S.

INSTITUT FRANÇAIS DU PÉTROLE

CONFIDENTIEL

LABORATORY STUDY ON CORES FROM STATOIL

INSTITUT FRANCAIS DU PETROLE

Direction de Recherche Gisements

CONFIDENTIAL

LABORATORY STUDY ON CORES

FROM

STATOIL

WELL 34/10-3

H. DESCHAMPS

D. LABONDE.

LABORATORY STUDY ON CORES

FROM

STATOIL

———

The cores sent by STATOIL your letter dated 14. 6.1979 were analysed by IFP core analysis laboratories.

This analysis includes :

- Determination of physical characteristics :
  Porosity, permeability,

- Relative permeability water/oil.

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WATER/OIL RELATIVE PERMEABILITY MEASUREMENTS

These measurements were performed on only 11 cores, because core n° B-53-85-153 has been broken during experiments.

The measurements performed were as follows :

- saturation of the core with water (100 g/l)
- flood with mineral oil (38 cps at 20°C)
- water displacement by water (100 g/l)

For each core, the following information was determined as function of water saturation expressed as % of pore volume.

Water/oil relative permeability = K'_w/K_o with connate water

Water relative permeability = K'_w/K_L or K_{rw} (fract)

Oil relative permeability = K'_o/K_L or K_{ro} (fract)

The principal results are shown in the tables.

The following data are included in these tables :

- Permeability to air K_a (md)
- Permeability to liquid K_L (md)
- Permeability to oil with connate water K'_o (md)
- Porosity $\emptyset$ (%)
- Oil recovery R_o (% PV)
- Water/oil relative permeability as a function of water
- Saturation (in % PV)
- Water relative permeability as a function of water
- Saturation (in % PV) - K_w/K_o
- Oil relative permeability as a function of water saturation
  (in % PV) K'_o/K_L or K_{rw}

- Oil relative permeability as a function of water
- Saturation (in % PV) K'_o/K_L or K_{ro}.

Experimental points measurements are plotted on the figures
1 to 22.

The shape of the curves may be altered by heterogeneity of the
core. The accuracy of the results cannot be warranted due to the small
size of the samples.

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RESULTS OF : POROSITY BY IMMERSION - AIR PERMEABILITY
WATER PERMEABILITY (100 g/1) - OIL PERMEABILITY WITH CONNATE WATER
WATER PERMEABILITY WITH RESIDUAL OIL

Core n°	Porosity %	Air permeability mD	Air permeability (KLINKENBERG)	Water permeability (100g/1)	Oil permeability with connate water	Water permeability with residual oil
11 T	33,0	6275	6175	1750	1150	508
23	31,9	51,5	43,0	35,6	33,0	10,2
44	31,2	125	112	92,2	88,0	18,0
68	31,3	29600	29500	15900	9730	819
80	34,6	970	930	403	378	137
82	30,4	3173	2993	920	585	235
83	33,2	2790	2710	1136	536	236
141	29,3	1177	1127	1057	1070	162
148	29,1	504	474	306	328	38,9
165	29,0	1492	1442	635	415	196
172	33,7	875	835	551	580	105

Company : STATOIL

Well   :

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 11 T   Depth

Permeability to air	K_a = 6275 md	Porosity	$\emptyset$ = 33,0 %
Permeability to liquid	K_l = 6175 md	Connate water	S_{cw} = 33,3 %
Permeability to oil with connate water	K_o' 1150 md	Oil in place (%PV)	S_o = 66,7 %
		Residual saturation (% PV)	S'_o = 30,6 %
Permeability to water with residual oil	K'_w 508 md	Oil recovery (% PV)	R_o = 36,1 %

Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 33,3			K'_o/K_L 0,186
50,98	0,195	0,0153	0,0782
54,27	0,458	0,0166	0,0582
56,64	0,750	0,0286	0,0422
63,28	5,813	0,0406	0,0070
64,71	14,576	0,0489	0,0033
65,77	29,181	0,0595	0,0020
67,62	146,023	0,0695	0,00017
68,37	584,181	0,0797	0,00014

Figure n° 1 gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 2 gives K_{ro} and K_{rw} versus total saturation in water (% PV)

Figure 1.

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Company : _____STATOIL_____   Formation:_____
Well : _____   Sample : _____11 T_____
Field : _____

$\emptyset =$ 33,0% %
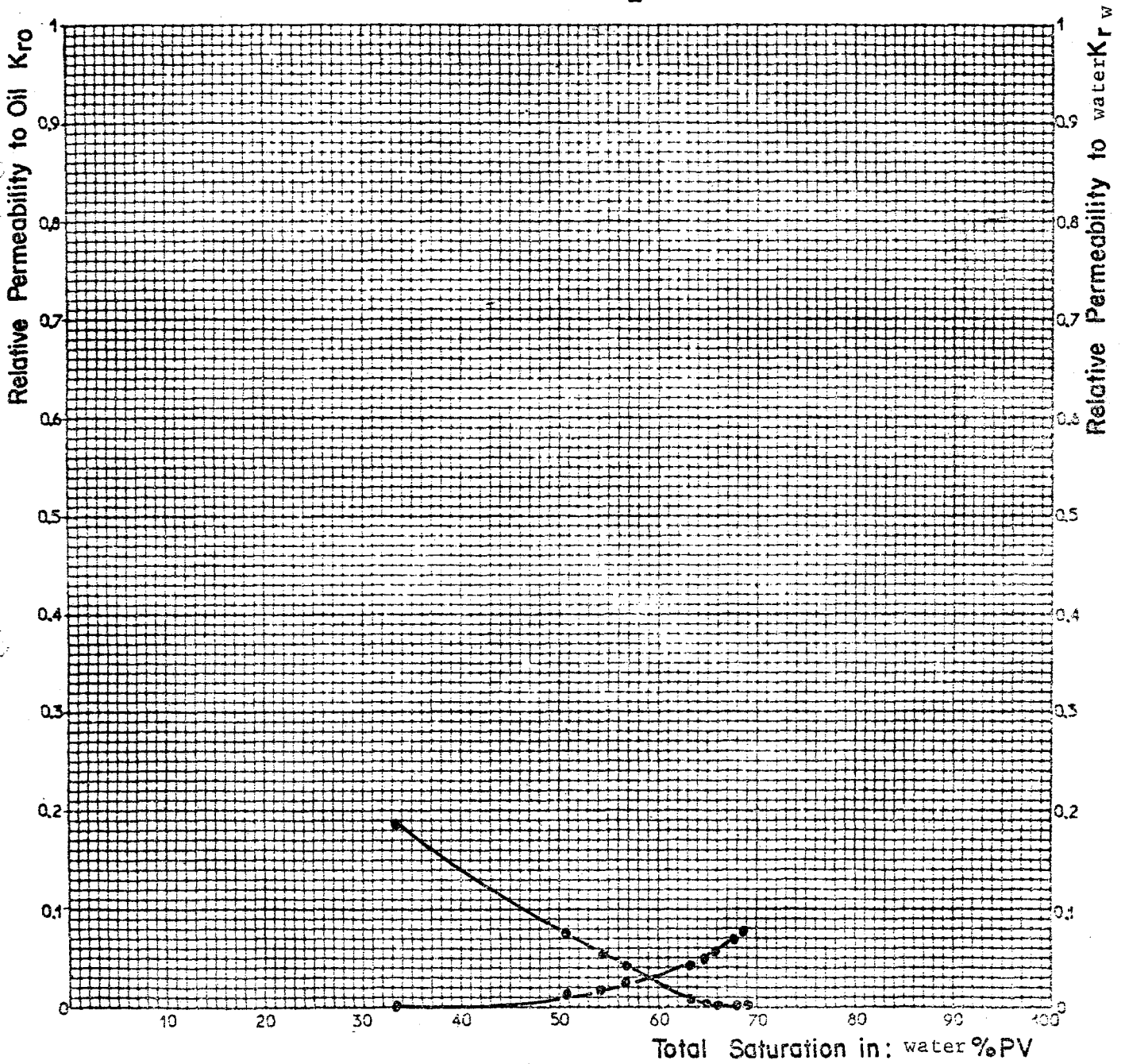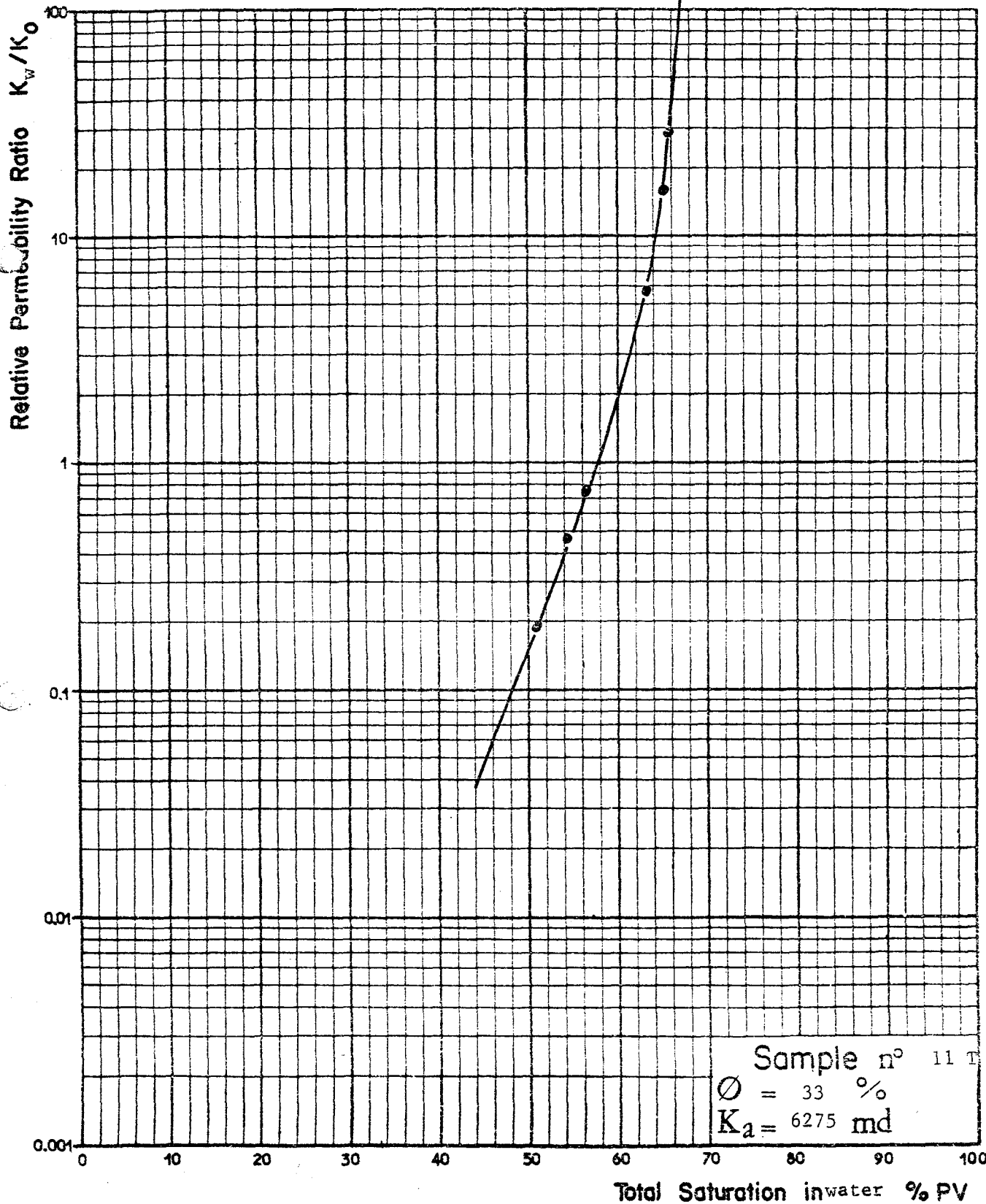$K_a =$ 6275 md

Total Saturation in: water % PV

Figure 2.

