

Impact of depositional environment on petrophysical reservoir characteristics in Obaiyed Field, Western Desert, Egypt

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Abstract Identification of the types of the depositional environments that have control or influence on the distribution of petrophysical parameters is required to assess the potential utility of these parameters in the reservoir analysis. The primary depositional facies plays an important role in the reservoir quality and assessment of the petrophysical characteristics of hydrocarbon bearing zones in exploration and development operations. Petrophysical characteristics, depositional environment, and hydrocarbon prospectivity of the Middle Jurassic Upper Safa reservoirs in the Obaiyed Field (Western Desert, Egypt) are described using data from wireline logs (gamma ray, density, neutron, sonic, and resistivity) from 14 wells. Petrophysical characteristics of Upper Safa reservoirs (unit A and unit B) change significantly with variations of depositional facies and lithology. These units are interpreted to be composed of fluvial channel sands (unit A) and tidal channel sands (unit B) based on a gamma ray curve signatures. Litho-saturation analysis, petrophysical parameters, and net pay thickness maps of the Upper Safa reservoirs show variations along the study area. The main factor controlling differences in petrophysical properties and thickness for these reservoirs is the type of sandstone facies. Shales cause a major reduction in the porosity and gas saturation of the reservoir sandstones especially in the unit B reservoir which has dispersed and laminated shale and low resistivity net pay zone. The best reservoir characteristics belong to the unit A, which has high effective porosity ($PHIE$), low shale content (V_{sh}), and high gas saturation (S_g). Maps of reservoir parameters based on precise understanding of its depositional

environment indicate the location of possible sites for future gas development activities in the Obaiyed Field.

Keywords Petrophysical reservoir characteristics · Well log analysis · Depositional environment · Upper Safa · Obaiyed Field

Introduction

Besides the number of hydrocarbon discoveries, the Western Desert of Egypt has the potential for additional oil and gas resources. We anticipate that the Western Desert will soon emerge as a great oil and gas province in Egypt. Many promising areas await detailed examination, and they are virtually untested by drilling. Numerous studies since 1990 concerning the petroleum resources of the Western Desert suggested that approximately 90 % of oil and 80 % of gas reserves are still undiscovered (EGPC 1992).

The Obaiyed gas/condensate field is located in the Western Desert of Egypt, some 50 km south of the Mediterranean coast (Fig. 1). Upper Safa Member, the main target of this study, is one of the four members constituting the Middle Jurassic Khatatba Formation in Shushan Basin. The Upper Safa reservoir has become an important exploration target in the Obaiyed Field and has helped to revitalize exploration in the northwestern part of the Western Desert.

The integration of the reservoir depositional environment identification and the petrophysical analysis resulted in a clearer and more precise picture of the reservoir and consequently improved the success rate of the hydrocarbon in the exploration and development fields (Abdel-Fattah and Slatt 2013; Pigott and Abdel-Fattah 2014; Abdel-Fattah 2014; Abdel-Fattah and Tawfik 2015). This integration clearly demonstrates the importance of building a depositional model for an improved understanding of the physical distribution of reservoir properties in these fields. Sediments from different depositional environments can be grouped broadly into

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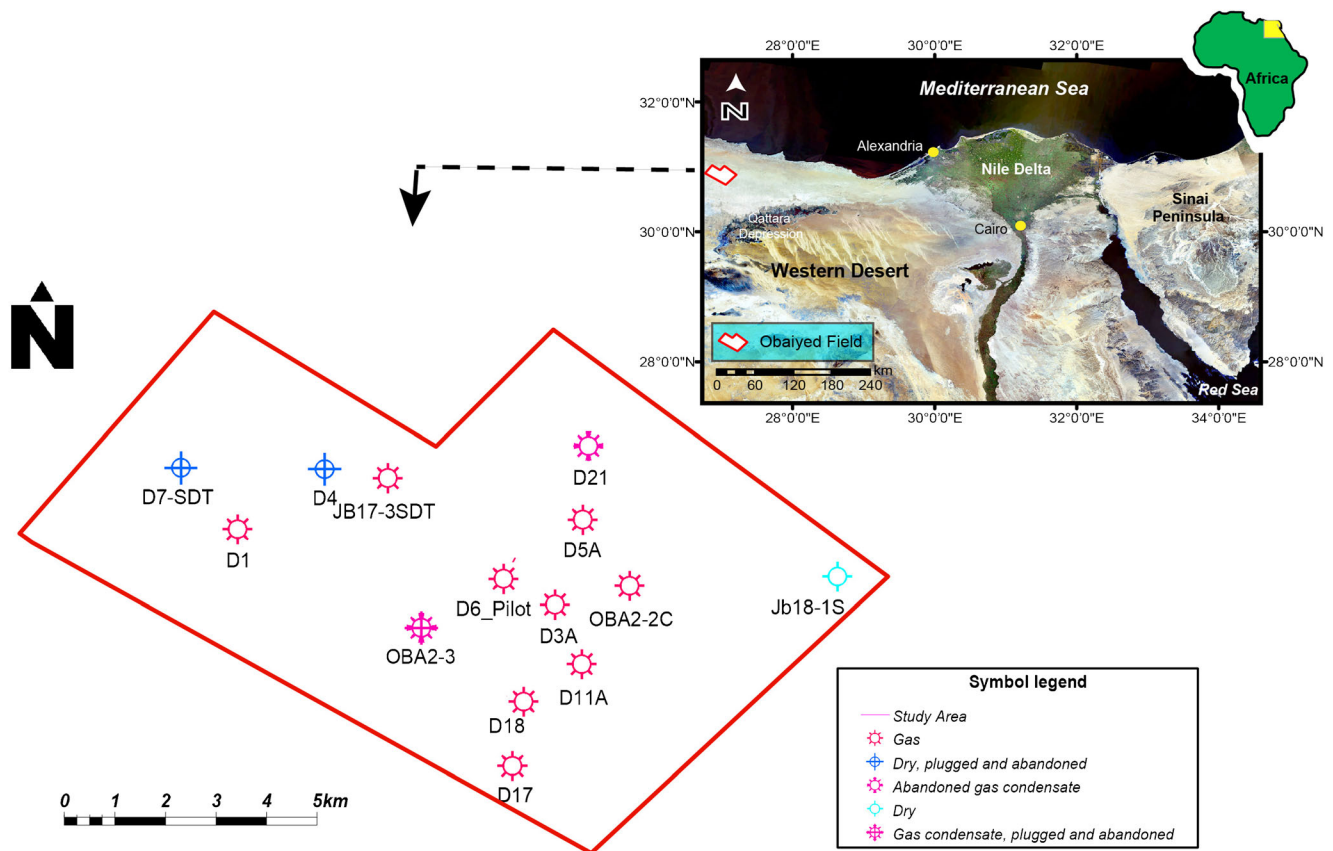


Fig. 1 Location map of the Obaiyed Field (Western Desert, Egypt) showing the studied wells

continental, transitional, and marine deposits. Each of the different depositional systems exhibits different architectural elements, with different sedimentological features resulting from the processes of sediment transport and subsequent deposition into the various environments. Shapes, sizes, net/gross values, continuity, orientation, and other reservoir characteristics are all a function of the nature of transport and depositional processes, basin configuration, climate, tectonic, and eustatic sea level fluctuations (Slatt 2006). Understanding the geologic complexities that control reservoir performance is very important to maximize the placement, orientation, and number of delineation and development wells to improve ultimate production and reservoir management.

Petrophysical well log analysis and interpretation are the most important task to detect the reservoir petrophysical parameters like porosity, water saturation, and thickness of hydrocarbon bearing zone (Schlumberger 1974; El-Gawad 2007). Well logging applications are primarily directed for determining the lithologic and petrophysical components through adequate assumptions and combinations of logging data. Well logs have been successfully used in exploration and development wells as a part of drilling practice, to provide more information and greater accuracy of reserve evaluation (Connolly 1965; Brown 1967). They can also be used to identify the depositional environment (Serra and Abbott 1982;

Serra 1985; Rider 1990, 1996), and the depth and thickness of productive zones. Additionally, they are used to distinguish between oil, gas, and water in reservoir and to estimate hydrocarbon reserves (Asquith et al. 2004). Therefore, petrophysical well log analysis was performed on the Middle Jurassic Upper Safa reservoirs in 14 wells in the Obaiyed Field (Fig. 1). To better understand the Upper Safa reservoir characterization based on their depositional environment, the quality of reservoir in terms of petrophysical characteristics (shale volume, effective porosity, water and hydrocarbon saturations) has been studied in the Obaiyed Field.

