Biostratigraphy and palaeoceanography of the early Turonian–early Maastrichtian planktonic foraminifera of NE Iraq

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ABSTRACT – The Upper Cretaceous Kometan and Shiranish formations of the Kurdistan region, NE Iraq, yield diverse planktonic foraminiferal assemblages, with a total of 93 species, which enable recognition of nine biozones and two subzones spanning the early Turonian to late early Maastrichtian. Sequential changes in planktonic foraminiferal assemblages map discrete intervals within the Kometan and Shiranish formations that suggest dominantly warm, nutrient-poor marine surface and near-surface conditions during the mid-Turonian to late Coniacian, latest Santonian, and late Campanian, and cooler more nutrient-rich surface and near-surface waters in the early Turonian, early to late Santonian, early Campanian and early Maastrichtian. These intervals appear to correlate with changes in water masses from other regions of the Cretaceous palaeotropics, and with a phase of global, early Maastrichtian climate cooling. The major intra-Campanian truncation surface between the Kometan and Shiranish formations, recognized from the foraminiferal biostratigraphy, represents a lowstand that appears to equate with regional tectonics and ophiolite obduction across the NE margin of the Arabian Plate.

KEYWORDS: biostratigraphy, palaeoceanography, Late Cretaceous, planktonic foraminifera, Iraq

INTRODUCTION
The evolution of planktonic foraminifera from the Turonian to the early Maastrichtian is characterized by increasing species richness and morphological complexity (Hart, 1999; Premoli Silva & Sliter, 1999). This overall trend shows a short period of rapid diversification in the Turonian with the appearance of complex morphotypes (marginotruncanids), followed by a longer period of stasis interrupted in the Santonian by the disappearance of marginotruncanids and the diversification of another group of morphologically complex taxa, the globotruncanids (Petrizzo, 2002). The globotruncanids reached their maximum species diversity in the late Campanian–early Maastrichtian (Premoli Silva & Sliter, 1999).

To analyse these evolutionary patterns in an Arabian context, the early Turonian to early Maastrichtian planktonic foraminiferal assemblages from two localities in the Kurdistan region, NE Iraq (Fig. 1) have been investigated. The assemblages have been quantified in terms of the taxonomic composition and abundance of planktonic foraminifera to establish a precise planktonic foraminiferal biozonation and to identify fluctuations in diversity and abundance of major morphotypes as a response to environmental change. This paper presents a revised and refined planktonic foraminiferal biozonation for the early Turonian to early Maastrichtian interval of NE Iraq and recognizes palaeontological changes that suggest warmer more nutrient-poor marine surface conditions during the mid-Turonian to late Coniacian, latest Santonian, and late Campanian, and cooler more nutrient-rich surface waters in the early Turonian, early to late Santonian, early Campanian and early Maastrichtian.

MATERIALS AND METHODS
Two sections, at Dokan (35°56′15″N, 44°57′21″E) and Azmer (35°37′30″N, 45°31′45″E; see Fig. 1), were chosen for foraminiferal analysis: these sections present near-complete Upper Cretaceous successions of rocks (Fig. 1). The Kometan and Shiranish formations are the most widespread lithostratigraphic units of the early Turonian–early Maastrichtian-aged succession in NE Iraq and contain rich and diverse planktonic foraminiferal assemblages that can be used for high-resolution biostratigraphy and to examine regional palaeoceanographic change (Fig. 2).

Some 411 samples, spaced c. 0.5 to 2 m apart, have been collected from the two formations. For the samples from the Kometan Formation, thin section analysis was used for planktonic foraminiferal identifications. Morphological preservation of these planktonic foraminifera is good, although the tests are commonly recrystallized and filled with calcite. The position of apertures and the presence of supplementary and accessory structures that can be used to help distinguish genera are not identifiable in thin sections (Caron, 1985). However, most of the diagnostic criteria, including the size and the shape of the test, thickness of the wall, size, shape, number and arrangement of chambers, and ornamentation such as ridges, spines, and the position and number of keels, can be recognized in axial and subaxial sections passing through or parallel to the axis of coiling (Sliter, 1989).

All samples from the Kometan Formation were thin sections. For the samples from the Shiranish Formation, both thin sections and a freeze–thaw method for disaggregating the rock have been used (Mogaddam, 2002; Jaff et al., 2014). Approximately 200–300 g of each friable sample was repeatedly frozen and thawed in
a supersaturated solution of sodium sulphate decahydrate until the rock disaggregated. The disaggregated sediments were then washed thoroughly through a 63 µm sieve and the residues separated by filtration and dried overnight with an oven temperature of 50°C. Dried residues were sorted using sieves from 500 µm to 63 µm. All foraminifera were picked and studied from the residue in the 63–300 µm size fraction, but planktonic foraminifera were not recorded in the >300 µm sieve. The foraminifera were imaged using a Hitachi S-3600N scanning electron microscope (SEM) at the University of Leicester, UK. Identifications of foraminifera largely follow the work of Smith & Pessagno (1973), Robaszynski et al. (1984), Caron (1985), Sliter (1989), Nederbragt (1989, 1991), Premoli Silva & Sliter (1994), Premoli Silva & Verga (2004) and Petrizzo et al. (2011). The specimens illustrated in this paper are deposited in the collections of the British Geological Survey, Keyworth, Nottingham, UK.

LITHOSTRATIGRAPHY
The Upper Cretaceous (early Turonian to early Maastrichtian age) strata of NE Iraq comprise two marine-deposited formations: the pelagic limestone of the Kometan Formation (early Turonian–early Campanian) and the marly limestones and marlstones of the Shiranish Formation (late Campanian–early Maastrichtian).

Kometan Formation
The type section of the Kometan Formation was first described in an unpublished report by H. V. Dunnington (1953, *fide* Van Bellen *et al.*, [1959] 2005) from the village of Kometan near Endezeh in NE Iraq. At Endezeh, the formation comprises some 36 m of light grey, thinly bedded, globigerinal–oligosteginal limestone, locally silicified, with chert nodules, and glauconite especially at the base of the formation. According to a number of authors (e.g. Kaddouri, 1982; Al-Jassim *et al.*, 1989; Al-Sheikhly *et al.*, 1989; Abawi & Hammoudi, 1997; Hammoudi & Abawi, 2006; Haddad & Amin, 2007) the age of the Kometan Formation is late Turonian at its base and extends to the early Campanian at the top. The Kometan Formation is interpreted to be an outer shelf or basinal deposit (Jassim & Goff, 2006), becoming increasingly argillaceous to the west and SW of Iraq. The base of the
Kometan Formation is unconformable on the underlying Balambo and Qamchuqa formations (which are early Cenomanian; Buday, 1980; Van Bellen et al., [1959] 2005; Jassim & Goff, 2006; Ameen & Gharib, 2014; Fig. 2).

The Kometan Formation has thicknesses of approximately 158 and 96.5 m in the Dokan and Azmer areas, respectively. In the Dokan area the formation is composed of well-bedded, light grey or white limestone with common chert nodules (Fig. 3a and d). The top of the Kometan Formation records a local extinction of large ammonites (Fig. 3i and j). This extinction might be related to the termination of pelagic limestone facies and a significant sea-level fall evident from examination of the top of the Kometan Formation. Moreover, the top of the Kometan Formation is extensively bioturbated with Planolites and Thalassinoides, which may indicate a period of slow or non-deposition (Fig. 3f). In the Azmer area the Kometan Formation is composed mainly of light grey, medium-bedded limestone (Fig. 3b): the lower part of the formation is associated with small, centimetre-scale ammonites, but towards the upper part of the formation there is a notable increase in the size of the ammonites, which also become more common. In the Azmer area the formation lacks chert nodules.

Shiranish Formation

The Shiranish Formation was first defined in an unpublished report by F. R. S. Henson (1940, fide Van Bellen et al., [1959] 2005) from the ‘High Folded Zone’ of northern Iraq, near the village of Shiranish Islam, NE of Zakho. The formation in its type section is about 228 m thick, and is informally subdivided into a ‘lower unit’ characterized by alternating marly limestone and calcareous marlstone that is rich in foraminifera, and an ‘upper unit’ that is dominated by blue-coloured marlstone (Aqrawi et al., 2010). According to several authors (Kennedy & Lunn, 2000; Al-Banna, 2010; Aqrawi et al., 2010; Jaff et al., 2014) the age of the Shiranish Formation is late Campanian to Maastrichtian, but it does not extend to the late Maastrichtian (Kassab, 1973; Jaff et al., 2014). The formation in its type area is interpreted to be an outer shelf to basinal deposit (Jassim & Goff, 2006) that unconformably overlies the Kometan Formation, and is succeeded conformably by marine clastic deposits of the Tanjero Formation (which is of late Maastrichtian age; Fig. 2).

