statoil

Residual gas measurements

Well 30/2-1

STATOIL
EXPLORATION & PRODUCTION
LABORATORY
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DEC. -83

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Title

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CONTENTS

1. SUMMARY

The residual gas saturations after waterflood were determined for ten samples from well 30/2-1 and the values obtained varied from 21.2 to 48.1 %.
It was tried to relate the residual gas saturation data to permeability, but no consistent correlations were found.

2. INTRODUCTION

Prolab was requested to make a study of trapped gas from well 30/2-1, Rannoch, Etive and Ness formation. 10 samples were used in this study.

3. THEORY

3.1 Residual gas

The residual gas saturation, Sgr, is the saturation of gas left in an initialy gas-containing, (Sgi), porous medium after imbibition by a wetting phase.

Land (1) found a relationship between the two saturations above.

$$(1-Swi)\ (1/Sgr - 1/Sgi) = C \qquad (1)$$

In the case of starting the imbibition process at initial gas saturation, Sgi = 1 - Swi, the equation becomes:

$$\frac{1 - Swi}{Sgr} - 1 = C \qquad (2)$$

C is called the trapping constant and is believed to be a function of the pore size distribution. The value of C is important in calculating the imbibition relative permeability as described by Standing (2).

4. EXPERIMENTAL PROCEDURE

4.1 Sample preparation

After the overburden measurements were finished by GECO, 10 plug samples (see table 4.1) were washed by extraction using methanol and then dried at 60^{o}C and 40 % humidity.

The samples were evacuated and saturated with simulated formation water (see Appendix I). To ensure complete saturation, a hydrostatic pressure of 40 bar was applied for 12 hours.

The plug samples were then saturated with gas at initial water saturation, using the porous plate technique.

Table 4.1

Plug no.	Depth	Formation
59.1	3718.33	Ness
63.1	3719.68	"
68.1	3721.12	"
75.1	3723.50	"
118.1	3749.43	"
131.1	3758.13	Etive
138.1	3761.12	"
142.1	3762.32	"
186.1	3777.87	"
214.1	3787.93	Rannoch

4.2 Residual gas measurements

The gas permeabilities were first measured with the plug samples at their irreducible water saturations, Kg(Swi), without Klinkenberg correction.

Then the plug samples were flooded with simulated formation water, 4 cc/hour, to determine the residual gas saturation Sgr. The plug samples varied in permeability and back pressure was applied to avoid effects from the compressibility to the gas due to the differential pressure.

The permeability to water with residual gas, Kw(Sgr), was then determined.

5. RESULTS

Table 5.1 lists the results from the residual gas measurements, the irreducible water saturation Swi, the residual gas saturation, Sgr, and the simulated formation brine permeability at Sgr, Kw(Sgr).

Table 5.2 lists the trapping constant C.

Fig. 5.1 shows a plot of Sgr versus K.

Fig. 5.2 shows a plot of Sgr versus Sgi.

Table 5.1

Residual gas data

Sample no.	Depth (m)	Helium porosity (%)	Klinkenberg corr. air perm. KL (mD)	Irreducible water saturation Swi (%)	Klinkenberg corr. air perm. at Swi k(Swi) (mD)	Residual gas saturation Sgr (%)	Effective water permeability at residual gas saturation Kw(Sgr) (mD)
59.1	3718.33	25.6	399	10.0	372	38.5	81
63.1	3719.68	26.8	991	9.4	869	46.4	187
68.1	3721.12	28.0	1493	7.4	1575	43.2	323
75.1	3723.50	22.0	57	47.1	54	21.2	17
118.1	3749.43	28.5	2672	8.6	2655	46.0	134
131.1	3758.13	27.3	168	21.4	163	41.3	16
138.1	3761.12	27.2	151	21.4	150	48.1	14
142.1	3762.32	29.3	326	19.6	425	31.7	45
186.1	3777.87	22.9	4.7	49.2	0.3	44.7	0.3
214.1	3787.93	23.2	2.4	51.2	0.5	30.1	0.1

Table 5.2

The trapping constant (C)

Sample no.	C
59.1	1.43
63.1	0.95
68.1	1.14
75.1	1.50
118.1	0.99
131.1	0.90
138.1	0.63
142.1	1.54
186.1	0.14
214.1	0.57