Stratigraphic setting

The Western Desert has a varied geological history. During the period when major reservoir bodies were deposited (Jurassic to Cretaceous, 195–65 Ma ago), the Tethys shoreline was moving across the area. As the Tethys extended southwards, coastal and tidal sandstones were deposited (Sestini 1984). After Cretaceous, the entire Western Desert region was covered by the Tethys, and marine carbonate mud was laid down on a sea floor.

The stratigraphic column of the northern Western Desert (EGPC 1992) includes sedimentary successions from

Ordovician to recent strata overlying Pre-Cambrian basement (Fig. 2). The total thickness, despite some anomalies, increases progressively to the north and northeast from about 6,000 ft in the south to about 25,000 ft along the Mediterranean coast. The stratigraphic succession of the northern Western Desert can be subdivided into four major regressive cycles, each terminated by a marine transgression (Sultan and Halim 1988). The earliest cycle consists of Middle and Upper Jurassic non-marine clastics (Ras Qattara Formation). These non-marine clastics are overlain by marine Jurassic clastics of Khatatba Formation. During the Late Callovian, shallow marine carbonates of the Masajid Formation were deposited. These represent the maximum extent of the Jurassic transgression. A major unconformity separates the Masajid Formation from the overlying Alam El Bueib Formation. The second cycle began in the Early Cretaceous with the deposition of the shallow marine clastics and carbonates of Alam El Bueib and ended with the thin Middle Barremian Dahab Shale. In Late Barremian to Early Aptian times, another unconformity separated the Dahab Shale from the Kharita Formation. The third cycle extended from the Middle Albian to the Early Tertiary. The continental and shoreline sands of the Kharita Formation represented the initial regressive period of sedimentation. The

final cycle consisted of the Dabaa and Moghra marine clastics. These were capped by the flat-lying Marmarica Limestone outcropping in many parts of the northern Western Desert (Zein El-Din et al. 2001).

There are several well-developed reservoir intervals in the Western Desert. The deepest are the Bahrein sandstones of the Lower Jurassic and the Middle Jurassic Khatatba Formation, a potential source rock which contains shale and sand intercalations (Younes 2002, 2003).

Jurassic sediments, in the Western Desert, are extensively developed toward the north (Keeley et al. 1990). The continental facies comprise shales, siltstones, and sandstones. The marine facies is represented by the Wadi El Natrun, Khatatba, and Masajid formations (Said 1962; Keeley and Wallis 1991). Transgression was initiated during deposition of the Early Middle Jurassic Wadi El Natrun Formation. It is comprised of lagoonal to marginal marine clastics and carbonates. The Middle Jurassic Khatatba Formation consists of shales and sandstones with limestone of shallow marine to estuarine character. Relations both laterally and vertically between the continental and marine facies are controlled by their position in the depositional basins (El Shazly 1978). Upper Safa Member, one of the four members constituting the Middle Jurassic

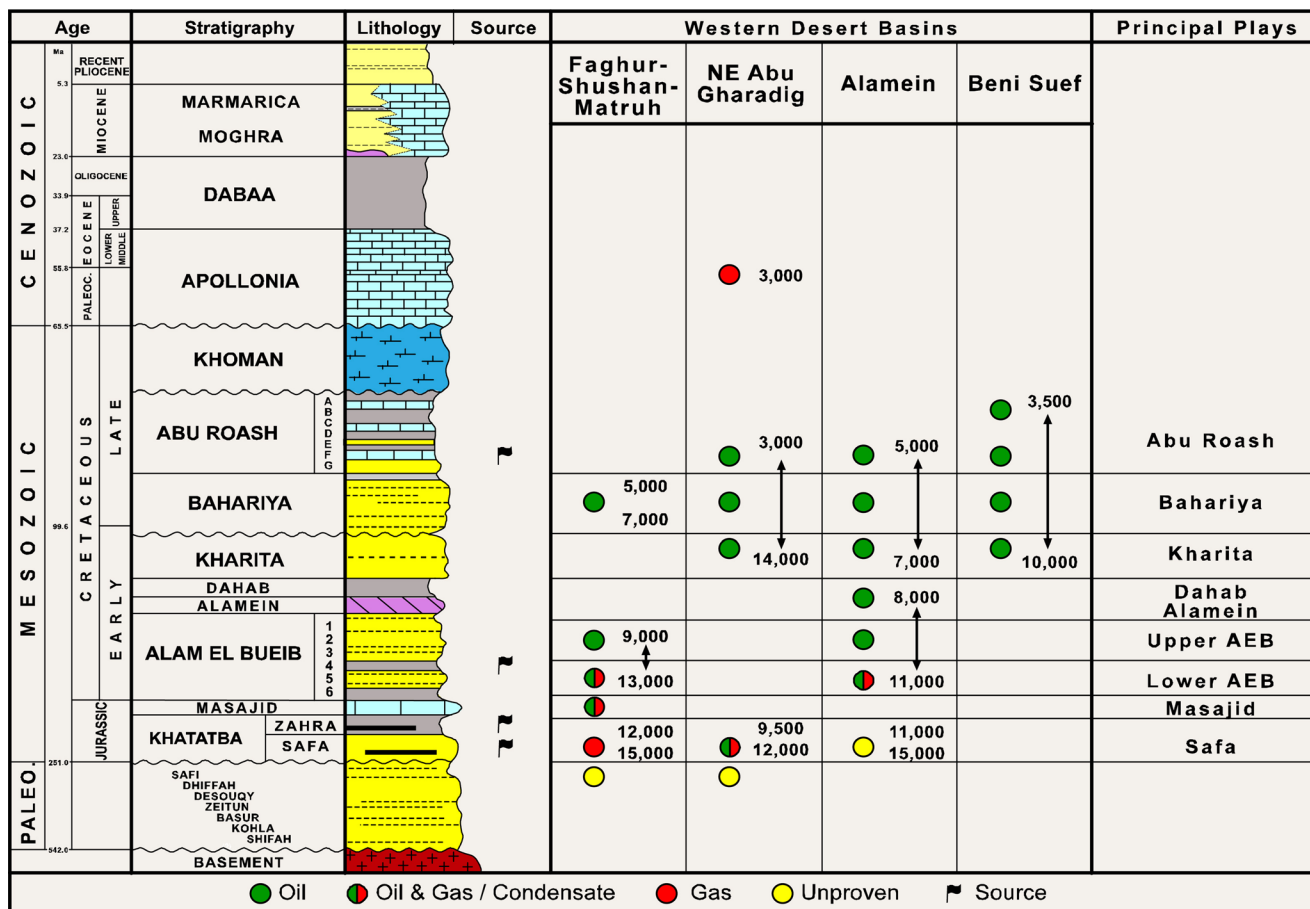


Fig. 2 Generalized litho-stratigraphic column of Western Desert, Egypt

Khatatba Formation, is underlain and overlain by the shelf carbonates of Kabrit and Zahra members, respectively. The Upper Safa consists of mainly shale with isolated sandstone intervals and some thin, laterally continuous carbonate streaks (Hantar 1990). It is a low net/gross sequence of flood plain to coastal marine deposits. The depth to the Upper Safa in Obaiyed Field varies from 3,478 m in the SW of the study area to 3,723 m in the east (Fig. 3). The Upper Safa total isopach, mapped as the depth from the top of Kabrit to the top of Zahra, is the thickest (183 m) in the northeast area in the Jb18-1S well (Fig. 4).

Material and methods

Fourteen wells provided by Badr Petroleum Company (BAPETCO) have been selected for investigating the Middle Jurassic Upper Safa clastic reservoir rocks and for evaluating the hydrocarbon potential in the study area. The petrophysical analysis of well logs aimed to qualitatively and quantitatively determine the properties of delineated reservoirs. Open-hole log data including the conventional tools such as resistivity log shallow and deep (ILD, ILS, and MSFL), neutron (CNL), density (RHOB), sonic (DT), and gamma ray (GR) for the studied units were collected and digitized.

