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BENTHIC FORAMINIFERAL BIOSTRATIGRAPHY OF THE OLIGOCENE SEQUENCE OF THE ASMARI FORMATION IN THE INTERIOR FARS SUB-ZONE, ZAGROS BELT, SW IRAN

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ABSTRACT – The benthic foraminifera of Oligocene carbonate deposits of the Asmari Formation in the Hoz-e-Bidmeshk section in the Interior Fars Sub-zone, Zagros Belt, SW Iran, were studied for biostratigraphic zonation. The Asmari Formation in the studied section is 388 m thick, conformably overlies the Paleocene–Eocene deposits of the Pabdeh Formation and is conformably overlain by the Gachsaran Formation. Nineteen genera and 20 species of benthic foraminifera were recognized in the Asmari Formation. Miliolids were identified only at the order level. The benthic foraminifera are assigned to two assemblage biozones in the formation: the *Lepidocyclina* spp.-*Nummulites fichteli-Nummulites intermedius-Nummulites vascus* and *Archaias kirkukensis-Archaias asmaricus-Archaias hensoni-Miogypsinoides* spp. zones. The biozones show that the studied carbonate succession of the Asmari Formation was deposited during the Rupelian and Chattian. In the late Chattian and Miocene, sea level fall prevented deposition of the Asmari Formation in the Interior Fars Sub-zone and the evaporites and shallow-marine marls of the Gachsaran Formation were deposited during the Miocene.

Keywords: micropaleontology, biozonation, Rupelian–Chattian, Hoz-e-Bidmeshk section, carbonate succession, Zagros.

RESUMO – Os foraminíferos bentônicos dos depósitos carbonáticos oligocênicos da Formação Asmari na seção Hoz-e-Bidmeshk na Subzona Interior de Fars, Cinturão de Zagros, SW do Irã, foram estudados para zonação bioestratigráfica. A Formação Asmari na seção estudada tem 388 m de espessura, sobrepõe-se conformavelmente aos depósitos do Paleoceno–Eoceno da Formação Pabdeh e é conformavelmente sobreposta pela Formação Gachsaran. Foram identificados dezenove gêneros e 20 espécies de foraminíferos bentônicos na Formação Asmari. Os miliolídeos foram identificados apenas em nível de ordem. Os foraminíferos bentônicos foram atribuídos a duas biozonas: as zonas *Lepidocyclina* spp.-*Nummulites fichteli-Nummulites intermedius-Nummulites vascus* e *Archaias kirkukensis-Archaias asmaricus-Archaias hensoni-Miogypsinoides* spp. As biozonas mostram que a sucessão carbonatada estudada da Formação Asmari foi depositada durante o Rupeliano e o Chattiano. No final do Chattiano e no Mioceno, a descida do nível do mar impediu a deposição da Formação Asmari na Subzona de Fars Interior e os evaporitos e margas marinhas pouco profundas da Formação Gachsaran foram depositados durante o Mioceno.

Palavras-chave: micropaleontologia, biozonação, Rupeliano–Chattiano, seção Hoz-e-Bidmeshk, sucessão carbonática, Zagros.

INTRODUCTION

The carbonate dominated Asmari Formation in the Zagros belt in southwestern Iran represents the largest hydrocarbon reservoir in Iran, and is one of the most significant reservoirs in the Middle East (Beydoun *et al*., 1992; Motiei, 1993; Alavi, 2004; Aghanabati, 2011; Burchette, 2012; Moradi *et al*., 2017). The age of the formation ranges from Oligocene to Early Miocene (Rupelian to Burdigalian: Wynd, 1965; Adams & Bourgeois, 1967; Ehrenberg *et al*., 2007; Laursen *et al*., 2009; Van Buchem *et al*., 2010; Kakemem *et al*., 2016; Allahkarampour Dill *et al*., 2020). Lithologically, the Asmari Formation consists mainly of limestones (argillaceous limestones, dolomitic limestones, pure limestones) with subordinate sandstones and evaporite deposits (James &Wynd, 1965; Motiei, 1993; Aghanabati, 2011; Roozpeykar & Maghfouri Moghaddam, 2016; Taheri *et al*., 2017). The limestones of the Asmari Formation were deposited in a carbonate platform, whereas the sandstones were deposited in the offshore marine zone, distal deltaic subtidal settings and coastal plain to terrestrial paleoenvironments (Van Buchem *et al*., 2010; Roozpeykar & Maghfouri Moghaddam, 2016). The deposition of the evaporite deposits of the Asmari Formation was controlled by significant eustatic sea-level fall that led to the formation of an isolated submarine saline basin (Van Buchem *et al*., 2010; Roozpeykar & Maghfouri Moghaddam, 2016). The fossil content of the Oligocene and Lower Miocene limestones of the Asmari Formation consists mainly of benthic foraminifera, coralline red algae and corals (Allahkarampour Dill *et al*., 2020). Benthic foraminifera, as one of the most abundant and diverse faunal components in the shallow marine carbonate deposits of the Asmari Formation in the Zagros belt, are represented by biostratigraphically and paleoecologically important taxa, such as nummulitids, lepidocyclinids, amphisteginids, soritids, peneroplids, alveolinids, miliolids (particularly austrotrilinids) and rotaliids (Adams & Bourgeois, 1967; Seyrafian, 2000; Ehrenberg *et al*., 2007; Vaziri-Moghaddam *et al*., 2006; Laursen *et al*., 2009; Van Buchem *et al*., 2010; Seyrafian *et al*., 2011; Habibi, 2016a, b, 2018; Allahkarampour Dill *et al*., 2020).

This study investigates the micropaleontology and biostratigraphy of the Oligocene strata of the Asmari Formation in the Zagros belt, southwestern Iran based on benthic foraminiferal associations.

GEOLOGICAL SETTING AND LOCALITY OF THE STUDIED SUCCESSION

The NW–SE trending Zagros belt with a length of about 2000 km is a part of the Alpine–Himalayan orogenic belt and extends from the East Anatolian fault in eastern Turkey to the south of Iran and into Oman (Alavi, 2004; Fakhari *et al*., 2008; Moosavizadeh *et al*., 2020). The Middle Eocene–Early Miocene marked the start of collision between the Arabian Plate and the southern margin of the Eurasian Plate, which resulted in elevation of the Zagros Mountains (Alavi, 2007). The Zagros belt resulted from the Arabia–Eurasian collision in northeastern margin of Gondwana (Beydoun *et al*., 1992; Alavi 2004, 2007; Fakhari *et al*., 2008). In the southwest of Iran, the Zagros belt is composed of thick (7–12 km) Precambrian to Holocene strata comprising carbonate, evaporitic and clastic deposits (James & Wynd, 1965; Setudehnia, 1978; Berberian & King, 1981; Heydari, 2008). The Zagros belt in Iran is subdivided into three tectonic zones, *i.e*., the imbricated zone, the Urumieh-Dokhtar magmatic zone and the Zagros fold–thrust zone (Stöcklin, 1968; Alavi, 2004, 2007). Based on the sedimentary history and the structural features of Iran, the Zagros belt is alternatively divided into the Fars Zone, Lurestan Zone, Dezful Embayment, Izeh Zone and High Zagros Zone (Falcon, 1974; Berberian & King, 1981; Motiei, 1993; Heydari, 2008; Figure 1A). The Fars Zone is subdivided into the Coastal Fars and Interior Fars sub-zones (James & Wynd, 1965; Ala, 1982; Habibi & Bover-Arnal, 2018; Figure 1A).

The studied stratigraphic succession of the Asmari Formation is situated in the Hoz-e-Bidmeshk section (29° 39' 25" N, 51° 40' 42" E) north of the town of Kazerun in the Interior Fars Sub-zone of the Zagros belt, southwestern Iran (Figures 1 and 2).

