



Seismic interpretation and hydrocarbon assessment of the post-rift Cenomanian Bahariya reservoir, Beni Suef Basin, Egypt

Amer A. Shehata¹ · Mohammad A. Sarhan²

Received: 14 February 2022 / Accepted: 24 May 2022 / Published online: 14 June 2022
© The Author(s) 2022

Abstract

The geophysical interpretations for a collection of high-quality 2D seismic data plus well logging data for six drilled wells exposed the structural controls and the hydrocarbon potentiality of the Beni Suef Basin, north Western Desert, Egypt. The created structural map on the top of the Early Cenomanian Bahariya Formation (the significant oil reserve in north Western Desert), exhibits a series of NW–SE normal faults as well as a master ENE strike-slip major fault. The extensional faults formed horst structures while the strike-slip fault created a negative flower structure in the central part of the study area. These structural features represent the main petroleum traps within Beni Suef Basin. The reservoir quality was assessed through the petrophysical analysis of the Bahariya Formation in wells; Azhar A2, Azhar E-2X, Azhar E3, Yusif-4X, Fayoum-2X and Beni Suef W-1X. This analysis proved that the Lower Bahariya unit has better reservoir quality than the Upper Bahariya reservoir, with shale volume less than 10%; effective porosity between 10 and 20%, water saturation between 25 and 75% and total pay thickness between 11 and 88 ft. The obtained results encourage drilling more exploratory wells in Beni Suef Basin to enhance the productivity from the sandstones of the Lower Bahariya reservoir.

Keywords Bahariya formation · Beni Suef Basin · Well logging · Seismic interpretation · Reservoir evaluation

Introduction

Rift basins are defined as prolific hydrocarbonaceous provinces with huge amounts of recoverable oil reserves (Lambiase and Morley 1999; Morley 1999; Withjack et al. 2002). Although structural evolution significantly affects the distribution of petroleum within rifts, the basin-fill as well as the stratigraphic characteristics define whether a basin is hydrocarbonaceous or not and provide the sources, reservoirs, and seals-rock units in the rift basin (Lambiase and Morley 1999; Withjack et al. 2002; Martins-Neto and Catuneanu 2010; Shehata et al. 2018, 2019, 2021a; Kassem et al. 2021, 2022). The integration of different types of datasets such as well logging, seismic and core analysis in addition to petrophysical and geophysical interpretations will enable to trace and evaluate the reservoir rock units in addition to

track their spatial distribution (Abdel-Fattah and Slatt 2013; Piggott and Abdel Fattah 2014; Dolson 2016; Radwan et al. 2021; Shehata et al. 2021b).

The Beni Suef Basin is NW rift basin developed in the Early Cretaceous, occurring at the NE corner of the African Plate with significant hydrocarbon potential that is put in the future plan of exploration in the north central Egypt. The basin is contiguous with known basins in the Nile Valley and North-western Desert (e.g., Shushan, Gindi, Asyut, Abu Gharadig Basin, Fig. 1a). Geographically, Beni Suef basin is divided into two main provinces (Fig. 1b) the western one which is called West of Nile (WON, which is our study area, Fig. 1c) and eastern one which is called East of Nile (EON).

In General, the north Western Desert basins showed different types of hydrocarbon entrapments, which are almost related to the latest Cretaceous tectonics of the Syrian-arc (Abu El Naga 1984; Moustafa 2008; Sakran et al. 2019). The resultant traps are three- and four-way closures, trap door, block faults trending NE–SW and NW–SE and horsts (Sultan and Abd El Halim 1988; Dolson et al. 2001; Salem and Sehim 2017; Sakran et al. 2019). The sandstone intervals in the Cretaceous sediments which are laterally-distributed in the majority of the North Western Desert basins, including

✉ Mohammad A. Sarhan
msarhan@du.edu.eg

¹ Geology Department, Faculty of Science, Port Said University, Port Said 42522, Egypt

² Geology Department, Faculty of Science, Damietta University, New Damietta 34517, Egypt

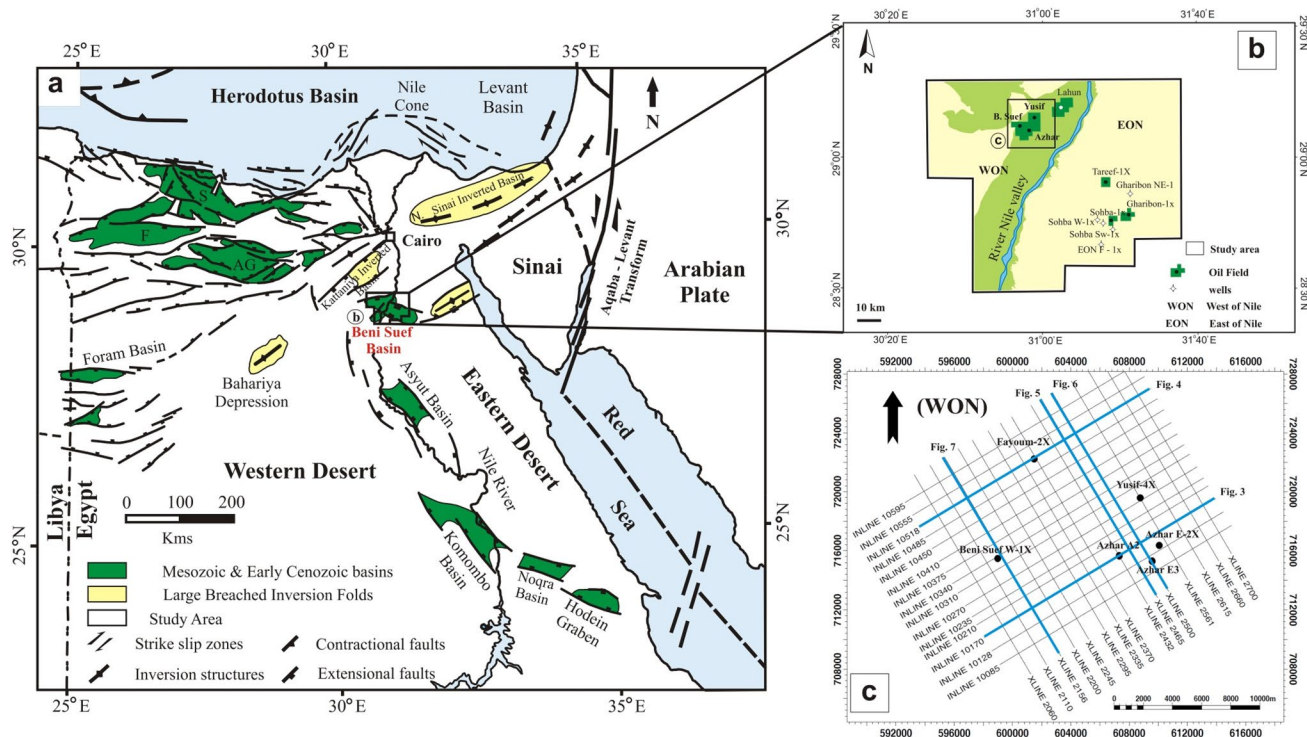


Fig. 1 a Mesozoic–Cenozoic basin distribution in Egypt. b Beni Suef Basin' location map and their main sectors. c Location map of the studied area including the seismic profiles and wells

the studied basin, formed the main reservoirs (Richardson et al. 1998; Nabawy et al. 2021; Sarhan 2017a; Sarhan et al. 2017a, b; Basal et al. 2019; Sarhan 2019; Elhossainy et al. 2021; Sarhan 2021a, b). These sandstones are encountered in Early Cretaceous Alam El-Bueib and Kharita formations, and Late Cretaceous Bahariya and Abu Roash formations.

The study area is situated in the western sector of Beni Suef basin (WON) between $31^{\circ} 30'$ & $29^{\circ} 50'$ E and between $29^{\circ} 25'$ & $28^{\circ} 31'$ N (Fig. 1) and included numerous oil fields such as Azhar, Fayoum, Beni Suef and Yusif (Fig. 1b, c). This study aimed to evaluate the hydrocarbon potential of sandstone intervals on Bahariya reservoirs in the Western Province of Beni Suef basin (WON) based on the overall integration of seismic and well-logging datasets from Six wells, that is, Azhar A2, Azhar E-2X, Azhar E3, Yusif-4X, Beni Suef W-1X and Fayoum-2X. The objectives include the seismic facies interpretations, structural mapping and petrophysical assessment of the entirely different sandstone intervals of the Bahariya Formation in these wells.

Geologic setting

The Beni Suef Basin is one of the intercontinental rift basins that formed in the Early Cretaceous and due to the breakup of Western Gondwana and South and Equatorial Atlantic

Oceans-opening (Moustafa 2008; Shehata et al. 2018, Bosworth et al. 2008; Sakran et al. 2019). Accordingly, active-rifting and the clockwise' rotation of the north-central Africa plate is happened (Guiraud and Maurin 1992; Guiraud et al. 2005). This basin is located just in the beginning of the unstable shelf of Egypt (Said 1962) within the Nile Valley (Fig. 1). Tectonically, the basin is subjected to two major tectonic phases; the syn-rift extensional one in the Early Cretaceous and the post-rift one in the latest Cretaceous which is affected by the Santonian Syrian-arc compressional regime (Salem and Sehim 2017; Shehata et al. 2018, 2020; Sakran et al. 2019).

The Beni Suef basin has a relatively thick lithostratigraphic succession that aged Cretaceous-Paleogene (Fig. 2a), starting with the deposition with thick fluvial siliciclastic that belongs to the Early Cretaceous Kharita Formation, then siliciclastic-dominated sediments belong to Cenomanian Bahariya Formation, followed by intercalations of clastic/carbonate units of Cenomanian-Santonian Abu Roash Formation and turned upward to carbonates and chalk of Campanian–Maastrichtian Khoman Formation (Zahran et al. 2011; Shehata et al. 2018, 2019, 2020).

The Cenomanian Bahariya Formation (Said 1962) overlies un-conformably the fluvial sediments of Kharita Formation and is conformably superimposed by the Abu Roash Formation of marine nature. Lithologically, it is composed

