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A Study of the Relationship between Overburden Pressure and Fluid Permeability in some Hydrocarbon Reservoir Rocks in Australia

by

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MINERAL RESOURCES BRANCH

PETROLEUM TECHNOLOGY SECTION

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INTRODUCTION

The determination of permeability in routine core analysis tests involves the measurement of flow of air or nitrogen through a sample which is contained in a flexible sleeve under nominal confining pressure. The resulting permeability value however, does not represent the potential of the rock to transmit fluids or gases under reservoir conditions.

It is accepted that the weight of the strata overlying a reservoir exerts a considerable effect on the permeability of the reservoir rock. A sandstone - shale sequence generally averages about 2.3 grams/c.c. bulk density, which is equivalent to a net confining pressure of approximately 0.6 psi/ft. of depth. This overburden pressure elastically deforms the reservoir rock, thereby, reducing its permeability in some extreme cases to one-tenth of the value measured in routine core tests. Neglect of this permeability reduction due to overburden may account significantly for the difference between well productivity calculated from routine analysis and the actual productivity measured under reservoir conditions.

In this investigation, flow capacities for oil and dry nitrogen were measured in core samples from five Australian oil producing reservoirs. Permeability measurements were made under routine conditions to nitrogen, and at various overburden conditions using oil with and without irreducible residual water saturation in the cores.

PROCEDURE AND APPARATUS

Altogether, 26 core samples from five separate oil reservoirs were used in these tests. The samples were drilled from whole and slabbed core sections using a $1\frac{1}{8}$-inch diameter diamond bit. These were trimmed with a diamond saw to a length of about $1\frac{1}{2}$ inches. The plugs were then cleaned with toluene in a centrifugal extractor for four hours, and dried in an oven at 110°C for 36 hours. Subsequently, the porosity of each plug was measured in a Ruska mercury porometer, and permeability to nitrogen was evaluated in a rubber sleeved Hassler cell at a sleeve pressure of 120 psig.

Flow tests with a simulated overburden confining pressure were carried out in the following manner. The 26 extracted and dried samples were deaerated, then saturated with oil (Soltrol-C). The samples were each separately placed in an overburden-pressure Hassler-cell which is illustrated in Figure 28, and subjected to a confining (sleeve) pressure of 120 psi. This cell is designed so that sleeve pressure is exerted in both transverse and longitudinal directions on the core sample, thus simulating reservoir confinement pressure conditions. Flow tests were carried out on each plug using Soltrol - C, at confining sleeve pressures of 120, 200, 500, 1000, 2000 3000, 4000 and 6000 psi.

Following these tests, a determination of oil permeability at overburden pressure with an irreducible water saturation was undertaken to further simulate reservoir conditions. All hydrocarbon reservoir rocks contain some water; it was therefore decided to test the theory that increased compression would inhibit flow through pore channels by further constriction of the pore throats with water emanating from the smaller pores.

These tests were conducted by first extracting and drying the samples, then saturating each one with 20,000 ppm brine in order to inhibit clay swelling. Each sample was then flushed with Soltrol-C until water production in the effluent had ceased, and an irreducible water phase had been established in the pore spaces of the plugs. Flow tests using Soltrol - C were then conducted in the overburden pressure cell in the manner described previously.

Precautions were taken throughout the flow tests to minimize any possible permeability reductions in the samples due to pore blocking. All fluids used were de-aerated and filtered prior to use, and line filters were used in the flowing stream. Pressure in the flowing phase was accurately monitored by an electronic pressure transducer, permitting very accurate differential readings to be made.

The overburden pressure test results were depicted in the following manner; the fluid permeability obtained at each succeeding overburden pressure was evaluated as a percentage of the permeability at zero effective overburden pressure. Each of these values was then plotted as a function (expressed in percent) of the confining sleeve pressure used during the tests. Values for each sample with and without water saturation were plotted on the same graphs for comparative purposes.

DISCUSSION OF RESULTS

The test results are as follows:

(1) Table 1 presents the porosity, gas and liquid permeabilities and residual water saturation test results.

(2) Figures 1-26 show the correlation between overburden pressure and fluid (oil) permeability for samples with and without residual water.

(3) Figures 27 and 28 show the overburden pressure cell and the configuration of the equipment used in the tests.

The test results in Figures 1-26 show the oil permeability at 6000 psi confining pressure with no residual water saturation in the cores, generally to lie between 60 percent and 85 percent of that at nominal overburden pressure. The maximum relative reduction in oil permeability in each case appears between nominal and 3000 psi confining pressure; beyond this pressure the curve becomes asymtotic. This supports the results reported by other observers (1,2).

The samples which showed the least oil permeability reduction with increasing overburden pressure were from the Mereenie field; the average oil permeability at 6000 psi overburden pressure for these samples was about 80 percent of the oil permeability at zero effective overburden pressure. These results correspond with the lithology of the oil producing Pacoota formation in the Mereenie field, which is a well indurated, fine grained clean sandstone having a well sorted pore distribution (3). Conversely, the samples from the Moonie field have shown the greatest reduction (52 percent of the permeability at zero overburden pressure) to oil permeability at maximum confining pressure. This again is consistent with the core type, for the producing interval at Moonie is generally a quite porous and loosely consolidated sandstone. In addition, a considerable content of clays and mineral fines is present in these samples, a condition which McLatchie (2) has shown to have an adverse effect on flow capacity during overburden pressure tests.

The most outstanding reduction in fluid permeability from increased confining pressure was shown by a sample from the Marlin field in the Gippsland Basin (Figure 11). Permeability to oil in this sample at confining pressures above 1000 psi was reduced to less than 1% of the value measured at nominal effective overburden pressure. A partial explanation of the reduction lies in the limited porosity development (7%) of this plug, consisting of two discrete channels of coarse grained loosely consolidated sandstone in a fine grained dense sandstone matrix. Part of this flow terminates on the circumference of the core, and may be increasingly blocked by the flexible rubber sleeve of the cell at higher pressures. However, it is apparent that compression of the limited pore space in this type of material has a noted effect on the ultimate flow capacity, and is an excellent example of discrepancies which may exist between routine and overburden pressure condition measurements.

Reductions in fluid permeability at maximum overburden pressure due to installation of residual water saturation were in the order of 5 percent to 10 percent lower than the flow tests without residual water. The Mereenie samples, (with the lowest water saturations established by dynamic displacement) showed the least permeability reduction from the addition of the water saturation, while the Gage Roads samples (having generally high residual water saturations) showed the greatest differences from the flow tests with no residual water. It could generally be stated that a residual water saturation has an adverse effect on flow capacity during permeability tests with overburden pressure; it should therefore be considered in all test work of this nature, to give a more accurate representation of actual reservoir flow capacity than flow measured under routine laboratory conditions.

CONCLUSIONS

Core samples from five Australian oil producing reservoirs were utilized in tests involving measurement of permeability under routine and overburden pressure conditions. The tests have shown that a significant reduction in fluid permeability occurs when confining pressures simulating the weight of overburden strata on a reservoir are applied to a core sample; the introduction of residual (irreducible) water saturation in the core samples causes a further decrease in permeability.

A relationship between the effect of overburden pressure on permeability and the lithology of core samples was shown to exist, the greatest general reduction in flow capacity appearing in loosely consolidated sandstone containing an argillaceous matrix.

REFERENCES

(i) FATT, I.
DAVIS, D.H.
"Reduction in Permeability with overburden Pressure". Petroleum Transactions, AIME, Volume 195 1952.

(ii) McLATCHIE, A.S.
HEMSTOCK, R.A.
YOUNG, J.W.
"The Effective Compressibility of Reservoir Rock and its Effects on permeability". Petroleum Transactions, AIME, Volume 253, 1958.

(III) McKAY, B.A.
Special Core Analysis Test on Samples from The Ordovician (Pacoota) Sandstone Reservoir, BMR Record No. 1967/121.

TABLE 1.

Well Name and Number	Sample Depth (Feet)	Porosity (percent bulk volume)	Permeability to Nitrogen (Md)	Permeability to Soltrol-C at Zero effective overburden Pressure (Md)		Residual water Saturation (by flushing with Soltrol-C) (% P.V.)
				Without Residual Water	With Residual Water	
E. Mereenie No. 4	4613	14.4	28	22	22	14.0
"	4625	10.5	14	11	11	9.0
"	4630	8.0	16	14	13	9.4
"	4635	8.0	7.6	6.0	5.4	16.0
"	4710	8.0	22	20	19	8.5
"	4742	11.3	52	50	49	15.2
"	4752	9.7	6.6	5.9	5.0	13.9
Marlin A-1	5121	25.0	510	505	410	31.1
"	5129	24.0	333	320	315	38.5
"	5131	25.3	620	615	502	27.5
"	5149	7.3	110	105	103	35.1
"	5165	23.0	1220	1207	1015	36.7
Gage Roads No. 1	5876	27.0	170	166	112	40.1
"	5880	25.0	380	371	324	40.2
"	5884	22.0	135	133	130	38.0
"	5892	27	535	500	403	18.2
Barrow Is. No. 1	6754	28	67	62	59	50.8
"	6760	26.5	41	39	32	48.4
"	6772	29.5	220	218	208	39.7
"	6831	25.0	18	16	16	52.7
"	6835	20.0	17	15	13	43.1
"	6839	28.0	95	91	86	48.0
Moonie No. 2	5645	19.0	20	18	17	25.4
"	5655	21.6	690	675	573	34.5
"	5667	19.7	720	675	555	37.3
"	5671	20.5	1130	1100	988	43.5

FIGURE 1

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - EAST MEREENIE No 4   SAMPLE DEPTH - 4613'

POROSITY - 14.4 %   PERM. TO NITROGEN - 28.Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER - Δ - 22 Md.
	WITHOUT RESID. WATER - ⊙ - 22Md.

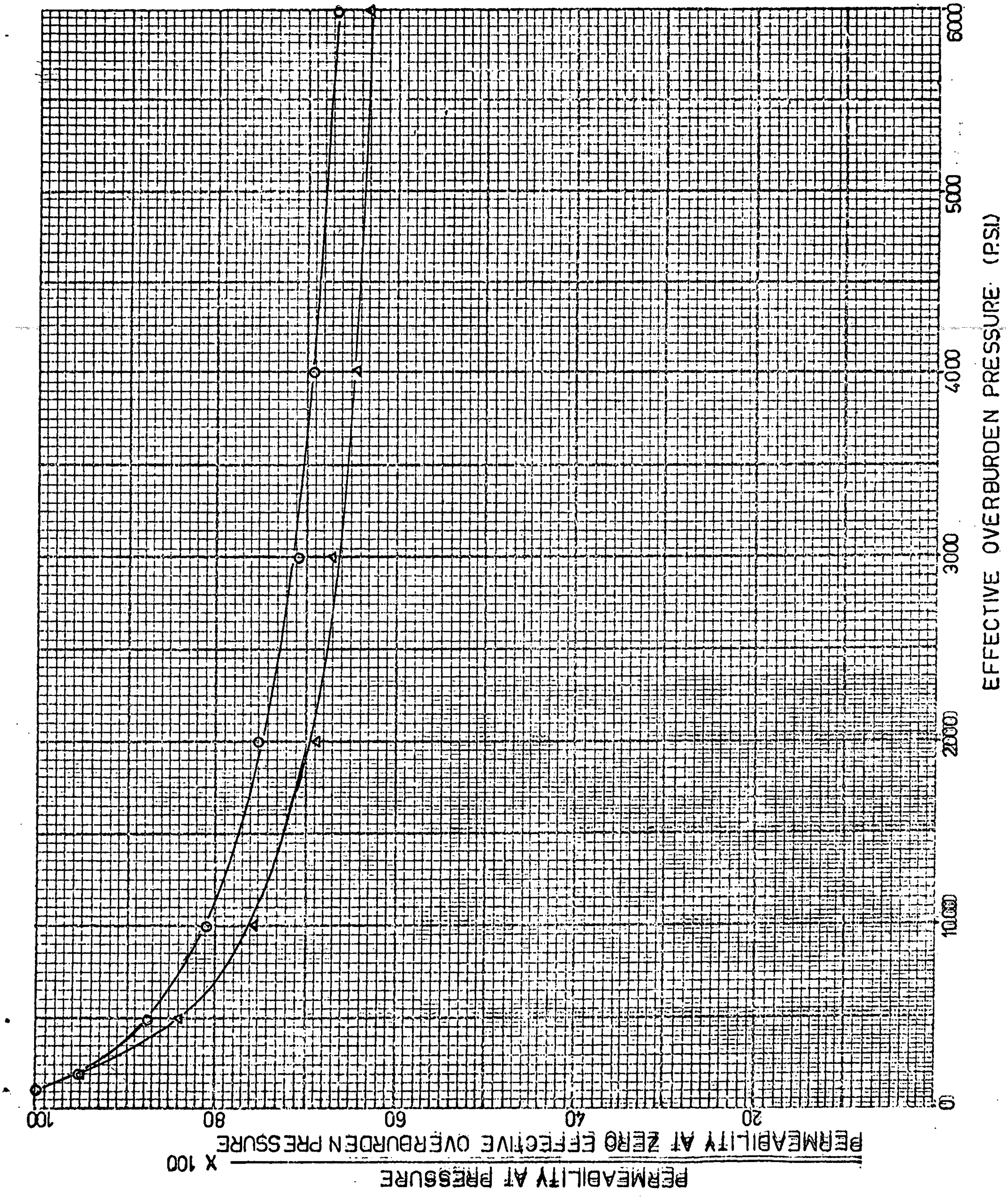

FIGURE 2

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL-EAST MEREENIE No. 4 SAMPLE DEPTH-4625'

POROSITY-10.5% PERM. TO NITROGEN-14Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER - Δ - 11 Md.
	WITHOUT RESID. WATER - ⊚ - 11 Md.

