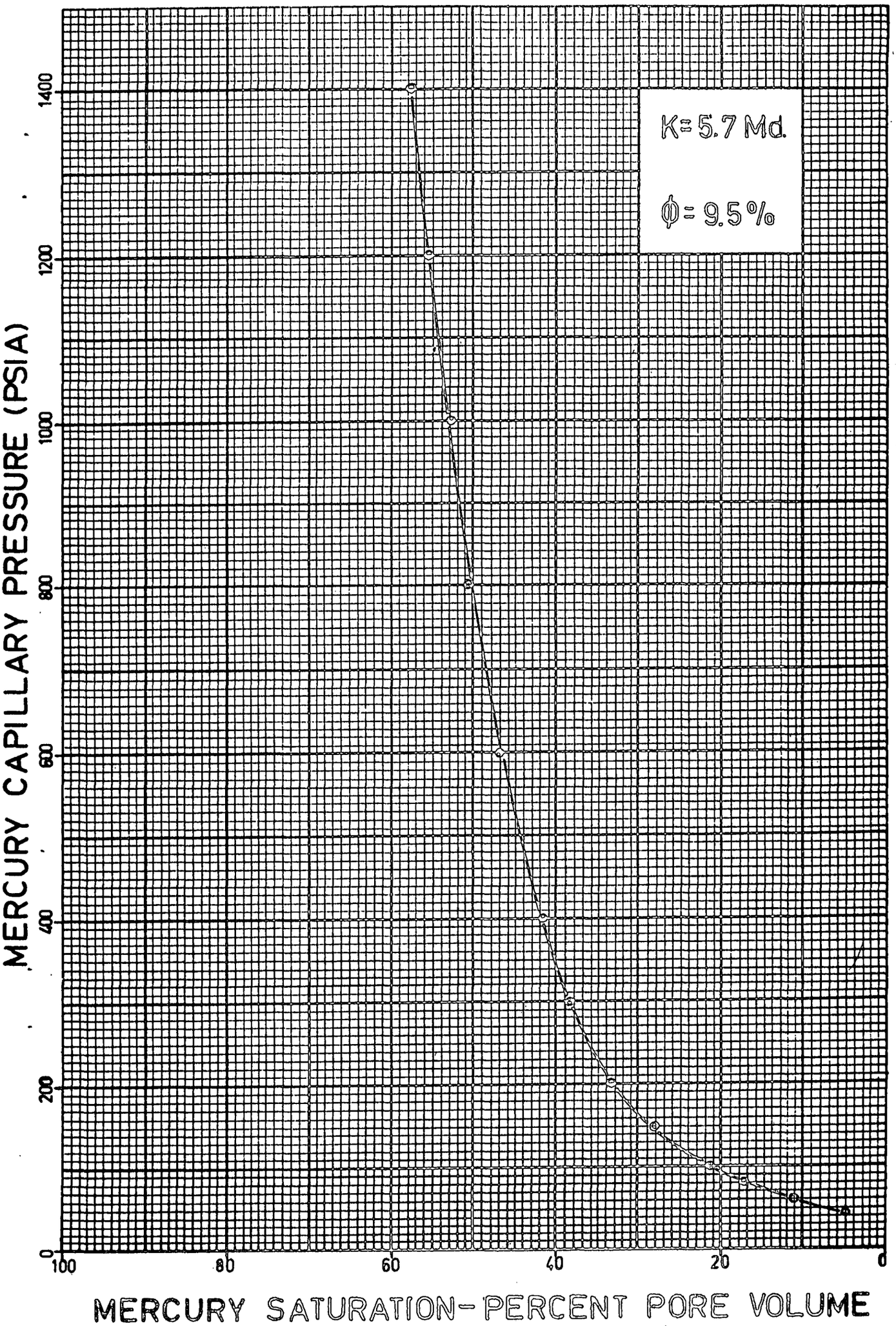


FIGURE 10

MERCURY CAPILLARY PRESSURE

WELL NAME - GILMORE No. 1 SAMPLE DEPTH - 12195

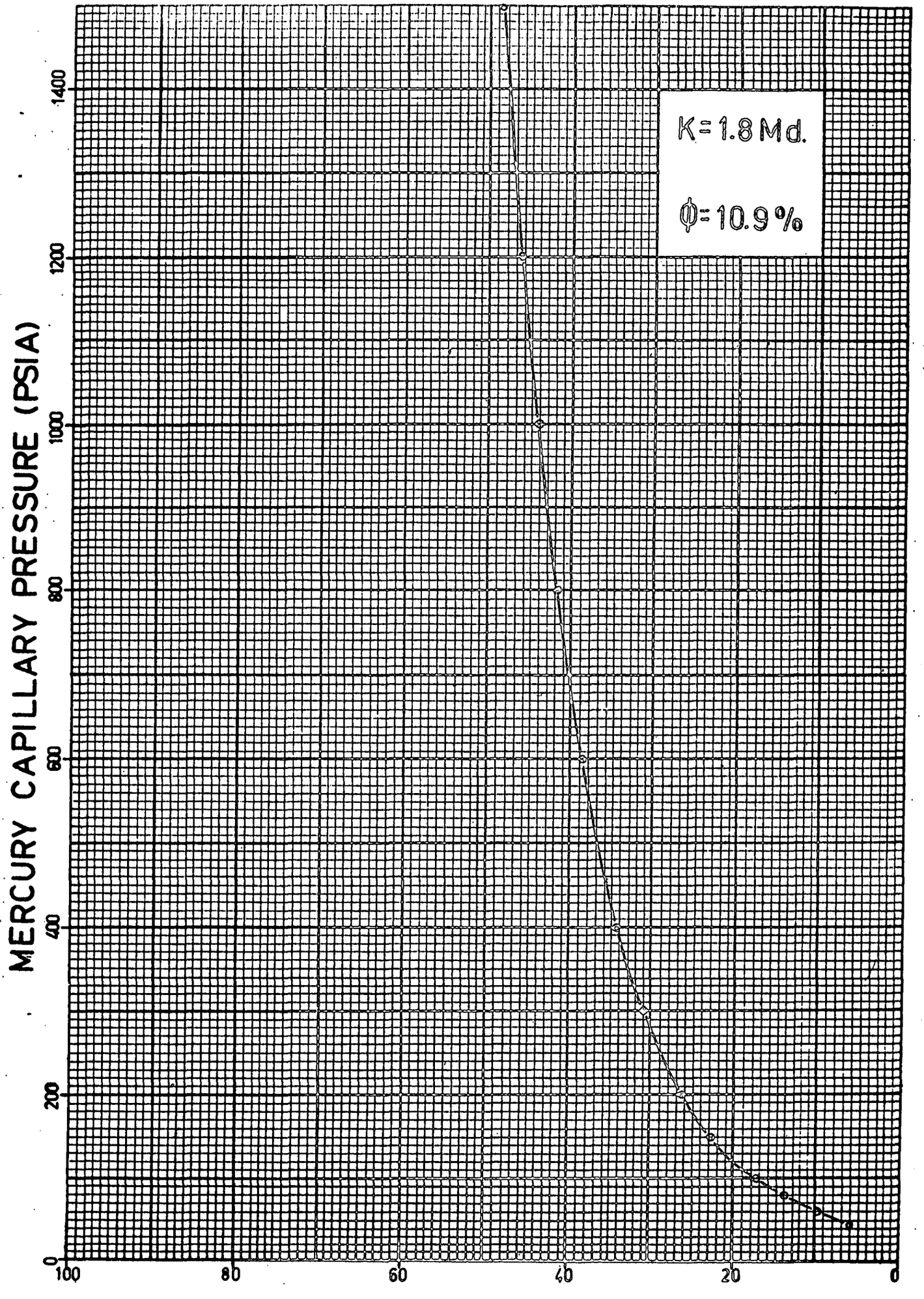


