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LABORATORY MEASUREMENTS OF CEMENTATION FACTOR AND SATURATION EXPONENT UNDER RESERVOIR CONDITIONS ON ASAB RESERVOIR ROCK SAMPLES

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ABSTRACT

The evaluation of saturations and thus of oil reserves from resistivity logs requires determination of both the cementation factor (m) and the saturation exponent (n) used in Archie's equation. Special laboratory apparatus using actual fluids (formation brine and crude oil) at reservoir temperature and under effective overburden pressure has been developed. Saturation was varied by the Porous Plate technique adapted for reservoir conditions. Prior to the test the effect of net overburden pressure on porosity and the formation factor was evaluated. For each rock sample, the formation factor and the resistivity index were measured first under room conditions and then under reservoir conditions. In addition, wettability indices were determined using Amott's test.
Data were collected on cores from the five main facies of the Asab Thamama Zone B reservoir.

The restoration of the effective overburden pressure gave a relative increase for m of about 6 % depending on the facies. Under reservoir conditions, the value of n was always higher than under room conditions. This increase of n was attributed to the change in the wetting properties. n increases up to 2.5 as the core becomes more oil-wet.

The consequence of the new m and n values on the calculated Sw is also discussed. Finally this paper emphasizes the need to determine electrical and capillary properties under reservoir conditions.

1. INTRODUCTION

Water saturation in oil reservoirs and hence oil reserves are often calculated from resistivity logs. Representative values of saturation exponent, n, and cementation factor, m, are required for these calculations. The values of coefficients m and n are mainly obtained from laboratory measurements carried out using various techniques under experimental conditions which differ greatly from reservoir conditions (pressure, temperature, effective stress, fluid...). When m and n are obtained under non representative reservoir conditions and applied without correction to interpret resistivity logs, they sometimes lead to Sw values that contradict the ones obtained by other methods (e.g. preserved core analysis or tracer techniques). This is particularly true for carbonate reservoirs which are often heterogeneous and exhibit mixed wet character with more affinity for oil than for water. This is the case for the Asab reservoir, as shown in SCA Paper No. 9109 by L. Cuiec and F.A. Yahya [1]. An evaluation of oil-in-place from resistivity logs was made for this reservoir using a single value of n = 1.69 for all the facies and various values of m from m = 2.20 down to m = 2.00 depending on the facies. Since the reservoir was thought to be partly oil wet, a laboratory research programme was conducted at the French Petroleum Institute (IFP) to evaluate the wettability and electrical properties of rock samples from Asab reservoir, Thamama Zone B.

The first objective was to confirm whether the initial values of m and n coefficients were valid. If significantly different values were found, interpretation of resistivity logs would be improved by using these values assumed to be more representative. The second objective was to investigate the phenomenological dependency of both m and n on various parameters, such as temperature, overburden pressure and wettability.

The experimental work included :

i) determination of wettability using various methods,
ii) porosity and formation factor measurements under stress at reservoir temperature and
iii) resistivity index measurements at reservoir temperature, at effective in-situ stress and using crude oil as displacing fluid.

In addition, formation factors and resistivity index were measured under ambient conditions on the same rock samples prior to these tests. The aim was to compare results under ambient versus reservoir conditions results.

Asab-Thamama Zone B Reservoir is briefly described in SCA paper No. 9109 [1]. Results of the wettability evaluation of selected rock samples from each of the five main facies are also included in Reference 1.

This paper describes the experimental approach used to select representative rock samples for each facies and to measure their electrical properties. The last part also provides an interpretation of these data and a discussion of the practical implications of the results.

2. GENERAL DESCRIPTION OF THE EXPERIMENTAL APPROACH

2.1. Selection of rock samples

A total of 59 plugs (3.9 cm in diameter, 5 to 6 cm in length) were taken horizontally in full-size core samples available from various wells. The zones where the plugs were cored from were selected after CT scanning examination to check their homogeneity.

After the first cleaning in Soxhlet using toluene and toluene-methanol azeotrope, the 59 cores were dried at 80°C and gas permeability and porosity were measured. Then, 25 plugs (five from each of the five facies to be investigated) were selected to represent the average characteristics of each facies. For each set of five plugs, four samples were from the oil zone and one from the water zone (Well Sb-h).

2.2. Electrical measurements under room conditions

The 25 plugs were subjected to a cleaning procedure by injection of toluene followed by successive slugs of isopropyl alcohol and methyl alcohol at 80°C. A total of about 100 pore volumes of solvent was required to obtain a colorless effluent.

After the plugs were dried at 80°C for two days, gas permeability was measured and the samples were pressure-saturated with synthetic formation brine. Prior to resistivity index measurements, electrical resistivity of the fully saturated samples, Ro, was measured. Then, the samples were placed in a "porous plate" cell and water-saturated nitrogen was introduced at increasing incremental pressure up to 45 psi. Equilibrium saturations were determined gravimetrically while the samples were removed from the cell. At the same time, their resistivity, Rt, was measured at each equilibrium point.

Table 1 sums up gas permeability, porosity and formation factor values, with the origin and the depth of each sample. Individual values of cementation factor (m) and saturation exponent (n) are also reported in Table 1.

To represent the resistivity law under room conditions, the standard Archie equation: $I_R = Sw^{-n}$, was used with a constant value for n irrespective of Sw. The value of n was calculated for each sample by linear regression, using the eight measurements plus the origin $I_R = 1$; $Sw = 1$.

