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Depositional environment of the Patala Formation in biostratigraphic and sequence stratigraphic context from Kali Dilli Section, Kala Chitta Range, Pakistan

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Abstract

The late Paleocene-early Eocene Patala Formation of the Kala Chitta Range represents a latest Paleocene foraminiferal dominated unit of the low latitude Tethyan carbonate platform benthic community evolution. The latest Paleocene stage is dominated by the *Ranikothalia* sp. and *Miscellanea* sp. larger foraminifera with subordinate dasycladacean green algae indicating Shallow Benthic zones 4 & 5 (SBZ4 & SBZ5). The late Paleocene benthic community in the Indus Basin is devoid of any coral taxa. The absence of coral taxa is attributed to the high temperature associated with the Paleocene Eocene Thermal Maximum (PETM). The hot temperature of the PETM in low latitude hampers the growth of temperature sensitive corals as noted in other low latitude Tethyan sections.

The latest Paleocene foraminiferal dominated unit is composed of 10 sub-microfacies types grouped into 3 microfacies including packstone, wacke-packstone and wackstone. The microfacies types indicate intertidal open marine foraminiferal shoal to intertidal lagoonal environment of deposition.

Microfacies analysis also yields a second order sequence (i.e., ThPat) of the latest Thanetian which is composed of a third order highstand system tract and six vertically stacked parasequences of fourth/fifth order showing aggradation.

Keywords: Paleocene; Patala Formation; Foraminifera; Kala Chitta Range; Pakistan

1. Introduction

The Paleogene represents a warm climate in the earth's climatic history (Zachos et al., 2001). This warming phase started at the Cretaceous/ Paleogene boundary and ended at the PETM. The PETM is a global warming event occurring at the Paleocene/Eocene (P/E) boundary and is superimposed on the overall warming trend of the Paleocene (Kennett and Stott, 1991). A negative Carbon Isotopic Excursion (CIE) associated with the PETM and marking the onset of this event is now worldwide used to demarcate the P/E boundary (Aubry and Ouda, 2003). A number of biotic, tectonic and climatic events are associated with the PETM (see Zachos et al., 2001).

A turnover of larger Foraminifera on the Tethyan shelf associated with the PETM has also been reported by Speijer et al. (1997) and Orue-Etxebarria et al. (2001). Following this work on Tethyan shelf benthic community evolution, Scheibner et al. (2005, 2007) reported that the Tethyan carbonate platforms evolved in three discrete stages during the early Paleogene warming phase. According to Scheibner et al. (2005) the first stage carbonate platform consisted of coral-algal reefs, the coral-algal reefs in the second stage survived only at middle latitudes (Scheibner et al., 2007) and this stage in low latitude is dominated by larger foraminifera bearing shoals (i.e., *Miscellanea* sp. and *Ranikothalia* sp.) and in the third and final stage the newly developing larger foraminifera lineages (i.e., *Alveolina* sp. and *Nummulites* sp.) took over the role as main carbonate-producing organisms in low to middle latitude. Scheibner et al. (2005) assigned biostratigraphic ages of Serra-Kiel et al. (1998) to these stages of carbonate platform evolution; first stage (SBZ3), second stage (SBZ4) and third stage (SBZ5-6).

The sedimentology and biostratigraphy of the Paleocene Patala Formation, Kala Chitta Range has been the subject of a number of previous studies (e.g., Butt, 1989, 1991; Akhtar and Butt, 1999, 2000). Recently, Afzal et al. (2010) gave a detail review of the larger foraminiferal biostratigraphy and designated the age of Patala Formation as SBZ4, based on the data from Akhtar and Butt (1999). However, there is a lack of an integrated study addressing the depositional environment, biostratigraphy/sequence stratigraphy and benthic community evolution in comparison with other Tethyan sections. This study attempts to assess the evolution of carbonate platform benthic community in a sequence stratigraphic and biostratigraphic context based on microfacies analysis from a stratigraphic section of the Formation in the Kala Chitta Range (Upper Indus Basin, Pakistan) compared with other Tethyan sections e.g., Pyrenean sections (Scheibner et al., 2007) and Galala Platform , Egypt (Scheibner et al., 2005).

2. Material and methods

The Kala Chitta Range forms the northern edge of the Potwar Sub-Basin (Upper Indus Basin). It merges laterally towards the east into the Hazara Mountains and Margala Hills and westwards into the Samana Range. The Range lies between latitudes 33° 30´ and 34°N and longitudes 72° and 72° 45´E. The Paleocene Patala Formation was measured and sampled at Kali Dilli section lying between latitude 33°39'9.4"N and longitude 72°18' 20"E and is linked by metalled, unmetalled and fair weather roads accessible by four-wheel drive vehicle (Fig. 1).

The Patala Formation is composed of limestone with shale interbeds. A total of 35 samples were collected from the Patala Formation (Fig. 2). Only the limestone samples were thin sectioned for petrographical analysis.

The microfacies types and the foraminifera are represented in Plates 1-4.

