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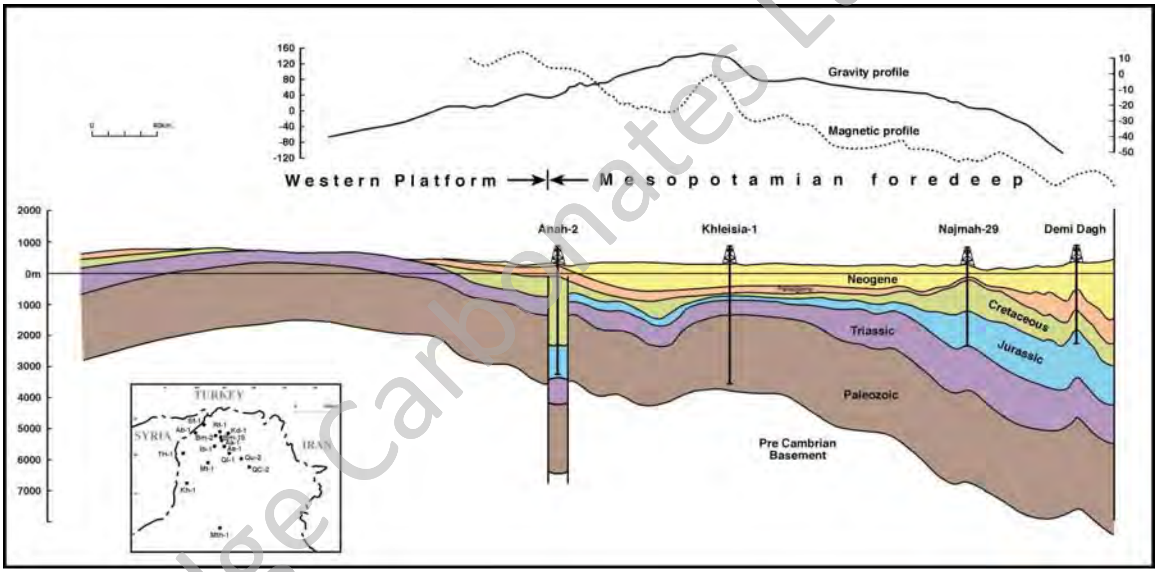

Andrew Horbury

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Northern Iraq Study

SUMMARY

The prospectivity of northern Iraq is significant. It sits on margin of two known hydrocarbon provinces, firstly the Mesopotamian basin with its major Jurassic source rocks and Cretaceous to Oligo-Miocene reservoirs in late Tertiary anticlinal traps to the SE (Kirkuk-Makhul-Hamrin area) and secondly, the ‘NW Iraq/NE Syria’ hydrocarbon province with likely Triassic source rocks and Triassic-Middle/Late Cretaceous reservoirs in inverted half-grabens to the north. The Khleisia High is largely unexplored, but possesses many strong geological similarities with the Euphrates Graben system of Syria, in which Silurian, Triassic and Late Cretaceous source rocks charge tilted fault-block traps in which reservoirs, consisting of a variety of lithologies, range in age from Carboniferous to Neogene.

In immediate vicinity, there are in-place recoverable reserves in the tens of billions of barrels, in Kirkuk (INOC est. 24 Billion recoverable), Jambur, Bai Hassan, Kabbaz, Ain Zalah, Butmah, TaqTaq, Chemchemal, Qaiyarah, Qasab, Najmah, and Jawan.

Prolific source rocks, mostly of Middle Jurassic-Early Cretaceous age with average yields in the order of 10kg/tonne, are distributed widely across the Mesopotamian Basin and Kurdistan. These are usually oil prone but some gas generation is occurring at the present day in more deeply buried areas of Kurdistan. This is the system that is important in charging central Iraq. However, for this system to be important in NW Iraq, long-distance migration would be required, and evidence suggests that these oils have reached the Jawan-Najmah structures and maybe not spilled beyond these traps. Triassic source rocks remain unquantified but geochemical data (sulphur isotopes and rare earth geochemical fingerprinting, in addition to the position of known production and shows outside of the Jurassic source kitchen) indicates that an active Triassic source system must exist, although it is likely to be of moderate rather than world-class ranking. A Palaeozoic source rock system, relying mostly upon the basal Silurian (Akkas Formation) and Tournaisian (Ora Shale Formation) may be sufficiently mature to have generated oils in more positive areas such as around the Khleisia High where there was insufficient burial of either Triassic or Jurassic source rocks.

There are cap rocks throughout the stratigraphy, typically present as flooding surface shales in Palaeozoic clastic systems, basinal marls developed as drowning units over karstified Mesozoic shelf limestones, or restricted salina/sabkha evaporites developed above porous, dolomitised reefal and platform margin carbonates of Mesozoic and Cenozoic age. These define a total of four reservoir plays in the Early-Middle Palaeozoic, seven in the Permo-Liassic, six in the Cretaceous, and one in the Cenozoic.

Successful traps proven to date comprise Late Tertiary inversion anticlines, which have been drilled to the virtual exclusion of other trap types. By analogy with nearby countries and as inferred from the database contained in this report, palaeostructures and a variety of stratigraphic traps are likely to exist. Of these, tilted fault blocks that sit between inversion anticlines, are probably the most interesting new opportunity. Successful exploration for these will open up new play fairways across wide areas of northern Iraq.

It is reasonable to assume that further accumulations remain to be discovered within northern Iraq. Until seismic mapping, volumetrics and play/prospect risk is assessed, it is difficult to put a precise figure on yet-to-find.

CONTENTS

the confidence that can be placed in published palaeontological and lithostratigraphical interpretations. In particular, the Triassic-Liassic and Early Miocene suffer from this problem. The main reason being, that in an alternating (cyclic) evaporitic-non evaporitic but mainly dolomitic stratigraphy, there are few reliable microfossils, whilst mis-identification of lithostratigraphic units is a very easy mistake to make. For example, it is suggested that some identifications of the probable Aquitainian 'Euphrates Limestone Formation' (e.g. by Abawi, 1989) are in fact of interbeds within the Lower Fars Formation. This is supported (again in this instance) by the quoted faunas being not only considerably younger than that which would be expected, but also in the 'wrong' facies being mostly planktonic rather than benthic. Problems with many interpretations of Liassic-Triassic stratigraphy suffer from the tendency to fit all formations (Alan, Mus, Adaiyah etc….) into the drilled stratigraphy, rather than accepting that the uppermost Liassic may be in large part eroded, thereby forcing younger ages onto units than should be expected. This in large part explains the discrepancy between Syrian and Iraqi stratigraphies in this interval (see Sadooni and Alsharan, 2004 for a review) but some internal stratigraphic inconsistencies in Iraq itself, are a result of this problem.

1.5. METHOD OF RESOURCE ASSESSMENT

Northern Iraq will be assessed in the context of a thorough description and interpretation of the Petroleum System of northern Iraq. Seal and reservoir units will be identified, and play fairways will be constructed from the relevant palaeogeographies. These will then be discussed with respect to the source rocks and burial history that are responsible for the entry of charge into the fairways, and finally, the trap types present at the time of charge. Palaeogeographies presented in this report are themselves based on the larger maps compiled by Cambridge Carbonates Ltd. over the past ten years, which are in turn based upon hundreds of public domain data sources. Each Cambridge Carbonates map (but note, not the other text figures) has the same colour legend for depositional environment Figure 2.

desert topography has had an important influence on the geological evolution of Northern Arabia since it represents an indenter against which the major folds terminate (Figure 4). The structural domains are discussed in more detail below.

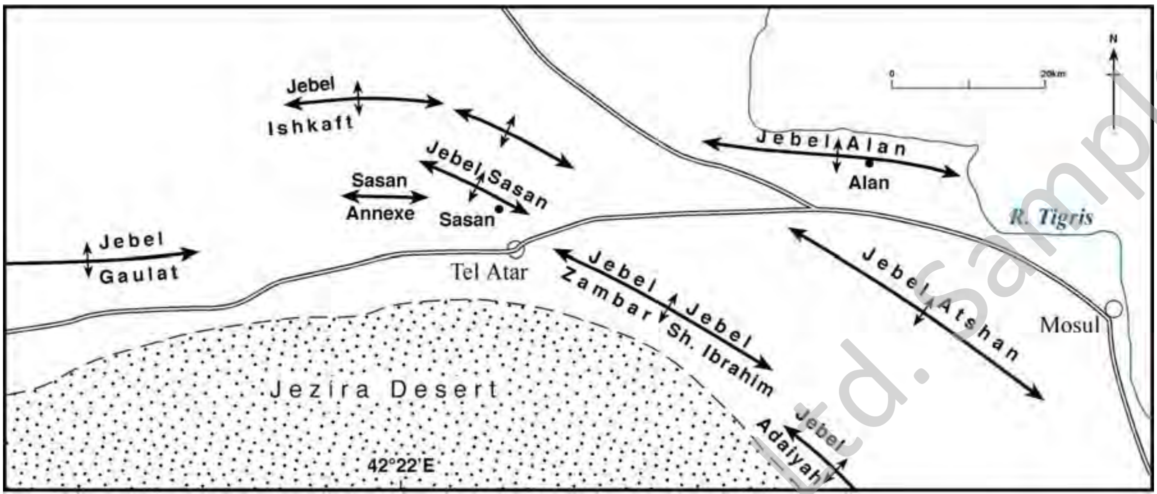


Figure 4 Anticlines 'wrapped around' the northern limit of the Khleisia High indenter. After Al Jumaily and Domeci (1976).

2.1.2. Nappe zone

This comprises the high mountainous zone developed on the NE border of Iraq with Iran (Figure 5). It comprises mostly metamorphosed Mesozoic and Palaeozoic rocks and ophiolites obducted from the Late Cretaceous onwards during the closure of Neo-Tethys. These have been thrusted over Miocene and older rocks of the folded zone in the Taurus belt. Mitchell-Thome (1960) recognised three thrust sheets, with relatively limited horizontal translations and steep dips. Takin (1972) and Stocklin (1974) noted two major thrusts along-strike in the Zagros belt.

high, dips are low, with a regional dip to the NE of under 1 degree and a granitic basement at less than 1km depth in places (Mitchell, 1956; Tikrity and Al-Ani, 1972). The present day limits of this high to the N and E are abrupt although a series of terraces are known along the margins of the high, particularly in Syria (de Ruiter et al., 1995) and as notably penetrated by wells such as Tel Hajar-1 (Figure 15). These basins and terraces are uninverted (or only marginally inverted) versions of the large anticlinal features seen along the N and NE margin of the Khleisia High.

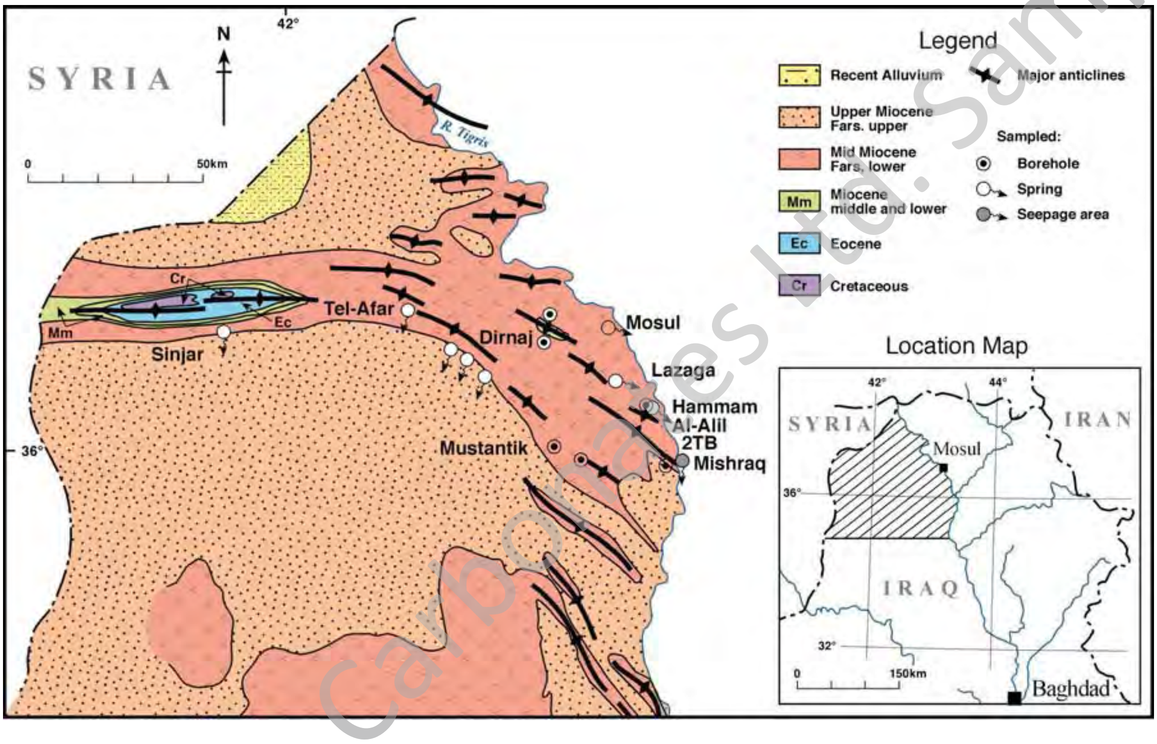


Figure 13 Surface geology of the Khleisia High and surrounding fold-thrust belt. After Al-Sawaf (1977).

