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# Key elements to clarify the 110 million year hiatus in the Mesozoic of eastern Syria

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## ABSTRACT

Log correlations, biostratigraphical results and seismic data were combined to show that from Late Triassic Norian to Early Cretaceous Aptian times, the Euphrates area (Eastern Syria) was part of a huge saddle-like northeast-trending ridge (the Hamad Uplift) characterized by a prolonged stratigraphic hiatus. This uplift, developed in the Late Triassic, was multiply reactivated during the Mesozoic, particularly in the Early Cretaceous Aptian-Albian times, during a major reorganization phase of the Neo-Tethyan rift system. This uplift marked the separation between two regions with distinctive tectono-sedimentary evolutions: an eastern isolated and starved region (Euphrates Graben) and a western region that was mainly influenced by the sedimentary dynamics of the westerly Bishri Trough, linked to the Palmyrides Basin. The Hamad Uplift broke-up into a N140°E-oriented graben system in late Albian times. This early NE-trending extensional stage was accompanied by volcanic activity and introduced the main phase of horst-and-graben development within the Euphrates Graben in the Late Cretaceous Senonian times.

## INTRODUCTION

Eastern Syria is characterized by a well-documented stratigraphical gap (hiatus) that spanned the Jurassic and Early Cretaceous upto the Aptian times (Best et al., 1993), a period of more than 110 million years (My). The geological cause of this hiatus is not yet explained: was it due to a marine regression, or non-deposition over a pre-existing ridge, or strong erosion following regional uplift? In this paper biostratigraphy, electrical log correlations, isopach maps and seismic data are combined to reconstruct the paleogeography of Eastern Syria in order to identify the cause of this Mesozoic hiatus.

## STUDY AREA AND METHODOLOGY

Three scales of observation have been chosen for the study. The regional scale involves Syria and parts of adjacent countries. The intermediate scale is constrained to the former petroleum "Deir Ez Zor contract" area (Figure 1), as this concession covers most of the Euphrates Graben. The local scale corresponds to the transition zone situated between the Eastern Palmyrides and the Euphrates Graben (Bishri area, Figure 1). The study is based on outcrop and subsurface data. The latter consists of seismic data and wells distributed across Syria, mostly in the Euphrates Graben. Among the 105 wells used as reference data in this study, 46 were drilled either by Elf (EAS/EHS) or by the operating company DEZPC (Deir-Ez-Zor Petroleum Company). Another 36 wells were drilled either by the Pecten/Shell/SSPD/AFPC group or by SAMOCO before 1988. On December 15th, 1988, Elf Aquitaine Syrie secured exploration rights in the Deir-Ez-Zor contract area and duly acquired information on the 36 wells drilled before that date. Six wells that were drilled after 1988 by the AFPC/SSPD group were obtained by well data exchange in 1994 and 1996. A complementary set of wells, particularly in Central Syria, was provided with the authorization of SPC (Syrian Petroleum Company), owner of the data. In the presented illustrations, none of these wells are indicated, except those mentioned in the text.

## REGIONAL GEOLOGIC FRAMEWORK OF SYRIA

In Syria, three Mesozoic basins may be distinguished: the Palmyrides Basin, the Euphrates Graben and Sinjar Trough (Figure 1). The Palmyrides Basin is a Permian-Early Mesozoic NE-trending basin connected to the Levantine passive margin. It was inverted and complexly deformed by the interfering effects of post-Oligocene movements along the Levant transform fault system and the Turkish Bitlis convergent zone (McBride et al., 1990; Chaimov et al., 1993; Salel, 1993; Salel and Séguret, 1994; Searle,

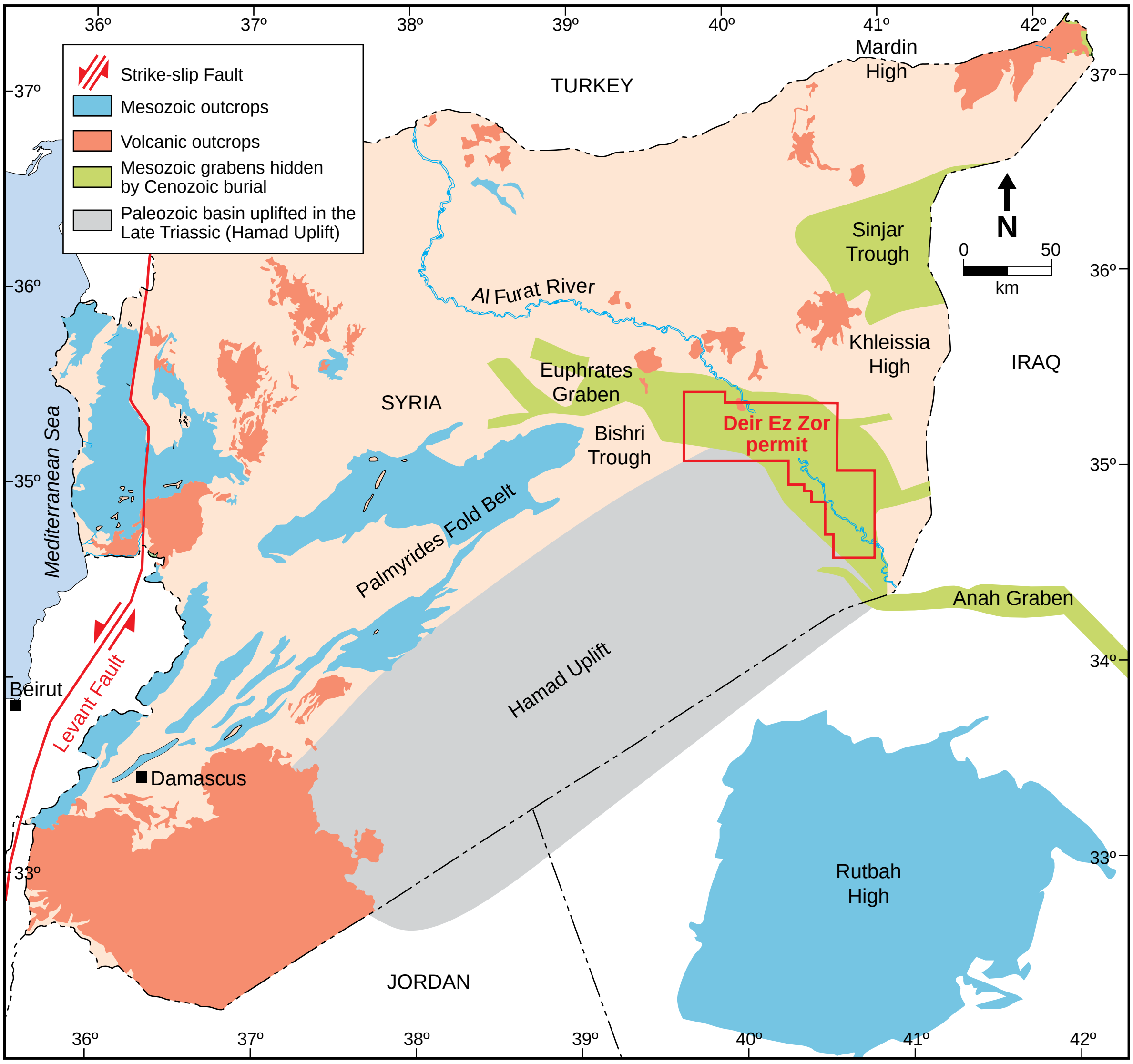


**Figure 1: Geological setting of Syria.**

1994). The west- to NW-trending Euphrates Graben extends approximately 160 km from the E-W Anah Graben in Iraq to the northeastern edge of the Palmyrides Fold Belt (Figure 1). It is about 90 km wide and reaches a maximum depth of about 5 km to the Triassic section. This graben is described as a fault-controlled basin, which resulted from flexuring of the northeastern margin of the Arabian Plate, before obduction of the Tethyan oceanic crust during the Late Cretaceous (Best et al., 1993; de Ruiter et al., 1994; Caron et al., 2000).

The Sinjar Trough, on trend with (and of the same origin as) the Palmyrides Basin, was strongly inverted in Pliocene-Pleistocene times (Brew et al., 1997; Kent and Hickman, 1997). The Bishri Trough corresponds to the northeastern part of the Palmyrides Basin. It formed during the Triassic (Figure 1) and later became inverted to form a broad (approximately 75 km wide) NE-plunging anticlinorium that terminates in a domal uplift (Jabal Bishri, McBride et al., 1990). The Sinjar and Bishri troughs are separated from one another by broad domal areas that remained stable and undeformed through Mesozoic and Cenozoic times. The Rawda High (or Khleissia High) lies to the east of the Euphrates Graben and formed in the Late Ordovician (Best et al., 1993) (Figure 1). The Hamad Uplift, a NE-SW structure running from southwest Syria to the Euphrates Graben, corresponds to the uplift of a 6-km-thick Paleozoic section (Best et al., 1993; Mouty, 1997). The Mardin High, mainly located in southern Turkey, formed in the Early Paleozoic (Sawaf et al., 1993). The Rutbah High, in southwest Iraq, is composed of Mesozoic outcrops culminating over the present Paleogene-Neogene Al Hamad plain (Dubertret, 1966; Ponikarov et al., 1966).

## How to Explain the 110 My Hiatus?

In Eastern Syria, the Lower Cretaceous unconformity is nearly concordant with the underlying Triassic rocks. The hiatus covers a period from Jurassic to Early Cretaceous (some 110 My). This unconformity correlates with a Late Jurassic hiatus in the Western Palmyrides belt (Mouty, 2000, Figure 2). Mouty (1997) attributed its origin to a regional NE-oriented Late Triassic uplift (Hamad Uplift), following the opening of the Neo-Tethys Ocean to the north of the Arabian Plate.

Best et al. (1993) suggested that sedimentary loading of the Levantine margin tilted the northern Arabian Plate during the Early Cretaceous. They attributed the hiatus to subaeral exposure and erosion of the Jurassic section caused by the uplift of eastern Syria. Sawaf et al. (1993) interpreted the Lower Cretaceous unconformity to simply represent a prolonged hiatus. They suggested that a Late Triassic-Early Cretaceous marine regression inhibited the preservation of Jurassic sediments in Eastern Syria.

Kent and Hickman (1997) proposed yet another scenario. They suggested that the Lower Cretaceous unconformity represents an early rifting stage, responsible for the generation of grabens and half-grabens along NW-trending faults, among which the Euphrates Graben system was created. This interpretation contrasts with the previous interpretations concerning the position of the syn-rift unconformity. It implies major tectonic movements occurred during the Early Cretaceous. However the Albian-Aptian Rutbah sandstones are commonly interpreted as part of the pre-rift section (de Ruiter et al., 1994, Litak et al., 1998). In fact the first rift pulse within the Euphrates Graben is reported in the Late Cretaceous, and represented by the base Turonian unconformity (Figure 2).

In the following section, the depositional history of Eastern Syria is discussed from the Jurassic to the Late Cretaceous Cenomanian (Rutbah-Judea section). We seek to determine whether this interval pertains to the early rifting episode or is part of the pre-rift history of the Euphrates Graben. We caution, at this point, that the presented Lower Cretaceous isopach maps may not reflect original depositional thickness. This is because significant Late Cretaceous erosion occurred in the eastern part of Syria.

