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EOCENE LARGER BENTHIC FORAMINIFERA FROM THE JAHRUM FORMATION (KALBIBAK SECTION, BOLDAJI REGION) IN HIGH ZAGROS, IRAN: AN APPROACH ON PALEONTOLOGY AND BIOSTRATIGRAPHY

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ABSTRACT – The Jahrum Formation is a major Eocene carbonate deposit of High Zagros in the west of Iran. It consists of thin bedded to thick massive limestone, accumulated on a shallow marine platform within the Neo- Tethys Ocean realm. Fifty-five surface samples were collected throughout a 215 m section in the Kalbibak area (Boldaji region, Chahar Mahal Bakhtiari province). The stratigraphic distribution of benthic foraminifers allows characterizing five foraminiferal biozones, which are in the following order: *Alveolina* aff. *schwageri* Taxon Range Zone, *A*. *decastroi* Taxon Range Zone, *A*. aff. *frumentiformis*–*A*. cf. *stercusmuris* Interval Zone, *A*. aff. *stercusmuris*–*A*. aff. *fusiformis* Interval Zone and *Nummulites*–*Alveolina* Assemblage Zone. The benthic foraminiferal associations in the studied area are similar to those recorded in Tethys realms and enable us to correlate the Jahrum Formation with the early to middle Eocene.

Keywords: benthic foraminifers, biostratigraphy, Jahrum Formation, Kalbibak section, West Iran.

RESUMO – A Formação Jahrum é um importante depósito de carbonato do Eoceno do Alto Zagros, no oeste do Irã. Ela consiste em calcário maciço de leito fino a espesso, acumulado em uma plataforma marinha rasa dentro do domínio do Oceano Neo-Tethys. Cinquenta e cinco amostras de superfície foram coletadas em uma seção de 215 m na área de Kalbibak (região de Boldaji, província de Chahar Mahal Bakhtiari). A distribuição estratigráfica dos foraminíferos bentônicos permite caracterizar cinco biozonas de foraminíferos, que estão na seguinte ordem: Zona de Amplitude do Táxon *Alveolina* aff. *schwageri*, Zona de Amplitude do Táxon *A*. *decastroi*, *A*. aff. *frumentiformis*–Zona de intervalo *A*. cf. *stercusmuris*, *A*. aff. *stercusmuris*–Zona de intervalo *A*. aff. *fusiformis* e Zona de Associação *Nummulites*–*Alveolina*. As associações de foraminíferos bentônicos na área estudada são semelhantes às registradas nos domínios do Tethys e nos permitem correlacionar a Formação Jahrum com o Eoceno inicial a médio.

Palavras-chave: foraminíferos bentônicos, bioestratigrafia, Formação Jahrum, seção Kalbibak, Irã ocidental.

INTRODUCTION

The Iranian platform consists of several micro-continents elements which were involved in multiphase Alpine orogenic events (Stöcklin, 1968, 1977). Each of these micro-continents is characterized by specific structural trends, magmatism, metamorphism, sedimentary/paleogeographic evolution and faunal communities. These elements include Alborz, Kopet Dagh, Central Iran, Zagros, Sanandaj-Sirjan, Urumieh-Dokhtar, Lut Block, eastern Iran Zone, and Makran (Figure 1). During the middle Triassic, the Paleo-Tethys closure in northern Iran (Alborz margin) and development of the main

Zagros thrust in the south of Iran were followed by the rifting and opening of a new oceanic basin (Neo-Tethys). The Neo-Tethys in southwestern and eastern Iran started to open gradually during the lower Cretaceous and several micro-continents drifted from Gondwana northward. These micro-continents were gradually amalgamated to Eurasia, while the subduction and closure of the corresponding ocean basins generated ophiolitic melanges during the late Cretaceous to late Eocene (Berberian & King, 1981; Babazadeh & De Wever, 2004a, b; Babazadeh, 2007). The Cenozoic formations, especially the Jahrum Formation, were studied by a number of researchers since the 1960's in different parts of Zagros (James & Wind, 1965; Rahaghi, 1978, 1980, 1983; Kalantari, 1980, 1986, 1992; Stöcklin & Setudehnia, 1991; Vaziri Moghaddam *et al*., 2002; Taheri *et al*., 2008; Khatibi Mehr & Moalemi, 2009; Nafarieh *et al*., 2009, 2019; Babazadeh & Pazooki Ranginlou, 2015; Babazadeh & Cluzel, 2022, 2023; Changaei *et al*., 2023; Javadian *et al*., 2023). The early Paleogene sediments were called by different names in the literature, depending on their facies and geographic locations: for example, Kashkan, Tarbor, Pabdeh, and Jahrum formations. These formations consist of sandstone, sandy limestone, limestone, and claystone, which developed in different environments. The shallow marine sedimentary succession of the Jahrum Formation was found in different localities of the Zagros Basin. In the type locality, the Jahrum Formation consists of gray to yellow dolomitic limestone and dolomite with sugary-grained texture; it disconformably overlies the Sachun Formation or locally, over the Kashkan, Tarbor, and Pabdeh Formations (James & Wind, 1965). In the studied section, the Jahrum Formation consists of thin to thick-bedded limestone and massive limestone. The lower contact of the Jahrum Formation with the Pabdeh Formation is faulted, and the upper contact is unconformably covered

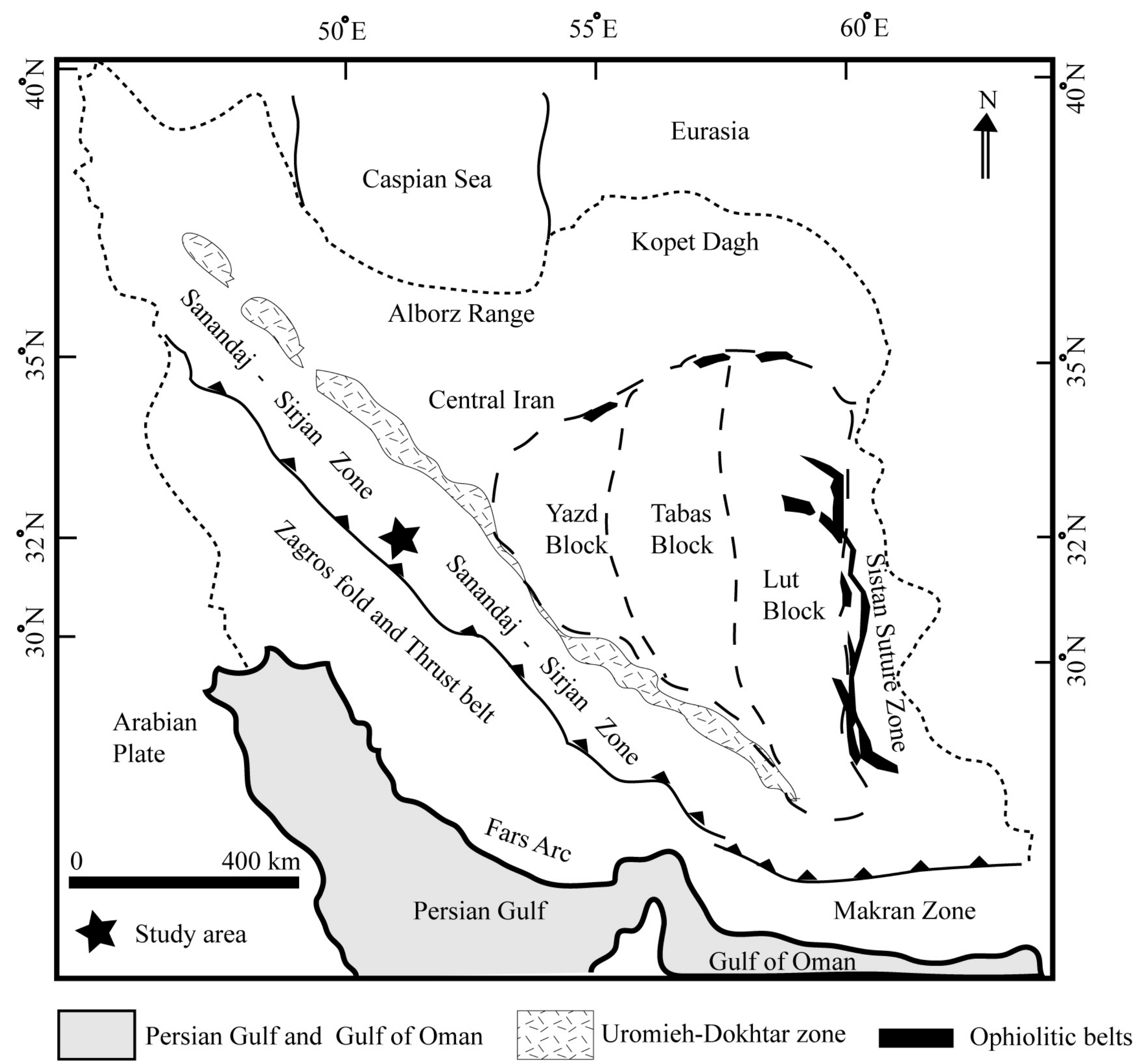

Figure 1. Iran sketch map showing the different geological domains (Alavi, 2004; modified by Babazadeh & Cluzel, 2022).

by the Asmari Formation. The Kalbibak section represents a unique sequence of fossiliferous shallow-water carbonate rocks. It contains abundant benthic foraminifers such as alveolinids, miliolids, orbitolitids, rotaliids, coskinolnids, and nummulitids. In this article, the alveolinids and some other shallow benthic foraminifers constitute the main subject of investigation, whereas nummulitids are only subordinate. Five foraminiferal biozones are recognized by the presence of several key taxa (mainly alveolinids) in the study section. They are ranged from early Eocene (early Cuisian) to middle Eocene (Lutetian–Bartonian).

The purpose of this study is: (i) to establish the biostratigraphic framework of the Jahrum Formation; (ii) to introduce the systematic descriptions of larger Foraminifera; and (iii) to correlate the benthic foraminiferal assemblages from the study area with the biozones established by Wynd (1965) at the type section, the standard shallow benthic zones (Serra-Kiel *et al*., 1998) of the Neo-Tethyan realm and other parts of Iran.

GEOLOGY AND TECTONIC SETTING

The geology of Chahar Mahal Bakhtiari province is subdivided into three fault-bounded tectonic zones (northeast, central, and southwest zones). The northeast zone (Z1) located in the northeast of Zayandehrud, consists of a Permian conglomerate with clasts of metamorphic rocks unconformably overlain by Cretaceous deposits. The Southwest zone (Z3), located to the southwest of the Karun River and the Karun Basin Mountains and to the south of the Bazoft thrust (F3) is composed of black shale, siltstone, and thin limestone. The Central Zone (Z2) is a part of the high Zagros and is located between the Saman - Fereidoon Shahr thrust (F1) and the Bazoft thrust (F3). It is subdivided into two smaller subzones (Z2a) and (Z2b) by the Main Zagros Thrust. The study area is located in the Z2b subzone of the structural division of Chaharmahal Bakhtiari province and extends from N 3°56’ to N 32° and from E 50°55’ to E 51° (Figure 2A, C). These two sub-zones are located in the Shahrekord region and consist of Cretaceous to Paleogene red clastic rocks, gray to cream limestone, and marl coeval with the Jahrum, Pabdeh, and Asmari formations (Zahedi & Rahmati Ilakhchi, 2006).

MATERIAL AND METHODS

Fifty-five surface samples were collected throughout a 215 m thin bedded to thick massif limestone section measured in the Kalbibak area (Boldaji region) for biostratigraphic analysis. The identification of foraminifers follows several authors: Hottinger (1960), Drobne (1977), Loeblich & Tappan (1988); Sirel (2003), Özgen-Erdem *et al*. (2005) and Sirel & Acar (2008). The stratigraphic range considered in the present article takes into consideration the reports of several researchers: Drobne (1977); Rahaghi (1978, 1980); Drobne & Trutin (1997); Sirel (1998, 2003); Hottinger (2007); Vecchio *et al*. (2007); Benedetti (2010); Drobne *et al*. (2011); Benedetti *et al*. (2018); Silva-Casal *et al*. (2021); Babazadeh (2022); Babazadeh & Cluzel (2023) as well as the previous biozonations by Wynd (1965), Serra-Kiel *et al*. (1998), Babazadeh & Cluzel (2023), and Changaei *et al*. (2023). The large foraminifers are found in litified limestones; therefore, it was impossible to get free alveolinid and nummulitic tests. The oriented thin sections were prepared following the method of Bozkurt & Gormus (2021). The methods that should be used in the preparation of thin sections to lead to the identification of fossils such as alveolinids. The thin sections of large foraminifers are housed in the geological laboratory of Tehran Payam Noor University, Iran. The stratigraphic nomenclature used in this article follows that of Serra-Kiel *et al*. (1998). The stratigraphic column and foraminiferal plate were done with Adobe Illustrator software.

