

LATE CRETACEOUS FORAMINIFERA FROM THE
KURDISTAN REGION, NE IRAQ: PALAEONTOLOGICAL,
BIOSTRATIGRAPHICAL AND PALAEOENVIRONMENTAL
SIGNIFICANCE

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Rawand B. N. Jaff

Abstract

The early Turonian-early Maastrichtian planktonic and benthonic foraminiferal faunas of the Kurdistan region, NE Iraq are evaluated. Some 93 planktonic foraminifera (24 species of the family Heterohelicidae are described in detail) from the Kometan and Shiranish formations, and 115 benthonic foraminifera from the Shiranish Formation are identified and illustrated. The fauna reveals new and important data bearing on the palaeontological, biostratigraphical and palaeoenvironmental significance of the Late Cretaceous successions in the Kurdistan region, NE Iraq.

Based on the planktonic foraminiferal assemblages, nine biozones and two subzones spanning the early Turonian to late early Maastrichtian were identified. 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.

Species of the benthonic foraminiferal genus *Bolivinoidea* provide a refined biostratigraphic biozonation for the late Campanian to early Maastrichtian Shiranish Formation in the Kurdistan region, NE Iraq. Three biozones and two subzones are identified for the first time in Iraq: the *Bolivinoidea decoratus* biozone (late Campanian) subdivided into a lower *B. decoratus* subzone and an upper *B. laevigatus* subzone; the *B. miliaris* biozone (earliest Maastrichtian); and the *B. draco* biozone (late early Maastrichtian). Combined, the *Bolivinoidea* and planktonic foraminiferal biostratigraphy enables the informal recognition of lower and upper intervals within both the *Globotruncana aegyptiaca* and *Gansserina gansseri* planktonic foraminifer biozones that may be important for a more refined inter-regional correlation in the Middle East and North Africa. The new *Bolivinoidea* biozonation precisely locates the Campanian-Maastrichtian boundary in NE Iraq. The benthonic foraminiferal assemblages are interpreted as representing outer shelf to middle slope environments, between ca 200 m to at least 600 m water depth, with maximum water depths in the late Campanian, followed by shallowing into the early Maastrichtian. The most likely control mechanism for the shallowing of sea level is the beginning of southern Neo-Tethys Ocean closure at this time.

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Chapter 1

Introduction

Chapter 1: Introduction

Introduction

Foraminifera are marine, free-living, amoeboid protozoa. They are single-celled eukaryotes, and they exhibit animal-like behaviour (Leckie 2009; BouDagher-Fadel 2013). Generally, they have a hard carbonate test, but some forms have a cemented test made of sedimentary particles (BouDagher-Fadel 2013). The foraminiferal test is divided into a series of chambers, which increase in number during growth. Foraminifera origins may date back to the late Proterozoic based on molecular and fossil data (Culver 1991; Pawlowski *et al.* 2003; Bosak *et al.* 2012). The earliest foraminifera were benthonic, and over the course of the Phanerozoic, they invaded most marginal to fully marine environments (Leckie 2009; BouDagher-Fadel 2013). They diversified to exploit a wide variety of niches, including, from the early Jurassic, the planktonic realm (BouDagher-Fadel 2013). The living and fossil foraminifera have a broad variety of shapes and they occupy different micro-habitats. Today they are abundant in most marine environments from near-shore to the deep sea, and from near surface to the ocean floor (Pessagno 1967; BouDagher-Fadel 2013).

Foraminifera can be divided into two types based on their life strategy, namely benthonic and planktonic foraminifera. Benthonic foraminifera occur in marine environments ranging from the intertidal zone to the deep ocean (Corliss 1980; Pawlowski & Holzmann 2008; Leckie 2009; BouDagher-Fadel 2013; Holbourn *et al.* 2013). They vary in size from less than 100 μm in diameter to a few centimetres. The test of benthonic foraminifera may be agglutinated, or may be primarily composed of calcite or aragonite (Wood 1949; BouDagher-Fadel 2013). They exhibit relatively slow evolution rates in comparison to planktonic foraminifera (Pawlowski *et al.* 1997; Kucera & Schönfeld 2007). On the other hand, planktonic foraminifera have a shorter geologic history that begins about 180 million years ago in the early Jurassic (Leckie 2009).

This study focuses on Late Cretaceous (early Turonian-early Maastrichtian) planktonic and benthonic foraminiferal biostratigraphy in two sections in the Kurdistan region, NE Iraq (Fig. 1.1). The sections have been chosen to provide an enhanced biostratigraphical tool for more precise inter-regional correlation in the Middle East and

North Africa. The analysis includes an assessment of palaeoceanography and palaeobathymetry in the Tethys Ocean during the Late Cretaceous.

The siliciclastic and carbonate deposits of the Late Cretaceous have been studied widely in Iraq, as many of these deposits are hydrocarbon-bearing or source rocks (Aqrawi *et al.* 2010). The Late Cretaceous (early Turonian-early Maastrichtian) in the Kurdistan region comprises two formations: the marine pelagic limestone of the Kometan Formation (early Turonian-early Campanian) and the marine shelf carbonates and mudstones of the Shiranish Formation (late Campanian-late early Maastrichtian). Planktonic and benthonic foraminifera are widely documented in the Late Cretaceous of Iraq, representing a range of different depositional marine environments from outer shelf to basinal (Jassim & Goff 2006). However, this is the first time that the foraminifera of the Kurdistan region have been documented in detail.

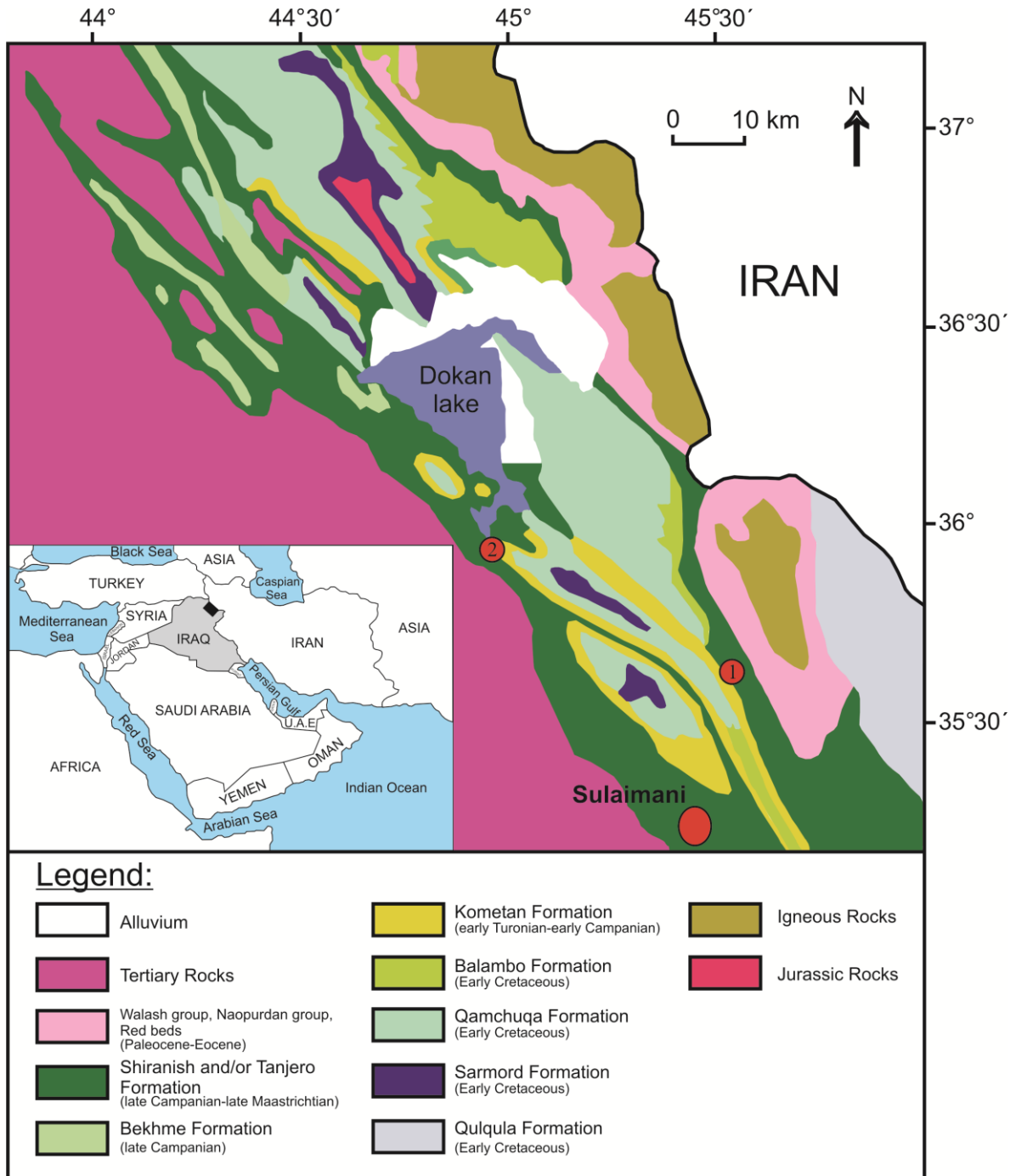


Figure 1.1. Geological context for the Azmer (1) and Dokan (2) sections of the Kometan and Shiranish formations in the Kurdistan region of NE Iraq (map after Sissakian 2000). The Dokan section runs parallel to the left bank of the Dokan Dam, near the Dokan tourist village. The Azmer section is located about 15 km to the NE of Sulaimani city. Small black rectangle on inset map represents study-area.

Outline of research

This work analyses the palaeontology, palaeoecology and biostratigraphy of the Late Cretaceous foraminiferal assemblages of the Kurdistan region, NE Iraq.

Specific aims

- Identification of the planktonic and benthonic foraminifera.
- Establish a biostratigraphical zonation that can be used for correlation on both local and regional scales, and to determine the duration of unconformities and other hiatuses in the successions.
- Highlight the diversity of Late Cretaceous Heterohelcidae in the western Tethys Ocean and place them in a stratigraphical framework.
- Recognise relationships with biostratigraphies established elsewhere, using more cosmopolitan benthonic (e.g. *Bolivinoides*) and planktonic taxa.
- Interpret the palaeoenvironmental conditions and depositional environments affecting the Late Cretaceous planktonic and benthonic faunas of the region.
- Illustrate the Late Cretaceous species of planktonic and benthonic foraminifera from the Kurdistan sector of the Tethys Ocean.

Late Cretaceous in the Kurdistan region, NE Iraq

The early Turonian-Danian megasequence is present throughout Iraq and it is thickest in NE Iraq (Jassim & Goff 2006). It was deposited following the onset of ophiolite obduction in the southern part of the Neo-Tethys Ocean (Jassim & Goff 2006). In Iraq, the megasequence can be divided into two sequences; an early Turonian-early Campanian sequence which was deposited in a relatively narrow seaway occupying the area of NE and central Iraq (Jassim & Goff 2006; see Fig. 1.2); and a late Campanian-Maastrichtian sequence associated with obduction and closure of the southern Neo-Tethys. The later sequence reflected a major transgression across the whole of Iraq (Jassim & Goff 2006). The two sequences are separated by the mid-Campanian unconformity in most parts of Iraq that extends to other countries in the Middle East (Fig. 1.2).

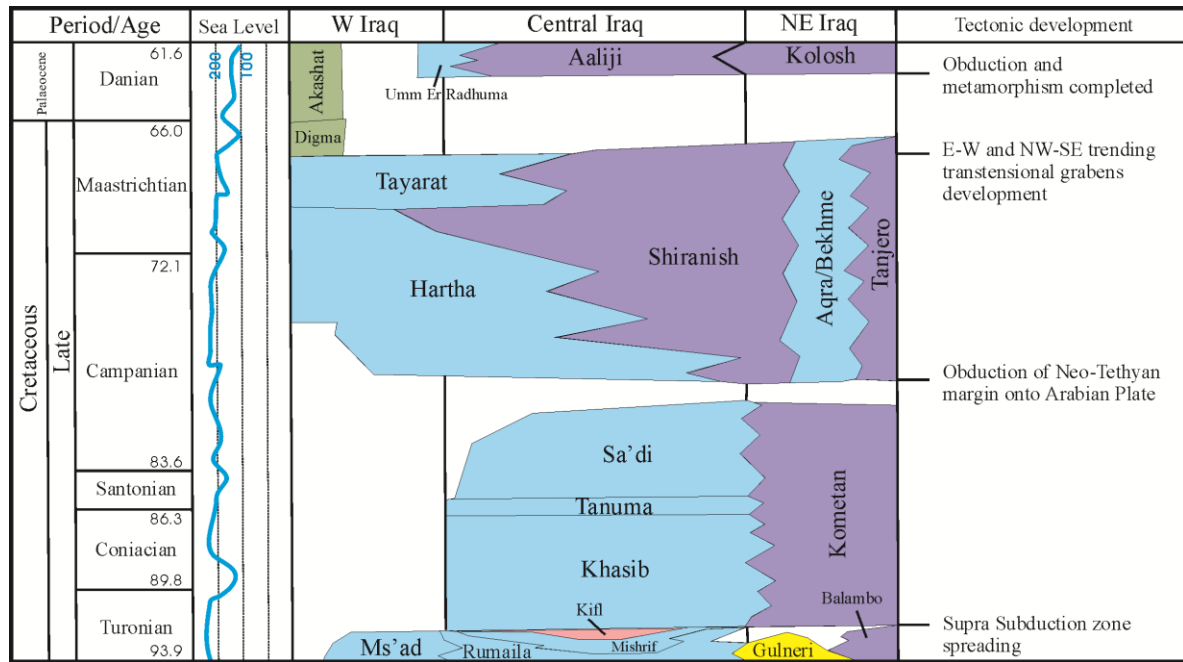


Figure 1.2. Stratigraphic correlation of formations of the early Turonian-Danian megasequence in different parts of Iraq (after Jassim & Goff 2006). Time scale adapted from Ogg & Hinnov (2012).

Kometan Formation (early Turonian-early Campanian)

The early Turonian-early Campanian Kometan Formation has been studied in different regions of Iraq. Most of these studies, particularly for north and northeast Iraq, addressed lithological, palaeontological, and palaeoenvironmental interpretations and the correlation of rock units within Iraq and with adjacent countries (Van Bellen *et al.* 2005; Al-Naqib 1967; Buday 1980; Jassim & Goff 2006, see Fig. 1.2). In the 1980s and 1990s the Iraqi North Oil Company (INOC) published many articles on the palaeontology and reservoir characteristics of the rock succession and placed particular emphasis on age determination of the Kometan Formation. Most recently according to Aqrawi *et al.* (2010) the Kometan Formation produces oil and gas in some wells in the north and northeast of Iraq (at the rates of 35,000 barrels/day).

Table 1.1 summarises the estimated biostratigraphical ages of the Kometan Formation based on foraminiferal data from previous studies in different localities in Iraq. In brief, the type section of the Kometan Formation from the village of Kometan near Endezeh in NE Iraq comprises 36 m of light grey, thin-bedded, globigerinal-oligosteginal limestone,

locally silicified, with a glauconitic bed at the base (Van Bellen *et al.* 2005; Jassim & Goff 2006). Most recently, Haddad & Amin (2007) divided the Kometan Formation in north and northeast Iraq into three parts based on subsurface lithology and well log analysis. The upper part is light grey, massive, vuggy with a chalky appearance and development of stylolites and calcite veins. The middle part is reported to be generally shaly with intercalations of limestone containing pyrite that indicates anoxic conditions. The lower part is similar in appearance to the upper part with intercalations of shaly limestone and calcareous shale. However, the exposed surface lithology of the Kometan Formation in NE Iraq is completely different to subsurface lithofacies. Therefore, the division of Haddad & Amin (2007) for the subsurface lithology of the Kometan Formation cannot be applied into the area studied.

The lithology, thickness, biostratigraphic age based on planktonic foraminifera and the lower boundary of the Kometan Formation in the localities studied are described in detail in Chapter 2.

Formation	Reference					
	Van Bellen <i>et al.</i> ([1959]-2005)	Youkhanna (1976)	Buday (1980)	Kaddouri (1982)	Al-Tamemmy (1986)	Al-Jassim <i>et al.</i> (1989)
Kometan	Turonian - Santonian	Turonian - Santonian	Turonian - Santonian	late Turonian - early Campanian	Turonian - early Campanian	late Turonian - early Campanian
	Al-Sheikhly <i>et al.</i> (1989)	Abawi & Hammoudi (1997)		Al-Khafaf (2005)	Hammoudi & Abawi (2006)	Sharbazhery (2008)
	late Turonian - early Campanian	late Turonian - early Campanian		mid Turonian - early Campanian	late Turonian - early Campanian	mid Turonian - early Campanian

Table 1.1. Biostratigraphical age assignments for the Kometan Formation in different localities in Iraq based on previous studies.

Shiranish Formation (late Campanian-early Maastrichtian)

The late Campanian-early Maastrichtian Shiranish Formation was deposited during a regional transgressive-regressive cycle in Iraq (Al-Qayim *et al.* 1986; Jassim & Goff 2006;

Al-Banna 2010). The formation crops out in most of north, northwest and northeast Iraq, and is also detected in the subsurface in many wells across the central part of Iraq (Al-Omari & Sadek 1974). The formation has been studied in different regions of Iraq as regards its lithological, palaeontological and sequence stratigraphical significance (Van Bellen *et al.* 2005, Buday 1980, Jassim & Goff 2006; Al-Banna 2010). According to Aqrawi *et al.* (2010), when the Shiranish Formation is marly, it tends not to produce oil, but when it is represented by fractured argillaceous limestones and micritic marls, it forms a significant secondary reservoir. In some wells in northern Iraq, the fractured Shiranish Formation has produced 30,000 barrels of oil/per day (Aqrawi *et al.* 2010).

Table 1.2 summarises the estimated ages of the Shiranish Formation based on planktonic foraminiferal data from previous studies in different localities in Iraq. In brief, the type section of the Shiranish Formation from the village of Shiranish Islam, NE of Zakho comprises 228 m of thin-bedded marly limestone in the lower part and blue marls in the upper part (Van Bellen *et al.* 2005; Buday 1980; Jassim & Goff 2006).

The lithology, depositional environment, thickness, estimated biostratigraphical age based on planktonic and benthonic foraminifera and the lower boundary of the Shiranish Formation in the localities studied are described in chapters 2, 4 and 5.

Formation	Reference					
	Van Bellen <i>et al.</i> ([1959]-2005)	Al-Naqib (1967)	Kureshy (1969)	Al-Shaibani (1973)	Kassab (1972, 1973)	Abawi <i>et al.</i> (1982)
Shiranish	latest Campanian - Maastrichtian	Maastrichtian	Senonian	mid Maastrichtian	Maastrichtian	Campanian - mid Maastrichtian
	Abdel-Kireem (1983, 1986a)	Al-Shaibani <i>et al.</i> (1993)	Kennedy & Lunn (2000)	Sharbazhery (2008)	Al-Hadiedi (2010)	Al-Banna (2010)
	Campanian - mid Maastrichtian	late Campanian - late Maastrichtian	Late Campanian	late Campanian - mid Maastrichtian	late Campanian - early Maastrichtian	late Campanian - early Maastrichtian

Table 1.2. Biostratigraphical age assignments for the Shiranish Formation in different localities in Iraq based on previous studies.

Material

Two sections, one at Dokan located in the north-western and the other at Azmer located in the north-eastern part of the Sulaimani Governorate were chosen for foraminiferal analysis since these sections present near-complete Late Cretaceous successions of rocks. The Kometan and Shiranish formations are the most widespread lithostratigraphic units of the early Turonian-early Maastrichtian succession in NE Iraq which contain rich and diverse planktonic foraminiferal assemblages that can be used for high-resolution biostratigraphy. The sections encompass the lateral and vertical facies changes, faunal assemblage changes and boundary contacts between the exposed formations from the Turonian to Maastrichtian along the Zagros Foreland Basin. All the materials were collected during fieldwork in the areas. The total thickness and geographical co-ordinates of each section are given in Table 1.3. The number of samples collected for each formation is given in Table 1.4.

Sections	Latitude N	Longitude E	Kometan thickness (m)	Shiranish thickness (m)
Dokan	35° 56' 15"	44° 57' 21"	158	260
Azmer	35° 37' 30"	45° 31' 45"	96.5	144

Table 1.3. Geographical positions and thicknesses of the selected Late Cretaceous successions in the Kurdistan region, NE Iraq.

Sections	Qamchuqa Formation (Early Cretaceous)	Balambo Formation (Early Cretaceous)	Kometan Formation (early Turonian-early Campanian)	Shiranish Formation (late Campanian-early Maastrichtian)	Tanjero Formation (late Maastrichtian)
Dokan	7	—	109	133	5
Azmer	—	10	67	102	4

Table 1.4. Number of collected samples in the studied sections. Samples from the Qamchuqa, Balambo and Tanjero formations have not been analysed in this study.

Geological setting

From a structural perspective the study area is located in the north-western segment of the Zagros Fold-Thrust Belt, directly to the southwest of the Main Zagros Suture Zone (Stocklin 1968; Buday 1980; Buday & Jassim 1987; McQuarrie 2004; Jassim & Goff 2006). The study area has been divided into two main tectonic zones that are separated from each other by major basement faults (Ibrahim 2009). According to the most recent tectonic classification of Iraq by Ibrahim (2009), the Azmer section is located in the Zagros Imbricate Zone of Iraq, while the Dokan section is situated in the Zagros Foreland High Folds Zone (Fig. 1.3).

The Zagros Imbricate Zone is intensively deformed and characterised by rock displacements and crustal thickening. Geomorphologically, it is characterised by high mountains with deep incised valleys, and is a product of imbricate thrust sheets and NE-dipping thrust faults. The present structural characteristics of this zone are a result of the Late Cretaceous obduction of ophiolites and Late Tertiary Arabian-Iranian collision (Ibrahim 2009).

The Zagros Foreland High Folds Zone are linear, curvilinear, asymmetrical, double plunging, high amplitude, convergent and divergent folds. Major NW-SE trending and SW dipping thrust faults are also one of the characteristic features of this zone (Ibrahim 2009).

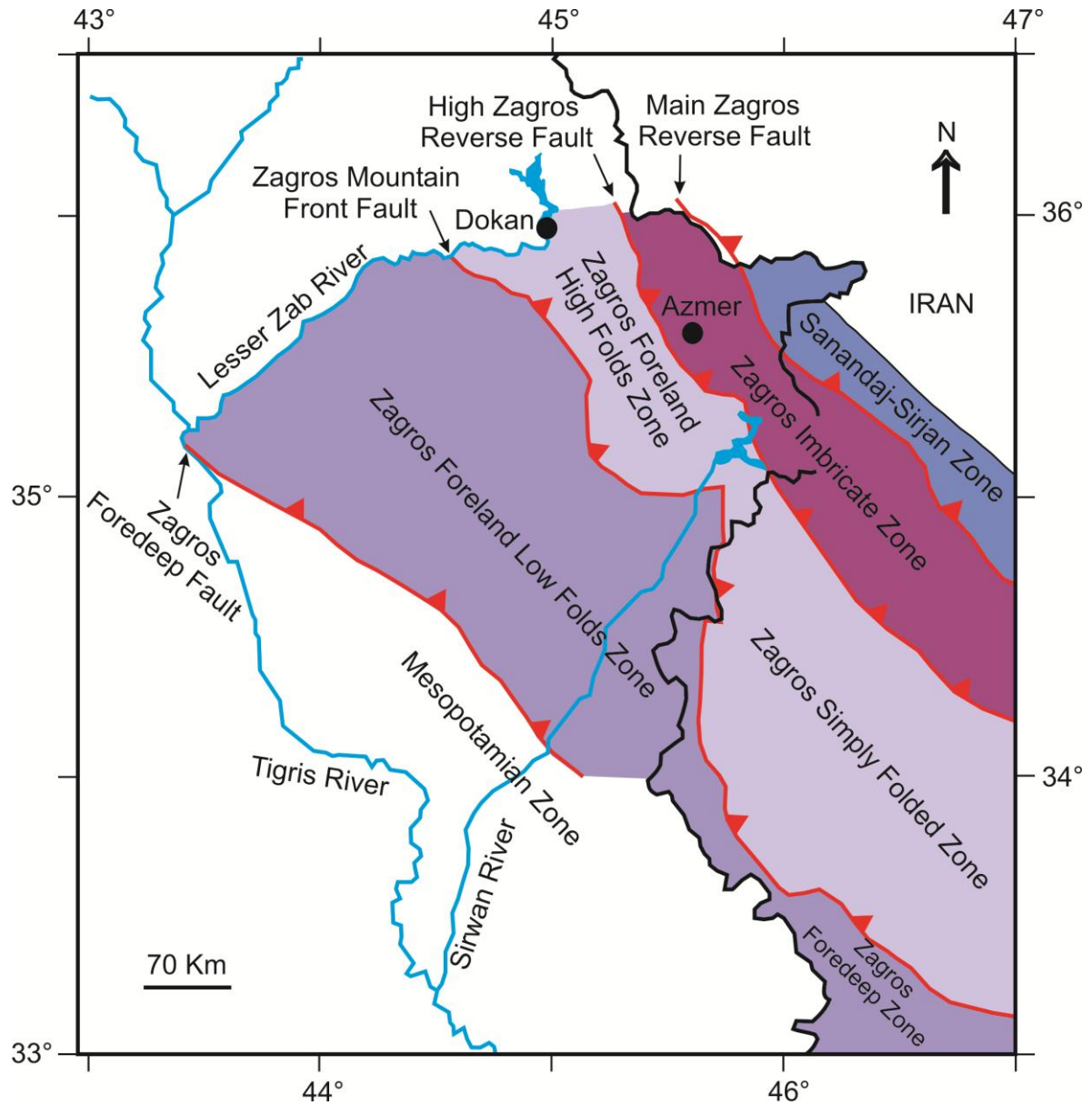


Figure 1.3. The main tectonic zones in the area studied and their continuation in Iran. The black zigzag line represents the formal boundary between Iraq and Iran. The major basement faults which separate the main tectonic zones are drawn in red lines (map after Ibrahim 2009). The locations of the sections studied in NE Iraq are shown as black circles.

Methodology and techniques

The methods used in this study are summarised here and also described in detail in each relevant chapter.

- Fieldwork collection and systematic sampling and recording of stratigraphic data over the selected two sections in the Kurdistan region, NE Iraq.
- Use of thin sections for identifying planktonic foraminifera, especially in the pelagic limestones of the Kometan Formation and the indurated marlstones and marly limestones of the Shiranish Formation.
- For friable samples of the Shiranish Formation, approximately 200-300 grams of each dried soft sample was processed by repeated freezing and thawing until the sediments disaggregated in a supersaturated solution of sodium sulphate. Disaggregated sediments were washed thoroughly through a 63 μm sieve and the residues separated by filtration and dried overnight. Dried residues were then size-sorted through sieves from 500 μm down to 63 μm . Foraminifera were picked using a fine brush under the binocular microscope and studied from the residue in the 63-300 μm size fractions for planktonic foraminifera and > 63 μm for benthonic foraminifera.
- Some extracted specimens from the Shiranish Formation were coated with gold aluminium alloy (Emitech K500X) and imaged with the scanning electron microscope Hitachi S-3600N at the University of Leicester.
- Planktonic foraminifera examined in thin section were photographed with a digital camera (Canon DS126201) at the University of Leicester.
- The SEM was used for identification of planktonic and benthonic foraminifera in each section.

Chapter summary

Overview of Chapter 2: This chapter describes in detail the Late Cretaceous planktonic foraminiferal biostratigraphy and palaeoceanography of the planktonic foraminifera from NE Iraq. It also describes the nature of the contact between the Kometan and the overlying Shiranish Formation in NE Iraq. These results form a research paper, submitted to the Journal of Micropalaentology (Rawand B. N. Jaff., Ian P. Wilkinson, Sarah Lee, Jan Zalasiewicz, Fadhil Lawa and Mark Williams. 'Biostratigraphy and palaeoceanography of the early Turonian-early Maastrichtian planktonic foraminifera of northeast Iraq') that is currently under press.

Overview of Chapter 3: This chapter describes the systematic palaeontology of the Late Cretaceous Heterohellicidae (planktonic foraminifera) in the Kurdistan region, NE Iraq. It also deals with the important role of this group played in biostratigraphic analysis when index species of dicarinellids, marginotruncanids and globotruncanids were absent. Some 24 species belonging to 8 genera are illustrated and described.

Overview of Chapter 4: In this chapter the role of species of the benthonic foraminiferal genus *Bolivinoidea* from the late Campanian-early Maastrichtian Shiranish Formation have been described in detail for the first time in Iraq, and correlated with biozonations for the Middle East and North Africa. These results have been published in *GeoArabia* (Jaff, R. B. N., Williams, M., Wilkinson, I. P., Lawa, F., Lee, S. and Zalasiewicz, J. 2014. 'A refined foraminiferal biostratigraphy for the late Campanian-early Maastrichtian succession of northeast Iraq.' *GeoArabia*, **19** (1), 161-180).

Overview of Chapter 5: This chapter documents the role of palaeoenvironments on the distribution of planktonic and benthonic foraminifera from the late Campanian-early Maastrichtian Shiranish Formation. It also deals with the important role of benthonic foraminifera in the palaeobathymetric analysis of the rock succession. Benthonic foraminiferal assemblages record a gradual decrease in water depth from the latest Campanian. Based on the upper depth limits of some benthonic foraminifera, the Shiranish Formation was deposited in a middle slope to outer shelf depositional setting.

With the exception of the introduction and conclusion chapters, each chapter of this thesis has been written in the format of a separate research paper.

Chapter 2

Biostratigraphy and
palaeoceanography of the
early Turonian-early
Maastrichtian planktonic
foraminifera of
northeast Iraq

Chapter 2: Biostratigraphy and palaeoceanography of the early Turonian-early Maastrichtian planktonic foraminifera of northeast Iraq

Abstract

The Late 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, recognised 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.

Introduction

The evolution of planktonic foraminifera from the Turonian to the early Maastrichtian is characterised 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 (Gandolfi 1955; Pessagno 1967; Premoli Silva & Sliter 1999; Pecimotika *et al.* 2014).

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. 2.1) 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 chapter presents a revised and refined planktonic foraminiferal biozonation for the early Turonian to early Maastrichtian interval of NE Iraq and recognises 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.

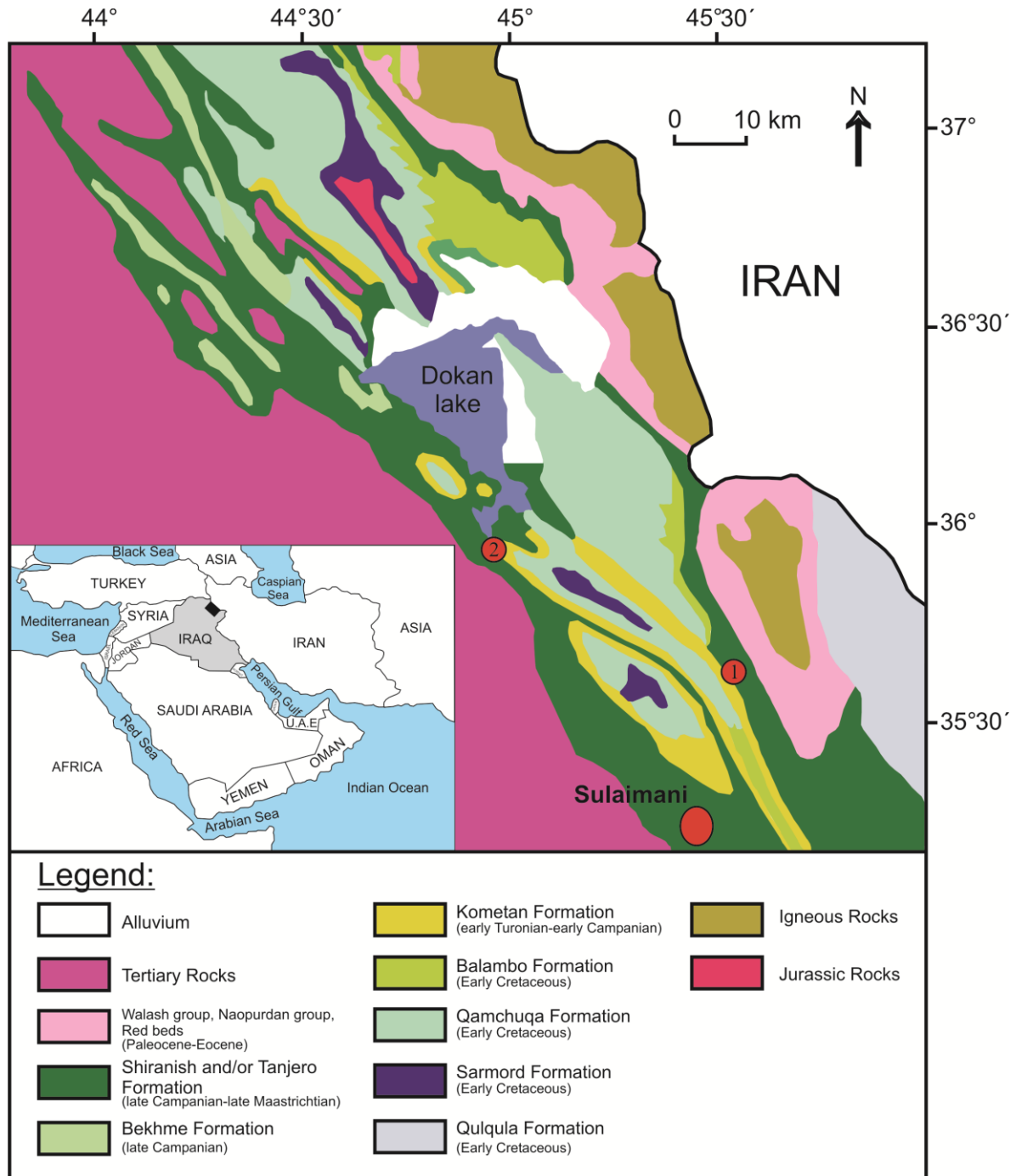


Figure 2.1. Geological context for the Azmer (1) and Dokan (2) sections of the Kometan and Shiranish formations in the Kurdistan region of NE Iraq (map after Sissakian 2000). The Dokan section runs parallel to the left bank of the Dokan Dam, near the Dokan tourist village. The Azmer section is located about 15 km to the NE of Sulaimani city. Small black rectangle on inset map represents study-area.

Materials and Methods

Two sections, at Dokan (latitude 35° 56' 15" N, longitude 44° 57' 21" E) and Azmer (latitude 35° 37' 30" N, longitude 45° 31' 45" E; see Fig. 2.1) were chosen for foraminiferal analysis: these sections present near-complete Late Cretaceous successions of rocks. The Kometan and Shiranish formations are the most widespread lithostratigraphic units of the early Turonian-early Maastrichtian 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. 2.2).

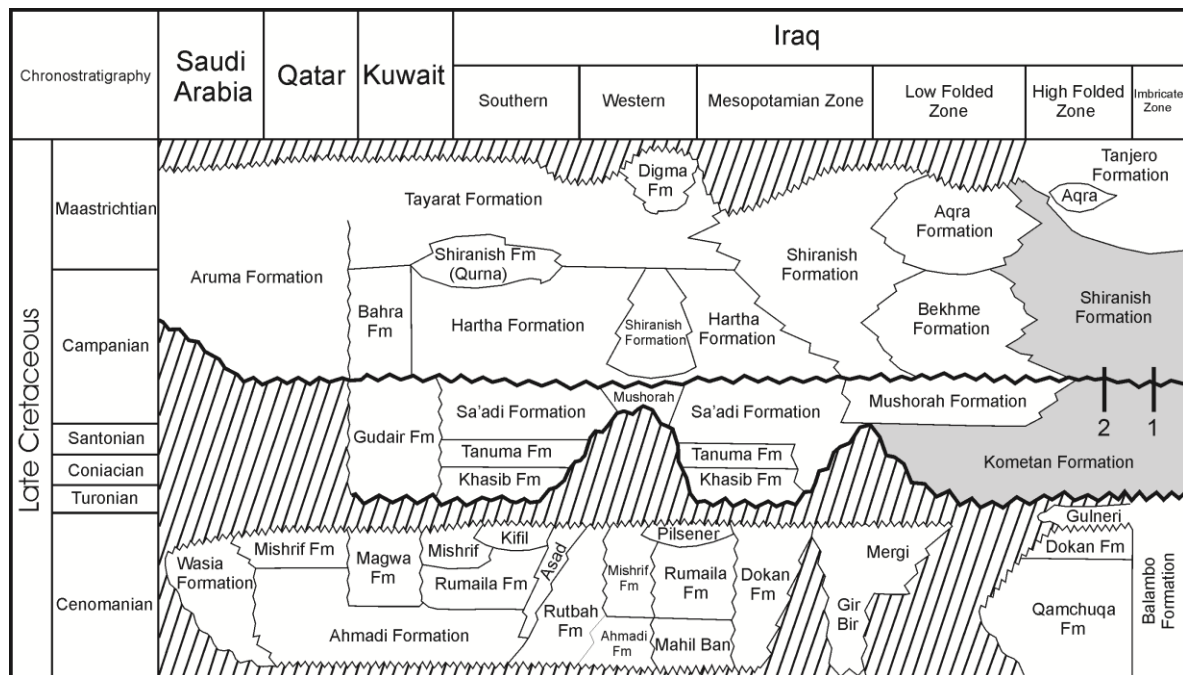


Figure 2.2. Lithostratigraphy and chronostratigraphy for the Late Cretaceous succession in Iraq and neighbouring Arabian countries. The lower and upper boundary and the distribution of the Kometan and Shiranish formations are indicated in light grey. The earliest Turonian and the mid to early late Campanian unconformities are shown in thick zigzag lines (modified from Al-Naqib 1967). The Azmer section is located in the Imbricate Zone indicated by the thick line as (1), while the Dokan section is situated in the High Folded Zone of Iraq (2).

Some 411 samples, spaced ca 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 recrystallised 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 recognised in axial and subaxial sections passing through or parallel to the axis of coiling (Sliter 1989; Sari 2006).

For the samples from the Shiranish Formation, both thin sections and a freeze-thaw method of disaggregating the rock have been used (Mogaddam 2002; Jaff *et al.* 2014). Approximately 200-300 grams 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 down to 63 μm . 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 El-Naggar (1966), Pessagno (1967), Postuma (1971), 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 chapter are deposited in the collections of the British Geological Survey, Keyworth, Nottingham, UK.

Lithostratigraphy

The Late Cretaceous (early Turonian to early Maastrichtian) strata of NE Iraq comprise two marine deposited formations: the pelagic limestone of the Kometan Formation (early Turonian to early Campanian) and the marly limestones and marlstones of the Shiranish Formation (late Campanian to 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.* 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 southwest of Iraq. The base of the Kometan Formation is unconformable on the underlying Balambo and Qamchuqa formations in NE Iraq (which are early Cenomanian; Van Bellen *et al.* 2005; Buday 1980; Jassim & Goff 2006; Ameen & Gharib 2014; see Fig. 2.2).

The Kometan Formation has thicknesses of approximately 158 m 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. 2.3A and C). The top of the Kometan Formation records a local extinction of large ammonites (Fig. 2.3I and J). This extinction might be related to the truncation 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* that may indicate a period of slow or non-deposition (Fig. 2.3F). In the Azmer area the Kometan Formation is mainly composed of light grey, medium-bedded limestone (Fig. 2.3B): 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.* 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' characterised by alternating marly limestone and calcareous marlstone that is rich in foraminifera, and an 'upper unit' that is dominated by blue marlstone (Van Bellen *et al.* 2005; 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 in NE Iraq (Sharbazheri 2008; see Fig. 2.2).

The Shiranish Formation is well exposed in the localities studied and is about 260 m 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. 2.3G 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 only locally developed and hence is not recognised as a separate member in the Shiranish Formation.

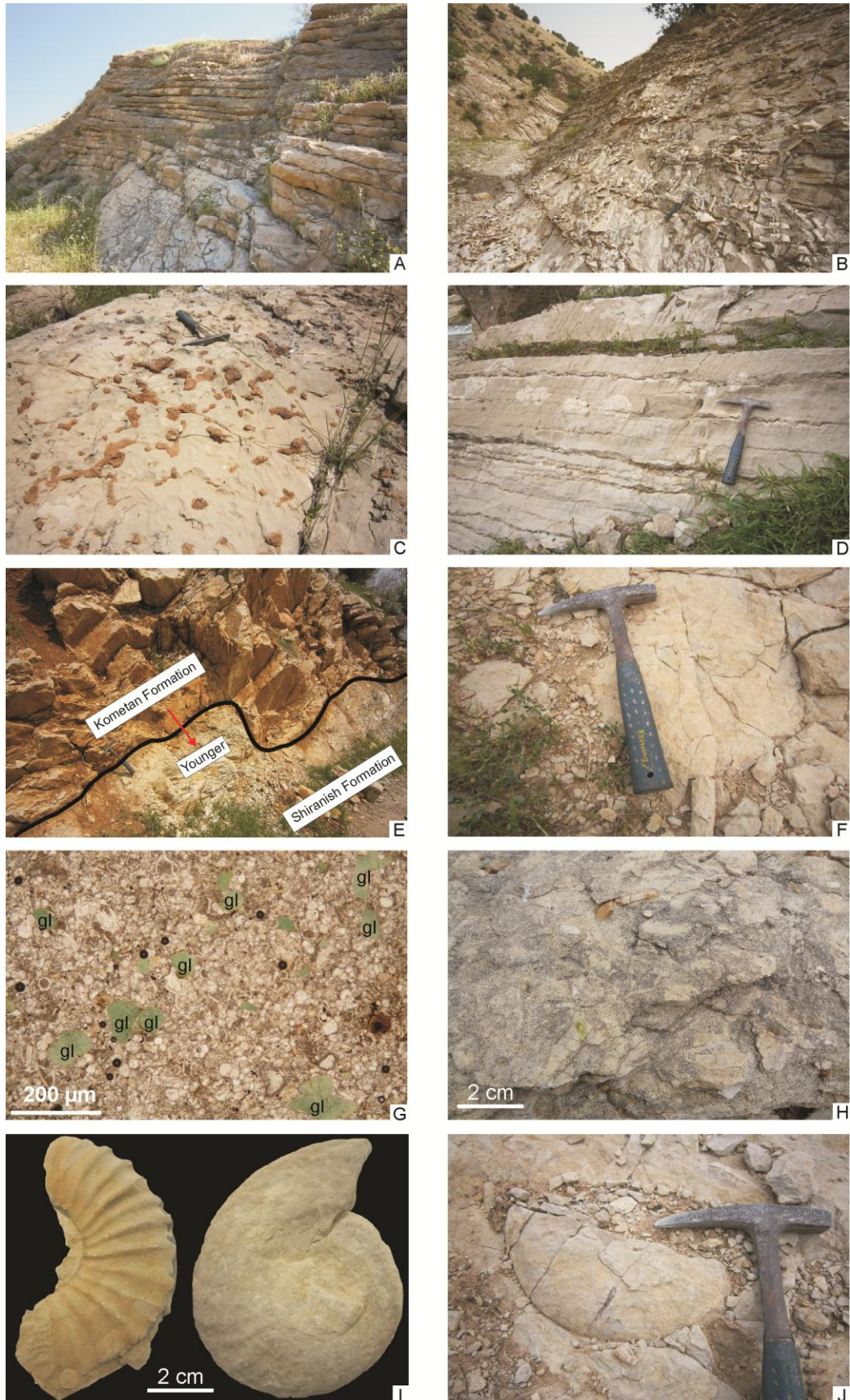


Figure 2.3. Field photos of the Kometan and Shiranish formations in the Dokan and the Azmer areas in the Kurdistan region, NE Iraq. A, B: Well-bedded, medium to thick-bedded pelagic limestone of the Kometan Formation. C: Chert nodules in the Kometan Formation, showing the long axes of the nodules to be 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 Shiranish Formation in the 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 in the Dokan area, near the contact with the overlying Shiranish Formation. G: Glauconite (gl) mineral seen with the binocular microscope at the base of the Shiranish Formation in the Dokan area. H: Glauconitic cherty sandstone bed at the base of the Shiranish Formation in the Dokan area. I, J: Large ammonites at the top of the Kometan Formation in the Azmer and Dokan areas respectively.

Planktonic foraminiferal biozonation

Some 93 planktonic foraminiferal species belonging to 23 genera have been identified in the Kometan and the Shiranish formations during the present study (Appendix 1). The stratigraphic distribution of these foraminifera permits the recognition of nine biozones and two subzones in the Late Cretaceous (early Turonian-early Maastrichtian) succession. Five of the biozones are identified as interval zones (IZ): the *Dicarinella primitiva* IZ, the *Dicarinella concavata* IZ, the *Globotruncana aegyptiaca* IZ, the *Gansserina gansseri* IZ (which can be subdivided into the *Pseudoguembelina excolata* and *Planoglobulina acervulinoides* subzones) and the *Contusotruncana 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 first and last appearance datum (FAD, LAD) of *Helvetoglobotruncana helvetica* (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 facies change at the unconformable contact with the underlying Balambo and Qamchuqa formations. It is uncertain, therefore, whether the base of the biozone as defined equates to the global FAD of *H. helvetica*. In the Azmer section the *H. helvetica* biozone is identified through about 5.5 m of strata, from sample numbers AK-1 to AK-3, and in the Dokan section through about 8 m of strata, from sample numbers DK-01 to DK-04 (see Fig. 2.4): the eponymous biozonal species occurs rarely in both sections. Although previous work suggested that *H. helvetica* is indicative of the mid-Turonian (Wonders 1980; Salaj 1980, 1997; Robaszynski *et al.* 1984; Caron 1985; Sliter 1989; Abdel-Kireem *et al.* 1995; El Albani *et al.* 1999; Tur *et al.* 2001; Premoli Silva & Verga 2004; Abawi & Mahmood 2005), it is now considered to denote an interval in the early Turonian (Caron *et al.* 2006; Desmares *et al.* 2007; Gebhardt *et al.* 2010; Ogg & Hinnov 2012; Zaghib-Turki & Soua 2013; Huber & Petrizzo 2014; Vahidinia *et al.* 2014; see Fig. 2.5). The *H. helvetica* biozone also represents the maximum abundance and diversity of whiteinellid planktonic foraminifera, with five species recorded. The most abundant planktonic foraminiferal species in this biozone are *Heterohelix moremani* and *H. globulosa* (see Figs 2.6, 2.7).

***Marginotruncana schneegansi* Partial Range Zone, mid-late Turonian**

This is a partial range zone between the LAD of *Helvetoglobotruncana helvetica* and the FAD of *Dicarinella primitiva* (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. 2.4). 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; El Albani *et al.* 1999). However, Robaszynski & Caron (1995) recognised 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. 2.5). 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 2.6 and 2.7.

***Dicarinella primitiva* Interval Zone, latest Turonian**

This biozone is an interval zone between the FAD of *Dicarinella primitiva* and the FAD of *Dicarinella concavata* (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 most useful subdivision of the late Turonian interval that has also been recognised 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. 2.4). Although several authors (for example Premoli Silva & Boersma 1977; Caron 1978, 1985; Robaszynski & Caron 1979; Wonders 1980; Marks 1984a, b; Abdel-Kireem *et al.* 1995; El Albani *et al.* 1999; Abawi & Mahmood 2005; see Fig. 2.5) have equated the first appearance 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; De Cabrera *et al.* 1999; Zapata *et al.* 2003; 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*. Most recently Elamri *et al.* (2014) recorded *D. primitiva* in northern Tunisia in the late Turonian, whilst Vahidinia *et al.* (2014) recorded the LO of *D. primitiva* before the LO of *D. concavata* in NE Iran and they assigned the level to the late Turonian. The maximum diversification of marginotruncanids, with seven species, is recognised within this biozone (Figs 2.6, 2.7).

***Dicarinella concavata* Interval Zone, early-late Coniacian**

In NE Iraq this biozone is defined as an interval zone between the FAD of *Dicarinella concavata* and the FAD of *Dicarinella asymetrica* (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. 2.4). Although several authors (for example Barr 1972; Premoli Silva & Bolli 1973; Premoli Silva & Boersma 1977; Caron 1978, 1985; Marks 1984a; Abdel-Kireem *et al.* 1995; Mancini *et al.* 1996; El Albani *et al.* 1999; Tur *et al.* 2001; Abawi & Mahmood 2005; Sari 2006, 2009; Farouk & Faris 2012; see Fig. 2.5) have equated the earliest occurrence of *D. concavata* with the mid-late Coniacian, Premoli Silva & Sliter (1994) recognised 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 & Hinnov 2012; Kochhann *et al.* 2014). In Africa, Iran and 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; Gebhardt 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 are marginotruncanids. The FAD of species of the genus *Globotruncana* (*Globotruncana angusticarinata*; see Appendix 1 for taxonomic comments) also falls within this biozone (see Figs 2.6, 2.7).

***Dicarinella asymetrica* Total Range Zone, early-late Santonian**

The lower and upper boundaries of this biozone are marked by the FAD and LAD of *Dicarinella asymetrica* (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. 2.4). Although several authors (for example Robaszynski *et al.* 1984; 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 & Özcan 1999;

Robaszynski *et al.* 2000; Bauer *et al.* 2001; Premoli Silva & Verga 2004; Sari 2006, 2009; Babazadeh *et al.* 2007; 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 (Lamolda *et al.* 2007; Gale *et al.* 2007). Based on the most recent calibration for the Late Cretaceous planktonic foraminiferal biozonation by Ogg & Hinnov (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 & Hinnov *op. cit.*, p. 805; Elamri *et al.* 2014; Vahidinia *et al.* 2014; Kochhann *et al.* 2014; see also Marks 1984b, p. 166; El Albani *et al.* 1999, fig. 3; De Cabrera *et al.* 1999, figs 2, 4-8; Zapata *et al.* 2003, figs 13, 14). Lamolda *et al.* (2014) used inoceramid bivalves (*Platyceramus undulatoaplicatus*) 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 FAD of *D. asymetrica* is taken as the approximate marker for the base of the Santonian. The LAD of *D. asymetrica* also defines the Santonian-Campanian boundary (Marks 1984b; Caron 1985; Honigstein *et al.* 1987; Sliter 1989; Dowsett 1989; Gvirtzman *et al.* 1989; Almogi-Labin *et al.* 1991; Gale *et al.* 1995; Ayyad *et al.* 1996; Mancini *et al.* 1996; El Albani *et al.* 1999; Özkan-Altiner & Özcan 1999; Zapata *et al.* 2003; Sari 2006, 2009; Babazadeh *et al.* 2007; Ogg & Hinnov 2012; Elamri & Zaghib-Turki 2014; Elamri *et al.* 2014; Kochhann *et al.* 2014). Recently, Sageman *et al.* (2014) based on a set of $^{40}\text{Ar}/^{39}\text{Ar}$, 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 FAD of *D. asymetrica* of Ogg & Hinnov (2012). Moreover, the LAD of *D. asymetrica* is regarded as equivalent to the boundary of the reversed polarity Chron C33r, the latter magnetic marker being considered for defining the base of the Campanian (Campanian Working Group of the International Commission on Stratigraphy, *fide* Ogg & Hinnov 2012, p. 806). This Chron boundary also coincides with the base of the *Scaphites leei* III ammonite biozone of the North American Western Interior (Ogg & Hinnov 2012 and references therein, fig. 27.6). Marginotruncanids tend to become rare within this biozone, except for *Marginotruncana coronata* and *M. marginata* (Figs 2.6, 2.7). In contrast, some five species of *Globotruncana* are recorded towards the top of the biozone where a distinct interval is recognisable, marked by the FAD

of *G. bulloides* (Figs 2.6, 2.7). In addition, the FAD of *Globotruncanita elevata* and *G. stuartiformis* also fall within this biozone (Figs 2.6, 2.7). The boundary between the *Dicarinella asymetrica* and the succeeding *Globotruncanita elevata* biozone marks the extinction of many mid-Cretaceous planktonic foraminifer species globally (Sliter 1989; Petrizzo 2002; Sari 2006, 2009; Elamri & Zaghib-Turki 2014; Elamri *et al.* 2014; Kochhann *et al.* 2014; Pecimotika *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 *Marginotruncana* (*M. coronata*, *M. marginata*) also disappear a little earlier in the succession.

***Globotruncanita elevata* Partial Range Zone, early Campanian**

This is a partial range zone, recognised in NE Iraq from the LAD 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 characterised by the dominance and abundance of globotruncanids and heterohelicids with common benthonic foraminifera such as *Lenticulina* and *Textularia* (Figs 2.6, 2.7), 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. 2.4).

Although some authors (for example Barr 1972; Wonders 1980; Salaj 1980, 1997; see Fig. 2.5) have equated the first appearance of *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 recognised, is coincident with the base of the Campanian (Premoli Silva & Bolli 1973; Robaszynski *et al.* 1984; Dowsett 1984, 1989; Caron 1985; Honigstein *et al.* 1987; Sliter 1989; Almogi-Labin *et al.* 1991; Abdel-Kireem *et al.* 1995; Ayyad *et al.* 1996; Mancini *et al.* 1996; Robaszynski 1998; El Albani *et al.* 1999; Özkan-Altiner & Özcan 1999; Robaszynski *et al.* 2000; Zapata *et al.* 2003; Chacón *et al.* 2004; Abawi & Mahmood 2005; Babazadeh *et al.* 2007; Li *et al.* 2011; Farouk & Faris 2012; Ogg & Hinnov 2012; Elamri & Zaghib-Turki 2014; Elamri *et al.* 2014; Kochhann *et al.* 2014; see Fig. 2.5).

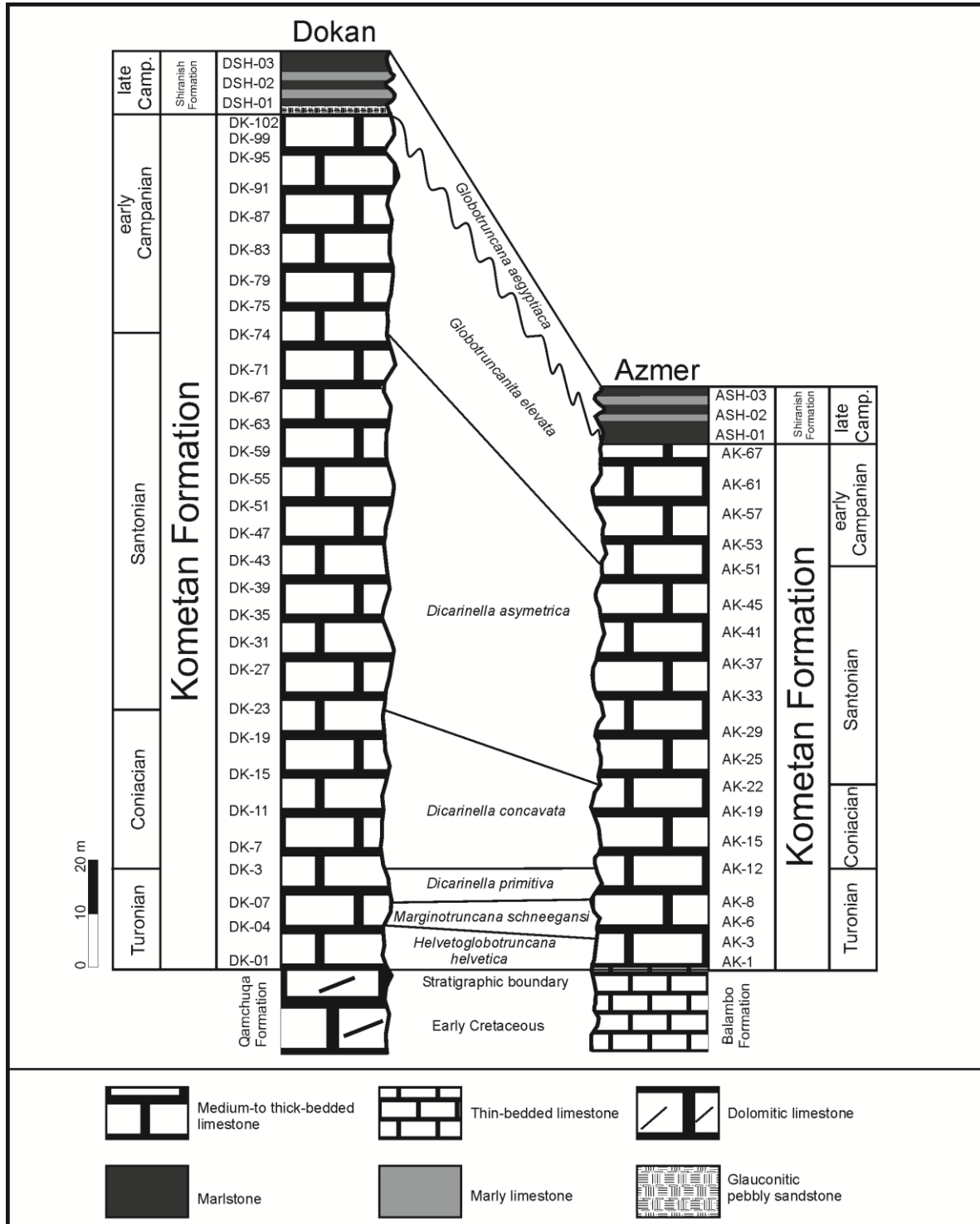


Figure 2.4. Planktonic foraminiferal biozonation for the Kometan Formation in the Kurdistan region, NE Iraq.

Age	Stages	Ma	Barr (1972)	Wonders (1980)	Abdel-Kireem et al. (1995)	Sari (2006, 2009)	Babazadeh et al. (2007)	Abawi and Mahmood (2005)	Ogg and Hinnov (2012)	This study	Datum Markers
Maastrichtian	late	66.0	Libya	Mediterranean	Egypt	Turkey	E. Iran	N. Iraq	General	NE. Iraq	Disappearance of all foraminifera F. C. contusa F. G. gansseri F. G. aegyptiaca
			Abathomphalus mayaroensis	Abathomphalus mayaroensis		Abathomphalus mayaroensis			Pl. hantkeninoides Pseudoguembelina hantkenensis Abathomphalus mayaroensis		
	early	72.1	Globotruncana gansseri	Globotruncana gansseri	Gansserina gansseri	Gansserina gansseri			Ricamiguembelina fructuosa P. palaeo	Contusotruncana contusa	
			Globotruncana tricarinata	Globotruncana tricarinata	Gansserina gansseri	Gansserina gansseri			Gansserina gansseri	Gansserina gansseri	
Campanian	late			Globotruncana calcarata	Globotruncana ventricosa	G. falsostuarta R. calcarata			G. aegyptiaca G. havanensis R. calcarata		Truncation of the Komelan Fm. L. D. asymetrica
			Globotruncana ventricosa	Globotruncana ventricosa					Contusotruncana plummerae		
	mid										
Santonian	early	83.6		Globotruncana elevata	Globotruncana elevata				Globotruncana elevata	Globotruncana elevata	F. D. asymetrica
			Globotruncana elevata	Globotruncana elevata							
	late			Globotruncana elevata							
			Globotruncana elevata	Globotruncana elevata							
Coniacian	early	86.3									F. D. asymetrica
	mid										
Turonian	early	89.8									F. D. primitiva F. D. primitiva L. H. helvetica F. H. helvetica
	late										
Maestrichtian	early	93.9									F. D. primitiva F. D. primitiva L. H. helvetica F. H. helvetica
	mid										



L: Last appearance

F: First appearance

Not studied

Hiatus

Figure 2.5. Correlation of the Late 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) lead 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 diachroneity 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 Ogg & 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.

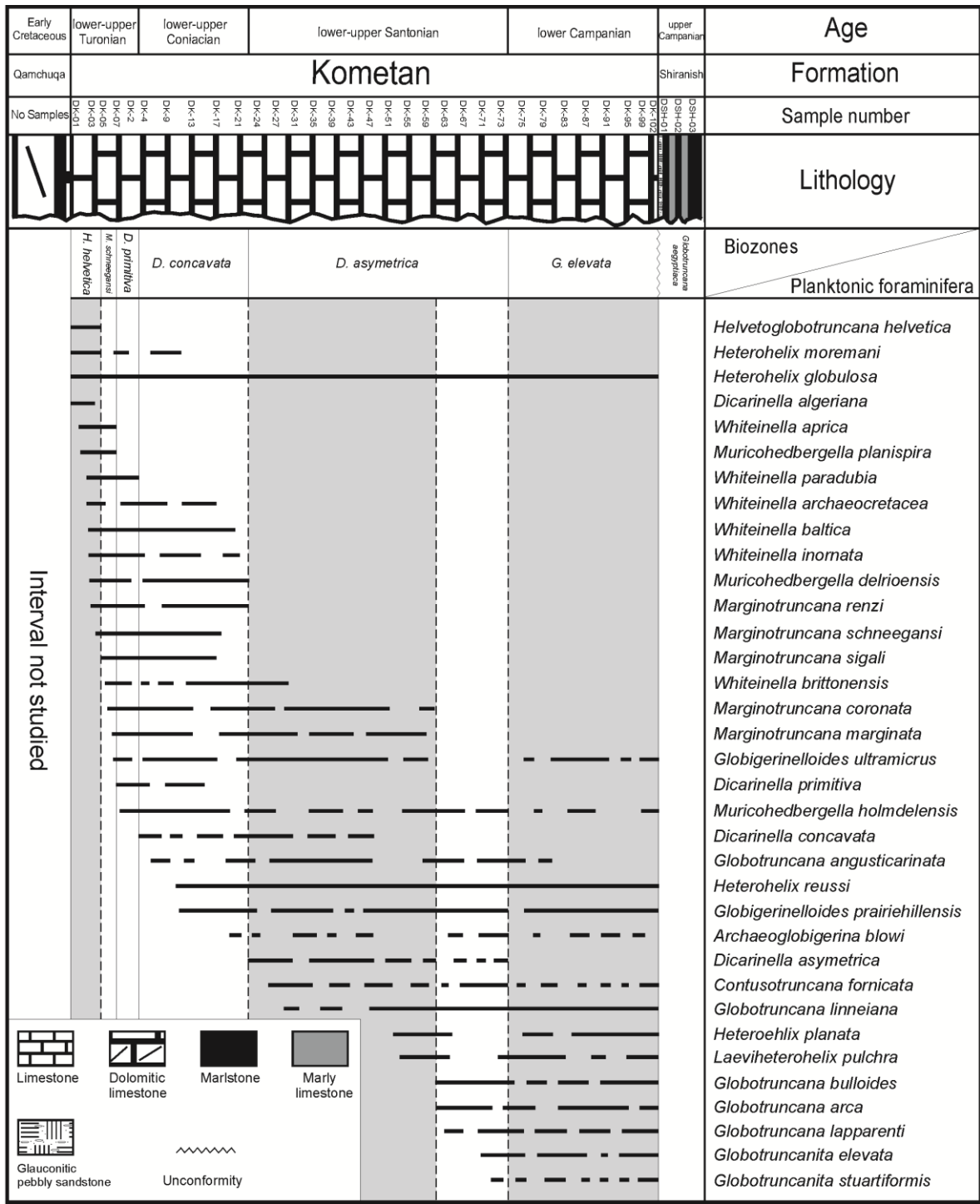


Figure 2.6. Stratigraphic ranges and distribution of recorded planktonic foraminifera for the early Turonian-early Campanian Kometan Formation in the Dokan section. For ranges in the overlying Shiranish Formation see Figure 2.9.

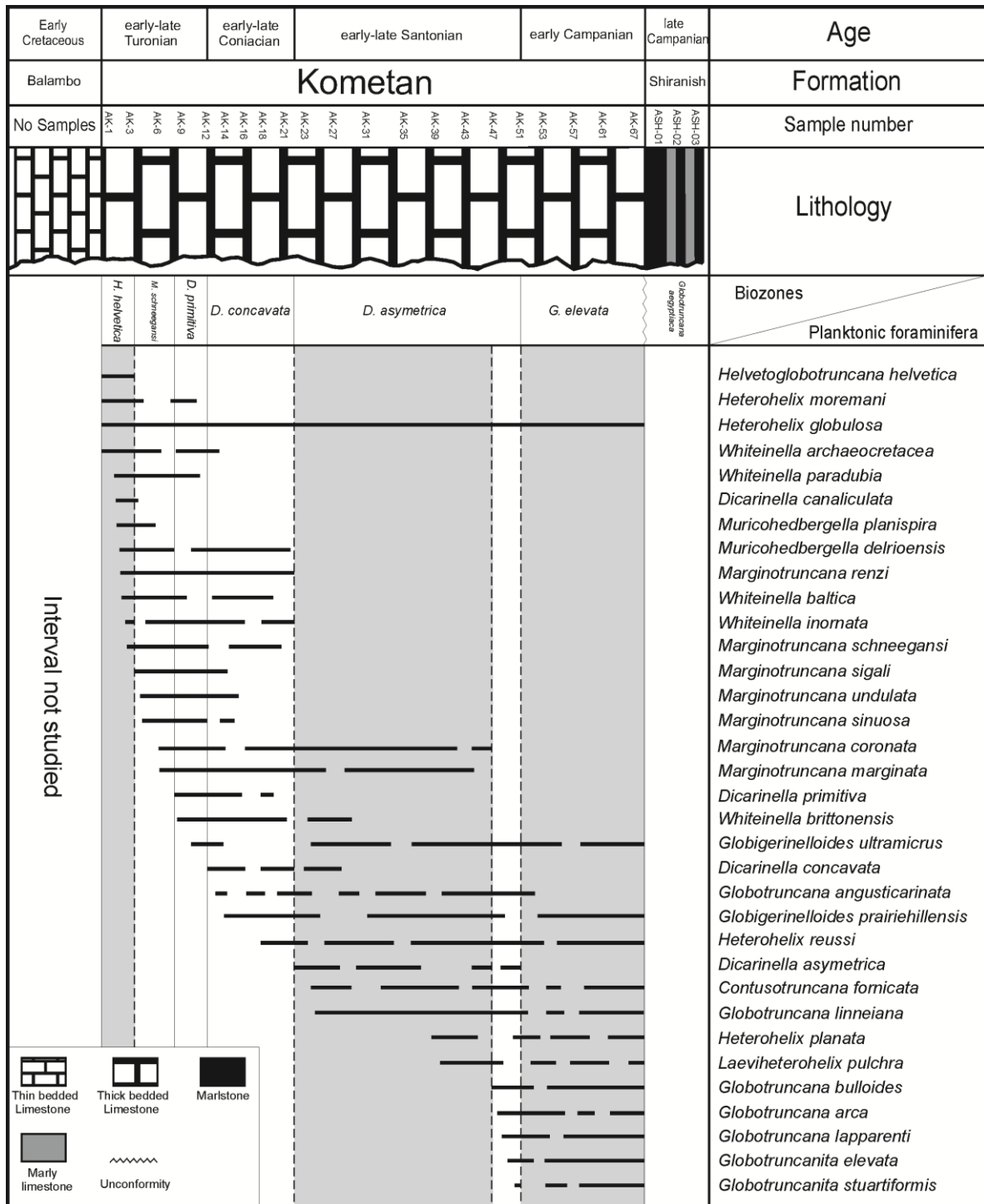


Figure 2.7. Stratigraphic ranges and distribution of recorded planktonic foraminifera for the early Turonian-early Campanian Kometan Formation in the Azmer section. For ranges in the overlying Shiranish Formation see Figure 2.10.

