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Depositional Environment and Bio-Sequence Stratigraphic Analysis of the Mishan Formation in the Fars zone, Zagros Basin, Southwest Iran

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Abstract

To study the deposits of Mishan Formation in the Fars area, 986 thin-section samples from three stratigraphic sections were examined. A meticulous analysis of the samples from Bastak, Farashband, and Kuh-e Khush reveals varying thicknesses of approximately 522 m, 530 m, and 380 m, respectively. Mainly, the Mishan Formation is composed of alternating layers of cream to light gray, medium to thick limestone, marly limestone, and marl. The lower boundary of the Mishan Formation is conformable with the gypsum layers of the Gachsaran Formation, while its upper boundary exhibits a gradual transition to the sandstones of the Aghajari Formation. In the biostratigraphic analysis, 23 species and 35 genera of benthic foraminifera were documented, and 4 benthic foraminifera based biozones were documented as follows: (1) *Miogypsina-Elphidium-Peneroplisfarsensis* assemblage zone, (2) *Miogypsinoides-Archias-Valvulinid* assemblage zone, (3) *Operculina complanata-Rotalia viennoti* assemblage zone, and (4) *Borelis melo curdica* zone. On the basis of identified biozones and fossil contents, the relative age of the Mishan Formation is discerned to span from Aquitanian to Burdigalian. Petrographical studies have identified nine microfacies, indicative of deposition in inner and middle shelf models. Facies analysis and sea level curve assessments have enabled the recognition of three depositional sequences. The sequence boundaries at the middle, lower, and upper boundaries of the Mishan Formation were found to be type II sequence boundary (SB2).

Keywords: Biozone; Facies; Sequence; Aquitanian; Burdigalian; Mishan Formation; Zagros (Iran).

1. Introduction

The Mishan Formation, which is a constituent of the Fars Group (Gachsaran, Mishan and Aghajari formations), was first presented by James and Wynd (1965) as a type section situated along the southern margin of the Gachsaran oil field, approximately 50 km SE of Gachsaran in Kohgiluyeh and Boyer-Ahmad Province. Within the type section, the Mishan Formation exhibits a thickness of 710 m and is characterized by its lithology, which comprises gray marl and fossiliferous clay limestone (Fashaki et al., 2003). Research conducted in southern Iran encompasses various topics such as the biostratigraphy of Mesozoic and Cenozoic Formations in diverse areas of the Zagros region, including the Mishan Formation and the stratigraphic investigations of southern deposits in Khuzestan, Fars and Lorestan provinces. Favre (1975) authored an internal report detailing the post Asmari Formations based on the interpretation of geophysical sections, and prepared line maps illustrating the relative thickness of these formations. In the Shahdadi area of southeastern Zagros Basin (north of Bandar Abbas), Hassani et al. (2019) analyzed the sedimentary environment and microfacies of the Mishan Formation. Yazdi et al. (2013) introduced crustacean fossils from analogous strata in the southwestern Zagros. Additionally, Movahed and Lasemi (1996) investigated the sedimentary environment, microfacies, and petrology and the Guri member (Mishan Formation) in Bandar Abbas. Litho-stratigraphy of the Mishan Formation was conducted by Rashidi et al. (2014) in west and north of Hormozgan province (south of Iran). Gholamalian et al. (2016) focused on the study of Miocene echinoid fossils (Mishan Formation) in the Gahreh section in the north of Bandar Abbas (Hormozgan province). Kroh et al. (2011) explored bivalves and echinoids from the Mishan Formation of Early Miocene age. Additionally, Homayoun Zadeh (2002) investigated the bio and lithostratigraphy of the Mishan Formation in the central portion of the

Dezful depression.

2. Geological Setting

The sedimentary basin of Zagros, situated in the southwest of Iran, is one of the region's key structural units (Agard et al., 2005). Throughout the Mesozoic and Cenozoic eras, it initially served as a passive margin and then later as a convergent orogeny (Bahroudi and Koyi, 2004; Heydari, 2008; Motiei, 1993). The basin encompasses areas within Lorestan, Khuzestan, and parts of the coastal Fars and Interior Fars provinces. The Farashband section, located approximately 35 km southwest of Shiraz, is within the folded Zagros Belt of International Fars. Its geographic coordinates are 28° 39' 14" N and 52° 17' 19.34" E. The Kuh-e Khush section, located about 45 km northwest of the city of Mishan, also resides in the folded Zagros Belt of International Fars. Lastly, the Bastak section is situated approximately 15 km southwest of the city of Bastak, within the folded Zagros Belt of Coastal Fars.

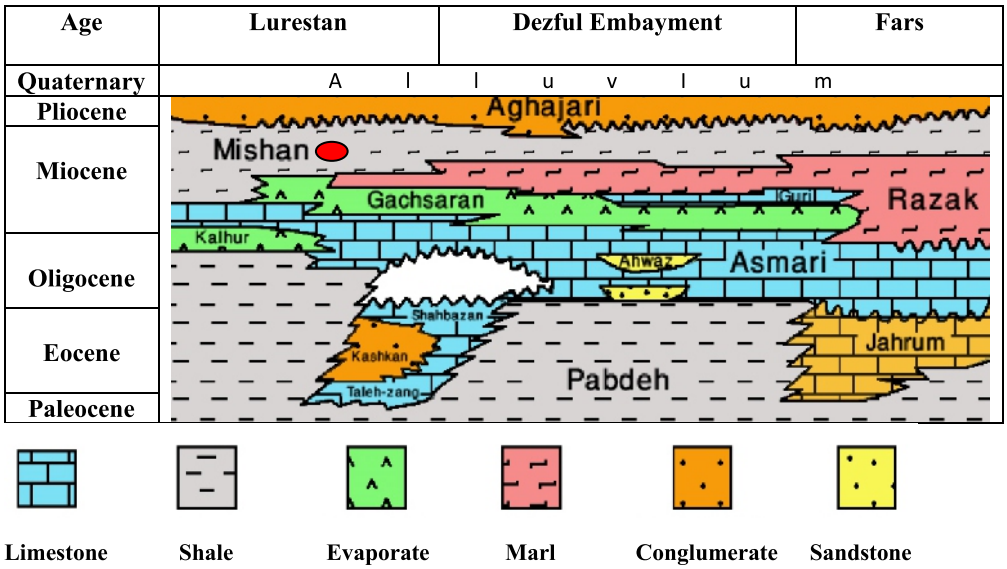

Fig. 1. Chart of stratigraphic correlation of the Neogene and Paleogene deposits of the Zagros Basin (James and Wynd, 1965).

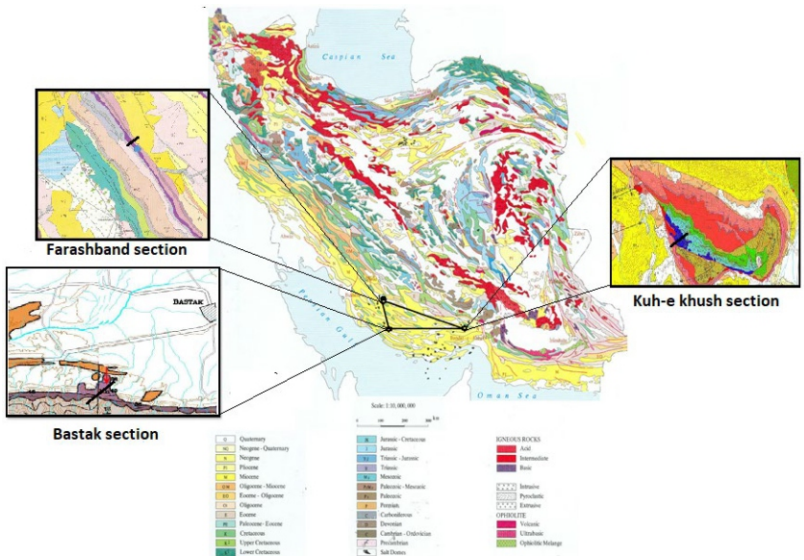

Fig. 2. Geological map location of the studied stratigraphic sections and their relative distances, as illustrated on the geological map of Iran (Aghanabati, 2006).

