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BIOSTRATIGRAPHY AND REGIONAL ASPECTS OF THE TARBUR FORMATION (MAASTRICHTIAN) IN CENTRAL ZAGROS, SOUTHWEST IRAN

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Abstract. The aim of this study is to investigate the biostratigraphy and regional stratigraphy of the Maastrichtian deposits (Tarbur Formation) in the high outreaches of the Zagros Mountains in Chahar Mahal and Bakhtiyari Province, southwest Iran. The thickness of the investigated sequences is about 600 m in Tang-e-Vanak, 156 m in Tang-e-Zendan, and 111 m in Kuh-e-Dozdaran sections. Shale and marls of the Gurpi Fm. (Campanian) mark the lower lithostratigraphic limit of the Tarbur Fm. in Kuh-e-Dozdaran section, whereas its upper limit is disconformably distinguished by the dolomitic Jahrom Fm. (Eocene). The Tarbur Fm. in Tang-e-Vanak and Tang-e-Zendan sections overlies the clastic Amiran Fm. (Maastrichtian) and is truncated with a sharp disconformity by the white dolomites of Shahbazan Fm. (Eocene). Biostratigraphically, the Tarbur Fm. is characterized by a *Loftusia-Omphalocyclus* assemblage zone, indicating a Maastrichtian age. Within this biozone, three regional subbiozones are proposed. They are: the *Loftusia arabica* range subzone, the *Loftusia persica* interval subzone, and the *Loftusia baykali* interval subzone. Based on the foraminiferal content, the age of the Tarbur Fm. in Kuh-e-Dozdaran section is assigned to the lower-middle parts of the Maastrichtian. Likewise, the Tarbur Fm. in Tang-e-Vanak and the Tang-e-Zendan sections is Maastrichtian in age, possibly extending locally into the Paleocene.

The identification of the biostratigraphic limits of the Tarbur Fm. in the studied areas assists the reconstruction of the sedimentary basin in the Late Cretaceous.

Riassunto. Vengono analizzati la biostratigrafia e la stratigrafia regionale dei depositi maastrichtiani (Formazione Tarbur) nei Monti Zagros delle province Chahar Mahal e Bakhtiyari, sud ovest dell'Iran. Lo spessore delle sezioni studiate varia dai circa 600 m della Tang-e-Vanak, ai 156 m della Tang-e-Zendan, sino ai 111 m nella sezione Kuh-e-Dozdaran. Nella sezione Kuh-e-Dozdaran argilliti e marne della Formazone Gurpi (Campanian) costituiscono la base litostratigrafia della Formazione Tarbur, mentre il limite superiore paraconcordante è costituito dalle dolomie della Formazione Jahrom (Eocene). Invece nelle sezioni Tang-e-Vanak e Tang-e-Zendan, la Formazione Tarbur sormonta l'unità terrigena Amiran (Maastrichtiano) e viene troncata con marcata discordanza dalle dolomie chiare della Formazione Shahbazan (Eocene). La Formazione Tarbur è caratterizzata biostratigraficamente dalla zona di associazione a *Loftusia-Omphalocyclus*, che indica un'età maastrichtiana. Entro questa biozona vengono proposte tre sottozone di valore regionale. Esse sono: sottozona di distribuzione con *Loftusia arabica,* sottozona di intervallo con *Loftusia persica,* e sottozona di intervallo con *Loftusia baykali.* Sulla base del contenuto in foraminiferi, l'età della Formazione Tarbur nella sezione Kuh-e-Dozdaran è assegnata alla parte medio-inferiore del Maastrichtiano. Ugualmente, la Formazione Tarbur nelle sezioni Tang-e-Vanak e Tang-e-Zendan è da attribuire al Maastrichtiano, con la possibilità che localmente si estenda al Paleocene. Il riconoscimento dei limiti biostratigrafici della Formazione Tarbur contribuisce alla ricostruzione dei bacini sedimentari nel Cretaceo superiore.

Introduction

The Zagros orogenic belt of Iran is part of the Alpine-Himalayan mountain chain and extends for about 2000 km in a northwest-southeast direction. The Tarbur Formation is one of the Upper Cretaceous rock units of the Zagros basin, which is related to the carbonate platform deposits of the Tethyan realm. It includes rudist reefs and patch reefs along the shelf margin, though dominance of *Loftusia* facies in this forma-

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tion indicates an outer shelf environment. The equivalent rock units of this formation on the Arabian platform are the Shiranish Fm. of Iraq and Syria, the Simsima Fm. of Qatar, United Arab Emirates and Oman, the Tayarrat Fm. of Kuwait, and the Aruma Fm. of Saudi Arabia and Bahrain (Al-Husseini 2008). Similar rock units are also present in southeastern Turkey (Meriç et al. 2001).

The Tarbur Fm. is well developed and extends across the interior Fars and Lorestan provinces of Zagros basin. In its type section, it consists of 527 m of massive, cliff-forming, anhydritic limestone (Stöcklin & Setudehnia 1970). Lithofacies of the Tarbur Fm. is comprised of massive fossiliferous limestone, of Campanian-Maastrichtian age. The lower lithostratigraphic limits of the Tarbur Fm. are marked by a sharp diachronous contact with the dark gray shales of the Gurpi Fm. Its upper lithostratigraphic limit in the type section area is bounded by an erosional surface contact with the Sachun Fm. (Stoneley 1974). The Tarbur Fm. is covered by different rock units in different parts of the Zagros basin, i.e. the Sachun, Amiran, Kashkan, Pabdeh, Taleh Zang, Jahrum and Shahbazan formations (Stöcklin & Setudehnia 1970; Vaziri Moghadam et al. 2005; Maghfouri Moghadam et al. 2009; Afghah 2010; Khazaei et al. 2010; Amiri Bakhtiar et al. 2010; Piryaei et al. 2010).

Cox (1937) made a major contribution on the study of the Upper Cretaceous microfauna of southwestern Iran by describing several new species of *Loftusia.* Henson (1950) studied the Cretaceous and Tertiary reef formations and associated sediments in Iran and adjacent areas in the Middle East. The initial studies on the biostratigraphy of the Tarbur Fm. were carried out by Farshadfar et al. (1960). James & Wynd (1965) established the type section of the Tarbur Fm. in Geydoon Mountain near Tarbur village, east of Shiraz (southwest Iran). According to its foraminiferal content, the Tarbur Fm. in the Fars area is of Campanian-Maastrichtian age. Khosravi (1968) and Kalantari (1976) studied this formation in the Fars region as part of their large-scale investigations. Recently, Afgah (2010) revised the lithostratigraphic and biostratigraphic aspects of this formation in the Shiraz area, and Vaziri Moghadam et al. (2005), Maghfouri Moghadam et al. (2009), Piryaei et al. (2010), Amiri Bakhtiar et al. (2010), and Khazaei et al. (2010) also studied different exposures of the Tarbur Fm. in the Zagros basin.

Although researchers have recorded different litho- and biofacies of the Tarbur Fm., and have deciphered the general depositional history of the Late Cretaceous carbonate platforms in the Zagros basin, there is no published evidence as yet for this rock and time unit from the Chahar Mahal and Bakhtiyari province. This is mainly due to the difficult geographical access to the sections and their high altitudes, which in some cases exceed 3500 m a. s. l. In order to study the litho- and biostratigraphy of the Tarbur Fm. in central Zagros, three stratigraphic sections (Tang-e-Vanak, Tang-e-Zendan, and Kuh-e-Dozdaran) were investigated in this research and a refined biozonation is presented for the first time.