***Globotruncana aegyptiaca* Interval Zone, late Campanian**

This is an interval zone from the FAD of the eponymous species to the FAD of *Gansserina gansseri* (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 FAD of *G. aegyptiaca* may not equate to the global FAD of this species. The biozone is expressed through some 47.5 m of rock in the Azmer section, from sample numbers ASH-01 to ASH-33, and in the Dokan section is about 121 m, from sample numbers DSH-03 to DSH-67 (Fig. 2.8). Some former publications (for example Robaszynski *et al.* 1984; Caron 1985; Sliter 1989; Ayyad *et al.* 1996; Mancini *et al.* 1996) have equated the first appearance of *G. aegyptiaca* with the early Maastrichtian, whilst later works have documented a first occurrence within the late Campanian (Premoli Silva & Sliter 1994, 1999; Li & Keller 1998a, b; Robaszynski 1998; Li *et al.* 1999; Özkan-Altiner & Özcan 1999; Abdelghany 2003; Premoli Silva & Verga 2004; Li *et al.* 2011; Al-Mutwali & Al-Doori 2012; Ogg & Hinnov 2012; Beiranvand & Ghasemi-Nejad 2013; see Fig. 2.5). Due to the rare and sporadic occurrence of *G. aegyptiaca*, the biozonal species was not used by Huber *et al.* (2008) on Blake Nose, IODP (DSDP) site 390A, and (ODP) sites 1049, 1050, and 1052. The maximum abundance and diversification of globotruncanids is in this biozone, coincident with global abundance data presented by Premoli Silva & Sliter (1999; see Figs 2.9, 2.10).

***Gansserina gansseri* Interval Zone, latest Campanian-early Maastrichtian**

This is an interval zone from the FAD of the eponymous species to the FAD of *Contusotruncana contusa* (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. 2.8). Although several authors (for example El-Naggar 1966; 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; Robaszynski *et al.*

2000; Abdelghany 2003; Chacón *et al.* 2004; Premoli Silva & Verga 2004; Sari 2006, 2009; Li *et al.* 2011; Al-Mutwali & Al-Doori 2012; Ogg & Hinnov 2012; Beiranvand & Ghasemi-Nejad 2013; Fig. 2.5). Due to the rare and sporadic occurrence of *G. gansseri*, this biozonal species was not used by Huber *et al.* (2008) on Blake Nose, IODP (DSDP) site 390A, and (ODP) sites 1049, 1050, and 1052. Based on co-occurring planktonic foraminifera in the Shiranish Formation, the *G. gansseri* biozone can be further subdivided into two heterohelicid-based subzones by: 1) the first occurrence of *Pseudoguembelina excolata* (latest Campanian); and 2) succeeding this interval, the first occurrence of *Planoglobulina acervulinoides* (early Maastrichtian; see Fig. 2.8). The *P. excolata* Subzone is represented through nearly 17.5 m and 37.5 m of succession in the Azmer and Dokan sections respectively (Fig. 2.8), and represents an equivalent stratigraphical interval to the lower part of the *G. gansseri* biozone (see Figs 2.8-2.10). The *P. acervulinoides* Subzone is represented through a thickness of about 26 m and 65.5 m in the Azmer and Dokan sections respectively (Fig. 2.8), and represents an equivalent stratigraphical interval to the upper part of the *G. gansseri* biozone (see Figs 2.8-2.10). In this study the FAD of *P. acervulinoides* is used to mark the Campanian-Maastrichtian boundary and this coincides with the FAD 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), Tunisia (Li *et al.* 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 FAD of *P. acervulinoides* coincides (at an earliest Maastrichtian level) with the FAD benthonic foraminifera *Bolivinoidea* 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).

***Contusotruncana contusa* Interval Zone, late early Maastrichtian**

This is an interval zone defined by the FAD of *Contusotruncana contusa* at its base. Although the base of the zone can be recognised in the Shiranish Formation in NE Iraq, the top of the zone cannot be identified due to the sudden disappearance of planktonic foraminifera at the top of the succession. The interval is also associated with the first

occurrences of *Contusotruncana walfischensis* and *Rugoglobigerina scotti* (Figs 2.9, 2.10). *Contusotruncana contusa* was not used either by Huber *et al.* (2008) or Ogg & Hinnov (2012) to discriminate a discrete biozone. Instead, they recognised a *Pseudoguembelina palpebra* biozone (Ogg & Hinnov 2012, fig. 27.6) for the interval succeeding the *G. gansseri* biozone. Given occurrences of *P. palpebra* in sedimentary deposits of latest Maastrichtian age in Tunisia (Li & Keller 1998a, b; Li *et al.* 1999), the South Atlantic (Li & Keller *op. cit.*, a, b; Li *et al. op. cit.*), 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 foraminifera-bearing assemblages in the Shiranish Formation: elsewhere in NE Iraq there are unpublished records of *P. palpebra* that require further investigation. According to Ogg & Hinnov (2012), *Racemiguembelina fructicosa* is a good indicator for the beginning of the late Maastrichtian, but is never found in the Shiranish Formation, although it is present in the overlying late 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-Rodríguez *et al.* (2012) recorded the FAD of *C. contusa* in the *P. palpebra* biozone. Ogg & Hinnov (2012, p. 1102), also show the FAD of *C. contusa* within the *P. palpebra* biozone. This suggests that the *C. contusa* biozone in NE Iraq is likely equivalent, at least in part, to the *P. palpebra* biozone recorded by Ogg & Hinnov (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. 2.8): the interval cannot be recognised in the Azmer section, probably because of lithofacies changes associated with shallowing. *Contusotruncana contusa* occurs frequently, but seems to be limited to the late early Maastrichtian (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. 2.5). Succeeding foraminiferal biozones cannot be recognised 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 that is about 1 m thick, bearing a mass of shallow marine rudist bivalves near the contact with the overlying Tanjero Formation.

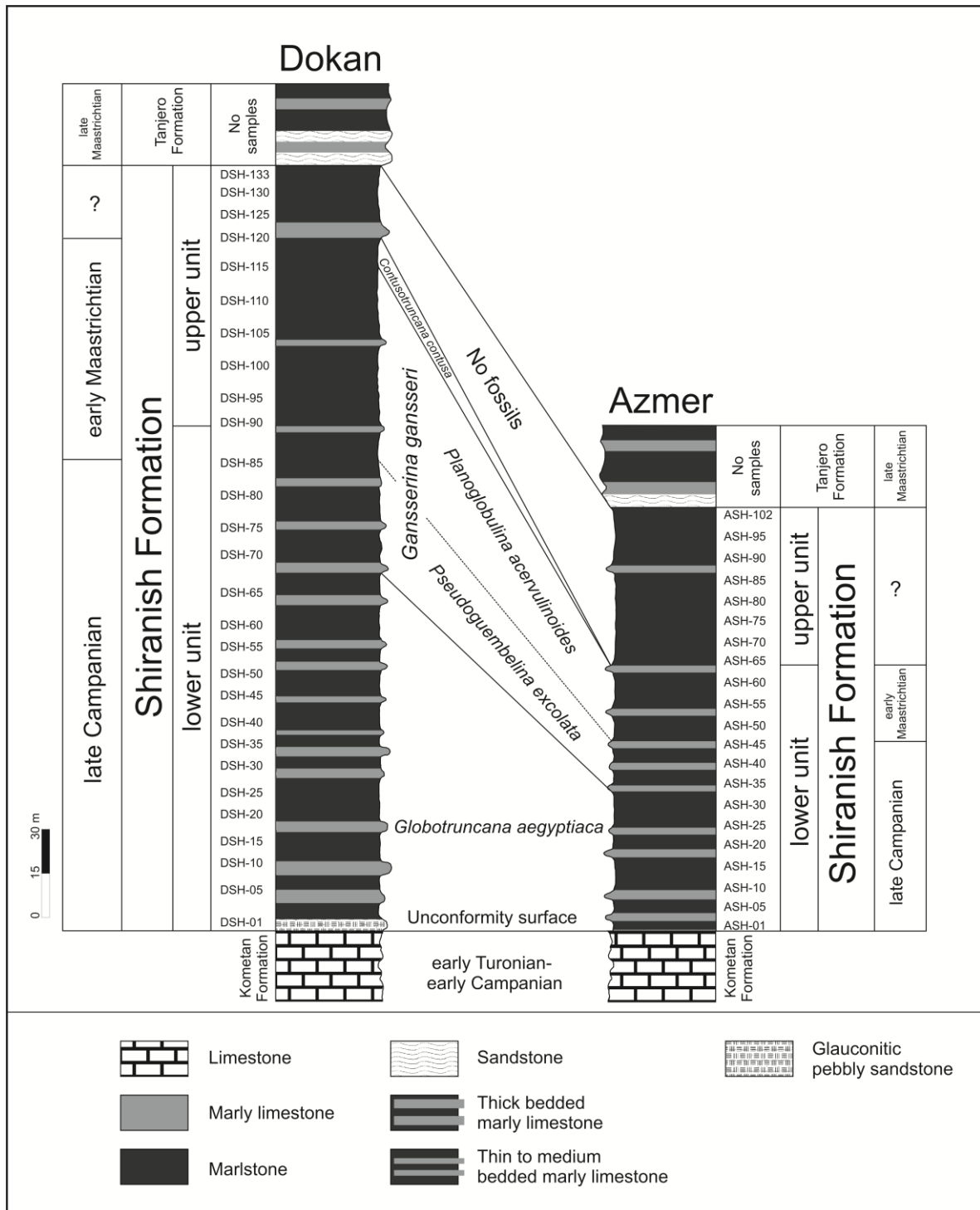


Figure 2.8. Planktonic foraminiferal biozonation for the Shiranish Formation in the Kurdistan region, NE Iraq. The FAD of *Planoglobulina acervulinoides* is used to identify the Campanian-Maastrichtian boundary.

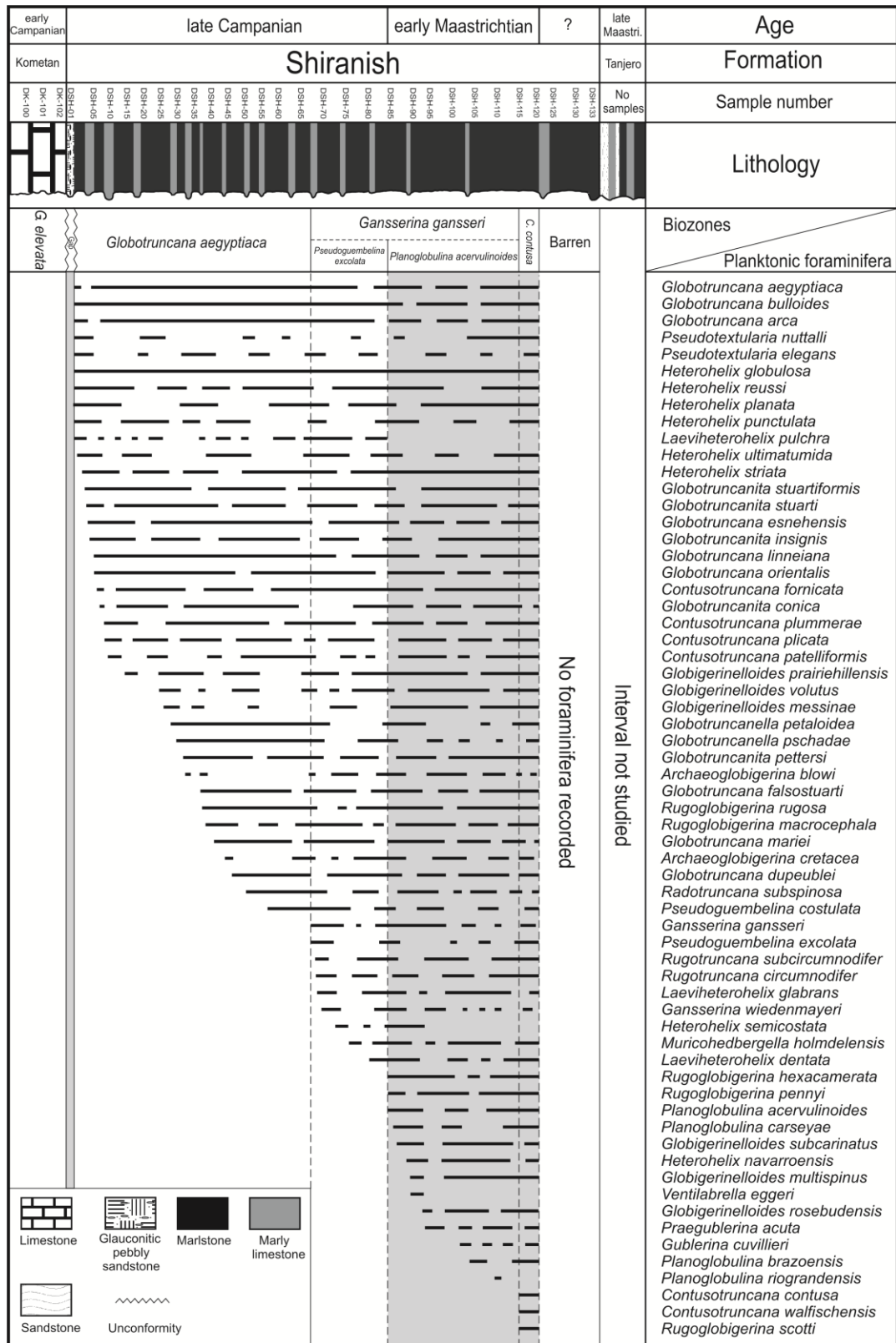


Figure 2.9. Stratigraphic ranges and distribution of planktonic foraminifera for the late Campanian-late early Maastrichtian Shiranish Formation in the Dokan section.

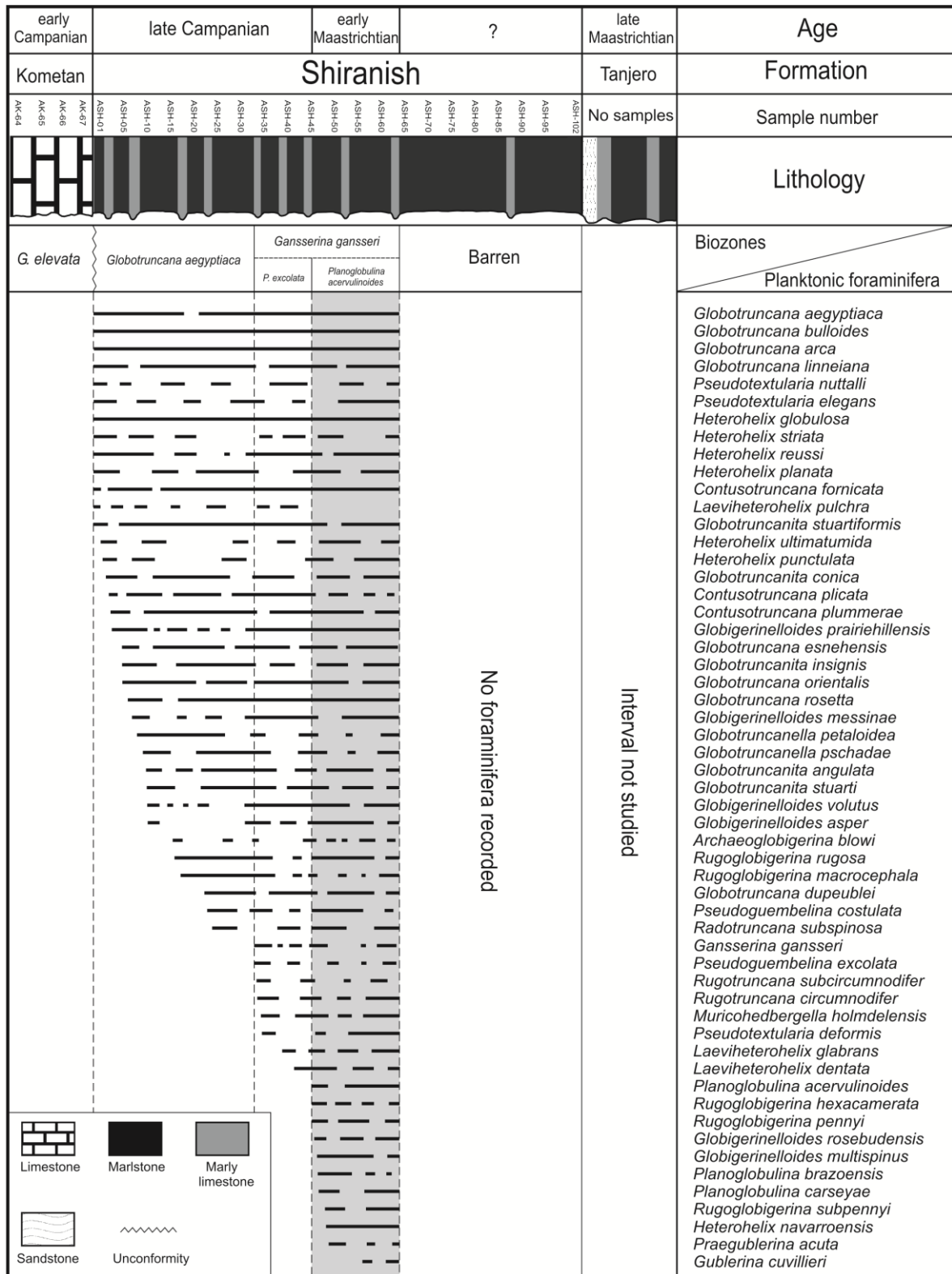


Figure 2.10. Stratigraphic ranges and distribution of planktonic foraminifera for the late Campanian-early Maastrichtian Shiranish Formation in the Azmer section.

The mid to early late Campanian unconformity

The unconformity between the Kometan and Shiranish formations is demarcated by *Globotruncanita elevata* as the youngest biozone in the pelagic limestones of the uppermost Kometan Formation, and *Globotruncana aegyptiaca* as the earliest biozone in the overlying Shiranish Formation. On the basis of the most recent Late Cretaceous planktonic foraminiferal biozonation compiled by Ogg & Hinnov (2012), the successive biozonal planktonic foraminiferal species *Contusotruncana plummerae* (= *Globotruncana ventricosa*) proposed by Petrizzo *et al.* (2011), *Radotruncana calcarata*, and *Globotruncanella havanensis* 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. 2.5). Based on calibration for the Cretaceous Time Scale proposed by Ogg & Hinnov (2012) for the FAD and LAD of the index Late Cretaceous planktonic foraminiferal biozones, the estimated age for the end of the *Globotruncanita elevata* and the beginning of the succeeding *Contusotruncana plummerae* biozones is 79.2 Ma, while the *Globotruncana aegyptiaca* biozone begins at 74.0 Ma. These suggest that the time gap in the sections studied is at least 5.2 Myr (79.2-74.0): 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 (Van Bellen *et al.* 2005; Buday 1980; Kaddouri 1982; Abawi *et al.* 1982; Abdel-Kireem 1986a; Jassim & Goff 2006; Aqrabi *et al.* 2010). It may represent a response to regional tectonics. In early and late Campanian time ophiolites were obducted across the NE margin of the Arabian Plate (Alavi, 1994; Guiraud & Bosworth 1997; Ziegler 2001; Jassim & Goff 2006), and the compression associated with this obduction caused uplift (Numan 1997; Ziegler 2001; Jassim & Goff 2006; see Fig. 2.2), 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 Syria (Pecimotika *et al.* 2014), Iran (Babazadeh *et al.* 2007), Turkey (Sari 2006, 2009), Kuwait, Qatar and Saudi Arabia (Al-Naqib 1967; see Fig. 2.2), and with the 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 & Bailey 1979; Hart 1980; Caron & Homewood 1983; Hallock *et al.* 1991; Huber 1992; Pflaumann *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 depth. Temperature appears to be the most important single factor controlling assemblage composition (Hart & Bailey 1979; 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 emphasised 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. 2.11). These groups are considered, tentatively, to signal ambient environmental regimes ranging from nutrient-rich to nutrient-poor, coupled with prevailing cooler or warmer seawater temperatures. Where possible, interpreted ecological preferences are quantified by reference to published stable isotope analyses of comparable foraminiferal assemblages.

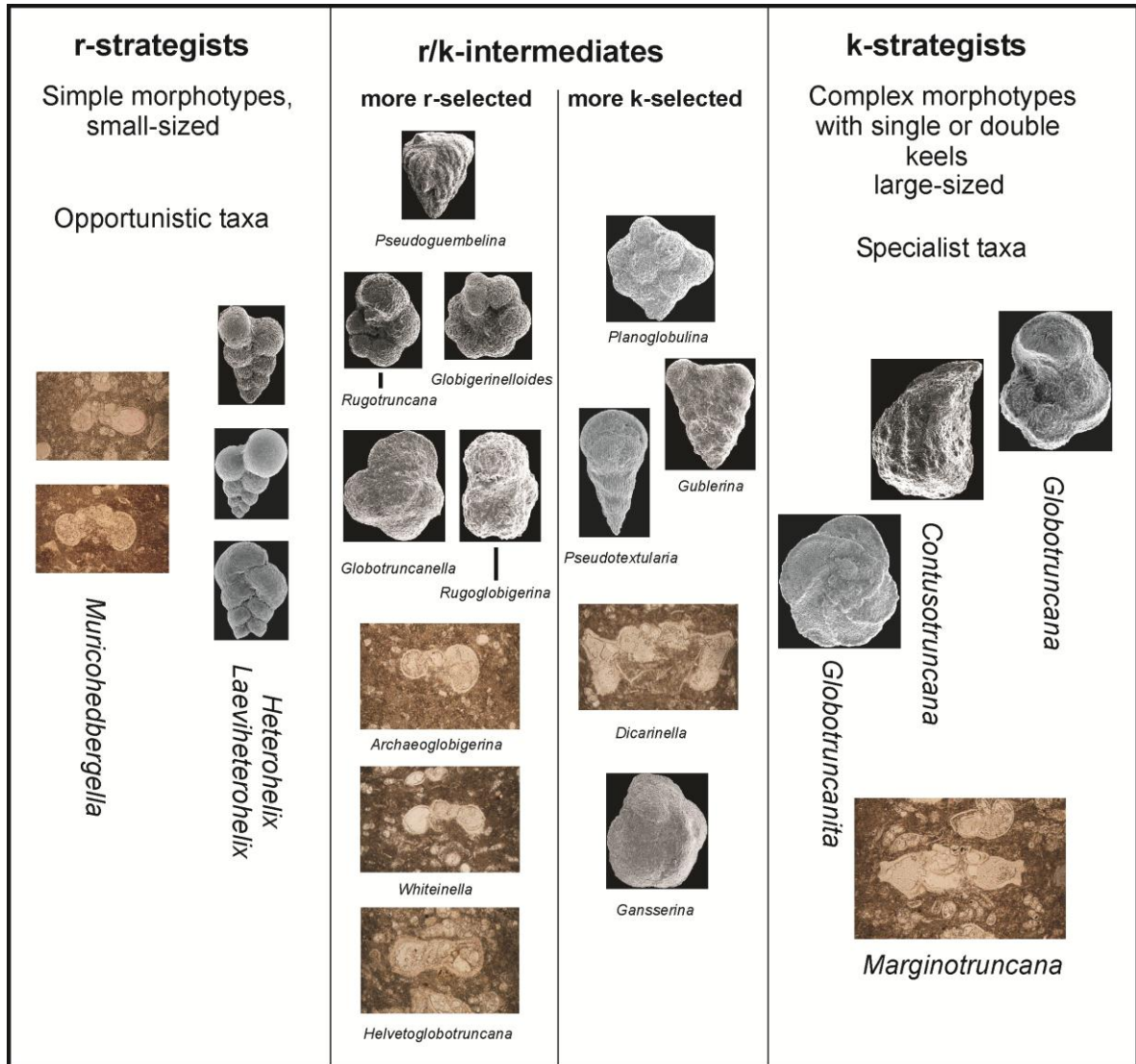


Figure 2.11. Scheme showing suggested planktonic foraminifera reproductive strategy. The r, k or r/k strategists are identified according to morphology (for methodology see Premoli Silva & Sliter 1999). Patterns of foraminiferal relative abundance are shown in Figures 2.12 and 2.13.

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 to characterise high latitudes, upwelling zones, shallow epicontinental seas and nearshore areas (Hart 1980; Caron & Homewood 1983; Leckie 1987; Keller *et al.* 2001). Cretaceous taxa interpreted to adopt 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 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 higher abundance at low latitudes may signal cooler waters.

2) Low-nutrient/oligotrophic Cretaceous marine environments that are also stable may be signaled by 'k-selected specialists' (Premoli Silva & Sliter 1999; Keller *et al.* 2001; Petrizzo 2002). K-strategists are interpreted to include species of the single-keeled *Globotruncana* and double-keeled *Marginotruncana*, *Contusotruncana* and *Globotruncana*. Specialist taxa, characterised 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 to occupy the oligotrophic portion of the mesotrophic spectrum (Premoli Silva & Sliter 1999; Petrizzo 2002; see Fig. 2.11). Subgroup 2 is the more r-selected r/k intermediates which have been interpreted to occupy 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. 2.11). Most of these r/k intermediate foraminifera can be recognised in the Shiranish Formation, with the exception of species of *Dicarinella*, *Helvetoglobotruncana* and *Whiteinella* that are only found in the Kometan Formation.

Species recorded in NE Iraq can be tentatively assigned to these biological groups (Fig. 2.11). 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 ca 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, signaling 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 recognised in the succession of NE Iraq (Figs 2.12, 2.13). These are interpreted to signal 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 recrystallised 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. delrioensis*) and *Heterohelix* (*H. globulosa* and *H. moremani*), together with more r-selected r/k intermediates such as *Whiteinella* (Fig. 2.12). The dominance of opportunistic species (of *Heterohelix* and *Whiteinella*) in the early Turonian has previously been widely recorded from Tethyan successions (Bauer *et al.* 2001 in Egypt; Caron *et al.* 2006 in Tunisia, and Gebhardt *et al.* 2010 for the northern Tethyan margin). In NE Iraq the maximum abundance and diversification of whiteinellids and

Heterohelix moremani are recorded through this interval. The more r-selected r/k intermediate *Helvetoglobotruncana helvetica* is rare in this interval in NE Iraq, and this is typical for a number of localities of this age worldwide (Kuhnt *et al.* 1997; Petrizzo 2001; Huber & Petrizzo 2014). The first k-strategists *Marginotruncana renzi* and *M. schneegansi* appear in this interval but are rare.

Based on analyses of stable oxygen and carbon isotopes from foraminiferal tests Huber & Petrizzo (2014) have interpreted helvetoglobotruncanids, including *H. helvetica*, as living in the surface mixed layer together with whiteinellids and biserial foraminiferal species. Moreover, stable isotope analysis confirm that species of *Muricohedbergella* and biserial taxa such as *Heterohelix*, including *H. moremani*, are typical of the shallowest part of the water column (Hart & Bailey 1979; Leckie 1987, 1989; Leckie *et al.* 1998; Nederbragt *et al.* 1998; Hart 1999; Premoli Silva & Sliter 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 suggest the influence of cooler sea surface temperatures (SSTs) (Petrizzo 2002) relative to the succeeding interval.

Species of whiteinellids are interpreted as taxa with a high tolerance toward eutrophic environments (Hart & Bailey 1979; 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 & Sliter 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 schneegansi* biozone, to the top of the *Dicarinella*

concovata biozone, and this is equivalent to the mid-Turonian and late Coniacian 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. 2.12).

Foraminiferal assemblage 2 is also characterised by more k-selected r/k intermediates such as species of *Dicarinella*. The interval is also characterised 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 whiteinellids 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 & Sliter 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); Zapata *et al.* (2003) 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 colonise. The apparent increase of tropical SSTs in the Arabian sector of the Tethys Ocean during this interval coincides with the mid-Turonian 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-late Santonian. The foraminiferal assemblages are characterised by a decrease in numbers of species interpreted as k-strategists, especially a rapid decline in the number of *Marginotruncana* species: only *M. coronata* and *M. marginata* are present throughout the interval. The top of this interval coincides with the disappearance of marginotruncanids.

Overall, Assemblage 3 suggests cooler, more nutrient-rich waters relative to the preceding interval. The decrease in the diversity and abundance of *Marginotruncana* is associated with: 1) the first appearance of *Contusotruncana* (*C. fornicata*); 2) increases in abundance of the r-strategist *Heterohelix* (including the FAD of *H. planata*); and 3) the FAD of the r-strategist *Laeviheterohelix* (*L. pulchra*, Fig. 2.12).

Based on evaluation of stable isotope data from the carbonate test (Abramovich *et al.* 2011), *H. planata* is inferred to be a mixed layer planktonic foraminifera that occupied subsurface waters. This species was most abundant in high palaeolatitudes of the Cretaceous (Nederbragt 1998), and therefore its appearance, when abundant, at lower palaeolatitudes may signal cooler sea temperatures (MacLeod *et al.* 2001). Falzoni *et al.* (2013) also used stable isotope data to interpret *Contusotruncana fornicata* as a mixed layer planktonic species. They suggested that both *Marginotruncana coronata* and *M. marginata* were adapted to water masses with the same or very similar ecological characteristics as those occupied by *C. fornicata*. The disappearance of most species of *Marginotruncana* and *Dicarinella* can also be interpreted as reflecting a decrease in near-surface sea temperature and development of more nutrient-rich conditions (Petrizzo 2002; Friedrich *et al.* 2008; Falzoni *et al.* 2013), and may be the result of a shallowing thermocline that resulted in the progressive removal of ecological niches occupied by the most specialised taxa (Petrizzo 2002; Falzoni *et al.* 2013). Increased surface productivity may be consistent with the abundance of *L. pulchra* through this interval, which may signal low oxygen and high productivity environments (Friedrich *et al.* 2008).

Assemblage 3 occupies an interval of time that is equivalent to the Santonian faunal turnover (Sliter 1989; Petrizzo 2002; Sari 2006, 2009; Elamri & Zaghib-Turki 2014; Elamri *et al.* 2014) which is ascribed to a cooling event strong enough to cause the extinction of the marginotruncanids, and the extinction of most of the specialised intermediate r/k taxa such as species of *Dicarinella*.

Assemblage 4

Planktonic foraminiferal Assemblage 4 of the Kometan Formation occurs through the interval of the top of the *Dicarinella asymetrica* biozone, and represents the interval of the latest Santonian. The interval is associated with the disappearance of *Marginotruncana* (see

also Petrizzo 2003; Vahidinia *et al.* 2014; Kochhann *et al.* 2014; Pecimotika *et al.* 2014), which coincides with the earliest diversification of the double-keeled *Globotruncana* and the first occurrence of the single-keeled *Globotruncanita* (*G. elevata* and *G. stuartiformis*). Assemblage 4 is interpreted to signal 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 asymerica* of the more k-selected r/k intermediates survives through this interval.

The progressive diversification and increasing abundance of globotruncanids through the latest Santonian, seen also in the Kometan Formation, likely relates to an increase in tropical SSTs (Boersma & Shackleton 1981; Petrizzo 2002; Ando *et al.* 2013; Falzoni *et al.* 2013). Falzoni *et al.* (2013) used stable isotope records to deduce that *Globotruncana bulloides* inhabited surface waters; whereas *G. arca* inhabited cooler/deeper waters at the depth of the thermocline. *Globotruncana linneiana*, *Globotruncanita stuartiformis* and *G. elevata* occupied intermediate levels between these end-members. The abundance and diversity of these species in the Kometan Formation indicates the development of a well-stratified water column, with a warm sea surface and a well-developed thermocline (see also Premoli Silva & Sliter 1999; Petrizzo 2002; Falzoni *et al.* 2013; see Fig. 2.12).

Assemblage 5

Planktonic foraminiferal Assemblage 5 occurs through the uppermost part of the Kometan Formation and spans the *Globotruncanita elevata* biozone, being equivalent to the early Campanian. The numerically dominant planktonic foraminifera are heterohelids and globotruncanids (Fig. 2.12). Overall, Assemblage 5 suggests cooler, more nutrient-rich waters relative to the preceding interval. In the k-strategist group, *Globotruncana arca* and *Globotruncanita elevata* were the most abundant species: *Globotruncana bulloides*, *Globotruncanita stuartiformis* and *Contusotruncana fornicata* were also common but occur intermittently. Based on wide geographic 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 characterised 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 utilising 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 Arabian sector of the Tethys Ocean during this interval coincides with a recorded SST drop in the eastern Indian Ocean during the early Campanian recorded at IODP (ODP) sites 762 and 763 (Petrizzo 2002). Moreover, Ando *et al.* (2013) reported that 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.

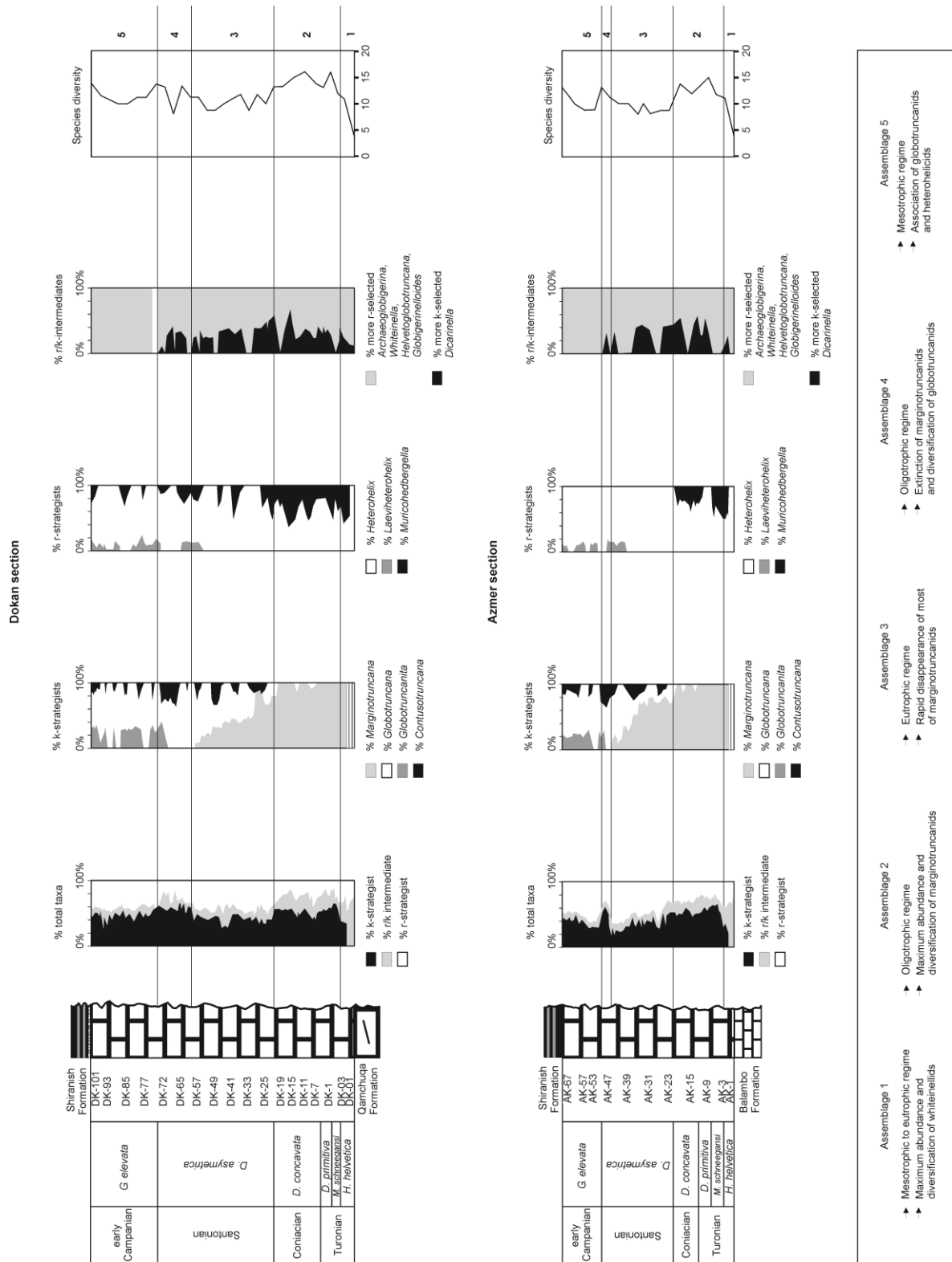


Figure 2.12. Relative abundance and species diversity for planktonic foraminifera in the Kometan Formation. Numbers in the right-hand column represent five assemblages that are distinguished on the basis of abundance of particular foraminifera displaying reproductive strategies interpreted as r-, k- or r/k intermediate (for designation to these groups see Figure 2.11). Assemblages 1, 3 and 5 are interpreted as indicative of less warm and more nutrient-rich sea surface conditions. Assemblages 2 and 4 are interpreted to represent warmer, more nutrient-poor intervals. The number of specimens counted for each sample ranges from 90 to 215: this range represents material from thin section analysis.

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 (equivalent to the late and latest Campanian). The numerically dominant planktonic foraminiferal taxa are those interpreted as k-strategists (see Fig. 2.13), including *Globotruncana*, *Globotruncanita* and *Contusotruncana* species. The maximum species diversity and abundance of globotruncanids occurs in this interval, and coincides with the global diversity peak of globotruncanids worldwide (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 *Pseudoguembelina* (*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 likely 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 abundance 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 colonise. Warmer SSTs relative to the preceding interval of the uppermost Kometan Formation are also consistent with a warm late Campanian climate (see Boersma & Shackleton 1981; Abramovich *et al.* 2003; Friedrich *et al.* 2005b; Zakharov *et al.* 2007; Darvishzad & Abdolalipour 2009; Linnert *et al.* 2014).

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* and the *Contusotruncana contusa* biozones (early Maastrichtian).

Towards the top of this interval the percentage abundance of globotruncanids decreases sequentially until all foraminifera disappear (Fig. 2.13). 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; Kroon & Nederbragt 1990; Barrera & Keller 1990; Leckie *et al.* 1998; Nederbragt *et al.* 1998; Premoli Silva & Sliter 1999; Keller *et al.* 2001; Keller & Pardo 2004; Pardo & Keller

2008). A relative increase in abundance of these species has been interpreted as indicating an expanded oxygen-minimum zone due to increased surface productivity and the depletion of oxygen in subsurface waters due to remineralisation of sinking organic carbon (Hart & Ball 1986).

This interval is also characterised by abundant thin-walled *Globigerinelloides* (*G. asper*, *G. subcarinatus*, *G. volutus*, *G. rosebudensis* and *G. multispinus*). Hart (1980) considered *Globigerinelloides* as living in intermediate surface waters, whilst stable oxygen isotope data suggest a shallow habitat (Douglas & Savin 1978; Boersma & Shackleton 1981). More recently, *Globigerinelloides* species have been considered to live between shallow surface dwelling and deep dwelling keeled forms (Keller *et al.* 2001; Norris *et al.* 2002; Coccioni & Luciani 2004). Other studies show that *Globigerinelloides* behaved opportunistically (Hart 1999; Premoli Silva & Sliter 1999), and species of *Globigerinelloides* may have become abundant during times of high surface water productivity (Almogi-Labin *et al.* 1993; MacLeod *et al.* 2001; Abramovich *et al.* 2010, 2011) and thus can be used as an index for eutrophic conditions (Almogi-Labin *et al.* 1993).

The temperature decrease signalled by the foraminifera of the Shiranish Formation in this interval is consistent with global models that suggest a marked phase of global cooling during the early Maastrichtian (Boersma & Shackleton 1981; Haq *et al.* 1987; Barrera 1994; Huber *et al.* 1995; Barrera *et al.* 1997; Hardenbol *et al.* 1998; Li & Keller 1998a, 1999; Barrera & Savin 1999; Adatte *et al.* 2002; Abramovich *et al.* 2003; Friedrich *et al.* 2005b; Hart 2007; Darvishzad & Abdolalipour 2009; Friedrich *et al.* 2012; Linnert *et al.* 2014)

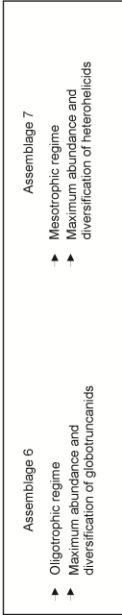


Figure 2.13. Relative abundance and species diversity for planktonic foraminifera in the Shiranish Formation. Numbers in the right-hand column identify two assemblages that are distinguished on the basis of abundance of particular foraminifera interpreted as displaying r-, k- or r/k intermediate strategies (for designation to these groups see Figure 2.11). Assemblages 6 and 7 are interpreted as the warmest and coolest intervals of the Late Cretaceous analysed for this study. The number of specimens counted for each sample ranges from 180 to 300: this represents specimens recovered from disaggregation of sedimentary rock. The percentage of more r-selected r/k intermediates includes species of *Archaeoglobigerina*, *Pseudoguembelina*, *Globigerinelloides*, *Globotruncanella*, *Rugoglobigerina* and *Rugotruncana*; whilst the percentage of more k-selected r/k intermediates includes species of *Gansserina*, *Planoglobulina*, *Gublerina* and *Pseudotextularia*.

Conclusions

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.

Planktonic foraminifera plates

Chapter 2: Biostratigraphy and palaeoceanography of
the early Turonian-early Maastrichtian planktonic
foraminifera of northeast Iraq

Plate 1 Foraminifera of the Kometan Formation

Scale bar as for Figure 3 of Plate 1

Globigerinelloides*, *Muricohedbergella*, *Whiteinella

- Fig 1: *Globigerinelloides prairiehillensis* Pessagno. *Dicarinella asymetrica* biozone, MPK14545, Dokan section, sample number DK-40.
- Figs 2, 3: *Globigerinelloides ultramicrus* Subbotina. *Dicarinella concavata* biozone, Fig. 2, MPK14546, Azmer section, sample number AK-13; Fig. 3, MPK14547, Dokan section, sample number DK-9.
- Fig 4: *Muricohedbergella delrioensis* (Carsey). *Dicarinella concavata* biozone, MPK14460, Azmer section, sample number AK-15.
- Fig 5: *Muricohedbergella holmdelensis* Olsson. *Globotruncanita elevata* biozone, MPK14461, Dokan section, sample number DK-86.
- Figs 6, 7: *Muricohedbergella planispira* (Tappan). *Marginotruncana schneegansi* biozone, Fig. 6, MPK14548, Fig. 7, MPK14549, Azmer section, sample number AK-5.
- Figs 8, 9: *Whiteinella archaeocretacea* Pessagno. *Dicarinella primitiva* biozone, Fig. 8, MPK14462, Azmer section, sample number AK-11; Fig. 9, MPK14550, Dokan section, sample number DK-2.
- Fig 10: *Whiteinella aprica* (Loeblich and Tappan). *Marginotruncana schneegansi* biozone, MPK14551, Dokan section, sample number DK-04.
- Figs 11, 12: *Whiteinella baltica* Douglas and Rankin. *Dicarinella concavata* biozone, Fig. 11, MPK14552, Dokan section, sample number DK-9; Fig. 12, MPK14553, Dokan section, sample number DK-16.
- Figs 13, 14: *Whiteinella brittonensis* (Loeblich and Tappan). *Dicarinella concavata* biozone, Fig. 13, MPK14463, Azmer section, sample number AK-13; Fig. 14, MPK14554, Dokan section, sample number DK-18.
- Figs 15, 16: *Whiteinella inornata* (Bolli). *Dicarinella primitiva* and *D. concavata* biozones, Fig. 15, MPK14555, Azmer section, sample number AK-9; Fig. 16, MPK14556, Dokan section, sample number DK-12.
- Figs 17, 18: *Whiteinella paradubia* (Sigal). *Dicarinella primitiva* biozone, Fig. 17, MPK14557, Fig. 18, MPK14558, Dokan section, sample number DK-2. Note that these are small specimens but show most of the characteristics of *W. paradubia*.

Plate 1

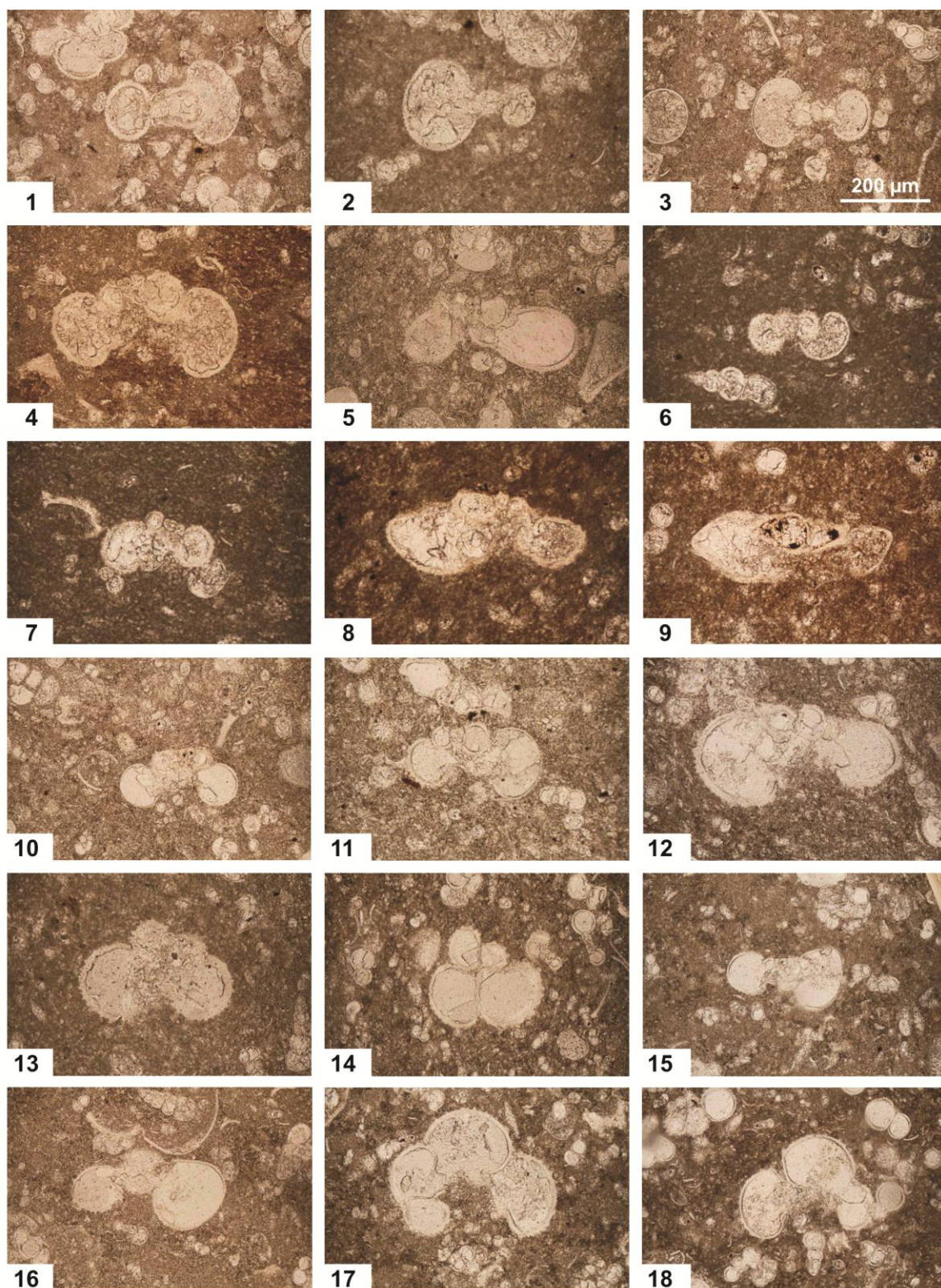


Plate 2 Foraminifera of the Kometan Formation

Scale bar as for Figure 3 of Plate 2

Helvetoglobotruncana, Marginotruncana, Dicarinella, Globotruncanita, Globotruncana

Figs 1, 2: *Helvetoglobotruncana helvetica* (Bolli). *Helvetoglobotruncana helvetica* biozone, Fig. 1, MPK14421, Azmer section, sample number AK-1; Fig. 2, MPK14422, Dokan section, sample number DK-02.

Figs 3, 4: *Marginotruncana schneegansi* Sigal. *Marginotruncana schneegansi* biozone, Fig. 3, MPK14423, Dokan section, sample number DK-05; Fig. 4, MPK14424, Azmer section, sample number AK-6.

Figs 5, 6: *Dicarinella primitiva* (Dalbiez). *Dicarinella primitiva* and *D. concavata* biozones, Fig. 5, MPK14425, Dokan section, sample number DK-6; Fig. 6, MPK14426, Azmer section, sample number AK-9.

Figs 7, 8: *Dicarinella concavata* (Brotzen). *Dicarinella concavata* biozone, Fig. 7, MPK14427, Dokan section, sample number DK-16; Fig. 8, MPK14428, Azmer section, sample number AK-19.

Figs 9, 10: *Dicarinella asymetrica* (Sigal). *Dicarinella asymetrica* biozone, Fig. 9, MPK14429, Dokan section, sample number DK-40; Fig. 10, MPK14430, Azmer section, sample number AK-23.

Figs 11, 12: *Globotruncanita elevata* (Brotzen). *Globotruncanita elevata* biozone, Fig. 11, MPK14431, Dokan section, sample number DK-82; Fig. 12, MPK14432, Azmer section, sample number AK-61.

Figs 13, 14: *Globotruncana arca* (Cushman). *Globotruncanita elevata* biozone, Fig. 13, MPK14559, Fig. 14, MPK14560, Dokan section, sample number DK-88.

Figs 15, 16: *Globotruncana bulloides* Vogler. *Globotruncanita elevata* biozone, Fig. 15, MPK14435, Azmer section, sample number AK-67; Fig. 16, MPK14561, Dokan section, sample number DK-86.

Figs 17, 18: *Globotruncana lapparenti* (Brotzen). *Globotruncanita elevata* biozone, Fig. 17, MPK14562, Dokan section, sample number DK-76; Fig. 18, MPK14436, Azmer section, sample number AK-61.

Plate 2

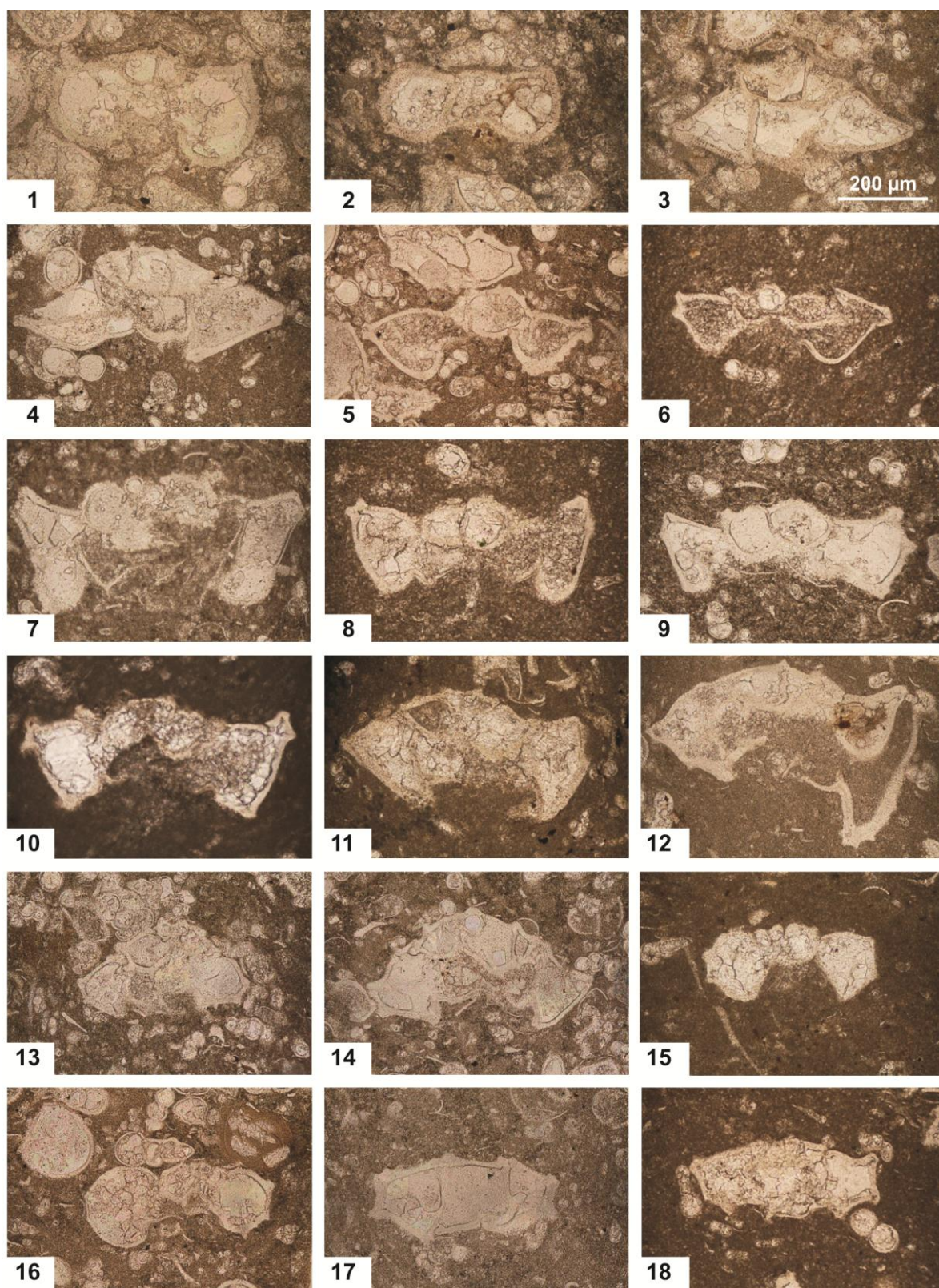


Plate 3 Foraminifera of the Kometan Formation

Scale bar as for Figure 3 of Plate 3

Globotruncana, Globotruncanita, Contusotruncana, Marginotruncana

Figs 1-3: *Globotruncana linneiana* (d'Orbigny). *Dicarinella asymetrica* and *Globotruncanita elevata* biozones, Fig. 1, MPK14563, Dokan section, sample number DK-50; Fig. 2, MPK14437, Dokan section, sample number DK-66; Fig. 3, MPK14564, Azmer section, sample number AK-67.

Figs 4, 5: *Globotruncanita stuartiformis* Dalbiez. *Globotruncanita elevata* biozone, Fig. 4, MPK14438, Dokan section, sample number DK-82; Fig. 5, MPK14565, Dokan section, sample number DK-88.

Figs 6, 7: *Contusotruncana fornicata* (Plummer). *Dicarinella asymetrica* and *Globotruncanita elevata* biozones, Fig. 6, MPK14566, Dokan section, sample number DK-72; Fig. 7, MPK14567, Dokan section, sample number DK-76.

Fig 8: *Marginotruncana coronata* (Bolli). *Dicarinella concavata* biozone, MPK14568, Azmer section, sample number AK-17.

Fig 9: *Marginotruncana marginata* (Reuss). *Dicarinella concavata* biozone, MPK14433, Dokan section, sample number DK-18.

Figs 10, 11: *Marginotruncana renzi* (Gandolfi). *Dicarinella primitiva* and *D. concavata* biozones, Fig. 10, MPK14569, Dokan section, sample number DK-12; Fig. 11, MPK14434, Azmer section, sample number AK-9.

Figs 12, 13: *Marginotruncana sigali* (Reichel). *Marginotruncana schneegansi* biozone, Fig. 12, MPK14570, Azmer section, sample number AK-5; Fig. 13, MPK14571, Dokan section, sample number DK-04.

Fig 14: *Marginotruncana undulata* (Lehmann). *Dicarinella primitiva* biozone, MPK14572, Azmer section, sample number AK-11.

Figs 15, 16: *Lenticulina* spp. *Globotruncanita elevata* biozone, Fig. 15, Azmer section, sample number AK-59; Fig. 16, Dokan section, sample number DK-101.

Figs 17, 18: *Textularia* spp. *Globotruncanita elevata* biozone, Fig. 17, Azmer section, sample number AK-55; Fig. 18, Dokan section, sample number DK-101.

Plate 3

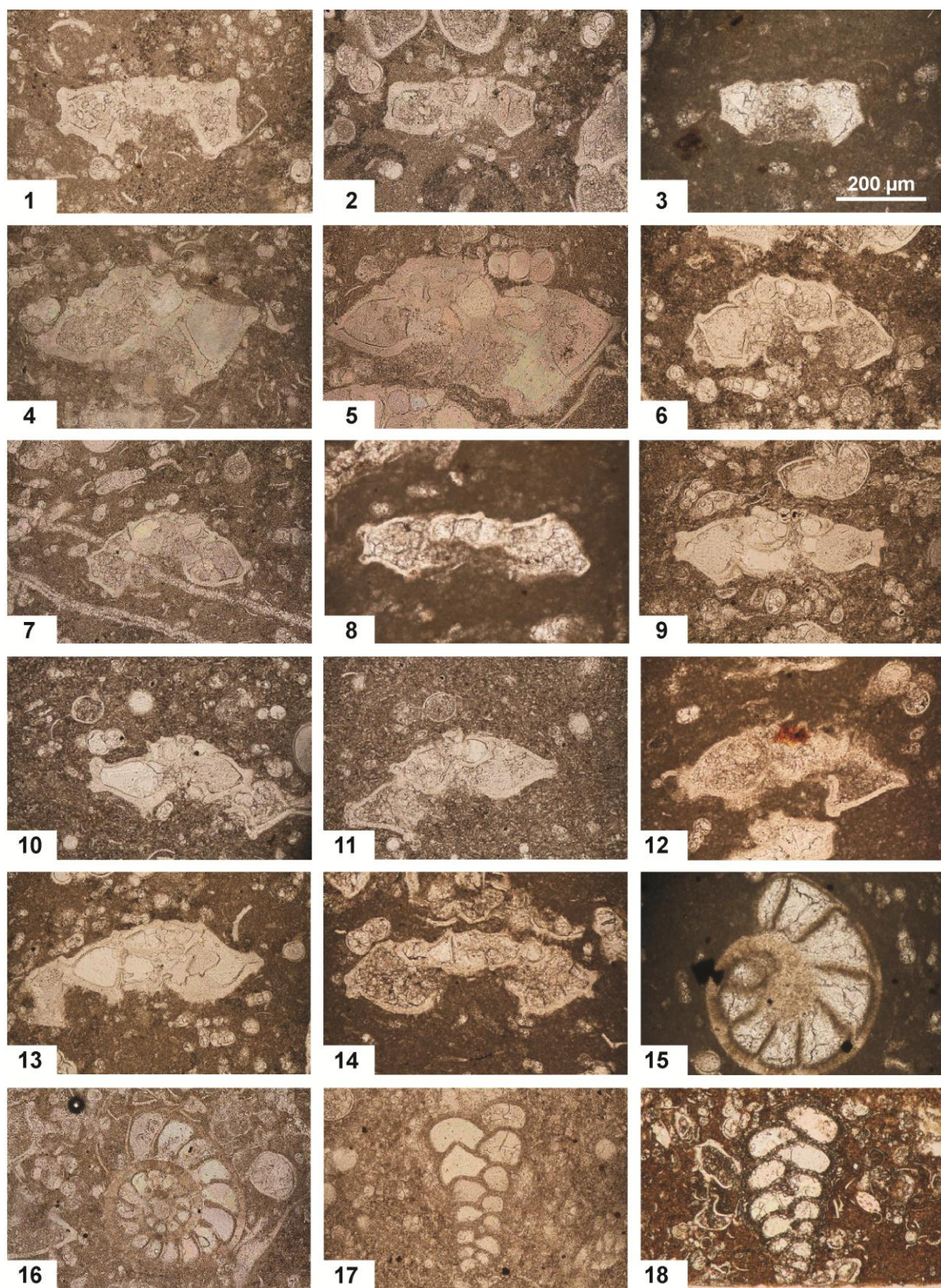


Plate 4 Foraminifera of the Shiranish Formation

Scale bar as for Figure 3 of Plate 4

Contusotruncana, Gansserina, Globotruncana

- Figs 1, 2: *Contusotruncana fornicata* (Plummer). *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Fig. 1, MPK14573, Dokan section, sample number DSH-62; Fig. 2, MPK14574, Azmer section, sample number ASH-36.
- Figs 3, 4: *Contusotruncana patelliformis* (Gandolfi). *Globotruncana aegyptiaca* biozone, Fig. 3, MPK14575, Dokan section, sample number DSH-24; Fig. 4, MPK14576, Dokan section, sample number DSH-40.
- Fig 5: *Contusotruncana plicata* (White). *Gansserina gansseri* biozone, MPK14464, Dokan section, sample number DSH-82.
- Fig 6: *Contusotruncana plummerae* (Gandolfi). *Gansserina gansseri* biozone, MPK14465, Dokan section, sample number DSH-86.
- Figs 7, 8: *Gansserina gansseri* (Bolli). *Gansserina gansseri* biozone, Fig. 7, MPK14577, Dokan section, sample number DSH-72; Fig. 8, MPK14466, Dokan section, sample number DSH-84.
- Fig 9: *Gansserina wiedenmayeri* (Gandolfi). *Gansserina gansseri* biozone, MPK14467, Dokan section, sample number DSH-84.
- Figs 10, 11: *Globotruncana aegyptiaca* Nakkady. *Globotruncana aegyptiaca* biozone, Fig. 10, MPK14578, Dokan section, sample number DSH-52; Fig. 11, MPK14579, Dokan section, sample number DSH-66.
- Fig 12: *Globotruncana arca* (Cushman). *Globotruncana aegyptiaca* biozone, MPK14468, Dokan section, sample number DSH-24.
- Fig 13: *Globotruncana bulloides* Vogler. *Gansserina gansseri* biozone, MPK14580, Azmer section, sample number ASH-40.
- Figs 14, 15: *Globotruncana dupeblei* Caron, Gonzales Donoso, Robaszynski and Wonders. *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Fig. 14, MPK14581, Azmer section, sample number ASH-30; Fig. 15, MPK14469, Dokan section, sample number DSH-76.
- Fig 16: *Globotruncana esnehensis* (Nakkady). *Globotruncana aegyptiaca* biozone, MPK14470, Azmer section, sample number ASH-30.

Figs 17, 18: *Globotruncana linneiana* d'Orbigny. *Gansserina gansseri* biozone, Fig. 17, MPK14582, Dokan section, sample number DSH-78; Fig. 18, MPK14583, Dokan section, sample number DSH-86.

Plate 4

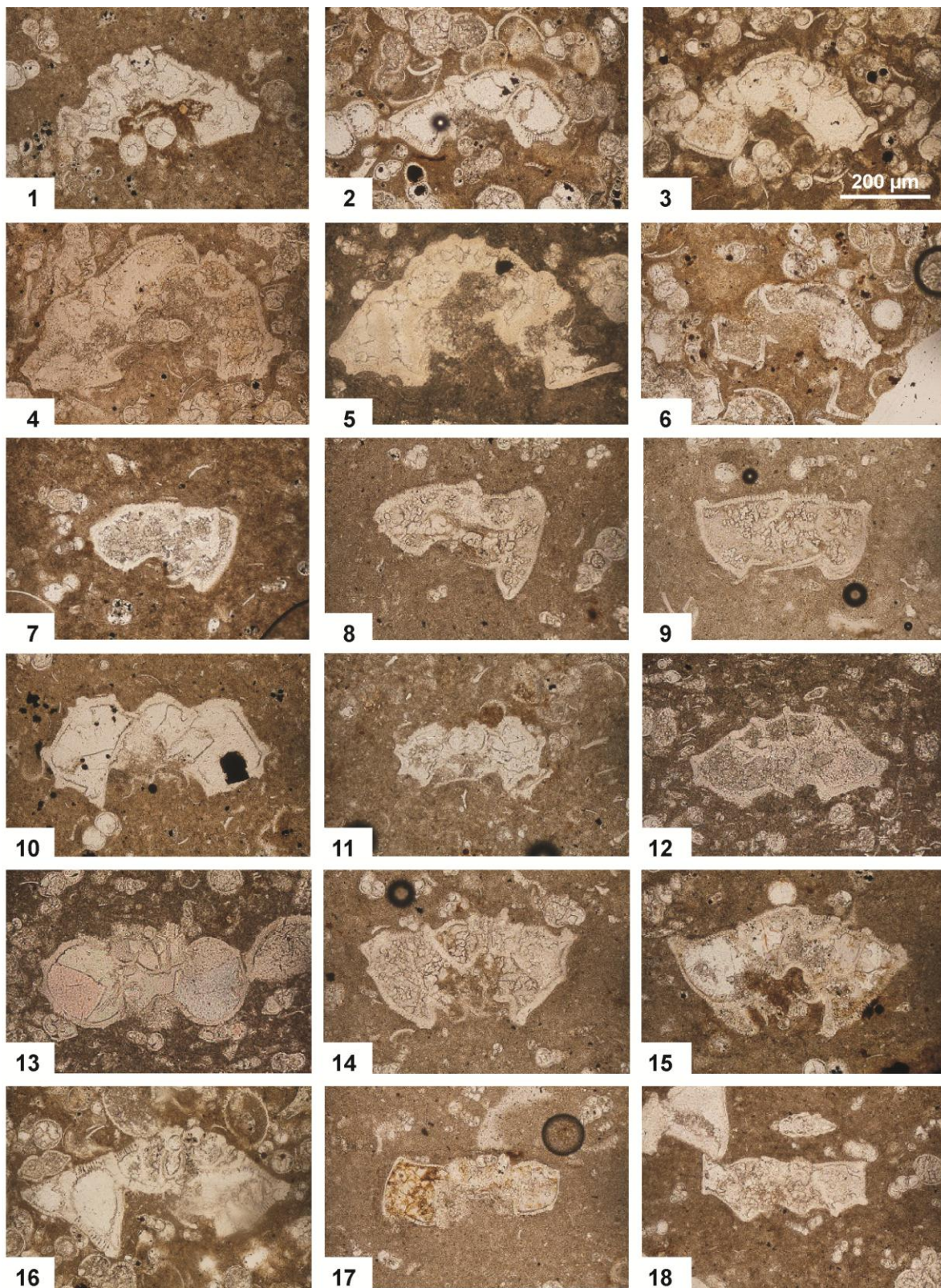


Plate 5 Foraminifera of the Shiranish Formation

Scale bar as for Figure 3 of Plate 5

Globotruncana, Globotruncanita, Radotruncana, Rugoglobigerina

- Figs 1, 2: *Globotruncana orientalis* El-Naggar. *Globotruncana aegyptiaca* biozone, Fig. 1, MPK14584, Fig. 2, MPK14585, Dokan section, sample number DSH-54.
- Fig 3: *Globotruncanita cf. conica* White. *Globotruncana aegyptiaca* biozone, MPK14586, Dokan section, sample number DSH-46.
- Fig 4: *Globotruncanita conica* White. *Globotruncana aegyptiaca* biozone, MPK14471, Dokan section, sample number DSH-60.
- Figs 5, 6: *Globotruncanita insignis* (Gandolfi). *Globotruncana aegyptiaca* biozone, Fig. 5, MPK14472, Azmer section, sample number ASH-26; Fig. 6, MPK14587, Dokan section, sample number DSH-24.
- Fig 7: *Globotruncanita pettersi* (Gandolfi). *Gansserina gansseri* biozone, MPK14473, Dokan section, sample number DSH-76.
- Figs 8, 9: *Globotruncanita stuarti* (de Lapparent). *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Fig. 8, MPK14588, Azmer section, sample number ASH-30; Fig. 9, MPK14419, Dokan section, sample number DSH-80.
- Fig 10: *Globotruncanita stuartiformis* Dalbiez. *Globotruncana aegyptiaca* biozone, MPK14589, Dokan section, sample number DSH-42.
- Figs 11, 12: *Radotruncana subspinosa* (Pessagno). *Gansserina gansseri* biozone, MPK14418, Dokan section, sample number DSH-88.
- Figs 13, 14: *Rugoglobigerina pennyi* Bronnimann. *Gansserina gansseri* biozone, Fig. 13, MPK14417, Dokan section, sample number DSH-88; Fig. 14, MPK14590, Azmer section, sample number ASH-52.
- Figs 15-17: *Rugoglobigerina rugosa* (Plummer). *Gansserina gansseri* biozone, Fig. 15, MPK14474, Dokan section, sample number DSH-80; Fig. 16, MPK14591, Dokan section, sample number DSH-82; Fig. 17, MPK14592, Dokan section, sample number DSH-80.
- Fig 18: *Rugoglobigerina* sp. *Gansserina gansseri* biozone, MPK14593, Dokan section, sample number DSH-84.

