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ORIGINAL ARTICLE

Biostratigraphic correlation of the transition of Maastrichtian–Thanetian based on calcareous nannofossils and planktonic foraminifera in Fars province, Zagros (Eastern Tethyan realm)

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Abstract

This study focuses on late Campanian–early Thanetian calcareous nannofossils and foraminifera assemblages from the Gurpi and Pabdeh formations in the Fars province (SW Iran). To conduct biostratigraphic studies, the upper part of the Gurpi Formation and the lower part of the Pabdeh Formation were studied in Morgah stratigraphic section in Fars province. In this section, the upper part of the Gurpi Formation with 63 m thickness is mainly composed of gray argillaceous limestones and shale. Also, the base of the Pabdeh Formation includes 7 m of purple shales and argillaceous limestones. The upper boundary of the Gurpi Formation is also discontinuously associated with purple shales at the base of the Pabdeh Formation. In the biostratigraphic studies of the upper part of the Gurpi Formation, while identifying 29 species belonging to 20 genera of calcareous nannofossils, five biozones were identified. In addition, in biostratigraphic studies of the lower part of Pabdeh Formation, while identifying six species belonging to five genera of calcareous nannofossils, one biozone was identified. Based on the identified biozones, the transition of Gurpi Formation to the Pabdeh Formation in the studied section of Late Maastrichtian–Thanetian was determined. Also, based on a study based on planktonic foraminifera, four biozones were identified in the transition deposits of the Gurpi Formation to Pabdeh Formation. Biostratigraphic studies eventually led to a correlation between the two fossil groups.

Keywords Cretaceous · Fars · Gurpi · Paleocene · Tethys · Zagros

Introduction

The Gurpi Formation, on the one hand, is a thick sedimentary sequence of the Cretaceous–Paleogene, and on the other hand, is the source rock or cap rock of petroleum reservoirs in southwestern Iran. This formation was deposited in a developed sedimentary environment across the Zagros Basin in southwestern Iran. Therefore, the Gurpi Formation is present throughout the basin, but the best this is developed in south Iran, especially Fars province. Accordingly, this formation has been considered by many researchers (e.g., Wynd 1965; Ghasemi-Nejad et al. 2006; Rafiei et al. 2013; Senemari and Afghah 2020 etc.). However, for the first time, this formation was precisely and formally defined by James and Wynd (1965). Lithologically, the Gurpi Formation is also characterized by limestones, marl, shale, and argillaceous limestones (Motiei 1993). The important point about Gurpi Formation is the lateral changes of lithology, thickness, and age range of this formation along the Zagros sedimentary basin. In addition, the lower and upper boundaries of this formation are not fixed along this basin, and are located continuously or discontinuously with the formations. Based on fossil studies (e.g., Nannofossils and Foraminifera) that have been done on this formation so far, changes in its age range from Coniacian to Thanetian

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have been reported. However, little work has been done on the correlation of these two fossils' groups in the Gurpi Formation in the Zagros Basin. In fact, in this article, the Morgah stratigraphic section was selected and subjected to detailed fossils analysis and biostratigraphic studies, to be correlated based on the distribution of nannofossils and foraminifera assemblages. Hence, the objectives of this study are: (1) recognition of fossils and provide biostratigraphic analysis of the Gurpi Formation and (2) develop a correlation model for both fossil groups in Eastern Tethyan.

Materials and methods

The studied section is located in Fars province, about 60 km northwest of Noorabad city. The way to reach Morgah section is possible through Noorabad to Yasuj road (Fig. 1a, b). In this route, in the place of Morgah pass, there is a road to the right, where the studied section is located at a distance of 8 km from the pass. The geographical coordinates of the studied section are 51° 36′ east longitude and 30° 22′ north latitude. To study the biostratigraphy of the upper part of Gurpi Formation and the base of Pabdeh Formation, 70 rock samples were taken at sampling intervals of 1 m. Then, thin sections and slide smears were prepared from the rock samples. Sources such as Olson et al. (1999), Premoli Silva et al. (2003), and Premoli Silva and Verga (2004) have been used to identify Foraminifera species and also to introduce related biozones. Also, in the case of calcareous nannofossils, they were also prepared using the standard smear slide method according to Bown and Young (1998). Samples were taken from fresh rock surface for calcareous nannofossils' studies based on lithological changes. Then, after preparation in the laboratory, the slides were studied under two cross-polarized