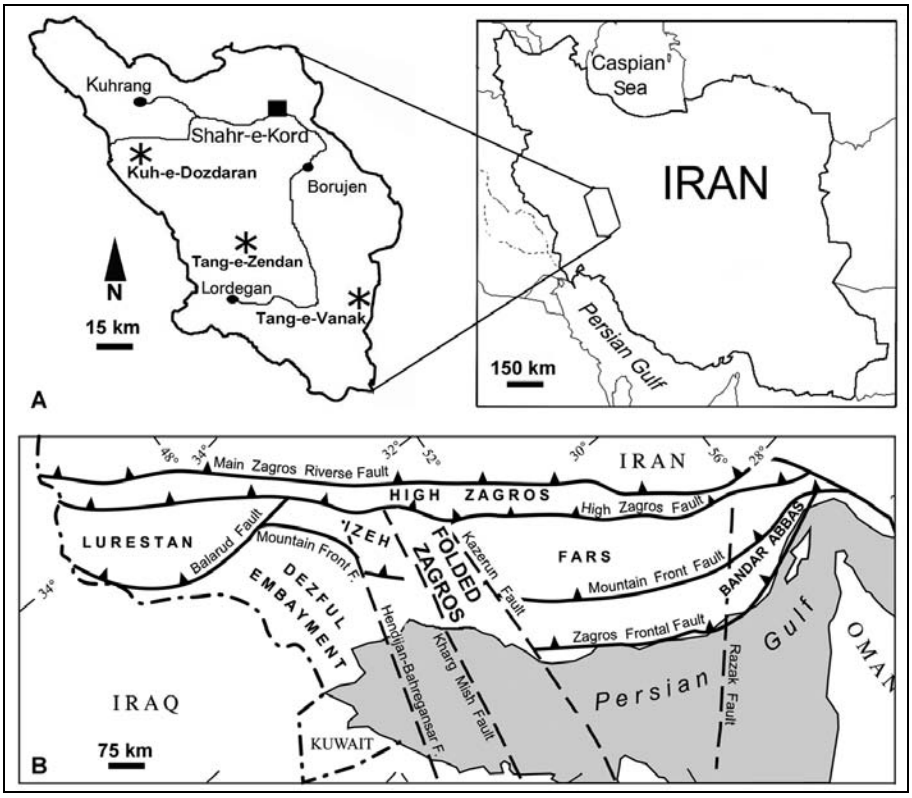

Fig. 1 - Location map of the studied sections in the Chahar Mahal and Bakhtiari province of Iran A), and the major subdivisions of the Zagros basin in Iran B); after Sherkati & Letouzey (2004).

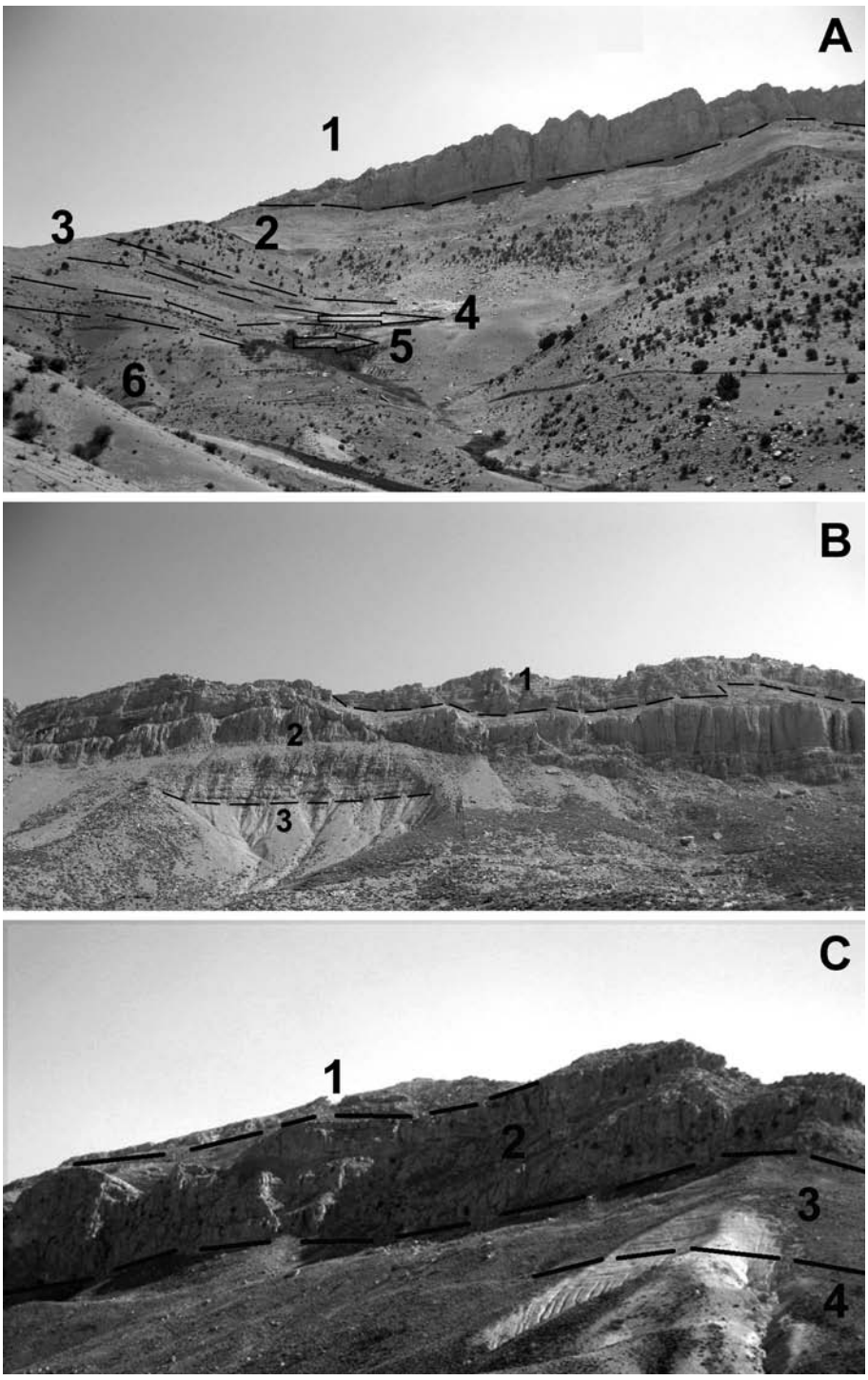

Fig. 2 - The general view of the studied sections and the lithostratigraphical units in A) Tang-e-Vanak, 1- Shahbazan Formation, 2- Tarbur Fm. B, 3- Amiran Fm. B, 4- Tarbur Fm. A, 5- Amiran Fm. A, 6- Gurpi Fm.; B) Kuh-e-Dozdaran, 1- Jahrom Fm., 2- Tarbur Fm., 3- Gurpi Fm.; and C) Tang-e-Zendan, 1- Shahbazan Fm., 2- Tarbur Fm., 3- Amiran Fm., 4- Gurpi Fm.

Material and Methods

The study sections (Fig. 1A) are Tang-e-Vanak (51°12'22"E, 31°36'16"N), Tang-e-Zendan (50°12' 20"E, 31°43'11"N), and Kuh-e-Dozdaran (50°15'20"E, 32°10'38"N). They are about 60 to 120 km apart from each other. According to the classification of Alavi (2004), the first two stratigraphic sections are located in the Folded Zagros zone, and the latter is situated in the High Zagros zone (Figs 1-2).

Field data collection, sampling and measuring of the sections were done systematically by obtaining closely spaced samples. Generally one sample was collected at every two meters, while near the boundaries every meter of the intervals was sampled. In total, about seven hundred thin sections were prepared and studied in order to establish the biostratigraphical framework and to distinguish the microfacies and the depositional environments of the investigated areas. Benthonic foraminiferal biozonation is established in accordance with the International Stratigraphic Guide by the International Commission on Stratigraphy (http://www.stratigraphy.org/upload/bak/bio.htm).

