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ORIGINAL PAPER

# Petroleum geochemistry of oil samples from shallow boreholes at Sakran site, western Iraq

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**Abstract** Findings of the oil source affinity for oil sample collected from shallow borehole already drilled for ground water purposes at the Sakran area, NE Haditha city, western Iraq, is performed in this study by biomarker studies with addition to the analysis of gravity map. Petroleum geochemistry study is carried out on oil sample. The terpane and sterane biomarker distributions, as well as the stable isotope values, are used for determining the validity of oil to correlate its source. The results showed that the oil belongs to the Jurassic age, with high sulfur content (2.75 %) and value of C28/C29 up to 0.75. The tricyclic terpanes values as well as hopanes indicated a source rock affinity of carbonates, whereas the pristine/phytane ratio indicated marine algal source of kerogen type II. All these information could confirm that the source rock affinity was the Sargelu Formation (Jurassic), in which their age's equivalent to the source in East Baghdad Oil Field and Tikrit Oil Field, with a difference from the oil family near the Akkas field, located to the west of the area. Chemical analyses of water sample collected from the borehole showed the following results: TDS=12,700 mg/l, EC=215,900 μs/cm, pH=6.8, DO=28 mg/l, and temperature=24 °C. Hydrochemical functions such as rNa/rCl (<1), (rNa–rCl)/$rSO_4$ (<0) and $rSO_4$/rCl (<1) indicate that the water is of marine origin, partially mixed with meteoric water. Analysis of the gravity map revealed two anomalous areas; the western one represents large anomaly with EW trend similar to the Anah graben to the north. The second one consists of many anomalies trending N–NW direction. The main local anomaly is identical with the seeps from the drilled borehole covering large area. The boundaries and trends of the main geological structures have been defined by gradient analysis procedure to the gravity data. The closed gravity anomalies with their large extensions reflect the importance of the results for further studies and promising area for oil reservoirs.

**Keywords** Petroleum geochemistry · Oil seeps · Reservoir prediction · Western Iraq

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## Introduction

Oil exploration works in Iraq are concentrated in the eastern and northern Iraq, mainly in the shallow Mesozoic and Tertiary reservoirs (Aqrawi et. al. 2010). The oil and gas exploration in the western Iraq are limited, whereas older Paleozoic sequences with great thickness have been reached by drilling (Al-Sakini 1992, Al-Haba et.al. 1994). However, oil seeps in the western Iraq reflect the existence of oil sources in the area as found along the western boundary of the Mesopotamian basin. The seepages are situated on the NS trending Abu-Jir fault zone (AJFZ). Bitumen lakes around 2 km in diameter are located at the Abu Jir, Ain Jabha, Ain Hit, and Ata'it (Aqrawi et al. 2010). Seepage activity begins in the Middle Miocene, and a substantial volume of oil has since been lost to the surface (Jassim and Al-Gailiani 2006). In the Hit area, the Lower Fars Formation has been eroded down to the top of underlying Euphrates Limestone. The seepages are from bitumen-saturated limestone beds of the Euphrates Limestone Formation. Bitumen-impregnated beds occur in Fatha Formation nearby the Awasil area, indicating that generation and migration had begun here by the Middle Miocene (Dunnington 1958).

The Jurassic petroleum system in Iraq includes source rocks of the Sargelu, Naokelekan, and Gotnia Formations and reservoirs of the same age (Verma et al., 2004). Sargelu Formation extends throughout of northern Iraq as well as south of Iraq. The formation is composed of thin bedded, black, bituminous limestone, dolomitic limestone and black papery shale with streaks of thin black chert in the upper part. They overlain by bituminous limestone and shale of the Upper Jurassic Naokelekan Formation with a contact of apparently gradational and conformable. The Upper Jurassic anhydrite seal is thick succession of the Gotnia Anhydrite Formation that covers most Jurassic sequence and extends through Mesopotamian Basin. Pitman et al. (2004) considered that the Sargelu and Naokelekan Formations are the most important Jurassic source rocks in Iraq and that Cretaceous source rocks had contributed only small amounts of oil to the Cretaceous Tertiary petroleum system. Most of Jurassic source rocks in Iraq have already reached or exceeded peak oil generation and have been started to generate significant quantities of gas. However, area of oil generation has spread westward through time.

To the west, in Akkas-1 highly mature, marine, organic-rich Ordovician shale was encountered. These are classified as good source rocks, whereas the total organic carbon (TOC) ranges from 0.9 to 5 %. Al-Haba et al. (1994) predicted that these TOC quantities could generate light hydrocarbon in Akkas-1 and Khleissia-1. Al-Ameri and Wicander (2008) presented a study about the source potential of gas and other hydrocarbons in the Ordovician Khabour Formation based on palynomorphs and palynofacies analyses from the Akkas-1 and Khleissia-1 boreholes. They concluded that some levels within the Ordovicain Khabour Formation in the Akkas-1 borehole have generated condensates, wet and dry gas. These hydrocarbon levels may extend westward toward Jordan and Syria and southward toward southwestern part of the Iraqi desert and the Saudia Arabia.

The present paper is concerning with findings of the oil affinity for oil sample collected from shallow borehole drilled for ground water at Al-Sakran area, NE Haditha city, western Iraq (Fig. 1). It also includes analysis of the gravity map of the area.