2.3. Formation factor measurements under stress at reservoir temperature

The 25 previously studied plugs were tested in an isostatic core-holder cell (axial = radial stress). The core were initially saturated with synthetic formation brine at 20°C, and then the temperature was raised to 121°C (reservoir temperature). Formation factors were measured first with 435 psi effective confining pressure (confining pressure 480 psi, pore pressure 45 psi). Then effective confining pressure was raised by six increments to 4785 psi, while pore pressure was kept constant at 45 psi. The reduction in pore volume was calculated from the volume of brine expelled from the core. Although the loading rate ($d\sigma/dt$) was relatively low, about 150 psi/hour, it was observed that pore volume was not always stabilized at the end of loading. A waiting period of 4 to 12 hours was sometimes needed to reach mechanical equilibrium for the sample under fixed stress. In fact, a serious question arises as to the minimum observation time required under a fixed stress. For the Asab samples, it was assumed that equilibrium was reached if the pore volume remained stable for 24 hours, at fixed stress.

The maximum effective stress applied was 4785 psi (330 bar) on all the samples, corresponding to a load gradient of 0.6 psi/ft. This is similar to the gradient proposed by Glanville in 1959 [2]. However, this value was too high since permanent deformation took place in most of the cores for effective stress of over 2610 psi or 3335 psi depending on the samples. This was attested by the reduction in pore volume versus effective stress curves, as shown for example on Figure 1 (sample M2-4). Isostatic stress, equivalent to reservoir stress was evaluated. A value ranging between 2240 and 2800 psi was found depending on the value of Poisson's ratio (0.2 or 0.3) for an average depth of 8000 ft. This is why the reduction of porosity and the increase in formation factor were taken into account for interpretation only up to 2610 psi of confining pressure (range of elastic deformation). The results are reported in Table 2 and discussed in Section 3.1.

2.4. Resistivity index measurements under reservoir conditions

This part was conducted on one sample per facies assumed to be representative of the facies considered. The equipment and procedure used to a perform resistivity measurements with crude oil were described in a previous paper by Longeron et al. [3]. Let us merely say here that the Porous Plate technique adapted to reservoir conditions was used to vary water saturations. Electrical core conductivity was continuously measured at 4 KHz frequency using a Four-Electrode system. Prior to resistivity index measurements, effective confining pressure of 4785 psi was restored step by step, as for formation factor measurements. As mentioned in 2.3, 4785 psi was too high compared to the estimated equivalent reservoir stress (about 2600 psi). Representativity of the n-value obtained under such stress was questionable since irreversible rock deformation occurred. To clarify this point, an additional test was run at 2610 psi confining pressure on another plug from the M2 facies (sample M2-1D2). The I_R - Sw relationship is plotted on Figure 2 and compared to the one obtained from sample M2-4 at 4785 psi confining pressure. The value of n = 2.37 (sample M2-1D2) is only 5 % lower than the one obtained at 4785 psi (n = 2.50) from sample M2-4. The difference can be attributed to different wetting properties, since sample M2-1D2 was less oil-wet (WI = -0.12) than sample M2-4 (WI = -0.61). However, to confirm how little impact stress has on n, the confining pressure was increased from 2610 psi to 4785 psi for sample M2-1D2 after drainage with crude oil had been completed. A reduction in Swi from 17.2 % to 13.7 %, and an increase in resistivity index were measured (See Figure 2). But it can be observed that both parts of the I_R - Sw relationship, i.e. at σ = 2610 psi and σ over 2610 psi, shown continuity, with no change in slope due to increase in confining pressure. This means that even if damage occurred on the core, it has practically no effect on resistivity index, hence on n.

3. ANALYSIS AND DISCUSSION OF THE RESULTS

Comparing electrical properties mainly serves to identify the influence of stress on porosity and cementation factor and the influence of two different procedures for measuring saturation exponent (room and reservoir conditions).

3.1. Measurements at total water saturation (F_R, ϕ, m)

Under ambient conditions, the values of a and m ($F_R = a.\phi^{-m}$) were calculated for each facies using linear regression based on the five measurements per facies. The values obtained for a were close to 1 (between 0.994 and 1.004). So the equation: $F_R = \phi^{-m}$ (a = 1) was used and the value of m ($m = -\log F_R/\log \phi$) was calculated for each sample. The average value of m ($\overline{m}$) was then determined by calculating the arithmetic mean of the 5 values per facies. Table 2 gives individual values of ϕ and m per sample at the four effective stress levels, the average value, $\overline{m}$, and corresponding standard deviation.

To summarize the data, the values of $\overline{m}$ obtained in room conditions and at the four levels of confining pressure are compared in the following Table.

Room Conditions $\sigma = 0$, T = 20°C		Confining Pressure and T = 121°C			
Facies	$\overline{m}$ (1)	$\sigma = 435$ psi $\overline{m}$ (2)	$\sigma = 1160$ psi $\overline{m}$ (3)	$\sigma = 1885$ psi $\overline{m}$ (4)	$\sigma = 2610$ psi $\overline{m}$ (5)
M1	1.86	1.84	1.84	1.85	1.87
M2	1.79	1.79	1.80	1.82	1.82
R2	1.75	1.74	1.78	1.81	1.84
M3A	1.74	1.78	1.80	1.82	1.84
LM	1.69	1.71	1.73	1.77	1.79

In room conditions, the value of $\overline{m}$ per facies decreased with increasing depth. The values of m are properly classified according to the order of the facies in the reservoir: M1, M2, R2, M3A, LM. This observation is not confirmed under overburden pressure, because at 2610 psi stress and 121°C, facies classification order according to the values of m is M1, R2, M3A, M2 and LM.