Many large (10's of miles long by several thousand feet high) surface anticlinal structures such as Jebel Sadid, Jebel Ibrahim, Jebel Makhul, Hamrin North, Hamrin South, and Jebel Sinjar stop abruptly at its margin (Figure 4 Figure 13), with little or no sign of deformation within the unfolded area itself, even a few km from its edge (Dunnington, 1958; Figure 4).

clastic fluvio-deltaic systems (Zubair, Nahr Umr and Rutbah) is best explained by drainage off the thermal dome(s) developing in Central Africa in response to opening of the South Atlantic (Al Fares et al., 1998).

In the Late Cretaceous (mid-Turonian onwards) an episode of renewed active rifting occurred on the northern edge of the Arabian Plate. This event was associated with the drifting of the Arabian Plate into the Anatolian subduction zone (Best et al., 1993). During this period, the Sinjar Trough, Euphrates and Anah Graben systems opened up within the Khleisia/ Ga'ara/Sufaiya High system. Faults were initially oriented E-W, and changed to a SW-NE orientation by the end of the Maastrichtian with no evidence of continued movement on the original fault planes (Hart and Hay, 1974). The Sinjar and Anah graben demonstrate on seismic at least 2km subsidence during the Campanian and Maastrichtian (Figure 9), whilst the continuation into the Jebel Abd El Aziz graben in Syria, was deep enough to contain large olistoliths of Tournaisian limestone (Fairbridge and Badoux, 1960; Hart and Hay, 1974; Kent and Hickman, 1998). On the shelf area to the SW, a major unconformity developed across the whole shield, and N-S oriented uplifts developed in more basinal settings close to the Zagros plate margin (Koop and Stoneley, 1982); one of these is present in northern Iraq, centred along the Greater Zab river. The change in plate motion also resulted in thrust-emplacement of obducted ophiolite and pelagic oceanic sediment as old as Triassic in age along the whole N/NE Arabian margin, and is also associated with the first evidence of clastic supply from the NE (Koop and Stoneley, 1982). There is no evidence for subduction or plate collision along the Zagros margin in this area at this time. Maastrichtian-Palaeocene plate motion was minimal, although there was a major phase of basin inversion related to renewed obduction in the latest Maastrichtian, such that nummulitic banks of Late Palaeocene-Eocene age were initiated directly on the eroded, inverted Late Cretaceous graben fills such as in Jebels Sinjar in Iraq, Abd-el Aziz and Bishri in Syria (Kent and Hickman, 1997). From the Upper Cretaceous until the end of the Oligocene, a threefold isopach/facies pattern developed parallel to the strike of the Zagros; there was a foredeep with thick flysch-type clastics and a thin belt of lagoonal/reefal carbonates, a starved basin centre, and a SW margin comprising a broad carbonate shelf (Koop and Stoneley, 1982; Figure 19).

whilst in Iran, the correlative is the Lalun Sandstone Formation, which may reach a total of 878m (Setudehnia, 1975).

Upon these basal formations rest distinctive carbonate formations, notably the Burj Formation of Jordan (Powell, 1989; Andrews, 1991; Elicki et al., 2002) and the Koruk of Turkey (Dean, 1975, 1982g, Dean et al., 1981, 1997). This ramp extends into Iran as the Mila Formation (Stocklin, 1968, 1972; Szabo and Kheradpir, 1978). In SE Turkey, the Koruk attains a thickness of 390m (Figure 21) whilst in Jordan, the Burj may reach a maximum of 225m in the GTZ-2D well, although it thins to absent in the Feinan/Dana area of Jordan (Powell, 1989; Telmeh et al., 1990; Andrews, 1991). In Syria, the Burj is only penetrated by one well (Khanasser-1) where it is approximately 250m thick and rests on igneous rocks (Best et al., 1993). However these carbonates form an important seismic marker, which has been used as a proxy for mapping top-economic basement in the less deformed areas of the Aleppo and Rutbah-Tanf highs in Syria (Al-Saad et al., 1992; Best et al., 1993).

Above these units in Jordan are diverse suite of formations; the Umm Ishrin, Disi and Umm Sahm in outcrop (Powell, 1989). In Turkey, post-Koruk units consist of at least 2,500m of the Seydisehir Formation of which the lower part falls within this interval (Dean, 1975, 1982a; Dean et al., 1981; Janvier et al., 1984; Figure 21). In Syria equivalents are the Sosink and Khanasser formations (Weber, 1963; Daniel, 1963; Ponikarov, 1967; Best et al., 1993). Given the analogous structural/plate setting, these older Cambrian units are likely to be developed beneath the oldest outcrops in northern Iraq.

The oldest rocks exposed in northern Iraq are an unbottomed section 800m thick of the Khabour Formation, present in the cores of thrusted anticlines in the nappe zone (Henson, 1951; Baker, 1953; Dunnington, 1958; van Bellen et al., 1959; Seilacher, 1963; Buday, 1980; Figure 22). Only the Llandeilo and older rocks are present in northern Iraq; the Caradoc in most areas and all of the Ashgill being absent due to erosion beneath the base-Late Devonian ‘Caledonian’ unconformity (Dunnington et al., 1959; Seilacher, 1963).

Group formations attributed to this interval consist of the Hiswah Sandstone and Dubaydib formations, and the basal Tubeiliyat Sandstone member of the Mudawarra Formation (Powell, 1989); of these the Hiswah and Dubaydib formations contain distinctive mudstone markers for the Llanvirn (O30 MFS) and Caradoc (O40 MFS) (Andrews, 1991). In Saudi Arabia the Tabuk Group correlates well with the Khreim of Jordan, of which the Qasim Formation is the Late Ordovician unit (Al Laboun, 1986; Husseini, 1989, 2000) and contains two distinctive intra-Ordovician mudstone markers, the Hanadir (O30 MFS) and Ra'an (O40 MFS) members (Al-Haijri and Owens, 2000). In Syria, formations are typified by the Swab and Afendi (Weber, 1963; Daniel, 1963; Ponikarov, 1967; Wetzel, 1974; Best et al., 1993). The most notable feature is however the pronounced cut-out of the stratigraphy in a northwards direction, such that the only stratigraphy present in Turkey, is a locally-developed remnant of the Seydisehir Formation in the Zap area of Turkey (Janvier et al., 1984; Dean et al., 1997) and the Bedinan Formation at Derik (Dean, 1967, 1980; Dean and Martin, 1992a).

Sequence stratigraphy Within this interval, lie the O30 and O40 maximum flooding surfaces of Sharland et al. (2001).

Palaeontology and Age The uppermost of the thick section of Khabour Formation at the base of the Khleisia-1 and Akkas-1 wells in NW Iraq are part of this sequence as now well-documented by palaeontology, specifically palynology, showing the complete range of Llanvirn to Ashgillian stratigraphy is present (Ameri and Baban, 2000, 2002; Figure 23). In the S.E. Turkish stratigraphy, the Sort Dere Fm. contains the trilobite *Calymenesun,* giving it an Ashgillian age. In Iraqi Kurdistan, the locally-defined Shish Fm. is dated as Caradocian (Seilacher, 1963).

In Jordan, the lowermost Khreim Group formations are marked at their base by the entry of the graptolite Didymograptus bifidus (Hall) indicating a Late Arenig-Early Llanvirn age whilst higher in the stratigraphy, the Dubaydib Formation is typified by burrows of *Sabellarifex* (Powell, 1989).

Lithofacies The uppermost of the thick section of Khabour Formation consists of mudstones and interbedded quartzitic sandstones at the base of the Khleisia-1 and Akkas-1 wells in NW Iraq (Buday, 1980; Aqrawi, 1998a; Ameri and Baban, 2000, 2002; Figure 26).

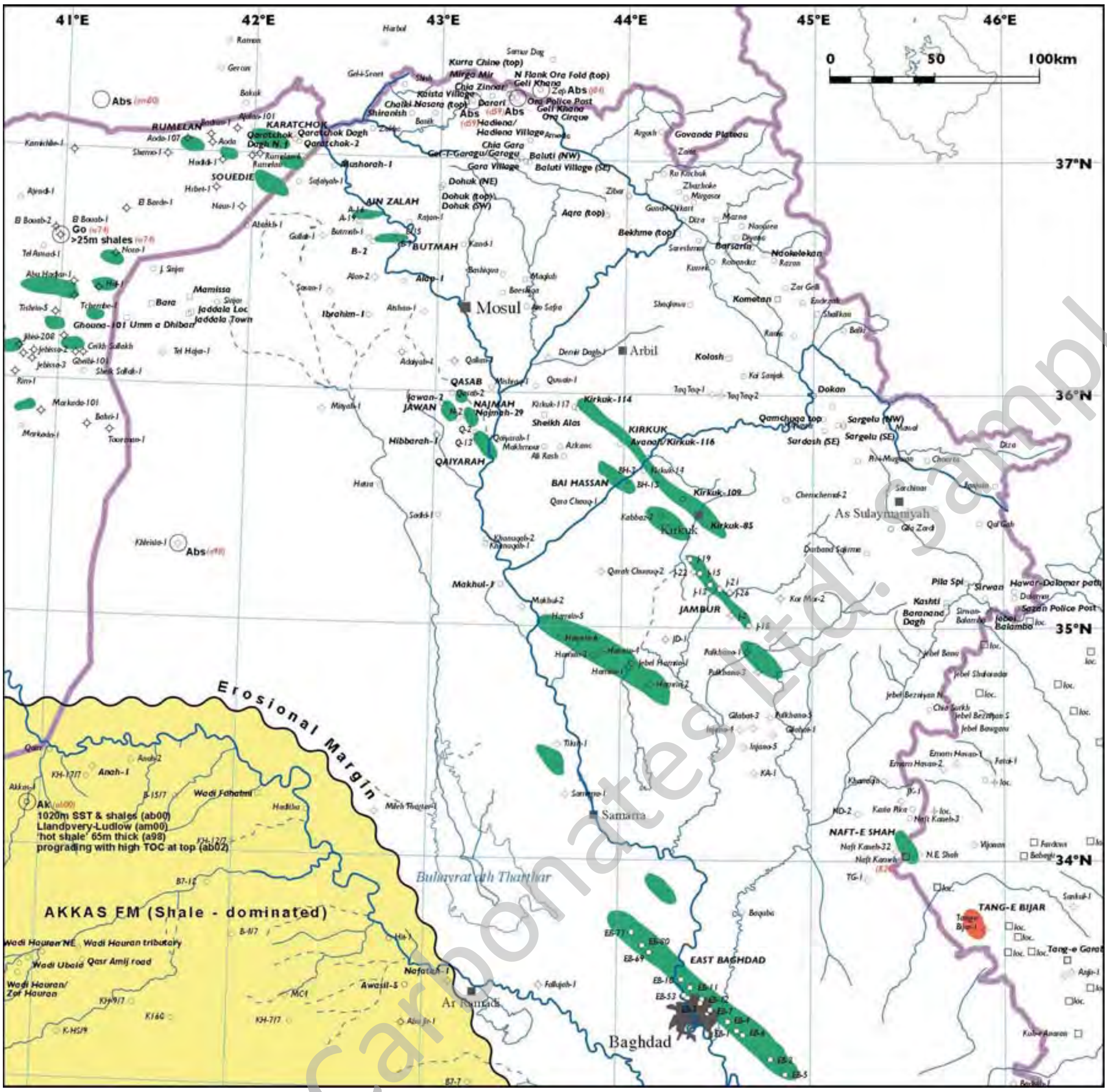


Figure 33 Facies in the Wenlockian, modified Cambridge Carbonates map

Summary of Economic Potential Where the stratigraphy is fully present there are locally reservoir facies in turbidite sandstones, e.g. the Suffi Formation in the Akkas-1 discovery in Iraq to the SW of the Anah Graben (Al-haba et al., 1994), but it is probable that such reservoir rocks either never reached northern Iraq, or may have been eroded below the base Late Devonian unconformity (Figure 33). The Akkas reservoir contains light oil (42-49° API) and sweet gas, compositionally estimated as being 85% methane and ethane, with no H_2S. Gas reserves in this accumulation are cited as being 1.1×10^9 m^3 whilst in the liquids, saturates and aromatics result in >96% of the total and there is only a limited asphalt content (Al-haba et al., 1994).