Plate 5

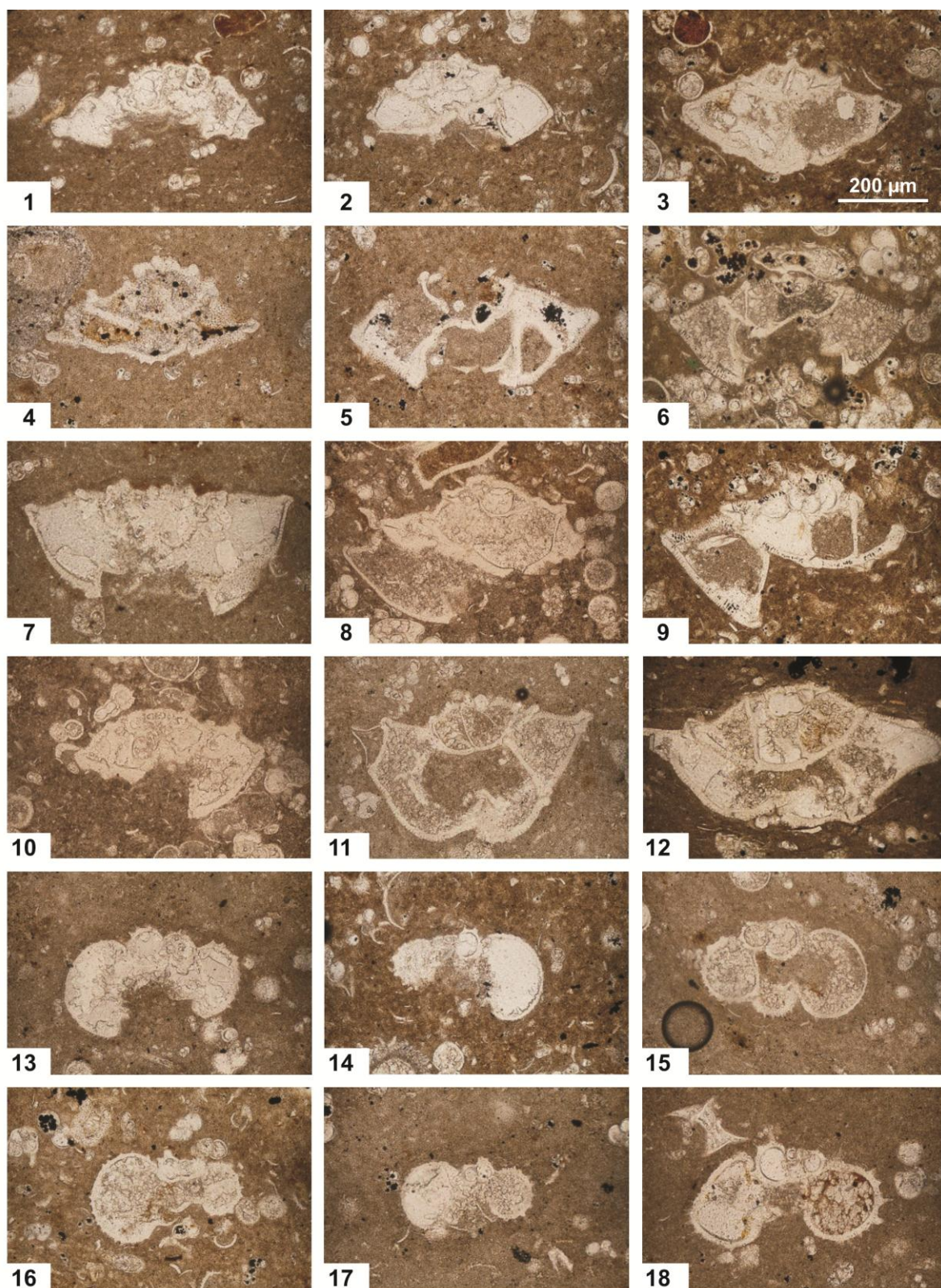


Plate 6 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Archaeoglobigerina, Contusotruncana

Figs 1, 2: *Archaeoglobigerina cretacea* (d'Orbigny). *Gansserina gansseri* biozone, MPK14594, Dokan section, sample number DSH-80.

Figs 3-6: *Contusotruncana contusa* (Cushman). *Contusotruncana contusa* biozone, Dokan section, Figs 3, 4, MPK14595, Fig. 5, MPK1442, sample number DSH-117; Fig. 6, MPK14596, sample number DSH-119.

Figs 7-12: *Contusotruncana fornicata* (Plummer). *Globotruncana aegyptiaca* biozone, Figs 7-9, MPK14597, Dokan section, sample number DSH-64; Figs 10-12, MPK14445, Azmer section, sample number ASH-10.

Figs 13-15: *Contusotruncana patelliformis* (Gandolfi). *Globotruncana aegyptiaca* biozone, MPK14443, Dokan section, sample number DSH-25.

Figs 16-18: *Contusotruncana plicata* (White). *Globotruncana aegyptiaca* biozone, MPK14598, Azmer section, sample number ASH-10.

Figs 19-23: *Contusotruncana plummerae* (Gandolfi). *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Figs 19-21, MPK14599, Dokan section, sample number DSH-64; Figs 22, 23, MPK14444, Azmer section, sample number ASH-50.

Figs 24, 25: *Contusotruncana walfischensis* (Todd). *Contusotruncana contusa* biozone, MPK14414, Dokan section, sample number DSH-117.

Plate 6

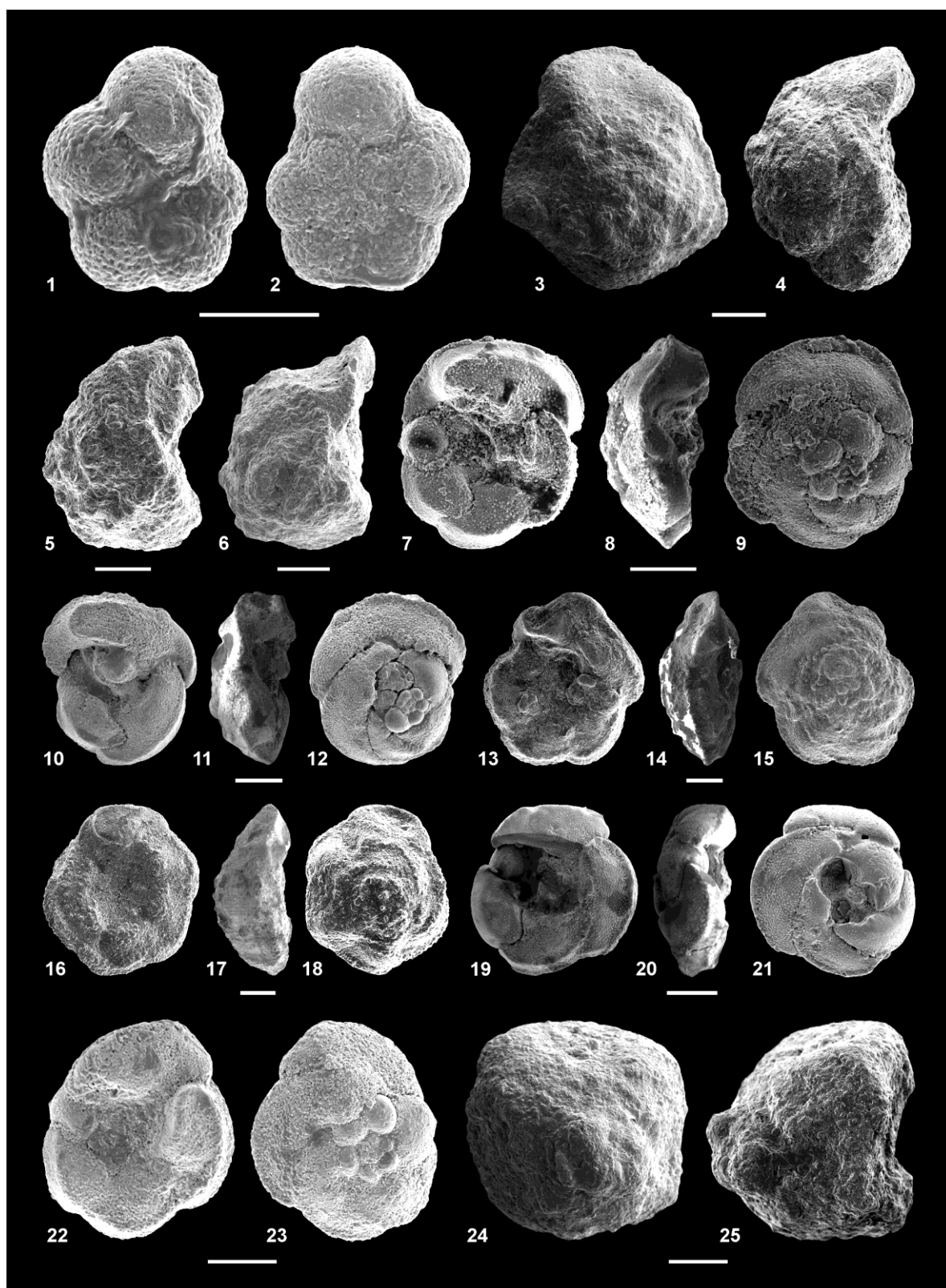


Plate 7 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Gansserina, Globotruncana

Figs 1-5: *Gansserina gansseri* (Bolli). *Gansserina gansseri* biozone, Figs 1, 2, MPK14439, Azmer section, sample number ASH-35; Figs 3-5, MPK14440, Dokan section, sample number DSH-85.

Figs 6-11: *Globotruncana aegyptiaca* Nakkady. *Globotruncana aegyptiaca* biozone, Figs 6-8, MPK14409, Azmer section, sample number ASH-02; Figs 9-11, MPK14410, Dokan section, sample number DSH-05.

Figs 12-14: *Globotruncana arca* (Cushman). *Globotruncana aegyptiaca* biozone, MPK14600, Azmer section, sample number ASH-30.

Figs 15-19: *Globotruncana bulloides* Vogler. *Globotruncana aegyptiaca* biozone, Figs 15-17, MPK14601, Azmer section, sample number ASH-20; Figs 18, 19, MPK14602, Dokan section, sample number DSH-15.

Figs 20-24: *Globotruncana dupeublei* Caron, Gonzales Donoso, Robaszynski and Wonders. *Globotruncana aegyptiaca* biozone, Figs 20, 21, MPK14603, Dokan section, sample number DSH-55; Figs 22-24, MPK14604, Azmer section, sample number ASH-30.

Figs 25-27: *Globotruncana linneiana* d'Orbigny. *Globotruncana aegyptiaca* biozone, MPK14412, Azmer section, sample number ASH-40.

Plate 7

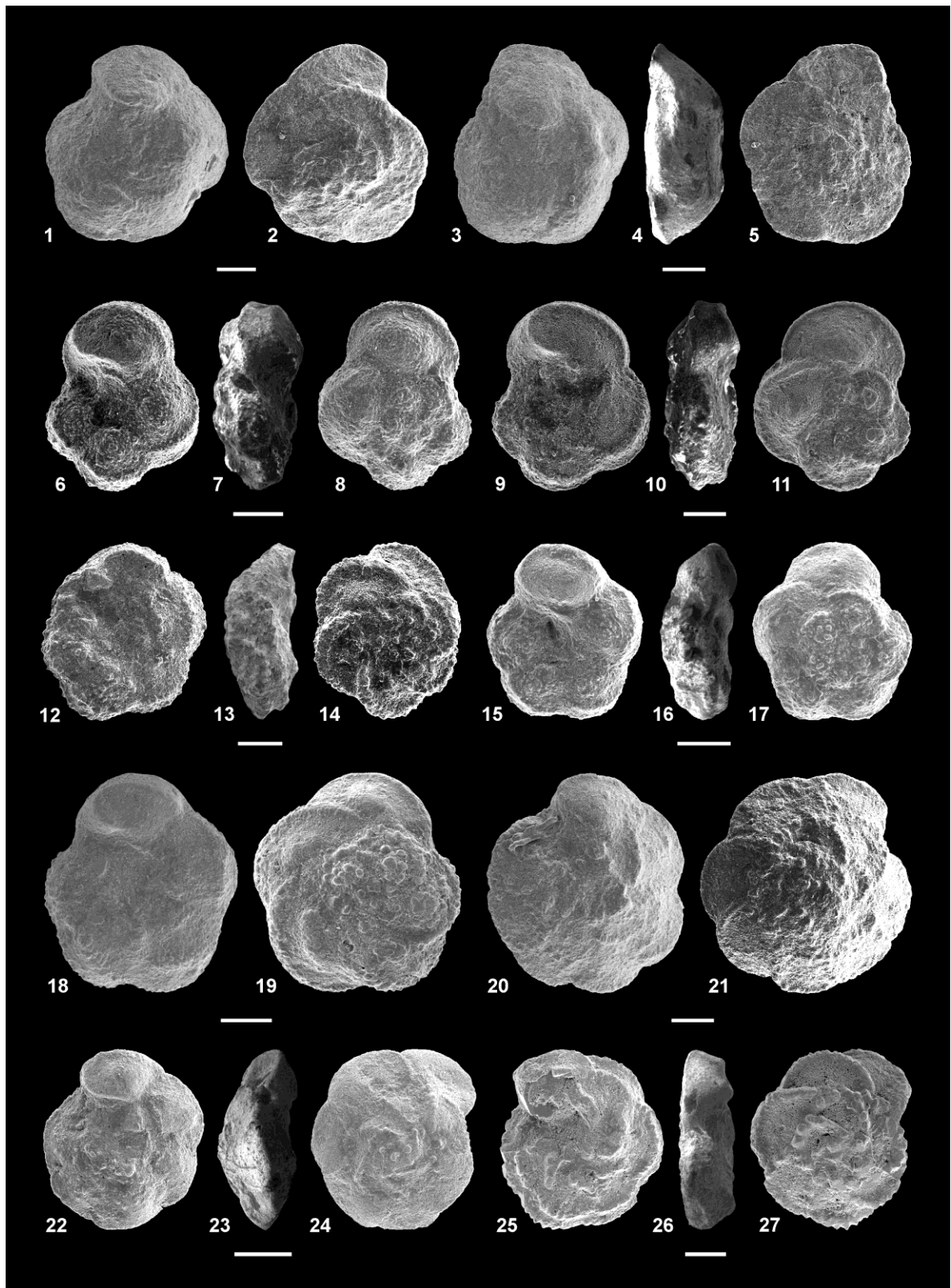


Plate 8 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Globotruncana*, *Globotruncanita

Figs 1-6: *Globotruncana orientalis* El-Naggar. *Gansserina gansseri* biozone, Figs 1-3, MPK14605, Dokan section, sample number DSH-88; Figs 4-6, MPK14606, Azmer section, sample number ASH-35.

Figs 7-10: *Globotruncana rosetta* (Carsey). *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Figs 7, 8, MPK14607, Azmer section, sample number ASH-30; Figs 9, 10, MPK14608, Azmer section, sample number ASH-35.

Figs 11-15: *Globotruncana* spp. *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Figs 11, 12, MPK14609, Azmer section, sample number ASH-30; Figs 13-15, MPK14610, Azmer section, sample number ASH-55.

Figs 16-20: *Globotruncana* spp. *Gansserina gansseri* biozone, Figs 16-18, MPK14611, Figs 19, 20, MPK14612, Dokan section, sample number DSH-88.

Figs 21-25: Possibly *Globotruncanita* spp. *Globotruncana aegyptiaca* biozone, Figs 21, 22, MPK14613, Azmer section, sample number ASH-10; Figs 23-25, MPK14614, Azmer section, sample number ASH-15. Note that internal moulds appear between each chamber.

Plate 8

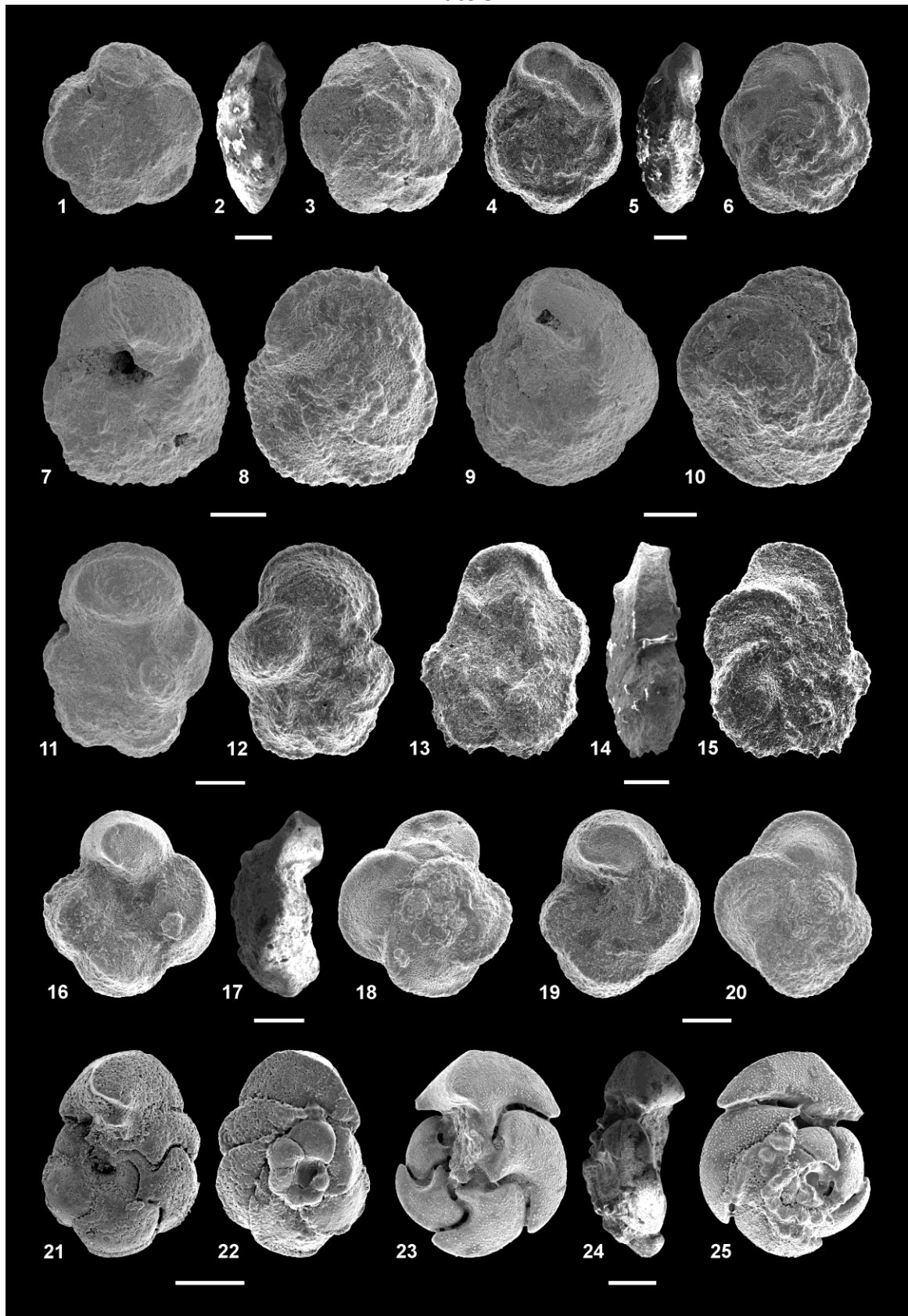


Plate 9 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Globotruncanita, Globotruncanella, Rugotruncana

Figs 1, 2: *Globotruncanita angulata* Tilev. *Globotruncana aegyptiaca* biozone, MPK14615, Azmer section, sample number ASH-20.

Figs 3-5: *Globotruncanita conica* White. *Globotruncana aegyptiaca* biozone, MPK14616, Dokan section, sample number DSH-50.

Figs 6, 7: *Globotruncanita pettersi* (Gandolfi). *Gansserina gansseri* biozone, MPK14617, Dokan section, sample number DSH-80.

Figs 8-10: *Globotruncanita stuarti* (de Lapparent). *Globotruncana aegyptiaca* biozone, MPK14618, Dokan section, sample number DSH-15.

Figs 11-13: *Globotruncanita stuartiformis* Dalbiez. *Globotruncana aegyptiaca* biozone, MPK14619, Dokan section, sample number DSH-15.

Figs 14-18: *Globotruncanella petaloidea* Gandolfi. *Globotruncana aegyptiaca* biozone, Figs 14-16, MPK14475, Dokan section, sample number DSH-40; Figs 17, 18, MPK14620, Azmer section, sample number ASH-20.

Figs 19-21: *Globotruncanella pschadae* Keller. *Globotruncana aegyptiaca* biozone, MPK14476, Dokan section, sample number DSH-60.

Figs 22, 23: *Rugotruncana circumnodifer* (Finley). *Gansserina gansseri* biozone, MPK14621, Azmer section, sample number ASH-62.

Figs 24-26: *Rugotruncana subcircumnodifer* Gandolfi. *Gansserina gansseri* biozone, MPK14622, Azmer section, sample number ASH-62.

Plate 9

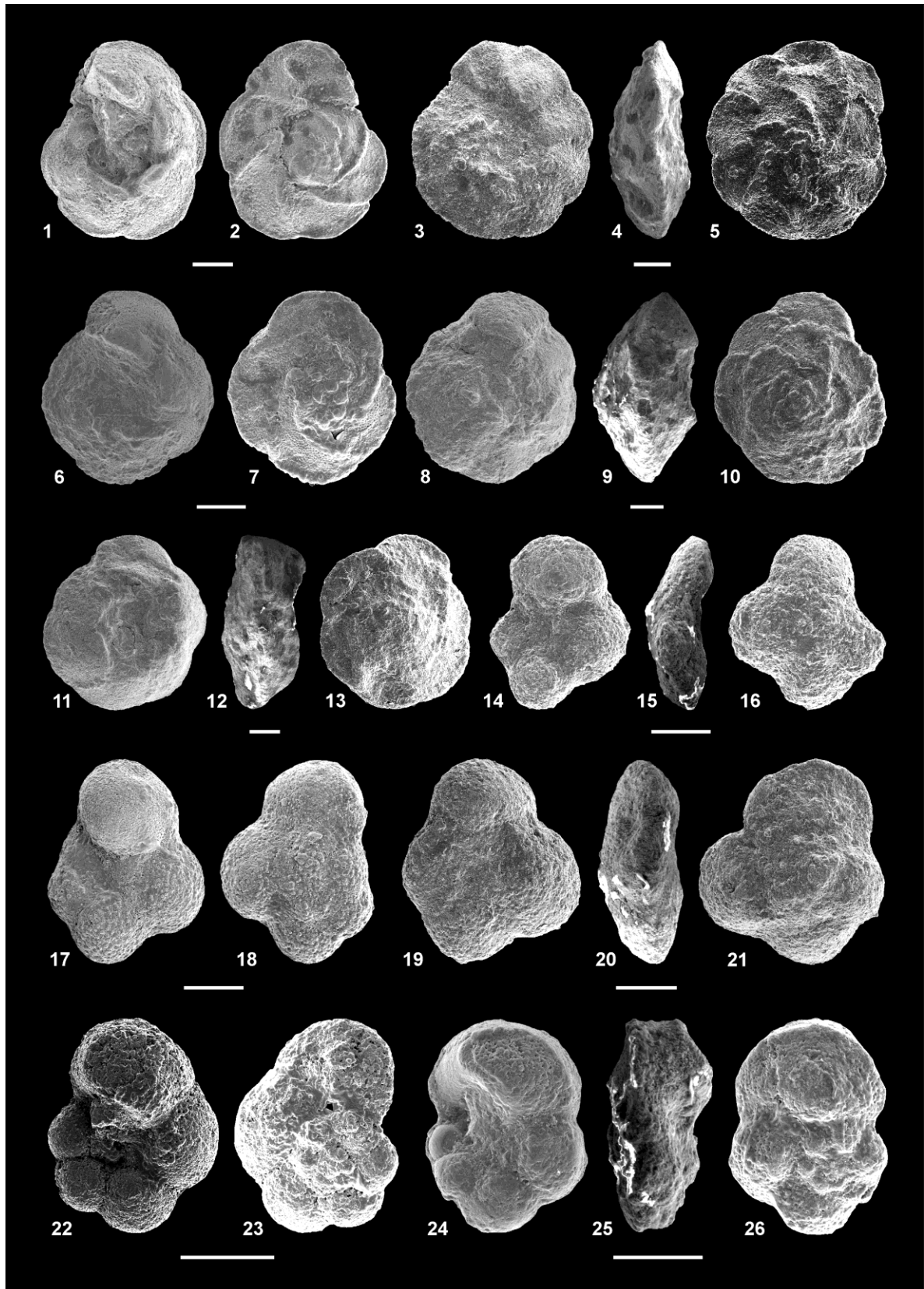


Plate 10 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Rugoglobigerina, Globigerinelloides

Figs 1-5: *Rugoglobigerina hexacamerata* Bronnimann. *Gansserina gansseri* biozone, Figs 1-3, MPK14623, Azmer section, sample number ASH-50; Figs 4, 5, MPK14413, Dokan section, sample number DSH-86.

Figs 6-8: *Rugoglobigerina macrocephala* Bronnimann. *Gansserina gansseri* biozone, MPK14624, Dokan section, sample number DSH-90. Note that the meridional ornamentation is absent due to heavily pyritized test.

Figs 9-11: *Rugoglobigerina rugosa* (Plummer). *Globotruncana aegyptiaca* biozone, MPK14625, Dokan section, sample number DSH-40.

Figs 12-14: *Rugoglobigerina scotti* Bronnimann. *Contusotruncana contusa* biozone, MPK14626, Dokan section, sample number DSH-117.

Figs 15-17: *Rugoglobigerina?* sp. *Gansserina gansseri* biozone, MPK14627, Azmer section, sample number ASH-62.

Figs 18-20: *Globigerinelloides asper* (Ehrenberg). *Gansserina gansseri* biozone, MPK14477, Azmer section, sample number ASH-40.

Figs 21-23: *Globigerinelloides messinae* (Bronnimann). *Gansserina gansseri* biozone, MPK14628, Dokan section, sample number DSH-95.

Figs 24-29: *Globigerinelloides multispinus* Lalicker. *Gansserina gansseri* and *Contusotruncana contusa* biozones, Figs 24-26, MPK14478, Dokan section, sample number DSH-117; Figs 27-29, MPK14629, Azmer section, sample number ASH-60.

Plate 10

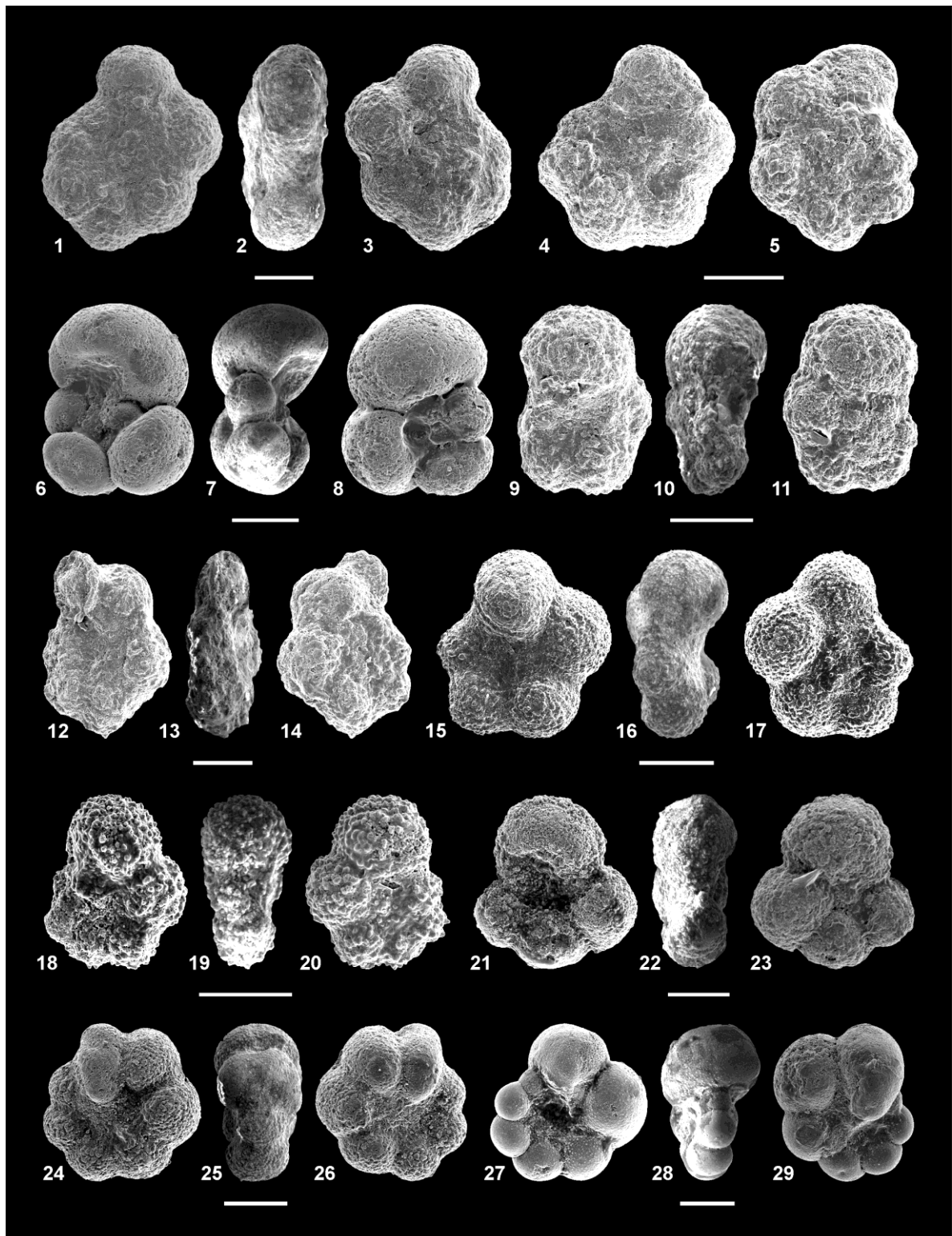


Plate 11 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Globigerinelloides

Figs 1-6: *Globigerinelloides prairiehillensis* Pessagno. *Gansserina gansseri* and *Contusotruncana contusa* biozones, Figs 1-3, MPK14479, Dokan section, sample number DSH-115; Figs 4-6, MPK14630, Azmer section, sample number ASH-62.

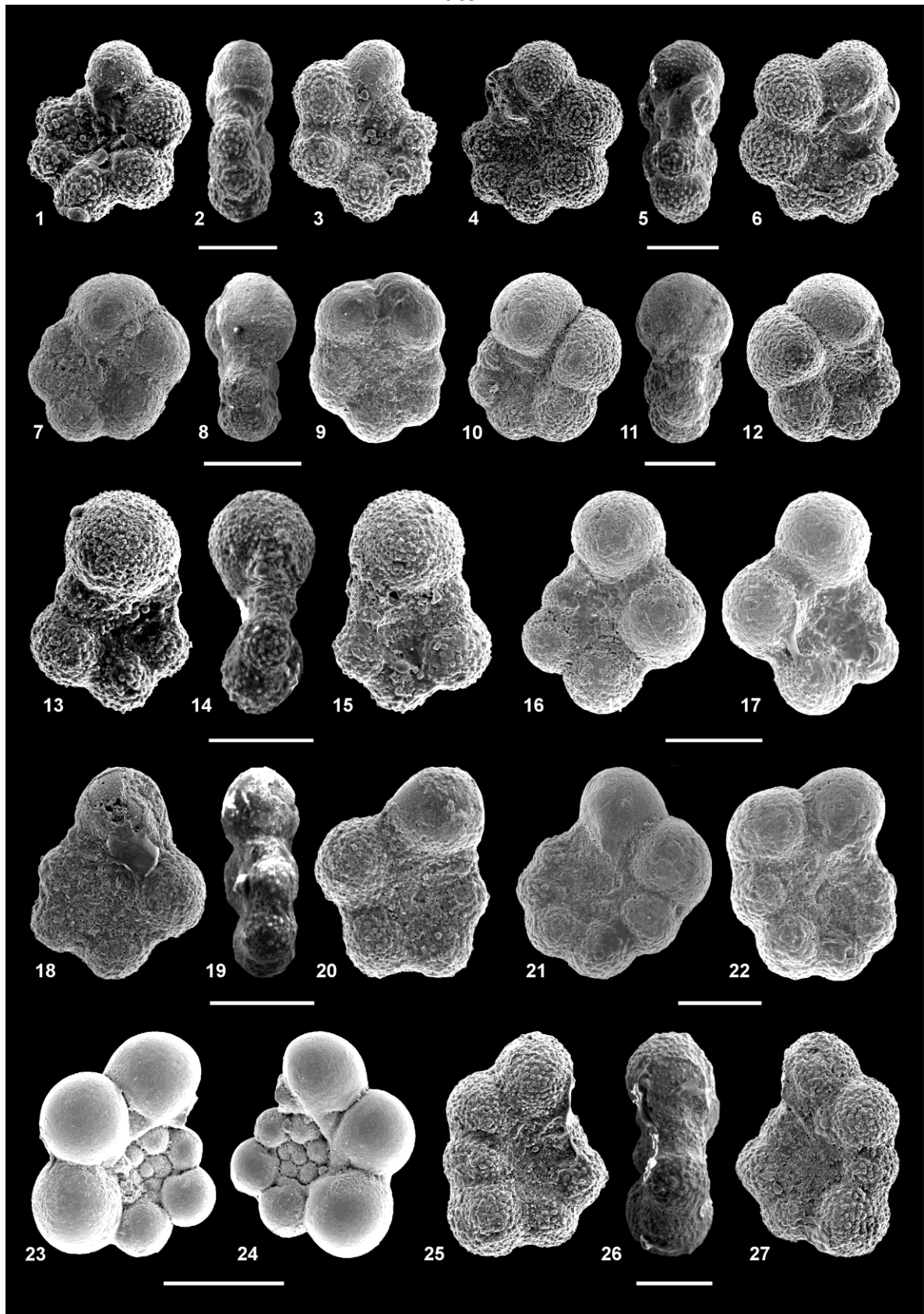
Figs 7-12: *Globigerinelloides rosebudensis* Smith and Pessagno. *Gansserina gansseri* and *Contusotruncana contusa* biozones, Figs 7-9, MPK14631, Dokan section, sample number DSH-117; Figs 10-12, MPK14480, Azmer section, sample number ASH-62.

Figs 13-15: *Globigerinelloides subcarinatus* Bronnimann. *Contusotruncana contusa* biozone, MPK14481, Dokan section, sample number DSH-117.

Figs 16-20: *Globigerinelloides volutus* (White). *Gansserina gansseri* biozone, Figs 16, 17, MPK14482, Dokan section, sample number DSH-80; Figs 18-20, MPK14632, Azmer section, sample number ASH-40.

Figs 21-27: *Globigerinelloides* spp. *Gansserina gansseri* and *Contusotruncana contusa* biozone, Figs 21, 22, MPK14633, Dokan section, sample number DSH-110; Figs 23, 24, MPK14634, Dokan section, sample number DSH-115; Figs 25-27, MPK14635, Dokan section, sample number ASH-117.

Plate 11



Chapter 3

Biostratigraphy and
systematic palaeontology
of Late Cretaceous
Heterohellicidae
foraminifera from the
Kurdistan region,
northeast Iraq

Chapter 3: Biostratigraphy and systematic palaeontology of Late Cretaceous Heterohellicidae foraminifera from the Kurdistan region, northeast Iraq

Abstract

The biostratigraphical importance and systematic palaeontology of early Turonian to early Maastrichtian Heterohellicidae planktonic foraminifera from Kurdistan are described. Some 24 species from 8 genera are recorded. Species abundance and diversity increases from the early Turonian to early Maastrichtian, perhaps signifying cooler sea temperatures in the Arabian sector of the Tethys Ocean during the early Maastrichtian. Despite the long biostratigraphical ranges of some species, the importance of the biserial and multiserial planktonic foraminifers in Late Cretaceous biostratigraphy is emphasised. From a biostratigraphic perspective, heterohellicids are important for the definition of the Campanian-Maastrichtian boundary in Kurdistan, with *Planoglobulina* species being especially important in this respect, as they are in Iran, Turkey and North Africa.

Introduction

The family Heterohellicidae Cushman 1927 forms one of the most common planktonic foraminiferal groups in the Late Cretaceous (early Turonian-early Maastrichtian) Kometan and Shiranish formations in the Kurdistan region, NE Iraq. Many heterohellicid species show biostratigraphical potential, yet in Kurdistan relatively little attention has been paid to them, and their biostratigraphic and biogeographic significance are poorly known. Brown (1969) mentioned the two main reasons why heterohellicids are often ignored: 1) the wide range of inter and intraspecific morphological variability; and 2) the poorly understood chamber arrangement of multiserial forms. Moreover, many genera have nomenclatural problems sufficient to discourage many workers (Martin 1972). Furthermore, certain key genera and species of families such as the Rotaliporidae, Marginotruncanidae and Globotruncanidae are already used successfully in Cretaceous foraminiferal biozonation (e.g. Wonders 1980; Caron 1985; Sliter 1989; Robaszynski & Caron 1995; Premoli Silva & Verga 2004), and consequently the Heterohellicidae have largely been ignored. However, more recently, Abdel-Kireem *et al.* (1996a), Robaszynski (1998), Li & Keller (1998a, b,

1999), Li *et al.* (1999), Abramovich & Keller (2002, 2003), Abramovich *et al.* (2002, 2003, 2010, 2011), Huber *et al.* (2008), and Ogg & Hinnov (2012) have developed an improved Late Cretaceous planktonic foraminiferal biozonation based on the Heterohellicidae.

The heterohellicid faunas from the Dokan and the Azmer rock successions of the Kurdistan region, NE Iraq have been studied and compared with the works of Pessagno (1967), Martin (1972), Smith & Pessagno (1973), Kassab (1974, 1978), Abdel-Kireem (1986b), Nederbragt (1989, 1991), Georgescu (1995, 2009), Abdel-Kireem *et al.* (1996b), and Georgescu *et al.* (2008). The objectives of this study are: 1) to describe the species of the Heterohellicidae from the Kometan and Shiranish formations; and 2) to investigate in detail the biostratigraphical distribution of the heterohellicid planktonic foraminifera in the Late Cretaceous (early Turonian-early Maastrichtian) of the Kurdistan region, NE Iraq.

Materials and Methods

Two sections, at Dokan (latitude 35° 56' 15" N, longitude 44° 57' 21" E) and Azmer (latitude 35° 37' 30" N, longitude 45° 31' 45" E) were chosen for foraminiferal analysis: these sections present near-complete Late Cretaceous successions of rocks. The Kometan and Shiranish formations are the most widespread lithostratigraphic units of the early Turonian-early Maastrichtian succession in the Kurdistan region, NE Iraq and contain rich and diverse planktonic foraminiferal assemblages especially heterohellicids that can be used for high-resolution biostratigraphy.

Some 411 samples, spaced ca 0.5 to 2 m apart, have been collected from the two formations. For indurated rock samples, thin section analysis was used for heterohellicid identifications. For friable rock samples, a freeze-thaw method of processing was used (Mogaddam 2002; Jaff *et al.* 2014). Approximately 200-300 grams 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 down to 63 µm. Heterohellicids were picked and studied from the residue in the 63-300 µm size fractions. As a relative measure, the heterohellicids are described as rare where there are less than 5 specimens per sample, and common where there are more than 5

specimens per sample. The heterohelicids were studied using a Hitachi S-3600N Scanning Electron Microscope (SEM) at the University of Leicester, UK. Materials for this study are deposited in the collections of the British Geological Survey, Keyworth, Nottingham, UK.

Systematic palaeontology

The terminology used to describe heterohelicids is shown in Figure 3.1. Descriptions here focus on the key characters displayed in the Kurdistan material, particularly where these are pertinent to establishing a refined biostratigraphy for the region. Dimensions are given for the specimens that are illustrated in plates 1-5. Synonymy lists are selective, and provide key references where material has been figured, or where the nomenclature or occurrence of a particular species has been discussed in detail. The stratigraphic ranges of the species as recorded by different authors, as well as in the present study, are shown in Figures 3.2-3.4 (see also Jaff *et al.* in press, for additional information). The taxonomic classification followed here is that of Pessagno (1967); Martin (1972), Smith & Pessagno (1973), Abdel-Kireem (1986b), Nederbragt (1989, 1991), Abdel-Kireem *et al.* (1996b), Georgescu *et al.* (2008), and Georgescu (1995, 2009).

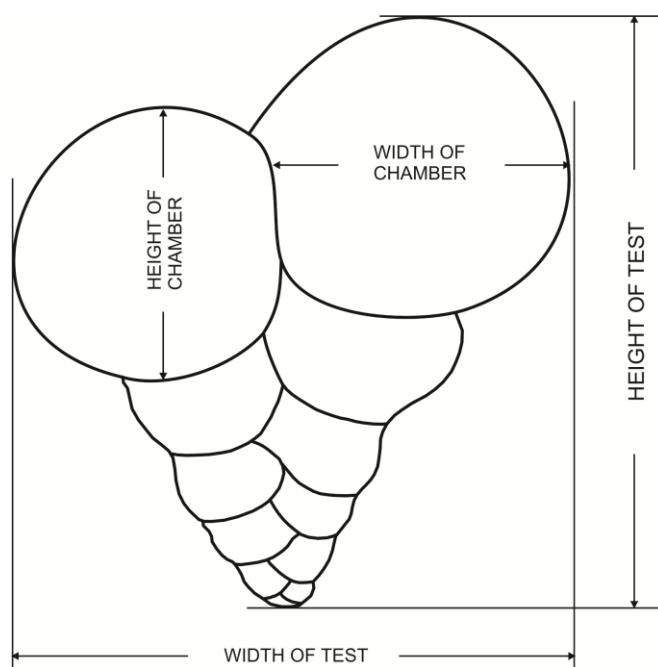


Figure 3.1. Idealized biserial heterohelicid showing terminology used to measure and describe the morphology of the test after Abdel-Kireem *et al.* (1996b).

Order Foraminiferida Eichwald 1830

Suborder Globigerinina Delage & Hérouard 1896

Superfamily Heterohelicea Cushman 1927

Family Heterohelcidae Cushman 1927

Subfamily Heterohelicinae Cushman 1927

Genus ***Praegublerina*** Georgescu, Saupe & Huber, 2008

Type species: *Gublerina acuta robusta* De Klasz, 1953, designated Georgescu, Saupe & Huber, 2008.

Praegublerina acuta (De Klasz, 1953)

Plate 1, figures 1-3

1953 *Gublerina acuta* De Klasz, pp. 246-247, pl. 8, fig. 3.

1983 *Gublerina acuta* De Klasz; Weiss, pp. 38-39, pl. 1, figs 1, 2.

1989 *Gublerina acuta* De Klasz; Nederbragt, p. 194, pl. 1, fig. 1.

1991 *Gublerina acuta* De Klasz; Nederbragt, p. 339, pl. 1, figs 1, 2.

2003 *Gublerina acuta* De Klasz; Abramovich *et al.*, p. 9, pl. II, fig. 9.

2008 *Praegublerina acuta* (De Klasz); Georgescu *et al.*, pp. 408-409, pl. 1, fig. A (3); pl. 4, figs 1-4; pl. 6, figs 4-6.

Material: 32 specimens from 20 samples, including MPK14483 to 14485.

Dimensions: 12 specimens measured give the following dimensions: height of test 0.47-0.70 mm, width of test 0.33-0.63 mm.

Description: A widely flaring test with a sub-triangular outline; the width of some tests is nearly equal to the height. In the early stage of the test, the chambers are biserial and become multiserial in the adult stage; chamber divergence begins in the middle part of the test; initial biserial chambers are globular, sub-rectangular to reniform and covered with thin costae; later multiserial chambers are smooth and reniform. Sometimes very thinly discontinuous costae are developed on the test.

Remarks: The species was originally described by De Klasz (1953) as *Gublerina acuta* from Bavaria, southeastern Germany, where it was reported to range from the late Campanian to the lower part of the late Maastrichtian. In Kurdistan, *P. acuta* is differentiated from material of the type species of *Gublerina*, *Gublerina cuvillieri* Kikoiné 1948, by the more acute shape of the initial part of its test and by its overall less widely flaring shape: it can also be distinguished by having fewer chambers in the biserial part of the test, by having a narrow area of divergence between two rows of chambers, by the commencement of chamber divergence in the middle stage of the test, and by the presence of progressive elongate, sub-rectangular to reniform chambers over the divergence area in the multiserial portion of the test.

Occurrence: *Praegublerina acuta* has been reported from the early to late Maastrichtian in the Tethyan Ocean (Weiss 1983), the latest Campanian to Maastrichtian in Tunisia (Nederbragt 1991), and from the late Campanian to Maastrichtian in a number of DSDP and ODP sites (for more details see Georgescu *et al.* 2008).

In Kurdistan, *P. acuta* is rare in the Shiranish Formation, occurring from the lower part of the *Planoglobulina acervulinoides* subzone within the *Gansserina gansseri* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Genus ***Gublerina*** Kikoiné, 1948

Type species: *Gublerina cuvillieri* Kikoiné, 1948, by original designation.

Gublerina cuvillieri Kikoiné, 1948

Plate 1, figures 4-6

1948 *Gublerina cuvillieri* Kikoiné, p. 26, pl. 2, figs 10a-c.

1953 *Gublerina cuvillieri* Kikoiné, De Klasz, p. 251, pl. 8, figs 1, 2.

1975 *Gublerina cuvillieri* Kikoiné; Darmonoian, pp. 196-197, pl. 2, fig. 16.

1983 *Gublerina cuvillieri* Kikoiné; Weiss, pp. 39-41, pl. 1, fig. 4.

1986b *Gublerina cuvillieri* Kikoiné; Abdel-Kireem, p. 220, pl. 1, fig. 1; pl. 3, fig. 4.

1989 *Gublerina cuvillieri* Kikoiné; Nederbragt, p. 194, pl. 1, figs 2, 3.

1991 *Gublerina cuvillieri* Kikoine; Nederbragt, pp. 339-340, pl. 1, figs 3, 4.

2003 *Gublerina cuvillieri* Kikoine; Abramovich *et al.*, p. 9, pl. II, figs 10, 11.

2008 *Gublerina cuvillieri* Kikoine; Georgescu *et al.*, pp. 412-414, pl. 1, figs A (5, 6); pl. 5, figs 6-11; pl. 6, figs 7-9.

Material: 23 specimens from 11 samples, including MPK14486 to 14488.

Dimensions: 10 specimens measured give the following dimensions: height of test 0.50-0.77 mm, width of test 0.40-0.60 mm.

Description: A widely flaring test with a triangular outline; early chambers quickly increase in size, chambers are sub-rectangular to reniform with width greater than height; chamber divergence begins in the early portion of the test; initial chambers flattened, later chambers becoming strongly inflated; ornamentation more strongly developed in the early portion of the test which is covered with coarse, irregular, discontinuous costae; the number of costae continuously decreases in the later portion of the test.

Remarks: *Gublerina cuvillieri* was originally described by Kikoine (1948) from Maastrichtian age strata in the Pyrenees, southern France. As noted above, in Kurdistan this species can be differentiated from *Praegublerina acuta* (De Klsz 1953) by more widely flaring shape, by having more chambers in the biserial part of the test, by having a wider area of divergence between the two rows of chambers, and by the commencement of chamber divergence at an early stage of the test.

Occurrence: *Gublerina cuvillieri* has been reported from the Maastrichtian in Iraq (Darmoian 1975; Abdel-Kireem 1986b) and Tunisia (Nederbragt 1991), the mid to late Maastrichtian in the Tethyan Ocean (Weiss 1983), and from the late Maastrichtian in a number of DSDP and ODP sites (for more details see Georgescu *et al.* 2008).

In Kurdistan, *G. cuvillieri* is rare in the Shiranish Formation, occurring from the top of the *Planoglobulina acervulinoides* subzone within the *Gansserina gansseri* biozone, to

the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Genus ***Heterohelix*** Ehrenberg, 1843

Type species: *Textilaria americana* Ehrenberg, 1843, designated Ellis & Messina, 1940.

Heterohelix globulosa (Ehrenberg, 1840)

Plate 1, figures 7-10; Plate 5, figures 1-4

1840 *Textularia globulosa* Ehrenberg, p. 135, pl. 4, figs 1B, 2B, 4B, 5B, 7B, 8B.

1929 *Gümbelina globulosa* (Ehrenberg); White, p. 36, pl. 4, fig. 10.

1938 *Gümbelina globulosa* (Ehrenberg); Cushman, pp. 6-7, pl. 1, figs 28-33.

1946 *Gümbelina globulosa* (Ehrenberg); Cushman, p. 105, pl. 45, figs 9-15.

1951 *Gümbelina globulosa* (Ehrenberg); Loeblich, p. 108, pl. 12, figs 4, 5.

1957 *Heterohelix globulosa* (Ehrenberg); Montanaro Gallitelli, p. 137, pl. 31, figs 12-15.

1967 *Heterohelix globulosa* (Ehrenberg); Pessagno, p. 260, pl. 87, figs 5-9, 11-13.

1972 *Heterohelix globulosa* (Ehrenberg); Govindan, p. 167, pl. 1, figs 1, 2.

1974 *Heterohelix globulosa* (Ehrenberg); Kassab, pp. 80-81, pl. 1, fig. 1.

1975 *Heterohelix globulosa* (Ehrenberg); Frerichs *et al.*, p. 300, pl. 1, figs 1, 2.

1980 *Heterohelix globulosa* (Ehrenberg); Masters, pp. 100-101, pl. 1, figs 6-8.

1982 *Heterohelix globulosa* (Ehrenberg); Odébodé, pp. 238-239, pl. I, figs 6, 7.

1983 *Heterohelix globulosa* (Ehrenberg); Weiss, p. 44, pl. 1, figs 8, 9.

1986b *Heterohelix globulosa* (Ehrenberg); Abdel-Kireem, p. 222, pl. 1, figs 2-4; pl. 3, figs 5, 6.

1989 *Heterohelix globulosa* (Ehrenberg); Nederbragt, p. 194, pl. 2, figs 3-5.

1991 *Heterohelix globulosa* (Ehrenberg); Nederbragt, pp. 341-343, pl. 2, figs 1, 2.

1995 *Heterohelix globulosa* (Ehrenberg); Georgescu, p. 95, pl. 1, figs 1, 2.

1995 *Heterohelix globulosa* (Ehrenberg); De Klasz *et al.*, p. 363, pl. 2, figs 3a-c.

1996b *Heterohelix globulosa* (Ehrenberg); Abdel-Kireem *et al.*, pp. 244-245, fig. 5 (1, 2).

2003 *Heterohelix globulosa* (Ehrenberg); Abramovich *et al.*, p. 9, pl. II, figs 1, 2.

2011 *Heterohelix globulosa* (Ehrenberg); Abramovich *et al.*, p. 147, pl. 2, figs 1-6.

Material: Over 10,000 specimens from all the samples of the Kometan and Shiranish formations, including MPK14449, 14450, 14489, and 14527 to 14530.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.22-0.45 mm, width of test 0.15-0.26 mm, height of last chamber 0.10-0.15 mm, width of last chamber 0.08-0.15 mm.

Description: Test biserial, 1½-2 times as long as wide, rapidly tapering, maximum width of the test is in the last pair of chambers; chambers distinct, sub-globular to globular and regularly increasing in size as chambers are added; last pair of chambers rapidly inflated and globular, the width and the height of the last pair of chambers are sub-equal; wall smooth, sometimes covered with weak, discontinuous costae; finely perforate.

Remarks: *Heterohelix globulosa* was first described by Ehrenberg (1840) as *Textularia globulosa* from Cretaceous strata of five different geographical localities: 1) Jutland, Denmark; 2) Gravesend, England; 3) Meudon, near Paris, France; 4) Mokattam Hills, near Cairo, Egypt; and 5) Thebes, Egypt. Nederbragt (1989, 1991) and Georgescu (1995) recorded *H. globulosa* with very fine costae and the Kurdistan specimens of *H. globulosa* have a range of surface ornamentation ranging from smooth to weakly developed discontinuous costae. *Heterohelix globulosa* can be distinguished from *H. striata* by the inflated and globular last pair of chambers: in the Kurdistan material *H. striata* also has much more pronounced costae.

Occurrence: *Heterohelix globulosa* has been reported from the late Campanian to Maastrichtian in northern and northeastern Iraq (Kassab 1974; Abdel-Kireem 1986b), the Cenomanian to Maastrichtian in southeastern Nigeria (Odébodé 1982), the Santonian to Maastrichtian in the Tethyan Ocean (Weiss 1983), the Turonian to Maastrichtian in Tunisia (Nederbragt 1991), the early Campanian to mid-Maastrichtian in the Black Sea (Georgescu 1995), and from the early Campanian to late Maastrichtian in Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *H. globulosa* is one of the most common species in the Kometan and Shiranish formations, occurring throughout the *Helvetoglobotruncana helvetica* biozone in the Kometan Formation, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (early Turonian to late early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Heterohelix moremani (Cushman, 1938)

Plate 5, figures 5, 6

1938 *Gümbelina moremani* Cushman, p. 10, pl. 2, figs 1-3.

1946 *Gümbelina moremani* Cushman; Cushman, p. 103, pl. 44, figs 15-17.

1967 *Heterohelix moremani* (Cushman); Pessagno, pp. 260-261, pl. 48, figs 10, 11; pl. 89, figs 1, 2.

1975 *Heterohelix moremani* (Cushman); Darmonoian, pp. 191-192, pl. 1, fig. 3.

1982 *Heterohelix moremani* (Cushman); Odébodé, pp. 239-240, pl. I, fig. 12.

1991 *Heterohelix moremani* (Cushman); Nederbragt, p. 344, pl. 2, figs 6, 7; pl. 3, figs 1, 2.

1995 *Heterohelix moremani* (Cushman); Georgescu, pp. 95-96, pl. 1, figs 3-5, 13.

1995 *Heterohelix moremani* (Cushman); De Klasz *et al.*, p. 363, pl. 2, fig. 4.

1996b *Heterohelix moremani* (Cushman); Abdel-Kireem *et al.*, p. 245, fig. 5 (3).

Material: 51 specimens from 17 samples, including MPK14531 and 14532.

Dimensions: 10 specimens measured give the following dimensions: height of test 0.27-0.42 mm, width of test 0.10-0.15 mm, height of last chamber 0.07-0.09 mm, width of last chamber 0.05-0.09 mm.

Description: Test biserial, compressed, elongate, slender, rectangular to sub-rectangular in outline, gradually tapering; the height of the test is nearly three times greater than the width of the test; 14-16 distinct sub-globular chambers, weak increase in size as chambers are added; the width of the test is nearly equal along the last three pairs of chambers; test wall appears smooth in thin section.

Remarks: *Heterohelix moremani* was first described by Cushman (1938) as *Gümbelina moremani* from the Cretaceous Eagle Ford Shale, along the southern bank of a small stream, Hill County, Texas. The species as originally described by Cushman (1938) has a smooth test surface, which was later confirmed by Caron (1985). However, Odébodé (1982) and Nederbragt (1991) recorded variable wall ornamentation ranging from smooth to slightly costate. De Klasz *et al.* (1995) recorded *H. moremani* in West Africa with the presence of very fine longitudinal striae. In Kurdistan, *H. moremani* can be separated from other biserial heterohelcids by having a smooth test surface, a larger number of chambers (reaching a maximum of 16; up to 18 chambers have been reported by Caron 1985; Nederbragt 1991; Abdel-Kireem *et al.* 1996b), and an elongate, slender shape.

Occurrence: *Heterohelix moremani* has been reported from the Coniacian in southeastern Iraq (Darmoian 1975), the Cenomanian to Santonian in southeastern Nigeria (Odébodé 1982), the Albian to Santonian in Tunisia (Nederbragt 1991), and from the Cenomanian to early Turonian in the Black Sea (Georgescu 1995) and Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *H. moremani* is rare in the Kometan Formation, occurring from the base of the *Helvetoglobotruncana helvetica* biozone, to the middle part of the *Dicarinella concavata* biozone (early Turonian to Coniacian; Fig. 3.2).

***Heterohelix navarroensis* Loeblich, 1951**

Plate 1, figures 11-13

1951 *Heterohelix navarroensis* Loeblich, pp. 107-108, pl. 12, figs 1-3b.

1957 *Heterohelix navarroensis* Loeblich; Montanaro Gallitelli, p. 137, pl. 31, figs 5-11.

1967 *Heterohelix navarroensis* Loeblich; Pessagno, p. 261, pl. 89, figs 8, 9.

1973 *Heterohelix navarroensis* Loeblich; Smith & Pessagno, pp. 18-19, pl. 3, figs 4-7.

1974 *Heterohelix navarroensis* Loeblich; Kassab, pp. 81-82, pl. 1, fig. 2.

1983 *Heterohelix navarroensis* Loeblich; Weiss, p. 44, pl. 1, figs 10, 11.

1986b *Heterohelix navarroensis* Loeblich; Abdel-Kireem, p. 222, pl. 1, fig. 5.

1989 *Heterohelix navarroensis* Loeblich; Nederbragt, p. 198, pl. 2, figs 6, 7.

1991 *Heterohelix navarroensis* Loeblich; Nederbragt, pp. 344-346, pl. 3, fig. 5.

1996b *Heterohelix navarroensis* Loeblich; Abdel-Kireem *et al.*, pp. 245-246, fig. 5 (4).

2011 *Heterohelix navarroensis* Loeblich; Abramovich *et al.*, p. 147, pl. 3, figs 1-4.

Material: Over 500 specimens from early Maastrichtian samples, including MPK14451, 14490 and 14491.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.22-0.35 mm, width of test 0.15-0.23 mm, height of last chamber 0.12-0.13 mm, width of last chamber 0.08-0.13 mm.

Description: Test biserial, small, about 1½-2 times as long as wide, weakly compressed laterally, sub-triangular in outline, tapering throughout; 8-10 distinct sub-globular chambers, increasing slowly in size as chambers are added; earliest chambers arranged in a flattened planispiral coil, last two pairs of chambers become weakly inflated; wall very finely costate and perforate.

Remarks: *Heterohelix navarroensis* was originally described by Loeblich (1951) from the Maastrichtian Kemp Clay, Guadalupe County, Texas. The presence of an initial planispiral coil is generally considered to be the most important characteristic of *H. navarroensis* (Loeblich 1951; Brown 1969; Pessagno 1967; Smith & Pessagno 1973; Masters 1977; Weiss 1983; Caron 1985). In the Kurdistan material, the initial planispiral coil is distinctive and well developed. On the basis of this character, the species can be distinguished from all other biserial heterohelcids. Moreover, the species can be differentiated from material of *H. striata* (Ehrenberg 1840) by being more laterally compressed, having a more finely costate surface, smaller test size, and chambers increasing less rapidly. *H. navarroensis* can be separated from material of *H. globulosa* (Ehrenberg 1840) by its initial planispiral coil and less inflated last two adult chambers.

Occurrence: *Heterohelix navarroensis* has been recorded from the Maastrichtian in Texas (Smith & Pessagno 1973), Iraq (Kassab 1974; Abdel-Kireem 1986b), the Tethyan Ocean (Weiss 1983) and Egypt (Abdel-Kireem *et al.* 1996b), and from the Campanian to Maastrichtian in Tunisia (Nederbragt 1991).

In Kurdistan, *H. navarroensis* is common in the Shiranish Formation, occurring from the lower part of the *Planoglobulina acervulinoides* subzone within the *Gansserina gansseri* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Heterohelix planata (Cushman, 1938)

Plate 1, figures 14-16; Plate 5, figure 7

1938 *Gümbelina planata* Cushman, pp. 12-13, pl. 2, figs 13, 14.

1946 *Gümbelina planata* Cushman; Cushman, p. 105, pl. 45, figs 6, 7.

1967 *Heterohelix planata* (Cushman); Pessagno, pp. 261-262, pl. 86, figs 3, 4; pl. 89, figs 6, 7.

1974 *Heterohelix planata* (Cushman); Kassab, pp. 82-83, pl. 1, fig. 3.

1975 *Heterohelix planata* (Cushman); Darmonoian, p. 192, pl. 1, fig. 8.

1975 *Heterohelix planata* (Cushman); Frerichs *et al.*, pp. 300-301, pl. 1, figs 5, 6.

1982 *Heterohelix planata* (Cushman); Odébodé, pp. 240-242, pl. I, fig. 13; pl. II, fig. 1.

1983 *Heterohelix planata* (Cushman); Weiss, pp. 44-45, pl. 2, figs 1-3.

1989 *Heterohelix planata* (Cushman); Nederbragt, p. 198, pl. 2, fig. 8; pl. 3, figs 1, 2.

1991 *Heterohelix planata* (Cushman); Nederbragt, p. 346, pl. 3, figs 3, 4.

1995 *Heterohelix planata* (Cushman); Georgescu, p. 96, pl. 1, figs 9-11.

1996b *Heterohelix planata* (Cushman); Abdel-Kireem *et al.*, p. 246, fig. 5 (5).

2003 *Heterohelix planata* (Cushman); Abramovich *et al.*, p. 9, pl. II, fig. 4.

2008 *Heterohelix planata* (Cushman); Georgescu *et al.*, p. 402, pl. 1, fig. A (1); pl. 3, figs 1-5.

2011 *Heterohelix planata* (Cushman); Abramovich *et al.*, p. 147, pl. 2, figs 15-17.

Material: Over 500 specimens from late Santonian to early Maastrichtian samples of the Kometan and Shiranish formations, including MPK14492 to 14494, and 14533.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.24-0.40 mm, width of test 0.15-0.28 mm, height of last chamber 0.08-0.13 mm, width of last chamber 0.10-0.15 mm.

Description: Test biserial, slender, 1½-2 times as long as wide, laterally compressed, tapering, maximum width in the last pair of chambers; earlier chambers are globular, adult chambers elongate to reniform, sometimes ovate, broader than high, increasing gradually as chambers are added; in the adult stages of some specimens the two rows of chambers may diverge; wall smooth or covered with thin, closely spaced, discontinuous costae; the number of costae gradually decreases in the last pair of chambers.

Remarks: *Heterohelix planata* was first described by Cushman (1938) as *Gümbelina planata* from the Late Cretaceous Taylor Marl, from a west-facing slope of Mustang Creek Valley, Red River County, Texas. The ovate and reniform adult chambers of this species are the characteristic feature for identification. Moreover, in some adult specimens an early stage of divergence between the two adult rows of chambers is seen. Cushman (1938) and Georgescu (1995) recorded *H. planata* with a keeled feature in the early portion of the test, but this feature is absent in Iraqi material (Kassab 1974; Darmonoian 1975), Tunisia (Nederbragt 1991), Egypt (Abdel-Kireem *et al.* 1996b), including that from Kurdistan. There is a superficial resemblance between the tests of *H. planata* and *Laeviheterohelix pulchra* (Brotzen 1936); however, *H. planata* differs by lacking broad reniform chambers and flanges.

Occurrence: *Heterohelix planata* has been reported from the Santonian to Maastrichtian in Iraq (Kassab 1974; Darmonoian 1975) and southeastern Nigeria (Odébodé 1982), the early Campanian to late Maastrichtian in the Tethyan Ocean (Weiss 1983), the late Santonian to Maastrichtian in Tunisia (Nederbragt 1991), the mid-Maastrichtian in the Black Sea (Georgescu 1995), the early Campanian to Maastrichtian in Egypt (Abdel-Kireem *et al.* 1996b), and from the late Santonian to Maastrichtian in a number of DSDP and ODP sites (for more details see Georgescu *et al.* 2008).

In Kurdistan, *H. planata* is rare in the Kometan Formation and common in the Shiranish Formation. It occurs from the upper part of the *Dicarinella asymetrica* biozone in the Kometan Formation, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (late Santonian to late early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Heterohelix punctulata (Cushman, 1938)

Plate 2, figures 1-3; Plate 5, figure 8

1938 *Gümbelina punctulata* Cushman, p. 13, pl. 2, figs 15, 16.

1946 *Gümbelina punctulata* Cushman; Cushman, p. 108, pl. 46, figs 13, 14.

1953 *Pseudoguembelina punctulata* (Cushman); Brönnimann & Brown, p. 154, text figs 7, 8.

1967 *Heterohelix punctulata* (Cushman); Pessagno, pp. 262-263, pl. 86, figs 7-10.

1974 *Heterohelix punctulata* (Cushman); Kassab, pp. 84-85, pl. 1, fig. 5.

1975 *Heterohelix punctulata* (Cushman); Darmonoian, pp. 193-194, pl. 2, fig. 1.

1983 *Pseudoguembelina ? punctulata* (Cushman); Weiss, pp. 58-59, pl. 7, figs 6, 7.

1986b *Heterohelix punctulata* (Cushman); Abdel-Kireem, p. 222, pl. 1, figs 8-10, 14; pl. 3, fig. 8.

1989 *Heterohelix punctulata* (Cushman); Nederbragt, p. 198, pl. 3, figs 5-7.

1991 *Heterohelix punctulata* (Cushman); Nederbragt, p. 346, pl. 3, fig. 6.

1996b *Heterohelix punctulata* (Cushman); Abdel-Kireem *et al.*, p. 246, fig. 5 (6, 7).

2003 *Heterohelix punctulata* (Cushman); Abramovich *et al.*, p. 9, pl. II, fig. 5.

Material: 92 specimens from late Campanian to early Maastrichtian samples, including MPK14495 to 14497, and 14534.

Dimensions: 10 specimens measured give the following dimensions: height of test 0.45-0.53 mm, width of test 0.30-0.37 mm, height of last chamber 0.20-0.25 mm, width of last chamber 0.15-0.20 mm.

Description: Test biserial, large, broad, 1½ times as long as wide, initial portion of the test rapidly tapering, later portion of nearly uniform width; initial chambers indistinct, compressed, short, narrow; later chambers distinct and rapidly inflated, globular to sub-globular; chambers increase slowly in size; wall in the early portion of the test is slightly costae, adult chambers covered by thick, discontinuous costae.

Remarks: *Heterohelix punctulata* was first described by Cushman (1938) as *Gümbelina punctulata* from the Late Cretaceous Taylor Marl, from a west-facing slope of Mustang Creek Valley, Red River County, Texas. *Heterohelix punctulata* is often included in *Pseudoguembelina*, because of its accessory and supplementary apertures (Brönnimann & Brown 1953; Masters 1977; Weiss 1983). However, Nederbragt (1991) integrated this species in *Heterohelix*, and mentioned that the accessory apertures are a rare feature, and even if present, they do not possess a distinct lip that is the characteristic of *Pseudoguembelina*. Moreover, the accessory apertures are not present in the very early stages of growth (Montanaro Gallitelli 1957; Pessagno 1967; Abdel-Kireem 1986b; Nederbragt 1991; Abdel-Kireem *et al.* 1996b). The Kurdistan material of *H. punctulata* is often recognised by the short initial portion of the test forming a ‘V’ shape and the rapidly increasing adult portion of the test with nearly uniform width in the last two or three pairs of chambers.