Petrophysical parameters obtained in the course of study include volume of shale, porosity (effective and total), net/gross thicknesses, and water and hydrocarbon saturation. The fluid types were determined by using the neutron density log. Litho-saturation cross-plots were used to show the lithological component of the Upper Safa clastic reservoirs. The shale content (V_{sh}) was calculated from gamma ray, neutron, and neutron density logs. The minimum shale content given by these shale indicators is likely to be close to the actual value of V_{sh} . The corrected porosity was estimated using a combination of the density and neutron logs after applying various corrections. The water saturation (S_w) was computed with a shale correction using the Simandoux equation (Simandoux

1963) and with application of the Indonesian equation. The Simandoux equation fails in sandstones with the dispersed shales, leading to the development of the modified Simandoux equation to better handle these types of sands. Statistically, the Indonesian equation gives better results than the modified Simandoux when dispersed shale fractions are high (Poupon and Leveaux 1971).

Shale can be distributed in Upper Safa sandstone reservoirs in three possible ways: (1) laminar shale, where shale can exist in the form of laminae between layers of clean sand; (2) structural shale, where shale can exist as grains or nodules within the formation matrix; and (3) dispersed shale, where shale can be dispersed throughout the sand, partially filling the intergranular interstices or can be coating the sand grains. All these forms can occur simultaneously in the same formation. Each form can affect the amount of rock porosity by creating a layer of closely bound surface water on the shale particle (Serra 1984). An essential step in the formation evaluation process is the determination of the amount of shale present in the formation because it is necessary to calculate formation porosity and fluid content (Kamel and Mabrouk 2003; Aly et al. 2003). Moreover, the presence of shale within any reservoir interval normally complicates the well log analysis when evaluating the potentials of these reservoirs (i.e., shale volume, effective porosity, permeability, and water and hydrocarbon saturations) (Luthi 2001). Knowing shale distribution by neutron/density porosity cross-plots (Thomas and Stieber 1975; Mezzatesta et al. 2002) can improve the characterization and interpretation of Upper Safa reservoirs because it dictates which approach or application is suitable for a particular reservoir and facilitates identification of missed net pay zone that are characterized by low resistivity in the laminated shaly sandstone.

For the reservoir facies analysis, gamma ray tool is the most useful due to its characteristic response to different lithologies (Posamentier and Allen 1999). The gamma ray log is frequently used as an indicator of shale content. The shapes of gamma ray are becoming more important as these have been

Fig. 3 Structure contour map of the top Upper Safa Member in the Obaiyed Field, Western Desert, Egypt

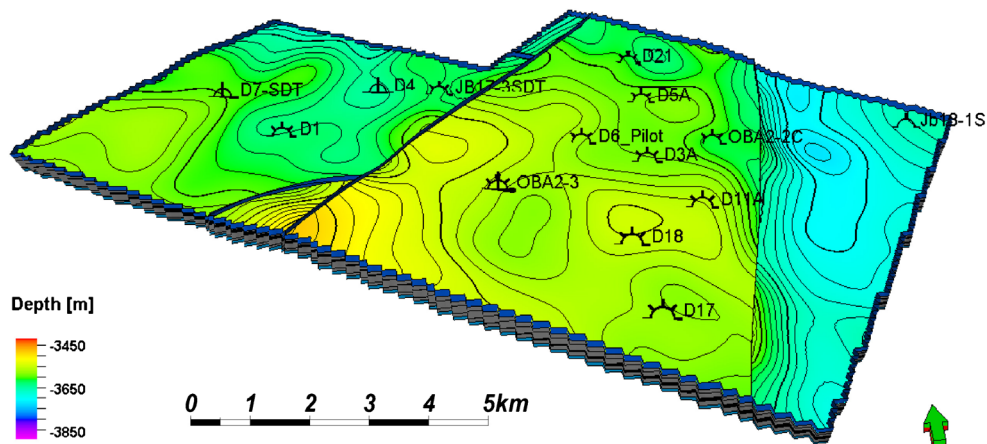
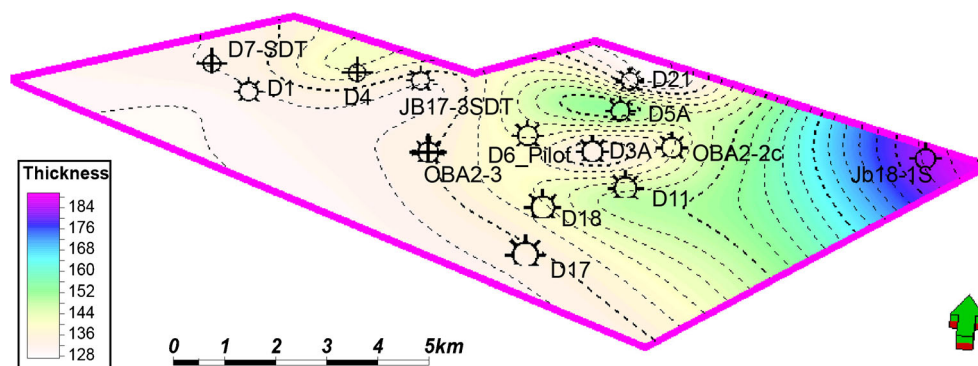


Fig. 4 Isopach contour map of the Upper Safa Member in the Obaiyed Field, Western Desert, Egypt



found to be related to the sediment character and depositional environment (Serra and Abbott 1982; Serra 1985; Rider 1990, 1996). Shapes on the gamma ray log are associated with the shaliness of the rock which also represents changes in grain size and sorting that are controlled by facies and depositional environment. Small grain size will correspond to higher gamma ray values and is mostly related to deposition in a low-energy environment where shale is also deposited. A decrease in gamma ray value will indicate an increase in grain size and cleanness of the sand. The sedimentological implication of this relationship leads to a direct correlation between facies and log shape of Upper Safa sandstone reservoirs.

Using the gamma ray log correlation of equivalent strata across the wells, the depositional environments were inferred from gamma log motifs. In order to increase the accuracy of qualitative and quantitative well log analysis, as well as to generate maps and well log cross section, geophysical software like LR Senenergy's Interactive Petrophysics and Schlumberger's Petrel were used to produce a comprehensive geophysical and geological evaluation of the study area.

Results

Reservoir litho-saturation analysis

The vertical distribution, in a form of litho-saturation cross-plot, shows irregular vertical variations in lithology and water and hydrocarbon contents (Figs. 5 and 6). Petrophysical parameters of the Upper Safa Member, including shale volume, porosity, and water saturation, vary from well to well in the Obaiyed Field. Figures 5 and 6 show vertical variations for these parameters in wells D6_Pilot and JB17-3SDT, respectively, over the interval of interest.

The litho-saturation analysis of Upper Safa Member in well D6_Pilot (Fig. 5) indicates that this well penetrated two gas-bearing reservoir intervals, unit A and unit B, which have high resistivity values against reservoir interval, especially for unit A. Some crossover between the neutron and density porosity occurs at the reservoir intervals, possibly representing the

presence of gas. The depth interval for the unit A ranges from 3,663.4 to 3,684.5 m true vertical depth subsea (TVDss). The gross thickness of this reservoir interval is 21.1 m, and the net pay thickness is 12 m, with the water cutoff values of hydrocarbon saturation >40 % and effective porosity >6 % (Table 1). The calculated shale volume in D6_Pilot well (Fig. 5) for the unit A reservoir ranges from 2 to 69 % (average 10 %); effective porosity ranges from 0 to 15 % (average 11 %); and water saturation ranges from 10.7 to 44.5 % (average 16 %). The unit B reservoir ranges from 3,591.5 to 3,616.1 m depth (TVDss). The gross thickness of this reservoir is 24.6 m, and the net pay thickness is 6 m. The calculated shale volume in D6_Pilot well (Fig. 5) for the unit B reservoir ranges from 4 to 84 % (average 39 %); effective porosity ranges from 0 to 8.5 % (average 6 %); and water saturation ranges from 19.9 to 77 % (average 41 % in net pay interval).

Litho-saturation analysis of the Upper Safa Member in JB17-3SDT well (Fig. 6) shows that the well also penetrated two gas-bearing reservoir intervals unit A and unit B. Unit B has low resistivity values against the shale-contaminated reservoir interval. The calculated shale volume for the unit A ranges from 1 to 45 % (average 24 %); effective porosity ranges from 4 to 10 % (average 8 %); and water saturation ranges from 3 to 63 % (average 29 %). The top of the unit A reservoir interval is at 3,705.2 m (TVDss), with a gross thickness of 22 m and a net pay thickness of 15 m. The top of the unit B reservoir interval is at 3,642.2 m (TVDss) with a gross thickness of 18.5 m and a net pay thickness of 10.75 m (Table 1). The calculated shale volume for the unit B reservoir ranges from 2 to 86 % (average 39 %); effective porosity ranges from 1 to 13 % (average 7 %), and the water saturation ranges from 15 to 67 % (average 45 % in net pay interval).