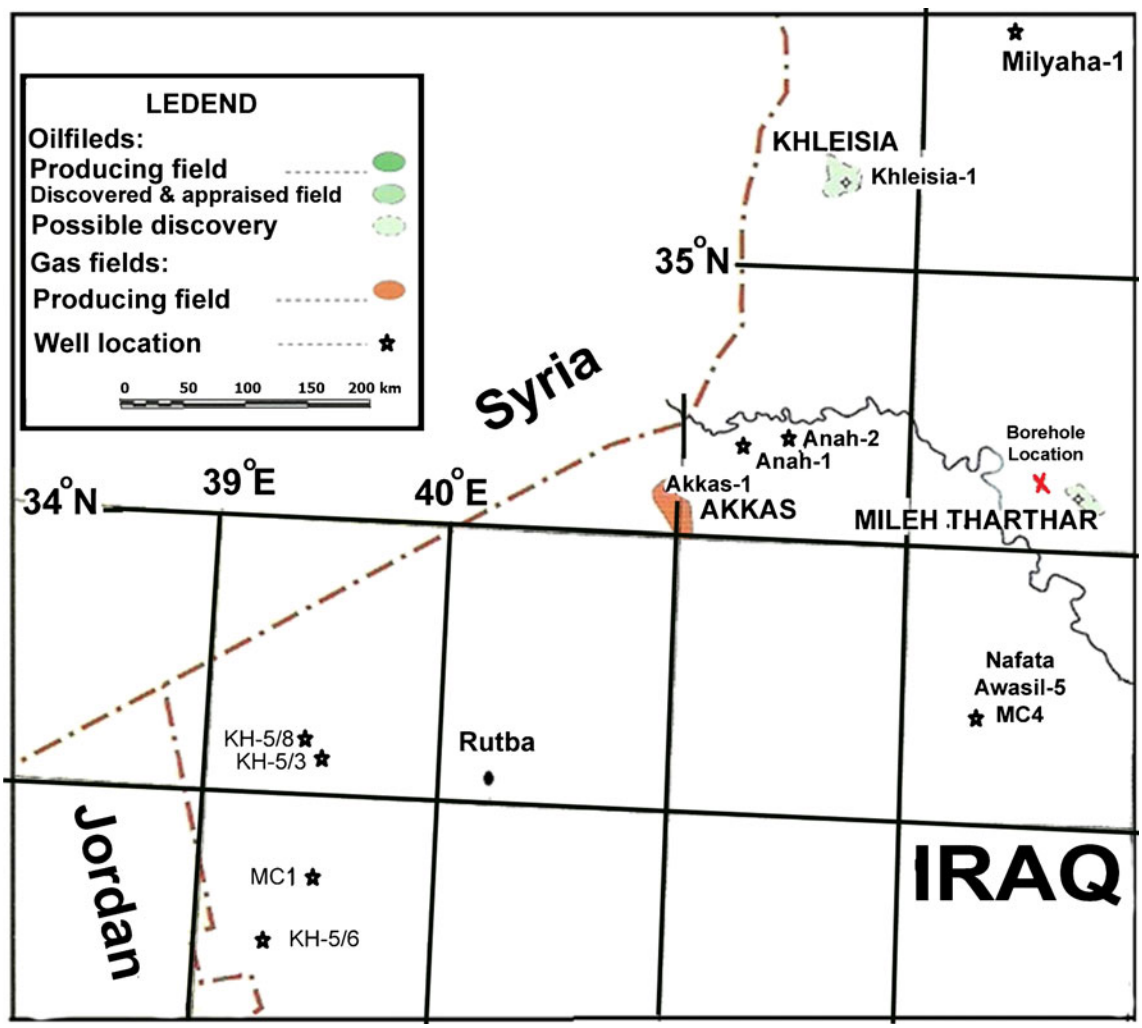



**Fig. 1** Location map of the borehole with the main wells drilled in the Western desert of Iraq

## Geology and tectonic of the area

The region is generally of low relief hilly character. Differences in the erodability of rocks resulted in the development of step morphology in this region. Stratigraphically, rocks exposed in the area range in age from the M. Oligocene up to the M. Miocene (Fouad and Nasir 2009). Most of the area is covered by the M. Miocene Fars (Injana and Fatha Formations), which are composed of alterations of calcareous claystone, carbonates, and evaporates. The Lower Miocene Euphrates Formation is composed of shallow marine fossilferous carbonate and calcareous claystone that are also exposed in many parts of the area.

The main sources of the subsurface stratigraphic information is obtained from well Anah-2 to the west, drilled to a depth of 3,527 m and Melih Tharthar well drilled to a depth of 3,843 m to the east. The Melih Tharthar well is the nearest deep exploration well that can be considered as a dominant stratigraphic feature in the area. This well penetrated the Mesozoic sequence (Fig. 2).

Aqrawi (1998) has reviewed the Paleozoic stratigraphy of the Western Desert of Iraq. Strata of the Ordovician Khabour Formation represent the oldest exposures in the northern Iraq (Van Bellen et al. 1959).The Silurian Akkas Formation in the subsurface were recorded from wells Khleissia 1–6 and Akkas 1 in the western Iraq. The Khabour Formation comprised of sedimentary rocks, which consist of entirely siliciclastics of thin bedded fine-grained sandstones, quartizite graywakes, and silt micaceous shale. The Khabour Formation can be correlated regionally with the Risha, Dubaydib, Hiswa, and Swab Formations of Jordan; the Affendi, bedinan, Swab, and Khanasser Formations of Syria; and the Saq and Qasim Formations of the Saudia Arabia (Al-Sharhan and Narin 1997; Al-Hajri and Owens 2000).

The overlying Silurian succession of alternating sandstones and gray shale is the Akkas Formation. The Akkas Formation can be correlated with the Mudawwara and Kish Sha Formations of Jordan, with Suffi and Tanf Formations in Syria and with the Qalibah and Taweal Formations in the Saudia Arabia (Al-Sharhan and Narin 1997). Al-Ameri (2010) has documented the Silurian Akkas and Ordovician Khabour successions in the western desert of Iraq in wells KH5/6 and Akkas based on palynological evidences. Kaista Formation, of upper Devonian ages, lies unconformably on the top of the Silurian Akkas Formation. The formation includes sequence of sediments represented by shale, siltstone, and limestone beds with occasional sandy streaks.

Tectonically, west Iraq represents the north parts of the Arabian plate. Orientations of structures in this tectonic unit were influenced by the geometry of underlying basement blocks and faults, Paleozoic epeirogenic events, and Mesozoic arching (Pollastro et al. 1999; Sharland et al. 2001). The depth of the Pre-Cambrian basement in western Iraq ranges between 7 and 13 km (Compagine General de Geophysique, unpublished data). West Iraq was tectonically divided into basins and uplifts. This leads to form many gravitational faults and grabens (Pollastro et al. 1999), as well as the Khleissia uplift to the north and Rutbah uplift to the south. In between of them, there are many grabens such as Anah, Tayarat, and Khleissia grabens in addition to the Widyan basins. The uplifts and subsided sites had formed many structural closures that may be formed oil traps. The tectonic map (Fig. 3) published by Ditmar et al. (unpublished report) shows the fault system with major extensions and displacements are dominated in the Al-Jazzera area. The main trends of graben system are almost E–W direction. The trend of the tectonic structures to the south of Anah graben and to the south of the borehole location, where oil sample was collected, is changing and becomes almost N–S direction. The previous tectonic map does not exhibit any features around the borehole site. Therefore, the borehole is situated between NS trend fault zone of the Abu-Jir south and EW trend Anah graben to the north. The relatively high geothermal gradient in the upper Euphrates basin in the west of Iraq indicated a fault plane was a path way for passing the spring water. Water along the AJFZ contains variety quantities of hydrocarbon. Hydrocarbon mixed with water was perfectly noticed within the groundwater at Haditha and Hit. All hydrocarbons are lighter than water, so that it floats on water surface. The escaped $H_2S$ dissolved gas from the spring water can be ignited with a flame of fire to a height of about 1 meter; this can clearly be seen where local people put fire on the $H_2S$ bubbles of the oil and gas seeps in the Hit area.

