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Marine and Fluvial Sedimentation Including Erosion and Sediment Flux in Peninsular Indian Phanerozoic Basins

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This review presents a brief appraisal of the present understanding regarding marine and fluvial sedimentation in peninsular India in the background of global tectono-thermal events and relative sea level changes during the Phanerozoic. Sedimentary basins hosting the Phanerozoic deposits of peninsular India can be broadly categorized into two viz. Gondwana related half grabens and Meso-Cenozoic passive margins. Recent investigations document marine incursions in the former category of basins based on careful analysis of trace fossil assemblage and tide- and wave- originated sedimentary structures. The study of continental carbonates in the Upper Gondwana reveals widespread microbially mediated carbonate formation in freshwater systems, while the mud-dominated fluvial deposits in these basins show unique characteristics of the channel to overbank sediment transfer, related to a balance between sediment flux and erosion. The application of sequence stratigraphy provides a high-resolution analysis of passive continental margin sedimentary succession in Kutch, Cauvery and Jaisalmer basins. The origin of authigenic minerals has been integrated with the sequence stratigraphic framework in several Mesozoic and Cenozoic basins. A thorough biostratigraphic investigation reveals different order of sea-level cycles in the sedimentary deposits of Cauvery and Kutch basins and hyperthermal events in the Cenozoic of Kutch. Distinct ichnological assemblages characterize the transgressive and regressive deposits in Kutch and Jaisalmer basins. Quaternary terrestrial sedimentary records provide a high-resolution palaeoclimatic reconstruction.

Keywords: Marine Incursion; Continental Carbonate; Sequence Stratigraphy; Fluvial Sedimentation; Passive Margins

Introduction

Phanerozoic sedimentary basins in peninsular India remained largely protected from the complex tectonic evolution caused by the collision of Indian landmass with the Eurasian block. These basins can be broadly categorized into two viz. half grabens formed within Gondwanaland and Meso-Cenozoic passive margins (Fig. 1). Fault-bounded half-graben type Gondwana basins, located along several palaeo-suture lineaments

within the Precambrian cratonic blocks of peninsular India hosts predominantly arenaceous-argillaceous facies succession of continental fluvial origin, and are significant for coal deposits. However, the depositional condition of the Lower Gondwana rocks (late Carboniferous-Permian) has been debated for possible marine influences. Although the Permo-Carboniferous Talchir Formation at the base bears evidence of Late Palaeozoic glaciation, recent studies recognize glacio-fluvial, glacio-lacustrine or glacio-marine deposit within

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Fig. 1: Distribution of major Phanerozoic sedimentary basins in peninsular India

the Formation (Bhattacharya and Bhattacharya, 2015; Bhattacharya and Banerjee, 2015; Bhattacharya *et al.*, 2018). The Permian coal-bearing Barakar Formation has been reinterpreted in terms of fluvial-marine interactions (Bhattacharya *et al.*, 2016, 2018). Triassic sedimentation in most Gondwana Basins is represented by arkosic to subarkosic sandstone in different basins. Thick quartz arenitic, coarse-grained sandstone of continental origin with occasional tholeiitic basaltic outpouring in some areas characterize the Gondwana sedimentation during the Jurassic time (Sengupta *et al.*, 2016).

During the Middle Jurassic new basins viz Kutch, Cambay and Narmada opened up along the western margin of Peninsular India, related to the breaking of eastern Gondwana from its western counterpart. The sedimentary deposits in these basins record the depositional history at the western margin of Indian craton since its rifting from Madagascar and Seychelles (Biswas, 2016). The Kutch Basin is the earliest to form in the western passive margin of the Indian craton during the break up of Gondwanaland

in Late Triassic. The Late Cretaceous Bagh Group in central India represents deposition within the eastwardly transgressing arm of Tethys along the Narmada rift.

Continental rifting followed by seafloor spreading between India, Australia and Antarctica in early Cretaceous opened the east coast of Indian subcontinent (Bastia and Radhakrishna, 2012). Stratigraphic records in these basins can be broadly subdivided into two viz. syn-rift and post-rift. The syn-rift records can be found up to early Cretaceous in the Cauvery and Krishna-Godavari basins. Whereas Permo-Triassic marks the end of syn-rift sedimentation in Mahanadi and Bengal basins. The objective of this report is to present a brief overview on recent progress in sedimentology and stratigraphy of Phanerozoic basins in peninsular India to highlight fluvial to marine transition and to present changing patterns of sediment flux and erosion, in stratigraphic order.

Glacio-marine and Post-glacial fluvio-marine Deposits in the Lower Gondwana

Detailed facies analysis supported with trace fossils attributes of the Talchir rocks in Damodar Valley coal basins, Mahanadi Valley coal basins and Satpura basins highlights the basal glacial deposition followed by sedimentation in storm-tide influenced ice-marginal shallow marine basins (Bhattacharya and Bhattacharya, 2015). The study of the glacial-periglacial processes, assessment of cyclicities and evaluation of sequence stratigraphic architecture across different sub-basins reveal alternating glacial advance-retreat phases with a shift in the palaeo-shorelines of the Talchir sea (Bhattacharya and Bhattacharya, 2015). Post-Talchir regression of the strandline caused by glacio-isostatic adjustments led to the deposition of fluvial sediments in fault-controlled terrestrial basins during the early Permian (viz. the Karharbari Formation).

Sandstone-shale-coal cyclothemic facies successions in progradational-retrogradational stratal packages within the Barakar Formation (early Permian) signify deposition initially in braided to meandering fluvial, later in mixed fluvio-tidal estuary and finally within tide-wave dominated outer estuary. Overall regressive to transgressive shift is attributed to a change in accommodation caused by the base

level fluctuations in response to post-glacial isostatic adjustments (Bhattacharya *et al.*, 2016, 2018). Phases of sagging triggered by reactivation of basin-marginal faults are demarcated by seismites in different stratigraphic horizons (Bhattacharya *et al.*, 2016).

The Barren Measures Formation (middle Permian), a distinct non-coaliferous lithounit sandwiched between the coal-bearing Barakar and the Raniganj formations, bear evidence of marine encroachments, e.g., abundant tidalites in the sandstone-shale heteroliths and wave generated sedimentary structures, like wave ripples and hummocky cross-stratification. The facies sequence of the Barren Measures Formation suggests a transgressive, tide-wave influenced estuarine depositional system, replacing the previous fluvial-lacustrine model (Bhattacharya and Banerjee, 2015). This transgression is possibly a consequence of opening up of the Neo-Tethys along the Indo-Australian plate margin (Bhattacharya and Banerjee, 2015). The coarsening-up fluvial sedimentary succession in the overlying Raniganj Formation attests to a predominant regressive phase.