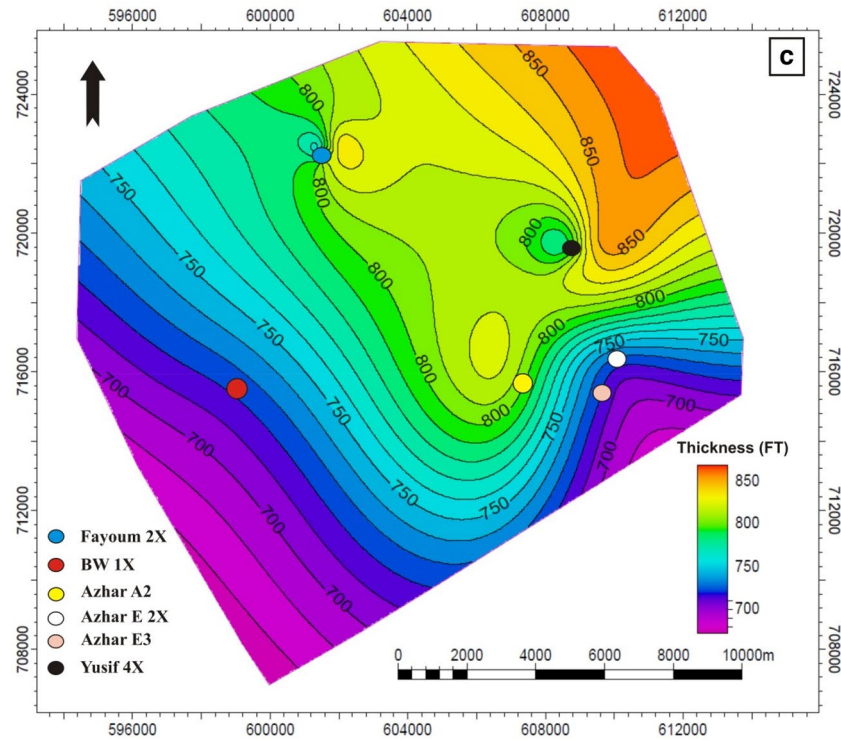
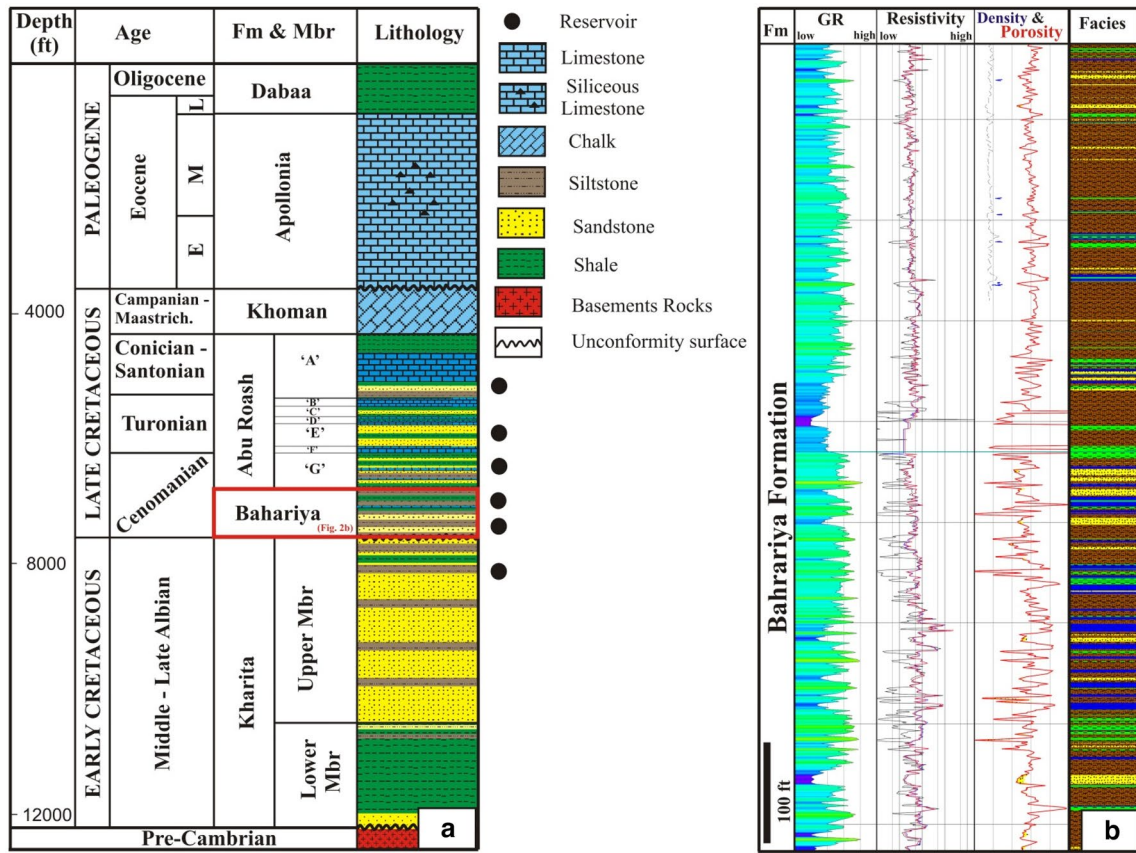


Fig. 2 a Lithostratigraphic section of the Beni Suef Basin. b Lithostratigraphic succession and logging of the Bahariya formation. c Thickness distribution map of the Bahariya sediments in the study area

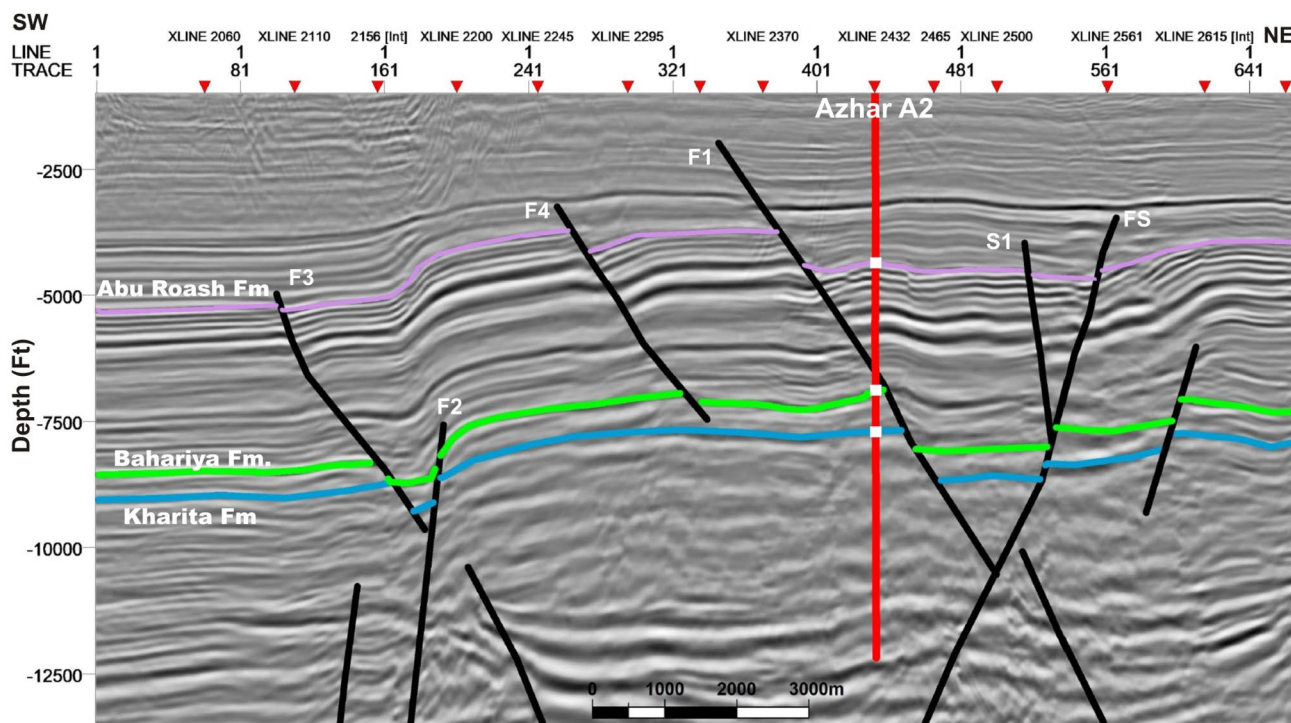


Fig. 3 Interpreted NE–SW inline seismic profile (no. 10170) (for location see Fig. 1c)

of sandstone/siltstone interbeds with some limestone and shale intercalations (Fig. 2b). The lower part of the formation is composed of sand-dominated units, displaying repetition patterns of blocky gamma-ray (Fig. 2b). On the other hand, the upper parts showing remarkable increase in the gamma ray/neutron porosity readings, which reflect the increase in upward mud-content (Fig. 2b). In the studied area, Bahariya Formation' thickness ranges from 708 to 801 feet with relative thickening toward the Southeastern parts from the NE, NW and SW parts (Fig. 2c). Depositionally, the Bahariya Formation is developed initially in Fluvial-deltaic environments, and gradually changed to shallow marine setting up-section (Said 1990; Mahmoud and Deaf 2007; El-Soughier et al. 2014; Shehata 2019; Nabawy et al. 2021).

Data and methodology

Thirty seismic profiles (SEG Y) in depth domain within the western province of Beni Suef Basin (Fig. 1c) were carefully examined and detailed interpreted. These seismic profiles

comprising fifteen inline trending NE-SW profiles and fifteen xline trending NW–SE profiles and are in good quality which satisfying our interpretations. It covers an area around 300 km² and encompasses four main productive fields in the basin namely Azhar, Beni Suef, Yusif and Fayoum oil fields (Fig. 1b). Six deep drilled wells are scattered in the study area and intersecting and tying with the seismic profiles (Fig. 1c). Azhar oil field comprises three wells namely: Azhar A2, Azhar E-2X and Azhar E3, Yusif field contain Yusif-4X well, Fayoum field has Fayoum-2X well and Beni Suef W-1X well is encountered in Beni Suef oil field.

The applied procedures for assessing the Bahariya sandstones in Beni Suef Basin started with the seismic interpretation stage. In this step, the seismic horizon corresponding to the top of the Bahariya Formation was picked and mapped with the related faults over the grid of the available seismic lines.

The next step was the qualitative examination for the well-log data of the accessible wells in order to delineate the hydrocarbon-bearing zones located within the Bahariya Formation. This was followed by the quantitative assessment for the petrophysical parameters of the promising zones by

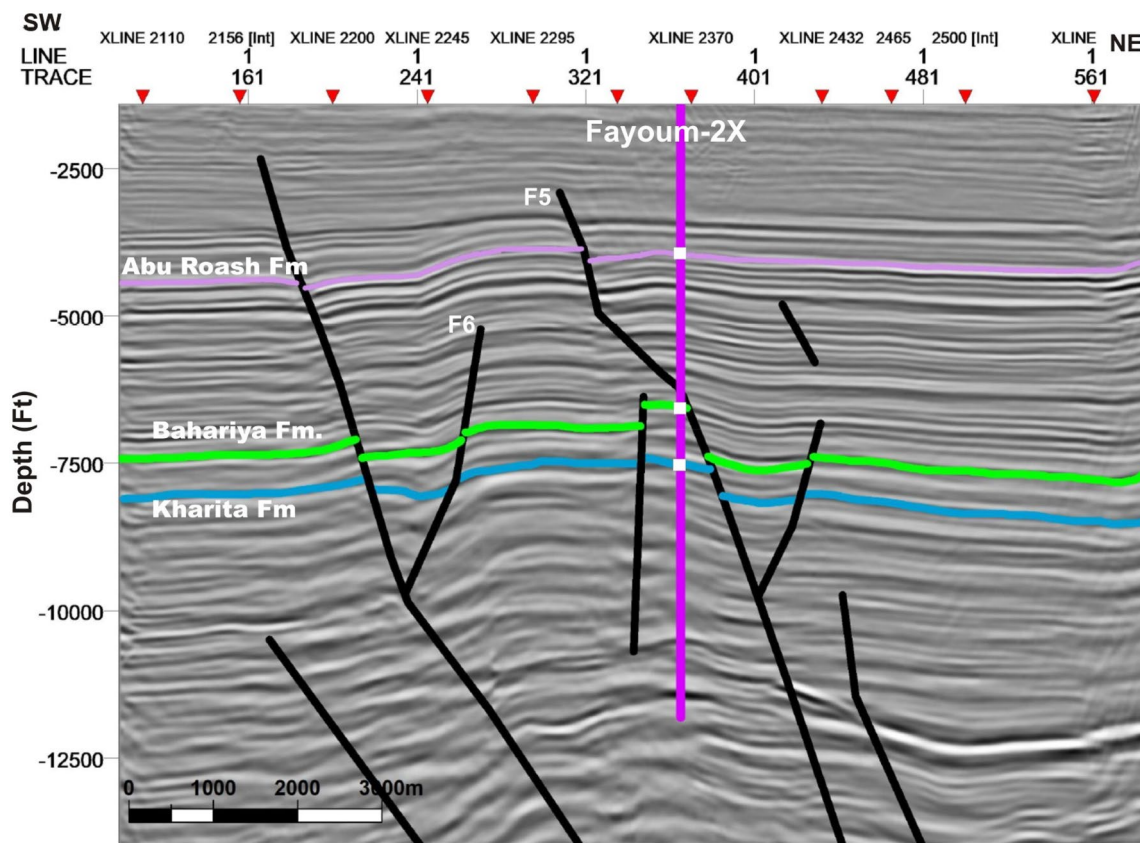


Fig. 4 Interpreted NE–SW inline seismic profile (no. 10518) (for location see Fig. 1c)

using Techlog software. The investigated parameters comprise; effective porosity (ΦE), total porosity (ΦT), water saturation (S_w) and shale volume (V_{Sh}). The parameters of V_{Sh} , ΦT and ΦE were calculated using formulae of Asquith and Gibson’s (1982) as follow:

$$V_{Sh} = (GR - GR_{min}) / (GR_{max} - GR_{min}) \tag{1}$$

where V_{Sh} is the shale volume; GR, is the gamma ray reading value; GR_{min} , is the lowest gamma ray value; and GR_{max} , is the maximum gamma ray value.

$$\Phi T = (\Phi N + \Phi D) / 2 \tag{2}$$

where ΦT is the total porosity, ΦN is the neutron porosity, and ΦD is the density porosity.

$$\Phi E = \Phi T * (1 - V_{Sh}) \tag{3}$$

where ΦE is the effective porosity, ΦT is the total porosity, and V_{Sh} is the shale volume.