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Gisements

Company STATOIL   Formation
Well _____
Field _____

Relative Permeability Ratio K_w/K_o

Total Saturation in water % PV

Sample n° 11 T
$\varnothing$ = 33 %
K_a = 6275 md

Company : STATOIL

Well :

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 23   Depth

Permeability to air K_a = 51,5 md   Porosity $\emptyset$ = 31,9 %

Permeability to liquid K_l = 43 md   Connate water S_{cw} = 40,3 %

Permeability to oil
with connate water K_o 33 md   Oil in place (%PV) S_o = 59,7 %

                                                     Residual saturation
                                                     (% PV) S'_o = 2,8 %
Permeability to water
with residual oil K'_w 10,2 md   Oil recovery
                                                     (% PV) R_o = 56,9 %

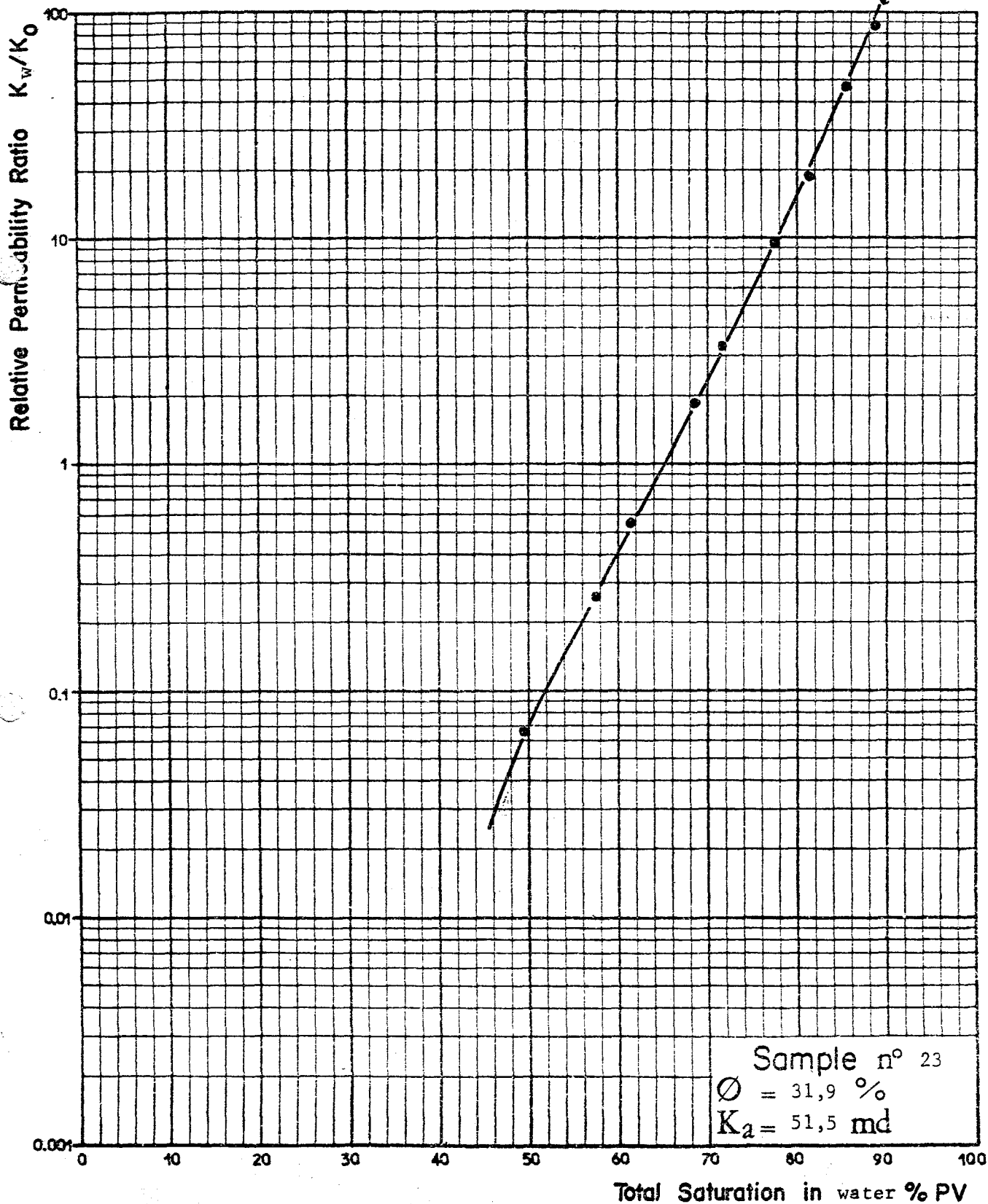| Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 40,3			K'_o/K_L 0,767
49,49	0,068	0,0337	0,424
57,09	0,263	0,0590	0,224
61,75	0,555	0,0850	0,153
71,57	3,216	0,130	0,044
77,56	9,708	0,168	0,017
81,11	19,440	0,195	0,010
85,59	48,650	0,228	0,0044
88,33	87,600	0,258	0,0029
89,76	116,810	0,297	0,0017

Figure n° 3   gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 4   gives K_{ro} and K_{rw} versus total saturation in water (% PV)

Figure 3.

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Gisements

Company___STATOIL_____ Formation _____
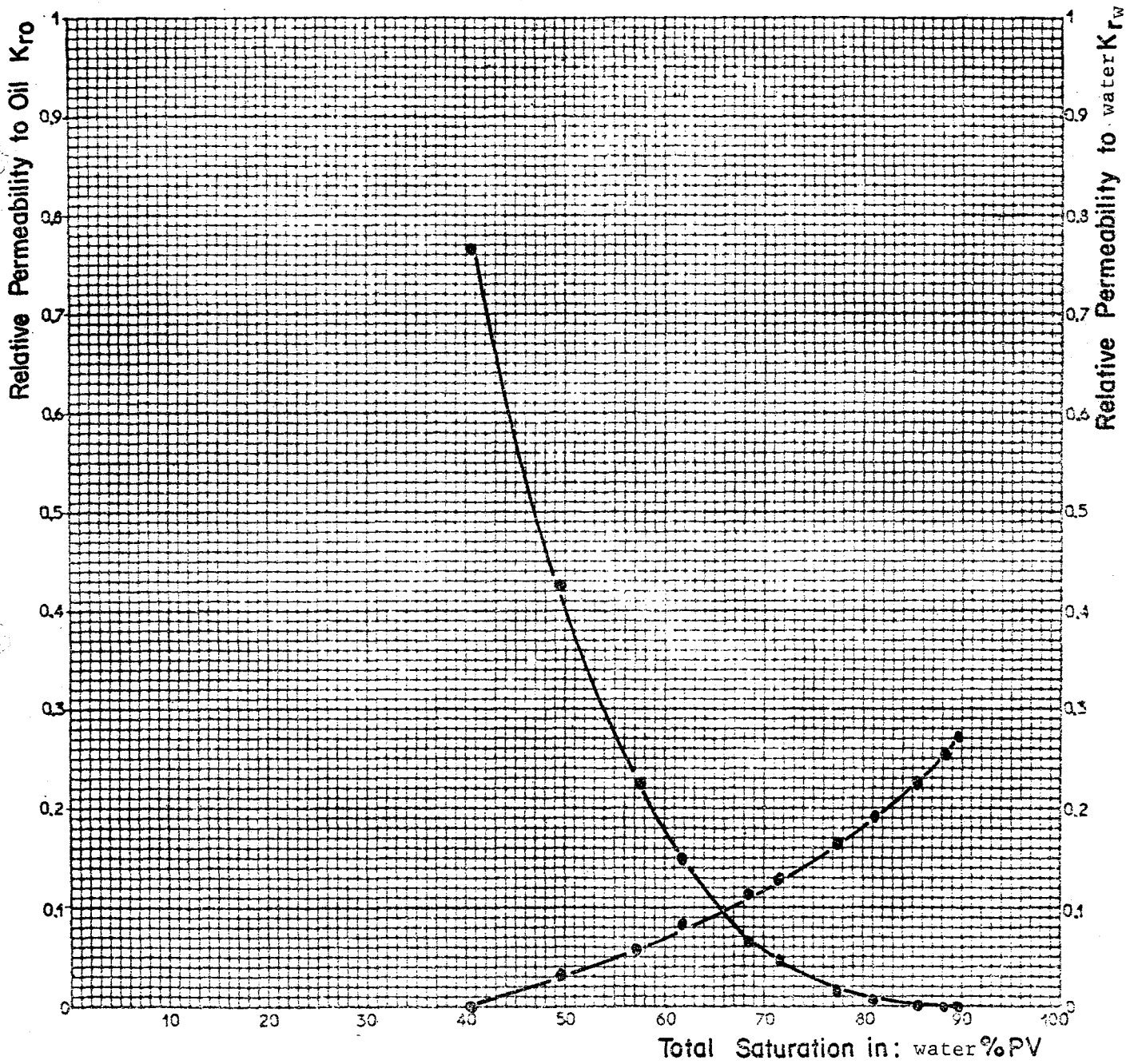Well _____
Field _____

Relative Permeability Ratio K_w/K_o

Total Saturation in water % PV

Sample n° 23
$\emptyset = 31,9$ %
$K_a = 51,5$ md

Figure 4.

Institut Français du Pétrole

Gisements

Company : _____STATOIL_____   Formation:_____
Well :_____   Sample : _____23_____
Field : _____

$$\emptyset = \quad 31,9 \quad \% $$
$$K_a = \quad 51,5 \quad md$$

Relative Permeability to Oil K_{ro}

Relative Permeability to water K_{rw}

Total Saturation in: water % PV

Company :   STATOIL

Well   :

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 44   Depth

Permeability to air	K_a =	125 md	
Permeability to liquid	K_l =	112 md	
Permeability to oil with connate water	K'_o	88 md	

Permeability to water with residual oil K'_w 18 md

Porosity $\emptyset$ = 31,2 %

Connate water S_{cw} = 30,0 %

Oil in place (%PV) S_o = 70,0 %

Residual saturation (% PV) S'_o = 9,3 %
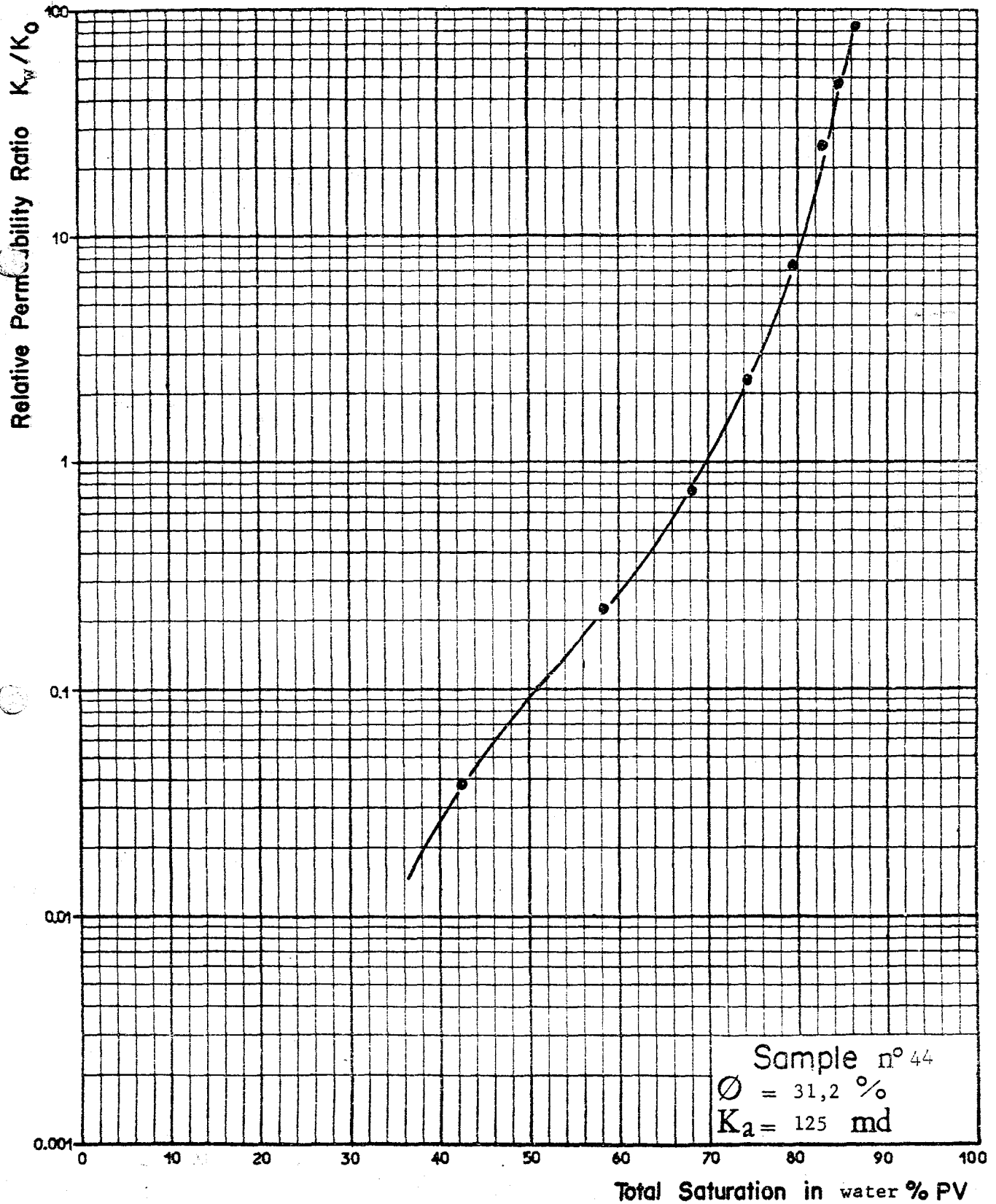
Oil recovery (% PV) R_o = 60,7 %

Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 30,0			K'_o/K_L 0,786
42,58	0,0387	0,0205	0,491
58,51	0,214	0,0458	0,214
68,11	0,750	0,0719	0,096
74,24	2,218	0,0949	0,043
79,36	7,273	0,119	0,0164
82,79	24,313	0,138	0,0057
84,54	48,655	0,155	0,0032
86,12	83,429	0,183	0,0013

Figure n° 5   gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 6   gives K_{ro} and K_{rw} versus total saturation in water (% PV)

Figure 5.

