

Distribution and Origin of a Tar mat in the S. Field (Abu Dhabi, U.A.E.)

B. Carpentier, A.-Y. Huc, F. Marquis, Institut Français du Pétrole, A.E.R. Badr, A.A. Al Aidarous and S. Al-Baker, ADCO.

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Abstract

This study has been conducted to investigate the distribution and origin of bitumen (tar mat) occurring in the Thamama Zone B reservoir (Upper Kharai Fm., Lower Cretaceous) of the S. Field in Abu Dhabi.

The main objective was to assess the continuity of the bitumen rich interval and its possible role as an intra-reservoir permeability barrier potentially responsible for the pressure anomalies recognized at the field scale during oil production.

Detection of bitumen was performed on 68 wells using petrophysical data, Rock-Eval and electrical-log derived methods. The result provides a realistic 3D image of the tar mat distribution at the field scale.

Biomarker analysis suggests that there is no difference in origin nor maturity between the tar mat and the overlying oil. Comparison between bitumen location, sedimentological facies, petrophysical properties, field structural history, present-day and paleo-OWCs were used to decipher the process and timing of the tar mat deposition.

Results, Observations and Conclusions

A tar mat (4 to 23 ft thick) is present in the crestal part of the field and is located at the base of Thamama Zone B, increasing the role of vertical permeability barrier formed by the underlying "Dense Limestone". The bitumen is clearly associated with the low porosity zone located at the base of the Thamama B and seems to be never present in the water leg nor related to the present day or paleo-OWCs. The formation of the tar mat is probably post-Dammam (Eocene) in age and is likely to be due to flowing down of a gravity segregated heavy fluid which is eventually trapped in the low porosity base of the reservoir.

Applications

The results demonstrate that the bitumen rich interval is not responsible for the pressure drop during production and will not play the role of permeability barrier between the central and northern part of the field where gas injection is planned. The provided 3 D distribution of the bitumen volume allows a better estimate of the OIP (oil in place).

Technical Contributions

1. Example of an integrated approach for bitumen risk evaluation in oil field.
2. Demonstration of the applicability of petrophysical, pyrolysis and electrical wireline log-based detection methods for tar mat detection in Thamama zone B reservoirs.
3. The distribution of the bitumen in the Thamama B reservoir can serve as a basis for the definition of a more time saving methodology which could be applied to other regional fields for bitumen risk evaluation.

Introduction

Tar mats can be described as sharply limited reservoir levels enriched in heavy compounds^{1,2,3,4}. These bitumen-rich intervals range from a few centimeters thick⁵ to tens of meters⁶ and can be located at, below, or above the OWC. Their main deposition processes include biodegradation⁷, in-reservoir oil mixing⁴; oil-gas mixing⁸; or gravity segregation in the oil column^{9,10}. Their high viscosity¹¹ at reservoir temperature makes them difficult to produce and tar mats often form horizontal permeability barriers damaging to oil production^{12,13,14,15}.

Bitumen occurrence in a reservoir reduces the total amount of producible oil in place. They potentially limit inter-layer communication and water drive efficiency.

Tar mats are common features in the Middle East fields where they were recognized for a long time at various stratigraphic levels^{16,12,6,17,18,19}. Recently, the possibility of producing bitumen rich intervals using horizontal wells²⁰ and EOR processes and the importance of a fine description of the reservoir fluid barriers to optimize oil production increase the interest in bitumen studies²¹.

The objective of the study was to detect, quantify and decipher the origin of bitumen in the S. Field in Abu Dhabi in order to define its potential impact on the producer/injector scheme.

General Framework

The S. Field is a NE-SW faulted anticline with 160 km² of

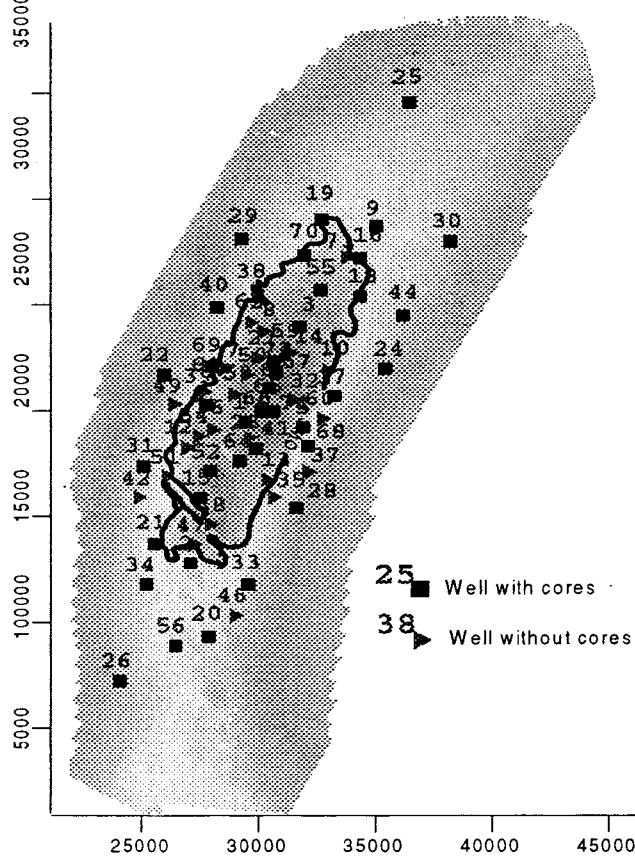


Figure 1: Well location

closure (Fig 1). Hydrocarbons are present in Zones A, B and C of the lower Cretaceous Thamama Group (KharaiB Fm.), each zone being separated from the other by a dense limestone unit. The main reservoir is the Thamama Zone B (Upper KharaiB Fm.) which is considered in this study. The major lithofacies are: - microskeletal pelletal packstone/wackestone; coarse algal, graded-bed packstone/wackestone; rudist pellet packstone; miliolid foram/pellet grainstone; skeletal/rudist /foram/pellet grainstone.