Continental Sedimentation in Upper Gondwana

The lower part of the Indian Gondwanas (i.e., Lower Gondwanas) has attracted more attention since the early days of exploration because of the presence of economically significant coal deposits and the plentiful occurrence of plant fossils. In recent years, the focus has turned towards the geology of the Upper Gondwana (Dasgupta *et al.*, 2017). Although the Upper Gondwana does not host coal deposits, they provide a wealth of geological information on sedimentary environments existing in various types of continental basins, climatic changes, the evolution of vertebrates and invertebrates, among others.

The Upper Gondwana strata are typically red in colour, which is related to sedimentation in the alluvial environment under arid climatic condition. Further, the absence of marine fossils and wave generated sedimentary structures, the presence of terrestrial fauna and plant remains, and the mineralogical and textural immaturity of sandstones point to deposition in fluvio-lacustrine environment. Triassic and Early Jurassic formations have been extensively studied in recent years to understand the overwhelming dominance of fines in a fluvial deposit

and the origin of freshwater carbonates.

Dominance of Fines in the Triassic Fluvial Deposits

The Middle and the Late Triassic part of the succession are characterized by a few hundreds of meters thick successions of red mudstones interbedded with a few meters thick beds of sandstones. The earlier studies considered sandy beds and mudstones as channel-fill and over bank deposits, respectively. However, it is difficult to explain such a succession in terms of existing fluvial facies models. Traditionally, traction-laden coarse clastics deposit within the channels and fine-grained clastics accumulate in overbank areas. The rate of aggradation is higher in the channel than in the overbank as coarser clastics preferentially deposit within the channels. Besides, the channels receive a more perennial supply of sediments, whereas the overbanks receive sediment input from the channels only during bank-topping flood events. The thickness of the channel-fill deposits is likely to be higher than that of the overbank deposits. The mudstone-dominated character of the Middle and Late Triassic successions contradicts this general trend (e.g., Denwa, Maleri, Tiki formations) of the Upper Gondwanas (Sengupta *et al.*, 2016; Dasgupta *et al.*, 2017; Dasgupta and Ghosh, 2018).

In the Middle Triassic Denwa Formation, Satpura Basin, lensoidal channel-fill bodies occur at several stratigraphic levels encased within very thick pedogenically modified, massive, red mudstones. As these channel-fills contain evidence of deposition of fines, Ghosh *et al.* (2006) proposed that the low-gradient Denwa fluvial system received a persistent supply of fines-dominated load from the source area. The channels used to relocate through avulsion than through lateral migration. This mode of relocation possibly reduced the probability of autogenic removal of overbank deposits, thereby, augmenting their preservation potential. These workers have identified several splay-avulsion deposits within the mudstone intervals (Ghosh *et al.*, 2006). They suggested that a mechanism for enhanced and more perennial channel to overbank sediment transfer existed during the deposition of the Denwa Formation. Besides, the anabranching character of the fluvial system allowed the interchannel (overbank) areas to receive supply from several adjacent channels, concurrently.

Similarly, the Late Triassic Maleri Formation in Pranhita-Godavari Basin exhibits a few meter-thick sheet sandstone bodies alternate with few tens of meter-thick intervals of red mudstones. The mudstone intervals consist of laminated, sandy siltstones containing a significant proportion of fine sand-sized pedogenic mud aggregates (Dasgupta *et al.*, 2017). The presence of dune-scale cross-stratification (Fig. 2a) in these fine-grained deposits testifies that the aggregates were transported as bedload by traction current. Dasgupta *et al.* (2017) proposed that the pedogenic mud aggregate-rich load was transported through a network of shallow, unconfined flow-paths in a discontinuous ephemeral stream system. Rather than size-dependent partitioning of sediments between channel and overbank, the alternation of sheet sandstone bodies and mud aggregate-rich fine-grained sediments reflect changing character of sediment supply, possibly induced by seasonality in precipitation.

The lithological character of the Upper Triassic Tiki Formation of the Rewa Basin and the Lower Triassic Panchet Formation of the Damodar Valley Basin is in many ways similar to that of the Denwa and Maleri formations.

Origin of Freshwater Carbonates Associated with Fluvial Deposits in Upper Gondwana

A large variety of freshwater carbonates are related to the Upper Gondwana fluvial deposits. Goswami *et al.* (2018) recently reported various features associated with the subaerial modification of the primary lime mud and algal activity in these limestones. Several studies have reported the occurrences of a rather unusual litho-type in the Middle to Late Triassic strata, viz. calcareous rubbly rock, lime-pellet rock, calcirudite-calcarenite, and grainstone from Maleri, Denwa and Tiki formations (Dasgupta and Ghosh, 2018). The framework of these cross-bedded clastic sedimentary rocks contains coarse sand to small pebble-sized carbonate clasts, admixed with a low amount of other sandy siliciclastic grains. Sarkar (1988) suggested that the microfabric of the grains in the Maleri Formation resemble those of pedogenic concretions. A similar origin has been proposed for those in the Denwa and Tiki formations (Ghosh *et al.*, 2006). In a recent development, Dasgupta and Ghosh (2018) have demonstrated that the grainstones of the Maleri Formation contain clasts of palustrine

and spring carbonates. The minute structures formed due to the microbially mediated carbonate precipitation at the sediment-water interface are still preserved in these grains (Fig. 2b). The recognition of signatures of microbial activity in the Late Triassic Maleri Formation and the Early Jurassic Kota Formation opens a new vista for reconstructing the punctuated record of microbial colonization in various freshwater environments during the Mesozoic.

Recent Sedimentological Investigations in Mesozoics of Kutch and Jaisalmer Basins

Although the Mesozoics in Kutch are well investigated for sedimentological and biostratigraphical implications, significant ichno-sedimentological studies have been carried in recent years. Fourteen major ichnological events are recorded in entire Mesozoic sections of western Kutch, of which six ichno events are documented from Middle Jurassic viz. *Diplocraterion-Arenicolites*, *Astereosoma-Rhizocorallium*, *Zoophycos-Chondrites*, *Zoophycos*, *Gastrochaeonolites* and *Zoophycos-Thalassinoides* (Desai, 2016).

