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Our ref: J2/D CL 384
Your ref:

29th January, 1981

Statoil,
Postboks 300,
4001 Stavanger,
Norway

Gentlemen,

In a letter of 11th March, 1980, we were requested to perform a series of special core analysis tests on samples of core from well 34/10-5. We now have pleasure in presenting our final report on this work (Report Number CL 384).

The opportunity to be of service is appreciated and if you have any queries concerning this report please do not hesitate to contact us.

Yours sincerely,

J.R. Hook
Chief Scientist

JRH/sk

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29th January, 1981

COREX LABORATORIES LIMITED

SPECIAL CORE STUDIES

COMPANY	STATOIL
WELL	34/10-5
LOCATION	NORTH SEA
COUNTRY	NORWAY
REPORT NO.	CL 384

CONTENTS

1. INTRODUCTION

Two pairs of plug samples (one of diameter 1.5 inches and one of diameter 1 inch) and two samples of preserved whole core from well 34/10-5 were received in the laboratory to be subjected to a series of special core analysis tests. Of the plug samples both members of one pair, from a depth of 1953.8m, were found on receipt to be fractured across the axis of the plug. However, since replacement samples could not be supplied it was decided to use these fractured plugs to give a pair of samples of reduced length. A pair of plug samples, one of diameter 1.5 inches and one of diameter 1 inch, was required to be cut from each of the pieces of preserved core. These plug samples were cut using thin walled diamond core drills with simulated formation brine as the drilling fluid. However, it was found to be impossible to successfully cut plugs from one of the core samples in this way because of the extremely friable nature of the sample. A further attempt was made to cut plugs from this sample using nitrogen as the drilling fluid but this also proved to be unsuccessful. Thus, a total of three pairs of plug samples were prepared for testing. The plug samples were cleaned in Soxhlet extractors using firstly methanol as the refluxing solvent, followed by toluene and finally methanol again. The samples were then dried of all solvents and helium porosity and gas permeability determined. The results of these tests, together with a brief lithological description of the plug samples are given in Table 1.

The one inch diameter samples were then used for the measurement of gas-brine capillary pressure curves, formation resistivity factor and resistivity index at room conditions. The 1.5 inches diameter plug samples were used for the determination of liquid permeability, porosity and formation resistivity factor at net confining pressures of 6.8, 13.6, 32.6 and 50.0 bar and the resistivity index at a net confining pressure of 50.0 bar.

For all tests involving formation brine, simulated formation brine was made to the analysis given in Table 2.

TABLE 1 BASIC PROPERTIES OF SAMPLES

Company Statoil Well 34/10-5

COREX SAMPLE CODE	DEPTH (m)	GAS PERM. (mD)	POROSITY (%)	GRAIN DENSITY ($g\ cm^{-3}$)	LITHOLOGICAL DESCRIPTION
GB 1A	1953.82	6530.	33.7	2.68	Light brown, medium grained micaceous sandstone. Poorly cemented. Slightly calcareous cement in parts. Abundant clay minerals, occasional carbonaceous material and green mineral grains (possibly glauconite).
GB 1B	1953.85	1760.	35.5	2.68	
GB 2A	1956.52	70.0	25.5	2.72	Pale brown, coarse grained micaceous siltstone. Abundant laminae of carbonaceous material. Small amount of calcareous material.
GB 2B	1956.69	84.7	30.4	2.75	
GB 3A	1967.99	1880.	35.3	2.65	Very pale brown/grey, fine grained micaceous sandstone. Poorly cemented. Very slightly calcareous cement. Abundant clay minerals Occasional carbonaceous material and green mineral grains (possibly glauconite).
GB 3B	1968.04	801.	33.5	2.67	

TABLE 2

BRINE ANALYSES

Company: Statoil Well: 34/10-5

Ion	Concentration (mgl^{-1})	
	Formation Brine	
Sodium	14000	
Calcium	1275	
Magnesium	335	
Barium	50	
Lithium	7.6	
Potassium	209	
Chloride	26200	
Bicarbonate	415	
Sulphate	30.8	
Bromide	62	

TABLE 3

FORMATION RESISTIVITY FACTOR

ROOM CONDITIONS

Company Statoil **Well** 34/10-5 **Brine Resistivity** 0.187 ohm m

Sample	Depth (m)	Porosity (%)	Formation Factor
GB 1B	1953.85	35.5	5.88
GB 2B	1956.69	30.4	8.12
GB 3B	1968.04	33.5	7.20

Figure 1.