However, the water saturation for the reservoir intervals was computed using Archie model (Archie 1942) since the sandstones which encompassing these zones in Bahariya Formation exhibit low shale content ($V_{Sh} < 10\%$) as follow:

$$S_w^2 = R_w / \Phi^2 * R_t \tag{4}$$

where S_w is the water saturation; Φ is the porosity; R_t is the deep resistivity; R_w is the connate water resistivity.

Results and interpretation

Seismic interpretation

The Bahariya Formation is displaying wedge/sheet-like geometry and characterized by variable reflectors’ amplitude with low/moderate continuity and chaotic/sub-parallel configuration (Figs. 3, 4, 5, 6 and 7).

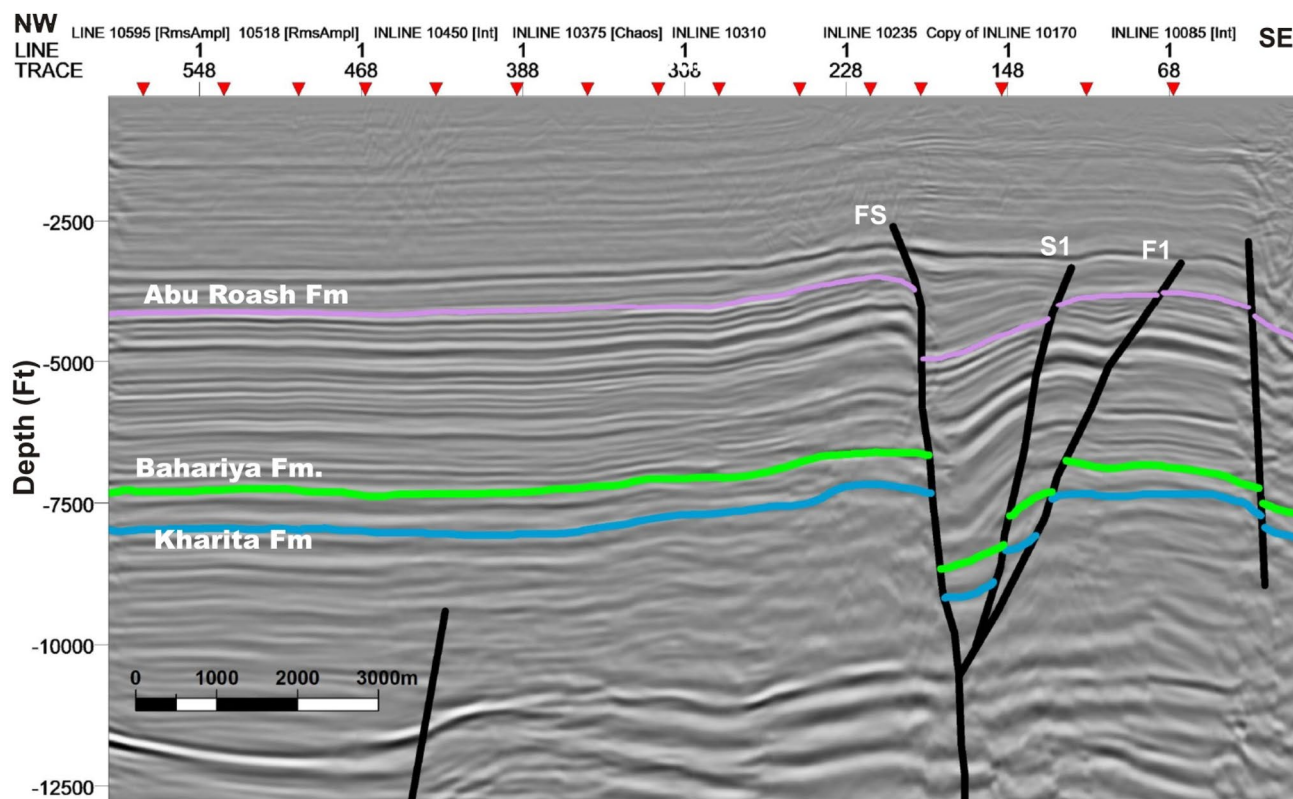


Fig. 5 Interpreted NW–SE xline seismic profile (no. 2465) (for location see Fig. 1c)

Interpretation of the NE–SW inline profiles indicated the predominant of NW–SE-oriented normal faults ($F1$, $F2$, $F3$, $F4$, $F5$, $F6$ and $F7$) (Figs. 3 and 4). Interaction between these faults resulted in the development of horst structures in the northwestern and central parts of the study area which affecting the Bahariya and Abu Roash formations (Figs. 3 and 4). The central horst is bounded by $F1$ and $F2$ that throwing SE and NE (Fig. 3) while the northwestern horst is bounded by $F5$ and $F6$ and become more narrower (Fig. 4). On the other hand, the interpretation of the NW–SE xline profiles showed the presence of master ENE-oriented strike-slip major fault (FS) in the central part of the study area (Figs. 5, 6 and 7). ENE Strike-slip fault is associated with some splays of normal faults ($F1$, $F3$, $F7$ and $F8$) and other segments of strike faulting ($S1$), which is forming a negative flower structure (Figs. 5, 6 and 7).

Normal NW faults and plunging/doubly plunging NE folds are the main prevailing structures in the depth structural map (Fig. 8). The ENE strike-slip fault is segmented to two right-stepped strike fault' segments which form a structural-low area called releasing bend in between (Fig. 8).

The releasing bend is associated with some WNW-trending normal faults with basin-ward throw (Fig. 8). Most of the normal faults are formed in the Early Cretaceous while the strike-slip and their associated structures are developed in the latest Cretaceous.

The Normal faulting and the strike-slip and their associated structures are responsible for the development of different entrapment types and closures in the basin. NW–SE horst closure is dominant in Yusif by (bounded $F9$ and $F10$) and Fayoum oil field (bounded $F5$ and $F6$), Trap-door block is encountered in Beni Suef oil field (FS and $F11$) and Azhar oil-field is characterized by the existence of three-way dip closure that formed due to the effect of the strike-slip major fault, its segments ($S1$ and $S2$) and the normal faults $F1$, $F4$ and $F8$ (Fig. 9).

Well logging interpretation

The Bahariya Formation sandstones in the investigated wells were detailed in the mud log' report (Fig. 10) as;

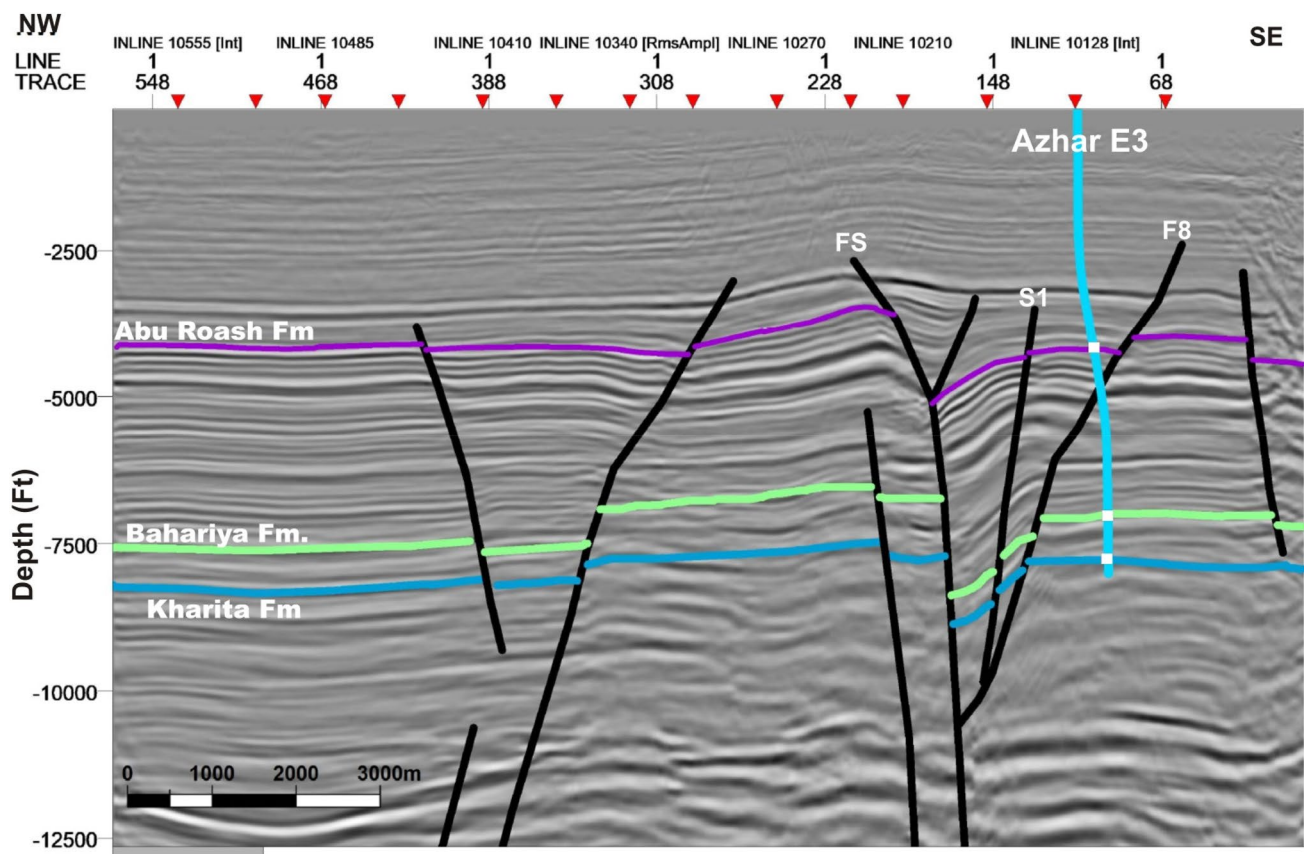


Fig. 6 Interpreted NW–SE xline seismic profile (no. 2500) (for location see Fig. 1c)

white/off-white, fine to very fine-grained, sub-rounded to sub-angular, moderately sorted, moderately hard to friable with silty cement, with traces of pyrite and kaolinite. All of the previous characters reveal the relatively good textural maturity of the Bahariya sandstones. Furthermore, these sandstones show uniform oil stain and occasionally spotted oil stain with pale yellow fluorescence with no stream-cut.