These different lithofacies show nearly similar porosity and permeability distributions with identical means and medians²². The reservoir (50 m thick) shows good porosity in the crestal part of the field and deteriorates down flank. This variation in porosity is likely to be controlled by closed-system chemical compaction²².

After production of the crestal part of the field, a rapid drop of the pressure was noted and implementation, on the flanks of the structure, of gas injection was decided in order to sustain production rate. However, anomalous pressure distribution around the field raised questions about the intra-reservoir communications and the efficiency of the injection project.

In this context, the potential role of a tar mat as permeability barrier in the Thamama B reservoir was studied using the following steps:

- Tar mat detection in wells: 1380 samples, coming from the Thamama zone B of 27 cored wells, were analyzed and their content in bitumen assessed.
- Mapping of the tar mat.
- Reconstruction of the filling history of the field in relation to the bitumen distribution, based on wells and 3D seismic.

Tar Mat Detection

Rock-Eval. The Rock-Eval pyrolysis program (reservoir mode) used in this study is designed to specifically discriminate NSO compounds^{23,24}. This technique does not provide a detailed composition of the fluid but can rapidly identify bitumen-rich samples. This approach allows a rapid screening of numerous samples. It was performed on the whole set of available core samples and proved to be well suited for bitumen detection in the S. field (Fig. 2).

Solvent extraction and asphaltene content. Core samples were crushed and extracted using Dichloromethane (DCM). The extractable organic matter (EOM) was recovered and weighed. Subsequently, thin layer chromatography was used to separate saturates, aromatics and NSO compounds. This method, which directly assesses the NSO content, yields good results with respect to tar mat location and additionally provides compositional information on the solvent extracts. This method, which is more time consuming, was performed on only 100 samples and was only used to confirm the applicability of the Rock-Eval method to the S. Field.

The core density approach. The core density approach for tar mat detection is based on routinely-determined petrophysical core data, i.e. core porosity, permeability and grain density²⁵. The core density method takes advantage of the fact that the core plugs used to determine the petrographic characteristics are routinely rinsed using toluene or other organic solvents before the measurements are made. In the presence of tar mat/heavy oil intervals, the petroleum present in the plugs is incompletely extracted. The petroleum remaining in the pores of the plugs results in a concomitant under-evaluation of the porosity, permeability and grain density. By using this artificially-

lowered grain density, tar mats can be detected. Subsequently, tar mats are assigned to intervals showing grain density lower than expected according to lithological logs (Fig. 2).

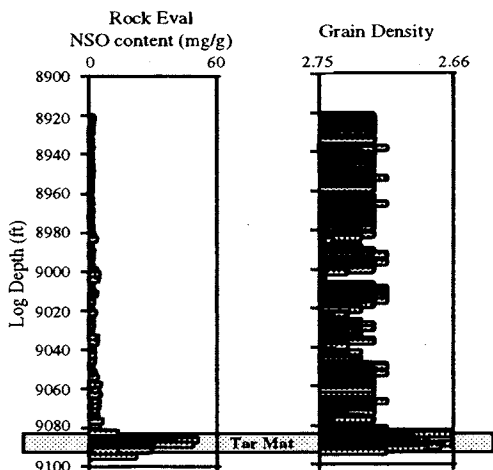


Figure 2 : Tar mat detection from Rock-Eval and Density.

Electric log approach. Electric logs are available for 68 wells and were interpreted in terms of bitumen content.

- This method²⁵ relies on the comparison between the water saturation in the uninvaded zone (S_w) calculated from a resistivity tool with a great depth of investigation (i.e. ILD) and the water saturation in the flushed zone (S_{xo}) calculated from a resistivity tool with a shallow depth of investigation (i.e. MSFL).

The difference between these two water saturation curves is directly related to the amount of moveable and producible oil (Fig. 3).

As the tar mats represent immobile oil, the coincidence of the two saturation curves associated with low values of S_w suggests that the porosity is filled with nonmoveable oil, i.e.

it may represent a tar mat. The electric log interpretation was calibrated by the analytical Rock-Eval data and the identification of a tar mat level was based on the following rule : "presence, at the base of Thamama B, of a relatively low porosity zone characterized by a high oil saturation associated with a high residual oil saturation calculated from micro-electrical log data".

