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Microfacies analysis, Depositional Environment and Biostratigraphy of the Early Eocene Dungan Formation, Kohlu area Balochistan, Pakistan

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Abstract

The shallow marine carbonate sequences of the Dungan Formation are well-exposed in Sulaiman Fold-Thrust Belt, Eastern Neotethys, Pakistan. In the study area, Palaeogene carbonate platform deposits of the Dungan Formation consists of medium to thick bedded shallow marine carbonate sediments. The exposed outcrop has a thickness of 56 m, underlain by Cretaceous Pab Formation and overlain by Eocene Ghazij Group. The Dungan Formation was analyzed for microfacies, depositional environment and the age diagnostic Larger Benthic Foraminifera (LBF) were utilized to date the formation. The formation contain rich LBF assemblages such as nummulitids, alveolinids *Lockhartia, Orbitolites,* miliolids and algae. The identified LBF suggest that the deposition of the Dungan Formation occurred in SBZ 5 to SBZ 7 biozones. On the basis of LBF, other associated biota, and the amount of matrix, six carbonate microfacies have been identified. These microfacies are interpreted to have been deposited in two major depositional environments including inner and middle ramp settings.

Keywords: *Larger Benthic Foraminifera (LBF); Microfacies; Early Eocene; Dungan Formation; Sulaiman Belt.*

1. Introduction

The Palaeogene of Pakistan represents thick sedimentary succession in the Indus Basin and Pishin Belt (Afzal et al., 2011a, b; Hanif et al., 2014, 2021; Bukhari et al., 2016; Babar et al., 2018; Uddin et al., 2019; Rahman et al 2021a, b; Abdullah et al., 2023). The Palaeocene to Early Eocene in the Sulaiman Belt of the Indus Basin is represented by the Dungan Formation which represent a range of lithofacies such as limestone, shale, siltstone with subordinate sandstone (Afzal et al., 2011a, b; Hanif et al., 2014). The carbonate facies in the Dungan Formation are well developed in the western part of the Sulaiman Belt such as Quetta, Harnai, Kohlu, Ziarat areas, whereas the clastic facies are dominant in the eastern part (e.g., Rakhi Nala) of the Sulaiman Belt (Afzal et al., 2011a, b; Rehman et al., 2018). The biota documented from the carbonate succession in western Sulaiman Belt is dominantly shallow marine biota, rich in Larger Benthic Foraminifera (LBF), whereas the clastic facies in the eastern Sulaiman Belt are rich in deep marine planktic and smaller benthic foraminifera, reflecting a strong lateral facies variation (Afzal et al., 2009; 2011a, 2011b; Hanif et al., 2014). The Early Eocene shallow marine carbonate sequence of the Dungan Formation in the Sulaiman Belt, formed by biotic and abiotic carbonate precipitation in the Eastern Neo Tethys (Afzal et al., 2011b). The LBF and other biotic assemblages are important age markers to determine age of the Early Eocene carbonates and recognize depositional environment (Afzal et al., 2011a, 2011b). The LBF assemblages in the studied section are dominated by perforate and imperforate LBF species, and few fragments of corals are also present in the basal part. These biotic and abiotic components in the shallow marine deposits represent facies which are paleoecological indicators, as the conditions in Early Eocene were favorable for the abundance and diversification of these components throughout the NeoTethys (Zhang et al., 2019; Kamran et al.,2021). Microfacies analysis with an aid of LBF and sedimentology directs for reconstructing the carbonates palaeodepositional environments, the controlling factors responsible for carbonate deposition and the distribution of organisms (Flügel, 2010). The Early Eocene carbonates of the Dungan Formation from some parts of the Sulaiman Belt (Quetta and Ziarat) are well studied for microfacies analysis (e.g., Afzal et al., 2011b) but some of the remote areas such as Kohlu Section which represent thick carbonate succession has not been studied yet.

The main aims of the current study are to (a) report larger foraminiferal assemblages of the Dungan Formation of the Kohlu section (b) use the obtained LBF diagnostic taxa to date the formation and (c) analyse microfacies to decipher the paleodepositional environment.

2. Geological Setting

The West Pakistan Fold-Thrust Belt (WPFTB) is the southern extension of the greater Himalayas, located on the north-western margin of the Indian Plate. The WPFTB evolved after the Indian Plate collided obliquely with the southern part of the Eurasian Plate (Afghan Block) (Sarwar and DeJong, 1979). The belt is divided into two segments: the northeastern arcuate belt is called the Sulaiman Fold-Thrust-Belt (SFTB) and southern linear belt is Kirthar Fold-Thrust-Belt (KFTB). The SFTB is bounded by Muslim Bagh Ophiolite and Pishin Belt in the west and Indus plains in the east. SFTB is divided into Sulaiman Range and Sulaiman Lobe. Sulaiman Lobe is separated from Sulaiman Range by the Western Sulaiman Transform Fault Zone, of which the Kingri Fault is the major fault. Bannert et al. (1992) considered the Harnai Fault as being the western boundary of the Sulaiman Lobe. Sulaiman lobe is more than 300 km wide between the Muslim Bagh ophiolites and Sui anticline (Fig. 1). It is tectonically active, convex to the south and consisting of major Nappes. Triassic to Cretaceous rocks outcrop in the cores of the Bibai, Gogai, Mazar Drik and Muslimbagh-Zarra nappes (Bannert et al., 1992; Ellouz et al., 1995a, 1995b). The nappes were generally emplaced southwards, possibly above a basal décollement in Lower Jurassic or older strata. Bannert et al. (1992) interpreted the Zarghun syncline (Miocene molasse) as a passive roof duplex that was thrusted northward over Eocene limestone. The study area lies in Mazar Drik Nappe, a part of Khattan-Domanda zone that belongs to toe frontal zones of the external slope of the Sulaiman-Kirthar Mega Anticlinorium. Karmari Thrust runs east-west in the block and Barkhan strike slip fault bound the block in the east. Eocene to upper Mesozoic strata outcrop in anticline cores in the Loralai and Mazar Drik nappes, where folding is also intense.

The oldest rocks exposed are Cretaceous, Mughal Kot Formation while rocks up to Jurassic have been penetrated by exploratory wells in the block. Carbonates of Chiltan Formation represents Jurassic in the area, which is underlain by shales and sandstones of Sembar and Goru formations (Lower Cretaceous). Carbonate and marl facies of Parh, Mughal Kot and Pab formations represents the Upper Cretaceous, which has unconformable contact with Paleocene (Muhammad et al., 2018; Ullah et al., 2022). Stratigraphically, the Dungan Formation unconformably overlies either the Late Cretaceous Fort Munro Formation, Parh Formation or and Pab Formation, and is overlain by the shales, clays and siltstones of the Ghazij Group (Afzal et al., 2011b).