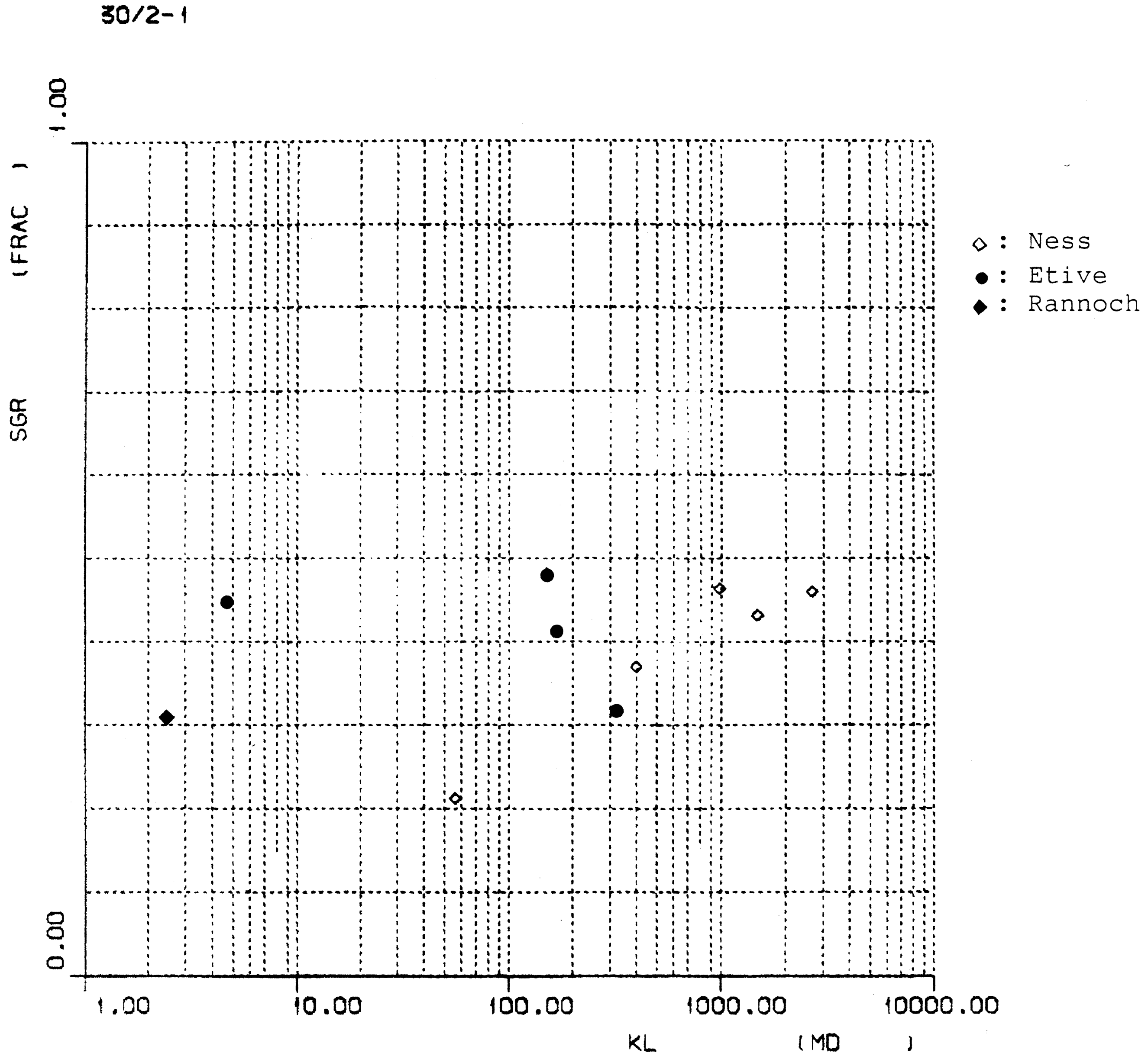


Fig. 5.1 Residual gas saturation, Sgr, versus Klinkenberg corrected permeability, KL.