Restoring of reservoir temperature (121°C) did not affect the values of m (comparison of $\overline{m}$ (1) and $\overline{m}$ (2)). This agrees with what is generally assumed for non shaly samples.

Restoring effective stress of 2610 psi had little effect on the value of $\overline{m}$ of facies M1 and M2 ($\overline{m}$ increased by 0.03). On the other three facies, however, the increase was greater (0.06 to 0.10). Figure 3 compares the values of m obtained in this study and the values initially used to interpret logs. The values measured at IFP tended to confirm the trend (decrease in m with depth) observed for the previous values.

The difference between IFP values (corresponding to estimated reservoir conditions, σ = 2610 psi, T = 121°C) and previous values is given below.

Facies	$\overline{m}$ values IFP	$\overline{m}$ values Previous	$\Delta m/m$, %
M1	1.87	2.20	- 15 %
M2	1.82	2.15	- 15 %
R2	1.84	2.15	- 14 %
M3A	1.84	2.05	- 10 %
LM	1.79	2.00	- 11 %

Using IFP values for m (lower) would lead to lower calculated values of Sw, all other things remaining equal. However, this effect is largely offset by the change in the value of n, as we will show in Section 4.

The average reduction in porosity, per facies, calculated for stress increasing from 435 psi to 2610 psi is given below.

Facies	ϕ_o (435 psi)	$\bar{\phi}$ (2610 psi)	$\frac{\bar{\phi}}{\bar{\phi}_o}$	$\Delta\phi = \bar{\phi}_o - \bar{\phi}$ (%)
M1	21.3 %	20.8 %	0.976	0.5
M2	29.4 %	28.5 %	0.969	0.9
R2	27.8 %	26.9 %	0.968	0.9
M3A	29.4 %	28.8 %	0.980	0.6
LM	28.9 %	28.3 %	0.979	0.6

It can be observed that facies M2 and R2 are the most compressible. They are the ones that have the greatest core compaction coefficient, $\bar{\phi}/\bar{\phi}_o$, about 0.97.

3.2. Measurements at variable water saturation (I_R, n)

- **Measurements under room conditions**

The saturation exponent, n, varies from one sample to another for a given facies (see Table 1). In addition, the n-value for the sample from the water zone was often lower than the values for the other 4 samples from the oil zone (facies M1, M2, M3A). This is why the average n-values (room) were calculated using only the four samples from the oil zone to compare n (ambient) and n (reservoir). The table below gives these values,with the average values of wettability index, $\overline{W}I$, measured on 10 cleaned cores (two per facies - See Reference 1)

Facies	$\bar{n}$	$\overline{W}I$ (after cleaning)
M1	1.85	+ 0.07
M2	1.61	+ 0.04
R2	1.52	+ 0.28
M3A	1.75	+ 0.20
LM	1.84	+ 0.48

The variation in $\bar{n}$ is essentially due to the influence of pore structure. Yet it may also be partly due to a rock surface condition different since the wettability index, $\overline{W}I$, varies from one facies to another. The samples from facies M1 and M2 display neutral behavior (WI ~ 0) despite intensive cleaning. Meanwhile, the other facies rock is slightly water-wet (WI between 0.20 and 0.48).

- **Measurements under reservoir conditions**

Before n was measured under reservoir conditions the samples were initially cleaned to make them as water wet as possible. Reservoir conditions were restored during drainage with reservoir oil. Many investigations [4,5] show that, in most cases, the rock/fluid equilibrium is rapidly reached (about 100 hours). Consequently, it seems legitimate to assume that the surface state of the rock has been restored after 32 to 37 days of drainage at the reservoir temperature. Yet it is not certain that the rock/fluid equilibrium is reached in the intermediate stages. This is why the n-value was calculated under reservoir conditions from the slope of line I_R/S_w passing through the origin ($I_R = 1$, $Sw = 1$) and the last measurement point. An example is shown on Figure 4 (Sample M2-4, n = 2.50).

The table below compares the values of saturation exponent and wettability index under room conditions and reservoir conditions.

Sample	Room conditions		Reservoir conditions	
	WI (after) cleaning)	n	WI (after restoration)	n
M1-1	+ 0.07	1.82	- 0.57	2.53
M1-4	+ 0.07	1.75	- 0.11	not measured
M2-1	- 0.02	1.52	- 0.15	not measured
M2-4	+ 0.07	1.66	- 0.61	2.50
R2-2	+ 0.20	1.48	- 0.25	2.21
R2-4	+ 0.37	1.48	+ 0.02	not measured
M3A-2	+ 0.06	1.68	- 0.11	not measured
M3A-4	+ 0.34	1.77	- 0.51	1.96
LM-2	+ 0.31	1.88	+ 0.10	not measured
LM-4	+ 0.65	2.06	+ 0.07	2.27

Under reservoir conditions, the value of n varied from one sample to the next, but was always higher than that obtained under room conditions on the corresponding sample (See Fig. 4 for sample M2-4). Since stress seems to have a negligible effect on resistivity, the significant increase in n, from 9 to 34 %, is mainly due to the restored cores' greater affinity for oil as compared to cleaned cores. This is reflected by a decrease in the corresponding wettability index values. The increase in saturation exponent as the rock becomes more oil wet has been observed for many years by a number of researchers [3, 6-10]. It was observed that if the core is oil wet, the water - which is the conducting phase - is less well connected than if the rock is water wet. This leads to an increase in core resistivity.

