Late Maastrichtian benthic foraminiferal response to palaeoenvironmental changes: a case study from the AbTalkh Formation, west of Kopeh-Dagh Basin, Iran

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Abstract

Benthic foraminiferal assemblages from Maastrichtian strata, *Gansserina gansseri-Abathamphalus mayaroensis* Planktonic Foraminiferal Zone, of the AbTalkh Formation at Aitamir section (west of the Kopeh-Dagh basin) were investigated in order to evaluate the palaeoenvironmental changes (organic matter flux and bottom-water oxygenation). Maastrichtian faunal assemblages are well preserved and diversified. Fluctuations in the percentage of infaunal and epifaunal morphogroups as well as simple diversity and heterogeneity index are recorded. The study indicates that an unstable environment with oligotrophic to weakly mesotrophic condition and high oxygenated bottom water condition was prevailed during the depositionof the sediments in the latest Cretaceous.

Keywords: *Maastrichtian, Benthic foraminifera, Palaeoenvironment, Kopeh- Dagh basin, Iran*

Introduction

Benthic foraminifers are proxies for nutrient supply as well as for oxygenation at the sea floor, and thus constitute an important tool to reconstruct palaeoenvironmental changes (Alegret & Thomas, 2005).

Furthermore, benthic foraminiferal tests are used to identify different deep-water masses based on environmental parameters such as salinity, temperature, and oxygenation (e.g., Barrera *et Al.,* 1997; Mackensen & Bickert, 1999; Thomas *et al*., 2000). There are numerous Late Maastrichtian studies concerning the distribution pattern of benthic foraminifera and their palaeoecological and paleo-ceanographic interpretation (e.g., Thomas, 1990; Widmark, 1995; Widmark & Speijer, 1997a, b). The palaeobiogeographic distribution of Late Maastrichtian benthic foraminifera was shown by Widmark & Malmgren (1992), Widmark & Speijer (1997a,b) and Widmark (2000). Widmark (1995) suggested that high-latitude fauna were dominated by taxa indicative of oligotrophic and high-oxygenated

environments, whereas low- latitude fauna were dominated by taxa reflecting more eutrophic and less-oxygenated bottom waters. In addition, numerous studies of benthic foraminifera have been carried out, especially on the palaeoecological interpretation of the terminal Maastrichtian, Cretaceous/Tertiary boundary (e.g., Speijer and Van der Zwaan, 1996; Alegret *et al*., 2001 Culver,

2003; Alegret & Thomas, 2004). This paper deals with a quantitative study of the Late Maastrichtian benthic foraminifera, from Aitamir Formation, (East of the Kopeh-Dagh basin) to evaluate the changes in the benthic foraminiferal ecosystem.

Methods and Location

The studied succession is located in the west of Kopeh-Dagh basin, in Aitamir Syncline, 100 km north of the Gonbad e kavous city, 6 km east of Aitamir and 3km north of Cherla villages in Golestan State, NE of Iran. At this section, the lower and upper boundaries of the formation with Abdraz and Chehel-kaman formations are transitional and conform (Afshar Harb, 1994; Aghanabati, 2004). The formation at this locality is 489 m thick and essentially composed of shales and marls, interlayered with limestone layers (Fig.1). One hundred and thirteen samples from Shaly and Marly interval of the AbTalkh Fm. were analyzed for this study.

All samples were disaggregated in diluted H2O2 and washed over a 63μm mesh, dried, and sieved into 63 - 125 μm, 125 - 250 μm and > 500 μm fractions.

To analyze benthic foraminiferal assemblages, 200-400 individuals/sample (planktonic and benthic foraminiferal specimens) were picked randomly from the 125–500 μm and >500 μm fractions. Where necessary, samples were split and counts were recalculated for the entire sample (in samples

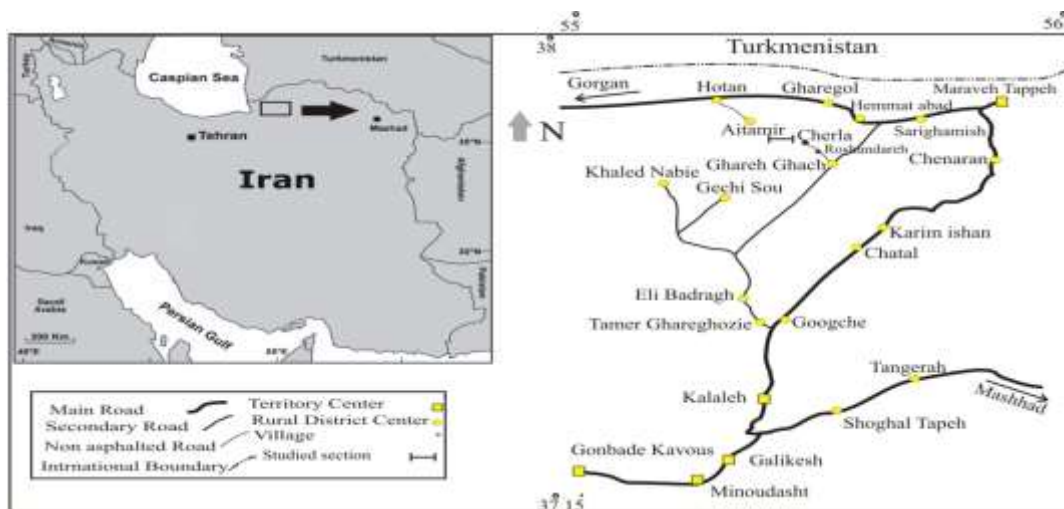with less than 200 individuals, the whole sample was picked) (Table.1).

Figure 1: Location map of the studied section.

All specimens were picked, identified, counted and mounted on microscope slides for a permanent record. Benthic foraminifers were identified at the generic level largely following Loeblich & Tappan (1987) and at the specific level following Alegret & Thomas (2001).

Diversity and benthic foraminiferal number (BFN) were also calculated for the samples. As proxies for diversity we calculated the H(S) Shannon–Weaver information function and also species richness (simple diversity). High values of H(S) indicate an even distribution of specimens over species; Murray (1991) calls H(S) the index of heterogeneity, with high heterogeneity values indicating high diversity. The Shannon–Weaver index H(S), (Shannon & Weaver, 1949; Murray, 1991) takes into account the number of taxa in a sample and their equitability of distribution within that sample.