Methodology

Based on the geological field observations and logging of shallow marine carbonate samples, sedimentological and biostratigraphical analysis were made from Kohlu section, Dungan Formation (figs 2, 3), in the southwest of Kohlu City. Sixty samples were picked at about one-meter interval from Kohlu section, and were thin sectioned to identify the age diagnostic LBF, and determine the major facies types (MFTs) by assessing biogenic and abiogenic components, matrix and cements. The description of MFTs, mainly is based on Flügel (2010) and Dunham (1962) carbonate classification scheme. For LBF taxonomic identification relevant published literature has been utilized such as Nuttall (1925), Davies (1927), Hottinger (1960), Adams (1970), Schaub (1981), Wan (1990), Serra-Kiel et al. (1998), Afzal et al. (2009, 2011a), and Kamran et al. (2021). The foraminiferal assemblages identified are utilized to establish LBF biostratigraphy for the Dungan Formation of the Kohlu section following standard biozones of Serra-Kiel et al. (1998). Paleoenvironmetal reconstructions are primarily established using distribution of the LBF and have been compared with Hottinger (1997), Pomar (2001) and Romero et al. (2002).

3. Results and Discussions

3.1 LBF Assemblages of the Early Eocene Dungan Formation

The Kohlu Section of the Dungan Formation has yielded rich and diverse LBF including many age diagnostic taxa. These identified age diagnostic LBF species include *Nummulites Fraasi, N. minervensis* (SBZ 6), (SBZ 5-6), *Alveolina pasticillata* (SBZ 6), (SBZ 6), *A. ellipsoidalis* (SBZ 6), *A. vredenburgi* (SBZ 5-6), *A. pisiformis* (SBZ 6-7), *A. aramaea aramaea* (SBZ 5), *Discocyclina ranikotensis* (SBZ 5-7), and *Orbitolites biplanus* define Early Eocene (Ypresian) age SBZ 5-7 (Serra-Kiel et al., 1998; Afzal et al., 2011a; Zamagni et al., 2012; Zhang et al., 2019;) (figs 4, 5). Other associated species include *Glomalveolina* sp., *Fallotella alavensis, Sakesaria* cf. *dukhani, Lockhartia roeae, Lockhartia paraehaimei, Glomalveolina levis, Assilina azilensis, Rotalia newboldi, Aberisphaera gambanica, Assilina dandotica, Lockhartia conditi,* miliolid sp., *Lockhartia tipperi, Assilina ornato, Operculina subsalsa, , Orbitolites* sp. and *Alveolina rotundata.*

4. Microfacies Analysis

Six microfacies were identified based on petrographic (frequent biogenic composition and depositional texture) analysis and field observations in the Kohlu Section (figs 6, 7, 8).

4.1 Bioclastic gastropodal wackestone (MF 1)

This microfacies contains fine grained lime mud with fragmented and rare complete gastropods (up to 35%; ≤2 mm). In this microfacies, other bioclast fragments are miliolids, bivalves, dasycladacean algae, echinoids, bryozoans with less than 25% abundance. Minor amount of silt sized quartz grains are also present. Most of the bioclasts, however, have been entirely dissolved and their outlines enveloped by thin micrite, which are then filled by cement (sparry calcite) (figs 6A, 6B).

Interpretation: Poor diversity of bioclasts dominated by gastropods, rich lime mud, with rare miliolids, suggest either a subtidal or intertidal low-energy conditions i.e., inner ramp-lagoon, where salinity and temperature are extreme (Purser and Seibold, 1973). In stressful environments (hypersaline), gastropods may be the major biotic constituents of these deposits (Scholle and Ulmer-Scholle, 2003). Dasycladal green algae prefer shallow warm water in a low energy lagoonal settings in inner ramp (Beavington-Penny et al., 2006; Granier, 2012). Bryozoan, echinoderms and bivalves are suggestive of a normal shallow marine environment (Sallam and Ruban, 2020). In correlation with equivalent modern marine deposits (e.g., the Persian Gulf), gastropods are common biotic components of the shallow subtidal settings, especially the shallowest water of the lagoonal environment from shoreline to depths less than 2 m (Purser and Seibold, 1973) (Fig. 8).

4.2 Algal foraminiferal wackestone (MF 2)

This microfacies (figs 6C, 6D) is dominanted by calcareous green algae that ranges between 20 and 30%. Miliolids, echinoids, alveolinids, *Opertorbitolites,* ostracods, broken mollusk fragments are less frequent (≤30%).

Interpretation: The occurrence of green algae, and rich lime mud matrix indicate low energy environmental conditions in warm water such as lagoonal setting of the inner ramp (Heckel, 1972). The occurrence of echinoderms, bivalves, gastropods and ostracods suggests shallow marine conditions (Scholle and Ulmer-Scholle, 2003; Sallam et al., 2015). Soritids favour upper euphotic zone in a shallow lagoonal environment (Hohenegger, 2004). Miliolids and *Alveolina* suggests shallow warm water environment of inner ramp conditions (Gilham and Bristow, 1998; Beavington-Penny and Racey, 2004). Hence, low to moderate algal diversity and the presence of shallow marine fauna indicates deposition in an inner ramp environment.

4.3 Bioclastic alveolinid nummulitid wackestone (MF 3)

This microfacies (figs 6E, 6F) is rich in alveolinids (≥30%; about <2.5 mm dia), *Nummulites* ((≥20%) and other common biogenic components like *Orbitolites* sp., miliolid, green algae, bivalve, echinoid, valvulinid, rotaliids, and gastropod (10 to 20%). Nummulitids, soritids, peloids, rare miscellaneids, and *Sakesaria dukhani* make up nearly 5%. Fractures filled with sparry calcite cement are present at places.

Interpretation: Living alveolinids such as *Borelis* and *Alveolinella quoyi* are common in a range of shallow marine settings from 3 m to a depth of 35 m (Severin and Lipps, 1989; Langer and Hottinger, 2000). *Alveolina* in the Eocene limestones is interpreted to have occupied a wide range of shallow, warm water environments from a range of 5 m down to a depth of about 80 m (Hohenegger et al., 1999; Racey, 2001). *Nummulites* occupied a wide spectrum of ramp environments from distal inner ramp to proximal outer ramp settings but lenticular *Nummulites* are documented in association with the *Alveolina* in distal inner ramp (Racey, 2001). Small rotaliids and miliolids are common in lagoonal setting in less restricted and hypersaline conditions (Geel, 2000). The dasycladacean algae is common in warm water, low energy lagoonal settings (Beavington-Penny et al., 2006). The diverse LBF with the dominance of *Alveolina* along with lenticular *Nummulites* in association with dasycladacean algae suggests a distal inner ramp setting for this microfacies.

