SOKOLOWIA HORIZON OF THE ZIARAT FORMATION (EASTERN ALBORZ, IRAN): BIOSTRATIGRAPHIC AND PALEOGEOGRAPHIC IMPLICATIONS

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Abstract The present study deals with molluscan accumulations of the *Sokolowia* horizon, which is a key-bed in the middle Eocene of the Kalateh section (Ziarat Formation, Eastern Alborz, Iran). The age of this “key horizon” is attributed to Bartonian based on presence of larger benthic foraminifera species such as *Nummulites lyelli* (D'Archiac & Haime), *Orbitoclypeus zitteli* (Checchia-Rispoli) and *Asterocyclina stella stella* (Gümbel) immediately below it. The paleogeographic distribution of *Sokolowia* occurrence from Tarim Basin in eastern Central Asia to the Transylvanian Basin in southeastern Europe indicates a middle Eocene seaway along the southern margin of an Eurasian epicontinental sea. In particular, the comparison of middle Paleogene sequences in different Central Asian regions reveals an apparent similarity between those basins pointing to their genetic relationship.

Keywords: *Sokolowia*; larger benthic foraminifera; Central Asia; Eastern Alborz

INTRODUCTION

During the Paleogene (65 to 23 Ma) the Earth experienced paleoclimatical and paleobiological variations, such as numerous extinction events, extreme temperature fluctuations, and changes in the diversity and frequency of different species (Thomas, 2003; Zachos et al., 2003; Gradstein et al., 2004). Among the various groups of organisms, oyster bivalves are the most abundant macrofossils in the Cenozoic shallow water sediments of Central Asian basins (see Berizzi Quarto di Palo, 1970; Lan, 1997; Bosboom et al., 2011). Despite not as diverse as other bivalve groups, oysters include some excellent index species with short time ranges between evolutionary appearance and extinction, being therefore very useful biostratigraphic tools in shallow marine settings (Griffin et al., 2005; Bosboom et al., 2015). Besides, many authors consider oysters for important proxies for paleoenvironmental conditions in epicontinental basins, however, only few studies have been conducted throughout the Tethys area over the Eocene time (Lan, 1997; Rusu et al., 2004; Griffin et al., 2005; Bosboom et al., 2011). The main objective of the present study is to establish a biostratigraphic correlation of the *Sokolowia* horizon from the Kalateh section (Ziarat Formation, Eastern Alborz) with the Central Asian basins to the East and the Transylvanian Basin to the West. In order to determine the age of the “*Sokolowia* horizon” in the studied section, biostratigraphic examination of larger benthic foraminifera was conducted in an earlier study (Hadi et al. 2019). That new data, contribute significantly to a more precise reconstruction of the paleo-sea way across the proto-Paratethys between the eastern parts of Central Asia (Tarim, Ferghana and Afghan-Tajik basins) and the Southeastern Europe (Transylvanian Basin) during the middle to late Eocene.

GEOLOGICAL SETTING AND STRATIGRAPHY

Being a part of the largest mountain belt of the Alpine-Himalayan system the Iranian plateau has been subdivided into eight sedimentary-structural provinces characterized by different tectonic and sedimentary events (Stöcklin, 1968; Aghanabati, 2004), (Fig. 1a): (1) Alborz, (2) Central Iran, (3) Zagros, (4) Kopet-Dagh, (5) Lut, (6) Sanandaj-Sirjan, (7) Urumieh- Dokhtar (Sahand-Bazman) magmatic arc, and (8) Makran (Fig. 1b). In northern Iran the Alborz range (about 600 km long and 100 km wide) is one of the most investigated geological-structural zones. The E-W trending Alborz mountains belt as one of the most tectonically active zone in the Alpine-Himalayan orogenic belt is located between the Caspian Sea Basin to the north and the Central Iran Basin to the south. The Alborz range spreads westward into the Pontides Arc (in easternmost Turkey) and the Lesser Caucasus (in Georgia and Armenia) (Asiabanha & Foden, 2012).