Figure 6.

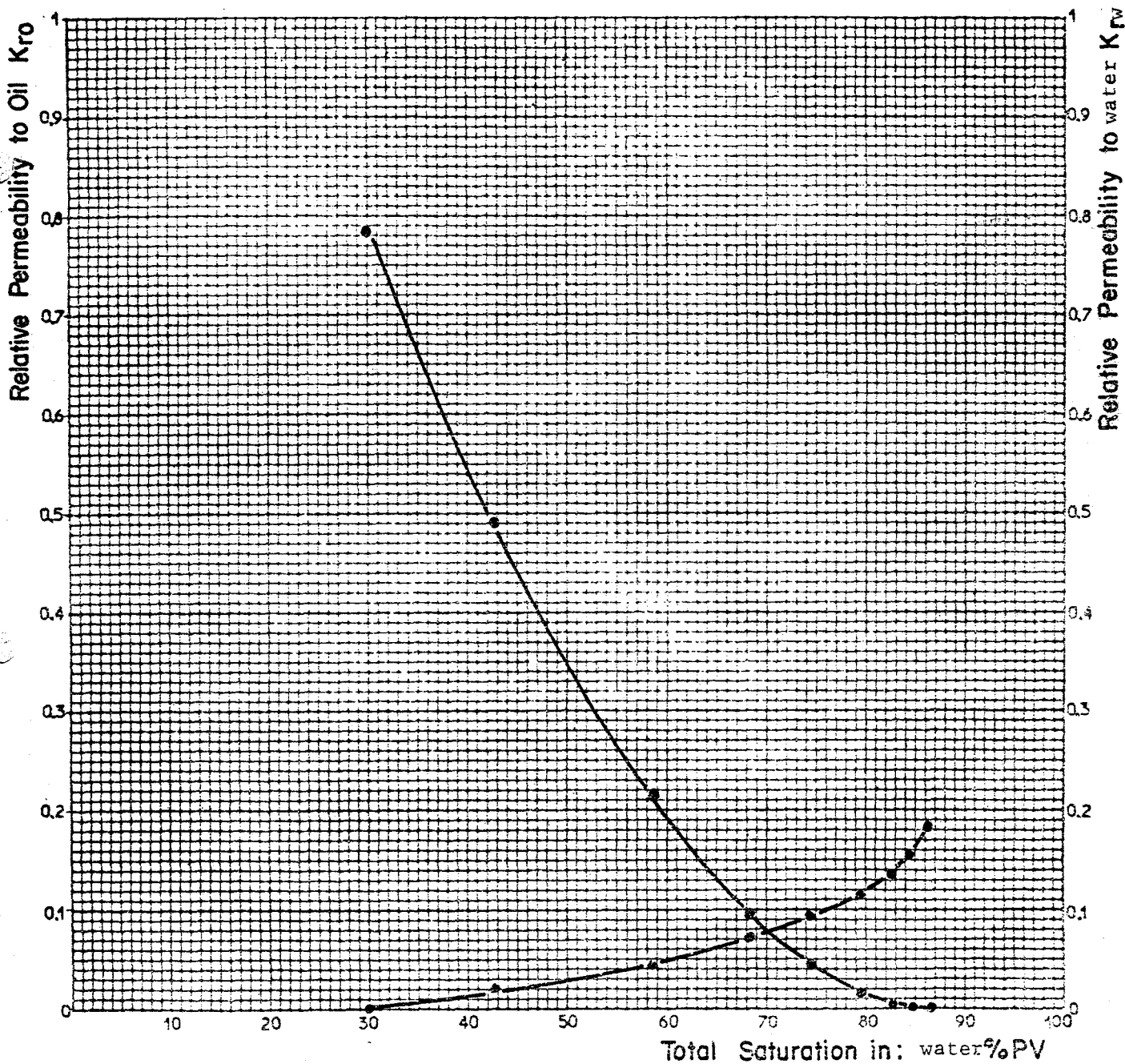Institut Français du Pétrole

Gisements

Company : _____ STATOIL _____ Formation: _____
Well : _____ Sample : _____ 44 _____
Field : _____

$\emptyset = 31,2$ %
$K_a = 125$ md

Total Saturation in: water% PV

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 68 Depth

Permeability to air	K_a = 29600 md	
Permeability to liquid	K_l = 29500 md	
Permeability to oil with connate water	K_o 9730 md	
Permeability to water with residual oil	K_w 819 md	

Porosity	$\emptyset$ = 31,3 %	
Connate water	S_{cw} = 25,8 %	
Oil in place (%PV)	S_o = 74,2 %	
Residual saturation (% PV)	S'_o = 11,3 %	
Oil recovery (% PV)	R_o = 62,9 %	

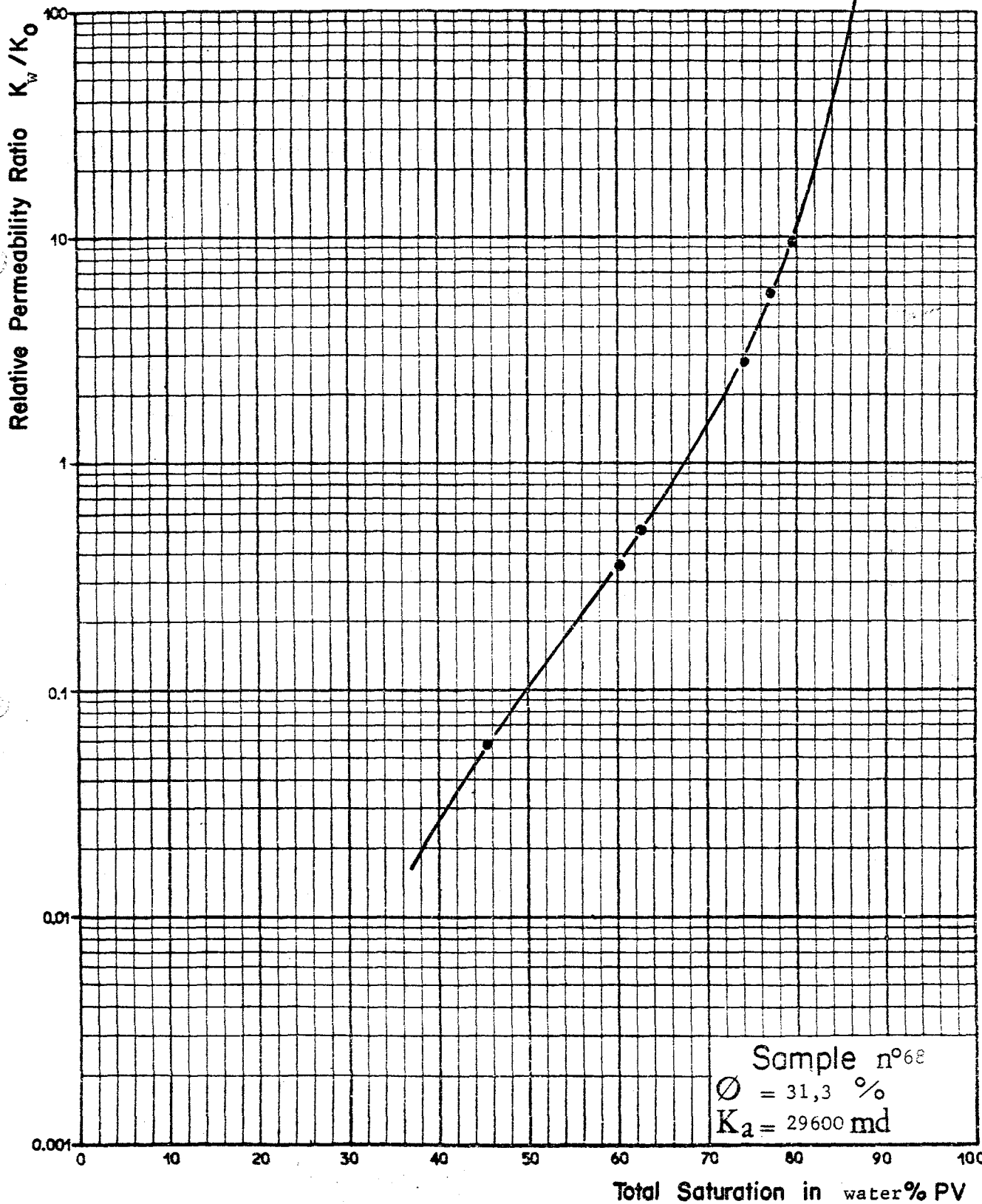| Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 25,8			K'_o/K_L 0,330
45,29	0,059	0,0059	0,0988
60,17	0,360	0,0162	0,0449
62,87	0,502	0,0206	0,0412
74,05	2,892	0,0238	0,0082
76,96	5,813	0,0257	0,0044
79,57	9,708	0,0275	0,0028
87,22	146,023	0,0275	0,00018
87,55	194,707	0,0280	0,00019

Figure n° 7 gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 8 gives K_{ro} and K_{rw} versus total saturation in water (% PV)
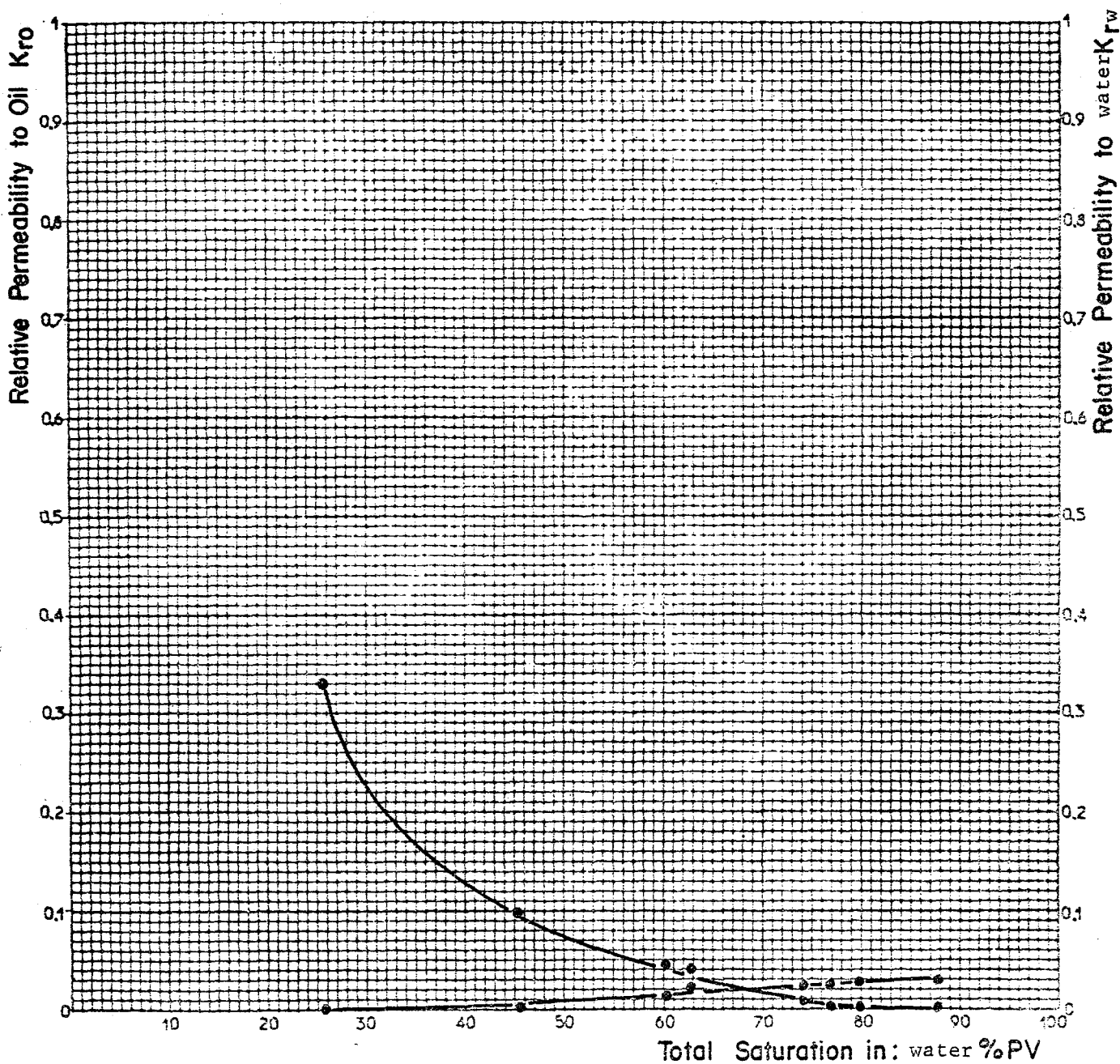
Figure 7.