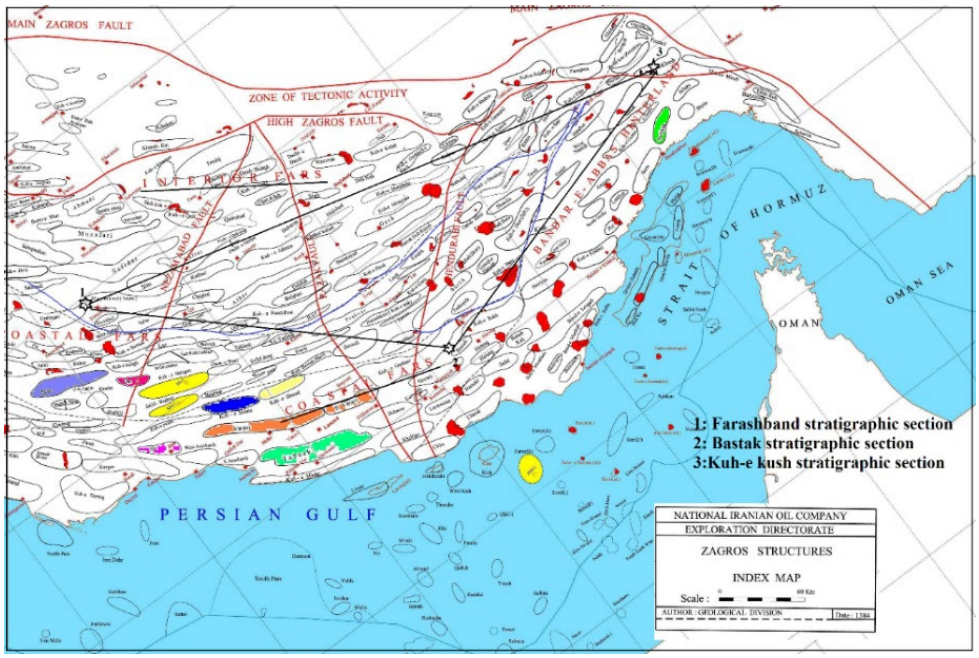

Fig. 3. Image of a portion of the Zagros structural map, indicating the structural locations of the studied stratigraphic sections. The Bastak and Kuh-e Khush sections are situated in the Coastal Fars region, while the Farashband section is located in the Inner Fars region (Alavi, 2004)

3. Methods and materials

This investigation employed library research, laboratory analysis, and field-work techniques to comprehensively study the Mishan Formation. Biostratigraphic investigations and sequence stratigraphy were also conducted as integral components of our methodology. Following a comprehensive field sampling, 986 microscopic thin sections were prepared and examined. Subsequently, biozones were identified, and the stratigraphic, biostratigraphic, and stratigraphic columns were constructed. In order to classify foraminifera, several studies were consulted including Loeblich and Tappan (1988), Adams and Bourgeois (1967), Wynd (1965), Kalantari (1992), Motiei (1993), Karami et al. (2020), The vertical and lateral changes in fossil contents and sedimentary facies were employed to reconstruct and interpret environment of sediments. The study of sequence stratigraphy was conducted on the basis of sequence stratigraphy principles outlined by Sharland et al. (2004), Gowhari et al. (2020), and Kamalifar et al. (2020).

4. Results and discussions

4.1 Lithostratigraphy

The Mishan Formation demonstrates varying thicknesses in the stratigraphic sections of Bastak, Farashband, and Kuh-e Khush, measuring approximately 522, 530, and 380 meters respectively (Figs. 6-8). Whereas the lower boundary of the Mishan Formation conforms seamlessly with the gypsum layers of the Gachsaran Formation, its upper boundary exhibits a gradual transition to the sandstones of the Aghajari Formation (Figs. 6-8). The Mishan Formation's base starts with alternating layers of light gray to cream, comprising medium layers of limestone and sandy limestone. The Mishan Formation's middle parts consist of the intermittent patterns, featuring cream to light gray, medium thick limestone layers, marly limestone, and marl. The uppermost part consists of buff to cream, massive thick limestone, with intercalation red thin-bedded sandstone layers.

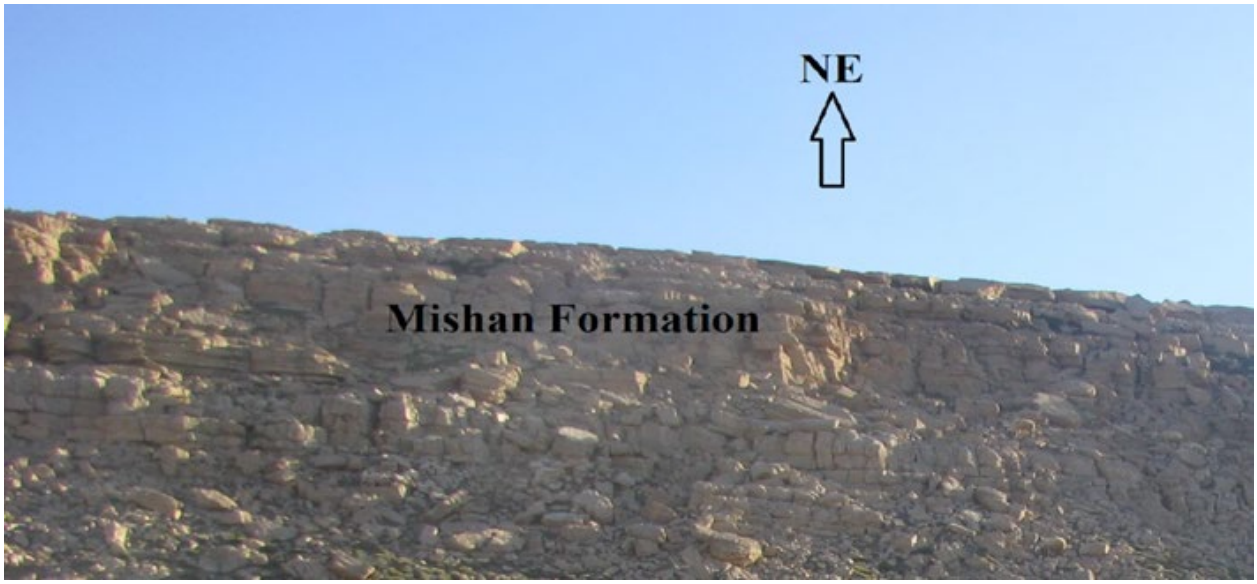

Fig. 4. Field photograph of the Bastak section (Mishan Formation).

Fig. 5. Field photograph of the Mishan and Aghajari Formations boundary in the Bastak section

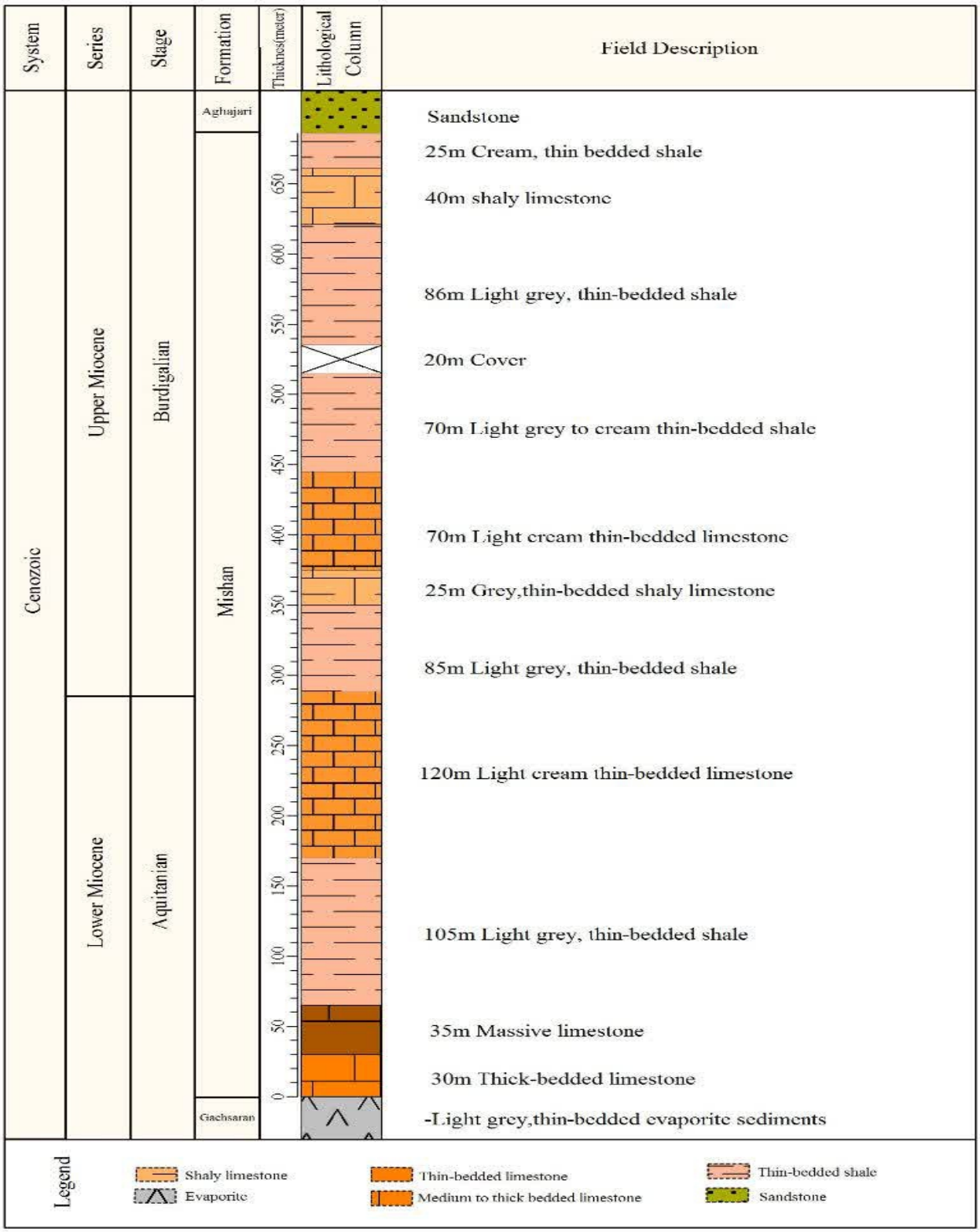

Fig. 6. Litho-stratigraphic column of the Mishan Formation (Bastak section).

