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ORIGINAL ARTICLE

Biostratigraphy of the Gurpi Formation (Santonian–Maastrictian) by using Globotruncanidae, Zagros Mountains, Iran

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Abstract The study of Globotruncanids of the Gurpi Formation at Sepidar anticline in Zagros Mountains led to distinguishing Santonian to Late Maastrichtian biozones. Eight biozones were determined: biozone I (*Dicarinella asymmetrica* Zone) belongs to Santonian. Biozone II (*Globotruncanita elevata* Zone), biozone III (*Globotruncana ventricosa* Zone), biozone IV (*Radotruncana calcarata* Zone), biozone V (*Globotruncana stuarti* Zone) and biozone VI (*Globotruncanella havanensis* Zone) are of the Early to Late Campanian. Biozone VII (*Gansserina gansseri* Zone) and VIII (*Contusotruncana contusa* Zone) suggest the latest Campanian to Late Maastrichtian.

Keywords Gurpi Formation · Upper Cretaceous · Globotruncanids · Zagros · Iran

Introduction

Iran is located within the active convergence zone between Eurasia and Gondwanaland. It is also located in the mid-part of the orogenic belt of the Alps-Himalaya region which starts from west of Europe and spreads as far as Tibet after passing through Turkey, Iran and Afghanistan (Aghanabati 2004; Darvishzadeh 2009).

The Zagros, which include west and southwest heights of Iran constitute a section of folded belt of the Alps-Himalaya. This NW–SE trending orogeny extends about 2000 km from the East Anatolian fault in eastern Turkey to Makran in southern Iran (Mouthereau 2011). The Zagros Mountains are the result of the Arabia/Eurasia collision initiated at ~35 Ma as the rifted Arabian lithosphere was underthrust beneath the Iranian plate due to its negative buoyancy (Mouthereau et al. 2012).

Zagros Mountains, which are considered young, tolerated the maximum Alpine Orogeny in the Pliocene although they are still under the imposed deformation (Aghanabati 2004; Darvishzadeh 2009). Studying the Zagros Mountains has a significant role in realizing the way the orogenic belt of the Alps-Himalaya as well as the land of Iran was created.

According to Motiei (2003), the Iranian segment of Zagros is divided in the following zones:

Interior Fars, Coastal Fares, Dezful Embayment, Khuzestan, Lurestan, Izeh and High Zagros.

Late Cretaceous is a time of great change in the Zagros sedimentary basin. Gurpi Formation is a deposit of the following Zagros time that is one of the major source-rocks of oil in Iran (Ziegler 2001; Motiei 2004; Aghanabati 2004; Darvishzadeh 2009). The study of this formation with its appropriate spread and exposures in Zagros can be useful in realizing the geological events of Zagros and Alp-Himalaya belt in the Late Cretaceous.

This formation in the type section is composed of 320 m of marl and bluish-gray shale, which consists of thin sub-layers of argillaceous limestone. It is placed on the Ilam Formation and is covered by Pabdeh Formation (James and Wynd 1965).

Lower and upper boundaries of this formation in different parts of the Zagros have different ages so the formation is diachronous. According to Motiei (2003), James and Wynd (1965) presented the biostratigraphy of the Gurpi Formation for the first time. The formation was studied later by Kalantary (1976, 1986, 1992), Vaziri

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Moghaddam (2002), Gasemi-Nejad et al. (2006), Esmaeilbeig (2012) and Fereydounpour et al. (2014), among others.

The Gurpi Formation in the Zagros Mountains has a vast expansion and a good exposure. The studied area (Sepidar anticline) is in these areas.

The main objective of this study was to determine the age and biozonation of the Gurpi Formation based on Globotruncaninds in the anticline defined above and then comparing these with the number of valid biozones.

Regional setting

The stratigraphic section of the northeast limb of the Sepidar anticline is located in the Interior Fars in the Zagros Mountains, 10 km south of Kavar. Kavar is located in Fars province 45 km from Shiraz. The geographic coordinates of this region are: N29.08 and N52.40. Sepidar anticline has a North West–South East trend and includes the Cenomanian (Sarvak Limestone Formation) to Pliocene sediments (Agha Jary Sandstone Formation), (Figs. 1, 2).

Materials and methods

To achieve pre-determined goals, 220 samples were taken at regular intervals, including the entire thickness of the Gurpi Formation, plus the final section of Sarvak, which is beneath, and primary sections of Pabdeh which is above it.