The Shannon–Weaver index is calculated as follows:

$$\mathrm{H}(S) = \sum_{i=1}^{s} piLnpi$$

Where H(S) is the heterogenity index or Shannon diversity, S is the number of species (simple diversity), ni is the number of individuals in species i (the abundance of species i). Also, n the total number of all individuals and pi is the relative abundance of each species, calculated as the proportion of individuals of a given species (*ni*) to the total number of individuals in the community (n): *ni/n*

This study follows diversity classification of Holbourn *et al*., (2001) and assigns H(S) values from 0 to <1 as low diversity assemblages, 1 to < 2 as moderate diversity assemblages and >2 as high diversity assemblages. We calculated the percentage of buliminid and rotaliid taxa for all samples; a high relative abundance of buliminid taxa has been related to high productivity and/or low levels of oxygen at the sea floor (e.g., Widmark and Speijer, 1997a; Fontanier *et al*., 2002) contrary to rotaliids, which favored oxygenated bottom water (Sen Gupta & Machain-Jorissen *et al*., 1993). Furthermore, the percentage of agglutinated foraminifers was calculated for all the studied samples, in order to infer probable microhabitat preferences as the nutrient supply to the seafloor or sea water oxygenation (e.g., Bernhard, 1986; Jorissen *et al*., 1995).

We divided all the specimens into infaunal and epifaunal morphogroups, following Corliss (1985), Jones & Chrnock (1985), Corliss & Chen (1988).

Infaunal species (living at > 1 cm depth) tend to have tests that are rounded and planispiral or flattened ovoid, flattened tapered, tapered and cylindrical or spherical in shape with pores all over the test, whereas foraminifers with planoconvex, biconvex and rounded troche-spiral tests, as well as tubular and coiled flattened tests, have an inferred epifaunal mode of life. Major changes in percentages of these morphogroups are considered to be significant (e.g., Gooday, 2003).

Table1: Benthic foraminiferal number in the studied samples

Table 1 (Continued).

Microhabitats cannot always be predicted correctly; assignments appear to be correct in about 75% of cases (Buzas *et al.*, 1993).

Kaiho (1991, 1992, 1994a) suggested that an oxygenation index could be derived from the relative abundance of different morphotypes of

calcareous taxa. Kaiho (1994b, 1999) defined a benthic foraminiferal oxygenation index (BFOI) using data on living foraminifers. Thus, we calculated the BFOI for our samples. Kaiho's indices are somewhat differently defined (Kaiho, 1991, 1994b, 1999); we used his 1994b definition. However, it has been documented by several authors that these values indicate some combination of oxygenation and food supply (e.g., Jorissen *et al*., 1995, 1998; Den Dulk *et al*., 2000; Morigi *et al*., 2001; see also review by Gooday, 2003).

Ecological concepts
Benthic foraminiferal number
The benthic foraminiferal number (BFN) is a useful proxy to estimate oxygen content and organic matter flux in the past (e.g., Kaiho and Hasegawa, 1994; Jorissen *et al*., 1995). In oxygen depleted sediments, the BFN generally decreases as observed, e.g., for Mid-Cretaceous black shales (Coccioni & Galeotti, 1993, Friedrich *et al*., 2003). In contrast, a higher BFN is observed with increasing organic matter flux to the seafloor. The Increasing organic matter flux 1986; Kaiho, 1994; Jorissen *et al*., 1992, 1995), however, leads to oxygen consumption at the seafloor and thus decreasing BFN if a certain threshold is passed (e.g., Murray, 2000). Consequently, the BFN is controlled by both oxygen content and organic matter flux .

To discern the role of each of these factors alone, other data from benthic foraminiferal assemblages besides the BFN are necessary.

Diversity
Assemblage diversity is presented as species richness (number of species per sample), and Shannon-Weaver index (H(S)).

Benthic foraminiferal diversity is another parameter to estimate oxygen content and organic matter flux for ancient bottom waters. In general, Quaternary assemblages exposed to low oxygen and/or high organic matter flux exhibit a low diversity and a dominance of a few taxa (e.g., Den Dulkc *et al*., 1998; Van der Zwaan *et al*., 1999). The same pattern was observed in Mesozoic Black shales (e.g., Holbourn *et al*., 2001). However, low diversity faunas also occur under oxygenated conditions if the organic matter flux is very low (e.g., Schmiedl *et al*., 1998). Therefore, together with other parameters (e.g., benthic foraminiferal

number, epifaunal–infaunal ratio), diversity can be used to estimate organic-matter flux and oxygenation of bottom-water environments .

Epifaunal– infaunal ratio
In order to infer probable microhabitat preferences and environmental parameters, such as the nutrient supply to the sea floor or sea-water oxygenation (e.g., Bernhard, 1986; Jorissen *et al*., 1995), all taxa were divided into infaunal and epifaunal morphogroups, following Nagy *et al*. (1995), and Vanden Akker *et al*. (2000). Infaunal foraminifers, living in the deeper layers of the sediment, with cylindrical or flattened tapered, spherical, rounded planispiral, flattened ovoid, globular unilocular or elongate multilocular tests become more abundant under low-oxygen conditions and/or high organic matter fluxes.

In contrast, epifaunal foraminifers, living on sediment surface or at the uppermost layers, with plano-convex, biconvex and rounded trochospiral, tubular and coiled-flattened tests, dominate in relatively low organic carbon fluxes and high-oxygen condition (Gooday, 1994; Jorissen *et al*., 1995). Therefore, a significant change in the dominance of one of the two groups could indicate changes in the ecological factors controlling benthic foraminiferal assemblages. We use the relative abundance of morphotypes indicating infaunal taxa as an overall indicator of delivery of food to the sea floor (Gooday, 2003).

Benthic foraminiferal assemblages
Studies on recent benthic foraminifera have shown that some species or groups exhibit preferences for specific oxygen and/or trophic levels, whereas others are tolerant to a wide range of oxygen availability and many types of food (e.g., Gooday, 2003; Geslin *et al.*, 2004a, b; Heinz *et al*., 2005; Nomaki *et al*., 2005, 2006). In general, based on TROX model, in which the penetration depth of benthic foraminiferal faunas, or microhabitat depth, is explained as a function of oxygen and food availability.