Reservoir rocks are made up of mixtures of minerals (quartz, calcite, clay); consequently, their physical properties influence the measured log responses. These log responses are not only functions of the mineral characteristics and their relative percentages present in the rock but also on the nature and percentages of the fluids occupying the pore spaces (Serra 1986). The lithology of the Upper Safa reservoirs from litho-saturation cross-plots (Figs. 5 and 6) appears to be dominated

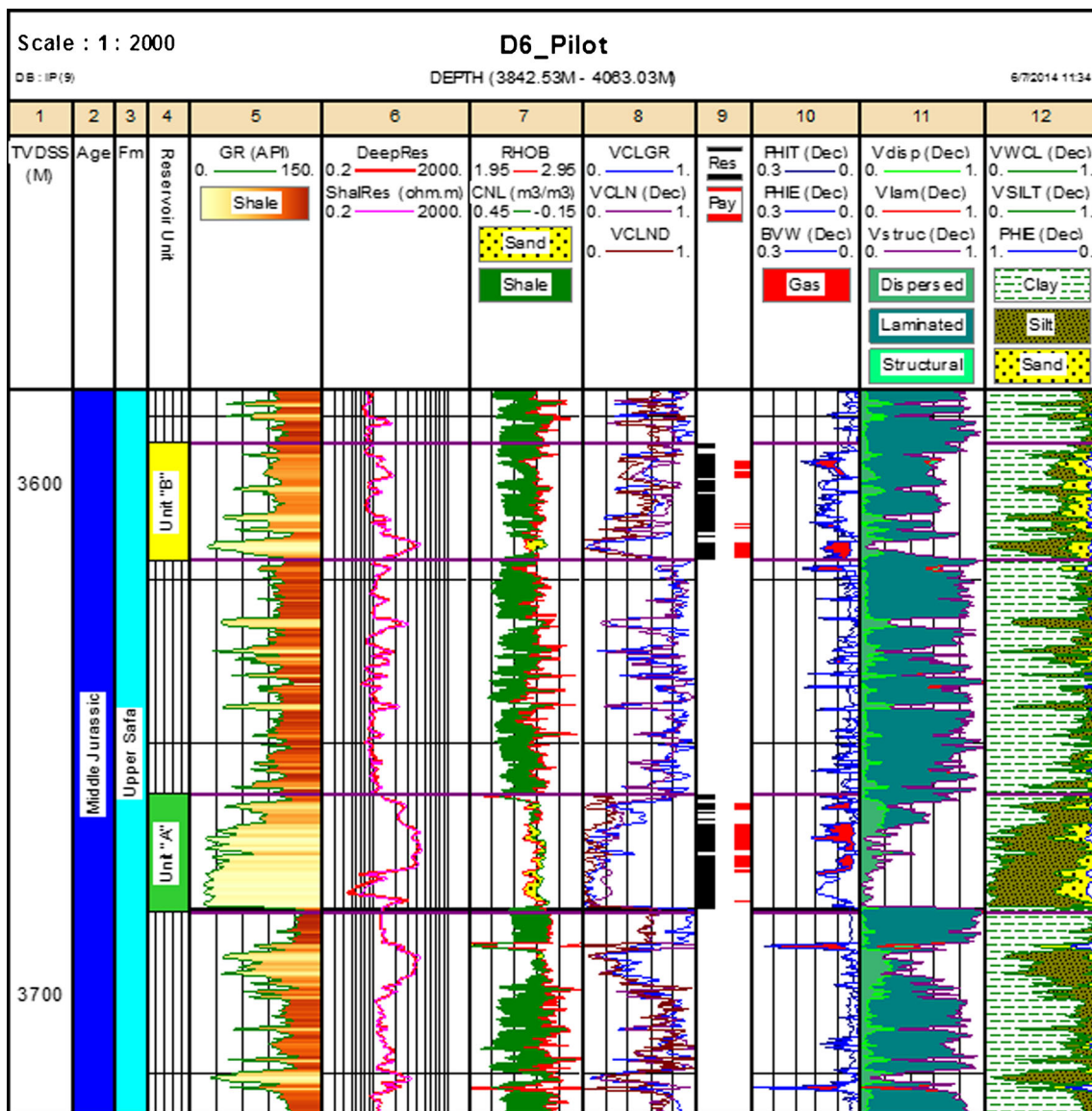


Fig. 5 Litho-saturation cross-plot showing vertical variations in the petrophysical characteristics of the Upper Safa reservoirs (unit A and unit B) intervals in D6_Pilot well

by sandstone, siltstone, and shale. On the basis of the results, lithological boundaries could be estimated in numerous wells. The interpretation of the shaly sandstone log data of these reservoirs has long been a challenge. Shale can be distributed in Upper Safa sandstone/siltstone reservoirs in three possible ways and forms: laminated, structural, and dispersed (Fig. 7). Each form can affect the amount of rock porosity by creating a layer of closely bound surface water on the shale particle. The laminae affect the porosity and vertical permeability. Structural shale is the shale deposited as an integral part of the matrix, but it does not affect the porosity. Dispersed shale occurs in the pores and can reduce the porosity and permeability of the formation (Dewan 1983). The cross-plots of neutron/density (N/D) porosity (Fig. 8) show dispersed and laminated habitats of shale type with little effect of heavy minerals. In these

cross-plots, the points shifted upward from the mineral identification due to the gas effect or the organic matter of the shale interbedded with this member (Fig. 8). The shale content of unit B is of greater amount when compared with that of unit A. It is dispersed and of laminated habitats as indicated by the N/D porosity cross-plots, and the gas effect appears through the shifted plotted zone toward the density axis (Fig. 8).

Reservoir iso-parametric maps

Based on well log analysis of the 14 wells in the Obaiyed Field, iso-parametric maps have been prepared (Figs. 9 and 10). They illustrate the lateral variation of the gross and net pay thicknesses of the Upper Safa reservoirs and the distribution of their petrophysical parameters including the shaliness