FORMATION RESISTIVITY FACTOR-POROSITY CORRELATION

COMPANY STATOIL FIELD

WELL 34/10 - 5 FORMATION

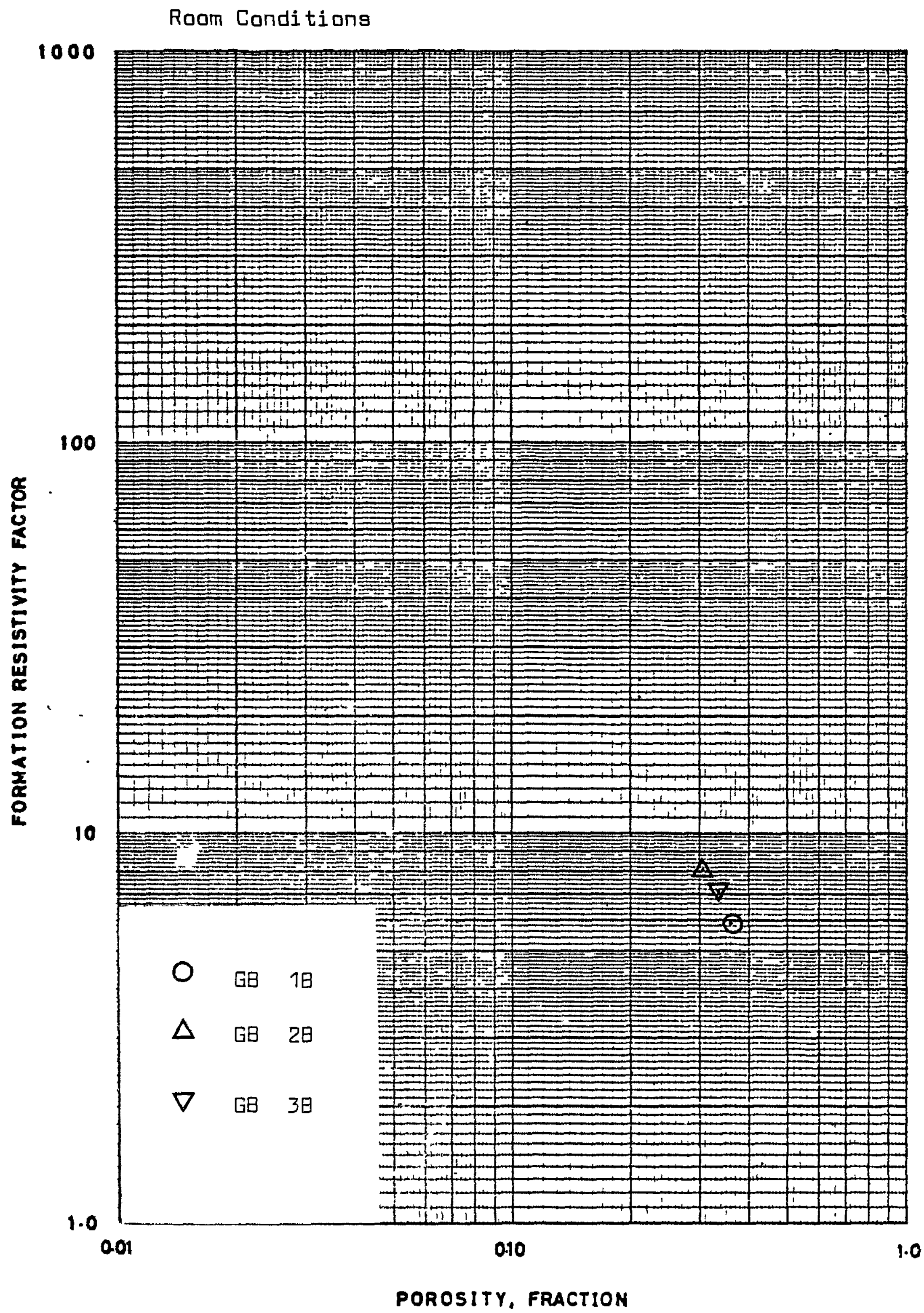


TABLE 4

RESISTIVITY INDEX

ROOM CONDITIONS

Company Statoil Well 34/10-5

SAMPLE	DEPTH (m)	BRINE SATN. (%)	RESISTIVITY INDEX
GB 1B	1953.85	41.3	5.17
		34.3	7.46
		27.4	11.4
		22.3	16.8
		19.7	21.4
		16.2	30.4
GB 2B	1956.69	SAMPLE DISINTEGRATED	
GB 3B	1968.04	95.0	1.10
		67.1	2.08
		50.4	3.46
		41.5	5.03
		34.1	7.15
		27.9	10.2

Figure 2.