In this model, Jorissen *et al*., (1995) suggest that foraminiferal species have both a certain critical oxygen requirement and certain food requirements. Of course, both parameters will vary considerably amongst the various species. The organic carbon flux to the sea floor is the predominant environmental parameter controlling the

composition of benthic foraminiferal assemblages, and the oxygen concentration becomes limiting when it reaches a critical level for a species. The amount of organic matter flux to the see floor, however, mainly governs the occurrence of species in the sediment, if oxygen content of bottom-water environments is not the limiting factor (Van der Zwaan *et al.*, 1999). In contrast to recent benthic foraminifera, the ecological pereferences of Late Cretaceous taxa are less well established. Some information is also available from the comparison of fossil and recent assemblages (e.g ., Kaiho, 1994; Van der Zwaan *et al.*, 1999), the interaction of benthic foraminifera with other proxies (e.g., geochemical data or planktic organisms), and the relation of different taxa to distinctive sedimentological layers, e .g ., black shales (e.g., Friedrich *et al.*, 2005b) or perturbation. The abundance ratio of buliminids (this group includes *Bolivina* d'Orbigny, *Bolivinoides* Cushman, *Eouvigerina* Cushman, *Loxostomum* Ehrenberg, *Neobulimina* Cushman and Wickenden, *Praebulimina* Hofker) to rotaliids (this group includes *Angulogavelinella* Hofker, *Cibicides* de Montfort, *Gavelinella* Brotzen *Gyroidinoides* Brotzen, *Nonionella* Cushman, *Osangularia* Brotzen) (B/R), were used for estimating the variability in bottom water aeration. The buliminids to rotaliids ratio is often used to determine the oxygenation level of the bottom water in modern and ancient sediments (Nyong and Olsson, 1984; Almogi-Labin *et al.*, 1993). Within the buliminids group, triserial buliminids are regarded as infaunal species, indicative of a very low-oxygenated seafloor and higher organic matter fluxes (e.g., Holbourn *et al.*, 1999a,b, 2001; Friedrich *et al.*, 2006; Friedrich, 2009).

Benthic Foraminiferal Oxygen Index (BFOI)
Deep-sea infaunal calcareous benthic foraminifera are abundant inhabitants of the top 15 cm of seafloor sediment in areas shallower than the calcium carbonate compensation depth (Corliss, 1991; Kaiho, 1994a). Changes in dissolved oxygen concentration at the sediment/water interface and related factors apparently play a major role in controlling the composition of benthic foraminiferal assemblages and morphotypic characteristics including test size, wall thickness, and morphology (Phleger & Soutar, 1973; Perez-Cruz & Machain-Castillo, 1990). These various

morphologic and taxonomic parameters have been quantified by Kaiho (1994a) in terms of the Benthic Foraminiferal Oxygen Index (BFOI). Calcareous benthic foraminifera are divided into dysoxic (0.1–0.3 ml/l), suboxic (0.3–1.2 ml/l), and oxic (>1.2 ml/l) indicators on the basis of relations between specific morphologic characters (or species composition) and oxygen levels and calcareous benthic foraminiferal microhabitat (Appendix A; Kaiho, 1994a). The following equations of Kaiho (1994a) were used to obtain the BFOI :

(1)When O is greater than zero [O/(O+D)] × 100 (where O and D are number of specimens of oxic and dysoxic indicators, respectively). (2) When O equals zero and SD (S is the number of specimens of suboxic indicators) is greater than zero, [S/S+D-1]×50.

Kaiho (1994a) recognized five ranges of dissolved oxygen levels (0.1–0.3, 0.3–1.2, 1.2–2.0, 2.0–3.2, 3.2–6.0ml/l) respect to BFOI. Specific dissolved oxygen values cannot be estimated using the BFOI because of potential errors caused by other environmental factors such as organic carbon flux, organic carbon content, and salinity (Kaiho, 1999). Only a range of dissolved-oxygen values can be assigned rather than specific values.

Kaiho (1999) presented six dissolved-oxygen conditions which can be identified using the BFOI instead of the original five proposed by Kaiho (1994a). Thus, the BFOI correlates well with the dissolved-oxygen levels in overlying waters for the entire range of oxygen. The results led to consider the application of the BFOI as a useful indicator for discrimination between the six conditions of dissolved oxygen in water column.
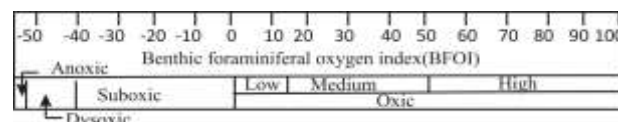

Figure 2: Empirical relation between benthic foraminiferal oxygen index and dissolved oxygen levels in modern ocean and six dissolved-oxygen conditions (Kaiho,1999).

Results
Abundance and species diversity
In total, 73 taxa of benthic foraminifera were identified in the studied succession. The fauna is strongly dominated by calcareous forms (more than 75% in all samples), indicating deposition well above the calcite compensation depth (Fig. 3).
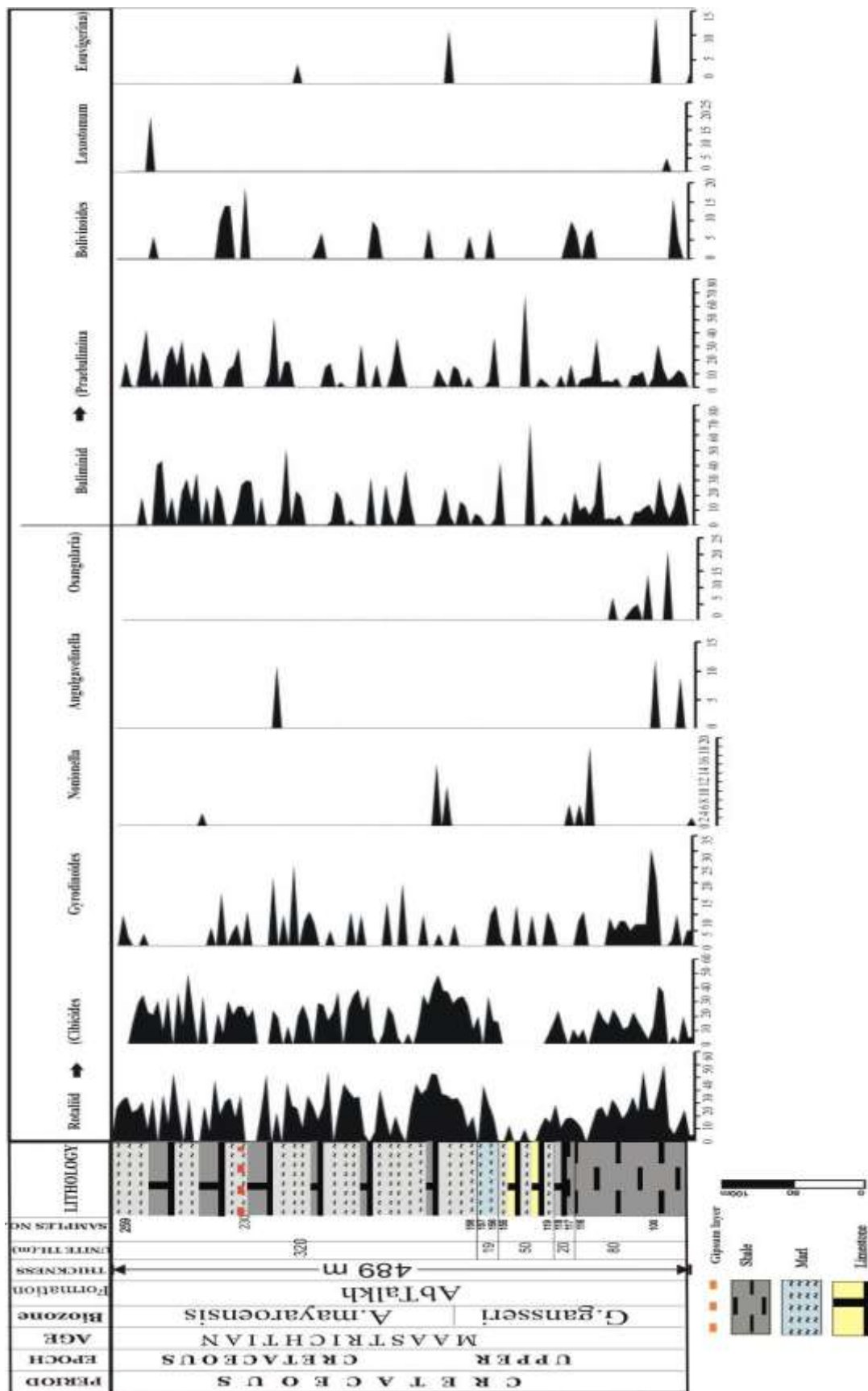
Figure 3: Occurrence and relative abundance of the rotaliids and buliminids benthic foraminiferal species in the studied section