The post-rift Upper Jurassic sediments of the Kutch Basin represent a significant regression marked by the development of the “Jhuran Delta” during mid-Kimmeridgian to Tithonian (Desai and Biswas, 2018). Ichnological and sedimentological parameters define fourteen lithofacies and seven lithofacies associations corresponding to various sub-environments in river-dominated and wave-influenced Jhuran Delta. The prodelta environment exhibits moderate ichnodiversity suggesting alternating brackish and fully saline water conditions (Desai and Biswas, 2018). Delta front and distributary mouth bar show moderate ichnodiversity of mixed river and marine environment. The Early Cretaceous shoreface deposited sands of the Katesar Member reveal the rich diversity of trace fossils forming *Gyrophyllite-Diplocraterion* ichno-assemblage (Desai, 2016). Palaeocommunity dynamics analysis within the Guneri Member reflects oscillatory flow conditions related to tide (Desai and Saklani, 2015). Bansal *et al.* (2017) provided the sequence stratigraphic framework of the Ukra Hill Member. Based on abundance and K₂O content of glauconite, these authors have distinguished the transgressive systems tract (TST) from highstand systems tract (HST) deposits, separated by a

Fig. 2: A) Dune-scale planar cross-beds (parallel to hammer head) in the red clayey siltstone of the Late Triassic Maleri Formation, Pranhita-Godavari Gondwana Basin. B) Photomicrograph of Maleri carbonate showing a curled flake with dark micritic core (white arrow) coated by clear calcite crystal dendrites. The interstitial space is filled with iron-stained clays, containing organic matter (black arrow)

glauconite-rich condensed zone. A thorough study of constituent facies in the lower part of the Bhuj Formation reveals an explicit record of relative sea level rise between two fluvial stratigraphic intervals and the development of estuarine conditions (Mandal *et al.*, 2016). A few studies focus on the source of Mesozoic sediments in the Kutch Basin based on integration of petrography, major and trace element concentration and heavy mineral chemistry (Chaudhuri *et al.*, 2018, 2019). The Jhuran Formation has been investigated for the possible anoxic event during the Jurassic (Arora *et al.*, 2015, 2017).

Pandey and Pooniya (2015) presented the sequence stratigraphic framework of the Baisakhi Formation (Oxfordian to Tithonian) in Jaisalmer Basin. These authors presented a general coarsening-upward

trend, accompanied by a change from the lower shoreface zone to the fluvial environment within the Kimmeridgian-Tithonian part of the Baisakhi Formation. Dolson *et al.* (2015) presented a detailed analysis of the sedimentary sequence in the Barmer Basin. These authors considered a rift sequence of Mesozoic fluvial rocks in this basin which is followed upward by an infilling of rift accommodation space by the deposition of fluvial, lacustrine and shallow marine sediments during Palaeocene-Eocene.

Transgressive and Regressive Cycles in the Cauvery Basin

The Cauvery Basin is a Mesozoic pericratonic rift basin filled with syn-rift fluvial and lacustrine sediments (Nagendra *et al.*, 2018), overlain by marine sediments. The excellent preservation of planktic foraminifera assigns a Late Aptian age for the transgressive upper part of the Terani Formation. This marine transgression event of the Terani Formation is a corollary to the terminal phase of syn-rift tectonics in the Cauvery Basin. Subtle unconformity across Terani and Dalmiapuram formations (Aptian/Albian) and major unconformities across the Karai and Garudamangalam formations (Late Turonian) and Sillakkudi and Kallankurichchi formations (Late Campanian) have equivalents in the adjoining Krishna-Godavari Basin (Raju and Reddy, 2016). The Karai Formation, exposed at the basin margin, contains diverse assemblages of ammonites, foraminifera and radiolarian and consists predominantly of glauconitic shale with abundant calcareous benthic foraminifera suggesting deposition in > 150m water depth (Fig. 3; Banerjee *et al.*, 2016a; Nagendra *et al.* 2018). The age of the Karai Shale, marking a major transgressive cycle ranges from Early Albian to Middle Turonian (Gowtham *et al.*, 2019). The Albian age, indicated by index fossil taxa, as well as new Ar/Ar dating of glauconite significantly improves the calibration of OAE 1d in the Cauvery Basin (Nagendra and Reddy, 2017; Bansal *et al.*, 2019a). The transition from the shallow shelf-originated Dalmiapuram Formation to the deeper shelf-originated Karai Shale Formation records a transgressive trend (Sarkar *et al.*, 2014).

Ichnofossil assemblage in the Kulakkalnattam Sandstone Member of the Garudamangalam Formation coincides with a rapid relative sea-level fall from deep outer neritic to inner neritic depth during

the Late Turonian. The ichnofossil assemblage consists mainly *Skolithos* and *Cruziana*, suggesting a typical shoreface, environment (Nagendra *et al.*, 2011). The marine carbonates in Kallankurichchi Formation are enriched in mollusks, including *Gryphaea*, *Alectronia*, *Pecten* and bryozoans that represent maximum flooding surfaces (Nagendra *et al.*, 2011). This unit also contains well preserved larger benthic foraminifera, particularly the *Lepidorbitoides-Siderolites* assemblage (Malarkodi *et al.*, 2017) and planktic foraminifera *Globotruncanaegyptiaca*, *G. linneiana* and *G. arca*, corresponding to the zone CF6 of the late Early Maastrichtian (Keller *et al.*, 2016). Recent magnetostratigraphic investigations reveal thirteen magnetozones comprising of 6 normal and 7 reversal events within the Cauvery Basin (Nagendra and Reddy, 2017). These polarity events corroborate with chron C34n to chron C30n of the Geologic Time Scale of Gradstein *et al.* (2012) and indicate a low southern latitude during the Late Cretaceous period for the Cauvery Basin.

Marine and Continental Deposits in Bagh Group and Lameta Formation

Cretaceous marine transgression has been revisited in Nimar Sandstone and Nodular Limestone with new sedimentological, palaeontological, ichnological and micropalaeontological data (Bhattacharya and Jha, 2014; Jha *et al.*, 2017). Jha *et al.* (2016) reported seismites, in the middle part of the Nimar Sandstone and interpreted a new phase of reactivation of the Son-Narmada South Fault during the Cenomanian period. These authors suggested that the lower part of litho-unit shows predominantly fluvial deposits, whereas the middle and upper parts exhibit tide-dominated estuarine to tide-wave influenced shoreface condition. Stacked fining-up transgressive cycles signify a rise in base level during the Cenomanian-Turonian accompanied by basinal subsidence caused by reactivation of basin marginal faults in the Narmada rift valley basin (Jha *et al.*, 2017). The subsidence caused the encroachment of open sea, hence further landward inundating the entire basin.