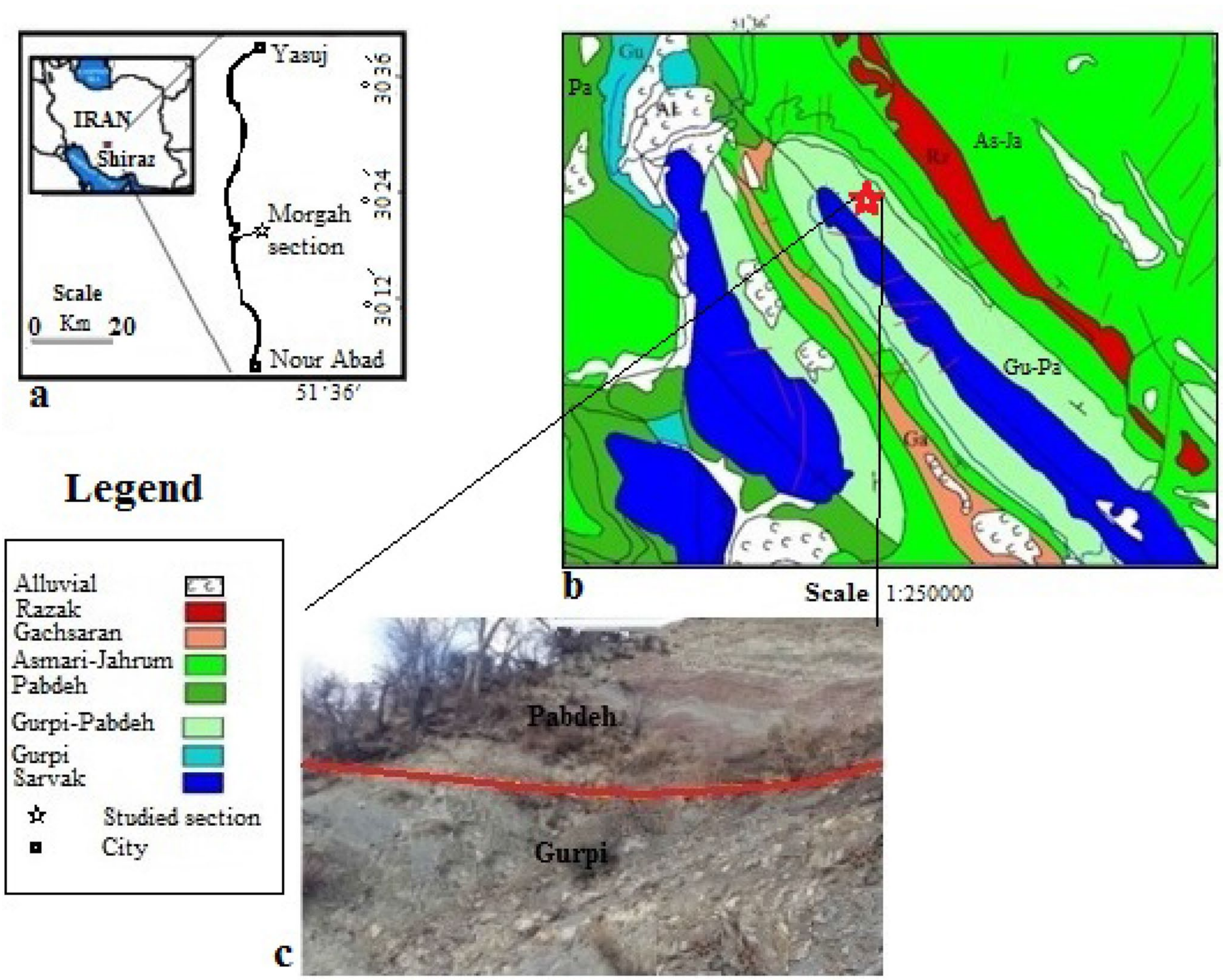


Fig. 1 (**a, b**) Geological map and access to the studied section. The position of the studied section is displayed by an asterisk. (**c**) View of the upper boundary of the Gurpi Formation with purple shales from the base of the Pabdeh Formation in the studied section

light (XPL) and plain polarized light (PPL) with an Olympus polarizing microscope with a magnification of × 1000. Identification of calcareous nannofossils was performed using the proposed classification of Perch-Nielsen (1985) and Agnini et al. (2014). In this study, for each slide, five to seven traverses (approximately 100 fields of View, FOVs) were counted to identify nannofossil assemblages, the First Occurrence (FO), the Last Occurrence (LO) of any species, and abundance. The first and last occurrences define the zonal boundaries. Other abbreviations used in this study, for the calcareous nannofossils zonation of Sissingh (1977) modified by Perch-Nilsen (1985), Burnett's (1998) boreal scale, and Agnini et al. (2014) are Coccoliths Cretaceous (CC), Upper Cretaceous (UC), and CNP (Calcareous Nannofossils Paleocene), respectively. In fact, the offered version of the zonal scheme is based on a combination of zones by Burnett, Sissingh, and Perch-Nilsen. Which follows, a regional zonal scheme for sequencing the Upper Cretaceous–Paleogene deposits is offered. Nannoplankton zones are correlated with the foraminiferan zonation that has been chosen as an independent scale. Bibliographic sources of the species can be found mostly in Perch-Nielsen (1985). Eventually, in the present study, using the identified species, a biostratigraphic chart was prepared and compared with the world standard zonings.

Results

Lithostratigraphy

In Fars province, Gurpi Formation does not have much lithological diversity, and is mainly composed of gray clay and shale limestones. In this section, all the thick of Gurpi Formation with a thickness of 140 m is located on the thick limestones of Sarvak Formation with an erosive discontinuity. At the boundary of the two formations, dissolution cavities along with iron oxide nodules are frequently seen. On the other hand, the upper boundary of the Gurpi Formation is located at the base of the purple shales at the base of the Pabdeh Formation, which is discontinuous (Fig. 1c). The sequence of the upper part of the Gurpi Formation in the transition to the lower part of the Pabdeh Formation in the studied section from the base upwards is as follows:

- 53 m alternate of thin argillaceous limestone with shale.
- 10 m of shale.

Subsequently, the samples from the base of the Pabdeh Formation including 7 m of purple shales and gray argillaceous limestones.

Biostratigraphy

The evolutionary pattern of nannofossils and foraminifera has been discussed in various studies such as biostratigraphy and studies related to oceanic sediments (Gradstein et al. 2012; Villa et al. 2008; Bralower 2005; Bornemann et al. 2003; Lees 2003; Burnett 1998; Bralower et al. 1995; Perch-Nielsen 1985; Roth 1978; Sissingh 1977; Thierstein 1976). Biostratigraphic criteria of the Gurpi Formation were established by James and Wynd (1965) and reviewed and continued by other researchers (e.g., Biranvand and Ghasemi Nejad 2013; Feridonpour et al. 2015). The special characteristics of these two fossil groups, such as their abundance, shortage range, and wide geographical distribution, make them important indicators in biostratigraphic studies (Perch-Nielsen 1985; Bralower et al. 1995; Burnett 1998; Lees 2003; Bralower 2005; Villa et al. 2008). All biostratigraphic models are presented based on the evolution of index species.

Planktonic foraminifera in the Gurpi–Pabdeh transition

In the deposits of the upper part of the Gurpi Formation and also the base of the Pabdeh Formation, 42 species belonging to 17 genera of planktonic foraminifera were identified. Based on the first and last occurrence of zonal markers observed, 4 biozones based on zonation of Premoli Silva et al. (2004) for this transition in the studied section have been introduced, which are explained below (Figs. 2, 3):

a. Planktonic foraminifera in the Gurpi Formation

The following biozones were identified in the sampled sequence of the upper part of the Gurpi Formation:

1) Gansserina gansseri interval zone

This biozone is defined from the first occurrence of *Gansserina gansseri* to the first occurrence of *Contusotruncana contusa* and has the late Campanian–early Maastrichtian age. The total thickness of the zone is about 26 m and some of its fossils are: *Rugoglobigerina rugosa*, *Globotruncana lapparenti*, *Globotruncana ventricosa*, *Globotruncana arca*, *Globotruncana aegyptiaca, Contusotruncana fornicata*, *Heterohelix globulosa, Globotruncanella havanensis, Gansserina gansseri, Rugotruncana subcircumnodifer, Globotruncanita stuarti*, and *Globotruncanita stuartiformis*. This biozone has been reported in different parts of the Zagros basin in the Gurpi Formation (Vaziri-Moghaddam 2002; Sadeghi and Darabi 2015).

