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WETTABILITY OF ASAB RESERVOIR ROCK : COMPARISON OF VARIOUS EVALUATION METHODS ROLE OF LITHOLOGY

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ABSTRACT

Wettability of carbonate reservoirs has long been recognized to be quite often not strongly affirmed for water.

In the present paper, the wettability of the Asab Thamama Zone B reservoir is broadly investigated. First, various evaluation methods have been compared. They are based on contact angle, n-heptanol adsorption, and spontaneous and forced displacement measurements. Secondly, the wettability of samples from various facies of the reservoir considered has been evaluated upon reception (preserved), after cleaning and after restoration.

The results have shown that the wettability evaluation does not depend on the method.

The wettability was found to have a heterogeneous nature (mixed wettability), and to be, on the whole, neutral to strongly preferential to oil from bottom to top.In spite of a quite complex cleaning procedure, it was impossible to bring the rock from some facies to strong water wetness.Finally, it was established that it is possible to restore the original surface properties by cleaning, saturation with reservoir fluids and aging.

INTRODUCTION

The importance of the wettability parameter has long been recognized (1-3). It controls the distribution of fluids. Consequently, it affects resistivity measurements used for the assessment of oil reserves (4) and kr/Pc measurements used for the prediction of oil production (1). Likewise, the obtaining of reliable data requires the use of representative reservoir rock samples.

Such representative reservoir rock samples can be obtained in two ways :
- by preserving the original surface properties (5),
- by restoring the original surface properties (3).

The first method needs to avoid any contamination with the drilling mud, not to have asphaltene or wax deposits during sampling, to avoid oxidation and contamination during handling, etc.The second method requires cleaning the sample and reestablishing fluid saturation, rock/fluid and fluid/fluid equilibria.

Before selecting the type of samples to be used for some special core analyses, it is recommended to evaluate the wettability of reservoir rock samples upon reception, after cleaning and after restoration. From such a study, the representativity of preserved samples can be evaluated, and a restoration procedure (including type of cleaning, aging time, etc.) can be

proposed, if necessary. In some cases, i.e., the use of composite cores, preserved samples unavailable or a series of experiments to be performed with a given sample, the restoration procedure is the only possibility. This problem is discussed in Reference 3.

Wettability can be evaluated by using various methods (3), based on the measurement of : contact angle, capillary pressure/saturation relationship, fluid recovery by spontaneous and forced displacements, etc.

In the scope of a large-scale special core analysis investigation of the Asab reservoir, the following experimental program concerning wettability was performed :

- comparison of various evaluation methods (contact angle, n-heptanol adsorption, Amott/IFP test under various conditions) and,
- evaluation of the wettability of samples from the various facies selected (upon reception, after cleaning and after restoration).

THE ASAB RESERVOIR

The Asab field is located in Abu Dhabi, United Arab Emirates, approximately 150 kilometers southwest of Abu Dhabi City. Figure 1 gives the structural contours of the top of Zone B.The Asab structure is approximately 30 km long and 10 km wide. Production has been established from the Lower Cretaceous carbonates of the Thamama group in Zones A, B and C. Zone B is the most important concerning oil initially in place, cumulative oil production and oil production rate.

The Thamama Zone B has been divided into six facies (Figure 2), subdivided into 12 layers. In the present study, samples from five facies, M1, M2, R2, M3 A and LM, were investigated (facies R1 was discarded).Some characteristics of the different facies are summarized in Appendix 1.

The selection of the samples was made after X-Ray Scanner, thin-section and SEM analyses of all available core samples and after measurement of the petrophysical characteristics. The wells where the samples come from are located in Figure 1.These wells were also selected for the study related to electrical measurements (see 1991 SCA Conference Paper number 9117 by D. Longeron and F. A. Yahya).

EXPERIMENTAL

- Comparison of wettability evaluation methods

This comparative study was performed on pieces of rock taken from the same core.sample This core was received perfectly wrapped so as to preserve the rock and its content from contact with the atmosphere. The core sample was from well Sb-a, depth 8038'8" - 8939'5", facies M2. It was found to be homogeneous by X-ray Scanner analysis.

The brief lithological description of a small sample taken from the top of the core sample consiudered is as follows: wackestone-packstone, microvugs, porous.The porosity of this small plug is 33.2% and the horizontal gas permeability is 104 mD.

Figure 3 shows the procedure adopted for the sampling.

Contact angle method

Two slices of rock were cut, using air as the bit lubricant. They were divided into four quarters.Various experiments were carried out at 85°C using such quarters . Asab stock-tank oil, previously topped at 85°C, and reconstituted brine, were used. The characteristics of the fluids are given in Table 1.

n-heptanol method

This method is described in Appendix 2.