The Alborz region is a tectonically active zone formed due to the collision between the Gondwana and the Eurasian plate after the closure of Paleo-Tethys Ocean in the Permo-Triassic time (Sengör & Burk, 1978; Stampfli et al., 1991). Following the northward subduction of the Palaeo-Tethys, the Alborz margin, divided into western, central, and eastern sector, was affected by the Cimmerian and Alpine orogenic phases (Alavi, 1996).

Generally, in the southern Alborz flank three lithostratigraphic formations are distinguished (Dellenbach, 1964; Stöcklin, 1972): (1) the Fajan Formation (Paleocene-early Eocene) is mainly composed of continental, terrestrial shales, red conglomerates and sandstones, (2) the Ziarat Formation (early-middle Eocene) mainly comprises foraminiferal limestones, sandy limestones, silty and calcareous marls, and (3) the Karaj Formation (middle Eocene) characterized a more than 3000 m-thick succession of shale, sandstone, tuffaceous sandstone and gypsum.

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Fig. 1 a Tethys mountain ranges (simplified from Okay, 1989 and Özcan et al., 2015) and location of studied region in eastern Alborz zone. b Modified sketch map of Iran showing geologic provinces (adapted from Stöcklin, 1968 and Aghanabati, 2004). c Simplified geological map from eastern Alborz region (after General geological map of Iran, 1:250000 from Sharabi, 1990). Modified after Hadi et al. (2019).

The *Sokolowia* shell accumulations have been studied in the Kalateh section, which belongs to the Ziarat Formation (middle Eocene). The section is located 5 km northwest of Kalateh village and 40 km northwest of Damghan city. It is situated in the Gorgan 1/250000 quadrangle (sheet-7855; after Sharabi, 1990) (coordinates: 36° 22' 50" N; 59° 23' 54" E) (Fig. 1c). The first note on the shallow marine deposits of the Kalateh section and its mollusk fauna was provided by Grewingk (1853), citing its position as valley to Surt (=Orost) near Namakeh (village N of Kalateh). From material collected there by botanist Fedor A. Buhse he erected the new species termed *Gryphea buhsei* (= *Sokolowia buhsii*). The Kalateh section (Fig. 2) consists of 25 m thick nummulitic and coralline red algal limestone, which is superposed by a 7 m thick interval of silty marl and marly limestone intercalated by *Sokolowia* accumulations. The lower boundary of *Sokolowia* marly limestone is sharp and erosional with nummulitic and coralline red algal limestone. The lower part of the *Sokolowia* accumulation is characterized by articulated and low fragmentation shells in silty mudstone matrix. The upper part is characterized by disarticulated, convex-up, highly fragmented and poorly

sorted large *Sokolowia* with normal grading, sharp and erosional base in the uppermost part. Here, we have three types of shell concentrations with thickness, including (1) 40-60 cm, (2) ~1.5 m, and (3) 0.5-1 m. Larger benthic foraminifera from the topmost part of the lower unit, about 1.5 m below the lowermost *Sokolowia* accumulation (Fig. 2) indicate biostratigraphic correlation with the zones SBZ17-SBZ18b suggesting the Bartonian age (Hadi et al. 2019).

MATERIALS AND METHODS

Oyster bivalves pertaining to the Ziarat Formation of the Kalateh section were collected with well-preserved for systematic descriptions from silty marl and marly limestone deposits. Thirty specimens for oysters were investigated and photographed by a Cannon 60D camera and macro lens L100. Also, the identification of the genus and species are mainly based on taxonomic descriptions given by Berizzi Quarto di Palo (1970), Stenzel (1971), Lan & Wei (1995). The material is housed in the collection at Ferdowsi University of Mashhad by M. Hadi.

Table 1 Simplified lithostratigraphic description of the Kalateh section in the eastern Alborz basin from the Paleogene deposits correlated with the Kopet-Dagh-Alborz basins which are summarized from Dellenbach (1964), Stöcklin (1972), Afshar-Harb (1994) and Rezaeian (2008).