Samples that seemed softer were used to get isolated Globotruncaninds, and thin sections were prepared from hard samples (which comprised the majority of samples). For preparing isolated Globotruncaninds, about 100 g of each sample was placed in water containing a few drops of Hydrogen Peroxide (H_2O_2) and the process of freezing and melting was applied alternatively until disaggregation occurred. Disaggregated sediments were washed in sieves that could not pass Globotruncaninds through their pores and then the remaining precipitates were dried in an oven. Globotruncaninds were then removed from the dried sediments and studied. Based on the hardness and the detrital content of most samples, the obtained Globotruncaninds did not have appropriate features for diagnosis; so they were considered inappropriate. The use of other separation methods such as Lirer (2000) and also using a different percentage of acetic acid did not lead to the appropriate fossils. However, some images were taken by SEM from a number of samples. For this reason, most studies have been performed on appropriate samples in thin sections. Globotruncanids taxonomy and nomenclature follows Bolli (1966), Postuma (1971), Sigal (1977), Robaszynski et al. (1984), Caron (1985), Sliter (1989), Robaszynski et al. (1990), Longoria and Vonfeldt (1991), Premoli Silva and Sliter (1994), Robaszynski and Caron (1995), Georgescu (1996), Robaszynski et al. (2000), Premoli Silva and Verga (2004) and Boudagher-Fadel (2013).

Results and discussion

In the studied area, Gurpi Formation has 288 m thickness and is mainly formed of shale and argillaceous limestone. Its underlying formation is Sarvak Limestone of the Cenomanian and the overlying formation is Pabdeh Shale of Paleocene-Oligocene origin (Motiei 2003; Aghanabati 2004; Darvishzadeh 2009).

The underlying contact of the Gurpi Formation is disconformable (Fig. 3). The lack of Turonian–Coniacian fossils and also the presence of glauconite grains in the basal parts of Gurpi Formation are the other indications of disconformity (Fig. 4). The lack of uppermost Maastrichtian Globotruncaninds in this area is an indication for an unconformable contact existing in the upper boundary of Gurpi Formation. The presence of glauconite grains (Fig. 5) at the base of Pabdeh Formation (where it covers the Gurpi Formation) is one of the other reasons of unconformity at the upper contact of this formation.

In most investigated samples various types of Globotruncanids were observed. Globotruncanids are one of the main tools for Cretaceous pelagic sediments biostratigraphy.

Based on identified eight genera and 27 species of Globotruncanids and their stratigraphic distribution (Figs. 6, 7), eight biozones were identified, including Santonian to Late Maastrichtian. Observed biozones of this regiony are presented in Fig. 8.

The age of each biozone, according to different researchers, is different. The age that is considered in this text is mainly adapted from Premoli Silva and Verga (2004), Briant et al. (2008) and Gradstein et al. (2012). In Table 1, the differences can be seen.

I-*Dicarinella asymetrica* Zone

Definition: Total range zone of *Dicarinella asymetrica* Sigal.

Characteristics: The dominant taxa in this zone are: *Dicarinella concavata* Brotzen, *Dicarinella primitiva* Dalbiez, *Globotruncana lapparenti* Brotzen, *Globotruncana bulloides* Vogler, *Marginotruncana coronata* Bolli, *Marginotruncana renzi* Gondolfi, *Contusotruncana fornicata* Plummer, *Globotruncana arca* Cushman, *Globotruncana linneiana* d'Orbigny and *Globotruncanita elevata* Brotzen.

Remarks: This zone contains the first appearance of *Globotruncana bulloides* Vogler, *Contusotruncana fornicata* Plummer, Globotruncana *linneiana* d'Orbigny *and*