Source rocks identified in the basal Silurian are widespread but are coarse-grained but relatively thin section northern Iraq Henson, 1951; Baker, 1953; Dunnington, 1958; Dunnington et al., 1959) may reflect a proximal setting within a rift basin, perhaps associated with a rift shoulder.

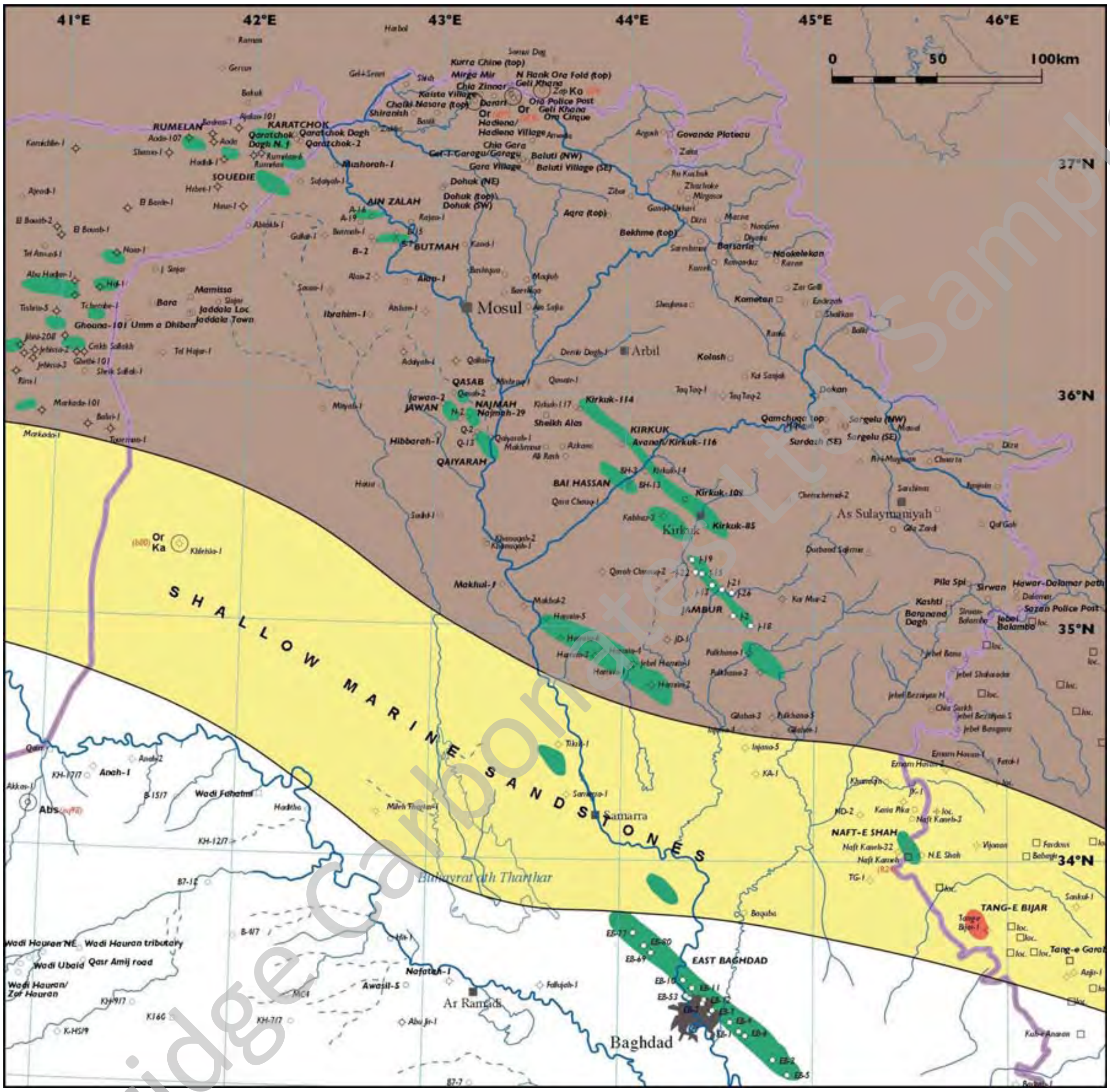
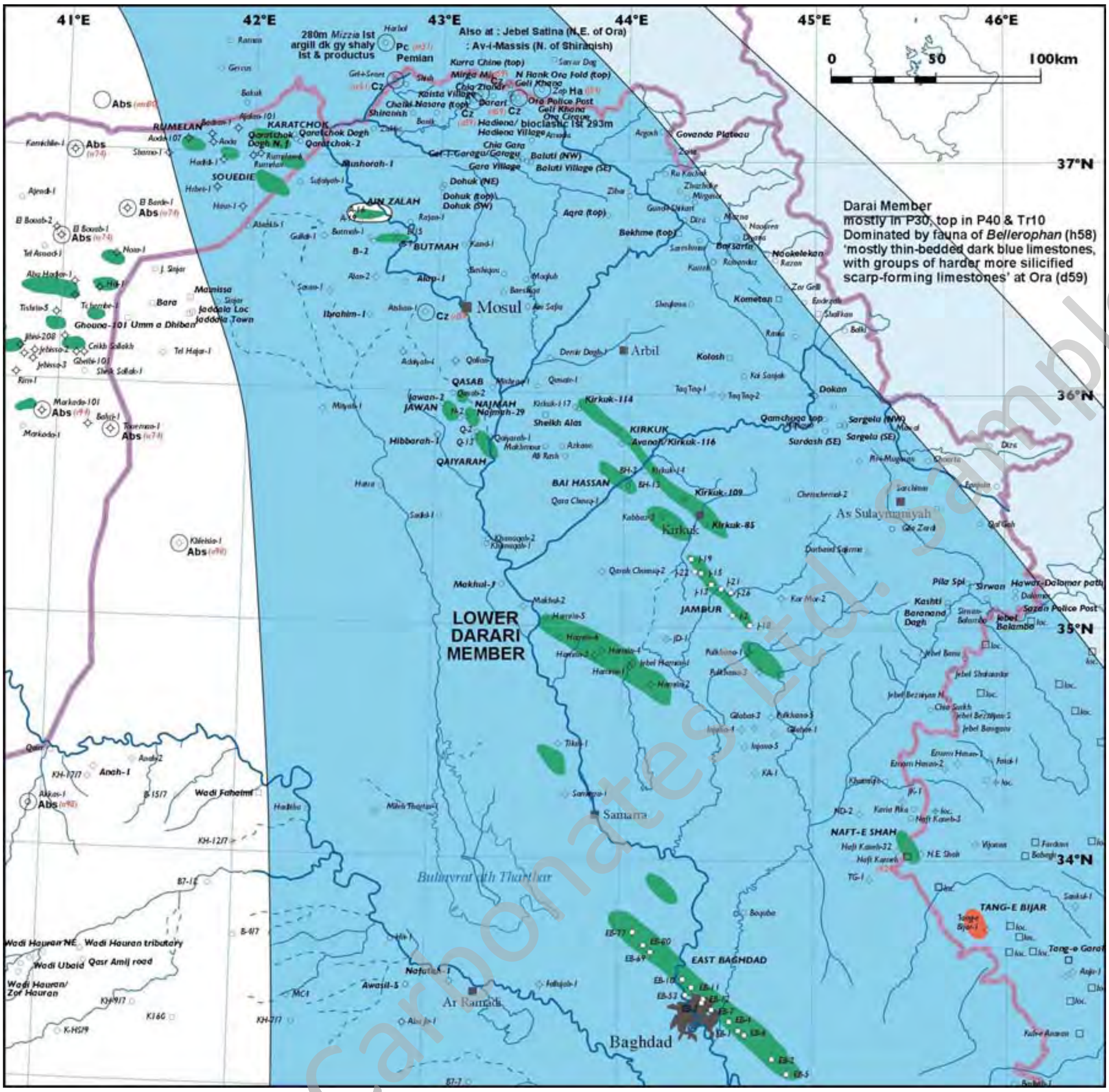


Figure 37 Early Tournaisian facies, modified Cambridge Carbonates map

The Pirispiki Formation represents continental (alluvial fan) environments, whilst the Chalki Fm. may represent rift-associated extrusives. These pass up into progressively more massive, marine facies. Basal clastics are in a marine facies in outcrop near Hazro and the Raman oilfield in SE Turkey, where they overlie marine mudstones (Tasman and Egeran, 1952). In the Zap area of SE Turkey, the Köprülü Formation was deposited in a low energy, mid-outer shelf setting (Janvier et al., 1984). To the SW in NE Syria, these Tournaisian facies are also shallow marine (Daniel, 1963; Dubertret, 1966; Ravn et al., 1994) whilst the uppermost coralline carbonates, clearly indicate of the Abba-1 well in Syria (Daniel, 1963), whilst isopach data indicate rapid subsidence along the Zagros margin of the plate in both Iraq (Sadooni, 1995) and Iran (Szabo and Kheradpir, 1978) as well as in Palymra in Syria (Bebeshev et al., 1988). Caron et al. (2000) note that rifting in the Triassic of Syria, was probably with respect to a stressfield oriented SW-NE. Total Triassic thicknesses of mostly shallow water sediments are 1,676m in Iraq, 1,219m in Syria (700m in the Euphrates Graben according to Caron et al., 2000) whilst Liassic thicknesses of up to 744m are noted in the subsurface of Iraq (Dunnington, 1958; Dunnington et al., 1959) give an insight into the rates of subsidence. Sadooni (1995) and Sadooni and Alsharan (2004) postulate the presence of a Sinjar-Khand basin in NW Iraq. By the end of the Triassic, evidence of active rifting had ceased, and the Liassic appears to have been a period of very widespread (epeirogenic) post-rift subsidence.

Much of the Liassic and Triassic of western Iraq and Syria have been removed, notably over the Khleisia High and its extension as far north as Shiranish. This erosion commenced during the Middle-Late Jurassic and later uplift of the Gotnia/Mesopotamian Basin margin. Erosion was only terminated by the final flooding of these highs in the Late Cretaceous and Palaeogene, e.g. in the Khleisia-1 and Toueman-1 wells (Tikrity and Al-Ani, 1972; Wetzel, 1974; Sadooni, 1996). Erosion is also noted in SE Turkey (Tasman and Egeran, 1952) and the SW Iranian High Zagros (Szabo and Kheradpir, 1978). The timing of initiation of the Khleisia high is clear when it is noted that the Triassic-Liassic stratigraphies are clearly similar from Iran through to Jordan, whilst there is major differentiation of the post-Liassic Mesozoic stratigraphies between Iran/Iraq in the east and Syria/Jordan in the west. Following the end-Liassic platform breakup, the next time that basins were essentially continuous between Syria and Iran, was in the Palaeocene. The Butmah Fm, for instance, thins from a maximum of 600m to 100m or less in the west. Similar erosion can be seen in Iran.



280m *Mizzia* lst
argill dk gy shaly
lst & productus

Also at : Jebel Satina (N.E. of Ora)
: Av-i-Massis (N. of Shiranish)

Darai Member
mostly in P30, top in P40 & Tr10
Dominated by fauna of *Bellerophan* (h58)
'mostly thin-bedded dark blue limestones,
with groups of harder more silicified
scarp-forming limestones' at Ora (d59)

Figure 45 Late Permian, P30 HST, modified Cambridge Carbonates map

The presence throughout the Mirga Mir and Beduh formations of fine-grained clastics gives hope that closer to the basin margins, coarser sandstones may be encountered that offer possibilities of reservoirs, perhaps as part of a stratigraphic pinchout trap related to the onlap of the Palaeozoic rocks of the Khleisia-Ga’ara Highs. In terms of the carbonate rocks, the high-energy oolites n the basal part of the stratigraphy, plus collapse breccias towards the top are the most likely candidates.

are equivalents of the basal Kurrachine of Iraq (Figure 59).