Figure 5 gives the n-values as a function of wettability index (WI) for the five samples analyzed (one per facies). The arrow shows the direction of change when conditions change from ambient to reservoir. The points corresponding to each sample are arbitrarily connected by lines. Also shown are the values of n and WI obtained under room conditions on the five additional samples initially selected. No measurements of n under reservoir conditions are available for this second batch of samples.

- **Attempt to average the results**

The main drawback of this study stems from the limited number of samples investigated for measurements of n under reservoir conditions (one per facies). This is obviously due to the time and cost involved in these measurements.

However, to estimate a probable value of n per facies, we attempted to make maximum use of available measurements, namely :

- 10 wettability evaluations, after cleaning and after restoration (two per facies).
- 20 measurements of n under room conditions : (four per facies).
- 5 measurements of n under reservoir conditions (one per facies).

The wettability data, after cleaning and after restoration, are summarized in the Table below. Three groups were finally formed for the five facies based on the similar variation in WI values measured on cleaned and restored cores, as shown below.

Sample	$\overline{W}I$ After cleaning			$\overline{W}I$ After restoration		
M1-1	+ 0.07	$\overline{W}I$ = + 0.07	$\overline{W}I$ = + 0.05	- 0.07	$\overline{W}I$ = - 0.34	$\overline{W}I$ = - 0.36
M1-4	+ 0.07			- 0.11		
M2-1	- 0.02	$\overline{W}I$ = + 0.04		- 0.15	$\overline{W}I$ = - 0.38	
M2-4	+ 0.07			- 0.61		
R2-2	+ 0.20	$\overline{W}I$ = + 0.28	$\overline{W}I$ = + 0.24	- 0.25	$\overline{W}I$ = - 0.13	$\overline{W}I$ = - 0.22
R2-4	+ 0.37			+ 0.02		
M3A-2	+ 0.06	$\overline{W}I$ = + 0.20		- 0.11	$\overline{W}I$ = - 0.31	
M3A-4	+ 0.34			- 0.51		
LM-2	+ 0.31	$\overline{W}I$ = + 0.48		+ 0.10	$\overline{W}I$ = + 0.09	
LM-4	+ 0.65			+ 0.07		

To calculate the mean value of n per group, we assumed a linear variation of $\overline{n}$ versus $\overline{W}$ I, as previously suggested by Morgan [7] and by Donaldson [9]. Based on the three linear WI/n relationships, a value of $\overline{n}$ was obtained per facies under reservoir conditions by interpolation from the mean values of WI calculated on restored cores (see Figure 6).

The average values of WI and n adopted for each group are given hereunder and reported in Figure 6.

Group	Room Conditions (cleaned samples) $\overline{W}I$	Room Conditions (cleaned samples) $\overline{n}$	Reservoir Conditions (restored samples) $\overline{W}I$	Reservoir Conditions (restored samples) $\overline{n}$
M1 M2	+ 0.05	1.73	- 0.36	2.22
R2 M3A	+ 0.24	1.64	- 0.22	1.94
LM	+ 0.48	1.84	+ 0.09	1.98

- **Influence of the values of m and n on Sw calculations**

We now compare the values of Sw, facies by facies, calculated with a), the values of m and n previously adopted, and, b) the values of $\overline{m}$ and $\overline{n}$ obtained in this study. Note that the influence of m reduced that of n in calculating of Sw. This is because the respective values of these coefficients vary in opposite directions. A decrease in m tends to reduce the calculated value of Sw, while an increase in n tends to increase it. This is illustrated below according to the analysis by Mahmood et al [11] and derived from a more general analysis by Chen and Fang [12]. The following two equations give the relative error on Sw due to the error made in measuring m and n :

$$\left[\frac{\Delta\, Sw}{Sw}\right]_m = -\frac{\Delta m}{n} \operatorname{Log} \phi$$

$$\left[\frac{\Delta\, Sw}{Sw}\right]_n = -\frac{\Delta n}{n} \operatorname{Log} Sw$$

By way of example, the values of the terms (Δ Sw/Sw)m and (Δ Sw/Sw)n for an arbitrary value of Sw = 10 %, and for an average porosity per facies are given below. The minus sign indicates that Sw is overestimated, and the plus sign indicates that Sw is underestimated.

Effect of m and n values for a given value of Sw = 10 %

Facies	Cementation factor, m		Saturation exponent, n		Average ϕ (%)	$\left[\frac{\Delta Sw}{Sw}\right]_m$	$\left[\frac{\Delta Sw}{Sw}\right]_n$	Calculated Sw (%)
	Previous values	This study	Previous values	This study				
M1	2.20	1.87	1.69	2.22	20.8	- 0.31	+ 0.72	14.1
M2	2.15	1.82	1.69	2.22	28.5	- 0.25	+ 0.72	14.7
R2	2.15	1.84	1.69	1.94	26.9	- 0.24	+ 0.35	11.1
M3A	2.05	1.84	1.69	1.94	28.8	- 0.15	+ 0.35	12.0
LM	2.00	1.79	1.69	1.98	28.3	- 0.15	+ 0.35	12.0

This table shows that an actual value of Sw can be obtained, ranging between 14.7 % and 11.1 %, instead of 10 %, depending on the facies. To illustrate the impact of the new values of m and n at various Sw levels, a calculation was made using the resistivity of the formation brine at reservoir temperature (Rw = 0.02 Ωm). The values of Sw_2, calculated with m and n values from this study, are plotted on Figure 7 versus Sw ranging between 0 and 20 %. This figure shows that unrecognized variation in m and n coefficients can induce an underestimation of Sw, hence an overestimation of So up to about five saturation units for facies M1 and M2. There is a less difference for facies LM and M3A and practically none for facies R2. Yet it should be noted that these calculations used average values of n estimated per group of facies. These differences in saturation would be greater if the value of n measured under reservoir conditions on a single sample per facies had been used.