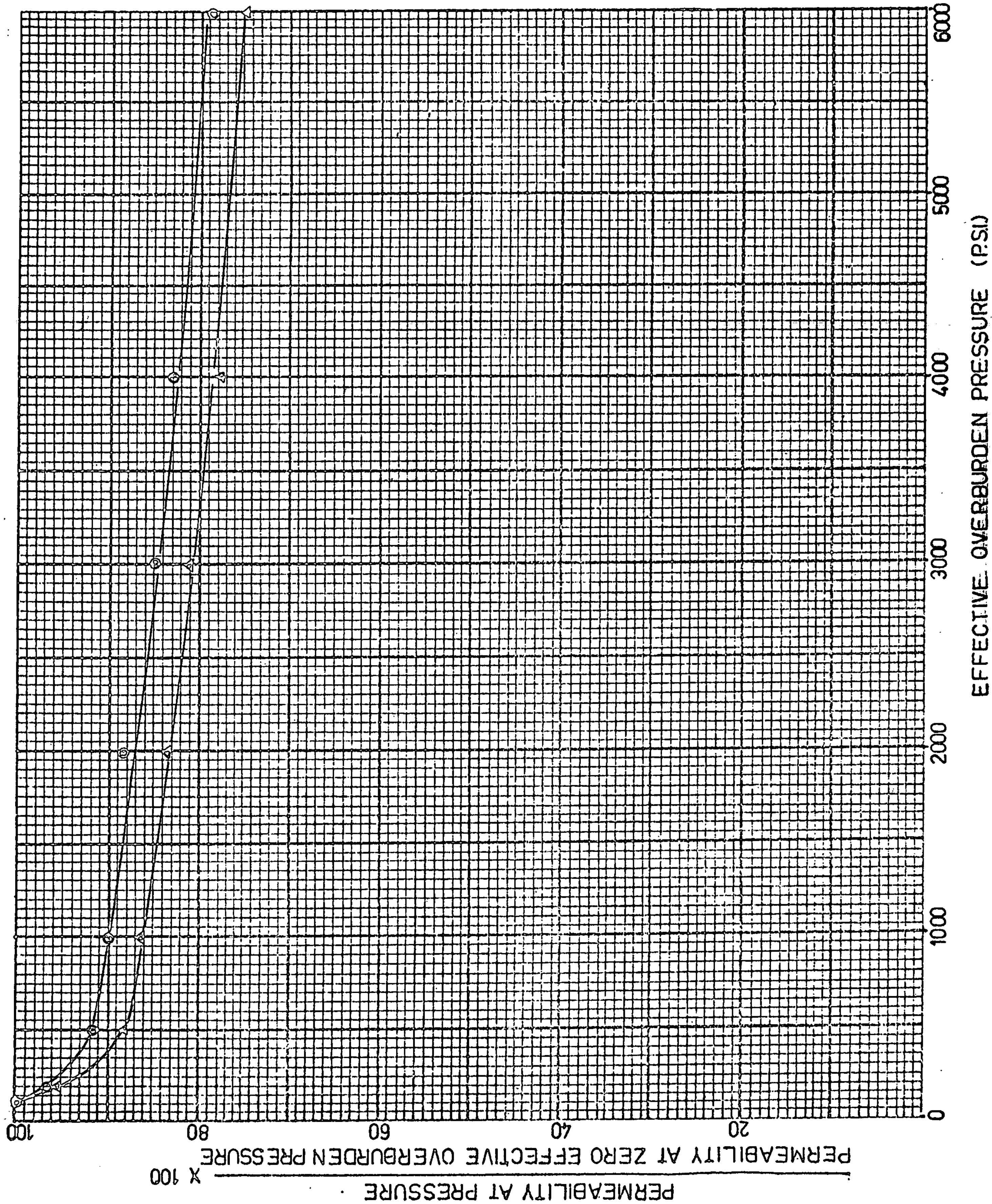

FIGURE 3

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - EAST MEREENIE No. 4 SAMPLE DEPTH - 4630'

POROSITY ~ 8.0 % PERM. TO NITROGEN - 16 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER - Δ - 13 Md.
	WITHOUT RESID. WATER - ⊙ - 14 Md.

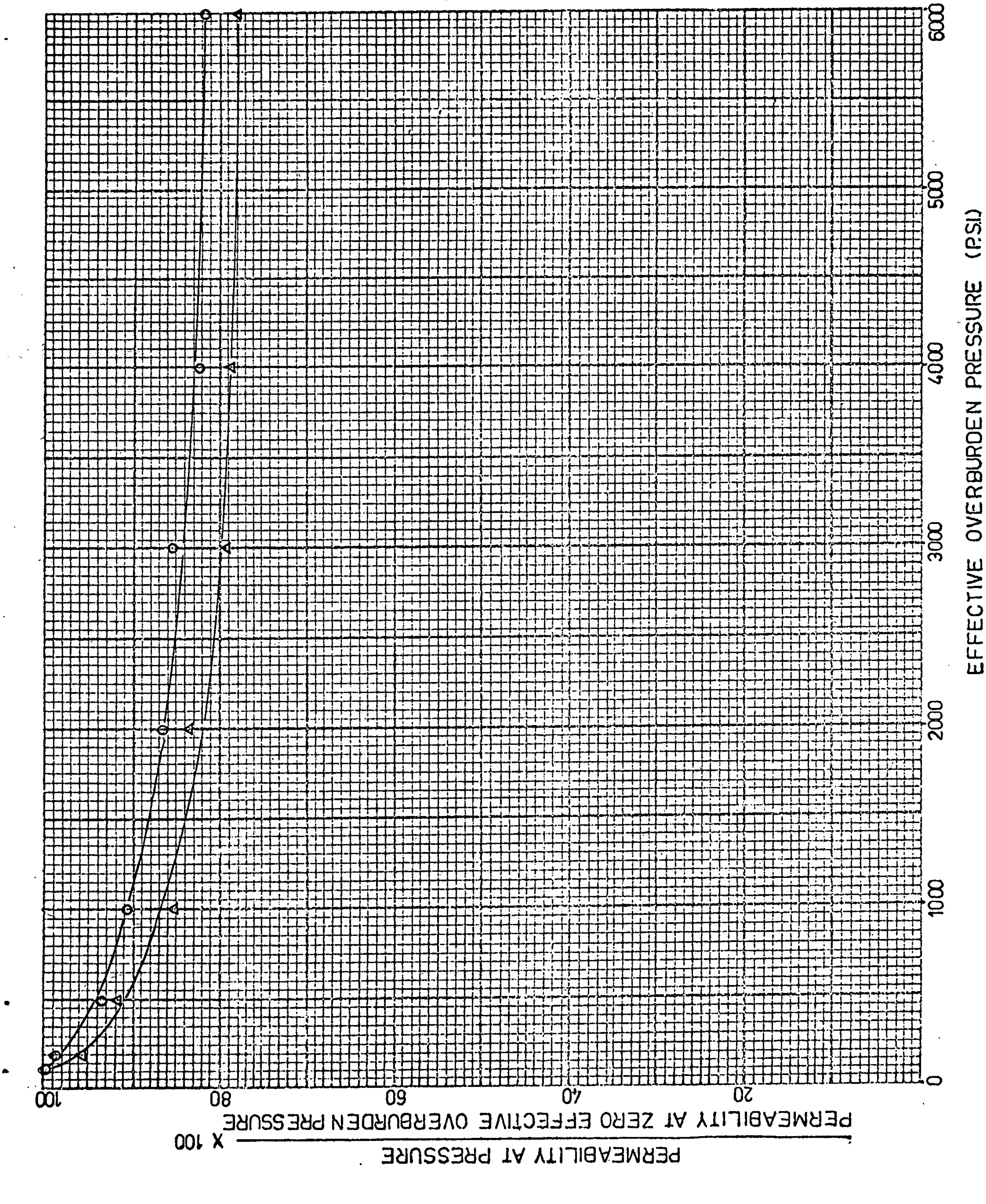

FIGURE 4

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - EAST MEREENIE No 4 SAMPLE DEPTH - 4635'

POROSITY - 8 % PERM. TO NITROGEN - 7.6 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER - △ - 5.4 Md.
	WITHOUT RESID. WATER - ⊙ - 6.0 Md.

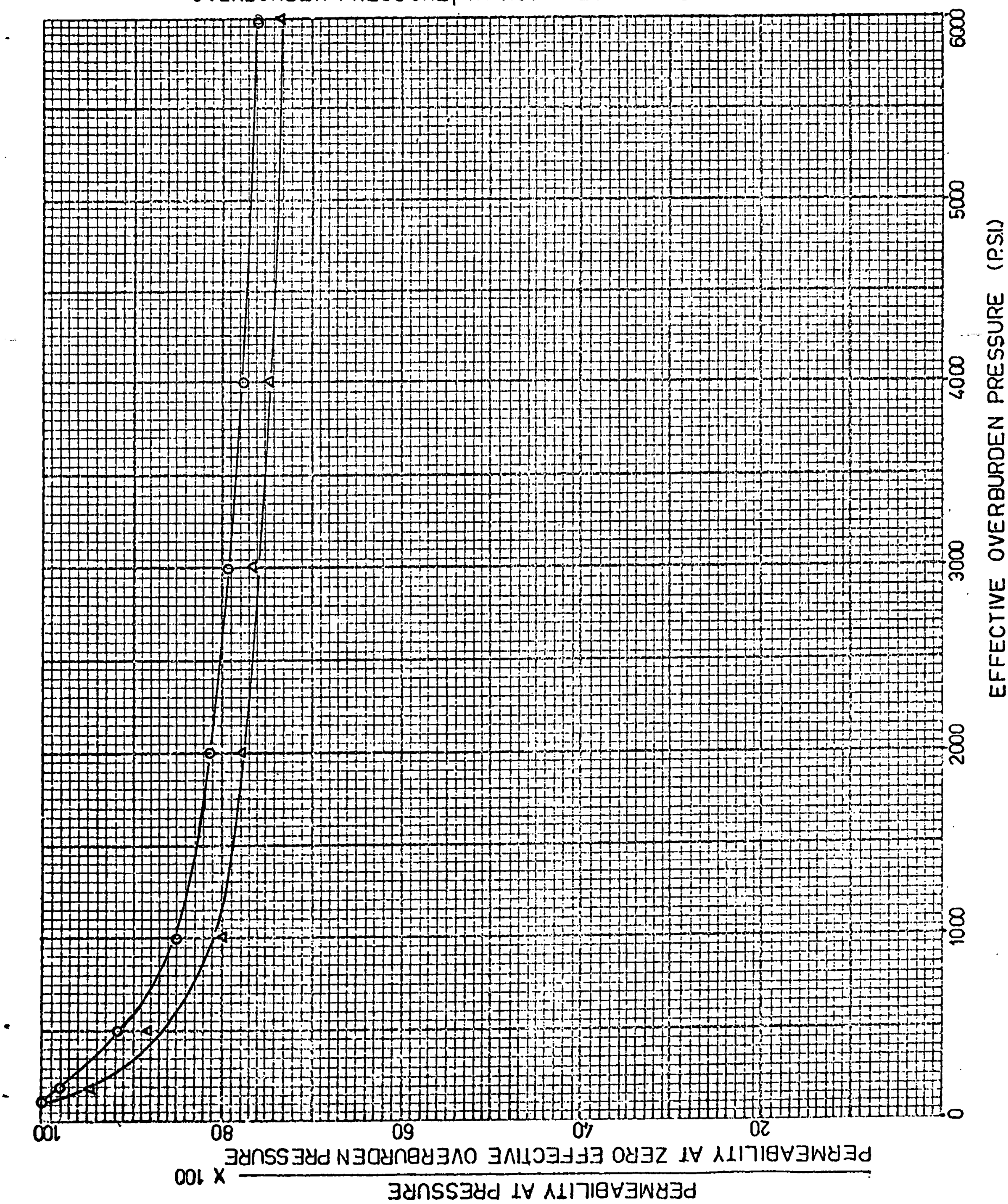

FIGURE - 5

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - EAST MEREENIE No 4 SAMPLE DEPTH - 4710'

POROSITY - 8.0% PERM. TO NITROGEN - 22 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	
	WITH RESIDUAL WATER - Δ - 19 Md.
	WITHOUT RESID. WATER - ⊙ - 20 Md.

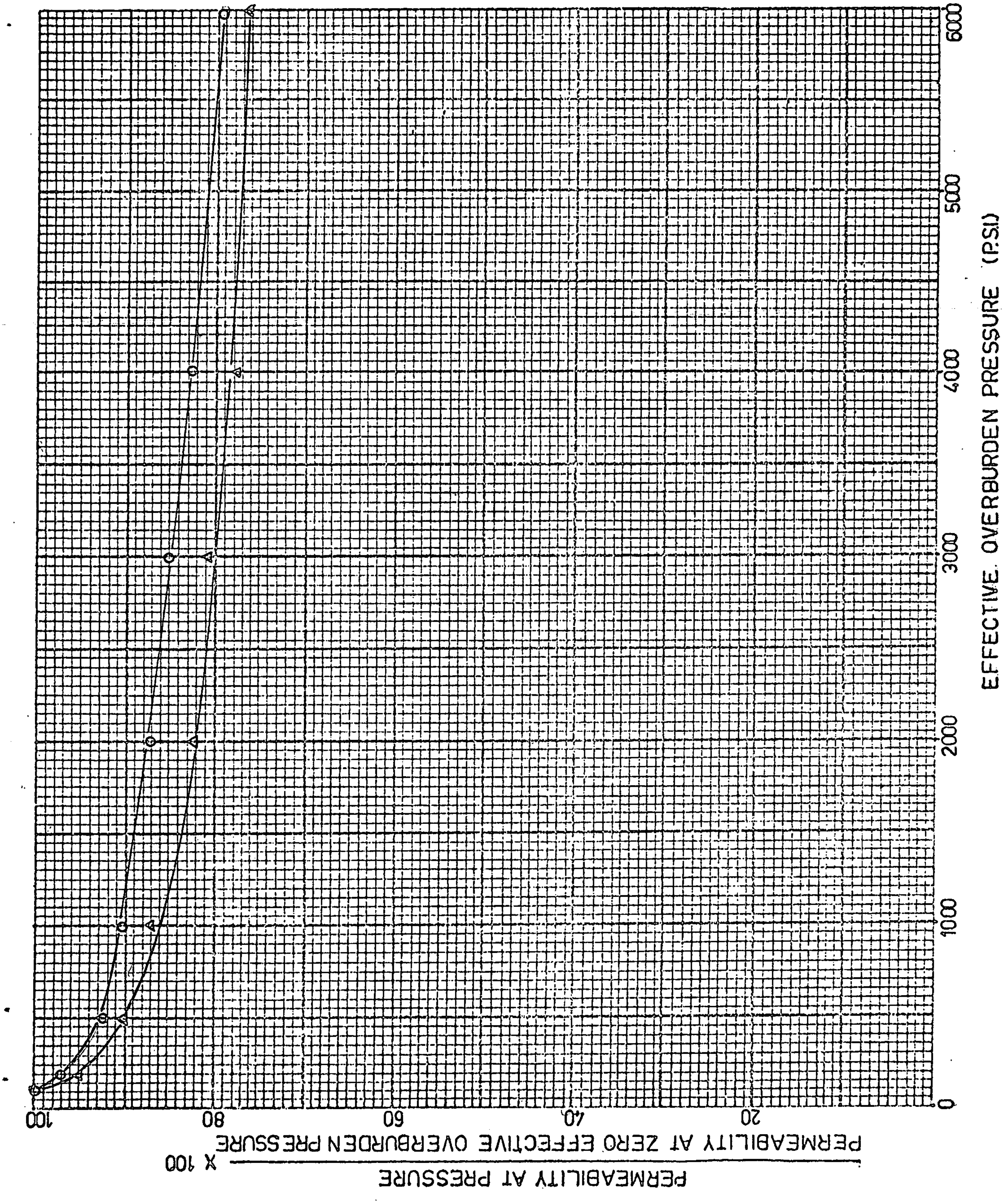

FIGURE 6

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - EAST MEREENIE No. 4 SAMPLE DEPTH - 4742'

