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Microfacies Analysis and Depositional Environment of Early Eocene Carbonates in the Balakot Region, Pakistan

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ABSTRACT

This paper examines microfacies, biostratigraphy, tectonic control and depositional setting of the Margalla Hill Limestone and Chorgali Formation in the Balakot area, Pakistan, during the Early Eocene. Based on a careful microfacies study, seven major microfacies types representing diverse energy regimes and depositional environments, extending from inner ramp-middle ramp settings to more limited, lagoonal environments, were recognized. Foraminiferal Bioclastic Wackestone, Assilina-Nummulites Bioclastic Wackestone, and Bioclastic Mudstone were the major microfacies employed for paleoenviromental and depositional environment interpretation. The work also defined the biostratigraphic zones SBZ8 and SBZ9 relying on the distribution of the main foraminiferal taxa like Nummulites, Assilina and Alveolina, thus, introducing the chronostratigra phic nomenclature for the area. The equivalent of the Margalla Hill Limestone represents the Nummulites Atacicus/Nummulites Globulus/Assilina Leymerie Biozone (SBZ8) and that of the Chorgali Formation is the Alveolina Indicatrix Biozone (SBZ9) which indicates a change in middle ramp setting to lagoonal setting. Further, the tectonic framework, driven by the Himalayan orogeny and the Main Boundary Thrust (MBT), was a key control on the carbonate sedimentation due to changes in subsidence, uplift, and erosion. The present work reconstructs the Early Eocene palaeoenvironmental conditions of the Balakot area in detail, which will improve our knowledge of the carbonate sedimentation, biostratigraphy, and tectonic control of the Himalayan foreland basins.

Keywords: *Balakot region, Margalla Hill Limestone, Chorgali Formation, Early Eocene microfacies, Biostratigraphy of Nummulites, Depositional environments of the Eocene,*

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Tectonic influence on carbonate deposition, Foraminiferal assemblages.

1. Introduction

Balakot is situated in northern Pakistan in the Sub-Himalayan region, which is tectonically very complex and characterised by the continuing Himalayan orogeny (Shen and Rybach, 1994). The area is located in the footwall of the MBT, where the sedimentary fills of this region are ideal for delineating tectonism and paleogeographic change in sedimentary sequences (Najman et al., 2002). Geological history of the area ranges from Cambrian to Miocene with excitement in the Early Eocene period marked by Margalla Hill Limestone and Chorgali Formation due to its carbonate deposits, which are asset in tracing palaeoenvironments, setting of deposits and tectonic controls during the formative phase of the Himalayan orogeny (Shah 1977; Munir et al.

The Margalla Hill Limestone and Chorgali Formation plays a vital role in the interpretation of carbonate sedimentation in the area, and the manner in which shallow marine environment dominated during the Early Eocene (DiPietro & Pogue, 2004). These formations consist mainly of carbonates and are interleaved with shales and marls, which provide evidence of varying environmental conditions during the Eocene (Jain, 1981). The faunal assemblages of large benthic foraminifera such as, Nummulites and Assilina are a rich feature of the Margalla Hill Limestone that are used as important biostratigraphic markers for determining age and palaeogeographic reconstruction (Shah, 1977; Munir et al., 2006). The overlying Chorgali Formation over the Margalla Hill Limestone also contributes towards the marine ecosystem of the area and the faunal assemblies of its time.

The deposition comparing with the sedimentary environment and the sedimentary process, which related to the forming of these carbonates, is an important clue to the restoring of paleogeography. The microfacies analysis of Margalla Hill Limestone and Chorgali Formation provides a clue about the shallow marine environments which existed during the early Eocene (Singh, 1991). Microfacies approach makes a possible to recognize proper assemblages and polution a type described above as mo-compatible with dynamic occuring syngenetic environmental phenomena during sedimentation of these carbonates. Interpretations for these microfacies types will be used to demarcate the inner ramp, middle ramp, and lagoon depositional environments and to infer energy regime and paleogeography during the time.

The main objective is to interpret the lithofacies of the Margall Hill Limestone and Chorgali Formation & to determine the depositional environments on the basis of Microfacies types identified. This investigation will improve our depositional model for the Early Eocene carbonates of the Balakot area, thus, enhancing our knowledge regarding the carbonate sedimentation in the shallow marine environment. The research in result will offer significant information on the regional tectonic history and paleogeographic evolution of the area during the Himalayan orogeny stage-Tectonic and environmental – nonlinear changes.

Research Objectives

1. Identification and classification of microfacies types in the Margalla Hill Limestone and Chorgali Formation, including foraminiferal bioclastic wackestones, Assilina-Nummulites bioclastic wackestones, and bioclastic mudstones.
2. Interpretation of the depositional environments of these carbonates, specifically inner ramp, middle ramp, and lagoonal settings, based on the identified microfacies.

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3. Discussion of sedimentary processes that shaped the Early Eocene carbonates in the context of tectonic and paleogeographic changes in the region.

2. Geological Setting

Regional Geology

The tectonically active Sub-Himalayan realm, formed due to the constructive plate boundary, known as the Himalayan orogenic belt (Molnar and Tapponier, 1975) envelops the northern Pakistan's Balakot area in it. The geological setting of this area is attributed to collision between the Indian and Eurasian plate, which started from the Late Cretaceous, and currently is still the actuation of fold-thrust belts, fault systems, and sedimentary basins (Yin, 2006). The occurrence of the MBT and other major faulting and folding on the northwestern limb of the Hazara-Kashmir Syntaxis is a significant feature in terms of the uplift and facial exposure of rocks and separation of older and younger strata such as Margalla hill Limestone and Chorgali Formation.

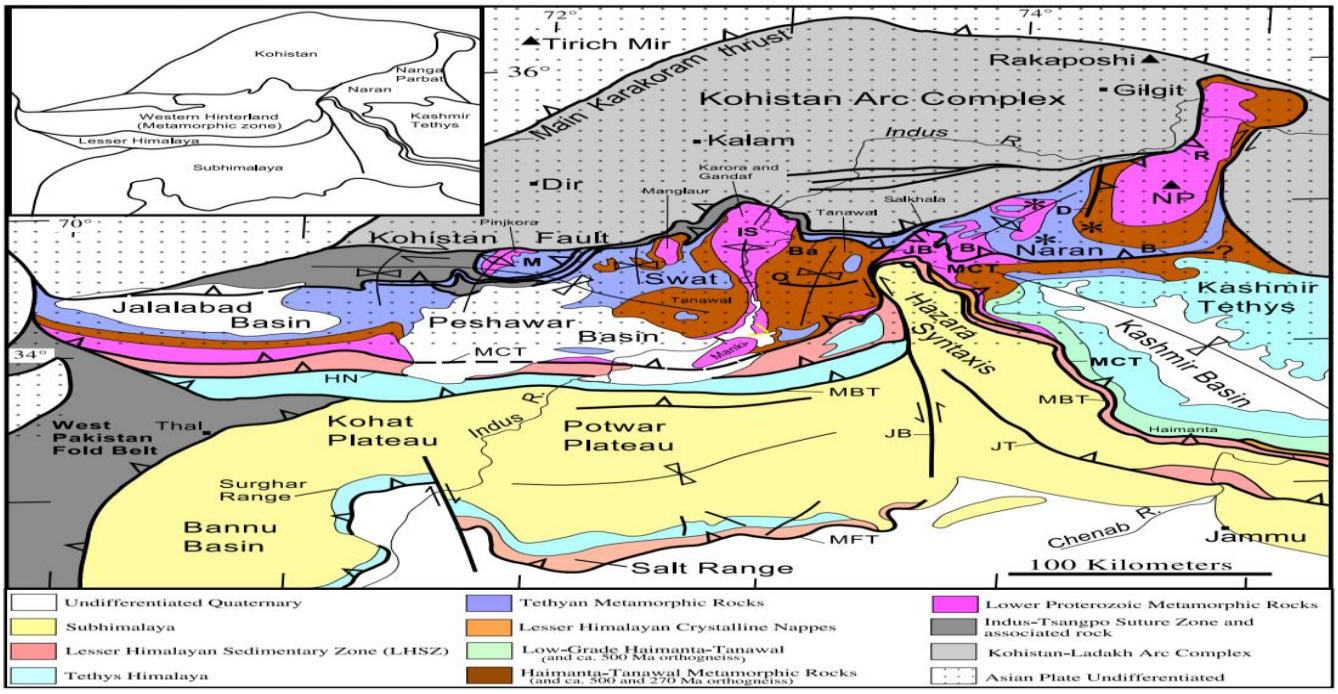


Figure 1: Tectonic Map of Northern Pakistan

This map illustrates the major structural boundaries and tectonic divisions in the region. It would complement your discussion of the tectonic setting, particularly the reference to the Balakot region's position in the Sub-Himalayan zone and its relationship with the MBT

