Journal of Himalayan Earth Sciences Volume 50, No 2, 2017, pp. 27-43

Evaluating paleoceanographic and planktonic foraminiferal diversification from the Cretaceous Mughal Kot Formation, Mughal Kot Section, Lower Indus Basin, Pakistan

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Submitted: 28/12/2016, Accepted: 20/10/2017 Published online: 30/11/2017

Abstract

The Mughal Kot Formation is well exposed in the Mughal Kot, where a section of 1000m was studied particularly for its planktonic foraminifera. The studied section is dominantly comprised of nodular marls with minor intercalation of graded bedded lenticular sandstone and thick bedded limestone. The biostratigraphic investigations revealed abundant planktonic foraminiferal species of *Globotruncana*, *Globotruncanita* and *Heterohelix.* Based on these species, a single local planktonic foraminiferal biozone i.e. *Globotruncana-Globotruncanita-Heterohelix* Assemblage is erected. The biozonal information is integrated with previous literature and early to late Maastrichtian age (76 Ma to 69 Ma) is assigned to the Mughal Kot Formation. This study suggests that the overall species richness is low in the Mughal Kot Formation due to the high rate of sedimentation i.e. 142 mm/1000 years. This high rate of sedimentation is further supported by turbidite sequences at different stratigraphic levels within the Mughal Kot Formation. Such high rate of sedimentation causes a dilution effect in the basin, which subsequently resulted in the overall low species richness in Mughal Kot Formation. Furthermore, the overall species richness within the Formation indicates a decreasing trend from base to top of the section. This decreasing trend in the species richness suggest a shift from the cooler climate to warmer climate i.e. the shift in the nutrient structure resulted from more stratified ocean in the early Maastrichtian (76 Ma to 73 Ma) to mixed ocean in the late Maastrichtian (73 Ma to 69 Ma).

Keywords: Foraminifera, Evolution, Paleoceanography, Anoxic events.

1. Introduction

The Mughal Kot Formation is comprised of dominant nodular marls, with minor intercalated shale and graded bedded channelized sandstone and thick bedded limestone. This rock unit is named by Williams (1959). The formation is best exposed in its type locality i.e. Mughal Kot Gorge of the Sulaiman Range, 3km west of the Mughal Kot check post.

The Mughal Kot Formation is exposed in different localities e.g. Rakhi Gaj, Tor Tana, Murgha Kibzai, Loralai, Quetta and Mughal Kot areas of Lower Indus Basin. The thickness of the Mughal Kot Formation varies greatly e.g. it is 1200m thick in its type locality, 360m thick at Dabbo Creek in subsurface, 150-300m around Kach (Shah, 2009). Such drastic variations within the Formation may have resulted from tectonic instability on the northwestern margin of the Indian plate e.g. the bathymetric highs up to 400m created during Late Coniacian-Early Santonian on the basin floor of the Indian Plate in Lower Indus Basin have affected the dispersal pattern of the Mughal Kot sandstones (Smewing et al., 2002). The Mughal Kot Formation is thought to be deposited in shallow marine and deltaic environment (Malkani, 2010) and has recorded coal seam, however the presence of planktonic foraminifera and turbidite sequences suggest its deposition on outer shelf/slope settings (e.g. William, 1959; Dorreen, 2010).

This rock unit was discussed by Malkani (2010) in his work on the stratigraphy and mineral exploration of Indus Basin, while Williams (1959) studied the lithological variations within the Mughal Kot Formation. Marks (1962) has investigated the Mughal Kot Formation for dating the exposed rock units. Recently, Dorreen (2010) studied Mughal Kot Formation for its biostratigraphic understanding and erected three Biozones. The age of Mughal Kot Formation is quite controversial, for instance, Williams (1959) reported Maastrichtian foraminiferal taxa from this rock unit, while Marks (1962) documented Campanian to early Maastrichtian fossils from the Rakhi Nala section. However, Dorreen (2010) utilized 1193-1223 rock samples for biostratigraphy and has reported Maastrichtian age for this rock unit.

This study is therefore aimed to re-evaluate the age of this unit based on planktonic foraminifera and to establish a possible link between the planktonic foraminiferal evolution and ambient paleoceanography during the time of its deposition.

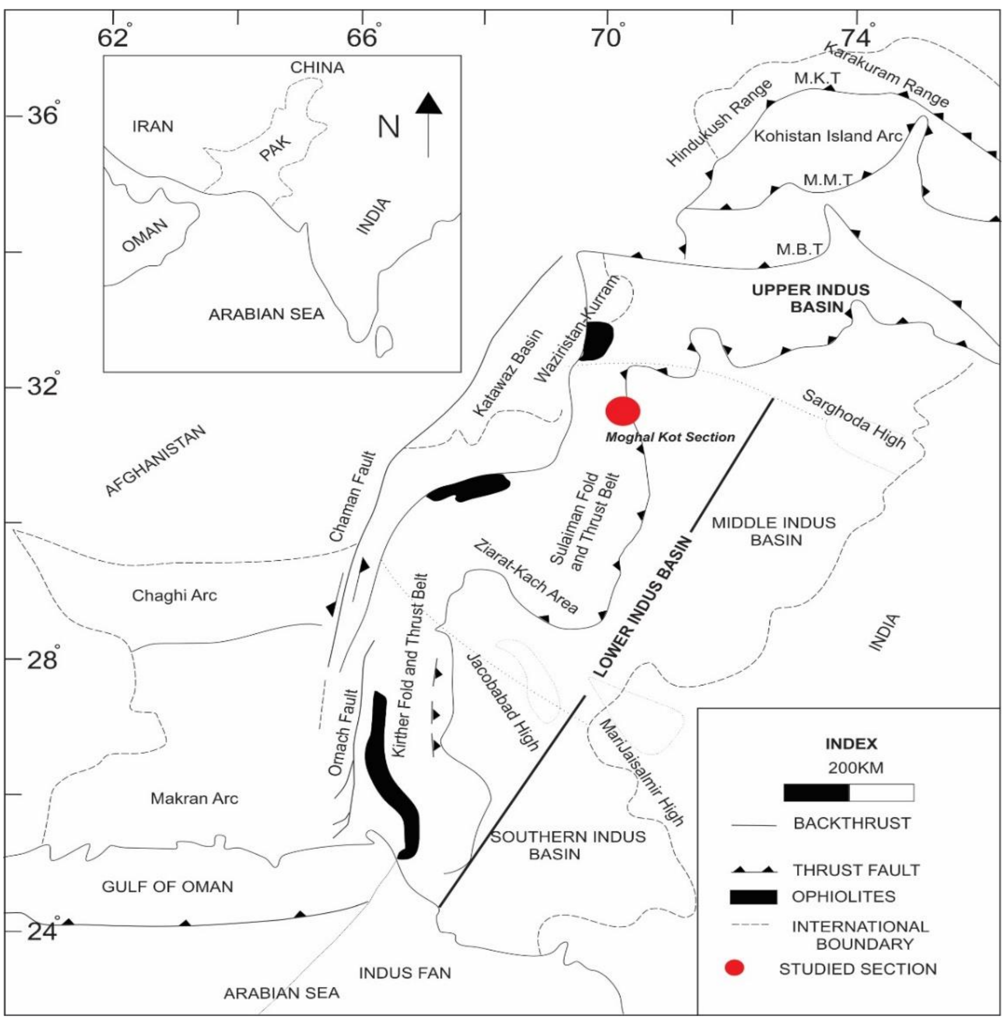

Fig. 1. Tectonic of Pakistan, showing the Indus Basin, modified after Banks & Warburton (1986), Kadri (1995) and Khan (2013).

