The Determination of Reservoir Pressure from Liquid Level Data, Imray & Pilot Bores – Lakes Entrance.

R. F. Thyer

DEPARTMENT OF SUPPLY AND SHIPPING.

MINERAL RESOURCES SURVEY BRANCH.

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The pressure of the liquid, or reservoir pressure, within the glauconitic sandstone at Lakes Entrance has been the subject of conjecture in recent years and the low yields of oil which typify the field have been attributed by some observers to low reservoir pressure. Reservoir pressure, however, is only one of a number of factors upon which the rate of yield depends. Other factors of equal importance are the permeability of the producing formations and viscosity of the fluids produced.

However, it was not until the Imray bore had been drilled by Austral Oil Ltd. that any satisfactory evidence was obtained which permitted a true estimate of reservoir pressure being made. In this bore, glauconitic sandstone was entered at 1253 feet from the surface and drilling was stopped after 21feet of glauconitic sandstone had been penetrated. It is probable that 10 to 20 feet of sandstone separates the bottom of the bore from the artesian water horizon. The sandstone provides an effective barrier to the ingress of water from the latter horizon. The bore is cased from the surface to the top of the glauconitic sandstone where it it seated in cement, and all aquifers above the sandstone are sealed off.

Bailing tests showed that the 23 feet of glauconitic sandstone exposed yielded a daily average of approximately 31 pints of oil and 9 pints of water. Later, the liquid yielded was allowed to accumulate in the bore casing and at intervals over a period of some 24 months, the liquid level was recorded. The curve in Fig. 1 shows the liquid level (H) plotted against time in months. The values used have been taken from a similar curve published in The Petroleum Times (1).

It will be observed that the rate of rise, for instance the rise per month, decreased as time went by - this decrease becoming more apparent towards the end of the test period. It is evident that the curve is tending asymptotically towards a value of H of the order 1200 to 1400 feet, at which value the back pressure provided by the liquid column would be sufficient to prevent the flow of liquid from the reservoir. In other words, the back pressure would be equal to the reservoir pressure.

A particular method of plotting enables a reasonably accurate estimation of reservoir pressure to be made from such a curve as Fig. 1 without the necessity of waiting until the liquid level reaches its final value. As this method will be applied to date from the Pilot bore as well as Imray, its description will be delayed until the Pilot bore and the data obtained in tests conducted on it are described.

The Pilot bore is the most recent in the Lakes Entrance district and was under close observation from its inception. It was drilled primarily to obtain information of the yield from water-bearing formations which the nearby shaft would penetrate, but, as has been described elsewhere (2), it provided valuable information about the oil and water yields from the glauconitic sandstone.

The bore is cased with five inch casing from the surface to the top of the glauconitic sandstone at 1196 feet, into which it is firmly cemented. Before proceeding with the drilling of the glauconitic sandstone, bailing tests proved that the cement provided a tight seal and no water entered the casing from formations above the glauconitic sandstone. This was of utmost importance to the subsequent bailing tests as it could be assumed that any fluid entering the bore after sections of the glauconitic sandstone had been drilled came from the glauconitic sandstone exposed.

The glauconitic sandstone was drilled in steps of approximately two feet and bailing tests were made after each successive two foot section was drilled. Drilling was suspended when 22 feet 10 inches of glauconitic sandstone had been penetrated. After the necessary bailing tests had been completed, the liquid yielded by the section of glauconitic sandstone was allowed to accumulate in the bore and daily records were kept of the height of the liquid column as it rose in the casing.

The height was found by lowering the bailer into the bore to a predetermined depth - withdrawing it and noting the position of the liquid coating on the bailer. With experience is was possible to determine in advance the depth to which the bailer should be lowered so that it penetrated this liquid by a matter of only two or three inches. A correction was applied to the liquid height to allow for the liquid displaced by the bailer. The test was conducted over a period of 65 days the final height of the liquid column being 513 feet 10 inches.

The liquid heights are shown in Fig. 2 plotted against the time in days. Because of the shorter time used in this test, the falling off in the rate of rise with time is not so marked in this curve as it is in the corresponding curve (Fig. 1) for the Imray test, but a comparison with the straight line drawn through the origin and tangential to the curve at the origin demonstrates the decline in the rate of rise with time.

<u>Determination of Reservoir Pressure from Liquid Level Data.</u>

Time and the liquid level are related to one another by the following relationship:- (3)

$$\frac{ygct}{a} = -\log_e \frac{He - H}{He - Hi} \quad - - - - \quad (1)$$

where y = density of liquid column.
g = gravitational constant.
c = productivity index which is a constant for the bore.
t = time
a = area of cross section of bore casing.
He = liquid height corresponding to reservoir pressure.
H = liquid height at time t.
Hi = liquid height at time zero.