Stratigraphy of the Study Area

The Balakot region's stratigraphy is dominated by Cenozoic deposits, particularly the Eocene units, which include the Margalla Hill Limestone and Chorgali Formation. These formations provide insight into Early Eocene depositional environments and tectonic history:

1. *Abbottabad Formation (Cambrian):* Marine dolomites, sandstones, and shales.
2. *Hangu Formation (Lower Paleocene):* Sandstones and carbonaceous shales, indicating shallow marine environments.

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3. *Lockhart Formation (Late Paleocene):* Limestones and calcareous sandstones, containing significant fossils.
4. *Patala Formation (Early Eocene*)**:** Shales and limestones from a shallow marine setting.
5. *Margalla Hill Limestone (Middle Eocene):* Nodular limestone with abundant larger benthic foraminifera, crucial for biostratigraphy (Shah, 1977).
6. *Chorgali Formation (Upper Eocene):* Nodular limestone with foraminiferal marls and shales, offering insights into paleogeographic history.

These units reflect dynamic depositional environments and sea-level changes, with the Margalla Hill Limestone and Chorgali Formation being key to understanding Early Eocene transgressive-regressive cycles and paleoclimatic conditions.

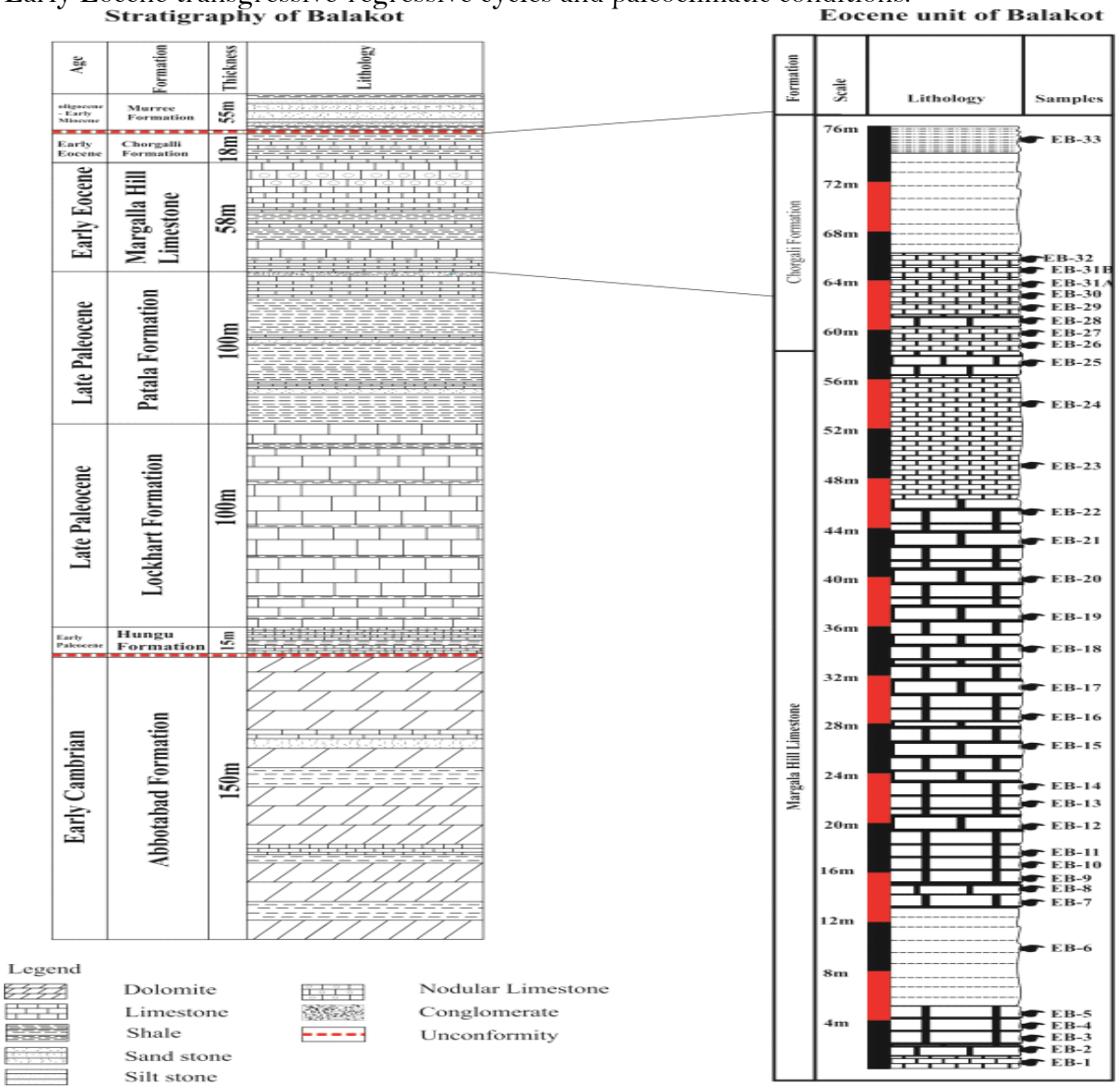


Figure 2: Detailed Geological Map of the Balakot Section

This figure provides a comprehensive view of the geological framework in the study area, which would be useful in illustrating the structural geology and stratigraphic

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units you describe.

Tectonic Setting

The Balakot area itself is in the footwall of the MBT and is tectonically active, having experienced significant deformation due to the Himalayan orogenesis. This tectonic environment has resulted in folding, thrusting, and strike-slip faulting, which have in turn uplifted and exhumed strata such as Margalla Hill Limestone and Chorgali Formation (Kapp & DeCelles, 2019). The MBT divides older sedimentary rocks from younger formations, thus controlling the region's sedimentary basins, which were filled with Early Eocene carbonates (affected by marine transgressions and tectonic subsidence).

3. Materials and Methods

Fieldwork and Sample Collection

Fieldwork was conducted along the Batsangra Road section in Balakot, where a 76-meter-thick stratigraphic section of the Margalla Hill Limestone and Chorgali Formation was exposed. The objectives included identifying lithological variations, collecting rock samples, and creating a detailed stratigraphic log.

Lithological variations were observed in color, texture, and bedding types to distinguish between the formations. A stratigraphic log documented the thickness, lithology, and fossil content of each unit, crucial for understanding facies distribution and depositional boundaries. Thirty-three rock samples were collected at intervals of approximately 1 meter, focusing on limestone and shale units, and were prepared for petrographic analysis.

Petrographic Analysis

Rock samples underwent petrographic analysis to identify microfacies and allochem types.

Thin sections were prepared by cutting samples into slices, mounting them on glass slides, and polishing to a thickness of 30 microns. The sections were analyzed under a petrographic microscope to identify allochems, including foraminiferal bioclasts, corals, and algae. Diagenetic features such as micritization and pyrite were noted, providing insights into the post-depositional processes. Microfacies were classified based on Dunham (1962) and Flügel (2004) schemes, identifying seven types associated with specific depositional environments (inner ramp, middle ramp, lagoonal).

Biostratigraphic Analysis

The biostratigraphic analysis focused on larger benthic foraminifera to establish biozones.