Kopet-Dagh basin			Alborz Basin			present study (eastern Alborz basin)		
Age	Formation	Lithology	Age	Formation	Lithology	Age	Formation	Lithology
early Eocene-early Oligocene	Khangiran	sandstone, silty marl and marl, bivalves (oysters)	Middle Eocene	Karaj	black shale, green tuff with intercalation of tuffaceous shale, tuffaceous-sandstone, sandstone, and calcareous shale, greyish-black calcareous and silty shale	middle Eocene	Karaj	sandstone, tuff, tuffaceous shale, gypsum shale
middle Paleocene-early Eocene	Chehelkaman	siliciclastic and limestone beds with evaporate interbeds, rich in molluscan assemblages specially oysters at the top	early Eocene-middle Eocene	Ziarat	evaporates (gypsum), gray to greenish marl, marly limestone, and limestone	early Eocene?-middle Eocene	Ziarat	gray marl, limestone, silty marl, marl with shell beds (oyster)
early Paleocene-middle Paleocene	Pesteligh	marl, mudstone and siltstone red bed with evaporate interbeds, sandstone, and conglomerates	early Paleocene-early Eocene	Fajan	conglomerate, red sandstones, and sandy marls	-	-	-

Fig. 2 Stratigraphic distribution of larger foraminiferal species and other fossil groups in the Kalateh section, eastern Alborz zone. Modified after Hadi et al. (2019)

RESULTS

Systematic paleontology of *Sokolowia* from study section

Class Bivalvia			
Suborder	Ostreina	Férussac,	1822
Superfamily	Ostreacea	Rafinesque,	1815
Family	Ostreidae	Rafinesque,	1815
Genus	<i>Sokolowia</i>	Böhm,	1933
Type species:	<i>Gryphaea buhsii</i>	Grewingk,	1853
<i>Sokolowia</i>	<i>buhsii</i> ,	Grewingk,	1853

Figure 3 a-j

* 1853 *Gryphaea buhsii*, Grewingk, p. 210, Fig.-t. 1871 *Gryphaea esterhazyi*, Pavay, p. 375, pl. 8, Fig.2; pl. 10, Fig.3.

1937 *Gryphaea esterhazyi*, Vialov, p. 20, pl. XI

1938 *Fatima esterhazyi*, Vialov, p. 16.

1948 *Fatima (Sokolowia) esterhazyi*, Vialov, p. 73, pl. 2-32.

1970 *Fatima (Sokolowia) esterhazyi esterhazyi*, Berizzi Quarto di Palo, p. 188, pl. 29, Figs. 1- 2, pl. 30, Fig. 1.

1971 *Sokolowia*, Stenzel, p. 1147, Figs. J121-J122.

2004 *Sokolowia esterhazyi*, Rusu et al., p. 451, pl. 1, Figs. 1-2

2011 *Sokolowia buhsii*- Salahi & Vahidinia, p. 56, pl. 1, Fig. 4

2014 *Sokolowia buhsii*- Bosboom et al., p. 110, Fig. 6. 9.

2016 *Sokolowia buhsii*- Bougeois et al., p. 613, Fig. 1. iii.

Material: eighteen left valves, twelve right valves, MASSH 0001 - MASSH 0030.

Stratigraphic occurrence in the Alborz Basin: Ziarat Formation, Kalateh Section: Horizon 1 at 26.5 m from the base; horizon 2 at 27.5 m from the base; horizon 3 at 29m from the base. Dimensions; (left valve): length (L) 54 mm, height (H) 79 mm, shell thickness 46 mm, (right valve): length (L) 32 mm, height (H) 43 mm, shell thickness 11 mm.