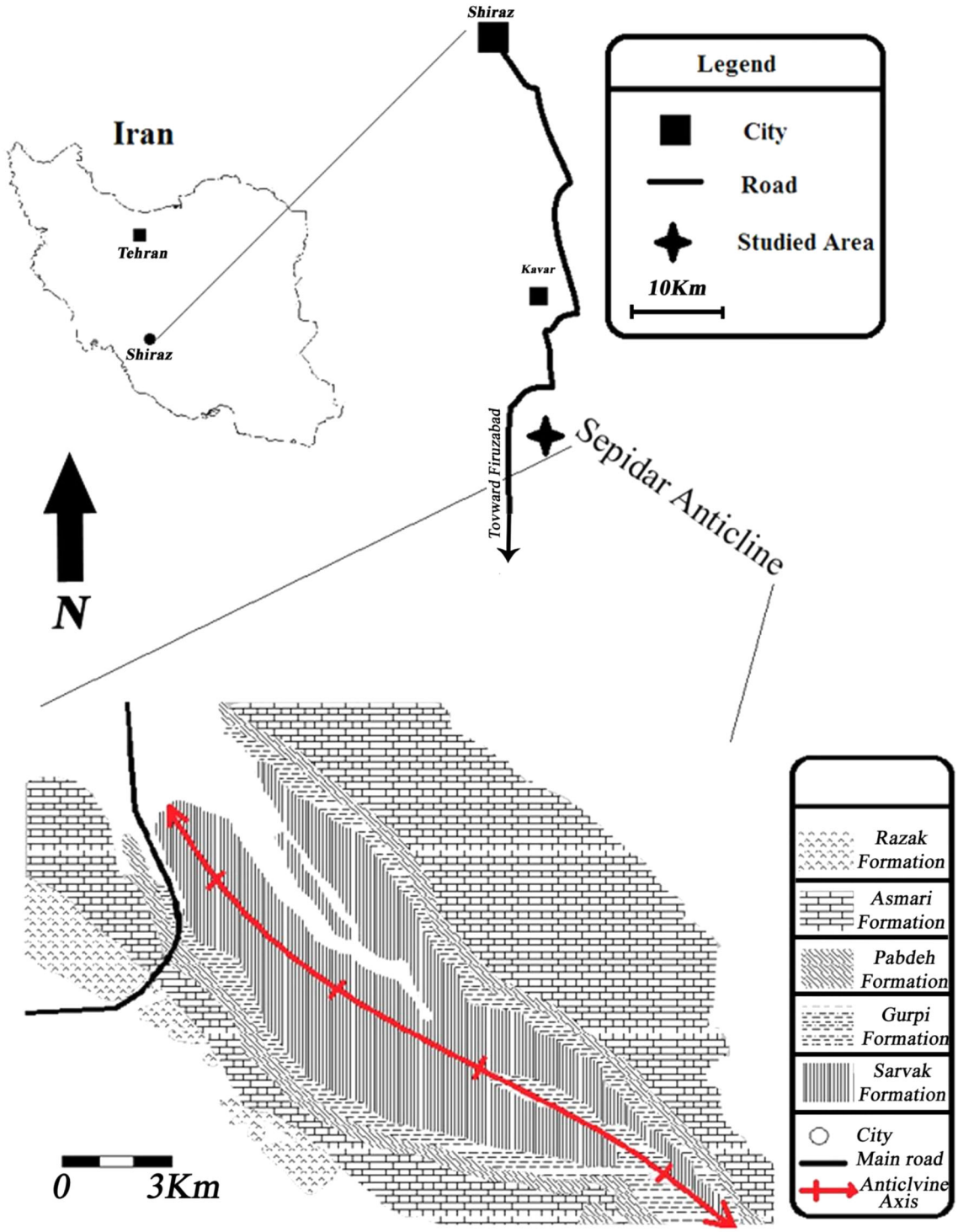


Fig. 1 Location map and simplified geological map of studied area

Globotruncanita elevata Brotzen and the last appearance of *Dicarinella primitiva* Dalbiez, *Dicarinella asymetrica* Sigal, *Dicarinella concavata* Brotzen and *Marginotruncana renzi* Gondolfi.

Age: Santonian

This biozone was recorded by Postuma (1971), Robaszynski et al. (1984), Caron (1985), Sliter (1989), Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004) and Ogg et al. (2008).

The thickness of this biozone is 48 m.

Fig. 2 General view of the area (to the North West), *Sv* Sarvak Formation, *GU* Gurpi Formation, *Pd* Pabdeh Formation, *As* Asmari Formation

Fig. 3 The *red* limestone of the end of Sarvak Formation

II-*Globotruncanita elevata* Zone

Definition: Partial range zone from the last appearance of *Dicarinella asymetrica* Sigal to the first appearance of *Globotruncana ventvicosa* White.

Characteristics: The dominant taxa in this zone are: *Globotruncana lapparenti* Brotzen, *Globotruncana arca* Cushman, *Globotruncana bulloides* Vogler, *Globotruncanita stuartiformis* Dalbiez, *Globotruncanita elevata* Brotzen, *Contusotruncana fornicata* Brotzen, *Marginotruncana coronata* Bolli and *Globotruncana linneiana* d'Orbigny.

Remarks: This zone contains the first appearance of *Globotruncanita stuartiformis* Dalbiez and the last appearance of *Marginotruncana coronata* Bolli.