4.4 Bioclastic alveolinid packstone (MF 4)

This microfacies (figs 7A, 7B) mainly consists of alveolinids, miliolids, *Orbitolites* and other LBF, embedded in micritie and spar cement. The dominant allochems (ave. 50%) are *Alveolina vredenburgi, Glomalveolina* sp., *Orbitolites* and milliolids. Other constituents include *Sakesaria* sp., *Operculina sp.* soritids, echinoderms, *Nummulites* sp., molluscs, brachiopods and ostracods (ave. 25%). Peloids (≤8%) are also found in irregular and rounded shapes. Less than 10% micritic cement is seen. The intergranular space present at places are filled by Sparry cement.

Interpretation: Peloids are present in shallow subtidal to intertidal environments (Flügel, 2010). Miliolids are abundant in shallow warm water environment, indicative of inner ramp settings (Geel, 2000). Alveolinids are most common in protected shelf and high energy shoal settings in comparatively deeper waters than orbitolids (Rasser et al., 2005). The presence of abundant spar cement, well sorted grains, fragmentation and rare mud matrix indicate high-energy conditions (Flügel, 2010). Peloids which are grainstone texture, are interpreted as a carbonate shoal environment above normal wave base (Wilson, 1975; Flügel, 2010). Dominance of restricted marine biota suggests a leeward carbonate shoal environment.

4.5 Bioclastic nummulitid wackestone-packstone (MF 5)

This microfacies (figs 7C, 7D) contains perforate and imperforate forms of LBF and smaller benthic foraminifera such as *Nummulites* sp. (up to 50%), alveolinids (<5%), *Lockhartia* sp., *Discocyclina* (15-20%), *echinoiderms,* bivalves, and gastropods (more than 5 percent).

Interpretation: *Nummulites* are found in distal inner ramp to proximal outer ramp environments but their high abundance is common in mid ramp environment (Geel, 2000; Mehar and Adabi, 2014). *Discocyclina* has a wide environment range within the photic zone distal inner ramp to deeper outer ramp. Their lenticular forms are common in distal inner ramp to mid ramp whereas the flattened forms are abundant in distal mid ramp to proximal outer ramp environment (Racey, 2001; Beavington-Penny et al., 2006). The dominance of *Nummulites* with some alveolinids, rotalids, bivalves, gastropods, echinoderms and occurrences of lenticular *Discocyclina* suggests a mid-ramp environment below FWWB.

4.6 Bioclastic Orbitolites wackestone-mudstone (MF 6)

This microfacies is present in the basal part of the formation at 2 m in light brownish colored limestone, dominated with *orbitolities* along with some miliolids and alveolinids. The microfacies has low foraminiferal diversity (<15%) and other scattered bioclasts (≤5%) such as echinoderms, and green algae (figs 7E, 7F).

Interpretation: Poorly sorted orbitolinids of this microfacies indicate deposition in restricted shallow platform in a lagoonal environment with moderate water circulation (Anketell and Mriheel, 2000) or in the back-reef environments in sheltered water (Ghose, 1977). This microfacies is comparable with RMF19/SMF12 and FZ8 of Flügel, 2010 and Wilson, 1975, respectively.

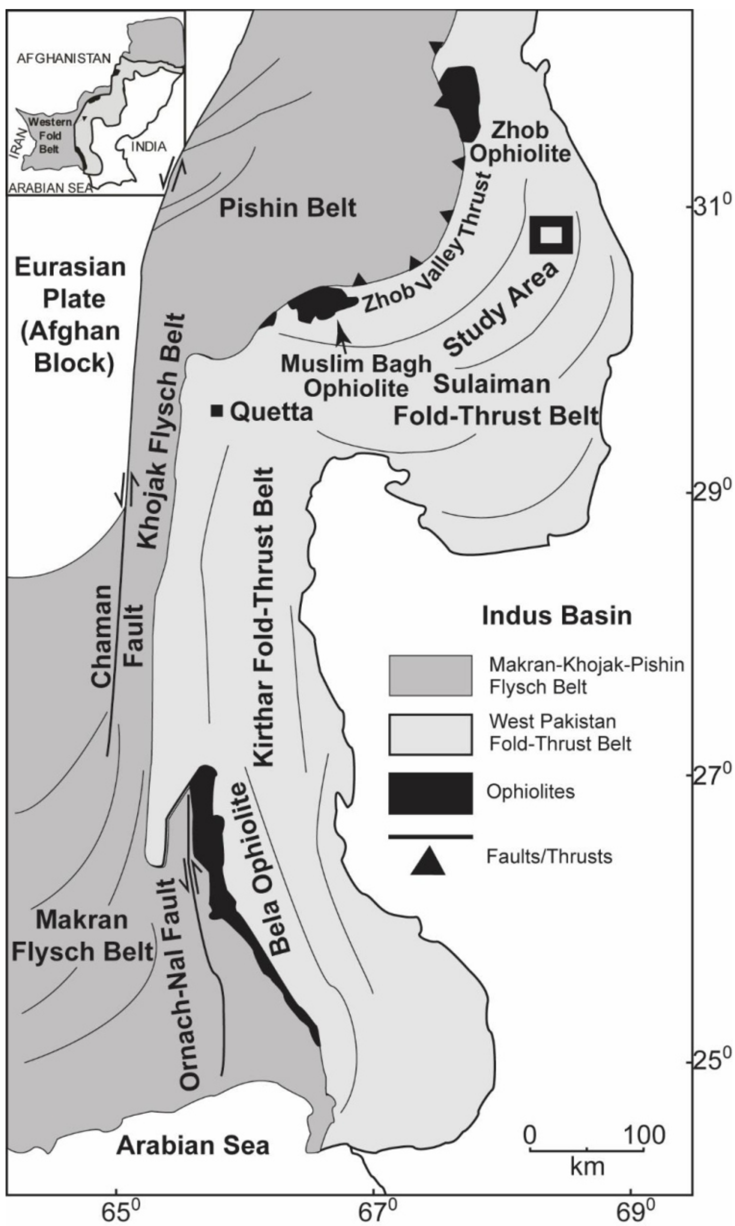

Fig. 1. Regional Geological map showing location of the study area (After Kasi et al., 2012).