CONCLUSIONS

The main conclusions are valid for the investigated zone of Asab Reservoir and can be summarized as follows:

- **Cementation factor, m**

1. The average cementation factor value measured under room conditions decreases with increasing depth, from 1.86 to 1.69, depending on the facies.

2. The restoration of reservoir temperature (121°C) at moderate confining pressure does not affect the value of m.

3. The application of an effective isostatic stress of 2610 psi gives a core compaction coefficient of about 0.97 and a maximum relative increase of m, (Δ m/m), of about 6 %. This gives to m-values in the range of 1.87 to 1.79.

4. These new values are about 10 % lower than the ones previously adopted to interpret resistivity logs. The work done in this study has been unable to explain this difference.

- **Saturation exponent, n**

5. The average value of n measured under room conditions varies from 1.52 to 1.85, without any particular trend with depth.

6. The value of n is always higher measured under reservoir conditions, than under room conditions on the same sample. This increase in n, from 9 to 34% , is mainly attributed to the change in wettability from cleaned to restored cores. After the surface state is restored, the affinity for oil increases appreciably for all samples.

7. The five facies investigated were classified in three groups by using a criterion based on the variation in wettability index measured on cleaned cores and on restored cores. The following average values were found for $\bar{n}$ under reservoir conditions :

M1 and M2 facies	:	$\bar{n}$ = 2.22
R2 and M3A facies	:	$\bar{n}$ = 1.94
LM facies	:	$\bar{n}$ = 1.98

8. Using these $\bar{n}$-values gives higher Sw values than the ones calculated with n = 1.69. But this effect is partly offset by the effect of the decrease observed for the cementation factor.

9. Finally, using the m and n-values obtained in this study can induce various corrections for oil saturation, of up to five saturation units depending on the facies.

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through the contact of matrix material and "interlocking" of asperities in fractures/cleats.

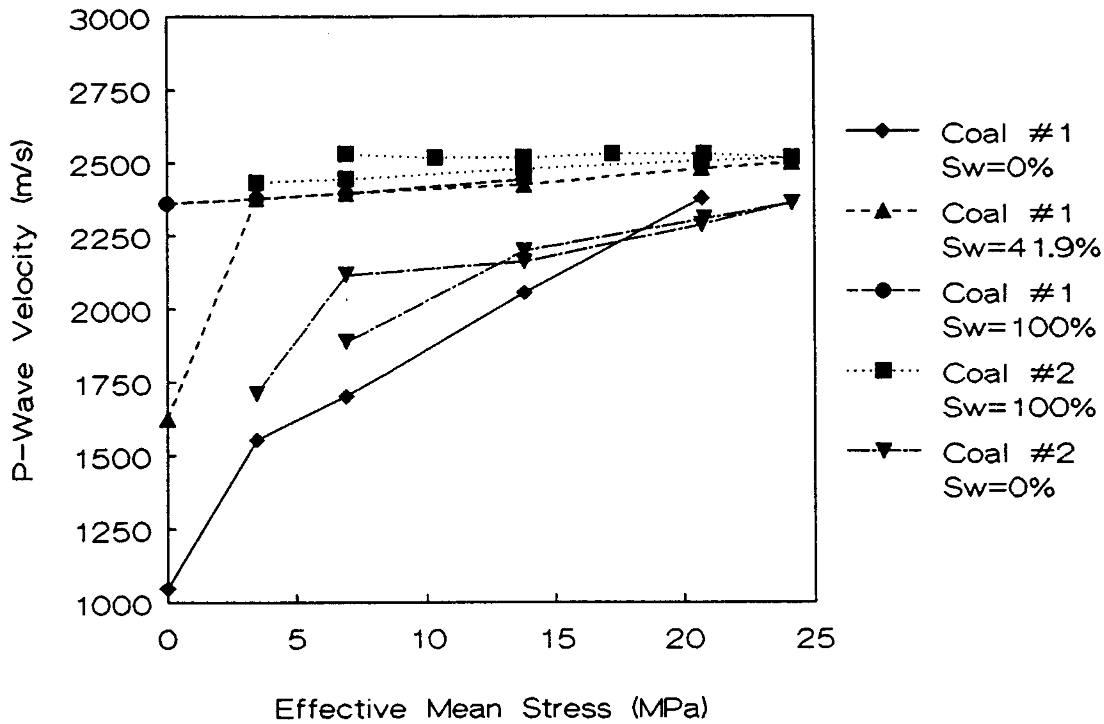

Figure 8. P-wave velocity as a function of effective stress.