Age: Early Campanion

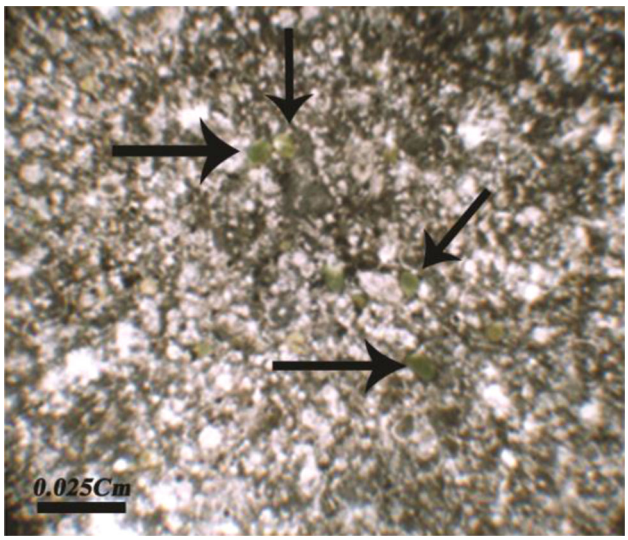


Fig. 4 The glauconites (*green* grains) in the basal parts of Gurpi Formation

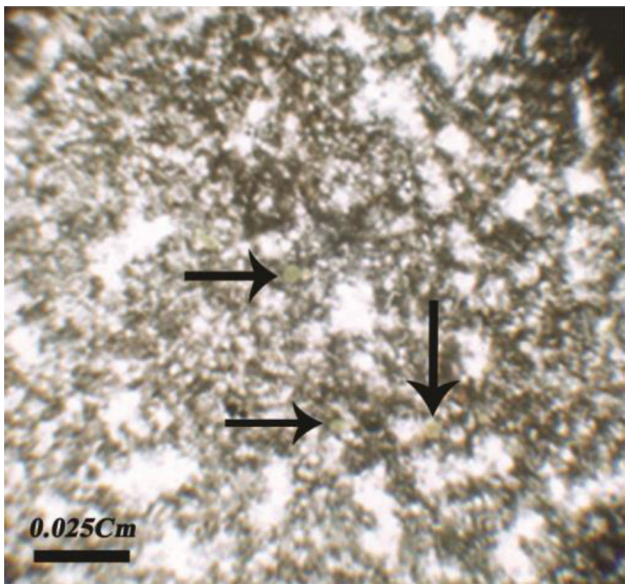
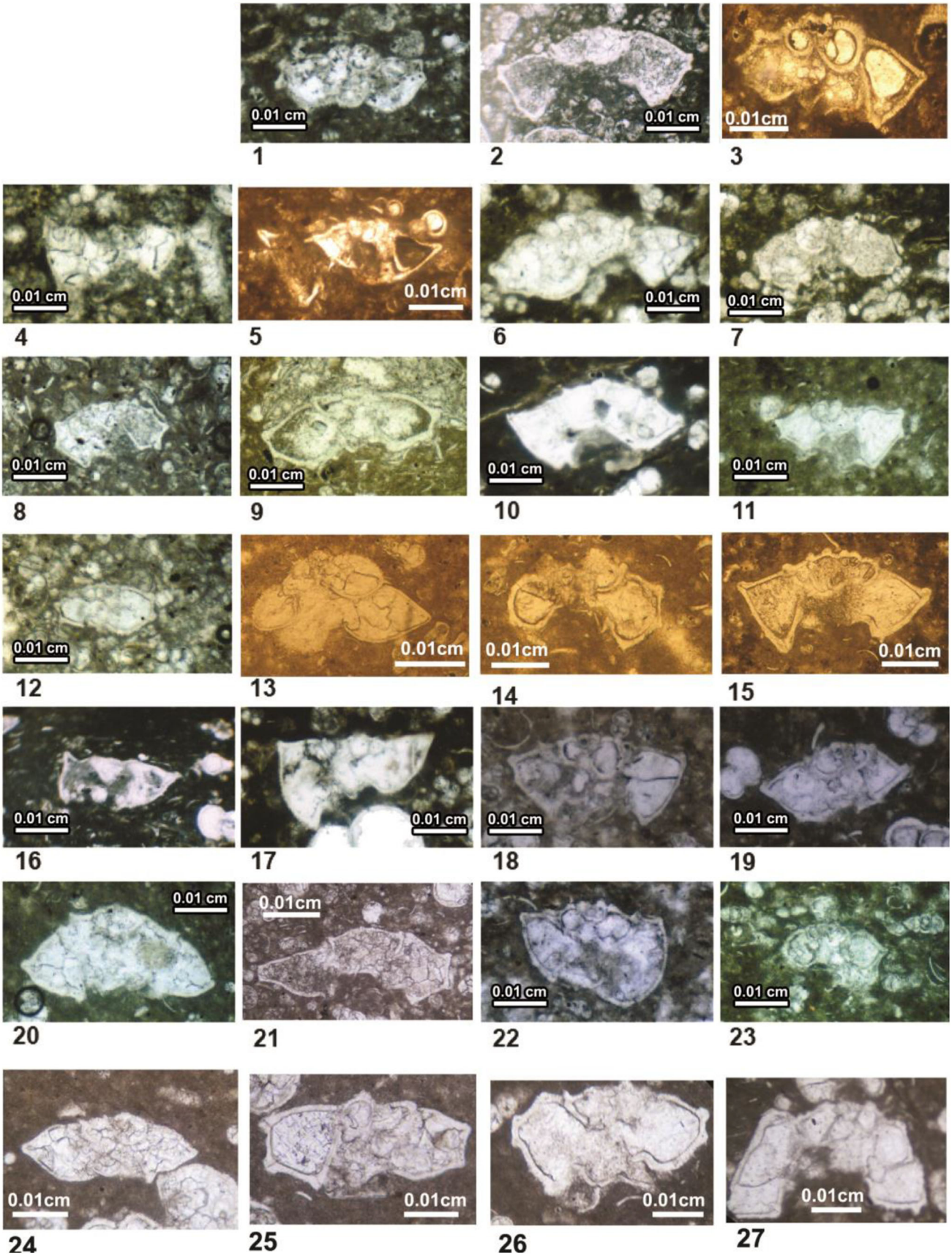