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Gisements

Company___STATOIL_____ Formation _____
Well _____
Field _____

Relative Permeability Ratio K_w/K_o

Total Saturation in water% PV

Sample n°68
$\emptyset = 31,3$ %
$K_a = 29600$ md

Figure 8.

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Gisements

Company : STATOIL   Formation:

Well :   Sample : _____ 68

Field :

$\emptyset =$ 31,3 %

$K_a =$ 29600 md

Total Saturation in: water % PV

Company : STATOIL

Well :

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 80   Depth

Permeability to air	K_a =	970	md	Porosity	$\emptyset$ = 34,6 %
Permeability to liquid	K_l =	930	md	Connate water	S_{cw} = 36,8 %
Permeability to oil with connate water	K_o	378	md	Oil in place (%PV)	S_o = 63,2 %
Permeability to water with residual oil	K_w'	137	md	Residual saturation (% PV)	S_o' = 19,8 %
				Oil recovery (% PV)	R_o = 43,4 %

Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 36,8			K_o'/K_L 0,406
54,07	0,088	0,0099	0,112
63,00	0,458	0,0170	0,0373
65,79	0,869	0,0220	0,0258
70,72	3,622	0,0303	0,0084
72,38	6,462	0,0413	0,0064
75,59	24,31	0,0632	0,0026
77,18	58,39	0,0923	0,0017
79,14	335,89	0,1264	0,00038

Figure n° 9 gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 10 gives K_{ro} and K_{rw} versus total saturation in water (% PV)

Figure 9.

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Gisements

Company___STATOIL_____ Formation_____
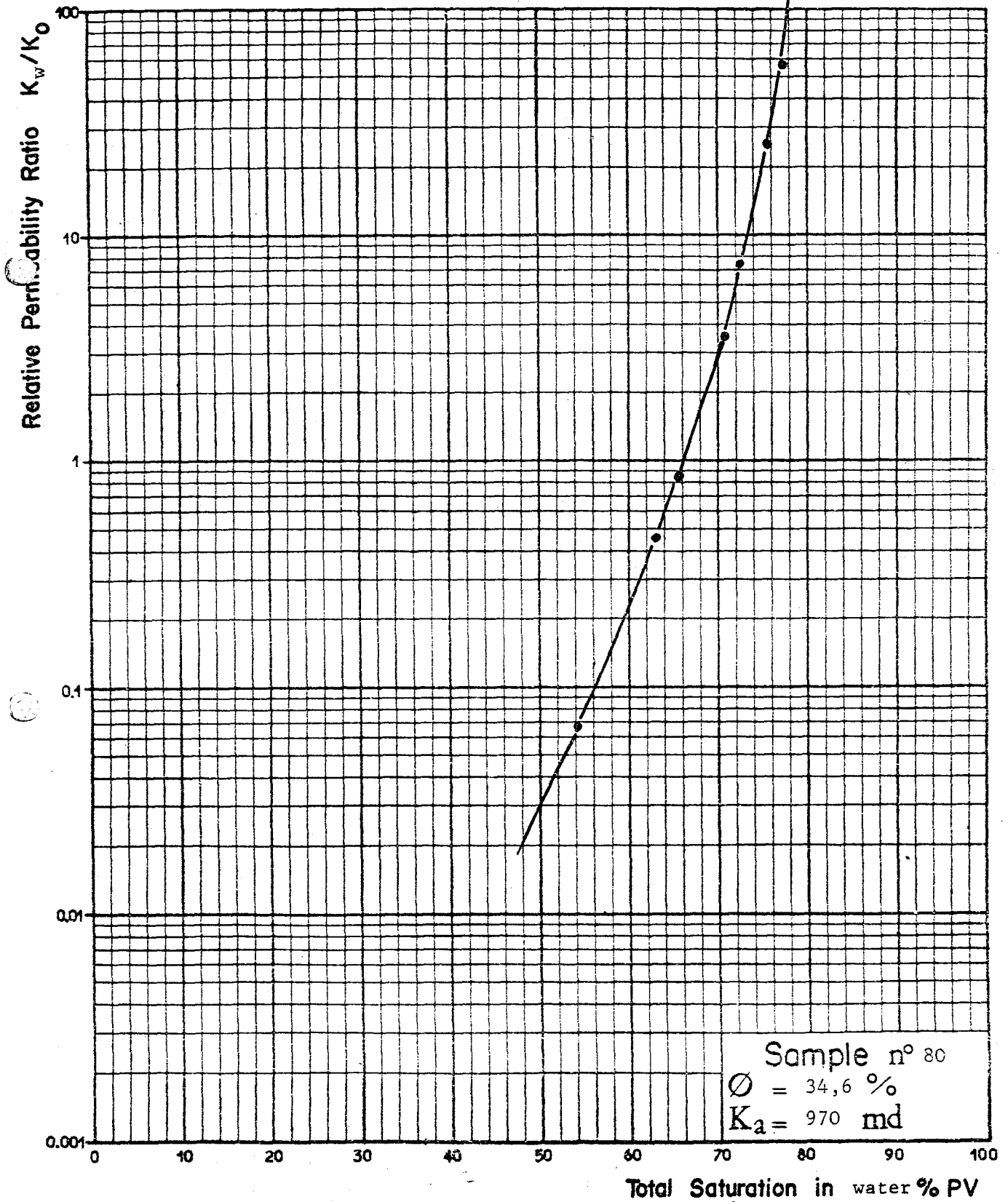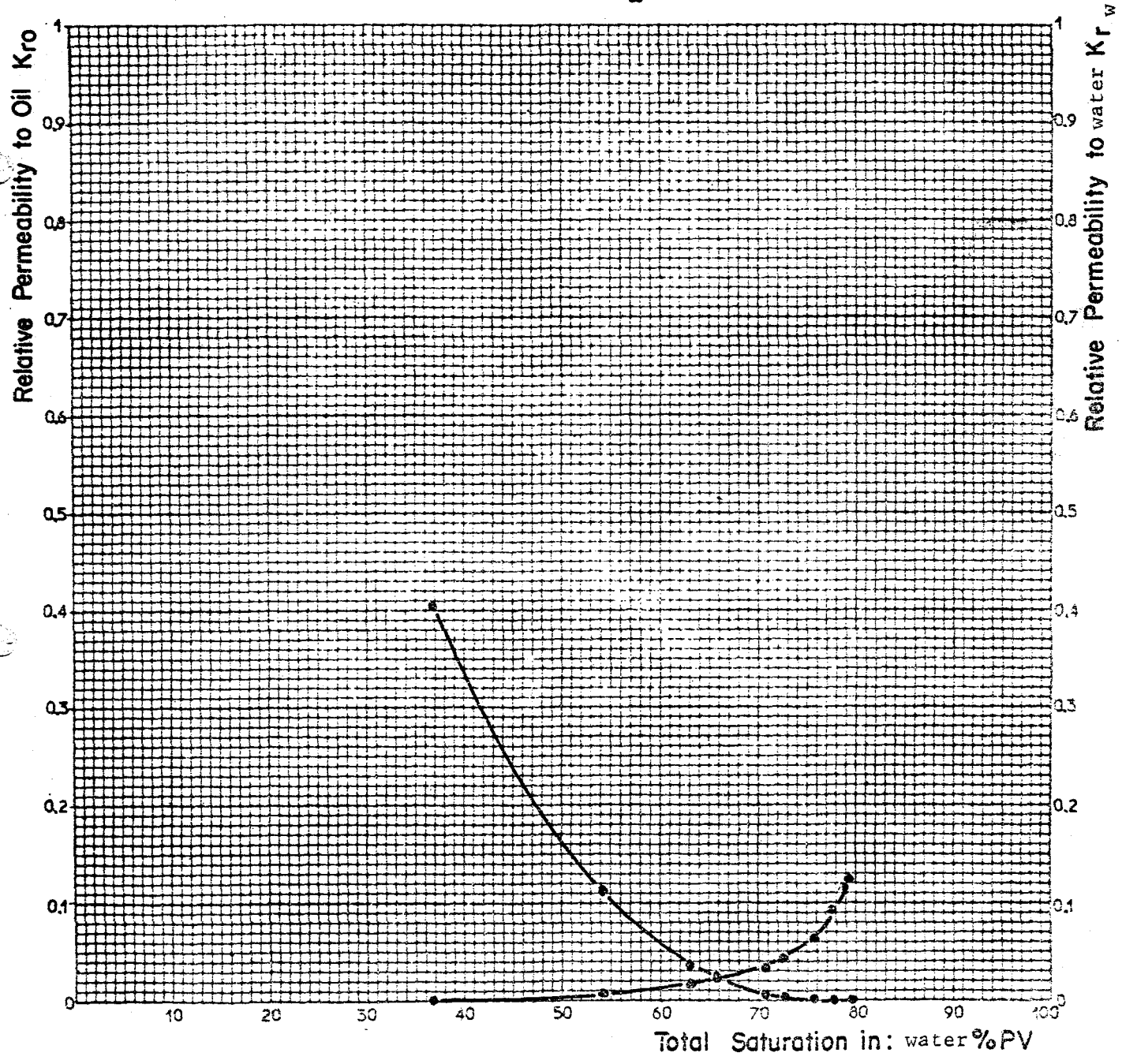
Well _____

Field _____

Relative Permeability Ratio K_w/K_o

Total Saturation in water % PV

Sample n° 80

$\varnothing$ = 34,6 %

K_a = 970 md

Figure 10.