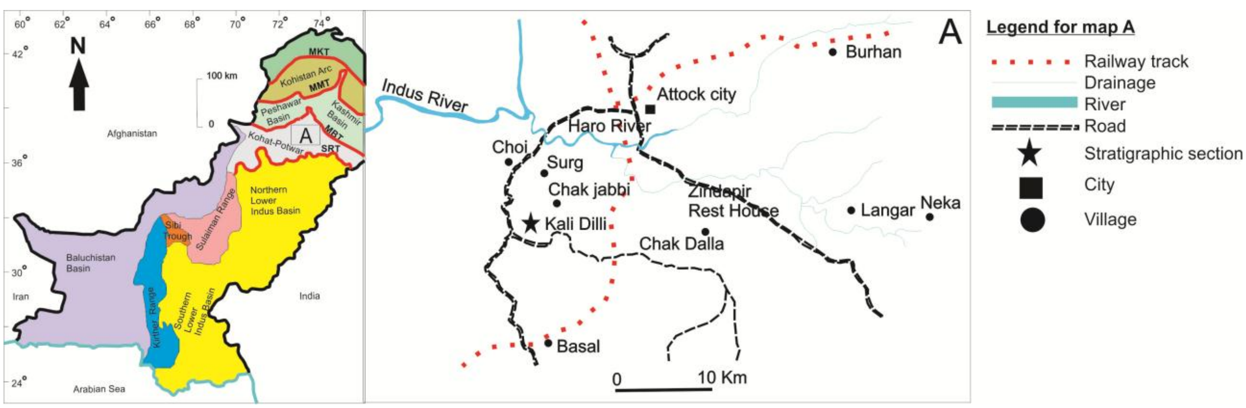


Fig. 1. Location of the Kali Dilli Section (A), Kala Chitta Range, Upper Indus Basin, Pakistan.

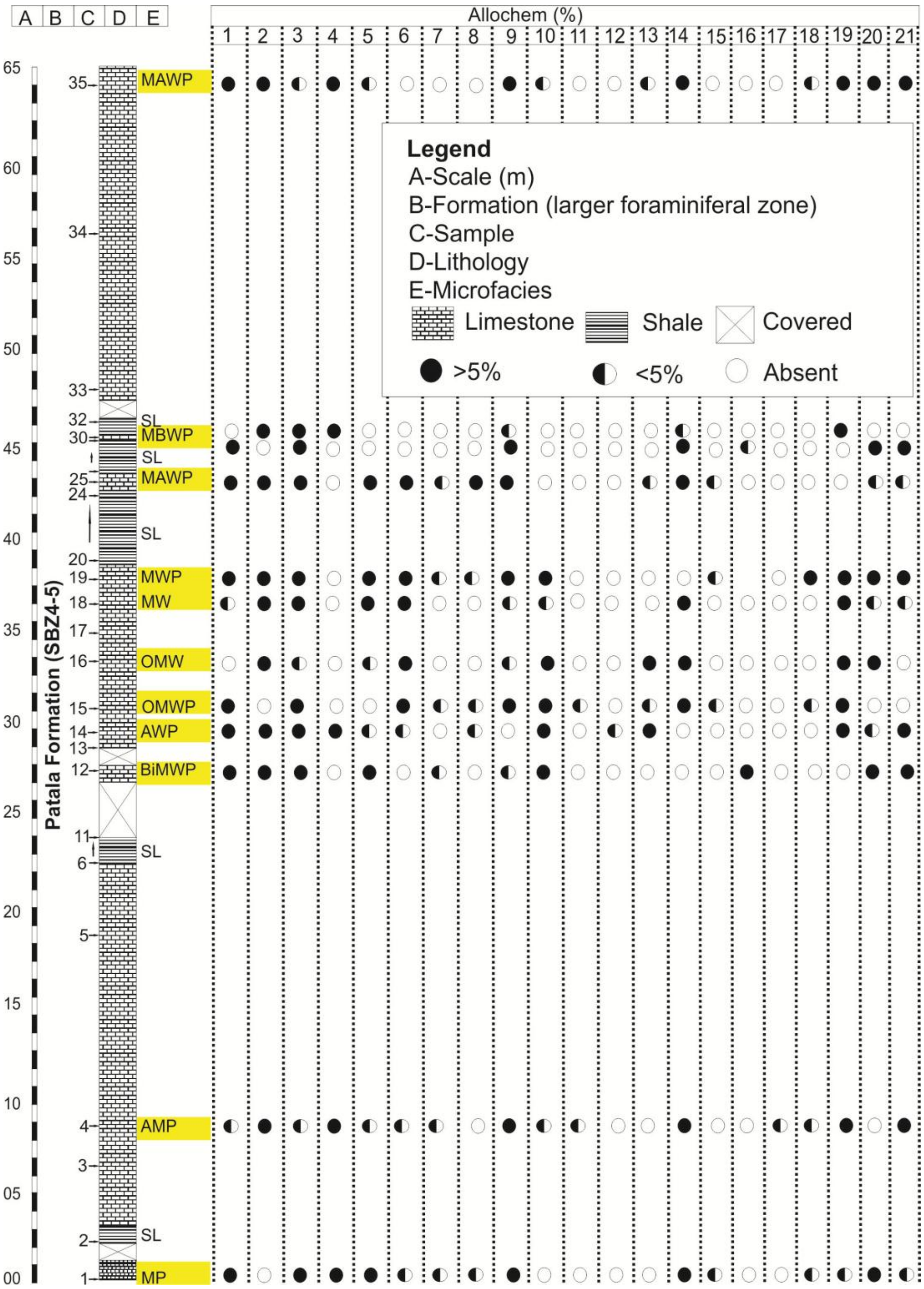


Fig. 2. Lithology, microfacies and allochem (in percents), Kali Dilli Section, Kala Chitta Range, Upper Indus Basin (Pakistan). 1. Miliolid, 2. *Miscellanea* sp., 3. *Miscellanea miscella*, 4. *Lockhartia* sp., 5. *Lockhartia conditi*, 6. *Lockhartia tipperi*, 7. *Lockhartia haimei*, 8. *Lockhartia conica*, 9. *Discocyclina ranikotensis*, 10. *Ranikothalia sindensis*, 11. *Ranikothalia sahnii*, 12. *Alveolina* sp.,13. Orbitoididea, 14. Dasyclad algae, 15. Unidentified foraminifera, 16. *Kathina selveri*, 17. *Assilina* sp., 18. Orbitoididea, 19. Smaller benthic foraminifera, 20. Mollusks, 21. Echinoderms, SL- Shale Lithofacies.

