

Upper Cretaceous planktonic foraminiferal biostratigraphy of the Zagros Basin (West Iran) with reference to sea-level changes

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ABSTRACT: In this study, an Upper Cretaceous sedimentary sequence in the Anaran Anticline (located in the central Zagros) is investigated to assess planktonic foraminiferal biozonations and implications for sea level changes. The thickness of this sequence is about 215 m, characterized by shales and limestones with thin marly limestone intercalations. In total, 51 species and 22 genera of planktonic foraminifera in 12 biozones spanning the middle Campanian to late Danian ages were delineated in the studied sequence. Additionally, planktonic foraminiferal morphological models, species abundance percentages, and the planktonic/benthonic foraminiferal ratio (P/B) ratios were assessed to reconstruct changes in sea level. The statistical studies on the different genera and species and the P/B ratio from the base to the top of the sequence indicate sea level transgressions during the middle Campanian and Maastrichtian in the *Contusotruncana plummerae* Interval Zone, *Radotruncana calcarata* Total Range Zone, *Globotruncanella havanensis* Partial Range Zone, *Globotruncana aegyptiaca* Interval Zone, *Contusotruncana contusa* Interval Zone, and part of the *Abathomphalus mayaroensis* Interval Zone. Moreover, species belonging to the deep-water morphotype (*G. arca*, *G. hilli*, *G. linneiana*, and *G. ventricosa*) are mostly present. Furthermore, two intervals of this sequence are associated with falling sea levels: 1) at the Campanian/Maastrichtian boundary in the middle of the *Gansserina gansseri* biozone; 2) from the late Maastrichtian close to the Cretaceous/Paleogene boundary with marly lithology.

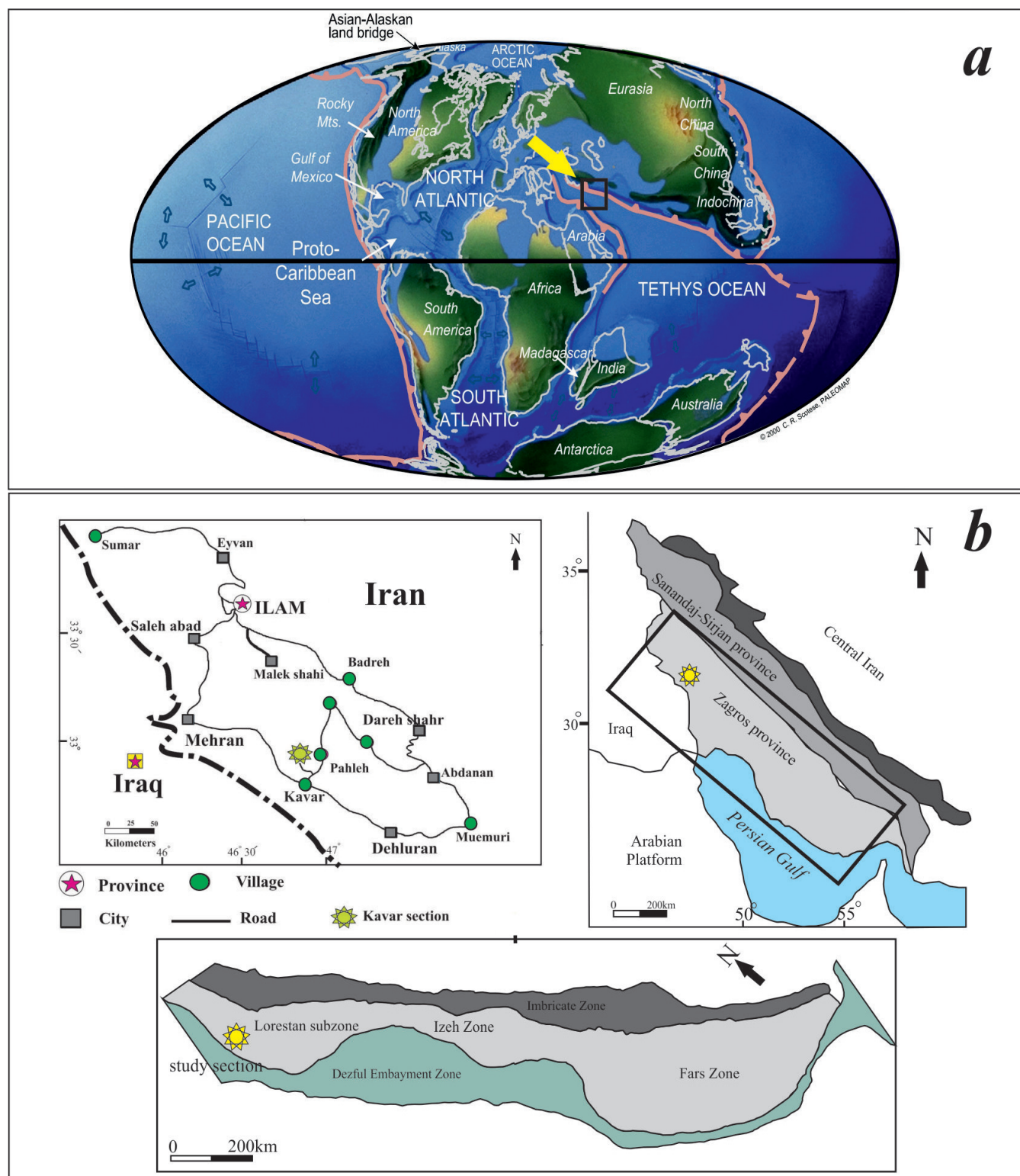
Keywords: Planktonic foraminifera, Upper Cretaceous, Zagros Basin, sea-level changes.

INTRODUCTION

The Campanian through Maastrichtian witnessed a series of environmental events, climate change, and sea level fluctuations (Li and Keller 1998a; Li et al. 2000). Planktonic foraminifera experienced the widest variation in morphology and taxonomy during the Late Cretaceous (Li and Keller 1998a). In this regard, two of the important planktonic foraminiferal bioevents of the Late Cretaceous may be mentioned as the Campanian/Maastrichtian (C/M) and the Cretaceous/Paleogene (K/Pg) boundaries. Many studies have focused on biostratigraphy of Cretaceous planktonic foraminifera (e.g., Robaszynski et al. 2000; Caron 1985; Sliter 1989; Petrizzo 2003; Premoli Silva and Verga 2004; Sari 2006, 2009; Huber et al. 2008; Petrizzo et al. 2011; Gardin et al. 2012; Davtalab et al. 2018; Honarmand et al. 2020). Several biostratigraphical studies have focused on the Campanian/Maastrichtian boundary interval in different parts of the world including: France, northern Spain, Iran, Turkey (Caron 1985; Sliter 1989; Odin et al. 2001; Petrizzo 2003; Pérez-Rodríguez et al. 2012; Razmjooei et al. 2018). Among the studies on sea level changes at the Campanian/Maastrichtian boundary, Poland and Ukraine are worth mentioning, indicating a drop in sea level at that time. (Barrera et al. 1997; Miller et al. 1999; Jarvis et al. 2002; Dubicka and Peryt 2012; Wolfgring et al. 2020). The K/Pg boundary is another important event at the end of the Cretaceous, and has been extensively studied in many parts of the world (Luterbacher and Premoli Silva 1964; Robaszynski and Caron 1995; Li and

Keller 1998a,b; Li et al. 1999, Gallala et al. 2009; Esmeray-Senlet et al. 2015; Keller et al. 2018; Khozyem et al. 2019; Zaky et al. 2020). Most studies on this boundary have been conducted in the Pacific and Atlantic Oceans and India (the Krishna-Godavari Basin) (e.g., Keller et al. 2011). However, this boundary has also been studied biostratigraphically in Iran by Darvishzad et al. (2007), Senemari and Foroghi (2019), Shirazi and Mirhoseini (2019), Beiranvand and Ghasemi-Nejad (2013), and Ezampanah et al. (2018). Nevertheless, no comprehensive study has been conducted on this event boundary in the Zagros region emphasizing bioevents and sea level changes. Despite several biostratigraphical studies in the Zagros Basin, which are mainly based on the biozonation of Premoli Silva and Verga (2004), the study of the planktonic foraminifera in this paper applied a more detailed biostratigraphic framework.

The studied sequence, the Gurpi Formation (James and Wynd 1965) in the Lorestan subzone is characterized by limestones of the Ilam Formation and overlying purple shales of the Pabdeh Formation. The type-section of this formation in the Lali oil-field northeast of Masjed Soleiman city predominantly yields gray shales and clayey limestone with a thickness of 320 m. Several studies have been carried out on the Gurpi Formation in the Zagros Basin, the following studies focused on planktonic foraminifera: Vaziri-Moghadam et al. (2013) in the Gardbishe Area, Hemmati Nasab et al. (2008) in the Kavar section, Daneshian et al. (2010) in east Kangan port and Ivan well,



TEXT-FIGURE 1

(a) Palaeogeography of the Late Cretaceous, after Gradstein et al. (2012) (b) Location of the studied section of the Gurpi Formation in the Zagros basin.

Asgharian Rostami (2012) at the Mish-Khas section, Fereydoonpoor et al. (2014) at the sections of Kuh-e Siah anticline and Tang-e Bulfares and Aghar anticline sections, Bakhshandeh et al. (2015) at the Banroshan section, Fazli (2015) at the Kuh-e Heram and Kuh-e Nargh, Sadeghi and Darabi (2015) at the Maroon oil fields, and Darabi et al. (2018) in the Lorestan subzone. The main aim of this paper is to investigate the biostratigraphy of the Campanian to Danian deposits in detail, emphasizing the C/M and K/Pg boundaries. The current study was developed based on the biozonation of Coccioni and Premoli Silva (2015). As such, after subdividing the studied sequence into the proposed biozones, we also investigated the C/M and K/Pg planktonic foraminiferal bioevents and compared them with the same bioevents of other regions. Changes in sea level are interpreted to have taken place during the deposition of Gurpi Formation.