POROSITY - 11.3% PERM. TO NITROGEN - 52 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - Δ - 49 Md.
| WITHOUT RESID. WATER - ⊙ - 50 Md

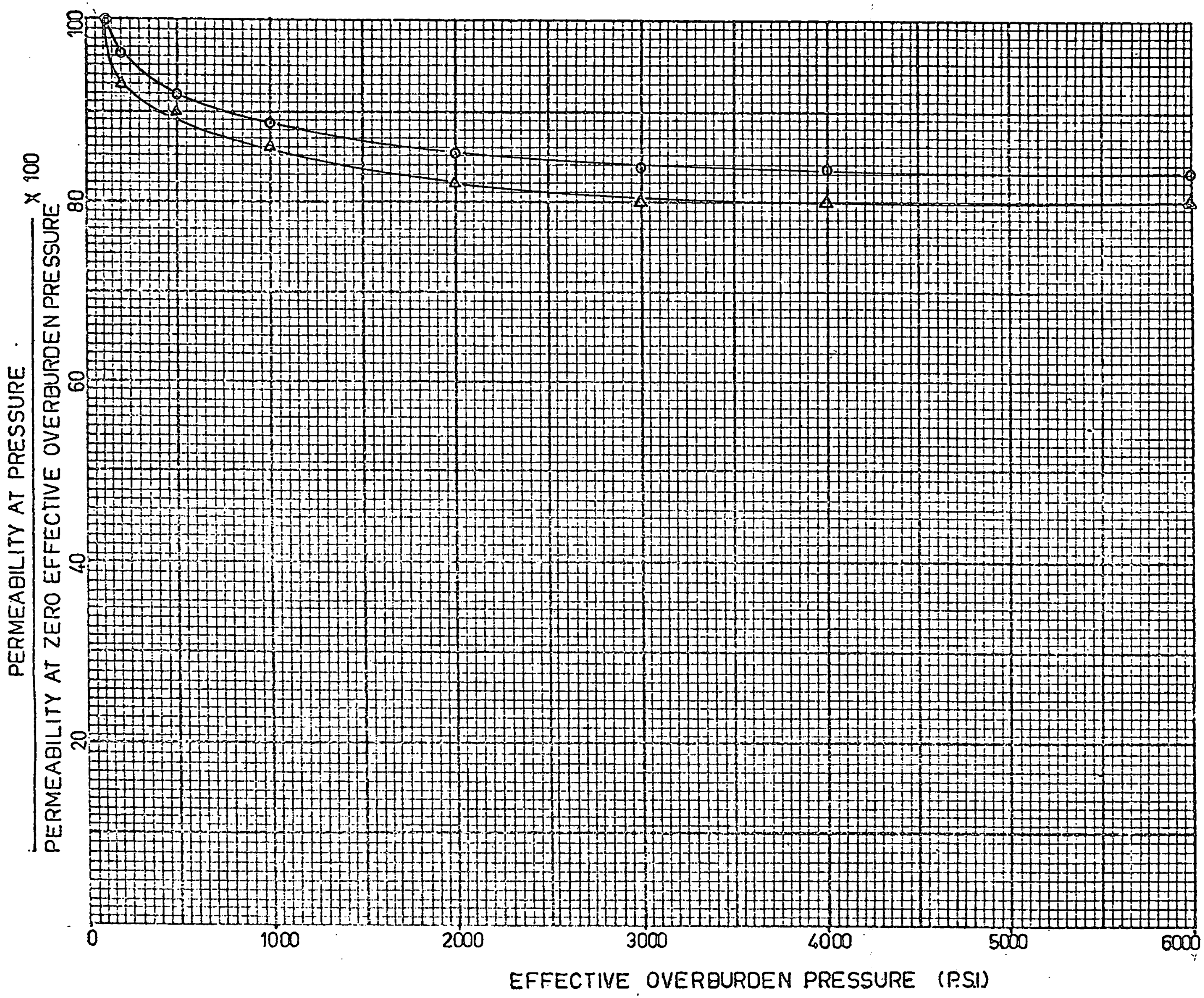

FIGURE 7

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL -EAST MEREENIE No. 4 SAMPLE DEPTH-4752'

POROSITY-9.7% PERM. TO NITROGEN-6.6%

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER - Δ - 5.0 Md.
	WITHOUT RESID. WATER - ⊙ - 5.9 Md.

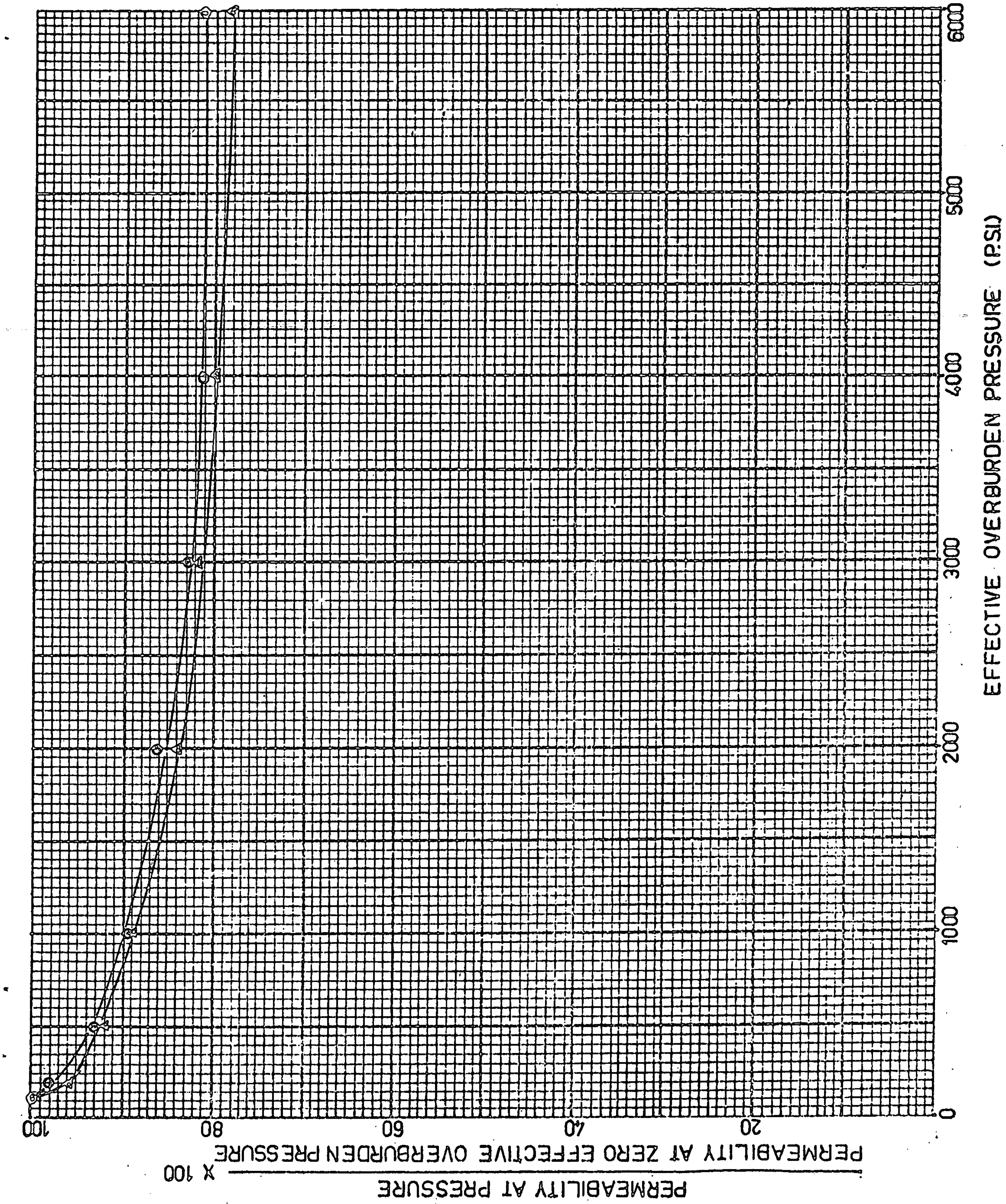

FIGURE 8

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - MARLIN A-1 | SAMPLE DEPTH - 5121'

POROSITY - 25%

PERM. TO NITROGEN - 510 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - Δ - 410 Md.
| WITHOUT RESID. WATER - ⊙ - 505 Md.

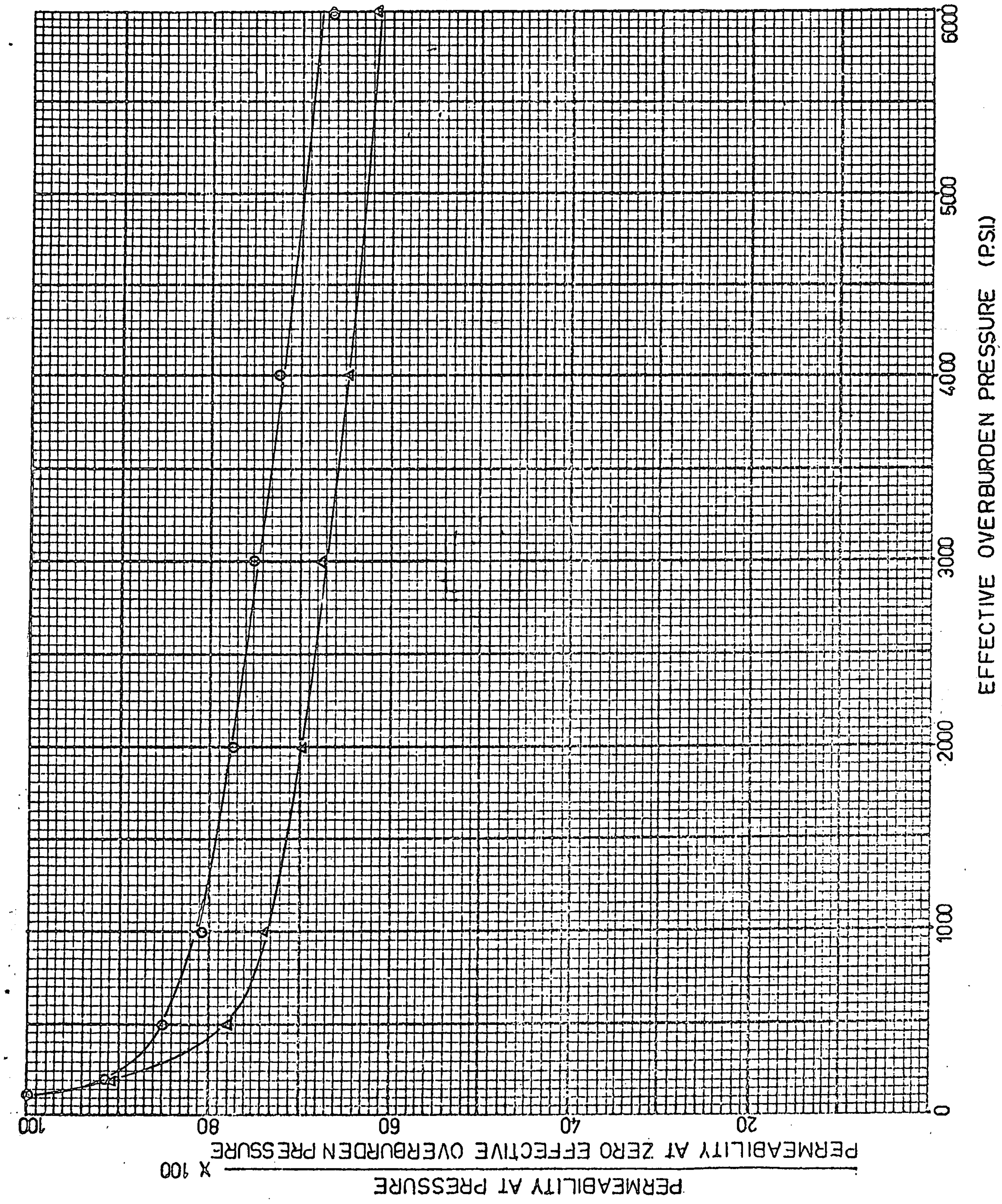

FIGURE 9

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - MARLIN A-1 SAMPLE DEPTH - 5129'

POROSITY - 24% PERM. TO NITROGEN - 333 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - △ - 315 Md.
WITHOUT RESID. WATER - ⊙ - 320 Md.

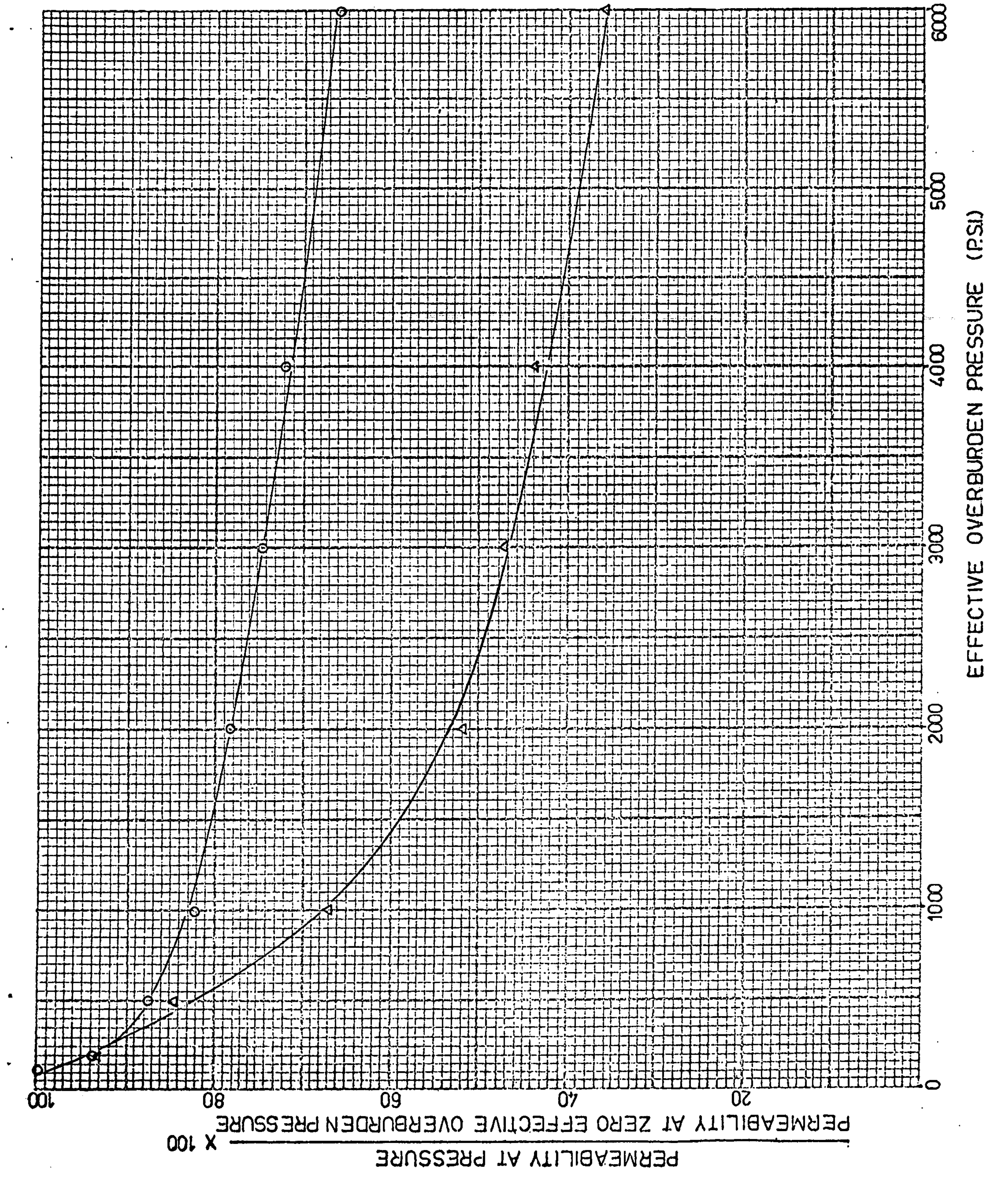

FIGURE 10

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - MARLIN A-1 | SAMPLE DEPTH - 5131'

POROSITY - 25.3% | PERM. TO NITROGEN - 620 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - Δ - 502 Md. | WITHOUT RESID. WATER - ○ - 615 Md.