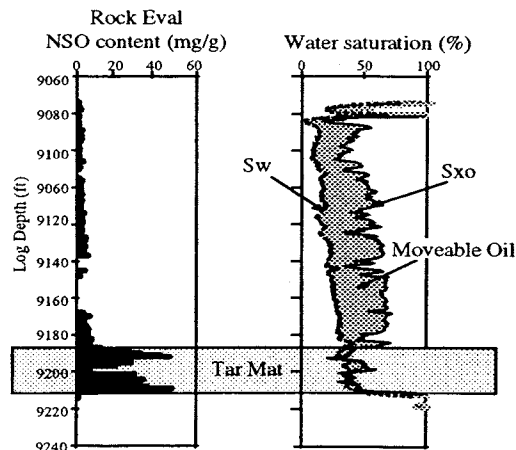


Figure 3 : Tar mat and E-log response

Bitumen distribution

Vertical distribution of bitumen. As a result of the NSO content, bitumen-rich levels have been detected in 21 wells. These zones can be described as single and clearly individualized levels (tar mat) with variable thickness and relatively high NSO content. They are systematically located at the base of the oil column, usually just above the permeability barrier formed by the Dense Limestone formation (Fig. 4).

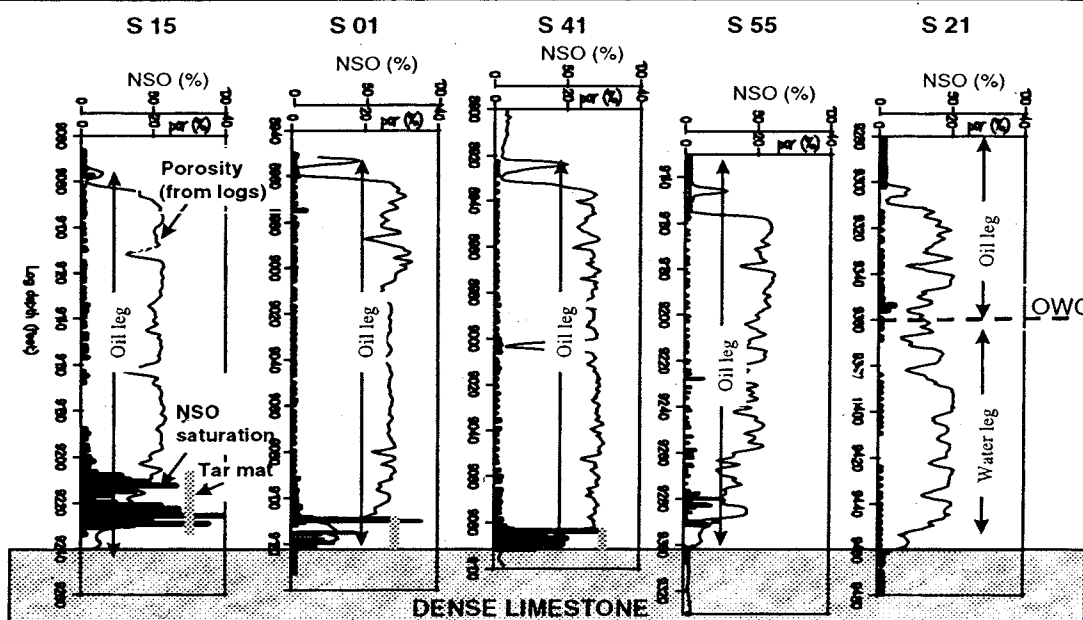


Fig. 4 : Typical NSO distributions in wells

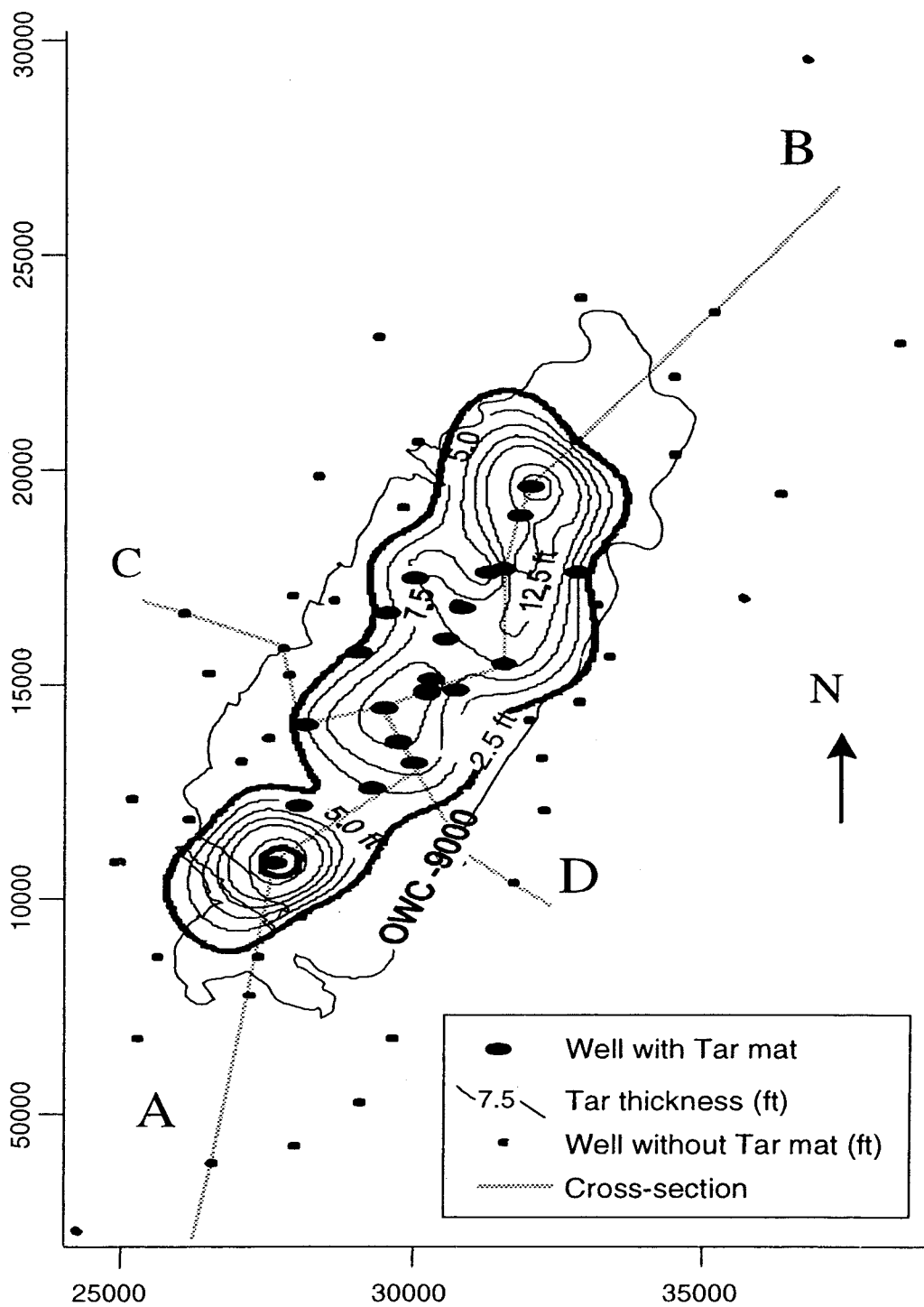


Figure 5: Lateral distribution of tar mats in the S. field

Based on both Rock-Eval data and electric log interpretation, no bitumen-rich interval was found outside the crestal part of the structure either in the water leg or at the Oil-Water contact (Figs. 5 and 6).

Horizontal distribution of bitumen. A kriged thickness of the tar zone, based only on well data, can be seen in Fig. 5. Cross-sections in Figure 6 show the structural location of the S. Field tar mat and illustrate the absence of relationship with the present-day OWC.