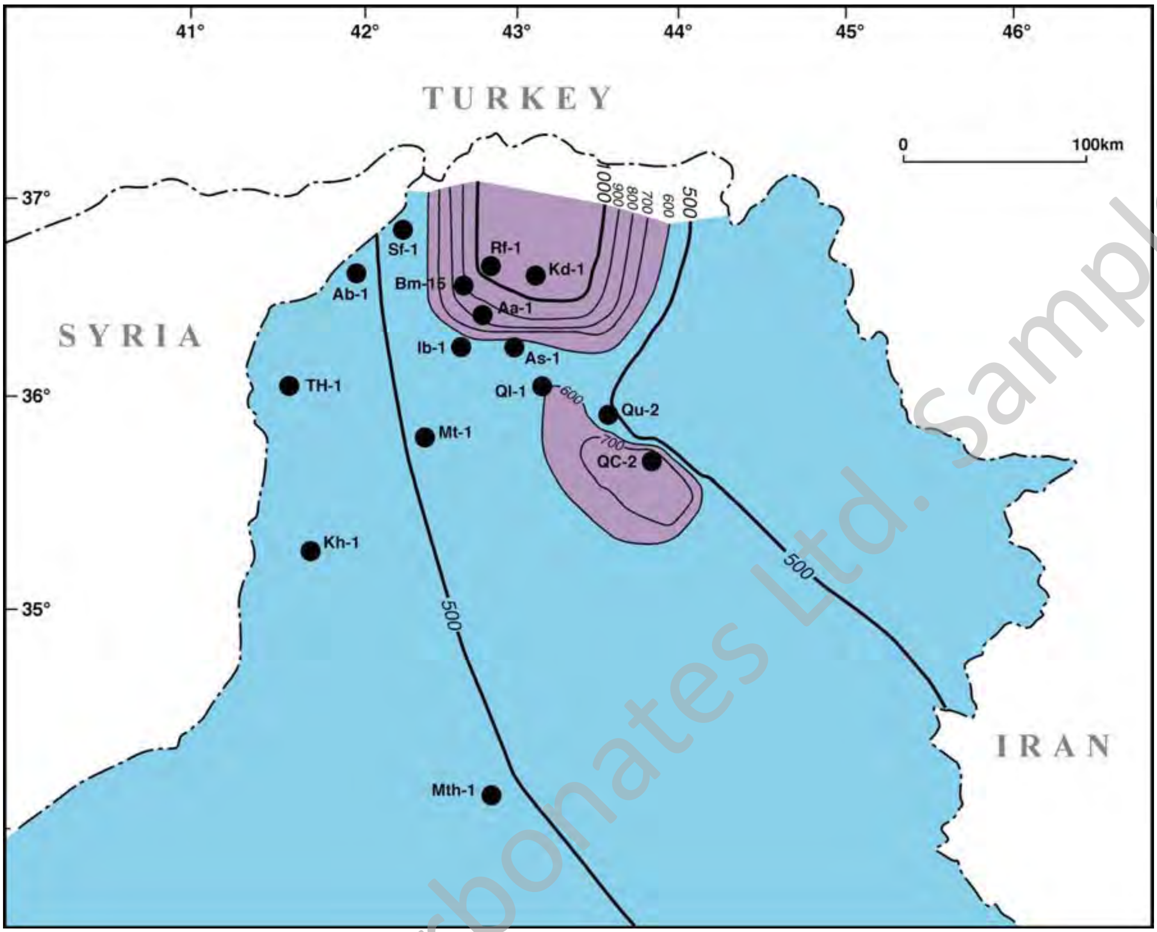


Figure 58 Isopach of Kurra Chine Formation (Tr60-70 sequence). After Sadooni, 1995

Sequence stratigraphy The lower part of the Kurra Chine Formation contains the Tr60 maximum flooding surface of Sharland et al. (2001). The evidence for this is the re-appearance of marine carbonates above the clear palaeokarstic surface at the top of the Geli Khana Formation (c.f. Dunnington et al., 1959), and in part, the presence of basal sandstones of the transgressive systems tract in both the Mileh Tharthar-1 and Awasil-5 wells in central Iraq (Buday, 1980).

3.2.7. Late Triassic (Norian-Rhaetian)

Resource potential in northern Iraq:

Reservoirs Oolites and peloidal grainstones in the basal carbonate unit form the deepest known commercial reservoirs in northern Iraq.

Caprocks Anhydrites and shales in the upper unit

Source rocks Possible source rocks in the upper unit in evaporite-associated mudstones

Trap types Stratigraphic, sealed by pinchout between two Kurra Chine anhydrite units, or Late Tertiary inversion structures. Late Cretaceous fault blocks and footwall highs, Probably not present in palaeostructures.

Lithostratigraphy of the systems tract and interpretation/palaeogeography:

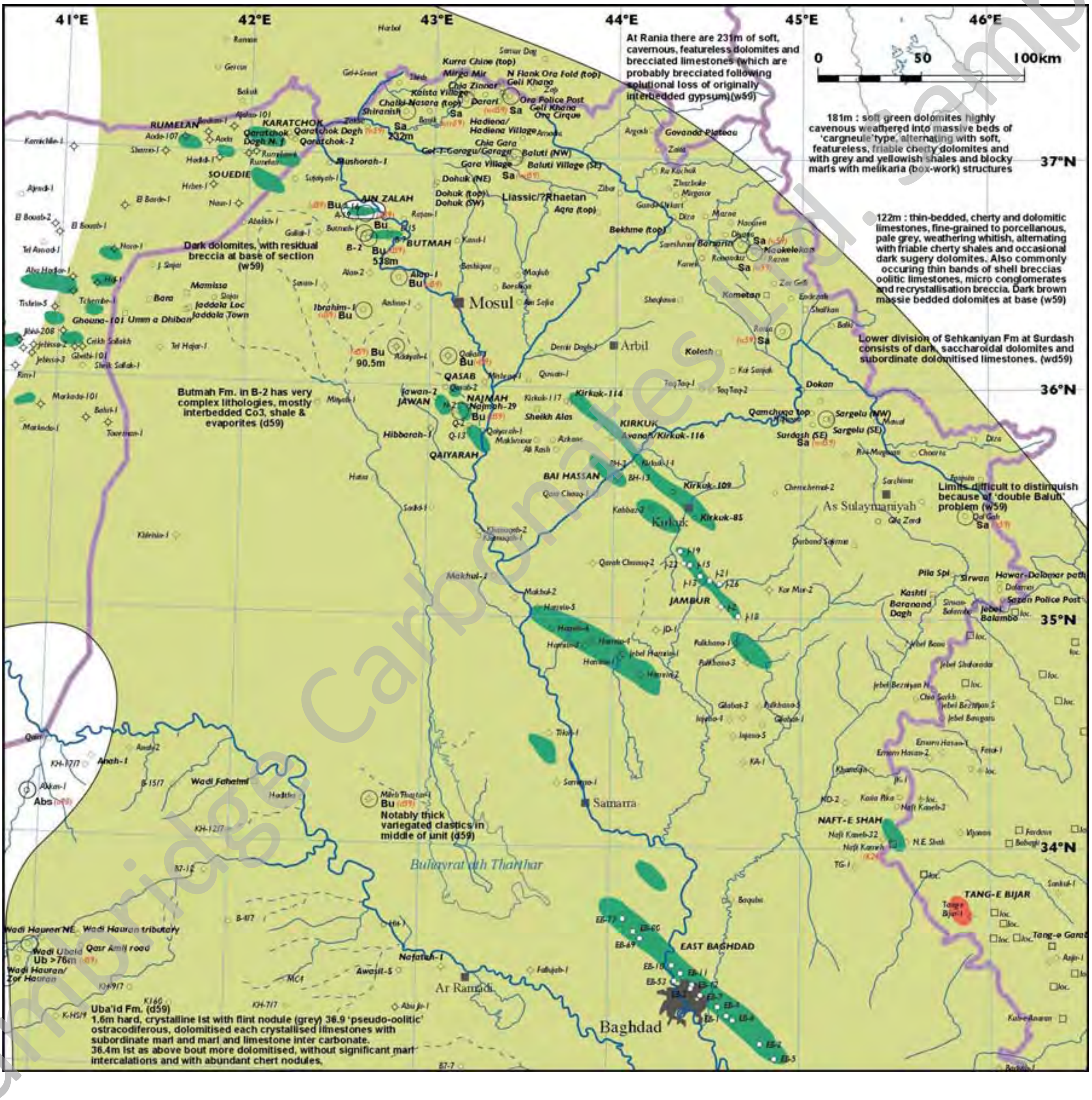
Lithostratigraphy and Contacts This interval comprises the upper part of the Kurra Chine Formation and the overlying Baluti Formation, where the latter is present and can be identified. Deposition is centred on a basin system located to the north of the Alan structure, termed the ‘Palaeo Sinjar Fault Zone’ and ‘Kand Sub-Basin’ of Sadooni (1995). This unit is penetrated in the Butmah, Ain Zalah, Rafan, Jebel Khand, Abtak and Sufaiya structures (Sadooni, 1995). It thickens to the south, into the controlling fault; thicknesses vary considerably, with up to 600m present locally. In SW Iran, the upper carbonates and evaporites 'B' to 'C' of the Dashtak Fm. are probably correlatives (Figure 62; Szabo and Kheradpir, 1978).

Sequence stratigraphy This interval contains the Tr70 maximum flooding surface of Sharland et al. (2001). It could be argued from the Iranian data (Szabo and Kheradpir, 1978) that there may be another flooding surface beneath the Dashtak ‘C’ evaporite, perhaps to be named Tr75.

Palaeontology and Age Fauna from the Kurra Chine Formation is similar to that noted for the Lower Kurra Chine. In addition both the Baluti Formation and the correlative Zor Hauran Formation of the Western Desert, contain good faunas giving a Rhaetian age (Kaddouri, 1986) as initially suspected but not proven by Dunnington et al. (1959).

Lithofacies Lithologies in the subsurface consist of dolomites, dolomitic and

The correlation of the basal unit as noted earlier, gives a strong indication of the extremely uniform nature of the platform top at this time, and the deposition in an epeirogenic or passive margin setting following the final separation of Iran from Arabia. This is also demonstrated by the very simple palaeogeographies (Figure 75 Figure 76 Figure 77 Figure 78). Facies in general represent low energy inner ramp and restricted lagoonal to intrashelf basinal environments.


At Rania there are 231m of soft, cavernous, featureless dolomites and brecciated limestones (which are probably brecciated following solutional loss of originally interbedded gypsum)(w59)

181m : soft green dolomites highly cavenous weathered into massive beds of 'cargneule'type, alternating with soft, featureless, friable cherty dolomites and with grey and yellowish shales and blocky marls with melikaria (box-work) structures

122m : thin-bedded, cherty and dolomitic limestones, fine-grained to porcellanous, pale grey, weathering whitish, alternating with friable cherty shales and occasional dark sugery dolomites. Also commonly occuring thin bands of shell breccias oolitic limestones, micro conglomerates and recrystallisation breccia. Dark brown massie bedded dolomites at base (w59)

Lower division of Sehkaniyan Fm at Surdash consists of dark, saccharoidal dolomites and subordinate dolomitised limestones. (wd59)

Limits difficult to distinguish because of 'double Balut' problem (w59)

Dark dolomites, with residual breccia at base of section (w59)

Butmah Fm. in B-2 has very complex lithologies, mostly interbedded Co3, shale & evaporates (d59)

Notably thick variegated clastics in middle of unit (d59)

Uba'id Fm. (d59)
1.6m hard, crystalline lst with flint nodule (grey) 38.9 'pseudo-oolitic' ostracodiferous, dolomitised each crystallised limestones with subordinate marl and marl and limestone inter carbonate.
36.4m lst as above bout more dolomitised, without significant marl intercalations and with abundant chert nodules.

Figure 75 Hettangian facies, Tr80 MFS, modified Cambridge Carbonates map

3.3.2. Late Toarcian-Bathonian

Resource potential in northern Iraq:

Reservoirs Limited to possible fractured carbonates of the Sargelu Formation and direct production from overpressured source rocks.

Caprocks Sargelu Fm. argillaceous limestones

Source rocks In the folded belt of northern Iraq, the Sargelu Formation has been proven to contain significant intervals of bituminous shales with source potential.

Trap types Late Tertiary inversion anticlines; rotated late Cretaceous fault blocks; palaeohighs on with isolated platform carbonates of the Muhaiwir Fm., stratigraphic pinchout traps with updip Sargelu Fm. basal seals.