BIOSTRATIGRAPHY

Most of the benthic foraminifers occurred in shallow water carbonate platforms, associated with oligotrophic reefs in tropical environments. They were widespread from the western (Europe and the Mediterranean) to the eastern (Indo-west Pacific) Neo-Tethys realm (Scheibner & Speijer, 2008; Ahmad *et al*., 2014) (Figure 3). The evolution of the benthic foraminifers was similar in the entire Neo-Tethyan Ocean, and it is characterized by the dominance of highly diversified *Alveolina*, *Orbitolites*, *Nummulites*, *Discocyclina*, and *Assilina* during the early Eocene (Zhang *et al*., 2013). They are widely used in regional biostratigraphy of Paleogene shallow marine carbonates where plankton are either absent or rarely found (Cahuzac & Poignant, 1997). In the study area, benthic foraminifers were collected from gray to cream-colored thin to thick-bedded limestones collected throughout the studied section. The regional foraminiferal associations represent five biozones (Figures 4 and 5) extending from the early Eocene (early Cuisian) to the mid-Eocene (Lutetian-Bartonian). The selected benthic foraminifers appear in Figures 6 and 7.

Biozone I. *Alveolina* aff. *schwageri* Taxon-Range Zone (**TRZ**).

Definition. This zone, characterized by the total range zone of *Alveolina* aff. *schwageri* Checchia-Rispoli has a thickness of 32.5 m (bed 1 to bed 10) (Figure 3). Several species such as *Alveolina* aff. *distefanoi* Checchia-Rispoli, *Cuvillierina vallensis* (Ruiz De Gaona), orbitoiltids and miliolids are abundant in this biozone. Other species recorded are *Glomalveolina minutula* (Reichel), *Nummulites fossulata* de Cizancourt, *Valvulina* sp., *Somalina* sp., *Victoriella* sp., and ornatorotalids.

Estimated age and duration. The stratigraphic range is assigned to the early Cuisian (early Eocene) (52.3–51 Ma). This biozone is equivalent to the biozone 44 (*Opertorbitolites* Zone) of Wynd (1965) (Figure 5) from the Fars area (south Iran) and the Shallow Benthic Zone (SBZ10) of Serra-Kiel *et al*. (1998). It is possibly equivalent to Zone P7 (*M. aragonensis–M. formosa*) and Zone E5 (*M. aragonensis–M. subbotinae* CRZ) of Berggren & Pearson (2005), Wade *et al*.

(2011) and Zone Pp5 (*Guembelitrioides lozanoi–Acarinina pentacamerata* IZ) of Babazadeh & Cluzel (2022). This biozone corresponds to the Biozone 10 (SBZ10) of Serra-Kiel *et al*. (1998).

Biozone II. *Alveolina decastroi* TRZ.

Definition. This biozone is defined by the total range zone of *Alveolina decastroi* Scotto Di Carlo. It extends from bed 11 to bed 29 in the studied section and is 41.5 m thick. The following benthic foraminifers are abundant in this biozone: *Alveolina cremae* Checchia-Rispoli, *Glomalveolina minutula* (Reichel), *Alveolina* aff. *distefanoi* Checchia-Rispoli, *Operculina* sp. 1, *Somalina* sp., and orbitoiltids. The other species consist of *Alveolina* aff. *ruetimeyeri* Hottinger, *Alveolina* cf. *cremae elongata* Sirel & Acar, *Nummulites* cf.

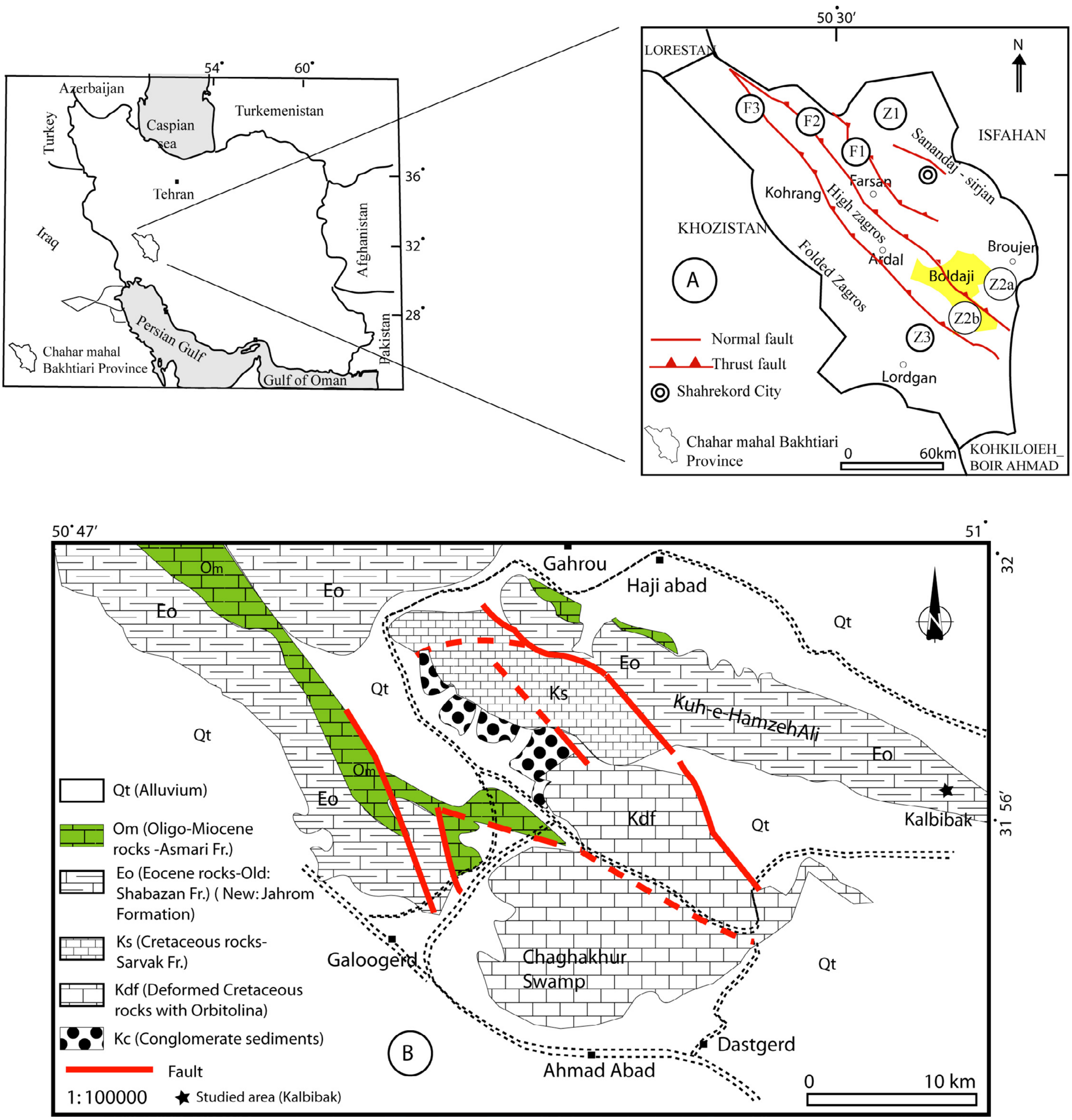

Figure 2. **A**, location of the study area in the Chahar Mahal Bakhtiari Province (1:250000); **B**, location of the study area on the Ardal geological map (Geological Survey and Mineral Exploration of Iran) (Redrawn by Babazadeh & Cluzel, 2023).

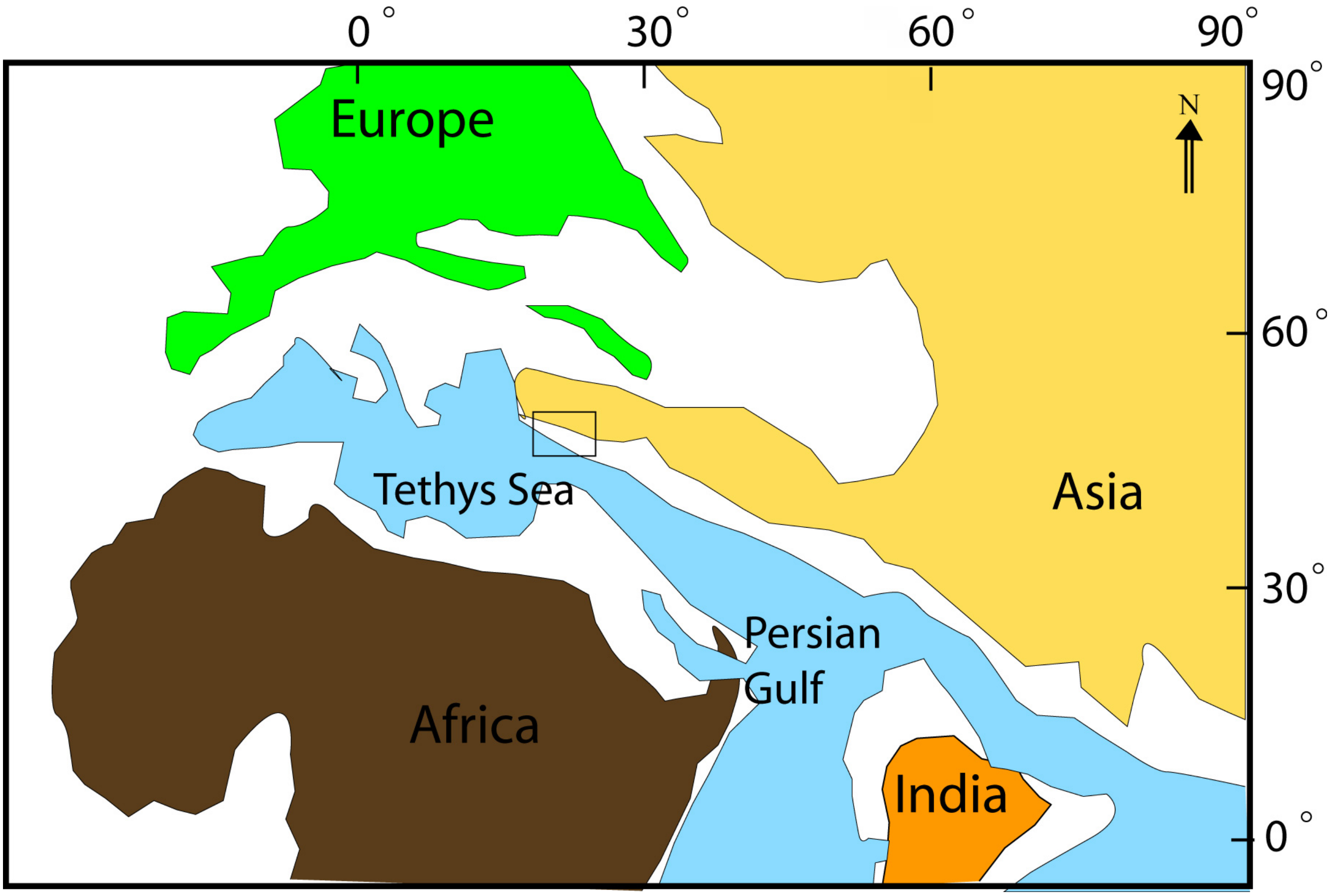

Figure 3. Paleogeographic reconstruction of the micro-continents within the Neo-Tethysian region showing the repartition of the Eocene carbonate platforms and the Neo-Tethys pathway (Hay *et al*., 1999; Hadi *et al*., 2021).

fossulata de Cizancourt, *Assilina* cf. *granulosa* (d'Archiac), *Cuvillierina vallensis* (Ruiz De Gaona), *Cribrobulimona* sp., coskinolinids, ornatorotalids and miliolids.

Estimated age and duration. The stratigraphic range hints to middle Cuisian (early Eocene) (51–50.4 Ma). This biozone can be equivalent to the biozone 44 (*Opertorbitolites* Zone) of Wynd (1965) (Figure 5) from the Fars area (south Iran). It is possibly equivalent to Zone P8 *(M. aragonensis* PRZ) of Berggren *et al*. (1995), Zone E6 *(A. pentacamerata* PRZ) of Berggren & Pearson (2005), Wade *et al*. (2011) and Zone Pp6 (*A. pentacamerata–Planorotalites palmerae* IZ of Babazadeh & Cluzel (2022). This biozone correlates with the Biozone 11 (SBZ11) of Serra-Kiel *et al*. (1998).