The Shiranish Formation is well exposed in the localities studied and is about 260 and 144 m thick in the Dokan and the Azmer areas, respectively. In the Dokan area there is a glauconitic pebbly sandstone bed of around 0.5 m at the base of the ‘lower unit’ that may indicate a very slow rate of deposition or period of non-deposition (Fig. 3g and h). In the Dokan area the uppermost part of the ‘upper unit’ of the Shiranish Formation also develops a massive bed of marly limestone that is about 1 m thick and bears a mass of rudist bivalves near the contact with the overlying Tanjero Formation. This rudist bed is developed only locally and hence is not recognized as a separate member in the Shiranish Formation.
PLANKTONIC FORAMINIFERAL BIOZONATION

Some 93 planktonic foraminifer species belonging to 23 genera have been identified in the Kometan and the Shiranian formations during the present study (Appendix A; Pls 1–5). The stratigraphic distribution of these foraminifera permits the recognition of nine biozones and two subzones in the Upper Cretaceous (early Turonian–early Maastrichtian time interval) succession. Five of the biozones are identified as interval zones (IZ): the Dicarinella primitiva IZ, the Marginotruncana schneegansi PRZ, the Globoturiculina euglypta IZ, the Gansserina gansseri IZ (which can be subdivided into the Pseudoguembelina excolata and Planoglobulina acervulinoidea subzones) and the Contusoturricula contusa IZ. Two biozones are total range zones (TRZ): the Helvetoglobo­truncana helvetica TRZ and the Dicarinella asymetrica TRZ. Two biozones are partial range zones (PRZ): the Marginotruncana schneegansi PRZ and the Globotruncanita eleva­ta PRZ. The definitions of the biozones follow Caron (1985), Sliter (1989), Premoli Silva & Sliter (1994), Robaszynski & Caron (1995), Premoli Silva & Verga (2004) and Sari (2006, 2009).

Helvetoglobo­truncana helvetica total range zone, early Turonian

This biozone is defined by the lowest and highest occurrences (LO, HO) of Helvetoglobo­truncana helvetica (see Dalbiez, 1955) and represents the oldest foraminiferal biozone identified in the lower part of the pelagic limestones of the Kometan Formation. The lower limit of this biozone in NE Iraq coincides with the Lo of the Dicarinella primitiva zone and the Lo of the Lo of the Marginotruncana schneegansi zone (Fig. 5). The diversification of Marginotruncana and the presence of large, compressed marginotruncanids, such as Marginotruncana undulata (recorded at Azmer), also fall within this biozone (Sliter, 1989). Other commonly associated planktonic foraminifera are shown in Figures 6 and 7.

Dicarinella primitiva interval zone, latest Turonian

This biozone is an interval zone between the LO of Dicarinella primitiva and the LO of Dicarinella concavata (see Caron, 1978). The D. primitiva biozone was not differentiated by Ogg & Hinnov (2012), who instead recorded this interval as the lower part of the Dicarinella concavata biozone. However, in the NE Iraq succession, D. primitiva provides a useful subdivision of the late Turonian interval that has also been recognized as a discrete biozone in Africa and Iran (Salaj, 1997, fig. 3; Gebhardt, 2004, fig. 3; Elamri et al., 2014; Vahidinia et al., 2014). Sample numbers AK-9 to AK-12 indicate a thickness of approximately 5.5 m for the interval of the D. primitiva biozone in the Azmer section, whilst sample numbers DK-1 to DK-3 suggest a thickness of about 6 m in the Dokan section (Fig. 4). Although several authors (e.g. Premoli Silva & Boersma, 1977; Caron, 1978, 1985; Robaszynski & Caron, 1979; Wonders, 1980; Marks, 1984a, b; Abdel-Kireem et al., 1995; Abawi & Mahmood, 2005; Fig. 5) have equated the LO of D. primitiva with the base of the Coniacian, later work shows that this taxon first occurs below the Turonian–Coniacian boundary (Robaszynski et al., 1990; Robaszynski & Caron, 1995; Salaj, 1997; Gebhardt, 2004, fig. 3; Premoli Silva & Verga, 2004; Gebhardt, 2008). Indeed, Robaszynski & Caron (1995) recorded the simultaneous occurrence of D. primitiva with the late Turonian ammonite Subprionocyclus neptuni (Geinitz, 1849). Most recently Elamri et al. (2014) recorded D. primitiva in northern Tunisia in the late Turonian–Maastrichtian planktonic foraminifera of NE Iraq.

Marginotruncana schneegansi partial range zone, mid-late Turonian

This is a partial range zone between the HO of Helvetoglobo­truncana helvetica and the LO of Dicarinella primitiva (see Dalbiez, 1955). The biozone is represented through some 7 m of strata in the Azmer section, from sample numbers AK-4 to AK-8, and in the Dokan section through about 4 m, from sample numbers DK-05 to DK-07 (Fig. 4). Many previous studies have restricted the earliest occurrence of M. schneegansi to the late Turonian (Premoli Silva & Bolli, 1973; Premoli Silva & Boersma, 1977; Caron, 1978, 1985; Salaj, 1980, 1997; Marks, 1984a; Robaszynski et al., 1984; Abdel-Kireem et al., 1995). However, Robaszynski & Caron (1995) recognized the full biostratigraphical range of this species to incorporate the mid- to late Turonian interval (see also Gebhardt, 2004, fig. 3; Ogg & Hinnov, 2012, fig. 27.6; Kochhann et al., 2014, herein Fig. 5). The diversification of Marginotruncana and the occurrence of large, compressed marginotruncanids, such as Marginotruncana undulata (recorded at Azmer), also fall within this biozone (Sliter, 1989). Other commonly associated planktonic foraminifera are shown in Figures 6 and 7.

Fig. 3. Field photos of the Kometan and Shiranian formations in the Dokan and the Azmer areas, NE Iraq. (a, b) Well-bedded, medium to thick-bedded pelagic limestone of the Kometan Formation. (c) Chert nodules in the Kometan Formation, showing the long axes of the nodules roughly parallel to bedding. (d) Stylolites running approximately parallel to bedding in the Kometan Formation. (e) Nature of the contact of the Kometan Formation with the overlying Shiranian Formation, Azmer area. The contact can be distinguished in the field by rapid changes of lithology from light-coloured limestone to blue-coloured marlstone and marly limestone. (f) Planolites trace fossil within the uppermost bed of the Kometan Formation, Dokan area, near the contact with the overlying Shiranian Formation. (g) Glauconite (gl) at the base of the Shiranish Formation, Dokan area. (i, j) Large ammonites at the top of the Kometan Formation in the Azmer and Dokan areas, respectively.
Fig 4. Planktonic foraminiferal biozonation for the Kometan Formation in the Kurdistan region, NE Iraq.
Turonian–Maastrichtian planktonic foraminifera of NE Iraq

Turonian, whilst Vahidinia et al. (2014) recorded the LO of *D. primitiva* before the LO of *D. concavata* in NE Iraq and they assigned the level to the late Turonian. The maximum diversification of marginotruncanids, with seven species, is recognized within this biozone (Figs 6 and 7).

**Dicarinella concavata interval zone, early–late Coniacian**

In NE Iraq this biozone is defined as an interval zone between the LO of *Dicarinella concavata* and the LO of *Dicarinella asymetrica* (see Sigal, 1955). The biozone occurs through about 15.5 m in the Azmer section, from sample numbers AK-13 to AK-22, and is represented through approximately 29.5 m in the Dokan section, from sample numbers DK-4 to DK-23 (Fig. 4). Although several authors (e.g. Barr, 1972; Premoli Silva & Bolli, 1973; Premoli Silva & Boersma, 1977; Caron, 1978, 1985; Marks, 1984a; Abdel-Kreem et al., 1995; Mancini et al., 1996; Abawi & Mahmoud, 2005; Sari, 2006, 2009; Farouk & Faris, 2012; Fig. 5) have equated the earliest occurrence of *D. concavata* with the mid-late Coniacian, Premoli Silva & Sliter (1994) recognized the full biostratigraphical range of this species to extend into the late Turonian in Italy (see also Robaszynski & Caron, 1995; Robaszynski, 1998; Premoli Silva & Sliter, 1999; Robaszynski et al., 2000; Bauer et al., 2001; Premoli Silva & Verga, 2004; Babazadeh et al., 2007; Ogg & Hinov, 2012; Kochhann et al., 2014). In Africa, Iran and the Caucasus the earliest occurrence of *D. concavata* has been placed at the base of the Coniacian (Salaj, 1980, 1984, 1987, 1997; Tur, 1996, fig. 2; Gebhardt, 2004, fig. 3; 2008; Vahidinia et al., 2014) and, given the presence of a well-defined *D. primitiva* biozone in the Iraqi succession, the earliest occurrence of *D. concavata* is equated to the base of the Coniacian. The dominant planktonic foraminiferal group in this biozone is the marginotruncanids. The LO of species of the genus *Globotruncana* (*Globotruncana angusticarinata*) also falls within this biozone (Figs 6 and 7).