FIGURE 11

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12197

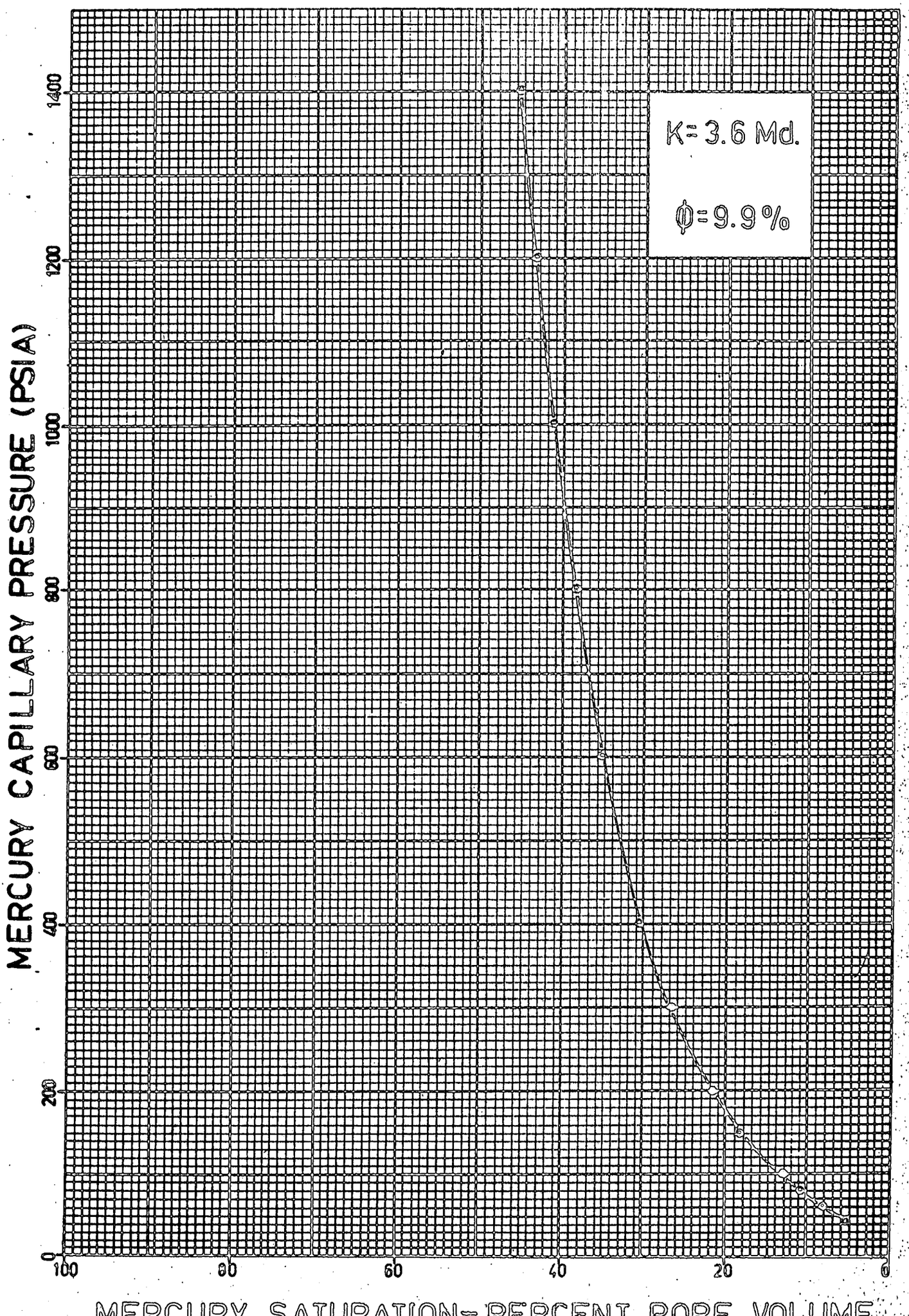


FIGURE 12