MATERIAL AND METHODS

A stratigraphic log of the studied carbonate-dominated succession of the Asmari Formation in the Hoz-e-Bidmeshk section was compiled during the fieldwork (Figure 2). Two hundred and seventy rock samples were collected from the exposed carbonate deposits and thin sections were prepared from each. In the laboratory, the thin sections were studied using a Yaxun Ak-21 Binocular Stereo Microscope equipped with a digital camera (CCD) model KECam. Benthic foraminifera were identified in 111 thin sections. The sample numbers of the thin sections are indicated in the stratigraphic column of the Asmari Formation (Figure 2). Higher-level classification of the benthic foraminifera follows Loeblich & Tappan (1987), but identification of specific taxa is based on the works of Hakimzadeh & Seyrafian (2008), Amirshahkarami (2013), Kakemem *et al*. (2016), Habibi (2016a, b, 2018), Taheri *et al*. (2017), and Habibi & Bover-Arnal (2018). The benthic foraminiferal biozones proposed herein are defined according to Allahkarampour Dill *et al*. (2020).

RESULTS

Lithostratigraphy

The Asmari Formation in the Hoz-e-Bidmeshk section (Figures 1 and 2) is 388 m thick. The formation conformably overlies the Paleocene–Eocene marls of the Pabdeh Formation and is conformably overlain by the Miocene shallow-water marls and evaporites of the Gachsaran Formation (Figure 2). In the studied section, the Asmari Formation is subdivided into eight informal lithostratigraphic units (Figure1B and 2). In stratigraphic order, these are: 1) Unit 1 (27 m thick) comprises light cream medium-bedded argillaceous limestones; 2) Unit 2 (47 m thick) consists of yellow thick-bedded limestones; 3) Unit 3 (18 m thick) is composed of light cream thin-bedded limestones; 4) Unit 4 (51 m thick) consists of grey thick-bedded limestones, laminations and nodular cherts are present in unit 4; 5) Unit 5 (15 m thick) is dominated by medium-bedded limestones with cross-bedding; 6) Unit 6 (67 m thick) is composed of thin-bedded argillaceous limestones with abundant horizontal laminations; 7) Unit 7 (118 m thick) comprises light grey thick-bedded limestones, the limestones are dominated by reefal structures and abundant fossil corals in the upper part of the unit; 8) Unit 8 (45 m thick) consists of thin-bedded limestones.

Biostratigraphy

Based on detailed micropaleontological analyses of rock thin sections, a total of 19 genera and 20 species of benthic foraminifera were recognized in the studied succession of the Asmari Formation (Figure 2). Miliolids were identified only at the order level.

Photomicrographs of the identified benthic foraminifera are shown in Figures 3–7. Two assemblage biozones (1 and 2) were defined based on the ranges of foraminiferal taxa in the stratigraphic succession of the Asmari Formation in ascending stratigraphic order (Figure 2).

Assemblage biozone 1

This assemblage biozone is characterized by the occurrence of the following benthic foraminifera: *Nummulites fichteli*, *Nummulites* cf. *fichteli*, *Nummulites fichteli-intermedius*,

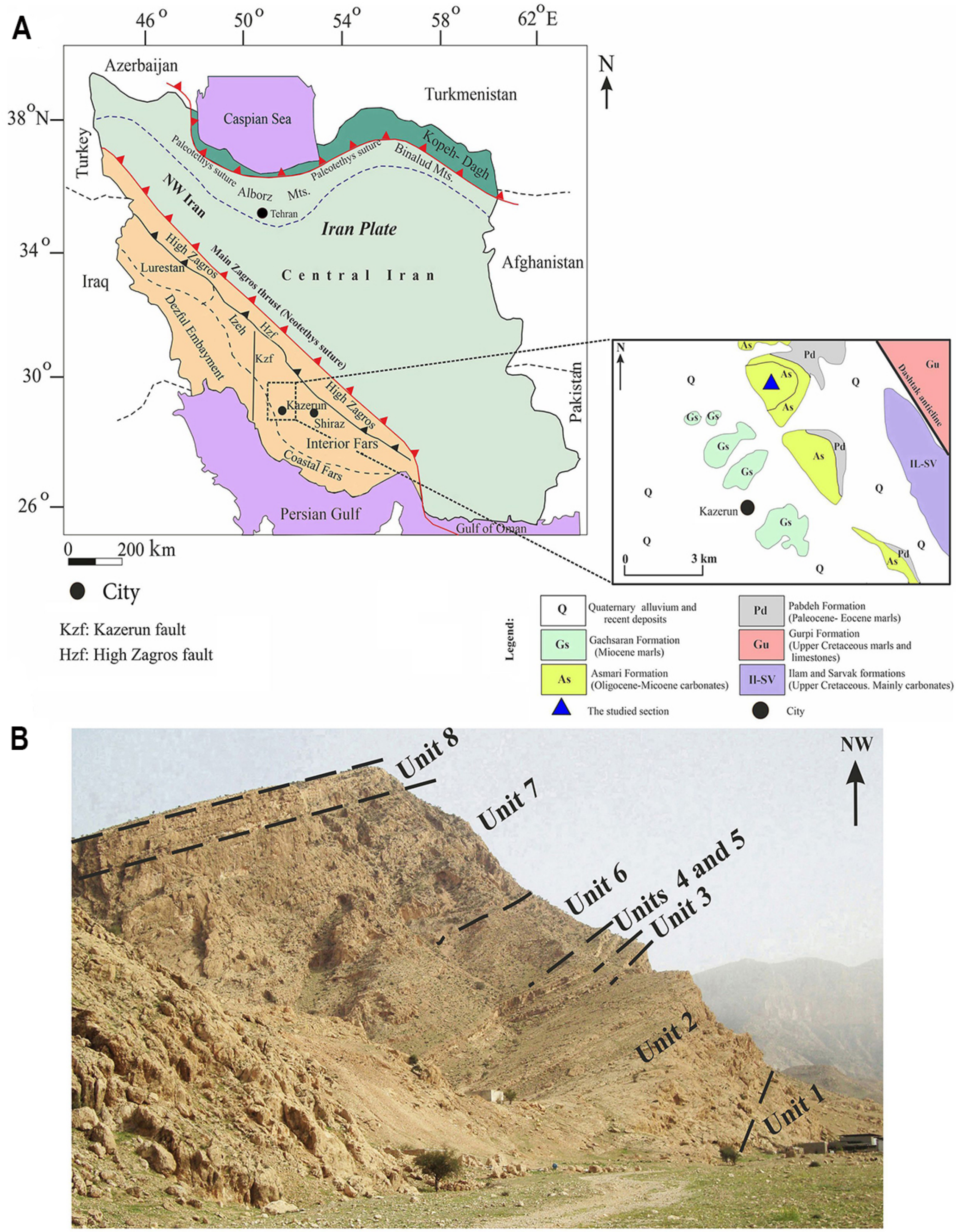

Figure 1. A, structural geological map of Iran and location of the studied stratigraphic succession of the Asmari Formation in the Hoz-e-Bidmeshk section. The section is situated north of the town of Kazerun in the Interior Fars Sub-zone of the Zagros belt, SW Iran (modified and redrawn from MacLeod & Majedi, 1972; Wilmsen *et al*., 2009; Rivandi & Moosavizadeh, 2015; Habibi, 2016b; Kakemem *et al*., 2016). Based on the sedimentary history and the structural features of Iran, the Zagros belt is divided into the Fars Zone, Lurestan Zone, Dezful Embayment, Izeh Zone and High Zagros Zone (Falcon, 1974; Berberian & King, 1981; Motiei, 1993; Heydari, 2008). **B**, outcrop view of the studied succession of the Asmari Formation in the Hoz-e-Bidmeshk section. In the section, the formation consists of eight informal lithostratigraphic units.

