Tectonic Evolution of Southern part of the Mesopotamian Foredeep Basin

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Abstract

This study investigated the tectonic evolution of the southern part of the Mesopotamian Foredeep basin. Subsidence and sedimentation rates were calculated for six oil wells distributed on the tectonic subzones of the sedimentary basin through the use of restored thickness rates according to Backstripping Method for Cretaceous and Tertiary sequences. The consequence of this study indicates the subsidence and sedimentation rates changing vertically and laterally through geologic time. As shown, the sequences of Albain subcycle are wide subsidence and sedimentation rates especially for the Mauddud Formation at the Am-1well which located in the eastern part of the sedimentary basin (Tigris subzone), as well as for the sequences of Cenomanian-Early Turonian subcycle especially for the Ahmadi and Mishrif formations were increase in subsidence and sedimentation rate toward (Am-2 and Mj-3) wells. Both wells located within the Tigris and the eastern part of Zubair subzone. This is in accordance with the closure of the South Tethys Sea because of the influences of the Austrian and Subhersynian orogenies. Three unconformity surfaces determine clearly in the depositinal basin of incompatibility during the Early Turonian, Danian and Oligocene epochs. Those unconformities affects all tectonic subzones except for the Am-1well where it was not influences by the unconformity during the Oligocene epoch. The subsidence and sedimentation process continued at high rates, reflecting the large thickness of the eastern part of the basin in the Tigris subzone area. Sedimentation rates augment significantly at the well (AG-19), which indicates the effect of faults on the Tigris subzone. This affects the degree of maturation and the source of hydrocarbons in the sedimentary basin.

KeyWords: Basin Analysis, Mesopotamian Foredeep, Iraq.

التطور التكتوني للجزء الجنوبي لحوض وادي الرافدين

الملخص:

جرى في هذا البحث دراسة التطور التكتوني لحوض وادي الرافدين (Mesopotamia Basin) من خلال حساب معدلات التجلس والترسيب لسبعة آبار نفطية موزعة على الانطقة الثانوي للحوض الترسيبي (الزبير، دجلة، الفرات)، ذلك من خلال استخدام معادلات السمك المسترجع (Backstripping) لتتابعات زمن الطباشيري والثلاثي (Cretaceous and Tertiary). بينت النتائج ان معدلات التجلس والترسيب تتغاير عموديا وجانبيا خلال الازمنة الجيولوجيةك المتتابعة، حيث شهدت تتابعات الدورة الثانوية (Albain) معدلات تجلس وترسيب عالية وخصوصا لتكوين مودود الجيري عند البئر(-AG 19, Am-1) الواقع في الجزء الشرقي من الحوض الترسيبي عند نطاق دجلة الثانوي، وكذلك بالنسبة للتتابعات الدورة الثانوية (Cenomanian-Early Turonian) خصوصا لتكوين الاحمدي والمشرف حيث يزداد معدل التجلس والترسيب باتجاه الآبار (AG-19, Am-2, Mj-3) الواقعة ضمن نطاقي دجلة والجزء الشرقي من نطاق الزبير، وهذا متوافق مع نهاية الانفتاح التيثس الجنوبي وبداية الانغلاق نتيجة الحركة النمساوية (Austrisn) والحركة شبه الهرسينية (Subhersanian). كما بينت النتائج ان الحوض الترسيبي شهد ثلاث اسطح عدم توافق خلال الازمنة (Early Torunian, Danian, Oilgocene) اثرت على جميع الانطقة التكتونية الثانوية باستثناء البئرين (AG-17, Am-1) حيث انه لم يتأثر بعدم التوافق الاخيرخلال زمن (Oligocene) اذ استمرت عملية التجلس والترسيب وبمعدلات عالية مما يعكس السمك الكبير لتتابعات الجزء الشرقي من الحوض عند نطاق دجلة الثانوي، وان معدلات الترسيب تزداد بشكل كبير عند البئر (AG-19) مما يشير الى تاثر الفوالق الثانوية على شبه نطاق دجلة وهذا بدورة يؤثر على درجة نضوج ومصدر الهيدروكابونات في الحوض الترسيبي.

Introduction

This study deals with the tectonic history of the Mesopotamian Basin through simulations of subsidence and sedimentation rates during Cretaceous, Tertiary and Quaternary periods in the method of Backstripping. This is achieved through the use of digital techniques based on experimental methods and mathematical equations to obtain curves and markers of the relationship of porosity with depth aimed at the detection and display of geological events over a time frame that gives an explanation of the variations of the stratigraphic columns of the sedimentary basin vertically and laterally, and linked to the tectonic events experienced by the Arabian plate during successive geological periods. Thus, the results of this analysis can be linked to the oil traps and the prediction of the maturity and source of hydrocarbons. The present study periods of the Mesopotamian basin consisted of four megasequence (AP8, Ap9, Ap10, and Ap11), which included more than 25 sedimentary formations distributed over a number of subsequence.

The Area of study

The study area consists of seven oil wells (Su-9, Ru-72, Mj-3, AG-19, Am-2, Kf-1, and Ns-1), which are distributed in the Zubair, Tigris and Euphrates subzones for Mesopotamian basin within the stable shelf as given in Figure (1) [1]. The study area is characterized by a thick sedimentary cover that increases toward east, short and large lengths folds with a north-south direction in the southern part of the sedimentary basin and northwest-southeast in the eastern part of the sedimentary basin along the passive margin [2].

Tectonic Setting

At the end of the Middle Permian-Cenomanian period, the Arabian plate was exposed to an extension force between the Iranian and Turkish margins from the edge of the eastern and northern Arabian plate [3]. This resulted in the opening of the Sea of Neo-Tethys and the Southern Neo-Tethys during the Middle Permian-Early Triassic and Mid Triassic-Cenomanian respectively [1[. This has caused the formation of half-graben basins resulted by the Listric Normal Faults [4] and was associated with the deposition of the higher part of the megasequence (AP6) and cycle sequences of megasequence (Ap7) and megasequence (AP8) [1]. The end of the Jurassic period and the beginning of the Cretaceous era marked the Geodynamic inversion from extension to Compression [5] due to the closure of the Southern Tethys during the early Masteriachtian-Turonian period, which appeared in the Kemerian orogeny in the Berriasian epoch and the Austrian orogeny at the end of Albain epoch [4]. During this period, the deposited of sequences of the (AP9) were ended with a regional unconformity resulting from the Laramidian orogeny, which represents the first phase of the alpine orogeny where a continental-continental collision occurred and the ophiollite emerged on the edge of the plate during the Masteriachtian period [1]. During the Middle Paleocene-recent period, the new Tethys Sea closed, which reached its peak during the Pliocene period of the Alpine orogeny [6], and deposited of megasequence (AP10) and AP11 were separated by a regional unconformity during the Oligocene period. To end the sedimentary events with the depositions of the marshes, marshes and river sediments during the Quaternary era [1]. To end sediment events with deposition of marshes, swamps and river sediments during Quaternary period [1].