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12401

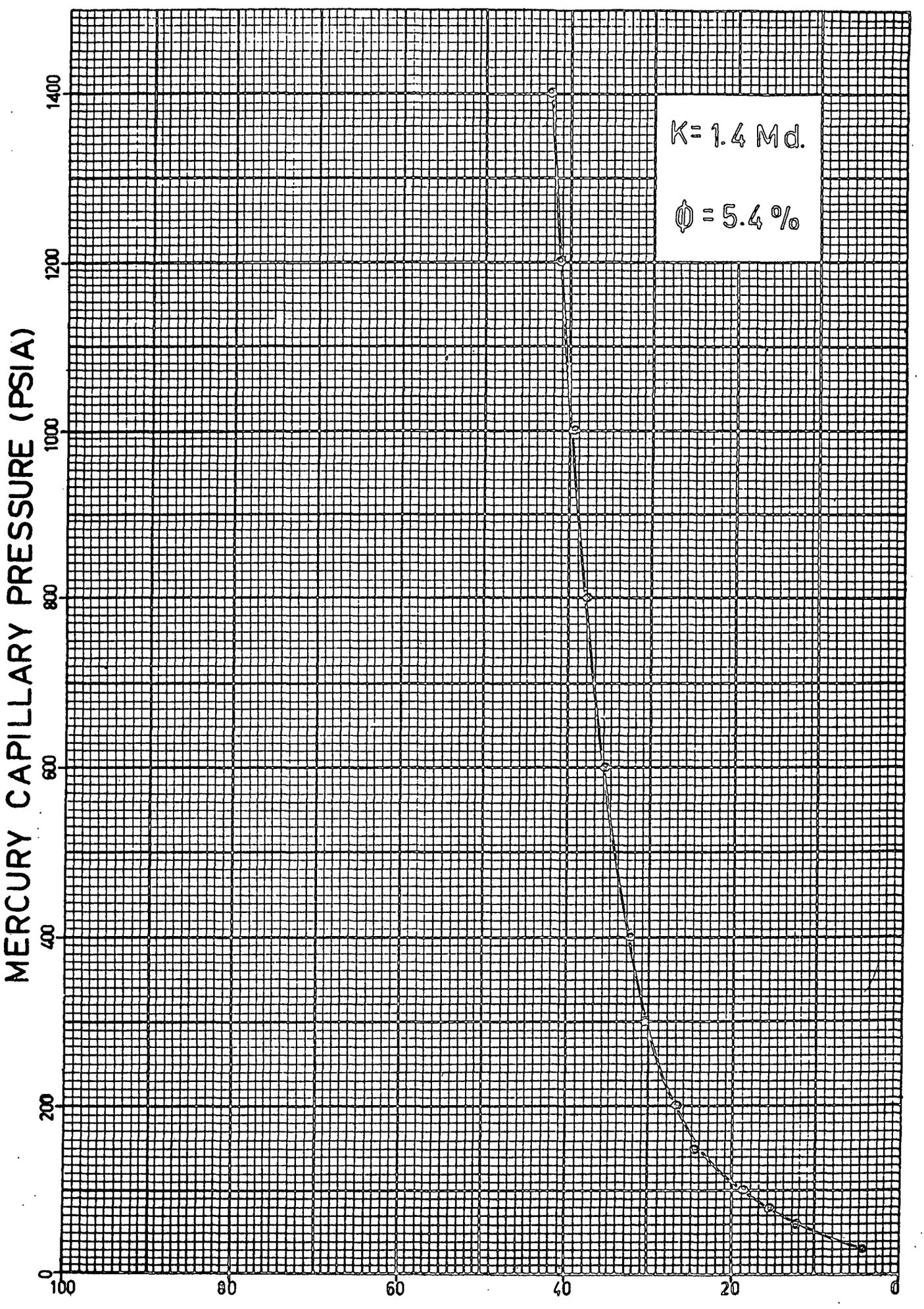


FIGURE 13

MERCURY CAPILLARY PRESSURE

WELL NAME GILMORE No 1 SAMPLE DEPTH 12479