Remarks. The extinction of ornatorotalids in bed 29 coincides with the appearance of *Gypsina* Carter, *Fabiania* Silvestri, and *Gyroidinella* Le Calvez in the upper bed, *i.e*., bed 30. This event is also consistent with the extinction of the middle Cuisian index alveolinids in bed 29 and the appearance of late Cuisian index alveolinids in bed 30. Therefore, bed 30 is considered as the boundary separating the middle Cuisian sedimentary succession from the upper Cuisian sedimentary succession. This boundary is introduced as the *Gyroidinella–Fabiania* Horizon for the first time in the Jahrum Formation. Therefore, some taxa such as *Gypsina marianensis* Hanzawa, and *Fabiania cassis* (Oppenheim) just occurred between biozone II and biozone III in this stratigraphic section.

Biozone III. *Alveolina* aff. *frumentiformis*–*A*. aff. *stercusmuris* Interval Zone (**IZ**).

Definition. This biozone is established by the presence of two nominal species such as *Alveolina* aff. *frumentiformis* Schwager at the base and *A*. aff. *stercusmuris* Mayer Eymar at the top. This interval zone extends from bed 30 to bed 40 and is 22 m thick. The associated benthic foraminifers of this biozone are *Alveolina* aff. *cuspidata* Drobne, *Gyrodinella magna* Le Calvez, *Fabiania cassis* (Oppenheim), *Gypsina marianensis* Hanzawa, *Assilina* cf. *granulosa*, *Assilina* cf. *laminosa* Gill, *Sphaerogypsina globulus* (Reuss), *Nummulites* sp., *Discocyclina* sp., and miliolids.

Estimated age and duration. The stratigraphic range is assigned to late Cuisian (early Eocene) (50.4–49 Ma). This biozone is equivalent to the Biozone 44 (*Opertorbitolites* subzone) of Wynd (1965) (Figure 5) from the Fars area (south Iran). It correlates with the Biozone 12 (SBZ12) of Serra-Kiel *et al*. (1998).

Biozone IV. *Alveolina* aff. *stercusmuris*–*A*. aff. *fusiformis* IZ.

Definition. This biozone, marked by FO of *Alveolina* aff. *stercusmuris* Mayer Eymar and FO of *Alveolina* aff. *fusiformis* Sowerby, is 20 m-thick (bed 41 to bed 50). The associated

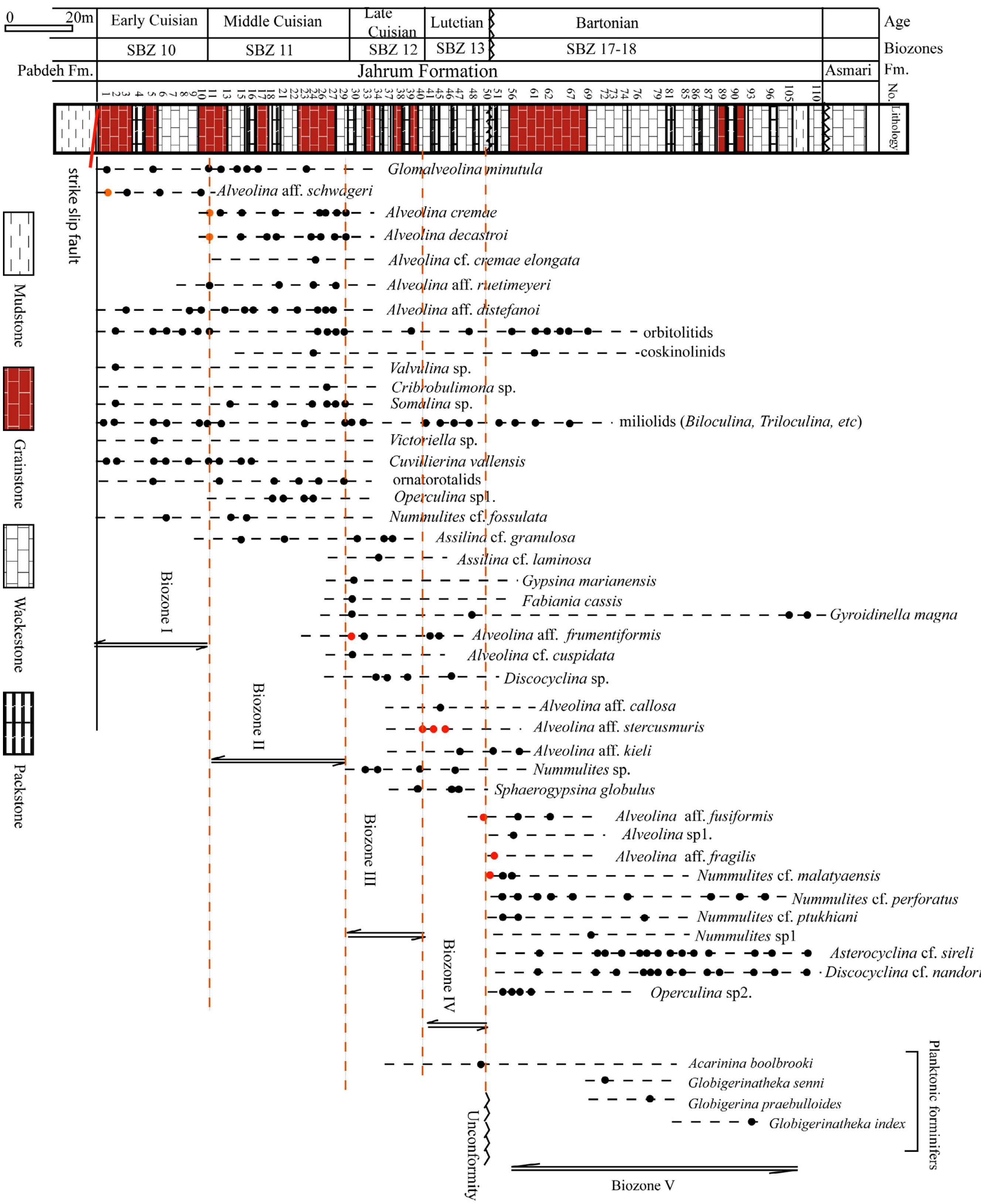

Figure 4. Distribution of foraminiferal taxa throughout the columnar section.

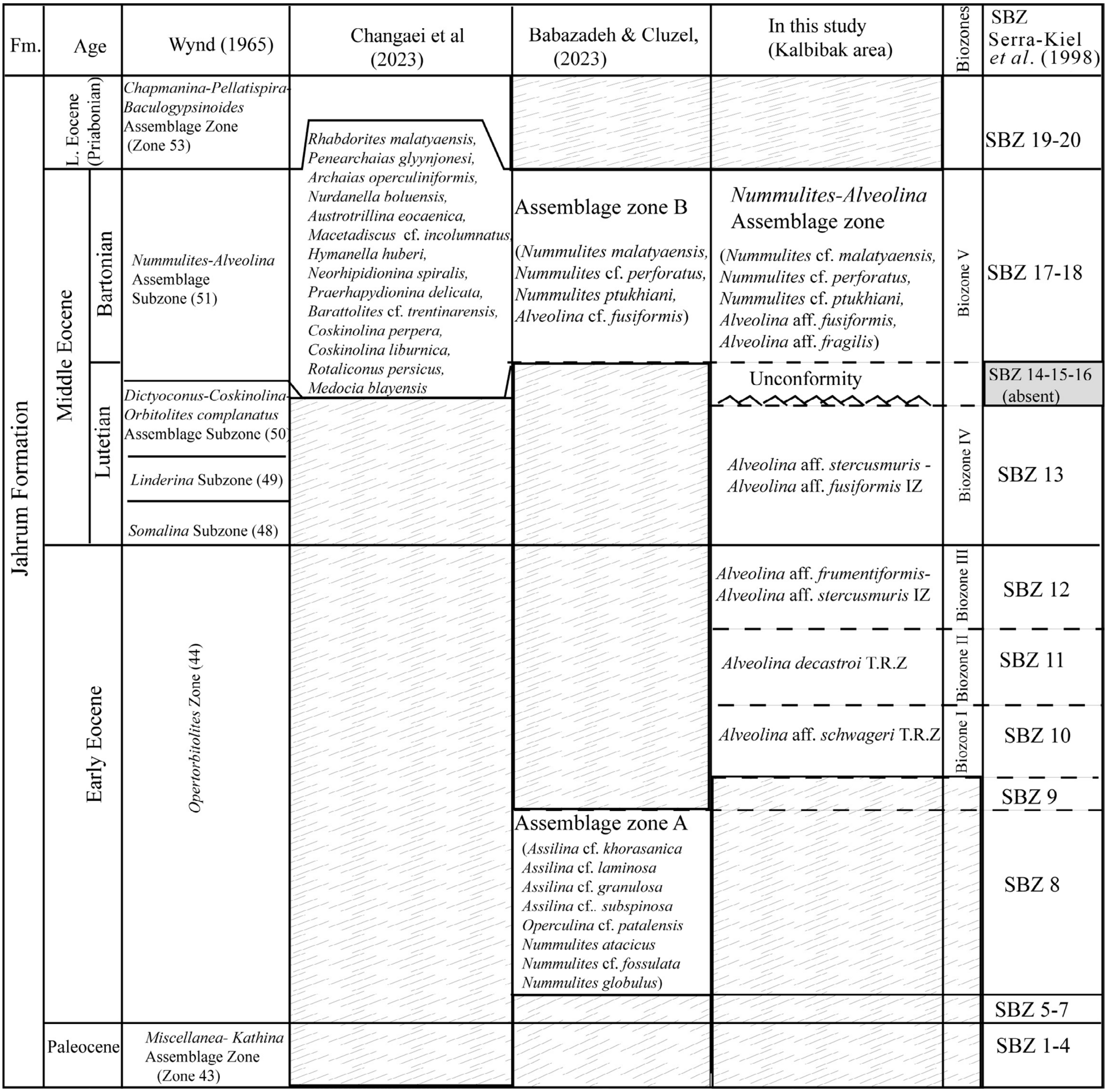

Figure 5. Biostratigraphic correlation between type section (Wynd, 1965), Kuh-e- Soukhteh and Gahrou area (Babazadeh & Cluzel, 2023; Changaei *et al*., 2023) and the study area (Kalbibak area). The standard shallow benthic zone (SBZ) according to Serra-Kiel *et al*. (1998).

benthic foraminifers of this biozone are *Alveolina* aff. *kieli* Sirel & Acar, *Alveolina* aff. *frumentiformis* Schwager, *Nummulites* sp., *Sphaerogypsina globulus* (Reuss), *Gyrodinella magna* Le Calvez, *Assilina* cf. *granulosa*, *Discocyclina* sp., orbitolitids, and miliolids.

Estimated age and duration. The stratigraphic range is assigned to early Lutetian (middle Eocene) (49–46 Ma). This biozone can be correlated to Biozones 48–50 (*Somalina* subzone, *Linderina* subzone, and *Dictyoconus-Coskinolina-Orbitolites complanatus* assemblage subzone) of Wynd (1965) (Figure 5) from the Fars area (south Iran). It correlates with the Biozone 13 (SBZ 13) of Serra-Kiel *et al*. (1998).

Remarks. The SBZs 14-15-16 of Serra-Kiel *et al*. (1998) are absent. It seems to be related to the late Lutetian event and followed by the disappearance of giant forms of nummulitids and orthophragminids.

Biozone V. *Nummulites–Alveolina* Assemblage Zone (**AZ**).

Definition. This assemblage zone is 100 m thick and occurs between bed 51 and bed 110, defined by the co-occurrence of *Nummulites* and *Alveolina*. This biozone is characterized by the presence of *Nummulites* cf. *perforatus* (De Montfort), *Nummulites* cf. *malatyaensis* Sirel, *Nummulites* cf. *Ptukhiani* Kacharava, *Nummulites* sp.1, *Alveolina* aff. *fragilis* Hottinger, *Alveolina* aff. *fusifomis* Stache, *Alveolina* aff. *kieli* Sirel &

Acar, *Operculina* sp2., *Asterocyclina* cf. *sireli* Özcan & Less, *Discocyclina* cf. *nandori* Less, *Gyroidinella magna* Le Calvez. The other fauna consists of coskinolinids, orbitolitids, and miliolids.

