A/S NORSKE SHELL

SPECIAL CORE ANALYSIS

WELL: 31/2-8

DATE: JULY 1983

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A/S NORSKE SHELL

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DATE: JULY 1983

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COMMENTS

GENERAL: Special core analyses have been completed on five frozen samples collected from well 31/2-8 at the depths agreed upon by Shell in March 1983. The samples were cylindrical plugs of 1½ inch diameter.

PREPARATION: All samples were gently drilled and cut in frozen condition using liquid nitrogen as a coolant and later cleaned with methanol and toluene. The samples used in the confining pressure measurements were first mounted frozen in a triaxial cell and allowed to thaw overnight with a hydrostatic sleeve pressure of approximately five bar. The cleaning process commenced the following day with subsequent gentle overnight air blow drying. For assurance of completely dry samples, the plugs were vacuum dried before the actual air permeability, porosity, and confining pressure measurements.

MEASUREMENTS: AIR PERMEABILITY

Air permeability was measured on all samples before water saturation using N_2 gas at three different back pressures. These values were the basis for calculating the Klinkenberg corrected permeability (k.e.l.). The reported permeabilities were obtained at a confining pressure of 15 bar in a triaxial sample holder. Both tabular and graphic compliations of data have been enclosed in this report.

POROSITY AND GRAIN DENSITY

Porosity values were determined by formation water saturation. The procedure employed was first to evacuate the plug confined in the triaxial cell and then inject a measured volume of water into the void pore space. To ensure better sample saturation, a 15 bar pressure was then applied to the injected water. A net confining pressure on the plug was maintained at a constant level of 15 bar during this operation.

After the subsequent confining pressure analysis was completed, methanol was pumped through each sample to remove the formation water. When the flushing/ cleaning process was complete the sample was removed from the triaxial cell and oven-dried overnight. Helium porosimeter grain volume and sample weight were measured on the following day to determine sample grain density.

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CONFINING PRESSURE MEASUREMENTS

Net overburden pressure was set in the laboratory without any Geertsma-factor correction. Porosity and formation resistivity factor were measured on all five samples at increasing pressure levels in the triaxial cell. The "atmospheric" pressure was set to 15 bar to avoid leakage along the sleeve and the plug. The confining pressure levels were as follows: 15 bar, 50 bar, 100 bar, 150 bar and 200 bar.

a) Permeability

Air and liquid permeability analyses were not requested on the samples included in this report.

b) Porosity

In these measurements it has been assumed that the sample porosities were preserved at 15 bar confining pressure ("atmospheric" condition). Pore pressure was kept constant at one atmosphere.

Porosity valves were determined by measuring pore volume reduction with a graduated pipette (vol. 1.0 ml, grad. 0.01 ml).

c) Formation Resistivity Factor (FRF)

The formation resistivity factor was measured using a frequency of 1 kHz. A platinum screen was placed at each end of the plug to ensure good electrical contact over the end surface of the plug. The parameters "a" and "m" in Archies formula were calculated both by least squares method forced through (FF = 1.0, ϕ = 1.0) and least squares method (free fit).

Archies formula $$FF = \frac{r_o}{r_w} = a \cdot \phi^{-m}$$

r_o = resistivity of sample (100 % saturated)

r_w = resistivity of saturating formation water

a = FF-value at fractional porosity of 1.0

ϕ = fractional porosity

m = cementation factor

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The data sets and the calculated values have been presented tabularly followed by a presentation of forced fit curves at the various confining pressures.

CATION EXCHANGE CAPACITY (C.E.C.)

C.E.C. was measured on all five samples (1½ inch plug trimmings) by employing the wet chemistry method.

The sample matrix was carefully broken down in an ultra sonic bath using methanol and toluene as cleaning solvents. Actual C.E.C. values were determined as the capacity of spending cobalt in a hexamin cobalt (III) chloride solution recorded by a UV-visible spectrophotometer.
The data have been reported together with the Klinkenberg corrected air permeability, porosity and grain density values measured on the 1½ inch plugs from the corresponding depth.

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FLUID PROPERTIES

FORMATION WATER

The formation water was made from chlorides of sodium according to this list:

Na^+	:	23776	ppm
Cl^-	:	36724	ppm

Resistivity (20 °C) : r_w = 0.121 Ω m

Resistivity (54.4°C) : r_w = 0.070 Ω m

Density (20 °C) : ρ = 1.043 g/cm^3

Viscosity (20 °C) : μ = 1.106 cP

NITROGEN GAS

Viscosity (20°C) : μ = 0.0176 cP

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PLUG SIZE

Depth (m)	Length (cm)	Diameter (cm)	Bulk volume (cm^3)
1848.6	7.18	3.63	74.31
1861.2	7.00	3.72	76.08
1872.2	6.97	3.72	75.75
1880.5	6.94	3.73	75.83
1887.7	7.00	3.76	77.73

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POROSITY AND GRAIN DENSITY

Depth (m)	Porosity (%)	Grain Density(g/cm^3)
1848.6	30.9	2.64
1861.2	11.5	2.69
1872.2	16.8	2.64
1880.5	15.7	2.63
1887.7	20.0	2.70

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KLINKENBERG CORRECTED AIR PERMEABILITY

Depth (m)	(Mean Pressure)$^{-1}$ (atm.abs.)$^{-1}$	Air permeability k_a(mD)	Klinkenberg corr. permeability k.e.l.(mD)
1848.6	0.903	5038	4387
	0.666	4894	
	0.501	4741	
1861.2	0.623	0.409	0.324
	0.500	0.392	
	0.401	0.379	
1872.2	0.648	1.26	0.963
	0.516	1.20	
	0.411	1.15	
1880.5	0.565	0.884	0.709
	0.462	0.855	
	0.376	0.825	
1887.7	0.868	465	426
	0.647	453	
	0.490	448	

KLINKENBERG CORRECTED AIR PERMEABILITY

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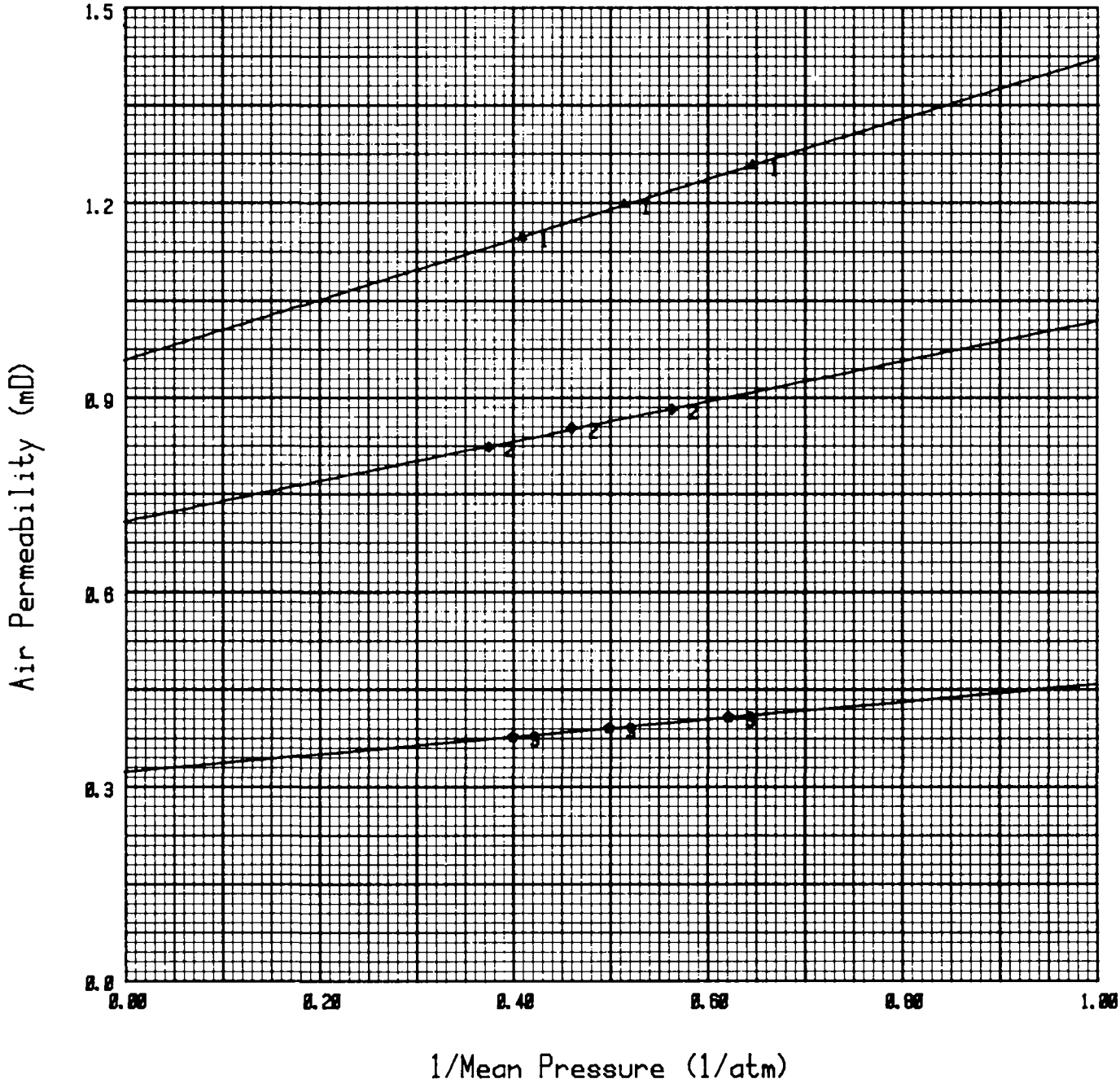
Curve no 1 : Sample no :
Depth : 1872.20 m
Klink. perm.: 0.963 mD