RESISTIVITY INDEX versus WATER SATURATION

COMPANY STATOIL FIELD

WELL 34/10 - 5 FORMATION

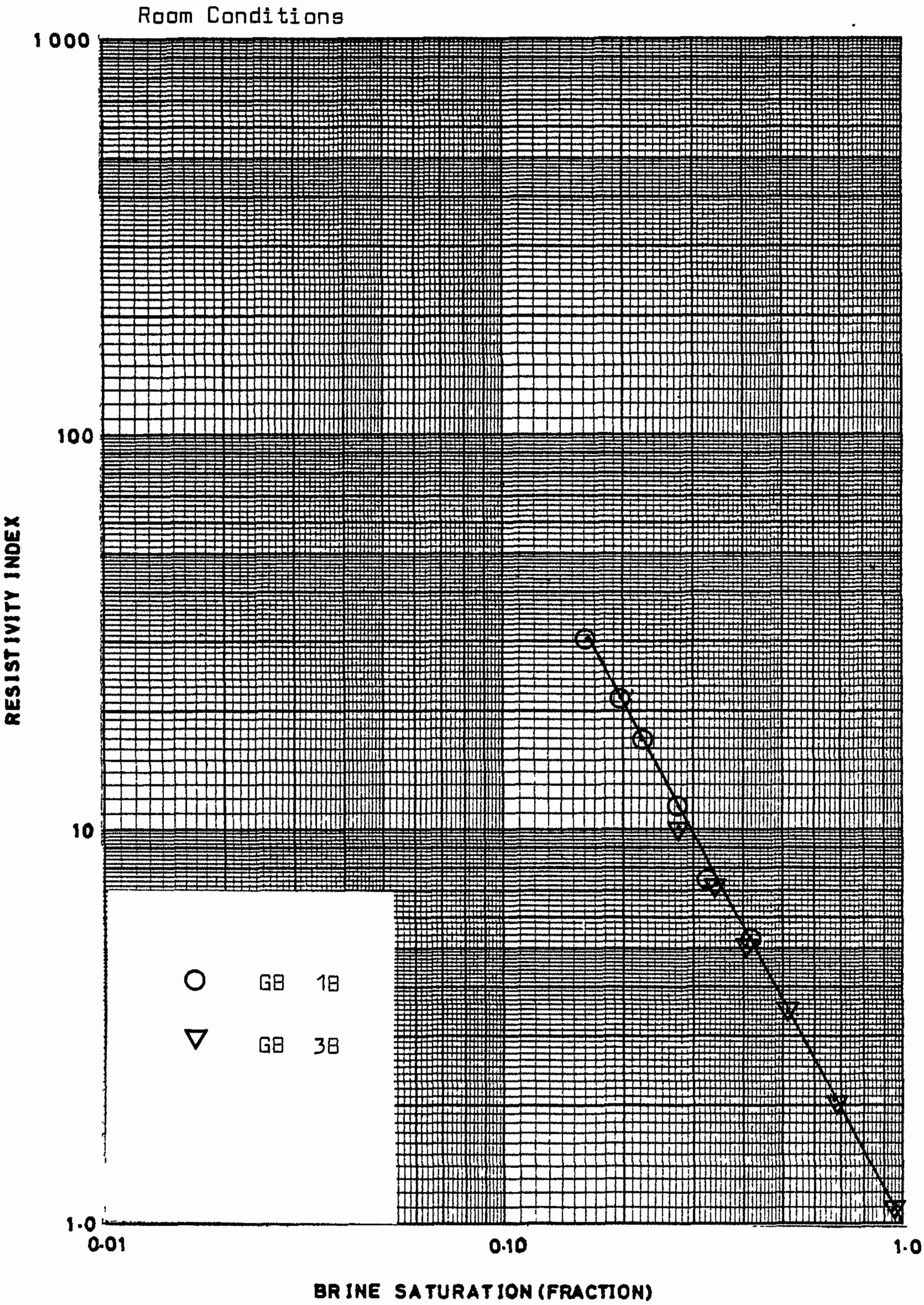


TABLE 5

GAS-BRINE CAPILLARY PRESSURE

Company: Statoil   Well: 34/10-5

Sample	Depth (m)	Porosity (%)	Gas Perm. (mD)	Brine Saturation (% pore space)					
				0.1b	0.2b	0.4b	0.8b	1.6b	2.8b
GB 1B	1953.85	35.5	1760.	41.3	34.3	27.4	22.3	19.7	16.2
GB 2B	1956.69	30.4	84.7		SAMPLE	DISINTEGRATED			
GB 3B	1968.04	33.5	801.	95.0	67.1	50.4	41.5	34.1	27.9

Figure 3.