The visual investigation of the well-log data corresponding to the Bahariya Formation in well Azhar A2 revealed that the oil reservoir intervals vary between 7475 and 7675 ft depth (Fig. 11). In well Azhar E-2X, the oil-bearing intervals locate between 8050 and 8275 ft (Fig. 12) and in well Azhar E3, the best intervals were found among depths 7775 and 7850 ft (Fig. 13). However, the potential zones in Beni Suef W-1X well are varying in depths; 7650–7925 ft (Fig. 14). The oil pay zones in Fayoum-2X well are between depths 6950 and 7375 ft (Fig. 15). Furthermore, in well Yusif-4X,

the oil-bearing intervals delineated among depths 7625 and 7750 ft (Fig. 16).

The superiority of the investigated intervals as possible oil reservoirs was judged based on several characteristics encompasses; low shale content, as evidenced by low gamma-ray and high deep-resistivity curves, the density curve is frequently to the left of the neutron curve (indicating the sandstone matrix), and the neutron curve's high porosity values. The total net pay thickness for the interpreted reservoir intervals in Azhar field reaches 43ft in Azhar A2 well, 26 ft in Azhar E3 and only 14ft in Azhar E-2X. However, the total thickness of the pay zones in Beni Suef W-1X well reaches 32 ft and only 11 ft in Yusif-4X, whereas the maximum net pay thickness was recorded in Fayoum-2X well with 88 ft thick.

The petrophysical calculations for the promising intervals within the Bahariya Formation in the studied wells

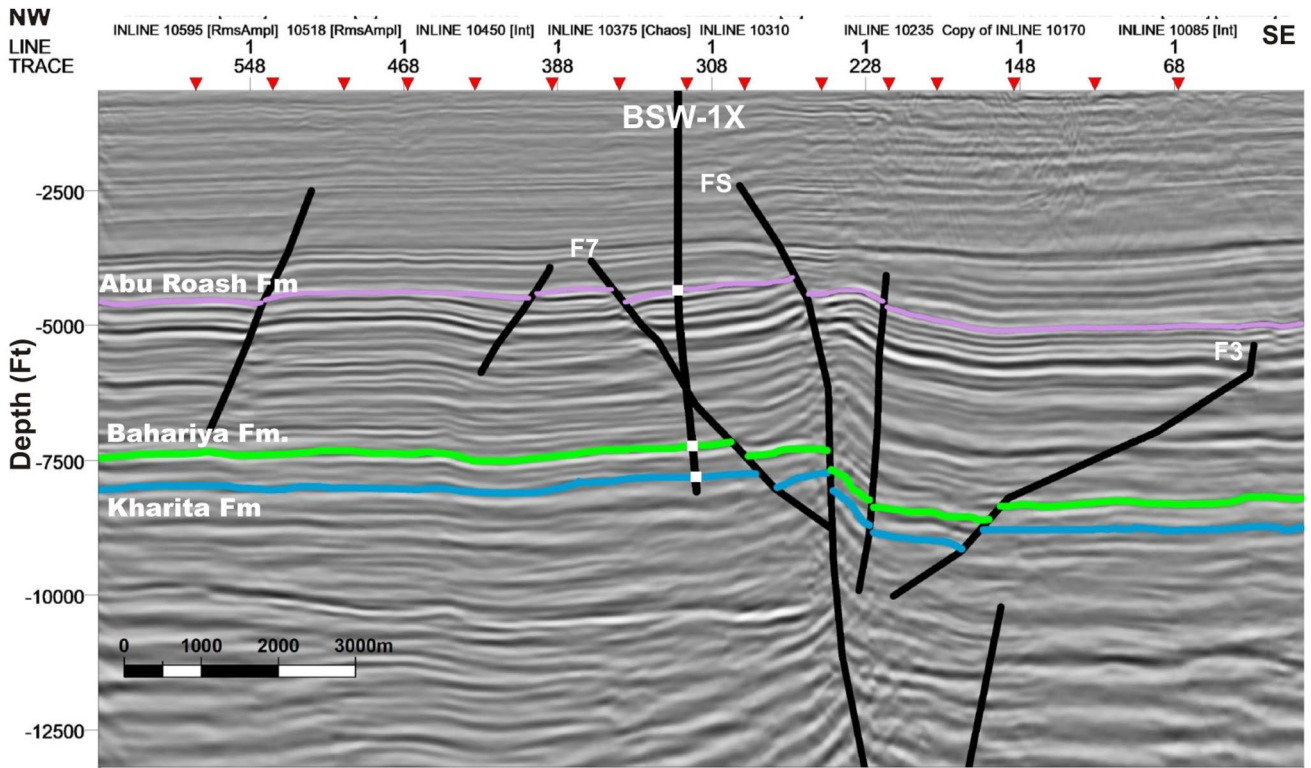


Fig. 7 Interpreted NW–SE xline seismic profile (no. 2156) (for location see Fig. 1c)

Fig. 8 Depth-structural contour map for the top of Bahariya formation

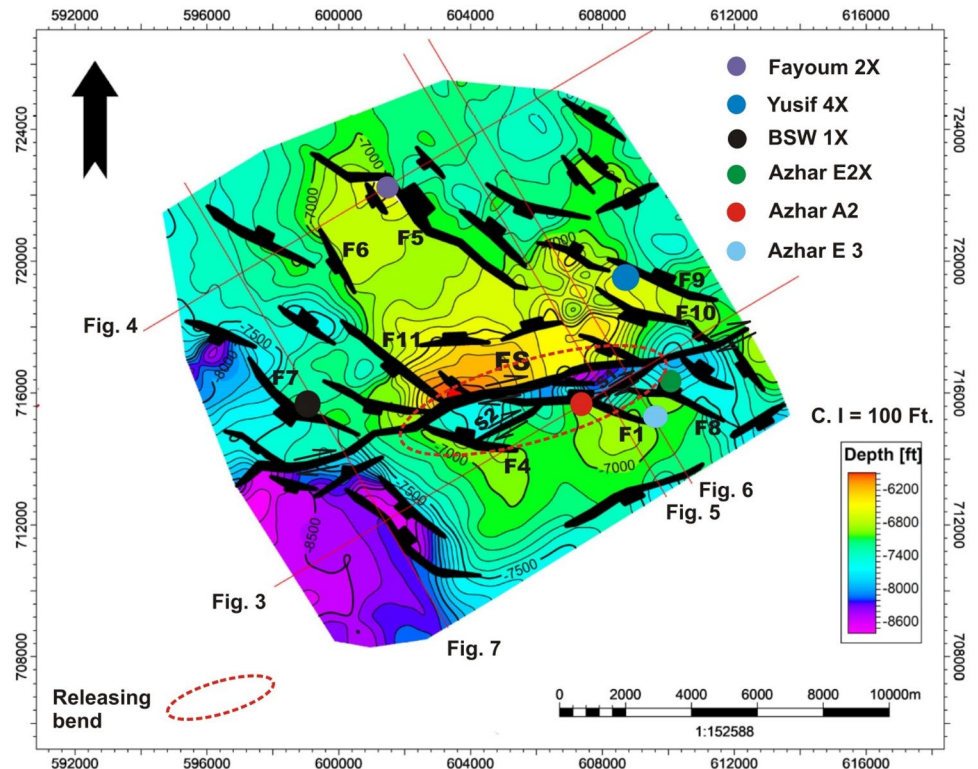
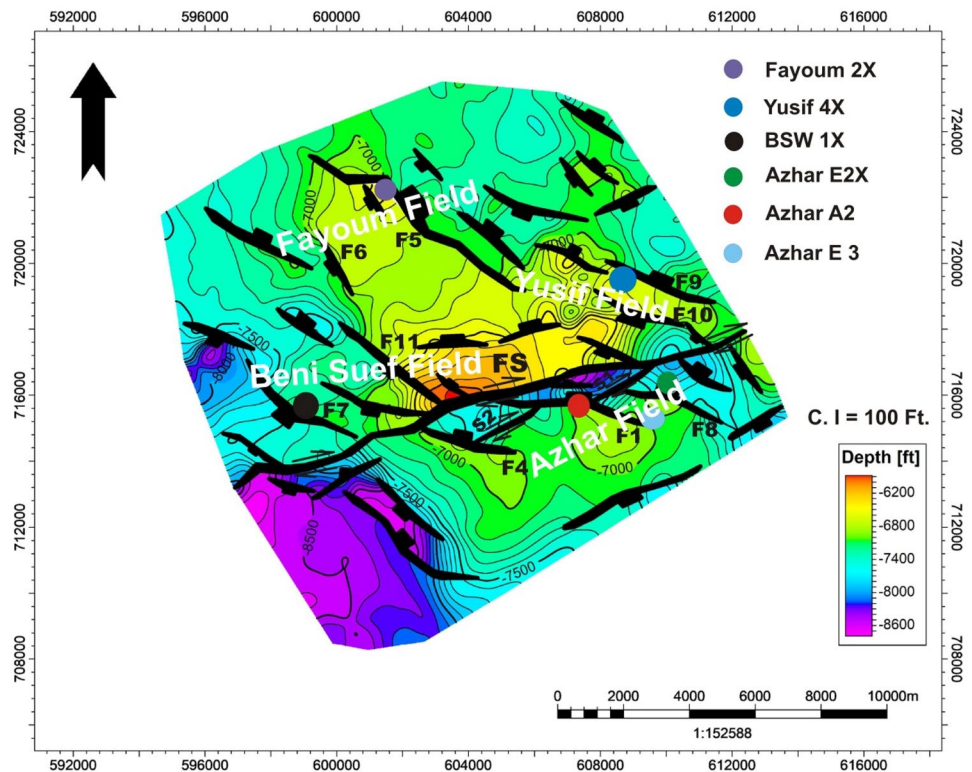


Fig. 9 Trapping styles via different oil fields in study area related to the Bahariya formation



show that the shale volume is usually lower than 10% and the effective porosity ranges between 10 and 20%. The calculated water saturation varies between 50 and 60% in Azhar A2 well; however in Azhar E-2X well it ranges between 25 and 60% and differs among 40 and 70% in Azhar E3 well. But, the computed water saturation of the pay zones in Beni Suf W-1X and Fayoum-2X wells fluctuates between 50 and 75%. While in Yusif-4X well, the water saturation is mostly around 50%.

The Pickett cross-plots (Pickett 1972) for the studied zones (Figs. 11, 12, 13, 14, 15 and 16) which demonstrate the relationship between deep resistivity (x -axis) and effective porosity (y -axis) in logarithmic scales were created. The constructed plots exhibit that the popular of the points describing the oil zones in the inspected wells are clustered above the $S_w = 25\%$ line and below the $S_w = 75\%$ line, reflecting the good potential of these intervals and confirming the performed petrophysical calculations.

Discussion

The Upper Cretaceous deposition in the northern Western Desert encompasses the studied basin reflects an actual evolution of a continuous transgressive-period (Kerdany and Cherif 1990; Guiraud and Bosworth 1999; Guiraud et al. 2005; Mahmoud et al. 2017; Shehata et al. 2019, 2020). This has been noticed from the deposition of the Cenomanian Bahariya Formation clastics in fluvio-deltaic to shallow marine nature, that upward-grade into deltaic to marine setting of alternating limestone and fine clastics in the Abu Roash Formation (Hantar 1990; Guiraud et al. 2005; Sarhan 2017b; Shehata et al. 2020, 2021b).

