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Planktonic Foraminiferal Biostratigraphy and Faunal Turnover across the Cretaceous-Tertiary Boundary in Southwestern Iran

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Abstract

The Kabirkuh section in the Ilam Province of southwestern Iran contains one of the most complete Late Maastrichtian to early Danian sequences similar to those known from the eastern Tethys realm. The Cretaceous-Tertiary boundary is marked by a 1-2 cm thick kidney-red shale in the uppermost Gurpi Formation. All Late Maastrichtian planktonic foraminiferal biozones CF1 to CF4 (equivalent to the *Abathomphalus mayaroensis* zone) and Danian zones P0 (*Parvularugoglobigerina extensa*), P1a (*Parvularugoglobigerina eugubina*) and *Parasubbotina pseudobulloides* are present. Faunal studies show that all but six of the Cretaceous species identified (22 of 29 species) disappeared at or below the K-T boundary in zone CF1 (*P. hantkeninoides).* Another 6 species (*Heterohelix globulosa, H. navarroensis, H. dentata, Hedbergella monmouthensis, H. holmdelensis, Guembelitria cretacea*) appear to have survived into the early Danian. Early disappearances appear to be environmentally controlled. Coarse ornamented species with small populations disappeared first, whereas small species with little or no ornamentation and generally large populations tended to survive after the environment changing. This indicates a pattern of gradual and selective faunal turnover in planktonic foraminifera during the latest Maastrichtian and into the earliest Danian that is similar to that observed at the El Kef stratotype of Tunisia, as well as K-T sequences in Egypt, Italy, Spain and Mexico.

Keywords: Cretaceous-Tertiary Boundary; Biostratigraphy; Plankton foraminifera

Introduction

The Gurpi Formation, which spans the Cretaceous-Tertiary transition in southwestern Iran, has been extensively studied before [13,3840,44,45]. A brief palynological investigation of the Abteymour Well No. 1 located 10 km. south of Ahvaz (Fig. 1) was published by Zahiri [46]. Norouzi located the KTB in southwestern Iran (Central Lorestan) in the upper part of the Gurpi Formation [31]. In the Fars Province of

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southwestern Iran, Hobbi reported the KTB in the upper part of the Gurpi Formation at the base of a 50 cm thick glauconitic layer based on palynology and foraminiferal stratigraphy [12]. A restudy of this section based on foraminifera and dinoflagellate cysts revealed a hiatus of at least 500 ky spanning the uppermost Maastrichtian to lowermost Danian [11].

Thus previous studies indicate that the KTB is located in the uppermost shale layers of the Gurpi Formation that the KTB is continuous in the southwestern Province of Ilam and in the southern Province of Khuzistan, but that a hiatus spanning about 500,000 years is present in the southwestern Fars Province.

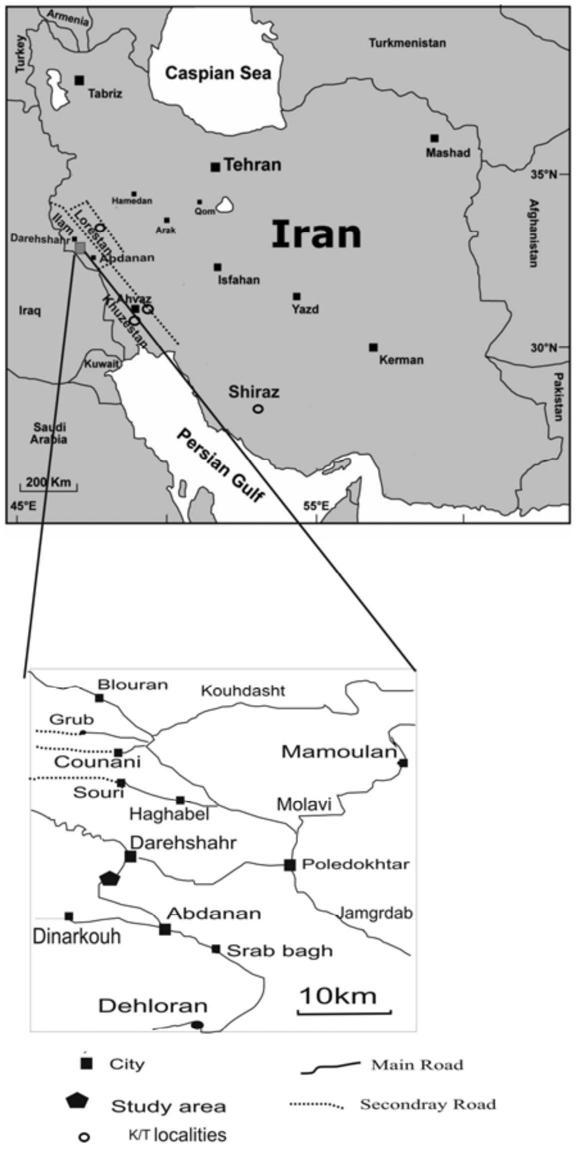

Figure 1. Location map of the K-T sequence studies in the Lorestan Province of southwestern Iran. Additional K-T localities mentioned in the text are marked by open circles.

Outcrops of the Gurpi Formation are widespread in the Kabirkuh region of the Zagros Mountains in southwestern Iran (Fig. 1), which was chosen for this study with the main objectives to detail the planktic foraminiferal record across the Late Maastrichtian through early Danian and compare and contrast the results with the K/T stratotype of Tunisia and other complete low latitude sequences.