Generally speaking, the complete succession exhibits high BFN (Abundance) and benthic foraminiferal diversity fluctuations. The lower part of the succession (shales) characterized by low fluctuations in benthic foraminiferal number (Fig.3), followed by solid and high fluctuations within the marls, intercalated with limestone. Benthic foraminiferal numbers show strong fluctuations between 0 and 241 individuals. High numbers generally are found in the middle part of the succession in the gray marl beds interbeded with limestone.

BFNs exhibit low numbers within the gypsum layer and intercalated dark limestone in the marls. Highest BFN in the investigated succession possibly reflects increase in oxygenation at the sea-floor, enabling more benthic foraminifera to survive. Thus, high BFN changes demonstrate high fluctuations in organic matter flux.

Increasing organic matter flux, however, leads to oxygen consumption on the sea floor due to the oxidation of the organic material and thus decreasing BFN.

In the studied interval both benthic foraminiferal heterogeneity index H(S) and species richness characterize by conspicuous fluctuations.

The amount of H(S) numbers range from 0 to 2.9 (Fig. 3). The numbers of lower and upper part of the succession shows minor variations between 2 and 2.9. In the black shale interval, and marls, H(S) increases to 3, then decreases to 0.6 and 0 within the Gypsum and intercalated limestones. High BFNs and high diversities in the studied section indicate well oxygenated bottom waters under more mesotrophic conditions. Very low BFNs and fluctuating diversity between 0 and 2.1 indicate low oxygenation and possibly high organic matter fluxes to the sea floor. High values of H(S) indicate an even distribution of specimens over species.

Benthic foraminifera assemblage

The epifaunal–infaunal ratio shows a marked dominance of epifaunal species through the studied succession. In the studied section assemblages are highly diverse, and contain both infaunal *(Praebulimina kickapooensis, Praebulimina reussi)* and epifaunal morphogroups *(Globorotalites, Nuttallides, Gyroidinoides, Anomalinoides* spp.). Epifaunal morphotypes make up 40-100% of the assemblages fluctuation (Fig. 4). Dominance of epifaunal species, often indicates high oxygen

condition and/or low nutrient concentration (Bernhard, 1986). Benthic foraminiferal assemblages dominated by epifaunal or mixed epifaunal-infaunal morphogroups suggest that the food supply to the benthos was less abundant in the latest Cretaceous (e.g. following Jorissen *et al.*, 1995; Van der Zwaan *et al.*, 1999). Benthic foraminiferal assemblages from the uppermost Maastrihtian *A. mayaroensis* Biozone are diverse, contain abundant rotalids and consist of both infaunal and epifaunal morphogroups (Fig. 3, 4). According to Jorissen *et al.* (1995) and Gooday (2003), assemblages composed of mixed infauna and epifaunal morphogroups may well have lived under mesotrophic conditions, with enough organic matter not only at the sediment surface, but also in the deeper layers of the sediment. The studied section is characterized by the high fluctuation of buliminids, and rotalids, but on the whole rotalids are dominant (70% of total benthic foraminifera) comprising *Anomalinoides*, *Cibicides* (Fig. 3).

Lower part, and also interval between 170-350m of the studied section is characterized by low abundance of rotalids (below 10%), and high abundance of buliminids, consisting mainly of *Praebulimina reussi* and *Praebulimin kickapooensis* (above 80 %). In the middle and upper part of the section, abundance of rotalids rises and varies between 55–80%. In the studied interval *bulimina* has low abundance (Fig.3). In the geological record *buliminids* have been found in association with high and fairly stable food supply and/or low levels of oxygen at the seafloor, contrary to rotalids, which favore oxygenated bottom water (Kaiho, 1994; Bernhard *et al.*, 1997; Leckie *et al.*, 1998).