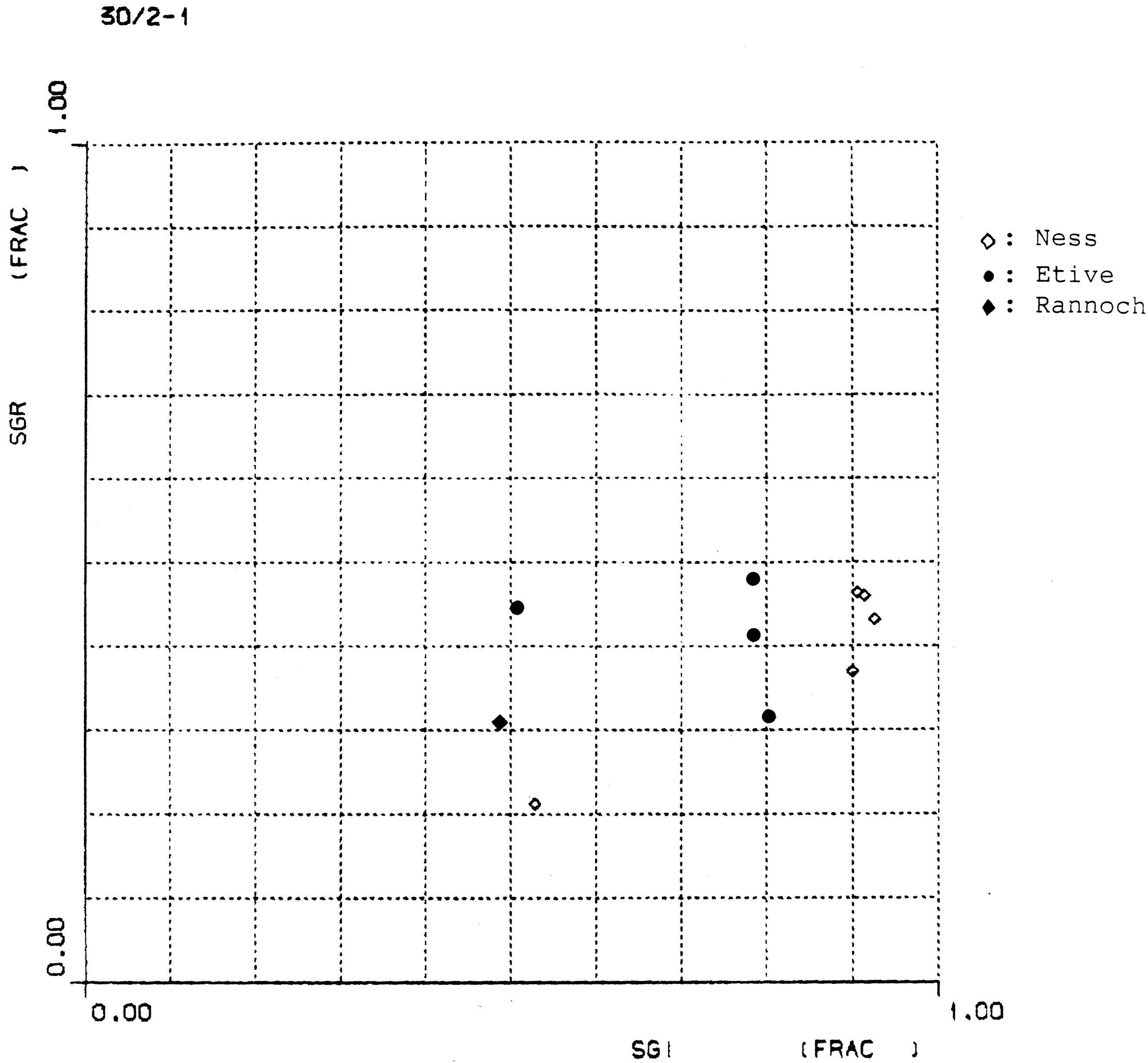
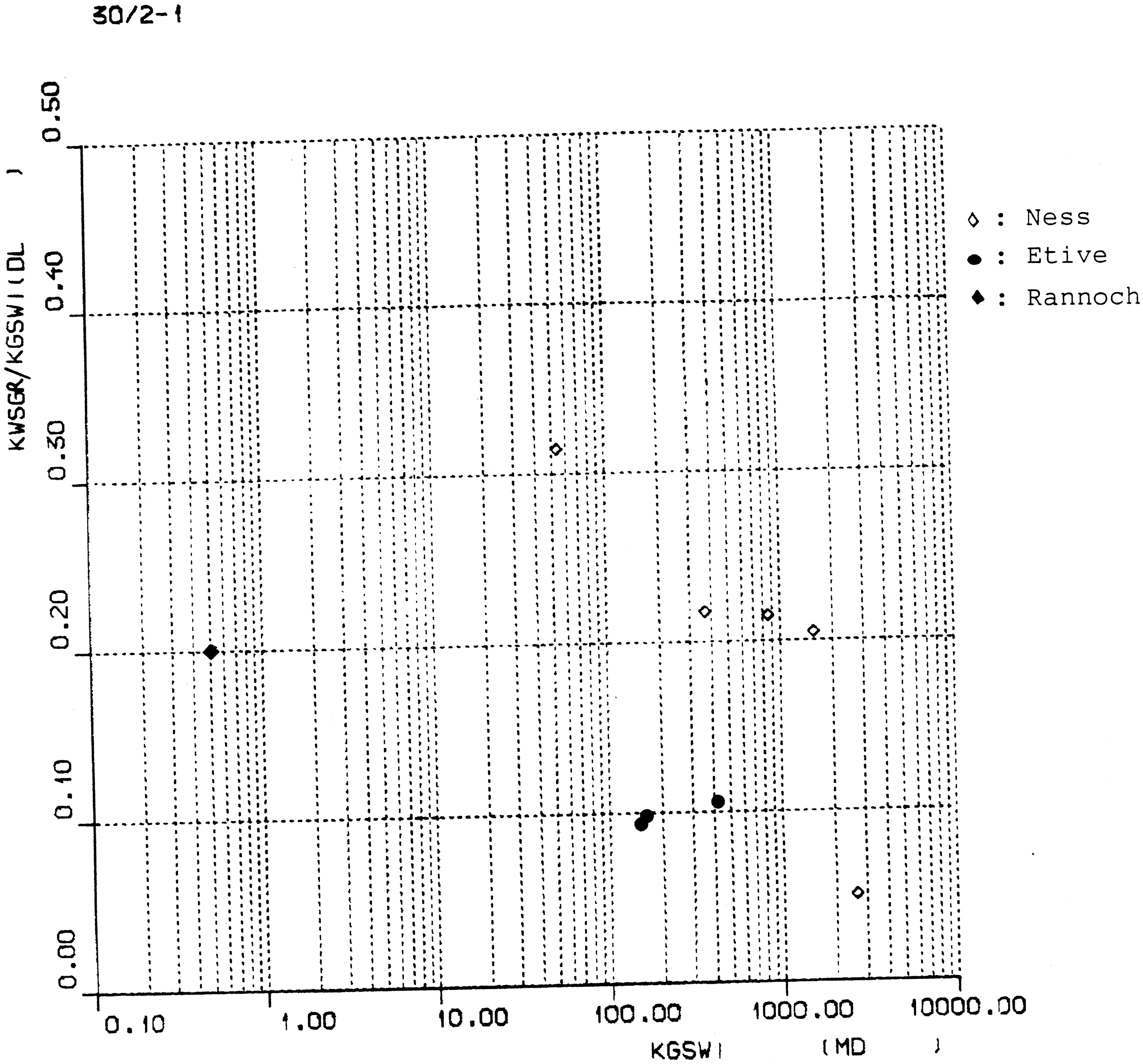