Foraminifera species such as *Nummulites*, *Assilina*, and *Alveolina* were identified in thin sections. The first and last appearances of these species were recorded to define biostratigraphic zones. The Margalla Hill Limestone was assigned to the Nummulites Atacicus/Nummulites Globulus/Assilina Leymerie Biozone (SBZ8), while the Chorgali Formation was placed in the Alveolina Indicatrix Biozone (SBZ9). Biozones were compared with regional studies for consistency and correlation with other Eocene sequences in the Himalayan foreland basin.

Data Integration and Environmental Interpretation

Microfacies data, biostratigraphy, and stratigraphic observations were integrated to reconstruct depositional environments.

The microfacies and diagenetic features were linked to specific depositional settings,

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including inner ramp, middle ramp, and lagoonal environments. A depositional model for the Balakot region was constructed, incorporating tectonic history, paleogeography, and climatic factors influencing carbonate deposition during the Early Eocene.

4. Microfacies Analysis

The microfacies analysis of the Margalla Hill Limestone and Chorgali Formation revealed distinct depositional environments ranging from shallow marine to lagoonal settings, reflecting the paleoenvironmental conditions of the Early Eocene. Seven microfacies types were identified, each representing different environmental conditions and depositional processes.

(MF-1).

The **Foraminiferal Bioclastic Wackestone Microfacies (MF-1)** is characterized by fine- to coarse-grained limestone, rich in foraminiferal bioclasts such as *Assilina*, *Nummulites*, and *Miscellina*. The grain-to-matrix ratio is 1:3, with the matrix consisting of micrite. Diagenetic features such as calcite veins and pyrite indicate post-depositional alterations. This microfacies suggests deposition in a high-energy inner ramp setting with shallow marine conditions near shore.

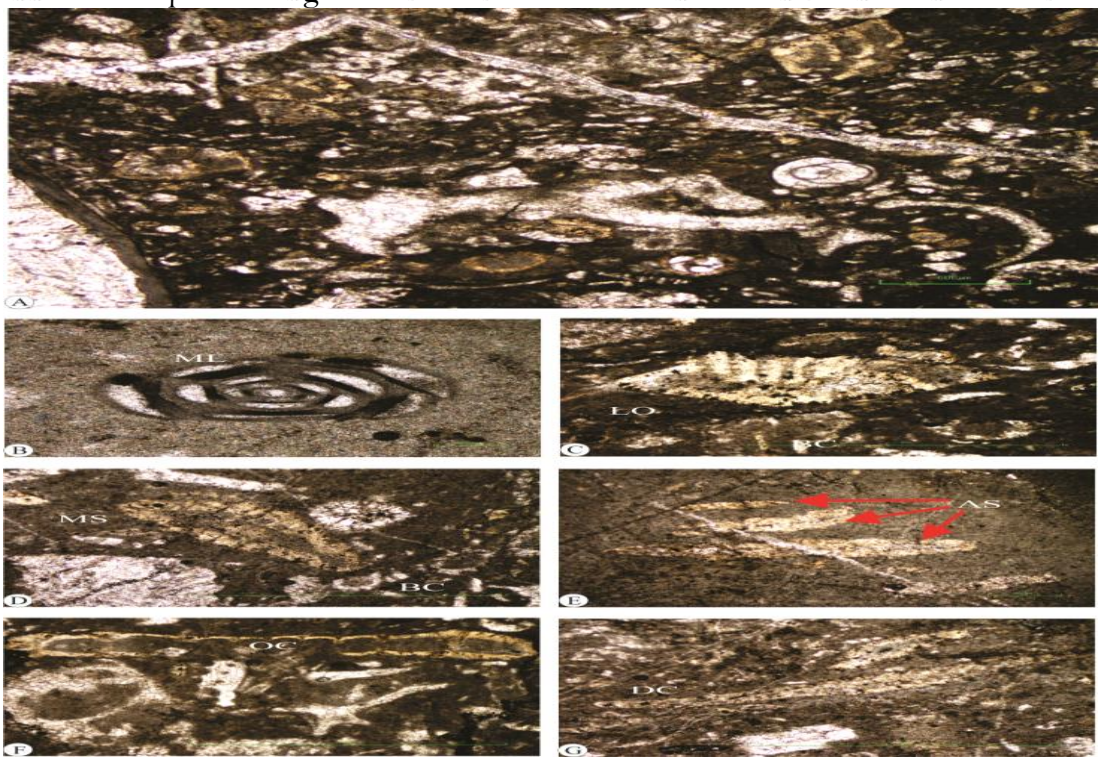


Figure 3 (A) Foraminiferal Bioclastic Wackestone Microfacies (MF-1): (B) Milliolid (ML) sp. (C) lockhartia (LO) sp. and Bioclasts (BC). (D) Miscellina (MS) sp. and Bioclasts (BC). (E) Assilina (AS) sp. (F) Operculina (OC) sp. and (G) Discocyclina (DC) sp.

(MF-2).

The **Assilina-Nummulites Bioclastic Wackestone Microfacies (MF-2)** consists of medium- to thick-bedded limestone dominated by *Assilina* and *Nummulites*, along with smaller foraminiferal species like *Lockhartia*. The grain-to-matrix ratio is 2:2, indicating moderately high bioclastic content. Diagenetic features such as stylolites

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and calcite veins are visible. This microfacies suggests deposition in a middle ramp environment, influenced by moderate energy levels.