Fig. 5 The glauconites (*green* grains) in the basal parts of Pabdeh Formation

Fig. 6 Globotruncanids from the Gurpi Formation: 1: *Dicarinella primitiva*, 2: *Dicarinella asymetrica*, 3: *Globotruncana falsostuarti*, 4: *Dicarinella concavata*, 5: *Globotruncanita pettersi*, 6:*Marginotruncana renzi*, 7: *Contusotruncana fornicate*, 8: *Globotruncana arca*, 9: *Globotruncana bulloides*, 10: *Globotruncanita stuartiformis*, 11: *Globotruncana ventricosa*, 12: *Globotruncana lapparenti*, 13: *Globotruncanella havanensis*, 14: *Globotruncana hilli*, 15: *Globotruncanita angulata*, 16: *Globotruncanita calcarata*, 17: *Globotruncanita elevata*, 18: *Globotruncana rosetta*, 19: *Globotruncanita stuarti*, 20: *Globotruncanita conica*, 21: *Marginotruncana coronata*, 22: *Gansserina gansseri*, 23: *Globotruncanella citae*, 24: *Globotruncana orientalis*, 25: *Globotruncana linneiana*, 26: *Globotruncanaa aegyptiaca*. 27: *Contusotruncana contusa*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This biozone is described by James and Wynd (1965), Postuma (1971), Caron (1985), Sliter (1989), Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004) and Ogg et al. (2008).

The thickness of this biozone is 13 m.

III-*Globotruncana ventricosa* Zone

Definition: Interval zone from the first appearance of *Globotruncana ventricosa* White to the first appearance of *Radotruncana calcarata* Cushman.

Characteristics: The dominant taxa in this zone are: *Globotruncanita elevata* Brotzen, *Globotruncanita stuartiformis* Dalbiez, *Globotruncana bulloides* Vogler, *Contusotruncana fornicata* Brotzen, *Globotruncana arca* Cushman, *Globotruncana linneiana* d'Orbigny and *Globotruncana lapparenti* Brotzen.

Age: Middle to Late Campanian.

This biozone was recorded by Caron (1985), Sliter (1989), Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004) and Ogg (2008).

The thickness of this biozone is 51 m.

IV-*Radotruncana calcarata* Zone

Definition: Total range zone of *Radotruncana calcarata* Cushman.

Characteristics: The dominant taxa in this zone are: *Globotruncana lapparenti* Brotzen, *Globotruncana arca* Cushman, *Globotruncana bulloides* Vogler, *Globotruncana ventricosa* White, *Globotruncanita elevata* Brotzen,*Globotruncanita stuarti* de Lapparent, *Globotruncanita stuartiformis* Dalbiez, *Globotruncana linneiana* d'Orbigny and *Contusotruncana fornicata* Plummer.

Remarks: This zone contains the first appearance of *Globotruncanita stuarti* de' Lapparent.

Age: Late Campanian.

This biozone is described by Postuma (1971), Caron (1985), Sliter (1989), Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004) and Ogg et al. (2008).

The thickness of this biozone is 17 m.

V-*Globotruncana stuarti* Zone

Definition: Partial range zone from the last appearance of *Radotruncana calcarata* Cushman to the first appearance of *Globotruncanella havanensis* Voorwijk.

Characteristics: The dominant taxa in this zone are: *Globotruncana lapparenti* Brotzen, *Globotruncana arca* Cushman, *Globotruncana bulloides* Vogler, *Globotruncana ventricosa* White, *Globotruncana falsostuarti* Sigal, *Globotruncanita elevata* Brotzen, *Globotruncanita stuartiformis* Dalbiez, *Globotruncana hilli* Pessagno, *Globotruncana linneiana* d'Orbigny and *Globotruncanita stuarti* de' Lapparent.

Remarks: This zone contains the first appearance of *Globotruncana falsostuarti* Sigal and *Globotruncana hilli* Pessagno and last appearance of *Contusotruncana fornicata* Plummer.

Age: Late Campanian.

This biozone is described by James and Wynd (1965), Bolli (1966), Von Hinte (1976) and Sigal (1977).

The thickness of this biozone is 16 m.

VI-*Globotruncana aegyptiaca* Zone

Definition: Interval zone from the first appearance of *Globotruncana aegyptiaca* Nakkady, to the first appearance of *Gansserina gansseri* Bolli.

Characteristics: The dominant taxa in this zone are: *Globotruncana lapparenti* Brotzen, *Globotruncana arca* Cushman, *Globotruncana bulloides* Vogler, *Globotruncana ventricosa* White, *Globotruncanita stuarti* de'Lapparent, *Globotruncana linneiana* d'Orbigny, *Globotruncanita elevata* Brotzen, *Globotruncanella havanensis* Voorwijk, *Globotruncana falsostuarti* Sigal, *Globotruncanita pettersi* Gondolfi and *Globotruncanita stuartiformis* Dalbiez.