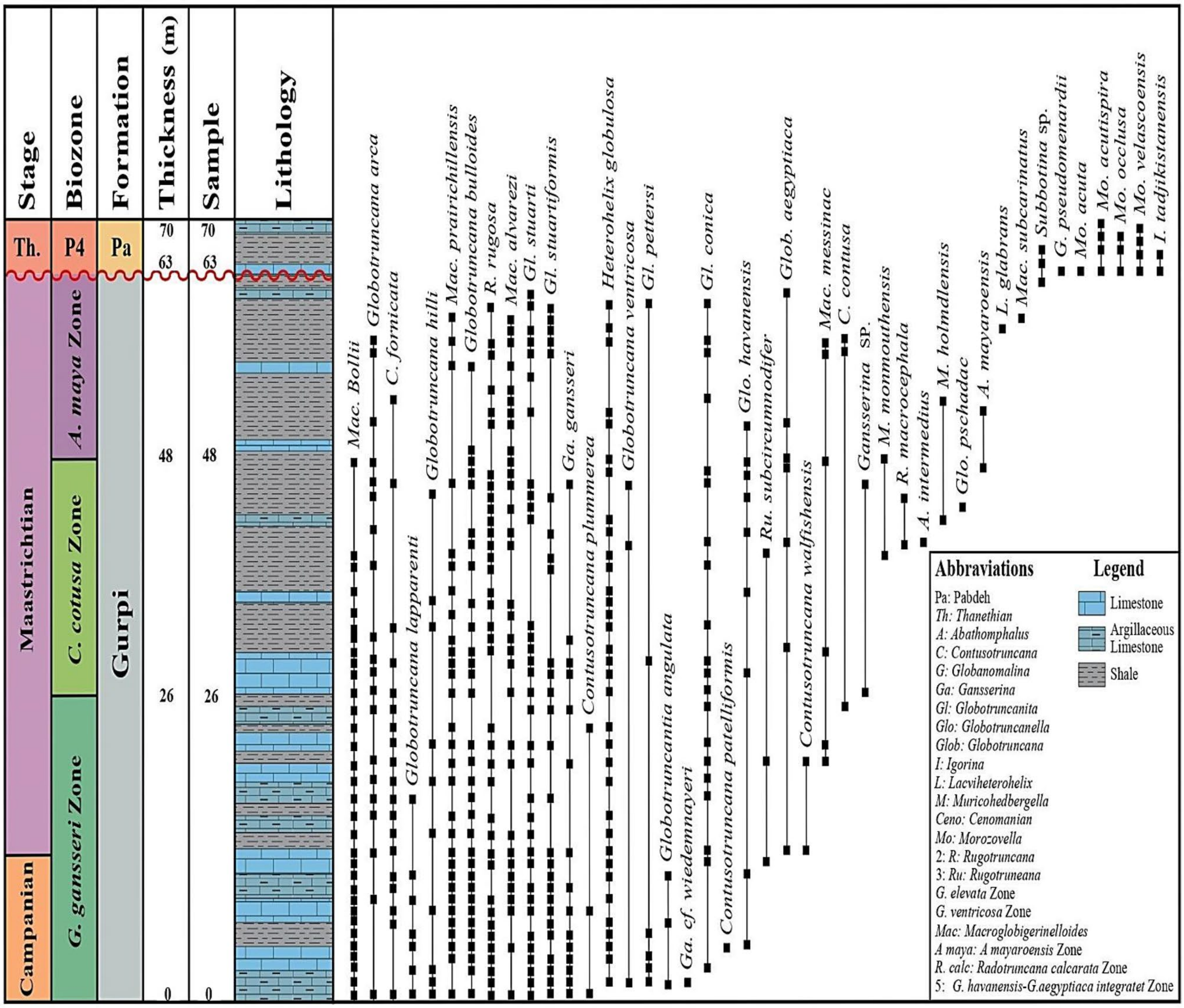


Fig. 2 Stratigraphic and biostratigraphic column of Gurpi Formation based on Planktonic foraminifera in Morgah section

2) Contusotruncana contusa interval zone

The next fossil unit is defined from the first occurrence of *Contusotruncana contusa* to the first occurrence of *Abathomphalus mayaroensis* and has the middle Maastrichtian age. The total thickness of the zone is about 22 m and some of its fossils are: *Rugoglobigerina rugosa*, *Globotruncana arca*, *Globotruncana ventricosa*, *Globotruncana bulloides*, *Globotruncanita stuarti*, *Globotruncanita stuartiformis, Globotruncana aegyptiaca, Heterohelix globulosa, Contusotruncana contusa, Contusotruncana fornicata, Rugotruncana subcircumnodifer, and Gansserina gansseri.* This biozone has been reported in different parts of the Zagros basin (Sadeghi and Darabi 2015; Razmjooei et al. 2018).

3) Abathomphalus mayaroensis interval zone

The last fossil zone recorded from the Gurpi Formation is defined from the first occurrence of *Abathomphalus mayaroensis* to the extinction of most species of planktonic foraminifera and has the late Maastrichtian age. The dominant taxa include *Abathomphalus mayaroensis, Gansserina gansseri*, *Globotruncanita stuarti*, and *Contusotruncana contusa.* This zone includes 15 m of Gurpi Formation. Also, this biozone has been reported in different parts of the Zagros basin (Darvishzadeh et al. 2007; Razmjooei et al. 2014, 2018; Rahimi et al. 2018).