Lithostratigraphy and geographical location of the studied section

The Zagros Orogen in Iran is part of the Alpine-Himalayan collision and occupies a central position between two important tectonic features which resulting from the closure of the Tethys Ocean: Tibetan Plateau and the Mediterranean Sea (Khadiji 2010). This orogen with northwest-southeast trend extends from the east of Anatolian Fault in the eastern part of Turkey to the Strait of Hormuz in southern Iran (Mouthereau 2011). Cretaceous marine sediments in the Zagros Basin contain significant potential for hydrocarbon exploration, with the Gurpi Formation as an important source rock (Ziegler 2001). This formation is extended in the Folded Zagros (James and Wynd 1965). This formation with an age range from Santonian to Paleocene, is one of the sedimentary sequences that are exposed in the southwestern provinces (Fars, Khuzestan and Lorestan).

The study area is located in the central part of the Lorestan Basin, in the Anaran Anticline. The geographical location of the studied section is eastern longitude 46° 48' 27" and northern latitude 32° 56' 13" (text-fig. 1). The studied section in the Lorestan subzone consists of a lower shale with a thickness of 62 m, Seymareh limestone with a thickness of 10 m, shale with a thickness of 38 m, the Imam Hassan limestone with a thickness of 27 m, shale and marl layers with a thickness of 15 m, gradual layers of shale and lime with 36 m thickness, and an upper shale with 27 m thickness, which together display a thickness of 215 m. The boundaries of the Ilam and Pabdeh formations are conformable.

MATERIALS AND METHODS

The Gurpi Formation in the 215 m thick section of Kavar village was measured, then 100 samples were taken from limestone and soft sediments. We applied a uniform sample spacing of 2 m in the Ilam and Gurpi formations and 3 m in the overlying shales. To investigate the K/Pg boundary precisely, samples were collected from the upper black shale to the purple shale with intervals of 0.5 m. The samples were then transferred to the lab and about 200 g of each sample were placed in 10% H₂O₂ solution for one day after being crushed into small pieces (Zapeda 1998, p. 109) and washed with water on 125- and 63-µm screens. Ultimately, washed residues were picked and micrographs of selected foraminiferal taxa were taken with a Leo 1450VP Scanning Electron Microscope in the laboratory of Ferdowsi University of Mashhad. The genera and species were then identified using resources such as Postuma (1971), Caron

%DWF	%SWF	%ESF
<i>Globotruncana</i>	<i>Muricohedbergella</i>	<i>Planoheterohelix</i>
<i>Globotruncanita</i>	<i>Macroglobigerinelloides</i>	<i>Pseudotextularia</i>
<i>Marginotruncana</i>	<i>Archaeoglobigerina</i>	<i>Guembelitrina</i>

TEXT-FIGURE 2

Morphotypes of planktonic foraminifera (after Leckie 1987).

(1985), Robaszynski and Caron (1979; 1995), Premoli Silva et al. (2003), Premoli Silva and Verga (2004) Olsson et al. (1999) and the Microtax, Neptune databases. After removing the samples with poor fossil preservation and barren samples (22, 23, 24 and 46), 72 samples were chosen to study sea level changes, and 300 foraminifera were counted in each sample. Then abundance of planktonic and benthic foraminifera was determined in each sample. The $P/P+B \times 100$ formula was used to obtain the %P. Also the P/B ratio and relative abundance percentage of planktonic foraminifera species was calculated. Up to now, many paleodepth models have been proposed using foraminifera, such as the Wright (1977) model, the Van der Zwaan et al. (1990) model, depth of life of benthic foraminifera, and the calcareous/agglutinated benthic foraminiferal ratio. Additionally, Cretaceous planktonic foraminifera have been subdivided to morphotypes by Hart and Bailey (1979), Hart (1980), Wonders (1980) and BouDagher-Fadel (2013). In this paper, we use the following models:

Based on the model proposed by Leckie (1987) the planktonic foraminifera can be categorized into three sub-categories according to habitat depth (Premoli Silva and Sliter 1994; Petrizzo 2002; Gallala et al. 2009), as listed in text-fig. 2: 1. Epicontinental Sea Forms (ESF) fauna; the related samples to this depth are straight test (biserial and triserial) such as *Planoheterohelix* and *Guembelitrina*. 2. Shallow Water Fauna (SWF); the samples of these depths contain trochospiral with spherical chambers trochospiral, without keel and with low ornamentations like *Muricohedbergella delrioensis*. Besides, a large proportion of small planispiral samples such as the species of *Macroglobigerinelloides*, are associated with relatively shallow epicontinental seas, epi- or marginal seabed fauna (Eicher 1969; Sliter 1972). These two morphotypes are attributed to the epicontinental seas. 3. Deep Water Forms (DWF): The species related to these depths possess a trochospiral test and primitive keels such as *Archaeoglobigerina* or with trochospiral test and with keels like *marginotruncanids* (Keller et al. 2002). Accordingly, the percentage of planktonic foraminifera species abundance was calculated for each morphotype group.

RESULTS

The studies performed on the samples taken from this sequence revealed a highly diverse, well preserved foraminiferal assemblage. We established an accurate biostratigraphy framework to investigate the biological events of the Campanian/Maastrichtian and Cretaceous/Paleogene boundaries. In addition, P/B ratio, a morphotype model (Leckie 1987), and the ratio of keeled to non-keeled planktonic foraminifera were exploited in order to assess the sea level changes. The statistical studies confirmed that the abundance of planktonic foraminifera varied between 177 and 285 in per sample. Accordingly, we recorded the highest abundance of different species of keeled forms such as

Stages	Planktonic Foraminifera Biozonations									
	This study	Li et al. (1999)	Petrizzo, 2003	Premoli silva & Verga, 2004	Huber et al. (2008)	Perez Rodriguez et al. (2012)	Coccioni & Premoli silva (2015)	Berggren & Pearson (2005)	Premoli silva et al. (2003)	Wade et al. (2011)
Danian	<i>Praemurica uncinata</i>							<i>P.uncinata</i>	<i>P.uncinata</i>	<i>P.uncinata</i>
								<i>Gl.compressa-P.inconstans</i>	<i>Gl.compressa-P.inconstans</i>	<i>Gl.compressa</i>
	<i>Parasubbotina pseudobulloides</i>							<i>S.triloculinoides</i>	<i>S.triloculinoides</i>	<i>S.triloculinoides</i>
								<i>P.pseudobulloides</i>	<i>P.pseudobulloides-Gl.archaeocopressa</i>	<i>P.pseudobulloides</i>
	<i>Parvularugoglobigerina eugubina</i>							<i>E.edita</i>	<i>P.pseudobulloides</i>	<i>E.edita</i>
								<i>P.eugubina</i>	<i>P.eugubina</i>	<i>P.eugubina</i>
								<i>G.cretacea</i>	<i>G.cretacea</i>	<i>G.cretacea</i>
Maastrichtian	<i>Pu. hantkeninoides?</i> <i>Pt. elegans</i>	<i>Pu. hantkeninoides</i> <i>Pg. palpebra</i>					<i>Pu. hantkeninoides?</i> <i>Pt. elegans</i>			
	<i>Pg. hariaensis</i>	<i>Pg. hariaensis</i>			<i>Pg. hariaensis</i>	<i>Pg. hariaensis</i>	<i>Pg. hariaensis</i>			
	<i>Ab.mayaroensis</i>	<i>Rc.fructicosa</i>	<i>Ab.mayaroensis</i>	<i>Ab.mayaroensis</i>	<i>Ab.mayaroensis</i> <i>/Rc.fructicosa</i>	<i>Ab.mayaroensis</i> <i>/Rc.fructicosa</i>	<i>Ab.mayaroensis</i>			
		<i>Pt.intermedia</i>								
	<i>C.contusa</i>	<i>C.contusa</i>		<i>C.contusa & Rc.fructicosa</i>			<i>C.contusa</i>			
	<i>Gs.gansseri</i>	<i>Gs.gansseri</i>	<i>Gs.gansseri</i>	<i>Gs.gansseri</i>	<i>Pg. palpebra</i>	<i>Pg. palpebra</i>	<i>Pt. acervulinoides</i> <i>/Pg. palpebra</i>			
72.1										
Campanian	<i>G.aegyptica</i>	<i>Ru.hexacamerata</i> <i>G.aegyptica</i>	<i>G.aegyptica</i>	<i>G.aegyptica</i>	<i>Gl. havanensis</i>	<i>Ru. rotundata</i>	<i>G.aegyptica</i>			
	<i>Gl. havanensis</i>	<i>G.subcarinatus</i>	<i>Gl. havanensis</i>	<i>Gl. havanensis</i>			<i>Gl. havanensis</i>			
	<i>R.calcarata</i>	<i>R.calcarata</i>	<i>R.calcarata</i>	<i>R.calcarata</i>			<i>R.calcarata</i>			
	<i>C.plummerae</i>	<i>G.ventricosa</i>	<i>G.ventricosa</i>	<i>G.ventricosa</i>			<i>C.plummerae</i>			

TEXT-FIGURE 3
Comparison of the standard biozonations of planktonic foraminifera.