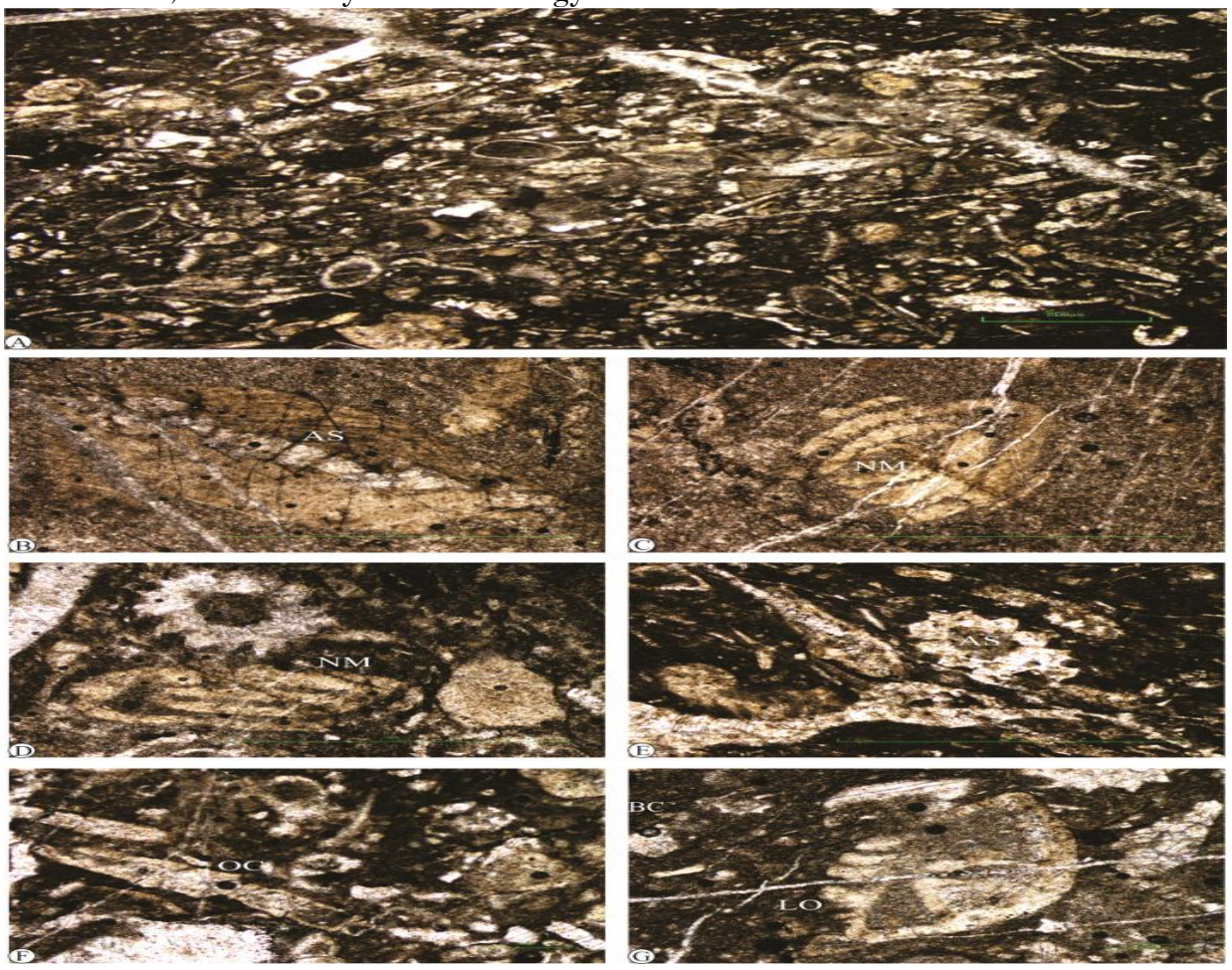


Figure 4: (A) Assilina-Nummulites Bioclastic Wackestone Microfacies (MF-2): (B) Assilina (AS) sp. (C) Nummulites (NM) sp. (D) Nummulites (NM) sp. (E) Assilina (AS) sp. (F) Operculina (OC) sp. (G) Lockhartia (LO) sp. and some Bioclasts (BC).

(MF-3)

The **Assilina Bioclastic Wackestone Microfacies (MF-3)** is composed of thick-bedded limestone, with *Assilina* as the dominant bioclast, along with minor *Nummulites* and *Lockhartia*. The grain-to-matrix ratio is 1:3, with stylolites and pyrite observed. This microfacies suggests deposition in a middle ramp setting, where moderate energy levels allow for the accumulation of larger foraminifera in deeper marine environments. **Figure 5** illustrates this microfacies, focusing on the bioclast content and diagenetic features.

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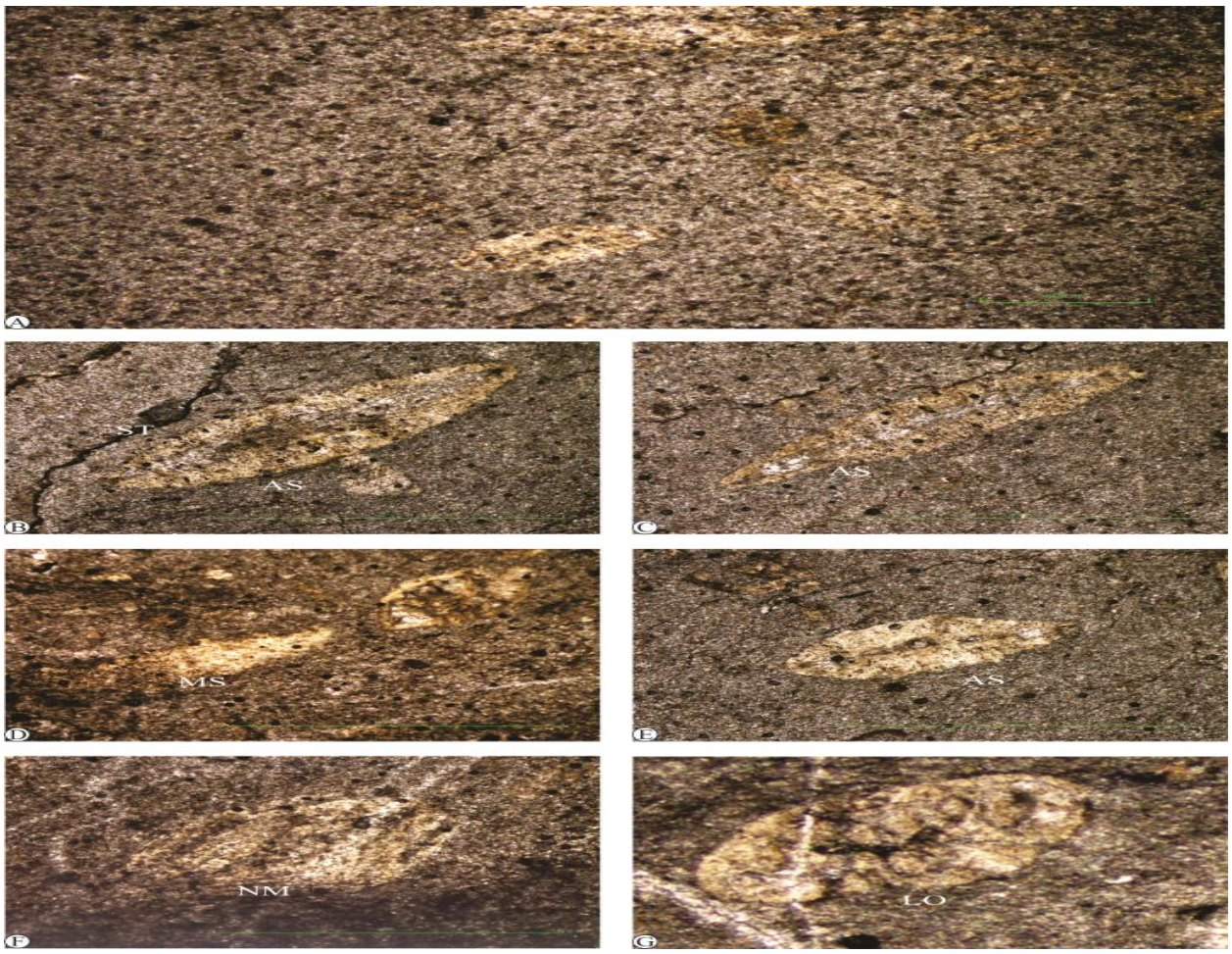


Figure: 5 (A) Assilina Bioclastic Wackestone Microfacies (MF-3): (B) Assilina (AS) sp. and Stylolites (ST). (C) Assilina (AS) sp. (D) Miscellina (MS) sp. (E) Assilina (AS) sp. (F) Nummulites (NM) sp. (G) Lockhartia (LO) sp.

(MF-4).

The **Bioclastic Mudstone Microfacies (MF-4)** consists of thin- to medium-bedded limestone, dominated by fine-grained micrite and sparse bioclasts, primarily *Miscellina*. The grain-to-matrix ratio is 1:5, and pyrite and stylolites are commonly observed. This microfacies suggests deposition in a lagoonal environment, with low-energy conditions and limited circulation, typical of low-oxygen environments. **Figure 4** depicts this microfacies, showing the fine-grained matrix and sparse bioclasts.