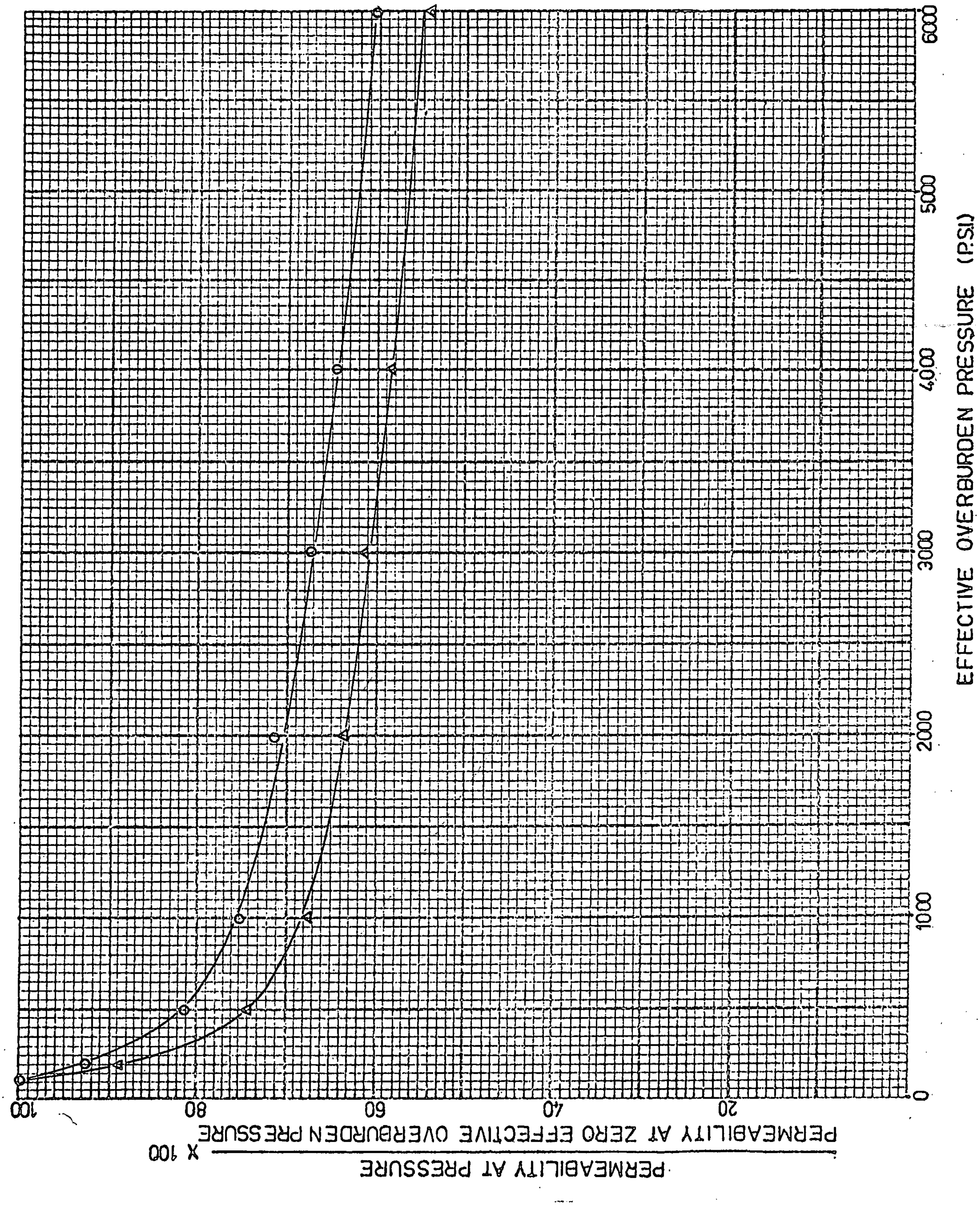

FIGURE 11

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – MARLIN A-1

SAMPLE DEPTH – 5149′

POROSITY – 7.3 %

PERM. TO NITROGEN – 110 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER – Δ – 103 Md.
	WITHOUT RESID. WATER – ⊙ – 105 Md.

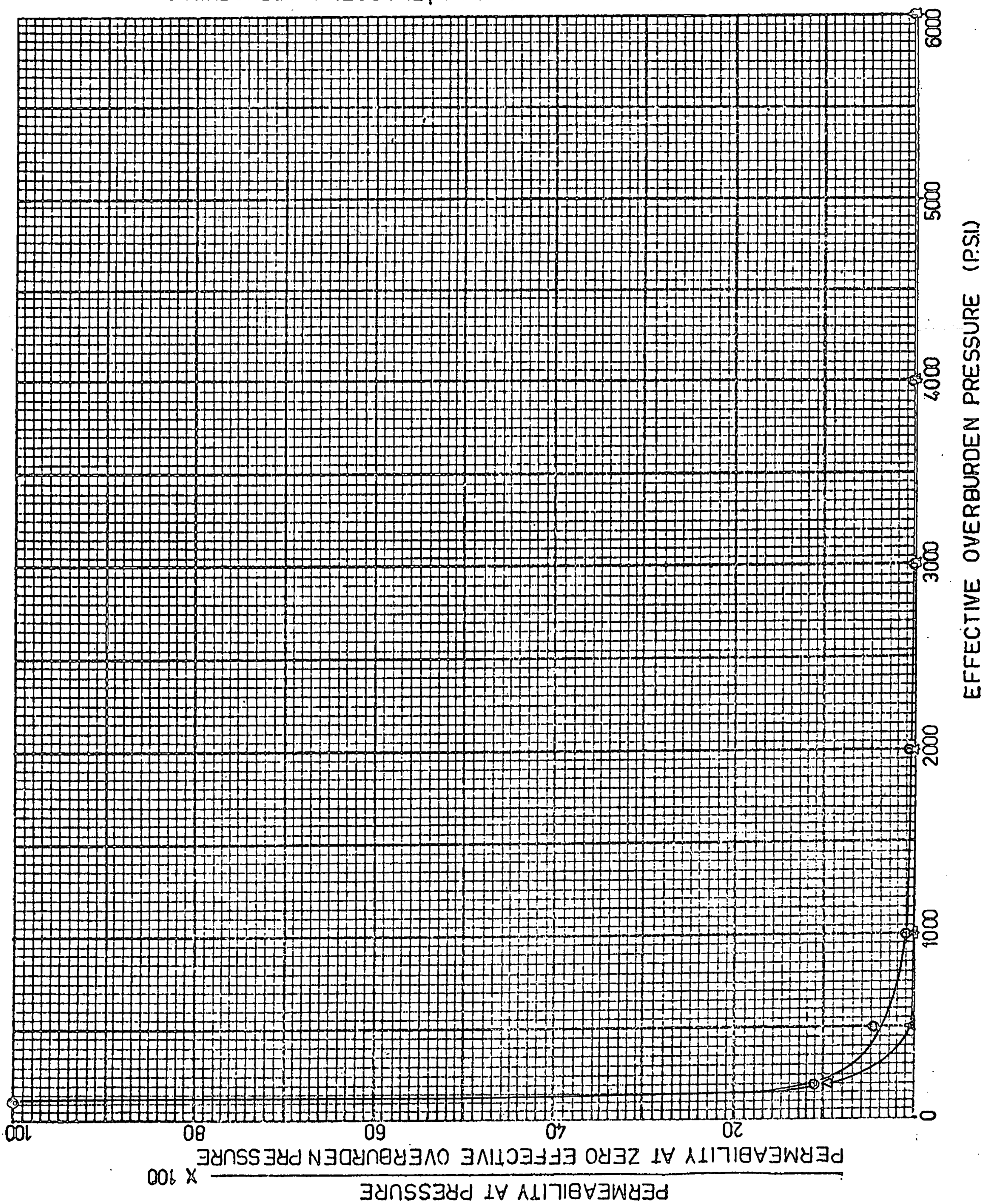

FIGURE 12

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - MARLIN A-1 | SAMPLE DEPTH - 5165'

POROSITY - 23% | PERM. TO NITROGEN - 1220 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - △ - 1015 Md.
| WITHOUT RESID. WATER - ⊙ - 1207 Md.

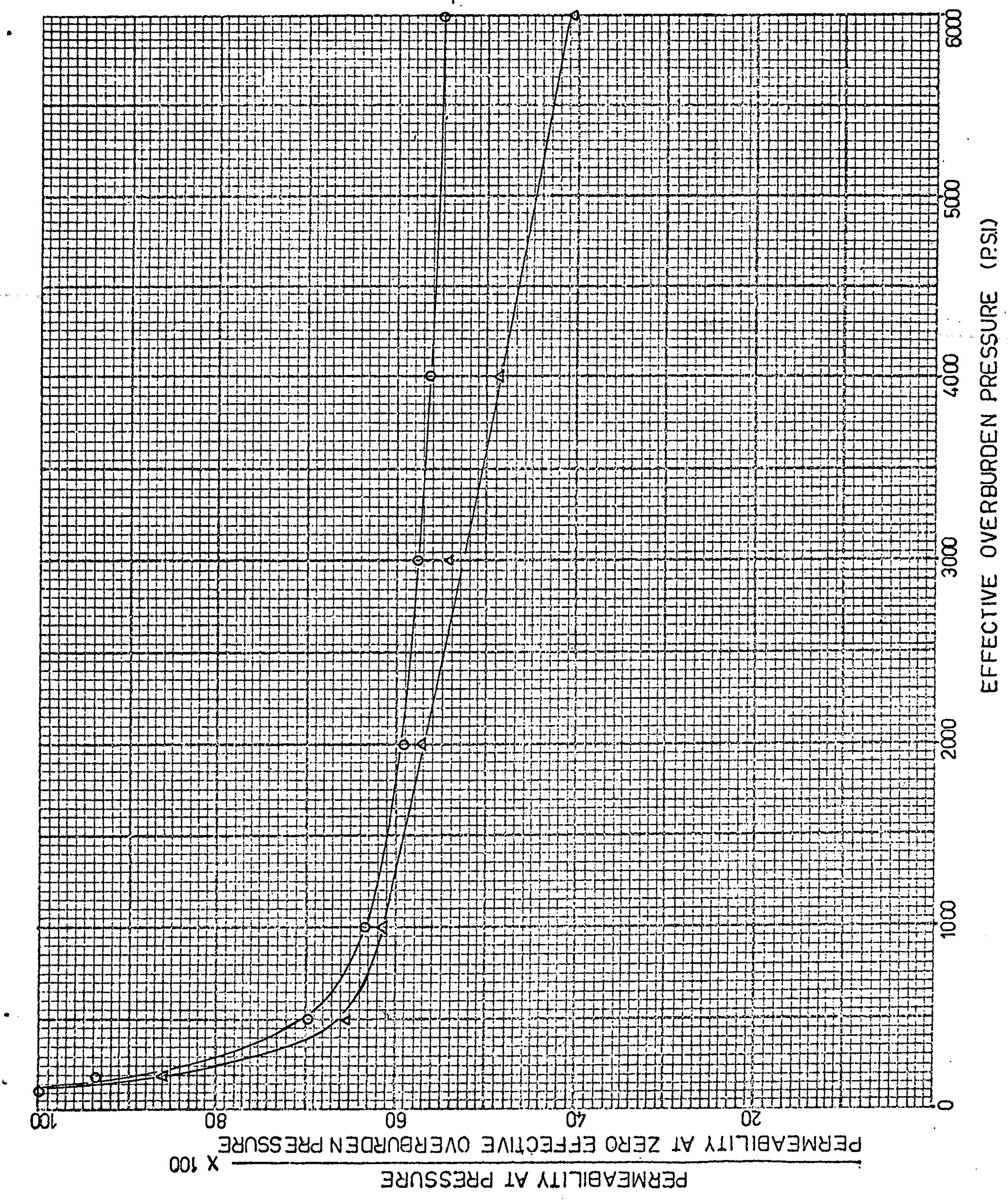

FIGURE-13

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - GAGE ROADS No 1

SAMPLE DEPTH - 5976'

POROSITY - 27%

PERM. TO NITROGEN - 170 Md.