Methodology

The original thickness and restored thickness are considered using the Backstripping method, based on mathematical equations. The porosity calculated based on the linear equation for shallow depths as shown below [6]:

$$\frac{1}{\emptyset_n} = \frac{1}{\emptyset_\circ} + CZ \qquad (1)$$

As for the deep depths, the equation [7]) is used:

$$\emptyset_n = \emptyset_\circ * e^{-cz} \qquad (2)$$

$\emptyset_n$: Porosity of the rock at depth (Z); e: The Basis of the Niberian Logarithms.

$\emptyset_\circ$: The porosity of the rock on the surface (Z = 0) based on [8].

C: The coefficient determines the porosity gradient with the depth and is also called the compaction constant (m-1).

The decompaction thickness is calculated according to the equation below:

$$T_d = \frac{(1 - \emptyset_\circ) * (T_n)}{1 - \emptyset_n} \qquad (3)$$

T_d: The original thickness before compaction; T_n: Current thickness.

Based on the original thickness and variations of the global sea level [10] , total subsidence was calculated according to [11]:

$$S = T_\circ + WD - \Delta SL \qquad (4)$$

We can also calculate the total subsidence and sedimentation rates according to [11]:

$$R_s = \frac{S}{A * 10} \qquad (5)$$

$$R_f = (T_o/A*10) \qquad (6)$$

R_s: total subsidence rate (cm per 1000 years); S: Total subsidence (meters) A: Age of rock unit (million years); R_f: Sedimentation rate (cm per 1000 years). T_o: Total thickness in meters.

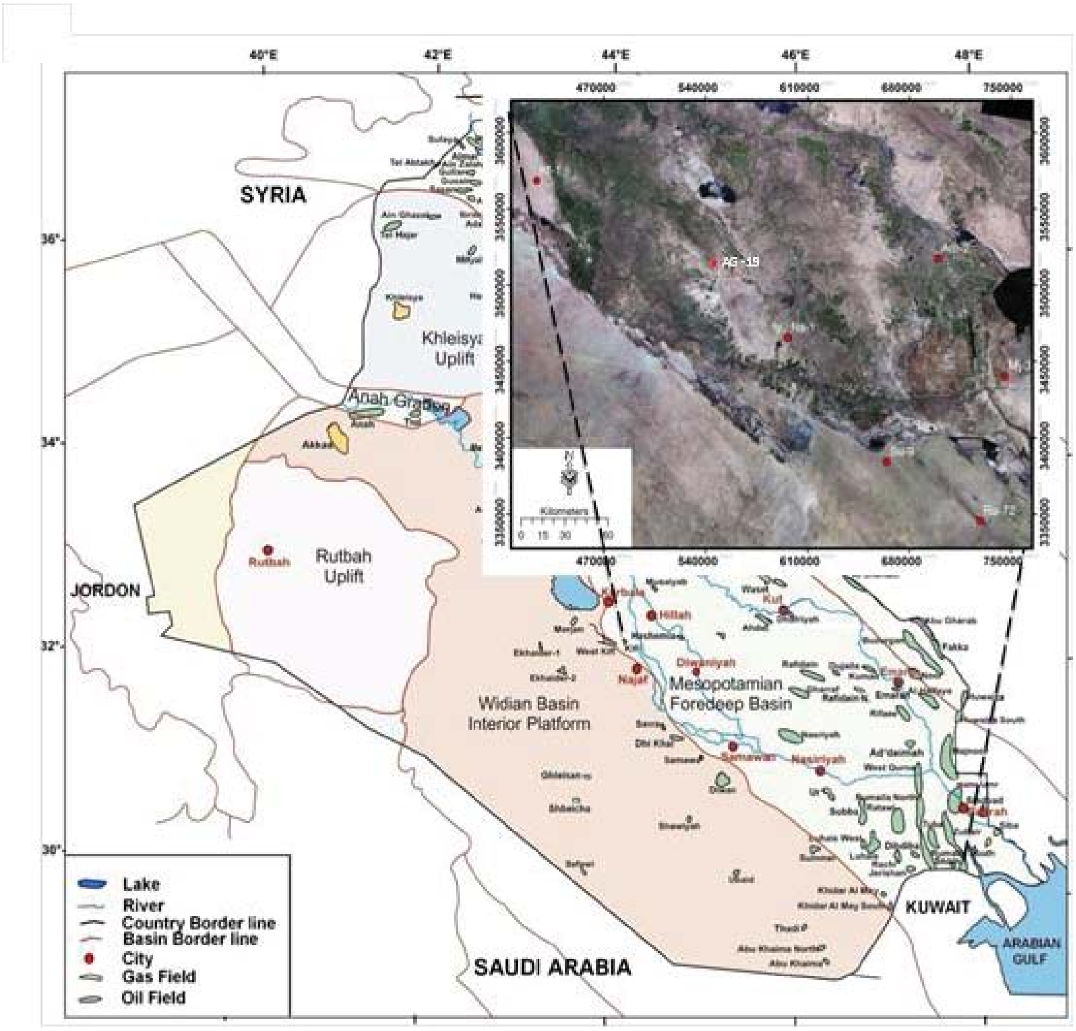

Fig. (1) Iraq map showing studied area and selected well sites.

The PetroMod program was used to find the curves of the subsidence and burial histories of the study wells. It was possible to calculate the eroded thicknesses to succession of the studied wells through the equation by [12]:

$$AGE_E = \frac{(R_1 * AGE_1) + (R_2 * AGE_2)}{R_1 + R_2} \qquad (7)$$

AGEE: Time of erosion; R1, R2: Sedimentation rate in both formations respectively.

AGE1: Deposition time deposited under the surface of erosion.

AGE2: deposition time deposited above the surface of erosion.

$$\text{ERODED THICKNESS} = R_1 * (AGE_E - AGE_1) \qquad (8)$$

Results and discussion

The deposition of the Mesopotamian basin included four Megasequence of the Late Tithonian period to the present. Each megasequence contains a number of sequences. The sedimentation times of each sequence were utilized [13]. The following are the rates of subsidence and sedimentation for these sequences:

1- Megasequence (AP8): Late Tithonian-Early Turonian (140-90 ma):

This megasequence included four sequences:

• Late Tithonian-Hauterivian (140-118 ma): In the beginning of this sequence, the starting of subduction of new Tethys under the Iranian and Turkish plates (Numan, 2000), which is represented by the Sulaiy, Yamama, and Ratawi formations where deposited in open lagoonic environments to restricted lagoons within the Sedimentary Basin of the Mesopotamia ([1] and [9]. The subsidence and sedimentation rates of succession for this sequence are low not more than 15 cm per 1,000 years and these rates are lower towards the northern margin at the well (Kf-1).

• Berriasian-Aptian sequence (118-107):

This sequence consists of depositing of Zubair deltaic Formation and Shuaiba limestone Formation [1]. The low rates of sedimentation and subsidence for the successions continued during this sequence, which is relatively increased to the formation of Zubair towards the wells (Ns-1, Su-9, and Ru-72) located south and south-west of the sedimentary basin due to proximity to the coastal line (shore line).