2. Materials and methods

The late Cretaceous sediments of the Mughal Kot Formation (1000m thick), Mughal Kot Section, Sulaiman Range, has been examined, measured, logged and sampled. Total of 101 samples were collected from the hemipelagic-turbidite sequence of the Mughal Kot section. Thin sections were prepared from the indurated rock samples for biostratigraphy using the standard thin sectioning techniques (Flügel, 2004). The marls were processed for extraction of foraminifera. To confirm the identification of taxa in thin section, some of the indurated rocks were also processed for the extraction of foraminifera using the Lirer (2000) technique i.e. the samples were treated with 80% acetic acid for 8 hours. The residue was sieved through 250 and 63 µm sieves. The left over fraction above 250 µm was discarded while the fraction between the 250 and 63 µm was ultrasonically cleaned in diluted Hydrogen per Oxide medium. The supernatant was sieved again through 63 µm and air dried. The foraminiferal specimens were picked under stereomicroscope and put on slides. Photomicrographs were taken using petrographic microscope Olympus SZ61. For establishing a possible link between the planktonic foraminiferal evolution and paleoceanography, the range charts of planktonic foraminiferal species are used. Sliter (1989) chart is used for assigning absolute ages to the sediments of Mughal Kot Section (Figs. 2 to 6). The 1000m thick strata of the Mughal Kot Formation is divided into equal time slices of 02 Ma by assuming the constant rate of sedimentation for the entire rock unit. The rate of sedimentation is calculated by dividing the thickness of the unit by the total time of its deposition.

3. Biostratigraphy

For the identification of planktonic foraminiferal species, chamber shape, test size, growth patterns, size of umbilicus, margin profile, thickness of the wall, shape and ornamentation of the test were taken into account. However, all these parameters were not observable in thin sections simultaneously; therefore, the identification is supported further by comparing the foraminiferal specimens of the Mughal Kot Formation with thin section illustrations of the same species in standard literature (e.g. Sliter & McGann, 1992; 1999; Premoli-Silva & Sliter, 1994; Postuma, 1971; Khan, 2013). Photomicrographs of different species in thin sections are shown in plates 1 and 2.

4. Results

4.1. Planktonic foraminiferal biozonation

In this study one local planktonic foraminiferal biozone within the Mughal Kot Formation is erected. Based on first and last occurrences of the species, the biozonation and species distributions charts are constructed (Figs. 2 to 6).

4.2. Globotruncana-Globotruncanita-Heterohelix Assemblage

Definition: The zone is marked by the concomitant appearance of *Globotruncana*, *Globotruncanita* and *Heterohelix* species assemblages from the base to the top of the section.

Species Assemblages:

Globotruncana arca, Globotruncana linneiana, Globotruncana stuartiformis, Globotruncana bulloides, Globotruncana hilli, Globotruncana rosetta, Globotruncana ventricosa,Globotruncana lapparenti, Globotruncanella minuta, Globotruncanita calcarata, Globotruncanita conica, Heterohelix sp., Heterohelix planata, Heterohelix globulosa, Heterohelix pulchra, Heterohelix sigalia, Heterohelix reussi, Globigerinelloides prairiehillensis, Hedbergella sp., Gansserina wiedenmayeri, Ventilabrella species, Ventilabrella glabrata and *Planoglobulina acervulinoides*.

