Oligocene stratigraphy in the Sinjar Basin, northwestern Iraq

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ABSTRACT

The distribution of the Oligocene succession (basinal and reef–back-reef deposits) in Iraq closely follows the pattern set in Middle to Late Eocene times. Reef–back-reef limestone has a linear outcrop across northern Iraq from northwest (the eastern part of the studied area) to southeast. In the Sinjar Basin, the Oligocene succession is unconformable on the Middle Eocene Jaddala Formation and unconformably to relative conformably underlies the Lower Miocene Anah or Ibrahim formations. Two surface sections on the Sinjar Anticline and one cored borehole in the Butmah Anticline formed the basis for our study.

Biostratigraphic analysis indicated four planktonic and three benthonic foraminifera biozones. The planktonic biozones are *Pseudohastigerina micra* and *Globigerina ampliapertura* Partial-Range zones, *Globorotalia opima opima* Total-Range Zone and *Globigerina ciperonesis ciperonesis* Partial-Range Zone; the three benthonic biozones are *Nummulites fichteli-Nummulites intermedius* Assemblage Zone, *Borelis pygmaeus* Total-Range Zone, and *Praerhapydionina delicata-Austrotrillina hovchini-Peneroplis evolutus* Assemblage Zone. Three depositional sequences are present in the sections and borehole and comprise two third-order sedimentary cycles. The first consists of the Palani, Sheikh Alas and Shurau formations and the lower part of the Tarjil Formation deposited in upper-bathyal to intertidal environments; the second is the upper Tarjil Formation and Bajwan Formation. The Baba Formation (a barrier deposit) was not seen in the studied sections, but probably reflects lateral stacking development of the barrier to the west. The upper Tarjil Formation was deposited in upper-bathyal to middle-shelf environments whereas the Bajwan Formation consists of subtidal to tidal-flat deposits.

Sequence-stratigraphic analysis, as calibrated by sedimentary facies and biostratigraphy, delineated the two third-order depositional cycles as the Oligocene First Cycle of Rupelian age and the Chattian Oligocene Second Cycle. This suggests that the studied Oligocene succession was deposited over a period of about 9 million years and shows good correlation of the northeastern Arabian Platform with other parts of the Platform and with European Oligocene sequences.

INTRODUCTION

The Oligocene succession in northwestern Iraq was studied through two surface sections on the Sinjar Anticline and the cored borehole BW-CH1 in the Butmah area. Figure 1 shows the location of the study area and the regional geology.

The Iraqi Oligocene succession was first described by van Bellen et al. (1959-2005) as three depositional sequences: the Palani, Sheikh Alas and Shurau formations (Lower Oligocene) for the first sequence; the Tarjil, Baba and Bajwan formations (Middle Oligocene) represented the second; and the third sequence consisted of the Ibrahim, Azkand and Anah formations. However, they state that this dating does not imply strict correlation with the European Oligocene and Miocene. Accordingly, the age of many of the formations of van Bellen et al. (1959-2005) was determined more on the basis of their stratigraphic position rather than on paleontological evidence (Figure 2). The Baba Formation, a barrier deposit in the second sequence, was not seen in the studied sections, but probably reflects lateral stacking to the west.
The results of further studies (Al-Eisa, 1992; Al-Banna, 1997; Al-Banna et al., 2002; Al-Banna and Al-Mutwali, 2002; Al-Banna, 2004a) promoted the Ibrahim Formation to the Lower Miocene (Aquitanian). Al-Banna (2008) placed the Oligocene/Miocene boundary between the Tarjil and Ibrahim sequences. He revised the succession of van Bellen et al. (1959-2005) and the maximum flooding surfaces of Sharland et al. (2001, 2004) and Simmons et al. (2007). This new position of the boundary provides an important time marker for regional correlation across the entire Arabian Plate and into the Red Sea (Al-Husseini, 2008). As a result, the Oligocene succession in northwestern Iraq is considered to consist of two major cycles (Palani-Sheikh Alas-Shurau-lower Tarjil; and upper Tarjil-Baba-Bajwan) and two MFSs (Pg30 and Pg40) (Figure 2).

This present study is a new application based on the above revision. Two surface sections and one cored borehole from three localities in the Sinjar Basin were logged. Investigations of the sedimentary facies, sedimentary model, biostratigraphy, and sequence stratigraphy of the two Oligocene cycles were undertaken.
**GEOLOGIC SETTING**

The paleogeography and depositional history of the Oligocene in northern Iraq follows a similar pattern to that established in the Middle to Late Eocene. Fore-reef and back-reef shoal limestones were deposited in two northeast-trending belts (Figure 1) separated by a deep-water basin containing globigerinal marl (Dunnington, 1958). Variations in the shape and extent of the Oligocene basin reflect the configuration of the ground surface at the time of deposition.

During the Middle to Late Eocene, inversion and sea-level fall, and widespread emergence, erosion and non deposition occurred across the northeastern part of the Arabian Plate as a result of the final phase of subduction and closure of the remnant Neo-Tethys Ocean (Numan, 1997; Sharland et al., 2001; Jassem and Goff, 2006).

Accordingly, many of the Eocene units were exposed and eroded. Evidence for the unconformity is found in the Jaddala Formation underlying the Palani Formation. The tectonic and sedimentologic evidence point to the large hiatus between the Middle Eocene and Oligocene that extended from the upper boundary of Biozone P11 to the lower boundary of Biozone P19 with a duration of 10.5 million years (My) (see Figure 11). A similar but less extreme situation existed between Oligocene and Early Miocene basins (Figure 2). Whereas the contact between the Tarjil and Ibrahim formations (deep marine deposits) is indicated by Late Oligocene shallow-deposit facies with few (if any) biozones being missing, there is a minor unconformity between the lagoonal Bajwan and Anah formations that points to exposure of the inner shelf during the Late Oligocene.

Lithologically, the two Oligocene cycles are formed of five formations; namely, the Palani, Tarjil, Sharau, Sheikh Alas, and Bajwan formations. The Palani and Tarjil formations crop out along the southern flank of the Jabal Sinjar Anticline. They consist of pale-brown to brown marl, marly limestone and limestone (with some arenaceous units in the Palani Formation). Samples were collected from the Jaddala section (N36°18'24", E41°40'37") and the Qaulat section (N36°23'56", E42°05'35") (Figure 3). In addition, the cored borehole BW-CH1 (N36°38'10", E42°38'02") in the Butmah area penetrated the Oligocene succession. It intersected brown to pale-brown limestone, gray to light-gray dolomic
limestone, dolomite and conglomerate. These rocks were assigned to the Shurau and Sheikh Alas formations of the first cycle and to the Bajwan Formation of the second cycle. The Baba Formation (Figure 2) was not detected in the borehole.