• Albain sequence (94-107m.a): This sedimentary sequence consists of deposits of the Nahr Umr and Mauddud formations [1]. The subsidence and sedimentation rates are medium to high especially for the Maudud Formation, where they reach more than (55) cm per 1000 years, especially in the two wells (AG-19, and Am-2) located in the center of the sedimentary basin, while the rate of subsidence and sedimentation to Nahr Umr Formation very low exceeds (3) cm per 1000 years at the center of the basin, as far as the distance from the source of processing in the south-west.

• Cenomanian-Early Turonian sequence (94-90 m.a): This sequence consists of the deposits of the Ahmadi limestone Formation under lagonic environment, then deposits of the Rumaila pelagic limestone and the deposits of the Mishrif reefal limestone [1]. The subsidence and sedimentation rates for this sequence are medium to high as they increase in the wells (AG-17, Am-2, and Mj-3) located in the center of the sedimentary basin and descending towards the north of the basin at the well(Kf-1). This sequence ends with regional unconformity at the top of the Mishrif Formation as a result of the lifting from the Austrian orogeny (First stage).

2- Megasequence (AP-9) Late Turonian-Danian(80-89):

This megasequence is divided into two sequences:

• Turonian-Early Companian sequence (80-89 my):

This sequence is characterized by deposited (Khasib, Tanuma and Sa'adi) formations in restricted Lagoon environments to deep lagoon environments [1]. This sequence is characterized by relatively high subsidence and sedimentation rates (Ns-1, Ru-72, and Su-9) located in the south and west of the sedimentary basin.

- Late Campanian- Masteriachtian sequence (65-80 my):

This sequence represents by deposits of Hartha and Tayarat formations precipitated in shallow environments and the Shiranish Formation, which is deposited in open marine environments [1]. The subsidence and sedimentation rate for this sequence is medium in wells (Su-9, Ru-72, and Ns-1) located south and south-west of the sedimentary basin and low rates in wells (1 AG-17, Am-2, Mj-3, and Kf-) center and north of the sedimentary basin. This sequence ends with regional unconformity at the top of the Tayrat Formation due to the uplifting and increase of the sea closure of the Southern Tethys and the occurrence of continental - continental collision during the Laramidian orogeny during the Masteriachtian period and the loss of most deposits of the Danian period.

Megasequence (AP-10) M. Paleocene- Eocene sequence (62.3-36.5m.a):

This megasequence is divided into two sequences:

• Mid Paleocene-Early Eocene sequence (62.3-45m.a): In this sequence there were variations in the type of sediment between the wells (AG-17, Am-2, and Kf-1), is located in the Tigris subzone, which included calcareous deposits of deep environments represented by the Aaliji Formation, indicating the reversal of the tectonic position, where subsidence and sedimentation rates are increasing towards the center of basin as a result of the new Tethys sea during the Alpine movement in Pliocene [6], as a result of the starting closed of new Tethys sea during the alpine orogeny in Pliocene [6]. The wells (Ns-1, Su-9, and Ru-72), located in the south and south-west of the sedimentary basin, are located in the Euphrates and Zubair subzones with deposits that alternate from shallow limestone rocks to evaporates rocks of Umm Radhuma and Rus formations respectively reflected that the shallow environments [1]. While, at the well (Mj-3) is reflect an overlap between shallow environments in the south and south-west, and deep environments in the center and north of the sedimentary basin. This is consistent with what he pointed out [14]. This sequence has seen low subsidence and sedimentation rates.

- Middle-Late Eocene sequence (36.5-45 M.A.): This sequence represented by deposits Dammam limestone Formation under lagoon environment (K-1, Ru-72, Ns-1, and Su-9), and sedimentation of the Jaddala Formation in the open sea in the basin center of sedimentary basin at the wells (AG-17, Am-2, and Mj-3). This sequence is characterized by low subsidence and sedimentation rates towards the center of the sedimentary basin at the two wells (AG-17, and Am-2). This sequence ends with regional unconformity in most of the study wells during the (Oligocene period) except for the two wells (AG-17, and Am-2) at the center of the sedimentary basin where the Kirkuk group deposits at high rates of sedimentation. This reflects the deep depth of the center sequence at the Tigris subzone, as well as the activity of the faults within this subzone.

3- Megasequence (AP-11) Latest Eocene–Pliocene (36.5-0 M.A):

This megasequence is divided into three sequences:

• Late Eocene-Oligocene sequence (36.5-23 M.A): This sequence consisted of an unconformity involving most of the study wells except for the wells (AG-17, and Am-2) located in the center of the sedimentary basin. This indicates that the continued subsidence of the Tigris subzone, separated from the Zubair subzone by the Takhadid Al-Qurna fault and the Euphrates subzone by Tikrit-Amara fault [1]. As a result of this subsidence, the Kirkuk Group is depositing at high sedimentation rates, and this sequence is compatible with the new Tethys closure during the Alpine orogeny.

• Early-Mid Miocene sequence (23-11M.A): This sequence represented by deposits by Euphrates-Jeribe Formation, which is deposited in shallow environments at the wells (AG-17, Am-2, Kf-, and Ns-1), while deposits of Ghar Formation at wells (Ru-72, Su-9, and Mj-) within the Zubair subzone. This sequence ended with the Fatha limestone Formation in all study wells. Subsidence and sedimentation rates are low in most study wells except wells (AG-17, Am-2, and Mj-3) where subsidence and sedimentation rates are medium.

• Late Miocene-Pliocene sequence (0-11): This sequence represented by deposits of Anjana Formation was the deposits under river environment condition at the wells (GR-17, Am-2, and Kf-1) and deposits the Dibdibba Formation in the other wells of the study (Su-9, Ns-1, Ru-72, and Mj-3). The subsidence and sedimentation rates are low in all study wells except for wells (GR-17, Am-2, and Mj-3) where the subsidence and sedimentation rates are medium, indicating that the subsidence will continue to occur in the Tigris subzone region as a result of the new Tethys closure, the end of this sequence is dominated by the deposition of marshes and swamp in the wells in the center of the basin during the Quaternary period.

Conclusions

1 - The study area was affected by four tectonic orogenies as a result of the closure of the southern Tethys and the new Tethys. This resulted in four megasequences and deposit twenty-seven formations distributed in 12 sequences within the megasequences.

2 - Austrain and and Subhercynian orogenies during the middle Cretaceous affected the subsidence and sedimentation rates of the cretaceous successions in the sedimentation area without alterations in the successions between the subzones of the sedimentary basin. Where the same formations were deposited along the recessive basin and increasing the subsidence and sedimentation rates towards the north-east of the basin at Tigris subzone region, indicating that the area was not subjected to compression stresses.

3 - The closure of Tethys and the convergent caused by the Laramdia orogeny in the Mastrachitian and the and the Alpine orogeny in the Pliocene period caused variations in the type of sediments and thicknesses between the Tigris subzone with the Zubair and Euphrates subzones. Dominate sediments were deposited in the deep environments of the Tigris subzone, while shallow, calcareous and evaporated sediments existed in the Zubair and Euphrates subzone regions.