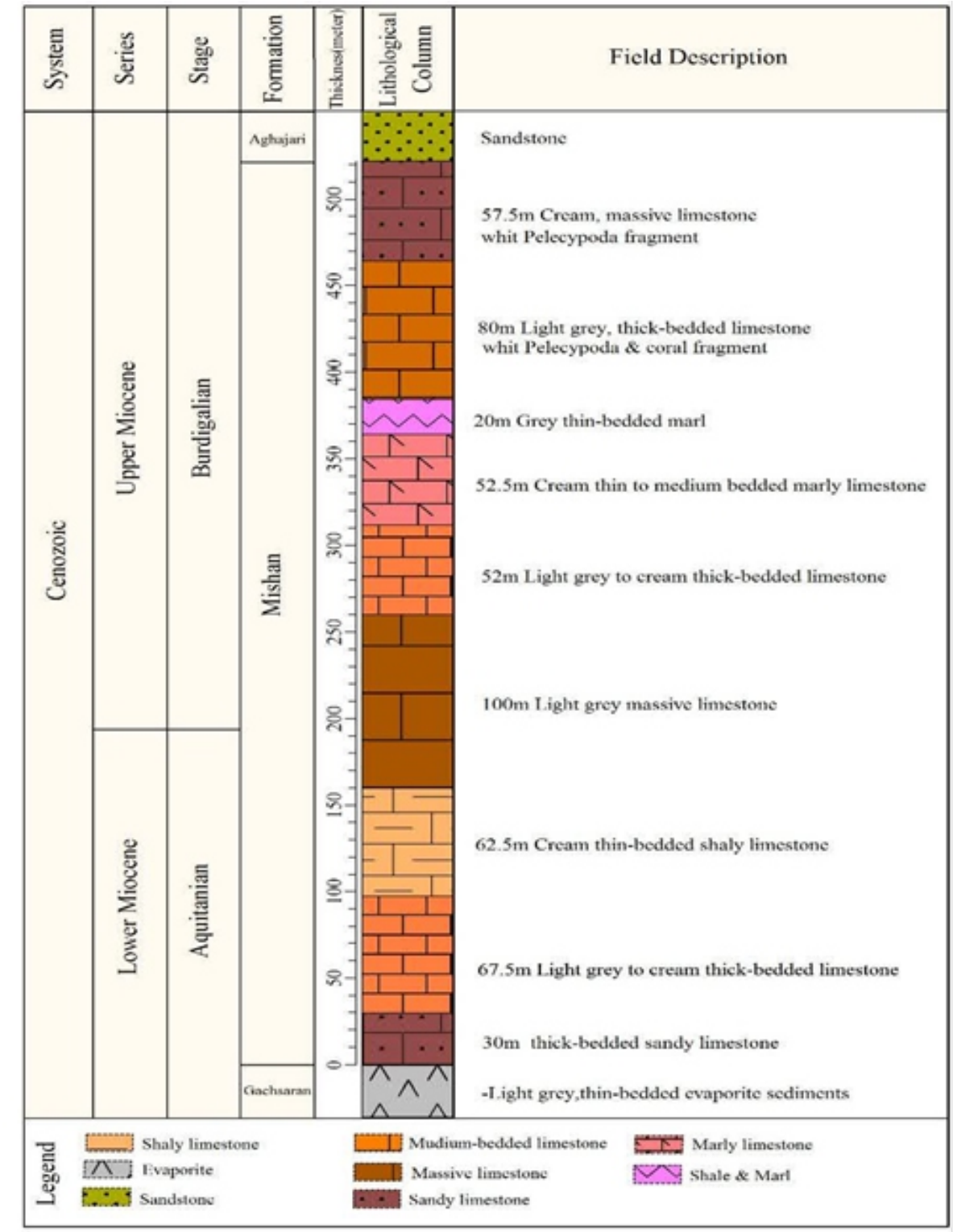

Fig. 7. Litho-stratigraphic column of the Mishan Formation (Farashband section).

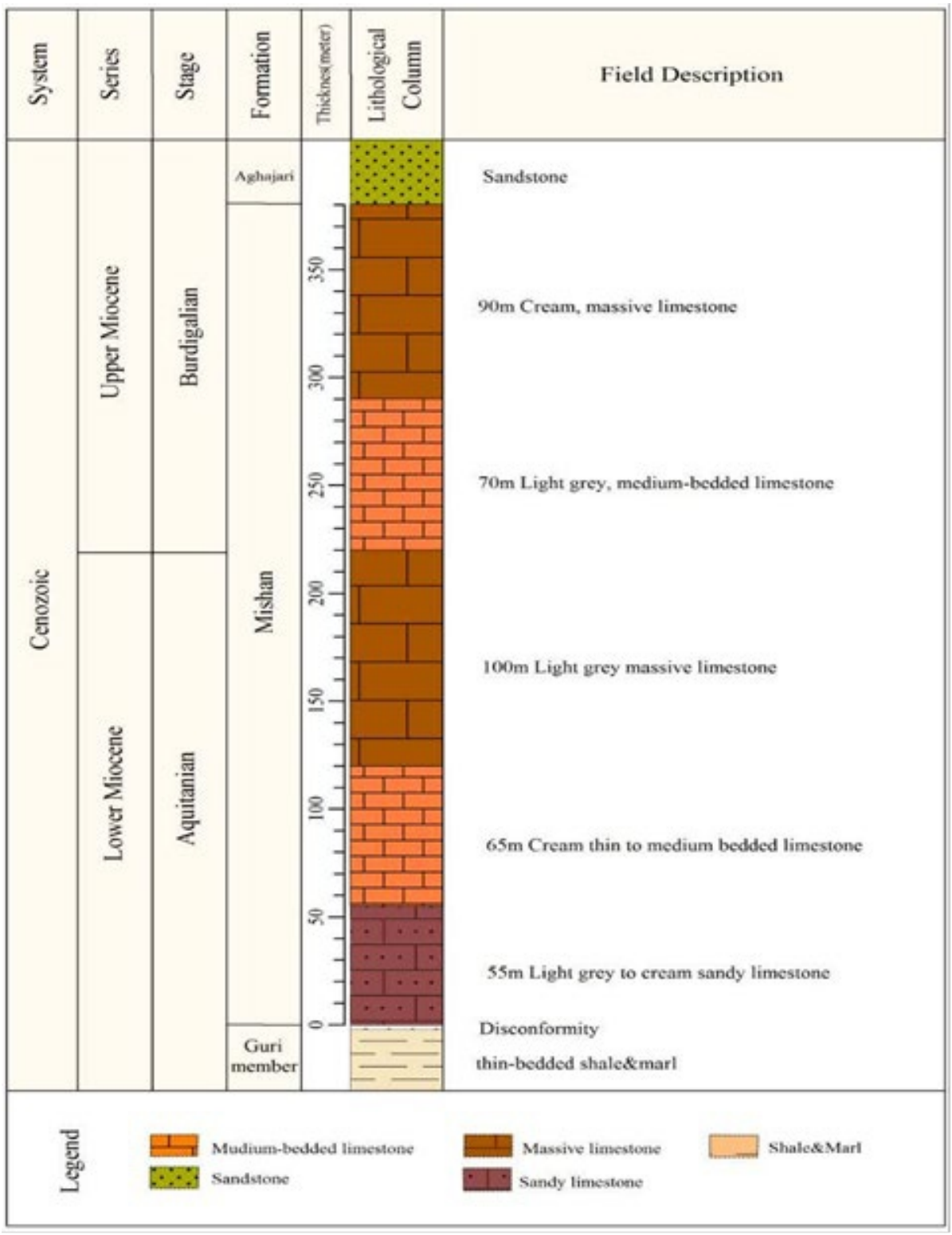

Fig. 8. Litho-stratigraphic column of the Mishan Formation (Kuh-e Khush section).

4.2 Biostratigraphy

Wynd (1965) established the biostratigraphy of the Mishan Formation and introduced following biozones: *Lepidocyclina-Operculina-Ditrupa* (zone 56) zones of assemblage for the Oligocene, and the Burdigalian age assemblage zone of *Borelis melo curdica.* Based on this revised biozonation, sediments of Late Oligocene age are assigned to the Miocene. The identified biozones have been correlated and compared with some research conducted in the type section and other parts of the Zagros zone.

The studies of previous biostratigraphy for the Asmari Formation are reevaluated by Adams and Bourgeois (1967) and proposed the following biozones: Oligocene age assemblage zone of *Eulepidina-Nephrolepidina-Nummulites;* Aquitanian age assemblage zone of *Miogypsinoides-Archaias-Valvulinid;* and assemblage subzones of *Archaias Asmaricus-Archaias hensoni* and *Elphidium* sp. *Miogypsina* for the Early to Middle and Middle to Late Aquitanian ages, respectively; and assemblage zone of the *Borelis* melo group-*Meandropsina iraniaca* (for the Burdigalian age).

The introduced biozones of Adams and Bourgeois (1967) and Wynd (1965) were further refined by Cahuzac and Poignant (1997) as: for the *Rupelian,* an assemblage zones of *Eulepidina formosoides* and *Nummulites vascus-Nummulites fichteli;* for the Early and Late Chattian, an assemblage zones of *Nummulites vascus-Nummulites fichteli* and *Eulepidina* as well as *Miogypsinoides-Eulepidina* respectively. For the Aquitanian *Austotrillina howchini-Miogypsina-Miogypsinoides deharti,* and for the Burdigalian age assemblage zone of the *Borelis melo* group-*Miogypsina.*

Strontium isotope stratigraphy has been by Ehrenberg et al. (2007) in certain localities in southwest Iran to date the Asmari Formation. They introduced four index fossils based events of biostratigraphy, species of *Spiroclypeus blankenhorni* and *Nummulites,* the genus of *Archaias* and *Miogypsina,* and the *Borelis melo curdica* species. According to this study, the last occurrence of *Nummulites* is approximately 1 Ma before the end of the Rupelian stage. The extinction of *Nummulites* near the end of the *Rupelian* was also reported by Racey (1995). Age determinations and biozonation are on the basis of strontium-isotope stratigraphy established recently by Laursen et al. (2009) for the Asmari Formation.

