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ORIGINAL PAPER

Oil and gas play and prospect assessments of Babel, Diwania and Karbala Governorates (Middle Euphrates Region), Iraq

Amer Jassim Al-Khafaji · Thamer Al-Ameri · Qusay Abeed

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Abstract This study was based on the results of geochemical analysis of 332 core and 10 cutting rock samples from Triassic Jurassic, Cretaceous, and Triassic age, in addition to seismic sections, logs, initial drilling results, final reports of oil wells, and previous studies. Constructing models from these data are to assess new oil reservoirs, evaluation, and development of the existing oil reservoirs and hydrocarbon potential, and suggesting petroleum systems in order to reduce exploration risk and develop simple risk assessment of oil fields in the studied area. In general, Abu-Jir fault zone divides the studied area into two petroleum provinces: Mesopotamian Foredeep Basin and Widyan Basin–Interior Platform. The Mesopotamian Fordeep basin are thick stratigraphic sequences with no exploration for oil or gas source rock intervals within the Paleozoic sequence. while the Mesozoic sequence offers the best potential. The transitional sequence of the Triassic period is expected to contain occasional fair to good quantity of oil source rock intervals. The Widyan Basin–Interior Platform is an area with possible deployment of low to moderate risk of Paleozoic play and Lower Mesozoic plays with fair Triassic and Mesozoic objectives. Oil has generated and expelled into traps in the studied area during two phases; the first is during Early Palaeogene that accumulated in traps of the Cretaceous structural deformation, while the second is during Late Neogene.

A. J. Al-Khafaji (✉)
Department of Chemistry, College of Science for women, Babylon University, Hillah, Iraq
e-mail: amersalman42@yahoo.com

T. Al-Ameri
College of science, University of Baghdad, Baghdad, Iraq

Q. Abeed
Institute of Geology and Geochemistry of Petroleum and Coal, RWTH-Aachen University, Aachen, Germany

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Introduction

Iraq is a large, insufficiently explored petroliferous country with generally large structures and multiple hydrocarbon-bearing intervals in most structures. It is considered to be the only country in the Middle East where structurally controlled giant oilfields can still be found. A number of new oil discoveries have been made utilizing basic requirement for exploration and development. Closely spaced improved seismic coverage is restricted to area with proven oil accumulations, and large areas remain insufficiently investigated by adequate seismic surveys. In many areas, seismic coverage was, and still is, incomplete and poorly controlled (Al-Sakini 1992; Beydoun et al. 1992; Jassim and Goff 2005)

This study is concerned with the total petroleum system (TPS) of the Jurassic–Cretaceous oil plays in the Euphrates River subzone; it is a part of the large TPS that includes many provinces, which cover most parts of especially West Iraq areas in the Western Desert like the Euphrates subzone and Rutba Uplift (Jassim and Goff 2005). The Paleozoic petroleum system is already recorded in the Widyan Basin of West Iraq within Akkas field (Al-Ameri 2010). This exploration could extend through the Western Desert to the Abu-Jir fault zone; towards Afaq and Musiayab, oil fields are thought to be Jurassic petroleum system, but Paleozoic might be expected, too. However, no deep drilling exists there to assess the Paleozoic oil occurrence (Aqrawi 1998; Buday and Jassim 1987; Verma et al. 2004).

The selected study area is located in Middle Iraq on the Eastern part of the Widian Basin and Western part of the Mesopotamian Foredeep Basin (Fig. 1), between 43°00″–45°40″ longitude and 31°50″–33°20″ latitude.

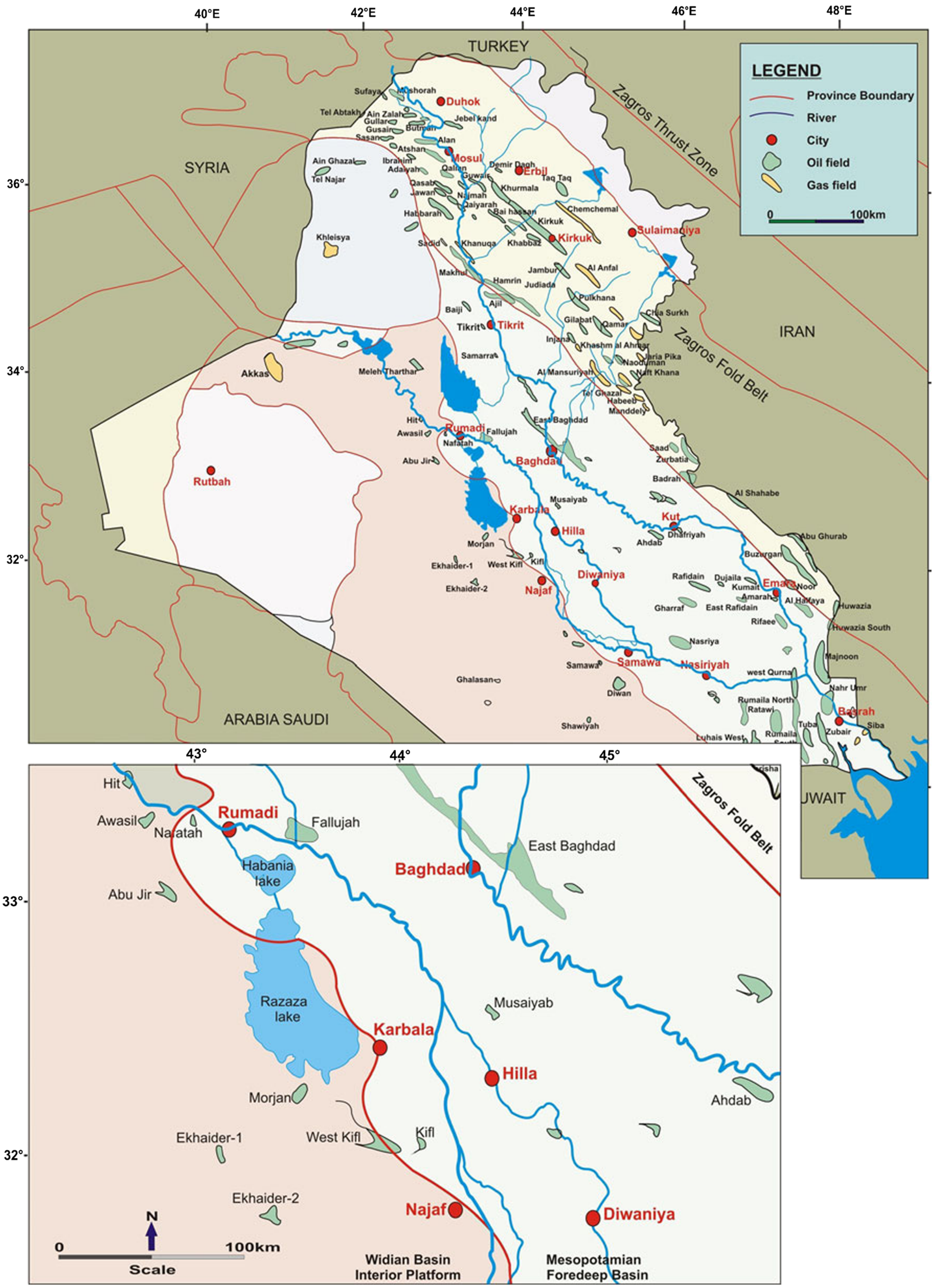

Fig. 1 Location map of the studied wells along with oil fields

The provinces' boundary according (Klett et al. 2000 and Jassim and Goff 2005) between the Mesopotamian Basin (number 2024) and Widyan–Interior Platform Basin (number 2023) is the Abu-Jir fault. Afaq, Musaiyab, Kifl, and West Kifl oil fields are located within province 2023, while Morjan, Ekheither-1, and Ekheither-2 oil fields are located within province 2024. Studied area begins from the deeper part of Stable Shelf of the Mesopotamian Basin (Afaq oil field), passing to near platform Flank of Mesopotamian Foredeep, evolving the north east slope of the African-Arbian platform (Kifl and Merjan oil fields), ending in the west part of the Stable Shelf (Ekheither-1, Ekheither-2, and West kifl oil fields). The boundary between these two units is located at the western boundary of the Mesopotamian depression. It continues along the Euphrates River near Nasriyah, then follows the Euphrates Boundary Fault to Razaza Lake, and Abu-Jir Fault line to Hit (Fig. 1).