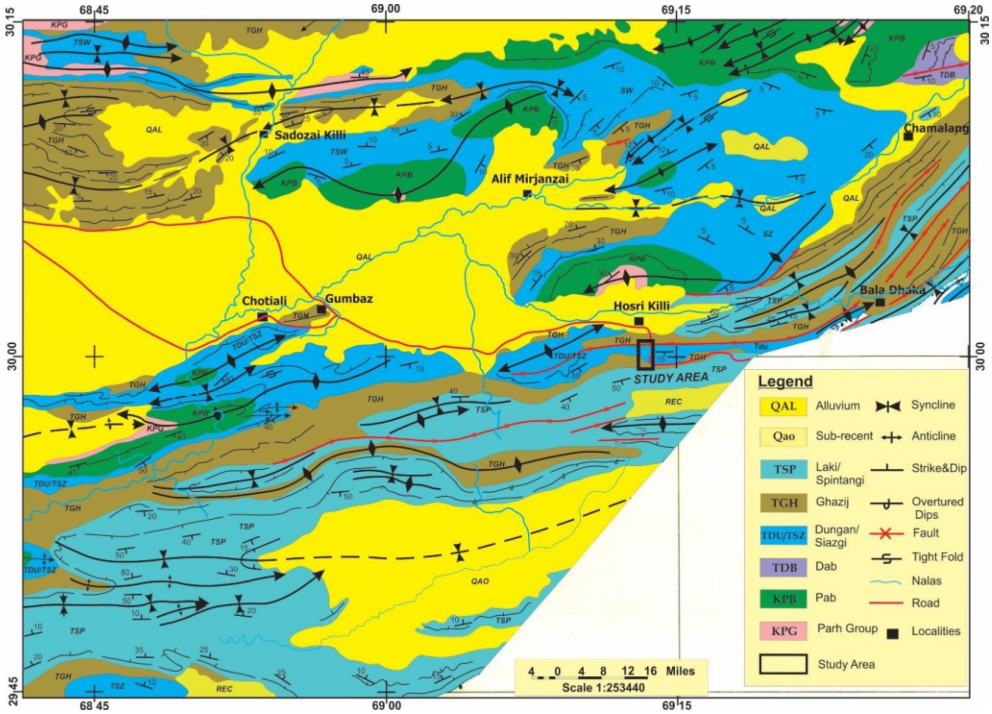

Fig. 2. Geological Map of District Kohlu and surroundings, showing position of the studied section (modified after Jones, 1961).

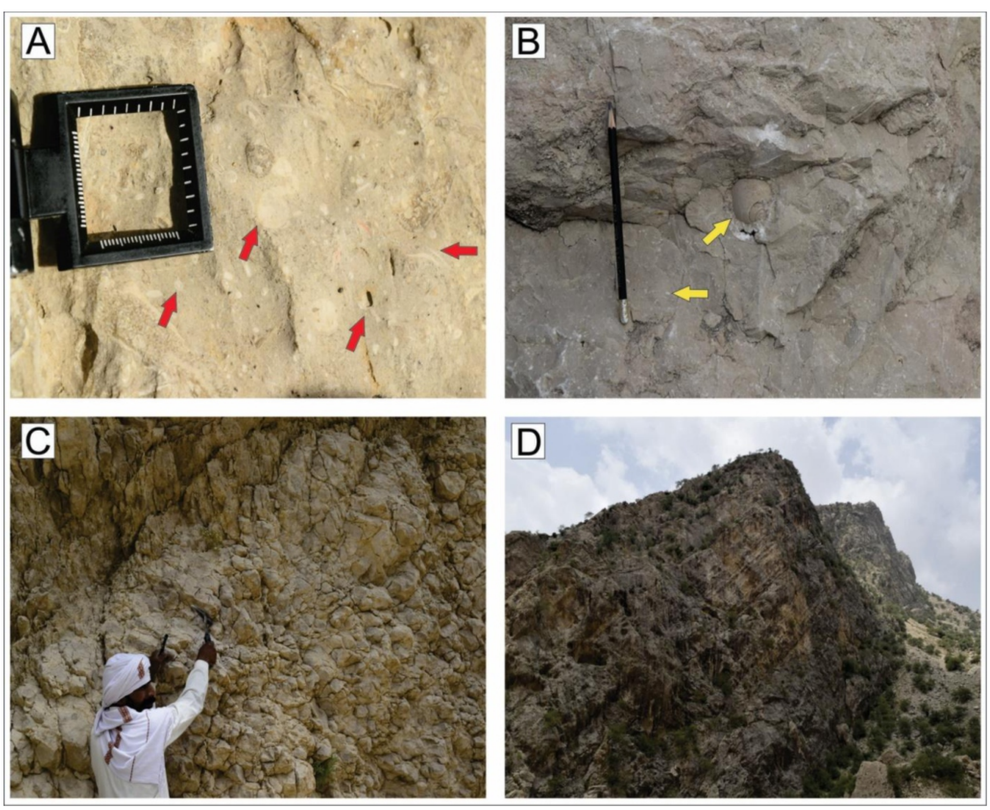

Fig. 3. Field photographs of the Dungan Formation at the Kohlu Section (A) showing fossiliferous limestone rich in LBF (red arrows) in the lower part of the formation, (B) gray to light gray fossiliferous limestone and gastropod (yellow arrows) in the middle part of the formation, (C) nodular limestone in the lower most of the Dungan Formation, (D) thick-bedded limestone of the Dungan Formation.