Results and Discussion

Regional stratigraphy

Due to the presence of a sequence of formations from the Upper Cretaceous to the Lower Cenozoic,

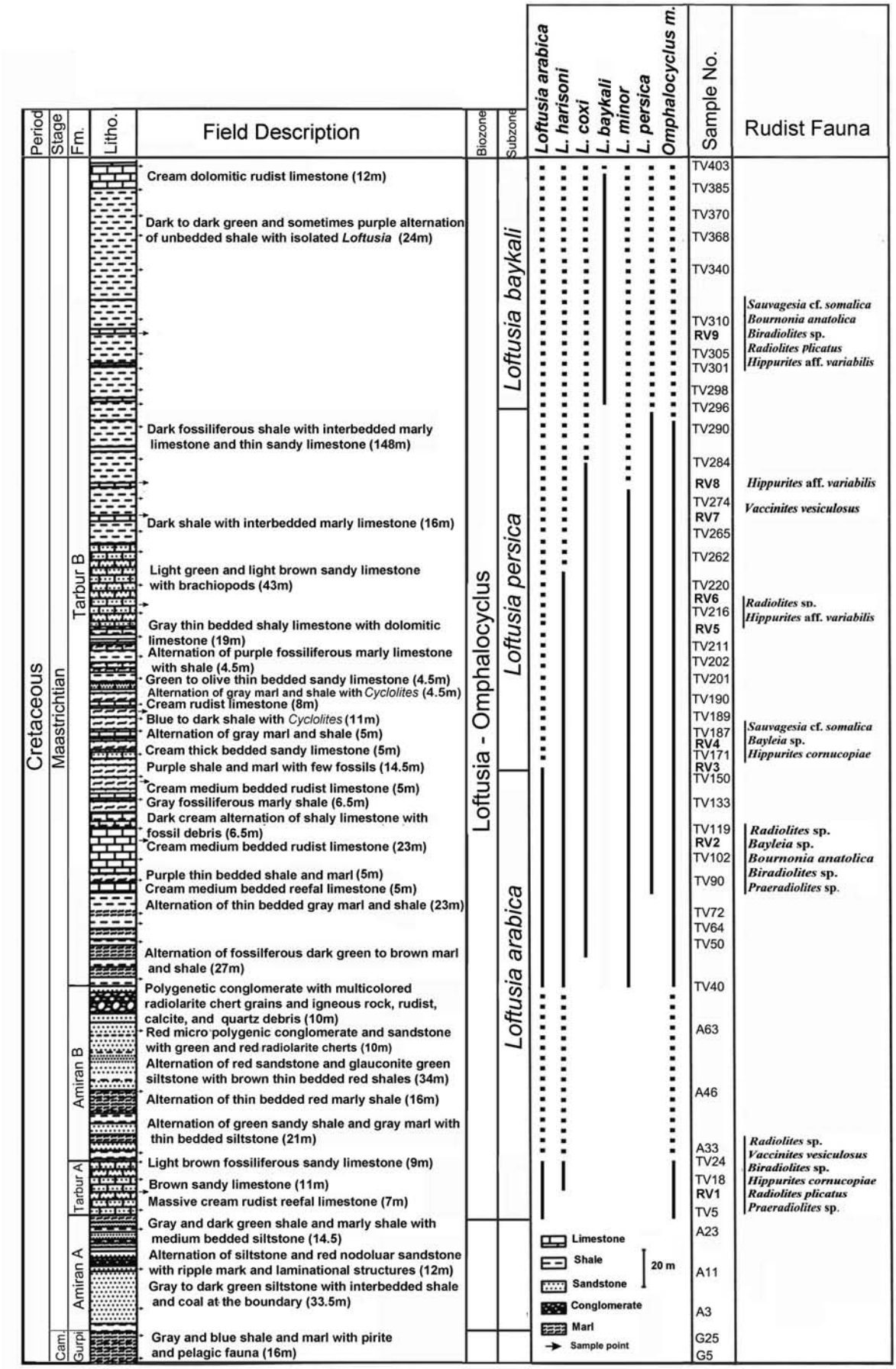

Fig. 3 - Stratigraphy, main micropaleontological and rudist markers, and biozonation of the Tarbur Formation in Tang-e-Vanak section. Abbreviations; Fm: Formation, Litho: Lithology, Cam: Campanian, m: macroporus. RV1-9 refers to the rudist sampling points and collections.

this study has provided interesting results in terms of bio- and lithostratigraphy. Detailed studies of thin sections show that the stratigraphical conditions and the age of the Tarbur Fm. in these sections are different.

Tang-e-Vanak and Tang-e-Zendan sections (Figs 3-4). The outcropping units in these valleys, bottom to top, are the Sarvak, Gurpi, Amiran, Tarbur, and Shahbazan formations. The overall characteristics of these formations were controlled by relative sea-level fluctuations, although compressional tectonics associated with the closing of the Neo-Tethys Ocean and basement faulting also played minor roles (Keyvani & Heydari 2004). The lithology of the Sarvak Fm. (Cenomanian) includes dark reefal, cream-colored to gray, compact, and sometimes sandy limestone. The Sarvak Fm. formed during the sea-level rise and highstand (Keyvani & Heydari 2004). This sequence, with an erosional disconformity, is covered with shale and marl of the Gurpi Fm. of Campanian-Maastrichtian age. A major transgression resulted in deposition of the dark gray shale of the Gurpi Fm. (Keyvani & Heydari 2004). The Amiran Fm. has a detrital, flysch facies including siltstone, radiolarian sandstone and polygenetic conglomerate. These deposits were formed along the Zagros belt as a result of the Neo-Tethys closure and the onset of the collision of the Arabian and Iranian plates during the Santonian-Maastrichtian (Berberian & King 1981).

The Amiran Fm., deposited on the Gurpi Fm. with a gradually interfingering boundary, is covered by the Tarbur Fm. with a similar boundary. However, these conditions vary in different parts of the region. Indeed, locally the Amiran Fm. gradually fades and the Tarbur Fm. is directly deposited on the Gurpi Fm.