3. Results and Discussion

3.1. Foraminiferal dominated stage

As already discussed, the Paleocene carbonate platforms of Tethy's are composed of two depositional stages with respect to benthic community evolution (e.g., Scheibner et al., 2005, 2007). The late Paleocene-early Eocene Patala Formation of the Kali Dilli Section, Kala Chitta Range (Upper Indus Basin) preserves the foraminiferal-algal stage resembling second stage of the benthic community evolution. This stage is composed of limestone with abundant larger foraminifera, algae is the second dominant allochem type.

The age determination of this Paleocene depositional unit is possible with larger foraminifera such as *Miscellanea* sp. and *Ranikothalia* sp.. The larger foraminiferal assemblage is composed of *Miscellanea miscella*, *Miscellanea* sp., *Lockhartia conditi*, *Lockhartia tipperi*, *Lockhartia haimei*, *Lockhartia conica*, *Lockhartia* sp., *Ranikothalia sindensis*, *Ranikothalia sahnii*, *Discocyclina ranikotensis*, *Alveolina* sp., *Assilina* sp., Orbitoididea and indicates SBZ4- 5.

3.2. Microfacies

We estimated the relative abundance of about 21 different constituents from detailed thin section analysis of 12 thin sections from the late Paleocene-early Eocene (SBZ4 & 5) Patala Formation of the Kali Dilli Section, Kala Chitta Range (Fig. 2). Major constituents are mainly biogenic components, belonging predominantly to larger foraminifera and algae. The relative abundance data of larger foraminifera is given in Figure 2. The abundance of allochem types are categorized into three different categories , these are; 1- empty circle (absent), 2- half filled circle (< 5%), 3- filled circle (>5%). The abundance data from the Patala Formation is clearly showing the predominance of larger foraminifera over algal elements and thus representing the second stage of the low latitude Tethyan carbonate platform benthic community, i.e., evolution from algal dominated to larger foraminiferal (*Ranikhothalia* sp. and *Miscellanea* sp.) dominated assemblages in the late Paleocene. A total of 10 sub-microfacies types grouped into three microfacies types have been identified. In order to interpret the depositional environments, these microfacies are compared with the Wilson (1975) standard microfacies types (SMF) and the facies zones are determined using the models of Wislon (1975) and Flügel (2004).

3.2.1. Packstone microfacies (Plates 1A & 1B)

This microfacies type is further categorized into two sub-microfacies named as *Miscellanea* packstone (MP) and Algal-*Miscellanea* packstone (AMP). Both sub-microfacies types are predominantly composed of larger foraminifera including *Miscellanea* sp., *Lockhartia* sp., *Ranikothalia* sp., Orbitoididea, *Assilina* sp., Miliolids and *Discocyclina* sp.. Algae are the second dominant constituent and are relatively more abundant in AMP sub-microfacies. Subordinate constituents include bivalve and mollusk fragments. The planktonic foraminifera occur as rare component in MP sub-microfacies. All constituents are embedded in micrite matrix. The amount of micrite matrix is < 30% in this microfacies type.

3.2.1a. Occurrence and interpretation

This microfacies type occupies the first 22.5m of the Kali Dilli Section (Fig. 2). The sub-type MP is dominantly composed of larger foraminifera in a packstone indicating intertidal foraminiferal shoal (Flügel, 2004). Sub-type AMP is composed of algae (i.e., predominantly dasyclad algae) in addition to larger foraminifera, such algal-larger foraminiferal association indicates deposition on intertidal distal foraminiferal back-shoal to intertidal lagoon (Flügel, 2004). This microfacies type (MFT) represents depositional environment ranging from intertidal foraminiferal shoal (MP) to distal foraminiferal back-shoal (AMP). An analogue of this MFT is reported from Pyrenees (Spain) by Scheibner et al. (2007) but their MFT ranges to subtidal depth of deposition based on the occurrence of red algae; however, this MFT from Indus Basin is devoid of red algae and is therefore restricted to intertidal open marine conditions and is comparable with the SMF-18 of Wilson standard microfacies types and represents Facies Zone (FZ) 7 of Wilson (1975) and Flügel (2004).