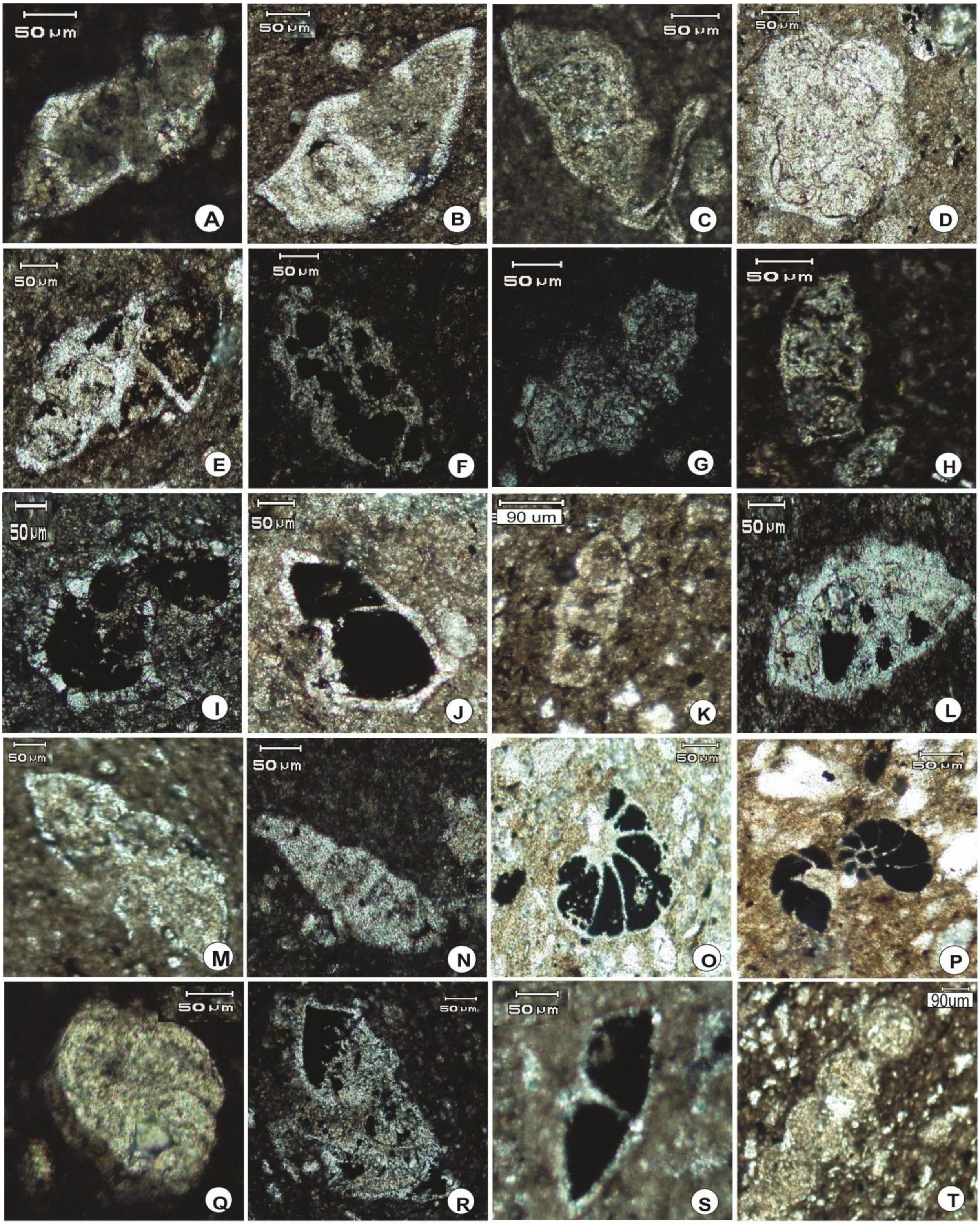

Plate 1: *A: Globotruncana sp., B-C: Globotruncanita calcarata, D: Globotruncana stuartiformis, E: Globotruncana ventricosa, F: Globotruncana arca, G: Globotruncana lapparenti, H: Globotruncana linneiana, I-J: Globotruncana hilli, K: Ventilabrella glabrata, L: Globotruncanita conica, M: Globotruncana rosetta, N: Ventilabrella sp., O-P: Globigerinelloides praieheniensis, Q: Aragonia velascoevensis, R: Gansserina wiedenmayeri, S: Globotruncana havenensis, T: Planoglobulina acervulinoides*

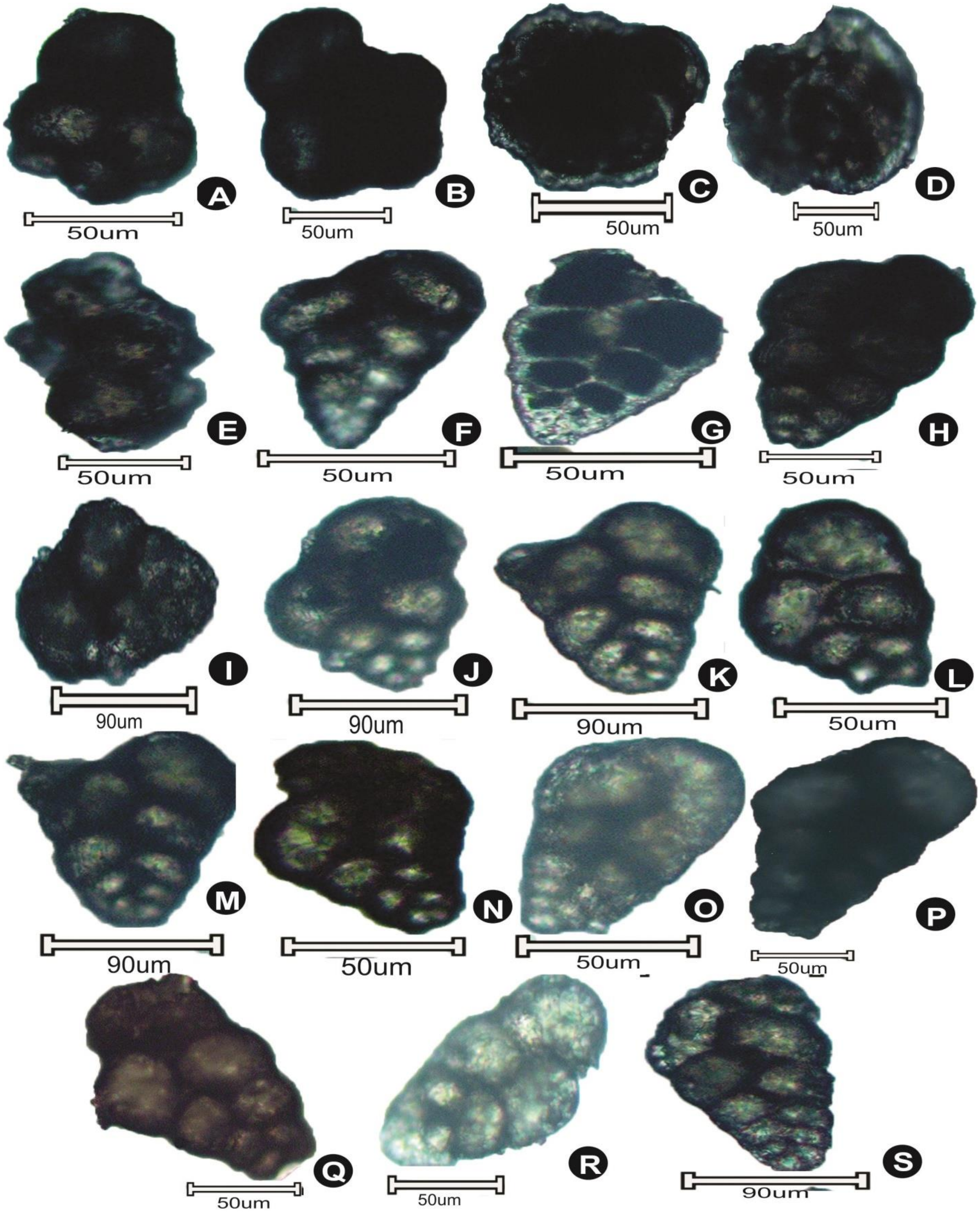

Plate 2: *A-B: Hedbergella sp., C-E: Globotruncana bulloides, F-G: Heterohelix reussi, H-I: Heterohelix planata, J-M: Heterohelix globulosa, N-Q: Heterohelix pulchra, R-S: Heterohelix sp.*