## The Jurassic Section in Central Syria

From a large well database provided by the Syrian Petroleum Company, Jurassic isopachs were contoured over Central Syria (Figure 3). Jurassic deposits define two NE to NNE-trending regional depocenters. The eastern Bishri Trough corresponds to the northeastern part of the Palmyrides Basin that formed during the Triassic and later became inverted, resulting in a broad anticlinorium (Jabal Bishri or Bishri block, McBride et al., 1990). Jurassic deposits are missing over a NE-SW area extending from the eastern part of the Frontal Palmyrides Belt to the northern platform of the Euphrates Graben. This area is termed 'Hamad Uplift' (Mouty et al., 1983; Mouty, 1997), but is incorrectly named in the literature "Rutbah High" (whereas the Rutbah High is a clearly defined structure located in Iraq, showing a completely different geological evolution, Figure 1).

The age of the Hamad Uplift is debated: Late Jurassic (Alsdorf et al., 1995), Late Triassic (Mouty, 1997) or Early Cretaceous (Best et al., 1993). The cause of this stratigraphical hiatus is also discussed. According to Mouty (1997), the hiatus is related to non-deposition of Jurassic and Lower Cretaceous series over the Hamad Uplift. Actually, this Late Triassic uplift would extend to the Euphrates Graben, defining a mega-structure running from Jordan to western Iraq. According to Best et al. (1993), the Jurassic section had a much wider areal distribution than presently observed. Tilting of the northern Arabian Plate toward the Levantine margin resulted in the uplift of eastern Syria and erosion of the higher levels of the Jurassic section, but a remnant section was preserved in the deeper parts of Mesozoic sub-basins. Electric log signatures and biostratigraphical data could help to determine whether the Jurassic deposits are eroded at the vicinity of this mega-structure or exhibit an onlap pattern compatible with a nondeposition interpretation.

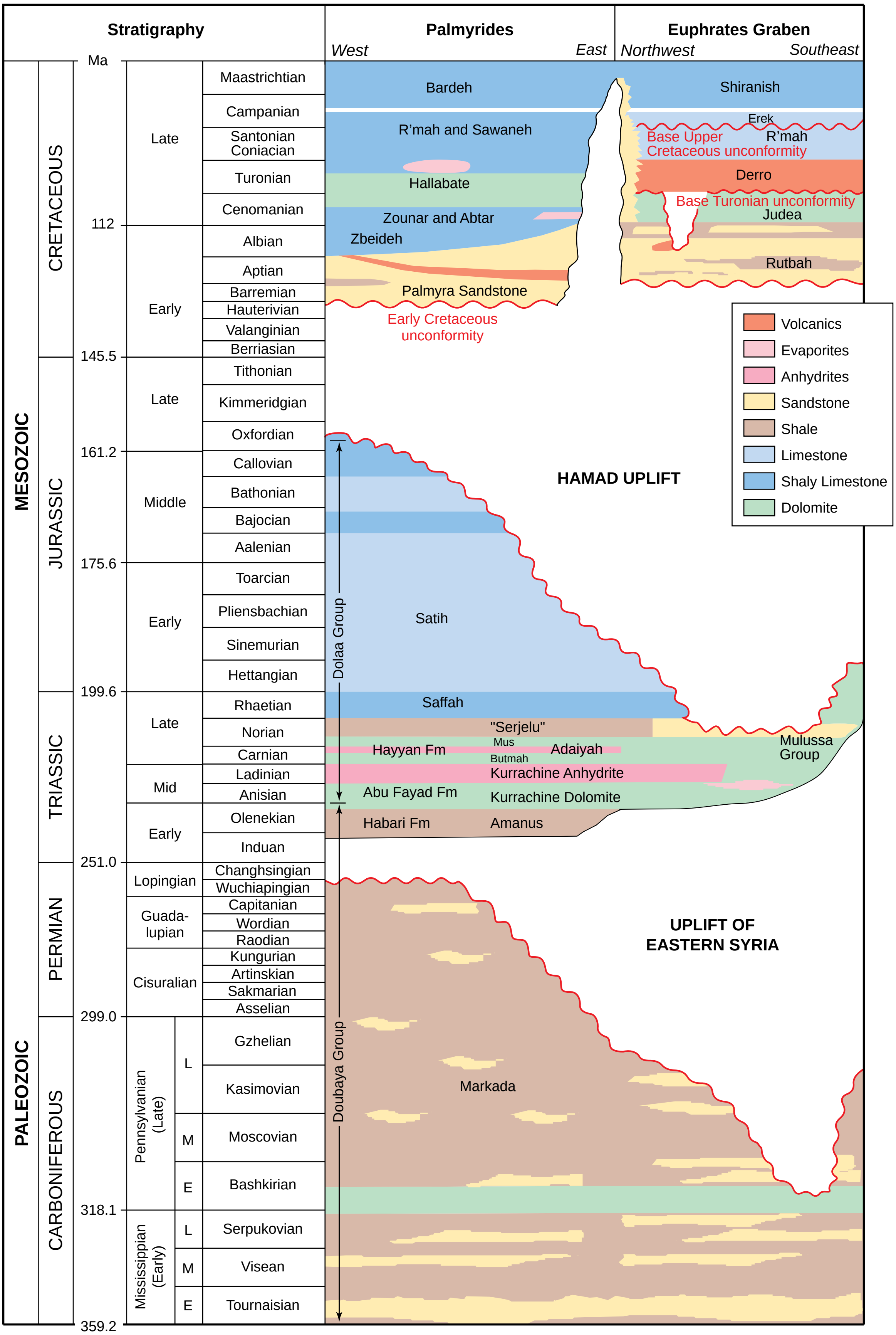


**Figure 2: Stratigraphical chart of the Palmyrides Basin and Euphrates Graben. Geological time scale after Gradstein et al. (2004).**

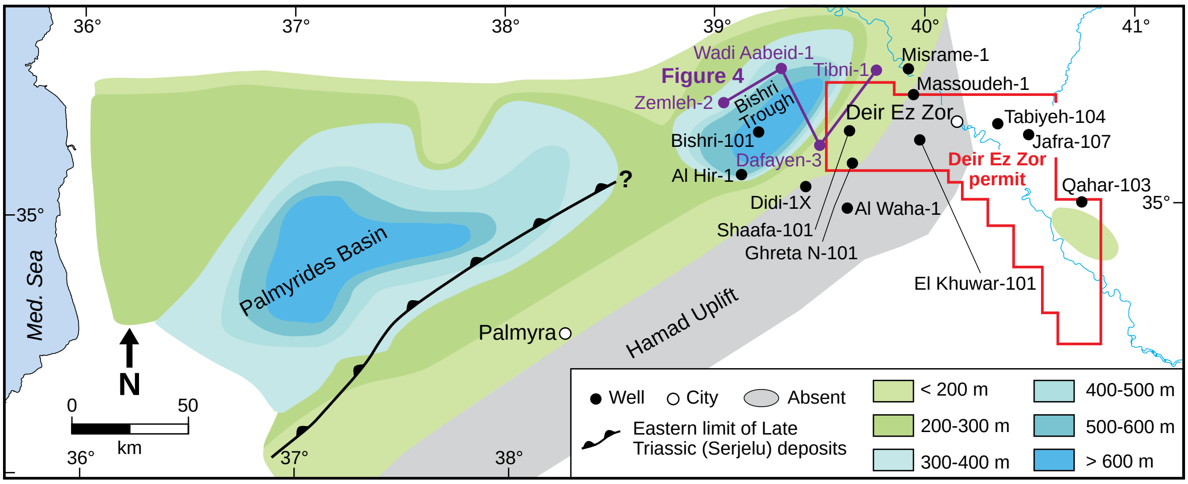


**Figure 3: Regional isopach map of the Jurassic Series in Syria, with location of the wells mentioned in that study.**

Our gamma-ray and sonic log correlation of the Jurassic section (Figure 4), drawn at the vicinity of the Hamad Uplift, indicates an onlap pattern of deposition, compatible with a non-deposition scenario over a pre-existing ridge. However, correlations are not straightforward. The conclusive element to consider is the dating of the Jurassic series in the vicinity of this ridge. Biostratigraphy in Shaafa-101 (see location in Figure 3) provided Middle to Late Jurassic (Bathonian to Kimmeridgian) ages for the Jurassic section, with the occurrence of a dinoflagellate assemblage assignable to the CG Microplankton Zone. Syrian Petroleum Company (SPC) in-house determinations indicate on Bishri-101 and nearby Bishri-1 well (location on Figure 3) that the uppermost levels of Jurassic are composed of 50 m of Oxfordian (Upper Jurassic deposits). The whole Jurassic section, composed of 40 m of claystones, in Al Hir-1 well (location on Figure 3) is also attributed by SPC to Upper Jurassic. The section present over the easternmost wells of the Palmyrides Basin therefore corresponds to the uppermost Jurassic. This indication, in addition to the log correlations, tends to support a non-deposition scenario, over a pre-existing ridge. This ridge (Hamad Uplift) was active as a positive feature in the Mesozoic starting in the Late Triassic, as suggested by Mouty (1997). Actually, the limit of the Upper Triassic deposits in Central Syria (Norian deposits known as Serjelu Formation, Figure 2) typically parallels the limit of the Jurassic deposits, with a shift to the west (Figure 3). The first Mesozoic movements along the Hamad Uplift were likely to have occurred at that time.

## The Lower Cretaceous Section in Syria and Adjoining Regions

### *Biostratigraphical data and sequential analysis*

Early Cretaceous outcrops in Syria are scarce and attributed a Barremian-Aptian age (Dubertret, 1966; Mouty, 2000). In the Anti-Lebanon Chain they are typically represented by a 200-m-thick succession with argillaceous limestones at the top and ferruginous sandy facies at the base with Barremian-Aptian volcanics (Mouty et al. 1992). They are reduced in the Coastal Chain to 25–50 m of argillaceous siltstones and marls, Aptian to lower Albian in age (Bab Janneh Formation) (Mouty, 1967; Mouty and Saint-Marc, 1982). In the Palmyrids the known outcrops are reduced to a 6–50 m mostly ferruginous quartzose section, with locally volcanic and argillaceous lateritic rocks, Barremian-Aptian in age (Mouty and Al Maleh, 1983).

In the Palmyrids, Lower Cretaceous series (Palmyra Formation or Palmyra sands) overlie Jurassic carbonates (Figure 2). In the Euphrates Graben, Lower Cretaceous deposits (Rutbah Sandstone) unconformably overly Upper Triassic (Mulussa) series (Lower Cretaceous unconformity). They are attributed a late Neocomian age (Sawaf et al., 1993). An Albian-Aptian age is also proposed for these sandstones (de Ruiter et al., 1994). From in-house qualitative and quantitative palynological studies (Total), the Rutbah Formation may be assigned to the Albian-Aptian times.