The Mesopotamian Basin is a depression, formed by tectonic processes of the Neo-Tethys Ocean Opening (Jassim and Goff 2005; Ditmar et al. 1972; Ibrahim 1983; Beydoun 1988), which is lined by basement rock, of igneous, metamorphic, and/or sedimentary rock. The basin fill includes the sediments, organic matter, and water. The studied areas at the Western part of the Mesopotamian Basin become shallower towards the Western desert and deeper towards the East. Traps are mainly formed by folding and faulting as result of plate collision and nappe abduction that began in the Late Cretaceous. Figure 2 shows that the thickness of stratigraphic sequences is less westward, where the edge of the Mesopotamian basin with concentration of oil well sites. The Mesopotamian zone contains buried faulted structures below the Quaternary cover, separated by broad synclines. They mainly trend NW–SE in the southern part; some NE–SW trending structures also occur. The Tigris subzone is the most extensive and mobile unit of the Mesopotamian Zone. It contains broad syncline and narrow anticlines trending predominantly NW–SE, accompanied by long normal faults (Buday and Jassim 1984).

Materials and methods

Ten cuttings rock samples from Jurassic and Cretaceous source and reservoir formations in Kifl-3 and Kifl-2 wells have been analyzed using gas chromatography flame ionization detector and gas chromatography mass spectroscopy to obtain biomarkers ratio and stable carbon isotope analysis. These analyses were carried out at GeoMark Research Ltd in Houston, TX, USA, and in the Biomarkers laboratory of the School of Geology and Environmental Science in Stanford University in California, USA.

Additionally, 332 core and cuttings rock samples from Jurassic and Cretaceous source and reservoir formations from oil exploration wells of Kifl-3, Kifl-4, West Kifl-1, Morjan-1, and Ekhaither-1 are subjected to Rock-Eval pyrolysis and total organic carbon evaluation in laboratories of Iraq Oil Exploration Company, as well as thin section preparation for petrographic description. These samples are obtained from stores of South Iraqi Oil Company in the city of Basrah.

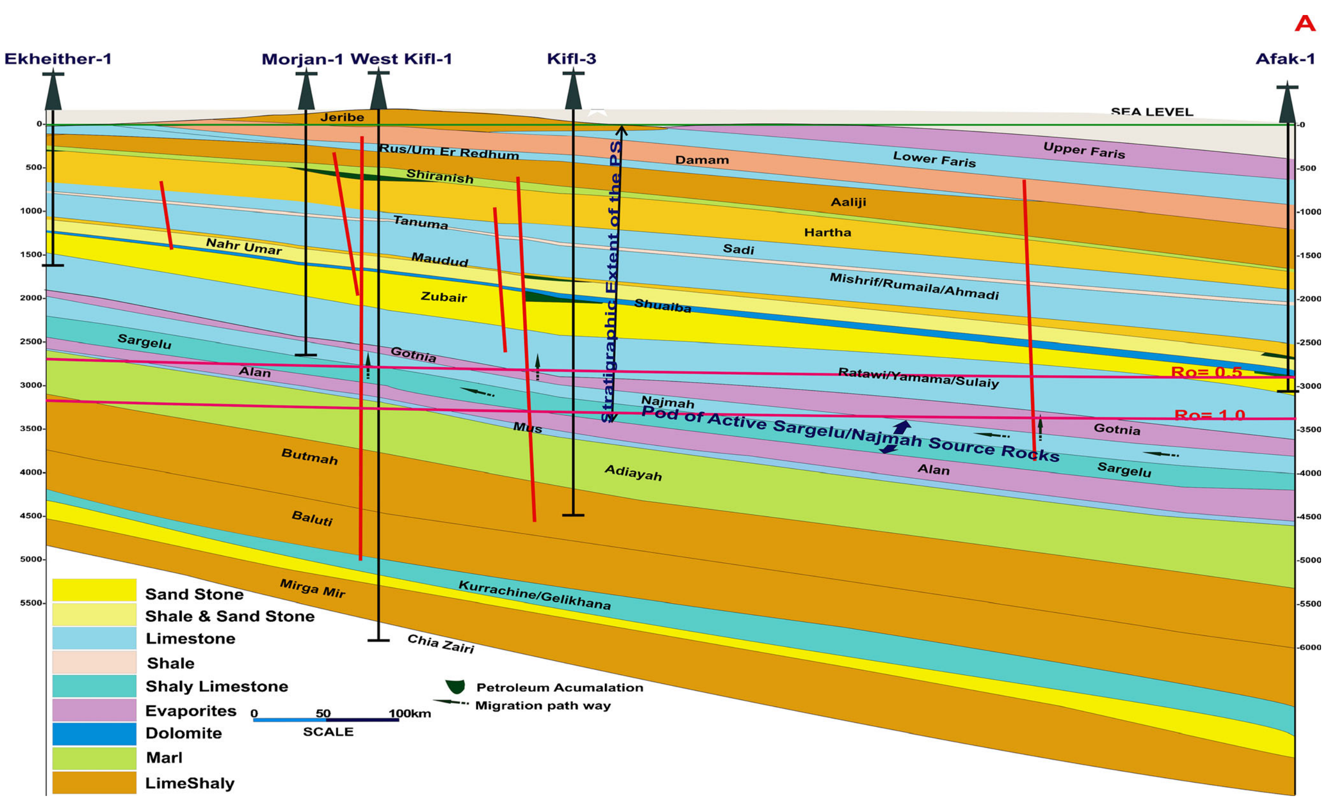

Fig. 2 Cross-section show the locations of the studied oil wells

Petroleum occurrences

Many hydrocarbon-producing areas in Iraq occur in the Zagros fold Belt, Mesopotamian Foredeep Basin and Widian–Interior Platform Basin, in addition to many prospected areas such as Khleisya Uplift, Rutba Uplift, Wadi-Surhan Basin, and Anah Graben provinces (Klett et al. 1997; Buday and Jassim 1984; Jassim and Goff 2005; Verma et al. 2004; Murris 1980; Al-Sakini 1992; Alsharhan and Nairn 1997; Aqrawi et al. 2010).

Kifl oil field is located near the platform flank of the Mesopotamian Foredeep, north eastern slope of African-Arabian platform. It shows closely spaced contours formed by faults due to the exposure region during the stage of tension movements and structural expansion, which affected the Arabian plate during the Permian–Triassic/ Early Cretaceous Periods, and caused N–S and NW–SE joints and faults and E–W, NE–SW strike slip faults. West Kifl, Kifl, and Morjan oil fields are located on the western part of unstable platform and near stable platform. This gives a special status of long distance from the affecting movements center that gives small structures and noses as in Morjan oil field.

The stable shelf is tectonically a stable monocline little affected by Late Cretaceous and Tertiary deformation, when the orientations of structures were influenced by geometry of underlying basement blocks and faults.

The Salman Zone is a monocline dipping towards the Euphrates River, where the Middle–Upper Eocene beds outcrop in the East. They are usually aligned with the NE–SW trending faults. Most structures in the Salman Zone strike NW–SE; they are relatively narrow, long anticlines, often accompanied by faults such as Ekheither-1 and Ekheither-2 anticlines, which are located at the east of Salman Zone near Najaf city (Fig. 3).