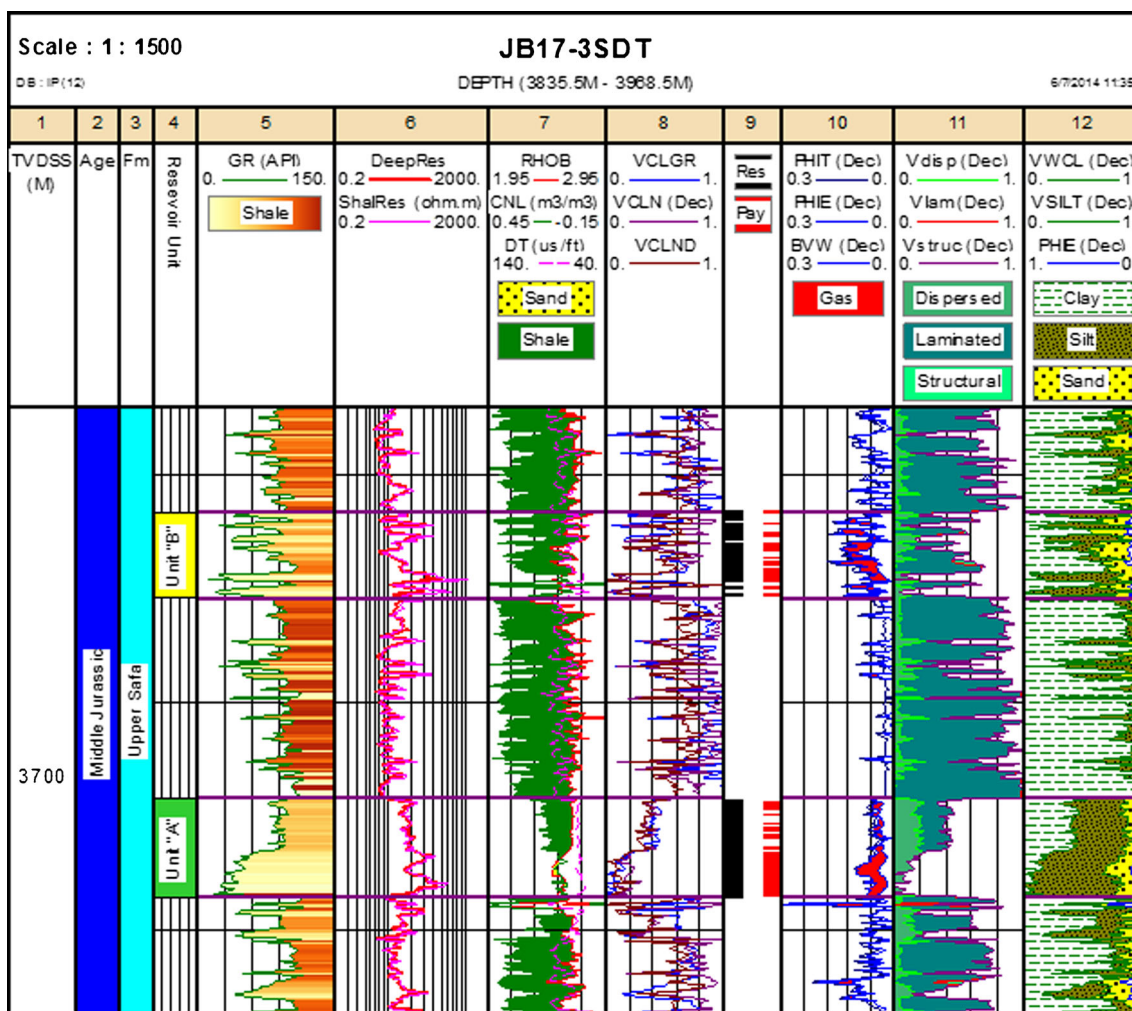


Fig. 6 Litho-saturation cross-plot showing vertical variations in the petrophysical characteristics of the Upper Safa reservoir (unit A and unit B) intervals in JB17-3SDT well

volume, the effective porosity, and the gas saturation maps (Figs. 11 and 12).

Gross thickness of unit A reservoir ranges from 8.37 to 32.07 m (Fig. 9a), while gross thickness of unit B reservoir (Fig. 10a) ranges from 1.5 to 32.97 m (Table 1). Net pay thickness of unit A reservoir (Fig. 9b) ranges from 2.33 to 25 m, while net pay thickness of unit B reservoir (Fig. 10b) ranges from 1.5 to 17.65 m (Table 1). The gross thickness contour map of the unit A reservoir shows that the maximum recorded reservoir thickness is 32.07 m at the D11A well in the middle of the study area (Fig. 9a), while it decreases gradually west and east ward with a minimum value of 1 m observed at the Jb18-1S well. Sediment thickens gradually toward the middle of the study area where most gas reserves and wells are concentrated. An isochore map of net pay delineates the thickness of the reservoir sand which contains hydrocarbons (gas-bearing zone). The net isopach map of the unit A reservoir shows a maximum recorded thickness of 25 m at the D5A well (Fig. 9b), while it decreases gradually west and east ward. The net isopach map of the unit B reservoir shows a maximum

recorded thickness of 17.65 m at the D11A well (Fig. 10b), while it decreases gradually north and south ward.

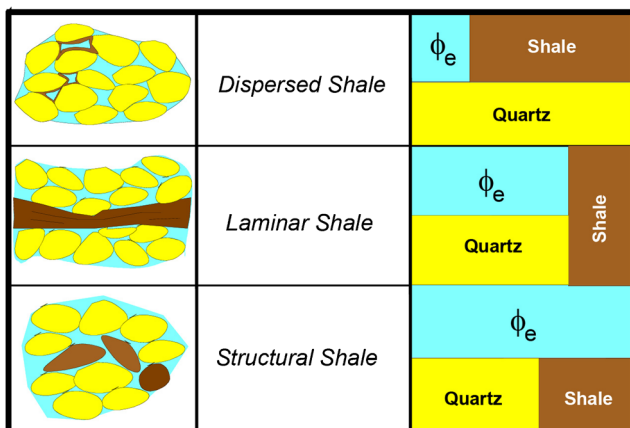
The iso-shaliness maps (Figs. 11a and 12a) represent the shale content distribution of reservoirs. The iso-shaliness map of the unit A reservoir shows an area of low values ranging between 3 and 40 % (average V_{sh} 34 %), which is located in the middle of the study area with the NW–SE trend. This explains the relative decrease of pay zone (sand) thickness in this area. The shale volume of the unit B ranges from 19 to 75 % (average V_{sh} 47 %). The iso-shaliness map of the unit B shows a relative increase toward the north and south directions.

The iso-effective porosity and gas saturation maps for the unit A (Fig. 11b, c) show an increase of porosity and gas saturation in the central part of the study area along the NW–SE direction. Porosity ranges from 3 to 12 %, while gas saturation ranges from 25 to 91 %. The sandstone reservoirs in this unit have a relatively high saturation of hydrocarbon content reaching up to 91 % in the D5A well (Table 1). The iso-effective porosity and gas saturation maps for the unit

Table 1 Petrophysical results for the Upper Safa reservoirs (unit “A” and unit “B”) intervals in the studied 14 wells, Obaiyed Field

Well	Depth (m)	Thickness (m)		Petrophysical Parameters (%)				
		Gross	Net	V _{sh}	PHIT	PHIE	S _w	S _h
Unit “B”								
D1		25.25	14.88	19	9	8	23	77
D11A		32.97	17.65	26	9	7	31	69
D17		1.5	0	75	3	2	85	15
D18		21.21	10.2	39	8	7	39	61
D21		11	2.5	55	5	4	67	33
D3A		17.23	11.56	26	10	8	28	72
D4		4.17	1.5	66	4	3	74	26
D5A		19.81	9.5	35	8	7	34	66
D6_Pilot		24.6	6	39	8	6	41	59
D7-SDT		2.5	0	68	4	2	76	24
Jb18-1S		21.98	0	60	5	3	78	22
OBA2-2C		14	5.8	43	6	4	61	39
OBA2-3		3.86	2.5	67	4	3	76	24
JB17-3SDT		18.5	10.75	39	8	7	45	55
Unit “A”								
D1		–	–	–	–	–	–	–
D11A		32.07	9.95	26	10	7	26	74
D17		22.46	13.6	12	11	8	23	77
D18		19.08	9.78	35	9	7	31	69
D21		16.97	8	40	8	6	36	64
D3A		26.46	9.55	39	9	7	32	68
D4		9.14	2.33	73	4	3	71	29
D5A		30.23	25	3	15	12	9	91
D6_Pilot		21.1	12	10	13	11	16	84
D7-SDT		–	–	–	–	–	–	–
Jb18-1S		8.37	0	85	4	3	75	25
OBA2-2C		22.11	17.45	16	11	8	26	74
OBA2-3		–	–	–	–	–	–	–
JB17-3SDT		22	15	24	10	8	29	71

B (Fig. 12b, c) show an increase of porosity and gas saturation along the western and central parts of the area. Porosity ranges

**Fig. 7** Three possible ways of shale distribution in formation (Serra 1984)

from 2 to 8 %, while gas saturation ranges from 24 to 77 %. These values decrease gradually to the north and south directions due to the shale effect. Water cutoff maps of reservoirs (Figs. 11d and 12d) show the area of the productive wells.