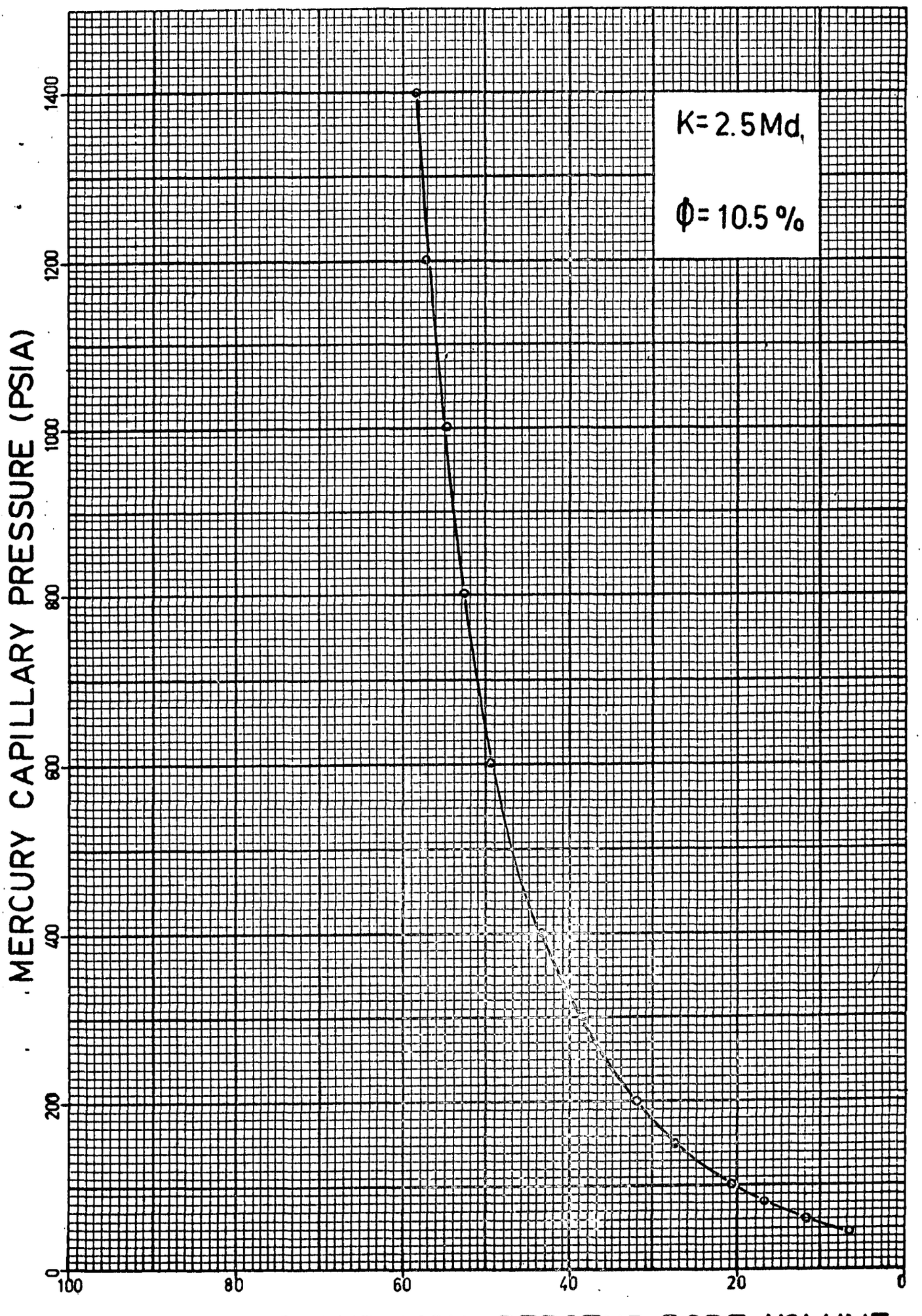


FIGURE 14

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12483

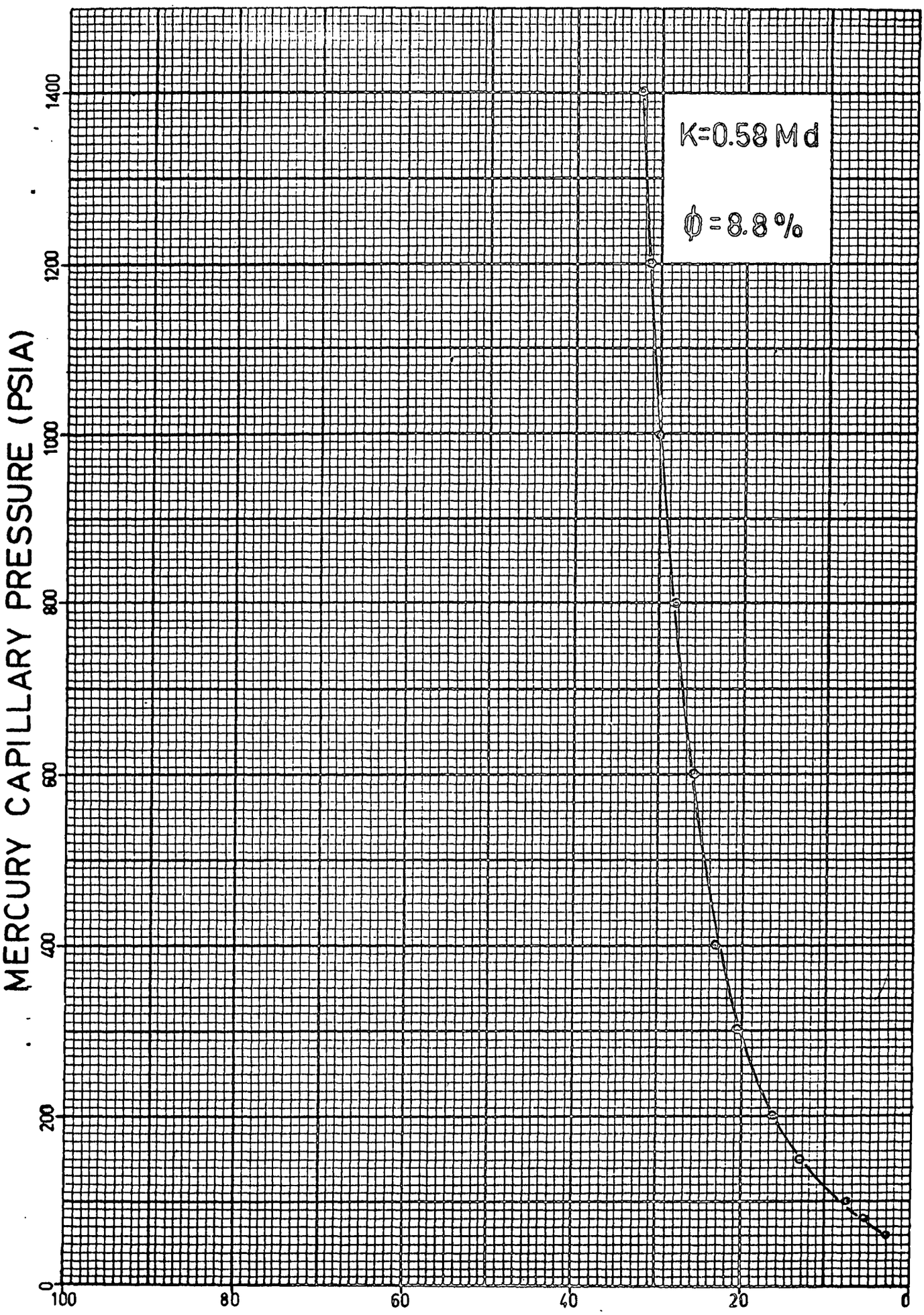


