

**A REFINED FORAMINIFERAL BIOSTRATIGRAPHY FOR THE LATE  
CAMPANIAN – EARLY MAASTRICHTIAN SUCCESSION OF  
NORTHEAST IRAQ**

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**ABSTRACT**

Species of the benthonic foraminiferal genus *Bolivinooides* 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 *Bolivinooides decoratus* Biozone (Late Campanian) subdivided into a lower *B. decoratus* Subzone and 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 *Bolivinooides* 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 *Bolivinooides* 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. 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 *Bolivinooides* species in the Shiranish Formation.

Here we identify stratigraphically important *Bolivinooides* species, establish a biozonation that is useful for regional and interregional correlation, and more precisely define 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.

## **MATERIALS AND METHODS**

Two stratigraphic rock successions, one at Dokan (latitude 35° 56' 15" and longitude 44° 57' 21") and the other at Azmer (latitude 35° 37' 30" and longitude 45° 31' 45"; see Fig. 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 *Bolivinoidea*. Samples were taken at stratigraphic intervals 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 foraminifer 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  $\mu\text{m}$  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  $\mu\text{m}$  down to 63  $\mu\text{m}$ . Foraminifera were picked and studied from the residue in the 63-300  $\mu\text{m}$  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 (Jassim & Goff, 2006; Buday, 1980; Bellen et al., 1959). The Shiranish Formation unconformably overlies the marine limestones of the Kometan Formation (Mid Turonian-Early Campanian), and is succeeded conformably by marine clastic deposits of the Tanjero Formation (Late Maastrichtian) (Fig. 2). Bellen et al. (1959) informally subdivided the Shiranish Formation into a 'lower unit' characterized by alternating foraminifer-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. 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.

### ***BOLIVINOIDES* BIOZONATION**

*Bolivinoides* species provide one of the most highly resolved biostratigraphic subdivisions of Late Cretaceous strata globally (e.g. El-Nady, 2006). In order to place the Kurdistan assemblages into the context of this global stratigraphy, a total of 118 specimens of *Bolivinoides* 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 1. We have not identified any intraspecific temporal trends in individual *Bolivinoides* species from our morphological analyses that would enable sub-division of zonal intervals. Nevertheless, the temporal succession in discrete *Bolivinoides* species can be used to establish three biozones and two subzones in the Shiranish Formation (Fig. 3).

#### **1. Late Campanian *Bolivinoides decoratus* Biozone**

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. 3). *Bolivinoides decoratus* (Jones) is common at both localities and is restricted to Late Campanian strata (Figs. 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) and North Africa (Khalil, 1998; El-Nady, 2006; Barr, 1970). 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. 5). Based on co-occurring planktonic foraminifera in the Shiranish Formation (see Fig. 6), the *B. decoratus* Biozone represents an equivalent stratigraphical interval to the *Globotruncana aegyptiaca* and lower part of the *Gansserina gansseri* planktonic foraminiferal biozones (for which, see Robaszynski, 1998; Premoli Silva & Sliter, 1999; Robaszynski et al., 2000; Premoli Silva & Verga, 2004; Sari, 2006, 2009). Combined, the 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 5, 6).

## **2. Earliest Maastrichtian *Bolivinoidea miliaris* Biozone**

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 *Bolivinoidea 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 paper we define the *B. miliaris* Biozone as a total range zone, with no overlap with *B. decoratus*. We believe 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. 6) of the planktonic foraminifera *Rugoglobigerina hexacamerata* Bronnimann, *R. pennyi* Bronnimann and *Planoglobulina acervulinoides* (Egger), which are regarded as markers for the basal Maastrichtian in other regions (Zepeda, 1998; Li et al., 1999; Guray, 2006; Beiranvand & Ghasemi-Nejad, 2013; see Fig. 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. 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. 3). *Bolivinooides miliaris* occurs rarely in Iraq and is restricted to the earliest Maastrichtian. *B. miliaris* is recorded from the same stratigraphical range in Europe (Hiltermann & Koch, 1950), North Africa (Le Roy, 1953; Said & Kenawy, 1956; Khalil, 1998; El-Nady, 2006; Barr, 1970), and the Caribbean (Beckmann & Koch, 1964). 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 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. 6).

### **3. Late Early Maastrichtian *Bolivinooides draco* Biozone**

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*. *B. draco* is very 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. 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 *Bolivinoidea paleocenicus* (Brotzen) and *B. peterssoni* Brotzen at the base of the *B. draco* Biozone as he defined it, though we have 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 we define it in Iraq most likely lies at a lower stratigraphic level than in Egypt (see Fig. 4).

The associated planktonic species within the *B. draco* Biozone of Iraq are *Contusotruncana contusa*, *C. patelliformis*, *C. walfischensis* and *Gansserina gansseri*, which also signal the early Maastrichtian and, in the case of *C. contusa*, the late early Maastrichtian (Fig. 6). These foraminifera indicate that the *B. draco* Biozone represents an equivalent stratigraphical interval to the upper part of the *Gansserina gansseri* and the lower part of the *Contusotruncana contusa* (Cushman) planktonic foraminiferal Biozone (for which, see Robaszynski, 1998; Premoli Silva & Sliter, 1999; Robaszynski et al., 2000; Premoli Silva & Verga, 2004; Sari, 2006; 2009).

