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Sedimentologic properties of mud-dominated deep-shelf carbonates of the Upper Indus Basin: The Paleocene-Eocene Patala Formation of the Hazara Sub-basin, Northern Pakistan

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Summary

Field and petrographic study of the Patala Formation of the Hazara Sub-basin led to the identification of six lithofacies that include: Organic rich shale (Pf1), Planktonic Foraminifera mudstone (Pf2), Bioclastic wackestone (Pf3), *Discocyclina-Ranikothalia* wackestone (Pf4), mixed benthic Foraminifera packstone (Pf5), and Mollusk Rudstone (Pf6). These lithofacies can be grouped in to two lithofacies associations: LA1 consists of Pf1, Pf2 and Pf6 and represent distal middle to proximal outer ramp and LA2 which consist of Pf3, Pf4 and Pf5. This second association is interpreted as low to moderate energy mid ramp accumulations. The presence of sedimentary structures, textures and association of fossils suggest the deposition occurred in a quiet subtidal setting. Besides the mud domination of the various facies of the formation and presence of planktonic foraminifera, absence of intertidal and supratidal signatures further suggest subtidal setting of open shelf conditions distant from the shallower facies represented by sandstone and coal deposits farther south of the study area.

Introduction

The late Paleocene-early Eocene Patala Formation is a lithologically heterogeneous unit that occurs in the upper Indus Basin of Northern Pakistan. During the Paleocene and Eocene epochs, the basin was a broad depositional site that belonged to the Neo-Tethys Ocean. Compressional tectonics related to the Indian-Eurasian collision fragmented the Indus Basin into discrete sub-basins that include salt range, Kohat, Potwar, Kala-Chitta range, and Hazara (Fig.1) (Afzal et al 2009; Umar et al., 2015). The Patala Formation occurs in all of these sub-basins. However, due to differential paleobathymetric conditions, from coastal/backshore to deep shelf, different lithologic units represent the formation. Such lithologic units include coal, sandstone, shales, marls and limestone lithofacies. Most of the previous studies addressed the coal-bearing and associated sandstone units of the formation due to the coal's potential as hydrocarbon source rocks. Sedimentologic and biostratigraphic attributes of the basinward shale and carbonate facies of the Patala Formation are relatively less understood, particularly in the Hazara Sub-basin. This study intends to explore these relatively deep shelf sediments of the Patala Formation in the Hazara Sub-basin (Fig. 1). The formation conformably overlies middle Paleocene Lockhart Limestone and is conformably overlain by Eocene Margalla Hill Limestone (Fig. 2).