Equation (1) may be expressed as:-

$$t = K \log_{10} (He - H) \quad - - - - \quad (2)$$

i.e. if values of t are plotted against corresponding values of $\log_{10}(He-H)$, the curve will be a straight line with a slope θ where tan θ = K.

In the examples under consideration, the value of He is unknown, but equation (2) provides a means of determining it. This can be done by a method of trial and error. Various values of He are assumed and curves derived from equation (2) are plotted. The correct value of He will give a straight line, whereas the curves for other values of He will depart from the straight line. In the case of the Imray bore, a set of such curves is shown in Fig. 3. Values of He range from 1200 feet to 1400 feet. It will be observed that the curve for He = 1250 feet is the closest to a straight line of those shown. A closer approximation could be found by choosing intermediate values of He, but as will be shown presently in connection with the results from the Pilot bore, the value of He which gives the closest approximation to a straight line can be found by another method.

The set of curves for the Pilot bore, corresponding to those in Fig. 3 for Imray, are shown in Fig. 5. Selected values of He range from 800 feet to 2000 feet.

A departure from a straight line is clearly evident in the curves for He = 800 and 1000 feet and is present, but not very obvious in some of the other curves.

The choice of the most probable value of He, i.e. the value that gives the closest approximation to a straight line, is not at all evident from these curves, but a value has been arrived at in another way, which has also been applied to the Imray results.

A set of values typical of those used in plotting the curves in Fig. 3 and 5 are tabulated below:-

Imray Bore.

Time (months)	H feet	He = 1200 feet. He - H	$\log_{10}$(He - H)	d. log (He - H)	Departure from mean
0	240	960	2.9823		
				.2713	.0961
5	686	514	2.7110		
				.3045	.0629
10	945	255	2.4065		
				.3273	.0401
15	1080	120	2.0792		
				.4994	.1320
20	1162	38	1.5798		
				.3674 (Mean value)	.3311 (Total)

The ratio of total departure to mean d.log (He-H) = $\frac{.3311}{.3674}$ = .90 and will be called the departure function.

Departure functions have been determined for each value of He for both the Imray and Pilot bores, and they are tabulated below.

Imray Bore.

He (ft.)	Dept.function
1200	.90
1250	.175
1300	.20
1400	.70

Pilot Bore.

He (ft.)	Dept.function
800	.81
1000	.35
1200	.136
1400	.106
1600	.138
1800	.175
2000	.244

When the departure function is a minimum the curve of equation (2) will more nearly approximate a straight line than for any other value of He.

The departure functions are plotted against the appropriate values of He. In the case of the Imray bore, this curve is shown in Fig. 4. It has a minimum value at approximately He = 1270 feet.

The corresponding curve for the Pilot bore is shown in Fig. 6. It has a very broad minimum as one would expect from the nature of the curves in Fig. 5. It extends from approximately 1280 feet to 1380 feet with a mean of 1330 feet.

The values of He obtained for the Imray and Pilot bores are 1270 feet and 1330 feet respectively. The average density of the fluid in the Imray bore was 0.99 and in the Pilot bore 0.97. The pressures corresponding to these values of He are respectively 550 lb/sq. inch and 560 lb/sq. inch. These pressures are very close to the estimated artesian water pressure of 600 lb/sq. inch and it is reasonable to assume that reservoir pressure is identical with artesian water pressure.

This seems a rational result in view of the fact that none of the bore logs examined or bore cores tested for permeability suggests the presence of an impermeable layer between the artesian water horizon and the glauconitic sandstone such as would of necessity be present if reservoir and artesian waters pressure were substantially different.

In many of the bore logs the cores when broughtto the surface have been described as being "dry". There is an inference in such a description that the pore spaces in the cores are incompletely saturated with liquid. If this is so, then the pores must contain gas at a pressure equal to reservoir pressure and one would expect, as a consequence of its very low viscosity relative to water andoil, a gas yield of a magnitude which would be immediately apparent. The amount of gas escaping from Imray and the Pilot bore is, however, of a negligible quantity.

It is the writer's belief that the pore spaces in the glauconitic sandstone are completely filled with liquid, this liquid being in contact through the pores of the rock with the water in the artesian horizon and in consequence, the liquid in the glauconitic sandstone (the reservoir) has a pressure comparable with that of the artesian water.