#### **THE CAMPANIAN-MAASTRICHTIAN BOUNDARY**

At the GSSP section at Tercis, southwestern France, the first appearance of the ammonite *Pachydiscus neubergicus* is taken as the marker of the Campanian-Maastrichtian (C-M) boundary, and this level also coincides with the first occurrences of the planktonic foraminifera *Rugoglobigerina scotti* and *Contusotruncana contusa* (Odin, 1996; 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 *Bolivinooides* specimens with 5 lobes on the last chamber (Odin & Lamaurelle, 2001). *Bolivinooides* 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. 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 benthic 5-lobed *Bolivinooides* species appear simultaneously at Tercis, but in Iraq the planktonic species post-dates the appearance of 5-lobed *Bolivinooides*. Here, based on the total succession of foraminifera in our assemblages, we take the appearance of 5-lobed *Bolivinooides* 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 foraminifer *Radotruncana calcarata* had long been used to define the C-M boundary (Van Hinte, 1965; Postuma, 1971; Wonders, 1980; Robaszynski et al., 1984; Olsson & Nyong, 1984; Caron, 1985; Sliter, 1989): 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 (for which see Robaszynski, 1998;

Premoli Silva & Sliter, 1999; Robaszynski et al., 2000; Premoli Silva and Verga, 2004; Sari, 2006, 2009: also Figs 5, 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 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 we use the first occurrences of the planktonic foraminifera *Planoglobulina acervulinooides*, *R. pennyi* and *R. hexacamerata* within the *Gansserina gansseri* Biozone (Li & Keller, 1998a, b; Li et al., 1999; Zepeda, 1998; Robaszynski, 1998; Guray, 2006; Esmeray, 2008; Beiranvand & Ghasemi-Nejad, 2013) as additional evidence to identify the C-M boundary. These first occurrences coincide with the FAD of *Bolivinooides* with 5 lobes, especially *B. miliaris*.

#### **PALAEOENVIRONMENTAL SIGNIFICANCE OF THE FORAMINIFERA**

Foraminifer 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*, *Allomorphina*, *Clavulinooides*, *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 *Clavulinooides trilatera* (Cushman), *Gavelinella stephensoni* (Cushman), *Marginulina bullata* Reuss, *Nuttallides truempyi* (Nuttall), *Gyroidinooides 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 benthic foraminifer assemblages are dominated by *Gavelinella*, *Gyroidinoides*, *Gaudryina*, *Lenticulina*, *Marginulinopsis*, *Neoflabellina*, *Osangularia*, *Praebulimina* and *Spiroplectammina* species, which suggest an upper slope environment with water depths ranging between 400 to 300 m (Sliter, 1972; Sliter & Baker, 1972). The top of the *B. decoratus* Biozone of the Shiranish Formation contains *Bathysiphon vitta* Nauss, *Gaudryina pyramidata* Cushman, *Loxostomum eleyi* (Cushman), *Marssonella 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 foraminifer assemblages at the level of the *B. miliaris* and *B. draco* biozones are species of *Bolivina*, *Dentalina*, *Fissurina*, *Gyroidinoides*, *Nodosaria* and *Oolina* which indicate an outer neritic shelf environment of about 200 m water depth (Sliter, 1972; Sliter & Baker, 1972). This unit also includes *Bolivina incrassata gigantea* Wicher and *Praebulimina carseyae* (Plummer) that are useful indicators for outer neritic shelf environments (Sliter & Baker, 1972; Olsson & Nyong, 1984). Planktonic foraminifer assemblages are characterized by *Rugoglobigerina*, *Globigerinelloides*, *Hedbergella* and *Heterohelix* species; according to Sliter (1972) and Hart (1980) species of these genera most likely characterised shallow marine depths.

## SEA LEVEL CHANGE IN THE SHIRANISH FORMATION

The intra-Campanian unconformity recognized 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 Bellen et al., 1959; 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 *Globotruncana ventricosa*, *Rodotruncana calcarata* and *Globotruncanella havanensis* are not recorded.

The lithofacies of the Shiranish Formation suggest a combination 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 *Bolivinoides decoratus* Subzone) represents a major deepening upwards succession indicated by an increasing planktonic to benthonic ratio. The middle part of the ‘lower unit’ of the Shiranish Formation (that part assignable to the *Bolivinoides laevigatus* Subzone) is marked by a Maximum Flooding Surface (MFS) with palaeodepths of at least 600 m (Fig. 7) and is characterized by marl beds associated with the predominance of a planktonic lime-mudstone facies. Thereafter, in the upper part of the ‘lower unit’ sea level begins to drop (see Fig. 7).

In the *B. miliaris* Biozone the Shiranish Formation is characterized 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 point to decreasing marine shelf depths to some 200 m (Sliter, 1972; Abdel-Kireem, 1983; Darvishzad & Abdolalipour, 2009; see Fig. 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. 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 *Bolivinooides* 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 (Al-Banna, 2010; Fayyadh, 2010; Abdel-Kireem, 1983; El-Anbaawy & Sadek, 1979). 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.

#### **TAXONOMIC NOTES ON SPECIES OF *BOLIVINOIDES***

Here we highlight key morphological characters that we have used to diagnose *Bolivinooides* species in the Shiranish Formation, comparing our material with the original descriptions of the species. Specimens figured in plates 1 to 3 are deposited in the collections of the British Geological Survey, Keyworth, Nottingham, UK and are identified by the prefix MPK.

*Bolivinooides australis* Edgell (Pl. 1, Figs 1, 2) was originally described from the Late Cretaceous succession of NW Australia (Edgell, 1954). Our material 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 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. *Bolivinooides laevigatus* can be distinguished from *B. decoratus* by its smaller test and more weakly developed ornamentation.

*Bolivinooides 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. *Bolivinooides 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. Our material possesses the characteristic morphology of the German material described by Hiltermann & Koch (1950).

*Bolivinooides praelaevigatus* Barr (Pl. 2, Figs 11, 12) was described from the Late Cretaceous of Britain (Barr 1966). 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 *Bolivinooides* biozones, the *B. decoratus* Biozone (Late Campanian), subdivided into lower *B. decoratus* and upper *B. laevigatus* biosubzones; *B. miliaris* Biozone (Earliest Maastrichtian) and *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.

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### **Figure, table and plate explanations**

Fig 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 right bank of the Dokan Dam, near the Dokan tourism village. The Azmer section is located about 15 km to the NE of Sulaimani city.

Fig 2: Lithostratigraphy of the Late Cretaceous succession in Iraq (after Bellen et al., 1959; Jassim & Goff, 2006).

Fig 3: *Bolivinooides* biozonation for the Shiranish Formation in the Kurdistan region, NE Iraq. The ‘lower’ and ‘upper’ units of the Shiranish Formation are informally defined (see Bellen et al., 1959; Buday, 1980). First occurrences of key planktonic foraminifera are also shown.

Fig. 4: Late Campanian-Early 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).