Location and Lithology

The Gurpi Formation is exposed along the northeastern flank of the Kabirkuh anticline of the Zagros Mountains in southwestern Iran. The Kabirkuh section of this report (E: 47° 40′ 21″ and N: 33° 20′ 09″) is located between the towns of Dare-Shahr and Abdanan in the Ilam Province, about 2 km south of Dare-Shahr (Fig. 1). At this locality, the Gurpi Formation consists of 234 m and crops out on both sides of the road. The lower part of the formation consists of white (milky) limestone and marly limestone. The upper part consists of soft dark grey shale alternating with marly shales. The K-T boundary occurs 147.19 meters above the lower contact of Gurpi Formation within the soft grey shale and is marked by a 1-2 cm thick kidney-red shale.

Methods

The Gurpi Formation was sampled three times for this study. The first reconnaissance sample collection identified the approximate age and foraminiferal biozones of the region. Based on this information, more detailed sampling at 30-40 cm intervals concentrated on the interval from 10 m below to 8 m above the red layer and K-T boundary (KTB). From this sample set the Upper Maastrichtian to Lower Paleocene biozones were identified and species ranges determined. To further evaluate the faunal turnover across the KTB, a third sample set was collected at 2-3 cm intervals from 30 cm below to 15 cm above the KTB and kidney-red layer.

Sample preparation followed standard techniques as described before [19]. Samples were crushed to pea-sized particles, soaked in water with diluted hydrogen peroxide, then washed through 38 μm and 63 μm sieves and dried. Planktonic foraminifera are common to abundant and relatively well preserved though recrystallized. Species were identified following [36]; [10] and [32]. Marker species and the most common species (deposited in Tehran University) are illustrated in Plates 1 and 2.