Description: Our *Sokolowia* specimens are characterized by well-preserved, medium to large sized, inflated, subequilateral, thick walled shells, homeomorphous with *Gryphaea* (gryph shaped). The left valve is strongly convex with a narrow, high and recurved umbo. The ligament area is oblique, the interior shell surface smooth. In the ovoid internal cavity the reniform and semicircular muscle scar is placed near its center. The right valve is inequilateral, flattened, concave and triangular in outline, without ribs, but with fine concentric growth lines. The left valve is covered partially or fully with weak to strong radial ribs; they are slender and densely spaced. In the umbonal region, they are a lot and in short distance, but almost disappear toward ventral margin part and only concentric lamellae can be visible.

Remarks: Ornamentations of the *Sokolowia buhsii* morph. *Buhsii* is present in the left valve from the umbonal region up to the ventral margin, whilst in the *Sokolowia buhsii* morph. *Esterhazyi* they are limited to the umbonal region, almost disappearing toward the ventral margin where concentric lamellae become prominent (Fig. 3). Note, that also Stenzel (1971) considered latter differences as morphological variation of the same species.

DISCUSSION

Paleobiology of *Sokolowia*

Sokolowia is probably one of the descendants of *Turkestrea* (Vyalov, 1936; Griffin et al., 2005). It shows a very rapid evolution, short duration and has a provincial paleobiogeographic extent, being restricted to the middle-late Eocene of Central Asia and Romania (Berizzi Quarto di Palo, 1970; Stenzel, 1971; Lan, 1997; Rusu et al., 2004; Bosboom et al., 2011; Salahi & Vahidinia, 2011). *Sokolowia* is known as a good environmental proxy from Eocene successions having great importance in the reconstruction of sedimentary environments, especially in relation to paleo-depth, water depth, salinity and substrate (Lan, 1997; Bougeois et al., 2016; Bosboom et al., 2011). From paleoecological perspective, *Sokolowia* was an epibenthic and suspension feeder, characterized by massive and large-sized shells. It was well adapted to solitary life in the subtidal shallow marine water conditions, with their left valves lying on soft muddy and sandy bottoms, partially sunk into the substratum, whereas their flat right valves attained nearly horizontal position (Stenzel, 1971; Lan, 1997; Rusu et al., 2004; Bosboom et al., 2011). Several authors (e.g. Stenzel, 1971; Lan, 1997; Meszaros et al., 1987) pointed out that *Sokolowia* lived in normal salinity conditions in a deeper part of the shallow water zone under the influence of wave action. Their thick-walled, heavy shells provided them practically immovable by water turbulence at the sea bottom.

Age of the *Sokolowia* horizons in NE Iran

The maximum age of the *Sokolowia buhsii* and *S. esterhazyi* horizon in the Kalateh section is Bartonian. Hadi et al. (2019), established this age for the preceding lithostratigraphic unit in the section bearing larger perforate hyaline foraminifera such as orthophragmines (*Orbitoclypeus* and *Asterocyclina*) and nummulitid assemblages (*Nummulites*) (Fig. 2). Nummulitid accumulations dominated by *Nummulites lyelli* (Fig. 4a-e) associated with A-forms of *Orbitoclypeus zitteli* (Fig. 4f-h) and *Asterocyclina stella stella* (Fig. 4i) along with other biogenic components within this interval including small benthic foraminifera (miliolids and rotaliids), larger benthic foraminifera such as *N. cf. deshayesi*, *Operculina* sp., and encrusting foraminifera (*Carpenteria* sp. and *Gyroidinella magna*) allow a precise biostratigraphic correlation with the SBZ17-SBZ18b of Serra-Kiel et al. (1998) and Less and Özcan (2012). Because, corresponding foraminifera are missing in the *Sokolowia* bearing unit in the study section, its upper age limit remains uncertain (Fig. 2). Still, the “*Sokolowia* horizon” from the Alborz region can be well compared with such accumulations from the Khangiran Formation in the Kopet-Dagh basin (NE Iran), in which Salahi & Vahidinia (2011) considered the “*Sokolowia* horizon” of the Lutetian-Bartonian age. Thus, we assume also for the corresponding horizon of the Kalateh section the Bartonian age.