Occurrence: *Heterohelix punctulata* has been recorded from the late Campanian to Maastrichtian in Iraq (Kassab 1974; Darmonoian 1975; Abdel-Kireem 1986b), the Campanian to late Maastrichtian in the Tethyan Ocean (Weiss 1983), the late Santonian to Maastrichtian in Tunisia (Nederbragt 1991), and from the early Campanian to Maastrichtian in Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *H. punctulata* is rare in the Shiranish Formation, occurring from the base of the *Globotruncana aegyptiaca* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (late Campanian to late early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Heterohelix reussi (Cushman, 1938)

Plate 2, figures 4-6; Plate 5, figures 9, 10

1938 *Gümbelina reussi* Cushman, p. 11, pl. 2, figs 6-9.

1946 *Gümbelina reussi* Cushman; Cushman, p. 104, pl. 44, figs 18, 19.

1957 *Heterohelix reussi* (Cushman); Montanaro Gallitelli, p. 137, pl. 31, fig. 18.

1967 *Heterohelix reussi* (Cushman); Pessagno, p. 263, pl. 85, figs 1-9; pl. 86, figs 1, 2.

1975 *Heterohelix reussi* (Cushman); Darmoian, p. 194, pl. 1, figs 16-20.

1975 *Heterohelix reussi* (Cushman); Frerichs *et al.*, p. 301, pl. 1, figs 3, 4.

1982 *Heterohelix reussi* (Cushman); Odébodé, p. 242, pl. II, figs 11, 12.

1983 *Heterohelix cf. reussi* (Cushman); Weiss, pp. 47-48, pl. 3, figs 1, 2.

1986b *Heterohelix reussi* (Cushman); Abdel-Kireem, pp. 222-223, pl. 1, figs 11, 12.

1995 *Heterohelix reussi* (Cushman); Georgescu, p. 96, pl. 2, figs 1-3.

1996b *Heterohelix reussi* (Cushman); Abdel-Kireem *et al.*, p. 247, fig. 5 (8, 9).

Material: Over 1000 specimens from Coniacian to early Maastrichtian samples of the Kometan and Shiranish formations, including MPK14498 to 14500, 14535 and 14536.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.15-0.30 mm, width of test 0.10-0.20 mm, height of last chamber 0.05-0.12 mm, width of last chamber 0.05-0.10 mm.

Description: Test biserial, small, 1½ times as long as wide, maximum width of the test is in the last pair of chambers, rapidly tapering; chambers weakly compressed, 5-6 pairs, gradually increase in size as chambers are added, globular to sub-globular, triangular depression between the adult chambers, wall smooth or covered with thin, closely spaced, discontinuous costae; the number of costae gradually decreases in the last pair of chambers.

Remarks: *Heterohelix reussi* was originally described by Cushman (1938) as *Gümbelina reussi* from the Cretaceous Austin Chalk, north of Sherman, Texas. Morphologically, it is similar to *H. globulosa* (Ehrenberg 1840) and *H. striata* (Ehrenberg 1840). Some authors (for example Pessagno 1967; Abdel-Kireem 1986b; Abdel-Kireem *et al.* 1996b) suggest

that *H. reussi* and *H. globulosa* represent two independent taxonomic species, while others (Nederbragt 1991) regard *H. reussi* as a junior synonym of *H. globulosa*. In Kurdistan, *H. reussi* can be distinguished from material of *H. globulosa* by having more compressed chambers, a triangular depression between the adult chambers, and a gradual increase of the last two adult chambers (rather than rapidly inflated chambers). *Heterohelix reussi* can be distinguished from material of *H. striata* by the absence of strong, continuous, closely spaced costae.

Occurrence: *Heterohelix reussi* has been reported from the Coniacian to Maastrichtian in Iraq (Kassab 1974; Darmonoian 1975; Abdel-Kireem 1986b), the early Turonian to Maastrichtian in southeastern Nigeria (Odébodé 1982) and Egypt (Abdel-Kireem *et al.* 1996b), the Santonian to early Campanian in the Tethyan Ocean (Weiss 1983), and from the late Santonian in the Black Sea (Georgescu 1995).

In Kurdistan, *H. reussi* is rare to common in the Kometan and Shiranish formations, occurring from the middle part of the *Dicarinella concavata* biozone in the Kometan Formation, to the uppermost fossiliferous bed of the Shiranish Formation within the *Contusotruncana contusa* biozone (Coniacian to late early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Heterohelix semicostata (Cushman, 1938)

Plate 2, figures 7, 8

1938 *Gümbelina semicostata* Cushman, p. 16, pl. 3, fig. 6.

1946 *Gümbelina semicostata* Cushman; Cushman, p. 107, pl. 46, figs 1-5.

1967 *Heterohelix semicostata* (Cushman); Pessagno, p. 263, pl. 98, fig. 21.

1975 *Heterohelix semicostata* (Cushman); Darmonoian, p. 194, pl. 2, fig. 3.

1983 *Heterohelix semicostata* (Cushman); Weiss, p. 48, pl. 3, figs 3, 4.

1991 *Heterohelix semicostata* (Cushman); Nederbragt, p. 348, pl. 4, figs 2, 4.

Material: 11 specimens from 8 samples, including MPK14452 and 14501.

Dimensions: 11 specimens measured give the following dimensions: height of test 0.30-0.36 mm, width of test 0.21-0.25 mm, height of last chamber 0.05-0.10 mm, width of last chamber 0.12-0.15 mm.

Description: Test biserial, $1\frac{1}{2}$ times as long as wide, strongly compressed in edge view, gradually tapering, initial end acute; chambers wider than high, wall in the middle and inner portion of the test smooth; toward the periphery the wall is covered with thick, widely spaced, continuous costae which follow the curve of the chambers.

Remarks: *Heterohelix semicostata* was originally described by Cushman (1938) as *Gümbelina semicostata* from the Late Cretaceous Taylor Marl, north of Lake City, Delta County, Texas. According to Nederbragt (1991), it can be distinguished from material of *Pseudoguembelina excolata* (Cushman 1926) in having costae concentrated along the margin of the test and in lacking the accessory apertures. In Kurdistan, *H. semicostata* can be distinguished from material of *P. excolata* by showing a more compressed test shape in edge view, by having a longer test, and by having costae concentrated along the periphery of the test. Pessagno (1967) considered *H. semicostata* to be an intermediate form between *Heterohelix* and *Gublerina*. However, Nederbragt (1991) put *H. semicostata* in the evolutionary lineage of heterohelcids as an intermediate form between *Heterohelix* and *Pseudoguembelina*.

Occurrence: *Heterohelix semicostata* has been reported from the Santonian in southeastern Iraq (Darmoian 1975), the late Campanian to late Maastrichtian in the Tethyan Ocean (Weiss 1983), and from the latest Campanian to earliest Maastrichtian in Tunisia (Nederbragt 1991).

In Kurdistan, *H. semicostata* is very rare in the Shiranish Formation, occurring from the lower part of the *Pseudoguembelina excolata* to the lower part of the *Planoglobulina acervulinoides* subzones within the *Gansserina gansseri* biozone (latest Campanian to earliest Maastrichtian; Fig. 3.2).

Heterohelix striata (Ehrenberg, 1840)

Plate 2, figures 9-11

1840 *Textularia striata* Ehrenberg, p. 135, pl. 4, figs 1-3.

1938 *Gümbelina striata* (Ehrenberg); Cushman, pp. 8-9, pl. 1, figs 34-40.

1946 *Gümbelina striata* (Ehrenberg); Cushman, p. 104, pl. 45, figs 4, 5.

1953 *Pseudoguembelina striata* (Ehrenberg); Brönnimann & Brown, p. 154, text fig. 6.

1967 *Heterohelix striata* (Ehrenberg); Pessagno, p. 264, pl. 78, figs 4, 5; pl. 88, figs 3-7; pl. 98, fig. 16.

1972 *Heterohelix striata* (Ehrenberg); Govindan, p. 168, pl. 1, figs 13, 14.

1973 *Heterohelix striata* (Ehrenberg); Smith & Pessagno, pp. 19-20, pl. 3, figs 8-11; pl. 4, figs 1-4.

1975 *Heterohelix striata striata* (Ehrenberg); Darmonoian, pp. 194-196, pl. 2, figs 4-7.

1975 *Heterohelix striata* (Ehrenberg); Frerichs *et al.*, p. 301, pl. 1, figs 11, 12.

1980 *Heterohelix striata* (Ehrenberg); Masters, p. 101, pl. 1, figs 9-11.

1983 *Heterohelix striata* (Ehrenberg); Weiss, p. 48, pl. 3, figs 5, 6.

1986b *Heterohelix striata* (Ehrenberg); Abdel-Kireem, p. 223, pl. 1, fig. 13, pl. 3, fig. 7.

1995 *Striatella striata* (Ehrenberg); Georgescu, p. 102, pl. 1, fig. 14; pl. 4, figs 7, 8.

1996b *Heterohelix striata* (Ehrenberg); Abdel-Kireem *et al.*, p. 247, fig. 5 (10).

2011 *Heterohelix striata* (Ehrenberg); Abramovich *et al.*, p. 147, pl. 2, figs 7-11.

Material: Over 200 specimens from late Campanian to early Maastrichtian samples, including MPK14502 and 14453.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.22-0.38 mm, width of test 0.12-0.20 mm, height of last chamber 0.10-0.12 mm, width of last chamber 0.06-0.12 mm.

Description: Test biserial, small, height of the test is about twice the width, tapering throughout, maximum width in the last pair of chambers, expanding moderately; chambers in 5-8 pairs, early chambers slightly flattened and sub-globular, later chambers increasingly inflated and globular, the width and the height of the last pair of chambers are sub-equal;

wall ornamented by strong, continuous, closely spaced costae, with very fine pores in between.

Remarks: *Heterohelix striata* was originally described by Ehrenberg (1840) as *Textularia striata* from Cretaceous strata of four different geographical localities: 1) Memel, Poland; 2) Jutland, Denmark; 3) Rügen Island off the coast of Pomerania, north Germany; and 4) the Hamam Faraun Mountains in the Arabian Sinai, Egypt. The most characteristic feature of this species is surface ornamentation of strong longitudinal costae. In Kurdistan, the species can be distinguished from material of *H. globulosa* (Ehrenberg 1840) in its well-developed, continuous, stronger costae, and less inflated adult chambers.

Occurrence: *Heterohelix striata* has been reported from the Maastrichtian in Texas (Smith & Pessagno 1973), the Coniacian to Maastrichtian in Iraq (Kassab 1974; Darmonoian 1975; Abdel-Kireem 1986b), the late Campanian to late Maastrichtian in the Tethyan Ocean (Weiss 1983), the mid-Maastrichtian in the Black Sea (Georgescu, 1995), and from the early Campanian to Maastrichtian in Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *H. striata* is rare in the Shiranish Formation, occurring from the base of the *Globotruncana aegyptiaca* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (late Campanian to late early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

Heterohelix ultimumida (White, 1929)

Plate 2, figures 12, 13

1929 *Gümbelina ultimumida* White, p. 39, pl. 4, fig. 13.

1938 *Gümbelina ultimumida* White; Cushman, pp. 13-14, pl. 2, figs 17, 18.

1946 *Gümbelina ultimumida* White; Cushman, p. 107, pl. 46, figs 6, 7.

1967 *Heterohelix ultimumida* (White); Pessagno, pp. 264-265.

1972 *Heterohelix ultimumida* (White); Govindan, p. 168, pl. 1, figs 3, 4.

1975 *Heterohelix ultimumida* (White); Darmonoian, p. 196, pl. 2, figs 10-13.

1996b *Heterohelix ultimumida* (White); Abdel-Kireem *et al.*, p. 248, fig. 5 (11).

2011 *Heterohelix ultimumida* (White); Abramovich *et al.*, p. 147, pl. 2, fig. 14.

Material: 86 specimens from late Campanian to early Maastrichtian samples, including MPK14503 and 14504.

Dimensions: 10 specimens measured give the following dimensions: height of test 0.33-0.50 mm, width of test 0.25-0.33 mm, height of last chamber 0.12-0.26 mm, width of last chamber 0.18-0.23 mm.

Description: Test biserial, 1½ times as long as wide, chambers are few, no more than 5 pairs, rounded to sub-rounded, initial chambers very slowly increase in size, last-formed chamber or pair of chambers rapidly increase in size and are much more inflated; wall ornamented by weak, discontinuous costae.

Remarks: *Heterohelix ultimumida* was originally described by White (1929) as *Gümbelina ultimumida* from the Late Cretaceous Mendez Shale, north of Chijol Station, East Mexico. It is closely related to *H. striata* (Ehrenberg 1840), but is distinguished by the presence of the enlarged penultimate and ultimate, and weaker costae. *Heterohelix ultimumida* can be distinguished from material of *H. globulosa* (Ehrenberg 1840) by having fewer chambers, and by the final chamber being more inflated than the previous chambers.

Occurrence: *Heterohelix ultimumida* has been recorded from the late Campanian to Maastrichtian in Iraq (Kassab 1974; Darmono 1975) and Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *H. ultimumida* is rare in the Shiranish Formation, occurring from the base of the *Globotruncana aegyptiaca* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (late Campanian to late early Maastrichtian; Fig. 3.2) as defined in Jaff *et al.* (in press).

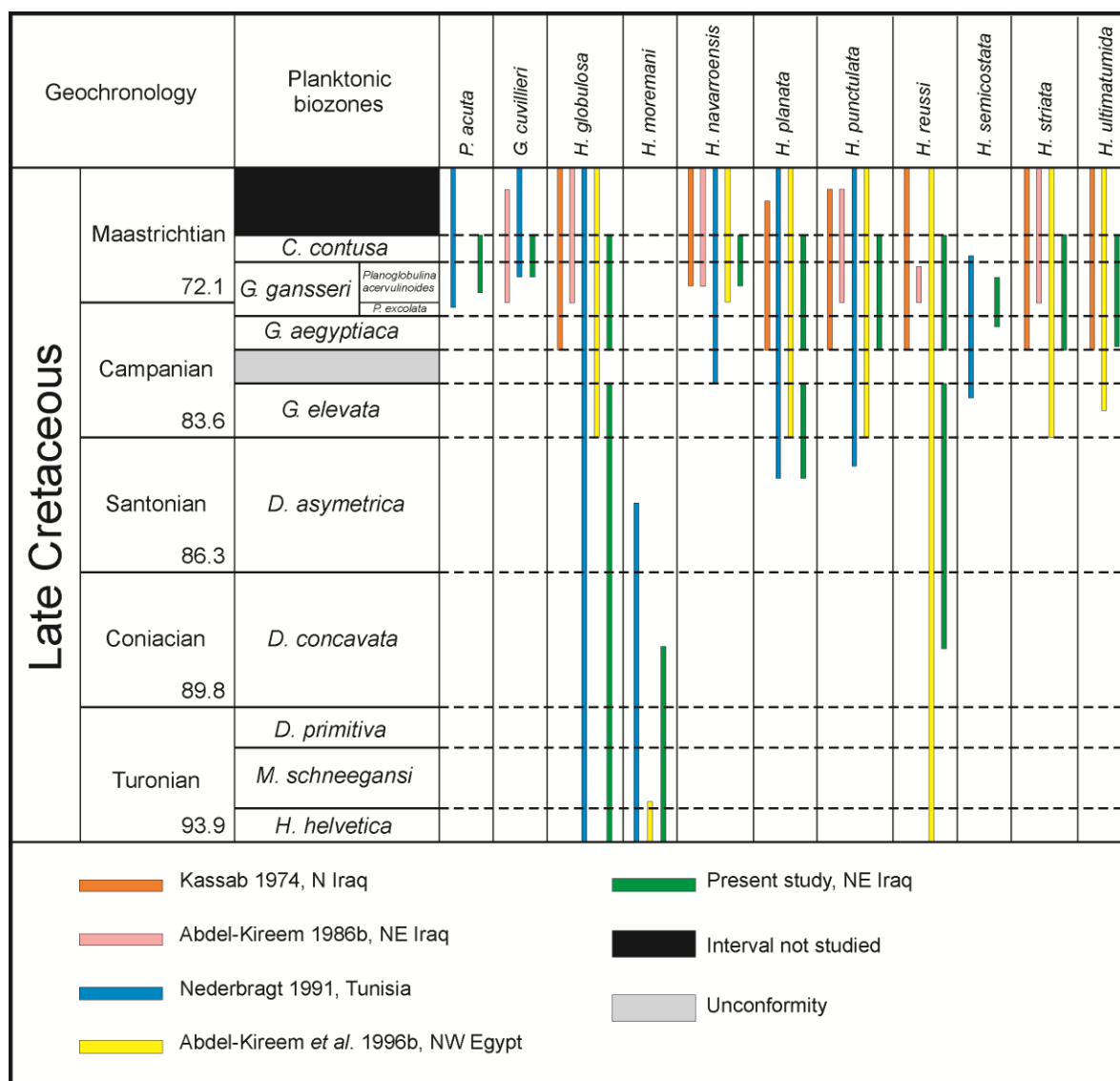


Figure 3.2. Biostratigraphic ranges of *Praegublerina*, *Gublerina* and *Heterohelix* species recorded in Kurdistan and their equivalent ranges in North Africa. Planktonic foraminiferal biozones after Jaff *et al.* (in press). Time scale adapted from Ogg & Hinnov (2012).

Genus *Laeviheterohelix* Nederbragt, 1991

Type species: *Gümbelina pulchra* Brotzen, 1936, designated Nederbragt, 1991.

Laeviheterohelix dentata (Stenestad, 1968)

Plate 2, figures 14-16

1968 *Heterohelix dentata* Stenestad, p. 67, pl. 1, figs 3-6, 8, 9; pl. 2, figs 1-3.

1989 *Heterohelix dentata* Stenestad; Nederbragt, p. 194, pl. 1, figs 4-7.

1991 *Laeviheterohelix dentata* (Stenestad); Nederbragt, p. 350, pl. 5, figs 1, 2.

Material: 54 specimens from 36 samples, including MPK14454, 14505 and 14506.

Dimensions: 12 specimens measured give the following dimensions: height of test 0.28-0.45 mm, width of test 0.15-0.30 mm, height of last chamber 0.06-0.12 mm, width of last chamber 0.10-0.20 mm.

Description: Test biserial, broad, compressed, about 1½-2 times as long as wide, rapidly tapering; chambers distinct, wider than high, sub-quadrate to reniform, increasing gradually as chambers are added; last two pairs of chambers overlap, the width of the last pair of chambers is about twice as high; wall smooth, finely perforate.

Remarks: *Laeviheterohelix dentata* was originally described by Stenestad (1968) as *Heterohelix dentata* from Maastrichtian age strata of Denmark. According to Nederbragt (1989, 1991), it could be a late Campanian descendant of *L. pulchra* (Brotzen 1936) and differs from the latter in having a more acute periphery. It can also be distinguished from *L. glabrans* (Cushman 1938) by its more sub-quadrate chambers. In Kurdistan, material of *L. dentata* can be distinguished by its sub-quadrate to reniform adult chambers and chambers overlapping in the adult portion of the test. Stenestad (1968) confirmed the presence of weak striae on the surface of *L. dentata*. However, Nederbragt (1991) in Tunisia, recorded *L. dentata* with a smooth wall surface. On the basis of this smooth surface, she recognised a new genus named *Laeviheterohelix* and now *L. dentata*, *L. glabrans* and *L. pulchra* are included therein.

Occurrence: *Laeviheterohelix dentata* has been reported from the late Campanian to Maastrichtian in Tunisia (Nederbragt 1991).

In Kurdistan, *L. dentata* is rare in the Shiranish Formation, occurring from the top of the *Pseudoguembelina excolata* subzone within the *Gansserina gansseri* biozone, to the

uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (latest Campanian to late early Maastrichtian; Fig. 3.3) as defined in Jaff *et al.* (in press).

Laeviheterohelix glabrans (Cushman, 1938)

Plate 3, figures 1-3

1938 *Gümbelina glabrans* Cushman, p. 15, pl. 3, figs 1, 2.

1946 *Gümbelina glabrans* Cushman; Cushman, p. 109, pl. 46, figs 17, 18.

1967 *Heterohelix glabrans* (Cushman); Pessagno, p. 259, pl. 88, figs 1, 2, 10, 11.

1972 *Heterohelix glabrans* (Cushman); Govindan, p. 169, pl. 1, figs. 11, 12.

1973 *Heterohelix glabrans* (Cushman); Smith & Pessagno, pp. 17-18, pl. 2, figs 8-10; pl. 3, figs 1-3.

1975 *Heterohelix glabrans* (Cushman); Darmonoian, p. 191, pl. 1, fig. 7.

1983 *Heterohelix glabrans* (Cushman); Weiss, p. 43, pl. 1, figs 6, 7.

1989 *Heterohelix glabrans* (Cushman); Nederbragt, p. 194, pl. 2, figs 1, 2.

1991 *Laeviheterohelix glabrans* (Cushman); Nederbragt, p. 352, pl. 5, fig. 6.

2003 *Laeviheterohelix glabrans* (Cushman); Abramovich *et al.*, p. 9, pl. II, fig. 6.

2011 *Laeviheterohelix glabrans* (Cushman); Abramovich *et al.*, p. 147, pl. 3, figs 10-12.

Material: Over 100 specimens from 46 samples, including MPK14507 to 14509.

Dimensions: 20 specimens measured give the following dimensions: height of test 0.28-0.35 mm, width of test 0.18-0.24 mm, height of last chamber 0.10-0.16 mm, width of last chamber 0.10-0.15 mm.

Description: Test biserial, much compressed, about 1½-2 times as long as wide, tapering throughout; initial chambers flattened, rounded to sub-rounded; penultimate chamber rounded, ultimate chamber becomes sub-quadrate to reniform, slightly inflated, about as high as broad, rapidly increasing in size as chambers are added; wall very weakly ornamented in the early chambers, later chambers smooth, sometimes with microperforation.

Remarks: *Laeviheterohelix glabrans* was originally described by Cushman (1938) as *Gümbelina glabrans* from the Late Cretaceous Kemp Clay, along a branch of the Mustang Creek, Williamson County, Texas. It shows a close resemblance to *L. dentata* (Stenestad 1968). The two species can be differentiated by the shape of the initial and penultimate chambers: those of *L. glabrans* are rounded to sub-rounded; while in *L. dentata* the chambers are sub-quadrate to reniform. *L. glabrans* can also be differentiated from *L. pulchra* (Brotzen 1936) by the shape of its penultimate and ultimate chambers, which are almost as broad as high, rather than reniform.

Occurrence: *Laeviheterohelix glabrans* has been recorded from the late Maastrichtian in Texas (Smith & Pessagno 1973), the Maastrichtian in northern Iraq (Kassab 1974), the early to late Maastrichtian in the Tethyan Ocean (Weiss 1983), and from the late Campanian to Maastrichtian in Tunisia (Nederbragt 1991).

In Kurdistan, *L. glabrans* is rare in the Shiranish Formation, occurring from the base of the *Pseudoguembelina excolata* subzone within the *Gansserina gansseri* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (latest Campanian to late early Maastrichtian; Fig. 3.3) as defined in Jaff *et al.* (in press).

***Laeviheterohelix pulchra* (Brotzen, 1936)**

Plate 3, figures 4-7; Plate 5, figures 11-13

1936 *Gümbelina pulchra* Brotzen, p. 121, pl. 9, fig. 3.

1938 *Gümbelina pulchra* Brotzen; Cushman, p. 12, pl. 2, fig. 12.

1957 *Heterohelix pulchra* (Brotzen); Montanaro Gallitelli, p. 137, pl. 31, fig. 20.

1967 *Heterohelix pulchra* (Brotzen); Pessagno, p. 262, pl. 87, fig. 4.

1972 *Heterohelix pulchra* (Brotzen); Govindan, p. 168, pl. 1, figs 9, 10.

1974 *Heterohelix pulchra* (Brotzen); Kassab, pp. 83-84, pl. 1, fig. 4.

1975 *Heterohelix pulchra* (Brotzen); Darmonoian, pp. 192-193, pl. 1, figs 9-15.

1975 *Heterohelix pulchra* (Brotzen); Frerichs *et al.*, p. 301, pl. 1, figs 7, 8.

1982 *Heterohelix pulchra* (Brotzen); Odébodé, p. 242, pl. II, figs 6-10.

1983 *Heterohelix pulchra* (Brotzen); Weiss, pp. 46-47, pl. 2, figs 9-13.

1989 *Heterohelix pulchra* (Brotzen); Nederbragt, p. 198, pl. 3, figs 3, 4.

1991 *Laeviheterohelix pulchra* (Brotzen); Nederbragt, pp. 352-354, pl. 5, fig. 7; pl. 6, fig. 1.

1995 *Heterohelix pulchra* (Brotzen); Georgescu, p. 96, pl. 1, figs 6-8.

2009 *Laeviheterohelix pulchra* (Brotzen); Georgescu, p. 322, figs 7 (1-5); 8 (1-3).

2011 *Laeviheterohelix pulchra* (Brotzen); Abramovich *et al.*, p. 147, pl. 3, fig. 13.

Material: Over 200 specimens from late Santonian to late Campanian samples of the Kometan and Shiranish formations, including MPK14510, 14456, and 14537 to 14539.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.26-0.46 mm, width of test 0.18-0.30 mm, height of last chamber 0.16-0.20 mm, width of last chamber 0.10-0.12 mm.

Description: Test biserial, strongly compressed, 1½-2 times as long as wide, maximum width in the last pair of chambers, rapidly tapering; chambers in 5-7 pairs, broad, reniform, regularly inflated, gradually increasing in size as chambers are added; last pair of chambers overlap and characterised by flanges, the high of the last pair of chambers is about twice as width; wall smooth, sometimes with microporification.

Remarks: *Laeviheterohelix pulchra* was first described by Brotzen (1936) as *Gümbelina pulchra* from early Senonian age strata in the Eriksdal, Sweden. As noted above, *L. pulchra* is similar to *L. glabrans* (Cushman 1938) and *Heterohelix planata* (Cushman 1938). It can be distinguished by its broad, reniform, final elongate chambers and smooth test. In Kurdistan, the most important characteristic feature of *L. pulchra* is the presence of flanges in the last two or three rows of the adult chambers: this character is virtually absent in the material of *H. planata* and other *Laeviheterohelix* species. Recently Georgescu (2009) recorded *L. pulchra* with a surface ornamentation of pore mounds.

Occurrence: *Laeviheterohelix pulchra* has been reported from the late Campanian to Maastrichtian in northern Iraq (Kassab 1974), the Coniacian to Santonian in southeastern

Iraq (Darmoian 1975), the Coniacian to Maastrichtian in southeastern Nigeria (Odébodé 1982), the early Campanian to late Maastrichtian in the Tethyan Ocean (Weiss 1983), the late Turonian to late Campanian in Tunisia (Nederbragt 1991), the mid-Maastrichtian in the Black Sea (Georgescu 1995), and from the late Coniacian to Campanian in a number of DSDP and ODP sites (for more details see Georgescu 2009).

In Kurdistan, *L. pulchra* is rare in the Kometan and Shiranish formations, occurring from the upper part of the *Dicarinella asymetrica* biozone in the Kometan Formation, to the top of the *Pseudoguembelina excolata* subzone within the *Gansserina gansseri* biozone (latest Santonian to latest Campanian; Fig. 3.3).

Genus ***Planoglobulina*** Cushman, 1927

Type species: *Gümbelina acervulinoides* Egger, 1899, designated Cushman, 1927.

Planoglobulina acervulinoides (Egger, 1899)

Plate 3, figures 8-10; Plate 5, figures 14, 15

1899 *Gümbelina acervulinoides* Egger, p. 36, pl. 14, fig. 20 (not figs 14-18, 21-22).

1929 *Planoglobulina acervulinoides* (Egger); White, p. 33, pl. 4, fig. 6.

1938 *Planoglobulina acervulinoides* (Egger); Cushman, p. 23, pl. 4, figs 5-8.

1946 *Planoglobulina acervulinoides* (Egger); Cushman, p. 111, pl. 47, figs 12-15.

1967 *Planoglobulina acervulinoides* (Egger); Pessagno, p. 271, pl. 87, fig. 14.

1972 *Planoglobulina acervulinoides* (Egger); Martin, p. 81, pl. 3, figs 3-6.

1978 *Pseudotextularia acervulinoides* (Egger); Kassab, pp. 73-75, pl. 1, figs 1, 2.

1983 *Planoglobulina acervulinoides* (Egger); Weiss, p. 50, pl. 4, figs 5-7.

1986b *Planoglobulina acervulinoides* (Egger); Abdel-Kireem, p. 223, pl. 2, fig. 1.

1989 *Planoglobulina acervulinoides* (Egger); Nederbragt, p. 200, pl. 4, figs 4-6; pl. 5, figs 1, 2.

1991 *Planoglobulina acervulinoides* (Egger); Nederbragt, p. 356, pl. 6, figs 5, 6; pl. 7, fig. 1.

1995 *Planoglobulina acervulinoides* (Egger); Georgescu, p. 97, pl. 2, figs 4-6, 9.

2003 *Planoglobulina acervulinoides* (Egger); Abramovich *et al.*, p. 13, pl. IV, fig. 11.

Material: 45 specimens from 41 samples, including MPK14416, 14456, 14511, 14540 and 14541.

Dimensions: 15 specimens measured give the following dimensions: height of test 0.50-0.56 mm, width of test 0.50-0.68 mm.

Description: Test flabelliform, inflated in the early part, six to eight chambers in the biserial part, more than 15 chambers in the multiserial part; biserial and central multiserial chambers are sub-globular, chambers along the margin are globular; surface of the initial part of the test covered with coarse, longitudinal, continuous costae; somewhat finer and discontinuous in the final chambers.

Remarks: *Planoglobulina acervulinoides* was originally described by Egger (1899) as *Gümbelina acervulinoides* from Late Cretaceous strata in the Bavarian Alps, Germany. In Kurdistan it can be distinguished from material of *P. brazoensis* Martin 1972 by having a less inflated test and more numerous chambers in the multiserial portion of the test.

Occurrence: *Planoglobulina acervulinoides* has been reported from the Maastrichtian in Texas and Mexico (Martin 1972), Iraq (Kassab 1973, 1978; Abdel-Kireem 1986b), the Tethyan Ocean (Weiss 1983), Tunisia (Nederbragt 1991) and the Black Sea (Georgescu 1995).

In Kurdistan, *P. acervulinoides* is rare in the Shiranish Formation, occurring from the base of the *Planoglobulina acervulinoides* subzone within the *Gansserina gansseri* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (early Maastrichtian; Fig. 3.3) as defined in Jaff *et al.* (in press).

***Planoglobulina brazoensis* Martin, 1972**

Plate 3, figures 11-13; Plate 5, figure 16

1972 *Planoglobulina brazoensis* Martin, pp. 82-83, pl. 3, fig. 7; pl. 4, figs 1, 2.

1973 *Planoglobulina brazoensis* Martin; Smith & Pessagno, p. 20, pl. 4, figs 5-10; pl. 5, figs 1, 2.

1983 *Planoglobulina brazoensis* Martin; Weiss, p. 51, pl. 4, figs 1-4.

1986b *Planoglobulina brazoensis* Martin; Abdel-Kireem, p. 223, pl. 2, fig. 4.

2003 *Planoglobulina brazoensis* Martin; Abramovich *et al.*, p. 13, pl. IV, fig. 10.

2011 *Planoglobulina brazoensis* Martin; Abramovich *et al.*, p. 148, pl. 4, figs 11, 12.

Material: 22 specimens from 17 samples, including MPK14457, 14512, 14513, and 14542.

Dimensions: 10 specimens measured give the following dimensions: height of test 0.53-0.58 mm, width of test 0.40-0.47 mm.

Description: Test flabelliform, six chambers in the early part, followed by six to ten inflated chambers in the multiserial part; chambers are globular, much inflated; wall covered with coarse, longitudinal, discontinuous costae, costae are finer in the final chambers of the multiserial part.

Remarks: *Planoglobulina brazoensis* was originally described by Martin (1972) from the Maastrichtian Kemp Clay, along the southern bank of Walkers Creek, Milam County, Texas. The Kurdistan specimens can be distinguished from other species of *Planoglobulina* by its globular chambers, which are greatly inflated in the later stage of the biserial portion, and the early stage of the multiserial portion of the test. The species is also separated from material of *P. acervulinoides* (Egger 1899) by having a more inflated test and smaller number of chambers in the multiserial portion of the test.

Occurrence: *Planoglobulina brazoensis* has been recorded from the Maastrichtian in Mexico and Texas (Martin 1972; Smith & Pessagno 1973), the Tethyan Ocean (Weiss 1983) and in northeastern Iraq (Abdel-Kireem 1986b).

In Kurdistan, *P. brazoensis* is rare in the Shiranish Formation, occurring from the lower part of the *Planoglobulina acervulinoides* subzone within the *Gansserina gansseri* biozone, to the last fossiliferous bed of the Shiranish Formation, within the

Contusotruncana contusa biozone (early Maastrichtian; Fig. 3.3) as defined in Jaff *et al.* (in press).

Planoglobulina carseyae (Plummer, 1931)

Plate 3, figure 14; Plate 4, figures 1, 2

1931 *Ventilabrella carseyae* Plummer, pp. 178-179, pl. 9, figs 7-9, not fig. 10.

1938 *Ventilabrella carseyae* Plummer; Cushman, pp. 26-27, pl. 4, figs 20-24.

1946 *Ventilabrella carseyae* Plummer; Cushman, p. 112, pl. 48, figs 1-5.

1951 *Ventilabrella carseyae* Plummer; Loeblich, p. 109, pl. 12, figs 6-8.

1957 *Planoglobulina carseyae* (Plummer); Montanaro Gallitelli, p. 141, pl. 32, fig. 13.

1967 *Planoglobulina carseyae* (Plummer); Pessagno, pp. 271-272, pl. 87, figs 10, 15, 16.

1972 *Planoglobulina ? carseyae* (Plummer); Martin, p. 83, pl. 4, figs 4-7.

1972 *Planoglobulina carseyae* (Plummer); Govindan, pp. 171-172, pl. 1, fig. 17.

1973 *Planoglobulina carseyae* (Plummer); Smith & Pessagno, pp. 21-22, pl. 5, figs 3-12.

1978 *Pseudotextularia carseyae* (Plummer); Kassab, pp. 75-77, pl. 1, fig. 3.

1983 *Planoglobulina carseyae* (Plummer); Weiss, pp. 51-52, pl. 5, figs 1-4.

1986b *Planoglobulina carseyae* (Plummer); Abdel-Kireem, p. 223, pl. 2, figs 2, 3; pl. 3, fig. 9.

1989 *Planoglobulina carseyae* (Plummer); Nederbragt, p. 200, pl. 5, figs 3-5.

1991 *Planoglobulina carseyae* (Plummer); Nederbragt, p. 356, pl. 7, figs 2, 3.

1995 *Pseudoplanoglobulina carseyae* (Plummer); Georgescu, p. 97, pl. 2, figs 7, 8.

2003 *Planoglobulina carseyae* (Plummer); Abramovich *et al.*, p. 13, pl. IV, fig. 9.

2011 *Planoglobulina carseyae* (Plummer); Abramovich *et al.*, p. 148, pl. 4, figs 13-16.

Material: 33 specimens from 31 samples, including MPK14514 to 14516.

Dimensions: 10 specimens measured give the following dimensions: height of test 0.40-0.50 mm, width of test 0.30-0.35 mm.

Description: Test biserial in the early part, occupying the majority of the test height, followed by one or two sets of multiserial chambers in the later part. Early biserial

chambers weakly flattened; later biserial and multiserial chambers are globular to slightly reniform; wall covered with thin, longitudinal, continuous costae in the early part of the test; the degree of costae decreases and becomes very thin in the final chambers of the multiserial part.

Remarks: *Planoglobulina carseyae* was first described by Plummer (1931) as *Ventilabrella carseyae* from the Maastrichtian Corsicana Formation, along the southern bank of Walkers Creek, Milam County, Texas. In Kurdistan, *P. carseyae* can be distinguished from other *Planoglobulina* species by its early biserial chambers occupying more than half of the test, followed by one or two sets of the multiserial chambers in the later portion of the test.

Occurrence: *Planoglobulina carseyae* has been reported from the Maastrichtian in Texas (Martin 1972; Smith & Pessagno 1973), Iraq (Kassab 1978; Abdel-Kireem 1986b), the Tethyan Ocean (Weiss 1983), Tunisia (Nederbragt 1991) and the Black Sea (Georgescu 1995).

In Kurdistan, *P. carseyae* is rare in the Shiranish Formation, occurring from the lower part of the *Planoglobulina acervulinoides* subzone within the *Gansserina gansseri* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (early Maastrichtian; Fig. 3.3) as defined in Jaff *et al.* (in press).

***Planoglobulina riograndensis* (Martin, 1972)**

Plate 4, figure 3

1972 *Ventilabrella riograndensis* Martin, pp. 88-89, pl. 2, figs 1-4.

1983 *Planoglobulina riograndensis* (Martin); Weiss, p. 54, pl. 5, figs 5, 6.

1989 *Planoglobulina riograndensis* (Martin); Nederbragt, p. 200, pl. 6, figs 1, 2.

1991 *Planoglobulina riograndensis* (Martin); Nederbragt, p. 358, pl. 7, figs 6, 7.

Material: 1 specimen from sample number DSH-110, MPK14517.

Dimensions: height of test 0.56 mm, width of test 0.55 mm.

Description: Test flabelliform, slightly compressed; six chambers in biserial part, expanding rapidly in size, followed by more than eight chambers in the multiserial part; biserial and central multiserial chambers are sub-globular to globular, chambers around the periphery become slightly pyriform; wall covered with fine, discontinuous, longitudinal costae; the number of costae gradually decrease in the pyriform chambers of the multiserial portion of the test.

Remarks: *Planoglobulina riograndensis* was originally described by Martin (1972) as *Ventilabrella riograndensis* from the early Maastrichtian Mendez Shale, along the northern bank of Arroyo Pedregoso, East Mexico. The Kurdistan specimen closely resembles *P. riograndensis* recorded by Nederbragt (1991, p. 357, pl. 7, fig. 7) in Tunisia. Martin (1972) mentioned that *P. riograndensis* resembles *Ventilabrella eggeri* Cushman 1928 in test shape, but the two differ in ornamentation. The Iraqi *P. riograndensis* also differs from *V. eggeri* by the shape of the penultimate and ultimate chambers.

Occurrence: *Planoglobulina riograndensis* has been recorded from the Campanian to Maastrichtian in Texas (Martin 1972), the Tethyan Ocean (Weiss 1983) and Tunisia (Nederbragt 1991).

In Kurdistan, *P. riograndensis* is very rare in the Shiranish Formation, occurring at the top of the *Planoglobulina acervulinoides* subzone within the *Gansserina gansseri* biozone (early Maastrichtian; Fig. 3.3).

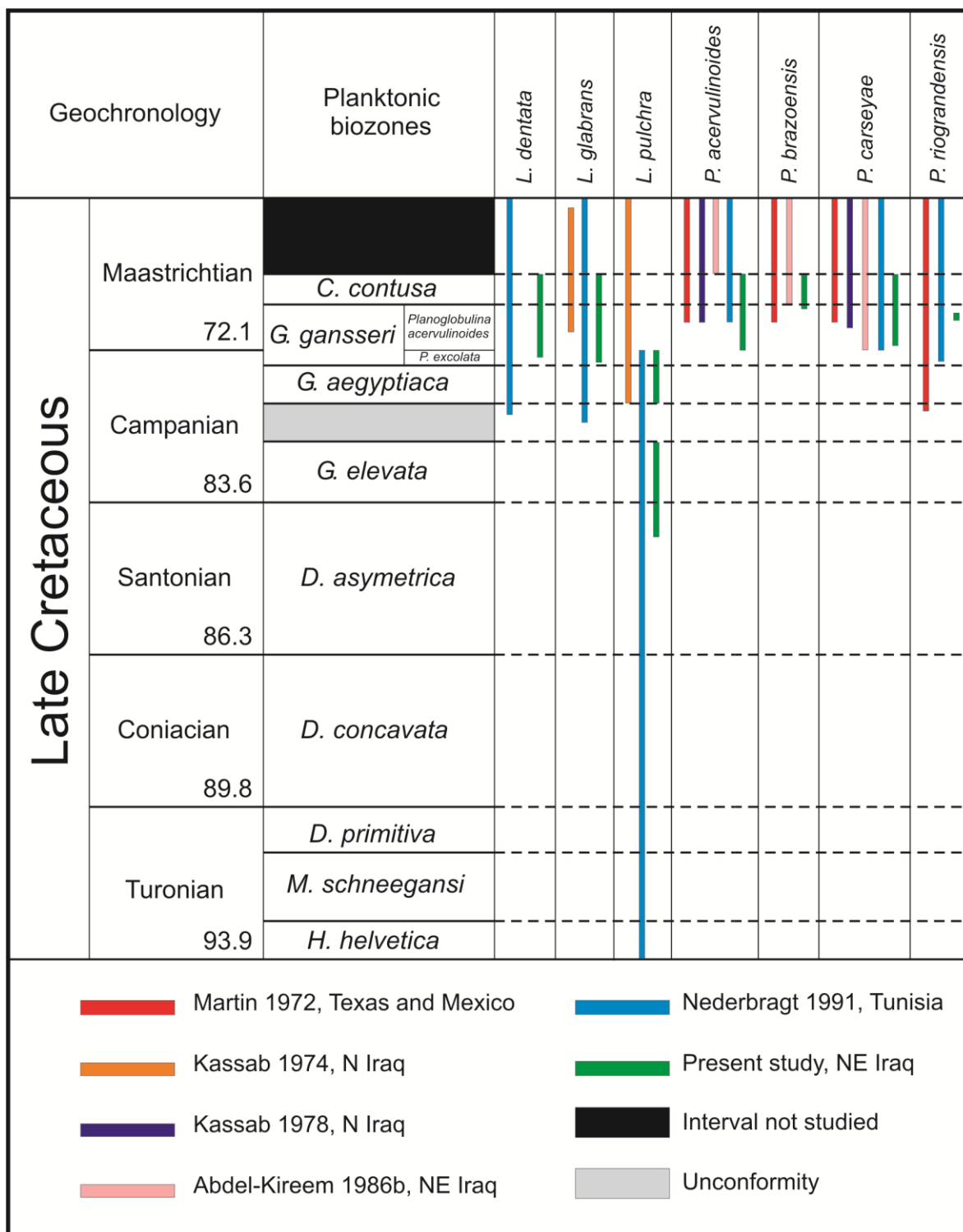


Figure 3.3. Biostratigraphic ranges of *Laeviheterohelix* and *Planoglobulina* species recorded in Kurdistan and their equivalent ranges in North Africa, Texas and Mexico. Planktonic foraminiferal biozones after Jaff *et al.* (in press). Time scale adapted from Ogg & Hinnov (2012).

Genus ***Pseudoguembelina*** Brönnimann & Brown, 1953

Type species: *Gümbelina excolata* Cushman, 1926, designated Brönnimann & Brown, 1953.

Pseudoguembelina costulata (Cushman, 1938)

Plate 4, figures 4, 5

1938 *Gümbelina costulata* Cushman, pp. 16-17, pl. 3, figs 7-9.

1946 *Gümbelina costulata* Cushman; Cushman, p. 108, pl. 46, figs 10-12.

1953 *Pseudoguembelina costulata* (Cushman); Brönnimann & Brown, pp. 153-154, text fig. 5.

1957 *Pseudoguembelina costulata* (Cushman); Montanaro Gallitelli, p. 139, pl. 31, figs 21, 22.

1967 *Pseudoguembelina costulata* (Cushman); Pessagno, p. 266, pl. 79, fig. 1; pl. 88, figs 8, 9; pl. 90, fig. 3.

1972 *Pseudoguembelina costulata* (Cushman); Govindan, p. 169, pl. 1, figs 15, 16.

1973 *Pseudoguembelina costulata* (Cushman); Smith & Pessagno, pp. 24-25, pl. 6, figs 1-5.

1975 *Pseudoguembelina costulata* (Cushman); Darmonoian, pp. 197-198, pl. 3, figs 1-5.

1983 *Pseudoguembelina costulata* (Cushman); Weiss, p. 56, pl. 6, figs 8-10.

1986b *Pseudoguembelina costulata* (Cushman); Abdel-Kireem, p. 224, pl. 1, fig. 15.

1989 *Pseudoguembelina costulata* (Cushman); Nederbragt, p. 200, pl. 6, figs 3-5.

1991 *Pseudoguembelina costulata* (Cushman); Nederbragt, p. 358, pl. 8, figs 3, 4.

1995 *Pseudoguembelina costulata* (Cushman); Georgescu, p. 101, pl. 4, figs 1-3.

1996b *Pseudoguembelina costulata* (Cushman); Abdel-Kireem *et al.*, p. 250, fig. 5 (16).

2003 *Pseudoguembelina costulata* (Cushman); Abramovich *et al.*, p. 9, pl. II, fig. 12.

2011 *Pseudoguembelina costulata* (Cushman); Abramovich *et al.*, p. 147, pl. 3, figs 14, 15.

Material: Over 500 specimens from latest Campanian to early Maastrichtian samples, including MPK14518 and 14519.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.20-0.30 mm, width of test 0.12-0.20 mm, height of last chamber 0.06-0.10 mm, width of last chamber 0.08-0.12 mm.

Description: Test biserial, about 1½-2 times as long as wide, slender, compressed, rapidly tapering, initial end acute; 5-7 pairs of slightly reniform chambers; initial portion of the test is slightly pointed; initial chambers indistinct, later chambers become slightly inflated, somewhat broader than high, increasing slowly in size as chambers are added; wall ornamented with thin to moderate, longitudinal, closely spaced, continuous costae, following the curve of the chambers.

Remarks: *Pseudoguembelina costulata* was originally described by Cushman (1938) as *Gümbelina costulata* from the Late Cretaceous Taylor Marl, Kickapoo Creek, Red River County, Texas. The Kurdistan specimens can be differentiated from material of *P. excolata* (Cushman 1926) by having a narrow and slender test, and by more closely spaced and finer costae.

Occurrence: *Pseudoguembelina costulata* has been reported from the Maastrichtian in Texas (Smith & Pessagno 1973), and from the Campanian to Maastrichtian in southeastern Iraq (Darmoian 1975; Abdel-Kireem 1986b), the Tethyan Ocean (Weiss 1983), Tunisia (Nederbragt 1991), the Black Sea (Georgescu 1995) and Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *P. costulata* is common in the Shiranish Formation, occurring from the upper part of the *Globotruncana aegyptiaca* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (latest Campanian to late early Maastrichtian; Fig. 3.4) as defined in Jaff *et al.* (in press).

***Pseudoguembelina excolata* (Cushman, 1926)**

Plate 4, figures 6, 7

1926 *Gümbelina excolata* Cushman, p. 20, pl. 2, fig. 9.

1929 *Gümbelina excolata* Cushman; White, p. 34, pl. 4, fig. 7.

- 1938 *Gümbelina excolata* Cushman; Cushman, p. 17, pl. 3, fig. 11.
- 1946 *Gümbelina excolata* Cushman; Cushman, p. 108, pl. 46, fig. 16.
- 1953 *Pseudoguembelina excolata* (Cushman); Brönnimann & Brown, p. 153, text figs 1-4.
- 1957 *Pseudoguembelina excolata* (Cushman); Montanaro Gallitelli, p. 139, pl. 31, fig. 23.
- 1967 *Pseudoguembelina excolata* (Cushman); Pessagno, pp. 266-267, pl. 68, figs 4, 5; pl. 90, fig. 5.
- 1973 *Pseudoguembelina excolata* (Cushman); Smith & Pessagno, pp. 25-26, pl. 6, figs 6-10.
- 1975 *Pseudoguembelina excolata* (Cushman); Darmonoian, p. 198, pl. 2, fig. 20.
- 1983 *Pseudoguembelina costata* (Carsey); Weiss, pp. 55-56, pl. 6, figs 5-7.
- 1986b *Pseudoguembelina excolata* (Cushman); Abdel-Kireem, p. 224, pl. 1, fig. 16.
- 1989 *Pseudoguembelina excolata* (Cushman); Nederbragt, p. 202, pl. 6, figs 6, 7.
- 1991 *Pseudoguembelina excolata* (Cushman); Nederbragt, p. 360, pl. 8, fig. 5.
- 1995 *Pseudoguembelina excolata* (Cushman); Georgescu, pp. 101-102, pl. 4, figs 4-6.
- 1996b *Pseudoguembelina excolata* (Cushman); Abdel-Kireem *et al.*, p. 250, fig. 5 (17, 18).
- 2003 *Pseudoguembelina excolata* (Cushman); Abramovich *et al.*, p. 9, pl. II, fig. 13.
- 2011 *Pseudoguembelina excolata* (Cushman); Abramovich *et al.*, p. 147, pl. 3, figs 16-19.

Material: Over 100 specimens from latest Campanian to early Maastrichtian samples, including MPK14446 and 14447.

Dimensions: 15 specimens measured give the following dimensions: height of test 0.25-0.30 mm, width of test 0.20-0.28 mm, height of last chamber 0.08-0.10 mm, width of last chamber 0.10-0.13 mm.

Description: Test biserial, tapering throughout, triangular in outline, the width of the test is almost equal to the height of the test; initial chambers indistinct, later chambers become slightly inflated, somewhat broader than high, increasing moderately in size as chambers are added; wall ornamented with very coarse, longitudinal, continuous costae; costae widely spaced, following the curve of the chambers.

Remarks: *Pseudoguembelina excolata* was originally described by Cushman (1926) as *Gümbelina excolata* from the Late Cretaceous Mendez Shale, along the eastern bank of the Tamuin River, San Luis Potosi, East Mexico. *Pseudoguembelina excolata* can be differentiated from material of *P. costulata* (Cushman 1938) in having a wider test, by being triangular in outline, and by possessing more widely spaced and thicker costae.

Occurrence: *Pseudoguembelina excolata* has been recorded from the late Maastrichtian in Texas (Smith & Pessagno 1973), and from the Maastrichtian in southeastern Iraq (Darmoian 1975), the Tethyan Ocean (Weiss 1983), Tunisia (Nederbragt 1991), the Black Sea (Georgescu 1995) and Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *P. excolata* is common in the Shiranish Formation, occurring from the base of *Pseudoguembelina excolata* subzone within the *Gansserina gansseri* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (latest Campanian to late early Maastrichtian; Fig. 3.4) as defined in Jaff *et al.* (in press).

Genus ***Pseudotextularia*** Rzehak, 1891

Type species: *Cuneolina elegans* Rzehak, 1891, designated Ellis & Messina, 1940.

Pseudotextularia deformis (Kikoine, 1948)

Plate 4, figures 8, 9

1948 *Gümbelina striata* (Ehrenberg) var. *deformis* Kikoine, p. 20, pl. 1, fig. 8.

1967 *Pseudotextularia deformis* (Kikoine); Pessagno, p. 269, pl. 90, fig. 16; pl. 92, figs 19-21; pl. 97, figs 16, 17; pl. 98, figs 15, 17, 18.

1973 *Pseudotextularia deformis* (Kikoine); Smith & Pessagno, p. 29, pl. 9, figs 1-4; pl. 10, fig. 1.

1978 *Pseudotextularia deformis* (Kikoine); Kassab, p. 77, pl. 1, figs 4, 5.

1983 *Pseudotextularia deformis* (Kikoine); Weiss, pp. 60-61, pl. 8, figs 1, 2.

1986b *Pseudotextularia deformis* (Kikoine); Abdel-Kireem, p. 226, pl. 2, figs 10-12; pl. 3, fig. 11.

2003 *Pseudotextularia deformis* (Kikoine); Abramovich *et al.*, p. 13, pl. IV, fig. 1.

Material: 18 specimens from 13 samples, including MPK14520 and 14521.

Dimensions: 10 specimens measured give the following dimensions: height of test 0.40-0.45 mm, width of test 0.26-0.35 mm, height of last chamber 0.12-0.13 mm, width of last chamber 0.18-0.22 mm.

Description: Test biserial, triangular in outline, about 1½ times as long as wide; 6-7 pairs of distinct chambers, bi-convex in edge view, increase gradual in size as chambers are added, last chambers expands slowly in height but rapidly in width, surface covered with moderate to thick, widely spaced, discontinuous costae.

Remarks: *Pseudotextularia deformis* was first described by Kikoin (1948) as *Gümbelina striata* var. *deformis* from Maastrichtian age strata of southwestern France. The Kurdistan specimens can be distinguished from material of the type species *P. elegans* (Rzehak 1891) by its broad, triangular outline in side view, chambers that expand slowly in height but rapidly in width, and by its coarser and less massive discontinuous costae and much thicker test wall.

Occurrence: *Pseudotextularia deformis* has been recorded from the Maastrichtian in Texas (Smith & Pessagno 1973), northern and northeastern Iraq (Kassab 1978; Abdel-Kireem 1986b) and the Tethyan Ocean (Weiss 1983).

In Kurdistan, *P. deformis* is rare in the Shiranish Formation, occurring from the base of the *Pseudoguembelina excolata* subzone within the *Gansserina gansseri* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (latest Campanian to late early Maastrichtian; Fig. 3.4) as defined in Jaff *et al.* (in press).

***Pseudotextularia elegans* (Rzehak, 1891)**

Plate 4, figures 10, 11; Plate 5, figures 17, 18

1891 *Cuneolina elegans* Rzehak, p. 4.

1929 *Gümbelina elegans* (Rzehak); White, pp. 34-35, pl. 4, fig. 8.

- 1967 *Pseudotextularia elegans* (Rzehak); Pessagno, pp. 268-269, pl. 75, figs 12-17; pl. 85, figs 10, 11; pl. 88, figs 14-16; pl. 89, figs 10, 11; pl. 97, fig. 18; pl. 98, figs 19, 20.
- 1972 *Pseudotextularia elegans* (Rzehak); Govindan, pp. 170-171, pl. 1, figs 5, 6; pl. 2, figs 6, 7.
- 1973 *Pseudotextularia elegans* (Rzehak); Smith & Pessagno, pp. 30-32, pl. 9, figs 5-15; pl. 10, figs 2-6.
- 1975 *Pseudotextularia elegans* (Rzehak); Darmonoian, p. 199, pl. 3, figs 16, 17.
- 1975 *Pseudotextularia elegans* (Rzehak); Frerichs *et al.*, pp. 301-302, pl. 1, figs 13, 14.
- 1978 *Pseudotextularia elegans elegans* (Rzehak); Kassab, p. 79, pl. 1, figs 6, 7.
- 1983 *Pseudotextularia elegans* (Rzehak); Weiss, pp. 61-63, pl. 8, figs 5-7.
- 1986b *Pseudotextularia elegans* (Rzehak); Abdel-Kireem, p. 226, pl. 2, figs 13-16; pl. 3, figs 12, 13.
- 1989 *Pseudotextularia elegans* (Rzehak); Nederbragt, p. 202, pl. 7, figs 7, 8.
- 1991 *Pseudotextularia elegans* (Rzehak); Nederbragt, p. 364, pl. 10, figs 1, 2.
- 1995 *Pseudotextularia elegans* (Rzehak); Georgescu, p. 97, pl. 3, figs 1-3.
- 1996b *Pseudotextularia elegans* (Rzehak); Abdel-Kireem *et al.*, p. 249, fig. 5 (14, 15).
- 2003 *Pseudotextularia elegans* (Rzehak); Abramovich *et al.*, p. 13, pl. IV, fig. 2.
- 2011 *Pseudotextularia elegans* (Rzehak); Abramovich *et al.*, p. 148, pl. 4, figs 7, 8.

Material: Over 500 specimens from late Campanian to early Maastrichtian samples, including MPK14458, 14459, 14543 and 14544.

Dimensions: 50 specimens measured give the following dimensions: height of test 0.30-0.58 mm, width of test 0.15-0.30 mm, height of last chamber 0.12-0.20 mm, width of last chamber 0.10-0.16 mm.

Description: Test biserial, about twice as long as wide, 5-6 pairs of distinct chambers, bi-convex in edge view, elongate, laterally compressed test; increase gradual in size as chambers are added; the last two pairs of chambers occupy 2/3rds or 1/2nd height of the test; last chambers expand rapidly in height but slowly in width, wall ornamented with

moderate to thick, closely spaced, discontinuous costae, following the curve of the chambers.

Remarks: *Pseudotextularia elegans* was originally described by Rzehak (1891) as *Cuneolina elegans* from the “argillaceous sand” of a quarry to the north of Vienna, Austria. As noted above, *P. elegans* can be distinguished from material of *P. deformis* (Kikoine 1948) by its narrower outline in side view, chambers that expand rapidly in height but slowly in width, more massive, closely spaced, discontinuous costae, and thinner test wall.

Occurrence: *Pseudotextularia elegans* has been recorded from the late Campanian to Maastrichtian in Iraq (Darmoian 1975; Kassab 1978; Abdel-Kireem 1986b), the early Campanian to late Maastrichtian in the Tethyan Ocean (Weiss 1983), and from the Maastrichtian in Texas (Smith & Pessagno 1973), Tunisia (Nederbragt 1991), the Black Sea (Georgescu 1995) and Egypt (Abdel-Kireem *et al.* 1996b).

In Kurdistan, *P. elegans* is rare to common in the Shiranish Formation, occurring from the base of the *Globotruncana aegyptiaca* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (late Campanian to late early Maastrichtian; Fig. 3.4) as defined in Jaff *et al.* (in press).

Pseudotextularia nuttalli (Voorwijk, 1937)

Plate 4, figures 12, 13

1937 *Gümbelina nuttalli* Voorwijk, p. 192, pl. 2, figs 1-9.

1975 *Heterohelix nuttalli* (Voorwijk); Darmoian, p. 192, pl. 1, figs 4-6.

1978 *Pseudotextularia nuttalli* (Voorwijk); Kassab, pp. 81-82, pl. 1, fig. 15.

1989 *Pseudotextularia nuttalli* (Voorwijk); Nederbragt, p. 204, pl. 8, figs 2, 3.

1991 *Pseudotextularia nuttalli* (Voorwijk); Nederbragt, pp. 364-366, pl. 10, figs 4, 6.

Material: Over 100 specimens from late Campanian to early Maastrichtian samples, including MPK14523 and 14524.

Dimensions: 20 specimens measured give the following dimensions: height of test 0.47-0.67 mm, width of test 0.32-0.40 mm, height of last chamber 0.18-0.23 mm, width of last chamber 0.16-0.20 mm.

Description: Test biserial, large, compressed, about 1½ times as long as wide, triangular in outline, rapidly tapering; 5-6 pairs of distinct chambers, inflated, broader than high, increasing rapidly in size, bi-concave in edge view, last pair of chambers become circular to ovate; wall covered with very thin, closely spaced, discontinuous costae.

Remarks: *Pseudotextularia nuttalli* was originally described by Voorwijk (1937) as *Gümbelina nuttalli* from Late Cretaceous strata in Havana, Cuba. In Kurdistan it differs from both *P. elegans* (Rzehak 1891) and *P. deformis* (Kikoine 1948) by its wider test in side view, very thin discontinuous costae developed on the surface of the test, and by its low arched aperture.

Occurrence: *Pseudotextularia nuttalli* has been recorded from the Santonian to Maastrichtian in Iraq (Darmoian 1975; Kassab 1978), and from the Coniacian to Maastrichtian in Tunisia (Nederbragt 1991).

In Kurdistan, *P. nuttalli* is rare in the Shiranish Formation, occurring from the base of the *Globotruncana aegyptiaca* biozone, to the uppermost fossiliferous bed of the Shiranish Formation, within the *Contusotruncana contusa* biozone (late Campanian to late early Maastrichtian; Fig. 3.4) as defined in Jaff *et al.* (in press).

Genus ***Ventilabrella*** Cushman, 1928

Type species: *Ventilabrella eggeri* Cushman, 1928, by original designation.

Ventilabrella eggeri Cushman, 1928

Plate 4, figures 14, 15

1928 *Ventilabrella eggeri* Cushman, p. 2, pl. 1, figs 10-12.

1938 *Ventilabrella eggeri* Cushman; Cushman, p. 25, pl. 4, figs 12-14.

1946 *Ventilabrella eggeri* Cushman; Cushman, p. 111, pl. 47, figs 17-22.

1972 *Ventilabrella eggeri* Cushman; Martin, p. 85, pl. 1, figs 6, 7.

1975 *Ventilabrella eggeri* Cushman; Darmonoian, p. 202, pl. 4, fig. 13.

1983 *Ventilabrella eggeri* Cushman; Weiss, pp. 66-67, pl. 9, figs 6-8.

1986b *Ventilabrella eggeri* Cushman; Abdel-Kireem, p. 228, pl. 3, fig. 1.

1991 *Ventilabrella eggeri* Cushman; Nederbragt, p. 369, pl. 12, figs 5-7.

Material: 5 specimens from 3 samples, including MPK14525 and 14526.

Dimensions: 5 specimens measured give the following dimensions: height of test 0.35-0.38 mm, width of test 0.30-0.37 mm.

Description: Test sub-triangular, biserial part occupies majority of test, chambers are globular to sub-globular; multiserial part consisting of only one row of three sub-globular to pyriform chambers, last row of chambers have 30° to 35° degree angle of inclination; wall covered with thin, discontinuous costae.

Remarks: *Ventilabrella eggeri* was first described by Cushman (1928) from the Late Cretaceous Taylor Marl, along the southern bank of Trading House Creek, McLennan County, Texas. The species in Kurdistan is similar to *Planoglobulina carseyae* (Plummer 1931), but can be differentiated by its regular arrangement of chambers in the last row of the test, which give a 30° to 35° degree angle of inclination.

Occurrence: *Ventilabrella eggeri* has been recorded from the early Campanian in Texas (Martin 1972), the Coniacian to Santonian in southeastern Iraq (Darmonoian 1975), the Santonian to early Campanian in the Tethyan Ocean (Weiss 1983), the Maastrichtian in northeastern Iraq (Abdel-Kireem 1986b), and from the Santonian to Campanian in Tunisia (Nederbragt 1991).

In Kurdistan, *V. eggeri* is very rare in the Shiranish Formation, occurring at the lower part of the *Planoglobulina acervulinoides* Subzone within the *Gansserina gansseri* biozone (early Maastrichtian; Fig. 3.4).

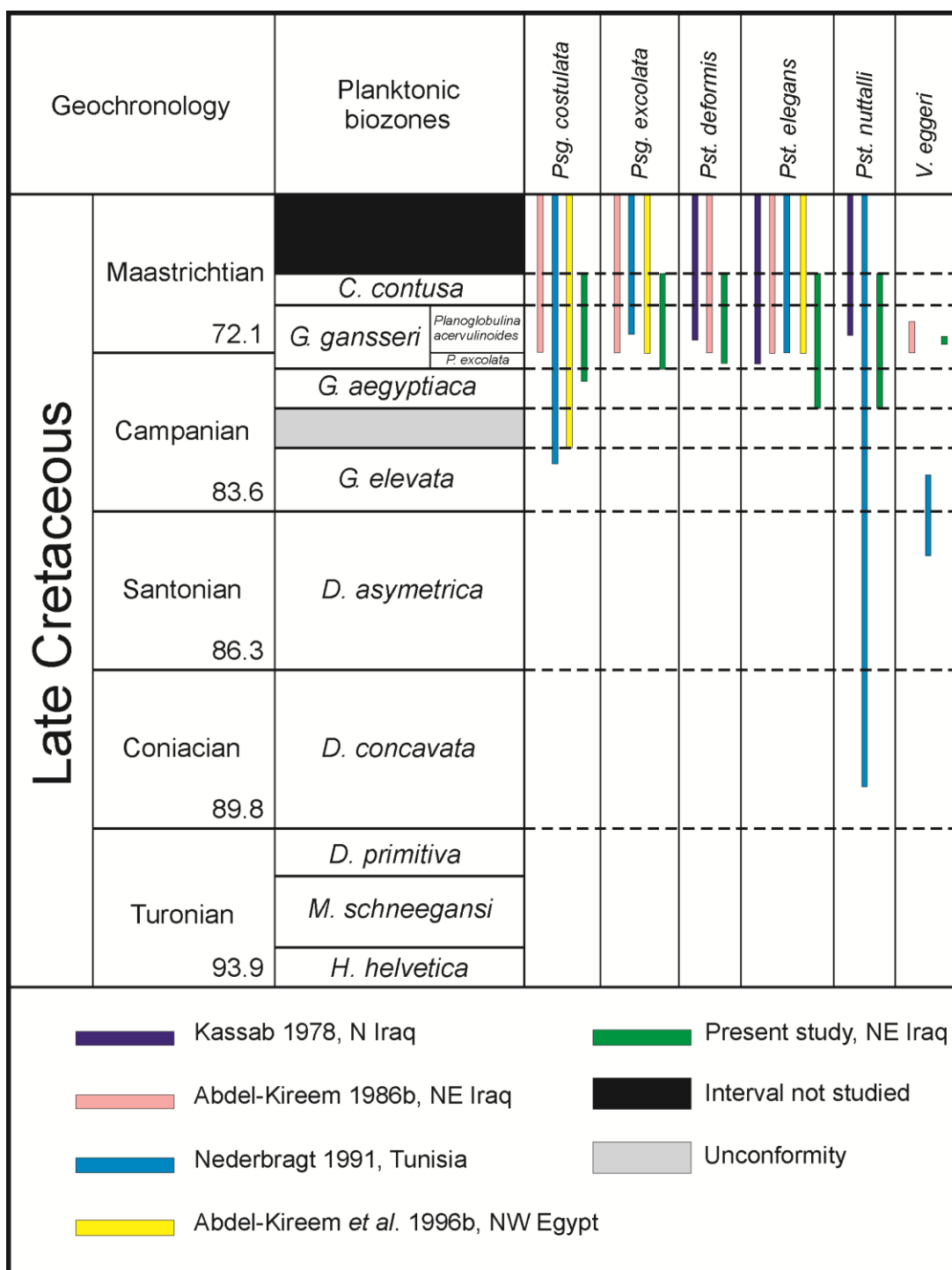


Figure 3.4. Biostratigraphic ranges of *Pseudoguembelina*, *Pseudotextularia* and *Ventilabrella* species recorded in Kurdistan and their equivalent ranges in North Africa. Planktonic foraminiferal biozones after Jaff *et al.* (in press). Time scale adapted from Ogg & Hinnov (2012). Note that *Ventilabrella eggeri*, has been reported from an earlier stratigraphic interval in Tunisia by (Nederbragt 1991).

Role of Heterohelcidae in Late Cretaceous biostratigraphy

In this study the heterohellicids are characterised by increasing numerical abundance, species diversity and intraspecific variability from the Turonian to the Maastrichtian. Heterohellicids are abundant in Kurdistan, except during the early Turonian, where only two species, *Heterohelix moremani* and *Heterohelix globulosa* are recorded within the *Helvetoglobotruncana helvetica* Total Range Zone (see Fig. 3.2).

From the mid-Turonian to mid-Santonian, heterohellicids are dominated by *Heterohelix globulosa* and *Heterohelix reussi*, and this is the case also in Tunisia (Nederbragt 1991), Egypt (Abdel-Kireem *et al.* 1996a, b) and Syria (Pecimotika *et al.* 2014; see Fig. 3.2). Due to long temporal ranges for these two species; their biostratigraphical utility in the Turonian to Santonian is only general where other index planktonic species of *Dicarinella* or *Marginotruncana* are absent: because of the low diversity of heterohellicids, Abdel-Kireem *et al.* (1996a) recognised only one heterohellicid biozone (*Heterohelix reussi* biozone) for the Turonian to mid-Santonian interval in Egypt.