The benthic foraminiferal assemblages of the studied section are quite similar to their Late Cretaceous counterparts in oligotrophic shelf and open ocean environments, such as those found in Mexico, Tunisia, North Atlantic and North Pacific (Li & Keller, 1999; Alegret *et al.*, 2001; Frank *et al.*, 2005; Friedrich & Hemleben, 2007). The benthic foraminiferal assemblages at these localities are more diverse and consist mostly of epifaunal and shallow infaunal species. The benthic assemblage of the studied section is dominated by epifaunal species. It has been suggested that Maastrichtian species of the genus *Buliminia* to reflect a high organic matter flux to the seafloor,
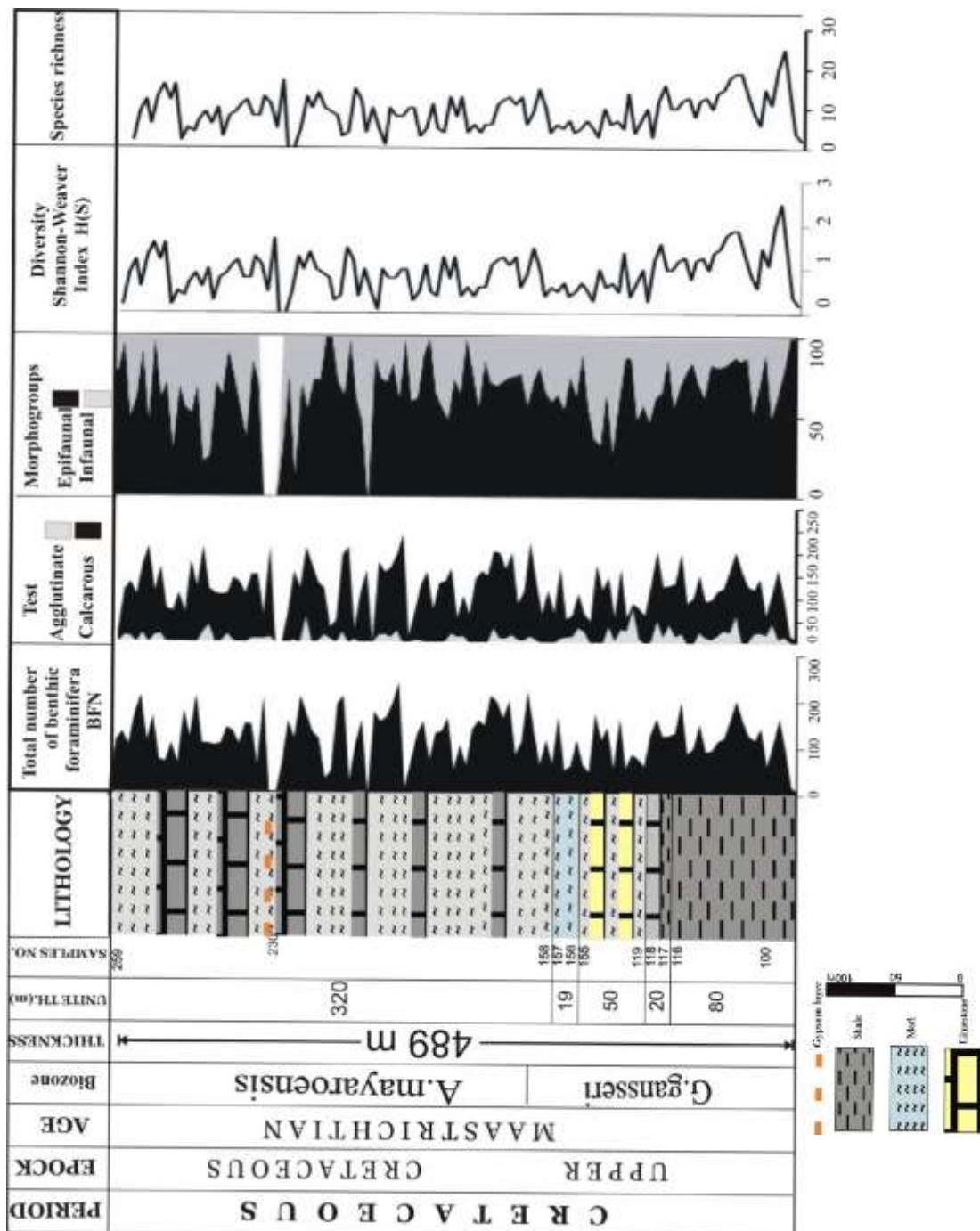
Figure 4: Distribution of Benthic foraminifera (BFN), percentages of benthic foraminifera with calcareous and agglutinated tests, relative abundances of infaunal and epifaunal morphogroups, Shannon-Weaver H(s) heterogeneity index, species richness through the formation studied.

combined with low oxygen contents in bottom waters (e.g., Coccioni *et al*., 1993; Widmark, 1997). In the studied section low abundance of *Bulimina* also indicate oligotrophic and low oxygen condition. Additionally, several taxa show low abundances in this succession (*Spiroplectammina*

spp.) These species have been reported to tolerate high organic matter fluxes and decreasing oxygen levels, (Schönfeld, 1990; Lommerzheim, 1991), regarded also as shallow water taxa (shelf to marginal marine).
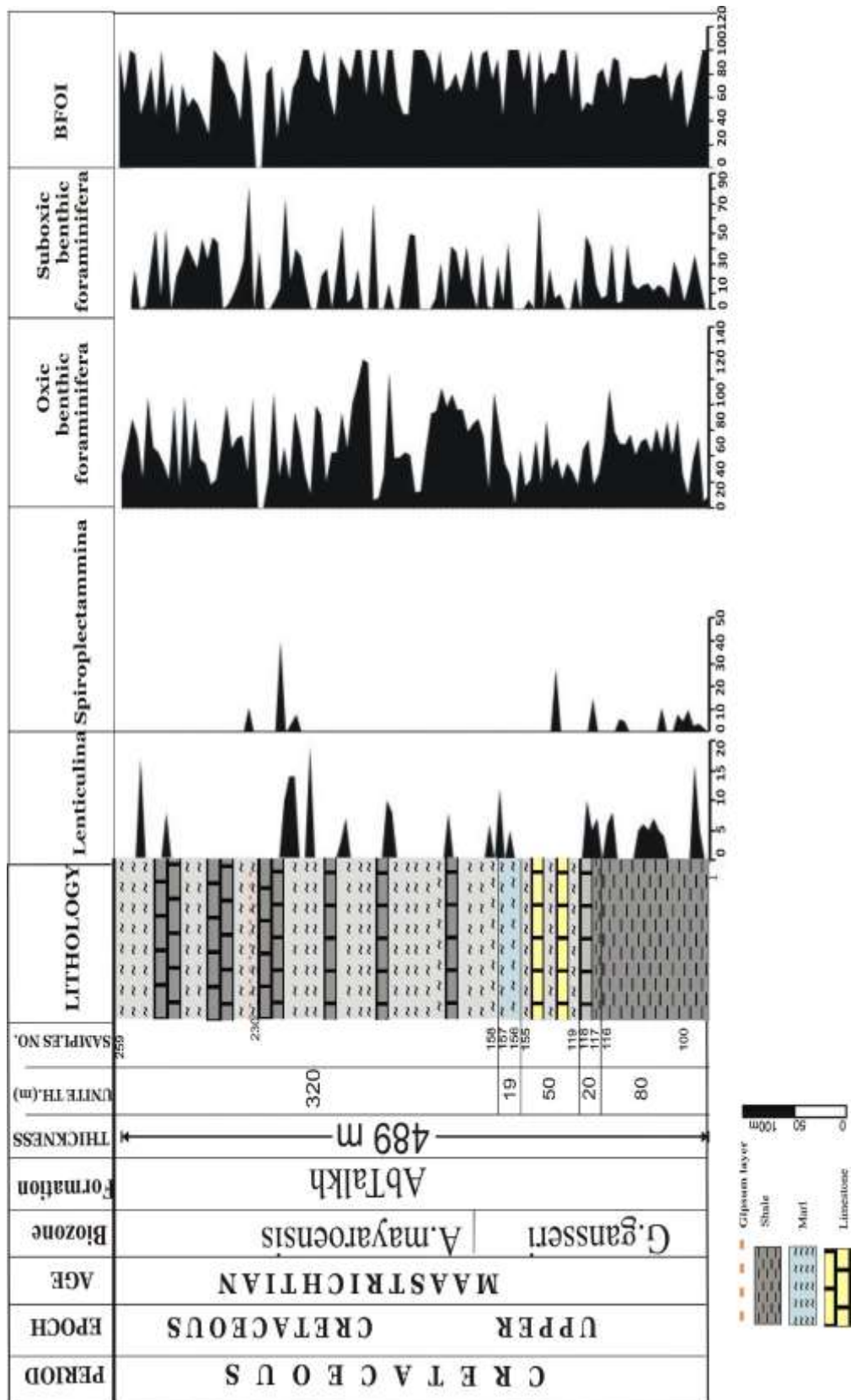
Figure 5: Presentation of relative abundance of some oxic, dysoxic benthic foraminiferal species and BFOI