Lithostratigraphy of the systems tract and interpretation/palaeogeography:

Lithostratigraphy and Contacts This interval consists of the Sargelu Formation across the whole of northern Iraq (Dunnington et al., 1959). This formation thins from 350m in the Najmah-29 well, down to 125-115m in the outcrop of Kurdistan, although at Ora and Chalki there is only 20m of the formation present (Dunnington et al., 1959). Towards the western Desert, the Sargelu formation passes laterally into the Amij (Bajocian) and Muhaiwir (Bathonian) formations (Dunnington et al., 1959; Kaddouri, 1986). The formation rests sharply upon transitional facies of the Alan Formation, which indicates that the megasequence boundary in fact, lies within the upper part of the Alan Formation. Normally, the Sargelu Formation is overlain disconformably by the Najmah Formation though a slight erosional unconformity is described between the Middle and Late Jurassic in the Qalian-Najmah area of N.W. Iraq (Dunnington, 1958). However, in the basin centre the Sargelu Formation is conformably overlain by the Naokelekan formation (Dunnington et al., 1959). The end-Jurassic unconformity has however strongly modified the Middle-Late Jurassic stratigraphy such that in western wells such as Adaiyah-1, the Najmah Formation (if it was ever present) has been eroded off and the Sargelu Formation is overlain by Early Cretaceous marls (Dunnington et al., 1959). These relationships persist into NE Syria, e.g. in the Ghouna-1 well (Dunnington et al., 1959). Between Adaiyah-1 and Khleisia-1, the formation has been completely eroded away nov., ?*Ataxioceras* sp. indet., *Nebrodites* ? sp. indet., *Planites* ?sp. indet., *Discosphinctes* ?sp. indet.; *Ataxioceras* sp. indet., *Ataxioceras polyplocus* (Rein.), *Idoceras* (or *Pianites*?) sp. indet., and *Streblites tenuilobatus* OPPEL. The **Coal Horizon** contains perisphinctids, *Prosphinctes* sp., ?*Epipeltoceras* sp., *Planites* (*Ataxioceras*) sp. indet., *Klematosphinctes* aff. *mirus* (Bukowski), *Glochiceras nimbatum* (Oppel), *Neospidoceras* sp. indet., *Vinalesphinctes* ?sp. indet., *Trimarginites* aff. *arolicus* (Oppel), *Ochetoceras* sp. juv. aff., *canaliculatum* (v. Buch) (all from near the top) with perisphinctids (?*Choffatia* sp.), *Peltoceras indicus* SPATH,?*Reineckia* sp. (all from near the base; Dunnington et al., 1959), giving clear Late Oxfordian to Early Kimmeridgian age and a possible Callovian age for the base (Dunnington et al., 1959).

Lithofacies The Naokelekan Formation at outcrop is represented by thin, ammonitic/radiolarian, euxinic shales and limestones. It has been divided into a tripartite stratigraphy, with a basal 'Coal Horizon' consisting of thin-bedded, extremely bituminous limestones and dolomites, with intercalated black, bituminous shales; a middle 'Mottled Bed', consisting of hard dark grey or bluish limestones that are mottled and calcite veined; and an upper bed that is generally poorly exposed but includes laminated shaly mudstones at its top (Dunnington et al., 1959). The age-equivalent Najmah Formation consists of oolites and peloidal limestones (Dunnington, 1958; Dunnington et al., 1959; Ibrahim, 1981; Figure 81). The Najmah Fm. (sic.) may also occur in a condensed basin centre facies similar to the Naokelekan Formation; this is the case in the Makhul-2 well and other wells in central Iraq such as Awasil-5 (Dunnington et al., 1959) but is better known as such from wells in southern Iraq, Kuwait and Saudi Arabia (ARAMCO, 1959; Jaber, 1975). In these cases, it consists of calcareous shales, with alternating 'pseudo oolitic' and coprolitic limestones, with some beds of 'highly characteristic' oolitic limestone (Dunnington et al., 1959). It should therefore be noted, that the term 'Najmah' in central and parts of southern Iraq, is synonymous with the term 'Naokelekan' in northern Iraq, or at least has more in common with the northern Iraqi Naokelekan Formation than the northern Iraqi Najmah Formation.

Interpretation The Late Jurassic limestones represent a further phase of infill of the 'Gotnia Basin' such that the Najmah Formation represents downstepping of the basin margin carbonates such that this wedge of shallow-water facies sits on the lower slope (mid-outer ramp part) of the older

3.4. EARLY CRETACEOUS MEGASEQUENCE

3.4.1. Introduction

Early Cretaceous rocks are present and crop out in Kurdistan and are also present in many of the wells which penetrate beneath the Tertiary section. The Early and Middle Cretaceous represent progressive drowning of the mid-Tithonian unconformity, with establishment of coastal deltaic complexes to the SW behind carbonate-evaporite lagoons. Platform margins and basinal sediments of this age are known from the outcrop in Kurdistan.

Given that the Cretaceous nomenclature is probably the most complex and confusing, and also because formation names in adjacent parts of Syria and Turkey are different to the Iraqi terms, a figure has been prepared for use with this and the following megasequence (Figure 88).

type II source rock in southern Iraq, with marine and admixed terrestrial kerogen including some plant, pollen and spore debris. TOC's range from 0.14 to 8.85%, with yields of 2-50kg HC/tonne, and HI of 200-400 mgHC/g. This source rock system in the Basrah area of southern Iraq entered the oil window in the early Miocene. Both the Balambo and Chia Gara formations are cited as source rocks for oils in the Yamama Formation of southern Iraq (Al-haba and Abdulla, 1989).

central Kurdistan, there are marls and limestones of the Ratawi Formation (Dunnington et al., 1959). This is also the case in the Ghouna-1 well in Eastern Syria, where marls and marly limestones are developed (Dunnington et al., 1959); these pass to the southwards towards the Euphrates Graben into clean lower sandstones of the Rutbah Formation (de Ruiter et al., 1995).

Interpretation The Aptian shelf development is interpreted as one of accretion (Wilson, 1975; Figure 95) as carbonate productivity kept pace with a subsequent transgression. Consequently, sediment was not supplied into the adjacent euxinic basin, and the shelf margin gradient steepened (Figure 95). Qamchuqa Formation grainstones and rudist reef/*Lithocodium* algal framestones and boundstones were interpreted by Henson (1950) as 'bank shoal reefs', passing westwards into the backreef dolomitised alga-foraminiferal limestone (Wilson, 1975; Figure 93). The shelf break passed through the SE culmination of the Jambur Field (Al-Rawi et al., 1980; Figure 91) and ought to be present along strike in the eastern part of central Iraq (Figure 97) as the Injana-5 well appears to penetrate purely basinal Balambo facies (Dunnington et al., 1959). The shelf margin reappears in SW Iran (Kent at al., 1951), but its course to the east the SE of northern Iraq ideally requires mapping on seismic.

Behind the platform margin carbonates, facies belts were dominated by the Upper Qamchuqa/Shu'aiba Formation platform top to lagoonal system (Figure 97). These locally pass into the lagoonal *Orbitolina* marls of the uppermost Ratawi Formation/Lower Ghouna Beds; these marls may represent influence of the coastal/shallow marine clastic systems of the Rutbah Formation that were prograding northwards onto the shelf from the Euphrates Graben area of Syria (de Ruiter et al., 1995; Caron et al., 2000).

Summary of Economic Potential The shelf carbonate facies produce light oil from both the Baba dome of the Kirkuk structure (31°API), Bai Hassan (22°API), and Jambur (40°API) (Dunnington, 1967; Al-Rawi et al., 1980). Breached accumulations are present in the Kurdistan outcrop, at Pir-i-Mugrun to the west of Sulaimania (Henson, 1950), and in other but unspecified anticlines (Dunnington, 1958). Dunnington notes (1958) that the shelf and reefal facies of the Qamchuqa Fm. in northern Iraq "are locally of high porosity and permeability; they are classed as excellent potential reservoir and carrier formations".

Dolomitisation of the Qamchuqa has not been well constrained. It could either have been via the effects of seawater reflux through the shelf margin into the evaporitic lagoonal complex, as associated with evaporitic lagoons and hypersaline ponds elsewhere, e.g. in the Early Permian Clear Fork Formation of Texas (Handford, 1981; Handford and Bassett, 1982) or it may have had a hydrothermal origin (c.f. the dolomitised Sarvak carbonates in the Anaran anticline; Sharp et al., 2003).

Summary of Economic Potential The Qamchuqa Formation is a productive reservoir in the Baba Dome of Kirkuk with 34°API (Dunnington, 1967), also in the Khabbaz Field with 24°API (Sadooni and Aqrawi, 2000) and also in the Ain Zalah (Hart and Hay, 1974) and Jambur (Al-Rawi et al., 1980) fields. Al-Shdidi et al. (1995) note core porosities of 15-25% (average 20%) with a log porosity of 18% in the Qamchuqa, contrasting with 2-3% porosity in the downdip Sargelu Formation slope facies. In Ain Zalah, the reservoir character is slightly different, and is likely to be analogous for Mauddud/Qamchuqa reservoir in NW Iraq. The ‘second pay’ in the Ain Zalah Field is approximately 400m thick in total, and is essentially a fracture reservoir with additional contribution from beds of permeable and porous dolomites, which offer the possibility of a large volume of sustained production (Gibson, 1948). They operate with a very effective water drive. In general though, dolomite content and the relationship to porosity is extremely variable and unpredictable (Henson, 1950).

In the northern Iraq the main reservoir issue is probably the presence and then preservation of the Mauddud Formation. The formation appears to be locally developed within the graben systems towards Ibrahim, but may be absent off the fault block highs. In addition to the productive fields, the Mauddud/Upper Qamchuqa formation is present in the Makhul-2, Awasil-5, Adaiyah-1, Atshan-1, Alan-1, Butmah-2 wells, but towards the SE corner of NW Iraq and specifically in the Sadid, Hibbarah, Jawan, Qalian, Najmah-29 wells the Qamchuqa passes into more evaporitic and less porous Jawan/Batiwah formations (Dunnington et al., 1959). The Mauddud Fm. has been suggested as a carrier bed for the Kirkuk palaeostructure, and for the fields in the Najmah area to the west of the Tigris (Dunnington, 1958; 1967). This is because of the widespread sheet-like development of this limestone (Figure 102) and its development above the thick pile of high-yield Jurassic

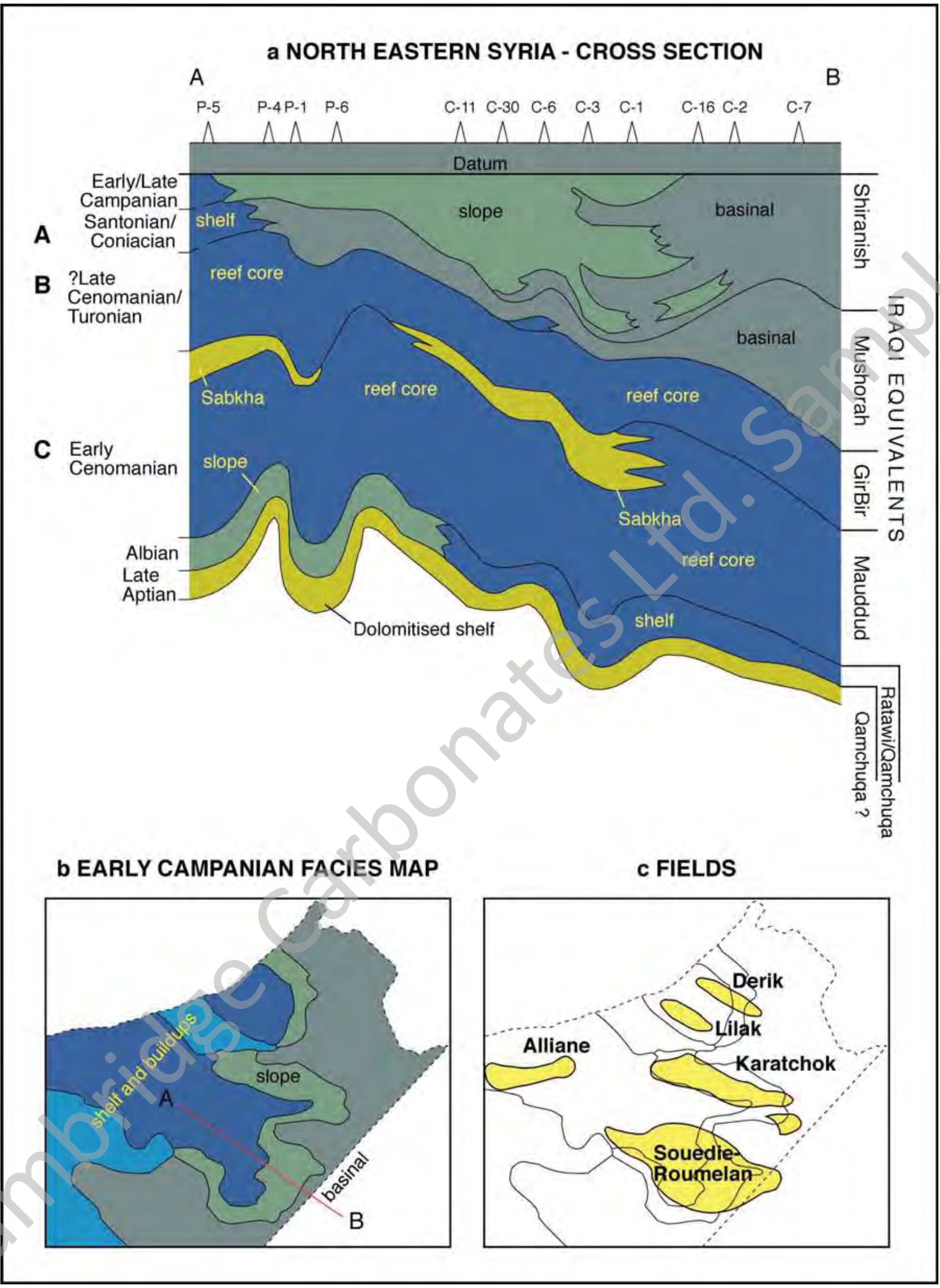


Figure 104 Cretaceous stratigraphy of NE Syria. After Nikolaevskiy, 1972

In SE Turkey, the Derdere Fm. is an upwards-shoaling carbonate (Tasman and Egeran, 1952; Wagner and Pehlivan, 1987). During the Middle Turonian field correlations. This demonstrated that there is an unconformity that is locally-developed on the top of the Mushorah, which is here interpreted as being possibly due to erosion prior to and during the Middle Campanian rifting.