In the late Santonian the diversity of heterohellicids increased towards the top of the *Dicarinella asymetrica* Total Range Zone (see Fig. 3.2). Both *Heterohelix planata* and *Laeviheterohelix pulchra* have their first occurrence in the late Santonian, but the latter species has an earlier stratigraphic occurrence elsewhere (Darmoian 1975; Odébodé 1982; Nederbragt 1991; Georgescu 2009). Nevertheless, *Heterohelix planata* defines the late Santonian in Tunisia (Nederbragt 1991), Egypt (Abdel-Kireem *et al.* 1996b), and in a number of DSDP and ODP sites around the world (Georgescu *et al.* 2008), and is therefore important for regional correlation at the level of the *Dicarinella asymetrica* Total Range Zone (see Fig. 3.2).

Most other biserial heterohellicid species have their first occurrence in the late Campanian, at the level equivalent to the *Globotruncana aegyptiaca* and *Gansserina gansseri* interval biozones, and their first occurrences are thus a proxy for these biozones where keeled planktonic foraminifera are rare or absent. Taxa appearing at this level include *Heterohelix punctulata*, *H. striata*, *H. ultimumida*, *Pseudotextularia elegans*, *Pseudoguembelina costulata* and *P. excolata* (Figs 3.2 and 3.4). The first occurrences of most of the above species are diachronous globally (Kassab 1974, 1978; Abdel-Kireem 1986b; Nederbragt 1989; 1991; Abdel-Kireem *et al.* 1996b; see Figs 3.2 and 3.4).

However, *Pseudotextularia elegans* and *Pseudoguembelina excolata* can be used to define the late and latest Campanian in Kurdistan and other regions (e.g. Martin 1972 in the USA; Robaszynski 1998 for several regions; Güray 2006 for Turkey; Pecimotika *et al.* 2014 for Syria; Jaff *et al.* in press for Kurdistan).

The maximum species diversity and abundance of heterohellicids in Kurdistan is recorded in the early Maastrichtian part of the *Gansserina gansseri* interval biozone, as is the case for Tunisia and Egypt (Nederbragt 1991; Abdel-Kireem *et al.* 1996b). The multiserial heterohellicids in Kurdistan, including species of *Gublerina*, *Praegublerina* and *Planoglobulina*, are recorded in the early Maastrichtian that can be used to define the Campanian-Maastrichtian boundary, or the early Maastrichtian at most Tethys Ocean sites (Fig. 3.3).

The First Appearance Datum (FAD) of *Planoglobulina acervulinoides* defines the Campanian-Maastrichtian boundary in Kurdistan (Jaff *et al.* 2014) and other regions (e.g. Robaszynski 1998; Güray 2006). According to Ogg & Hinnov (2012 and references therein) its FAD is estimated at 72.97 Ma, which is very close to the age datum assigned to the Campanian-Maastrichtian boundary at 72.1 Ma (Ogg & Hinnov *op. cit.*). In some areas such as Iran and Tunisia, the FAD of *Planoglobulina carseyae* defines the Campanian-Maastrichtian boundary instead of *Planoglobulina acervulinoides* (see Li *et al.* 1999; Darvishzad & Abdolalipour 2009). However, the species is very rare in Kurdistan (see Fig. 3.3).

Conclusions

The biostratigraphical importance and systematic palaeontology of early Turonian to early Maastrichtian Heterohellicidae planktonic foraminifera from Kurdistan are described. Some 24 species from 8 genera are recorded. The early Turonian-early Maastrichtian succession of Kurdistan yields diverse heterohellicid species which can be used for planktonic foraminiferal biozonation when the index species of dicarinellids, marginotruncanids and globotruncanids are absent. The maximum species diversity and abundance of Heterohellicidae in Kurdistan is recorded in the early Maastrichtian, which is consistent with the global record. The first occurrences of the flaring heterohellicids with more than two chambers per row (e.g. *Planoglobulina*, *Praegublerina* and *Gublerina*) are recorded in

the earliest Maastrichtian; this can be used to define the Campanian-Maastrichtian boundary throughout Tethys Ocean Cretaceous successions.

Heterohelcidae foraminifera plates

Chapter 3: Biostratigraphy and systematic
palaeontology of Late Cretaceous Heterohelcidae
foraminifera from the Kurdistan region, northeast Iraq

Plate 1 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Praegublerina, Gublerina, Heterohelix

Figs 1-3: *Praegublerina acuta* (De Klasz). *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 1, MPK14483, Fig. 2, MPK14484, Dokan section, sample number DSH-117; Fig. 3, MPK14485, Azmer section, sample number ASH-50.

Figs 4-6: *Gublerina cuvillieri* Kikoine. *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 4, MPK14486, Fig. 5, MPK14487, Dokan section, sample number DSH-117, Fig. 6, MPK14488, Azmer section, sample number ASH-62.

Figs 7-10: *Heterohelix globulosa* (Ehrenberg). *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Fig. 7, MPK14449, Fig. 8, MPK14450, Dokan section, sample number DSH-64; Fig. 9, MPK14489, Azmer section, sample number ASH-40; Fig. 10, discontinuous costae on the surface of ultimate chamber of *H. globulosa*.

Figs 11-13: *Heterohelix navarroensis* Loeblich. *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 11, MPK14451, Dokan section, sample number DSH-105; Fig. 12, MPK14490, Dokan section, sample number DSH-117; Fig. 13, MPK14491, Azmer section, sample number ASH-58.

Figs 14-16: *Heterohelix planata* (Cushman). *Globotruncana aegyptiaca* and *Contusotruncana contusa* biozones, Fig. 14, MPK14492, Dokan section, sample number DSH-117; Fig. 15, MPK14493, Fig. 16, MPK14494, Azmer section, sample number ASH-30.

Plate 1

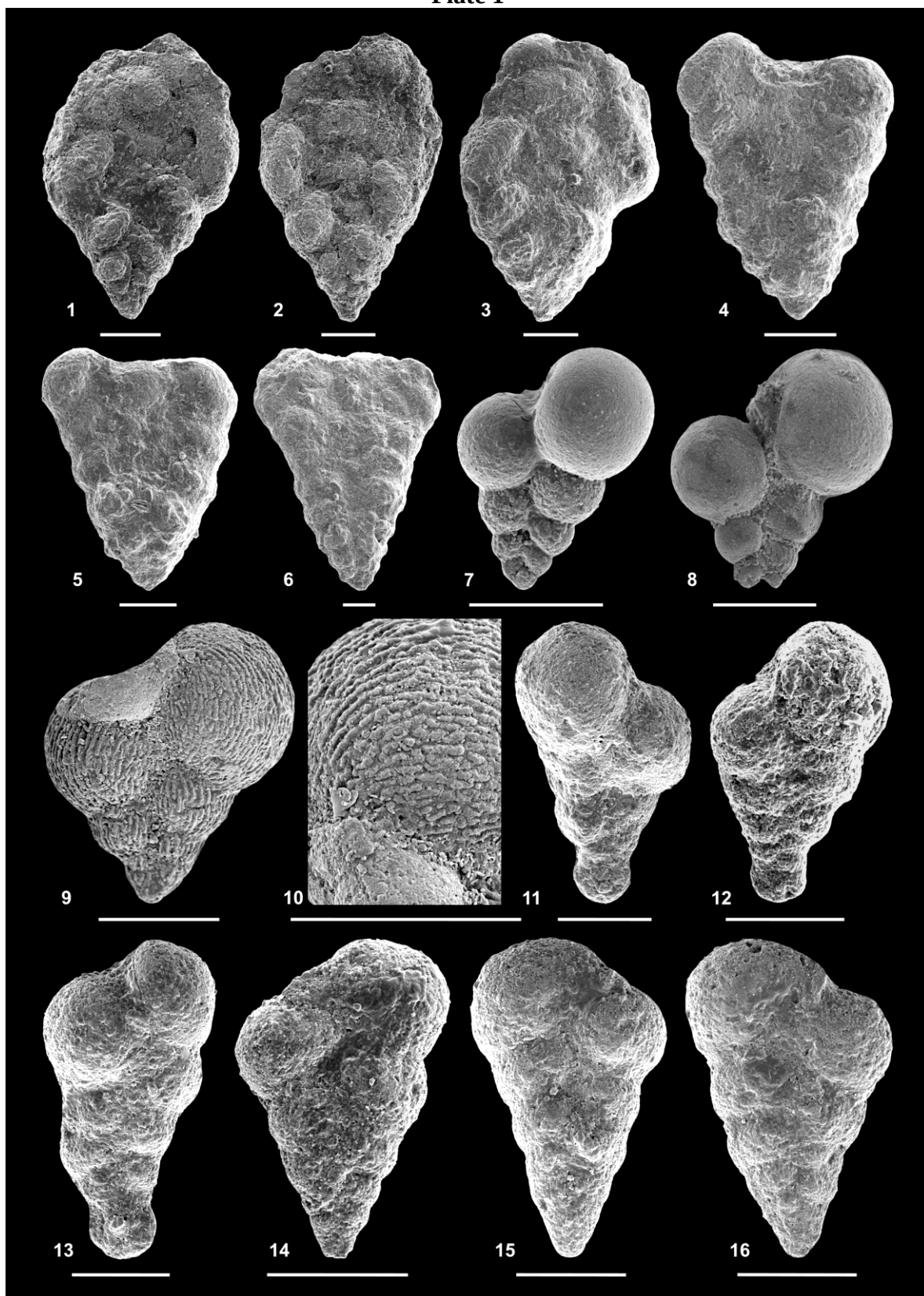


Plate 2 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Heterohelix, Laeviheterohelix

- Figs 1-3: *Heterohelix punctulata* (Cushman). *Globotruncana aegyptiaca* biozone, Fig. 1, MPK14495, Azmer section, sample number ASH-09; Fig. 2, MPK14496, Azmer section, sample number ASH-10; Fig. 3, MPK14497, Dokan section, sample number DSH-45.
- Figs 4-6: *Heterohelix reussi* (Cushman). *Globotruncana aegyptiaca* biozone, Fig. 4, MPK14498, Dokan section, sample number DSH-64; Fig. 5, MPK14499, Fig. 6, MPK14500, Azmer section, sample number ASH-05.
- Figs 7, 8: *Heterohelix semicostata* (Cushman). *Gansserina gansseri* biozone, Fig. 7, MPK14452, Dokan section, sample number DSH-80; Fig. 8, MPK14501, Dokan section, sample number DSH-88.
- Figs 9-11: *Heterohelix striata* (Ehrenberg). *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 9, MPK14502, Dokan section, sample number DSH-90; Fig. 10, MPK14453, Dokan section, sample number DSH-117; Fig. 11, continuous costae on the surface of ultimate chamber of *H. striata*.
- Figs 12, 13: *Heterohelix ultimumida* (White). *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 12, MPK14503, Azmer section, sample number ASH-48; Fig. 13, MPK14504, Dokan section, sample number DSH-117.
- Figs 14-16: *Laeviheterohelix dentata* (Stenestad). *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 14, MPK14454, Dokan section, sample number DSH-82, Fig. 15, MPK14505, Dokan section, sample number DSH-117; Fig. 16, MPK14506, Azmer section, sample number ASH-50.

Plate 2

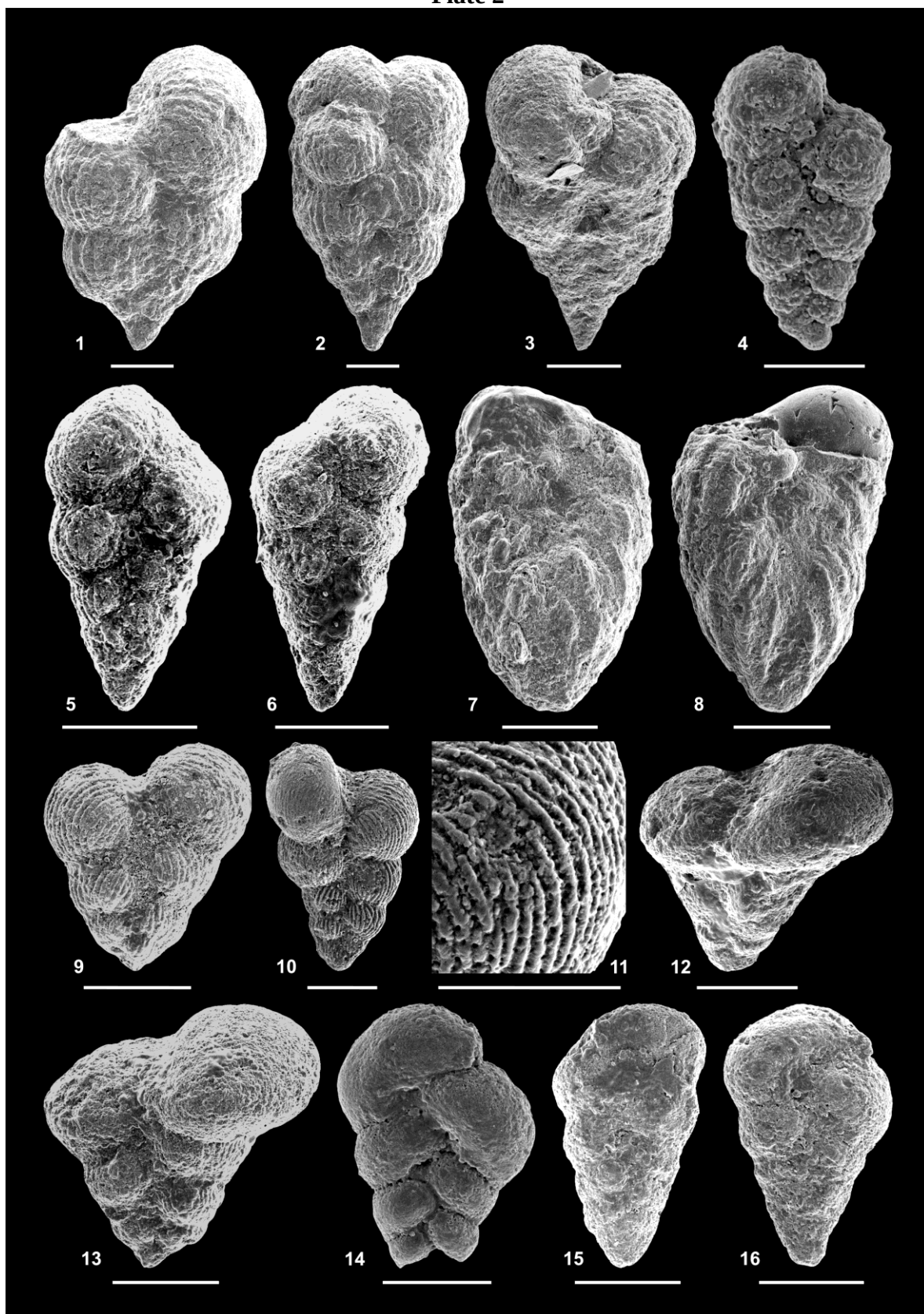


Plate 3 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Laeviheterohelix*, *Planoglobulina

Figs 1-3: *Laeviheterohelix glabrans* (Cushman). *Gansserina gansseri* biozone, Fig. 1, MPK14507, Fig. 2, MPK14508, Dokan section, sample number DSH-110; Fig. 3, MPK14509, Azmer section, sample number ASH-60.

Figs 4-7: *Laeviheterohelix pulchra* (Brotzen). *Globotruncana aegyptiaca* biozone, Figs. 4, 5, MPK14510, Dokan section, sample number DSH-60, Figs. 6, 7, MPK14455, Dokan section, sample number DSH-64. Figs. 5 and 7 side views of *L. pulchra* show well developed flanges in the last pair of chambers.

Figs 8-10: *Planoglobulina acervulinoides* (Egger). *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 8, MPK14456, Azmer section, sample number ASH-60, Fig. 9, MPK14416, Dokan section, sample number DSH-88; Fig. 10, MPK14511, Dokan section, sample number DSH-117.

Figs 11-13: *Planoglobulina brazoensis* Martin. *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 11, MPK14457, Fig. 12, MPK14512, Dokan section, sample number DSH-117, Fig. 13, MPK14513, Azmer section, sample number ASH-52.

Fig 14: *Planoglobulina carseyae* (Plummer). *Contusotruncana contusa* biozone, MPK14514, Dokan section, sample number DSH-115.

Plate 3

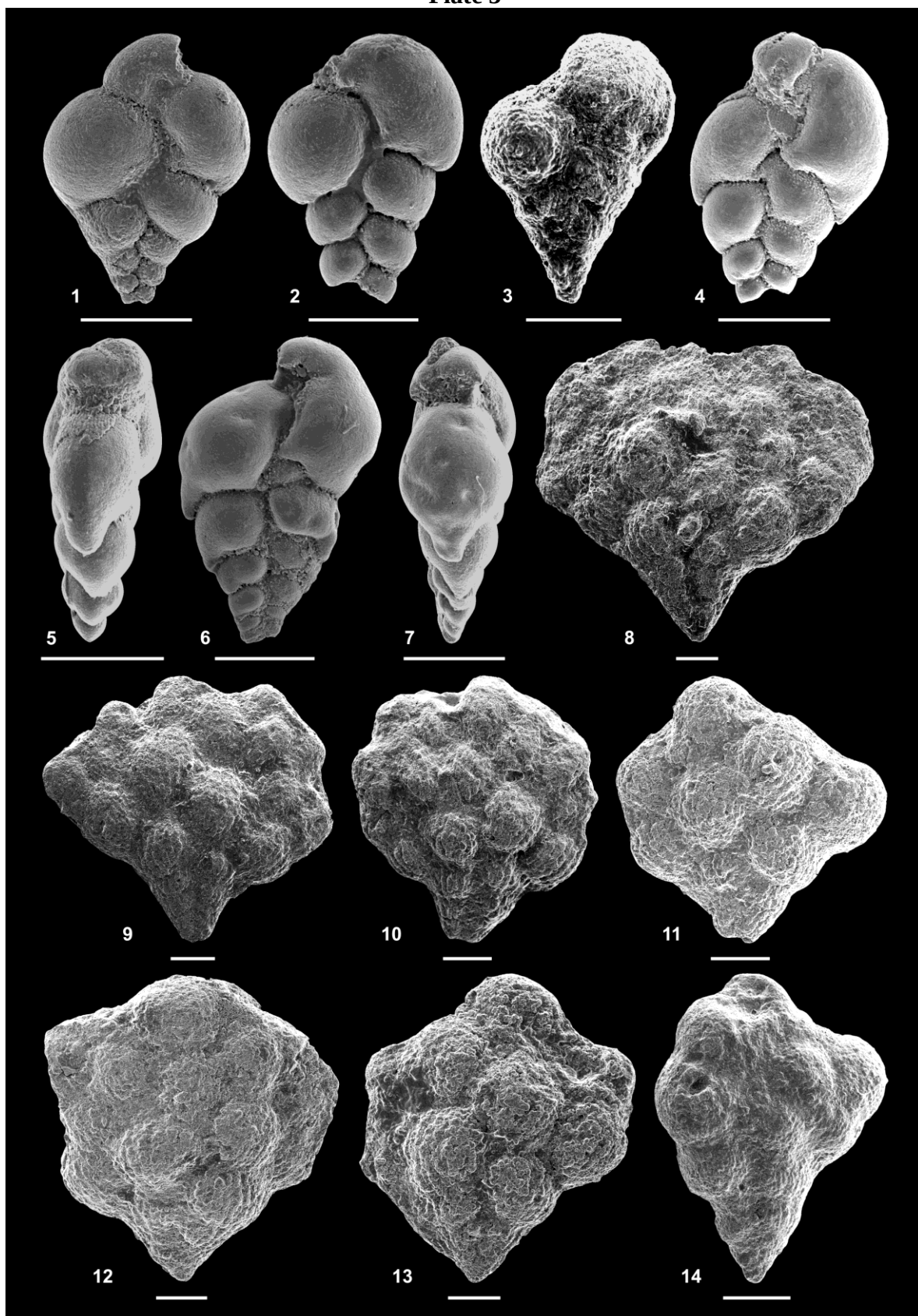


Plate 4 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Planoglobulina*, *Pseudoguembelina*, *Pseudotextularia*, *Ventilabrella

- Figs 1, 2: *Planoglobulina carseyae* (Plummer). *Gansserina gansseri* and *Contusotruncana contusa* biozones, Fig. 1, MPK14515, Dokan section, sample number DSH-117; Fig. 2, MPK14516, Azmer section, sample number ASH-47.
- Fig 3: *Planoglobulina riograndensis* (Martin). *Contusotruncana contusa* biozone, MPK14517, Dokan section, sample number DSH-117.
- Figs 4, 5: *Pseudoguembelina costulata* (Cushman). *Gansserina gansseri* biozone, Fig. 4, MPK14518, Dokan section, sample number DSH-86; Fig. 5, MPK14519, Azmer section, sample number ASH-55.
- Figs 6, 7: *Pseudoguembelina excolata* (Cushman). *Gansserina gansseri* biozone, Fig. 6, MPK14446, Azmer section, sample number ASH-42; Fig. 7, MPK14447, Dokan section, sample number DSH-70.
- Figs 8, 9: *Pseudotextularia deformis* (Kikoine). *Gansserina gansseri* biozone, Fig. 8, MPK14520, Azmer section, sample number ASH-54; Fig. 9, MPK14521, Azmer section, sample number ASH-60.
- Figs 10, 11: *Pseudotextularia elegans* (Rzehak). *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Fig. 10, MPK14458, Azmer section, sample number ASH-02; Fig. 11, MPK14459, Dokan section, sample number DSH-05.
- Figs 12, 13: *Pseudotextularia nuttalli* (Voorwijk). *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones, Fig. 12, MPK14523, Dokan section, sample number DSH-20; Fig. 13, MPK14524, Azmer section, sample number ASH-55.
- Figs 14, 15: *Ventilabrella eggeri* Cushman. *Gansserina gansseri* biozone, Fig. 14, MPK14525, Dokan section, sample number DSH-90; Fig. 15, MPK14526, Dokan section, sample number DSH-92.

Plate 4

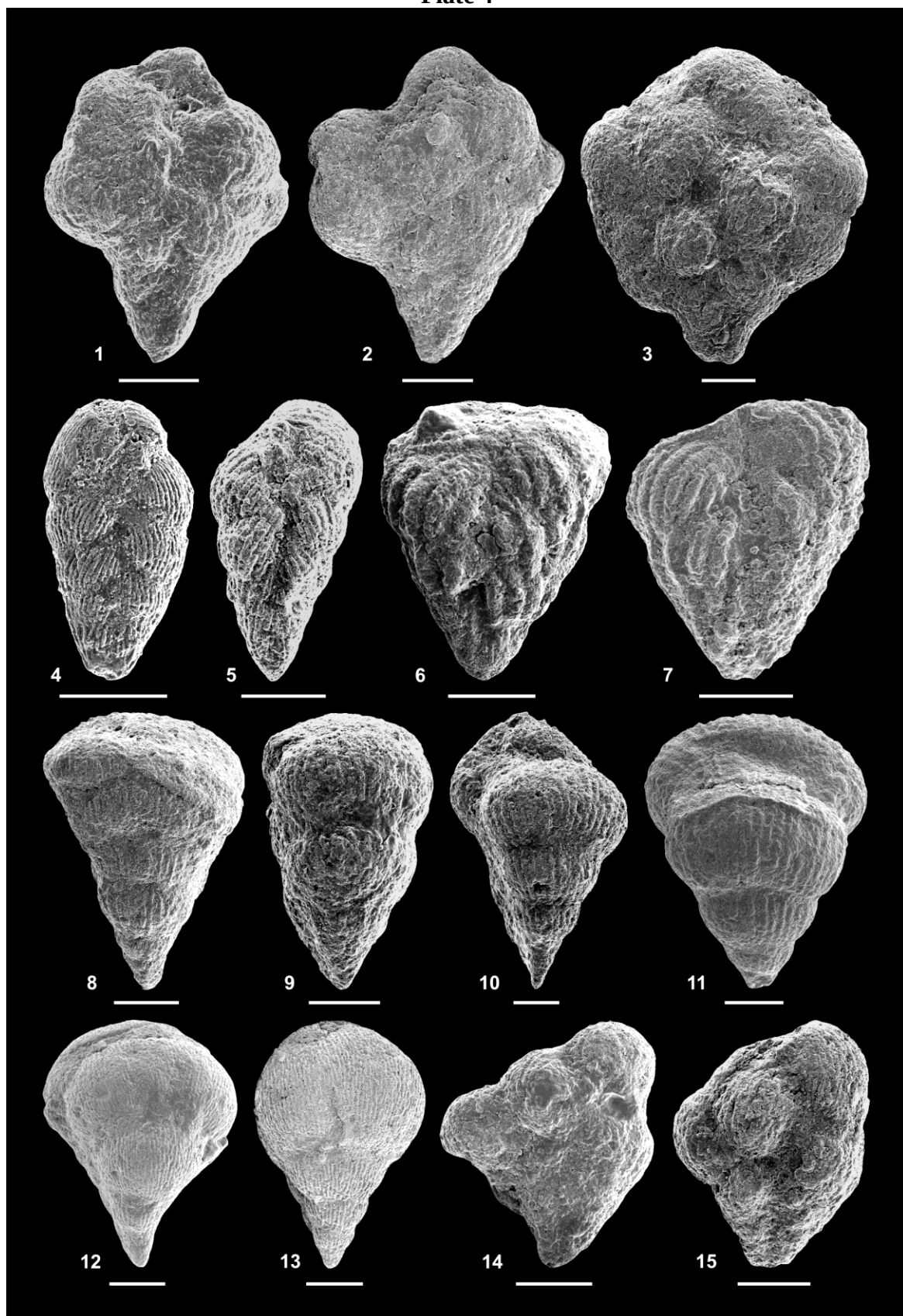


Plate 5 Foraminifera of the Kometan and Shiranish formations

Scale bar as for Figure 3 of Plate 5

Figures 1-3, 5-7, 9, 10, 12, 13 are specimens from the Kometan Formation, and 4, 8, 11, 14-18 are specimens from the Shiranish Formation

Heterohelix*, *Laeviheterohelix*, *Planoglobulina*, *Pseudotextularia

Figs 1-4: *Heterohelix globulosa* (Ehrenberg). *Dicarinella concavata*, *D. asymetrica*, *Globotruncanita elevata* and *Globotruncana aegyptiaca* biozones, Fig. 1, MPK14527, Azmer section, sample number AK-17; Fig. 2, MPK14528, Dokan section, sample number DK-24; Fig. 3, MPK14529, Dokan section, sample number DK-74; Fig. 4, MPK14530, Dokan section, sample number DSH-48.

Figs 5, 6: *Heterohelix moremani* (Cushman). *Helvetoglobotruncana helvetica* and *Dicarinella concavata* biozones, Fig. 5, MPK14531, Dokan section, sample number DK-12; Fig. 6, MPK14532, Dokan section, sample number DK-2.

Fig 7: *Heterohelix planata* (Cushman). *Dicarinella asymetrica* biozone, MPK14533, Dokan section, sample number DK-36.

Fig. 8: *Heterohelix punctulata* (Cushman). *Gansserina gansseri* biozone, MPK14535, Azmer section, sample number ASH-57.

Figs 9, 10: *Heterohelix reussi* (Cushman). *Dicarinella asymetrica* biozone, Fig. 9, MPK14534, Azmer section, sample number AK-35; Fig. 10, MPK14536, Dokan section, sample number DK-34.

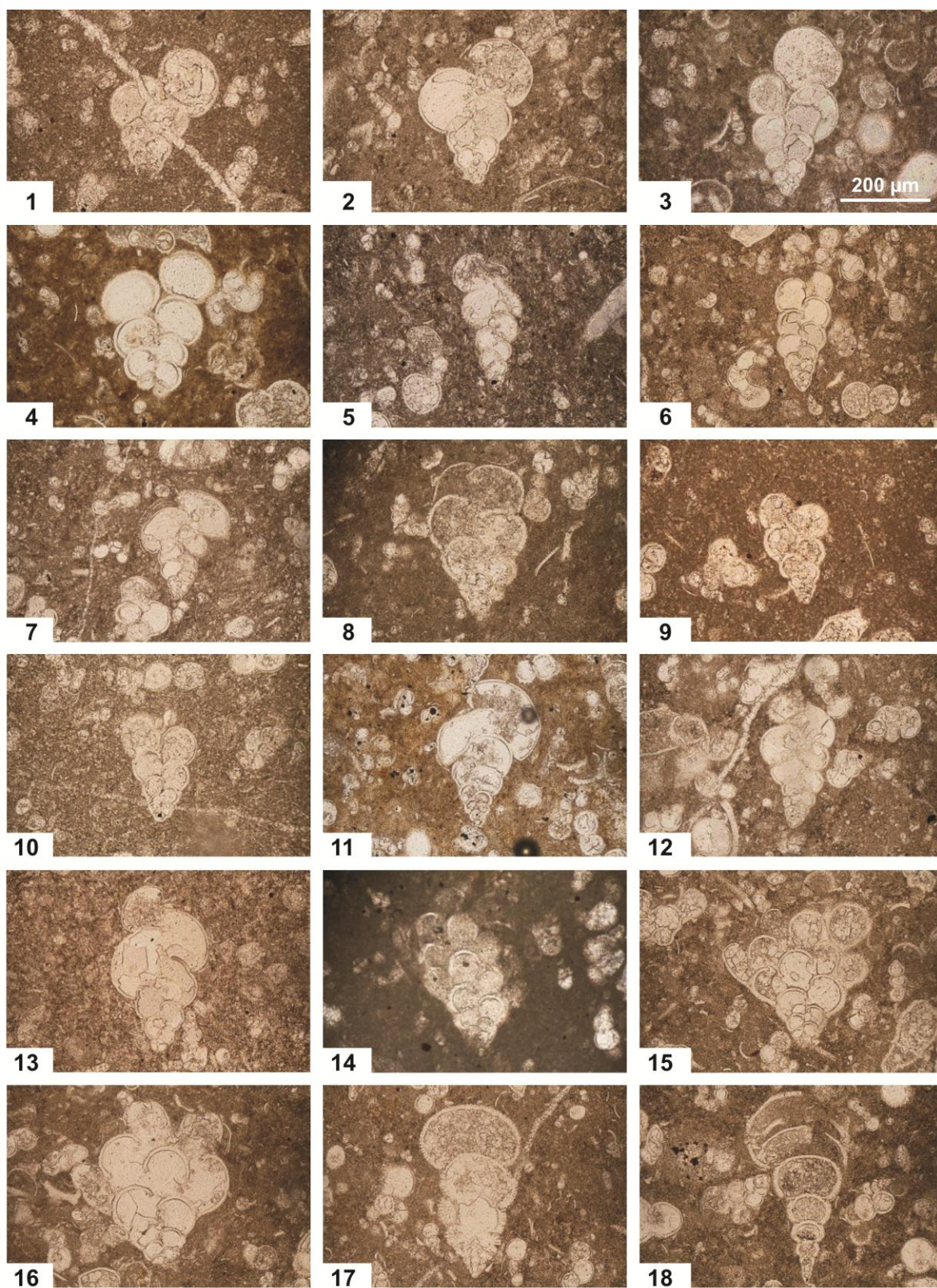
Figs 11-13: *Laeviheterohelix pulchra* (Brotzen). *Dicarinella asymetrica* and *Globotruncana aegyptiaca* biozones, Fig. 11, MPK14537, Dokan section, sample number DSH-43; Fig. 12, MPK14538, Fig. 13, MPK14539, Dokan section, sample number DK-68.

Figs 14, 15: Possibly *Planoglobulina acervulinoides* (Egger). *Gansserina gansseri* biozone, Fig. 14, MPK14540, Azmer section, sample number ASH-59; Fig. 15, MPK14541, Dokan section, sample number DSH-88.

Fig 16: *Planoglobulina brazoensis* Martin. *Gansserina gansseri* biozone, MPK14542, Azmer section, sample number ASH-60.

Figs 17, 18: *Pseudotextularia elegans* (Rzehak). *Globotruncana aegyptiaca* biozone, Fig. 17, MPK14543, Dokan section, sample number DSH-48; Fig. 18, MPK14544, Azmer section, sample number ASH-15.

Plate 5



Chapter 4

A refined foraminiferal
biostratigraphy for the
late Campanian-early
Maastrichtian succession
of northeast Iraq

Chapter 4: A refined foraminiferal biostratigraphy for the late Campanian-early Maastrichtian succession of northeast Iraq

Abstract

Species of the benthonic foraminiferal genus *Bolivinoidea* provide a refined biostratigraphic biozonation for the late Campanian to early Maastrichtian (Late Cretaceous) Shiranish Formation in NE Iraq. Three biozones and two subzones are identified: the *Bolivinoidea decoratus* biozone (late Campanian) subdivided into a lower *B. decoratus* subzone and an upper *B. laevigatus* subzone; the *B. miliaris* biozone (earliest Maastrichtian); and the *B. draco* biozone (late early Maastrichtian). These zones can be related to the biostratigraphical interval of the *Globotruncana aegyptiaca* (late Campanian), *Gansserina gansseri* (latest Campanian-early Maastrichtian) and *Contusotruncana contusa* (late early Maastrichtian) planktonic foraminiferal biozones. Combined, the benthonic and planktonic foraminiferal biostratigraphy enables the informal recognition of lower and upper intervals within both the *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones that may be important for more refined inter-regional correlation in the Middle East and North Africa. The new *Bolivinoidea* biozonation precisely locates the Campanian-Maastrichtian boundary in NE Iraq. The foraminiferal assemblages also constrain the timing of a shallowing marine trend in the Shiranish Formation beginning from the latest Campanian that is consistent with shallowing facies noted globally at this time.

Introduction

The Shiranish Formation is the most geographically widespread lithostratigraphic unit of the late Campanian-early Maastrichtian succession in Iraq and contains rich and diverse benthonic and planktonic foraminiferal assemblages, including species of the benthonic foraminiferal genus *Bolivinoidea* that can be used for high-resolution biostratigraphy. The Dokan and Azmer localities of the Kurdistan region, NE Iraq, have been selected for this study because they provide nearly complete successions through the Shiranish Formation (Fig. 4.1). The lithostratigraphy and planktonic foraminiferal biostratigraphy of the Shiranish Formation have been described by several authors, most recently by Al-Banna

(2010) and Hammoudi (2011). None of these studies have identified the biostratigraphic significance of *Bolivinoidea* species in the Shiranish Formation.

Here the present author identifies stratigraphically important *Bolivinoidea* species, establishes a biozonation that is useful for regional and interregional correlation, and more precisely defines the Campanian-Maastrichtian boundary in NE Iraq. The newly refined biostratigraphy provides temporal constraint on the shallowing marine trend identified in NE Iraq, and enables regional comparisons with sea level change on the Arabian Plate and globally.

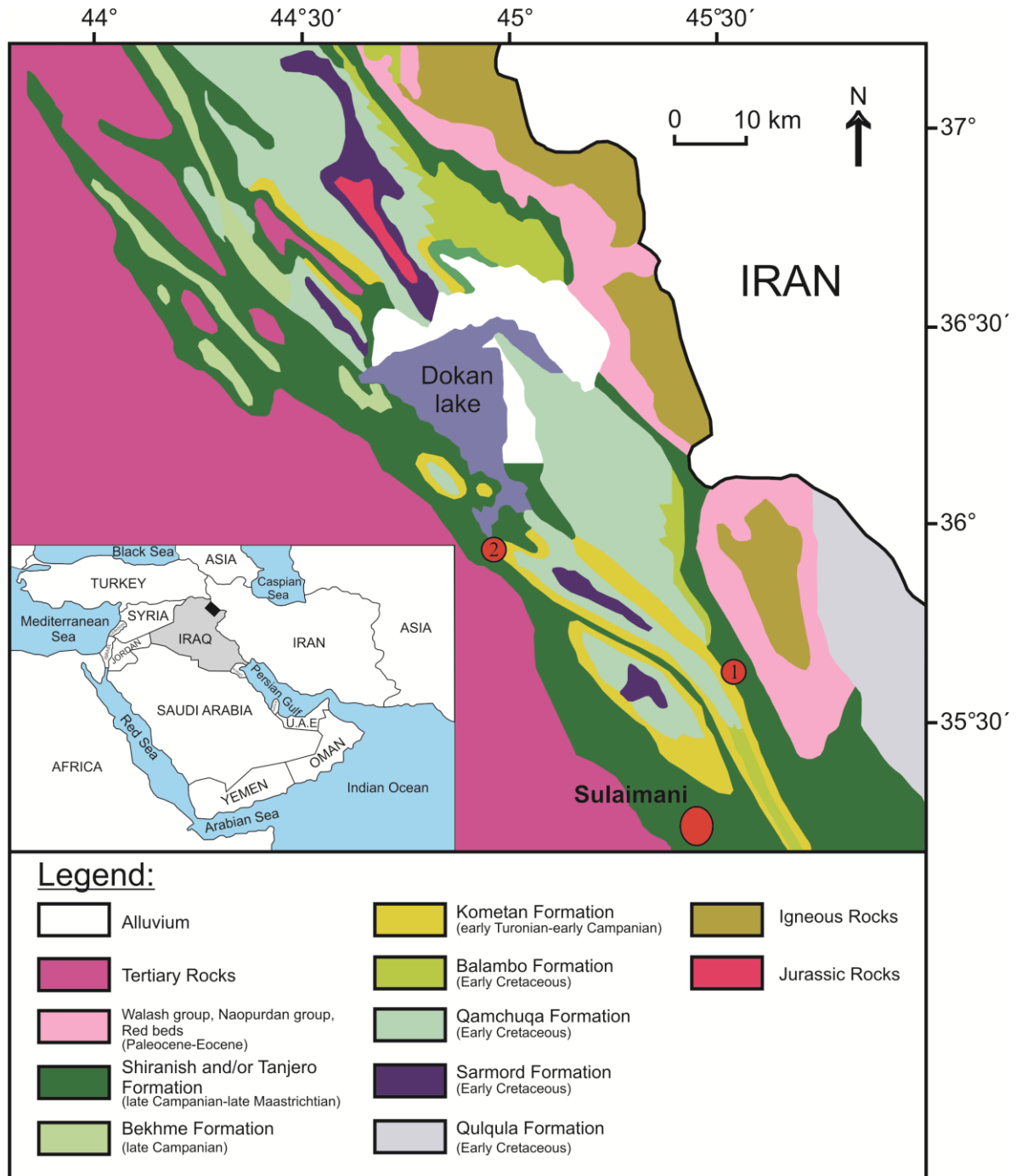


Figure 4.1. Geological context for the Azmer (1) and Dokan (2) sections of the Shiranish Formation in the Kurdistan region of NE Iraq (map after Sissakian 2000). The Dokan section runs parallel to the left bank of the Dokan Dam, near the Dokan tourist village. The Azmer section is located about 15 km to the NE of Sulaimani city. Small black rectangle on inset map represents study-area.

Materials and Methods

Two stratigraphic rock successions, one at Dokan (latitude 35° 56' 15" N and longitude 44° 57' 21" E) and the other at Azmer (latitude 35° 37' 30" N and longitude 45° 31' 45" E; see Fig. 4.1) have been chosen for analysis. These sections present near-complete Late Cretaceous successions of the Shiranish Formation that contain rich and diverse planktonic and benthonic foraminifer assemblages, especially of *Bolivinooides*. Samples were taken at a spacing ranging from 0.5 m in the soft marlstones to 2 m in the indurated marlstones and marly limestones. For indurated rock samples, thin section analysis was used for planktonic foraminiferal identifications. For friable samples, a freeze-thaw method of processing was used (Mogaddam 2002). Approximately 200-300 grams of each friable sample was repeatedly frozen and thawed in a supersaturated solution of sodium sulphate until the rock disaggregated. 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 down to 63 µm. Foraminifera were picked and studied from the residue in the 63-300 µm size fractions. The foraminifera were studied using a Hitachi S-3600N Scanning Electron Microscope (SEM) at the University of Leicester, UK.

Lithostratigraphy

The Shiranish Formation represents marine shelf-deposited carbonates and mudstones that are rich in microfossil and macrofossil taxa (Van Bellen *et al.* 2005; Buday 1980; Jassim & Goff 2006). The Shiranish Formation unconformably overlies the marine limestones of the Kometan Formation (early Turonian-early Campanian), and is succeeded conformably by marine clastic deposits of the Tanjero Formation (Sharbazheri 2008; Fig. 4.2). Van Bellen *et al.* (2005) informally subdivided the Shiranish Formation into a 'lower unit', characterised by alternating foraminifera-rich marly limestone and calcareous marlstone, and an 'upper unit' that is dominated by blue marlstone in which the abundance of foraminifera decreases. The Shiranish Formation in the Dokan and Azmer areas is about 260 m and 144 m thick respectively. There is a glauconitic pebbly sandstone bed of about 0.5 m at the base of the Shiranish Formation (base of the 'lower unit') in the Dokan area (Fig. 4.3) that may indicate a very slow rate of deposition or period of non-deposition. In

the Dokan area the uppermost part of the ‘upper unit’ of the Shiranish Formation includes a massive bed of marly limestone that is about 1 m thick, bearing a mass of rudist bivalves near the contact with the overlying Tanjero Formation: this rudist bed is only locally developed and hence is not differentiated as a separate member in the Shiranish Formation.

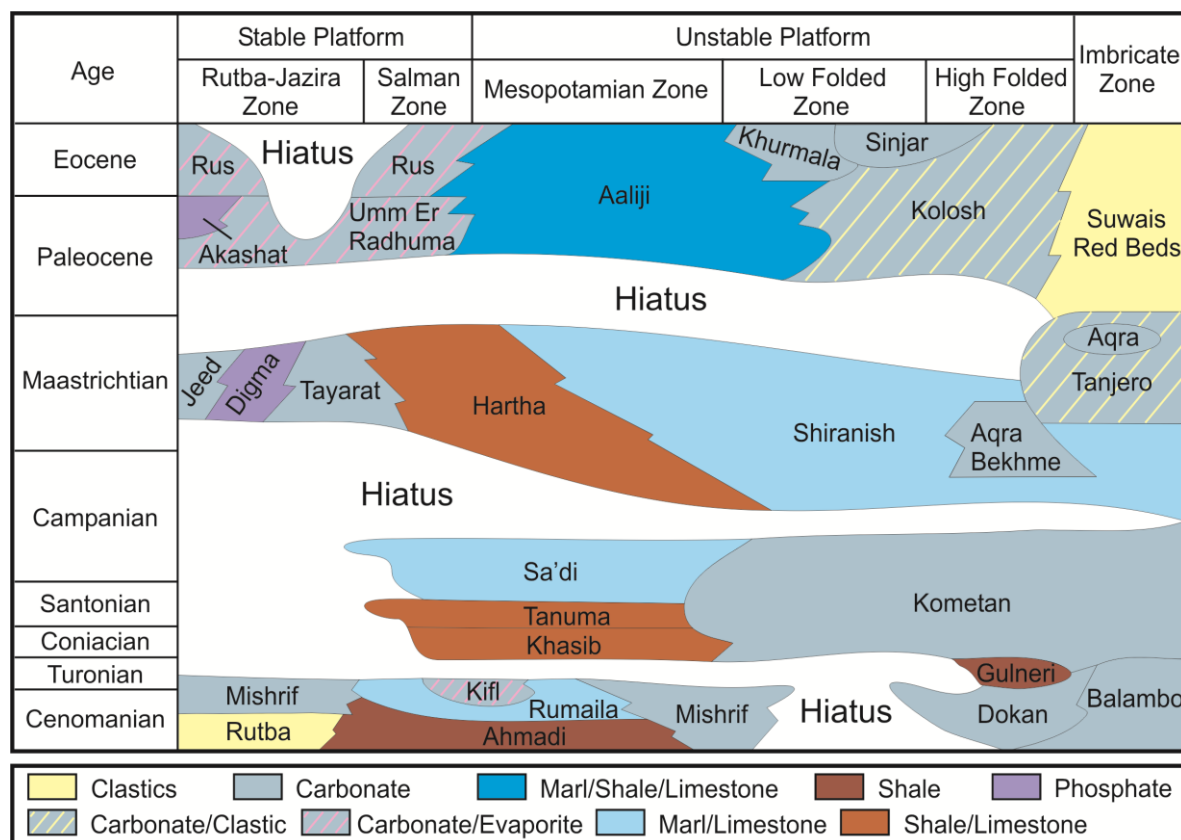


Figure 4.2. Simplified lithostratigraphy of the Late Cretaceous succession in Iraq (after Van Bellen *et al.* 2005; Jassim & Goff 2006) with some modifications.

***Bolivinoidea* biozonation**

Bolivinoidea species provide one of the most highly resolved biostratigraphic subdivisions of Late Cretaceous strata globally (e.g. Plumhoff & Schumann 1966; Barr 1970; Petters 1977; Swiecicki 1980; El-Nady 2006). In order to place the Kurdistan assemblages into the context of this global stratigraphy, a total of 118 specimens of *Bolivinoidea* have been collected from the Azmer and Dokan sections. Dimensions of the test and the number of lobes on the final chamber on the 114 complete specimens are shown in Table 4.1. The author has not identified any intraspecific temporal trends in individual *Bolivinoidea*

species from morphological analyses that would enable sub-division of zonal intervals. Nevertheless, the temporal succession in discrete *Bolivinoidea* species can be used to establish three biozones and two subzones in the Shiranish Formation (Fig. 4.3).

No.	Length L (mm)	Breadth B (mm)	L/B	No. of lobes on last chamber	species name
1	59.6	31.4	1.9	4	<i>B. decoratus</i>
2	58.8	36.4	1.6	4	<i>B. decoratus</i>
3	57.3	34.1	1.7	4	<i>B. decoratus</i>
4	60.3	36.4	1.7	4	<i>B. decoratus</i>
5	59.1	36.9	1.6	4	<i>B. decoratus</i>
6	57.2	30.5	1.9	4	<i>B. decoratus</i>
7	60.4	33	1.8	3	<i>B. decoratus</i>
8	56.1	31	1.8	3	<i>B. decoratus</i>
9	59	37.1	1.6	4	<i>B. decoratus</i>
10	58.8	32.4	1.8	4	<i>B. decoratus</i>
11	59.4	28.7	2.1	4	<i>B. decoratus</i>
12	Broken	No	No	No	No
13	61.5	30.5	2	4	<i>B. decoratus</i>
14	55.8	30.8	1.8	3	<i>B. decoratus</i>
15	61.5	31.5	2	4	<i>B. decoratus</i>
16	61.6	30.5	2	4	<i>B. decoratus</i>
17	57.5	34.7	1.7	4	<i>B. decoratus</i>
18	56.9	36	1.6	4	<i>B. decoratus</i>
19	57.8	32.6	1.8	4	<i>B. decoratus</i>
20	60	34.4	1.7	4	<i>B. decoratus</i>
21	56.7	31.5	1.8	4	<i>B. decoratus</i>
22	56.5	33.9	1.7	4	<i>B. decoratus</i>
23	55.2	30.4	1.8	4	<i>B. decoratus</i>
24	57.5	31.7	1.8	3	<i>B. decoratus</i>
25	58.7	32	1.8	4	<i>B. decoratus</i>
26	Broken	No	No	No	No
27	55.1	32.7	1.7	3	<i>B. decoratus</i>
28	56.2	33	1.7	3 or 4	<i>B. decoratus</i>
29	55.2	30.7	1.8	3	<i>B. decoratus</i>
30	57.6	29.9	1.9	4	<i>B. decoratus</i>
31	Broken	No	No	No	No
32	56.2	30.5	1.8	4	<i>B. decoratus</i>
33	57.7	29.4	2	4	<i>B. decoratus</i>
34	57.5	31.1	1.8	3	<i>B. decoratus</i>
35	57.4	34.3	1.7	3	<i>B. decoratus</i>

Table 4.1. *continued*

No.	Length L (mm)	Breadth B (mm)	L/B	No. of lobes on last chamber	species name
36	55.5	32.1	1.7	4	<i>B. decoratus</i>
37	58.2	32	1.8	4	<i>B. decoratus</i>
38	59.1	30.9	1.9	4	<i>B. decoratus</i>
39	58.9	32.2	1.8	4	<i>B. decoratus</i>
40	56.4	27.7	2	4	<i>B. decoratus</i>
41	60.2	35.9	1.7	4	<i>B. decoratus</i>
42	60.8	27.4	2.2	3	<i>B. praelaevigatus</i>
43	60.7	26.3	2.3	3	<i>B. praelaevigatus</i>
44	60	27.3	2.2	3	<i>B. praelaevigatus</i>
45	58.5	26.5	2.2	2 or 3	<i>B. praelaevigatus</i>
46	Broken	No	No	No	No
47	56.2	26.4	2.1	3	<i>B. praelaevigatus</i>
48	57.8	24.8	2.3	2 or 3	<i>B. praelaevigatus</i>
49	59.2	26.2	2.3	3	<i>B. praelaevigatus</i>
50	57.7	28	2.1	3	<i>B. praelaevigatus</i>
51	59.4	31.7	1.9	3	<i>B. laevigatus</i>
52	59.1	31.9	1.9	3	<i>B. laevigatus</i>
53	59.3	31.5	1.9	3	<i>B. laevigatus</i>
54	59.9	31.2	1.9	3	<i>B. laevigatus</i>
55	55.1	29.5	1.9	3	<i>B. laevigatus</i>
56	58.7	31.5	1.9	3	<i>B. laevigatus</i>
57	59.7	31.7	1.9	3	<i>B. laevigatus</i>
58	59.9	30.5	2	3	<i>B. laevigatus</i>
59	58.9	31.8	1.9	3	<i>B. laevigatus</i>
60	61	30.6	2	3	<i>B. laevigatus</i>
61	60	31.5	1.9	3	<i>B. laevigatus</i>
62	58.4	30.1	1.9	3	<i>B. laevigatus</i>
63	57.6	28.7	2	4	<i>B. sp.</i>
64	58.8	33	1.8	4	<i>B. sp.</i>
65	58.9	34.5	1.7	3	<i>B. sp.</i>
66	55.2	26.8	2.1	4	<i>B. sp.</i>
67	59.2	34.5	1.7	4	<i>B. sp.</i>
68	56.7	27.5	2.1	?	<i>B. sp.</i>
69	53.5	29	1.8	?	<i>B. sp.</i>
70	59.7	30.3	2	4	<i>B. sp.</i>
71	59.2	35.9	1.6	3	<i>B. sp.</i>
72	60.4	29.5	2	?	<i>B. sp.</i>
73	57.1	29.8	1.9	3	<i>B. sp.</i>
74	60.4	35.7	1.7	?	<i>B. sp.</i>

Table 4.1. *continued*

No.	Length L (mm)	Breadth B (mm)	L/B	No. of lobes on last chamber	species name
75	56.5	37.1	1.5	5	<i>B. draco</i>
76	55	37	1.5	5	<i>B. draco</i>
77	50.8	36.7	1.4	5	<i>B. draco</i>
78	55.9	39	1.4	5	<i>B. draco</i>
79	57.6	40	1.4	5	<i>B. draco</i>
80	51.5	34.8	1.5	5	<i>B. draco</i>
81	49.7	38.2	1.3	5	<i>B. draco</i>
82	51.2	34.3	1.5	5	<i>B. draco</i>
83	53.8	38	1.4	5	<i>B. draco</i>
84	52.8	37.6	1.4	5	<i>B. draco</i>
85	51.5	39.8	1.3	5	<i>B. draco</i>
86	54.8	39.1	1.4	5	<i>B. draco</i>
87	51.2	39.4	1.3	5	<i>B. draco</i>
88	51.3	38.7	1.3	5	<i>B. draco</i>
89	58.5	38.5	1.5	5	<i>B. draco</i>
90	55.4	39.7	1.4	5	<i>B. draco</i>
91	46.7	35.7	1.3	5	<i>B. draco</i>
92	56.6	39.7	1.4	5	<i>B. draco</i>
93	55.6	39.6	1.4	5	<i>B. draco</i>
94	55.2	36.7	1.5	5	<i>B. draco</i>
95	52.2	36.6	1.4	5	<i>B. draco</i>
96	53.1	38.1	1.4	5	<i>B. draco</i>
97	54.2	41.3	1.3	5	<i>B. draco</i>
98	54	41.7	1.3	5	<i>B. draco</i>
99	56.1	37	1.5	5	<i>B. draco</i>
100	45.8	37.5	1.2	5	<i>B. miliaris</i>
101	43.5	38.5	1.1	5	<i>B. miliaris</i>
102	42.3	38.4	1.1	5	<i>B. miliaris</i>
103	51.8	46.7	1.1	5	<i>B. miliaris</i>
104	52.7	47	1.1	5	<i>B. miliaris</i>
105	55	46.2	1.2	5	<i>B. miliaris</i>
106	55.2	46.3	1.2	5	<i>B. miliaris</i>
107	50.7	42	1.2	5	<i>B. miliaris</i>
108	53	44.3	1.2	5	<i>B. miliaris</i>
109	51.4	42.3	1.2	5	<i>B. miliaris</i>
110	55.3	45.1	1.2	5	<i>B. miliaris</i>
111	58.5	57.6	1	5	<i>B. miliaris</i>
112	58.5	56.5	1	5	<i>B. miliaris</i>
113	55.7	50.8	1.1	5	<i>B. miliaris</i>

Table 4.1. *continued*

No.	Length L (mm)	Breadth B (mm)	L/B	No. of lobes on last chamber	species name
114	55.9	35.6	1.6	5	<i>B. australis</i>
115	58.1	40.6	1.4	5	<i>B. australis</i>
116	59	41.2	1.4	5	<i>B. australis</i>
117	59.5	42.1	1.4	5	<i>B. australis</i>
118	59.4	42	1.4	5	<i>B. australis</i>

Table 4.1. Dimensions of the test (in millimetres) and number of lobes on the final chamber of *Bolivinoidea* recorded in the Shiranish Formation, NE Iraq.

***Bolivinoidea decoratus* Biozone, late Campanian**

In NE Iraq this biozone is defined as the interval from the first to the last appearance datum of the nominate species and it is therefore a total range zone. It is identified in the ‘lower unit’ of the Shiranish Formation through a thickness of 158.5 m in the Dokan section and nearly 65 m in the Azmer section (Fig. 4.3). *Bolivinoidea decoratus* (Jones) is common at both localities and is restricted to late Campanian strata (Figs. 4.4, 4.5). It was previously recorded with the same stratigraphical range in Europe (Hiltermann & Koch 1950, 1955, 1962; Hofker 1958; Hiltermann 1963; Barr 1966a, b; Van Hinte 1967; Swiecicki 1980; Bailey *et al.* 2010), Atlantic Coastal Plain of New Jersey (Petters 1977) and North Africa (Barr 1970; Khalil 1998; El-Nady 2006). The first appearance datum of *B. laevigatus* Marie within the *B. decoratus* biozone of NE Iraq enables subdivision of this interval into a lower *B. decoratus* subzone and an upper *B. laevigatus* subzone (see Fig. 4.5). Based on co-occurring planktonic foraminifera in the Shiranish Formation (see Fig. 4.6), the *B. decoratus* biozone represents an equivalent stratigraphical interval to the *Globotruncana aegyptiaca* and lower part of the *Gansserina gansseri* planktonic foraminiferal biozones (see Robaszynski 1998; Premoli Silva & Sliter 1994, 1999; Robaszynski *et al.* 2000; Premoli Silva & Verga 2004; Sari 2006, 2009). The combined benthonic and planktonic foraminiferal biostratigraphy for the *B. decoratus* biozone also enables the informal recognition of lower and upper *Globotruncana aegyptiaca* and lower *Gansserina gansseri* intervals that may be important for more refined inter-regional correlation in the Middle East and North Africa (see Figs 4.5, 4.6).

***Bolivinooides miliaris* Biozone, earliest Maastrichtian**

The lower boundary of the *B. miliaris* biozone has been defined in Egypt (Khalil 1998; see also El-Nady 2006) by the Last Appearance Datum (LAD) of *B. decoratus*, while the upper boundary of the zone is identified by the last appearance of *B. miliaris* (Hiltermann & Koch). In Egypt, *B. miliaris* and *B. decoratus* have overlapping ranges through much of the upper *decoratus* biozone as recognised there (El-Nady 2006), through an interval assigned to the late Campanian (El-Nady *op cit.*, fig. 3). Therefore, the base of the *miliaris* biozone as it is recognised in Egypt is also identified by the FADs of *Bolivinooides draco giganteus* (Hiltermann & Koch) and *B. draco draco* (Marsson). However, El-Nady (2006, p. 685) stated, in contradiction to his range chart, that *B. miliaris* is an excellent marker for the Campanian-Maastrichtian boundary. In this chapter the author defines the *B. miliaris* biozone as a total range zone, with no overlap with *B. decoratus*. The author believes that the *decoratus-miliaris* biozonal boundary equates to the Campanian-Maastrichtian boundary, as this level is also associated with the FAD of *Bolivinooides draco* in Iraq, and with the FADs (Fig. 4.6) of the planktonic foraminifera *Rugoglobigerina hexacamerata* Brönnimann, *R. pennyi* Brönnimann and *Planoglobulina acervulinoides* (Egger), which are regarded as markers for the basal Maastrichtian in other regions (Zepeda 1998; Li *et al.* 1999; Tantawy *et al.* 2001; Kassab *et al.* 2004; Güray 2006; Beiranvand & Ghasemi-Nejad 2013; Farouk 2014; see Fig. 4.6). The *B. miliaris* biozone is identified in the uppermost part of the ‘lower unit’ and the lower part of the ‘upper unit’ of the Shiranish Formation (Fig. 4.3), in the Dokan succession occupying a stratigraphic thickness of 39 m. However, in the Azmer section, the biozone is confirmed only through 26 m of strata: this is due to the rapid disappearance of foraminiferal assemblages upwards in the rock succession at Azmer (Fig. 4.3). *Bolivinooides miliaris* occurs rarely in Iraq and is restricted to the earliest Maastrichtian. *Bolivinooides miliaris* is recorded from the same stratigraphical range in Europe (Hiltermann & Koch 1950; Swiecicki 1980; Schönfeld & Burnett 1991; Bailey *et al.* 2010), Atlantic Coastal Plain of New Jersey (Petters 1977), Syria (Plumhoff & Schumann 1966), North Africa (Le Roy 1953; Said & Kenawy 1956; Barr 1968, 1970; Khalil 1998; El-Nady 2006), Caribbean (Beckmann & Koch 1964), and the northwestern Australian margin (Campbell *et al.* 2004). In NE Iraq the *B. miliaris* biozone represents an equivalent stratigraphical interval to the middle part of the *Gansserina gansseri* planktonic

foraminiferal biozone (for which, see Robaszynski 1998; Premoli Silva & Sliter 1994, 1999; Robaszynski *et al.* 2000; Premoli Silva & Verga 2004; Sari 2006, 2009): this is based on the co-occurrence of *B. miliaris* with *G. gansseri*, and on its stratigraphic position above the *B. decoratus* biozone. Combining the benthonic and planktonic foraminifer occurrences allows the informal recognition of an upper *Gansserina gansseri* interval in the Iraqi succession (see Fig. 4.6).

***Bolivinoides draco* Biozone, late early Maastrichtian**

In Iraq, the *B. draco* (Marsson) biozone is a partial range zone that is defined as the interval from the last appearance datum of *B. miliaris* to the last appearance datum of *B. draco*. *Bolivinoides draco* is rare in its lowermost range in Iraq, where it overlaps with *B. miliaris*, and becomes abundant after the extinction of *B. miliaris*. The *B. draco* biozone is identified in the upper part of the 'upper unit' of the Shiranish Formation in the Dokan section through nearly 37 m of strata. A succeeding biozone is not recognised in the Dokan section, while the *B. draco* biozone is absent at Azmer (Fig. 4.3), probably as a consequence of environmental change caused by the rapid shallowing-up succession and the concomitant disappearance of foraminifera. In Egypt, El-Nady (2006) recognised the incoming of *Bolivinoides paleocenicus* (Brotzen) and *B. peterssoni* Brotzen at the base of the *B. draco* biozone as he defined it, though the author has not identified these taxa in Iraq. El-Nady (2006) also recorded *B. miliaris* as rare in the lowermost *B. draco* biozone. Therefore, the base of the *B. draco* biozone as the author defines it in Iraq most likely lies at a lower stratigraphic level than in Egypt (see Fig. 4.4).

The associated planktonic species within the *B. draco* biozone of Iraq are *Contusotruncana contusa*, *C. walfischensis* and *Gansserina gansseri*, which also signal the early Maastrichtian and, in the case of *C. contusa* and *C. walfischensis*, the late early Maastrichtian (Fig. 4.6). These foraminifera indicate that the *B. draco* biozone represents an equivalent stratigraphical interval to the upper part of the *Gansserina gansseri* planktonic foraminiferal biozone and the lower part of the *Contusotruncana contusa* (Cushman) planktonic foraminiferal biozone (for which, see Robaszynski 1998; Premoli Silva & Sliter 1994, 1999; Robaszynski *et al.* 2000; Premoli Silva & Verga 2004; Sari 2006, 2009).

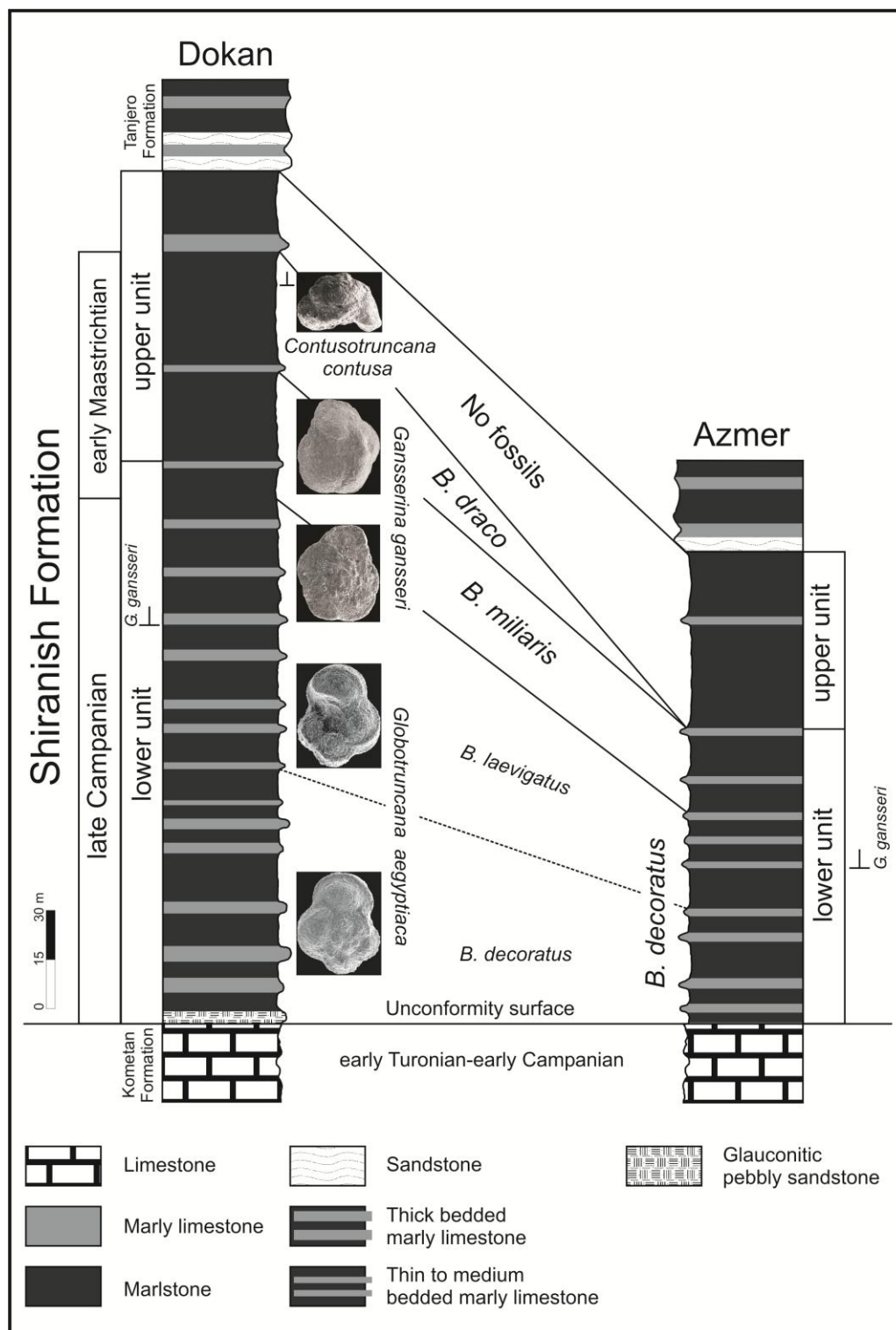


Figure 4.3. *Bolivinoidea* biozonation for the Shiranish Formation in the Kurdistan region, NE Iraq. The lower and upper units of the Shiranish Formation are informally defined (see Van Bellen *et al.* 2005; Buday 1980). First occurrences of key planktonic foraminifera are also shown.

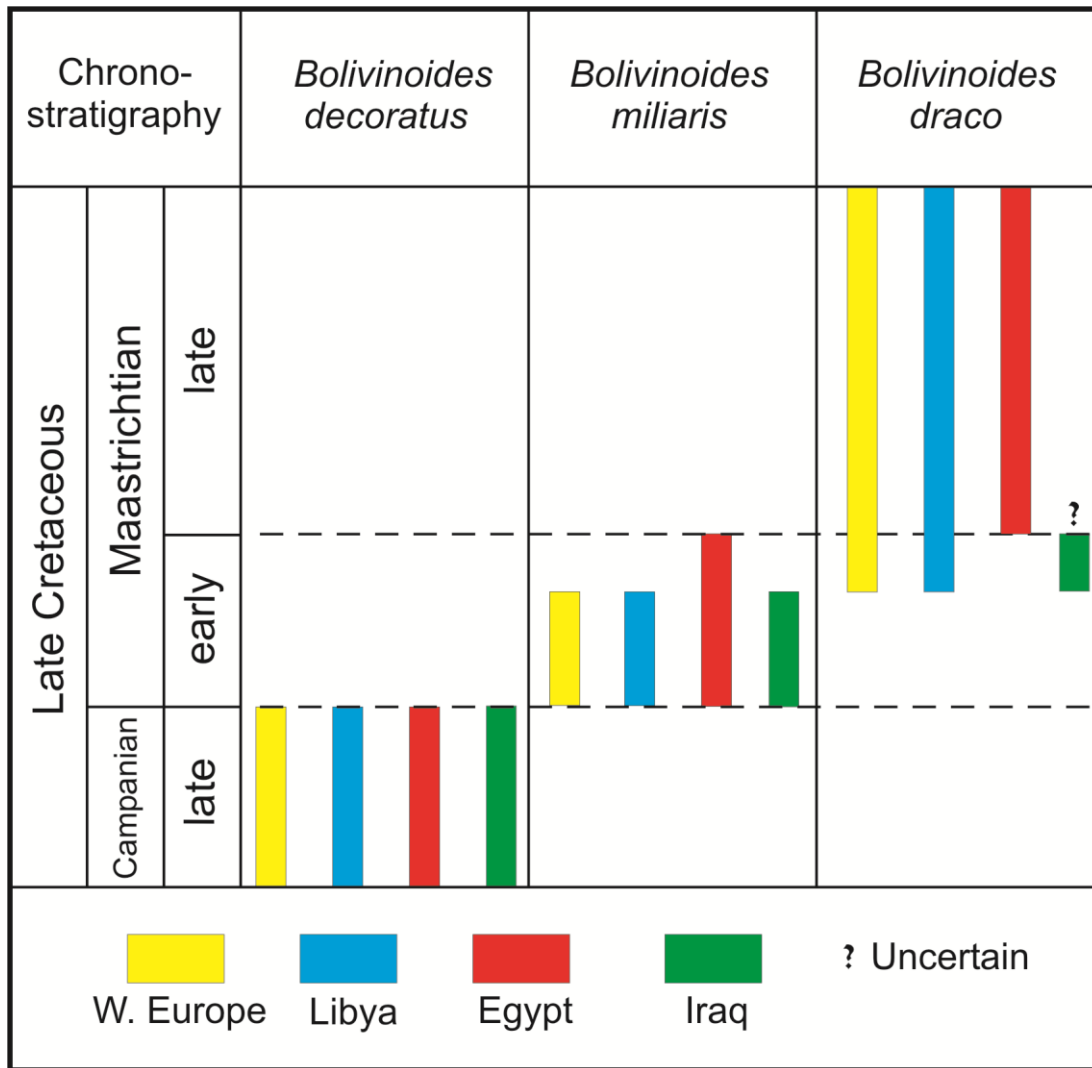


Figure 4.4. The late Campanian-late Maastrichtian *Bolivinooides* biozones from different regions of the world. The ranges of the *Bolivinooides* zones in western Europe and Libya are based on Barr (1970) and for Egypt on El-Nady (2006).