G. arca, *G. hilli*, *G. linneiana* and *G. ventricosa* during the Middle Campanian and Maastrichtian, which was a sign of sea level transgression. Hence, the highest percentage of different species of the globotruncanids is related to samples 1-20 and 33-25. Meanwhile, the percentage of *G. arca* reaches 25% in samples 9, 31, and 50, the percentage of *G. linneiana* increases to 20% in samples 219, 26, 27, and 33 and also *G. lapparenti* percentage reaches 20% in samples of 17, 19, and 46, the abundance of *G. ventricosa* is about 25% in samples 12, 15, 43, and 44. In the upper Maastrichtian, the percentage of keeled planktonics gradually decreases.

Biostratigraphy of the Gurpi Formation

The biozonation used in this study (text-fig. 3) is similar to the published schemes of Coccioni and Premoli Silva (2015) and Premoli Silva et al. (2003). The Paleocene biozonation has similarities with the biozonation provided by Berggren and Pearson

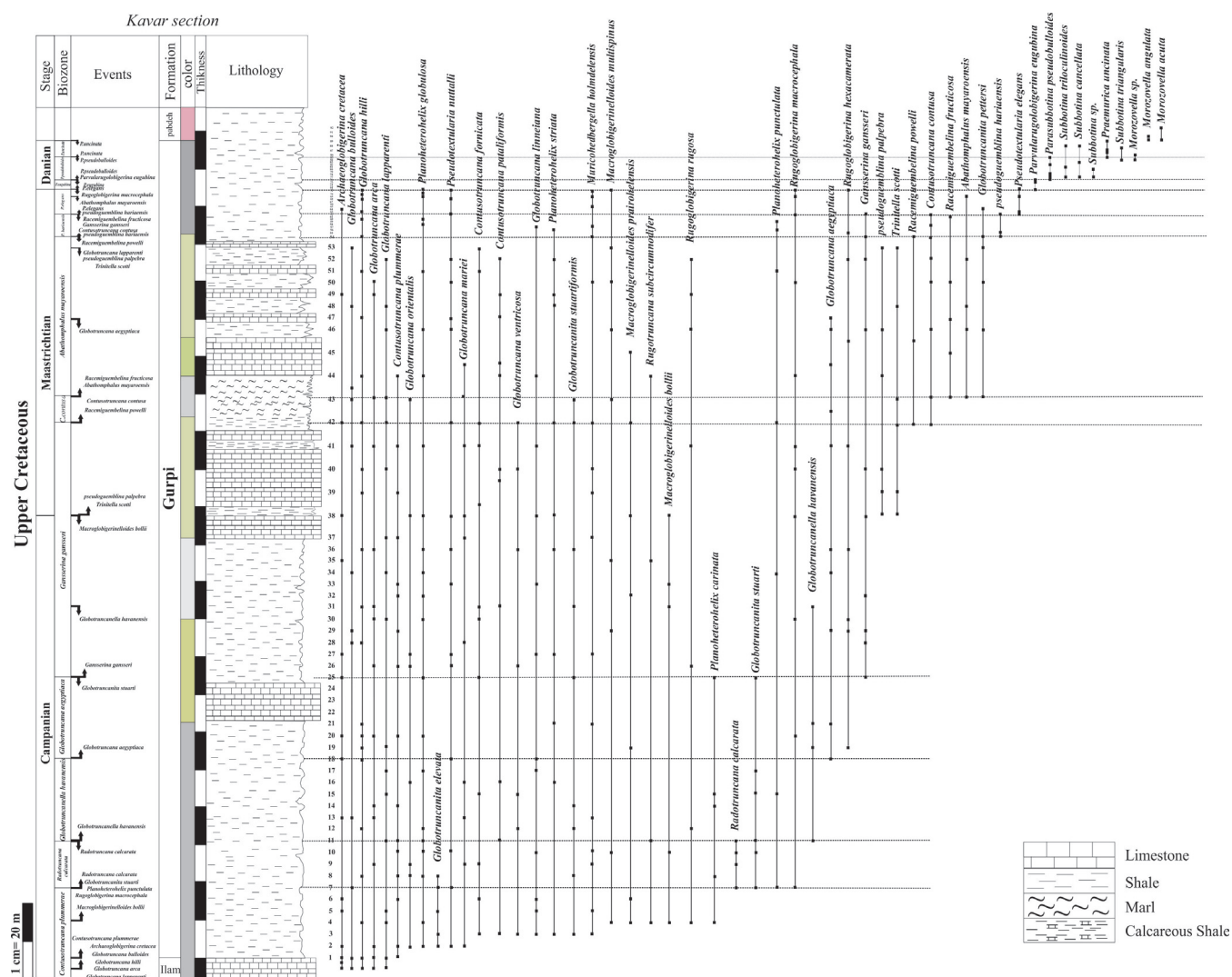
(2005) and Wade et al. (2011) but their P1 biozone (*Eoglobigerina edita* Partial-range Zone) was not identified in the present study. In this research into the Gurpi Formation in the Kavar section, 51 species were distinguished belonging to 22 genera in the framework of 12 biozones as follows (text-fig. 4):

Contusotruncana plummerae Interval Zone

Age: Middle Campanian.

Author: Petrizzo et al. (2011).

Definition: This biozone is an interval between the first occurrence (FO) of *Contusotruncana plummerae* and the FO of *Radotruncana calcarata*. The thickness of this zone is 18 m and its main lithological units include shale and limestone of the



TEXT-FIGURE 4
The biostratigraphy of the Gurpi Formation in the Kavar section.

Ilam Formation. The most important species in this zone include:

Archaeoglobigerina blowi (Pessagno 1967), *Archaeoglobigerina cretacea* (d'Orbigny 1840), *Contusotruncana fornicata* (Plummer 1931), *Contusotruncana patelliformis* (Gandolfi 1955) *Globotruncana arca* (Cushman 1926) *Globotruncana bulloides* (Vogler 1941), *Globotruncanella elevata* (Brotzen 1934), *Globotruncana hilli* (Pessagno 1967), *Globotruncana linneiana* (d'Orbigny 1839), *Globotruncana lapparenti* (Brotzen 1936) *Globotruncana mariei* (Banner and Blow 1960), *Globotruncana orientalis* (El Naggar 1966), *Globotruncana ventricosa* (White 1928), *Globotruncanella stuartiformis* (Dalbiez 1955), *Macrolobigerinelloides bollii* (Pessagno 1967), *Macrolobigerinelloides multispinus* (Lalicker 1984), *Macrolobigerinelloides prairiehillensis* (Pessagno 1967), *Pseudotextularia nuttalli* (Voorwijk 1937).

The diversity and abundance of planktonic foraminifera species are high in this zone. Petrizzo et al. (2011) in Bottaccione sec-

tion (Italy) replaced the *Globotruncana ventricosa* biozone with the *Contusotruncana plummerae* biozone that is equivalent to *Globotruncana ventricosa* biozone introduced by Premoli Silva and Verga (2004) and Petrizzo (2003) in the Tethys Basin. In the upper sections of this zone, *G. ventricosa* is prevalent and *G. elevata* is quite rare.