**JADDALA SECTION**

**Palani Formation**

**Facies and Depositional Setting**

The formation was first described by van Bellen et al. (1959-2005) in well K/85 on the Kirkuk structure. In the type section it consists of dolomitized globigerinal marly limestone. It is unconformable on the Middle Eocene Jaddala Formation and unconformably underlies the Oligocene (Late Rupelian – Chattian) Tarjil Formation. Two facies (PA1 and PA2) are recognized in Palani Formation; these are:

**Basal conglomerate facies (PA1):** The facies has a total thickness of about 2 m in the Jaddala section (Figure 4). It consists of extracasts of chert, glauconite, magnetite, hematite, and sedimentary rock fragments, with mollusca shells and echinoid fossils. The facies shows a fining-upward grain size. The rocks contain planktonic foraminifera of various ages from Middle Eocene to Early Oligocene represented by *Globigerina*, *Globorotalia*, *Catapsydrax* and *Acaranina*. Some of the Eocene foraminifera are present in the clasts, whereas others were found in washed samples from the matrix; they are therefore reworked fossils.

The sedimentological properties, the variable content of rock fragments, different types of fossils (exotic fossils) and the variety of foraminiferal index species indicate a depositional environment in the lower part of a marine fan (Emery and Myers, 2006).

**Planktonic foraminiferal wackestone facies (PA2):** The thickness of the PA2 wackestone is 8 m in the Jaddala section. It is characterized by pale-brown marly limestone (Figure 4). Skeletal fossil remains constitute between 15 and 40 percent of the unit. Of these, planktonic foraminifera are the most abundant as represented by *Globigerina*, *Globorotalia*, *Catapsydrax* and *Pseudohastigerina*. The micrite matrix includes glauconite and iron oxide grains.

The sedimentological features and biological content indicate an outer-shelf to upper-bathyal environment possibly in the upper part of a marine fan (Emery and Myers, 2006).
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Whereas the Palani Formation is restricted to the Jaddala section, the Tarjil Formation is present in both the Jaddala and Qaulat sections.

**Tarjil Formation**

*Facies and Depositional Setting*

The type section of slightly dolomitized globigerinal marly limestone (van Bellen, 1956) is located in Well K/85 in the Kirkuk Field. The Formation unconformably overlies the Palani Formation and grades upward into the Baba Formation in the type section. Four facies (T1–T4) were recognized in the studied sections. They are named according to the classification of Dunham (1962) as follows:

**Planktonic foraminiferal lime mudstone facies (T1):** The facies has a mud-supported texture and allochems make up less than 10 percent of the total. The predominant allochems are planktonic foraminifera represented by *Globigerina* and *Globorotalia* genera. The few benthonic foraminifera recorded are *Cibicidoides*, *Anomalinaeoides* and *Bulimina*. The characteristic features of the facies indicated an outer shelf depositional environment (Gibson, 1989). It has a thickness that ranges from 5 to 46 m.

**Bioturbated lime mudstone facies (T2):** The facies is characteristically a brown limestone with abundant irregular burrows of organisms (0.5–1 cm in diameter) and, in some localities, pelecypod shells and fish remains (Figure 5). In the Qaulat section the facies is affected by dolomitization that points to the rocks being in the diagenesis zone close to the ground surface. The paleontological and
sedimentological evidence indicates an inner-middle shelf environment. The facies has a thickness of between 5 and 10 m.

**Benthonic foraminiferal lime wackestone facies (T3):** The facies consists of pale-brown limestone and marly limestone with a skeletal component of less than 40 percent of the total facies content (Figure 6). Benthonic foraminifera are the abundant skeletal remains represented by *Cibicidoides, Planulina, Lenticulina, Spirolectammina, Uvigerina, Bulimina* and *Nodosaria* together with a few planktonic foraminifera affiliated to *Globigerina, Globorotalia* and *Catapsydrax*. Solution of the micritic matrix produced vugs. The paleontological evidence indicated an outer-shelf depositional environment. The facies has a thickness that ranges between 7 and 30 m.

**Planktonic foraminiferal lime wackestone facies (T4):** The facies consists of white to light-brown limestone and marly limestone between 5 and 14 m thick. The allochem percentage of less than 40 consists of diverse planktonic foraminiferal species. The genera *Globigerina, Globorotalia* and *Catapsydrax* amount to 40 to 65 percent of the foraminiferal assemblage (Figure 7). A few benthonic foraminifera belong to the *Planulina, Spirolectammina* and *Bulimina* genera. Micrite forms most of the matrix of the wackestone but some recrystalization of micrite to sparite has occurred. Iron oxide and microsparite fill the chambers of some forams. Sedimentological and paleontological evidence points to an outer-shelf to upper-bathyal depositional environment (Gibson, 1989). The thickness of this facies ranges from 6 to 14 m.

**PLANKTONIC FORAMINIFERAL ZONES OF THE PALANI AND TARJIL FORMATIONS**

The Oligocene rocks exposed in the Sinjar area consist of deep-marine carbonates. Washed residues from these rocks were investigated for common diverse planktonic foraminifera to be used as biostratigraphic tools for investigating the deep-marine setting of the Palani and Tarjil formations.
The Palani Formation is characterized by an abundance of well-preserved planktonic foraminifera; similarly, the Tarjil Formation is characterized by the abundance of common planktonic foraminifera in most parts of the Formation, but with only rare occurrences in some intervals. Thirty-three species and subspecies belonging to five genera were identified in the two formations, and their stratigraphic distribution permits the recognition of four biozones (Figures 9 and 10), P19 in the Palani Formation and three (P20-P22) in the Tarjil Formation. These zones are correlated with similar ones established by other authors as shown in Table 1. The zonal scheme (P zones) followed in this study is that of Blow (1969). The four recognized zones are described in ascending order as follows:

**Pseudohastigerina micra** Partial-Range Zone (P19): Early Rupelian

**Definition:** Partial range of the nominate taxon is bounded at the base by the disappearance of Middle Eocene planktonic foraminifera at the disconformity with the underlying Jaddala Formation. The top of the zone is placed at the last appearance of *Pseudohastigerina micra* (Figures 8b and 9).