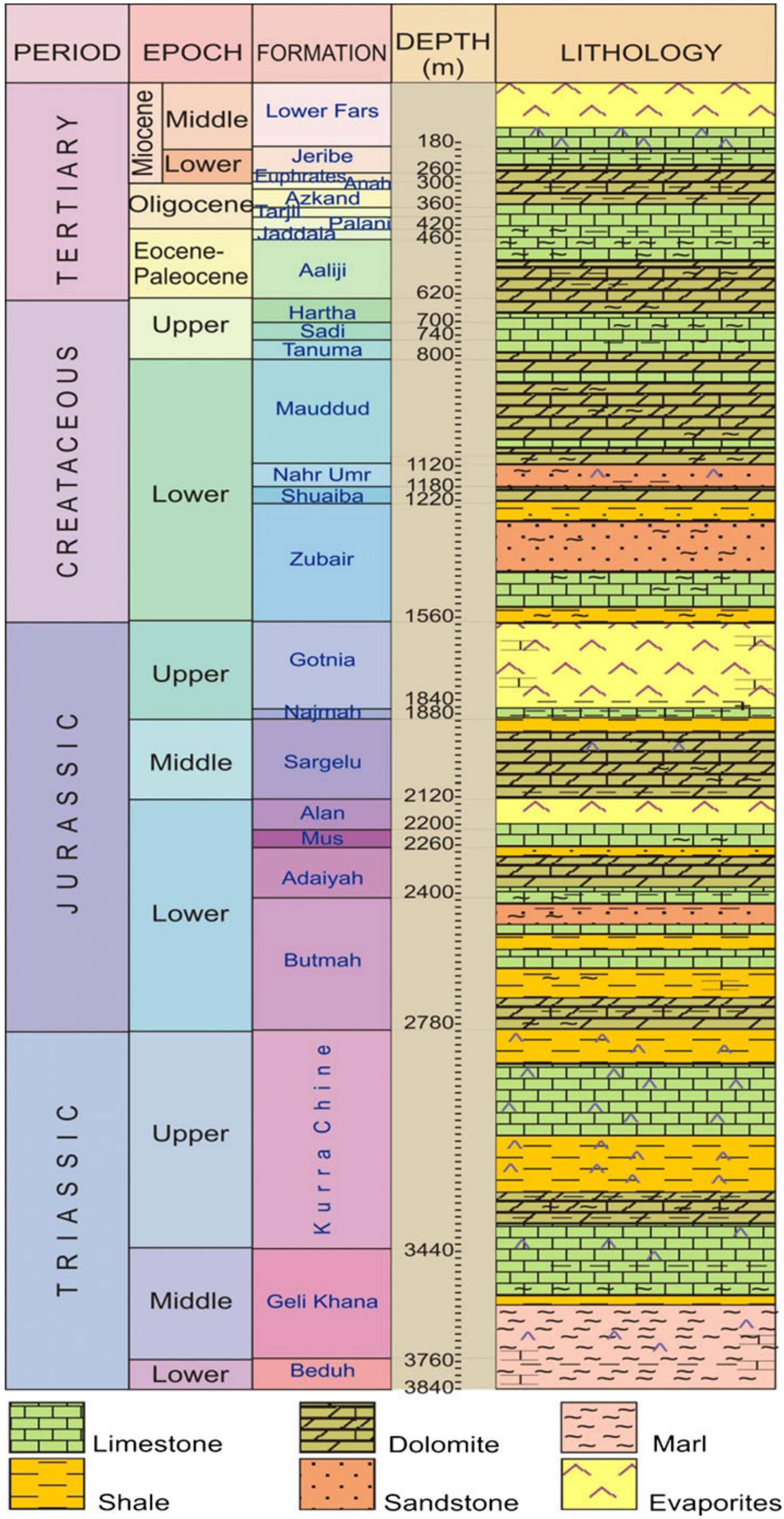
## Oil seep affinity

Oil seep samples are collected from the locality of Sakran, NE Haditha, along with the pumped water from shallow borehole. These samples are subjected for stable carbon isotopic composition, gas chromatography (GC) and combined gas chromatography–mass spectrometry (GC-MS) in order to find their source age as well as source environment and lithological composition on the basis of correlation with global studies of oil and source rocks performed by Hunt (1996), Peter et al. (2005), and Geomark Research Limited (of Houston, TX, USA) geochemical data base.

Terpanes of mz=191 amu and Steranes of mz=217 amu biomarkers are used for the GC-MS instrument. The data obtained from this analysis are tabulated on the geochemical summary sheet (Fig. 4).

From these analyses, the organic remains show little or no change in the alkane peaks from their parent organic

**Fig. 2** Stratigraphic column of Melh Tharthar (*MTh-1*) well



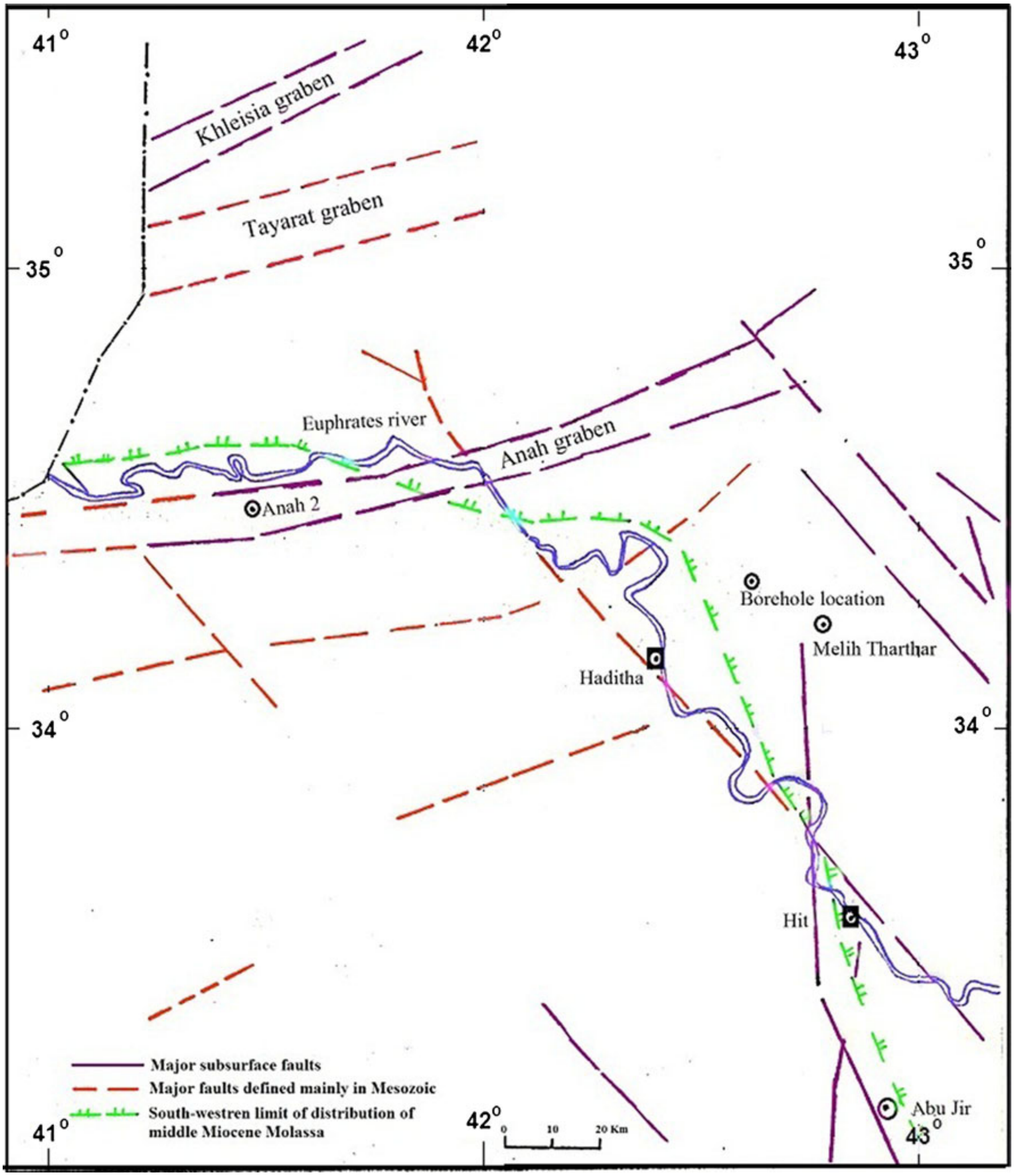



**Fig. 3** Tectonic map of the area (after Ditmar et al., unpublished report)

molecules in the living organisms (Hunt 1996; Paul Philp 2003; Peters et al. 2005). For that reason, the organic matters have persisted in petroleum, rocks, and oil seeps as biomarkers that include pristane, phytane, sterane, triterpane, and porpherins. These peaks are used to find correlation between oil and the kerogen of the source rocks.