Reservoir facies

Facies of Upper Safa reservoir (unit A) is characterized by a boxcar (or blocky), serrated, and cylindrical motif in the gamma ray logs (Figs. 13 and 14). Lower boundaries of this facies on logs show a concave signature, whereas upper boundaries show a slight curvature toward increasing shale content. The gamma ray values of this facies vary from 5 to 125 API units, and the thickness varies from 1.5 to 32.97 m. According to well log analysis, the main lithology of this facies is sandstone, with silt and shale. The log character also shows a

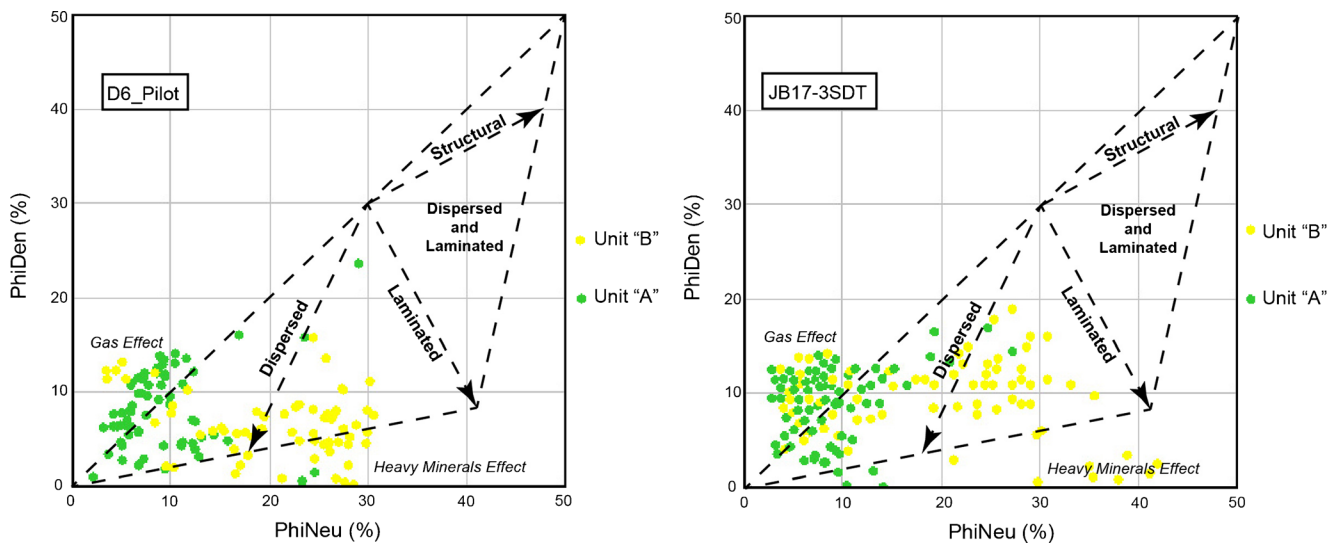


Fig. 8 Neutron porosity (PhiNeu) vs. density porosity (PhiDen) cross-plots showing habitat of shale in the Upper Safa reservoirs (unit A and unit B) in the D6_Pilot and JB17-3SDT wells

change in grain size from base to top reflecting a fining-upward character (Fig. 13).

Facies of Upper Safa reservoir (unit B) is generally characterized by irregular-shaped motif in the gamma ray logs (Figs. 13 and 14). Lower and upper boundaries of this facies are closer to the shale baseline. The gamma ray values vary between 10 and 115 API. The thinner beds in this facies show sharp deflections toward the sand base. According to well log analysis, the main lithology of this facies is shale with thin-interbedded siltstone and fine-grained sandstone.

Discussion

In the absence of biostratigraphic and other well data, gamma ray curve signatures were used to deduce the depositional environments based on their characteristic patterns. Gamma ray log is often used to measure the shaliness of a formation. In reality, the shaliness often does not change suddenly but occurs gradually with depth. Such gradual changes are indicative of the litho-facies and the depositional environment of the rock and are associated with changes in grain size and

Fig. 9 Gross reservoir (a) and net pay (b) isopach map of the Upper Safa reservoir (unit A)

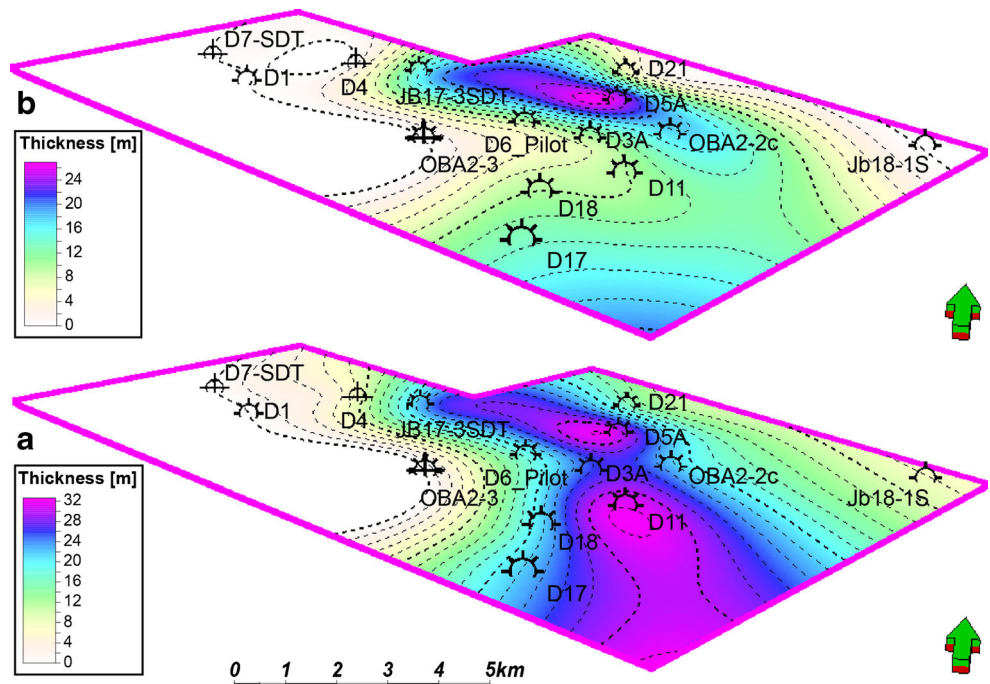
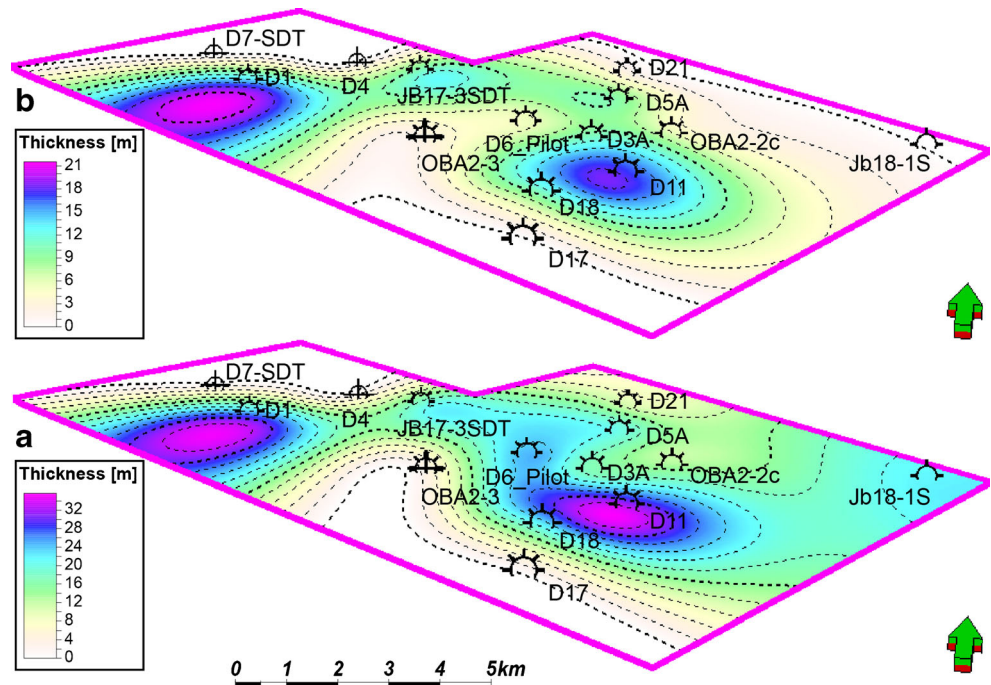


Fig. 10 Gross reservoir (a) and net pay (b) isopach map of the Upper Safa reservoir (unit B)



sorting that are controlled by facies and depositional environment (Serra and Abbott 1982; Serra 1985; Rider 1990, 1996). Figure 13 shows the shape of gamma ray log responses for various depositional environments of the Upper Safa reservoirs. The thick gamma ray motif within the context of serrated and fining-upward elements and absence of significant

mudstone deposits indicate a fluvial environment (Posamentier and Allen 1999).