**Thickness:** The Zone is 8 m thick in the Jaddala section.

**Characteristics and Age:** Blow (1969) divided the Early Oligocene into two biozones: a lower *Globigerinatheka tapuriensis* Zone (P18) and an upper *Globigerinella selli/Pseudohastigerina barbadoensis* Zone (P19). However, Bolli and Saunders (1985) suggested that the most reliable way to recognize the Lower Oligocene is by using the overlap of *Cassigerinella chipolensis* and *Pseudohastigerinella micra*, whereas Berggren and Miller (1988) used the overlapping of *Chiloguembelina cubensis* and all *Pseudohastigerinidae* in order to avoid nomenclature problems.

Al-Mutwali and Al-Banna (2002) identified the index species *Cassigerinella chipolensis* in the Palani Formation in the Sinjar section near Sinjar city, where the Formation is represented by a condensed marine interval; however, in this study we did not recognize the species *Cassigerinella chipolensis* within the Palani Formation in the Jaddala section.
Figure 9: Distribution of planktonic foraminifera in the Jaddala section. A. = *Acarinina*, G. = *Globigerina*, Ggk. = *Globigerinatheka*, Gr. = *Globorotalia*, Gs. = *Globigerinoides*, P. = *Pseudohastigerina*, M. = *Morazovella*, and Tu. = *Turborotalia*.

| EPOCH         | STAGE      | FORMATION | BIOZONE | Thickness (m) | Sample Number | LITHOLOGY |
|---------------|------------|-----------|---------|---------------|---------------|-----------|
| Miocene       | Aqaiatian  | Ibrahim   | N4      | 75            | 160           | Limestone |
| Oligocene     | Chattian   | Tarjil    | P22     | 140           | 65            | Marly limestone |
| Oligocene     | Chattian   | Tarjil    | P21     | 120           | 55            | Marl |
| Oligocene     | Chattian   | Tarjil    | P20     | 100           | 45            | Conglomerate |
| Eocene        | Lutetian   | Jaddala   | P19     | 80            | 35            | Limestone |
| Eocene        | Lutetian   | Jaddala   | P11     | 60            | 25            | Marly limestone |

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Figure 10: Distribution of planktonic foraminifera in the Qaulat section. G. = Globigerina, Ga. = Globigerinella, Gr. = Globorotalia, Gs. = Globigerinoides.
The Zone contains the following planktonic species and subspecies: *Pseudohastigerina micra*, *Globigerina ampliapertura*, *G. sellii*, *G. ouachitaensis ouachitaensis*, *G. praebulloides praebulloides*, *G. praebulloides leroyi*, *G. euapertura*, *G. tapurienensis*, *G. ciperoensis angustiumbilicata* and *Globorotalia opima nana*. The Zone is equivalent to the younger part of the *Cassigerinella chipolensis/Pseudohastigerina micra* Zone (Bolli, 1957, 1966; Bolli and Sanders, 1985) and *Globigerina sellii/Pseudohastigerina barbadoensis* Zone (P19 of Blow, 1979; Bolli and Krasheninnikov, 1977; Krasheninnikov and Pflaumann, 1977). All these zones are of late Early Oligocene age.

**Globigerina ampliapertura Partial-Range Zone (P20): Late Rupelian**

**Definition:** The partial range of the nominate taxon occurs between the extinction of *Pseudohastigerina micra* (Figure 8b) at the base and the initial appearance of *Globototalia opima opima* (Figure 8c) at the top (Figures 9 and 10).

**Thickness:** The Zone is 30 m thick and 18 m thick, respectively, in the Qaulat and Jaddala sections.

**Characteristics and Age:** It was first defined by Bolli (1957) and revised by the same author (Bolli, 1966). He characterized it by the occurrence of *Globigerina ampliapertura* (Figure 8d), *G. venezuelana* and *G. ouachitaensis ouachitaensis*, which are recognized in our Zone.

The characteristic planktonic species and subspecies are *Globigerina ampliapertura*, *G. praebulloides praebulloides*, *G. praebulloides leroyi*, *G. galavisi*, *G. selli*, *G. praesepis*, *G. pseudAMPLiapertura*, *G. angiporides*, *G. yaguaensis*, *G. ciperoensis angustiumbilicata*, *Globorotalia opima nana*, *Globorotaloides suteri* and *Catapsydrax unicavus*.

The Zone is equivalent to the Early Oligocene (Rupelian) *Globigerina ampliapertura* Zone (Bolli, 1957, 1966, Bolli and Krasheninnikov, 1977; Blow, 1969; Bolli and Saunders, 1985).

**Globorotalia opima opima Total-Range Zone (P21): Late Rupelian – Early Chattian**

**Definition:** Total range of nominate taxon.

**Thickness:** Thicknesses of 83 and 80 m, respectively, were measured in the Qaulat and Jaddala sections.

**Characteristics and Age:** The predominant planktonic foraminifera are *Globorotalia opima opima* (Figure 8c), *Globorotalia opima nana*, *Globigerina ciperoensis ciperoensis*, *G. ciperoensis angustiumbilicata*, *G. praebulloides praebulloides*, *G. praebulloides leroyi*, *G. ouachitaensis ouachitaensis*, *G. euapertura*, and *G. tripartite*. The Zone is identical to the *Globorotalia opima opima* Zone (Bolli, 1957, 1966) and the *Globorotalia opima* Zone (Stainforth et al., 1975; Bolli and Krasheninnikov, 1977; Bolli and Saunders, 1985; Lidz and McNeill, 1995), both of Late Oligocene (Late Chattian) age.

**Globigerina ciperoensis ciperoensis Partial-Range Zone (P22): Late Chattian**

**Definition:** Partial range of the nominate taxon (Figures 9 and 10) that occurs between the extinction of *Globorotalia opima opima* (Figure 8c) and the initial appearance of *Globigerinoides primordius* (Figure 8f).