If, as is implied above, the glauconitic sandstone is completely saturated with liquid and the reservoir pressure is of the order of 600 lb. per sq. inch, it may seem surprising that so little liquid is yielded by the glauconitic sandstone. The writer believes, however, that the known physical properties of the glauconitic sandstone provide an explanation.

The rate at which a bore hole will produce liquid depends upon the reservoir pressure and the permeability of the producing formation, other factors being constant for any given bore hole. If a reservoir pressure of approximately 600 lb. per sq. inch exists, then the low yield rate is apparently due to extremely low permeability.

Tests of permeability on samples of glauconitic sandstone from 1255 feet to 1291 feet in the No. 10 bore (4) gave an average value of approximately 2.2 millidarcies for dry samples. This section of No. 10 bore corresponds to the glauconitic sandstone exposed in the Imray and Pilot bores. This figure, however, of 2.2 millidarcies would be considerably decreased by the presence of water as was shown in a number of tests conducted for the purpose of ascertaining the magnitude of this effect. It was shown (5) that in certain types of glauconitic sandstone, the effect was more marked than in others. For instance, samples from 1277 - 1278 feet showed an average devrease of 2.4 per cent. in permeability for 1 per cent. water saturation, while samples from 1291 - 1300 feet showed an average of only 0.73 per cent. decrease per 1 per cent. water saturation.

It is believed that in the latter case the decrease may be due entirely to the reduction in the cross-section of the interstices between the grains due to water adhering to the grains. In the former case, however, the effect appears to be too great to be explained in this fashion and an alternative explanation is offered, namely, that some of the material comprising the sandstone takes up water and swells, and that this swelling is partly responsible for the decrease in permeability.

Garrison (1939) in an article on the surface chemistry of clays and shales describes the swelling which can occur when certain minerals take up 'planar water' by the agency of weak electrostatic forces on the tops and bottoms of flat plates of micaceous minerals. Bentonite exhibits an extreme case of this swelling. The swelling of deep shales from which the planar water has been pressed out by the pressure of overburden is attributed to the re-entry of planar water. If favourable minerals are present in the glauconitic sandstone the abnormal reduction in permeability may be due to such minerals taking up 'planar water' and swelling.

Sandstone of the kind represented by the samples from 1277' - 1278' would tend to have very low permeability at moderately high water saturations. It is believed that the sandstone exposed in Imray and the Pilot bores is of this kind. The latter kind are typical of the section 1294 - 1300 feet in No. 10 bore. Sandstone of this latter kind could be expected to have appreciable permeability at high water saturations and thus yield apprecialbe quantities of water as was found to be the case when they were penetrated in the No. 10 bore.

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References.

(1) The Petroleum Times, Page 502. Sept., 18th, 1943.

(2) L. C. Noakes, Preliminary Report on the Examination of Cores from the Pilot Bore - Lakes Entrance, Vic., Comm. Min. Res. Surv. Report No. 1945/24.

(3) Morris Muckat - Use of Data on the Build-up of Bottom-hole Pressure. A.I.M.M.E. Trans. Vol. 123, 1937, p.45.

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(5) R.F. Thyer. op cit, page 11.

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R. F. THYER.
GEOPHYSICIST.

