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Deciphering terrestrial-marine interactions, sedimentology, taphonomy, and palaeobiogeography of the sauropod-bearing Upper Cretaceous (Turonian) Nimar Sandstone, Narmada Valley, India

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ABSTRACT:

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A Late Cretaceous succession displaying a fluvial-marginal-marine transition in the Nimar Sandstone Formation contains dinosaurs in District Dhar, Madhya Pradesh, India. New data from calcareous nannofossils and ostracods suggest an Early Turonian rather than a Cenomanian–Turonian age. Sauropod bone beds are found in the lower Nimar Sandstone (fluvial) and the upper Nimar Sandstone (intertidal-shallow-marine). The lower bone assemblage is fragmentary and disarticulated condition, whereas the upper assemblage – characteristic of marine influence, with oysters and other 'marine' ostracods – is relatively more complete. The present contribution integrates sedimentological, palaeontological and floral evidences, suggesting a warm and humid deltaic-estuarine coastal environment with river channels, marshy inland areas, and mangrove-like vegetation. Preliminary identification of isolated fossil wood as Angiospermae cf. *Rhizophora* sp., if substantiated by future work, indicates mangrove-type vegetation along transgressive Late Cretaceous shores. Taphonomic evidence favours mainly terrestrial, disarticulated sauropod material that underwent post-mortem disarticulation, with limited short-distance transport and/or hydraulic reworking. These results augment the understanding of Late Cretaceous saurischian palaeoecology, landscape diversity, depositional environments, and Gondwanan palaeobiogeography in the Indian subcontinent. Shared dinosaur groups between India, Madagascar, Africa, and South America suggest Gondwanan biotic connections during the Turonian (Late Cretaceous), possibly via transient land links or island chains, despite emerging marine barriers.

Key words: Turonian; Nimar Sandstone Formation; Bagh Group; Narmada Valley; India.

INTRODUCTION

The Cretaceous period is renowned as a classic example of a greenhouse era, one of the most extreme climatic states in the Phanerozoic Eon, characterised by high global temperatures, elevated CO_2 levels, and significantly higher sea levels than those noted today (Vilović *et al*. 2023 and references therein). This period is a crucial reference point for studying extreme climate scenarios, as the Earth's surface and biosphere



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were profoundly impacted by sustained global warmth and minimal polar ice (Nordt *et al*. 2024). Key drivers of this Cretaceous greenhouse world included the widespread formation of Large Igneous Provinces (LIPs), such as the Deccan Traps and the Ontong Java Plateau, which released massive volumes of volcanic gases, including CO_2, into the atmosphere (e.g., Turgeon and Creaser 2008; Keller *et al*. 2009, 2020).

These geologic and climatic events, which coincided with high atmospheric CO_2 concentrations, drove global warming and seawater thermal expansion, resulting in greatly increased global sea levels due to both thermal effects and processes such as accelerated seafloor spreading (Barral *et al*. 2017). The markedly higher sea levels in the Cretaceous caused extensive flooding of continental interiors, resulting in the development of vast epicontinental seas over several Gondwanaland fragments, most notably modern-day Africa, South America, and India (Khosla and Lucas 2016). A thorough stratigraphic record of recurring transgressive-regressive cycles was captured and preserved by these shallow marine settings, which served as vast sedimentary basins. In addition to documenting sea-level variations, this well-preserved sedimentary record offers vital information on how greenhouse climate systems operate. Accordingly, the Cretaceous period is an essential natural laboratory for recreating past climate conditions and comprehending the complex interplay of global temperatures, atmospheric carbon levels, and eustatic sea-level fluctuations (Keller 2008; Chatterjee and Scotese 2010).

The Indian Subcontinent (Text-fig. 1A), during the Late Cretaceous (Text-fig. 1B), experienced major palaeogeographic changes, including cratonic block fragmentation and north-eastward movement, which led to the development of several pericratonic basins filled with thick, fossil-rich sedimentary successions (Biswas 1987). This period also saw a marine encroachment into central India, especially along the Narmada Valley (Narmada Rift; Text-fig. 1B), resulting in the deposition of the Bagh Group rocks that are exposed in isolated areas mainly along the northern flank of the Narmada River (Text-fig. 1C, D) across 4000 km^2 in West Central India (Text-fig. 1A).

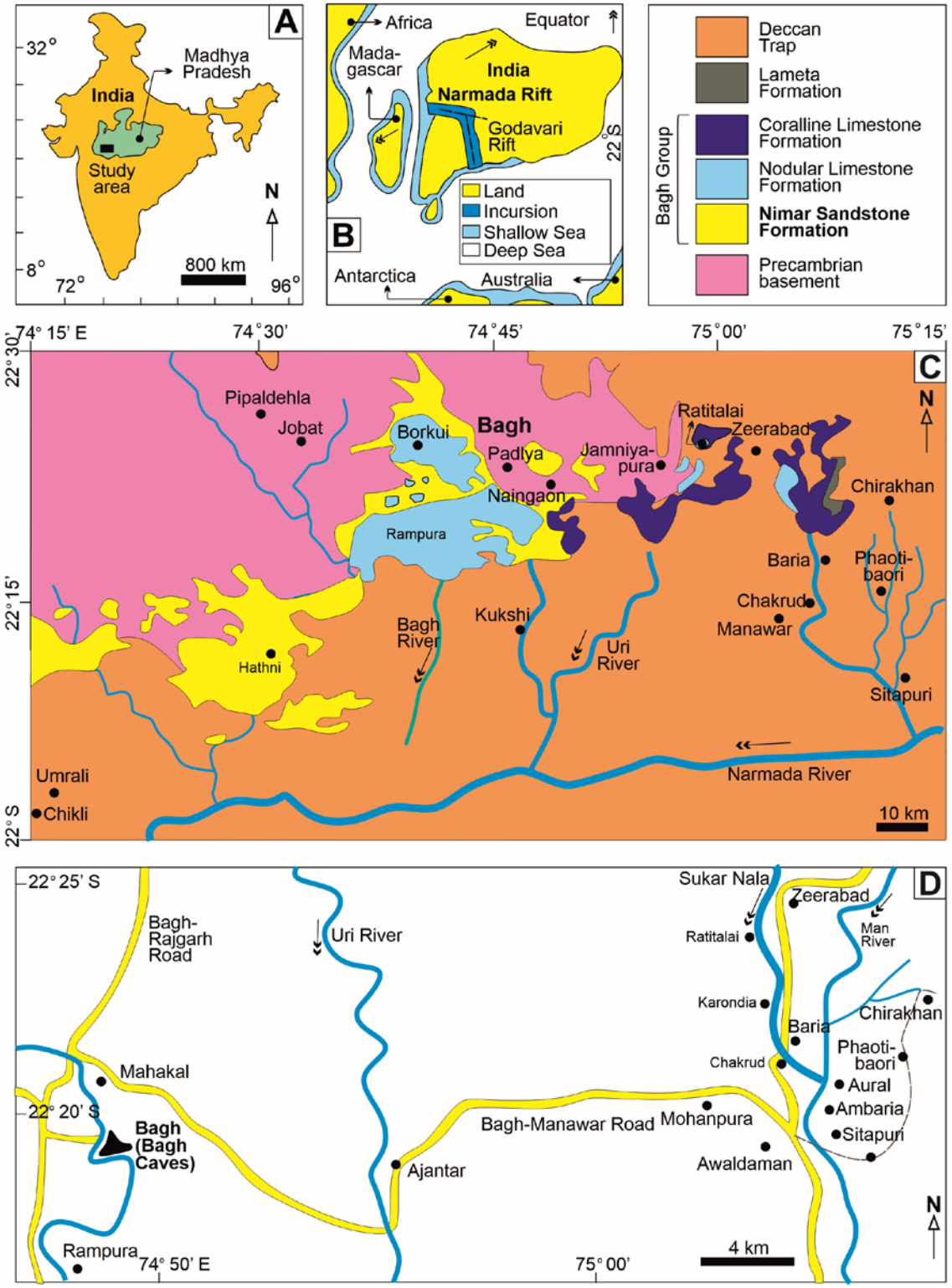
The Bagh Group (or Bagh Beds in classical literature), a rich siliciclastic-carbonate rock succession (Text-fig. 2), is crucial for understanding Mesozoic marine life and habitats due to its diverse marine fauna, including echinoids (Smith 2010), bivalves (Kumar *et al*. 2018 and references therein), bryozoans (Guha 1976), and ammonites (e.g., Gangopadhyay and Bardhan 2000; Kennedy *et al*. 2003; Jaitly and Ajane 2013; see also Khosla and Lucas 2016 and references therein).

Geologically speaking, the Bagh Group is considered to have been formed by a major marine incursion that most likely took place during the Late Cretaceous Turonian Stage (Text-fig. 1B; see also Keller *et al*. 2020). Parts of central India were submerged by an eastern arm of the Tethys Sea that moved inward during this period, creating warm, shallow epicontinental marine conditions (Text-fig. 1B). These conditions promoted the growth of diverse and rich marine ecosystems, and were ideal for the deposition of carbonates. The vertical stratigraphic succession of the Bagh Group, where sedimentary facies move upward from fluvial or nearshore deposits at the base to entirely marine carbonate facies at higher stratigraphic levels, amply demonstrates the evidence for this transgressive event (Text-fig. 2B). Thus, the Bagh Group provides a valuable record of the palaeoecological conditions, sea-level fluctuations, and Tethyan marine impact in central India throughout the Mesozoic.

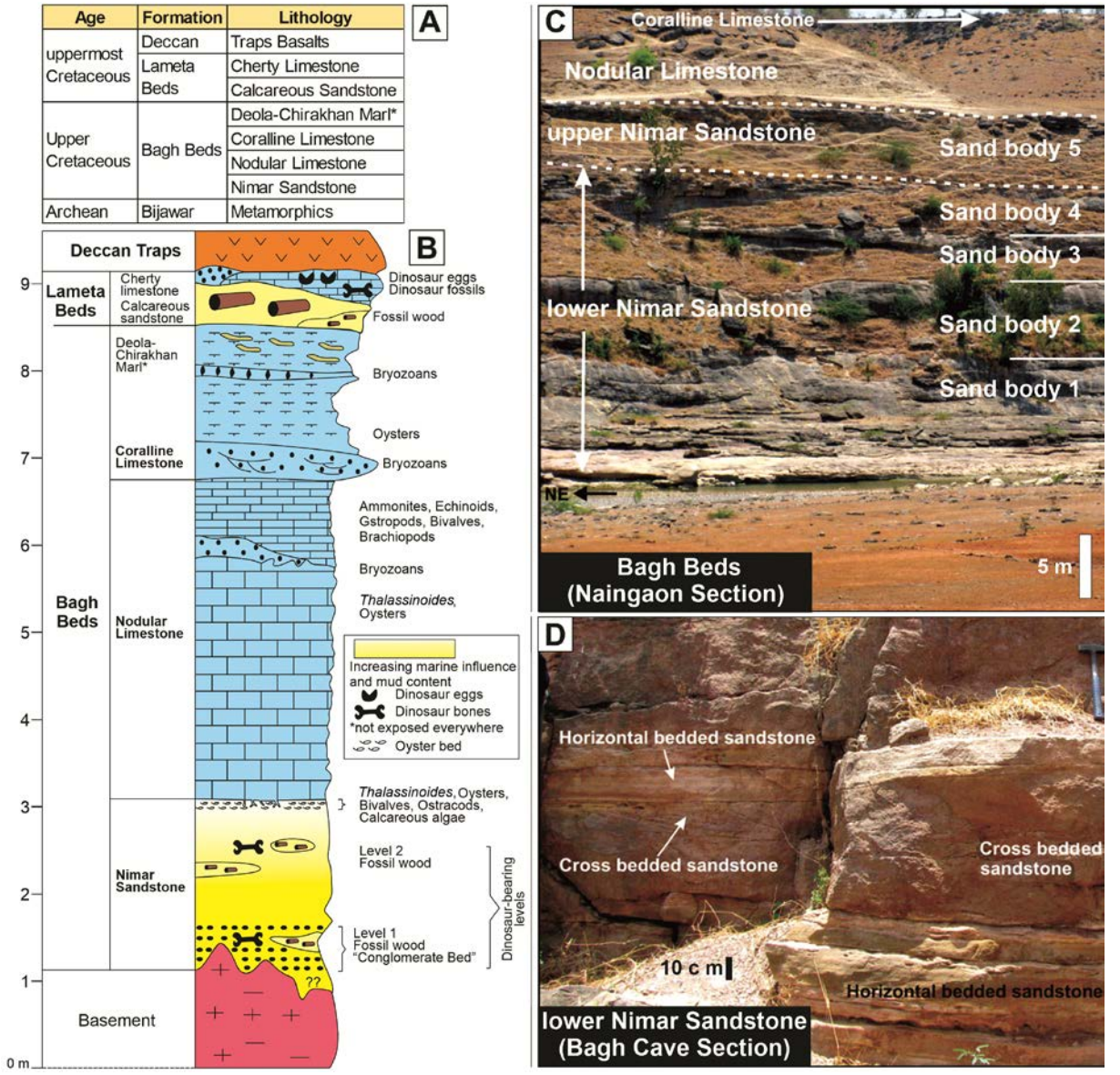
The Nimar Sandstone Formation (Text-fig. 2C, D) is the lowermost lithostratigraphic unit within the Bagh Group that is exposed in central India's Narmada Valley (Text-fig. 1A, B). It is buff red to yellow in colour due to its ferruginous matrix (Text-fig. 2C, D) and forms part of the Lower Gondwana succession, lying unconformably over the Precambrian basement rocks of the Bijawar and Mahakoshal groups of Archean age (Text-fig. 2A, B). This formation is distinguished by thick layers of cross-bedded sandstones, siltstones, and subordinate mudstones (Text-fig. 2C, D).

The Nimar Sandstone (Text-fig. 2) is difficult to correlate across sedimentary basins due to its vertical and lateral facies variations, fossil content, and stratigraphic occurrences of the fauna, emphasising the critical need for more focused research to clarify its basin-wide relationships and geological importance (Text-figs 3 and 4). Typically, this 20–30 m-thick formation exhibits a distinct upward-fining trend that documents a major palaeoenvironmental transition over time, from fluvial (river-dominated) environments at the base to increasingly marine-influenced transitional settings towards the top. This vertical facies change is indicative of larger sea level and geodynamic shifts, making the Nimar Sandstone a prime example of a dynamic depositional system that records a change from terrestrial to marginal marine conditions, making it a valuable unit for reconstructing past environments and understanding the interplay of tectonics, climate, and sea-level variations.

By combining previously published data from sedimentology, palaeontology, and petrology, this

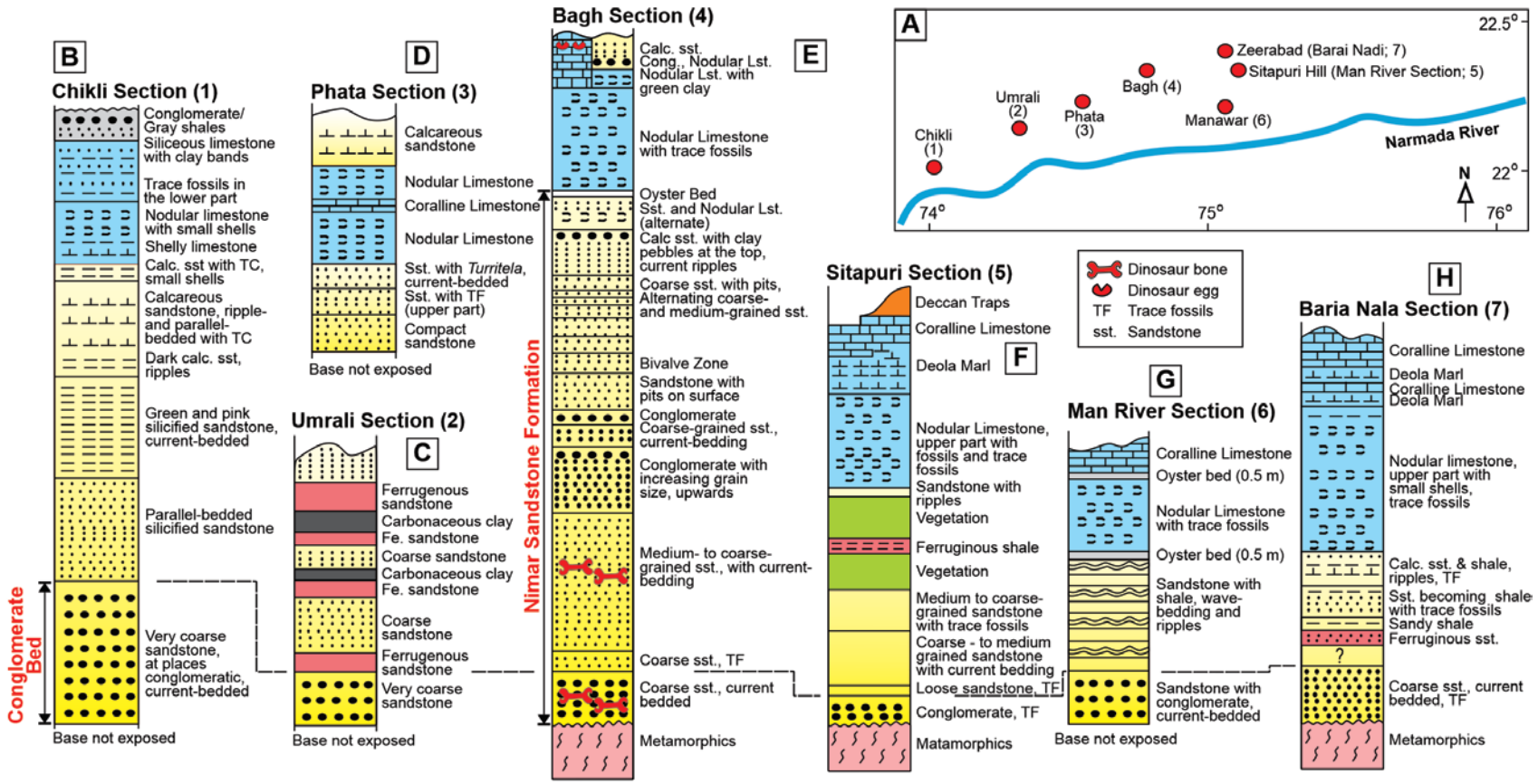


Text-fig. 1. Geological and location map of the Narmada rift basin. A – Map of India showing the location of the study area within the state of Madhya Pradesh (India); B – Cenomanian–Turonian boundary palaeomap showing the position of India and the Narmada Seaway incursion along the Narmada Rift with adjoining land masses of Africa, Madagascar, Antarctica, and Australia; C – Geological map of the study area showing the distribution of the Bagh Group rocks; D – Location map showing major localities discussed in the text. Map in B modified after Keller *et al*. (2020), maps in C, D modified after Kumari *et al*. (2020).