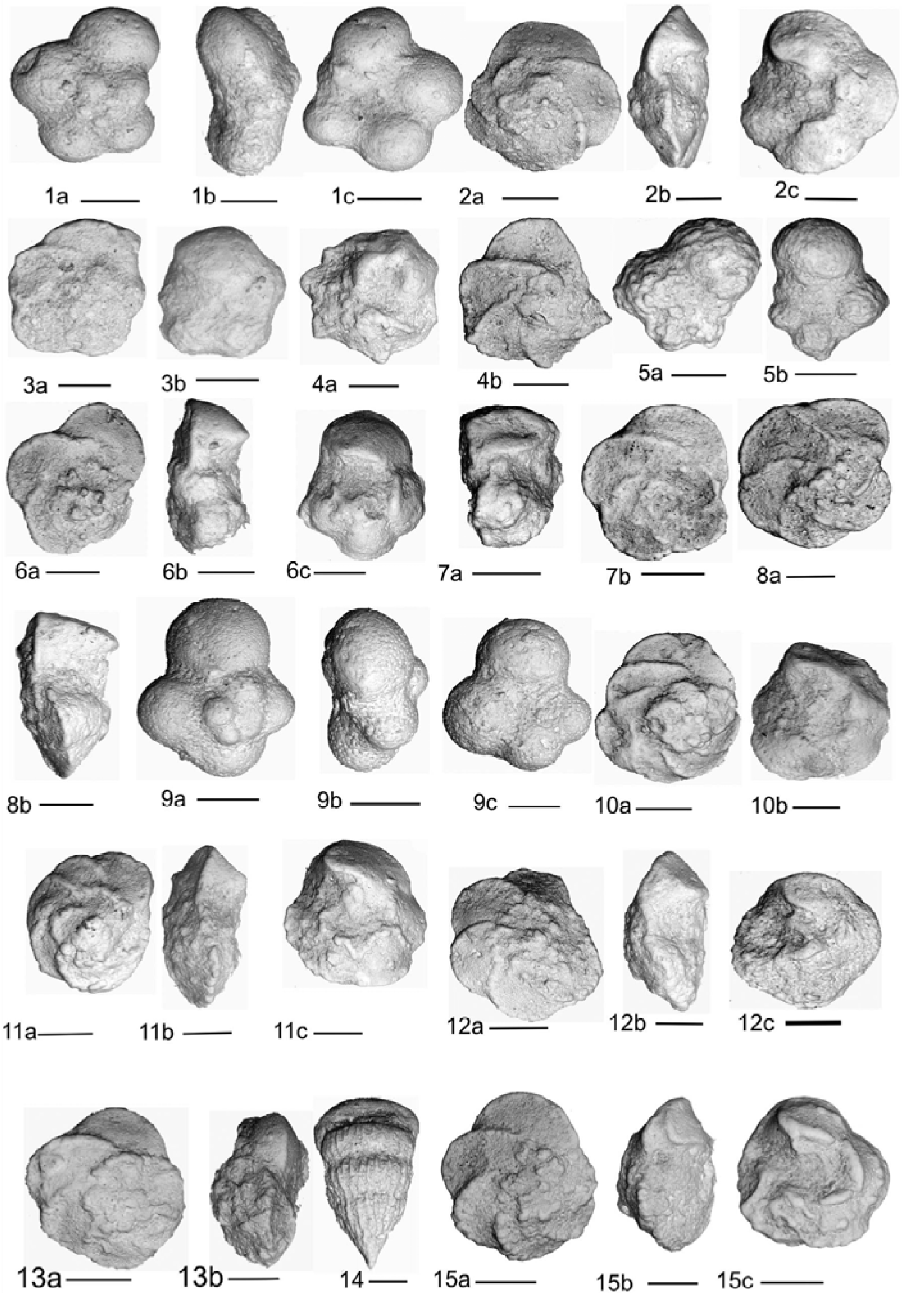

Plate 1. Figure 1a-b: *Globotruncanella havanensis* (Voorwijk), 1937 (Scale bar: a-b =50 µm; c = 80 µm) (placed in zone CF4). Figure 2a-c: *Globotruncana esnehensis* Nakkady, 1950 (Scale bar = 50 µm) (placed in zone CF3). Figure 3a-b: *Gansserina gansseri* (Bolli), 1951 (Scale bar = 50 µm) (placed in zone CF4). Figure 4a-b: *Kassabiana pseudocalcarata* (Kerdany & Abdelsalam), 1969 (Scale bar: a = 50 µm, b =55 µm) (placed in zone CF1). Figure 5a-b: *Rugoglobigerina reicheli* (Bronnimman), 1952 (Scale bar: a = 45 µm, b = 50 µm) (placed in zone CF1). Figure 6a-c: *Globotruncana aegyptiaca* (Nakkady), 1950 (Scale bar = 50 µm) (placed in zone CF4). Figure 7a-b: *Globotrunanita pettersi* (Gandolfi), 1955 (Scale bar = 60 µm) (placed in zone CF4). Figure 8a-b: *Globotruncanita angulata* (Tilev), 1951. (Scale bar; a = 45 µm, b = 50 µm) (placed in zone CF2). Figure 9a-c: *Globotruncanella petaloidea* (Gandolfi), 1955 (Scale bar: (a, b = 50 µm, c = 60 µm) (placed in zone CF4). Figure 10a-b: *Globotruncanita stuartiformis* (Dalbiez), 1955 (Scale bar =50 µm) (placed in zone CF4). Figure 11a-c: *Globotruncanita stuarti* (De Lapparent), 1918 (Scale bar = 50 µm) (placed in zone CF4). Figure 12a-c: *Globotruncana falsostuarti* (Sigal), 1952 (Scale bar = 50 µm) (placed in zone CF4). Figure 13a-b: *Abathomphalus intermedius* (Bolli), 1951 (Scale bar: a = 50 µm, b = 60 µm) (placed in zone CF2). Figure 14: *Pseudotextularia elegans* (Rzehak), 1895 (Scale bar = 50 µm) (placed in zone CF2). Figure 15a-c: *Globotruncana arca* (Cushman), 1926 (Scale bar = 50 µm) (placed in zone CF4).