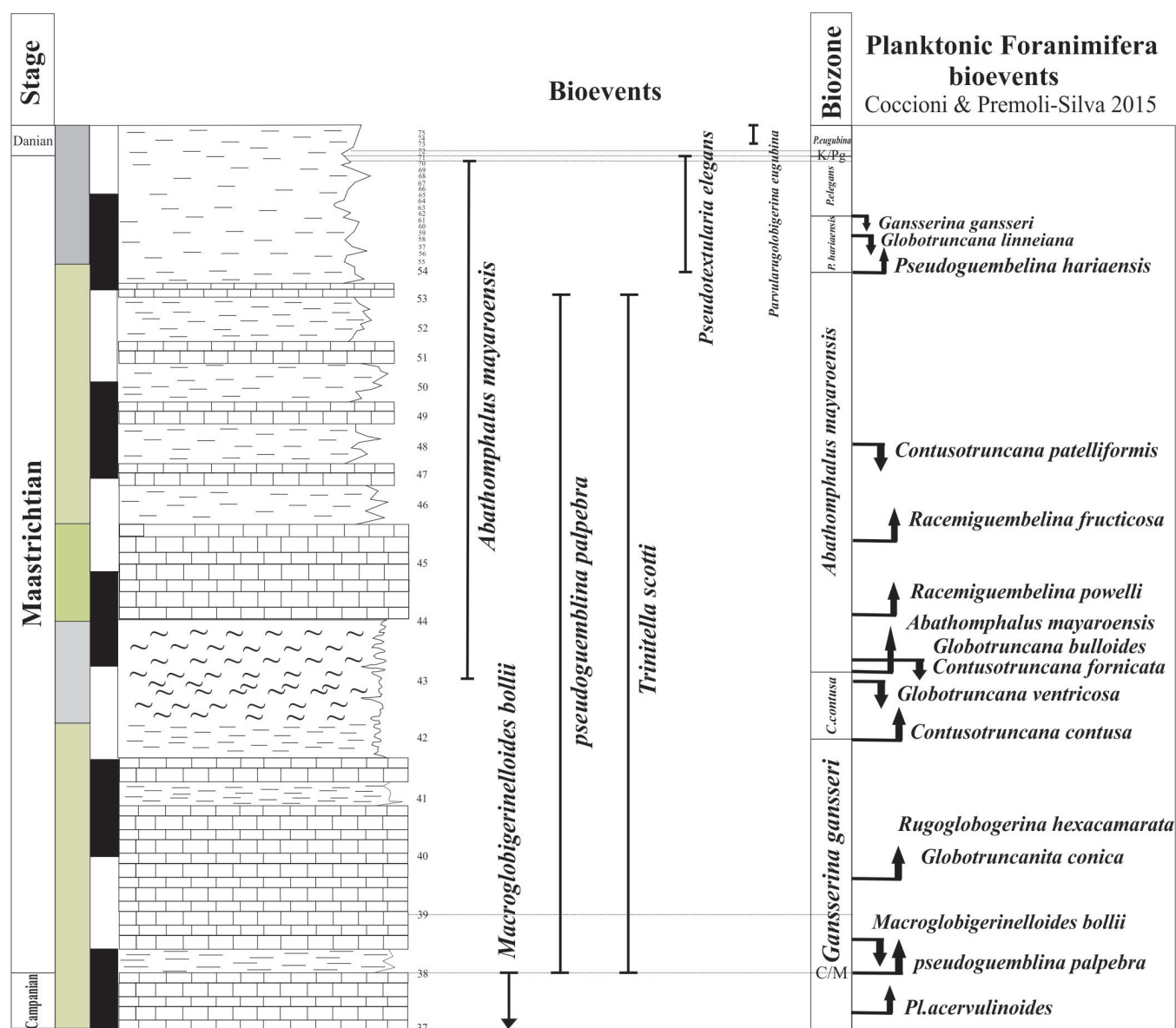
Radotruncana calcarata Total Range Zone

Age: late Campanian.

Author: Herm (1962).

Definition: This biozone is an interval of the total range of *Radotruncana calcarata*.

The thickness of this biozone in the Kavar section is 13 m and its dominant lithology is shale. The planktonic foraminiferal assemblages in this zone are similar to the previous zone, but the first appearance of *Globotruncanella stuarti* (de Lapparent 1918), *Rugoglobigerina macrocephala* (Brönnimann 1952),



TEXT-FIGURE 5
Campanian–Maastrichtian and Cretaceous–Paleocene bioevents.

Planoheterohelix punctulata (Cushman 1938), *Radotruncana calcarata* (Cushman 1927) occur here. This zonal marker is rarer than the other species. Moreover, this biozone is equivalent to the biozones offered by Petrizzo (2003), Premoli Silva and (2004) and Li et al. (1999) in the Tethys Basin.

Globotruncanella havanensis Partial Range Zone

Age: Late Campanian.

Author: Caron (1978).

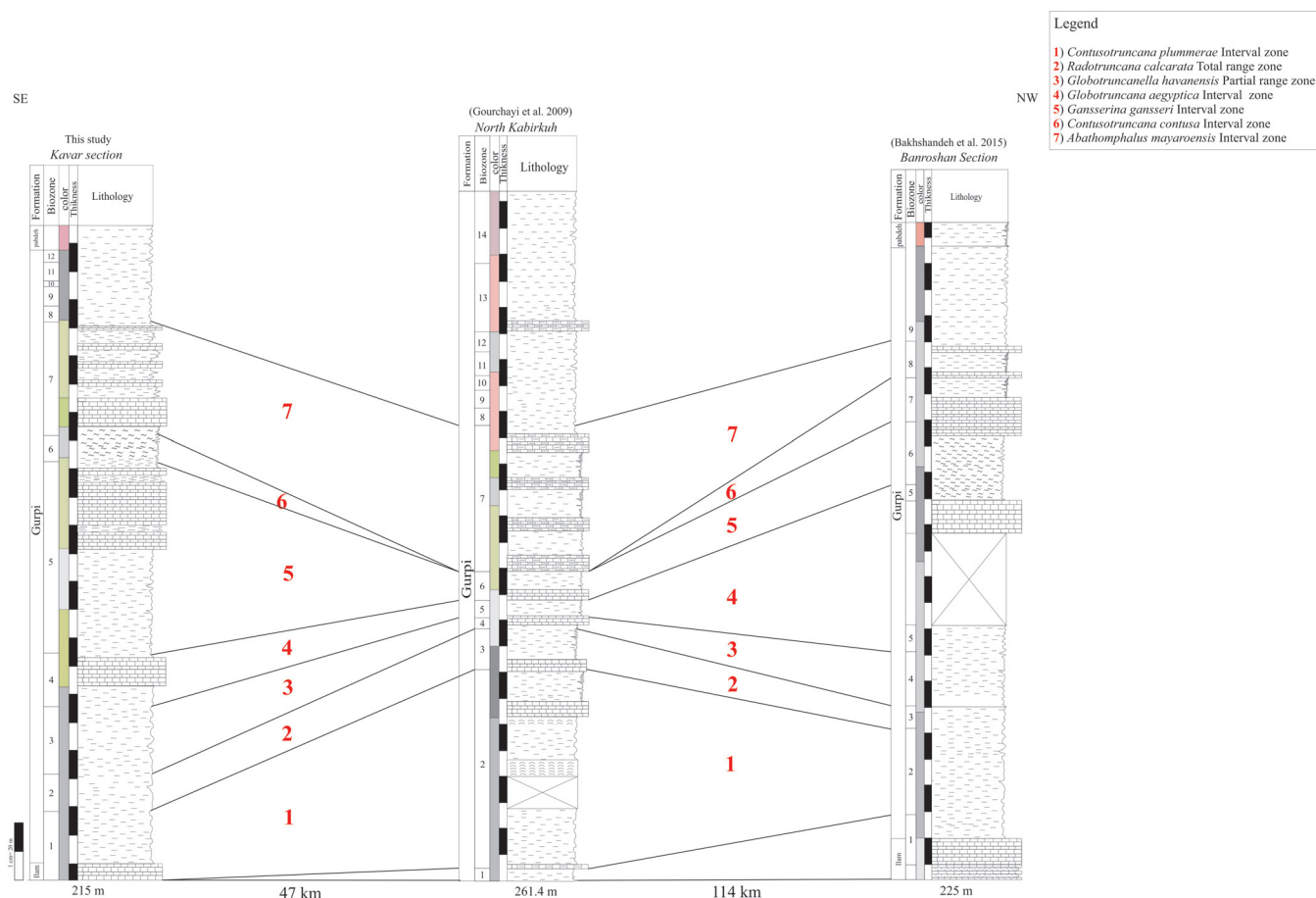
Definition: This biozone is an interval from the last occurrence (LO) of *Radotruncana calcarata* to the FO of *Globotruncana aegyptiaca*.

The thickness of this biozone in the studied section is 22 m and its dominant lithology is gray shale. The nominate taxon is rare in the Kavar section. The planktonic foraminiferal assemblages in this zone are similar to the previous zones, but the first appearance of *Globotruncanella havanensis*, (Voorwijk, 1937) occurs here. Comparisons between this biozone and the biozones provided for the Tethyan Basin by Petrizzo (2003) and Premoli Silva and Verga (2004) show the late Campanian temporal similarity for these biozones.

Globotruncana aegyptiaca Interval Zone

Age: Late Campanian.

Author: Caron (1985).



TEXT-FIGURE 6

Correlation of the Gurpi Formation in the Kavar section with the North Kabir-Kuh Anticline and Banroshan sections in the Lorestan subzone.

Definition: The interval between the FO of *Globotruncana aegyptiaca* and the FO of *Gansserina gansseri*. The thickness of this biozone is 21 m, and the lithology consists mainly of shale and limestone. The planktonic foraminiferal assemblages in this zone are similar to the previous zones, but the FOs of *Globotruncana aegyptiaca* (Nakkady 1950), and *Rugoglobigerina hexacamerata* are recorded here. The common species that appear in this zone are *Globotruncanella havanensis* (Voorwijk 1937), *Globotruncanella stuarti* (de Lapparent 1918), *Rugoglobigerina macrocephala* (Brönnimann 1952), *Planoheterohelix punctulata* (Cushman 1938), and *Globotruncana hilli* (Pessagno 1967). In this biozone, *G. lapparenti* appears less frequent. This zone is equivalent to the biozone introduced by Li et al. (1999), Premoli Silva and Verga (2004), and Coccioni and Premoli Silva (2015).

Gansserina gansseri Interval Zone

Age: Latest Campanian through early Maastrichtian.

Author: Brönnimann (1952).

Definition: This biozone is defined by the interval between the FO of *Gansserina gansseri* and the FO of *Contusotruncana contusa*. The thickness of this zone was calculated as 68 m and the lithology includes gray shale and limestone. The planktonic foraminiferal assemblages in this zone are similar to the previ-

ous zones, but the LOs of *Globotruncanella stuarti* (de Lapparent 1918), and *Planoheterohelix carinata* (Cushman 1938) are recorded here. In this zone, the FO of *Pseudoglobigerinelloides bollii* disappeared in the early part of this biozone. In general, the events that occurred in the middle part of this biozone indicate the C/M boundary. In previous studies this biozone was introduced by Li et al. (1999), Premoli Silva and Verga (2004), and Coccioni and Premoli Silva (2015) in the Tethys Basin.

Contusotruncana contusa Interval Zone

Age: Middle Maastrichtian.

Author: Li and Keller (1998a,b).

Definition: This biozone is an interval between the FO of *Contusotruncana contusa* and the FO of the *Abathomphalus mayaroensis*. The thickness of this zone is 9 m which consist mainly of marl and shale. The planktonic foraminiferal assemblages in this zone are similar to the previous zones, but the FOs of *Contusotruncana contusa* (Cushman 1926) and *Racemiguembelina powelli* (Smith and Pessagno 1973) occur here. The presence of *G. gansseri* is also observed in the upper part of this biozone. We have witnessed the disappearance of *G. ventricosa*.