AIR-BRINE CAPILLARY PRESSURE CURVE

COMPANY STATOIL FIELD

WELL 34/10 - 5 SAMPLE G8 18 DEPTH (m) 1953.83m

GAS PERMEABILITY 1760mD POROSITY 35.5%

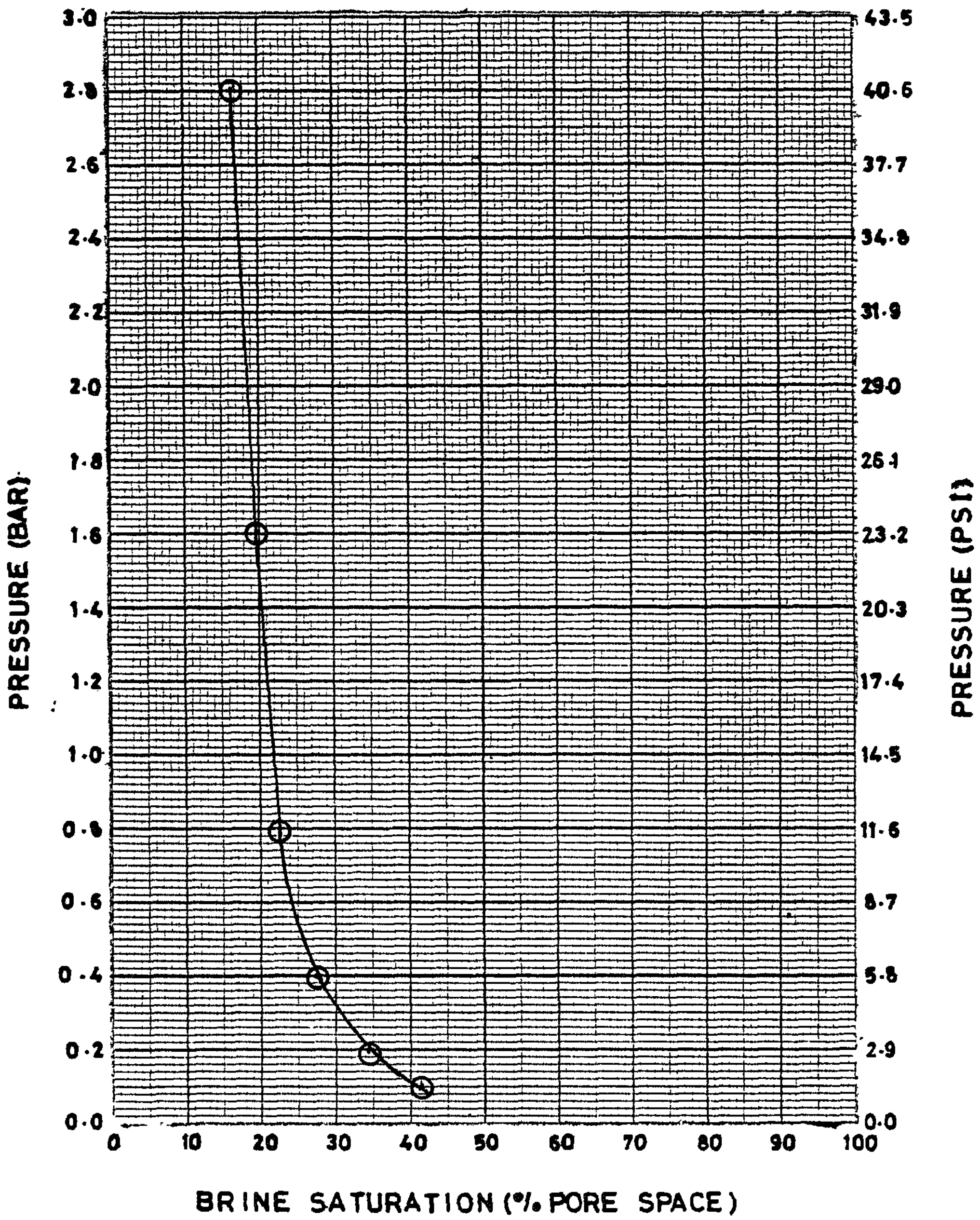


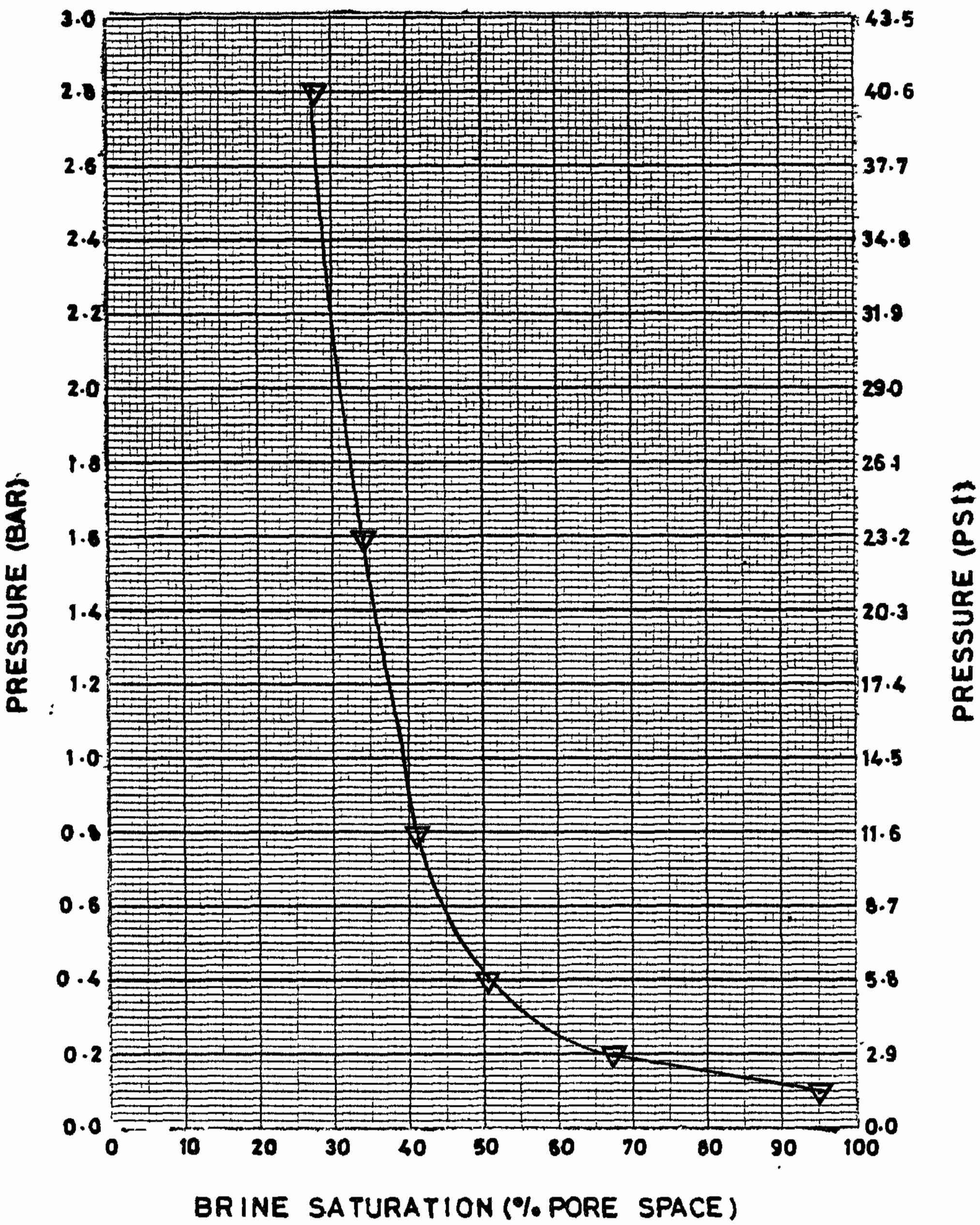
Figure 4.

AIR-BRINE CAPILLARY PRESSURE CURVE

COMPANY STATOIL FIELD -

WELL 34/10 - 5 SAMPLE GB 38 DEPTH 1968.04m

GAS PERMEABILITY 801mD POROSITY 33.5%



3. TESTS AT NET CONFINING PRESSURE

These tests were performed with the samples confined in a hydrostatic core holder. The samples were mounted between end pieces in a rubber sleeve and immersed in oil in a pressure vessel. A hydrostatic confining pressure of 6.8 bar was applied and the samples were saturated by evacuation followed by injection of a metered volume of simulated formation brine. Several pore volumes of brine were flushed through each sample and the samples were then allowed to reach electrical equilibrium. When equilibrium had been attained the electrical resistance of each sample was measured as described in section 2 of this report and the formation resistivity factor determined. The liquid permeability was then determined by flowing brine through the sample and measuring the pressure drop across the sample and the liquid flow rate. The permeability was then calculated using Darcy's law.

On completion of the permeability measurement the net confining pressure was raised to the next required value while the change in pore volume of the sample was monitored. When the samples had stabilised the formation resistivity factor and liquid permeability were re-determined as described above. In addition the porosity at the value of net confining pressure was calculated using the change in pore volume from the previous value of net confining pressure.

This process was repeated for each required value of net confining pressure (6.8, 13.6, 32.6 and 50.0 bar).

The results of the liquid permeability and porosity measurements are given in Table 6 while the formation resistivity factor results are given in Table 7 and Figures 5-8.

On completion of these measurements the resistivity index test was performed at the final value of net confining pressure of 50 bar. The brine saturation of each sample was reduced by flushing with refined oil at a constant pressure and monitoring the volume of brine expelled from the sample. When the volume expelled became constant the resistivity of the sample was determined as described previously. This value was divided by the resistivity at a brine saturation of 100% to give the resistivity index. The flushing pressure of oil was then increased and the resistivity index again determined when the volume of brine expelled had reached a constant value. This process was repeated until a total of 6 values of brine saturation had been achieved. The results are given in Table 8 and Figure 9.

A linear regression analysis of the data, together with the point, brine saturation = 100%, resistivity index = 1.00, for each sample, gave a value of 1.96 for the saturation exponent, n.

TABLE 6

POROSITY AND LIQUID PERMEABILITY AT OVERBURDEN PRESSURES

Company: Statoil Well: 34/10-5

Sample:	GB 1A		GB 2A		GB 3A			
Depth (m)	1953.82		1956.52		1967.99			
Net confining pressure: (bar)	Porosity (%)	Perm. (mD)	Porosity (%)	Perm. (mD)	Porosity (%)	Perm. (mD)		
6.8	33.0	2410.	24.8	0.24	35.0	743.		
13.6	32.3	2400.	24.3	0.28	34.7	364.		
32.6	30.9	2330.	23.3	0.28	34.3	354.		
50.0	30.0	2290.	22.6	0.21	33.9	279.		

TABLE 7 FORMATION RESISTIVITY FACTOR

OVERBURDEN PRESSURE CONDITIONS

Company: Statoil **Well:** 34/10-5 **Brine Resistivity:** 0.188 ohm m

Net confining pressure (bar)		6.8		13.6		32.6		50	
Sample	Depth (m)	Porosity	Formation Factor	Porosity	Formation Factor	Porosity	Formation Factor	Porosity	Formation Factor
GB 1A	1953.82	33.0	5.2	32.3	5.3	30.9	5.3	30.0	5.3
GB 2A	1956.52	24.8	12.0	24.3	12.3	23.3	12.8	22.6	13.3
GB 3A	1967.99	35.0	5.78	34.7	5.86	34.3	5.96	33.9	6.09

Figure 5.

