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Microfacies and sequence stratigraphy of the Late Campanian Bekhme Formation in the Dohuk area, north Iraq

Majid M. Al-Mutwali, Nabil Y. Al-Banna and Jamal S. Al-Ghrear

ABSTRACT

The Bekhme Formation represents the lower part of a regional Upper Cretaceous (Campanian - Maastrichtian) succession that was deposited over most of Iraq and adjacent regions. The formation unconformably overlies the Qamchuqa Limestone Formation (Hauterivian-Albian) and is overlain by the Shiranish Formation (Upper Campanian - Maastrichtian). Northeast of the city of Dohuk, an incomplete, but well-exposed, section of the Bekhme Formation crops out in a 75-m-thick section that formed the basis for our study. Twenty-five samples were collected from the section and used for biostratigraphic and microfacies analysis. The study of planktonic foraminifera resulted in the recognition of two Campanian biozones: the *Globotruncanita calcarata* Zone and the *Globotruncanita stuartiformis*–*Globotruncanita stuarti* Zone, both considered to be of Late Campanian age. Three main microfacies were distinguished throughout the formation, which represent middle-shelf, outer-shelf and upper-bathyal environments. Sequence stratigraphic analysis, as calibrated by microfacies, delineated five depositional sequences of probable fourth-order, thus suggesting the studies section was deposited in about 2.0 million years and represents an overall third-order sequence.

INTRODUCTION

The Bekhme Formation represents the lower part of an Upper Cretaceous (Campanian and Maastrichtian) regional transgressive-regressive depositional sequence that flooded nearly all of Iraq (Dunnington, 1958). This paper presents a study of an incomplete, but well-exposed, section of the Upper Campanian Bekhme Formation, located on the southern limb of the Bekher Anticline to the north of the city of Dohuk (Al-Alawi, 1980) (Figure 1). The regional flooding event occurred after the termination of middle Cretaceous orogenesis (Turonian - Early Campanian), and was terminated by another phase of uplift and regression (Late Maastrichtian and Danian; Buday, 1980; Figures 2 and 3, after Jassim and Goff, 2006).

In northeast Iraq strong subsidence and basin-filling (the Tanjero Formation, consisting of thick flysch sediments derived from the northeast) characterize the Campanian - Maastrichtian sequence (Figures 2 and 3, after Jassim and Goff, 2006). The basin was separated from the unstable shelf by a ridge that is now located in the folded zone in the Zakho-Dohuk-Aqra-Rawandoz-Ranya areas (Figure 1). Over the ridge, the Tanjero flysh sediments (on the northeast side) are progressively replaced either by the Bekhme and Aqra formations (reef and shelf facies) or the Shiranish Formation (deep-marine facies); the latter is generally developed with a relatively reduced thickness and intertongues with both the Aqra-Bekhme and Tanjero formations (Figures 2 and 3, after Jassim and Goff, 2006).

Ditmar et al. (1971) accepted, in principle, the suggestions by Chatton and Hart (1961, unpublished report) that the Aqra and Bekhme formations are the same unit and that one of the names should be abandoned. This proposal was formally published by Sadooni and Aqrawi (2000). Towards western and southern Iraq, the Aqra-Bekhme sequence passes to the Hartha, Shiranish and Tayarat formations (Al-Naqib, 1967; Figures 2 and 3, after Jassim and Goff, 2006). The Bekhme and Aqra limestones in northern Iraq may be considered to be the respective equivalents of the Hartha and Tayarat formations in southern Iraq, and the Aruma Formation of Saudi Arabia (see also Sharland et al., 2001).

The present study was based on 25 samples collected from a surface section that is 80 m thick (75 m attributed to the Bekhme Formation and the upper 5 m to the Shiranish Formation). The study involved a detailed field lithological description and identification of microfossils, especially foraminiferal

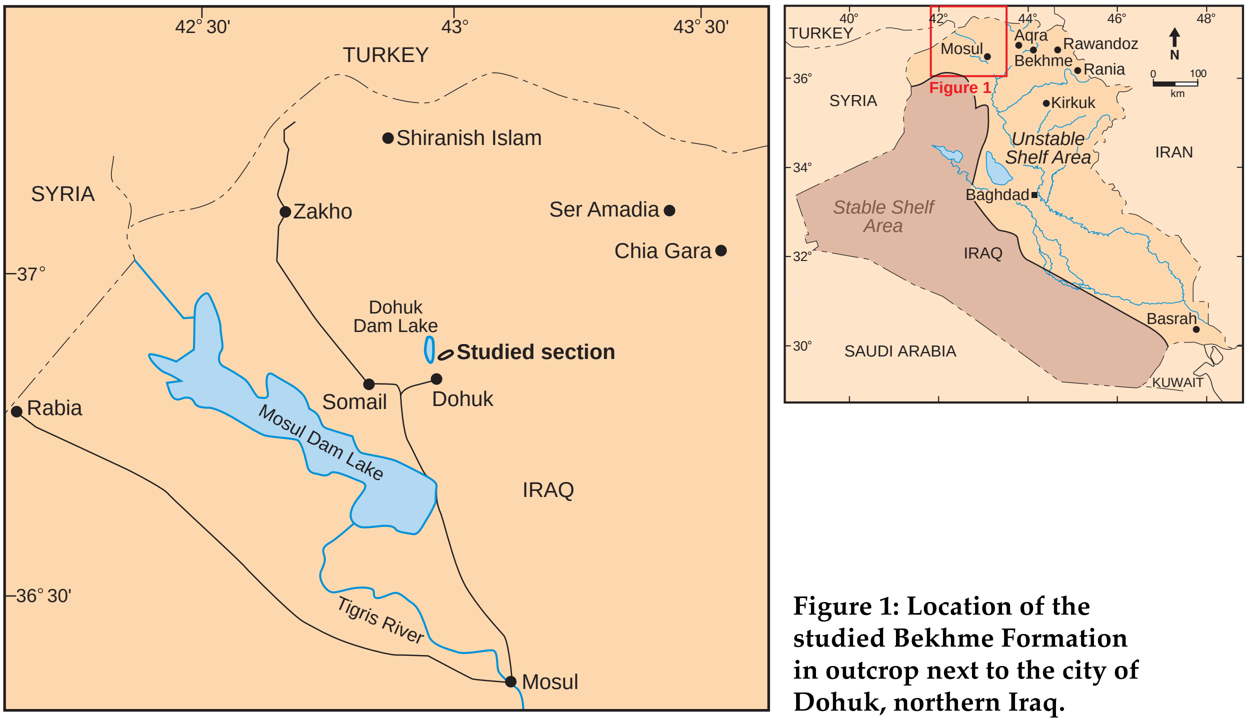


Figure 1: Location of the studied Bekhme Formation in outcrop next to the city of Dohuk, northern Iraq.

assemblages. The assemblages from this incomplete section (base of the Bekhme Formation is not seen) are interpreted as Late Campanian based on calibration to standard planktonic zones (Caron, 1985; Li et al., 1999, 2000; Gradstein et al., 2004). Based on paleontological and sedimentary criteria, microfacies were recognized and used to interpret the sequence stratigraphy of the Bekhme Formation.