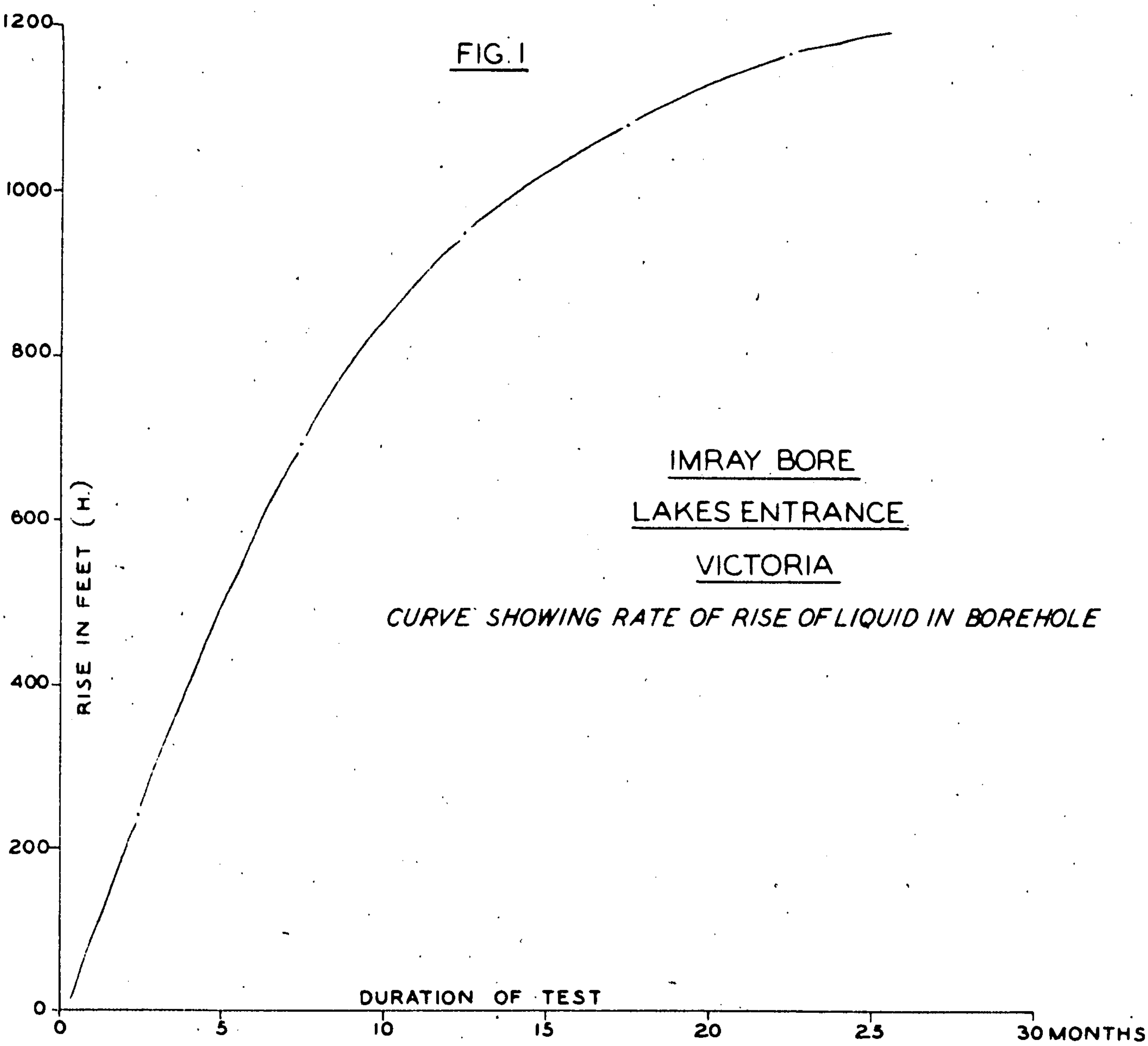


FIG. I
IMRAY BORE
LAKES ENTRANCE
VICTORIA
CURVE SHOWING RATE OF RISE OF LIQUID IN BOREHOLE
RISE IN FEET (H.)
1200
1000
800
600
400
200
0
DURATION OF TEST
0
5
10
15
20
25
30 MONTHS