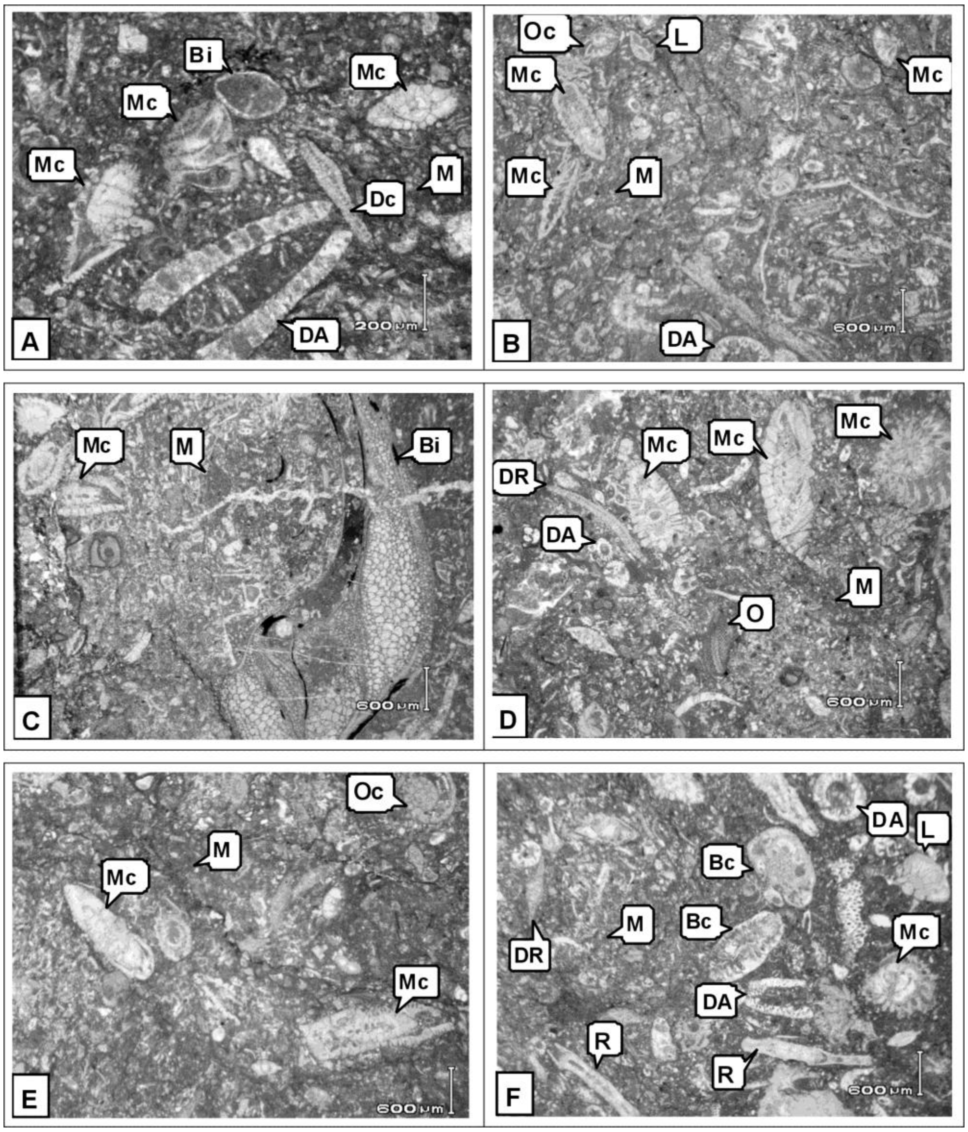
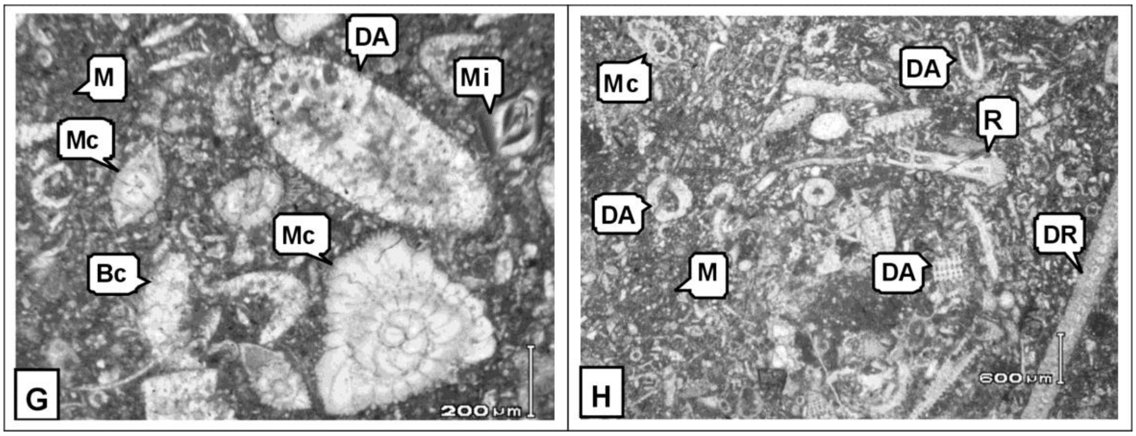


Plate 1

A. Photomicrograph of *Miscellenea* packstone sub-microfacies displaying *miscellenea* sp. (Mc), bivalve (Bi), *Discocylina* sp. (Dc) and dasycladecean algae (DA) embedded in micrite matrix (M) (PPL, Sample # 01).
B. Photomicrograph of Algae-*Miscellenea* packstone sub-microfacies displaying *miscellenea* sp. (Mc), dasycladecean algae (DA), *Operculina* sp. (Oc) and *Lockhartia* sp. (L) embedded in micrite matrix (M) (PPL, Sample # 04).
C. Photomicrograph of Bivalve-*Miscellenea* wacke-packstone sub-microfacies displaying *Miscellena* sp. (Mc) and bivalve (Bi) embedded in micrite matrix (M) (PPL, Sample # 12).
D. Photomicrograph of Orbitoididea -*Miscellenea* wacke-packstone sub-microfacies displaying *Miscellenea* sp. (Mc), dasycladecean algae (DA), Orbitoididea, (O) and *Discocylina ranikotensis* (DR) embedded in micrite matrix (M) (PPL, Sample # 15).
E. Photomicrograph of *Miscellenea* wackestone sub-microfacies displaying *Miscellenea* sp. (Mc) and *Operculina* sp. (Oc) embedded in micrite matrix (M) (PPL, Sample # 18).
F. Photomicrograph of *Miscellenea* wacke-packstone sub-microfacies displaying *Miscellenea* sp. (Mc), dasycladecean algae (DA), *Discocylina ranikotensis* (DR), *Ranikothalia* sp. (R), *Lockhartia* sp. (L) and bioclasts (Bc) embedded in micrite matrix (M) (PPL, Sample # 19).



G. Photomicrograph of Algae-*Miscellenea* wacke-packstone sub-microfacies displaying *Miscellenea* sp. (Mc), dasycladecean algae (DA), Miliolids (Mi) and bioclasts (Bc) embedded in micrite matrix (M) (PPL, Sample # 25).