TYPE SECTION OF THE BEKHME FORMATION

In this section we review the type section of the Bekhme Formation as first described by R. Wetzel (1950, *in* van Bellen et al., 1959) in the High Folded Zone, northeast Iraq (Figure 1). The formation was previously known as the "Bekhme limestones" (Hudson, 1954).

Location and Thickness: R. Wetzel (1950, *in* van Bellen et al., 1959) reported that the type section lies on the eastern bank of the Greater Zab River at the northern end of the Bekhme Gorge and outside the gorge at its southern end. The base of the section is located at 36°41′45″N, 44°16′30″E, and the top at 36°41′57″N, 44°16′37″E. In the type section it has a thickness of 315 m (1,033.2 ft), but away from this area the formation wedges out relatively rapidly and (mainly towards the southeast) it forms tongues of relatively small thickness within the Shiranish and Tanjero formations (Buday, 1980).

Lithology: R. Wetzel (1950, *in* van Bellen et al., 1959) reported that the basal conglomeratic division (10 m, 32.8 ft thick) is comprised of globigerinal and foraminiferal limestones and polygenetic breccia-conglomerates, with ferruginous globigerinal marls locally. The middle division (94 m, 308 ft thick) is recognized informally as the "*Cosinella* zone", and is comprised of reef-detrital limestones with rudist debris, etc., alternating with fore-reef shoal limestones with rich foraminiferal faunas. The upper division (211 m, 692 ft thick) consists of bituminous secondary dolomites with dispersed glauconite, replacing glauconitic, organic, detrital limestones: some globigerinal limestone intercalations with macrofossil detritus, etc.

Lower Boundary and Underlying Formation: The type section of the Bekhme Formation overlies is the Qamchuqa Formation. The contact is an erosional unconformity, without appreciable angular discordance, but with polygenetic conglomerate at the base of the Bekhme Formation and extensive dolomitization below. The conglomerate is variable in thickness (3–20 m, 9.8–65.6 ft) and character.

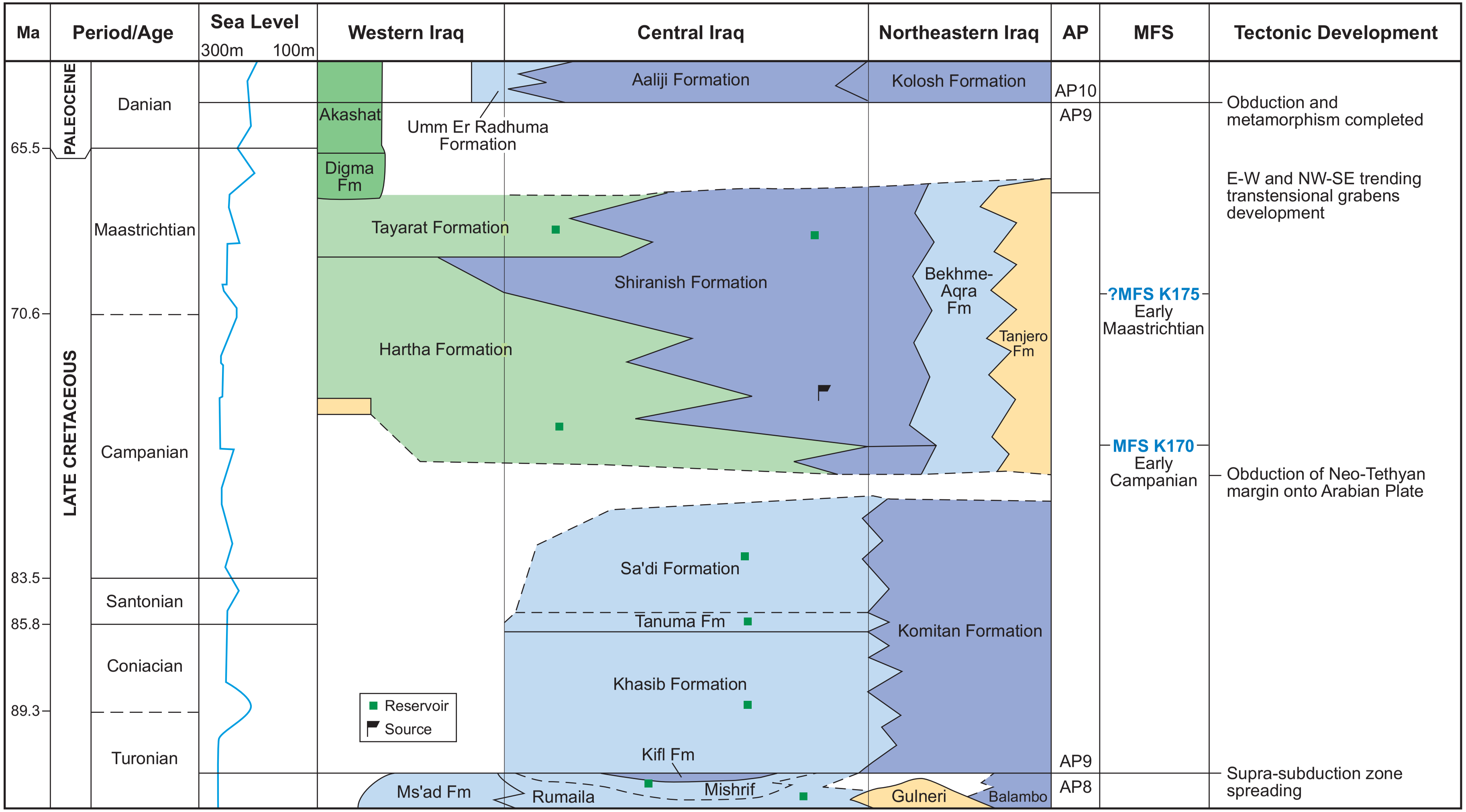


Figure 2: Stratigraphic correlation of formations of Turonian (Late Cretaceous) to Danian (Paleogene) age in northwestern, central and western Iraq (after Jassim and Goff, 2006). The studied Bekhme Formation is of Late Campanian age and was deposited between Late Campanian MFS K170 and ?Early Maastrichtian MFS K175 (Sharland et al., 2001; M. Simmons, 2007, written communication).