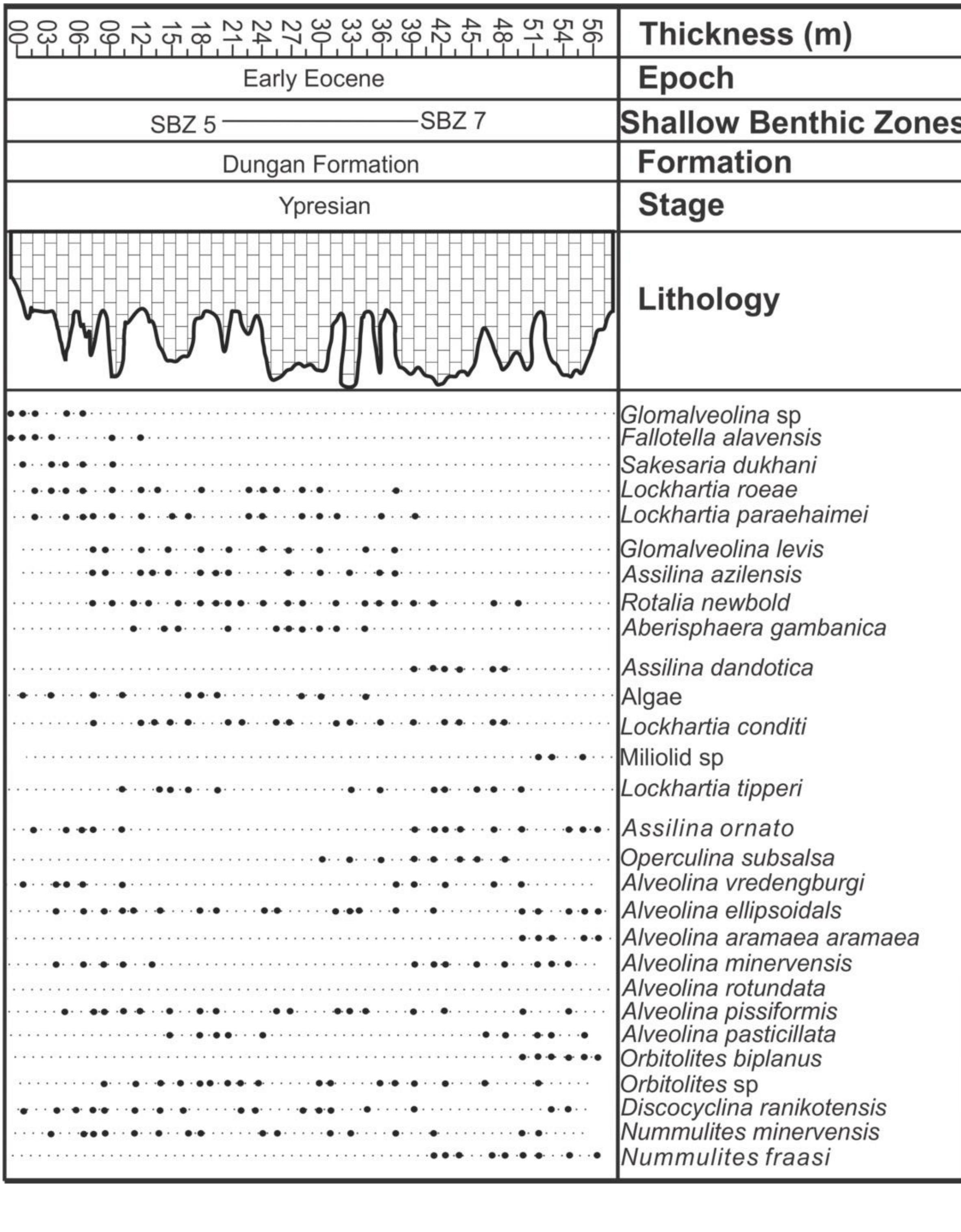

Fig. 4. Biostratigraphic ranges of LBF of the Early Eocene Dungan Formation.