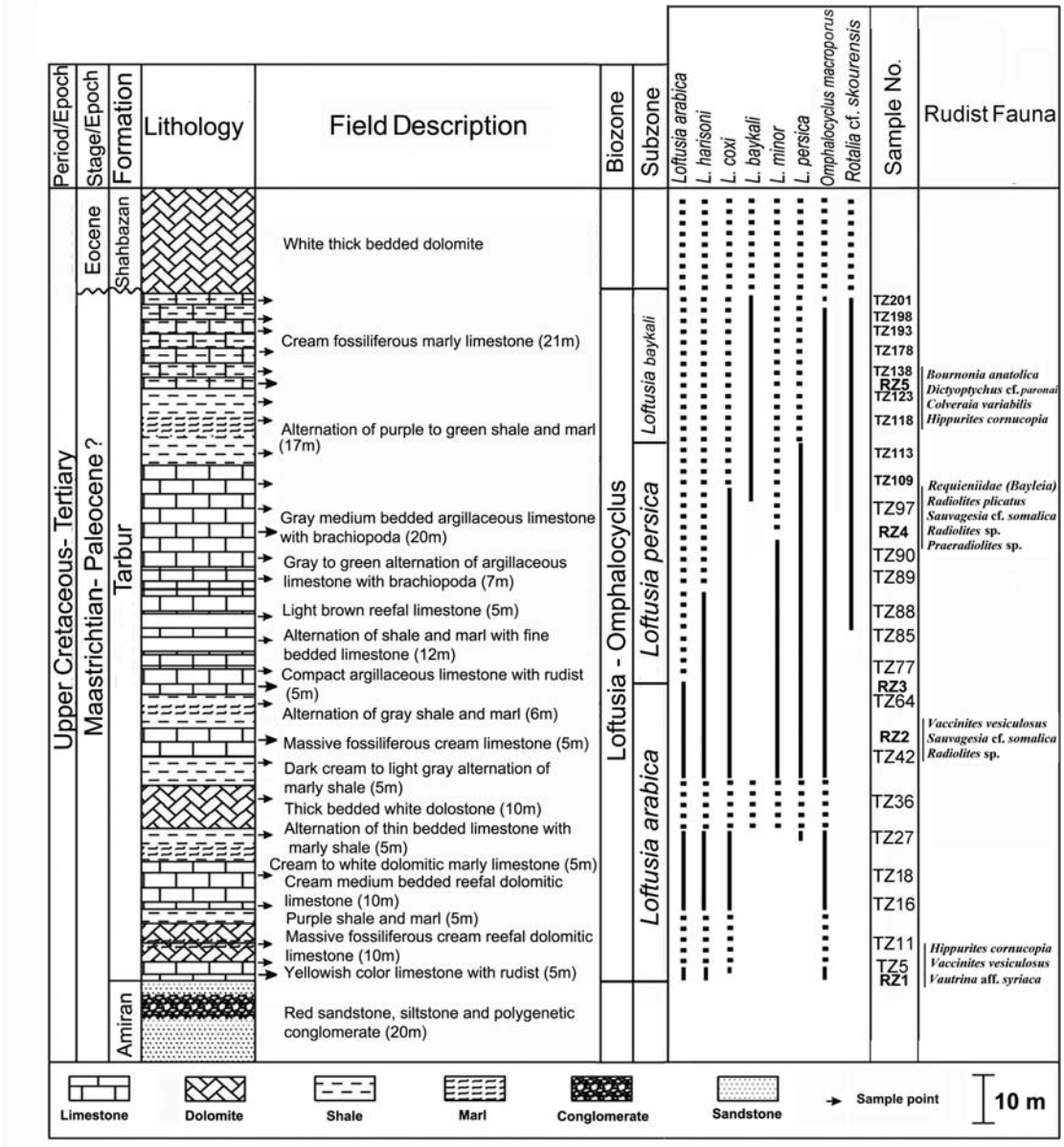

Fig. 4 - Stratigraphy, main micropaleontological markers, and biozonation of the Tarbur Formation in Tang-e-Zendan section. RZ1-5 refers to the rudist sampling points and collections.

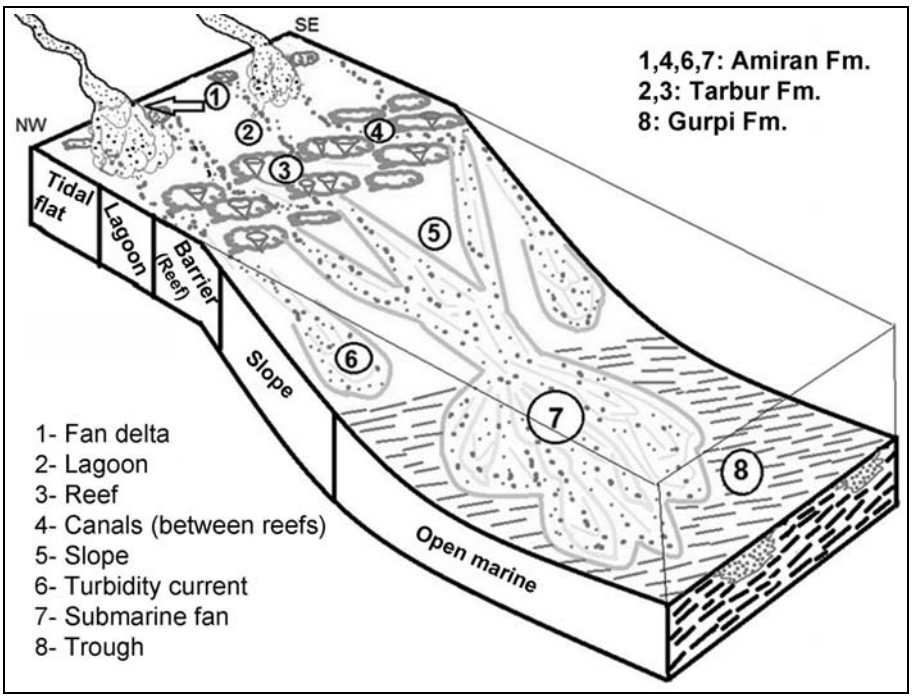

Fig. 5 - Paleoenvironmental reconstruction and depositional systems of the sedimentary units in the studied sections.

Moreover, the Tarbur Fm. occasionally overlaps the Amiran Fm. (Stonely 1974). Afghah (2010) reported a similar case from Tang-e-Shabikhoon section in the Lorestan province, where a wedge of Amiran Fm. is present in the basal part of the Tarbur Fm. According to Afgah (2010), the global sea level rise in the Maastrichtian lead to the partial submersion of the Amiran Fm. in Lorestan province and some other parts of the Zagros basin. Thus, suitable conditions were set for the development of shallow low-energy carbonate platforms, which nurtured the growth and spread of the rudist limestone of the Tarbur Fm.

In the Tang-e-Vanak section, two wedges of the Amiran Fm. (marked by part A and B) are present in the Tarbur Fm. (Fig. 3). This sequence, from base to the top, includes: part A of the Amiran Fm. (61.5 m thick), part A (the lower parts) of the Tarbur Fm. (31 m), part B of the Amiran Fm. (92 m) and part B of the Tarbur Fm. (424 m). The Amiran Fm. is also present in the Tang-e-Zendan section and forms a 15 m thick wedge at the base of the section. It is positioned between the Gurpi and Tarbur formations and can be regarded as a submarine fan (Figs. 4-5). In these sections, Tarbur Fm. sediments are cream colored, rudist-bearing limestone with alternation of shale and marl, white dolostone, dolomitic limestone, and fossiliferous marly limestone. The Tarbur Fm. in Tang-e-Zendan section is covered with the white, dolomitic deposits of the Shahbazan Fm. (Eocene) with a disconformable boundary.

In order to enhance the preciseness of the age determinations, 30 meters of the terminal part of the Gurpi Fm. and all the Amiran Fm., along with the Tarbur Fm. were sampled in these sections. The study of thin sections clarified that all three formations belong to the Maastrichtian. However, due to the presence of foraminifers resembling *Laffitteina* and *Miscellanea* (Inan et al. 2005), the terminal parts of the Tarbur Fm. may be of Paleocene age. Unfortunately, due to the poor preservation and inappropriate thin sections of these benthic foraminifers, this age assignment remains doubtful and needs further investigations.

Apparently, the mentioned formations were concurrently deposited in the Maastrichtian in different environmental settings (Fig. 5). In the deep part of the sea, shale and marls of the Gurpi Fm. were formed, and in the shallow environments the Tarbur Fm. settled. In the deltaic environments of the shallow depths, the Amiran Fm. was deposited. Occasionally, in some areas, the shallow environments of the Tarbur Fm. were bypassed and the turbidites extended into the deep parts of the basin and even covered the upper parts of the Gurpi Fm.

The boundaries between the Gurpi, Tarbur and Amiran formations show gradual interfingering as they gradually transform into one another. This has been observed and verified in the studied sections. Vaziri Moghadam et al. (2005) reported that in central Fars and the high Zagros zones, the Tarbur Fm. extends towards the southwest and it changes into thin layers of limestone of deep-water environments. It is finally replaced by shale facies of the Gurpi Fm.

The Tarbur Fm. has different age boundaries in different parts of the Zagros basin and is evidently a diachronous unit. Its age span in the type section is Campanian-Maastrichtian (James & Wynd 1965). In the outcrops of Kuh-e-Khaneh Kat and Chehel-Chesh-