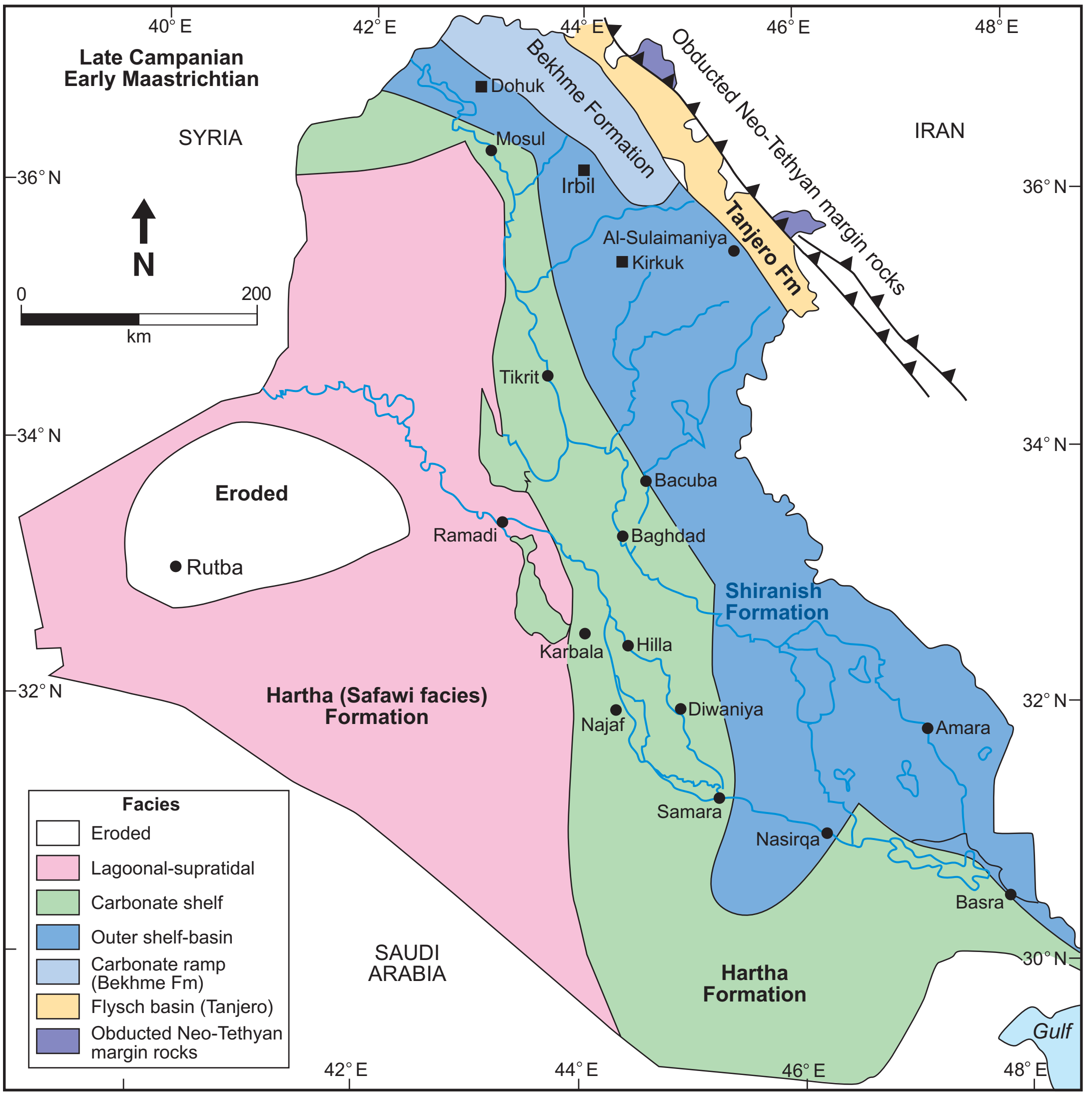


Figure 3: Paleogeographic distribution of the Late Campanian and Early Maastrichtian rock units in Iraq (after Jassim and Goff, 2006).

The derived elements in the conglomerates include Qamchuqa Formation dolomites and limestones, globigerinal limestones of Campanian age, rare pebbles with *Pseudosiderolites* cf. *heracleae* (Arni), and several types of recrystallized and dolomitized limestones of uncertain attribution.

Similar conglomerates are found between the Qamchuqa and Bekhme Limestone formations at Ser Amadia and Chia Gara (Figure 1). At Shiranish Islam, where ?Turonian Mergi Limestone intervenes between the Qamchuqa and the Bekhme, the basal conglomerate includes pebbles of Mergi Limestone with *Praealveolina* sp., and further lenticular pebble beds, passing laterally into marls with plant debris, occur higher up within the lower part of the Bekhme.

Upper Boundary and Overlying Formation: In the type section, the Bekhme Formation is overlain by the Shiranish Formation. The contact is abrupt, marked by condensation of planktonic foraminiferal fauna and by glauconite concentration, doubtfully conformable and without any angular discordance (R. Wetzel, 1950, *in* van Bellen et al., 1959). In the type area of the Aqra Limestone, the contact between the Maastrichtian Aqra and Campanian Bekhme formations is a minor erosional unconformity in some sections. Where the Aqra directly occurs above the Bekhme without intervention by the Shiranish or Tanjero formations, the term "Aqra/Bekhme limestone" (e.g. Figures 2, after Jassim and Goff, 2006) may be used (R. Wetzel, 1950, *in* van Bellen et al., 1959)

In the type description of the Bekhme Formation (Wetzel, 1950, *in* van Bellen et al., 1959), a list of planktonic and benthonic foraminifera is provided that is said to indicate the following ages: "Upper Campanian at the base, Upper Campanian or perhaps Lower Maastrichtian at the top". This age assessment needs to be reviewed in terms of the revisions to the understanding of the biostratigraphic calibration of the Campanian and Maastrichtian stages and especially the definition of the base Maastrichtian that have occurred in the last 50 years or so (e.g. Odin, 2001; Gradstein et al., 2004). Likewise the foraminifera need to be described in terms of modern taxonomic understanding before they can be fully interpreted. The fauna listed in the type description (Wetzel, 1950, *in* van Bellen et al., 1959) can be said to indicate a general Campanian - Maastrichtian age. Detailed new description such as that provided herein provides more precise age assignment.

STUDIED SECTION OF THE BEKHME FORMATION

Location and Thickness: The studied section is located on the southern limb of the Bekher Anticline, north of the city of Dohuk (Figure 1). This succession was identified as the Bekhme Formation by Al-Alawi (1980). Here the Bekhme Formation is 75 m (246 ft) thick and its lower contact is not exposed.

Lithology (Figure 4)**:** The lowermost part consists of pale brown intra-formational conglomerate. It is followed by a repetition of pale brown, friable marly limestone (4–5 m thick) with brownish limestone beds of (0.5–1 m thick), intra-formational conglomerate (10 cm thick) and shale-marl beds. The same lithology continues in the upper part of the formation. Two horizons of intra-formational conglomerate occur within the studied section; the first one in the middle part (6 m thick) while the second (2 m thick) at the lowermost part of the section. Flat pebble conglomerate beds (12 m thick) occur in the uppermost part of the section. The pebbles consist of carbonate lithoclasts ranging in diameter between 3 and 30 cm.