Fig. 5: Ranges of recorded Late Campanian-Early Maastrichtian *Bolivinooides* species in the Kurdistan region, NE Iraq. The *Bolivinooides* biozonation in Egypt is based on Khalil (1998) and El-Nady (2006). Note that our definition of the *B. draco* Biozone is based on the first occurrence of the nominate species in abundance, which places our zone 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 *Bolivinooides* and planktonic foraminifer species.

Fig. 6: Biostratigraphic interval recognized in the Shiranish Formation using both *Bolivinooides* and planktonic foraminifera. Key *Bolivinooides* and planktonic foraminiferal occurrences are indicated. In successions where both *Bolivinooides* and planktonic foraminifera are present, it is possible to recognize informally a ‘lower *Gansserina gansseri*’ interval, which represents the latest Campanian, and may therefore be of value for correlation in other Tethyan successions.

Fig. 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 Puceat et al. (2003). The Campanian-Maastrichtian boundary was adapted from Gradstein et al. (2012). Question marks represent uncertainty for the first appearance datum of *Globotruncana aegyptiaca* and the last appearance datum of *Contusotruncana contusa*.

Table 1: Dimensions of the test (in millimetres) and number of lobes on the final chamber of *Bolivinooides* recorded in the Shiranish Formation, NE-Iraq.

### Plate I

Scale bars 100  $\mu\text{m}$

Figs 1, 2: *Bolivinooides australis* Edgell. Uppermost part of the 'lower unit', Shiranish Formation, Earliest Maastrichtian: Fig. 1, MPK14381, from the Azmer section, sample number ASH-52; Fig. 2, MPK14382, from the Dokan section, sample number DSH-90.

Figs 3-9: *Bolivinooides decoratus* (Jones). The 'lower unit' of the Shiranish Formation, Late Campanian: Fig. 3, MPK14383 and Fig. 4, MPK14384, from the Azmer section, sample number ASH-15; Fig. 5, MPK14385 and Fig. 6, MPK14386, from the Dokan section, sample number DSH-05; Fig. 7, MPK14387, from the Dokan section, sample number DSH-15; Fig. 8, MPK14388 and Fig. 9, MPK14389, from the Dokan section, sample number DSH-36.

Figs 10-12: *Bolivinooides draco* (Marsson). The 'upper unit' of the Shiranish Formation, late Early Maastrichtian, Dokan section: Fig. 10, MPK14390 and Fig. 11, MPK14391, sample number DSH-116; Fig. 12, MPK14392, sample number DSH-117.

Figs 13, 14: *Bolivinooides laevigatus* Marie. The 'lower unit' of the Shiranish Formation, Late Campanian, Dokan section: Fig. 13, MPK14393 and Fig. 14, MPK14394, sample number DSH-48.

Figs 15, 16: *Bolivinooides miliaris* (Hiltermann and Koch). Uppermost part of the 'lower unit', Shiranish Formation, Earliest Maastrichtian, Azmer section: Fig. 15, MPK14395 and Fig. 16, MPK14396, sample number ASH-62.

## Plate II

Scale bars 100  $\mu\text{m}$

Figs 1-5: *Bolivinooides decoratus* (Jones). The 'lower unit' of the Shiranish Formation, Late Campanian: Fig. 1, MPK14397, Fig. 2, MPK14398 and Fig. 3, MPK14399, from the Azmer section, sample number ASH-10; Fig. 4, MPK14400 and Fig. 5, MPK14401, from the Dokan section, sample number DSH-36.

Figs 6, 7: *Bolivinooides draco* (Marsson). The 'upper unit' of the Shiranish Formation, late Early Maastrichtian, Dokan section: Fig. 6, MPK14402 and Fig. 7, MPK14403, sample number DSH-110.

Fig. 8: *Bolivinooides laevigatus* Marie. The 'lower unit' of the Shiranish Formation, Late Campanian, Azmer section, MPK14404, sample number ASH-25.

Figs 9, 10: *Bolivinooides miliaris* (Hiltermann and Koch). Lower part of the 'upper unit', Shiranish Formation, Earliest Maastrichtian, Dokan section: Fig. 9, MPK14405 and Fig. 10, MPK14406, sample number DSH-103.

Figs 11, 12: *Bolivinooides praelaevigatus* (Barr). The 'lower unit' of the Shiranish Formation, Late Campanian, Dokan section: Fig. 11, MPK14407 and Fig. 12, MPK14408, sample number DSH-08.

## Plate III

**Scale bars 100 µm**

Figs 1-4: *Globotruncana aegyptiaca* Nakkady. The ‘lower unit’ of the Shiranish Formation, Late Campanian: 1 and 3 umbilical views, 2 and 4 spiral views, from the *Globotruncana aegyptiaca* Biozone: Figs 1, 2, MPK14409, Azmer section, sample number ASH-02; Figs 3, 4, MPK14410, Dokan section, sample number DSH-05.

Figs 5, 6: *Gansserina gansseri* (Bolli). The ‘upper unit’ of the Shiranish Formation, Early Maastrichtian: 5, umbilical view, 6, spiral view, from the *Gansserina gansseri* Biozone, MPK14411, Dokan section, sample number DSH-88.

Figs 7, 8: *Globotruncana linneiana* d’Orbigny. The ‘lower unit’ of the Shiranish Formation, Late Campanian: 7, umbilical view, 8, spiral view, from the *Gansserina gansseri* Biozone, MPK14412, Azmer section, sample number ASH-40.

Figs 9, 10: *Rugoglobigerina hexacamerata* Bronnimann. Uppermost part of the ‘lower unit’, Shiranish Formation, Early Maastrichtian: 9, umbilical view, 10, spiral view, from the *Gansserina gansseri* Biozone, MPK14413, Dokan section, sample number DSH-86.

Figs 11, 12: *Contusotruncana walfischensis* (Todd). The ‘upper unit’ of the Shiranish Formation, late Early Maastrichtian: 11, spiral view, 12, side view, from the *Contusotruncana contusa* Biozone, MPK14414, Dokan section, sample number DSH-117.

Figs 13, 14: *Contusotruncana contusa* (Cushman). The ‘upper unit’ of the Shiranish Formation, late Early Maastrichtian: 13, spiral view, 14, side view, from the *Contusotruncana contusa* Biozone, MPK14415, Dokan section, sample number DSH-117.

