



# Jurassic-Lower Cretaceous petroleum system of Faghur Basin, North Western Desert, Egypt

Mai A. El Sherief<sup>1</sup> · Mohamed A. Elbastawesy<sup>2</sup> · Abdelaziz L. Abdeldayem<sup>1</sup> · Shadia A. Mohamed<sup>1</sup>

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## Abstract

Different parts of the Lower Cretaceous Alam El Bueib (AEB) and the Jurassic Khatatba source and reservoir rock units in the Faghur basin, like in other basins in the north Western Desert, act as hydrocarbon sources and reservoirs. In the present study, well-log data from five wells in Phiops field and geochemical data from the Neith S-2X well from the neighbor Neith field together with reflection 2D seismic data of thirty (30) lines have been utilized to evaluate the Jurassic-Lower Cretaceous petroleum system in the Faghur basin and to give evidence for future hydrocarbon exploration and development in the study area. Source rock evaluation shows that several units from both Alam El Bueib and the Jurassic Khatatba shale source rocks represent good source rocks. Total organic carbon (TOC) values of the studied units of Alam El Bueib shale source rocks range from 0.27 to 6.39 wt.% that reflect fair to very good source rock, while Toc value for the Alam El Bueib-6 shale source rock is 2.52 wt.% that indicates a very good source rock. These units are characterized by type (III) kerogen, reflecting their ability to produce gas with minor oil. On the other hand, the characterization of the Khatatba shale source rocks indicates a very good to fair organic richness and a type (III) kerogen with an input of type (II) as well, which appears their ability to generate gas with minor oil. Most of Alam El Bueib and Khatatba shale source rocks are found to be in the mature stage. Petrophysical evaluation indicates four definite reservoir units from the Alam El Bueib reservoirs (Alam El Bueib-3D, Alam El Bueib-3E, Alam El Bueib-3G, Alam El Bueib-6) and the Khatatba reservoir. Values for the net reservoir, hydrocarbon saturation, and water saturation indicate that these units represent very promising reservoirs in the studied Phiops field in Faghur basin. Local intra-formational shale intervals most probably seal these reservoirs in the AEB and carbonate interval of the Masajid Formation in the Khatatba Formation. Moreover, analysis and interpretation of the 2D seismic lines showed that both structural and stratigraphic traps dominate. Integration of geochemical, petrophysical, and seismic results, in light of available geological information, indicates a complete Mesozoic petroleum system in the Faghur basin.

**Keywords** Mesozoic · Faghur · Alam El Bueib · Khatatba · Petroleum System · North Western Desert · Phiops · Neith

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✉ Mai A. El Sherief  
mai.elsherief@yahoo.com

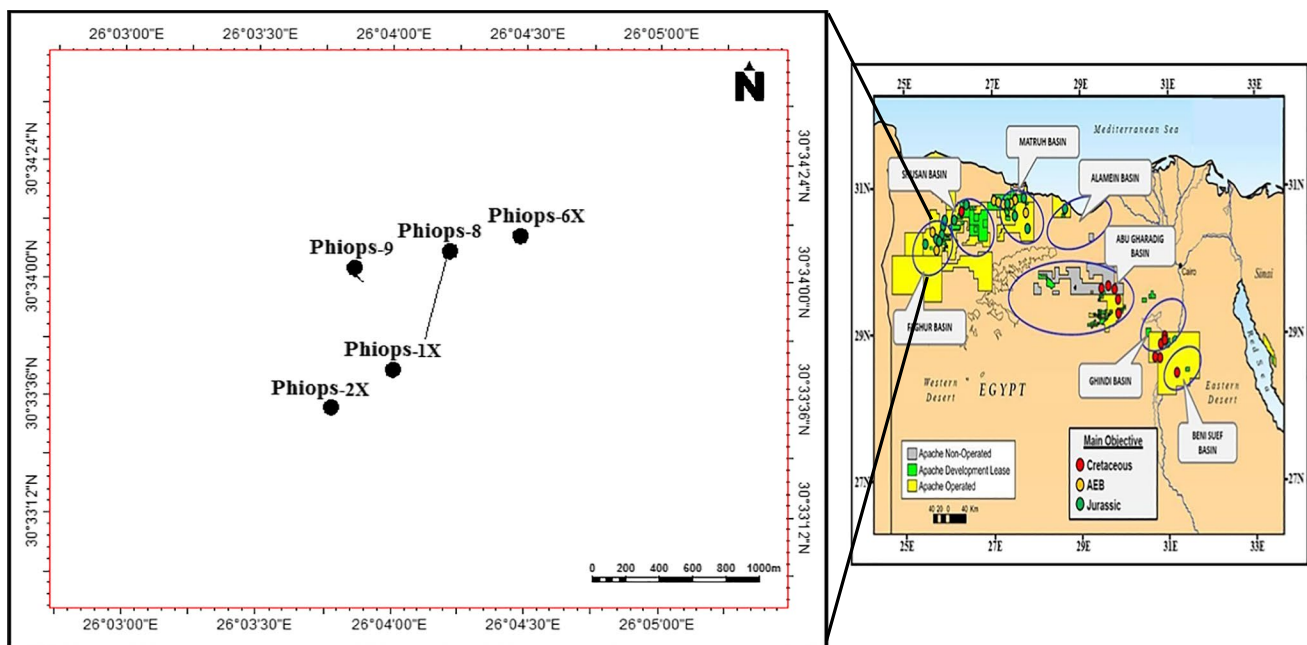
<sup>1</sup> Geology Department, Faculty of Science, Tanta University, Tanta 31527, Egypt

<sup>2</sup> Khalda Petroleum Company, New Maadi, P.O Box 560, Cairo, Maadi, Egypt

## Introduction

Among other potential sedimentary basins in the north Western Desert of Egypt, Faghur basin represents one of them (Fig. 1) (EGPC 1992; Dolson et al. 2001). The Western Desert of Egypt contains probably 90% of undiscovered oil reserves and 80% of undiscovered gas reserves (Zein El-Din et al. 2001).

This study discusses the Jurassic-Lower Cretaceous petroleum system in the northeastern of Faghur basin through a detailed study of the Alam El Bueib and Khatatba source and reservoir rocks in the Phiops field. The latter is considered one of the most productive oil fields in the Faghur Basin. The area of study lies between latitudes 30° 33' 12''



**Fig. 1** Location map of the study area and the location of used five wells in Phiops field, Faghur basin, north Western Desert, Egypt

N and  $30^{\circ} 34' 24''$ N and longitudes  $26^{\circ} 03' 00''$  E and  $26^{\circ} 05' 00''$  E (Fig. 1).

## Geological setting

The stratigraphic and structural settings of the North-Western Desert of Egypt have been the subject of considerable research (e.g., Shata 1953; Shukri 1954; Sigaev 1959; Amin 1961; Said 1962; Kostandi 1963; El-Shazly 1977; Meshref et al. 1980; El-Ayouty 1990; Hanter 1990; Kerdany and Cherif 1990; Carlos et al. 2001; Zein El-Din et al. 2001; Abdou et al. 2009; El-Khadragy et al. 2010; Shalaby et al. 2013).

The stratigraphic section in the North-Western Desert (Schlumberger 1995) ranges in age from Pre-Cambrian basement complex to Recent (Fig. 2). The sedimentary section has been subdivided into three sequences based on lithology: the lower clastic unit from Cambrian to pre-Cenomanian, the middle carbonate units from Cenomanian to Eocene, and the upper clastic unit from Oligocene to recent (Said 1962). The Alam El Bueib Formation, on the other hand, consists of fine to coarse-grained sandstone with siltstone and subordinate gray shale (EGPC, 1992). It has a quite thick sequence that is subdivided into six units from bottom to top as Alam El Bueib-6, Alam El Bueib-5, Alam El Bueib-4, Alam El Bueib-3, Alam El Bueib-2, and Alam El Bueib-1. The Alam El Bueib-3 unit itself was subdivided further into

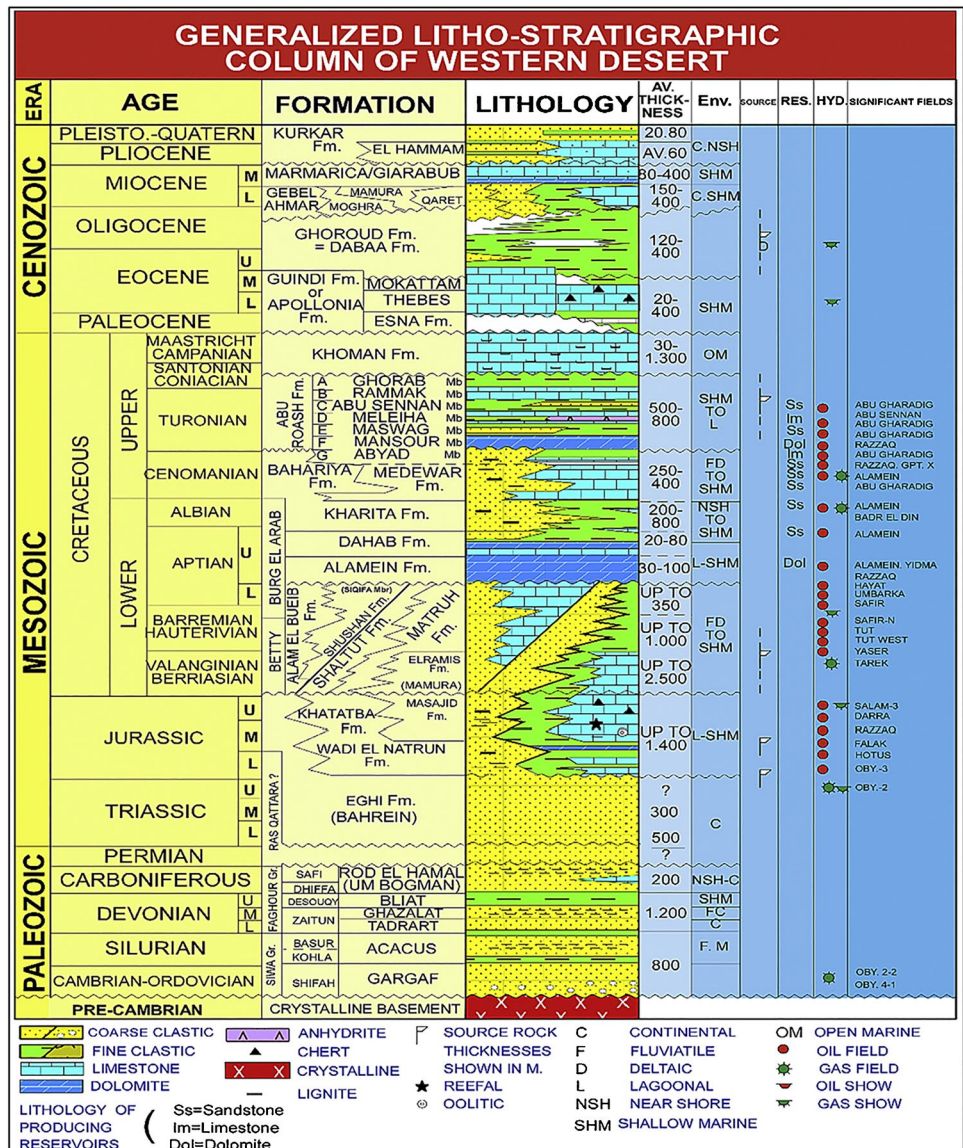
six subunits: G, F, E, D, C, and A (Abu El Naga 1984). The Khatatba Formation consists of a thick shallow marine carbonaceous shale series with interbedded sandstone, coal seams and limestone streaks (Schlumberger 1984).

Most of the basin-bounding faults in the North-Western Desert strike E-W to ENE-WSW, parallel to the old Neotethyan continental margin to the north. NNW-SSE to NNE-SSW trending structures are also present and result in complicated regional basin geometries (Bosworth et al. 2015). The subsurface of the North-Western Desert is described by a complex system of Mesozoic rift basins that cover an area of around 200,000 km<sup>2</sup> (Hantar, 1990; Sehim 1993; Bosworth et al. 2008; Dolson et al. 2014; Bosworth et al. 2015). These basins compose a series of various discrete E-W to ENE-WSW and NE-SW-oriented half-graben basins (Fig. 3) that were started in the Jurassic and incessant subsidence during the Cretaceous, such as the Abu Gharadig, Alamein, Faghur, Matruh, and Shoushan basins (Sultan and Abd 1988; Emam et al. 1990; Taha 1992; Moustafa 2008; Bevan and Moustafa 2012; Bosworth et al. 2015).