Estimated age and duration. The biostratigraphic range of this biozone is assigned to the Bartonian (middle Eocene) (42.2–37 Ma). This biozone corresponds to Biozone 51 (*Nummulites-Alveolina* assemblage subzone) of Wynd (1965) from the Fars area (south Iran), SBZ 17–18 of Serra-Kiel *et al*. (1998), Assemblage Zone B of Babazadeh & Cluzel (2023) and Assemblage Zone of Changaei *et al*. (2023) respectively.

Larger benthic foraminifers

Larger benthic foraminifers (LBF) such as alveolinids, orbitolitids, and nummulitids are abundant biogenic components in all our samples. The other benthic foraminifers including the miliolids (*Quinqueloculina*, *Biloculina*, and *Triloculina*), rotaliids, ornatorotalids, and coskinolnids are present.

PALEONTOLOGICAL AND STRATIGRAPHIC REMARKS

The most important species of benthic foraminifers with their stratigraphic position are selected for a general description and stratigraphic range.

***Glomalveolina minutula* (Reichel).** It has a spherical test with a very small proloculus which is followed by the streptospiral chambers in the early stage and continued by the planispirally coiled whorls. The tightly coiled spherical whorls begin from the first to the last whorls of the adult generation (Figures 6D1, 6N1, 7D). This species differs from *Glomalveolina lepidula* (Reichel) and *Glomalveolina primaeva* Reichel in possessing many chamberlets and finer structures of the test, respectively.

Glomalveolina minutula (Reichel) was considered from early Ilerdian to early Cuisian (Hottinger, 1960; Özgen-Erdem *et al*., 2005). According to Serra-Kiel *et al*. (1998), its biostratigraphic range extends from late Ilerdian to middle Cuisian. This species is reported from the uppermost early Cuisian to the lowermost middle Cuisian limestones in Turkey (Sirel & Acar, 2008).

Stratigraphic range. In this work, *Glomalveolina minutula* (Reichel) occurs in early–middle Cuisian limestones with *Alveolina* aff. *schwageri* Checchia-Rispoli, *A*. *cremae* Checchia-Rispoli, *A*. *distefanoi* Checchia-Rispoli, and *Cuvillierina vallensis* (Ruiz De Gaona).

***Alveolina* aff. *schwageri* Checchia-Rispoli.** It is characterized by the fusiform test with the first two tightly coiled spherical whorls in the nepionic stage and followed by five or six whorls which are elongated along the axial zone (Figure 6E). The poles of the test are more or less sharp. The axial thickening of the basal layer is greater than the basal layer of the equatorial spirals. *Alveolina schwageri* Checchia-Rispoli differs from all other species of the same genus in its fusiform test shape and spherical early whorls. *Alveolina schwageri* Checchia-Rispoli is distinguished from *A*. *decastroi* Scotto Di Carlo by the tightly coiled two spiral whorls during the early growth stage and gradually open apart along the axial zone, whereas the spiral whorls of later specimen looser in the adult stage.

Alveolina schwageri Checchia-Rispoli was observed in early Cuisian Berdoulou fauna (Gan, south of Pau, France) and Pierrefonds (near Cruise, Paris Basin, France) (Hottinger, 1960). This species was found in the lower Eocene (early–middle Cuisian) limestone from Slovenia and Istrie (Drobne, 1977). It was documented by Drobne & Trutin (1997) from the middle Cuisian of the Adriatic carbonate platform (Bunic section, Croatia). This species was reported by Özgen-Erdem *et al*. (2005) in the early Cuisian of the Kolatepe section (Turkey) that is equivalent to the Shallow Benthic Zone (SBZ 10) of Serra-Kiel *et al*. (1998). According to Sirel & Acar (2008), *Alveolina schwageri* Checchia-Rispoli occurred in the early–middle Cuisian limestone of the Cayraz section (Turkey) with *A*. *canavarii* Checchia-Rispoli, *A*. *cremae elongata* Sirel, and the other alveolinid species.

Stratigraphic range. In the study area, this recorded species is found in the lower part of the section and its biostratigraphic range is assigned to the early Cuisian (SBZ 10).

***Alveolina* aff. *distefanoi* Checchia-Rispoli.** It is a large fusiform in shape with the first 3–4 tightly sub-spherical whorls in the nepionic stage and followed by seven or eight loose spiral whorls which are elongated along the axial zone (Figure 6C). A few additional chamberlets with thick septula are present always in the axial region of the elongated spiral whorls. The growth of the spire in the initial whorls is slow and becomes faster in further whorls. *Alveolina distefanoi* Checchia-Rispoli is distinguished from *A*. *schwageri* Checchia-Rispoli by its larger dimensions, looser spire, and more pronounced elongation. It differs from *A*. *cremae* Checchia-Rispoli (form B) in its much more pronounced.

Alveolina distefanoi has a wide geographic distribution in the Tethyan region. This species was examined by Hottinger (1960) on the faunas of the Vicentine in Sicily (Collection Schlumberger), Termini-Imerese, and Palerme region. It was reported from the early-middle Cuisian (SBZ 10–11) of the Gargano region in southern Italy (Scotto di Carlo, 1966), the Istria region in Slovenia, and western Tethys (Drobne, 1977; Serra-Kiel *et al*., 1998). It occurred in the spot limestone samples of the Darende area, West Malatya, with *A*. *parva*, *A*. *schwageri*, *A*. *minuta*, *A*. *rugosa*, *A*. *cremae elongata*, and *A*. *fomasini malafyensis* of the early-middle Cuisian age (Sirel & Acar 2008).

Stratigraphic range. In this work, its biostratigraphic range is assigned to early-middle Cuisian (SBZ 10–11) based on the co-occurrence of other biostratigraphic markers such as *Alveolina* cf. *schwageri* Checchia-Rispoli, *A*. *cremae* Checchia-Rispoli, and *A*. *decastroi* Scotto Di Carlo.

***Alveolina decastroi* Scotto Di Carlo.** It is ovoid with pointed poles in the adult stage. This species is distinguished from *A*. *schwageri* by the looser spiral whorls in the adult stage. It differs from the *A*. *decastroi s*. *s*. in its smaller size (Figure 6B). According to Drobne (1977) and Drobne *et al*., (2011), *A*. *decastroi* is associated with forms of *A*. *ruetimeyeri* in the

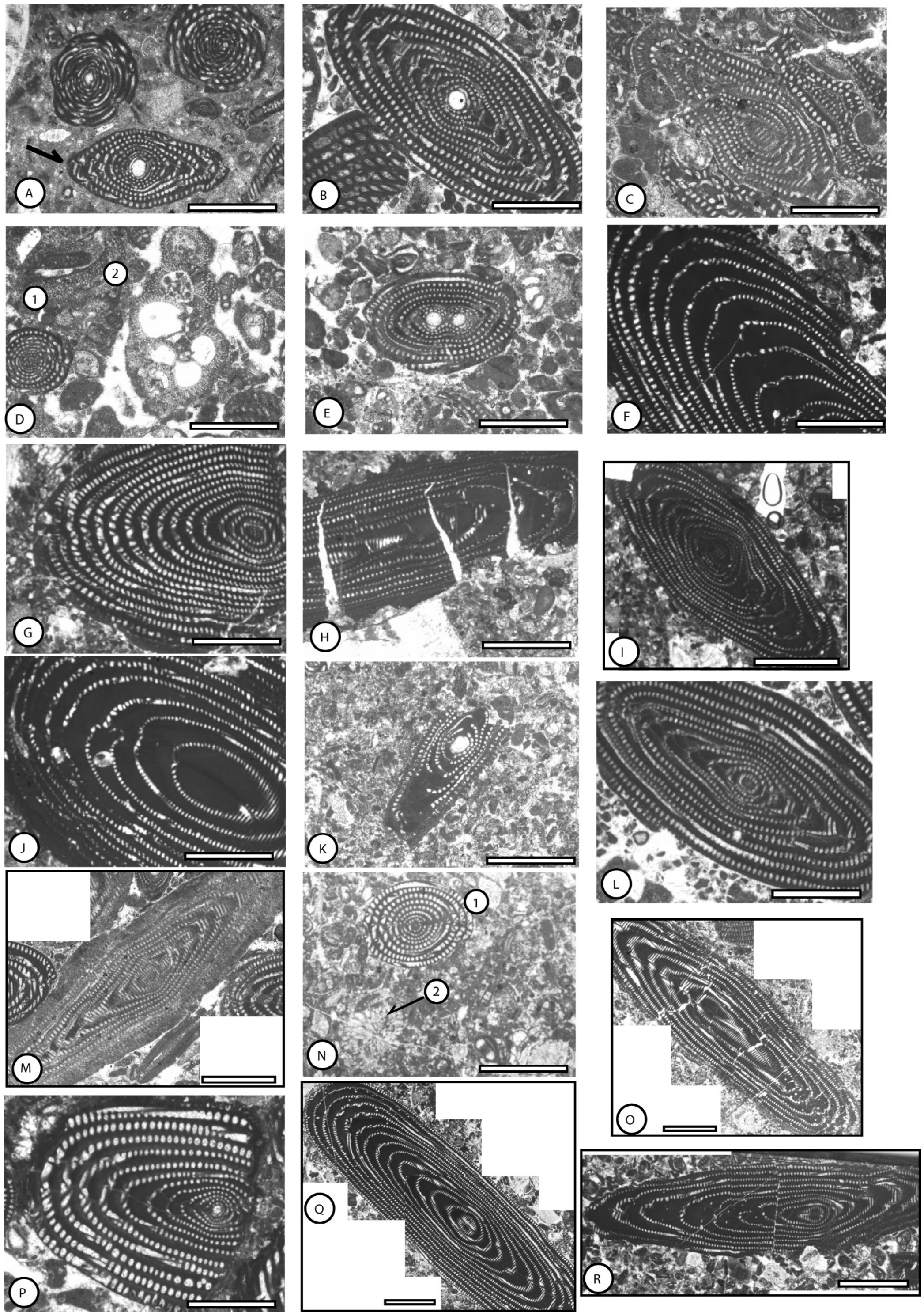

Figure 6. Photomicrographs displaying benthic foraminifers. **A**, *Alveolina cremae* Checchia-Rispoli, Kalbibak section, J15, SBZ 11, M. Cuisian; **B**, *Alveolina decastroi* Scotto Di Carlo, Kalbibak section, J27, SBZ 11, M. Cuisian; **C**, *Alveolina* aff. *distefanoi* Checchia-Rispoli, Kalbibak section, J13, SBZ 10–11, E. M. Cuisian; **D**, D1- *Glomalveolina minutula* (Reichel), D2 - *Victoriella* sp., Kalbibak section, J5, SBZ 9-10-11, L. Ilerdian-M. Cuisian; **E**, *Alveolina* cf. *schwageri* Checchia-Rispoli, Kalbibak section, J3, SBZ 10, E. Cuisian; **F**, *Alveolina* aff. *frumentiformis* Schwager, Kalbibak section, J31, SBZ 12–13, L. Cuisian-E. Lutetian; **G**, *Alveolina* aff. *kieli* Sirel & Acar, Kalbibak section, J52, SBZ 13-17, Lutetian-Bartonian; **H**, *Alveolina* aff. *fragilis* Hottinger, Kalbibak section, J50, SBZ 17, E. Bartonian; **I**, *Alveolina* aff. *cuspidata* Drobne, Kalbibak section, J31, SBZ 12, Bartonian; **J**, *Alveolina* aff. *stercusmuris* Mayer Eymar, Kalbibak section, J41, SBZ 13–14, Lutetian; **K**, *Alveolina* aff. *callosa* Hottinger, Kalbibak section, J44, SBZ 13, E. Lutetian; **L**, *Alveolina* aff. *ruetimeyeri* Hottinger, Kalbibak section, J27, SBZ 11–12, M. L. Cuisian; **M**, *Alveolina* cf. *cremae elongata* Sirel & Acar, Kalbibak section, J24, SBZ 11, M. Cuisian; **N**, N1- *Glomalveolina* cf. *minutula* (Reichel), Kalbibak section, J12, SBZ 9-15, E. Ilerdian–Lutetian, N2 - *Ornatorotalia* sp., Kalbibak section, J12, SBZ 11, M. Cuisian; **O**, *Alveolina* aff. *fusiformis* Stache, Kalbibak section, J67, SBZ 51, Bartonian; **P**, *Alveolina* aff. *ruetimeyeri* Hottinger, Kalbibak section, J10, SBZ 10–11, E. M. Cuisian; **Q**, *Alveolina* sp. 1, Kalbibak section, J56, SBZ 17, Bartonian, Lutetian-Bartonian; **R**, *Alveolina* aff. *fusiformis* Stache, Kalbibak section, J50, SBZ 17, Bartonian. Scale bars = 1 mm.

middle Cuisian of Slovenia and the Istrian region. It was observed in middle Cuisian deposits of central and southern Italy (Benedetti *et al*., 2011), the Monte Postale section (northern Italy) (Papazzoni *et al*., 2017), and middle Cuisian limestones of the Mahallat region (central Iran) (Babazadeh, 2022). This species was known as an index fossil of the middle Cuisian (SBZ 11) (Serra-Kiel *et al*., 1998).
Stratigraphic range. In the study area, its biostratigraphic range is attributed to the middle Cuisian (SBZ 11).