By the Early Cenomanian, a significant land subsidence associated with wide marine invasion started to push its way southwards over the entire northern territories of Egypt, including Beni Suf Basin, and redistributed the Lower Cretaceous fluvial coarse-grained Kharita

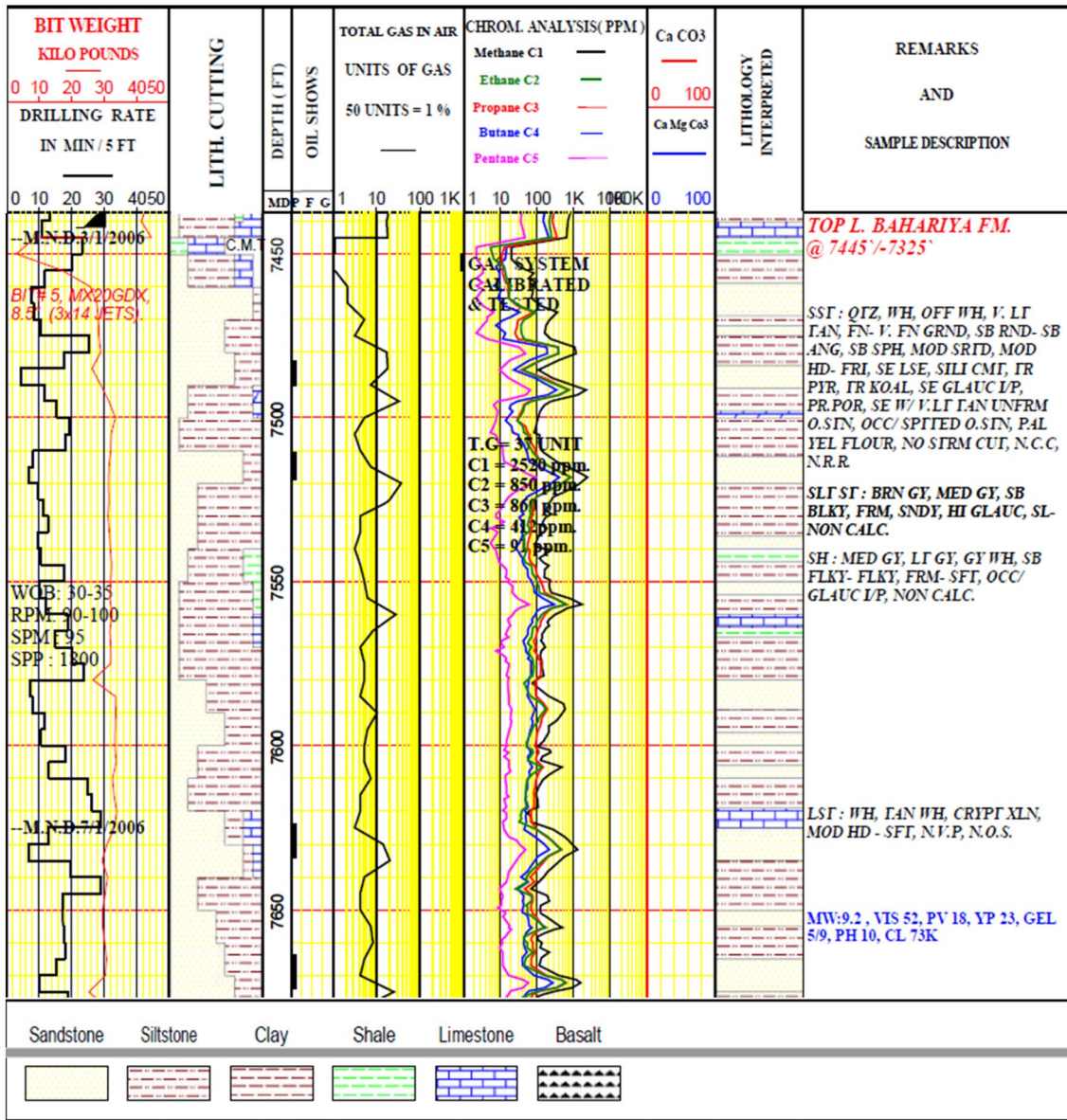


Fig. 10 Mud log displays the lowermost part of the Bahariya formation in Azhar A2 Well. Note the presence of positive criteria for the oil-bearing interval between depths 7475 and 7675 ft including; the

higher values of chromatographic gas analysis, the presence of oil shows, the appearance of pale yellow fluorescence and the attendance of oil stain as reported in the samples description

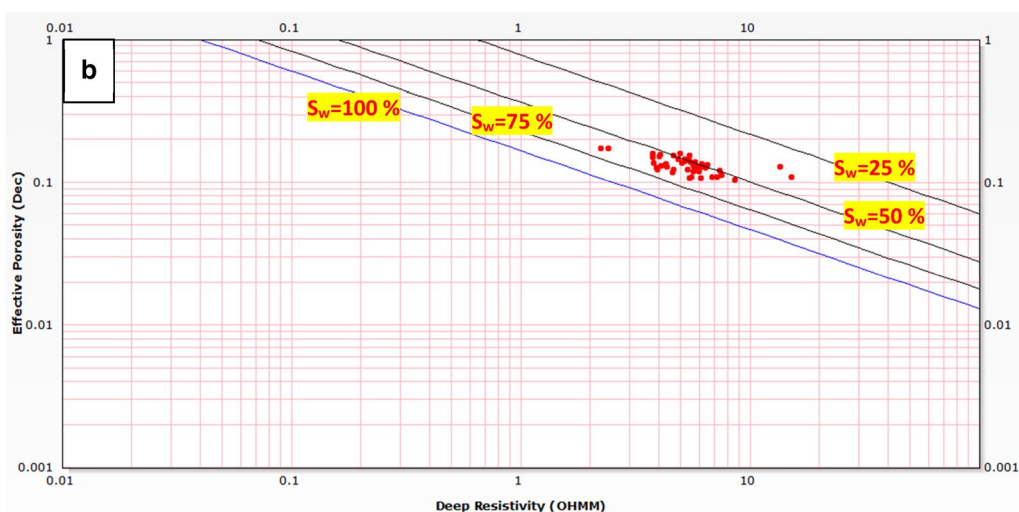
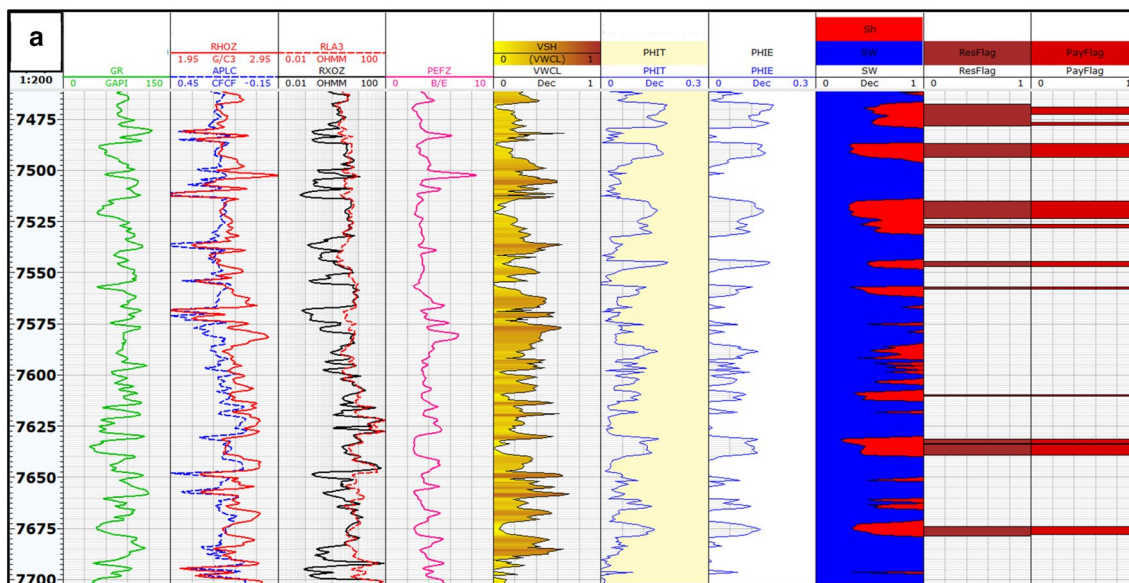


Fig. 11 a Wireline logs with interpretation showing the oil-pay zones between depths 7475 and 7675 ft in Azhar A2 well. b Pickett plot for the pay zones in Azhar A2 well

Formation sandstones, yielded deposition of thick mixed siliciclastic/carbonate succession of Bahariya Formation (Fig. 17) (Said 1990; Guiraud et al. 2005; Mahmoud et al. 2017; Shehata et al. 2018, 2019, 2020).

The deposition of Bahariya Formation is developed in post-rift phase of Beni Suf Evolution (Sakran et al. 2019; Shehata et al. 2018, 2019). It started with siliciclastic-dominated unit (the lower Bahariya sediments) developed in fluvio-deltaic/

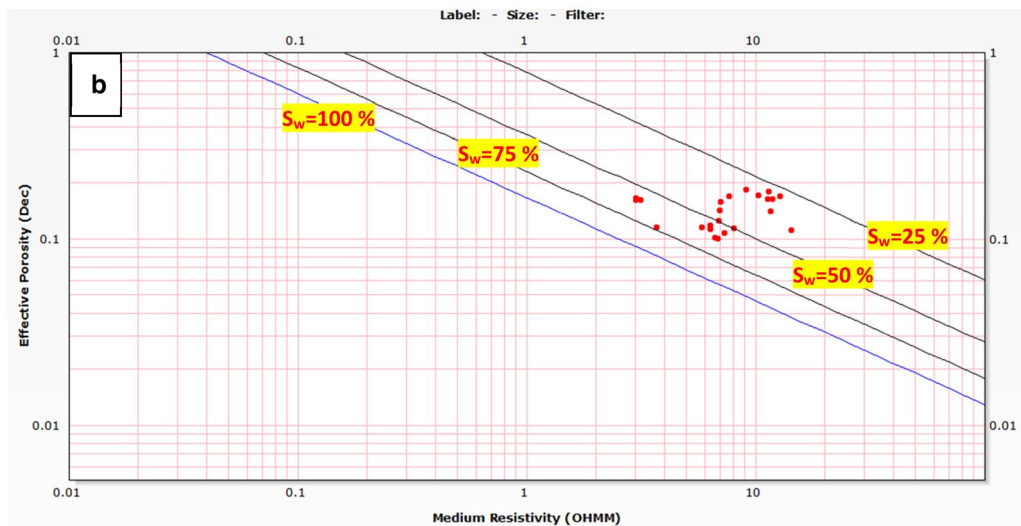
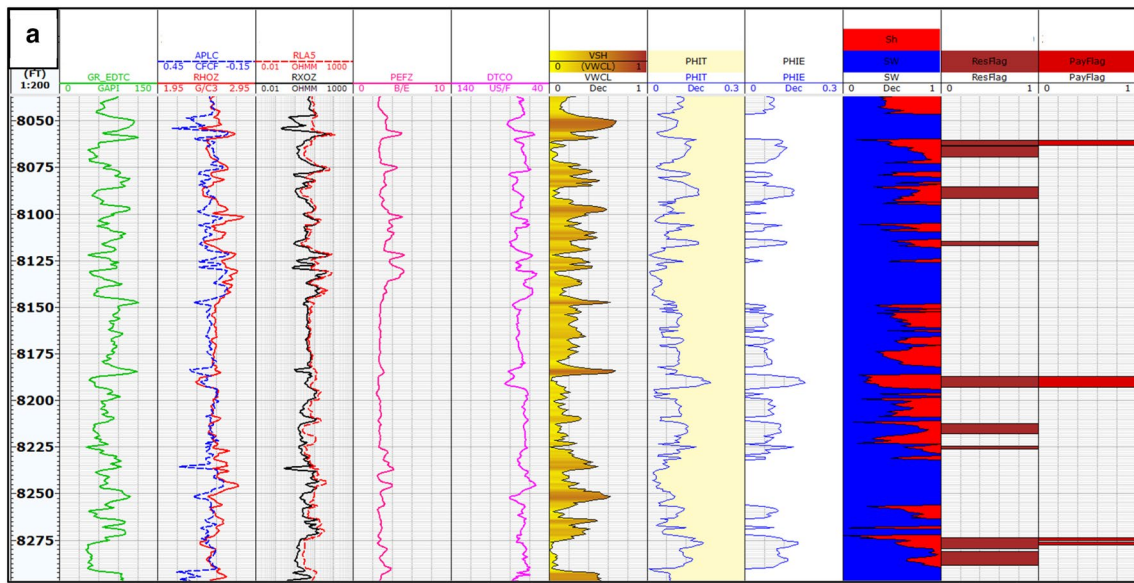


Fig. 12 **a** Wireline logs with evaluation display the oil-pay zones between depths 8050 and 8275 ft in Azhar E-2X well. **b** Pickett plot for the corresponding pay zones in Azhar E-2X well

shallow-marine setting (Figs. 2b and 17A). While the upper Bahariya sediments are characterized by deepening -fining upward units of mixed carbonate/siliciclastic with a remarkable increase in the mud-content and deposited under shallow-marine to inner-shelf setting (Figs. 2b and 17B).