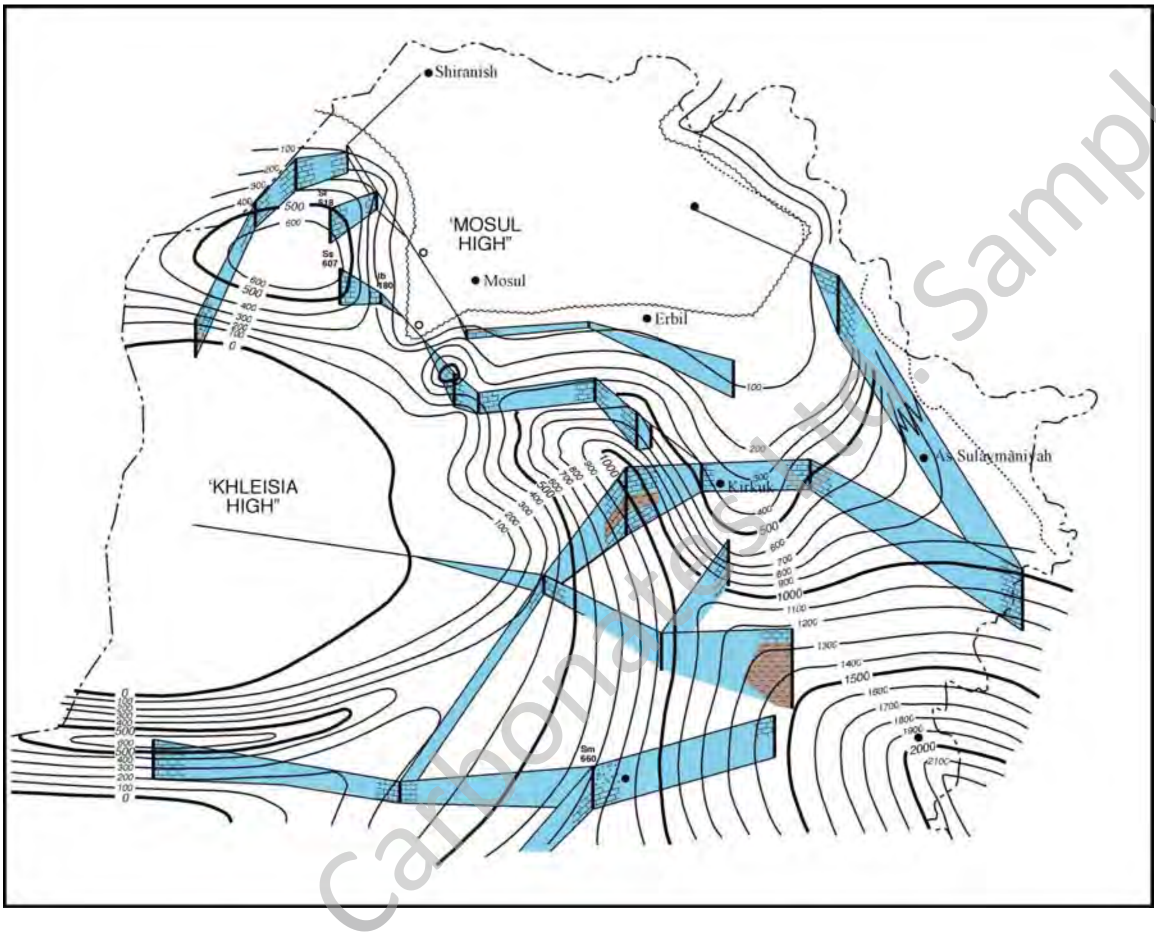


Figure 109 Correlation of Middle Turonian-Early Campanian units in northern Iraq. After Kaddouri, 1982b

Sequence stratigraphy Within this interval, are the K150 and K160 maximum flooding surfaces of Sharland et al. (2001). In addition, a further surface (K165) can be identified in northern Iraq, sitting within the Early Campanian, at the contact of the Wajnah and Mushorah formations in the Ain Zalah Field (cf. Hart and Hay, 1974). Deposition followed the Middle Turonian eustatic lowstand, whilst further lowstands resulted in incursions of clastic-dominated units, notably the Derro/Tanuma formations as lowstands to the K160 MFS, and a marly unit within the Sadi (Hamarina Marl Member) as lowstand to the K165 MFS.

Palaeontology and Age The Gulneri Formation has been very well-dated as Early (but not earliest) Turonian (Dunnington et al., 1959).

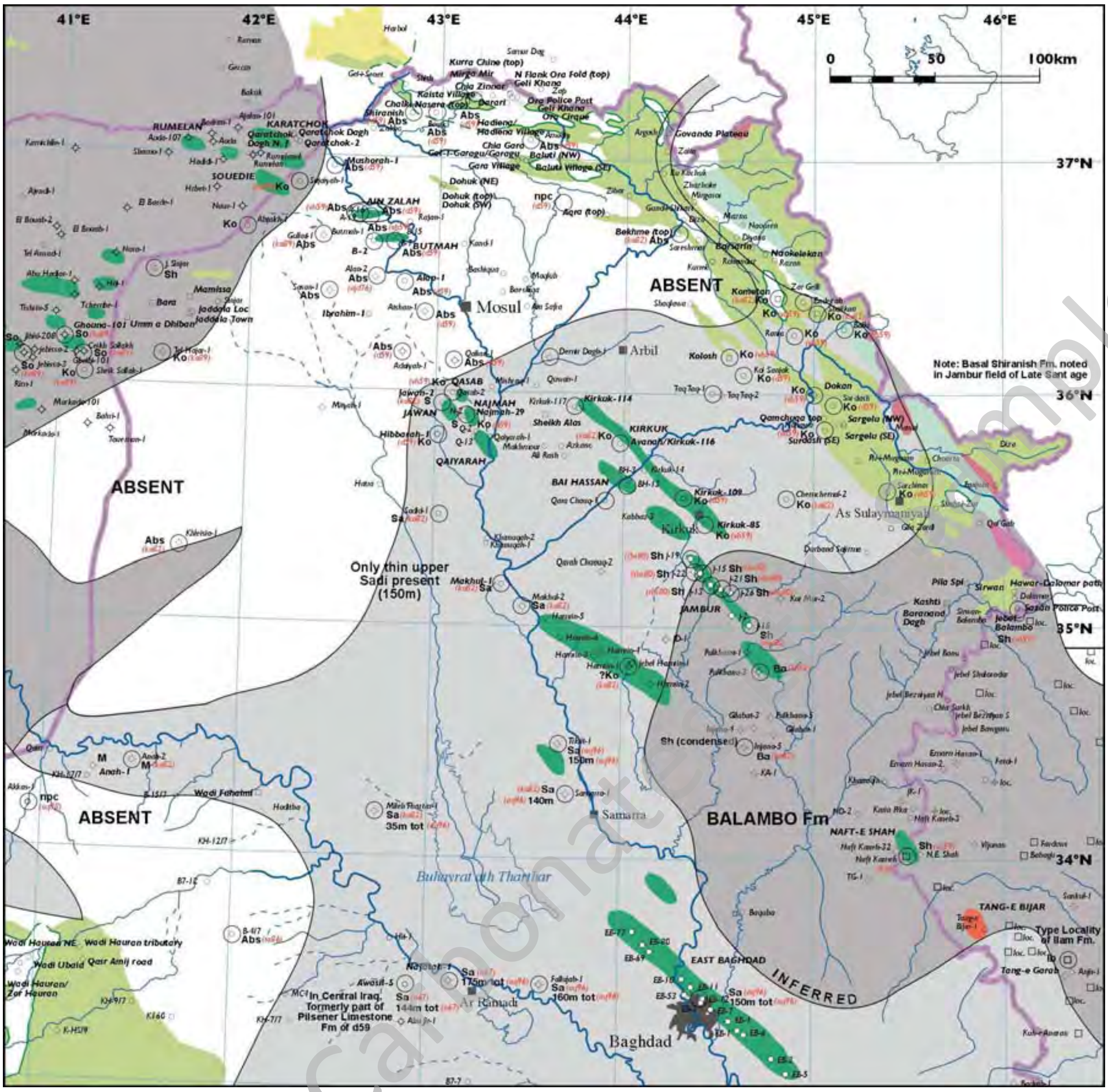


Figure 115 Santonian facies, K160 HST, modified Cambridge Carbonates map.

The depositional environment of the Rmah and Karababa-A formations was probably that of an oxygen-minimum shelf, probably due to the platform top being silled to the N and E by slices of obducted ophiolite thrusts, and input of iron and phosphate from weathering of the Arabian shield centre to the S and W probably added to the degree of organic activity (cf. Glenn and Arthur, 1990) although input of these nutrients could probably also be achieved by weathering of ophiolite sheets (N. Pickard, pers. comm.., 2006). The more restricted intervals were associated with the Early Santonian age transgression (K160 MFS of Sharland et al., 2001), which was also a time of emergence on the Khleisia-Mosul high. Continued emergence or elevation is also indicated by the prominence of the Joura Ridge at the NW end of the

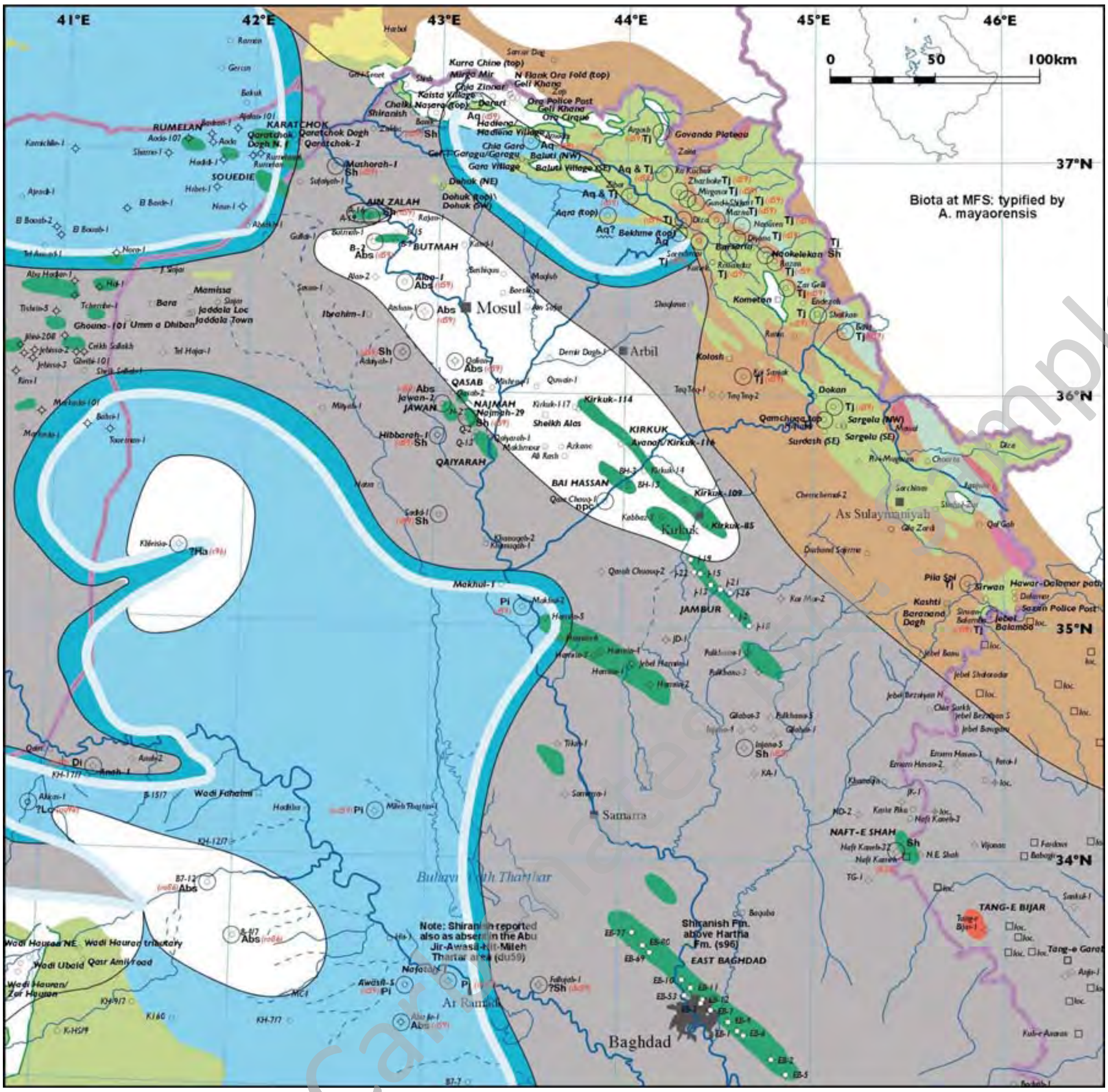


Figure 120 Late Campanian facies, K175 HST, modified Cambridge Carbonates map.