Racey *et al.* (2016) proposed a revised chronostratigraphic framework for the Bagh Group of rocks. Patel *et al.* (2018) reported trace fossils viz. *Conichnusconicus*, *Conostichusbroadheadi*

and *C. stouti* from intercalated micritic limestone shale sequence of the Bagh Group of rocks exposed in Man river basin. They have interpreted these ichnospecies as resting/dwelling structures characterizing a shallow marine environment of deposition. Ruidas *et al.* (2018) revisited the stratigraphic set-up and proposed a new division of the Nodular Limestone and also explained the nature and origin of modularity. Kumar *et al.* (2018) proposed a Turonian age for the Nodular Limestone Formation of Bagh area based on ammonoid and *Inoceramus* index taxa. Recently, Bansal *et al.* (2019b) reported a glauconite bed within the Late Bryozoan Limestone Formation of the Bagh Group in central India. These authors recorded the existence of a 'glauconitic sea' along the margins of the Palaeo-Tethys Ocean during the Late Cretaceous on the basis of existing records and detailed geochemical analysis.

The Lameta Formation of the Maastrichtian age, traditionally considered to be fluvial, reveals the evidence of short-lived marine incursion based on careful analysis of ichnofossils, lithological architecture, calcareous algae (Srivastava *et al.*, 2018) and authigenic glauconite (Bansal *et al.*, 2018). Mankar and Srivastava (2015) proposed a new basin of deposition for the Lameta sediments in central India, viz., Salbardi-Belkhar inland basin and identified three different lithofacies revealing fluvial-lacustrine set-up for the same. Dinosaur remains and egg nests have been reported in recent studies (Srivastava and Mankar, 2015; Aglawe and Lakra, 2018; Fernández and Khosla, 2015; Khosla *et al.*, 2015). Sonkusare *et al.* (2016) reported plant remains and diverse spores and pollens within Lameta sediments.

Facies and Sequence Stratigraphic Analysis the Cenozoic Successions in Kutch and Jaisalmer

The sequence stratigraphic architecture of the Palaeogene succession of Kutch has been addressed in recent studies based on the detailed sedimentary facies and biostratigraphic analysis (Fig. 4; Chatteraj *et al.*, 2016; Catuneanu and Dave, 2017; Banerjee *et al.*, 2018; Srivastava and Singh, 2019). The Naredi Formation, overlying the unfossiliferous Matanomadh Formation, represents the products of the earliest marine transgression in the Palaeogene of Kutch (Chatteraj *et al.*, 2009; Sarkar *et al.*, 2012; Saraswati *et al.*, 2012). The presence of age-diagnostic benthic

Fig. 3: Litholog showing palaeobathymetric variations, key sequence stratigraphic surfaces, tectonic and magnetic polarity events

foraminifera assigns an Early Eocene age for the lower part of the Naredi Formation (Saraswati *et al.*, 2014, 2018; Khanolkar *et al.*, 2017). The lower part of the glauconitic Naredi Formation records an overall deepening upward trend until the deposition of an *Assilina*-bearing limestone, representing a transgressive systems tract (TST). The upper part of the Naredi Formation shows an overall shallowing upward trend and comprises the highstand systems tract (HST). An extended break in sedimentation follows this HST (Chattoraj *et al.*, 2016; Catuneanu and Dave, 2017; Saraswati *et al.*, 2016a,b, 2018). The unconformity at the contact between the Naredi and Harudi formations is marked by regionally extensive laterite (Banerjee *et al.*, 2012a, 2018). A combined sedimentological and micropalaeontological analysis reveals an overall deepening upward trend within the Harudi Formation (Banerjee *et al.*, 2012a; Chattoraj *et al.*, 2016). The overall deepening upward, glauconitic Harudi Formation represents a transgressive systems tract which is followed upward by the shallow marine Fulra Limestone. The latter is dominated by nummulite accumulations and exhibits several smaller order sealevel oscillations (Chattoraj *et al.*, 2012; Banerjee *et al.*, 2018). A prominent palaeokarst surface at the top of the Fulra Limestone represents a distinct break in sedimentation during the Late Eocene time (Banerjee *et al.*, 2018). A glauconitic shale marks the transgressive lower part of the Oligocene Maniyara Fort Formation (Banerjee *et al.*, 2012b, 2018). Banerjee *et al.* (2016b) indicated that the origin of shallow marine glauconites in the Palaeogene of Kutch might be different from those forming in the modern deep marine environment.

A carbonate-siliciclastic deposit represents the Early Miocene succession in Kutch, consisting of Khari Nadi and Chhasra Formation. A combined sedimentological, trace fossil assemblage and micropalaeontological analysis reveals the sequence stratigraphic background and identifies key stratal surfaces (Kumar *et al.* 2016). The transgressive systems tract exhibits a gradual change in foraminiferal assemblage indicating deepening-upward succession in the overall middle shelf environment, accompanied by a change of trace fossil assemblage from *Psilonichnus* to *Skolithos* and finally to *Thalassinoides* assemblage, from the bottom to the

top (Kumar *et al.*, 2016). Shekhar *et al.* (2018) presented the sequence stratigraphic frame for the Middle to Upper Miocene Sandhan Formation. These authors considered the Sandhan Formation as a product of wave-dominated TST and HST followed by the forced regressive deposit of FSST.

Patra and Singh (2015) presented a detailed facies analysis of the Palaeocene-Eocene succession of the Jaisalmer Basin and inferred that the sandstones deposited in shoreface to foreshore zone and the carbonate-shale alternations formed in lagoonal and tidal environments within a mixed siliciclastic-carbonate ramp/platform.

