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LITHOSTRATIGRAPHY AND SUBSURFACE GEOLOGY OF THE ALBIAN ROCKS OF SOUTH IRAQ

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The Nahr Umr Formation is argued here to be in physical and possible chronological continuity with the exposed Rutbah Sandstone Formation of Western Iraq. This stratigraphic relation is postulated on the basis of subsurface mapping.

The presently available information, i.e. lithofacies data, well logs, petroleum occurrences, and structural traps availability were evaluated in order to present a preliminary prospect evaluation. It appears that the Albian petroliferous belt coincides with: a marginal-marine environment of deposition, a sand/shale ratio of >1 <8, and a Cretaceous growth of structural traps.

INTRODUCTION

The Albian rocks of South Iraq are composed of the sandy Nahr Umr Formation (Albian) and the calcareous Mauddud Formation (Albian) (Dunnington *et al.*, 1959). This study is an analysis of the subsurface geology of the Mauddud and Nahr Umr Formations, using final well reports of boreholes drilled in South Iraq and surrounding areas (Table 1 and Fig. 1). The Albian lithostratigraphic units are bounded by the post-Shuaiba unconformity below and a post-Mauddud/pre-Ahmadi dis-conformity above (Fig. 2).

The present-day stratigraphic picture of the Middle East tends to unify the stratigraphic correlations of the exposed Rutbah Sandstone Formation and the carbonate Cenomanian Wasia group of Iraq with that of the sandy and carbonate facies of the Wasia Formation of Saudi Arabia (Dunnington, 1967; Powers *et al.*, 1966; Powers, 1968).

Apart from the Nahr Umr oilfield, the Nahr Umr Formation is not exploited as an oil producing zone in South Iraq.

Stratigraphic Units

Nahr Umr Formation (Glynn Jones, 1948)

The name Nahr Umr Formation was first applied in 1948 by Glynn Jones to describe a sandy and shaly interval between what were later known as the Shuaiba and Mauddud Formations of Southern Iraq (unpublished oil company report, 1948). The type section was later published by Owen and Nasr (1958) from Well Nahr Umr No. 2, between drilling depths 8,688-9,321 feet. Lithologically, the type section consists of "black shales interbedded with medium-to-fine grained sands and sandstones with lignite, amber and pyrite" (Owen and Nasr, *op. cit.*).

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The upper contact of the Nahr Umr with the overlying Mauddud Formation is conformable and gradational, placed at the base of the limestone of the Mauddud Formation and at the top of the black shale of the Mahr Umr Formation (Naqib, 1967).

The lower contact of the Nahr Umr Formation at the type section is with the Shuaiba Formation, where an unconformity was established on regional evidence (Dunnington, 1967), though Owen and Nasr had accepted conformable relations between these two formations. Fossil contents include *Orbitolina concava* (Lamarck), *Orbitolina discoidea, Orbitolina lenticularis* (Blumenbach), *Hemicyclammina whitei* (Henson), *Iraqia simplex* (Henson), pelecypods, algae, amber and plant remains. An Albian age was accepted on the basis of the fossil content.

However, the Nahr Umr Formation has been dated as Cenomanian in well Abu Khema B-1 in south western Iraq, by Venkatachala and Rawat (1980), basing their conclusion on the occurrence of an assemblage which is "distinguished by the appearance of triporate pollen *(Triporopollenites)* in association with *Tetracolpites, Monoporopollenites, Psiladiporites* and pteridophyte spores".

This palynologically based dating could indicate a simple case of mis-identification (with perhaps the Ahmadi Formation being mistakenly identified with the Nahr Umr). Future palynological age determination of the Nahr Umr Formation in its type region is desirable and could settle the anomalous dating at Abu Khema B-1.

The Nahr Umr Formation has been penetrated by many deep wells in Southern Iraq; it was thought to pinch out over the eastern flank of the Hail Rutbah Arch (Dunnington *et al.*, 1959). In the northern half of Iraq, the Nahr Umr Formation was reported from well Awasil No. 5, Nafatah No. 1, Fallujah No. 1, Mileh Tharthar No. 1, and it is thought to die out by lateral passage into Jawan Formation in wells Makhul No. 1 and 2. It is directly correlatable with the Burgan Formation of Kuwait.

The Rim Siltstone Formation of Well Alan No. 1 in northern Iraq is homologous and correlative with the Nahr Umr Formation (Dunnington *et al.*, 1959, p. 207).

Mauddud Formation (Henson, 1940)

The name was first applied by Henson (1940b) to a section in well Dukhan No. 1 (unpublished report cited by Dunnington *et al.*, 1959). This was revised by Sugden (1958) and published by Owen and Nasr (1958), where they cited a reference section in well Zubair No. 3, between drilling depths 8,457-8,910 feet, and described it as of "organic, detrital, locally pseudo-oolitic, cream-coloured limestone broken by occasional green or bluish shale layers" (Owen and Nasr, *ibid.*).

They also listed the following fossils from the Mauddud section of well Zubair No. 3: *Orbitolina concava* (Lamarck), *Iraqia simplex* (Henson), *Rabanitina basraensis* (Smout), *Trocholina* sp. and *Archaeolithiothamnium* sp.

The age of the Mauddud Formation was first published as Cenomanian (Owen and Nasr, 1958); this was later disputed by Dunnington *et al.* (1959), and an Albian age was favoured. The dating problem of the Mauddud Formation will be discussed later.

The upper contact of the Mauddud with the Ahmadi Formation is disconformable in Southern Iraq, taken at the top of orbitolinal limestones of the Mauddud Formation and below the dominantly shaly lower beds of the Ahmadi Formation. Marly or chalky limestones do occur at the base of the Ahmadi Formation in few localities, such as wells Buzurgan No. 2, Dujaila No. 1 and Kifl No. 1, but they are still more shaly than the underlying limestones. The Mauddud Formation pinches out on the eastern flank of the Hail-Rutbah Arch (Figs. 1 and 4), also it vanishes between Wara and Nahr Umr in Western Kuwait.