The oil values of C28/C29 sterane (0.715), the stable carbon isotopes of $\delta^{13}C$ (‰) of C15+saturate (−27.21), C15+aromatic (−27.43), Canonian variable (−3.7), and sulfur content (2.74 %) are used to determine the age of the kerogen that formed this oil seep. The Upper Jurassic to Early Cretaceous aged kerogen charged the reservoirs with oil that has affinity with the Sulaiy Formation with Tithonian–Berriasian ages above the thick Gotnia Anhydrite seal based on the stratigraphic section of Bellen et al. (1959). The biomarkers scheme (Fig. 5) of Peter et al. (2005) confirms the Upper Jurassic and Early Cretaceous ages for the kerogen that formed the oil. This is based on the value C28/ C29 of about 0.715. For determination of source rock ages (Zumberge and Summons, 2004) in petroleum systems with carbonate/marl source units, the C28/C29 regular

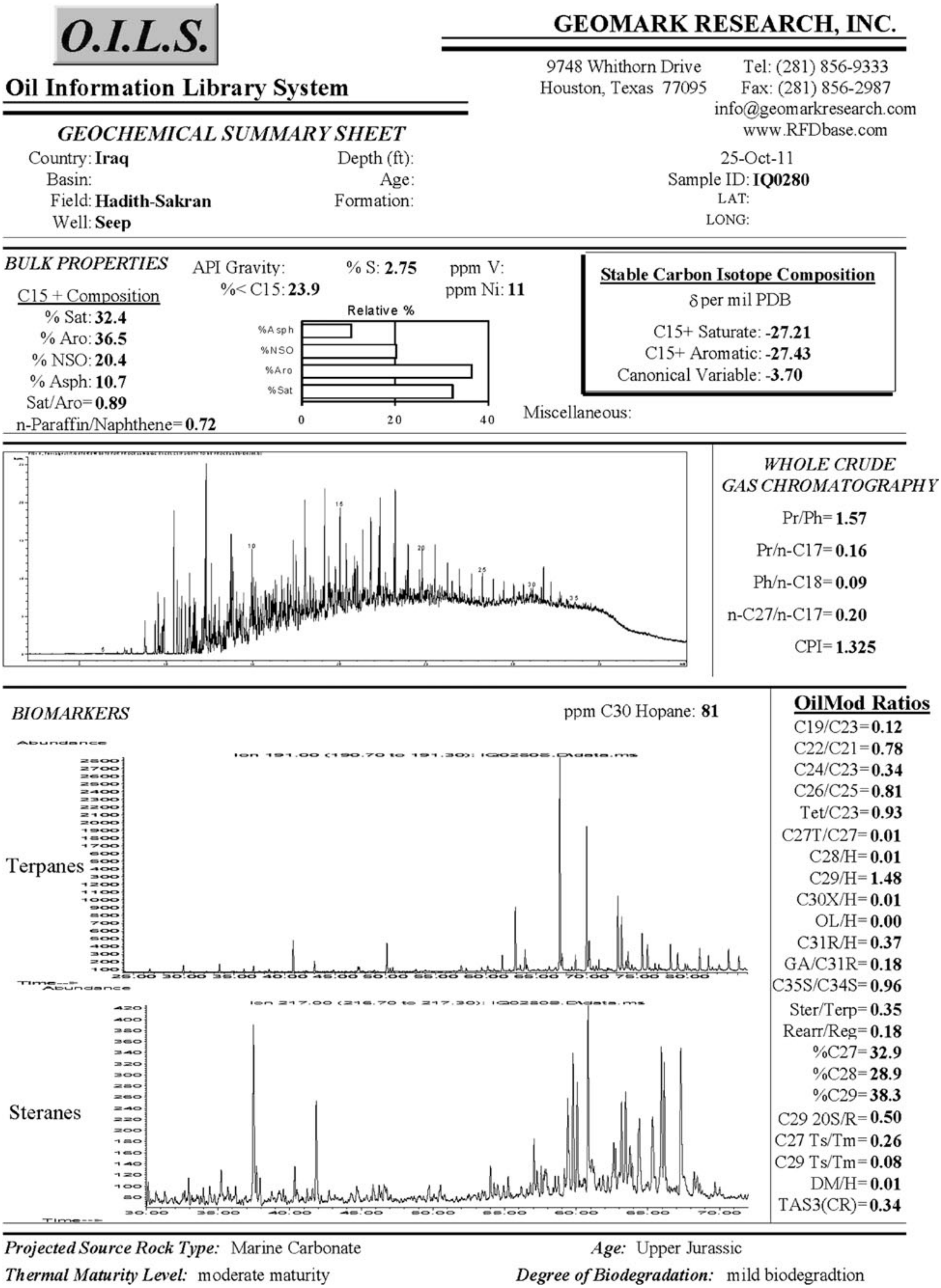



**Fig. 4** Sakran oil seep analysis chart with tabulated data obtained

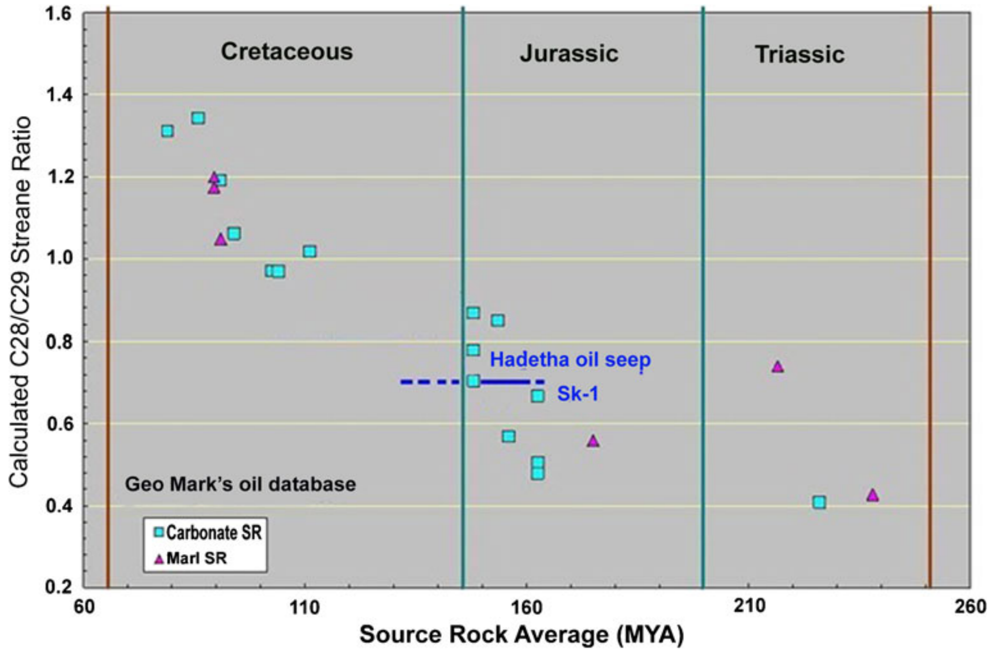



**Fig. 5** Sterane ratio source age diagram for the oil seep

sterane ratio is useful. As illustrated in Fig. 5, the calculated C28/C29 ratio, using both regular and triaromatic steranes, suggests that the oil seeps from the Haditha area in the locality of Sakran were generated mainly from Upper Jurassic carbonate source rocks. This assumption have been confirmed in this study by the plotting oil seep data of Sakran on pristine–phytane diagram (Fig. 6) of Hunt (1996).