FORMATION RESISTIVITY FACTOR-POROSITY CORRELATION

COMPANY STATOIL FIELD

WELL 34/10 - 5 FORMATION

Overburden Pressure Conditions

Net Confining Pressure (Bar) 6.8

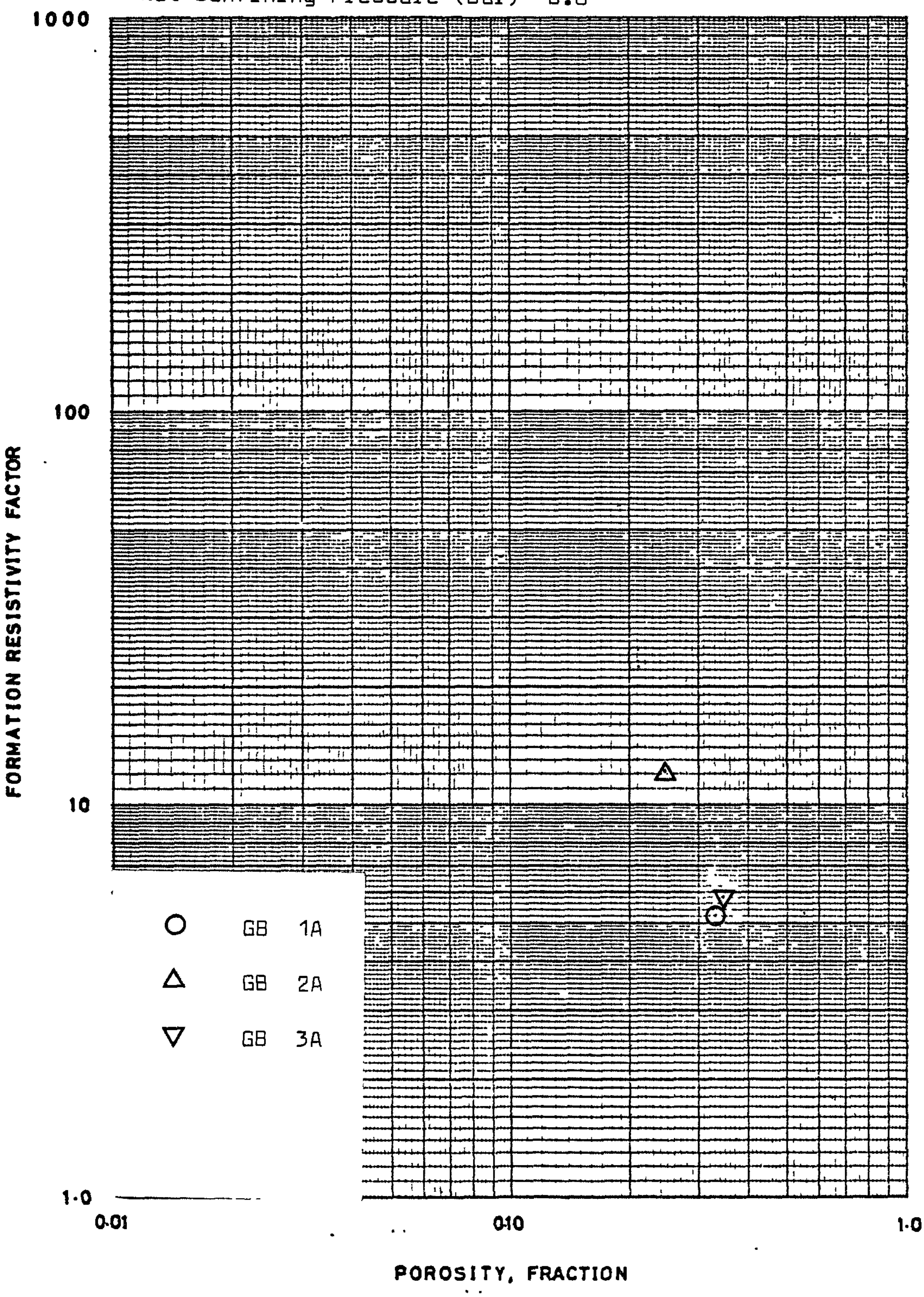


Figure 6.

