PETROGRAPHY, DIAGENESIS AND DEPOSITIONAL ENVIRONMENT OF NAHR UMR FORMATION, FROM SELECTED WELLS IN CENTRAL IRAQ

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ABSTRACT

Nahr Umr Formation is a siliciclastic deposit of the Mesopotamian basin. This formation is mainly composed of sandstone interlaminated with siltstone and shale, with occurrence of thin limestone beds. Nahr Umr Formation is subdivided into three lithostratigraphic units of variable thicknesses on the basis of lithological variations and log characters.

Mineralogically and texturally, mature quartz arenites and sandstones are the common type of the Nahr Umr Formation. The sandstones are cemented by silica and calcite material and have had a complex diagenetic history and are cemented by silica and calcite. Compaction, dissolution and replacements are the main diagenetic processes.

Prodelta; distal bar; distributary mouth bar; distributary channel; over bank and tidal channel are the main depositional environments recognized for the Nahr Umr Formation, within the studied wells. This formation was deposited in shallow marine and fluvial – deltaic environments and exhibit progradational succession of facies.

دراسة بتروغرافية والعمليات التحويرية والبيئة الرسوبية لتكوين نهر عمر في آبار مختارة من وسط العراق

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المستخلص

يعتبر تكوين نهر عمر احد التكوينات الفتاتية للعصر الكريتاسي والمترسب ضمن حوض ترسيب السهل الرسوبي. يتكون هذا التكوين بشكل رئيسي من تتابعات متداخلة من الحجر الرملي، الحجر الغريني والسجيل مع وجود طبقات نحيفة من الحجر الجيري أحياناً. قسم هذا التكوين، في هذه الدراسة الى ثلاث وحدات صخارية - طباقية مختلفة السمك وذلك بالاعتماد على الاختلافات الصخارية وخصائص المجسات البتروفيزيائية المتوفرة.

يعد معدن المرو المكون الرئيسي لصخور الحجر الرملي من نوع كوارتز ارينايت لتكوين نهر عمر، حيث يتكون من حبيبات المرو الناضجة معدنيا ونسيجيا. أن لصخور الحجر الرملي تأريخ تحويري معقد حيث يكون مترابطاً بالمواد السمنتية السليكية والكلسية، وتكون العمليات التضاغطية، الاذابة والاحلال من أهم العمليات التحويرية المؤثرة على صخور هذا التكوين.

ترسب هذا التكوين في بيئة بحرية ضحلة وبيئة نهرية - دلتاوية ذو سحنات تتابعية - تقدمية. كما تم التعرف على البيئات الرسوبية الثانوية للدلتا وسحنات جوانب القناة والقنوات المدية.

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INTRODUCTION

The Nahr Umr Formation is one of the siliciclastic deposits of the Cretaceous sequence of Iraq, and has been intensively studied and fully surveyed by Iraqi oil companies and many foreign oil companies. Among them are: Chatton and Hart (1960); Al-Naqib (1967); Ditmar (1972); Al-Siddiki (1978); Al-Badry *et al*. (1983); Ibrahim (1983); Al-Jawadi (1990); Al-Khirsan (1992) and Al-Hadithy (1994).

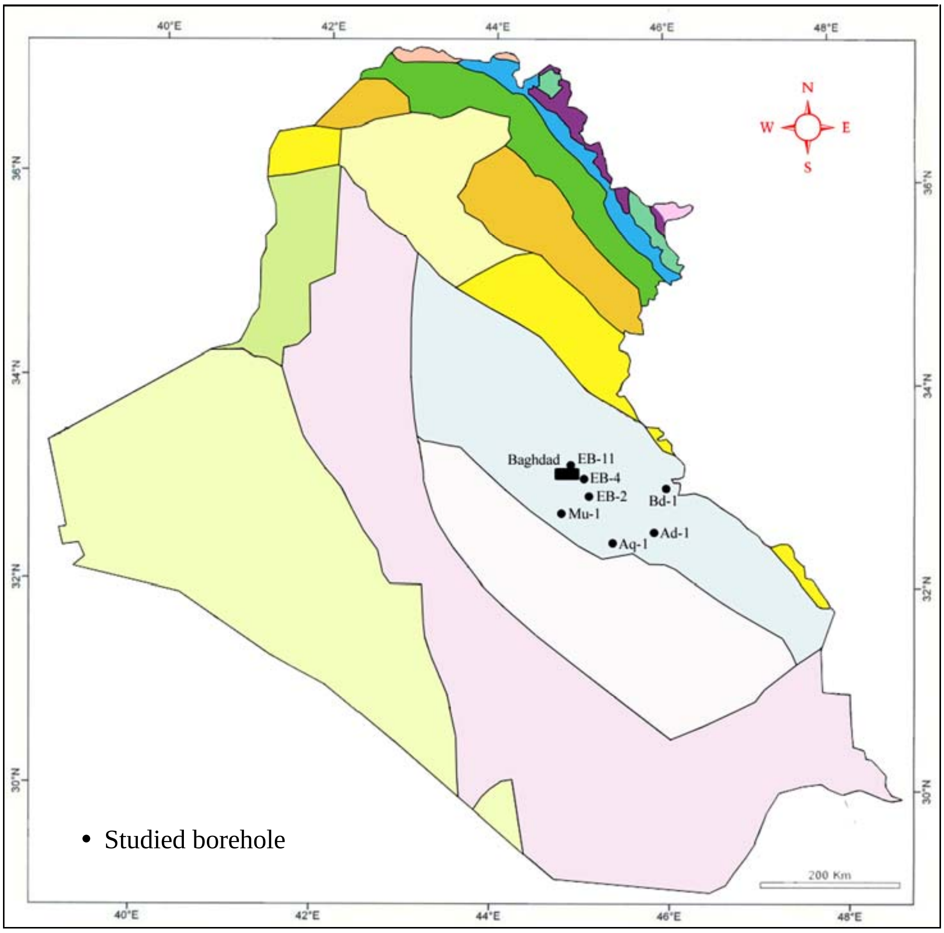
The main purpose of this study is to evaluate and reconstruct the depositional environment of the Nahr Umr Formation in wells located in the central part of Iraq, using sedimentologiucal approaches, which include sandstone petrography, diagenesis and facies analysis of its different lithological members. This formation is composed generally of interbedded black shale with medium to fine-grained sandstones (Bellen *et al*., 1959). Facial change occurs from the sandy sediments of Nahr Umr Formation to the carbonate shoal facies of Qamchuqa Formation, causing the development of evaporite facies represented by the Jawan Formation (Al-Khirsan, 1992). The Mesopotamian and Salman Zones of Central Iraq are characterized by a clastic inner shelf (Nahr Umr Formation), which is covered by a carbonate shelf (Mauddud Formation) (Jassim and Goff, 2006). Regional unconformity and sedimentary hiatus separated the Shuaiba Formation (Aptian) from the Nahr Umr Formation (Albian), (Ziegler, 2001). Far- field stresses are thought to have resulted in the uplift and erosion of the western part of the Arabian Craton and the supply (eastwards) of large amount of terrigenous clastic and shallow marine sands (Al-Fares *et al*., 1998). As shown in Fig. (1), the examined wells are located in the central part of Iraq along the Tigris Subzone, which belongs to Mesopotamian Zone of the Stable Shelf (Jassim and Goff, 2006). These wells are chosen from East Baghdad Oil Field (EB-2, EB-4 and EB-11), Badrah Oil Field (Bd-1), Mussaib Well (Mu-1), Afaq well (Aq-1), and Ahdab Oil Field (Ad-1). The basic data used in this study is summarized in Table (1).

Table 1: Summary of the basic geologic data, used in this study.

Well No.	Formation	Total Thickness (m)	Total number of slides	Type of studied logs
EB-2	Nahr Umr	86	83	GR, FDC-CNL, Sp, Δt
EB-4	Nahr Umr	101.5	60	GR, FDC-CNL, Sp, Δt
EB-11	Nahr Umr	93	57	GR, FDC-CNL, Sp, Δt
Bd-1	Nahr Umr	64	78	GR, FDC-CNL
Ad-1	Nahr Umr	85	80	GR, FDC-CNL
Mu-1	Nahr Umr	147.5	141	Sp, Resistivity
Aq-1	Nahr Umr	146	109	Sp, Δt

STRATIGRAPHY

The type section of the Nahr Umr Formation is originally described from southern Iraq by Owen and Nasr (1958) at the Nahr Umr Oil field (NU-2) (North of Basrah province). This formation is encountered in all the studied wells with variable thicknesses. Lithologically, it consists mainly of varicolored friable to slightly tough and fine to coarse-grained sandstone. Sandstone beds are interlaminating in different levels with thin dark to reddish brown shale beds. The latter are occasionally fissile, rich with organic matter; pyrite and some lignite.



Stable Shelf
Rutba-Jezira Zone
Rutba Subzone
Jezira Subzone

Salman Zone
Salman Zone

Mesopotamian Zone
Zubair Subzone
Tigris Subzone
Euphrates Subzone

Unstable Shelf
Foothil Zone
Makhul-Hemrin Subzone (Kirkuk Embayment)
Makhul-Hemrin Subzone (Mosul High)
Makhul-Hemrin Subzone (Sinjar basin)
Butmah-Chemchemal Subzone (Mosul High)
Butmah-Chemchemal Subzone (structurally lower blocks)

High Folded Zone
High Folded Zone

Imbricated Zones
Balmbo-Tanjero Zone
Northern (Ora) Thrust zone

Zagros Suture Zones
Qulqula-Khuwakurk Zone
Penjween-Walash zone
Shalair Zone

Fig.1: Tectonic frame work of Iraq (after Jassim and Goff, 2006), with location of the studied boreholes

The Nahr Umr Formation is a sand-dominated clastic unit in the west and southwest, and shale-dominated in the east, (Jassim and Goff, 2006). Carbonates (limestone, dolostone) and siltstone beds are also interlaminating with the sandstone and shale beds in different parts, throughout the sections.

The upper contact with the overlying Mauddud Formation is conformable and gradational, which is located at the base of the limestone or dolostone beds of the Mauddud Formation or at the top of the sandstone or shale beds of the Nahr Umr Formation (Qaradaghi, 2001). The lower contact of the Nahr Umr Formation with the underlying Shuaiba Formation is unconformable surface and taken at the base of the dark-black, fissile shale beds of the Nahr Umr Formation or at the top of the yellow-pale gray, dolostone beds of the Shuaiba Formation, (Fig. 2a, b, c, d, e, f and g).

LITHOSTRATIGRAPHIC SUBDIVISIONS

Al-Badry *et al.* (1983) subdivided the Nahr Umr Formation at the East Baghdad Oil Field to three (lower; middle and upper) parts. Consequently, the Nahr Umr Formation within the current study is divided into three lithostratigraphic units (Fig.2a, b, c, d, e, f and g). This subdivision depends on studying the cutting and available core samples and examining the prepared thin sections from these samples. In addition to lithological information provided by interpretation of the available log sets of Spontaneous Potential (SP), Sonic (Δt), Neutron – Density (FDC – CNL) and Gamma Ray (GR) logs. The basis for separation of the units from each other depends on the most dominant lithology dispersed through each unit.