Sr isotope dating has been employed by Van Buchem et al. (2010) for the Asmari Formation. Van Buchem et al. (2010) proposed new biozones based revised time intervals: for the *Rupelian,* an assemblage zonea of *Nummulites vascus-Nummulites fichteli;* for the Rupelian-Chattian, an assemblage zone of *Lepidocyclina-Operculina-Ditrupa;* for the Aquitanian, *Archaias asmaricus-A. hensoni-Miogypsinoides complanatus,* and for the Burdigalian, an assemblage zone of *Borealis melo curdica-Borealis pygma.*

As previously mentioned, four foraminifera assemblages have been identified within the Mishan Formation in the study area. More recent biostratigraphic studies of the Mishan Formation have been conducted by Seyrafian et al. (1996), Hakimzadeh and Seyrafian (2008), Maghfouri-Moghaddam et al. (2009), Maghfouri-Moghaddam (2013), Laursen et al. (2009), Seyrafian and Mojikhalifeh (2005), Amirshahkarami et al. (2010), Ghanavati (2015), Gholamalian et al. (2016).

4.2.1 Assemblage biozone description

The biostratigraphy of the Mishan Formation has been investigated through paleontological analysis in Farashband, Kuh-e Khush, and Bastak sections within the Zagros Basin. In this study, four biozones have been determined on the basis of benthic foraminifera distribution in the study areas. These biozones in ascending order of stratigraphy are discussed as follows:

Biozone No 1. *Miogypsina-Elphidium-Peneroplisfarsensis* Assemblage zone

Biozone No 2. *Miogypsinoides-Archias-Valvulinid* Assemblage zone

Biozone No 3. *Operculina complanata-Rotalia viennoti* Assemblage zone

Biozone No 4. *Borelis melo curdica* zone (Figs. 10-12).

Biozone No 1. Miogypsina-Elphidium-Peneroplisfarsensis Assemblage Zone

This assemblage zone, established by Laursen et al. (2009), is depicted in Figure 10. The most significant foraminifera include *Spiroclypeus* sp., *Elphidium* sp., *Ammonia beccarii, Rotalia* sp., *Spirulina, Miogypsinoides complanatus, Pyrgo* sp., *Quinqueloculina* sp., *Discorbis* sp., *Lithophyllum* sp., *Lithothamium* sp., *Subterrani phylum thomasi, Rupertia* sp., *Tubucellaria* sp., and *Pyrgo* sp. *Quinqueloculina* sp. and *Elphidium* sp. The age of this biozone is Aquitanian based on microscopic studies.

Biozone No 2. Miogypsinoides-Archias-Valvulinid Assemblage Zone

This assemblage zone was established by Wynd (1965). The most important foraminifera include *Valvulina* sp., *Peneropelis thomasi, Miliolida* sp., *Elphidium* sp., *Eulepidina dialata, Quinqueloculina* sp., *Pyrgo* sp., *Praerhapydionina delicata, Asterocyclina* sp., and *Peneroplis* sp. Based on microscopic studies, the age of this biozone is Aquitanian.

Biozone No 3. Operculina complanate-Rotalia viennoti Assemblage Zone

This assemblage zone was established by Wynd (1965), with the most important foraminifera including *Valvulina* sp., *Peneropelis thomasi, Miliolida* sp., *Elphidium* sp., *Eulepidina dialata, Quinqueloculina* sp., *Pyrgo* sp., *Praerhapydionina delicata, Asterocyclina* sp., and *Peneroplis* sp. The assemblage is attributed to the Aquitanian epoch based on the content of foraminifera.

Biozone No 4. Borelis melo curdica Zone-Borelis melo group, Meandropsina iranica Assemblage Zone.

This Assemblage zone was established by Laursen et al. (2009) (Fig. 9). The most important foraminifera include *Spiroclypeus* sp. *Blankenhorni, Peneroplis* sp., 149. *P. thomasi, Archaias hensoni, Spirolina* sp., *Triloculina trigonula, Borelis pygmaea, Borelis melo, Meandropsina iranica, Miogypsinoides complanatus, Miliolid, Pyrgo* sp., *Miliola* sp., *Quinqueloculina* sp., *Schlumbergerina* sp., *Lithophyllum* sp., *Lithothamnium* sp., *Subterraniphyllum thomasi, Rupertia* sp., *Onychocella* sp., and *Tubucellaria* sp. The age of this biozone is determined to be Burdigalin based on microscopic studies.

Table. 1. Comparison of the Mishan Formation biozones (established by Wynd, 1965; Adams and Bourgeois, 1967; Cahuzac and Poignant, 1997; and Laursen et al., 2009)

<table>
<tr><th>Stage</th><th>Wynd (1965)</th><th colspan="2">Adams & Bourgeois (1967)</th><th>Cahuzac and Pignant(1997)</th><th>Laursen et al. (2009)</th><th>This study</th></tr>
<tr><td>Burdigalian</td><td>Borelis melo curdica (zone 61)</td><td colspan="2">Borelis melo group - Meandropsina iranica</td><td>Borelis melo group- Miogypsina</td><td>Borelis melo curdica Borelis melo melo</td><td>Borelis melo group</td></tr>
<tr><td rowspan="4">Aquitanian</td><td rowspan="4">Austrotrilina howchini Peneroplis evolutus (zone 59)</td><td>Elphydium sp. 14. Miogypsina</td><td rowspan="4">Miogipsinoides Archias - Valvulinid</td><td rowspan="4">Austrotrilina howchini – Miogysina-Miogypsinoides deharti</td><td>Indeterminate</td><td>Operculina – Rotalia viennoti</td></tr>
<tr><td rowspan="2">Archias asmaricus</td><td rowspan="3">Miogypsina-Elphydium sp. Peneroplis farsensis</td><td rowspan="2">Miogypsina – Elphydium sp. Peneroplis farsensis</td></tr>
<tr><td>Miogypsinoides-Archias - Valvulinid</td></tr>
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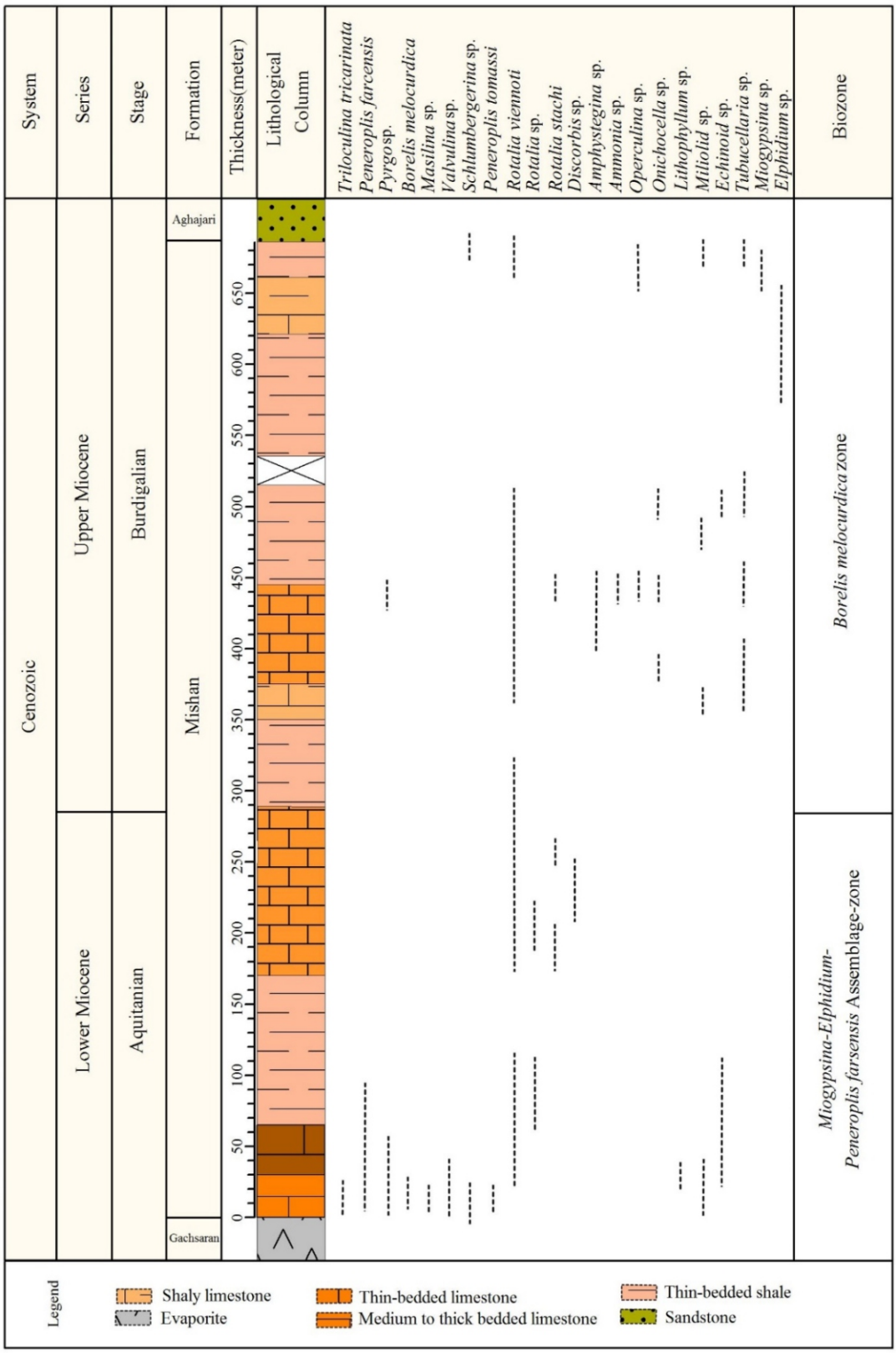

Fig. 10. Distribution of biostratigraphic and foraminifera biozonation of the Bastak section.