Lower Boundary and Underlying Formation: The lower contact of the studied Bekhme section is not exposed, whilst at

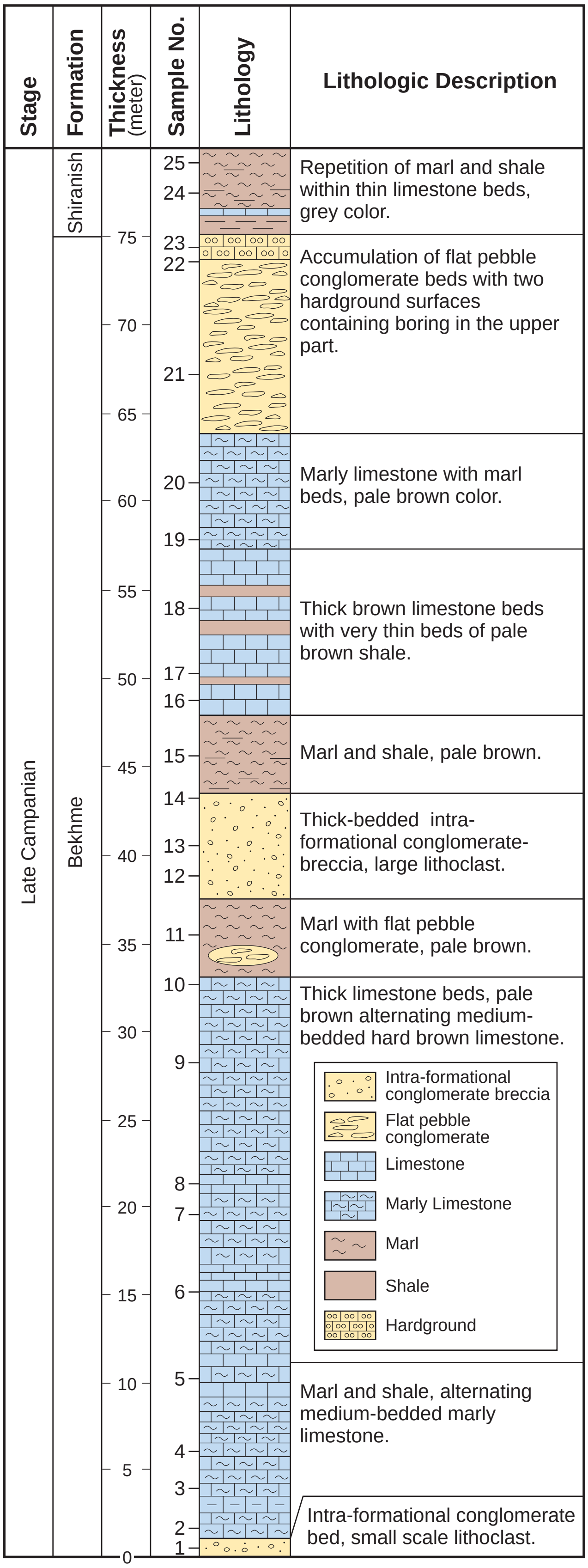


Figure 4: Lithologic description of the studied Bekhme Formation in outcrop next to the city of Dohuk, northern Iraq.

other localities the lower contact of the formation is invariably unconformable (see Type Section above). The formation in these cases usually contains conglomerates at its base and overlies, in the type area, mostly the Qamchuqa Limestone Formation (Hauterivian-Albian) (van Bellen et al., 1959).

Upper Boundary and Overlying Formation: The Shiranish Formation (Late Campanian - Maastrichtian) overlies the Bekhme Formation in the studied area. The contact is very sharp and is placed at the top of the massive pebble conglomerate bed (12 m thick) with a hardground at its upper surface (Figures 4 and 5), and beneath blue gray marls of the Shiranish Formation.

Figure 5: The contact between the studied Bekhme and Shiranish formations next to the city of Dohuk, northern Iraq.

Biostratigraphy

There is a clear relationship between lithotypes and the abundance of planktonic foraminifera, such that planktonic foraminiferal species were most commonly recorded within marl, shale, marly limestone and some limestone beds. Most of the limestone and conglomerate beds (in the matrix) show the appearance of larger foraminifera (*Orbitoides*) and other shallow-marine fossils, with only rare planktonic foraminifera. Seventeen planktonic foraminiferal species belonging to nine genera have been identified. The stratigraphic distribution of these species indicated two biozones of Late Campanian age (Figure 6 and Table 1). These zones are from base to top:

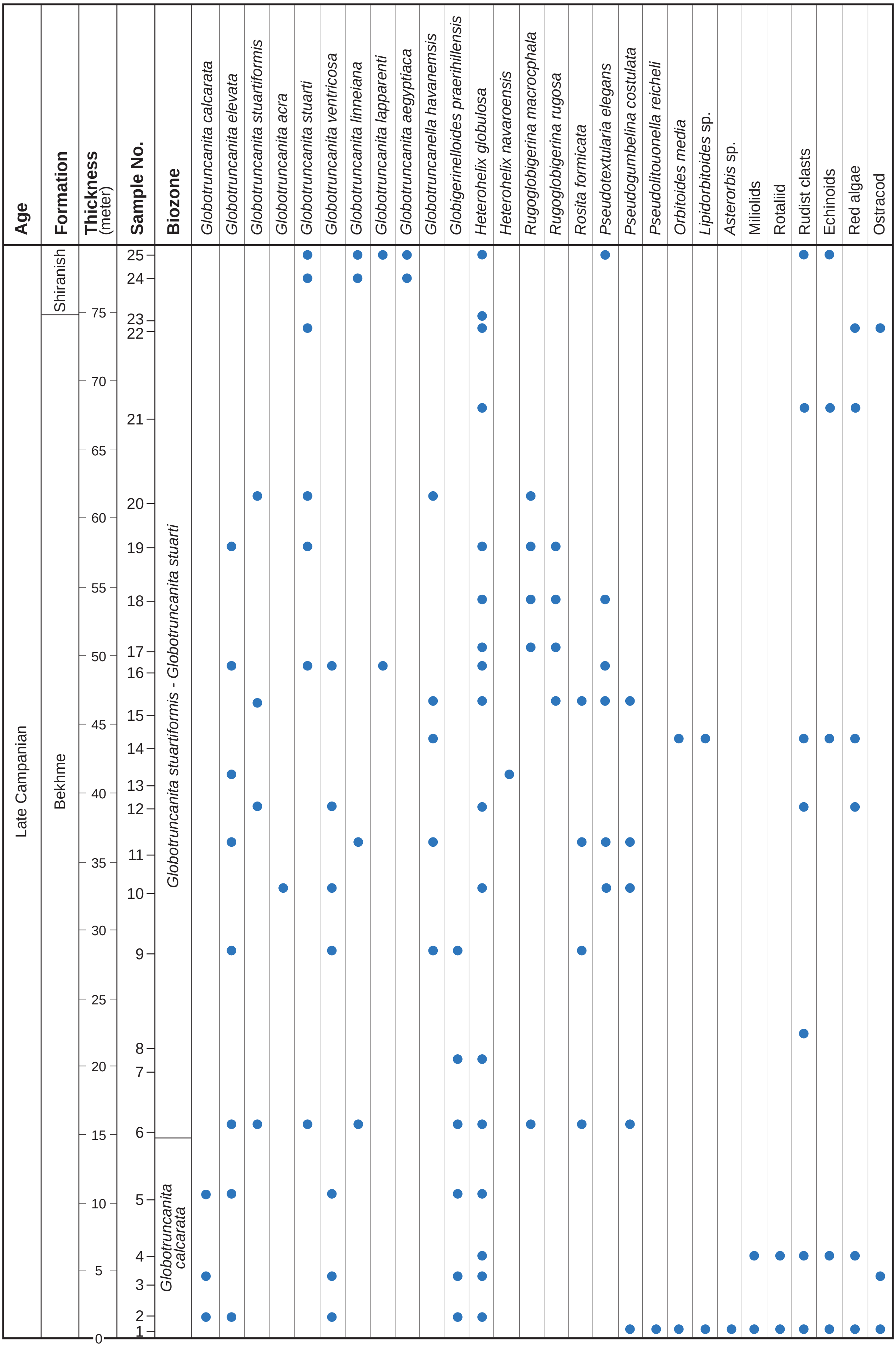
Globotruncanita calcarata Total Range Zone (part)

Definition: Total range zone of the index species *Globotruncanita calcarata* (Cushman) (Figure 7a).
Age: Late Campanian.
Thickness of Zone: 15 m.
Boundaries: The base of this zone is not exposed in the studied section but usually for the Bekhme Formation it is indicated by the first appearance of the nominated taxon. The top of this zone is placed at the extinction of this species.
Characteristics: In addition to the nominate taxon, the following species have been recognized: *Globotruncanita elevata*, *Globotruncanita ventricosa*, *Herterohelix globulosa* and *Globigerinelloides praeihillensis*.