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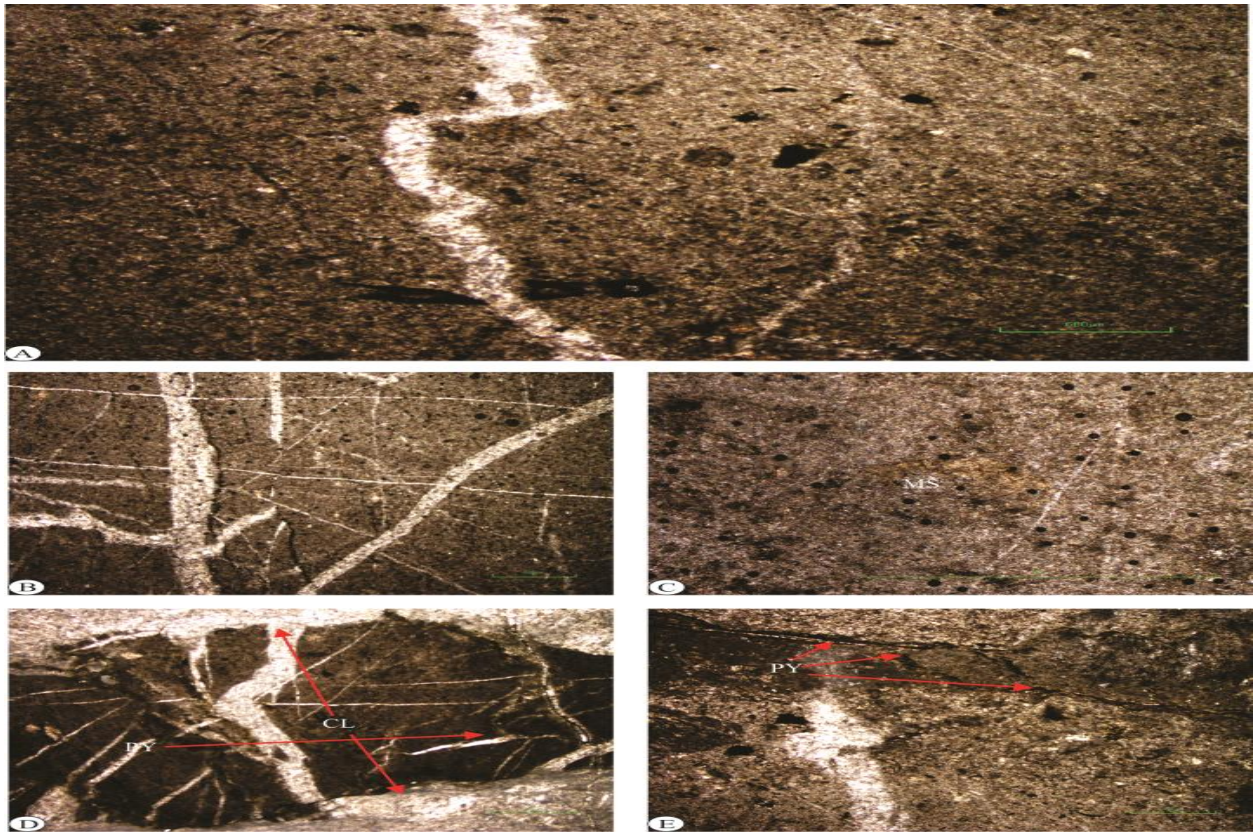


Figure 6 (A) Bioclastic Mudstone Microfacies (MF-4): (B) Bioclastic Micrite having Calcite veins. (C) Miscellina (MS) sp. in micrite. (D) Bioclastic Mudstone having pyritization (PY) and blocky calcite veins (CL). (E) Bioclastic mudstone having pyritization (PY).

(MF-5).

The **Assilina-Alveolina Bioclastic Wackestone Microfacies (MF-5)** is composed of thin-bedded limestone, dominated by *Assilina* and *Alveolina*, with a grain-to-matrix ratio of 1:3. Diagenetic features such as micritization and recrystallization are observed. This microfacies indicates deposition in an inner ramp environment, where relatively low-energy conditions preserve smaller foraminifera species like *Alveolina*.

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Volume 2, Issue 4 (2024)

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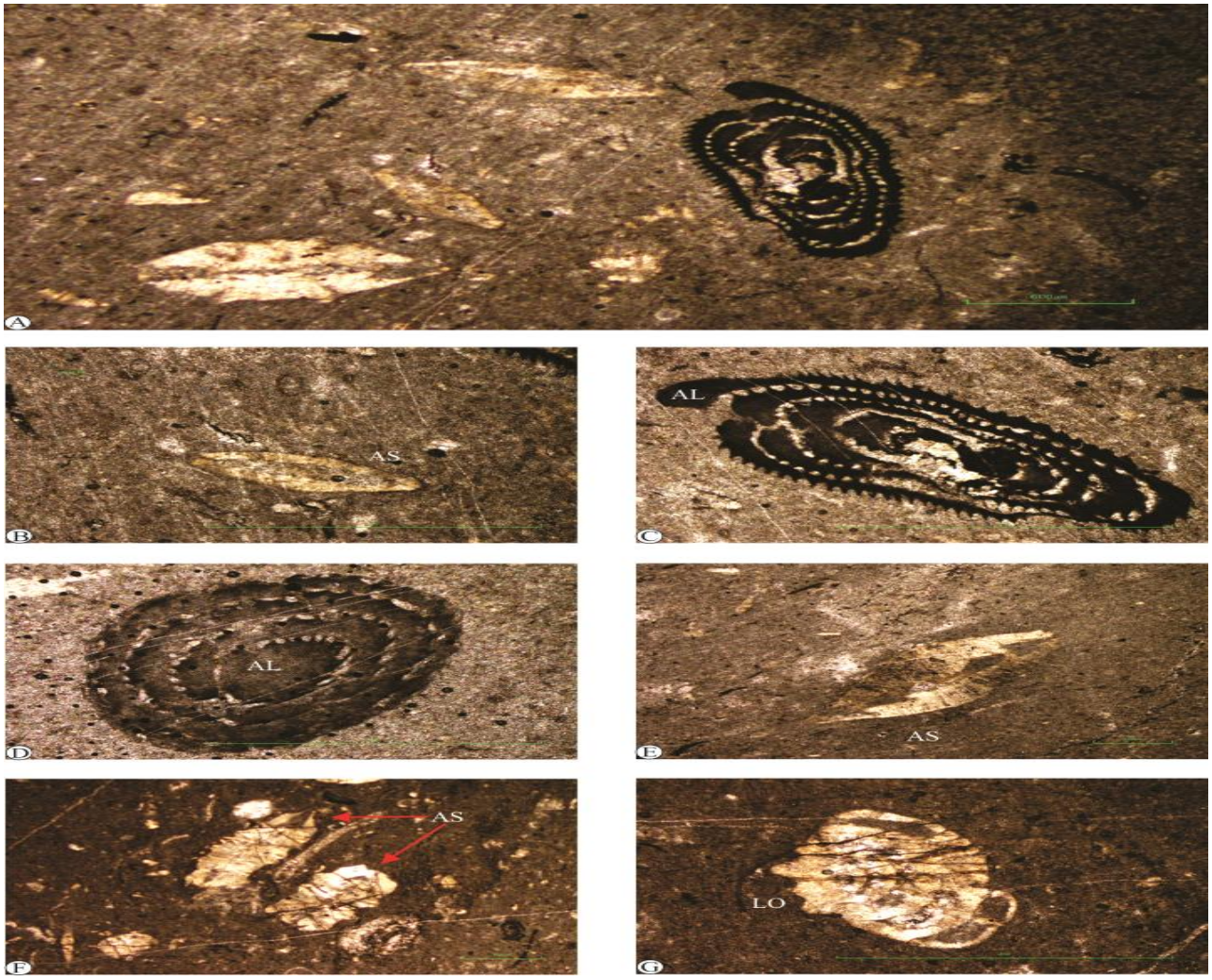


Figure 7: (A) Assilina-Alveolina Bioclastic Wackestone Microfacies : (B) Assilina (AS) sp. (C) Alveolina (AL) sp. (C) Alveolina (AL) sp. (D) Assilina (AS) sp. (E) Assilina (AS) sp. (F) Lockhartia (LO) sp.

(MF-6).

The **Foraminiferal Assilina Bioclastic Wackestone Microfacies (MF-6**) is dominated by *Assilina*, with minor *Nummulites* and *Miliolid*. The grain-to-matrix ratio is 1:3, with diagenetic features like calcite veins and pyrite. This microfacies suggests deposition in a middle ramp environment, where moderate energy conditions support the accumulation of larger foraminifera. **Figure 8** provides detailed images showing the bioclast content and diagenetic features of this microfacies.