Stratigraphic correlation

A. *The Relationship of the Nahr Umr to the Rutbah Sandstone Formation*

The Rutbah Sandstone Formation was first reported by Foran and Keller (1937, unpublished report). Henson (1940b) selected the type section which was later

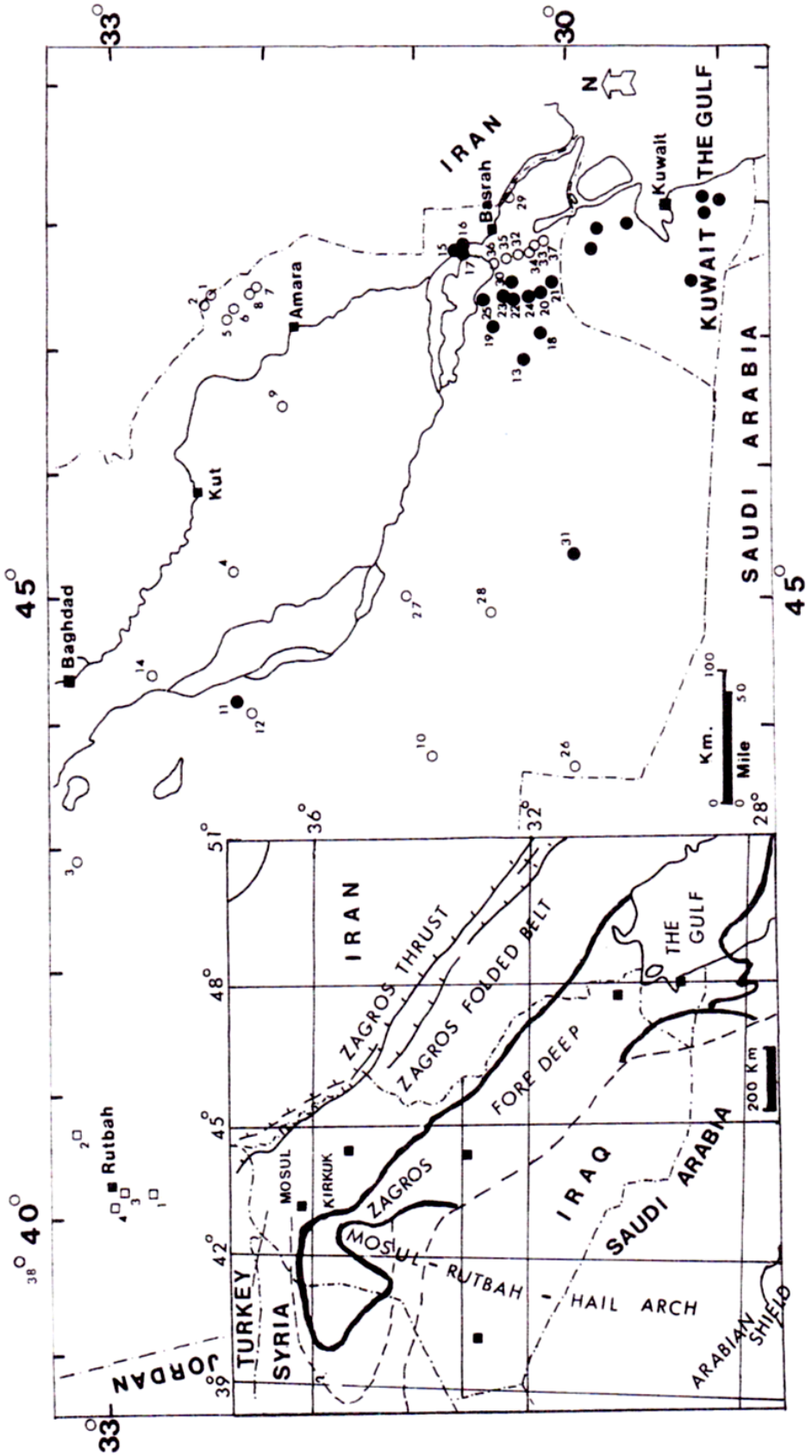

Fig. 1. Location map, solid well locations indicate producible oil from Nahr Umr Formation.

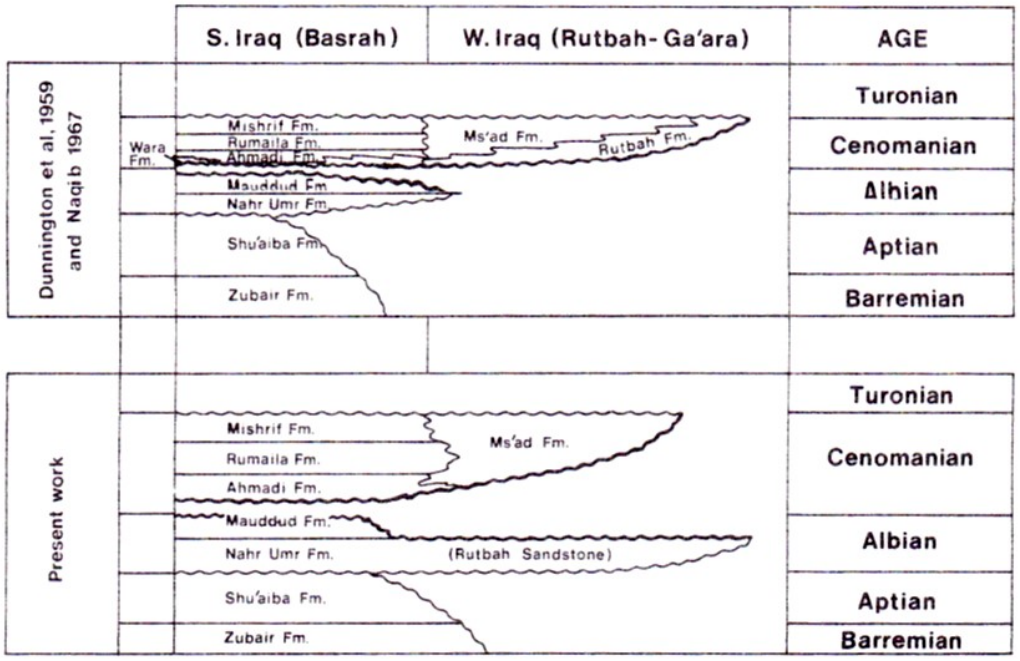

Fig. 2. Stratigraphic relationship of the Albian-Cenomanian rocks in S. Iraq.

published by Dunnington *et al.* (1959). The locality of the type section is between Wadi Ubeila and Rutbah. The base of the formation lies approximately at Lat. 33° 04′20″, Long. 40° 12′50″. It is 75 ft thick, of "vari-coloured, white and ferruginous, coarse to fine sands, and sandstones, locally cemented to quartzites". "Basal parts possibly of ontinental origin, upper parts marine" (Dunnington *et al.*, 1959).

No fossils were reported from the Rutbah Formation. The type section of the formation overlies the Mulussa Formation (Late Triassic) unconformably, with erosional discordance. It is overlain by the Ms'ad Formation in what was described as a transitional, gradational contact "taken at the base of the first definite limestone bed above the continuous sandstones of the Rutbah Sandstone" (Dunnington *et al., loc. cit.*).