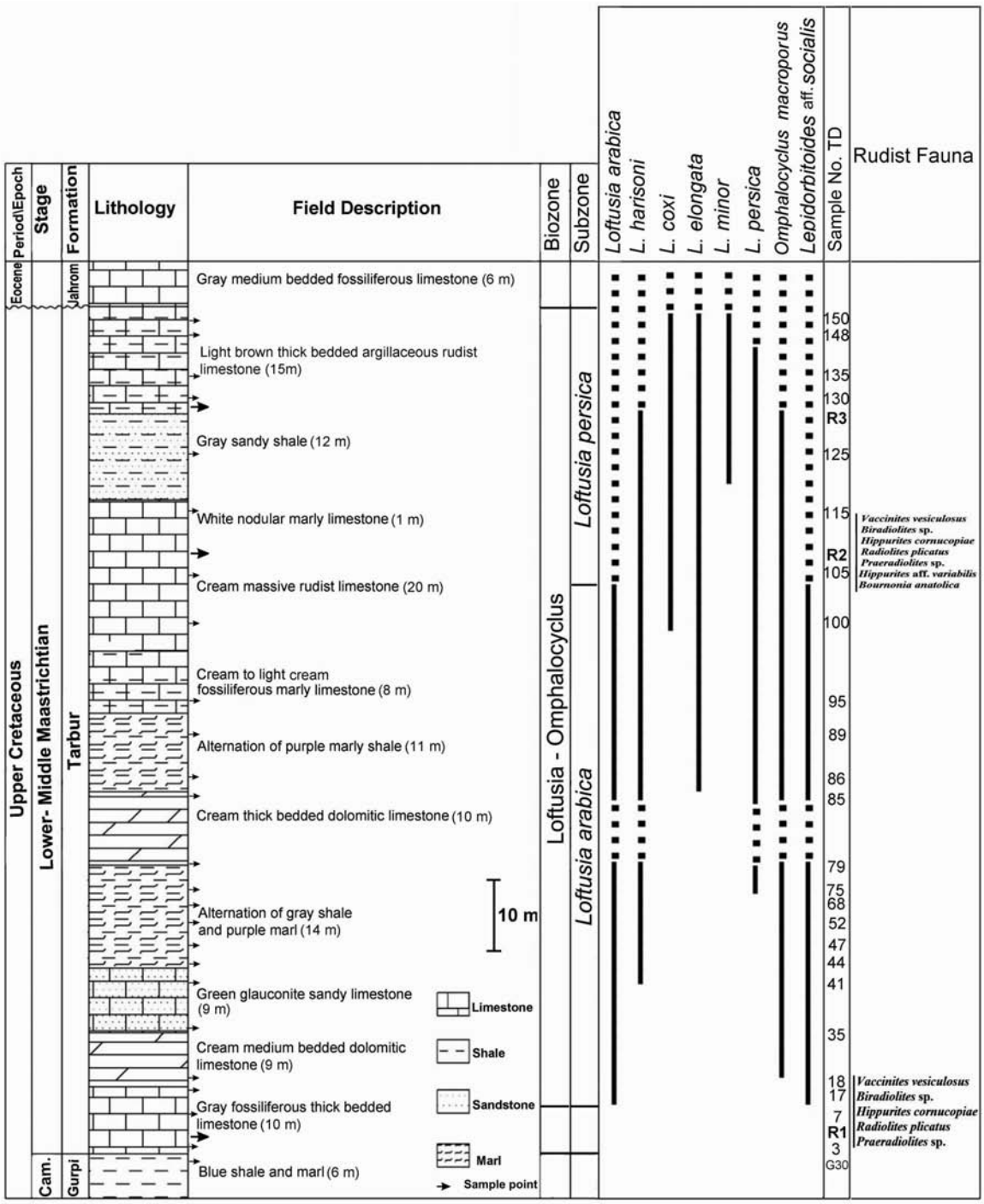

Fig. 6 - Stratigraphy, main micropaleontological and rudist markers, and biozonation of the Tarbur Formation in Kuh-e-Dozdaran section. Abbreviations; Cam: Campanian. R1-3 refers to the rudist sampling points and collections.

meh sections, east of Shiraz, its age is Campanian to early Paleocene (Afghah 2010). Southeast of the Kharameh area, Tarbur Fm. age is the middle-late Maastrichtian (Afghah 2010), and in the Naghan district, it is Maastrichtian (Maghfouri Moghadam et al. 2009). This shows that because of the tectonic conditions at the end of the Cretaceous period and the effect of the Laramian orogenies, the shallow, reef-forming conditions were not the same in all parts of the Neo-Tethys. In Zagros basin, the reefs of Tarbur Fm. were more widespread in Fars area and are less well developed in the central Zagros. This was merely related to the conditions of paleotopography and the tectonic activity of the basin and the consequent influx of the clastic sediments into the local basins.

Kuh-e-Dozdaran section (Fig. 6). As indicated earlier, the Tarbur Fm. in this area is located in the High Zagros zone. There are several clear differences in the stratigraphy of the Tarbur Fm. in this area compared to other sections. In Kuh-e-Dozdaran section, the rock units cropping out are the Sarvak, Gurpi, Tarbur, and

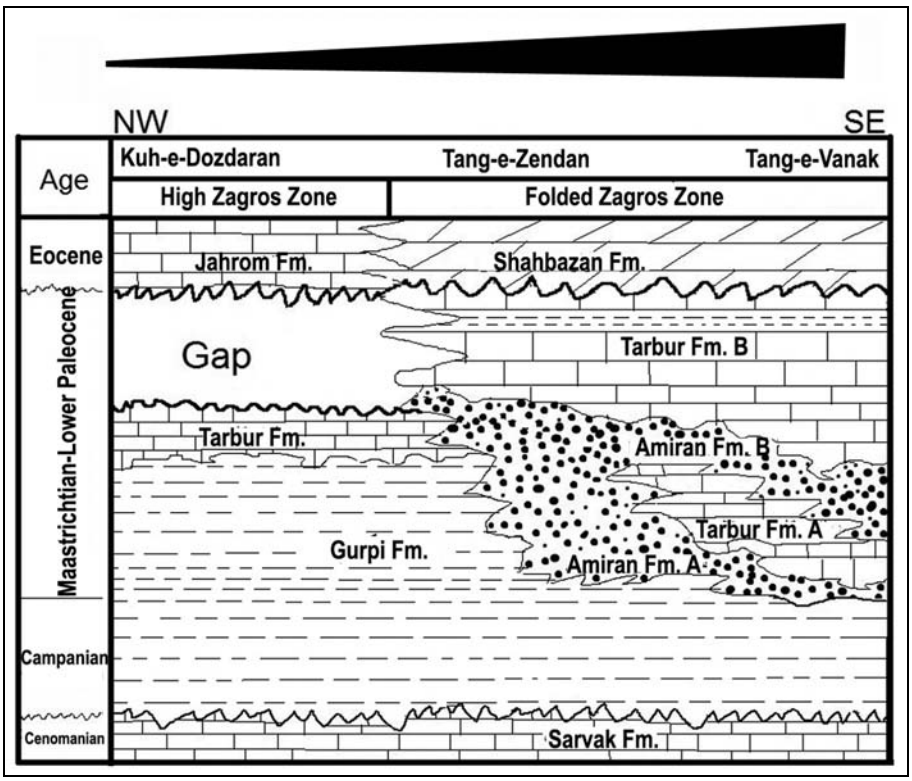

Fig. 7 - Schematic relationships of the main stratigraphical units in the studied areas and their lateral and vertical relationships. The black wedge at the top shows the thickening trend of the Tarbur Fm. from northwest to the southeast.

Jahrom formations, which cover an interval from Cenomanian to Eocene. In this section, the Tarbur Fm. is 111 meters thick and consists mostly of rudist bearing, cream-colored limestone, dolomitic limestone, shale, marl, and glauconite sandy limestone. This sequence was deposited over the Gurpi Fm. The study of the microfossil content of the Gurpi Fm. indicates a Campanian-Maastrichtian age (Ghasemi-Nejad et al. 2006). In this section, the Jahrom Fm. limestone and dolostones (Eocene) are deposited over the Tarbur Fm. with a conformable boundary and form a disconformity. The main difference of this section in comparison with Tang-e-Vanak and Tang-e-Zendan sections is the absence of Amiran Fm. (Fig. 6). Therefore, carbonate sediments of the Tarbur Fm. are directly deposited over the Gurpi Fm. Moreover, the age of the Tarbur Fm. in Tang-e-Vanak and Tang-e-Zendan sections is Maastrichtian to possibly Paleocene, but in this section the age of the formation is restricted to early to middle Maastrichtian. The thickness of the Tarbur Fm. in Kuh-e-Dozdaran is also less than the other studied sections. It is evident that the Tarbur Fm. becomes thicker toward the folded Zagros zone (Fig. 7). Additionally, *Lepidorbitoides* aff. *socialis* (Leymerie, 1851), an index of the Maastrichtian (Özcan 2007), is present in Kuh-e-Dozdaran section. Although *Lepidorbitoides* and *Orbitoides* are reported from Tarbur Fm. in the type section area in Fars province, they are absent from Tang-e-Vanak and Tang-e-Zendan sections. The probable reason for the absence of these foraminifers in these areas is the shallow depth of the basins (Özcan 1993) and the abundance of terrigenous input (Amiran Fm. clastics) in the sedimentary environments, and possibly the high level of nutrients in the basin. In the other words, conditions of eutrophication exist in these basins, which were ideal for the growth of rudists and agglutinated foraminifera like *Loftusia* (Meriç & Görmüş 2001).