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Gisements

Company : _____ STATOIL _____   Formation:_____

Well : _____   Sample : _____ 80 _____

Field : _____

$\emptyset =$ 34,6   %

$K_a =$ 970   md

Relative Permeability to Oil Kro (vertical left axis)

Relative Permeability to water Kr w (vertical right axis)

Total Saturation in: water % PV

Company : STATOIL

Well :

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 82   Depth

Permeability to air	K_a =	3173 md		Porosity	$\emptyset$ =	30,4 %
Permeability to liquid	K_1 =	2993 md		Connate water	S_{cw} =	31,7 %
Permeability to oil with connate water	K'_o	585 md		Oil in place (%PV)	S_o =	68,3 %
				Residual saturation (% PV)	S'_o =	35,6 %
Permeability to water with residual oil	K'_w	235 md		Oil recovery (% PV)	R_o =	32,7 %

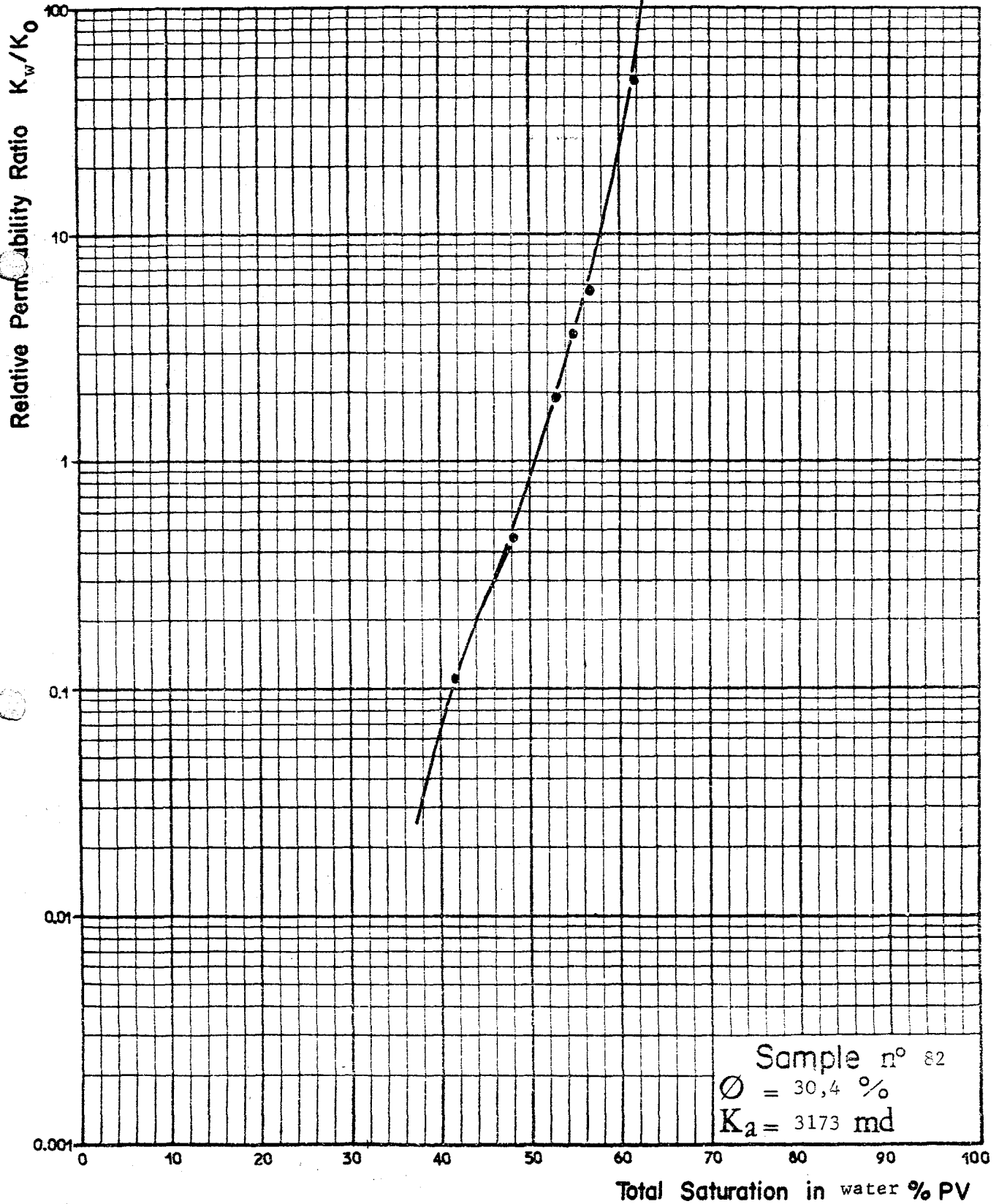| Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 31,7			K'_o/K_L 0,195
41,59	0,110	0,0145	0,1023
48,12	0,458	0,0233	0,0509
53,01	1,918	0,0332	0,0173
54,80	3,622	0,0421	0,0116
56,60	5,813	0,0532	0,0091
61,91	48,65	0,0714	0,0013
63,06	146,02	0,0787	0,00049
63,97	584,18	0,0811	0,00012

Figure n° 11 gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 12 gives K_{ro} and K_{rw} versus total saturation in water (% PV)
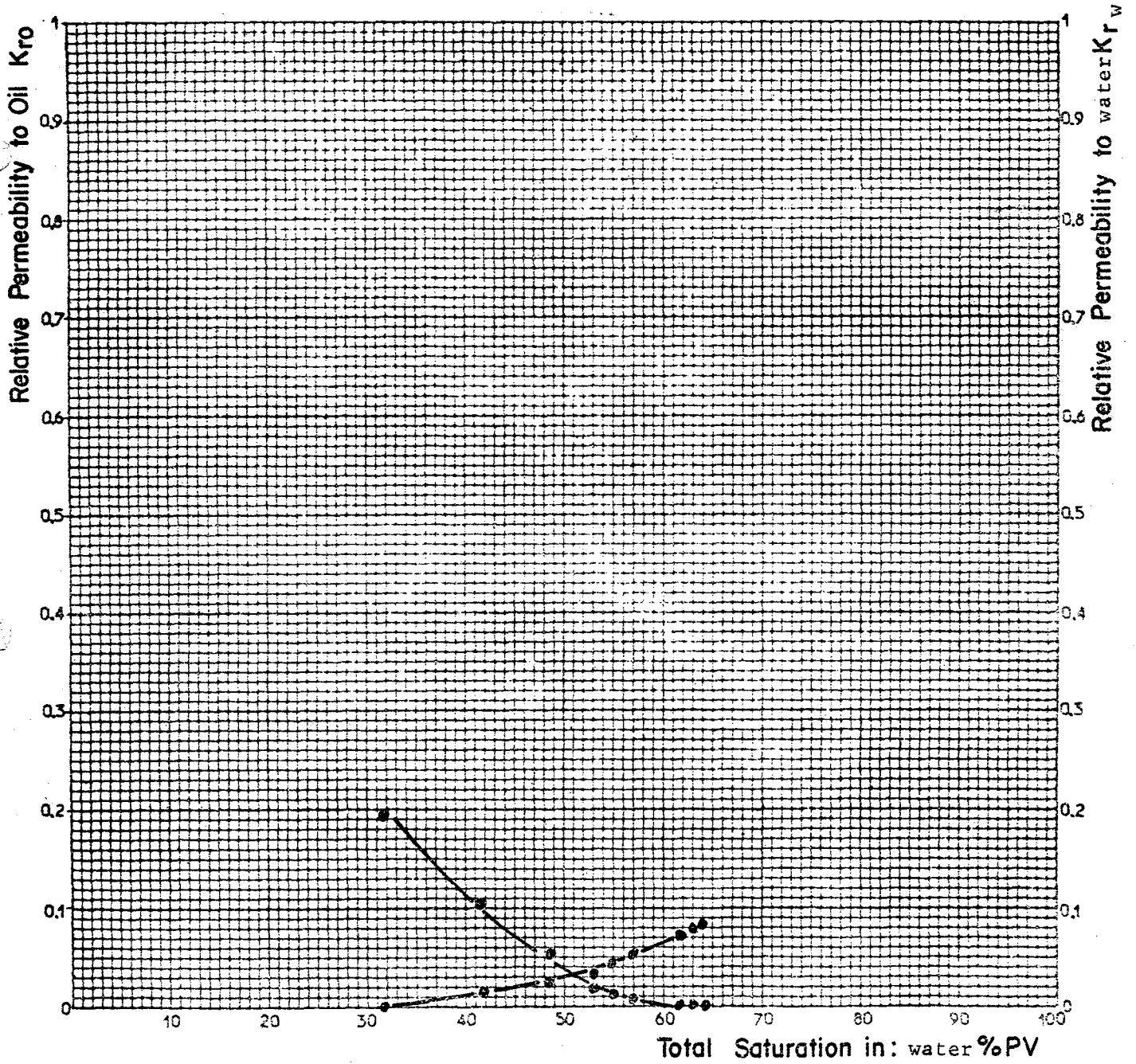
Figure 11.

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Gisements

Company___ STATOIL _____   Formation _____
Well _____
Field _____

Sample n° 82
$\emptyset = 30,4 \%$
$K_a = 3173$ md

Total Saturation in water % PV

Figure 12.

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Gisements

Company : _____STATOIL_____   Formation:_____
Well : _____   Sample : ____82____
Field : _____

$\emptyset$ = 30,4   %
K_a = 3173   md

Total Saturation in: water % PV

Company : STATOIL

Well   :

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 83   Depth

Permeability to air	K_a = 2790 md	Porosity	$\emptyset$ = 33,2 %
Permeability to liquid	K_1 = 2710 md	Connate water	S_{cw} = 43,2 %
Permeability to oil with connate water	K_o 533 md	Oil in place (%PV)	S_o = 56,8 %
		Residual saturation (% PV)	S'_o = 18,4 %
Permeability to water with residual oil	K_w 236 md	Oil recovery (% PV)	R_o = 38,4 %

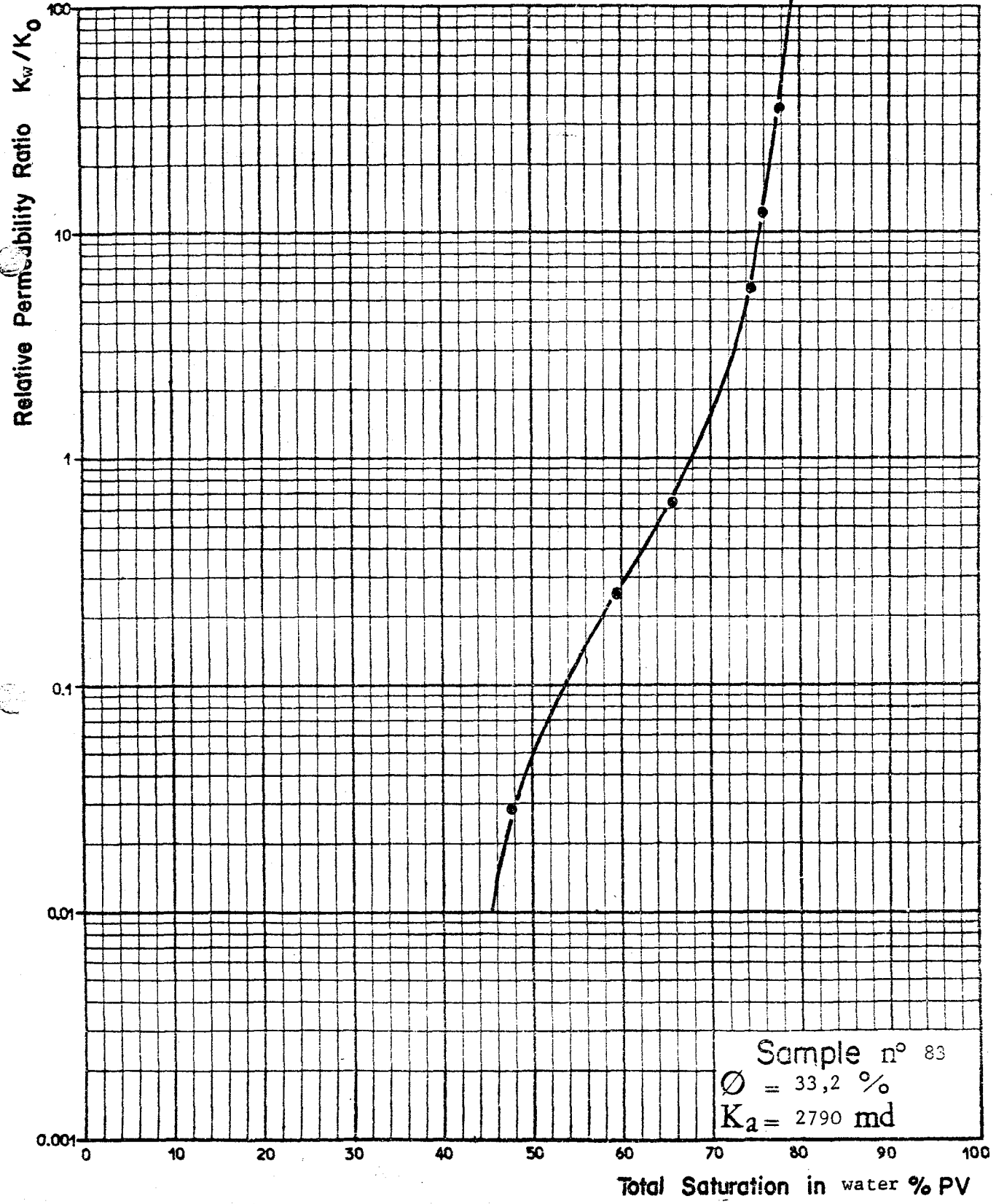| Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 43,2			K'_o/K_L 0,198
47,77	0,00292	0,0031	0,152
59,93	0,0204	0,0133	0,065
65,84	0,620	0,0201	0,0325
74,43	5,81	0,0454	0,0045
75,60	11,65	0,0480	0,0026
77,30	36,48	0,0526	0,0014
81,32	584,18	0,0639	0,00010

Figure n° 13   gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 14   gives K_{ro} and K_{rw} versus total saturation in water (% PV)

Figure 13.