Kifl oil field The Kifl oil field was drilled in 1960 and is located along the westernmost flank of the Basrah

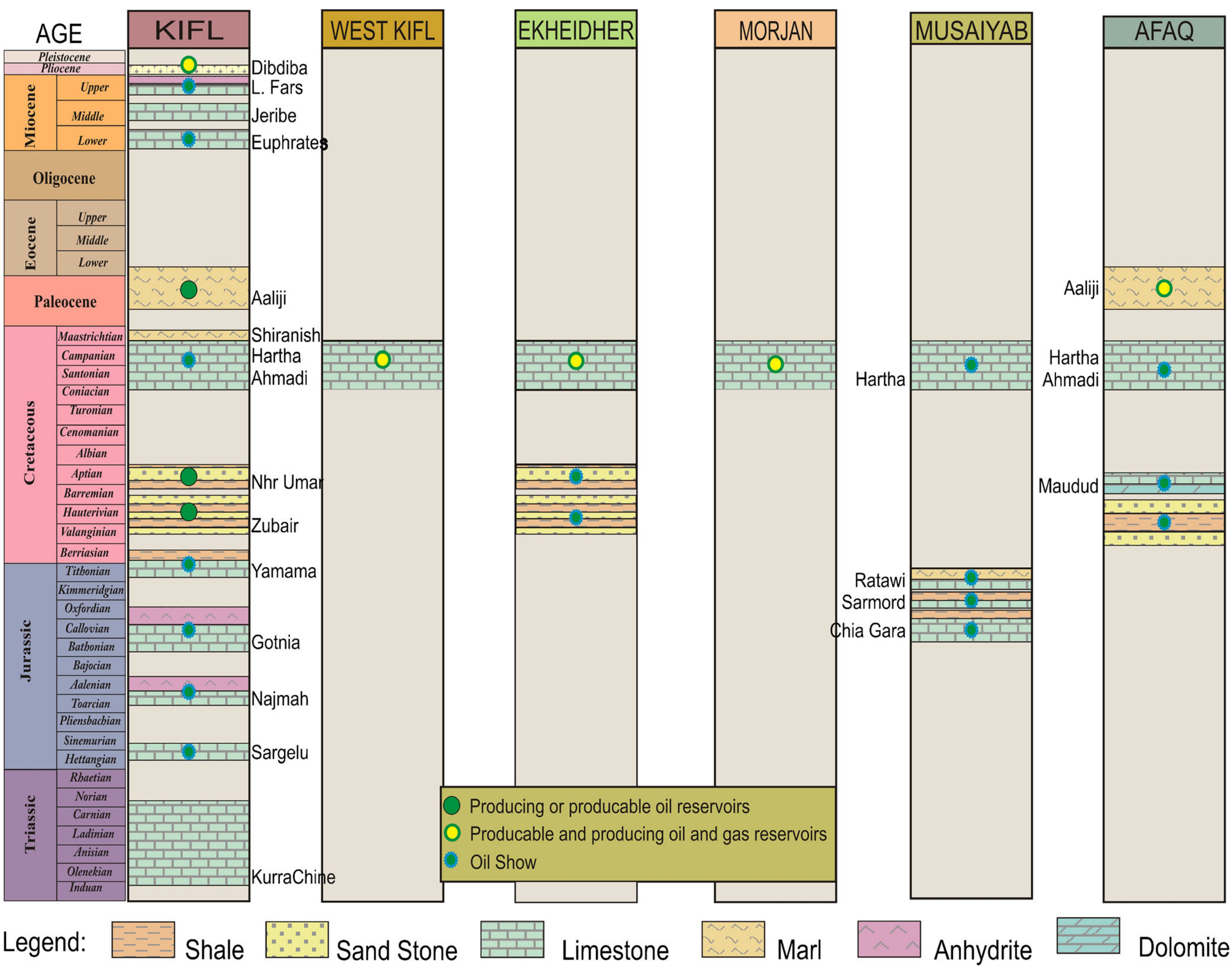

Fig. 3 Stratigraphic occurrences of oil and gas fields and discoveries of the studied area

Depression, Euphrates Subzone, about 125 km southwest Baghdad, 20 km west Kifl and 40 km south Karbala (Figs. 1 and 3).

Drilling reached Sargelu Formation in well Kifl-1 (Fig. 2) and showed the presence of oil in Zubair and Nahr Umr Formations. Upon inspection, it appears that the upper part of Zubair Formation had produced oil. The productivity was calculated to be 5,600 barrel per day. Kifl-2 was drilled 13.5 km north of Kifl-1, but there was no sign of oil presence because its drill location is shown to be located outside the structural closure of the field.

On 1972, and depending on the results of seismic surveys over Kifl area, Kifl-3 well was drilled. The aim was to explore the Triassic reservoirs, in addition to assessing oil accumulation that have emerged in the Kifl-1 well. Drilling reached a depth of 4,330 m, in the Kurrachine Formation. Depending on the results of mobile studies in 1982, this interpreted the presence of oil in a Zubair reservoir, as a stratigraphic trap. Kif-4 was drilled, 5.5 km west of Kifl-1.

Kifl-1 was drilled as a stratigraphic test on the crest of small seismic closure. Sporadic oil shows and bitumen were noted while drilling through the Dibdibba clastics, Miocene Fatha carbonates, Paleocene Aaliji limestone, Hartha, Yamama, Upper Gotnia, Najmah, and Sargelu limestone Formations. Well-2 was drilled close to Kifl-1 but was abandoned without achieving its objectives due to mechanical problems.

The main production from the Kifl structure was a flow of 21.7° API gravity slightly sulfurous oil from the top the Lower Cretaceous Zubair sandstone below depth 1,800 m (SOC final reports). Figure 2 shows the location of Kifl-3, at the edge of the Mesopotamian Basin, towards the Western Desert.

West Kifl oil field West Kifl-1 oil well was drilled in 1985 and located on a structural dome, 10 km long, which is a part of structure trending NW–SE, 40 km south west Karballa, and south of Razaza lake.

Main reservoir is Hartha limestone, while NahrUmr, Zubair, and Yamama formations are secondary reservoirs. Najmah Formation contains Tar and bitumen (Fig. 4).

Morjan oil field Morjan-1 oil well was drilled in 1983 and located between the unstable shelf and the stable shelf on regional nois, 10 km long, trending NW–SE, with two faults trending NW–SE, 45 km south Karballa and 55 km west Kifl-1. Hartha limestone was the main reservoir, too, with 26° API oil.

Musaiyab oil field Musaiyab oil well was drilled in 1958, on anticlinal nose, 35 km long trending NW–SE, plunging and closing to the SE. Major hydrocarbons were absent, some sulfurous gas was present with water in Oligocene equivalent strata and minor dead oil indications as heavy streaks in the topmost Hartha Formation with sulfurous water below. Heavy oil staining is seen in Ratawi Formation, within the Sarmord/Chia Gara interval, and there was evidence of gas and oil in several thin sands and limestones.

Oil staining was present in Maudud, Nahr Umar, and Zubair Formations. Oil exploration well of Musaiyab-1 has given stratigraphic importance of a valuable link between the middle and the south of Iraq (Fig. 5).

Afaq oil field Afaq-1 well was drilled in 1960, located on a southeast plunging nose, and located regionally in eastward, deeper part of the unstable shelf of the Middle East Basin. No evidence of major faulting in this well is seen. It was drilled primarily as stratigraphic test and to test a small positive closure indicated by both gravity and seismic reconnaissance. Much valuable stratigraphic information was obtained from the well. None of the formations penetrated showed oil in commercial quantities.

A test was made on only one interval in the well, and this was negative. The excellent reservoir sands of Nahr Umr and Zubair formations were barren of oil and gas. Figure 5 shows Afaq lithological section, evidence of gas and oil in several thin sands and limestones are seen in the Ratawi Formation and within the Sarmord/Chia Gara interval.

Oil staining was present in Maudud, Nahr Umar, and Zubair. Musaiyab-1 has given stratigraphic importance of a valuable link between the middle and the south of Iraq (Fig. 5).

Ekheither-1 and Ekheither-2 oil fields Ekheither-1 and Ekheither-2 were located on the stable shelf. Ekheither-1 and 2 wells were drilled in 1984 to explore the hydrocarbon accumulation in Hartha, Nahr Umr, and Zubair Formations. No commercial hydrocarbon accumulation are encountered.

Oil and gas show in Hartha Formation, and oil and bitumen in Nahr Umr and Zubair Formations are observed (Figs. 2 and 3).

Plays and prospects

The play and prospect are used by the explorations to present geologic argument to justify drilling for undiscovered, commercial petroleum accumulations (Magoon and Dow 1994). The sedimentary sequence of the Mesopotamian Basin and basement rocks deepen in general to the east. There are many transverse and normal faults in the area study, and the Mesozoic rifting phase caused subsidence in many places.

More than 5,000 m Mesozoic sediments and 1,500 m of Tertiary sediments were deposited in the area of study.

The Mesozoic and Tertiary sediments in particular dip and thicken to the east.