This biozone is equivalent to the biozones described by Coccioni and Premoli Silva (2015).

Abathomphalus mayaroensis Interval Zone

Age: Middle to late Maastrichtian.

Author: Brönnimann (1952).

Definition: This biozone is an interval between the FO of *Abathomphalus mayaroensis* and the FO of the *Pseudoguembelina hariaensis*. This biozone is 41 m thick and consists mainly of shale and limestone. Li and Keller have divided the Maastrichtian into 4 biozones in their studies and they used *Abathomphalus mayaroensis* from CF1 (*Plummerita hantkeninoides*), CF2 (*Pseudoguembelina palpebra*), CF3 (*Pseudoguembelina hariaensis*), CF4 (*Racemiguembelina fruticosa*) (Li and Keller 1998a, b). The planktonic foraminiferal assemblages in this zone are similar to the previous zones, but the FOs of *Racemiguembelina fruticosa* (Egger 1899), *Globotruncana pettersi* (Gandolfi 1955), and *Abathomphalus mayaroensis* (Bolli 1951) are recorded in this zone. The most important events in this biozone are the first occurrence of *Racemiguembelina fruticosa* and the LOs of *C. fornicata* and *G. bulloides*.

Pseudoguembelina hariaensis Interval Zone

Age: Late Maastrichtian.

Author: Coccioni and Premoli Silva (2015).

Definition: This biozone is an interval between the FO of *Pseudoguembelina hariaensis* and the LO of *Gansserina gansseri*. The thickness of this zone is 5 m and its dominant lithology is shale. *Globotruncana linneiana* disappears in the middle part of this zone. The planktonic foraminiferal assemblages in this zone are similar to the previous zones, but the LO of *Racemiguembelina fruticosa* (Egger 1899) is recorded at the top of this zone and the LO of *Racemiguembelina powelli* (Smith and Pessagno 1973) occurs at the base of the *Pseudoguembelina hariaensis* zone.

Pseudotextularia elegans Interval Zone

Age: Latest Maastrichtian.

Author: Coccioni and Premoli Silva (2015).

Definition: The biozone is an interval between the LO of *Gansserina gansseri* and the FO of *Plummerita hantkeninoides*. In this section, based on the lack of *P. hantkeninoides*, the latest presence of *P. elegans* was used to determine this biozone. This zone is equivalent to the *Pg. palpebra* biozone introduced by Li and Keller (1998b), which is the marker for latest Maastrichtian. The thickness of this biozone is 6 m and its dominant lithology is shale. The most important foraminifera in this biozone include:

Abathomphalus mayaroensis (Bolli 1951), *Contusotruncana contusa* (Cushman 1926), *Gansserina gansseri* (Bolli 1951), *Globotruncana aegyptiaca* (Nakkady 1950), *Globotruncana arca* (Cushman 1926), *Globotruncana mariei* (Banner and Blow 1960), *Pseudotextularia elegans* (Rzehak 1891), *Pseudotextularia nuttalli* (Voorwijk 1937), *Planoheterohelix globulosa* (Ehrenberg 1840), *Pseudoguembelina hariaensis* (Nederbragt 1991).

Parvularugoglobigerina eugubina Total Range Zone

Age: Earliest Danian.

Author: Luterbacher and Premoli Silva (1964).

Definition: This biozone covers the total range of *Parvularugoglobigerina eugubina*. The *hedbergellids* disappear in the early parts of the biozone. This biozone is equivalent to the *Parvularugoglobigerina eugubina* Taxon-range Zone of Berggren and Pearson (2005) and Wade et al. (2011). This zone is 2 m thick. The most important foraminifera in this biozone include *Subbotina triloculinoides* (Plummer 1926), and *Subbotina cancellata* (Blow 1979).

Parasubbotina pseudobulloides Interval Zone

Age: Danian.

Author: Premoli Silva et al. (2003).

Definition: This biozone is the interval between the LO of *Parvularugoglobigerina eugubina* and the FO of *Praemurica uncinata*. This biozone equivalent to the *Eoglobigerina edita* partial-range Zone of Berggren and Pearson (2005) and Wade et al. (2011). We did not detect the *Eoglobigerina edita* Zone in this study and identified *Parasubbotina pseudobulloides* zone. This zone is 6 m thick and its dominant lithology is shale. Moreover, this biozone is subdivided into 3 subzones which specify the times of the previous Danian. Among the associated species are: *Parvularugoglobigerina eugubina* (Luterbacher and Premoli Silva 1964), *Subbotina triloculinoides* (Plummer 1926), *Subbotina cancellata* (Blow 1979), and *Subbotina* sp.

Praemurica uncinata Interval Zone

Age: Latest Danian.

Author: Bolli (1957).

Definition: This biozone is an interval between the FO of *Praemurica uncinata* and the FO of *Morozovella angulata*. This zone is equivalent to the *Praemurica uncinata* Interval Zone of Berggren and Pearson (2005) and Wade et al. (2011). Its thickness in the studied section is 4 m, and its dominant lithology is black shale. The most important foraminifera in this biozone include: *Subbotina triangularis* (White 1928) and *Subbotina triloculinoides* (Plummer 1926).

Campanian/Maastrichtian boundary

The Global Stratotype Section and Point (GSSP) of this boundary is located in Tercis, France, based on the first occurrence of the ammonite *Pachydiscus neubergicus*, which is lower than the first occurrence of calcareous nannofossils *Uniplanarius gothicus* and *U. trifidus* Gardin and Monechi (2001). Caron (1985) and Sliter (1989) proposed the *Radotruncana calcarata* Zone to define the Campanian/Maastrichtian boundary. Odin et al. (2001) reported the first occurrence of *Contusotruncana contusa* and *Trinitella scotti* slightly higher than the C/M boundary. Some researchers in the global type section placed this boundary at the first occurrence of *Contusotruncana contusa* or somewhat higher (Arz and Molina 2001). The *Pseudoguembelina palpebra* zone was proposed for the C/M boundary by Pérez-Rodríguez et al. (2012). In Egypt, Farouk (2014) considered the C/M boundary equivalent to the planktonic foraminiferal *Rugoglobigerina hexacamerata* Zone.

Studied section		Banroshan section		North Kabirkuh section	
Thick. m	Biozone	Thick.	Biozone	Thick.	Biozone
				10	<i>Morozovella velanscoensis</i>
		12	<i>Globanomalina pseudomenardii</i>	80	<i>Planorotalites pseudomenardii</i>
				1	<i>Planorotalites pusila</i>
				4	<i>Morozovella angulata</i>
				5	<i>Morozovella uncinata</i>
4	<i>Praemurica uncinata</i>			1	<i>Morozovella trinidadensis</i>
6	<i>Parasubbotina pseudobulloides</i>	12	<i>Parasubbotina pseudobulloides</i>	1	<i>Parasubbotina pseudobulloides</i>
2	<i>Parvularugoglobigerina eugubina</i>			0.8	<i>Parvularugoglobigerina eugubina</i>
6	<i>Pseudotextularia elegans</i>	11	<i>Abathomphalus mayaroensis</i>	2.20	Cf4
5	<i>Pseudoguembelina hariaensis</i>			3.80	Cf3
				2.20	Cf2
41	<i>Abathomphalus mayaroensis</i>			19.5	Cf1
9	<i>Contusotruncana contusa</i>	24	<i>Contusotruncana contusa</i>		
68	<i>Gansserina gansseri</i>	29	<i>Gansserina gansseri</i>	10	<i>Gansserina gansseri</i>
21	<i>Globotruncana aegyptiaca</i>	7	<i>Globotruncana aegyptiaca</i>	10	<i>Globotruncana aegyptiaca</i>
22	<i>Globotruncanella havanensis</i>	25	<i>Globotruncanella havanensis</i>	4	<i>Globotruncanella havanensis</i>
13	<i>Radotruncana calcarata</i>	9	<i>Globotruncanita calcarata</i>	11	<i>Globotruncanita calcarata</i>
18	<i>Contusotruncana plummeri</i>	21	<i>Globotruncana ventricosa</i>	86	<i>Globotruncana ventricosa</i>
		30	<i>Globotruncanita elevata</i>	3	<i>Globotruncanita elevata</i>

TEXT-FIGURE 7

Comparison of the proposed biozones in this studied section, Banroshan, and North Kabir-Kuh sections.

Robaszynski and Caron (1995), Petrizzo (2003), Premoli Silva and Verga (2004), and Coccioni and Premoli Silva (2015) placed the boundary in the middle part of the *G. gansseri* biozone. Saidi and Zaghib Turki (2016) recorded the C/M boundary at the *Rugoglobigerina scotti* Subzone in Tunisia. Also, Razmjooei et al. (2018) in the Shahneshin section recorded the FOs of *G. gansseri* and *G. aegyptiaca* and the LO of *U. trifidus* in the position of the C/M Boundary. Hewaidy et al. (2019) recorded the FO of *Gansserina gansseri* as a marker for the basal Maastrichtian stage in Egypt. Wolfgring et al. (2020) placed the C/M boundary in the Göynük section between the FO of *Gansserina gansseri* and the LO of the nannofossil *Uniplanarius trifidus*. In the studied section the C/M boundary is positioned in the middle of the *Gansserina gansseri* biozone. We recorded the LO of *Macroglobigerinelloides bollii* in sample number GuK38. Also, we detected the FO of the species *Pseudoguembelina palpebra* and *Trinitella scotti* in this sample (GuK38). This boundary is located at sample number GUK38 (40 m above the FO of *G. gansseri*) (text-fig. 5).