4 - Calcareous deposits are increasing in thickness towards the wells located in the north - east of the sedimentary basin while the Clastic sedimentary deposits increase their thickness towards the wells located in the south - west of the basin, and this result of proximity and distance from the center of the basin and the source of processing.

5 - The impact of the sedimentary basin with three unconformity surfaces where the first unconformity at the top of the Mishrif Formation and strongly impacted the direction of the two wells (AG-17, andAm-2) at Tigris subzone , while the second unconformity at the top of the Tayrat and Shiranish formations and hard effected at the well (Su-9) located in the west of the sedimentary basin at the Zubair, subzone ,while the third unconformity during the Oligocene period strongly affected all wells except the study wells (AG-17 , and Am-2) located at the center of the basin, near the Tigris subzone , where the subsidence and sedimentation rate was very high. This means that the Zubair, Euphrates, and the northern part of the Tigris subzones were exposed to elevation due to movements along longitudinal and transverse faults, while the Tigris subzone is characterized by a very high subsidence, especially at the eastern part of the well (AG-17), Figures (2, 3, 4, 5,and 6).

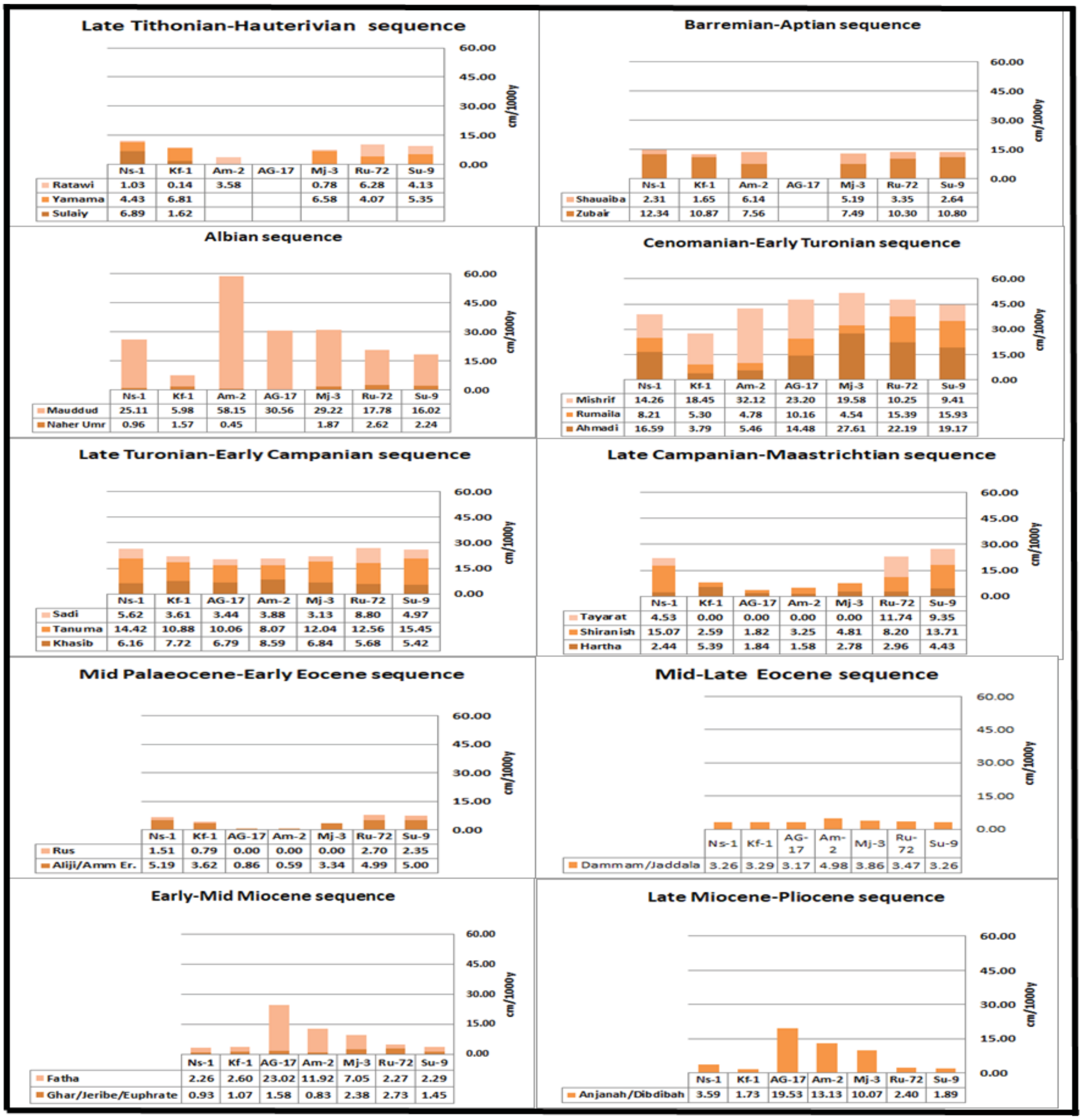

Fig. (2) Sedimentation rates for the succession of Mesopotamia basin in all study wells.

Su-9

Fm./age(m.y.)	0.0	11.0	16.2	23.0	36.5	45.0	53.0	62.3	65.0	68.2	70.4	80.0	86.0	87.0	89.0	90.0	92.0	93.0	94.0	95.0	107.0	112.0	118.0	125.0
Dibdba	107.0																							
Fatha	90.0	92.1																						
Ghar	81.0	81.2	81.9																					
Unconf.	0.0	0.0	0.0	357.5	582.6																			
Dammam	215.5	229.5	222.1	225.1	225.1																			
Rus	153.0	155.2	167.0	159.0	159.0	164.7																		
Umm-Er-Radh.	441.5	446.7	451.5	456.0	456.0	469.4	480.4																	
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	233.1	509.3															
Tayarat	210.0	213.5	216.7	219.9	219.9	229.9	238.7	276.2	276.2															
Shiranish	181.5	184.1	186.4	188.7	188.7	195.9	202.1	227.9	227.9	246.6														
Hartha	263.0	266.1	268.9	271.7	271.7	280.2	287.5	316.8	316.8	337.3	360.4													
Sadi	192.3	194.2	195.9	197.6	209.5	202.7	207.0	224.1	224.1	235.6	248.3	273.2												
Tanuma	64.7	65.5	66.3	67.0	62.1	69.2	70.9	77.6	77.6	81.9	86.5	95.1	103.5											
Khasib	38.5	38.8	39.1	39.4	57.9	40.3	41.0	43.9	43.9	45.8	47.9	51.8	55.8	57.4										
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.1	243.4								
Mishrif	112.5	113.9	115.0	116.2	116.2	119.4	122.0	130.9	130.9	136.1	141.2	150.0	157.6	160.5	162.3	162.3								
Rumaila	91.8	92.9	93.8	94.7	94.7	97.2	99.2	106.1	106.1	110.1	114.0	120.7	126.5	128.7	130.1	130.1	134.3							
Ahmadi	120.7	122.0	123.2	124.3	124.3	127.5	130.0	138.6	138.6	143.6	148.4	156.7	163.8	166.4	168.1	168.1	173.2	177.7						
Mauddud	94.5	95.5	96.4	97.2	80.6	99.6	101.5	107.8	107.8	111.5	115.1	121.2	126.3	128.3	129.5	129.5	133.2	136.4	141.2					
Naher Umr	221.0	222.2	223.3	224.4	258.3	227.7	230.4	240.5	240.5	247.0	253.7	266.1	277.6	282.2	285.0	285.0	294.2	302.8	315.8	327.7				
Shauaiba	69.5	70.2	70.7	71.3	59.5	72.8	74.0	78.1	78.1	80.4	82.6	86.4	89.6	90.7	91.4	91.4	93.7	95.6	98.4	100.8	107.1			
Zubair	443.5	445.3	447.0	448.6	512.8	453.4	457.3	471.9	471.9	481.0	490.4	507.3	522.6	528.5	532.2	532.2	543.9	554.6	570.6	584.7	625.3	640.8		
Ratawi	213.0	214.6	216.0	217.3	217.3	221.1	223.9	233.6	233.6	239.0	244.1	252.6	259.7	262.2	263.8	263.8	268.6	272.8	278.7	283.6	296.5	301.0	336.2	
Yamama	302.5	304.6	306.4	308.1	308.1	312.9	316.6	328.9	328.9	335.7	342.2	352.9	361.6	364.8	366.8	372.3	372.7	377.8	385.1	391.1	406.8	412.2	453.9	479.6