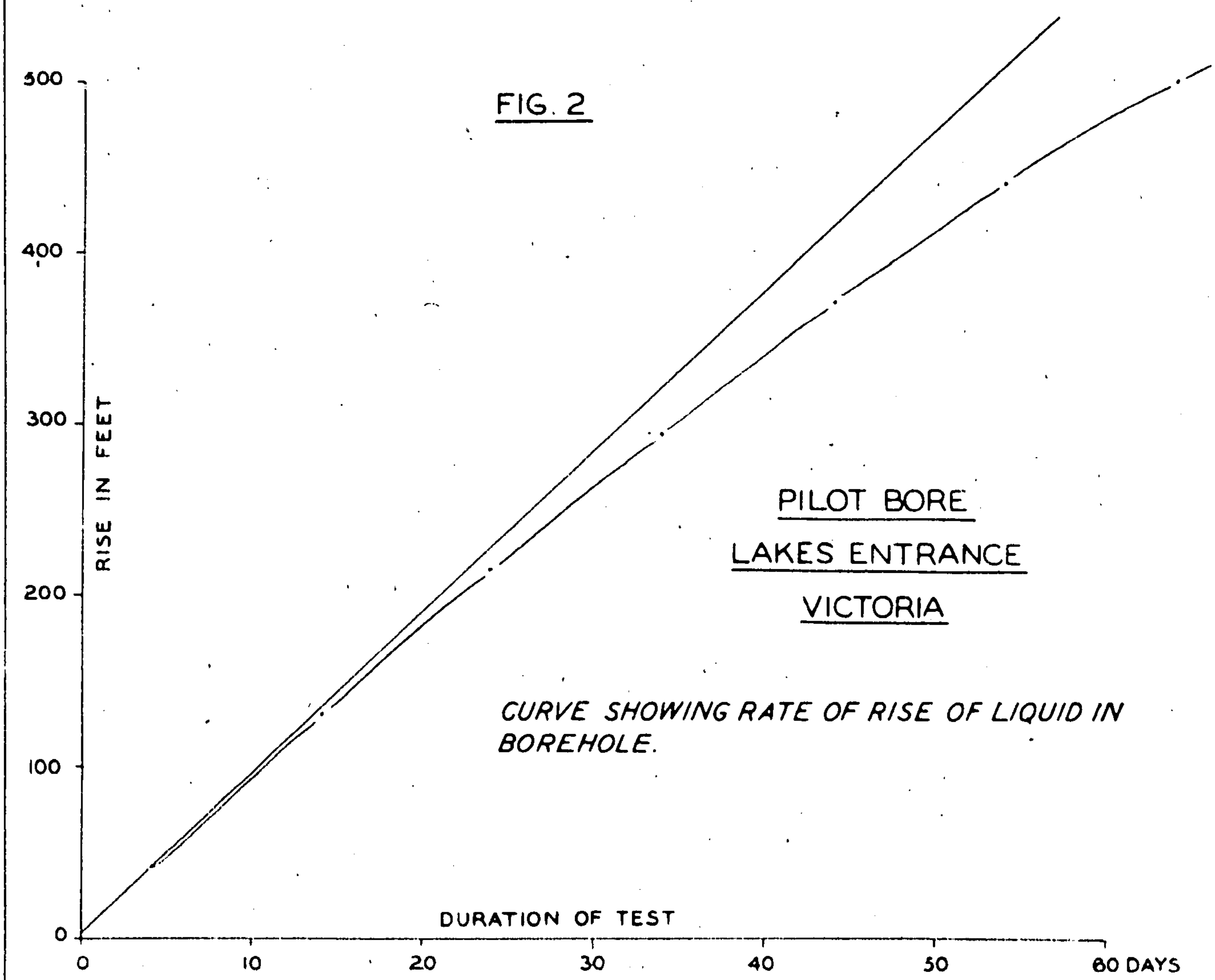


FIG. 2
PILOT BORE
LAKES ENTRANCE
VICTORIA
CURVE SHOWING RATE OF RISE OF LIQUID IN BOREHOLE.
RISE IN FEET
500
400
300
200
100
0
DURATION OF TEST
0
10
20
30
40
50
60 DAYS