## Materials and methods

In this study, well-log data from five wells (Phiops-1X, Phiops-2X, Phiops-6X, Phiops-8, and Phiops-9) have been used to evaluate the petrophysical properties, including effective porosity, shale volume, net sand, net pay, and

**Fig. 2** The stratigraphic section in the northern Western Desert (Schlumberger 1995)

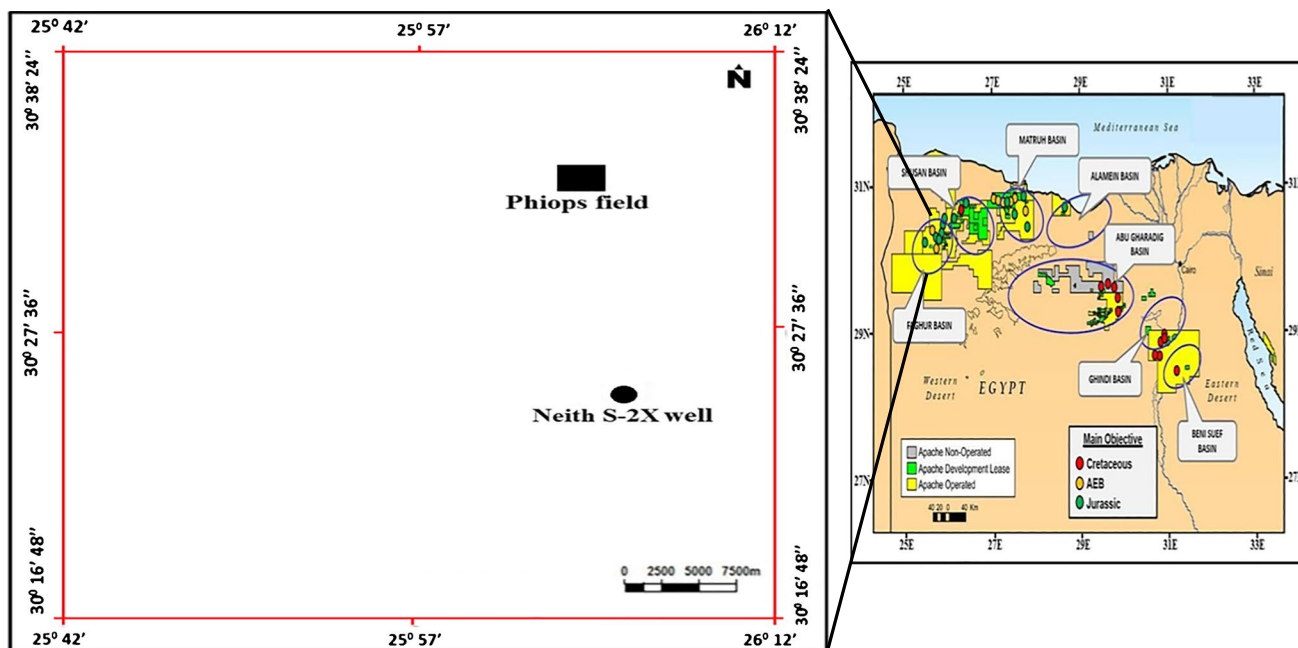
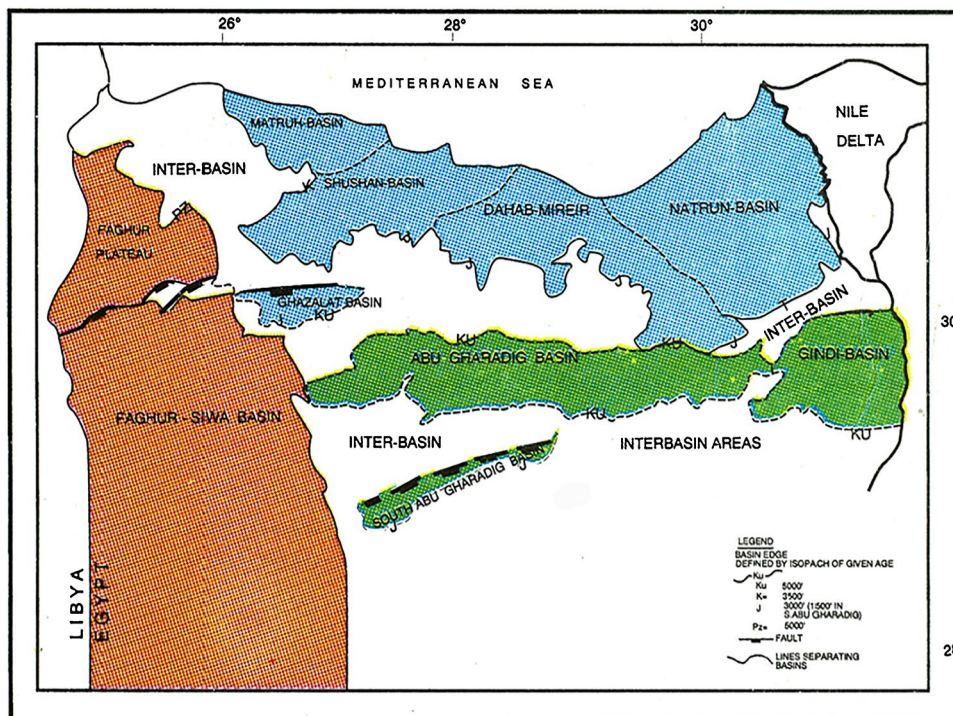


hydro-carbon saturation for Alam El Bueib reservoir units (Alam El Bueib-3D, Alam El Bueib-3E, Alam El Bueib-3G, and Alam El Bueib-6) and Khatatba reservoir. Geochemical data were made possible from the Neith S-2X well from the neighbor Neith field within the Faghur basin as there is no geochemical data available for wells from the present Phiops field (Fig. 4).

Geochemical data analysis of the present Alam El Bueib shale source rock units (Alam El Bueib-1, Alam El Bueib-2, Alam El Bueib-3A, Alam El Bueib-3C, Alam El Bueib-3D, Alam El Bueib-3G, and Alam El Bueib-6) and Khatatba shale source rocks included measurements of total organic carbon (TOC), hydrogen index (HI), oxygen index (OI), genetic potential (GP), maximum temperature ( $T_{max}$ ), and

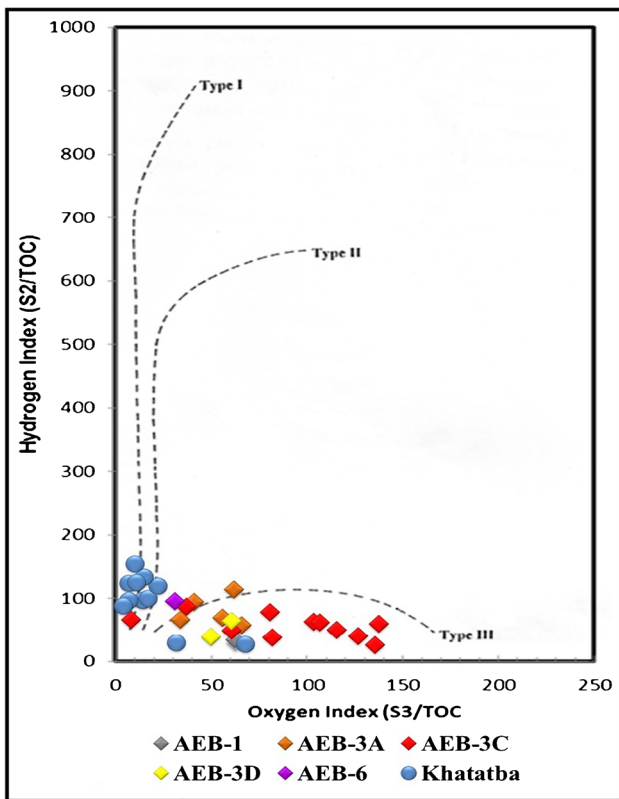
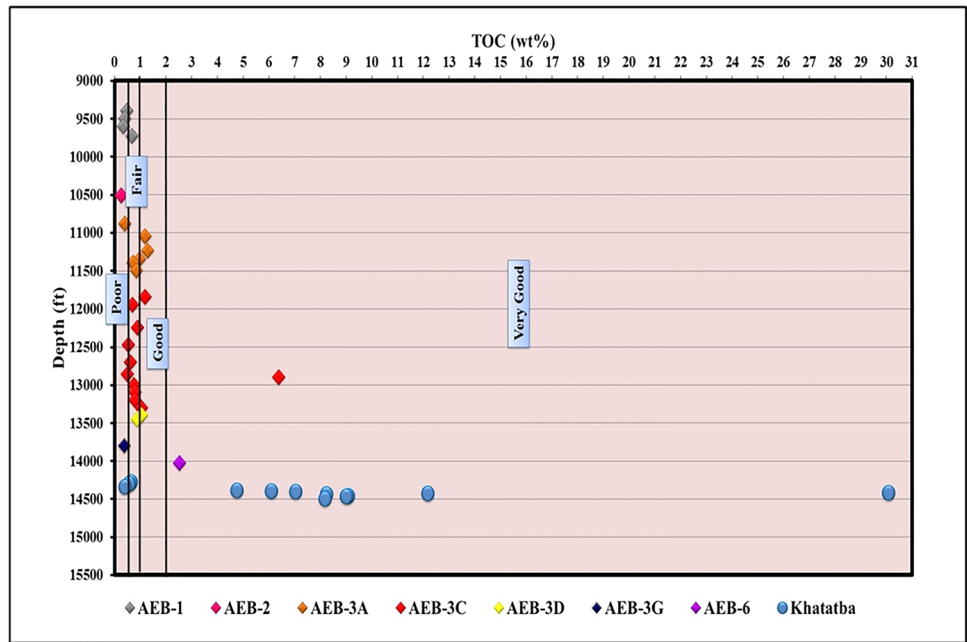
vitrinite reflectance (%Ro) to predict hydrocarbon maturation, generation, and good source rocks. Reflection 2D seismic section of 30 lines and well velocity survey were also used for seismic interpretation to characterize the stratigraphical and lithological boundaries of the rock units and the structural setting including the type of controlling traps. Then, building a log database to identify petrophysical parameters (total thickness, total porosity, effective porosity, shale volume, net sand, net pay, water saturation, and hydrocarbon saturation) of Alam El Bueib (Alam El Bueib-3D, Alam El Bueib-3E, Alam El Bueib-3G, Alam El Bueib-6) and Khatatba reservoirs and then illustrate them on 2D maps to identify the lateral variation, structural setting, reservoir thickness, and proper locations for new productive wells.

**Fig. 3** Mesozoic and Cenozoic basins in the Western Desert and Sinai (EGPC 1992)



**Fig. 4** Location map of Neith S-2X well, Neith field, Faghur basin, north Western Desert, Egypt

**Fig. 5** Total organic carbon richness (TOC) of Alam El Bueib and Khatatba source rocks in Neith S-2X well (after Peters 1986)



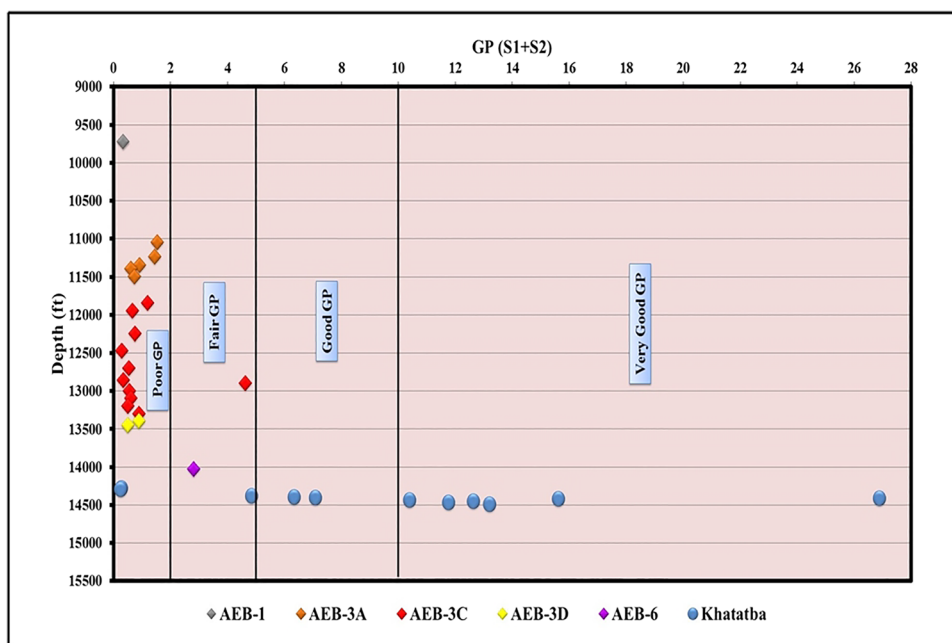
**Fig. 6** Modified Van Krevelen (1961) type diagram showing kerogen type of Alam El Bueib and Khatatba source rocks in Neith S-2X well (modified by Espitalié et al. 1977)