The age of the Rutbah Sandstone could range from post-Triassic or Upper Triassic to pre-Cenomanian or Early Cenomanian according to Dunnington *et al.* (1959).

Barber (1948, p. 61) stated that the Rutbah Sand is equivalent to the Nahr Umr Formation and proposed an Albian age for both. This was later disputed by Dunnington *et al.* (1959, p. 206) conveying the field evidence of Wetzel and others that the Rutbah Sandstone is in gradational contact with the Upper Cenomanian Ms'ad Formation. The author believes that Wetzel's continuity and intergradation can be explained by reworking of loose sand into the base of the high-energy sediments of transgressive Ms'ad Limestone Formation.

The Ms'ad Formation at Rutbah area reflects a higher energy environment, capable of reworking the loose sand of the underlying Rutbah Formation (? hence giving an apparent gradational lower contact).

Naqib (1967) argued for a Cenomanian age for the Rutbah Sandstone and correlated it with the Ahmadi shale (Cenomanian); as the Ahmadi Shale was thought to grade laterally southward into the Wara Formation and into the Rutbah Sandstone Formation towards the W and NW of Southern Iraq (Naqib, 1967). However, the shale isolith and the sand isolith maps of the Cenomanian rocks (where shale and shaly carbonates are mainly the constituents of the Ahmadi Formation) show a pattern that suggests a southern source for the Cenomanian shale (Fig. 3),

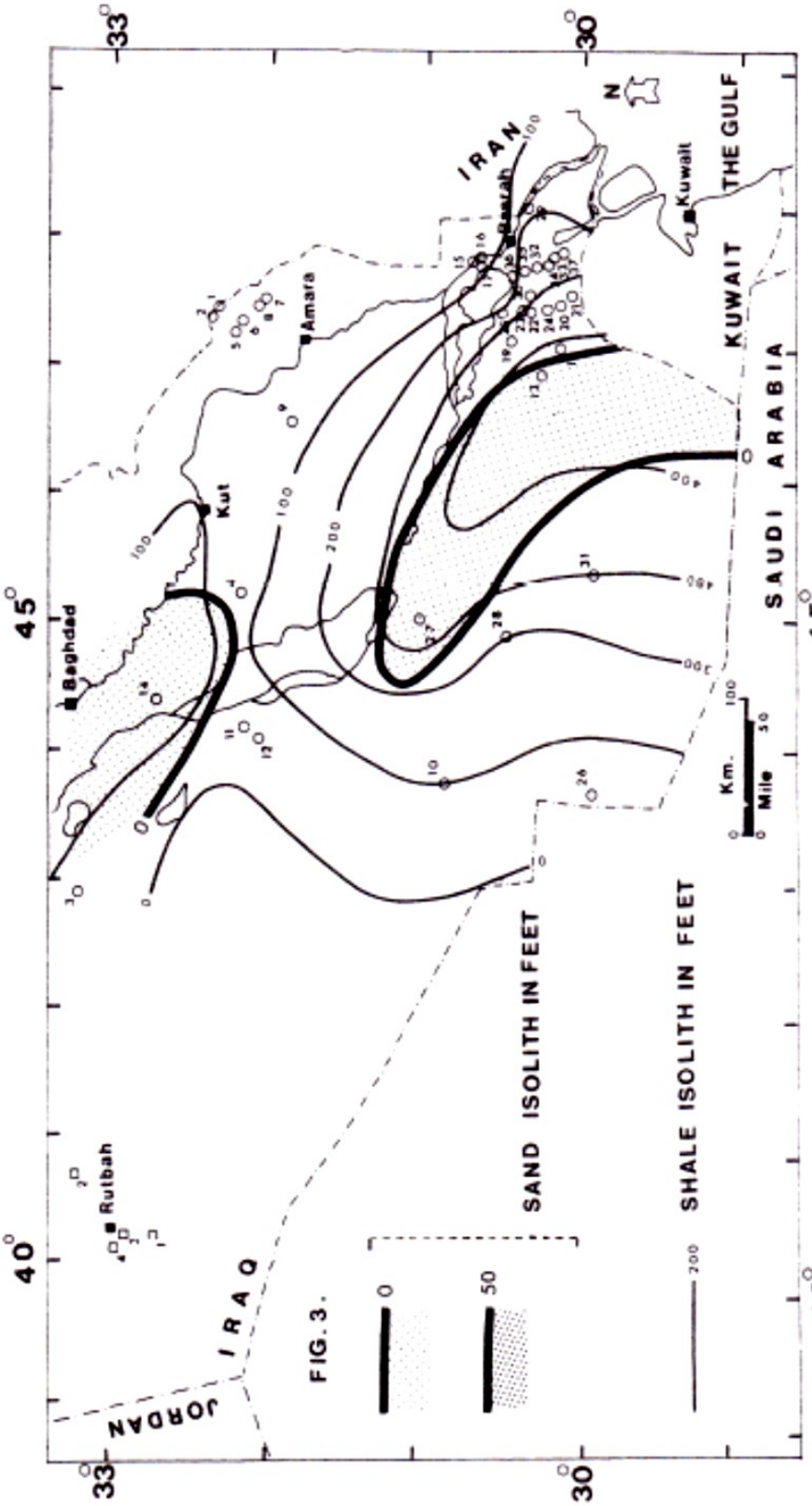

Fig. 3. Sand and shale isoliths map of the Cenomanian rocks of S. Iraq.

which could be genetically related to the Upper Wasia Group of Saudi Arabia and western Kuwait. The Rutbah Sandstone, on the other hand, is unlikely to have been deposited during the Cenomanian as there are no such obvious effects as sand interdigitations in the Cenomanian sediments of wells Safawi No. 1, Ghalaisan No. 1 and Kifl Nos. 1 and 2.

The Wara Formation has recently been drawn to be equated and intertonguing with the upper portion of the Mauddud Formation in the Kuwait and Basrah area, by Riché and Prestat (1980). Tongues of sand and shale have been reported by El-Sayed (1978) in the Mauddud Formation of the *Greater Burgan* field in Kuwait which can be attributed to the Nahr Umr and Wara Formations, but the Wara Formation is indistinguishable in South Iraq (Al-Khersan and Hassan, 1978; Ibrahim, 1978; Al-Saddiki, 1978). Although minor sandstone tongues occur in the Ahmadi Formation at well Rumaila No. 1 and in the Mauddud Formation at well Rachi No. 1. Shale tongues are present in the Mauddud Formation at wells Zubair No. 1 and Siba No. 1. Hence there is no parallel in the form of a mappable Wara Formation below the post Mauddud-Wara unconformity in Kuwait as suggested by Riché and Prestat (1980) and the Albians of South Iraq.