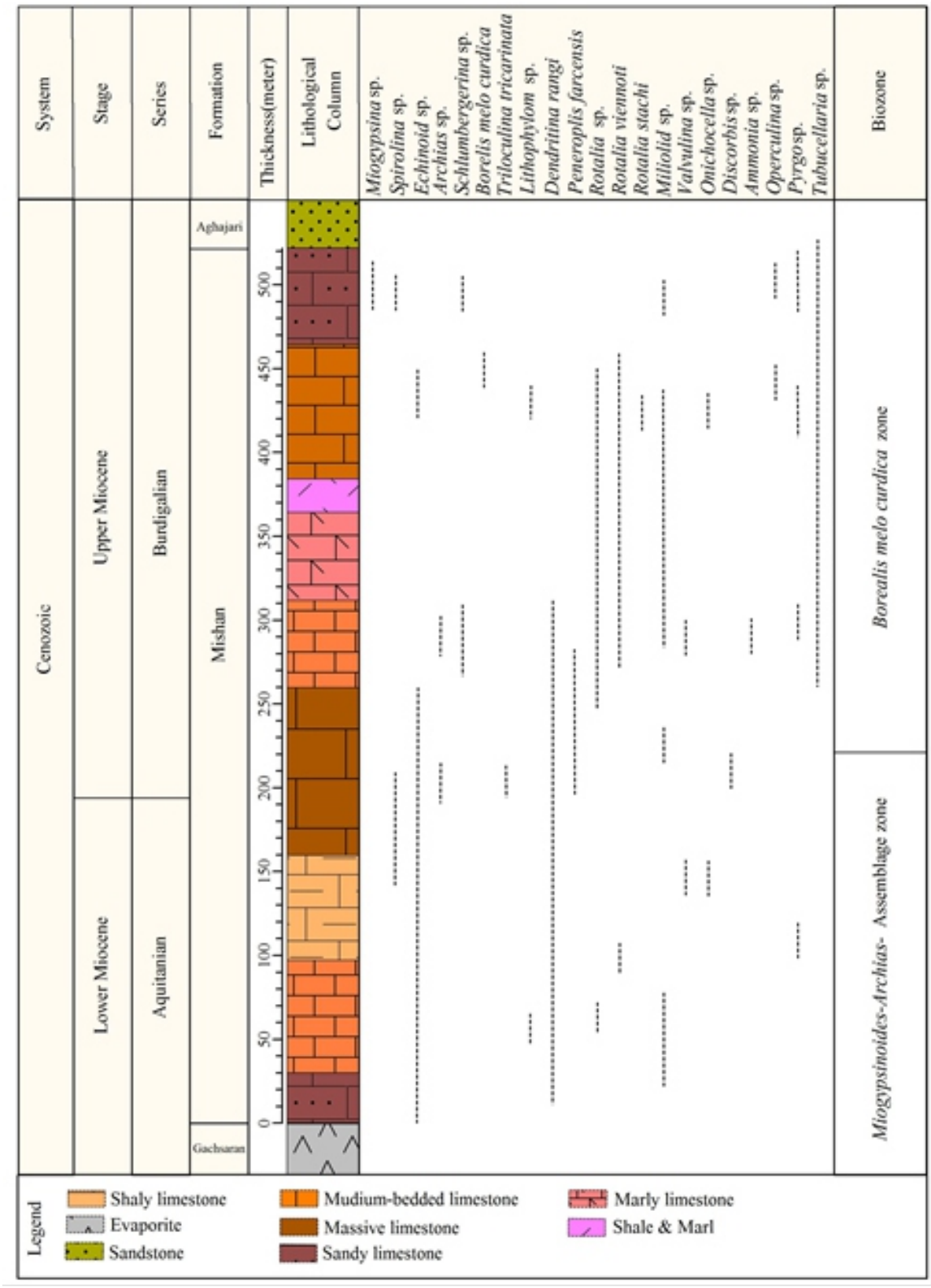

Fig. 11. Distribution of Foraminifera and biostratigraphic biozonation the Farashband section.

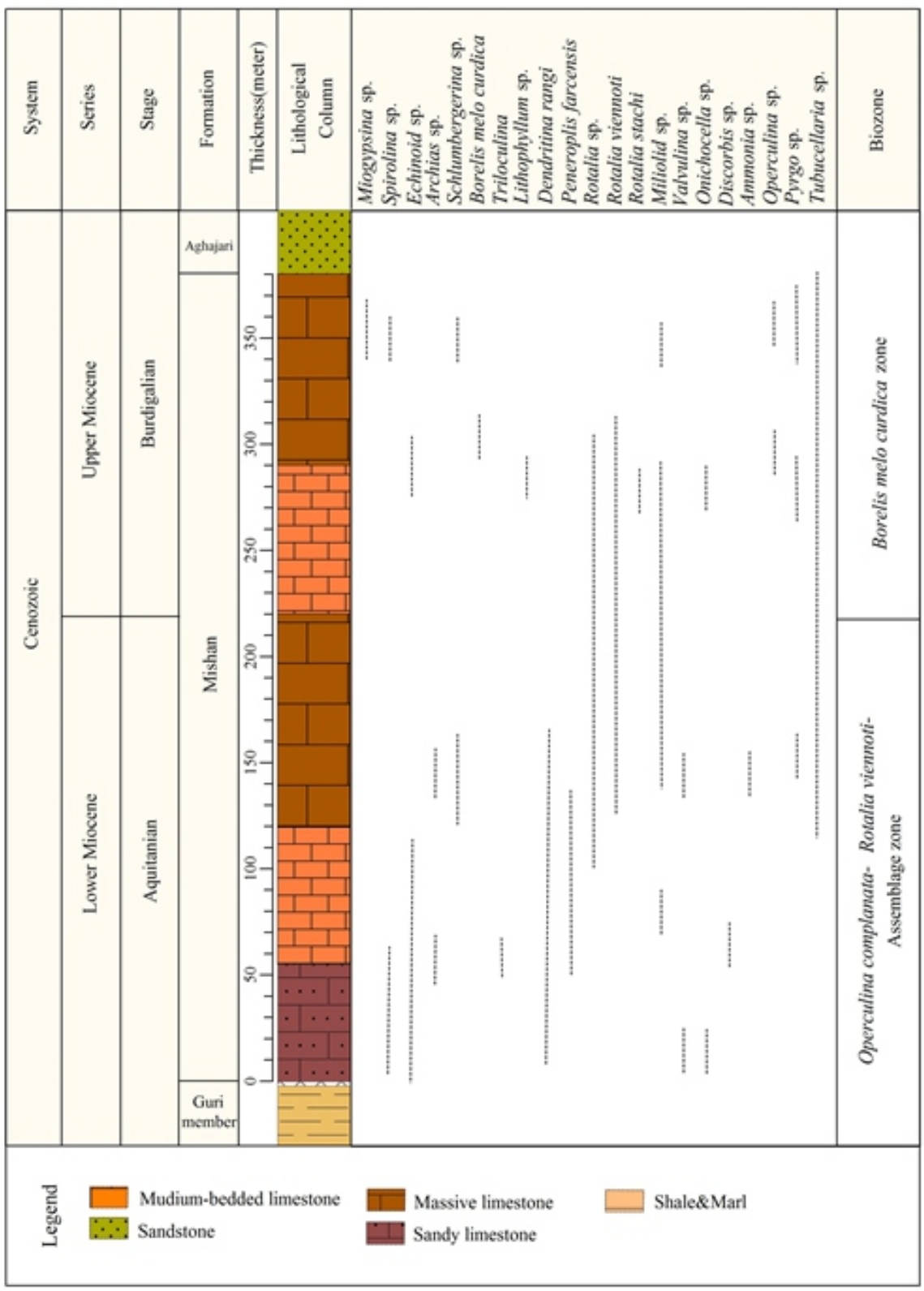

Fig. 12. Distribution of Foraminifera and biostratigraphic biozonation of the Kuh-e Khush section.

4.3 Facies analysis

In the study area, the Mishan Formation facies analysis is resulted in the description of 8 facies types of MF.1 to MF.8 which characterize platform development.