K/Pg boundary

After the K/Pg extinction event, the new species and genera of planktonic foraminifera evolved from the surviving taxa. The early Paleocene species were very minute in size (<100 µm) and possessed globular and subglobular chambers and low trochoidal coiling and biserial arrangement in the adult stage. Planktonic foraminifera evolved, showing an increase in size and diversity within the round chambered trochoidal forms (Premoli Silva et al. 2003). There are various opinions with regard to determining the boundary based on the findings of planktonic foraminifera. Many researchers have identified this boundary at the same time with the last occurrence of *Plummerita hantkeninoides* (e.g., Li and Keller 1998a, b). In the Carpathian Basin, researchers recorded the first occurrence of *Abathomphalus mayaroensis* in earliest late Maastrichtian, and this species continues until the K/Pg boundary (Machaniec 2002; Tshakreen and Gasinski 2004). In Iran the boundary was studied in Kabir-Kuh section which revealed the biozonation and its events were similar to the global type section at El Kef, and also it was thought that the first occurrence of *Plummerita hantkeninoides* before the K/Pg boundary (Darvishzad et al. 2007). Studies carried out in southwestern France on the K/Pg show that the disappearance of *Archaeoglobigerina cretacea* occurred 2 m below this boundary (Gallala et al. 2009). In a study of Upper Cretaceous rocks in Egypt, Orabi and Zahran (2014) identified the *Plummerita hantkeninoides* zone below the K/Pg boundary. In the Haymana Basin of Turkey, Esmeray-Senlet et al. (2015) introduced the *P. hariaensis* and *Guembelitra cretacea* biozones as the last biozone of the Maastrichtian stage and the first biozone of the Danian, respectively. Sarigul et al. (2017) determined the *Racemiguembelina fructicosa* zone below the K/Pg boundary. Also, they could not recognize the *Plummerita hantkeninoides* zone in the studied sections. Karabeyoğlu et al. (2019) proposed the *Plummerita hantkeninoides* zone as the last Maastrichtian biozone. Hewaidy et al. (2019) introduced the *Pseudoguembelina palpebra* biozone for the latest Maastrichtian, they reported that the *Plummerita hantkeninoides* zone was absent in the Wadi Qena section, Egypt. Machaniec et al. (2020) reported that late Maastrichtian *Abathomphalus mayaroensis* Zone and its equivalents the earliest Danian *Guembelitra cretacea* were the markers of the K/Pg boundary in Poland. In this paper to study the K/Pg boundary samples were taken with intervals of 0.5 m. The foraminiferal events recorded in the studied section at the K/Pg

boundary include: the interval with gradual disappearance of keeled planktonic foraminifera, and the LO of *Pseudotextularia elegans* in sample GUK71. Furthermore, we recorded the LO of *Abathomphalus mayaroensis* in sample GUK70 was used just below this boundary for further verification of the K/Pg boundary position. The fact that we could not detect *Plummerita hantkeninoides* in the studied section may be due to changes in the conditions of the sedimentary basin, paleoenvironment changes, or rarity and dispersion of the species. Therefore, we have observed a gap of fossils at the K/Pg boundary in the studied section (text-fig. 5).

Biocorrelation

In this study, the correlations between the Kavar stratigraphy section and northern Kabir-Kuh Anticline section (Ghouchayi et al. 2009) and the Banroshan section (Bakhshandeh et al. 2015) were assessed (text-fig. 6). The purpose of biostratigraphy correlation is that show what standard biozonation used by authors in each section. This correlation allows us to interpret changes in the thickness of biozones from the northwest to the southeast of the Lorestan subzone. The number of biozones provided in each section was compared with the ones in the other sections and then the deposition time in each section was determined. Accordingly, 10 biozones in the Banroshan section were suggested by the authors in the following order, from bottom to top: 1- *Globotruncanella elevata* Partial Range Zone, 2- *Globotruncana ventricosa* Interval Zone, 3- *Globotruncanella calcarata* Interval Zone, 4- *Globotruncanella havanensis* Partial Range Zone, 5- *Globotruncana aegyptiaca* Interval Zone, 6- *Gansserina gansseri* Interval Zone, 7- *Contusotruncana contusa* Interval Zone, 8- *Abathomphalus mayaroensis* Interval Zone, 9- *Parasubbotina pseudobulloides* Interval Zone, 10- *Globanomalina pseudomenardii* Interval Zone, that represents the age of Campanian to Paleocene (text-fig. 7). Furthermore, 15 biozones in the northern Kabir-Kuh Anticline were presented as follows: 1- *Globotruncanella elevata* Partial Range Zone, 2- *Globotruncana ventricosa* Interval Zone, 3- *Globotruncanella calcarata* Interval Zone, 4- *Globotruncanella havanensis* Partial Range Zone, 5- *Globotruncana aegyptiaca* Interval Zone, 6- *Gansserina gansseri* Interval Zone, 7- *Abathomphalus mayaroensis* Interval Zone, 8- *Parvularugoglobigerina eugubina* Total Range Zone, 9- *Parasubbotina pseudobulloides* Interval Zone, 10- *Morozovella trinidadensis* Interval Zone, 11- *Morozovella uncinata* Interval Zone, 12- *Morozovella angulata* Interval Zone, 13- *Planorotalites pusilla* Interval Zone, 14- *Planorotalites pseudomenardii* Total Range Zone, 15- *Morozovella velascoensis* Interval Zone, indicating a Campanian to Paleocene age for this section (text-fig. 7). Therefore, comparing the Gurpi Formation in the Kavar section with the two above-mentioned sections indicates that sedimentation in these sections is initiated with a delay compared to the other sections in the middle Campanian. In the studied section, unlike in the northern Kabir-Kuh Anticline section and at Banroshan, sediments belonging to the late Paleocene have not been observed (text-fig. 7).

Sea level changes

After identifying the microfossils and determining their age, first, 300 foraminifera were counted in each sample and then placed in their morphotypic groups. Their abundance was obtained as a percentage in the studied samples (Appendix 1). Upon evaluating the abundance of different planktonic foraminiferal faunal groups (SWF, DWF and ESF), we can

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identify six intervals that represent different environmental settings (text-figs. 8, 9):

1. Samples 1-7: *Contusotruncana plummerae* Interval Zone (base of the Gurpi section to 14 m). The abundance of planktonic foraminifera reaches 95%. In this biozone, the DWF morphotype is dominant and their abundance reaches 44% during the middle Campanian and SWF abundance reaches 46%. A marked increase in abundance of DWFs occurs in this biozone as the percentage of keeled forms such as *G. arca* increase to 10% in samples 1 and 2. The highest percentage of *G. linneiana* is 15-20% in samples 4 and 6, whereas the percentage of SWF forms like *A. cretacea* increases to 5% and the ESF forms including *P. globulosa* reaches 10% in samples 1-7.

2. Samples 7-11: *Radotruncana calcarata* Total Range Zone. The abundance of planktonic foraminifera in these samples is 85%. DWFs are dominant, and their abundance reaches 28%. The highest percentage of *G. linneiana* and *G. stuartiformis* increase to 18% in samples 8-10, while the lowest abundance of SWF forms such as *M. multispinus* is recorded in samples 9 and 10, and the percentage of *P. globulosa* is 5% in sample 11.

3. Samples 11-18, *Globotruncanella havanensis* Zone and the late Campanian, contain 75-95% planktonic foraminifera. The highest abundance of DWF forms in these samples reaches 45%, and SWF is 42%. The highest percentage of keeled species such as *G. ventricosa* increase to 15%, while the percentage of SWF forms like *A. cretacea* reaches 3% in samples 12, 17, and 18. Furthermore, the percentage of ESF forms like *P. globulosa* decrease to 3% (text-fig. 9).

4. Samples 18-25, *Globotruncana aegyptiaca* Zone, planktonic foraminifera reaches 89%, with the exception of samples 22, 23, and 24, which are related to Seymareh limestone and do not include the planktonic foraminifera samples. Also, DWF forms dominate in this interval. The percentage of keeled forms like *G. linneiana* and *G. stuartiformis* increase to 20%, whereas the percentage of SWF forms reaches 40% in samples 18 to 25.

5. This section is located in the middle of the *Gansserina gansseri* biozone in samples 37 and 38, At the C/M boundary, we observed a slight decrease in the abundance of planktonic foraminifera, which is associated with a relative increase in the abundance of ESF morphotype species about 26%. A marked increase in abundance of SWFs and ESFs occurs in this interval, as the percentages of *M. multispinus*, *M. prairehillensis* and *P. globulosa* increase to 20%.

6. Samples 42-72, the upper interval of studied section (*Contusotruncana contusa* Interval Zone, *Abathomphalus mayaroensis* Interval Zone, *Pseudoguembelina hariaensis* Interval Zone, *Pseudotextularia elegans* Interval Zone). Again, we recorded an increase in the abundance of DWF forms (88%) in samples 42-45. Their abundance decreases approaching the K/Pg boundary, indicating a gradual decrease in depth. The percentage of ESF forms increase from 18% to 35% in these samples (text-fig. 9).