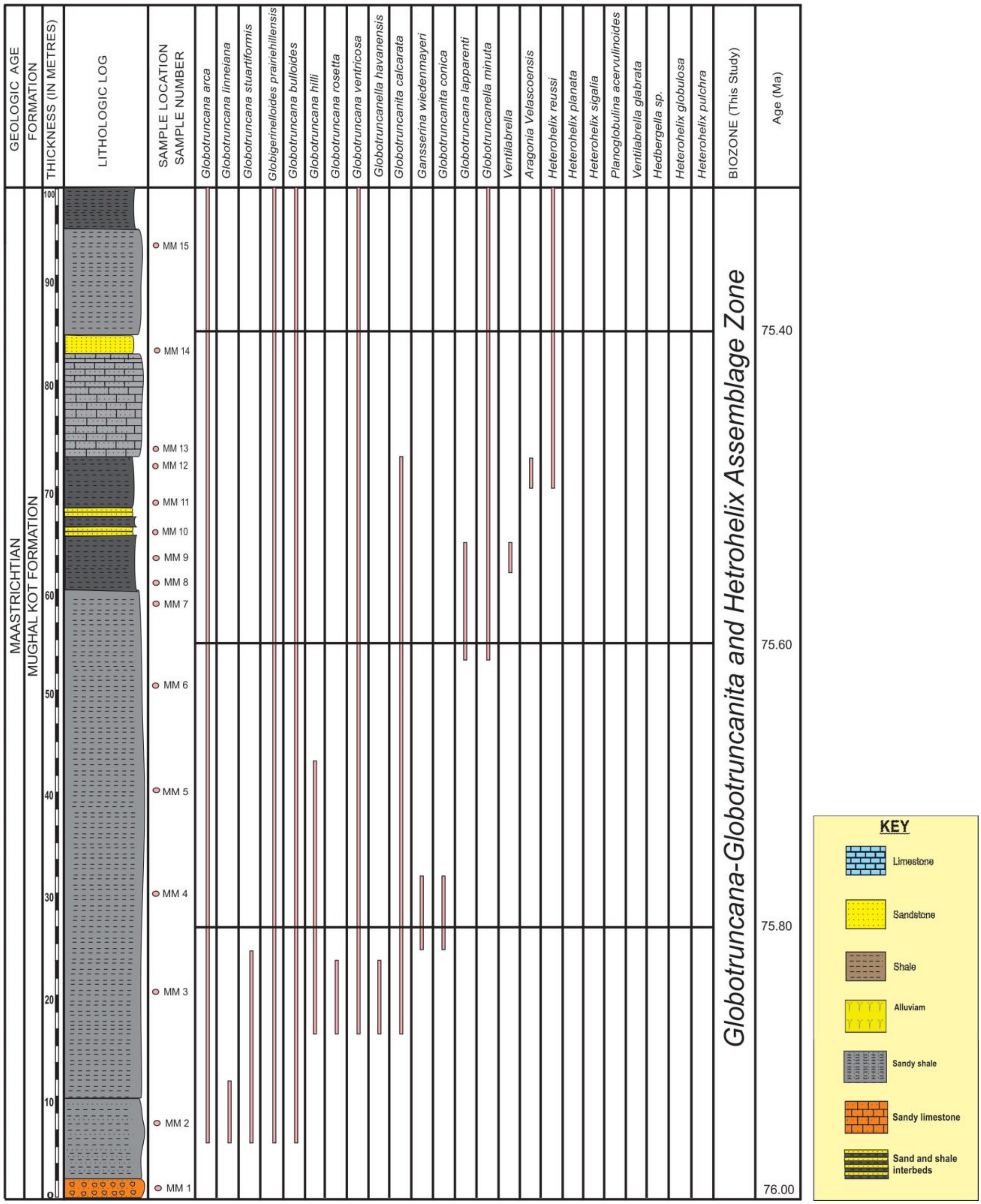

Fig. 2. Showing stratigraphic range/biozonation chart of the Mughal Kot Formation, Mughal Kot Section.

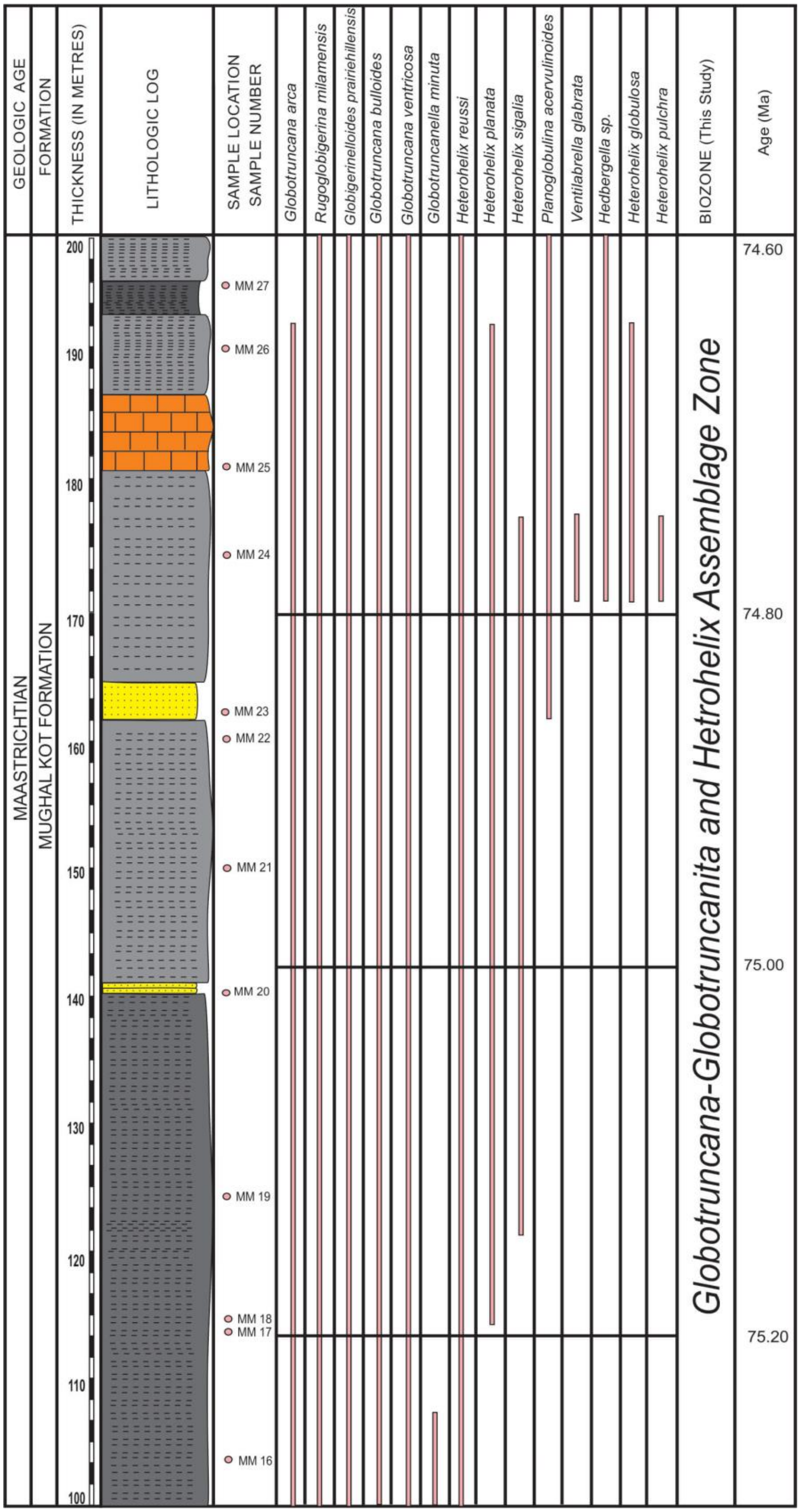

Fig. 3. Showing stratigraphic range/biozonation chart of the Mughal Kot Formation, Mughal Kot Section.