– Unit A

It consists mainly of alternating fine to medium grained, varicolored porous partially calcareous cemented and consolidated to friable sandstone beds, alternating with thin bedded shales, with thin beds of carbonates (limestone, dolomitized limestone and dolostone) and streaks of siltstone beds also occur. The thickness of this unit is variable throughout the studied sections ranging from (10.5 – 65.50) m (Table 2).

– Unit B

It consists mainly of sandstone layer, as indicated from well log interpretations and according to the shape of the gamma ray; spontaneous potential log curves and full Sp deflection. Furthermore, thin section examination revealed that this unit consists mainly of sandstone beds, which are composed of fine to medium, subrounded to rounded quartz grains. Thin beds of shale, siltstone and occasionally thin carbonate (limestone and dolostone) beds occur and intercalated with the main sandstone beds. The thickness of this unit is variable in thickness and ranges from (16.0 – 80.9) m.

– Unit C

It is a shale-dominated unit, consisting mainly of dark-reddish brown shale beds occasionally fissile, rich with organic matter, pyrite, and glauconitic. Thin beds of sandstone, carbonates and siltstone in some intervals are intercalated with shale beds. The thickness of this unit is also variable, ranges from (7.5 – 26.2) m.

Table (2) shows the identified lithostratigraphic units with thicknesses of the Nahr Umr Formation. The sand/ shale ratio is variable through out the studied sections and changes according to the position of these sections in the depositional basin. The sand/ shale ratio increases to the west and northwest directions, precisely in the selected wells of East Baghdad oil field, and decreases eastwards, towards Iraqi-Iranian borders in well Bd-1 (Table 3). The carbonate percentage is in contrast to the sand/ shale ratio and it increases eastwards, especially in well Bd-1, whereas this ratio decreases westwards, in other studied boreholes.

Cross bedding, cross lamination and bioturbation are the main sedimentary structures recognized in the available core samples from the sandstone and shale beds of the Nahr Umr Formation.

On the basis of stratigraphic position and fossils content (Owen and Nasr, 1958; Bellen *et al*., 1959; Al-Naqib, 1967; Buday, 1980; Jassim *et al*., 1984 and Al-Azzawi, 1999), an Albian age is suggested for this formation and accepted in the present work.

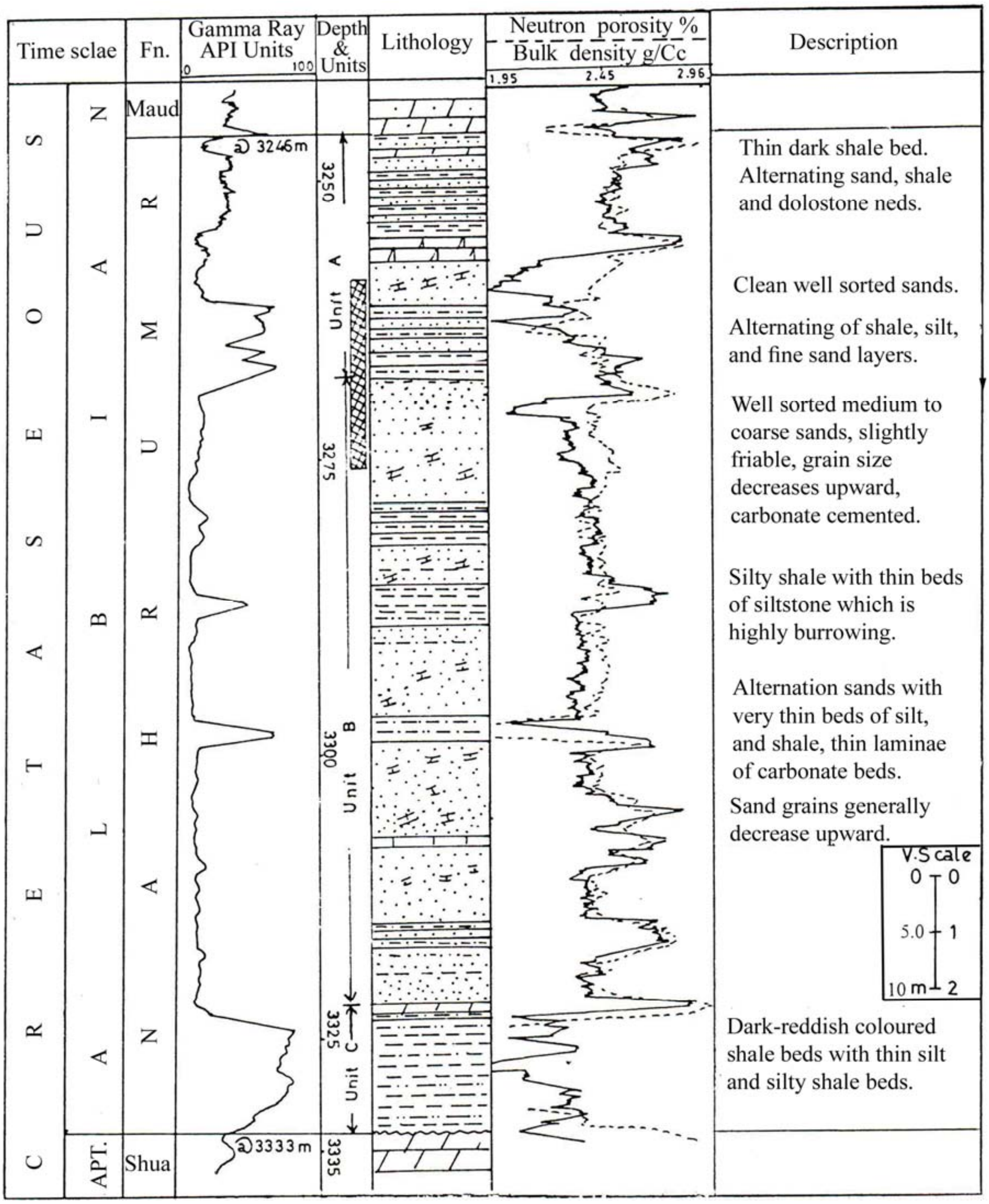
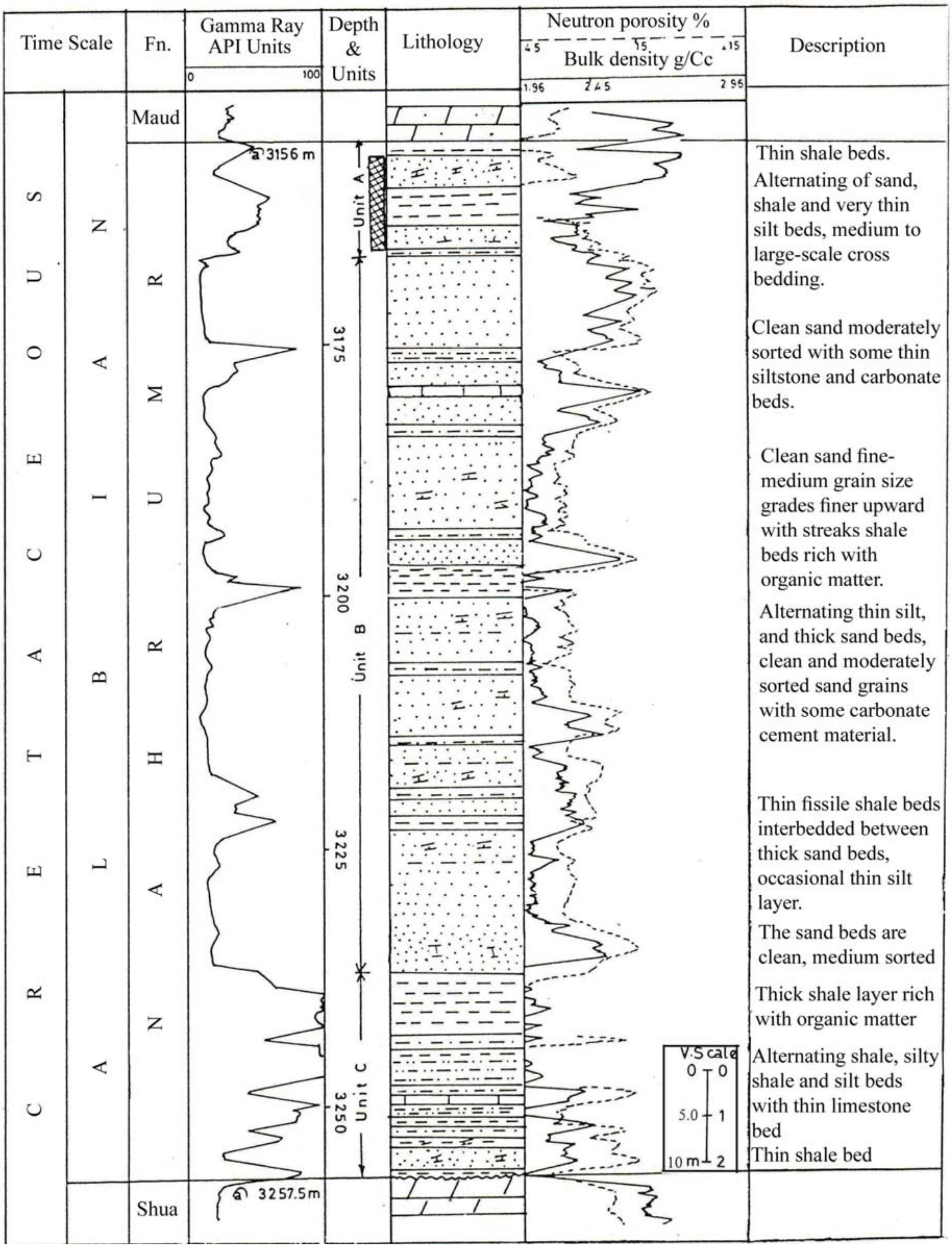


Fig.2
a: General stratigraphic column of Nahr Umr Formation in the studied Well EB-2