In contrast, in Kuh-e-Dozdaran section, *Lepidorbitoides* is present due to the absence of Amiran Fm. and dominance of oligotrophic conditions. Hottinger (1997) stated that *Lepidorbitoides* and *Orbitoides* are frequent species in oligotrophic conditions and disappear after environmental change toward mesotrophic and eutrophic conditions.

Biostratigraphy

Micropaleontological study of the Tarbur Formation resulted in the identification of several benthonic and rare planktonic foraminifera (Fig. 8), as well as some algae. The benthonic foraminifera of the studied sections, compared with the planktonic species, show high diversity, frequency, and abundance and are hence used for the biostratigraphy of the Tarbur Fm.

The dominant biozone of the Tarbur Fm. in Tang-e-Vanak, Tang-e- Zendan, and Kuh-e-Dozdaran sections is *Loftusia-Omphalocyclus* assemblage zone. This biozone is compatible with the assemblage zone 37 reported by James & Wynd (1965) and is referred to the Maastrichtian.

The main microfauna from Tang-e-Vanak section (Fig. 8) includes: *Loftusia harrisoni* Cox, 1937*; L. coxi* Henson, 1948; *L. minor* Cox, 1937; *L. persica Brady*,

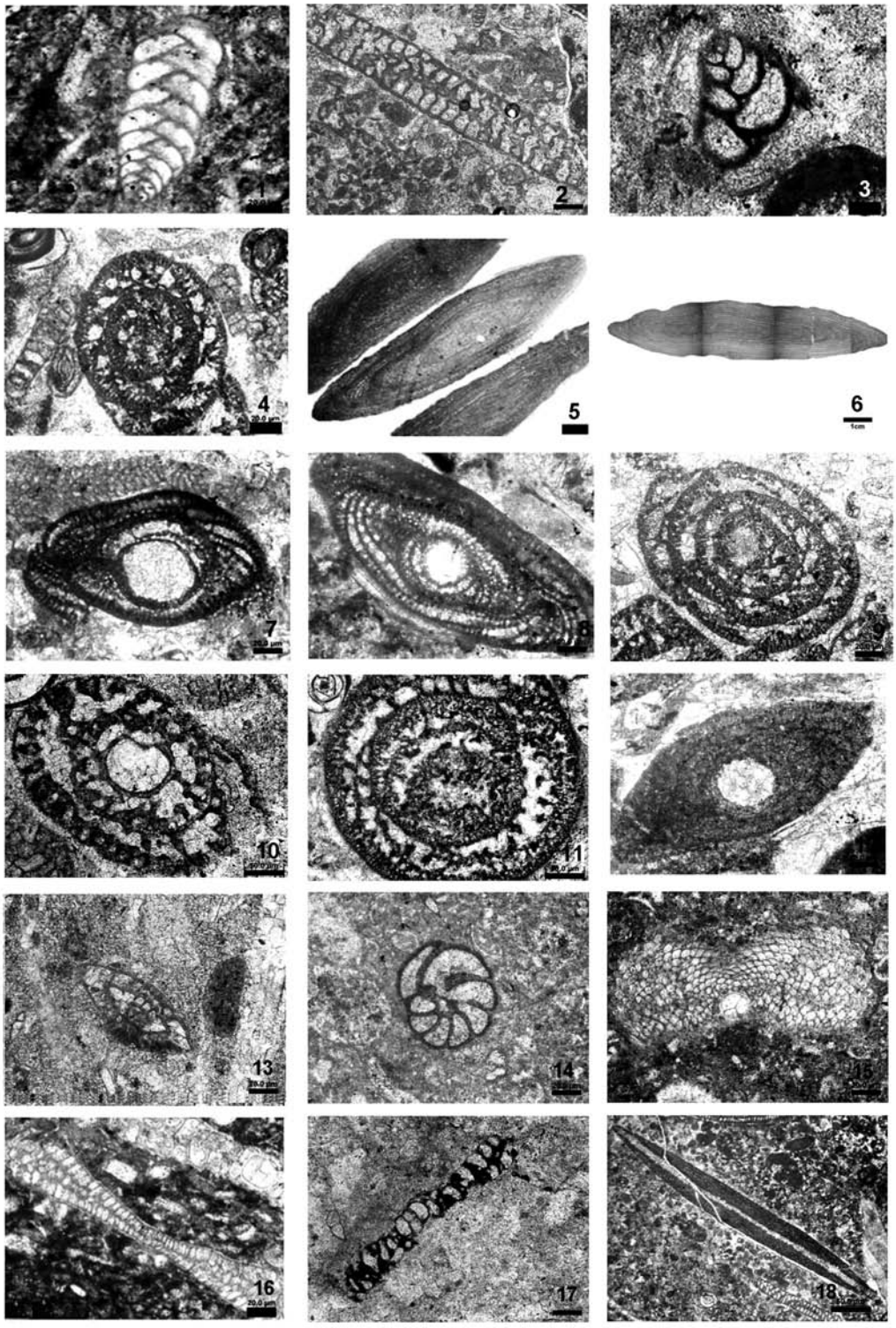

Fig. 8 - Selected foraminiferal taxa from the studied sections (numbers in parenthesis indicate sample numbers).
1) *Pseudotextularia elegans,* axial section, scalebar 0.2 mm, Tang-e-Vanak (TV 171); 2)?*Broeckinella* indet., axial section, scale bar 0.5 mm, Tang-e-Zendan. (TZ 36); 3) *Minouxia conica,* longitudinal section, scale bar 0.2 mm, Kuh-e-Dozdaran (TD 18); 4) *Loftusia coxi*, transverse section, scale bar 0.2 mm, Kuh-e-Dozdaran (TD 68); 5) *Loftusia elongata,* axial section, scale bar 0.2 mm, Tang-e-Vanak (TV 201); 6) *Loftusia persica,*longitudinal section, scale bar 10 mm, Kuh-e-Dozdaran (TD 52); 7) *Loftusia arabica*, axial section, scale bar 0.2 mm, Tang-e-Vanak (TV 24); 8) *Loftusia harrisoni*, axial section, scale bar 0.2 mm, Tang-e-Vanak (TV 187); 9) *Loftusia baykali*, transverse section, scale bar 0.2 mm, Tang-e-Zendan (TZ 193); 10) *Loftusia morgani,* transverse section, scale bar 0.5 mm, Kuh-e-Dozdaran (TD 79); 11) *Loftusia persica*, transverse section, scalebar 0.5 mm, Tang-e-Vanak (TV 189); 12) *Loftusia minor*, axial section, scale bar 0.2 mm, Kuh-e-Dozdaran (TD 28); 13) *Rotalia* cf. *skourensis,* transverse section, scale bar 0.2 mm, Tang-e-Zendan (TZ 193); 14) *Nezzazatinella picardi*, equatorial section, scale bar 0.2 mm, Tang-e-Vanak (TV 211); 15) *Omphalocyclus macroporus*, subequatorial section, scale bar 0.2 mm, Tang-e-Vanak (TV 64); 16) *Omphalocyclus macroporus,* axial section, scale bar 0.2 mm, Kuh-e-Dozdaran (TD 17); 17) *Omphalocyclus* cf. *anatoliensis*, axial section, scale bar 0.2 mm, Tang-e-Zendan (TZ 18); 18) *Lepidorbitoides* aff. *socialis,* longitudinal section, scale bar 0.5 mm, Kuh-e-Dozdaran (TD 44).