In contrast to the Quaternary, lenticulinids are common taxa of Cretaceous assemblages and dominate in several low-oxygen environments (Bernhard, 1986; Coccioni & Galeotti, 1993;

Friedrich *et al*., 2003, 2005). This is indicated that (Friedrich *et al*., 2005) Cretaceous *lenticulinids* association with black shales suggest certain adaptational mechanisms, including tolerance in dysoxia and have the ability to use degraded organic matter as a potential food source. Thus, Cretaceous *Lenticulina* species may have occupied a deep infaunal microhabitat. Samples from the middle part of the section show extremely low BFN, while abundance in thick-walled species such as *lenticulinids* increases. This probably reflects dissolution of the tests, because decrease in BFN could be a result of high sedimentation rate and/or the selective preservation of dissolution-resistant taxa.

The shallow infaunal *Eouvigerina* is regarded as an adapted taxon to upper– middle bathyal environments with relatively high food supply, but reasonably oxygenated bottom water (Widmark, 2000; Alegret *et al*., 2001). Similarly Late Cretaceous *Gyroidinoides* is limited to abyssal depth and regarded also as a shallow infaunal taxon that thrived under mesotrophic (Alegret *et al*., 2001; Alegret & Thomas, 2005; Friedrich *et al*., 2005). In the relative abundanc curve, these species show the shortest peaks, except in the base of the section, possibly reflecting high-oxygen conditions as well as environmental instability(Fig. 3,5). In the studied section, BFOI as heterogeneity, species richness (Simple diversity) has high fluctuation but generally shows a high percentage at the whole

section (Fig. 5). The species richness, the percentage of infaunal morphogroups, and the heterogeneity index markedly decreased towards the upper part of the section whereas the BFOI increases, Calcareous taxa slightly decrease in abundance and buliminids show lower percentages. Marked decrease in abundance of both infaunal taxa and buliminid clearly indicates fully oligotrophic conditions.

Results

Maastrichtian benthonic foraminifer assemblages are diversified and heterogeneous (based on H(S) index) with high fluctuations, and contain a mixture of abundant epifaunal and less numerous infaunal taxa, thus indicating unstable environment and oligotrophic to weakly mesotropic conditions during the latest Cretaceous. Some notable peak in the relative abundance curves of some opportunistic species is also recorded, possibly reflecting local, short-term input of food (opportunistic species have been reported to tolerate high organic matter fluxes and decreasing oxygen levels). The combination of benthic assemblages in the studied succession shows low organic matter flux to the seafloor, with occasional fluctuations.

These assemblages are characterized by high dominance of epifaunal species, especially rotaliids and low relative abundances of buliminids.