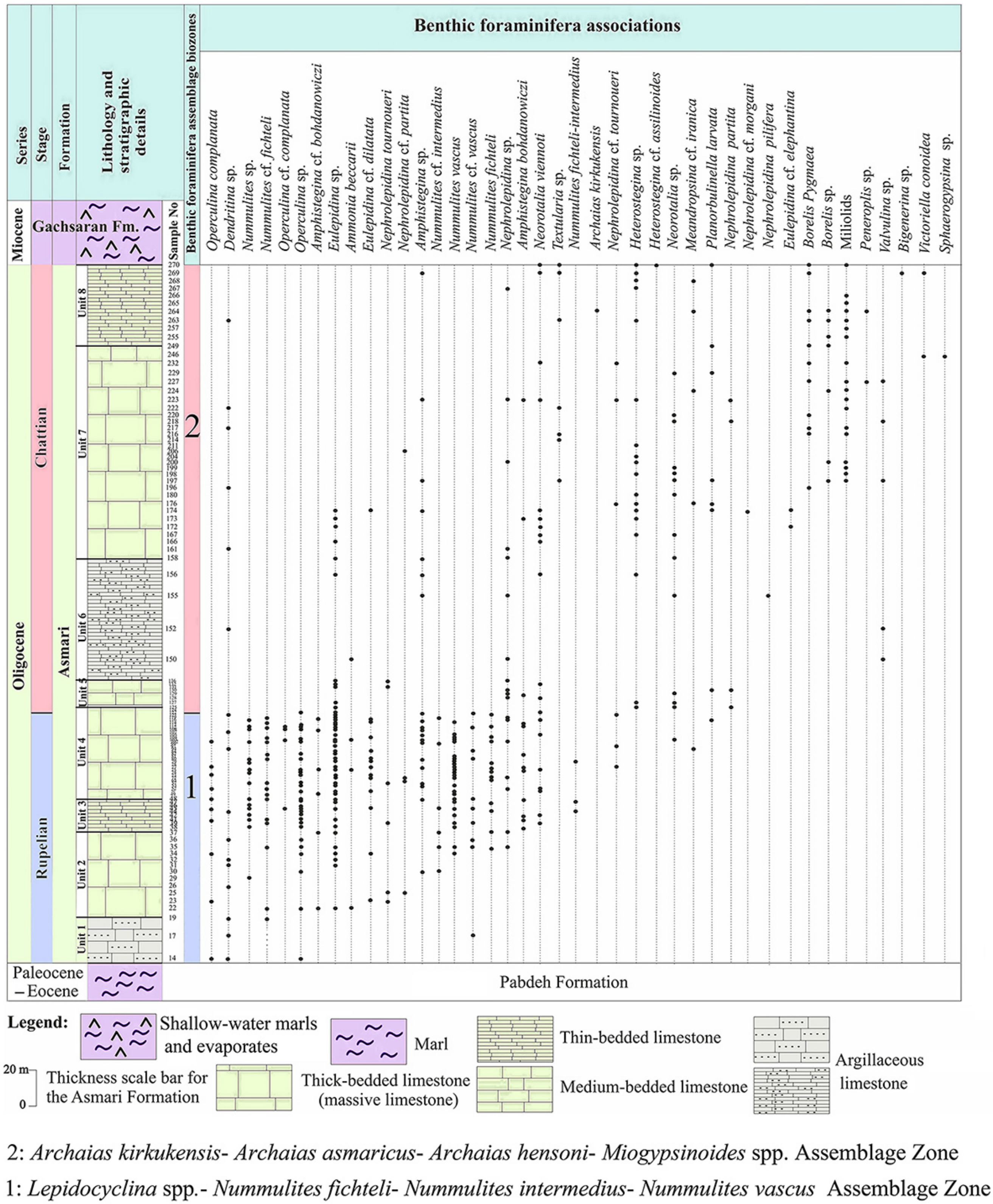

Figure 2. Stratigraphic distribution of the identified benthic foraminifera and the assemblage biozones in the studied succession of the Asmari Formation in the Hoz-e-Bidmeshk section.

Nummulites cf. *intermedius*, *Nummulites vascus*, *Nummulites* cf. *vascus*, *Nummulites* sp., *Eulepidina* sp., *Eulepidina* cf. *dilatata*, *Nephrolepidina tournoueri*, *Nephrolepidina* cf. *tournoueri*, *Nephrolepidina* sp., *Nephrolepidina* cf. *partita*, *Operculina* sp., *Operculina complanata*, *Operculina* cf. *complanata*, *Amphistegina bohdanowiczi*, *Amphistegina* cf. *bohdanowiczi*, *Amphistegina* sp., *Neorotalia* sp., *Neorotalia viennoti*, *Ammonia beccarii*, *Dendritina* sp., *Meandropsina* cf. *iranica*, and *Planorbulinella larvata*. The dominant foraminifera in the assemblage biozone 1 include *Nummulites* and lepidocyclinids. Stratigraphically, the assemblage biozone 1 range from the basal part of lithostratigraphic unit 1 to the upper part of the lithostratigraphic unit 4 of the Asmari Formation (between sample numbers 14 and 122; Figure 2). The upper boundary of the assemblage biozone 1 is indicated by the last occurrence of the genus *Nummulites* in the studied succession.

Assemblage biozone 2

Assemblage biozone 2 is characterized by the presence of the benthic foraminifera: *Dendritina* sp., *Eulepidina* sp., *Eulepidina* cf. *elephantina*, *Eulepidina* cf. *dilatata*, *Nephrolepidina* sp., *Nephrolepidina tournoueri*, *Nephrolepidina* cf. *tournoueri*, *Nephrolepidina partita*, *Nephrolepidina* cf. *partita*, *Nephrolepidina* cf. *morgani*, *Nephrolepidina pilifera*, *Neorotalia* sp., *Neorotalia viennoti*, *Heterostegina* sp., *Heterostegina* cf. *assilinoides*, *Amphistegina* sp., *Amphistegina bohdanowiczi*, *Ammonia beccarii*, *Textularia* sp., *Archaias kirkukensis*, *Meandropsina* cf. *iranica*, *Planorbulinella larvata*, *Borelis* sp., *Borelis pygmaea*, *Peneroplis* sp., *Valvulina* sp., *Bigenerina* sp., *Sphaerogypsina* sp., *Victoriella conoidea*, and miliolids. Stratigraphically, the biozone 2 ranges from the upper part of the lithostratigraphic unit 4 to the uppermost part of the lithostratigraphic unit 8 of the Asmari Formation (between sample numbers 122 and 270; Figure 2). The base of the assemblage biozone 2 is indicated by the last occurrence of the genus *Nummulites* in the studied succession.

BIOZONATION AND AGE OF THE ASMARI FORMATION IN THE STUDIED SECTION

Owing to the wide distribution, abundance, evolutionary patterns and sudden extinctions of benthic foraminifera, these microorganisms are regarded as useful tools in biostratigraphic analyses of marine carbonate platforms (Hottinger, 1977, 1983; Cahuzac & Poignant, 1997; Serra-Kiel *et al*., 1998; Beavington-Penney & Racey, 2004; BouDagher-Fadel, 2008; Vaziri- Moghaddam *et al*., 2010; Pignatti & Papazzoni, 2017).

Benthic foraminiferal assemblages have been widely used to date the shallow marine carbonate deposits of the Asmari Formation in the Zagros belt, SW Iran (*e.g*., Vaziri-Moghaddam *et al*., 2006, 2010; Hakimzadeh & Seyrafian, 2008; Taheri & Vaziri-Moghaddam, 2010; Kalanat *et al*., 2010; Sooltanian *et al*., 2011; Rahmani, *et al*., 2012; Amirshahkarami, 2013; Saleh, 2014; Zabihi Zoeram *et al*., 2015; Zare *et al*., 2015; Sattari *et al*., 2016; Kakemem *et al*., 2016; Habibi, 2016a, b, 2018; Khoshnood *et al*., 2016; Taheri *et al*., 2017; Habibi & Bover-Arnal, 2018; Moradi *et al*., 2019; Goodarzi *et al*., 2020; Allahkarampour Dill *et al*., 2020; Monjezi & Saeedi Razavi, 2021). The key biozonations of the Asmari Formation based on benthic foraminifera (mainly *Nummulites*, *Borelis melo* group, *Austrotrillina howchini*, *Peneroplis*, *Archaias*, *Miogypsina, Miogypsinoides*, lepidocyclinids, *Operculina*, *Spiroclypeus*, *Elphidium* and *Dendritina rangi*) were erected by Wynd (1965), Adams & Bourgeois (1967), Laursen *et al*. (2009), Van Buchem *et al*. (2010) and Allahkarampour Dill *et al*. (2020) (Figure 8). Wynd (1965) established the first biozones in the Asmari Formation and identified three biozones in the Oligocene and two biozones in the Miocene deposits of the formation (Figure 8). The Zone 56 of Wynd (1965) represents the Rupelian stage (the lower stage of the Oligocene), whereas zones 57 and 58 indicate the Chattian stage (the upper stage of the Oligocene; Figure 8).