## Results and interpretation

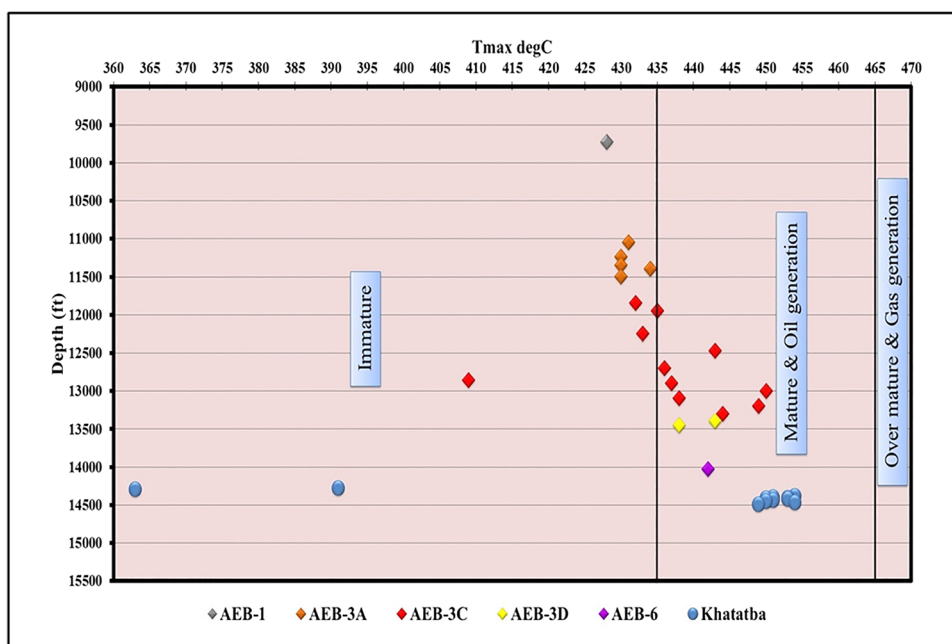
### The source rock

TOC values of the Lower Cretaceous Alam El Bueib shale source rock units (Alam El Bueib-1, Alam El Bueib-2, Alam El Bueib-3A, Alam El Bueib-3C, Alam El Bueib-3D, and Alam El Bueib-3G) range from 0.27 to 6.39 wt.%, indicating fair to good source rock quality, with those from the Alam El Bueib-6 shale unit which is 2.52 wt.%, in particular, showing a very good source rock. These rocks are characterized by type (III) kerogen that can generate gas with minor oil (Figs. 5 and 6). On the other hand, TOC values of the Jurassic Khatatba shale source rocks show very good to fair organic richness ranging from 0.41 to 30.09 wt.%. They are described by kerogen type (III) with an input of type (II) kerogen indicating that their ability to generate gas with minor oil. The potential genetic values of Alam El Bueib shale source rock units (Alam El Bueib-1, Alam El Bueib-3A, Alam El Bueib-3C, and Alam El Bueib-3D) and Khatatba shale source rocks range from 0.35 to 4.62 mg/g and 0.26 to 15.62 mg/g, respectively. This indicates that most of Alam El Bueib shale source rock units are poor in genetic potential. The only exception is that the Alam El Bueib-6 shale unit value is 2.81 that is considered fair in genetic potential. Most of values of Khatatba shale source rocks, on the other hand, belong to the range of fair to very good source genetic potential (Fig. 7). The

**Fig. 7** Genetic potential (GP) of Alam El Bueib and Khatatba source rocks in Neith S-2X well (after Hunt 1996)



**Fig. 8** Maximum temperature ( $T_{max}$ ) of Alam El Bueib and Khatatba source rocks in Neith S-2X well (after Bordenove et al. 1993)

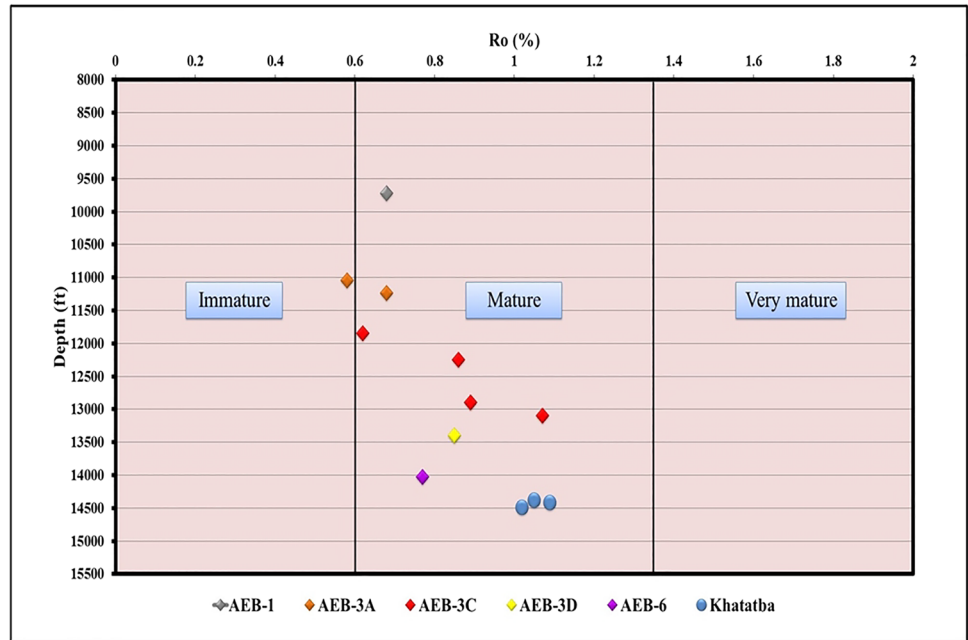


$T_{max}$  and vitrinite reflectance (% $R_o$ ) values range from 409 to 450 °C and from 0.58 to 1.07% for studied Alam El Bueib shale source rock units and from 363 to 454 °C and 1.02 to 1.09% for Khatatba shale source rocks, respectively. This indicates that most of Alam El Bueib shale source rocks are in mature stage within the oil generation window, while the Khatatba shale source rocks are mature inside the oil to condensate/gas generation window (Figs. 8 and 9).

### The reservoir rock

Reservoir parameters of the selected four Alam El Bueib clastic reservoir units (Alam El Bueib-3D, Alam El Bueib-3E, Alam El Bueib-3G, Alam El Bueib-6) and Khatatba reservoirs in the Faghur basin are illustrated on iso-parametric maps such as shale volume, effective porosity, net sand, net pay, water saturation, and hydrocarbon saturation. These maps reveal that the central

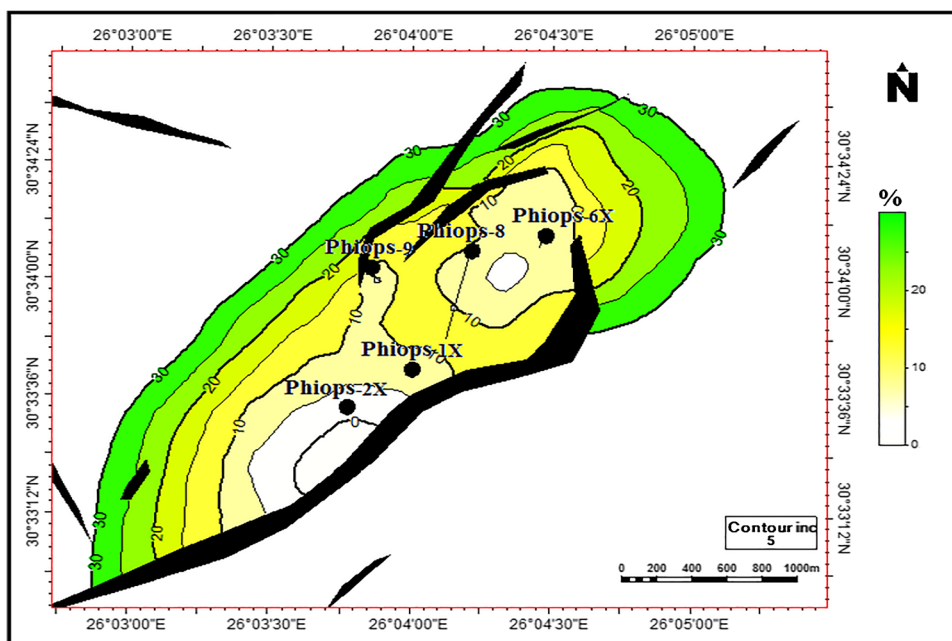
**Fig. 9** Vitrinite reflectance (%R<sub>o</sub>) of Alam El Bueib and Khatatba source rocks in Neith S-2X well (after Waples 1985)



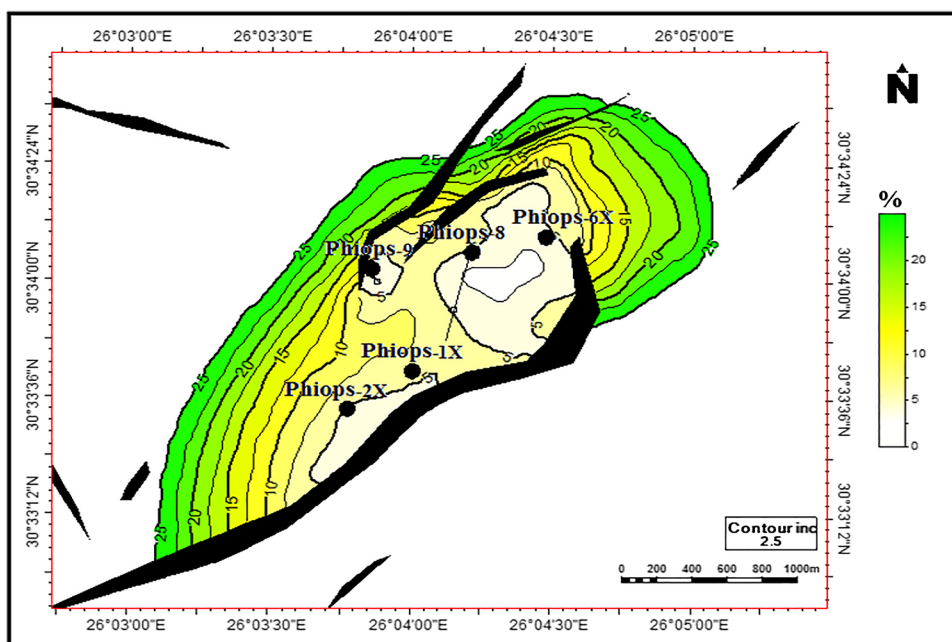
**Table 1** Well-log parameters of the Alam El Bueib and Khatatba reservoirs in Phiops Field, Faghur Basin

Well	Reservoir	Total thickness (ft)	Total porosity (%)	Effective porosity (%)	Shale volume (V <sub>sh</sub> , %)	Gross sand (ft)	Net pay (ft)	Water saturation (S <sub>w</sub> , %)	Hydrocarbon saturation (S <sub>h</sub> , %)
Phiops-1X	Alam El Bueib-3D	149.0	15.2	12.8	7.6	18.0	17.5	23.7	76.3
Phiops-2X		148.0	17.9	17.6	1.7	11.0	6.5	44.0	56.0
Phiops-6		136.0	15.7	14.3	7.6	52.0	52.0	9.1	90.9
Phiops-8		139.0	14.4	13.2	10.1	6.5	5.5	34.9	65.1
Phiops-9		131.0	10.2	9.3	8.7	9.0	7.0	39.9	60.1
Phiops-1X	Alam El Bueib-3E	122.0	15.4	13.6	5.8	71.0	71.0	10.5	89.5
Phiops-2X		126.0	17.7	16.5	5.0	83.5	56.5	20.2	79.8
Phiops-6		139.0	13.4	12.6	4.1	104.0	102.5	19.7	80.3
Phiops-8		129.0	15.9	15.3	4.6	36.5	6.5	35.8	64.2
Phiops-9		106.0	13.4	12.6	3.4	61.5	45.0	15.8	84.2
Phiops-1X	Alam El Bueib-3G	159.0	13.5	11.9	5.2	68.5	57.0	20.4	79.6
Phiops-2X		154.0	15.2	13.4	6.6	104.0	12.0	51.1	48.9
Phiops-6		159.0	12.4	11.3	5.8	113.0	0.0	86.0	14.0
Phiops-8		173.0	12.9	12.0	7.2	98.5	49.5	14.2	85.8
Phiops-9		181.0	11.1	10.2	4.1	67.0	0.0	97.6	2.4
Phiops-1X	Alam El Bueib-6	197.0	8.2	7.0	5.5	3.5	3.5	13.4	86.6
Phiops-2X		230.0	19.3	12.4	24.8	9.0	7.0	22.9	77.1
Phiops-6		268.0	13.4	9.9	12.6	12.0	11.5	23.9	76.1
Phiops-8		229.0	9.6	8.8	9.0	112.0	5.5	7.8	92.2
Phiops-9		230.0	11.8	10.9	7.0	4.5	4.5	8.0	92.0
Phiops-1X	Khatatba	575.0	12.7	10.4	11.3	25.0	25.0	15.8	84.2
Phiops-2X		554.0	14.3	13.0	9.9	40.5	33.5	25.5	74.5
Phiops-6		548.0	12.5	7.3	18.4	2.5	2.5	17.7	82.3
Phiops-8		642.0	13.5	12.8	7.4	7	7	9.8	90.2
Phiops-9			N/A						

**Fig. 10** Shale volume map of the Alam El Bueib-3D reservoir in the study area



**Fig. 11** Shale volume map of the Alam El Bueib-3E reservoir in the study area



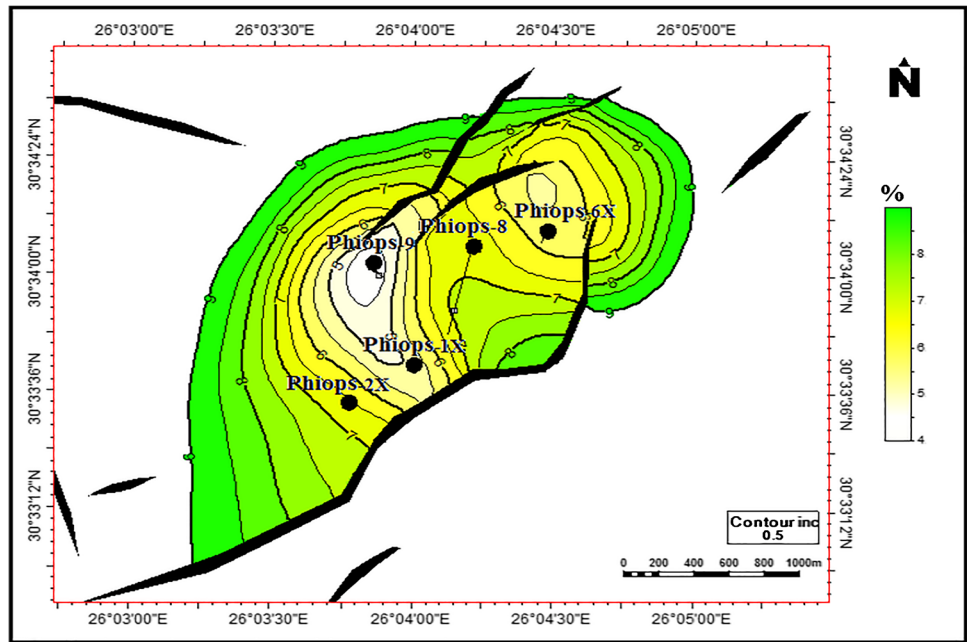
parts of study area along the master fault are attractive locations to drill more productive wells due to increase in net gross sand, net pay thickness, and hydrocarbon saturation with low shale volume and water saturation values; therefore, the studied reservoirs are of high-quality reservoirs (Table 1) (Figs. 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39).