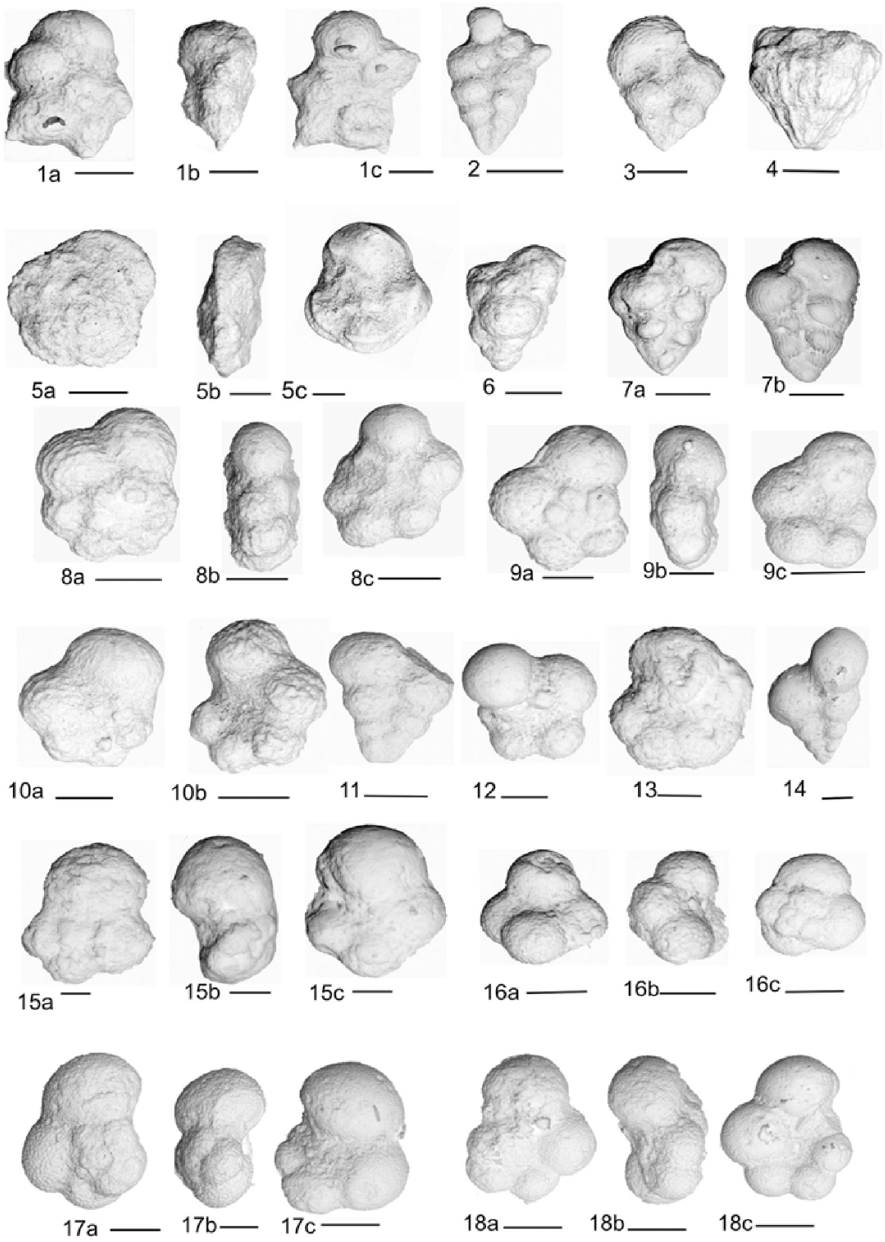

Plate 2. Figure 1a-1c: *Plummerita hantkeninoides* (Bronnimann), 1952 (Scale bar: 1a = 50 µm, b, c = 60 µm) (placed in zone CF1). Figure 2: *Pseudoguembelina hariaensis* (Nederbragt), 1991 (Scale bar =100 µm) (placed in zone CF3). Figure 3: *Pseudoguembelina palpebra* (Bronniman & Brown), 1953 (Scale bar = 50 µm) (placed in zone CF2). Figure 4: *Racemiguembelina fructicosa* (Nederbragt), 1991 (Scale bar =60 µm) (placed in zone CF4). Figure 5a-c: *Abathomphalus mayaroensis* (Bolli), 1951 (Scale bar: a,b = 50 µm, c = 30 µm) (placed in zone CF4). Figure 6: *Guembelitria cretacea* (Cushman), 1933 (Scale bar = 15 µm) (placed in zone CF1). Figure 7a-b: *Heterohelix dentata* (Stenestad), 1968 (Scale bar = 60 µm) (placed in zone CF4). Figure 8a-8c: *Rugoglobigerina hexacamerata* (Plummer), 1926 (Scale bar = 50 µm) (placed in zone CF4). Figure 9a-9c*: Hedbergella monmouthensis* (Olsson), 1960 (Scale bar: a, b = 25 µm, c = 50 µm) (placed in zone CF4). Figure 10a-b: *Rugoglobigerina rugosa* (Plummer), 1926 (Scale bar = 50 µm) (placed in zone CF4). Figure 11: *Heterohelix navarroensis* (Loeblich), 1951 (Scale bar = 50 µm) (placed in zone CF4). Figure 12: *Hedbergella holmdelensis* (Olsson), 1960 (Scale bar = 25 µm) (placed in zone CF4). Figure 13: *Parvularugoglobigerina longiapertura* (Lutherbacher & Premoli Silva), 1964 (Scale bar = 10 µm) (placed in P1a). Figure 14: *Heterohelix globulosa* (Ehrenberg), 1840 (Scale bar = 25 µm) (zone CF4). Figure 15a-c: *Eoglobigerina fringa* (Subbotina), 1950 (Scale bar: a = 6 µm, b, c = 10 µm) (placed in zone P1a). Figure 16a-c: *Globoconusa daubjergensis* (Bronnimann), 1953 (Scale bar: a, b = 15 µm, c = 22 µm) (zone P1a). Figure 17a-c: *Parasubbotina pseudobulloides* (Plummer), 1926 (Scale bar: a, b = 40 µm, c = 50 µm) (placed in zone *P. pseudobulloides*). Figure 18a-c: *Praemurica inconstans* (Bolli), 1957 (Scale bar = 50 µm) (placed in zone *P. inconstans*).

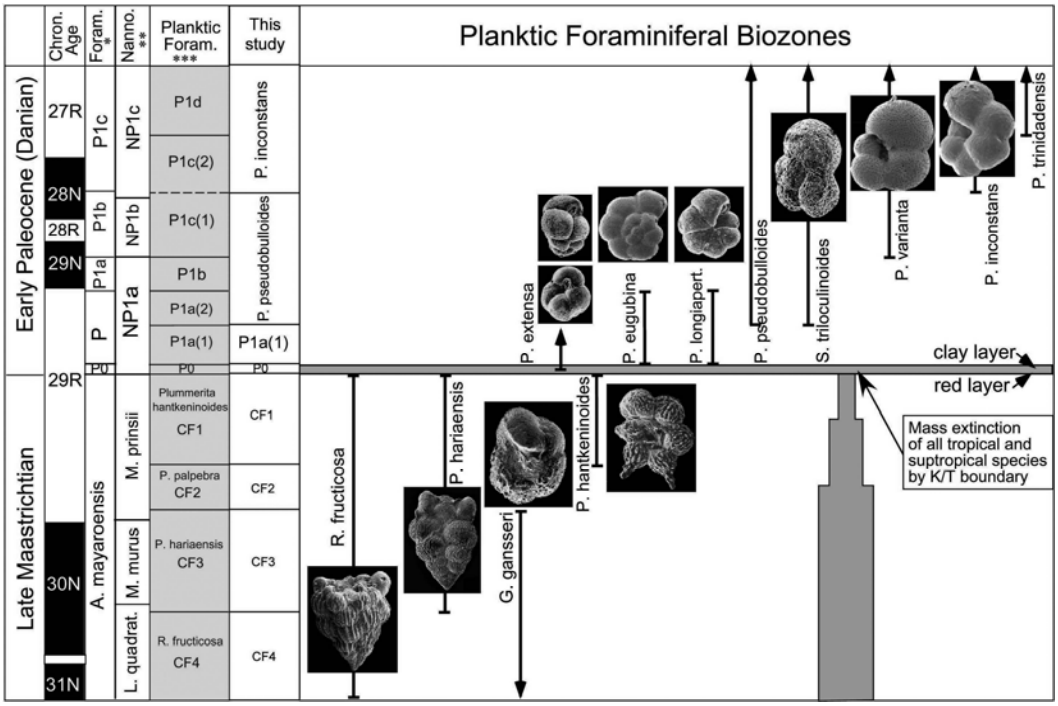

Figure 2. Comparison of biozones of the studied area with * [8]; ** [41]; *** [19,23].