Text-fig. 2. Stratigraphy of the Bagh Group. A – General stratigraphy of the Bagh Group. B – Lithostratigraphy of the Bagh Group (modified after Bhattacharya *et al*. 2020). C – Field photograph showing the multi-storied nature of the Nimar Sandstone displaying the gradational contact between the lower and upper Nimar Sandstone, and the overlying Nodular Limestone, capped by Coralline Limestone, Naingaon section. D – Sedimentary structures in the lower Nimar Sandstone, Bagh Cave section; note planar cross-bedded sandstone (topset) bounded by a horizontally bedded sandstone (bottomset), and the well-defined reactivation surfaces implying episodic bedform movement under tidal action. C and D modified after Saha and Shukla (2022).

study seeks to provide a thorough, multifaceted understanding of the Nimar Sandstone Formation depositional setting that ranges from braided to meandering channels and floodplain environments, developed under semi-arid to sub-humid conditions, and occasionally influenced by minor tidal processes. The contribution aims to develop a comprehensive understanding of the formation's origin, lithological composition, depositional history, and palaeogeographic implications by combining knowledge from various related domains. Additionally, the striking blend of terrestrial evidence (dinosaur remains) for the lower Nimar Sandstone and of marine fossils (e.g., oysters, shark teeth, and trace fossils) dominantly from the upper part documents the complex land-sea interactions, thus offering valuable palaeoecological and



Text-fig. 3. Lithostratigraphy of the sections discussed in the text (modified after Singh and Srivastava 1981).

palaeoceanographic context for the region during the Late Cretaceous. In addition to improving existing geological interpretations, this integrated method also aims to pinpoint knowledge gaps and direct future research and study in the region.

LOCATION AND GEOLOGICAL SETTING

The Upper Cretaceous sedimentary rocks, known as infratrappean strata (Lameta Formation), found in the Narmada Valley of western and central India were deposited within an intracratonic basin developed on ancient Precambrian basement rocks (Biswas 1987; Tripathi 2006; Text-fig. 2A, B). This basin, which has a characteristic linear, trough-like shape, allowed for the accumulation of a relatively thin yet regionally important sedimentary succession during the Cretaceous. The succession is formally divided into two distinct stratigraphic units: the Lameta Formation in the central Narmada Valley and the Bagh Group in the western part (e.g., Khosla *et al*. 2003; Shukla and Srivastava 2008; Khosla and Lucas 2020a–e, 2023; Saha and Shukla 2022; Text-figs 1B, C; 2A, B). Though separated in space, the Upper Cretaceous (Maastrichtian) cherty limestone and calcareous sandstone of the Lameta Formation in District Dhar, Madhya Pradesh, bearing dinosaur eggs and very fragmentary bone material, occurs as separate isolated, irregular, and discontinuous outcrop patches in the Narmada Valley (Khosla and Sahni 1995, 2003; Khosla 2001; Khosla *et al*. 2003; Vianey-Liaud *et al*. 2003; Fernández and Khosla 2015; Khosla and Verma 2015; Prasad *et al*. 2017; Kapur and Khosla 2019; Khosla and Lucas 2020a–e, 2023; Text-figs 1C, 2A, B, 4D–G).). Although laterally discontinuous, the formation was deposited under broadly similar settings with similar lithological features, corresponding to different phases of *in situ* continental sedimentation; these of course would have been characterised by local differences in conditions of sediment supply, accommodation space, hydrological regimes, and palaeoenvironment within the intracratonic Narmada Basin (Tandon *et al*. 1995; Kumari *et al*. 2021; Khosla and Lucas 2023).

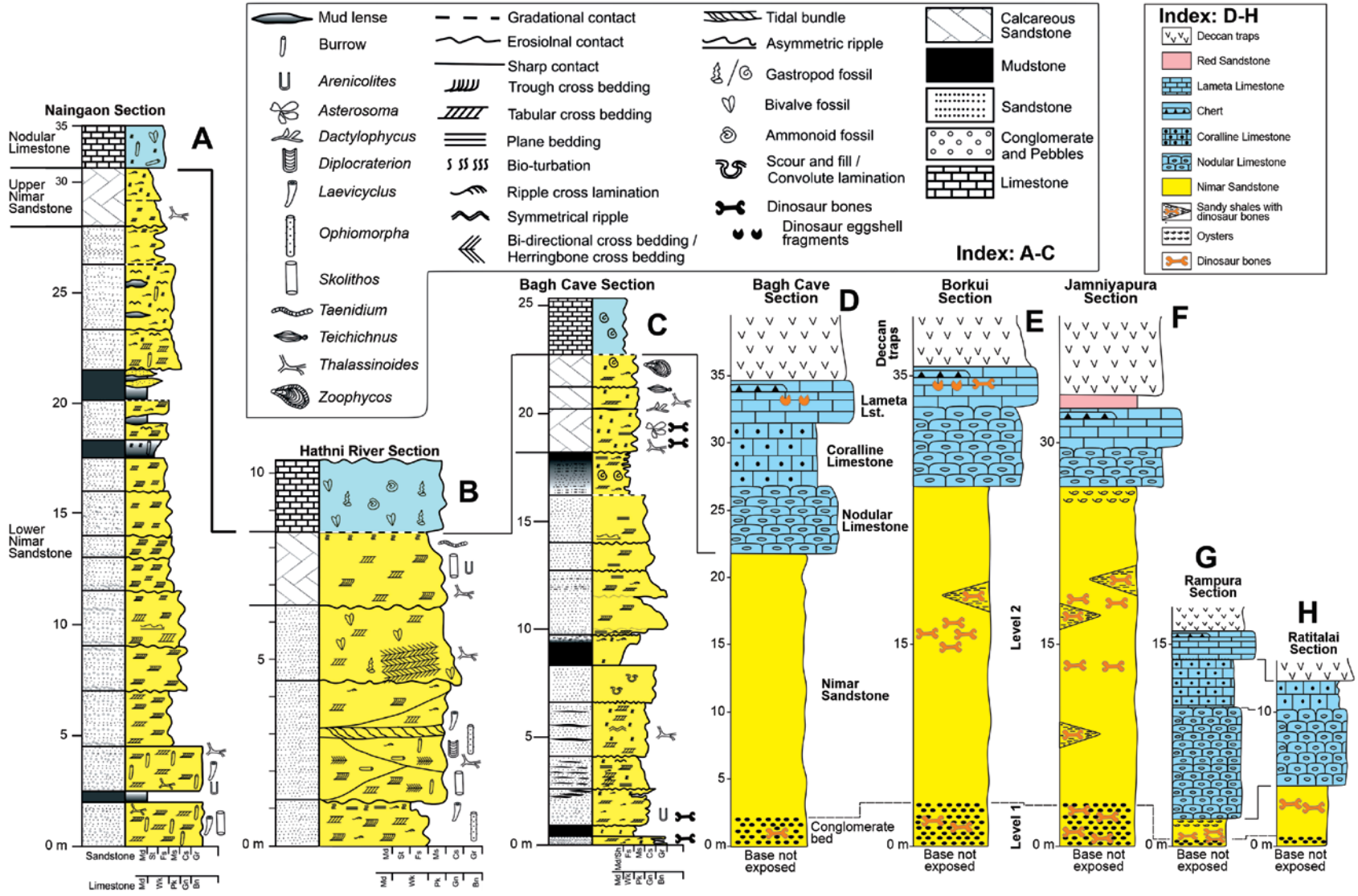
The type section of the Nimar Sandstone Formation, which is the primary subject of this study, is well-exposed at the Bagh Caves, also known as the Panch Pandav Caves. These caves are situated near the town of Bagh in District Dhar, Madhya Pradesh (Text-figs 1C, D, 3E, 4C, D) and were initially documented in early geological surveys (Blanford 1869; Bose 1884).

MATERIALS, METHODOLOGY AND REPOSITORIES

The exclusive sauropod (dinosaur) material comes from extensive and continued field investigations conducted for over nearly two decades by one of us (AK) across districts Dhar and Jhabua of Madhya Pradesh during the years 1993–2012 (Text-figs 1A, C, D, 4D–H).). Surface collection involved the careful gathering of disarticulated bone fragments that were naturally exposed due to weathering and erosion. Larger and more intact skeletal elements, such as femur, humerus, radius, and ulna, were excavated *in situ* using standard palaeontological field techniques. The excavation process employed tools, including shovels, hammers, and chisels, to carefully remove the overlying sediment while minimizing damage to the fossils. Once the bones were sufficiently exposed, they were stabilised and protected using field-grade consolidates where necessary.

To ensure safe transportation of the larger and more fragile specimens, particularly the femora, a protective plaster of Paris field jackets was prepared by Ashu Khosla and applied. The fossils were first wrapped in layers of soft tissue paper or cloth to prevent direct contact with the plaster. Subsequently, strips of burlap dipped in wet plaster of Paris were layered over the protected bones to create sturdy jackets. After the jackets had hardened, the encased fossils were carefully elevated from the surrounding matrix and transported to the laboratory of the Geology Department, Panjab University, Chandigarh for further preparation and study.

During the field seasons of 1996–2012, AK documented significant palaeontological finds within the Turonian deposits of the Nimar Sandstone. These included well-preserved sauropod dinosaur remains (fieldwork conducted with the National Geographic team comprising Professors Paul Sereno and Jeffrey A. Wilson in 2001) alongside fossilised wood specimens identified as *Rhizophora* sp. All taphonomic and palaeoecological data presented herein in this paper are restricted to the results of detailed field investigations of AK in District Dhar from 1996 to the present. The field investigations (observations, data collection, and subsequent documentation) included: recording of taphonomic and palaeoecological data on sauropod bones, invertebrates like oysters and plant fossils i.e., *Rhizophora* sp.; sampling and collecting of associated sediments; and recording of sedimentological data during field investigations. Taphonomic, stratigraphic (age) assessment and palaeoecological data of this paper are exclusively based



Text-fig. 4. Lithostratigraphy of the sections discussed in the text (A–C modified after Saha and Shukla 2022; D–H modified after Khosla *et al*. 2003). The basal 'Conglomerate Bed' forms the dinosaur-bearing Level 1, whereas Level 2 is within fine-grained red shales.

on all field investigations and observations of AK. All field photographs used in this paper, including those of the skeletal material, dinosaur bone-bearing Nimar Sandstone, and *Rhizophora* sp. plant fossils (Text figs. 5–9), were taken by Ashu Khosla using a Ricoh and Canon EOS 500D camera.

Abbreviations used in the present study include VPL for Vertebrate Palaeontology Laboratory and the respective fossil localities, Rampura (RPA), Borkui (BKU), Jamaniyapura (JP), and Ratitalai (RT). This series of locality codes is followed by the suffix AKH, denoting Ashu Khosla, the collector and curator of the material. All described fossil specimens are housed in the Vertebrate Palaeontology Laboratory (VPL), Department of Geology, Panjab University, Chandigarh, India.

STRATIGRAPHIC ASSIGNMENT OF THE NIMAR SANDSTONE

A pervasive challenge in Indian stratigraphy, particularly concerning fossil-bearing units, is the perennial difficulty with the accuracy and stratigraphic resolution of recorded fossil occurrences, an issue well-documented across numerous fossil groups (see Jain 2025). This problem is especially pronounced in pre-2000 datasets, where the stratigraphic context for reported trace fossils, calcareous algae, nannofossils, plant megafossils, and palynomorphs is often poorly constrained or ambiguously characterised. Since many of these records lack precise stratigraphic placement, correlating them and interpreting them within a larger palaeoenvironmental framework is both challenging and unreliable. To resolve this, systematic resampling across key localities is urgently needed, focusing on documenting fossil occurrences within meticulously measured and logged stratigraphic sections to guarantee the accuracy and repeatability of biostratigraphic data. A comparable issue was addressed in the Cretaceous strata of the south Indian Cauvery Basin, where improved stratigraphic controls significantly enhanced age and environmental interpretations (Jain 2025).

The lack of stratigraphic precision and the often-scattered nature of diverse fossil groups cause that the age of the Nimar Sandstone remains highly controversial, with age determinations largely inferred. The difficulty in pinpointing the age is exacerbated by the scarcity of reliable indicator fossils like ammonites, likely due to the shallow marine to marginal depositional setting of the unit. Further uncertainty arises from the low repeatability of data from calcareous nannofossils, plant macrofossils, and palynology. This broad, ambiguous chronological framework is reflected in varying interpretations of the Nimar Sandstone basal strata, which have been assigned either to the Cenomanian or the Turonian. Therefore, this study undertakes a critical re-evaluation of the age of the entire Nimar Sandstone Formation, aiming to synthesise available biostratigraphic, sedimentological, and ichnological data with a specific focus on improving stratigraphic precision and resolving these existing chronological inconsistencies.

Lower Nimar Sandstone

The age of the Nimar Sandstone Formation has long been controversial because the lower, predominantly sandy part of the formation is poor in age-diagnostic marine macro- and microfossils, whereas the upper calcareous part yields a rich assemblage of marine macro- and microfossils. Dinosaur bone-bearing lower Nimar Sandstone, as shown in the Borkui, Jamaniyapura, Bagh Cave, Rampura, and Ratitalai sections (Text-fig. 4D–H), comprises the lower, ferruginous and coarse facies of the Nimar Sandstone. It is mainly conglomerate and coarse-grained sandstone with subordinate shales and mudstone. Previous workers had assigned the lower Nimar Sandstone to a very broad concept of the Upper Cretaceous, and Khosla *et al.* (2003) also based on the dinosaur-bearing horizons and associated stratigraphic hierarchy, tentatively thought the Nimar Sandstone to be Cenomanian–Turonian in age. The dinosaur-bearing lower part was thought to be deposited dominantly in a typical freshwater to fluvial environment. The lower, dinosaur-bearing conglomerate- and sandstone-rich beds are almost entirely fluvial in origin, whereas the upper beds, which contain oyster beds, are of intertidal to shallow-marine origin, with all groups of oysters present and no terrestrial fossils found. A more recent age interpretation was proposed by Saha and Shukla (2022), who separated the ferruginous lower Nimar Sandstone from the calcareous upper Nimar Sandstone and considered the Nimar Sandstone a Cenomanian unit in their generalized stratigraphic table. More detailed stratigraphic data were provided by Jafar (2023) based on a high-resolution calcareous nannofossil study, which assigned an Early Turonian age to the Nimar Sandstone. The formation was correlated with the lower part of nannofossil zones UC7 (Burnett 1998), NC13 (Roth 1978), and CC11 (Perch-Nielsen 1985).

Consequently, at least for the dinosaur-bearing lower Nimar Sandstone, a tentative Early Turonian

age seems most appropriate at present; however, this should be weighed against the previous assignment of an older age to the dinosaur-bearing horizons in the subunit, which was initially reported to occur within the Cenomanian–Turonian interval (Khosla *et al*. 2003; Khosla and Lucas 2023). The data also imply that the lower sandstone is primarily a record of continental to fluvially dominated sedimentation, eventually evolving under the influence of a rising tide and/or a marginal-marine environment.

Plant fossils were found by Murty *et al.* (1963) in the lower Nimar Sandstone around Umrali within District Jhabua (Text-fig. 3C). Murty *et al*. (1963) reported *Ptilophyllum cutchense* (Morris) Bose and Kasat (1972), *P. acutifolium* Morris, 1840, and a peltate scale along with trilete spores and pollen of Bennettitalean–Cycadalean affinity, and suggested a Late Jurassic age. *Ptilophyllum cutchense* is the most commonly found leaf fossil in the Jurassic–Cretaceous sedimentary deposits of India (Bose and Banerji 1984). Both *P. cutchense* and *P. acutifolium* are known to range from the middle Late Jurassic to the Early Cretaceous and have also been recorded from the Kachchh Basin (see also Bose and Banerji 1984). A thorough description of a conifer-rich palynoflora collected from the same carbonaceous clay beds was provided by Kumar (1994), who considered the palaeobotanical assemblage as Late Jurassic and the carbonaceous clays to have accumulated in a warm, humid, freshwater swamp setting. Age implications of these fossils need to be taken with caution. Jafar (2023) considered the plant and palynomorph material of Early Cretaceous age, found within the lower Nimar Sandstone to be derived from older non-marine horizons (probably the Jabalpur Formation) and dated the Nimar Sandstone itself as Early Turonian based on calcareous nannofossils. Accordingly, the Umrali plant and palynomorph assemblage is best interpreted as a record of older vegetation and source area but not specific to the age of the Nimar Sandstone deposition. Thus, the older Jurassic–Early Cretaceous age implied by the Umrali terrestrial fossils versus the Early Turonian age implied by the marine microfossils is due to the reworking of older terrestrial deposits into the younger Nimar depositional system. This scenario is more likely than dating the lower Nimar Sandstone through the Umrali assemblage.