The Campanian-Maastrichtian boundary

At the Global Stratotype Section and Point (GSSP) at Tercis, southwestern France, the first appearance of the ammonite *Pachydiscus neubergicus* is taken as the marker of the Campanian-Maastrichtian (C-M) boundary (Birkelund *et al.* 1984; Odin 1996; Odin & Lamaurelle 2001), and this level also coincides with the first occurrences of the planktonic foraminifera *Rugoglobigerina scotti* and *Contusotruncana contusa* (Odin & Lamaurelle 2001). At the GSSP the evolutionary lineages of the genus *Bolivinooides* have also been used to recognise the C-M boundary, the base of the Maastrichtian coinciding with the

FAD of *Bolivinoides* specimens with 5 lobes on the last chamber (Odin & Lamaurelle 2001). *Bolivinoides* with 5 lobes on the final chamber also characterise the base of the Maastrichtian in NE Iraq, but the first occurrences of *R. scotti* and *C. contusa* appear later in the Iraqi succession (see Fig. 4.6), a situation apparently repeated in Iran (Dervishzad & Abdolalipour 2009), Tunisia (Li & Keller 1998a, b; Li *et al.* 1999) and NE Iraq (Sharbazheri 2010; Ismael *et al.* 2011). The relative ranges, therefore, of the key planktonic and benthonic foraminifer species differ between the type section at Tercis and Iraq. Thus, the planktonic species *R. scotti*, *C. contusa* and the benthonic 5-lobed *Bolivinoides* species appear simultaneously at Tercis, but in Iraq the first occurrence of the planktonic species post-dates the appearance of 5-lobed *Bolivinoides*. Here, based on the total succession of foraminifera assemblages, the author takes the appearance of 5-lobed *Bolivinoides* as the more reliable marker for the C-M boundary and infer that the appearances of *R. scotti* and *C. contusa* are diachronous globally.

Before the selection of the GSSP, the extinction of the planktonic foraminifera *Radotruncana calcarata* had long been used to define the C-M boundary (Van Hinte 1965; Plumhoff & Schumann 1966; Postuma 1971; Wonders 1980; Marks 1984b; Birkelund *et al.* 1984; Robaszynski *et al.* 1984; Olsson & Nyong 1984; Caron 1985; Gvirtzman *et al.* 1989; Sliter 1989; Schönfeld & Burnett 1991): however, several subsequent studies have shown that the LAD of *R. calcarata* significantly pre-dates the FAD of the boreal belemnite species *Belemnella lanceolata* (Burnett *et al.* 1992; Hancock *et al.* 1992) which has been regarded as another index for the C-M boundary. Based on these findings, Hancock *et al.* (1992) suggested that the position of the C-M boundary in Tethyan sections was best placed at the FAD of the planktonic foraminifera *Gansserina gansseri*. However, recent studies show that the FAD of *Gansserina gansseri* also pre-dates the C-M boundary (Robaszynski 1998; Premoli Silva & Sliter 1999; Robaszynski *et al.* 2000; Premoli Silva & Verga 2004; Sari 2006, 2009: also Figs 4.5, 4.6). Li *et al.* (1999) informally used the FAD of the planktonic foraminifer *Rugoglobigerina hexacamerata* for the C-M boundary based on biostratigraphic correlation with the geomagnetic time scale at Deep Sea Drilling Project (DSDP) site 525 in northwest Tunisia. Zepeda (1998) used the FAD of *Rugoglobigerina pennyi* for defining the C-M boundary in the Exmouth Plateau, northwest Australia and eastern Indian Ocean.

In NE Iraq the author uses the first occurrences of the planktonic foraminifera *Planoglobulina acervulinoides*, *R. pennyi* and *R. hexacamerata* within the *Gansserina gansseri* biozone (Li & Keller 1998a, b; Zepeda 1998; Robaszynski 1998; Li *et al.* 1999; Tantawy *et al.* 2001; Kassab *et al.* 2004; Güray 2006; Esmeray 2008; Beiranvand & Ghasemi-Nejad 2013; Farouk 2014) as additional evidence to identify the C-M boundary. These first occurrences coincide with the FAD of *Bolivinoidea* with 5 lobes, especially *B. miliaris*.

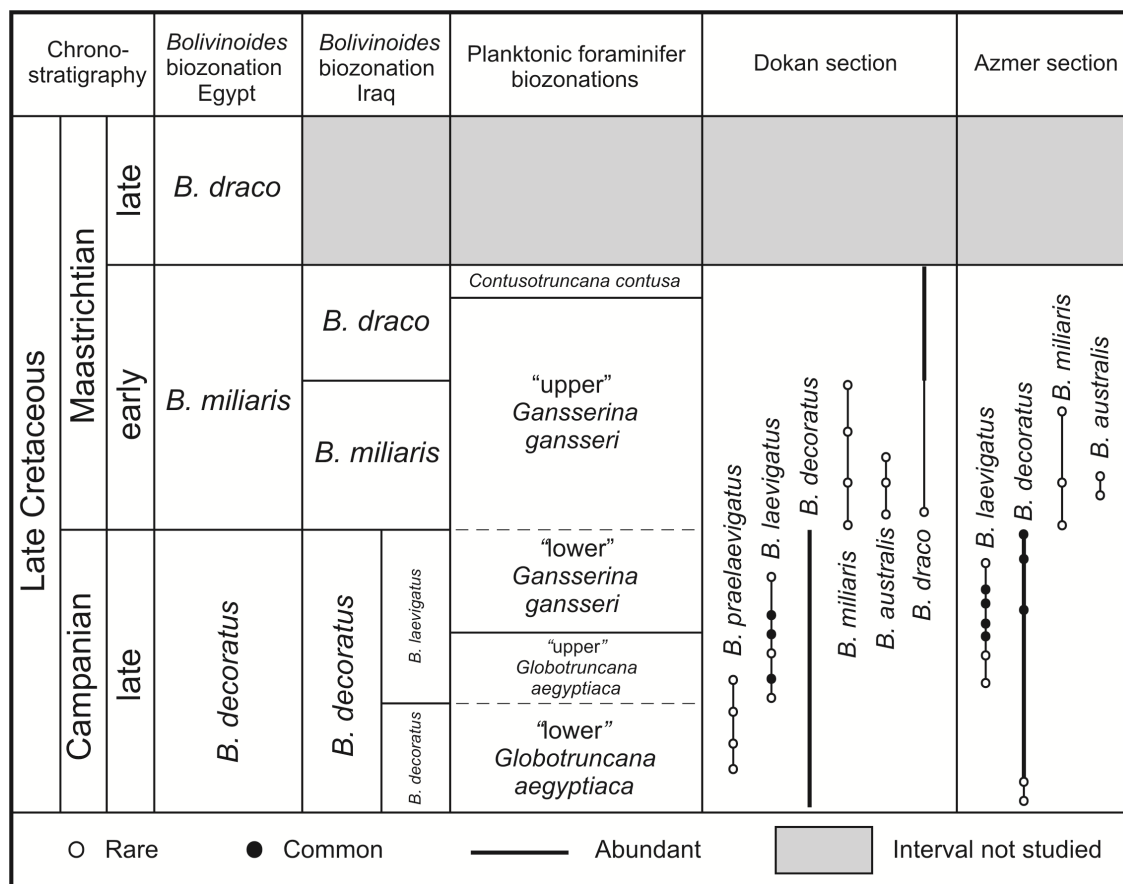


Figure 4.5. Ranges of recorded late Campanian-early Maastrichtian *Bolivinoidea* species in the Kurdistan region, NE Iraq. The *Bolivinoidea* biozonation in Egypt is based on Khalil (1998) and El-Nady (2006). Note that the definition of the *B. draco* biozone is based on the first occurrence of the nominate species in abundance, which places the *B. draco* biozone at an earlier chronostratigraphic level than in Egypt, but is compatible with the zonation in Libya and western Europe (Barr 1970). The informal subdivisions of the planktonic foraminifer biozones (horizontal dashed lines) represent the combined ranges of *Bolivinoidea* and planktonic foraminifer species.

Chrono-stratigraphy			Formation	<i>Bolivinoidea</i> biozonations	Planktonic foraminifer biozonations	First occurrence markers for planktonic foraminifera	
Late Cretaceous	Maastrichtian	early	Shiranish	upper unit	<i>B. draco</i>	<i>Contusotruncana contusa</i>	┴ <i>Contusotruncana contusa</i> <i>Rugoglobigerina scotti</i> ┴ <i>Rugoglobigerina hexacamerata</i> <i>Rugoglobigerina pennyi</i> <i>Planoglobulina acervulinoides</i> ┴ <i>Gansserina gansseri</i>
					<i>B. miliaris</i> T	“upper” <i>Gansserina gansseri</i>	
					<i>B. miliaris</i>		
	Campanian	late		lower unit	<i>B. draco</i> <i>B. miliaris</i> ┴	----- “lower” <i>Gansserina gansseri</i>	
					<i>B. decoratus</i> T		
					<i>B. decoratus</i>	<i>B. laevigatus</i>	
<i>B. decoratus</i> <i>B. decoratus</i> ┴							
┴ First Appearance Datum T Last Appearance Datum							

Figure 4.6. Biostratigraphic interval recognised in the Shiranish Formation using both *Bolivinoidea* and planktonic foraminifera. Key *Bolivinoidea* and planktonic foraminiferal occurrences are indicated. In successions where both *Bolivinoidea* and planktonic foraminifera are present, it is possible to recognise informally a ‘lower *Gansserina gansseri*’ interval, which represents the latest Campanian, and may therefore be of value for correlation in other Tethyan successions.

Palaeoenvironmental significance of the foraminifera

Foraminiferal assemblages in the Shiranish Formation indicate a gradual decrease in marine shelf water depth through the succession. High diversity foraminiferal assemblages characterise the ‘lower unit’ of the Shiranish Formation and include agglutinated species. These assemblages comprise species of the benthonic foraminifera *Ammodiscus*, *Clavulinoides*, *Glomospira*, *Pleurostomella*, *Praebulimina*, *Pullenia*, *Osangularia* and *Quadriformina*, and in particular the taxa *Bathysiphon*, *Dorothia* and *Gaudryina* that suggest a middle slope environment with water depths of at least 600 m (Sliter & Baker 1972; Sliter 1973). This ‘lower unit’ of the Shiranish Formation also contains the benthonic

foraminifera *Clavulinoides trilaterus* (Cushman), *Hemirobulina bullata* (Reuss), *Nuttallides truempyi truempyi* (Nuttall), *Gyroidinoides globosus* (Hagenow) and *Praebulimina kickapooensis* (Cole) that are useful indicators for middle slope environments (Sliter & Baker 1972; Olsson & Nyong 1984; Alegret & Thomas 2001): the 'lower unit' is also characterised by rich planktonic assemblages of *Globotruncana* species. Towards the top of the *B. decoratus* biozone the benthonic foraminiferal assemblages are dominated by species of *Gavelinella*, *Gyroidinoides*, *Gaudryina*, *Marginulinopsis*, *Neoflabellina*, *Osangularia*, *Praebulimina* and *Spiroplectammina* species, which suggest an upper slope environment with water depths ranging between 500 to 300 m (Sliter 1972a; Sliter & Baker 1972). The top of the *B. decoratus* biozone of the Shiranish Formation contains *Bathysiphon vitta* Nauss, *Gaudryina pyramidata* Cushman, *Marssonella oxycona oxycona* (Reuss), *Nuttallinella florealis* (White) and *Osangularia cordieriana* (d'Orbigny) that are useful indicators for upper slope environments (Sliter & Baker 1972; Olsson & Nyong 1984; Alegret & Thomas 2001).

Foraminiferal assemblages in the topmost part of the 'lower unit' in the Azmer section and the 'upper unit' in the Dokan section of the Shiranish Formation suggest shallower marine conditions. The benthonic foraminiferal assemblages at the level of the *B. miliaris* and *B. draco* biozones are species of *Coryphostoma*, *Dentalina*, *Laevidentalina*, *Gyroidinoides*, *Nodosaria*, *Lagena* and *Oolina* which indicate an outer neritic shelf environment of about 200 m water depth (Sliter 1972a; Sliter & Baker 1972). This unit also includes *Coryphostoma incrassata gigantea* Wicher, *Loxostomum eleyi* (Cushman) and *Praebulimina carseyae* (Plummer) that are useful indicators for outer neritic shelf environments (Sliter & Baker 1972; Olsson & Nyong 1984). Planktonic foraminifer assemblages are characterised by *Rugoglobigerina*, *Globigerinelloides* and *Heterohelix* species; according to Sliter (1972a) and Hart (1980), species of these genera most likely characterised shallow marine depths.

Sea level change in the Shiranish Formation

The intra-Campanian unconformity recognised across the Arabian Plate is represented in the Dokan and Azmer sections at the cessation of deposition of pelagic limestones of the Kometan Formation (early Campanian) followed by deposition of glauconitic pebbly

sandstone at the base of the overlying Shiranish Formation (see Van Bellen *et al.* 2005; Jassim & Goff 2006; Aqrabi *et al.* 2010; Lawa *et al.* 2013). The marine erosional surface represents a gap of the mid to early late Campanian in which the biostratigraphically useful species *Contusotruncana plummerae* (= *Globotruncana ventricosa*) proposed by Petrizzo *et al.* (2011), *Radotruncana calcarata* and *Globotruncanella havanensis* are not recorded.

The lithofacies of the Shiranish Formation suggest the combined influence of eustasy and local subsidence on sea level change, the latter resulting from structural loading of the Arabian plate by obducted Neo-Tethyan margin rocks (Jassim & Goff 2006). The lower part of the 'lower unit' of the Shiranish Formation (within the *Bolivinoidea decoratus* subzone) represents a major deepening-upwards succession indicated by an increasing planktonic to benthonic foraminifer ratio. The middle part of the 'lower unit' of the Shiranish Formation (that part assignable to the *Bolivinoidea laevigatus* subzone) is marked by a maximum flooding surface with palaeodepths of at least 600 m (Fig. 4.7) and is characterised by marl beds associated with the predominance of a planktonic lime-mudstone facies. Thereafter, in the upper part of the 'lower unit' foraminiferal evidence suggest that sea level begins to fall (see Fig. 4.7).

In the *B. miliaris* biozone the Shiranish Formation is characterised by continued sea level fall that is identified by increasing dominance of benthonic foraminifera, a sudden drop in the abundance of globotruncanids, and an increase in the heterohelcid population associated with the presence of *Pseudotextularia* and *Planoglobulina* species. Collectively these suggest decreasing marine shelf depths to some 200 m (Sliter 1972a; Abdel-Kireem 1983; Darvishzad & Abdolalipour 2009; see Fig. 4.7).

Haq *et al.* (1987) and Hardenbol *et al.* (1998) proposed a major marine regression in the early Maastrichtian that coincided with major global cooling phases at 71.2-69.2 Ma (Fig. 4.7). Moreover, Barrera (1994) noted that the early Maastrichtian was the coolest interval of the Cretaceous following the peak warmth of the earlier Late Cretaceous. Therefore, sea level change in the Iraq succession might relate to Late Cretaceous climate change, as indicated by correlation from the *Bolivinoidea* biozonation. The same period of sea level regression is also recorded in Iran (Darvishzad & Abdolalipour 2009), Turkey (Sari 2006, 2009) and in other parts of Iraq (El-Anbaawy & Sadek 1979; Abdel-Kireem 1983; Al-Banna 2010; Fayyadh 2010). In this study the sea level curve for NE Iraq is

generally consistent with the Haq *et al.* (1987) global sea level curve, but it is substantially different from the Arabian Plate sea level curve of Sharland *et al.* (2001), suggesting strong regional tectonic controls on relative sea level on the Arabian Plate during the Late Cretaceous.

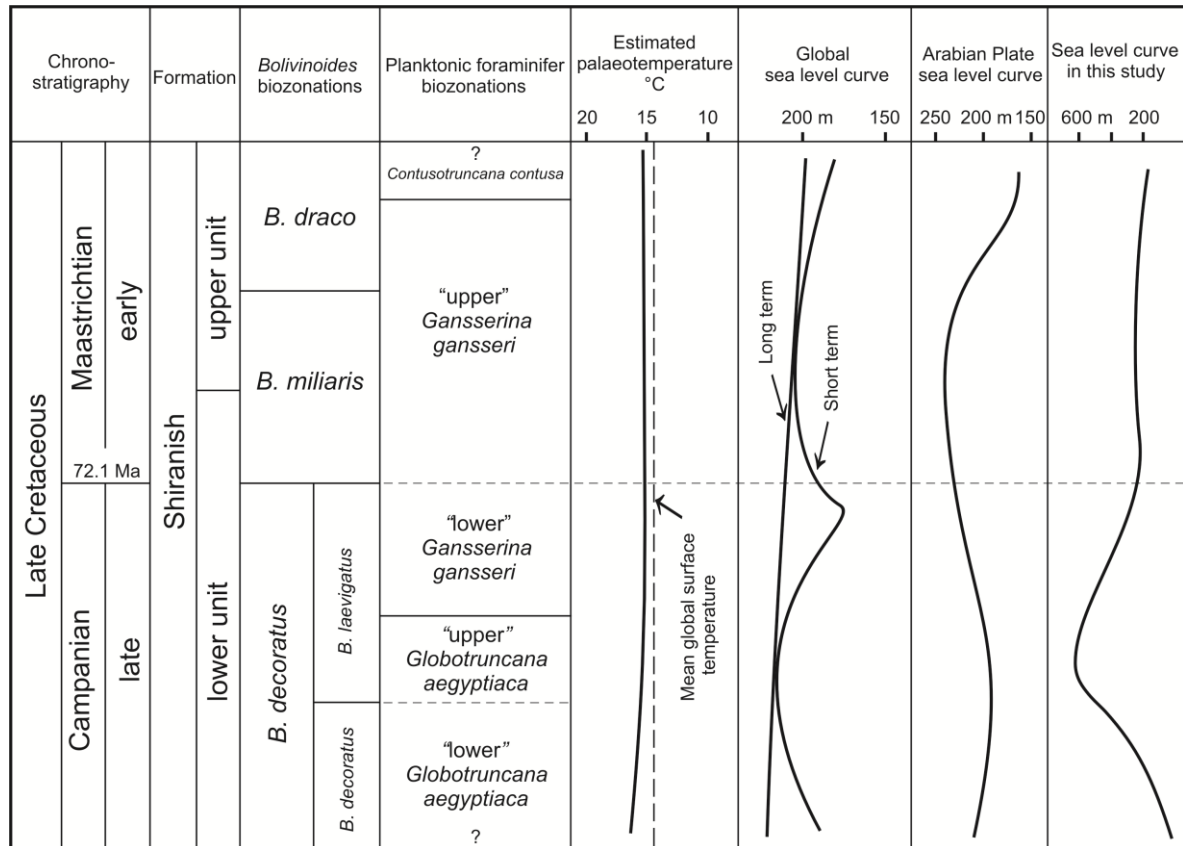


Figure 4.7. Correlation of sea level reconstructed globally (Haq *et al.* 1987) and for the Arabian Plate (Sharland *et al.* 2001). The global mean surface temperature is based on Puc  at *et al.* (2003). The Campanian-Maastrichtian boundary was adapted from Ogg & Hinnov (2012). Question marks represent uncertainty for the first appearance datum of *Globotruncana aegyptiaca* and the last appearance datum of *Contusotruncana contusa*.

Taxonomic notes on species of *Bolivinoidea*

Here the author highlights key morphological characters used to diagnose *Bolivinoidea* species in the Shiranish Formation, comparing materials from NE Iraq with the original descriptions of the species. Specimens figured in plates 1 to 2 are deposited in the

collections of the British Geological Survey, Keyworth, Nottingham, UK and are identified by the prefix MPK.

Bolivinoides australis Edgell (Pl. 1, Figs 1, 2) was originally described from the Late Cretaceous succession of NW Australia (Edgell 1954). The material in NE Iraq is conspecific with that of Edgell (*op. cit.*) based on its pyriform lateral shape and ovate cross-section; its smooth initial chambers, while later chambers are pustulate; and in possessing a final chamber that typically has between 5 and 6 thick, closely spaced lobes. The length/breadth ratio of the Iraqi material is between 1.4 and 1.6, thereby differentiating *B. australis* from *B. decoratus*, which has a smaller length/breadth ratio, a different shape, and more closely spaced lobes on the final chambers.

Bolivinoides decoratus (Jones) (Pl. 1, Figs 3-9; Pl. 2, Figs 1-5) was originally described and illustrated in Wright (1886) from the Chalk Group at Keady Hill, County Derry, Northern Ireland. However, the name had been used before by Jones (1884) in unpublished work and for that reason, Wright graciously attributed Jones with authorship of *Bolivina* [= *Bolivinoides*] *decorata*. The Iraqi material is typical of this species in being kite-shaped in lateral view, with an elliptical cross-section. The earliest chambers are smooth or weakly lobed; ornamentation on later chambers is more prominent, with 3 to 4 thick, distinct lobes on the final chambers. The length/breadth ratio is between 1.5 and 2.1, most commonly between 1.7 and 1.9.

Marsson (1878) described *Bolivina* [= *Bolivinoides*] *draco* (Pl. 1, Figs 10-12; Pl. 2, Figs 6, 7) from the Maastrichtian of Rügen Island in the Baltic Sea, Germany. The material from the Shiranish Formation possesses the typical diamond-shaped lateral morphology of this species and the test also has a compressed cross-section. The ornament comprises two, species-diagnostic, centrally positioned parallel ribs extending along the entire length of the test, separated by a central depression. In larger forms, the ribs are intersected by overlapping side-ribs at an angle of about 35° to 40° in the later part of the test. The length/breadth ratio of the test is generally between 1.3 and 1.5.

The type material of *Bolivinoides laevigatus* Marie (Pl. 1, Figs 13, 14; Pl. 2, Fig 8) is from the late Campanian of the Paris Basin (Marie 1941). Iraqi specimens have the characteristic narrow, slowly expanding test and elliptical cross-section of Marie's material. Earlier chambers are smooth or with up to two lobes, later chambers become weakly lobate,

and there are three lobes on the final chambers. Lobation weakens towards the periphery. The length/breadth ratio is between 1.9 and 2.0. *Bolivinoidea laevigatus* can be distinguished from *B. decoratus* by its smaller test and more weakly developed ornamentation.

Bolivinoidea miliaris Hiltermann & Koch (Pl. 1, Figs 15, 16; Pl. 2, Figs 9, 10) is a distinctive taxon with its broad rhomboidal lateral shape and elliptical to ovate cross-section. The ornament comprises long irregular lobes, numbering five on the last pair of chambers. The maximum breadth of *B. miliaris* is near the mid-point of the test. The length/breadth ratio is between 1.0 and 1.2, most commonly 1.2. *Bolivinoidea miliaris* is most similar to *B. draco*, but is distinguishable by its long, irregular, discontinuous lobes, the absence of central ribs, and by its broader rhomboidal shape. The material in NE Iraq possesses the characteristic morphology of the German material described by Hiltermann & Koch (1950).

Bolivinoidea praelaevigatus Barr (Pl. 2, Figs 11, 12) was described from the Late Cretaceous of Britain (Barr 1966a). It has a very distinctive, gradually tapering, narrow test, with a compressed shape in cross-section. The test surface is smooth to weakly lobed, with 2 or 3 lobes on the final chambers. Its length/breadth ratio is very distinctive at between 2.1 and 2.3.

Conclusions

The late Campanian-early Maastrichtian succession of NE Iraq can be subdivided into three *Bolivinoidea* biozones: the *B. decoratus* biozone (late Campanian), subdivided into lower *B. decoratus* and upper *B. laevigatus* subzones; the *B. miliaris* biozone (earliest Maastrichtian) and the *B. draco* biozone (late early Maastrichtian). This zonal scheme provides greater precision in the regional correlation of the Shiranish Formation in NE Iraq, firmly establishes the Campanian-Maastrichtian boundary, and constrains the timing of sea level fall from the latest Campanian onwards, which is consistent with evidence for marine regression globally.

***Bolivinoidea* foraminifera plates**

Chapter 4: A refined foraminiferal biostratigraphy for
the late Campanian-early Maastrichtian succession of
northeast Iraq

Plate 1 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Bolivinoidea

Figs 1, 2: *Bolivinoidea australis* Edgell. *Bolivinoidea miliaris* biozone, Fig. 1, MPK14381, Azmer section, sample number ASH-52; Fig. 2, MPK14382, Dokan section, sample number DSH-90.

Figs 3-9: *Bolivinoidea decoratus* (Jones). *Bolivinoidea decoratus* biozone, Fig. 3, MPK14383 and Fig. 4, MPK14384, Azmer section, sample number ASH-15; Fig. 5, MPK14385 and Fig. 6, MPK14386, Dokan section, sample number DSH-05; Fig. 7, MPK14387, Dokan section, sample number DSH-15; Fig. 8, MPK14388 and Fig. 9, MPK14389, Dokan section, sample number DSH-36.

Figs 10-12: *Bolivinoidea draco* (Marsson). *Bolivinoidea draco* biozone, Fig. 10, MPK14390 and Fig. 11, MPK14391, Dokan section, sample number DSH-116; Fig. 12, MPK14392, Dokan section, sample number DSH-117.

Figs 13, 14: *Bolivinoidea laevigatus* Marie. *Bolivinoidea decoratus* biozone, Fig. 13, MPK14393 and Fig. 14, MPK14394, Dokan section, sample number DSH-48.

Figs 15, 16: *Bolivinoidea miliaris* (Hiltermann and Koch). *Bolivinoidea miliaris* biozone, Fig. 15, MPK14395 and Fig. 16, MPK14396, Azmer section, sample number ASH-62.

Plate 1

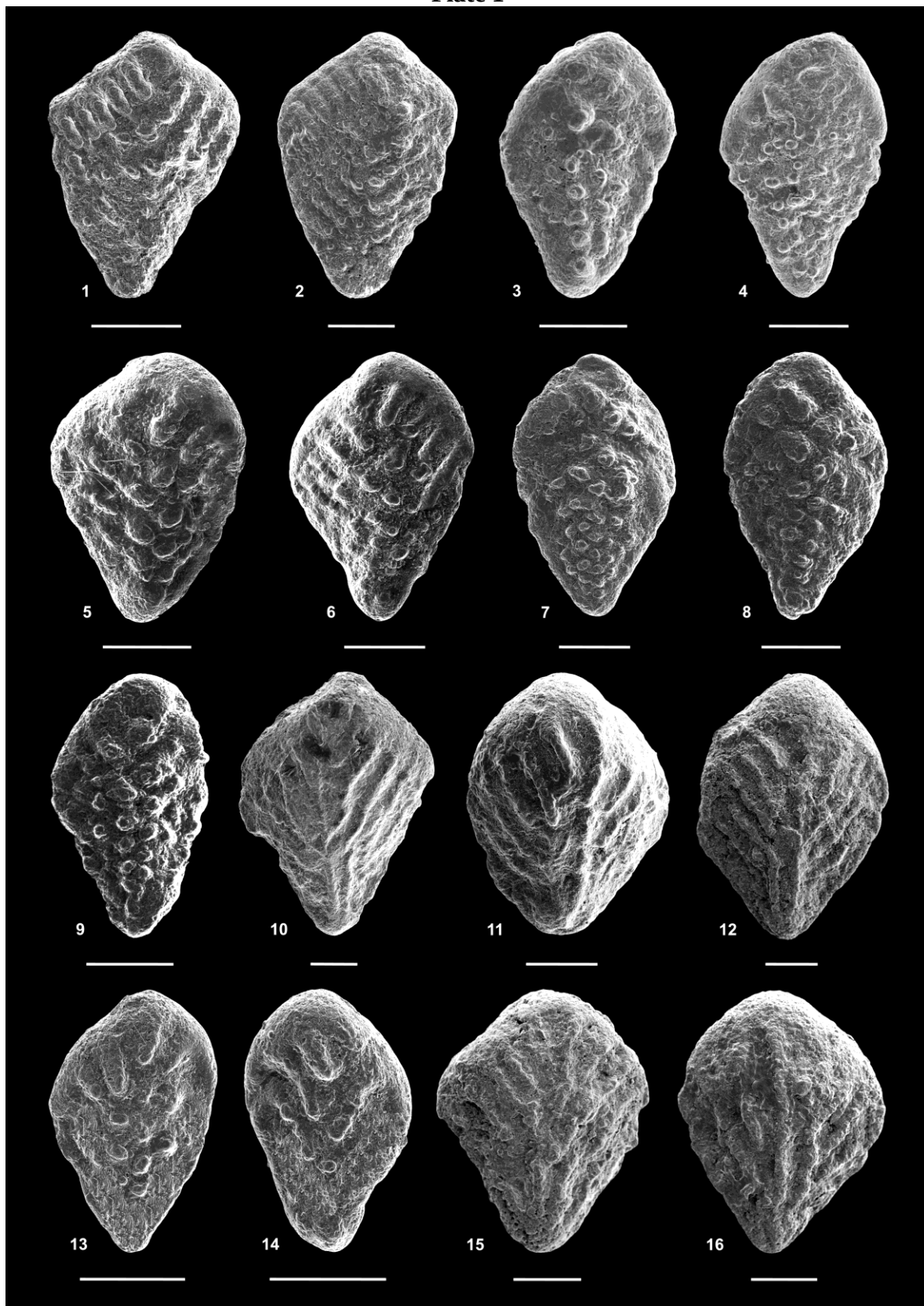


Plate 2 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Bolivinoidea

Figs 1-5: *Bolivinoidea decoratus* (Jones). *Bolivinoidea decoratus* biozone, Fig. 1, MPK14397, Fig. 2, MPK14398 and Fig. 3, MPK14399, Azmer section, sample number ASH-10; Fig. 4, MPK14400 and Fig. 5, MPK14401, Dokan section, sample number DSH-36.

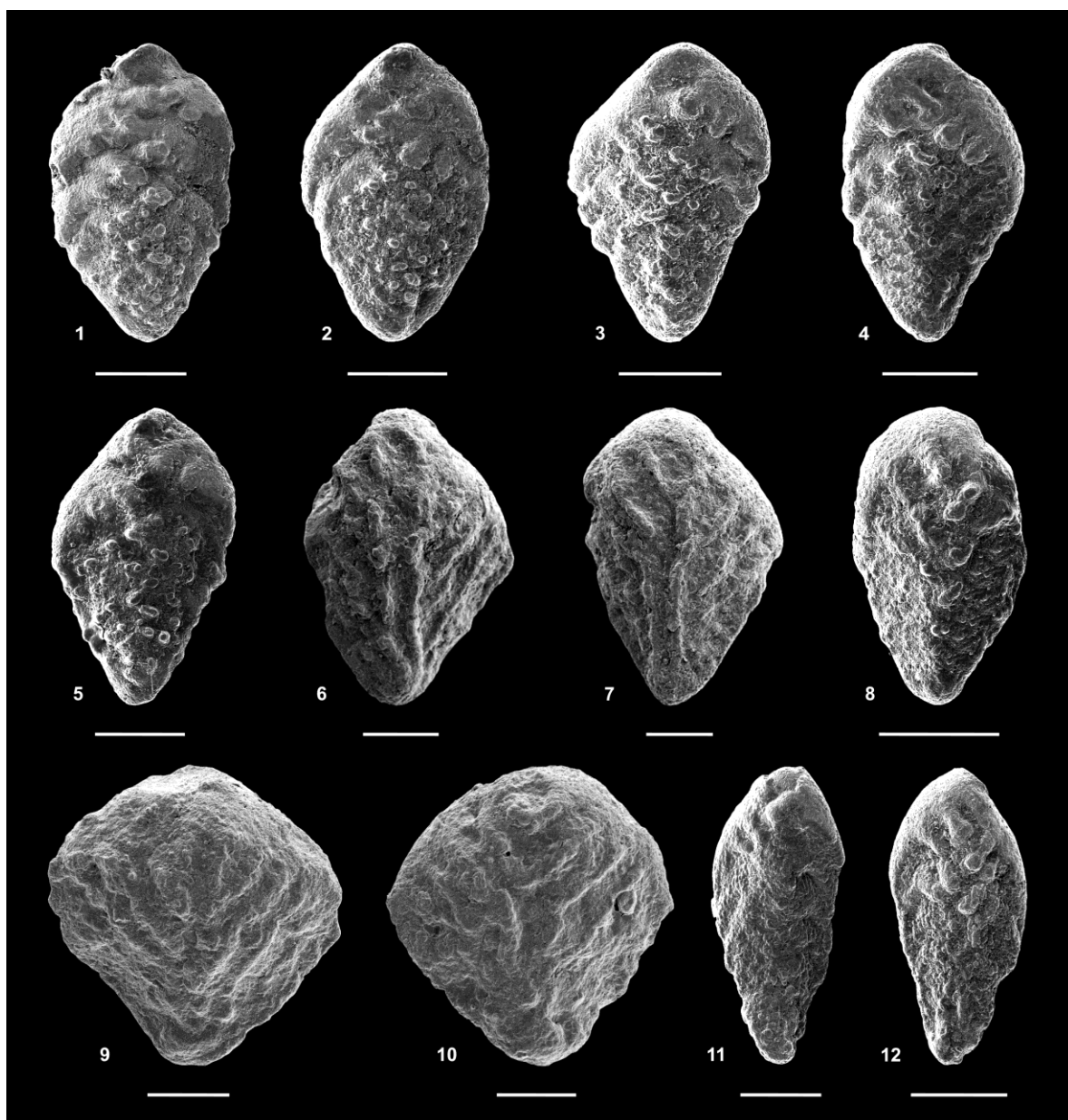
Figs 6, 7: *Bolivinoidea draco* (Marsson). *Bolivinoidea draco* biozone, Fig. 6, MPK14402 and Fig. 7, MPK14403, Dokan section, sample number DSH-110.

Fig. 8: *Bolivinoidea laevigatus* Marie. *Bolivinoidea decoratus* biozone, MPK14404, Azmer section, sample number ASH-25.

Figs 9, 10: *Bolivinoidea miliaris* (Hiltermann and Koch). *Bolivinoidea miliaris* biozone, Fig. 9, MPK14405 and Fig. 10, MPK14406, Dokan section, sample number DSH-103.

Figs 11, 12: *Bolivinoidea praelaevigatus* (Barr). *Bolivinoidea decoratus* biozone, Fig. 11, MPK14407 and Fig. 12, MPK14408, Dokan section, sample number DSH-08.

Plate 2



Chapter 5

Palaeoenvironmental
signature of the late
Campanian-early
Maastrichtian benthonic
foraminiferal assemblages
of Kurdistan, northeast Iraq

Chapter 5: Palaeoenvironmental signature of the late Campanian-early Maastrichtian benthonic foraminiferal assemblages of Kurdistan, northeast Iraq

Abstract

The late Campanian to early Maastrichtian benthonic foraminiferal assemblages in the Shiranish Formation of NE Iraq are placed into three temporally distinct assemblages that are interpreted to reflect environmental change, principally involving factors associated with palaeodepth. In stratigraphic succession the assemblages are: the *Lenticulina macrodiscus-Lenticulina pseudosecans* Assemblage (late Campanian), occupying a succession of strata that are equivalent to the lower and upper parts of the *Bolivinoides decoratus* subzone within the *Bolivinoides decoratus* benthonic foraminiferal biozone; the *Gavelinella monterelensis-Gavelinella stephensoni* Assemblage (late to latest Campanian), occupying a succession of strata that are equivalent to the uppermost part of the *Bolivinoides decoratus* and *B. laevigatus* subzones within the *Bolivinoides decoratus* benthonic foraminiferal biozone; and the *Coryphostoma incrassata gigantea-Praebulimina carseyae-Loxostomum eleyi* Assemblage (early Maastrichtian), occupying a succession of strata that are equivalent to the *Bolivinoides miliaris* and *B. draco* benthonic foraminiferal biozones. The foraminiferal assemblages are interpreted as representing outer shelf to middle slope environments, between ca 200 m to at least 600 m water depth, with maximum water depths in the late Campanian, followed by shallowing into the early Maastrichtian. The most likely control mechanism for shallowing sea level was the beginning of southern Neo-Tethys Ocean closure at this time.

Introduction

Benthonic foraminifera live in abundance at a range of marine depths from the shallow continental shelf to the deep ocean (e.g. Pawlowski & Holzmann 2008; Leckie 2009; BouDagher-Fadel 2013; Holbourn *et al.* 2013). They have often been used to infer palaeodepths, and their distributional patterns can also be used to infer relative changes in oxygen-level, salinity, temperature and nutrient conditions (e.g. Sliter & Baker 1972; Van Morkhoven *et al.* 1986; Keller 1988, 1992; Widmark & Malmgren 1988; Widmark 1995;

Speijer & Van der Zwaan 1996; Li *et al.* 1999; Friedrich *et al.* 2003, 2005b, 2006). Cretaceous palaeodepth determinations are generally based on the interpreted upper depth limits of certain benthonic foraminiferal species, taking into account possible post-mortem transportation of assemblages (Li *et al.* 1999).

The rich and diverse late Campanian-early Maastrichtian benthonic foraminiferal assemblages from the Shiranish Formation of NE Iraq, forms the basis for this study (Fig. 5.1). A total of 115 benthonic species and subspecies belonging to 52 genera and 25 families were identified (see Appendices 2 and 3), of which 92 species and subspecies occur in the Dokan section, and 83 species and subspecies occur in the Azmer section (Fig. 5.1). The foraminiferal assemblages bear a close resemblance to Cretaceous deep-water faunas from other regions, but most notably from Egypt (Ayyad *et al.* 1997; Khalil 1998; El-Nady 2006; Ismael 2012), Tunisia (Li *et al.* 1999), Libya (Barr 1970), the USA (Sliter 1968, 1972a; Sliter & Baker 1972; Petters 1977; Olsson & Nyong 1984; Nyong & Olsson 1984), and the Indian (Quilty 1992c) and Atlantic oceans (Dailey 1983).

Most recently Jaff *et al.* (2014) studied species of the benthonic foraminiferal genus *Bolivinoidea* in the Shiranish Formation and developed a biozonation that enabled correlation with Cretaceous successions across the Middle East and North Africa, but there has been no systematic study of the entire benthonic faunal assemblages. Jaff *et al.* (in press) have also identified three planktonic biozones and two subzones within the Shiranish Formation. Here the present author examines the distribution patterns of the benthonic foraminiferal assemblages to determine how these reflect changes in palaeodepth evolution in the Shiranish Formation and the likely controls on sea level. The author combines environmental evidence from the benthonic foraminifera with evidence from sedimentology, the abundance and diversity of associated planktonic foraminifera, and the planktonic to benthonic ratio of foraminifera to determine an overall picture of palaeodepth evolution in the Shiranish Formation of NE Iraq.

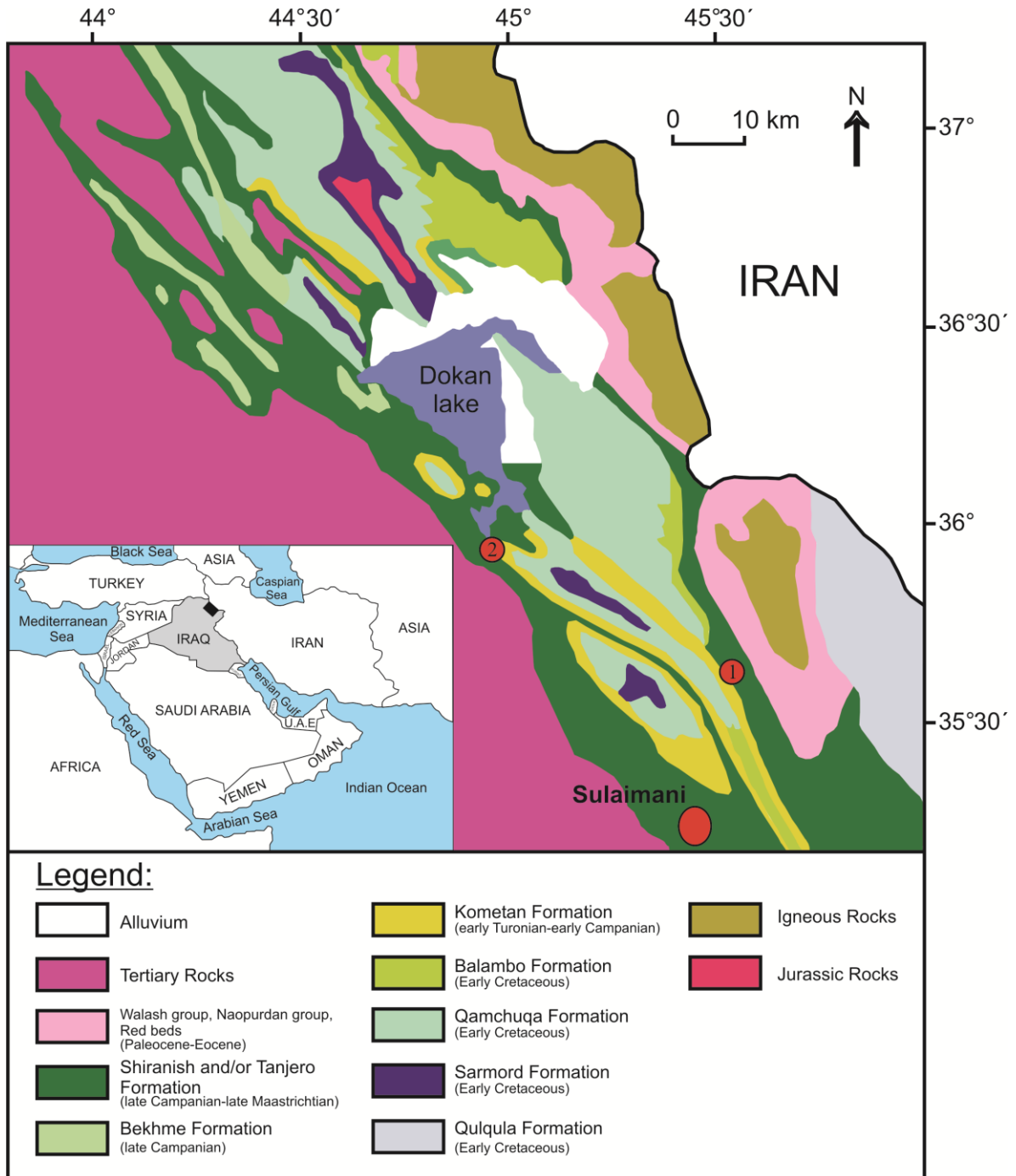


Figure 5.1. Geological context for the Azmer (1) and Dokan (2) sections of the Shiranish Formation in the Kurdistan region of NE Iraq (map after Sissakian 2000). The Dokan section runs parallel to the left bank of the Dokan Dam, near the Dokan tourist village. The Azmer section is located about 15 km to the NE of Sulaimani city. Small black rectangle on inset map represents study-area.

Stratigraphical setting

The late Campanian-early Maastrichtian Shiranish Formation was deposited during a regional transgressive-regressive cycle in Iraq (Al-Qayim *et al.* 1986; Jassim & Goff 2006; Al-Banna 2010). The formation outcrops across north, northwest and northeast Iraq, and is also detected in the subsurface in many wells through central Iraq (Al-Omari & Sadek 1974; Al-Banna 2010). The type section is located at Shiranish Islam village, about 17 km NE of Zakho, close to the Iraqi-Turkish boundary (see Van Bellen *et al.* 2005 for the original description). Later, Al-Qayim *et al.* (1986) divided the formation into three informal units. The 'lower unit' of the Shiranish Formation consists mainly of alternating light grey, medium to thick-bedded marly limestone with thin, softer and darker limey marlstone beds. The 'middle unit' consists of thick, grey and hard, medium-bedded sandy limestones alternating with blue softer and thinner marlstone interbeds. The 'upper unit' is represented by a thick succession of thin-bedded blue marlstone. According to Al-Qayim (1992) the 'middle unit' shows a distinctive cyclical pattern that includes the development of *Teichichnus* burrows. Al-Qayim (1992) suggested that the 'middle unit' might represent storm deposits (tempestites) formed in a deep-water ramp setting. The 'middle unit' can only be discerned in the NW region of Iraq.

According to several authors (Kennedy & Lunn 2000; Al-Banna 2010; Aqrabi *et al.* 2010; Jaff *et al.* 2014) the age of the Shiranish Formation in NE Iraq 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 in NE Iraq (late Maastrichtian; Sharbazheri 2008).

In NE Iraq, the Dokan and Azmer localities provide nearly complete successions through the Shiranish Formation (Fig. 5.1), which is represented by about 260 m at Dokan and 144 m at Azmer. In both areas the Shiranish Formation consists of only two lithological units, the 'lower unit' and the 'upper unit' with no evidence for the 'middle unit' as it is recorded by Al-Qayim *et al.* (1986) in the type section area. 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. 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 only locally developed and hence is not recognised as a separate member in the Shiranish Formation.

Materials and Methods

Sample sections

Two Late Cretaceous rock successions, one at Dokan (latitude 35° 56' 15" N and longitude 44° 57' 21" E) and the other at Azmer (latitude 35° 37' 30" N and longitude 45° 31' 45" E; see Fig. 5.1) have been analysed. These sections present near-complete successions of the Shiranish Formation that contain rich and diverse planktonic and benthonic foraminiferal assemblages (e.g. Jaff *et al.* 2014; Jaff *et al.* in press). Morphological preservation of these planktonic and benthonic foraminifera is good, although the tests are commonly recrystallised and filled with calcite. Some 235 samples have been collected from the Shiranish Formation in both sections. Samples were taken at a spacing ranging from 0.5 m in the soft marlstones to 2 m in the indurated marlstones and marly limestones.

Sample processing

For friable samples, a freeze-thaw method of processing was used (Mogaddam 2002; Jaff *et al.* 2014). Approximately 200–300 grams of each friable sample was repeatedly frozen and thawed in a supersaturated solution of sodium sulphate until the rock disaggregated. Disaggregated sediments were then washed thoroughly through a 63 µm sieve, the residues separated by filtration and dried overnight in an oven at 50°C. Dried residues were sorted using sieves from 500 µm down to 63 µm.

Abundance analysis

Generally, the numerical abundance of planktonic and benthonic foraminifera per measured sample in the Shiranish Formation in the Azmer section is lower than in the Dokan section (Fig. 5.2). Numerical abundance in samples taken from the ‘lower unit’ of the Shiranish Formation is much greater than for the ‘upper unit’.

Planktonic foraminifera were picked and studied from the residue in the 63-300 μm size fractions. The $> 63 \mu\text{m}$ fraction was then used for picking benthonic foraminifera because it captures both juvenile and adult specimens. Some 10 g of dry sediment was used for counting planktonic and benthonic foraminifera in each sample. For the analysis of planktonic species diversity, 10 g of dry sediment were analysed for each sample until 300 specimens were counted: for those samples that contained less than 300 specimens, the maximum number of specimens were counted. Benthonic foraminifera are less abundant than planktonic forms in the samples, and the maximum number of specimens recovered from 10 g of dry sediment was 95 (see Fig. 5.2). Most samples (164 of 183) have more than 30 specimens per 10 g of sediment (Appendix 4); for these samples benthonic foraminiferal abundance is described according to the following criteria: abundant ($>15\%$), common (15-10%), uncommon (9-5%), and rare ($<5\%$) of the total benthonic foraminiferal fauna per 10 g of sediment sample. A small number of samples have less than 30 specimens. Within these samples no single species has abundance greater than 10% (that is, there are never 3 or more individuals of a single species per sample), though some species are present in abundances between 5-9%.

Abundance in the 'lower unit'

In the Dokan section, the 'lower unit' of the Shiranish Formation has planktonic foraminifer abundances varying from approximately 182 to more than 300 individuals/10 g of dry sediment. In contrast, the benthonic foraminifera abundances record the lowest values from the 'lower unit', typically ranging between 21 and 85, with the exception of samples DSH-03 to DSH-06 that have 89 and 95 individuals/10 g of dry sediment respectively (Fig. 5.2).

The Azmer section has planktonic foraminiferal abundances ranging between 180 and 277, with very few samples having 300 individuals/10 g of dry sediment in the lower part of the 'lower unit' of the Shiranish Formation (Fig. 5.2). Towards the upper part of the 'lower unit' of the Shiranish Formation the planktonic foraminifer numbers in the Azmer section decrease to a minimum of 180 individuals/10 g of dry sediment (Fig. 5.2). In contrast, the benthonic foraminifer abundances range between 23 and 67 individuals/10 g of dry sediment (Fig. 5.2).

Abundance in the 'upper unit'

In the 'upper unit' of the Shiranish Formation there is no record of planktonic and benthonic foraminifera in the Azmer section.

In the Dokan section, the abundance of planktonic foraminifer typically ranges from 181 to 254, with the exception of samples DSH-119 and DSH-120 that have 271 and 283 individuals/10 g of dry sediment respectively (Fig. 5.2). The benthonic foraminifer abundances range between 47 and 85 individuals/10 g of dry sediment (Fig. 5.2), with no record of planktonic and benthonic foraminifera in the upper part of the 'upper unit' of the Shiranish Formation. The possible cause for the disappearance of all foraminifera might be indicated by the presence of a massive bed of marly limestone in the Dokan section that is about 1 m thick, bearing a mass of shallow marine rudist bivalves near the contact with the overlying Tanjero Formation.

Sample imaging and repositories

A number of specimens were selected and coated with gold aluminium alloy (Emitech K500X) and imaged with the scanning electron microscope Hitachi S-3600N at the University of Leicester, UK. The specimens illustrated in this chapter are deposited in the collections of the British Geological Survey, Keyworth, Nottingham, UK.

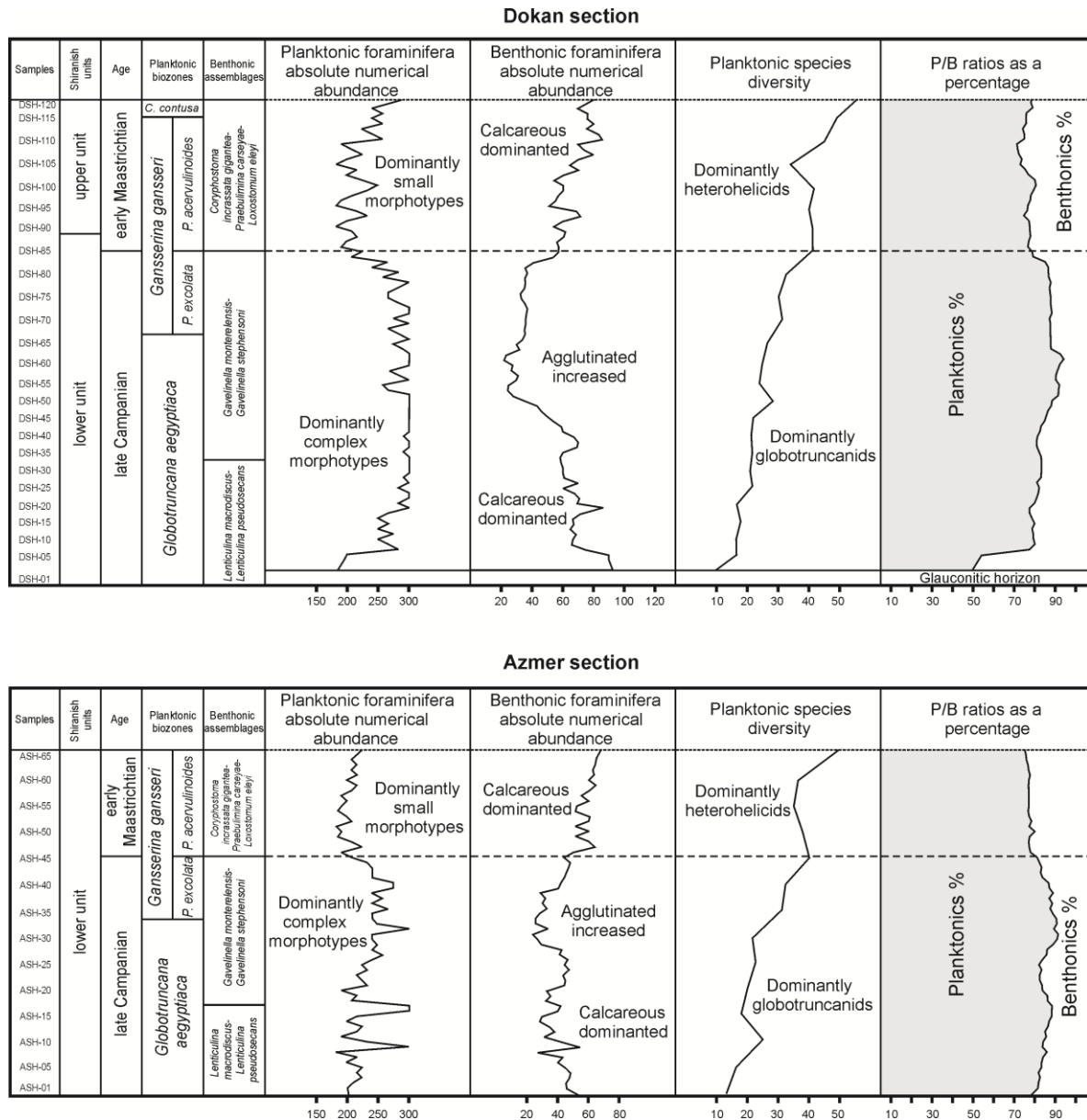


Figure 5.2. Trends of foraminiferal numerical abundance, planktonic foraminiferal species diversity and planktonic/benthonic ratios for the Shiranish Formation in the Dokan and Azmer sections, NE Iraq. Planktonic foraminiferal biozones and subzones follow Jaff *et al.* (in press). Absolute abundances are given relative to 10 g of sediment analysed. The glauconitic horizon at the base of the Dokan section bears no foraminifera. The upper unit of the Shiranish Formation in the Azmer section yielded no foraminifera and is omitted from the chart.

Benthonic foraminiferal assemblages

Jaff *et al.* (2014) demonstrated that the Late Cretaceous succession of northeastern Iraq can be subdivided into a series of biozones based on the distribution of members of the benthonic foraminiferal genus *Bolivinoides*. Superimposed on this biostratigraphical scheme are temporally distinct benthonic foraminiferal assemblages that are interpreted to reflect environmental change, principally in palaeodepth. Based on the occurrences of key benthonic foraminifera relative to a succession of prevailing lithofacies and the abundance of associated planktonic foraminifera, three stratigraphically discrete faunal assemblages have been identified in the Dokan and Azmer successions.

- 1- *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage (late Campanian, equivalent to the lower and upper parts of the *Bolivinoides decoratus* Subzone within the *Bolivinoides decoratus* benthonic foraminiferal biozone; Fig. 5.3).
- 2- *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage (late to latest Campanian, equivalent to the uppermost part of the *Bolivinoides decoratus* and *B. laevigatus* subzones within the *Bolivinoides decoratus* benthonic foraminiferal biozone; Fig. 5.3).
- 3- *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage (early Maastrichtian, equivalent to the *Bolivinoides miliaris* and *B. draco* benthonic foraminiferal biozones; Fig. 5.3).

***Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage**

This assemblage is marked by the dominance of *Lenticulina pseudosecans* and *L. macrodiscus* in both sections. *Lenticulina pseudosecans* is more common than *L. macrodiscus* and together they form about 15% of the total benthonic foraminiferal assemblage per 10 g of sediment sample. This assemblage occupies some 58 m and 25.5 m of the 'lower unit' of the Shiranish Formation in the Dokan and the Azmer sections respectively (late Campanian, see Fig. 5.4). Lithologically, this interval of the Shiranish Formation consists mainly of alternating light grey, medium to thick-bedded indurated marly limestone with thin, softer and darker limey marlstone beds. The interval of this assemblage are characterised by species of *Dentalina*, *Fissurina*, *Laevidentalina*, *Nodosarella*, *Nodosaria* and *Pleurostomella* with limited occurrences of species of

Gavelinella, *Gyroidinoides* and *Neoflabellina* (Figs 5.5, 5.6). The abundance of most of the species of *Dentalina*, *Laevidentalina*, *Lenticulina* and *Nodosarella* decreases towards the top of this assemblage (Figs 5.5, 5.6). However, some agglutinated species of the genera *Bathysiphon*, *Dorothia*, *Gaudryina* and *Verneuilinga* appear for the first time (Figs 5.5, 5.6).

***Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage**

This assemblage is marked by the dominance of both *Gavelinella monterelensis* and *G. stephensoni* in both the Azmer and Dokan sections. *Gavelinella monterelensis* is the most abundant species and forms about 15% of the total benthonic foraminiferal assemblage per 10 g of sediment sample. The *Gavelinella monterelensis*-*Gavelinella stephensoni* assemblage occupies some 100.5 m and 39.5 m of the ‘lower unit’ of the Shiranish Formation in the Dokan and the Azmer sections respectively (late to latest Campanian, Fig. 5.4). Lithologically, this interval of the Shiranish Formation consists chiefly of alternating light grey, thin to thick-bedded marly limestone with thin, softer and darker limey marlstone beds. This assemblage contains the maximum diversity and abundance of deep-water agglutinated species of the genera *Ammodiscus*, *Bathysiphon*, *Clavulinoides*, *Dorothia*, *Gaudryina*, *Glomospira*, *Marssonella*, *Pseudoclavulina*, *Tritaxia* and *Verneuilinga* (Figs 5.5, 5.6). The abundance and diversity of deep-water agglutinated species dramatically decrease towards the top of this assemblage.

***Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage**

This assemblage is marked by the dominance of *Coryphostoma incrassata gigantea*, *Praebulimina carseyae* and *Loxostomum eleyi* in both the Azmer and Dokan sections. Together they form about 25% of the total benthonic foraminiferal assemblage per 10 g of sediment sample. This assemblage occupies approximately 74.5 m and 26 m of the ‘lower unit’ and the ‘upper unit’ of the Shiranish Formation in the Dokan and the Azmer sections respectively (early Maastrichtian, see Fig. 5.4). Lithologically, this interval of the Shiranish Formation is mainly represented by thick succession of thin-bedded blue marlstone, occasionally alternated with light grey, thin-bedded indurated marly limestone. In both sections the author takes the first appearance datum of the benthonic foraminifer

Coryphostoma incrassata gigantea to define the Campanian-Maastrichtian boundary (Al-Shaibani 1971, 1973). This coincides with the first appearance datum of 5-lobed representatives of the genus *Bolivinooides*, which defines the Campanian-Maastrichtian boundary at the Global Stratotype Section and Point (GSSP) at Tercis, southwestern France (Odin & Lamaurelle 2001) as well as in NE Iraq (Jaff *et al.* 2014). Towards the top of this assemblage, the abundance of both *Coryphostoma incrassata gigantea* and *Loxostomum eleyi* gradually increase, while the abundance of *Praebulimina carseyae* decreases. In addition, this interval of the Shiranish Formation is also characterised by the common intermittent occurrence of species of *Fissurina*, *Lagena* and *Oolina* with rare intermittent occurrence of the agglutinated species of the genus *Dorothia*, *Quasispiroplectammina* and *Spiroplectammina*.

Age		Planktonic foraminiferal biozones		Bolivinoïdes biozones		Environmentally controlled benthonic foraminiferal assemblages			
		NE Iraq, Jaff <i>et al.</i> (in review)		NE Iraq, Jaff <i>et al.</i> (2014)		NE Iraq, This study		Sinai, Egypt, Khalil 1998	
Maastrichtian	late							<i>Praebulimina-Corphostoma-Stensioina</i>	
	early	<i>Contusotruncana contusa</i>		<i>Bolivinoïdes draco</i>		<i>Coryphostoma incrassata gigantea-Praebulimina carseyae-Loxostomum eleyi</i>		<i>Spiroplectammina knebeli</i>	
<i>Gansserina gansseri</i>		<i>Planoglobulina acervulinoides</i>	<i>Bolivinoïdes miliaris</i>						
<i>Pseudoguembelina excolata</i>		<i>Globotruncana aegyptiaca</i>	<i>Bolivinoïdes decoratus</i>	<i>B.laevigatus</i>	<i>Gavelinella monterelensis-Gavelinella stephensoni</i>	<i>Vaginulinopsis directa-Lenticulina pseudosecans</i>			
Campanian	late			<i>B.decoratus</i>	<i>Lenticulina macrodiscus-Lenticulina pseudosecans</i>				

Interval not studied

Gap

Figure 5.3. Late Cretaceous depth related benthonic foraminiferal assemblages in NE Iraq and comparable units in Sinai, Egypt. The assemblages are correlated with the foraminiferal biozonation in the Iraqi succession: the correlation is tentative for Sinai, hence dotted lines.

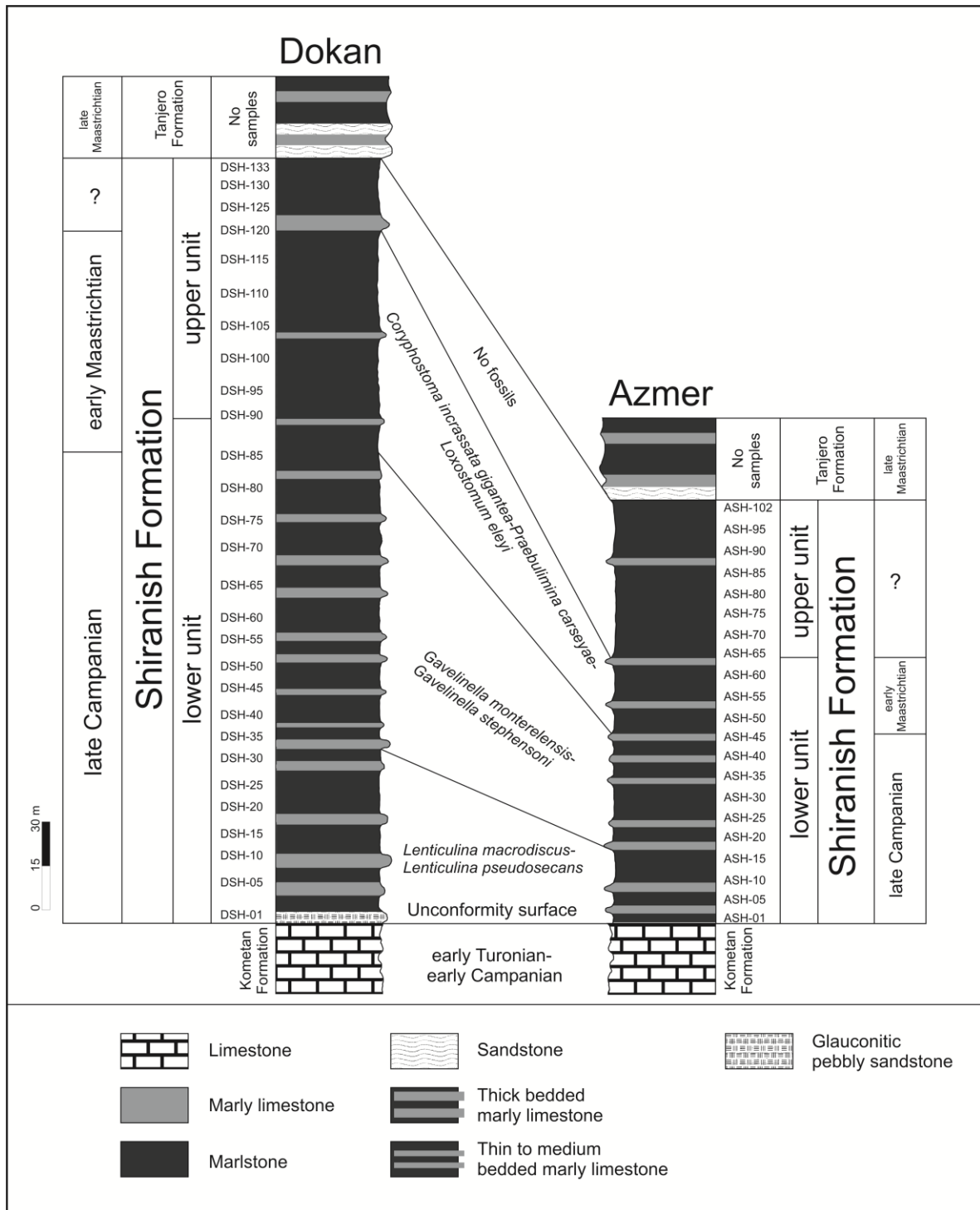


Figure 5.4. Benthonic foraminiferal assemblages for the Shiranish Formation in the Kurdistan region, NE Iraq as they equate to the lithostratigraphy. The first appearance datum of *Coryphostoma incrassata gigantea* marks the Campanian-Maastrichtian boundary in this study.