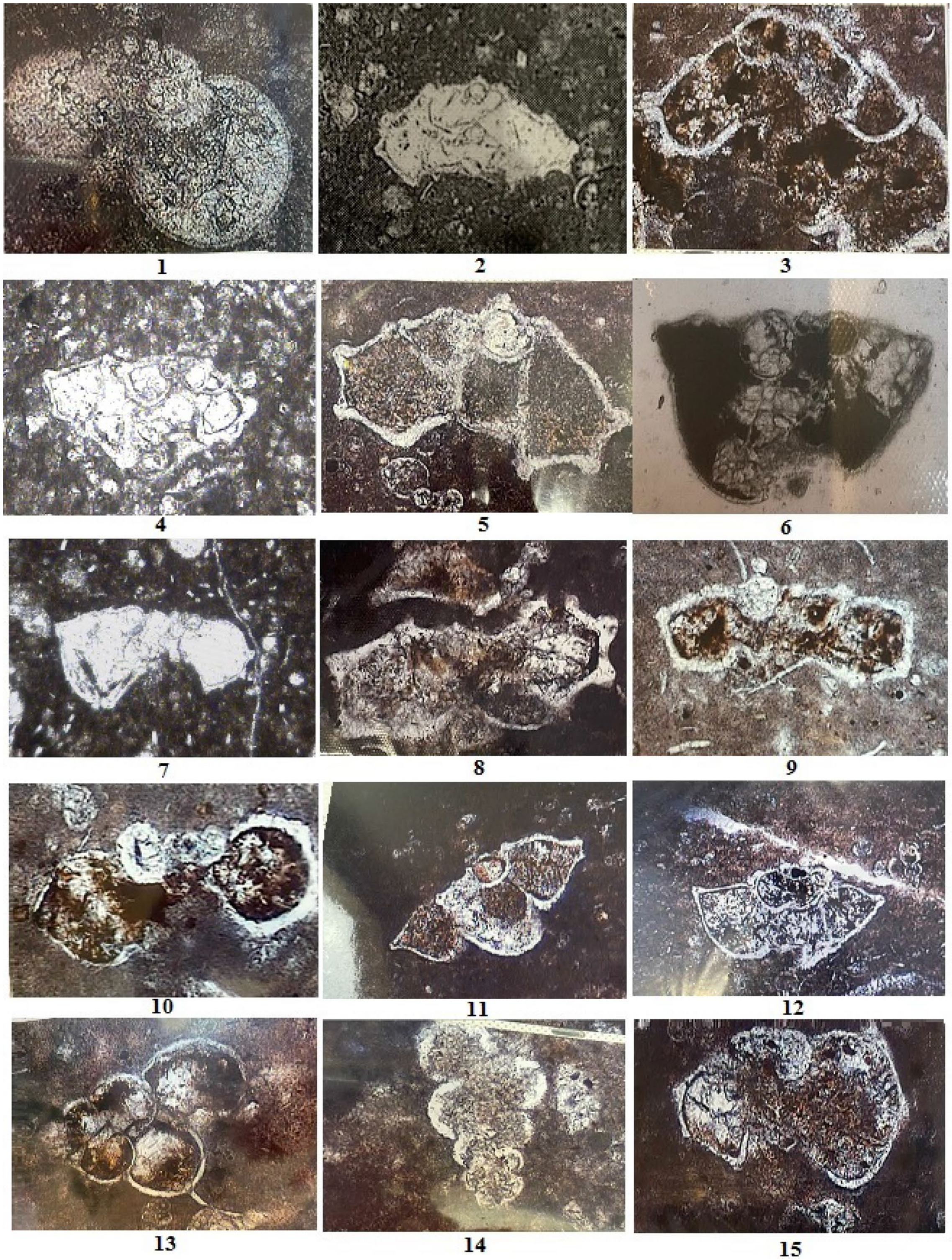


Fig. 3 All figures (XPL) light micrographs, **1.** *Rugoglobigerina rugosa* (Plummer 1927), **2.** *Globotruncana arca* (Cushman 1926), **3.** *Contusotruncana contusa* (Cushman 1926), **4.** *Globotruncana ventricosa* (White 1928), **5.** *Contusotruncana fornicata* (Plummer 1931), **6.** *Gansserina gansseri* (Bolli 1951), **7.** *Globotruncana aegyptiaca* Nakkady (1950), **8.** *Globotruncana bulloides* Vogler (1941), **9.** *Globotruncana lapparenti* Brotzen (1936), emended, Pessagno 1967, **10.** *Globotruncanella havanensis* (Voorwijk 1937), **11.** *Globotruncanita stuarti* (de Lapparent 1918), **12.** *Globotruncanita stuartiformis* (Dalbiez 1955), **13.** *Heterohelix globolusa* (Ehrenberg 1840), **14.** *Heterohelix globolusa* (Ehrenberg 1840), **15.** *Rugoglobigerina rugosa* (Plummer 1927)

b- Planktonic foraminifera in the base of the Pabdeh Formation

The following biozone was identified in the base of Pabdeh Formation:

1) *Globanomalina pseudomenardii zone*

The following planktonic foraminifera has been identified in 7 m sampled from the base of Pabdeh Formation, including: *Morozovella velascoensis, Morozovella acuta, Morozovella occlusa, Globanomalina pseudomenardii,* and *Igorina tadjikistanensis*. This fossil assemblage is consistent with the Globanomalina pseudomenardii Zone (= P4a: Acarinina subsphaerica Interval Subzone) from the zonation of Premoli Silva et al. (2003). In addition, according to the mentioned microfossil assemblage for the base part of the Pabdeh Formation in the studied section, the late Selandian–early Thanetian is suggested in terms of age.

a. Calcareous nannofossils in the Gurpi Formation

In this study, by identifying the components of calcareous nannofossils in the sequence of the Gurpi Formation, while identifying 29 species, the zones of Quadrum trifidum Zone to Nephrolithus frequens Zone based on Sissingh zoning (Sissingh 1977) were diagnosed as follows (Figs. 4, 5):

1) *Quadrum trifidum zone (CC22)*

The first biozone in this study is defined from the first occurrence (FO) of *Quadrum trifidum* to the last occurrence (LO) of *Reinhardtites anthophorus,* and has the late Campanian age. The dominant taxa include *Quadrum trifidum, Reinhardtites anthophorus, L. grillii, W.barnesiae, W. biporta, M. decoratus, M. decussata, E. eximius, E. turriseiffelii, L. carniolensis, Q. gothicum, Q. sissinghii, T. phacelosus, A. cymbiformis, A. parcus constrictus, C. obscurus, C. aculeus, and C. platyrhethus*. In this zone, due to the lack of *E. parallelus* species, it was not possible to separate the UC15d^{TP} and UC15e^{TP} subzones. In fact, Zone CC22 corresponds to the UC15d^{TP}/UC15 e^{TP} combined subzones of the Burnett zoning (Burnett 1998). The thickness of the zone is about 8 m.