DISCUSSION

The biostratigraphy of Upper Cretaceous sediments in the Tethys and elsewhere in the world has been established by various researchers, of which the most important are the studies by Caron (1985), Li and Keller (1998a, b), Petrizzo (2003), and Premoli Silva and Verga (2004). The Paleocene biozonation

was provided by Premoli Silva et al. (2003), Berggren and Pearson (2005) and Wade et al. (2011). The biozonation used in this study is similar to those of Coccioni and Premoli Silva (2015) and Premoli Silva et al. (2003), and we identified a total of 12 biozones. Based on the study of Coccioni and Premoli Silva (2015), the *Plummerita hantkeninoides* Total Range Zone shows the extinction of most of the Cretaceous planktonic foraminifera and K/Pg boundary. However, in this study we did not detect this biozone in the late Maastrichtian.

Biostratigraphic correlation of the studied sections was carried out to investigate the lateral extent of the biozones in the north-western and southeastern sectors of the Lorestan Zone and changes in the thickness of the biozones. Variations in thicknesses can be due to sea level changes.

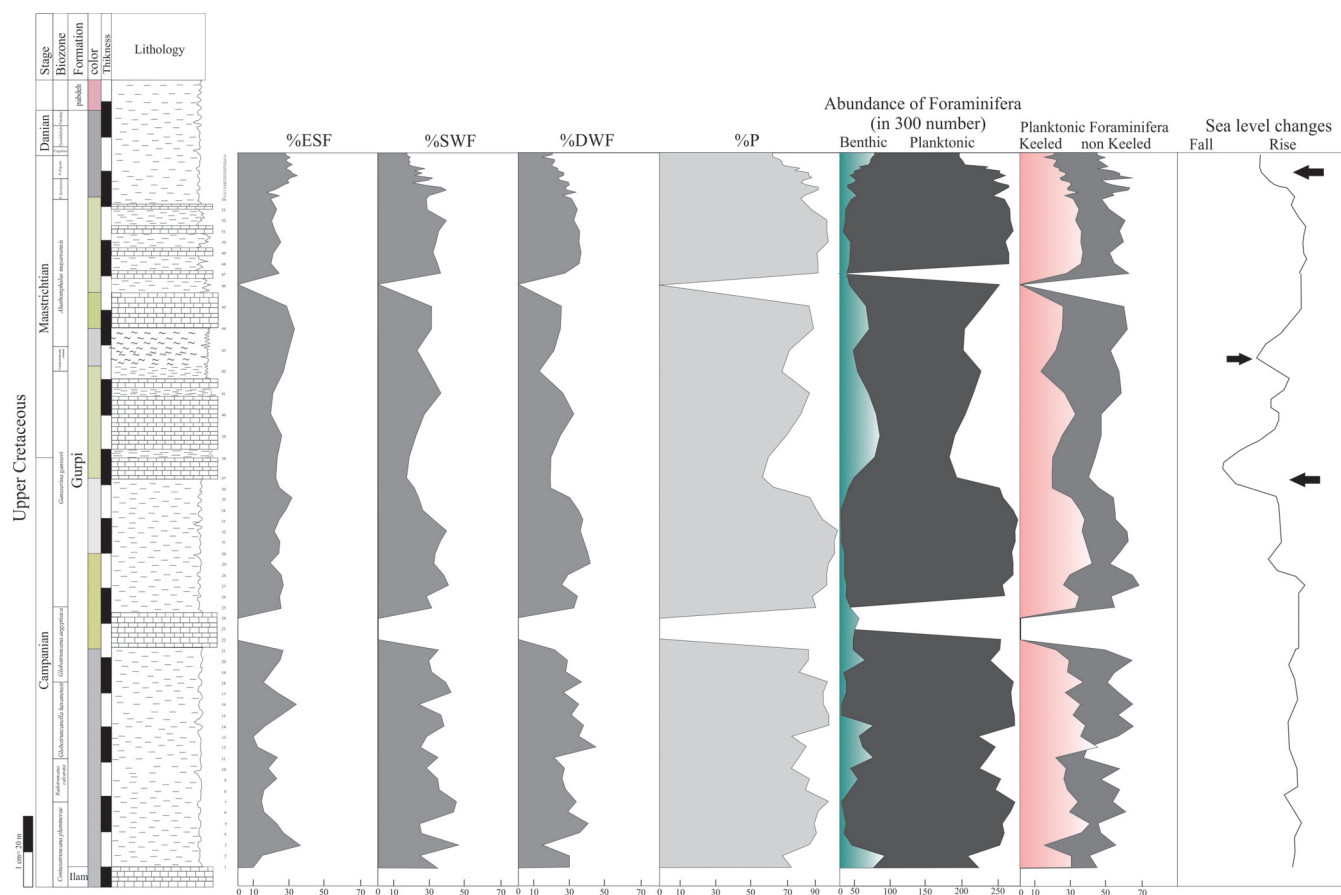
In the middle Campanian and Maastrichtian deep-dwelling *globotruncanids* such as *G. arca*, *G. hilli*, *G. linneiana* and *G. ventricosa* dominated. At both times seawater transgressions and increasing water depth are determined. In the upper Maastrichtian, the relative abundance of keeled planktonic foraminifera gradually decreases, and different species of ESF forms (biserials) increase. Also, during the Campanian-Maastrichtian boundary interval and in the late Maastrichtian, a relative decrease occurred in sedimentary basin depth with a decrease in the P/B ratio, abundance of the DWF and SWF morphotype groups, as well as an increase in the presence of shallow index species such as *P. globulosa*, *P. striata* and *P. nuttalli*. Therefore, the maximum abundance of *M. prairehillensis* in samples 32, 36, and 38 is 15%; *M. holmdelensis* is 15% in samples 3, 13, 27, 49, and 50; *P. globulosa* reaches 20% in samples 35, 38, 51, and 53; and *P. nuttalli* in samples 38, 42, and 45 is 25%. The comparison of sea level with foraminiferal population changes and their abundance at the studied section recorded different transgressive/regressive phases in sea level curves. Finally, at the time of deposition of the Gurpi Formation we recorded two sea level rises and according to the percentage of planktonic foraminifera (%P) it is interpreted as a deep sequence.

CONCLUSIONS

The study of planktonic foraminifera in the Gurpi Formation in the Kavar section shows that the deposition of this formation began in the middle Campanian and lasted until the late Danian. We recognized a total of 51 species belonging to 22 genera of planktonic foraminifera. The abundances of different species of planktonic foraminifera as well as their high total percentage compared to benthics in the studied section, their distribution in different morphotypes, and the ratio of keeled/non keeled planktonic foraminifera indicate two sea level rises at the time of deposition of the Gurpi Formation during the middle Campanian and Maastrichtian. This is reflected by an increase in the P/B ratio and percentage of DWF forms, and the highest abundances of *G. arca*, *G. hilli*, *G. linneiana* and *G. ventricosa*. A gradual decrease in sea level at the C/M boundary as well as from late Maastrichtian to the K/Pg boundary is recorded, associated with a relative increase in the abundance of non-keeled foraminifera and ESF forms, and a decrease in DWF and SWF morphotypes.

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TEXT-FIGURE 9

Proportions of different morphotypes related to sea level changes in the Gurpi Formation, Kavir section, using the Leckie (1987) morphotype model, Epicontinental Sea Fauna (ESF), Shallow Water Fauna (SWF), and Deep Water Fauna (DWF). Barren sample numbers are 22, 23, 24 & 46.

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PLATE 1

Scale bar represents 100 µm.

1a,b,c *Globotruncana* cf. *bulloides* (Vogler 1941);

2a,b,c *Contusotruncana plummerae* (Gandolfi 1955);

3a,b,c *Contusotruncana fornicata* (Plummer 1931);

4a,b,c *Globotruncanita elevata* (Brotzen 1934);

5a,b,c *Gansserina gansseri* (Bolli 1951);

6a,b,c *Globotruncana aegyptiaca* (Nakkady 1950);

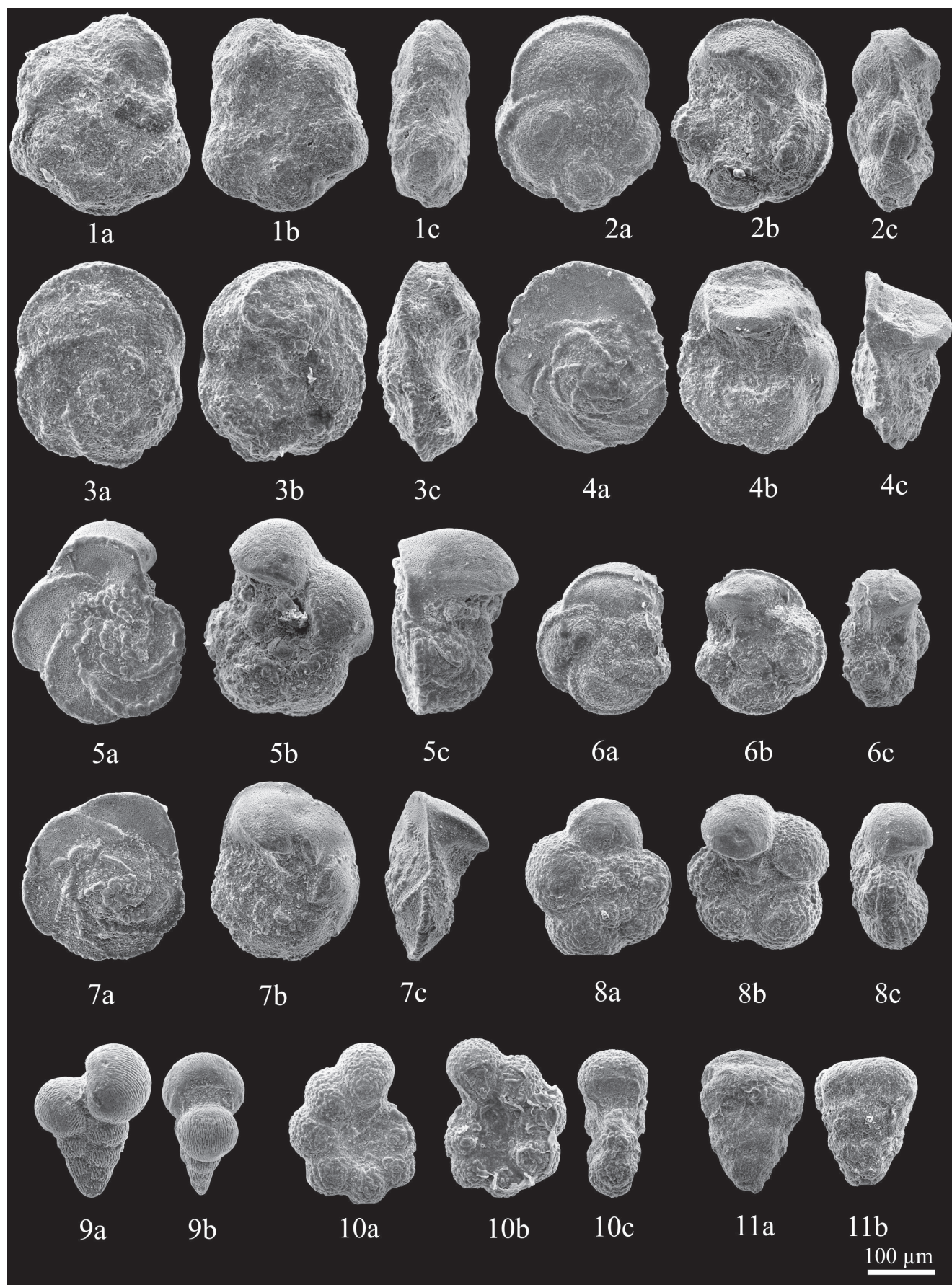
7a,b,c *Globotruncanita stuartiformis* (Dalbiez 1955);