### Seal rocks

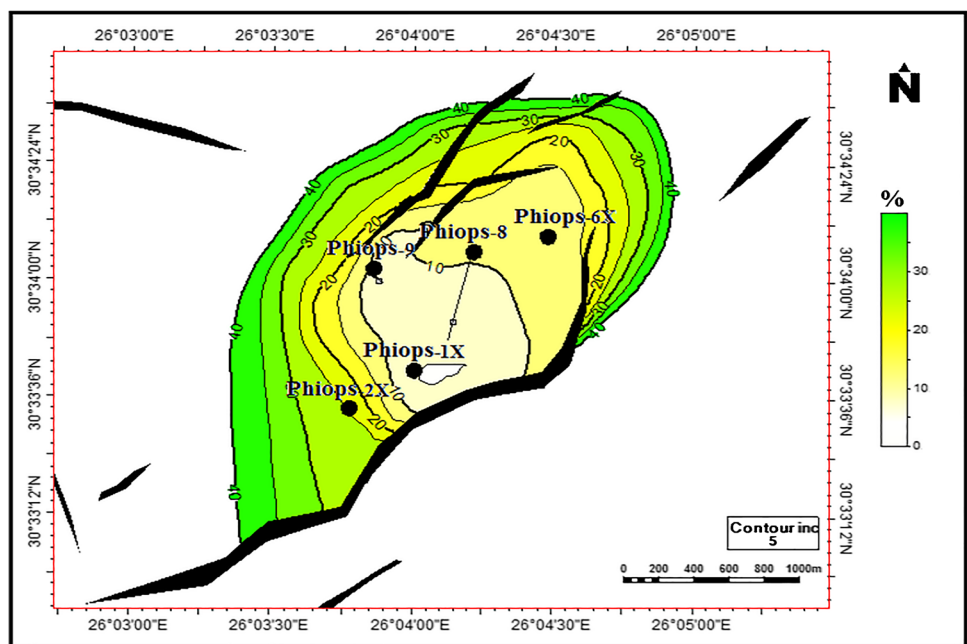
Different shale and compact limestone and dolomite beds of Jurassic, Cretaceous, Eocene, and Oligocene ages represent efficient seal rocks in the northern Western Desert (Vavra et al. 1992). In the study area, the Alam El Bueib and Khatatba reservoirs are generally sealed by petrophysically identified local intra-formatinal shale intervals within of Alam El Bueib-3C, Alam El Bueib-3F, Alam El Bueib-6,



**Fig. 12** Shale volume map of the Alam El Bueib-3G reservoir in the study area



**Fig. 13** Shale volume map of the Alam El Bueib-6 reservoir in the study area



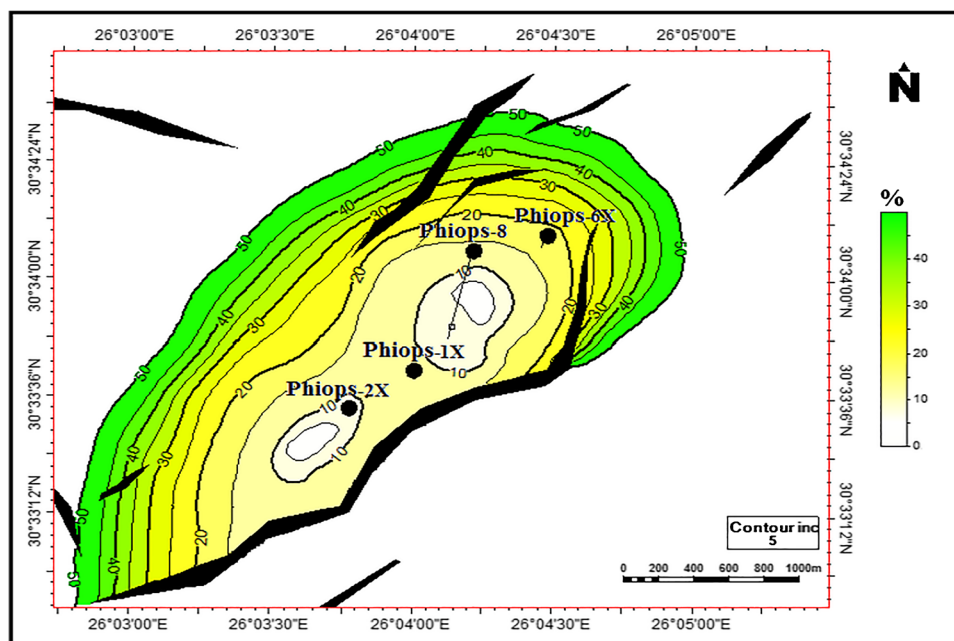
and Khatatba Formation and carbonate interval of the Masajid Formation.

**Traps**

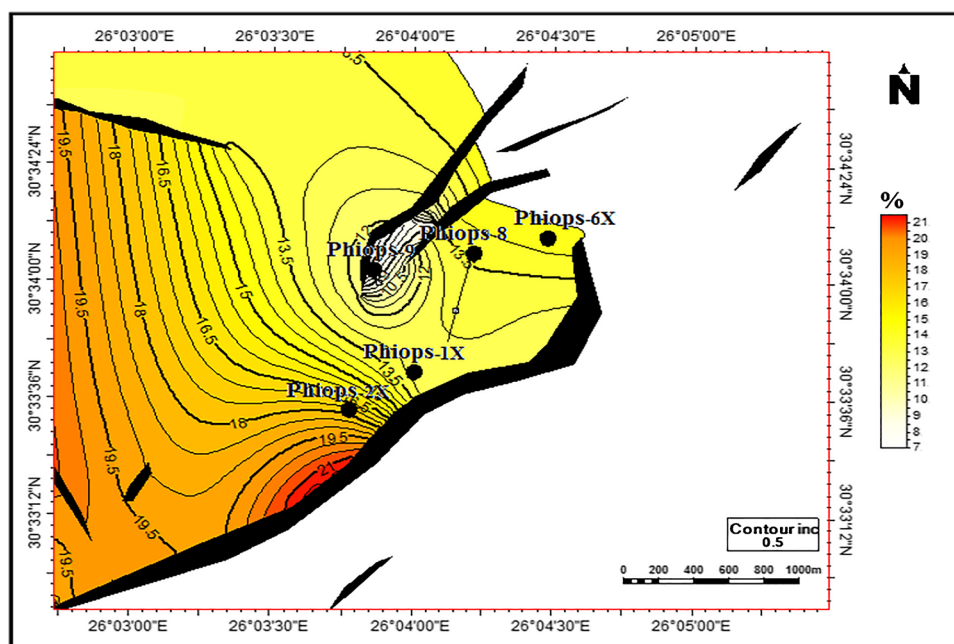
Interpretation of available 2D seismic lines indicates that both structural and stratigraphic traps are present in the Faghur basin. Close inspection of these lines indicates that most traps are usually of structural type, consisting mainly of faulted anticlinal features forming a horst block in the area. A recognized master normal fault (Fault-1)

trending NE-SW seems to have formed in the Early Jurassic probably as a result of African plate movement and was rejuvenated during the Cretaceous time to form horst blocks with associated faults leading to entrapment of hydrocarbon in the central part of the area (Fig. 40). This trapping fault combination is quite remarkable in the way that it has brought the shale layers of Alam El Bueib-3C, and Alam El Bueib-3F against those of Alam El Bueib-3D, Alam El Bueib-3G, and Alam El Bueib-3E sandstone reservoirs. It also brought the Zahra shale and Masajid limestone against the Khatatba reservoirs. The identified

**Fig. 14** Shale volume map of the Khatatba reservoir in the study area



**Fig. 15** Effective porosity map of the Alam El Bueib-3D reservoir in the study area

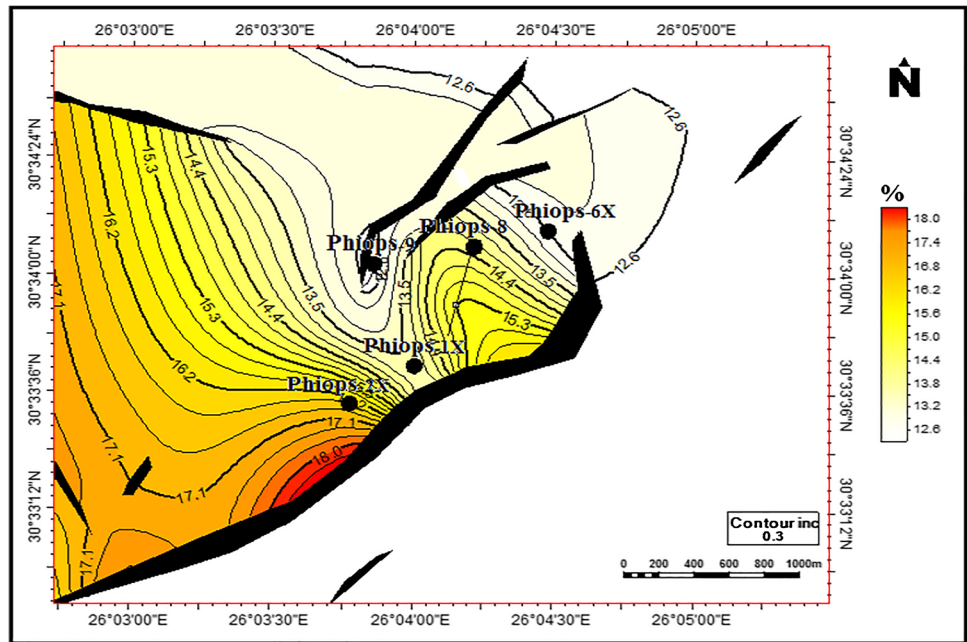


anticline trends along the northeast and southwest and was probably created due to the compressional force that associated the Syrian arc movement in the Late Cretaceous. On the other hand, stratigraphic traps are represented by lenses of sandstone unconformably overlain by impermeable shale layers, as in the case of the Alam El Bueib-6 reservoir.

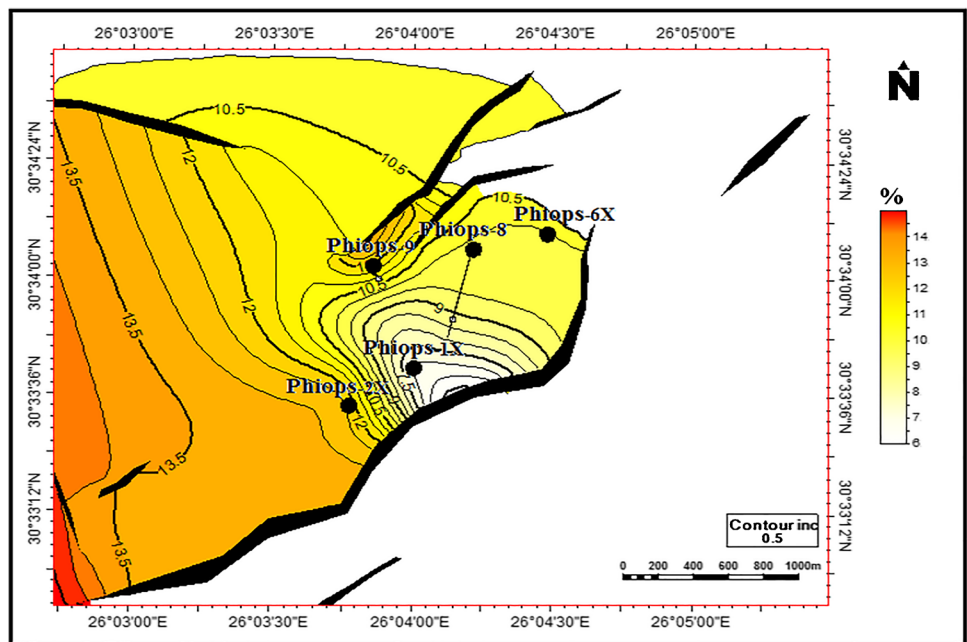
## Discussion and conclusion

Petroleum system is the main geologic concept used to determine oil and gas resources and contains all genetically related processes that control the significant processes of generation, expulsion, migration, entrapment, and preservation of petroleum (Magoon and Dow 1994a, 1994b).