Additionally, the lower stage of the Early Miocene (Aquitanian) and the upper stage of the Early Miocene (Burdigalian) correspond to zones 59 and 61 of Wynd (1965), respectively (Figure 8). Subsequently, the biozones were reviewed by Adams & Bourgeois (1967) in an unpublished report. They recognized one assemblage zone in the Oligocene, but did not subdivide this series into stages (Figure 8). Adams and Bourgeois (1967) recognized three assemblage biozones within the Aquitanian stage and one in the Burdigalian stage (Figure 8).

Laursen *et al*. (2009) and Van Buchem *et al*. (2010) established a new biozonation for the Asmari Formation (Figure 8) based on integration of benthic foraminiferal biostratigraphy and strontium isotope stratigraphy. They defined five assemblage zones and an indeterminate zone to separate the Rupelian stage from the Chattian stage and to differentiate the Aquitanian stage from the Burdigalian stage (see Figure 8). Allahkarampour Dill *et al*. (2020) have recently reviewed the previously defined biozonations of the Asmari Formation and have introduced nine new biozones (Figure 8) based on statistical and quantitative analyses of benthic foraminifera in 10000 thin-sections prepared from 49 subsurface and surface logged-sections. The Zones 2 and 4 (Interval zones), 3 (concurrent Range Zone) and 5 (assemblage zone) of Allahkarampour Dill *et al*. (2020) are representative of the Rupelian stage (Figure 8), whereas zones 6 and 7 (assemblage zones) indicate the Chattian stage (Figure 8). The Zone 8 (Interval Zone) and zone 9 (Partial Range Zone) of Allahkarampour Dill *et al*. (2020) represent the Aquitanian stage (Figure 8). The Burdigalian stage is indicated by the *Borelis melo* group Taxon Range Zone of Allahkarampour Dill *et al*. (2020) (Figure 8). The benthic foraminiferal biozones of the Asmari Formation in the Zagros basin are time equivalent to the benthic foraminiferal biozones SBZ 21–SBZ 25 (Figure 8) introduced by Cahuzac & Poignant (1997) for dating the Oligocene–Miocene deposits of the European basin.

In this study, the assemblage biozone 1 (Figure 2) correlates with the *Lepidocyclina* spp.- *Nummulites fichteli*-*Nummulites intermedius*-*Nummulites vascus* assemblage zone

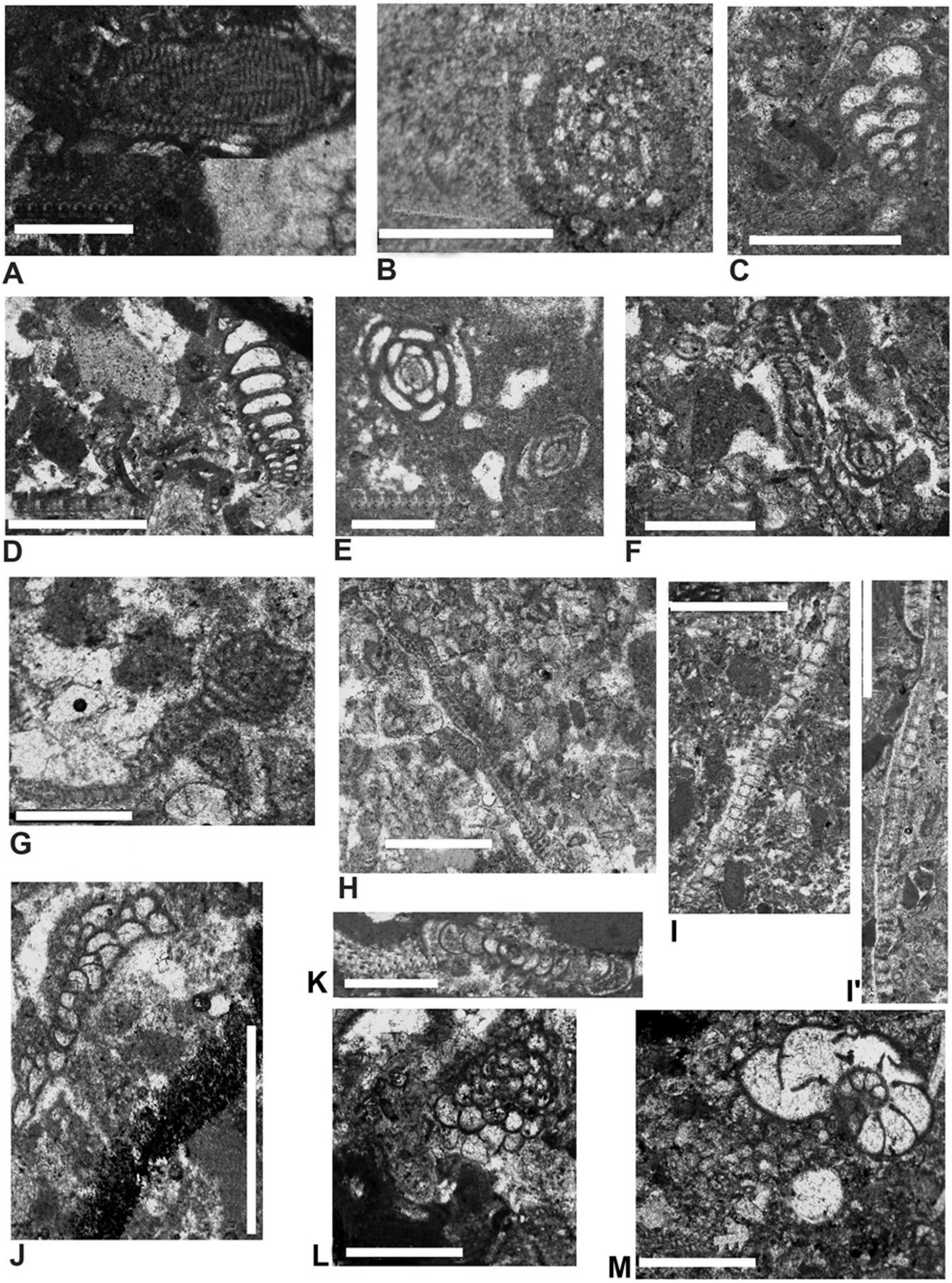

Figure 3. Photomicrographs of the identified benthic foraminifera. **A**, *Borelis pygmaea*, oblique section, sample no. 270; **B**, *Borelis* sp., sample no. 255; **C**, *Textularia* sp., axial section, sample no. 214; **D**, *Bigenerina* sp., subaxial section, sample no. 269; **E**, Miliolids, equatorial section, sample no. 232; **F**, *Peneroplis* sp., subaxial section, sample no. 227; **G**, *Peneroplis* sp., oblique section, sample no. 264; **H**, *Archaias kirkukensis*, subaxial section, sample no. 264; **I-I'**, *Meandropsina* cf. *iranica*, equatorial sections, sample numbers. 176 and 268; **J**–**L**, *Planorbulinella larvata*, **J**, sample no. 197, subaxial section; **K**, sample no. 116, subaxial section; **L**, sample no. 130, subequatorial section; **M**, *Valvulina* sp., sample no. 150. Scale bars: A–B, E, G, K, M = 0.5 mm; C–D, F, H–L = 1 mm.