Curve no 2 : Sample no :
Depth : 1880.50 m
Klink. perm.: 0.709 mD

Curve no 3 : Sample no :
Depth : 1861.20 m
Klink. perm.: 0.324 mD



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KLINKENBERG CORRECTED AIR PERMEABILITY

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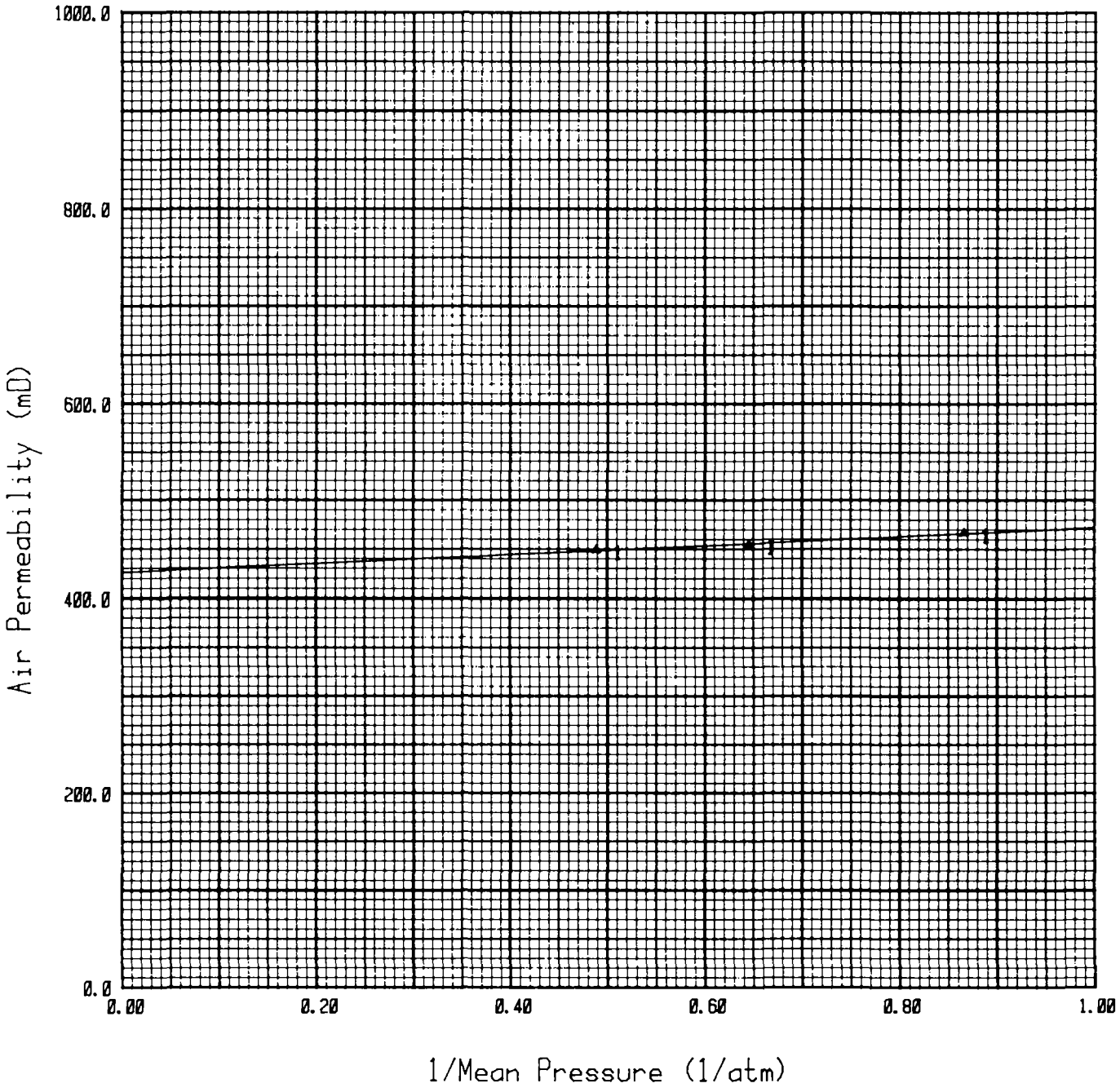
Curve no 1 : Sample no :
Depth : 1887.70 m
Klink. perm.: 426 mD



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KLINKENBERG CORRECTED AIR PERMEABILITY

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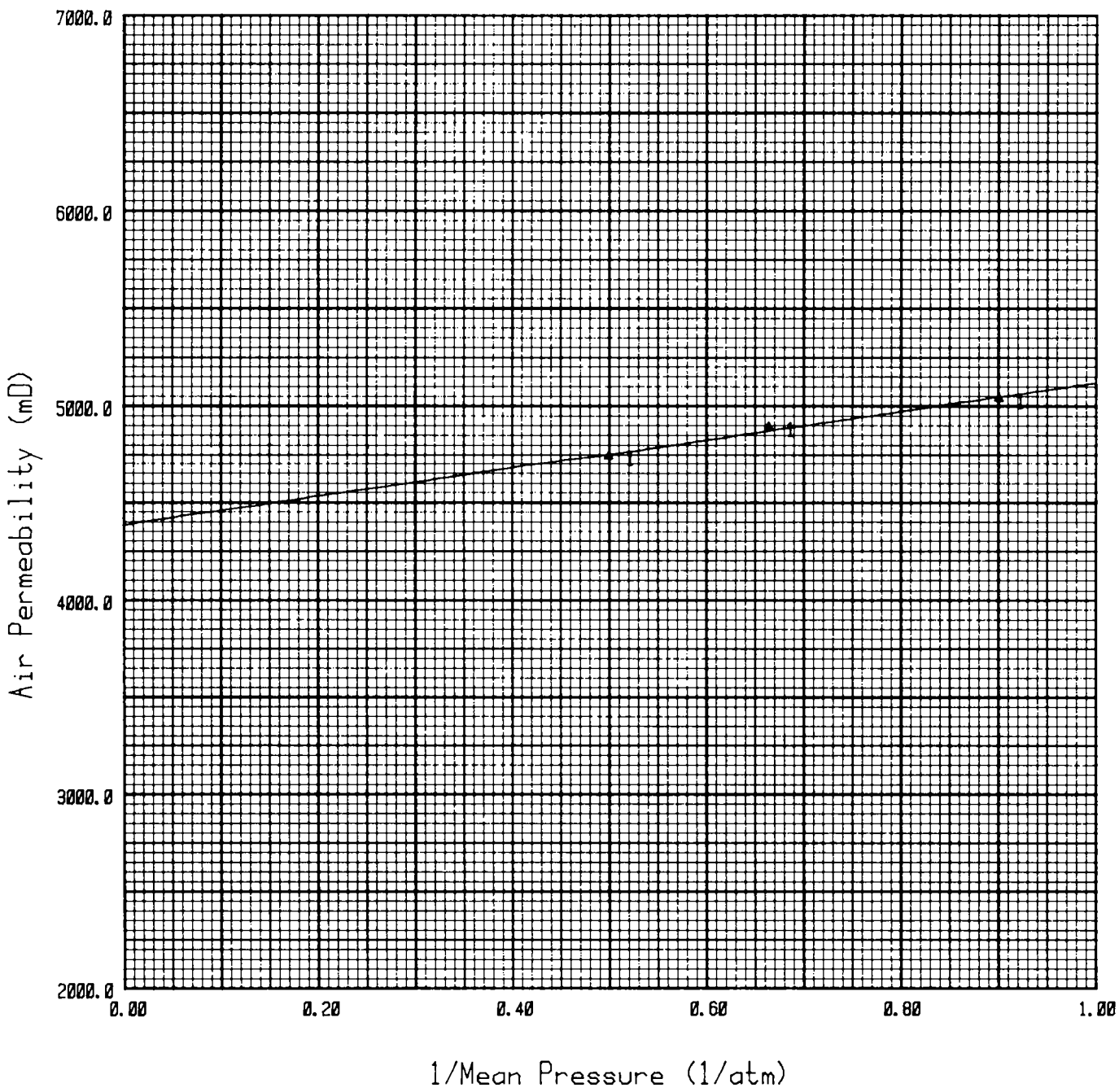
Curve no 1 : Sample no :
Depth : 1848.60 m
Klink. perm.: 4387 mD