MF.1. Bioclastic (*Rotalia* and *Operculina*) packstone; MF.2. Large benthic foraminifera and coral boundstone; MF.3. Bioclastic wackestone-packstone; MF.4. Bioclastic (*Miliolids*) wackestone; MF.5. Bioclastic (*Rotalia Viennoti*) packstone; MF.6. Miliolids peloids bioclastic wackestone; MF.7. Marl facies; and MF.8. Intraclast bioclastic wackestone

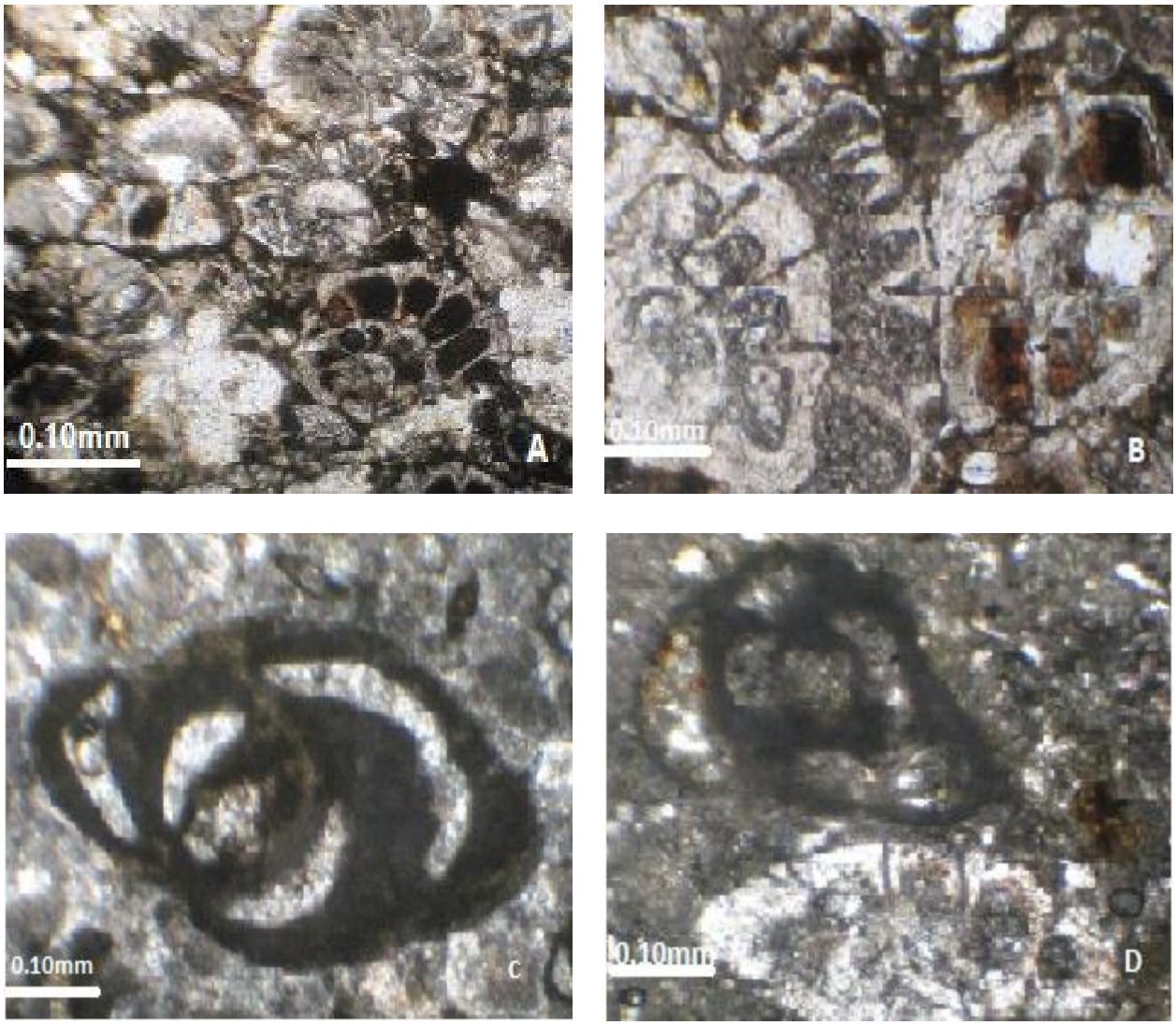

Fig. 13. Photomicrograph of microfacies of the Mishan Formation: a) Bioclast packstone (Rotalia Viennoti), b) Bioclast packstone, c) Bioclast wackestone, and d) Intraclast bioclastic wackestone.

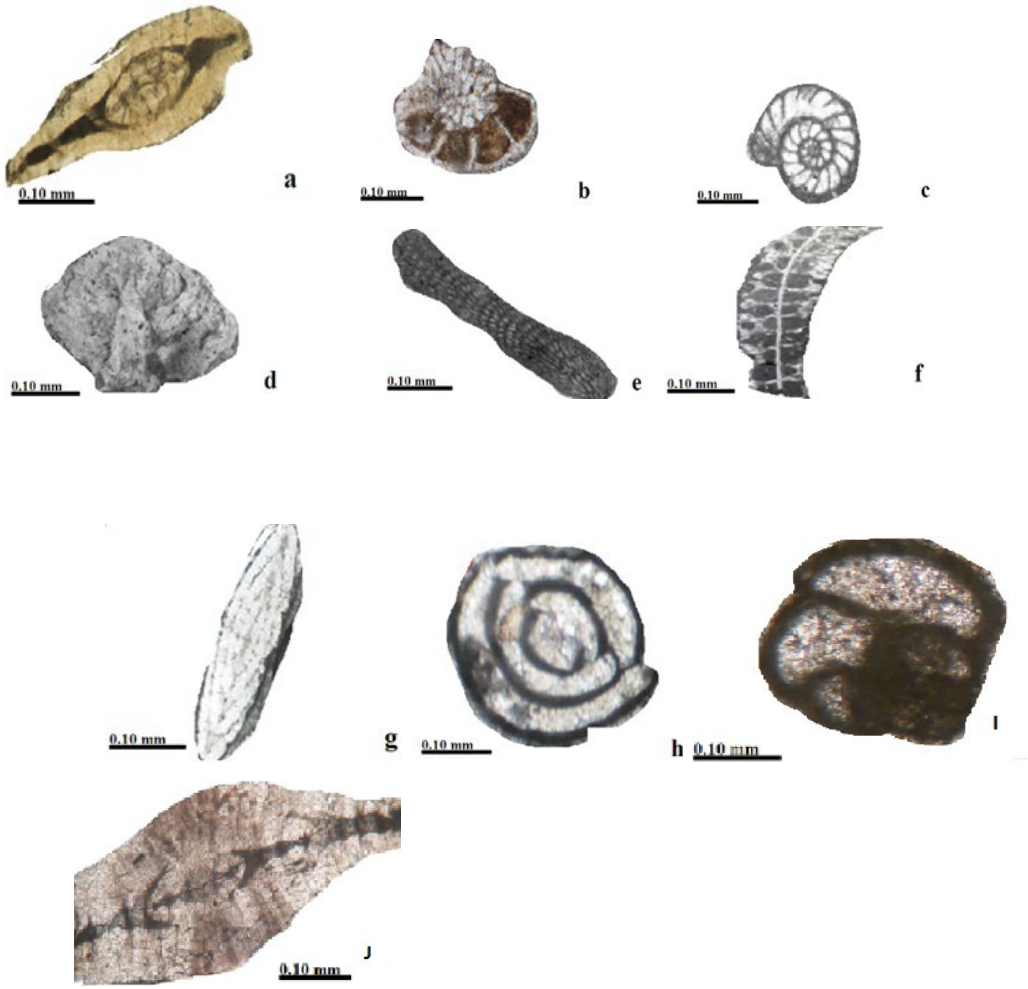

Fig. 14. Photographs of foraminifera in thin sections of the Mishan Formation: a) *Operculina* sp., b) *Ammonia* sp., c) *Elphidium* sp., d) *Rotalia* sp., e) *Lithophyllum* sp., f) *Tubucellaria* sp., g) *Nummulites* sp., h) *Pyrgo* sp., i) *Valvulina* sp., and j) *Operculina complanata.*

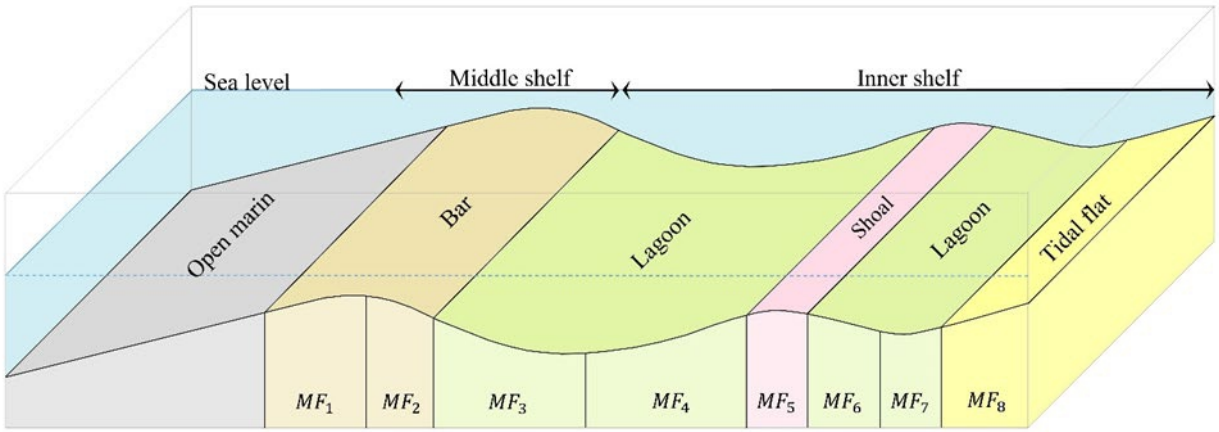

Fig. 15. Schematic block diagram of depositional model of the Mishan Formation in the study areas

4.4 Sequence stratigraphy

It is important to highlight that the varying facies of the Mishan Formation within the study area can be attributed to distinct paleogeographic conditions in the respective basins and the influence of local tectonic activity within the study area. The recognition of disconformity levels has been accomplished through field observations, microfacies analysis, and lithologic evaluations. In a broader context, based on sequence stratigraphy investigations, two third-order sedimentary sequences (third-order cycles) have been identified for the sediments of the Mishan Formation within the analyzed stratigraphic sections (Emery and Myers, 1996; Baum and Vail, 1988).