Palaeogene Hyperthermal Events in Kutch

In the past decades, there have been two major developments of consequence to the Palaeogene stratigraphy. Firstly, the biostratigraphy of the Tethyan shallow marine successions has been refined by Shallow Benthic Zonation to facilitate regional correlations. Secondly, global hyperthermal events of the Eocene, marked by carbon isotope excursions (CIE), are also recognized in the marginal marine to shallow marine sequences of India (Khanolkar and Saraswati, 2015; Khanolkar *et al.*, 2017). These hyperthermal events are marked by enhanced weathering and erosion and an increase in hydrological intensity. The identification of these events necessitated updating the biostratigraphy of the best developed Palaeogene sequence of India in Kutch. The larger benthic foraminifera comprising *Nummulites*, *Lepidocyclina* and orthophragminids were re-studied biometrically to compare them with their current taxonomy in western Tethyan sequences (Saraswati *et al.*, 2018). These biostratigraphic studies integrated with Sr-isotope stratigraphy have led to propose shallow benthic zonation and an updated stratigraphy of the Palaeogene (Saraswati *et al.*, 2018). While the CIEs are marked in the Cambay Basin, the effect of warming on shallow marine foraminifera has been attempted in Cambay and Kutch basins (Sharma and Saraswati, 2015; Khanolkar and Saraswati, 2015, 2016; Khanolkar *et al.*, 2017; Khanolkar and Sharma, 2019). However, the role of hyperthermal events on enhanced chemical weathering of terrestrial silicates is yet to be documented from the Palaeogene deposits in India.

Fig. 4: A composite graphic log of the Palaeogene succession of Kutch showing unconformities, transgressive surfaces, maximum flooding surfaces and systems tracts. Occurrences of glauconite marked by asterisks. (modified after Chattoraj *et al.*, 2016)

Quaternary Sedimentation and Palaeoclimaticre Construction

In last few years, considerable progress has been made towards Quaternary terrestrial sedimentation and palaeoclimatic reconstruction (Raj *et al.*, 2015; Sridhar *et al.*, 2016; Sridhar and Chamyal, 2018; Khonde *et al.*, 2017a, b; Prizomwala *et al.*, 2018). Contribution have also been made on calcrete profiling (Srivastava and Basand, 2019), palaeosol geochemistry (Srivastava *et al.*, 2019) and nature, occurrence, lithological and depositional set-up of Youngest Toba Tuff (YRR) ash (Srivastava and Singh, 2019b) that are preserved in Quaternary alluvial sediments of Purna basin, Central India. Based on the study of sediments in Pariyaj Lake in Gujarat Plains Raj *et al.* (2015) indicated a wet climate and high

lake stand during ~11,000, 7630 and between 4680 and 3500 cal yr BP. Bhushan *et al.* (2018) indicated a persistent millennial to centennial-scale monsoon variability during the Holocene within relict lake sediments occurring at the boundary between lesser and higher central Himalayas. Based on high-resolution geochemical data supported by radiocarbon dating, these authors inferred six phases of enhanced Indian Summer Monsoon (ISM) with varying scales between 10,000-9600, 9500-9200, 8600-5800, 5000-4200, 3500-2400 and 1800-1000 cal yr BP. Misra *et al.* (2018) compiled lake records from India and found that only about 14 lake records provide a reasonably time-resolved natural climate variability throughout the Holocene, and only 9 other lake records provide palaeoclimate information for a duration of more than ~8 kyr. Khonde *et al.* (2017b) indicated that the lost Saraswati River mentioned in the ancient Indian tradition is postulated to have flown independently of the Indus River into the Arabian Sea, perhaps along courses of now-defunct rivers such as Ghaggar, Hakra and Nara. Sridhar *et al.* (2016) documented the record of the Little Ice Age based on the temporal variations in the major and trace elements and the Sr and Nd isotopic composition of the silicate component of palaeoflood deposits. Their study demonstrates that the geochemical signatures of the flood sediment are largely controlled by the weathering intensity in the catchments, the river discharge and mineral sorting.

Saha *et al.* (2016) presented the morphology and evolution of tidal sand ridges and bars in the macro-tidal Gulf of Khambhat. They reported several km long, narrow and several meters high ridges within the outer gulf. While the sand bars associated with macrotidal estuaries along the flanks of Gulf of Khambhat typically range in length from a few 100 m to a few km long. Saha *et al.* (2018) reported the uniqueness in the tide-dominated sediment depositional system based on their study of Tapti, Narmada, Dhadhar and Mahi estuaries. These authors documented a mixing of sediments as fluvial currents interact with and tidal flows.

Concluding Remarks

The Phanerozoic sedimentary record in the Peninsular India holds promises of hosting significant evidence of tectono-eustatic fluctuations, plate tectonic reconstruction and the evolution of Earth's atmosphere

and hydrosphere. An integration of sedimentological and palaeobiological data has provided a high-resolution interpretation of stratigraphic records. Although significant progress has been made in recent years, a detailed study on source-to-sink systems is necessary to indicate sediment generation and associated routing systems including erosion, sediment

flux, deposition and storage.