Further a field, depositional environments probably did not differ radically to those seen in northern Iraq. However, the organic-rich Campanian age Karabogaz Fm. of SE Turkey is thought to indicate deposition on a shelf exposed to upwelling, oxygen-poor and nutrient-rich water (Wagner and Pehlivan, 1987). The subsequent deposition of the Sayindere Formation is also organic rich at its base, but this is attributed to global Cretaceous deepwater anoxic events (Wagner and Pehlivan, 1987).

resulted in compression and uplift of the Late Cretaceous flysch basin, and in migration of the Palaeogene flysch-filled foreland basin to the southwest. This depocentre passed into a carbonate shelf along the line of the Kirkuk structure, with slope/basinal environments developed to the southwest of that (Figure 124). The Kolosh Formation clastics are developed close to the thrust front, from which they were derived following uplift of the ophiolite (Figure 122 Figure 124). The Khurmala Formation represents restricted lagoonal overlain by tidal mud flat and biohermal sediments that built out from the clastic hinterland. Isotopic work indicates that the formation in Kirkuk was stabilised in a well-oxygenated meteoric aquifer (Majid and Vezier, 1986).

Initially, in the Palaeocene a clastic ramp system developed comprising the Kolosh Fm. flysch sandstones and Aaliji Fm. basinal mudstones (Majid and Vezier, 1986). The transition of the initial clastic ramp to a carbonate rimmed shelf (Majid and Vezier, 1986) occurred at the same time as colonisation of inversion structures, such as Jebel Sinjar in N. Iraq and Jebel Abd-El-Aziz in Syria, by nummulites and other shelf benthics (Daniel, 1954). These often became sites of Late Palaeocene “bank reef” development (c.f. Henson, 1950). In the Early Eocene, a thin and patchy nummulite bank complex with bank, fore-reef and washover grainstones (the Sinjar Limestone Fm.) developed across NE Iraq, whilst many areas which had not previously received any Palaeocene sedimentary cover became sites of basinal (Aaliji Fm.) deposition (Figure 124; Henson, 1951; Tasman and Egeran, 1952).

Stratigraphically younger sections of the Kolosh Fm. clastic flysch sediments demonstrate an 'intricate' interrelationship behind the rimmed shelf margin, intercalating with nearshore mudstone and limestones of the Khurmala Fm., Sinjar Fm. nummulitic bank facies, and fore-reef and globigerinal marls of the Sinjar/Aaliji and Aaliji formations (Dunnington, 1958). These suggest that the detailed sedimentology of the basin fill is complex, with many changes in water depth due to variations in subsidence and infill rate. The fore slope and the nearshore/mudflat sediments updip, in conjunction with the role of the structural highs, prevented clastics of the Kolosh Fm. from bypassing the shelf margin carbonates and infilling the basin to the SW.

3.6.4. Oligocene

Resource potential in northern Iraq:

Reservoirs None

Cap rocks The Ibrahim/Tarjil/Palani basinal formations have potential to be cap rocks

Source rocks None known

Trap types Not applicable

Lithostratigraphy and interpretation/palaeogeography:

Lithostratigraphy and Contacts The Oligocene stratigraphy of the Kirkuk Group may be subdivided into three intervals, with an Early Oligocene aged sequence, (Shurau/Sheikh Alas/Palani formations), a Middle Oligocene aged sequence (Bajawan/Baba/Tarjil formations) and a younger Late Oligocene (Chattian) aged sequence (Anah/Azkand/Ibrahim formations).

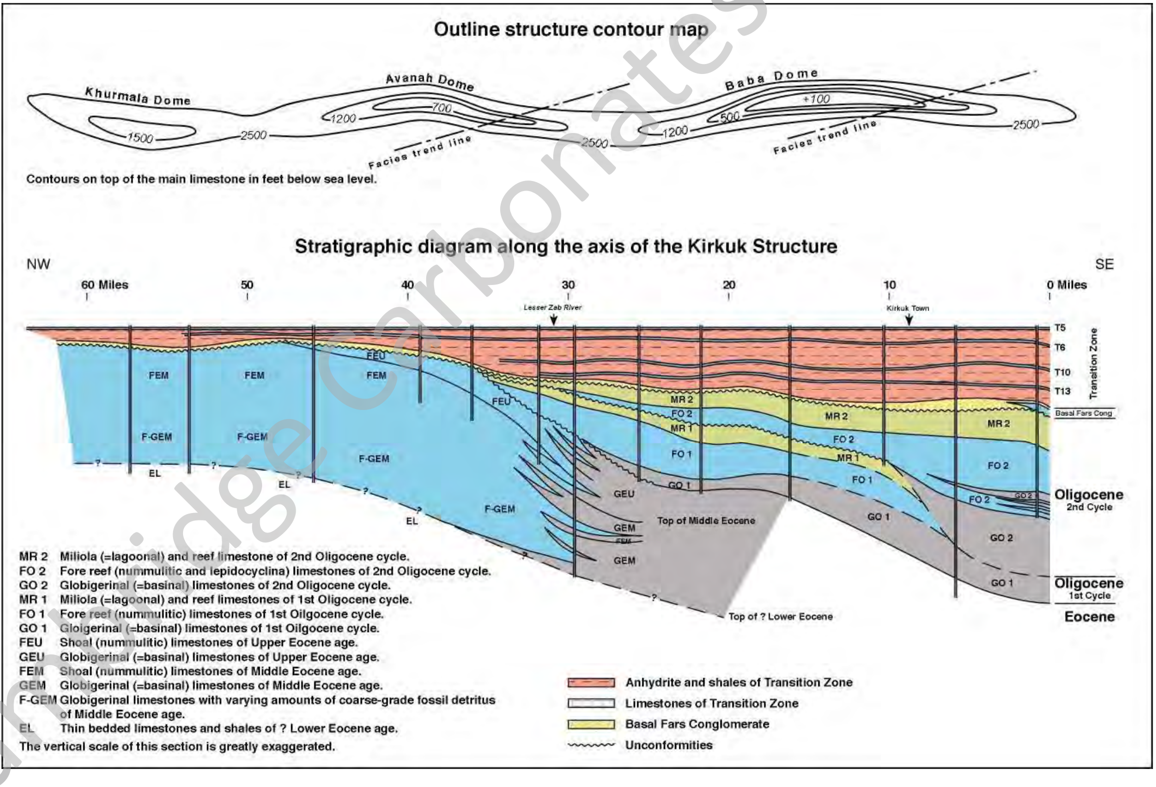


Figure 126 Organisation of facies belts along the Kirkuk anticline. After Daniel, 1954

These represent offlap of the stratigraphy into the basin (Figure 126), as may be expected following the major early Chattian lowstand as marked on the Vail/Haq curve. One example of these divisions is seen in Ain Zalah, where Hart and Hay (1974) describe the 41m thick Sheikh Alas Fm. as fine to

impermeable.
3. Fractured Oligocene lagoonal and reef facies, which are generally porcellaneous and non-porous.
4. Porous and permeable Oligocene nummulite bank or fore-reef limestones, and diagenetically altered nummulite washover facies of Eocene age.
5. Porous but low permeability Oligocene and Eocene aged thin bedded and well jointed basinal globigerinal limestones.
6. Middle Eocene age slope turbidites, in which bioclastic detritus is present in poorly bedded globigerinal limestones.

These zones pass down into basinal mudstones, the contact of which is variable and gradational. The total thickness of the first pay is approximately 300m. Each culmination has a slightly different Tertiary unit at different depths within the main (first) pay zone; the Khurmala dome has Eocene nummulite bank and backreef carbonates at 760m, the Avanah dome Middle-Late Eocene nummulite bank to Oligocene backreef carbonates at 610m, and the Baba dome, Oligocene carbonates at 300m (IPC, 1956; Dunnington, 1958).

There is an almost instantaneous transmittal of pressure drop over great distances across this pay during production, reflecting the extreme connectivity and the development of the reservoir as a single pressure sink (Freeman, 1952a). Wells on the flanks of the Baba dome alone could probably drain the entire pay, albeit slowly according to Daniel (1954), who also cites that the maximum water rise of the OWC was 40km (25 miles) distant from the production facilities in 1954.

A gas cap was originally present in the Tertiary reservoir of the Khurmala dome and there is an active surface gas seep at the present day in the Baba dome. As of 1956, production had resulted in sufficient drop in formation pressure that a gas cap developed in the Baba dome and was developing in the Avanah dome (IPC); only the Tertiary of the Baba and Avanah domes were produced by IPC at this time. GOR of the original oils was 200-220 cu. ft. /bbl. Production was initially by water drive, with gas cap drive increasingly important as the pressure dropped. Oil was driven up towards the OGC via fractures during production, resulting in lowering of the saturation pressure and liberation of gas into the gas cap (IPC, 1956). The intense fracturing also resulted in rapid pressure communication of the Tertiary reservoir across the field. There are also high production rates from wells which have a very small

Carbonates map.

Onlap onto the Oligocene is probably due to the Oligocene margin subsiding at a greater rate than the more active NE margin. The Euphrates Limestone developed on many of the areas of the Palaeogene basin floor that had previously been sites of condensed deposition, supporting the hypothesis that the Palaeogene foreland basin floor was uneven and had intrabasinal highs that received little sediment (Dunnington, 1958) until the sea level was low enough for the Euphrates to be nucleated on them. Elsewhere, the Euphrates Limestone thins over present-day structural highs (van Bellen, 1959), indicating that there was some slight inversion during the Early Miocene.

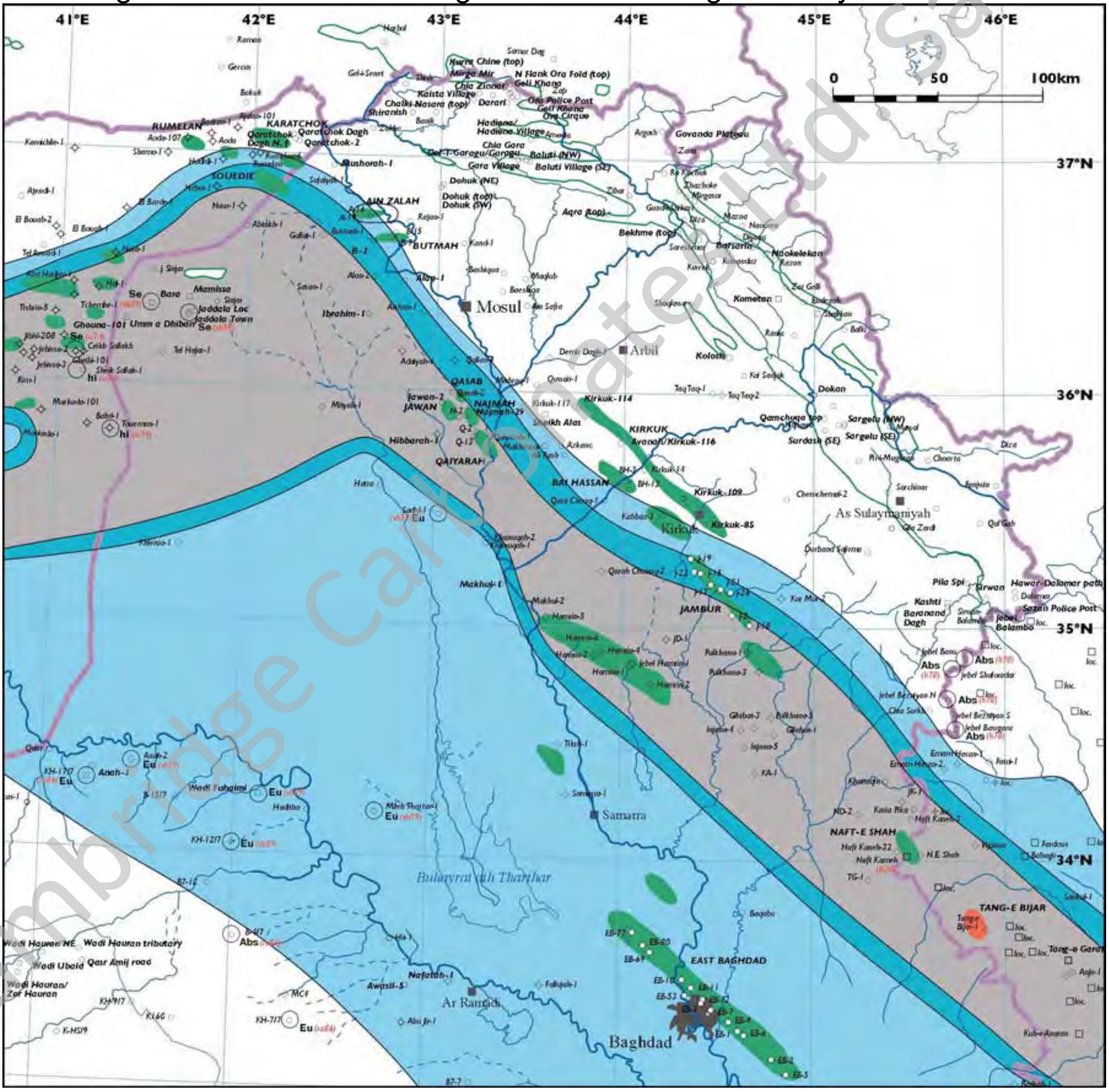


Figure 133 Earliest Aquitainian facies, Ng10 MFS, modified Cambridge Carbonates map.