**Thickness:** Thicknesses of 43 and 44 m, respectively, were measured in the Qaulat and Jaddala sections.

**Characteristics and Age:** The Zone is characterized by the presence of small planktonic foraminifera, such as, *Globigerina ciperoensis ciperoensis*, *G. ciperoensis angustiumbilicata*, *G. venezuelana*, *G. praebulloides praebulloides*, *G. praebulloides leroyi*, *G. tripartita*, *G. galavisi*, *Globorotalia opima nana*, and *Globorotalia obesa*. The uppermost zone of Oligocene age, the *Globorotalia kugleri* Zone of Bolli (1957), was not detected in the studied sections. This was probably because of the poor assemblage of planktonic foraminifera in the Late Oligocene.
Therefore, we considered the Globigerina ciperoensis ciperoensis Zone to represent the Upper Oligocene up to the boundary with the Lower Miocene Globigerinoides primordius Zone of the Ibrabim Formation. This Zone is equivalent to the Globigerina angulisuturalis Zone (P22 and N3) of Blow (1969, 1979) and Abawi and Maroof (1988). It is also equivalent to the Late Oligocene Globigerina ciperoensis and Globorotalia kugleri zones (Bolli 1957, 1966; Bolli and Krasheninnikov, 1977; Bolli and Saunders, 1985; Lidz and McNeill, 1995) (Table 1).

### SEQUENCE STRATIGRAPHY OF THE JADDALA AND QAULAT SECTIONS

The sequences vary in thickness and are interpreted in terms of sequence boundaries (SB), lowstand systems tracts (LST), lowstand systems fans (LSF), transgressive surfaces (TS) and transgressive system tracts (TST), maximum flooding surfaces (MFS) or intervals (MFI), and high system tracts (HST).

The geological time scale of Gradstein et al. (2004) was used in the calculation of time duration as being the most recent time scale available. The time scale of Haq et al. (1989) (Figures 11 and 12) was used to estimate the ages of the MFS events in order to correlate with the MFSs of Sharland et al. (2001, 2004) and Al-Banna (2008) (Pg30 and Pg40).

### Jaddala Section

The sequence-stratigraphic analyses of the Jaddala section delineated three sequences, designated Jaddala sequences 1 to 3 (Figure 11).

#### Jaddala Sequence 1

Facies PA1 represents the LSF of this 36-m-thick sequence (Figure 11); it is followed by facies PA2, T3 and T4 showing increasing water depth and the TST with a retrogradational stacking pattern. The top of T4 is picked as the MFS in the Globigerina ampliapertura Zone (P20). The overlying facies T1 is interpreted as the HST. The lower and upper boundaries are type-1 and 2, respectively.

The third-order sequence was deposited between 32.1 and 29.0 Ma and spans about 3.1 My. The age of the MFS as calculated from the biozone is 30.1 Ma according to Gradstein et al. (2004) and 33.1 Ma according to Haq et al. (1988) (Figure 11).

#### Jaddala Sequences 2 and 3

The base of the 75-m-thick Sequence 2 is a type-2 SB. The overlying T3 and T4 facies show increasing water depth and represent the TST. The MFS occurs at the top of T4 within the Globorotalia opima Zone.
Figure 11: Lithostratigraphy, biostratigraphy and sequence stratigraphy of the Jaddala section.
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| EPOCH   | STAGE       | FORMATION | BIOZONE | Thickness (m) | Sample Number | Lithology | Sequence Stratigraphy | Bathymetric Curve | Haq et al. (1988) | Sharland et al. (2004) MFS | Gradstein et al. (2004) (Ma) | Al-Banna (2008) MFS |
|---------|-------------|-----------|---------|---------------|---------------|-----------|----------------------|------------------|-----------------|---------------------------|-----------------------------|---------------------|
| Miocene | Aquitanian  | Ibrahim   | N4      | 160           | P22           | T1        | Sequence Boundary     | High             | 15.9            | 15.9                       | 15.9                        | 15.9                |
| Oligocene | Chattian   | Tarjil    | P21     | 150           | T1            | HST       | Sequence 1            | Low              | 15.9            | 15.9                       | 15.9                        | 15.9                |
| Rupelian | Chattian   | Tarjil    | P20     | 45            | T1            | HST       | Sequence 2            | Low              | 15.9            | 15.9                       | 15.9                        | 15.9                |

**Figure 12:** Lithostratigraphy, biostratigraphy and sequence stratigraphy of the Qaulat section.
opima Zone (P21). The overlying facies T1 and T2 reflect decreasing water depth of the HST. The upper boundary is a type-2 SB. The duration of Sequence 2 is probably greater than 1 My.

Jaddala Sequence 3 is bounded by a type-2 SB. The lower part consists of facies T4 that corresponds to the TST. Absolute sea level was high as indicated by the difference in depth between facies T4 in both sequences; the MFS occurs in facies T4. The HST of the Sequence is represented by facies T1. The MFS (121 m) extended throughout the basin.

The two sequences form a third-order sequence with a total thickness of about 115 m and a duration of approximately 5.7 My.

Qaulat Section

The sequence-stratigraphic analyses of the Qaulat section delineated three sequences, designated as Qaulat sequences 1 to 3 (Figure 12).

Qaulat Sequence 1

The lower boundary of this third-order sequence does not crop out in the section but is thought to start at the Eocene/Oligocene boundary. The lower part of the Sequence is represented by facies T3 that corresponds to a TST. An MFS occurs at the upper boundary of facies T3 where it is overlain by facies T1 that equates with the HST of the Sequence. The upper boundary of the Sequence is a type-2. The Sequence is 75 m thick and had a duration of about 1.7 My.

Qaulat Sequences 2 and 3

Sequence 2 is bounded by two type-2 SBs for a thickness of 15 m. The Sequence begins with the deposition of facies T4 that corresponds to a TST, the upper boundary of which is an MFS, which followed by deposition of facies T2 as HST. This Sequence has a duration of less than 1 My. It is a fourth-order sequence.

Sequence 3 commences with the deposition of facies T4 that shows an upward deepening of the depositional environment that is a TST. The MFS at the top of facies T4 is overlain by a HST as indicated by facies T1. The upper type-2 boundary is the Oligocene/Miocene boundary. The Sequence is 70 m thick. The MFS of Sequence 3 is at 102 m. The relative age of the MFS, as calculated from the biozone is 27.1 Ma according to Gradstein et al. (2004) and at 28.7 Ma according to Haq et al. (1988) (Figure 12).

Qaulat sequences 2 and 3 collectively form a third-order sequence with a total thickness of 85 m and duration of 5.4 My.

BOREHOLE BW-CH1, BUTMAH SECTION

The studied Oligocene succession in borehole BW-CH1 consists (in ascending order) of the Shurau, Sheikh Alas and Bajwan formations (see Figures 18 and 19). The Early Miocene Anah Formation that is unconformable on the Bajwan Formation was not part of the study.