**Dicarinella asymetrica total range zone, early–late Santonian**

The lower and upper boundaries of this biozone are marked by the LO and HO of *Dicarinella asymetrica* (see Postuma, 1971). The biozone is represented by around 40.5 m of strata in the Azmer section, from sample numbers AK-23 to AK-51, and in the Dokan section it is identifiable through about 70 m, from sample numbers DK-24 to DK-73 (Fig. 4). Although several authors (e.g. Robaszynski et al., 1984, 2000; Caron, 1985; Honigstein et al., 1987; Almogi-Labin et al., 1991; Premoli Silva & Sliter, 1994, 1999; Ayyad et al., 1996; Mancini et al., 1996; Robaszynski, 1998; Özkan-Altiner & Özcân, 1999; Sari, 2006, 2009; Babazadeh et al., 2007; Ogg & Hinov, 2012; Farouk & Faris, 2012) have equated the earliest occurrence of *D. asymetrica* with the mid-Santonian, some recent studies have identified this species from the late Coniacian (Gale et al. 2007; Lamolda et al., 2007). Based on the most recent calibration for the Late Cretaceous planktonic foraminiferal biozonation by Ogg & Hinov (2012, pp. 810–811, fig. 27.6), the first occurrence of the biozonal species is regarded as an approximate indicator for the base of the Santonian (Ogg & Hinov, 2012, p. 805; Elamri et al., 2014; Kochhann et al., 2014; Vahidinia et al., 2014; see also Marks, 1984b, p. 166). Lamolda et al. (2014) used inoceramid bivalves (*Platyceramus undulatoplicatus* Roemer, 1852) to define the base of the Santonian in Olazagutia, northern Spain. The common occurrence of *D. asymetrica* is 1.4 m above this level in that succession. Given the absence of supporting bivalve data in the Iraqi succession, the LO of *D. asymetrica* is taken as the approximate marker for the base of the Santonian. The HO of *D. asymetrica* is used to define the Santonian–Campanian boundary (Marks, 1984b; Caron, 1985; Honigstein et al., 1987; Dowsett, 1989; Gvirtzman et al., 1989; Sliter, 1989; Almogi-Labin et al., 1991; Gale et al., 1995; Ayyad et al., 1996; Mancini et al., 1996; Özkan-Altiner & Özcân, 1999; Sari, 2006, 2009; Babazadeh et al., 2007; Ogg & Hinov, 2012; Elamri & Zaghibb-Turki, 2014; Elamri et al., 2014; Kochhann et al., 2014). Recently, Sageman et al. (2014), based on a set of 40Ar/39Ar, U–Pb and astronomical tuning data from the Cretaceous Niobrara Formation, USA, estimated the Coniacian–Santonian boundary to be at about 86.49 ± 0.44 Ma, close to the interpreted LO of *D. asymetrica* of Ogg & Hinov (2012). Moreover, the HO of *D. asymetrica* is regarded as equivalent to the boundary of the reversed polarity Chron C33r, this magnetic marker being considered for defining the base of the Campanian (Campanian Working Group of the International Commission on Stratigraphy, *ide* Ogg & Hinov, 2012, p. 806). This Chron boundary also coincides with the base of the *Scafiphites leei* III ammonite biozone of the North American Western Interior (Ogg & Hinov, 2012 and references therein; fig. 27.6). Marginotruncanids tend to become rare within this biozone, except for *Marginotruncaneta coronata* and *M. marginata* (Figs 6 and 7). In contrast, some five species of *Globotruncaneta* are recorded towards the top of the biozone where a distinct interval is recognizable, marked by the LO of *G. bulboides* (Figs 6 and 7). In addition, the LO of *Globotruncaneta elevata* and *G. stuartiformis* also fall within this biozone (Figs 6 and 7). The boundary between the *Dicarinella asymetrica* biozone and the succeeding *Globotruncaneta elevata* biozone marks the extinction of many mid-Cretaceous planktonic foraminifer species globally (Sliter, 1989; Petrizzo, 2002; Sari, 2006 2009; Elamri & Zaghibb-Turki, 2014; Elamri et al., 2014; Kochhann et al., 2014). In NE Iraq the local manifestation of this extinction event is the disappearance of *Dicarinella asymetrica*, though a couple of species of *Marginotruncaneta* (*M. coronata*, *M. marginata*) also disappear a little earlier in the succession.

**Globotruncaneta elevata partial range zone, early Campanian**

This is a partial range zone, recognized in NE Iraq from the HO of *Dicarinella asymetrica* to the top of the Kometan Formation, which is marked by its unconformable contact with the overlying Shiranish Formation: the upper boundary represents the major regional intra-Campanian unconformity. The G. elevata biozone is characterized by the dominance and abundance of marginotruncanids and heterohelicids with common benthonic foraminifera, such as *Lenticulina* and *Textularia* (Figs 6 and 7), but most notably by the persistent occurrence of the eponymous zone fossil. The thickness of strata represented by this biozone in the Azmer section is about 22.5 m, from sample numbers AK-52 to AK-67, and in the Dokan section is about 40.5 m, from sample numbers DK-74 to DK-102 (Fig. 4).

Although some authors (e.g. Barr, 1972; Salaj, 1980, 1997; Wonders, 1980; see Fig. 5) have equated the first appearance of
| Age | Barr (1972) | Wonders (1980) | Abdel-Kireem et al. (1995) | Sari (2006, 2009) | Babazadeh et al. (2007) | Abawi & Mahmood (2005) | Ogg & Hinnov (2012) | This study | Datum Markers |
|-----|-------------|----------------|---------------------------|-------------------|------------------------|------------------------|----------------------|-------------|--------------|
|     | Libya       | Mediterranean  | Egypt                      | Turkey            | E. Iran                | N. Iraq                | General              | NE. Iraq    | Disappearance of all foraminifera |
| 66.0| Abathomphalus mayaroensis* | Abathomphalus mayaroensis* | Globotruncanita elevata | Abathomphalus mayaroensis* | Gansserina gansseri | Gansserina gansseri | Gansserina gansseri | P. acervulinoides | L  C. contusa |
| 72.1| Globotruncanita elevata | Globotruncanita elevata | Globotruncanita elevata | Globotruncanita elevata | Hemitrichia primitiva | Dicarinella primitiva | Dicarinella primitiva | D. concavata | L  D. concavata |
| 63.5| Dicarinella concavata | Dicarinella concavata | Dicarinella concavata | Dicarinella concavata | Helvetoglobotruncanita helvetica | Helvetoglobotruncanita helvetica | Helvetoglobotruncanita helvetica | H. helvetica | L  H. helvetica |
| 68.0| Marginotruncanita carinata | Marginotruncanita carinata | Marginotruncanita carinata | Marginotruncanita carinata | Marginotruncanita carinata | Marginotruncanita carinata | Marginotruncanita carinata | Marginotruncanita carinata | L  L  H  L  L  L  H |

*Not studied
G. elevata with different levels within the Santonian in the North African and Mediterranean regions, later work shows that the base of the biozone, as internationally recognized, is coincident with the base of the Campanian (Premoli Silva & Bolli, 1973; Robaszynski et al., 1984, 2000; Dowsett, 1984, 1989; Caron, 1985; Honigstein et al., 1987; Slier, 1989; Almogi-Labin et al., 1991; Abdel-Kireem et al., 1995; Ayyad et al., 1996; Mancini et al., 1996; Robaszynski, 1998; Özkan-Altiner & Özcan, 1999; Chacón et al., 2004; Abawi & Mahmood, 2005; Babazadeh et al., 2007; Li et al., 2011; Farouk & Faris, 2012; Ogg & Hinov, 2012; Elamri & Zaghib-Turki, 2014; Elamri et al., 2014; Kochhann et al., 2014; see Fig. 5).

Globotruncanina aegyptiaca interval zone, late Campanian
This is an interval zone from the LO of the eponymous species to the LO of Gansserina gansseri (see Caron, 1985) and it represents the oldest foraminiferal biozone identified in the lower part of the Shiranish Formation. At the base of the Shiranish Formation there is an unconformity, and the local LO of G. aegyptiaca may not equate to the global LO of this species. The biozone is recognized through some 47.5 m of rock in the Azmer section, from sample numbers DSH-68 to DSH-114 (Fig. 8). Although the base of the biozone can be recognized in the Shiranish Formation in NE Iraq, the top of the biozone is represented through nearly 17.5 and 37.5 m of succession in the Azmer and Dokan sections, respectively (Fig. 8), and represents an equivalent stratigraphical interval to the lower part of the G. gansseri biozone (Figs 8–10). Due to the rare and sporadic occurrence of G. aegyptiaca with the LO of the planktonic foraminifera Rugoglobigerina hexacamerata and R. pennyi which are regarded as markers for the basal Maastrichtian in NE Iraq (Jaff et al., 2014), the eastern Indian Ocean (Zepeda, 1998), the equatorial Pacific IODP (DSDP) site 463 (Li & Keller, 1999), the equatorial Pacific IODP (DSDP) site 463 (Li & Keller, 1999), Egypt (Tantawy et al., 2001; Kassab et al., 2004; Farouk, 2014) and Iran (Beiranvand & Ghasemi-Nejad, 2013). The LO of P. acervulinoides coincides (at a lowermost Maastrichtian level) with the LO of benthonic foraminifer Bolivinoides specimens with 5 lobes on the terminal chamber that marks the basal Maastrichtian in Iraq (Jaff et al., 2014) as well as at the Global Stratotype Section and Point (GSSP) at Tercis, France (Odin & Lamaurelle, 2001).