Ru-72

Fm./age(m.y.)	0.0	11.0	16.2	23.0	36.5	45.0	53.0	62.3	65.0	68.2	70.4	80.0	86.0	87.0	89.0	90.0	92.0	93.0	94.0	95.0	107.0	112.0	118.0	125.0
Dibdba	163.0																							
Fatha	88.0	90.9																						
Ghar	167.0	166.2	168.7																					
Unconf.	0.0	0.0	0.0	385.5	628.2																			
Dammam	228.0	247.7	236.2	242.7	242.7																			
Rus	176.0	179.5	196.0	185.9	185.9	192.9																		
Umm-Er-Radh.	432.0	439.2	443.5	452.3	452.3	466.1	478.7																	
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	201.4	554.0															
Tayarat	264.0	269.8	273.4	281.1	281.1	294.0	306.6	352.6	352.6															
Shiranish	88.6	90.3	91.3	93.5	93.5	97.2	100.7	113.2	113.2	125.3														
Hartha	155.4	158.1	159.7	163.2	163.2	169.0	174.4	193.6	193.6	211.6	219.4													
Sadi	363.0	368.1	371.2	377.7	400.5	388.4	398.4	432.5	432.5	463.3	476.2	502.9												
Tanuma	45.5	46.3	46.8	47.8	44.3	49.4	50.8	55.5	55.5	59.4	61.0	64.2	74.6											
Khasib	41.5	42.0	42.3	42.9	63.2	43.9	44.8	47.9	47.9	50.5	51.6	53.9	61.3	62.6										
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	89.5	268.6								
Mishrif	122.0	124.1	125.3	127.8	127.8	131.5	134.8	144.3	144.3	151.6	154.3	159.6	174.7	177.0	179.1	179.1								
Rumaila	86.5	87.9	88.8	90.4	90.4	93.0	95.1	101.6	101.6	106.4	108.3	111.8	121.7	123.2	124.6	124.6	128.9							
Ahmadi	139.0	141.2	142.5	145.0	145.0	148.9	152.2	162.0	162.0	169.3	172.1	177.3	192.2	194.4	196.4	196.4	202.9	207.9						
Mauddud	104.5	106.1	107.0	108.8	90.4	111.6	113.9	120.8	120.8	126.0	128.0	131.6	142.0	143.5	144.9	144.9	149.3	152.7	158.8					
Naher Umr	251.0	252.8	253.9	256.2	294.6	259.9	263.3	274.2	274.2	283.3	286.9	294.0	316.2	319.7	323.0	323.0	333.8	342.6	359.0	373.6				
Shauaiba	91.0	92.2	92.9	94.3	78.9	96.3	98.1	103.2	103.2	107.0	108.4	111.0	118.3	119.4	120.4	120.4	123.4	125.8	129.8	133.2	142.6			
Zubair	417.5	419.7	421.1	423.8	483.5	428.3	432.3	445.0	445.0	455.5	459.5	467.6	491.6	495.3	498.8	498.8	510.0	519.0	535.2	549.3	591.8	611.1		
Ratawi	306.5	309.7	311.5	315.2	315.2	320.6	325.3	338.4	338.4	347.9	351.4	357.9	375.6	378.1	380.4	380.4	387.6	393.0	402.4	410.0	430.6	439.1	486.3	
Yamama	215.5	217.5	218.7	221.0	221.0	224.5	227.4	235.7	235.7	241.7	243.9	247.9	258.8	260.4	261.8	259.5	266.2	269.5	275.2	279.8	292.2	297.2	324.9	351.7

Mj-3

Fm./age(m.y.)	0.0	11.0	16.2	23.0	36.5	45.0	62.3	65.0	70.4	80.0	86.0	87.0	89.0	90.0	92.0	93.0	94.0	95.0	107.0	112.0	118.0	125.0
Anjanah/Dibdibah	1012.0																					
Fatha	287.0	339.6																				
Ghar	115.0	128.6	134.7																			
Uncon.	0.0	0.0	0.0	390.6	636.5																	
Jaddala	209.0	231.4	241.3	245.9	245.9																	
Aliji/Amm Er.	451.0	491.4	508.4	516.2	516.2	532.5																
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	102.3	306.8														
Shiranish	139.0	154.6	162.6	166.6	166.6	175.3	204.5	204.5														
Hartha	136.0	149.6	156.5	159.8	159.8	167.2	191.1	191.1	202.0													
Sadi	108.0	117.8	122.6	125.0	125.0	130.1	146.5	146.5	153.8	162.6												
Tanuma	41.0	46.1	48.5	49.6	49.6	52.0	59.3	59.3	62.4	66.0	69.4											
Khasib	56.0	60.6	62.8	63.9	63.9	66.3	73.6	73.6	76.9	80.7	84.3	85.9										
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	182.8	548.3								
Mishrif	244.0	271.8	282.9	287.9	287.9	298.0	325.0	325.0	335.2	346.3	356.0	360.0	365.5	365.5								
Rumaila	13.0	14.4	15.0	15.2	15.2	15.7	17.0	17.0	17.5	18.1	18.6	18.7	19.0	19.0	20.4							
Ahmadi	170.0	187.7	194.6	197.7	197.7	204.0	220.5	220.5	226.7	233.4	239.2	241.5	244.8	244.8	261.1	262.1						
Mauddud	175.0	191.9	198.5	201.5	201.5	207.3	222.8	222.8	228.6	234.7	240.1	242.2	245.2	245.2	260.0	260.9	273.2					
Naher Umr	185.0	193.6	197.6	199.5	199.5	203.5	215.2	215.2	220.0	225.4	230.3	232.3	235.3	235.3	250.5	251.4	265.4	283.8				
Shauaiba	146.0	158.3	163.0	165.1	165.1	169.2	180.0	180.0	183.9	188.1	191.7	193.2	195.2	195.2	205.0	205.6	213.6	223.0	234.5			
Zubair	292.0	302.1	306.8	309.0	309.0	313.5	326.7	326.7	332.0	337.8	343.1	345.2	348.3	348.3	364.0	364.9	378.8	396.4	419.6	442.7		
Ratawi	61.0	65.4	67.1	67.8	67.8	69.2	72.9	72.9	74.3	75.7	76.9	77.4	78.1	78.1	81.3	81.5	84.0	87.0	90.7	93.9	101.6	
Yamama	374.0	398.8	408.2	412.3	412.3	420.3	440.8	440.8	448.2	455.9	462.5	465.1	468.8	468.8	486.3	487.3	501.3	517.3	536.5	553.5	593.7	603.3