The recorded peaks in the analyzed oil samples are the alkanes C17–C21 that correlate with organic matters of marine algal sources of restricted palaeoenvironment. The organic matter is coming from the kerogen in the Sulaiy source rocks that have generated the oil, and the value among C18–C19 confirms the lipid occurrence from the algal sources (Fig. 7).

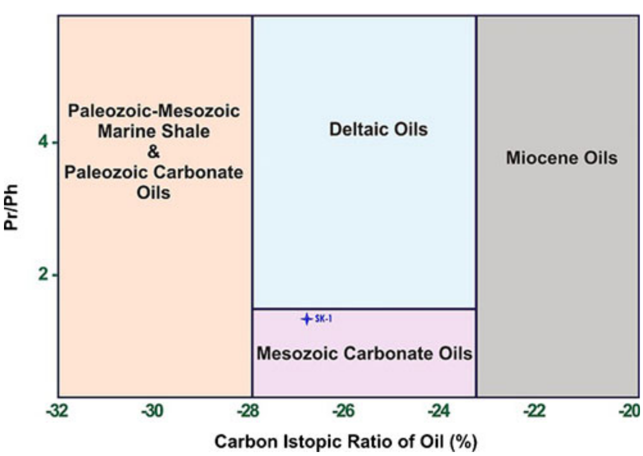



**Fig. 6** Pr–Ph with carbon isotope composition of the seep for source age assessment

The anoxic marine environment of mixed carbonate and shale could be explained by the values pristane/phytane=1.57, phytane/*n*C8=0.09, saturate/aromatic=0.89, hopane index pc C31 R/H=0.37 and low trisnohopane C27 Ts/Tm (Peters et al., 2005). Plots of pristane *n*/C17 versus phytane n/C18 on the Hunt (1996) global diagram (Fig. 6) indicate sources of kerogen mixed type II and III of marine transition between reducing and oxidizing environments. The plots show mature organic matters source of low degradation. Plots of tricyclic terpane ratio of 0.78 C22/C21 versus 0.34 C24/C23 (Fig. 8) indicate marine carbonate source by comparison with global standard environments of Zumberge et al. (2005) and Peter et al. (2005).

These all could confirm source rock affinity to the Upper Jurassic Sulaiy (equivalent to Chia Gara) Formation, which is age equivalent to the source in East Baghdad Oil Field that sourced from the Chia Gara source rocks (Al-Ameri 2011) with different oil family from the nearby Akkas Field that have sourced from Lower Palaeozoic strata (Al-Ameri 2010).

## Hydrochemistry

The physical and chemical parameters of water collected from Sakran well are listed in Tables 1 and 2, respectively. Total dissolved solid (TDS) and electrical conductivity (EC) appear to be extremely high (Table 1) with slight tendency toward acidic nature due to the dissolution processes through the geological time. Chloride participates with high concentration where forms of 40 % of the total components, whereas sodium forms only 9 % indicating a connate water type.

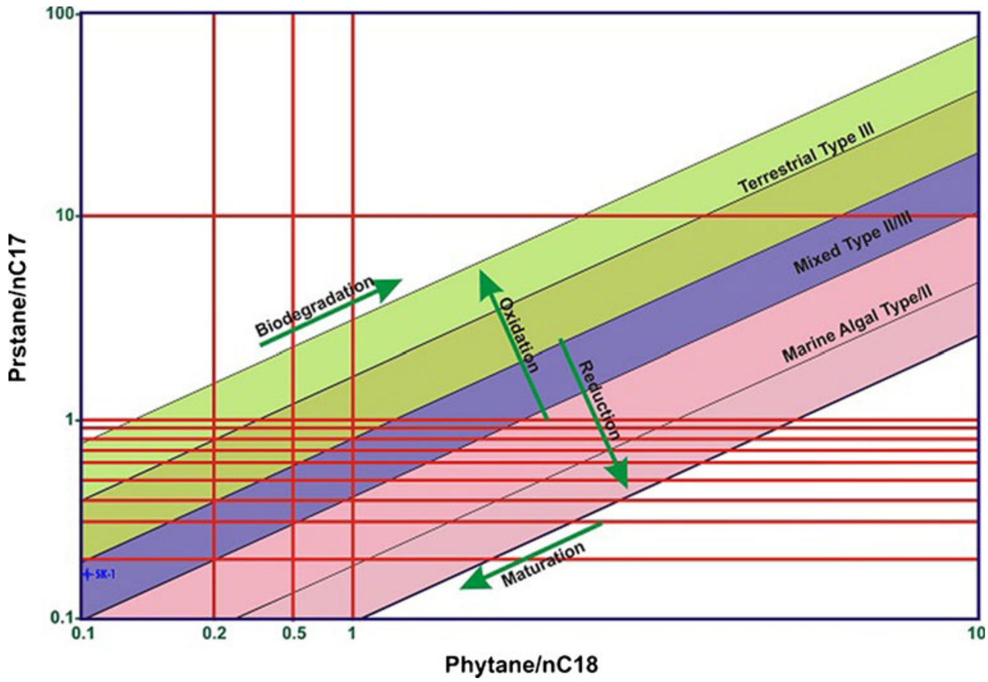



**Fig. 7** Pristane–phytane diagram of Sakran oil seep for the assessment source environment and maturation

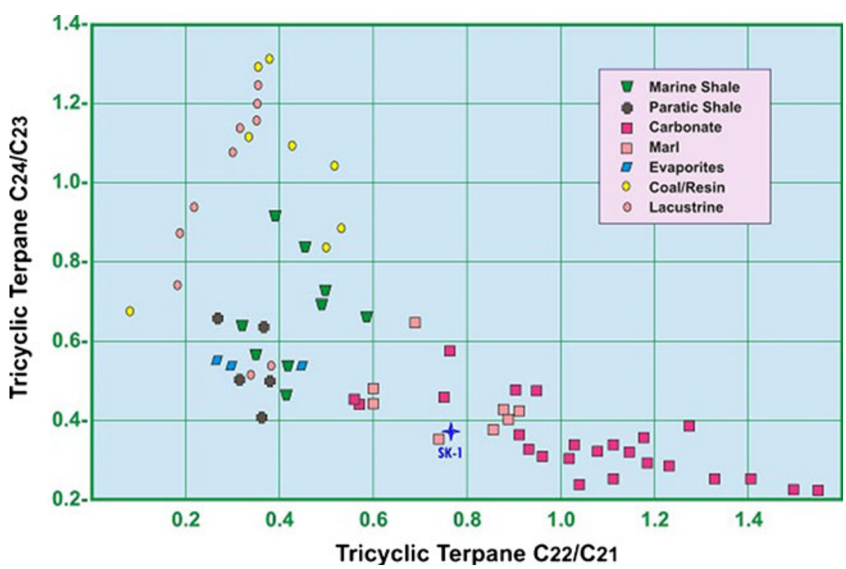



**Fig. 8** Tricyclic terpane diagram for oil seep to assess source rock lithology

**Table 1** Physical parameters of Sakran well water

| Sample no. | TDS (mg/l) | EC (μs/cm) | pH | DO (ppm) | *T* (°C) |
|---|---|---|---|---|---|
| 1 | 12,700 | 215,900 | 6.8 | 28 | 24 |

**Table 2** Chemical parameters of Sakran well water

| Sample number and unit | | Cations | | | | Anions | | | Hydrochemical functions | | | Interpretation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $Cl^-$ | $SO_4^{2-}$ | $HCO^-$ | rNa/rCl | (rNa/rCl)/$rSO_4$ | $rSO_4$/rCl | |
| 1Sk | Ppm | 1,150 | 85 | 2,900 | 690 | 5,100 | 2,510 | 190 | – | – | – | Marine origin |
| | Epm | 2.18 | 50 | 145 | 57.5 | 145.7 | 52.3 | 3.1 | 0.015 | -93.4 | 0.36 | |