Accordingly, the lower Bahariya units commences a numerous and multi-levels of sandstones with considerable total thickness of oil reservoir intervals ranged from 11 to 88 ft and resemble a good reservoir and pay zones with effective porosity varies from 10 to 20% and water saturation fluctuates

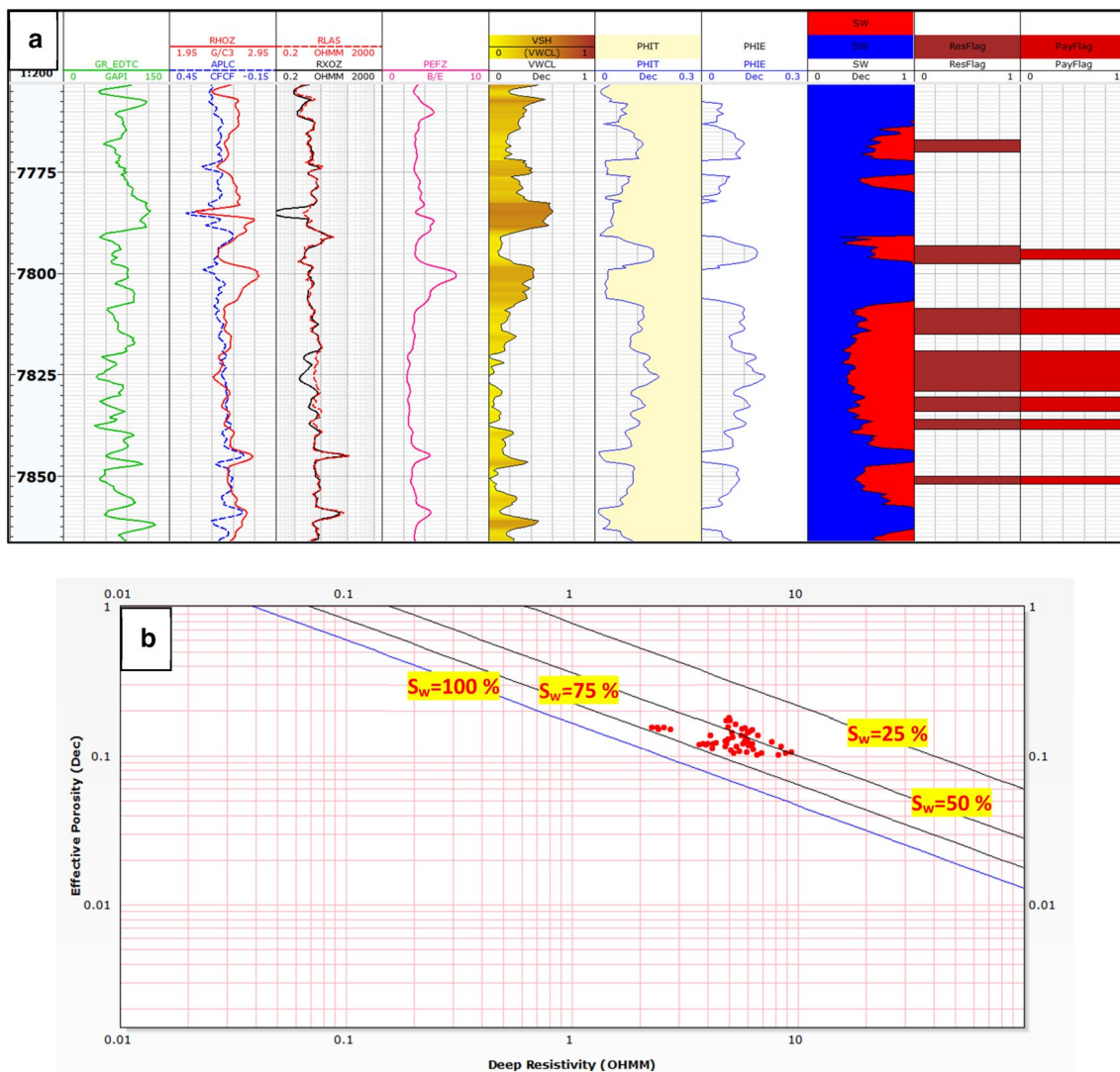


Fig. 13 a Wireline logs with interpretation showing the oil-pay zones between depths 7775 and 7850 ft in Azhar E3 well. b Pickett plot for the pay zones in Azhar E3 well

between 25 and 75%. While, the upper Bahariya sediments have only few sandstone-streaks which considered as non-promising pay zones. Moreover, the lesser volume of the shale content in the lower Bahariya sediments than the upper unit, raises the quality as well as the sandstone pay zones in the lower unit (Fig. 18).

Conclusions

- The Cenomanian Bahariya Formation within Beni Suf Basin exhibiting wedge/sheet-like geometry intersected with NW–SE-oriented normal faults in addition to a master ENE-oriented strike-slip major fault.

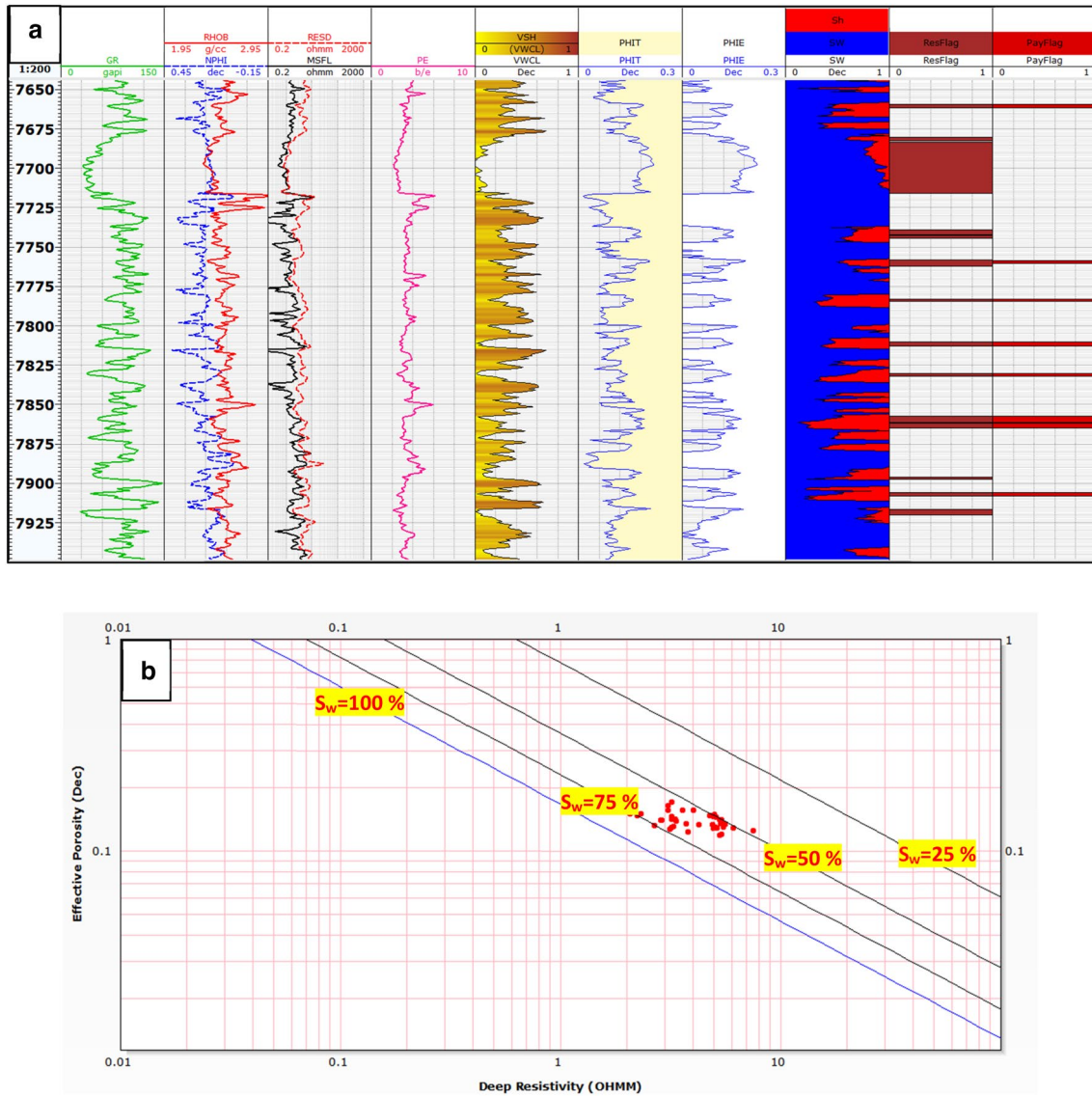


Fig. 14 **a** Wireline logs with interpretation displaying the oil-pay zones between depths 7650 and 7925 ft in Beni Suf W-1X well. **b** Pickett plot for the net pay zones in Beni Suf W-1X well

- The NW–SE normal faults resulted in the development of horst structures in the northwestern and central parts of the study area while the ENE strike-slip major fault is generating a negative flower structure in the central of the study area.
- The interpreted normal faults and the strike-slip, as well as their related structures, are responsible for the construction of various structural traps and closures through Beni Suf Basin.