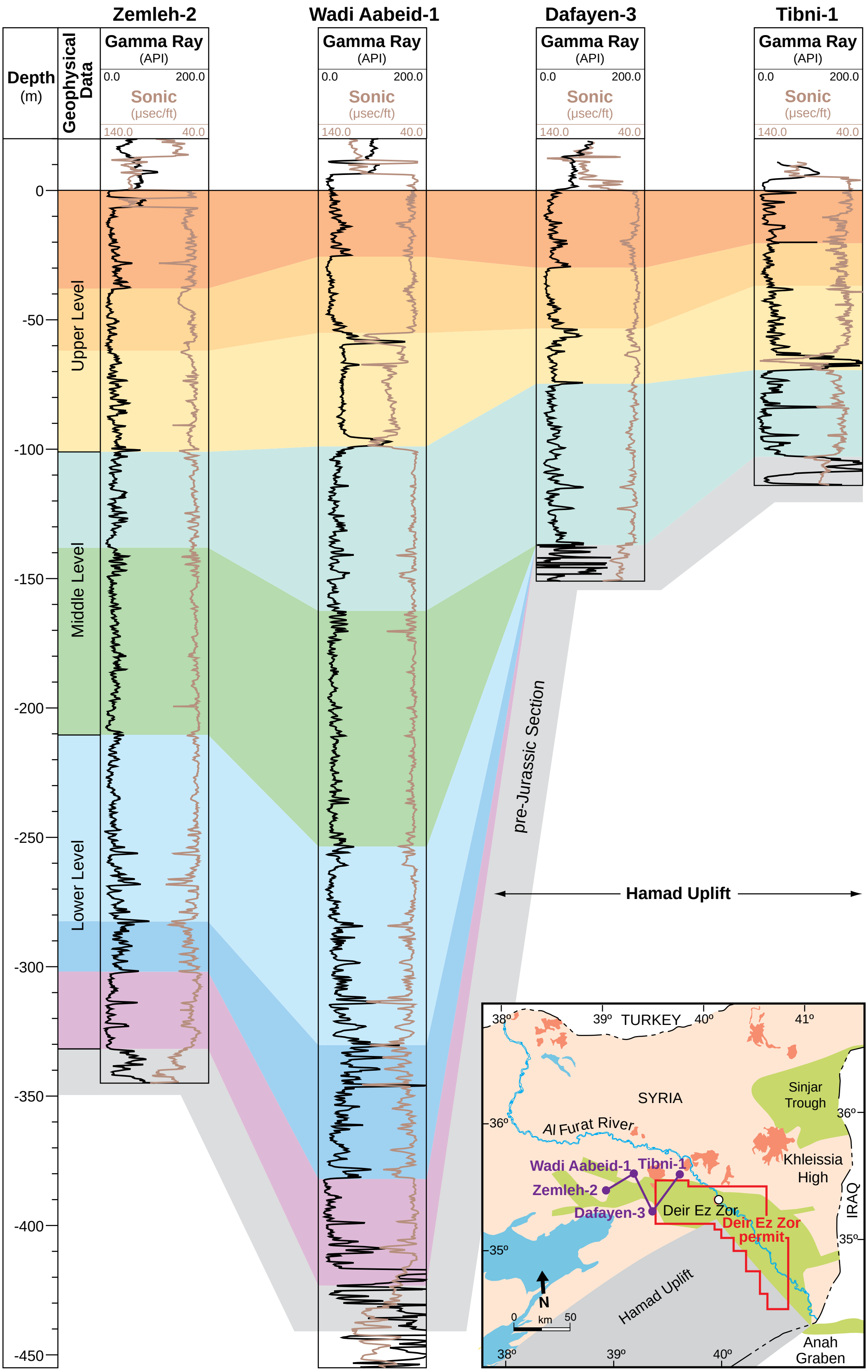


**Figure 4: Log correlation of the Jurassic series, flattened at top of Jurassic.**

The Rutbah Formation was first proposed by Forand and Keller (1937) in a locality situated in Iraq where the Lower Cretaceous sandstones are only 23 m thick. This locality is now part of the Rutbah High (or Rutbah anteklise, Figure 1).

In the Euphrates Graben, the Rutbah/Mulussa boundary may reliably be located on the basis of palynological qualitative determinations. Indeed, biostratigraphical reference taxa are dominated by pollen species in the Triassic interval, while spores and dinoflagellates assemblages largely prevail in the Cretaceous Period (Figure 5, in-house data from Total). This marked difference in palynofloral composition is closely related to changes in depositional environments. The appearance of dinoflagellates, the occurrence of numerous botryococcus and the increased amount of pteridophyte spores clearly indicate a change from continental (Triassic) to marine conditions (Lower Cretaceous). Palynofacies analyses support this interpretation. The organic matter is land-derived (MOX, MOB) in the Mulussa clastics, while the amorphous organic matter content (MOA derived from the degradation of microalga) typically increases upwards in the Rutbah Formation. From a biostratigraphical point of view, the upper section of the Rutbah is characterized by a mass occurrence of dinoflagellates (*Subtilisphaera* spp.) while the lower section contains spores of the genus *Cicatricosisporites* and *Callialasporites* (Figure 5). Detailed qualitative and quantitative palynological studies performed in the Sedimentary Geology Department of Total (Pau, France) allow accurate determination of the biozonations within the Rutbah sequence.

Three units may be recognized on the basis of the respective statistical abundance of pollens, spores and dinoflagellates (Figure 5):

(1) Upper Rutbah unit: "*Subtilisphaera* spp. zone" characterized by a large prevalence of dinoflagellates over pollenospores and by the abundance of microforams;
(2) Middle Rutbah unit: "Mixed zone" composed of alternating levels either rich in dinoflagellates or spores according to sea-level variations; and
(3) Lower Rutbah unit: "Spores zone" including a high content of pollenospores.

Six long-term sequences have been identified in the Rutbah Formation from the vertical facies association (core analysis, in-house data from Total). The general stacking pattern is shown in Figure 5.

The first sequence shows only a transgressive system tract above the erosion boundary of the Lower Rutbah. The second sequence corresponds to a complete regressive-transgressive sequence, but is often truncated by the regressive system tract of the overlying sequence. The downward shift observed inside the regressive system tract of the third sequence corresponds to the deposition of massive sand bodies above more argillaceous facies, and is a valuable correlation surface at a regional scale. The third sequence exhibits a very thin transgressive system tract indicative of rapid flooding. The fourth sequence is rarely entirely visible, as it is either cut by faults or eroded by the fifth sequence. Actually, the latter one begins with an important erosive surface, due to a major downward shift (tectonic origin?). The sixth sequence is partly or totally eroded by the base Turonian unconformity.

The schematic sequential evolution of the Rutbah Formation and the depositional environments inferred from core and palynological studies in the Euphrates Graben (in-house data from Total) can be summarized as follows. It begins with a landward-stepping (transgressive) episode (sequence 1), culminating with a maximum flooding surface. This episode is followed by a seaward stepping (regressive) phase (sequences 2 and 3), from distal shoreface at the base to foreshore and coastal plain at the top, culminating with the development of soils corresponding to the maximum of progradation (top of sequence 4). Then, a new landward-stepping episode starts with the flooding of a coastal plain (sequences 5 and 6).

## *Tectono-Sedimentary Evolution*

The regional Lower Cretaceous isopach map (Figure 6), mainly based on subsurface data from the literature, shows an active depocenter over the South Lebanon, Palestine and Jordan areas, with up to 1,000 m of series in coastal Lebanon. A second depocenter, with up to 450-m-thick Lower Cretaceous sequences, appears in the eastern part of the Palmyrides (Bishri Trough, approximately E-W trending), at the transition with the Euphrates Graben. In the latter graben, the Lower Cretaceous may be up to 300 m thick and is hydrocarbon-bearing.