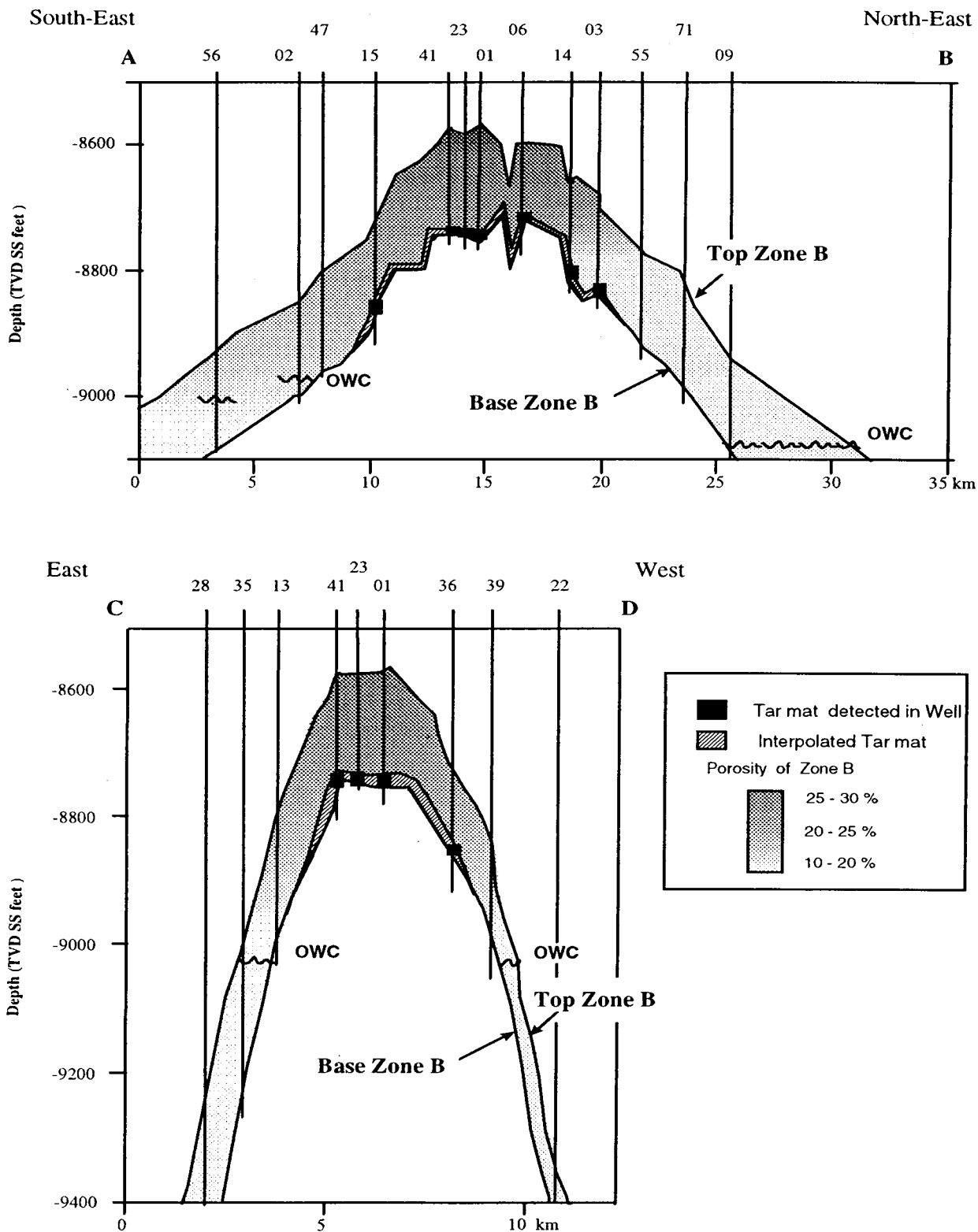


Figure 6 : S. Field N-S and E-W cross-sections

According to the data, a single continuous tar mat seems to exist in the S. field. It is located at the top of the structure, in the area where Thamama B has its best reservoir

characteristics in terms of oil saturation, permeability and porosity (Fig. 6).

However, within this overall good-quality reservoir, the tar mat is located at the base of the reservoir and is associated with lower porosity zones where the porosity is around 10 % (Fig. 7).

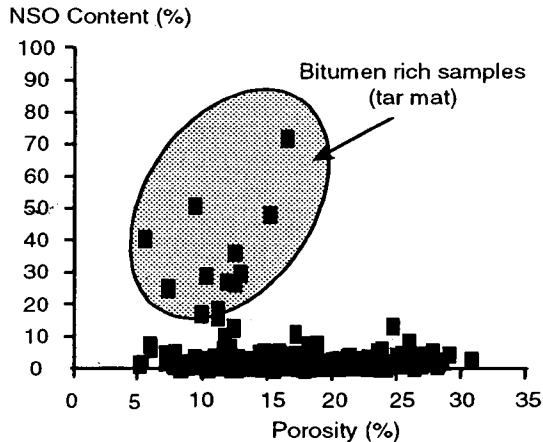


Fig 7 : Bitumen and porosity relationship

Effect of the tar mat on reservoir communication. The tar mat in the S Field, which is located just above the Dense Limestone and without any relationship to the present-day OWC, probably has only little effect on the connectivity of the reservoir and does not play the role of horizontal or lateral barrier within the Thamama B reservoir.

As the S. Field tar mat is located at the bottom of the reservoir and is characterized by a very low permeability, it probably increases the role of permeability barrier already played by the "Dense Limestone" between the reservoirs Thamama B and Thamama C. Consequently any interpretation of pressure data from the reservoirs Thamama zone B and Thamama zone C have to take into account the presence or absence of bitumen.

Moreover the tar mat reduces the volume of recoverable oil and must be taken in account in the reservoir simulations.

If the distribution of bitumen in the S. Field is, by itself, valuable information for production purposes, the prediction of tar mat occurrences and distribution in other regional fields needs to rely on an understanding of the factors which control the formation of the bitumen-rich intervals.