FORMATION RESISTIVITY FACTOR-POROSITY CORRELATION

COMPANY STATOIL FIELD

WELL 34/10 - 5 FORMATION

Net Confining Pressure (Bar) 13.6

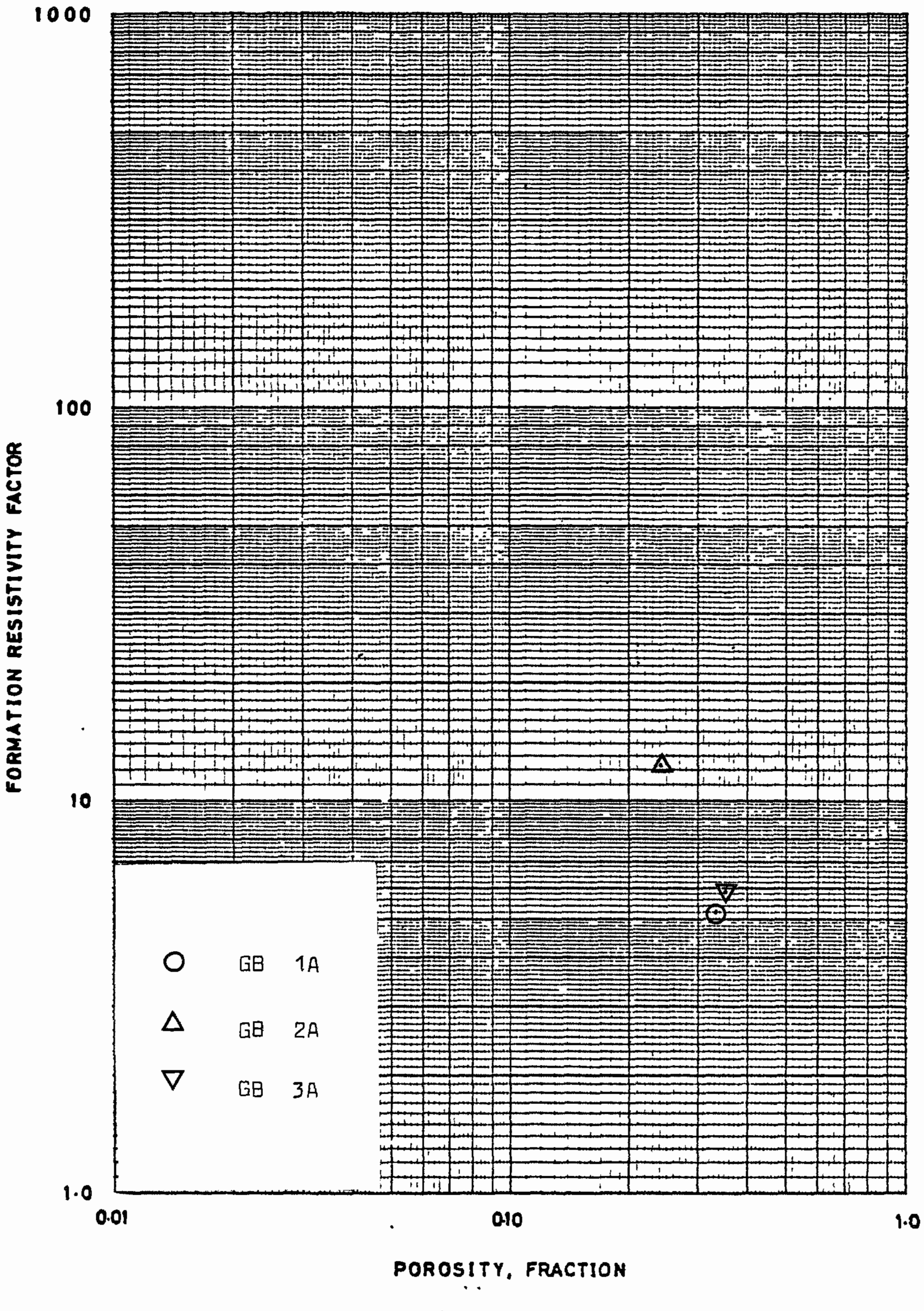


Figure 7.

FORMATION RESISTIVITY FACTOR-POROSITY CORRELATION

COMPANY STATOIL FIELD

WELL 34/10 - 5 FORMATION

Net Confining Pressure 32.6

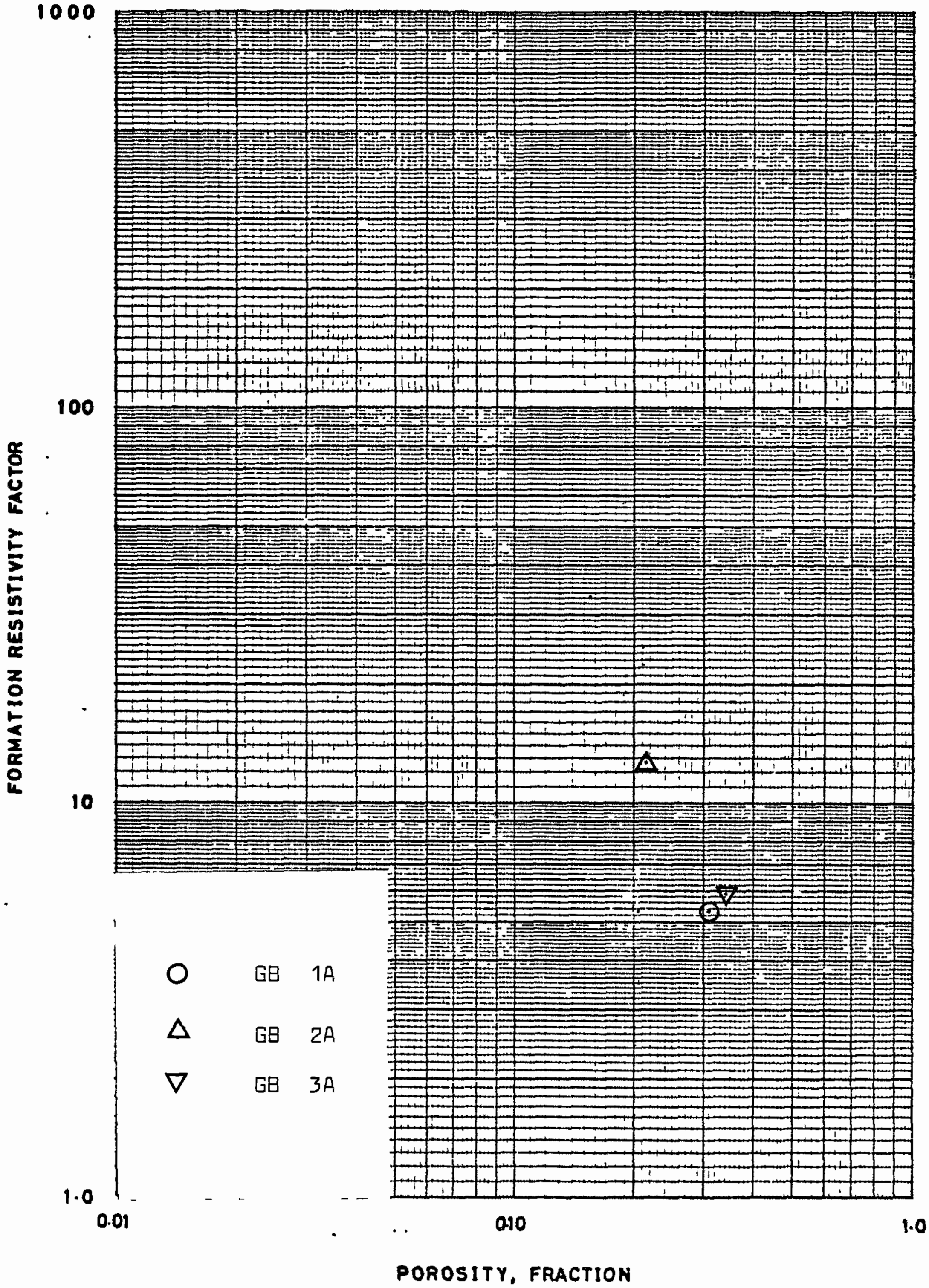


Figure 8.