The present investigation proposes a physical correlation between the Nahr Umr and Rutbah based on the following data:

(1) There is no report of Rutbah Sandstone Formation in the Cenomanian subsurface sections around the exposed section of Rutbah Formation (e.g. no Rutbah Sand or any significant sand influx in wells Safawi No. 1, Kifl No. 1 and 2, Ghalaisan No. 1, Awasil No. 5, Fallujah No. 1 etc.). The Albian Nahr Umr Sandstone Formation, on the other hand, occurs in all of them. The absence of Rutbah Formation in these wells seems to contradict the strong NE cross-bedding transport direction of the sandstone of Rutbah Formation as measured by Kukal and Saadallah (1970) in the Rutbah area.

(2) The Ms'ad Formation thins northwards of Rutbah and wedges out E of Rutbah. The broadly correlative Mahilban Formation was reported from wells: Kifl No. 1, Awasil No. 5, Fallujah No. 1 and Mileh Tharthar No. 1 whereas the Rutbah Sandstone Formation, which thickens towards the E of Rutbah, was not recorded in these wells; Nahr Umr was reported instead.

(3) No influence of this sand body (Rutbah Formation) was noticed on the deposition of the post Mauddud Ahmadi Shale Formation, as was generally expected along with the Cenomanian dating of the Rutbah Sandstone Formation. The source of the main sandy facies that intertongues with the Ahmadi Formation has no relation to the Rutbah Sandstone Formation outcrops, as shown by Fig. 3.

(4) The apparently gradational contact between the overlying high-energy, Ms'ad Formation and the loose sand of the Rutbah Formation might possibly be due to reworking. Such situations do occur where the Mahilban (=? Ms'ad) Formation overlies the Nahr Umr Formation (e.g. at 3,764 ft below RTKB, in well Mileh Tharthar No. 1 in central-north Iraq).

(5) The isopach map of Nahr Umr Formation (Fig. 4) shows the possibility of accommodating up to a 100 foot thick sandstone section at the type locality of the Rutbah Formation in the Wadi Ubeila section, where a 75 ft thick continental Rutbah Formation section was measured.

(6) The Zubair Sandstone Formation is another possible correlative to Rutbah Sandstone Formation, but it was shown to pinch out on the eastern flank of the Hail-Rutbah arch and does not extend to the Rutbah and Ga'ara areas (Dunnington, 1958; Ibrahim, 1978).

(7) The minor sandstone anomaly in northern South Iraq (Fig. 3) is caused by the occurrence of glauconitic micropebbles of recrystallised limestone in the basal Mahilban Formation of well Awasil No. 5, and also in basal Mahilban and basal Fahad Formation in well Nafatah No. 1. Those occurrences and a sandstone interval in the lower part of the Ahmadi Formation at well Musaiyib No. 1 are (by virtue of location) probably derived from an elevated block at Mileh Tharthar No. 1 locality.

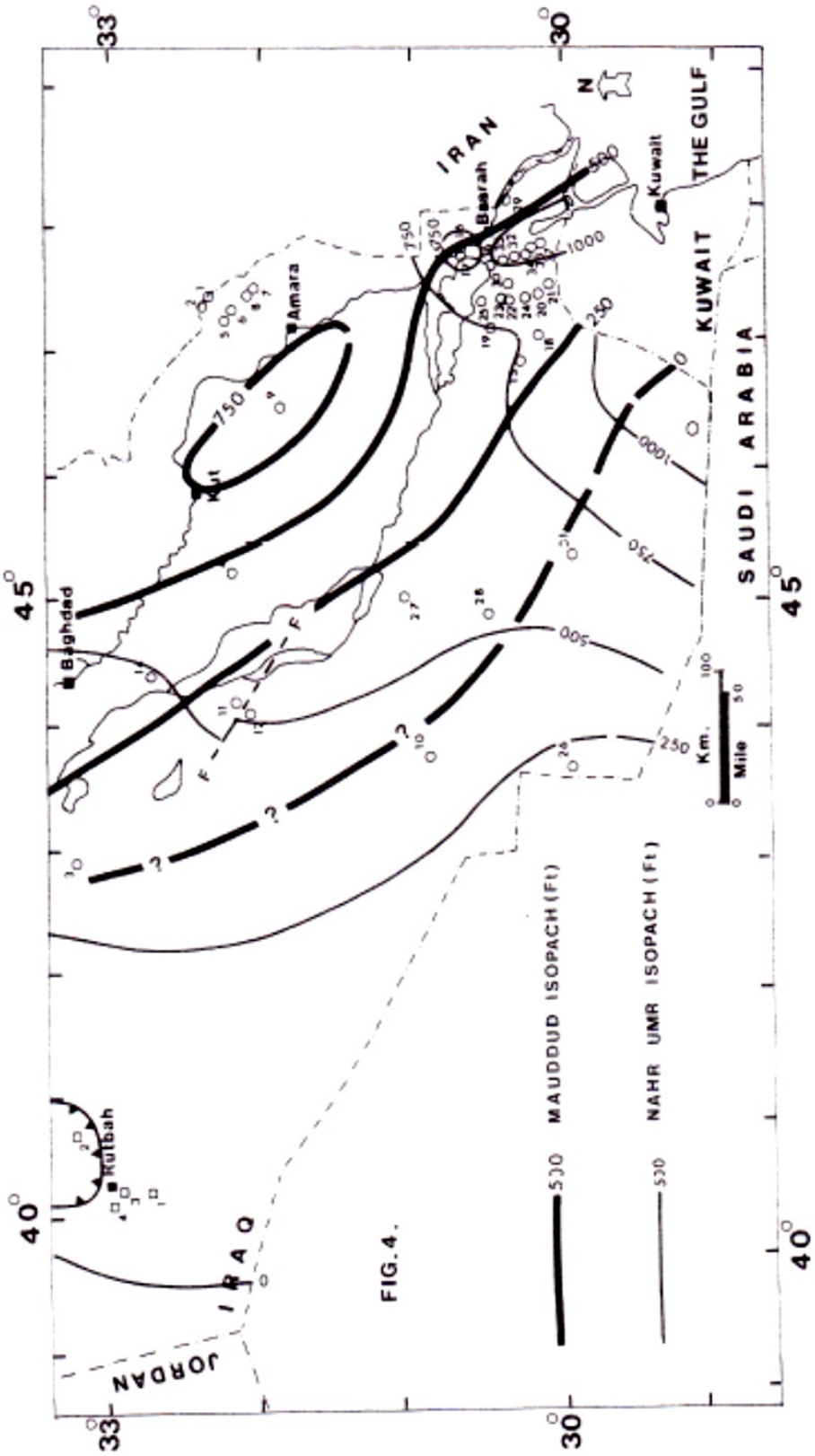

Fig. 4. Isopach of the Nahr Umr and Maudduad Formations, Ruthah Formation is assumed to be equivalent to Nahr Umr Formation.

where the Mahilban rests on an eroded Nahr Umr Formation. A re-worked Rutbah is a possible but not a probable source.