**Fig. 16** Effective porosity map of the Alam El Bueib-3E reservoir in the study area



**Fig. 17** Effective porosity map of the Alam El Bueib-6 reservoir in the study area



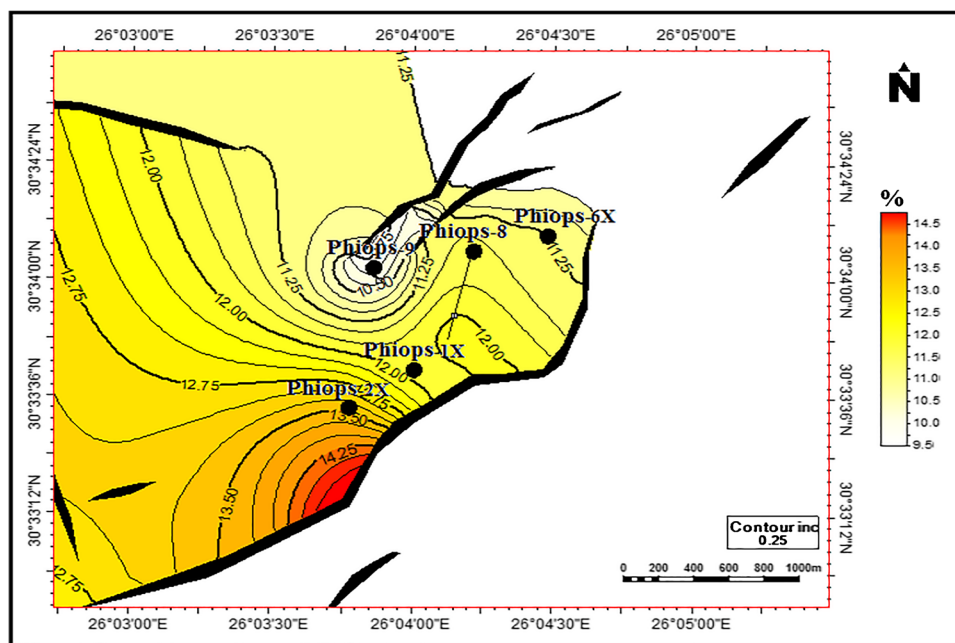
Analysis of present geochemical data and obtained percentage values of vitrinite reflectance (%R<sub>o</sub>) for both the Alam El Bueib and Khatatba shale source rocks indicates that most of these units are in the mature stage within the oil generation window. Reconstruction of the thermal and burial histories of the present Faghur basin (Fig. 41), based on data from well Neith S-2X, indicates that the Lower Cretaceous Alam El Bueib shale source rock units are a mature source rock with good ability for generating gas with minor oil. These rocks seem to have entered the oil window during the Early/Late Cretaceous to Neogene

times especially for Alam El Bueib-3A, Alam El Bueib-3C, and Alam El Bueib-6.

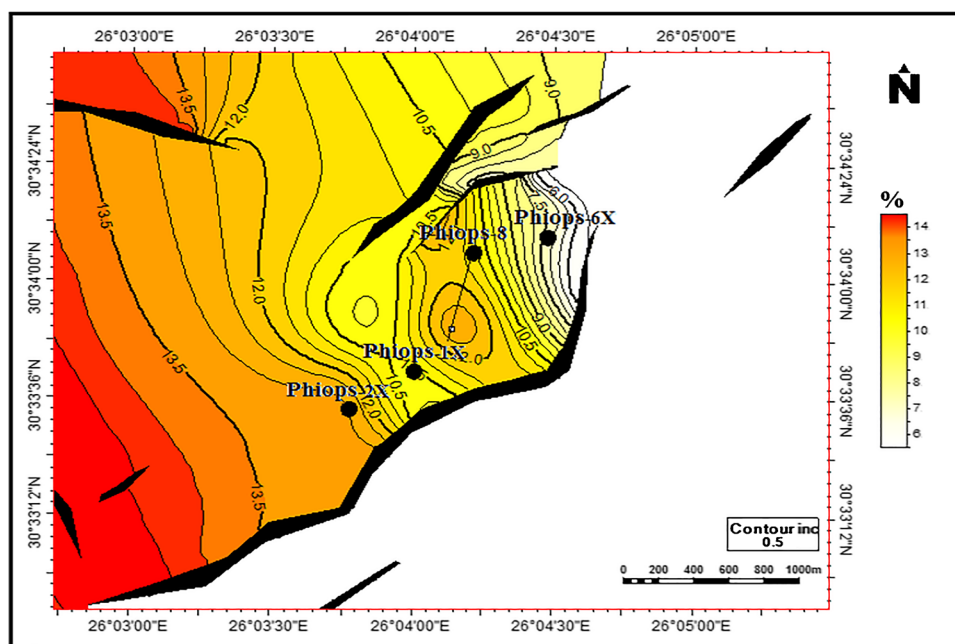
The Jurassic Khatatba shale source rocks, on the other hand, seems to bear a mature source rock as it yielded a very good to fair generating capability for gas with minor oil. It started the oil window during Early Cretaceous to Miocene times and formation of the condensate gas since Miocene until now (Fig. 41).

The Jurassic Khatatba reservoir seems to have been charged directly from the local intra-formational shale intervals within this formation through a proposed

**Fig. 18** Effective porosity map of the Alam El Bueib-3G reservoir in the study area



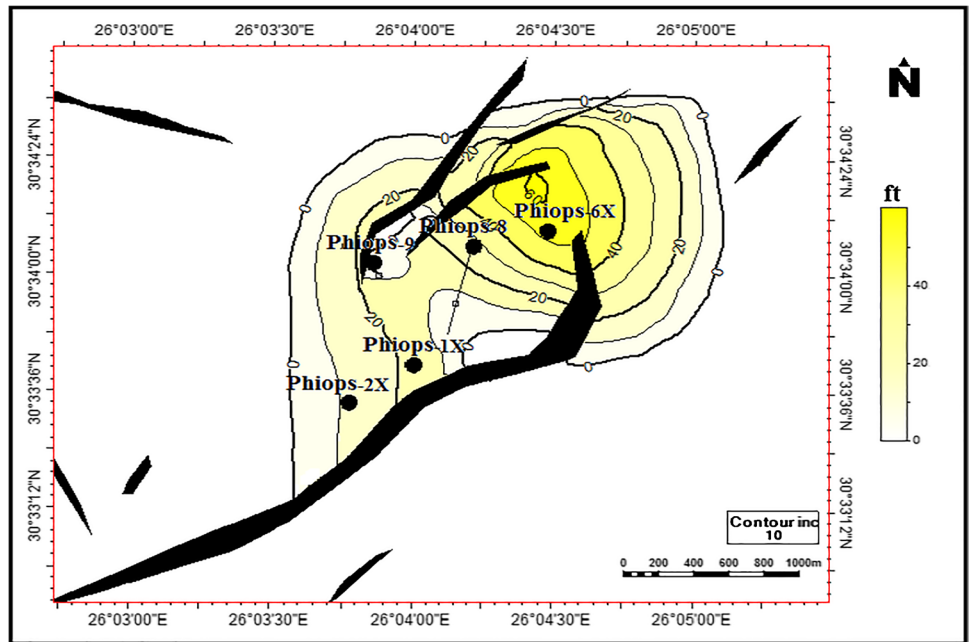
**Fig. 19** Effective porosity map of the Khatatba reservoir in the study area



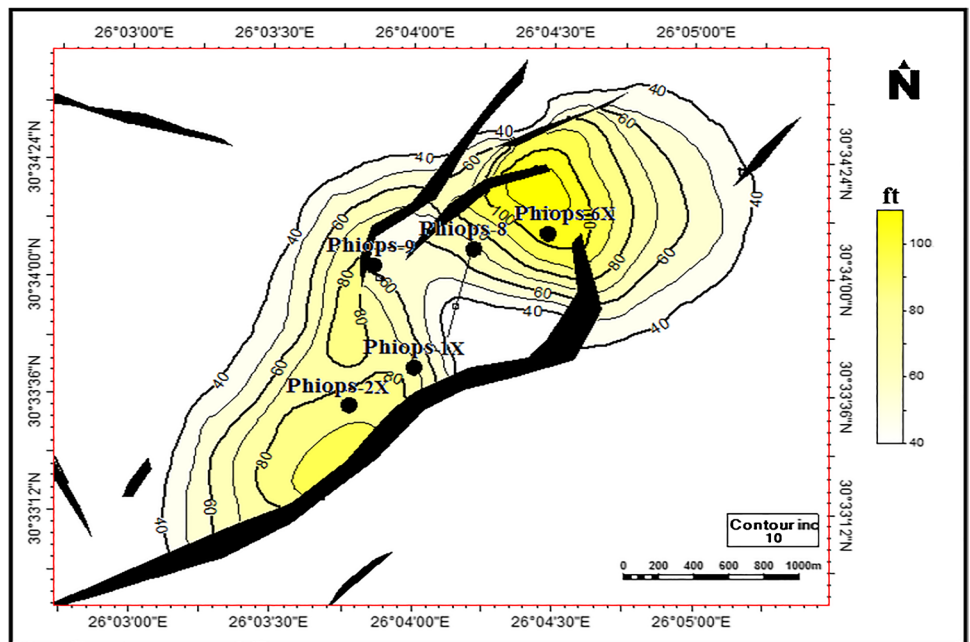
short-distance vertical migration along the fault plane, then accumulated, and preserved in situ. These hydrocarbons seem to have continued moving up charging the Lower Cretaceous Alam El Bueib reservoirs. This is in addition to the feeding related to the depocenter of the Alam El Bueib shale source rock units, including the Alam El Bueib-3A, Alam El Bueib-3C, and Alam El Bueib-6 shale rock units.

These processes when integrated with the above-mentioned interpreted geochemical, petrophysical, and seismic results that confirm the presence of effective source rocks and well-sealed reservoir rocks that are well trapped all lead to the successful formulation of a complete petroleum system in the Faghur basin during the Jurassic-Cretaceous time. Oil companies working in the study area are therefore invited to drill more wells in the central part of the area to enhance hydrocarbon productivity.

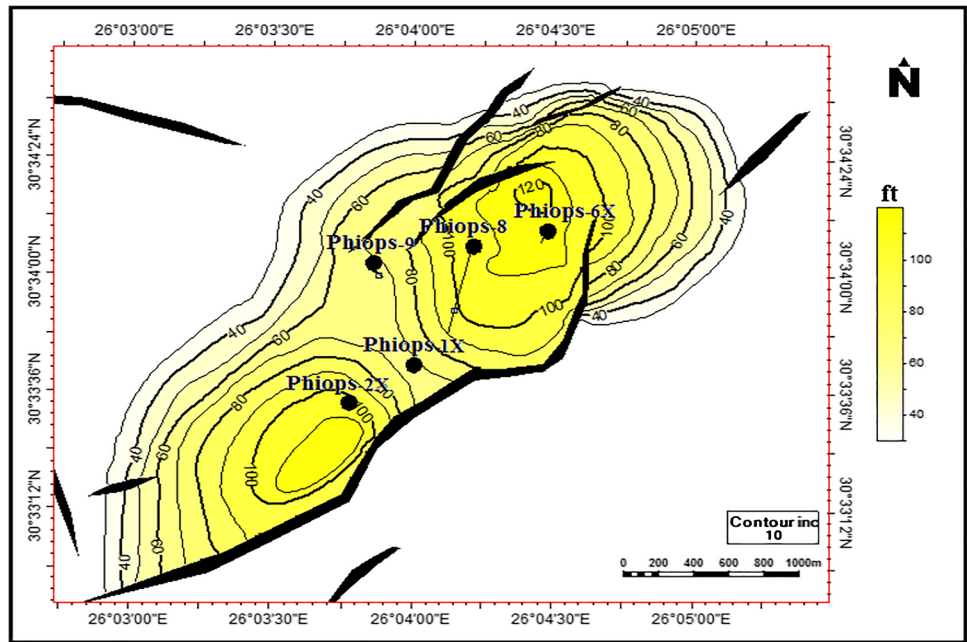
**Fig. 20** Net reservoir map of the Alam El Bueib-3D reservoir in the study area