Gansserina gansseri interval zone, latest Campanian–early Maastrichtian
This is an interval zone from the LO of the eponymous species to the LO of Contusotruncana contusa (see Brönnimann, 1952). The biozone is represented through nearly 43.5 m of strata in the Shiranish Formation in the Azmer section, from sample numbers ASH-34 to ASH-64, and through 103 m in the Dokan section, from sample numbers DSH-68 to DSH-114 (Fig. 8). Although several authors (e.g. Barr, 1972; Premoli Silva & Bolli, 1973; Wonders, 1980; Caron, 1985; Sliter, 1989; Ayyad et al., 1996; Mancini et al., 1996; Li & Keller, 1998a, b; Li et al., 1999) identified the first appearance of this biozonal species within the Maastrichtian, other authors, including more recent studies, have documented a first occurrence in the latest Campanian (Premoli Silva & Sliter, 1994, 1999; Robaszynski, 1998; Özkan-Altiner & Özcan, 1999; Chacón et al., 2004; Abawi & Mahmood, 2005; Babazadeh et al., 2007; Li et al., 2011; Farouk & Faris, 2012; Ogg & Hinov, 2012; Elamri & Zaghib-Turki, 2014; Elamri et al., 2014; Kochhann et al., 2014; see Fig. 5).

Contusotruncana contusa interval zone, late early Maastrichtian
This is an interval zone defined by the LO of Contusotruncana contusa at its base. Although the base of the biozone can be recognized in the Shiranish Formation in NE Iraq, the top of the biozone cannot be identified due to the sudden disappearance of planktonic foraminifera at the top of the succession. The interval

Fig. 5. Correlation of the Upper Cretaceous planktonic foraminiferal biozonation of the Kurdistan region, NE Iraq, with the biozonation for other regions of the Middle East, North Africa and the Mediterranean. The earlier definitions of some biozones (see text) led to significant differences in the chronostratigraphic position of the base of the H. helvetica, M. schneegansi, D. primitiva, D. concavata, D. asymetrica and G. gansseri biozones in some schemes. Therefore, the apparent diachronity of these zonal boundaries is largely an artefact of the use of different correlations in different studies. The biozonation of this study is correlated with the standard biozonation of Oggi & Hinnov (2012). The dashed lines between the D. primitiva and D. concavata biozones, and between the D. concavata and D. asymetrica biozones represents uncertainty regarding the recognition of the Turonian/Coniacian and Coniacian/Santonian boundaries. Identified planktonic foraminiferal biozones indicate the presence of a significant stratigraphic hiatus between the Kometan and Shiranish formations corresponding to the mid-Campanian to early late Campanian.

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| Early Cretaceous | lower-upper Turonian | lower-upper Coniacian | lower-upper Santonian | lower Campanian | upper Campanian | Age | Formation | Sample number | Lithology |
|------------------|----------------------|-----------------------|-----------------------|----------------|----------------|-----|-----------|--------------|-----------|
| Gamchuqa | No Samples | | | | | | | | |
| | | | | | | | | | |
| Interval not studied | H. moremani | H. globulosa | D. algeriana | W. aprica | M. planispira | W. paradubia | W. archaeoetacea | W. baltica | W. inornata | M. delrioensis | M. renzi | M. schneegansi | M. sigali | M. brittonensis | M. coronata | M. marginata | G. ultramicrus | D. primitiva | M. holmdelensis | D. concavata | D. asymetrica | G. elevata | H. aegyptica | C. fornicata | A. blowi | D. asymetrica | A. linneiana | H. reussi | G. prairiehillensis | A. bulloides | G. arca | G. lapparenti | G. elevata | G. stuartiformis |
| Limestone | Dolomitc limestone | Marlstone | Marly limestone | Glaucocitic pebbly sandstone | Unconformity | H. helvetica | D. concavata | D. asymetrica | G. elevata | Planktonic foraminifera |

Fig. 6. Stratigraphic ranges of planktonic foraminifera for the lower Turonian to lower Campanian Kometan Formation in the Dokan section. For ranges in the overlying Shiranish Formation, see Figure 9.
Turonian–Maastrichtian planktonic foraminifera of NE Iraq

| Age            | Formation | No Samples | Sample number |
|----------------|-----------|------------|---------------|
| Early Cretaceous | Kometan   |            |               |
| lower-upper Turonian |          | ASH-01     |               |
| lower-upper Coniacian |        | ASH-02     |               |
| lower-upper Santonian |      | ASH-03     |               |
| lower Campanian | Shiranish | ASH-04     |               |
| upper Campanian |           | ASH-05     |               |

**Lithology**

- Marlstone
- Thick bedded Limestone
- Thin bedded Limestone
- Marly limestone
- Unconformity

**Biozones**

- *H. h. helvetica*
- *H. m. morremani*
- *H. g. globulosa*
- *W. a. archaeocretacea*
- *W. p. paradubia*
- *D. c. canaliculata*
- *M. s. planispina*
- *W. p. planispina*
- *W. baltica*
- *W. i. inornata*
- *M. s. sinuosa*
- *M. s. coronata*
- *M. s. marginata*
- *D. p. primitiva*
- *W. b. brittonensis*
- *G. u. ultramicrus*
- *D. c. concavata*
- *G. a. angusticarinata*
- *G. a. praehilliensis*
- *H. r. reussi*
- *D. a. asymetrica*
- *C. f. formicata*
- *G. a. inaeiana*
- *H. p. planata*
- *L. p. pulchra*
- *G. b. bulloides*
- *G. b. arca*
- *G. b. lapparenti*
- *G. b. stuartiformis*

**Systematic Table**

| Sample number | AK-1 | AK-3 | AK-6 | AK-9 | AK-12 | AK-23 | AK-27 | AK-31 | AK-35 | AK-39 | AK-43 | AK-47 | AK-51 | AK-67 |
|---------------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Biozones      |      |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. a. aegyptiaca* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *H. m. helvetica* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *H. m. morremani* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *H. m. globulosa* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *W. a. archaeocretacea* |   |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *W. p. paradubia* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *D. c. canaliculata* |   |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *M. s. planispina* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *W. p. planispina* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *W. baltica* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *W. i. inornata* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *M. s. sinuosa* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *M. s. coronata* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *M. s. marginata* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *D. p. primitiva* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *W. b. brittonensis* |   |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. u. ultramicrus* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *D. c. concavata* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. a. angusticarinata* |   |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. a. praehilliensis* |   |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *H. r. reussi* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *D. a. asymetrica* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *C. f. formicata* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. a. inaeiana* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *H. p. planata* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *L. p. pulchra* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. b. bulloides* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. b. arca* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. b. lapparenti* |     |      |      |      |       |       |       |       |       |       |       |       |       |       |
| *G. b. stuartiformis* |   |      |      |      |       |       |       |       |       |       |       |       |       |       |

Fig. 7. Stratigraphic ranges of planktonic foraminifera for the lower Turonian to lower Campanian Kometan Formation in the Azmer section. For ranges in the overlying Shiranish Formation, see Figure 10.
is also associated with the LO of *Contusotruncana walfischensis* and *Rugoglobigerina scotti* (Figs 9 and 10). *Contusotruncana contusa* was not used either by Huber et al. (2008) or Ogg & Hinov (2012) to discriminate a discrete biozone. Instead, they recognized a Pseudoguembelina palpebra biozone (Ogg & Hinov, 2012, fig. 27.6) for the interval succeeding the G. gansseri biozone. Given occurrences of *P. palpebra* Brönnimann & Brown, 1953 in sedimentary deposits of latest Maastrichtian age in Tunisia (Li & Keller, 1998a, b; Li et al., 1999), the South Atlantic (Li & Keller 1998a, b; Li et al. 1999), Madagascar (Abramovich et al., 2002), Egypt (Obaidalla, 2005) and the USA (Abramovich et al., 2011), it is probable that the species has a delayed occurrence in the Iraqi succession, and this may be above the level of termination of foraminifer-bearing assemblages in the Shiran Formation; elsewhere in NE Iraq there are unpublished records of *P. palpebra* that require further investigation. According to Ogg & Hinov (2012), *Racemiguembelina fructicosa* (Egger, 1899) is a good indicator for the beginning of the late Maastrichtian, but is never found in the Shiran Formation, although it is present in the overlying upper Maastrichtian Tanjero Formation (Sharbazheri, 2010; Ismael et al., 2011). On this basis, the *C. contusa* biozone is considered older than the late Maastrichtian. In addition, Pérez-Rodriguez et al. (2012) recorded the LO of *C. contusa* in the *P. palpebra* biozone; Ogg & Hinov (2012, p. 1102) also show the LO of *C. contusa* within the *P. palpebra* biozone. This suggests that the *C. contusa* biozone in NE Iraq is probably equivalent, at least in part, to the *P. palpebra* biozone recorded by Ogg & Hinov (2012).

The *C. contusa* biozone is represented through nearly 10 m of fossiliferous strata in the Dokan section, from sample numbers DSH-115 to DSH-120 (Fig. 8); the interval cannot be recognized in the Azmer section, probably because of lithofacies changes associated with marine shallowing. *Contusotruncana contusa* occurs frequently, but seems to be limited to the late early Campanian *Contusotruncana contusa* associated with marine shallowing.