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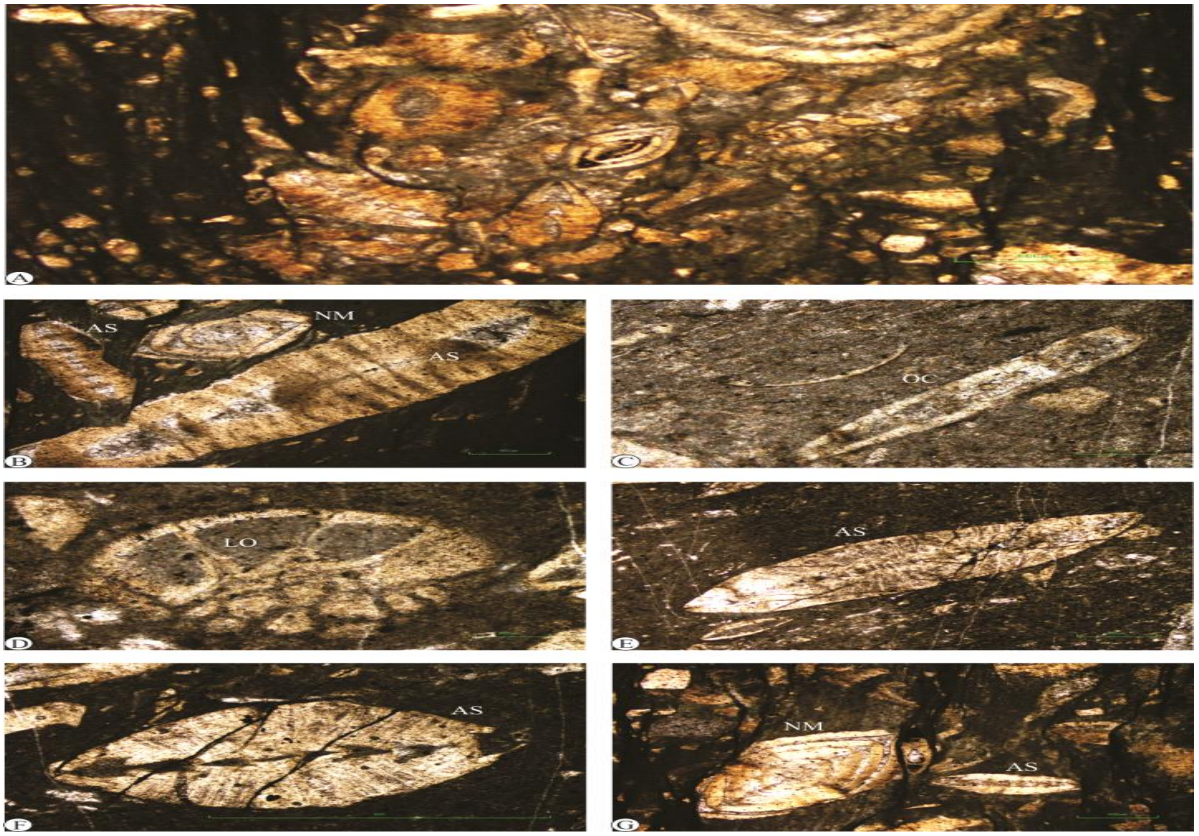


Figure 8: (A) Foraminiferal Assilina Bioclastic Wackestone Microfacies (MF-6): (B) Assilina (AS) sp. and Nummulites (NM) sp. (C) Operculina (OC) sp. (D) Lockhartia (LO) sp. (E) Assilina (AS) sp. (F) Assilina (AS) sp. (G) Nummulites (NM) and Assilina (AS) sp.

(MF-7).

The **Bioclastic Mudstone and Lithoclastic Shale Microfacies (MF-7)** consists of fine-grained limestone with minimal bioclast content, dominated by micrite. The grain-to-matrix ratio is 1:5, and pyrite is commonly observed. This microfacies indicates deposition in a lagoonal or shallow restricted marine environment with low-energy conditions, promoting the accumulation of fine-grained materials.

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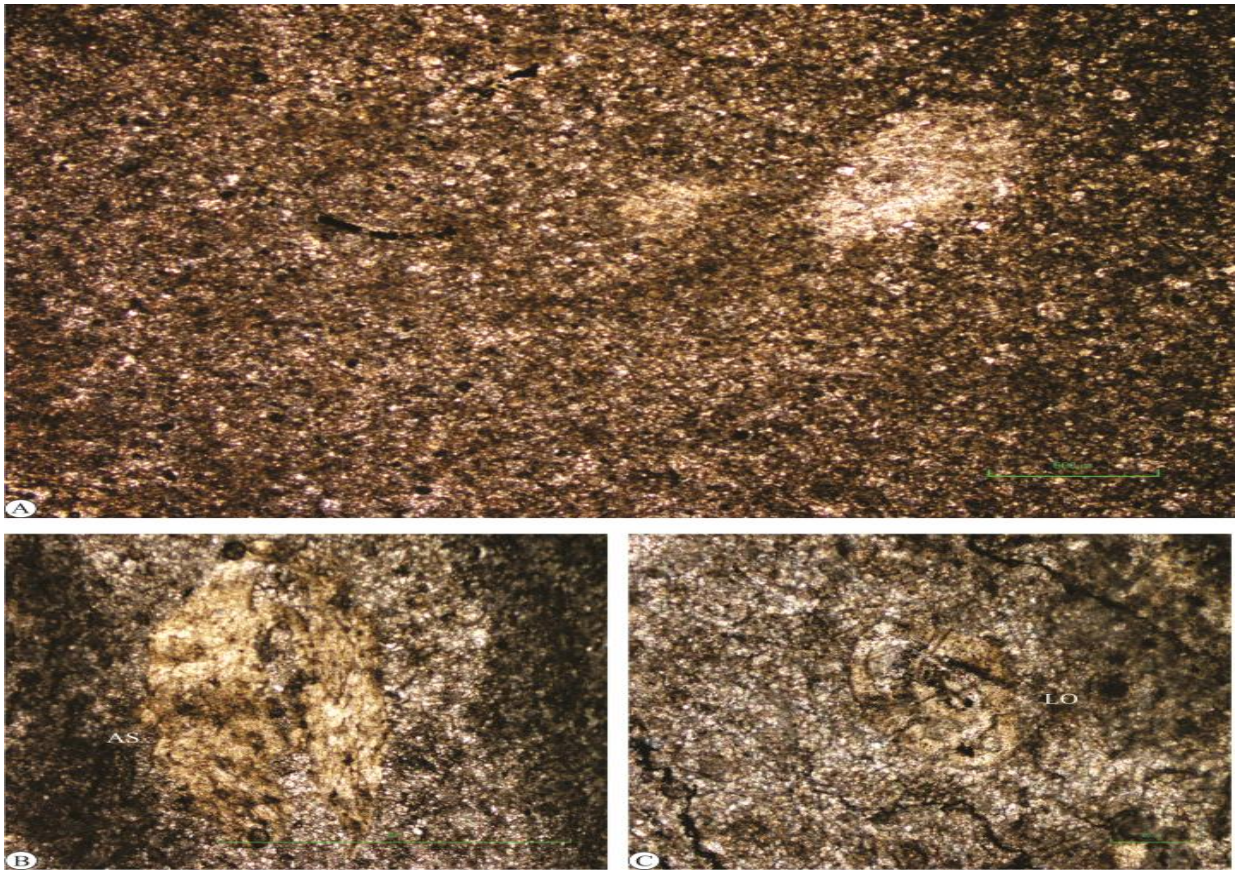


Figure 9: (A) Bioclastic Mudstone and Lithoclastic Shale Microfacies (MF-7): (B) Assilina (AS) sp. (C) Lockhartia (LO) sp.