Correlation of the *Sokolowia* horizon in adjacent basins

Sokolowia had extensive paleogeographic distribution throughout the Central Asian Basin System representing

Fig. 3 a-f *Sokolowia buhsii* morph. *Buhsii*; g-j *Sokolowibuhsii* morph. *esterhazyi* from Kalateh section (Eastern Alborz region).

Fig. 4 Biostratigraphically significant larger foraminifera taxa: **a-e** Equatorial and axial sections of both megalospheric and microspheric form *Nummulites lyelli* (D'Archiac & Haime). **a-b** microspheric form, equatorial section, sample N59-N60, **c** microspheric form, axial section, sample N61, **d** megalospheric form, equatorial section, sample N55, **e** external view, **f-g** Equatorial sections of megalospheric form *Orbitoclypeus zitteli* (Checchia-Rispoli), sample O25 & O45, **h-i** Equatorial sections of megalospheric form *Asterocyclina stella stella* (Gümbel), sample O32. Modified after Hadi et al. (2019).

Fig. 5 The palaeogeographic distribution of *Sokolowia* in the middle Eocene-late Eocene of the Central Asian and Europe (Black Sea area) (modified after Scotese, 2001; Popove et al., 2004; Abels et al., 2011). **a** Tarim basin (Lan, 1997; Bosboom et al., 2011). **b** Ferghana basin (Vyalov, 1935; Berizzi Quarto di Palo, 1970). **c** Afghan-Tajik (Vyalov, 1935; Berizzi Quarto di Palo, 1970). **d** Syr Darya (Romanovsky, 1880; Gorizdro, 1913). **e** Amu Darya (Vyalov, 1935; Berizzi Quarto di Palo, 1970). **f** Kopet-Dagh (Salahi & Vahidinia, 2011). **g** Alborz (Grewing, 1853; present study). **h** Transylvanian (Rusu et al., 2004).

the eastern and central part of the proto-Para Tethys epicontinental sea during the middle to late Eocene time-span (Bosboom et al., 2015). Therefore, they can be considered as stratigraphic index fossils diagnostic for that interval. Besides, *Sokolowia* has always been considered as an important macrofossil for determining the age of formations in central Asian marine deposits (e.g., Vialov, 1937, 1948; Osipova, 1958; Lan, 1997).

The presence of the *Sokolowia* accumulations in the Ferghana basin in the eastern of Uzbekistan, the Amu-Darya basin of Turkmenistan and Uzbekistan as well as the northwest of Afghanistan demonstrates a widespread dispersal in central Asian basins during the late Lutetian to the early Priabonian (e.g. Berizzi Quarto di Palo, 1970; Ulmishek, 2004). Further east, in the Tarim Basin (NW China) the “*Sokolowia* horizon” was also reported from the late Lutetian to early Priabonian Kalatar Formation by Bosboom et al. (2011, 2015) and Bougeois et al. (2016). Therefore, the Eocene deposits containing *Sokolowia* in the Central Asian region, including the Kopet-Dagh,

Amu-Darya, Syr-Darya, Afghan-Tajik, Ferghana, Tarim and Alborz basins comprise the late Lutetian-early Priabonian time-interval.

Conspicuously, this prominent Central Asian key-horizon is known from Europe only in the Transylvanian Basin of western Romania (Rusu et al., 2004). There, the *Sokolowia eszterhazyi* horizon is situated below the *Nummulites perforatus* accumulations indicating the late Lutetian-early Bartonian age. It belongs to the Capuşu Formation, attributed to the late Lutetian-early Bartonian biozones P12 (planktonic foraminifera) and NP16 (calcareous nannoplankton) (Rusu et al., 2004; Gradstein et al., 2004). In this unit, Odin (1978) reported the age of 41.2 ± 2.1 Ma for *Sokolowia eszterhazyi* beds by radiometric date (K/Ar analyses).