H. Photomicrograph of Algae-*Miscellenea* wacke-packstone sub-microfacies displaying *Miscellenea* sp. (Mc), dasycladecean algae (DA), *Discocylina ranikotensis* (DR) and *Ranikothalia* sp. (R) embedded in micrite matrix (M) (PPL, Sample # 35).

3.2.2. Wacke-Packstone microfacies (Plates 1C, 1D, 1F, 1G & 1H)

A number of sub-microfacies can be recognized in this micorfacies type, these sub-microfacies types include; Bivalve- *Miscellanea* wacke-packstone (BiMWP), Algal wacke-packstone (AWP), Orbitoididea - *Miscellanea* wacke-packstone (OMWP), *Miscellanea* wacke-packstone (MWP), *Miscellanea* - algal wacke-packstone (MAWP), *Miscellanea*-bioclastic wacke-packstone (MBWP). The microfacies type is dominated by larger foraminifera predominantly composed of *Miscellanea* sp.. Algae are the second dominant allochem type. Other larger foraminifera (such as *Lockhartia* sp., Miliolids, *Ranikothalia* sp., *Discocylina* sp., Orbitoididea and *Assilina* sp.) occurs only as minor component in BiMWP, AWP, OMWP, MWP and MBWP. *Alveolina* sp. occurs as minor constituent only in AWP representing SBZ5 component. Bivalves occur only in BiWWP and MAWP. All allochem types are embedded in up to 50% micrite matrix.

The sub-microfacies types are recognized based on the second dominant constituents such as bivalves in BiMWP, algae in AWP, Orbitoididea in OMWP, *Miscellanea* in MAWP and in MBWP sub-microfacies. However, MWP sub-microfacies is named after the predominance of *Miscellanea* sp.. The allochem types mentioned earlier are present with the following exceptions; Miliolids and *Discocyclina* sp. are absent in BiMWP, *Discocyclina* sp. is absent in AWP, *Lockhartia* sp. is absent in OMWP, *Ranikothalia* sp. and Orbitoididea are absent in MBWP.

3.2.2a. Occurrence and interpretation

The MFT first occurs in the middle of the Kali Dilli Section and is repeated four times up-section with intervals of lagoonal facies i.e., MW, OMW and Shale Lithofacies (Fig. 3). The sub-type represents sub environments of deposition as proximal foraminiferal back-shoal (BiMWP), foraminiferal back-shoal to lagoon (AWP), distal foraminiferal back-shoal (OMWP), proximal foraminiferal back-shoal (MWP), distal foraminiferal back-shoal to lagoon (MAWP) and distal foraminiferal back-shoal (MBWP). Therefore, the overall depositional environment of the MFT is ranging from intertidal proximal foraminiferal back-shoal to intertidal lagoon. A more or less similar MFT has been reported by Scheibner et al. (2007), their MFT is based on the high abundance of Orbitoididea, small Miliolids together with the presence of dasyclad green algae and they named their MFT as *Alveolina*-O*rbitolites* packstone. However, Scheibner et al. (2007) reported proximal inner platform setting for their MFT but the MFT in Indus Basin displays wacke-packstone texture and is interpreted as distal foraminiferal back-shoal to intertidal lagoon. This MFT is comparable with the SMF-18 of Wilson standard microfacies types and represents FZ 7 to FZ 8 of Wilson (1975) and Flügel (2004).

3.2.3. Wackstone microfacies (Plate 1F)

This microfacies type includes Orbitoididea – *Miscellanea* wackstone (OMW) and *Miscellanea* wackestone (MW) sub-microfacies. Dominant allochem type is larger foraminifera predominated by *Miscellanea* sp. and Orbitoididea and the dominance of these taxa form the basis for sub-microfacies recognition. *Lockhartia* sp. are absent, *Discocyclina* sp., Miliolids, *Assilina* sp. and *Ranikothalia* sp. occur as rare component, Orbitoididea is absent in MW. Algae occur as rare in MW to absent in OMW. The allochem type is composed in > 80% micrite matrix and therefore giving a wackstone fabric.