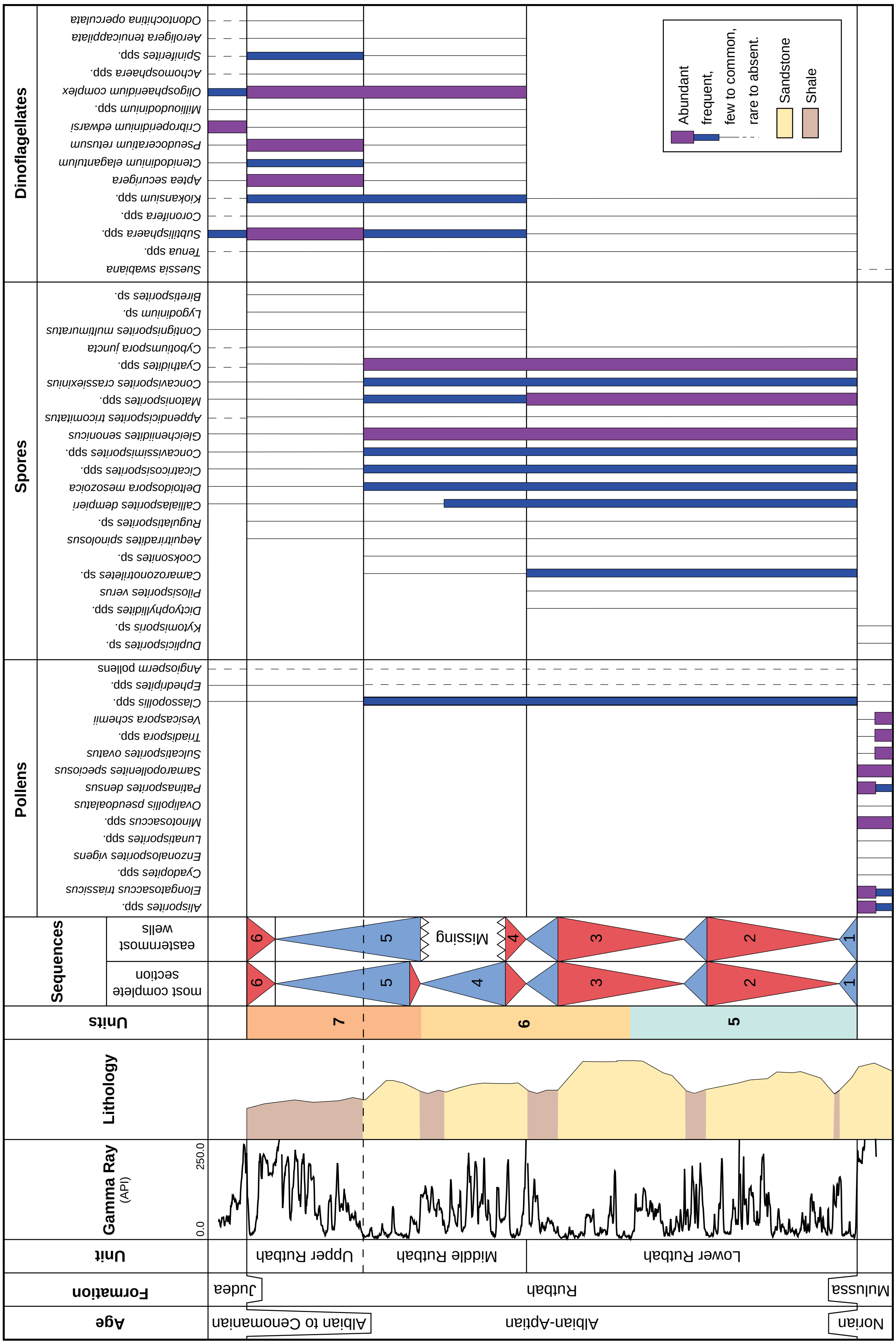

**Figure 5: Main characteristics of the Rutbah Formation within the Euphrates Graben.**

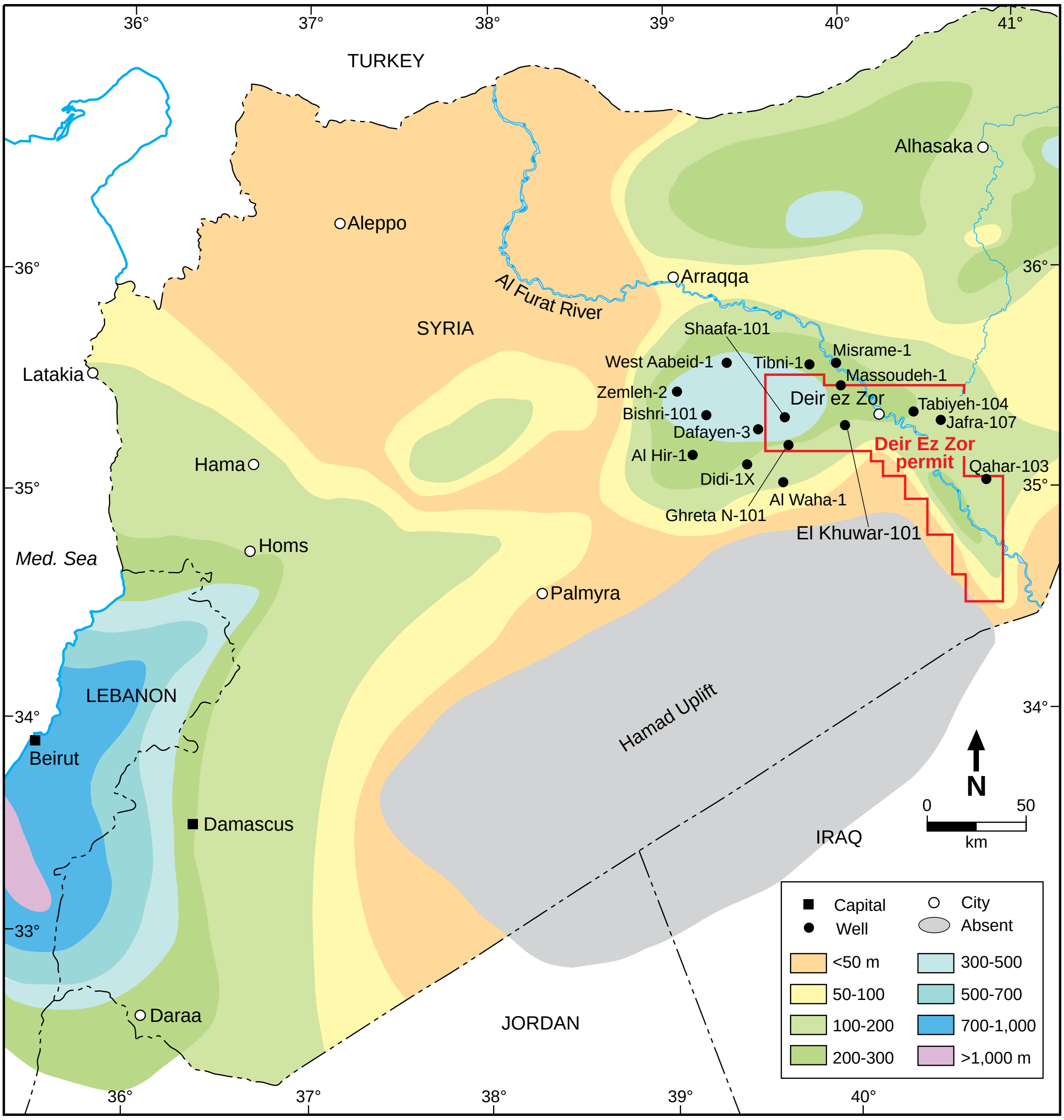


**Figure 6: Regional isopach map of the Lower Cretaceous Series in Syria and Lebanon.**

The regional Lower Cretaceous isopach map (Figure 6) also shows a large NE-trending structure, where the Lower Cretaceous deposits are absent. This area is closely superimposed over the previously defined area, where no Jurassic deposits were recorded, and corresponds to the Hamad Uplift. Typically, the Lower Cretaceous facies (Figure 7a) are carbonate-rich in the northeast (Sinjar Trough), in the northwestern and southwestern parts of Syria, and in North and Central Lebanon, whereas they display sand-prone facies in Central and East Syria (Palmyrides, Euphrates Graben), as well as in South Lebanon (> 250 m; Dubertret, 1966), in Palestine (> 400 m; Shaw, 1947) and in Jordan (230 m; Wetzel and Morton, 1959) (Figure 7b). However, Lower Cretaceous argillaceous sediments prevail to the northwest of the Hamad Uplift, reflecting the distance from this ridge, which is commonly considered to be the main source for Triassic and Lower Cretaceous clastics.

In order to understand the Early Cretaceous tectono-sedimentary evolution, gamma-ray and sonic log correlation have been drawn from WNW to ESE, in the Bishri Trough, located at the transition between the Euphrates Graben and Palmyrides Basin. As no sequential analysis was available in the

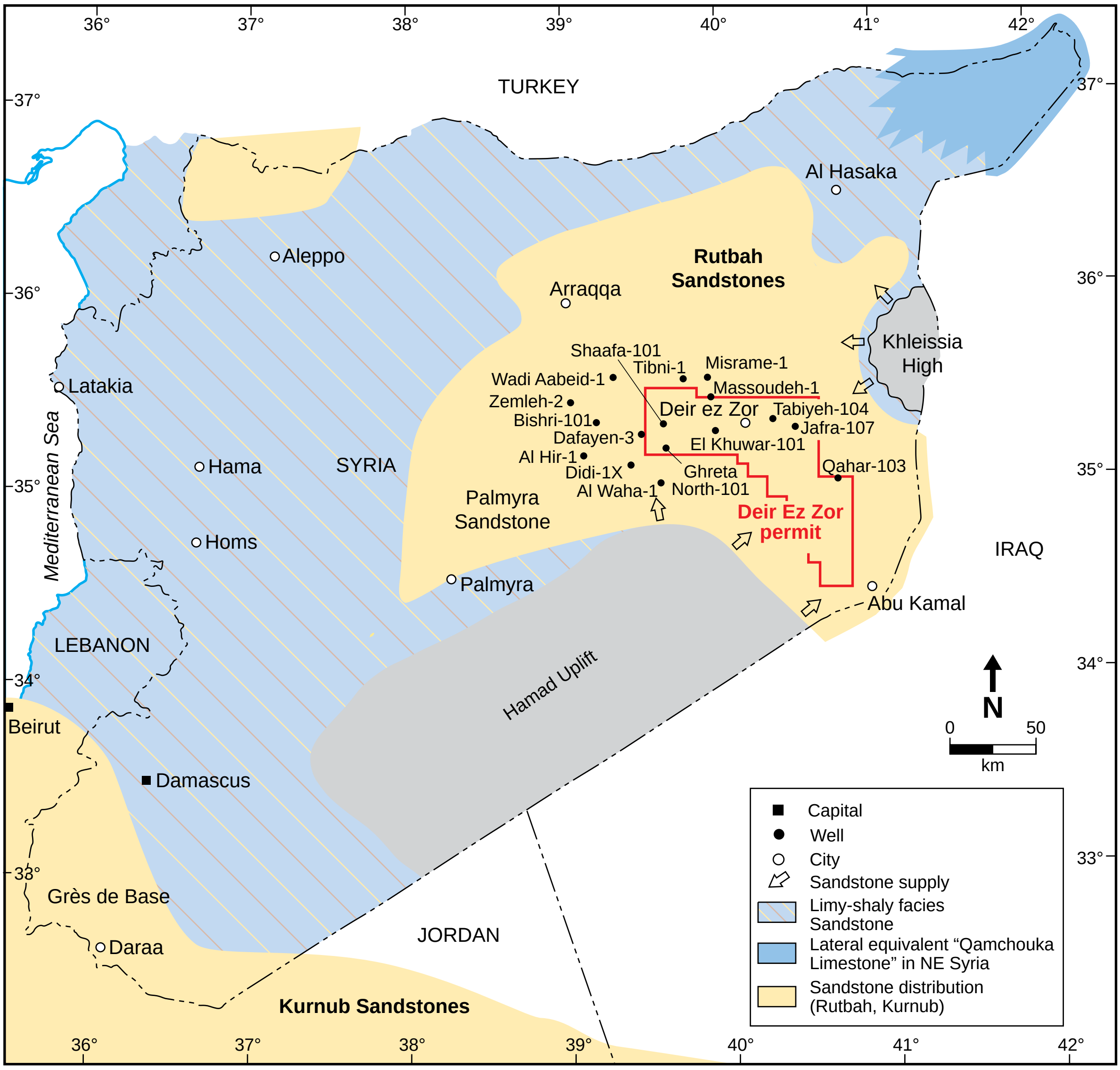


**Figure 7a: Regional facies map of the Lower Cretaceous Series in Syria, Lebanon and North Jordan.**

wells of the Bishri Trough, we have chosen to subdivide the Rutbah Formation into seven units. The correlation between these units and the sequential analysis of the Rutbah section in the Euphrates Graben is shown in Figure 5.

Log correlation 1 (Figure 8) shows two distinct depositional phases. The first phase corresponds to the deposition of units 1 to 4, with a clear E-W-trending depocenter centered on the location of the well Bishri-101 (Figure 8), and an onlap pattern of deposition roughly parallel to the Hamad Uplift (see attached location map, Figure 8). These units are totally absent to the east, except for unit 4 in Qahar area. The second phase of deposition (units 5 to 7, Figures 8 and 9) corresponds to a NE-trending depocenter, mainly parallel to the northwestern fringe of the Hamad Uplift. The isopach map of unit 7 (Figure 9) shows the persistence of a NE-trending depocenter and a widening of Rutbah deposition eastwards, toward the Euphrates Graben.

In Figures 8 and 9, regional correlations based on log signatures are well-defined in the western wells. Unit 7 displays rather similar log curves, with a characteristic smooth and low gamma-ray signal corresponding to a section that is almost exclusively sandy, with rare argillaceous levels at the decimetric scale observed on core samples. Conversely, the log profiles of unit 7 look different in the wells of the eastern area and any attempt to correlate them to the western wells seems highly