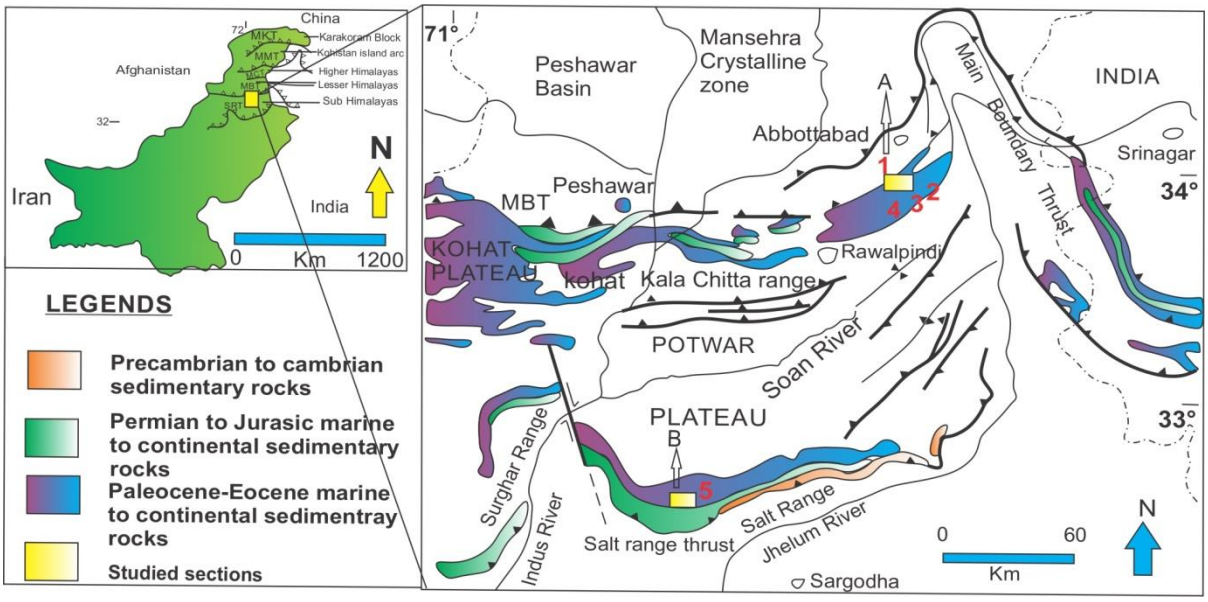


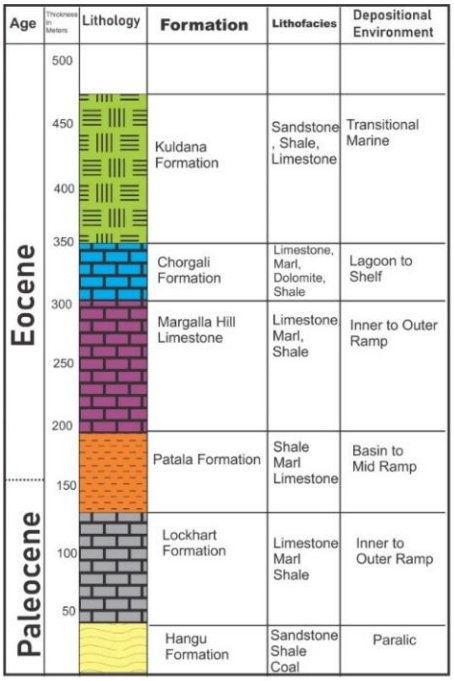
Fig.1: Geological map of the study area which occurs in the north Pakistan. The studied sections occur in the two yellow boxes A (Hazara Basin) and B (Salt Range) (Modified from Kazmi and Rana, 1982)).

Lithologic properties of the Patala Formation

In the study area (Fig. 1, Fig. 3), the formation varies from 60m to 180m thick that can be divided in to three units: lower unit of shale-limestone interbeds, middle shale unit and upper unit of shale-limestone interbeds (Fig. 4). Five outcrop sections (Fig. 1, Fig. 3) were studied in the field, samples collected and studied petrographically. Six lithofacies (PF1 to PF6) were recognized and include: Organic-rich Shale (PF1): dark gray to black, medium to thickly bedded shale that forms the most abundant lithologic facies of the formation; Planktonic Foraminifera Mudstone (PF2): dark gray, thin to thickly bedded mudstone associated with PF1; Bioclastic Wackestone (PF3): light to dark gray limestone with different planktonic and benthic foraminifera species, thin-walled ostracodes and crinoids; *Discocyclina-Ranikothalia* wackestone (PF4): dark gray, medium to thickly bedded limestone with larger benthic foraminifera; Mixed Benthic

Foraminifera Packstone (PF5): light to dark gray, medium to thickly bedded limestone with different types of benthic foraminifera tests and Mollusk Rudstone (PF6): light to dark gray, thin to medium bedded, normally-grading limestone with gastropod and bivalve shells. PF6 has basal erosional surfaces and associated with PF1 and PF2. Recognized trace fossils include *Planolites* and *Zoophycos*. Examples of the different lithofacies types are shown in Fig. 5

Fig.2: (upper left): Stratigraphic column showing the Paleogene stratigraphy of the study area (Modified from Shah, 1977).