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KLINKENBERG PERMEABILITY VS. POROSITY

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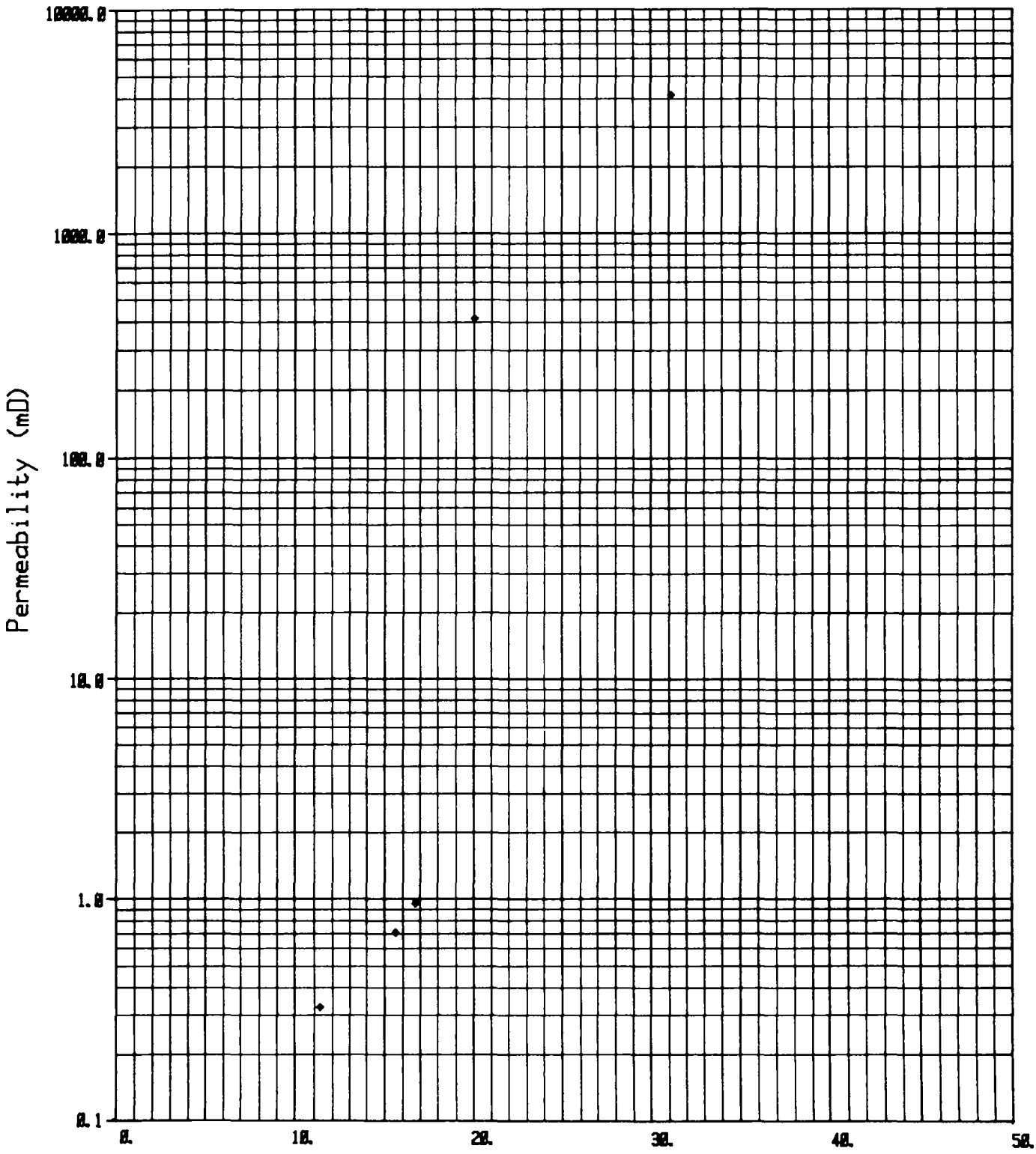
Company : A/S Norske Shell
Well : 31/2-8



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CONFINING PRESSURE MEASUREMENTS

Depth (m): 1848.6

Measurements	"Atmospheric" 15 bar	50 bar	100 bar	150 bar	200 bar
Porosity (%):	30.9	30.1	29.7	29.5	29.3
Porosity reduction: (frac. of original)	1.000	0.975	0.962	0.954	0.949
Pore volume (cm^3):	22.96	22.14	21.73	21.47	21.30
Pore volume reduction: $\frac{\Delta \text{ PV}}{\text{org. PV}}$ (frac. of original)	0.000	0.036	0.054	0.065	0.072
Formation resistivity factor (1 kHz)	6.50	6.94	7.13	7.26	7.33
FRF - Increment: (fraction of original)	1.00	1.07	1.10	1.12	1.13

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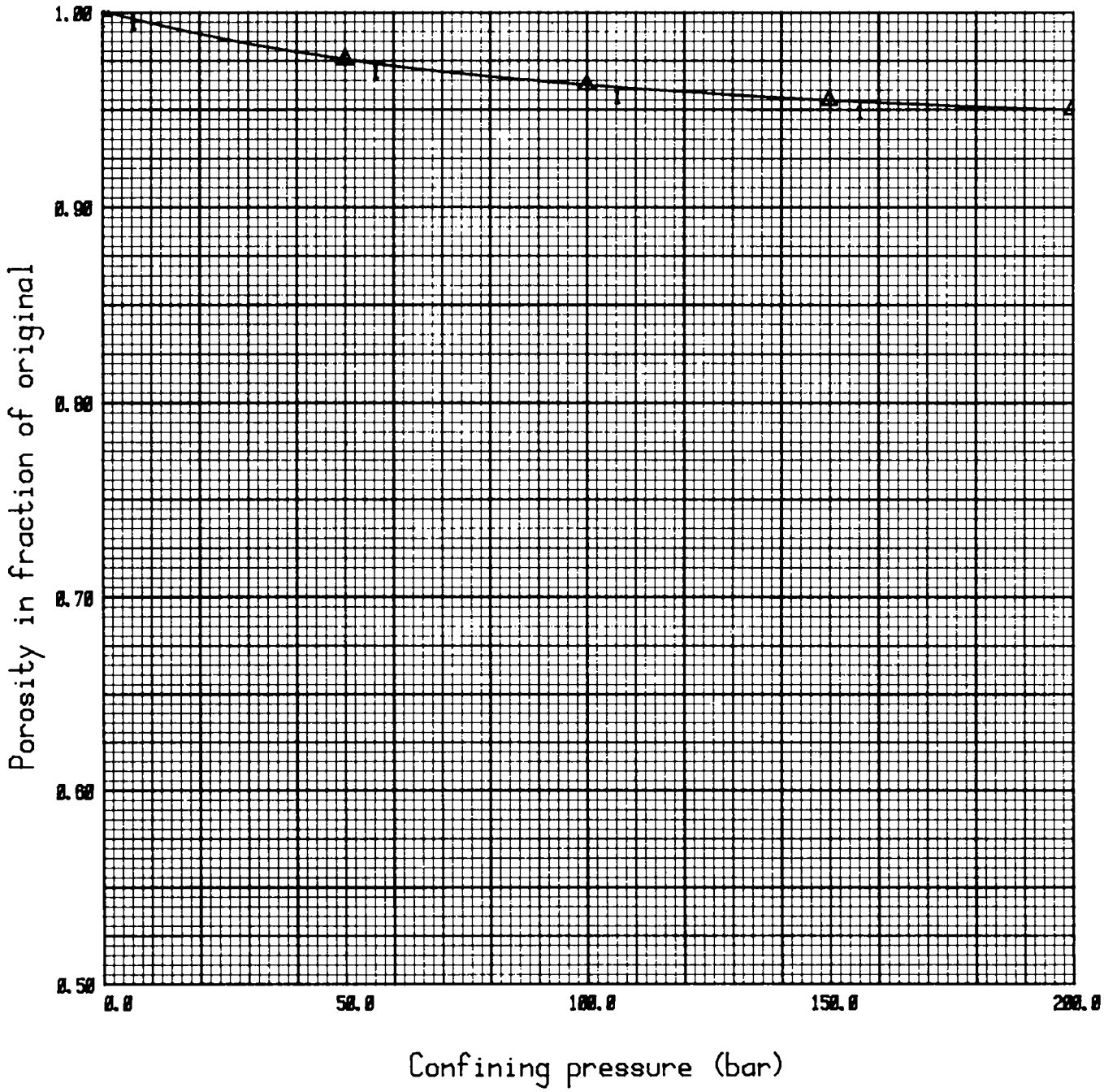
POROSITY VERSUS CONFINING PRESSURE