DSH-115 to DSH-120 (Fig. 8); the interval cannot be recognized fossiliferous strata in the Dokan section, from sample numbers Hinnov (2012).

That the *C. contusa* biozone in NE Iraq is probably equivalent, at least in part, to the *P. palpebra* biozone, and that the species has a delayed occurrence in the Iraqi succession, and this may be above the level of termination of foraminifer-bearing assemblages in the Shiran Formation; elsewhere in NE Iraq there are unpublished records of *P. palpebra* that require further investigation. According to Ogg & Hinov (2012), *Racemiguembelina fructicosa* (Egger, 1899) is a good indicator for the beginning of the late Maastrichtian, but is never found in the Shiran Formation, although it is present in the overlying upper Maastrichtian Tanjero Formation (Sharbazheri, 2010; Ismael et al., 2011). On this basis, the *C. contusa* biozone is considered older than the late Maastrichtian. In addition, Pérez-Rodriguez et al. (2012) recorded the LO of *C. contusa* in the *P. palpebra* biozone; Ogg & Hinov (2012, p. 1102) also show the LO of *C. contusa* within the *P. palpebra* biozone. This suggests that the *C. contusa* biozone in NE Iraq is probably equivalent, at least in part, to the *P. palpebra* biozone recorded by Ogg & Hinov (2012).

The *C. contusa* biozone is represented through nearly 10 m of fossiliferous strata in the Dokan section, from sample numbers DSH-115 to DSH-120 (Fig. 8); the interval cannot be recognized in the Azmer section, probably because of lithofacies changes associated with marine shallowing. *Contusotruncana contusa* occurs frequently, but seems to be limited to the late early Campanian (Li & Keller, 1998a, b; Li et al., 1999; Abramovich et al., 2002, 2003, 2010, 2011; Sharbazheri, 2010; Ismael et al., 2011; Al-Mutwali & Al-Doori, 2012; see Fig. 5).

Succeeding foraminifer biozones cannot be recognized in NE Iraq, due to the absence of planktonic foraminifera in a rapidly shallowing marine succession. This is indicated by the presence of a massive bed of marly limestone about 1 m thick, bearing a mass of shallow-marine rudist bivalves near the contact with the overlying Tanjero Formation.

THE MID- TO EARLY LATE CAMPANIAN UNCONFORMITY

The unconformity between the Kometan and Shiranish formations is demarcated by *Globotruncana elevata* as the youngest biozone in the pelagic limestones of the uppermost Kometan Formation, and *Globotruncanella aegyptiaca* as the earliest biozone in the overlying Shiranish Formation. On the basis of the most recent Upper Cretaceous planktonic foraminiferal biozonation compiled by Ogg & Hinov (2012), the successive biozonal planktonic foraminiferal species *Contusotruncana plummerae* (= *Globotruncanella ventricosa*) proposed by Petrizzo et al. (2011), *Radotruncana calcarata* (Cushman, 1927) and *Globotruncanella havanensis* (Voorwijk, 1937) are absent in the sections studied in NE Iraq. It is likely, therefore, that the mid- and early late Campanian is not represented (see Fig. 5). Based on calibration for the Cretaceous time-scale proposed by Ogg & Hinov (2012) for the LO and HO of the index Upper Cretaceous planktonic foraminiferal biozones, the estimated age for the end of the Globotruncanita elevata biozone and the beginning of the succeeding *Contusotruncana plummerae* biozones is 79.2 Ma, while the Globotruncanita aegyptiaca biozone begins at 74.0 Ma. These suggest that the time gap in the sections studied is at least 5.2 Ma (79.2–74.0 Ma): this gap may represent components of both non-deposition and erosion prior to the deposition of the Shiranish Formation. The unconformity surface at this stratigraphic level has been identified in several areas of Iraq and is a regional feature (Buday, 1980; Abawi et al., 1982; Kaddouri, 1982; Abdel-Kireem, 1986; Van Bellen et al., 1959) to 2005; Jassim & Goff, 2006; Agrawi et al., 2010). It may represent a response to regional tectonics. In late Campanian time ophiolites were obducted across the NE margin of the Arabian Plate (Ziegler, 2001; Jassim & Goff, 2006), and the compression associated with this obduction caused uplift (Numan, 1997; Ziegler, 2001; Jassim & Goff, 2006; see Fig. 2), during which a considerable thickness of early Turonian–early Campanian sedimentary deposits of the Kometan Formation may have been eroded (Jassim & Goff, 2006). The unconformity also appears to correlate with a major regional unconformity evident in Iran (Babazadeh et al., 2007), Turkey (Sari, 2006, 2009), Kuwait, Qatar and Saudi Arabia (Al-Naqib, 1967; see Fig. 2), and with Arabian Plate sea-level fall recorded by Sharland et al. (2001).

PALAEOCEANOGRAPHIC SIGNIFICANCE

Planktonic foraminifera are widely used for palaeoceanographic reconstruction and to provide estimates of past sea surface temperatures for the calibration of General Circulation Models of palaeoclimate (e.g. Dowsett et al., 2013). The composition of extant planktonic foraminiferal assemblages is influenced by water properties including temperature, density and salinity, by nutrient supply, and by the degree of stratification of the water column (Bé & Hamilton, 1967; Bé & Tolderlund, 1971; Bé, 1977; Hart, 1980; Caron & Homewood, 1983; Hallock et al., 1991; Huber, 1992; Pflaummann et al., 1996; Mulitza et al., 1997; Leckie et al., 1998; Keller et al., 2001; Malmgren et al., 2001). These characteristics vary both spatially and by water depth. Temperature appears to be the most important single factor controlling assemblage composition (Morey et al., 2005), diversity (Rutherford et al., 1999) and test size (Schmidt et al., 2004). The highest diversity and largest sizes of planktonic foraminiferal assemblages are found in oligotrophic subtropical waters (Huber, 1992; Kucera, 2007). Most likely a combination of higher light intensity, higher carbonate saturation and greater niche diversity encourages growth to larger and heavier test sizes in warm subtropical and tropical oceans (Schmidt et al., 2004). Temperature effects appear to control test size in planktonic foraminifera even at the species level (Kucera, 2007). Other authors have emphasized the importance of nutrient supply on foraminiferal assemblage structure (Hallock, 1987; Almogi-Labin et al., 1993; MacLeod et al., 2001; Petrizzo, 2002).

Based on the known palaeo-latitudinal and environmental distribution of Cretaceous planktonic foraminifera, and possible links with overall morphology, three major groups have been identified (following Premoli Silva & Sliter, 1994, 1999; Keller et al., 2001; Petrizzo, 2002; see Fig. 11). These groups are considered, tentatively, to signal ambient environmental regimes ranging from nutrient-rich to nutrient-poor, coupled with prevailing cooler or
Fig. 8. Planktonic foraminiferal biozonation for the Shiranish Formation in the Kurdistan region, NE Iraq. The LO of *Planoglobulina acervulinoidea* is used to identify the Campanian–Maastrichtian boundary.
Fig. 9. Stratigraphic ranges of planktonic foraminifera for the upper Campanian to upper lower Maastrichtian Shiranish Formation in the Dokan section.
### Turonian–Maastrichtian planktonic foraminifera of NE Iraq

**Fig. 10.** Stratigraphic ranges and distribution of planktonic foraminifera for the upper Campanian to lower Maastrichtian Shiranish Formation in the Azmer section.
| r-strategists | r/k-intermediates | k-strategists |
|---------------|------------------|--------------|
| Simple morphotypes, small-sized | more r-selected | more k-selected |
| Opportunistic taxa | Pseudoguembelina | Pseudotextularia |
| Muricohedbergella | Globigerinelloides | Planoglobulina |
| Heterohelix | Rugotrunccana | Gublerina |
| Laeviheterohelix | Globotruncanella | Pseudotextularia |
| E. Heterohelix | Rugoglobigerina | Planoglobulina |
| More r-selected | | |
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Turonian–Maastrichtian planktonic foraminifera of NE Iraq

Species diversity

Dokan section

Shiranish Formation

| Lower Campanian | G. elevata |
|-----------------|-----------|
| DK-101          |           |
| DK-93           |           |
| DK-85           |           |
| DK-77           |           |
| DK-72           |           |
| DK-65           |           |
| DK-57           |           |
| DK-49           |           |
| DK-41           |           |
| DK-33           |           |
| DK-25           |           |
| DK-19           |           |
| DK-15           |           |
| DK-11           |           |
| DK-7            |           |

| Santonian       | D. asymetrica |
|-----------------|---------------|
| DK-1            |               |
| DK-03           |               |

| Coniacan        | D. concavata |
|-----------------|--------------|
| DK-13           |               |
| DK-07           |               |
| DK-01           |               |

| Turonian        | G. primitiva |
|-----------------|--------------|
| DK-05           |               |
| DK-01           |               |