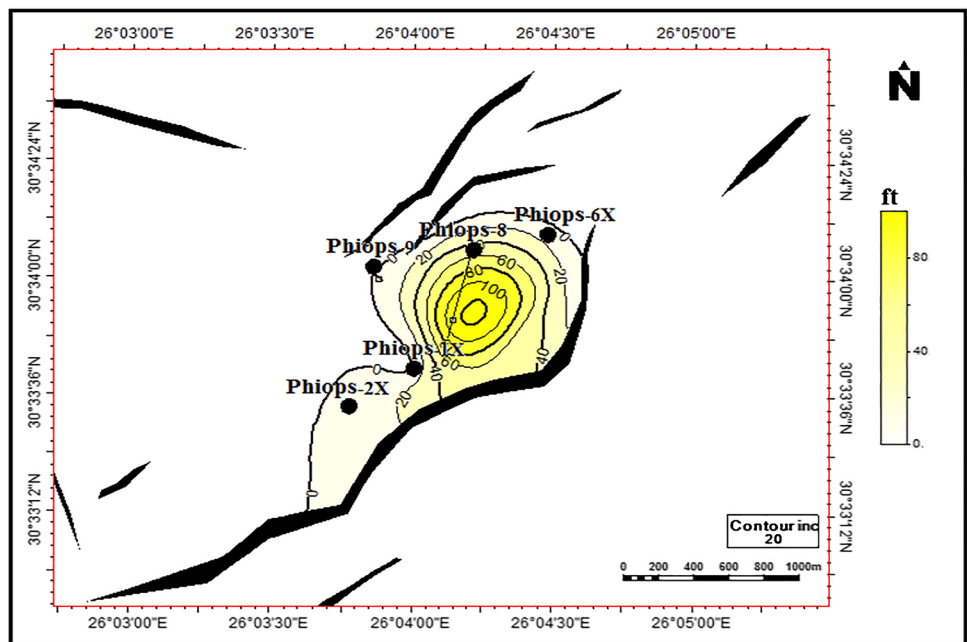
**Fig. 21** Net reservoir map of the Alam El Bueib-3E reservoir in the study area



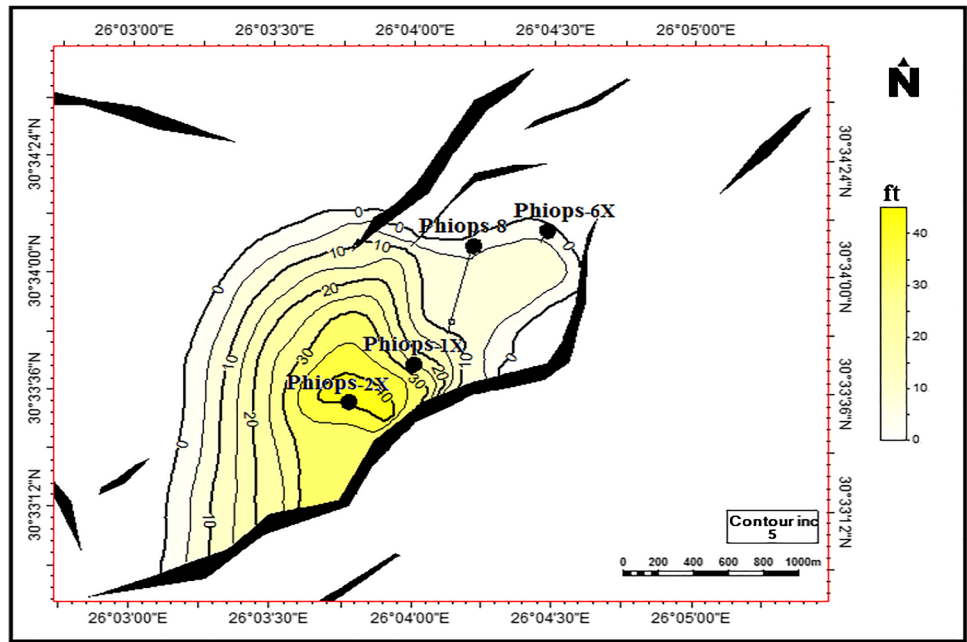
**Fig. 22** Net reservoir map of the Alam El Bueib-3G reservoir in the study area



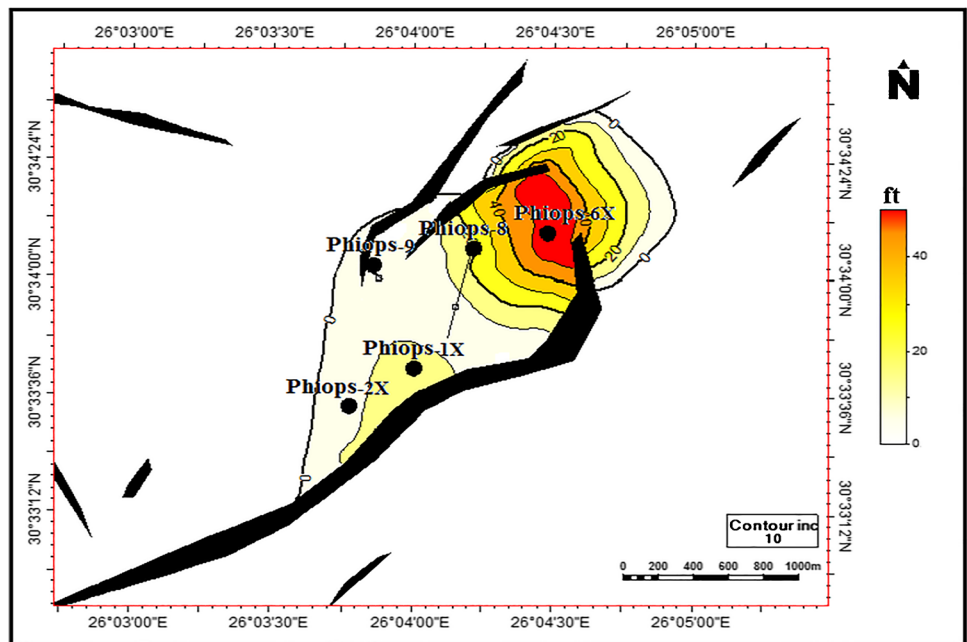
**Fig. 23** Net reservoir map of the Alam El Bueib-6 reservoir in the study area



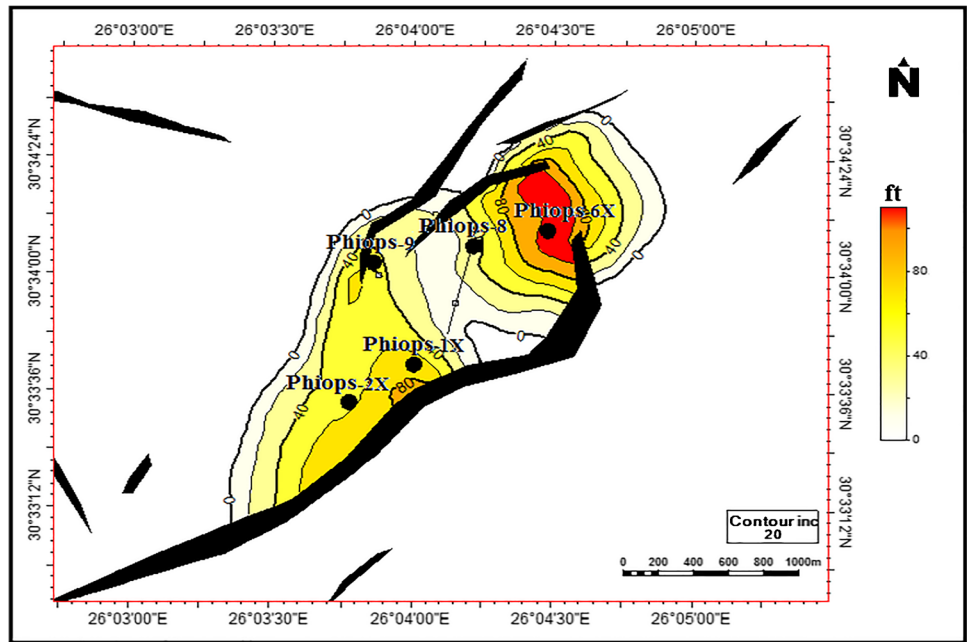
**Fig. 24** Net reservoir map of the Khatatba reservoir in the study area



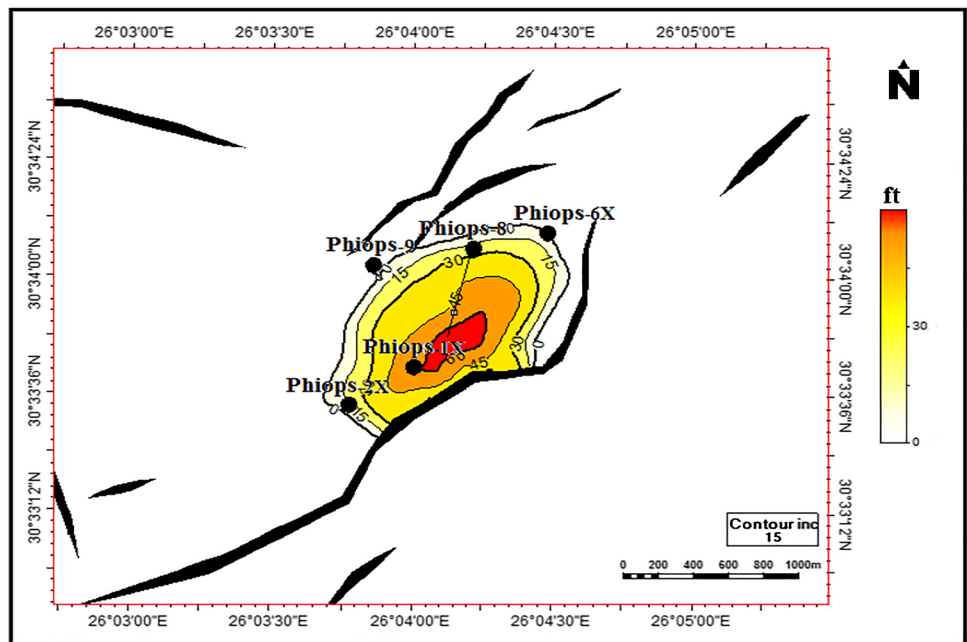
**Fig. 25** Net pay thickness map of the Alam El Bueib-3D reservoir in the study area



