PALAEOGENE SUCCESSION OF INDUS BASIN USING PALAEOCEANOGRAPHIC RECONSTRUCTION APPROACH

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ABSTRACT

This study seeks to establish a robust stratigraphic framework for the Palaeogene succession of the Indus Basin by examining strata variations in relation to sea level fluctuations and climatic influences on sediment distribution. It also aims to identify palaeoceanographic constraints through the response of the marine ecosystem. The key objectives include identifying climatic perturbations, palaeoenvironmental constraints, and the response of marine biota to these climatic variations, ultimately to infer the prevailing trophic regime. Three stratigraphic sections comprising four stratigraphic units were selected for this study from the Zindapir area of the Sulaiman Fold and Thrust Belt, within the Lower Indus Basin, Pakistan. The investigated units include the Dungan Formation (106.4 m), the lower part of the Shaheed Ghat Formation (40 m), the Pirkoh Limestone (8.1 m), and the lower part of the Drazinda Formation (13.5 m). The study area lies along the northwestern margin of the Indian Plate and forms part of the eastern Tethyan domain. Palaeogeographic reconstructions suggest that during the time interval between approximately 54 and 40 Ma, this region was positioned within the tropical belt (0–30° latitude). In the initial phase of this study, the Dungan Formation was examined for its well-preserved assemblages of larger benthic and planktic foraminifera found within limestone, shale, and marl lithologies. A 106.4m thick stratigraphic section, consisting of 90 samples, was analyzed, out of which 47 limestone samples were thin sectioned to develop a biostratigraphic framework and conduct microfacies analysis. These investigations aimed to interpret the evolution of the carbonate platform during a global warming phase in the early Eocene. The Dungan Formation is dated to the Ypresian and spans Shallow Benthic Zones (SBZ) 5 to 9, which correspond to Orthophragminid Zones (OZ) 2 to 4. A notable unconformity is recorded at 38 meters from the base of the section, marked by the absence of SBZ-7. At 37 meters, a significant biotic turnover event Larger Foraminiferal Extinction and Origination (LFEO), restricted to the eastern Tethys is recognized at the boundary between SBZ-5 and SBZ-6. Microfacies analysis reveals a carbonate

ramp setting that evolved from inner ramp and lagoonal conditions to open marine environments. Two distinct evolutionary stages are identified: Stage-II, dominated by *Miscellanea*, *Ranikothalia,* and *Operculina*; and Stage-III, characterized by the appearance of *Alveolina*, *Discocyclina*, and *Nummulites*. The presence of red coralline algae suggests the development of patch reef systems. The integration of biostratigraphic and sedimentological data facilitated the identification of intervals linked to early Eocene hyperthermal events. In the second phase, the study focused on the upper Dungan Formation (limestone-shale alternations) and the lower part of the Shaheed Ghat Formation (mainly shale) at Zindapir. This interval, known for hosting several early Eocene hyperthermal events, was assessed for biostratigraphy and palaeoenvironmental conditions. Planktonic foraminifera suggest deposition in biozones E4 to E5, within lower bathyal (approximately 1500 m) to upper abyssal (up to 3000 m) depths. These interpretations were based on the planktonic-to-benthic (P/B) ratio and the presence of depth-indicator taxa. Three ecological zones were distinguished based on planktonic and benthic foraminiferal assemblages. Zone 1, the *Morozovella* Zone, includes two subzones: Subzone I (unaltered), dominated by *Morozovella*, indicating oligotrophic surface and eutrophic bottom waters; and Subzone II (altered/chert zone), marked by reduced *Morozovella*, increased *Subbotina*, and radiolarians, suggesting enhanced eutrophication. Zone 2, the *Acarinina* Zone, shows dominance of *Acarinina*, reflecting mesotrophic surface waters influenced by intermittent continental nutrient pulses, resulting in fluctuating bottom water conditions. Zone 3, the Radiolarian Zone, is defined by abundant radiolarians and *Pseudohastigerina*, with a decrease in *Acarinina*, indicating strong eutrophication and oxygenation from continental runoff, supported by benthic infauna oscillations. Marine biotic responses indicate the presence of early Eocene hyperthermal intervals within the succession. Intervals comparable to ETM-2, H-2, and I-1 are recognized at the top of the Dungan Formation, while intervals resembling J and K/X (possibly corresponding to ETM-3) are recorded in the lower part of the Shaheed Ghat Formation. The I-2 event is notably absent. Contrary to previous studies, the current findings do not support the presence of an unconformity between the Dungan and Shaheed Ghat formations. Field evidence suggests that the contact instead represents sediment reworking from the platform interior via turbidity currents. In the final phase of this study, a 21.6 m thick sedimentary succession, consisting of the Pirkoh Limestone and its overlying Drazinda Formation, was analyzed. The succession records deposition under middle neritic to bathyal conditions and is

biostratigraphically assigned to Eocene Zone E12, encompassing the interval of the Middle Eocene Climatic Optimum (MECO). Temporal variations in foraminiferal assemblages were systematically evaluated to reconstruct changes in trophic resource availability through time. The Pirkoh Limestone is characterized by initially oligotrophic conditions, reflected by the dominance of larger benthic foraminifera and the presence of *Orbulinoides beckmanni*. Up-section, oligotrophy becomes more pronounced, accompanied by an increase in warm-water planktonic taxa and infaunal elements, culminating in the development of an organic-rich horizon (OH-1). This interval is followed by a gradual shift toward mesotrophic conditions, indicated by the appearance of moderately warm-water taxa, increased infaunal abundance, and fluctuating low-oxygen indicators, most plausibly linked to enhanced continental runoff. With the transition into the Drazinda Formation, mesotrophic conditions become more strongly established and are locally associated with hypoxia, as evidenced by mixed warm- and cold-water assemblages. This part of the succession records a diverse faunal community with abundant *O. beckmanni*, before passing upward into a relative return to oligotrophic conditions with larger benthic forms, likely influenced by runoff, as indicated by the presence of *Cibicidoides eocaenus* and *Angulogerina muralis*, which occasionally obscure trophic signals. Higher in the section, eutrophication intensifies, expressed by a decline in warm-water taxa, persistent hypoxic conditions, elevated infaunal abundance, and the formation of a second organic-rich horizon (OH-2). Above this level, mesotrophic to eutrophic conditions dominate, culminating in peak eutrophication during the deposition of a third organic-rich interval (OH-3). Despite the prevailing eutrophic signal, the sporadic presence of oligotrophic indicators suggests intermittent overprinting by terrestrial runoff. The uppermost strata reflect overall mesotrophic conditions with evidence of eutrophication affecting both surface and bottom waters. However, the continued occurrence of oligotrophic larger benthic foraminifera implies that continental input locally modified the expected trophic regime. Collectively, the integrated biostratigraphic, microfacies, and palaeoecological data provide a refined framework for understanding carbonate platform evolution, trophic dynamics, and the timing and environmental impact of hyperthermal events across the early to middle Eocene in the eastern Tethys realm.