***Alveolina cremae* Checchia-Rispoli.** It is fusiform to ovoid in shape with rounded to pointed poles in the adult stage. The nepionic stage has tightly coiled 3–4 spheric-subspherical spiral whorls followed by five elongated ovoid whorls (Figure 6A). The axial thickening of the basal layer is thicker than the basal layer of the equatorial spiral whorls. In the geological literature, *A*. *cremae* is found in three forms: fusiform, ovoid, and elongated with a loose spire (Drobne, 1977). The recorded species is ovoid to sub-fusiform with sub-rounded to pointed poles. *A. cremae* occurred in the middle Cuisian deposits of Slovenia, Istria, and the Adriatic carbonate platform (Drobne, 1977; Drobne *et al*., 2011). It was also documented in the middle Cuisian (SBZ 11) by Serra-Kiel *et al*. (1998), Sirel & Acar (2008), Benedetti *et al*. (2011), Papazzoni *et al*. (2017) and Babazadeh (2022).
Stratigraphic range. In the study area, its biostratigraphic range is assigned to the middle Cuisian (SBZ 11).

***Alveolina* cf. *cremae elongata* Sirel & Acar** differs from *A*. *cremae* in its elongated test with a greater index of elongation and thicker basal layer in the polar sector (Sirel & Acar, 2008) (Figure 6M).
Stratigraphic range. *Alveolina* cf. *cremae elongata* is found in middle Cuisian sedimentary succession with *Alveolina cremae, A. decastroi* Scotto Di Carlo, *Alveolina* cf. *pinguis* Hottinger, *Alveolina* aff. *ruetimeyeri* Hottinger, *Alveolina* cf. *distefanoi*, *Nummulites* cf. *fossulata* de Cizancourt, *Cuvillierina vallensis* (Ruiz De Gaona) and *Assilina* cf. *granulosa* in the study area.

***Alveolina* aff. *ruetimeyeri* Hottinger.** In megalospheric specimens, the medium-sized test is elongated with rounded poles. The spherical proloculus is followed by two spherical-subspherical whorls in the nepionic stage and continued by elongated whorls in the adult stage (Figure 6L, P). Slight differences in the megalospheric forms appear in the equatorial whorl which is sometimes tight and sometimes loose. The equatorial whorls are relatively loose. In fact, it is looser in early Cuisian specimens than in more recent forms.

Alveolina ruetimeyeri Hottinger was reported in the middle Cuisian deposits of Slovenia, Istria, and the Adriatic carbonate platform (Drobne, 1977; Drobne *et al*., 2011). It was also documented by Hottinger (1960), Serra-Kiel *et al*. (1998), and Sirel & Acar (2008) in the early–middle Cuisian (SBZ 10–11).
Stratigraphic range. In this work, the biostratigraphic range is middle Cuisian (SBZ 11).

***Alveolina* aff. *frumentiformis* Schwager** is elongate and cylindrical with rounded poles in the adult stage. It is a little inflated in the equatorial region. After the juvenile stage, the equatorial spirals become loose in the adult stage (Figure 6F). The recorded specimen has the same values and morphological features as the specimens of *A. frumentiformis* Schwager described by Drobne (1977).

Alveolina frumentiformis Schwager was reported from middle Cuisian to early Lutetian (SBZ 13) of an Adriatic carbonate platform, Sabzewar area (north-east Iran), the middle Eocene of Birjand region (east Iran), and late Cuisian of lower Indus Basin, Pakistan (Eastern Neo-Tethys) respectively (Drobne, 1977; Rahaghi, 1980; Schlagintweit & Hadi, 2018; Rahman *et al*., 2021). According to Serra-Kiel *et al*. (1998), its biostratigraphic range extends from late Cuisian (SBZ 12) to early Lutetian (SBZ 13).
Stratigraphic range. In this work, its biostratigraphic range extends from late Cuisian to early Lutetian (SBZ 12–13).

***Alveolina* aff. *cuspidata* Drobne** is fusiform in shape with a medium-sized proloculus and pointed poles. It shows an elongation in the early stage (Figure 6I). *Alveolina* aff. *cuspidata* differs from all the contemporary species in its small size of the proloculus, its equatorial diameter, and its pointed poles. A small bulge is marked in the center of the test. The equatorial spires (whorls) are tight and rarely loose. This species is often associated with *A. azzarolii* Drobne and *A. rakoveci* Drobne indicating the late Cuisian (Drobne, 1977).
Stratigraphic range. In this work, its biostratigraphic range is assigned to late Cuisian (SBZ 12).
***Alveolina* aff. *stercusmuris* Mayer-Eymar** is sub-cylindrical in shape with sub-spheric proloculus and rounded poles in the adult stage. The nepionic stage has tightly coiled 2–3 spheric-sub spheric spiral whorls followed by 9–10 elongated whorls (Figure 6J). The equatorial spiral whorls are tight whereas the axial spiral whorls gradually separate along the axial region, or they are loose in the axial zone. But the last spiral whorls are quite closely spaced. The flosculinization in the early stage, which is a characteristic of *Alveolina elliptica* Sowerby, is lacking in this form.

This form was detected by Drobne (1977) in the early Lutetian of Pican-Slovenia. According to Sirel & Acar (2008), this species is found in the limestones of the Akçadağ area, west Malatya, with some important indicator benthic foraminifers as of Bartonian. Also, *A. stercusmuris* Mayer-Eymar was described and figured by Deveciler (2010, 2014) in the Bartonian limestones of the Çayraz section and Yakacık-Memlik Region with *Nummulites perforatus* De Montford and *Nummulites malatyensis* Sirel.
Stratigraphic range. In this study, this species is found with *Alveolina* aff. *frumentiformis* Schwager, *A*. aff. *callosa* Hottinger, *A*. aff. *kieli* Sirel & Acar, *Nummulites* sp., *Sphaerogypsina globulus* (Reuss), *Gyrodinella magna* Le Calvez, *Assilina* cf. *granulosa* and *Acarinina boolbrooki* (Bolli). This species is restricted to the assemblages of the Lutetian (SBZ 13).

***Alveolina* aff. *callosa* Hottinger** is sub-cylindrical in shape with a large-sized proloculus and rounded poles in the adult stage. The spheric to subspherical proloculus is 0.25–0.3 mm in diameter and followed by 7–8 elongated whorls in the axial region (Figure 6K). The axial thickening increases gradually from the proloculus to the last whorl. The basal layer of the equatorial spiral whorls is thin concerning the axial thickening in the axial region.

This specimen was assigned to early Lutetian (SBZ 13) by Serra-Kiel *et al*. (1998). According to Silva-Casal *et al*. (2021), this species occurred along with *Nummulites lehneri* Schaub and *Assilina spira abrardi* (Schaub) and is attributed to the early Lutetian (SBZ 13). This species was found together with *Alveolina* cf. *fragilis*, *A*. cf. *fusiformis*, *Nummulites* cf. *malatyensis*, and *Fabiania* sp. in the Yakacık-Memlik Region (north Ankara, Central Turkey) and considered to be of Bartonian age (Deveciler, 2014).

Stratigraphic range. In this work, this specimen is associated with *Alveolina* aff. *stercusmuris* Mayer-Eymar, *A*. aff. *frumentiformis* Schwager, *Alveolina* aff. *kieli* Sirel & Acar, *Nummulites* sp., *Sphaerogypsina globulus* (Reuss), *Gyrodinella magna* Le Calvez, *Assilina* cf. *granulosa*, and *Acarinina boolbrooki* (Bolli), indicating a Lutetian age.

***Alveolina* aff. *kieli* Sirel & Acar** is ovoid to sub-cylindrical in shape with rounded, slightly truncated poles in the adult stage. The spheric proloculus (0.2–0.25 mm in diameter) is followed by 2−3 sub-spherical whorls of the nepionic stage and followed by 4–5 elongated ovoids with and loosely coiled whorls at the adult stage in the axial direction and continued by last 5–6 sub-cylindrical whorls at the senile stage (Figure 6G).

Alveolina kieli Sirel & Acar differs from *A. stercusmuris* in having tightly coiled whorls in the axial sector and a smaller index of elongation. It differs from *Alveolina elliptica* (Sowerby) in having a coarser internal structure, smaller size, and tightly coiled whorls in the senile stage. This species differs from *Alveolina nuttalli* (Davies) in the absence of a flosculinized layer in the axial sector. *Alveolina* cf. *kieli* Sirel & Acar has the same morphological features and growth pattern as species in *Alveolina elliptica* group *sensu* Hottinger (1960, 1974) and Hottinger & Drobne (1988). *Alveolina kieli* was reported by Sirel & Acar (2008) from early to middle Lutetian based on the following association: *Alveolina callosa* Hottinger, *A. stipes* Hottinger, *A. tenius* Hottinger, *A. violae* Checchia-Rispoli, *Nummulites* aff. *laevigatus* Brugiere, and *Fabiania* sp. According to Serra-Kiel *et al*. (2016), this species was found in the isolated samples of the ESDs of the Qara and Andhur mbs. on Socotra Island of early–middle Lutetian age.

Stratigraphic range. In this work, this specimen is associated with *A*. aff. *stercusmuris* Mayer-Eymar, *Alveolina* aff. *frumentiformis* Schwager, *Nummulites* sp., *Sphaerogypsina globulus* (Reuss), *Gyrodinella magna* Le Calvez, *Assilina* cf. *granulosa*, and *Acarinina boolbrooki* (Bolli). Its biostratigraphic range indicates an early–middle Lutetian age.

***Alveolina* aff. *fragilis* Hottinger** shows a cylindrical shape with rounded poles. The megalospheric generation has a large-sized and elongated test in the axial direction. The equatorial whorls are extremely tight, the basal layer is very thin in the equatorial sector, and its thickness increases in the axial sector (Figure 6H). Due to the existence of the large elongated megalosphere, extremely thin frame, and tightly coiled equatorial whorls, this species was described as *Alveolina fragilis* Hottinger. The young tests of both generations (microspheric and megalospheric forms) have a cylindrical shape without any bulge (convexity) in the central part of the test. The last character and the greater elongation distinguish them from *A*. aff. *fusiformis* Stache (Hottinger, 1960).

Alveolina fragilis Hottinger was assigned to the Bartonian stage (Biarritzian, SBZ 17) according to Serra-Kiel *et al*. (1998). This species is found in the Bartonian argillaceous limestone of the Sogut area, North Bilecik, western Turkey with rich foraminiferal species, such as *Fabiania cassis* (Oppenheim), *Gyroidinella magna* (Le Calvez), *Nummulites* spp. (small-sized), *Orbitolites* sp., *Asterigerina* sp., and miliolids (Sirel & Acar, 2008). It was reported from the Bartonian of Yakacık-Memlik Region (north Ankara, Central Turkey) (Deveciler, 2014). According to Silva-Casal *et al*. (2021), the biostratigraphic range of *A*. aff. *fragilis* Hottinger extends from middle Lutetian 2 (SBZ 15) to late Lutetian (SBZ 16).

Stratigraphic range. In this study, *Alveolina* cf. *fragilis* Hottinger is found together with *A*. aff. *fusiformis* Hottinger, *A*. aff. *kieli* Sirel & Acar, *Nummulites* cf. *perforatus* (De Montfort), *N*. cf. *Ptukhiani* Kacharava, *N*. cf. *malatyensis* Sirel, *Asterocyclina* cf. *sireli* Özcan & Less, *Discocyclina* cf. *nandori* Less, *Sphaerogypsina globula* (Reuss), *Gyroidinella magna* Le Calvez, orbitolitids, coskinolinids and miliolids in the Bartonian limestones.