Fig. (3) The present, corrected and restored thicknesses of wells (Su-9, Ru-72, and Mj-3).

AG-17

Fm./age(m.y.)	0.0	11.0	16.2	23.0	36.5	45.0	62.3	65.0	70.4	80.0	86.0	87.0	89.0	90.0	92.0	93.0	94.0
Anjanah	2,052.0																
Fatha	932.0	1,170.0															
Jeribe-Euphrate	62.0	70.9	80.5														
Kirkuk Group	307.0	336.6	357.8	359.4													
Jaddala	143.0	160.0	176.7	178.3	187.2												
Aliji	79.0	88.0	96.6	97.4	104.4	104.4											
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	21.6	64.9									
Shiranish	27.0	30.3	35.4	36.0	39.5	43.3	43.3	43.3									
Hartha	70.0	78.1	90.8	92.2	100.9	109.9	109.9	109.9	111.2								
Sadi	115.0	127.4	146.4	148.4	161.1	176.0	174.1	174.1	176.0	181.3							
Tanuma	27.0	31.6	37.4	38.0	41.6	47.0	45.1	45.1	45.6	47.0	49.6						
Khasib	53.0	58.2	66.1	66.9	72.0	83.9	77.2	77.2	77.9	80.0	83.9	84.9					
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	219.0	657.1			
Mishrif	268.0	315.6	360.5	364.5	386.9	438.0	406.5	406.5	409.1	416.2	428.6	431.7	438.0	438.0			
Rumaila	45.0	52.5	59.4	60.0	63.5	71.1	66.4	66.4	66.8	67.9	69.7	70.2	71.1	71.1	76.6		
Ahmadi	77.0	89.5	101.0	102.0	107.7	129.1	112.5	112.5	113.2	114.9	118.0	118.7	120.2	120.2	129.1	130.8	
Mauddud	170.0	196.3	220.1	222.2	233.8	280.5	243.7	243.7	245.0	248.5	254.7	256.3	259.3	259.3	277.1	280.5	286.6

Am-2

Fm./age(m.y.)	0.0	11.0	16.2	23.0	36.5	45.0	62.3	65.0	70.4	80.0	86.0	87.0	89.0	90.0	92.0	93.0	94.0	95.0	107.0	112.0	118.0
Anjanah	1,348.0																				
Fatha	488.0	592.8																			
Jeribe-Euphrate	24.0	27.2	29.4																		
Kirkuk Group	338.5	364.3	377.0	377.7																	
Jaddala	276.5	305.3	322.9	324.0	340.9																
Aliji	45.0	49.3	51.9	52.1	54.5	57.1															
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	60.3	181.0													
Shiranish	79.0	89.0	97.2	97.7	107.0	118.4	120.7	120.7													
Hartha	56.0	62.7	68.1	68.4	74.5	81.9	83.4	83.4	86.3												
Sadi	136.5	151.5	163.5	164.3	177.6	193.4	196.6	196.6	202.7	207.5											
Tanuma	17.0	19.7	21.6	21.7	23.7	25.9	26.4	26.4	27.2	27.9	29.7										
Khasib	78.0	85.8	91.8	92.2	98.9	106.6	108.1	108.1	111.1	113.4	119.8	120.7									
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	308.2	924.6							
Mishrif	407.0	464.1	497.1	499.0	528.8	558.8	564.2	564.2	574.3	581.8	601.4	604.0	616.4	616.4							
Rumaila	14.0	15.8	16.8	16.9	17.8	18.7	18.9	18.9	19.2	19.4	20.0	20.0	20.4	20.4	22.8						
Ahmadi	25.0	28.2	30.0	30.1	31.7	33.3	33.6	33.6	34.1	34.5	35.6	35.7	36.3	36.3	40.4	40.6					
Mauddud	358.5	400.7	424.3	425.7	446.6	467.1	470.8	470.8	477.6	482.6	495.7	497.4	505.5	505.5	556.7	558.8	562.5				
Naher Umr	71.0	74.6	77.1	77.3	79.9	82.7	83.2	83.2	84.2	85.0	87.0	87.3	88.6	88.6	97.8	98.2	98.9	113.0			
Shauaiba	171.5	189.1	198.8	199.4	207.8	216.0	217.5	217.5	220.1	222.1	227.2	227.9	231.0	231.0	250.6	251.3	252.7	276.2	281.8		
Zubair	292.0	303.2	311.2	311.6	319.5	327.9	329.5	329.5	332.5	334.7	340.6	341.4	345.2	345.2	370.8	371.9	374.0	410.3	419.7	446.5	
Ratawi	177.0	192.2	200.4	200.8	207.8	214.5	215.7	215.7	217.9	219.4	223.5	224.1	226.6	226.6	241.7	242.3	243.4	261.0	265.0	275.7	297.7