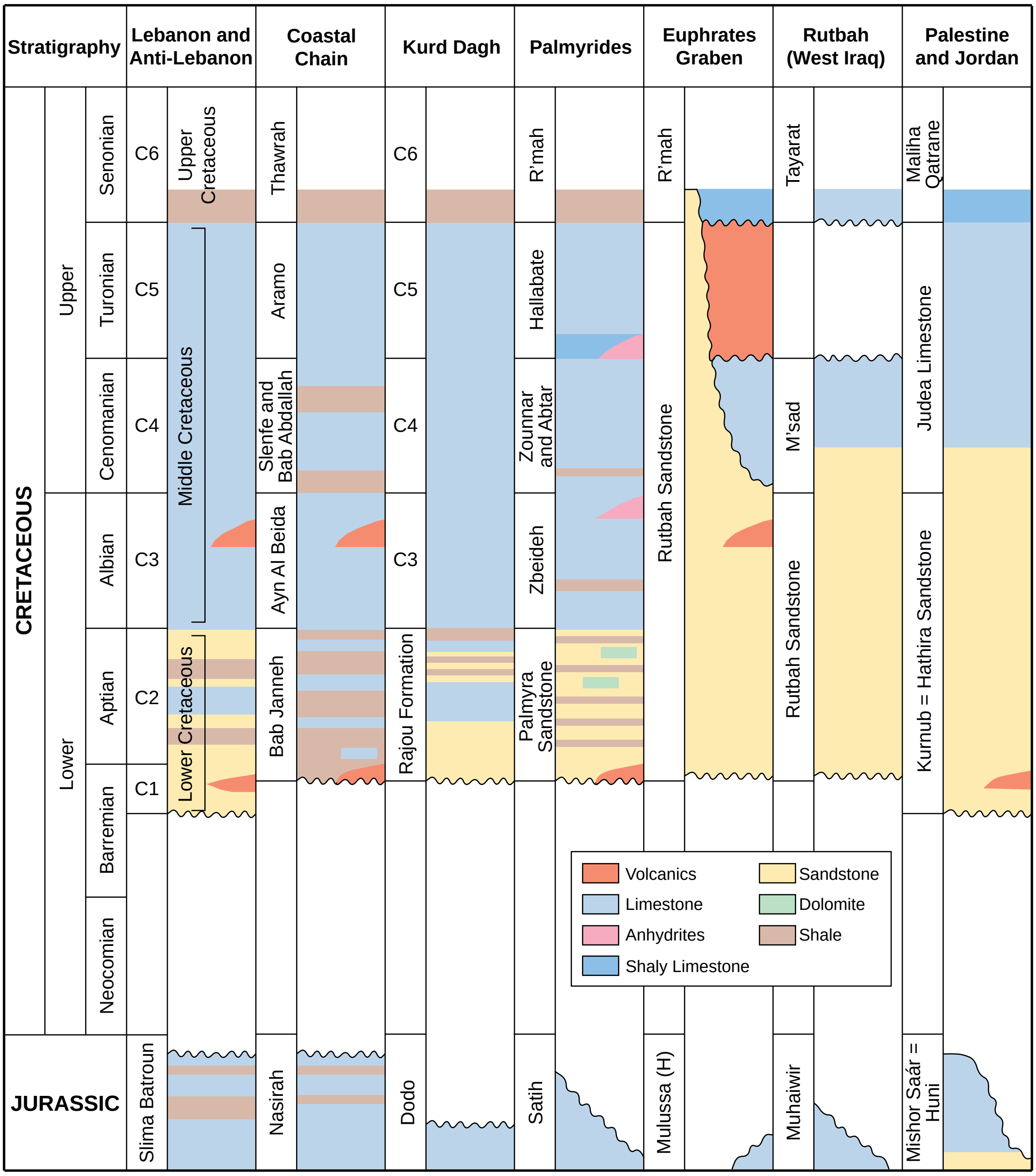


**Figure 7b: Correlation of Cretaceous series in Syria and neighboring countries.**

subjective. In the eastern wells, an Upper Rutbah sequence developed, mainly composed of shales. The latter unit would correspond to the sixth sequence, and to the end of the transgressive system tract of the fifth sequence (Figure 5).

Biostratigraphical data are quite useful for correlating time lines more precisely. It appears that the Rutbah sandstones of the western wells display palynofloral assemblages found in the fifth and sixth sequences of the eastern wells. Among the spores and dinoflagellates recorded in both sets of wells, the *Ephredipites concinnus* species and the *Spiniferites brevispinosus-Odontochitina operculata genera* are significant.

On the basis of these palynofloral data, the sandstones of the western wells, for which correlations were debatable, may be attributed to the Upper Rutbah unit (sequences 5 and 6, top of unit 7, Figure 5). As a consequence, the absence of Upper Rutbah shales in the western area (Figure 9) is

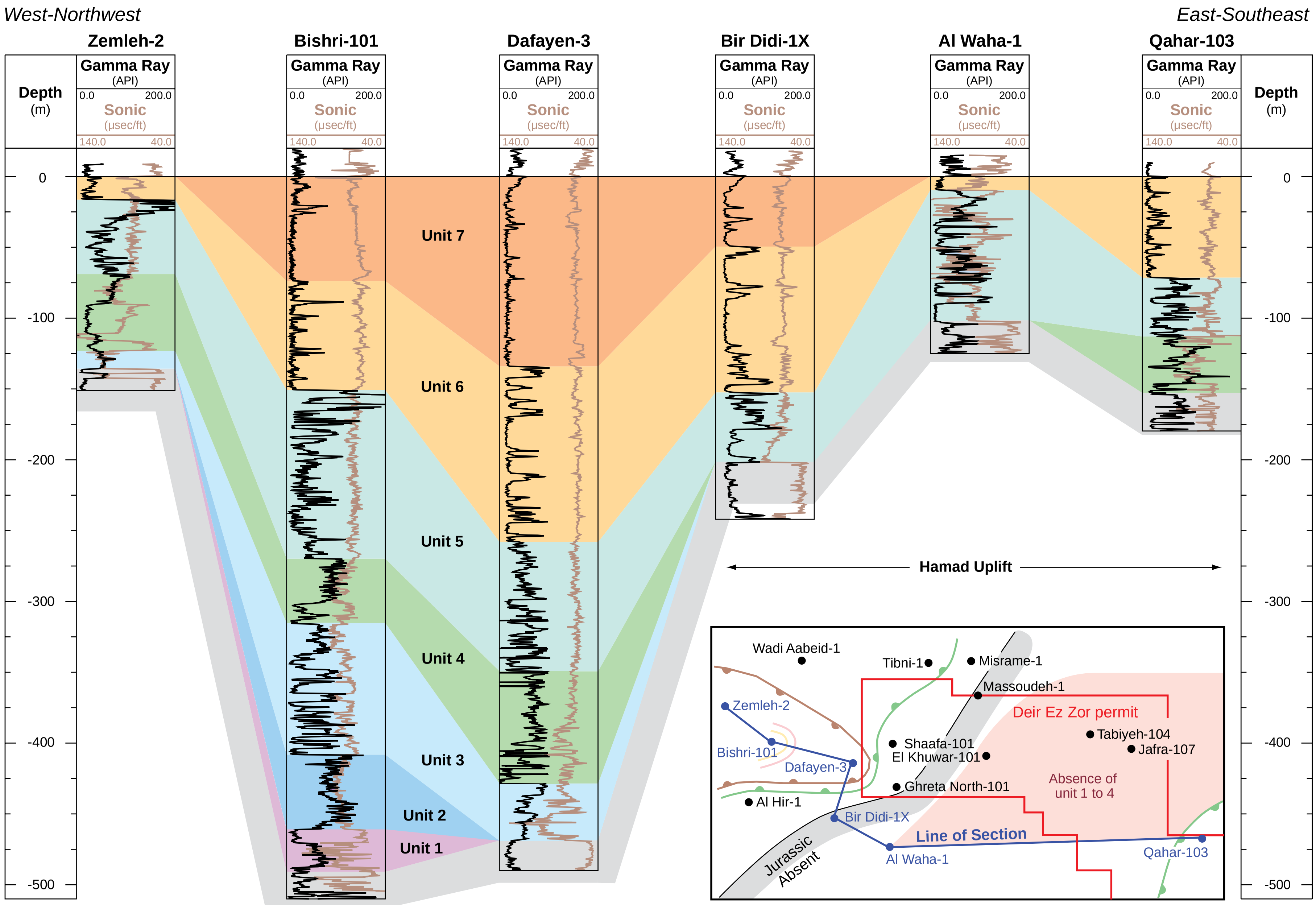


**Figure 8: WNW-ESE log correlation 1 of the Lower Cretaceous (Rutbah) series, flattened at top of Lower Cretaceous. See location on sketch map.**

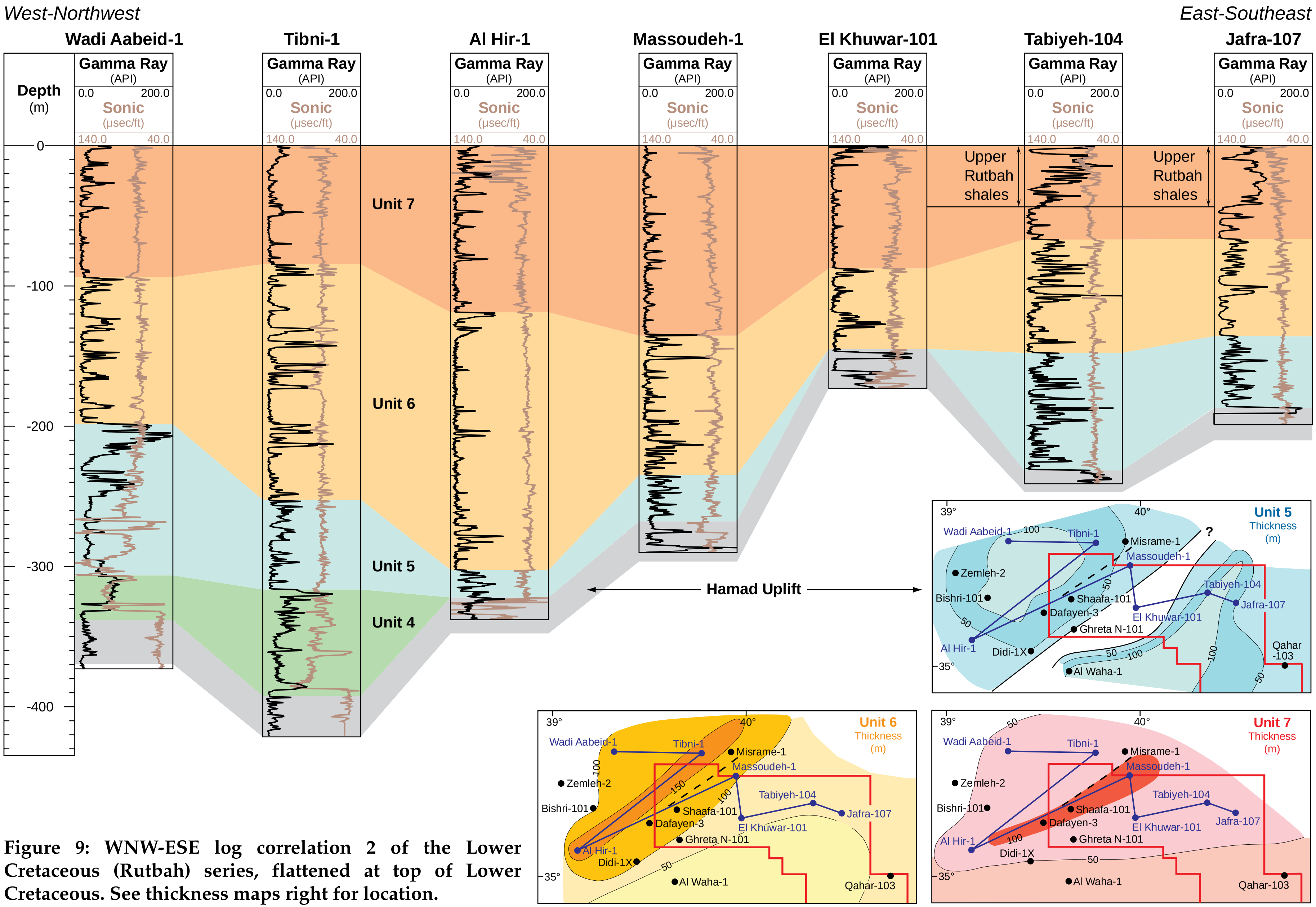


Figure 9: WNW-ESE log correlation 2 of the Lower Cretaceous (Rutbah) series, flattened at top of Lower Cretaceous. See thickness maps right for location.