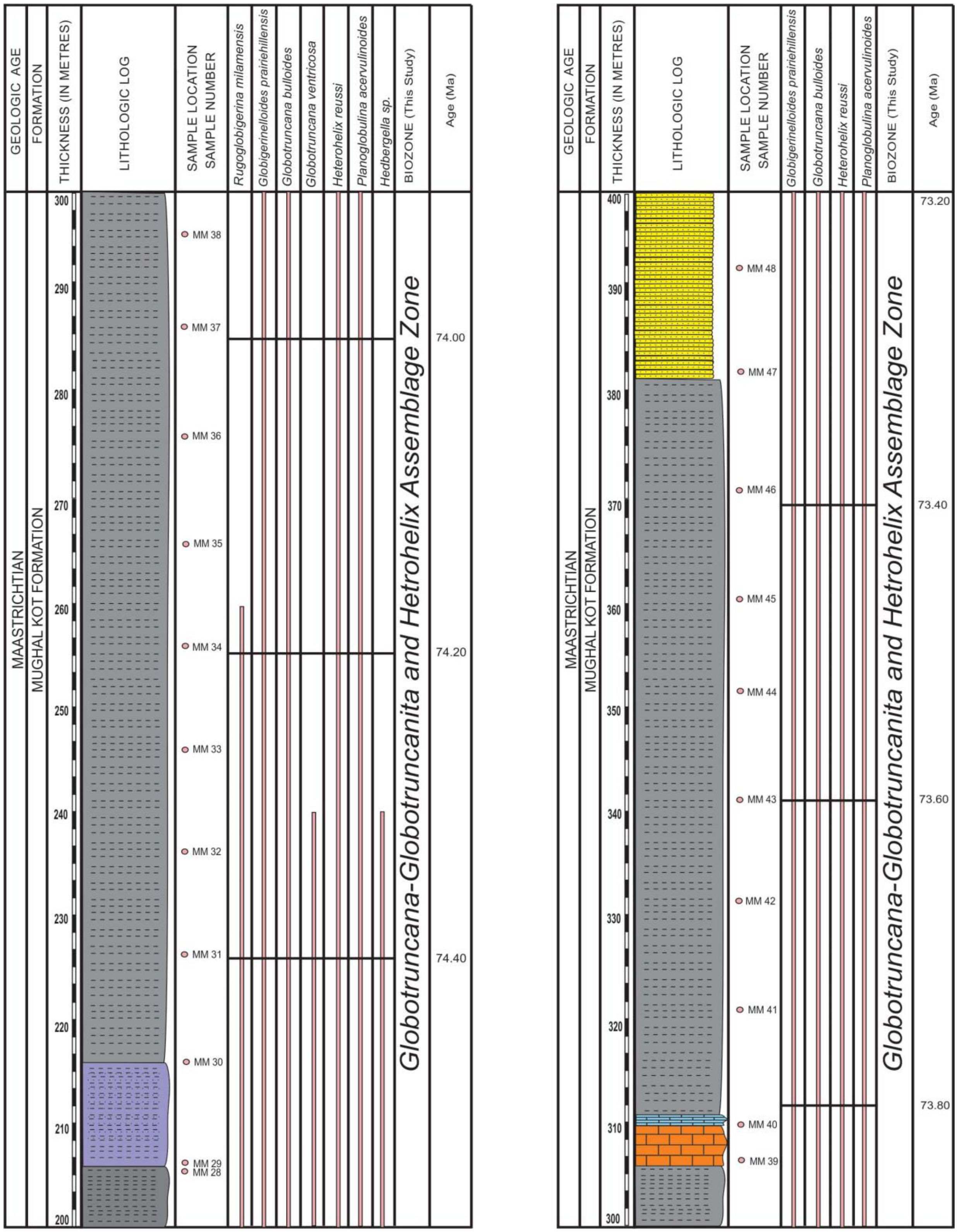

Fig. 4. Showing stratigraphic range/biozonation chart of the Mughal Kot Formation, Mughal Kot Section.