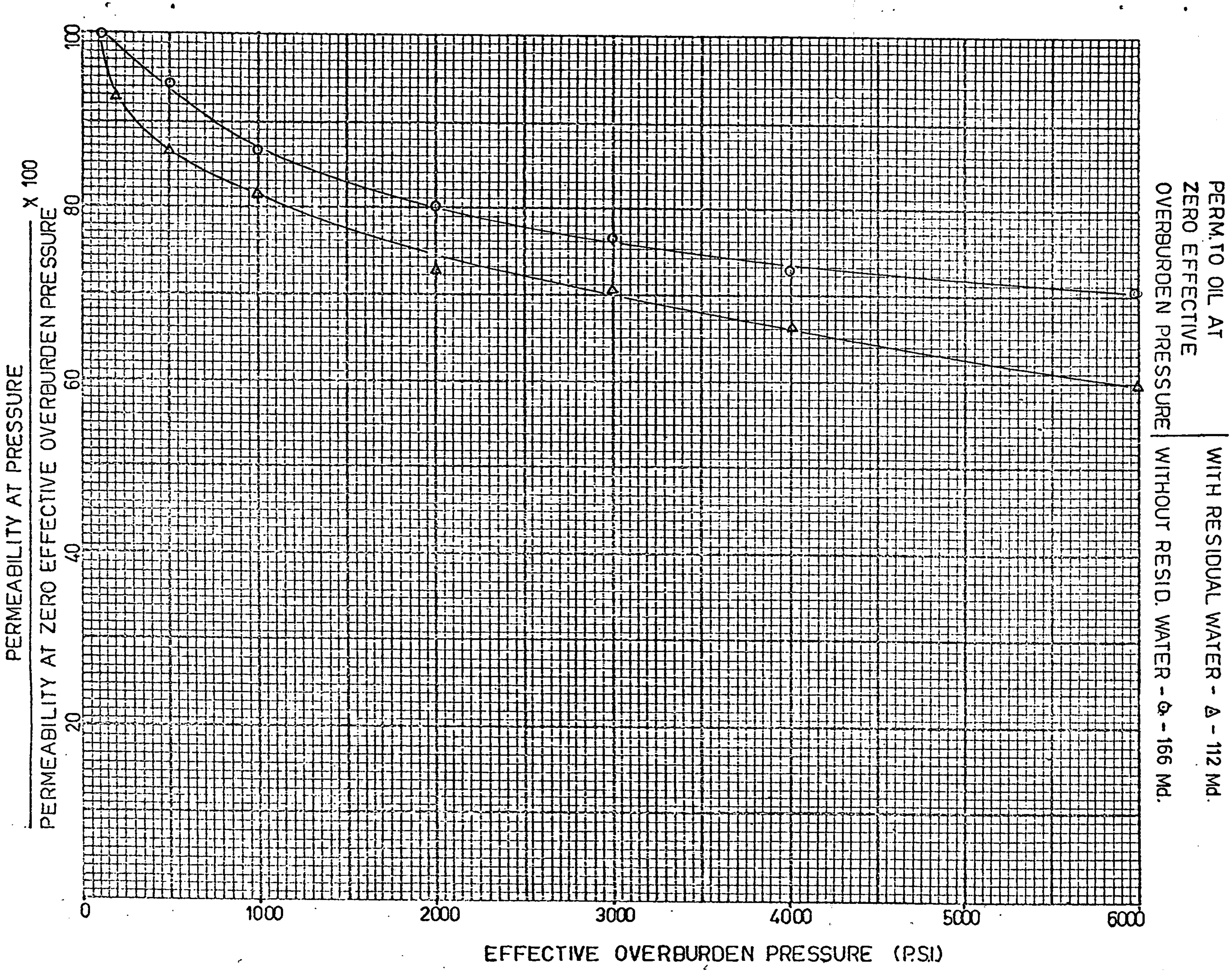

FIGURE 14

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL-GAGE ROADS No. 1 — SAMPLE DEPTH - 5880'

POROSITY - 25% — PERM. TO NITROGEN - 380 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - Δ - 324 Md.
| WITHOUT RESID. WATER - ⊙ - 371 Md.

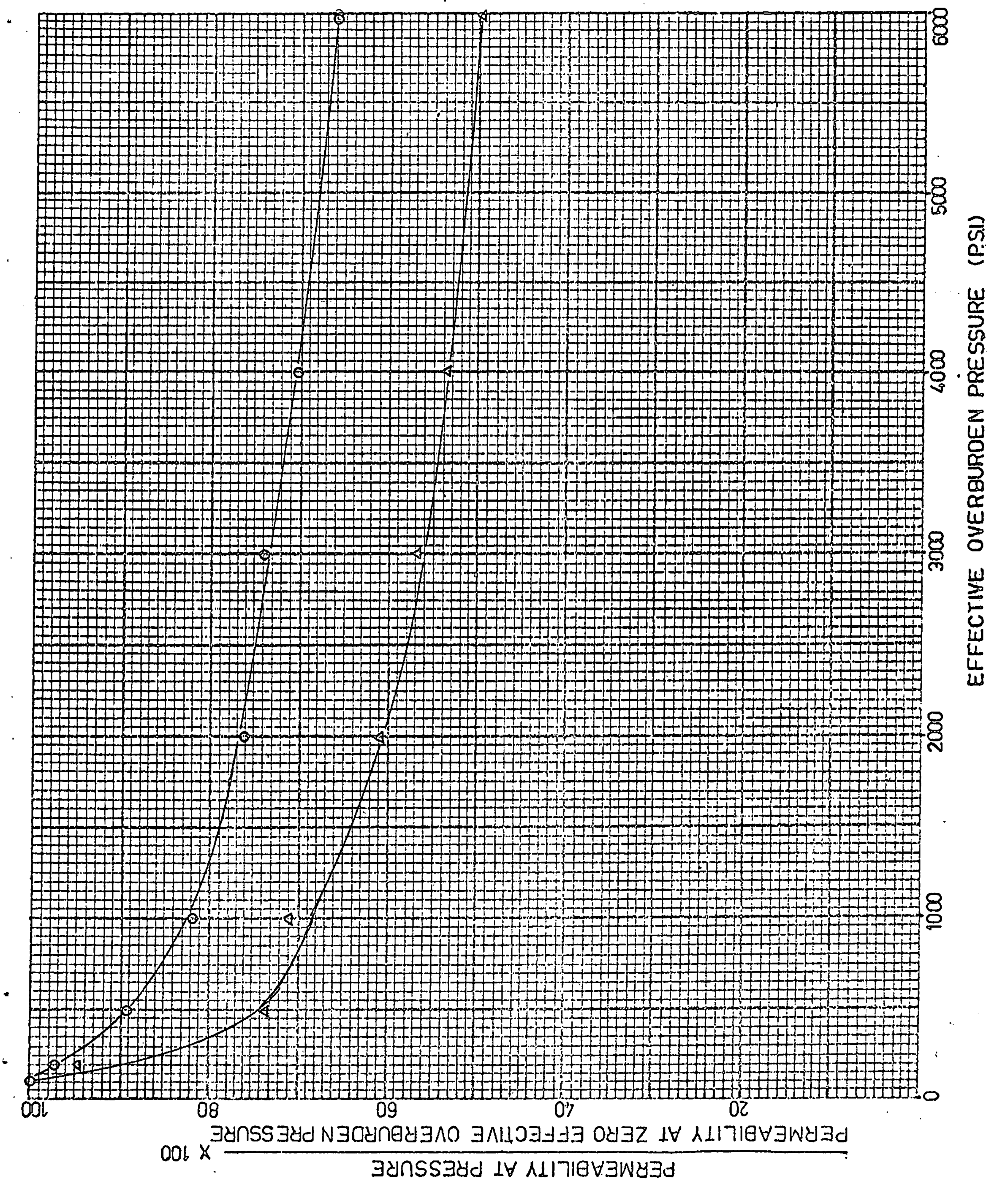

FIGURE 15

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - GAGE ROADS No 1 | SAMPLE DEPTH - 5884'

POROSITY - 22 % | PERM. TO NITROGEN - 135 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER - Δ - 130 Md.
	WITHOUT RESID. WATER - ⊙ - 133 Md.

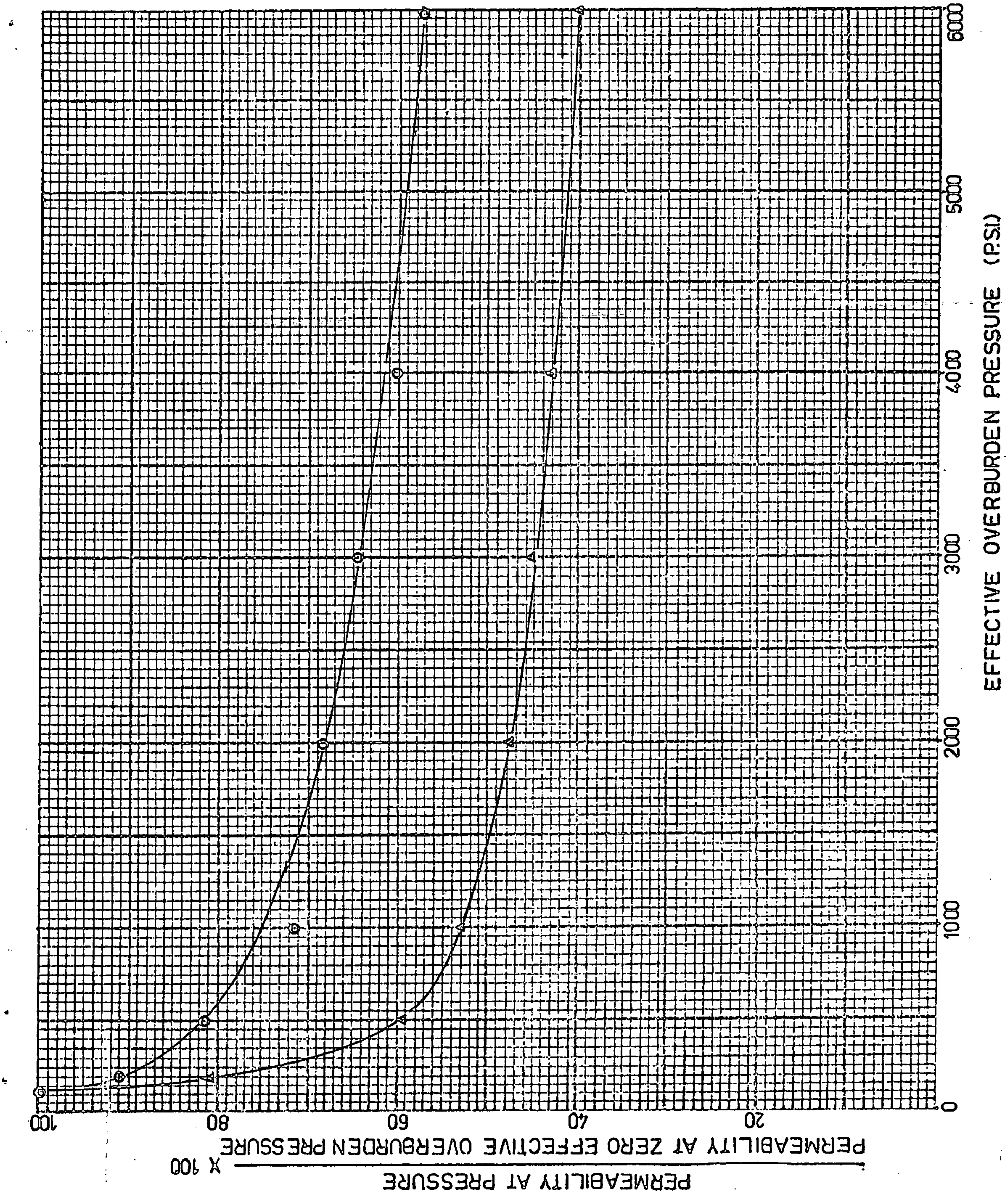

FIGURE 16

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - GAGE ROADS No 1 SAMPLE DEPTH - 5892'

POROSITY - 27% PERM. TO NITROGEN - 535 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - Δ - 403 Md.
| WITHOUT RESID. WATER - ⊙ - 500 Md.

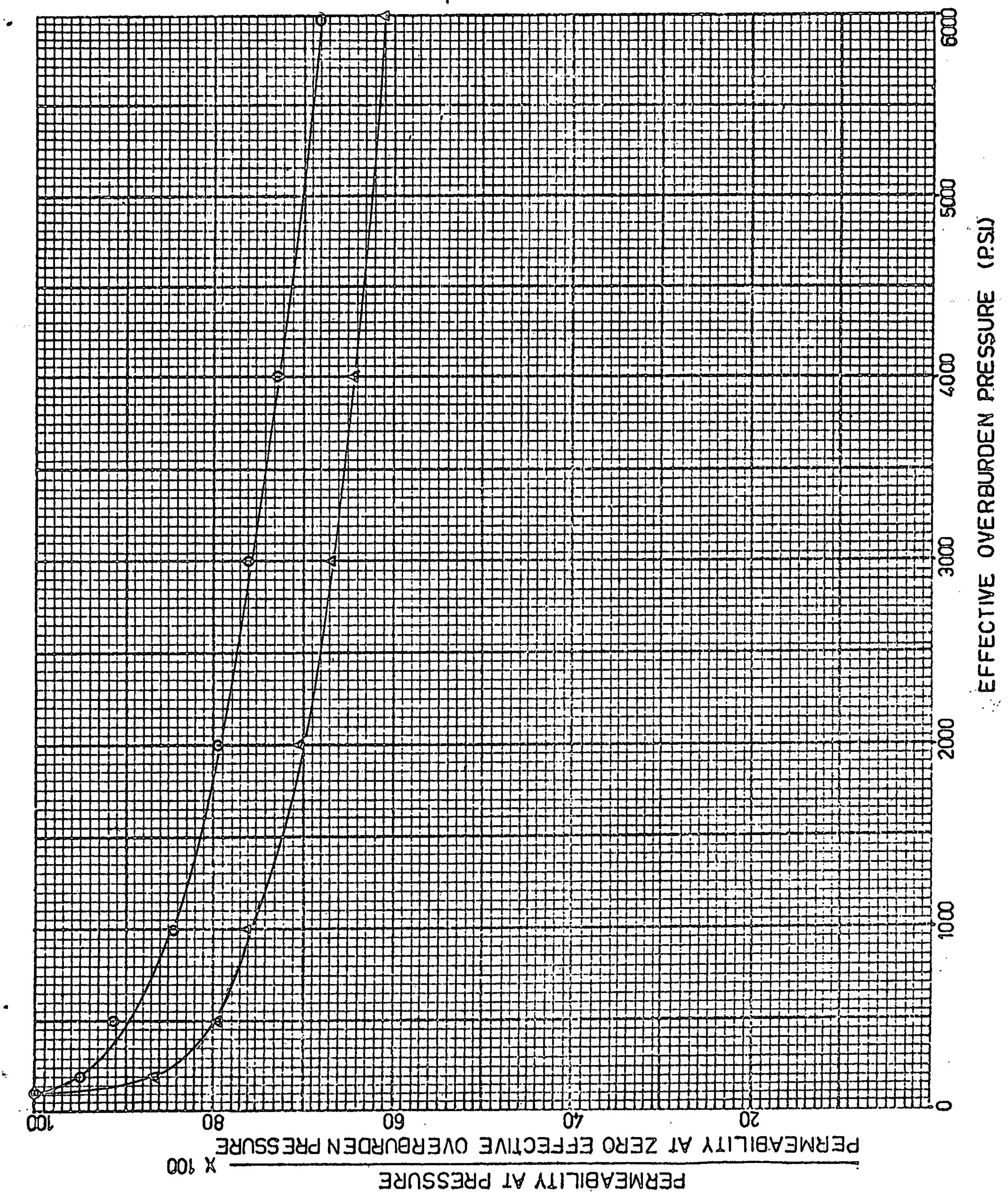

FIGURE 17

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL - BARROW ISLAND No 1 SAMPLE DEPTH - 6754'

POROSITY - 28% PERM. TO NITROGEN - 67 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - Δ - 59 Md. | WITHOUT RESID. WATER - ⊙ - 62 Md.