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Gisements

Company STATOIL   Formation
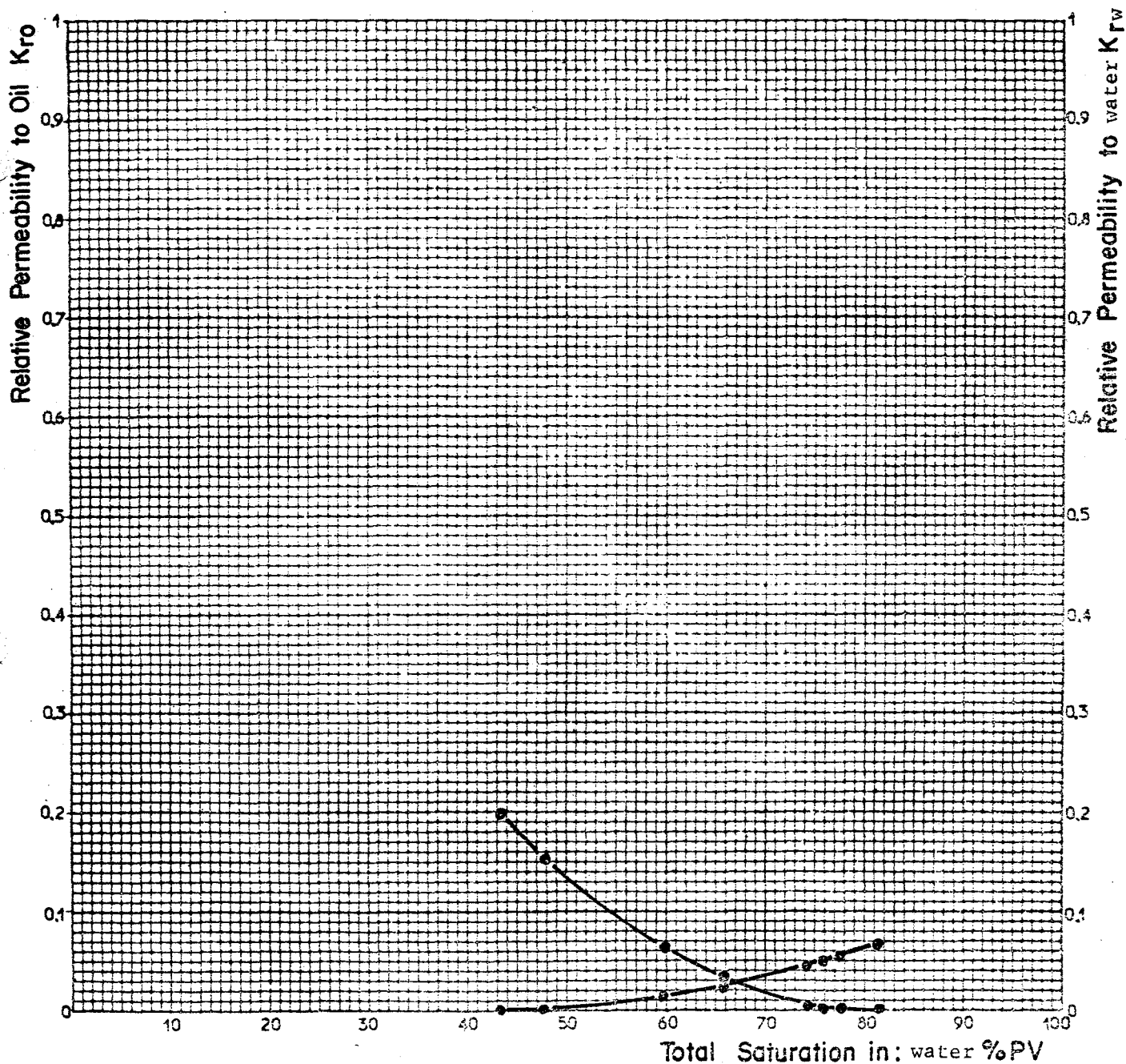Well
Field

Relative Permeability Ratio K_w/K_o

Total Saturation in water % PV

Sample n° 83
$\emptyset = 33,2\ \%$
$K_a = 2790\ md$

Figure 14.

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Gisements

Company : _____ STATOIL _____   Formation : _____

Well : _____   Sample : _____ 83 _____

Field : _____

$$\emptyset = 33,2 \quad \%$$
$$K_a = 2790 \quad md$$

Total Saturation in: water % PV

RELATIVE PERMEABILITY : WATER/OIL

Sample n°   141   Depth

Permeability to air K_a = 1177   md   Porosity $\emptyset$ = 29,3 %

Permeability to liquid K_1 = 1127   md   Connate water S_{cw} = 26,8 %

Permeability to oil   ,   Oil in place (%PV) S_o = 73,2 %
with connate water K_o 1070   md
                                                   Residual saturation
Permeability to water   ,   (% PV) S'_o = 18,3 %
with residual oil K_w 162   md
                                                   Oil recovery
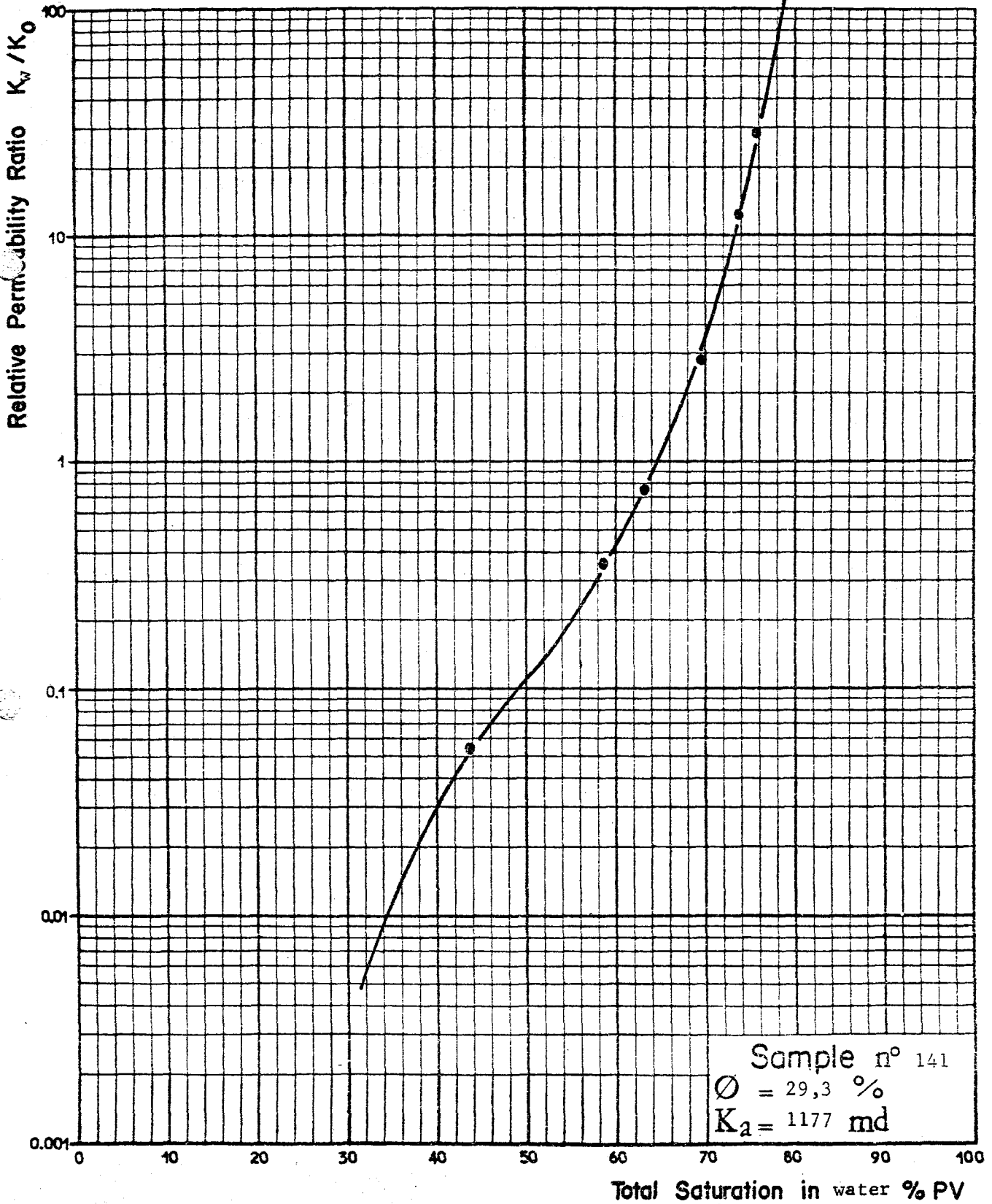   (% PV) R_o = 54,9 %

Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 26,8			K'_o/K_L 0,949
43,9	0,054	0,0107	0,272
58,76	0,360	0,0385	0,091
63,19	0,750	0,0530	0,0585
69,73	2,892	0,0763	0,0264
73,75	11,655	0,095	0,0081
75,51	29,181	0,110	0,0033
75,64	29,210	0,112	0,0032
79,89	116,81	0,142	0,00079

Figure n° 15   gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 16   gives K_{ro} and K_{rw} versus total saturation in water (% PV)

Figure 15.

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Gisements

Company __ STATOIL _____ Formation _____
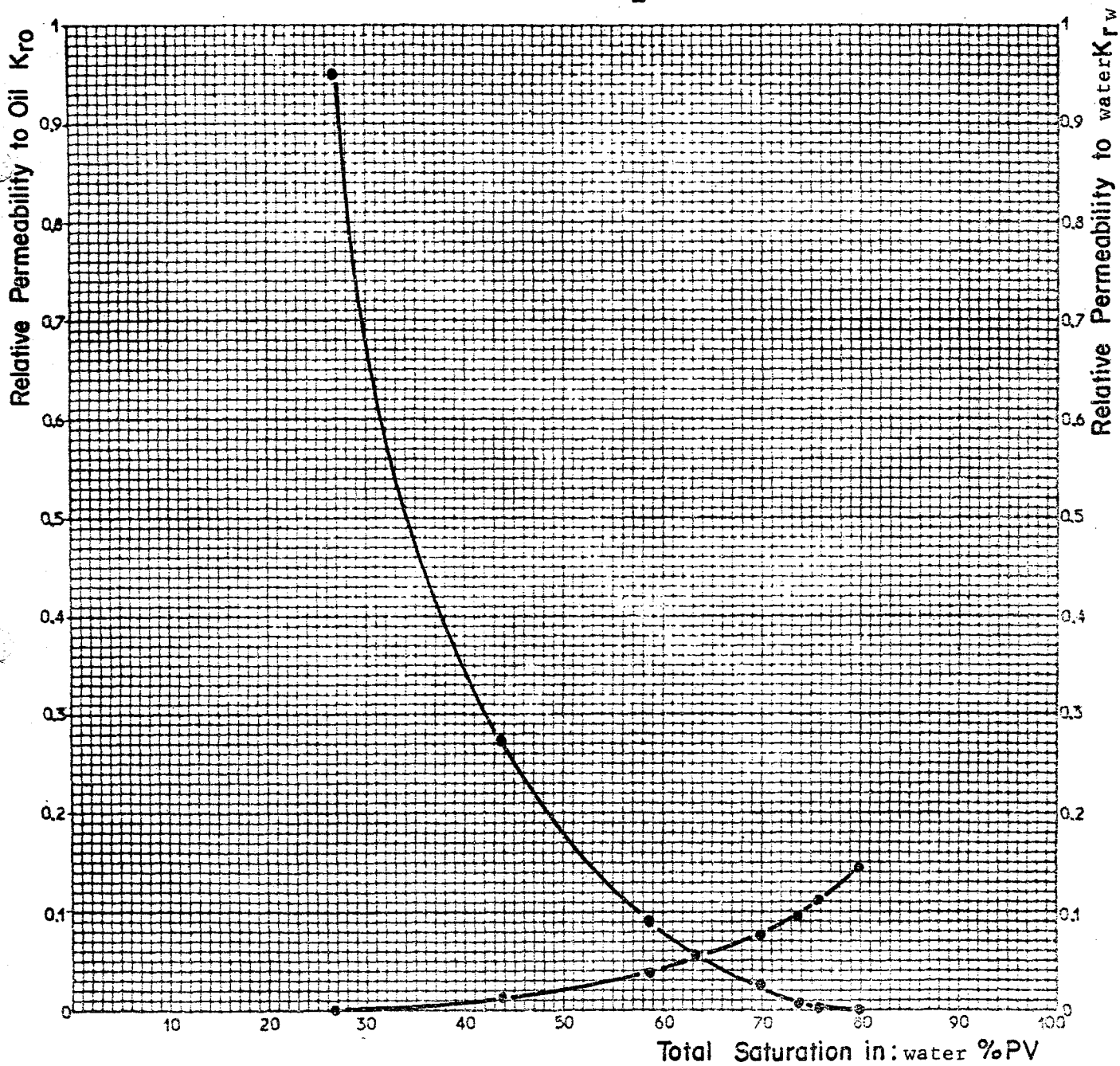Well _____
Field _____

Sample n° 141
$\emptyset$ = 29,3 %
K_a = 1177 md

Relative Permeability Ratio K_w/K_o

Total Saturation in water % PV

Figure 16.