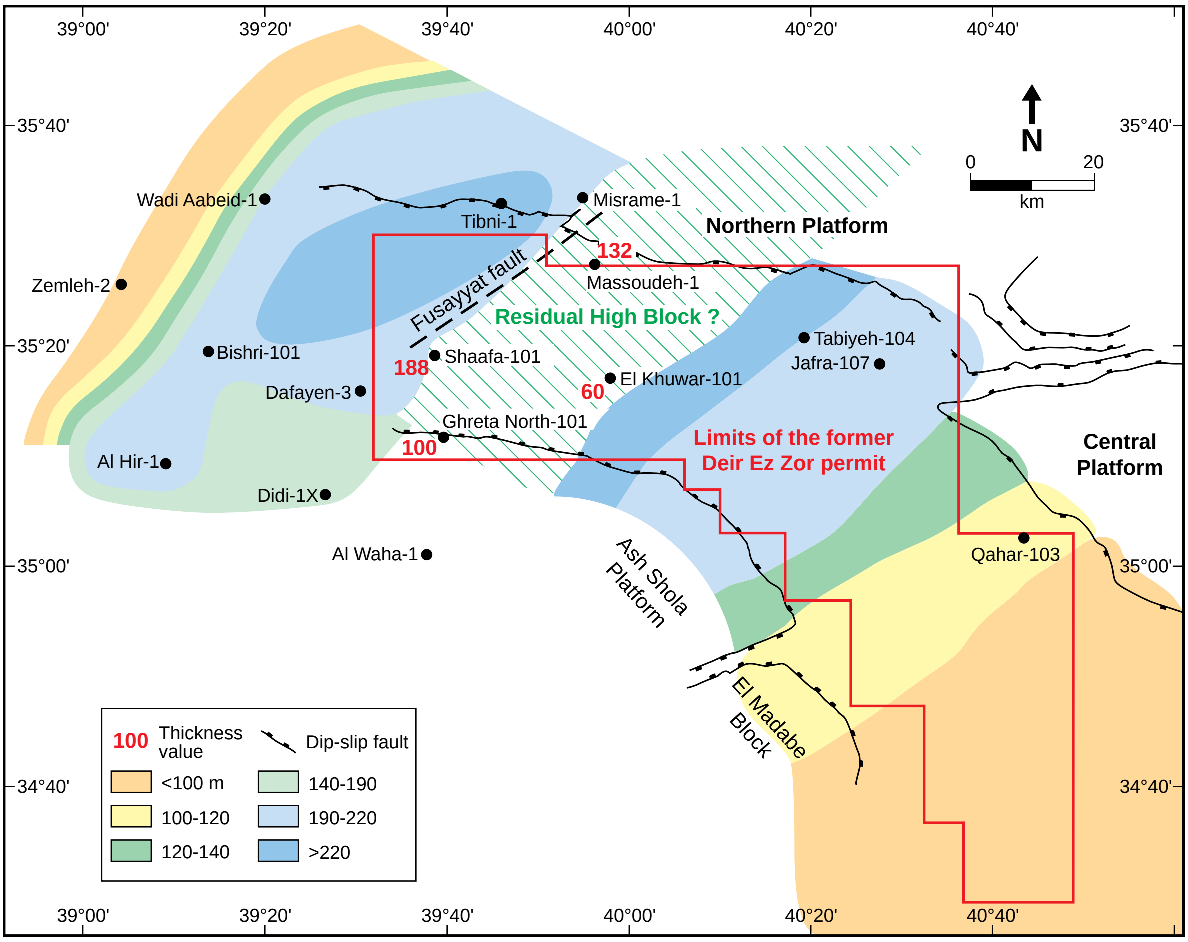


**Figure 10: Isopach map of the Lower and Middle Rutbah deposits.**

neither explained by erosion nor non-deposition but by a lateral facies change from east to west. In-house dating (Total) indicates that the red section in El Khuwar-101 well (unit 7, sandy sequence) is time-equivalent to the Upper Rutbah shales of Tabiyeh-104. This section is late Albian. It can be inferred that the reduced section observed over the Hamad Uplift is not due to erosion but rather to onlap.

However, because precise biostratigraphical data are not available for all the wells, it is difficult to draw time lines within unit 7 of the western wells. It is particularly difficult to trace the base of the Upper Rutbah shaly section (Figure 9). For that reason, Figures 10 and 11 are tentative maps and should be considered with caution. Figure 10 is the isopach map of the "Lower and Middle Rutbah" sandstones (units 5 and 6 in the Euphrates Graben and units 5, 6 and lower part of unit 7 in the Bishri Trough, Figure 5).

Figure 11 corresponds to the isopach map of unit 7 in the Bishri Trough and top part of unit 7 (Upper Rutbah Formation) in the Euphrates Graben. Figure 10 shows that, within the limits of the Deir Ez Zor concession, the "Lower and Middle Rutbah" sandstones gradually thin from northwest (> 190 m) to southeast (< 100 m). The transition zone between the Bishri Trough and the Euphrates Graben is marked by anomalous thickness values, lower than in adjacent areas. It is postulated that this difference represents onlap against a residual NE-trending block pertaining to the Hamad Uplift (see unit 5, Figure 9).

The "Upper Rutbah" isopachs (Figure 11) exhibit a clear NW-SE trend with a well-defined central depression where the shales may be up to 100 m thick. Figure 5 shows that these shales are of marine affinity, as their palynofloral assemblages contain a mass occurrence of dinoflagellates. The decrease in thickness appears symmetrical on either side of this depression. The feature may suggest either a

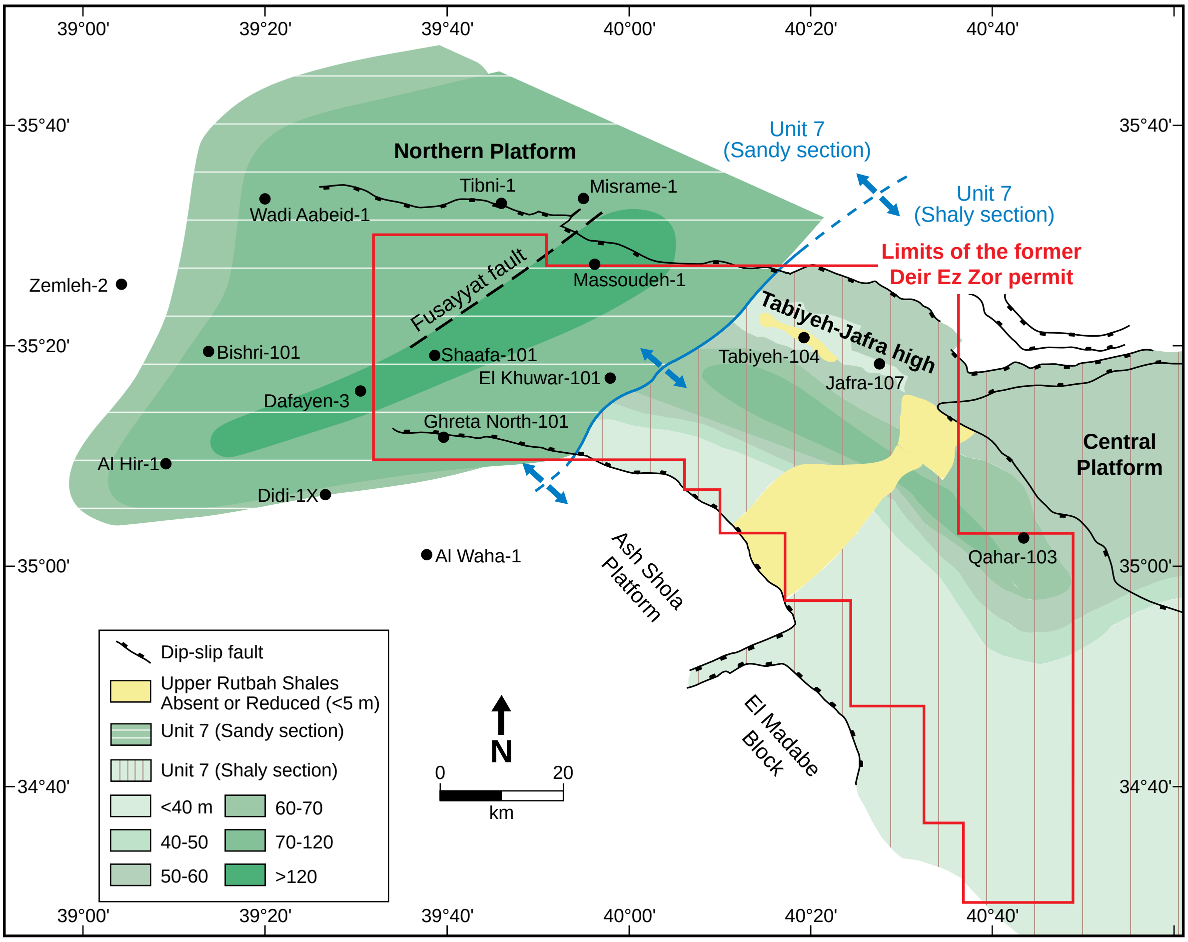


**Figure 11: Isopach map of the Upper Rutbah deposits.**

paleo-valley infill or early tectonic faulting at the site of the future Late Cretaceous Euphrates Graben. On the basis of seismic and well data, Litak et al. (1998) also mentioned a thickening of the Rutbah Formation along the axis of the N140°E-trending graben system. They attributed this thickening to the effects of post-depositional erosion rather than onlap. Instead, we interpret this feature to indicate syntectonic deposition during early tectonic faulting at the site of the future Late Cretaceous graben.

Indeed, isopach mapping of the Cenomanian deposits (Judea Formation) do not show a similar pattern (Figure 12). Post-depositional erosion is however suggested to account for the absence or reduction of the Upper Rutbah and Judea deposits over the NE-trending belt lying southeast from the Tabiyeh-Jafra High (Figures 11 and 12). It is postulated that this erosion is related to the base Turonian unconformity (Figure 2). Figure 12 also shows a lack of Cenomanian deposits over the area lying south of the Northern Platform. This zone could be a residual block of the Hamad Uplift, reactivated at the time of Upper Rutbah-Lower Judea deposition, and progressively transgressed by Cenomanian deposits, as suggested by the gradual southeast decrease of Judea carbonates to the west of it. It could also be an area of intense erosion following the Turonian block faulting.

In the northwestern part of the Euphrates Graben, the thickness of the Judea Formation increases toward the west. This depositional pattern illustrates the proximity of the subsiding Bishri Trough to the west. Of particular interest is the NE-trending regional shape of the isopachs, suggesting the activity of a NE-trending fault or system of faults in that area. This trend was also expressed in the Lower Cretaceous isopachs (units 6 and 7, Figure 9) and corresponds to the Massoudeh-Ghreta North line (Figure 8), to the east of which Jurassic deposits are absent. It is inferred that this trend is a persistent element in the Mesozoic history of the study area (Figure 8 to Figure 12). Some evidence from seismic is presented in the next section.