Remarks: This zone contains the first appearance of *Globotruncanita pettersi* Gondolfi, *Globotruncanella havanensis* Voorwijk and the last appearance of *Globotruncana lapparenti* Brotzen and *Globotruncanita elevata* Brotzen.

Age: Late Campanian.

This biozone was recorded by Caron (1985), Sliter (1989), Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004) and Ogg et al. (2008).

The thickness of this biozone is 5 m.

VII-*Gansserina gansseri* Zone

Definition: Interval zone from the first appearance of *Gansserina gansseri* Bolli to the first appearance of *Contusotruncana contusa* Cushman.

Characteristics: The dominant taxa in this zone are: *Globotruncana arca* Cushman, *Globotruncana bulloides* Vogler, *Globotruncana ventricosa* White, *Globotruncana falsostuarti* Sigal, *Globotruncana aegyptiaca* Nakkady, *Globotruncanita stuarti* de'Lapparent, *Globotruncanita stuartiformis* Dalbiez, *Globotruncanella citae* Bolli, *Globotruncana hilli* Pessagno, *Globotruncana linneiana* d'Orbigny, *Globotruncanita pettersi* Gondolfi, *Globotruncana orientalis* El-Naggar and *Globotruncanella havanensis* Voorwijk.

Remarks: This zone contains the first of *Globotruncanella citae* Bolli and *Globotruncana orientalis* El-Naggar and the last appearance of *Globotruncanella citae* Bolli, *Globotruncana linneiana* d'Orbigny, *Globotruncana ventricosa* White, *Globotruncana aegyptiaca* Nakkady *and Globotruncanella havanensis* Voorwijk.

The Campanian–Maastrichtian boundary is located within this biozone.

Age: Latest Campanian to early Maastrichtian.