Fig. 5.2 Residual gas saturation, Sgr, versus initial gas saturation, Sgi.



<u>Fig 5.3</u> The ratio KwSgr/KgSwi versus KgSwi.
All samples except no 186.1

6. DISCUSSION/CONCLUSION

The original Swi values obtained by Geco were averagely a little higher than the Statoil values. But, due to insufficient packing during transportation from Geco, the water saturations were reduced with about two saturation percents. The newest Swi's are given in table 5.1.

The air permeabilities at irreducible water saturation were measured without back pressure so that $\frac{1}{\bar{p}m} \approx 1$. The Core Lab corrections were used to convert the data to Klinkenberg corrected permeabilities. These Kg(Swi) values should be equal to or less than K_L, which holds for all samples except no 68.1 and 142.1.
The residual gas data obtained varied from 21.1 to 48.1 %, which is considered normal.
These data were determined in two ways, by measuring the displaced gas volume with 20 bar back pressure and after expansion to atmospheric conditions. When evaluating the data, it was found that the first method gave the best results; the second method must be further investigated. Therefore, only one set of data is reported. An attempt was made, to correlate the residual gas saturation and the trapping constant to permeability, by the equation

$$y = a + b \log x$$

Regression analysis was used to determine a and b. The method is of course limited by the small amount of data available, and no consistent correlations were found.

The ratios between Kw(Sgr) and Kg(Swi) were calculated, and varied from 0.05 to 0.3. It was found that the highest permeability sample got the largest permeability reduction.

7. LITTERATURE

1. Land, C.S.: "Calculations of imbibition relative permeability for two - and three - phase flow from rock properties" Trans. AIME 251 (1971) II, 149.

2. Standing, M.B.: "Notes on relative permeability relationshipes" NTH, Aug. 1974

8. APPENDIX 1

Simulated formation water composition:

Na :	11.480	ppm
K :	1.490	ppm
Mg :	1.230	ppm
Ca :	61	ppm

The chloride ions of the cations above were mixed. The spesific conductivity of the water at 20^{O}C:

5.32 S/m