Depth : 1848.60 m Original Porosity (curve 1) : 30.9 %



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CONFINING PRESSURE MEASUREMENTS

Depth (m): 1861.2

Measurements	"Atmospheric" 15 bar	50 bar	100 bar	150 bar	200 bar
Porosity (%):	11.5	11.2	10.9	10.7	10.5
Porosity reduction: (frac. of original)	1.000	0.969	0.947	0.927	0.911
Pore volume (cm^3):	8.77	8.47	8.25	8.06	7.90
Pore volume reduction: $\frac{\Delta \text{ PV}}{\text{org. PV}}$ (frac. of original)	0.000	0.034	0.060	0.081	0.099
Formation resistivity factor (1 kHz)	38.4	42.0	45.4	47.9	50.0
FRF - Increment: (fraction of original)	1.00	1.09	1.18	1.25	1.30

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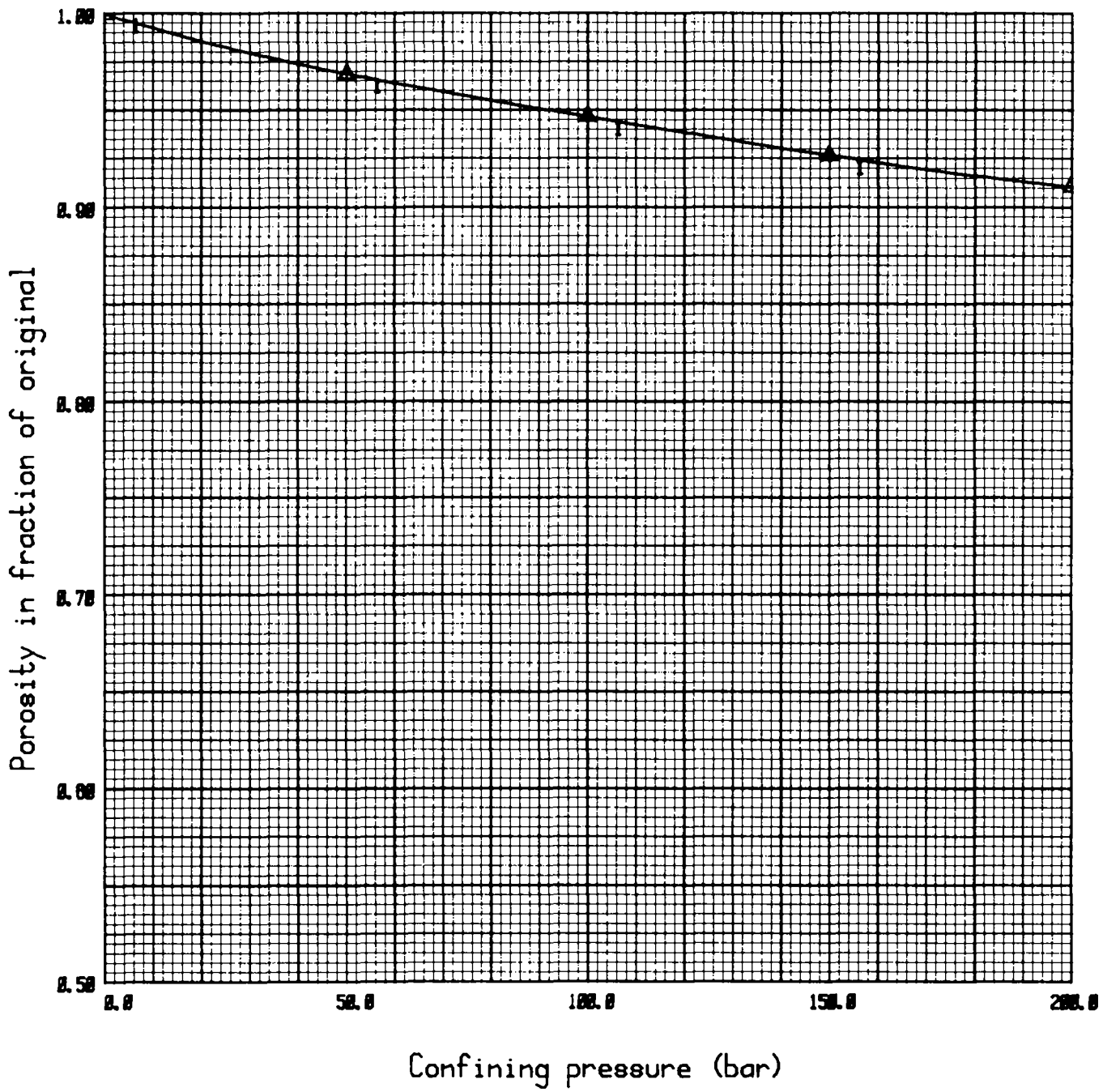
POROSITY VERSUS CONFINING PRESSURE

Depth : 1861.20 m Original Porosity (curve 1) : 11.5 %



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CONFINING PRESSURE MEASUREMENTS

Depth (m): 1872.2

Measurements	"Atmospheric" 15 bar	50 bar	100 bar	150 bar	200 bar
Porosity (%):	16.8	16.3	16.0	15.8	15.7
Porosity reduction: (frac. of original)	1.000	0.971	0.952	0.941	0.934
Pore volume (cm^3):	12.70	12.26	11.97	11.81	11.70
Pore volume reduction: $\frac{\Delta \text{ PV}}{\text{org. PV}}$ (frac. of original)	0.000	0.035	0.058	0.070	0.079
Formation resistivity factor (1 kHz)	20.9	23.6	25.8	27.0	27.9
FRF - Increment: (fraction of original)	1.00	1.13	1.23	1.29	1.33