Fig. 15: *Planoglobulina acervulinoides* (Egger). Lower part of the 'upper unit', Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14416, Dokan section, sample number DSH-88.

Fig. 16: *Rugoglobigerina pennyi* Bronnimann. Lower part of the 'upper unit', Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14417, Dokan section, sample number DSH-88.

Fig. 17: *Rodotruncana subspinosa* (Pessagno). The 'upper unit' of the Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14418, Dokan section, sample number DSH-88.

Fig. 18: *Globotruncanita stuarti* (de Lapparent). The 'upper unit' of the Shiranish Formation, Early Maastrichtian: from the *Gansserina gansseri* Biozone, MPK14419, Dokan section, sample number DSH-80.

### **Appendix 1: Stratigraphic position of sample numbers given in plates 1-3.**

The specimens illustrated in this paper are deposited in the British Geological Survey, Keyworth, Nottingham. The MPA numbers are the British Geological Survey numbers for the samples from which the fossil specimens come from.

#### Azmer section

ASH-02, MPA63960, 1.5 m above the base of the Shiranish Formation.

ASH-10, MPA63961, 15 m above the base of the Shiranish Formation.

ASH-15, MPA63962, 22 m above the base of the Shiranish Formation.

ASH-25, MPA63963, 37 m above the base of the Shiranish Formation.

ASH-40, MPA63964, 57 m above the base of the Shiranish Formation.

ASH-52, MPA63965, 73 m above the base of the Shiranish Formation.

ASH-62, MPA63966, 87 m above the base of the Shiranish Formation.

#### Dokan section

DSH-05, MPA63967, 12.5 m above the base of the Shiranish Formation.

DSH-08, MPA63968, 17.5 m above the base of the Shiranish Formation.

DSH-15, MPA63969, 29.5 m above the base of the Shiranish Formation.

DSH-36, MPA63970, 64 m above the base of the Shiranish Formation.

DSH-48, MPA63971, 85 m above the base of the Shiranish Formation.

DSH-80, MPA63972, 148.5 m above the base of the Shiranish Formation.

DSH-86, MPA63973, 162 m above the base of the Shiranish Formation.

DSH-88, MPA63974, 167 m above the base of the Shiranish Formation.

DSH-90, MPA63975, 171 m above the base of the Shiranish Formation.

DSH-103, MPA63976, 195.5 m above the base of the Shiranish Formation.

DSh-110, MPA63977, 212 m above the base of the Shiranish Formation.

DSH-116, MPA63978, 226.5 m above the base of the Shiranish Formation.

DSH-117, MPA63979, 228 m above the base of the Shiranish Formation.