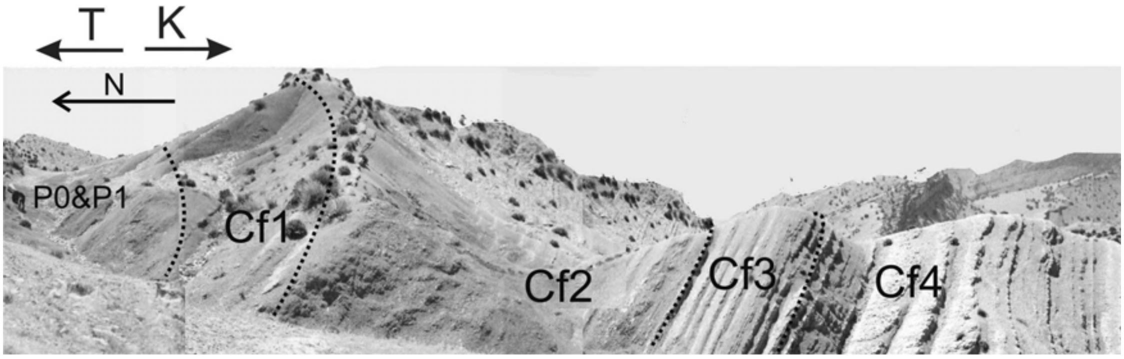

Figure 3. Delineated uppermost Maastrichtian and lower Danian biozones on the studied area.

Biostratigraphy

For the Late Maastrichtian the biozonation of [23] and [24] was used, which subdivides the *Abathomphalus mayaroensis* zone into four Cretaceous Foraminiferal (CF) biozones (CF1 to CF4, Fig. 2). For the earliest Danian zones P0 and P1a (*Parvularugoglobigerina eugubina* zone), the biozonation of [19] was used. The subsequent Danian zones of [19] were not recognized in the employed sample strategy and therefore were zoned based on the biozonation of [42]. These biozonal schemes are shown in Figure 2 in comparison with other commonly used biozones.

Late Maastrichtian

Abathomphalus ayaroensis Total Rang Zone:

This biozone was defined previously as the interval from the first to the last appearance of *A. mayaroensis*, which spans the entire late Maastrichtian interval [10,42].

In the Kabirkuh section the *A. mayaroensis* zone encompasses 27.6 meters of Maastrichtian shale, which can be subdivided into the four CF zones of [23] (Figs. 3 and 4).

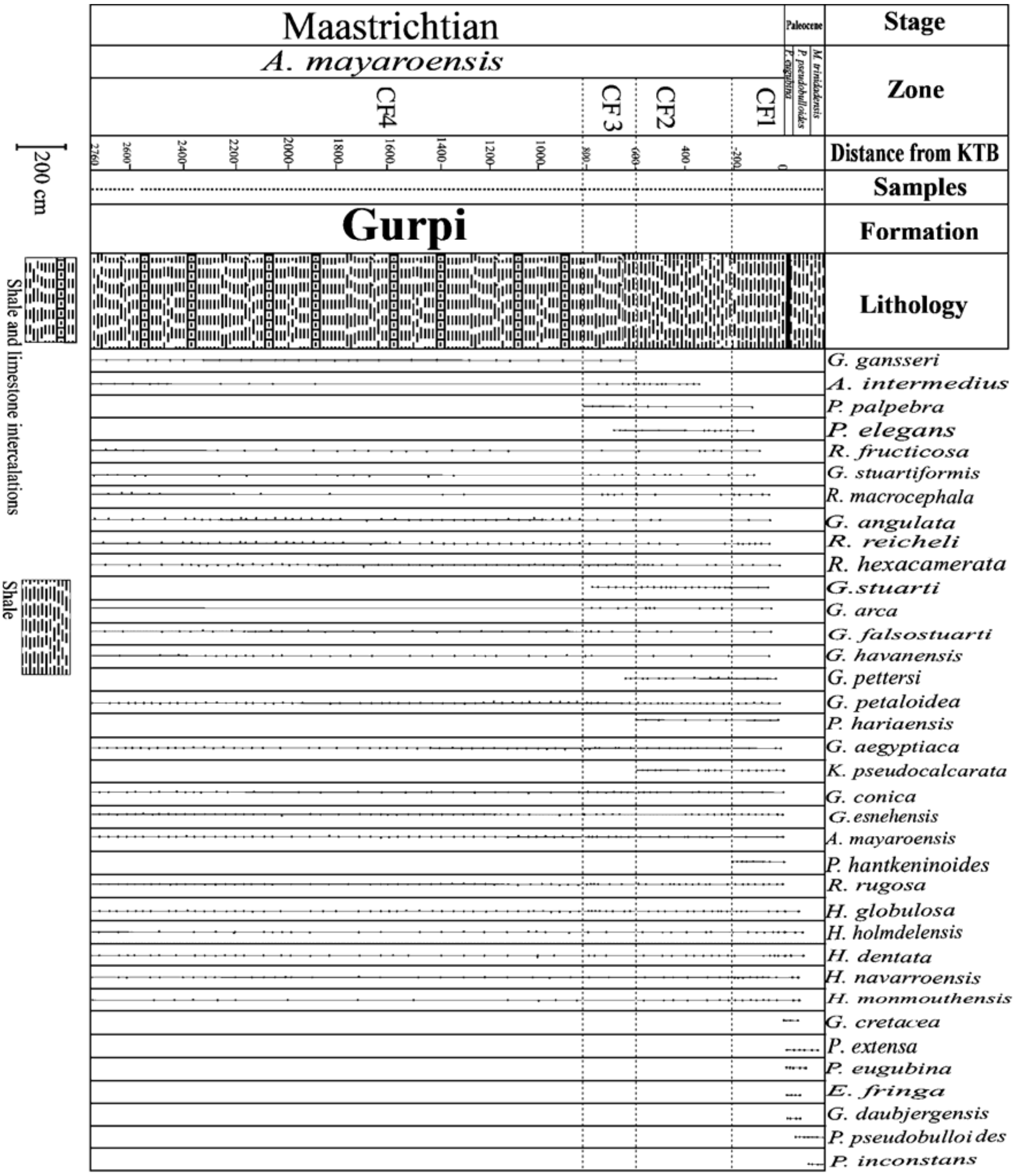

Figure 4. Late Maastrichtian to Danian planktonic foraminiferal species ranges from the Kabirkuh section, southwestern Iran. Samples collected at 30-40 cm intervals.