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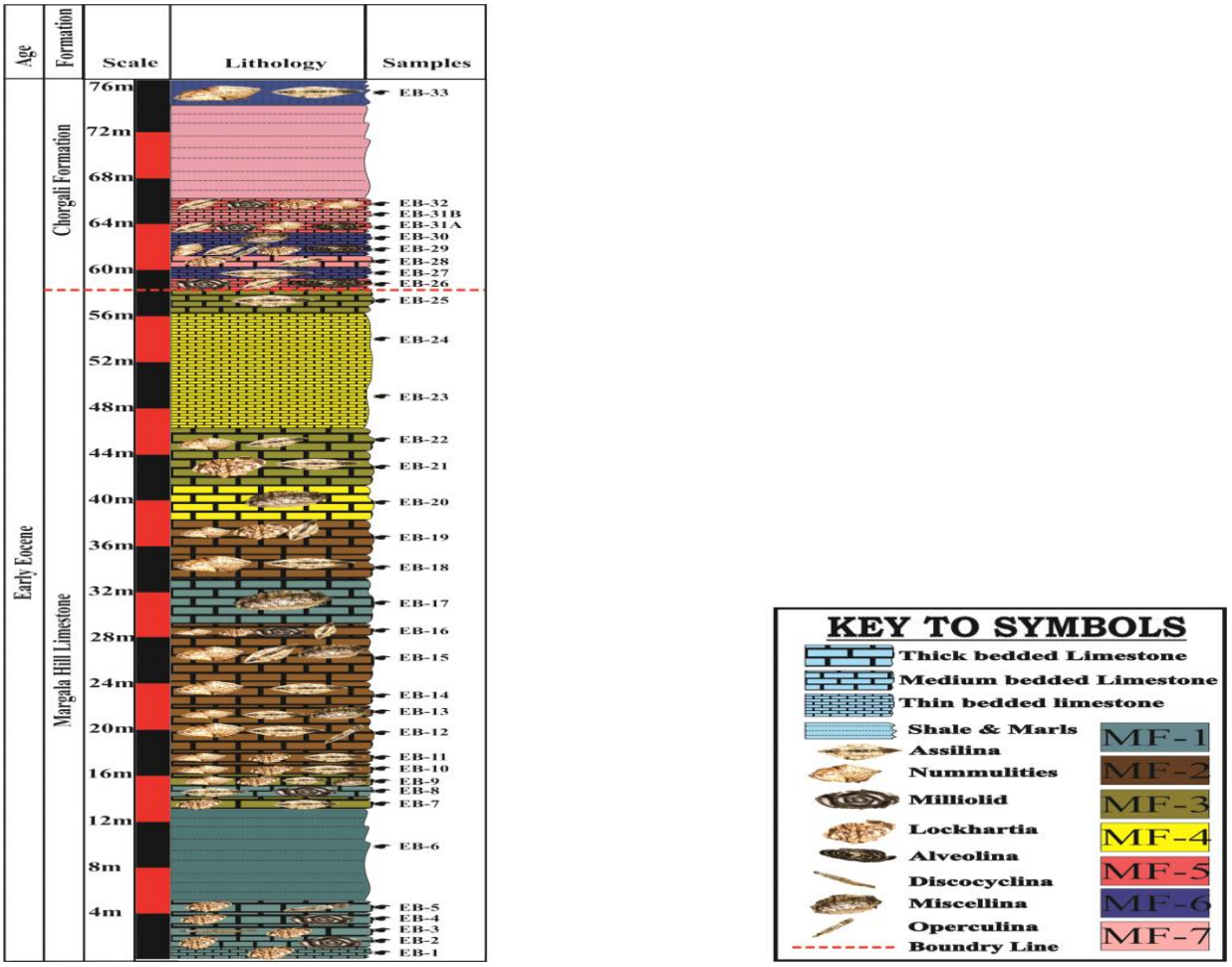


Figure 6 depicts this microfacies, showing the fine-grained matrix and pyrite content.

These microfacies types reflect varying depositional environments in the Balakot region, providing valuable insights into the paleogeographic evolution of the area during the Early Eocene. The integration of microfacies data with biostratigraphy has allowed for the reconstruction of a transgressive-regressive cycle, influenced by sea-level fluctuations and tectonic activity.

5. Biostratigraphic Analysis

The biostratigraphic analysis focused on identifying key larger benthic foraminifera species, leading to the establishment of two biozones:

- *Margalla Hill Limestone (SBZ8):* The *Nummulites Atacicus / Nummulites Globulus / Assilina Leymerie* Biozone, corresponding to the Middle Illerdian-2 stage.
- *Chorgali Formation (SBZ9):* The *Alveolina Indicatrix* Biozone, corresponding to the Upper Illerdian stage.

These biozones were used to establish the chronostratigraphy of the region and provide insights into the paleogeographic relationships with other regional sequences.

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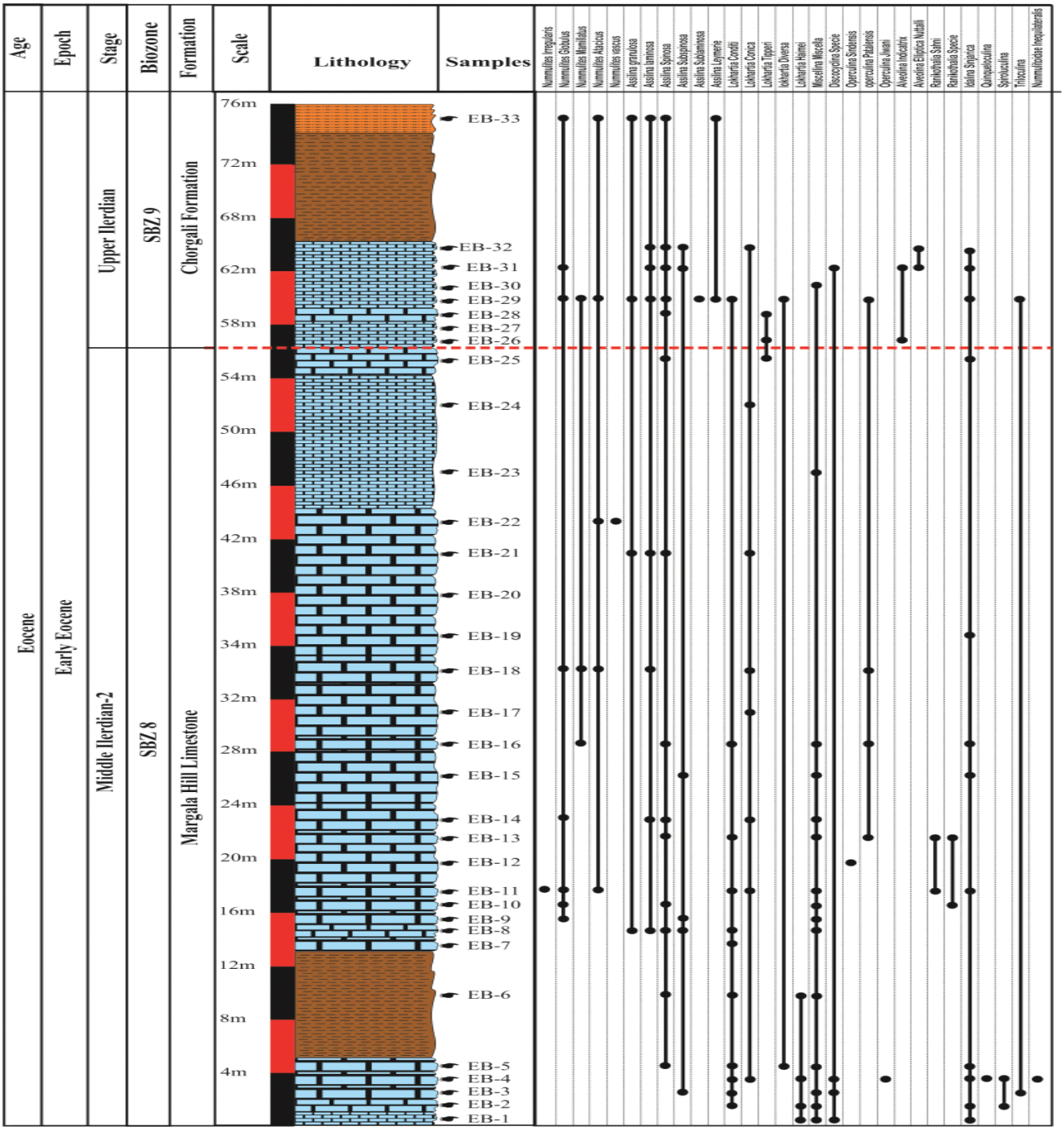


Figure 7 shows the biostratigraphic zones and species illustrations, correlating *Nummulites*, *Assilina*, and *Alveolina* with their respective biozones.

6. Depositional Environment Interpretation

The seven identified microfacies reflect varying depositional environments during the Early Eocene, including inner ramp, middle ramp, and lagoonal settings. The presence of foraminiferal-rich wackestones and bioclastic mudstones suggests fluctuations in energy conditions and sea-level changes. The integration of microfacies data with biostratigraphy reveals a transgressive-regressive cycle,

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influenced by sea-level fluctuations and climatic conditions.