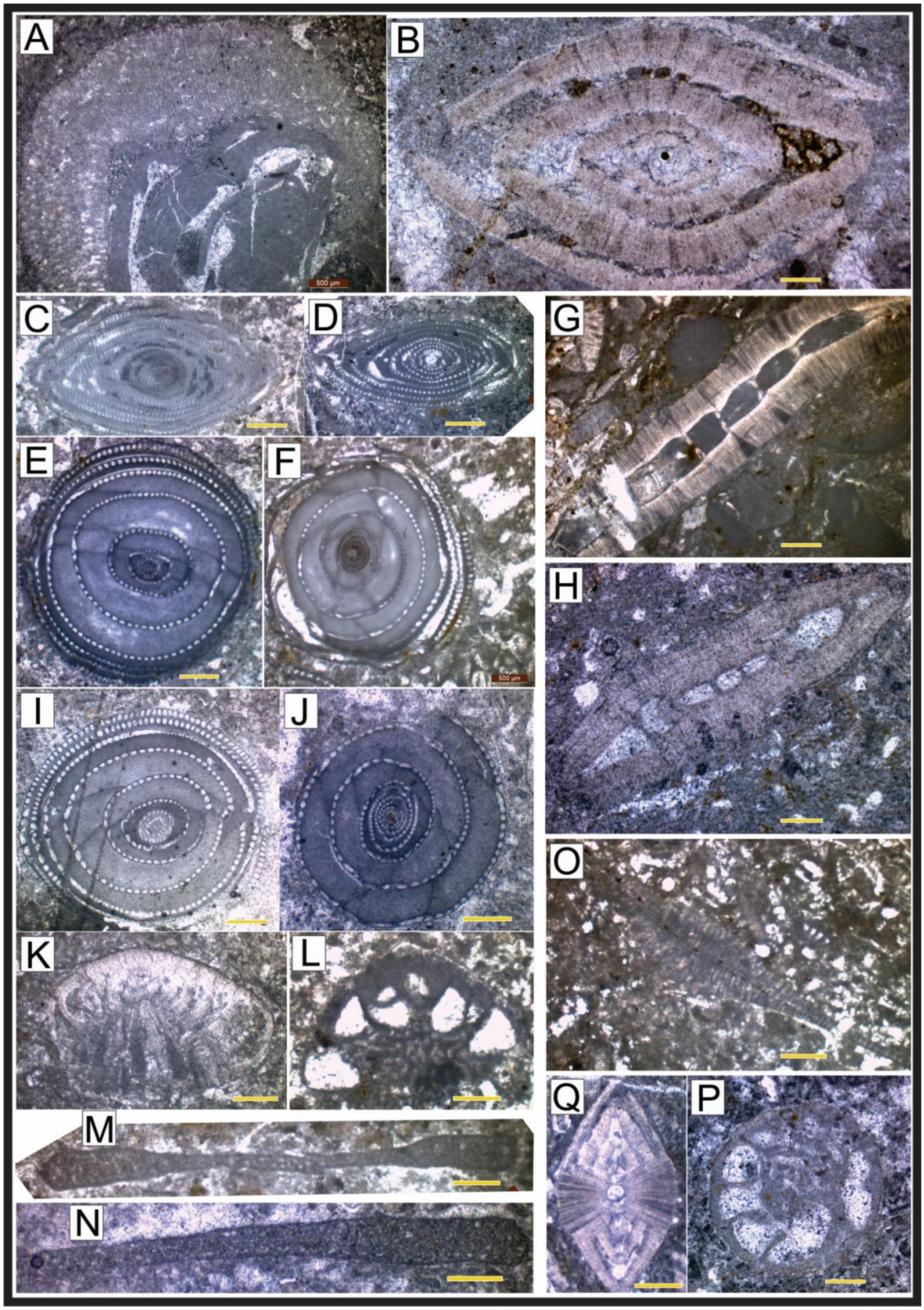

Fig. 5. Biostratigraphically significant LBF of the Early Eocene Dungan Formation. (a) Algae (b) *Nummulities minervensis* (c) *Alveolina ellipsoidalis* (d) *Alveolina vredenburgi* (e) *Alveolina pasticillata* (f) *Alveolina* cf. *aramaea aramaea* (g) *Assilina azilensis* (h) *Assilina dandotica* (i) *Alveolina pissiformis* (j) *Alveolina minervensis* (k) *Lockhartia* praehaimei (l) *Lockhartia roaeae* (m) *Orbitolites biplanus* (n) *Orbitolites* sp. (o) *Discocyclina ranikotensis* (P) *Sakesaria* cf. *dukhani* and (q) *Nummulites fraasi.* Scale bar is 500 µm.

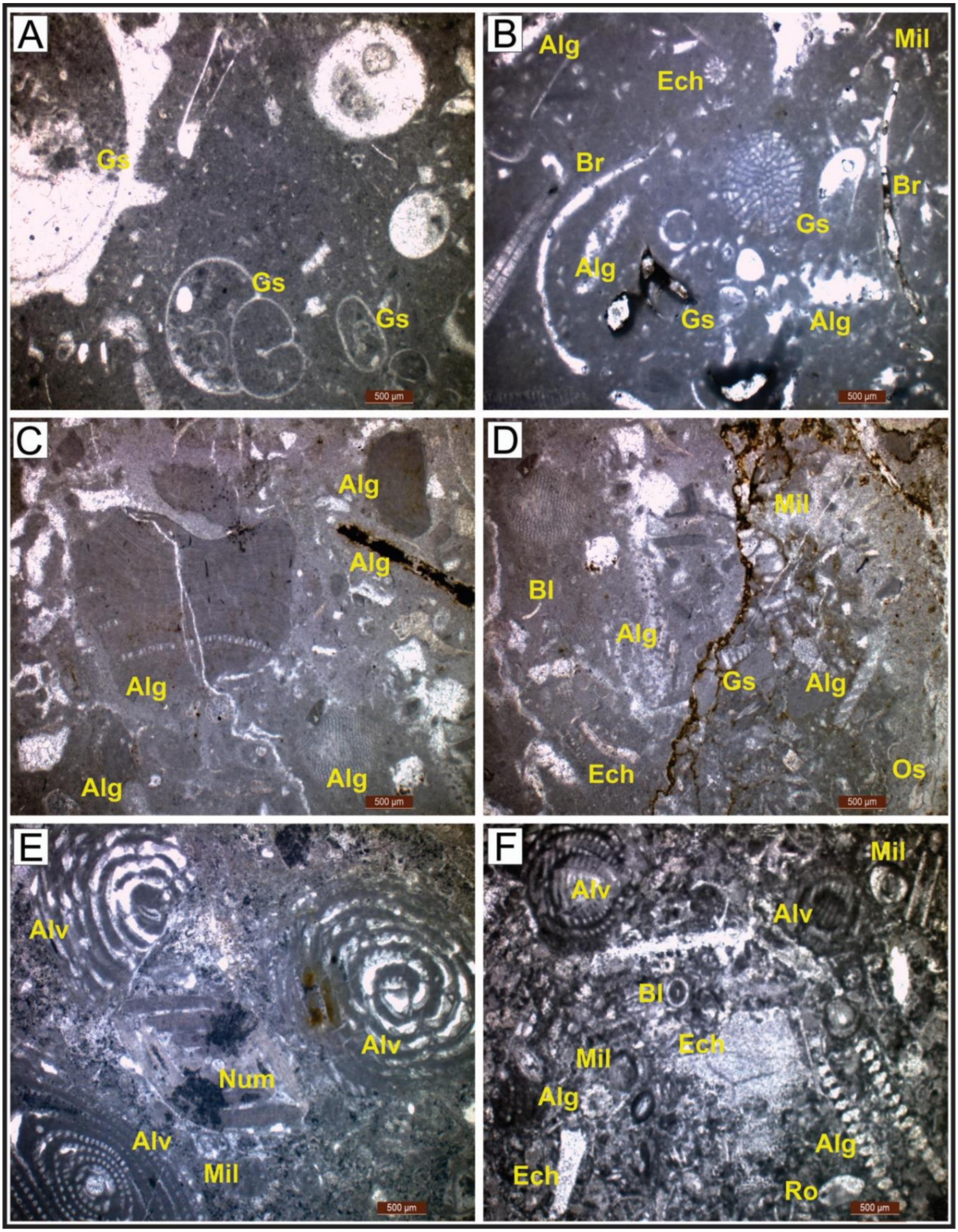

Fig. 6. Thin-section photomicrographs showing: (A, B) Bioclastic gastropodal wackestone (MF 1), (C, D) Algal foraminiferal wackestone (MF 2) and (E, F) Bioclastic alveolinid nummulitid wackestone (MF 3). Scale bar is 500 µm.