Sedimentary Sequence No. 1: This sequence is associated with the Mishan Formation and corresponds to the Aquitanian age. The thickness of this sequence varies across the studied sections, with 290 m in the Bastak section, 260 m in the Farashband section, and 220 m in the Kuh-e Khush section. The maximum flooding surface (MFS) within this zone is observed in the wackestone limestone section, characterized by the presence of *Ammonia beccarii, Rotalia* sp.,and *Eulepidina* foraminifera. This sequence encompasses lowstand systems tract (LST), highstand systems tract (HST), and transgressive systems tract (TST) facies. The LST and TST facies groups include tidal flat facies limestones, while the HST facies group comprises lagoon facies (Figs. 16-19).

Sedimentary Sequence No. 2: The age of this sequence ranges from Aquitanian to Burdigalian. The lower and upper lithostratigraphic limits are of the SB2 type. The thickness of this sequence varies across the studied sections, with 160 m in the Bastak section, 260 m in the Farashband section, and 160 m in the Kuh-e Khush section. The maximum flooding surface (MFS) in the studied sections is characterized by packstone facies containing glauconite, benthic foraminifera, and algae such as *Miliolid, Quinqueloculina* sp., *Schlumbergerina* sp., *Lithophyllum* sp., *Lithothamnium* sp., and *Subterraniphyllum thomasi.* This sequence encompasses transgressive systems tract (TST) facies groups, including open lagoon and shoal environments, and highstand systems tract (HST) facies groups, consisting of lagoon and tidal flat facies. The parasequence stacking pattern in HST exhibits a retrogradational form, whereas aggradational stacking is observed in TST (Emery and Myers, 1996) (Figs. 16-19).

Sedimentary Sequence No. 3: It is associated with the Burdigalian age and is related to the Mishan Formation. The lower and upper lithostratigraphic limits are of the SB2 type. The thickness of this sequence in the Bastak section is 220 m. The upper limit of this sequence is of the SB2 type, situated below the Aghajari Formation, and corresponds to the Burdigalian age. Sequence No. 1 in the Farashband, Kuh-e Khush, and Bastak sections exhibits a lithostratigraphic limit of the SB2 type, positioned above the Gachsaran Formation. The upper limit of this sequence is of the SB2 type, placed beneath Sequence No. 2, and corresponds to the Aquitanian age. Sequence No. 2 in the Farashband, Kuh-e Khush, and Bastak sections has a lithostratigraphic limit of the SB2 type, located above Sequence No. 1. The upper limit of this sequence is of the SB2 type, positioned below the Aghajari Formation in the Kuh-e Khush anticline section, and the Farashband and Bastak sections are placed beneath Sequence No. 3, which corresponds to the Aquitanian age. Sequence No. 3 in the Bastak section exhibits a lithostratigraphic limit of the SB2 type, situated above Sequence No. 2. The upper limit of this sequence is of the SB2 type, positioned below the Aghajari Formation, and corresponds to the Aquitanian-Burdigalian age (Figs. 16-19).

5. Conclusions

In this study, three stratigraphic sections related to the Mishan Formation were chosen and scrutinized. Upon examining the foraminifera within these sections, four biozones were discerned and introduced. Biozone No 1. *Miogypsina-Elphidium-Peneroplisfarsensis* Assemblage zone, Biozone No 2. *Miogypsinoides-Archias-Valvulinid* Assemblage zone, Biozone No 3. Operculina complanata-Rotalia viennoti Assemblage zone, Biozone No 4.

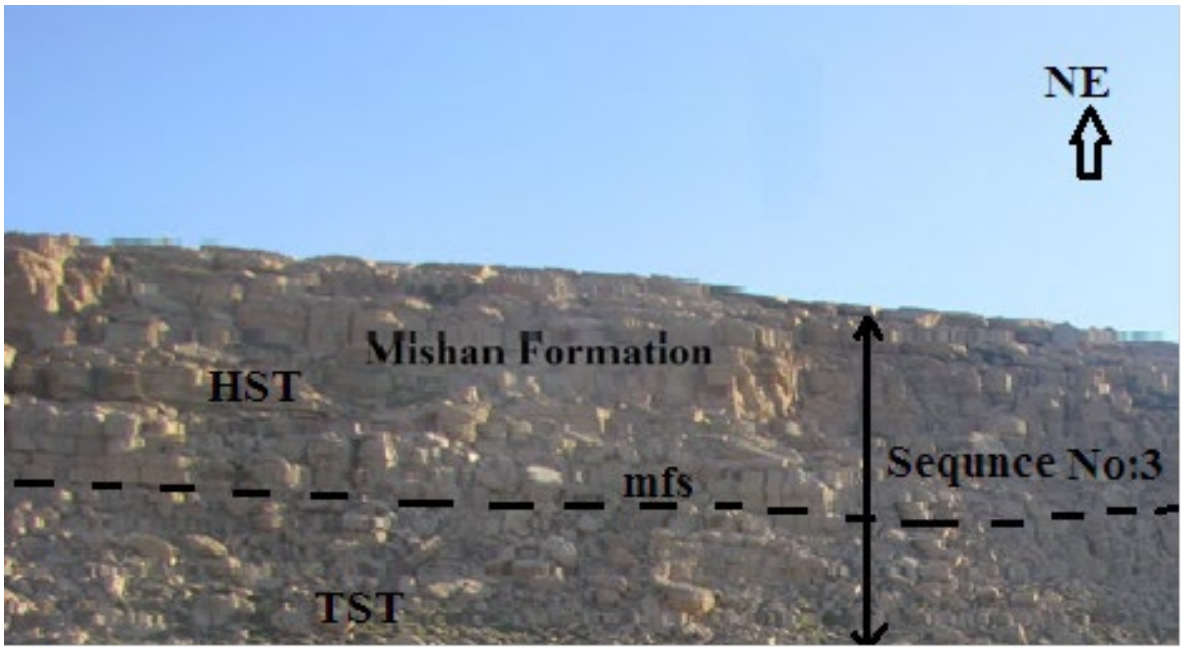

Fig. 16. Photograph of the facies of Sequence No. 3 and the maximum transgressive level in the Bastak stratigraphic section

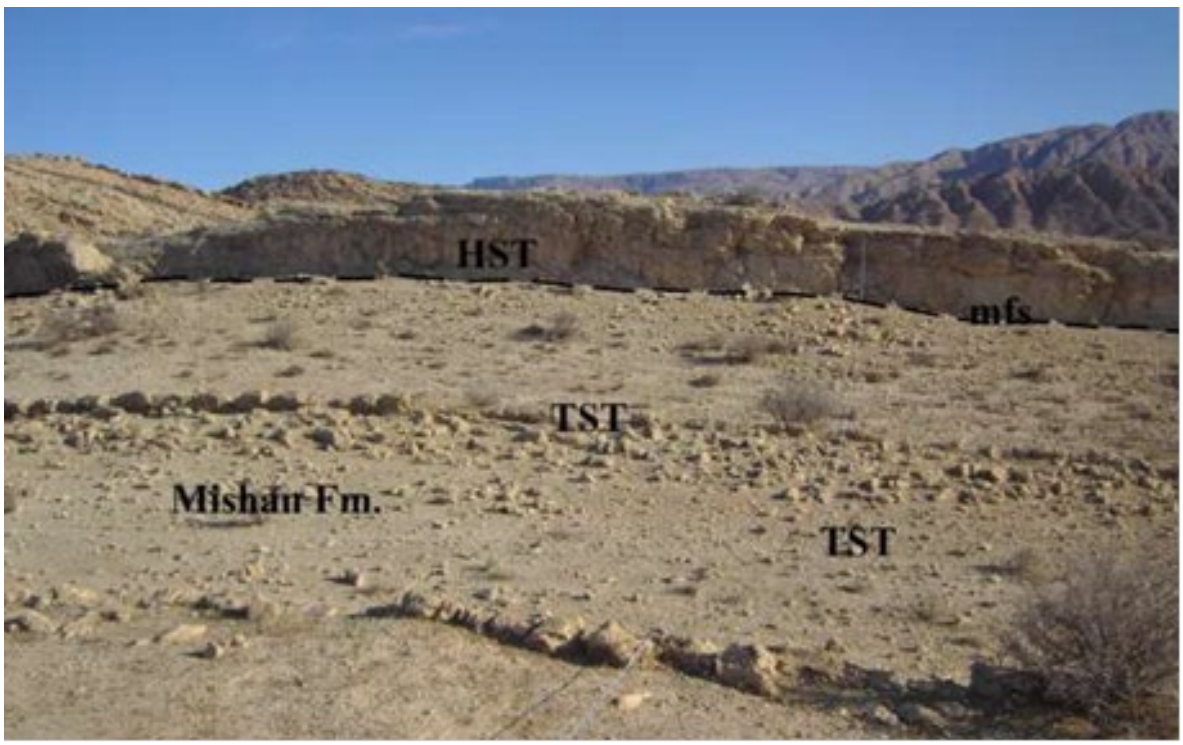

Fig. 17. Photograph of TST and HST facies related to the Mishan Formation in the Farashband stratigraphic section.