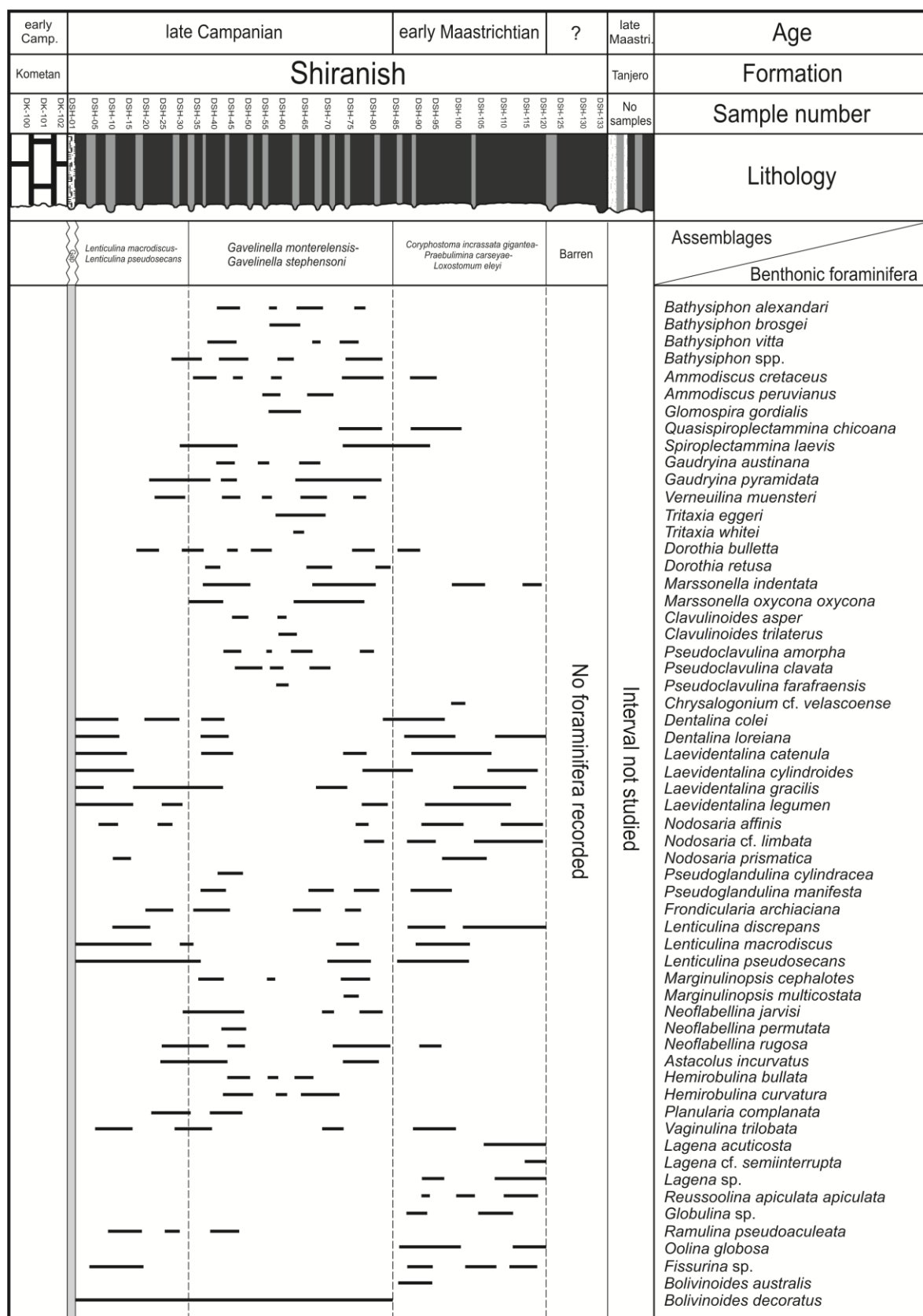


Figure 5.5. continued

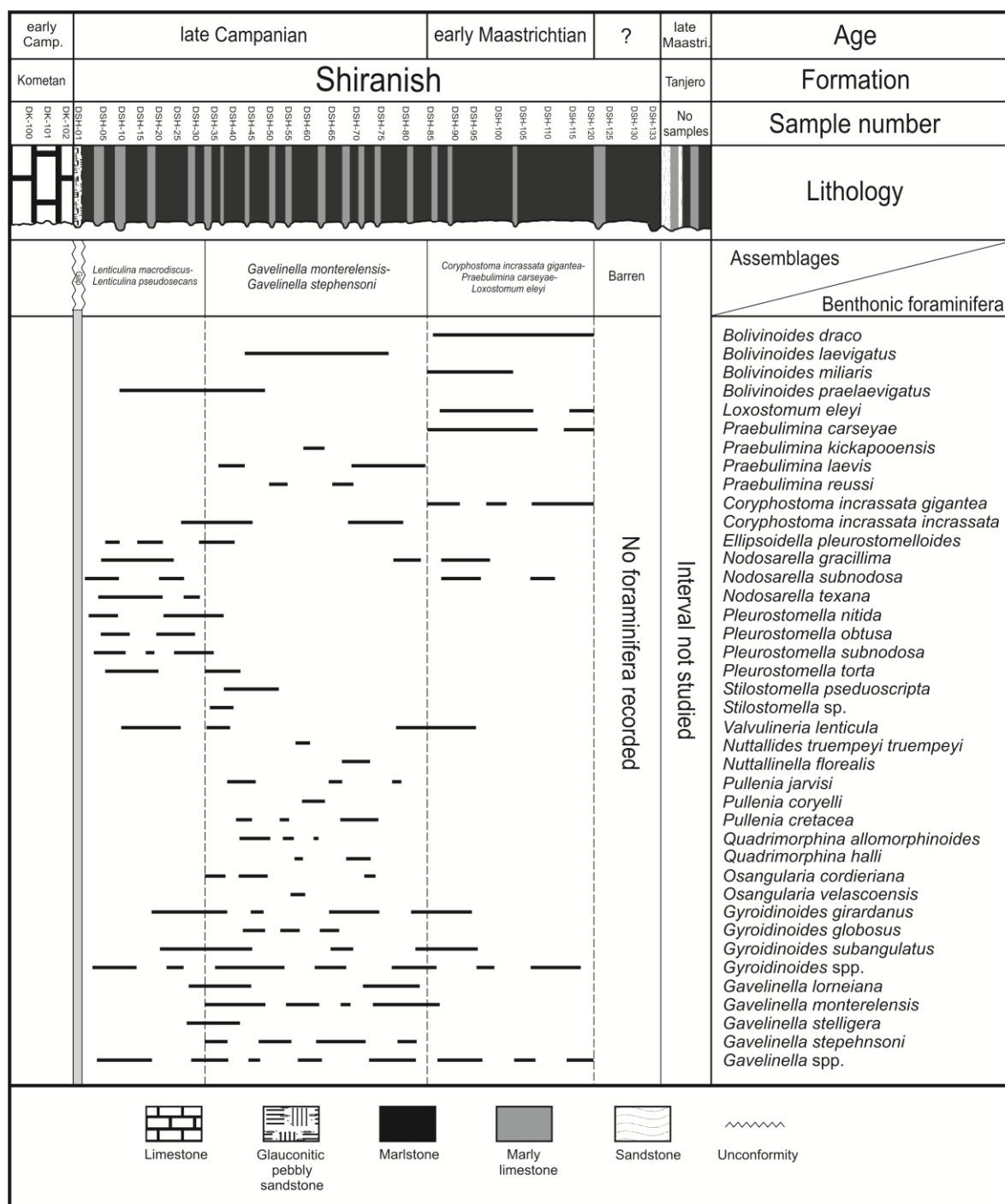


Figure 5.5. Distribution of benthonic foraminifera for the late Campanian-early Maastrichtian Shiranish Formation in the Dokan section. Taxa are arranged systematically by families following Loeblich & Tappan (1988) and Bolli *et al.* (1994).

early Campanian	late Campanian	early Maastrichtian	?	late Maastrichtian	Age
Kometan	Shiranish			Tanjero	Formation
AK-64	AK-67	AK-68	AK-69	AK-70	Sample number
Lithology					
Assemblages					
Benthonic foraminifera					
Lenticulina macrodiscus-Lenticulina pseudosecans Gavelinella monterelensis-Gavelinella stephensoni Coryphostoma incrassata gigantea-Præbulimina carseyae-Loxostomum eleyi Barren					No foraminifera recorded Interval not studied
					Bathysiphon dubia Bathysiphon vitta Bathysiphon spp. Ammodiscus cretaceus Ammodiscus peruvianus Glomospira gordialis Glomospira sp. Spiroplectammina laevis Vulvulina cf. colei Gaudryina austinana Gaudryina pyramidata Gaudryina spp. Verneuilina muensteri Tritaxia eggeri Tritaxia whitei Dorothia bulletha Dorothia retusa Marssonella indentata Marssonella oxycona oxycona Clavulinoides asper Clavulinoides trilaterus Pseudoclavulina clavata Dentalina granti Dentalina oligostegia Laevidentalina communis Laevidentalina cylindroides Laevidentalina gracilis Laevidentalina legumen Nodosaria limbata Pseudoglandulina manifesta Lingulina pymaea Lingulina taylorana Fronicularia striatula Lenticulina macrodiscus Lenticulina pseudosecans Lenticulina rotulata Lenticulina spissocostata Marginulinopsis cephalotes Marginulinopsis multicostata Marginulinopsis praetschoppi Neoflabellina jarvisi Neoflabellina numismalis Neoflabellina rugosa Neoflabellina spp. Astacolus incurvatus Hemirobulina bullata Hemirobulina cf. tripleura Hemirobulina texasensis Planularia liebusi Vaginulina trilobata Lagena semilineata Lagena sp. Reussoolina apiculata apiculata Ramulina pseudoaculeata Oolina globosa Fissurina sp. Bolivinooides australis Bolivinooides decoratus Bolivinooides laevigatus Bolivinooides miliaris Loxostomum eleyi

Figure 5.6. continued

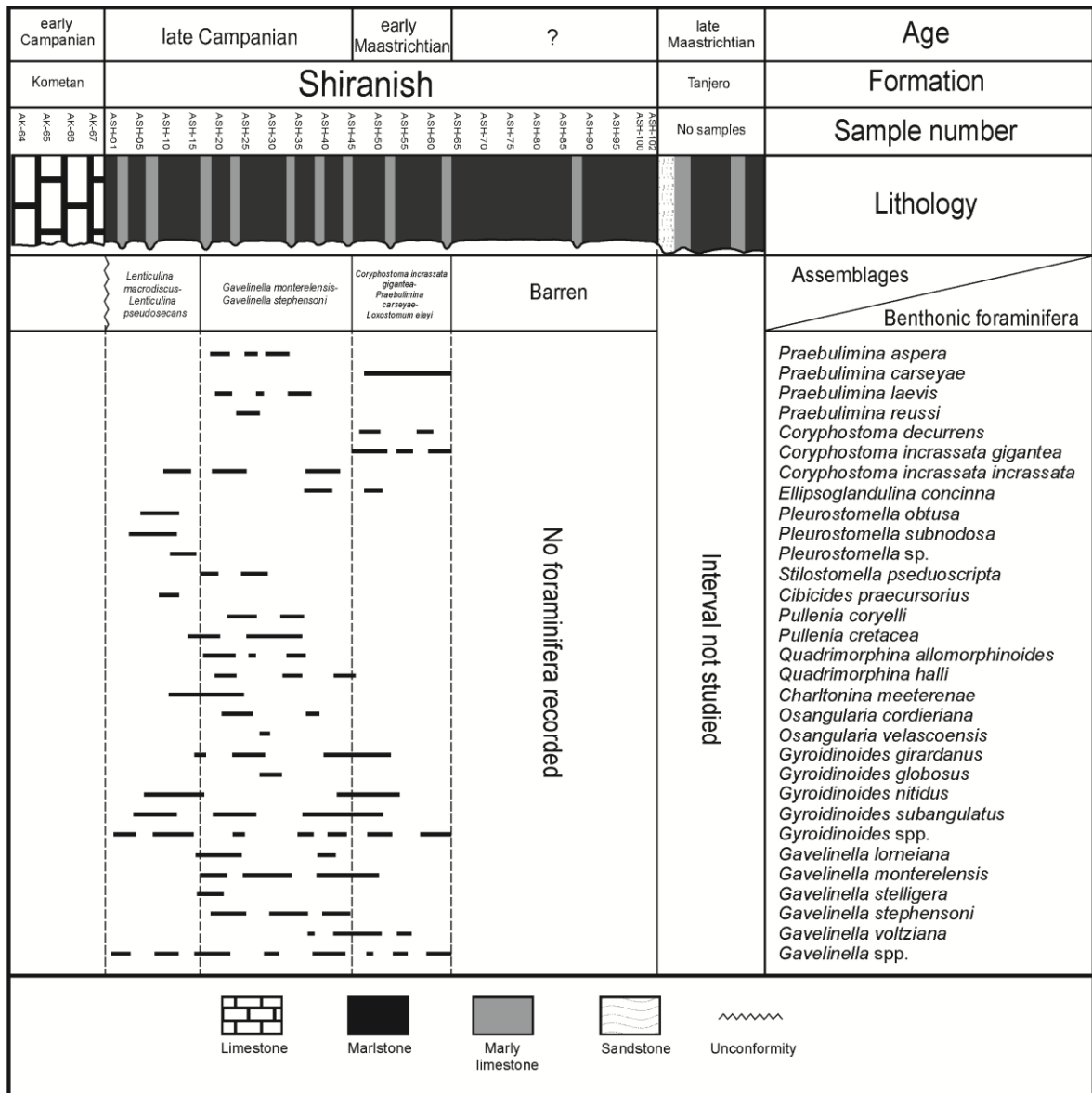


Figure 5.6. Distribution of benthonic foraminifera for the late Campanian-early Maastrichtian Shiranish Formation in the Azmer section. Taxa are arranged systematically by families following Loeblich & Tappan (1988) and Bolli *et al.* (1994).

Palaeoenvironmental interpretations

The Shiranish Formation has been classically interpreted as a succession of deep-water deposits (Kassab 1972, 1973; Al-Shaibani 1973; El-Anbaawy & Sadek 1979; Abawi *et al.* 1982; Kettaneh & Sadik 1989; Al-Qayim 1992; Al-Banna 2010). The formation is typically poor in macrofauna in NE Iraq. It represents neritic sedimentary deposits, with foraminiferal faunas dominated by planktonic foraminifera.

The palaeo-depths indicated by the benthonic foraminiferal faunas are clearly of importance for the interpretation of the environment of deposition (Culver 1988; Alegret *et al.* 2001). For the analysis of palaeodepth, trends of characteristics such as: 1) planktonic species abundance and diversity; 2) planktonic/benthonic ratios; 3) benthonic foraminiferal distribution and abundance; and 4) environmental evidence from lithofacies and associated fauna are utilised. Collectively these have great value in the interpretation of both palaeoecology and palaeobathymetry.

Planktonic species abundance and diversity

Many authors have noted that Cretaceous planktonic foraminifera occupied different levels in the water column (Frerichs 1971; Sliter 1972b; Hart 1980; Nyong & Olsson 1984; Van der Zwaan *et al.* 1990; Petrizzo 2002; Abramovich *et al.* 2003, 2011; Keller 2004; Falzoni *et al.* 2013; Jaff *et al.* in press) and that their abundance and diversity increases from shallower to deeper water across shelf sea areas. Planktonic foraminifera are abundant and diverse in the *Lenticulina macrodiscus*-*Lenticulina pseudosecans* and *Gavelinella monterelensis*-*Gavelinella stephensoni* assemblages in both the Dokan and Azmer sections (Fig. 5.2). Overall species diversity is high (total number of species is 51), with globotruncanids being the most abundant taxa (from 38% to 72% of specimens per sampled horizon; see Fig. 2.13 in Chapter 2 for more details). These assemblages, which are represented in the ‘lower unit’ of the Shiranish Formation in both sections, signal deep water settings, probably of the distal shelf.

In the *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage that occurs in the uppermost part of the ‘lower unit’ in the Azmer section and ‘upper unit’ of the Shiranish Formation in the Dokan section (see Fig. 5.4), the abundance of globotruncanids noticeably decreases (25% to 49% of specimens recovered from samples; see Fig. 2.13 in Chapter 2 for more details). Conversely, the most abundant taxa in this interval are simple morphotypes such as *Heterohelix* and *Laeviheterohelix* (typically 27% to 60% of specimens, see Fig. 2.13 in Chapter 2 for more details). This change signals a shift to shallower marine facies.

Planktonic/Benthonic ratio

Modern studies on recent foraminifera illustrate that planktonic/benthonic (P/B) ratios are lowest in shallower water and normally increase with water depth until the calcium carbonate dissolution depth of *ca* 4000 m is reached. Nyong & Olsson (1984) and Culver (1988) based on fossil foraminifera assemblages noticed that the outer shelf (depths of 100-200 m) is characterised by 55-65% planktonic foraminifera, the upper slope (depth 300-500 m) by more than 75%, whilst a middle slope depth of at least 600 m is characterised by 90% planktonics and a slight increase in diversity of agglutinated benthonic forms.

The P/B ratios in the *Lenticulina macrodiscus-Lenticulina pseudosecans* Assemblage show values of 78 to 84% and 80 to 88% in the Dokan and the Azmer sections respectively (Fig. 5.2). Most of the recorded benthonic foraminifera in this interval indicate outer shelf and upper slope depositional settings (see below). Towards the middle part of the *Gavelinella monterelensis-Gavelinella stephensoni* Assemblage, P/B ratios reach a value of 93% in the Dokan section, and 91% in the Azmer section (Fig. 5.2). Most of the recorded benthonic foraminifera belong to deep calcareous and agglutinated forms, which suggest that water depth had increased relative to the lower part of the interval.

A decrease in the P/B ratios is indicated in the *Coryphostoma incrassata gigantea-Praebulimina carseyae-Loxostomum eleyi* Assemblage. Most values are between 72 and 75% in both sections (Fig. 5.2). The benthonic foraminifera in this part of the Shiranish Formation are dominated by species that mostly indicate outer shelf depositional settings. In conjunction with findings from the analysis of the planktonic foraminifera noted above (see also Chapter 2), this suggests that the ‘upper unit’ of the Shiranish Formation was deposited in a shallower marine setting compared to the ‘lower unit’.

Benthonic foraminiferal distribution and abundance in relation to palaeodepth

Benthonic foraminiferal abundance is important for determining palaeoenvironment as some species can be directly related to palaeo-water depths and can be used to define the palaeobathymetry (e.g. Culver 1988). Detailed studies have established typical depth ranges for various taxa (see table 5.1).

In the late Campanian within the *Lenticulina macrodiscus-Lenticulina pseudosecans* Assemblage, the most common benthonic foraminiferal species are of the genera

Lenticulina and *Laevidentalina* which represent about 20% and 18% of the total benthonic foraminiferal fauna per 10 g of sediment sample respectively. The abundance of *Lenticulina* and *Laevidentalina* species decreases dramatically toward the *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage. The abundant occurrence of species of *Lenticulina* and *Laevidentalina* in addition to the common occurrence of species of *Dentalina* and *Pleurostomella* in the lower part of this assemblage might indicate an outer shelf (200 m water depth) depositional setting (Sliter 1972a; Sliter & Baker 1972; see Fig. 5.7). Toward the upper part of this assemblage the first appearance of rare agglutinated species of *Bathysiphon*, *Dorothia*, *Gaudryina* and *Verneuilinga* might indicate a slight increase in water depth.

In the late to latest Campanian within the *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, the most common benthonic foraminiferal species are of *Gavelinella* and *Gyroidinoides* representing about 25% and 18% of the total benthonic foraminiferal fauna per 10 g of sediment sample respectively. Agglutinated benthonic foraminifer species of *Ammodiscus*, *Bathysiphon*, *Clavulinoides*, *Dorothia*, *Gaudryina*, *Glomospira*, *Pseudoclavulina*, *Tritaxia* and *Verneuilinga* form about 26% of the total benthonic foraminiferal fauna, but most of these taxa disappear in the uppermost part of the assemblage. The co-occurrence of the deep calcareous species of *Gavelinella*, *Gyroidinoides*, *Neoflabellina*, *Osangularia*, *Praebulimina*, *Pullenia* and *Quadrinorina* with the above mentioned agglutinated forms might indicate upper and middle slope depositional settings (Sliter 1972a; Sliter & Baker 1972; see Fig. 5.7). The upper slope (300 to 500 m water depth) is indicated for the lower and upper parts of the *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage by the appearance of *Bathysiphon vitta*, *Coryphostoma incrassata*, *Gaudryina pyramidata*, *Marssonella oxycona*, *Nuttallinella florealis* and *Osangularia cordieriana* (Sliter & Baker 1972; Olsson & Nyong 1984; Nyong & Olsson 1984; Van Morkhoven *et al.* 1986; Widmark & Speijer 1997; Alegret *et al.* 2002; see Table 5.1). The middle slope (at least 600 m water depth) is indicated for the middle part of the *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage of the Shiranish Formation in both localities. The depth-dependent benthonic foraminiferal species in this interval include *Clavulinoides trilaterus*, *Gyroidinoides globosus*, *Hemirobulina bullata*, *Nuttallides truempyi*, *Osangularia velascoensis*,

Pullenia coryelli and *Pseudoclavulina amorphia* (Sliter & Baker 1972; Vincent *et al.* 1974; Berggren & Aubert 1975; Tjalsma & Lohmann 1983; Olsson & Nyong 1984; Van Morkhoven *et al.* 1986; Speijer 1994; Widmark 2000; Alegret & Thomas 2001; Alegret *et al.* 2002; see Table 5.1). In the *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, the size of some species of *Bathysiphon*, *Clavulinoides*, *Dorothia*, *Gaudryina* and *Tritaxia* reach nearly 1 mm in length. According to Sliter & Baker (1972) the Cretaceous species increase in size with increasing water depth from shelf to slope assemblages.

In the early Maastrichtian within the *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, the most common benthonic foraminiferal species are of *Coryphostoma*, *Praebulimina* and *Loxostomum*. Together they form about 27% of the total benthonic foraminiferal fauna per 10 g of sediment sample. Species of *Fissurina*, *Lagena*, *Oolina* and *Reussolina* are also common but they appear intermittently. The co-occurrence of species of *Coryphostoma*, *Fissurina*, *Lagena*, *Loxostomum*, *Oolina* and *Reussolina* in this assemblage might indicate an outer shelf (200 m water depth) depositional environment (Sliter 1972a; Sliter & Baker 1972; see Fig. 5.7). In this interval, the depth-dependent benthonic foraminiferal species are *Praebulimina carseyae*, *Loxostomum eleyi*, *Coryphostoma incrassata gigantea* and *Lenticulina spissocostata* (Sliter & Baker 1972; MacNeil & Caldwell 1981; Olsson & Nyong 1984; Nyong & Olsson 1984; McDougall 1987; Widmark & Speijer 1997; Alegret *et al.* 2001, 2002; see Table 5.1).

The maximum water depths can be interpreted for the foraminiferal assemblage of the late Campanian within the *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, followed by shallowing upwards into the early Maastrichtian. Therefore, there is a consistent pattern of deep water settings interpreted for the 'lower unit', followed by shallowing interpreted for the 'upper unit', that is indicated by the patterns of planktonic and benthonic foraminiferal abundance and taxa.

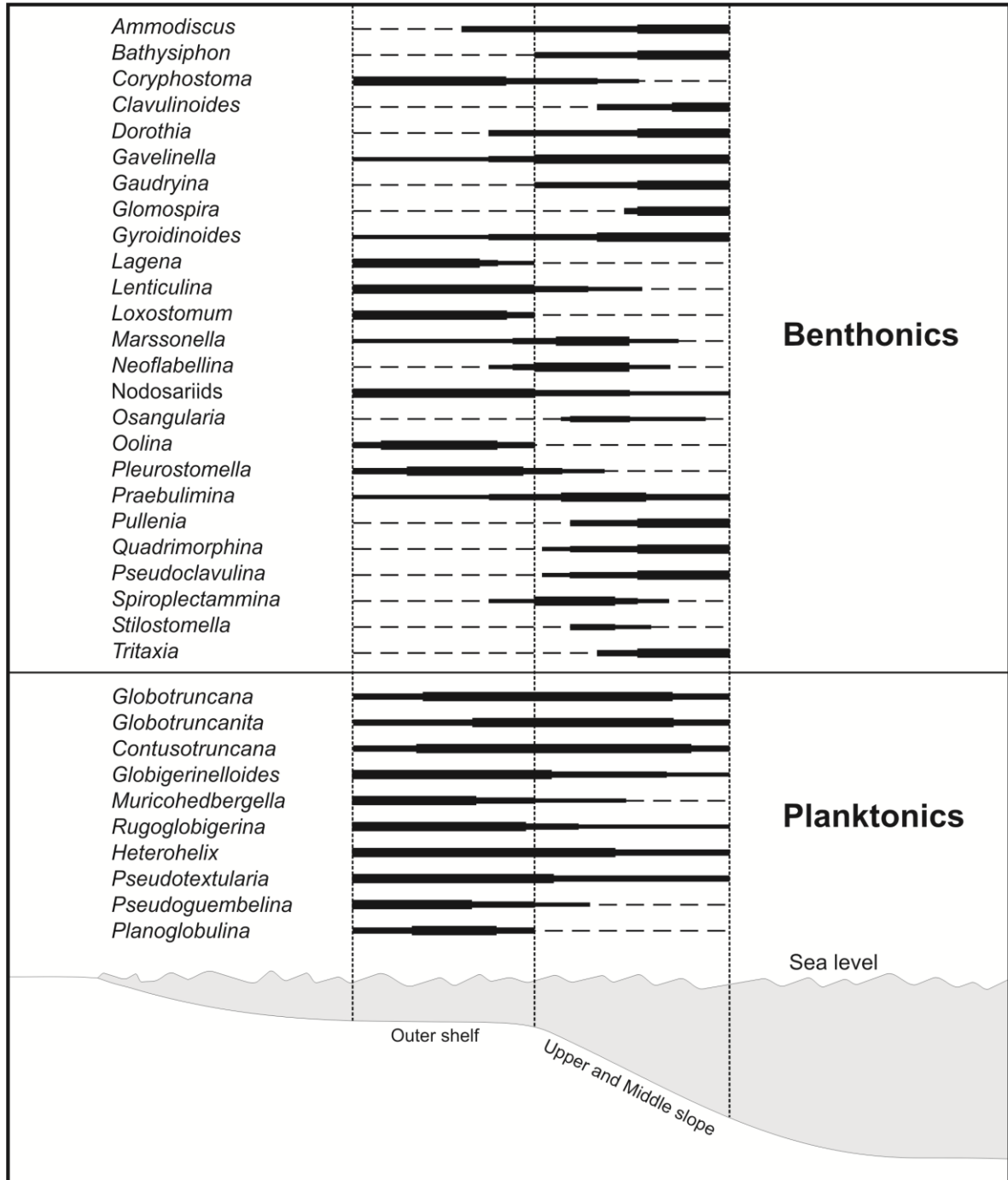


Figure 5.7. Suggested distribution patterns of Late Cretaceous planktonic and key benthonic foraminifers from NE Iraq (plotted for genera). Thickness of bars is proportional to abundance.

Depth-related species	Upper-depth limit	Common distribution
<i>Bathysiphon vitta</i> Nauss	-----	Upper-middle bathyal (9)
<i>Clavulinoides trilaterus</i> (Cushman)	-----	Bathyal and abyssal (5); lower bathyal-abyssal (1, 3); middle shelf (8, 10)
<i>Coryphostoma incrassata</i> (Reuss)	-----	Outer neritic and bathyal (1); upper-middle upper-middle bathyal (9)
<i>Coryphostoma incrassata gigantea</i> (Wicher)	-----	Netritic-upper bathyal (6); most common upper-middle bathyal, less common lower bathyal (6); outer shelf (9, 10)
<i>Gaudryina pyramidata</i> Cushman	200-300 m (1)	Bathyal-abyssal (5); lower bathyal and abyssal (3); upper-middle bathyal, less common lower bathyal (6)
<i>Gyroidinoides globosus</i> (Hagenow)	200-300 m (2)	Middle bathyal-abyssal (3); middle bathyal (10), upper bathyal (8)
<i>Gyroidinoides nitidus</i> (Reuss)	-----	Upper-middle bathyal (8); Outer shelf (9, 10)
<i>Gavelinella stephensoni</i> (Cushman)	-----	Upper-middle bathyal (9)
<i>Hemirobulina bullata</i> (Reuss)	-----	Middle-lower bathyal (9)
<i>Lenticulina spissocostata</i> (Cushman)	-----	Most common shelf (11)
<i>Loxostomum eleyi</i> (Cushman)	100-250 m (8)	Outer shelf (7); outer shelf-upper bathyal (10)
<i>Marssonella oxycona oxycona</i> (Reuss)	500-1500 m (8)	Upper bathyal (1, 8, 10)
<i>Nuttallides truempyi truempyi</i> (Nuttall)	500-700 m (1, 2)	Bathyal and abyssal (5); middle-lower bathyal and abyssal (1, 2, 3, 4); upper-middle bathyal (11)
<i>Nuttallinella florealis</i> (White)	-----	Bathyal and abyssal (1, 5)
<i>Osangularia cordieriana</i> (d'Ordigny)	-----	Most common upper-middle bathyal (8, 10)
<i>Osangularia velascoensis</i> (Cushman)	-----	Most common upper-middle bathyal (1, 11); lower bathyal-abyssal (3)
<i>Praebulimina aspera</i> Cushman and Parker	-----	Most common outer shelf, less common middle shelf (10)
<i>Praebulimina carseyae</i> (Plummer)	100-200 m (8, 9, 10)	Most common outer shelf (8, 9, 10); less common middle shelf (10)
<i>Praebulimina reussi</i> (Morrow)	500-1500 m (8)	Bathyal to abyssal (6)
<i>Pullenia coryelli</i> White	-----	bathyal to abyssal (1, 3); most common lower bathyal (1)

(1) Van Morkhoven *et al.* (1986); (2) Speijer (1994); (3) Tjalsma & Lohmann (1983); (4) Widmark (2000); (5) Berggren & Aubert (1975); (6) Widmark & Speijer (1997); (7) MacNeil & Caldwell (1981); (8) Nyong & Olsson (1984); (9) Sliter & Baker (1972); (10) Olsson & Nyong (1984); (11) Alegret *et al.* (2002).

Table 5.1. Upper depth limits and palaeobathymetric distribution of Late Cretaceous benthonic foraminifera.

Environmental evidence from lithofacies and associated fauna

Although the Shiranish Formation has been subdivided into three lithological units in the NW of Iraq, the ‘middle’ lithofacies unit recognised by Al-Qayim *et al.* (1986) is not encountered in the NE region and is not considered here. In NE Iraq, the Shiranish Formation comprises of only two units. The ‘lower unit’ equivalent to *Lenticulina macrodiscus*-*Lenticulina pseudosecans* and *Gavelinella monterelensis*-*Gavelinella stephensoni* assemblages consists mainly of alternating light grey, medium to thick-bedded indurated marly limestone with thin, softer and darker limey marlstone beds. It is characterised by abundant planktonic foraminifera in a dominantly calcareous micritic matrix, and benthonic foraminifera comprise calcareous and agglutinated taxa suggesting an outer shelf to slope depositional setting. Associated organisms include rare ostracodes, echinoids and some radiolarians. The abundance of planktonic foraminifera and micrite suggests deposition in quiet, fairly deep water conditions. The mineralogical and geochemical study of the Shiranish Formation by Kettaneh & Sadik (1989) suggests that the ‘lower unit’ is dominated by calcite, glauconite, and clay minerals such as illite. The occurrence of glauconite and illite may indicate prevalence of reducing conditions in a quiescent marine environment (El-Anbaawy & Sadek 1979; Kettaneh & Sadik 1989).

The ‘upper unit’ equivalent to the *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage consists of a thick succession of thin-bedded blue marlstone, occasionally alternated with light grey, thin-bedded indurated marly limestone. It differs, however, from the ‘lower unit’ in the greater amount of clay materials and the lower abundance of planktonic to benthonic foraminifera (Fig. 5.2): benthonic foraminifera are mostly represented by forms with a calcareous wall. Very few agglutinated benthonic foraminifera are found in this unit that, together with the dominance of calcareous benthonic faunas, suggests an outer shelf depositional setting. Other associated organisms include ostracodes and echinoids, but no radiolarians. 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. This rudist bed is only locally developed and hence is not recognised as a separate member in the Shiranish Formation. This lithofacies indicates shallowing of the basin at the end of the deposition of the Shiranish Formation near the contact with the overlying Tanjero clastic Formation. In

the 'upper unit' the clay content is higher. Al-Qayim *et al.* (1986) stated that the most probable reason for this is an increase in sedimentation rate and abundance of fine terrigenous influx from the land. According to Kettaneh & Sadik (1989) the most abundant clay mineral in the 'upper unit' is montmorillonite. In addition, chlorite and kaolinite are also present but in minor amounts. According to El-Anbaawy & Sadek (1979) the abundance of montmorillonite with trace amounts of kaolinite may represent deposition in shallow marine conditions of normal salinity, subjected to moderate wave action. Thus the overall sedimentological signal also supports deeper water 'lower unit', followed by shallowing in the 'upper unit' of the Shiranish Formation.

Comparison of environmentally controlled assemblages in NE Iraq with those of Sinai, Egypt

The three benthonic foraminiferal assemblages recognised in NE Iraq can be compared with environmentally controlled benthonic foraminifer assemblages recognised in Sinai, Egypt (Khalil 1998). Although the assemblages in the two regions have different overall compositions, those of Sinai also appear to be influenced by changes in palaeodepth.

In the late Campanian, the *Lenticulina macrodiscus*-*Lenticulina pseudosecans* and the *Gavelinella monterelensis*-*Gavelinella stephensoni* assemblages in NE Iraq can be correlated with the *Vaginulinopsis directa*-*Lenticulina pseudosecans* Assemblage in Sinai, Egypt (Fig. 5.3). In both regions the assemblages are characterised by abundant *Lenticulina* and nodosariids (*Dentalina*, *Laevidentalina* and *Nodosaria*). According to Khalil (1998) in the youngest levels of the *Vaginulinopsis directa*-*Lenticulina pseudosecans* Assemblage the abundance of nodosariids decreases, while only a few *Lenticulina* species extend to a younger level in the Maastrichtian. The same trend of decreasing nodosariids and *Lenticulina* species diversity can be found in NE Iraq in the *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage (late and latest Campanian; see Figs 5.5, 5.6).

In the early Maastrichtian, the *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage in NE Iraq can be compared with the *Spiroplectamina knebeli* Assemblage in Sinai, Egypt (Fig. 5.3). In both regions, the assemblages are characterised by species of *Spiroplectamina*, *Praebulimina* and *Coryphostoma* (Figs 5.5, 5.6). According to Khalil (1998) the maximum distribution of

species of *Gyroidinoides* is recorded in the *Spiroplectammina knebeli* (early Maastrichtian) Assemblage in Sinai, Egypt. However, in NE Iraq, the maximum distribution of *Gyroidinoides* can be found in the older *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage (late to latest Campanian).

According to Khalil (1998) the late Campanian *Vaginulinopsis directa*-*Lenticulina pseudosecans* Assemblage in Sinai, Egypt indicates an outer shelf (200 m water depth) depositional setting. Within the early Maastrichtian *Spiroplectammina knebeli* Assemblage in Sinai, Egypt, an increase in benthonic foraminiferal species diversity and changes in the composition of benthonic foraminiferal assemblages reflects a deeper marine (upper slope 300 to 500 m water depth) depositional setting. A decrease in water depth is indicated by the late Maastrichtian *Praebulimina*, *Coryphostoma*, *Stensioeina* Assemblage in Sinai, Egypt (Fig. 5.3). Thus, the pattern of depth-related foraminiferal assemblages indicates a similar pattern of sea level change in the Late Cretaceous of Egypt and Iraq.

Palaeobathymetric summary

Benthonic foraminiferal assemblages in the Shiranish Formation record a gradual decrease in water depth starting from the latest Campanian. Water depths of about 200 m to more than 600 m are interpreted for the Shiranish Formation in the Dokan and the Azmer sections in NE Iraq. There is a consistent pattern of deep water settings interpreted for the ‘lower unit’ of the Shiranish Formation, followed by shallowing interpreted for the ‘upper unit’, that is indicated by the patterns of planktonic species abundance and diversity, planktonic/benthonic ratio, benthonic foraminiferal distribution and abundance in relation to palaeodepth and evidence from lithofacies and associated fauna.

The faunal differences between the late Campanian and early Maastrichtian succession of the Shiranish Formation are thought to reflect variation in palaeobathymetry in the depositional environment as well as variation in the oxygen content of the water and the influx of organic material to the slope basin deposits (see Chapter 2 for more details). The gradual decrease in water depth interpreted for the Shiranish Formation in NE Iraq seems primarily related to the closure of the southern Neo-Tethys Ocean in the Eastern Arabian Plate during the latest Campanian and Maastrichtian (for more details see Jassim & Goff 2006; Ibrahim 2009). Moreover, it may also relate to worldwide lowering of sea level

at the end of the Campanian Stage (Sliter & Baker 1972; Haq *et al.* 1987; Barrera 1994; Huber *et al.* 1995; Barrera *et al.* 1997; Hardenbol *et al.* 1998; Barrera & Savin 1999; Adatte *et al.* 2002).

Conclusions

The Late Cretaceous benthonic foraminifers of the Shiranish Formation in NE Iraq range in age from late Campanian to early Maastrichtian based on co-occurrence with biostratigraphically significant *Bolivinoidea* and planktonic foraminiferal species. The foraminiferal assemblages are interpreted as representing outer shelf to middle slope environments, between ca 200 m to at least 600 m water depth, with maximum water depths in the late Campanian, followed by shallowing into the early Maastrichtian.

In general, benthonic foraminiferal assemblages together with other associated organisms suggest that the sedimentary deposits of the 'lower unit' of the Shiranish Formation were deposited in outer shelf and slope water depths with continuous and gradual deepening of the basin bottom throughout the late Campanian. In the 'lower unit' the common benthonic foraminiferal assemblages are represented by deep calcareous species of *Gavelinella*, *Gyroidinoides*, *Neoflabellina*, *Osangularia*, *Praebulimina* and large agglutinated forms of *Bathysiphon*, *Clavulinoides*, *Dorothia*, *Gaudryina*, *Marssonella*, *Pseudoclavulina* and *Tritaxia*.

The foraminiferal assemblages suggest outer shelf water depths during the deposition of the 'upper unit' of the Shiranish Formation in the early Maastrichtian. In this unit the common benthonic foraminiferal assemblages belong to the species of *Coryphostoma*, *Dentalina*, *Fissurina*, *Laevidentalina*, *Lagena*, *Nodosaria*, *Oolina* and *Reussoolina*. The shallowing up successions in NE Iraq might be primarily related to the closure of southern Neo-Tethys Ocean in the Eastern Arabian Plate starting in the latest Campanian.

Benthonic foraminifera plates

Chapter 5: Palaeoenvironmental signature of the late
Campanian-early Maastrichtian benthonic
foraminiferal assemblages of Kurdistan, northeast Iraq

Plate 1 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Bathysiphonidae, Ammodiscidae, Spiroplectamminidae

- Fig 1: *Bathysiphon alexanderi* Cushman. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14636, Dokan section, sample number DSH-65.
- Figs 2, 3: *Bathysiphon brosegi* Tappan. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 2, MPK14637, Dokan section, sample number DSH-60; Fig. 3, MPK14638, Dokan section, sample number DSH-64.
- Fig 4: *Bathysiphon dubia* (White). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14639, Azmer section, sample number ASH-35.
- Fig 5: *Bathysiphon vitta* Nauss. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14640, Azmer section, sample number ASH-20.
- Figs 6-9: *Bathysiphon* spp. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 6, MPK14641, Azmer section, sample number ASH-30; Fig. 7, MPK14642, Dokan section, sample number DSH-60; Fig. 8, MPK14643, Fig. 9, MPK14644, Dokan section, sample number DSH-64.
- Figs 10, 11: *Ammodiscus cretaceus* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 10, MPK14645, Dokan section, sample number DSH-58; Fig. 11, MPK14646, Azmer section, sample number ASH-40.
- Figs 12, 13: *Ammodiscus peruvianus* Berry. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 12, MPK14647, Dokan section, sample number DSH-58; Fig. 13, MPK14648, Azmer section, sample number ASH-30.
- Figs 14, 15: *Glomospira gordialis* (Jones and Parker). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 14, MPK14649, Dokan section, sample number DSH-58; Fig. 15, MPK14650, Azmer section, sample number ASH-30.
- Fig 16: *Glomospira* sp. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14651, Azmer section, sample number ASH-30.
- Figs 17, 18: *Quasispiroplectamina chicoana* (Lalicker). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 17, MPK14652, Fig. 18, MPK14653, Dokan section, sample number DSH-90.

Fig 19: *Spiroplectammina laevis* (Roemer). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14654, Dokan section, sample number DSH-90.

Plate 1

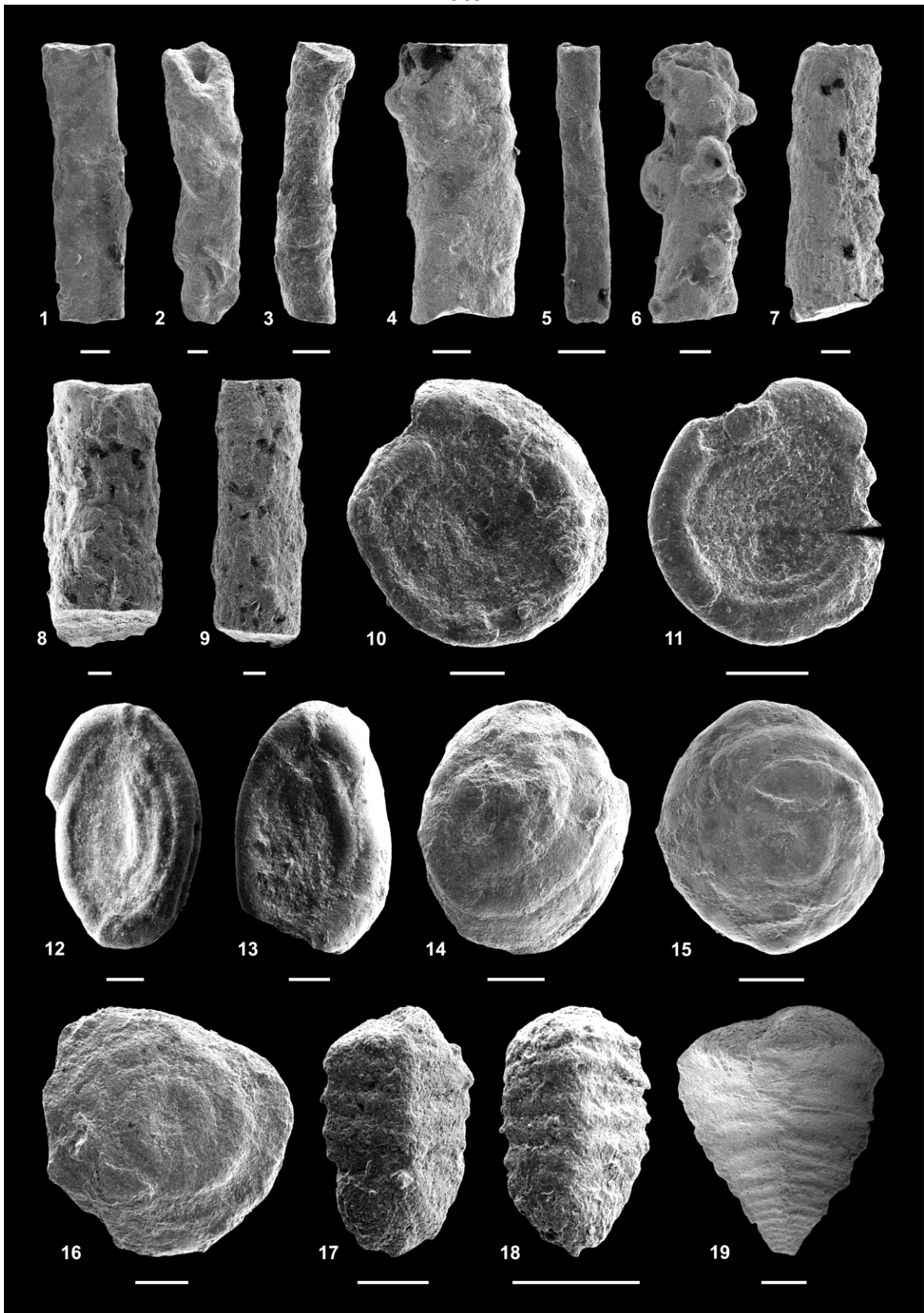


Plate 2 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Spiroplectamminidae, Verneulinidae, Tritaxiidae, Eggerellidae

- Fig 1: *Spiroplectammina laevis* (Roemer). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14655, Azmer section, sample number ASH-40.
- Fig 2: *Vulvulina* cf. *colei* Cushman. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14656, Azmer section, sample number ASH-10.
- Figs 3, 4: *Gaudryina austinana* Cushman. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 3, MPK14657, Dokan section, sample number DSH-45; Fig. 4, MPK14658, Azmer section, sample number ASH-35.
- Figs 5-7: *Gaudryina pyramidata* Cushman. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 5, MPK14659, Azmer section, sample number ASH-40; Fig. 6, MPK14660, Fig. 7, MPK14661, Dokan section, sample number DSH-68.
- Fig 8: *Gaudryina* sp. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14662, Azmer section, sample number ASH-30.
- Figs 9, 10: *Verneulina muensteri* Reuss. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 9, MPK14663, Dokan section, sample number DSH-65; Fig. 10, MPK14664, Azmer section, sample number ASH-30.
- Figs 11-13: *Tritaxia eggeri* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 11, MPK14665, Dokan section, sample number DSH-60; Fig. 12, MPK14666, Fig. 13, MPK14667, Azmer section, sample number ASH-30.
- Figs 14, 15: *Tritaxia whitei* (Cushman and Jarvis). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 14, MPK14668, Dokan section, sample number DSH-60; Fig. 15, MPK14669, Azmer section, sample number ASH-25.
- Figs 16-18: *Dorothia bulletta* (Carsey). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 16, MPK14670, Fig. 17, MPK14671, Dokan section, sample number DSH-45; Fig. 18, MPK14672, Azmer section, sample number ASH-25.

Plate 2

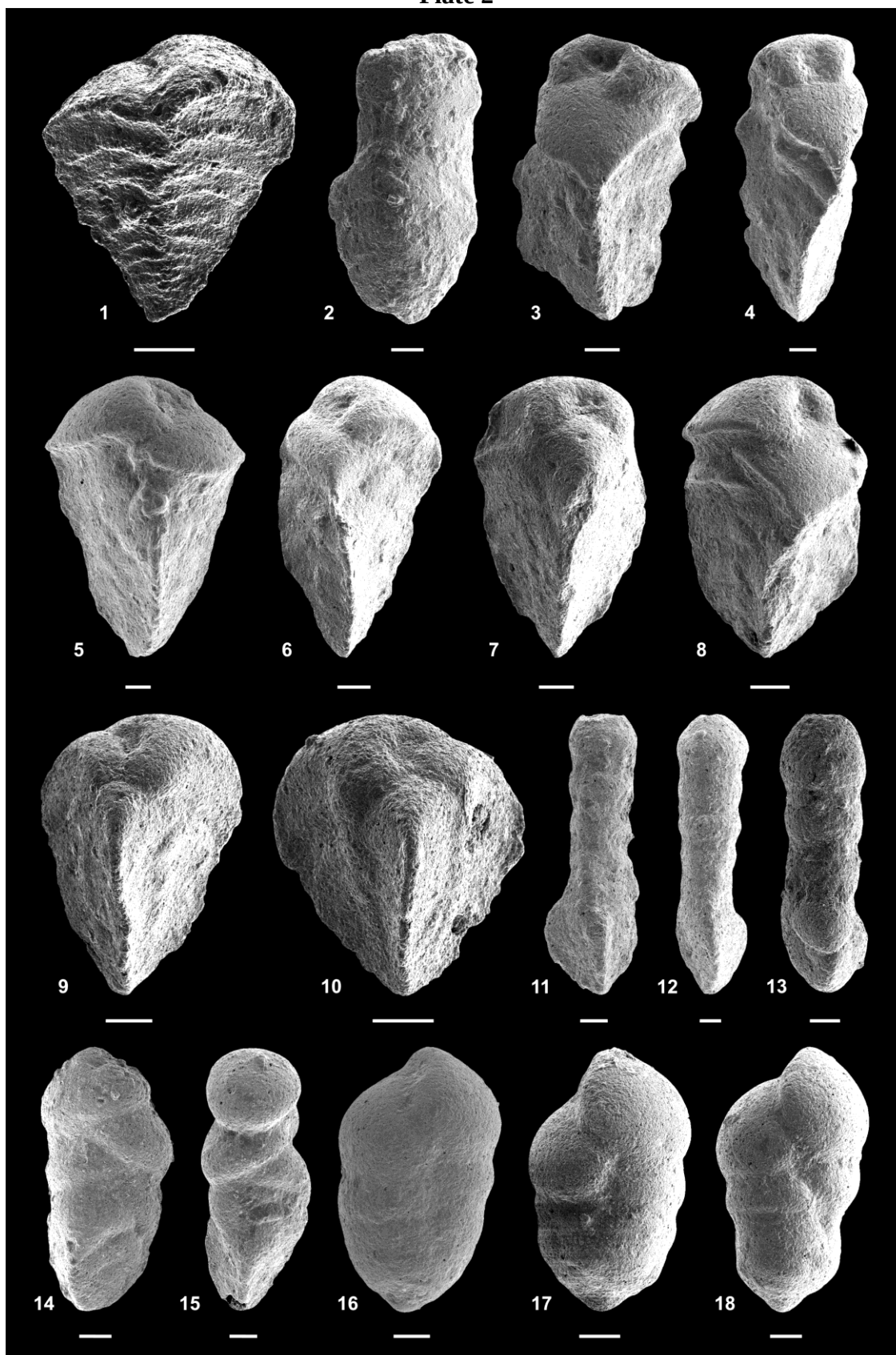


Plate 3 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Eggerellidae, Pseudogaudryinidae, Nodosariidae

- Figs 1-3: *Dorothia retusa* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 1, MPK14673, Dokan section, sample number DSH-40; Fig. 2, MPK14674, Fig. 3, MPK14675, Azmer section, sample number ASH-20.
- Figs 4, 5: *Marssonella oxycona oxycona* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 4, MPK14676, Dokan section, sample number DSH-36; Fig. 5, MPK14677, Azmer section, sample number ASH-25.
- Figs 6, 7: *Marssonella indentata* (Cushman and Jarvis). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* and *Gavelinella monterelensis*-*Gavelinella stephensoni* assemblages, Fig. 6, MPK14678, Dokan section, sample number DSH-40; Fig. 7, MPK14679, Azmer section, sample number ASH-15.
- Figs 8, 9: *Clavulinoides asper* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 8, MPK14680, Dokan section, sample number DSH-60; Fig. 9, MPK14681, Azmer section, sample number ASH-25.
- Figs 10, 11: *Clavulinoides trilaterus* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 10, MPK14682, Dokan section, sample number DSH-60, Fig. 11, MPK14683, Azmer section, sample number ASH-20.
- Fig 12: *Pseudoclavulina amorpha* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14684, Dokan section, sample number DSH-48.
- Figs 13, 14: *Pseudoclavulina clavata* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 13, MPK14685, Dokan section, sample number DSH-60; Fig. 14, MPK14686, Azmer section, sample number ASH-30.
- Fig 15: *Pseudoclavulina farafraensis* LeRoy. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14687, Dokan section, sample number DSH-60.
- Fig 16: *Chrysalogonium* cf. *velascoense* (Cushman). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14688, Dokan section, sample number DSH-100.
- Fig 17: *Dentalina colei* Cushman and Dusenbury. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14689, Dokan section, sample number DSH-05.

Fig 18: *Dentalina granti* (Plummer). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14690, Azmer section, sample number ASH-05.

Fig 19: *Dentalina lorneiana* (d'Orbigny). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14691, Dokan section, sample number DSH-08.

Fig 20: *Dentalina oligostegia* (Reuss). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14692, Azmer section, sample number ASH-10.

Fig 21: *Laevidentalina catenula* (Reuss). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14693, Dokan section, sample number DSH-05.

Plate 3

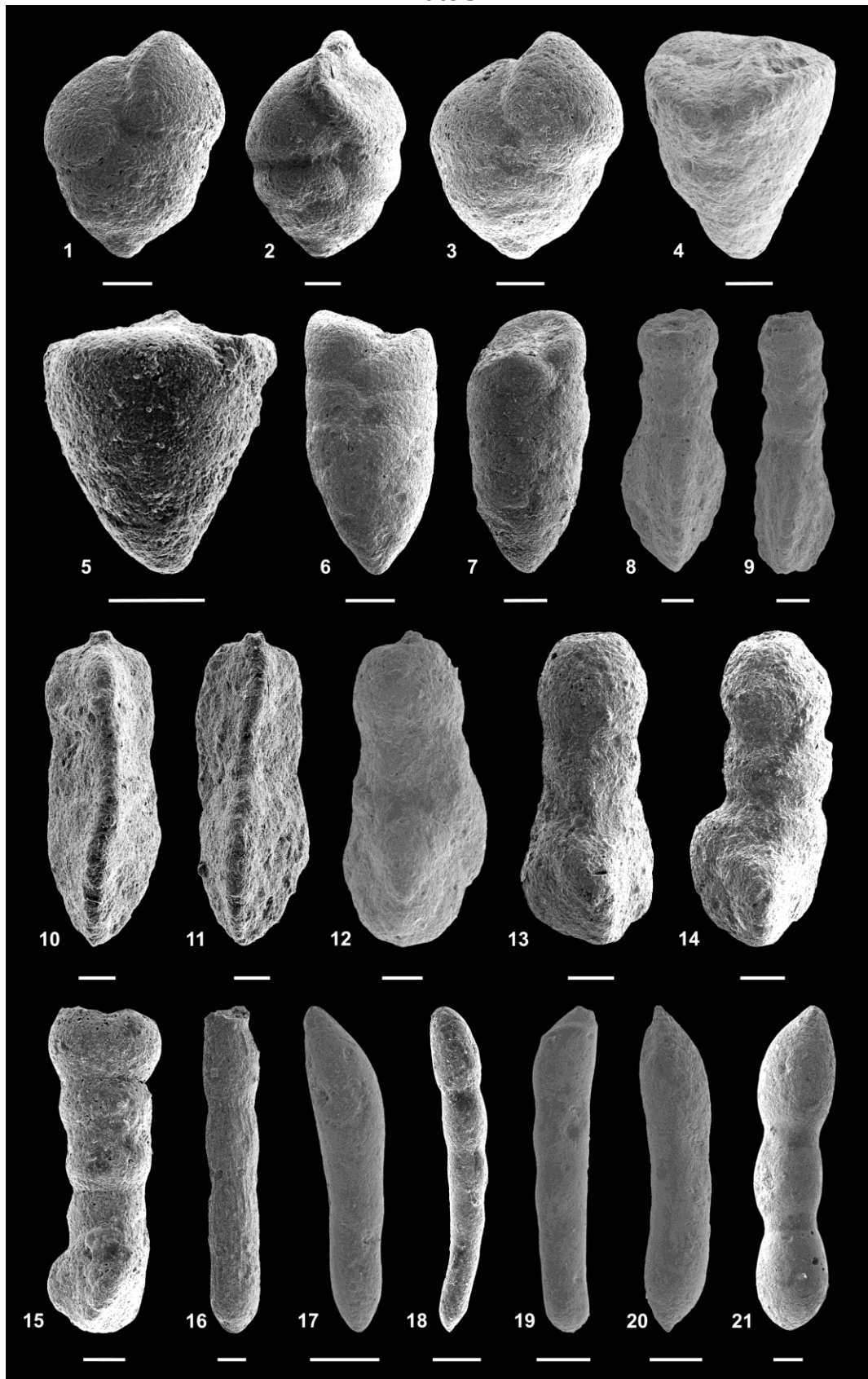


Plate 4 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Nodosariidae, Vaginulinidae

- Fig 1: *Laevidentalina communis* (d'Orbigny). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14694, Azmer section, sample number ASH-10.
- Figs 2, 3: *Laevidentalina cylindroides* (Reuss). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, Fig. 2, MPK14695, Dokan section, sample number DSH-08; Fig. 3, MPK14696, Azmer section, sample number ASH-02.
- Figs 4, 5: *Laevidentalina gracilis* (d'Orbigny). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, Fig. 4, MPK14697, Dokan section, sample number DSH-05; Fig. 5, MPK14698, Azmer section, sample number ASH-02.
- Figs 6-8: *Laevidentalina legumen* (Reuss). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, Fig. 6, MPK14699, Dokan section, sample number DSH-10, Fig. 7, MPK14700, Fig. 8, MPK14701, Azmer section, sample number ASH-05.
- Fig 9: *Nodosaria affinis* Reuss. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14702, Dokan section, sample number DSH-08.
- Fig 10: *Nodosaria limbata* d'Orbigny. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14703, Azmer section, sample number ASH-60.
- Fig 11: *Nodosaria* cf. *limbata* d'Orbigny. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14704, Dokan section, sample number DSH-90.
- Fig 12: *Nodosaria prismatica* Reuss. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14705, Dokan section, sample number DSH-15.
- Fig 13: *Pseudoglandulina cylindracea* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14706, Dokan section, sample number DSH-45.
- Figs 14, 15: *Pseudoglandulina manifesta* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 14, MPK14707, Dokan section, sample number DSH-40; Fig. 15, MPK14708, Azmer section, sample number ASH-40.
- Fig 16: *Lingulina pygmaea* Reuss. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14709, Azmer section, sample number ASH-20.

- Fig 17: *Lingulina taylorana* Cushman. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14710, Azmer section, sample number ASH-20.
- Fig 18: *Frondicularia archiaciana* d'Orbigny. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14711, Dokan section, sample number DSH-25.
- Fig 19: *Frondicularia striatula* Reuss. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14712, Azmer section, sample number ASH-58.
- Figs 20-22: *Lenticulina discrepans* (Reuss). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Figs. 20, 21, MPK14713, Fig. 22, MPK14714, Dokan section, sample number DSH-100.
- Figs 23-25: *Lenticulina macrodiscus* (Reuss). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14715, Azmer section, sample number ASH-10.

Plate 4

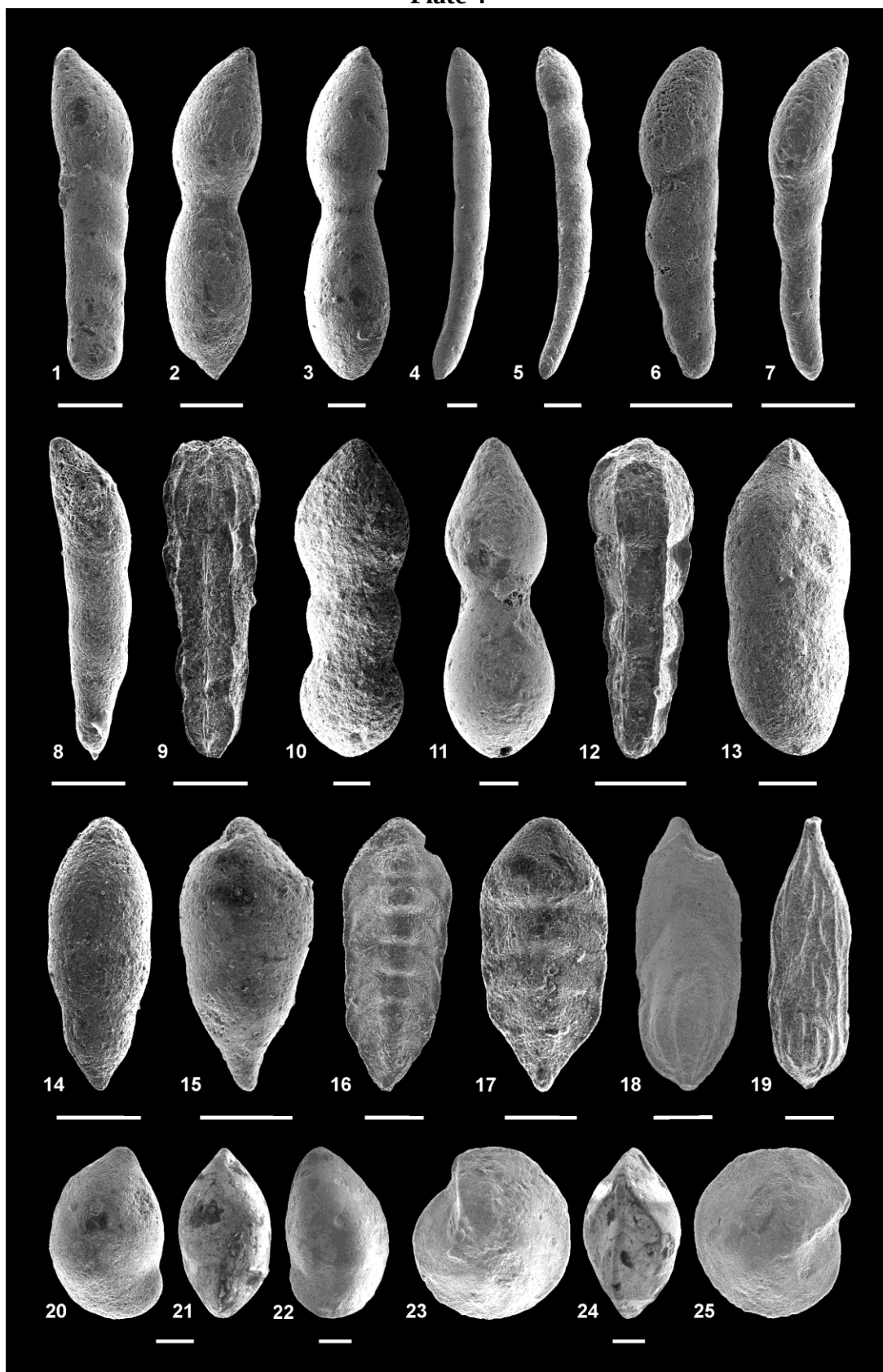


Plate 5 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Vaginulinidae

- Figs 1-5: *Lenticulina pseudosecans* (Cushman). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, Figs. 1-3, MPK14716, Dokan section, sample number DSH-15; Figs. 4, 5, MPK14717, Azmer section, sample number ASH-10.
- Fig 6: *Lenticulina rotulata* Lamarck. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14718, Azmer section, sample number ASH-05.
- Figs 7, 8: *Lenticulina spissocostata* (Cushman). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14719, Azmer section, sample number ASH-58.
- Figs 9, 10: *Marginulinopsis cephalotes* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 9, MPK14720, Dokan section, sample number DSH-56; Fig. 10, MPK14721, Azmer section, sample number ASH-35.
- Fig 11: *Marginulinopsis multicostata* (Lipnik). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14722, Dokan section, sample number DSH-76.
- Fig 12: *Marginulinopsis praetschoppi* Trujillo. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14723, Azmer section, sample number ASH-35.
- Figs 13, 14: *Neoflabellina jarvisi* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 13, MPK14724, Dokan section, sample number DSH-45; Fig. 14, MPK14725, Azmer section, sample number ASH-25.
- Figs 15, 16: *Neoflabellina numismalis* (Wedekind). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 15, MPK14726, Azmer section, sample number ASH-20; Fig. 16, MPK14727, Azmer section, sample number ASH-25.
- Fig 17: *Neoflabellina permutata* (Koch). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14728, Dokan section, sample number DSH-48.
- Fig 18, 19: *Neoflabellina rugosa* (d'Orbigny). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 17, MPK14729, Dokan section, sample number DSH-48; Fig. 18, MPK14730, Azmer section, sample number ASH-25.
- Fig 20: Juvenile *Neoflabellina* sp. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14731, Azmer section, sample number ASH-15.

Plate 5

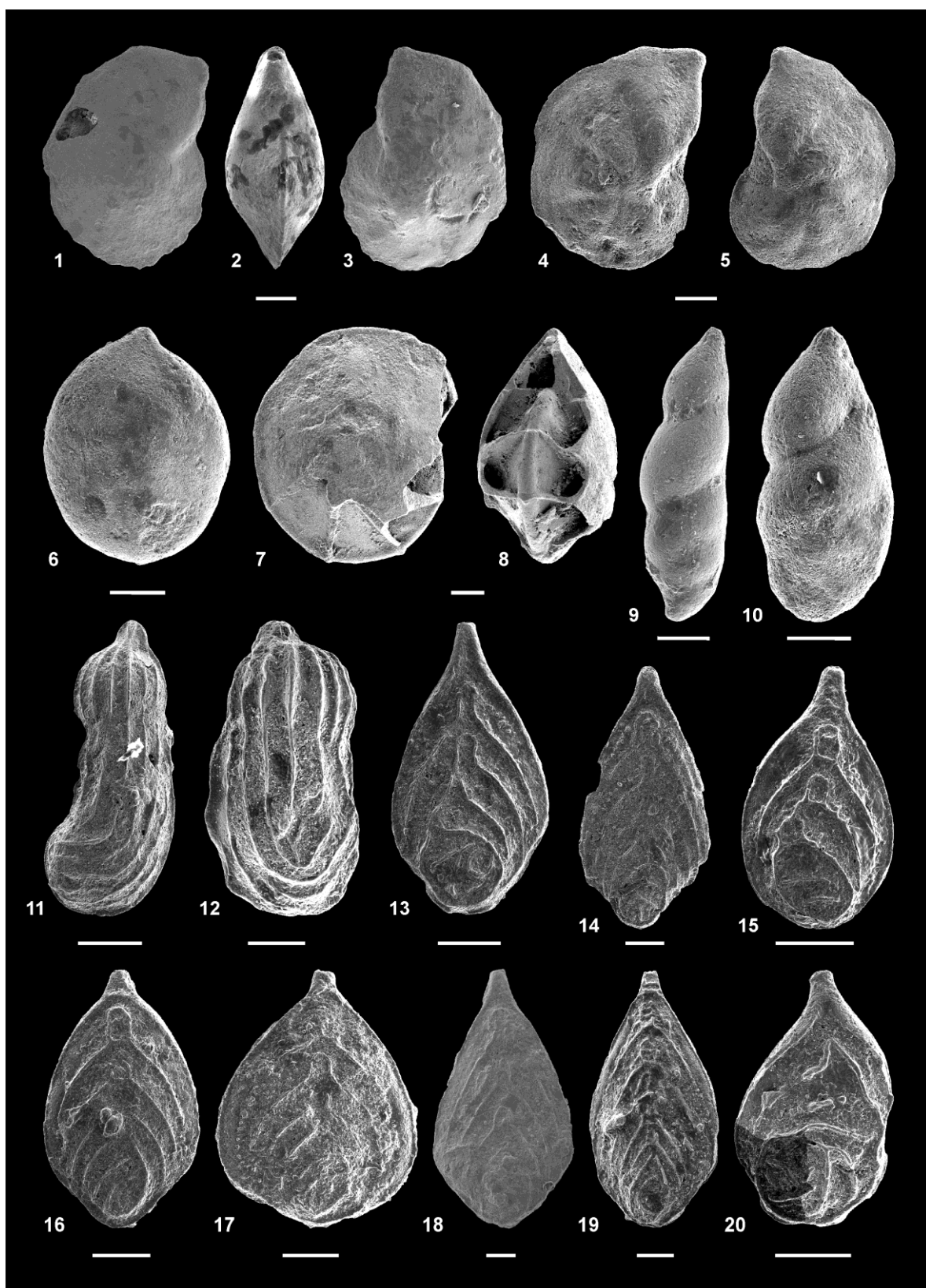


Plate 6 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Vaginulinidae, Lagenidae, Polymorphinidae

- Fig 1: *Astacolus incurvatus* Reuss. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14732, Azmer section, sample number ASH-35.
- Figs 2, 3: *Hemirobulina bullata* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 2, MPK14733, Dokan section, sample number DSH-50; Fig. 3, MPK14734, Azmer section, sample number ASH-30.
- Fig 4: *Hemirobulina curvatura* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14735, Dokan section, sample number DSH-60.
- Fig 5: *Hemirobulina* cf. *tripleura* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14736, Azmer section, sample number ASH-20.
- Fig 6: *Hemirobulina texasensis* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14737, Azmer section, sample number ASH-25.
- Figs 7, 8: *Planularia complanata* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 7, MPK14738, Dokan section, sample number DSH-40; Fig. 8, MPK14739, Dokan section, sample number DSH-45.
- Fig 9: *Planularia liebusi* Brotzen. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14740, Azmer section, sample number ASH-25.
- Fig 10: *Vaginulina trilobata* (d'Orbigny). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14741, Dokan section, sample number DSH-36.
- Fig 11: *Lagena acuticosta* Reuss. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14742, Dokan section, sample number DSH-110.
- Fig 12: *Lagena* cf. *semiinterrupta* Berry. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14743, Dokan section, sample number DSH-117.
- Figs 13, 14: *Lagena semilineata* Wright. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14744, Azmer section, sample number ASH-60.

- Figs 15, 16: *Lagen* sp. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 15, MPK14745, Dokan section, sample number DSH-110; Fig. 16, MPK14746, Azmer section, sample number ASH-60.
- Figs 17, 18: *Reusoolina apiculata apiculata* (Reuss). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 17, MPK14747, Dokan section, sample number DSH-117; Fig. 18, MPK14748, Azmer section, sample number ASH-60.
- Fig 19: *Globulina* sp. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14749, Dokan section, sample number DSH-90.