FIGURE 15

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12486

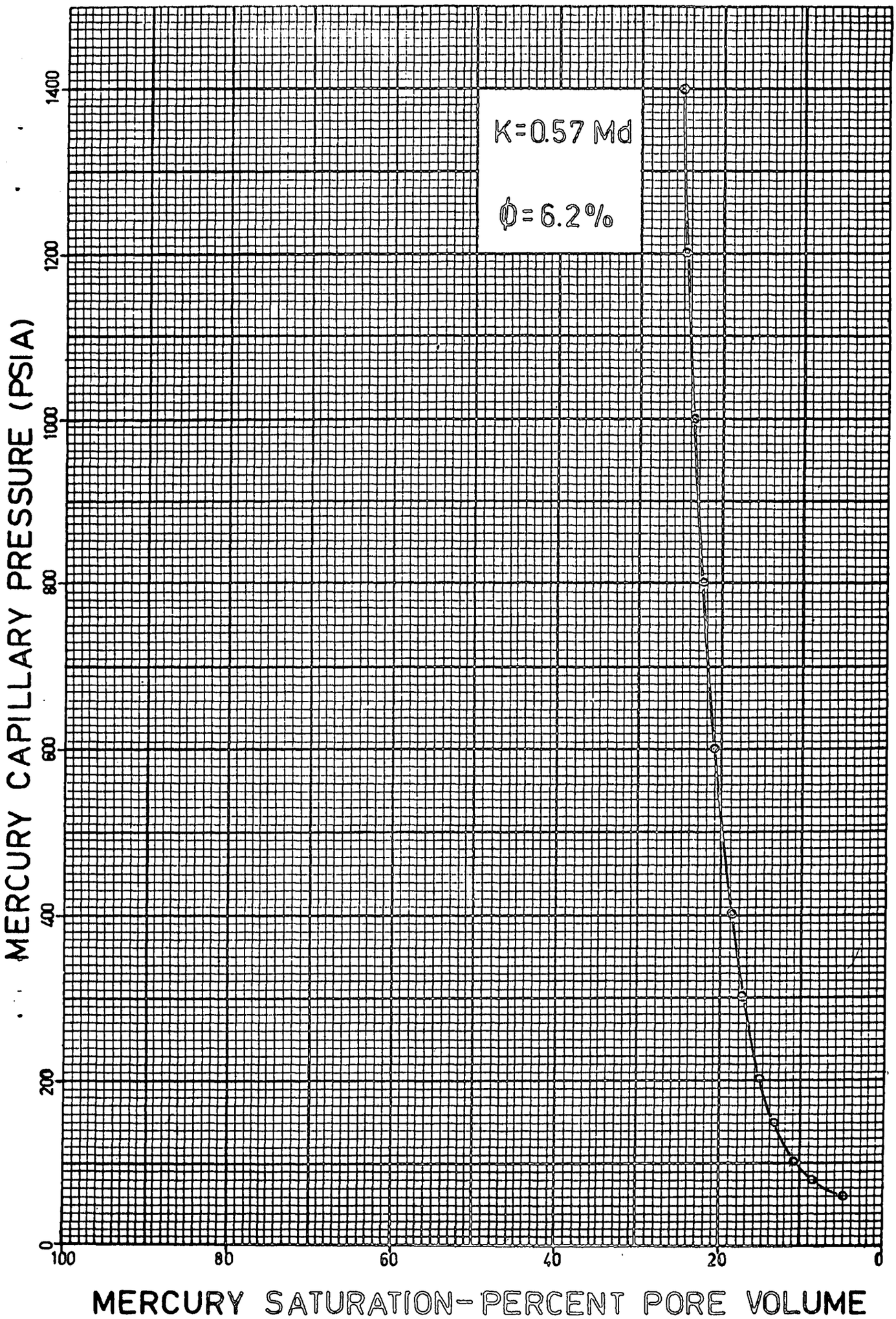


FIGURE 16

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12490