In conclusion, the author finds the probabilities of physical correlation between the Nahr Umr and the Rutbah Formation rather convincing. Fig. 5 shows the proposed relationship of the Nahr Umr to the Rutbah Formations in a cross-sectional diagram. Exact stratigraphic correlation of the Rutbah and Nahr Umr, however, can only be achieved through bio- and/or chrono-stratigraphic studies.

B. *Age and Time Correlation of the Mauddud Formation*

After the recognition of the Mauddud Formation in Qatar by Henson (1940b), Smout (1956) published a list of the foraminifera of the Mauddud Formation including *Rabanitina basraensis* (Smout), *Iraqia simplex* (Henson), *Orbitolina concava* (Lamarck) and *Trocholina altispira* (Henson), etc.

Sugden (1958) (cited by Dunnington *et al.*, 1959, p. 178) argued for an Albian to intra-Cenomanian age for the Khatiyah Formation, which lies above the top of the type section of Mauddud in Qatar, so that the Mauddud was regarded as being of Albian age or older. Owen and Nasr (1959) argued for a Cenomanian age for the Mauddud on the basis of the now discounted co-occurrence of *Begia* sp., *Praealveolina* sp. and *Orbitolina concava* in the upper parts of the Mauddud Formation in well Zubair No. 3, though they recognised that the relation between the Cenomanian Wara Formation and the Mauddud may express a minor disconformity.

In 1959, Dunnington *et al.* proposed an Albian age on the basis of regional correlation with the upper Qamchuga limestone Formation of N Iraq, and suspected, at that time, a contamination to explain the occurrence of the typically Cenomanian (or younger) *Praealveolina* sp. mentioned by Owen and Nasr (1958). Similar misdating of the type Mauddud because of cavings of *Praealveolina* sp. was recorded in Qatar (Sugden and Standring, 1975, p. 52).

James and Wynd (1965) published the stratigraphic nomenclature of the SW part of Iran, citing a Mauddud Member of the Sarvak Formation (Mauddud Member is equivalent to Mauddud Formation) for which they accepted a Cenomanian age.

Sayyab (1966) drew the Mauddud as a lateral equivalent to the Ahmadi Formation, citing an Albian age for both.

Naqib (1967) argued in favour of an Albian age for Mauddud, but he did not exclude a Lower Cenomanian age in Awasil area in west-central Iraq.

In 1975, Al-Shamlan, who studied the microfacies of the Mauddud Formation of the Sabriya and Raudhatain fields of N Kuwait, took the age of the Mauddud Formation to be Albian.

Sugden and Standring (1975) accepted Cenomanian age for the base of the Ahmadi and Albian age for the Mauddud in Qatar.

Ovalveolina sp. (Reichel) was reported by the early Basrah Petroleum Co geologists from the Mauddud Formation in well Rumaila No. 1. This species has a late Albian-Turonian age (Dilley, 1973), but early records of it in Basrah fields may be erroneous, while the late Albian *Rabanitina basraensis* (Smout) was re-reported from the middle parts of the Mauddud Formation in wells Siba No. 1 and Dujaila No. 1.

From the above fossil records and that the Mauddud Formation is overlain by the Ahmadi Formation (Early Cenomanian), a late Albian age is very probable for the Mauddud Formation. However, according to Naqib, it remained possible that it may range up into the basal Cenomanian especially in the E and NE part of S Iraq (Naqib, 1967), especially as typically Cenomanian forams of *Ovalveolina* sp., and *?Praealveolina* sp. have been recently documented by Al-Siddiki (1978) from the Mauddud in SE Iraq, who dated the Mauddud as Early to Mid-Cenomanian.

According to Murris (pers. comm. 1981) "a close correlation in several areas such as Qatar, Abu Dhabi, Kuwait-Khuzestan, Oman, etc., establishes that we have a Mauddud Limestone with *Orbitolina concava* and no *Praealveolina* sp., overlain by a limey/marly basal Ahmadi with both forams present. This basal Ahmadi/Khatiyah

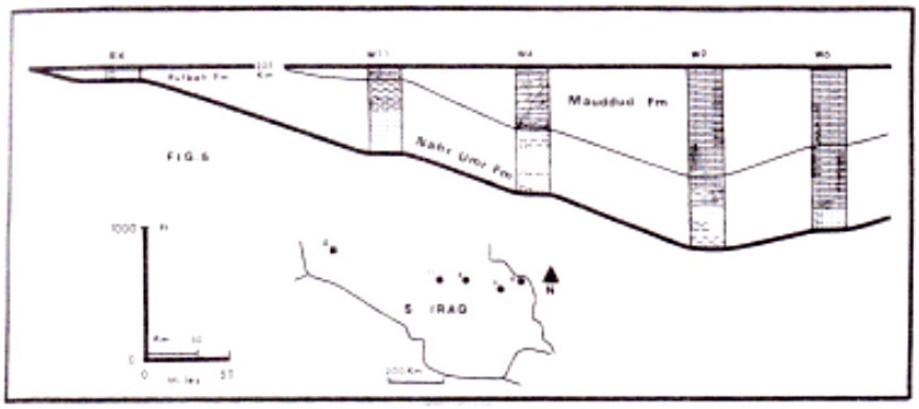

Fig. 5. Stratigraphic correlation diagram of the Albian rocks in S Iraq. The solid thick line is an unconformable contact and the thin line is the bio-stratigraphic contact. Note the presence of inter-tonguing between the Nahr Umr and Mauddud.

grades from shale in the W to purer limestone in the E, where it becomes indistinguishable from the underlying Mauddud". It seems, therefore, that outer neritic-fore-reefal limestone facies (Riché and Prestat, 1980) of the basal Ahmadi Formation might have been grouped within the Mauddud in the eastern parts of S Iraq rather than that caving might have caused the persistently re-occurring reports of *Praealveolina* in Mauddud, for the Ahmadi Formation exhibits a lateral facies change over S Iraq, where it changes gradually from a dominantly shale composition over southern S Iraq to a limestone dominated association over north, east and NE S Iraq (Ibrahim, 1978).