Sharua Formation

Facies and depositional setting

The Formation was first named by van Bellen (1956) in the Kirkuk oil field. The type section is 18 m thick and consists of dense gray limestone and porous coralline limestone. Two facies (S1 and S2) were identified in the studied sections.

Lime mudstone facies (S1): Allochems form less than 10 percent of the total content of the lime mudstone facies. They consist of fragmented shells of unidentifiable benthonic foraminifera whose internal structure has been destroyed by partial or complete dolomitization. This process of dolomitization gave rise to sieve and fogged mosaics and floating rhombs fabrics (Figure 13).
Randazzo and Zakhos (1984) identified the origin of these dolomitic rocks as lime mudstone. The mudstone was deposited in a low-energy environment that allowed the formation of micrite; such an environment is not conducive to the preservation of skeletal remains.

In the lower part of the facies, at a depth of 98.0 m in borehole BW-CH1 a narrow interval of dedolomitization is present. The dedolomitization, whereby calcite replaces dolomite, is generally regarded as a surface or near-surface process below an unconformity (Al-Hashimi and Hemingway, 1973; Budi et al., 1984). The dedolomitization took place in a vadose zone where fresh water percolated through the dolomite (Longman, 1982; Heekle, 1982).

The paleontological and sedimentological evidence is indicative of deposition within the warm intertidal zone of a platform having restricted water circulation (Flugel, 1982).

**Benthonic lime packstone facies (S2):**
The predominant allochem components are benthonic foraminiferal tests. Pelecypod, gastropod and coral remains are less abundant. The main benthonic genera are *Peneroplis, Austrotillina, Archaias* and *Borelis* and various miliolids (Figure 14).

The matrix consists of micrite and microspar. Examples of several diagenesis processes are present, including solution vug porosity in which the vugs are filled with drusy cement. Scattered floating rhombs of dolomite in the matrix are the result of partial dolomitization.

The presence of the benthonic genera and associated organisms indicates deposition in a subtidal environment where depths ranged between 20 and 50 m (Reiss and Hottinger, 1984; Adams, 1984; Hallock and Glenn, 1986).

**Sheikh Alas Formation**

**Facies and depositional setting**
The first description of the Formation was by van Bellen (1956). Lithologically, the type section consists of dolomitic and recrystallized limestone, generally porous and occasionally rubbly. The formation in the studied section consists of a brown to pale-gray limestone occurring as a tongue within the Shurau Formation.
Nummulitic lime packstone facies (SA1): The facies is dominated by *Nummulites fichteli* (Michelotti), *N. intermedius* (D’Archaic) and *N. vascus*; together they form 60 percent of the total content (Figure 15). Also present are fragments and tests of *Austrotrillina howchini* (Shunberger), *Austrotrillina paucialveolata* (Grimsdale).

Lithologically, the unit consists of a brown to pale-gray limestone bed with a total thickness of 2.05 m in borehole BW-CH1. Micrite and microspar form the matrix of the facies, which is affected by solution and accordingly small vugs are present. The sedimentological and paleontological evidence points to a shallow-marine environment of deposition in the form of a bank of nummulites that has been partly winnowed (Batholdy et al., 1999).

**Bajwan Formation**

*Facies and depositional setting*

The Formation was first identified by van Bellen (1956) in the Kirkuk oilfield. The type section is 39 m thick and is characterized by compact, cream-colored back-reef miliolid limestone, alternating with more porous, partly dolomitized algal-reef limestone containing abundant fossil fragments. In the type section, the lower contact is conformable with the Baba Formation and the upper contact is unconformable with Fatha Formation (previously the Lower Fars Formation). Three facies (B1, B2 and B3) are recognized.

Lime mudstone facies (B1): The facies consist of pale-gray compact carbonate rocks. It has been affected by dolomitization that formed suture-mosaic and sieve-mosaic fabrics. Where dolomitization of the mudstone was complete, a micro-texture sutured mosaic was formed (Randazzo and Zachos, 1984) that contains ghosts of miliolids. Our study indicates that the type of dolomite present in borehole BW-CH1 reflects the original fabric of the rock, which was lime mudstone.

Drusy rim cement forms mantles around bioclasts that show moldic porosity. Their condition corresponds to a marine phreatic zone in which the cement was precipitated (Carozzi, 1981). In addition, the facies contains mold pores that are cement-free or only partially cemented, thus indicating an upper vadose zone (Flugel, 1982). The facies accumulated in a shallow, warm-water platform environment with restricted water circulation (Wilson, 1975; Flugel, 1982).

Lime wackestone facies (B2): This facies consists of pale-brown to gray carbonate rocks. The main allochems are benthonic foraminifera (miliolids, *Austrotrillina*, *Archaias* and *Dentritina*) and small gastropods that form 10 to 20 percent of the total mass. Dolomitization created spotted mosaic and sieve-mosaic textures. According to Randazzo and Zachos (1984), these textures occur where there is solution of allochems in wackestone (Figure 16). Some vugs are filled by drusy or blocky calcite cement (Figure 17). We suggest that the type of dolomite occurring in this facies reflects the original fabric of the rock, which was a lime wackestone.

Lithological and paleontological parameters point to deposition in shallow, warm water within a tidal-flat environment. Thus, it can be matched with the Stander Microfacies (SMF) 19 in Facies Zone (FZ 8) of Wilson (1975) and Flugel (1982).
Lime benthonic foraminiferal packstone facies (B3): White to pale-brown compact limestone has an allochem content of 70 to 80 percent consisting of benthonic foraminifera belonging to the *Austrotrillina*, *Praerhaphydionia*, *Meandropsina*, *Peneroplis*, *Archaias*, *Pyrgo*, *Triloculina*, *Quinqueloculina* and *Spiroloculina* genera. In addition, there are pelecypod, ostracod and echinoderm fragments.

Generally, the biological and sedimentological parameters indicated a shallow, warm-water environment. It can be matched with SMF18 within FZ7-FZ8 of Wilson (1975) and Flugel (1982). In intervals where the pelecypod percentage increases and red algae and coral fragments occur, shallowing took place to form a coastal depositional environment.

**BENTHONIC FORAMINIFERAL ZONES OF THE BUTMAH BOREHOLE**

A detailed study was made of thin sections of samples from the Sheikh Alas, Shurau and Bajwan formations from cored borehole BW-CH1.