***Alveolina* aff. *fusifomis* Stache** is defined by a more or less undulating (wavy) surface, a slightly inflated central part, and rounded poles. The equatorial whorls are extremely tight, especially in the inner whorls (Figure 6O, 6R). The additional chamberlets are numerous in the lateral part of the test. If it is necessary to distinguish two different varieties of *A. fusiformis* Stache and *A. boscii* (Defrance in Bronn), the initial chamber of the first species is larger than that of *A. boscii* (Defrance in Bronn). *Alveolina fusifomis* Stache is distinguished from contemporary elongated cylindrical *Alveolina* by its shape (fusiform) and by a few numbers of elongated whorls. It is distinguished from the equally fusiform species of the Lutetian by its less pronounced elongation, and by the much tighter whorl in the young whorls of form B. In form A, also the whorl is tighter, and the specific variability has much greater amplitude. Form A of *Alveolina levantina* Hottinger is much less elongated than that of *A. fusiformis* Stache, while form B resembles each other by their outward appearance. According to Hottinger (1960), Drobne (1977), Serra-Kiel *et al*. (1998), and Sirel & Acar (2008), *Alveolina fusiformis* Stache is an indicator species of Bartonian (Biarritzian, SBZ 17). In the collected material by Silva-Casal *et al*. (2021), the biostratigraphic range of *Alveolina fusiformis* Stache extends

from middle Lutetian (SBZ 14) to late Lutetian (SBZ 16) and probably up to early Bartonian (SBZ 17).
Stratigraphic range. In the study area, its biostratigraphic range is similar to that of *Alveolina* cf. *fragilis* Hottinger.

***Nummulites* cf. *malatyaensis* Sirel** has an inflated lenticular test in megalospheric form and represents a rounded periphery. A large central knob can be observed in the axial sections and radial septal filaments cover the surface of the test (Figure 7H–I). The spire is thick in all whorls and increased gradually in four whorls and continues constantly until the last whorl. The very small chambers are arranged tightly, and heights are similar concerning their widths. The septa are straight or slightly curved throughout the ontogeny. This typical *Nummulites* species was first described and figured by Sirel (2003) in the Bartonian limestone of the Develi section (Malatya).
Stratigraphic range. In this study, this form was found with *Alveolina* cf. *fragilis* and *A*. aff. *fusifomis* Stache, *A*. aff. *kieli* Sirel & Acar, *Asterocyclina* cf. *sireli* Özcan & Less, *Discocyclina* cf. *nandori* Less, and *Gyroidinella magna* Le Calvez indicating the Bartonian stage.

***Nummulites ptukhiani* Kacharava** is inflated and lenticular in shape with a central boss. The septal filaments are radial with granules and curved backward. The spiral laminae are thick. The height of the chambers is greater than the width in the inner whorls and becomes wider than the height in the outer whorls (Figure 7E−F). In the equatorial section, the spire is regular and relatively constant in height, with a maximum of three complete whorls. Pillars are visible, creating the surface granules, and are particularly prominent in the umbilical region.

Nummulites ptukhiani Kacharava was recognized in the Bartonian succession of Kutch (Saraswati *et al*., 2017). This species was recorded in the United Arab Emirates and Oman in the Priabonian deposits (Boukhary *et al*., 2005).
Stratigraphic range. In this study, its age is assigned to the Bartonian.

***Assilina* cf. *granulosa* (d'Archiac)** is flattened to lenticular in shape with a rounded periphery. This specimen is characterized by a small depression in the central area and a heavily granulated surface with distinct septal ridges (Figure 7C).

Assilina cf. *granulosa* was reported from middle Ilerdian (SBZ 8) by Munir *et al*. (2005), Ghazi *et al*. (2010), and Babazadeh & Cluzel (2023). The biostratigraphic range of this species extends from early Ilerdian (SBZ 5) to middle Ilerdian (Ahmad *et al*., 2014, 2017) or from early Ilerdian (SBZ 5) to early Lutetian (SBZ 13) (Sameeni *et al*., 2013).
Stratigraphic range. In the study area, it is associated with *Glomalveolina minutula* (Reichel), *Alveolina cremae* Checchia-Rispoli, *Alveolina decastroi* Scotto Di Carlo, *Alveolina* cf. *cremae elongata* Sirel & Acar, *Alveolina* aff. *ruetimeyeri* Hottinger, *Alveolina* cf. *distefanoi*, *Alveolina* cf. *cuspidata* Drobne, *Alveolina* cf. *frumentiformis* Schwager, *Nummulites* cf. *fossulata* de Cizancourt, *Cuvillierina vallensis* (Ruiz De Gaona), indicating the middle-late Cuisian (SBZ 11, 12).

***Asterocyclina* cf. *sireli* Özcan & Less.** The test is medium to large and flat in shape with four radial ribs. The embryonic chamber is small. The adauxiliary chamberlets are few (2–4) in number, low, and moderately wide. The equatorial annuli are arranged usually in four rays (Ozcan *et al.*, 2018). This species was first introduced from the upper Lutetian of the Sivas Basin (Turkey) for asterocyclinid specimens displaying mostly four ribs and an embryonic chamber different from contemporaneous asterocyclinids in Western Tethys (Özcan *et al*., 2006). It was later recorded from the Bartonian Reineche Limestone in Tunisia and the Fulra Limestone in India (Ben İsmail-Lattrache *et al*., 2014).
Stratigraphic range. In this study, this form was found with *Asterocyclina* aff. *fragilis* and *A*. aff. *fusifomis* Stache, *A*. aff. *kieli* Sirel & Acar, *Discocyclina* cf. *nandori* Less, *Nummulites* cf. *ptukhiani* Kacharava and *Gyroidinella magna* Le Calvez indicating the Bartonian.

***Discocyclina* cf. *nandori* Less** shows a ribbed pattern shape with a small, semi-nephro- to trybliolepidine embryonic chamber. The equatorial chambers are low near the embryonic chamber and high at the peripheries. This specimen was recorded from the Amravati Formation in the Cambay Basin in India by Özcan *et al*. (2016) and represented the only ribbed discocyclinid in the Sulaiman Range.

Discocyclina cf. *nandori* Less was reported from the middle Eocene of western Tethys (Özcan *et al*., 2010). It was later recorded from the Bartonian in the Indian subcontinent (Özcan *et al*., 2016).
Stratigraphic range. In this study, this form was found with *A*. cf. *fragilis* and *A*. cf. *fusifomis* Stache, *A*. cf. *kieli* Sirel & Acar, *Asterocyclina* cf. *sireli* Özcan & Less, *Nummulites* cf. *ptukhiani* Kacharava and *Gyroidinella magna* Le Calvez indicating the Bartonian.

***Cuvillierina vallensis* (Ruiz De Gaona).** The test is lenticular with almost planispiral chambers that are involute on both sides. It has perforated calcareous shells, bilamellar layers, and angular peripheral margins without keels. The small, spherical proloculus is followed by numerous chambers in the expanding whorls (Figure 7L). The enveloping canal system is derived from heavy feathering of the ventral septal sutures. The chambers increase rapidly in number and size in the last whorl. The thick pillars extend from the proloculus to the external surface of both dorsal and ventral sides (Loeblich & Tappan, 1988; Sirel, 1998). This species differs from *Cuvillierina yarzei* (Ruiz De Gaona) in its larger size of the test and more or less angular periphery. It is distinguished from *Cuvillierina courmae* (Babazadeh) by the smaller size of the test and not developed radial filaments (chevron-like) toward the periphery (Babazadeh, 2005). The last chamber is almost triangular and rectangular in *Cuvillierina vallensis* (Ruiz De Gaona) and *Cuvillierina courmae* (Babazadeh), respectively (Babazadeh, 2006).

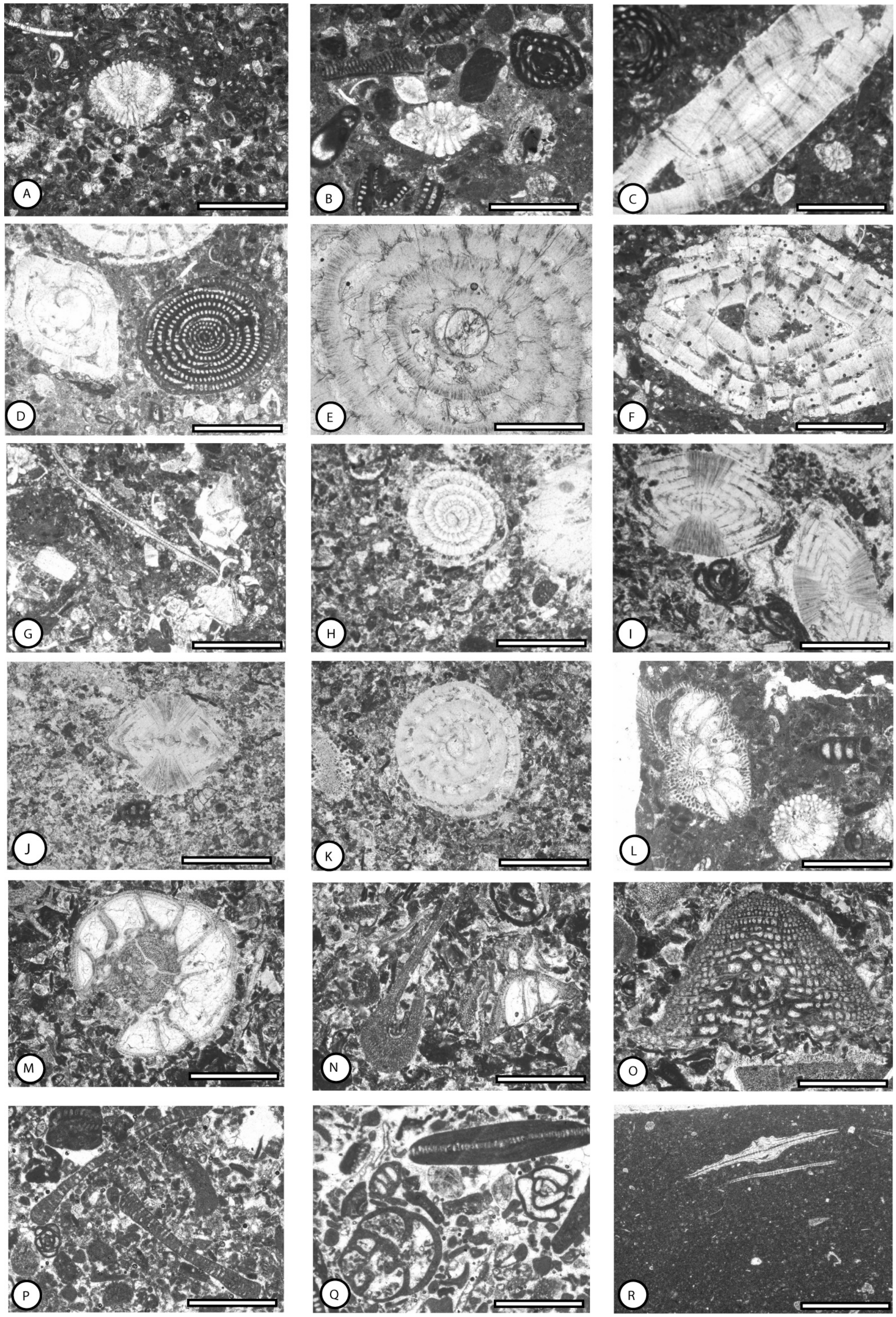

Figure 7. Photomicrographs displaying benthic foraminifers. **A**, *Ornatorotalia granum* Benedetti, di Carlo & Pignatti, Kalbibak section, J12, SBZ 11, M. Cuisian; **B**, *Granorotalia sublobata* Benedetti, di Carlo & Pignatti, Kalbibak section, J15, SBZ 11, M. Cuisian; **C**, *Assilina* cf. *granulose* (d'Archiac), Kalbibak section, J15, SBZ 11, M. Cuisian; **D**, *Glomalveolina* cf. *minutula* and *Nummulites* sp., Kalbibak section, J50, SBZ 9–15, E. Ilerdian–Lutetian; **E–F**, *Nummulites* cf. *ptukhiani* Kacharava, Kalbibak section, **E**, J53 and **F**, J75, SBZ 17–18, Bartonian; **G**, *Discocyclina* cf. *nandori* Less, Kalbibak section, J 74, SBZ 17–18, Bartonian; **H–I**, *Nummulites* cf. *malatyaensis* Sirel, Kalbibak section, J53, SBZ 17-18, Bartonian; **J–K**, *Nummulites* sp. Kalbibak section, J69, SBZ 17–18, Bartonian; **L**, *Cuvillierina vallensis* (Ruiz De Gaona), Kalbibak section, J 8, SBZ 11, Middle Cuisian; **M**, *Gyroidinella magna* Le Calvez, Kalbibak section, J30, SBZ 11, Middle Cuisian; **N**, *Gypsina marianensis* Hanzawa, Kalbibak section, J30, SBZ 11, Middle Cuisian; **O**, *Fabiania cassis* (Oppenheim), Kalbibak section, J30, SBZ 11, Middle Cuisian; **P**, *Orbitolites* sp., Kalbibak section, J27, SBZ 11, Middle Cuisian; **Q**, *Cribrobulimina* sp. and *Somalina* sp., Kalbibak section, J27, SBZ 11, Middle Cuisian; **R**, *Asterocyclina* cf. *sireli* Özcan & Less, Kalbibak section, J72, SBZ 17, Bartonian. Scale bars = 1 mm.