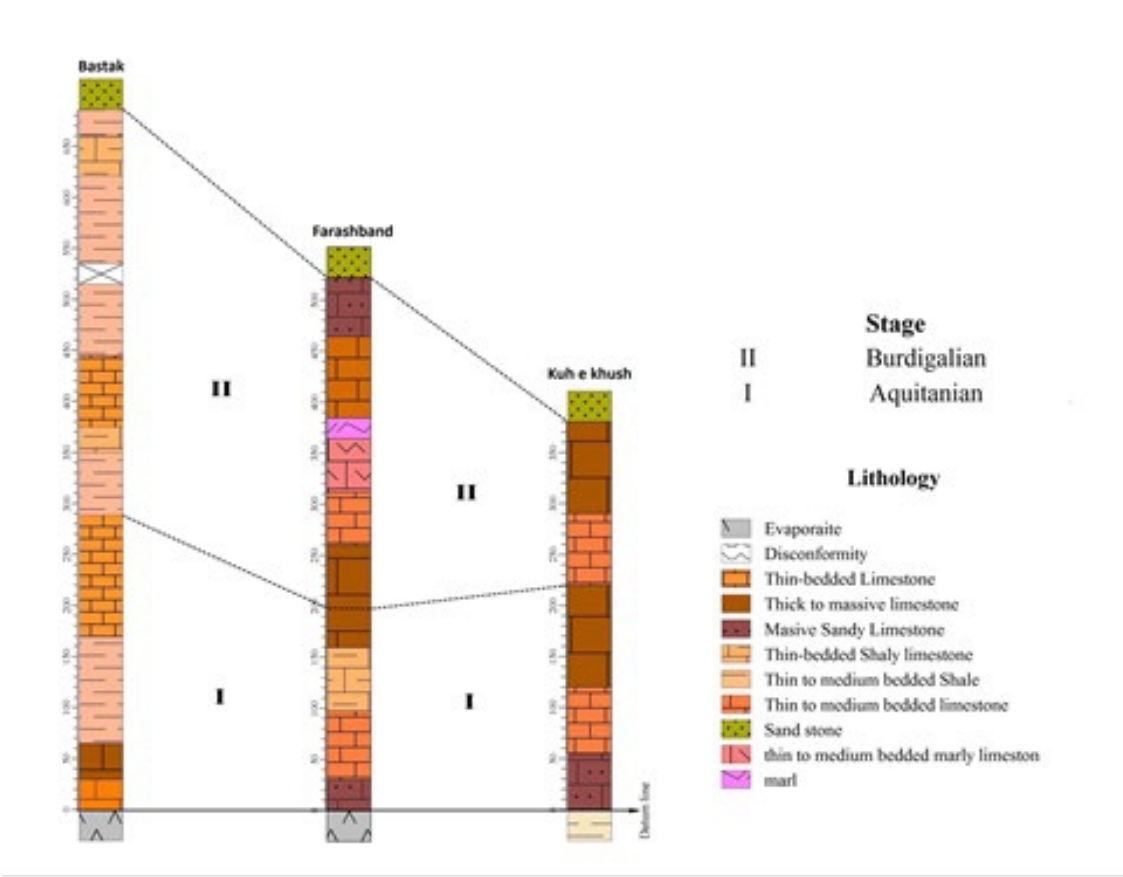

Fig. 18. Sequence stratigraphic correlation of the Mishan Formation in the Bastak, Farashband, and Kuh-e Khush sections.

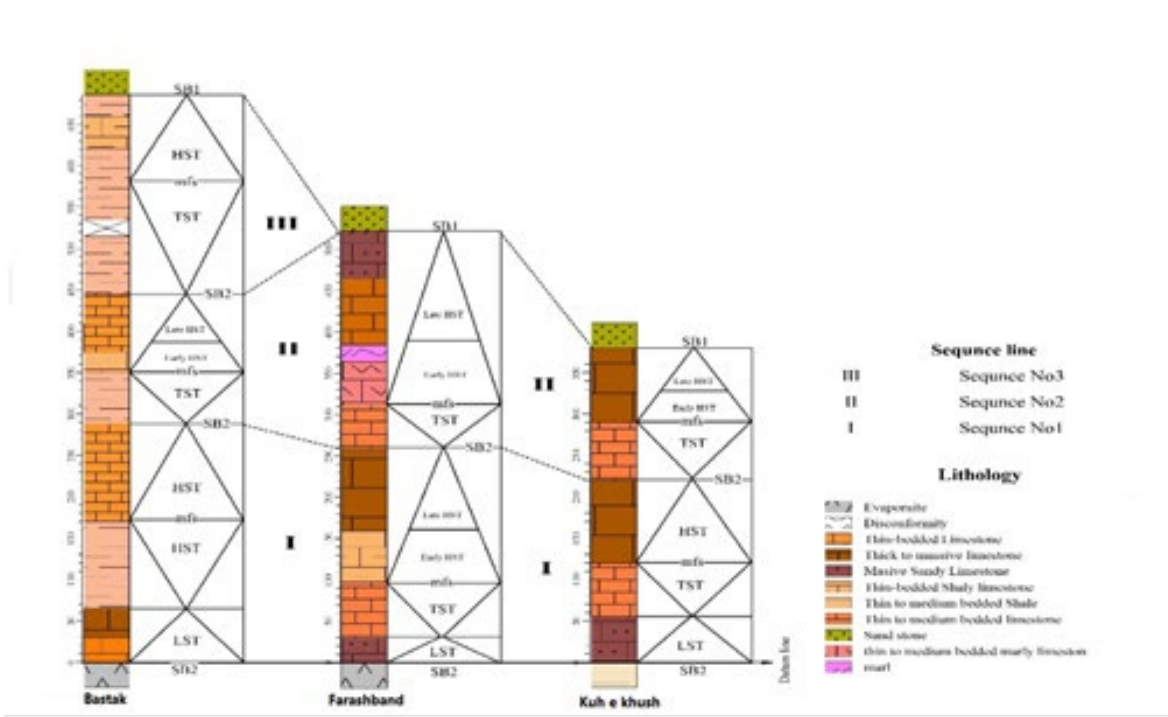

Fig. 19. Sequence stratigraphic correlation of the Mishan Formation in the Bastak, Farashband, and Kuh-e Khush sections.

Borelis melo curdica zone. Furthermore, three sedimentary sequences were elucidated. Sedimentary Sequence No. 1: The thickness of this sequence varies across the studied sections, with 290 m in the Bastak section, 260 m in the Farashband section, and 220 m in the Kuh-e Khush section. Sedimentary Sequence No. 2: The thickness of this sequence varies across the studied sections, with 160 m in the Bastak section, 260 m in the Farashband section, and 160 m in the Kuh-e Khush section. Sedimentary Sequence No. 3: The thickness of this sequence in the Bastak section is 220 m. Index foraminifera in thin sections of the Mishan Formation embodies *Operculina* sp, *Ammonia* sp, *Elphidium* sp, *Rotalia* sp, *Nummulites* sp, *Pyrgo* sp, *Valvulina* sp, *Operculina complanata.* In the study area, the Mishan Formation' facies analysis is resulted in the classification of 8 facies types (MF.1 to MF.8). MF.1=Bioclastic packstone (*Rotalia* and *Operculina*), MF.2=Large benthic foraminifera and coral boundstone, MF.3=Bioclastic wackestone-packstone, MF.4=Bioclastic (*Miliolids*) wackestone. Wynd (1965) ascertained the Mishan Formation' age in the type section as being of Early to Middle Miocene. Fashaki and Ghalavand (2003) determined the age of the Mishan Formation in the Type Section as going back to Middle Miocene, based on calcareous nannofossils. Homayoun Zadeh (2002) studied the Mishan Formation's biostratigraphy and lithostratigraphy in central part of Dezful embayment, and introduced its age from Aquitanian to Burdigalian. Daneshian et al. (2015) studied the Paleogeography of depositions of Mishan Formation in sedimentary basin of Hendoun section and introduced its age from Burdigalian to Langhian. In the studied stratigraphic sections, the age of the Mishan Formation, as indicated by microfossil studies, spans from the Aquitanian to the Burdigalian.

Authors Contribution

Rouzbeh Tavallali, proposed the main concept and involved in write up. Vahid Ahmadi, assisted in establishing sequence stratigraphy of the section. Reza Mirzee Mahmoodabadi, collected field data. Rouzbeh Tavallali, did provision of relevant literature, and review and proof read of the manuscript. Vahid Ahmadi, did technical review before submission and proof read of the manuscript.Rouzbeh Tavallali, did collection of field data. Vahid Ahmadi, was involved in 14 assistance in preparation of illustration and plates of figures.

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