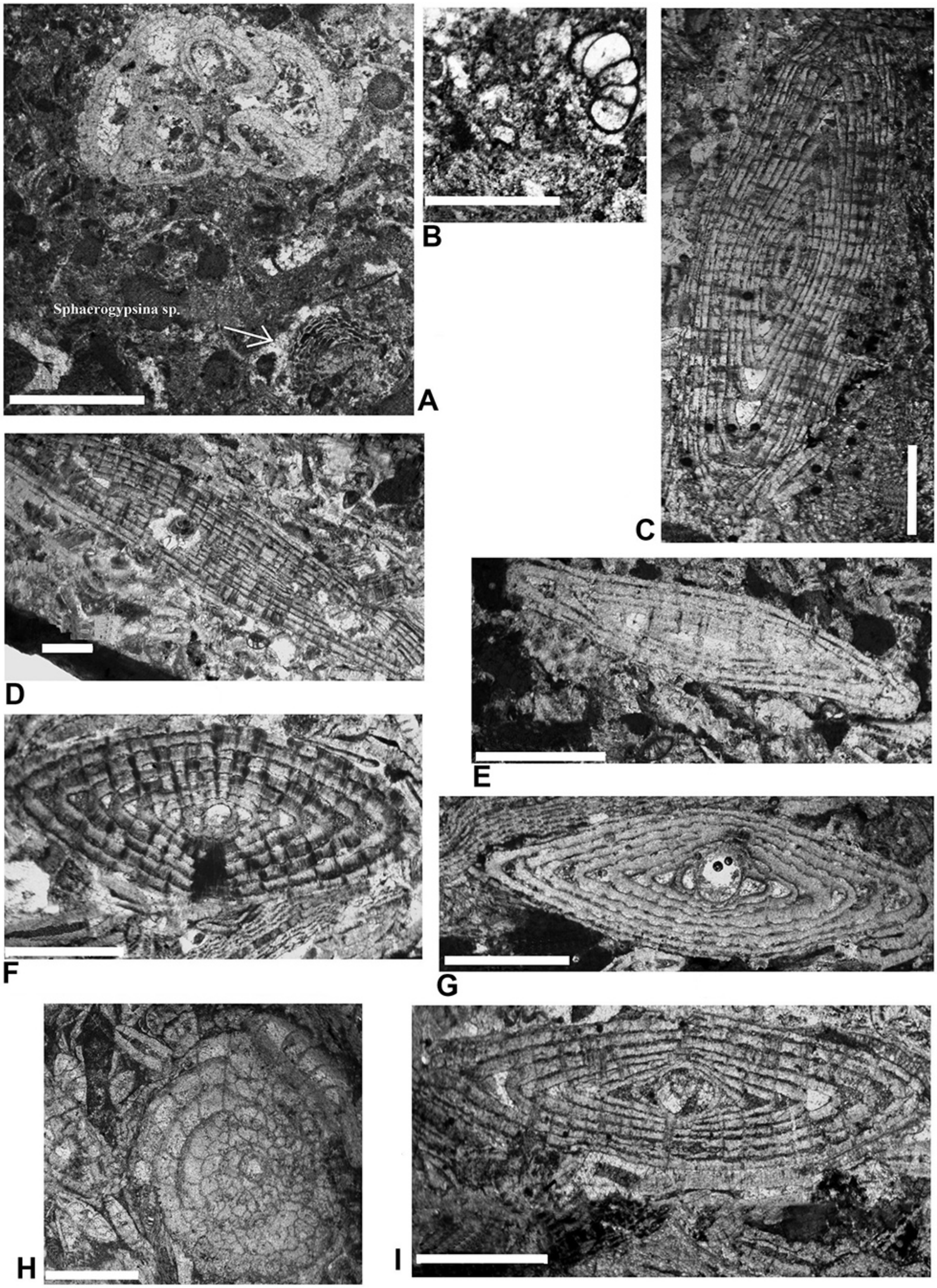

Figure 4. Photomicrographs of the identified benthic foraminifera. **A**, transversal section of *Victoriella conoidea* (upper part of the photomicrograph) and equatorial section of *Sphaerogypsina* sp. (lower part of the photomicrograph), sample no. 246; **B**, *Dendritina* sp., sample no. 17; **C**, **D**, *Nummulites fichteli-intermedius*, subaxial section, sample numbers 79 and 47; **E**, *Nummulites* cf. *intermedius*, subaxial section, sample no. 119; **F–I**, *Nummulites fichteli*, **F**, axial sections, megalospheric forms, sample no. 77; **G**, Axial section, sample no. 122; **H**, subequatorial section, sample no. 75; **I**, axial section, sample no. 105. Scale bars: A, C, E–I = 1 mm; B, D = 0.5 mm.