Upper Nimar Sandstone

The Upper Nimar Sandstone is mainly composed of less coarse, calcareous sandstone, which reveals marine macrofossils like ammonites, bivalves, and echinoids, as well as sedimentary structures suggesting a gradual increase in marine influence. The upper part of the Nimar Sandstone was assigned to the Cenomanian–Turonian based on marine macrofossils (ammonites, etc.) by Kumar (1967). Jafar (1982) assigned it to the Turonian on the basis of calcareous nannoplankton from the Chikli (Text fig. 3B) and Sitapuri sections (Text fig. 3F) of District Dhar. Similarly, Kundal and Sanganwar (1998) inferred a Cenomanian–Turonian age on the basis of calcareous algae from the Pipaldehla section (Text fig. 1C) of District Jhabua, Madhya Pradesh.

Independently, Kalal *et al.* (2024) recorded fifty ostracod species from the top calcareous part of the upper Nimar Sandstone from various localities and suggested an Early Turonian age for their assemblage. This finding was later supported by Nagori *et al.* (2024) following their analysis of ostracods from the upper calcareous Nimar Sandstone of the Pipaldehla succession (Text-fig. 1C) and other western exposures, which indicated an Early Turonian age for the assemblage. This is consistent with the reported ostracod assemblage from the Upper Nimar Sandstone. The ostracod assemblage from the upper calcareous Nimar Sandstone at Pipaldehla shares several common faunal elements with the assemblage recorded from the lower part of the Nodular Limestone in the Bagh-Jeerabad area, District Dhar, providing an additional biostratigraphic link between the Nimar Sandstone and the overlying strata. A subsequent study of ostracods from the upper Nimar Sandstone exposed in districts Jhabua and Alirajpur also indicated an Early Turonian age for the succession (Kalal *et al.* 2024).

This age has now been modified by Jafar (2023), who re-analysed the calcareous nannofossil assemblages from the upper Nimar Sandstone at the Bagh Cave section (at ~20 m; Text-figs 3E, 4C, D) and suggested an age "neither older nor younger than Turonian" (Jafar 1982, p. 17). This correlation placed the succession between the first appearance (FAD) of *Quadrum gartneri* Prins and Perch-Nielsen in Manivit *et al.* 1977 at the base and the FAD of *Helvetoglobotruncana helvetica* Bolli, 1945 at the top; therefore, this new correlation provides a much more precise age range of less than c. 1 my and suggests that the Nimar Sandstone is relatively younger than some of the previous correlations. However, a closer inspection reveals that neither of these key species was actually found in the original collections (Jafar 1982, his table 1, p. 25), questioning the validity of the early Turonian age based on these markers. Conversely, the presence of *Prediscosphaera*

columnata (Stover) Perch-Nielsen, 1984, a calcareous nannofossil with a well-established last occurrence (LO) near the top of the Turonian Stage (Bown 1998; Burnett 1998; see also Jain 2025), is a more reliable chronostratigraphic indicator supporting a putative late Turonian age for the upper Nimar Sandstone. This revised age, which is more consistent with the known fossil record, has implications for understanding the timing of marine incursions in the region.

The likely age of the dinosaur-bearing lower Nimar Sandstone is currently early Turonian, but the older Cenomanian–Turonian age should be considered, as dinosaur-bearing horizons were originally reported from this interval. There is some evidence that those lower sandstones mainly consist of continentally to fluvially derived sediments, ultimately transitioning to tidally and marginally marine-influenced sediments. Thus, the dinosaur-bearing lower Nimar Sandstone of District Dhar was considered older than the Cenomanian–Turonian by Khosla *et al.* (2003), but is best considered simply as early Turonian in age, based on direct biostratigraphic evidence, although age-diagnostic marine microfossils are relatively scarce in the lower sandstone. Its age is thus largely deduced from its stratigraphic association with the upper, more firmly dated, part of the formation and from the dinosaur fossils of the same depositional belt. On the other hand, the upper Nimar Sandstone has a very strong direct biostratigraphic basis owing to the presence of marine macrofossils such as echinoids, ammonites, and bivalves (Dassarma and Sinha 1975; Chiplonkar *et al.* 1977), foraminifers (Rajshekhar 1995), calcareous algae, ostracods (Kalal *et al.* 2024; Nagori *et al.* 2024), and calcareous nannofossils (Jafar 1982, 2023). In conclusion, contrary to what Khosla *et al.* (2003) earlier claimed, the available data clearly point to an early Turonian age for both the lower and upper Nimar Sandstone (Khosla, work in progress). The latter concept of the Cenomanian–Turonian is entirely appropriate when discussing the historical age assignment of Khosla *et al.* (2003), but not the present synthesis.

SEDIMENTOLOGY

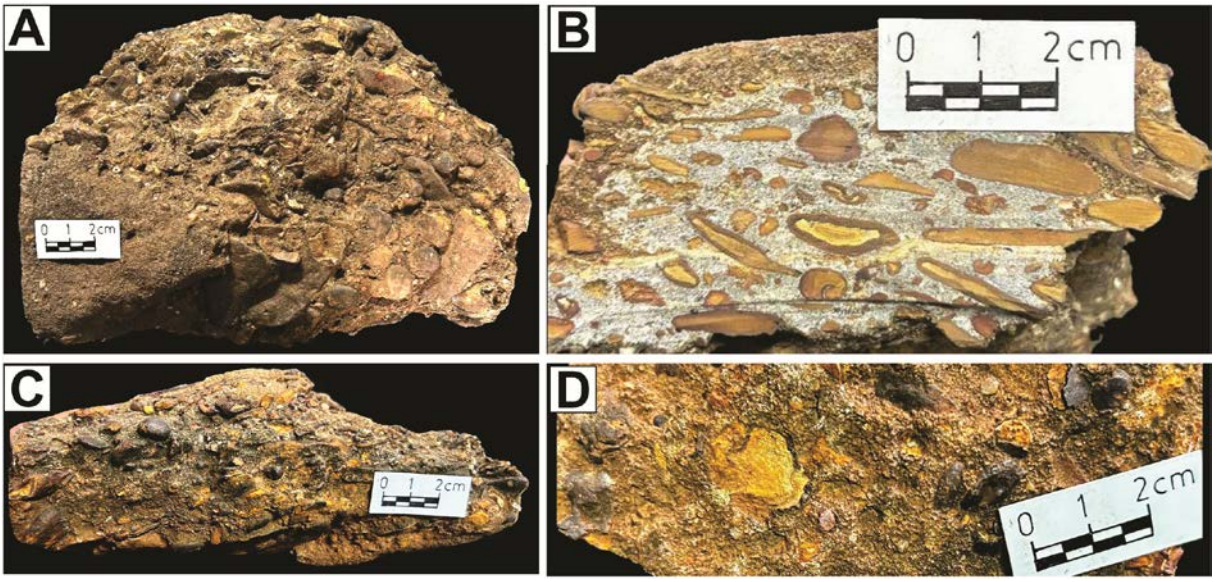
The Nimar Sandstone Formation (Text-fig. 2C, D) exhibits a multi-story architecture, composed of a stratified sequence of sandstone beds interlayered with minor shale containing fragmentary dinosaur bones and siltstone-mudstone-conglomerate units (Khosla *et al.* 2003). This sedimentary assemblage contains diverse sedimentological features that indicate deposition in environments influenced by both fluvial (river) and shallow marine processes (Khosla *et al.* 2003; Saha and Shukla 2022 and references therein). Based on a detailed lithological study and the classification proposed by Saha and Shukla (2022), the Nimar Sandstone is divided into two distinct stratigraphic members: (a) the lower Nimar Sandstone (ferruginous sandstone) and (b) the upper Nimar Sandstone (calcareous sandstone) (Text-figs 2–4).

The lower Nimar Sandstone is well-exposed at the Bagh Cave section (Text-figs 2D, 3E, 4C, D). It is characterised by thick, massive beds of ferruginous, red sandstone, frequently interbedded with thin siltstone layers and pebbly to conglomeratic lenses, suggesting episodic, high-energy depositional events (Khosla *et al.* 2003; Khosla and Lucas 2023). Conversely, the upper Nimar Sandstone exhibits a more varied lithology of coarse, medium, and fine-grained sandstones. The inclusion of interbedded siltstone layers and multiple distinct glauconitic horizons indicate a shift toward marine influence during the later stages of its deposition.

Lower Nimar Sandstone

The base of the lower Nimar Sandstone is defined by a distinct conglomeratic horizon, here informally designated as the dinosaur-bearing 'Conglomerate Bed', a coarse-grained conglomeratic sandstone (Text-figs 3, 4). This basal unit consists of sub-rounded to well-rounded pebbles set within a coarse-grained sandstone matrix with a fining-upward trend (Text-fig. 5).

The most accessible and well-preserved exposure of the 'Conglomerate Bed' is found at the Bagh Cave section (Text-figs 3E, 4C, D), allowing for clear observation of its lithology and fossil content (Text-figs 3, 4). The iron oxide cementation in the 'Conglomerate Bed' gives the unit a ferruginous look with a brownish to reddish-brown coloration (Text-figs 5 and 6). Granules, coarse sand-sized grains, and sub-rounded to rounded pebbles comprise this poorly sorted rock, wherein quartz, chert, and iron-rich lithic fragments make up the majority of the heterolithic clasts (Text-fig. 5). The pebbles vary in size from a few millimetres to over a centimetre in diameter, showing irregular packing and moderate imbrication (Text-fig. 5). The clasts are embedded in a sandy to silty matrix made of iron oxides (goethite and hematite) with minor amounts of silica that serve as cement. The hardness and reddish colour of the rock, which indicate oxidizing diagenetic conditions, are caused by this ferruginous cementation. The ferruginous clast ar-

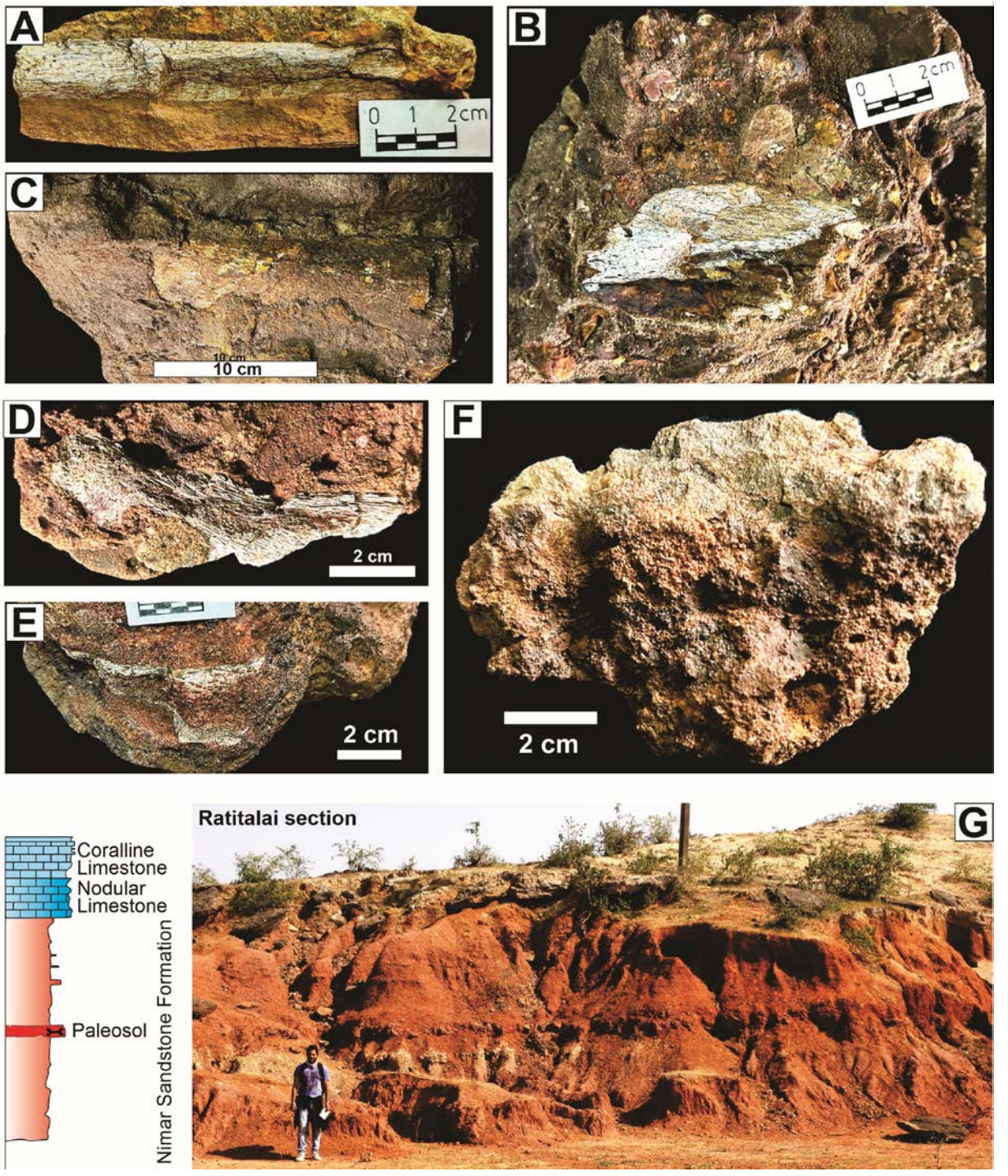


Text-fig. 5. 'Conglomerate Bed'. A – Hand specimen of coarse, ferruginous, poorly sorted conglomeratic sandstone (VPL/RPA/AKH/3516), lower Nimar Sandstone, Rampura village; the rock has a ferruginous appearance and a brownish to reddish-brown coloration due to iron oxide cementation; the poorly sorted rock is composed of granules, coarse sand-sized grains, and sub-rounded to rounded pebbles. B – Polished hand specimen (VPL/RPA/AKH/3516) from Rampura village with elongated, ovoid to sub-rounded, ferruginous clasts embedded in a coarse-grained sandstone matrix, typifying a fluvial channel lag deposit within a braided river system with high-energy braided river system, oxidizing diagenetic conditions and proximal sediment derivation; ferruginous clasts and coarse texture are diagnostic of continental red-bed sedimentation associated with the Nimar Sandstone. C – Side view of hand specimen (VPL/RPA/AKH/3516) from the lower part of the lower Nimar Sandstone displaying a coarse, ferruginous, clast-supported conglomeratic sandstone, reflecting deposition in a high-energy fluvial system within a braided river environment; texture, clast morphology, and ferruginous cementation of the rock point to proximal sediment input and oxidizing continental conditions, compatible with deposition in a semi-arid to arid fluvial system. D – Hand specimen (VPL/JP/AKH/4500) with a matrix-supported conglomeratic texture with poor sorting, lower Nimar Sandstone, Jamaniyapura village; the rock contains sub-angular to sub-rounded pebbles and granules of variable size (typically 2–10 mm, some up to ~15 mm), irregularly distributed within a ferruginous sandy matrix; the pebbles are mostly dark brown, purplish-brown, and yellowish in colour, reflecting iron oxide impregnation and diagenetic oxidation.

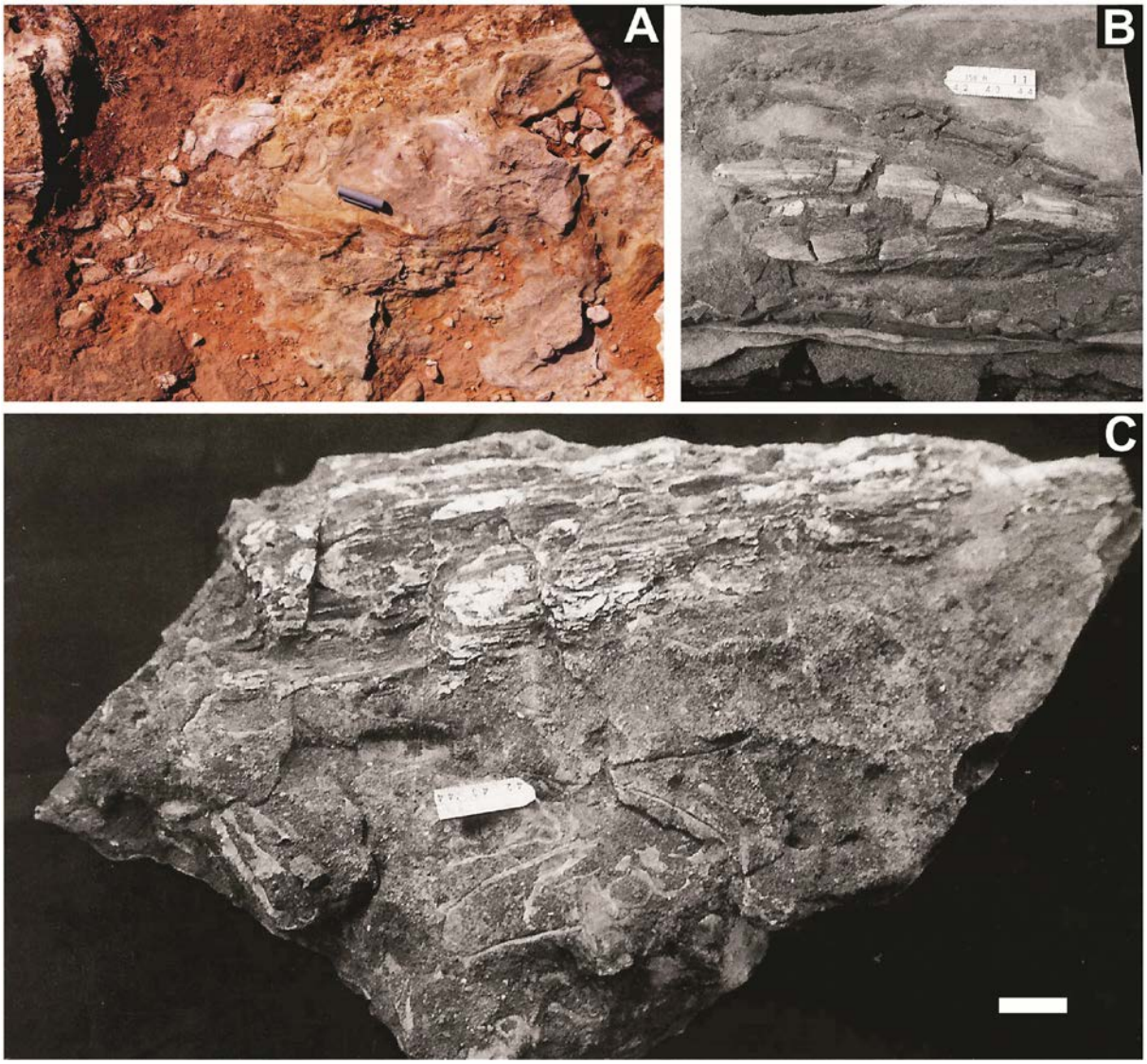
rangement points to a fabric that is partially supported by clasts, with pore gaps being filled by interstitial fine material (Text-fig. 5B). High-energy depositional processes, typical of channel-lag or proximal fluvial deposits, are suggested by the uneven orientation and various clast sizes (Text-fig. 5). Rapid deposition in a turbulent environment is compatible with the absence of fine laminations, whereas intense weathering and subaerial exposure are suggested by the brown to reddish-brown coloration and iron-rich crusts (Text-fig. 5A, C, D), compatible with deposition in semi-arid to arid fluvial settings.