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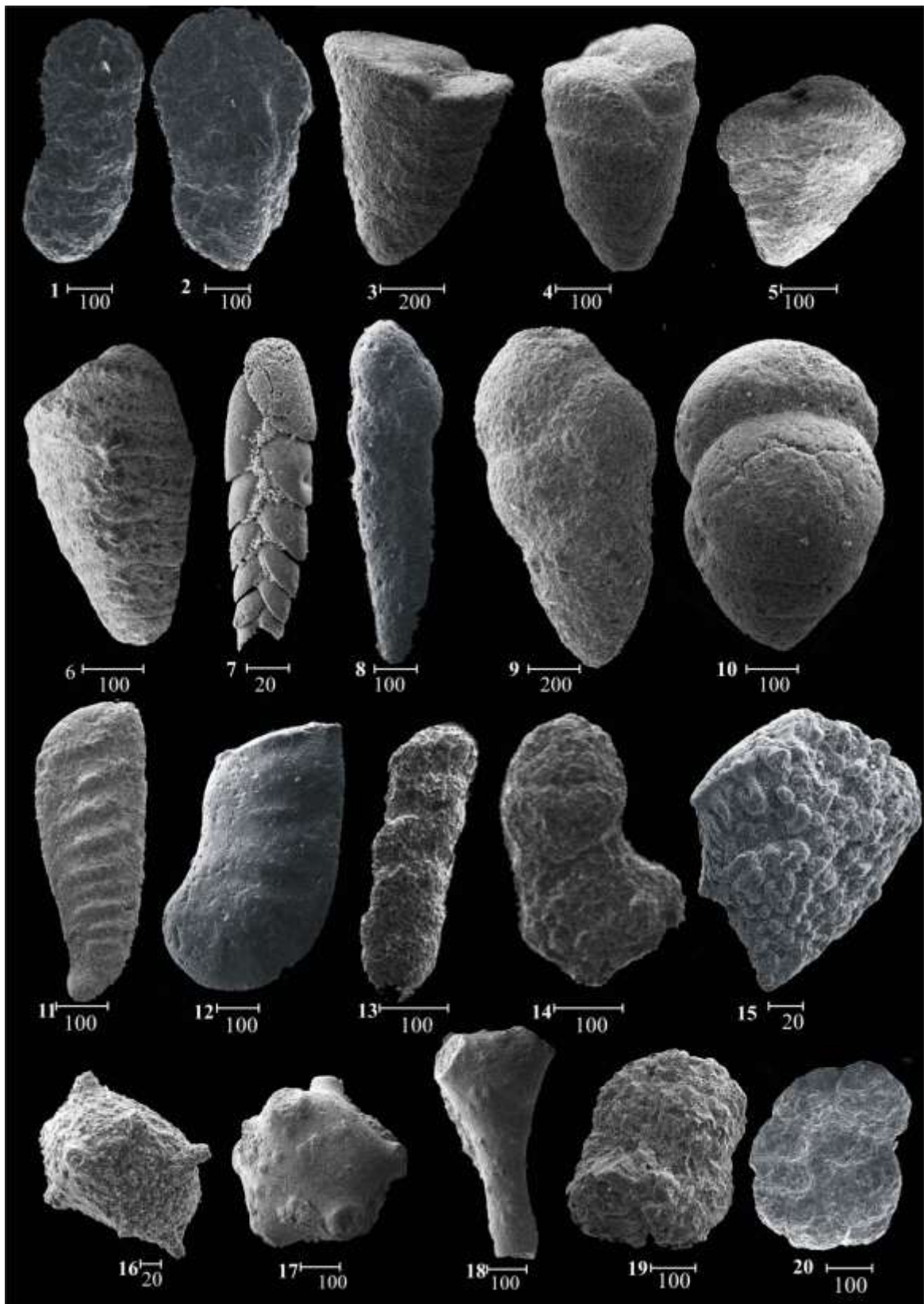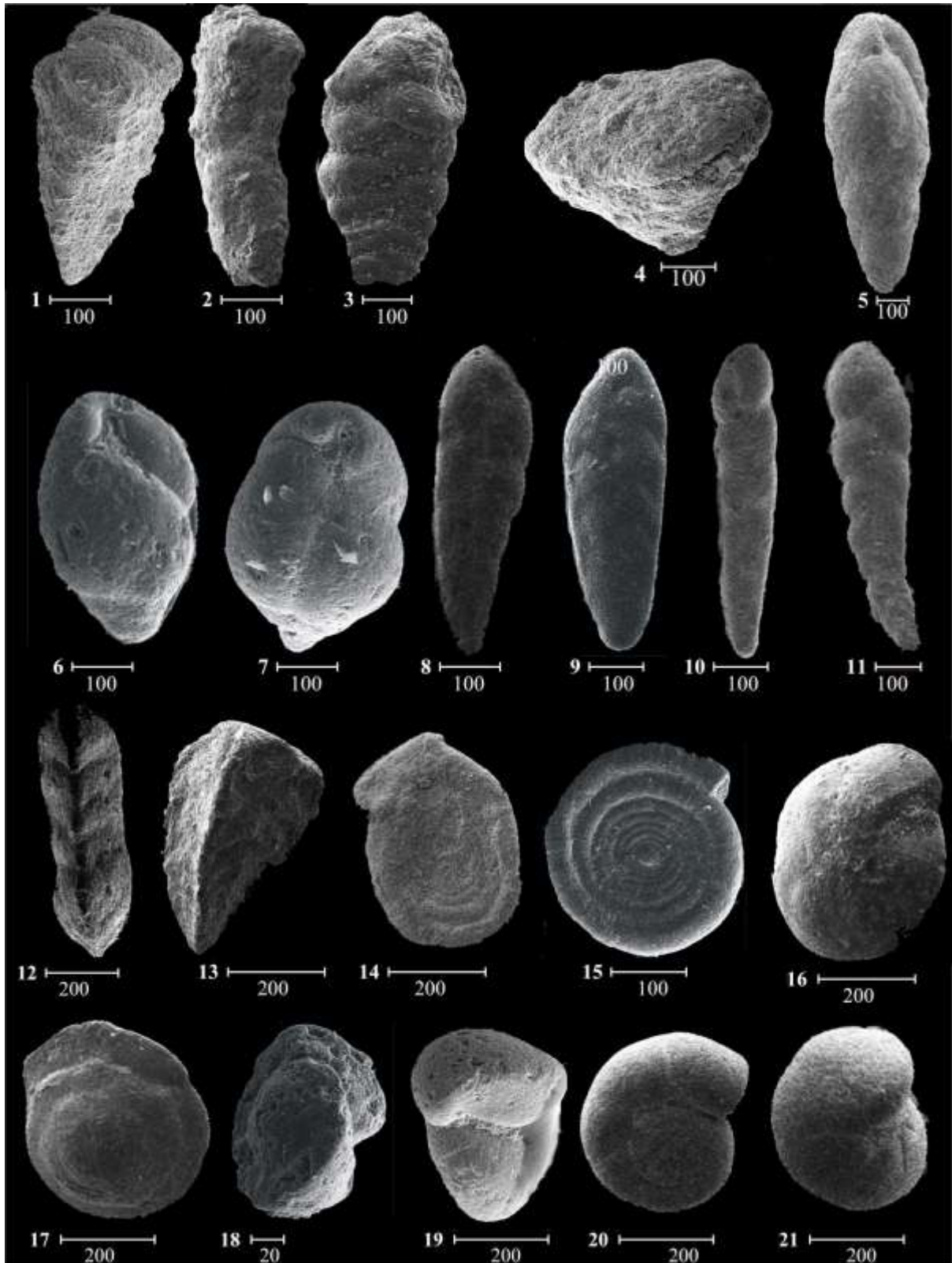