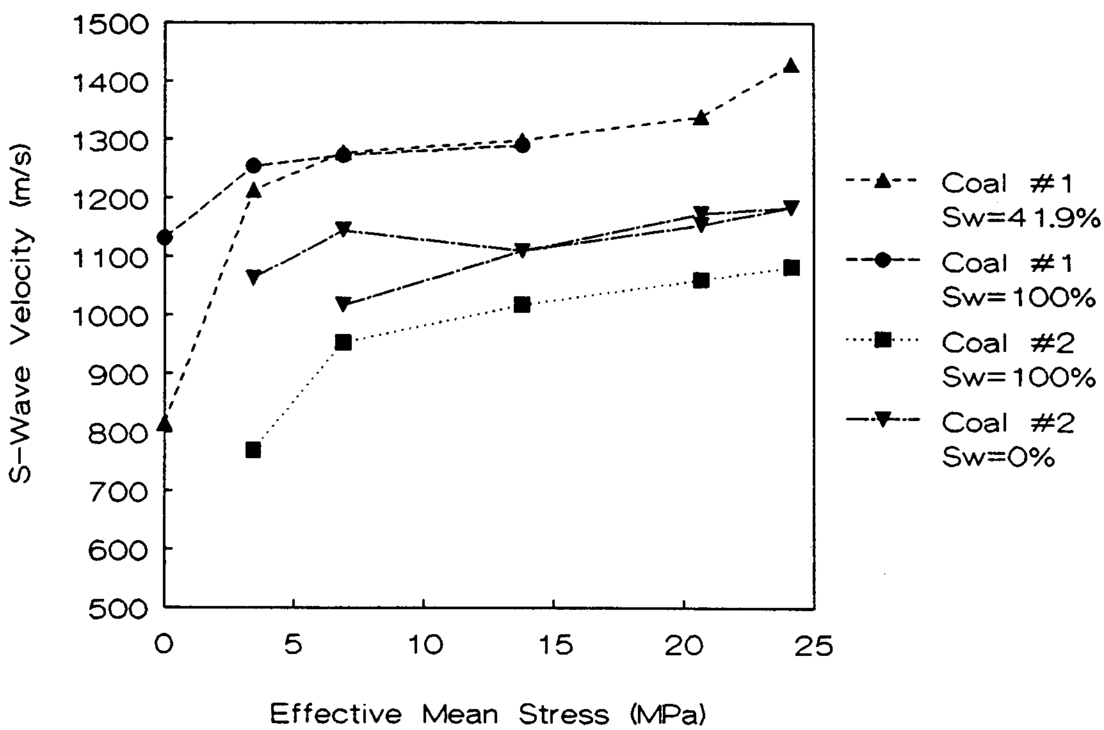

Figure 9. S-wvae velocity as a function of effective stress.

Table 2
Formation factor and porosity measurements under stress
T = 121°C

Sample	NET OVERBURDEN PRESSURE							
	σ = 435 psi		σ = 1160 psi		σ = 1885 psi		σ = 2610 psi	
	Ø (%)	m	Ø (%)	m	Ø (%)	m	Ø (%)	m
M1-1	18.5	1.95	18.3	1.95	18.1	1.96	18.0	1.98
M1-2	22.1	1.81	22.0	1.81	21.9	1.82	21.8	1.82
M1-3	25.3	1.79	25.1	1.80	25.0	1.80	24.9	1.81
M1-4	21.8	1.82	21.6	1.84	21.5	1.85	21.2	1.88
M1-5	18.8	1.82	18.5	1.82	18.3	1.84	18.2	1.85
	$\bar{m}$ = 1.84	S.d. = 0.06	$\bar{m}$ = 1.84	S.d. = 0.05	$\bar{m}$ = 1.85	S.d. = 0.06	$\bar{m}$ = 1.87	S.d. = 0.06
M2-1	28.6	1.83	28.3	1.86	28.0	1.87	27.7	1.87
M2-2	32.0	1.71	31.8	1.72	31.6	1.77	31.4	1.78
M2-3	31.2	1.72	31.2	1.73	31.1	1.75	31.0	1.76
M2-4	31.0	1.93	30.7	1.93	30.4	1.93	30.1	1.93
M2-5	24.1	1.75	23.8	1.76	22.8	1.77	22.4	1.77
	$\bar{m}$ = 1.79	S.d. = 0.08	$\bar{m}$ = 1.80	S.d. 0.08	$\bar{m}$ = 1.82	S.d. = 0.07	$\bar{m}$ = 1.82	S.d. = 0.07
R2-1	32.7	1.71	32.5	1.73	32.2	1.78	32.2	1.83
R2-2	28.5	1.80	28.2	1.83	28.0	1.87	27.8	1.89
R2-3	31.6	1.80	31.4	1.86	31.2	1.90	31.0	1.96
R2-4	27.6	1.70	27.1	1.73	26.9	1.76	26.4	1.80
R2-5	18.6	1.71	18.4	1.73	17.7	1.73	17.1	1.73
	$\bar{m}$ = 1.74	s.d. 0.05	$\bar{m}$ = 1.78	S.d. = 0.06	$\bar{m}$ = 1.81	S.d. = 0.07	$\bar{m}$ = 1.84	S.d. = 0.07
M3A-1	29.4	1.82	29.3	1.86	29.2	1.90	29.0	1.91
M3A-2	28.4	1.78	28.1	1.80	28.0	1.80	27.9	1.81
M3A-3	32.7	1.80	32.2	1.84	31.6	1.88	31.0	1.94
M3A-4	30.4	1.80	30.2	1.80	30.1	1.82	30.0	1.83
M3A-5	26.3	1.68	26.2	1.69	26.2	1.71	26.1	1.72
	$\bar{m}$ = 1.78	S.d. = 0.05	$\bar{m}$ = 1.80	S.d. = 0.06	$\bar{m}$ = 1.82	S.d. 0.07	$\bar{m}$ = 1.84	S.d. = 0.07
LM-1	32.3	1.64	32.2	1.68	32.1	1.73	32.0	1.76
LM-2	30.8	1.66	30.5	1.68	30.4	1.73	30.2	1.76
LM-3	29.7	1.69	29.5	1.73	29.3	1.77	29.2	1.79
LM-4	32.3	1.86	32.0	1.89	31.8	1.92	31.5	1.93
LM-5	19.4	1.68	19.0	1.69	18.9	1.70	18.8	1.70
	$\bar{m}$ = 1.71	S.d. = 0.08	$\bar{m}$ = 1.73	S.d. 0.08	$\bar{m}$ = 1.77	S.d. = 0.07	$\bar{m}$ = 1.79	S.d. = 0.07