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Gisements

Company : _____STATOIL_____   Formation:_____
Well : _____   Sample : ___141___
Field : _____

$\varnothing =$ 29,3   %
$K_a =$ 1177   md

Total Saturation in: water %PV

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 148   Depth

Permeability to air K_a = 504 md	Porosity	$\emptyset$ = 29,1 %
Permeability to liquid K_l = 474 md	Connate water	S_{cw} = 20,7 %
Permeability to oil with connate water K'_o 328 md	Oil in place (%PV)	S_o = 79,3 %
	Residual saturation (% PV)	S'_o = 36,6 %
Permeability to water with residual oil K'_w 38,9 md	Oil recovery (% PV)	R_o = 42,7 %

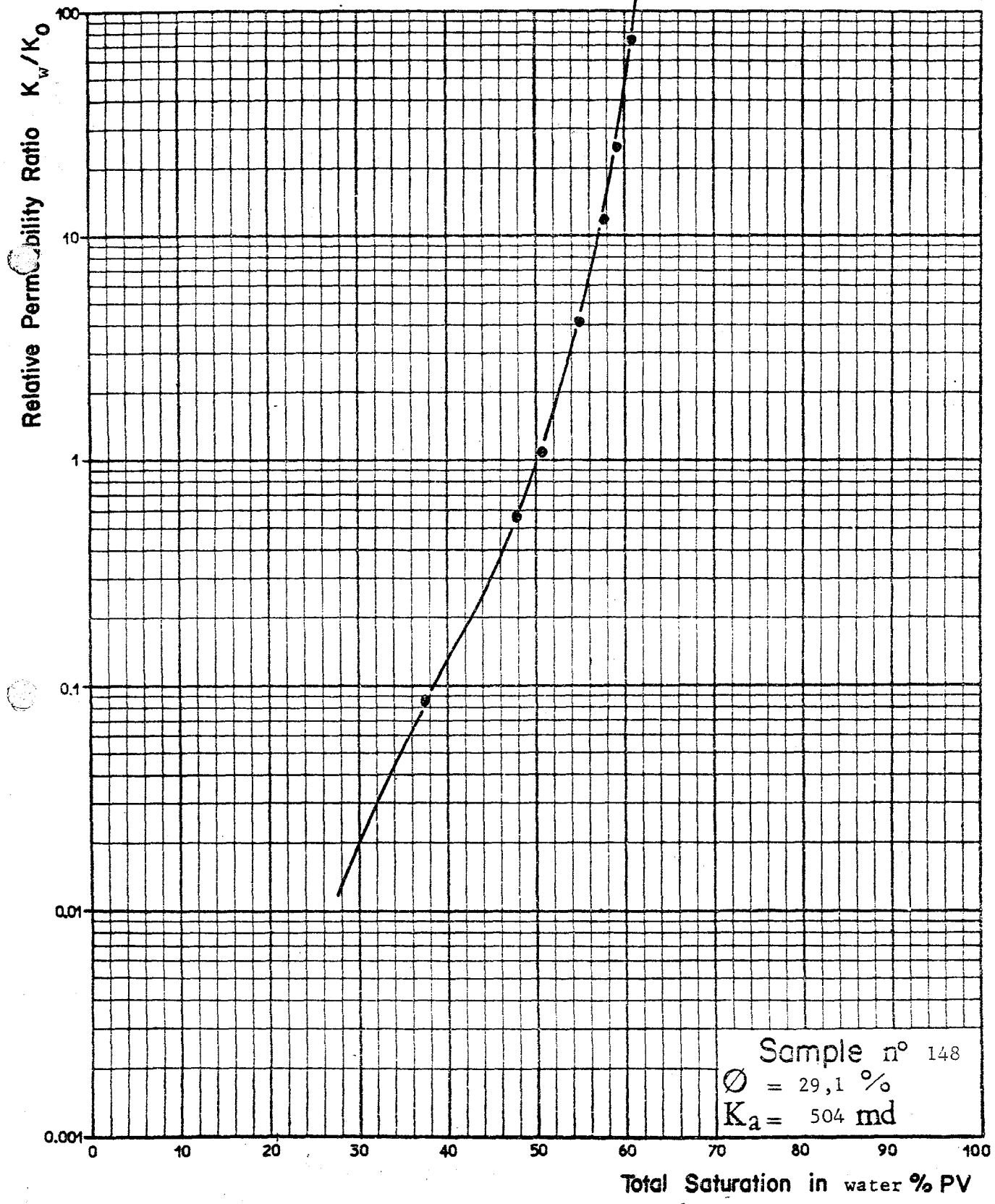| Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 20,7			K'_o/K_L 0,691
37,82	0,0876	0,0179	0,204
47,92	0,555	0,0431	0,0777
50,75	1,139	0,0494	0,0434
54,91	4,144	0,0561	0,0135
57,29	11,655	0,0628	0,0054
58,81	24,313	0,0714	0,0029
60,90	72,99	0,0756	0,0009
62,54	292,08	0,0879	0,0002

Figure n° 17 gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 18 gives K_{ro} and K_{rw} versus total saturation in water (% PV)
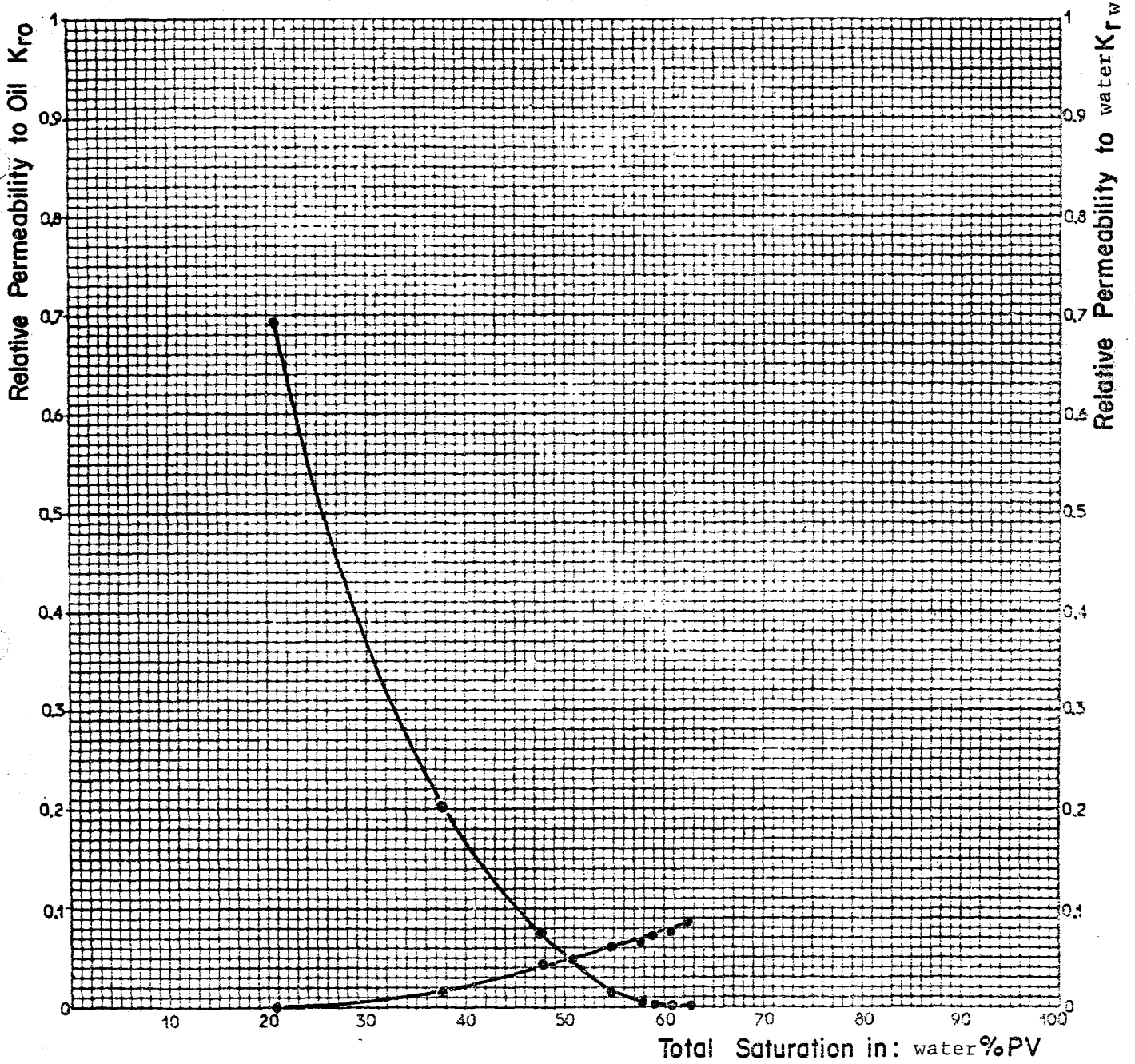
Figure 17.

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Gisements

Company _____ STATOIL _____ Formation _____
Well _____
Field _____

Sample n° 148
∅ = 29,1 %
K_a = 504 md

Relative Permeability Ratio K_w/K_o

Total Saturation in water % PV

·Figure 18.

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Gisements

Company : _____ STATOIL _____   Formation:_____
Well : _____   Sample : _____ 148 _____
Field : _____

$$\emptyset = \quad 29,1 \qquad \%$$
$$K_{a} = \quad 504 \qquad md$$

Total Saturation in: water%PV

Company :   STATOIL

Well   :

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 165   Depth

Permeability to air	K_a	=	1492 md	Porosity	$\emptyset$ =	29,0 %
Permeability to liquid	K_l	=	1442 md	Connate water	S_{cw} =	23,5 %
Permeability to oil with connate water	K_o		415 md	Oil in place (%PV)	S_o =	76,5 %
				Residual saturation (% PV)	S'_o =	35,6 %
Permeability to water with residual oil	K'_w		196 md	Oil recovery (% PV)	R_o =	40,9 %