C. Regional Stratigraphic Correlation of the Albian Rocks

The Albian rocks of S Iraq are correlatable with Upper Qamchuga and Jawan Formation in North Iraq (Dunnington *et al.*, 1959; Dunnington, 1967). A possible diachronous lithological relationship could exist between the Nahr Umr Formation and the upper parts of the Sarmord Formation in Kirkuk area (Naqib, 1959).

In Khuzestan (Iran), the Kazhdumi Formation and the Mauddud Members of the Albian-Turonian Sarvak Formation are in lithological continuity with the Albian rocks of South Iraq, though the post-Mauddud dis-conformity has not been accorded notice in the deeper part of basin in Iran, where sedimentation is thought to have included few erosional unconformities (James and Wynd, 1965; Setudehnia, 1972; Setudehnia, 1978). The Burgan and Mauddud Formations are the lithological correlatives in Kuwait for the Albian rocks of Southern Iraq (Owen and Nasr, 1958). In N Saudi Arabia, the Khafji, Safaniya and Mauddud Members (all of Albian age) of the supposedly Albian-Turonian Wasia Formation are probable lithological correlatives of the Albian rocks of Southern Iraq (Powers, 1968). Across the Hail-Rutbah Arch, in Jordan, the Hathira Sandstone Formation is equivalent in age to the Albian rocks of Southern Iraq.

Subsurface Geology

The Mauddud and Nahr Umr Formation express an inter-tonguing relationship. The Mauddud/Nahr Umr contact of Fig. 5 shows the biostratigraphic contact. The rocks show a general increase in thickness in a NE trend until they begin to thin to the NE corner of S Iraq. The depo-axis (more than 1,250 ft) lies along a NW trend striking from E of Basrah towards Amara city (Fig. 6). Rocks of these formations pinch out over the E flank of the Hail-Rutbah Arch. Quantitatively, the rocks are divided into five lithological associations as shown by Fig. 6 (local lithological variations on top of structural oilfields were omitted).

(1) An area dominated by sandstone in the W and SW reflects the synchronous influx of clastics from the SW and the W, whilst calcareous equivalents were being deposited towards the NE (revealed by the discordance of the clastic ratios with the isopachs which keep an oblique, but constant spacing).

(2) An association of sand and shale, along short strips at the SE borders of the W-SW sandy zone (Zone 1), at Samawa area (well 27), and E of Abu Jir No. 1 (Well 3).

(3) An area covered mainly by sand and carbonates, located along the S flank of the Kifl structure, which could reflect the deposition of a lateral facies of the main sand body at area (1) (Fig. 6). A minor patch appears in the Luhais area.

(4) An area composed mainly of carbonates and shale, lying to the E of Basrah and in the NE part of S Iraq along the strike of the depo-axis.

(5) A central area, dominated by clastics, occupying a NW-trending central strip in the S of Iraq, which engulfs the location of the Rumaila and Zubair oilfields. This strip partially coincides with the area inferred to be dominated by a marine marginal-inner neritic environment (Figs. 6 and 7).

Dunnington (personal communication, 1980) believes that the Mauddud, Nahr Umr and Shuaiba Formations and the upper parts of Zubair Formation are all planed off the Safawi section (well 26) and that all the sandstone reported there is Zubair, and what the BPC geologists had identified as Mauddud Formation being perhaps the Mishrif Formation, the Rumaila Formation or the Tuba Member of the Ahmadi Formation. The author identified the Nahr Umr on the basis of well-to-well correlation of the electrical log motifs, as the Shuaiba is missing there and the Nahr Umr rests directly on the Zubair sandstones, and there is no fossil evidence to prove the presence of the Mauddud Formation there, hence a zoro isopach was set on the basis of contour spacing (Fig. 4).

The 1,250 ft isopachs in Fig. 6 are slightly different in location from those of Dunnington (1958, Fig. 6); another difference occurs in the pinch-out lines, but the lithofacies generally coincides.

Environments of Deposition

The dominant environment of deposition of the Albian rocks (inferred from the lithological documentation of the well logs) is displayed in Fig. 7, which shows the following:

(1) An area dominated by continental environments in the SW part of S Iraq lies to the W of the line joining wells Rachi No. 1 and Samawa No. 1. The continental environment is best represented by the Nahr Umr section of well Safawi No. 1 where it was described as fine-grained sandstone with clear frosted grain-surfaces, rounded to sub-rounded grains, and some fissile shales and siltstones; no fossils were reported. The roundness and frosting of the fine, uncemented sands, the diversity of the dip of the bedding planes and the absence of fossils all point to a continental type of environment of deposition (possibly with an eolian element).

Another type of continental environment can be inferred from the lower part of the Nahr Umr Formation at well Rachi No. 1 where the medium-coarse, angular-subangular, ill-sorted, loose, argillaceous and carbonaceous sandstone, with black fissile non-calcareous and occasionally carbonaceous shale, all indicate a unidirectional subaqueous transportation with quiet areas of abundant vegetation, typical of flood-plain/delta-plain environments.

The exposed Rutbah Formation was inferred to indicate continental environments of deposition by Naqib (1967), Kukal and Saadallah (1970) and (in part) by Dunnington *et al.* (1959).

(2) A marine marginal-inner neritic type of environment is inferred to occupy a central NW-trending area of S Iraq. A typical section in well Kifl No. 1, consists of a lower medium-fine, sub-angular-rounded, partly consolidated sandstone, which grades upwards into orbitolinal limestones, through a glauconitic silt and ostracodal shale interval; all this indicates influx of sand under sub-aqueous environment of