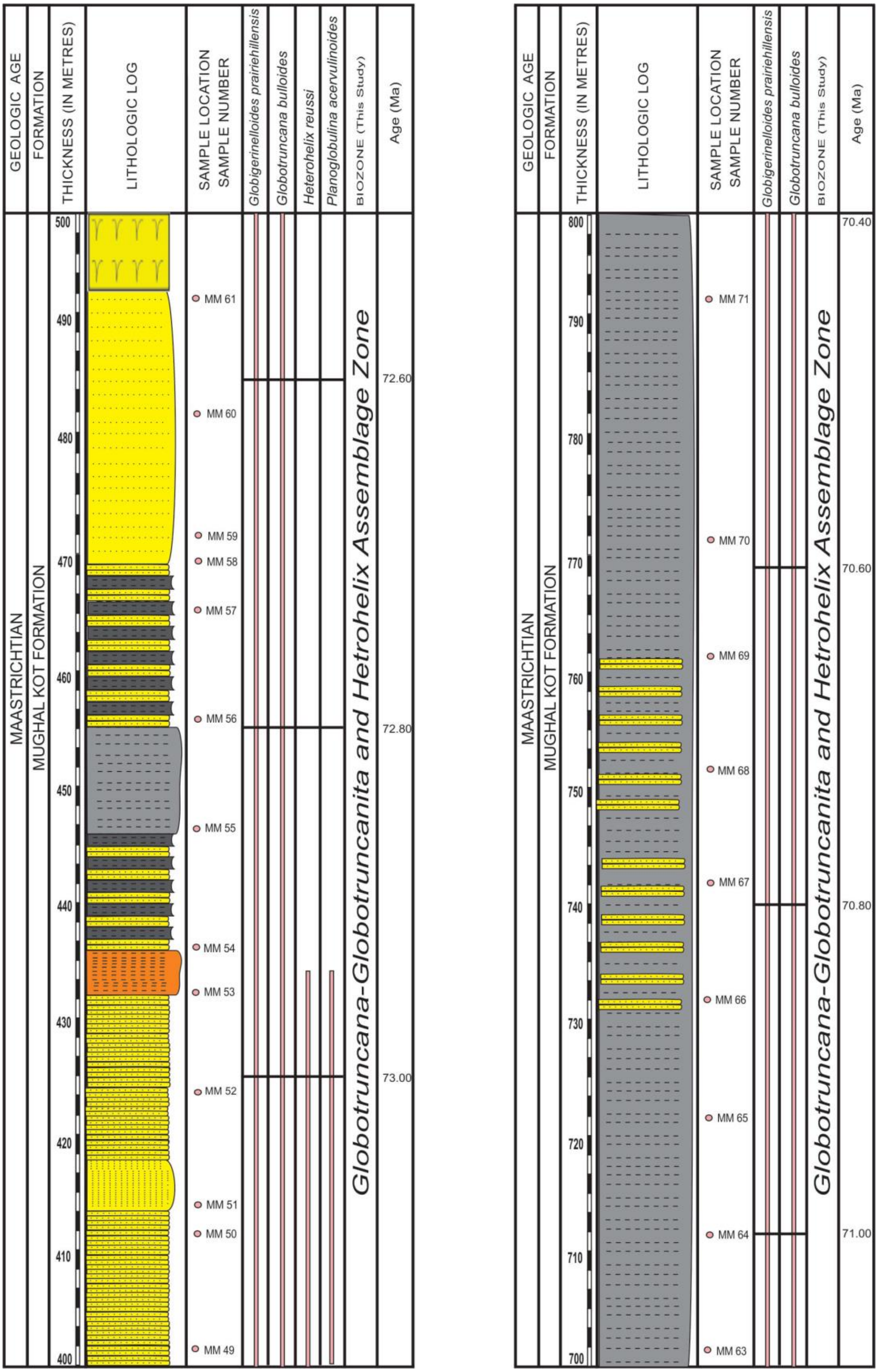

Fig. 5. Showing stratigraphic range/biozonation chart of the Mughal Kot Formation, Mughal Kot Section.

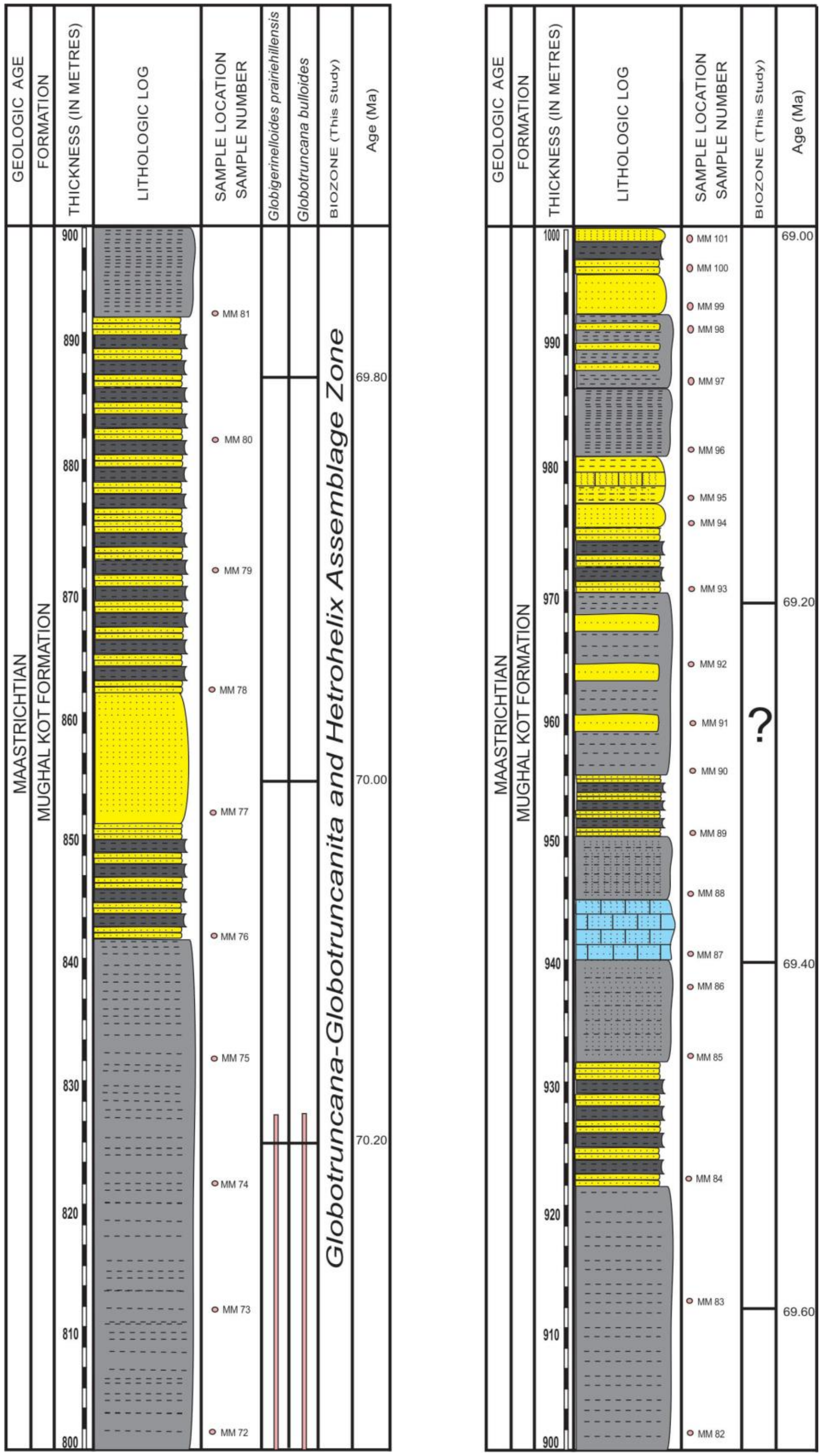

Fig.6. Showing stratigraphic range/biozonation chart of the Mughal Kot Formation, Mughal Kot Section.