Globotruncanita stuartiformis-Globotruncanita stuarti Interval Zone

Definition: Interval zone of the two nominates taxa (Figures 7b and 7c).
Age: Late Campanian.
Thickness of Zone: 60 m.
Boundaries: The lower boundary is defined by the last occurrence of *Globotruncanita calcarata*. The top of the zone is placed at the first appearance of *Globotruncana aegyptiaca* in the Shiranish Formation.
Characteristics: In addition to the nominate taxa this zone is characterized by the occurrence of: *Globotruncana linneiana*, *Heterohelix globulosa*, *Globigerinelloides praerihillensis*, *Rugoglobigerina macrocephala*, *Rosita fornicata*, *Globotruncanita arca*, and *Globotruncanella havanensis*.

Figure 6 (facing page): Distribution of planktonic foraminifera and other fossils in the studied section.


Age
Formation
Thickness (meter)
Sample No.
Biozone
Globotruncanita calcarata
Globotruncanita elevata
Globotruncanita stuartiformis
Globotruncanita acra
Globotruncanita stuarti
Globotruncanita ventricosa
Globotruncanita linneiana
Globotruncanita lapparenti
Globotruncanita aegyptiaca
Globotruncanella havanensis
Globigerinelloides praerihillensis
Heterohelix globulosa
Heterohelix navaroensis
Rugoglobigerina macrocphala
Rugoglobigerina rugosa
Rosita formicata
Pseudotextularia elegans
Pseudogumbelina costulata
Pseudolitouonella reicheli
Orbitoides media
Lipidorbitoides sp.
Asterorbis sp.
Miliolids
Rotaliid
Rudist clasts
Echinoids
Red algae
Ostracod
Late Campanian
Shiranish
Bekhme
Globotruncanita stuartiformis - Globotruncanita stuarti
Globotruncanita calcarata
0
5
10
15
20
25
30
35
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45
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65
70
75
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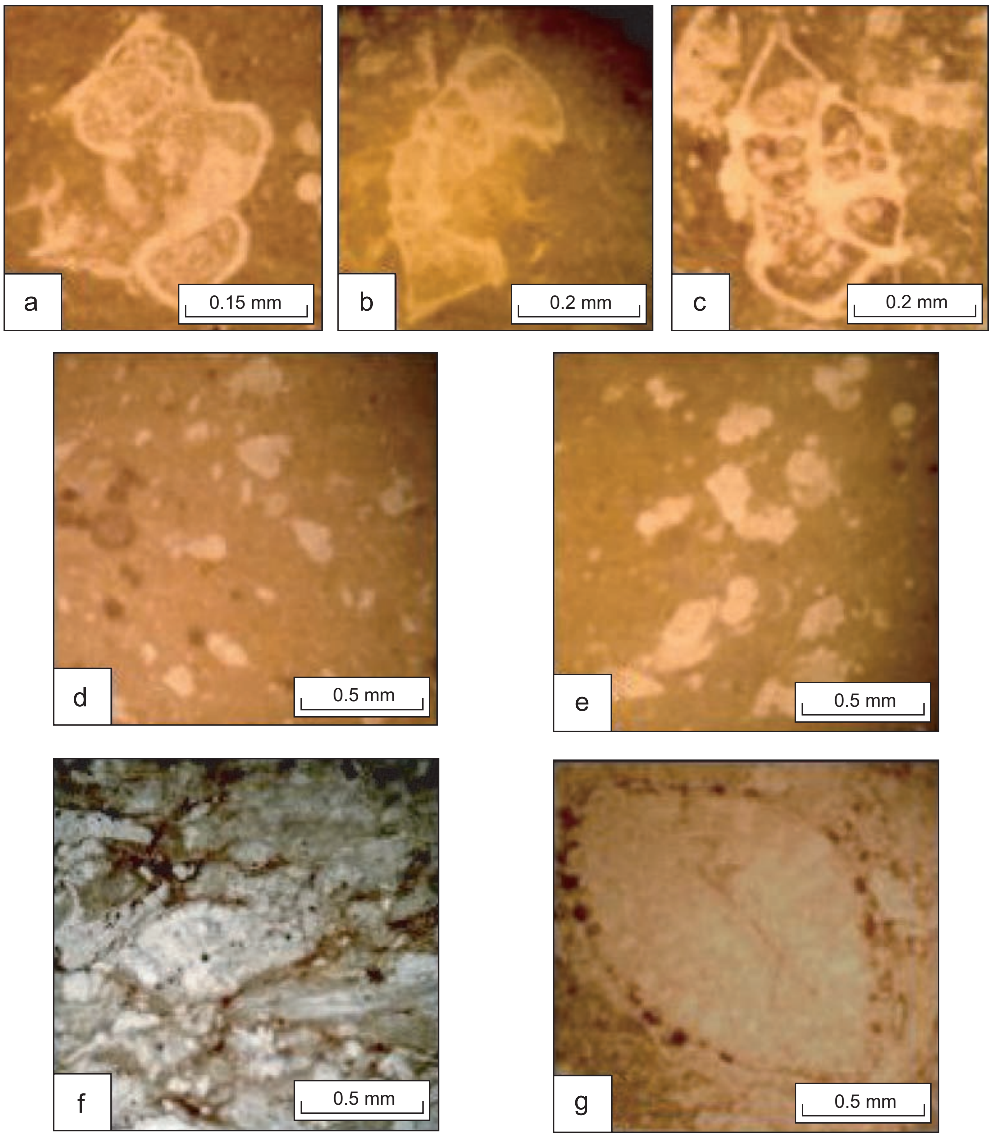

Figure 7:
(a) *Globotruncanita calcarata* (Cushman);
(b) *Globotruncanita stuartiformis* (Dalbiez);
(c) *Globotruncanita stuarti* (De Lapparet);
(d) Submicrofacies A1: Globular chamber planktonic foraminiferal wackestone-mudstone;
(e) Submicrofacies A2: Keeled planktonic foraminiferal wackestone-mudstone;
(f) Microfacies B: Allochems mainly consist of test fragments and sand-size lime lithoclasts;
(g) *Orbitoides media*.