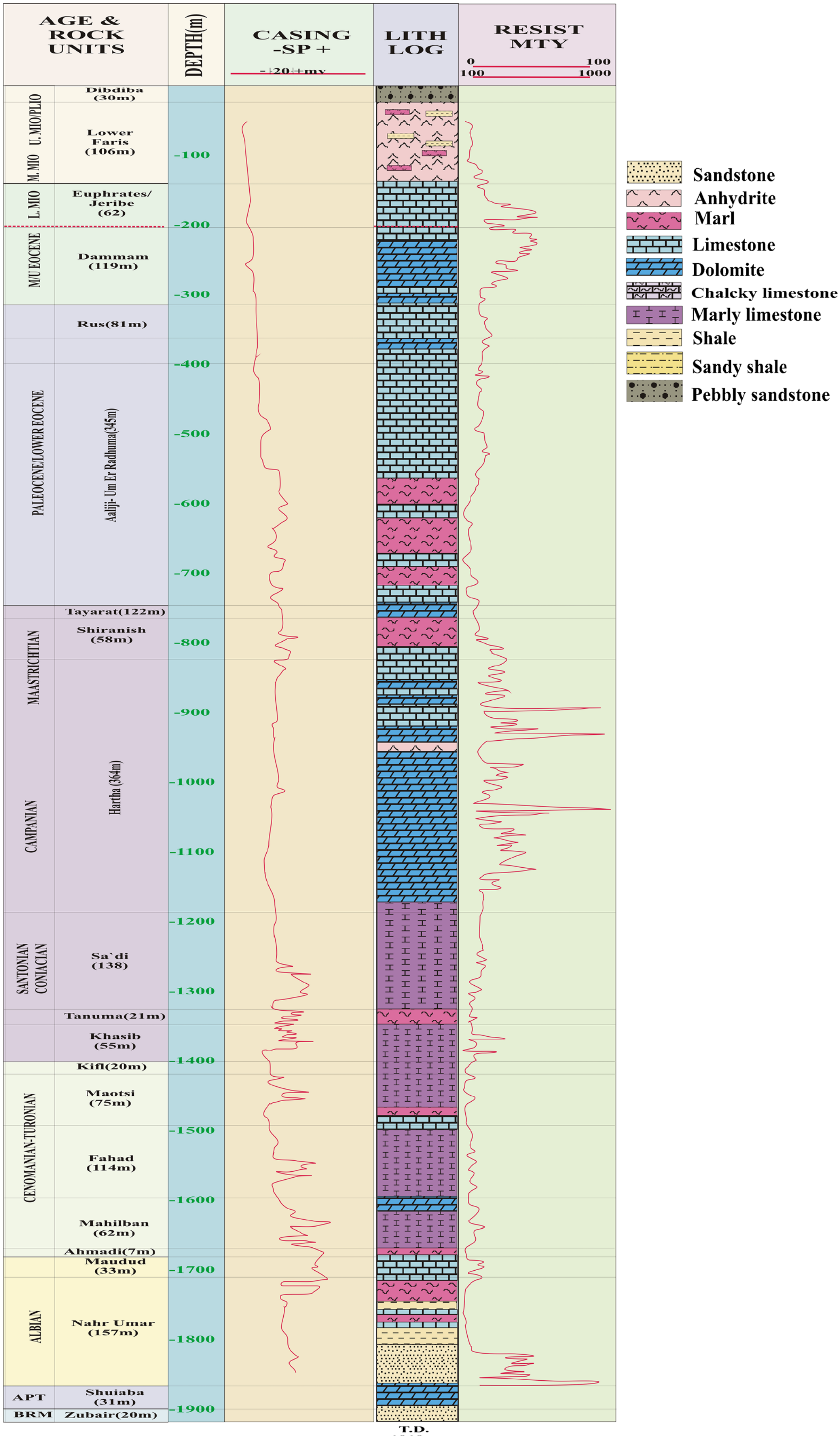

Fig. 4 Kifl-1 lithological section

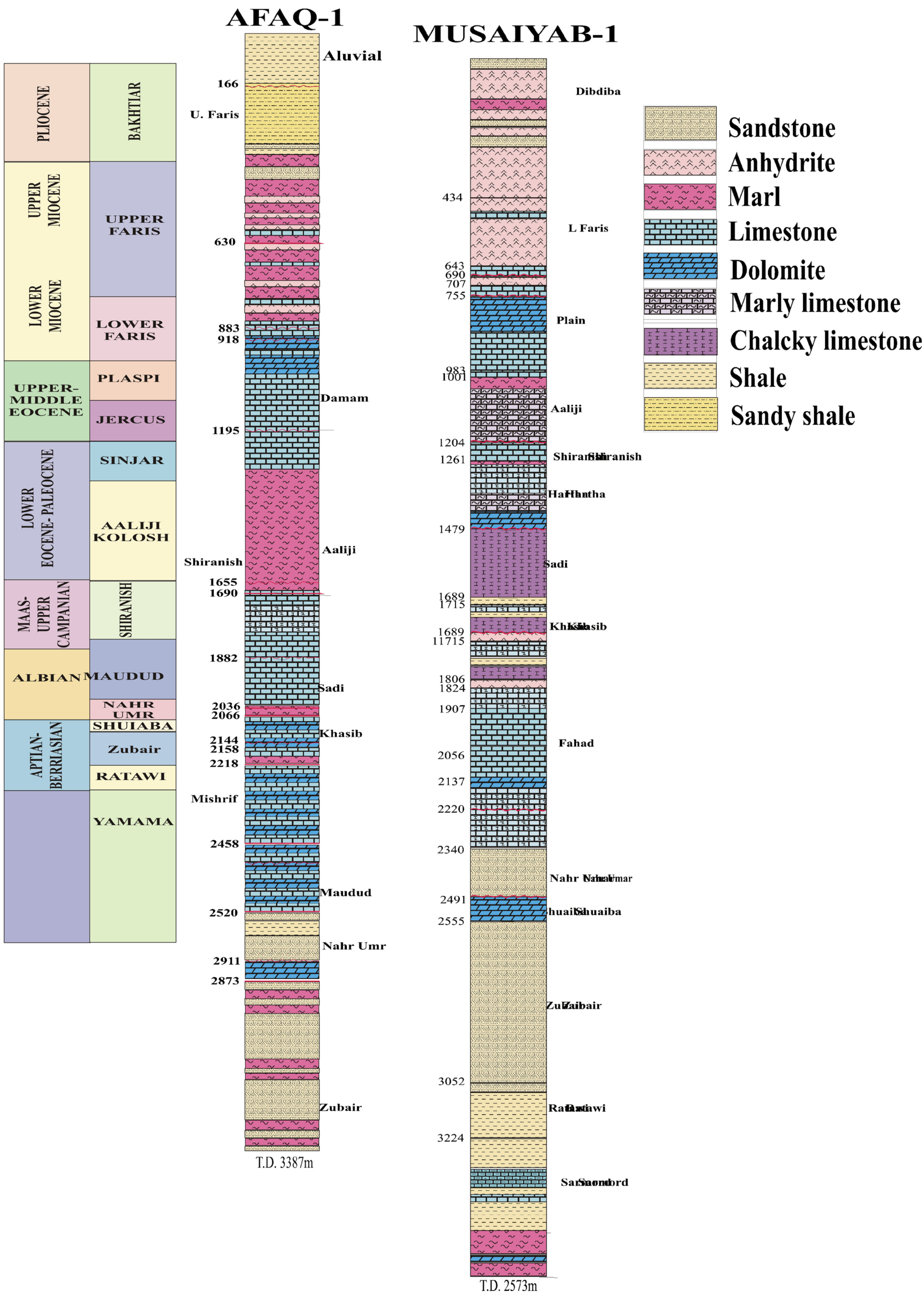

Fig. 5 Afaq and Musaiyab lithological sections

Palaeozoic and Triassic The Paleozoic succession of the area of study is very deep, and no significant Cambrian or Ordovician reservoirs are recorded (Beydoun 1988). The Silurian and Devonian sequences are expected to be widely absent in many parts of Iraq due to erosion after deposition, while they represent mainly gas fields in the western part of Iraq (Al-Ameri 2010).

The Carboniferous sequence is expected to be about 600 m thick, possibly represented by interbedded shale and sandstone. The sequence is considered deep, and its sandstones are expected to exhibit poor reservoir properties.

However, the preserved Carboniferous sequence is modeled to contain intervals capable of generating fair gas quantities everywhere in the area of study (Sadooni and Aqrawi 2000; Pitman et al. 2004; Al-Husseini, 1991; Buday 1980).