Remarks:

The Mughal Kot Formation overlies the Parh Formation in the study area. In this area the upper most part of the Parh Formation i.e. the contact between the Parh and Moghal Kot Formations is marked by the *Globotruncanita calcarata* zone of early Maastrichtian age. The presence of *Globotruncanita calcarata*, *Planoglobulina acervulinoides*, *Globotruncanita conica* and dominance of *Heterohelix* species suggest Maastrichtian age for the Mughal Kot Formation (see e.g. Sliter, 1989; Premoli-Silva and Sliter, 1999; Abramovich, 2002). The Heterohelix species were also dominant during Maastrichtian time (Premoli-Silva and Sliter, 1999). However, according to Sliter (1989) the important taxa such as *Globotruncana bulloides, Globotruncana linneina* and *Globotruncana ventricosa* have their last appearances in *Gansserina gansseri* Zone. This biozone is ranging in age from early to late Maastrichtian. The presence of *Globotruncana bulloides, Globotruncana linneina* and *Globotruncana ventricosa* even in the uppermost part of the Mughal Kot Section suggest that the Mughal Kot Formation at least fall within the *Gansserina gansseri* biozoneor older biozones of the Maastrichtian age. For the sake of convenience the upper part of the Mughal Kot Formation is thought to be deposited within the *Gansserina gansseri* biozones. The presence of *Globotruncanita calcarata* at the contact of the Parh and Mughal Kot Formation suggest that the lower part of the Mughal Kot Formation is deposited in the *Globotruncanita calcarata* range zone. Hence the studied rock unit is deposited in the *Globotruncanita calcarata*, *Globotruncanita aegyptiaca*, and *Gansserina gansseri* biozones therefore according to Sliter (1989) early to late Maastrichtian age is assigned to the Mughal Kot Formation. The exact demarcation between the early and late Maastrichtian is not shown because the absence of biozonal taxa e.g. *Gansserina gansseri* etc. However as discussed for the sake of practical purpose its upper part is assumed to corresponds to the late Maastrichtian.

5. Species richness

The species richness of planktonic foraminifera of the Maastrichtian Mughal Kot Section is calculated according to Leckie et al. (2002) and results are presented in Table 1. According to the species richness graph constructed for the Maastrichtian (Fig. 7), the number of species decreases in the Mughal Kot Formation over time. Species richness was highest in the early Maastrichtian (e.g. equivalent to *Globotruncanita calcarata zone*) and has achieved its highest peak at about ~74.8-74.6 Ma followed by a major drop. This drop is followed by a stepwise drop in species richness till the end of the section i.e. in late Maastrichtian (equivalent to *Gansserina gansseri* zone).

6. Discussion

The Cretaceous planktonic foraminiferal evolution is forced by the paleo-oceanographic changes associated with Oceanic Anoxic Events (OAEs) because major turnover are recorded along these events (Premoli-Silva & Sliter, 1999; Leckie et al., 2002). The OAEs are recorded as discrete beds of black shale and pronounced carbon isotopic excursions (Leckie et al., 2002), e.g. latest Aptian-early Albian boundary and the Cenomanian-Turonian boundary (Leckie, 1989).The Aptian-Albian time was characterized by high tectonic activity, long term global sea level rise and overall increase of global temperature (Takashima et al., 2004). Such dynamic paleo-oceanographic changes controlled the course of planktonic foraminiferal evolution during the mid-Cretaceous time (Leckie, 1989; Premoli-Silva & Sliter, 1999; Leckie et al., 2002). The subtle changes in oceanic productivity and shifts in productivity centers with rising sea level, and the changes in density structure through time strongly influenced the history of Aptian-early Cenomanian planktonic foraminifera (Leckie, 1989; Takashima et al., 2009).The global warming induced warmer bottom water within the Campanian oceans was replaced by cooler water during early Maastrichtian, suggesting an increase in the rate of global cooling, ocean stratification and subsequent planktonic foraminiferal diversity (Frank et al., 2005).

The Maastrichtian time was characterized by significant global climatic and paleo-oceanographic changes dominated by progressive cooling as a result of glacio-eustacy (Thibault et al., 2016). During the Maastrichtian time, the globe can be tectonically divided into two distinct hemispheres; one dominated by deep oceanic basin of the Pacific and the other consisting of well-dispersed continents originated form Laurasia and Gondwana (Hunter et al., 2008). The Tethys Ocean joined the North Atlantic and Caribbean with the proto-Indian Ocean in the west (Hunter et al., 2008). During much of the Cretaceous time, sea level was at its high level coupled with shoaling of carbonate compensation depth; however the latest Cretaceous oceans were having relatively shallow carbonate compensation depth (Thierstein, 1979; Arthur et al., 1985) because of the water stratification. This stratification resulted from the global cooling during Maastrichtian time with onset of polar glaciers (Friedrich et al., 2004) which has caused three second order regressions (Haq et al., 1987). This cooling was mainly due to changes in ocean circulation due to plate tectonic movements which resulted in a progressive deep water exchange between the deep oceanic basins (Jung et al., 2012).

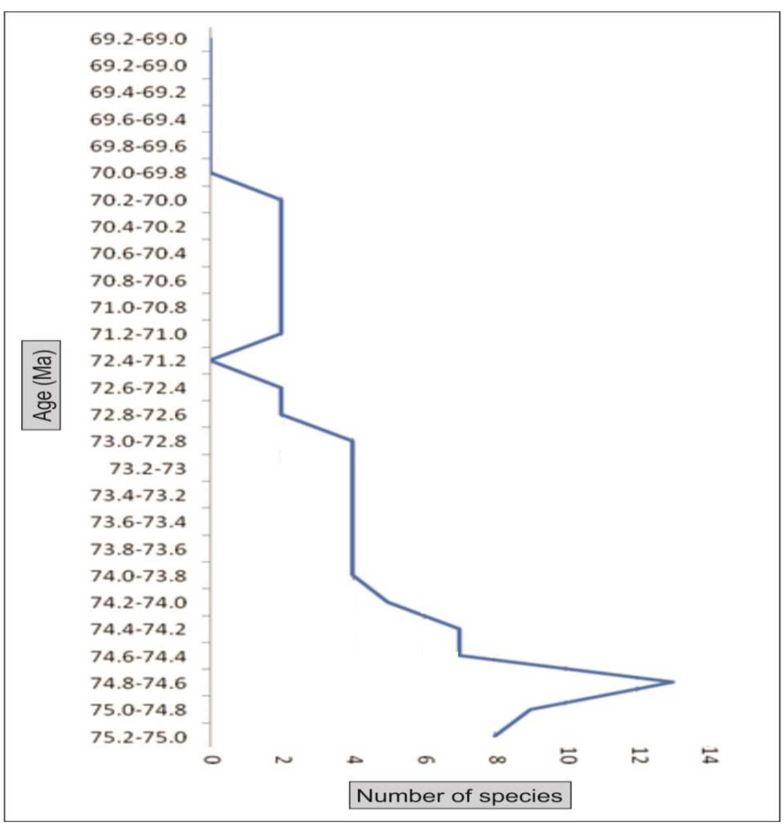

Fig.7. Cretaceous planktonic foraminiferal species richness record of the Mughal Kot Formation, Mughal Kot Section.

Table 1. Showing the ages in million years, stratigraphic heights in meters and species richness.