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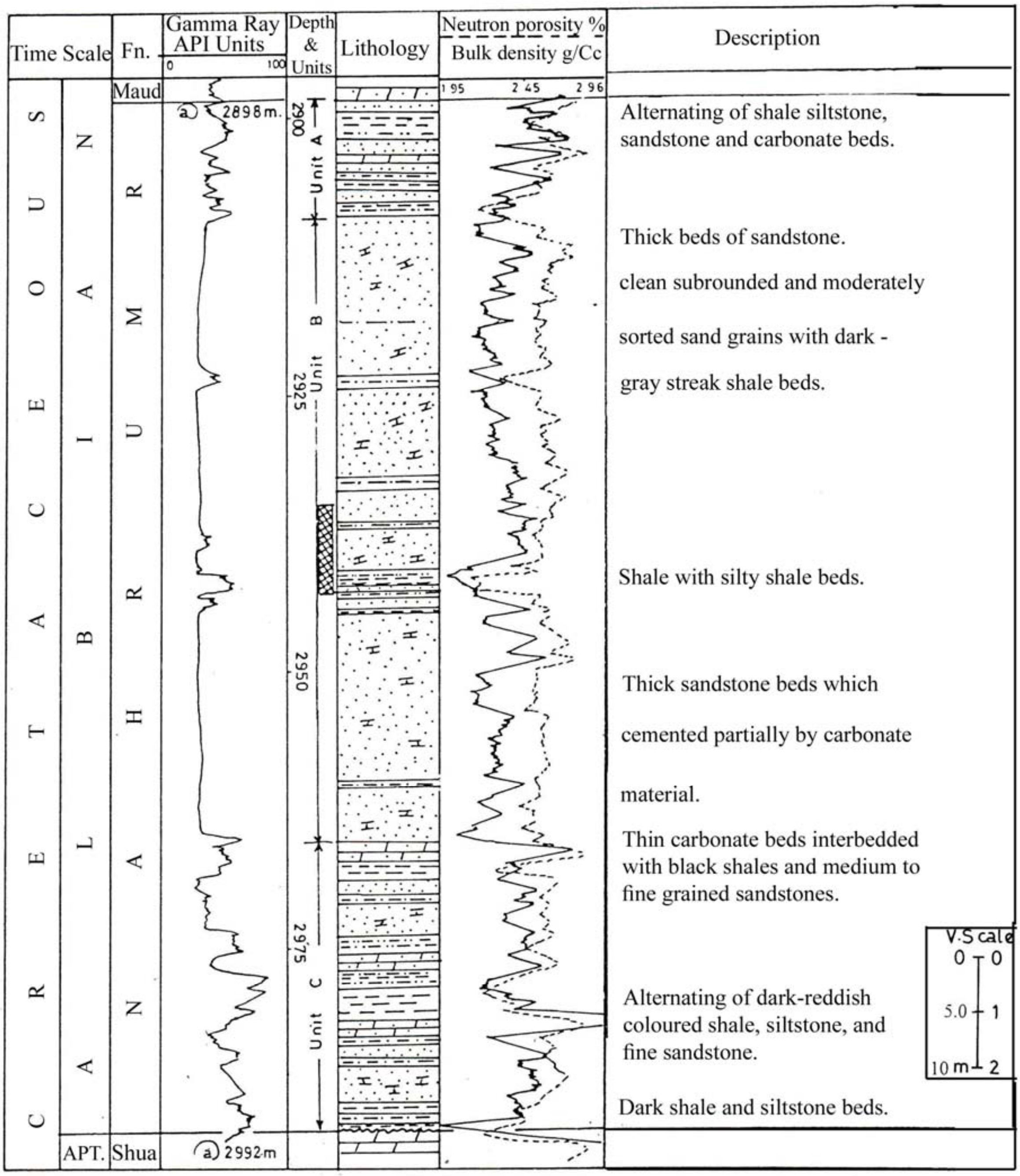
b: Well EB- 4

Maud. = Mauddud Formation
Shua. = Shuaiba Formation



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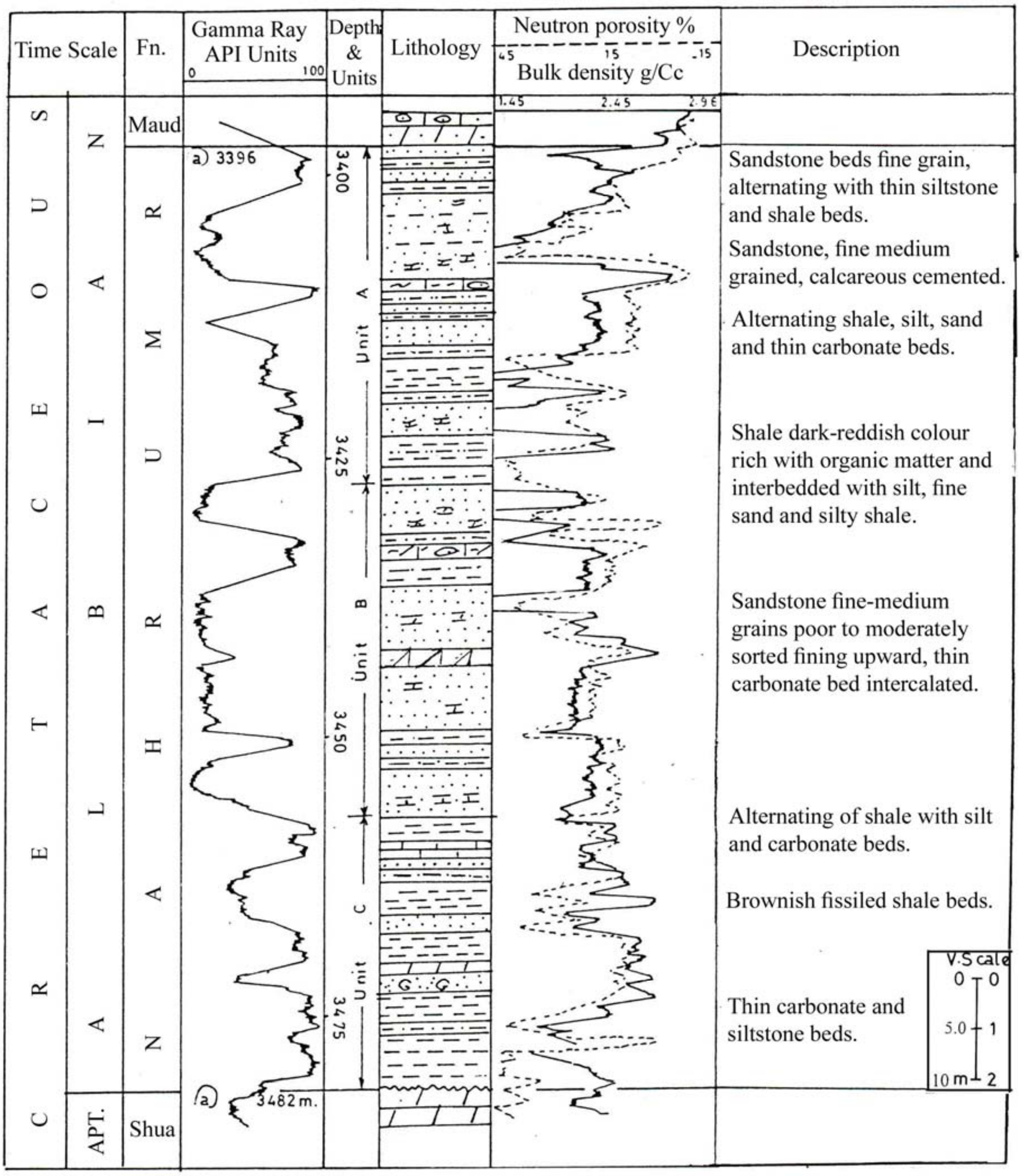
c: Well EB-11



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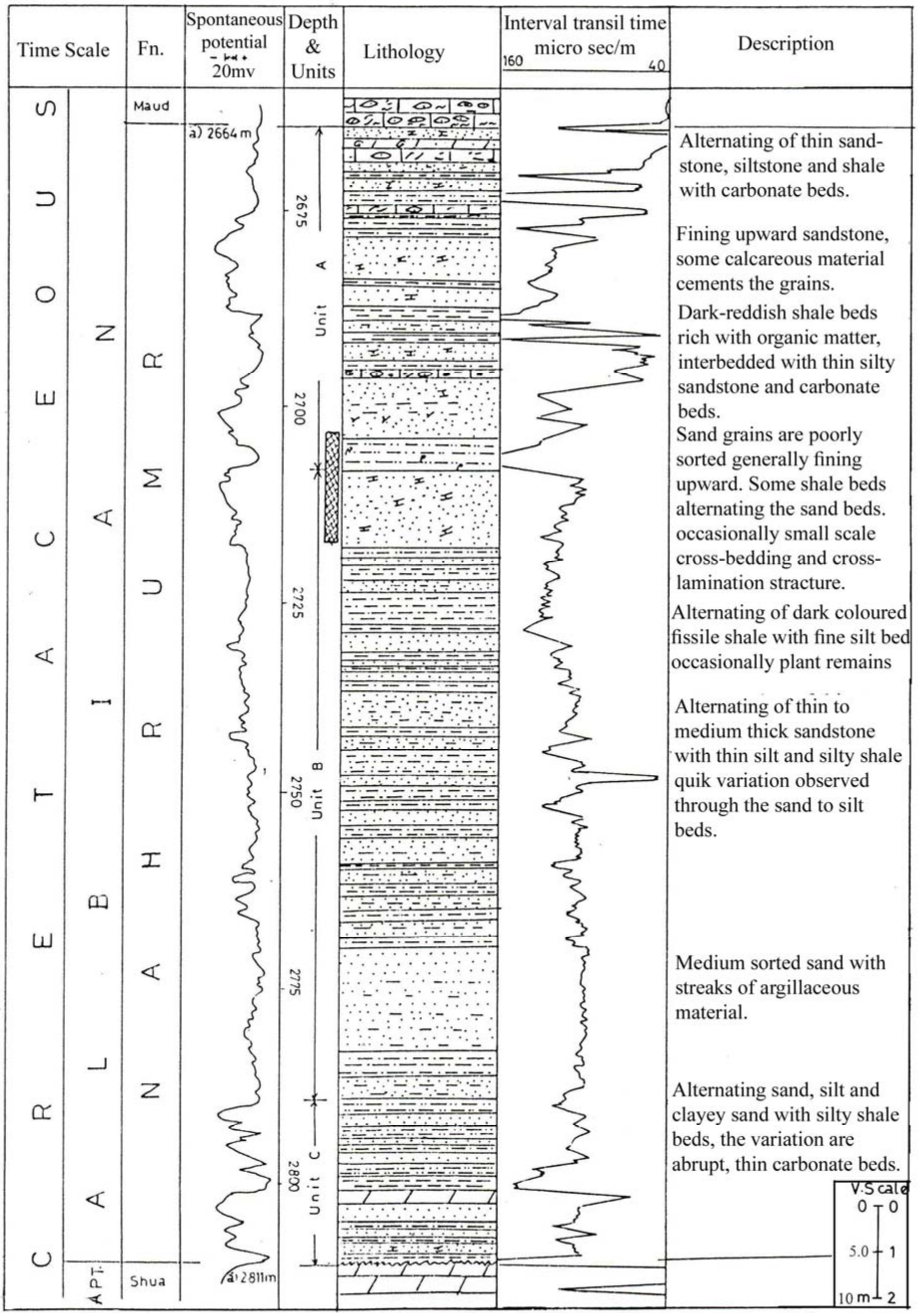
d: Well Ad-1