Throughout Euphrates Limestone deposition, the former Eocene-Oligocene shelf was emergent and probably undergoing somewhat more karstification

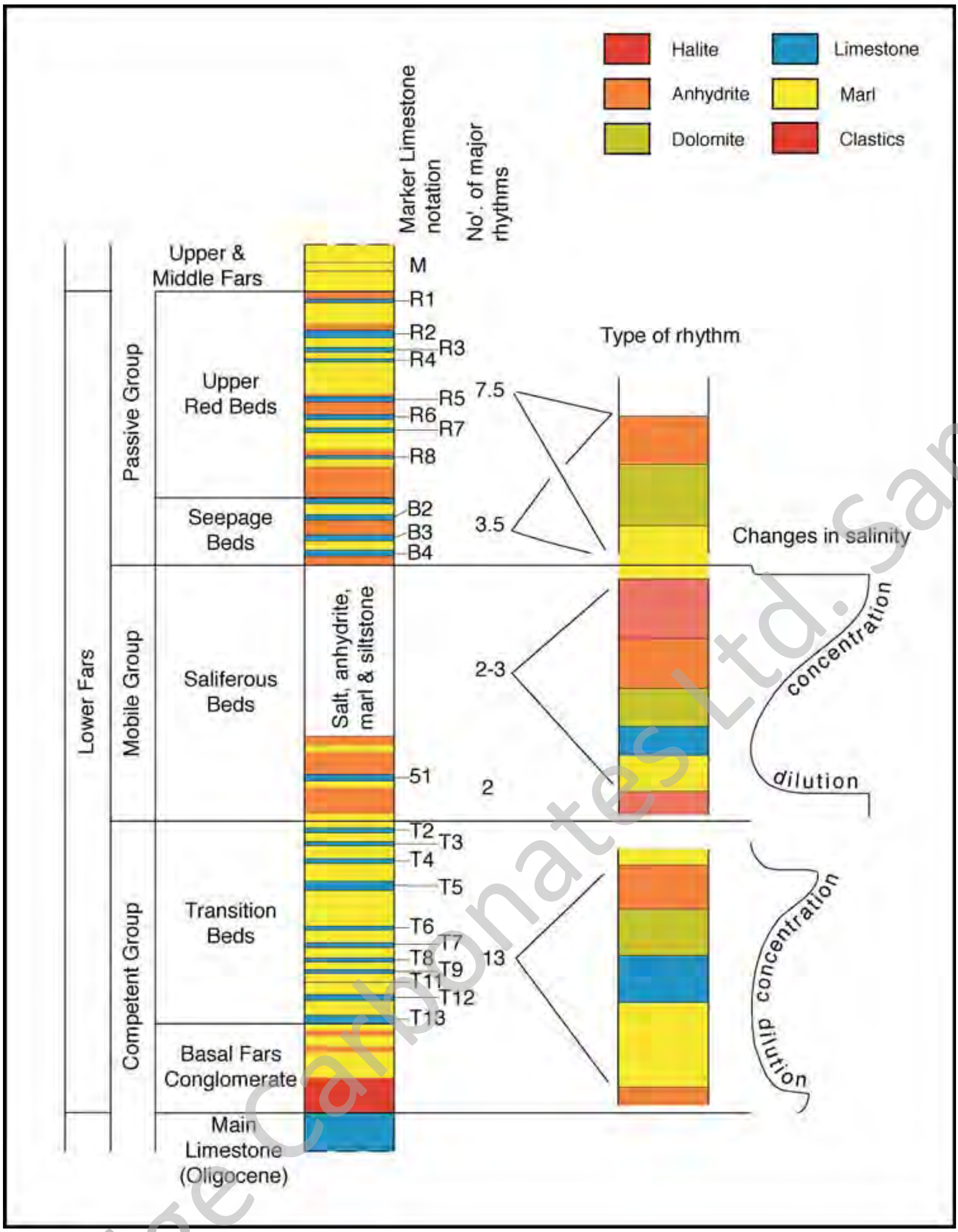


Figure 138 Organisation of large and small-scale cyclicity in the Lower Fars Formation of Kirkuk. After Dunninton, 1968

On highs, such as the basin margins, the succession is thinner (Figure 139). Cycles contain thick stromatolitic and algal laminated carbonates, laminated peloidal and bioclastic limestones, massive and bioturbated packstones and cross-bedded grainstones. The packstones and grainstones have a fauna of bivalves, gastropods, bryozoans, foraminifera, echinoids and crustaceans, with additional allochems such as ooids and oncolites. Halite is absent, and the anhydrites are in nodular facies (Shawkat and Tucker, 1978; Tucker and Shawkat, 1980). Fine grained clastics are sometimes present in the cycle bases on the northern margin of the basin and anhydrite, although ubiquitous, is most widespread on the southern side of the basin (Dunnington, 1958).

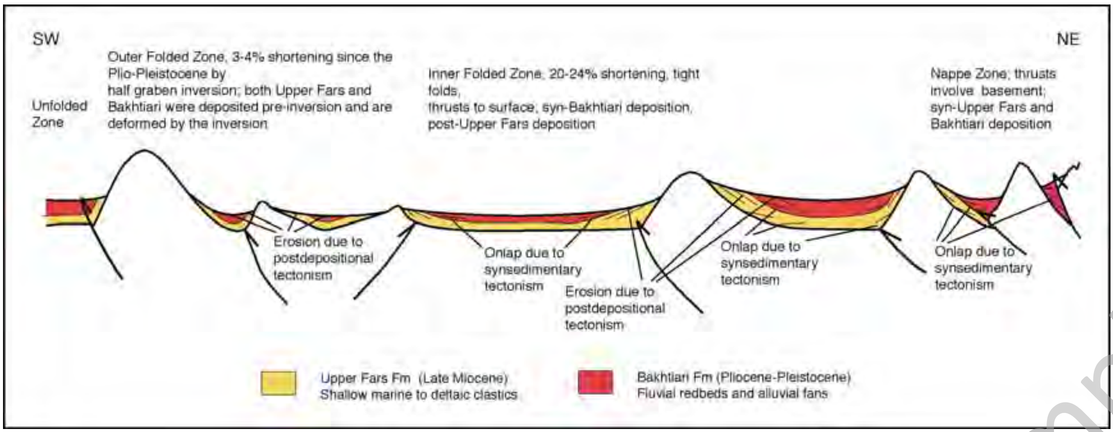


Figure 144 Model for Upper Fars and Bakhtiari deposition. Modified Cambridge Carbonates figure.

Summary of Economic Potential The Bakhtiari Formation represents the main phase of Jurassic source-rock maturation, because of the extreme loading of deeper parts of the basin system. In terms of other possible features of economic interest, it is possible that locally the fluvial/alluvial sandstones and conglomerates may form poor quality reservoirs. Cap rocks could be represented by poorly developed intraformational mudstones, and there are possible plays within pinchouts of sandstones onto the flanks of the inversion anticlines and growth structures.

4.2.2. O40 MFS seal/O30 HST reservoir

The play risk beneath this seal is summarised on Figure 147

Play potential in northern Iraq:

Reservoirs Probable poor quality reservoir in the Khabour Formation sandstones, due to their fine-grained and probably thin-bedded nature. However, these sandstones are likely to be extensive and the stratigraphic thickness would indicate that at least some net:gross should be expected. Reservoir quality will probably deteriorate rapidly into non-reservoir due to burial compaction off the flanks of the Khleisia High.

Cap rock O40 MFS shales (Raan equivalent); these are classified as low risk because the shale unit appears to be thicker than the underlying O30 MFS shales.

Source rocks This system would likely be sourced by potential within the same O40 MFS shales, or possibly from deeper (Cm20 to O30 MFS associated) organic-rich mudrocks. Given the burial history, a dry gas charge would be expected.

Trap types Late Tertiary inversion anticlines; rotated late Cretaceous fault blocks; possible complex stratigraphic pinchout traps between individual sandbodies (similar to Risha in Jordan).

4.2.7. Tr50 MFS and Early HST seal/Tr40 HST reservoir

The play risk beneath this seal is summarised on Figure 152

Play potential in northern Iraq:

Reservoirs Here the collapse breccias at the base of the Geli Khana, together with possible associated sandstones, are the likely reservoir target. In this case, it is likely that the updip sandstones could be a better quality reservoir than the down-dip collapse breccias, which may remain plugged with anhydrite. Reservoir quality is likely to decrease towards the east due to increasing burial.

Cap rock The flooding surface at the base of the Upper Geli Khana is here identified as a possible regional seal. Risks involved with this are it being fractured if too carbonate-rich. Updip to the west, the seal is likely to be sandier and therefore, poorer quality.

Source rocks This play would probably rely mainly upon the Ora Shale and/or S10 (Akkas Formation) source rock. It is possible that there could be a contribution from a Tr30 and Tr40 MFS source rock by analogy with discoveries in Syria, but this source remains unproven in Iraq.

Trap types Late Tertiary inversion anticlines; rotated late Cretaceous fault blocks.

4.2.12. K40-60 MFS to HST seals/K30 HST reservoir

The play risk beneath this seal is summarised on Figure 157

Play potential in northern Iraq:

Reservoirs The probable reservoir is the Garagu Formation. Reservoir quality is likely to be moderate that although oolitic, little or no production is known from this interval in northern Iraq. Reservoir quality is limited to the west by the limits of Early Cretaceous onlap, and to the east, by transition into deeper-water Sarmord and Balambo facies.

Cap rock Marls, shales and mudstones of the Ratawi (formerly Middle Sarmord Formation) are the likely cap rock. These have an uncertain sealing capacity, but are thought to be of best quality where not too sandy (i.e. away from the Zubair deltaic facies to the SW) and not too limestone dominated leading to problems of fracturing (i.e. not too close to the shelf margin).

Source rocks It is most likely that the main source rock system that would charge this play is the Middle Jurassic-Early Neocomian system of the Gotnia Basin, above which much of the reservoir unit has prograded. Shallower source rocks are likely to be immature. There are possible contributions from older source rocks as noted previously, but these are likely to be insignificant. Long distance migration is also possible given the sheet-like nature of the reservoir facies.

Trap types Late Tertiary inversion anticlines; onlap traps; rotated late Cretaceous fault blocks.

This is productive in the Kirkuk and Ain Zalah fields. It is most productive (most fractured) where end-Cretaceous erosion and recrystallisation modified original depositional textures.

Cap rock Marls, lime mudstones and shales of the Aaliji, Jaddala and Ibrahim/Tarjil/Palani formations are sealing facies. These basinal formations are often present only very locally due to stratigraphic condensation within the Palaeogene basin floor, but some stratigraphy is usually present over most of the basin. However, towards the NE, they pass into more flyschoid and shallow-water carbonate shelf facies, that have little or no sealing potential.

Source rocks It is most likely that the main source rock system that would charge this play is the Middle Jurassic-Early Neocomian system of the Gotnia Basin, above which much of the reservoir unit has prograded. There are possible contributions from older source rocks as noted previously, but these are likely to be insignificant. Shallower source rocks are likely to be immature. Long distance migration is also possible given the sheet-like nature of the reservoir facies.

Trap types Late Tertiary inversion anticlines.

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