Significantly, this conglomeratic unit is also palaeontologically important, as it has yielded exclusively fragmentary sauropod (dinosaur) skeletal remains at several locations (near the Bagh Cave section and Manawar area) across the Narmada Valley (Text-figs 3E, 4C, D). Besides Bagh, important dinosaur fossil discoveries (Text-fig. 6) have also been documented from Rampura (Text-fig. 6A, B, D–F) and Borkui (Text-figs 4E and 6C).

A substantial number of fossilised wood logs have been documented from the lower conglomeratic horizon of the Nimar Sandstone Formation, indicating widespread preservation of plant material (Text-fig. 7) during the initial stages of deposition, particularly from the Rampura section (Text-fig. 4G). These fossil logs, embedded within coarse-grained (Text-fig. 7), high-energy channel or debris flow deposits, suggest that large woody debris was transported and buried rapidly, possibly during episodes of flooding or high-discharge events in a fluvial system (Khosla *et al*. 2003). In addition to these occurrences in the lower part of the formation, well-preserved fossil wood logs have also been recorded from the upper fine-grained sandstone units, which are notably associated with abundant oyster shells (as noted in the Rampura section; Text-figs 4G and 7B, C), reflecting a transition to a more marine-influenced or marginal marine depositional setting (Text-fig. 8). These fossil woods from the finer sediments are remarkable not only for their preservation but also for their probable



Text-fig. 6. Vertebrates from the Nimar Sandstone Formation. A – Fragmentary piece of dinosaur bone (VPL/RPA/AKH/4000) from the upper Nimar Sandstone at Rampura section. B – Fragmentary piece of dinosaur bone (VPL/RPA/AKH/3515) from the lower Nimar Sandstone at Rampura section (after Khosla *et al*. 2003). C – Fragmentary piece of big dinosaur bone (VPL/BKU/AKH/4001) from the lower Nimar Sandstone at Borkui section (Khosla, work in progress). D – Fragmentary piece of dinosaur bone (VPL/RPA/AKH/4002) from the lower Nimar Sandstone at Rampura section (Khosla, work in progress). E – Fragmentary piece of dinosaur bone (VPL/RPA/AKH/4003) from the lower Nimar Sandstone at Rampura section. F – Lower part of the conglomeratic Nimar Sandstone (VPL/RPA/AKH/3515) at Rampura section showing coarse-grained particles. G – Dinosaur-yielding palaeosol bed (Level 2) at Ratitalai section.



Text-fig. 7. Fossil wood logs. A – Field photograph taken by Ashu Khosla in 2003 showing fossil wood logs (cf. *Rhizophora* sp.) near a 5.5 cm pen cap for scale, embedded in the lower part of the conglomeratic Nimar Sandstone at Rampura village (after Khosla *et al*. 2003). B – Field photograph showing a fossil wood log (cf. *Rhizophora* sp., VPL/RPA/AKH/3540), embedded in the upper fine-grained part of the conglomeratic Nimar Sandstone at Rampura village (after Khosla *et al*. 2003); scale = 2.3 cm. C – Field photograph showing a fossil wood log (cf. *Rhizophora* sp., VPL/RPA/AKH/3541) with oysters, embedded in the upper fine-grained part of the conglomeratic Nimar Sandstone at Rampura village (after Khosla *et al*. 2003); scale = 2.3 cm.

taxonomic affinity (Khosla *et al*. 2003; Khosla, work in progress).

Based on preliminary morphological assessment, some of these wood specimens (Text-fig. 7) have been tentatively assigned to Angiospermae (cf. *Rhizophora* sp.), a taxon commonly associated with modern mangrove environments. These occurrences are primarily reported from the Rampura section (Text-fig. 4G; see also Khosla *et al*. 2003). If confirmed, the identification of *Rhizophora*-like woods would be significant, as it suggests the development of mangrove-like vegetation along the margins of transgressive coastal systems during the Late Cretaceous. Such a setting is consistent with the sedimentological and faunal evidence pointing to a tidally influenced, estuarine to shallow marine environment in the upper Nimar Sandstone (see also Bhattacharya *et al*. 2021; Saha and Shukla 2022).

Overall, the vertical distribution and preservation of fossil woods, from the fluvially dominated lower



Text-fig. 8. Oysters embedded in the upper part of the fine-grained Nimar Sandstone (VPL/RPA/AKH/4008) at Rampura section.

conglomerates to the marine-associated upper fine sandstones, reflect changing depositional regimes and provide key insights into the palaeobotanical composition, palaeoclimate, and landscape dynamics of the region during the time of Nimar Sandstone deposition (Khosla, work in progress).

Saha and Shukla (2022) noted that the lower Nimar Sandstone is also characterised by several typical sedimentary structures, which provide important clues about the depositional environment and prevailing hydrodynamic conditions. Among the key features identified are herringbone cross-beds, interference ripple marks, syn-sedimentary deformation structures, and trace fossils dominated by paired burrow openings (Text-fig. 4A–C). When combined, these features support the idea that the lower Nimar Sandstone was deposited in a tidally influenced environment and contribute to the increasing amount of data showing that fluvial and marine processes interacted dynamically throughout its accumulation (Text-fig. 4). The identified ichnotaxa include *Arenicolites* isp., *Diplocraterion* isp., *Laevicyclus* isp., *Ophiomorpha* isp., *Skolithos* isp. and *Thalassinoides* isp., suggesting the *Skolithos* ichnofacies, reflecting a fining upward sequence (towards relatively calmer waters with mudstone interbeds; see Text-fig. 4A–C). However, Saha and Shukla (2022) noted that these traces point to the *Glossifungites* ichnofacies, which represents a *Thalassinoides–Rhizocorallium–Diplocraterion*-dominated assemblage of a peaty or xylic substrate. The latter (peaty or xylic substrate) are characterised by trace fossils of wood-boring ichnotaxa commonly noted in transgressive conditions where coastal forests were inundated by the sea, leading to an influx of wood into marine environments. For now, the *Skolithos* ichnofacies is envisaged (Text-fig. 4A–C).

Sedimentological analysis by Saha and Shukla (2022) identified eight specific lithofacies within the lower Nimar Sandstone (Text-fig. 4A–C). These are: (i) cross-bedded gravelly sandstone, (ii) planar cross-bedded sandstone, (iii) herringbone cross-bedded sandstone, (iv) ripple cross-laminated sandstone, (v) horizontal bedded sandstone, (vi) interbedded sandstone-siltstone-mudstone, (vii) gravelly mudstone, and (viii) bioturbated mottled mudstone lithofacies. The upper limit of the lower Nimar Sandstone is a gradational boundary marked by an interbedded sandstone-siltstone-mudstone unit. This heterolithic unit indicates a shift in depositional conditions, likely transitioning from dominantly fluvial or tidal-flat settings to environments with increasing marine influence. Overlying this transition is the upper Nimar Sandstone, which begins abruptly, suggesting a distinct change in sedimentation style, potentially triggered by a transgressive pulse or an alteration in sediment supply and accommodation space. The Bagh Cave section (Text-figs 3E and 4C, D) is a key site for studying the depositional evolution of the Nimar Sandstone Formation.

Upper Nimar Sandstone

The upper part of the Nimar Sandstone shows a clear shift from a predominantly siliciclastic to an increasingly calcareous composition. This change coincides with a subtle fining-upward trend, with the grain size gradually becoming smaller toward the top. The calcareous sandstone bodies formed during this interval are hard, compact, and well-cemented, indicating a high degree of post-depositional (diagenetic) alteration. These units are typically arranged in thin, discrete beds that alternate rhythmically with layers of mudstone and fine-grained sandstone. Notably, the upper portion lacks the thick, widespread mudstone units commonly noted in the lower Nimar Sandstone, suggesting a fundamental change in the depositional environment or sediment source during this later phase of the formation (see Text-fig. 4).

For the upper Nimar Sandstone, Saha and Shukla (2022) identified four lithofacies: (i) sandstone with tidal bundles (tidalites or tidal rhythmites), (ii) small-scale cross-bedded calcareous sandstone, (iii) interbedded calcareous sandstone-siltstone-mudstone, and (iv) fossiliferous calcareous sandstone. The topmost part of the formation is marked by a distinct oyster bed of Singh and Srivastava (1981), best observed at the Bagh Cave section (Text-figs 3E, 4C, D and 8) and Rampura section (Text-figs 4G, 7B, C and 8).

Further analysis by Bhattacharya *et al.* (2021) highlighted several important features in the upper part, including thick massive mudstones, thinly laminated sandstone-mudstone interbeds, trough cross-stratified sandstones, and wave-rippled sandstones containing shells of the bivalve *Ostrea* sp. and gastropod *Turritella* sp., along with trace fossils of *Thalassinoides* isp. and *Ophiomorpha* isp., best noted at the Bagh Cave section (Text-fig. 4C, D). Collectively, these characteristics demonstrate a gradual upward increase in mud content and a corresponding rise in marine trace and body fossils (Text-fig. 4A–C). Generally, the upper Nimar Sandstone, composed of calcareous interbeds of sandstone, siltstone, and mudstone, exhibits a slow fining-upward trend in grain size and is distinguished by sedimentary structures such as parallel lamination along with flaser and lenticular bedding (see Text-fig. 4). Saha and Shukla (2022) noted well-developed burrow systems of various orientations, ranging from millimetre to centimetre sizes, in the Bagh Cave section (Text-fig. 4C).

Saha and Shukla (2022) also documented a significantly diverse assemblage of ichnospecies from the Nimar Sandstone, including *Arenicolites* isp., *Asterosoma* isp., *Dactylophycus* isp., *Skolithos* isp., *Taenidium* isp., *Teichichnus* isp., *Thalassinoides* isp., and *Zoophycos* isp. They interpreted these traces as indicative of the *Glossifungites* and *Cruziana* ichnofacies. In the present context, the lower part of the upper Nimar Sandstone, where *Asterosoma* isp. and *Thalassinoides* isp. are noted and followed upward by *Teichichnus* isp. and *Zoophycos* isp., likely represents a transitional zone between the shallower *Skolithos* ichnofacies and the relatively deeper *Cruziana* ichnofacies, consistent with a lower shoreface setting (see Pemberton *et al*. 2012). This vertical progression is marked by a noticeable increase in both the intensity of bioturbation and the diversity of trace fossils from the base to the top of the section (see also Text-fig. 4A–C), also reflecting a shift in depositional energy and substrate conditions over time. In light of these observations, a brief overview of the current status of trace fossil records from the Narmada Basin is warranted and provided herein.

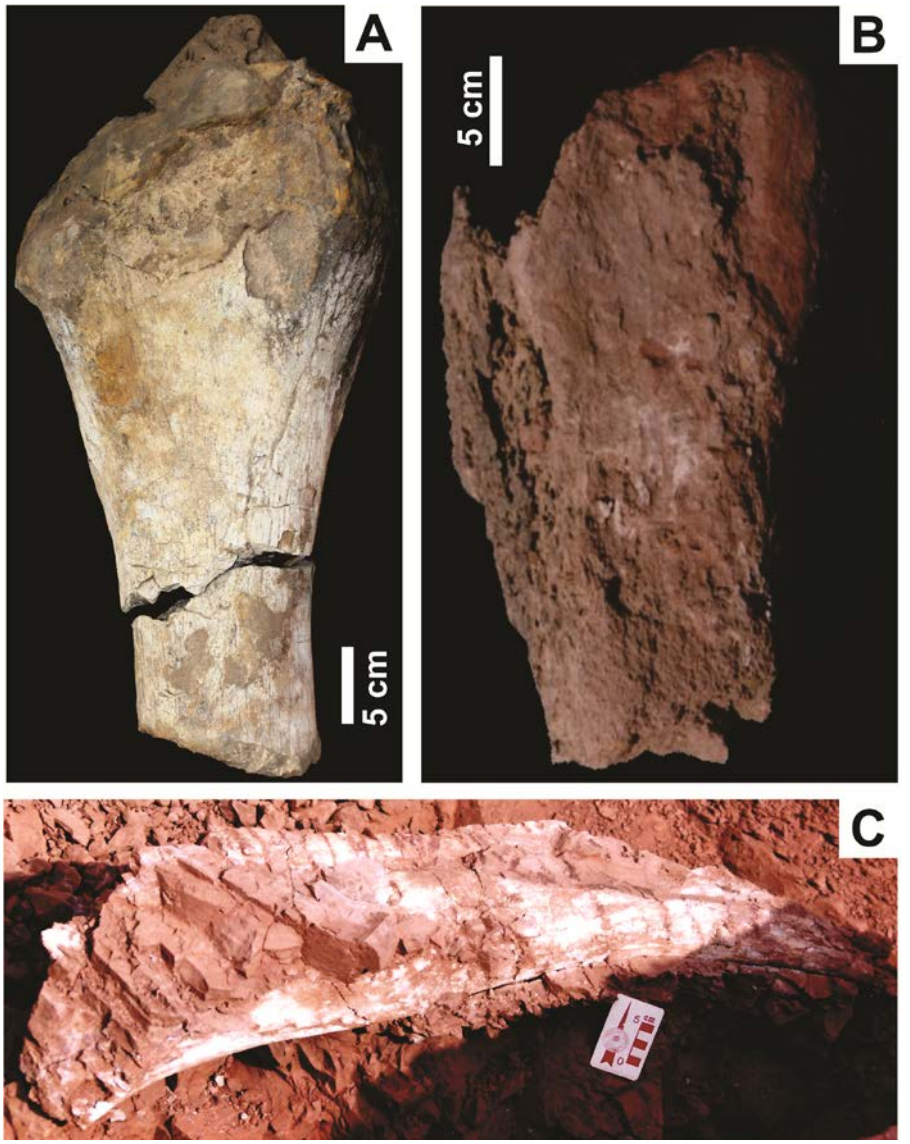
VERTEBRATE PALAEONTOLOGY: SAUROPOD REMAINS

The Nimar Sandstone Formation is significant for yielding some of the earliest Cretaceous dinosaur fossils documented in India, primarily consisting of sauropod remains (Khosla *et al*. 2003; Khosla 2017; Khosla and Lucas 2023; Text-fig. 4). These fossils, which include isolated, fragmentary bone pieces and partial skeletons, offer key insights into the Late Cretaceous dinosaur diversity in the Indian subcontinent.

A partial humerus, radius, and ulna were recovered from the Jamaniyapura section (Text-fig. 4F) and assigned to Sauropoda based on several synapomorphic features characteristic of the group (Wilson and Sereno 1998), including subterminal distal condyles, an anteroposteriorly compressed humeral midshaft, rugose articular surfaces, and a straight limb axis (see also Khosla *et al*. 2003). However, a more precise phylogenetic placement of the Bagh sauropod remains uncertain. Continued fieldwork and additional discoveries from these important sedimentary units are essential for a clearer understanding of their taxonomic and evolutionary significance.

The fragmentary dinosaur bones are preserved within coarse-grained, conglomeratic sandstones showing poor sorting, sub-angular to sub-rounded quartz and lithic clasts, and a reddish ferruginous coloration indicative of oxidation (Text-fig. 6A–F). The association of fragmentary fossils with coarse detrital sediments (Level 1 in Text-fig. 4C–H) suggests deposition in proximal channel or bar-margin settings subject to periodic reworking. The presence of fragmentary dinosaur bones within these coarse-grained, conglomeratic facies indicates fluvial transport and reworking prior to burial. Their fragmentation and ferruginisation suggest limited *in situ* preservation but effective fossilisation under oxidising conditions. Collectively, the sedimentological and taphonomic features point to episodic, high-energy channel processes operating across a low-relief alluvial plain in central India.

Overall, the skeletal material recovered from the upper Nimar Sandstone from the Borkui and Jamaniyapura sections (Level 2 in Text-fig. 4E, F, respectively, Table 1) represents at least two individuals of sauropod indet. and includes five broken femora, two partial humeri, radii, an ulna, and other broken elements (Khosla *et al*. 2003; Khosla and Lucas 2023; Table 1). Additionally, several broken and fragmentary dinosaur bones were recovered from Level 1 of the Jamniyapura section (lower Nimar Sandstone, Text-fig. 4F). Partial limb elements such as portions of a humerus (Text-fig. 9B), radius, and ulna, along with numerous indeterminate skeletal fragments representing different parts of the postcranial skeleton, were also recovered from Level 2 of the Jamniyapura section (Text-fig. 4F). The record of a partial humerus from the Jamniyapura section has an anteroposteriorly flat-



Text-fig. 9. Sauropoda indet. from the Nimar Sandstone Formation. A – Incomplete distal end of a right femur in posterior view, VPL/BKU/AKH/3500, Borkui section; B – Proximal end of an incomplete right humerus in medial view, VPL/JP/AKH/3503, Jamaniyapura section; C – Fragmentary femur, VPL/RT/AKH/3502, Ratitalai section (modified after Khosla *et al*. 2003; Khosla and Lucas 2003); scale bar is 5 cm.

tened cross-section, expands distally, and maintains a straight longitudinal axis in medial view (Text-fig. 9B; see also Khosla *et al*. 2003). The incomplete ulna from Level 2 of the Jamaniyapura section is noteworthy for its prominent, rounded olecranon process, which is continuous with the shaft (Khosla *et al*. 2003).