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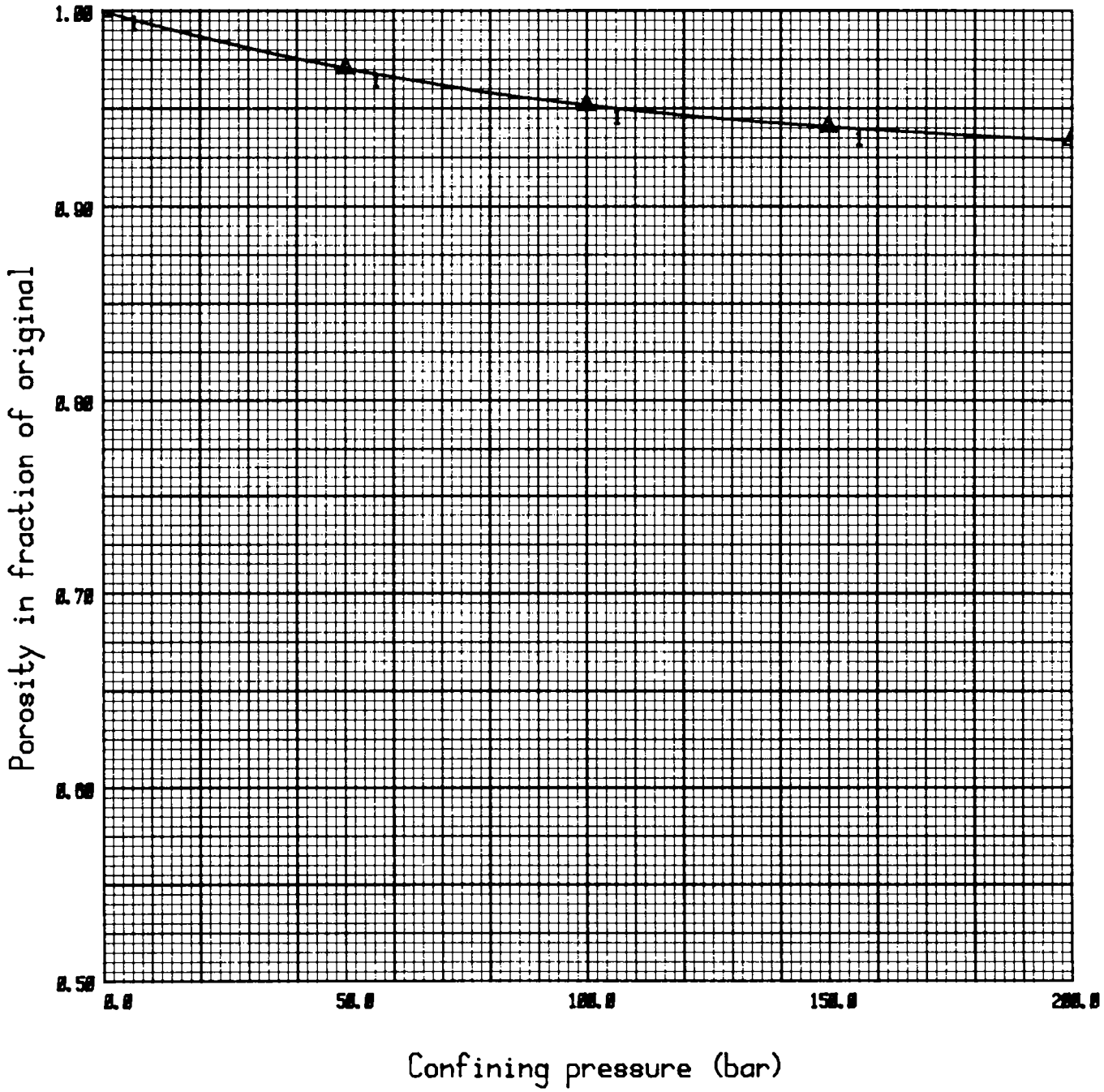
POROSITY VERSUS CONFINING PRESSURE

Depth : 1872.20 m Original Porosity (curve 1) : 16.8 %



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CONFINING PRESSURE MEASUREMENTS

Depth (m): 1880.5

Measurements	"Atmospheric"	15 bar	50 bar	100 bar	150 bar	200 bar
Porosity (%):		15.7	15.3	15.0	14.8	14.7
Porosity reduction: (frac. of original)		1.000	0.973	0.954	0.943	0.935
Pore volume (cm^3):		11.90	11.52	11.25	11.10	10.99
Pore volume reduction: (frac. of original)	$\frac{\Delta \text{ PV}}{\text{org. PV}}$	0.000	0.032	0.055	0.067	0.076
Formation resistivity factor (1 kHz)		22.6	25.1	27.4	28.7	29.6
FRF - Increment: (fraction of original)		1.00	1.11	1.21	1.27	1.31

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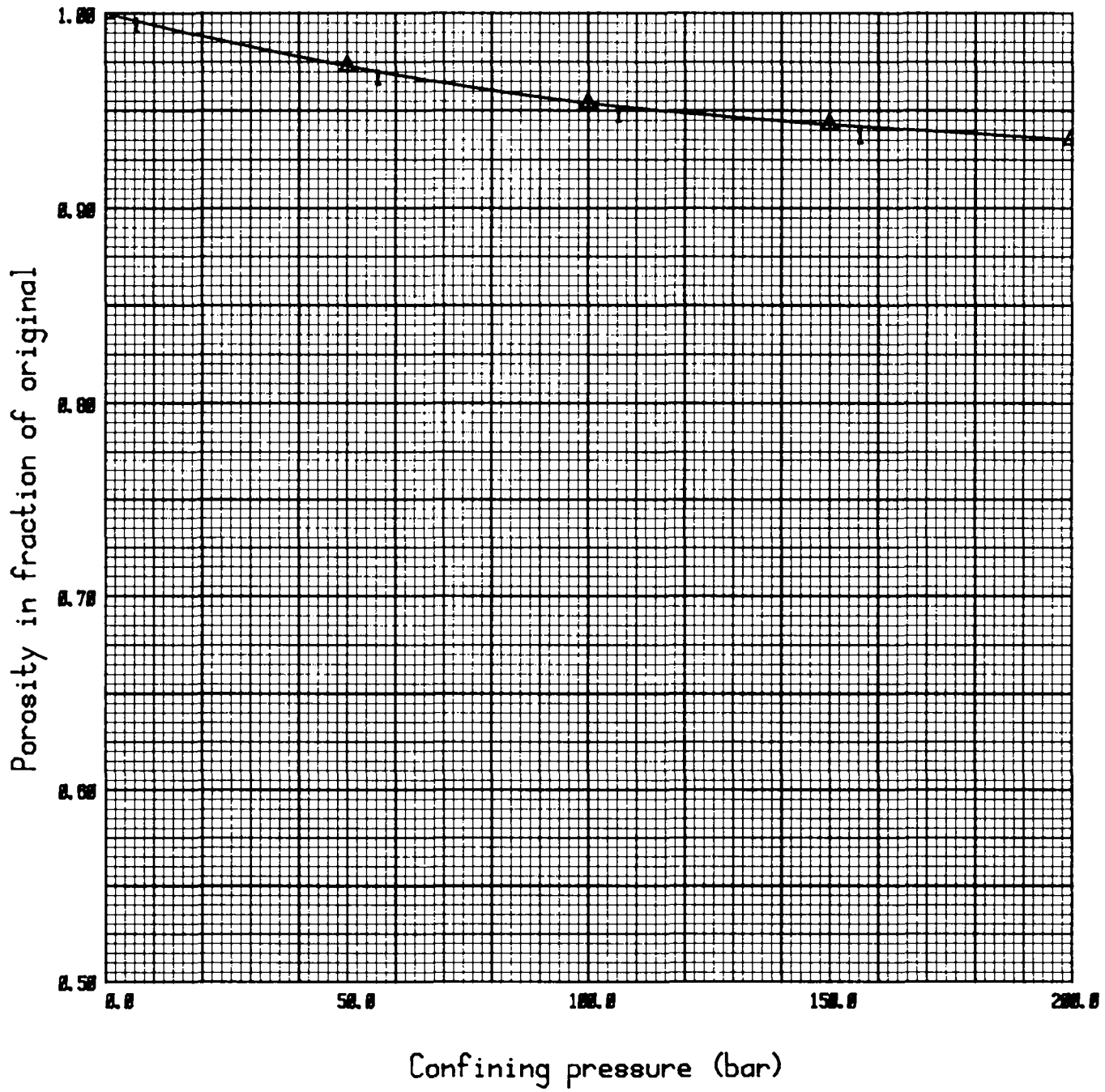
POROSITY VERSUS CONFINING PRESSURE

Depth : 1880.50 m Original Porosity (curve 1) : 15.7 %



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CONFINING PRESSURE MEASUREMENTS

Depth (m): 1887.7

Measurements	"Atmospheric" 15 bar	50 bar	100 bar	150 bar	200 bar
Porosity (%):	20.0	19.6	19.4	19.2	19.1
Porosity reduction: (frac. of original)	1.000	0.980	0.967	0.960	0.954
Pore volume (cm^3):	15.56	15.17	14.93	14.79	14.68
Pore volume reduction: $\frac{\Delta \text{ PV}}{\text{org. PV}}$ (frac. of original)	0.000	0.025	0.040	0.500	0.057
Formation resistivity factor (1 kHz)	15.2	15.9	16.4	16.8	17.1
FRF - Increment: (fraction of original)	1.00	1.05	1.08	1.11	1.13