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References

- Aglawe V A and Lakra P (2018) Upper Cretaceous (Maastrichtian) dinosaur eggs *Megaloolithus cylindricus* from Salbardi-Ghorpend area, Betul district, Madhya Pradesh *J Pal Soc India* **63** 191-196
- Arora A, Banerjee S and Dutta S (2015) Black shale in Late Jurassic Jhuran Formation of Kutch: Possible indicator of Oceanic Anoxic Event *J Geol Soc India* **85** 265-278
- Arora A, Dutta S, Gogoi B and Banerjee S (2017) The effects of igneous dike intrusion on organic geochemistry of black shale and its implications: Late Jurassic Jhuran Formation, India *Int J Coal Geol* **178** 84-99
- Banerjee S, Chatteraj S L, Saraswati P K, Dasgupta S and Sarkar U (2012a) Mineralogy and geochemistry of lagoonal glauconites and their implications on origin and maturation: Oligocene Maniyara Fort Formation, western Kutch, India *Geol J* **47** 357-371
- Banerjee S, Chatteraj S L, Saraswati P K, Dasgupta S and Sarkar U (2012b) Substrate control on formation and maturation of glauconites in the Middle Eocene Harudi Formation, western Kutch, India *Mar Petrol Geol* **30** 144-160
- Banerjee S, Bansal U, Pande K and Meena SS (2016a) Compositional variability of glauconites within the Upper Cretaceous Karai Shale Formation, Cauvery Basin, India: implications for evaluation of stratigraphic condensation *Sediment Geol* **331** 12-29
- Banerjee S, Bansal U and Thorat A (2016b) A review on palaeogeographic implications and temporal variation in glaucony composition *J Palaeogeogr* **5** 43-71
- Banerjee S, Khanolkar S and Saraswati P K (2018) Facies and depositional settings of the Middle Eocene-Oligocene carbonates in Kutch *Geodinamica Acta* **30** 119-136
- Bansal U, Banerjee S, Pande K, Arora A and Meena S S (2017) The distinctive compositional evolution of glauconite in the Cretaceous Ukra Hill Member (Kutch Basin, India) and its implications *Mar Petrol Geol* **82** 97-117
- Bansal U, Banerjee S, Ruidas D K and Pande K (2018) Origin and geochemical characterization of the glauconites in the Upper Cretaceous Lameta Formation, Narmada Basin, Central India *J Palaeogeogr* **7** 99-116
- Bansal U, Pande K, Banerjee S, Nagendra R and Jagadeesan K C (2019a) The timing of oceanic anoxic events in the Cretaceous succession of Cauvery Basin: Constraints from $^{40}\text{Ar}/^{39}\text{Ar}$ ages of glauconite in the Karai Shale Formation *Geo J* **54** 308-315
- Bansal U, Banerjee S, Pande K and Das DK (2019b) Unusual seawater composition of the Late Cretaceous Tethys imprinted in glauconite of Narmada basin, central India *Geol Mag* <https://doi.org/10.1017/S0016756819000621>
- Bastia R and Radhakrishna M (2012) Basin Evolution and Petroleum Prospectivity of the Continental Margins of India. Developments in Petroleum Science 59 Elsevier Oxford
- Bhattacharya B and Jha S (2014) Late Cretaceous diurnal tidal system: A study from Nimar Sandstone, Bagh Group, Narmada Valley, Central India *Current Science* **107** 1032-1037
- Bhattacharya B and Banerjee P P (2015) Record of Permian Tethyan transgression in eastern India: A reappraisal of the Barren Measures Formation, West Bokaro Coalfield *Mar Petrol Geol* **67** 170-179
- Bhattacharya B, Bhattacharjee J, Banerjee S, Bandyopadhyay S and Das R (2016) Seismites in Permian Barakar Formation, Raniganj Basin, India: implications on Lower Gondwana basin evolution *Arab J Geoscience* **9** 300
- Bhattacharya B, Bhattacharjee J, Bandyopadhyay S, Banerjee S and Adhikari K (2018) Early Permian transgressive–regressive cycles: sequence stratigraphic reappraisal of the coal-bearing Barakar Formation, Raniganj Basin, India *J Earth Sys Sci* **127** 29 <https://doi.org/10.1007/s12040-018-0922-7>
- Bhattacharya H N and Bhattacharya B (2015) Lithofacies architecture and paleogeography of Late Paleozoic glaciomarine Talchir Formation, Raniganj Basin, India *J Palaeogeogr* **4** 269-283
- Bhushan R, Sati, SP, Rana, N, Shukla AD, Mazumdar AS and

- Juyal N (2018) High-resolution millennial and centennial scale Holocene monsoon variability in the Higher Central Himalayas *Palaeo Palaeo Palaeo* **489** 95-104
- Biswas S K (2016) Tectonic framework, structure and tectonic evolution of Kutch Basin, western India *Spec Publ Geol Soc India* **88** 129-150
- Catuneanu O and Dave A (2017) Cenozoic sequence stratigraphy of the Kachchh Basin, India *Mar Petrol Geol* **86** 1106-1132
- Chattoraj S, Banerjee S and Saraswati P K (2009) Glauconites from the late Palaeocene Early Eocene Naredi Formation, Western Kutch and their genetic implications *J Geol Soc India* **73** 567-574
- Chattoraj S L, Sarkar U, Banerjee S and Saraswati P K (2012) Facies and Paleogeography of the Middle Eocene Fulra Limestone Kutch *J Indian Asso Sediment* **31** 1-10
- Chattoraj S L, Banerjee S, Saraswati P K and Bansal U (2016) Origin, depositional setting and stratigraphic implications of Palaeogene glauconite of Kutch *Spl Publ Geo Soc India* **6** 75-88
- Chaudhuri A, Banerjee S and Le Pera E (2018) Petrography of Middle Jurassic to Early Cretaceous sandstones of the Kutch Rift Basin: Implications on provenance and basin evolution *J Palaeogeogr* **7** 239-252
- Chaudhuri A, Banerjee S and Chauhan G (2019) Compositional evolution of sediments recording the increasing tectonic stability of a pericratonic rift: Mesozoic Kutch Basin, western India *Mar Petrol Geol* <https://doi.org/10.1016/j.marpetgeo.2019.08.026>
- Dasgupta S and Ghosh P (2018) Freshwater carbonates within a Late Triassic siliciclastic fluvial system in a Gondwana rift basin: The Maleri Formation, India *Sed Geol* **373** 254-271
- Dasgupta S, Ghosh P and Gierlowski-Kordesch E (2017) A Discontinuous Ephemeral Stream Transporting Mud Aggregates In. A Continental Rift Basin: The Late Triassic Maleri Formation, India *J Sediment Res* **87** 838-865
- Desai B G (2016) Ichnological Events Associated with Evolution of Kachchh Rift Basin, Western India. In M Thakkar (Ed.) Recent Studies on the Geology of Kachchh *Spl Publ Geo Soc India* **6** 114-128
- Desai G and Saklani R D (2015) Palaeocommunity Dynamics and Behavioral Analysis of *Conichnus*: Bhuj Formation (Lower Cretaceous), Kachchh-India *Ichnos* **22** 43-55
- Desai B G and Biswas S K (2018) Postrift deltaic sedimentation in western Kachchh Basin: Insights from ichnology and sedimentology *Palaeo Palaeo Palaeo* **504** 104-124
- Dolson J, Burley, S D, Sunder, V R, Kothari, V, Naidu, B, Whiteley, N P, Farrimond, P, Taylor A, Direen N and Ananthakrishnan B (2015) The Discovery of the Barmer Basin, Rajasthan, India, and its petroleum geology *AAPG Bull* **99** 433-465
- Fernández M S and Khosla A (2015) Parataxonomic review of the Upper Cretaceous dinosaur eggshells belonging to the family *Megaloolithidae* from India and Argentina *Hist Biol* **27** 158-180
- Ghosh P and Sarkar S (2011) Pedogenic and sedimentologic criteria for recognition of overbank sub-environments in a Triassic anabranching river deposit: In: From River to Rock Record: The Preservation of Fluvial Sediments and Their Subsequent Interpretation (Eds: Davidson S K, Leleu S and North C P) SEPM Special Publication **97** 125-142
- Ghosh P, Sarkar S and Maulik P (2006) Sedimentology of a muddy alluvial deposit: Triassic Denwa Formation, India *Sed Geol* **191** 3-36
- Goswami S, Gierlowski-Kordesch E and Ghosh P (2018) Sedimentology of the Early Jurassic limestone beds of the Kota Formation: record of carbonate wetlands in a continental rift basin of India *J Paleolimnol* **59** 21-38
- Gowtham J P, Pandey B, Jaitly A K, Pathak D B, Kumar S and Tiwari D N (2019) Early Albian Ammonites from the Karai Formation, Cauvery Basin, South India *Earth Sci India* **12** 53-70
- Gradstein F M, Ogg J G, Schmitz M D and Ogg G M (2012) The Geological Time Scale. Amsterdam, Elsevier
- Jha S, Bhattacharya B and Nandwani S (2017) Significance of seismites in the Late Cretaceous transgressive Nimar Sandstone succession, Son-Narmada rift valley, Central India *Geol J* **52** 768-783
- Keller G, Jaiprakash B C and Reddy A N (2016) Maastrichtian to Eocene subsurface stratigraphy of Cauvery Basin and correlation with Madagascar *J Geo Soc India* **87** 3-34
- Khanolkar S and Saraswati P K (2015) Ecological response of shallow-marine foraminifera to early Eocene warming in equatorial India *J Foram Res* **45** 293-304
- Khanolkar S and Saraswati P K (2016) Some observations on an atypical planktic foraminifer from the Middle Eocene of Kutch, India *J Micropalaentol* **35** 54-61
- Khanolkar S and Sharma J (2019) Record of Early to Middle Eocene paleoenvironmental changes from lignite mines, western India *J Micropalaentol* **38** 1-24
- Khanolkar S, Saraswati P K and Rogers K (2017) Ecology of foraminifera during the middle Eocene climatic optimum in Kutch, India *Geodinamica Acta* **29** 181-193
- Khonde N N, Maurya D M and Chamyal L S (2017a) Late