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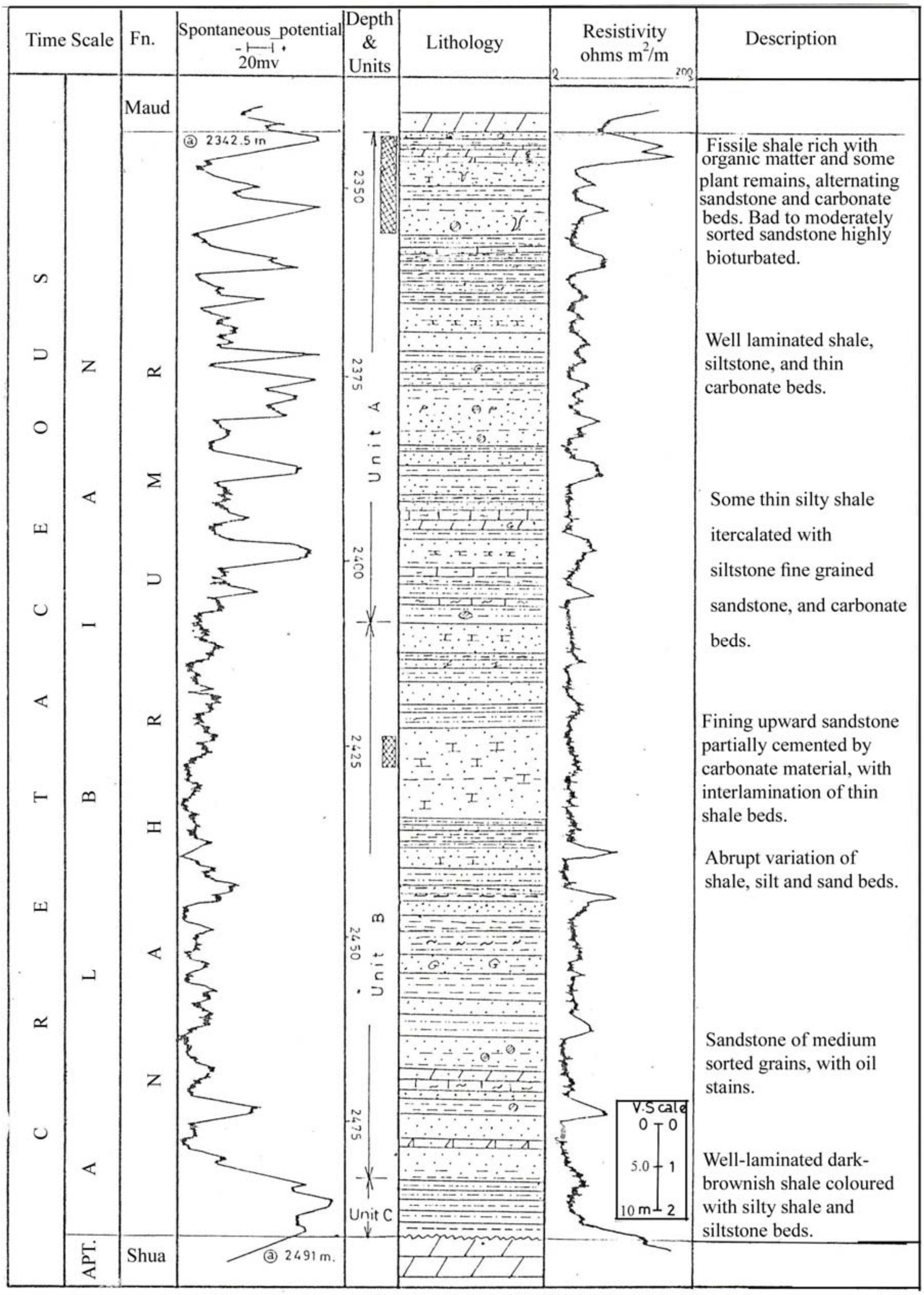
e: Well Aq-1



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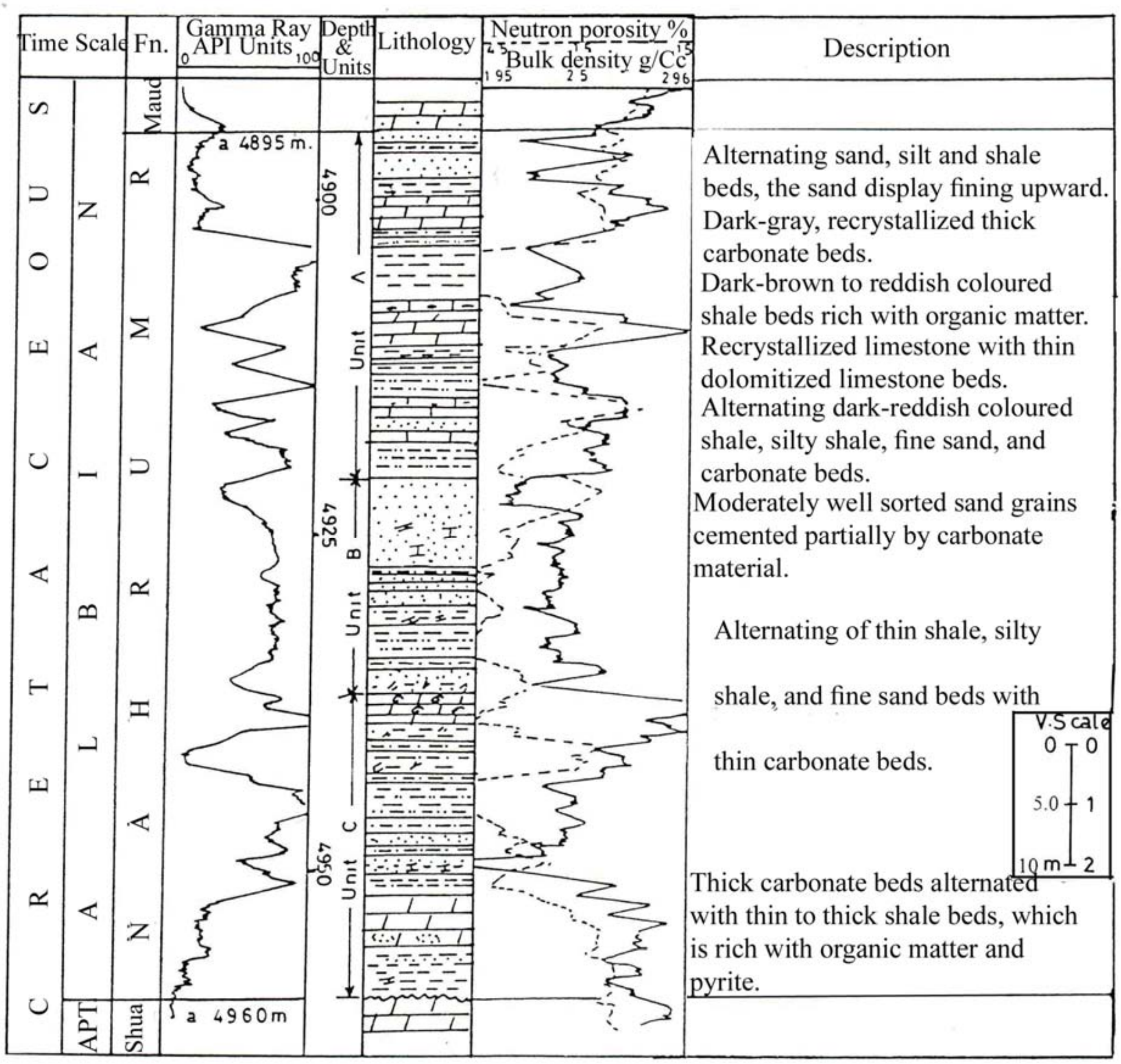
f: Well Mu-1



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g: Well Bd-1

SANDSTONE PETROGRAPHY

The sandstone beds represent the most abundant constituent rocks among the clastic sediments of the formation. Therefore, the following discussion is concentrated on the petrography of the sandstone fraction of the formation:

- **Quartz**

Quartz grains are the abundant detrital constituents and form more than 95% of the total minerals in most studied samples (Fig.3.1 and 2). These grains are mainly fine to medium and occasionally coarse, subangular – subrounded to well rounded and moderately sorted. Thin section examinations revealed that quartz grains are totally monocrystalline, with non-undulose extinction, and very few grains with undulose extinction. The polycrystalline quartz grains are absent because they are less stable and disaggregate into more stable single grains (Blatt *et al.*, 1980).

Table 2: Lithostratigraphic units of Nahr Umr Formation and their detailed lithologic components

Well No.	Unit	Total Thickness (m)	Top of the unit (m) from RTKB	Bottom of the unit (m)	Average lithological thickness (m)			
					Sandstones	Siltstones	Shales	Carbonates
EB-2	A	21.0	3246.0	3267.0	10.3	3.2	4.5	3.0
	B	53.7	3267.0	3320.7	41.5	3.0	8.2	1.0
	C	11.3	3320.7	3332.0	-	0.5	9.8	1.0
EB-4	A	11.0	3156.0	3167.0	5.2	0.8	5.0	-
	B	70.5	3167.0	3237.5	59.3	5.0	5.5	0.7
	C	20.0	3237.5	3257.5	2.4	4.2	12.6	0.8
EB-11	A	10.5	2898.0	2908.5	4.4	0.6	4.5	1.0
	B	56.3	2908.5	2964.8	50.3	1.5	4.5	-
	C	26.2	2964.8	2991.0	8.3	4.3	8.8	4.8
Bd-1	A	25.5	4895.0	4920.5	5.0	0.5	12.0	8.0
	B	16.0	4920.5	4936.5	10.0	2.2	3.8	0.0
	C	22.5	4936.5	4959.0	2.2	3.3	11.0	6.0
Ad-1	A	30.5	3396.0	3426.5	16.5	5.0	8.0	1.0
	B	29.7	3426.5	3456.2	21.2	2.0	3.5	3.0
	C	24.8	3456.2	3481.0	4.5	2.30	15.5	2.5
Aq-1	A	44.0	2664.0	2708.0	24	3.6	10.6	5.8
	B	80.9	2708.0	2788.9	52.4	18.5	10.0	0.0
	C	21.1	2788.9	2810.0	8.1	2.7	8.3	2
Mu-1	A	65.5	2342.5	2408.0	35.0	5.0	17.5	8.0
	B	74.5	2408.0	2482.5	43.0	12.0	16.0	3.5
	C	7.5	2482.5	2490.0	-	2.75	4.75	-

Table 3: Percentages of the recognized lithologies of Nahr Umr Formation in the studied wells

Well No.	Total Thickness (m)	Unit Thickness (m)			Unit Percentage		
		Sandstone*	Shale	Carbonates	Sandstone (%)	Shale (%)	Carbonate (%)
EB-2	86.0	58.5	22.5	5.0	68.0	26.2	5.8
EB-4	101.5	76.9	23.1	1.5	75.8	22.7	1.5
EB-11	93.0	69.4	17.8	5.8	74.6	19.2	6.2
Bd-1	64.0	23.2	26.8	14.0	36.25	41.9	21.9
Ad-1	85.0	51.5	27.0	6.5	60.6	31.8	7.6
Aq-1	146	109.3	28.9	7.8	74.9	19.8	5.3
Mu-1	147.5	97.75	38.25	11.5	66.3	26.0	7.7

(*****) Sum of the sandstone and siltstone beds

Most of the quartz grains are of unimodal with existence of few bimodal quartz grains (Fig.3.3). This indicates the derivation of the quartz grains from more than one source. The scarcity of clay minerals and the absence of feldspar minerals with the near absence of rock fragments may indicate the compositional maturity of the sandstone beds. The rock fragments are rare and observed only in four samples from Well Aq-1 and represented by carbonate rock fragments (Fig.3.6). Regarding Pettijohn *et al*. (1973) classification, the sandstone of the Nahr Umr Formation can be classified as quartz-arenites, which is composed mostly of quartz grains (95%), except for few samples that show a decrease in quartz grains to 85% and increase in clay matrix to about 15%, of the total constituents, therefore, are classified as quartz-wacke. Climate in the source area can also play a major role in producing quartz arenite. A warm humid climate will lead to the removal of many unstable grains, if coupled with low relief and slow sedimentation rates (Tucker, 1991). It is concluded that, the sandstone of the Nahr Umr Formation may be derived from recycled sedimentary rocks, because the extraordinary richness in quartz is fundamentally the result of recycling from quartz rich sedimentary rocks (Cardona *et al*., 1997), which are subjected to a long period of weathering in the source area and during transportation to depositional basin. Due to this, quartz arenite was quite durable under normal conditions of transportation, while other unstable minerals and unstable rock fragments were lost and removed by the processes of weathering, transportation, and diagenesis. These processes may play a prominent role in modifying and increasing the maturity of sandstones of the Nahr Umr Formation. Consequently, the quartz grains are increased over the less resistant clastic types, such as feldspar and rock fragments. According to their well-rounded grains, the sandstones in the studied area are considered compositionally and texturally as mature rocks.