Species diversity

Azmer section

Shiranish Formation

| Lower Campanian | G. elevata |
|-----------------|-----------|
| AK-67           |           |
| AK-65           |           |
| AK-63           |           |
| AK-47           |           |
| AK-39           |           |
| AK-35           |           |
| AK-31           |           |
| AK-23           |           |
| AK-15           |           |

| Santonian       | D. asymetrica |
|-----------------|---------------|
| AK-1            |               |

| Coniacan        | D. concavata |
|-----------------|--------------|
| AK-13           |               |
| AK-07           |               |
| AK-01           |               |

| Turonian        | M. schneegansi |
|-----------------|---------------|
| AK-9            |               |
| AK-5            |               |

Species diversity

Assemblage 1
- Mesotrophic to eutrophic regime
- Maximum abundance and diversification of whiteinellids

Assemblage 2
- Oligotrophic regime
- Maximum abundance and diversification of marginotruncanids

Assemblage 3
- Eutrophic regime
- Rapid disappearance of most of marginotruncanids

Assemblage 4
- Oligotrophic regime
- Extinction of marginotruncanids and diversification of globotruncanids

Assemblage 5
- Mesotrophic regime
- Association of globotruncanids and heterohelicids
### Dokan section

| Assemblage 6 | Oligotrophic regime | Maximum abundance and diversification of globotruncanids |

### Azmer section

| Assemblage 7 | Mesotrophic regime | Maximum abundance and diversification of heterohelicids |
warmer seawater temperatures. Species recorded in NE Iraq can be tentatively assigned to these biological groups (Fig. 11). Where possible, the interpreted ecological preferences for planktonic foraminifera are quantified by reference to published stable isotope analyses of comparable foraminiferal assemblages.

(1) Nutrient-rich/eutrophic Cretaceous marine environments, and also those subject to environmental instability have been interpreted to favour ‘r-selected opportunists’ (Premoli Silva & Sliter, 1999; Keller et al., 2001; Petrizzo, 2002). These foraminiferal assemblages are interpreted as characterizing high latitudes, upwelling zones, shallow epicontinental seas and nearshore areas (Hart, 1980; Caron & Homewood, 1983; Leckie, 1987; Keller et al., 2001). Cretaceous taxa interpreted as adopting r-strategy include species of the thin-walled *Muricohedbergella* and thin-walled biserial heterohelicids (*Heterohelix* and *Laeviheterohelix*). Opportunistic taxa increase their population densities by rapid reproduction and, as a result, tend to be of small dimensions. They predominate in higher latitudes and generally have a low dominance at low latitudes compared to k-strategists (Herb, 1974; Hart, 1980; Krasheninnikov & Basov, 1983; Leckie, 1987; Huber, 1988, 1990, 1991a, b, 1992; Quilty, 1992a, b; Keller et al., 2001; Petrizzo, 2002). Consequently, their abundance at low latitudes may signal cooler waters.

(2) Low-nutrient/oligotrophic Cretaceous marine environments that are also stable may be indicated by ‘k-selected specialists’ (Premoli Silva & Sliter, 1999; Keller et al., 2001; Petrizzo, 2002). The k-strategists are interpreted as including species of the single-keeled *Globotruncana* and double-keeled *Marginotruncana, Contusotruncana* and *Globotruncana*. Specialist taxa, characterized by long-lived individuals, low reproductive potential (and usually larger size), prefer lower and middle latitudes and, consequently, they are considered indicators of warmer-water environments (Emiliani, 1971; Caron & Homewood, 1983; Leckie, 1987, 1989; Huber, 1988, 1992; Hallock et al., 1991; Keller et al., 2001; Petrizzo, 2002; Falzoni et al., 2013).

(3) Between these end-members, foraminifera tolerant of Cretaceous mesotrophic environments exhibit a range of strategies and are termed ‘r/k intermediates’ and have been further subdivided into two subgroups: Subgroup 1 are the more k-selected r/k intermediates and include those with high trochospires, hemispherical chambers with marginal keel(s), flaring heterohelicids with more than two chambers per row, and medium-sized heterohelicids with chambers arranged from biserial to annular; these have been interpreted as occupying the oligotrophic portion of the mesotrophic spectrum (Premoli Silva & Sliter, 1999; Petrizzo, 2002; see Fig. 11). Subgroup 2 is the more r-selected r/k intermediates which have been interpreted as occupying the eutrophic part of the mesotrophic spectrum, and comprise forms with planispiral, low to medium trochospiral tests with sub-globular chambers and include biserial heterohelicids with a supplementary aperture (Premoli Silva & Sliter, 1999; Petrizzo, 2002; see Fig. 11). Most of these r/k intermediate foraminifera can be recognized in the Shiranish Formation, with the exception of species of *Dicarinella, Helvetoglobotruncana* and *Whitelinella* that are only found in the Kometan Formation.

The NE Iraqi sector of the Cretaceous Tethys Ocean represents tropical waters in an epicontinental sea setting. Interpreted water depths for the Kometan Formation are estimated at c. 200 m (Jassim & Goff, 2006), whilst water depths for the Shiranish Formation are estimated at greater than 600 m, based on associated benthonic foraminiferal assemblages (Jaff et al., 2014). However, in both formations there is a shallowing-upwards marine succession, and in the upper part of the Shiranish Formation planktonic foraminifera disappear, signalling a shallow shelf setting (Jaff et al., 2014). Using morphology as a tentative basis for interpreting water properties, and coupled with detailed abundance data, seven temporally distinctive assemblages are recognized in the succession of NE Iraq (Figs 12 and 13). These are interpreted as indicating possible changes in near-surface and sea surface temperatures and nutrient availability. In assessing relative sea temperatures as ‘warmer’ or ‘cooler’, Sellwood & Valdes (2007) used a General Circulation Model to interpret sea surface temperatures of about 28°C for the Late Cretaceous in the Arabian sector of the Tethys Ocean. These results have not been tested with precise proxy data in this region and, indeed, the planktonic foraminifera studied here are recrystallized and not suitable for geochemical analysis. It is notable, however, that the foraminiferal assemblages suggest temporal variation in sea temperature through the interval of the Late Cretaceous, and this variation is compared with changes noted in other Cretaceous palaeotropical settings.

**Assemblage 1**

Planktonic foraminiferal Assemblage 1 is present through the basal part of the Kometan Formation, and occurs through an interval equivalent to the early Turonian Helvetoglobotruncana helvetica biozone. This assemblage is numerically dominated by simple test morphotypes, particularly those interpreted as r-strategists, such as species of *Muricohedbergella (M. planispira)* and *M. cognata*.
as r-strategists, together with whiteinellids, suggests that near-sur-
et al. Coccioni & Luciani, 2004; Bornemann & Norris, 2007; Friedrich
erance toward eutrophic environments (Leckie, 1987, 1989;
stratigraphic interval. The more r-selected r/k intermedi-
ate Helvetoglobotruncana helvetica is rare in this interval in NE
Iraq, and this is typical for a number of localities of this age
world-wide (Kuhnt et al. 1997; Petrizzo, 2001; Huber & Petrizzo,
2014). The first k-strategists Marginotruncana renzi and M. sch-
neegansi appear in this interval but are rare.

Based on analyses of stable oxygen and carbon isotopes from
foraminiferal tests, Huber & Petrizzo (2014) have interpreted hel-
vetoglobotruncanids, including H. helvetica, as living in the surface
mix layer together with whiteinellids and biserial foraminiferal species. Moreover, stable isotope analysis confirms that species of Muricohedbergella and biserial taxa such as Heterohelix, including H. moremani, are typical of the shallowest part of the water column (Leckie, 1987, 1989; Leckie et al., 1998; Nederbragt et al., 1998; Hart, 1999; Premoli Silva & Sli
er, 1999; Keller et al., 2001; Coccioni & Luciani, 2004; Bornemann & Norris, 2007; Friedrich et al., 2008; Falzoni et al., 2013). Overall, the numerical dominance of Muricohedbergella. Heterohelix and Whiteinella species suggests the influence of cooler sea surface temperatures (SSTs) (Petrizzo, 2002) relative to the succeeding stratigraphic interval.

Species of whiteinellids are interpreted as taxa with a high tol-
erance toward eutrophic environments (Leckie, 1987, 1989; Leckie et al., 1998; Huber et al., 1999; Keller et al., 2001; Coccioni & Luciani, 2004; Bornemann & Norris, 2007; Friedrich et al., 2008). Therefore, the abundance of foraminifera interpreted as r-strategists, together with whiteinellids, suggests that near-surface waters experienced high nutrient levels (possibly mesotrophic to eutrophic; see also Premoli Silva & Sli
er, 1994, 1999; Keller et al., 2001; Petrizzo, 2002; Friedrich et al., 2008). Biotic evidence for high surface productivity coupled to a major expansion of the oxygen minimum zone is seen in the low species-richness in planktonic foraminifera, near absence of deeper-marine dwellers, dominance of Heterohelix, and the relatively high abundance of surface dwellers (species of Muricohedbergella and Whiteinella).