- Pleistocene–Holocene clay mineral record from the Great Rann of Kachchh basin, Western India: Implications for palaeoenvironments and sediment sources *QuatInt* **443** 86–98
- Khonde K, Singh S K, Maurya D M, Rai V K, Chamyal L S and Giosan L (2017b) Tracing the Vedic Saraswati River in the Great Rann of Kachchh *Sci Rep* **7** 5476
- Khosla A, Chin K, Alimohammadin H and Dutta D (2015) Ostracods, plant tissues, and other inclusions in coprolites from the Late Cretaceous Lameta Formation at Pisdura, India: Taphonomical and palaeoecological implications *Palaeo Palaeo Palaeo* **418** 90–100
- Kumar P, Saraswati P K, Banerjee S and Ghosh A (2016) Sequence stratigraphic analysis of a shallow marine, mixed carbonate-siliciclastic system, early Miocene, Kutch *Spl Publ Geo Soc India* **6** 55–74
- Kumar S, Pathak D B, Pandey B, Jaitly A K and Gautam J P (2018) The age of the Nodular Limestone Formation (Late Cretaceous), Narmada Basin, central India *J Earth Sys Sci* **127** doi: Org/10.1007/S12040-018-1017-1
- Malarkodi N, Özcan E, Venkataraman D, Suresha Gowda S C, Nagaraja P K T and Ali O (2017) *Lepidorbitoides* (foraminifera) from the lower Maastrichtian Kallankurichchi Formation, Cauvery Basin, India: Morphometry and paleobiogeography *Cret Res* **77** 143–157
- Mandal A, Koner A, Sarkar S, Tawfik H A, Chakraborty N, Bhakta S and Bose P K (2016) Physico-chemical tuning of palaeogeographic shifts: Bhuj Formation, Kutch, India *Mar Petrol Geol* **78** 474–492
- Mankar R S and Srivastava A K (2015) Salbardi–Belkher inland basin: a new site of Lameta sedimentation at the border of districts Amravati, Maharashtra and Betul, Madhya Pradesh, Central India *Current Science* **109** 1337–1344
- Misra P, Tandon S K and Sinha R (2018) Holocene climate records from lake sediments in India: Assessment of coherence across climate zones. *Earth-Science Reviews* <https://doi.org/10.1016/j.earscirev.2018.12.017>
- Nagendra R and Nallapa Reddy A (2017) Major geological events of the Cauvery Basin, India and their correlation with global signatures-A Review *J Palaeogeogr* **6** 69–83
- Nagendra R, Kamalakkannan B V, Sen G, Gilbert H, Bakkiaraj D, Nallapa Reddy A and Jaiprakash B C (2011) Sequence surfaces and paleobathymetric trends in Albion to Maastrichtian sediments of Ariyalur area, Cauvery Basin, India *Mar Petrol Geol* **28** 895–905
- Nagendra R, Sathiyamoorthy P, Reddy A N, Gilbert H and Jaiprakash B C (2013) Stratigraphic status, age and paleobathymetry of the Grey Shale Member of the Dalmiapuram Formation, Cauvery Basin, India *Arabian J Geos* **7** 4133–4144
- Nagendra R, Reddy A N, Jaiprakash B C, Gilbert Harry, Zakharov D Y and Venkateshwarlu M (2018) Integrated Cretaceous stratigraphy of the Cauvery basin, south India *Stratigraphy* **15** 245–259
- Pandey D K and Pooniya D (2015) Sequence stratigraphy of the Oxfordian to Tithonian sediments (Baisakhi Formation) in the Jaisalmer Basin *Volumina Jur* **13** 65–76
- Patel S J, Shitole A D and Joseph J K (2018) Plug shaped burrows *Conichnus-Conostichus* from the Late Cretaceous of Bagh Group, Gujarat, Western India *J Geol Soc India* **91** 41–46
- Patra A and Singh B P (2015) Facies characteristics and depositional environments of the Paleocene–Eocene strata of the Jaisalmer basin, western India *Carb Evap* **30** 331–346
- Prizomwala S P, Yadav G, Bhatt N and Sharma K (2018). Late Pleistocene relative sea-level changes from Saurashtra, west coast of India *Curr Sci* **115** 2297–2301
- Racey A, Fisher J, Bailey H and Roy S K (2016) The value of fieldwork in making connections between onshore outcrops and offshore models: an example from India: In: The value of outcrop studies in reducing subsurface uncertainty and risk in hydrocarbon exploration and production (Eds: Bowman M, Smyth H R, Good T R, Passey S R, Hirst J P P and Jordan C J) *Spl Publ Geol Soc London* **436** <https://doi.org/10.1144/SP436.9>
- Raj R, Chamyal L S, Prasad V, Sharma A, Tripathi J K and Verma P (2015) Holocene climatic fluctuations in the Gujarat Alluvial Plains based on a multiproxy study of the Pariyaj Lake archive, western India *Palaeo Palaeo Palaeo* **421** 60–74
- Raju D S N and Reddy A N (2016) Why there is a substantial dichroneity in biostratigraphic dating of Cretaceous sediments in the Krishna-Godavari Basin and Cauvery Basin -a review *ONGC Bull* **51** 119–134
- Ruidas D K, Paul S and Gangopadhyay T K (2018) A reappraisal of stratigraphy of Bagh Group of rocks in Dhar District, Madhya Pradesh with an outline of origin of nodularity of Nodular Limestone Formation *J Geol Soc India* **92** 19–26
- Saha S, Burley S, Banerjee S, Ghosh A and Saraswati P K (2016) The morphology and evolution of tidal bar sand bodies in the macrotidal Gulf of Khambhat, western India *Mar Petrol Geol* **74** 714–730
- Saha S, Burley S and Banerjee S (2018) Mixing processes in modern estuarine sediments from the Gulf of Khambhat, western India *Mar Petrol Geol* **91** 599–621