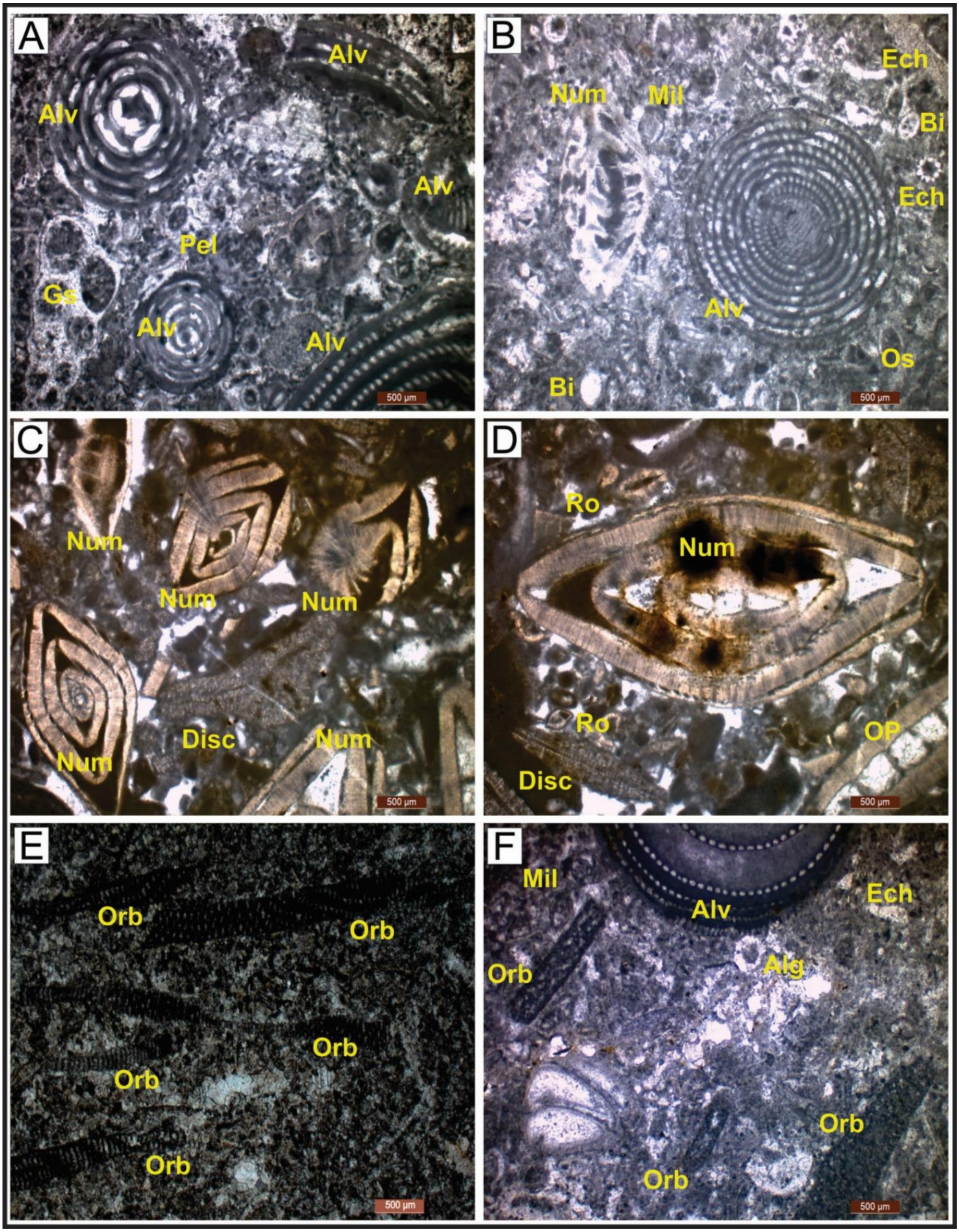

Fig. 7. Thin-section photomicrographs showing: (A, B) Bioclastic alveolinid packstone (MF 4), (C, D) Bioclastic nummulitid wackestone/packstone (MF 5) and (E, F) Bioclastic Orbitolites wackestone/mudstone (MF 6). Scale bar is 500 µm.

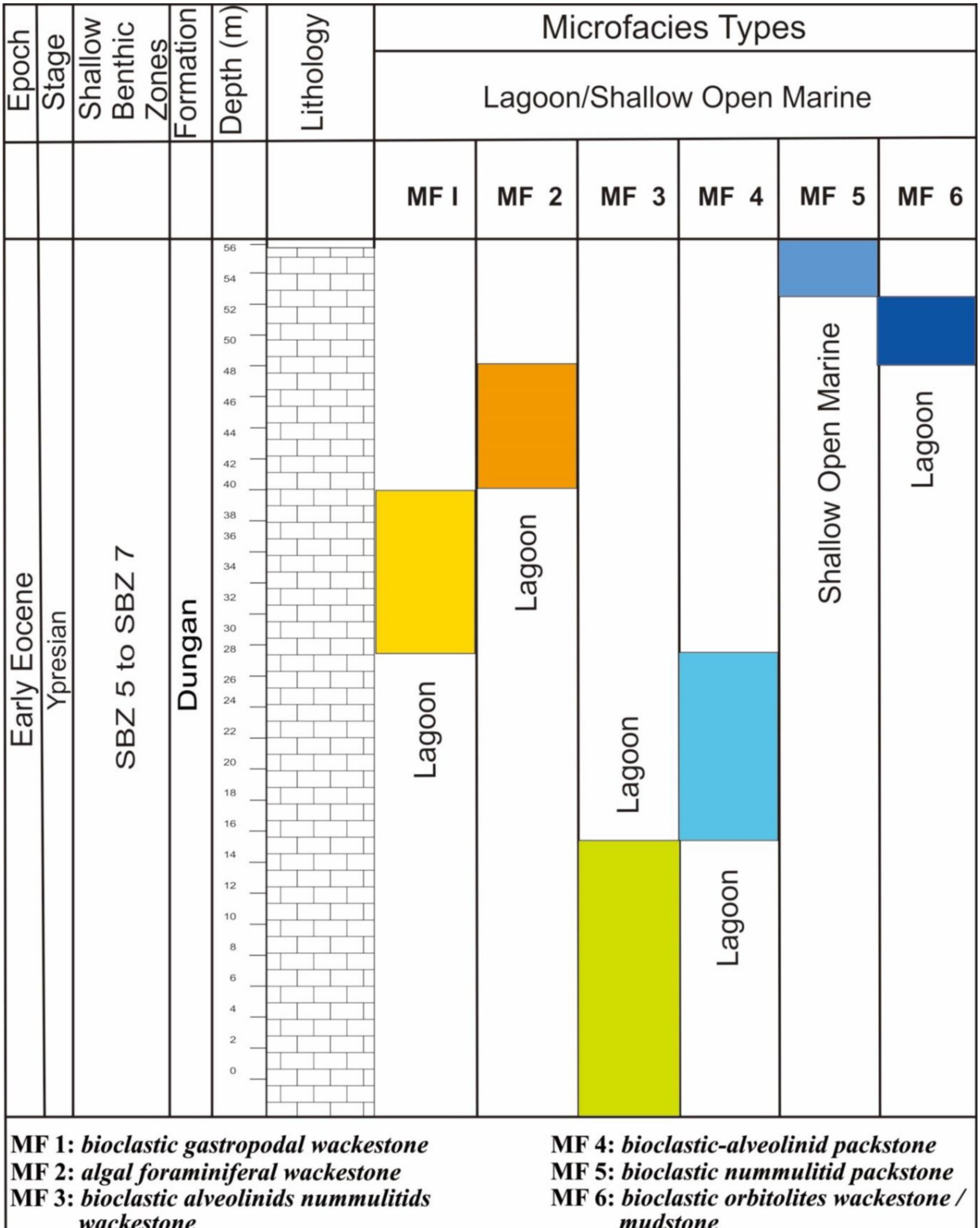

Fig. 8. Lithological column and vertical distribution of microfacies types suggested for Dungan Formation at the Kohlu Section in Sulaiman Belt.