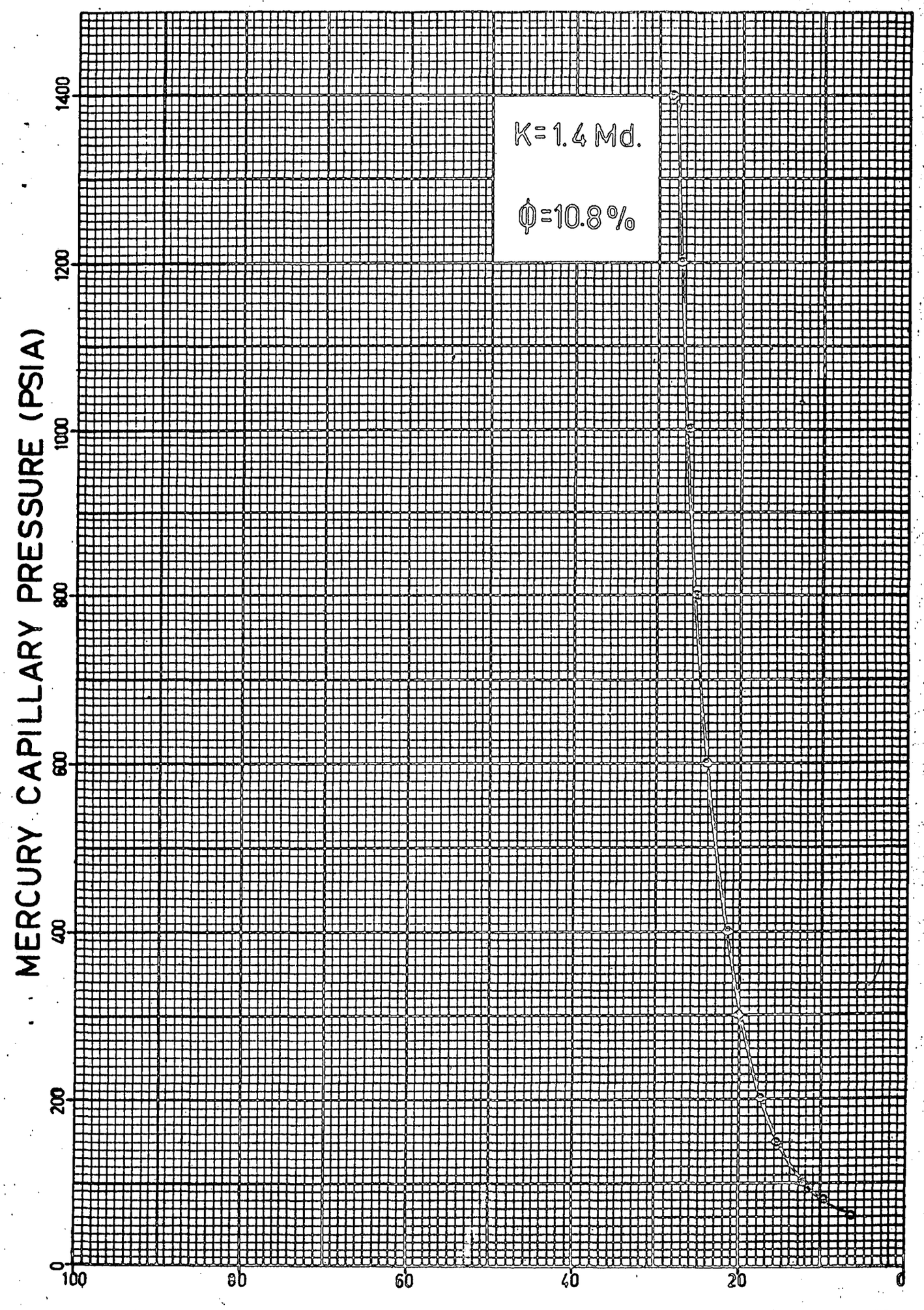


FIGURE 17

MERCURY CAPILLARY PRESSURE

WELL NAME- GILMORE No.1 SAMPLE DEPTH-12495