In 2001, a remarkably well-preserved distal end of a broken femur (Text-fig. 9A) was found in the red sandy shale bands (Level 2) of the Borkui section (Text-figs 4E, 6C) along with several fragmentary dinosaur bones embedded within the lower part of the conglomeratic Nimar Sandstone (Level 1 in Text-fig. 4E). This femoral fragment, measuring 0.77 m in maximum length and 0.43 m in width, attests to the large size of the animal, with its shaft slightly wider proximally than distally, and its distal condyles positioned subterminally on the posterior side (Khosla *et al.* 2003; Khosla and Lucas 2023). These fossils point to the existence of large terrestrial vertebrates within this stratigraphic interval and offer substantial evidence that dinosaur remains may be found in both the lower conglomeratic (Level 1) and the upper fine-grained ferruginous parts of the Nimar Sandstone succession (Level 2).

Nimar Sandstone Formation			Vertebrate fossils	Age
Members	Lithology	Environment		
upper Nimar Sandstone	fine-grained marine sediments interbedded with bands of red sandy shale; including quartzitic, gritty, ferruginous, and sometimes conglomeratic sandstone horizons	dynamic, tidally affected nearshore or intertidal environment (Level 2 in Text-figs 2 and 4E–H)	femur, humerus, radius, and ulna, along with numerous indeterminate skeletal fragments representing different parts of the postcranial skeleton (sauropods)	Turonian
lower Nimar Sandstone	coarse-grained, conglomeratic facies	fluvial transport and reworking prior to burial (Level 1 in Text-figs 2 and 4E–H)	distal end of a broken femur and fragmentary sauropod (dinosaur) bones	Turonian

Table 1. Record of vertebrate (sauropod) fossils from the Nimar Sandstone Formation.

In addition to these findings, a single broken femur (Text-fig. 9C) has also been recovered from the red palaeosol sandy horizon (Level 2) at the Ratitalai section (Text-figs 4H, 6G and 9C). This specimen is fragmentary and shows signs of surface weathering, suggesting partial exposure and transport prior to burial. It is thinner and more fragmentary, measuring 1.08 m (Khosla *et al*. 2003; Khosla and Lucas 2023). At the Rampura section (Text-fig. 4G), in coarse, conglomeratic, fluvial Lower Nimar Sandstone rocks (Level 1), very small, highly fragmentary pieces of dinosaur bones have also been recovered (see Text-fig. 6A, B, D–F).

The fact that dinosaur remains are preserved in ferruginous and occasionally conglomeratic sandstone horizons (Level 2) indicates that they were deposited in a dynamic, tidally affected nearshore or intertidal environment, where the fragmentation and dispersal of the bones may have been facilitated by periodic high-energy events. In this horizon (Level 1 'Conglomerate Bed'; Text-figs 2B and 4), the dinosaur remains are generally poorly preserved and highly weathered, suggesting considerable post-depositional breakage and transport. Despite their fragmentary nature, the specimens provide evidence of dinosaurian activity within the stratigraphic interval exposed at the Borkui and Jamniyapura sections (Text-fig. 4E, F). Hence, their presence across several locations (Borkui, Jamniyapura, and Bagh Cave sections; Text-fig. 4C–F) indicates that dinosaur remains were rather frequent, despite their diminutive size and fragmentary preservation.

Chatterjee (2020) proposed that these Nimar Sandstone sauropods might represent a smaller titanosaur, with predicted femur lengths exceeding 1.2 m. Chatterjee (2020) suggested that the sauropod fossils from the Nimar Sandstone may belong to a new titanosaur species, potentially an ancestral form to the well-known titanosaurs of the younger Maastrichtian-aged Lameta Formation in peninsular India.

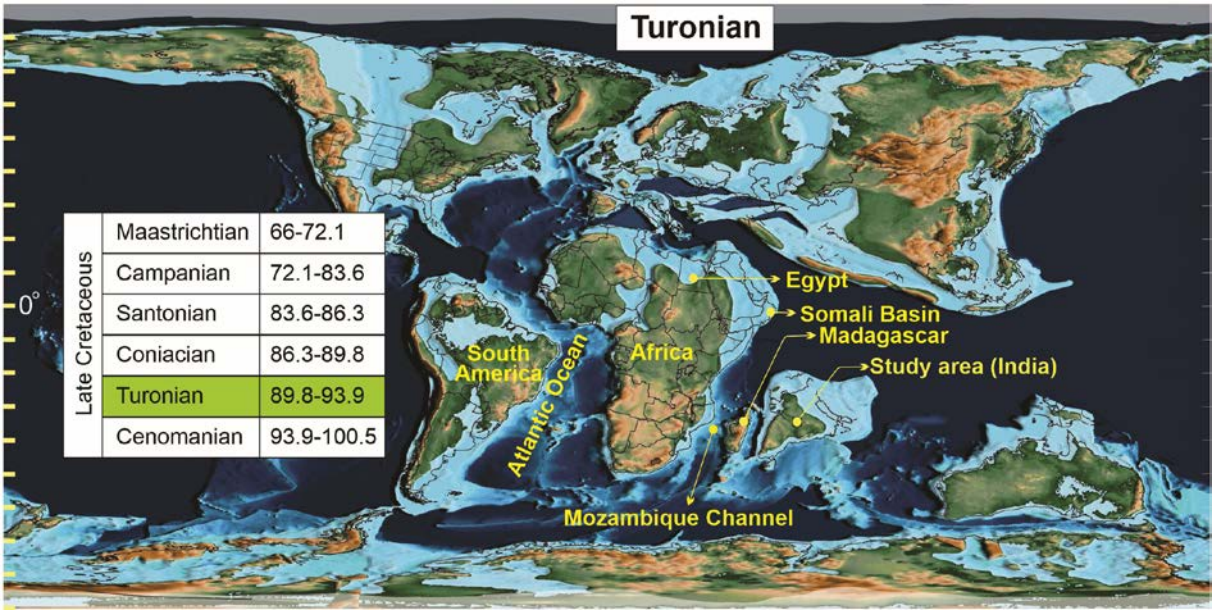
Thus, these discoveries establish that the 'Conglomerate Bed' is a crucial stratigraphic horizon for vertebrate fossil assemblages within this region. Further research for several more sections may very well make this distinctive bed a crucial stratigraphic marker (a useful unit for event stratigraphy; see Text-fig. 3 for its lateral extension across the basin).

DISCUSSION

Palaeobiogeography

The vertebrate fossil evidence from the lower Nimar Sandstone includes the record of large sauropod humerus and femora bones (Khosla *et al*. 2003; Khosla and Bajpai 2021; Khosla and Lucas 2023). It provides critical new data on the palaeobiogeography of dinosaurs in the Late Cretaceous (Turonian) Indian subcontinent. Furthermore, the palaeobiogeographic data from the Nimar Sandstone contributes to broader debate concerning faunal relationships with other Gondwanan landmasses; since India was a drifting continental fragment moving northward after splitting from Gondwana, its dinosaur composition offers crucial insights into the concepts of endemism, dispersal pathways, and evolutionary connections with contemporaneous faunas in Africa, Madagascar, and South America (e.g., Verma *et al*. 2016; Khosla and Lucas 2020e; Khosla 2021; Khosla and Bajpai 2021, Text-fig. 10).

Comparable geological and palaeontological conditions to those at Borkui and Rampura (Text-fig. 4E, G) have been documented in other Upper Cretaceous (but Cenomanian) coastal deposits – most notably within the Bahariya Formation of Egypt (e.g., Dominik 1985; Smith *et al*. 2001; El-Saadawi *et al*. 2016; Text-fig. 10). However, the Bahariya Formation has a different age based on different taxa. It is assigned to the early Cenomanian based on foraminiferal evidence (Barakat *et al*. 1974), or to the late Cenomanian based on the presence of macrofossils including vertebrates and an assortment of oysters (Hantar 1990). Dominik (1985) noted the occurrence of the ammonites *Neolobites*

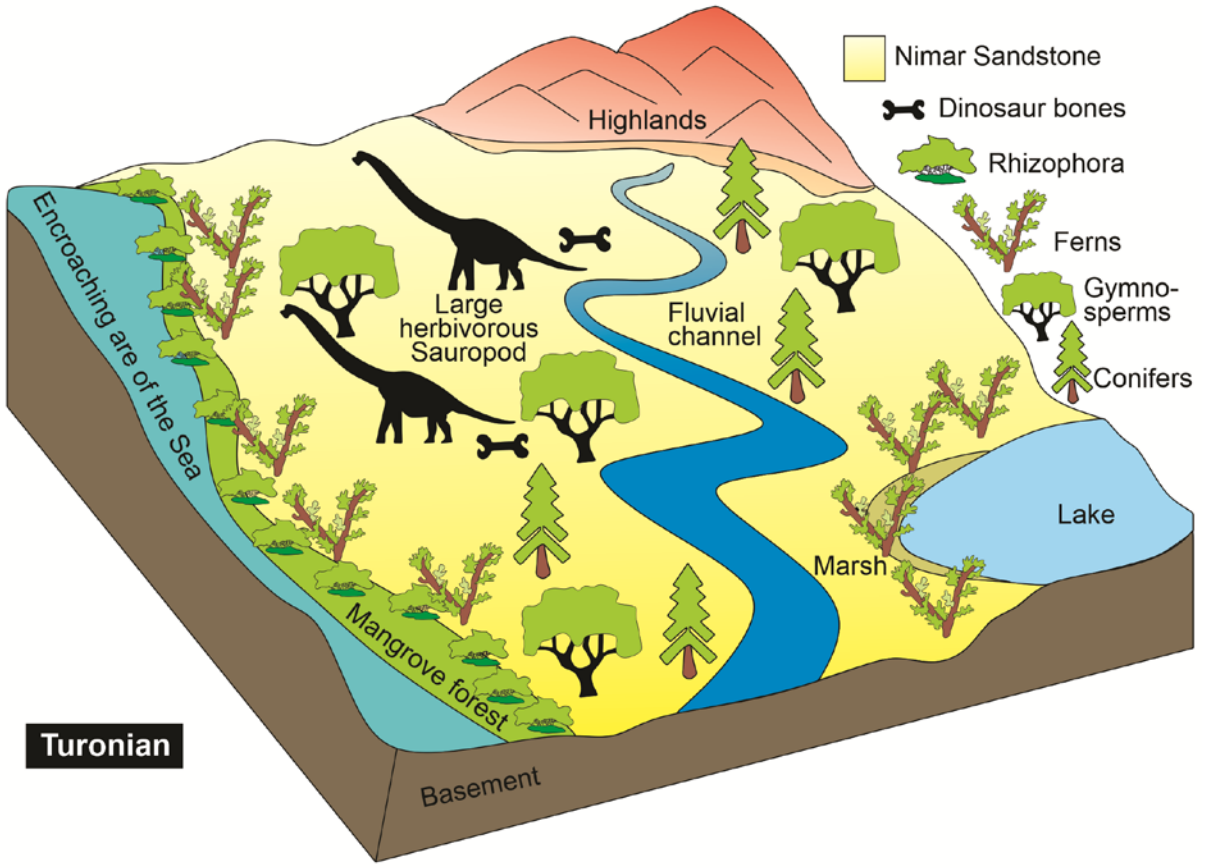


Text-fig. 10. Turonian palaeobiogeography of the study area against the main landmasses.

vibrayeanus (d'Orbigny, 1841), *Neolobites peroni* (Hyatt, 1903), and *Neolobites schweinfurthi* (Eck, 1914), excellent age indicators, which occur in the thin lagoonal to shallow marine intercalations of the Gebel Dist Member and mainly in the El Heiz Member, proving, similarly as the oysters, a late Cenomanian age of the complete sequence of the Bahariya Formation. He further noted that the formations were deposited first under fluviatile conditions, then under estuarine conditions, and finally under lagoonal conditions based on lithological and palaeontological evidence. Thus, for both Bahariya and Nimar Sandstone, fossil assemblages including sauropod remains and mangrove-associated fossils provide evidence of coastal and paralic depositional environments, with Bahariya being somewhat younger in age. Smith *et al.* (2001) described the new species *Paralititan stromeri*, a giant titanosaurid sauropod from the Bahariya Formation. The partially scavenged remains were found in mangrove-associated, low-energy coastal sediments composed of vegetated tidal flats and channels. Brown, friable shales rich in plant remains and rhizoliths, resting conformably above glauconitic marine sands, indicate a mangrove palaeoenvironment similar to modern coastal systems. This facies succession resembles modern low-energy coastlines where mangroves expand seaward over active shorefaces. Such depositional settings suggest that titanosaurids like *Paralititan stromeri* (Smith *et al.* 2001) likely inhabited or moved through mangrove-dominated coastal zones, similar to those noted in the sauropod-bearing deposits of the Borkui and Rampura sections (see Text-figs 4E, G and 11).

The suggestion that the sauropods found in the Nimar Sandstone may include a dwarf titanosaur implies that their body size and diversity were influenced by evolutionary adaptations to local pressures like resource availability (Text-figs 10 and 11) or geographic isolation (Text-fig. 10). These findings are consistent with discoveries at other Upper Cretaceous sites in India, such as the well-studied Lameta Formation, and collectively demonstrate the widespread distribution of dinosaurs across the subcontinent in diverse environments, from coastal areas to floodplains (Text-fig. 11). This broad environmental range supports the idea that India was a significant biogeographic region hosting a unique dinosaur fauna.

During the deposition of the peninsular India, particularly the Narmada Valley region of central India, was situated between 30º S and 40º S latitude (Text-fig. 10), drifting across the Tethys Ocean (van Hinsbergen *et al.* 2012), with a humid to sub-humid climate ideal for conducive rich flora (Text-figs 10 and 11). After rifting from Africa, Madagascar stayed mostly unchanged, situated towards the western edge of the Indian Ocean, just south of the equator (Text-fig. 10). It seems that more or less similar faunal and floral assemblages were found on the continental margins of Madagascar and India at this period, indicating temporary biogeographic connections or



Text-fig. 11. Inferred palaeoenvironment of the Nimar Sandstone Formation based on vertebrate and palynological data.

stepping-stone dispersion events before total separation. The advancing South Atlantic Ocean, which was growing as South America moved westward, had an impact on the western regions of Africa (Pérez-Díaz and Eagles 2017 and references therein).

The fact that large herbivorous dinosaurs (sauropods) are present in central India implies that by that time, dinosaur faunas were established on the Indian craton and possibly engaged in faunal exchanges with neighbouring Gondwanan fragments. India and Madagascar probably had intermittent terrestrial or island-chain connections before their complete oceanic separation (~88 Ma, Coniacian; Chatterjee and Scotese 2010; Khosla 2021; Khosla and Bajpai 2021). The Late Cretaceous faunas of Madagascar and India have biogeographic similarities (discussed below in alternative biogeographic explanations), indicating that ecological and genetic interchange persisted until the Late Cretaceous (Krause *et al*. 1999). The Somali Basin and the northern Mozambique Channel may have been stepping-stone routes or temporary dispersal corridors for faunal migration, but India had already started to drift away (Text-fig. 10). It has been suggested that during the mid-Cretaceous (approximately 115–90 Ma; Aptian–Turonian), the Kerguelen Plateau may have functioned as an important land or shallow-marine connection linking India with the Australia-Antarctica landmass (Ali and Aitchison 2008). This vast volcanic plateau is thought to have included a series of emergent or near-surface highs that intermittently rose above sea level. These features could have formed temporary dispersal corridors, facilitated limited faunal exchange, and maintained biogeographic continuity among the separating fragments of Gondwana (Ali and Aitchison 2008). With the progressive northward drift of the Indian Plate during the Late Cretaceous (around 85–65 Ma; Santonian–Maastrichtian), new potential connections may have emerged. The Seychelles-Mascarene Plateau and adjacent elevated regions of the western Indian Ocean seafloor are believed to have acted as intermittent land bridges or shallow seaways between southern India and Madagascar. Such elevated topographic highs could have provided

migration routes for terrestrial and coastal faunas, enabling periodic biotic interchange across the diminishing oceanic barriers prior to India's complete isolation (Ali and Aitchison 2008).

Around 98 Ma (i.e., during the Cenomanian), India and Africa were remnants of the once-unified Gondwanan supercontinent but were already undergoing significant tectonic separation. The evolving palaeogeography between India and Africa was dominated by the nascent Indian Ocean, which was in the process of opening as continental rifting advanced (Hay *et al.* 1999). At this time, the Indian Plate was drifting northward, detaching progressively from Antarctica and Madagascar. Temporary land connections may have persisted through the Kerguelen Plateau, Sri Lanka, and possibly the Ninety East Ridge, which together could have formed a partial link between India and Antarctica. Meanwhile, Madagascar, previously connected to Africa, had begun to move eastward, creating the Mozambique Channel (Text-fig. 10). The Davie Fracture Zone, running through this channel, included relatively shallow sections that may have intermittently functioned as migration routes between Africa and Madagascar (Hay *et al.* 1999).