- **Other Minerals**

The accessory minerals in the sandstone beds of Nahr Umr Formation include heavy minerals, pyrite and glauconite. The relative amounts of these minerals depend on their abundance in the source rocks and their resistant to mechanical and chemical weathering.

- **Heavy Minerals**

The heavy minerals, which typically form not more than 1% of the sandstone constituents, are considered as secondary minerals, and they are most useful for source rock interpretation. Zircon, Tourmaline and Rutile (ZTR) (Fig.3.7) are the main recognized heavy minerals from thin section examination of this study.

- **Glauconite**

Glauconite is one of the authigenic minerals, chemically precipitated in marine sedimentary environment and it is most common in essentially pure quartz sandstone of shallow marine origin (Adams *et al*., 1987 and Blatt and Tracy, 1996). From thin section examination, the glauconite occurs as green or brownish green granular grains of sand size grade, structureless, of nearly spherical to rounded shape (Fig.3.8). Glauconite grains appear to have developed as a minor constituent of some sandstone or as disseminated grains in the original framework grains or as a major constituent of green sandstone (Fig.3.9). Glauconite can be used as an indicator of low sedimentation rate and it is a useful feature for sequence stratigraphic analysis (Nichols, 1999).

- **Pyrite**

Pyrite commonly occurs in sandstones, shale and carbonates and it is observed in various forms, such as framboids, single euhedral crystals (isolated cube) and more commonly as fine disseminated particles. Fine grained pyrite usually forms in organic-rich environments under reducing conditions.

Fig. 3.1 – 3.10

1. Quartz arenite sandstone composed more than 95% of subrounded, moderately sorted quartz grains cemented by silica material. EB-11, depth 2971 m, X.N., 190X.

2. Highly interlocked sand grains, point; straight and concavo – convex contact (boundary) between the grains. EB-2, depth 3331 m, X.N. 190X.

3. Quartz arenite sandstone, characterized by bimodal, badly sorted quartz grains, highly interlocked. Aq-1, depth 2716 m, X.N., 38X.

4. Quartz overgrowth (↑). Notice the dust-line developed between the overgrowth and the quartz grains. It is also illustrates the contact boundaries between the quartz grains. Ad-1, depth 3475 m, X.N., 380X.

5. Quartz arenite sandstone rounded to subrounded quartz grains. Notice the concavo – convex (⇑) and straight (arrow) grain boundaries. EB-2, depth 3281 m, X.N., 95X.

6. Coarse carbonate rock fragments (R) occur within the sandstone. Aq-1, depth 2747 m, X.N. 95X.

7. Prismatic Zircon mineral. EB-11, depth 2917 m, P.P., 38X.

8. Glauconite with brown margin, which indicates the oxidization of ferrous iron to limonite. Bd-1, depth 4925 m, P.P., 380X.

9. Glauconite as major constituents in sandstone. Ad-1, depth 3471 m, X.N., 38X.

10. Silica mineral cement for the sand grains. Notice the silica overgrowth (↑). Mu-1, depth 2348.2 m, X.N., 190X.

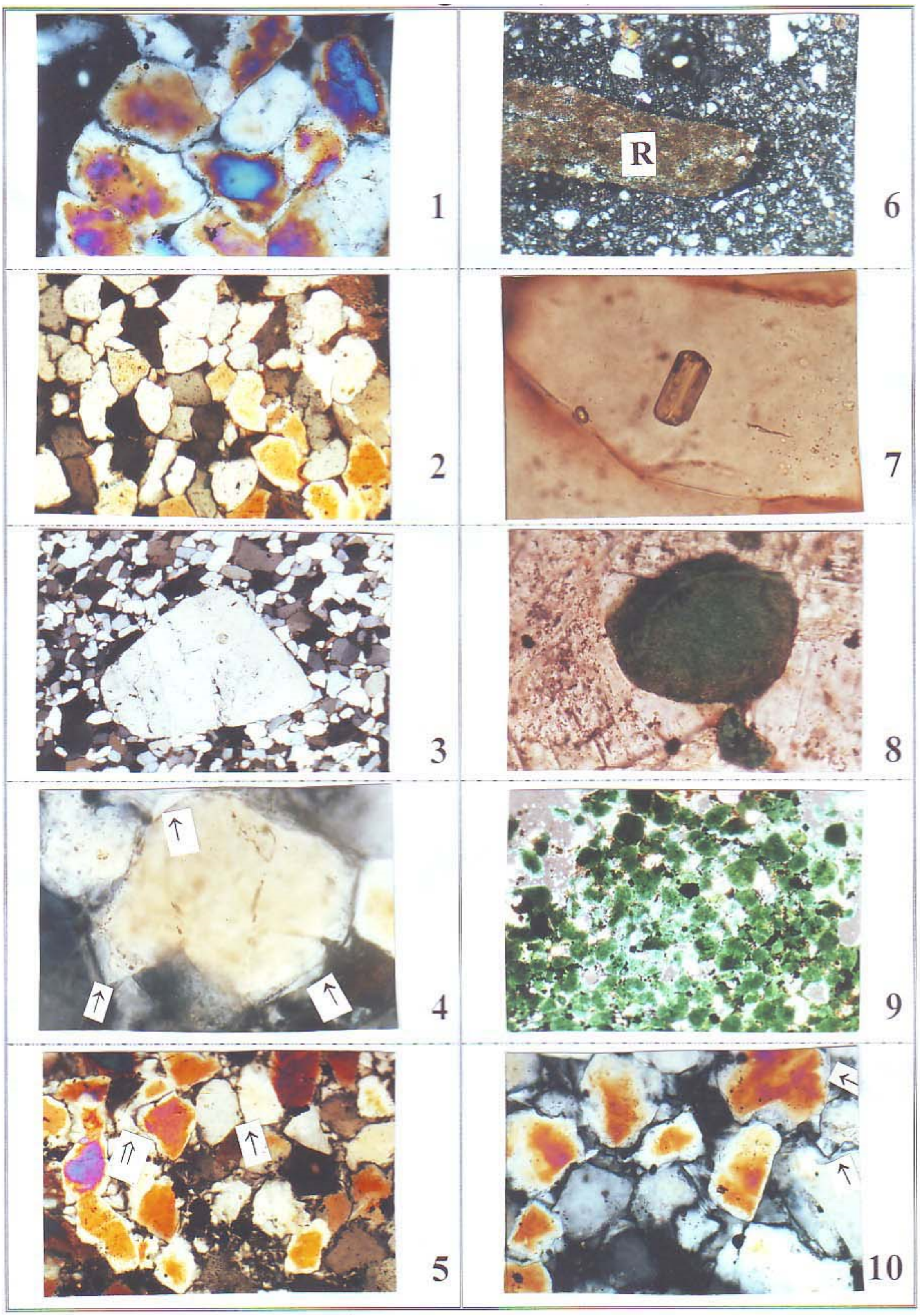


Fig. 3.1 – 3.10

SANDSTONE DIAGENESIS

Sandstones of the Nahr Umr Formation have been affected by the following diagenetic processes:

▪ **Cementation**

The most common cements of sandstones are silica and carbonates, which are the dominant types in sandstones of the Nahr Umr Formation, whereas the iron oxides, clay minerals and anhydrite cements are very rare. It is possible to find one or two or all types of cements in a rock sample. The effect of these type of cements is clear in destroying the porosity of sandstone layers.

 Silica Cement: One of the most common types of silica cement is quartz overgrown, in optical continuity, on detrital quartz grains (Fig.3.4 and 10). In many cases, a thin oxide-clay (which is of a detrital origin) coating was observed between the overgrowth and the grain (a dust-line); while in other cases, the boundary between the original grain and overgrowth cement can not be distinguished. Occasionally, the quartz grains of sandstone are tightly interlocked and appear as an angular grain (Fig.3.2 and 3). So, it makes some difficulty to recognize this type of cement. Overgrowths on quartz require generally a pH below 9 and a source of silica (Boyd and Lewis, 1995).

Clay matrix content and burial depth are the most effective factors controlling the formation of silica cement (Dutton *et al*., 1991). Extensive pressure solution processes over the grains led to the formation of sutured contact (Fig.3.1).

The sources of silica for silica cement formation in the sandstone beds of the Nahr Umr Formation are:

1- Circulation of meteoric water. Under warm and humid climate conditions, extensive meteoric water flushing results in the dissolution of unstable detrital silicate grains (may be mica or feldspars). This process causes silica rich solution, which is dependent on the volumes of unstable silicate grains and meteoric water involved (Ketzer *et al.,* 2003).

2- Some **silica rich solutions** may have been expelled from compacted shale beds, which interlaminate the sandstone beds of the Nahr Umr Formation. These shale beds contain high quantity of clay minerals, which regard as a principal source of silica. Silica solution from shale beds infiltrates to the sandstone beds and precipitate between sand grains as silica cement (Sibley and Blatt, 1976). This may be an important source for early diagenetic silica cement.

3- The original **quartz grains** are corroded and etched by carbonate cement in the points of grain contacts, this process causes dissolving of the silica, which later on re-precipitates between grains.

 Carbonate Cement: Calcite is the common carbonate mineral cementing the sandstones of the Nahr Umr Formation, which occurs with or without silica cement (Fig.4.1 and 2), whereas dolomite or ferroan dolomite (ankerite) are less common carbonate cement in this formation. Bjorlykke (1983) mentioned that the carbonate cement is common and considered as early diagenetic cements in sandstones.

Carbonate cement in sandstones of Nahr Umr Formation has resulted in the formation of the following features:

- Poikilitic texture (Fig.4.3).
- Corrosion and etching quartz grain margins, due to the reaction between sand and carbonate cements (Fig.4.1). This feature led to porosity enhancement.

The sources of the carbonate cement in the sandstone of Nahr Umr Formation are:

- Calcite supersaturated pore water.
- Dissolution of carbonate materials within the formation or within the accompanying formations.