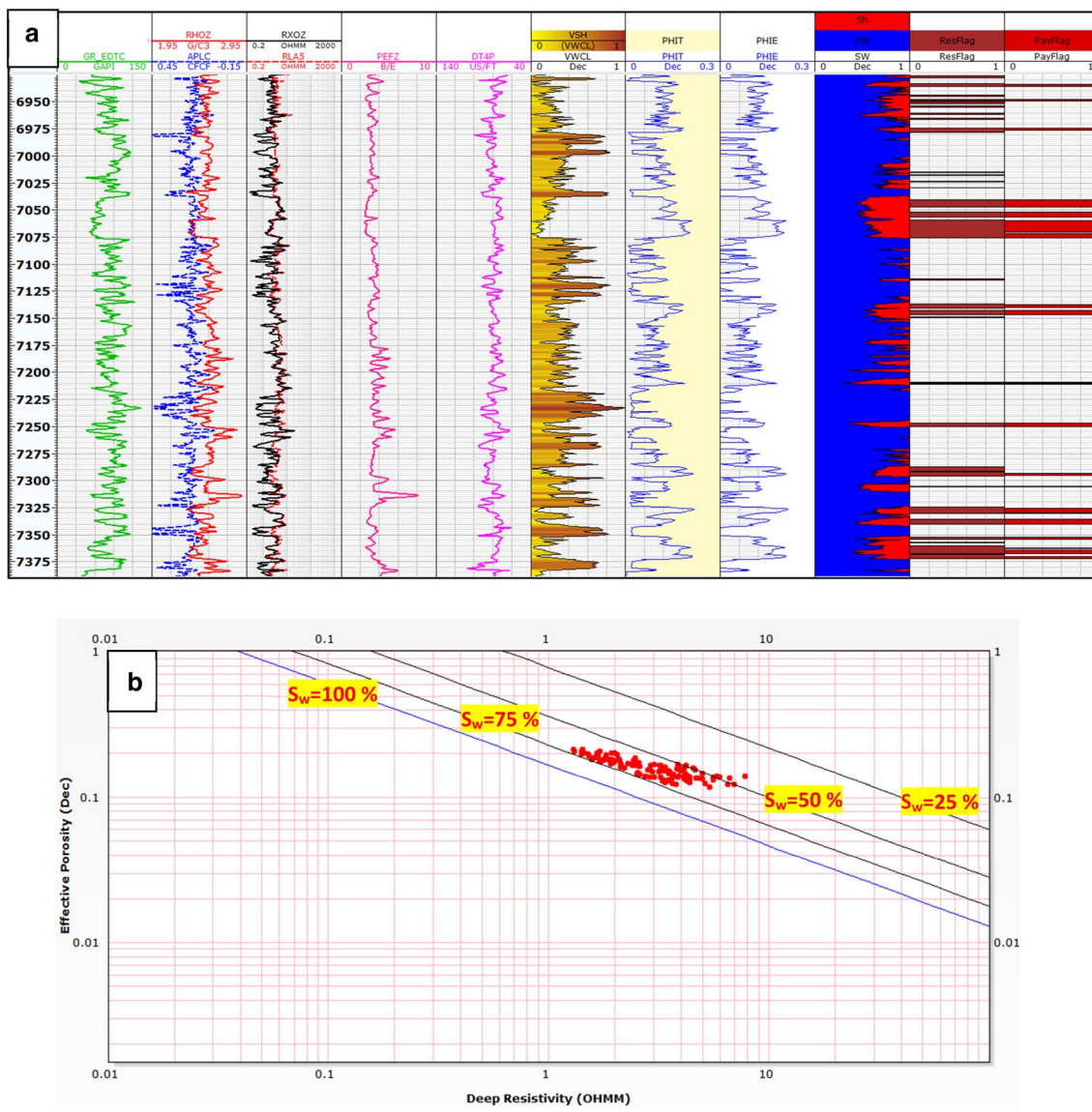


Fig. 15 a Wireline logs with evaluation presenting the oil-pay zones between depths 6950 and 7375 ft in Fayoum-2X well. b Pickett plot for the corresponding pay zones in Fayoum-2X well

- The petrophysical properties of the Bahariya reservoir units in the Beni Suef Basin were evaluated using a complete wireline log set from six deep drilled wells (Azhar A2, Azhar E-2X, Azhar E3, Yusif-4X, Fayoum-2X and Beni Suef W-1X).
- The oil pays intervals in the studied wells located within the lower Bahariya Formation with total thickness varies within 11–88 ft; effective porosity within 10–20%; shale volume less than 10%; and water saturation ranges between 25 and 75%.

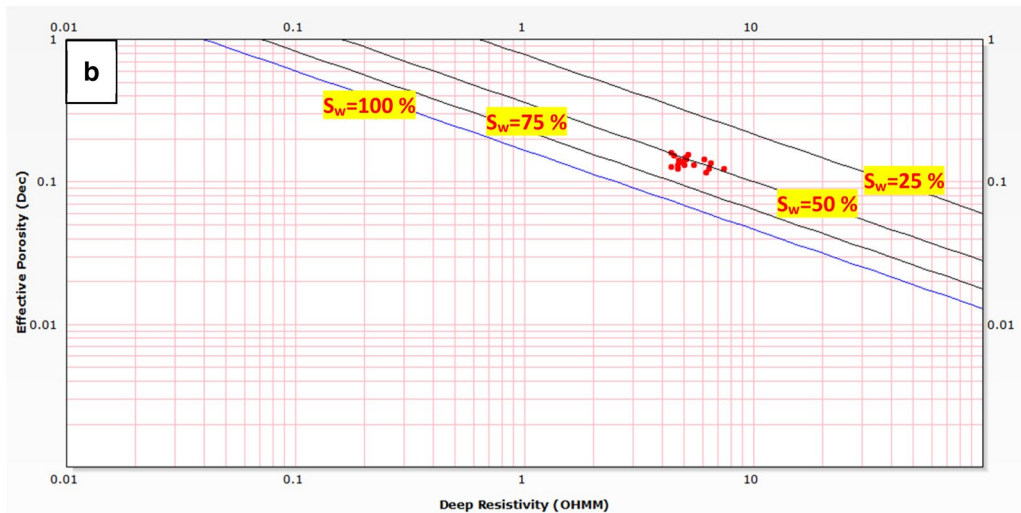
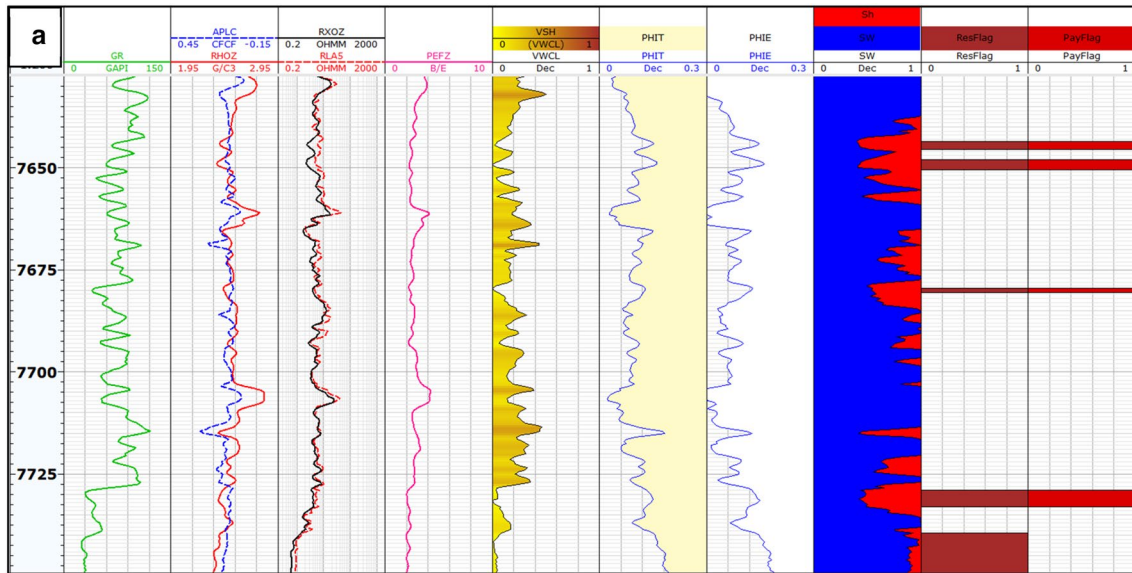


Fig. 16 **a** Wireline logs with interpretation showing the oil-pay zones between depths 7625 and 7750 ft in Yusif-4X well. **b** Pickett plot for the pay zones in Yusif-4X well

- The upper Bahariya Formation in Beni Suef Basin displays limited sandstone-streaks which considered as less efficient pay zones.
- As a recommendation, future exploration in Beni Suef Basin should target the lower Bahariya sandstones rather than the upper Bahariya sandy intervals.

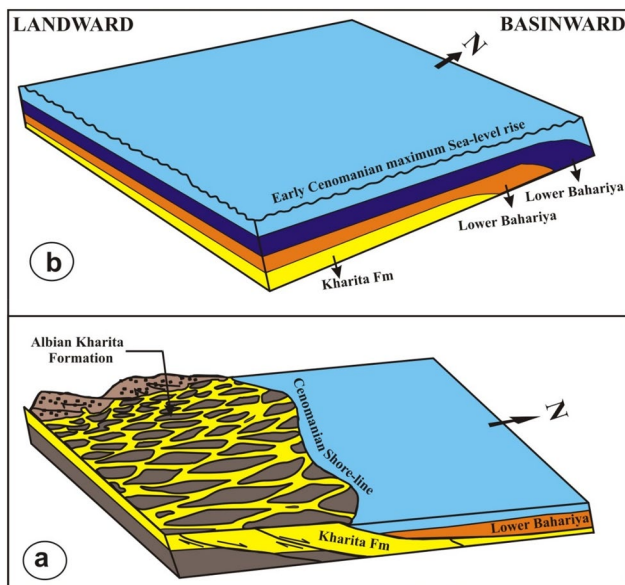


Fig. 17 Hypothetical evolution models of the Early Cenomanian Bahariya formation; **A** lower Bahariya formation and **B** upper Bahariya formation

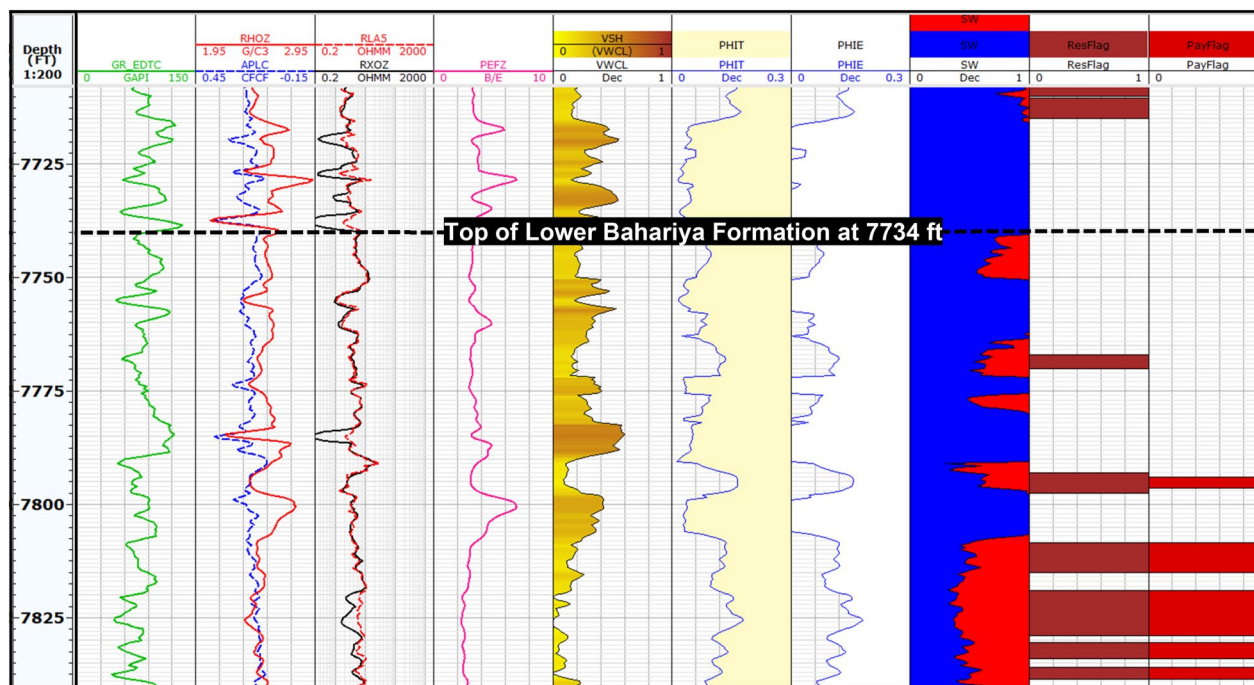


Fig. 18 Wireline logs with interpretation displaying the bottom-most part of upper Bahariya formation and the topmost part of lower Bahariya formation in Azhar E-3 well. Note the red arrow exhibits the decrease in shale content toward the Lower Bahariya Formation which supporting by the decline in gamma-ray (first track), the reduc-

tion in photoelectric log (fourth track), the decrease in calculated shale volume (fifth track), the decrease in water saturation (eighth track) and the presence of several pay zones with the Lower Bahariya Formation (last track)

Acknowledgements We are grateful to the Egyptian General Petroleum Corporation and Qarun Petroleum Company for allowing us to use the geophysical data in the present work. Special thanks to the petrophysicists at Qarun Petroleum Company for their assistance in the well logging evaluation step.