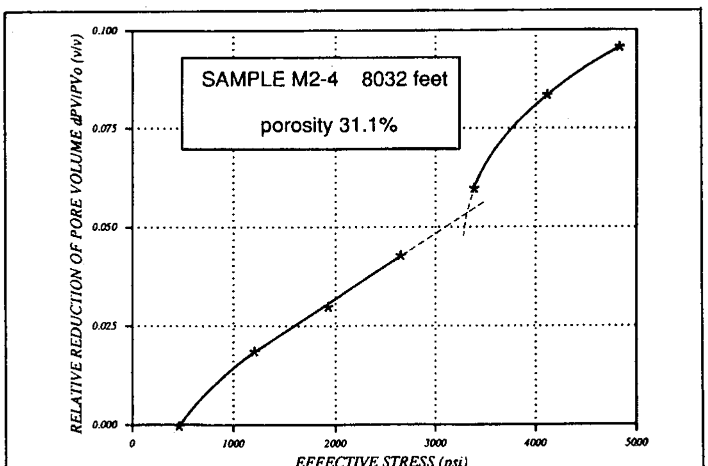

Fig. 1 : *Effect of stress on the reduction of pore volume. The discontinuity above 2610 psi indicates a permanent deformation of the core.*

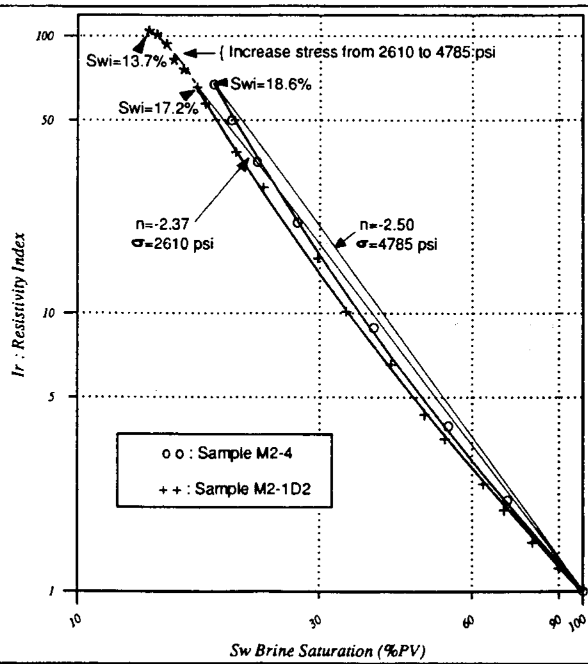

Fig. 2 : *Resistivity Index versus Sw for two levels of confining pressure. n = 2.50 at σ = 4785 psi and n = 2.37 at σ = 2610 psi.*

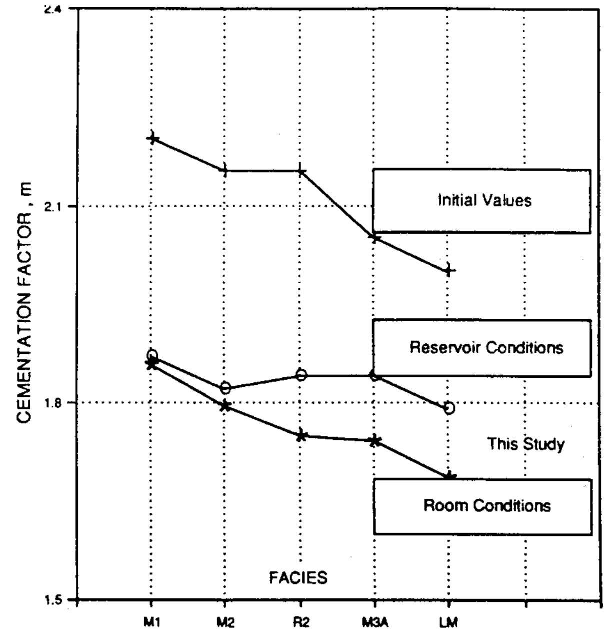

Fig. 3 : *Comparison of Cementation Factor values (5 samples per facies)*

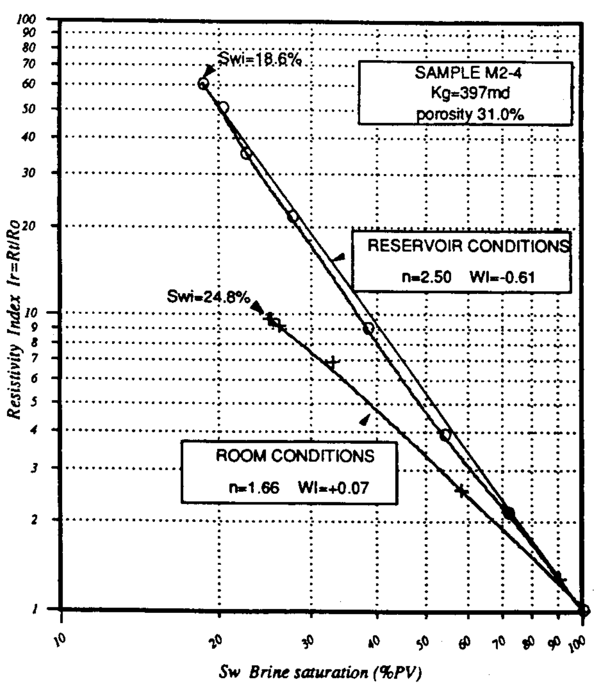

Fig. 4 : *Comparison of I_R vs. Sw at Room and at Reservoir Conditions. This figure illustrates the increase of n when the core, initially neutral (WI = + 0.07) becomes oil wet (WI = - 0.61)*