**Fig. 26** Net pay thickness map of the Alam El Bueib-3E reservoir in the study area

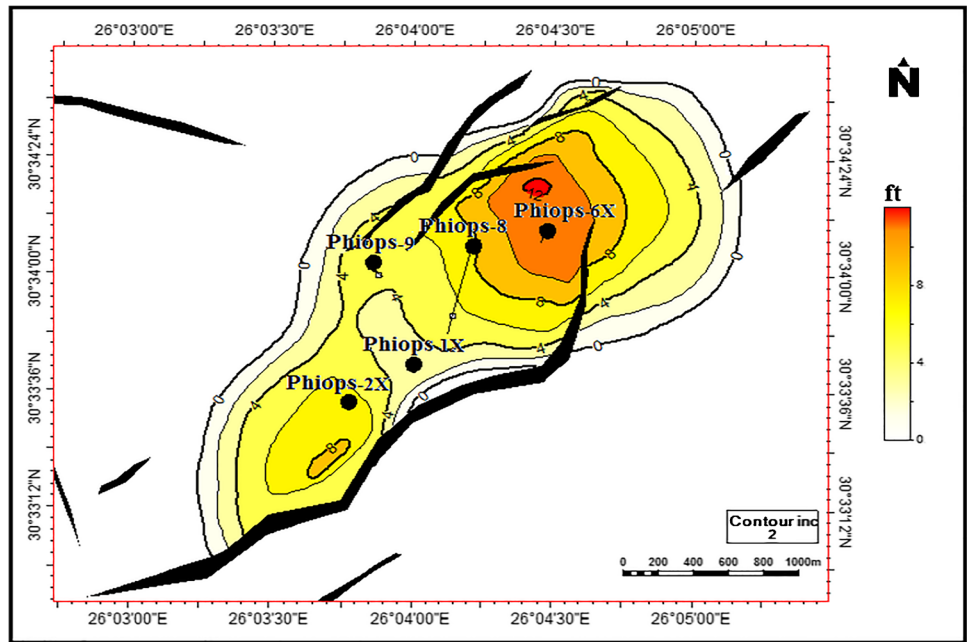


**Fig. 27** Net pay thickness map of the Alam El Bueib-3G reservoir in the study area

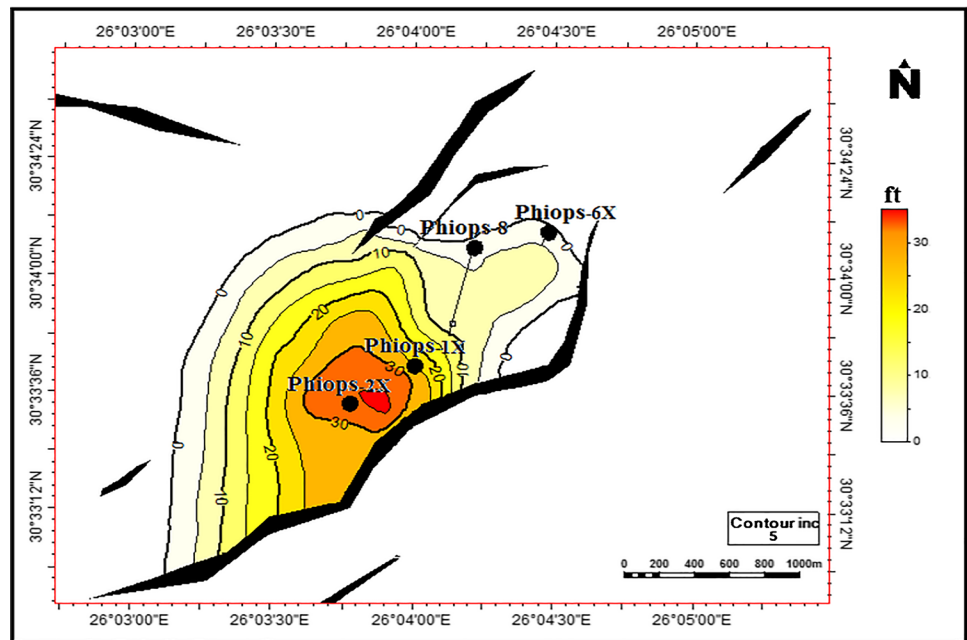




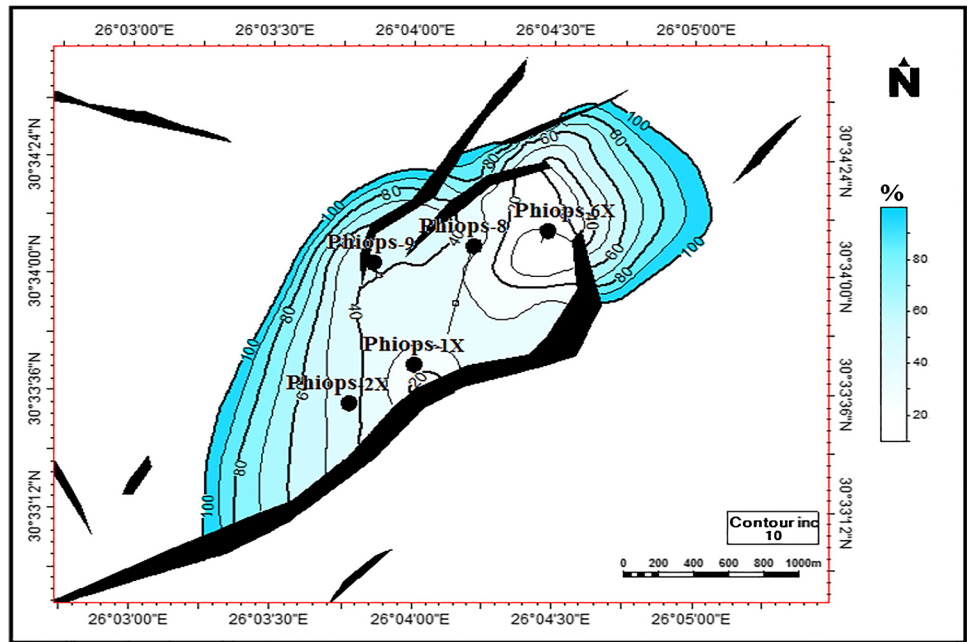
**Fig. 28** Net pay thickness map of the Alam El Bueib-6 reservoir in the study area



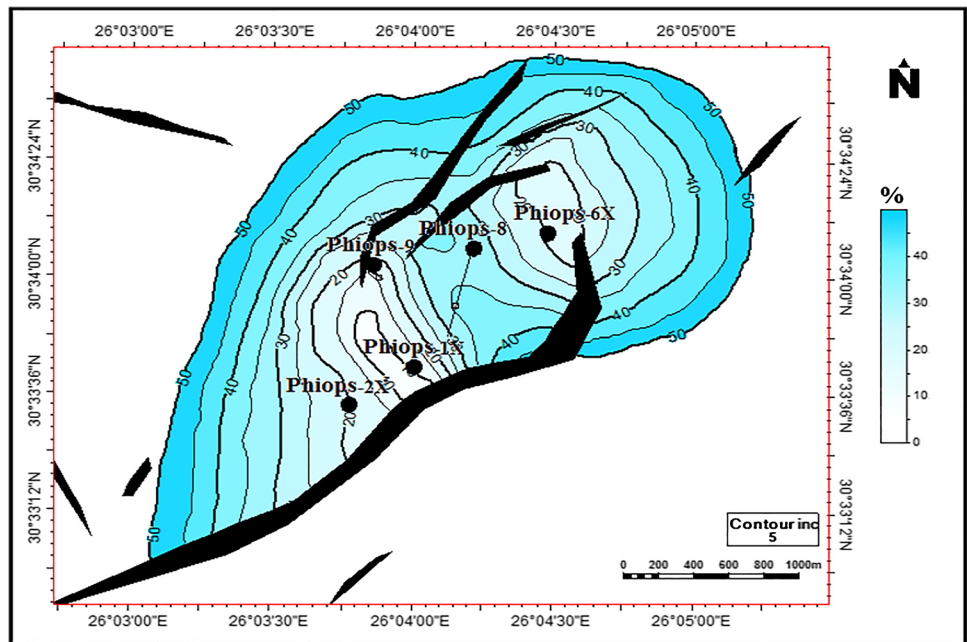
**Fig. 29** Net pay thickness map of the Khatatba reservoir in the study area



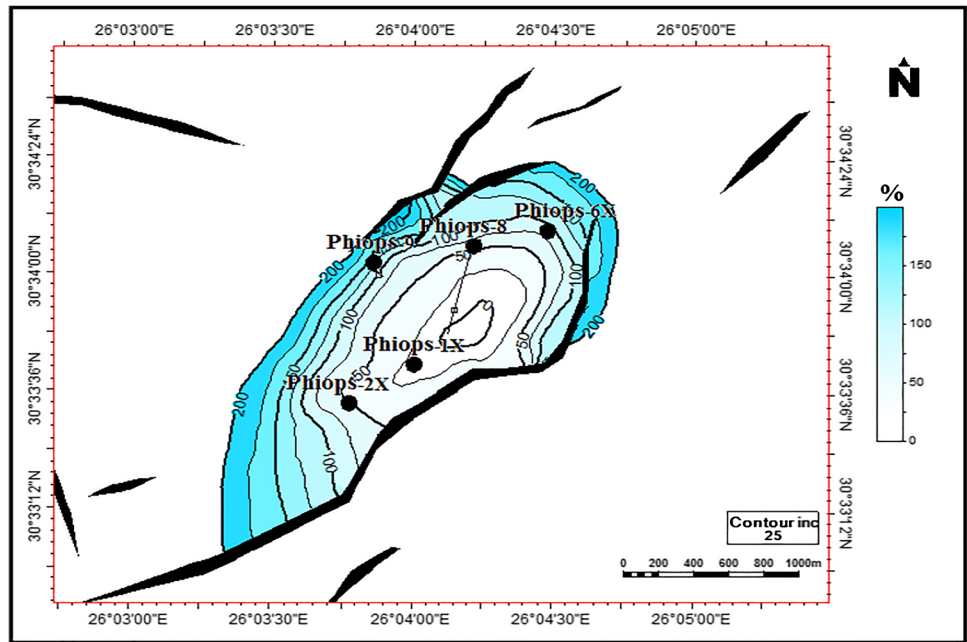
**Fig. 30** Water saturation map of the Alam El Bueib-3D reservoir in the study area



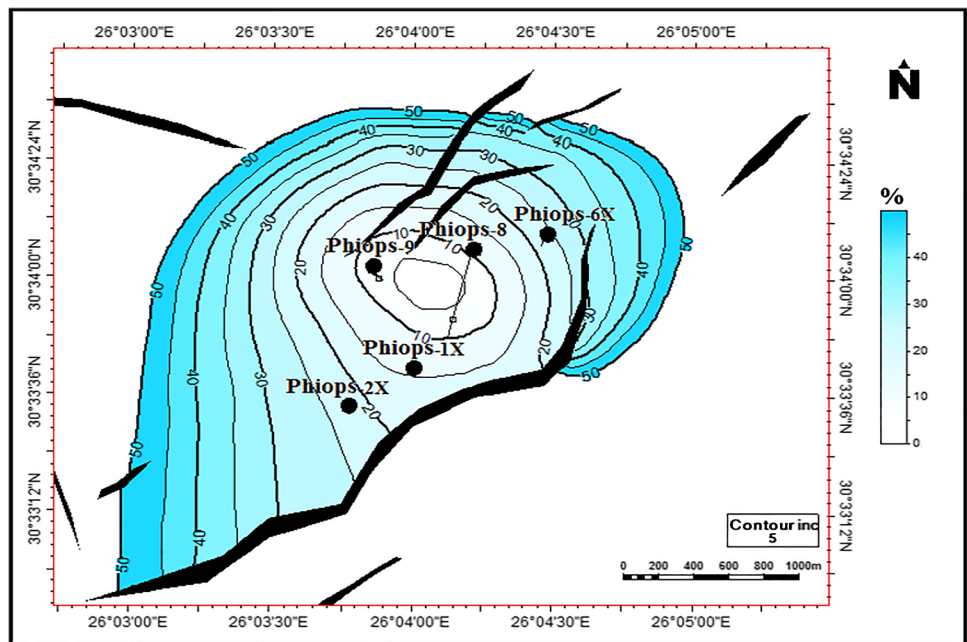
**Fig. 31** Water saturation map of the Alam El Bueib-3E reservoir in the study area



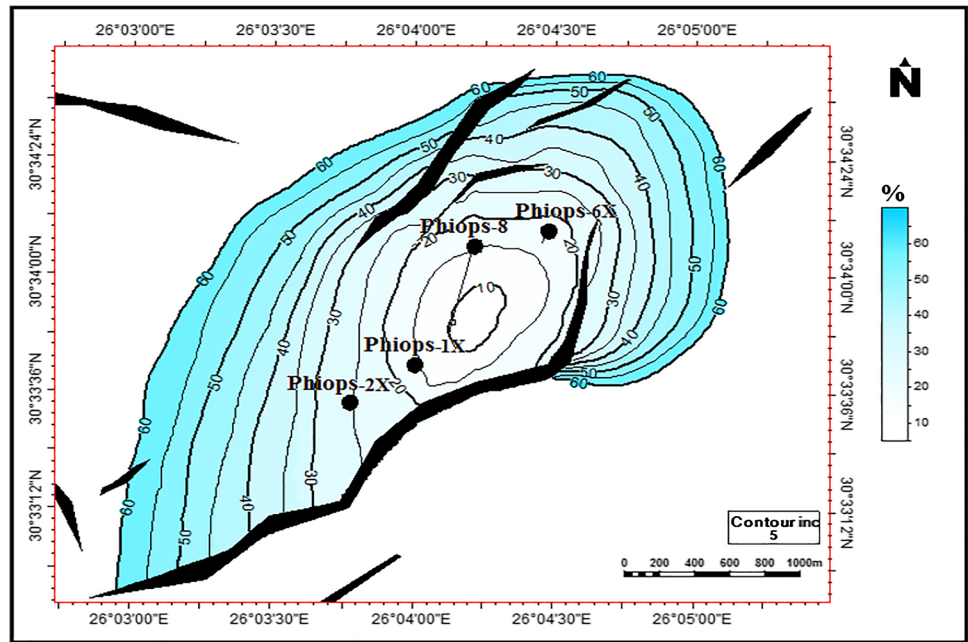
**Fig. 32** Water saturation map of the Alam El Bueib-3G reservoir in the study area



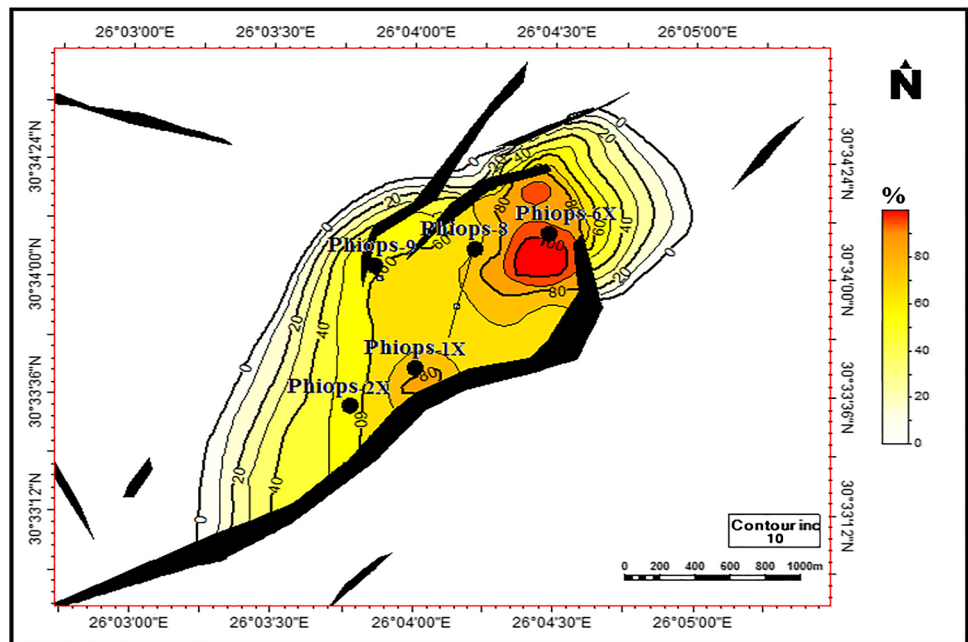
**Fig. 33** Water saturation map of the Alam El Bueib-6 reservoir in the study area