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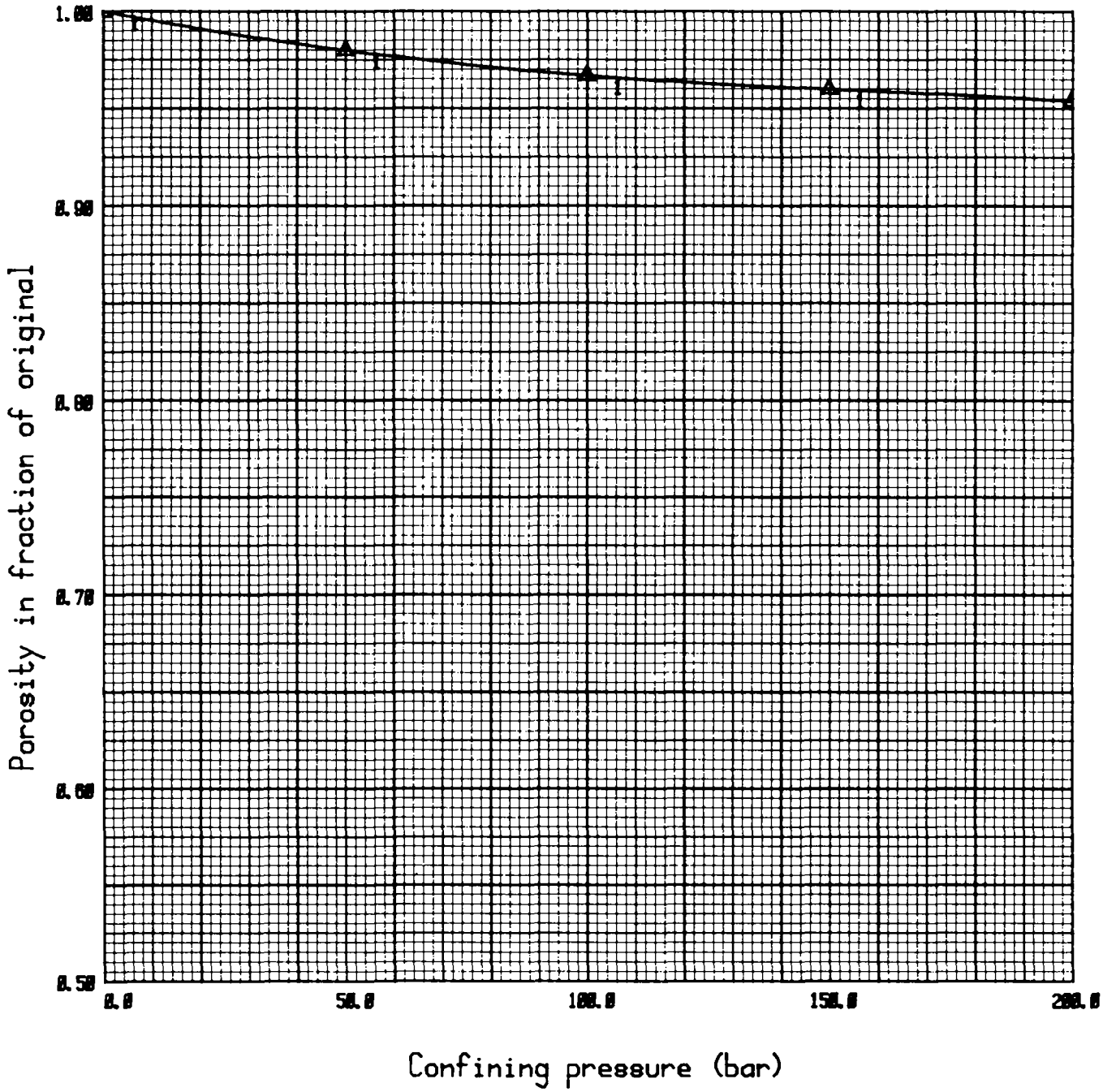
POROSITY VERSUS CONFINING PRESSURE

Depth : 1887.70 m Original Porosity (curve 1) : 20.0 %



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CONFINING PRESSURE: FORMATION FACTOR / POROSITY

WELL 31/2-8

Depth (m)	"Atmospheric" 15 bar FF	frac.por.	50 bar FF	frac.por.	100 bar FF	frac.por.	150 bar FF	frac.por.	200 bar FF	frac.por.
1848.6	6.50	0.309	6.94	0.301	7.13	0.297	7.26	0.295	7.33	0.293
1861.2	38.4	0.115	42.0	0.112	45.4	0.109	47.9	0.107	50.0	0.105
1872.2	20.9	0.168	23.6	0.163	25.8	0.160	27.0	0.158	27.9	0.157
1880.5	22.6	0.157	25.1	0.153	27.4	0.150	28.7	0.148	29.6	0.147
1887.7	15.2	0.200	15.9	0.196	16.4	0.194	16.8	0.192	17.1	0.191

Forced fit: $FF = \phi^{-1.68}$ $FF = \phi^{-1.71}$ $FF = \phi^{-1.73}$ $FF = \phi^{-1.74}$ $FF = \phi^{-1.74}$

Free fit : $FF = 0.81 \cdot \phi^{-1.80}$ $FF = 0.79 \cdot \phi^{-1.84}$ $FF = 0.76 \cdot \phi^{-1.88}$ $FF = 0.75 \cdot \phi^{-1.89}$ $FF = 0.74 \cdot \phi^{-1.91}$

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FORMATION RESISTIVITY FACTOR VERSUS POROSITY

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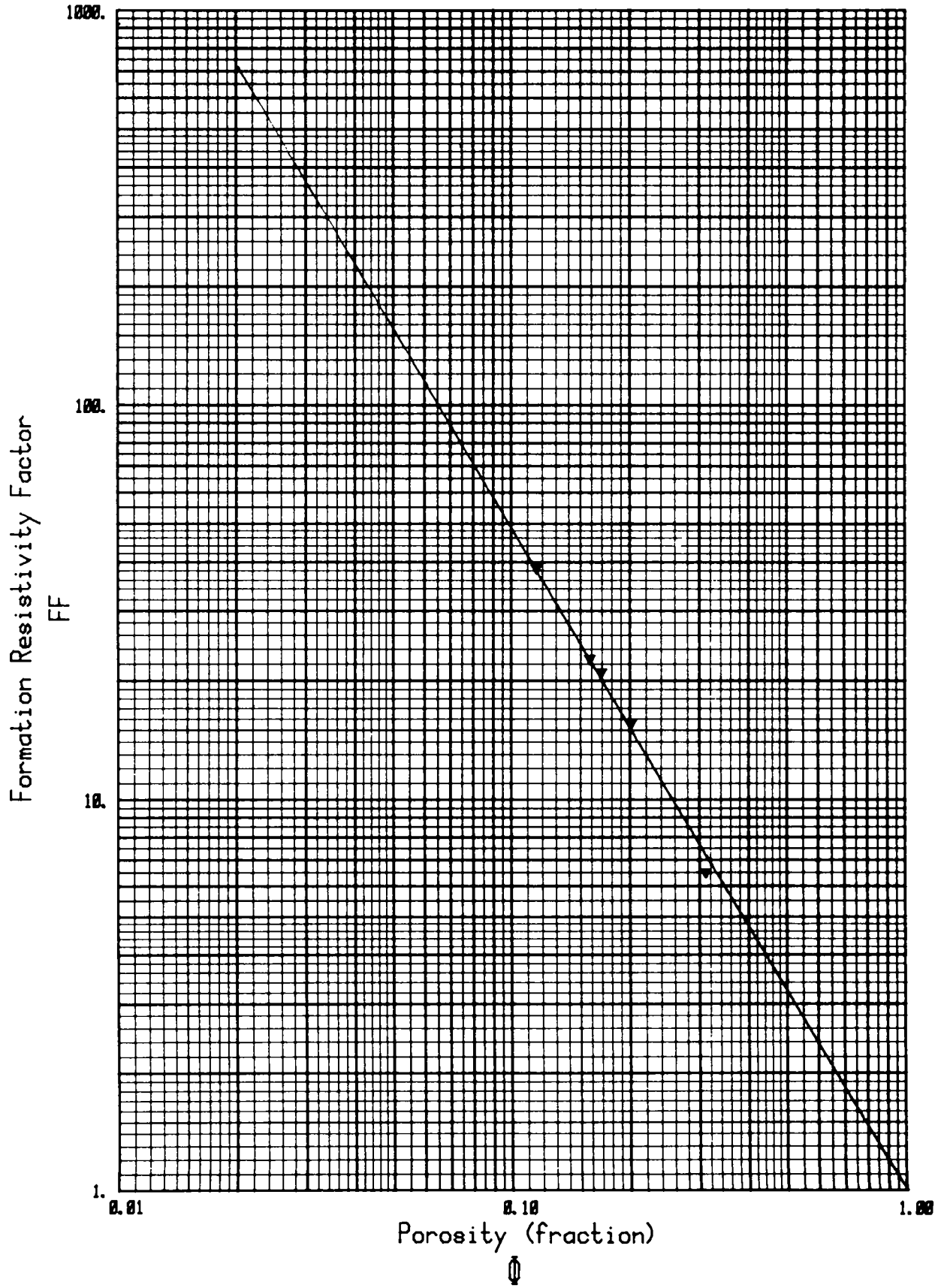
Company : A/S Norske Shell
Well : 31/2-8
Confining pressure : Atmospheric pressure. (15 bar)
FF = 1.00 * $\phi^{-1.68}$