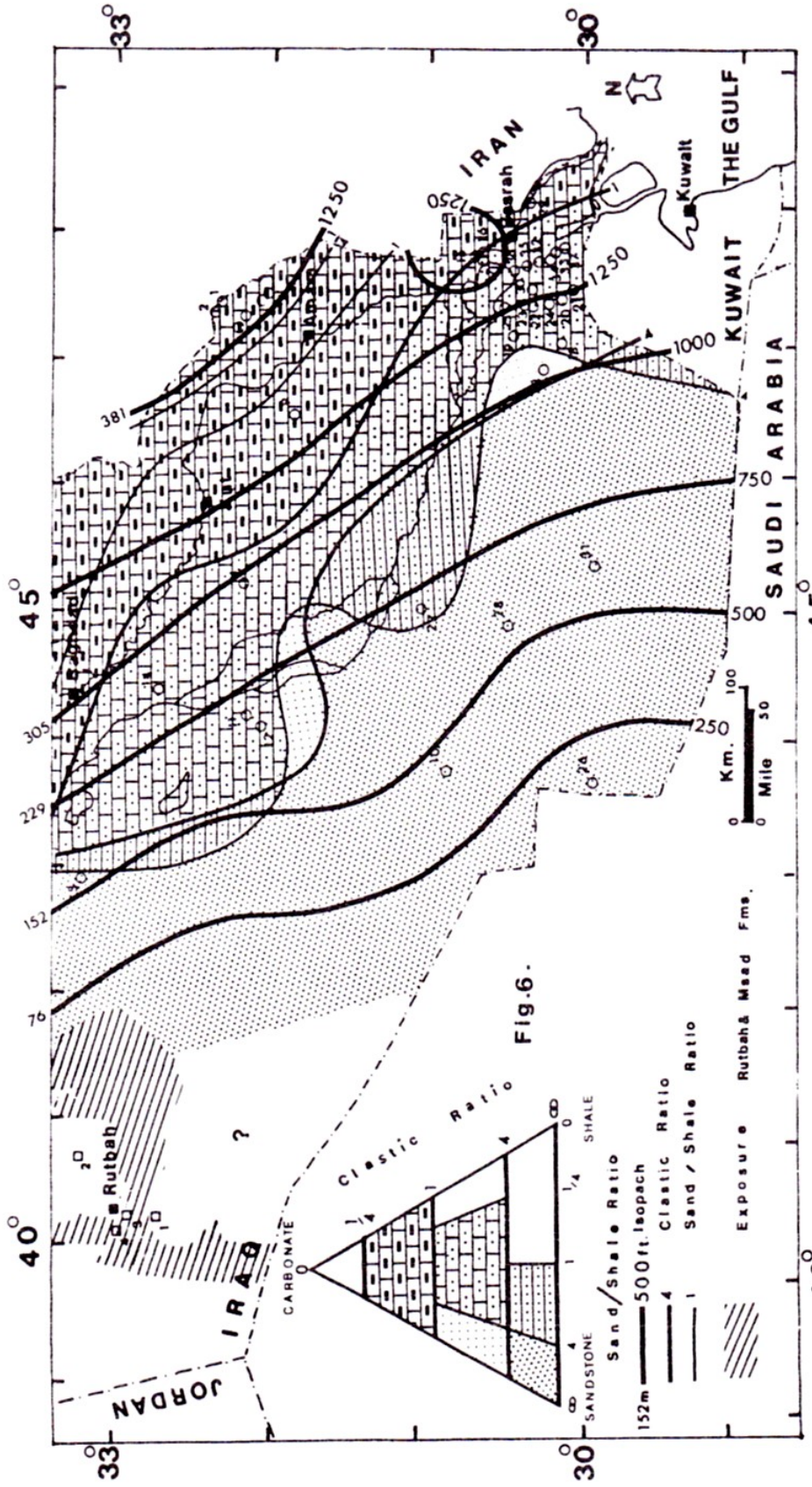

Fig. 6. Quantitative isopach-lithofacies map of the Albian rocks (Nahr Umr, Rutbah and Mauddud Formations) of S Iraq. Exposure shown is that of Rutbah and Ms'ad Formations.

marine and non-marine characters, hence a marine marginal-inner neritic type of environment is deduced.

(3) To the extreme E and NE of S Iraq, an outer neritic environment dominated depositional processes during Albian time. Its deposits can be typified by the lower parts of the Mauddud Formation section in well Siba No. 1, where a light-grey, chalky limestone is interbedded with dark grey to brown, micritic and pyritic limestone with ostracods, echinoids, gastropods and *Orbitolina* sp., all generally indicative of outer neritic environments.

The environments of deposition presented in this study are broadly compatible with those indicated in Figs. 17 and 18 of Murris (1980), where similar trends are shown under a different terminology.

Present status of the petroleum geology of the Nahr Umr Formation

Availability of data controlled the variables that were amenable to consideration to the following: petroleum occurrences, lithofacies, inferred source-rocks and availability of structural traps in relation to times and directions of petroleum migrations.

(1) *Lithofacies* The Albian Nahr Umr, Kazhdumi Shales and the Lower Cretaceous shales of the Zubair Formation, and the Garau Formation have been identified as potential source rocks (Ala *et al.*, 1980; Murris, 1980; Ibrahim, 1978). Nahr Umr sandstones and the porous Mauddud carbonates are proven reservoir rocks in the Middle East.

The already discovered petroleum traps in the Nahr Umr reservoirs seem to be approximately aligned within limiting sand/shale ratio contours of $>1<8$ (Fig. 6).

Proper reservoir and carrier/cap and source rock ratios are found to delineate areas of producing oil fields (Dicker and Rohn, 1955). Such ratios probably express the optimum combination of source, reservoir and cap rocks in an oil producing province.

(2) *Trap availability in relation to times and direction of petroleum migration* The abundance of Albian oil traps in the SE corner of S Iraq and Kuwait is due to the occurrence of salt tectonic structures that exhibit pre-Albian to Recent continuous structural growth (Brown, 1972; Ibrahim, 1979). The rest of S Iraq can be divided into several subsurface structural style zones, each of which exhibits intermittent pulses of structural growth with different starting times (Ibrahim, 1978).

The ?Infra-Cambrian salt tectonic area in the SE corner of S Iraq (Brown, 1972) engulfs most of the economic oilfields in S Iraq and Kuwait. Another area that expresses similar, but intermittent, structural growth history extends from the triple intersection of the Iraqi-Kuwaiti-Saudi Arabian borders to the Habbaniyah lake, W of Baghdad (Ibrahim, 1978).

Continuous structural growth is a positive factor in oilfields all over the world (Law, 1957; Scholten, 1959), and S Iraq presents no exception to this rule. Areas exhibiting such structural growth behaviour are considered to have a relatively higher petroleum trapping potential (Ibrahim, 1978).

Most of the wells shown in Fig. 1 were drilled on structural prospects, and there are many delineated by seismic mapping that await drilling.

In general, the earlier the anticline formed after the time of deposition, the greater are the chances that it will have entrapped oil (Scholten, 1959), (that is if all other variables were equal).

Although the Nahr Umr, Zubair and Rumaila anticlines shared similar growth histories, their successes as traps (as demonstrated by oil content of different formations) were quite different.