The piece of rock selected for this evaluation was divided in two parts. One was used directly as "preserved", the other one was cleaned and restored.Restoration was performed using the cleaning procedure described in Appendix 4, followed by a saturation with brine, a flood with stock tank oil and aging for one week at 85°C.

Amott / IFP method

This method is described in Appendix 3.

The evaluation was made using a "restored" sample and three types of experimental conditions:

1. T = 85°C (185°F), fluids: topped Asab stock tank oil and synthetic brine,
2. T = 25°C (77°F), fluids: refined oil and synthetic brine,
3. T = 121°C (250°F) (res.temp.), fluids: Asab recombined oil and synthetic brine.

Restoration was performed as indicated previously.

The samples were chosen as shown in Figure 3. For the first two cases, the same sample was used. Its dimensions were as follows: diameter = 3.9 cm, length = 6 cm. The cylindrical face of the sample was coated with a heat-shrinkable PTFE sleeve. For the third case, the dimensions of the sample were: diameter = 5 cm, length = 10 cm.

- Evaluation of the wettability as a function of the facies

This evaluation was made using the Amott / IFP method at 85°C, described in Appendix 3, with topped Asab stock-tank oil and synthetic brine.

Two preserved samples from each facies were selected. Considering the number of experiments to be performed successively on each sample and the poor quality of consolidation, the cylindrical face of the ten samples was maintained with a heat-shrinkable PTFE sleeve.The list of samples is given in Table 2.

The experiments were performed as follows:

- removal of the gas phase by crude oil flooding, under pressure,
- wettability upon reception ("preserved"),
- cleaning (see Appendix 4),
- saturation with synthetic brine and flooding with viscous refined oils (Marcol 172 followed by Marcol 52),
- wettability test after cleaning,
- cleaning,
- saturation with synthetic brine and flooding with Asab topped stock-tank oil,
- aging for one week at 85°C
- wettability after restoration.

RESULTS AND DISCUSSIONS

- Comparison of various evaluation methods

Contact angle

When a drop of oil was deposited on the rock surface (of a preserved sample), it spread and was immediately imbibed . On the contrary, when a drop of brine was deposited on the rock surface, it did not spread or become imbibed. A contact angle of 60 to 80° was obtained. Such

experiments indicate that the affinity of the rock for water is quite small, and that the rock has more affinity for oil.

Another piece of rock was submerged in topped stock-tank oil at 85°C, in a closed bottle for several weeks so as to displace as much gas as possible by oil. Then, a drop of brine was deposited on the solid. It did not spread and a contact angle of about 90° was obtained. Similarly, the gas was displaced by brine and a drop of oil was deposited. It spread and the contact angle was quite low.

Similar experiments were performed with pieces of rock previously restored (cleaning, saturation with reservoir fluids and aging). The results were identical to the previous ones.

Experiments were also performed with oil and brine on preserved surfaces. When a drop of Asab crude oil was deposited on the rock submerged in brine, the contact angle was about 45° immediately after the deposit, and about 80° after equilibrium. When a drop of brine was deposited on the rock submerged in oil (refined oil to determine the contact angle), the contact angle was immediately close to 90° and remained at this value.

From these last two experiments, the wettability of Asab reservoir rock must be considered to be neutral.

n-heptanol test
The main results were:

preserved rock (cleaned only with cyclohexane), 78% of the rock surface must be considered to be oil wet.
restored rock (cleaned only with cyclohexane), 62% of the rock surface must be considered to be oil wet.

These results show the heterogeneous nature of the rock wettability, with a preferential affinity for oil on the whole.

But, only one experiment of each type was performed (preserved and restored), with two different samples. Due to the heterogeneous nature of the wettability properties, more experiments would have been necessary to evaluate the influence of the scale of this heterogeneity on the results of the n-heptanol test. Consequently, the difference in the values (62 and 78%), giving the size of hydrophobic surfaces, might not be very significant.

Amott / IFP method
The results are given in Tables 3 to 5. Whatever the experimental conditions, spontaneous displacements of oil by brine and of brine by oil were obtained, indicating mixed wettability (6).

The volumes recovered were always similar and in the 1.3 - 4.2% PV range . The affinity of the sample investigated for oil and for water is similar.

From the results obtained in these three wettability tests, it may be concluded that the wettability of the rock investigated (after "restoration" of the surface properties) is not affected by:
- the nature of the oil (refined oil, topped stock-tank oil or recombined oil) ;
- the thermodynamic conditions (T = 25, 85 or 121°C and P = atm. press. or 204 bar).