FIG. 3

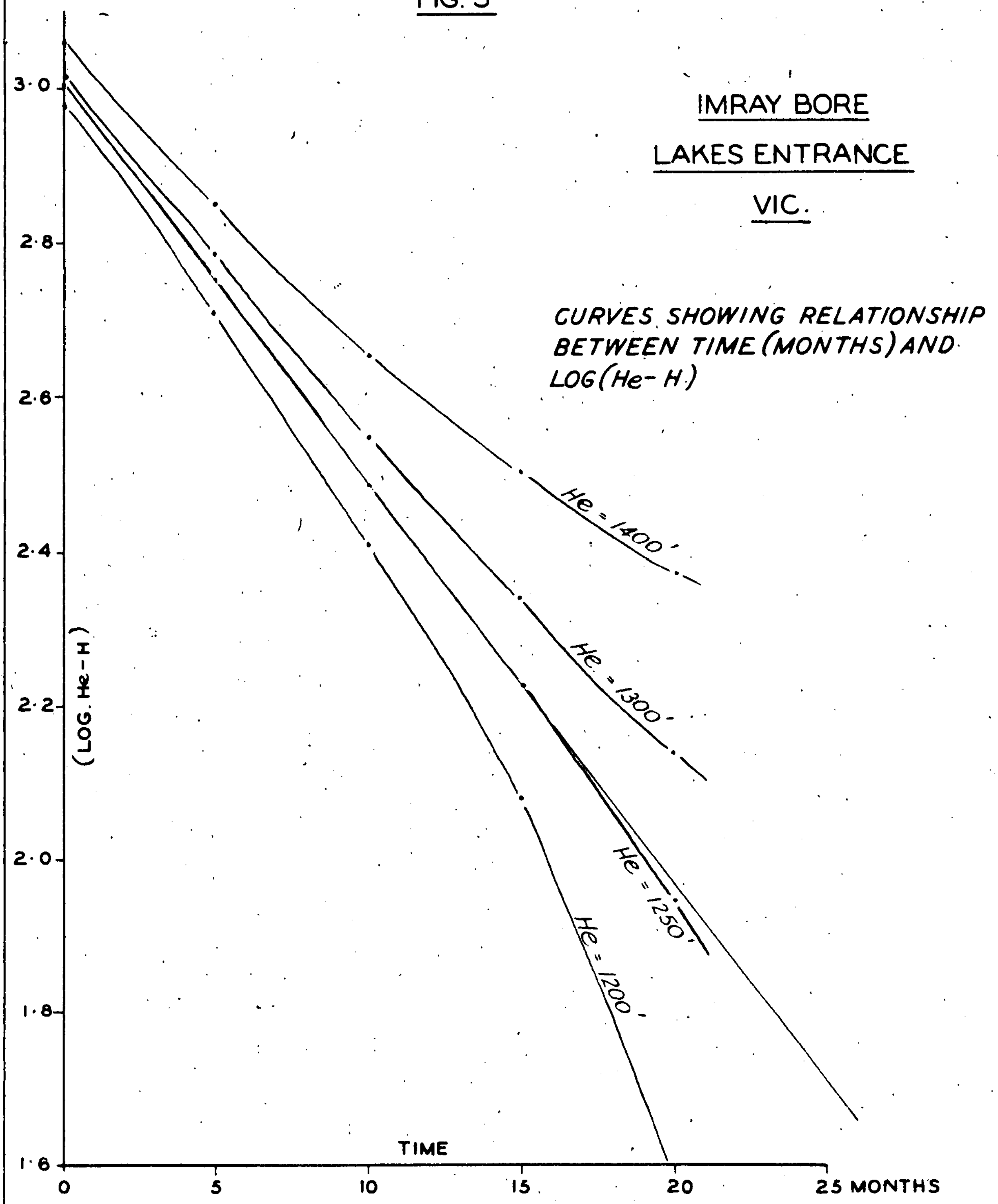
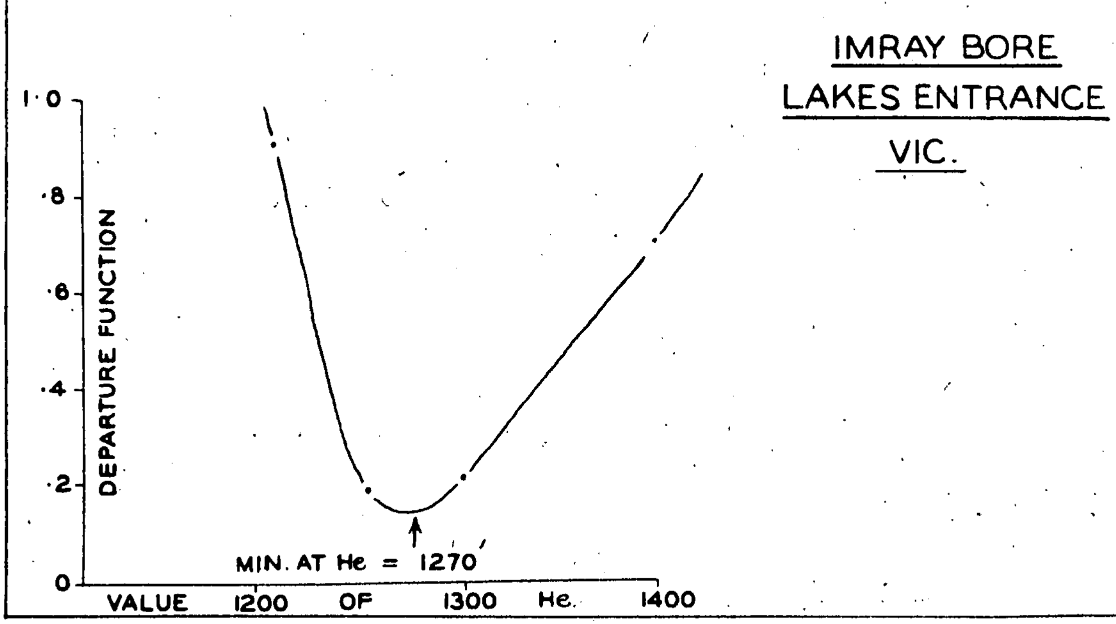