FORMATION RESISTIVITY FACTOR-POROSITY CORRELATION

COMPANY STATOIL FIELD

WELL 34/10 - 5 FORMATION

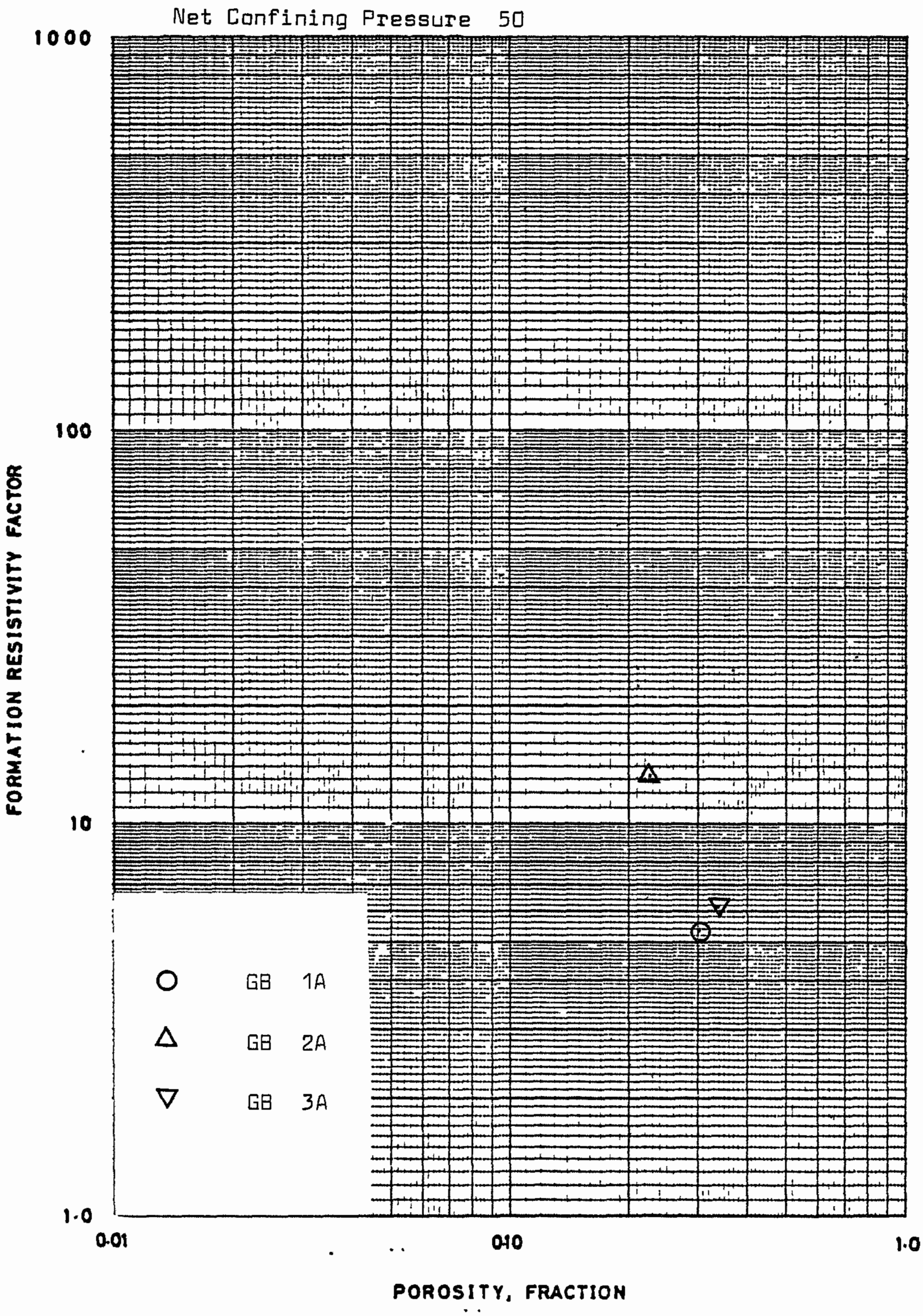


TABLE 8

RESISTIVITY INDEX

NET CONFINING PRESSURE 50 BAR

Company Statoil Well 34/10-5

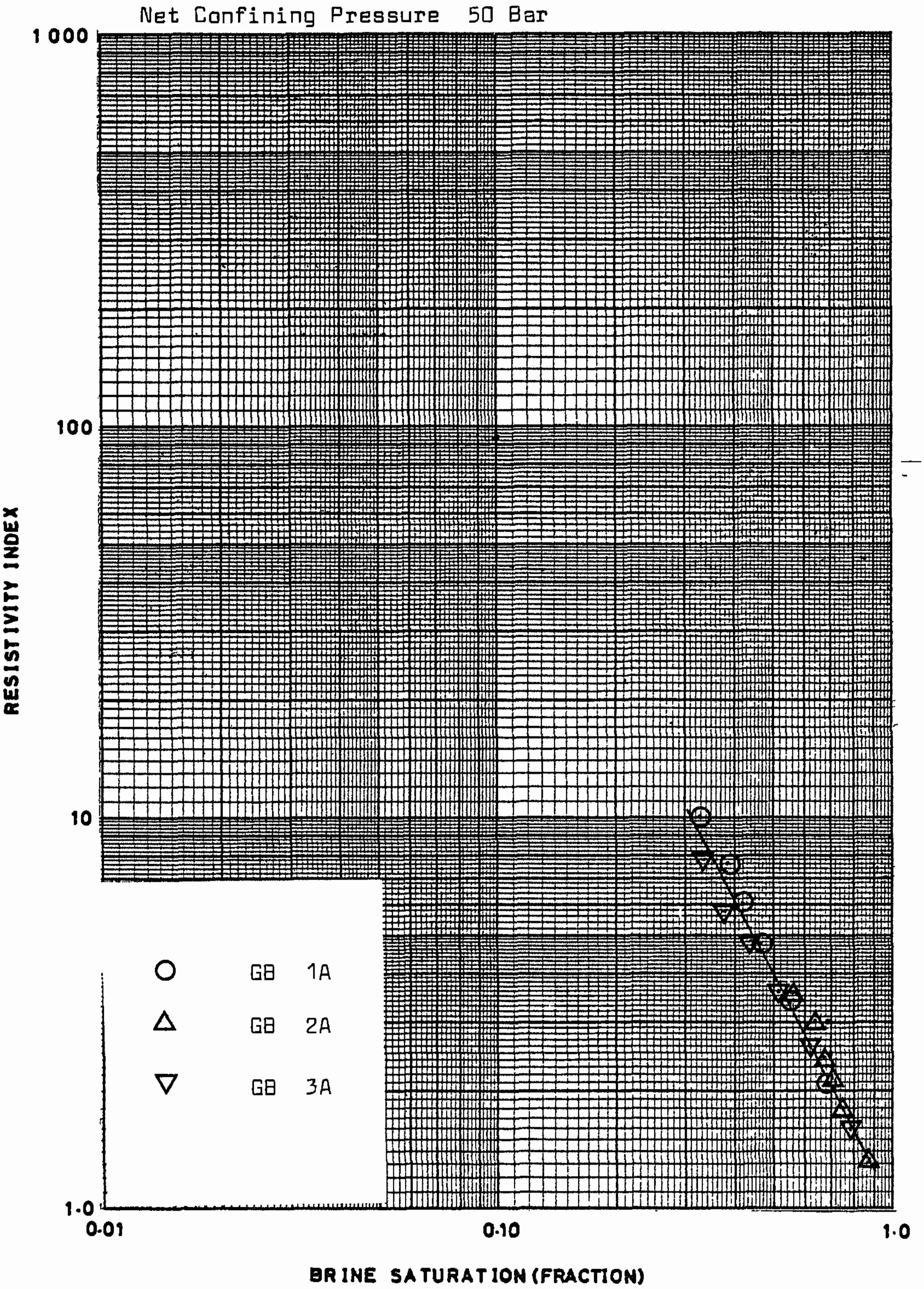
SAMPLE	DEPTH (m)	BRINE SATN. (%)	RESISTIVITY INDEX
GB 1A	1953.82	68.2	2.03
		54.5	3.34
		46.3	4.76
		42.0	6.00
		38.1	7.60
		32.5	10.0
GB 2A	1956.52	86.2	1.32
		75.4	1.82
		70.0	2.15
		67.1	2.44
		63.8	3.03
		55.0	3.60
GB 3A	1967.99	78.0	1.60
		61.3	2.61
		50.5	3.60
		44.4	4.82
		37.8	5.58
		33.5	7.95

Figure 9.

RESISTIVITY INDEX versus WATER SATURATION

COMPANY STATOIL FIELD

WELL 34/10 - 5 FORMATION



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KOMMENTAR TIL COREX RAPPORT CL384 - 34/10-5

Formasjons vann og plugger

Barium, 50 mg/l, og sulfate 30.8 mg/l, er en supermettet løsning m.h.p. $BaSO_4$. Utfelling av $BaSO_4$-krystaller er en fare og burde kanskje vært unngått. Men siden væske-permiabilitet ikke ble kjørt er det ikke kritisk for noen av målingene. Noe vann ble flushet gjennom ved metning m/flushing. To plugger sprakk på tvers og en brøt sammen.

Corex ble bedt om å gjøre Klinkenberg korrigerte permeabilitetsmålinger. Hverken i introduksjonen eller tabell 1 sies det noe om at dette ble gjort.

Rombetingelsesmålinger

Formasjonsfaktor ble målt ved 5 frekvenser. Dataene burde vært oppgitt for alle frekvensene slik at Statoil kunne få et bilde av frekvensavhengigheten.

Formasjonsfaktorene ligger tett på Figur 1, p.g.a. liten distribusjon av porositeten. Punktene har bra linearitet.

$F = \emptyset^{-m}$ gir m = 1.76

Det ble ikke bedt om beregning av m.
Kapillærtrykkskurvene og n-eksponent er kjørt på porøsplate-metoden med gass - vann.

Dette er meget løst konsolidert materiale antagelig med stort "grain-loss" som gir øket usikkerhet i vannmetningsdataene.