As a consequence, in this case, adsorption phenomena do not seem to be involved in explaining the wettability properties of the rock after restoration. The nature of the rock surface, independently of the water/oil system might have to be considered.

Likewise, the results of this study can be summarized as follows (see Table 5):

- For the core sample investigated, the wettability must be considered to be neutral.
- Whatever the method, the result is similar or close.
- The best agreement is obtained with the Amott/IFP method when the contact angle is measured under the most reliable conditions (oil/water system).
- From the Amott/IFP test, additional information is obtained: both spontaneous displacements of oil by water and water by oil are possible (between 1.3 and 4.2% PV). But the recoveries were smaller than the ones obtained for the M2 facies samples investigated in the second part of this paper. This shows that samples from a given facies, taken from the same well, at close depths (about 7 ft difference), may behave somewhat differently.
- The nature of the oil (refined, dead oil, recombined oil) does not affect the wettability evaluation.
- The thermodynamic conditions (T from 25 to 121°C - 77 to 250°F, and pressure from atmospheric pressure to 204 bar - ~3000 psi) do not affect the wettability.

Considering both the previous two results (no influence of the nature of the oil and of the thermodynamics conditions on wettability and, the neutral wettability obtained after a quite complex and long cleaning procedure (see previous section), it may be assumed that the neutral wettability obtained for the M2 sample investigated in the present section is mainly due to the rock surface properties and not to the adsorption of polar components contained in the stock -tank oil used in the restoration process.

- When a given method is used, the wettability evaluation is not very different for preserved and restored samples.

- **Evaluation of the wettability of samples from the five facies selected**

This evaluation was made for two samples from each facies, upon reception, after cleaning and after restoration. The Amott/IFP method was adopted, under the following conditions: 85°C, atmospheric pressure. For the tests upon reception and after restoration, topped Asab stock tank oil was used. For the test after cleaning, a refined oil (Marcol 52) was used.

The origin of the samples as well as their petrophysical characteristics (obtained after cleaning) are given in Table 2.

The oil spontaneously displaced by brine (in % PV) and the brine spontaneously displaced by oil (in % PV) are given in Figures 4 to 6, for the three wettability evaluations respectively (upon reception, after cleaning and after restoration). The wettability indices are given in Figure 7.

Upon reception, the spontaneous displacement of one fluid by the other is always possible in both directions. This is not linked to the influence of gravity forces on spontaneous displacement. Interfacial tension has a standard value (about 23 mN/m) and the permeability is not high in most cases.

Likewise, upon reception we can notice that:

- The wettability of all samples for the five facies is heterogeneous, and of the ***mixed*** type, with continuous oil wet and water wet surfaces.
- The wettability of the samples from facies M1 is, on the whole, clearly preferential to oil.

- The samples from facies M2, R2, M3A and one sample from LM (LM.2) have, on the whole, a wettability preferential to oil, but at a lower level than for facies M1.
- For the second sample from facies LM (LM.4), the wettability is, on the whole, slightly preferential to water.

After cleaning, during imbibition in oil, brine recovery is nil or almost nil for 4 samples and low for the last six samples.Finally, after cleaning, the wettability is as follows:

- samples from facies M1 : neutral (but $I_W > I_O$)
- samples from facies M2 : neutral
- samples from facies R2 : slightly to strongly water wet
- samples from facies M3A : one neutral, one strongly water wet
- samples from facies LM : strongly water wet.

After restoration, the results can be interpreted as follows:

- The spontaneous displacement of one fluid by the other one is possible in both directions in 8 out of 10 cases. Consequently, the wettability must be considered as heterogeneous in these 8 cases (or "***mixed***").
- Samples from facies M1, M2 and M3A have, on the whole, a slight-to-strong preferential affinity for oil.
- Samples from facies R2 have either a moderate preferential affinity for oil or no preferential affinity for either of the two fluids.
- Samples from facies LM have a slight preferential affinity for water.

Additional work using thin-sections, Scanning Election Microscopy (SEM) and Cryo-SEM analyses would probably enable an interpretation to be made concerning the wettability / facies relationship . Promising preliminary results have already been obtained in this field.

Comparison of wettability upon reception and after restoration

The wettability upon reception was evaluated with samples taken from well preserved pieces of core samples. In addition, the pieces of cores considered were drilled with a nondamaging coring fluid (a water-base mud) containing fine calcium chloride, HEC (polymer), magnesium oxide and brine water. Maximum care was taken during handling in the laboratory. As a consequence, reasonable motives exist to consider the surface properties upon reception to be representative of the ones in situ.

In spite of the complex cleaning procedure adopted, some affinity for oil remains in most of the cases (Figure 5), and the affinity for water is not often strong, particularly for samples from facies M1 and M2.