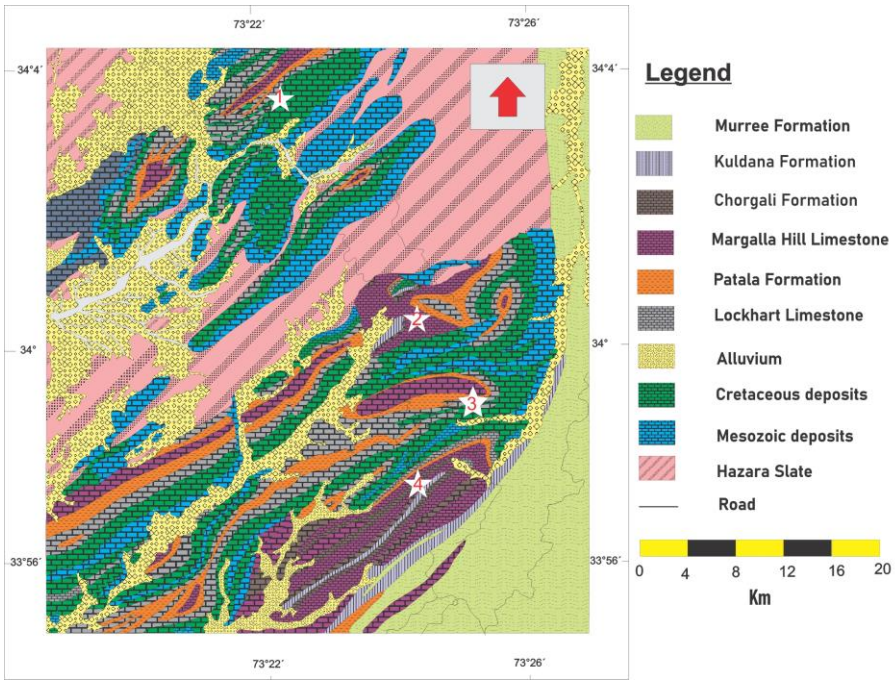
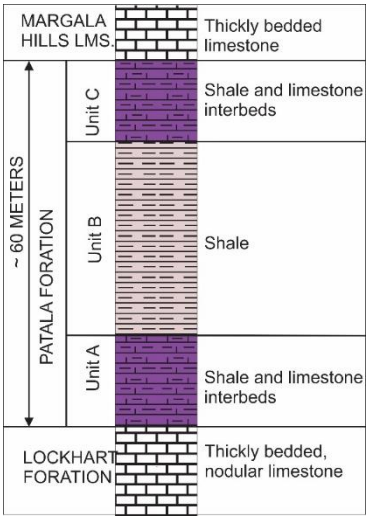


Fig.3: (upper right) Geologic map of the study area with the locations of the four sections in the Hazara Sub-Basin. The fifth section is located in the Salt Range area shown in Box B in Fig. 1.

Fig.4: Tripartite division of the Patala Formation: lower and upper units consist of shale and limestone lithofacies whereas the middle unit, which is the thickest among the three units of the formation, consists of dark grey shales. The underlying and overlying thick carbonates of the Lockhart and Margalla Hill formations are also shown.