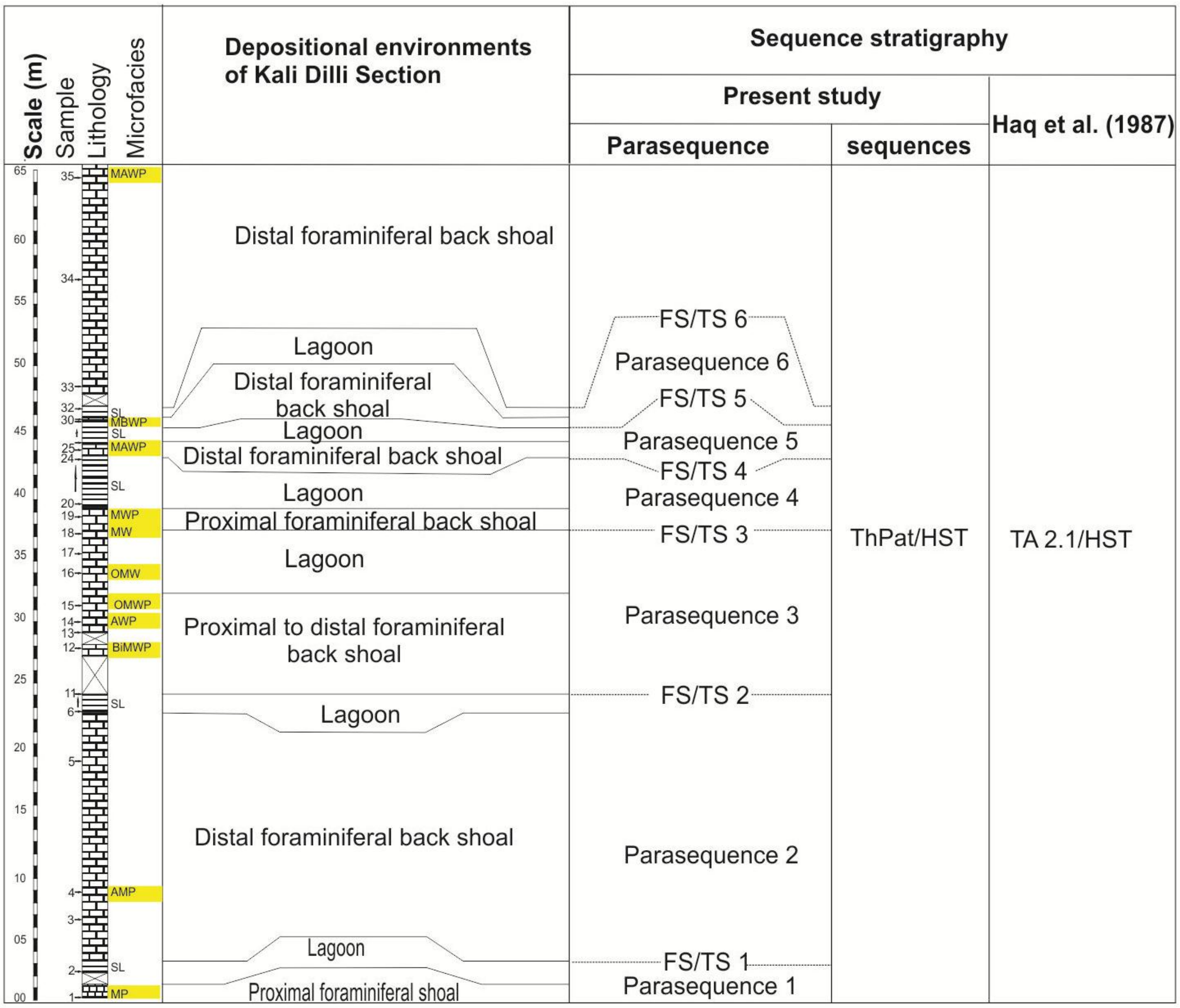


Fig. 3. Depositional environments and sequence stratigraphy of the Patala Formation (Depositional unit II/SBZ4), Kali Dilli Section, Kala Chitta Range, Upper Indus Basin (Pakistan), FS/TS = Flooding surface/Transgressive surface, HST = Highstand system tract, ThPat (name for local second order sequence), Th = Thanetian and Pat = Patala.