Age (Ma)	Height (m)	Species
69	1000	0
69.2	969	0
69.4	940.5	0
69.6	912	0
69.8	883.5	0
70	855	0
70.2	826.5	2
70.4	798	2
70.6	769.5	2
70.8	741	2
71	712.5	2
72.6	484.5	2
72.8	456	2
73	427.5	4
73.2	399	4
73.4	370.5	4
73.6	342	4
73.8	313.5	4
74	285	4
74.2	256.5	5
74.4	228	7
74.6	199.5	7
74.8	171	10
75	142.5	8
75.2	144	6
75.4	85.5	6
75.6	57	7
75.8	28.5	8
76	0	0

The oceanic circulation was predominantly driven by sinking of warm and saline waters in low latitude regions with excessive evaporation (Brass et al., 1982). During the Campanian to Maastrichtian cooling period, intermediate to deep water may have started to form in the Atlantic Ocean (Saltzman and Barron, 1982) and may have been located in the high latitude South Atlantic (Barrera and Huber, 1990) and in the North Atlantic (Corfield and Norris, 1996). In the light of the established paleoclimate during Maastrichtian, the evolution of planktonic foraminifera of the Mughal Kot section (located at -20° S tropical settings (Fig. 8) are discussed as below.

The rise in species richness (Fig. 7) at the base (74.8-74.6 Ma) of Mughal Kot Formation is probably artificial and is controlled by the local tectonics because the basal most part of the rock unit is composed of sandy conglomeratic carbonate. Such shallow facies are not suitable for the preservation of planktonic foraminifera. The hemipelagic facies above this conglomeratic unit has recorded rise in species richness suggesting that the early Maastrichtian part (corresponding to the *Globotruncanita calcarata* zone) corresponds to the cooler environment; hence the species richness is higher as a result of niche portioning which offers habitats to species at different depths.

However the overall species richness within the Mughal Kot Formation decreases from its lower part (i.e. early Maastrichtian corresponding to *Globotruncanita calcarata* biozone) to its upper part (late Maastrichtian corresponding to *Gansserina gansseri* biozone). This decreasing trend may be associated with the shift in the nutrient structure resulted from more stratified ocean in the early Maastrichtian to mixed ocean in the late Maastrichtian i.e. the stratified ocean offers different niches for the foraminiferal communities while the mixed ocean resulted in the destruction of such niches hence proliferation of only opportunistic taxa. Within the cooler Maastrichtian a trend from cooler to relatively warmer Maastrichtian is also observed elsewhere (Frank et al., 2005; Norris et al., 2001).

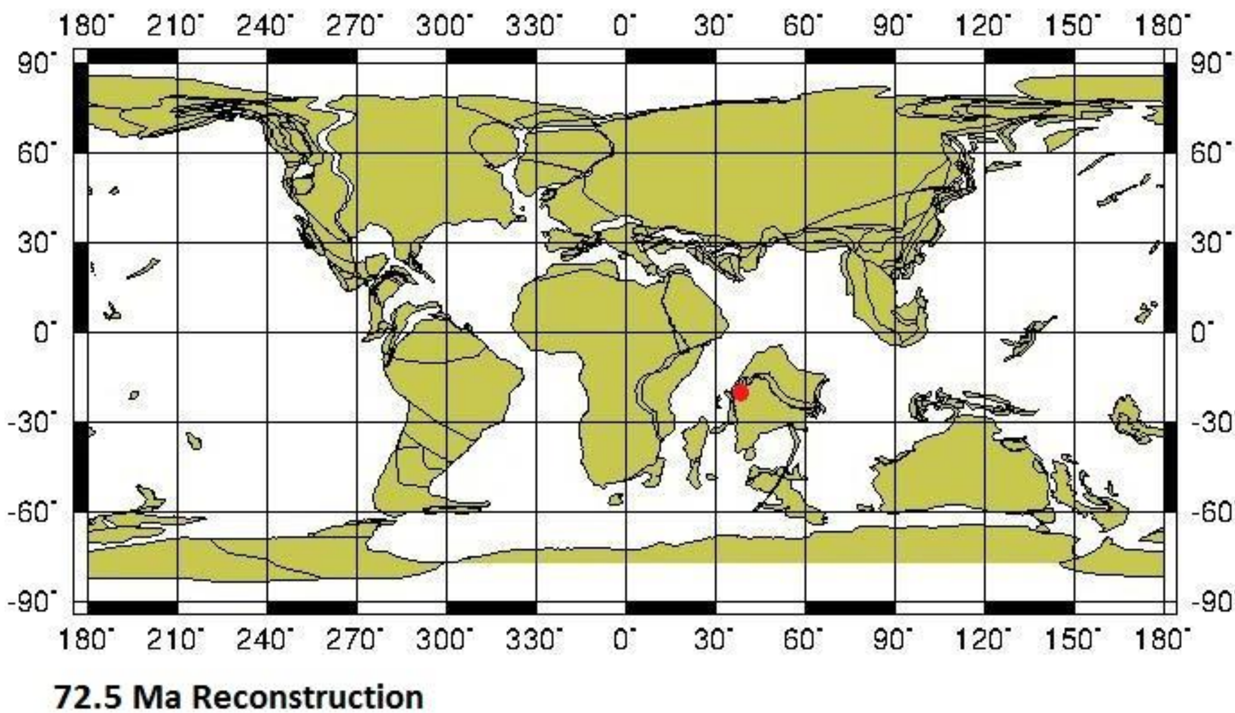

Fig. 8. Paleogeographic reconstruction of the Maastrichtian time; red dot shows location of Mughal Kot Section (http://www.odsn.de/odsn/services/paleomap/paleomap.html).

7. Conclusion

It is evident from this study that the overall richness of species is low in the Mughal Kot Formation. This decrease in species richness is due to the high rate of sedimentation i.e. 142mm/1000 years in the Mughal Kot Formation. This high rate of sedimentation is further supported by the presence of turbidite sequences within Mughal Kot Formation, suggesting that a sediment shed area was closer to the basin. Such high rate of sedimentation causes a dilution effect in the basin, which resulted in overall low species richness in Mughal Kot Formation. Within this overall low species richness, an overall decreasing trend is observed, which suggest a shift from cooler to warmer Maastrichtian climate.

Authors' contribution

Suleman Khan supervised the geological fieldwork, biostratigrphic results and interpretation. He also finalized the draft of *the manuscript. Bilal Wadood was involved in geological fieldwork, in the identification of foraminiferal taxa, preparation of plates and figures and main draft of manuscript. Sajjad Ahmad helped in finalization of the discussion section of the manuscript. Abdullah Khan involved in fieldwork and identification of species. Farhan Ahmed and Hamid Khan were involved in filed work and preparation of plates and tables.*

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