The presence of a characteristically cleaning-down succession in unit A facies indicates channel fill deposits (Rider 1990; Abdel-Fattah and Slatt 2013). The well log analysis indicates that the best reservoir characteristics is observed in

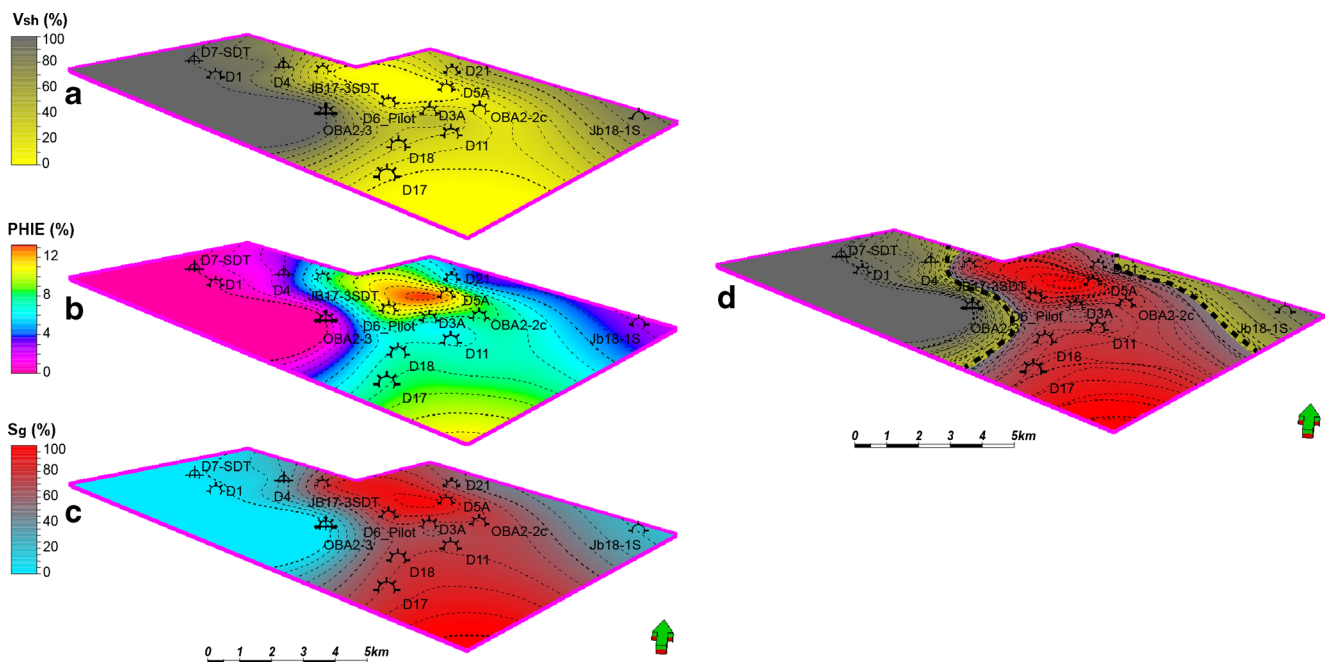


Fig. 11 Iso-parametric maps of the Upper Safa reservoirs (unit A) from well data analysis showing lateral variations in petrophysical characteristics: **a** shale volume (V_{sh}), **b** effective porosity (PHIE), **c** gas

saturation (S_g), and **d** cutoff area (shale volume <40 %, effective porosity >6 %, and gas saturation >40 %)

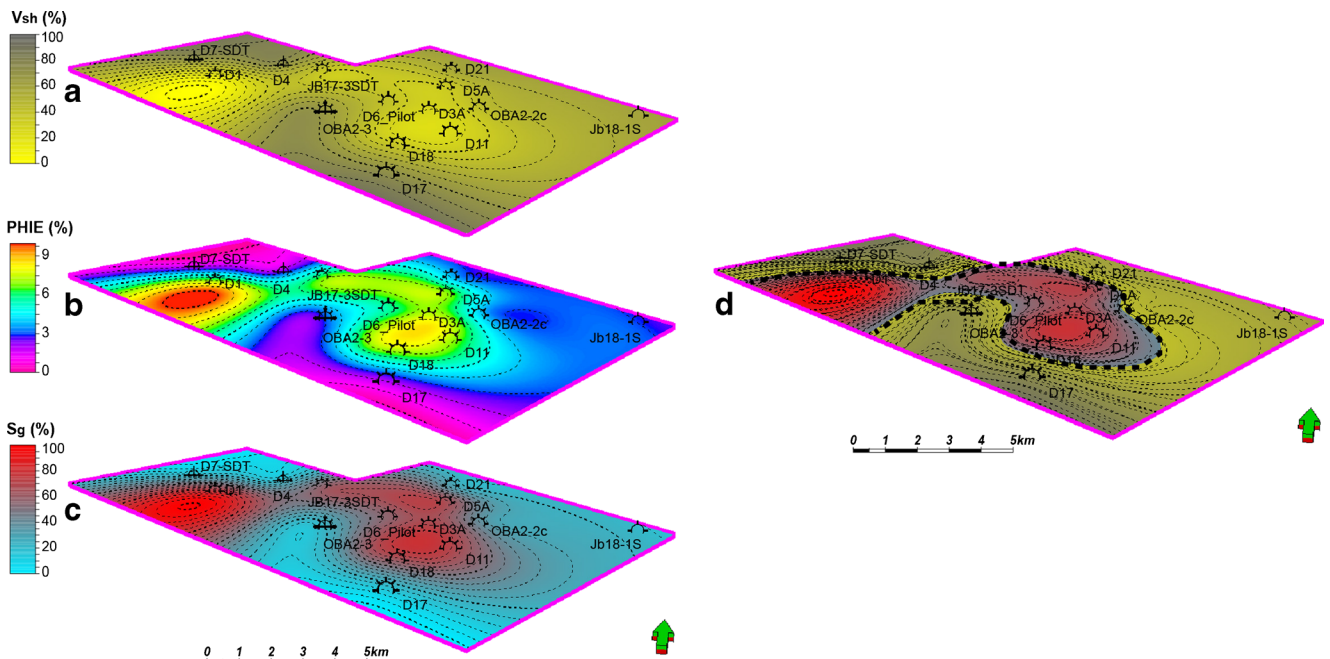


Fig. 12 Iso-parametric maps of the Upper Safa reservoirs (unit B) from well data analysis, showing lateral variations in petrophysical characteristics: **a** shale volume (V_{sh}), **b** effective porosity (PHIE), **c** gas

saturation (S_g), and **d** cutoff area (shale volume <40 %, effective porosity >6 %, and gas saturation >40 %)

unit A, which has high porosity, low shale content, good net pay thickness, and low water saturation (Fig. 11). These petrophysical parameters are distributed in the same trend as the fluvial channels in the central part of the study area trending NW–SW direction (Fig. 11). Figures 13 and 14 show different architectural channel fill elements of unit A. These elements have cylindrical, bell-shaped, and smooth or slightly serrated appearance on the gamma ray log (Cant 1992; Posamentier and Allen 1999). Their sharp bases indicate

generally downcutting into clay- or silt-rich floodplain sediments (Juhász et al. 2004). Gamma ray log shapes record the presence of two types of channels: single-story and multi-story. Single-story channels are expressed as cylindrical-shaped signature with a sharp base and a slightly fining-upward trend toward top (Figs. 13 and 14). Multi-story channels are expressed as a boxcar or cylindrical shape (rarely irregular) with thinner individual sandstone bodies and fining-upward trends. The slightly fining-upward trend in the uppermost