Kf-1

Fm./age(m.y.)	0.0	11.0	16.2	23.0	36.5	45.0	53.0	62.3	65.0	70.4	80.0	86.0	87.0	89.0	90.0	92.0	93.0	94.0	95.0	107.0	112.0	118.0	125.0	135.0
Anjanah	94.0																							
Fatha	106.0	108.3																						
Euphrates	44.0	44.7	45.5																					
Unconf.	0.0	0.0	0.0	313.8	511.4																			
Dammam	190.0	192.7	196.1	197.6	197.6																			
Rus/Emm Er.R.	73.0	74.0	75.1	75.7	75.7	78.1																		
Aliji	271.0	274.2	278.1	279.8	279.8	288.0	291.4																	
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.5	127.6															
Shiranish	67.0	68.4	70.1	70.9	70.9	74.8	76.6	85.0	85.0															
Hartha	364.0	370.1	377.7	381.2	381.2	398.2	405.9	441.4	441.4	452.3														
Sadi	142.0	143.9	146.3	147.4	147.4	152.6	154.9	165.4	165.4	168.5	191.8													
Tanuma	39.0	39.6	40.4	40.8	40.8	42.5	43.2	46.4	46.4	47.4	54.1	57.8												
Khasib	74.0	74.9	76.0	76.5	76.5	78.8	79.9	84.6	84.6	86.0	96.1	101.7	103.4											
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	171.5	514.5									
Mishrif/kifl	258.0	261.4	265.4	267.1	267.1	275.2	278.6	292.6	292.6	296.4	321.1	332.7	336.2	343.0	343.0									
Rumaila	20.0	20.2	20.5	20.7	20.7	21.3	21.5	22.5	22.5	22.8	24.5	25.4	25.6	26.1	26.1	28.0								
Ahmadi	17.0	17.2	17.5	17.6	17.6	18.1	18.3	19.1	19.1	19.3	20.8	21.5	21.7	22.1	22.1	23.7	23.9							
Mauddud	29.0	29.3	29.8	29.9	29.9	30.8	31.1	32.6	32.6	33.0	35.4	36.6	36.9	37.6	37.6	40.3	40.6	40.8						
Naher Umr	173.0	174.4	176.2	177.0	177.0	180.7	182.4	189.6	189.6	191.7	206.1	213.6	215.9	220.6	220.6	241.0	242.9	244.6	247.6					
Shauaiba	40.0	40.4	41.0	41.2	41.2	42.2	42.7	44.5	44.5	44.9	48.0	49.4	49.8	50.6	50.6	53.9	54.2	54.4	54.8	57.6				
Zubair	465.0	467.9	471.5	473.1	473.1	480.6	483.8	498.0	498.0	502.0	529.4	543.2	547.4	555.8	555.8	591.4	594.7	597.5	602.5	636.4	645.5			
Ratawi	22.0	22.2	22.4	22.5	22.5	23.0	23.2	24.0	24.0	24.2	25.5	26.1	26.2	26.6	26.6	27.9	28.0	28.1	28.3	29.3	29.6	33.4		
Yamama	427.5	431.0	435.2	437.0	437.0	445.2	448.6	462.2	462.2	465.9	488.6	498.8	501.7	507.5	507.5	530.0	531.9	533.5	536.3	554.4	558.9	622.4	626.0	
Sulaiy	35.5	35.8	36.1	36.2	36.2	36.8	37.1	38.1	38.1	38.4	40.1	40.8	41.1	41.5	41.5	43.1	43.3	43.4	43.6	44.9	45.2	49.8	50.0	56.0

Ns-1

Dibdba/Recent	294.0																								
Fatha	86.0	90.6																							
Ghar	45.0	45.5	46.2																						
Unconf.	0.0	0.0	0.0	357.2	582.1																				
Dammam	211.0	229.2	223.2	224.9	224.9																				
Rus	89.0	92.5	98.5	94.3	94.3	97.7																			
Umm-Er-Radh.	454.0	469.1	474.1	476.8	476.8	491.1	497.9																		
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	102.9	224.9																
Tayarat	90.0	94.4	96.0	96.9	96.9	101.7	104.1	122.0	122.0																
Shiranish	205.0	213.8	217.0	218.7	218.7	228.1	232.8	266.9	266.9	276.6															
Hartha	121.0	125.5	127.1	128.0	128.0	132.8	135.1	151.8	151.8	156.4	169.4														
Sadi	224.0	231.3	233.8	235.2	249.4	242.8	246.4	272.1	272.1	279.0	298.2	312.4													
Tanuma	59.0	61.4	62.2	62.7	58.0	65.0	66.2	73.6	73.6	75.6	80.8	84.5	93.2												
Khasib	49.0	50.4	50.8	51.1	73.0	52.5	53.1	57.7	57.7	59.0	62.3	64.7	70.4	72.2											
Unconf.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	129.6	388.7									
Mishrif	183.0	189.6	191.7	192.8	192.8	198.7	201.4	217.7	217.7	221.5	231.3	237.8	251.5	255.6	259.1	259.1									
Rumaila	39.0	40.3	40.8	41.0	41.0	42.2	42.7	46.0	46.0	46.8	48.7	50.0	52.7	53.5	54.2	54.2	57.1								
Ahmadi	104.0	107.5	108.6	109.2	109.2	112.2	113.6	122.0	122.0	124.0	129.0	132.3	139.2	141.2	143.0	143.0	150.2	151.9							
Mauddud	158.0	163.0	164.6	165.4	136.7	169.8	171.8	183.8	183.8	186.6	193.6	198.2	207.9	210.7	213.1	213.1	223.1	225.5	232.1						
Naher Umr	115.5	117.6	118.3	118.6	137.0	120.7	121.7	128.1	128.1	129.7	134.0	137.0	143.8	145.9	147.7	147.7	155.8	157.7	163.5	174.2					
Shauaiba	59.5	61.2	61.8	62.1	51.5	63.5	64.2	68.3	68.3	69.2	71.5	73.1	76.2	77.2	78.0	78.0	81.2	81.9	84.1	87.6	90.6				
Zubair	517.0	523.9	526.3	527.6	606.1	534.3	537.5	558.4	558.4	563.6	577.2	586.6	607.3	613.5	619.0	619.0	642.4	648.1	664.4	693.6	719.0	733.6			
Ratawi	75.0	76.7	77.3	77.6	77.6	79.0	79.7	83.6	83.6	84.5	86.7	88.1	91.0	91.8	92.5	92.5	95.4	96.1	97.9	100.9	103.4	104.7	119.4		
Yamama	247.0	252.3	254.0	254.9	254.9	259.4	261.5	273.5	273.5	276.2	282.9	287.2	296.0	298.5	300.7	300.7	309.3	311.3	316.8	325.9	333.1	337.1	380.3	388.1	
Sulaiy	199.0	202.9	204.2	204.9	204.9	208.2	209.7	218.5	218.5	220.5	225.3	228.5	234.8	236.6	238.2	238.2	244.4	245.8	249.7	256.1	261.3	264.1	294.0	299.3	319.5

Fig. (4) The present, corrected and restored thicknesses of wells (AG-19, Am-2, Kf-1, and Ns-1).