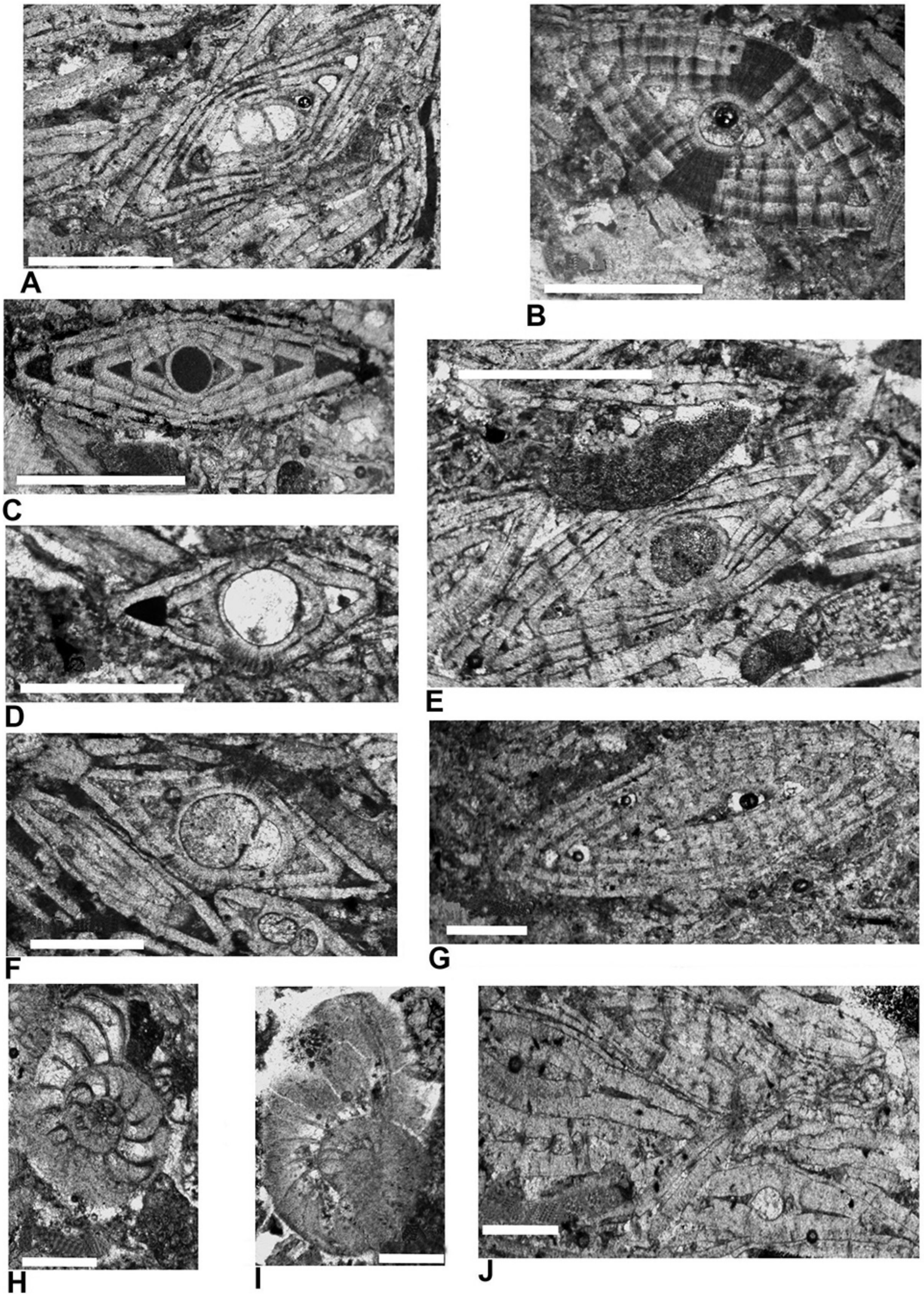

Figure 5. Photomicrographs of the identified benthic foraminifera. **A**, *Nummulites fichteli*, axial section, sample no. 45; **B**, *Nummulites* cf. *fichteli*, axial section, sample no. 114; **C**–**F**, *Nummulites vascus*; **C**, axial section, sample no. 49; **D**, **E**, axial section, sample no. 48; **F**, axial section, sample no. 75; **G**, *Nummulites* sp., subaxial section, sample no. 112; **H**, **I**, *Operculina complanata* (subequatorial section), sample no. 52; **J**, *Operculina* sp., axial section, sample no. 75. Scale bars: A–C, E = 1 mm; D, F–J = 0.5 mm.

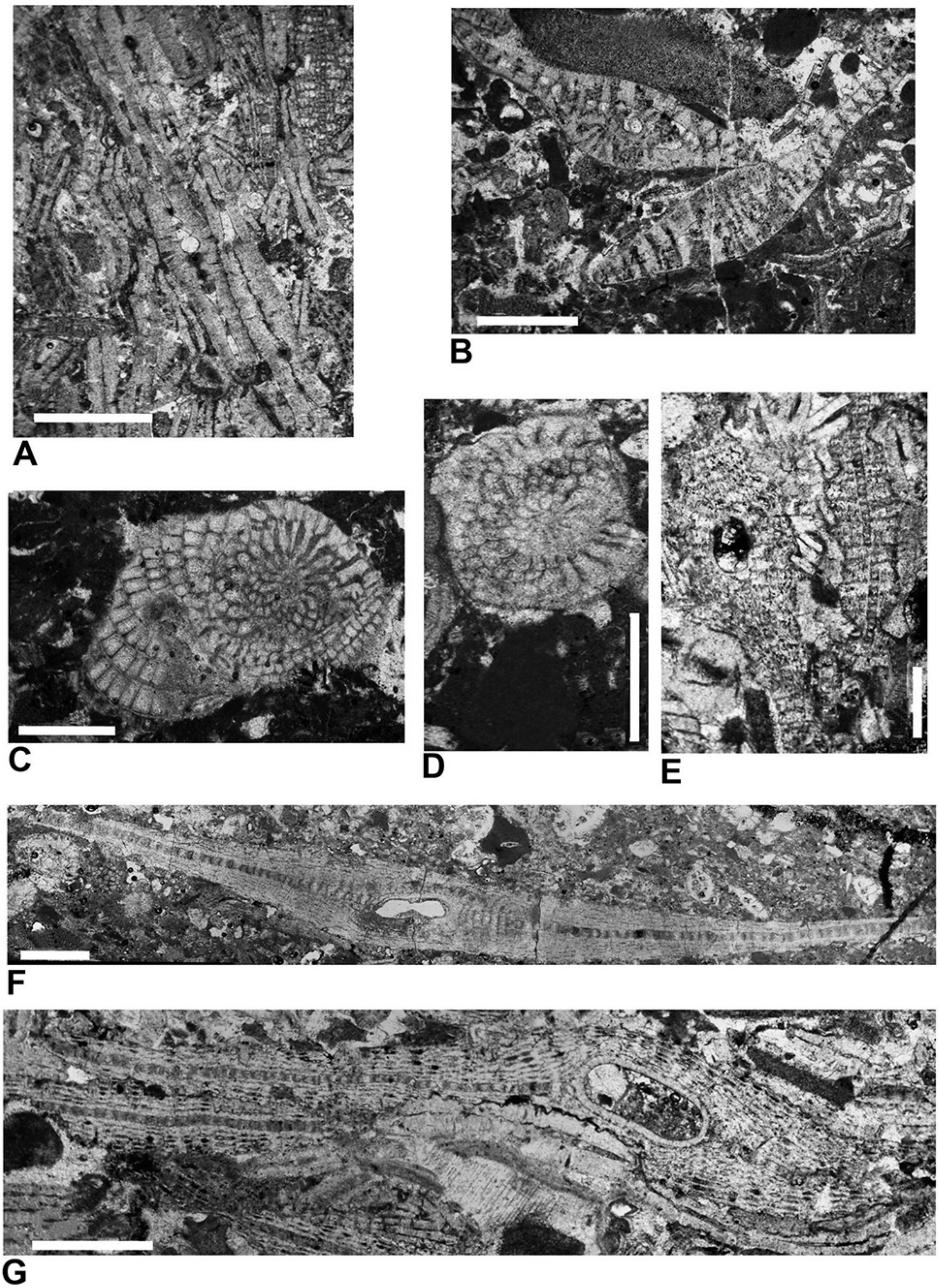

Figure 6. Photomicrographs of the identified benthic foraminifera. **A**, *Operculina complanata*, axial section, sample no. 45; **B**, *Heterostegina* sp., sample no. 269; **C**, *Heterostegina* sp., subequatorial section, sample no. 270; **D**, *Heterostegina* cf. *assilinoides*, subequatorial section, sample no. 270; **E**, *Nephrolepidina* sp., axial section, sample no. 72; **F**, *Eulepidina* cf. *elephantina*, axial section, sample no. 172; **G**, *Eulepidina* cf. *dilatata*, axial section, sample no. 80. Scale bars: A–D, F–G = 1 mm; E = 0.5 mm.