2) *Tranolithus orionatus zone (CC23)*

This biozone is defined from the last occurrence of *Reinhardtites anthophorus* to the last occurrence of *Tranolithus phacelosus* and has the late Campanian–early Maastrichtian age. The dominant taxa include *Tranolithus phacelosus, A. parcus constrictus, E. eximius, Quadrum gothicum, Quadrum trifidum, Quadrum sissinghii, Watznaueria barnesiae, Watznaueria biporta, Micula decussata, Microrhabdulus decoratus, Rhagodiscus angustus, Reinhardtites levis, Lithraphidites carniolensis, Eiffellithus turriseiffelii, Calculites obscurus, Ceratolithoides aculeus, Arkhangelskiella cymbiformis, and Chiastozygus platyrhethus.* In this zone, the last presence of *A. parcus constrictus* causes the zone to be divided into two subzones (Sissingh 1977). This zone corresponds to UC16 and UC17 zones. In this study, the UC16 zone is based on the last presence of *E. eximius* to the last presence of *A. parcus constrictus* and UC17 zone is determined based on the last presence of *A. parcus constrictus* to the last presence of *Q. trifidum* and *T. orionatus*. The total thickness of the zone is about 12 m.

3) Reinhardtites levis zone (CC24)

This biozone is defined from the last occurrence of *Tranolithus phacelosus* to the last occurrence of *Reinhardtites levis* and has the late early Maastrichtian age. The dominant taxa include *Arkhangelskiella cymbiformis, Ceratolithoides aculeus, Calculites obscurus, Eiffellithus turriseiffelii, Reinhardtites levis, Microrhabdulus decoratus, Prediscosphaera cretacea, Rhagodiscus angustus, Braarudosphaera biglowii, Lucianorhabdus cayeuxii, Lithraphidites carniolensis, Micula decussata, Watznaueria barnesiae, and Watznaueria biporta.* This zone corresponds to the UC18 zone of the Burnett zoning (Burnett 1998). In this zone, the zoning indices are the same for Burnett (1998) and Sissingh (1977). The thickness of the zone is about 6 m.

4) Arkhangelskiella cymbiformis Zone (CC25)

This biozone is defined from the last occurrence of *Reinhardtites levis* to the first occurrence of *Nephrolithus frequens* and has the early late Maastrichtian age. The dominant taxa include *Micula murus, Eiffellithus turriseiffelii, Thoracosphaera operculata, Watznaueria biporta, Watznaueria barnesiae, Micula decussata, Lithraphidites quadratus, Ceratolithoides aculeus, Arkhangelskiella cymbiformis, Lucianorhabdus cayeuxii, and Braarudosphaera biglowii.* However, since *Nephrolithus frequens* was not identified in the studied section, the upper limit of the zone was determined based on the occurrence of *Micula murus*. According to Sissingh (1977), the CC25 zone can be divided into subzones by the first presence of *L. quadratus* and *M. murus*. In this zone, both species were recorded, and therefore, the desired zone can be divided into three subzones a, b, c. The CC25 zone corresponds to the UC19 and UC20 zones (UC20a^{TP}-UC20b^{TP}) of the Burnett zoning (Burnett 1998). The thickness of the zone is about 26 m.