Assemblage 2
Planktonic foraminiferal Assemblage 2 is present in the Kometan Formation through the interval of the Marginotruncana schnee-
gansi biozone, to the top of the Marginotruncana concavata biozone, and this is equivalent to the mid-Turonian to late Coniacian time interval. Assemblage 2 suggests warmer, nutrient-poor waters relative to the preceding interval, with Marginotruncana species interpreted as k-strategists becoming more abundant and more diverse (maximum abundance and diversification with seven species), suggesting warmer surface waters (Petrizzo, 2002; Fig. 12).

Foraminiferal Assemblage 2 is also characterized by more k-selected r/k intermediates, such as species of Dicarinella. The interval is also characterized by an abrupt decrease in species of Whiteinella, which disappear at the top of this interval, with the exception of Whiteinella brittonensis. The reduction of whiteinell-
lids is associated with the increase in abundance of Marginotruncana and the first appearance of Globotruncana (G. angusticarinata). This suggests that the mesotrophic to eutrophic environment interpreted for the preceding (Assemblage 1) interval gave way to a well-stratified water mass with a reduced oxygen minimum zone (Premoli Silva & Sli
er, 1999; Keller et al., 2001; Petrizzo, 2002); this is also suggested by the increasing size of Dicarinella and Marginotruncana species compared to the preceding interval. According to Leckie (1987, 1989), Keller et al. (2001), Petrizzo (2002) and Falzoni et al. (2013), the greater diversity and abundance of Dicarinella and Marginotruncana species may relate to greater stratification of surface and near-surface waters that provided a wider range of ecological niches for specialist foraminifera to colonize. The apparent increase of tropical SSTs in the Arabian sector of the Tethys Ocean during this interval coincides with the mid-Turo-
nian to Coniacian SST maximum recorded by Boersma & Shackleton (1981) in the Central Pacific, at IODP (DSDP) sites 463 and 465, and with maximum SSTs in the eastern Indian Ocean during the Coniacian recorded at IODP (ODP) sites 762 and 763 (Petrizzo, 2002).

Assemblage 3
Planktonic foraminiferal Assemblage 3 of the Kometan Formation occurs through the interval of the lower and mid part of the Dicarinella asymetrica biozone, equivalent to the early to late Santonian time interval. The foraminiferal assemblages are characterized by a decrease in numbers of species interpreted as

Explanation of Plate 1. Planktonic foraminifera of the Kometan Formation. figs 1, 2. Helvetoglobotruncana helvetica (Bolli). H. helvetica biozone: 1, MPK14421, Azmer section, sample number AK-1; 2, MPK14422, Dokan section, sample number DK-02. figs 3, 4. Marginotruncana schneegansi Sigal. M. schneegansi biozone: 3, MPK14423, Dokan section, sample number DK-05; 4, MPK14424, Azmer section, sample number AK-6. figs 5, 6. Dicarinella primitiva (Dalbiez). D. primitiva biozone: 5, MPK14425, Dokan section, sample number DK-6; 6, MPK14426, Azmer section, sample number AK-9. figs 7, 8. Dicarinella concavata (Brotzen). D. concavata biozone: 7, MPK14427, Dokan section, sample number DK-16; 8, MPK14428, Azmer section, sample number AK-19. figs 9, 10. Dicarinella asymetrica (Sigal). D. asymetrica biozone: 9, MPK14429, Dokan section, sample number DK-40; 10, MPK14430, Azmer section, sample number AK-23. figs 11, 12. Globotruncanita elevata (Brotzen). G. elevata biozone: 11, MPK14431, Dokan section, sample number DK-82; 12, MPK14432, Azmer section, sample number AK-61. fig. 13. Marginotruncana marginata (Reuss). D. concavata biozone, MPK14433, Dokan section, sample number DK-18. fig. 14. Marginotruncana renzi (Gandolfi). D. primitiva biozone, MPK14434, Azmer section, sample number AK-9. fig. 15. Globotruncana bulloides Vogler. G. elevata biozone: 15, MPK14435, Azmer section, sample number AK-67. figs 16, 17. Globotruncana linneiana d’Orbigny. G. elevata biozone: 16, MPK14436, Azmer section, sample number AK-67; 17, MPK14437, Dokan section, sample number DK-66. fig. 18. Globotruncana stuartiformis Dalbiez. G. elevata biozone, MPK14438, Dokan section, sample number DK-82. Scale bar for all figures as in figure 3.
Planktonic foraminiferal Assemblage 4 of the Kometan Formation occurs through the interval of the top of the Dicarinella asymetrica biozone, and represents the latest Santonian time interval. The interval is associated with the disappearance of Marginotruncana (see also Petrizzo, 2003; Kochhann et al., 2014; Vahidinia et al., 2014), which coincides with the earliest diversification of the double-keeled Globotruncana and the first occurrence of the single-keeled Globotruncana (G. elevata and G. stuartiformis). Assemblage 4 is interpreted as signalling warmer surface waters, stronger stratification and an overall nutrient-poor environment relative to the preceding interval. Species of the r-strategist Heterohelix and Muricohedbergella are present as a rare component of the assemblage. Only Dicarinella asymetrica of the more k-selected r/k intermediates survives through this interval.

Assemblage 5 Planktonic foraminiferal Assemblage 5 occurs through the uppermost part of the Kometan Formation and spans the Globotruncana elevata biozone, being time-equivalent to the early Campanian. The numerically dominant planktonic foraminifera are heterohelicids and globotruncanids (Fig. 12). Overall, Assemblage 5 suggests cooler, more nutrient-rich waters relative to the preceding interval. In the k-strategist group, Globotruncana arca and Globotruncana elevata were the most abundant species; Globotruncana bulloides, Globotruncana stuartiformis and Contusotruncana fornicata were also common but occur intermittently. Based on wide geographical distribution, Premoli Silva & Sliter (1999) and Falzoni et al. (2013) concluded that G. bulloides was a generalist species, being adaptable to changing surface environments.
This interval of the Kometan Formation is also characterized by abundant benthonic *Lenticulina* and *Textularia*. Lenticulinids, in particular, are considered to be dominant in low-oxygen seabed environments (Honigstein et al., 1986; Friedrich et al., 2003, 2005a), where they may be adapted for utilizing degraded organic matter as a food source (Friedrich et al., 2006). Therefore, their abundance in the Kometan Formation might signal increased organic input from the overlying water column, and would be consistent with a more nutrient-rich water column and higher productivity. Decreased abundance of *Globotruncana* species relative to the preceding interval may signal cooler SSTs (Petrizzo, 2002; Falzoni et al., 2013). This possible decrease of SSTs in the mid-Cretaceous hothouse persisted to the latest Santonian at the Shatsky Rise in the Pacific Ocean, and then switched to a cooler state during the early Campanian.

**Assemblage 6**

Planktonic foraminiferal Assemblage 6 occurs through the lower part of the Shiranish Formation immediately post-dating the mid-Campanian unconformity, and represents the interval of the Globotruncana aegyptiaca biozone to the lower part of the Gansserina gansseri biozone (time-equivalent to the late and latest Campanian). The numerically dominant planktonic foraminiferal taxa are those interpreted as k-strategists (Fig. 13), including *Globotruncana*, *Globotruncanita* and *Contusotruncanita* species. The maximum species diversity and abundance of globotruncanids occurs in this interval, and coincides with the global diversity peak of globotruncanids world-wide (Premoli Silva & Sliter, 1999). Based on stable isotope records by Abramovich et al. (2003), most keeled globotruncanids occupied warm shallow subsurface habitats during the late Campanian. Almogi-Labin et al. (1993), MacLeod et al. (2001) and Frank et al. (2005) stated that globotruncanids are relatively abundant during times of low surface productivity.

Within those taxa interpreted as r/k intermediates, species of the genera *Rugoglobigerina* (*R. rugosa* and *R. macrocephala*), *Pseudotextularia* (*P. elegans*) and *Pseudoguenelberlinia* (*P. costulata*) become abundant in this interval. According to Abramovich et al. (2003, 2011), these assemblages are characteristic of subsurface water masses, except for *P. costulata* which is an index taxon for upper surface waters. Stable isotope analyses suggest that *Rugoglobigerina* species probably lived in the mixed layer and inhabited relatively warm waters (MacLeod et al., 2001; Abramovich et al., 2003; Falzoni et al., 2013, 2014; contra Zepeda, 1998). According to Malmgren (1991) and Olsson et al. (2001), the abundances of *P. elegans* and *P. costulata* are also good indicators for warm waters.

Based on stable isotopic analyses of a range of planktonic foraminifer tests, including globotruncanids (Abramovich et al., 2003, 2011), the planktonic foraminiferal assemblages in this interval of the Shiranish Formation also suggest well-developed stratification of surface and near-surface waters that provided a greater range of ecological niches for specialist foraminifera to colonize. Warmer SSTs relative to the preceding interval of the uppermost Kometan Formation are also consistent with a warm late Campanian climate (see Abramovich et al., 2003; Friedrich et al., 2005b; Zakharov et al., 2007; Darvishzad & Abdolalipour, 2009; Linnert et al., 2014).