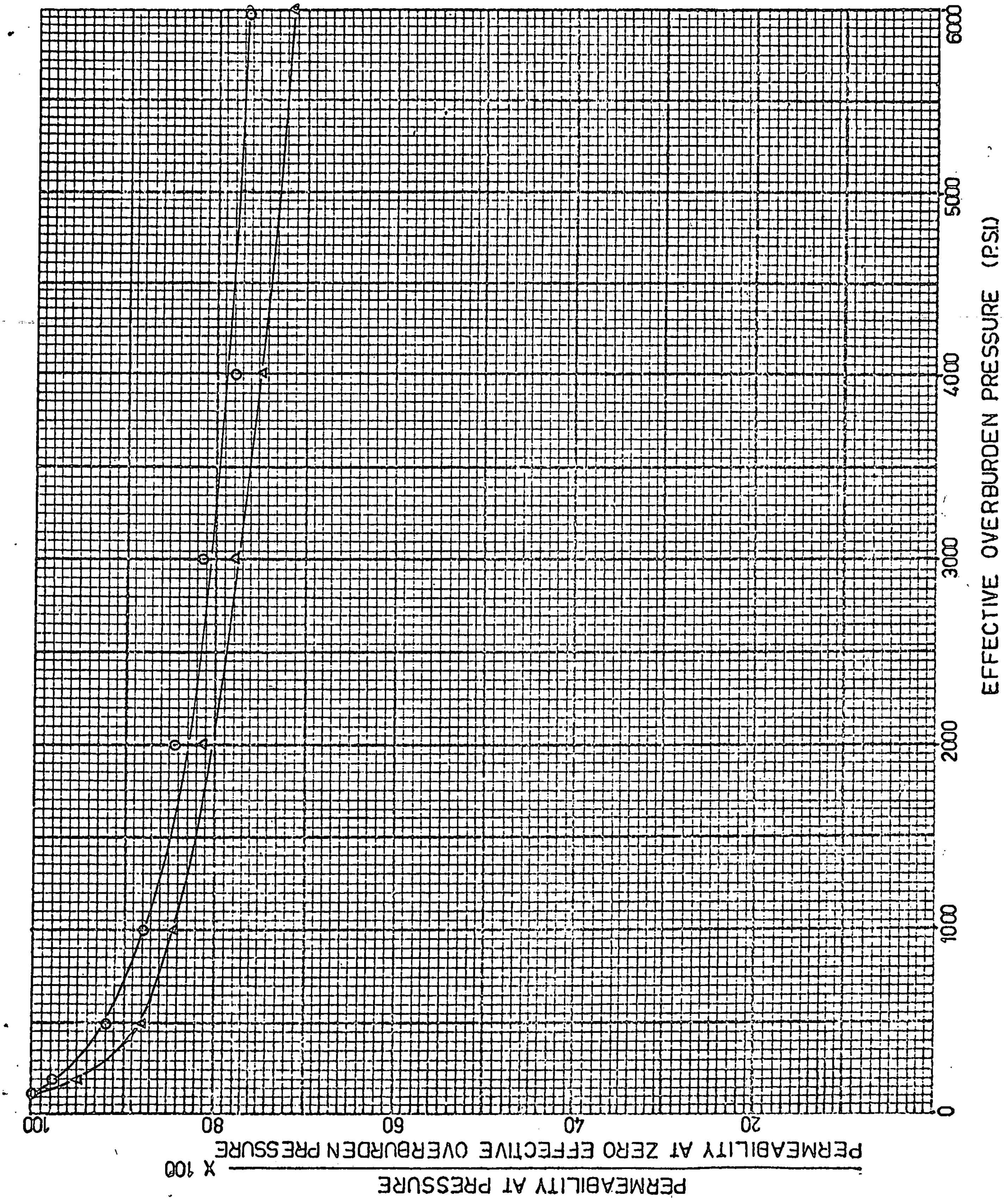

FIGURE 18

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – BARROW ISLAND No 1 SAMPLE DEPTH – 6760'

POROSITY – 26.5 % PERM. TO NITROGEN – 41 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	
WITH RESIDUAL WATER – Δ – 32 Md.	
WITHOUT RESID. WATER – ⊙ – 39 Md.	

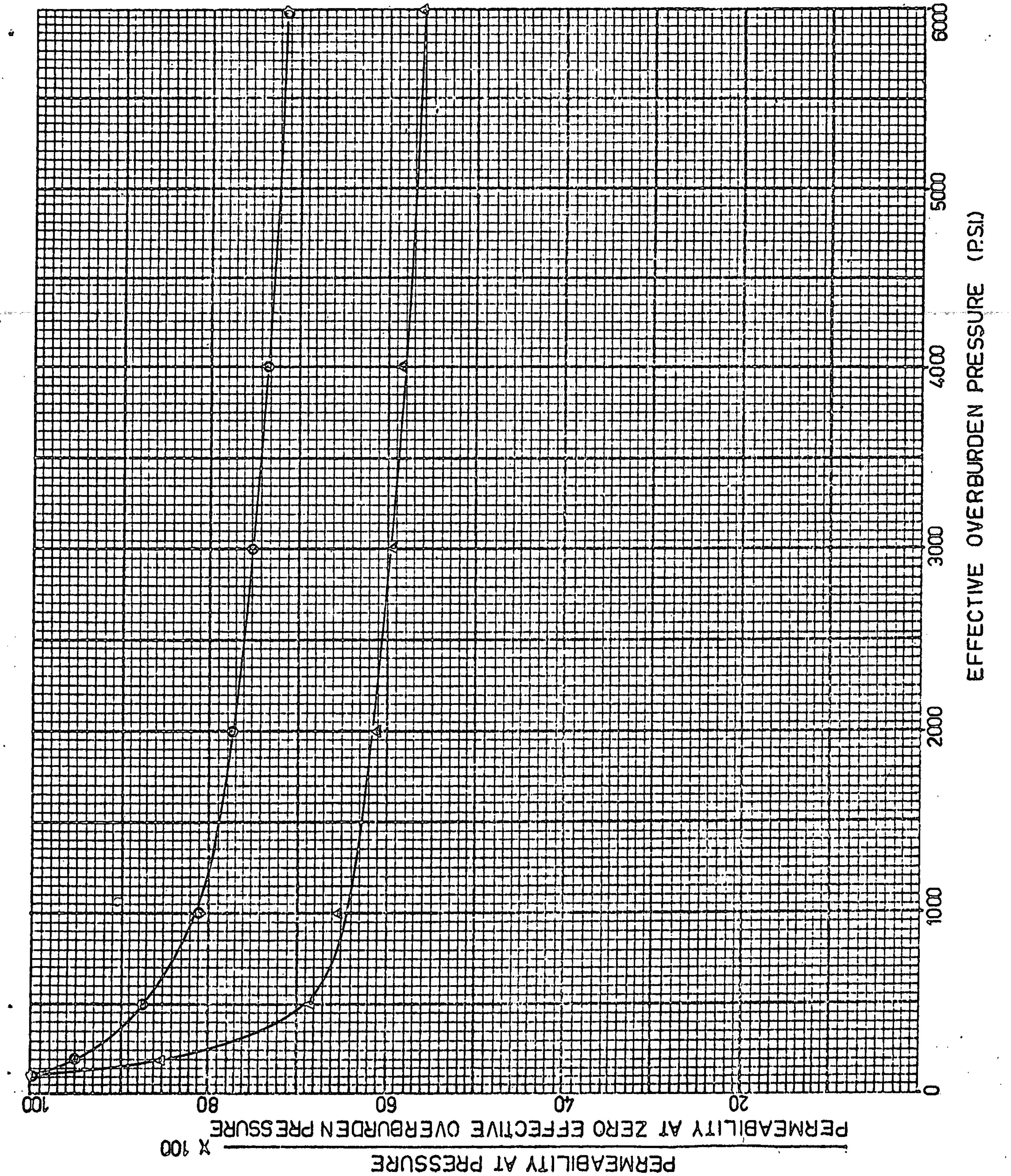

FIGURE 19

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – BARROW ISLAND No 1 SAMPLE DEPTH – 6772'

POROSITY – 29.5% PERM. TO NITROGEN – 220 Md

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	
	WITH RESIDUAL WATER – Δ – 208 Md
	WITHOUT RESID. WATER – ⊙ – 218 Md.

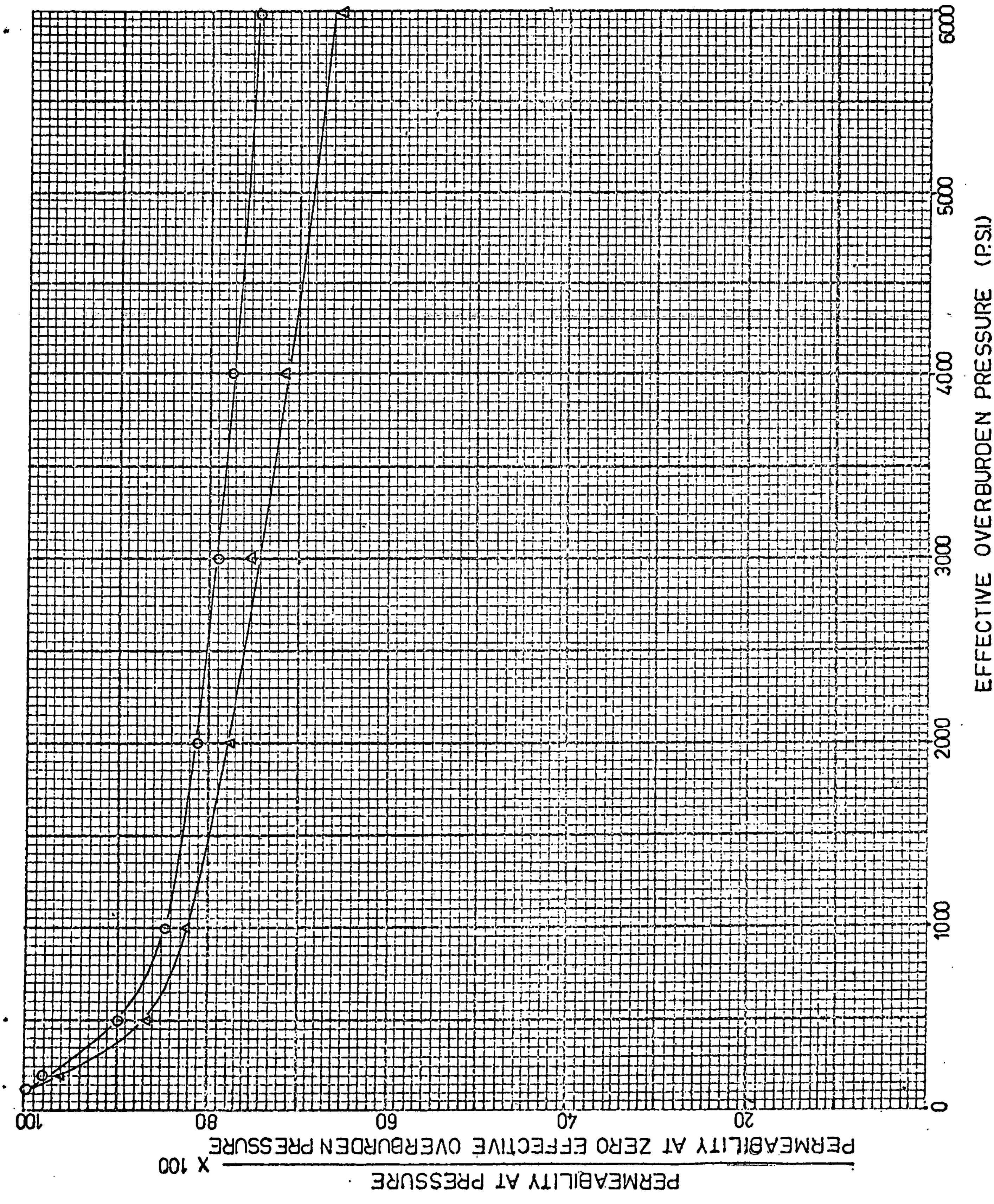

FIGURE 20

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – BARROW ISLAND No 1 SAMPLE DEPTH – 6831′

POROSITY – 25% PERM. TO NITROGEN – 18 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	
	WITH RESIDUAL WATER – Δ – 16 Md.
	WITHOUT RESID. WATER – ⊙ – 16 Md.

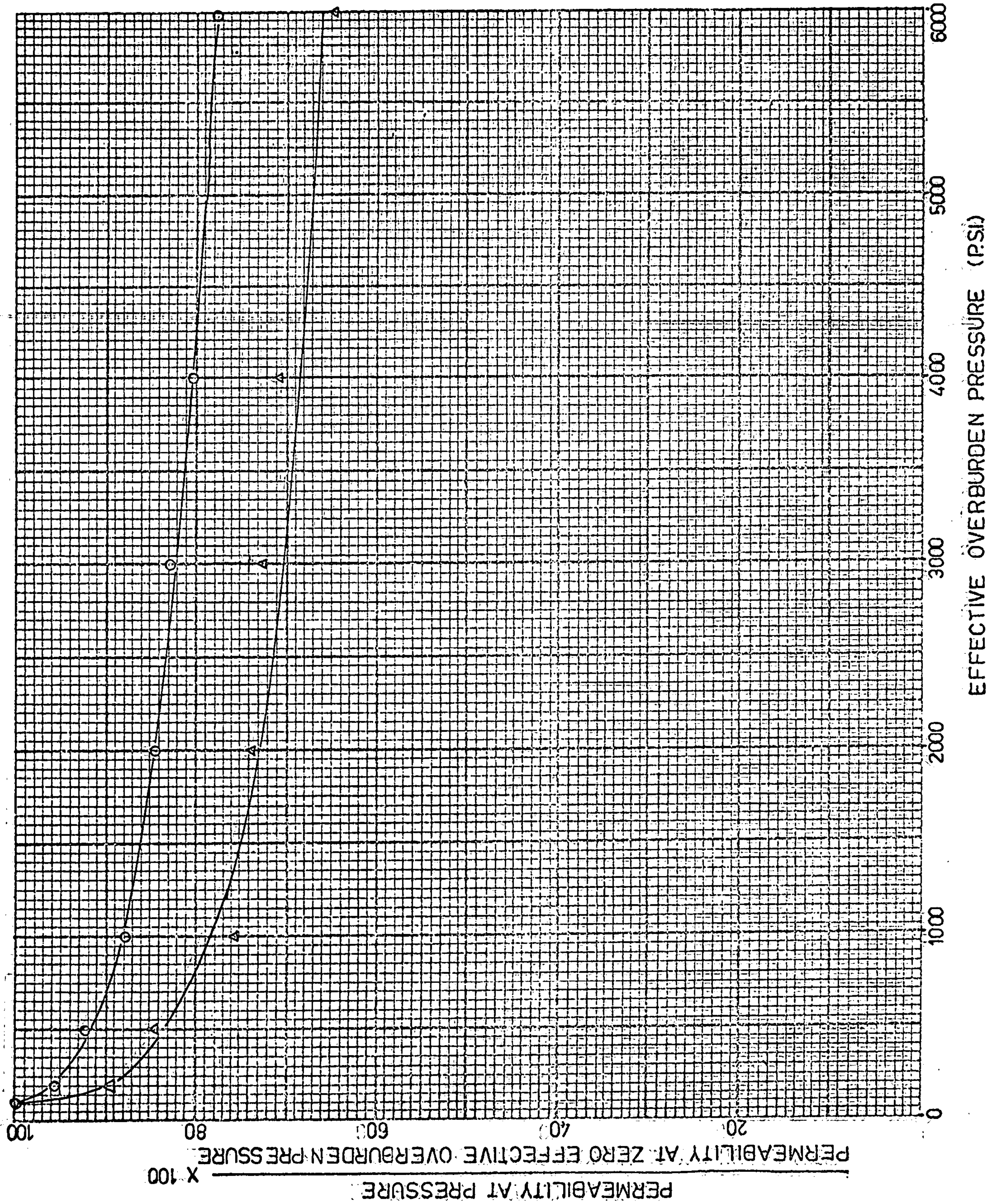

FIGURE 21

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – BARROW ISLAND No.1 SAMPLE DEPTH – 6835'

POROSITY – 20.0% PERM. TO NITROGEN – 17 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER – Δ – 13 Md.
| WITHOUT RESID. WATER – ⊙ – 15 Md.