These dynamic palaeogeographic features indicate that, even as India and Africa drifted apart, intermittent land bridges, shallow seaways, and island arcs may have continued to facilitate limited biotic dispersal and faunal interchange among the Gondwanan fragments (Hay *et al.* 1999). Therefore, periodic faunal exchange between Africa and India may have been made easier by island arcs or marine regression phases along the rift margins (Ali and Aitchison 2008). Another mechanism that might have facilitated terrestrial dispersion is the formation of temporary land bridges along rift margins during phases of marine regression. The fluvio-to-shallow marine depositional setting and marine transgression may also demonstrate how dinosaur living was made easier by ecological corridors (coastal plains, floodplains) in these changing settings. The dinosaur bones are found in regimes that were near coasts or tidal/shore environments, as the Nimar Sandstone records the transition from fluvial to estuarine/marine settings. This implies that low-lying coastal plains adjacent to transgressing seas were inhabited by sauropods (Text-fig. 11). This may indicate niche partitioning or faunal resilience in the face of sea-level rise, and it has relevance to how dinosaurs adapted to dynamic coastal and estuarine ecosystems.

Thus, the discoveries of the Nimar Sandstone offer an earlier baseline: the existence of sauropods in the Turonian suggests that their lineages were already established and may have been diversifying in India prior to the later, more complete diversification. On the Indian plate, this has implications for endemism, evolution, and faunal turnover. Fossil evidence suggests that dinosaurs from Africa dispersed during the Late Cretaceous, indicating that India was not completely isolated during this northward drift. This sporadic linkage is supported by the fact that some dinosaur groups (such as abelisaurids and titanosaurs) are found in both India and Africa as well as Madagascar and South America (Kapur and Khosla 2016, 2019; Khosla 2021; Khosla and Lucas 2023).). These overlapping dinosaur families present an interesting palaeobiogeographic conundrum, indicating that connections were preserved in spite of the significant marine barriers that formed during India's northward journey. Understanding the connections between the faunas of Madagascar, India, and other Gondwanan landmasses not just needs a re-evaluation but also a more rigorous stratigraphic tie point. Thus, to refine the palaeobiogeographic narrative (such as to determine whether Indian sauropods show Gondwanan affinities, endemism, or unique evolutionary trajectories), more thorough phylogenetic work, enhanced stratigraphic control (age constraints), and additional fossil discoveries (from both lower fluvial and upper shallow-marine parts) are needed.

In conclusion, the existence of large herbivorous dinosaurs (sauropods) in India throughout a critical geologic interval is strongly supported by the dinosaur remains found in the Turonian upper Nimar Sandstone in central India (Text-fig. 11). They advance our knowledge of the biogeography of Late Cretaceous dinosaurs by showing that dinosaurs first appeared in the Indian subcontinent, probable faunal connections and Gondwanan links between India and other continents, dinosaur palaeoecological occupation of coastal and estuarine environments, and a starting point for subsequent endemism and diversity of dinosaurs in India. These discoveries, despite their current lack of taxonomic detail and somewhat loose stratigraphic control, are important for reconstructing dinosaur palaeobiogeography and will provide the basis for further research and comparative studies throughout the continents of Gondwana.

Persistence of older Gondwanan lineages after continental fragmentation

Similarities among the latest Cretaceous faunas of India, Madagascar, Africa, and South America do not necessarily indicate active land connections among these continents during the latest Cretaceous. Instead, they may reflect lineage dispersal prior to

major continental breakup phases with descendant groups diversifying independently on their respective continents without subsequent contact. Information from stratigraphically calibrated phylogenetic analyses of terrestrial vertebrates (e.g., Halliday *et al*. 2017) and Gondwanan titanosaurians (Ali and Krause 2011) suggests that multiple groups found within the Upper Cretaceous record of India and Madagascar diverged well before their Late Cretaceous appearances. This points to a long history of regional distinctiveness rather than active dispersal after 108 Ma, the estimated date of divergence of the Indian *Isisaurus* Wilson and Upchurch, 2003 from American lineages (Gorscak and O'Connor 2016; Halliday *et al*. 2017; Krause *et al*. 2019; Khosla and Lucas 2023).

This explanation applies to the Indian Nimar Sandstone record, which preserves only Sauropoda indet. remains. The fossil material may lack sufficient phylogenetic resolution to verify a distinct dispersal event and may instead represent an early branch of a lineage that persisted and diversify locally in the Indian subcontinent. These bones could even capture an early stage of Gondwanan titanosaurian evolution (Khosla and Lucas 2023). Although it may be closely related to later Lameta Formation taxa, the fragmentary nature of the Nimar assemblage precludes definitive phylogenetic assignment (Khosla and Lucas 2023).

Parallel survival of relict clades in geographically isolated Gondwanan regions

An interesting interpretation is the parallel survivorship of different disparate clades throughout isolated Gondwanan landmass, whereby during the fragmentation of the Gondwana landmass, ancestor lineages survived relatively undisturbed across all the fragmented parts of Gondwanaland, and their consequent descendant clades could survive to latest Cretaceous time. Their similarity at this date does not therefore entail active migration at latest Cretaceous, but rather their ancestry from a common stock, surviving in each geographical part independently; this explains why there appears to be faunal congruence between disparate continental lands (India and Madagascar: Cauvery Basin and Maevarano Basin, respectively; see Krause *et al.* 1999, 2019; Halliday *et al.* 2017) since the major group of creatures that could live in terrestrial Gondwanaland during latest Cretaceous, the titanosaurs and the abelisauroids, have long ghost lineages extending beyond the ages of their youngest existing fossils (Ali and Krause 2011). In contrast to earlier hypotheses, a lineage dispersed before continents fragmented and later survived separately on individual parts of the continental landmass; Krause *et al.* (2019) argued that increasing geographical separation of Gondwanan continental lands produce more isolated faunal provinces, and thus we have been successful in obtaining Gondwanan dinosaur fossils on disparate parts of the continent landmass. However, what remains unknown and what most authors are ignoring are two points: 1) how was it possible for such diverse and geographically isolated parts of Gondwanaland landmass to retain similar assemblages, and 2) were the dinosaurs present at least until the Late Cretaceous on separated lands really Gondwana-related, and the oldest ones that were present in Gondwanaland had already migrated and dispersed to and all over the continent lands?

Taxonomic uncertainty associated with fragmentary Indian dinosaur material

It might be hypothesized that the Gondwanan dinosaur taxa are similar because of convergence driven by similar environmental factors and evolutionary pressures in different parts of the world at the end of the Cretaceous. But palaeobiogeographical conclusions are hampered by the poor quality of Indian Cretaceous dinosaur fossils. Fragmentary remains of disarticulated bones, like much of the Nimar Sandstone material, often do not have diagnostic characters to establish the taxon at the genus or species level (Khosla *et al.* 2003; Khosla and Lucas 2023). Hence, the comparison of Late Cretaceous Gondwanan faunas necessitates the correct taxonomic level. Broad similarities of postcranial fragments may give rise to false palaeobiogeographic inferences (Loyal *et al.* 1996). Fragmentary Indian dinosaur fossils demand more detailed skeletal descriptions to decipher diagnostic features and to link fossils by means of formal phylogenetic tests. Comparison of indeterminate sauropod fossils from India with African, South American and Madagascar assemblages should therefore be based on diagnostic skeletal characters and phylogenetic results.

Convergent ecological and evolutionary patterns

Similar geographic circumstances of climate, vegetation, and sustenance can drive fauna on isolated landmasses to develop convergent phylogenetic, structural, or adaptive changes. This possibility becomes particularly relevant when diagnostic, high-resolution features are lacking. For instance, large tetanurans often exhibited parallel shifts in

body proportions, driven by shared ecological niches as continental apex predators or large herbivores, rather than indicating continuous land connections or simultaneous dispersal.

Modern palaeobiogeography offers numerous instances where disparate continental locations share superficially similar faunas that are better explained by parallel evolution than by transient land bridges (Halliday *et al*. 2017). Strong arguments support the independent evolution of isolated faunal assemblages following the breakup of Gondwana, producing distinct yet morphologically congruent forms. Nonetheless, clear indicators of phylogenetic relationships remain visible, such as the Late Cretaceous (Turonian) Nimar faunal assemblage, which shares affinities with lineages documented in other Gondwanan regions.

Taphonomical and palaeoecological implications of sauropod material from the Nimar Sandstone

The sauropod fossil remains within the Nimar Sandstone represent an important terrestrial vertebrate assemblage from a Late Cretaceous sedimentary sequence, documenting a transition from continental and fluvial to estuarine and shallow marine environments, beginning under tidal influence. Khosla *et al*. (2003), and Khosla and Lucas (2023) documented sauropod elements collected from districts Dhar and Jhabua, including localities such as Jamniyapura, Borkui, the Bagh Caves, Rampura, and Ratitalai. The collection includes several large limb elements (Text-fig. 9A–C), specifically five reasonably well-preserved yet fragmentary femora, two radii, two humeri, and an ulna, along with numerous small, fragmentary skeletal elements representing at least two individuals. The assemblage has been tentatively referred to Sauropoda based on fragmentary features.

The occurrence of fossils of terrestrial vertebrates in marginal-marine sediments does not imply that the animals were part of a marine ecosystem or that they were adapted to survive in the marine realm. Saha and Shukla (2022) identified two zones of land-based and oceanic influences in the lower ferruginous and upper calcareous beds, whereas Jafar (2023) argued that the sequence was an early Turonian estuarine deposit, corroborated by the early Turonian ostracods from Pipaldehla (Nagori *et al.* 2024). These studies provide evidence of wide-ranging marine and tidal incursions, but are not evidence that sauropods were ecologically linked to shoreline migration or that they had any adaptations to intertidal environments. Hypotheses of behavioural responses to relative sea-level rise are, therefore, purely speculative. Like marine ichnofossils, terrestrial vertebrate remains could have been transported in fluvial systems, dispersed by marine bloat-and-float, or reworked into the sediments, and the dinosaur bones should not be construed as tracking a moving shoreline.

Taphonomic evidence and its importance for ecological interpretation and transport history

On the whole, taphonomic data indicate that the sauropod fauna is largely disassociated from articulated skeletal elements. Khosla *et al*. (2003) suggested that the fauna is autochthonous or experienced only minor transport prior to entombment. The skeletal elements are distributed throughout both the conglomeratic sandstone and red sandy-shale intervals. While the fluvially influenced nature of the deposits may have caused some dispersal would have preceded extensive separation of elements. Following decomposition, possible water-mediated dispersal of relatively lighter, mobile skeletal parts is plausible. The minimal weathering surfaces observed on the bone elements suggest a relatively brief period of subaerial exposure prior to final burial.

This interpretation is important because it indicates that the Nimar sauropod association cannot be dismissed as a casual assemblage of allochthonous, highly transported dinosaur remains. However, designation as autochthonous should remain tentative rather than absolute. Definitive autochthony requires demonstrating that the animals perished at or very close to their final site of burial. Within the sandstone-rich fluvial or estuarine regime where most Nimar material was deposited, large, well-preserved bones could easily be transported over some distance without sustaining severe fragmentation or abrasion. Distinguishing true autochthony from parautochthonous accumulation therefore requires a comprehensive and systematic quantitative taphonomic study.

Degree of reworking, transport, fragmentation, hydraulic sorting, and disarticulation

Most of the sauropod remains found from the Nimar Sandstone are disarticulated, fragmentary, and of individual elements resulting from post-mortem disarticulation and subsequent reworking before deposition (Khosla *et al*. 2003). Khosla *et al*. (2003) attributed the lower Nimar Sandstone to a fluvial environment and the upper Nimar Sandstone to an intertidal environment, whereas Jafar (2023) considers the Nimar Sandstone as an estuarine system in which

land-sourced dinosaur remains were deposited. The preservation of long, sturdy bones such as the femur, humerus, radius, and ulna indicate low hydraulic sorting and mechanical breakdown. Disarticulation of bones does not necessarily mean transport over a long distance; it may simply be a result of natural decomposition before extensive hydraulic processes are acting on any individual elements.

Therefore, the available evidence indicates minimal post-mortem reworking and potentially short transport distances rather than long-distance transport, which warrants confirmation by future investigation. Quantitative data on abrasion, weathering, fragmentation, orientation and size frequency distribution, distribution of skeletal element and palaeocurrent direction, and relation between the bone size and density to sediment grain size would provide greater control on transport and hydraulic sorting. Without these data, hydraulic sorting should be regarded as a probability rather than an established fact. Therefore, based on the available material, the best interpretation is an in situ or minimal post-mortem reworking transported a relatively short distance hydraulically to its depositional environment in a fluvial to estuarine system (Jafar 2003; Khosla *et al*. 2003).

Surface abrasion, exposure, weathering, and pre-burial damage

Surface weathering and abrasion could indicate the interval between death, exposure, and final burial. Low abrasion may indicate transport over a short distance and prompt burial, whereas a high degree of surface rounding and modification could indicate transport over a long distance and extensive reworking (Behrensmeyer 1978; Behrensmeyer *et al.* 2000; Fernández-Jalvo and Andrews 2016). Some fossils from the Nimar Sandstone show considerable pre-burial exposure. Bones lying on or close to the land surface therefore undergo weathering and mechanical/physical degradation. Evidence of pre-burial weathering includes surface cracking and flaking of the outermost cortical bone, which could indicate prolonged exposure on land, sun exposure, and cyclic dryness and swelling. Desiccation can cause rapid cracking of bones (Text-fig. 9A–C), followed by flaking (Behrensmeyer 1978; Fernández-Jalvo and Andrews 2016).

Specimens from the marine-influenced Nimar Sandstone may also show effects of alternating high and low tide levels (Text-fig. 9C). Bone elements exposed to alternating wet and dry cycles, such as tidal flats and near-shore environments, are more susceptible to cracking through expansion and contraction associated with changes in humidity, together with chemical processes such as leaching of mineral substances from the bone structure (Fernández-Jalvo and Andrews 2016). Abrasion caused by waves and mechanical stress associated with the movement of waves and sediments can modify the bone surface, resulting in rounding of features and making delicate structures more difficult to distinguish (Shipman 1981; Behrensmeyer *et al.* 2000).

The weathering processes should be individually recorded to determine whether each specimen has undergone weathering, surface cracking, cortical exfoliation, abrasion, rounding, bio-erosion, and/or encrustation. Such observations can help establish whether elements from the uppermost marine beds were reworked during transport into the intertidal environment (Behrensmeyer 1978; Behrensmeyer *et al.* 2000; Fernández-Jalvo and Andrews 2016). Small size, fragmentary morphology, and high abrasion may further support interpretations of chemical and physical degradation of bones within different environmental regimes prior to burial (Behrensmeyer 1978; Shipman 1981; Fernández-Jalvo and Andrews 2016).

Orientation patterns of sauropod bones

Quantitative data on the orientation of sauropod bones in the Nimar Sandstone are lacking in the published literature. Because most sauropod remains are isolated, there is probably limited evidence for in situ transport, although partial hydraulic redistribution after disarticulation and before burial could have occurred (Khosla *et al.* 2003; Khosla and Lucas 2023). If a preferred alignment with the palaeocurrent is present, it would need to be established through field measurements of the orientation and attitude of fossil long bones, including systematic determination of azimuth, dip, and imbrication directions.

Relationship between sauropod remains and sedimentary facies

The sum of these diverse fossils does not suggest the presence of a particular environment, thus implying that deposition occurred in fluvio-marine environment within the Nimar system. Khosla *et al.* (2003) proposed that two different types of environmental conditions constitute the succession bearing Nimar dinosaur material. They are dominantly fluvial, with lower Nimar Sandstone comprising coarse heterolithic sandstones, while in upper Nimar Sandstone, where marine fossils occur, fine, cross-bedded con-

glomerates are observed. While strata containing marine fossils represent the intertidal to shallow marine regime, lower beds within the dinosaur-bearing Nimar Sandstone imply a freshwater, fluviatile regime (Khosla *et al*. 2003; Khosla and Lucas 2023).

A more thorough examination of the ichnology and sedimentary structures during the development of the Nimar succession has made it possible to make more accurate interpretations since Khosla *et al*. (2003). The succession has been interpreted as a generally fluvial setting tending towards a tidally dominant estuarine regime (Saha and Shukla 2022), both having divided it into the lower and higher levels. The lower Nimar Sandstone has been further divided in various lithofacies, where a predominantly conglomeratic, cross-bedded, and heterolithic facies has been highlighted (Text-fig. 4). In the upper Nimar Sandstone, calcareous sandstones and further lithofacies include heterolithic and tabular bundles of estuarine and tidal lithofacies, respectively, along with important ichnofossils having estuarine to subtidal character (Saha and Shukla 2022).

Jafar (2023) presented calcareous nannofossil evidence suggesting that the Nimar Sandstone Formation developed through the Early Turonian and that strongly fluvial deposits occur in lower Nimar, while there is an increased amount of marine influence associated with tidal and wave action in the higher part of the succession. In addition, Jafar (2023) suggested that the sauropod remains represent terrestrial input associated with a Nimar depositional system and are evidence of how Nimar deposits accumulated. They are not evidence of how sauropods might have lived in the marine to estuarine marginal- marine environments represented by the deposits of higher Nimar strata. The Nimar Sandstone represents a system, in this instance estuarine marine, that was active for approximately a quarter of a million years from ~92 to ~90 Ma (Jafar 2023); therefore, terrestrial remains may well have washed into these marginal marine environments from coastal plains or other more terrestrial settings *via* rivers, storms, or tidal processes. We must be aware that there are exceptions to what has been interpreted above and that Nimar rocks cannot yet be used as direct indicators of sauropod ecologies, only as indicators for depositional environments wherein dinosaur fossils have been deposited (Jafar 2023).

The presence of various marine organisms such as oysters, *Turritella* sp., and various species of teeth, together with sedimentological and ichnological studies (as detailed above), has allowed to reconstruct the depositional environments. These indicate deposition at varying times within the early Turonian and a predominantly shallow-marine regime prevailing in the upper Nimar, with increasing tidal influx upward in the succession.