Punktene på I-SW-plottet, Figur 2, ligger svært lineært. Linjen som er trukket gjelder bare plugg GB 1B. Punktene fra GB 3B ligger under linjen.
Regresjonsanalyse på hver av datasettene gir:

GB 1B $n = 1.88$, $R^2 = .9998$

GB 3B $n = 1.83$, $R^2 = .9999$

Corex oppgir en gjennomsitts $n = 1.88$
Kapillærtrykkskurven for GB 3B er dårlig trukket.

<u>Målinger ved overlagringstrykk</u>

Alle porositetene viser jevn reduksjon med økende overlagstrykk. Porositeten målt med væske stemmer bra med Helium porositetene fra Tabell 1.

Redusjon av permeabilitetsverdiene var ventelig hvis en sammenligner gass mot væskepermeabilitetene. Reduksjonen er stor for pluggene GB 1A og 3A, ca. 60%.
For plugg GB 2A er redusjonen så stor at en må anta at den brøt sammen eller at mye materiale ble revet løs og plugget porene. Den andre pluggen av paret 2A - 2B brøt sammen under rombetingelsesmålingene.

Formasjonsfaktorene viser jevn økning med trykket F - Ø plott av A-pluggsettet viser mye dårlige linearitet enn B-pluggsettet.

$F = Ø^{-m}$ gir:

$m = 1.67$ ved 6.8 bar

$m = 1.62$ ved 50 bar

Corex var ikke bedt om å beregne <u>m</u>.

n-eksponenten ble målt ved å floode den vannmettede kjernen med olje for å oppnå gradvis lavere vannmetning. Det kan gi kontaktproblemer ved elektrodene.

I - Sw plottene viser en bra linearitet hver for seg.
Beregning av n-eksponenten for hver av de tre pluggene:

GB 1A n = 2.05 R^2 = .9938
GB 2A n = 2.22 R^2 = .971
GB 3A n = 1.87 R^2 = .9904

Regresjonanalyse på hele datasettet ga n = 1.99, R^2 = 0.973.
Ved en slik analyse vil dataene fra de lave metningene dominere, d.v.s. pluggene GB 1A, GB 3A.
Corex oppgir en samlet n = 1.96.

Corex burde laget ett plott, I-Sw, for hver kjerne slik at man lettere kan bedømme kvaliteten og lineæriteten. Videre bør det forlanges at Corex beregner n for hver plugg og oppgir koeffisienten R^2 som uttrykker avvik fra linearitet.