- Saraswati P K, Sarkar U and Banerjee S (2012) *Nummulites solitarius* – *Nummulitesburdi galensis* lineage in Kutch with remarks on the age of Naredi Formation *J Geo Soc India* **79** 476-482
- Saraswati P K, Khanolkar S, Raju D S N, Dutta S and Banerjee S (2014) Foraminiferal biostratigraphy of lignite mines of Kutch, India: Age of lignite and fossil vertebrate's *J Palaeogeogr* **3** 90-98
- Saraswati P K, Banerjee S, Sarkar U, Chakraborty S and Khanolkar S (2016a) Eocene Depositional Sequence and Cycles in Kutch *Spl Publ Geol Soc India* **6** 46-56
- Saraswati P K, Khanolkar S, Raju D S N and Banerjee S (2016b) An updated Eocene stratigraphy of Kutch *Spl Publ Geo Soc India* **6** 25-31
- Saraswati P K, Khanolkar S and Banerjee S (2018) Paleogene stratigraphy of Kutch, India: an update about progress in foraminiferal biostratigraphy *Geodinamica Acta* **30** 100-118
- Sarkar S (1988) Petrology of caliche-derived peloidal calcirudite/calcarenite in the late Triassic Maleri Formation of the Pranhita-Godavari valley, south India *Sediment Geol* **55** 263-282
- Sarkar S, Chakraborty N, Mandal A, Banerjee S and Bose P K (2014) Siliciclastic-carbonate mixing modes in the river-mouth bar palaeogeography of the Upper Cretaceous Garudamangalam Sandstone (Ariyalur, India) *J Palaeogeogr* **3** 233-256
- Sarkar U, Banerjee S and Saraswati P K (2012) Integrated borehole and outcrop study for documentation of sea level cycles within the Early Eocene Naredi Formation, western Kutch, India *J Palaeogeogr* **1** 126-137
- Sengupta S, Sengupta D P and Bandyopadhyay S (2016) Stratigraphy of the upper Gondwana formations around Sohagpur, western part of the Satpura Gondwana Basin, Central India *J Geol Soc India* **87** 503-519
- Sharma J and Saraswati P K (2015) Lignites of Kutch, Western India: Dinoflagellate biostratigraphy and palaeoclimate *Rev de Micropaleontol* **58** 107-119
- Shekhar S, Shukla A and Kumar P (2018) Sedimentary record of forced regression along the margin of Kutch Basin: Terminal Cenozoic succession (Sandhan Formation), western India *J Indian Ass of Sedimentol* **35** 23-35
- Sonkusare H, Samant I B and Mohabey D M (2016) Microflora from Sauropod Coprolites and Associated Sediments of Late Cretaceous (Maastrichtian) Lameta Formation of Nand-Dongargaon Basin, Maharashtra *J Geol Soc India* **89** 391-397
- Sridhar A, Bhushan R, Balaji D, Band S and Chamyal L S (2016) Geochemical and Sr–Nd isotopic variations in palaeoflood deposits at mainstem–tributary junction, western India: Implications on late Holocene flood events *Catena* **139** 32-43
- Sridhar A and Chamyal L S (2018) Implications of palaeohydrological proxies on the late Holocene Indian Summer Monsoon variability, western India *Quat Int* **479** 25-33
- Srivastava A K and Bansod M N (2019) Morphology and field association of calcretes from Quaternary sediments of Purna alluvial basin, Maharashtra *Proc Natl Acad Sci India, Sect A Phys Sci* doi: 10.1007/s40010-019-00164-7
- Srivastava A K and Mankar R S (2015) Megaloolithus dinosaur nest from the Lameta Formation of Salbardi area, districts Amravati, Maharashtra and Betul, Madhya Pradesh *J Geol Soc India* **85** 457-462
- Srivastava A K and Singh A (2019a) YTT ash from Quaternary sediments of Kapileshwar area, Purna alluvial basin, central India *Quat Int* **500** 96-107
- Srivastava A K and Singh A (2019b) Nature, occurrence and lithological set up of Youngest Toba Tuff. volcanic ash. Purna alluvial basin, central India *J Geol* **127** 1-18
- Srivastava A K, Bansod M N, Singh A and Sharma N (2019) Geochemistry of Paleosols and calcretes from Quaternary sediments of Purna alluvial basin, central India : An emphasis on paleoclimate *Rhizosphere* **11** 1-12
- Srivastava A K, Kandwal N K, Humane S K, Humane S S, Kundal P and Khare N (2018) Record of calcareous algae from the Lameta Formation: a new insight for possible sea incursion during the Maastrichtian time *Arabian J Geos* **11**.14. <https://doi.org/10.1007/s12517-017-3333-1>
- Srivastava V K and Singh B P (2019) Depositional environments and sources for the middle Eocene Fulra Limestone Formation, Kachchh Basin, western India: Evidences from facies analysis, mineralogy, and geochemistry *Geo J* **54** 62-82.