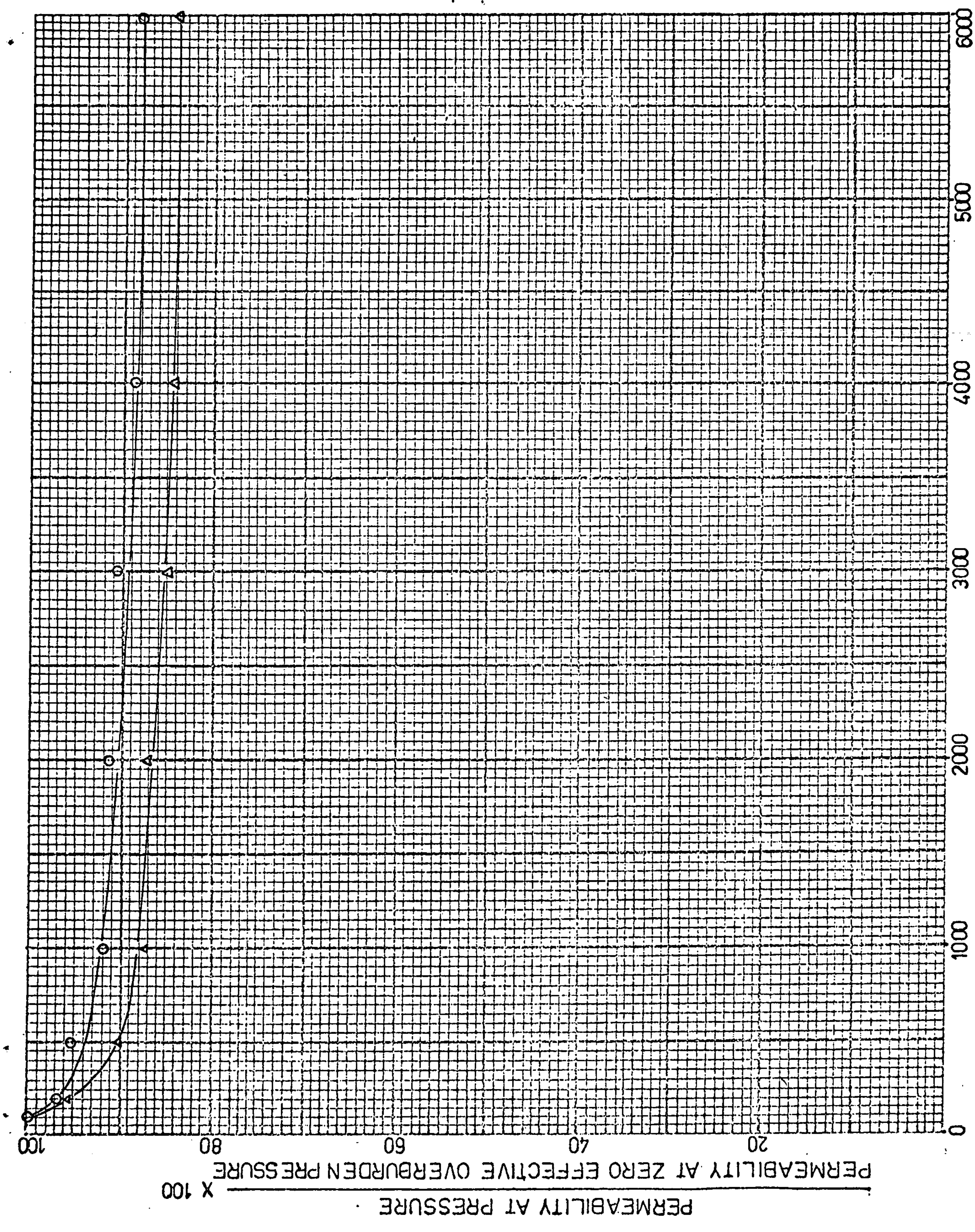

FIGURE 22

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – BARROW ISLAND No.1 SAMPLE DEPTH – 6839′

POROSITY – 28% PERM. TO NITROGEN – 95 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER – Δ – 86 Md.
WITHOUT RESID. WATER – ⊙ – 91 Md.

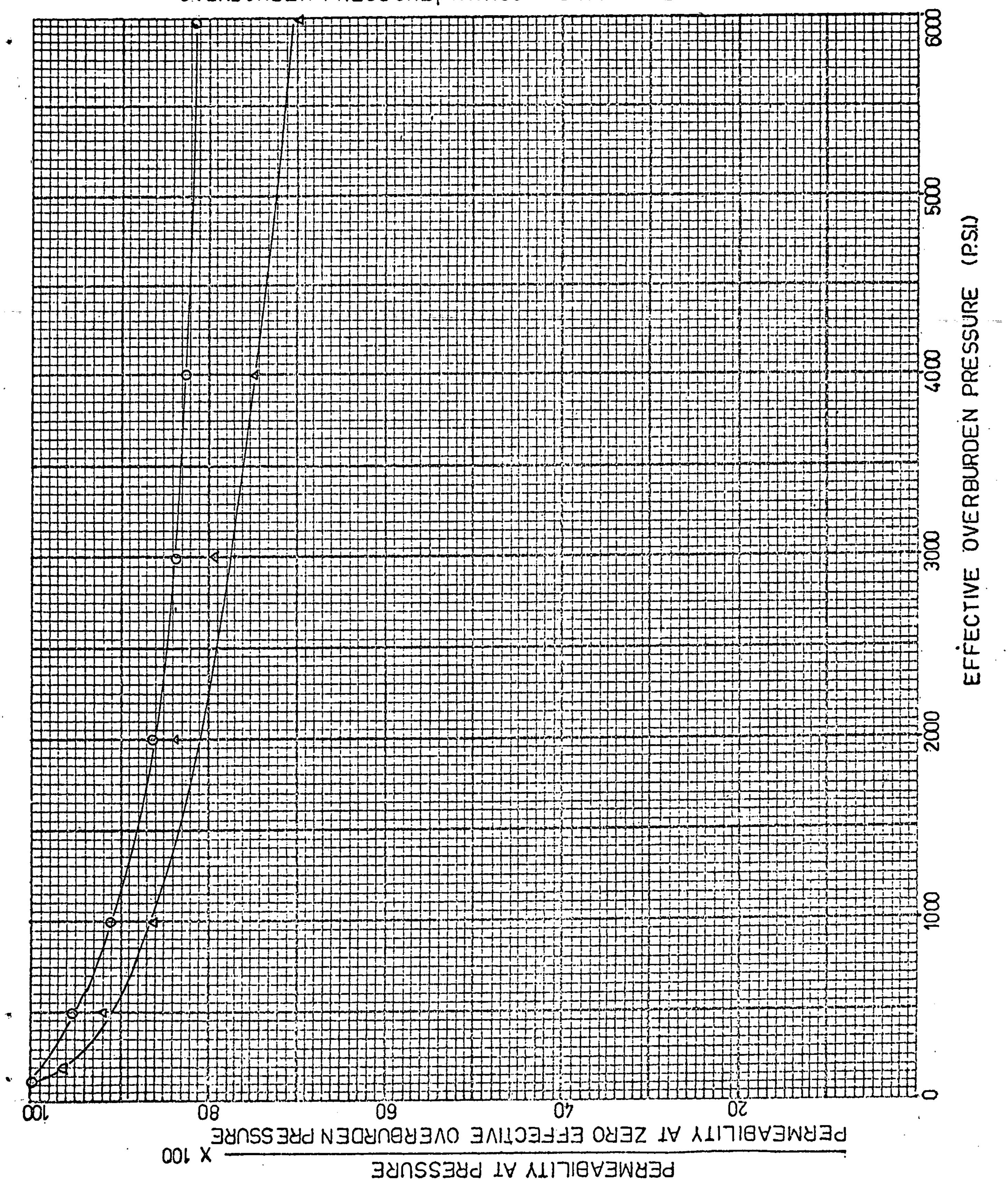

FIGURE 23

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – MOONIE No. 2   SAMPLE DEPTH – 5645′

POROSITY – 19 %   PERM. TO NITROGEN – 20 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	WITH RESIDUAL WATER – Δ – 17 Md.
	WITHOUT RESID. WATER – ⊙ – 18 Md.

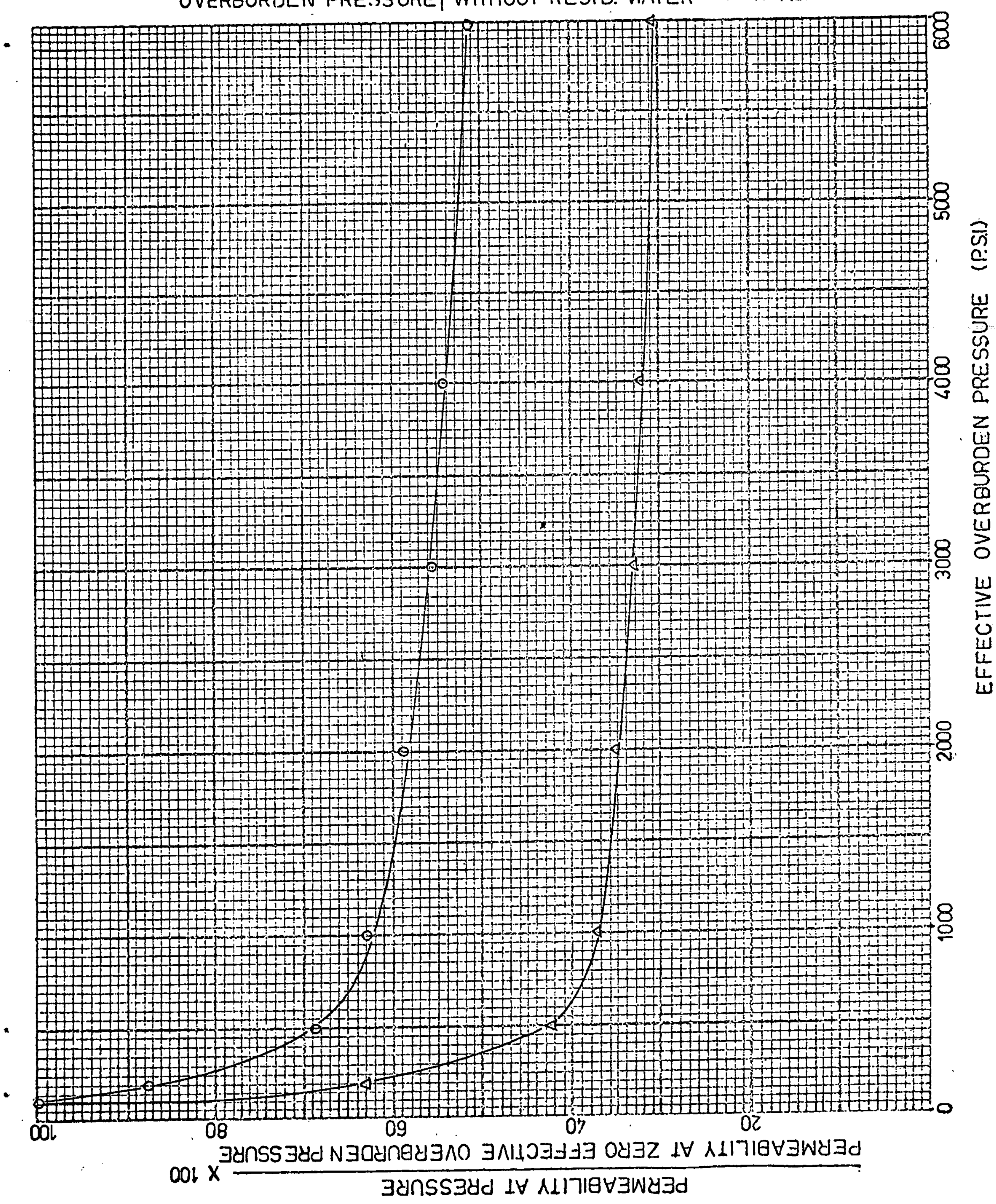

FIGURE 24

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – MOONIE No 2   SAMPLE DEPTH – 5655'

POROSITY – 21·6 %   PERM. TO NITROGEN – 690 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE	
WITH RESIDUAL WATER – △ – 573 Md.	WITHOUT RESID. WATER – ⊙ – 675 Md.