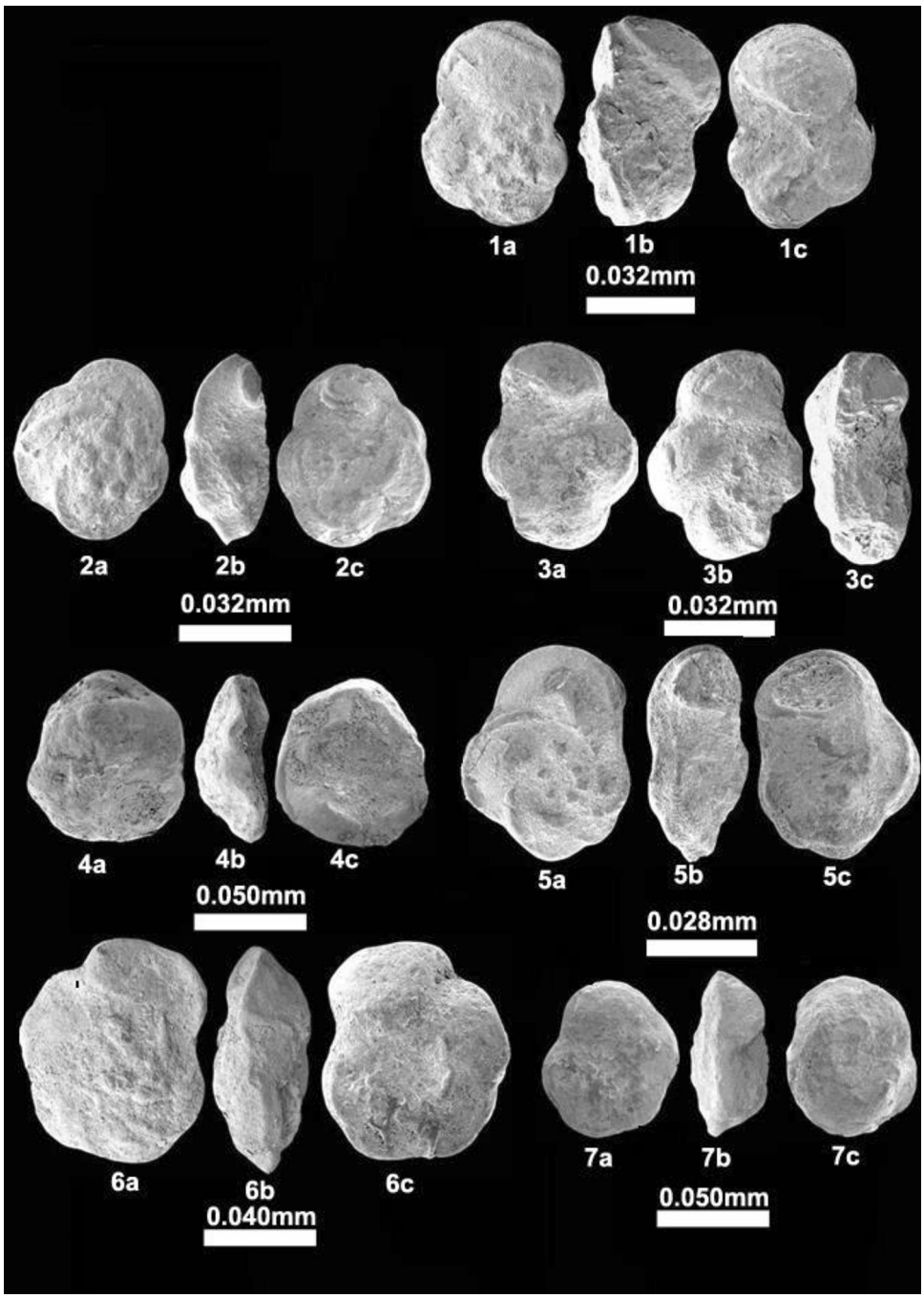

Fig. 7 Globotruncanids from the Gurpi Formation (by SEM): 1: *Gansserina gansseri*, *1a* Spiral side, *1b* Lateral side, *1c* Umbilical side, 2: *Globotruncana arca, 2a* Spiral side, *2b* Lateral side, *2c* Umbilical side, 3: *Globotruncana bulloides*, *3a* Spiral side, *3b* Lateral side, *3c* Umbilical side, 4: *Globotruncanita conica*, *4a* Spiral side, *4b* Lateral side, *4c* Umbilical side, 5: *Globotruncana* cf. *lapparenti*, *5a* Spiral side, *5b* Lateral side, *5c* Umbilical side, 6: *Globotruncanita stuartiformis, 6a* Spiral side, *6b* Lateral side, *6c* Umbilical side, 7: *Globotruncanita stuarti*, *7a* Spiral side, *7b* Lateral side, *7c* Umbilical side

This biozone is described by Postuma (1971), Caron (1985), Sliter (1989), Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004) and Ogg et al. (2008).

The thickness of this biozone is 99 m

VIII-*Contusotruncana contusa* Zone

Definition: Interval zone from the first appearance of *Contusotruncana contusa* Cushman to the extinction of Globotruncanids.

Characteristics: The dominant taxa in this zone are: *Globotruncana arca* Cushman, *Globotruncana bulloides* Vogler, *Globotruncana falsostuarti* Sigal,*Globotruncana rosseta* Carsay, *Gansserina gansseri* Bolli, *Globotruncanita stuarti* de Lapparent, *Globotruncanita stuartiformis* Dalbiez, *Globotruncanita conica* White, *Globotruncanita angulata* Tilev,*Globotruncanita pettersi* Gondolfi, *Globotruncana orientalis* El-Naggar and *Contusotruncana contusa* Cushman.

Remarks: This zone contains the first appearance of *Globotruncana rosseta* Carsay, *Globotruncanita angulata* Tilev and *Globotruncanita conica* White and the last