The biotic assemblages are dominated by large and small benthonic foraminifera; other bioclastic components consist of bivalves, gastropods, coralline red algae (*Lithophyllum* spp.), coral, echinoids and ostracods (Figure 18). Based on the benthonic foraminifera, three assemblage zones have been determined for the Oligocene shallow-marine formations (Figure 19). These zones are correlated with similar ones established by other authors as shown in Table 2 and described in ascending order below.

**Nummulites fichteli-Nummulites intermedius Assemblage Zone (BZ1): Rupelian**

**Definition:** Assemblage zone of the nominate taxons.

**Thickness:** The Zone is recognized in limestone of the Sheikh Alas Formation, which interfingers with the Shurau Formation in borehole BW-CH1, in a 2.05-m-thick interval between 100.3 and 98.25 m.

**Characteristics and Age:** The Zone is characterized by the common occurrence of *Nummulites fichteli*, *N. intermedius* and *N. vascus*, and rare occurrences of *Austrotrillina howchini* and *A. paucialveolata*. It is equivalent to the Nummulites of van Bellen (1956) that corresponds to the Early Oligocene Sheikh Alas Formation in the Kirkuk oilfield. It also correlates with the *N. fichteli-N. vascus* Zone from the Early Oligocene Sheikh Alas Formation in northern and western Iraq (Al-Hashimi, 1974; Al-Hashimi and Amer, 1985). It is of Rupelian (Early Oligocene) age as indicated by the presence of *N. fichteli* and *N. vascus* (Gradstein et al., 2004).

**Borelis pygmaeus Total-Range Zone (BZ2): Rupelian**

**Definition:** The total range of the nominate taxon that occurs below the conglomerate bed separating the Shurau and Bajwan formations.

**Thickness:** It is 11.5 m thick in borehole BW-CH1 (95–83.5 m) within the Shurau Formation.

**Characteristics and Age:** The zonal fossil *Borelis pygmaeus* is dominant. Other fossil components are *Austrotrillina howchini*, *A. paucialveolata*, *Peneroplis evolutus*, *P. planatus*, *Archaias asmaricus* and *Quinqueloculina* sp., and ostracods, pelecypods and corals.
The Zone is equivalent to the Early Oligocene *Dendrophyllum-Austrotrillina paucialveolata* Zone of van Bellen (1956). The zonal taxon *Borelis pygmaeus* was described by Adams and Belford (1974) from the Oligocene deposits of the Indian Ocean. Adams (1984) also identified this species in the Oligocene of the western Pacific Ocean. Al-Hashimi (1974) recorded *Borelis pygmaeus* from the Early Oligocene Shurau Formation in the Western Desert of Iraq.

The zone correlates with the *Subterraniphyllum* Zone established by Mohammad (1983) and with the *Subterraniphyllum thomasi-Austrotrillina paucialveolata* Zone of Abid (1997) (Table 2); these zones were assigned an Early Oligocene age in central and northern Iraq. The benthonic foraminiferal species found in these zones are *Austrotrillina paucialveolata*, *Archaias asmaricus*, *Peneroplis evolutus* and *Subterraniphyllum thomasi*. All these species were identified in the present study except for *Subterraniphyllum thomasi*.

**Figure 18: Distribution of benthonic foraminifera in the Butmah (BW-CH1) borehole.**

| EPOCH  | STAGE     | FORMATION | BIOZONE | Depth (m) | Sample Number | LITHOLOGY |
|--------|-----------|-----------|---------|-----------|---------------|-----------|
| Miocene| Aquitabian| Anah      |         |           |               |           |
| Oligocene| Chattian | Bajwan    | BZ1     |           |               |           |
|        | Rapetian  | Shurau    | BZ2     |           |               |           |
|        |           |           | BZ3     |           |               |           |
| Eocene | Lutetian  | Avanah    |         |           |               |           |

The Zone is equivalent to the Early Oligocene *Dendrophyllum-Austrotrillina paucialveolata* Zone of van Bellen (1956). The zonal taxon *Borelis pygmaeus* was described by Adams and Belford (1974) from the Oligocene deposits of the Indian Ocean. Adams (1984) also identified this species in the Oligocene of the western Pacific Ocean. Al-Hashimi (1974) recorded *Borelis pygmaeus* from the Early Oligocene Shurau Formation in the Western Desert of Iraq.

The zone correlates with the *Subterraniphyllum* Zone established by Mohammad (1983) and with the *Subterraniphyllum thomasi-Austrotrillina paucialveolata* Zone of Abid (1997) (Table 2); these zones were assigned an Early Oligocene age in central and northern Iraq. The benthonic foraminiferal species found in these zones are *Austrotrillina paucialveolata*, *Archaias asmaricus*, *Peneroplis evolutus* and *Subterraniphyllum thomasi*. All these species were identified in the present study except for *Subterraniphyllum thomasi*.
Oligocene stratigraphy, Sinjar Basin, northwestern Iraq

Definition: The assemblage zone for the nominate taxons occurs between the first appearance of Praerhapydionina delicata and Peneroplis evolutus to the last appearance of Austrotrillina howchini and Peneroplis evolutus.

Thickness: The Zone is 36.5 m thick in the Bajwan Formation in borehole BW-CH1 (83.5–47.0 m).

Characteristics and Age: The zone is characterized by Meandropsina anahensis, Austrotrillina paucivalveolata, Dendritina rangi, Archaeis operculiformis, A. kirkukensis, Peneroplis thomasi, Spirolina sp., Lithophyllum sp., Pyrgo sp., Quinqueloculina sp., Triloculina sp., echinoids, corals, gastropods and pelecypods. This faunal assemblage is correlated with the Archaeis kirkukensis-Praerhapydionina delicata Zone (Table 2), which was recognized in central and northern Iraq and assigned a Chattian age (van Bellen, 1956; Abid, 1977; Mohammad, 1983; and Al-Hashimi and Amer, 1985).
SEQUENCE STRATIGRAPHY OF THE BUTMAH BOREHOLE

Sequence-stratigraphic analysis of the Oligocene shallow-marine deposits of the Butmah borehole identified three depositional sequences designated Butmah Sequences 1 to 3 (Figure 19).

The sequences vary in thickness and are interpreted in terms of sequence boundaries (SB), lowstand systems tracts (LST), transgressive surfaces (TS), lowstand system tracts (TST), maximum flooding surfaces (MFS) or intervals (MFI), and high system tracts (HST).