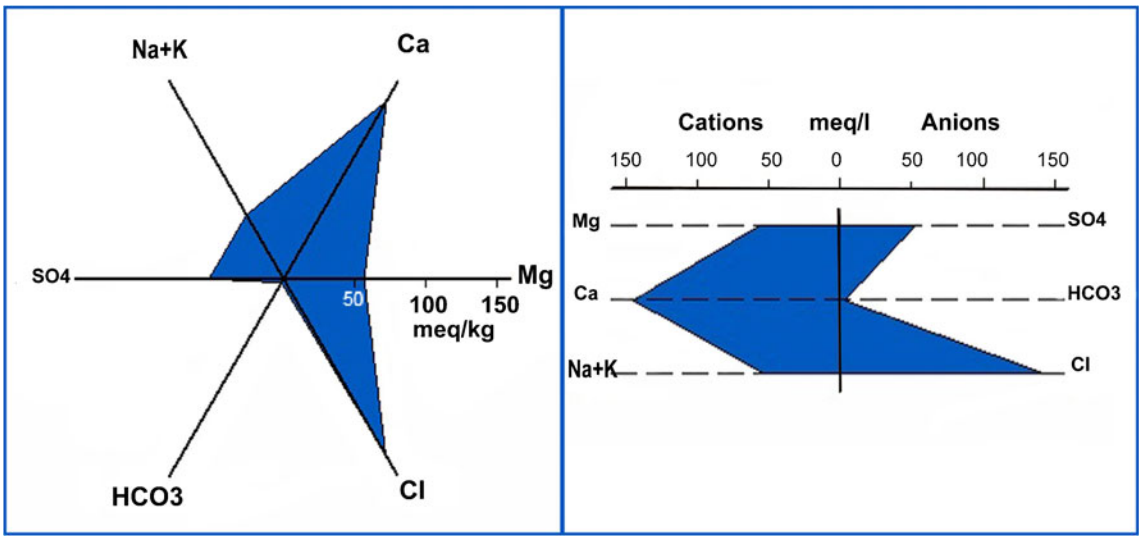
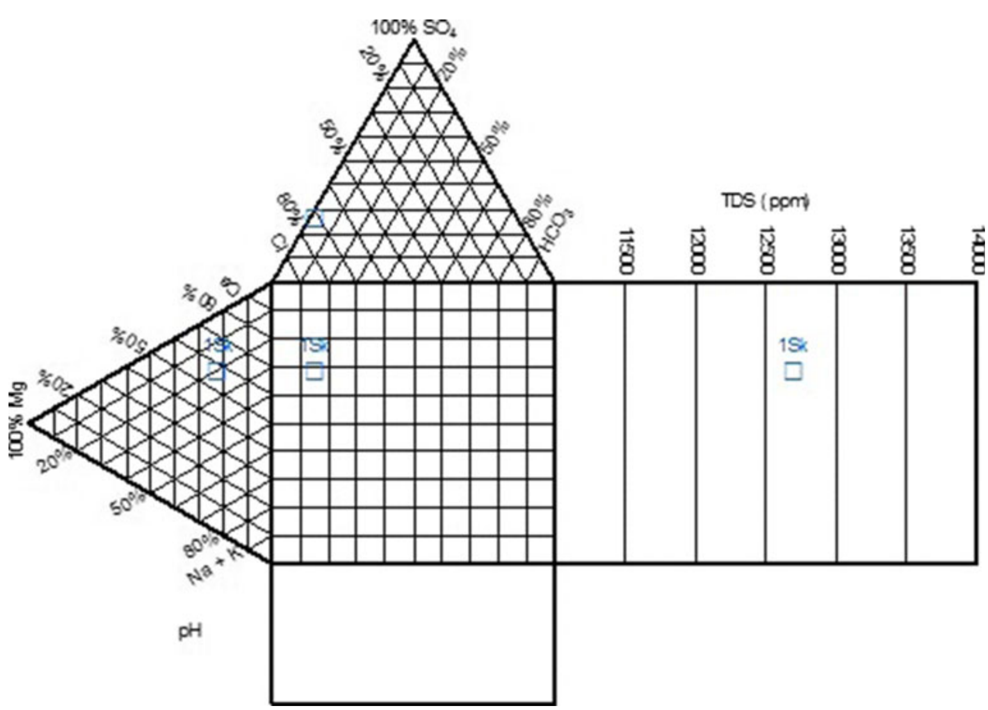



**Fig. 9** Radial diagram (*left*) and Stiff diagram (right) illustrate water type of Sakran well

**Fig. 10** Durov diagram displays how TDS distributed as ionic components



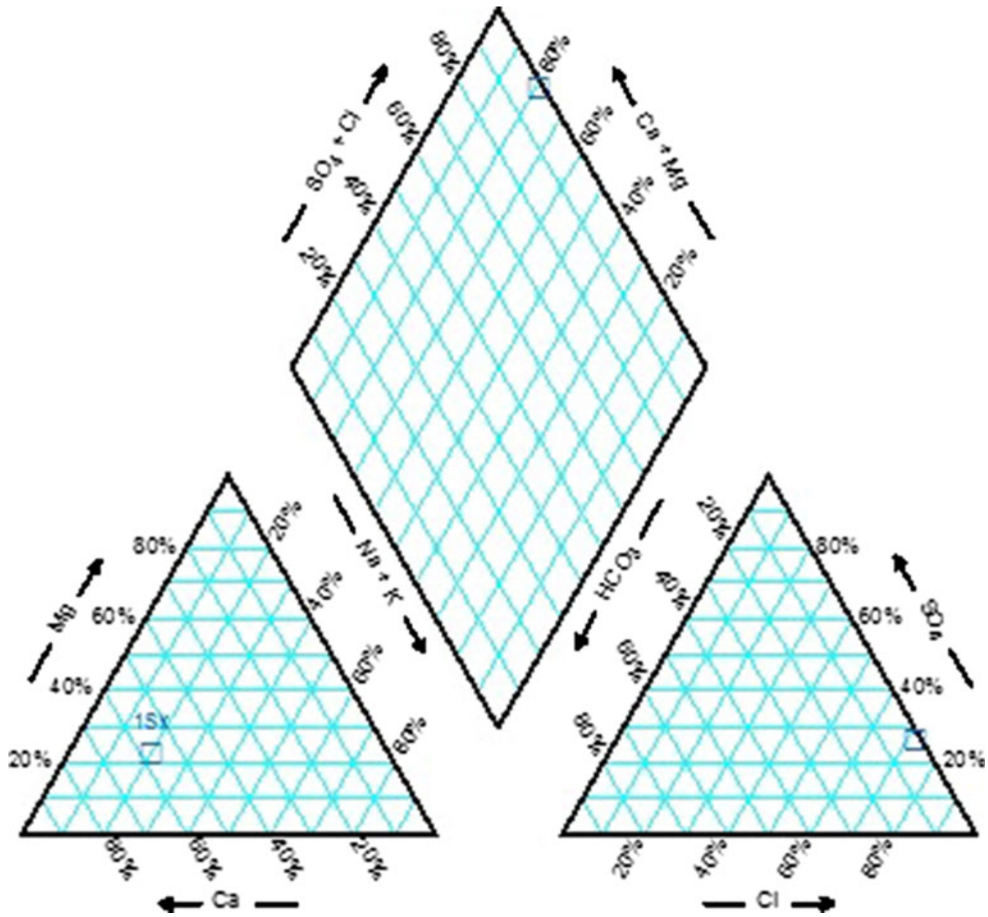



**Fig. 11** Piper diagram displays the water of Sakran well is occupied the field of earth alkali water with alkalis prevailing chloride and sulfate