The aforementioned reports show the “*Sokolowia* horizon” as a valuable marker bed, which can be well used for the correlation of adjacent basins in the vast region from the easternmost central Asia (China) to the south-eastern Europe (Romania) (Berizzi Quarto di Palo, 1970;

Fig. 6 **a** Outcrop view of the Khangiran Formation and Neogene red beds in the Yaghol section (Kopet-Dagh region). **b** Panoramic view of the Ziarat Formation, Karaj Formation and Neogene red beds in the Kalateh section (Alborz region). **c** Close-up view of the *Nummulites* tests in the Kalateh section. **d-e** *Sokolowia* samples of the calcareous marl deposits in the Kalateh section.

Dzhalilov et al., 1982; Lan, 1997; Rusu et al., 2004; Bosboom et al., 2011; Salahi & Vahidinia, 2011). Such a distribution can only be explained by a seaway connecting easternmost Central Asia with the Transylvanian Basin (Fig. 5). Already, Burtman (2000) and Popov et al. (2004) referred to the Eocene Tarim Basin (China) as the easternmost part of a huge Eurasian sea extending throughout the Ferghana, Afghan-Tajik, Syr-Darya, Amu-Darya and Kopet-Dagh basins, into the Alborz basin of NE Iran (Fig. 5). This vast epicontinental sea belonging to the Tethys domain gave rise in the Oligocene

to the Paratethys Sea (see Royal, 1999; Popov et al., 2004; Dercourt et al., 1993; Bosboom et al., 2014; Tang et al., 1992; Burtman & Molnar, 1993; Bosboom et al., 2015).

Lithostratigraphic comparison of Paleogene successions in central Asian basins

The lithostratigraphic studies of the Kalateh section pertains a regional scale comparison of the Ziarat Formation in the eastern Alborz region with other parts of Alborz (Central-Western Alborz) (e.g. see Khatibi-Mehr and

Fig. 7 **a** Field photographs of the “*Sokolowia* horizon” from the Ziarat Formation, Kalateh section (Alborz region). **b-c** Close-up view of densely packed oyster concentrations and **d-f** shells commonly show sparse distribution.

Time (Ma)	Chronostratigraphy		Lithology	Alborz	Kopet-Dagh	Amu darya	Afghan- Tajik	Fergana	Syr darya	Tarim
2.58	Cenozoic	Quaternary		Neogene red bed	Neogene red bed			Soh		
5.333		Pliocene						Baktry		
23.03		Miocene						Massaget	Sarmation	Anjuan
33.9		Oligocene		Karaj	Khangiran	Rustak	Karanak	Fergana	Kegincol	Bashibulake
37.8						Koshtangine	Kingou			Wulagen
47.8		Eocene		Ziarat	Chehelkaman	Shefai	Balzoan	Alay Turkestan	Sangryk	Kalatar
56.0						Sumsar	Shuryasay			Upper Qimugen
59.2						Tajikan	Rishtan, Isfarin, Kharabod			Lower Qimugen
61.6						Turkestan	Beshkent			Aertashi
66.0		Paleocene		Fajan	Pesteligh	Alay	Jukar	Alay	Kamsaktygol Manisay	
						Suzak	Givar	Suzak		
						Bokhara	Tabakcha, Arukfan, Karatag	Bokhara		
							Akdjar			

Fig. 8 Stratigraphic chart of Paleogene formations in different Central Asian basins, including Alborz (Aghanabati, 2004), Kopet-Dagh (Afshar-Harb, 1994), Amu Darya (Ulmishek, 2004), Afghan-Tajik (Ulmishek, 2004), Ferghana (Bande et al., 2015), Syrdarya (King et al., 2013) and Tarim (Yang et al., 2013). Highlights on the stratigraphic chart show the presence of the *Sokolovia* horizon in the basins of Kopet-Dagh (Salahi & Vahidinina, 2011), Amu darya (Berizzi Quarto di Palo, 1970), Afghan-Tajik (Berizzi Quarto di Palo, 1970), Ferghana (Vyalov, 1935), Syrdarya (Romanovski, 1880; Gorizdro, 1913), Tarim (Lan, 1997; Bosboom et al., 2011) and Alborz (present study).