Benthonic foraminiferal assemblages in this interval suggest gradual deepening of the marine basin throughout the late Campanian (*Globotruncana aegyptiaca* biozone). Common benthonic foraminifera are represented by calcareous species of *Gavelinella, Gyroidinoides, Neoflabellina, Osangularia* and *Praebulimina* and large agglutinated forms of *Bathysiphon, Clavulinoidea, Dorothea, Gaudryina, Marsonella, Pseudoclavulina* and *Trityxia* (see Jaff et al., 2014). According to Jaff et al. (2014), water depths of c. 600 m can be interpreted for this part of the Shiranish Formation.

**Assemblage 7**

Planktonic foraminiferal Assemblage 7 occurs through the middle and upper part of the Shiranish Formation, being the interval of the upper part of the Gansserina gansseri biozone and the Contusotruncanita contusa biozones (early Maastrichtian age).

Towards the top of this interval the percentage abundance of globotruncanids decreases sequentially until all foraminifera disappear (Fig. 13). Abramovich et al. (2003) stated that most keeled globotruncanids occupied the deeper thermocline layer during the cool early Maastrichtian. The decrease in globotruncanids through this interval is associated with the maximum diversification and abundance of taxa interpreted as r-strategists, including *Heterohelix, Laeviheterohelix* and more r-selected r/k intermediate *Globigerinelloides*. Overall, Assemblage 7 suggests cooler, more nutrient-rich waters relative to the preceding interval.

Within heterohelicids from this interval of the Shiranish Formation the most abundant species are small biserial forms (*H. globulosa, H. planata, H. navarroensis*) that are surface and subsurface dwellers that became abundant during times of high surface productivity (Keller et al., 2001; MacLeod et al., 2001; Frank et al., 2005; Pardo & Keller, 2008; Abramovich et al., 2011). Small heterohelicids are also often considered to be tolerant of low-oxygen conditions, thriving within the oxygen-minimum zone (Leckie, 1987; Barrera & Keller, 1990; Kroon & Nederbragt, 1990; Leckie et al., 1998; Nederbragt et al., 1998;
Kurdistan region, NE Iraq. Most previous studies suggested that subzones for the Kometan and Shiranish formations of the index planktonic foraminifera demarcate nine biozones and two in this study 93 species of early Turonian to late early (Jassim & Goff, 2006).

Iraq might be related to the closure of southern Neo-Tethys gested for this part of the Shiranish Formation. Shallowing in NE more nutrient-rich surface and near-surface waters in the early Turonian, early to late Santonian, early Campanian and early Maastrichtian. These intervals appear to correlate with changes in water masses from other regions of the Cretaceous palaeotropics.  

**APPENDIX A: TAXONOMIC LIST**

An alphabetical list of planktonic foraminifera recorded in this study is provided below. Selected species are illustrated in Plates 1–5

**CONCLUSION**

In this study 93 species of early Turonian to late early Maastrichtian planktonic foraminifera have been identified. The index planktonic foraminifera demarcate nine biozones and two subzones for the Kometan and Shiranish formations of the Kurdistan region, NE Iraq. Most previous studies suggested that the base of the Kometan Formation is late Turonian; however, based on the appearance of *Helvetoglobotruncana helvetica*, the base of the Kometan Formation is here interpreted as early Turonian. The distinct intra-Campanian unconformity between the Kometan and overlying Shiranish Formation is seen in other parts of the Arabian Plate, and is ascribed to regional Arabian tectonics. On the basis of planktonic foraminiferal assemblages, 7 temporally distinct intervals within the Kometan and Shiranish formations can be distinguished that reflect evolving surface ocean conditions with dominantly warm, nutrient-poor marine surface and near-surface conditions during the mid-Turonian to late Coniacian, latest Santonian, and late Campanian, and cooler more nutrient-rich surface and near-surface waters in the early Turonian, early to late Santonian, early Campanian and early Maastrichtian. These intervals appear to correlate with changes in water masses from other regions of the Cretaceous palaeotropics.
Globigerinelloides rosebudensis Smith & Pessagno, 1973; Plate 4, figs 11, 12
Globigerinelloides subcarinatus Brönnimann, 1952; Plate 4, figs 13, 14
Globigerinelloides ultramicrus Subbotina, 1949
Globigerinelloides volutus (White, 1928); Plate 4, figs 15, 16
Globotruncanca aegyptiaca Nakkady, 1950; Plate 3, figs 1, 2
Globotruncanca angusticarinata (Gandolfi, 1942)
Globotruncanca arca (Cushman, 1926); Plate 2, fig. 9
Globotruncanca bulloides Vogler, 1941; Plate 1, fig. 15
Globotruncanca dupeubliei Caron et al., 1984; Plate 2, fig. 10
Globotruncanca esnehensis (Nakkady, 1950); Plate 2, fig. 11
Globotruncanca falsostuari Sigal, 1952
Globotruncanca lapparenti (Brotzen, 1936)
Globotruncanca linneiana d’Orbigny, 1839; Plate 1, figs 16, 17
Globotruncanca mariei (Banner & Blow, 1960)
Globotruncanca orientalis El-Naggar, 1966
Globotruncanella petaloidea Gandolfi, 1955; Plate 4, figs 1, 2
Globotruncanella pschadae Keller, 1946; Plate 4, figs 3, 4
Globotruncanita angulata Tiele, 1951
Globotruncanita conica White, 1928; Plate 2, fig. 12; Plate 3, figs 3, 4
Globotruncanita elevata (Brotzen, 1934); Plate 1, figs 11 and 12
Globotruncanita insignis (Gandolfi, 1955); Plate 2, fig. 13
Globotruncanita pettersi (Gandolfi, 1955); Plate 2, fig. 14
Globotruncanita stuarti (de Lapparent, 1918); Plate 2, fig. 15
Globotruncanita stuartformis Dalbiez, 1955; Plate 1, fig. 18
Gublerina cuvillieri Kikoine, 1948
Helvetoglobotruncanca helvetica (Bolli, 1945); Plate 1, figs 1, 2
Heterohelix globulosa (Ehrenberg, 1840); Plate 5, figs 6, 7
Heterohelix moremani (Cushman, 1938)
Heterohelix navarroensis Loeblich, 1951; Plate 5, fig. 8
Heterohelix planata (Cushman, 1936)
Heterohelix punctulata (Cushman, 1938)
Heterohelix reussi (Cushman, 1938)
Heterohelix semicostata (Cushman, 1938); Plate 5, fig. 9
Heterohelix striata (Ehrenberg, 1840); Plate 5, fig. 10
Heterohelix ultimatumida White, 1929
Laeviheterohelix dentata (Stenestad, 1968); Plate 5, fig. 11
Laeviheterohelix glabrans (Cushman, 1938)
Laeviheterohelix pulchra (Brotzen, 1936); Plate 5, fig. 12
Marginotruncana coronata (Bolli, 1945)
Marginotruncana marginata (Reuss, 1845); Plate 1, fig. 13
Marginotruncana renzi (Gandolfi, 1942); Plate 1, fig. 14
Marginotruncana schneegansi Sigal, 1952; Plate 1, figs 3, 4
Marginotruncana sigali (Reichel, 1950)
Marginotruncana sinuosa Porthault, 1970
Marginotruncana undulata (Lehmann, 1963)
Muricohedbergella delrioensis (Carsey, 1926); Plate 2, fig. 1
Muricohedbergella holmdelensia Osllson, 1964; Plate 2, fig. 2
Muricohedbergella planispira (Tappan, 1940)
Planoglobulina acervulinoides (Egger, 1899); Plate 5, figs 13, 14
Planoglobulina brazoensis Martin, 1972; Plate 5, fig. 15
Planoglobulina carseyaee (Plummer, 1931)
Planoglobulina riograndensis Martin, 1972
Praegublerina acuta De Klasz, 1953
Pseudoguembelina costulata (Cushman, 1938)
Plate 5, fig. 5
Pseudoguembelina excolata (Cushman, 1926); Plate 5, figs 3, 4
Pseudotextularia deformis (Kikoine, 1948)
Pseudotextularia elegans (Rzehak, 1891); Plate 5, figs 1, 2
Pseudotextularia nutalli (Voorwijk, 1937)
Rugotruncanca subsinuosa (Pessagno, 1960); Plate 2, fig. 16
Rugotruncanca circummodifer (Finley, 1940); Plate 4, figs 5, 6
Rugotruncanca subcircummodifer Gandolfi, 1955
Rugoglobigerina hexacamerata Brönnimann, 1952
Rugoglobigerina macrocephala Brönnimann, 1952
Rugoglobigerina pennyi Brönnimann, 1952; Plate 2, fig. 17
Rugoglobigerina rugosa (Plummer, 1926); Plate 2, fig. 18
Rugoglobigerina scotti Brönnimann, 1952
Rugoglobigerina subpennyi (Gandolfi, 1955)
Ventilabrella eggeri Cushman, 1928
Whiteinella archaeocreataea Pessagno, 1967; Plate 2, fig. 3
Whiteinella aprica (Loeblich & Tappan, 1961)
Whiteinella baltica Dougall & Rankin, 1969
Whiteinella brittonensis (Loeblich & Tappan, 1961); Plate 2, fig. 4
Whiteinella inornata (Bolli, 1957)
Whiteinella paradubia (Sigal, 1952)

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