Plate 6

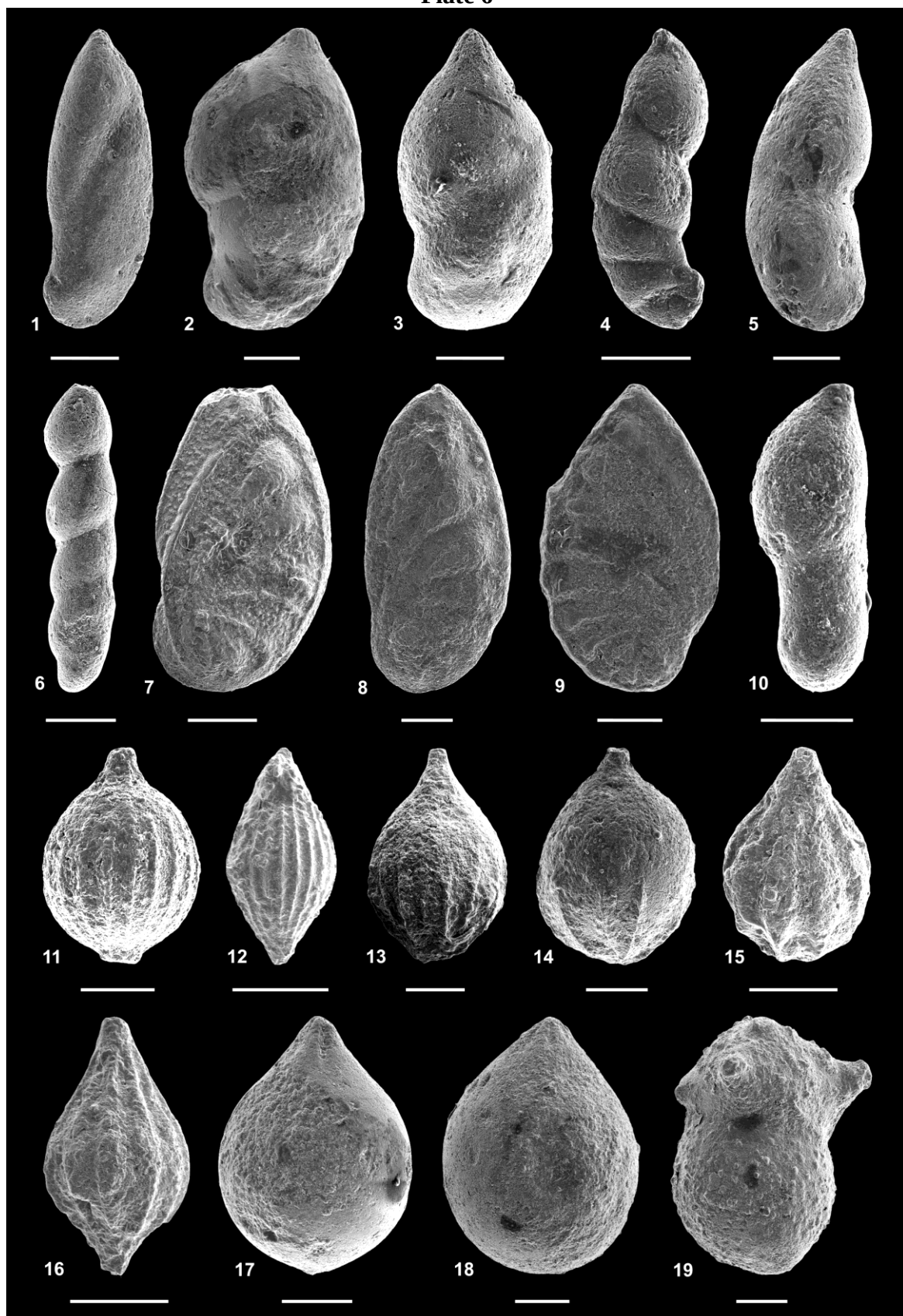


Plate 7 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Polymorphinidae, Ellipsolagenidae, Loxostomatidae, Turritinidae, Fursenkoinidae

- Fig 1: *Ramulina pseudoaculeata* (Olsson). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14750, Azmer section, sample number ASH-15.
- Figs 2, 3: *Oolina globosa* (Montagu). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 2, MPK14751, Dokan section, sample number DSH-117; Fig. 3, MPK14752, Azmer section, sample number ASH-60.
- Figs 4, 5: *Fissurina* spp. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 4, MPK14753, Dokan section, sample number DSH-117; Fig. 5, MPK14754, Azmer section, sample number ASH-60.
- Figs 6, 7: *Loxostomum eleyi* (Cushman). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 6, MPK14755, Dokan section, sample number DSH-117; Fig. 7, MPK14756, Azmer section, sample number ASH-60.
- Figs 8, 9: *Praebulimina aspera* Cushman and Parker. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14757, Azmer section, sample number ASH-30.
- Figs 10, 11: *Praebulimina carseyae* (Plummer). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 10, MPK14758, Dokan section, sample number DSH-100; Fig. 11, MPK14759, Azmer section, sample number ASH-58.
- Fig 12: *Praebulimina kickapooensis* Cole. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14760, Dokan section, sample number DSH-60.
- Figs 13, 14: *Praebulimina laevis* (Beissel). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 13, MPK14761, Dokan section, sample number DSH-82; Fig. 14, MPK14762, Azmer section, sample number ASH-35.
- Figs 15, 16: *Praebulimina reussi* (Morrow). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 15, MPK14763, Dokan section, sample number DSH-80; Fig. 16, MPK14764, Azmer section, sample number ASH-25.
- Figs 17, 18: *Coryphostoma decurrens* (Ehrenberg). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 17, MPK14765, Azmer

section, sample number ASH-50; Fig. 18, MPK14766, Azmer section, sample number ASH-60.

Figs 19, 20: *Coryphostoma incrassata gigantea* (Wicher). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Fig. 19, MPK14767, Dokan section, sample number DSH-90; Fig. 20, MPK14768, Azmer section, sample number ASH-60.

Fig 21: *Coryphostoma incrassata incrassata* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14769, Dokan section, sample number DSH-76.

Plate 7

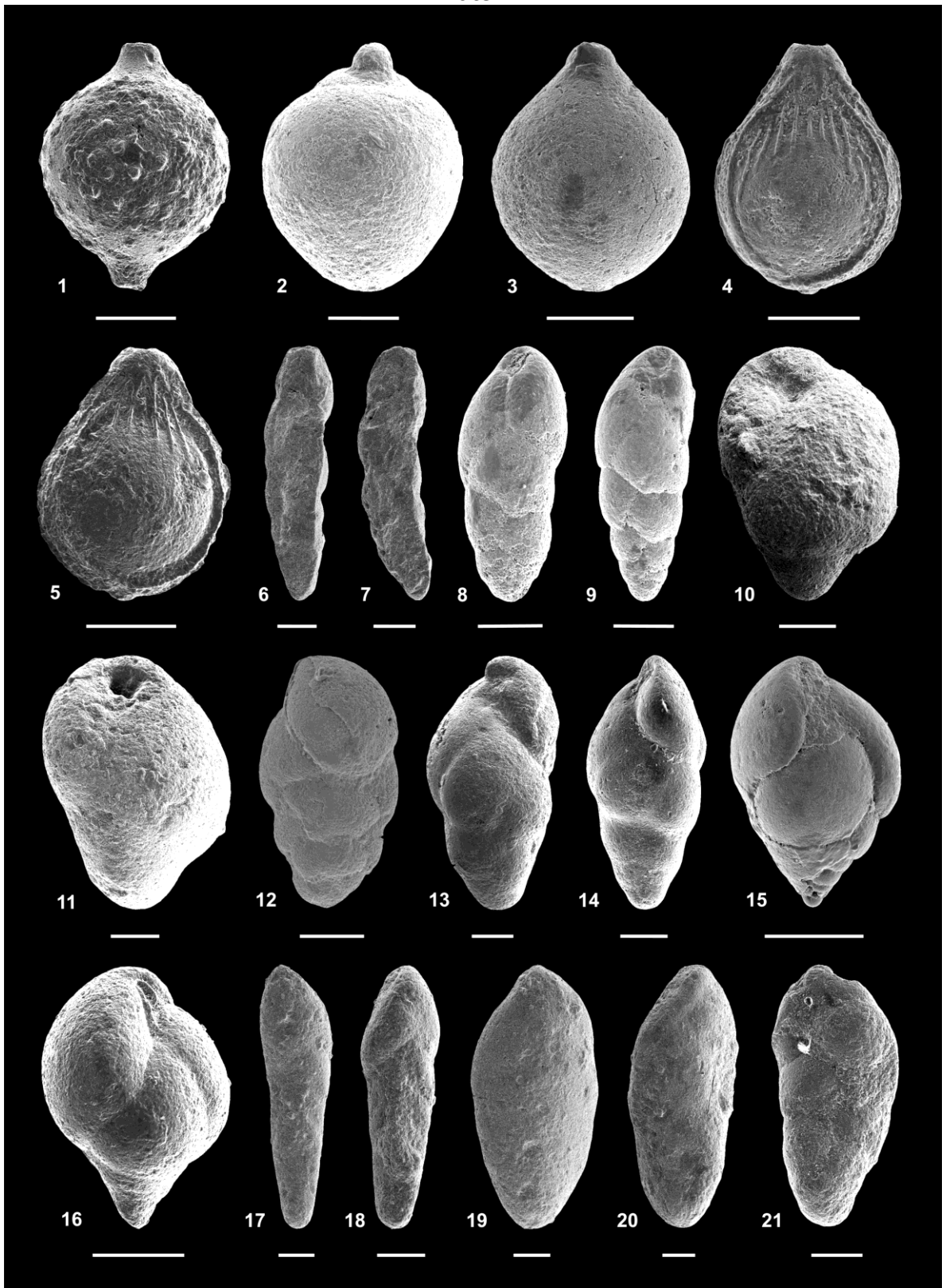


Plate 8 Foraminifera of the Shiranish Formation

Scale bars 100 µm

Pleurostomellidae, Stilostomellidae, Bagginidae, Cibicididae, Epistomariidae

- Fig 1: *Ellipsoglandulina concinna* Olbertz. *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14770, Azmer section, sample number ASH-50.
- Fig 2: *Ellipsoidella pleurostomelloides* Heron-Allen and Earland. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14771, Dokan section, sample number DSH-15.
- Fig 3: *Nodosarella gracillima* Cushman. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14772, Dokan section, sample number DSH-15.
- Fig 4: *Nodosarella subnodosa* (Guppy). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14773, Dokan section, sample number DSH-05.
- Fig 5: *Nodosarella texana* (Cushman). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14774, Dokan section, sample number DSH-10.
- Fig 6: *Pleurostomella nitida* Morrow. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14775, Dokan section, sample number DSH-25.
- Fig 7: *Pleurostomella obtusa* Berthelin. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14776, Azmer section, sample number ASH-10.
- Figs 8, 9: *Pleurostomella subnodosa* (Reuss). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, Fig. 8, MPK14777, Dokan section, sample number DSH-25; Fig. 9, MPK14778, Azmer section, sample number ASH-10.
- Fig 10: *Pleurostomella torta* Cushman. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14779, Dokan section, sample number DSH-15.
- Fig 11: *Pleurostomella* sp. *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14780, Azmer section, sample number ASH-15.
- Figs 12-14: *Stilostomella pseudoscripta* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Fig. 12, MPK14781, Dokan section, sample number DSH-50; Figs. 13, 14, MPK14782, Azmer section, sample number ASH-25.
- Fig 15: *Stilostomella* sp. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14783, Dokan section, sample number DSH-36.

- Figs 16-20: *Valvulineria lenticula* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* and *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* assemblages, Figs. 16, 17, MPK14784, Dokan section, sample number DSH-82; Figs. 18-20, MPK14785, Dokan section, sample number DSH-88.
- Figs 21-23: *Cibicides praecursorius* (Schwager). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14786, Azmer section, sample number ASH-10.
- Figs 24-26: *Nuttallides truempyi truempyi* (Nuttall). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14787, Dokan section, sample number DSH-58.

Plate 8

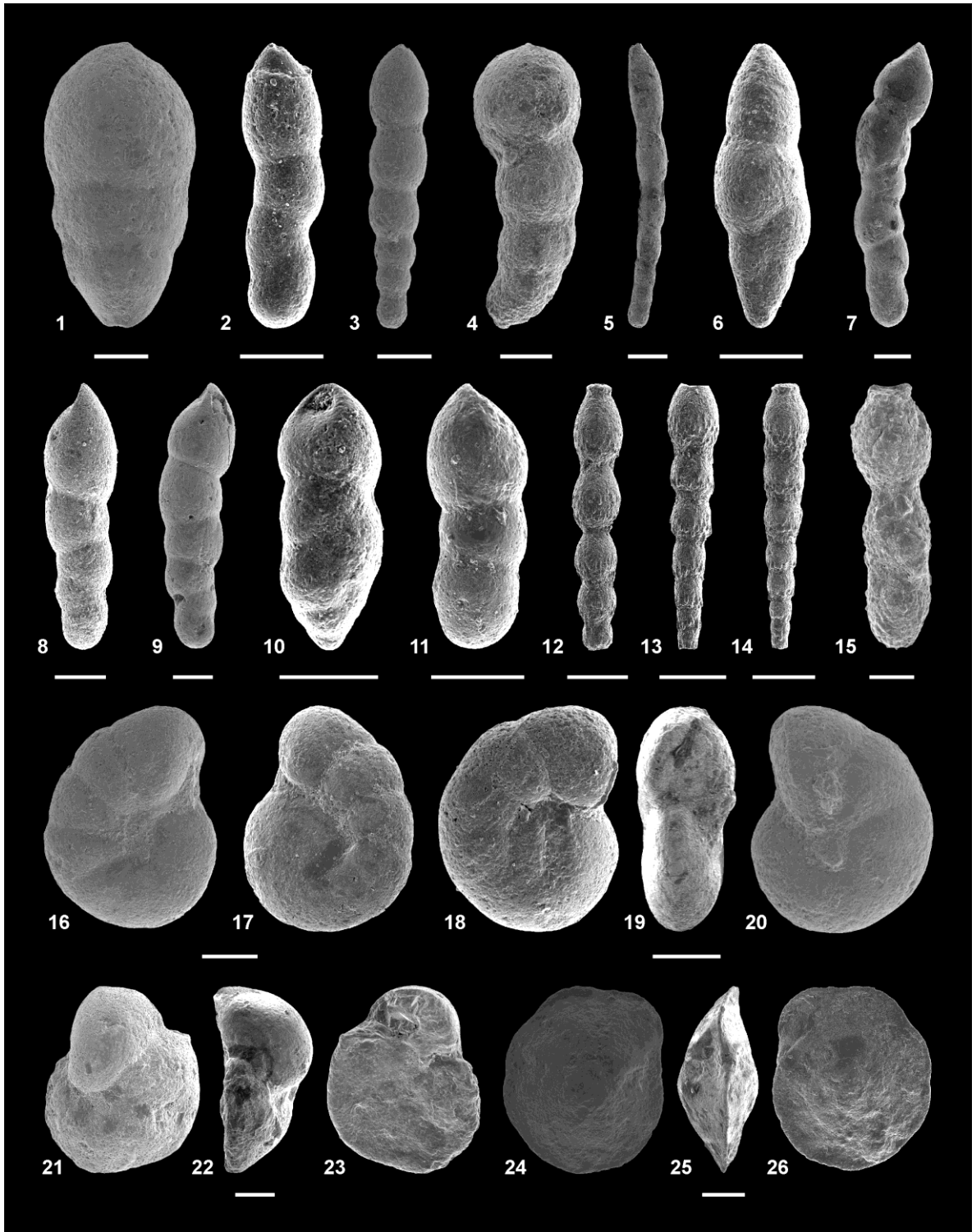


Plate 9 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Epistomariidae, Nonionidae, Quadrimorphinidae, Osangulariidae

Figs 1-3: *Nuttallinella florealis* (White). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14788, Dokan section, sample number DSH-70.

Figs 4-6: *Pullenia jarvisi* Cushman. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14789, Dokan section, sample number DSH-45.

Figs 7, 8: *Pullenia coryelli* White. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14790, Azmer section, sample number ASH-35.

Figs 9-14: *Pullenia cretacea* Cushman. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Figs. 9-11, MPK14791, Dokan section, sample number DSH-70; Figs. 12-14, MPK14792, Azmer section, sample number ASH-35.

Figs 15-19: *Quadrimorphina allomorphinoides* (Reuss). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Figs. 15-17, MPK14793, Dokan section, sample number DSH-45; Figs. 18, 19, MPK14794, Azmer section, sample number ASH-20.

Figs 20-22: *Quadrimorphina halli* (Jennings). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14795, Azmer section, sample number ASH-35.

Figs 23-28: *Charltonina meeterenae* (Visser). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14796, Azmer section, sample number ASH-20.

Plate 9

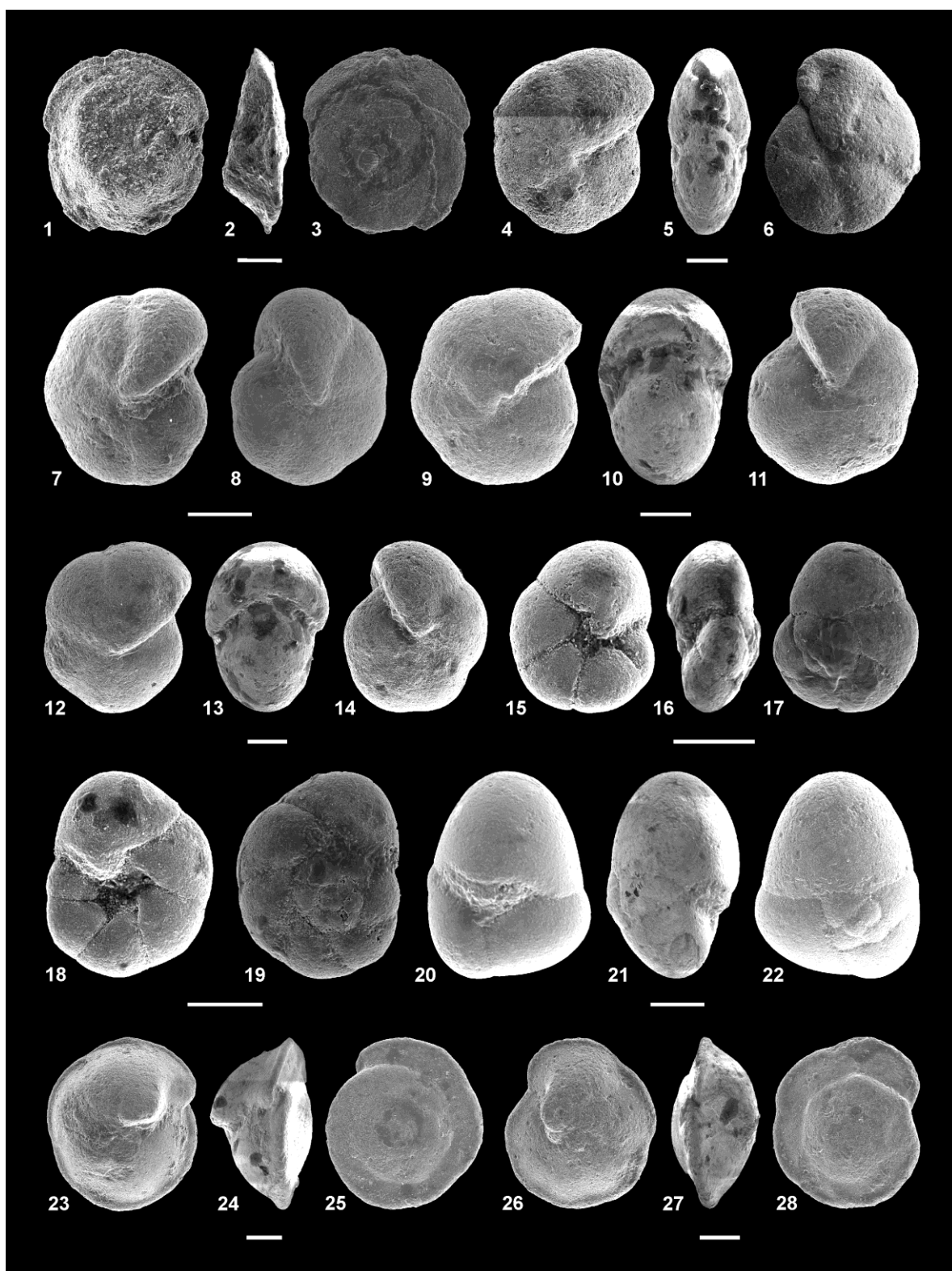


Plate 10 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Osangulariidae, Gavelinellidae

- Figs 1-8: *Osangularia cordieriana* (d'Orbigny). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Figs. 1, 2, MPK14797, Dokan section, sample number DSH-45; Figs. 3-5, MPK14798, Figs. 6-8, MPK 14799, Azmer section, sample number ASH-25.
- Figs 9-11: *Osangularia velascoensis* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14800, Azmer section, sample number ASH-25.
- Figs 12-14: *Gyroidinoides girardanus* (Reuss). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14801, Dokan section, sample number DSH-88.
- Figs 15-18: *Gyroidinoides globosus* (Hagenow). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Figs. 15, 16, MPK14802, Dokan section, sample number DSH-58; Figs. 17, 18, MPK14803, Azmer section, sample number ASH-30.
- Figs 19-23: *Gyroidinoides nitidus* (Reuss). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, Figs. 19-21, MPK14804, Figs. 22, 23, MPK14805, Azmer section, sample number ASH-50.
- Figs 24-26: *Gyroidinoides subangulatus* (Plummer). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14806, Dokan section, sample number DSH-88.

Plate 10

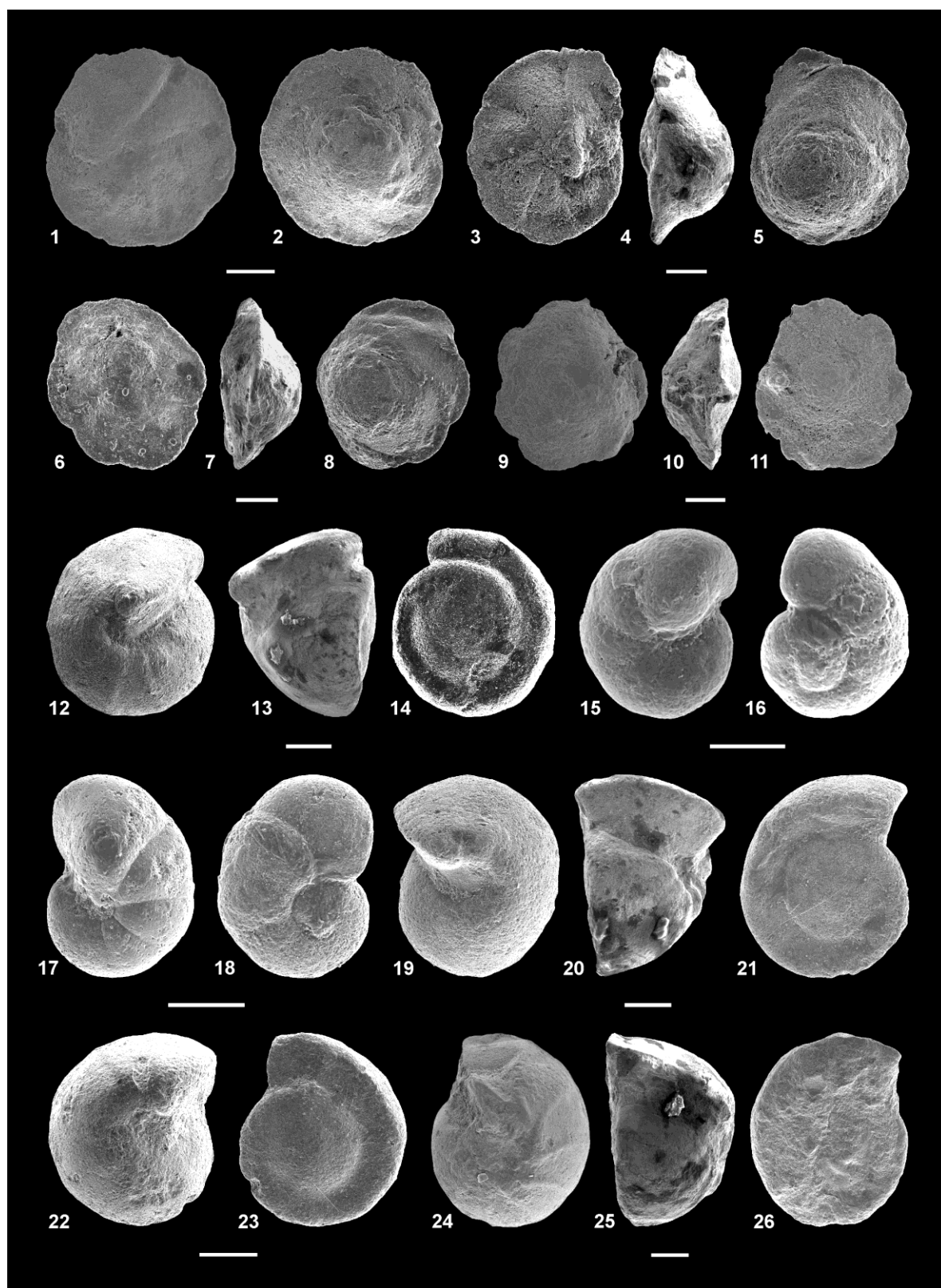


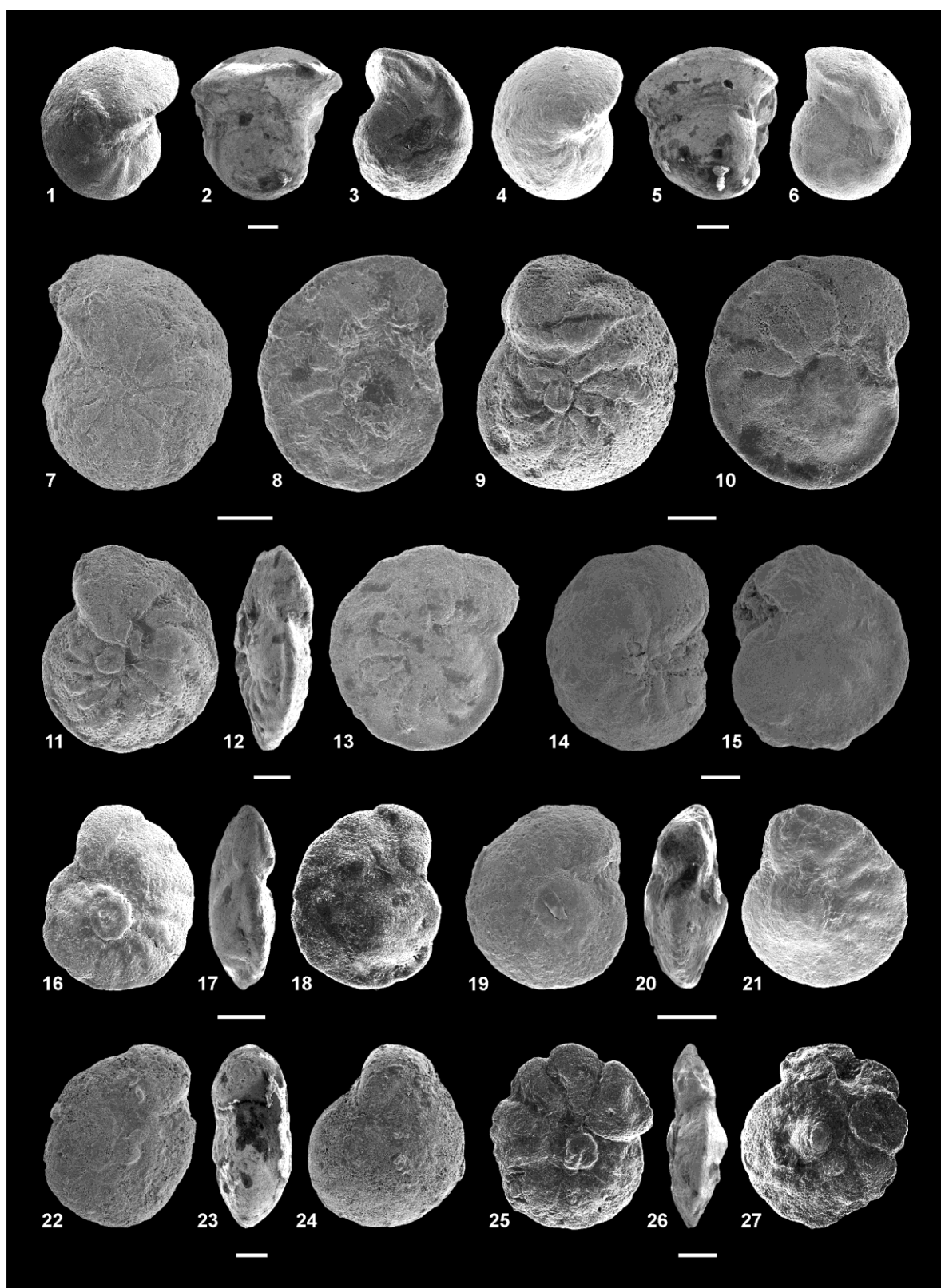
Plate 11 Foraminifera of the Shiranish Formation

Scale bars 100 μ m

Gavelinellidae

- Figs 1-6: *Gyroidinoides* spp. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Figs. 1-3, MPK14807, Dokan section, sample number DSH-64; Figs. 4-6, MPK14808, Azmer section, sample number ASH-35.
- Figs 7, 8: *Gavelinella lorneiana* (d'Orbigny). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14809, Dokan section, sample number DSH-20.
- Figs 9-13: *Gavelinella monterelensis* (Marie). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Figs. 9, 10, MPK14810, Dokan section, sample number DSH-60; Figs. 11-13, MPK14811, Azmer section, sample number ASH-30.
- Figs 14, 15: *Gavelinella stelligera* (Marie). *Lenticulina macrodiscus*-*Lenticulina pseudosecans* Assemblage, MPK14812, Dokan section, sample number DSH-36.
- Figs 16-21: *Gavelinella stephensoni* (Cushman). *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, Figs. 16-18, MPK14813, Azmer section, sample number ASH-30; Figs. 19-21, MPK14814, Dokan section, sample number DSH-36.
- Figs 22-24: *Gavelinella voltziana* (d'Orbigny). *Coryphostoma incrassata gigantea*-*Praebulimina carseyae*-*Loxostomum eleyi* Assemblage, MPK14815, Azmer section, sample number ASH-50.
- Figs 25-27: *Gavelinella* sp. *Gavelinella monterelensis*-*Gavelinella stephensoni* Assemblage, MPK14816, Dokan section, sample number DSH-36.

Plate 11



Chapter 6

Conclusions

Chapter 6: Conclusions

The aim of this study was to determine the palaeontological, biostratigraphical, and palaeoenvironmental significance of the Late Cretaceous foraminiferal fauna of NE Iraq, and to identify the broader distributional patterns of Late Cretaceous foraminiferal assemblages in the Tethys Ocean. These studies have produced the following results.

Identification of 93 planktonic foraminiferal species belonging to 23 genera permits the recognition of nine biozones and two subzones in the Late Cretaceous (early Turonian-late early Maastrichtian) succession in NE Iraq. Five of the biozones are identified as interval zones (IZ): the *Dicarinella primitiva* IZ, the *Dicarinella concavata* IZ, the *Globotruncana aegyptiaca* IZ, the *Gansserina gansseri* IZ (which can be subdivided into the *Pseudoguembelina excolata* and *Planoglobulina acervulinoides* subzones) and the *Contusotruncana 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 planktonic foraminiferal biozonations permit the recognition of a major intra-Campanian unconformity between the Kometan and the overlying Shiranish formations, with duration of at least 5.2 Myr.

Based on comparison with the structure of extant planktonic foraminiferal assemblages, two life history strategies have been identified for Cretaceous planktonic foraminifera. Nutrient-rich, eutrophic and unstable environments appear to favour 'r-selected opportunists' which increase their population densities by rapid reproduction, are of small dimensions and typically inhabit shallower depths in the water column, and are usually equated with cooler sea surface temperatures. In contrast, low-nutrient, oligotrophic and stable environments appear to be more suitable for 'k-selected specialists', characterised by long-lived individuals, low reproductive potential and larger size, and indicating warmer sea surface temperatures. Detailed analysis of planktonic foraminiferal assemblages shows that warmer sea surface temperatures are dominant in the mid-Turonian to late Coniacian, latest Santonian, and late Campanian, and cooler sea surfaces in the early Turonian, early to late Santonian, early Campanian and early Maastrichtian.

Taxonomic studies of the Heterohelcidae planktonic foraminifera from the early Turonian-early Maastrichtian in NE Iraq identify 24 species belonging to 8 genera. Species

abundance and diversity increases from the early Turonian to early Maastrichtian, perhaps signifying cooler sea temperatures in the Arabian sector of the Tethys Ocean during the early Maastrichtian and consistent with other planktonic foraminiferal distribution patterns. Despite the long biostratigraphical ranges of some species, the importance of the biserial and multiserial planktonic foraminifers in Late Cretaceous biostratigraphy is emphasised.

Analysis of benthonic foraminifera provides a refined biostratigraphy for the late Campanian to early Maastrichtian (Late Cretaceous) Shiranish Formation in NE Iraq. Three biozones and two subzones are identified for the first time in Iraq and the surrounding countries: the *Bolivinoidea decoratus* biozone (late Campanian) subdivided into a lower *B. decoratus* subzone and an upper *B. laevigatus* subzone; the *B. miliaris* biozone (earliest Maastrichtian); and the *B. draco* biozone (late early Maastrichtian). Combined, the benthonic and planktonic foraminiferal biostratigraphy enables the informal recognition of lower and upper intervals within both the *Globotruncana aegyptiaca* and *Gansserina gansseri* biozones that may be important for more refined inter-regional correlation in the Middle East and North Africa. Moreover, the new *Bolivinoidea* biozonation precisely locates the Campanian-Maastrichtian boundary in NE Iraq.

The late Campanian to early Maastrichtian benthonic foraminiferal assemblages in the Shiranish Formation of NE Iraq are placed into three temporally distinct assemblages that are interpreted to reflect environmental change, principally from factors associated with palaeodepth. In stratigraphic succession the assemblages are: the *Lenticulina macrodiscus-Lenticulina pseudosecans* Assemblage (late Campanian); the *Gavelinella monterelensis-Gavelinella stephensoni* Assemblage (late to latest Campanian); and the *Coryphostoma incrassata gigantea-Praebulimina carseyae-Loxostomum eleyi* Assemblage (early Maastrichtian). The foraminiferal assemblages are interpreted as representing outer shelf to middle slope environments, between ca 200 m to at least 600 m water depth, with maximum water depths in the late Campanian, followed by shallowing into the early Maastrichtian. The most likely control mechanism for shallowing sea level was the beginning of southern Neo-Tethys Ocean closure at this time.

Appendices

Appendices

Appendix 1: Taxonomic list of planktonic foraminifera

Alphabetical list of planktonic foraminifera recorded in this study.

Archaeoglobigerina

Archaeoglobigerina blowi Pessagno, 1967.

Archaeoglobigerina cretacea (d'Orbigny, 1840).

Contusotruncana

Contusotruncana contusa (Cushman, 1926).

Contusotruncana fornicata (Plummer, 1931).

Contusotruncana patelliformis (Gandolfi, 1955).

Contusotruncana plicata (White, 1928).

Contusotruncana plummerae (Gandolfi, 1955).

Contusotruncana walfischensis (Todd, 1970).

Dicarinella

Dicarinella algeriana (Caron, 1966).

Dicarinella asymetrica (Sigal, 1952).

Dicarinella canaliculata (Reuss, 1854).

Dicarinella concavata (Brotzen, 1934).

Dicarinella primitiva (Dalbiez, 1955).

Gansserina

Gansserina gansseri (Bolli, 1951).

Gansserina wiedenmayeri (Gandolfi, 1955).

Globigerinelloides

Globigerinelloides asper (Ehrenberg, 1854).

Globigerinelloides messinae (Brönnimann, 1952).

Globigerinelloides multispinus Lalicker, 1948.

Globigerinelloides prairiehillensis Pessagno, 1967.

Globigerinelloides rosebudensis Smith and Pessagno, 1973.

Globigerinelloides subcarinatus Brönnimann, 1952.

Globigerinelloides ultramicrus Subbotina, 1949.

Globigerinelloides volutus (White, 1928).

Globigerinelloides spp.

Globotruncana

Globotruncana aegyptiaca Nakkady, 1950.

Globotruncana angusticarinata (Gandolfi, 1942). Postuma (1971) figured this species as *Globotruncana angusticarinata* rather than *Marginotruncana angusticarinata*, as did Barr (1972) in a study of specimens from Libya. Postuma (1971) clearly stated that the primary aperture in *Globotruncana angusticarinata* is umbilical covered by a tegillum. However, the primary aperture in the genus *Marginotruncana* is umbilical and extraumbilical covered by portici (Caron 1985). This character can be used to distinguish the genus *Marginotruncana* from *Globotruncana*.

Globotruncana arca (Cushman, 1926).

Globotruncana bulloides Vogler, 1941.

Globotruncana dupeblei Caron, Gonzales Donoso, Robaszynski and Wonders, 1984.

Globotruncana esnehensis (Nakkady, 1950).

Globotruncana falsostuarti Sigal, 1952.

Globotruncana lapparenti (Brotzen, 1936). Note that *Globotruncana lapparenti* can be distinguished from *G. linneiana* based on its slightly convex spiral side. However, *G. linneiana* can be distinguished by its flattened spiral side.

Globotruncana linneiana d'Orbigny, 1839.

Globotruncana mariei (Banner and Blow, 1960).

Globotruncana orientalis El-Naggar, 1966.

Globotruncana spp.

Globotruncanella

Globotruncanella petaloidea Gandolfi, 1955.

Globotruncanella pschadae Keller, 1946.

Globotruncanita

- Globotruncanita angulata* Tilev, 1951.
Globotruncanita conica White, 1928.
Globotruncanita elevata (Brotzen, 1934).
Globotruncanita insignis (Gandolfi, 1955).
Globotruncanita pettersi (Gandolfi, 1955).
Globotruncanita stuarti (de Lapparent, 1918).
Globotruncanita stuartiformis Dalbiez, 1955.
Globotruncanita spp.

Gublerina

- Gublerina cuvillieri* Kikoine, 1948.

Helvetoglobotruncana

- Helvetoglobotruncana helvetica* (Bolli, 1945).

Heterohelix

- Heterohelix globulosa* (Ehrenberg, 1840).
Heterohelix moremani (Cushman, 1938).
Heterohelix navarroensis Loeblich, 1951.
Heterohelix planata (Cushman, 1936).
Heterohelix punctulata (Cushman, 1938).
Heterohelix reussi (Cushman, 1938).
Heterohelix semicostata (Cushman, 1938).
Heterohelix striata (Ehrenberg, 1840).
Heterohelix ultimumida White, 1929.

Laeviheterohelix

- Laeviheterohelix dentata* (Stenestad, 1968).
Laeviheterohelix glabrans (Cushman, 1938).
Laeviheterohelix pulchra (Brotzen, 1936).

Marginotruncana

- Marginotruncana coronata* (Bolli, 1945).
Marginotruncana marginata (Reuss, 1845).
Marginotruncana renzi (Gandolfi, 1942).
Marginotruncana schneegansi Sigal, 1952.
Marginotruncana sigali (Reichel, 1950).
Marginotruncana sinuosa Porthault, 1970.
Marginotruncana undulata (Lehmann, 1963).

Muricohedbergella

- Muricohedbergella delrioensis* (Carsey, 1926).
Muricohedbergella holmdelensis Olsson, 1964.
Muricohedbergella planispira (Tappan, 1940).

Planoglobulina

- Planoglobulina acervulinoides* (Egger, 1899).
Planoglobulina brazoensis Martin, 1972.
Planoglobulina carseyae (Plummer, 1931).
Planoglobulina riograndensis Martin, 1972.

Praegublerina

- Praegublerina acuta* (De Klasz, 1953).

Pseudoquembelina

- Pseudoquembelina costulata* (Cushman, 1938).
Pseudoquembelina excolata (Cushman, 1926).

Pseudotextularia

- Pseudotextularia deformis* (Kikoine, 1948).
Pseudotextularia elegans (Rzehak, 1891).
Pseudotextularia nuttalli (Voorwijk, 1937).

Radotruncana

Radotruncana subspinoso (Pessagno, 1960).

Rugotruncana

Rugotruncana circumnodifer (Finley, 1940).

Rugotruncana subcircumnodifer Gandolfi, 1955.

Rugoglobigerina

Rugoglobigerina hexacamerata Brönnimann, 1952.

Rugoglobigerina macrocephala Brönnimann, 1952.

Rugoglobigerina pennyi Brönnimann, 1952.

Rugoglobigerina rugosa (Plummer, 1926).

Rugoglobigerina scotti Brönnimann, 1952.

Rugoglobigerina subpennyi (Gandolfi, 1955).

Rugoglobigerina spp.

Ventilabrella

Ventilabrella eggeri Cushman, 1928.

Whiteinella

Whiteinella archaeocretacea Pessagno, 1967.

Whiteinella aprica (Loeblich and Tappan, 1961).

Whiteinella baltica Douglas and Rankin, 1969.

Whiteinella brittonensis (Loeblich and Tappan, 1961).

Whiteinella inornata (Bolli, 1957).

Whiteinella paradubia (Sigal, 1952).

Appendix 2: Taxonomic list of benthonic foraminifera

Alphabetical list of benthonic foraminifera recorded in this study.

Ammodiscus

Ammodiscus cretaceus (Reuss, 1845).

Ammodiscus peruvianus Berry, 1928.

Astacolus

Astacolus incurvatus Reuss, 1863.

Bathysiphon

Bathysiphon alexanderi Cushman, 1933.

Bathysiphon brosgiei Tappan, 1957.

Bathysiphon dubia (White, 1928).

Bathysiphon vitta Nauss, 1947.

Bathysiphon spp.

Bolivinooides

Bolivinooides australis (Edgell, 1954).

Bolivinooides decoratus Jones, 1884.

Bolivinooides draco Marsson, 1878.

Bolivinooides laevigatus (Marie, 1941).

Bolivinooides miliaris (Hiltermann and Koch, 1950).

Bolivinooides praelaevigatus (Barr, 1966).

Charltonina

Charltonina meeterenae (Visser, 1950).

Chrysalogonium

Chrysalogonium cf. *velascoense* (Cushman, 1928).

Cibicides

Cibicides praecursorius (Schwager, 1883).

Clavulinoides

Clavulinoides asper (Cushman, 1926).

Clavulinoides trilaterus (Cushman, 1926).

Coryphostoma

Coryphostoma decurrens (Ehrenberg, 1854).

Coryphostoma incrassata gigantea (Wicher).

Coryphostoma incrassata incrassata (Reuss).

Dentalina

Dentalina colei Cushman and Dusenbury, 1934.

Dentalina granti (Plummer, 1927).

Dentalina lorneiana (d'Orbigny, 1840).

Dentalina oligostegia (Reuss, 1845).

Dorothia

Dorothia bulletta (Carsey, 1926).

Dorothia retusa (Cushman, 1926).

Ellipsoglandulina

Ellipsoglandulina concinna Olbertz, 1942.

Ellipsoidella

Ellipsoidella pleurostomelloides Heron-Allen and Earland, 1910.

Fissurina

Fissurina sp.

Frondicularia

Frondicularia archiaciana d'Orbigny, 1840.

Frondicularia striatula Reuss, 1844.

Gaudryina

Gaudryina austinana Cushman, 1936.

Gaudryina pyramidata Cushman, 1926.

Gaudryina spp.

Gavelinella

Gavelinella lorneiana (d'Orbigny, 1840).

Gavelinella monterelensis (Marie, 1941).

Gavelinella stelligera (Marie, 1941).

Gavelinella stephensoni (Cushman, 1938).

Gavelinella voltziana (d'Orbigny, 1840).

Gavelinella spp.

Globulina

Globulina sp.

Glomospira

Glomospira gordialis (Jones and Parker, 1860).

Glomospira sp.

Gyroidinoides

Gyroidinoides girardanus (Reuss, 1851).

Gyroidinoides globosus (Hagenow, 1842).

Gyroidinoides nitidus (Reuss, 1845).

Gyroidinoides subangulatus (Plummer, 1927).

Gyroidinoides spp.

Hemirobulina

Hemirobulina bullata (Reuss, 1845).

Hemirobulina curvatura (Cushman, 1938).

Hemirobulina cf. *tripleura* (Reuss, 1860).

Hemirobulina texasensis (Cushman, 1938).

Laevidentalina

Laevidentalina catenula (Reuss, 1860).

Laevidentalina communis (d'Orbigny, 1826).

Laevidentalina cylindroides (Reuss, 1860).

Laevidentalina gracilis (d'Orbigny, 1840).

Laevidentalina legumen (Reuss, 1845).

Lagena

Lagena acuticosta Reuss, 1861.

Lagena cf. *semiinterrupta* Berry, 1929.

Lagena semilineata Wright, 1886.

Lagena sp.

Lenticulina

Lenticulina discrepans (Reuss, 1863).

Lenticulina macrodiscus (Reuss, 1863).

Lenticulina pseudosecans (Cushman, 1938).

Lenticulina rotulata Lamarck, 1804.

Lenticulina spissocostata (Cushman, 1938).

Lingulina

Lingulina pygmaea Reuss, 1875.

Lingulina taylorana Cushman, 1938.

Loxostomum

Loxostomum eleyi (Cushman, 1927).

Marginulinopsis

Marginulinopsis cephalotes (Reuss, 1863).

Marginulinopsis multicostata (Lipnik, 1961).

Marginulinopsis praetschoppi Trujillo, 1960.

Marssonella

Marssonella indentata (Cushman and Jarvis, 1928).

Marssonella oxycona oxycona (Reuss, 1860).

Neoflabellina

Neoflabellina jarvisi (Cushman, 1935).

Neoflabellina numismalis (Wedekind, 1940).

Neoflabellina permutata (Koch, 1977).

Neoflabellina rugosa (d'Orbigny, 1840).

Neoflabellina spp.

Nodosarella

Nodosarella gracillima Cushman, 1933.

Nodosarella subnodosa (Guppy, 1894).

Nodosarella texana (Cushman, 1938).

Nodosaria

Nodosaria affinis Reuss, 1846.

Nodosaria limbata d'Orbigny, 1840.

Nodosaria prismatica Reuss, 1860.

Nuttallides

Nuttallides truempyi truempyi (Nuttall, 1930).

Nuttallinella

Nuttallinella florealis (White, 1928).

Oolina

Oolina globosa (Montagu, 1803).

Osangularia

Osangularia cordieriana (d'Orbigny, 1840).

Osangularia velascoensis (Cushman, 1925).

Planularia

Planularia complanata (Reuss, 1845).

Planularia liebusi Brotzen 1936.

Pleurostomella

Pleurostomella nitida Morrow, 1934.

Pleurostomella obtusa Berthelin, 1880.

Pleurostomella subnodosa (Reuss, 1851).

Pleurostomella torta Cushman, 1926.

Pleurostomella sp.

Praebulimina

Praebulimina aspera Cushman and Parker, 1940.

Praebulimina carseyae (Plummer, 1931).

Praebulimina kickapooensis Cole, 1938.

Praebulimina laevis (Beissel, 1891).

Praebulimina reussi (Morrow, 1934).

Pseudoclavulina

Pseudoclavulina amorpha (Cushman, 1926).

Pseudoclavulina clavata (Cushman, 1926).

Pseudoclavulina farafraensis LeRoy, 1953.

Pseudoglandulina

Pseudoglandulina cylindracea (Reuss, 1845).

Pseudoglandulina manifesta (Reuss, 1851).

Pullenia

Pullenia jarvisi Cushman, 1936.

Pullenia coryelli White, 1929.

Pullenia cretacea Cushman, 1936.

Quadrimorphina

Quadrimorphina allomorphinoides (Reuss, 1860).

Quadrimorphina halli (Jennings, 1936).

Quasispiroplectammina

Quasispiroplectammina chicoana (Lalicker, 1935).

Ramulina

Ramulina pseudoaculeata (Olsson, 1960).

Reussoolina

Reussoolina apiculata apiculata (Reuss, 1851).

Spiroplectammina

Spiroplectammina laevis (Roemer, 1841).

Stilostomella

Stilostomella pseudoscripta (Cushman, 1946).

Stilostomella sp.

Tritaxia

Tritaxia eggeri (Cushman, 1936).

Tritaxia whitei (Cushman and Jarvis, 1932).

Vaginulina

Vaginulina trilobata (d'Orbigny, 1840).

Valvulineria

Valvulineria lenticula (Reuss, 1845).

Verneuilinga

Verneuilinga muensteri Reuss, 1854.

Vulvulina

Vulvulina cf. *colei* Cushman, 1932.

Appendix 3: Systematic list of benthonic foraminifera

The benthonic fauna identified in this thesis consists of 115 species and subspecies which represent 52 genera and 25 families listed below (the number of species for each genus is added in brackets). The arrangement of the taxa follows Loeblich & Tappan (1988) and Bolli *et al.* (1994).

Family Bathysiphonidae: *Bathysiphon* (4).

Family Ammodiscidae: *Ammodiscus* (2), *Glomospira* (1).

Family Spiroplectamminidae: *Quasispiroplectammina* (1), *Spiroplectammina* (1),
Vulvulina (1).

Family Verneuilingidae: *Gaudryina* (2), *Verneuilinga* (1).

Family Tritaxiidae: *Tritaxia* (2).

Family Eggerellidae: *Dorothia* (2), *Marssonella* (2).

Family Pseudogaudryinidae: *Clavulinoides* (2), *Pseudoclavulina* (3).

Family Nodosariidae: *Chrysalogonium* (1), *Dentalina* (4), *Laevidentalina* (5), *Nodosaria* (3), *Pseudoglandulina* (2), *Lingulina* (2), *Frondicularia* (2).

Family Vaginulinidae: *Lenticulina* (5), *Marginulinopsis* (3), *Neoflabellina* (4), *Astacolus* (1), *Hemirobulina* (4), *Planularia* (2), *Vaginulina* (1).

Family Lagenidae: *Lagen* (3), *Reussolina* (1).

Family Polymorphinidae: *Globulina* (1 unidentified species), *Ramulina* (1).

Family Ellipsolagenidae: *Oolina* (1), *Fissurina* (1 unidentified species).

Family Bolivinoididae: *Bolivinoides* (6).

Family Loxostomatidae: *Loxostomum* (1).

Family Turrilinidae: *Praebulimina* (5).

Family Fursenkoinidae: *Coryphostoma* (3).

Family Pleurostomellidae: *Ellipsoglandulina* (1), *Ellipsoidella* (1), *Nodosarella* (3), *Pleurostomella* (4).

Family Stilostomellidae: *Stilostomella* (1).

Family Bagginidae: *Valvulinaria* (1).

Family Cibicididae: *Cibicides* (1).

Family Epistomariidae: *Nuttallides* (1), *Nuttallinella* (1).

Family Nonionidae: *Pullenia* (3).

Family Quadrimorphinidae: *Quadrimorphina* (2).

Family Osangulariidae: *Charltonina* (1), *Osangularia* (2).

Family Gavelinellidae: *Gyroidinoides* (4), *Gavelinella* (5).

Appendix 4: Quantitative and semi-quantitative data for samples of the Shiranish Formation in the Dokan and Azmer sections, Kurdistan region, NE Iraq. Samples with less than 30 specimens are highlighted by the grey box (see chapter 5).

4.1 Planktonic and benthonic foraminifera numbers in the Shiranish Formation, Dokan section

Sample numbers	Weight	Planktonic numbers	Benthonic numbers	Total numbers
DSH-01	10 g	No foraminifera recorded, glauconite horizon		
DSH-02	10 g			
DSH-03	10 g	182	95	277
DSH-04	10 g	192	91	283
DSH-05	10 g	195	90	285
DSH-06	10 g	201	89	290
DSH-07	10 g	279	74	353
DSH-08	10 g	274	71	345
DSH-09	10 g	269	68	337
DSH-10	10 g	252	67	319
DSH-11	10 g	261	68	329
DSH-12	10 g	273	66	339
DSH-13	10 g	255	64	319
DSH-14	10 g	256	65	321
DSH-15	10 g	258	66	324
DSH-16	10 g	253	66	319
DSH-17	10 g	255	70	325
DSH-18	10 g	262	73	335
DSH-19	10 g	285	82	367
DSH-20	10 g	300	85	385
DSH-21	10 g	286	71	357
DSH-22	10 g	300	72	372
DSH-23	10 g	300	64	364
DSH-24	10 g	293	62	355
DSH-25	10 g	281	61	342
DSH-26	10 g	300	68	368
DSH-27	10 g	296	64	360
DSH-28	10 g	290	60	350
DSH-29	10 g	300	60	360
DSH-30	10 g	300	61	361
DSH-31	10 g	300	60	360
DSH-32	10 g	300	59	359
DSH-33	10 g	300	59	359

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DSH-34	10 g	300	60	360
DSH-35	10 g	292	61	353
DSH-36	10 g	300	70	370
DSH-37	10 g	300	71	371
DSH-38	10 g	300	70	370
DSH-39	10 g	295	67	362
DSH-40	10 g	293	66	359
DSH-41	10 g	300	60	360
DSH-42	10 g	300	59	359
DSH-43	10 g	300	58	358
DSH-44	10 g	300	55	355
DSH-45	10 g	300	52	352
DSH-46	10 g	300	46	346
DSH-47	10 g	300	45	345
DSH-48	10 g	300	43	343
DSH-49	10 g	300	40	340
DSH-50	10 g	300	37	337
DSH-51	10 g	300	27	327
DSH-52	10 g	300	27	327
DSH-53	10 g	283	24	307
DSH-54	10 g	263	23	286
DSH-55	10 g	258	23	281
DSH-56	10 g	300	31	331
DSH-57	10 g	281	28	309
DSH-58	10 g	271	25	296
DSH-59	10 g	300	26	326
DSH-60	10 g	300	23	323
DSH-61	10 g	300	26	326
DSH-62	10 g	300	21	321
DSH-63	10 g	300	23	323
DSH-64	10 g	289	32	321
DSH-65	10 g	280	31	311
DSH-66	10 g	300	35	335
DSH-67	10 g	281	36	317
DSH-68	10 g	267	35	302
DSH-69	10 g	300	37	337
DSH-70	10 g	279	37	316
DSH-71	10 g	300	38	338
DSH-72	10 g	300	38	338
DSH-73	10 g	294	36	330
DSH-74	10 g	284	35	319
DSH-75	10 g	265	35	300
DSH-76	10 g	265	36	301

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DSH-77	10 g	282	37	319
DSH-78	10 g	300	38	338
DSH-79	10 g	261	38	299
DSH-80	10 g	283	39	322
DSH-81	10 g	246	38	284
DSH-82	10 g	260	42	302
DSH-83	10 g	243	48	291
DSH-84	10 g	215	55	270
DSH-85	10 g	223	59	282
DSH-86	10 g	197	58	255
DSH-87	10 g	199	58	257
DSH-88	10 g	216	61	277
DSH-89	10 g	207	60	267
DSH-90	10 g	181	57	238
DSH-91	10 g	202	60	262
DSH-92	10 g	237	62	299
DSH-93	10 g	214	72	286
DSH-94	10 g	218	70	288
DSH-95	10 g	181	47	228
DSH-96	10 g	184	57	241
DSH-97	10 g	200	58	258
DSH-98	10 g	208	58	266
DSH-99	10 g	238	60	298
DSH-100	10 g	249	61	310
DSH-101	10 g	222	57	279
DSH-102	10 g	201	59	260
DSH-103	10 g	207	61	268
DSH-104	10 g	210	70	280
DSH-105	10 g	182	63	245
DSH-106	10 g	200	72	272
DSH-107	10 g	224	80	304
DSH-108	10 g	203	74	277
DSH-109	10 g	195	70	265
DSH-110	10 g	254	85	339
DSH-111	10 g	240	82	322
DSH-112	10 g	228	78	306
DSH-113	10 g	251	80	331
DSH-114	10 g	250	79	329
DSH-115	10 g	247	78	325
DSH-116	10 g	252	78	330
DSH-117	10 g	250	75	325
DSH-118	10 g	247	71	318
DSH-119	10 g	271	78	349

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DSH-120	10 g	283	80	363
DSH-121	10 g			
DSH-122	10 g			
DSH-123	10 g			
DSH-124	10 g			
DSH-125	10 g			
DSH-126	10 g			
DSH-127	10 g	No foraminifera recorded		
DSH-128	10 g			
DSH-129	10 g			
DSH-130	10 g			
DSH-131	10 g			
DSH-132	10 g			
DSH-133	10 g			

4.2 Planktonic and benthonic foraminifera numbers in the Shiranish Formation, Azmer section

Sample numbers	Weight	Planktonic numbers	Benthonic numbers	Total numbers
ASH-01	10 g	201	46	247
ASH-02	10 g	210	45	255
ASH-03	10 g	224	48	272
ASH-04	10 g	217	49	266
ASH-05	10 g	225	45	270
ASH-06	10 g	200	40	240
ASH-07	10 g	215	42	257
ASH-08	10 g	180	27	207
ASH-09	10 g	300	55	355
ASH-10	10 g	246	42	288
ASH-11	10 g	195	32	227
ASH-12	10 g	215	39	254
ASH-13	10 g	225	36	261
ASH-14	10 g	200	29	229
ASH-15	10 g	214	30	244
ASH-16	10 g	300	40	340
ASH-17	10 g	300	41	341
ASH-18	10 g	209	33	242
ASH-19	10 g	213	37	250
ASH-20	10 g	196	34	230
ASH-21	10 g	237	43	280
ASH-22	10 g	226	44	270
ASH-23	10 g	214	42	256

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ASH-24	10 g	236	47	283
ASH-25	10 g	226	45	271
ASH-26	10 g	243	47	290
ASH-27	10 g	252	41	293
ASH-28	10 g	245	42	287
ASH-29	10 g	249	30	279
ASH-30	10 g	245	27	272
ASH-31	10 g	245	23	268
ASH-32	10 g	300	33	333
ASH-33	10 g	249	26	275
ASH-34	10 g	246	26	272
ASH-35	10 g	246	29	275
ASH-36	10 g	262	32	294
ASH-37	10 g	245	30	275
ASH-38	10 g	253	31	284
ASH-39	10 g	247	30	277
ASH-40	10 g	277	40	317
ASH-41	10 g	276	41	317
ASH-42	10 g	244	43	287
ASH-43	10 g	245	48	293
ASH-44	10 g	233	49	282
ASH-45	10 g	206	43	249
ASH-46	10 g	198	50	248
ASH-47	10 g	223	62	285
ASH-48	10 g	203	60	263
ASH-49	10 g	182	52	234
ASH-50	10 g	190	60	250
ASH-51	10 g	180	51	231
ASH-52	10 g	202	60	262
ASH-53	10 g	199	61	260
ASH-54	10 g	184	51	235
ASH-55	10 g	187	52	239
ASH-56	10 g	200	60	260
ASH-57	10 g	192	58	250
ASH-58	10 g	205	61	266
ASH-59	10 g	211	64	275
ASH-60	10 g	204	60	264
ASH-61	10 g	212	62	274
ASH-62	10 g	207	61	268
ASH-63	10 g	213	63	276
ASH-64	10 g	206	64	270
ASH-65	10 g	214	67	281

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ASH-66	10 g
ASH-67	10 g
ASH-68	10 g
ASH-69	10 g
ASH-70	10 g
ASH-71	10 g
ASH-72	10 g
ASH-73	10 g
ASH-74	10 g
ASH-75	10 g
ASH-76	10 g
ASH-77	10 g
ASH-78	10 g
ASH-79	10 g
ASH-80	10 g
ASH-81	10 g
ASH-82	10 g
ASH-83	10 g
ASH-84	10 g
ASH-85	10 g
ASH-86	10 g
ASH-87	10 g
ASH-88	10 g
ASH-89	10 g
ASH-90	10 g
ASH-91	10 g
ASH-92	10 g
ASH-93	10 g
ASH-94	10 g
ASH-95	10 g
ASH-96	10 g
ASH-97	10 g
ASH-98	10 g
ASH-99	10 g
ASH-100	10 g
ASH-101	10 g
ASH-102	10 g

No foraminifera recorded

Appendix 5: Quantitative and semi-quantitative data for samples of the Kometan Formation in the Dokan and Azmer sections, Kurdistan region, NE Iraq.

5.1 Thin section analysis (MiEKiNiA Lab in Warsaw, Poland)

Planktonic foraminifera numbers in the Kometan Formation, Dokan section

Sample numbers	Thin section size (standard) Length* Width	Planktonic numbers
DK-01	48x28 mm	108
DK-02	48x28 mm	95
DK-03	48x28 mm	92
DK-04	48x28 mm	116
DK-05	48x28 mm	138
DK-06	48x28 mm	165
DK-07	48x28 mm	183
DK-1	48x28 mm	206
DK-2	48x28 mm	198
DK-3	48x28 mm	195
DK-4	48x28 mm	203
DK-5	48x28 mm	191
DK-6	48x28 mm	188
DK-7	48x28 mm	176
DK-8	48x28 mm	181
DK-9	48x28 mm	184
DK-10	48x28 mm	194
DK-11	48x28 mm	206
DK-12	48x28 mm	200
DK-13	48x28 mm	196
DK-14	48x28 mm	186
DK-15	48x28 mm	180
DK-16	48x28 mm	215
DK-17	48x28 mm	212
DK-18	48x28 mm	209
DK-19	48x28 mm	197
DK-20	48x28 mm	177
DK-21	48x28 mm	172
DK-22	48x28 mm	169
DK-23	48x28 mm	162
DK-24	48x28 mm	179
DK-25	48x28 mm	183
DK-26	48x28 mm	165

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DK-27	48x28 mm	158
DK-28	48x28 mm	173
DK-29	48x28 mm	170
DK-30	48x28 mm	161
DK-31	48x28 mm	152
DK-32	48x28 mm	149
DK-33	48x28 mm	156
DK-34	48x28 mm	168
DK-35	48x28 mm	161
DK-36	48x28 mm	155
DK-37	48x28 mm	158
DK-38	48x28 mm	170
DK-39	48x28 mm	164
DK-40	48x28 mm	150
DK-41	48x28 mm	147
DK-42	48x28 mm	143
DK-43	48x28 mm	154
DK-44	48x28 mm	157
DK-45	48x28 mm	166
DK-46	48x28 mm	174
DK-47	48x28 mm	177
DK-48	48x28 mm	182
DK-49	48x28 mm	172
DK-50	48x28 mm	171
DK-51	48x28 mm	179
DK-52	48x28 mm	163
DK-53	48x28 mm	166
DK-54	48x28 mm	171
DK-55	48x28 mm	177
DK-56	48x28 mm	179
DK-57	48x28 mm	180
DK-58	48x28 mm	183
DK-59	48x28 mm	188
DK-60	48x28 mm	176
DK-61	48x28 mm	192
DK-62	48x28 mm	196
DK-63	48x28 mm	184
DK-64	48x28 mm	189
DK-65	48x28 mm	190
DK-66	48x28 mm	213
DK-67	48x28 mm	203
DK-68	48x28 mm	211
DK-69	48x28 mm	195

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DK-70	48x28 mm	210
DK-71	48x28 mm	208
DK-72	48x28 mm	199
DK-73	48x28 mm	194
DK-74	48x28 mm	196
DK-75	48x28 mm	193
DK-76	48x28 mm	202
DK-77	48x28 mm	188
DK-78	48x28 mm	195
DK-79	48x28 mm	179
DK-80	48x28 mm	205
DK-81	48x28 mm	209
DK-82	48x28 mm	201
DK-83	48x28 mm	192
DK-84	48x28 mm	191
DK-85	48x28 mm	194
DK-86	48x28 mm	192
DK-87	48x28 mm	196
DK-88	48x28 mm	198
DK-89	48x28 mm	203
DK-90	48x28 mm	208
DK-91	48x28 mm	204
DK-92	48x28 mm	206
DK-93	48x28 mm	201
DK-94	48x28 mm	189
DK-95	48x28 mm	194
DK-96	48x28 mm	172
DK-97	48x28 mm	164
DK-98	48x28 mm	186
DK-99	48x28 mm	153
DK-100	48x28 mm	168
DK-101	48x28 mm	173
DK-102	48x28 mm	151

5.2 Thin section analysis (MiEKiNiA Lab in Warsaw, Poland)

Planktonic foraminifera numbers in the Kometan Formation, Azmer section

Sample numbers	Thin section size (standard) Length* Width	Planktonic numbers
AK-1	48x28 mm	90
AK-2	48x28 mm	91

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AK-3	48x28 mm	95
AK-4	48x28 mm	99
AK-5	48x28 mm	166
AK-6	48x28 mm	177
AK-7	48x28 mm	174
AK-8	48x28 mm	188
AK-9	48x28 mm	186
AK-10	48x28 mm	184
AK-11	48x28 mm	179
AK-12	48x28 mm	173
AK-13	48x28 mm	199
AK-14	48x28 mm	194
AK-15	48x28 mm	193
AK-16	48x28 mm	192
AK-17	48x28 mm	206
AK-18	48x28 mm	211
AK-19	48x28 mm	202
AK-20	48x28 mm	197
AK-21	48x28 mm	191
AK-22	48x28 mm	185
AK-23	48x28 mm	196
AK-24	48x28 mm	183
AK-25	48x28 mm	185
AK-26	48x28 mm	188
AK-27	48x28 mm	189
AK-28	48x28 mm	191
AK-29	48x28 mm	195
AK-30	48x28 mm	202
AK-31	48x28 mm	206
AK-32	48x28 mm	183
AK-33	48x28 mm	174
AK-34	48x28 mm	165
AK-35	48x28 mm	174
AK-36	48x28 mm	179
AK-37	48x28 mm	162
AK-38	48x28 mm	169
AK-39	48x28 mm	170
AK-40	48x28 mm	172
AK-41	48x28 mm	157
AK-42	48x28 mm	187
AK-43	48x28 mm	181
AK-44	48x28 mm	193
AK-45	48x28 mm	169

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AK-46	48x28 mm	153
AK-47	48x28 mm	176
AK-48	48x28 mm	173
AK-49	48x28 mm	184
AK-50	48x28 mm	196
AK-51	48x28 mm	184
AK-52	48x28 mm	189
AK-53	48x28 mm	197
AK-54	48x28 mm	192
AK-55	48x28 mm	182
AK-56	48x28 mm	175
AK-57	48x28 mm	177
AK-58	48x28 mm	162
AK-59	48x28 mm	159
AK-60	48x28 mm	153
AK-61	48x28 mm	142
AK-62	48x28 mm	146
AK-63	48x28 mm	142
AK-64	48x28 mm	139
AK-65	48x28 mm	146
AK-66	48x28 mm	141
AK-67	48x28 mm	134

Appendix 6: CD-Rom of an Excel file containing detail Late Cretaceous Heterohellicidae measurements for 581 specimens.

Appendix 7: CD-Rom of an Excel file containing British Geological Survey (BGS), Keyworth, Nottingham repository numbers for the studied samples of the Kometan and Shiranish formations, Kurdistan region, NE Iraq.

Appendix 8: CD-Rom of a PDF file containing a research paper published in *GeoArabia* (Jaff, R. B. N., Williams, M., Wilkinson, I. P., Lawa, F., Lee, S. and Zalasiewicz, J. 2014. A refined foraminiferal biostratigraphy for the late Campanian-early Maastrichtian succession of northeast Iraq. *GeoArabia*, **19** (1), 161-180).

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