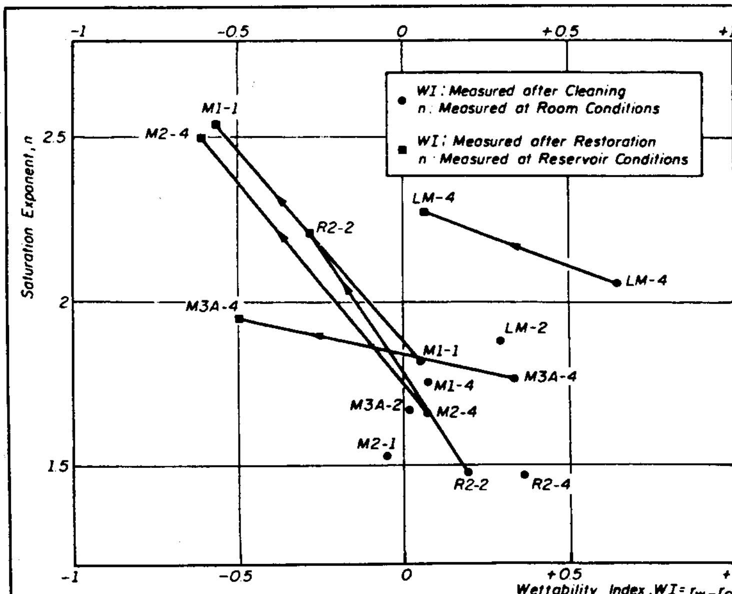

Fig. 5 : *Saturation Exponent vs. Amott Wettability Index for all samples*

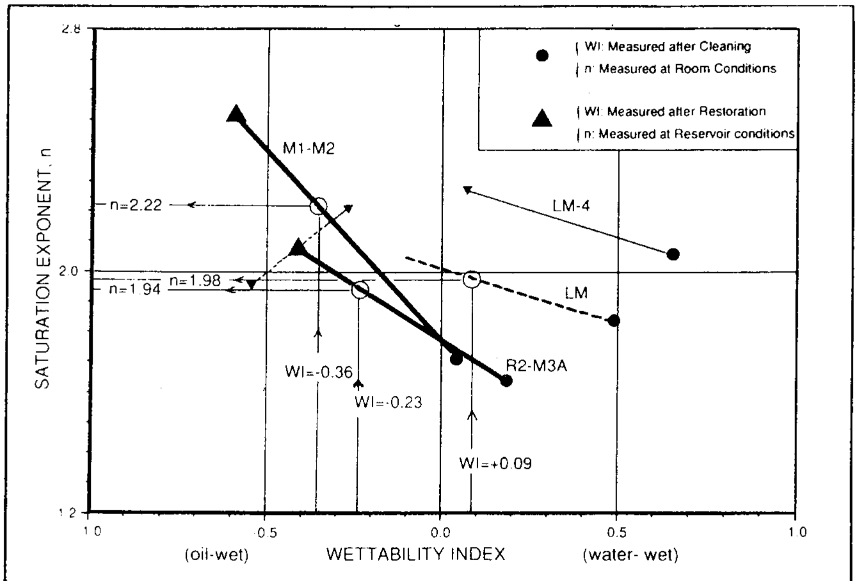

Fig. 6 : *Evaluation of an average Saturation Exponent value for each group of facies*

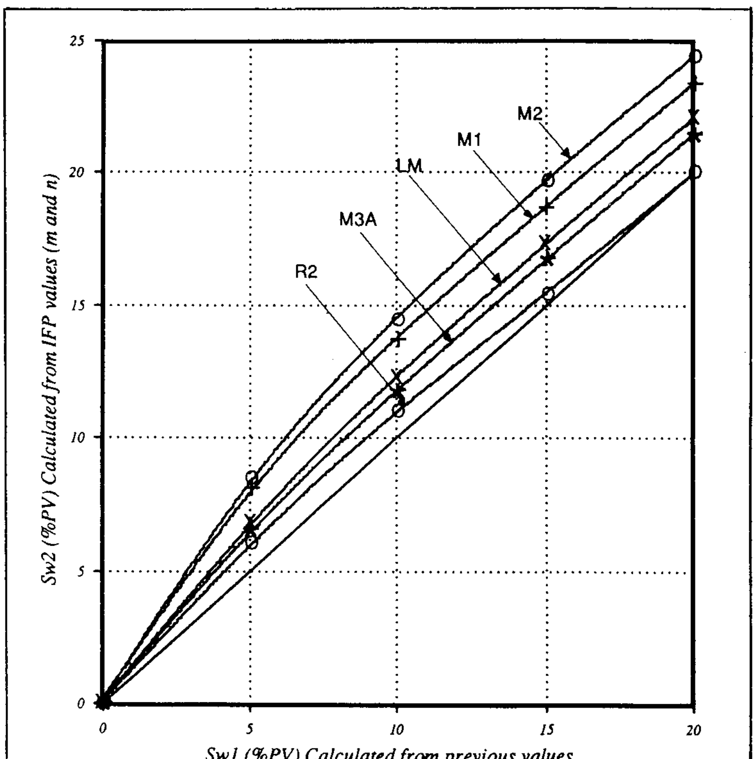

Fig. 7 : *Effect of m and n on calculated Sw values*