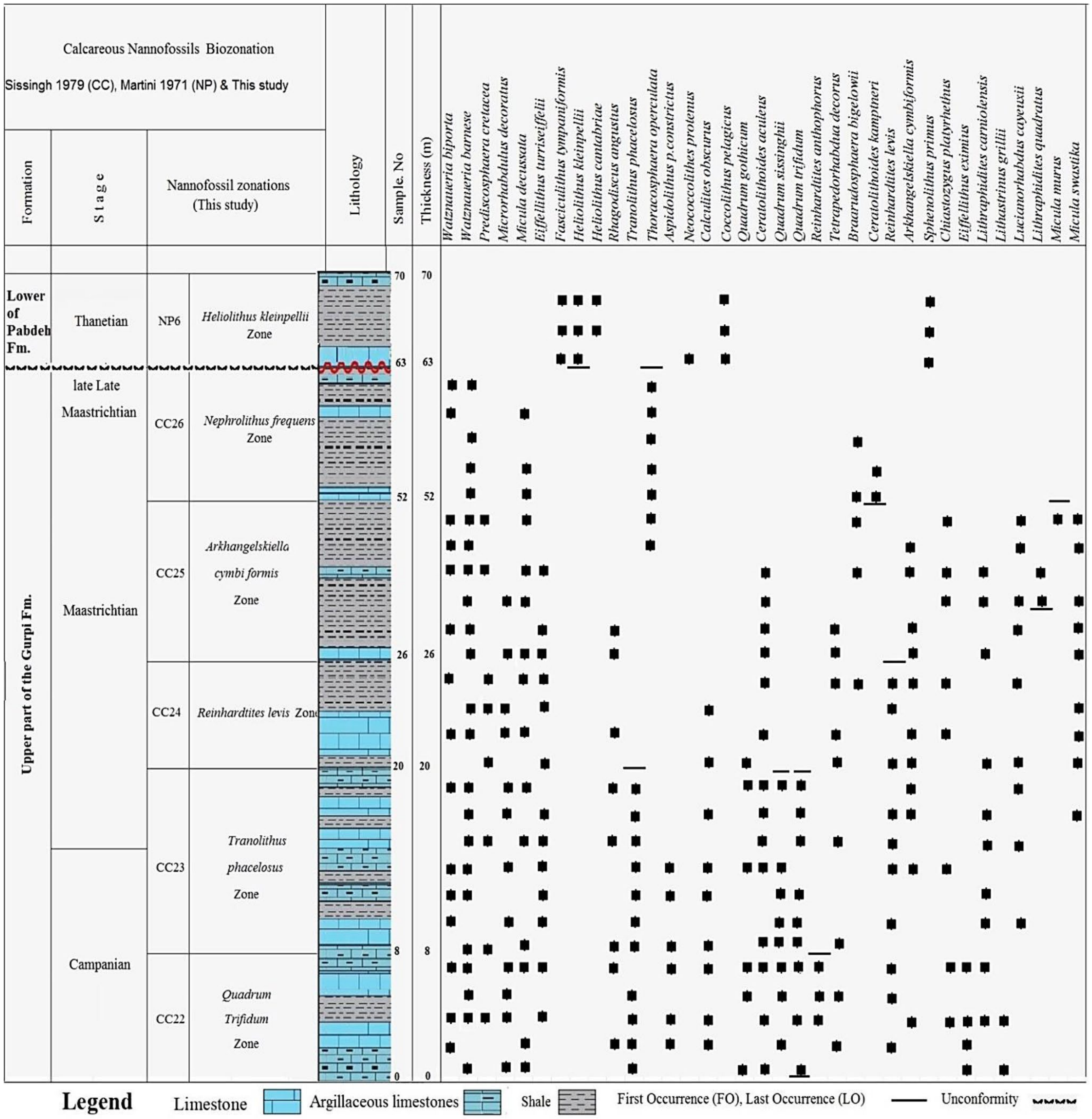
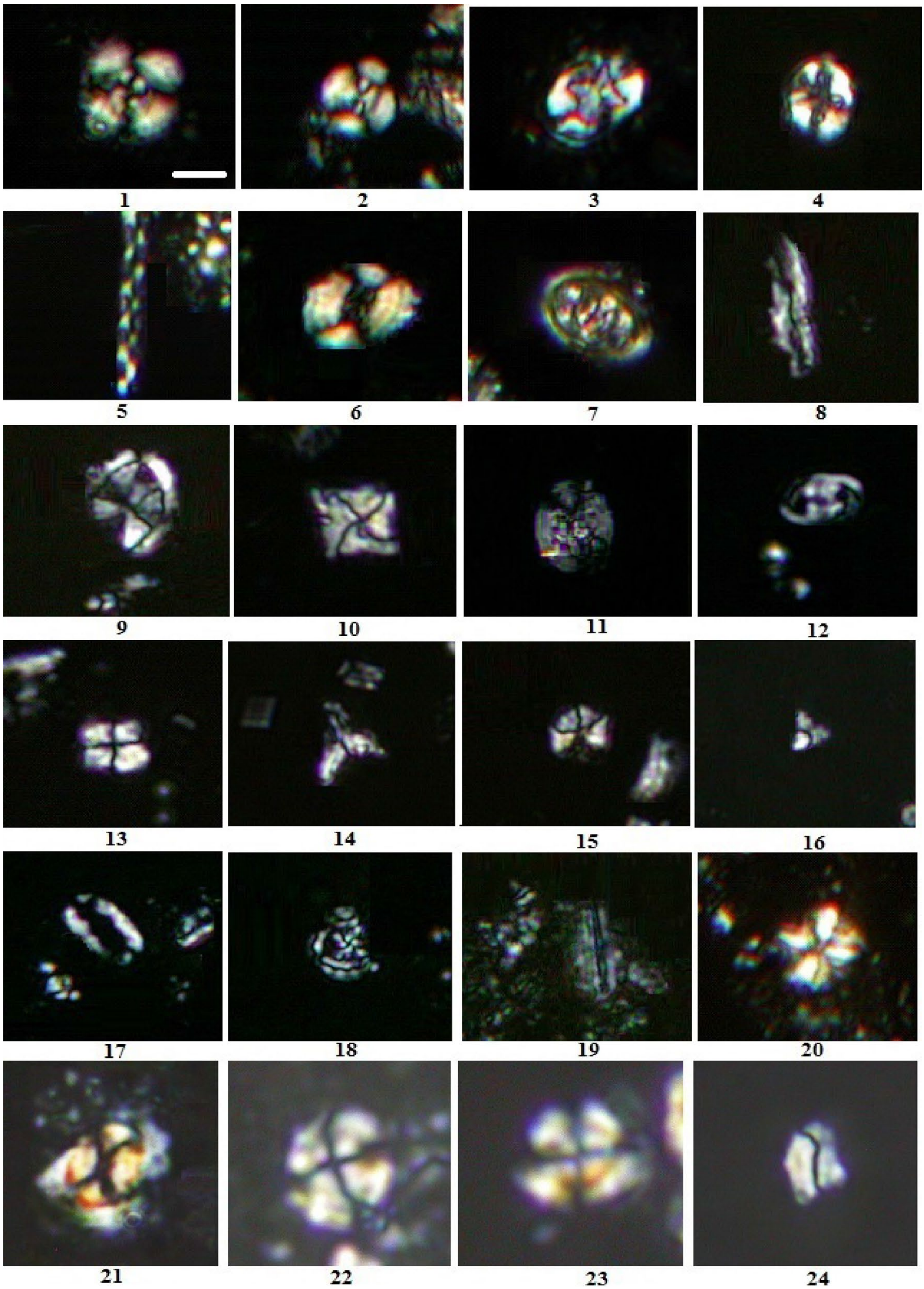


Fig. 4 General lithology, location of samples, species distribution of the Campanian-to-Thanetian interval, and evolving nannofossils in the upper part of the Gurpi Formation and lower part of the Pabdeh Formation, in the studied section, south of Iran

5) *Nephrolithus frequens zone (CC26)*

This biozone is defined from the first to last occurrence of *Nephrolithus frequens* and has the late Maastrichtian age. The dominant taxa include *Micula murus, Lithraphidites quadratus, and Thoracosphaera operculata.* In the studied section, the species *N. frequens* was not recorded. Therefore, in this study, the beginning of the zone with the presence of *Ceratolithoides kamptneri* and the upper limit of the zone is determined based on the reduction of calcareous nannofossils and acme in *Thoracosphaera operculata*. In this study, *Micula prinsii* was not recorded. Therefore, this zone is not divided into two subzones CC26a and CC26b. The first presence of this species (*Micula prinsii*) marks the UC20d zone in Burnett (1998) zoning. Therefore, the upper part of the UC20 zone has not been determined, but an increase in



◂**Fig. 5** All figures (XPL) light micrographs × 1000 magnification; Scale bar: 5 µm, the taxa considered in the present figure are referenced in Perch-Nielsen (1985). **1.** *Watznaueria barnesiae* (Black in Black and Barnes 1959) Perch-Nielsen (1968), **2.** *Watznaueria biporta* Bukry (1969), **3.** *Eiffellithus turriseiffelii* (Deflandre in Deflandre and Fert 1954) Reinhardt (1965), **4.** *Eiffellithus eximius* (Stover 1966) Perch-Nielsen (1968), **5.** *Microrhabdulus decoratus* Deflandre (1959), **6.** *Aspidolithus parcus* subsp. *constrictus* (Hattner et al. 1980) Perch-Nielsen (1984), **7.** *Reinhardtites anthophorus* (Deflandre 1959) Perch-Nielsen (1968), **8.** *Lucianorhabdus cayeuxii* Deflandre (1959), **9.** *Arkhangelskiella cymbiformis* Vekshina (1959), **10.** *Micula swastica* Stradner and Steinmetz (1984), **11.** *Reinhardtites levis* Prins and Sissingh in Sissingh (1977), **12.** *Tranolithus phacelosus* Stover (1966), **13.** *Quadrum gothicum* Deflandre (1959), **14.** *Ceratolithoides aculeus* (Stradner 1961) Prins and Sissingh in Sissingh (1977), **15.** *Lithastrinus grillii* Stradner (1962), **16.** *Quadrum trifidum* (Stradner In Stradner and Papp 1961) Prins and Perch-Nielsen in Manivit et al. (1977), **17.** *Rhagodiscus angustus* (Stradner 1963) Reinhardt (1971), **18.** *Prediscosphaera cretacea* (Arkhangelsky 1912) Gartner (1968), **19.** *Lithraphidites quadratus* Bramlette and Martini (1964), **20.** *Micula decussata* Vekshina (1959), **21.** *Coccolithus pelagicus* (Wallich 1877) Schiller (1930), 22 and 23. *Heliolithus kleinpellii* Sullivan (1964), **24.** *Fasciculithus tympaniformis* Hay and Mohler in Hay et al. (1967)