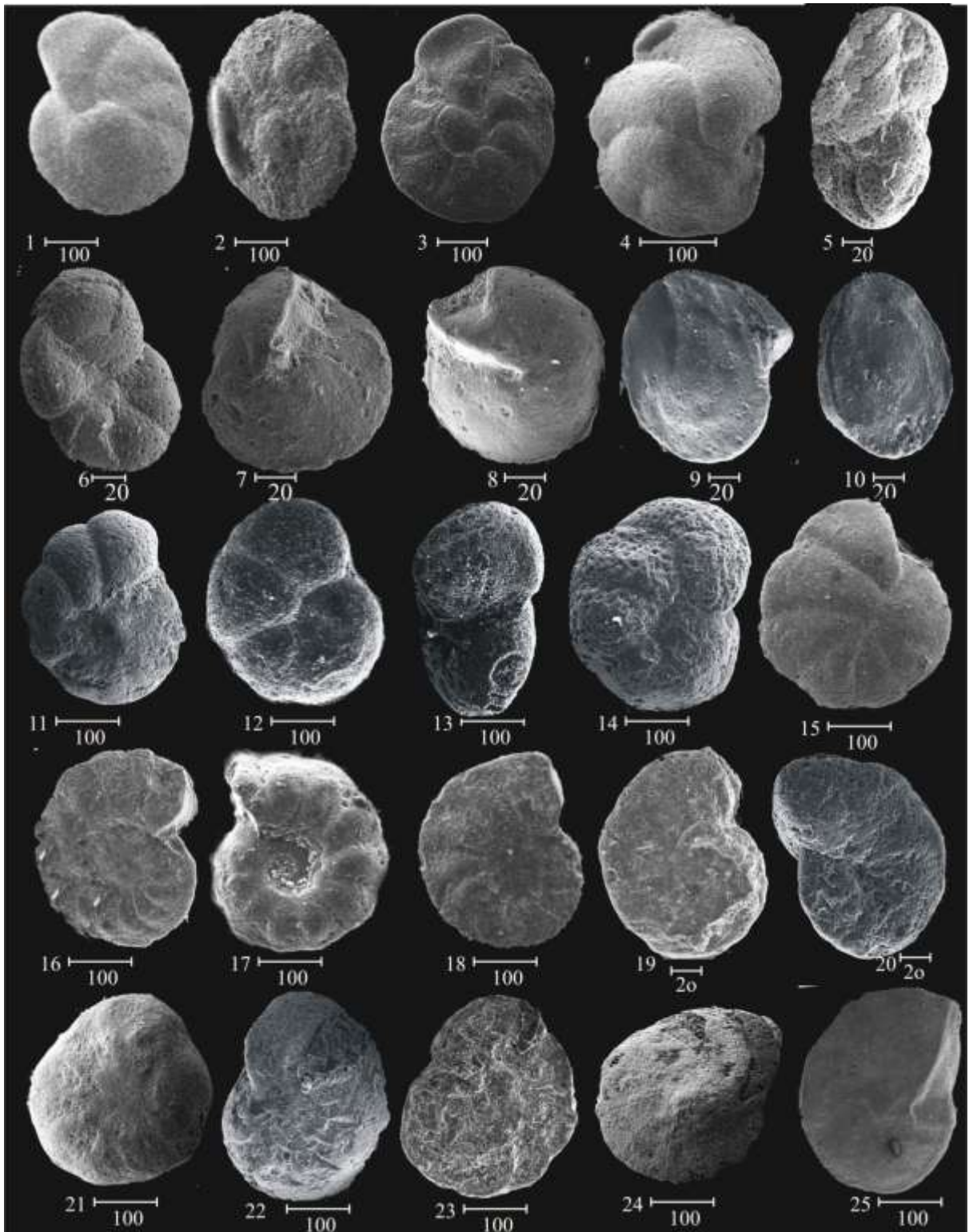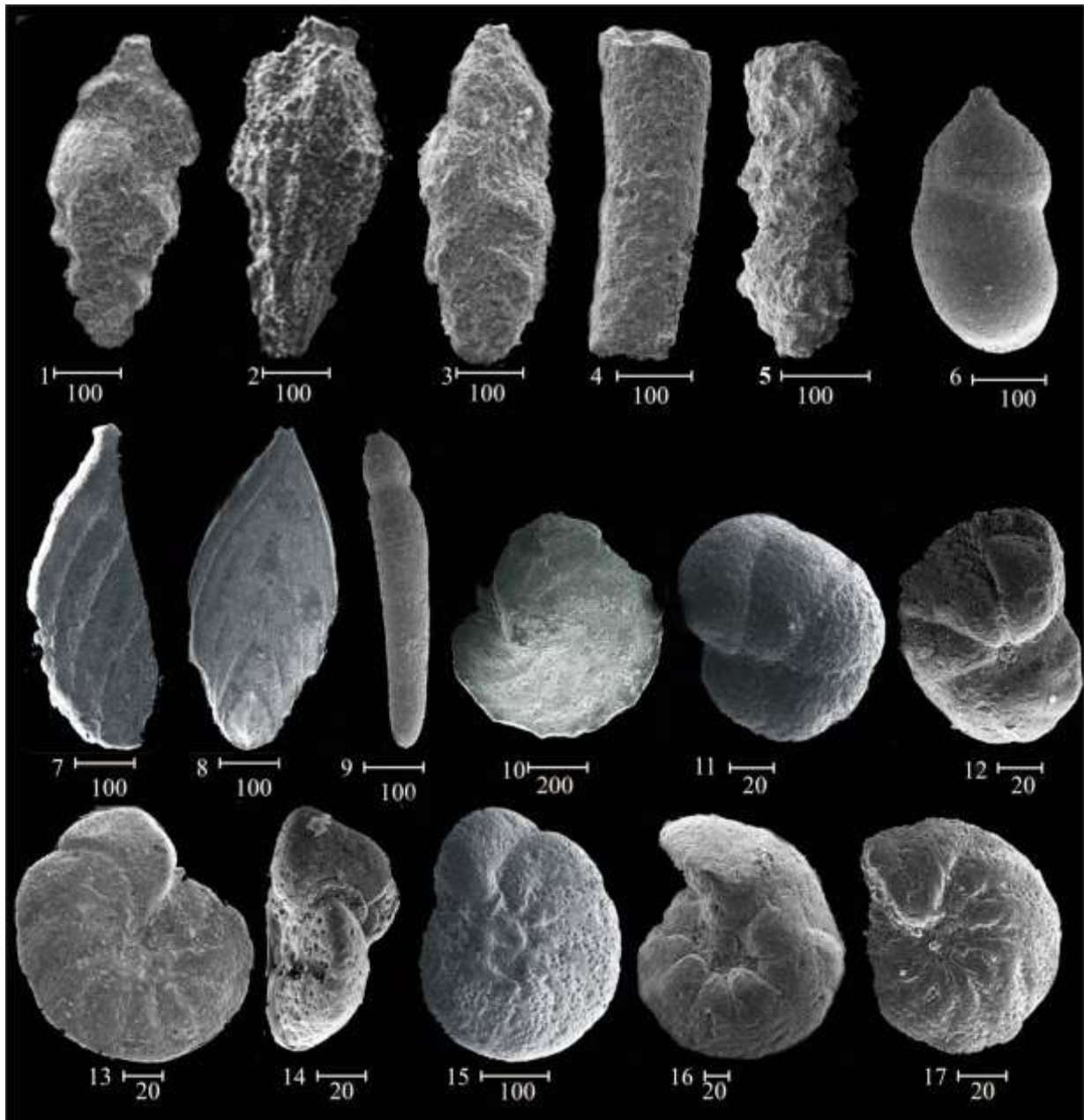
Plate 1

Plate 2

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Plate 3

Plate 4