In the next part of this paper, we try to decipher the factors which potentially control the tar distribution. The approach, which combines molecular information, regional knowledge and reservoir description, provides additional information on the timing of oil emplacement, structural variations and diagenetic evolution. This integrated information is very helpful to understand the filling history, the porosity distribution and the meaning of the observed fluid contacts, not only in the S. Field itself but also in other regional fields which would have experienced the same evolution.

Origin of the tar mat

Elemental analysis (carbon, oxygen, hydrogen, sulfur) was performed on the asphaltene fraction of a sample coming from the tar mat, a production deposit and an oil sample.

They show similar composition suggesting a similar organic source for these samples.

Biomarkers analysis of the saturate and aromatic fractions of several samples from the oil leg and the tar mat have been performed. Results show that there is only minute variation between the oil and tar mat zones, supporting that no noticeable difference in maturity and origin seems to exist between the tar mat and the overlying oil zone. This result rules out the hypothesis of an early charge of the structure by a low mature, asphaltene rich fluid, fluid which would be later flushed out by a more mature reservoir oil. The above tar mat features imply that the S. Field bitumen deposits are likely to be due to a post-filling phenomenon which likely took place in the crestal part of the field.

This phenomenon can be related to 1) a destabilization of the asphaltene content of the oil resulting in the segregation of an asphaltene rich fluid settled at the base of the oil column, 2) the result of an alteration of the base of the oil column at a paleo-OWC.

In order to detect the possible relationships between the tar mat and paleo-OWC's, a reconstruction of the structural history of the S. Field has been made on the basis of seismic and well data.

Structural evolution, OWC and tar mat architecture.

The paleo-depth of the Thamama B reservoir was calculated for the Nahr Umr (Albian), Halul (Santonian), Fiqa (Campanian), Simsima (Maastrichtian), Umm Er Radhuma (Paleocene to Eocene) and Dammam (Eocene) formation deposition ages.