Funding Open access funding provided by The Science, Technology & Innovation Funding Authority (STDF) in cooperation with The Egyptian Knowledge Bank (EKB). No funding available for this study.

Declarations

Conflict of interest Here, we authorize that there is no conflict of interest.

Ethical approval We certify that this manuscript has never been published before and is not presently being considered for publication anywhere. Furthermore, the paper reflects our own research and the results are suitably contextualized in light of prior and continuing research. Also, all the sources utilized are properly attributed in correct citation.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Abdel-Fattah MI, Slatt RM (2013) Sequence stratigraphic controls on reservoir characterization and architecture: case study of the Messinian Abu Madi Incised-Valley Fill. *Egypt Cent Eur J Geosci* 5:497–507
- Abu El Naga M (1984) In paleozoic and mesozoic depocenters and hydrocarbon generating areas, northern western desert. In: 7th petroleum and exploration seminar. Egyptian General Petroleum Corporation, Cairo. vol 8, pp 269–287
- Archie GE (1942). The electrical resistivity log as an aid in determining some reservoir characteristics: petroleum technology, vol 5, pp 54–62
- Asquith G, Gibson C (1982) Basic well log analysis for geologists: methods in exploration series. AAPG, Tulsa, Oklahoma
- Basal AM, Sarhan MA, Omran MA, Mowafy MH (2019) Bahariya reservoir performance as deduced from well logs data interpretation at east Bahariya concession, Western desert. *Egypt Sci J Damietta Fac Sci* 9(1):7–19
- Bosworth W, El-Hawat AS, Helgeson DA, Burke K (2008) Cyrenaican “shock absorber” and associated inversion strain shadow in the collision zone of northeast Africa. *Geology* 36:695–698
- Dolson JC, Shann MV, Matbouly S, Harwood C, Rashed R, Hammouda H (2001) The petroleum potential of Egypt. In: Downey MW, Threeth JC, Morgan WA (Eds) *Petroleum Provinces of the 21st century*. AAPG Memoir, 74, pp 453–482
- Dolson JC (2016) What will it take to bring a renaissance to Gulf of Suez exploration: Has the time arrived to try some unconventional source rock plays? AAPG geoscience technology workshop, Alexandria, Egypt, 20–23 May 2016
- Elhossainy MM, Basal AK, ElBadrawy HT, Salam SA, Sarhan MA (2021) Well logging data interpretation for appraising the performance of Alam El-Bueib reservoir in safir oil field, Shushan Basin. *Egypt J Pet Explor Prod Technol* 11(5):2075–2089
- El-Soughier MI, Deaf AS, Mahmoud MS (2014) Palynostratigraphy and palaeoenvironmental significance of the cretaceous palynomorphs in the Qattara Rim-1X well, north western desert. *Egypt Arab J Geosci* 7:3051–3068
- Guiraud R, Bosworth W (1999) Phanerozoic geodynamic evolution of north eastern Africa and the north western Arabian platform. *Tectonophysics* 315:73–108
- Guiraud R, Maurin JC (1992) Early cretaceous rifts of Western and Central Africa: an overview. *Tectonophysics* 213:153–168
- Guiraud R, Bosworth W, Thierry J, Delplanque A (2005) Phanerozoic geological evolution of Northern and Central Africa: an overview. *J Afr Earth Sci* 43:83–143
- Hantar G (1990) North Western Desert. In: Said R (Ed) *Geology of Egypt*. Rotterdam, Netherlands, Balkema, pp 293–320
- Kassem AA, Hussein WS, Radwan AE, Anani N, Abioui M, Jain S, Shehata AA (2021) Petrographic and diagenetic study of siliciclastic jurassic sediments from the Northeastern margin of africa: implication for reservoir quality. *J Petrol Sci Eng* 200:108340
- Kassem AA, Osman OA, Nabawy BS, Baghdady AR, Shehata AA (2022) Microfacies analysis and reservoir discrimination of channelized carbonate platform systems: an example from the Turonian Wata formation, Gulf of Suez. *Egypt J Pet Sci Eng* 212:110272
- Kerdany MT, Cherif OH (1990) Mesozoic. In: Said R (ed) *Geology of Egypt*. Balkema, Rotterdam, pp 407–437
- Lambiase JJ, Morley CK (1999) Hydrocarbons in rift basins: the role of stratigraphy. *Phill Trans R Soc London* 357:877–900
- Mahmoud MS, Deaf AS (2007) Cretaceous palynology (spores, pollen and dinoflagellate cysts) of the Siqueifa 1-X borehole, northern Egypt. *Riv Ital Paleont Strat* 113:203–221
- Mahmoud MS, Deaf AS, Tamam MA, Khalaf MM (2017) Palynofacies analysis and palaeoenvironmental reconstruction of the upper cretaceous sequence drilled by the Salam-60 well, Shushan Basin: implications on the regional depositional environments and hydrocarbon exploration potential of northwestern Egypt. *Rev Micropaleontol* 60(4):449–467
- Martins-Neto MA, Catuneanu O (2010) Rift sequence stratigraphy. *Mar Petrol Geol* 27:247–253
- Morley CK (1999) Basin evolution trends in East Africa. In: Morley CK (Eds) *Geoscience of rift systems—evolution of East Africa*. American Association Petroleum Geologists (AAPG), Memoir 44, pp 131–150
- Moustafa AR (2008) Mesozoic–Cenozoic basin evolution in the northern western desert of Egypt. *Geol East Libya* 3:35–42
- Nabawy BS, Lashin AA, Barakat MKh (2021) Implementation of lithofacies and microfacies types on reservoir quality and heterogeneity of the late cretaceous upper Bahariya Member in the Shourek field, Shoushan basin, north western desert. *Egypt J Asian Earth Sci* 224:105014
- Pickett GR (1972) *Practical formation evaluation*. Golden, Colorado, G.R. Pickett, Inc
- Pigott JD, Abdel-Fattah MI (2014) Seismic stratigraphy of the Messinian Nile delta coastal plain: recognition of the fluvial regressive systems tract and its potential for hydrocarbon exploration. *J Afr Earth Sci* 95:9–21
- Radwan AE, Abdelghany WK, Abdelghany WK (2021) Present-day in-situ stresses in southern Gulf of Suez, Egypt: insights for stress rotation in an extensional rift basin. *J Struct Geol* 147:104334

- Richardson MS, Vivian N, Cook JR, Wilkes M, Hussein H (1998) Application of fault seal analysis techniques in the western desert, Egypt. In: Macgregor SD, Moody JTR, Clark Lowes DD (eds) *Petroleum geology of North Africa*. Geological Society of London, London, pp 297–315
- Said R (1962) *The geology of Egypt*. Elsevier Amsterdam, New York, USA, pp 197–214
- Said R (1990) Cretaceous paleogeographic maps. In: Said R (ed) *The geology of Egypt*. Balkema, Rotterdam, pp 439–449
- Sakran Sh, Shehata AA, Osman O, El Sherbiny M (2019) Superposed tectonic regimes in west Beni Suef basin, Nile valley, Egypt: implications to source rock maturation and hydrocarbon entrapment. *J Afr Earth Sci* 154:1–19
- Salem E, Sehim A (2017) Structural imaging of the East Beni Suef Basin, north eastern desert. *Egypt J Afr Earth Sci* 136:109–118
- Sarhan MA (2017a) Wrench tectonics of Abu Gharadig basin, western desert, Egypt: a structural analysis for hydrocarbon prospects. *Arab J Geosci* 10(18):1–14
- Sarhan MA (2017b) Seismic-wireline logs sequence stratigraphic analyses and geologic evolution for the upper cretaceous succession of Abu Gharadig basin. *Egypt J Afr Earth Sci* 129:469–480
- Sarhan MA (2019) Seismic delineation and well logging evaluation for Albian Kharita formation, south west Qarun (SWQ) field, Gindi basin. *Egypt J Afr Earth Sci* 158:103544
- Sarhan MA (2021a) Geophysical appraisal for the sandy levels within Abu Roash C and E members in Abu Gharadig field, western desert. *Egypt J Pet Explor Prod* 11(3):1101–1122
- Sarhan MA (2021b) Geophysical assessment and hydrocarbon potential of the Cenomanian Bahariya reservoir in the Abu Gharadig field, western desert. *Egypt J Pet Explor Prod Technol* 11(11):3963–3993
- Sarhan MA, Basal AMK, Ibrahim IM (2017a) Integration of seismic interpretation and well logging analysis of Abu Roash D Member, Gindi basin, Egypt: implication for detecting and evaluating fractured carbonate reservoirs. *J Afr Earth Sci* 135:1–13
- Sarhan MA, Basal AMK, Ibrahim IM (2017b) Seismic and well logging interpretation for evaluation of the lower Bahariya reservoir, southwest Qarun (SWQ) field, Gindi basin. *Egypt Mar Geophys Res* 38(3):271–290
- Shehata AA, El Fawal FM, Ito M, Abdel Aal MH, Sarhan MA (2018) Sequence stratigraphic evolution of the syn-rift early cretaceous sediments, west Beni Suef basin, the western desert of Egypt with remarks on its hydrocarbon accumulations. *Arab J Geosci* 11:313–331
- Shehata AA, El Fawal FM, Ito M, Abdel Aal MH, Sarhan MA (2019) Cenomanian–Turonian depositional history of a post-Gondwana rift succession in the west Beni Suef Basin. *Egypt J Afr Earth Sci* 129:469–480
- Shehata AA, El Fawal FM, Ito M, Aboulmagd MA, Brooks HL (2020) Senonian platform-to-slope evolution in the tectonically-influenced Syrian Arc sedimentary belt: Beni Suef basin. *Egypt J Afr Earth Sci* 170:103934
- Shehata AA, Kassem AA, Brooks HL, Zuchuat V, Radwan AE (2021a) Facies analysis and sequence-stratigraphic control on reservoir architecture: Example from mixed carbonate/siliciclastic sediments of Raha formation, Gulf of Suez. *Egypt Mar Pet Geol* 131:105160
- Shehata AA, Osman OA, Nabawy BS (2021b) Neural network application to petrophysical and lithofacies analysis based on multi-scale data: an integrated study using conventional well log, core and borehole image data. *J Nat Gas Sci Eng* 93:104015
- Sultan N, Halim MA (1988). Tectonic framework of northern western desert, Egypt and its effect on hydrocarbon accumulations. In: *Proceedings of the 9th petroleum exploration and production conference*, vol 2. EGPC, Cairo, pp 1–22
- Withjack MO, Schlische RW, Olsen PE (2002) Rift basin structure and its influence on sedimentary systems. *Soc Sed Geol Special Publication* 73:57–81
- Zahran H, Abu Elyazid K, Mohamad M (2011) Beni Suef basin the key for exploration future success in upper Egypt. Search and discovery article #10351 AAPG Annual Convention and Exhibition, Houston, Texas, USA

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.