Fair to good quality oil source rocks are expected within the Ordovician sequence of the Basin. These are modeled to be postmature and within the dry gas phase of maturation. Prior to that phase, gas/condensate generation was achieved during Palaeogene and Cretaceous times and oil generation during Carboniferous to Jurassic times (Al-Mashadani, 1986; Fox and Ahlbrandt 2002; Al-Gailani 1996)

The Silurian sequence is possibly restricted to the western flank of the Mesopotamian Basin. Fairly rich source rock intervals may be present. Hydrocarbon generation modeling could represent dry gas phase of the generation. The source rocks must have generated oil during Carboniferous to Early Cretaceous times and gas/condensate during Late Cretaceous and Palaeogene times (Aqrawi 1998).

The Devonian sequence, which could be preserved in the western part of the area, may lack potential source rock intervals. No significant oil or gas source rock intervals are expected within the Permian sequence. The Permian sequence of the area is fairly deep and expected to contain poor quality, compact but thick carbonate, and multiple compact sandstone reservoirs (Fig. 6). The preserved Triassic sequence is expected to contain fractured and vuggy, dolomitized carbonate reservoirs, sealed by interbedded shale and anhydrite.

The Lower Triassic section in the study area is expected to be represented by clastic sediments and the Middle to Upper Triassic section by carbonate and evaporate (Fig. 7).

The Triassic sequence is expected to contain occasional fair quality of oil source rock intervals in the eastern half of the Mesopotamian Basin. Source rocks are modeled to be at present middle mature in the west, and late mature in east of the area (Fig. 7).

Oil generation since Late Jurassic times may have taken place in the eastern half of the area. The sequence is fairly deep in the central and eastern parts of the area of study and considered economically accessible in the west. The reservoirs of the western sector (Fig. 8) are fed with oil from the mature Triassic source rocks and overlying Jurassic source rock intervals (Alsharhan and Nairn 1997; Aqrawi 1998; Al-Ameri et al. 2009; Al-Mashadani 1986; Ditmar and Iraqi-Soviet team 1972; Verma et al. 2004).

The presence of deep faults can also facilitate feeding of the Triassic reservoirs with commercial gas from the

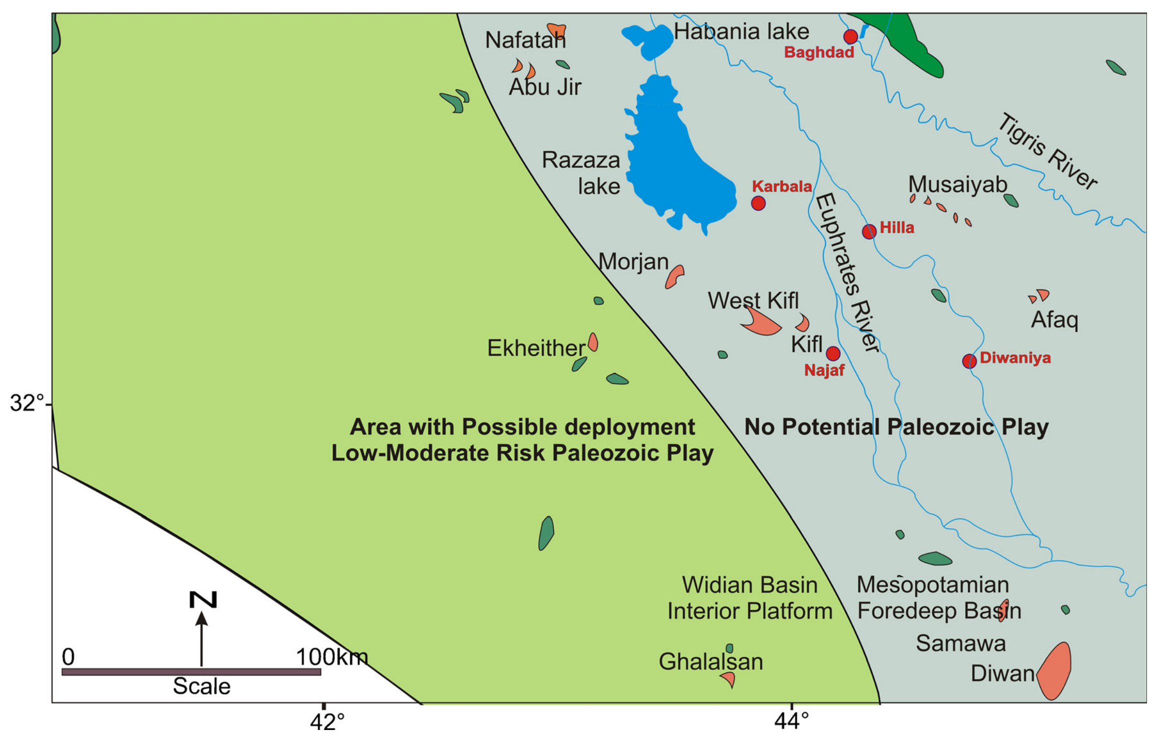

Fig. 6 Low to moderate risk areas for exploring the Paleozoic plays of the studied area

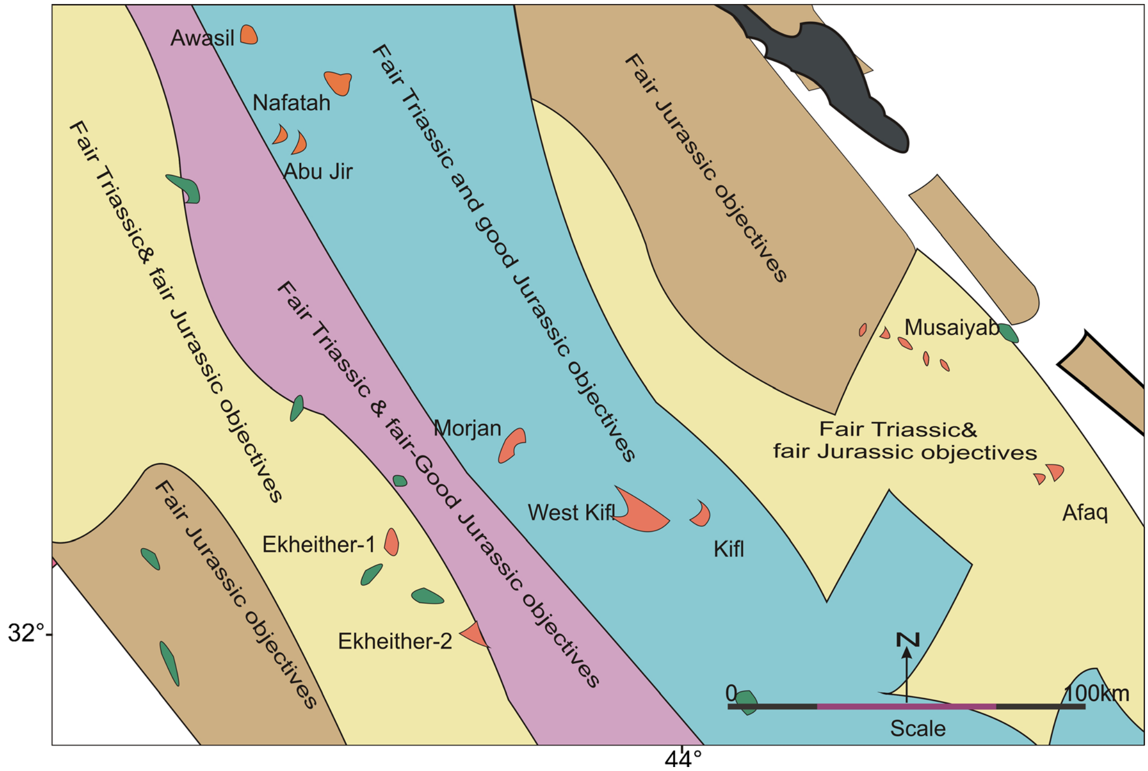

Fig. 7 Lower Mesozoic objectives

Carboniferous source rocks. The Triassic carbonate and clastic reservoirs of the western part of the study area are worth consideration as secondary objectives. The reservoirs could be oil and gas bearing (Fig. 6), showing that the studied area have low to moderate risk areas for exploring the Paleozoic plays of the studied area.

Fig. 8 Upper Mesozoic objective

Jurassic and Cretaceous

The upper part of the Jurassic section in the studied area generally consists of shale and limestone especially in the west and evaporitic facies in the east. These sediments are underlain by sandy limestone of the Upper Jurassic, too. Below the Upper Jurassic succession is a stratigraphic break that is recognizable throughout most of Iraq, which is underlain by argillaceous limestone and shale of Middle to Early Jurassic age. The widely developed Jurassic sequence is about 1,245 m in west of the area of study (West Kifl-1 section) and more than 2,000 m thick in the East.