For each age, the paleo-depth was calculated by subtracting from the today reservoir depth, the cumulative thickness of the formations stratigraphically located above the top of the formation considered. This calculation was done for each well and for each formation where 3 D seismic data was available.

The structural closures of the top of the Thamama B reservoir were defined from the paleo-depth maps calculated from the 3D seismic data. No decompaction was made before the calculations. If we suppose that, at each considered age, the structure was filled by hydrocarbon down to its spill point and that the paleo-OWC was horizontal, the depth of the paleo-OWC at the considered age is assumed to be at the depth of the paleo-structural closure. These paleo-OWC's have been compared with the location of the bitumen level hypothesizing its presence at the age considered (Fig. 8). The result shows that for Halul to Dammam times :

- Tar mats are never located on a unique paleo-horizontal level but are always distributed over a large range of depth in reservoirs which can be located above, below or at the paleo-OWCs (Fig. 8).

These observations lead to considering the bitumen formation as not related to an effect of the OWC.

Figure 9 shows a schematic NW-SE cross-section illustrating the relative position of the base of the reservoir (Dense Limestone), the tar mats, and the OWC at different selected times. It is apparent that the tar mat is not associated with either paleo- or present-day OWC's.

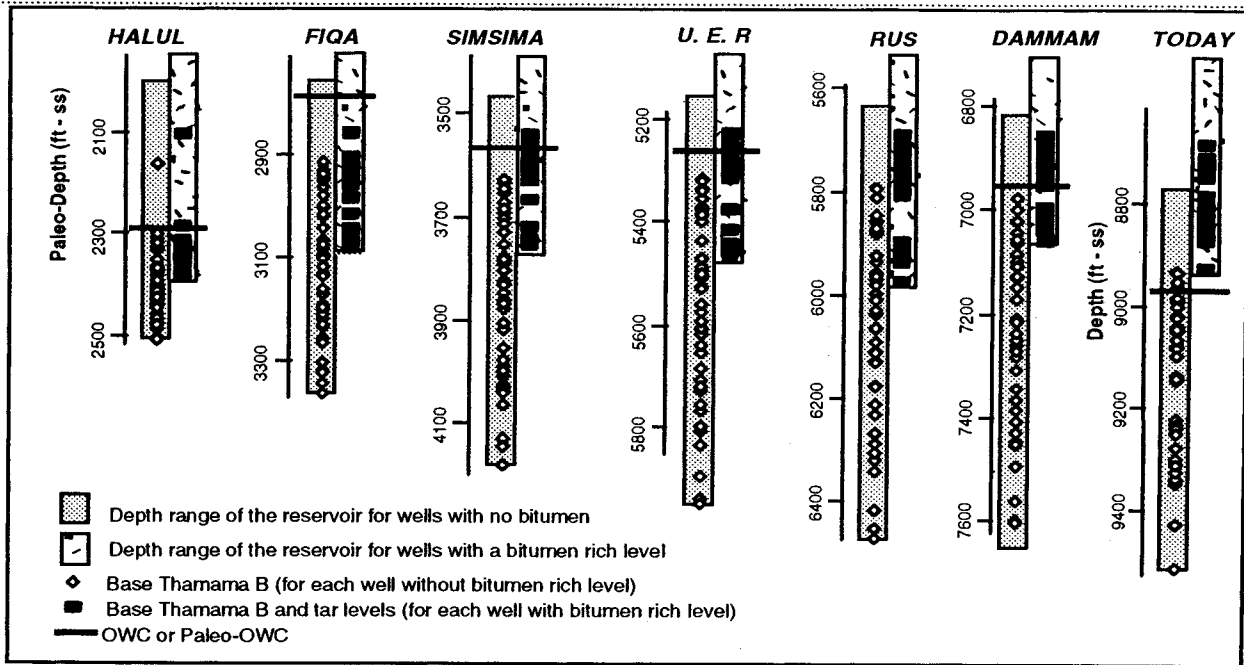


Figure 8 : Tar mat location and Paleo-OWC

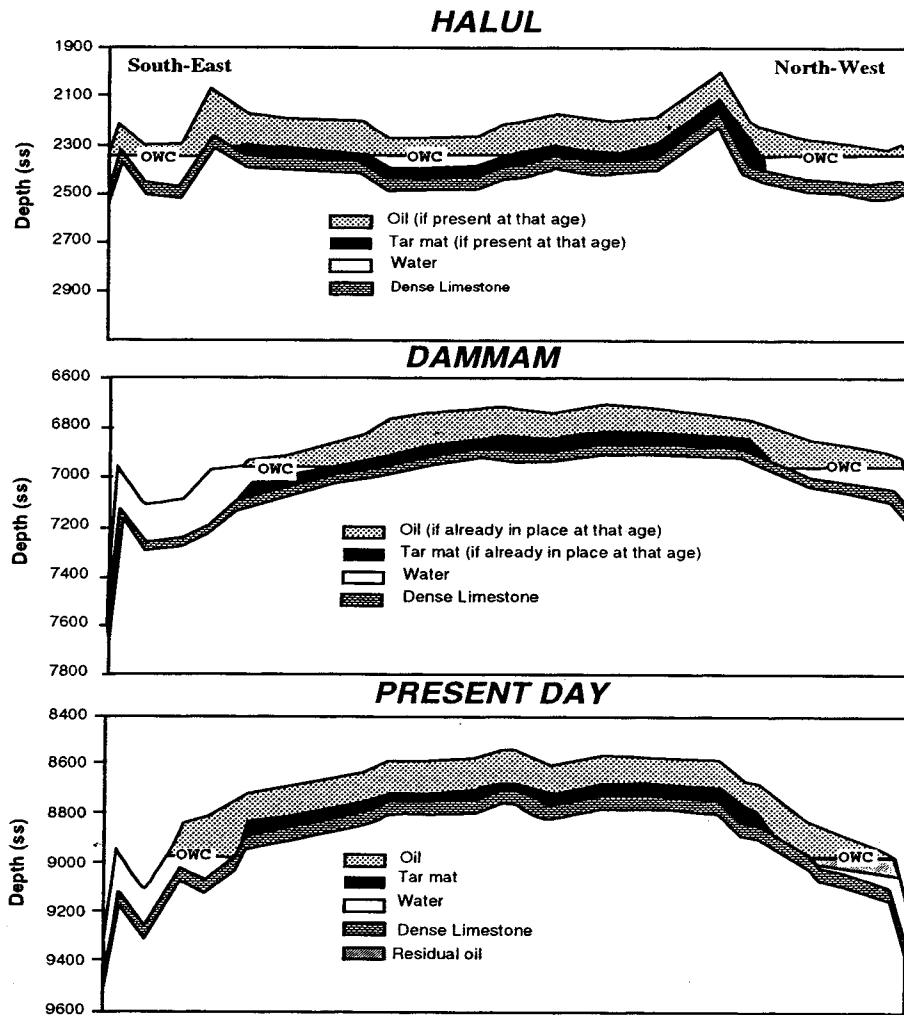


Fig. 9 : Schematic NW-SE cross-sections

Scenario for the tar mat emplacement

The S. Field tar mat shows the following characteristics :