8a,b,c *Archaeoglobigerina cretacea* (d’Orbigny 1840);

9a,b *Planoheterohelix striata* (Ehrenberg 1840);

10a,b,c *Macroglobigerinelloides bollii* (Pessango 1967);

11a,b *Pseudotextularia elegans* (Rzehak 1891).



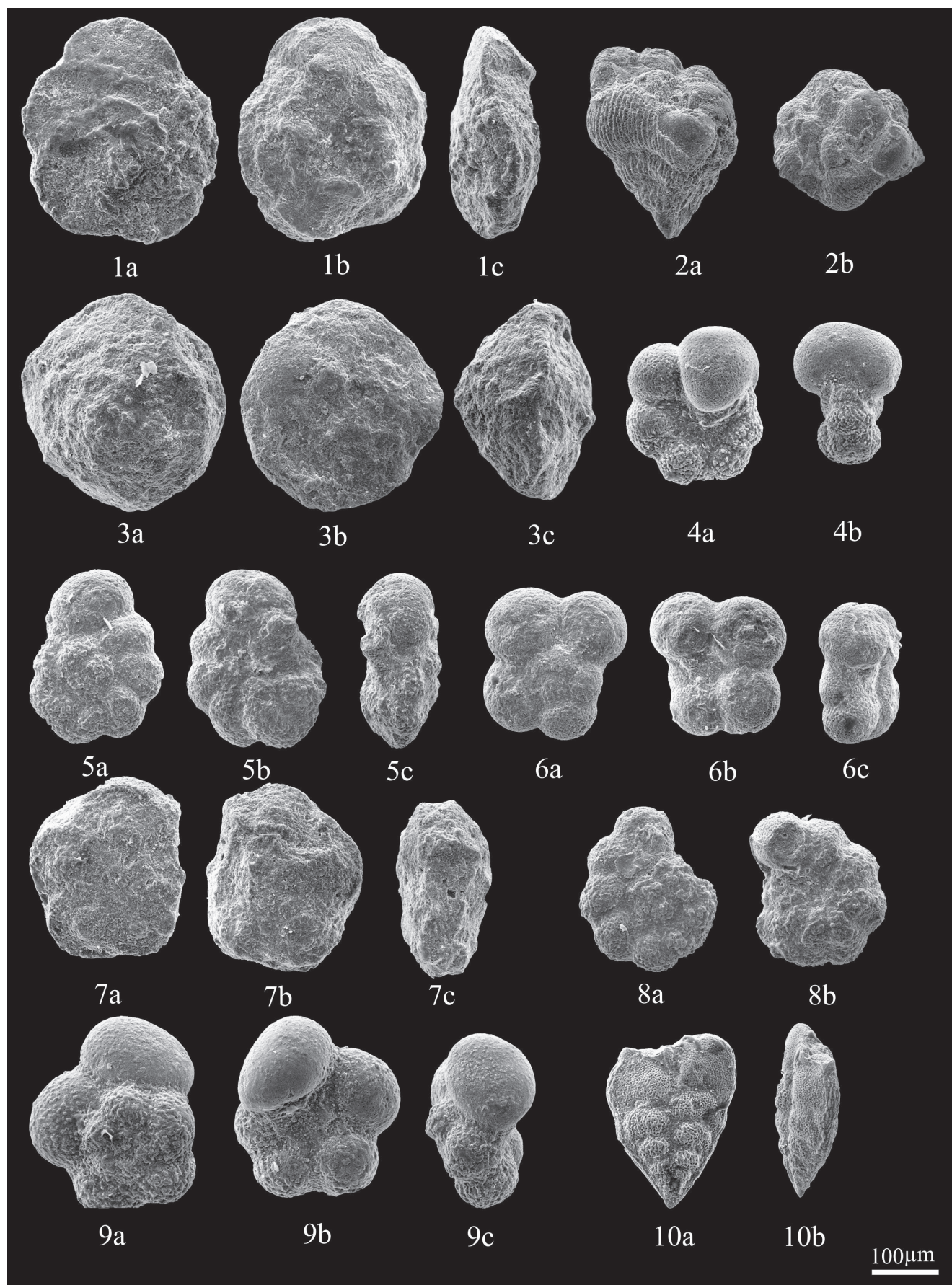
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PLATE 2

Scale bar represents 100 µm.

1a,b,c *Globotruncana lapparenti* (Brotzen 1936);
 2a,b *Racemiguembelina fruticosa* (Egger 1899);
 3a,b,c *Contusotruncana* cf. *contusa* (Cushman 1926);
 4a,b *Macroglobigerinelloides prairiehillensis* (Pessagno 1967);
 5a,b,c *Praemurica uncinata* (Bolli 1957);

6a,b,c *Parasubbotina pseudobulloides* (Plummer 1926);
 7a,b,c *Globotruncana linneiana* (d'Orbigny 1839);
 8a,b *Parvularugoglobigerina eugubina* (Luterbacher and Premoli Silva 1964);
 9a,b,c *Rugoglobigerina hexacamerata* trans. *R. rugosa* (Brönnimann 1952);
 10a,b *Planoheterohelix carinata* (Cushman 1938).



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APPENDIX 1

Abundance counts for morphotypic groups as a percentage of the studied samples.

Sample.NO	%P	%ESF	%SWF	%DWF	Foraminifera number	Sample.NO	%P	%ESF	%SWF	%DWF	Foraminifera number
1	75	10	35	30	225	37	59	22	18	19	177
2	70	15	25	30	210	38	62	23/5	19	19/5	186
3	85	25	32	28	255	39	72	26	22	24	216
4	89	30	26	33	267	40	80	20	28	32	240
5	88	23	25	40	264	41	85	21	38	26	255
6	90	17	29	44	270	42	70	28	30	12	210
7	95	15	46	34	285	43	74	30	23	21	222
8	82	17	37	28	246	44	88	32	31	25	264
9	85	22	36/5	26/5	255	45	85	29	31	25	255
10	75	19	29	27	225	46	0	0	0	0	0
11	79	23	35	21	237	47	90	25	37	28	270
12	82	12	25	45	246	48	90	20	35	35	270
13	75	10	29	36	225	49	89	21	32	36/5	267
14	95	18	39	38	285	50	95	26	34	35	285
15	95	26	38	31	285	51	94	22	36	36	282
16	92	33	24	35	276	52	94	20/5	40	33/5	282
17	92	23	42	27	276	53	87	23/5	29/5	34	261
18	94	17	40	37	282	54	80	20	28/5	31/5	240
19	79	20	31	28	237	55	82	25	30	27	255
20	84	25	30	29	252	56	87	18	36	33	261
21	84	27	36	21	252	57	90	22	40	28	270
22	0	0	0	0	0	58	90	25	37	28	270
23	0	0	0	0	0	59	84	27	27	30	252
24	0	0	0	0	0	60	80	30	21	29	240
25	89	25/5	31	32/5	267	61	82	29	29	24	255
26	88	25	29	34	264	62	87	31	33	23	261
27	94	27	41	26	282	63	85	35	23	27	255
28	94	26/5	39	29	282	64	85	32	26	27	255
29	94	20	33	41/5	282	65	77	31	23	23	231
30	98	24/5	34	40	294	66	79	28	28	23	237
31	98	25	37	36/5	294	67	72	30	22	20	216
32	99	21/5	40	37/5	297	68	70	32	18	20	210
33	92	24/5	32	36	276	69	70	29	19	22	210
34	89	29	27	33	267	70	68	28	18	22	204
35	85	31	24	30	255	71	65	31	19	15	195
36	65	25	21	19	195	72	65	28	17	20	195