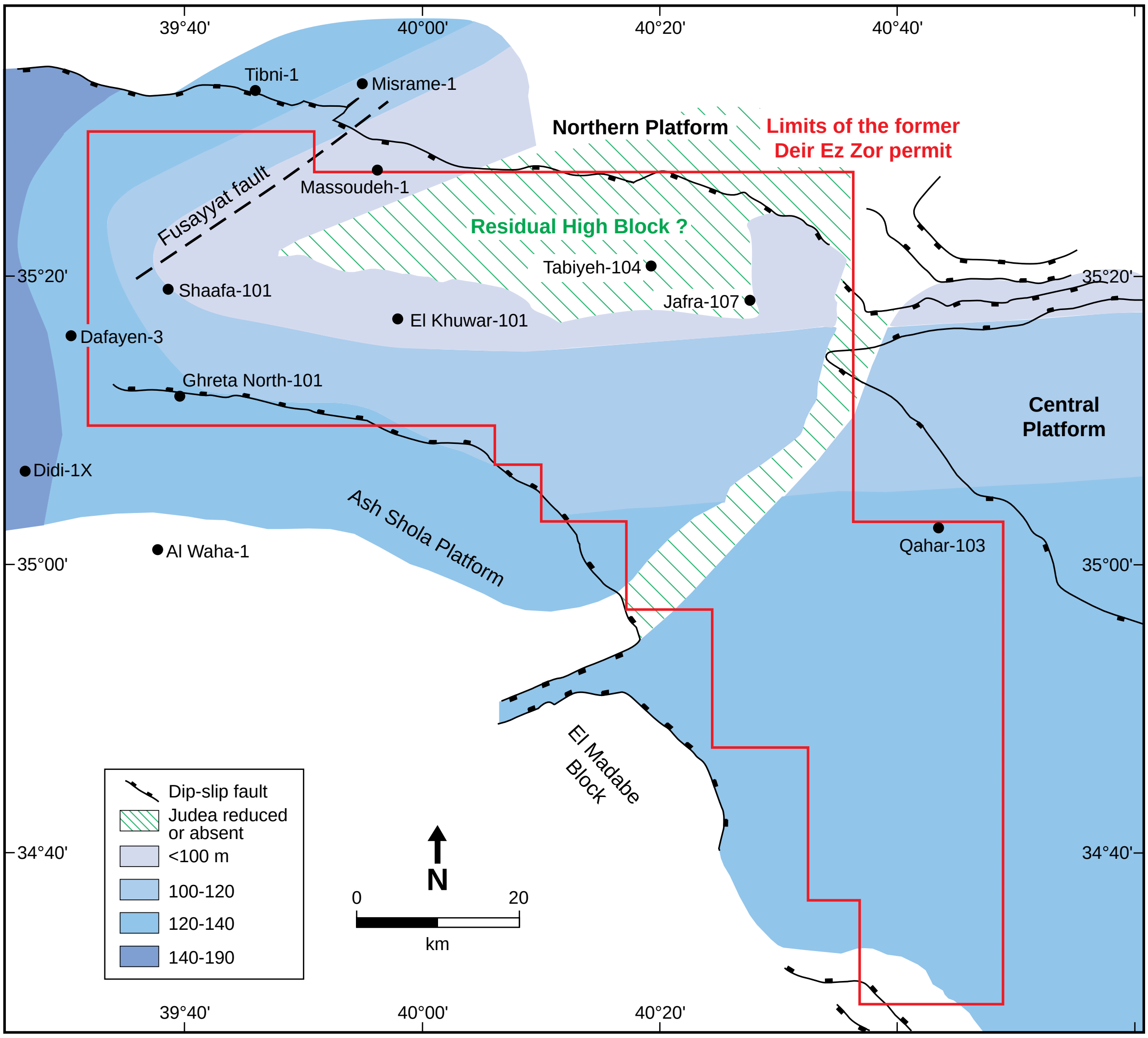


**Figure 12: Isopach map of the Cenomanian deposits (Judea Formation) in the Euphrates basin.**

## *Tectonic Control for NE Depositional Trends*

Figure 13 shows the presence of a major NE-trending normal fault at the base Upper Cretaceous level, located west of the Massoudeh-Ghreta North line. This fault (Fusayyat Fault) delineates an upthrown compartment to the northwest. It is noticeable that N140°E-trending faults at the base Upper Cretaceous level end-up against the inner Fusayyat Fault. This fault has been located on all the maps from Figure 9 to Figure 12. It marks the likely limit between the western Euphrates Graben System and the Mesozoic Palmyrides Basin. Alsdorf et al. (1995) also noted that NE-trending strike-slip faults separate the two areas but they concluded these were Cretaceous normal faults reactivated as strike-slip faults during the late Neogene. Actually, this network of faults was already active in Jurassic and Early Cretaceous times. This fault bounds two domains: a western zone characterized by active depocenters in Jurassic and Lower Cretaceous (unit 1 to 6, Figures 8 and 9) and an eastern area of positive relief, which can be viewed as a northern extension of the Hamad Uplift in the Euphrates Graben area. This pre-existing high was subsequently dissected into a system of grabens and horsts, during the Late Cretaceous major phase of rifting.

## *Clastic Sources*

The sand dilution pattern observed in Figure 10 and the lateral facies change noticed in Upper Rutbah times (from sandstones in the west to shales in the eastern wells) suggest a sediment entry point located to the northwest of the study area. This could be a high-relief zone linked to the NE-trending Hamad Uplift. However, the pattern could be local, not reflecting two other possible source areas.

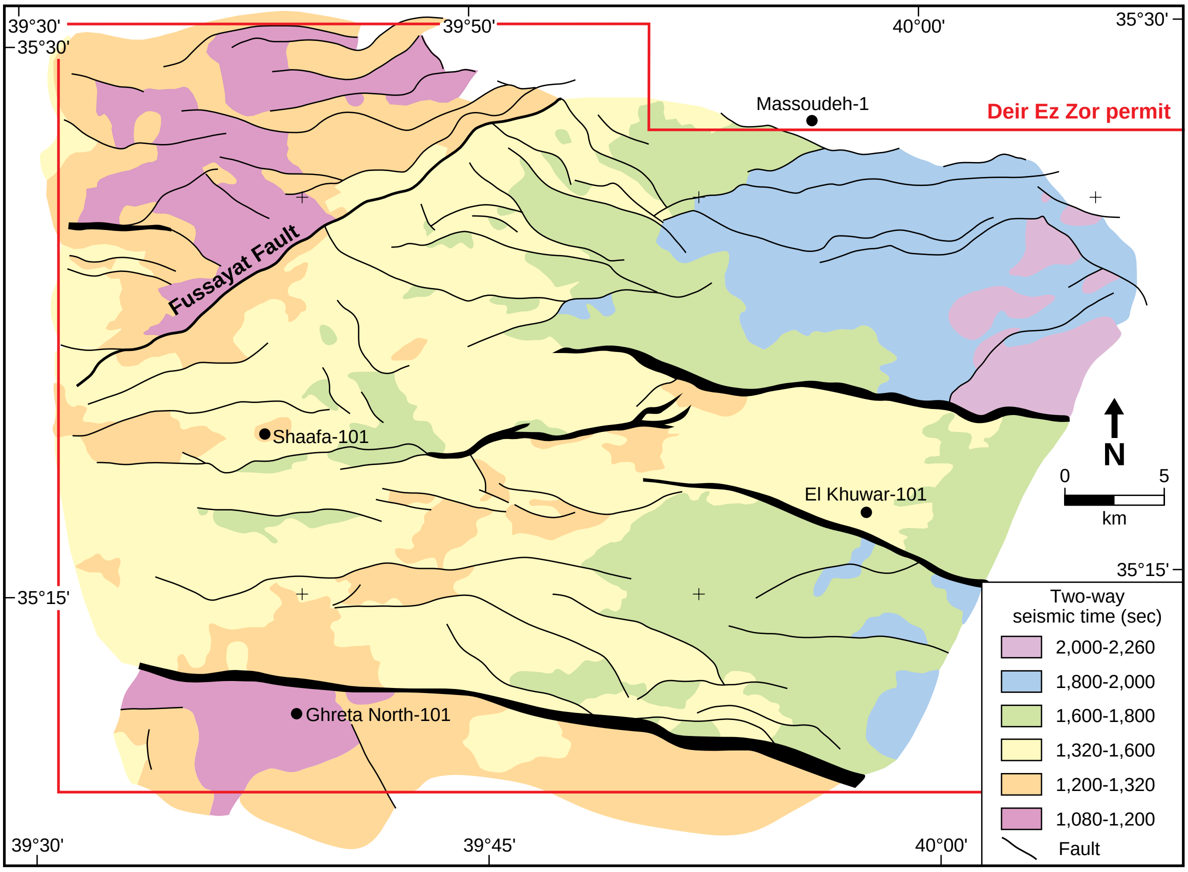


**Figure 13: Base Upper Cretaceous isochron map (two-way Time in milliseconds) of the northwestern part of the Euphrates Graben. Datum plane is 300 m above sea level.**

Sands could have been sourced by the erosion of Upper Paleozoic detrital series over the Hamad Uplift to the south-southwest. There, subcrop data indicate that Paleogene shallow-marine sediments rest unconformably upon Lower Carboniferous marls and clayey limestones interbedded with black and gray flints (Ponikarov et al., 1966; Best et al., 1993). Mesozoic sands could also have been sourced by the erosion of the Khleissia High to the northeast (Figure 7a), for which subcrop data indicate that upper Campanian-Maastrichtian shallow neritic sediments cover unconformably Lower Carboniferous-Tournaisian dolomites with shaly and silty interbeds (Buday, 1980). However, the precise age and location of clastic sources still remain unclear. Combined sources are probable.

## RECONSTRUCTION OF THE MESOZOIC HISTORY

By reconciling all the data presented in the previous sections we propose a new scenario for the deposition of the Mesozoic formations over the study area.

In the Late Triassic (late Norian), the Hamad Uplift developed as a separate tectono-stratigraphic domain (Figure 14), at the site of a former Paleozoic terrigenous basin (Jamal et al., 2000). It was a NE-trending arch, which terminated into the northwestern part of the Euphrates Graben. Norian sandstones, proved to be of continental origin in the Euphrates Graben, were probably derived from the erosion and the reworking of Upper Paleozoic sands exposed over this ridge. This NE-trending arch caused the isolation of most of the Euphrates Graben from the great Levantine margin until the Early Cretaceous (Figure 14), resulting in a hiatus of some 110 My, predominantly attributed to non-deposition. Westwards, in Central Syria, Jurassic sedimentation was continuous and controlled by NE-trending synsedimentary structures. By the Barremian-Aptian, sandy units 1 to 3 were deposited within an E-W-trending depocenter (Bishri Trough, Figure 8). These units are absent in the Euphrates Graben. By the Aptian, regional positive structures (Hamad Uplift potentially) may have been