Thoracosphaera has been shown. The thickness of the zone is about 11 m.

b. Calcareous nannofossils in the base of the Pabdeh Formation

The following biozone was identified in the base of this formation:

1) Heliolithus kleinpellii Zone (NP6)

This nannofossil unit spans the interval from the FO of *Heliolithus kleinpellii* to the FO of *Discoaster mohleri.* Besides the marker species, the dominant taxa include *Coccolithus pelagicus, Sphenolithus primus,* and *Fasciculithus tympaniformis.* Also, within the NP6 zone were recorded significant changes in the decrease abundance of nannofossil assemblages. The thickness of the zone is about 7 m. In the present study, our data nearly agree with the results suggested by Martini (1971) and the zonation of Agnini et al. (2014). This zone corresponds to the CNP8 of the Agnini et al. (2014) zoning. The zonal interval, is Late Selandian–Early Thanetian. According to the Global Standard Stratotype section, the boundary of Selandian/Thanetian at the Zumaia section of northern Spain (Schmitz et al. 2011).

Discussion

Comparison of calcareous nannofossils and planktonic foraminifera

The stratigraphic study of the Morgah section is the first data that deals with the biostratigraphic distribution of the upper Cretaceous foraminifera and calcareous nannofossils in this area. The correlation between zones of calcareous nannofossils and foraminifera in the Gurpi Formation in this section is also applicable proof for other correlations in different parts of the Zagros Basin. The zonal schemes are compared with the Tethyan standard zonation (e.g., Sissingh 1977) and other biozonation (e.g., Caron 1985; Premoli Silva and Verga 2004). In the present study, the first zone is defined *Gansserina gansseri* Zone, which was described from Tethys (Premoli Silva and Verga 2004). The determined biozone correlates with the CC22, CC23, and CC24 zones from Sissingh (1977) zonation. Therefore, the latest Campanian-to-early Maastrichtian age is acceptable for the *Gansserina gansseri* Zone, which coincides with the first occurrence of *Quadrum trifidum* to the last occurrence of *Reinhardtites levis* from the zoning of the Sissingh (1977). Here, according to our data, the Campanian/Maastrichtian boundary stays on within the *Gansserina gansseri* Zone. On the other hand, this boundary also stays within the CC23 zone, according to the zonation of Sissingh (1977) (Fig. 6). Subsequently, the next biozone in the studied stratigraphic column is *Contusotruncana contusa* Zone, which is the first occurrence of *Contusotruncana contusa* to the first occurrence of *Abathomphalus mayaroensis* from zonation of the Premoli Silva and Verga (2004). This zone synchronous with the CC25 zone based on calcareous nannofossils that the interval from the last occurrence of *Reinhardtites levis* to the first occurrence of *Micula murus* (a good marker event in the low latitudes) (Perch-Nielsen 1985). Here, in the studied sequence upward, the FO of *Micula murus,* along with a total range of *Contusotruncana contusa* and, then the FO of *Abathomphalus mayaroensis* are all bioevents, which are useful for determining the late Maastrichtian. At the end of the Cretaceous, the *Abathomphalus mayaroensis* Zone is defined from the FO of *Abathomphalus mayaroensis* to the extinction of most species of planktonic foraminifera in the standard scheme of Premoli Silva and Verga (2004). In the present study, this zone coincides with the CC26 zone. In the *Nephrolithus frequens* Zone (CC26), we also observed a decline in nannofossil species. In fact, in the uppermost