1869; *L. morgani* Douvillé, 1904; *L. elongata* Cox, 1937; *L. arabica* El-Asa'ad, 1989; *L. baykali* Meriç, 1965; *Omphalocyclus macroporus* (Lamark, 1816); *Rotalia* cf. *skourensis* Pfender (in Moret, 1938); *Pseudotextularia elegans* (Rzehak, 1891), *Pseudorotalia persica* Rahaghi, 1976; *Minouxia conica* Gendort, 1963 and *Nezzazatinella picardi* (Henson, 1948).

The main microfauna of Tang-e-Zendan section (Fig. 8) includes: *Lofusia persica, L. minor, L. coxi, L. harrisoni, L. arabica*, *L. baykali*, *Omphalocyclus macroporus*, *O.* cf. *anatoliensis* Özcan, 2007; *Rotalia* cf. *skourensis*, and *Nezzazatinella picardi.* There are no remains of *Orbitoides* and *Lepidorbitoides* in these sections.

The following key taxa were identified at Kuh-e-Dozdaran section (Fig. 8): *Loftusia harrisoni, L. minor, L. elongata, L. coxi, L. arabica, L. persica*, *Omphalocyclus macroporus*, *Lepidorbitoides* aff. *socialis, Rotalia* cf. *skourensis, Pesudotextularia elegans, Minouxia conica,* and *Nezzazatinella picardi.*

In figures 3, 4, and 6 the vertical ranges of the important larger foraminifera from the studied sections are given. The age of the Tarbur Fm. in the studied areas, based on its fossil assemblages, is mainly Maastrichtian. The microfaunas of these fossiliferous sections and their age closely correspond to the deposits from southeastern Turkey (Özcan 1993; Görmüş and Meriç 2000; Meriç et al 2001; Çaglar & Önal 2009) and Northern Iraq (Al-Omari & Sadek 1976). In contrast, there are differences with the Maastrichtian deposits from western side of the Northern Oman Mountains (Abdelghany 2003, 2006), Saudi Arabia (El-Asa'ad 1989), Qatar (Meriç et al. 2001), Greece, and former Yugoslavia (Meriç et al. 2001; Zambetakis-Lekkas & Kemeridou 2006).

The abundance and diversity of the microfossil assemblages from these sections, especially the *Loftusia* species (Figs 3, 4, 6), allows us to propose three new sub-biozones (subzones) for the Tarbur Fm. These subzones may help to distinguish the lower, middle and upper Maastrichtian within the Tarbur Fm.

***Loftusia arabica* range subzone** (Figs 3, 4, 6). The lower boundary of this subzone is defined by the lowest stratigraphic occurrence of the *L. arabica* and its upper boundary is the highest stratigraphic occurrence of this species. This subzone comprises the lower part of the studied sections and corresponds to the lower part of the Maastrichtian. *L. arabica* is reported from the early Maastrichtian of Saudi Arabia (El-Asa'ad 1989). *L. harrisoni*, mainly recorded from the middle Maastrichtian, is also present in the earlier strata (Meriç & Görmüş 2001) and occurs in this zone. This species is recorded from Turkey and Iran (Meriç et al. 2001).

In Tang-e-Vanak, this zone includes the part A, and the lower 80 m of the part B of the Tarbur Fm. (Fig. 3). In Tang-e-Zendan, this zone is limited to the lower 50 m of the section (Fig. 4). In Kuh-e-Dozdaran section, this zone includes the lower part of the interval from 30 to 100 m (Fig. 7).

***Loftusia persica* interval subzone** (Figs 3, 4, 6). The lower boundary of this subzone is defined by the last stratigraphic occurrence of *L. arabica* and its upper boundary is the last stratigraphic occurrence of *L. persica*. This subzone is an indicator of the middle part of the Maastrichtian. In addition to *L. persica*, its assemblage consists of *L. minor, L. coxi*, *L. elongata*, and *L. harrisoni. Omphalocyclus macroporus,* which also occurs in the middle Maastrichtian (Özcan 2007), is present in this subzone. This foraminiferal assemblage (excluding *O. macroporus*) is mostly found on the Arabian platform and is rare in other areas (Meriç et al, 2001). These species were observed in the part B of the Tarbur Fm. in Tang-e-Vanak (Fig. 3), the middle parts of the Tarbur Fm. in Tang-e-Zendan (Fig. 4), and the upper parts of the Tarbur Fm. in Kuh-e-Dozdaran (Fig. 6).

In Tang-e-Vanak (Fig. 3), this zone is present from 300 to 480 m interval of the section. In Tang-e-Zendan section (Fig. 4), the interval from 50 to 90 m belongs to this zone. In Kuh-e-Dozdaran (Fig. 6), this zone starts at 80 m level and ends at the top of the section.

***Loftusia baykali* interval subzone** (Figs 3-4). The lower boundary of this zone is defined by the last stratigraphic occurrence of *L. persica* and its upper boundary is the last occurrence of *L. baykali*. This subzone is an indicator of the upper Maastrichtian and is recorded also from Turkey. In addition to *L. baykali*, *L. morgani* and *Omphalocyclus macroporus* also occur in the late Maastrichtian (Özcan 2007). They are commonly found on the Arabian platform and Turkey (Meriç et al. 2001). These species are recorded in the upper parts of the Tang-e-Vanak and Tang-e-Zendan sections. Only *O. macroporus* is observed, in association with the middle Maastrichtian fauna, in Kuh-e-Dozdaran section in the top 20 meters of the section.

In Tang-e-Vanak section (Fig. 3), this zone is present from 480 m level and ends near the top of the section. In Tang-e-Zendan section (Fig. 4), this zone is found at 90 m level and is 20 m thick.

From the top 30 m of the Tarbur Fm. in Tang-e-Vanak section, and the last 10 m interval of this formation in Tang-e-Zendan, a larger foraminiferal assemblage (not illustrated here), possibly including taxa similar or corresponding to those reported by Afghah (2010) is observed. This interval may be referred to the Paleocene, in accordance with the *Vania anatolica* biozone reported by Afghah (2010) from the Tarbur Fm. in Kuh-e-Chehel Cheshmeh.