It can therefore be concluded that the sedimentological context of the Nimar Sandstone demonstrates fluvio-marine deposition and increasing marginal-marine influence upward the succession (Saha and Shukla 2022; Jafar 2023; Khosla and Lucas 2023), which is undoubtedly a critical context for the existence of the sauropod fossils. Nevertheless, it does not provide direct environmental evidence of sustained use of these marginal marine settings by the sauropods. One should keep in mind that when a fossil of a long extinct dinosaur is found in a sediment that was laid down in a marine environment, it does not mean that dinosaurs would have anything to do with this marine influenced coastal environment; it might be a terrestrial animal that was washed into a marginal-marine environment. Therefore, while exceptions to the interpretation above should be considered, the available evidence does not provide direct environmental evidence for sustained use of these marginal-marine settings by sauropods.

Evidence for long-term occupation of coastal habitats: implications for palaeoenvironmental interpretation of the Nimar coastal environment

The taphonomy of sauropod remains can be used to infer the depositional context rather than the living environment of these animals. The occurrence of dinosaur bones in the uppermost Nimar Sandstone is set within a succession independently interpreted as having considerable tidal and marine influence. Lithofacies and trace fossil evidence presented by Saha and Shukla (2022) indicate a transition from a fluvial regime to a tide-influenced, seaward estuarine setting, while Jafar (2023) interpreted the Nimar Sandstone as a lower Turonian succession with increasing marine influence. Kulkarni and Uchman (2022) described arthropod trace fossils in the tidally influenced siliciclastic formations of the Nimar Sandstone, reinforcing the presence of active tidal regimes. Nagori *et al.* (2024) also recorded diverse ostracod species from the calcareous upper Nimar deposits, further constraining the age and palaeoenvironmental context. If the inference that the Nimar coastal area supported long-term sauropod populations is to be maintained, more data than those simply derived from a straddling of vertebrate material in an estuarine package are needed. Such evidence would be a relatively high density of sauropod remains in individual marginal-marine horizons, with little sign of abrasion or weathering, along with terres-

trial palaeosols, plant debris and non-marine sediment bodies in the same era.

Independent evidence confirms that coastal and proximal marine environments existed during the deposition of specific Nimar strata. However, current observations do not support the hypothesis that sauropods permanently occupied these tidal environments. The most parsimonious interpretation remains that terrestrial habitat adjacent to the Nimar shoreline sustained sauropod populations, and their remains were progressively washed into the fluvial-estuarine-marine system.

Repeated occurrence of sauropod remains in marginal-marine facies

The spatial distribution of sauropod material might be critical in testing this hypothesis. Sauropod remains from multiple localities across District Dhar, spanning both the lower and upper horizons of the Nimar Sandstone, have been documented by Khosla *et al*. (2003). These remains do not appear to belong to a single, continuous bone-bearing stratum implying that dinosaur remains entered the Nimar depositional system on multiple occasions. However, their presence across five distinct sites does not justify regarding these occurrences as evidence of recurrent coastal ecosystem occupation, especially given the lateral variability and diverse lithofacies of the Nimar Sandstone.

The lower Nimar Sandstone is predominantly coarse and fluvially influenced, whereas upper portions exhibit marine-influenced lithofacies and trace-fossil assemblages. Consequently, the repeated occurrences of sauropod remains across multiple horizons does not inherently indicate recurring residence in a single coastal habitat; instead, presence at various stratigraphic levels more likely reflects episodic terrestrial carcass input into the estuarine system rather than recurring residence in a single coastal habitat. Evaluating these occurrences requires comparing the stratigraphic position of each dinosaur-bearing horizon with the lithofacies framework established by Saha and Shukla (2022). Such an approach helps to determine whether the bone concentrations are restricted to specific tidal or estuarine facies, exhibit minimal transport, and associate with terrestrial ecological indicators, strengthening evidence for recurrent coastal habitat use. Future data collection should compile exact vertical occurrences, lithofacies context, and associated data including lithology, grain size, depositional structures, bioturbation intensity, marine fossil and taphonomic signatures. This sort of data would aid in establishing whether the bone concentrations are confined to certain tidal or estuarine facies, and whether the remains show little evidence of transport. Statistically robust spatial, chronological, and environmental analyses of the dinosaur material are essential for evaluating habitat occupation hypotheses. Because remains are frequently recovered from high-energy channels and active hydraulic environments, distinguishing between permanent coastal habitation and the repeated fluvial transport of carcasses into estuarine networks (Khosla, work in progress).

Independent palaeoecological indicators

Multiple independent fossil lines of evidence indicate marine and near-shore environments during deposition of the upper Nimar Sandstone. The initial dinosaur report noted the co-occurrence of marine molluscs, ostracod shells, and fossil wood tentatively assigned to cf. *Rhizophora* sp. within the topmost successions (Text-fig. 7A–C; Khosla *et al*. 2003; Khosla and Lucas 2023). Saha and Shukla (2022) documented diverse trace fossil assemblages and demonstrated increasing tidal and marine influence up-sequence. Ostracods provide an independent line of evidence; Nagori *et al*. (2024) described 15 ostracod species belonging to 11 genera from the uppermost calcareous sequence at Pipaldehla. The assemblage indicates an early Turonian age, correlates with the previously described marine ostracod faunas from the Bagh sequence, and suggests that the upper Nimar Sandstone accumulated in shallow tropical, moderate-energy, subtidal waters confirming marine conditions.

Despite these independent indicators of a marine-coastal setting, they do not imply the existence of marine-tolerant sauropods inhabiting that ecosystem. The presence of cf. *Rhizophora* sp. fossil wood may indicate an incipient coastal woodland. However, this interpretation warrants caution because the open nomenclature indicates taxonomic uncertainty; and isolated *Rhizophora*-like wood does not constitute definitive proof of a contemporary mangrove habitat. Substantiating such a hypothesis would require additional plant remains from the same stratigraphic unit, comprehensive palynological data, and detailed wood anatomical analyses (Khosla, work in progress).

Implications for the Turonian transgression

The Nimar Sandstone is now widely recognised as a record of transgressive environmental change. Saha and Shukla (2022) interpreted the lithological

sequence as a transgressive systems tract, establishing an upward progression from riverine deposition to a tide-dominated estuarine environment and ultimately to marine-influenced conditions. Similarly, Jafar (2023) assigned an early Turonian age to the marine Nimar Sandstone, noting its estuarine provenance and a progressive increase in marine influence. While this provides a framework for examining interactions between terrestrial vertebrate faunas and coastal morphology, correlating sea-level rise with sauropod occurrences does not inherently demonstrate an adaptive response. The most defensible current interpretation is that the terrestrial environments housing sauropod remains were progressively inundated and replaced by marine conditions due to the Turonian transgression. Whether sauropods actively altered their habitat use in response to these environmental shifts remains uncertain.

Interpretation of cf. *Rhizophora* sp. wood

The presence of fossil wood as cf. *Rhizophora* sp. in the upper Nimar Sandstone is significant for developing the palaeoenvironments of the Bagh Basin. Khosla *et al*. (2003) noted a fossil log interpreted as Angiospermae cf. *Rhizophora* sp. from Rampura and Jamniyapura. These fossils are associated with oysters and other related fossils that demonstrate marine environments (Text figs 7B, C and 8). The occurrence is compatible with a marginal-marine setting related to transgression within the upper Nimar Sandstone, but the identification is regarded as preliminary. Hence, the fossil should be accepted cautiously as cf. *Rhizophora* sp. rather than a definite *Rhizophora* sp. of Turonian age. Correct identification depends on detailed wood anatomy with respect to vessel arrangement, morphology, perforation plate, intervessel pits, axial parenchyma, rays, and fibers. In the absence of a valid anatomical description and comparison with extant and fossil collections, the species identification remains unclear. The ecological preferences of extinct taxa cannot be presumed to be the same as those of their modern counterparts (Plaziat *et al*. 2001; Srivastava and Prasad 2019). Therefore, the reported wood should be attributed cautiously to a mangrove-like or woody vegetation species under marine influence and can support the construction of the palaeoenvironment rather than being considered definitive proof of *Rhizophora*-type vegetation (Khosla, work in progress). The relation of oysters with this wood indicates marine influence of shallow-marine conditions of the tidal environment in which the Nimar Sandstone was deposited.

PALAEOENVIRONMENT AND DEPOSITIONAL SETTING

The initial and widely held interpretation of the lower Nimar Sandstone is that it is a predominantly fluvial deposit, i.e., originated in river systems, a view first proposed by Pascoe (1959), and supported by Robinson (1967), Khosla *et al*. (2003), and Khosla and Lucas (2023). However, subsequent studies revealed a more complex depositional history for the lower Nimar Sandstone Formation. The notion of tidal influence was first introduced by Sarkar (1973), and Singh and Srivastava (1981), who suggested that tidal processes were instrumental in shaping the sedimentary architecture. Further refining this, Bose and Das (1986) interpreted the Nimar Sandstone, particularly its upper sections, as a transgressive sequence deposited in a shallow, wave-dominated shelf environment, influenced by both fair-weather wave action and storm events.

Further refinement of the depositional model came with the identification of a marine influence, at least in the upper stratigraphic levels, an interpretation supported by Raiverman (1975), Chiplonkar *et al*. (1977), Singh and Srivastava (1981), Khosla *et al*. (2003), and Khosla and Lucas (2003), all of whom noting features consistent with partial or wholly marine environments. This evolving understanding is strongly corroborated by the Nimar Sandstone fossil contents that document a clear terrestrial-to-marine ecological transition: the lower Nimar Sandstone has yielded a robust assemblage of dinosaur bones and terrestrial plant fossils, indicating continental conditions (Khosla *et al*. 2003; Khosla and Lucas 2023), while the upper Nimar Sandstone contains marine fossils like oysters and shark teeth, signalling a major marine incursion (e.g., Singh and Srivastava 1981; Khosla *et al*. 2003; Samanta *et al*. 2018; Bhattacharya *et al*. 2020). Together, the fossil record and sedimentological evidence establish the Nimar Sandstone as a quintessential example of a dynamic depositional system influenced by the interaction of fluvial, tidal, and marine processes, clearly demonstrating a shift from a primarily terrestrial environment in the lower part to a more marine-influenced setting in the upper part, which highlights the complex response of sedimentary systems to changes in regional tectonics and relative sea level.

The transition observed in the Nimar Sandstone from fluvial (river-dominated) to marine conditions provides a crucial opportunity to better understand Late Cretaceous palaeoclimate dynamics, as it suggests fluctuating sea levels and climatic shifts im-

pacted the ecosystems of the region (Samanta *et al*. 2018). Specifically, the lower Nimar Sandstone exhibits predominantly fluvial characteristics, supported by its sedimentology (Bhattacharya *et al*. 2021) and trace fossil occurrences (Saha and Shukla 2022), while the upper part clearly displays marine influence, illustrating a definite environmental shift from a terrestrial to a marine setting.

The palynological assemblage of the lower Nimar Sandstone, as reported by Kumar (1994), especially from exposures close to Umrali village in District Jhabua, allows for broad palaeoenvironmental interpretations (see Text-fig. 3C). The existence of particular palynomorphs offers important information about the kind of flora and the climate that prevailed at the time of deposition.

The record of the palynomorph *Cyathidites* Couper, 1953 which is attributed to ferns closely related to the modern *Cyathea* Smith, 1793, is a key finding in the lower Nimar Sandstone. Given that modern *Cyathea* ferns thrive in tropical semi-evergreen and evergreen forest zones, the presence of these spores suggests the ancient plant cover during the lower Nimar Sandstone deposition was similarly lush and supported by a warm, humid, and equable climate (Cheng and Liu 2017; Text-fig. 11). This interpretation points to a heavily vegetated landscape, likely composed of ferns, gymnosperms, and seed ferns, which flourished under conditions of high rainfall and stable temperatures (Text-fig. 11). Such an environment would have facilitated the preservation of plant material and palynomorphs within the fine sediment's characteristic of low-energy fluvial or floodplain settings (Text-fig. 11). Thus, the palynological data from Umrali confirms that the lower Nimar Sandstone was deposited in a terrestrial, fluvially influenced setting while simultaneously offering insights into the palaeoclimate, suggesting a tropical, warm, and humid environment during the Late Jurassic–Early Cretaceous transition (see also Kramer 1990; Conant *et al*. 1995). Additionally, a variety of gymnospermous pollen taxa found in the palynological assemblage provide further palaeoenvironmental information on the lower portion of the Nimar Sandstone. These include *Araucariacites* I.C. Cookson *ex* R.A. Couper, 1953, *Podocarpidites* Cookson, 1947, *Abiespollenites* F. Thiergart *ex* G.V. Raatz, 1937, and *Callialasporites* Dev, 1961, all of which aid in recreating the ecological and climatic conditions that prevailed at the time of deposition.

In palaeoenvironmental reconstructions, *Callialasporites*, a pollen type originating from coniferous gymnosperms, are very important. Warm, humid climates that supported thick coniferous forests are typically linked to its occurrence (Schrank 2010). In addition to its climatic implications, *Callialasporites* has been found in a variety of depositional environments. Research has connected its existence to a variety of hydrodynamic environments, including reed marshes, shoreline habitats, and proximal shelf settings with heterolithic facies (de Azevedo *et al*. 2019). Additionally, Sajjadi and Playford (2002) linked flora that produces *Callialasporites* to (sub)tropical to warm temperate climates. These plants usually thrive in lowland environments that are dotted with lakes, rivers, and wetlands (Text-fig. 11). This points to a dynamic terrain with marginal sea zones and floodplains that sustain abundant, conifer-dominated flora.

Warm, humid weather is also indicated by *Abiespollenites*, another form of pollen generated from conifers. Its presence lends credence to the idea of a mesothermal to megathermal temperature regime, which is favourable for the growth of dense coniferous flora throughout the landscape (Lin *et al*. 2022).

Usually belonging to the Podocarp family, *Podocarpidites* was also well suited to warm, moist environments. Its presence in the palynoflora highlights the predominance of warm climatic conditions during sediment deposition, and these plants frequently formed part of mixed forests in tropical and subtropical zones (Gnaedinger *et al*. 2017).

Because of its ecological ramifications, *Araucariacites* pollen from trees that resemble *Araucaria* sp., is especially notable. These conifers were frequently found in subtropical and coastal regions, which frequently experienced seasonal dryness. Warm temperatures were ideal for the flora represented by *Araucariacites*, which has been linked to habitats that could sustain large herbivorous dinosaurs, particularly high-browsing species (Filatoff 1975; Schrank 2010). Their existence suggests the existence of coastal forest ecosystems or open-canopied, subtropical forests close to deltaic and fluvial systems (Text-fig. 11).

The varied collection of gymnospermous palynomorphs form the lower Nimar Sandstone suggests a humid, (sub)tropical to mild temperate environment with significant biological diversity (Text-fig. 11). Additional information on the palaeoenvironmental conditions during the early stages of its deposition may be gained from the record of *Cycadopites* Wodehouse, 1933 pollen in the palynological assemblage from the lower Nimar Sandstone. Usually ascribed to cycads or cycad-like plants (i.e., gymnosperms), these pollen grains have been found in a range of ancient depositional environments, such as shallow-water lagoons and lacustrine (lake) environments (Text-fig. 11). The

sediments in which they are found, especially those near the base of the lower Nimar Sandstone, may have been deposited in or close to standing bodies of freshwater, such as lakes and ponds, based on their relationship with such low-energy, wet settings (Abbink *et al*. 2004; Schrank 2010).

A (sub)tropical to warm temperate, humid environment that supported a very diversified vegetative cover is suggested by integrating the palynological data from *Cycadopites*, *Callialasporites*, *Abiespollenites*, *Podocarpidites*, *Araucariacites*, and *Cyathidites* (Schrank 2010).

Lowland forests with lakes, marshes, and occasionally dry coastal regions scattered throughout were probably the predominant feature of the palaeolandscape (Text-fig. 11). A dynamic habitat characterised by climatic variations and ecological diversity is suggested by the presence of both evergreen and seasonally dry forest markers.

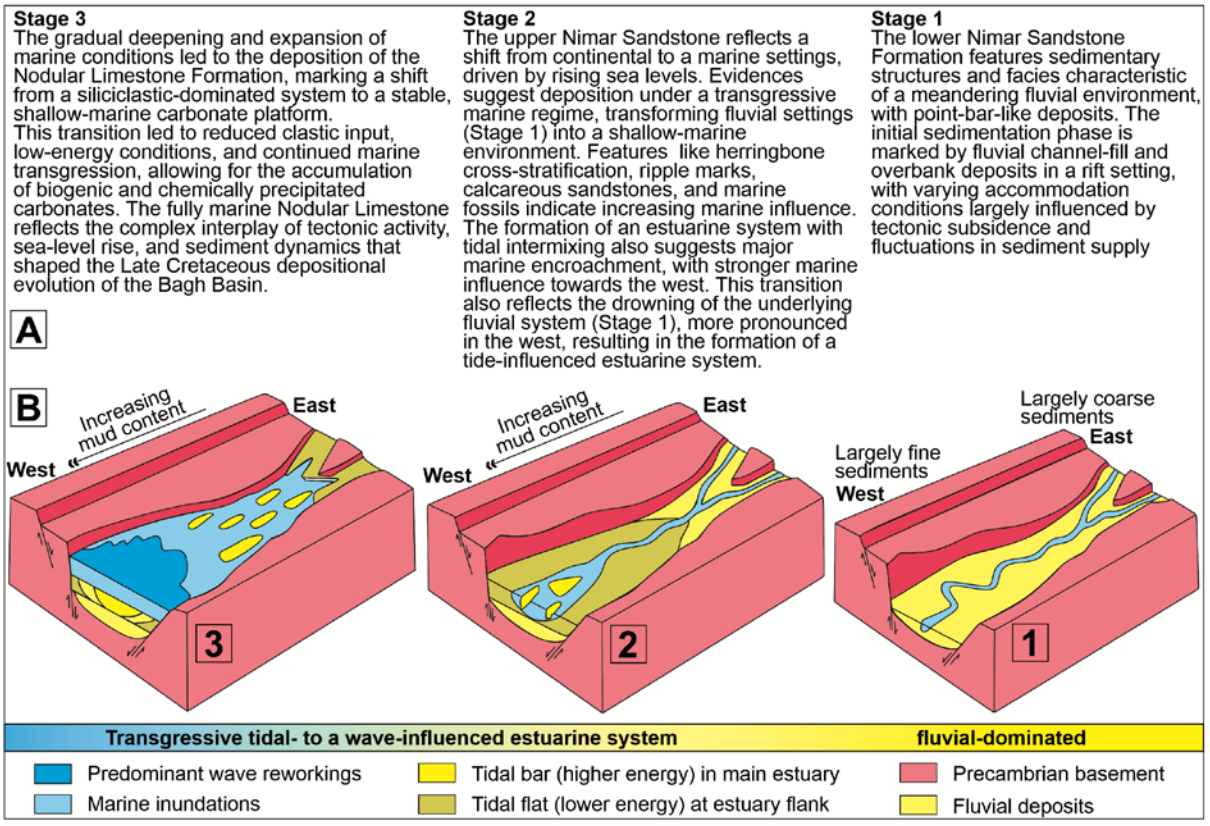
Vertebrate fossil material substantially supports this palaeobotanical framework. The basal layers of the lower Nimar Sandstone have yielded a large number of isolated bones and partial dinosaur skeletons (Khosla *et al.* 2003; Khosla and Lucas 2023 and references therein; Khosla, work in progress). Herbivorous dinosaurs, especially high-browsing species that were suited to consuming tall gymnosperm-dominated vegetation, such as trees producing *Araucariacites*, would have been supported by the flora shown by the palynological record (Text-fig. 11). The fossil-rich horizon from this stratigraphic interval, i.e., the 'Conglomerate Bed' (Text-figs 3, 4D–H and 5), is a key depositional phase in the Nimar Sandstone, indicating the start of sediment accumulation after a substantial unconformity over the Precambrian basement. Its abundance of vertebrate fossils, diverse pollen assemblages, and coarse sediments make it a crucial unit for comprehending the formation's palaeoecological setting and sedimentary history.