Petroleum migration directions have generally been from the ENE towards the WSW (i.e. perpendicular to the axes of basinal subsidence) and the post-Eocene axes were no exception (Ibrahim, 1979).

(3) *Source rocks* It is possible that the Zubair shale and/or deeper Sarmord source rocks contributed to the entrapped oil in the Nahr Umr Formation; six out of the

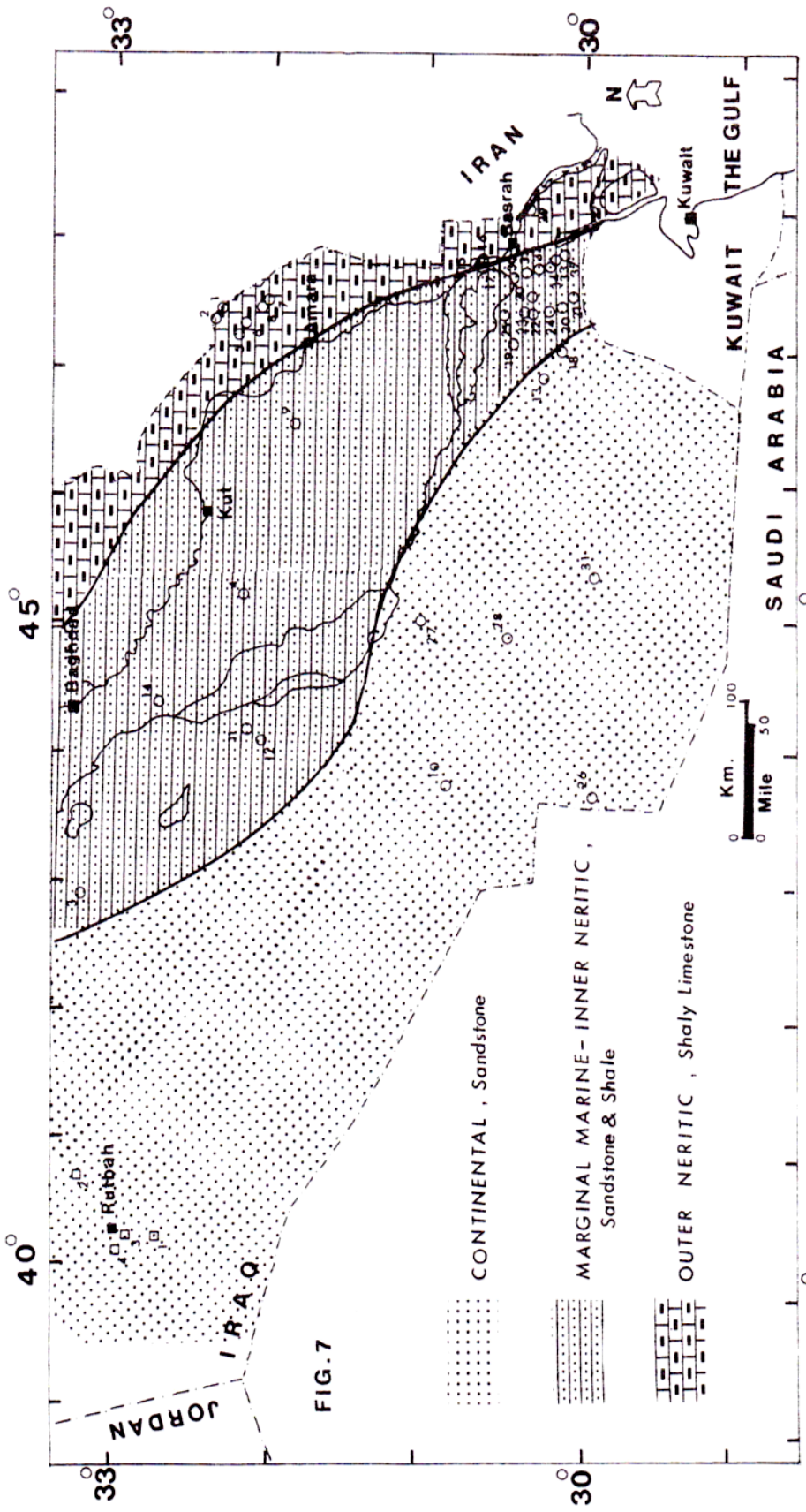

Fig. 7. Inferred environments of deposition of the Albian rocks of S Iraq.

eight discovered producible oil traps in the Nahr Umr Formation are in economic Zubair reservoir oilfields (see key of Fig. 1). The two exceptions are (a) the intensely-deformed Nahr Umr oilfield where the Zubair reservoir contains producible gas, and (b) Well Ubaid No. 1 where the effectiveness of the Zubair cap rocks is probably on the low side, as reflected by high sand/shale ratio of the Zubair, Ratawi and Shauiba Formations (Ibrahim, 1978).

Conclusion

Physical and probably also chronological correlations between the Nahr Umr Formation of S Iraq and the Rutbah Formation of W Iraq are inferred from subsurface mapping evidence.

In S Iraq, producible oil, in Nahr Umr Formation, appears to have:

(a) a sand/shale ratio greater than one and generally less than eight;

(b) a continuous and/or intermittent Cretaceous-Recent growth of structural traps;

(c) been located within and at the western periphery of the marine marginal belt of depositional environments; and

(d) a common presence of producible oil in the Lower Cretaceous Zubair Sandstone Formation in the same field. This may suggest a common source and/or migration path.

Table 1

List of Wells and Exposures Used in this Work

Exposures

1. Jabal Tayarat
2. Wadi Husainiya
3. Wadi Ms'ad
4. Wadi Ubeilah

Wells

1. Abu Ghirab 1
2. Abu Ghirab 2
3. Abu Jir 1
4. Afaq 1
5. Buzurgan 1
6. Buzurgan 2
7. Buzurgan 3
8. Buzurgan 4
9. Dujaila 1
10. Ghalaisan 1
11. Kifl 1
12. Kifl 2
13. Luhais 1
14. Musaiyib 1
15. Nahr Umr 1
16. Nahr Umr 2
17. Nahr Umr 3
18. Rachi 1
19. Ratawi 1
20. Rumaila 1
21. Rumaila 15
22. Rumaila 20
23. Rumaila 21
24. Rumaila 32
25. Rumaila 35
26. Safawi 1
27. Samawa 1
28. Shawiya 1
29. Siba 1
30. Tuba 1
31. Ubaid 1
32. Zubair 1
33. Zubair 2
34. Zubair 15
36. Zubair 31
37. Zubair 39

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