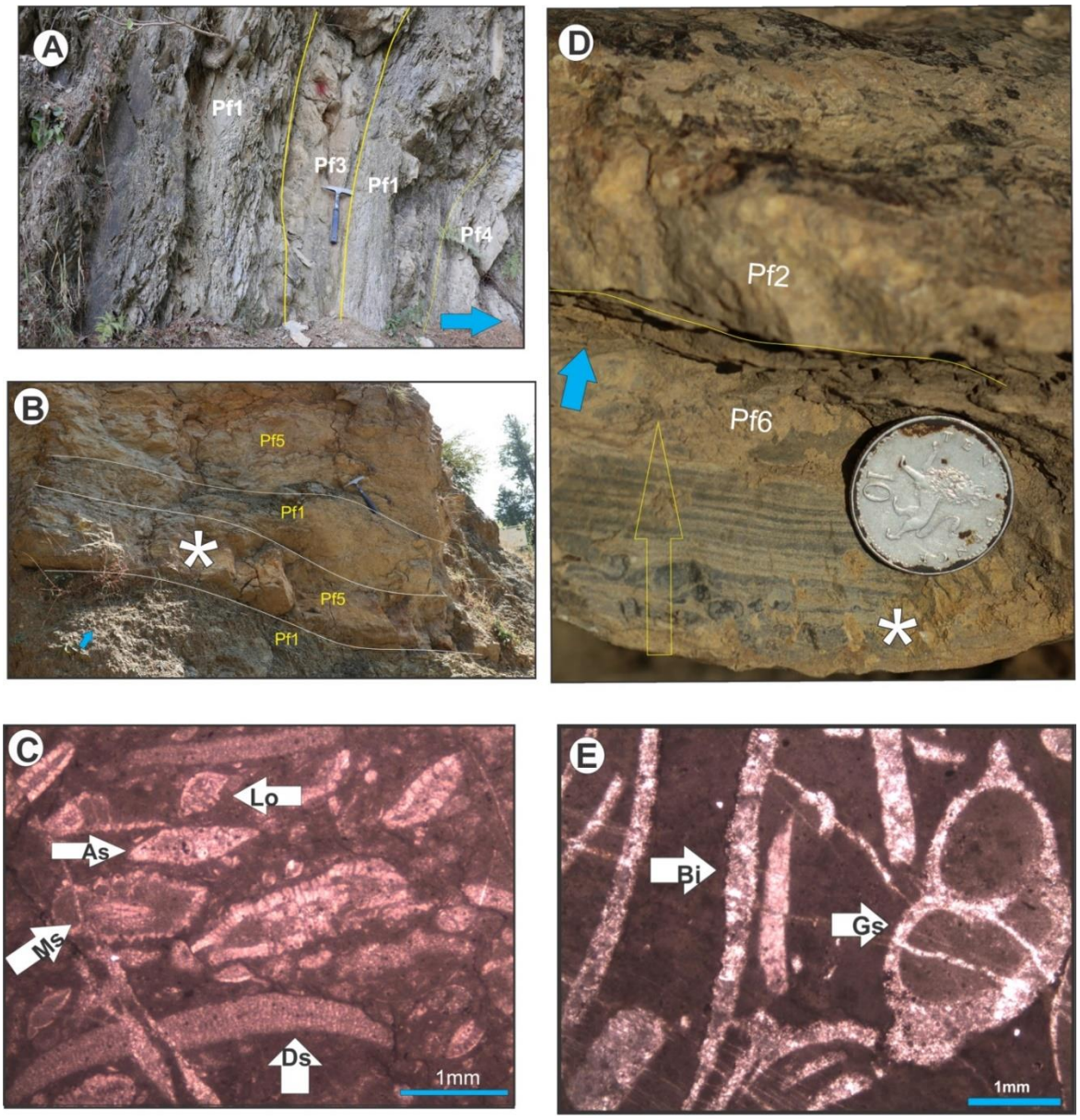


Fig. 5 A) Layers of shale and different mudstone lithofacies of the Patala Fm. Horizontal field view is about 3.5 m long. B) Shale unit (lower) and packstone (PF5). The asterisk shows the packstone facies of photomicrograph C. (Hammer is 33 cm long). C) Bioclastic packstone with *Lockartia* (Lo), *Assilina* (As), *Discocyclina* (Ds) and *Miscellena* (Ms). D) Normally grading unit characterized by lower mollusk rudstone gradually followed by laminated thick mudstone at the top. The unit has a basal erosional contact. The asterisk shows the sample of the rudstone lithofacies shown in photomicrograph E. The coin is 24.5mm in diameter. E) Thin section photomicrograph of the rudstone lithofacies with gastropod (Gs) and bivalve (Bi) shells.

Depositional setting

The six lithofacies can be arranged under two lithofacies associations (LA1 and LA2). LA1 consists of interbedded PF1 and PF2 with subordinate occurrence of PF6, and LA2 consists of PF3, PF4 and PF5 interbeds. LA1 represents distal middle to proximal outer ramp where fine-grained planktonic and organic rich PF1 and PF2 accumulated with rare storm deposits of PF6. LA2 is envisaged as mid ramp deposits of low to moderate energy setting. Absence of any intertidal and supratidal signatures and presence of the planktonic organisms, thin-walled ostracods, trace fossils and the overall dominance of the fine-grained texture suggest that deposition of the formation in the study area took place mainly in a quiet subtidal setting (Fig. 6).

Patala Formation lithofacies in the landward areas of the basin is characterized by coal-bearing facies with sandstone interbeds (Warwick et al., 1990; Yasin et al., 2021). These landward deposits were deposited in coastal areas with swamps, backshore and foreshore environments farther away from the carbonate and shale-dominated depositional site addressed in this study. Further work on correlating foreshore to backshore facies with the deeper shelf deposits are in progress.