Discussion

Microfacies characteristics of the Margalla Hill Limestone and Chorgali Formation indicate a dynamic depositional history for the Balakot area in the Early Eocene. seven microfacies have been identified, indicating inner ramp and middle ramp and lagoonal envi-ronments, these can be used to gain useful information regarding the paleoenvironmental factors and carbonate deposi-tion controlling processes. The Foraminiferal Bioclastic Wackestone Microfacies (MF-1) from the Margalla Hill Limestone indicates high-energy inner ramp deposits in a shallow marine setting with well-developed tidal currents. The predominance of foraminiferal bioclasts like Nummulites and Assilina suggest that large foraminiferans rapidly flourished in this high-energy environment which is concordant with observations in other studies (Flügel, 2004). On the other hand, the Assilina-Nummulites Bioclastic Wackestone (MF-2) and Assilina Bioclastic Wackestone (MF-3) correspond to a middle ramp setting where moderate energy conditions resulted in the accumulation of larger foraminifera with more micritic matrix and fewer high energy features.

The heavily bioclast-rich mudstone microfacies of the Chorgali Formation shifted towards a more lagoonal environment which is related to low-energy, restricted conditions (MF-4). This depositional setting, which contains micritic matrix with a fine-grained texture and pyrite and stylolites, reflects an overall low oxygen environment associated with lagoonal conditions. This is further evident from MF-5, Assilina-Alveolina Bioclastic Wackestone and MF-6, Foraminiferal Assilina Bioclastic Wackestone showing lesser wave action and occasional sea-level changes in shallow marine environment. Bioclastic Mudstone and Lithoclastic Shale Microfacies (MF-7), present in the Chorgali Formation, represents the nearly stagnant environment with low energy system characterized by limited water circulation which are not uncommon in lagoonal or shallow restricted marine settings.

The biostratigraphic analysis is critical to the dating of these formations. Biostratigraphy Based on the index fossils of Margalla Hill Limestone indicates that SBZ8 corresponds to the Middle Illerdian-2 stage (Fig.3) which indicate the shallow marine to transgressive marine effect during the deposition. The Alveolina Indicatrix Biozone (SBZ9) in the Chorgali Formation indicates a change to more restricted, deeper marine conditions, which also agrees with the change in depositional setting suggested from the microfacies. These biozones improve the precision of the chronostratigraphic record of the region, and can be compared with other Eocene sections around the Tethyan belt, which contributes to the further biostratigraphic framework in the region.

The tectonic history of the Balakot region has had a significant influence on the depositional settings of the Margalla Hill Limestone and Chorgali Formation. The ongoing Himalayan orogeny, through processes such as subsidence, uplift, and erosion, has shaped the local paleogeography, creating space for carbonate deposition. The Main Boundary Thrust (MBT) and associated tectonic activity have led to local subsidence, allowing for the deposition of carbonates during the Early Eocene. The study's findings align with previous research, such as Shah (1977) and Munir et al. (2006), which also identified the Margalla Hill Limestone and Chorgali

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Formation as key units for understanding Eocene carbonate deposition in the region. However, this study builds upon those works by providing a more detailed microfacies analysis and a refined biostratigraphic framework, enhancing the understanding of paleogeographic and tectonic reconstructions in the region.

In comparison with other studies, such as Azhar et al. (2013), which also identified similar depositional environments in the southern Hazara Fold-Thrust Belt, and Shahzad et al. (2017), who explored the Margalla Hill Limestone in the Muzaffarabad area, the current study offers a more detailed interpretation of the microfacies and depositional settings. Moreover, Rehman (2024) and Bilal et al. (2022) have corroborated the findings of lagoonal and middle ramp environments in the Chorgali Formation, supporting the interpretations made in this study. These comparisons further refine the understanding of the depositional history and the role of tectonics in shaping the region's carbonate sedimentation.

Through these detailed analyses, this study not only contributes to the understanding of the Margalla Hill Limestone and Chorgali Formation but also provides a clearer biostratigraphic and depositional model for the Early Eocene carbonate deposits in the region. The findings enhance the existing chronostratigraphic framework and offer new insights into the role of tectonics and sea-level fluctuations in carbonate deposition during the Eocene.

Conclusion

This research presents an integrated study of the Margalla Hill Limestone and Chorgali Formation in the Balakot area, emphasizing microfacies types, depositional environments, biostratigraphy, and tectonic control. Analysis of seven different microfacies demonstrate a changing depositional environment from shallow marine in the inner and middle ramp to restricted (lagoonal) conditions in the Chorgali formation. The microfacies recognized such as Foraminiferal Bioclastic Wackestone, Assilina-Nummulites Bioclastic Wackestone and Bioclastic Mudstone reflect the energy level and sedimentation processes that took place during the Early Eocene.

The biostratigraphic study resulted in two significant biozones for the area, the Nummulites Atacicus/Nummulites Globulus/Assilina LeymerieBiozone (SBZ8) for Margalla Hill Limestone and the Alveolina Indicatrix Biozone (SBZ9) for Chorgali Formation. These biozones are useful for stratoigraphic association of the study area with other Eocene sequences within Tethyan belt and provide a strong chronostratigraphic framework for Margalla Hill limestone and chorgali formation. Recognition of these biozones also strengthens the paleoenvironmental interpretation of the tract in the Early Eocene.

It is also important to mention that the tectonic setting of the Balakot area which is disturbed by the Himalayan orogeny and displaced by MBT (Main Boundary Thrust), has a significant effect on the deposition of these carbonates. Tectonic movements of subsidence, uplift and erosion have generated the accommodation space for carbonate deposition and influenced sea level variation that is manifested as transgressive and regressive depositional cycles observed in the Margalla Hill Limestone and Chorgali Formation..

Implications for Paleoenvironmental Reconstruction

These study results are significant for the paleoenvironmental interpretation of Balakot area in the early Eocene. The microfacies analysis with high resolution not

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http://amresearchreview.com/index.php/Journal/about

only gives a more precise deposition zones model in shallow marine, but also reveals sensitivity on how tectonic regime and paleoclimatic condition controlled the carbonate deposition in the area. The construction of biostratigraphic zones adds an extra degree of precision to the chronostratigraphy of the Balakot locality and thus the correlation with other Eocene sequences in the foreland basin of the Himalaya.

This research helps elucidate the tectonic history and sedimentary evolution of the Balakot area in the Early Eocene, in order to understand the effect of the Himalayan orogeny and related tectonic changes on the carbonate depositional regime. The study is a relevant contribution to further researches on carbonate sedimentation, biostratigraphy, tectonic evolution and basin analysis in a Tethyan geological framework.

Suggestions for Future Research

Although this study provides a detailed understanding of the Margalla Hill Limestone and Chorgali Formation, several avenues for further research remain. First, the identification of additional microfacies types and the use of more advanced techniques such as stable isotope analysis (e.g., δ 18O and δ 13C) could offer further insights into the paleoenvironmental conditions during the Early Eocene. These techniques could provide more detailed information about water temperature, salinity, and sea-level changes.

Additionally, high-resolution temporal and spatial studies across the Balakot region could further refine the biostratigraphic framework, allowing for more precise correlations between the Margalla Hill Limestone, Chorgali Formation, and other regional formations. Further geochemical analyses of the carbonate units would be beneficial in understanding the diagenetic processes and their impact on carbonate mineralogy.

Moreover, exploring the influence of tectonic uplift and subsidence on the depositional patterns of carbonates would help build a clearer model for how tectonics influences sedimentation in tectonically active areas like the Himalayan foreland basin.

Final Thoughts

This study provides a robust framework for understanding the Early Eocene carbonate deposition in the Balakot region, with a particular focus on microfacies, biostratigraphy, and tectonic influences. The combination of field observations, petrographic analysis, and biostratigraphic data has not only contributed to the understanding of the depositional history of the Margalla Hill Limestone and Chorgali Formation but has also enhanced the knowledge of Himalayan orogeny-driven tectonic and sedimentary processes. The findings from this study offer valuable insights into the broader understanding of shallow marine environments and carbonate deposition in the Himalayan foreland basin during the Early Eocene and can serve as a foundation for future research in this region.

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