Age Calibration

The lower planktonic foraminiferal zone, the *Globotruncanita calcarata* Zone, is correlated to the standard Late Campanian *Globotruncanita calcarata* Zone of Caron (1985) and Li et al. (1999, 2000) (see age calibration in Gradstein et al., 2004). The upper zone, the *Globotruncanita stuartiformis - Globotruncanita stuarti* Zone represents the interval between the last occurrence of *Globotruncanita calcarata* and the last appearance of *Globotruncana aegyptiaca* in the lowermost part of Shiranish Formation. This is equivalent to the standard *Globotruncanella havanensis* Zone of Caron (1985) and *Globotruncanella subcarinatus* Zone of Li et al. (1999), both of Late Campanian age (Table 1).

Table 1

Formation	Age	Studied Section	Biozone Li et al. (1999)	Age Li et al. (1999)	Standard Zones Caron (1985)
Shiranish	Early Maas-trichtian	↑	*Rugoglobigerina hexacamerata*	71.0 Ma	*Gansserina gansseri*
	Late Campanian	*Globotruncana aegyptiaca*	*Globotruncana aegyptiaca*	72.5 Ma	*Globotruncana aegyptiaca*
Bekhme		*Globotruncanita stuartiformis - Globotruncanita stuarti*	*Globotruncella subcarinatus*	74.0 Ma	*Globotruncanella havanensis*
		Globotruncanita calcarata	*Globotruncanita calcarata*	74.8 Ma	*Globotruncanita calcarata*

MICROFACIES AND DEPOSITIONAL ENVIRONMENT

The Bekhme Formation is comprised of three microfacies denoted as A, B and C, and four submicrofacies (A1, A2, C1 and C2). The biotic content and their alternation reflect the paleoecology and bathymetry.

Microfacies A: Planktonic Foraminiferal Lime Wackestone-Mudstone

Microfacies A is a pale brown, thin- to medium-bedded, marly limestone and shaly limestone, and is the most widespread. Allochems range between 1–40% of the total area. Planktonic foraminifera are the main allochems in addition to fragments of planktonic foraminifera, ostracods, iron oxides and locally, glauconite. Two main types of planktonic foraminiferal assemblages are recognized:

(1) a globular chamber planktonic foraminifera assemblage, which indicate a warm shallow-water carbonate platform (epicontinental sea fauna) (Leicke, 1987); and
(2) a keeled planktonic foraminifera assemblage; keeled morphotype species are rarely found in shelf environments (Leicke, 1987).

Generally the microfacies indicates middle shelf to upper bathyal and it can be correlated with SMF3 of facies zone 3 (Flugel, 1982). Accordingly the ratio between the two main types of planktonic assemblages is used to divide the microfacies into two submicrofacies, A1 and A2.

Submicrofacies A1: Globular Chamber Planktonic Foraminiferal Wackestone-Mudstone

The allochems mainly consist of planktonic foraminifera; their percentage reaches up to 40% of the total allochem content. Foraminifera are dominated by globular chamber forms (Figure 7d) such as *Heterohelix, Pseudogumbelina, Pseudotextularia, Rugoglobigerina* and *Globtruncanella;* their percentage reaches up to 70% of the planktonic foraminiferal population. According to paleontological lines of evidence, the depositional environment of this submicrofacies is middle- to outer-shelf, with water depths ranging between 50–150 m (Leicke, 1987; Gibson, 1989). Water depths probably reached into the middle shelf (where *Heterohelix* species increase relative to *Globigerinelloides* species). The increasing ratio of *Heterohelix* to *Globigerinelloides* species indicates an environment nearer to the shoreline (Leicke, 1987).

Submicrofacies A2: Keeled Planktonic Foraminiferal Wackestone-Mudstone

The keeled forms of planktonic foraminifera represent the main allochems in this submicrofacies (Figure 7e), their percentage reaches 80% of the planktonic foraminifera population. Generally the assemblage includes *Globotruncana* and *Globotruncanita;* these taxa are easily observed and have a normal size. They are believed to have been the deepest-dwelling Late Cretaceous planktonic foraminifera (Sliter, 1972; Leicke, 1987; Koutsoukos and Hart, 1990). The planktonic foraminifera are packed into laminae, which usually resulted from deep currents that winnowed the tests of planktonic foraminifera. We observed an increase in the ratio of keeled/globular planktonic foraminifera and test sizes. The depositional environment of this submicrofacies is considered to be outer-shelf to upper-bathyal with water depths ranging from 100–250 m.

Microfacies B: Orbitoidal Lime Packstone

This microfacies is typically a hard brownish thick- to thin-bedded limestone, often alternating with marly limestone in the lower part of the Bekhme Formation. The allochems mainly consist of test fragments in addition to sand-size lime lithoclasts (Figure 7f). The biotic components include *Orbitoides* (especially *Orbitoides media* (Figure 7g), *Lepidoorbitoides*, rotaliids, small planktonic foraminifera and ostracods. Other bioclasts are echinoids, rudists and red algae. Micrite cement fills the porosity and some small vugs between the allochems, whilst blocky calcite cement may also fill vugs. Sand-size grains of glauconite are scattered throughout the matrix.

The presence of shallow-water bioclasts indicates that the facies was affected by storms and other currents, which may transport the shallow-water sediment into a deeper, sub-wavebase part of the basin (Allen, 1984). The paleontological and lithological lines of evidence indicate a middle-shelf depositional environment for this microfacies.

Microfacies C: Lime Conglomerate-Breccia

This microfacies includes different sizes of carbonate lithoclasts in addition to carbonate matrix, which consists of millimetric-size lithoclasts and benthonic forams represented by orbitoids, echinoderm fragment and red algae. According to the shape, density and origin of the pebbles, the depositional setting of the lime conglomerate-breccia microfacies can be divided into submicrofacies C1 and C2.

Submicrofacies C1: Intra-formational Conglomerate-Breccia

The submicrofacies consists of subrounded to subangular pebbles ranging in size between a few centimeters to several tens of centimeters. Generally they show sharp edges and sometimes the edges appear rounded to subrounded (Figures 8 and 9). The evidence indicates that the submicrofacies was deposited in the middle-shelf as lowstand deposits. The evidence includes the distribution of the submicrofacies, the types of carbonate lithoclast (lime mudstone-wackestone) admixed with matrix content bioclasts (including larger forams, miliolids and echinoderms) and lithoclast coated by iron oxide filament that acted as cement.

Submicrofacies C2: Flat Pebble Conglomerate

The submicrofacies consists of flat pebbles having shapes ranging from tabular-ovoid to lenticular, up to a maximum length of 30 cm (Figure 10). Millimetric length clasts are present within the matrix, whilst the lithology of the flat pebbles consists of lime mudstone-wackestone, probably of an original shallow-marine environment. The matrix consists of large benthonic foraminifera such as orbitoids,

Figure 8: Intraformational conglomerate with small scale clasts, at the base of the section. The rod is approximately 5 cm.

Figure 9: Intra-formational conglomerate with large scale clasts, at interval 36–43 m. The geological hammer is approximately 30 cm.