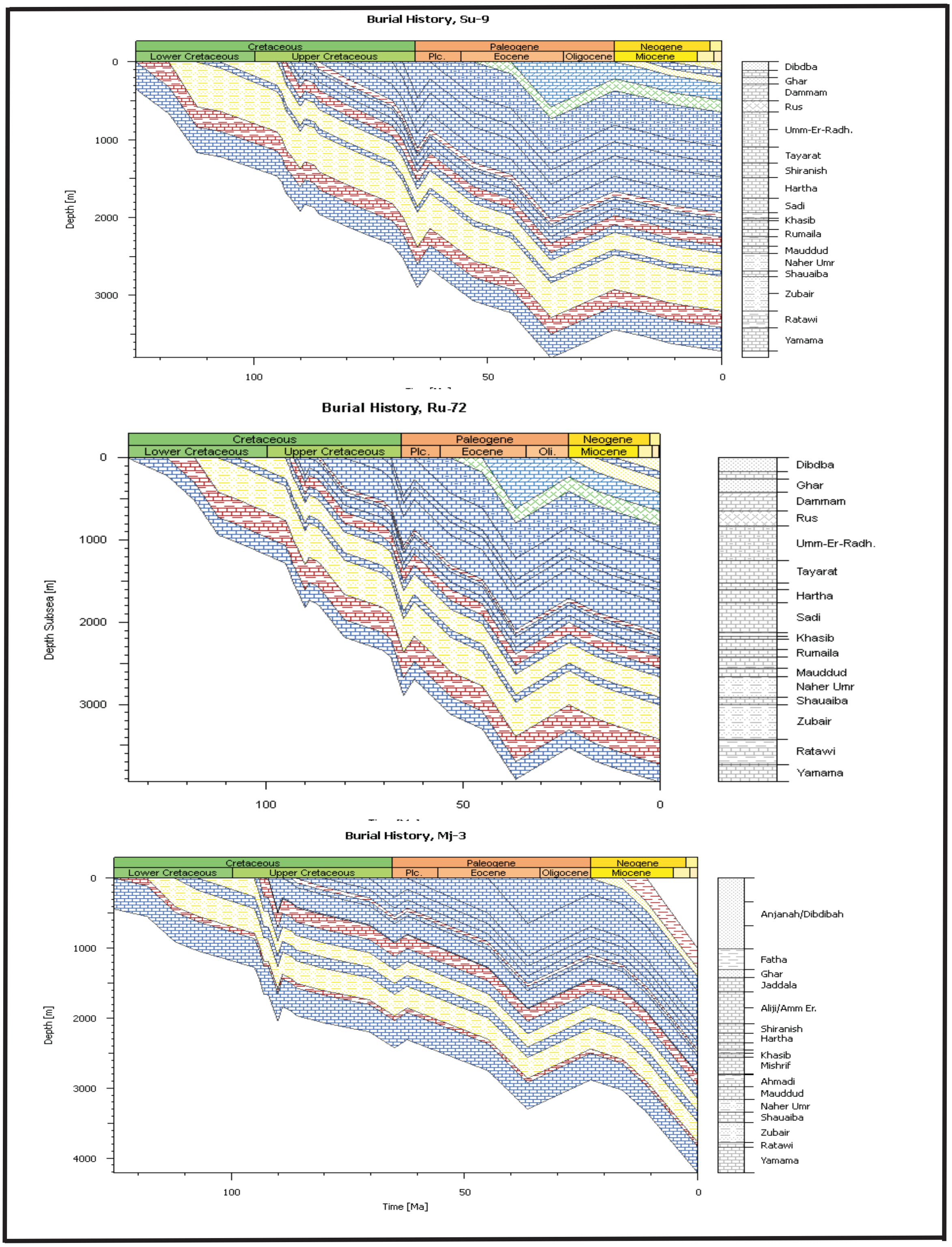

Fig. (5) Burial and subsidence history charts of wells (Su-9, Ru-72, and Mj-3).

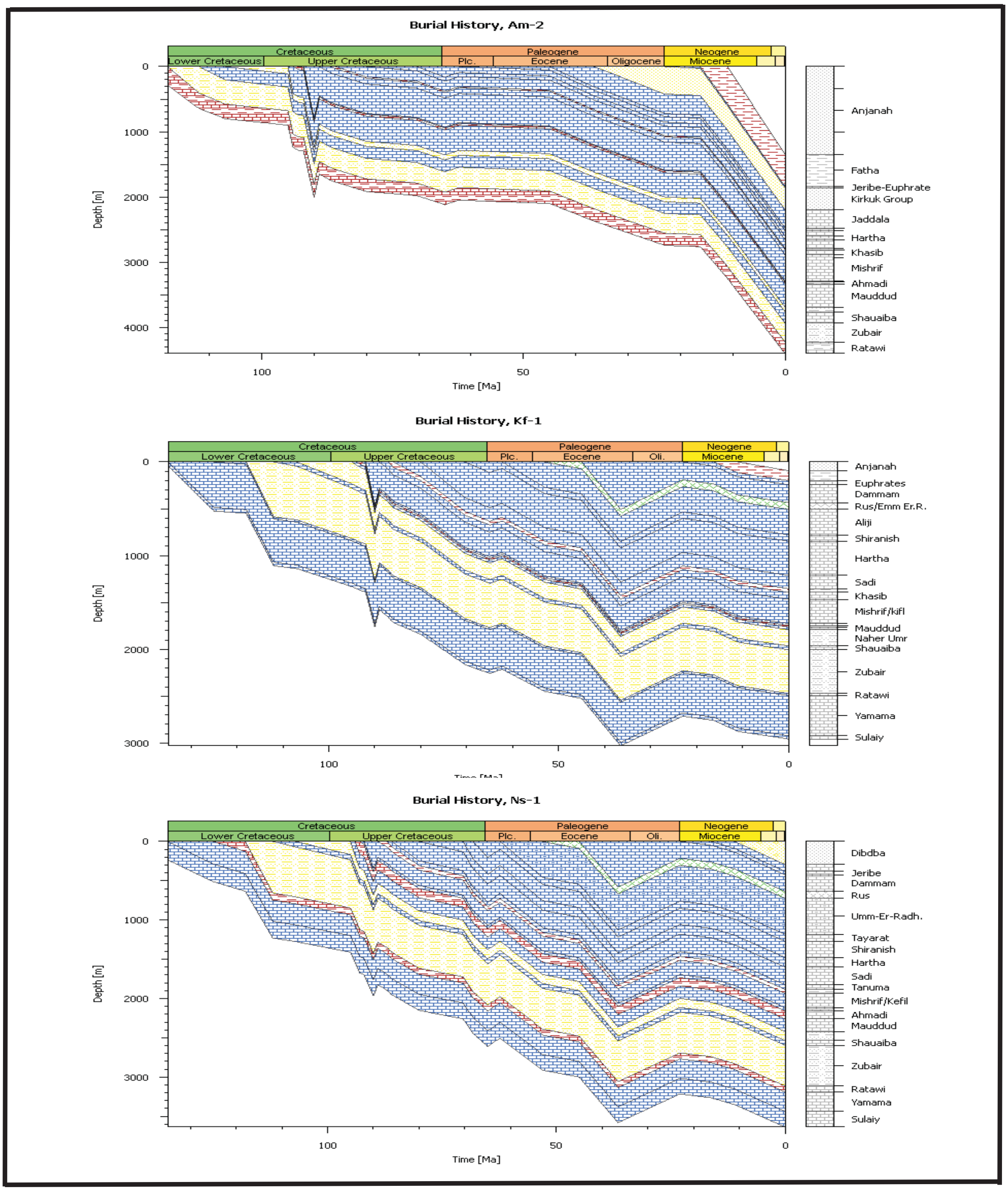

Fig. (6) Burial and subsidence history charts of wells (Am-2, Kf-1, and Ns-1).

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