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FORMATION RESISTIVITY FACTOR VERSUS POROSITY

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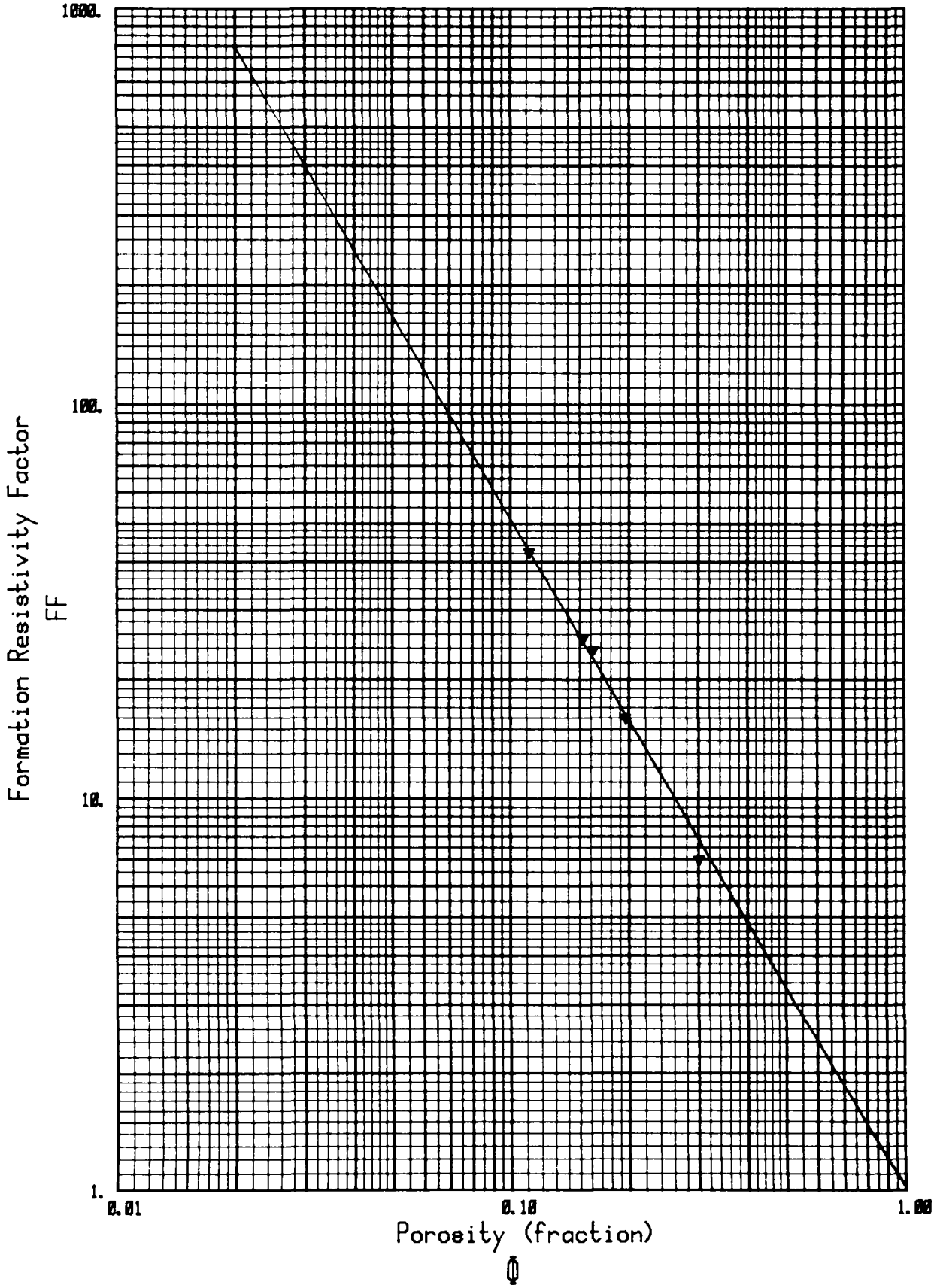
Company : A/S Norske Shell
Well : 31/2-8
Confining pressure : 50 bar
$FF = 1.00 * \Phi^{-1.71}$



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FORMATION RESISTIVITY FACTOR VERSUS POROSITY

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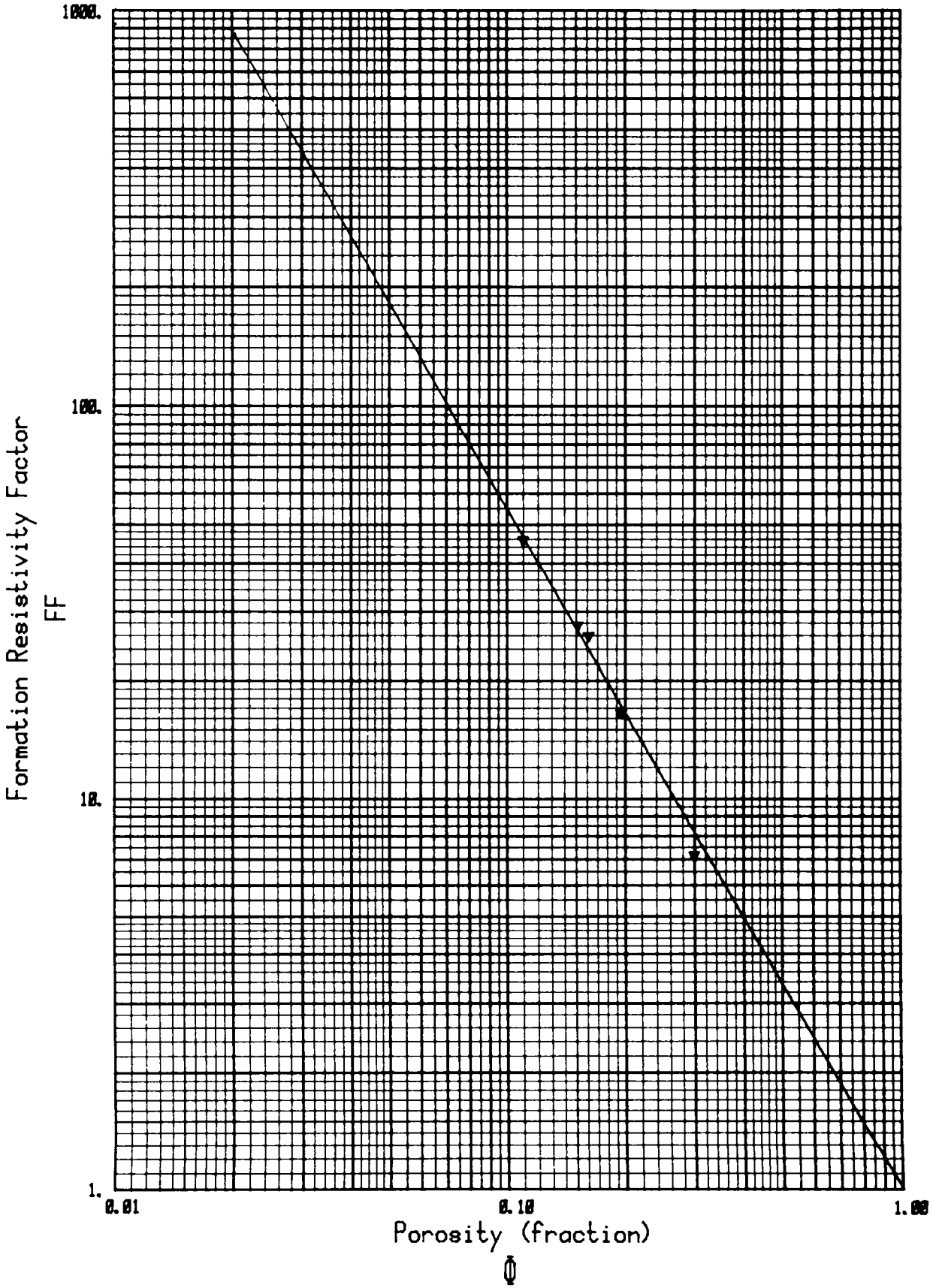
Company : A/S Norske Shell
Well : 31/2-8
Confining pressure : 100 bar
$FF = 1.00 * \phi^{-1.73}$