- Oxidation of the organic matter that is present within the sandstone and shale beds of the formation acts to increase the alkalinity of the environment and enhances the carbonate cement precipitation.
- During the process of clay minerals transformation (smectite to illite) in shale beds, ions such as Fe, Mg and Ca may release in to pore solution (Aktas and Cocker, 1994). This solution being squeezed out by compaction processes, there would be more calcite cement added between quartz grains.

 Anhydrite Cement: Sulphates, as cementing materials are less common than silica and carbonates and are represented by patches of anhydrite cement (Fig.4.3) in sandstones of the Nahr Umr Formation. The occurrence of anhydrite cement is very limited, so the determination of its origin is very difficult.

- **Compaction – Pressure Solution**

Physical compaction affected the arrangement of sand grains after deposition leading to a gradual reduction in pore volume in sandstones of Nahr Umr Formation. Aktas and Cocker (1994) quoted in their study about uncemented sandstones that the physical compaction has reduced the intergranular pore volume from around 40% down to less than10%. Due to the effect of compaction process, different contact types are observed between the quartz grains: it may be straight and concavo-convex contacts (Fig.3.2, 4, and 5). The effect of compaction increases with depth of burial, which causes dissolution of grains at point contact, and produces sutured contact between the dissolved grains of similar solubility (Fig.3.1).

- **Replacement**

The etched and corroded margins of quartz grains, which have resulted from carbonate cementation, are gradually replaced by calcite cement (Fig.4.1). According to Dapples (1979), the locomorphic stage comprises the main lithification phase and involves dewatering, compaction, compression (deformation), cementation, crystallization and recrystallization. Therefore, within the current study the process of quartz replacement by carbonate cement, can be regarded or interpreted as a process not necessarily to be a late diagenetic process. Patches of anhydrite, as a replacement material in carbonate cement, occur commonly in the sandstones of Nahr Umr Formation and are usually of a late diagenetic in origin.

- **Dissolution and Porosity Evolution**

Dissolution of different types of cements and unstable detrital grains generate secondary porosity in sandstones of the Nahr Umr Formation (Fig.4.4). The absence of any significant amount of feldspar is attributed to their removal through grain dissolution. Diverse chemical changes can generate secondary porosity by dissolution, when carbonate cement is subjected to physico – chemical conditions that vary considerably from those under which they have been formed; they may dissolve and reprecipitate at various scales. The composition, of the sandstone, is the major factor in porosity evolution, (Tucker, 1991). Porosity is generally destroyed after burial by compaction and cementation.

- **Diagenetic History**

Different, early and late, diagenetic processes have affected sandstones of the Nahr Umr Formation. After the deposition of uncemented clean sands, the physical process of compaction is the major burial diagenesis affecting the sediments through gradual reducing of the interparticle porosity. The early chemical diagenetic processes are represented by either oxidation or reduction and effecting mainly organic matters and some ions, such as iron and sulphur.

Fig. 4.1 – 4.10

1. Corrosion and etching sand grains by the carbonate cement. Ad-1, depth 3429 m, X.N., 95X.

2. Large single crystal, completely enveloped lumps of sand grains producing poikilotopic crystals. EB-11, depth 2910 m, X.N. 190X.

3. Anhydrite cement, filling the pore space and replacing the carbonate cement. Mu-1, depth 2344 m, X.N., 95X.

4. Secondary porosity (P), generated as a result of dissolving unstable grains. Aq-1, depth 2666 m, X.N., 190X.

5. Grading of sandstone to silty sandstone. EB-11, depth 2951 m, X.N., 38X.

6. Grading and interlamination between fine sandstone and silty shale (dark color) beds. Ad-1, depth 3446 m, X.N., 38X.

7. Bioclastic wackestone microfacies. Notice the presence of large foraminifera (*Orbitolina sp.*) and bioclasts. Ad-1, depth 3434 m, X.N., 95X.

8. Arenaceous dolostone microfacies. Ad-1, depth 3411 m, X.N., 95X.

9. Cross bedding structure of core sample, Nahr Umr Formation, EB-4, depth 3166.0 m.

10. Cross lamination structure showing the alteration of very fine sandstone and shale laminae, Nahr Umr Formation, EB-2, depth 3268.5 m.

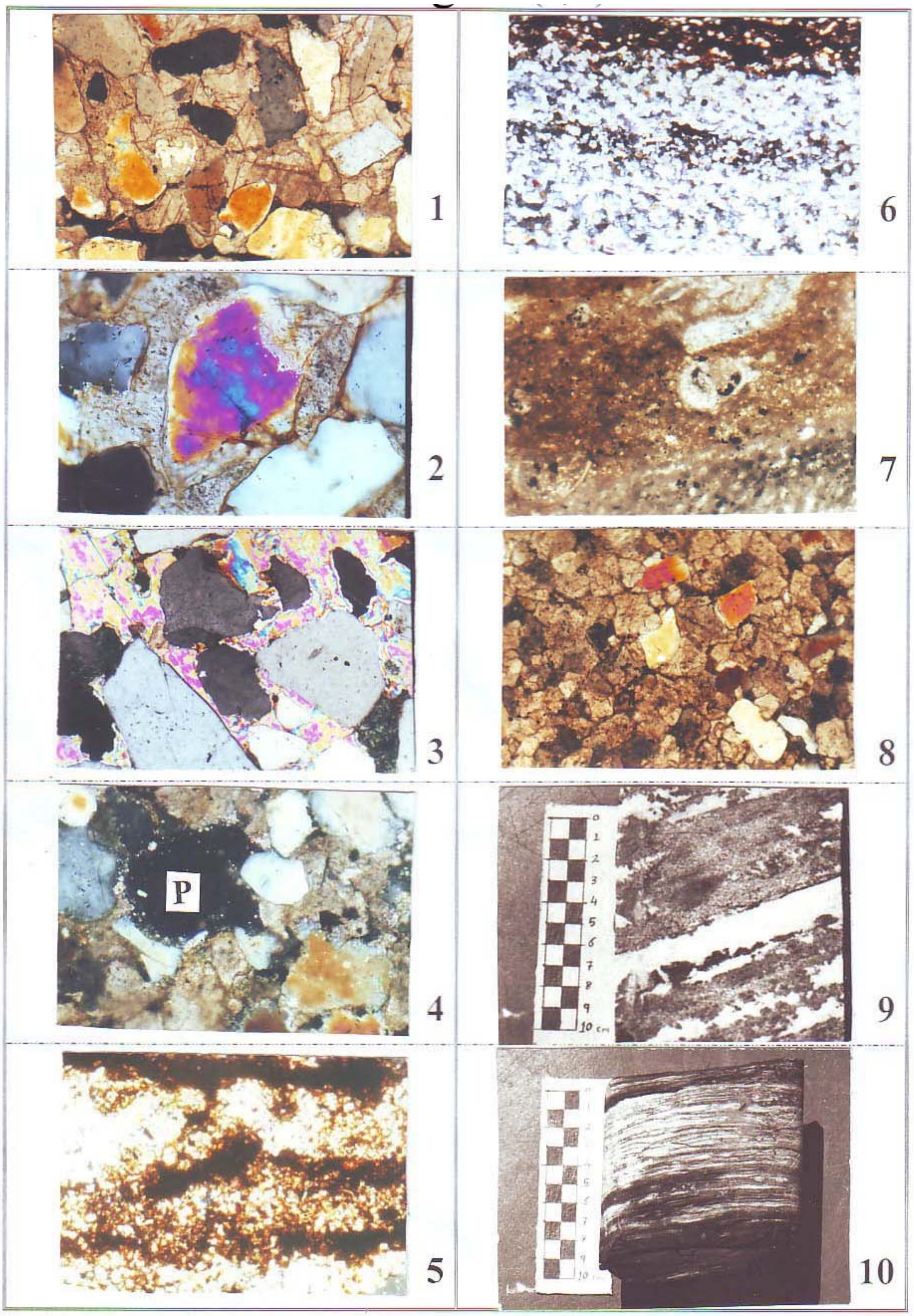


Fig. 4.1 – 4.10

The type of pore solutions controls types of formed minerals by diagenetic processes within sandstone grains. The most common chemical diagenetic changes of sandstone after burial are formation of different types of cementing materials. There are many chemical reactions, which occur during sandstone diagenetic history, affecting the types of cementation and porosity evolution.

The solubility of silica increases with increasing pH of pore solutions, while the solubility of calcite decreases. In acidic pore solutions, such as of meteoric waters, calcite tends to dissolve and to form quartz overgrowth, while in alkaline pore solutions, calcite cement develops, (Selley, 1982). Development of quartz overgrowth causes formation of the frame building cement and reduces the porosity of the sandstones of Nahr Umr Formation. Quartz overgrowths may develop very early in diagenesis (Dapples 1979b in: Boyd and Lewis, 1995).

Other chemical changes, which take place after burial, are the dissolution of unstable silicate minerals, such as mica minerals or grains, and transformations of clay minerals, in addition to the occurrence of etched quartz overgrowth and grains by corrosive solution, (Fig.5.5). Silica cement is developed then carbonate cement and later on anhydrite cement, which is very rare and developed as limited case.

An early phase of carbonate precipitation, which derived from solution rich with calcium carbonate, causes filling of pores and/ or replacing silica cement. Even it may replace some quartz grains. The occurrence of carbonate cements indicates the alkali type of pore solution, which is expelled by physical compactions. With increasing burial depth, the quartz grains become highly interlocked. At greater depth of burial, type of grain contacts changes from straight or nearly straight to concavo – convex contacts, while sutured contacts dominate at even greater depth (Selley, 1988). Consequently, with higher grain interlocking, due to compaction and presence of different tight contacts; the porosity reduces greatly. In addition, the chemical reactions of cementing materials and quartz grains with pore solution generate secondary porosity by dissolution processes of cementing materials and even detrital quartz grains. Most of the diagenetic history of Nahr Umr Formation is illustrated in Fig. (5).

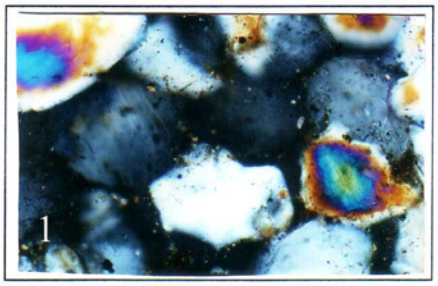
FACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENTS

The Nahr Umr Formation within these studied wells consists of various sedimentary facies such as sandstones, mudstone and carbonates. Different depositional environments have been suggested for this formation by different authors. The available data for this work was obtained mainly from detailed lithological information from studying the cuttings; and few core samples and available set logs of the studied wells. These data were correlated with the information, which provided from thin section examination.