Zone CF4 (Racemiguembelina fructicosa):

Zone CF4 is defined as the interval from the first appearance of *R. fructicosa* to the first appearance of *Pseudoguembelina hariaensis* [23]. In the Kabirkuh section, zone CF4 encompasses 19.40 m of the dark grey shale (Figs. 3 and 4). The CF4 assemblage is characterized by *Abathomphalus intermedius*, *A. mayaroensis*, *Gansserina gansseri*, *Globotruncana aegyptiaca*, *G. arca*, *G. esnehensis*, *G. falsostuarti*, *Globotruncanella havanensis*, *G. petaloidea*, *Globotruncanita conica*, *G. stuartiformis*, *G. stuarti*, *Hedbergella holmdelensis*, *H. monmouthensis*, *Heterohelix dentata*, *H. globulosa*, *H. navarroensis*, *Racemiguembelina fructicosa*, *Rugoglobigerina hexacamerata*, *R. macrocephala*, *R. reicheli*, (Fig. 4).

Zone CF3 (Pseudoguembelina hariaensis):

Zone CF3 defines the interval from the first appearance of *Pseudoguembelina hariaensis* at the base to the disappearance of *Gansserina gansseri* at the top [23,24]. This biozone spans 2.20 m of grey shale (Figs. 3 and 4). Other species identified in CF3 include *Abathomphalus intermedius, A. mayaroensis, Gansserina gansseri, Globotruncana aegyptiaca, G. arca, G. falsostuarti, Globotruncanita conica, G. stuartiformis, G. stuarti G. pettersi, Hedbergella holmdelensis, H. monmouthensis, Heterohelix dentata, H. globulosa, H. navarroensis, Pseudoguembelina hariaensis*, *P. palpebra, Rugoglobigerina rugosa, R. macrocephala* and *R. reicheli* (Fig. 4).

Zone CF2 (Pseudoguembelina palpebra):

This zone spans the interval from the last appearance of *Gansserina gansseri* to the first appearance of *Plummerita hantkeninoides* [23,24]. In the Kabirkuh section, this zone spans 3.80 m of grey shale (Fig. 3). The assemblage includes *Abathomphalus intermedius*, *A. mayaroensis, Globotruncana aegyptiaca, G. arca, G. falsostuarti, Globotruncanita angulata, G. stuarti, G. stuartiformis, Hedbergella holmdelensis, H. monmouthensis, , Heterohelix dentata, H. globulosa, H. navarroensis Pseudoguembelina hariaensis, Rugoglobigerina macrocephala, R. reicheli* and *R. rugosa* (Fig. 4).

Zone CF1 (Plummerita hantkeninoides):

Zone CF1 is defined by the total range of *Plummerita hantkeninoides*. Which marks the last 300 ky of the Maastrichtian [23,24,33]. In the Kabirkuh section zone CF1 spans the uppermost 2.2 m of grey shale below the kidney-red KTB horizon. Other species identified in this interval include *Abathomphalus mayaroensis, Globotruncana aegyptiaca, G. arca, G. esnehensis, G. falsostuarti, Globotruncanella citae, G. petaloidea, G. havanensis, Globotruncanita angulata, G. conica, G. pettersi, G. stuarti, G. stuartiformis, Heterohelix globulosa, H. navarroensis, Hedbergella monmouthensis, Kassabiana falsocalcarata, Plummerita hantkeninoides, Pseudoguembelina hariaensis, P. palpebra, Pseudotextularia elegans, Rugoglobigerina macrocephala, R. riecheli* and *R. rugosa* (Fig. 4).

Early Danian

Zone P0 (Parvularugoglobigerina extensa):

The base of zone P0 coincides with the base of the kidney-red layer and the extinction of all tropical and subtropical species, and within a few cm the first appearance of Danian species including *P. extensa* (formerly known as *Globoconusa conusa*, [32]). The top of zone P0 is defined by first appearance of *Parvularugoglobigerina eugubina* and/or *P. longiapertura*.

The zone P0 interval is generally only a few cm thick, except at the El Kef stratotype where it spans 50 cm. The zone P0, or K/T layer, commonly consists of clayey shale or red clay enriched with iron and may contain an Ir anomaly and Ni-rich spinels [37]. In the Kabirkuh section zone P0 is only 2.5 cm thick and marked by the presence of *P. extensa.* Associated species include *Guembelitria cretacea*, *Hedbergella holmdelensis, H. monmouthensis*, *Heterohelix dentata, H. globulosa,* and *H. navarroensis* (Fig. 5).

Zone P1a (Parvularugoglobigerina eugubina):

Zone P1a is defined by the total range of *Parvularugoglobigerina eugubina* and/or *P. longiapertura* [19]. In the Kabirkuh section zone P1a is 80 cm thick and consists of dark grey shale of the Gurpi Formation. The P1a zone assemblage includes *Eoglobigerina fringa, Globoconusa daubjergensis, Parvularugoglobigerina eugubina, P. extensa. P. longiapertura*. *Parasubbotina pseudobulloides* was not observed in this interval and therefore the subdivision of zone P1a(1)/P1a(2) could not be applied.