Considering the nature of the crude oil,the solvents used and the procedure adopted for cleaning (forced displacement at 80°C),it can be concluded that a fraction of the surface of the rock from Asab-Thamama Zone B contains hydrophobic material strongly linked to the rock (or hydrophobic surface sites ?). The size of this fraction, compared to the total solid surface, depends on the sample and/or the facies considered. Due to the existence of spontaneous displacement of brine by oil, this type of surface must be considered to have a more or less continuous nature.

Finally, from Figure 7, if we discard three samples, M1.4, M2.4 and M3A.4, the difference between wettability upon reception and after restoration is small. The differences observed for samples M1.4, M2.4 and M3A.4 could be due to some change in the surfaces controlling the imbibition phenomenon (in some cases, thin slices had to be removed from the two faces of the samples).

On the whole, the wettability of the samples upon reception and after restoration is satisfactorily similar, and, concerning surface properties, either preserved or restored samples can be reasonably considered as representative of reservoir rock samples. Of course, it is assumed that no nonextractible deposit took place on the solid surface when the samples were being brought up to the surface.

CONCLUSIONS

The main conclusions are given hereunder:

- The average wettability of Asab reservoir rock is as follows:
  - Facies M1, M2 and M3A — slightly to strongly preferentially oil wet
  - Facies R2 — neutral to slightly preferentially oil wet
  - Facies LM — neutral to slightly preferentially water wet
- Wettability has a heterogeneous nature (***mixed***).
- The wettability of preserved or retained samples is not very different from the wettability of restored samples.
- In spite of a cleaning with a quite complex series of solvents, it was impossible to bring the rock from the upper facies (M1 and M2) to a strong water wetness.
- The wettability behavior could be at least partly due to the nature of the solid surface (presence of nonextractible organic material?).
- Whatever the method adopted, wettability evaluation is similar or close.

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Appendix 1

Characteristics of the different layers

M1 : The lithology is mainly miliolid pelletoidal packstone/grainstone grading locally to packstone/wackestone.

M2 : The lithology is similar to that of the M1 facies unit, with some lateral faunal variation.

R2 : The lithology is composed of rudistid packstone/wackestone. Rudist fragments are rare to locally abundant.

M3A : The lithology is composed of miliolid, algal lump pelletoidal packstone/grainstone. In the middle of the facies, presence of medium to coarse pellets and algal lumps. In the lower part of the facies, a smaller grain size distribution is observed with a slight increase in limemudstone content as cementing material.

LM : The lithology is mainly fine limemudstone/wackestone with local patches of packstone, scattered Orbitolina and delomite rhombs. Greater abundance of Orbitolina is observed in the lower part of this facies, with a noticeable compaction.

Appendix 2

Description of the n-heptanol test

This new method was proposed by Trabelsi (7).

Wettability is evaluated by a physico-chemical characterization of the rock surface's affinity towards hydrocarbons in competition with water. It consists of a measurement of the hydrophobic site density on the mineral surface by recording n-heptanol adsorption isotherms from aqueous solutions.

The principle of this test is as follows: the n-heptanol molecules have an equilibrated hydrophilic/hydrophotic balance with a hydrophilic end (OH) and a hydrophobic end (CH_3 groups). In an aqueous solution and in the presence of solids having hydrophobic sites, these molecules will preferentially be adsorbed to water molecules, with the hydrophobic ends interacting with the sites, and the hydrophilic end (OH) remaining oriented towards the bulk aqueous phase.

The calculation of the number of n-heptanol molecules adsorbed per surface unit area on the solid surface will give the hydrophobic sites density on the surface. Since the surface occupied per molecule of n-heptanol (parking area) is known to be equal to 40.10^{-20} m^2, for a completely covered or 100 % hydrophobic surface, a density of 4.2 micromoles/m^2 is deduced. This means that a density of x micromoles/m^2 will correspond to a hydrophobicity of (100 x / 4.2%).

Before performing the n-heptanol test, the samples were:
- cleaned with cyclohexane,
- crushed (BET specific surface areas were measured).

Tests were performed on these crushed and cleaned samples.

A study of crushing conditions was performed, different crushing times and processes were tried. After each crushing test the grain-size distribution and the specific surface area were determined, and the shape of the grains was examined by an optical microscope. The optimum crushing conditions chosen for the adsorption experiments were those giving the same grain-size and shape shown by SEM and optical microscope examinations of the original consolidated rock. The median diameter of the grains under these conditions was in the range 5-6 micrometers.