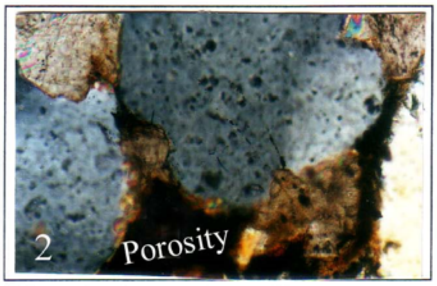
The following depositional environments are recognized in the Nahr Umr Formation:

Prodelta

It is the seaward part of a delta that is below the effective depth of wave erosion, which is located beyond the delta front, very fine particles are transported as a suspension material; settle quietly in this area (Bhattacharya and Walker, 1998). This environment in the current study is characterized by low lithological variation and it is represented by mudstone facies, which is composed of fine graded siltstone beds with dark coloured claystone (or shale) bed of dark occasionally black color rich with organic matter. Within the wells EB- 2, 4 and 11 and Bd-1, the mud shelf environment, which is characterized by fine material sediments may be intercalated and interbedded with the prodelta environment, (Fig.6). The mudstone facies within the prodelta environment is characterized by variable thickness ranging from few centimeters to about 2 m.

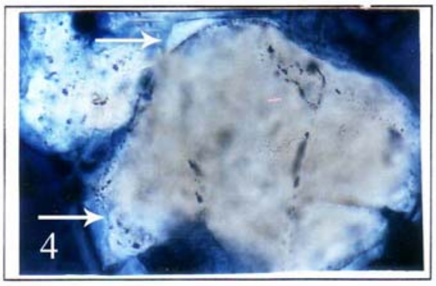


Physical process of compaction, gradually reducing the interpartical porosities

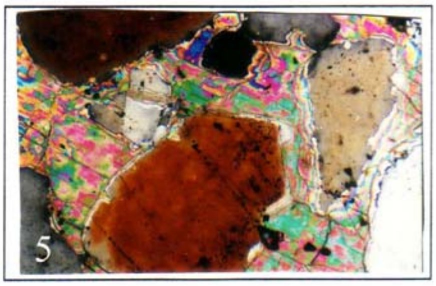


Chemical reaction effecting type of cementation and causing porosity evolution

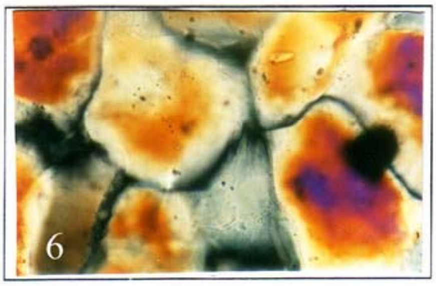
Precipitation of calcite cement between quartz grains



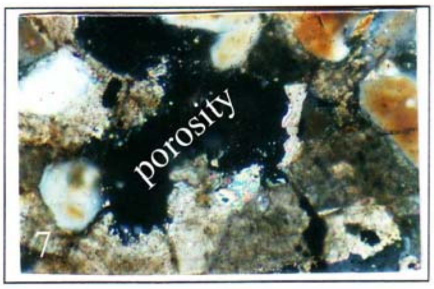
Quartz overgrowth



Eatching and corrosion the quartz grains and anhydrite cement replacing other cements



With increasing depth of burial, Quartz grains become highly interlocked



Secondary porosity generation

Fig (5): Diagenetic history of sandstone in Nahr Umr Formation

The prodelta sediments are characterized by colour variation of light to dark coloured, fine siltstone and shale beds. Thin carbonate facies of limestone and dolostone beds of variable thickness, ranging from 0.3 to about 3 m were observed in this environment. The limestone facies is subdivided into many submicrofacies such as: Bioclastic mudstone, bioclastic wackestone (Fig.4.7), and packstone. Benthonic foraminifera of various sizes are the most common skeletal grains, particularly species of orbitolinids, miliolids and *Nezzazata sp*. Other bioclasts include molluscan shell fragments, some echinodermal plates, and ostracoda.

The basal portion of the lower stratigraphic succession of Wells Bd-1, Ad-1, EB-2 and EB-4 represents the shallower part of the prodelta environment, (Fig.6a, b, d, and g).

Distal bar

The distal bar environment of the Nahr Umr Formation is characterized by coarsening upwards sedimentation grading from shale to silty shale and fine sandstone, which represent alternating mudstone facies with sandstone facies. Calcareous siltstone was also observed interlaminated with very fine sandstone and shale beds. This environment is the seaward-sloping margin of the advancing delta sequence (Coleman and Prior, 1981). Thin carbonate facies are observed with this environment, (Fig.6c, d, e and f). Pyrite, glauconite and few fine detrital sand grains are the subordinate mineralogical components of the limestone facies.

Distributary mouth bar

The distributary mouth bar is the area of shoaling associated with the seaward terminus of a distributary mouth channel (Coleman and Prior, 1981). It has been observed at Well Ad-1 only (Fig.6d) and its sediments are composed of clean-moderately-sorted sands that have been delivered by river. It shows a transition from muddier facies, of the prodelta into sandier facies, of the mouth bar environments (Elliott, 1986) and its thickness depends on the scale of the delta and the water depth (Bhattacharya and Walker, 1998).

Distributary channel

The distributary channel environment is the dominant and the most widespread environment in the Nahr Umr Formation, in Central Iraq. Generally, the sand grains of the sandstone facies are fining upwards and ranging from medium sand, in the base to fine sand in the top. Sandstone beds range in thickness from (2.5 – 14.5) m and represent this environment. Grading of sandstone to silty sandstone or clayey sandstones was observed especially in Wells EB-11, EB-4, Aq-1 and Ad-1 (Fig.4.5 and 6). Horizontal cross lamination was observed in Wells EB-2 at depth 3268.5 m; EB-11 at depth 2938 m (Fig.4.10), which is produced by the alternation of coarse and fine-grained material.

From the gamma-ray log; the occasional occurrence of thin shale beds associated with sandstone beds indicates the presence of a number of subsequent distributary channels. The distributary channel environment can be recognized from the gamma-ray log curve, which have sharp base and top, while the middle part of the stratigraphic succession of the Nahr Umr Formation, have mostly a cylindrical shape (Fig.2a), EB-2 at depth 3300 to 3325 and Fig. (2b), EB-4 at depth (3177 – 3198) m and at depth (3200 – 3222.5) m from the same well. The log curve profile of the present work coincides with those of Cant (1998) and Nichols, (1999) suggestion on facies analysis, from the log curve shapes.

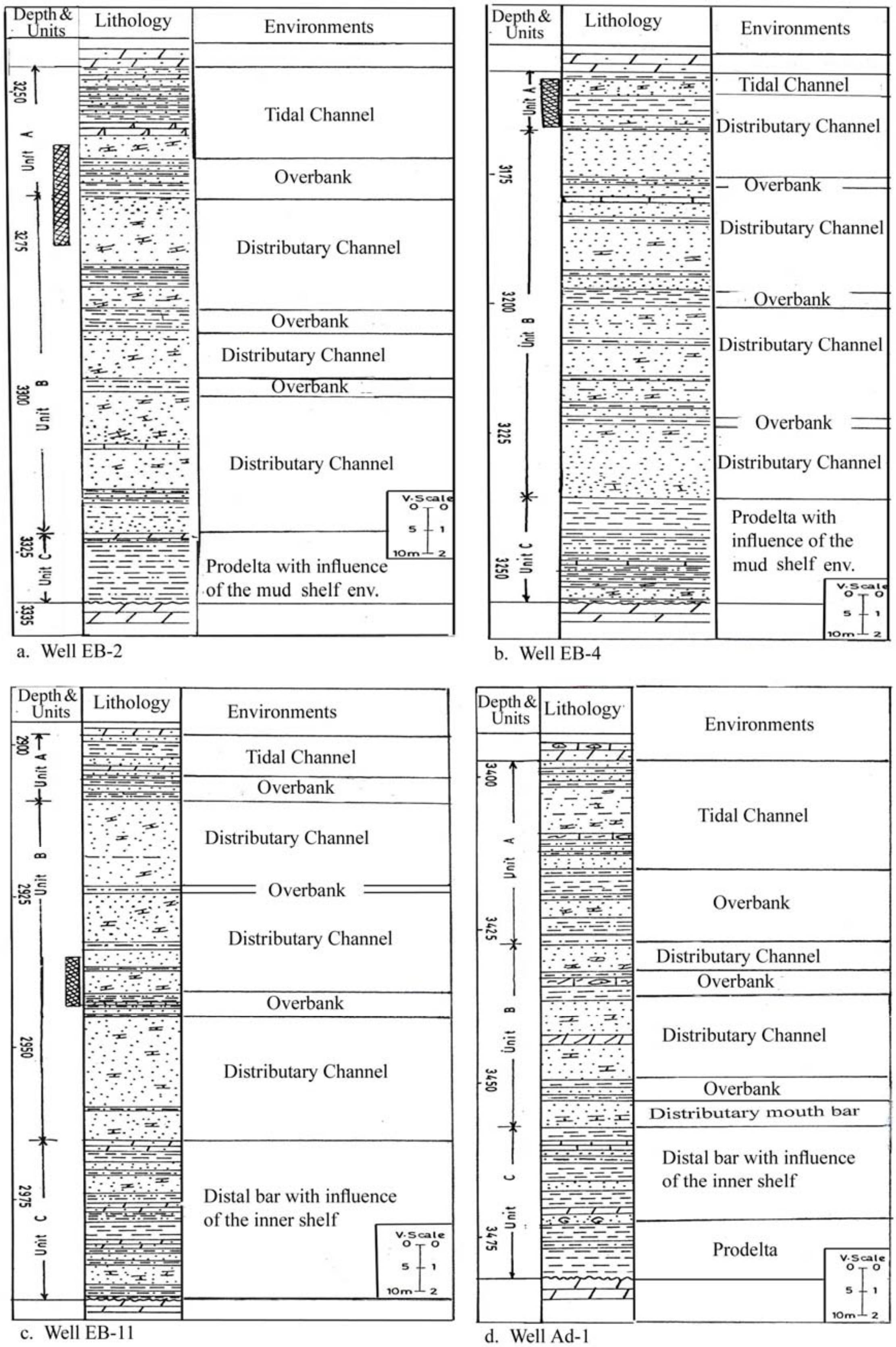
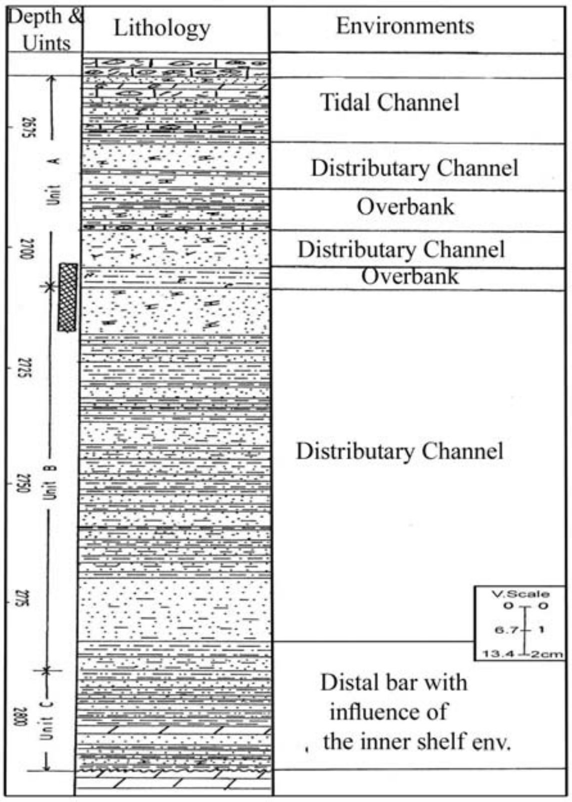
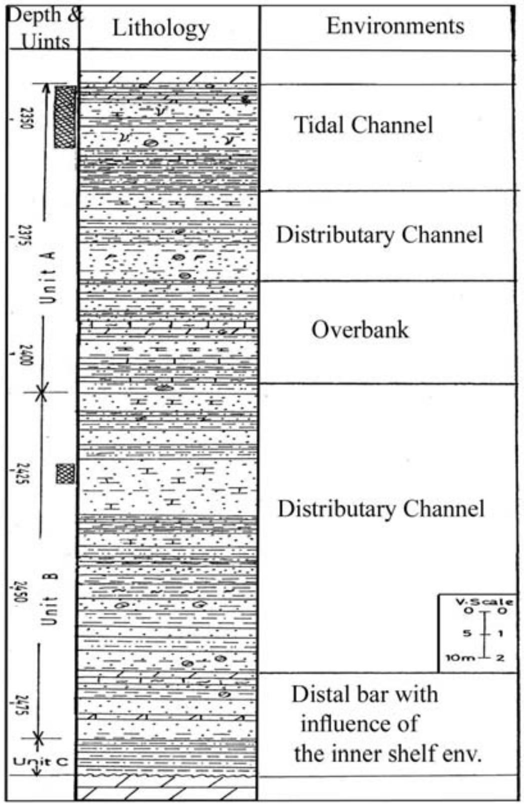