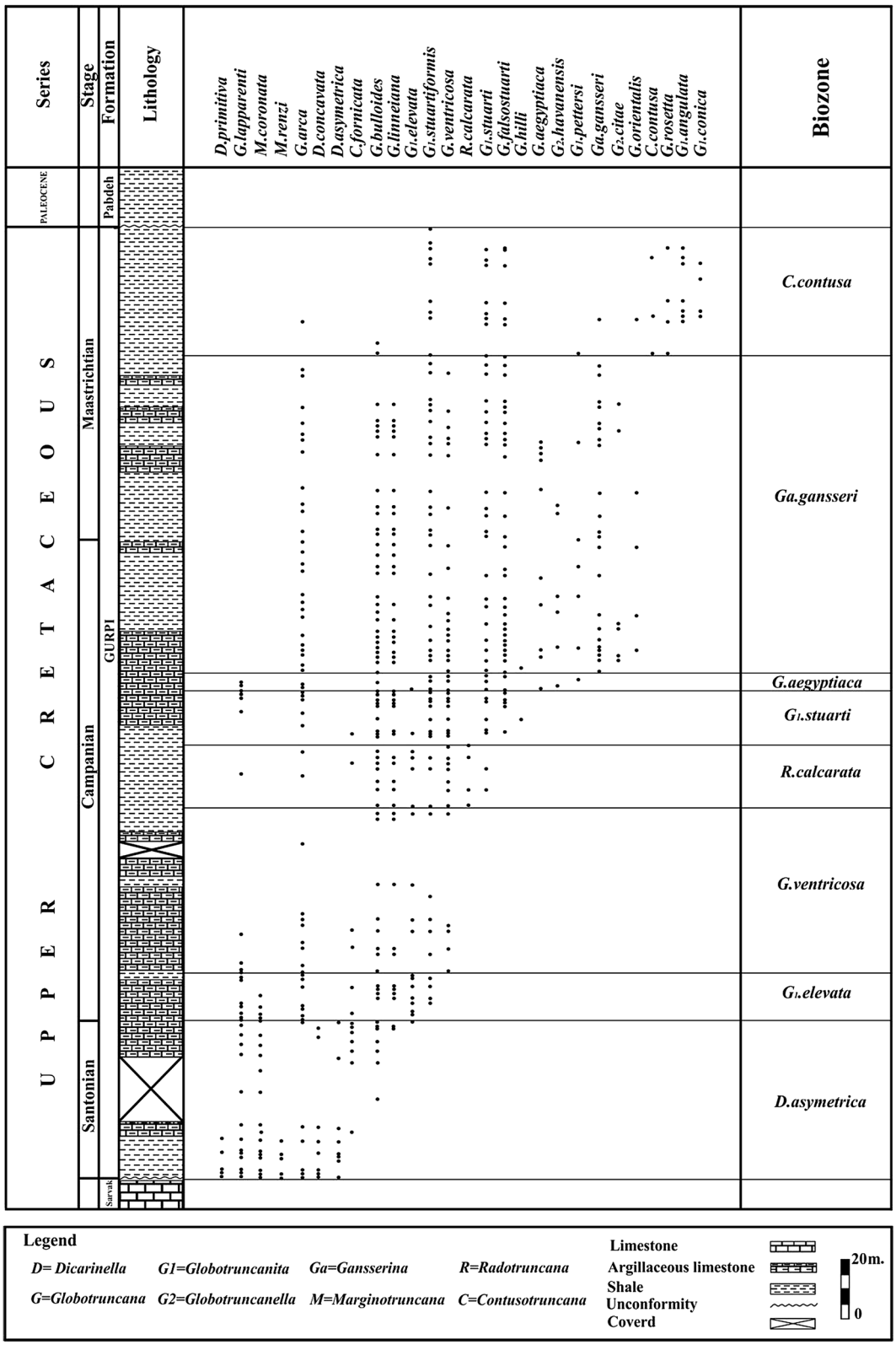

Fig. 8 The stratigraphic distribution of the identified planktonic foraminiferal species of Gurpi Formation in studied area

Table 1 Correlation of the proposed biostratigraphic zonal scheme at this study with other accepted standard biozones by some well-known researchers

Stage	Premoli Silva and Sliter (1994)	Premoli Silva and Verga (2004)	After Ogg et al. (2008)	Briant et al. (2008)	After Gradstein et al. (2012)	This Study Sepidar
Maastrichtian	*mayaroensis*	*mayaroensis*	*mayaroensis*	*hariaenesis*	*hantkeninoides*	
					hariaenesis	
				mayaroensis	*mayaroensis*	
	fructicosa	*fructicosa* + *contusa*	*fructicosa*	*fructicosa*	*fructicosa*	*contusa*
					palpebra	
Campanian	*gansseri*	*gansseri*	*gansseri*	*palpebra*	*gansseri*	*gansseri*
	aegyptiaca	*aegyptiaca*	*aegyptiaca*		*aegyptiaca*	*aegyptiaca*
	havanensis	*havanensis*	*havanensis*	*havanensis*	*havanensis*	*stuarti*
	calcarata	*calcarata*	*calcarata*	*calcarata*	*calcarata*	*calcarata*
	ventricosa	*ventricosa*	*ventricosa*	*ventricosa*	*plummerae*	*ventricosa*
	elevata	*elevata*	*elevata*		*elevata*	*elevata*
Santonian	*asymetrica*	*asymetrica*	*asymetrica*		*asymetrica*	*asymetrica*
Coniacian	*concavata*	*concavata*	*concavata*			

appearance of all of Globotruncanidae occur at the end of this bio zone.

Age: Early to Late Maastrichtian.

This biozone was recorded by Premoli Silva and Sliter (1994), Premoli Silva and Verga (2004) and Ogg et al. (2008).

The thickness of this biozone is 39 m

Due to the lack of the biozone of *Abathomphalus mayaroensis*, and also glauconite-bearing shales on the last biozone, sedimentary discontinuity is clear and the contact of Gurpi Formation with its overlying formation (Pabdeh) is unconformable, which could be due to the Laramian tectonic phase.

Table 1 shows the correlation of proposed biostratigraphic zonation in this study with some zonal schemes by well-known researchers.

Conclusion

(a) Eight genera and 26 species of Globotruncanids were identified in the Gurpi Formation in Sepidar anticline, Zagros Mountains, Iran.

(b) Eight biozones including *Dicarinella asymetrica*, II-*Globotruncanita elevata*, III-*Globotruncana vantricosa*, IV-*Radotruncana calcarata* V-*Globotruncana stuarti*, VI-*Globotruncanella havanensis,* VII-*Gansserina gansseri* and VIII-*Contusotruncana contusa* were determined.

(c) Biozone I indicate Santonian age, biozones II, III, IV, V and VI are of early to late Campanian, biozone VII indicates latest Campanian to early Maastrichtian and biozone. VIII indicates early to late Maastrichtian.

(d) The age of Gurpi Formation in this section is Santonian to late Maastrichtian.

(e) Due to the effect of Laramide Revolution in this area, the *Abathomphalus mayaroensis* biozone that characterized upper most Maastrichtian is not distinguished.

(f) The upper and lower boundaries of this formation are discontinuous.

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