IMRAY BORE
LAKES ENTRANCE
VIC.
CURVES SHOWING RELATIONSHIP BETWEEN TIME (MONTHS) AND LOG (He- H)
(LOG. He-H)
3·0
2·8
2·6
2·4
2·2
2·0
1·8
1·6
He = 1400'
He = 1300'
He = 1250'
He = 1200'
TIME
0
5
10
15
20
25 MONTHS

FIG. 4


IMRAY BORE
LAKES ENTRANCE
VIC.
DEPARTURE FUNCTION
1·0
·8
·6
·4
·2
0
MIN. AT He = 1270'
VALUE
1200
OF
1300
He.
1400

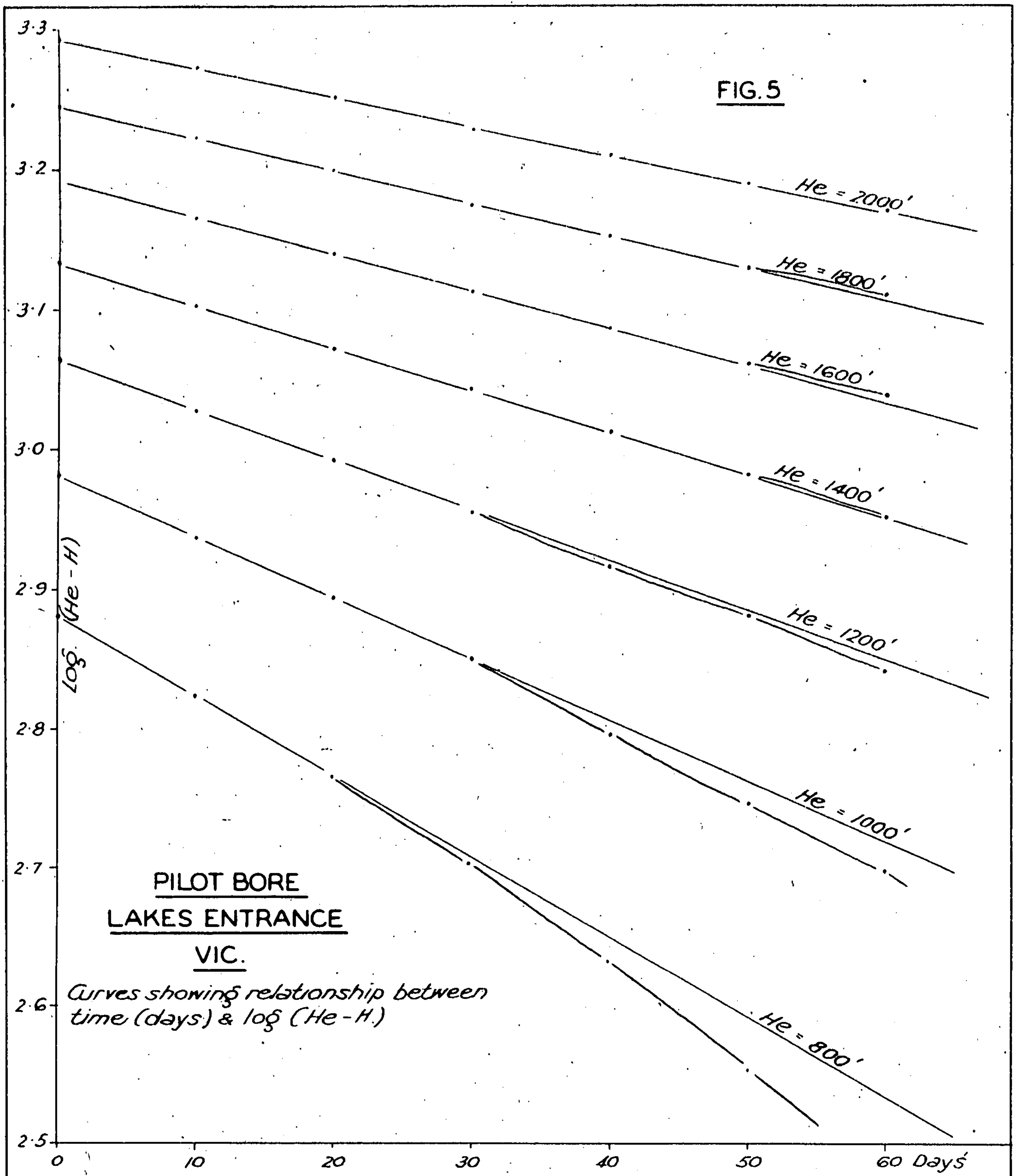


FIG. 5
PILOT BORE
LAKES ENTRANCE
VIC.
Curves showing relationship between
time (days) & log (He - H)
He = 2000'
He = 1800'
He = 1600'
He = 1400'
He = 1200'
He = 1000'
He = 800'
Log (He - H)
3·3
3·2
3·1
3·0
2·9
2·8
2·7
2·6
2·5
0
10
20
30
40
50
60 Days