The Jurassic section is economically accessible in the central and western parts of the area and is considered fairly deep in the eastern part. The Upper Jurassic section has been encountered at depth of 3,569 m in the Musaiyab-1 well, drilled in the area of study; the section gradually deepens to the east and shows shallower depth towards the west.

The Upper Jurassic succession ranges in thickness between 100 and 350 m, while the Lower and Middle Jurassic succession is of about 1,100 m in West Kifl-1 and about 1,800 m in the east. The section preserved everywhere in the area of study with basinal facies that characterize the sequence in the eastern part of the studied area and shallow shelf facies in the west. The Jurassic carbonate reservoir is very attractive in the western part of the studied area, fairly attractive in the central part, and considered with deteriorating reservoir properties towards the east (Al-Gailani 1996; Sadooni 1997).

The upper part of Jurassic sequence was penetrated in well Musaiyab-1. Frequent oil shows, and impregnations are noted while drilling the Chia Gara Formation. The presence of oil in the attractive carbonate of the Najmah Formation at well Kifl-1 is a testimony to the attractive potential of the Jurassic play (Sadooni 1997; Fig. 9).

Very rich and excellent oil-prone source rocks intervals are present within the Lower to Middle Jurassic sequence of the area of study. The source rocks of the Sargelu Formation are thicker and organically richer in the central and eastern parts of the area than in the east. The Sargelu Formation source rocks can feed such reservoirs with oil while the Upper Jurassic Gotnia Formation salt and anhydrites (400–500 m thick in the east part) had provided excellent regional seals to the reservoirs. Najmah/Sargelu carbonate gave light oil and gas shows in well Kifl-3. The source rocks are present within the oil window that could have made major oil generation in most places (Al-Ahmed 2008).

Maximum expulsion from the source rocks was achieved in Late Cretaceous and Paleogene times. Commercial in situ oil generation from the Sargelu Formation and accumulation within the attractive Jurassic carbonate reservoirs are likely everywhere in the area of study. Such hydrocarbon accumulations are worth of investigation initially in the western

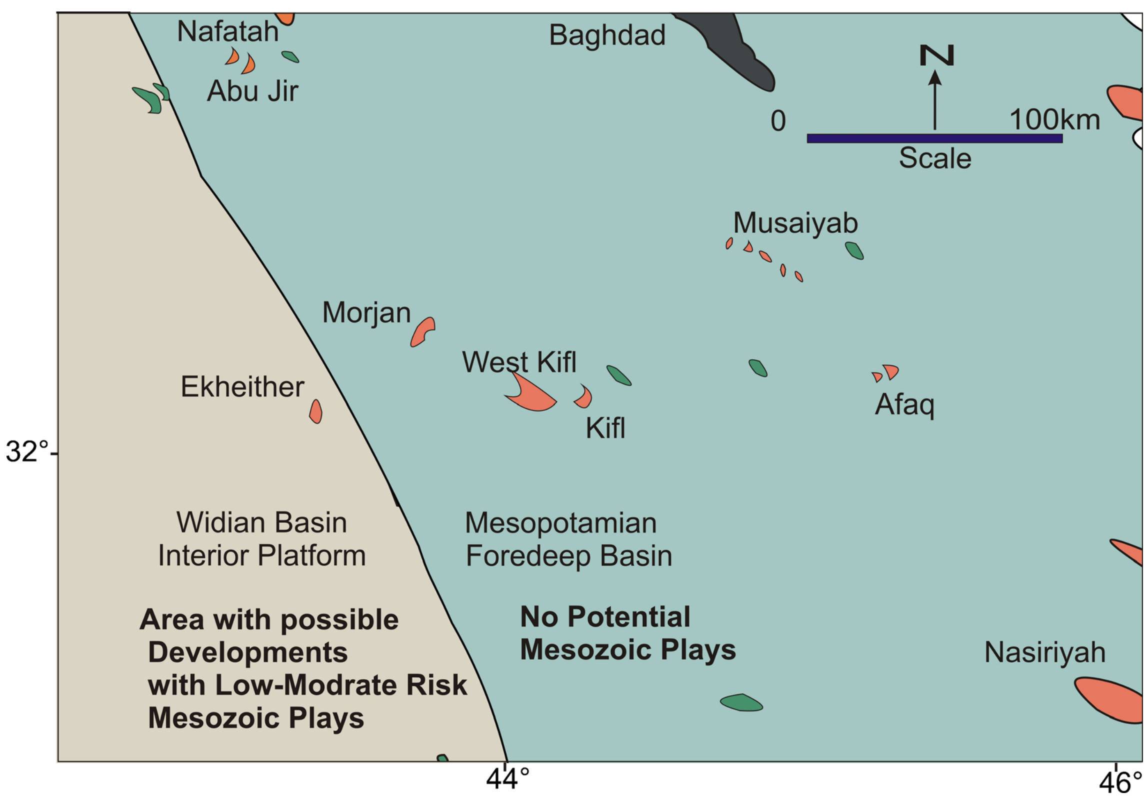

Fig. 9 Possible and proven Mesozoic plays

parts of the studied area, then the central part, and finally within the deeper eastern part of the area of study.

The Upper Jurassic sequence contains some fair quality oil-prone source rock intervals in the eastern part of the area of study. Source rock richness deteriorates towards the western part.

The Upper Jurassic source rocks are at present middle mature in the easternmost part of the area study and early mature in the central and western parts. Good oil generation must have taken place in the eastern sector of the studied area and fair oil generation in the central part throughout the Tertiary times.

The Jurassic play of the study area is worth serious consideration by drilling its objectives wherever they are economically accessible. The play is likely to provide attractive carbonate objectives in the central and western parts of the study area. The oolitic, calcareous, and bioclastic limestone are at economically accessible depths and warrant investigation. The reservoirs are well protected from flushing of meteoritic water (Al-Ameri et al. 2009; Beydoun et al. 1992; Less 1950).

The preserved Cretaceous sequences are represented by Maastrichtian to Upper Campanian sediments (sandy limestone and marl overlying cleaner carbonates). They lie with minor unconformity on chalky limestone, shallow, and basinal limestone of Early Campanian to latest Turonian age. A regional stratigraphy break separates chalky and marly limestone of Aptian dolomite. The Barremian to Neocomian intervals is represented by sandstone or shale overlying limestone and shale (van Bellen et al. 1959). The Neocomian to Barremian sequence is represented by the Ratawi, Zubair, and Sarmord Formations. The preserved sequence ranges in thickness between 700 m in the west to about 1,200 m in the east. The deposited facies reflect basinal conditions in the east and shallow shelf environment in the west.

The Ratawi Formation consists mainly of shale and argillaceous limestone, with some sandy intervals near porous and permeable with good reservoir characteristics. They are well sealed by interbedded shale as seen between 317 and 3,224 m in the Musaiyab-1 well. Good oil shows, and impregnation noted in the thin sandstone reservoirs are likely to be found in the western part of the study area.

The Zubair Formation offers the best sandstone objectives within the entire area of study. Multiple highly porous (20–30 %) and permeable (500–1,000 mD) sandstone reservoirs, sealed by interbedded shale, are widely developed within the study area.

These excellent sandstone reservoirs produced oil in the Kifl field at depth of 1,990 m tested 21.7° API gravity oil. In addition, good oil stains have been found in the sandstone reservoirs of the Musaiyab-1 well, but the intervals are water bearing (Verma et al. 2004; Sadooni 1997).

The Sarmord Formation is mainly represented by shale argillaceous limestones, which have no significant carbonate or sandstone reservoir. Oil staining has been noted in the carbonate at Musaiyab-1 well. Improved, reworked carbonate reservoirs are probably present to the east of this well location.

The widespread Lower Cretaceous sequence contains good quality oil source in the easternmost part, fair source rocks in the west. The source rocks are at present middle mature in the east and early mature in the central part. Good oil generation must have taken place in the eastern part of the study area and fair oil generation in the central part. The source rocks entered the oil window during Paleogene times, and hydrocarbon generation is continuing to the present day.

Lower Cretaceous reservoirs of the western sector could be oil bearing.

The Neocomian–Barremian sandstone reservoirs are well sealed in the central and eastern parts of the study area. The interbedded shale and marl provide the seals and also act as mature source rocks capable of directly feeding the reservoirs are ideally positioned above the widely developed and mature Jurassic source rocks, and this means even the Aptian sequence is very thin ranging in thickness between 50 and 60 m in the western part of the study area to about 100 m in the east.