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FORMATION RESISTIVITY FACTOR VERSUS POROSITY

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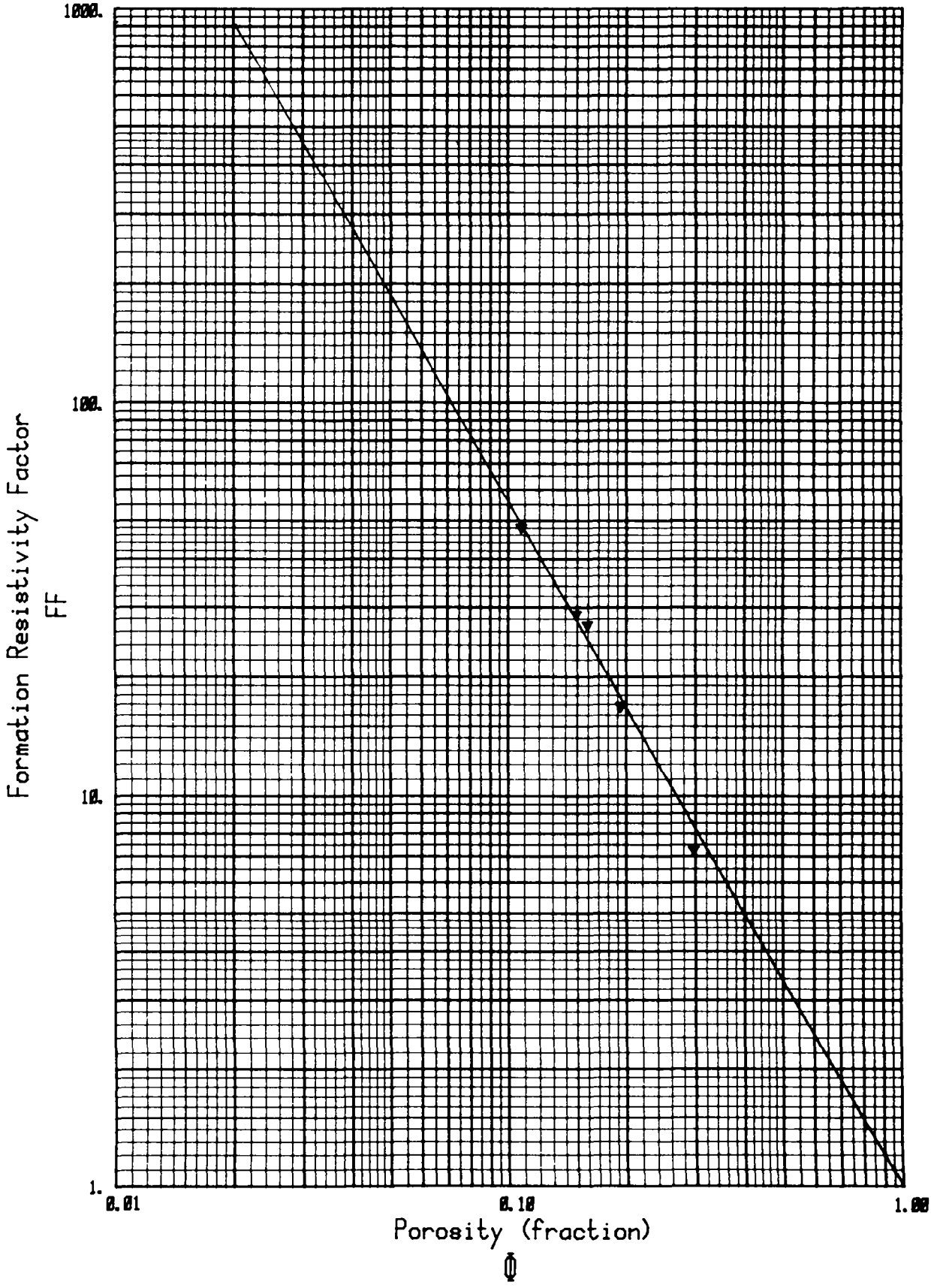
Company : A/S Norske Shell
Well : 31/2-8
Confining pressure : 150 bar
FF = 1.00 * $\Phi^{-1.74}$



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FORMATION RESISTIVITY FACTOR VERSUS POROSITY

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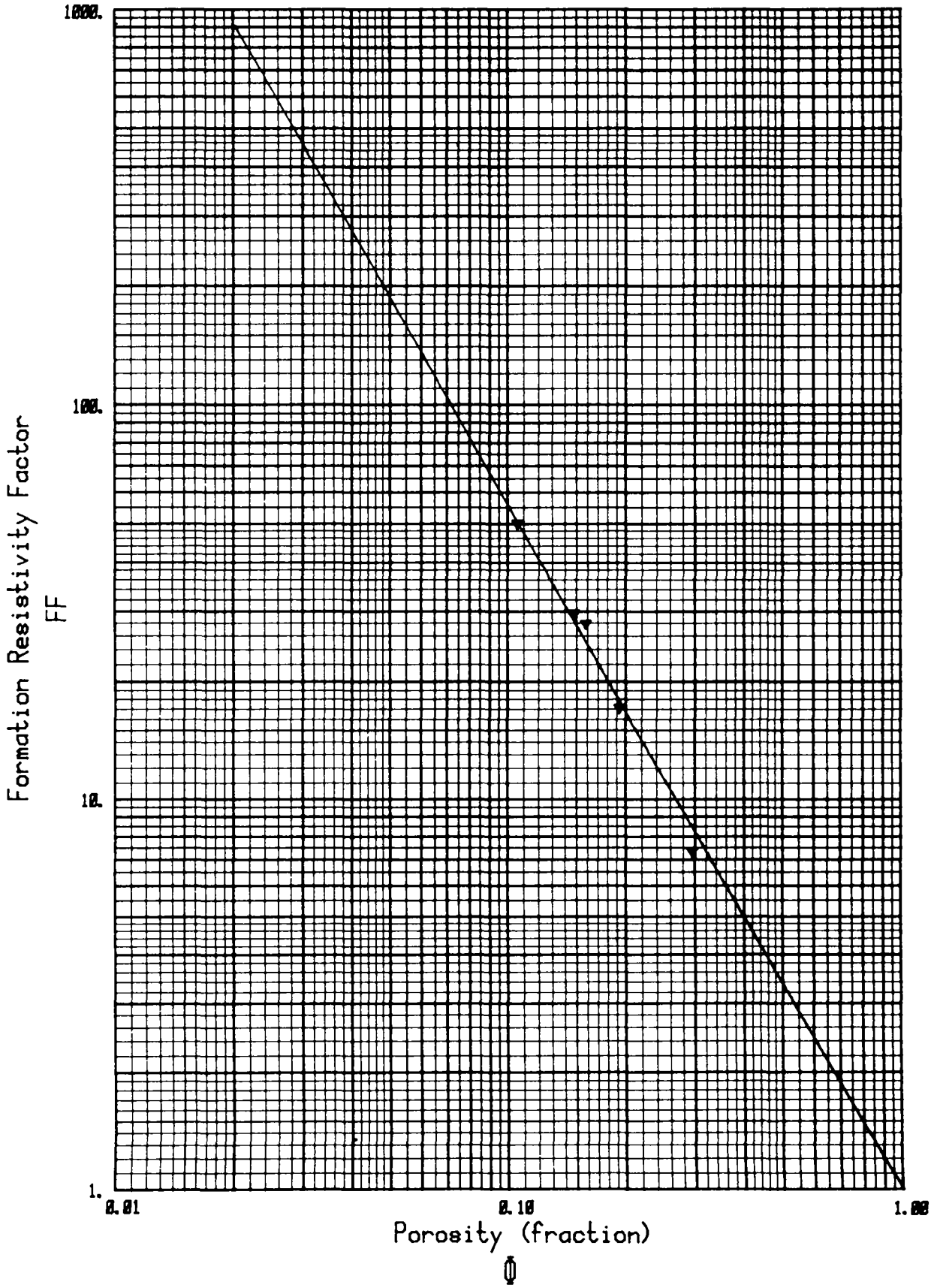
Company : A/S Norske Shell
Well : 31/2-8
Confining pressure : 200 bar
$FF = 1.00 * \phi^{-1.74}$



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CATION EXCHANGE CAPACITY

Depth (m)	Klinkenberg perm. (mD)	Porosity (%)	Grain Density (g/cm^3)	C.E.C. (meq/100g)
1848.6	4387	30.9	2.64	2.52
1861.2	0.324	11.5	2.69	6.2
1872.2	0.963	16.8	2.64	7.0
1880.5	0.709	15.7	2.63	14
1887.7	426	20.0	2.70	1.0