Crushed samples were placed int contact with the aqueous solution of n-heptanol at the given concentration in 50-ml.vessels The vessels were shaken during 16 hours at 25 ±0.1°C to achievethermodynamic equilibrium.

After solid/liquid separation by centrifuging, the concentration of the solution in n-heptanol was determined by gas chromatography.

The amount of n-heptanol adsorbed on the solid was then calculated by difference as follows:

Co : was the initial concentration of n-heptanol in pure water,(in moles/liter),
Ce : was the equilibrium concentration (in moles/liter),
V : was the volume of the solution used (in liters),
m : was the weight of the mineral (in grams),
S : was the specific surface area of the mineral (in m^2/g),
N : was the Avogadro number,

then, the adsorbed amount is (in moles/m^2): $Na = \frac{N\,(Co-Ce)\,V}{m\,S}$.

For recording the whole isotherm different concentrations were used in the 10^{-4} to $1.2\ 10^{-1}$ mole/L range (solubility limit).

Appendix 3

Description of the Amott/IFP wettability test

- Saturation of sample by oil and brine at S_{oi} and S_{wi}
- Stages of the test:
  - imbibition in brine → oil displaced : A
  - displacement by brine → oil displaced : B
  - imbibition in oil → brine displaced : C
  - displacement by oil → brine displaced : D
- Water wettability index: $I_W = A/_{A+B}$
  Oil wettability index: $I_O = C/_{C+D}$
- Wettability index: $WI = I_W - I_O$
- Wettability scale:

WI	-1	-0.3	-0.1	+0.1	+0.3	+1
WETTA-BILITY INDEX	Preferentially oil wet		Intermediate			Preferentially water wet
			Slightly oil wet	Neutral	Slightly water wet	

Appendix 4

Cleaning procedure

The following sequence was used:

- successive forced displacements, at 80°C by:
  - . toluene saturated with water (25 PV)
  - . mixture toluene/methanol (70/30) (25 PV)
  - . chloroform (PV),
- immersion in the mixture methanol/acetone/toluene (15/15/70), 2 days at 50°C,
- immersion in methanol, 2 days at 50°C.

Table 1 : Characteristics of the fluids used

	Temperature °C	Density g/cm^3	Viscosity cP
Synthetic formation water	20	1.1078	1.44
	80	1.0878	0.56
Marcol 52	20	0.8305	11.50
	80	0.7970	2.30
Marcol 172	20	0.8550	68.0
	80	0.8190	7.50
Topped stock tank oil S/S (a) (> 85°C fraction)	20	0.8390	6.10
	80	0.8020	1.72
Topped stock tank oil L/S (b) (> 85°C fraction)	20	0.8420	5.90
	80	0.8040	1.76

(a) used for facies M1, M2 and R2 , (b) used for facies M3A and LM
Oil/brine interfacial tension, mN/m : 23 at 85°C

Table 2 : Characteristics of the samples

Sample No.	M1.1	M1.4	M2.1	M2.4	R2.2	R2.4	M3A.2	M3A.4	LM.2	LM.4
Well	Sb-i	Sb-a	Sb-e	Sb-a	Sb-e	Sb-b	Sb-e	Sb-b	Sb-e	Sb-a
Facies	M1	M1	M2	M2	R2	R2	M3A	M3A	LM	LM
Depth	8091'6	8918'	7957'6	8031'5	7969'4	8100'8	7982'8	8121'9	8103'6	8088'5
Porosity, (%)	18.3	21.5	29.2	30.6	28.6	28.1	28.7	30.2	31.2	32.1
k_w , (mD)	115	97	1236	188	26	79	418	26	29	30

Table 3 : Amott/IFP wettability test, at 85°C, Fluids: synthetic brine/topped stock tank oil

Well: Sb-a; Facies: M2; Depth: 8038'11		
Cleaning (see Appendix 4)		
Saturation with formation water	PV, cm^3	22.9
	Ø, %	33.1
	k_w, 10^{-3} μm^2 (mD)	155
Establishment of S_{wi} : flood with stock tank oil and restoration at 85°C	S_{oi}, % PV	61.7
Aging for one week, at 85°C		
	Wettability test at 85°C	
Imbibition in synthetic brine	Oil displaced, % PV	1.3
Displacement by synthetic brine	Oil displaced, % PV	35.4
	S_{orw}, % PV	25.0
Imbibiton in stock tank oil	Brine displaced, % PV	4.2
Displacement by stock tank oil	Brine displaced, % PV	34.1
	$S_{omax.}$, % PV	63.3
Wettability	I_w	0.04
	I_o	0.11
Indices	$WI = I_w - I_o$	-0.07