Parasubbotina pseudobulloides zone:

In this study, this zone marks the interval from the first appearance of *P. pseudobulloides* to the first appearance of *Praemurica inconstans*. The zone spans one meter of grey shale and the assemblage includes *Globoconusa daubjergensis and Subbotina triloculinoides* (Fig. 4).

Comparison with other K/T Sections

The late Maastrichtian and lower Danian biozones identified in this study are similar to those identified from stratigraphically complete sequences throughout the Tethys, including Spain [6,9,30,33], Italy [27], Austria [35], Tunisia [2,7,23,24,28], Egypt [1,15,16,17], USA (Texas) [14], Mexico [5,20,26,39], Belize and Guatemala [21]. The similarity of the faunal assemblages and biozones in the Kabirkuh section of Iran with those throughout the Tethys Ocean is due to the relatively continuous sedimentary record preserved and attests to the relatively uniform environmental conditions in low latitudes before and after the K/T event. However, because of the relatively shallow water environment of the Kabirkuh section there are also significant differences, including the low species diversity and gradual disappearance of most species prior to the KTB as discussed below.

K/T Boundary and Mass Extinction

The Kabirkuh KTB is marked by the coincidence of a 1-2.5 cm thick kidney-red layer, the extinction of all ornate large tropical and subtropical species, including all globotruncanids, rugoglobigerinids and racemiguembelinids at or below the red layer, and the first appearance of early Danian species immediately above it (Figs. 4, 5). Species diversity is relatively low with a total of 29 species identified, but comparable to shallow water faunal assemblages from Egypt [15,18].

Of the 29 Cretaceous species identified, 3 (~10%) disappeared in the CF3-CF2 interval (Fig. 4), 20 species (69%) disappeared in the top 28 cm of CF1 below the KTB and 6 species (~20%) survived into the early Danian zones P0 and P1a (Fig. 4).

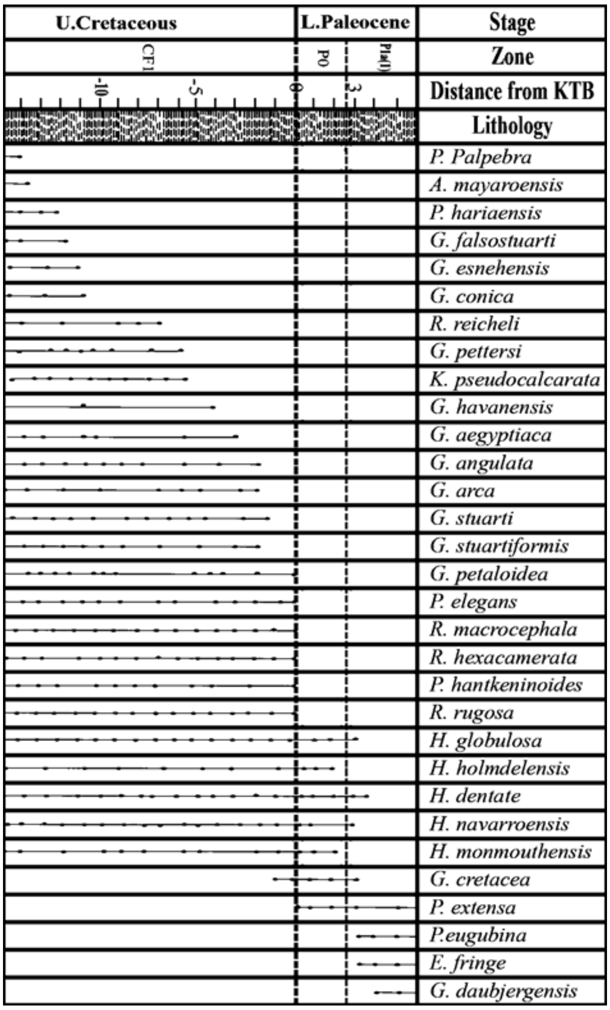

Figure 5. Planktonic foraminiferal species ranges across the K/T boundary at Kabirkuh, southwestern Iran. Samples collected at 2-3 cm intervals.

This gradual extinction pattern may be due, at least in part, to preservation or rarity of species. However, similar patterns observed in shallow water Tethys environment (e.g., Mexico, Texas, Egypt) suggest also environmental effects. The onset of severe biotic stress can be identified in the upper zone CF3 to lower CF2 interval where all globotruncanids including *G. arca* and *G. havanensis* decreased in relative abundances and *G. gansseri* disappeared. At the same time, heterohelicids increased in relative abundance along with hedbergellids and thrived through zone CF1 to the end of Maastrichtian. The surface dwellers rugoglobigerinids and *Plummerita hantkeninoides* thrived during zone CF1.

Similar extinction patterns were also observed in Egypt [15,18]. The observed faunal changes can be correlated to global climate and sea level changes.

The late Maastrichtian zones CF3-CF2 interval was characterized by global cooling and a major sea level regression, which culminated about 500 ky before the KTB. Therefore, rapid greenhouse warming with increased temperatures of 3-4°C occurred between 400 and 200 ky prior to the KTB, followed by gradual cooling during the last 100-200 ky of the Maastrichtian [4,25].

The greenhouse warming is widely believed to be related to the concurrent massive Deccan Trap volcanic activity [4,22,32].

Stable isotope ranking of planktic foraminiferal species in the water column indicates that globotruncanids were intermediate to deep dwellers [4]. Their early decline and eventual demise may have been related to the increased biotic stress associated with climatic warming and related changes in the water mass stratification that decreased their habitat. But in the shallow water sequences of Egypt, as well as the Kabirkuh section of Iran, the early disappearance of these species is likely due to the sea level regression and hence shallowing environment.