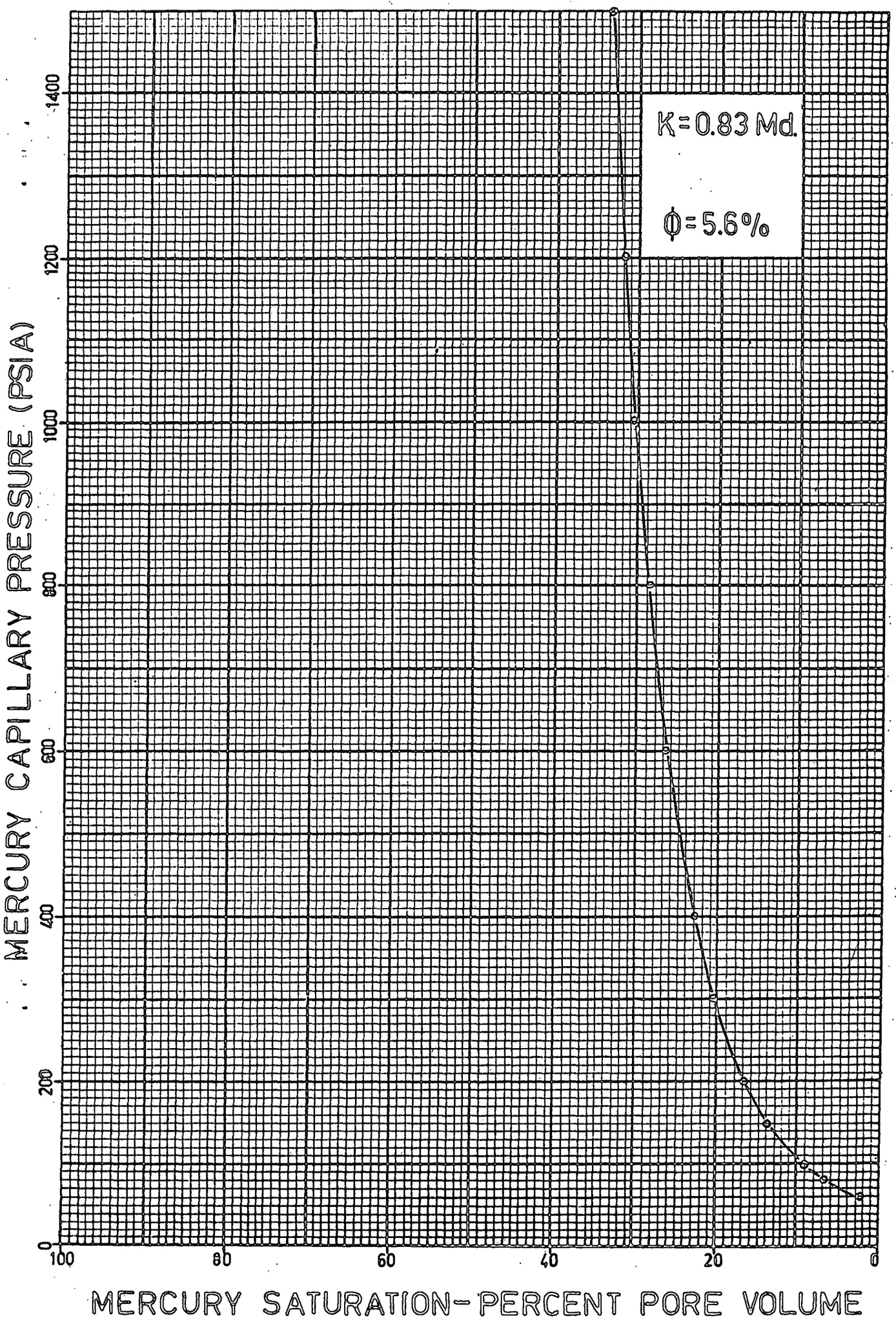


FIGURE 18

MERCURY CAPILLARY PRESSURE

WELL NAME-GILMORE No 1 SAMPLE DEPTH-12840

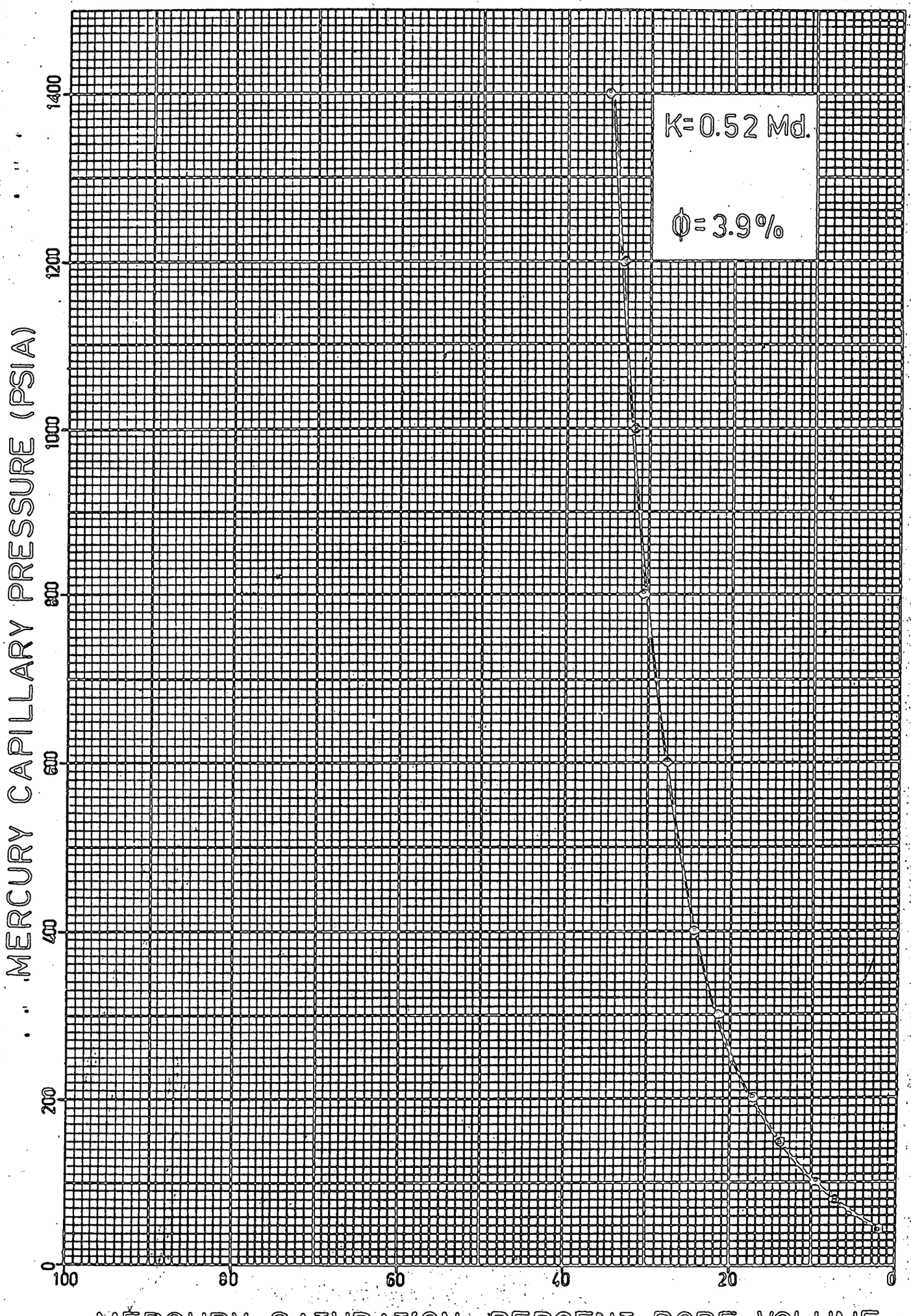


FIGURE 19