Table 4 : Amott/IFP wettability, at 25°C, Fluids : synthetic brine/refined oil

Well: Sb-a, Facies: M2, Depth: 8938'1		
Petrophysical characteristics	PV, cm^3	22.9
	Ø, %	33.1
	k_w, 10^{-3} μm^2 (mD)	155
Displacement of stock tank oil by refined oil at 25°C (a)	brine displaced, % PV	0
	S_{oi}, % PV	63.3
	Wettability test at 25°C	
Imbibition in synthetic brine	Oil displaced, % PV	1.3
Displacement by synthetic brine	Oil displaced, % PV	36.7
	S_{orw}, % PV	25.3
Imbibition in refined oil	Brine displaced, % PV	3.1
Displacement by refined oil	Brine displaced, % PV	36.7
	$S_{omax.}$, % PV	65.1
Wettability	I_w	0.03
	I_o	0.08
Indices	$WI = I_w - I_o$	-0.05

(a) This displacement was performed after the test given in Table 3.

Table 5 : Amott/IFP wettability, reservoir conditions
Fluids : synthetic brine/recombined Asab crude oil

Well: Sb-a, Facies: M2, Depth: 8039'0"-8039'4"

Saturation with brine	Pore Volume, cm^3	52.3
	Porosity, %	32.0
	k_w, 10^{-3} μm^2 (mD)	38
Displacement by Marcol 172	S_{oi}, % PV	80.0
Displacement by recombined oil (a)	Brine displaced, % PV	0
	S_{oi}, % PV	80.0

Wettability test, at 121°C, 204 bar (2958 PSI)

Imbibition in synthetic brine	Oil displaced, % PV	3.2
Displacement by synthetic brine	Oil displaced, % PV	45.3
	S_{orw}, % PV	31.5
Imbibition in recombined oil	Brine displaced, % PV	2.4
Displacement by recombined oil	Brine displaced, % PV	31.0
	$S_{omax.}$, % PV	64.9
Wettability	I_w	0.06
	I_o	0.07
Indices	$WI = I_w - I_o$	-0.01

(a) After the displacement by Marcol 172 refined oil the sample was successively flooded by Marcol 52 refined oil and by topped stock-tank oil before using recombined Asab crude oil. No more brine was displaced.

Table 6 : Comparison of wettability deduced from various methods
Asab - Thamama Zone B
Sample reference: well Sb-a, facies M2, depth 8038'8" - 8039'5"

Wettability test	Conditions	Wettability evaluation
Contact angle (85°C)	Preserved (as received) water/air and oil/air systems	Preferential affinity for oil
	Preserved (without gas) water/air and oil/air systems	Preferential affinity for oil
	Restored water/air and oil/air systems	Preferential affinity for oil
	Preserved (as received) water/oil system	Neutral
n-heptanol test (25°C)	Preserved	Preferential affinity for oil
	Restored	Preferential affinity for oil
Amott/IFP test	Restored Routine conditions refined oil, 25°C	Neutral (mixed wettability type)
	Restored intermediate conditions stock tank oil, 85°C atmospheric pressure	Neutral (mixed wettability type)
	Restored reservoir conditions recombined oil, 121°C 204 bar	Neutral (mixed wettability type)

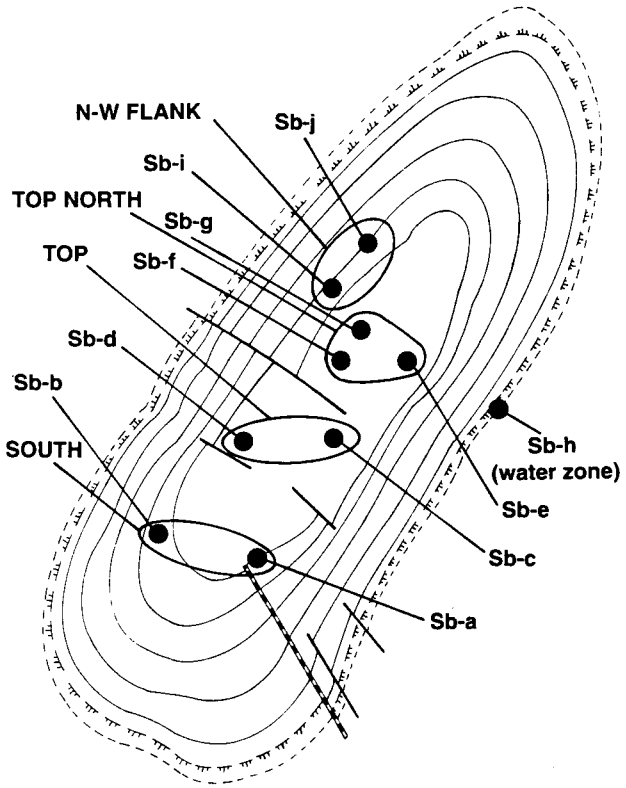

Figure 1 - Structure contours and location of the wells selected for sampling.