Good quality porous and vuggy dolomite and dolomitic limestone reservoirs are present within the sequence. The formation was encountered at a depth of 2,490 m in the Musaiyab-1 well. Absent of adequate seals seriously downgrades the potential of these reservoirs (Sadooni and Aqrawi 2000; Verma, et al. 2004; Al-Hashimi and Amer 1977; Jassim and Goff 2005).

The Lower Albian sequence is about 100 m thick in the northern part and about 250 m in the south of the study area. The sequence contains multiple, good quality sandstone reservoirs, and these are sealed by thin interbedded shale.

The sandstone of Nahr Umr Formation is considered to exhibit good reservoir properties everywhere in the study area, where porosities range between 20 and 27 %, and permeabilities exceed 2,000 mD in places. Impregnation of medium-grade sweat oil was noted in Kifl-1 well, and testing of the interval at depth of 1,800 m produced a sour emulsion (Verma et al. 2004; Al-Mashadani 1986).

However, seal potential is considered to be fair in the western half of the area and good in the eastern half. The Nahr Umr Formation was encountered at a depth of 2,339 m at the Musaiyab-1 well. In this well, occasional bitumen impregnations were noted while drilling the Nahr Umr Formation. Significant oil generation must have taken place in the eastern part along the Afaq trend. A notable occurrence of oil in the Zubair Formation was in Kifl-1 well, where the lithology is mostly sandstone with streaks of shale or siltstone. A 10-m sandstone interval at the top of Formation was impregnated with light oil in addition to dark bituminous, sporadic oil staining. The Formation was tested and produced 5,600 BOPD of 220° API gravity oil.

The reservoirs of the Zubair and Nahr Umr Formations are sealed by interbedded shale, which also provides mature source rocks.

The Yamama/Sulaiy Formation are expected to provide porous and fractured carbonate reservoir. The Yamama carbonate at Kifl-1 gives good heavy oil and bitumen shows; seal potential to the carbonate reservoirs is provided by the interbedded shale and several compact carbonate intervals. Local oil generation from the Lower Cretaceous and Jurassic source rocks can feed the Zubair and Nahr Umr sandstone. In addition to up dip oil generation from the basinal Lower Cretaceous and Jurassic facies also feed the reservoir of the study are.

The Lower Cretaceous play is locally investigated and successfully tested commercial oil. Further exploration is likely to reveal numerous oil accumulations within the porous and permeable sandstone reservoir of the Zubair and Nahr Umr Formations (Al-Mashadani 1986; Beydoun et al. 1992; Sadooni and Aqrawi 2000; Sharland et al. 2001).

The Upper Albian Mauddud Formation consists of chalk with good reservoir properties. The lack of adequate seal seriously downgrades the potential of these reservoirs (Sharland et al. 2001; Ditmar and Iraqi-Soviet team 1972).

In general, the Lower Cretaceous objectives are economically accessible everywhere and offer the best drilling targets in the eastern half of the study area. The Zubair Formation sandstone and Nahr Umr Formation produced oil at Kifl and Afaq oil fields. The best reservoirs are the sandstone of the Zubair Formation, and these are worth investigation as primary objectives in the central and eastern parts of the study area. The second best reservoirs are those of the Nahr Umr Formation. These are worthy of investigation as secondary objectives in the eastern half of the study area. Commercial oil accumulations could be detected in the Lower Albian sandstone of the eastern half of the study area.

The Cenomanian to Turonian sequence ranges in thickness between 300 and 400 m and consists of carbonate facies. Reefal and calcarenitic or bioclastic facies are widely developed within the sequence, particularly in the central and eastern parts. Musaiyab-1 well drilled close to central part of the study area, encountered the sequence at the depth of 1,805 m.

The sequence is represented by the Ahmadi, Mauddud, Mahliban, Fahad, Moatsi, and Kifl Formations. The reefal–bioclastic facies of the typical Mishrif Formation are not present in this well and the main lithology is that of chalky limestone (Verma et al. 2004; Sadooni and Aqrawi 2000). Figure 7 shows the Lower Mesozoic objective.

Good to very good quality oil source rocks are present within the Upper Cretaceous sequence of eastern and central parts of the study area and fair quality source rocks in the west. The source rocks at present time are of middle mature in the east, early mature in the central part, and immature in the west.

The Upper Turonian to Lower Campanian sequence is represented by Khasib, Tanuma, and Sadi Formations. No potential carbonate reservoirs have been found in porous but impermeable chalk and chalky limestone.

The Upper Campanian to Maastrichian sequence is represented by Hartha and Shiranish Formations. The sequence is about200 m thick in the eastern part and about 400 m in the west (Sadooni and Aqrawi 2000; Beydoun 1988).

The Hartha Formation consists of chalk and marly limestone with interbeds of dolomites and bioclastic and dolomitic intervals provide fair reservoir properties, sealed by interbedded marly limestone intervals. The Hartha Formation reservoir is expected to be thinner and dirtier, but well sealed in the deep eastern part of the study area. Interbedded marls and the local marl of overlying Shiranish Formation are adequate seals to Hartha Formation limestone and dolomite reservoir (van Bellen et al. 1959). At Kifl-1 well, the reservoirs are sealed by locally developed interbedded anhydrite. Sporadic oil staining has been noted in Afaq-1 and Kifl-1 wells. Figure 8 shows the Upper Mesozoic objective, while Fig. 9 shows the possible and proven Mesozoic plays.

Tertiary

The Paleocene section is represented by marly limestone and marl (Aaliji Formation) and the Eocene section by thin limestone of the Jaddala Formation. Depth to Eocene section at Musaiyab-1 well is 983 m. The section contains porous and slightly fractured limestone reservoirs, but these lack adequate seals. Frequent oil staining has been noted while drilling the Aaliji Formation at the Afaq-1 and Kifl-1 wells.

The Oligocene sequence is represented by the Kirkuk group, which includes the Palani, Sheikh Alas, Baba, and Jawan Formations. It provides excellent reservoirs, but these lack adequate intraformational seals. Depth to the top of Oligocene sequence is 754 m at Musaiyab-1 well (Beydoun 1988; Beydoun et al. 1992; Al-Mashadani 1986; Less 1950; van Bellen et al. 1959; Jassim and Goff 2005).

The Lower Miocene sequence is represented by the Euphrates and Jeribe Formations. Good quality, porous, vuggy, and cavernous limestone reservoirs are present in these formations, and a good evaporitic seal is provided by the overlying Middle Miocene Fatha (Lower Fars) Formation. The reservoirs are shallow (643 m depth at Musaiyab-1) and flushed by meteoric water. Slight and pachy oil staining was reported from the Afaq-1 well and from the Kifl-1 well.

No potential carbonate or sandstone reservoir is likely to be found within the Middle to Upper Miocene to Pliocene