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Fig. 1

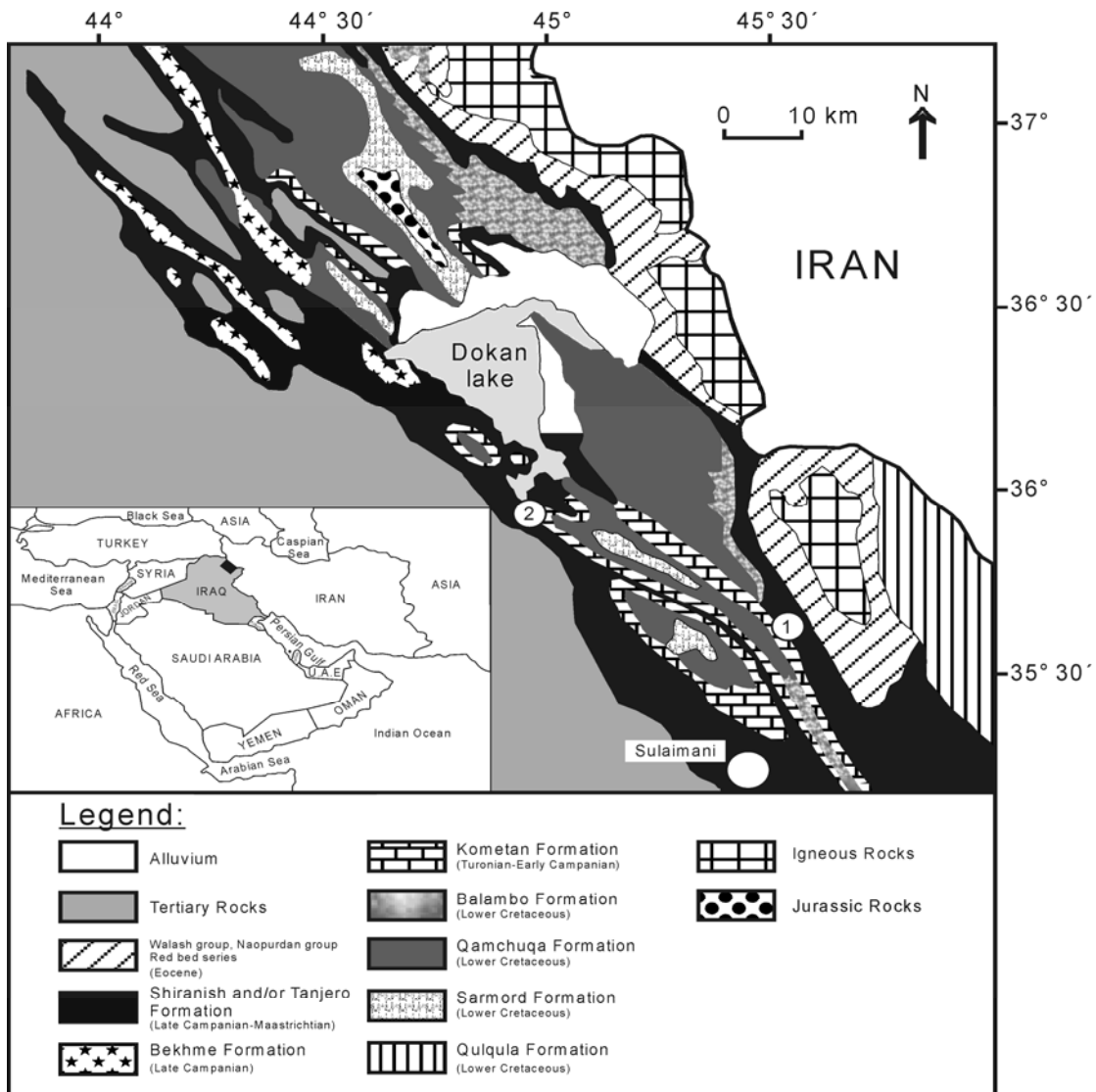


Fig. 2

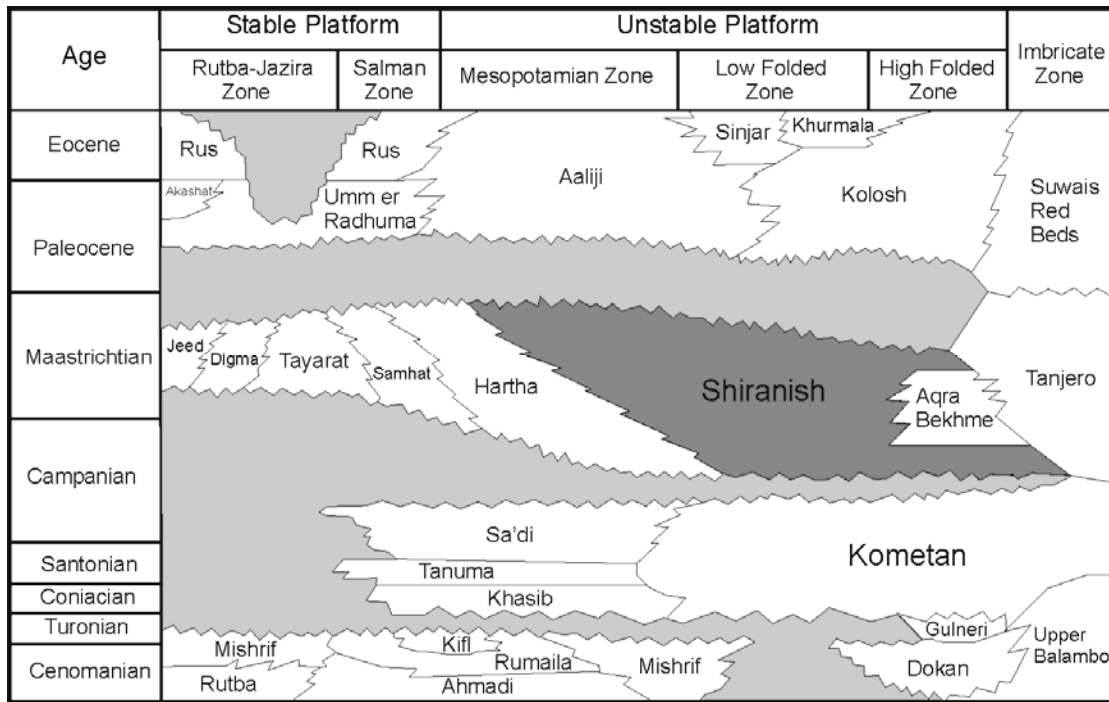


Fig. 3.

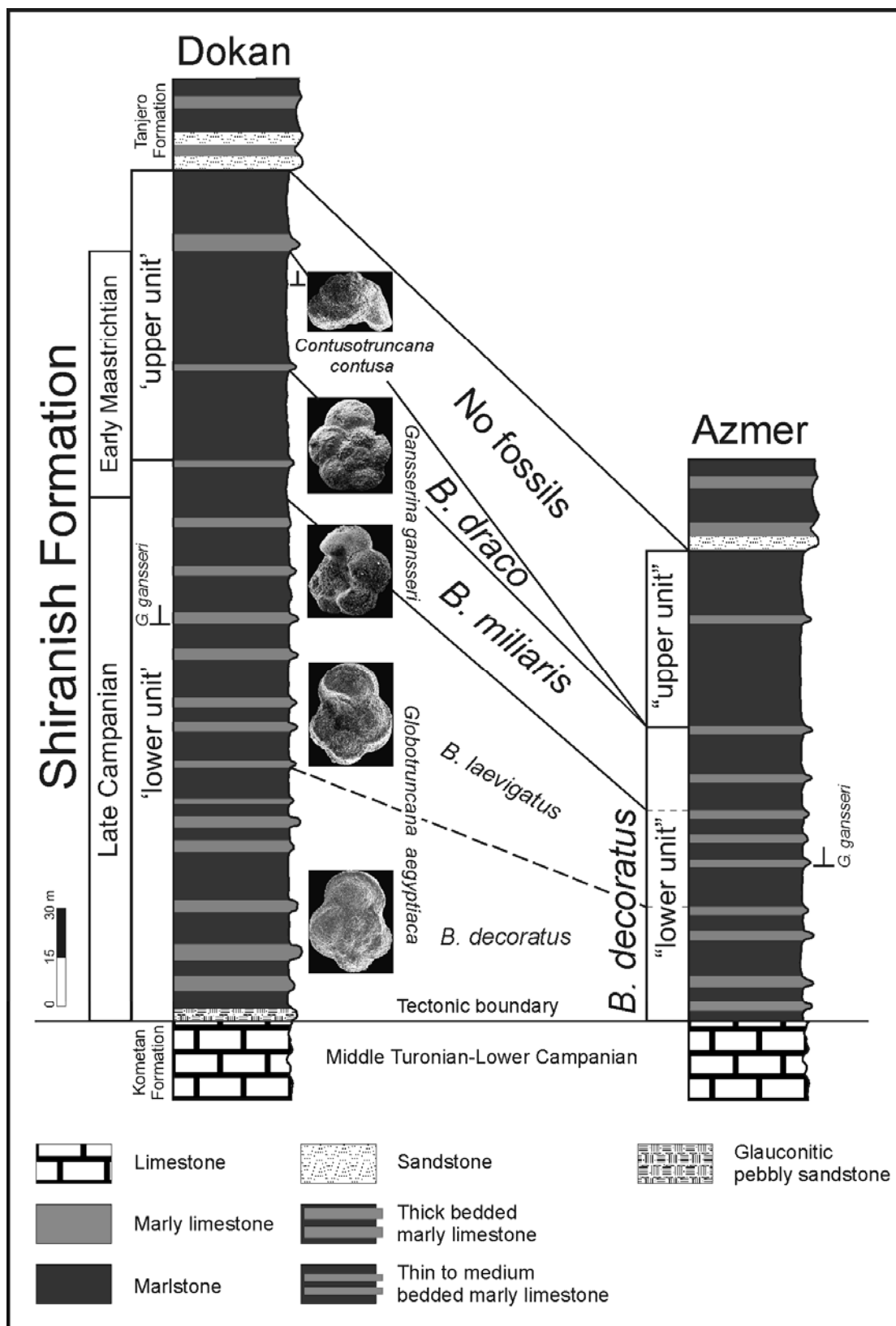


Fig. 4.