5. Paleodepositional Environment

The studied section of the Dungan Formation at Kohlu represent rich LBF along with other biota such as molluscs, echinoderms, brachiopods, red and green algae, and rare corals (figs 6, 7, 9). The abundance of biotic components indicate a progressive water deepening from the euphotic zone represented by biota such as *Orbitolites,* alveolinids and large and flat nummulitids of the oligophotic zone and, biota including ostracods and echinoderms which are independent of photic zone (Speijer, and Morsi, 2002; Zhang et al., 2012). There is no evidence of a major break on the slope as signified by the absence of framework building biota (barrier bar), calciturbidites, slump and slide structure, oncoids, and aggregate grains, indicative of rimmed shelf settings. Most of these evidences are mentioned by Afzal et al. (2011b) and Ahmad et al. (2020) of other sections of the Dungan Formation. By considering the facies variations, due to a relative sea-level fall, the shallow facies of the ramp simply moved basinwards (detrital clasts were carried by tidal channels to the basin) and thus, no evidence of subaerial exposure. While, even during a major sea-level fall, there is no evaporites or resedimented lowstand deposits (Ahmad et al., 2020). These reveals low angle of slope and suggest a carbonate ramp setting. The best development of a carbonate ramp occurs either in a foreland sedimentary basin, cratonic-interior basin or along passive margins, where subsidence is flexural and gradients are minor over large areas, as in foreland and cratonic-interior basins and along passive margins (Burchette and Wright, 1992). The Sulaiman Foreland Basin has a width of 200 km and a length exceeding 300 km and is part of a passive continental margin composed relatively of passive-margin carbonates, and had a stable, undergoing slow and steady subsidence (Bannert, 1992). The mud dominated microfacies such as wackestone and packstone, and absence of reef building corals suggests a ramp depositional setting for the Dungan Formation in the study area (Pomar, 2001; Afzal et al., 2011b) (Fig. 9).

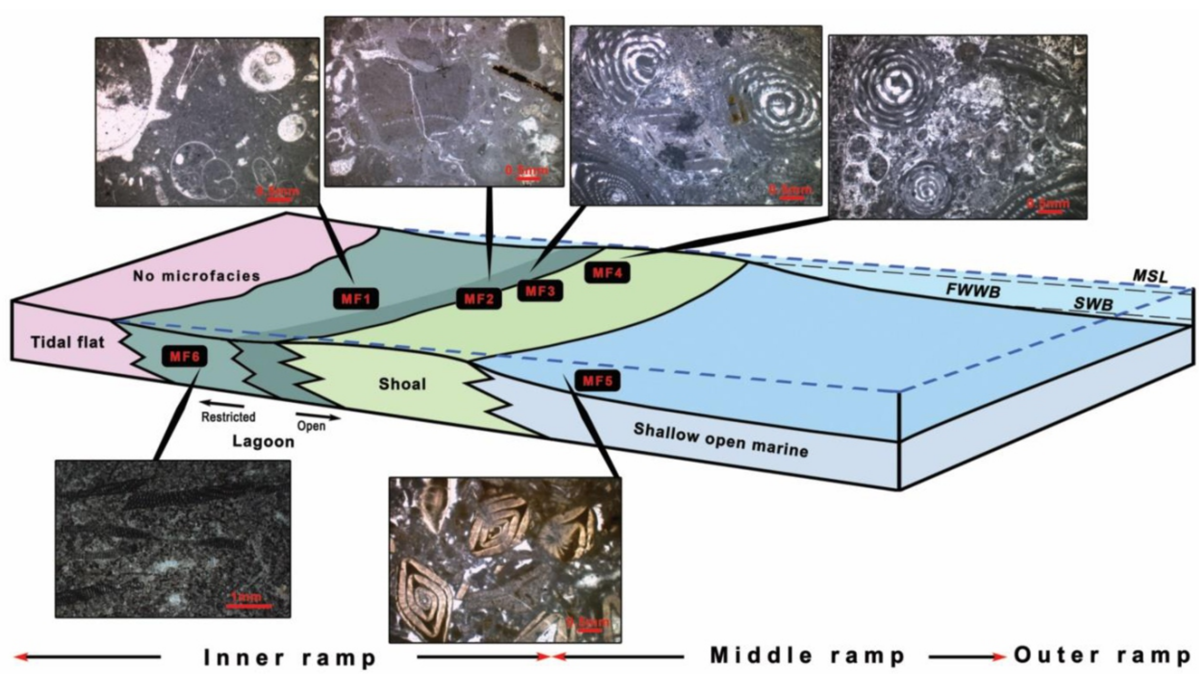

Fig. 9. Depositional model for the Dungan Formation based on the identified facies in Kohlu section, Sulaiman Belt.

6. Conclusions

The Dungan Formation at Kohlu represents thick to medium bedded limestone which has yielded rich and diverse LBF including many age diagnostic species such as *Nummulites minervensis Nummulites Fraasi, Alveolina vredenburgi, Alveolina ellipsoidalis, Alveolina pasticillata, Alveolina pisiformis, Alveolina minervensis, Alveolina aramaea aramaea, Discocyclina ranikotensis,* and *Orbitolites biplanus* which suggest Early Eocene age for the studied section spanning between SBZ 5 to SBZ 7.

The microfacies analysis revelead six microfacies abundant with LBF along with algae, echinoids, gastropods, bivalves, rare corals suggesting deposition in an inner to mid ramp environment. The deposition on a ramp is supported by gradual facies change between subenvironments, presence of insitu fauna and larger Foraminifera as the main producers, prevalence of mud in identified microfacies, lack of organic build up, slump and slide structure, calciturbidite, oncoid and aggregate grains.

Authors' Contribution

Mohibullah Mohibullah proposed the main concept and was involved in write up. Abdullah Abdullah, assisted in establishing biostratigraphic zonation of the section. Shams ul Alam, collected field data and was involved in writing up, lab analysis and drawing graphics. Tahseen Mukhtiar Hussain and Ghulam Mustafa Thebo were involved in preparation of graphical illustration and writing up. Aimal Khan Kasi did technical review prior to paper submission

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Conflict of Interest

The authors have no conflict of interest.

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