MERCURY CAPILLARY PRESSURE

WELL NAME- GILMORE No 1 SAMPLE DEPTH - 12843

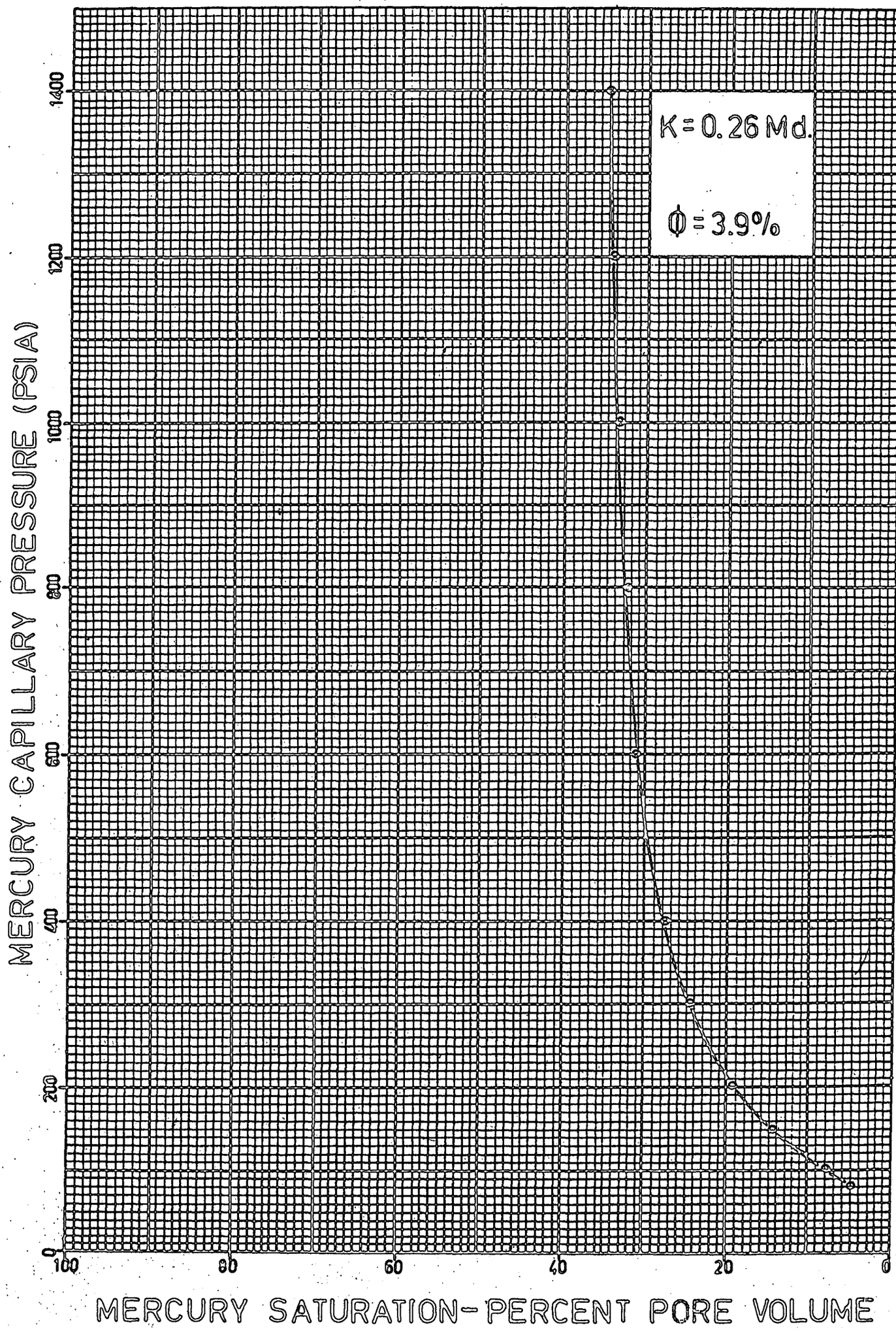


FIGURE 20

GILMORE No. 1 ELECTRICAL LOG