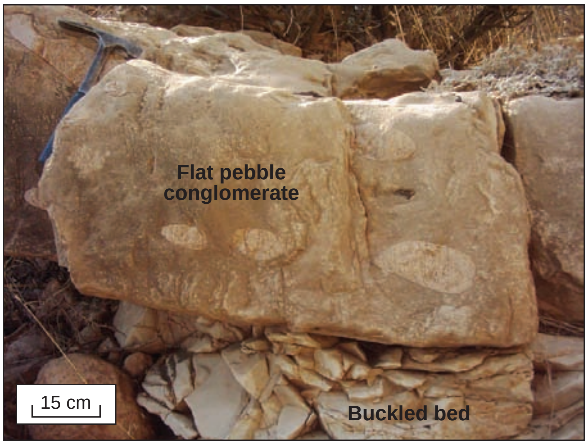

Figure 10: Flat pebble conglomerate and buckled bed, at thickness 34 m.

Figure 11: Buckled bed as mounded structure of debris flow, at thickness 42.5 m. Geological hammer shown for scale.

also with echinoderms and red algae and rare planktonic forams. Spary calcite cement filled vugs and fracture, whilst micrite cement bounded allochems. Buckled beds are also associated with flat pebble conglomerate beds; these appear as mounded structures with snouts that are similar to debris flow (Figure 11). Flat pebble conglomerates are generally thought to be deposited in the middle of the shelf environment below storm wave-base (Myrow et al., 2004).

Figure 12: Hardground showing dwelling borings on the upper contact of the Bekhme Formation.

The formation of buckled beds and flat pebble beds resulted from the failure of the lime mudstone-wackestone of the shoreface during storms and its subsequent downslope movement to the offshore. Mixing of benthonic foraminifera, red algae and sand-sized echinoderm debris, and the disarticulation of clasts in buckled beds, may lead to mass flow and deposition of a flat pebble conglomerate in the deeper part of the middle shelf (Myrow et al., 2004). After the accumulation of storm deposits, a thin bed of limestone was slowly deposited in a low-energy environment, which allowed benthonic fauna to bore into the upper surface of the bed forming a hardground surface (Figures 12 and 13).

SEQUENCE STRATIGRAPHY

Our analyses interpreted five depositional sequences, designated Bekhme Sequences 1 to 5 (Figure 14). The sequences, which vary in thickness from 6 to 26 m, are interpreted in terms of sequence boundaries (SB), lowstand systems tracts (LST), transgressive surfaces (TS) and systems tracts (TST), maximum flooding surfaces (MFS) or intervals (MFI) and highstand systems tracts (HST).

Bekhme Sequence 1

The sequence, 6 m (19.7 ft) thick, begins with a 1-m-thick (3.28 ft) bed of intra-formational conglomerate (submicrofacies C1) that are considered as the LST deposits. Lithoclasts reach up to several centimeters in diameter (Figure 8). The overlying TST and MFS are interpreted within the marly limestone of submicrofaces A1. At 4 m (13 ft) above the section base, the marly limestones pass-up into shallower-

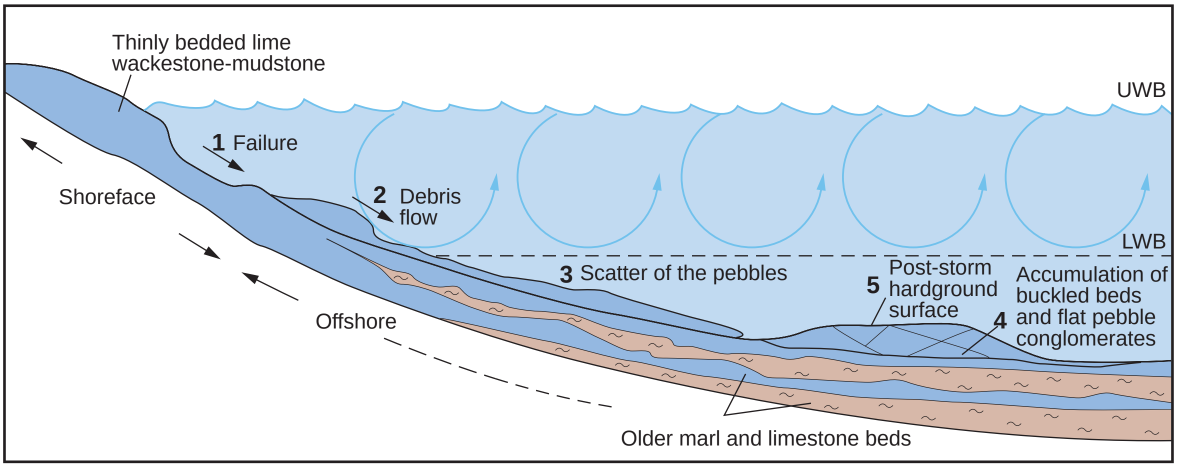

Figure 13: Model for the formational stages of the flat pebble conglomerate along a wave- and storm-dominated carbonate shoreline (modified after Myrow et al., 2004).

water limestone and marl of the same submicrofacies (A1) that represent the beginning of the HST. A 1-m-thick bed of microfacies B (orbitoidal lime packstone) terminated HST deposition. The lower sequence boundary is interpreted as a Type-1 SB, whereas the upper one is Type-2.

Bekhme Sequence 2

The sequence is 16 m (52.5 ft) thick. It began with the deposition of marly limestone submicrofacies A1 reflecting the TST. The MFI is represented by a 1.0-m-thick bed (3.28 ft) of submicrofacies A2. It is overlain by alternating beds of marly limestone, limestone and shale (submicrofacies A1) that are interpreted as the HST, and a capping limestone bed (microfacies B). Both the lower and upper contacts are interpreted as Type-2 SB.

Bekhme Sequence 3

The sequence is 15 m (49 ft) thick and consists of marl and shale beds alternating with thin hard limestone beds (submicrofacies A1). The TST is interpreted by an upward increase in the planktonic foraminiferal percentage that typically implies increasing water depth (Gibson, 1989). In the middle of the sequence concentrations of planktonic foraminifera indicate the position of the MFS. It is followed by a decreasing percentage of planktonic forams up through the HST. The lower contact is interpreted as a Type-2 SB, while the upper contact as a Type-1 SB.

Bekhme Sequence S-4

The sequence is 26 m (85.3 ft) thick. It began with the deposition of a 6-m-thick (19.7 ft) intra-formational conglomerate (submicrofacies C2), which is assigned to the LST. The overlying marl of submicrofacies A1 is considered to represent the TST deposits. The MFI is correlated to a 1-m-thick limestone bed (submicrofacies A2). The HST is represented by a repetition of thick limestone and thin shale beds (submicrofacies A1). The lower and upper boundaries of the sequence are sharp and are interpreted as two Type-1 SB.

Bekhme Sequence S-5

Deposition of this sequence started with an 11-m-thick (36 ft) flat pebble conglomerate unit (submicrofacies C2), at the top of which are two bored hardground layers. These layers mark the upper boundary of the Bekhme Formation. The overlying shale and marl beds belong to the Shiranish Formation and represent the transgressive deposit of the fifth and final sequence.