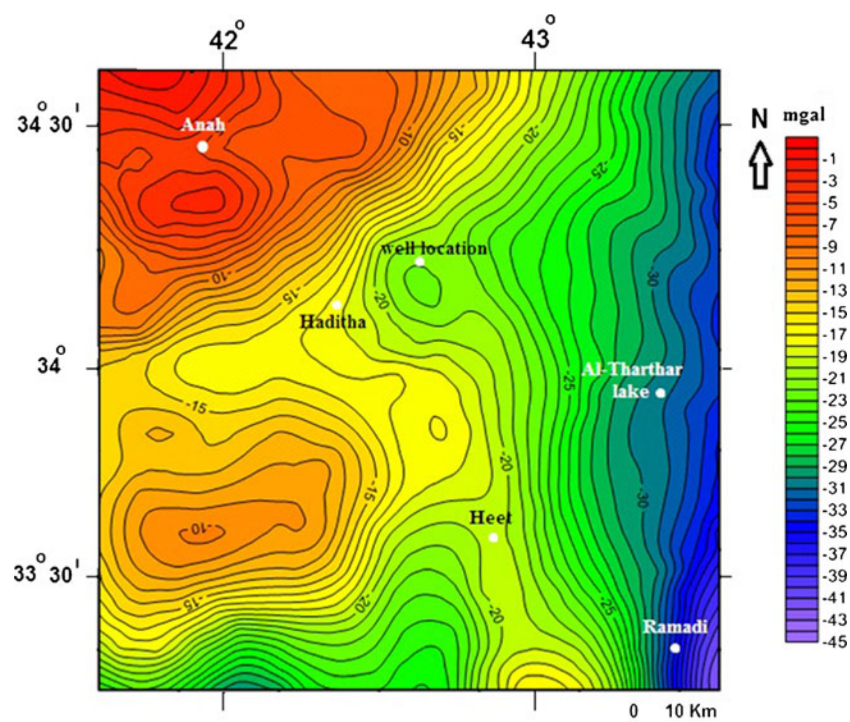



**Fig. 12** Bouguer anomaly of the area around the borehole site

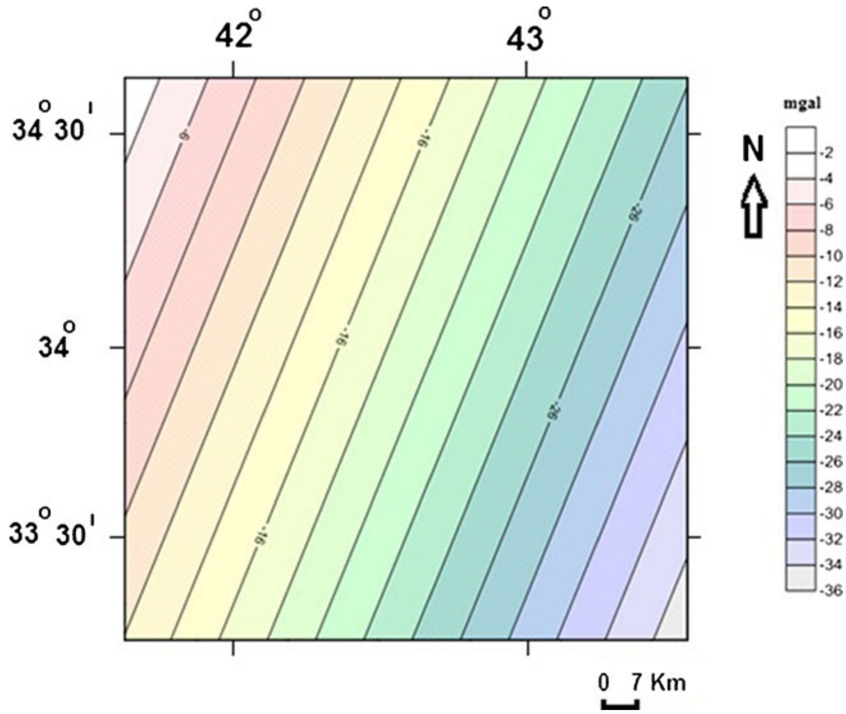



**Fig. 13** First degree polynomial fitting to the gravity data

Hydrochemical formula was computed to be formulated as:

$$TDS_{(12.7\,g/l)}\frac{Cl^{-}{}_{(145.7)}SO_4^{2-}{}_{(52.3)}}{Ca^{2+}{}_{(145)}Mg^{2+}{}_{(57.5)}Na^{+}{}_{(50)}}pH_{(6.8)}$$

Radial and Stiff diagrams show how chloride and calcium dominant (Fig. 9) Hydrochemical data of Schoeller classification revealed that the water type as anions as $Cl^-$ $>SO_4^{2-}>HCO_3^-$ and as cations as $Ca^{2+}>Mg^{2+}>(K^++Na^+)$ belongs to the family of $Ca^{2+}$–$Cl^-$ and $Cl^-$ group. Based on the abundance of chloride and calcium, they participated

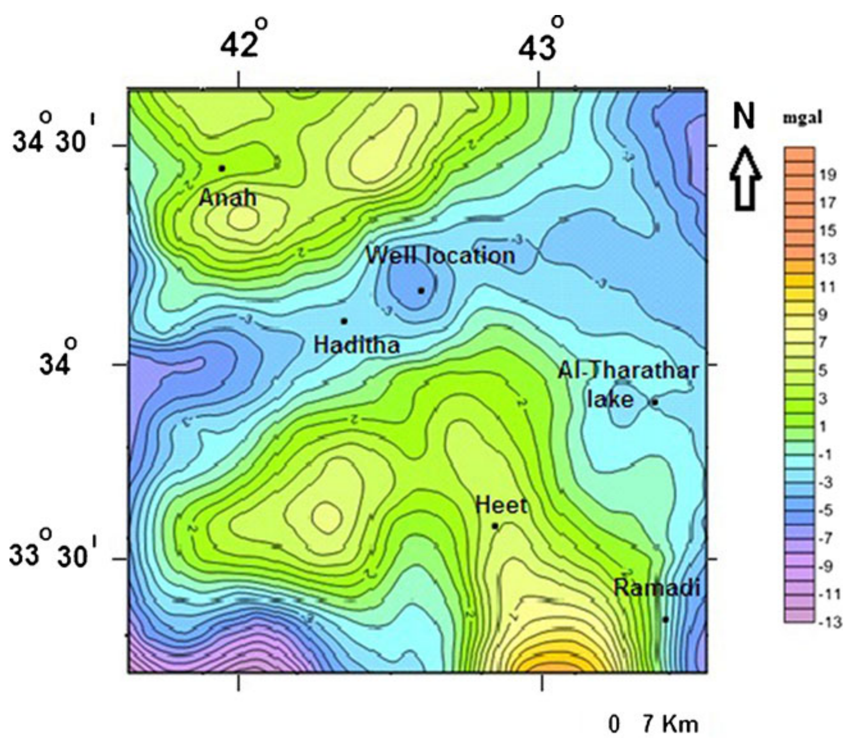



**Fig. 14** Residual map of the gravity data exhibited the main anomalies that reflect geological features of interests

more than 60 % of TDS (Fig. 10). Hydrochemical data plotted on Piper diagram revealed that the nature of water is earth alkali water with alkalis prevailing chloride and sulfate (Fig. 11).