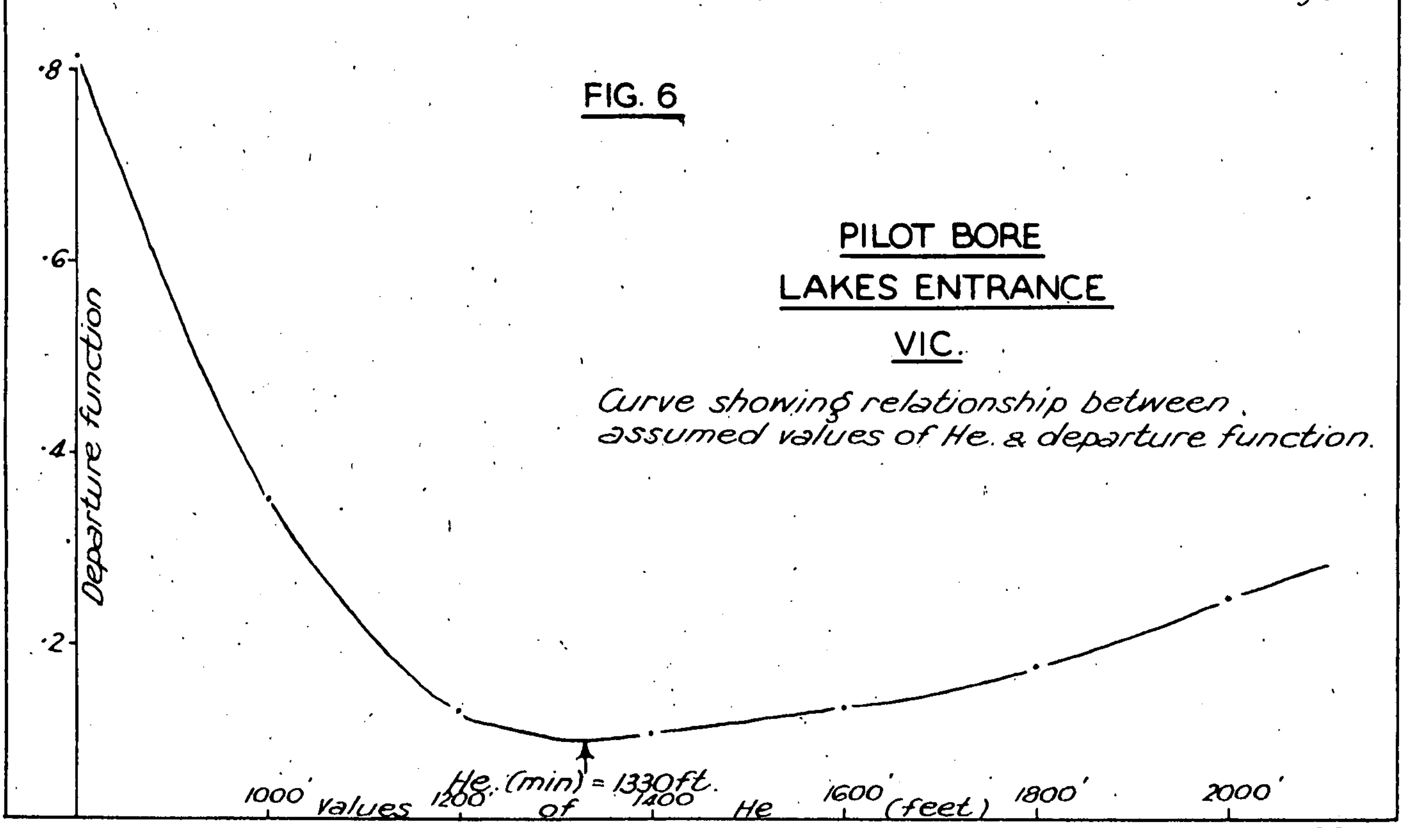


FIG. 6
PILOT BORE
LAKES ENTRANCE
VIC.
Curve showing relationship between
assumed values of He & departure function.
Departure function
·8
·6
·4
·2
He (min) = 1330 ft.
1000'
1200'
1400'
1600'
1800'
2000'
Values of He (feet)