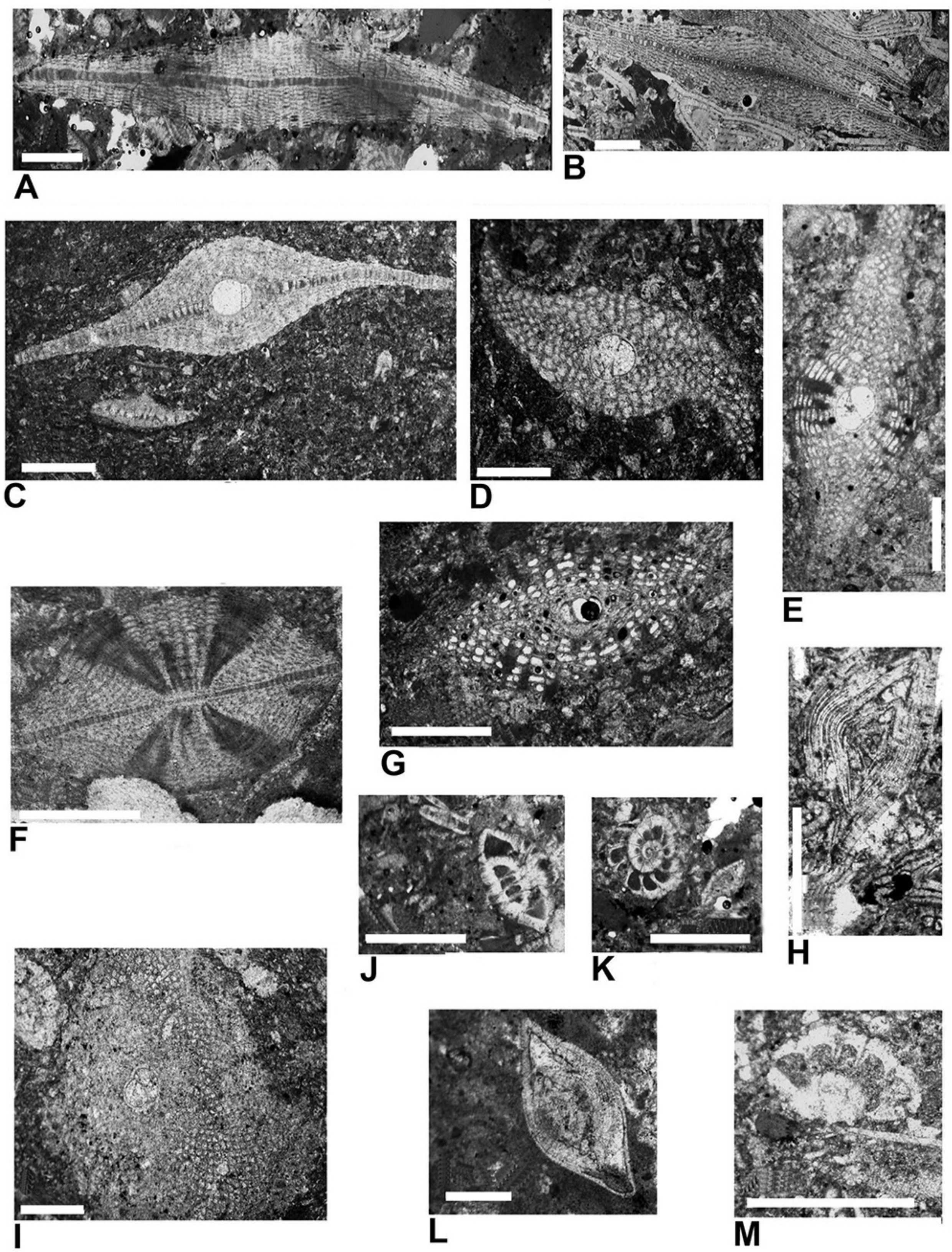

Figure 7. Photomicrographs of the identified benthic foraminifera. **A, B**, *Eulepidina* spp. (subaxial section), **A**, Sample no. 174; **B**, sample no. 122. **C**, *Nephrolepidina* cf. *morgani*, axial section of megalospheric form, sample no. 174; **D**, *Nephrolepidina pilifera*, axial section, sample no. 155; **E**, *Nephrolepidina tournoueri*, axial section, sample no. 23; **F**, *Nephrolepidina partita*, axial section of microspheric form, sample no. 223; **G, I**, *Nephrolepidina* spp., **G**, axial section, sample no, 158; **I**, oblique section, sample no. 150. **H**, *Amphistegina bohdanowiczi*, subaxial section, sample no. 48; **J, K**, *Neorotalia viennoti* (sample no. 174), **J**, axial section; **K**, equatorial section. **L**, *Amphistegina* sp., axial section, sample no. 197; **M**, *Ammonia beccarii*, axial section, sample no. 150. Scale bars: A–C, F, J–K, M = 1 mm; D–E, G–I, L = 0.5 mm.

(Biozone 5) of Allahkarampour Dill *et al*. (2020) and indicates Rupelian (Early Oligocene) age. The assemblage biozone 1 is time equivalent to the *Nummulites fichteli-Nummulites vascus* assemblage zone of Laursen *et al*. (2009) and Van Buchem *et al*. (2010). The assemblage biozone 2 in the studied succession (Figure 2) represents the *Archaias kirkukensis-Archaias asmaricus-Archaias hensoni-Miogypsinoides* spp. assemblage zone (Biozone 7) of Allahkarampour Dill *et al*. (2020) and indicates a Chattian (Late Oligocene) age. Additionally, the assemblage biozone 2 is time equivalent to the *Archaias asmaricus–Archaias hensoni–Miogypsinoides complanatus* assemblage zone of Laursen *et al*. (2009) and Van Buchem *et al*. (2010). The absence of *Nummulites* and the presence of *Archaias* in the assemblage biozone 2 (Figure 2) confirm the Chattian age (*e.g*., Racey, 1994; Ehrenberg *et al*., 2007; Habibi, 2016b). Also, the absence of benthic foraminifera such as *Austrotrillina howchini* (*e.g*., Cahuzac & Poignant, 1997; Kakemem *et al*., 2016), *Miogypsina*, *Borelis melo melo* and *Borelis melo curdica* in the assemblage biozone 2 suggests the Oligocene age.

MICROBIOSTRATIGRAPHIC CORRELATION OF THE ASMARI FORMATION IN THE ZAGROS BELT

Benthic foraminiferal biostratigraphic correlation of the Asmari Formation across the Zagros belt based on the Hoz-e-Bidmeshk section in this study and the 14 most reliable stratigraphic sections selected from the Fars Zone, Lurestan Zone, Dezful Embayment, Izeh Zone and the High Zagros Zone (Figure 9), shows that the Rupelian stage in the Zagros belt is commonly recognized by the occurrence of the genus *Nummulites* and the *Nummulites vascus-Nummulites fichteli* Assemblage Zone. The nummulitid associations in the Zagros belt are similar to those reported from the Indo-Pacific area and the Mediterranean region and north of the Tethys (see Amirshahkarami, 2013 and Habibi, 2018 for the paleogeographic details). The correlation (Figure 9) also indicates that the Chattian stage in the Zagros belt is commonly represented by the *Archaias asmaricus–Archaias hensoni–Miogypsinoides complanatus* Assemblage Zone (Figure 9). The faunal associations of this biozone are similar to the Chattian faunal assemblages in the Indo-Pacific and Mediterranean basins (Amirshahkarami, 2013; Habibi, 2018). Additionally, the lower stage of the Early Miocene (Aquitanian) and the upper stage of the Early Miocene (Burdigalian) in the Zagros belt are commonly defined by the *Miogypsina-Peneroplis farsensis-Elphidium* sp. 14 Assemblage Zone and the *Borelis melo curdica-Borelis melo melo* assemblage zone, respectively (Figure 9).

Biostratigrapic correlation of the Asmari Formation in the Zagros belt based on foraminifera (Figure 9) also shows that the age of the Asmari Formation varies between structural zones of the Zagros belt and that the deposition of the carbonate facies of the formation was not synchronous throughout the region (Figure 9). The Izeh Zone and the Dezful Embayment host relatively continous successions