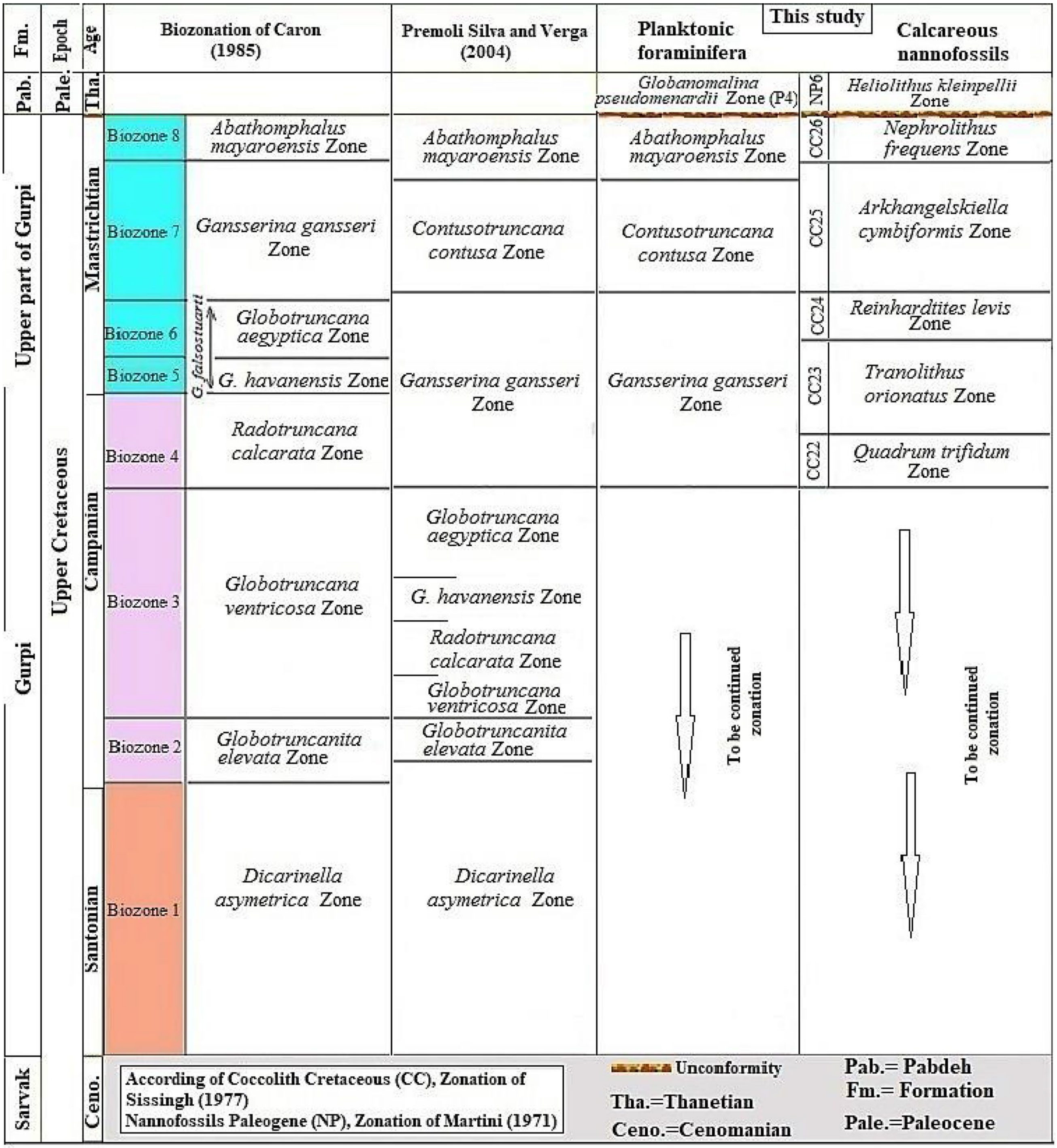


Fig. 6 The correlation of upper Campanian-to-Thanetian biostratigraphic data based on calcareous nannofossils and planktonic foraminifera in the studied section

layer of the Gurpi Formation, the amount of nannofossils generally reduced, so that the final samples are without nannofossils. This issue is also common in other regions of Zagros. Also, the CC26 is very rare in the low latitudes (Perch-Nielsen 1985). Here, at the top of the CC26 zone, the interval from the FO of *M. murus* up to the FO of *Heliolithus kleinpellii* (at base of NP6) was identified gap biostratigraphy or hiatus in the studied section. In fact, the upper part of CC26 Zone (latest Cretaceous) has not been recorded in the upper part of the Gurpi Formation, and also in some of the studied biohorizons (e.g., NP1, NP2, NP3, NP4, and NP5) and so a non-continuous trend can be observed, while in some previous studies such as Izeh Province, a continuous trend of the CC26-NP6 can be recorded (Beiranvand and Ghasemi-Nejad 2013a, b). Also, in the Lorestan Province, Shahriari et al. (2017) delineated a continuous trend throughout the late Cretaceous to the Paleogene (K/Pg). Therefore, the presence of such sediment absence in addition to the studied section, in other areas of Fars, and parts of the Zagros basin has been reported by various researchers (e.g., Ghasemi Nejad et al. 2006; Rahimi et al. 2015; Zarei and Ghasemi-Nejad 2014; Darabi and Sadeghi 2017; Razmjoui et al. 2014, 2018; Esmaeilbeig 2018). In this regard, the biostratigraphic hiatus between the Gurpi and Pabdeh formations can be due to the compression phase, which occurred simultaneously with the late Cretaceous/early Paleogene in the Zagros Basin (Eastern Tethys). Here, the distribution of nannofossil species indicates four biozones in Maastrichtian in the studied section. These biozones coincide with the three biozones of planktonic foraminifera according to Premoli Silva and Verga's (2004) zonation, and four biozones of Caron's (1985) scheme. In this study, Cretaceous assemblages lead to a less diverse Paleogene assemblage, which is entirely evident. Also, changes in biota assemblages can be due to late Cretaceous climate changes, which the first in the form of global cooling and then due to warming weather near the K/Pg boundary (Thibault and Gardin 2007; Thibault et al. 2012). In this study, the main components of the Gurpi Formation deposits are mainly planktonic foraminifera and nannofossils. Also, based on these predominantly identified fossil groups, it can be said that the deposits of the Gurpi Formation in Fars province have been deposited in the deep parts of the open sea (Ebrari et al. 2011).

Conclusions

A biostratigraphic sequence was examined from the upper part of the Gurpi Formation to the lower part of the Pabdeh Formation in the Fars Province in the Zagros Basin (south of Iran, EasternTethys). In this study, diverse calcareous nannofossil assemblages and planktonic foraminifera were used to analyze the biozones. There are considerable relationship in the position of zonal groups in compared to foraminiferal zones. Twenty-five genera and thirty-five species of nannofossils were identified for the first time in this sequence. Analysis of calcareous nannofossils in the upper part of the Gurpi Formation and lower part of the Pabdeh Formation led to the identification of six biozones from the base to the top of the sequence. The studied sequence indicates an incomplete succession, dating from the late Cretaceous (late Campanian) to the late Paleocene (early Thanetian). The biozones determined in the upper part of the Gurpi Formation in our study are summarized as following: *Quadrum trifidum* Zone (CC22), *Tranolithus orionatus* Zone (CC23), *Reinhardtites levis* Zone (CC24), *Arkhangelskiella cymbiformis* Zone (CC25), and *Nephrolithus frequens* Zone (CC26), which is equivalent to *Gansserina gansseri* Interval Zone, *Contusotruncana contusa* Interval Zone, and *Abathomphalus mayaroensis* Interval Zone from planktonic foraminifera zoning in the Gurpi Formation. Subsequently, *Heliolithus kleinpellii* Zone (NP6), that is equivalent to *Globanomalina pseudomenardii* Zone of foraminifera zoning in the Pabdeh Formation. Therefore, the zonal schemes of foraminifera are compared with the Tethyan nannofossil standard zonation. This can most probably be explained by the diachronous distribution of calcareous nannofossils and planktonic foraminfera, dependence of the stratigraphic ranges on the local ecology in eastern Tethys. Hence, the validity of late Campanian-to-early Thanetian was examined based on calcareous nannofossils and planktonic foraminifera. This study also focuses on the development of fossil assemblages and environmental conditions in the K/Pg boundary. Both fossil groups respond to environmental fluctuations and changes in environmental surface water conditions. In this regard, a biostratigraphic hiatus occurred between the Gurpi Formation and Pabdeh Formation, which may be due to environmental and structural changes in the studied section. Also, the presence of fossils with low-latitude dependence indicates tropical regions throughout the late Cretaceous to Paleocene.

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Declarations

Conflict of interest The authors declare that they have no competing interests.

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