DISCUSSION AND CONCLUSIONS

Based on biostratigraphic analysis, the 75-m-thick studied outcrop section of the Bekhme Formation was interpreted to be of Late Campanian age. The microfacies analysis of the section identified five

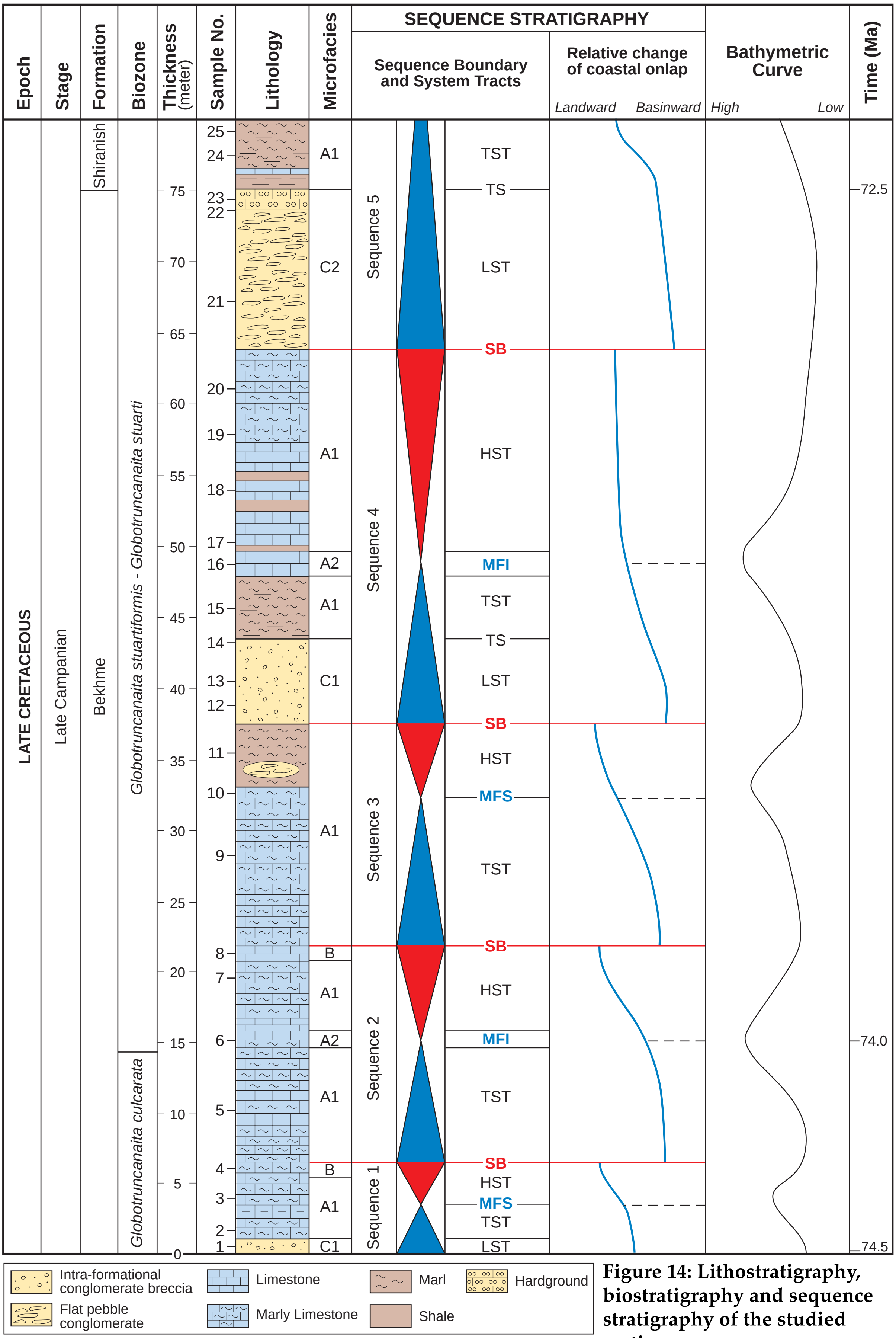

Figure 14: Lithostratigraphy, biostratigraphy and sequence stratigraphy of the studied section.

depositional sequences ranging in thickness from 6 to 26 m (Figure 14). These sequences may be of fourth-order (c. 400,000 years) thus suggesting the entire Bekhme at this location may represent a third-order sequence that was deposited in a period of about 2 million years.

The biostratigraphic calibration of the studied section (*calcarata* and *havanensis* Zones of the planktonic foraminiferal standard (Caron 1985; age calibration as in Gradstein et al., 2004), makes correlation with the Arabian Plate sequence stratigraphic framework of Sharland et al. (2001, 2004) problematic.

K170 MFS of Sharland et al. (2001) lies in the *ventricosa* planktonic foraminifera, which is slightly older than the section studied here (Figure 2). These authors considered that K170 MFS lies in the basal part of the Bekhme Formation, which cannot be demonstrated from our section, although our section is incomplete. Although not formally defined, Sharland et al. (2001) also mention a K175 surface that they tentatively placed in the basal Maastrichtian part of the Shiranish Formation. The third-order MFS that we position in Bekhme Sequence 3 might, with better understanding of the biostratigraphic calibration of K175, equate with this MFS, or it might be a surface intermediate between K170 and K175.

The Bekhme-Aqra and Shiranish formations may be regionally correlated to the Aruma Formation in the outcrops of central Saudi Arabia. In central Saudi Arabia, the Aruma Formation unconformably overlies the middle Cretaceous Wasia Formation and was divided into the lower Khanasir Member, middle Hajajah Member and upper Lina Member. The ages of the Khanasir and Hajajah members are Late Campanian and Maastrichtian (Y.-M. Le Nindre et al., written communication *in* Al-Husseini and Matthews, 2005), whereas the Lina Member is dated as Paleocene (Philip et al., 2002). Philip et al. (2002) interpreted the lower Khanasir Member as one third-order sequence, and the Hajajah as two more, all of which contain several fourth-order sequences.

It therefore seems possible to correlate the Bekhme third-order sequence to the lower Khanaser third-order sequence. In this correlation the Shiranish Formation above the Bekhme Formation would correlate to the Hajajah sequence. Although these correlations are very tentative, they suggest that the northern Arabian Platform was regionally flooded in Late Campanian times.

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ABOUT THE AUTHORS

Majid M. Al-Mutwali *is a Professor in the Geological Department at the University of Mosul, Iraq. He holds a BSc in Geology from the same university, and gained MSc and PhD degrees in Stratigraphy and Paleontology from Mosul University in 1983 and 1992, respectively. Majid is interested in the study of micropaleontology (foraminifera) and sequence stratigraphy of Cretaceous and Tertiary rocks of Iraq.*

mmutwali2006@yahoo.com

Nabil Y. Al-Banna *obtained a BSc in Geology from Mosul University, Iraq, in 1978 and received an MSc in Sedimentology (Clastic rocks) and a PhD in Sedimentology (Carbonate rocks) from Mosul University in 1983 and 1997, respectively. Between 1983 and 1998 Nabil worked as a Geologist in the Underground Storage Team of the Iraq Oil Company. In 1999 he moved to Mosul University as a Lecturer at the Dams and Water Resource Research Center. Since 2000 Nabil's main research interests are in sedimentology and sequence stratigraphy of the Mesozoic and Cenozoic.*

n_albanna2005@yahoo.com

Jamal S. Al-Ghrear *gained a BSc in Geology from Mosul University, Iraq, in 1983. He received an MSc in Igneous Petrology and PhD in Sedimentology from Mosul University in 1983 and 2001, respectively. Jamal is presently a Lecturer in the Geological Department of Mosul University.*

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