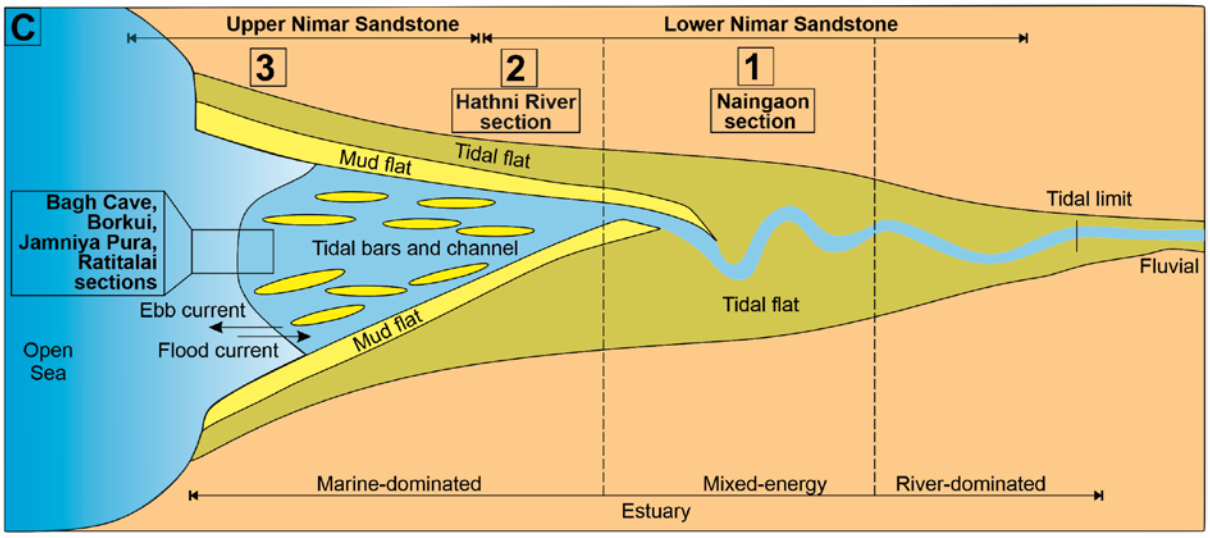
Thus, in summary, the palynological data from the lower Nimar Sandstone, primarily near Umrali (Text-fig. 3C), confirms a terrestrial, fluvially influenced setting during the Late Jurassic–Early Cretaceous transition. Key palynomorphs like *Cyathidites* (ferns) and diverse gymnosperm pollens (*Callialasporites*, *Araucariacites*) indicate a tropical, warm, and humid climate supporting lush, diverse forests (Text-fig. 11). This flora would have sustained the large herbivorous dinosaurs whose bones are found in the basal 'Conglomerate Bed' (Khosla *et al.* 2003; Khosla and Lucas 2023). Thus, the fossil and pollen records together paint a picture of a dynamic, well-vegetated palaeolandscape crucial to the regional ecosystem.

Thus, based on a critical re-evaluation of published data and a reinterpretation of its trace fossil assemblages, the lower Nimar Sandstone can now be confidently assigned to the *Skolithos* ichnofacies (Seilacher 1967). This ichnofacies is the classic indicator of high-energy, physically dominated, shallow marine environments, such as beaches, upper shorefaces, and tidal sandbars (e.g., Pemberton *et al*. 2012). This interpretation is strongly supported by the dominance of vertical, cylindrical trace fossils, including *Skolithos* isp., *Diplocraterion* isp., and other suspension-feeding burrows, which reflect colonisation by opportunistic infaunal organisms adapted to high-energy conditions. These features are consistent with rapid sedimentation, frequent reworking by waves and currents, and well-oxygenated substrates typical of nearshore marine systems.

Thus, the palaeoenvironment of the Nimar Sandstone during the Turonian suggests a dynamic coastal to fluvio-marine setting shaped by marine transgression and continental influences (Text-fig. 11). The presence of *Rhizophora*-type woods within the lower Nimar Sandstone provides strong evidence for mangrove vegetation along transgressive coastal plains, marking one of the earliest records of such environments in the Indian subcontinent (Text-fig. 11). Thus, based on plant and wood fossils, palynological, sedimentological, and trace fossil evidence, a landscape characterised by fluvial channels draining from nearby highlands and flowing toward an encroaching sea is envisaged (Text-fig. 11). Along these coastal margins, mangrove forests-dominated by *Rhizophora*-like vegetation, occupying intertidal zones, indicating the development of mangrove ecosystems under warm, humid, and tidally influenced conditions (Text-fig. 11). These mangrove belts would have formed a palaeoecological transition between terrestrial and marine realms, trapping sediments and organic matter during rising sea levels.

The deposition of the Nimar Sandstone can be explained in three stages reflected in three facies associations: (a) Stage 1, fluvial facies; (b) Stage 2, fluvial-tidal mixed facies, and (c) Stage 3, shoreface facies (Text-fig. 12; see also Bhattacharya and Jha 2014; Jha *et al*. 2017; Bhattacharya *et al*. 2020). Stage 1 is best noted at Naingaon (Text-fig. 4A), Chikli (Text-fig. 3B), Phata (Text-fig. 3D) and Umrali (Text-fig. 3C), Stage 2 is best noted at Hathni River (Text-Fig. 4B), Sitapuri (Text-fig. 3F), Man River (Text-fig. 3G), and Baria Nala (Text-fig. 3H) sections; and Stage 3 is best noted at Bagh Cave (Text-figs 3E, 4C, D), Borkui (Text-fig. 4E), Jamniyapura (Text-fig. 4F), Rampura (Text-fig. 4G), and Ratitalai sections (Text-figs 4H, 6G).





D	Upper Nimar Sandstone	Lower Nimar Sandstone
	Arenicolites, *Asterosoma*, *Dactylophycus*, *Skolithos*, *Taenidium*, *Teichichnus*, *Thalassinoides*, and *Zoophycos* Assemblages dominated by suspension, dwelling, and deposit feeders Between *Cruziana* and *Skolithos* ichnofacies Supratidal- subtidal to inner neritic setting Cream colored hard and compact calcareous sandstone, cycles of thinly bedded fine sandstone and mudstone-siltstone-fine sandstone cycles with intense bioturbation	*Arenicolites*, *Diplocraterion*, *Laevicyclus*, *Ophiomorpha*, *Skolithos*, and *Thalassinoides* Assemblages dominated by suspension-feeders *Skolithos* ichnofacies River dominated estuary to tide dominated estuary (base to top) Brick red colored, ferruginous well-persistent channelized sand bodies separated by thick bioturbated gravelly mudstones

Text-fig. 12. Depositional model explaining the deposition of the Nimar Sandstone Formation, based on sedimentological and ichnological data (modified after Bhattacharya *et al*. 2020; Saha and Shukla 2022).

The 'Conglomerate Bed' (Text-fig. 5) corresponds to Facies 1A of Bhattacharya *et al.* (2020), who interpreted it as a channel-fill deposit. Its textural and compositional characteristics suggest that it represents a proximal bar facies or basal channel lag to point bar deposits formed within a low-sinuosity, high-energy meandering fluvial system (Text-fig. 5). Imbrication, rounded clasts, and poor sorting all point to tractional bedload transport in high-energy braided or meandering river channels. Rapid, high-energy flows, probably during flood episodes that altered pre-existing sediments and transported them over short distances, are reflected in the mixing of pebble- to sand-sized grains and the presence of coarse detritus (Text-fig. 5). This facies marks the initial phase of sedimentation and is followed up by the Stage 1 fluvial facies of the lower Nimar Sandstone (Text-fig. 12).

Stage 1, the initial depositional phase, best exemplified by the Naingaon section (Text-fig. 4A), shows a unique association of facies indicative of a wave- and tide-influenced estuary environment (Text-fig. 12). The sedimentary record here consists of numerous small-scale fining-upward (retrograding) phases, where wave-tide-interactive facies are repeatedly stacked above fluvial deposits, suggesting multiple, short-lived transgressive events (Bhattacharya and Jha 2014). This retrograding stacking illustrates a lateral shift in depositional environments, gradually transitioning from an open, wave-dominated coast to a more protected, tide-influenced estuarine outlet, a process attributed to a significant west-to-east maritime transgression causing shoreline retreat (Jha *et al*. 2017; Bhattacharya *et al*. 2020). This stage also records the earliest appearance of marine trace fossils, with Bhattacharya *et al.* (2020) documenting *Skolithos* isp., and Saha and Shukla (2022) further reporting *Arenicolites* isp. and *Thalassinoides* isp., all pointing to a distinct increase in marine influence. Consequently, the lower Nimar Sandstone is interpreted to represent an evolutionary transition from a river-dominated estuary to a tide-dominated estuarine system (Text-fig. 12).

Stage 2 of deposition, prominently observed at the Sitapuri (Text-fig. 3F) and Man River (Text-fig. 3G) sections, records a clear transition from a fluvial-dominated floodplain environment to one influenced by tides (Text-fig. 12). The initial overbank facies association (Bhattacharya *et al*. 2020) is characterised by interbedded sandstone-mudstone units with sheet-like geometry, indicating low-energy, laterally continuous traction and suspension deposition on floodplains, followed by plane-laminated sandstone (suggesting supercritical flow during peak floods) capped by ripples (signifying subcritical flow in shallow channels). This is succeeded by a tide-affected fluvial association featuring large-scale trough cross-stratified sandstones (Bhattacharya *et al.* 2020) with lateral accretion and mud-draped foresets, which point to bar migration driven by tidal currents and frequent flow reversals during slack water. This association is completed by planar cross-stratified sandstones capped by ripples, indicating lower flow-regime deposition in channel bars within the fluvial-tidal transition zone.

Stage 3 of the Nimar Sandstone deposition is clearly visible at the Bagh Cave section (Text-figs 3E and 4C, D), and encompasses both a tide-dominated fluvio-tidal facies association and an overlying shoreface facies association (Text-fig. 12; Bhattacharya *et al*. 2020). The fluvio-tidal section begins with heterolithic sandstone-mudstone units (indicating low-energy tidal influence) that transition upward into plane-laminated, intensely bioturbated (featuring *Thalassinoides–Ophiomorpha*-dominated ichnoassemblages), and green sandstones; the glauconite within the green sandstones is characteristic of shallow marine conditions. The subsequent shoreface facies is marked by a fossiliferous unit containing *Turritella* sp. (gastropod), *Cardium* sp. and *Ostrea* sp. (bivalves), suggesting a warm, nutrient-rich, and well-oxygenated shallow marine habitat, with the *Ostrea* sp. indicating a protected nearshore or estuarine setting. Overlying this is a mudstone unit interbedded with fine-grained sandstones that exhibit intense bioturbation (*Thalassinoides* isp. and *Ophiomorpha* isp.), confirming a shallow, low-energy, oxygenated marine environment with established benthic life, while small symmetrical ripples indicate periodic wave reworking. The sequence culminates in a thick, massive mudstone unit that lacks bioturbation, suggesting deposition from suspension under extremely low-energy conditions and a shift toward more anoxic bottom waters, possibly due to increasing water depth and reduced circulation.

Herein and for now, Stage 1 represents the lower part of the lower Nimar Sandstone, Stage 2 the upper part of the lower Nimar Sandstone, whereas Stage 3 correlates with the upper Nimar Sandstone.

CHALLENGES AND FUTURE RESEARCH

What is left is a lot of questions: even after years of investigation, key gaps still exist in our knowledge about the age, depositional history, palaeoenvironment, and biogeographical implications of the

Nimar Sandstone. A multi-disciplinary study, involving sedimentology, stratigraphy, palaeontology, palynology and geochronology, is needed to address these issues.

Precise chronostratigraphy: A detailed high-resolution chronostratigraphic framework can only be achieved from integrated magnetostratigraphy, event stratigraphy, biostratigraphy, and isotopic dating. Existing geochronological constraints based on various palaeofloral groups, limited calcareous nannofossil data and ostracods are not sufficient, specifically for the age of the base of the lower Nimar Sandstone. Improved stratigraphic control and better dated sections are needed for acceptable intra- and inter-basin correlations.

Palaeoenvironmental models: A multi-proxy approach with sedimentological and stratigraphic data including palynology, megafloral, vertebrate and invertebrate assemblages will allow further detailed reconstruction of palaeoclimatic, palaeoenvironmental and palaeoecological histories to be achieved, in both the Nimar depositional system as a whole and within the wider Late Cretaceous Gondwanan context.

Advent of marine incursions: Until now it has not been possible to determine the timing and extent of the marine incursions, especially in the lower Nimar Sandstone, due to a lack of high-resolution stratigraphy and well-constrained palaeontology. Sedimentological and palaeontological data should be combined in order to identify the environment change from fluvial to marginal, deltaic, intertidal and shallow-marine, as well as the time relationship between these environments.

Insights into dinosaur diversity and distribution patterns: Late Cretaceous dinosaur diversity and palaeobiogeography of India with a special reference to sauropod dinosaur discoveries in India are limited both in diversity and distribution. More discoveries are needed to resolve issues related to taxonomy, palaeoecology, palaeobiogeography, and dispersal of Indian dinosaurs as well as to establish the faunal links of Indian dinosaurs with those of other Gondwanan landmasses (Khosla, work in progress).

CONCLUSIONS

- The Nimar Sandstone Formation is a key lithostratigraphic and palaeontological unit which provides evidence for a dynamic fluvial to marginal-marine depositional system with a confluence of land-sea processes in the Late Cretaceous.
- The Nimar Sandstone was previously given a Cenomanian–Turonian age, with sauropods occurring in the lower and upper parts of this formation (Khosla *et al.* 2003). However, new biostratigraphic data (calcareous nannofossils) show it to be a better fit with the earlier part of the early Turonian (Saha and Shukla 2022; Jafar 2023).
- The preservation aspect of this formation is extensive, and includes a significant number of fossils, especially the remains of sauropods. This makes the formation a significant contributor to Late Cretaceous terrestrial ecosystems, palaeoecology, palaeoclimatic conditions, and depositional environments of the drifting Indian Plate.
- Two main levels of sauropod occurrence with respect to the depositional environment are: Level 1 – fluvial deposits of the lower Nimar Sandstone, and Level 2 – intertidal to shallow-marine deposits of the upper Nimar Sandstone. The lower remains tend to be fragmented and scattered. Better-preserved bones are found in the marine-influenced upper Nimar Sandstone where they are associated with oysters and other indicators of marine conditions.
- The combined sedimentological, palaeontological, and floral evidence indicates a warm, humid, deltaic to estuarine coastal environment, with river channels, marshes and possible mangrove vegetation during marine incursions.
- If confirmed, a preliminary identification of the Rampura fossil wood as Angiospermae cf. *Rhizophora* sp. would constitute evidence for mangrove-type plants on transgressive coasts during the Late Cretaceous and be in agreement with a tidally-affected, estuarine to shallow-marine environment.
- The occurrence of sauropods within this succession provides important information on Late Cretaceous terrestrial ecosystems and Gondwanan biogeography, particularly in the context of the palaeogeographic relationship between India, Madagascar, and Africa.
- Most of the material in the sauropod assemblage represents fragmentary and disarticulated remains of skeletons, comprising femora, humeri, radii, and ulnae. This degree of fragmentation alone does not signify extended transport, but could result from decomposition, post-burial processes and weak hydraulic sorting. Overall, the evidence indicates post-mortem disarticulated terrestrial dinosaur bones with limited movement or hydraulic re-sorting before deposition.
- In conclusion, the evidence suggests that the skeletal remains of mainly terrestrial dinosaurs were

disarticulated after death, and did not undergo long-term estuarine transport or hydraulically reworked by marine water to any large extent. Additional taphonomic, sedimentological, ichnological and palaeontological work is necessary to further evaluate this scenario, and to better understand the depositional and palaeoenvironmental history of the Nimar Sandstone (Khosla, work in progress).

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