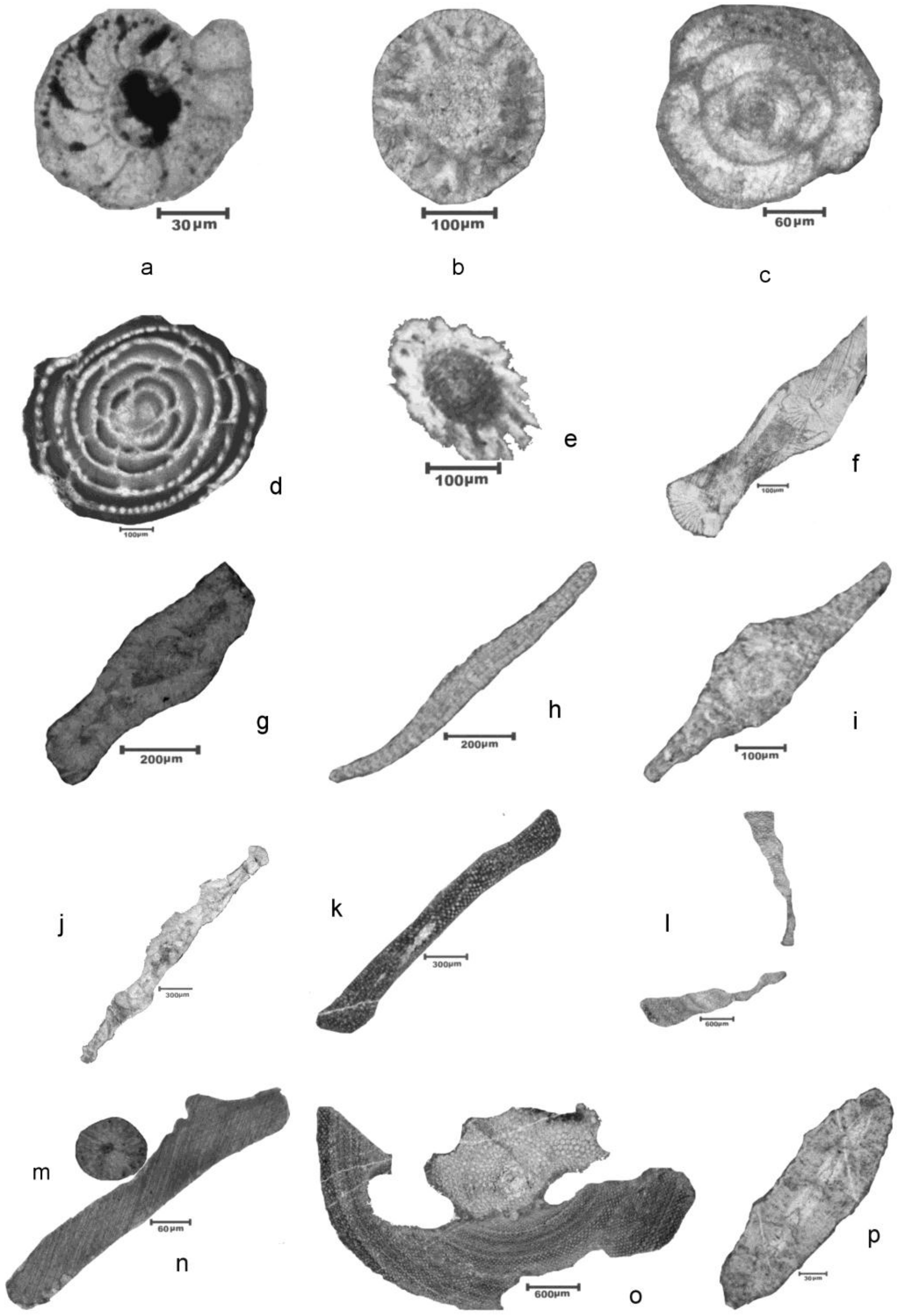


Plate 2

a. Small benthic foraminifera
b. Dasyclad algae, vertical section
c. Miliolid
d. *Alveolina* sp.
e. Algae, oblique section
f. *Ranikothalia sindensis* (Davies)
g. *Ranikothalia* cf. *sahni* (Davies)
h. *Discocyclina ranikotensis* (Davies)
i. *Discocyclina* sp.
j. *Ranikothalia sindensis* (Davies)
k. Orbitoididea
l. Orbitoididea
m. Echinoderm, transverse section
n. Echinoderm, longitudinal section
o. Orbitoididea
p. *Assilina* sp.

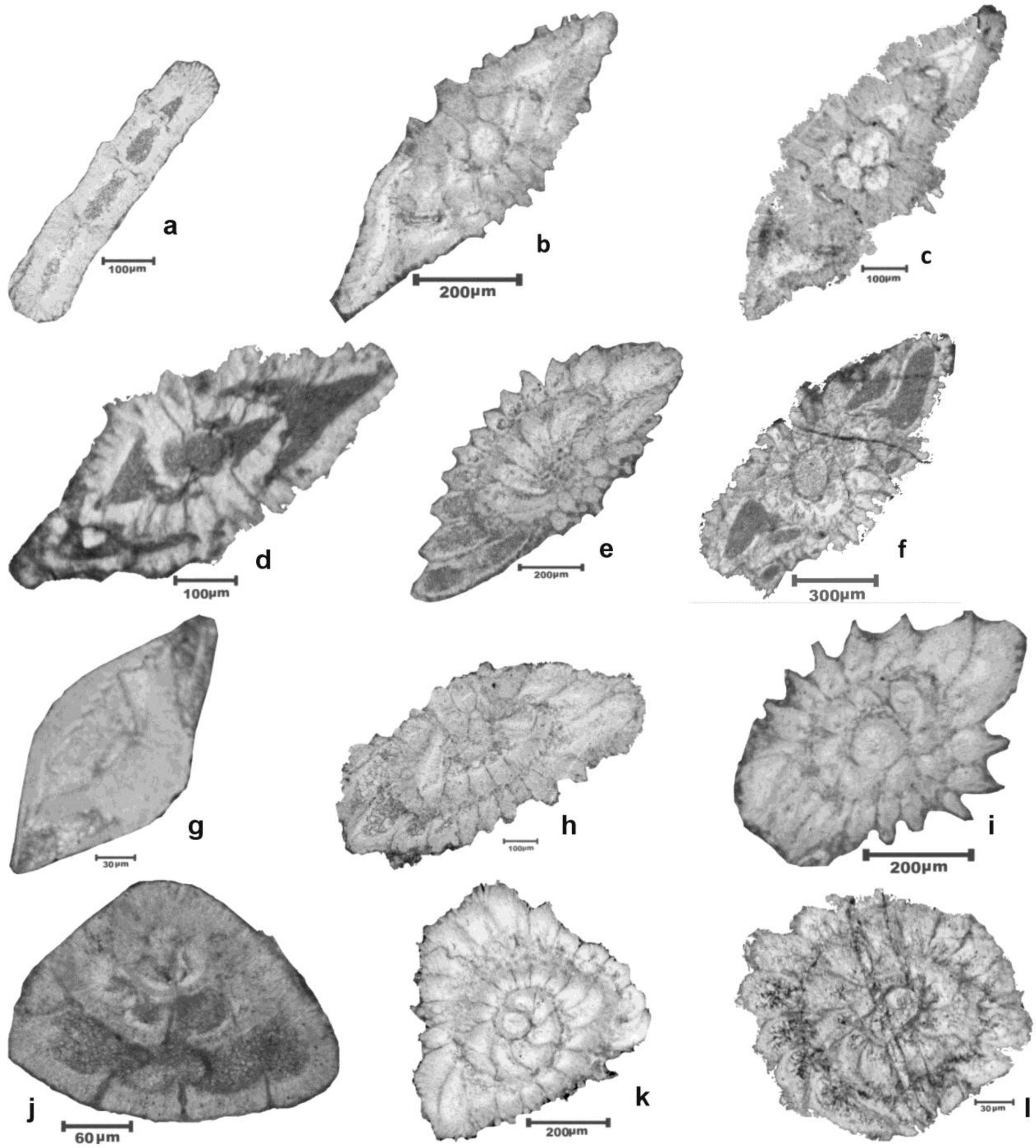


Plate 3

a. *Assilina* sp.
b. *Miscellanea miscella* (d’ Archaic & Haime)
c. *Miscellanea miscella* (d’ Archaic & Haime)
d. *Miscellanea* sp. (Höttinger et al., 2009)
e. *Miscellanea miscella* (d’ Archaic & Haime)
f. *Miscellanea miscella* (d’ Archaic & Haime)
g. Unidentified
h. *Miscellanea miscella* (d’ Archaic & Haime)
i. *Miscellanea miscella* (d’ Archaic & Haime)
j. *Lockhartia conica* (Davies)
k. *Miscellanea miscella* (d’ Archaic & Haime)
l. *Miscellanea miscella* (d’ Archaic & Haime)