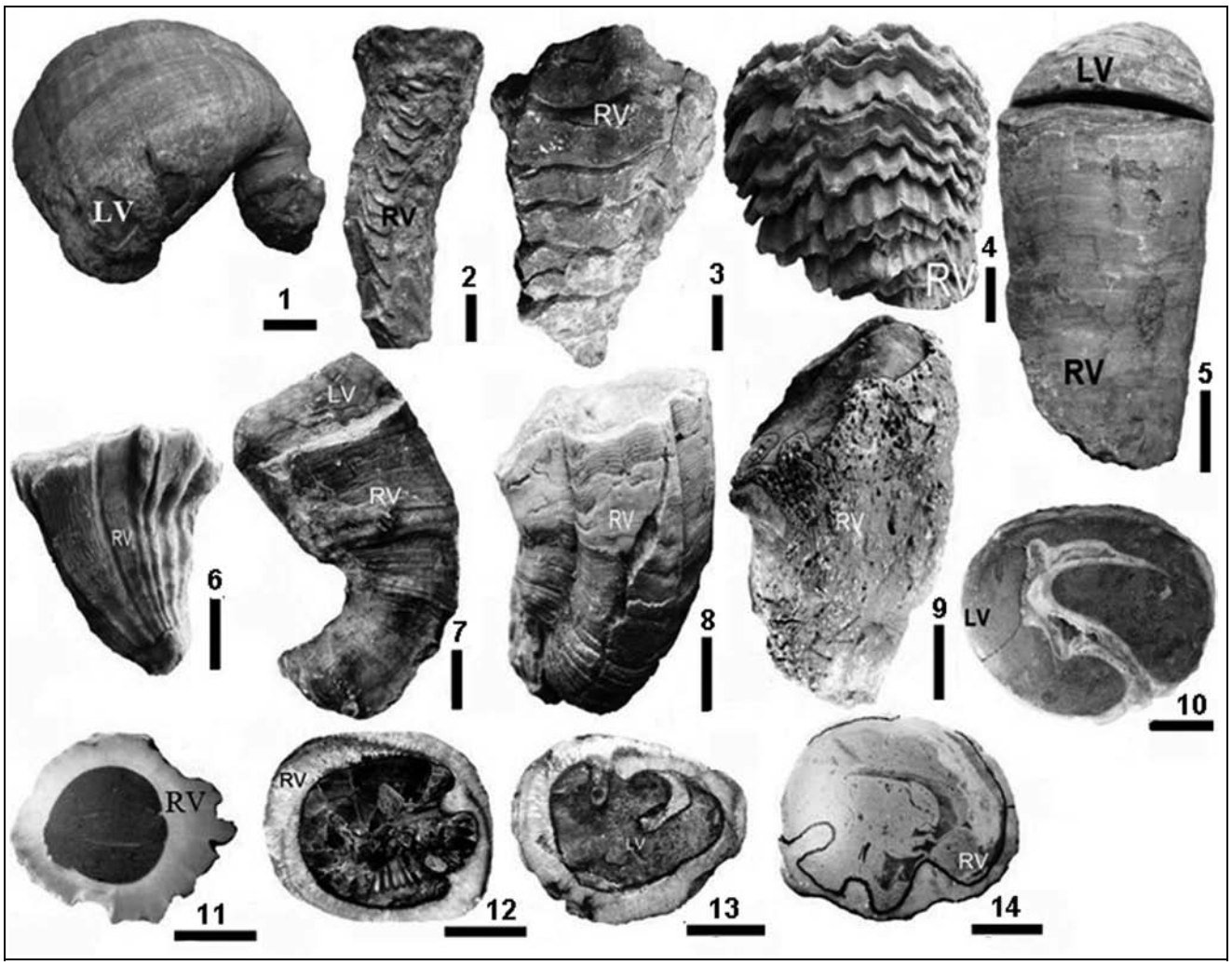

Fig. 9 - Rudist fauna from the studied sections (for sampling points refer to figs 3-4, 6).
1) *Bayleia* sp., left valve, scale bar 20 mm, Tang-e-Vanak (RV2); 2) *Biradiolites* sp., right valve, scale bar 20 mm, Kuh-e-Dozdaran (R2); 3) *Praeradiolites* sp., right valve, scale bar 30 mm, Tang-e-Vanak (RV2); 4) *Radiolites plicatus*, right valve, scale bar 30 mm, Tang-e-Vanak (RV9); 5) *Bournonia anatolica,* right and left valves, scale bar 40 mm, Kuh-e-Dozdaran (R2); 6) *Sauvagesia* cf. *somalica*, right valve, scale bar 50 mm, Tang-e-Vanak (RV4); 7) *Hippurites* aff. *variabilis*, right and left valves, scale bar 50 mm, Kuh-e-Dozdaran (R2); 8) *Hippurites cornucopiae*, right valve, scale bar 40 mm, Tang-e-Vanak (RV3); 9) *Vaccinites vesiculosus*, right valve, scale bar 50 mm, Tang-e-Vanak (RV7); 10) *Bournonia anatolica,* left valve transversal section, scale bar 40 mm, Kuh-e-Dozdaran (R2); 11) *Sauvagesia* cf. *somalica*, right valve transversal section, scale bar 30 mm, Tang-e-Vanak (RV9); 12) *Hippurites* aff. *variabilis,* right valve transversal section, scale bar 30 mm, Kuh-e-Dozdaran (R2); 13) *Hippurites cornucopiae*, left valve transversal section, scale bar 30 mm, Kuh-e-Dozdaran (R1); 14) *Vaccinites vesiculosus*, right valve transversal section, scale bar 30 mm, Tang-e-Vanak (RV1).

Based on the aforementioned evidence, the Tarbur Fm. in Kuh-e-Dozdaran section is lower-middle Maastrichtian, whereas in Tang-e-Vanak and Tang-e-Zendan sections, it is lower to upper Maastrichtian, possibly extending into the lower Paleocene.

Rudist fauna

Rudists are among the most important components of the shallow carbonate platforms of the Tethyan realm during the Cretaceous (Skelton 2003). These extinct bivalves had a sessile life style and were suspension feeders, living in eutrophic environments in the internal parts of carbonate platforms. Rapid development of carbonate platforms and rudists' ability to tolerate changes in temperature, salinity and light exposure and living in restricted muddy environments, resulted in their rapid expansion (Schluter 2008).

Rudists are reported from several areas and localities in the Zagros basin of Iran (see Khazaei et al. 2010 for a review). The following rudist bivalves were identified in Tang-e-Vanak, Tang-e-Zendan, and Kuh-e-Dozdaran sections (Figs. 3-4, 6, 9): *Bayleia* sp., *Biradiolites* sp., *Bournonia anatolica* Özer, 1988; *Colveraia variabilis* Klinghardt, 1921; *Dictyoptychus* cf. *paronai* (Kühn, 1929); *Hippurites* aff. *variabilis* Munier- Chalmas, 1867; *Hippurites cornucopiae* Defrance, 1821; *Praeradiolites* sp.; *Radiolites plicatus* Lajard, Toulousan and Negrel, 1824; *Radiolites* sp.; *Sauvagesia* cf. *somalica*

Tavani, 1949; *Vaccinites vesiculosus* (Woodward, 1855); and *Vautrinia* aff. *syriaca* (Vautrin, 1933).

Among these species, *Hippurites cornucopiae* is one of the rudist index species for the Maastrichtian of the Tethyan Mediterranean bioprovince. *Vaccinites vesiculosus* is also a Campanian-Maastrichtian species from the Arabian platform. This fauna confirms the Maastrichtian age for the Tarbur Formation in the studied areas, as was already inferred from its microfauna.

Paleoenvironmental interpretation

Field observations and microfacies analyses resulted in the identification of four facies belts: tidal flat (T), lagoon (L), barrier (B), and open marine (O) environments in the studied areas of central Zagros (Fig. 5). The tidal flat and lagoonal facies are more developed in Tang-e-Vanak and Tang-e-Zendan, while barrier facies is best observed in Tang-e-Vanak. Dolomitization occurs in Tang-e-Zendan and Kuh-e-Dozdaran. This paleoenvironment study indicates that the Tarbur Formation deposits in the study areas were deposited on a carbonate platform of a homoclinal ramp (Asgari Pirbaluti et al. in press).

Conclusions

1. The Tarbur Formation in Tang-e-Vanak section in the Folded Zagros zone is composed of two parts (A and B). It includes 455 m of carbonate sediments, shale, and marl of the early Maastrichtian-Early Paleocene. In Tang-e-Zendan section, Tarbur Fm. is 156 m thick and shows the same lithology and age. The Tarbur Fm. in Kuh-e-Dozdaran section in the High Zagros zone is 111 m thick and belongs to the early-middle Maastrichtian.

2. Parts of the Gurpi, Tarbur and Amiran formations have been deposited simultaneously in central Zagros. The Gurpi Fm. deposits are shale and marl of a deep open sea zone, the Tarbur Fm. is composed of the carbonate sediments and shale of a shallow environment and the Amiran Fm. is composed of clastics deposited at shallow depth. The relationships and the boundaries of these formations with one another are gradual with interfingering.

3. The lower boundary of the Tarbur Fm. in Tang-e-Vanak and Tang-e-Zendan sections is marked by the Amiran Formation. Dolostones of the Shahbazan Formation (Eocene), with an unconformity, form the upper boundary of this rock unit. The lower boundary of the Tarbur Fm. in Kuh-e-Dozdaran section is marked by the Gurpi Fm. and its upper unconform boundary is with the Jahrom Fm. (Eocene).

4. Three regional larger foraminiferal subbiozones (subzones) are proposed for the Maastrichtian succession of the studied sections for the first time. These are the *Loftusia arabica* range subzone for the lower part of the Maastrichtian, the *Loftusia persica* interval subzone for the middle part of the Maastrichtian, and *Loftusia baykali* interval subzone for the upper part of the Maastrichtian.

5. The Tarbur Fm. is a diachronous unit in the Zagros basin, and has different age boundaries in different areas. This reflects differences in local tectonic activity and paleotopography of the Tethyan basin on the deposition of this unit in Late Cretaceous times.

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