- It is located at the base of the reservoir above a vertical permeability barrier (the underlying Dense Limestone)

- It is located at the top of the present-day structure and is associated with the wells where the reservoir experienced only small diagenetic cementation.

- It is located within a relative low porosity zone already present before the tar mat emplacement as it corresponds to a lithofacies which marks the transition between the dense limestone (muddy carbonates of low energy) and the more porous facies which forms most of the overlying reservoir.

- It is within the area defined by the present day - 8870 ft (ss) contour,

- It is independent of the present day OWC.

- No difference at the molecular level (biomarkers) between the tar mat and the oil has been detected. The

organic fluids seem to have been generated by the same source-rock(s) at the same maturity level(s).

- The tar mat seems to be thicker at the northern and southern edge of the tar mat zone.

These characteristics lead us to propose the following scenario of emplacement of the tar mat:

It is likely to be the result of a gravitational segregation of the oil in the more porous and permeable reservoir of the crestal area (Fig. 10).

The "heavy oil" created by gravity at the base of the oil column would have moved toward the flanks of the structure. Originating from the crestal area of the field, this "heavy phase" would have been trapped during its progression in the low porosity zone located at the base of the reservoir (Fig. 10). The lateral extension of the tar zone would have been controlled by the total amount of heavy oil created, itself directly related to the total volume of the oil present in the crestal area.