The decrease and disappearance of globotruncanids is associated with increased aboundance of biserial species (*e.g., Heterohelix globulosa, H. dentata* and *H. navarroensis*), which are interpreted as ecological generalists, characterized by medium or small test sizes, simple morphologies and little surface ornamentation. They appear to have tolerated significant fluctuations in temperature and thrived in nutrient-enriched low oxygen conditions where few other species survived. High abundances of heterohelicids thus indicate high biotic stress related to the expansion of the oxygen minimum zone during climate warming, or isolated basin environments with high terrestrial nutrient influx [15].

In the Kabirkuh section, the heterohelicids (primarily

H. globulosa) dominate in the >150 µm size fraction of zone CF3 to CF1. In the upper part of zone CF1, the relative abundance of heterohelicids in the larger size fraction decreased rapidly and smaller sized heterohelicids (63-150 µm) dominate. In the earliest Danian (zone P0), the relative abundance of these species drops to <5% and they disappeared in zone P1a (Fig. 5).

This pattern of abundance and size changes, or dwarfing, is commonly observed throughout the Tethys during the latest Maastrichtian in heterohelicids and other species groups [14,15,29]. Dwarfing has been recognized as a common response to high-stress environmental conditions in foraminifera as well as other marine organisms at other mass extinction events (*e.g.*, [34] and [43]).

Dwarfing can be directly correlated with biotic stress induced by climate warming [3] and the migration of tropical-subtropical species into higher latitudes [4,22,32]. Although the direct cause of species dwarfing is still unknown, preliminary data suggests increased biotic stress induced by enhanced nutrient influx during high terrestrial runoff associated with climate change [18].

The surface dwellers *Plummerita hantkeninoides* and *Rugoglobigerina reicheli* thrived during the climate warming of zone CF1 along with *Kassabiana falsocalcarata*. However, these species decreased rapidly during the global cooling of the last 100-200 ky of the Maastrichtian as also observed in Tunisia, Egypt.

The ecological opportunist or disaster species *Guembelitria cretacea* (>63 µm) is present in very lower abundances (<2%) during the late Maastrichtian in the Kabirkuh section. During the early Danian zones P0 and P1a, the relative abundance of *Guembelitria* reaches only about 10%. This very low *Guembelitria* abundance is in marked-contrasts with the high abundances (60-80%) generally found in the basal Danian throughout the Tethys in shallow near shore or open marine environments [18].

There are several possible explanations for this anomaly in the Kabirkuh section: 1) this section represents an unusual post-K/T environment with less biotic stress than observed throughout the Tethys realm. This is unlikely because the pre-K/T faunal assemblages show similar stress conditions as elsewhere and the post-K/T assemblages show similar biozone assemblages. 2) The earliest Danian zones P0 and P1a are condensed with the maximum *Guembelitria* abundance peak missing. This is very likely for the short (2.5 cm thick) zone P0, but not likely for the 80 cm thick zone P1a, which should also have very high *Guembelitria* abundances. 3) There is a preservation effect, which selectively eliminates very small fragile species. This is a possibility either due to diagenesis or mechanical breaking during sample processing. And 4) *Guembelitria* species, which are generally found in the 63-100 um size fraction, may be dwarfed in the Kabirkuh section with most of the specimens in the 38-63 µm size fraction. This is a likely possibility because such dwarfing of *Guembelitria* is frequently observed in K/T sequences (*e.g.*, [15] and [19]) and will have to be tested in future quantitative studies of the Kabirkuh section.

Summary and Conclusions

The Cretaceous-Tertiary boundary in the Kabirkuh section of southwestern Iran reveals an expanded Late Maastrichtian and early Danian sedimentary record similar to the El Kef stratotype in Tunisia, except for a very condensed (3 cm thick) zone P0 as compared with 50 cm at El Kef. In Egypt sections, very condensed (<10 cm) zone P0 intervals tend to be truncated by erosion [15,16]. Species extinction and survivorship patterns are similar to those observed in Tunisia, Egypt, Spain, Italy and Mexico.

The onset of the terminal K/T mass extinction and faunal turnover began during climatic cooling in zone CF3, accelerated during the rapid warming in zone CF1 and culminated at the boundary event. The first phase of this extended faunal turnover affected largely globotruncanids and other large tropical species, which decreased in abundance, whereas heterohelicids and hedbergellids thrived.

The second phase began during the climate warming 200-400 ky before the K/T boundary event and accelerated during the cooling of the last 100-200 ky of the Maastrichtian. Dwarfed species are common during the climate warming. Dwarfing has been interpreted as a sign of early sexual maturation and rapid reproduction to favor survival during high biotic stress. Tropical species abundances are very low with most species dwarfed and/or sporadically present. Some species disappeared well before the K/T boundary, for others, sporadic occurrence prevents accurate assessment of the extinction level (Signor-Lipps effect). Nevertheless, the rarity of tropical species and their apparent disappearances prior to the K/T boundary indicate increasing biotic stress preceding the K/T boundary event. This is also indicated by the high heterohelicid abundance, suggesting an expanded oxygen minimum zone, possibly due to increased nutrients from enhanced terrestrial runoff associated with the climate change.

The third phase marks the boundary event itself with the disappearance of all tropical and subtropical species, the terminal decrease of heterohelicids and blooms of the disaster opportunist *Guembelitria* species. The latter appears to be missing in the Kabirkuh section in the size fraction examined. This phase clearly marks the cataclysmic end of the mass extinction brought about by yet another environmental perturbation (impact, volcanism) that exceeded threshold conditions for the already endangered tropical and subtropical species and led to the terminal decline of the generally robust heterohelicids and hedbergellids, leaving only the disaster opportunist *Guembelitria* to thrive.

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