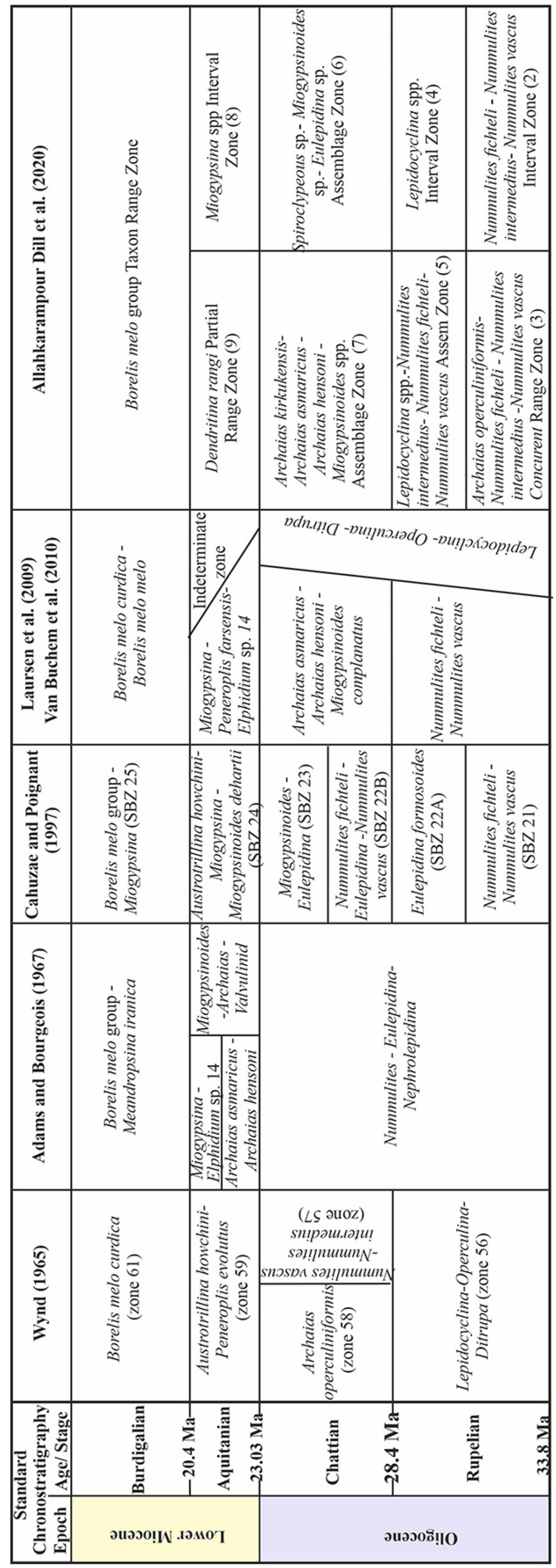

Figure 8. The key biozonations of the Oligocene–Miocene shallow marine carbonate deposits of the Asmari Formation in the Zagros belt based on benthic foraminifera (Wynd, 1965; Adams & Bourgeois, 1967; Laursen *et al*., 2009; Van Buchem *et al*., 2010; Allahkarampour Dill *et al*., 2020) and strontium isotope data (Laursen *et al*., 2009; Van Buchem *et al*., 2010). Cahuzac & Poignant (1997) defined biozones for the Oligocene–Miocene shallow marine carbonate deposits of the European basins. The standard chronostratigraphy chart in Figure 8 is based on Gradstein *et al*. (2004).

of the Asmari Formation in the Zagros belt ranging from Rupelian to Burdigalian (*e.g*., Figure 9). In contrast, the High Zagros Zone may host an incomplete succession of the Asmari Formation that is primarily Rupelian in age. In the Interior Fars Sub-zone, the Asmari Formation was deposited during the Rupelian and Chattian (*e.g*., Sooltanian *et al*., 2011; Khoshnood *et al*., 2016; Habibi, 2016a, 2018 and this study; Figure 9). The biozones and the age of the Asmari Formation in the studied section correlate with the biozones and age of the formation in other parts of the Interior Fars Sub-zone (*e.g*., Sooltanian *et al*., 2011; Khoshnood *et al.,* 2016; Habibi, 2016a, 2018; Figure 9). During the late Chattian and the Miocene, sea level fall restricted deposition of the Asmari Formation and subsequently resulted in deposition of terrigenous sediments and evaporites of the Razak and Gachsaran formations during the Miocene in the Fars Zone (Aghanabati, 2011; Habibi, 2016a, b, 2018).

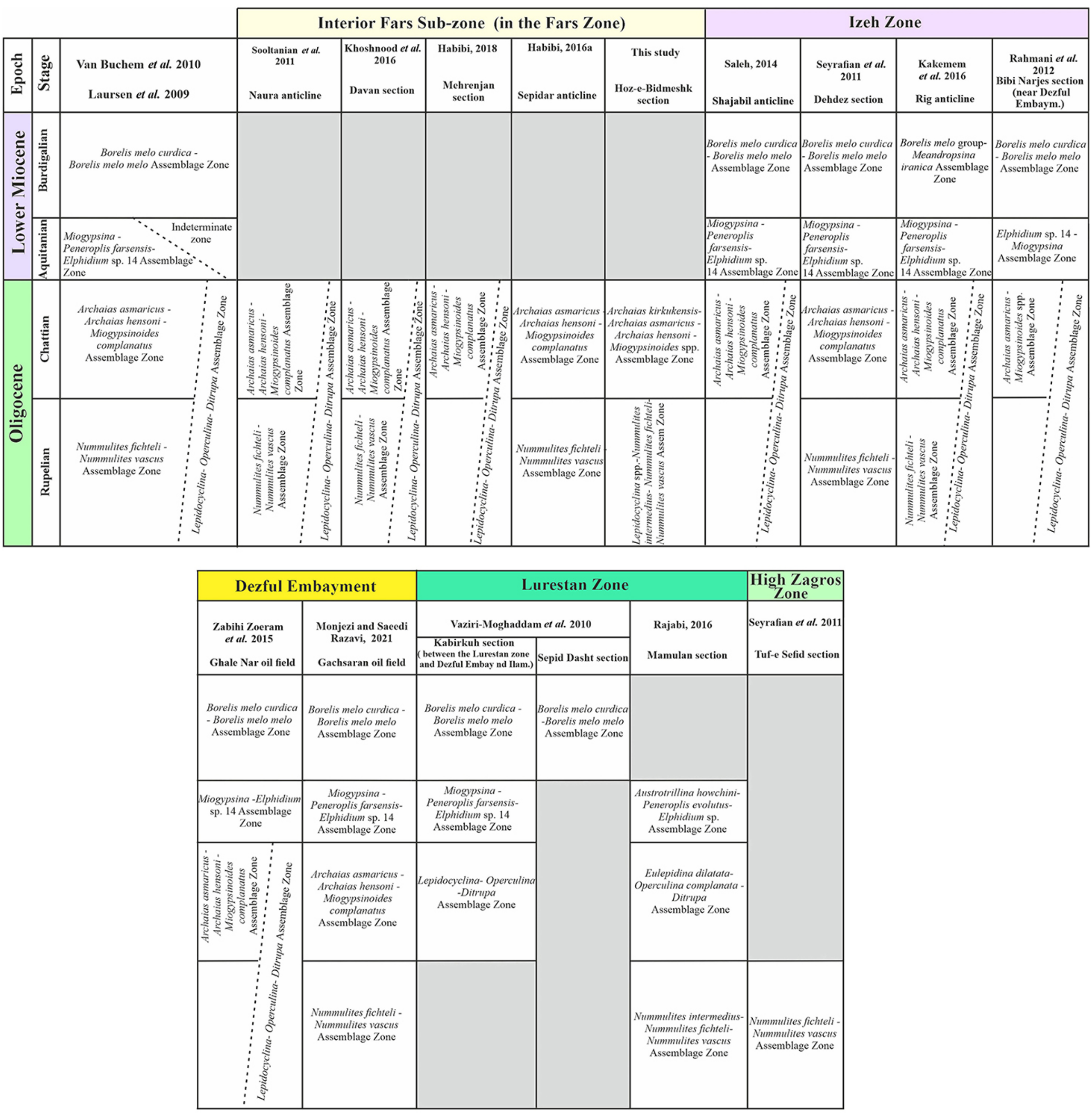

Figure 9. Microbiostratigraphic correlation chart of the Asmari Formation based on this study (Hoz-e-Bidmeshk section) and previous studies carried out on benthic foraminiferal biozones in different parts (zones) of the Zagros belt.

CONCLUSIONS

Micropaleontological analyses of the Oligocene carbonates of the Asmari Formation in the Hoz-e-Bidmeshk section north of Kazerun in the Interior Fars Sub-zone, Zagros Belt, southwestern Iran, yielded 19 genera and 20 species of benthic foraminifera. Miliolids were identified only at the order level. Based on the vertical distribution of foraminifera in the studied succession of the Asmari Formation, the two following assemblage biozones were recognized in ascending stratigraphic order: 1–*Lepidocyclina* spp.- *Nummulites fichteli-Nummulites intermedius-Nummulites vascus* and 2–*Archaias kirkukensis-Archaias asmaricus-Archaias hensoni-Miogypsinoides* spp. The first assemblage zone dominated by *Nummulites* and lepidocyclinids correlates with the Rupelian stage, whereas the second assemblage zone, lacking *Nummulites* and Miocene foraminifera but containing *Archaias* indicates the Chattian stage. During the late Chattian and Miocene, sea level fall limited deposition of carbonates of the Asmari Formation in the Interior Fars Sub-zone. Subsequently, the shallow-marine marls and evaporites of the Gachsaran Formation were deposited on the Asmari Formation during the Miocene.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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