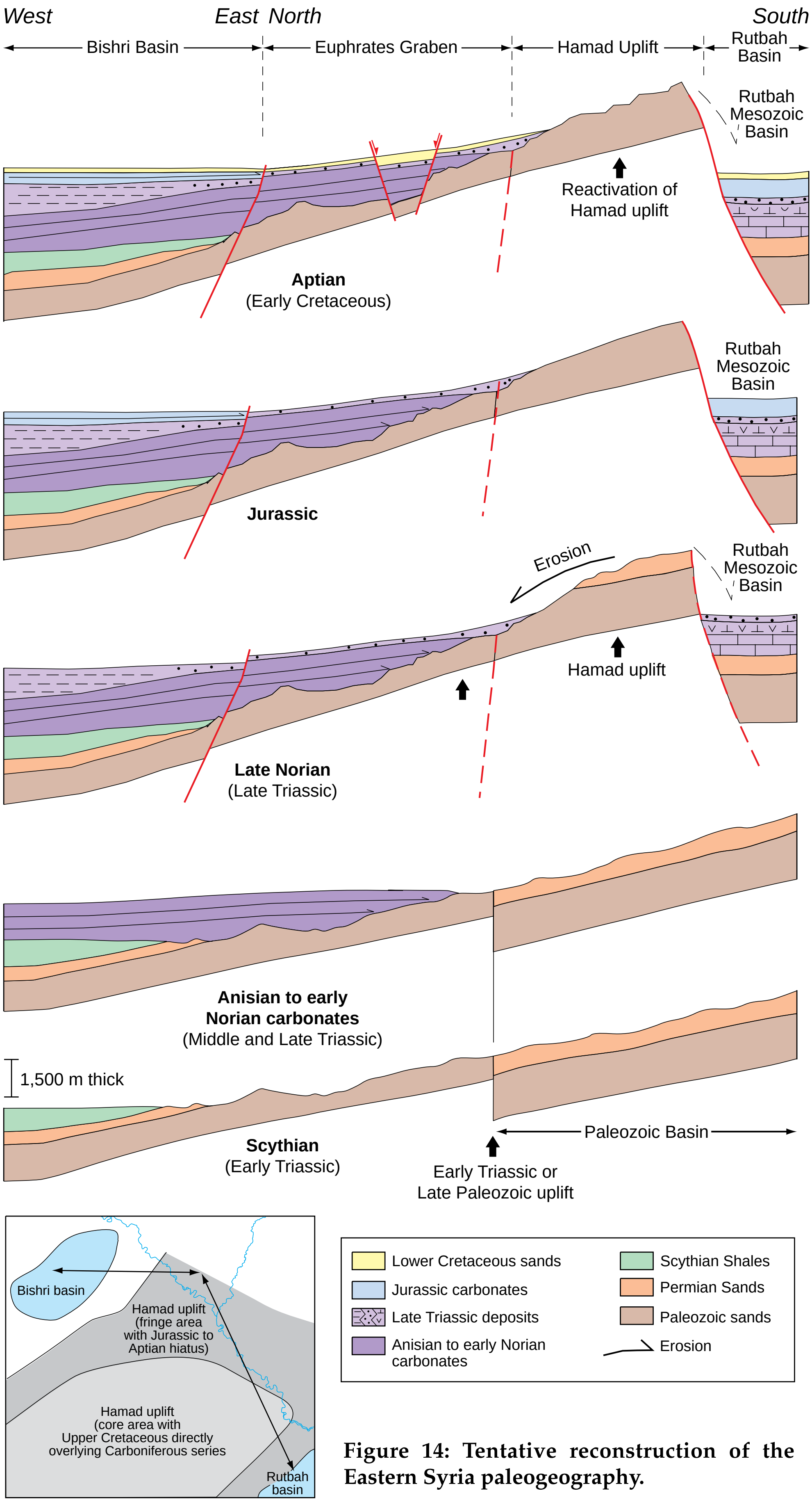


**Figure 14: Tentative reconstruction of the Eastern Syria paleogeography.**

reactivated, leading to the deposition of unit 4 within the Bishri Trough and the southeastern-most part of the Euphrates Graben (Qahar area, Figure 8). A stronger reactivation phase occurred during the deposition of unit 5 (Lower Rutbah in the Euphrates Graben).

At that stage, the eastern part of the Hamad Uplift was for the first time in its Mesozoic history dissected by a large NE-trending depression (Figure 9), with more than a 100-m-thick series. Then, during the deposition of unit 6 (Lower-Middle Rutbah), the tectono-sedimentary activity, that had concentrated until that time to the site of the Bishri-101 well, shifted to the east, but again followed a NE trend. This eastward shift of tectonic activity continued during the deposition of unit 7 (Middle-Upper Rutbah), with a large widening to the whole Euphrates Graben. The NE-trend was expressed until the end of the deposition of unit 6 and is clearly visible on the total isopach map of the Lower and Middle Rutbah Formation (Figure 10). Sands of unit 6 are of mixed origin, presumably supplied by the erosion of neighboring ridges (Hamad and Khleissia uplifts), followed by reworking and deposition in a littoral environment. During the deposition of unit 7, the local tectono-sedimentary setting changed sharply, with a rotation of the depocenter axis. Upper Rutbah (end of unit 7) was the time when a new trend appeared: the N140°E trend that would characterize all the Cretaceous evolution of the Euphrates graben (Figure 11). This time period also corresponds to a change in palynofloral assemblages, with the first occurrence of dinoflagellates (Figure 5).

At the end of the fifth sequence and during the sixth sequence (Figure 5), shallow-marine sandstones of the northwestern area shale-out to the east-southeast. NW-trending normal faults developed in the eastern part of the Euphrates Graben, filled with marine shales (Figure 11). We consider these faults as zones of earlier weakness, precursors of the Turonian rifting phase. They are syn-sedimentary, as evidenced by the gradual changes in thickness detected on either side of the central proto-graben (Figure 11) and by the non-exposure (non-erosion) of overlying formations (Figure 12). At that time, the early "rifting" phase (NE-SW extension) was accompanied by basaltic activity. K-Ar ages as old as late Albian-early Cenomanian (95 Ma) have been obtained on the volcanics associated with the "syn-rift" unconformity (in-house data from Total) (Figure 2). In the Abd Al Aziz Trough, which is on-trend with (and possibly of similar origin to) the Sinjar Trough (Figure 1), the first "rift" pulse is also recorded at the base of the Lower Cretaceous sequence (Kent and Hickman, 1997).

## Significance of NE-trending Lineaments

The N50°E Fusayyat Fault (Figures 8 to 13) should be regarded as the northwestern-most edge of the Hamad Uplift. This NE-trending uplift played an important role in the Mesozoic depositional history of the Euphrates Graben and Bishri Trough. Recognized from Jordan to northeast Syria, this uplift separated throughout the Late Triassic to the Early Cretaceous two subsiding sedimentary basins in Syria: (1) the Palmyrides Basin to the northwest; and (2) the Rutbah Basin to the southeast (Mouty, 1997).

It is interesting to link this uplift to the geological history of Syria and of the Northern Arabian Plate in general. The NE-trending Hamad Uplift is described by Kazmin et al. (1986) as the "Palmyra line" (Figure 15). For these authors the 'Palmyra line' and associated high is one of the numerous NE-striking fault zones crossing the Arabian Shield, roughly parallel to the zone of major continental break-up, i.e. to the southeast coast of the Arabian Peninsula (Figure 15).

In the framework of the Euphrates Graben, this ridge was segmented for the first time during the Early Cretaceous. The Euphrates Graben, which was previously cut-off from the active Mesozoic East Palmyrian trough (Bishri Trough) and behaved as a relative topographic high, was subjected to strong deepening at that time. This event occured at the transition stage between the Lower and Middle Rutbah, i.e. during the fourth sequence and partly during the regressive system tract of the fifth sequence. Palynofloral age determinations are not accurate enough to place time constraints upon this event and are not even suitable to define the Albian-Aptian boundary within the Rutbah Formation.

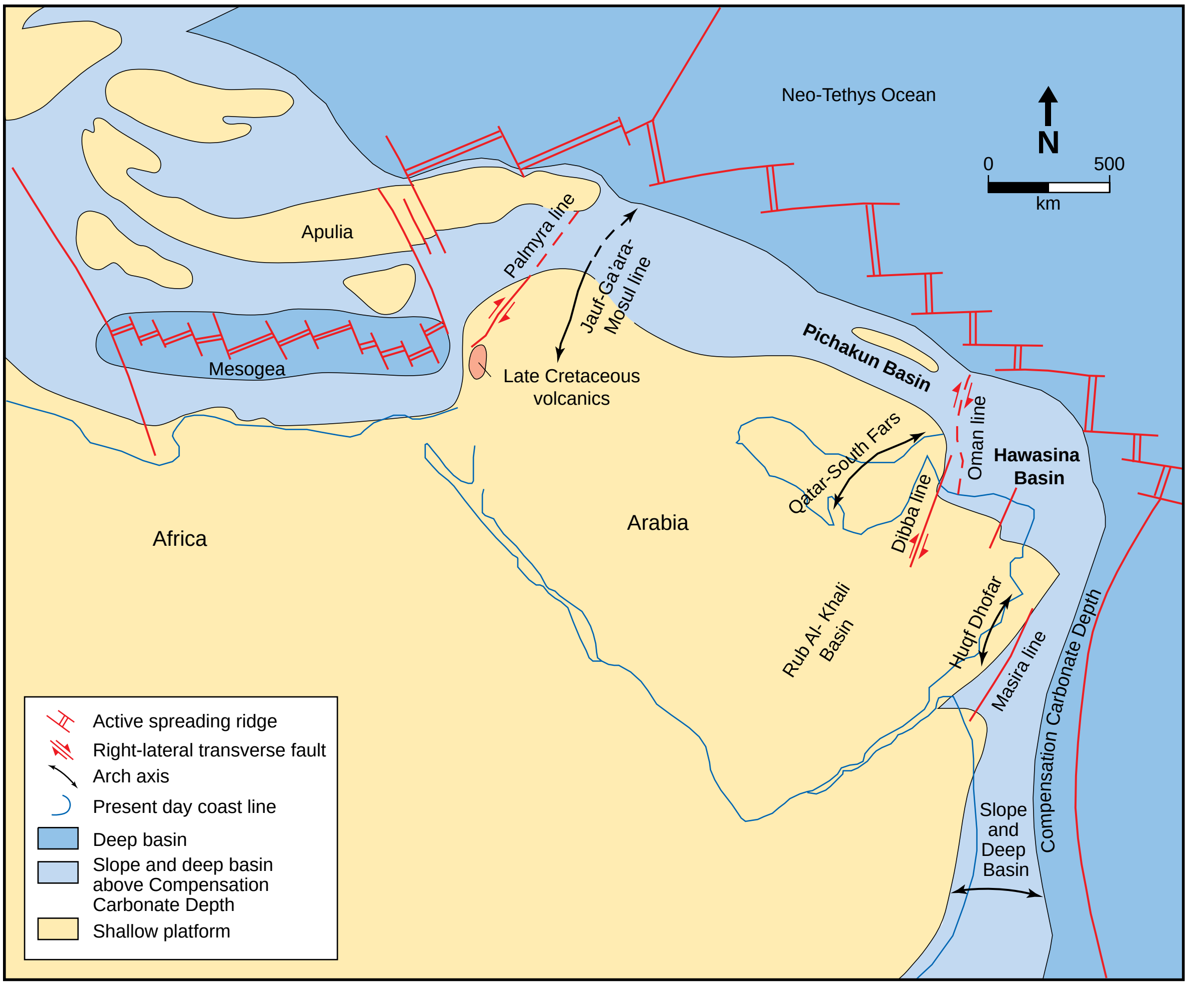


**Figure 15: Plate tectonic reconstruction at Aptian times (from Dercourt et al., 1993, and Kazmin et al., 1986)**

## CONCLUSION

Biostratigraphical data and regional log correlations suggest that the 110 My hiatus in Eastern Syria is the result of non-deposition over a NE-trending regional uplift of Late Triassic age (Hamad Uplift). The hiatus was enhanced by tectonic faulting starting as early as Early Cretaceous time as a precursor to the formation of the Euphrates Graben System. Accordingly, the Early Cretaceous section should not be considered as part of the pre-rift history of the Euphrates Graben System. Major differential structural relief controlled by NW-SE faulting was already evident in the Early Cretaceous. At least until this period of early fault-controlled subsidence, all depositional trends between the Bishri Trough and the Euphrates Graben were controlled by the NE-trending Hamad Uplift.

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