The genus *Cuvillierina* Debourle was introduced as a guide fossil for the lower Eocene of the Mediterranean region, from Libya to Spain (Debourle, 1955). According to Pignatti (1995) and Serra-Kiel *et al*. (1998), *Cuvillierina vallensis* (Ruiz De Gaona) is considered to be early to middle Cuisian age. This species was reported by Babazadeh (2005, 2006) from Cuisian calcareous deposits in eastern Iran. It was documented by Benedetti (2011) from the middle Cuisian deposits of Sicily and central Italy. Hottinger (2014) extended the stratigraphic range to the late Cuisian (SBZ12).

Stratigraphic range. In this work, the biostratigraphic range of *Cuvillierina vallensis* is assigned to early-middle Cuisian (SBZ 10-11) based on index alveolinids foraminifers.

***Fabiania cassis* (Oppenheim).** It has a depressed conical shape with a bluntly rounded apex and hollow center. The test has a thick calcareous and finely perforated hyaline wall. The dorsal part of the test is convex, and the ventral part is completely concave (Figure 7O). The longitudinal section of some samples has a deep and oblique depression. The early stage consists of globular and perforate chambers and is followed by cyclic chambers. The genus *Fabiania* Silvestri was attributed to *Patella cassis* (Oppenheim) for the first time and then it was introduced by Silvestri (1926) as a *Fabiania* Silvestri. Since 1947, the genus *Fabiania* has been accepted by some researchers such as Nagappa (1956) and Cole (1957). They have mentioned this name (*Fabiania* Silvestri) in their articles. Cole (1957) was the first to recognize that *Fabiania* was a foraminifer belonging to the family Cymbaloporidae. The genus *Fabiania* Silvestri is one of the most important genera which ranges from late Paleocene to late Eocene. It has been reported from different parts of the world such as France, Italy, Spain, India, Japan, Cuba, and Turkey (Loeblich & Tappan, 1988). It has been reported from the middle Eocene of Karaj Formation (Iran) in central Alborz (Babazadeh, 1992; Shemirani *et al*., 1994). According to Butterlin (1981) and Robinson & Wright (1993), the age range of this species is from the middle Eocene to late Eocene.

Stratigraphic range. In this work, the biostratigraphic range of *Fabiania cassis* is assigned to the late Cuisian (SBZ 12).

***Granorotalia sublobata* Benedetti, Di Carlo & Pignatti.** The test is lenticular to biconvex in shape. It is characterized by well-developed piles on both ventral and dorsal sides. The periphery of the test is acute and poorly ornamented (Figure 7B). According to Benedetti *et al*. (2018), *G. sublobata* differs from *Neorotalia alicantina* Colom by the presence of vertical funnels on the dorsal side and a more irregular pattern of the piles.

According to Benedetti *et al*. (2011, 2018), the biostratigraphic range of *G. sublobata* is the middle Cuisian. It was documented by Babazadeh (2022) from the middle Cuisian deposits of the Mahallat region in central Iran.

Stratigraphic range. In this work, the biostratigraphic range of *Granorotalia sublobata* is assigned to the middle Cuisian based on index alveolinids foraminifers.

***Ornatorotalia granum* Benedetti, Di Carlo & Pignatti.** The test is trochoid and inequally biconvex. Both sides are covered by coarse piles. Thicker umbilical piles are commonly abundant in the umbilical region of the ventral side. The periphery is rounded to subangular with very little ornamentation (Figure 7A). This species differs from *O. spinosa* Benedetti, Di Carlo & Pignatti in being smaller, with a smaller proloculus, a more biconvex test, and a lack of piles near the periphery.

Stratigraphic range. The biostratigraphic range of *Ornatorotalia granum* was assigned to the middle Cuisian (Benedetti *et al*., 2011).

***Victoriella* Chapman & Crespin (type species: *Carpenteria proteiformis* Goës).** The test is conical in shape with a low trochospiral coil in the early stage and followed by 3-4 globular to inflated chambers per whorl which increase rapidly in size. Wall consists of thick hyaline perforate calcareous layers with depressed sutures (Figure 6D2). The three species of *Victoriella* such as *V. plecte* (Chapman), *V. aquitanica* Debourle & Delmas, and *V. conoidea* (Rutten) are fully synonymous based on Glaessner & Wade (1959).

According to Loeblich & Tappan (1988), this species is found in upper Eocene to middle Oligocene sedimentary rocks of Europe, New Zealand, and Australia. This taxon was reported from the early Rupelian Caltavuturo Formation (Sicily) (Benedetti, 2010).

Stratigraphic range. In this study, this species is found with *Glomalveolina minutula* (Reichel), *Alveolina* cf. *schwageri* Checchia-Rispoli, *Alveolina* cf. *distefanoi* Checchia-Rispoli, *Nummulites* cf. *fossulata* de Cizancourt, *Cuvillierina vallensis* (Ruiz De Gaona), *Valvulina* sp. and *Somalina* sp., indicating early Cuisian (SBZ 10).

***Orbitolites* Lamarck (Type species: *Orbitolites complanatus* Lamarck).** It has a large and discoidal shape. The central part of the test is very slightly biconcave. There is an inflated nucleoconch due to the presence of a large proloculus and a second chamber. The later cyclic chambers are subdivided into many chamberlets, those of successive cycles alternating in position. The chamberlets of a single cycle are not interconnected but those of successive cycles are connected by a crosswise oblique stolon system (Figure 7P). According to Loeblich & Tappan (1988), this species ranges from early to middle Eocene in France, Spain, Italy, and Egypt. *Orbitolites complanatus* Lamarck was reported from Eocene deposits of Iraq and Iran (Rahaghi, 1983; Al-Hashimi & Amer, 1985; Ghafor & Qadir, 2009; Babazadeh & Alavi, 2013; Babazadeh, 2020). According to Lehman (1961), this species can be assigned to Lutetian. This species was documented from the upper Cuisian-Lutetian deposits in the platform margin of Zakynthos Island, Greece (Di Carlo *et al*., 2010). The middle Eocene biostratigraphic range is admitted by Serra-Kiel *et al*. (1998).

Stratigraphic range. In this work, the biostratigraphic range of *Orbitolites* Lamarck is considered to be Eocene.

***Somalina* Silvestri.** The porcellaneous wall of *Somalina* consists of thick vacuolated lateral laminae (layers) on both sides of the test (Figure 7Q). Whereas, the porcellaneous wall of *Opertorbitolites* Nuttall has lateral laminae without vacuoles. In addition, no lateral lamellar walls were found on both sides of *Orbitolites* Lamarck (Nuttall, 1925; Lehmann, 1961; Loeblich & Tappan, 1988). The large size of *Somalina* with a diameter of up to 33 mm (*S. gigantea* Rahaghi, Shiraz region) has been mentioned by Rahaghi (1978). Therefore, the Iranian specimens of *Somalina* are larger than those from Egypt and Somalia.

The *Somalina* sensu stricto was not recorded from deposits older than the lower Eocene sedimentary rocks. Its biostratigraphic range can probably correlate with the late Cuisian (SBZ 12) (late *Alveolina violae* Zone) (White, 1997). The *Somalina stefaninii* Silvestri was originally reported from lower Eocene deposits of Somalia and Egypt (Gebel Ataka, Collection of J. Cuvillier) (Silvestri, 1938, 1939). According to Beun (1982), *S. stefaninii* Silvestri was found in the lower Eocene deposits of SE Afghanistan, accompanied by *Assilina spinosa* Davies, and *A. placentula* Deshayes. This species was illustrated by Kureshi (1969) from the lower Eocene of western Pakistan. Henson (1948, 1950) mentioned *Somalina danieli* Henson from the middle and late Eocene of Iraq. The *Somalina stefaninii* Silvestri was recorded from the middle Eocene of Afghanistan (Kaever, 1970), Iran (James & Wynd, 1965; Sampo, 1969; Rahaghi, 1978; Javadian *et al*., 2023), Egypt (Shamah & Helal, 1994) and Somalia (Azzaroli, 1952; Forteleoni & Radrizzani, 1972). The occurrence of *Somalina* Silvestri in the sedimentary deposits of Egypt, Somalia, Iraq, Iran, Pakistan, etc, provides further evidence of a link between, the NW African-Arabian domain and the middle East domain.

Stratigraphic range. In this work, the biostratigraphic range of *Somalina* Silvestri is assigned to the early–middle Cuisian.

Other foraminiferal taxa

***Nummulites* cf. *fossulata* de Cizancourt** shows a small lenticular shape with a central depression and sharp periphery. Its shape represents an angular "dumbbell" in an axial section. Due to the unique shape of this species, the biometric information is based on the axial section (Babazadeh & Cluzel, 2023). This species was first reported by de Cizancourt (1938) from Afghanistan in the early Eocene. It was documented later by Racey (1995) in upper Cuisian to lower Lutetian deposits. This species was identified in the Jahrum Formation (North Gahrou section, Sharekord region) with the association of *Nummulites globulus* Leymerie and *N. atacicus* Leymerie, indicating an early Eocene age (Babazadeh & Cluzel, 2023).

Stratigraphic range. In this study, the biostratigraphic range of *Nummulites* cf. *fossulata* is considered to be early–middle Cuisian (SBZ 10−11) due to its association with *Alveolina* aff. *schwageri*, *Alveolina* aff. *distefanoi* Checchia-Rispoli, *Alveolina cremae* Checchia-Rispoli and *Alveolina decastroi* Scotto Di Carlo in the study area.

***Nummulites* cf. *perforatus* (de Montfort)** has a small, rather inflated lenticular test with a rounded peripheral margin in megalospheric forms. The external surface of the test is covered by numerous rather big granules distributed everywhere. No microspheric forms were found in our material. The width of the chambers is greater than the height. Pillars are developed over the regular spiral whorls and are made up of thick wedge-shaped structures. Septa are inclined and slightly curved at their distal end.

Stratigraphic range. In this work, the recorded species is associated with *Nummulites* cf. *ptukhiani* Kacharava, *Nummulites* cf. *malatyaensis* Sirel, *Alveolina* aff. *fragilis* Hottinger, *Alveolina* aff. *fusifomis* Stache, *Alveolina* aff. *kieli* Sirel & Acar, *Discocyclina* cf. *nandori* Less, *Asterocyclina* cf. *sireli* Özcan & Less, and its biostratigraphic range is assigned to the Bartonian.

***Gypsina marianensis* Hanzawa.** The test is typically concave-convex to plano-convex with a polygonal outline (Figure 7N). It consists of a few encrusting layers of chambers (Hanzawa, 1957). The basal concave of the test is compatible with an epiphytic habitat. In the axial section, the chambers show an arcuate outline with stolons located at the base of the chambers. In the vertical section, the chambers of the median zone are situated in an upward conical zone and the spherical proloculus is placed on the apex of the cone. The ventral zone of the test consists of several layers of chambers which fill hollow on the ventral side of the cone. The median zone consists of a spherical proloculus and is followed by a single layer of spirally disposed chambers in nepionic and neanic stages. The dorsal zone consists of two or three layers of chambers that cover uniformly median zone (Hanzawa, 1957).

This species was documented in Lutetian to Priabonian deposits (Özgen-Erdem *et al*., 2005), whereas its range was reported by Hanzawa (1957) from Oligocene to Miocene.