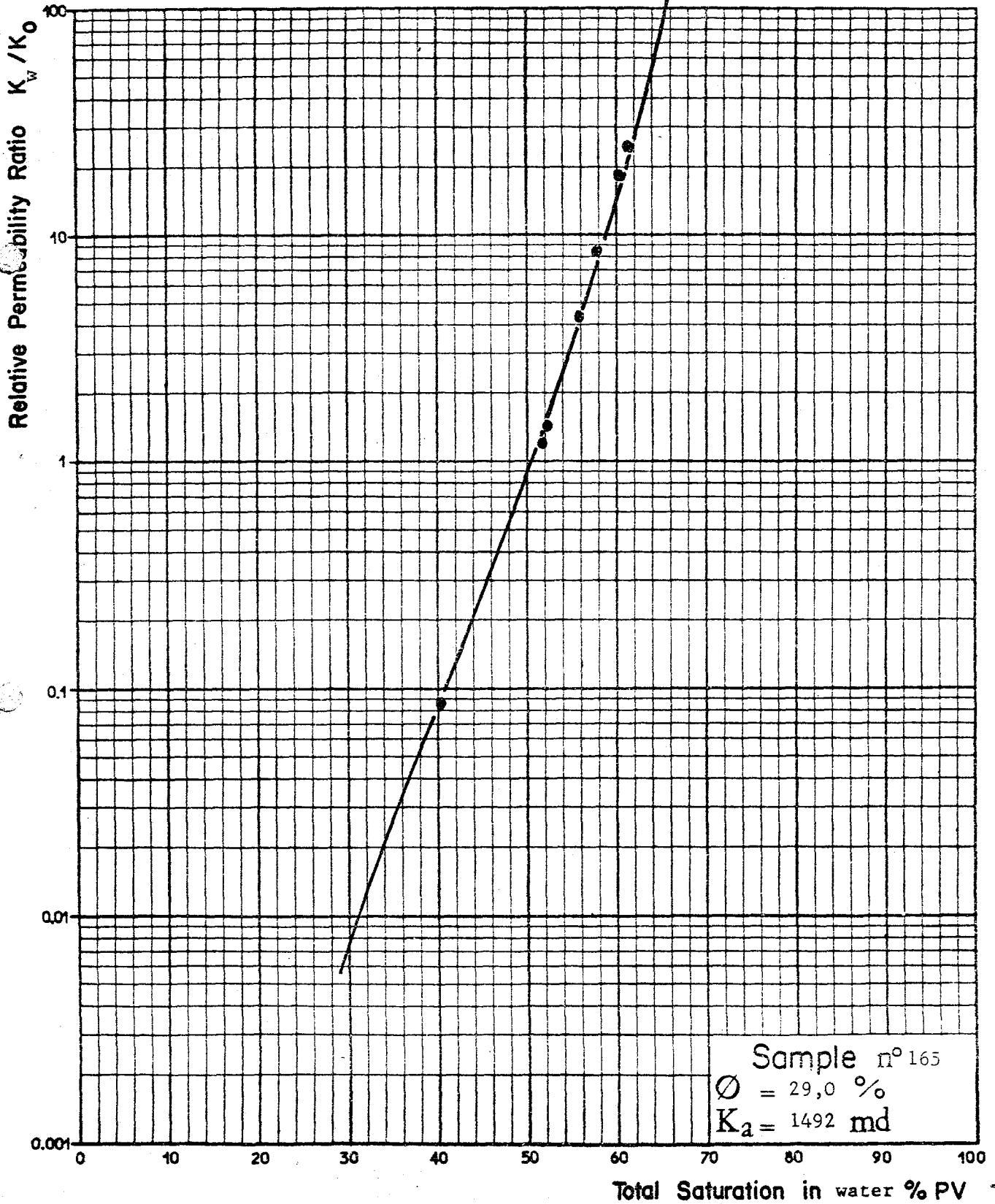| Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 23,5			K'_o/K_L 0,288
40,16	0,0876	0,0101	0,0952
51,75	1,139	0,0237	0,0208
52,43	1,431	0,0295	0,0206
55,66	4,143	0,0350	0,0084
57,68	8,317	0,0423	0,0050
60,05	18,227	0,0547	0,0030
61,05	22,440	0,0620	0,0015
68,39	584,18	0,0985	0,0002

Figure n° 19 gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 20 gives K_{ro} and K_{rw} versus total saturation in water (% PV)
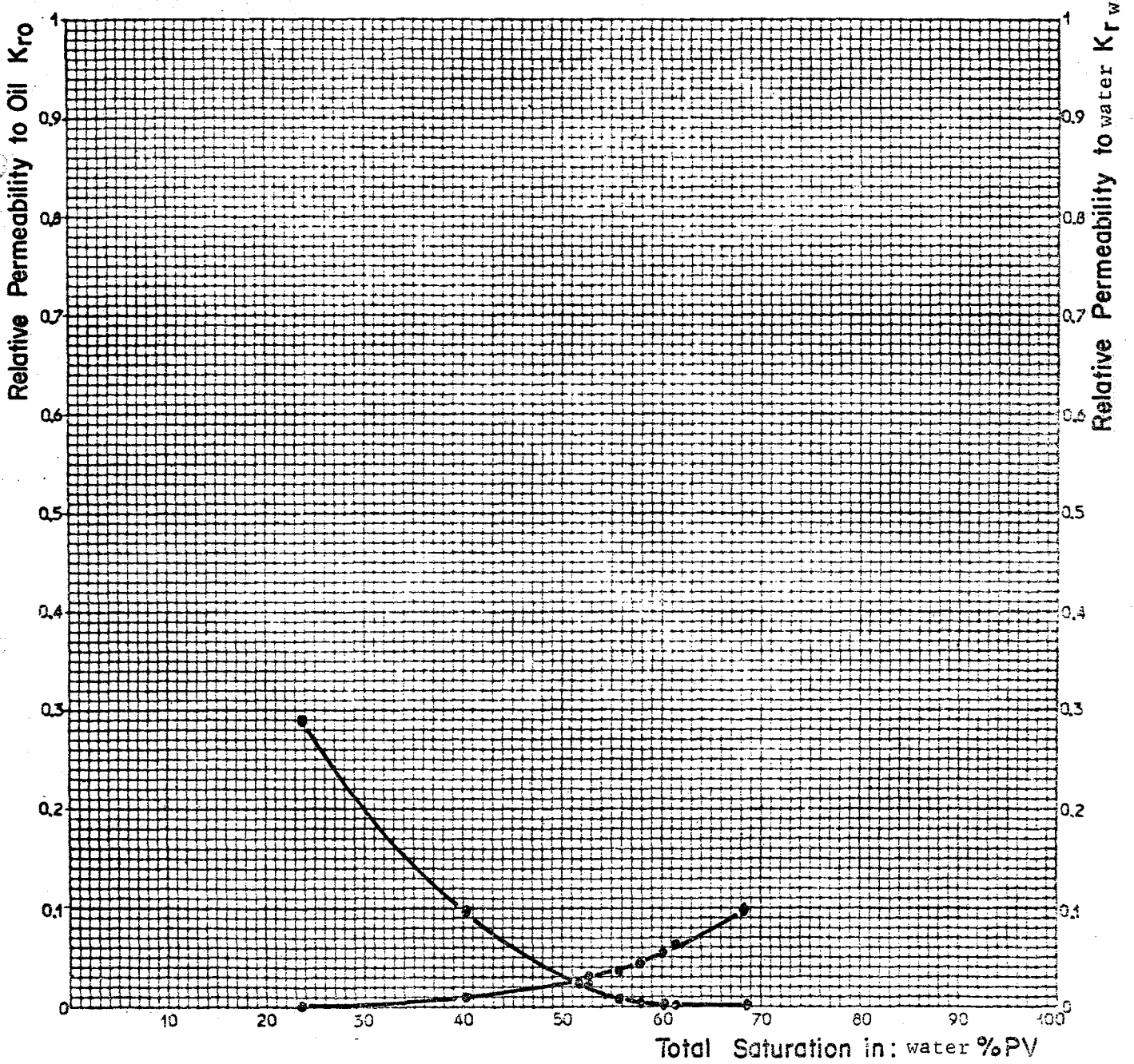
Figure 19.

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Gisements

Company _____ STATOIL _____ Formation _____
Well _____
Field _____

Sample n° 165
Ø = 29,0 %
K_a = 1492 md

Total Saturation in water % PV

Figure 20.

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Gisements

Company : _____STATOIL_____   Formation:_____
Well :_____   Sample : _____165_____
Field :_____

$$\emptyset = 29 \quad \%$$
$$K_2 = 1492 \quad md$$

Total Saturation in: water %PV

RELATIVE PERMEABILITY : WATER/OIL

Sample n° 172   Depth

Permeability to air	K_a =	875	md	Porosity	$\emptyset$ = 33,7 %
Permeability to liquid	K_l =	835	md	Connate water	S_{cw} = 20,6 %
Permeability to oil with connate water	K_o	586	md	Oil in place (%PV)	S_o = 79,4 %
Permeability to water with residual oil	K_w	105	md	Residual saturation (% PV)	S'_o = 33,3 %
				Oil recovery (% PV)	R_o = 46,1 %

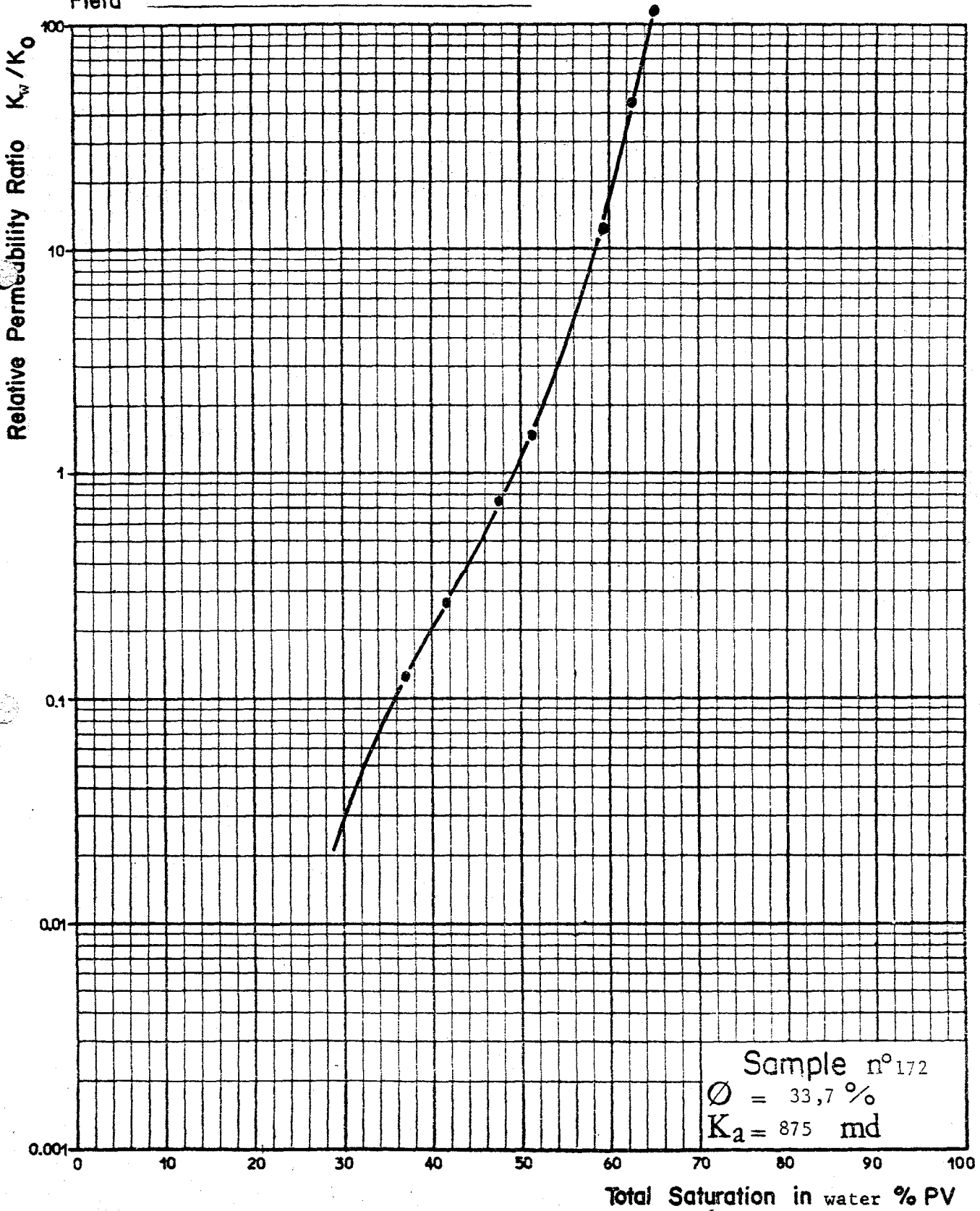| Total saturation in water (% PV)	K_w/K_o ratio	Rel. perm. to water (fraction) K_{rw}	Rel. perm. to oil (fraction) K_{ro}
S_{cw} 20,7			K'_o/K_L 0,702
36,85	0,119	0,0191	0,195
41,46	0,267	0,0352	0,132
47,51	0,763	0,0538	0,0706
51,20	1,456	0,0657	0,0451
59,04	11,86	0,0916	0,0069
59,65	14,83	0,0933	0,0063
62,58	42,42	0,107	0,0025
64,76	118,83	0,117	0,00098

Figure n° 21 gives the K_w/K_o ratio versus total saturation in water (% PV)

Figure n° 22 gives K_{ro} and K_{rw} versus total saturation in water (% PV)

Figure 21.

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Gisements

Company ___ STATOIL ___ Formation ___
Well ___
Field ___

Relative Permeability Ratio K_w/K_o

Total Saturation in water % PV

Sample n° 172
Ø = 33,7 %
K_a = 875 md

Figure 22.

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Gisements

Company : _____ STATOIL _____   Formation:_____
Well :_____   Sample : _____ 172 _____
Field : _____

$\emptyset =$ 33,7   %
$K_a =$ 875   md