Butmah Sequence 1

The Sequence is 24.75 m thick and has a duration of 5.45 My. The lower boundary has a sharp contact with the Middle Eocene Avanah Formation. The paleontological evidence points to a hiatus at the Eocene/Oligocene boundary in the study area; the contact is a type-1 SB. The Sequence commences with the deposition of lime mudstone (facies S1) followed by Nummulitic lime packstone (facies SA1), the two forming a retrogradational stacking pattern that indicates the TST of the Sequence. The MFI, equivalent to MFS Pg30 of Sharland et al. (2004) and Al-Banna (2008), is represented by a 2.05-m-thick Nummulitic bank deposit (facies SA1). It is overlain by facies S1 and S2 (lime mudstone and benthonic lime packstone, respectively) that form a progradational stacking pattern indicative of an HST that is ended by SB type-1. The sequence is interpreted as a third-order sequence.

Butmah Sequences 2 and 3

Sequence 2 is 18.70 m thick and has a duration of less than 3.0 My. The base of the sequence is a 0.5-m-thick conglomerate representing the LST. It is overlain by lime mudstone (facies S1) and lime packstone (B3). They form a retrogradational stacking pattern that corresponds to the TST of the sequence. Facies B3 represents the MFI and is overlain by facies B2 (lime wackestone). Together, these facies indicate a progradational stacking pattern corresponding to the HST of the sequence. The upper boundary of sequence 2 is a type-2 SB.

Butmah Sequence 3 is 25 m thick and has a less than 2.8 My duration. The lower part consists of facies B3 that forms a retrogradational stacking pattern (TST). Near the middle of facies B3, the content of pelecypods and red algae increases upward to indicate a shallower environment than in the lower part of the sequence, the boundary being the MFS. The upper part of facies B3 is overlain by facies B1 that collectively forms the HST that was ended by a type-1 SB.
Sequences 2 and 3 are together interpreted as a third-order sequence with a total thickness of 43.70 m and a duration of about 5.4 My. Their MFS occurs at a depth of 54 m. It is equivalent to MFS Pg40 of Sharland et al. (2004) and Al-Banna (2008).

**REGIONAL CORRELATION**

On the basis of the lithologic and biostratigraphic data, the study area shows a variety of sedimentary facies within each formation. The grouping of facies within each formation and their distribution within the Sinjar Basin has been interpreted as upper-bathyal to intertidal depositional environments. Accordingly, the Oligocene deposits were subdivided into the following two sedimentary cycles:

**Oligocene First Cycle: Rupelian**

This Cycle consists of the Palani, Sheikh Alas and Shurau formations extending through a variety of depositional environments (van Bellen et al., 1959-2005). Ditmar et al. (1971) considered the Palani and part of the Tarjil and Sheikh Alas formations as forming one cycle in the Late Eocene. This was based on the premise that *Nummulites* in the absence of *Lepidocyclina* indicated a Rupelian age using the Geologic Time Scale of Gradstein et al. (2004). In addition, Jassim and Goff (2006) stated, “In the SE and NW part of the Baba Dome, the Palani Formation is overlain by the Tarjil and Sheikh Alas formations, respectively”. Thus, the lower part of the Tarjil Formation is equivalent to the Sheikh Alas Formation in the Kirkuk area of northern Iraq. These earlier studies support the present interpretation in the Sinjar Basin that the Oligocene First Cycle consists of the Palani, Sheikh Alas and Shurau formations, and the lower part of the Tarjil Formation.

Oligocene deposits overlie the Middle Eocene Jaddala Formation in the western part of the study area, whereas they overlie the Avanah Formation of similar age in the eastern part. The Eocene/Oligocene boundary is an unconformity that represents an interval of 10.5 My.

A marine transgression flooded the western part of the study area during the Early Oligocene (Rupelian). It is represented by marine-fan sediments consisting of basal conglomerate (facies PA1).
containing a variety of extraclast pebbles and fossils. This facies grades upward into planktonic foraminiferal wackestone (facies PA2) indicating outer-shelf to upper-bathyal environments. The lithological and sedimentological evidence suggests that it can be affiliated to the upper part of the marine fan of Emery and Myers (2006). Facies PA1 and PA2 (see Figure 11) are represented by rocks of the Palani Formation in the western part of the study area (Figure 20).

Farther east, near Sinjar city, Al-Banna and Al-Mutwali (2002) recognized a condensed succession belonging to the Palani Formation. On the northern limb of Jabal Sinjar at Sharafiddin village (see Figure 3), no Early Oligocene sediments were found (Abawi and Maroof, 1988) and elsewhere the Palani Formation is represented by a conglomerate bed less than 10 cm thick containing pelecypod shells on its upper surface (Figure 21).

In both the Jaddala and Qaulat sections, the Palani Formation is overlain by deep-marine deposits of the lower part of the Tarjil Formation whose deposition in the Late Rupelian marked the upper part of the Oligocene First Cycle.

The maximum thickness of the Palani Formation is 10 m in the Jaddala section and 8 m was recorded near Bara by Ismail (2006) (Figure 3). The thickness diminishes eastward. Al-Hashimi and Amer (1985) and Al-Banna (1997) recorded 3.5 m of the Palani Formation in the Sheikh Ibrahim and Sasan areas. The barrier facies of the cycle was recognized in borehole BW-CH1, where Nummulite packstone facies (Sheikh Alas Formation) interbedded with lagoonal facies (Shurau Formation) indicate the presence of a Nummulite bank between the Sasan and Butmah areas (Figures 3 and 14). Near the eastern margin of the study area, the Early Oligocene succession consists of lime mudstone and benthonic lime packstone facies that collectively indicate a subtidal to intertidal lagoonal environment of the Shurau Formation.

**Oligocene Second Cycle: Chattian**

The Early Rupelian transgression continued into the Late Rupelian to Early Chattian. It showed fluctuations but was generally more extensive than the earlier transgressive cycle. The western part of the Cycle consists of four main lime planktonic mudstone and wackestone facies (T1, T2, T3 and T4; see Figures 11 and 12) of the Tarjil Formation. Their depositional environment extended from
inner shelf to upper bathyal. The depocenter of the Tarjil Formation was near Sinjar city where the maximum thickness of about 200 m was recorded (Al-Banna and Al-Mutwali, 2002) (Figure 22). The deep-marine sediments of the Tarjil Formation diminish in thickness westward to be about 140 m at Jaddala and 40 m thick in the Bara area near to the border with Syria (Ismail, 2006). To the east, the Qaulat section is 157 m thick and there is a minimum thickness of 10 m at Sasan (Al-Banna, 1997). The thickness of the Formation also diminishes to the north of Sinjar city where, at Sharafiddin village, it is 76 m thick, and to the south in Khleissia Well No.1 it has a thickness of 13 m (Youhanna, 1983).