Stratigraphic range. In the study area, it is associated with *Alveolina* cf. *frumentiformis* Schwager, *Alveolina* cf. *cuspidata*, *Gyrodinella magna* Le Calvez, *Fabiania cassis*, *Assilina* cf. *granulosa*, *Assilina* cf. *laminosa* Gill, *Sphaerogypsina globulus* (Reuss) and *Somalina* sp. indicating the late Cuisian (SBZ 12).

***Valvulina* d'Orbigny.** The tri-serial agglutinated test has flattened sides and shows a triangular shape in thin sections. The test is canaliculate so that canaliculi are sealed externally to form pseudopores. The aperture is in an interiomarginal position at the junction of the chambers of the final whorl (Loeblich & Tappan, 1988). According to Loeblich & Tappan (1988), the biostratigraphic range of this specimen extends from the middle Eocene to the Holocene.

Stratigraphic range. In this work, the biostratigraphic range of *Valvulina* d'Orbigny is considered to be early Cuisian.

***Cribrobulimina* Cushman.** The agglutinated wall with a pseudo-keriothecal texture consists of tri-serial and triangular in the early stage as in *Valvulina* d'Orbigny and followed by a loose spiral of five or more chambers per whorls (Figure 7Q). Both the outer wall and septa are canaliculated. Aperture is interiomarginal in the early stage as in *Valvulina* d'Orbigny (Loeblich & Tappan, 1987). The spiral whorls are composed of simple and undivided inflated chambers with a marginal trough. The chambers are stacked one upon another in a loose trochospiral of 5–6 chambers per whorl (Vecchio & Hottinger, 2007).

Cribrobulimina was reported from late Cuisian to early Lutetian by Hottinger & Drobne (1980) in Croatia from Molat and Silba islands. According to Vecchio & Hottinger (2007), the biostratigraphic range of this taxon is early Eocene.

Stratigraphic range. In this work, the recorded specimen is observed in the Jahrum Formation from the middle Cuisian.

DISCUSSION

The lower Eocene alveolinids-nummulitids facies were widespread from western Neo-Tethys to eastern Neo-Tethys and originally recorded in literature, *e.g.*, from Spain and France (Hottinger, 1960), Southern Italy (Scotto Di Carlo, 1966), Central Italy (Accordi & Carbone, 1988), Slovenia and the Istrian region (Castellarin & Zucchi, 1966; Drobne, 1977), Sicily (Checchia-Rispoli, 1905; Montanari, 1965), Turkey (Sirel, 1976; Özgen-Erdem *et al*., 2005; Sirel & Acar, 2008); Iraq (Bouday, 1980), Iran (Kalantari, 1980; Rahaghi, 1978, 1980, 1983) and from Pakistan and India (Davies, 1940; Rahman *et al*., 2021).

The larger benthic foraminifers such as *Nummulites*, *Assilina*, *Operculina*, *Orbitolites* and *Alveolina* associated with some specimens such as *Ranikothalia* and *Lockhartia* became more diverse in Paleogene carbonate deposits from the south and west Iran (Jahrum Fm., Zagros mountains), north Iran (Ziarat Fm., Alborz mountains), central Iran (Mahallat region) and eastern Iran (Sistan Suture Zone) during early Eocene (Rahaghi, 1978, 1980, 1983; Hottinger, 2007; Taheri *et al*., 2008, Nafarieh *et al*., 2019; Babazadeh, 2022; Babazadeh & Cluzel, 2023; Javadian *et al*., 2023).

The earliest studies were focused on facies associations and the introduction of foraminifers while systematic description and biostratigraphy are rarely mentioned (Kalantari, 1980, 1986, 1992; Vaziri-Moghaddam *et al*., 2002; Nafarieh *et al*., 2012; Khatibi Mehr & Moalemi, 2009; Babazadeh, 2008, 2010, 2011; Babazadeh & Alavi, 2013). The agglutinated foraminifers, like coskinolinids, which are indicative of very shallow waters, were rare and poorly preserved. Additionally, remains of bivalves, gastropods, echinoids, corals, and red and green algae occur frequently.

Biozone I (early Cuisian) is defined by the total range zone of *Alveolina* aff. *schwageri* Checchia-Rispoli. Therefore, the lower and upper boundaries of this zone coincide with the presence and extinction of nominal species. The nominated species were found in the lowermost sample bed 1 and topmost sample bed 10 of the study section, which confirms that the succession was deposited completely during the early Cuisian. *Alveolina* aff. *schwageri* Checchia-Rispoli along with *Alveolina* aff. *distefanoi* Checchia-Rispoli and *Cuvillierina vallensis* (Ruiz De Gaona), orbitoiltids and miliolids are recorded most consistently in the studied samples, showing the highest frequency and abundance among all the benthic foraminiferal species. The other foraminifers such as *Glomalveolina minutula* (Reichel), *Cuvillierina vallensis* (Ruiz De Gaona), *Nummulites* cf. *fossulata* de Cizancourt, *Valvulina* sp., *Somalina* sp., *Victoriella* sp., and ornatorotalids are present. This biozone is established by the presence of *Alveolina schwageri* Checchia-Rispoli and is considered to be early Cuisian (SBZ 10). The represented faunal association is almost similar to the early Eocene foraminiferal fauna of the western edge of the Sivas Basin (Central Anatolia, Turkey) (Özce *et al*., 2013), Zanskar Tethyan Zone, Ladakh Region (India) (Mathur *et al*., 2009) and eastern Neo-Tethys realm such as the Tethyan Himalaya of Tibet (Zhang *et al*., 2013), north India (Meghalaya, eastern part of the relic eastern Tethys/Neo-Tethys (Sarkar, 2019).

Biozone II (middle Cuisian) is characterized by the total range zone of *Alveolina decastroi* Scotto di Carlo. The occurrence of *Alveolina decastroi* Scotto di Carlo along with *Alveolina cremae* Checchia-Rispoli assigns an early Eocene (middle Cuisian) age corresponding to the SBZ11. This biozone is supported by the following benthic foraminifera: *Glomalveolina minutula* (Reichel), *Alveolina cremae* Checchia-Rispoli, *Alveolina decastroi* Scotto Di Carlo, *Alveolina* cf. *cremae elongata* Sirel & Acar, *Alveolina* aff. *ruetimeyeri* Hottinger, *Alveolina* aff. *distefanoi* Checchia-Rispoli, *Nummulites* cf. *fossulata* de Cizancourt, *Cuvillierina vallensis* (Ruiz De Gaona), *Assilina* cf. *granulosa*, *Operculina* sp. 1, *Somalina* sp., *Cribrobulimona* sp., miliolids, ornatorotalids, coskinolinids and orbitolitids. The faunal association identified in this biozone is similar to the lower Eocene foraminiferal fauna of Zanskar Tethyan Zone, Ladakh Region (India) (Mathur *et al*., 2009), central Neo-Tethys realm such as central and eastern Turkey (Sirel & Deveciler, 2017, 2018) and western Neo -Tethys realm such as central and southern Italy (Benedetti *et al*., 2011, 2018; Ahmad *et al*. 2014).

Biozone III (late Cuisian) is identified by the first occurrence (FO) of *Alveolina* cf. *frumentiformis* Schwager at the base and the first occurrence of *Alveolina* aff. *stercusmuris* Mayer-Eymar at the top. It coincides with the extinction of *Alveolina cremae* Checchia-Rispoli, *Alveolina decastroi* Scotto Di Carlo, *Alveolina* aff. *ruetimeyeri* Hottinger, *Alveolina* aff. *distefanoi* Checchia-Rispoli, and ornatorotalids. The species of *Alveolina* aff. *frumentiformis* Schwager is characteristically indicative of the SBZ 12, and the co-occurrence of this species and *Alveolina* aff. *cuspidata* Drobne can confirm the attribution to the SBZ 12. The faunal association is exclusively represented by the following benthic foraminifera: *Alveolina* aff. *cuspidata* Drobne, *Gyrodinella magna* Le Calvez, *Fabiania cassis* (Oppenheim), *Gypsina marianensis* Hanzawa, *Assilina* cf. *granulosa* (d'Archiac), *Assilina* cf. *laminosa* Gill, *Sphaerogypsina globulus* (Reuss), *Somalina* sp., *Nummulites* sp., *Discocyclina* sp., ornatorotalids, and miliolids. The other components of this assemblage consist of echinoid and bivalve fragments.

This foraminiferal association corresponds to the faunal association of the Bolu Region in Turkey, which was assigned to the Lutetian, whereas this association is considered to be the late Cuisian in the study area. This biozone can be correlated to the topmost of the Zongpu and Zhepure Shan formations in the Tingri area (Tibetan Himalayas).

Biozone IV (early Lutetian) shows an interval zone as the lower boundary of this zone is defined by the first occurrence of *Alveolina* cf. *stercusmuris* Mayer-Eymar and the upper boundary is determined by the first occurrence of *Alveolina* aff. *fusiformis* Sowerby.

The associated fauna consists of *Alveolina* aff. *frumentiformis* Schwager, *Alveolina* aff. *kieli* Sirel & Acar, *Nummulites* sp., *Sphaerogypsina globulus* (Reuss), *Gyrodinella magna* Le Calvez, *Assilina* cf. *granulosa* (d'Archiac), orbitolitids and miliolids. The planktonic foraminifers consist of *Acarinina boolbrooki* (Bolli). The stratigraphic range of this biozone is assigned to the early Lutetian (middle Eocene). A similar association of Lutetian larger benthic foraminifera was considered from the central Neo-Tethys realm such as the Malatya basins (eastern Turkey) (Caglar-Kaya, 2009), Sivas Basin in central Anatolia (Özce *et al*., 2013), western Anatolia (Bozkurt & Gormus, 2019), northwestern Turkey (Bolu area) (Özgen-Erdem, 2000, 2001) and also in the eastern Neo -Tethys realm such as the Kohat Basin in northern Pakistan (Mirza *et al.,* 2005).

Biozone V (Bartonian) represents an assemblage zone including some marker benthic foraminifers such as *Nummulites* cf. *perforatus* (de Montfort), *Nummulites* cf. *malatyaensis* Sirel, *Nummulites* cf. *Ptukhiani* Kacharava, *Alveolina* aff. *fragilis* Hottinger, *Alveolina* aff. *fusifomis* Stache, *Alveolina* aff. *kieli* Sirel & Acar, *Operculina* sp. 2, *Asterocyclina* cf. *sireli* Özcan & Less, *Discocyclina* cf. *nandori* Less, *Gyroidinella magna* Le Calvez, orbitolitids, coskinolinids and miliolids. The planktonic foraminifers consist of *Globigerinatheka senni* (Beckmann), *Globigerina praebulloides* Blow, and *Globigerinatheka index* (Finlay). This foraminiferal association is similar to the ones in the central Neo-Tethys realm (south, center, and east Turkey) (Örcen, 1985; Sirel, 2003; Deveciler, 2010, 2013).

CONCLUSIONS

The shallow benthic foraminifers are relatively abundant in the Jahrum Formation and among them, alveolinids are of great importance. They are involved in the age determination of Eocene carbonate deposits in the Kalbibak section of the Boldaji region (Chahar Mahal Bakhtiari province).

Five foraminiferal biozones were identified in the study area. They range from the early Eocene (early Cuisian) to middle Eocene (Bartonian).

The standard biozones (SBZs 14-15-16) of Serra-Kiel *et al*. (1998) from middle to late Lutetian are absent due to the regional sedimentary hiatus. It seems to be related to a late Lutetian event that led to the disappearance of giant forms of nummulitids and orthophragminids.

An integrated biostratigraphic scheme can provide potential regional correlation, so that Biozones I to III are equivalent to Biozone 44 of Wynd (1965), Biozone IV correlates to Biozones 48-50 of Wynd (1965) from the Fars area (south Iran), and Biozone V is equivalent to the Assemblage Zone B of Babazadeh & Cluzel (2023) from the Chahar Mahal Bakhtiari province.

The extinction of ornatorotalids in bed 29 coincides with the appearance of *Gypsina* Carter, *Fabiania* Silvestri, and *Gyroidinella* Le Calvez in the upper bed, *i.e*., bed 30. This event is also consistent with the extinction of the middle Cuisian index alveolinids in bed 29 and the appearance of late Cuisian index alveolinids in bed 30. Therefore, bed 30 is considered as the boundary separating the middle Cuisian from the upper Cuisian sedimentary succession. This boundary is introduced as the *Gyroidinella–Fabiania* Horizon for the first time in the Jahrum Formation. Therefore, some taxa such as *Gypsina marianensis* Hanzawa, and *Fabiania cassis* (Oppenheim) just occurred between biozone II and biozone III in this stratigraphic section.

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