Hydrochemical functions such as $rNa^+/rCl^-$ (0.015) is <1.0, $(rNa^+–rCl^-)/rSO_4^{2-}$(−93.4) is <0 and $rSO_4^{2-}/rCl^-$ (0.36) is close to 0 indicate marine origin water. The positive value of $rSO_4^{2-}/rCl^-$ is due to gypsum dissolution which appears in the area at the top of the stratigraphic sequence. The downward mechanism of the rain water through the gypsum bed provides sulfatic oxygenated water to the aquifer. Accordingly, dissolved oxygen and $SO_4^{2-}$ were recorded as 28 and 2,510 ppm, respectively (Table 2).

Finally, data above suggest that water is connate water of marine origin, which has partially mixed with meteoric water.

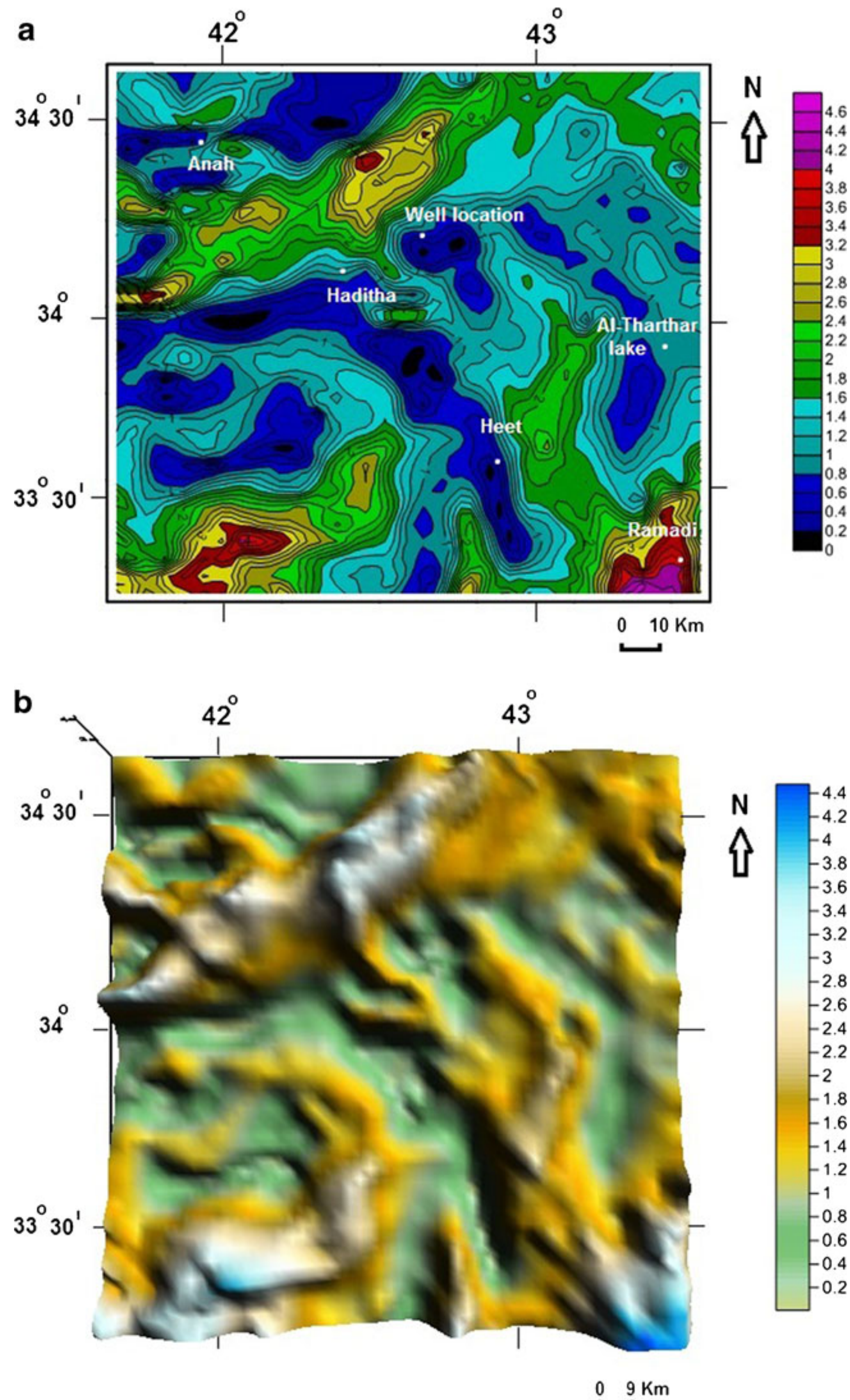



**Fig. 15** **a** Horizontal gradient map of the gravity data delineating the possible boundaries of gravity anomalous sources. **b** Three-dimensional presentation of gradient map that defining the boundaries of the main geological features in the area

## The Gravity map of the area

The gravity map of the area (Fig.12) with contour interval of 1 mgal is characterized by a sequence of an EW elongated, high and low gravity anomalies, throughout area. The site of the borehole is within the large gravity low. These anomalies occupy the western parts of the area, and they are separated from NS steep gradient contour lines to the east. The NS trend of contours represents a continuous extension of the steep gravity gradient associated with the Abu-Jir fault. These contours also show many NW–SE trend undulations reflecting possible fault system in this direction. The gravity map has been digitized with interval of 2.5 km and was analyzed to illustrate the possible geological features of these anomalies.

## Interpretation of the gravity map

A simple procedure to outline the possible sources of gravity anomalies was made by fitting a polynomial surface to the data (Fig.13). The residual anomalies (Fig. 14) are outlined by subtracting the first order polynomial fitted to the data from the original gravity map. The residual map highlights of a large continuous negative anomaly indicate either a basin or a graben system. The orientation of this large anomaly coincides with known graben system to the north. The source of this anomaly may represent an important geological feature to be significant for the hydrocarbon exploration.

The boundaries of the gravity anomalies that reflect geological features are clearly defined by gradient map of the gravity data (Fig. 15a, b). This map outlined a series of EW trend features in the western parts of the map, whereas the eastern part shows the features of NW–SE. This map reflects two tectonic setting in this area, one with EW trend similar to the Anah graben, and the second one has NW trend matches the Hamrin mountain.

## Conclusion

It is evident from this study that the subsurface strata near Haditha city may be generated the oil and gas from the Juassic Sargelu Formation as a source, then hydrocarbons are accumulated within a pay of petroleum system of Cretaceous to Tertiary ages. Oil in this area is the same type of that of the East Baghdad oil field existed in the Mesopotamian Basin to the east, but it appears to be different type in comparison with the Akkas field (Paleozoic) located in the Wedian Basin to the west. The general feature of the gravity anomalies indicated the possible basin or graben in the western and in the eastern parts of the studied area. The present findings may confirm the extension of Mesopotamian basin to the north as indicated by structural and stratigraphic studies given by Fouad and Nasir (2009). It seems that Anah graben plays a great role in dividing the region into two different hydrocarbons characters. The area to the north of the graben may has gas reservoir due to the gas leaking from the shallow borehole drilled for water purposes, but to the south of the graben, where oil seeps, might have oil reservoir. Farther hydrocarbon sites could be aided by the geophysical and structural reconnaissance.

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