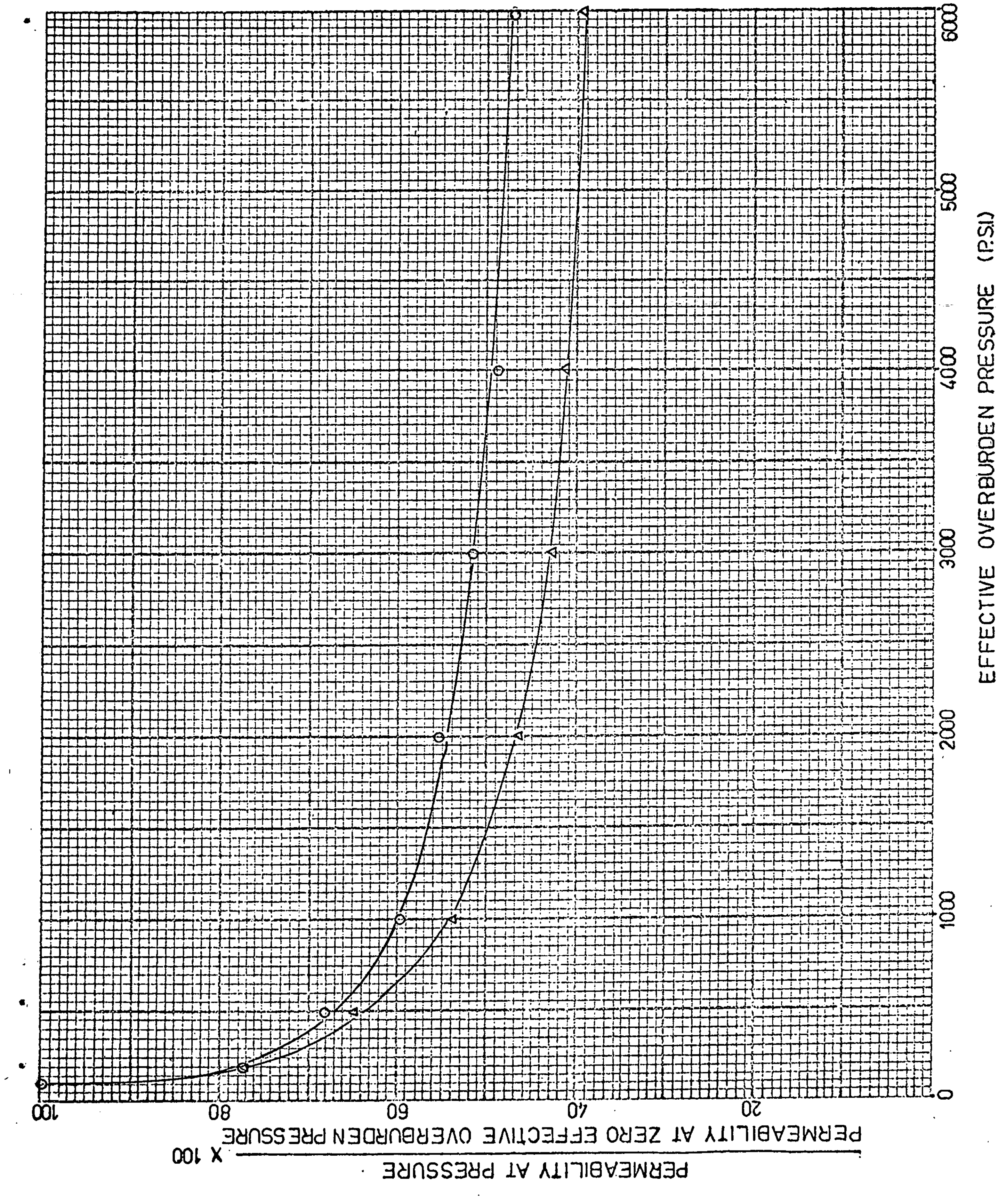

FIGURE 25

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL—MOONIE No 2 | SAMPLE DEPTH—5667′

POROSITY —19.7% | PERM. TO NITROGEN—720 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER - Δ - 555 Md.
WITHOUT RESID. WATER - ⊙ - 675 Md

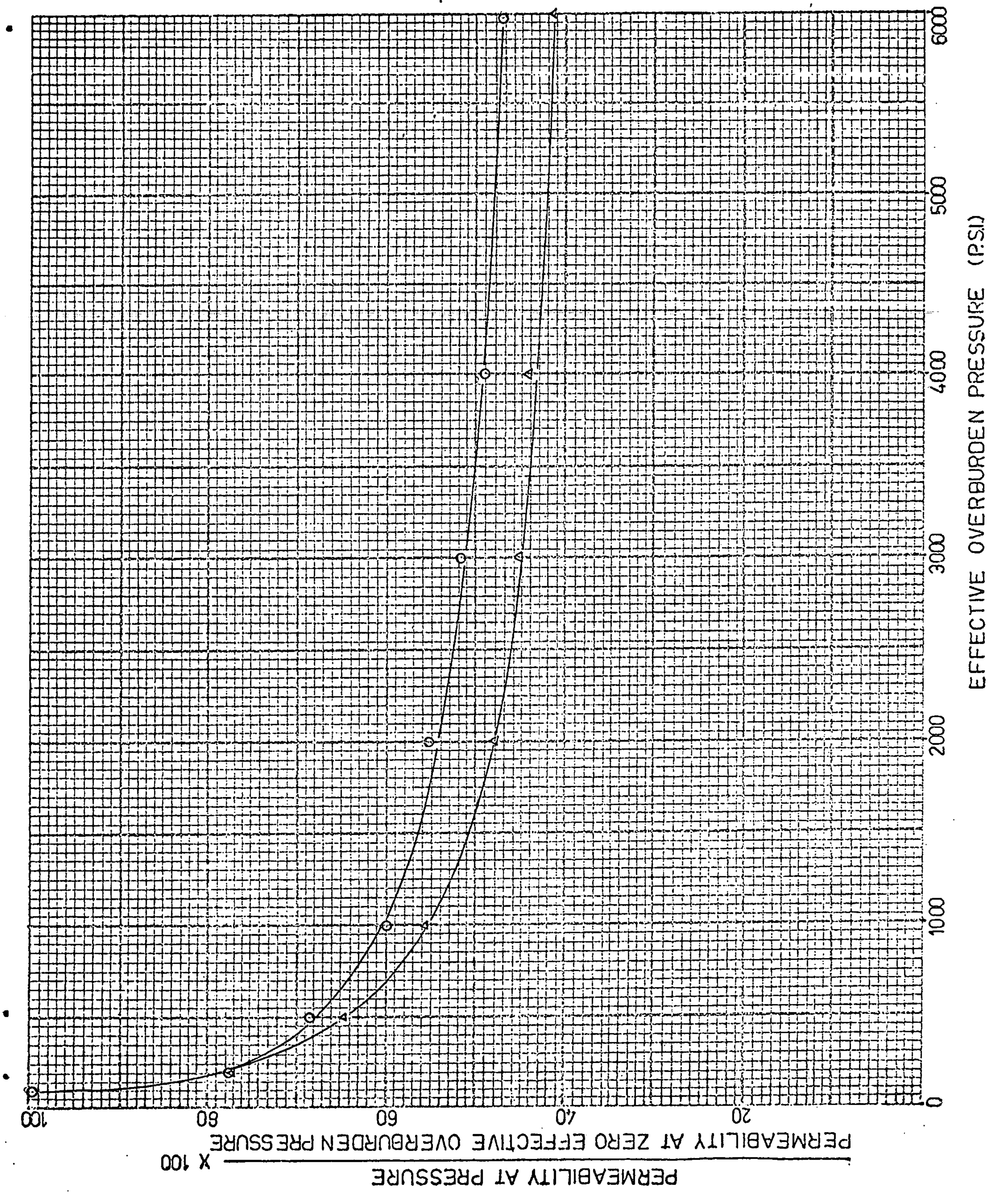

FIGURE 26

OVERBURDEN PRESSURE Vs PERMEABILITY

WELL – MOONIE No. 2 | SAMPLE DEPTH – 5671'

POROSITY – 20.5 % | PERM. TO NITROGEN – 1130 Md.

PERM. TO OIL AT ZERO EFFECTIVE OVERBURDEN PRESSURE | WITH RESIDUAL WATER – △ – 988 Md.
WITHOUT RESID. WATER – ⊙ – 1100 Md.

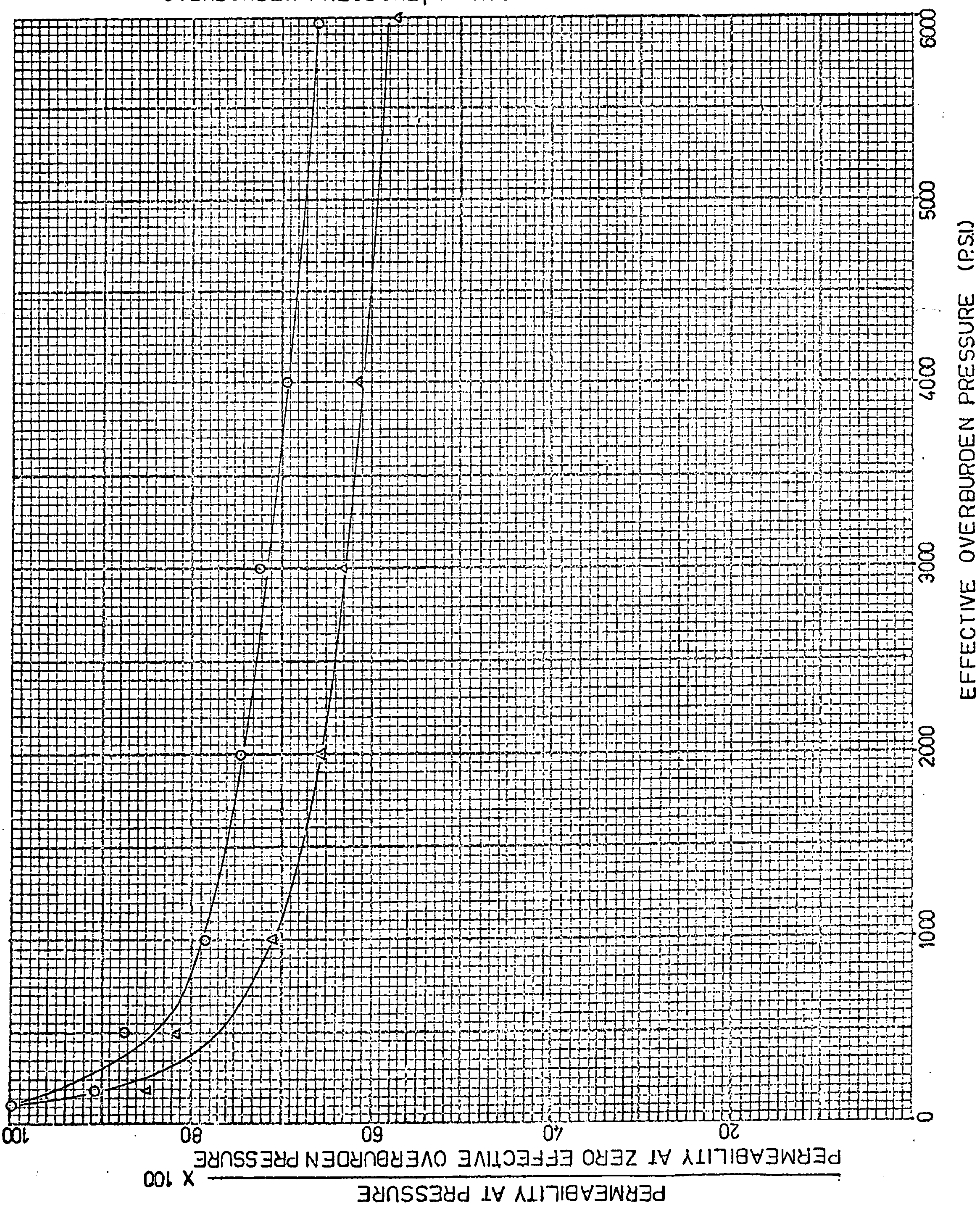

FIGURE 27

OVERBURDEN PRESSURE FLOW-TEST EQUIPMENT

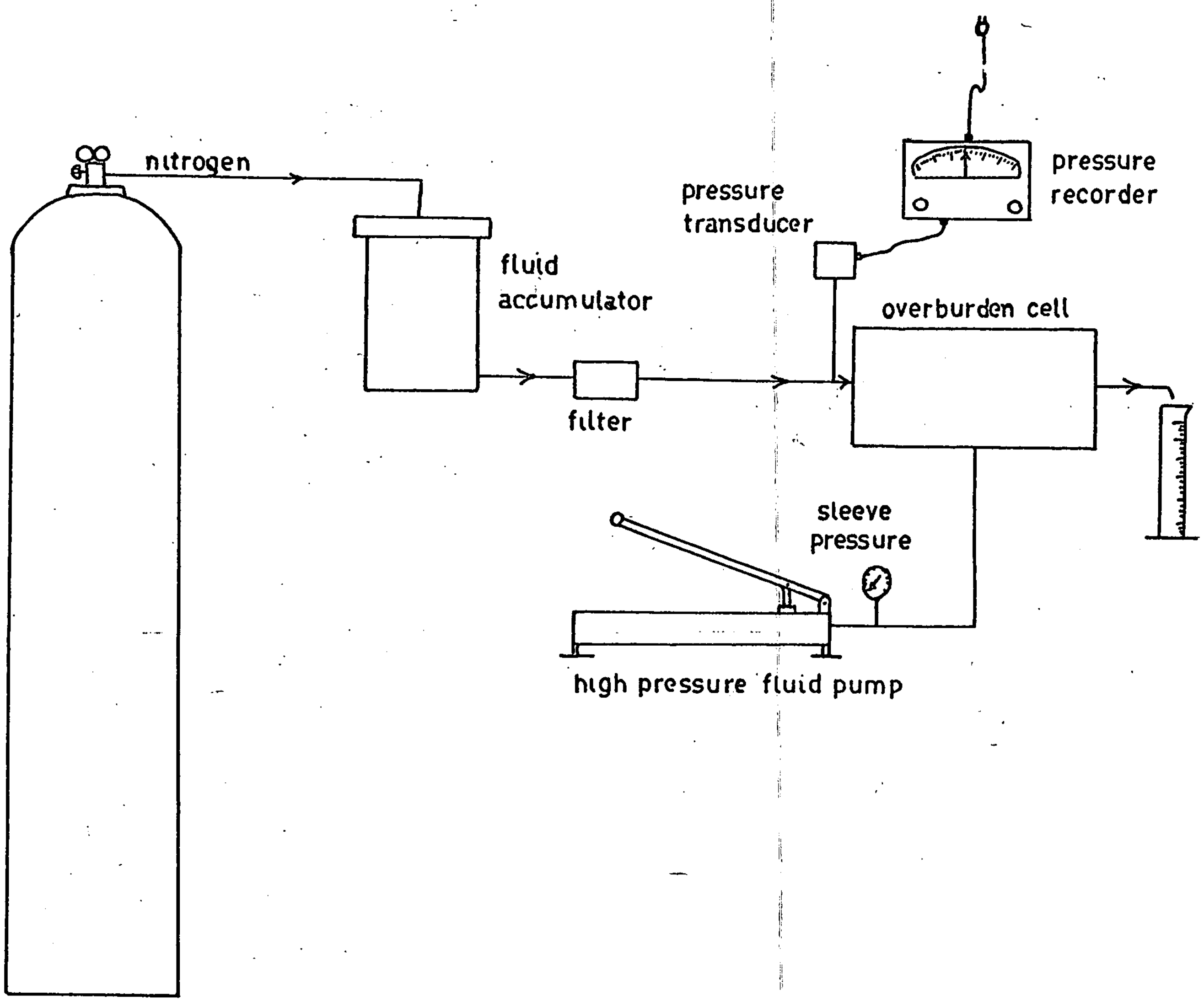

FIGURE 28

OVERBURDEN PRESSURE CELL

(EXPLODED VIEW)