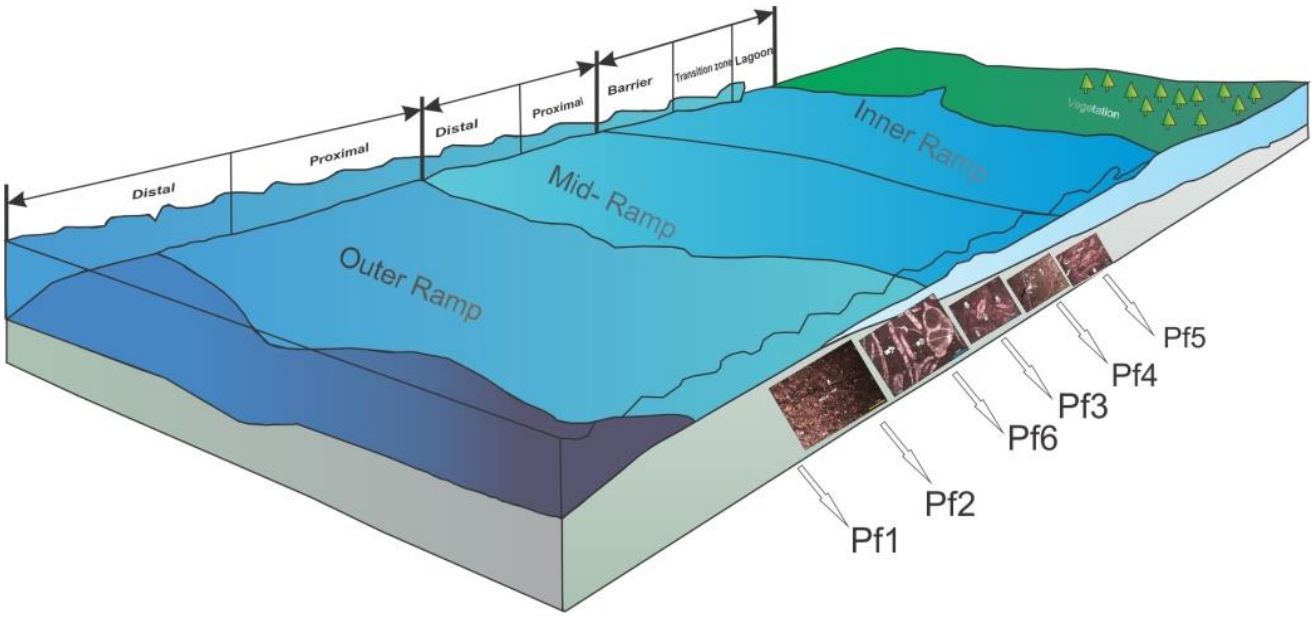


Fig. 6: Depositional setting of the Patala Formation in the study area. The lithofacies deposited at different parts of the ramp, where (Pf1) represents Organic-rich Shale, Planktonic Foraminifera Mudstone (Pf2), Bioclastic Wackestone (PF3), *Discocyclina-Ranikothalia* wackestone (PF4), Mixed Benthic Foraminifera Packstone (PF5), and Mollusk Rudstone (PF6).

Conclusion

As a total of five sections were studied thoroughly in the study area. The petrographic study and field observations led to the identification of six lithofacies i.e. Pf1: Organic rich shale, Pf2: Planktonic Foraminifera mudstone, Pf3: Bioclastic wackestone, Pf4: *Discocyclina-Ranikothalia* wackestone, Pf5: Mixed benthic Foraminifera packstone, and Pf6: Mollusk Rudstone. Pf1, Pf2 and Pf6 represent distal middle to proximal outer ramp and are interpreted as lithofacies association (LA1); however Pf3, Pf4 and Pf5 (LA2) suggest the deposition took place in a low to moderate energy conditions. The presence of sedimentary structures, textures and association of fossils suggest the deposition occurred in a quiet subtidal setting. Absence of intertidal and supratidal signatures further suggest subtidal setting.

Acknowledgments

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