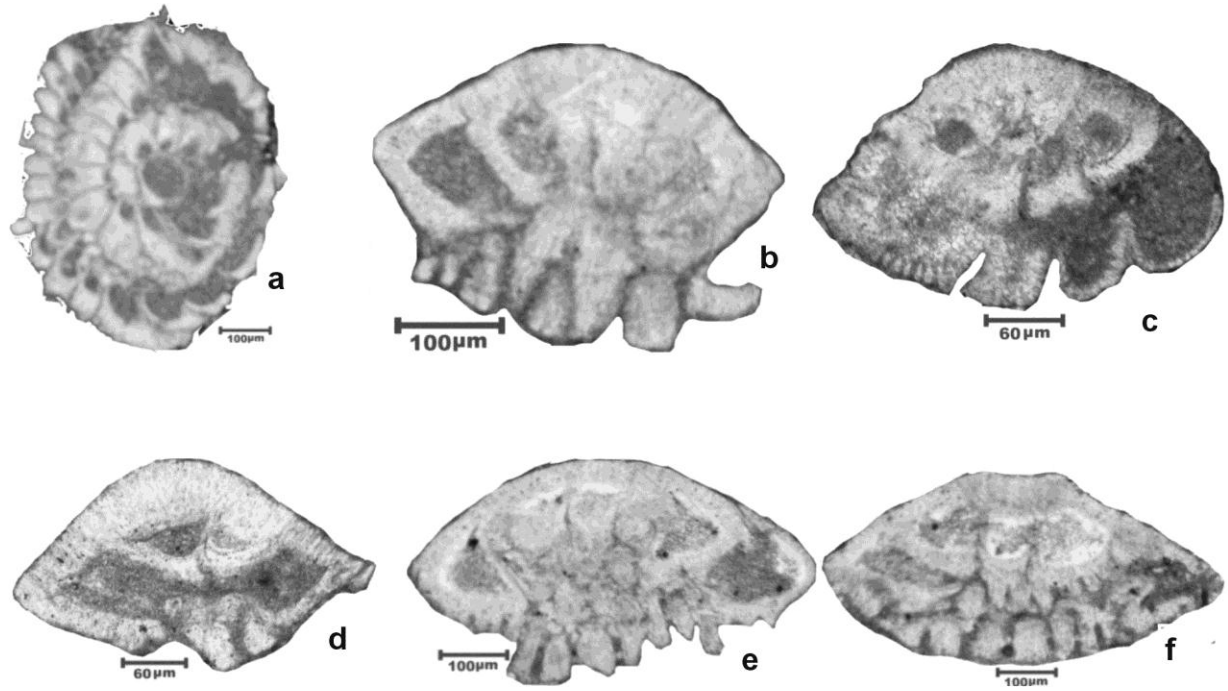


Plate 4

a. *Miscellanea* sp.
b. *Lockhartia conditi* (Nuttal)
c. *Lockhartia conditi* (Davies)
d. *Lockhartia tipperi* (Davies)
e. *Lockhartia haimei* (Davies)
f. *Lockhartia haimei* (Davies)

3.2.3a. Occurrence and interpretation

The MFT occurs in the middle of the stratigraphic Section (Fig. 2). The presence of wackstone together with Miliolids, Orbitoididea and dasyclad algae in sub-types represent deposition on an intertidal proximal foraminiferal back-shoal (OMW) to intertidal distal foraminiferal back-shoal-intertidal lagoon (MW). This MFT is comparable with the small benthic Miliolid wackstone of Eichenseer and Luterbacher (1992) and Scheibner et al. (2007) from Pyrenees (Spain) and falls in SMF-18 of Wilson standard microfacies types and represents FZ 8 of Wilson (1975) and Flügel (2004).

3.2.4. Shale lithofacies (SL)

Thin shale beds occur at intervals (Fig. 2). Microfacies data for the shale intervals was not generated and therefore, based on their relationships with the underlying and overlying microfacies of intertidal back shoal to intertidal lagoonal setting, these shale intervals are interpreted as shales of intertidal lagoonal origin representing FZ 8 of Wilson (1975).

3.3. Sequence stratigraphy

Based on the microfacies data and biostratigraphic data, a sequence stratigraphic model for the Patala Formation is proposed. The Paleocene foraminiferal dominated stage (Patala Formation/SBZ4 & 5) is composed of six parasequences of fourth/fifth order bounded by seven transgressive/flooding surfaces which are displaying vertically stacked aggrading pattern. These parasequences are grouped into a second order sequence named as ThPat which is composed of a third order HST - high stand system tract (Fig. 3). The ThPat is comparable with the HST of the late Thanetian second order sequence (i.e., TA2.1) of Haq et al. (1987).

4. Conclusions

The Patala Formation yields the larger foraminiferal (i.e., *Miscellanea* sp. and

Ranikothalia sp.) dominated second stage of the low latitude Tethyan Paleocene carbonate platform benthic community evolution and indicating SBZ 4-5. This depositional unit is composed of three microfacies (i.e., packstone, wacke-packstone and wackstone) and a shale lithofacies. Based on the microfacies analysis the depositional environment is interpreted to be ranging from an intertidal lagoon (wackstone) to intertidal distal foraminiferal back-shoal (wacke-packstone) to proximal foraminiferal back-shoal (packstone). The shale lithofacies occur in intervals in close association with the lagoonal microfacies and based on this relationship the shale lithofacies is interpreted to be part of the intertidal lagoon.

Sequence stratigraphic analysis based on the microfacies data indicate a second order sequence named as ThPat which includes a third order high stand system tract and six fourth order parasequences bounded by seven transgressive/ flooding surfaces.

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