Shallow-marine sediments occur in the eastern part of the area (Figure 23). They include lime mudstone and wackestone facies containing an abundance of benthonic foraminifera that are affected by dolomitization, solution and cementation processes. These features suggest a shallow, warm-water lagoonal environment in the Butmah area. The barrier facies of the Second Cycle were not detected in either boreholes or surface sections but the previous studies of Al-Banna (1997) and Al-Banna (2004b) in the Sasan and Butmah areas indicated the presence of the shallow-water Baba Formation. The suggestion is that the barrier lies between the Butmah (borehole BW-CH1) and Sasan areas (borehole SS-CH13) (Figure 23) with the development of laterally stacked facies to the west.

**DISCUSSION AND CONCLUSIONS**

The stratigraphic lexicon of Iraq (van Bellen et al., 1959-2005) was revised for the Oligocene succession based on the biostratigraphic and lithostratigraphic data obtained from this study. The new biostratigraphic study points to a major unconformity at the Eocene/Oligocene boundary in the Sinjar Basin, reflecting a hiatus of about 10.5 My between the upper boundary of Biozone P11 (Middle Eocene Jaddala Formation) and the base of Biozone P19 (Early Oligocene Palani Formation) (see Figure 11). Also, the study showed a shallowing of the environment in the upper part of the
Oligocene succession (Tarjil Formation, P22) followed by a marine transgression represented by the Ibrahim Formation (Early Miocene, Biozone N4). Four planktonic biozones are recognized in deep-marine deposits of the Palani and Tarjil formations (P19-P22) in the Jaddala and Qaulat sections (see Figures 11 and 12) and three benthonic biozones (BZ1-BZ3) in shallow-marine deposits of the Sheikh Alas, Shurau, and Bajwan formations in borehole BW-CH1 (see Figure 19) indicative of a depositional duration of less than 10.9 My.

The sedimentological study of the Oligocene succession in the two surface sections and the Butmah borehole resulted in its subdivision into three depositional sequences that form two sedimentary cycles (see Figures 2, 20 and 23). The first cycle consists of the Palani, lower Tarjil, Sheikh Alas and Shurau formations. Depositional facies throughout this cycle range from marine fans to upper bathyal and barrier to intertidal zones on a platform with restricted circulation. The second cycle is made up of the upper Tarjil and Bajwan formations that were deposited in upper bathyal to tidal-flat environments, also on a restricted platform.

According to the Oligocene sequence stratigraphy of Sharland et al. (2001), MFS Pg30 occurs in the Nummulites fichteli Zone present in Oman, the United Arab Emirates and Iran. Sharland et al. (2004) revised these results for the Oligocene succession of Iraq and clarified the presence of MFS Pg30 at the base of the Palani Formation, while adding MFS Pg40 from the middle of the Tarjil Formation and MFS Pg50 within the Ibrahim Formation (see Figure 2). Their interpretation was based on the older ages and stratigraphic cycles of van Bellen et al. (1959-2005). These cycles were calibrated by Al-Banna (2008) who identified the Oligocene MFSs to be Pg30 and Pg40 in the Palani and Tarjil formations, respectively. He revised the Ibrahim Formation (Ibrahim sequence) to the Lower Miocene and the Pg50 of Sharland et al. (2004) to be Ng10 (see Figure 2). However, the present study (see Figures 11 and 12) shows that both Pg30 and Pg40 lie within the Tarjil Formation as shown in Figure 24.

The sequence-stratigraphic interpretation of the surface and borehole sections indicated that the two sedimentary cycles (see Figures 11, 12 and 19) are of third-order rank. The First Cycle (of Rupelian...
Oligocene stratigraphy, Sinjar Basin, northwestern Iraq

The First Cycle consists of the depositional third-order Sequence 1, present throughout the study area, and includes the Globigerina ampliapertura Zone (P20) of the Tarjil Formation, and the Nummulites fichteli-Nummulites intermedius Zone (BZ1) of the Sheikh Alas Formation. The MFS of the sequence (Pg30) was dated at 30.1 Ma in the Jaddala section according to Gradstein et al. (2004) and at 33.1 Ma according to Haq et al. (1988) (see Figure 11). It can be correlated with Pg30 of Sharland et al. (2001, 2004) in Oman and Iraq, respectively, and Al-Banna (2008) in Iraq, and with the Rupelian transgressive surface of Gradstein et al. (2004) in Europe.

The Second Cycle is Chattian and consists of depositional Sequence 2, a fourth-order sequence, and the depositional third-order Sequence 3. Sequence 2 has a maximum thickness of 75 m and lasted about 2.5 My in the Jaddala section (see Figure 11). It thins eastward to be about 15 m thick in the Qaulat section (with a duration of about 1 My) and is absent in the Sasan area (Al-Banna et al., 2002). Sequence 3 is found throughout the Sinjar Basin. The combined sequences form the third-order Second Cycle with an MFS (Pg40) dated at 27.1 Ma (Gradstein et al., 2004) and at 28.7 Ma (Haq et al., 1988) (see Figure 12). Therefore, it can be correlated in Iraq with MFS Pg40 of Sharland et al. (2004) and Al-Banna (2008), and with the Chattian transgressive surface of Gradstein et al. (2004) in Europe.

Further to the east in the Sasan area (see Figure 24), only sequences 1 and 3 are recognized (Al-Banna et al., 2002). The first sequence is represented by the Rupelian Palani Formation that correlates with the lower part of Sequence 1 in the Jaddala and Qaulat sections. The second sequence consists of the upper part of the Tarjil Formation (uppermost Chattian) that correlates with Sequence 3 in the Jaddala and Qaulat sections.

The relative correlations of sedimentary cycles and MFSs of the Oligocene deposits suggest that the north Arabian platform was flooded twice during the Oligocene (the Rupelian and Chattian transgressions). Good correlation exists with other parts of the Arabian Plate and with the European Oligocene.

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