THAMAMA B SUBZONES		RESERVOIR MODEL UNITS (LAYERS)	THAMAMA B FACIES
B I	1	M-1	M-1
D1 STYLOLITE	2	R1-A	R-1
	3	R1-B	
B II	4	M-2	M-2
	5	R-2	R-2
D2 STYLOLITE	6	M3AU-1 (M3A UPPER)	M 3 A
B III U	7	M3AU2 (M3A UPPER-2)	
B III	8	M3AL (M3A LOWER)	
B III L	9	LM-1	LM
D3 STYLOLITE	10	LM-2	
B IV	11	LM-3	
	12	LM-4	

Figure 2 - Asab field - Thamama Zone B Subzones / Facies Units Correlation Section.

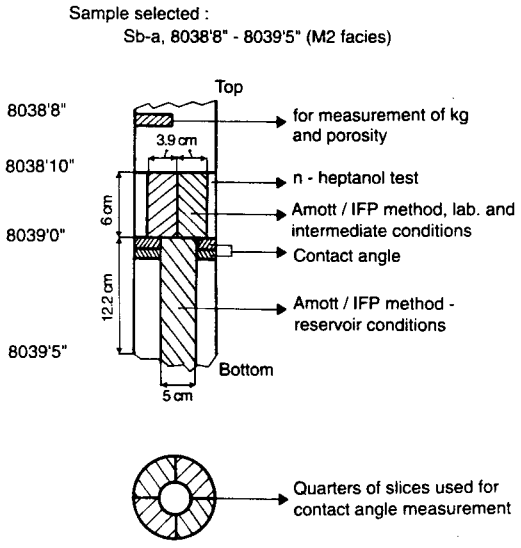

Figure 3 - Comparison of wettability evaluation methods. Procedure for sampling.

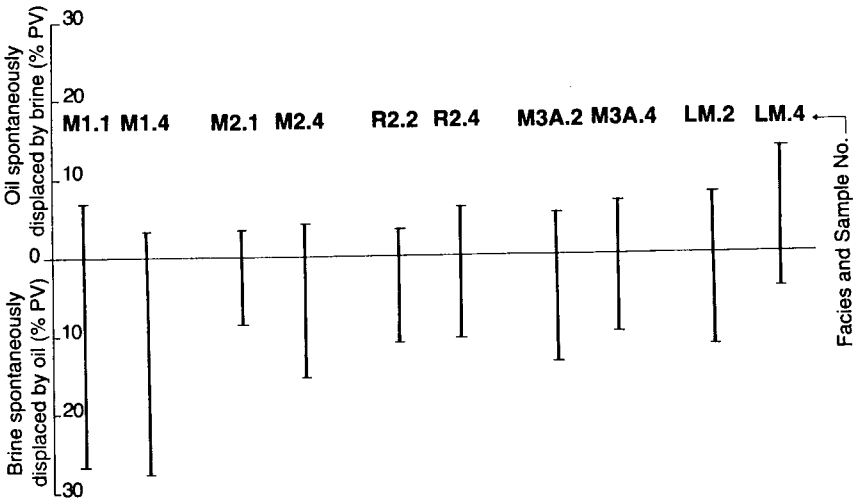

Figure 4 - Comparison of water-oil and oil-water spontaneous displacements
Samples from Asab-Thamama zone B-wettability test upon reception.