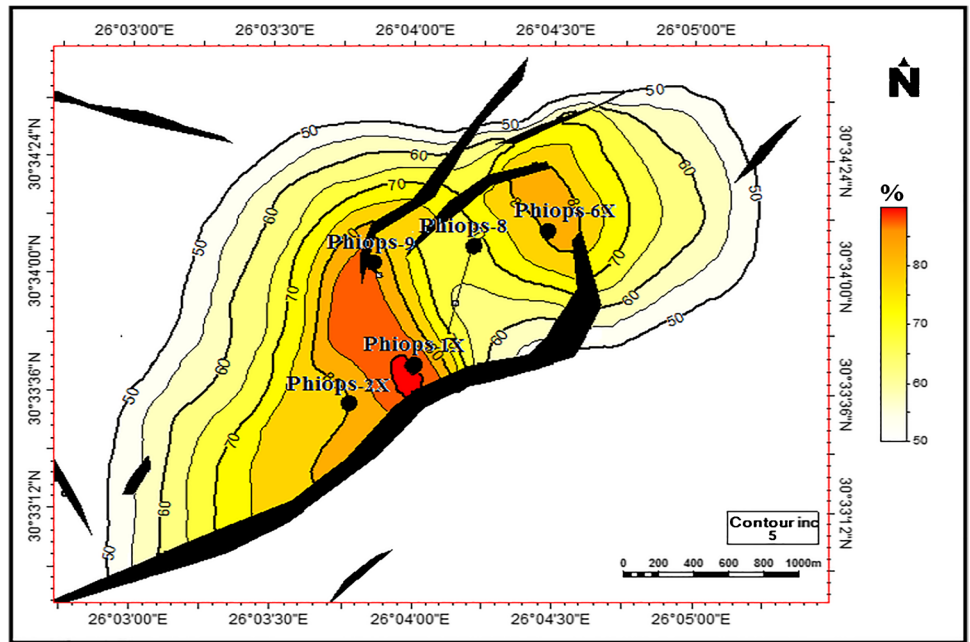
**Fig. 34** Water saturation map of the Khatatba reservoir in the study area



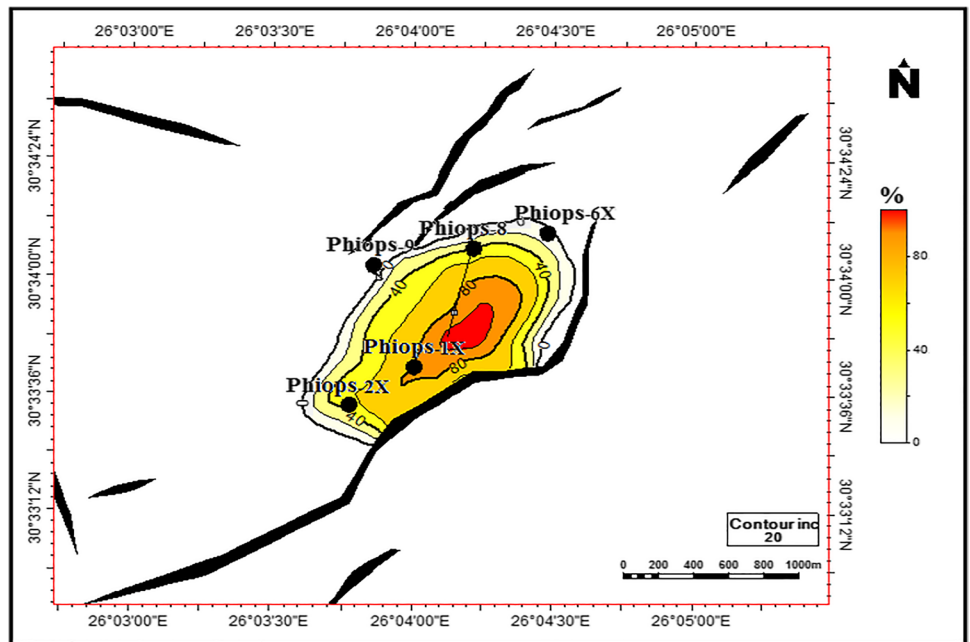
**Fig. 35** Hydrocarbon saturation map of the Alam El Bueib-3D reservoir in the study area



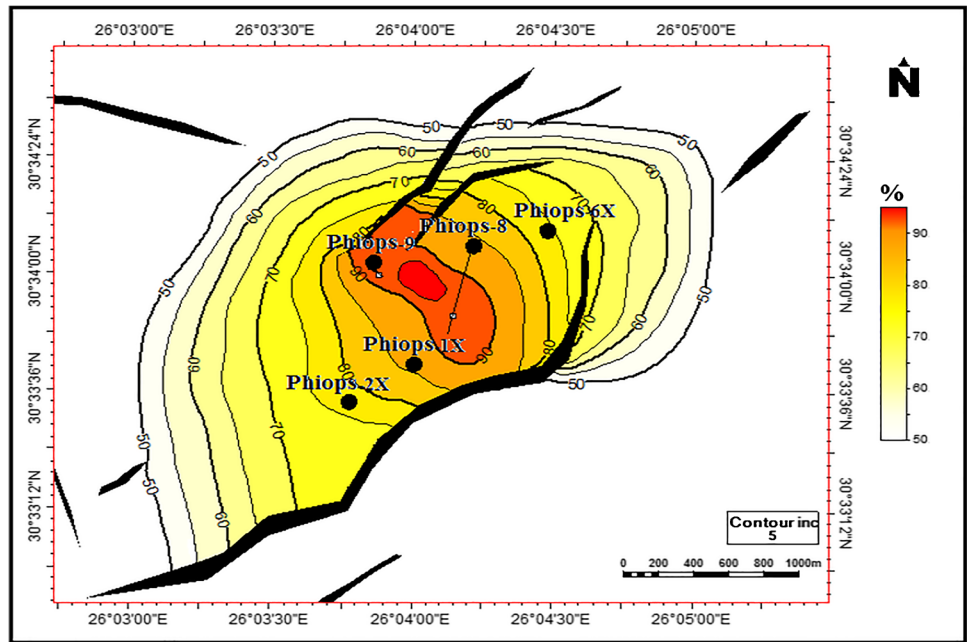
**Fig. 36** Hydrocarbon saturation map of the Alam El Bueib-3E reservoir in the study area



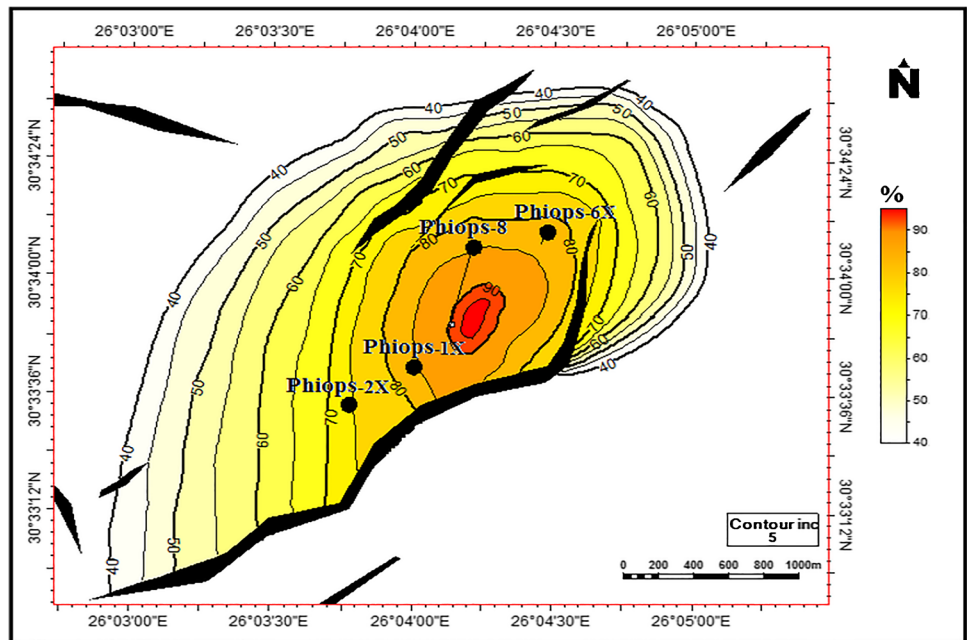
**Fig. 37** Hydrocarbon saturation map of the Alam El Bueib-3G reservoir in the study area



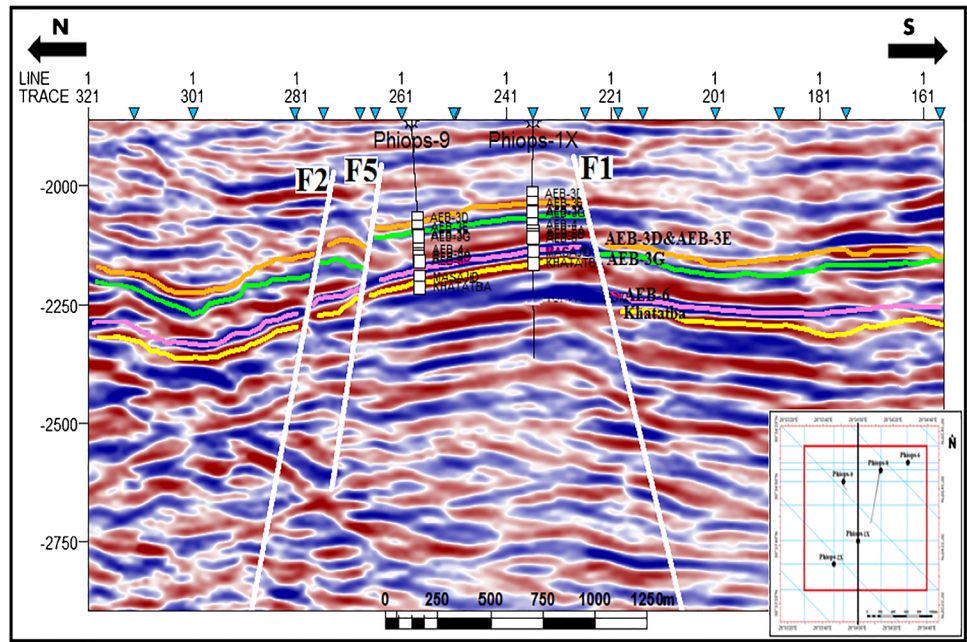
**Fig. 38** Hydrocarbon saturation map of the Alam El Bueib-6 reservoir in the study area



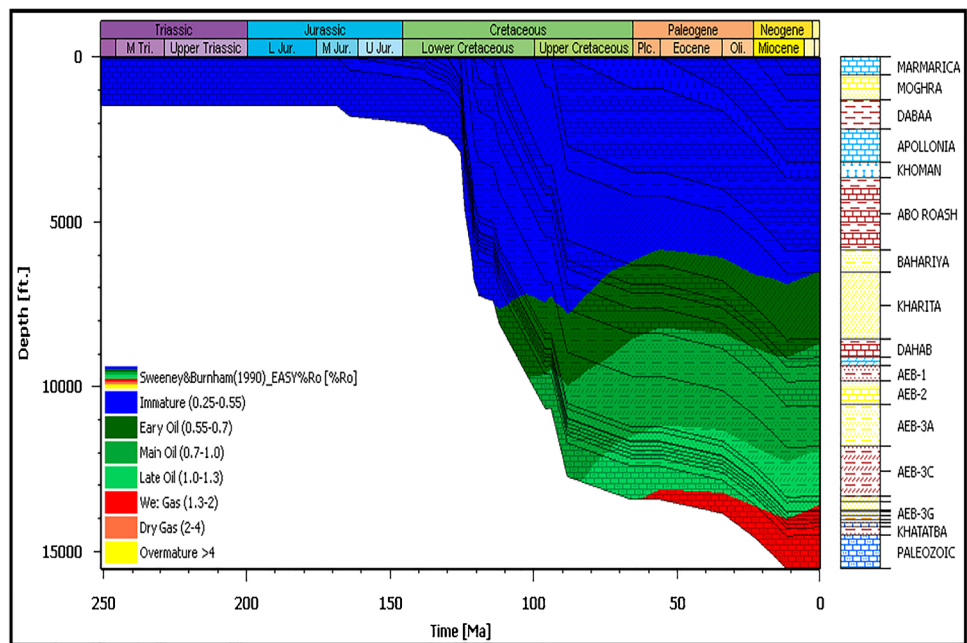
**Fig. 39** Hydrocarbon saturation map of the Khatatba reservoir in the study area



**Fig. 40** Seismic line with interpreted/ constructed horizons in a 2D window



**Fig. 41** The burial history and hydrocarbon zones of Alam El Bueib, Khatatba, and Paleozoic source rocks in Neith S-2X well



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#### Declarations

I declare that the contents of this research paper have not previously been submitted at any journal.

**Conflict of interest** The authors declare no competing interests.

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