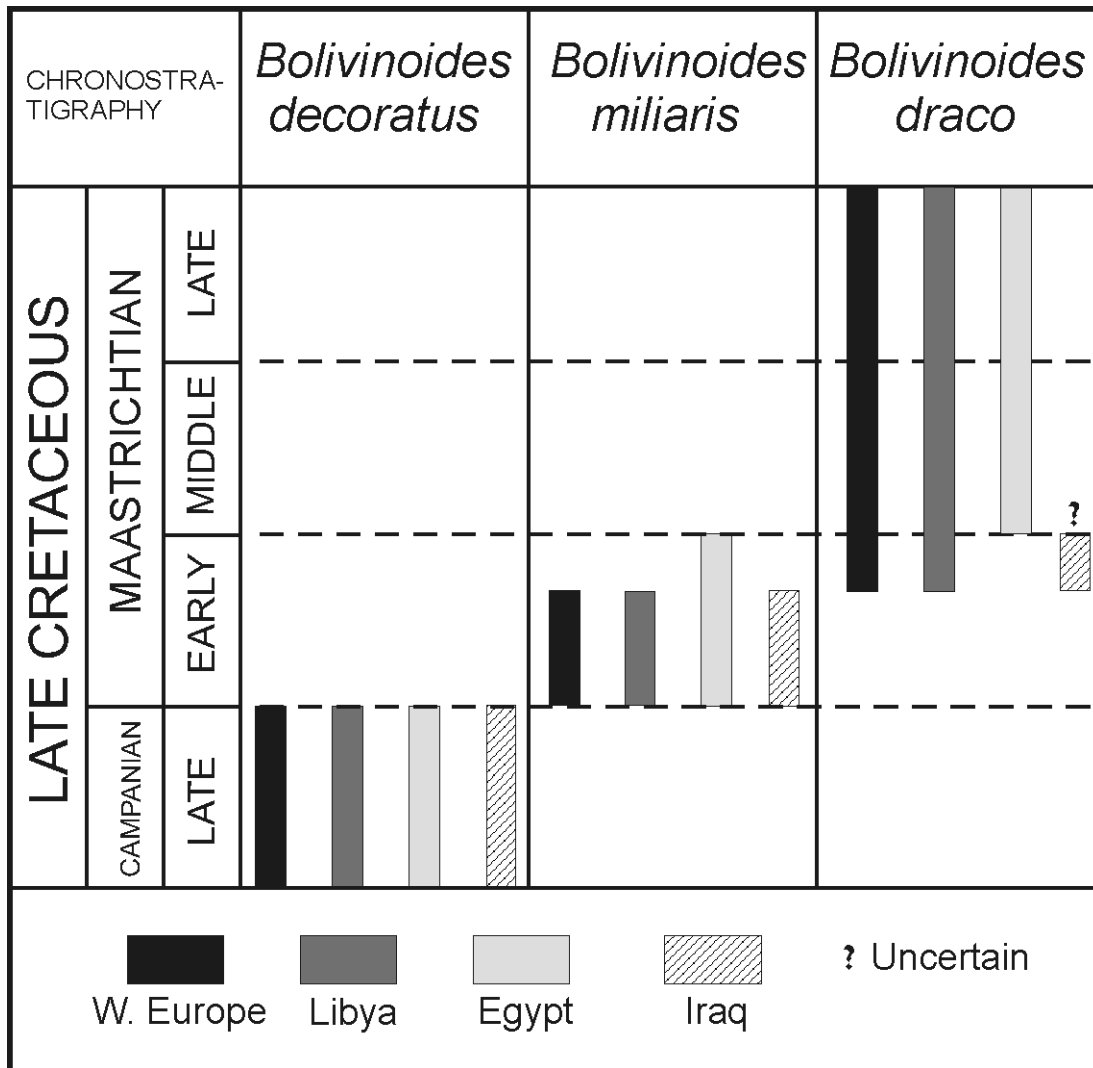


Fig. 5.