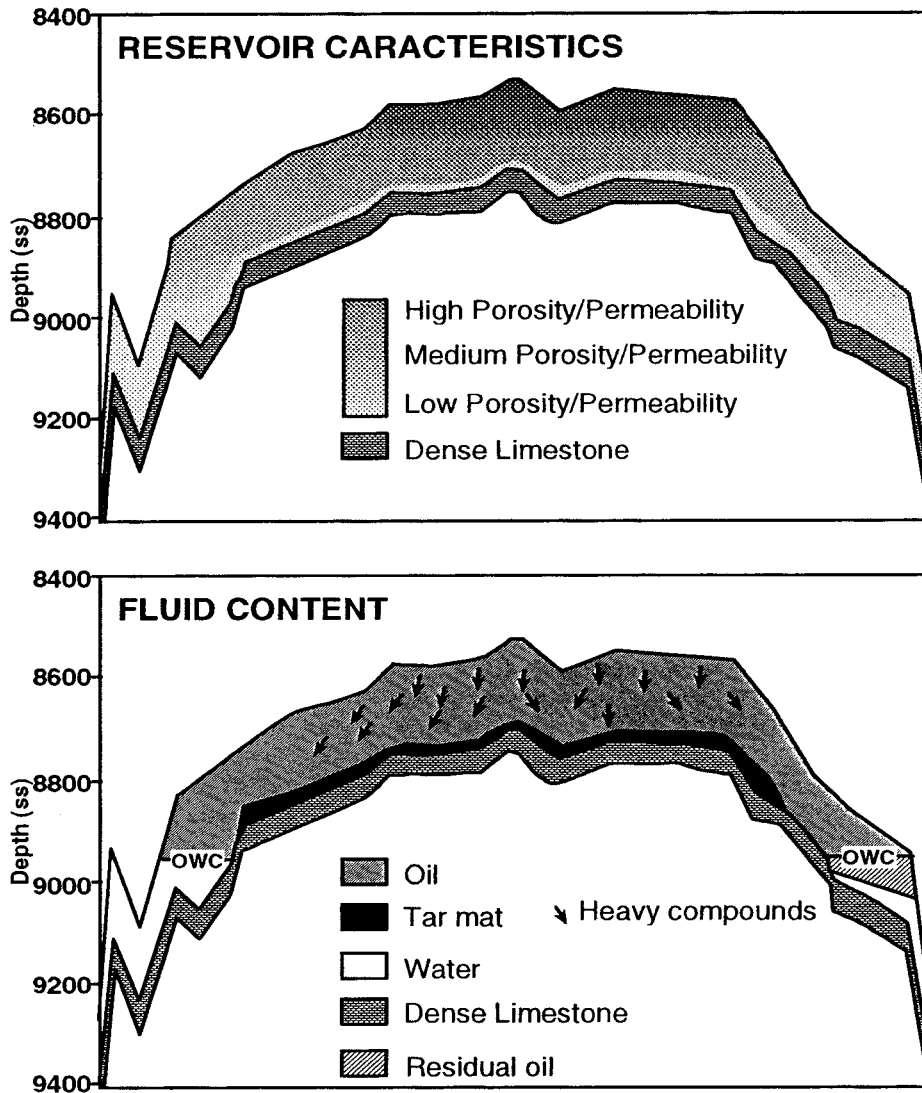


Figure 10 : Possible Scenario for Tar mat emplacement

According to such a mechanism, the extension of the tar mat zone is directly related to the composition of the oil, the shape and the extension of the structure. In the S. field, the absence of tar mat at the OWC was perhaps only due to the fact that the available total amount of the "heavy" phase originating from the crestal area was not sufficient to allow this "heavy" fluid to reach the OWC.

Timing for the tar mat emplacement. The similarity between the horizontal extension of the tar mat (in the crestal area of the field) and the location of the good quality reservoir leads to consider that the porosity distribution is one of the controlling factors for the tar mat deposition. As the distribution of the present-day porosity at the field scale is mainly due to a stylolisation process likely to be inhibited by the arrival of oil²², the tar mat emplacement is likely to be subsequent to the porosity reduction.

Figure 11 illustrates the relationship between porosity and vertical depth. The average porosity of the reservoir shows, as a function of depth, a progressive reduction in the upper part of the structure, vertical evolution of the porosity which does not exist in the water zone, below the present-day OWC.

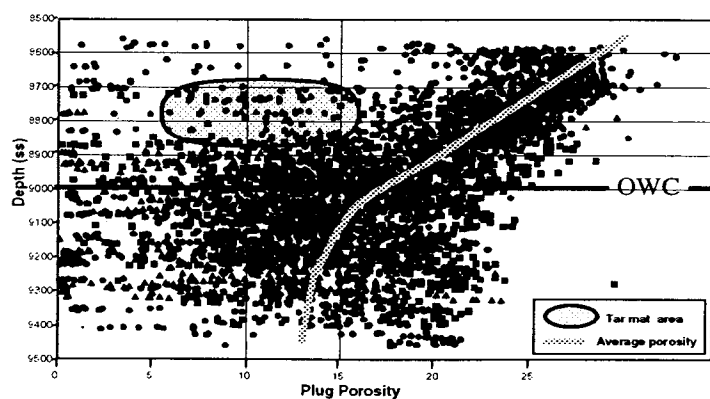


Fig. 11 : Porosity - depth relationship

This OWC corresponds to a very recent structural closure of the field (post-Dammam). Then, the stylolisation of the reservoir and the related porosity reduction is likely to be a continuous phenomenon, beginning perhaps very early in the filling history but surely ending very late, probably at a very recent time.

This filling-related control of the porosity leads to consider that the tar mat emplacement is also a very recent phenomenon, probably post-Dammam in age. Such a recent age for the tar mat would explain the absence of bitumen in the Northern part of the field, part which experienced an independent structural evolution only at a post-Dammam age resulting in the presence of residual oil (fig. 9) in the Northern area.

Conclusion

A 3D representation of the distribution of bitumens in the S. Field has been constructed using a combined approach based on a wireline log interpretation calibrated on

geochemical data. The bituminous zone is only present at the crestal part of the field and is systematically located at the base of the porosity, just above the horizontal permeability barrier formed by the Dense Limestone formation. It is associated with a well individualized, relatively low porosity/permeability, geological level located at the base of the reservoir.

No bitumen was found at the OWC nor in the water leg. This fact associated with the location of the tar mat (at the base of the reservoir) leads to consider that it does not play any role in the anomalous pressure distribution observed after production. In this field the tar mat probably has only little impact on the connectivity of the reservoir.

The reconstruction of the filling history of the S. Field demonstrated that there is no relationship between the bitumen distribution and the Paleo-OWC's. A possible scenario for the bitumen emplacement was proposed. This scenario, consistent with the whole set of data, implies a late (post-Dammam) filling of the structure and a gravity driven mechanism for the tar depositions.

Acknowledgments

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Conversion factor :

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