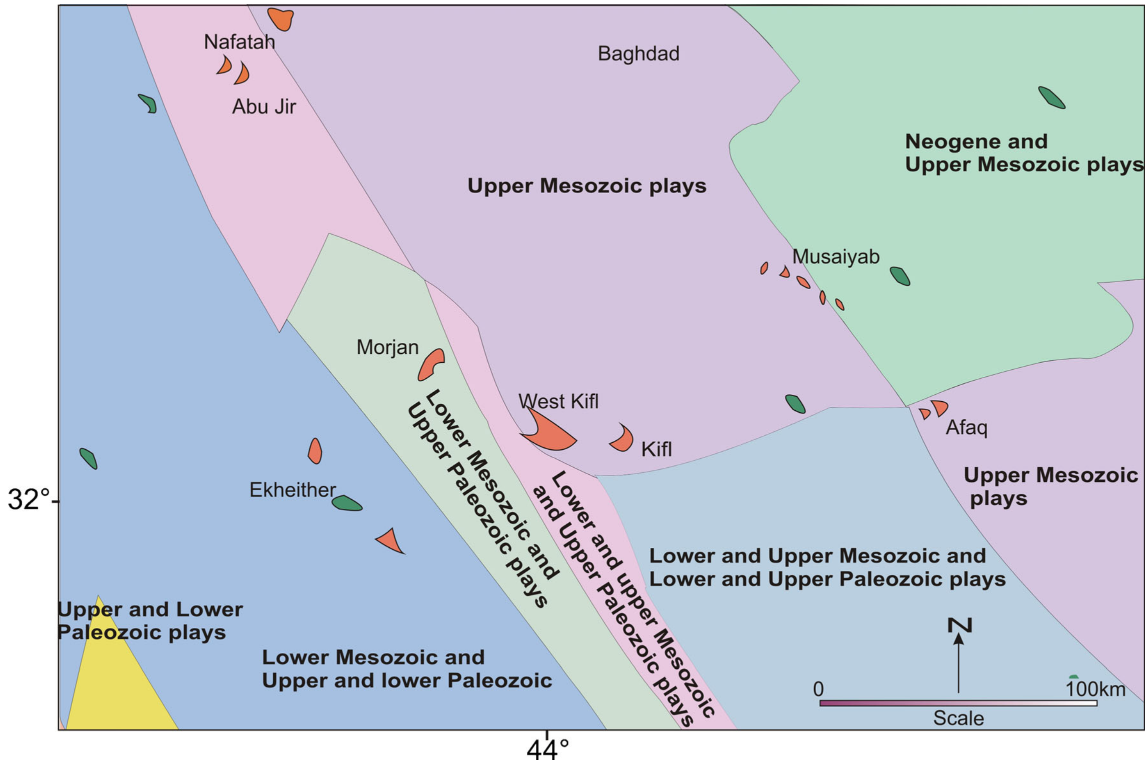

Fig. 10 Prospectively map of the studied area

stages (Lower Fars and Dibdibba Formations) of the study area. High porous and permeable sandstone reservoirs are present in the Dibdibba Formation, but they are near the surface and are water bearing. Tertiary source rock intervals cannot generate significant hydrocarbons due to shallow burial and immaturity of source rocks. No potential

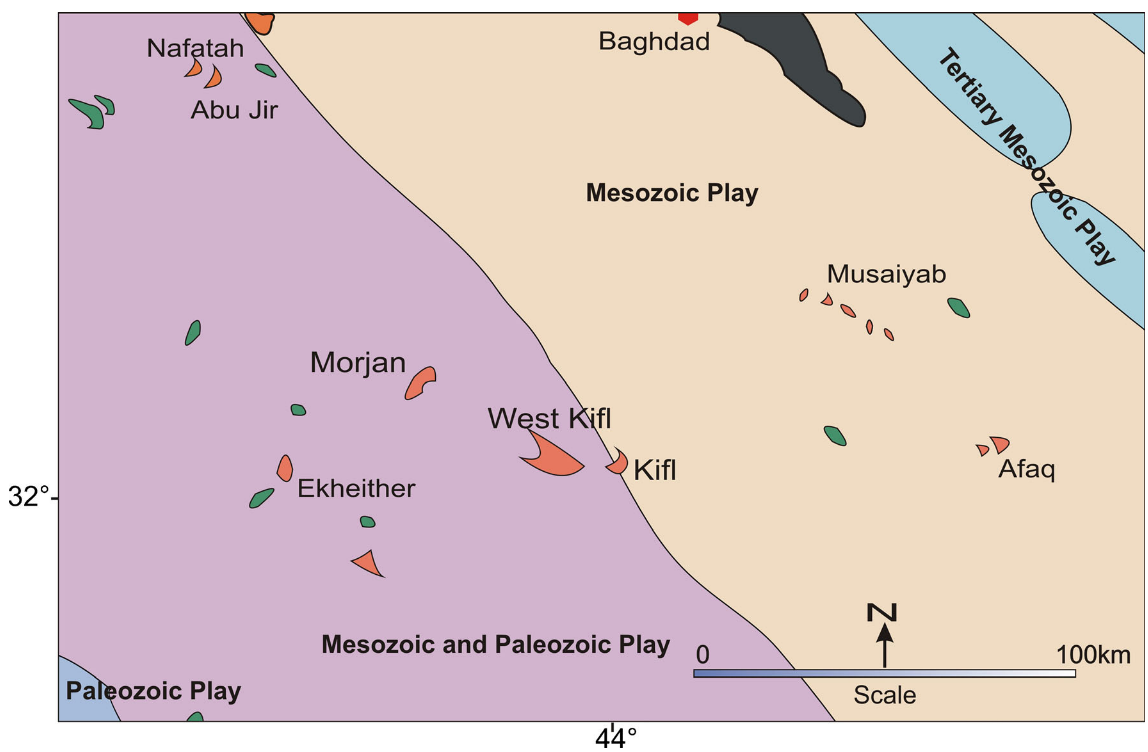

Fig. 11 General possible and proven of studied area

reservoirs are expected within the Tertiary sequence of the area (Ditmar and Iraqi-Soviet team 1972; Less, 1950; Verma et al. 2004; Beydoun et al. 1992; Al-Mashadani, 1986; Alsharhan and Nairn 1997). Figure 10 shows prospectively the map of the studied area.

Exploration intensity

Generally, the studied areas are very low exploration intensity. It is possible to conclude that potential petroliferous carbonate reservoirs are widely developed within the Tithonian–Berriasian sequence. The oolitic and bioclastic carbonates are oil producers in northern, central, and southern Iraq. They are well sealed in most places and associated with mature Cretaceous source rocks and overlying mature Jurassic source rocks. The reservoirs are deep in the Basrah and Tigris depression and in area further east along the Iranian border with Iraq. They are only sparsely investigated in Iraq, and further exploration is likely to reveal widespread development of potential reservoirs.

In fact, the Tithonian–Lower Cretaceous sequence was not even reached in several structures, even though it is buried at moderate depths. Further exploration along the paleo-shelf edge and the adjacent platforms is considered rewarding. Thus, drilling along the western flank of the Basrah Depression, Salman Shelf, Heet Shelf, Samawa and Diwania Highs, Baghdad Depression, and various ridges of the Basrah Arches could revel several new commercial oil accumulations that could be confirmed by the studies of Al-Hashimi and Amer (1977), Al-Mashadani (1986), and Al-Sharhan and Narin (1997). Figure 11 shows the general possible and proven of studied area.

Conclusions

The most attractive places for exploring commercial oil, gas, and condensate accumulations are within the Paleozoic play in Western Iraq, as well as within the Jurassic/Cretaceous play in the area along Abu-Jir Fault, including the study area.

Reinterpreted factual data coupled with modeled maturity, source rocks richness, organic geochemistry included biomarkers, reservoir concepts, and PetroMod modelling and allowed a better understanding of the hydrocarbon habitat of the studied area.

The Triassic sandstone and carbonate objectives are accessible in the western part. Attractive bioclasstic carbonate objectives of Jurassic sequence are also widespread along the western part. Good multiple sandstone and, in places, carbonate objectives are present within the Lower Cretaceous sequence of the western part and fair objectives in the east of the studied area. In addition, the upper Cretaceous carbonate objectives are considered fair in the central and western areas and good in the east. The multiple Cretaceous carbonate reservoirs are well sealed in the most places by interbedded shale, marl, and argillaceous limestone and associated with mature oil source rocks.

The Jurassic source rocks can feed the Cretaceous strata with commercial oil quantities. The main objectives of the studied area are of Triassic, Jurassic, and Cretaceous ages.

The Triassic sequence is expected to provide fair carbonate reservoirs in the western part of the area of study. The reservoirs are possibly gas bearing. The Jurassic carbonate objectives are worth of investigation by drilling in the central and western parts of the studied area. Commercial oil accumulations could be expected within the reservoirs everywhere, even in the deep eastern sector of the area of study. The Lower Cretaceous objectives (Zubair Formation) are likely to be petroliferous in the central and eastern parts. The Upper Cretaceous sequence can also provide attractive objectives in the central and eastern parts. At least, they are worthy of serious investigation in the eastern part. It becomes evident that the Mesozoic sequence offers the best potential in the region.

Most available structures in the area of study contain elements of stratigraphic entrapment. Lateral facies changes and interfingering of the Lower Cretaceous Zubair Formation and Nahr Umr Formation shallow marine sandstone with shale are examples. Permeability traps, due to lateral and vertical facies changes of calcarenitic and oolitic carbonate to compact facies, are expected to be quite common in the Jurassic sequence. These carbonate are ideal for the development of stratigraphic traps along the western part and worth consideration wherever associated with subsurface structures.

Paleozoic play is possible in the western part of the studied area and may be provided with Jurassic reservoirs of gas and oil.

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