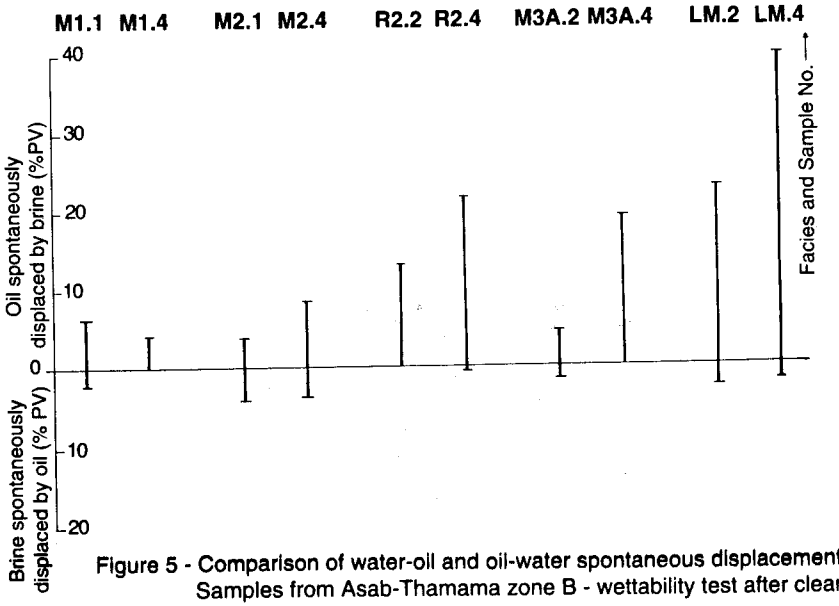

Figure 5 - Comparison of water-oil and oil-water spontaneous displacements
Samples from Asab-Thamama zone B - wettability test after cleaning.

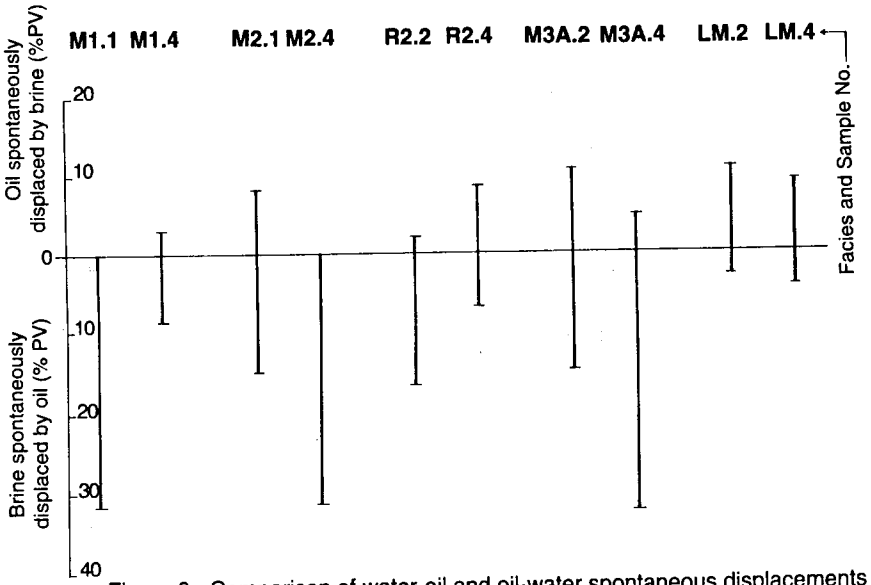

Figure 6 - Comparison of water-oil and oil-water spontaneous displacements
Samples from Asab-Thamama zone B - wettability after restoration.

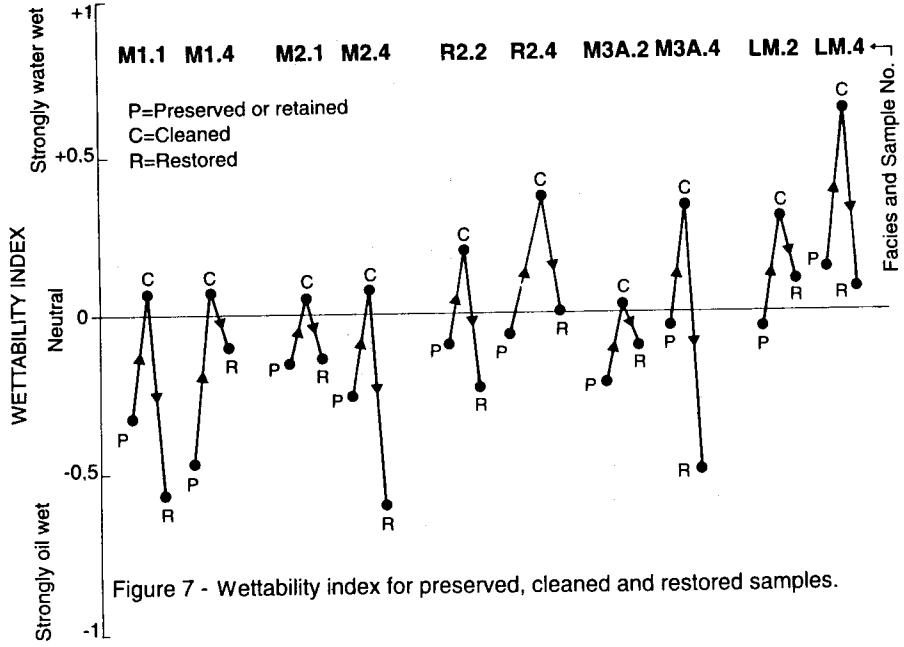

Figure 7 - Wettability index for preserved, cleaned and restored samples.