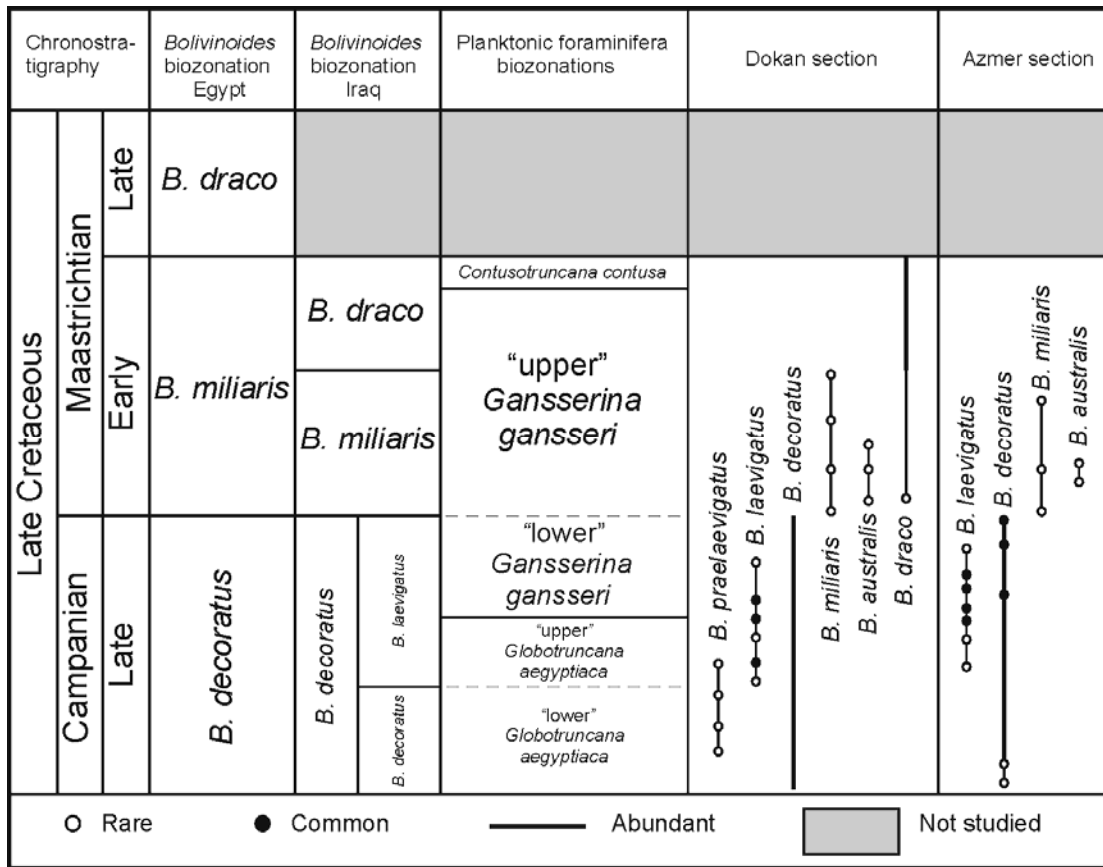


Fig.6.

Chronostratigraphy		Formation	<i>Bolivinoidea</i> biozonations	Planktonic foraminifera biozonations	First occurrence markers for planktonic foraminifera	
Late Cretaceous	Maastrichtian	Shiranish	'upper unit'	<i>B. draco</i>	<i>Contusotruncana contusa</i>	↓ <i>Contusotruncana contusa</i> <i>Rugoglobigerina scotti</i>
				<i>B. miliaris</i> T	"upper" <i>Gansserina gansseri</i>	
	<i>B. miliaris</i>		↓ <i>Rugoglobigerina hexacamerata</i> <i>Rugoglobigerina pennyi</i> <i>Planoglobulina acervulinoides</i>			
	<i>B. draco</i> <i>B. miliaris</i> ↓			"lower" <i>Gansserina gansseri</i>	↓ <i>Gansserina gansseri</i>	
<i>B. decoratus</i> T	"upper" <i>Globotruncana aegyptiaca</i>					
Campanian	Late	'Lower unit'	<i>B. decoratus</i>	<i>B. laevigatus</i>	"lower" <i>Globotruncana aegyptiaca</i>	
				<i>B. decoratus</i> ↓		
			<i>B. decoratus</i> ↓			

↓ First Appearance Datum      T Last Appearance Datum

Fig. 7.