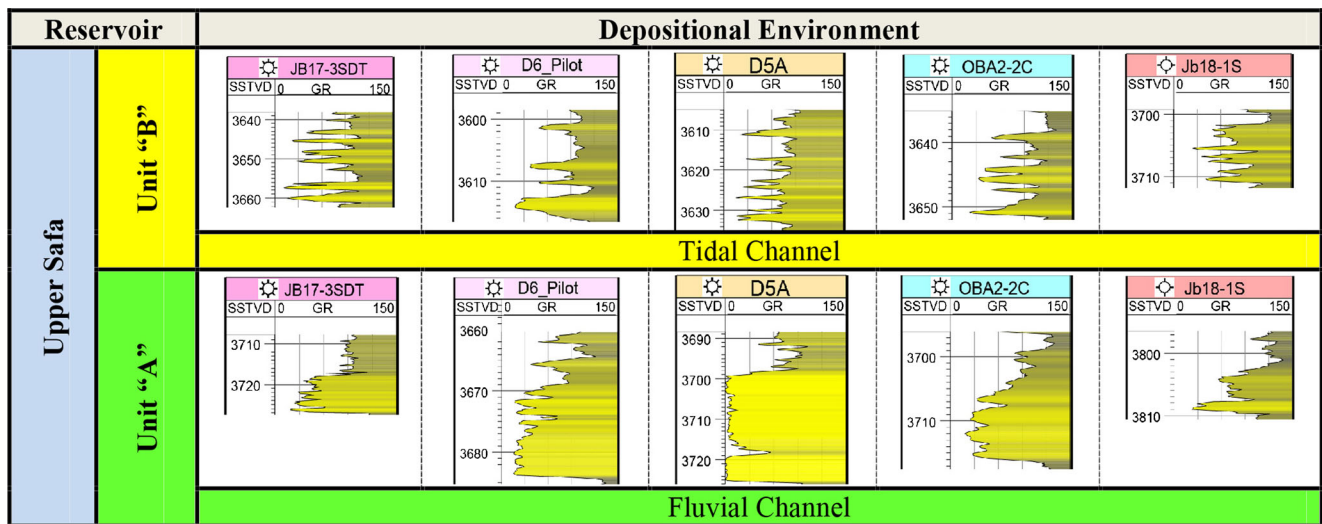


Fig. 13 The gamma ray log and depositional environments of the Upper Safa reservoirs (unit A and unit B)

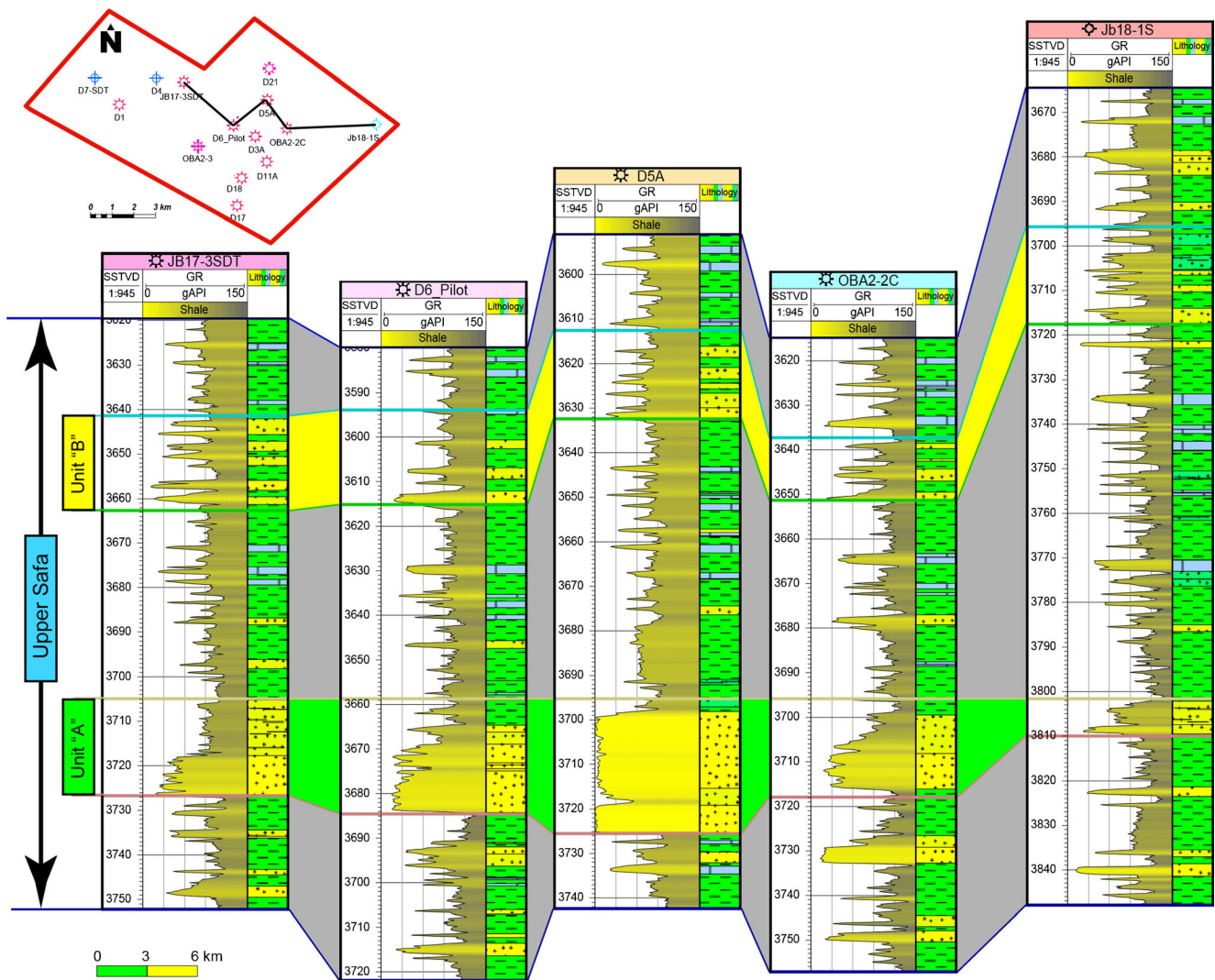


Fig. 14 A stratigraphic cross section showing the Upper Safa reservoirs (unit A and unit B) in Obaiyed Field (Western Desert, Egypt)

parts of motifs, the presence of isolated sandbodies within thick overbank fine units, and the sharp erosional basal contact are all characteristics of a single-story channel. Multi-story channels are identified by their rather thinner individual signatures and by their superimposed nature on each other, with small thicknesses of fine-grained material between (Juhász et al. 2004).

Facies of unit B is generally characterized by irregular-shaped motif in the gamma ray logs (Figs. 13 and 14). The thick irregular-shaped motif in the gamma ray log, with erosional top and intervening fine-grained sandstone and siltstone signature, indicates floodplain deposits (Cant 1992). The presence of interbedded siltstone and sandstone are mainly responsible for the irregular shape of the gamma ray log curve (Cant 1992). An irregular-shaped log with gamma ray value increasing upwards to a lower value indicates increasing clay content. This type of sandstone is characteristics of tidal channel in the delta plain. The productivity of these reservoirs is quite poor,

and the main reason attributed for the poor performance is due to poor reservoir properties (Fig. 12).

Conclusions

Geological observations and information obtained from well log analyses in the Obaiyed Field (Western Desert, Egypt) have been used to evaluate the petrophysical characteristics, depositional environment, and hydrocarbon prospectivity of the Middle Jurassic Upper Safa Member. This member in the Obaiyed Field is composed mainly of shale with two major sandstone reservoir intervals, namely unit A and unit B, which are pay zones for gas production. In terms of depositional facies, and based on gamma ray curve signatures, the reservoirs are interpreted to be composed of fluvial channel sands (unit A) and tidal channel sands (unit B). The fluvial channel deposits of unit A are composed of single- and multi-story

channels and are characterized by a cylindrical, bell-shaped, and smooth or slightly serrated appearance on the gamma ray log. This interval is mainly made up of coarse to fine-grained sandstone at the base with thin beds of siltstone and shale at the top. The unit A exhibits a fining-up sequence. However, the unit B is composed of tidal channel deposits, which are characterized by a generally irregular-shaped gamma ray log motif. It is composed of thinly interbedded siltstone and fine-grained sandstone. In such environments, reservoir quality is driven by the amount of sand within the channel fill. As the sand content increases and the shale content decreases, the porosity and permeability increase.

Petrophysical parameters and net pay thickness maps of the Upper Safa reservoirs show different values along the study area. The main factor controlling differences in petrophysical properties and thickness of these reservoirs is the type of sandstone facies. Shales cause a major reduction in the porosity and consequently reduce the gas saturation as observed in unit B. This reservoir is normally characterized by low resistivity net pay zone. The best reservoir characteristics were observed in unit A, which has high porosity, low shale content, and low water saturation. Maps of reservoir parameters indicate areas for future gas development in the central part of the Obaiyed Field along a belt in the NW–SE direction.

The information contained in this paper clearly demonstrates the importance of building a depositional model for an improved understanding of the petrophysical distribution of Upper Safa reservoir properties in the Obaiyed Field. This study used the litho-stratigraphic framework and defined well log relationships to create a local picture of the depositional environment for the Upper Safa interval. The depositional environment, and its impact on the petrophysical characteristics of Upper Safa reservoirs, allows for improved recognition of potential hydrocarbon charged regions for economic gas production.

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