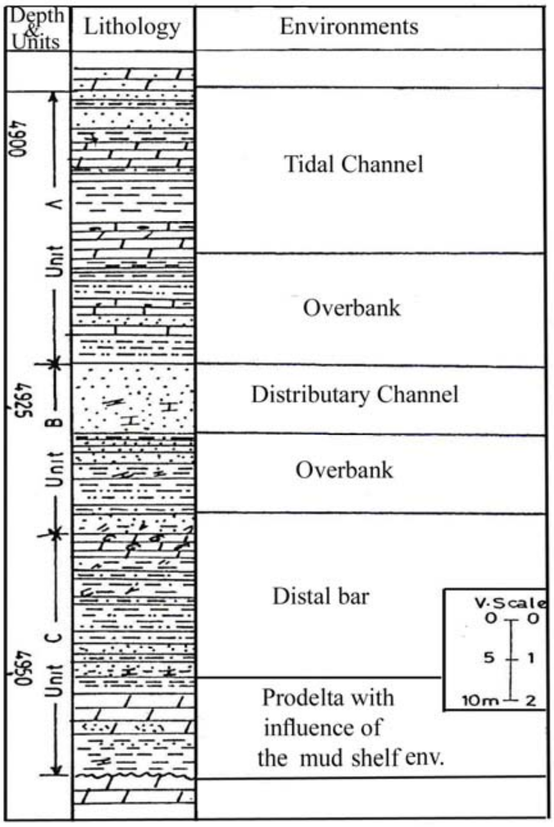
Fig.6: General lithology and depositional environment of Nahr Umr Formation in the studied wells



e. Well Aq-1



f. Well Mu-1



g. Well Bd-1

…. continue Fig .6

 Overbank

The mudstone facies are the dominant sediments of the overbank environment with occasional occurrence of fine sand. The shale (clay) beds are mostly of brown to reddish brown or dark in color with high organic content, occasionally with plant debris and amber crystals. The fine-grained sediments are deposited from suspension load on a flood plain by flood water that can be within the stream channel.

During the flood stages of the river, the mudstone facies are deposited on the flood plain, in bays, swamps, marshes and on other standing bodies as overbank materials (Bhattacharya and Walker, 1998 and Nichols, 1999). The above mentioned type of sediments represents the deposition in swamps, marshes and interdistributary bays. When it is partially open and connected to the sea, thin beds of carbonate will be deposited, consequently within the overbank sediments at depth (2384 – 2397) m (Fig.6f), and at depth (4911 – 4921) m (Fig.6g).

Detrital sand grains that occur commonly in various proportions from (15 – 20) % and locally form arenaceous dolostone facies (Fig.4.8). The occurrence of pyrite and glauconite crystals indicates reducing or euxinic conditions of deposition. Parallel lamination of fine grained siltstone layers with shale (fissile) beds, are the main recognizable sedimentary structures within the mudstone facies of Nahr Umr Formation.

 Tidal channel

The facial variations and distribution of the Nahr Umr Formation in the studied wells indicate that: It is a major channel, followed by the tidal currents extending from offshore into a tidal marsh or a tidal flat (Bates and Jackson, 1980).

The upper part of the Nahr Umr Formation is composed of sandstone facies interbedded with thin shale beds (mudstone facies) and occasional thin carbonate facies, which contain some benthonic foraminifera, such as *Orbitolinoids* and other shell fragments (Fig.6).

The interbedding of the carbonate beds with shale and calcareous sandstone indicates a deposition in tidal channel environment, where the sediments are fining upwards. Reducing of the terrigenous supply and the presence of interlaminated sediments indicate a near shore and shallow open marine environment. Depending on tidal strength, a tidal signature may penetrate deep into delta plain favoring the development of tidal influenced lagoons and tidal flats (Emery and Myers, 1996).

Medium to small scale cross bedding in well EB-4 at depth 3164 m (Fig.4.9) is the main sedimentary structure, which is observed and determined within this environment. This sedimentary structure is a characteristic of fluvial, deltaic and tidal beach environments (Reineck and Singh, 1980 and Coleman and Prior, 1981).

Finally the depositional environments of the Nahr Umr Formation are characterized by the presence of different sedimentary environments and represented by the shoreline influence in the upper part, fluvial and delta environments in the middle and the lower parts with the influence of inner shelf environments.

Figure (7) represent schematic model for illustrating the main depositional environment and its sub environments of Nahr Umar Formation, in the studied wells.

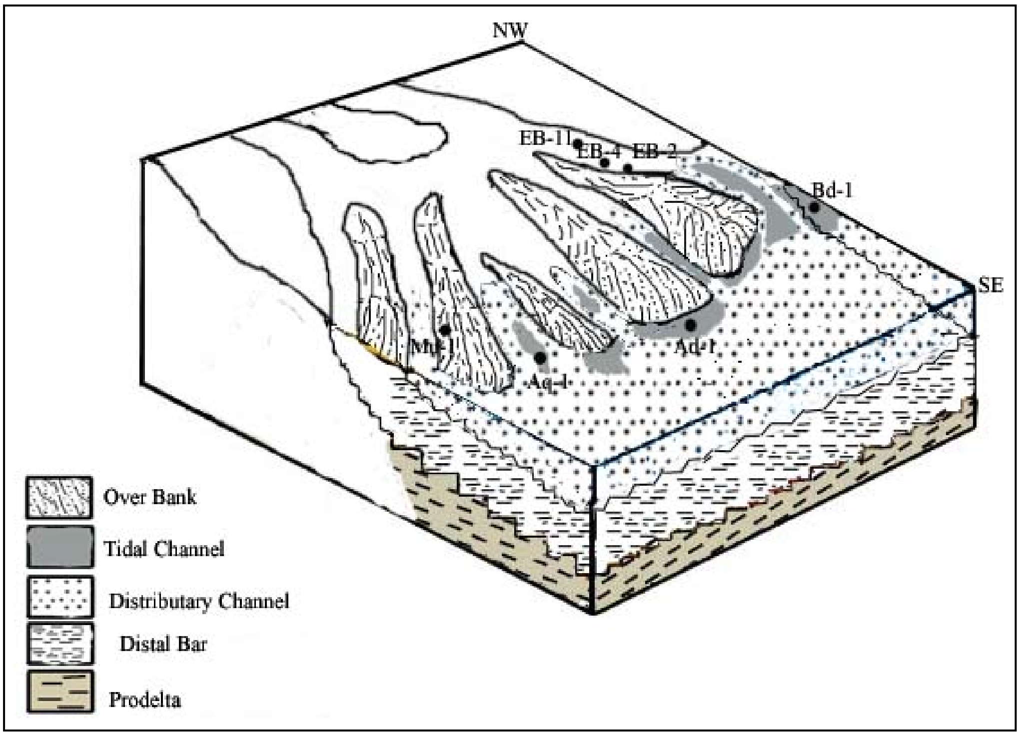


Fig.7: Schematic NW – SE model showing the depositional model of the Nahr Umr Formation, in the studied wells

CONCLUSIONS

- The thickness of the Nahr Umr Formation is variable according to its location and reaches a maximum thickness of about 147.5 m, southwest direction in Well Aq-1 and a minimum thickness of 64 m, east direction in Well Bd-1.
- The sandstones within the studied wells are considered to be mineralogically and texturally matured. Compositionally, they are classed as quartz arenite, subrounded to round of moderately sorted sand grains making 95% of the bulk. Pyrite, glauconite is forming only 5% of the sandstones.
- The sandstones were derived from source areas dominated by sedimentary rocks. Sandstone of Nahr Umr Formation is the final product of more than one sedimentary cycle, which represents prolonged combinations of geological processes and several diagenetic alterations.
- The dominance of the sand deposits in samples from Wells Aq-1, Mu-1, EB-2, EB-4 and EB-11 reflects a significant increase of sand influx (increasing of sand/ shale ratios) from source area (Arabian Shield), which was close or near the depositional basin of the Nahr Umr Formation. The dominance of carbonate deposits in samples from Wells Bd-1 and Ad-1 reflects a significant increase of marine carbonate sediments while the depositional basin of the formation was located away from the sand source area. Consequently; the influence of the marine environments is reduced to the west and northwest direction, while the influence of the continental environment was significant. In contrary, to the east and southeast directions the effect of marine environment was increased. As a result, a noticeable increase in sand ratio and sand beds thickness were observed towards north and northwest directions, in samples from Wells: Aq-1, Mu-1, EB-2, EB-4 and EB-11.

Therefore, it can be concluded, that Wells Bd-1 and Ad-1 are located closer to the shoreline and marine influence than the remaining wells.

- Compaction-pressure solution, cementation, dissolution and replacement are the main diagenetic processes. Compaction and packing are usually reducing porosity and their effect is reflected by nature of detrital grain contacts.
- Three types of cement have been recognized; silica cement is the most common type, while carbonate and anhydrite cements are less common.
- The main diagnostic sedimentary structures indicated in this study are represented by cross bedding; horizontal laminations; graded bedding and bioturbation.
- Multi-depositional conditions were suggested and six distinct depositional environments have been recognized: prodelta, distal bar, distributary channel, overbank and tidal channel.
- The upper part of the formation is characterized by fining upwards sediments, and interlaminations of carbonate beds with shales and calcareous sandstones, which indicate a deposition in a tidal channel with the influence of near shore, shallow open marine conditions. The middle and lower parts are mainly of fluvial and deltaic, with the influence of the inner-shelf environments.

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