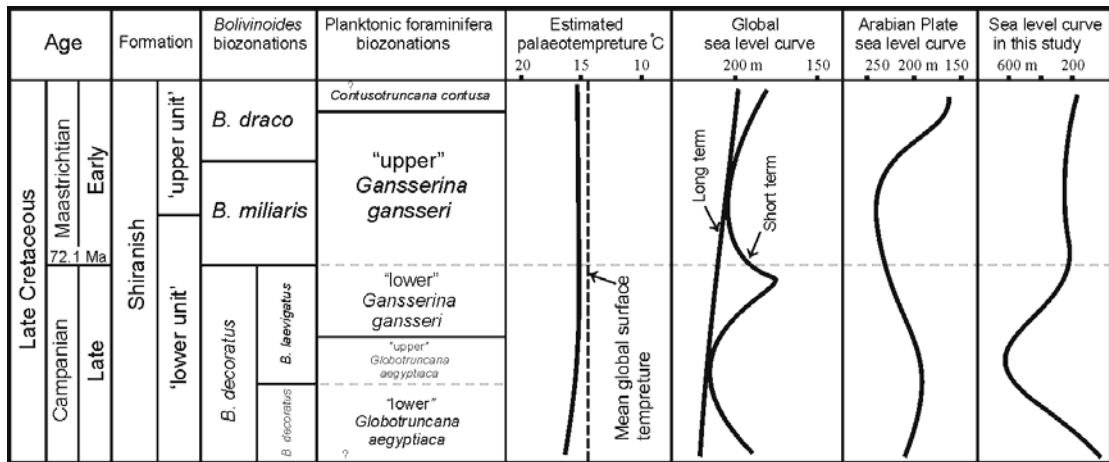


Plate 1

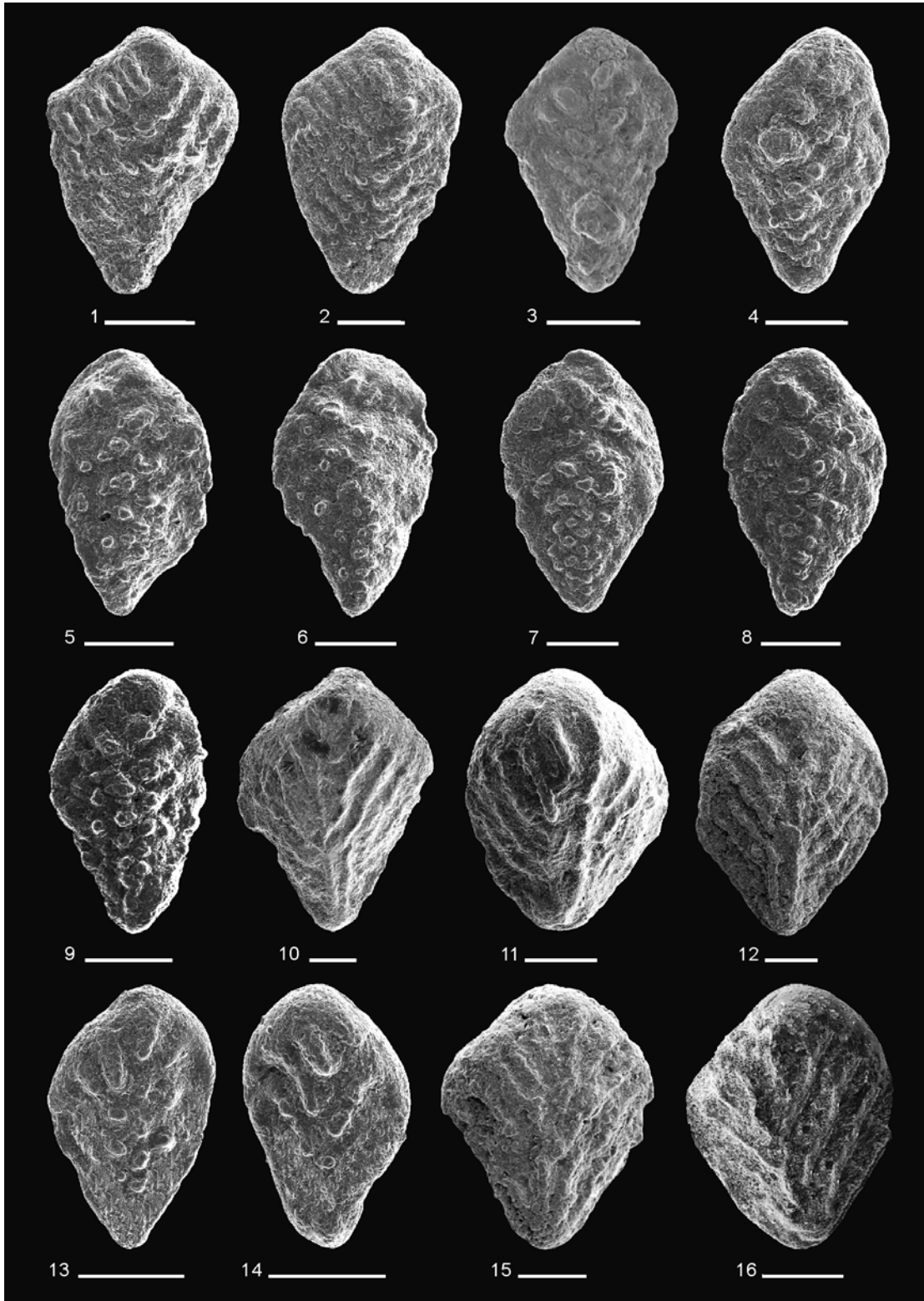


Plate 2

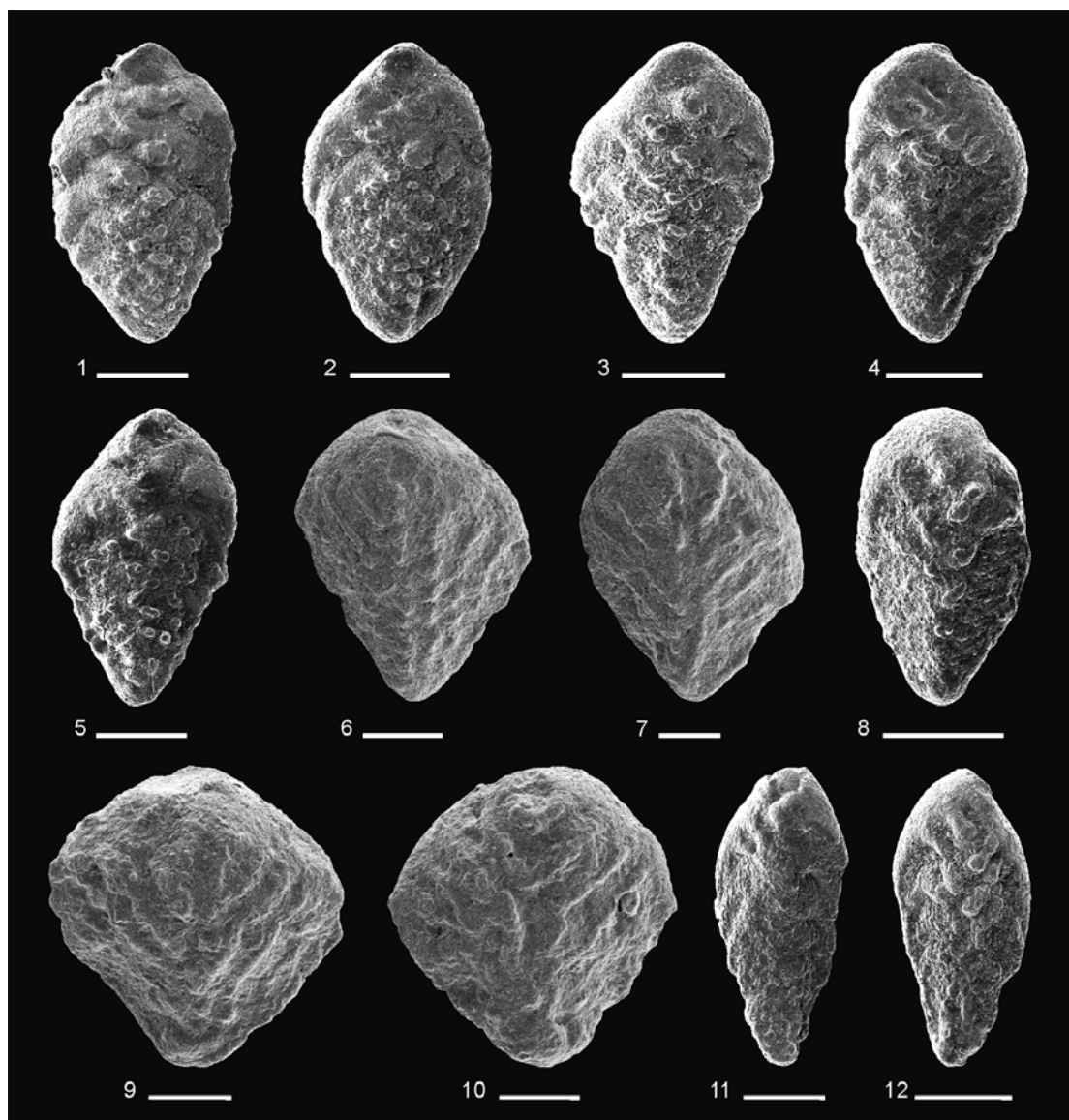


Plate 3