Adabi, 2014; Hadi et al., 2016). Furthermore, they indicate relationship with the sequences of Khangiran Formation in the Kopet-Dagh region in the north-northeastern Iran during the early Paleogene (Figs. 6-7).

At a larger scale, the Paleogene deposition in Central Asian basins often started with red continental clastics in the early Paleocene, such as Fajan Formation in Alborz, Pesteligh Formation in Kopet-Dagh and Bokhara Formation in the Amu-Darya. Red beds are also present in the some parts of Aertashi Formation in Tarim Basin (Bosboom et al., 2015) (Fig. 8). The late Paleocene sediments continue mainly with shallow carbonate deposits, as well as terrigenous rocks and anhydrite (partly Ziarat Formation in Alborz, Chehelkaman Formation in Kopet-Dagh, Suzak Formation in Amu-Darya and Lower Qimugen Formation in Tarim). At the beginning of the Eocene, the deposition continues by limestone, marly limestone and rarely silty marl in Ziarat Formation, and afterward starts with siliciclastics, such as shale, siltstone, sandstone or even silty marl, and in some places also by volcanic deposits (green tuffs). Corresponding sediments are present in Karaj Formation in Alborz, Khangiran Formation in Kopet-Dagh, Alay and Turkestan Formation in Amu-Darya, and Upper Qimugen and Kalatar Formation in Tarim) (Fig. 8; e.g., see Otto, 1997; King et al., 2013; Bosboom et al., 2014; Bougeois et al., 2016). Finally, the Oligocene deposits are often represented by red continental clastics that are in most cases discontinuously located on Eocene marine deposits. They include Sumsar Formation in the former Soviet Union, Kezilouyl Formation in the Tarim Basin of China, and Lower Red Formation in the Kopet-Dagh and Alborz Basins of Iran (e.g., see Egamberdyev & Mayvandi, 1992; Bosboom et al. 2014; Bougeois et al. 2016).

These lithostratigraphical features and macro-benthic data similarities show related paleoenvironmental histories of the Alborz, Kopet-Dagh, and the adjacent basins of Central Asian regions during the Paleogene time. On the other hand, the paleogeography, controlling mechanisms (e.g. eustasy and tectonism) and paleoenvironmental impacts of the proto-Paratethys sea in the easternmost parts from Central Asia are studied in details (see Royal, 1999;

Popov et al., 2004; Bosboom et al., 2014; Bosboom et al., 2015), while the aforementioned data has not been yet properly examined in Iran. The names of known formations of Paleogene sequences in the mentioned areas are shown in Fig. 8.

CONCLUSION

During the middle Eocene, the Eastern Alborz region as apart of the Alpine-Himalayan orogenic system on the southern margin of the Caspian Sea was covered by shallow-marine deposits bearing high abundance larger foraminifera along with oyster bivalves. The present study provides a new insight into the Eocene sequences of the eastern Alborz region by the following results:

- 1- The studied oyster bivalves *Sokolowia buhsii* morph. *buhsii* and *S. buhsii* morph. *eszterhazyi* from the Ziarat Formation in the eastern Alborz region, found on top of larger benthic foraminifera accumulations with *Nummulites lyelli*, *Orbitoclypeus zitteli* and *Asterocyclina stella stella*, are most likely Bartonian in age.
- 2- The presence of *Sokolowia* key horizon in NE Iran at the crossroads between Central Asia and Southeastern Europe suggests a well-established seaway along the southern margin of a large-sized Eurasian epicontinental sea during middle-late Eocene (late Lutetian-early Priabonian).
- 3- Correlation of the middle Paleogene sedimentary sequence of eastern Alborz basin with different sedimentary basins in vast areas of Central Asia strikes out similarities in their tectono-stratigraphic architecture, suggesting a related geodynamic and paleoenvironmental history shaped apparently by the Alpine-Himalayan orogenic system.

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